

Roadmap for Astronomy
in Switzerland
2007–2016

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Till Credner, AlltheSky.com

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A Hubble Space Telescope image of a small region of M27, the Dumbbell Nebula, showing small dense knots of gas ejected by the dying star, each containing a few times the mass of the Earth. NASA/ESA

The purpose and scope of this document

Who was this document prepared by?

This Roadmap for Astronomy 2007-2016 was prepared by the 21 elected Professors in Astrophysics at Swiss universities, plus representatives of three independent laboratories: IRSOL, ISSI, and PMOD/WRC.

We are the College of Helvetic Astronomy Professors (CHAPS) which represents the full range of astronomical interests within our community, and is small enough that all members were strongly involved in the production of the Roadmap. The members of CHAPS are:

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Two members of the PSI, Alex Zehnder and Manuel Guedel, contributed greatly to the preparation of this document before the closure of the PSI Laboratory for Astrophysics at the end of 2006. Preparation and production of the Roadmap was co-ordinated by Simon Lilly, assisted by a Writing

Committee composed of Willy Benz, Eva Grebel, George Lake and Georges Meylan. All members of CHAPS have explicitly endorsed this Roadmap.

Why was this Roadmap needed?

In working groups and meetings of the full CHAPS, we reviewed our current activities and future ambitions in order to develop a coherent vision of astrophysics in Switzerland. This unique exercise was initiated for several reasons:

- to plan effective investment in research projects and infrastructure that have long duration and significant cost;
- to set our priorities for the future directions and facilities of the European organizations ESO and ESA;
- to provide our input to a European-wide vision for astrophysics;
- to coordinate our activities in education and outreach;
- to provide a national context for decisions at the local level.

The Roadmap covers the next decade 2007-2016. It provides a detailed view of the next five years, and a necessarily more tentative plan for the subsequent period. The Roadmap document was essentially frozen in October 2006 following a first oral presentation of the plan to the Secretary of State for Education and Research (SER). It therefore reflects the situation in Swiss astronomy at that time.

The Roadmap is aimed at a diverse readership – politicians and government, University administrators, our fellow scientists and the general public. We recognise that some readers may wish to skip much of the scientific detail of Chapters 3 and 4.

What are astronomy and astrophysics?

Astronomy is one of the oldest and most widely recognised sciences, originating with the simple fascination and wonder of the night sky. Over the centuries, astronomy has evolved into a physical science where theories are rigorously tested against precise observations. We also use observations of the Universe to refine, and sometimes revolutionize, our ideas about fundamental physics.

We will use the terms “astrophysics” and “astronomy” interchangeably. Many find that “astronomy” provides a warmer interface to the public while astrophysics provides a better description of our science. We embrace this duality and apply either term to the modern research methods that we use.

Astronomy, or astrophysics, does not have sharply defined boundaries. It is intimately intertwined with many other branches of physics. Currently, there is a particularly strong synergy between particle physics and cosmology, as well as cosmic ray astrophysics and neutrino astrophysics. There are also close ties between nuclear

physics and the astrophysics of stars and stellar explosions. Planetary astrophysics has strongly allied interests with geophysics while the growing interest in the development of the conditions necessary for the emergence of Life has spawned a vigorous new field of astrobiology, bringing together astrophysics, chemistry and biology.

These scientific inter-connections will provide much of the excitement and relevance of 21st century astrophysics. Nevertheless, to define our community and our ambitions, we are forced to draw boundaries between these intertwined scientific interests. We choose to do so on the basis of the research methods used. Nearly all of CHAPS are members of the International Astronomical Union (IAU) and their research relies on facilities that are generally designated as astrophysical laboratories or observatories. As a result, we have explicitly excluded from our considerations ground-based γ -ray observatories, such as MAGIC, and neutrino observatories, such as the IceCube experiment, and other subjects more closely related to particle physics.

Summary

Astrophysics is in a golden age. New observing facilities and space missions have produced a dazzling array of startling discoveries and stimulated dramatic advances in our theoretical understanding of the cosmos. These developments now motivate our next generation of experiments and observations.

Swiss Astronomy has grown by 25% in the last five years with the creation of six new Chairs. A comparable increase worldwide has been fuelled by intense public interest in one of the most dynamic areas of science. Recent discoveries address timeless questions about humanity's place in the Universe and point to fundamental new physics.

Swiss astrophysics is at the forefront of this progress. We leverage our membership in ESO and ESA to lead observational research in areas such as extra-solar planet detection, solar and stellar astrophysics, extragalactic astrophysics and cosmology, and in the in situ exploration of the Solar System. This has gone hand in hand with the development of innovative technology. Swiss theorists have leading roles in the areas of stellar evolution, supernova explosions, planet formation, and galaxy evolution and cosmology.

To guide our future directions, we identify four major questions that drive our own scientific ambitions and resonate with the general public:

Our Physics

What does the Universe, with its extreme conditions and its vast reaches of space and time, tell us about fundamental physics and the nature of matter?

Our Origins

What physical processes have operated over cosmic time to produce the Universe that we see today?

Our Neighbours

Are other worlds like the Earth common and do they support Life?

Our Home

How does the Sun and the nearby astronomical environment affect the Earth?

None of these questions is simple and all will require years of co-ordinated research with our international partners, combining information from the network of telescopes and spacecraft that together form an "integrated observing system". Each will need the development of associated theory to understand the flood of data from new observations on the ground and in space, and to guide the design of the next generation of facilities and missions.

Switzerland has high profile research teams in all of these areas. To take these to the next level, we have built research networks to consolidate our efforts across the country. These collaborations at a national level secure our leadership at the international level, and will produce the maximum return from the Swiss investment in the international organisations.

We address the relationship of our field to society at large and address future direction for teaching in Universities, public education and our relationship with Switzerland's strong technical workforce.

The record of Swiss Astronomy is outstanding, playing a role in many of the greatest discoveries of the last decade. With the following Recommendations, we position our community to continue on this course. Implementation of the proposed program will require budgetary and human resources that are broadly based on current levels with a 5% annual increase sustained over the next five years.



Part of the Ultra Deep Field image taken by the Hubble Space Telescope. This is the deepest view of the distant Universe and reveals galaxies at such large distances that they are seen as they were when the Universe was in its infancy. NASA/ESA

Summary Statements, Findings and Recommendations

A] Summary Statements (no explicit associated recommendations)

Summary statement 1

This comprehensive review of Swiss astrophysics has led to renewed appreciation of the breadth and interconnectedness of astronomy, and convergence on four emerging science themes – simply encapsulated as our Physics, our Origins, our Neighbours and our Home.

Summary statement 2

Swiss astrophysics leads the world in key areas. While it is best known for the discoveries of exosolar planets, there is excellence and international leadership across a broad range of astrophysics. The annual Saas-Fee course is an outstanding success and also contributes to the high international reputation of Switzerland in astronomy.

Summary statement 3

Collaboration between institutes across the country has strengthened our research community and offers a solid basis for future growth. Stimulated by this Roadmap review, the Swiss community is establishing ad hoc research networks to develop collaborative and synergistic research.

Summary statement 4

Switzerland's memberships in ESO and ESA provide the basis for most of our experimental/observational astrophysical research. Swiss astronomers make effective and high-profile use of the common-user observational facilities of both ESO and ESA, and of space platforms.

Summary statement 5

The unique institutions of ISDC and ISSI add value to the Swiss research community, and to the Swiss contribution to ESA.

Summary Statement 6

Local institutional funding is the bedrock for all other funding sources, not only providing many salaries but also seed funding for projects that then attract external funds.

Summary statement 7

SNF support of astrophysics is critical because it targets "fundamental science", compared with many other sources that are tied to applied science and commercial applications.

Summary statement 8

Astronomy has an impact on applied sciences and industry, and has significant support from diverse funding sources, including Swiss Federal organizations for metrology, topography, and meteorology. Funding from European institutions and industry are also important. Private philanthropic funding has great promise, but it has not been developed in Europe to the degree that is seen in North America.

Summary statement 9

The development of technology for innovative astrophysical research offers wider benefits to Swiss industry beyond the immediate astrophysical applications.

B] Findings and associated recommendations

Concerning ground-based astronomy at ESO

Finding 1

The ESO E-ELT is the highest priority new large project in ground-based astronomy for the Swiss astrophysics community. It is much more important to us than the SKA and the other large research infrastructure projects currently being considered by the ESFRI Forum.

Recommendation 1

The Swiss delegation to ESO should support an increase in the subscriptions from ESO member states so as to ensure an early and timely implementation of the E-ELT project by ESO.

Finding 2

The FINES program provides critical support for ESO instrumentation projects. This enables high impact science using the large amounts of associated “guaranteed observing telescope time” (GTO), time that is especially valuable as it exploits brand new observational capabilities. The existing and projected demand for FINES support of ESO-approved programs will continue to grow with the implementation of the VLT 2nd generation, VLT-I, and E-ELT programmes.

Recommendation 2a

The SER's FINES fund must be continued in 2008-2011 to ensure completion of the 2nd generation instruments for the ESO VLT (SPHERE and MUSE) and the instrumentation for the VLTI (PRIMA). The detailed future investment required from FINES in 2008-2011 is summarized in Table 4: Swiss participation in future E-ELT instrumentation development should be supported through an augmented continuation of the FINES fund at a level of CHF 1.5M in 2012 and beyond.

Recommendation 2b

A small instrument incubator program should be established to fund technological development of instrument concepts for ESO instrumentation, through to a proof of concept prototype. Support for this should come from FINES. Awards should

be based on both the scientific case and the potential for a successful ESO-approved project.

Recommendation 2c

In managing the cash-flow of the FINES program, the SNF needs a system of “pre-proposals” to gain information on instrumentation programs as they progress through the earliest phases of development and not only after they have been approved by ESO and the need for FINES funding becomes urgent. The Swiss representatives at ESO should also be charged with maintaining a running overview of potential Swiss participation in ESO instrument projects so as to brief the SNF.

Finding 3

ESO's investment in the global ALMA project, currently under construction, offers great opportunities for Swiss astronomers in the rapidly developing area of millimeter wave observations of star-, planet- and galaxy-formation and evolution – scientific areas that are central to our research programs. ALMA is the most complex major astronomical instrument ever built, yet it is intended for a wide community of astronomers. Furthermore, as a global project, competition for access to ALMA and for the exploitation of ALMA data will be intense. As a result, most European countries, including those with a substantial heritage in millimeter-wave observatories, are establishing national or regional support centres to support the use of ALMA by their astronomical communities.

Recommendation 3

The SER should fund a small team that is dedicated to the support of the Swiss astronomical community's use of ALMA (and before that the APEX Pathfinder). This urgently needed team should be composed of at least two experienced researchers who would be tasked with providing this support and with providing an interface to other ALMA European support centres.

Concerning the pan-European co-ordination of large ground-based research facilities

Finding 4

It is important that Switzerland participates in the growing co-ordination of scientific research in Europe, both in developing a common scientific vision and in planning for investment in large facilities.

Recommendation 4

The SER should participate, with appropriate community consultation, in European-wide planning forums such as the ERANET Astronet. It is important that these complement in a constructive way the strategic planning of the European organisations to which Switzerland belongs, such as ESO, the success of which is vital to the Swiss research community.

Concerning Solar System exploration and space astrophysics

Finding 5

Implementation of ESA's "Cosmic Vision" program is the highest priority for space-based astrophysics research in Switzerland.

Recommendation 5a

The Swiss delegation to ESA should support the allocation of a sufficient level of resources to ESA's Mandatory Science Program so as to realize an effective and early implementation of the "Cosmic Vision" Program.

Recommendation 5b

The Swiss delegation to ESA should ensure that Switzerland is selective in its participation in the ESA Optional Program "Aurora", concentrating on those areas that are most strongly science driven (e.g. ExoMars).

Finding 6

PRODEX and the "Mesure d'accompagnement" programs have provided crucial support for Swiss involvement in space missions.

Recommendation 6a

The PRODEX and the "Mesures d'accompagnement" programmes must be maintained at a combined inflation-adjusted level of approximately CHF 18M (12M) per year over the next 10 years, so as to fund Swiss participation in the current ESA missions (Bepi-Colombo, EXOMARS, Solar Orbiter, Gaia, LISA), as well as future missions undertaken by ESA in "Cosmic Vision" and non-ESA missions. The anticipated investment required from these two funds is summarized in Table 5, and is expected to be in the ratio 2:1 for PRODEX/Mesure d'accompagnement.

Recommendation 6b

A small instrument incubator program should be established to fund technological development of space instrument concepts, through to a proof of concept prototype. Support for this should come from Mesures d'accompagnement funds. Awards should be based on both the scientific case and the potential for a successful PRODEX project.

Finding 7

While the space research group at Bern provides a centre for solar system research missions, the equivalent for astronomical space projects is missing. The Swiss astronomy community will not be able to participate effectively in future space astrophysics projects if it does not contain the necessary technical expertise with whom strong collaborations can be developed by groups for particular projects.

Recommendation 7

The SER should ensure that Switzerland retains a capability in space astrophysics instrument development. The SER and CHAPS should jointly develop an implementation plan. This capability should be based on a full-time development core team, ideally embedded within a larger technical and engineering organisation, and should be located in close proximity to an active University-level education.

Concerning the SNF funding of astrophysics

Finding 8

SNF funding for data analysis is important to recoup the national investment in the large ground and space facilities of ESO and ESA.

Adequate funding for theory is also required for a balanced national programme.

Recommendation 8

SNF funding for astrophysics research should increase annually by 5% for the next five years. This is motivated by the rapid development of this research field, especially in the areas of planetary science and cosmology.

Finding 9

There are a number of areas where the institutional and funding structure in Switzerland produce a non-optimal development of personnel in research projects, and a difficult career path for young scientists.

Recommendation 9

The SNF should review the impact of (a) the short-term nature of SNF-funded post-doctoral appointments; (b) the general absence of mid-level long term positions in Switzerland; and (c) the difficulty of funding technical staff with SNF funds.

Finding 10

The OECD report on Large Projects in Astronomy emphasizes that „support for theoretical investigations must be proportional and synchronized with the great data gathering projects undertaken in laboratories and observatories“. Increased investment in new observational facilities must be matched by similar increases in theoretical work.

Recommendation 10

It is a high priority that SNF-funding for theory be increased commensurate with funding for ground-based observatories and space missions. We commission a study by theoretical astrophysicists about the best way to develop theoretical astrophysics in the country, with a report to be produced for CHAPs within six months.

Concerning University-level education

Finding 11

At the undergraduate level, approximately half of the teaching effort by Swiss Astronomy Professors is devoted to teaching basic Physics (and Computational Science) courses, and almost all of the courses that are delivered in astrophysics are part of a broader physics curriculum, either of physics specialists or of other scientists. The teaching effort by astronomers reaches well beyond astronomy. The most important co-ordination of teaching at the undergraduate level takes place „locally“ within individual universities and the scope for meaningful co-ordination nationally is limited. However, at the graduate level, PhD level students at Swiss universities could benefit more from the expertise in related research topics that exists elsewhere in the country.

Recommendation 11

CHAPS should organise a yearly “national school in astrophysics” beginning in 2008. This should take the form of an intensive event (approximately two weeks in duration) during the semester break and should focus each year on a broad suite of related topics covering the research areas of the “networks” already identified. The topic and location will rotate around the country, with lecturers chosen from the active Swiss research community. This course should complement and not replace or compete with the Saas-Fee courses. This school should be funded by the PRODOC programme and/or the Swiss University Conference.

Concerning Public Outreach

Finding 12

The development of individual partnerships between astronomers and high school educators has proved very successful in Switzerland and elsewhere.

Recommendation 12

CHAPS should co-ordinate the creation of a center for developing and strengthening these astronomer-educator partnerships across the country. Sustainability should be given greater emphasis in this effort than innovation.



Part of the Eagle Nebula, a nearby region in our Galaxy where stars are being formed. Dense gas clouds in which stars form are ablated by the intense radiation of nearby young stars.
NASA/ESA

Why is Astronomy important today?

Within the last decade, the science of astrophysics has progressed at an astonishing rate:

- We answered the age-old question of whether our Solar System is unique. Following UniGE's discovery of 51 Peg, we know that planetary systems are common in the Galaxy raising the prospect of finding Life elsewhere in the Universe;
- We discovered new types of objects in the Solar System, blurring the traditional definition of a planet, and found that the Solar System is a chaotic dynamical system;
- We solved the Solar neutrino "problem" through the "mixing" of the three neutrino species, simultaneously opening avenues of new fundamental physics beyond the "standard model", while validating our understanding of the solar interior;
- We identified the mysterious gamma-ray bursts as being the result of explosions occurring at immense distances during the final stages of the collapse of massive stars;
- We verified that super-massive black-holes, a hundred million times the mass of the Sun, lurk in the centres of galaxies like our own Milky Way;
- We have observed galaxies and quasars at such immense distances that their light has been travelling towards us for 95% of the time since the Big Bang, revealing the evolution of the Universe through cosmic time;
- For the first time, we have a successful cosmological model that describes the Universe on the largest scales with a handful of numbers that are determined with unprecedented precision from a suite of independent observations. Yet, the natures of the principal constituents of the Universe, "dark energy" and "dark matter", remain uncertain and raise profound questions about fundamental physics.

In this introductory Chapter, we explore the motivation for this intense interest and excitement within four "big themes" that, in an interlinked way, explain the relevance and application of astronomy and astrophysics today. These themes are used later, in Chapter 4, as the landscape in which our Roadmap for the development of Swiss astrophysics has been charted.

The intellectual and emotional interest of astronomy and astrophysics is thus at an all time high, both amongst scientists and the general public. Around the world, this is leading to major new investments in people and facilities.

Four themes and four questions

Our Physics

What does the Universe, with its extreme conditions and its vast reaches of space and time, tell us about fundamental physics and the nature of matter?

Our Origins

What physical processes have operated over cosmic time to produce the Universe that we see today?

Our Neighbours

Are other worlds like the Earth common and do they support Life?

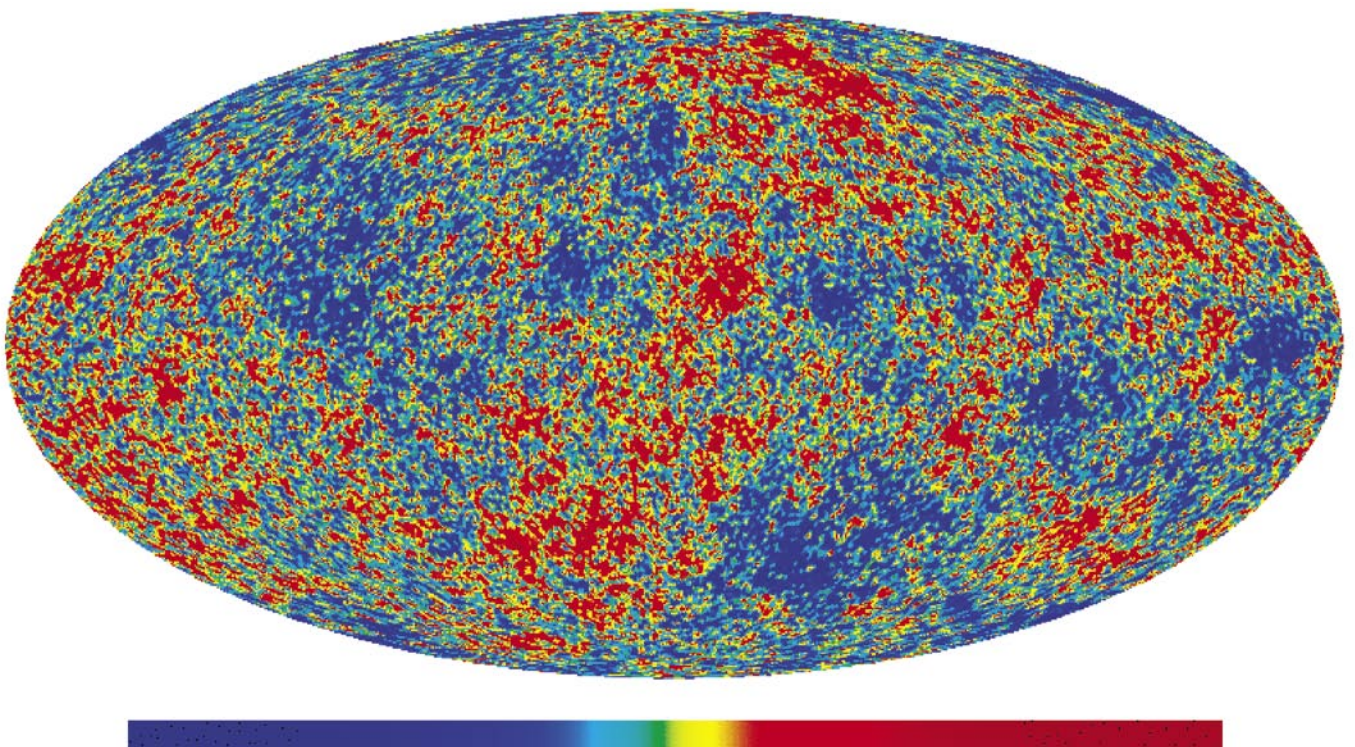
Our Home

How does the Sun and the nearby astronomical environment affect the Earth?

Recent Nobel Prizes in Physics from astrophysics

1967	Bethe	Fusion as the energy source in the Sun
1970	Alfvén	MHD and its use in cosmic physics
1974	Ryle & Hewish	Radio astronomy
1978	Penzias & Wilson	Cosmic Microwave Background
1983	Chandrasekhar & Fowler	White dwarfs and stellar nucleosynthesis
1993	Hulse & Taylor	Binary pulsar as test of General Relativity
2002	Koshiba, Davis & Giacconi	Cosmic neutrinos, X-ray astronomy
2006	Mather & Smoot	Cosmic Microwave Background fluctuations

A simulation of the entire sky, as it will be observed by the ESA Planck satellite, to be launched in 2008. The 2.7K cosmic microwave radiation is a relic of the primeval fireball of the Big Bang. ESA



1.1 “Our Physics” fundamental physics and the emergence of “new” physics

Astrophysics has been at the heart of revolutions in our understanding of the Laws of Nature. The discovery of Gravity in the 1600's led to the broad “Newtonian Revolution” in Physics. The first successes of Einstein's General Relativity came from explaining the subtle shifts in Mercury's orbit, and its first decisive test was made in 1919 through observations of the bending of light during a total solar eclipse. It soon provided a natural explanation of the expansion of our Universe.

This close and productive link between astronomy and fundamental physics continues today with the solving of the solar neutrino “problem” (the identification of which led to the 2002 Nobel Prize in Physics) in terms of neutrino mixing, and the remarkable developments in cosmology. For the first time, we have a self-consistent cosmological model, the “Big Bang” that describes the observable Universe on the largest scales with only a handful of parameters determined with impressive precision. The so-called “Concordance Cosmology” self-consistently points to a Universe that contains six times more “dark matter” than the familiar material of protons, neutrons and electrons that make up terrestrial matter, and even more “dark energy”, a mysterious component that dominates the accelerating expansion of the Universe.

The dark matter might be a stable massive and largely non-interacting particle lying outside of the “standard model” of particle physics. Astrophysical observations can determine, or at least constrain, many of the properties of these particles without ever directly detecting them. Even more mysterious is the “dark energy” that behaves like a false vacuum energy level, and accelerates the present Universal expansion. It mimics, but may be quite different from, the Inflationary phase of rapid accelerating expansion that is believed to have taken place in the earliest moments of the Big Bang.

We are far from understanding the dark energy phenomenon theoretically and can confidently predict that its solution will involve a revolution in Physics comparable to those of the first years of the 20th century. Further astronomical measurements can provide essential clues in this search,

including the determination of the equation of state of the dark energy component.

Extreme environments in the Universe provide a laboratory to observe physics under conditions that would be completely unattainable (or completely unsafe!) on Earth – extremely high, or low, densities, very high temperatures and extremely strong gravity. Gravitationally collapsed objects such as neutron stars and black holes provide tests of General Relativity, e.g. the binary pulsar discovery that led to the 1993 Nobel Prize in Physics, and generate environments where very high energy particles interact with very strong magnetic fields. The properties of neutron stars constrain the equation of state of matter at nuclear densities. The merging of neutron stars and of black holes provide the best opportunities to detect gravitational waves, a fundamental prediction of General Relativity that has not yet been directly detected.

As well as a natural neutrino laboratory, the nearest star, the Sun, also provides opportunities to understand plasma magneto-hydrodynamics. The phenomena associated with stellar gravitational collapse, e.g. supernovae and γ -ray bursts, provide unique laboratories for studying explosive events of unimaginable power.

At the other extreme, diffuse gas clouds in the Galaxy offer extremely low density environments for the study of near-vacuum gas phase chemistry.

Understanding the dark energy phenomenon will involve a revolution in Physics comparable to those of the first years of the 20th century.

1.2 “Our Origins” stars, galaxies and the evolving Universe

One of the most profound results from 20th century science has been the realization that our Universe began with a “creation-like event” 13.8 billion years ago, and has subsequently expanded and evolved towards its present state.

The objects and structures that we see around us, from nearby stars and planets, objects with extreme physical properties like black holes and neutron stars in our Galaxy, out to the other galaxies and the largest structures in the Universe, these all form and evolve over time through the action of different physical processes. Together, these processes produce the still-evolving Universe that we see around us today.

Astrophysicists seek not only to describe what we observe in the Universe, but also to understand why it has the form and appearance that it does in the framework of causal physical processes. Why do galaxies form in the first few billion years of the Universe and what then controls the rate at which stars are formed within them? What determines the masses and lifetimes of these stars? How are the chemical elements formed in stars and then returned to the gaseous medium between the stars during the various stages of

stellar evolution? How do the energetic events occurring around the super-massive black holes in the centres of galaxies influence events in the surrounding galaxy and beyond? What controls the formation and nature of planetary systems around stars?

These questions are not only fascinating in their own right, but have a much broader appeal as they bear on the question of humanity’s own place in the Universe, since we ourselves are a product of these processes. These evolutionary phenomena that we observe in the Universe form a complex web of interactions involving physical processes on a vast range of scales. They begin with the generation of microscopic density fluctuations in the primordial Universe and end with the emergence of complex molecules on planetary surfaces. We cannot hope to understand the different parts of this story in isolation, but rather need to link them together and understand how they are related to each other.

The nearby barred spiral galaxy NGC1300, observed with the NASA/ESA Hubble Space Telescope. NASA/ESA



1.3 “Other Worlds” planets and the search for Life

Planetary environments have a particular interest to humans for it is here that we find ourselves. We may expect Life to have developed elsewhere in the Universe in similar environments. Furthermore, the other planetary surfaces within our own Solar System provide the only realistic possibilities for human migration away from Earth for the foreseeable future. Vast audiences have followed in real time our first tentative robotic explorations of these other worlds, participating in this way in missions that have brought us a much deeper scientific understanding of the formation and evolution of our planetary system.

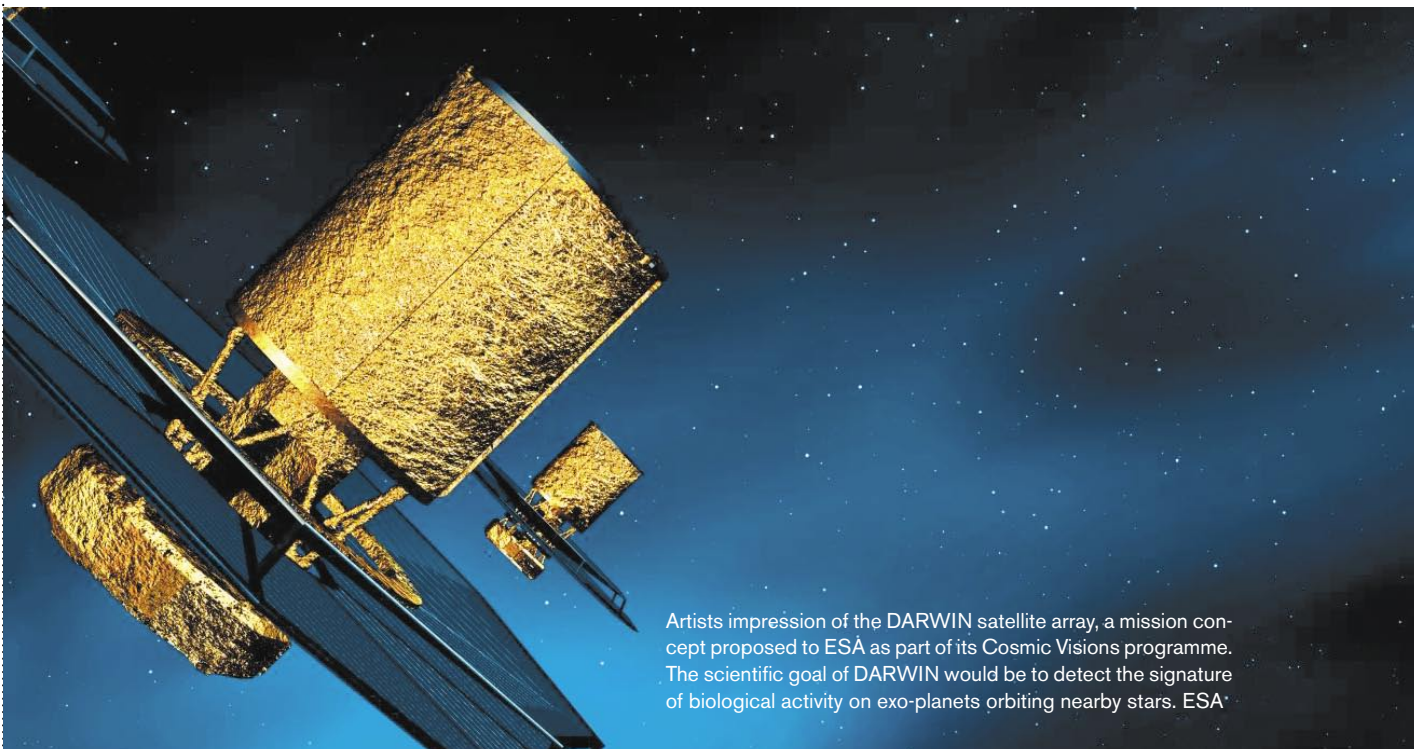
Understanding of other planets also comes from studying the Earth. Earth provides the ideal test-bed to study the gravitational field, rotation and orbital dynamics of a planet. Very accurate knowledge of these, obtained from precise astronomical measurements, can then be applied to understand the dynamics of other planets.

The planetary realm now extends beyond our own Solar System. After centuries of speculation, we now know for sure that there are other planetary systems in our cosmos. The first observation of a planet around another star, 51 Peg, by UNiGE

astronomers Michel Mayor and Didier Queloz in 1995, has been followed by the discovery of many more -- currently over 200 are known. We now know that planetary systems are common in our Galactic neighbourhood, at least around stars similar to the Sun. These new planetary systems have however been quite different from our own Solar System, overturning our theoretical ideas of how planets form. We do not yet know whether planetary systems like our Solar System, which seem well suited to the emergence of Life, are the usual outcome, or the exception.

As we improve our knowledge of the diversity of planetary systems through the application of increasingly sophisticated observational techniques, we are prompted to ask what determines the existence and nature of these planetary systems, which of them will have been conducive to the emergence of Life, and why, and will we soon be able to detect the signatures of such Life?

We now know that planetary systems are common in our Galactic neighbourhood, at least around stars similar to the Sun.



Artists impression of the DARWIN satellite array, a mission concept proposed to ESA as part of its Cosmic Visions programme. The scientific goal of DARWIN would be to detect the signature of biological activity on exo-planets orbiting nearby stars. ESA

1.4 “Our cosmic home” the impact of the space environment on Earth

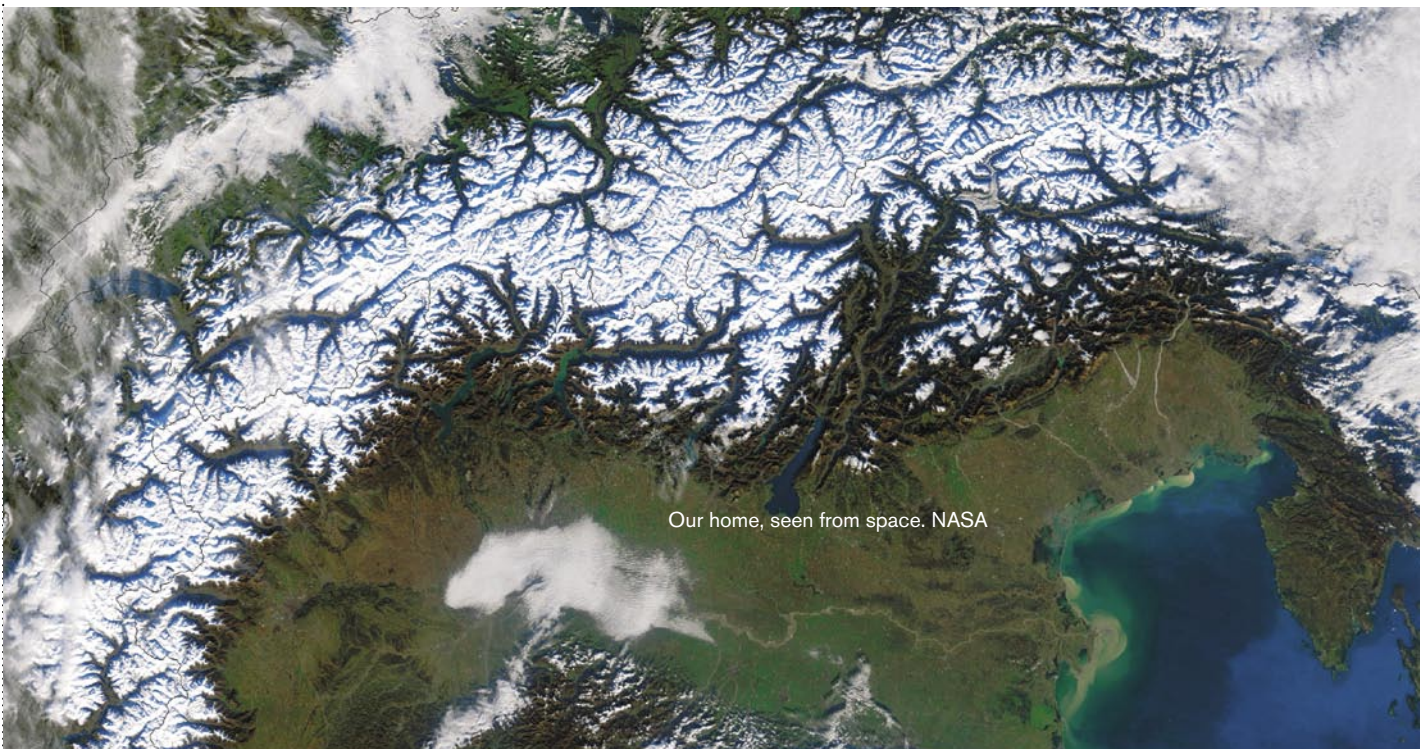
As our understanding of the Universe around us has increased, so has our awareness of the fragility of our own terrestrial environment. We have become increasingly aware that the wider space environment has profoundly affected the development of Life on Earth in the past, for example through the impact of large meteorites and comets, and have understood its potential to do so again in the future.

In parallel, as we have witnessed the measurable effects of human activities on our climate, we have appreciated the urgent need to understand the interaction of the immediate space environment on the Earth. We need to determine the effect of natural variations, such as the fluctuations in the solar irradiance, on the Earth's atmosphere in order to understand the significance of short term trends, to interpret correctly the historical record, and to predict with confidence the changes that will come in the future.

At the same time, as our society has become more technologically dependent on orbiting satellites, and as we raise our ambitions for an extended human presence in space, we have realized the importance of monitoring and understanding the “space weather” associated with the flux of energetic particles produced by eruptions and coronal mass ejections from the Sun. These jeopardize communications satellites and are potentially deadly for astronauts.

We have come to realise too, other practical applications of astronomical knowledge, such as in the global satellite navigation systems which rely on the fundamental reference frames of positional astronomy and the precise knowledge of satellite orbits.

We need to determine the effect of natural variations, such as the fluctuations in the solar irradiance, on the Earth's atmosphere in order to understand the significance of short term trends, to interpret correctly the historical record, and to predict with confidence the changes that will come in the future.



Our home, seen from space. NASA

The broader context of Swiss Astrophysics

Astronomy is a very broad and diverse research discipline, benefiting directly from scientific and technological inputs from other sciences.

We emphasize that the remarkable developments in astrophysics over the last twenty years have come from a wide range of research facilities, research methods, and research styles. They have come:

- from across the full electromagnetic spectrum, from γ -rays to radio waves, and also with unique information added from neutrino detectors and, hopefully in the near future, from the detection of gravitational waves;
- from both ground- and space-based observatories, as well as from laboratory studies and from in situ measurements by spacecraft in the Solar System;
- from observations of objects on all possible scales, from small bodies in the Solar System to measurements encompassing the whole observable Universe;
- from detailed studies of single objects and from statistical measurements of very large samples of 100,000 or more stars or galaxies;
- from small research teams composed of only a few individuals, and from very large international collaborations involving hundreds;
- from both improvements in traditional astronomical methods and from the development and application of novel techniques and technology.

It is this breadth and diversity that makes 21st century astronomy uniquely exciting and challenging.

In this Chapter, we explore the broader context for our Roadmap: the evolving nature of the discipline globally, the synergistic links and overlaps with other scientific disciplines, the specific international partnerships in which Switzerland participates to construct and operate forefront research facilities, as well as the local environments in our individual universities. Finally we provide a snapshot of the Swiss astronomical research community in 2006 in terms of its personnel and budget.

2.1 The changing face of astrophysics

The global landscape of Astronomy is changing: from the ever increasing sophistication of our measurements and theories to the way that we combine theory and observations, to our approach to observational data.

Scientific advances have different dimensions of “exploration”, “precision” and “synthesis”. After an exciting period of “exploration” since the Second World War, astrophysics is making a transition to a high precision science. As examples, planets are found by measuring the speed of distant stars with a precision of 1 ms^{-1} (the speed of a human walk), while the breakthroughs in cosmology have come through the measurement of temperature shifts of a few μK (a few millionths of a degree centigrade) in the cosmic microwave background and from the precise statistical analysis of the positions of hundreds of thousands of galaxies.

Another change is the role of theory and simulation. Numerical simulation has emerged as a way to explore the complex outcomes of apparently simple theoretical ideas. An example is the emergence of the complicated filamentary “cosmic web” of the largest scale cosmic structure from initially Gaussian initial conditions, acted upon by simple Newtonian gravity. Similar gravitational simulations are also applied to the formation of planetary systems and to the dynamical evolution of the Solar System. Another more complex example is the detailed understanding of stellar evolution, from star-formation to the final supernovae, using complete models of stellar interiors that

incorporate a multitude of physical processes, each individually simple, but complex in their combined effects.

Information technology is also changing our approach to observational data. More and more, discoveries are being made from combining multiple observations made at complementary wavelengths using different telescopes. The digital nature of data, and the fact that astronomical phenomena often change only very slowly, has led to the emergence of “data mining” of archival data as an increasingly important mode of astrophysical research. The International Virtual Observatory (IVO) is being created to support this mode of research -- seamlessly linking large databases, distributed around the world but accessible in almost real time by any qualified researcher, anywhere. This resource provides an integration of major data sources, services, and software tools to support both research and education. Astrophysics is perhaps uniquely demonstrating the enhancement of a scientific field through the practical application of the new information technology.

2.2 The synergies with other scientific fields

Astronomy has a strong synergy with many other scientific fields. Synergies with other scientific fields arise naturally due to aligned scientific interests, but can also arise unexpectedly from the transfer of research techniques from astrophysics to very different scientific fields, such as medicine, or to other practical applications. While there are many examples, we point to just a few here:

The central questions of the nature of the dominant constituents of the Universe, the Dark Energy and the Dark Matter, are being addressed using a wide spectrum of techniques from across the traditional particle physics and astrophysics domains. The techniques are quite different but the questions are ultimately the same, and the final answers will likely come from synthesizing our knowledge across this broad spectrum. The same is also true for other fundamental cosmological questions such as the nature of the inflation in the early Universe, the generation of the initial fluctuations that grew into galaxies and the largest scale structures in the Universe, the excess of matter over antimatter, and the generation of cosmic magnetic fields. Particle physics and astrophysics also come together in ground-based γ -ray astronomy where particle-physics detection techniques are applied to either observe celestial sources of γ -ray emission directly from space or to detect the interaction of very high γ -rays with the Earth's atmosphere.

While most astrophysics is concerned with the detection and analysis of electromagnetic radiation, other avenues to study the Universe are offered through the detection of energetic particles (cosmic rays), neutrinos and gravitational waves, and are becoming significant. These areas naturally straddle the divide between astrophysics and other parts of physics.

Understanding the abundances of the chemical elements produced during nucleosynthesis in the first few minutes of the Big Bang, in stellar interiors and during supernova explosions, is naturally related to advances in nuclear physics, including the detailed knowledge of reaction rates and of the properties of many stable and unstable nuclei.

Our understanding of plasma physics, with its potential for fusion energy in Tokamak reactors, has profited from studies in the laboratory and in cosmic environments, such as solar and stellar coronae, the interstellar medium, the solar wind, and the magnetospheres of Earth and Jupiter.

Planetary sciences, including the in situ exploration of other worlds in our own Solar System is another area that naturally straddles astronomy and geophysics.

The synergies are sometimes unexpected: The radio astronomy technique of Very Long Baseline Interferometry (VLBI) that was developed to image radio sources with extreme angular resolution, has contributed to geology and geodesy by measuring intercontinental distances with an accuracy of centimeters, showing continental drift in real time. Fundamental astronomy defines the terrestrial and celestial positional reference frames by monitoring the Earth's motion and orientation in space using the precise modeling of satellite orbits in the Earth's gravitational field. This has enabled the deployment of and worldwide use of global navigation satellite systems (GNSS) for both science and society at large. In the other direction, expertise developed by geophysicists to measure very small accelerations needed to characterize earthquakes will be applied to measuring gravitational waves in space.

Recent advances in numerical integration techniques have provided us with very accurate long-term positional data for the Earth. The link between our global climate and changes in the incident solar flux due to variations in the Earth's orbit (the Milankovich Theory) and the Sun's own variability, is now well established. In a related area, the high altitude Jungfraujoch observatory was built for solar astrophysics and is now used primarily to follow the increase of greenhouse gases in the Earth's atmosphere.

Transfer of know-how in data processing from astronomy into medicine and other areas has also been increasingly important. Astronomers have always been leaders in the area of generating 2D and 3D images from sparsely sampled data, a technique that began with the development of aperture synthesis for radio astronomy (which resulted in the 1974 Nobel Prize for Physics). These techniques are now used in a wide variety of med-

ical imaging applications (CAT scans, MRI, Positron Electron Tomography) as well as in the use of seismic imaging for the discovery of petroleum reserves. Astronomers have also been at the forefront of the field of "imaging with errors", with applications in such diverse areas as post-genomic biology and cardiac angiography.

Synergies with other scientific fields arise naturally due to aligned scientific interests, but can also arise unexpectedly from the transfer of research techniques from astrophysics to very different scientific fields.

2.3 The international, national and local contexts

To meet these challenges, our astrophysics “enterprise” in Switzerland pools resources to tackle projects that were unthinkable only a few years ago.

Switzerland contributes to the European Southern Observatory (ESO) and the European Space Agency (ESA) via an annual subscription. ESO and ESA provide an infrastructure for observational research that is the best, or equals the best, available worldwide. Swiss teams, that win observing time on these facilities with competitive peer-reviewed proposals, are guaranteed to be at the forefront of the global research in their field and reap the benefit from the Swiss subscriptions to these organizations.

ESO operates “night-time” telescopes for observational research at two sites in Chile (La Silla and Cerro Paranal), including two 4-m class telescopes and the four 8-m telescopes of the Very Large Telescope (VLT). The VLT is widely acknowledged to be the best ground-based optical-infrared observatory in the world. In addition to their superb performance as conventional individual telescopes, the four telescopes can be linked together interferometrically to form the unique facility of the VLT Interferometer (VLT-I). Looking ahead, ESO, the USA and Japan are building the 50-antenna Atacama Large Millimeter Array (ALMA) at a third site in northern Chile. All ESO facilities are open to Swiss astronomers through competitive observing proposals.

ESA operates similar open-access observatories in space including the XMM-Newton X-ray observatory, INTEGRAL, and in association with NASA, the Hubble Space Telescope (HST). In addition, ESA provides space platforms for Principal Investigator instruments built at Swiss institutes.

The facilities of ESO and ESA benefit all of us, from the largest scientific teams in the country down to individual graduate students working on their theses. As a result, Swiss astronomers are deeply involved in these international organizations, with active representatives on the major advisory committees that define their future scientific directions.

Summary statement 4

Switzerland’s memberships in ESO and ESA provide the basis for most of our experimental/observational astrophysical research. Swiss astronomers make effective and high-profile use of the common-user observational facilities of both ESO and ESA, as well as ESA space platforms for in situ space research.

The Swiss research community has a direct and sometimes disproportionate influence on the direction of ESO and ESA. Nevertheless, the decisions are ultimately made based on the aspirations of all the partners. This means that our community must retain a flexibility to respond to the changing international context in which we operate. We need a large spectrum of scientific interests, both individually and as a community, to ensure that we can best take advantage of the missions and facilities that are implemented by ESO and ESA.

The Swiss community has adapted well to this international environment. The collective European decision to go to Mercury with Bepi-Colombo led to a successful re-orientation of our research efforts. Building the VLT fostered new research projects in the existing community and attracted leading observational astronomers from abroad to Swiss universities, resulting in a dramatic increase in the utilization of the VLT by our community in the last few years. In the future, we anticipate ALMA’s completion with excitement even though we have not, in the past, had a major strength in sub-mm astronomy.

Similar issues will be faced in the future as ESA selects missions within its Cosmic Vision program for detailed study and eventual implementation. Swiss astronomers are involved in developing several such proposals, including DUNE, XEUS, Darwin and several competing concepts for planetary exploration. Swiss participation in these next generation missions will be shaped by the European-wide selection decisions that will define the Cosmic Vision program. This uncertainty requires us to retain flexibility in our planning.



Located atop the 2600m Cerro Paranal in Chile, the four 8-m telescopes of the European Southern Observatory's VLT system constitute the most powerful ground based observatory in the world in the visible and near-infrared wavebands. The telescopes may also be linked together as an interferometer. ESO

As the European research community becomes more integrated, not least through the initiatives of the European Commission, it will be important that Swiss astronomers are actively involved in the Europe-wide planning and consensus building exercises, such as the EraNet activity ASTRONET, in parallel to our involvement in and advocacy of ESO activities.

Finding 4

It is important that Switzerland participates in the growing co-ordination of scientific research in Europe, both in developing a common scientific vision and in planning for investment in large facilities.

Recommendation 4

The SER should participate, with appropriate community consultation, in European-wide planning forums such as the ERANET Astronet. It is important that these complement in a constructive way the strategic planning of the European organisations to which Switzerland belongs, such as ESO, the success of which is vital to the Swiss research community.

At the broadest international level, Swiss astronomers are active at all levels in the International Astronomical Union (IAU), founded in 1919 to preserve and safeguard the science of astronomy. There are 8900 members in 62 countries.

At the national level, we are represented by the National Commission for Astronomy and the National Commission for Space Research. The National Commission for Astronomy should be comprised of elected Professors and other community leaders, as we have done for CHAPS. These commissions are the appropriate forum for routine matters. However, for larger activities, such as the preparation of a national Roadmap, it is the broader CHAPS group that captures the full breadth of the community and vests a democratic legitimacy to any decision.

To maximize the return on the substantial Swiss investment in the international organisations, our community within Switzerland needs three core elements: (a) a strong scientific re-

search community in both experiment and theory which is necessarily spread over geographically separated institutes, (b) a strong technical infrastructure “in house” to develop advanced instrumentation, from conceptual design, through prototypes, to operational hardware, and (c) a healthy partnership with Swiss industry capable of building the final complex instrumentation, particularly for participation in space missions.

Most astrophysicists and the technical staff involved in astrophysics research in Switzerland are university faculty and staff. As such, they are hired based on the local priorities and needs of the individual universities and laboratories. The majority of the resources of the faculty, their senior staff and their technical support infrastructure come from their universities. The choice and development of research fields at the local level gives the Swiss community the valuable flexibility to respond to the changing international environment that we described above. On the other hand, there is also the danger that research areas or capabilities that are important within the national scene can be given up through purely local considerations.

Historically, the main technical laboratories have been UniGE for ground based instrumentation (e.g. the HARPS and PRIMA instruments), UniBe for planetary exploration missions and the PSI for space astrophysics (e.g. XMM-Newton, RHESSI, and now JWST/MIRI). The decision to terminate astrophysics at PSI may have a negative impact on future Swiss participation in space astrophysical missions. Maintaining and developing the technical competence that can be used to participate in space missions and sharing this across disciplines and between institutes is essential to Swiss astrophysics. This aspect is addressed more fully in Chapter 6.

Other institutions also have, or have the potential for, a national role over and above their purely local mandate. Systematically processing the data from large international facilities has become an important element in the chain leading to the scientific exploitation of complex instruments. Switzerland has been given the responsibility to provide this link in the case of ESA's γ -ray astrono-

my satellite INTEGRAL. The INTEGRAL Science Data Centre (ISDC) was created and developed in Versoix as part of the UniGE observatory. The ISDC has been operational since 2002 and has the capacity to contribute to the exploitation of other major astronomical facilities.

The increasing specialization of the scientific community can sometimes make it difficult to synthesize knowledge from space missions with that from ground-based observatories and from theory. For this reason, the International Space Science Institute (ISSI) was founded in 1995. Its main task is to promote a deeper understanding of the results from space-research missions, adding value through multi-disciplinary research in an atmosphere of international cooperation. The ISSI is organized as a foundation funded by both ESA and by Swiss sources. It has a small number of resident scientists and staff, but supports some 350 visiting scientists annually in Workshops and Teams. Topics are concentrated on solar system science but range from astrobiology to the study of the Earth from space.

Summary statement 5

The unique institutions of ISDC and ISSI add value to the Swiss research community, and to the Swiss contribution to ESA.

Solar astronomy in Switzerland is supported by institutes in Locarno and Davos, Istituto Ricerche Solari Locarno (IRSOL) and Physical-Meteorological Observatory Davos / World Radiation Center (PMOD/WRC). IRSOL houses a telescope facility that is used for spectro-polarimetric observations while PMOD/WRC develops instrumentation for space missions to record variations of the solar irradiance. A Swiss Virtual Institute for Solar Science (SVISS) promotes and coordinates the various activities in solar physics in the country.

ESO and ESA provide an infrastructure for observational research that is the best, or equals the best, available worldwide... Swiss teams, that win observing time on these facilities with competitive peer-reviewed proposals, are guaranteed to be at the forefront of the global research in their field.

2.4 A snapshot of Swiss astronomy in 2006

Table 1 shows the personnel employed in Swiss astrophysics as of June 1, 2006. There are about 270 astrophysical researchers, of whom 111 (40%) are students undertaking research for their PhD degrees. These will obtain employment not only in astronomy but in a wide range of fields where their analytic training is highly valued.

Less than 60 (22%) astrophysics researchers in Switzerland have “permanent” research po-

sitions, and there are over one hundred PhD-scientists on short term postdoctoral contracts and 110 PhD students.

About 110 non-astronomers work within our institutes as engineers and technicians working on instrumentation projects (75%) or providing secretarial, information technology or administrative support.

Table 1
Current employment in Swiss astrophysics (June 1, 2006)

	Elected Professors	Permanent Senior Scientific Staff	Non-permanent Scientific Staff (with PhD)	PhD students	Technical/engineering staff	Secretarial/Administrative (incl. IT support)	Total
University of Basel	2	2	6	15	1	1	27
University of Bern	4	5	22	22	26	5	84
UniGE/EPFL Joint Center	8	11	29	25	35	8	116
UniGE Physics	2	0	6	4	0	0	12
EPFL Physics	2	0	6	6	0	0	14
University of Zurich	2	3	6	10	2	1	24
ETH Zurich	3	2	11	24	4	4	48
IRSOL (Locarno)	0	2	0	0	1	0	3
ISSI (Bern)	0	3	4	1	0	5	14
PMOD/WRC	0	4	5	2	7	4	22
PSI	0	4	6	2	3	0	15
Total	23	36	102	111	79	27	377
Total Astrophysics Research Personnel				271			
Total Technical and Support Personnel							106

Finding 9

There are a number of areas where the institutional and funding structure in Switzerland produce a non-optimal development of personnel in research projects, and a difficult career path for young scientists.

Recommendation 9

The SNF should review the impact of (a) the short-term nature of SNF-funded post-doctoral appointments; (b) the general absence of mid-level long term positions in Switzerland; and (c) the difficulty of funding technical staff with SNF funds.

Table 2 shows the breakdown of funding for Swiss astrophysics in 2006. Astrophysics research is supported from many different sources. Through

their support of the universities, the Swiss cantons provide 37% of the funding for research.

Table 2
Current funding breakdown of Swiss Astrophysics

Source	Type	Amount per year (thousand CHF)
Cantons	University salaries	13,154
	University operating funds	1,843
	other salaries	2,040
	other operating funds	640
ETH domain:	salaries	6,849
ETHZ, EPFL, PSI	operating funds	1,541
SNF	Operating grants	8,254
	SNF Professors and Fellows	1,240
SER	ESO Subscription	6,677
Other Swiss	FINES fund	700
Federal Offices	Mesures d'accompagnement	2,410
	Various	300
ESA	PRODEX fund	6,451
	Other ESA funding	1,955
EU	FP6 and other programmes, Marie Curie Fellowships, EURYI etc.	2,166
Other sources		790
Industry		50
Total		57,060

Summary Statement 6

Local institutional funding is the bedrock for all other funding sources, not only providing many salaries but also seed funding for projects that then attract external funds.

Summary statement 7

SNF support of astrophysics is critical because it targets “fundamental science”, compared with many other sources that are tied to applied science and commercial applications.

Summary statement 8

Astronomy has an impact on applied sciences and industry, and has significant support from diverse funding sources, including Swiss Federal organizations for metrology, topography, and meteorology. Funding from European institutions and industry are also important. Private philanthropic funding has great promise, but it has not been developed in Europe to the degree that is seen in North America.

Building on a strong foundation Swiss astronomy in the past decade

Switzerland is a small country with a reputation for technological strength and scientific excellence. Although the astronomical community cannot (and should not) hope to be present in every sub-field of the discipline, Swiss research groups have established a strong international presence in many of the most current areas of research. These span

a broad spectrum within the field. This current strength and vigorous activity provides the foundation upon which the future directions of the community can be based.

In this Chapter, we survey the current activities and recent achievements of Swiss astrophysics.

The Swiss 1.2m Euler telescope, at ESO's La Silla site in Chile. Geneva Observatory



3.1 The Sun

We can explore the Sun in great detail, and can see its impact throughout the Solar System. Many astrophysical processes and tools that are needed for exploring and understanding the more distant Universe were initially developed in the nearby astrophysical laboratory of the Sun. The solar wind, eruptions and coronal mass ejections drive the highly volatile space weather that is a major concern for manned space flight. The magnetic variability of the Sun also influences its brightness that affects the Earth's ozone layer and the global climate in the troposphere.

The Sun as a star

The magnetic field of the Sun governs the structure, variability, and thermodynamics of the solar atmosphere. Cosmic magnetic fields in planets, stars and galaxies are generated by dynamo processes. Owing to its proximity and brightness, we can probe the sun's dynamo using polarimetry to study the magnetic field pattern down to the smallest scales at the limit of our spatial resolution. ETHZ's latest imaging spectro-polarimetry, ZIMPOL, has a polarimetric accuracy of about 0.0005% – nearly two orders of magnitude better than other systems. This has resulted in the discovery of the so-called “second solar spectrum” in polarized light, which has opened up new ways to explore solar magnetic fields, and in particular the very small scale fractal structure, and also to explore the fundamental quantum physics phenomena that govern the formation of astrophysical spectra. ZIMPOL's home base is at IRSOL in Locarno, but it also earns significant observing time on larger solar telescopes in the USA and Canary Islands.

Swiss astronomers have also made major contributions to helio-seismology. The modal structure of solar oscillations and the precise frequencies of the multitude of resonant modes are a result of the varying sound speed deep within the Sun, and therefore provide a probe of its physical structure. PMOD/WRC has been a major player in this field during the past two decades, most recently with its VIRGO instrument on the SOHO satellite. Astronomers at UniGE have also used this technique to model both the rotation profile and the surface abundance of lithium in solar-type stars of

various ages, and have shown how the rotational profile is coupled to the generation of magnetic fields in the star.

The heating of the solar corona to a temperature of millions of degrees and the enormous energy release in flares are both linked to the release of energy stored in the coronal magnetic field. Energy release also takes place in smaller but much more numerous events in quieter regions of the Sun, and these may be sufficient to account for the temperature of the corona as a whole. Radio observations at ETHZ have focused on meter to decimetre spectroscopy to study the narrowband “spikes”, suspected to be related to electron acceleration in solar flares, and the statistics of radio bursts.

RHESSI, a NASA Small Explorer satellite mission built partly at PSI and with a European Data Center maintained at ETHZ, observes the hard X-ray and gamma-ray emissions of solar flares with high spatial and energy resolution. RHESSI data have been used by PSI and ETHZ to determine the spectral characteristics and temporal fine structures of electron acceleration in flare regions and to study hard X-ray sources in the corona. The results have been consistent with stochastic acceleration by turbulent waves, excited by the reconnection process.

UniBe has also had a major presence in space missions that have explored, in situ, the physical conditions in the solar wind, in the heliosphere (e.g. the ISEE-3, Ulysses, WIND, SOHO, ACE missions) and in interplanetary gas (e.g. LDEF and COLLISA). This began with solar wind foil experiments put on the Moon during the Apollo era and their focus continues to be on the composition of the solar wind and interplanetary energetic particles. The measured particle abundances are directly related to the processes that heat the solar corona and to the mechanisms of particle acceleration on the Sun. UniBe is also currently involved in NASA's STEREO (Solar Terrestrial Relations Observatory) mission which is designed to obtain 3-D mapping of coronal structures and to advance our understanding of the origin, evolution and the consequences of coronal mass ejections.

The Cosmic Ray Group at the UniBe have also neutron monitors at Jungfraujoch and Gornegrat (SONTEL) to study proton, gamma-ray and

neutron emission from solar flares, cosmic ray propagation in the inner heliosphere, and the space weather.

Solar irradiance variability and its role for the global terrestrial climate

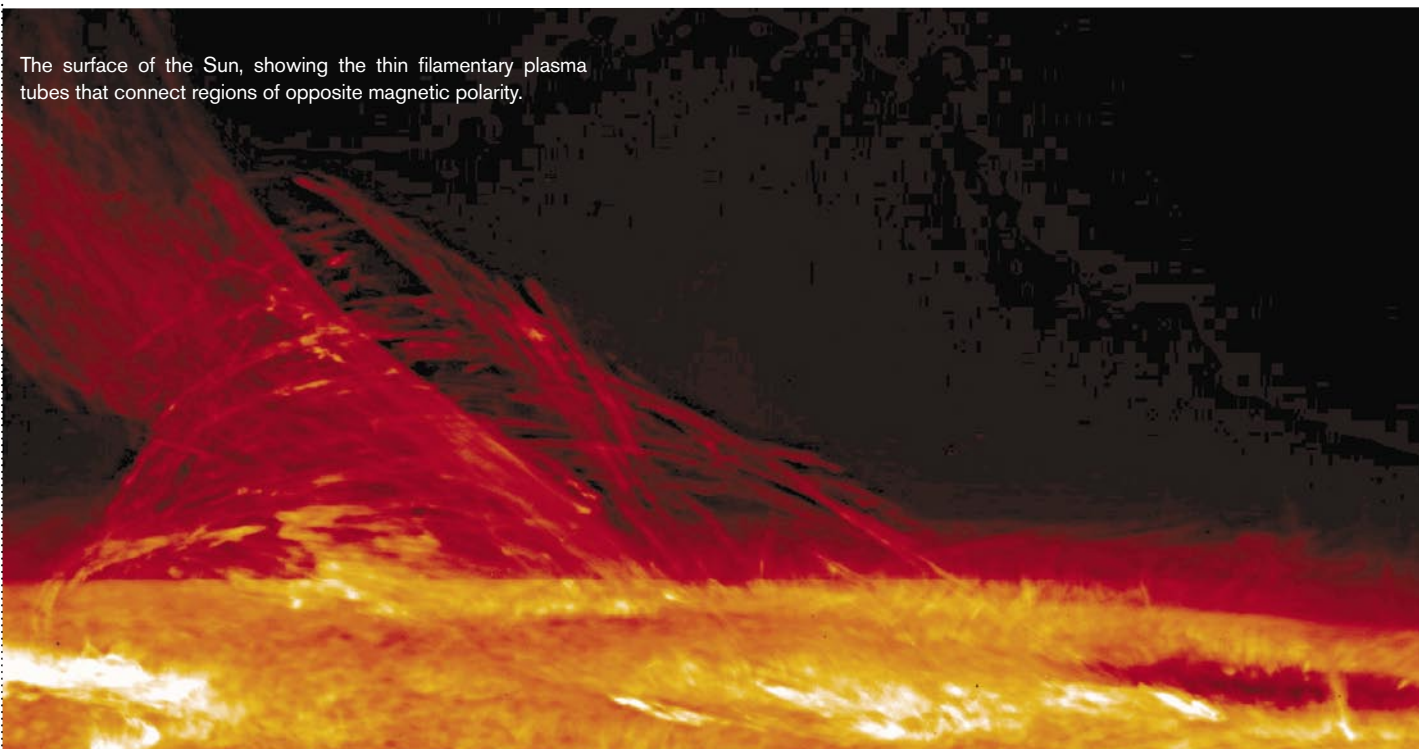
The magnetic activity of the Sun with its well-known 11-year cycle induces fluctuations in the energy radiated by the Sun. While the Sun's brightness varies by only 0.1% at visible wavelength, the variations can be up to 100% at ultraviolet wavelengths that shape the Earth's stratosphere, and by orders of magnitude at X-ray wavelengths.

The "Variability of the Sun and Global Climate" collaboration within Switzerland examines the impact of these variations through a close collaboration between PMOD/WRC, EAWAG, and the ETHZ Institutes of Astronomy and of Atmospheric and Climate Science. The astronomical part of this collaboration focuses on the physical origins of the solar irradiance variability owing to changes in the solar surface magnetic fields. A deep understanding of the internal structure of sunspots is important to predict variations of the solar irradiance and their effect on the evolution of the terrestrial climate. With

new tools, the solar irradiance in the more extended past can be reconstructed from other indices of solar activity. PMOD/WRC determines the solar irradiance variability in the deep UV part of the spectrum, accounting for various types of active features on the Sun (sunspots, faculae, networks). Space experiments to measure the solar irradiance such as LYRA/PROBA2 or PREMOS/PICARD were proposed and built by PMOD/WRC. The third partner in this project, the ETHZ Institute for Atmospheric and Climate Science, models the final impact on the Earth.

The level of solar activity in the past can be determined over time scales of thousands of years by using cosmogenic radio nuclides like ^{10}Be and ^{14}C that are produced by galactic cosmic rays in the terrestrial atmosphere. The Sun's magnetic activity modulates the propagation conditions in the heliosphere (the solar wind region), such that the abundance of ^{14}C in tree rings and ^{10}Be in ice cores contain imprints from which the level of solar activity can be extracted. The group at EAWAG has been a world leader in using such proxies for deducing the longer term variability of the Sun.

The surface of the Sun, showing the thin filamentary plasma tubes that connect regions of opposite magnetic polarity.



3.2 Solar System research

Fundamental astronomy

Precision studies of the orbital and rotational motion of the Earth, and of the Earth's gravitational field establish the basic reference frames for the Earth and other planets, and are needed for studying planetary gravity fields and flying space missions. Spacecraft orbital trajectories determine the high order moments of planetary densities, providing knowledge of planetary interiors. UniBe defines, establishes, and maintains the reference frames on Earth and in the sky, monitors the transformation between these frames and describes the motion of all celestial bodies with respect to these frames. UniBe also maintains a strong observational capability by using the Zimmerwald observatory to monitor the orbit of a number of satellites using laser ranging as well to search for and observe objects near to the Earth (satellites, space debris, near-Earth asteroids) as well as more distant objects in the Solar System, such as the Minor Planets in the asteroid belt and in the Kuiper belts, and comets. Highly accurate orbits for these objects are determined and their long-term evolution studied.

In situ exploration of the Solar System

In the 50 years since the first successful spaceflight, Solar System research has focused on understanding the physical processes that shaped our planetary system. In the last decade, this field has expanded to the study of potential habitats for present and past Life. We want to understand how our planet has evolved from its formation to the emergence of Life and to predict how it may change in the future. This research has two key elements; (a) solar-planetary/terrestrial interactions, and (b) Solar System exploration. Both need sophisticated lightweight experiments flown on spacecraft.

The interaction of the solar wind with the atmospheres of planets is important for their evolution and their habitability. The in situ study at the other terrestrial planets (Mars, Venus and Mercury) has been a focus of UniBe's participation in three ESA missions (Mars Express, Venus Express, and Bepi-Colombo to Mercury) and has relied on UniBe's development of novel techniques for

measuring energetic neutral particles. UniBe's COLLISA experiment on the Mir space station measured the He isotopic ratio in the local interplanetary medium, and led to participation in NASA's Interstellar Boundary Explorer (IBEX) mission to analyze the composition of the local interstellar medium.

The in situ analysis of the chemical and isotopic composition of different solar system bodies gives information on the physical and chemical processes that occurred during planetary formation and evolution. Comets are particularly interesting as they are virtually pristine, unprocessed, debris left over from the planetary formation epoch. UniBe led the development of the ROSINA experiment on ESA's comet rendezvous mission Rosetta, which was launched in March 2004. This is a set of two high resolution mass spectrometers that determine the composition of the gas emitted from the cometary nucleus. Together with scientific involvement in 4 other experiments on the mission, UniBe has a unique position in experimental cometary science.

The successes of NASA's recent rover missions to Mars, the Mars Pathfinder and Mars Exploration Rovers, raise the exciting possibility of a search for present or past Life on that planet. UniBe contributed the ASPERA-3 experiment on ESA's Mars Express, to study atmospheric mass loss. UniBe also participates in the high resolution imaging system (HiRISE) circling Mars on NASA's Mars Reconnaissance Orbiter (MRO). This spacecraft is searching for potential landing sites for the 2007 Phoenix mission that will carry an atomic force microscope built by the Swiss company CSEM. HiRISE will also investigate hydrothermal sources of astrobiological interest.

The remote observations and in situ measurements within the Solar System provide a wealth of precise information. Our theoretical ideas of planetary formation must account for these and for the broad diversity that has been observed so far amongst the extra-solar planetary systems that have been discovered.

3.3 Extra-solar planets and planetary systems

The landmark discovery in 1995 of the first extra-solar planets by Mayor and Queloz (UniGE) generated an unprecedented worldwide interest and sparked the fastest growing field of modern astronomy. In ten years, the detection and study of extra-solar planets and the search for Life outside the solar system has become the science driver of many individual team efforts as well as of some of the largest international ground- and space-based astronomy projects. It is remarkable that the current cornerstone of NASA's strategic plan in space science rests on Swiss discoveries.

Extrasolar planets

Starting in the seventies with the Coravel instrument, UniGE has the worldwide lead in high accuracy radial velocity measurements. The Elodie instrument installed at the OHP (France) and the Coralie instrument installed on the Euler telescope at La Silla (Chile) demonstrated the performance and efficiency of the cross-correlation technique adopted by UniGE. Elodie discovered the first extra-solar planet, 51 Peg and the two instruments together have detected more than 60 of the currently known planets.

The current generation HARPS instrument (built by a consortium led by UniGE and including UniBe) was installed on ESO's 3.6m telescope in 2003. With 500 guaranteed nights of observing time over a five-year period, it is comprehensively searching for Neptune mass planets. HARPS' most stunning discovery so far has been a triple system of Neptune-mass planets orbiting within 0.63 AU of their parent star. The group at UniBe has already developed a theoretical explanation of the formation of this remarkable system.

Planetary transits, together with radial velocity measurement follow-up, determine unambiguously planetary masses and radii (and hence their mean density). Ground-based surveys have so far discovered 9 transiting planets; UniGE is carrying out follow-up observations of transiting planets detected by the OGLE collaboration. Swiss institutes are also involved in the large SUPERWASP ground-based transit-survey program (UniGE) as well as in the Corot (CNES/ESA) space mission (UniGE, UniBe), launched in October 2006.

Ten years after the discovery of 51Peg, 180 extra-solar planets are now known with masses ranging from 7.5 to nearly 15 Earth masses. While all these planets have only been detected indirectly, the reliable determination of their orbital characteristics has overturned many ideas about planet formation that assumed that all systems would be similar to the Solar System. Swiss research groups lead many of the large efforts to understand planetary systems with new innovative hardware and advanced computational techniques to simulate formation.

Planet formation

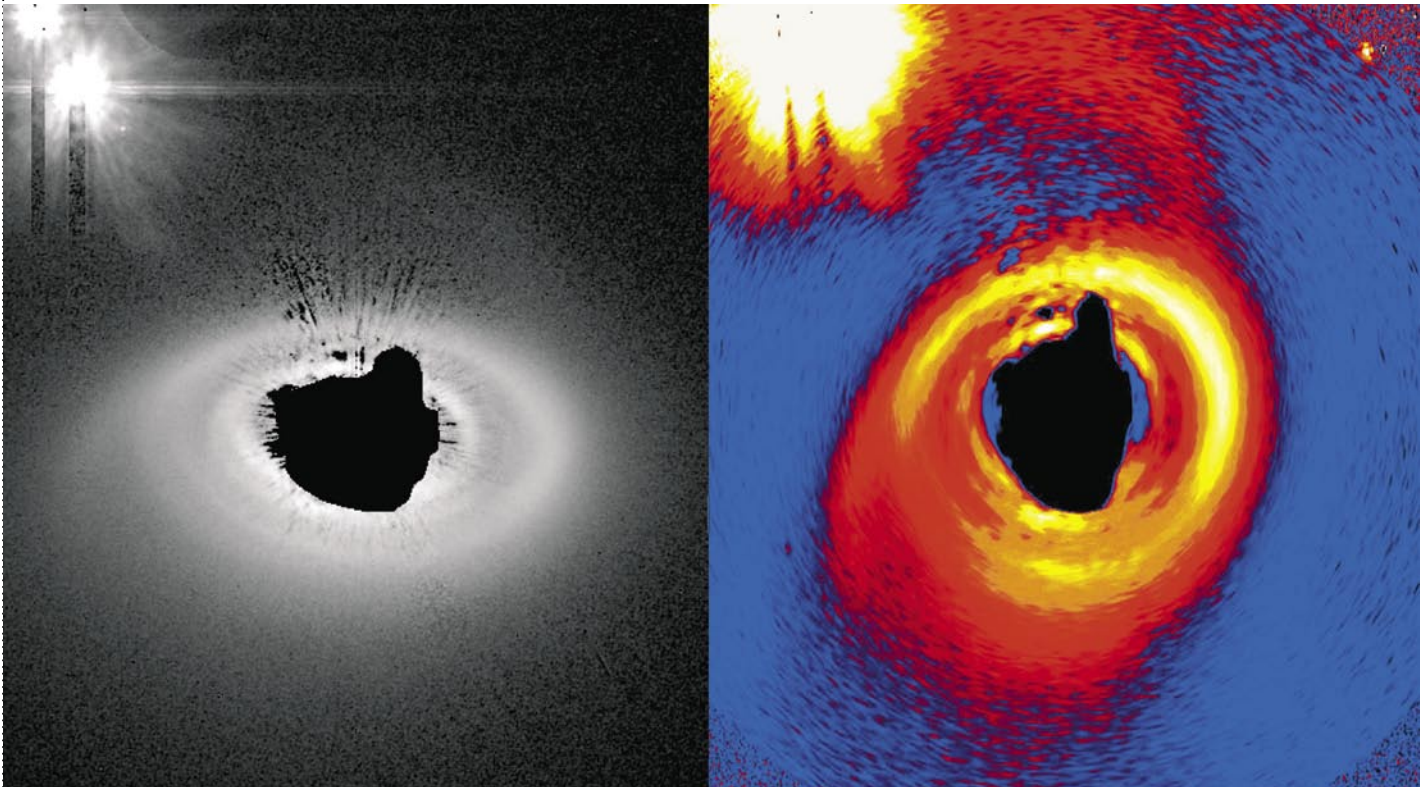
The growth of terrestrial planets and the cores of giant planets is being studied by UniBe and ETHZ/UniZH using two complementary approaches. The former group uses a statistical method based on a Monte Carlo scheme while the latter is attacking the problem with direct N-body integrations. UniBe uses large numerical simulation including fracture physics to study collisions during the growth of the planetessimals. Collisions and impacts are part of the planetary growth process, may form moons and control the size distribution and internal structure of small bodies in the present day solar system.

Numerical simulations address the most important aspects of impact processes that involve bodies of different internal structure, ranging from the gentle early agglomeration of planetessimals to the violent giant impacts that give birth to the Moon or to Mercury (UniBe). The model for forming Jupiter and Saturn by gas accretion onto a growing core was developed at UniBe. They have shown that it is possible to account not only for the bulk internal structure and composition of the planets (i.e. total mass, distance to the sun, mass of the core, enrichment in heavy elements) but also for the atmospheric composition, particularly of volatile species such as Ar, Kr, Xe, C, N, S. The core-accretion model has been extended to exosolar planets formation and evaporation in collaboration with ENS-Lyon (France). An alternate giant planet formation model, based on the gravitational instability of gaseous protoplanetary disks, has been studied with state-of-the-art hydrodynamical simulations at UniZH and ETHZ.

Planet formation is deeply connected to the physics of star formation (see section 3.4). Both ETHZ and PSI have recently worked on the physical conditions in proto-planetary disks to understand physical processes such as the role of X-rays from young stars in the complex molecular gas phase

chemistry of the inner regions of the proto-planetary disk and in determining the ionization state of the gas. These highly complex calculations are then compared with observational data of the abundance of molecular species.

Caption p.34: The Circumstellar disk around the young star HD141569, observed in visible light with the HST. The light from the central star has been removed by a coronagraph. The image to the left shows the system as observed, that on the right shows the disk as it would be observed from directly above. Planets form in such circumstellar disks, through processes which are at present poorly understood. Planet formation is probably associated with the asymmetries in this disk. NASA/ESA.



3.4 The Formation and Evolution of Stars and Stellar Populations

Stars are a very basic and highly visible component of the Universe with many outstanding questions: how do they form, how do they evolve, and how does their life-cycle end? How do they influence their surroundings, and what legacy do they leave when they die?

Star formation

Stars form in very cold, contracting clouds of molecular gas and dust – a nearby example being the Orion Nebula. Infalling material forms an equatorial accretion disk around the developing protostar for subsequent planet formation. The interplay between the accretion disk, stellar magnetic fields and the protostar's radiation induce a complex network of mass transport, heating of the surrounding gas and chemical reactions. Mass ejection from young stars stirs up the stellar environment out to distances of several light years. Astronomers at PSI have made major contributions to the study of high-energy processes and the evolution of magnetic fields around those youngest stars, especially exploiting the ESA XMM-Newton X-ray observatory, launched in 1999, to which PSI contributed components of the spectrometers.

Theoretical and observational studies of the complex chemistry in protostellar molecular clouds (ETHZ) are linked to the structure and composition of accretion disks by means of infrared observations (PSI). Numerical simulations of star-formation are also important. The PSI group have undertaken numerical simulations to determine the influence of magnetic fields on the disk stability while the group at UniGE numerically simulate the star-formation process including the accretion of material from the surrounding disk of material.

The lives of individual stars

How stars subsequently evolve after their formation depends primarily on their mass and chemical composition. The most widely used detailed models for the evolution of stars have been developed at UniGE. These cover the entire range of stellar masses, ages, chemical compositions, as well as previously neglected physical parameters such as stellar rotation. The results of these calculations

are compared to the surface temperatures and sizes of a large number of stars in the UniGE and UniBas databases, covering all phases of stellar evolution.

Key tests use more detailed information on stellar interiors from acoustical oscillations of the stellar surfaces that depend on the speed of sound within the star, a technique that was used for many years on the Sun. UniGE's advances in this new field of asteroseismology are due to the precision spectrographs Coralie on the Swiss EULER telescope and HARPS at the ESO 4-m telescope, both on La Silla in Chile.

Massive stars end their lives in extremely luminous supernova, or even hypernova/collapsar explosions when they eject their outer layers leaving behind a neutron star or black hole. Less massive stars collapse into planetary size, dense white dwarfs that are supported by degenerate electron pressure. Accretion onto these compact remnants can ignite explosive nuclear burning leading to novae, Type 1a supernovae or X-ray bursts.

Almost all of the elements heavier than Helium are created in the interiors of stars through thermonuclear fusion during the stars lifetime or rapid neutron capture during the final phases of stellar evolution. A major computational astrophysics effort at UniBas concentrates on stellar nucleosynthesis and on the explosive events associated with the late stages of stellar evolution, combining nuclear astrophysics with magneto-hydrodynamics and radiation and neutrino transport.

The formation and evolution of stars of very low metallicity present special problems, but are of great interest because the very first stars to have formed in the Universe (known as "First Light") must have been of this type. They would have had a major influence on the early formation of galaxies, both by producing the first chemical enrichment and by re-ionizing the Universe (UniBas and UniGE).

Stellar populations and Galactic astronomy

The evolutionary history of the Milky Way and its neighbours is being studied at UniBas using the large international survey programs of the Sloan Digital Sky Survey (SDSS) and the Radial Velocity Experiment (RAVE). Measurements of the radial velocity of stars in our own Galaxy and its near neighbours with the VLT give information on the underlying dark matter distribution, especially of very low mass galaxies, and have revealed extensive streams of stars that are fossil record of the merging of satellite galaxies with the Milky Way. These programs include the detailed study of the chemical enrichment, feedback and dynamical interactions of galaxies covering a wide range of masses.

UniGE and UniBas have also developed theoretical tools for the study of composite stellar populations. These evolutionary synthesis codes are combined with the latest chemo-dynamical galaxy models to analyze and interpret galaxy evolution as a function of redshift. The heavy elements produced in stellar nucleosynthesis enter the inter-

stellar medium in galaxies, change the composition of the star-forming gas and hence determine the properties and evolution of the subsequently formed stars. These tools are also useful to study the intense episodes of star formation, called starbursts, that play a major role in a wide range of astrophysical questions ranging from the formation of the first stars, cosmic re-ionisation, and our understanding of cosmic history of star formation and galaxy evolution.

“Micro-lensing” studies detect otherwise invisible compact dark objects by monitoring millions of background stars for rare alignments that lead to gravitational lensing and brightening (UniZH, EPFL). Such events have been detected by monitoring vast numbers of stars in the Milky Way Bulge, the Magellanic Clouds and the Andromeda galaxy. In one case, these lensing events have revealed the existence of a planet orbiting the lensing star.

3.5 High Energy Astrophysics

During the decades following the Second World War, mankind gained access to space. The new spectral windows that this access opened, revealed a far more diverse range of objects in the Universe than had been seen from the ground. Among these were the bright X-ray sources discovered in the early 1960's that opened up the new field of high energy astrophysics and led to the Nobel Prize for Physics in 2002. High temperature plasmas in groups and clusters are the dominant reservoir of baryons in the Universe and are best studied in the X-ray band.

Material in the neighbourhood of collapsed objects such as neutron stars and black holes moves at relativistic speeds and interacts with the very strong magnetic fields associated with the collapsed objects, causing them to radiate at a broad range of frequencies. To understand these exotic objects, we need observations over many decades of frequency within the electro-magnetic spectrum, from radio waves to gamma rays, and direct measurements of the high energy particles in the form of cosmic rays.

Very high energy gamma ray observatories have seen a number of galactic and extra-galactic sources, thus extending the observed spectral domain by several decades of energy. In the future the measurements obtained through electro-magnetic radiations of all energies from radio waves to very high energy gamma rays will be complemented by measurements obtained through gravitational radiation and neutrinos.

High temperature plasmas are ubiquitous in the Universe and X-ray instruments therefore have a scientific application across a very broad range of astrophysics.

In Switzerland important contributions to high energy astrophysics have been made in Geneva and in the Zurich area. PSI developed instrumentation for the XMM-Newton large X-ray observatory of ESA and the RHESSI solar gamma ray observatory of NASA. The group at PSI for instance has used both XMM-Newton and RHESSI to study X-ray emission from the Sun and other normal stars. The study of active galactic nuclei has been a major impetus for the development of high energy astrophysics at UniGE. This then led to the establishment of the ISDC in Versoix. Scientists at the ISDC also contribute to the scientific exploitation of these data in the field of active galactic nuclei and galactic high energy sources. The discovery of many sources that were not known previously from observations in the softer X-ray domain has revised the census of high energy sources in our Galaxy.

In Zurich, the particle-physics group in the ETH Institute for Particle Physics are partners in the very high energy γ -ray telescope MAGIC. Finally, all the data from ESA's γ -ray satellite INTEGRAL are processed at ISDC.

In the area of gravitational waves, the UniGE group is involved in the data analysis of the EXPLORER and NAUTILUS experiments and participates in the VIRGO collaboration. Swiss leadership for the LISA project is at UniZH.

3.6 Extragalactic astrophysics and cosmology

In the last decades, we have improved our knowledge of the Universe beyond our Galaxy almost beyond imagination. This has been the largest growth area of the Swiss professorate in the last five years, with seven new Professors appointed at ETHZ, EPFL, UniBas and UniZH – six of these occupying newly-created chairs in astrophysics.

This progress has been driven by a new generation of observing facilities, including 10m-class telescopes (notably the ESO VLT and the US 10-m Kecks), radio telescopes in the sub-mm waveband, such as the 15-m JCMT and in the future ALMA, the NASA Great Observatories space program (Hubble Space Telescope, Spitzer Infrared Telescope, Chandra X-ray Observatory, Compton Gamma Ray Observatory) and the equivalent ESA missions XMM-Newton and INTEGRAL. Equally important have been the extensive sky surveys, such as the Sloan Digital Sky Survey, coupled with new measurements of the microwave background from the ground and space.

The formation and evolution of galaxies and large scale structure

The progenitors of galaxies similar to our own can be studied out to $z \sim 6.5$, corresponding to a look-back time of more than 90% of the age of the Universe (UniGE and ETHZ). We have local samples of 10^6 galaxies that put the properties of galaxies at the present epoch on an unprecedentedly strong statistical footing. New connections between the evolution of galaxies and their super-massive black holes have been identified though still poorly understood, and new tools, such as gravitational lensing, have proven to have applications well beyond those originally expected.

We now understand that the formation and evolution of galaxies is intimately linked to the underlying cosmology, and represents an interplay between the dominant dark matter and the more familiar baryonic matter.

Strong Swiss research programs focus on many aspects of this. Scientists at UniGE, EPFL, UniZH and UniBas have worked on characterising the mass distributions within galaxies, UniBas using data from the Sloan Digital Sky Survey (SDSS) for this purpose. Major focuses at ETHZ are the

properties of galactic nuclei, including the central star-clusters and super-massive blackholes, using the Hubble Space Telescope, and the study of how and why galaxy properties depend on the surrounding environment, through the ZENS Large Program being carried out at ESO. UniZH focuses on the central density structure of dark halos using lensing and the dynamics of stars and gas.

The most luminous galaxies in the local Universe, the Ultra Luminous Infrared Galaxies (ULIRGs), are studied by ETHZ using the 15m JCMT mm wave telescope to characterise the gas and understand why they form stars 100-1000 times faster than the Milky Way. These observations provide clues to the ULIRG's evolutionary state and serve as a benchmark for future ALMA surveys.

ETHZ is a major partner in the global COSMOS consortium to survey a distant volume comparable to the "local" SDSS. This project combines observations over a wide range of wavelengths to generate a galaxy census when the Universe was less than a half of its present age. The goal is to understand the physical processes that shaped galaxy evolution over cosmic time, and in particular to understand how galaxies interact with their environments and their central black holes. They have developed novel tools for the automated and systematic classification of the images and automated estimation of redshifts from photometric data. It also leads the zCOSMOS observing program to measure spectroscopic redshifts for some 40,000 galaxies throughout the COSMOS volume, the largest ESO VLT research program to date (600 hours). This provides the crucial third dimension to probe the evolution of structure on scales from galaxy groups to the 100 Mpc scales of the cosmic web.

Most baryons in the Universe are outside of galaxies in an intergalactic medium of diffuse warm (105 K) to hot (108 K) gas. Galaxies exchange material with this reservoir through the accretion of cooling gas and the subsequent ejection of gas heated by supernovae or active galactic nuclei. ETHZ has developed new techniques to study this intergalactic component of matter including fluorescent emission and the Faraday rotation of background quasars by the magnetized plasma.

Numerical simulations

With exponential gains in computational power coupled with even greater advances from new algorithms, we compute the complex nonlinear formation and evolution of structure in the Universe and make detailed comparisons with observational data. Researchers who are now at UniZH were key players in the original Beowulf project that put supercomputing onto the consumer price curve (using PCs and networks to build powerful parallel supercomputers). The first Beowulf in Switzerland was built at UniGE in 1998. The current generation of zBox computer systems at UniZH are among the most powerful systems in Switzerland, and the world.

Newer, more powerful, numerical simulations carried out at UniZH, ETHZ and UniGE show how the dark matter and gas build galaxies and how galaxies evolve by internally and externally driven processes. The UniZH group realized that when small galaxies fall into clusters, they are subject to strong shocks from the fast flyby collisions of large galaxies. These elevate the star formation rate leading to the puzzling excess of blue galaxies in clusters first discovered in the 1970s. To perform these simulations, they made ground breaking advances in the area of parallel computing that has permitted the use of the world's largest computers, sometimes for simulations that took up to 1,000 hours on 512 processors. As a result, these simulations set many records in supercomputing and provided new insights into the formation and evolution of large scale structure.

Numerical hydrodynamical simulations can follow the formation of purely gaseous structures such as the intracluster medium in rich clusters of galaxies. The role of shocks and magnetic fields in heating particles in the intracluster medium is studied at ETHZ with an aim of understanding the origin of cosmic rays and their role in heating of the intergalactic medium.

Early Universe cosmology

For the first time, we have both a quantitative model for the Universe as a whole and an emerging self-consistent physical paradigm for structure formation in the Universe. The Universe contains about 4%

baryons, 20% Cold Dark Matter and 76% Dark Energy of a yet mysterious form. Density fluctuations, of a nearly scale-free nature and probably introduced during an initial inflationary stage in the expansion of the Universe, grow through gravitational instability to form the structures seen in the Universe today – galaxies, clusters and the filamentary structure of the cosmic web. There are active groups in theoretical cosmology (UniGE, EPFL and UniZH) who study the very earliest phases of the Universe. These may provide insights into quantum gravity, the 'missing link' in a consistent framework of physical interactions. These groups also investigate braneworlds, the idea that our Universe may be a 3+1 dimensional sub-manifold of a higher dimensional space-time, phase transitions in the early universe, theoretical models of inflation, dark energy, and dark matter, and the generation and evolution of cosmic magnetic fields.

Summary statement 1

This comprehensive review of Swiss astrophysics has led to renewed appreciation of the breadth and interconnectedness of astronomy, and convergence on four emerging science themes – simply encapsulated as our Physics, our Origins, our Neighbours and our Home.

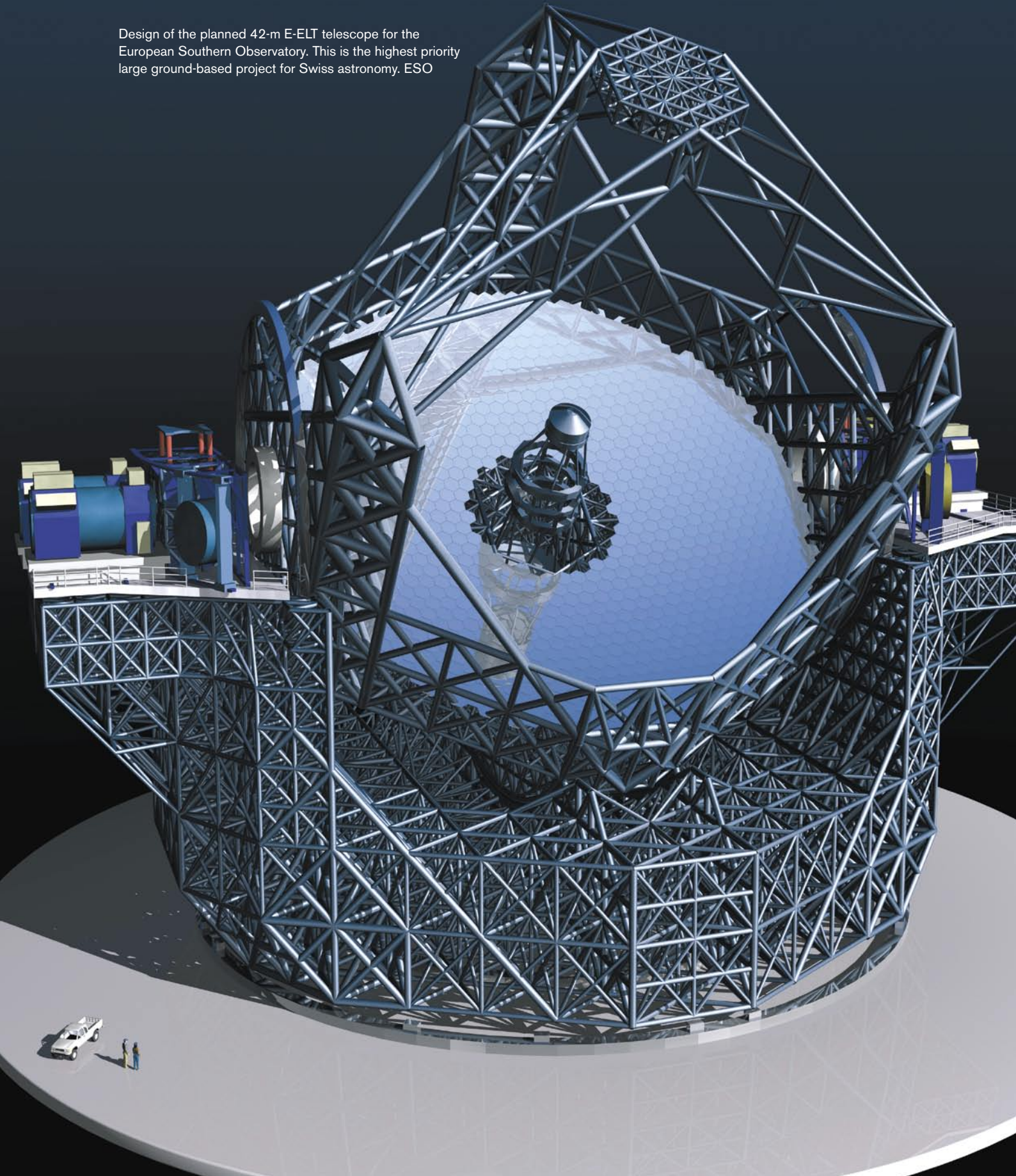
Summary statement 2

Swiss astrophysics leads the world in key areas. While it is best known for the discoveries of exosolar planets, there is excellence and international leadership across a broad range of astrophysics. The annual Saas-Fee course is an outstanding success and also contributes to the high international reputation of Switzerland in astronomy.

Summary statement 3

Collaboration between institutes across the country has strengthened our research community and offers a solid basis for future growth. Stimulated by this Roadmap review, the Swiss community is establishing ad hoc research networks to develop collaborative and synergistic research.

Design of the planned 42-m E-ELT telescope for the European Southern Observatory. This is the highest priority large ground-based project for Swiss astronomy. ESO



The future scientific development of Swiss astrophysics

Astronomy is a broad science with roots in physics and broad connections with the Earth sciences and other branches of Science. It derives strength from its broad philosophical and educational implications for society in general.

Astronomy in the 21st Century cannot be boiled down to one or two questions. Nevertheless, with the limited resources of a small country, we must focus the activities of our research community on a limited number of themes that simultaneously address important research topics and interest society at large.

In this chapter we review in more detail our four broad themes, identified in Chapter 1, highlighting those particular facilities and projects that will have the largest impact.

All of these research fields are challenging and will progress globally through national and international collaborations. In this Chapter, we emphasize the contributions and roles that we in Switzerland should make.

Some of these projects will not require substantial new capital investment, because they use the common facilities of ESO and ESA, or because they are based on existing international partnerships. These projects will require organization and manpower, and operating support from Swiss granting agencies (SNF). Others will also require in addition significant future capital investment, especially from the FINES and PRODEX and the Mesures d'accompagnement funds.

Graduate students in astrophysics at the ETH Zurich.
ETH Zurich



4.1 Theme 1 Fundamental Physics

Astrophysics is deeply entwined with fundamental physics. Astrophysics can be either the application of physical law to cosmic phenomena, or the use of cosmic phenomena to provide insights into physical laws. Newton's great insight was that the physics in the cosmos was the same as the physics on the Earth, and his "Universal Gravity" is still at the heart of the connection between physics and astrophysics.

Astrophysical environments can be so extreme that we can examine, in Nature's own laboratories, physical conditions that are completely unattainable on Earth and thereby learn about the nature of the fundamental forces of Nature. The solution of the "solar neutrino problem" in terms of neutrino oscillations is a very good example. Astronomical systems are also the only way to test gravity theory in the case of strong fields.

The revolution in cosmology from the last decade has left us with the most basic questions:

- what is the dark matter, what is the dark energy and why do such different components as baryons, dark matter and dark energy all have similar densities today despite having radically different equations of state?
- why is there an asymmetry between matter and anti-matter in the Universe?
- what produced inflation in the early Universe and what caused the spectrum of density fluctuations that subsequently grew to be the large scale structure in the Universe?
- what can we learn about astrophysical objects via gravity waves and is there a cosmological background of gravity waves which contains information about the very early Universe?

The answers to these questions will require new physics beyond the "standard model" of particle physics. Ultimately they may be answered with new theoretical insights, guided perhaps by terrestrial physics experiments, or by new cosmological measurements by astrophysicists. The astrophysical approaches continue to offer excellent opportunities to further refine our empirical understanding of these profound phenomena.

The answers to these questions will require new physics beyond the "standard model" of particle physics.

The Dark Matter

In 1933 Swiss astrophysicist Fritz Zwicky discovered that clusters of galaxies were unusually “dark”, with a hundred times more mass than expected from their luminosity. The dark matter dominates the matter density of the Universe. It cannot be “normal” baryonic material (i.e. protons, neutrons and their associated electrons) that is simply not luminous, because this would produce an inconsistency with both the abundance of light elements in the early Universe, and with the fluctuations in the cosmic background radiation. The dark matter clearly interacts normally gravitationally but must interact weakly, if at all, in other ways.

A most exciting prospect is to detect the dark matter directly in one of four possible ways – by seeing the elastic scattering of a dark matter particle in a terrestrial laboratory detector, by detecting an unidentified γ -ray signal from the annihilation of dark matter particles in the densest regions of dark matter haloes, by searching for a line in X-ray spectrum originating from radiative decays of dark matter particles in dwarf spheroidal galaxies or by producing or inferring a particle of the right properties in accelerator experiments (or in cosmic ray showers in the upper atmosphere).

Dark matter has been characterized as “cold” (in a technical sense) because we know that it first clusters on very small scales and then larger objects grow hierarchically to produce galaxies and ultimately clusters of galaxies. This hierarchical assembly occurs from a scale free initial power spectrum of fluctuations that is predicted by inflationary theory and has been observed in fluctuations of the microwave background. The combination of “cold” and scale free fluctuations is known as the Cold Dark Matter (CDM) model. CDM has been a phenomenally successful theory on the scales of clusters of galaxies and above and much of the focus is now on smaller scales. Numerical simulations (UniZH) suggest that the predicted internal structure of the dark haloes of galaxies may be inconsistent with kinematical and lensing observations (UniBas, UniZH). The theory predicts rapidly rising densities at the center of the dark halo (“cusps”) whereas the observations all point toward a plateau in the central density (“cores”). There are also possible dis-

crepancies in the number of sub-structures found within larger dark matter haloes.

The number of these „sub-haloes“ agrees well on cluster scales, but there appear to be too few sub-haloes on galactic scales – e.g. there are not enough dwarf galaxies around the Milky Way.

Dark sub-haloes could be detected via their gravitational lensing effects. Collectively, these problems are known as “the small scale crisis”: they may be pointing towards a new development in the theory. There have been interesting ideas: a lower mass limit to substructure associated with a mass of the dark matter particle in the warm dark matter (WDM) regime, as in the sterile neutrino model developed at EPFL, or of a significant self-interaction of the dark matter particle. Constraints on the small scale power, and thus on the properties of the dark matter particle also come from analysis of fluctuations in the matter field sampled by observations of Lyman- α absorption in the spectra of quasars (UniZH).

The mass distribution in the Universe produces detectable shearing distortions of the images of background galaxies. These have been detected both in the strong regime around large clusters of galaxies and, statistically, in the general field. The combination of the DUNE satellite and Large Panoramic Surveys on the ground (see the next section) will characterise the dark matter distributions around cosmic structures with unprecedented accuracy enabling the density profiles to be determined. These in turn can be used to detect or constrain the degree of self-interaction of the dark matter, an important clue as to its nature.

The equation of state of the Dark Energy

The dark matter seems almost familiar compared with the startling discovery from the last decade: most of the Universe isn't even “matter” at all, but a form of dark energy that accelerates the Universe, reversing the deceleration expected from the gravitational pull of matter. Our best estimate of the current cosmic constituency is 76% dark energy, 20% dark matter and 4% normal “baryonic” matter. Repulsive gravity was always possible in General Relativity, Einstein's “Cosmological Constant” being the earliest case explored. The mod-

ern view of gravitational repulsion is that it arises from an equation of state for an energy field that leads to a negative pressure or tension: the so-called “dark energy”. The relationship between the tension and the energy density is the “equation of state parameter”, w . Einstein’s Cosmological Constant is the special case of $w = -1$. We know so little about the dark energy that measuring its equation of state parameter has a high importance.

There are four main astrophysical approaches to the determination of w that are based on either (or both) the determination of the redshift-distance relation or the growth of structure in the Universe, both of which depend on the equation of state. These are:

- Refinement of the magnitude-redshift relation, the most promising method is to use a large number of Supernovae of Type 1a in the redshift interval $0 < z < 1.5$
- Lensing tomography: measurement of the image shear in background galaxies due to weak-lensing by gravitational structures along the line of sight as a function of redshift.
- Baryonic acoustic oscillations: features seen in the microwave background at $z \sim 1000$ can also be measured in the spatial correlation function of galaxies. This provides a large dynamic range for the relationship between size and angular diameter that depends on the evolution of the Universe set by w .
- $N(z)$ of clusters: measurement of the change in number density of collapsed objects on the most massive scales ($> 10^{14} M_{\odot}$), e.g. through the identification and redshift measurement of very large samples of X-ray or Sunyaev-Zeldovich selected clusters over $0 < z < 1.5$. The freezing of growth of structure by the transition to an accelerated expansion is governed by w .

Each of these requires a massive observational effort to achieve the required statistical accuracy free from systematic uncertainties. Fortunately, the four approaches are quite independent and will be

limited by different potential systematic effects.

In addition, all four approaches need the same sort of observational data, namely, deep and very wide angle surveys of the distant Universe. To achieve a useful precision ($\sim 1\%$ in w) we need a sample of approximately one billion galaxies with photometrically estimated redshifts good to a few percent. This can be done with a multicolour imaging survey of one quarter of the whole sky down to about the 25th magnitude. Such a ground based survey must be complemented by an all-sky space imaging survey to yield the image quality necessary for the gravitational lensing work. The international community is starting to organise to undertake these Large Panoramic Surveys (e.g. the joint ESO-ESA working group on “Fundamental Cosmology”).

Several groups in Switzerland will participate. EPFL and UniZH have expertise in gravitational lensing, while ETHZ is a leader in the derivation of photometric redshifts and the undertaking of very large spectroscopic surveys, which will be required to support and calibrate the photometric redshifts, through its involvement in the 2 deg^2 COSMOS and zCOSMOS surveys.

One specific concept for the space imaging survey is DUNE, which will be proposed for study under ESA’s Cosmic Vision program by a large European consortium including EPFL and ETHZ. As well as the determination of w , the combination of DUNE with a massive ground-based photometric and spectroscopic survey will provide an extraordinary dataset for the study of galactic evolution, being over a thousand times larger than COSMOS. In fact, since it will cover an appreciable fraction of the whole sky, these surveys will be an “ultimate resource” that will be fundamentally limited by the size of the observable Universe, a kind of cosmic “genome”.

Testing Inflation

Inflation is a period of rapid acceleration in the early Universe ($< 10^{-35} \text{ s}$) that is postulated to account for a number of features of the Universe, including its longevity and large size and the near “scale-free” spectrum of density fluctuations within it. During Inflation, the ubiquitous quantum fluctuations are am-

plified and finally freeze in as classical density fluctuations. These fluctuations grow via gravitational instability to become the observed cosmic structure of galaxies, clusters, filaments and voids. In the inflationary scenario, the smallest quantum fluctuations give rise to the largest structures in the Universe.

At present we have neither a well-motivated and tested theory of inflation nor even the basic physics at these very high energies, which are more than 10 billion times higher than the energies that will be reached at CERN's Large Hadron Collider (LHC).

An inflationary phase can originate from string theory, in braneworld models or in simple scalar field models motivated by Grand Unified Theories of physics. All these ideas lead to specific predictions that can be tested experimentally, especially using the anisotropies and polarisation of the cosmic microwave background (CMB), but also by other cosmological data sets. Already now, data is starting to favour a $V = m^2\phi^2$ model for the inflation potential rather than the $V = \lambda\phi^4$ potential considered earlier. More decisive test will come from measurements of the so called B-mode polarisation of the CMB induced by gravity waves. These are also generated during inflation in very characteristic amounts and with a spectrum depending strongly on the model of inflation.

Continuing Concordance: measurement of H_0

The current "concordance" cosmological model has achieved something that has been illusive for years: it is observationally self-consistent with essentially no observational discrepancies. The problem is that we don't understand the most fundamental things about it. For clues to the next theoretical breakthrough, cosmologists must search for those discrepancies that show where the current paradigm is failing.

One way to do this is to measure the fundamental parameters of the Universe with greater precision. While some cosmological parameters have errors of only 1-2%, the basic Hubble constant that describes the current expansion rate of the Universe is known to only about 10%. One promising way to reduce this is by measuring the

properties of quasars that are so strongly lensed that we see multiple images. The time delays between the images are proportional to the image separations and the age of the Universe (i.e. the expansion rate). EPFL, UniGE and UniZH are all involved in COSMOGRAIL, the COSmological MONitoring of GRAvitational Lenses. This project will use an international network of telescopes to monitor 30 lensed quasars for 5 years to get to the targeted accuracy.

Gravitational Waves and tests of Gravity Theories

Gravitational waves are a natural consequence of General Relativity. They have already been indirectly detected in the binary pulsar, a system of two neutron stars in a close orbit that decays at precisely the rate expected. Direct detection of gravitational waves will open a new window to testing General Relativity in strong gravitational fields and provide a unique census of collapsed objects. Detection of a gravity wave cosmological background would probe exotic physics in the early Universe.

The detection of gravitational waves is extremely challenging as it requires distance measurements to the extreme precision of 10^{-22} . The best approach is laser interferometry between free-flying spacecraft that are in perfect free-fall. The Laser Interferometer Space Antenna (LISA) is a joint NASA and ESA mission planned for launch in 2016. LISA will detect waves generated by binaries within the Milky Way Galaxy and by massive black holes in more distant galaxies. The LISA Pathfinder mission, an ESA Technology Demonstrator Mission, planned for 2009, will test the novel drag-free and attitude control technology needed for LISA (ETHZ Geophysics and UniZH).

Other tests of Gravity come from the ultra-precise measurement of distances within the Solar System, i.e. currently from the Earth to the Moon. The development of laser transponders (UniBe) will allow the extension of this work over much longer distances, e.g. to the neighbour planets, which in turn will allow tests of gravity at an unprecedented level of accuracy.

4.2 Theme 2

Origins: stars, galaxies and the evolving Universe

We live in a Universe that changes with time as structures form, evolve and in some cases “die”. As we describe astronomical phenomena, we see a complex and interwoven web of related events and processes that produce the self-consistent view of why the Universe appears as it does. We can no longer hope to understand phenomena in isolation; rather they must be understood in the context of how the Universe has coevolved. The traditional boundaries between solar, stellar and extragalactic astronomy are fading gracefully.

Essential questions to be answered in the next decade include:

- What were the first luminous objects to form in the Universe and when did they end the “Dark Ages” and re-ionize the Universe?
- How was material assembled into galaxies, and how does the dark matter and baryonic material interact? What controls the rate at which galaxies form stars through cosmic time?
- How does star formation start in molecular clouds within galaxies and what determines the masses of stars?
- What happens during supernova explosions and what is the origin of the Gamma-Ray Bursts (GRBs), the most powerful explosions in the present-day Universe?
- How do supermassive black holes form in the centres of galaxies and how is their development linked to that of the surrounding galaxy?

Partial answers may come from the current generation of large telescopes, but many will require the future telescopes and instruments that are being designed and built to address these questions. Sophisticated numerical simulations will also be an increasingly important element of the confrontation between theory and experiment.

Star-formation

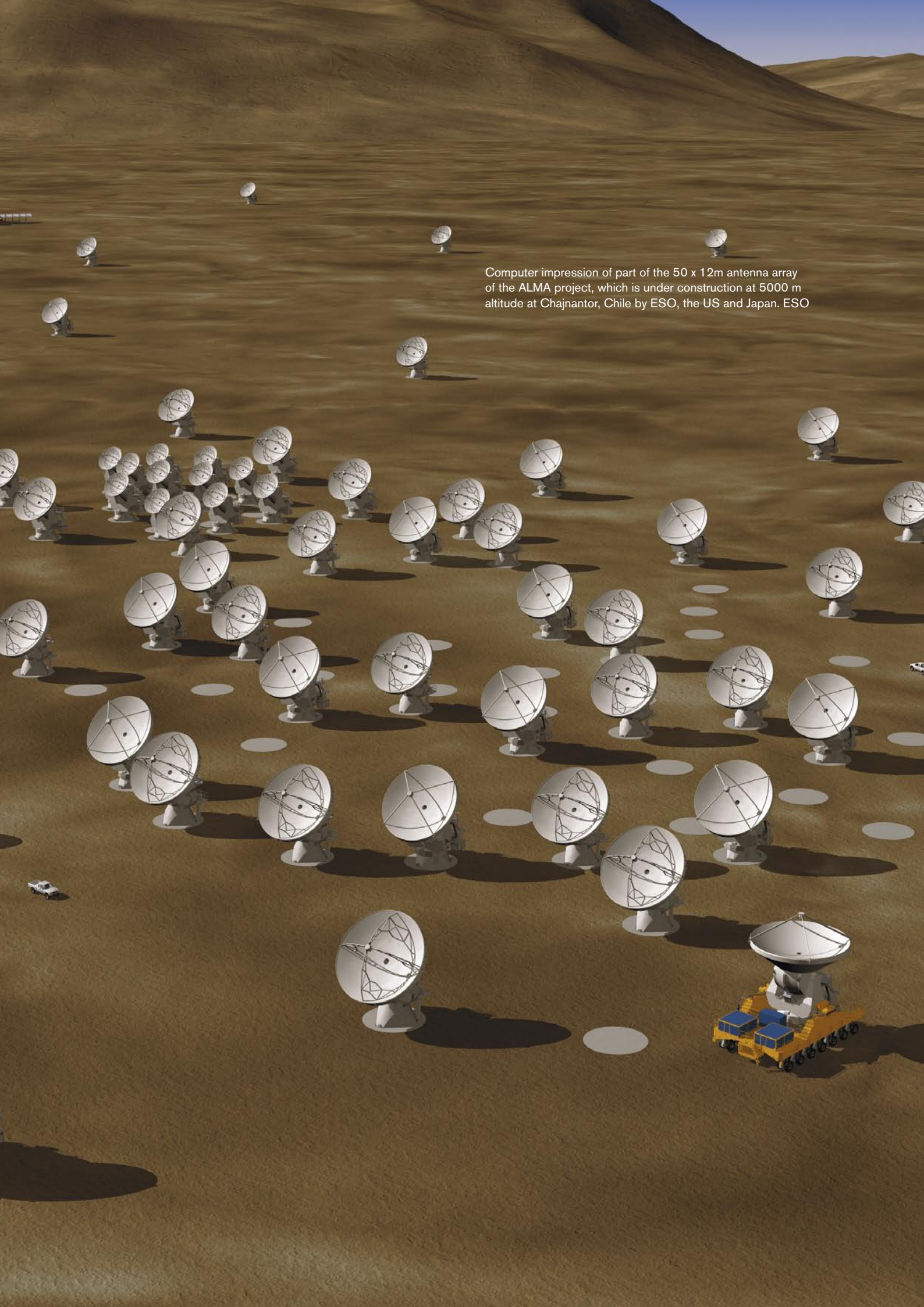
Most studies of star-formation require observations at long wavelengths because star forming regions are cool, and shrouded by dust causing visible light to be absorbed. The next decade will

see a revolution in our capability to make observations at the long wavelengths where spectral lines from molecular transitions penetrate the dust, revealing the physical state of this cool material.

The central question in star-formation is what regulates the distribution of masses of the stars that form. The mass of a star affects all aspects of its structure and evolution, including its temperature and luminosity, the production and release of heavy elements, and the nature of final collapsed objects. It is a major factor in the habitability of any associated planetary system. The formation of massive stars holds particular puzzles. The modelling of such systems (UniGE) will require the development of complex hydrodynamic models with radiation transport that include core collapse and accretion disk physics.

In 2008, ESA will launch the Herschel observatory with the HIFI spectrometer built partly by ETHZ. Although it is above the atmosphere, and thus able to observe H₂O and other otherwise inaccessible molecular species in star forming regions, the 3.5m Herschel telescope will have spatial resolution limited to at best a few arcsec. In contrast, the ALMA array of 50 12-m millimeter-wave telescopes with an interferometric baseline of up to 14 km being built by ESO, the US and Japan at 5000m altitude in Chile, will observe star forming regions at 0.01 arcsecond resolution, corresponding to just a few Astronomical Units (the Earth-Sun distance) in nearby star-forming regions. It will resolve structure in protoplanetary disks, in the disk-star interaction region, and in the outflow acceleration region. Herschel and ALMA will be highly complementary.

In the longer term, the 6.5-m NASA/ESA JWST offers corresponding gains in sensitivity and angular resolution at mid-IR wavelengths ($\lambda < 28.5 \mu\text{m}$). Its MIRI instrument (built partly by PSI) will be ideal to study accretion and jet formation around young stellar objects and to map the mineralogy and structure of associated protoplanetary disks, including the presently almost unobservable molecular Hydrogen emission. At slightly shorter wavelengths, JWST will detect and study the low mass end of the mass distribution of stars produced in star-formation regions. In the more distant



Computer impression of part of the 50 x 12m antenna array of the ALMA project, which is under construction at 5000 m altitude at Chajnantor, Chile by ESO, the US and Japan. ESO

future, the ESO E-ELT will also have a major role to play with its phenomenal light gathering power and high spatial resolution.

ALMA, Herschel and the JWST will all be observatory-style projects that are open to the whole Swiss community through competitive proposals. A substantial Swiss user community for these facilities should develop from the existing groups interested in star formation at ETHZ, UniBe, and UniGE strengthened by new faculty recruitment.

Stellar evolution

The overall goal of stellar modelling at UniGE is to produce accurate evolutionary tracks of stars from formation through the final stages of stellar collapse, for a full range of chemical compositions and a wide range of single and binary star environments. The main improvements will be 2-D and 3-D numerical hydrodynamical models of the transport of angular momentum and heavy elements through instabilities and gravity waves. This mixing of their interiors may substantially modify the tracks near the explosive endpoints. The interactions between stars in binary systems has a major, but still poorly understood, impact on the final stages of stellar evolution.

The ESA Gaia satellite, with an anticipated launch in 2011, will lead to a dramatic improvement in many aspects of stellar research through the enormous volume of astrometric, photometric and spectroscopic data that it will produce. Gaia will determine astrometric distances and proper motions for more than one billion stars. Ushering in a new era of stellar photometric data processing, UniGE will establish a "Variability Processing Coordination Unit" and build a pipeline to produce a catalogue of several tens of million variable stars. Both the Swiss EULER telescope at La Silla and the Belgian MERCATOR telescope at La Palma will be used as test-beds for this program, and to undertake major new research programs on asteroseismology targets, supernovae, pulsating stars, gravitational lenses, and the optical counterparts of high-energy sources such as GRB.

The Sun is a unique laboratory to compare the predictions of stellar evolution theory with extremely accurate and detailed measurements. In

the past, the theoretical standard solar model agreed with the sound speed and density as functions of solar radius determined with helio-seismology, as well as with the surface helium abundance and the depth of the convection zone. However, recent solar models with lower heavy element abundances inferred from new analyses of the solar atmosphere now strongly disagree with the helio-seismic data. In this context, UniGE will test the importance of several processes that are not included in the standard solar models, like meridional circulation and shear-mixing, internal gravity waves, and magnetic fields.

Stellar death: explosions, collapsed objects and nucleosynthesis

Stars produce heavy elements, all the chemical elements, except Hydrogen and Helium, are produced in stars and stellar explosions. Their newly synthesized and often radioactive elements imprint in the interstellar medium the detailed traces of stellar evolution and provide a natural clock to trace the evolution of the Galaxy.

Progress in this field at UniBas will build on three key ingredients to link increasingly sophisticated theoretical models with new observations: (a) improved nuclear equation of state determining the pressure of matter at super-nuclear densities, the properties of nuclei far from the valley of stability, and interaction of neutrinos with matter; (b) extension of self-consistent hydrodynamic calculations to more realistic multi-dimensional models that include the effects of magnetic fields; and (c) new observations, including those of the neutrino flashes, light-curves and spectra of supernovae and the abundances of the chemical elements in galaxies. Future efforts in this latter category will concentrate on abundance observations of the oldest stars in our Galaxy, whose chemical abundances bear witness to pollution by the very first, so-called Population III, stars.

The core collapse mechanism in Type II supernovae is still poorly understood. The influence of neutrino interactions on the expected chemical composition of the material ejected from the innermost zones (responsible for the production of heavy elements up to Thorium and Uranium) is

also an unsolved problem. We do not well understand the transition from core collapse supernova explosions to hypernovae and the Gamma-ray Bursts (GRB). Models of Type Ia supernovae do not reproduce the observed relationship between total brightness and characteristic decay time of the lightcurves that are nevertheless used empirically to determine the acceleration of the Universe.

Stellar populations in nearby galaxies: the fossil record of cosmic evolution

The Radial Velocity Project (RAVE), the second Sloan Digital Sky Survey (SDSS-II), and the proposed NASA Space Interferometer Mission (SIM) are international projects that will explore the stellar distribution of the Milky Way Galaxy. UniBas will find and characterise the accretion streams that are the fossil records of satellite galaxies accreted by the Galaxy. They will also measure the distribution of dark matter in the Local Group by mapping the gravitational potential to a distance of 250 kpc. Within our own Milky Way Galaxy, the astrometry, spectroscopy and accurate photometry of more than a billion stars observed by the ESA Gaia mission will detect small perturbations to the global gravitational Galactic potential, due to surviving sub-haloes of dark matter.

Matter in extreme conditions

Directly observing matter close to the event horizons of black holes would provide a test of General Relativity and illuminate the accretion processes that power quasars, the most energetic phenomena in the Universe. An X-ray telescope with new mirror and detector technology could provide the required high spatial resolution and large collecting area. ISDC is part of a European concept study team for XEUS, a 5-10 m² X-ray telescope with grazing incidence mirrors on one space platform and the detectors flying at some distance behind on an independent spacecraft. This “formation flight” configuration allows for a large focal length without an impossibly large structure. XEUS will be proposed as part of ESA’s Cosmic Vision programme.

Galaxy formation and evolution in the distant Universe

Long away is far ago. We can directly observe the evolution of the Universe because of the time that light takes to travel from exceedingly distant objects. At present the most distant objects have redshifts $z \sim 7$, corresponding to a “look-back time” of 95% of the total age of the Universe providing a view of galaxies, quasars and the intergalactic medium when the Universe was less than a billion years old.

The formation of dark matter structures and gravitational potential wells by the dark matter is reasonably well understood in the CDM concordance cosmogony on galactic scales and larger. However, the more complex behaviour of the baryonic material in galaxies offers a number of outstanding problems. The cooling of gas, and the injection of energy (e.g. by supernovae and active galactic nuclei) play crucial roles in regulating galaxies. Interactions and mergers of galaxies also play a large role in structural transformations of galaxies, and also stimulate bursts of star-formation when major stellar populations are produced quickly. Matter is also redistributed by “secular” internal dynamical instabilities. For all of these reasons, the environment of galaxies likely plays a major role in their evolution, particularly their structural morphologies and their star-formation histories.

Studying the evolution of galaxies combines both a statistical approach, since each galaxy is seen from a single viewpoint and instant in time we can only see evolutionary changes with populations, and the detailed study of individual galaxies. Even COSMOS with 10⁵ distant galaxies is limited by cosmic variance – the sample is not large enough to be completely representative of the Universe. The next generation of surveys (see Theme 1 above) will target samples of a billion galaxies requiring data handling tools far beyond those currently available.

The MUSE panoramic integral field spectrograph being developed for the VLT (ETHZ) will measure 90,000 simultaneous spectra, fed by a new adaptive optics system. Starting in 2011, MUSE will undertake very deep spectroscopic surveys of the progenitors of galaxies assembling at



The gravitational field of the rich cluster of galaxies Abell 1689 forms a natural lens, magnifying and distorting the images of background galaxies into long thin arcs. NASA/ESA

redshifts $1 < z < 7$. MUSE will study the complex Ly α -emitting gas clouds that surround young galaxies to understand the flow of mass between galaxies and the surrounding intergalactic medium. At lower redshifts, $z < 1$, a look-back time of half the cosmic age, the spectral and spatial resolution of MUSE will probe the internal dynamics, stellar population gradients and chemical abundances of galaxies to follow the scaling relations between these through cosmic time. ETHZ will use 225 nights of GTO time for these deep surveys.

At wavelengths one thousand times longer, ALMA will observe the cool dust and molecular gas of star-forming regions (especially CO emission) in normal galaxies to $z \sim 3$. ALMA will be able to determine the dynamical mass of nearly any high redshift galaxy, and will elucidate the nature of the ULIRGs that dominate the luminous energy output of the Universe at high redshifts. Like MUSE, to which it is highly complementary, ALMA will produce data “cubes” of position and velocity for line emitting gas for regions of the sky approximately 1 arcmin² in area.

At $z \sim 7$, galaxies are already enriched with heavy elements and are not “primordial”. Microwave background observations imply that the Universe was reionized at $z \sim 10$. When launched in 2013, the NASA/ESA/CSA James Webb Space Telescope (JWST) will observe large numbers of galaxies at the redshifts $7 < z < 12$ or beyond. ETHZ will have important early guaranteed time on JWST owing to a NASA-selected Interdisciplinary Scientist and a member of the NIRCam and MIRI instrument teams.

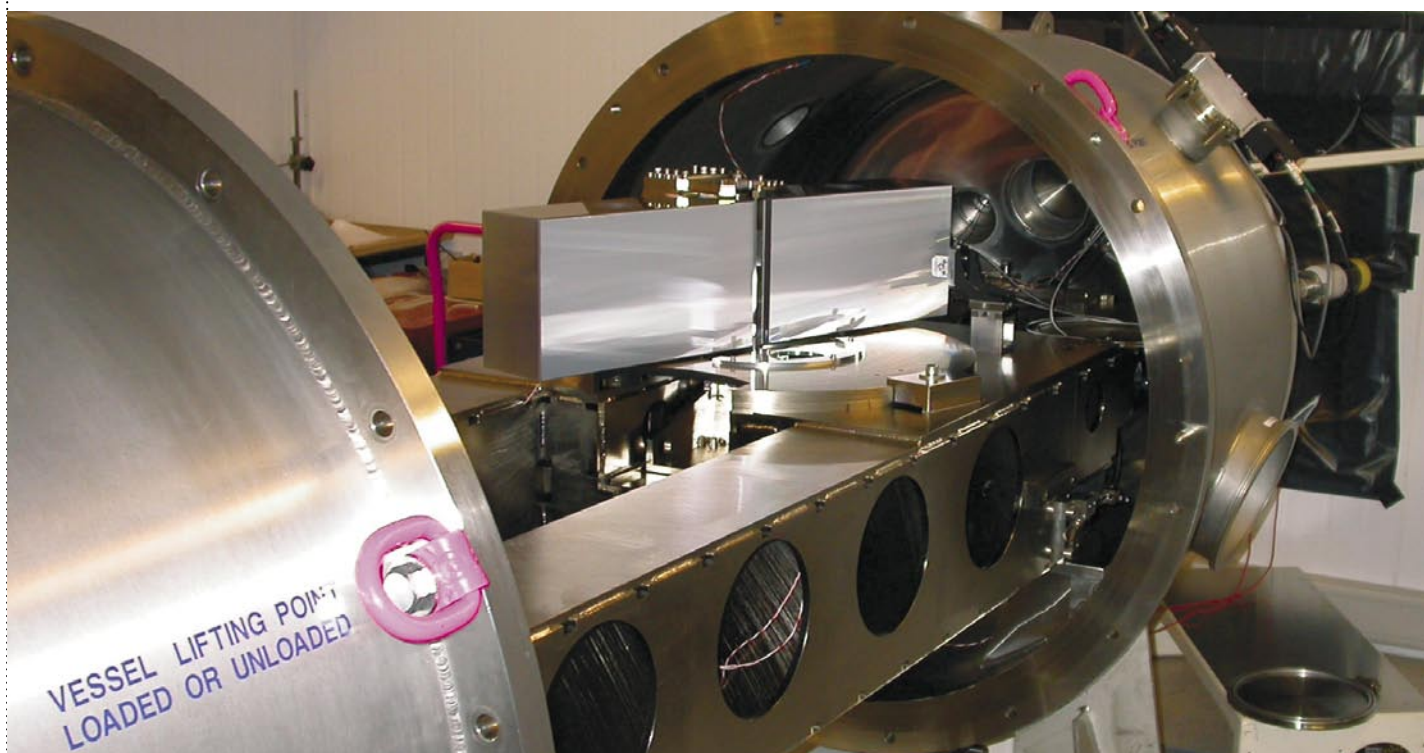
When studying the early Universe, there is no substitute for light-gathering power. Several worldwide projects target the next generation of telescopes such as the 20-m Giant Magellan Telescope and Thirty Meter Telescope projects in the US. The European Extremely Large Telescope (E-ELT), with an aperture of 30-60 m, has been identified as ESO’s top priority after ALMA’s completion. The E-ELT will have a light collecting power 15-50 times that of the VLT and its sophisticated adaptive optics system will increase the point-source sensitivity by 200-2000. The European Extremely Large Telescope (E-ELT) will open dramatic new oppor-

tunities for the study of the distant Universe (and many other branches of astrophysics). Like HST and the VLT today, the combination of the JWST and the E-ELT will be required to first find and then study the most distant galaxies as the frontier moves out beyond $z \sim 7$. To do this, the first-generation E-ELT instruments should include an integral field spectrograph similar to MUSE.

Numerical simulation will play a leading role in motivating and interpreting these ambitious observational programs. These simulations will combine the non-interacting dark matter with the highly interacting baryonic gas to explore the relevant physical processes both on cosmological scales and on the scales of individual galaxies and groups of galaxies (UniZH and ETHZ).

The European Extremely Large Telescope (E-ELT) will open dramatic new opportunities for the study of the distant Universe.

The diffraction grating and vacuum chamber of the HARPS instrument built by Geneva Observatory to discover large numbers of extrasolar planetary systems. Geneva Observatory



4.3 Theme 3

Planets and the emergence of Life

Few questions for humankind are as old as “are there other worlds like Earth?” and “are we alone?” These have a broad cultural impact on Society and are inherently multi-disciplinary from physics and chemistry to geology and biology. In the next 20 years, there will be answers to such fundamental questions as:

- Are Earth-like planets common in the Galaxy?
- What physical processes control the formation of planetary systems, determine the properties of the planets and establish the conditions for Life?
- Has Life developed elsewhere in our own Solar System?
- Can we detect biological activity on planets elsewhere in the Galaxy?

Observations, laboratory measurements and theoretical modelling will all play major roles in defining the technology requirements, carrying out the science operations and analyzing the results.

Exosolar Planet detection

Almost all of the known exosolar planetary systems were discovered by the reflex motion of their parent star, the method adopted by Mayor and Queloz at UniGE that led to the 1995 discovery of the first extra-solar planet around 51 Peg.

In extra-solar planet detection, the future challenge is (a) to diversify the detection methods to eliminate current biases, (b) to increase the total number of planetary systems for a statistical understanding of their properties, and (c) to isolate the light from the planets to observe their detailed characterisation and search for the signatures of biological activity.

High precision astrometry of the parent stars, rather than Doppler radial velocity measurements, will be an effective indirect detection technique that is sensitive to lower mass long-period planets. The VLTi PRIMA-DDL will provide baselines up to hundreds of meters. As a result of their development work on this system, UniGE, EPFL and CSEM have 220 nights of guaranteed observation time for a planet search in the years 2008-2012.

Starting in 2012, ESA's Gaia satellite will perform a high-precision astrometric survey of more than a billion stars. Gaia can detect giant planets orbiting around the ~300,000 stars within 200 parsecs. Gaia will also measure stellar brightness to 0.1%, sufficient to detect several thousand transiting planets to determine the detailed mass-radius relationship for giant planets. UniGE are working on the Gaia astrometric data reduction pipeline.

NASA SIM is an interferometric astrometry mission in space that will detect planets down to Earth mass around the nearest stars, and Jupiter-mass planets out to a kpc. Starting in 2016, UniGE will survey for Earth-like planets in habitable regions around nearby Sun-like stars.

After launch in late 2006, the ESA-CNES Corot satellite will be a watershed in transit searches. Corot will detect planets as small as the Earth in the habitable zone of stars as they transit in front of the parent stars. This transiting also permits a glimpse of the atmospheres of the planets through differential absorption during the transit. UniGE and UniBe, through the HARPS consortium, and as co-investigator in the core Corot program (UniGE), will be in a leading position to find the first direct evidence of a rocky planet like the Earth.

The holy grail of extra-solar planet searches is the direct detection of the light of an Earth-like planet located in the habitable zone of another star. Isolating planetary light will open the door to using spectroscopy to study their physical and chemical characteristics including possible biosignatures. The Swiss are clear leaders in the long and technologically challenging path towards this goal.

Launched two or more years after Corot, and with increased sensitivity, NASA's Kepler satellite should detect dozens of Earth- and Neptune-sized planets on close-in orbits. The radial-velocity follow-up will confirm the planetary nature of these companions and determine their masses (and densities). UniGE will build an exact copy of HARPS for telescopes of the Harvard-Smithsonian Center for Astrophysics as part of the Harvard Origin of Life Initiative.

UniGE and ETHZ are both part of a European consortium to develop one of the four 2nd generation instruments for the ESO VLT. SPHERE will be a high performance „extreme“ adaptive-optics instrument aimed at the direct detection of light from an exoplanet, using either differential imaging spectroscopy or differential imaging polarimetry, the latter based on ETHZ's ZIMPOL technology. This instrument will detect the light of "old" planets larger than 3 Jupiter masses and of recently formed planets larger than 0.5 Jupiter masses. SPHERE will use 260 nights of guaranteed time for a comprehensive planet search starting in 2010.

On a longer timescale, a near-infrared space interferometer with low resolution spectroscopy capabilities, the DARWIN mission concept will be proposed for ESA's Cosmic Vision (2015-2025) Program by a European consortium including UniGE and UniBe. This unique and stunning space facility would study the atmospheric structure and composition of Earth-like planets orbiting nearby stars, thereby opening the door to comparative exoplanetology. The identification of unique spectral features related to the existence of biological activities would provide the first detection of life outside the solar system. This mission is one of the most ambitious scientific endeavours of all time with the potential for a deep cultural impact.

On a similar timescale, UniGE is participating in a design concept for a high resolution spectrograph CODEX for the E-ELT, based on their past successes with Elodie, Coralie and HARPS. CODEX could detect the reflex motions of stars produced by planets with masses as low as the Earth's. It is also likely that a follow-on to the VLT's SPHERE extreme adaptive optics instrument will also be amongst the first light E-ELT instrumentation.

Planet formation and proto-planetary disks

The discovery of exosolar planetary systems with such different properties from our own Solar System has overturned our theoretical understanding of how planets and planetary systems form. Addressing the question of what physical processes control the existence and nature of planetary systems forming around young stars, will be a major

focus for theoretical and observational astrophysics in Switzerland and elsewhere that strongly complements the study of mature exoplanetary systems.

One goal is to develop a theoretical understanding of planet formation and evolution that stands up to the observational confrontation with quantitative predictions that guide the direction of future observations. This requires not only understanding of how planets form, but also how they are likely to evolve afterwards.

Major theoretical efforts can be carried out in a coordinated and cooperative way throughout Switzerland. These efforts require progress in many areas for a holistic approach where formation is followed from dust grains to giant planets capturing the physical and chemical complexity of the processes involved. Since proto-planetary discs of dust and gas provide the initial conditions for planet formation, their dynamical evolution must be followed over millions of years with both embedded planets and the interaction with the star. Many new numerical tools and modes are needed, to follow the hydrodynamics, mechanical properties and chemical evolution of these systems.

We underscore the previously mentioned importance of the ESO ALMA telescope array, ESA Herschel and NASA/ESA JWST to study dust and molecular gas in proto-planetary disks and therefore to understand, observationally, the physical conditions prevailing in the environments where planets are forming.

Exploration of the Solar System

In situ solar system exploration complements studies of distant planetary systems in the effort to produce a comprehensive understanding of the formation and evolution of planetary systems, our own Earth in particular. Comparative studies of the 4 terrestrial planets pinpoint the key geological and atmospheric processes for evolution on long timescales. It also illuminates the solar-terrestrial connection for the development and sustainability of Life as well as other astronomical hazards such as catastrophic impacts.

In particular, in situ Solar System exploration provides detailed information on (a) chemical and isotopic compositions that reveal the planet formation process, (b) the structural characteristics of

materials, and (c) evidence for present or past biological activity. Our own Solar System is the only place, for the foreseeable future, where we study all of the components of a planetary system together – from Giant Planets down to small meteorites.

The number of known objects in the solar system has grown rapidly in the last decade and is poised to explode in the near future. Gaia alone will discover tens of thousands of new objects that will need to be followed to determine accurate orbits with facilities such as UniBe's Zimmerwald Observatory.

Within the next decade, ESA's Venus Express (2007) and Rosetta (2007-2016) and NASA's Mars Reconnaissance Orbiter MRO (2007-09) will be in their primary science phases. UniBe built the neutral particle analyzer for Venus Express, as well as two mass spectrometers and a pressure sensor for Rosetta, and participated in surface photometric studies and scientific targeting for MRO. The Swiss science participation will focus on the loss processes in the Venusian atmosphere, on the chemical composition, surface structure and sublimation of a cometary body, and on water and CO² sublimation processes on the surface of Mars. Rosetta will perform a compositional analysis of the gas released during sublimation to assess the physical state and composition of the solar nebula when the comet formed. The remote sensing experiments will determine the chemical and physical homogeneity of the nucleus. Substantial heterogeneity would argue for rapid mixing in the solar nebula prior to final comet accretion. The Lander experiments will establish the degree of surface processing to test the assumption that pristine material exists only metres beneath the surface, essentially unaltered for 4.5 billion years.

Recent observations from Mars Express and the Mars Exploration Rovers suggest that liquid water ceased playing a significant role in Martian evolution at least 3.5 billion years ago, making the search for potential biological habitats a challenge. Using its 25 cm resolution, MRO observations will search for sites showing evidence of aqueous and/or hydrothermal activity that have the best chances for finding evidence of Life. MRO will map and characterize the stratigraphy, geologic structure,

and composition to understand Mars' complex terrain.

The loss rates from the atmospheres of Mars and Venus are important for understanding their evolution: Mars would have lost an amount of water equivalent to several metres depth if the current loss rates had persisted for the past billion years. Although more water probably still exists in the subsurface layers of Mars, similar processes probably had a major influence on the evolution of the atmospheres of all the terrestrial planets. The experiments on Mars Express, Venus Express and, in the future, Bepi-Colombo will address these questions.

Bepi-Colombo to Mercury will be the next major mission within the ESA planetary science programme. Mercury's density is the highest in the Solar System, suggesting a high iron concentration that likely owes to the planet's formation so close to the Sun. There are three models proposed for Mercury's unusual composition: equilibrium condensation at high temperatures, vaporization of an outer silicate mantle by the hot early Sun, or some mechanical differentiation mechanism, such as giant impacts, to selectively remove silicates. The UniBe-led laser altimeter aboard Bepi-Colombo should resolve this issue by studying the planet's internal structure for an understanding of planetary formation processes in the immediate solar proximity. The data analysis requires a close co-operation with the UniBe fundamental astronomy group.

In parallel, ESA has initiated a Mars robotic exploration program as a precursor to manned exploration. UniBe and ETHZ are both involved in different aspects of the first mission, Exo-Mars, that focuses on a search for signs of existent or extinct life. Using improvements in miniaturization technologies, novel concepts are being developed for precision measurements of mineralogy, organics and surface temperature to fly in 10-15 years.

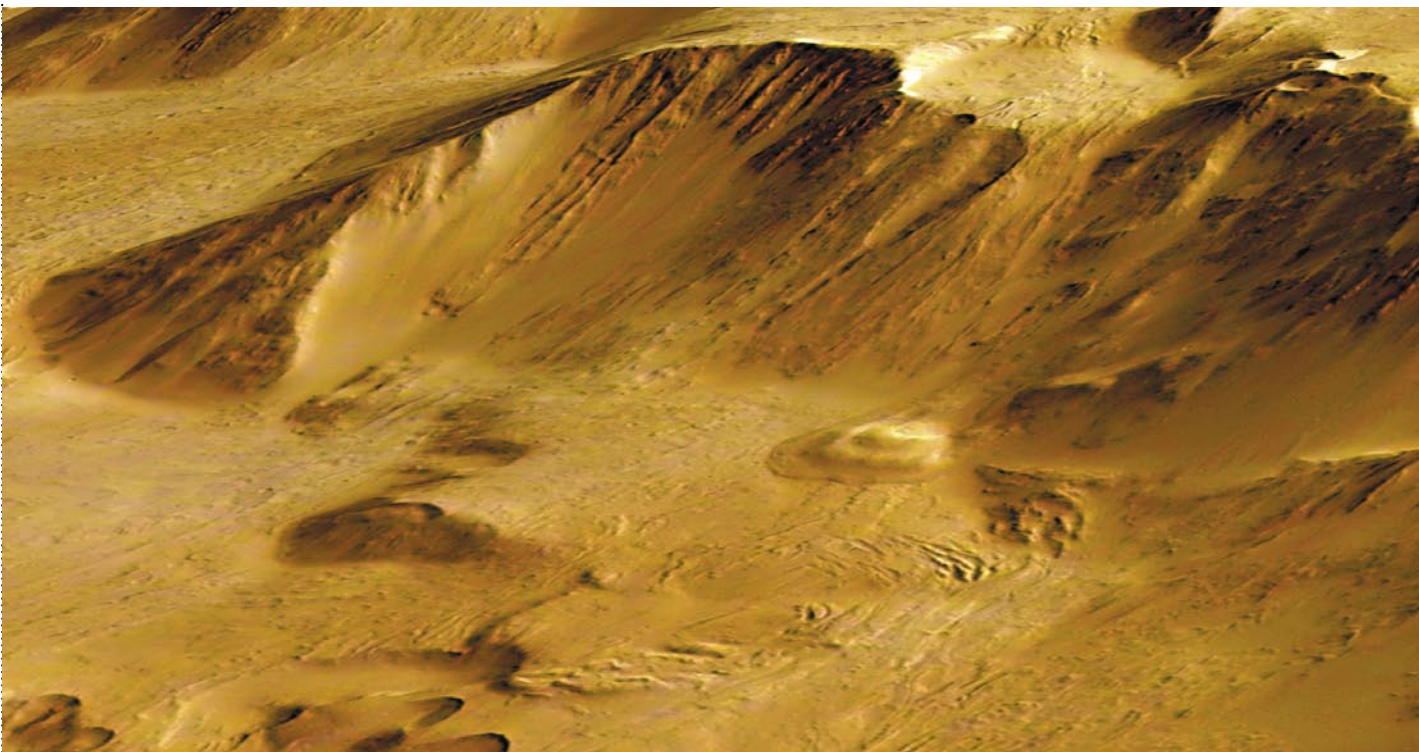
ESA Cosmic Vision program calls for the exploration of the solar system including in situ sensors and sample return, the study of the link between star and planet formation, as well as the detection of earth-like planets and exosolar biosignatures. Detailed investigations of the Jupiter system, including its two remarkable satellites Europa and Io, will be a high priority for the Swiss research

community when initial mission concepts are selected in 2007. UniBe is active in the preliminary definition of the science goals of this mission. Sample return missions from comets (following on from

the Rosetta mission) and from near-Earth asteroids are also candidate missions that would bring significant advances in solar system studies for the Swiss groups.

Our own Solar System is the only place, for the foreseeable future, where we study all of the components of a planetary system together – from Giant Planets down to small meteorites.

The surface of Mars, as revealed by cameras aboard the ESA Mars Express mission. ESA



4.4 Theme 4

Our home and the impact of the space environment on Earth

One of the greatest issues facing mankind today is global climate change. The problem is now acknowledged to be largely man-made, and it is urgent to improve our capabilities to forecast how the climate will evolve in the future. To do so, we need to understand how the Earth responds to perturbations of different kinds such as the variable energy input from the Sun.

We live close to an active star whose variability is due to magnetic activity. This leads to three major questions for the coming decades:

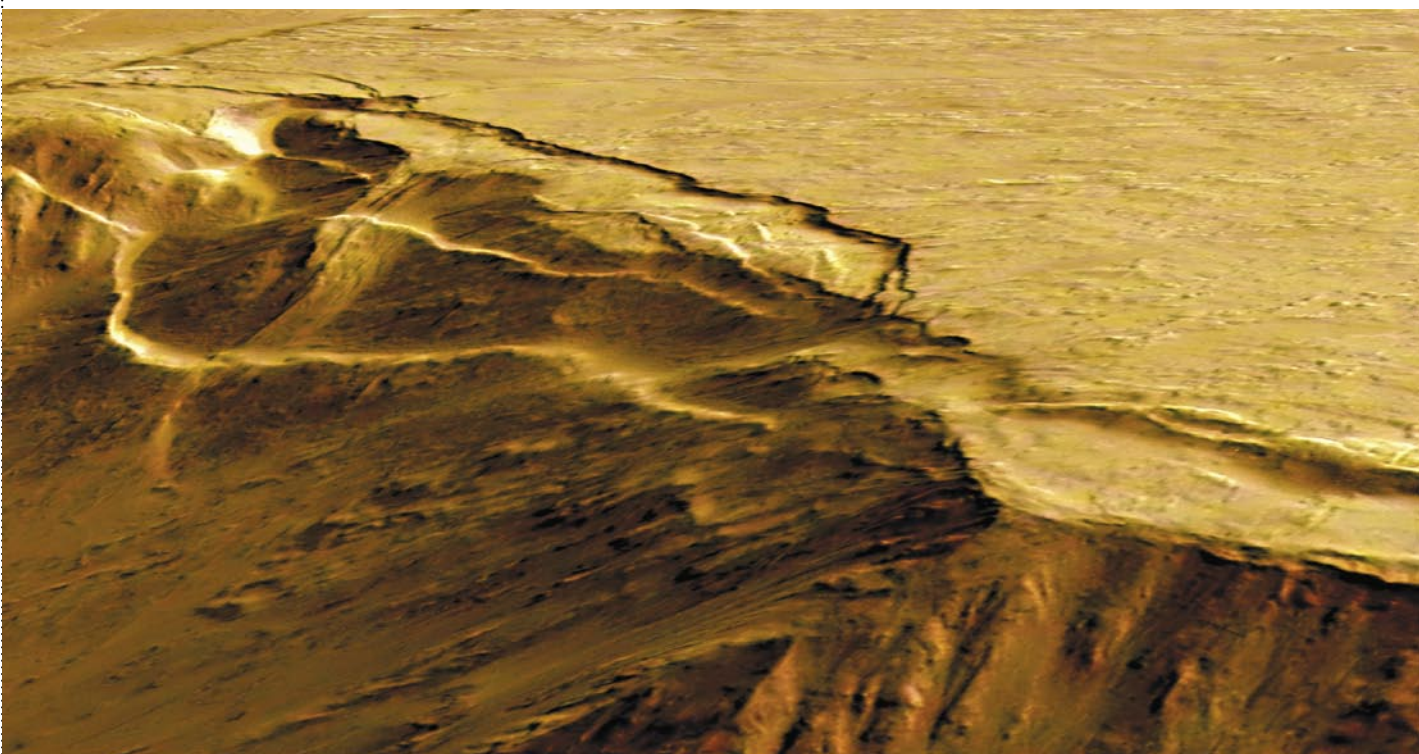
- how are magnetic fields generated, recycled and distributed in the solar interior?
- what mechanisms are responsible for eruptive high-energy releases in the solar chromosphere and corona?
- how does solar variability influence the heliosphere and Earth's climate on short and long time scales, including the forecast of global warming and minor ice ages?

A renaissance of solar physics

New and upcoming facilities are producing rapid progress in solar physics. On the ground, we have

the GONG+ international network for helioseismology, SOLIS (solar synoptic observatory at Kitt Peak), SST (1m Swedish Solar Telescope on La Palma), Gregor (1.5m German solar telescope on Tenerife), and the future ATST (4m Advanced Technology Solar Telescope on Maui). Three major solar space missions are scheduled for launch in the next 3 years: Solar B, STEREO – Solar Terrestrial Relations Observatory, and SDO – Solar Dynamics Observatory. The Solar and Heliospheric Observatory, SOHO, launched in 1995, continues to deliver excellent data on the dynamic, magnetized Sun.

ETHZ will upgrade its ZIMPOL imaging polarimeter system at IRSOL with a state-of-the-art adaptive optics system and a fully tunable narrow-band Fabry-Perot optical filter system. These improvements will address major questions in solar physics on the generation and distribution of magnetic fields at various spatial scales, including evolution of the global magnetic field, internal structure of sunspots and turbulent magnetic fields. Molecular spectro-polarimetry in cooler and denser environments reveals otherwise hidden structure of the solar atmosphere, such as enigmatic magneto-convection in the sunspot umbra, the finest filigree of network magnetic



fields, and puzzling cloudy structures of the upper photosphere. This research impacts our understanding of the generation and evolution of magnetic dynamos in brown dwarfs, planets and protoplanetary disks. As it is the world's most sensitive polarimeter, Swiss solar physicists get large time allocations with ZIMPOL at the largest solar telescopes around the world. There are plans to place a ZIMPOL system on the next-generation international ATST facility in 2014.

Understanding the impact of coronal processes on the heliosphere from the Sun to the termination shock at the interface between the solar wind and the interstellar medium will be the aim of several solar missions in the near future. The in situ solar wind experiment PLASTIC (Plasma and Suprathermal Ion Composition) on STEREO, developed at UniBe, will trace solar wind particles in the heliosphere. For the International Heliospheric Year in 2007, copies of the ETHZ radio spectrometer Calisto are being installed in India, Japan and the USA to provide 24 hour coverage of the solar low-frequency radio emission. These instruments complement observations from the interferometric radio-telescope FASR (Frequency Agile Solar Radio Telescope) planned to begin operation in 2009. This will be invaluable for relating solar radio emission to space weather physics and forecasts.

Solar variability and the global climate

The magnetic variability of the Sun also influences its brightness, affecting the Earth's climate. For the quantitative understanding of global climate change and the man-made greenhouse effect, we must quantify changes to the global climate system driven by variable solar irradiance. Reconstructing past irradiance variations is crucial for explaining historical climate changes, such as the 17th century "Little Ice Age". Forecasting solar eruptions will be essential for long term manned space flights in the solar system.

The collaborative project "Variability of the Sun and Global Climate", (section 3.1) will continue. PMOD/WRC is developing PREMOS (a filter radiometer) for the PICARD mission, to be launched in 2009, that will monitor the solar irradiance to reveal the relation between the solar diameter, differential rotation and solar constant as well as their intrinsic variability. To address whether solar irradiance variations owe to flux redistribution or luminosity variations, PMOD/WRC is proposing SIM3D (Solar Irradiance Monitor 3D-View) for the Solar Orbiter mission (to be launched in 2013) that will provide a 3-dimensional view of the solar radiation.

The magnetic variability of the Sun also influences its brightness, affecting the Earth's climate.

4.5 Summary

The required investment for the Roadmap

The scientific program outlined above represents a co-ordinated and multi-faceted approach to problems at the forefront of science. We highlight several features of this program.

The importance of international partnerships

Essentially all of the telescopes, instruments and space missions are international partnerships, primarily within Europe but many involving the USA and Japan. Swiss astrophysicists are leaders in key scientific investigations that are embedded within the broader international effort.

The need for multiple facilities

All of the major questions of the four themes will be answered with information from multiple ground and space observing platforms. Likewise, nearly all facilities have high impact across the themes. The facilities of the future will form an integrated observing “system” (see Table 3). Swiss astrophysicists need access to this “system”.

The importance of theoretical work

The OECD Report on Future Large Programmes and Projects in Astronomy and Astrophysics emphasizes that “support for theoretical investigations must be proportional and synchronized with the great data gathering projects undertaken in laboratories and observatories”. This is underscored by the entries for theoretical work in Table 3.

The benefits of networking

With our integrated questions and themes, we highlight the interwoven interests of Swiss astrophysicists, without finding any significant duplication of effort. This emphasizes the benefits from closer co-operation between teams. Already there are four areas of research where Swiss groups have agreed to enhance their research potential and international competitiveness through coordinated competence networks in:

- (a) Planet Formation and Discovery (UniBe, UniGE, UniZH, ETHZ)
- (b) Galaxy Formation and Cosmology (UniBas, UniGE, UniZH, EPFL, ETHZ)
- (c) Stellar evolution (UniBas, UniGE, ETHZ)

(d) Solar Science (the existing SVISS network). The membership of these networks is listed in Appendix A. Of course, some significant areas of research, e.g. high energy astrophysics, are not so geographically distributed at present, making a “network” unnecessary.

The need for support of existing facilities

The VLT, ALMA, Herschel, JWST, and the future E-ELT of ESO) are supported through Switzerland's international subscriptions and their use is won through competitive peer-reviewed proposal. Many individual instruments or experiments that will be prominent in the scientific landscape in the next few years are either already in operation (e.g. the spacecraft already orbiting around Venus and Mars) or fully funded (e.g. the PRIMA delay lines for the VLTI). The future investment needed for these programs is focussed on the very important tasks of data analysis and interpretation. It is vital that SNF operating funds provide adequate funds for these continuing ground-based and space-based observational programs.

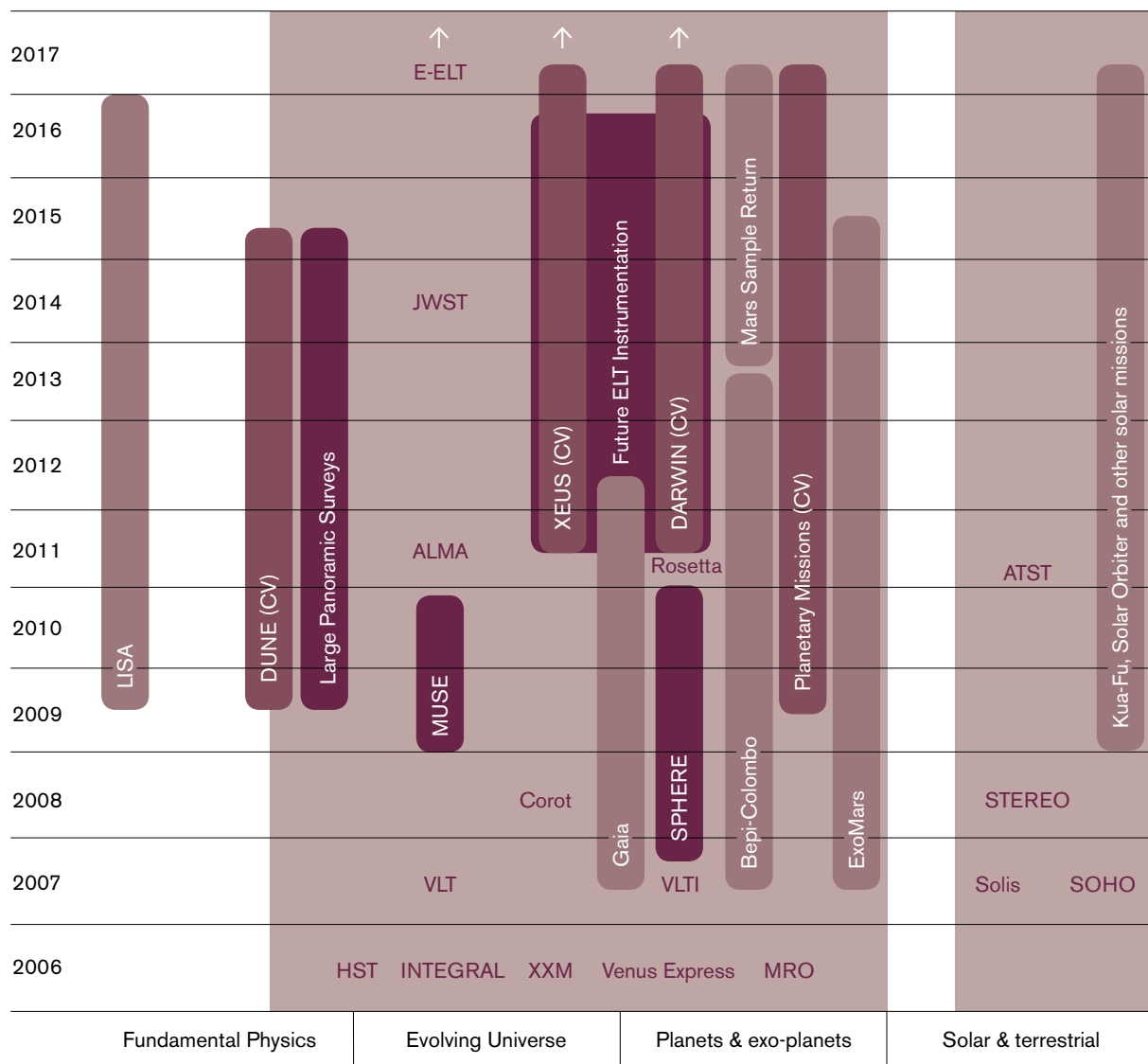
The need for continuing capital investments

Looking ahead, some future projects will require new capital investments. Some of these are projects that are in the construction or final planning stages. The two second-generation instruments for the VLT (SPHERE and MUSE), and the ESA space missions such as Gaia, LISA, Bepi-Colombo and ExoMars are in this category. It is anticipated that these can be funded from the existing or augmented FINES fund for ESO-related instrumentation, and from the ESA PRODEX and the Mesures d'accompagnement funds for space missions.

In the longer term, the observational projects are necessarily in an earlier stage of scientific definition, partnership building, and budgetary approval. Examples in this category are the ESO E-ELT instrumentation and the space missions for the ESA Cosmic Vision programme. In both cases, Swiss astronomers are already actively involved in concept study teams.

Figure 1

shows the balance and complementarity between the existing, or fully funded, projects and those that require new capital investments. The funding required from the FINES and PRODEX/Mesures d'accompagnement funds over the next ten years is shown in Tables 5 and 6.



- A The instruments or missions represented in red on the light red background are either existing or fully-funded and require no additional capital investment, but need support for data analysis and scientific interpretation.
- The foreground boxes show instruments requiring capital investment for the ground (dark red) and space (light reds).
- The boxes represent proposed Cosmic Vision missions. It is assumed that only two of these four will be selected.

Table 3

Which facilities address the different questions identified in the four astrophysical research themes?

	Theme 1 The nature of dark matter and dark energy Origin of the baryon asymmetry Inflation and density perturbations Gravity waves	Theme 2 First Light and reionization The assembly and evolution of galaxies Star-formation and stellar evolution Explosive events Supermassive blackholes	Theme 3 Are Earth-like planets common Formation of planetary systems Search for Life in the Solar System Search for Life elsewhere in the Galaxy	Theme 4 Magnetic fields in the Sun The heating of the solar corona The solar influence on the Earth
Existing or fully funded projects				
Ground-based telescopes				
ESO VLT	•	• • • • •	•	
ESO VLT-I		•	• •	
ESO 4-m (HARPS)		•	•	
EULER + MERCATOR		• •	•	
ALMA + APEX + IRAM		• • • •	•	
Solar Telescopes				• •
Others (incl. Zimmerwald)			•	
Space-based telescopes				
HST	•	• • • • •	•	
XMM-Newton		• • • • •	•	
INTEGRAL	•		• •	
Spitzer		• • • •	•	
Herschel		• • • •	•	
JWST		• • • • •	•	
Others (incl. Kepler, Corot)		• •	• •	
Solar System Exploration				
Venus Express			•	
Mars Reconnaissance Orbite			•	
Rosetta			• •	
Other (incl. SOHO)				• • •
THEORY	• • • •	• • • • •	• •	• • •

4.5.1 ESO instrumentation: the FINES fund

Support for Swiss participation in approved instrumentation projects for the ESO telescopes. Two of the four “2nd generation” instruments for the VLT will require FINES funding in the next four year period between 2008-2011; these are the SPHERE “Planetfinder” instrument (UniGE and ETHZ) and the MUSE deep integral field surveyor instrument (ETHZ). The proposed funding profile for these two projects 2008-2011 is shown in Table 4.

Swiss institutes are not participating in ALMA instrumentation projects. Swiss teams are already participating in preliminary design studies for instrumentation for the E-ELT. The instrumentation for this extremely powerful facility will almost

certainly include developments of both the SPHERE and MUSE instrument concepts, and an ultra-high resolution spectrograph CODEX. By 2011, we expect that E-ELT development will have proceeded to the point where these instruments are being constructed. The E-ELT instrumentation will be far larger and more complex, and technically more demanding, than the present state-of-the-art instruments being built for the 8-m VLT telescopes. We regard it as essential that the resources of the FINES fund be augmented after 2011 to the level of CHF 1.5 M per year in order that Swiss research teams be able to participate effectively in the E-ELT instrumentation programme.

Table 4
Forward look on FINES fund for ESO instrumentation (new proposals only)

ESO Instrument	Institute	2007	2008	2009	2010	2011	2012–2017
SPHERE	UniGE + ETHZ	207	762	852	350	350	–
MUSE	ETHZ	–	–	300	300	–	–
ELT instruments		–	–	–	–	450	1,500 per year
Total		207	762	1152	650	800	1,500 per year

4.5.2 Space instruments the PRODEX and the Mesures d'accompagnement funds

In the near term, Swiss astrophysicists seek to participate in four of the current generation of major ESA science missions – Gaia (astronomy), Bepi-Colombo (Solar System exploration), Solar Orbiter (solar physics) and LISA (gravitational wave physics), as outlined in the preceding sections of this chapter.

The future of European space science rests with ESA's Cosmic Vision programme – the initial call for mission proposals will be in early 2007. Swiss institutes expect to be major participants in several of the 15-20 such proposals which may be made. Swiss interest is highest in DUNE (Cosmology) and in planetary missions – the Giant Planet exploration missions (to the Jovian System and to Saturn) and in a Near Earth Object sample return mission. There is also keen interest in the larger and longer term XEUS and DARWIN missions. These will almost certainly extend well beyond the

2016 horizon of this Roadmap, and it is again likely that only one of these will be accepted. For planning purposes, we assume that Switzerland will be represented in one medium mission and in one or two of the two larger, longer term, missions.

The Solar System exploration community in Switzerland also intends to participate in ESA's Aurora Mars Exploration program in the form of Exo-Mars, and in the longer term, the proposed Mars Sample Return mission.

Finally, the space programmes of other major nations (e.g. NASA, France, China and Japan) provide opportunities for small scale involvement in "Missions of Opportunity", including the proposed Swiss involvement in Corot and KuaFu.

Table 5 gives the total budgeted cost of these proposed involvements.

Table 5
Forward look on support of space instrumentation (new proposals only)

Mission	Years of development	cost (kCHF)	cost (k€)
Large ESA Science Programme Missions			
Gaia	2007–2012	22,500	15,000
Bepi Colombo	2007–2013	22,500	15,000
Solar Orbiter	2009–2015	15,000	10,000
LISA	2009–2016	15,000	10,000
	DUNE	2009–2016	22,500
	Planetary	2009–2016	22,500
	XEUS	2013–2020	22,500
	Darwin	2013–2020	22,500
ESA Exploration Missions (Aurora Programme)			
Exo-Mars	2007–2016	15,000	10,000
Mars Sample Return	2013–2020	22,500	15,000
Non-ESA missions			
Various missions, including KuaFu, Kepler	2007–2016	4,500 per year	3,000 per year
	2007–2016	180,000	120,000
Average cost per annum		approx 18,000	approx 12,000

Participation in space research missions is mainly supported by the PRODEX development programme, in collaboration with Swiss industries (where most of the funds are spent). We expect that significant Swiss contributions to space astronomy projects will continue in the future through both the PRODEX and the new Mesures d'accompagnement programmes.

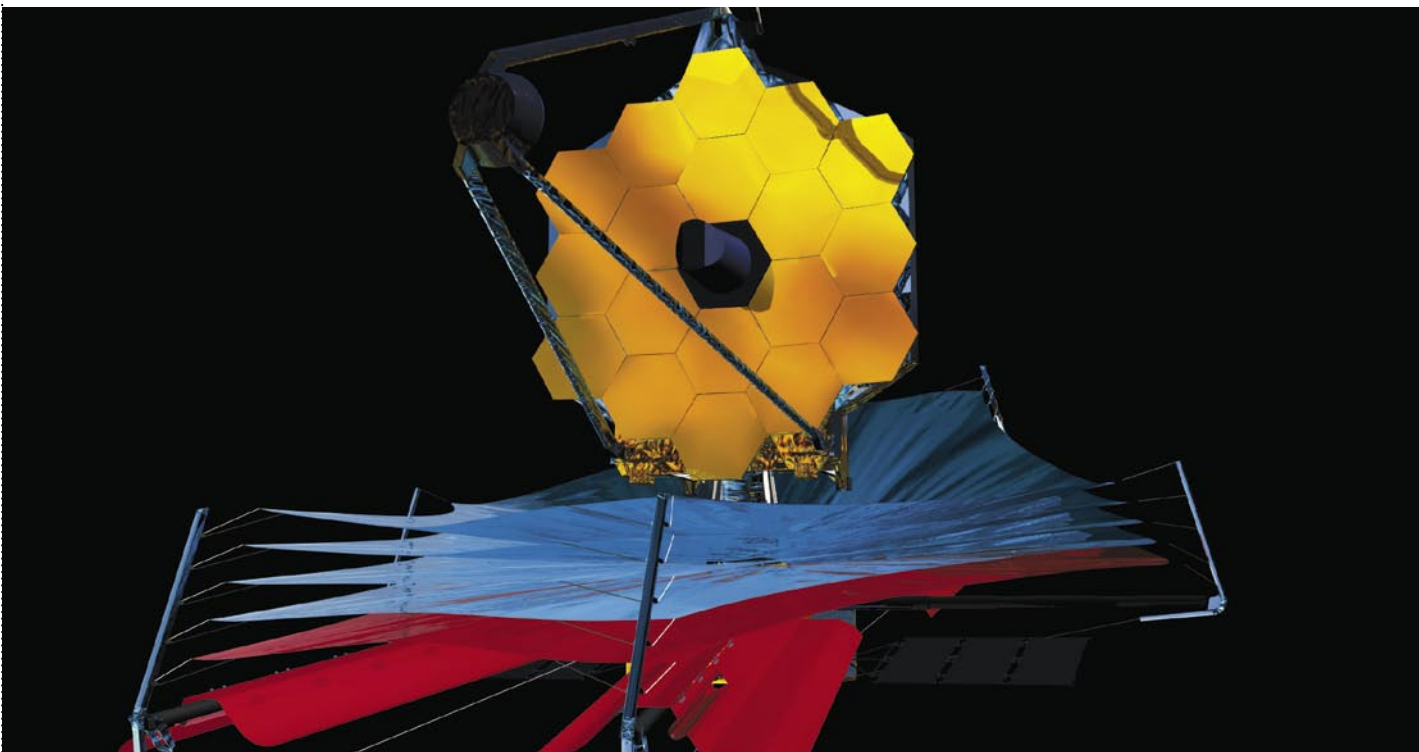
The PRODEX and Mesures d'accompagnement programmes have different terms of reference. PRODEX is geared towards development in collaboration with industrial partners within ESA programmes, whereas the Mesures d'accompagnement may be used for activities related to research, including software development, and also to non-ESA programmes.

While it is very difficult to estimate for each project the fraction of funding that will be needed in each of these different types of activities, we estimate that approximately 2/3 of the expenditures

will be geared towards PRODEX technical development, the remaining 1/3 being used both upstream and downstream of the major development activities and should be supported by the Mesures d'accompagnement.

Implementation of the above program would require resources in the PRODEX and Mesures d'accompagnement programmes to be approximately double their recent average levels.

The James Webb Space Telescope, scheduled for launch in 2013. The PSI is building part of the MIRI instrument for this telescope, while ETH Zurich is part of the Flight Science Team and NIRCcam instrument team. NASA/ESA/CSA



4.5.3 Scientific manpower resources

The scientific manpower for the above projects is identified in Table 6. This is arranged by the observational “facility”, with a separate entry for theoretical work in each of the four themes. This manpower plan fits within an envelope defined by the current manpower of Swiss astrophysics (see Table 1), augmented by 25% over the next five years. This augmentation:

- (a) reflects the continuing intellectual strength of astrophysics, especially in the rapidly developing fields of cosmology and planetary science;
- (b) reflects the past growth of Swiss astronomy over the last five years; and
- (c) should form part of the general European drive to increase spending in all parts of R&D.

The entries in Table 6 should not be taken as an inflexible or immutable plan, but rather are intended to show that execution of this exciting research programme can be undertaken within these reasonable bounds. The different entries also indicate the relative involvement of the Swiss research community in the different projects, all the while emphasizing the inter-related nature of the different projects (see Table 4) and the importance of theoretical work.

Table 6
Manpower resources associated with research using different facilities and with theory

Facility	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Fully-funded projects not requiring further capital investment										
Ground-based observatories										
ESO VLT	23	26	26	25	18	18	18	17	16	16
ESO VLT-I	4	5	6	6	6	6	6	6	6	6
ESO 4-m (HARPS)	4	4	4	4	3	2	2	2	2	2
Solar Telescopes	12	8	8	8	8	9	9	9	9	9
ALMA + APEX + IRAM	2	6	12	14	20	22	24	24	23	23
Others (incl. Zimmerwald, Euler, Mercator, OHP etc.)	25	23	22	21	20	19	18	18	18	18
Space observatories										
HST	11	11	11	5	2	1	1	–	–	–
XMM-Newton (X-ray)	8	8	8	9	9	9	9	11	11	11
Integral	15	14	13	11	11	9	9	7	5	4
Spitzer	2	3	2	2	2	–	–	–	–	–
Herschel	1	4	4	4	2	1	–	–	–	–
JWST	–	–	–	–	1	5	6	11	16	17
Others (incl. Kepler, Corot)	5	4	4	4	4	3	3	3	3	3
Planetary exploration space missions										
Venus Express	3	3	3	3	1	1	1	1	1	–
Mars Reconnaissance Orbiter	3	3	3	3	2	1	–	–	–	–
Rosetta	4	4	4	4	5	6	7	9	9	9
Other (incl. SOHO)	19	18	18	16	16	12	12	10	10	10
Theoretical Research										
Fundamental Physics	17	17	17	17	18	18	18	19	19	20
Evolving Universe	51	50	47	48	49	51	52	51	51	51
Planetary systems	14	15	17	17	18	20	20	23	24	25
Solar and terrestrial connection	5	5	6	6	6	6	6	6	6	6
Total research Manpower										
Table 6 A	228	231	235	227	221	219	235	227	229	231

Table 6
continued

Facility	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total research Manpower										
Table 6 A	228	231	235	227	221	219	235	227	229	231
Future projects requiring capital investment										
Ground-based instruments										
SPHERE	3	4	4	5	7	11	11	9	9	9
MUSE				1	7	8	8	8	6	5
Large Panoramic Surveys	2	2	2	9	12	11	10	9	6	6
E-ELT instrumentation	–	–	1	1	2	2	2	2	2	2
ESA and other space missions										
Gaia	6	7	8	9	12	13	16	16	16	16
LISA	2	2	4	4	4	4	4	4	4	4
Bepi-Colombo	6	6	9	9	9	8	7	6	6	7
ExoMars	1	2	2	2	2	2	2	3	3	3
Solar Orbiter and other solar missions	2	3	6	8	10	12	12	12	12	12
"Cosmic Vision" Proposed ESA missions										
DUNE	1	1	2	2	3	4	5	7	8	8
Planetary mission(s)	1	1	2	3	4	4	7	7	8	8
XEUS	1	1	1	3	4	4	7	8	8	8
Darwin	1	1	1	3	4	4	7	8	9	8
Total research manpower	254	261	277	286	301	306	319	326	326	326

Many of our findings and associated recommendations follow from the research plan that has been outlined in this Chapter and summarized in this final section.

Finding 1

The ESO E-ELT is the highest priority new large project in ground-based astronomy for the Swiss astrophysics community. It is much more important to us than the SKA and the other large research infrastructure projects currently being considered by the ESFRI Forum.

Recommendation 1

The Swiss delegation to ESO should support an increase in the subscriptions from ESO member states so as to ensure an early and timely implementation of the E-ELT project by ESO.

Finding 2

The FINES program provides critical support for ESO instrumentation projects. This enables high impact science using new observational capabilities and the large amounts of associated “guaranteed observing telescope time” (GTO). The existing and projected demand for FINES support of ESO-approved programs will continue to grow with the implementation of the VLT 2nd generation, VLT-I, and E-ELT programmes.

Recommendation 2a

The SER's FINES fund must be continued in 2008-2011 to ensure completion of the 2nd generation instruments for the ESO VLT (SPHERE and MUSE) and the instrumentation for the VLTI (PRIMA). The detailed future investment required from FINES in 2008-2011 is summarized in Table 4: Swiss participation in future E-ELT instrumentation development should be supported through an augmented continuation of the FINES fund at a level of CHF 1.5M in 2012 and beyond.

Recommendation 2b

A small instrument incubator program should be established to fund technological development of instrument concepts for ESO instrumentation, through to a proof of concept prototype. Support

for this should come from FINES. Awards should be based on both the scientific case and the potential for a successful ESO-approved project.

Recommendation 2c

In managing the cash-flow of the FINES program, the SNF needs a system of “pre-proposals” to gain information on instrumentation programs as they progress through the earliest phases of development and not only after they have been approved by ESO and the need for FINES funding becomes urgent. The Swiss representatives at ESO should also be charged with maintaining a running overview of potential Swiss participation in ESO instrument projects so as to brief the SNF.

Finding 3

ESO's investment in the global ALMA project, currently under construction, offers great opportunities for Swiss astronomers in the rapidly developing area of millimeter wave observations of star-, planet- and galaxy-formation and evolution -- scientific areas that are central to our research programs. ALMA is the most complex major astronomical instrument ever built, yet it is intended for a wide community of astronomers. Furthermore, as a global project, competition for access to ALMA and for the exploitation of ALMA data will be intense. As a result, most European countries, including those with a substantial heritage in millimeter-wave observatories, are establishing national or regional support centres to support the use of ALMA by their astronomical communities.

Recommendation 3

The SER should fund a small team that is dedicated to the support of the Swiss astronomical community's use of ALMA (and before that the APEX Pathfinder). This urgently needed team should be composed of at least two experienced researchers who would be tasked with providing this support and with providing an interface to other ALMA European support centres.

Finding 5

Implementation of ESA's "Cosmic Vision" program is the highest priority for space-based astrophysics research in Switzerland.

Recommendation 5a

The Swiss delegation to ESA should support the allocation of a sufficient level of resources to ESA's Mandatory Science Program so as to realize an effective and early implementation of the "Cosmic Vision" Program.

Recommendation 5b

The Swiss delegation to ESA should ensure that Switzerland is selective in its participation in the ESA Optional Program "Aurora", concentrating on those areas that are most strongly science driven (e.g. ExoMars).

Finding 6

PRODEX and the "Mesures d'accompagnement" programs have provided crucial support for Swiss involvement in space missions.

Recommendation 6a

The PRODEX and the "Mesures d'accompagnement" programmes must be maintained at a combined inflation-adjusted level of approximately CHF 18M (12M) per year over the next 10 years, so as to fund Swiss participation in the current ESA missions (Bepi-Colombo, EXOMARS, Solar Orbiter, Gaia, LISA), as well as future missions undertaken by ESA in "Cosmic Vision" and non-ESA missions. The anticipated investment required from these two funds is summarized in Table 5, and is expected to be in the ratio 2:1 for PRODEX/Mesures d'accompagnement.

Recommendation 6b

A small instrument incubator program should be established to fund technological development of space instrument concepts, through to a proof of concept prototype. Support for this should come from Mesures d'accompagnement funds. Awards should be based on both the scientific case and the potential for a successful PRODEX project.

Finding 8

SNF funding for data analysis is important to recoup the national investment in the large ground and space facilities of ESO and ESA. Adequate funding for theory is also required for a balanced national programme.

Recommendation 8

SNF funding for astrophysics research should increase annually by 5% for the next five years. This is motivated by the rapid development of this research field, especially in the areas of planetary science and cosmology.

Finding 10

The OECD report on Large Projects in Astronomy emphasizes that "support for theoretical investigations must be proportional and synchronized with the great data gathering projects undertaken in laboratories and observatories". Increased investment in new observational facilities must be matched by similar increases in theoretical work.

Recommendation 10

It is a high priority that SNF-funding for theory be increased commensurate with funding for ground-based observatories and space missions. We commission a study by theoretical astrophysicists about the best way to develop theoretical astrophysics in the country, with a report to be produced for CHAPS within six months.

Representatives of the next generation of astrophysicists
ETH Zurich



Transforming Professional Astrophysics Education in Switzerland

Swiss astronomers have a history of coordinating research and teaching at the institutional and national levels. With just over 20 professors in the country, such cooperation is both natural and necessary.

Undergraduate education

Essentially all of the undergraduate teaching by astronomy professors in Switzerland is embedded within a curriculum in physics, or in other related disciplines, such as computational science at UniZH.

Many astronomy professors in Switzerland teach more courses in physics, than in astrophysics. These physics courses may be in, for example, basic electromagnetism or quantum mechanics, and may be given to either physics specialists or, as service courses, to students in other disciplines, such as Biology and Medicine, Earth and Environmental Sciences, or Architecture.

Astronomy professors also teach astrophysics in the context of physics Bachelor or Masters degrees, either as a core course or as an optional advanced course. Currently, there are no Bachelor or Masters degrees in Astronomy in Switzerland, although it is possible to take a Physics degree with a “Minor” in Astronomy at UniBe and with an “Orientation” in Astrophysics at UniGE and UniZH.

The close association with physics teaching is inevitable given that

- astrophysics is an important part of physics, or a par with other core areas such as particle physics or solid state physics;
- the high general interest in astronomy is recognized to be effective at drawing students into the physical sciences;
- applications of most types of physics can be found within astrophysics, making astrophysics a natural and attractive vehicle for students to synthesize understanding from across the field;
- a solid education in physics or a related field is the best preparation for a postgraduate career specializing in astrophysics.

The educational “reach” of astronomy professors in Switzerland thus extends well beyond astronomy itself, to physics and beyond physics, to other sciences also.

This very close involvement in physics education means that the most important co-ordination for the undergraduate teaching effort of astronomy professors is in fact with our colleagues in other branches of Physics within our own universities, rather than with other astronomers across Switzerland.

The teaching of astronomy is partly integrated between EPFL and UniGE. In Zurich, most of the optional astrophysics courses are open to students from both ETHZ and UniZH.

Graduate education

Education at the graduate level is a preparation for the research environment and is necessarily less structured than at earlier stages. There are many fewer formal courses and much greater reliance on individual training and mentorship within the environment of a research group. When students enter the research environment, they naturally move to Ph.D. positions at those universities that best match their interests. As Swiss universities move towards the Bologna plan for higher education, student mobility might shift to the start of the MSc.

For more than 30 years, the Swiss Astronomical Society (SSAA/SGAA), with sponsorship by the Swiss Academy of Natural Sciences, has organized an annual weeklong advanced course on a topical area of astrophysics in the Alps. These outstanding courses, traditionally delivered by experts from outside of Switzerland, also attract many participants from abroad. A book has been published for each of these “Saas-Fee Courses” (although the courses are no longer held in Saas-Fee) and these books have become key texts in graduate education throughout the world and many are regarded as classics. The Saas-Fee courses are an important element in the training of our own PhD students and illustrate the power of cooperation in graduate level education.

A strength of the Swiss astronomical community has been its diversity, with each institute often having unique core competencies, even as their scientific interests may have overlapped. Nonetheless, we find that each institute in the country has at least one ongoing collaboration with a group elsewhere in Switzerland. We are committed to now work to capture the diversity of these interests and make out of them a greater asset for the national education pro-

gramme. As outlined in Chapter 4 (Appendix 1), there are areas of research where there are groups at several Swiss universities that have agreed to enhance their research efforts through coordinated competence networks. To capitalize on this co-operation, we will start a programme of yearly “national schools in astrophysics”. These will take the form of an intensive event, approximately two weeks in duration, during the semester break in the Swiss academic year, and will focus each year on a broad suite of related topics, perhaps covering the research areas of one of the “networks” already identified. The topic and location will rotate around the country, with lecturers chosen from within the active Swiss research community. This course will complement and not replace or compete with the Saas-Fee courses. This school should be funded by the PRODOC programme or by the Swiss University Conference and will be organised by the CHAPS group.

Finding 11

At the undergraduate level, approximately half of the teaching effort by Swiss Astronomy Professors is devoted to teaching basic Physics (and Computational Science) courses, and almost all of the courses that

are delivered in astrophysics are part of a broader physics curriculum, either of physics specialists or of other scientists. The teaching effort by astronomers reaches well beyond astronomy. The most important co-ordination of teaching at the undergraduate level takes place “locally” within individual universities and the scope for meaningful coordination nationally is limited. However, at the graduate level, PhD level students at Swiss universities could benefit more from the expertise in related research topics that exists elsewhere in the country.

Recommendation 11

CHAPS should organise a yearly “national school in astrophysics” beginning in 2008. This should take the form of an intensive event (approximately two weeks) during the semester break and should focus each year on a broad suite of related topics covering the research areas of the “networks” already identified. The topic and location will rotate around the country, with lecturers chosen from the active Swiss research community. This course should complement and not replace or compete with the Saas-Fee courses. This school should be funded by the PRODOC programme and/or the Swiss University Conference.

Making Science possible

Technology Development for Astronomy

Progress in astrophysics has always been intimately tied to technological development. The links between scientific and technological advances have strengthened as observing platforms have moved into space and as new electromagnetic windows on the Universe have opened. New space and ground based telescopes, as well as completely new ways of studying the Universe, such as neutrino astrophysics and gravitational wave detection, ensure that the important role of technology will continue in the foreseeable future. The “synthesis” frontier of science has increasing importance. Here information technology is becoming a third pillar of science together with experiment and theory.

By its very nature, there are only a few direct applications of astrophysics for commerce: of these, fusion power has the greatest potential of changing society. Indirect applications are more common. For instance, the GNSS systems (GPS, Glonass, and the future European Galileo systems) are deeply rooted in the methodology and fundamental reference frames of modern astronomy. These have already had an immense impact on society as a whole.

Nevertheless, there are many opportunities for technology transfer stemming from the ambitious technological demands of large astrophysical projects. The high cost and technological complexity of the state-of-the-art astrophysical observatories being developed by both ESA and ESO demand international co-operation. Swiss institutions are active and even leading partners in many of these projects, playing major and highly visible roles in defining the initial science requirements, building key hardware elements and leading in the generation of forefront scientific results. Although instrument development is expensive the rewards are high: Even on observational facilities with open competitive scientific access, such as the ESO telescopes and many of the ESA observatories, participation in the development of instruments is generally rewarded by getting the first access to the new technology “on sky” with the associated opportunity to reap the largest scientific rewards. The knowledge gained during instrument development gives participants a huge advantage in opti-

mizing the use of the instrument and in the most effective data analysis.

Space- and ground-based equipment for sensitive astrophysical observations requires sophisticated and complex technologies. Space hardware demands miniaturization, power optimization and high levels of robustness in the hostile space environment. On the ground, the performance of optical, infrared and radio instruments relies on advanced mechanical and optical engineering.

To develop and qualify instruments for ground- and space-based applications, Swiss universities and institutes must share infrastructures and know-how. UniBe possesses facilities for thermal vacuum, vibration, and mass-spectrometer and optical calibration. PSI operates the Proton Irradiation Facility (PIF) to space-certify electronic components. It has also operated various low-temperature facilities for instrument-development. The PSI synchrotron facility SLS offers a number of beam lines to test and calibrate detectors from X-ray to infrared energies. Typically, Swiss participation requires specific technological know-how within several astronomical Institutes as well as industrial partners for final development and construction. The close proximity within many institutes of scientific and technical personnel offers a very fruitful and dynamic development environment.

By its very nature, there are only a few direct applications of astrophysics for commerce. Nevertheless, there are many opportunities for technology transfer stemming from the ambitious technological demands of large astrophysical projects.

6.1 Ongoing technological development in astronomy in Switzerland

Mass Spectrometers

UniBe develops miniaturized mass spectrometers for spaceflight with particular specialty in ion sources and time-of-flight instrumentation. Key technologies are the integration of micro-lasers and a ceramic metal brazing technology for the miniaturization of complex ion sources (used for several elements of the ROSINA experiment).

Laser altimeters and laser ranging

UniBe is also currently developing Europe's first laser altimeter for planetary exploration. This device (which is slated to fly to Mercury) relies upon several new technological developments, including lightweight reflective baffles (incorporating heat rejection thin film coatings), diamond-turned copper-coated beryllium mirrors, robust high power lasers (with possible uses in telecommunications) and novel software solutions (with uses in ground-based laser ranging). The device also has applications in Earth remote sensing (e.g. climate change monitoring). The UniBe observatory Zimmerwald is developing its laser ranging system with the goal to extend the range from artificial satellites to the Moon and other planets, using also transponder technology. The upgraded CCD component of the observatory will be efficient for follow-up observations of NEOs, as well as Solar System objects detected by Gaia.

Detectors and cryogenic technology for astrophysical satellites

PSI had a long tradition in research and development of new cryogenic detectors for further X-ray astronomy space missions like XEUS, but was also working on various instrument components for astrophysical satellites, mostly in the domain of cryogenic technology and electronics. Previous contributions were made to ESA's XMM-Newton and Integral and to NASA's RHESSI satellite, while the most important recent effort is on components (cryo-harness, contamination control cover, cryogenic test chamber) for the MidInfrared Instrument (MIRI) on JWST and contributions to the Near-Infrared Spectrometer (NIR-Spec).

High-precision imaging spectro-polarimetry

ETHZ's imaging polarimeter system ZIMPOL (Zurich

Imaging Polarimeter) has a polarimetric accuracy that is two orders of magnitude better than any other.

Technology for exosolar planet searches

UniGE developed the fully automatic EULER 1.2m telescopes located at La Silla, Chile. Together with the Coralie and HARPS spectrographs, they discovered exosolar planets.

Solar Irradiance

PMOD/WRC is developing the technology of precise radiometers and complete space experiments to measure the solar irradiance. They designed, built, and operated the space experiments IPHIR on PHOBOS (1988), SOVA2 on EURECA (1992/93), and VIRGO on SOHO (1996/2007).

Cryogenic microwave electronics

ETHZ developed cryogenic electronics for the HIFI instrument on the ESA Herschel millimeter wave observatory. These constitute the first section of the seven-channel receiver in the frequency range between 480GHz and 1.9THz and are followed by the intermediate frequency IF2-Box. The noise of this front-end is mostly produced by the amplifiers and determines the overall sensitivity for observations.

High Performance Computing for Astrophysical Simulation

UniZH builds state of the art supercomputing from commodity parts. The Zbox was built in 2002 as a dedicated machine for cosmological N-body simulations, and, when built, ranked 144th on the 2003 list of the World's Top 500 Supercomputers, ranking 3rd in Switzerland. Commodity supercomputing clusters cost only about CHF1.5K/cpu, more than an order of magnitude less than commercial supercomputers that have a typical cost of CHF30K/cpu. The next generation Zbox2 came on-line in December 2005. In addition to the hardware projects, the team is recognized as world leaders in parallel software for simulation and analysis of N-body systems.

Software Tools and Grid Technology for the International Virtual Observatory

Data processing will be of ever increasing importance with the increasingly large volumes of data obtained

from observational projects. The instrument characteristics must be described and taken into account before the data can be fully exploited by the community. This requires that centers like the ISDC for the INTEGRAL mission must be put in place to perform this task. Switzerland can take a very active role in this domain, building on the successful experience of the ISDC.

Preparation of SOVIM, an experiment to observe the Total Solar Irradiance, at the PMOD/WRC. SOVIM is expected to be launched with a space shuttle to the ISS in December 2007, together with the European ISS-module Columbus.

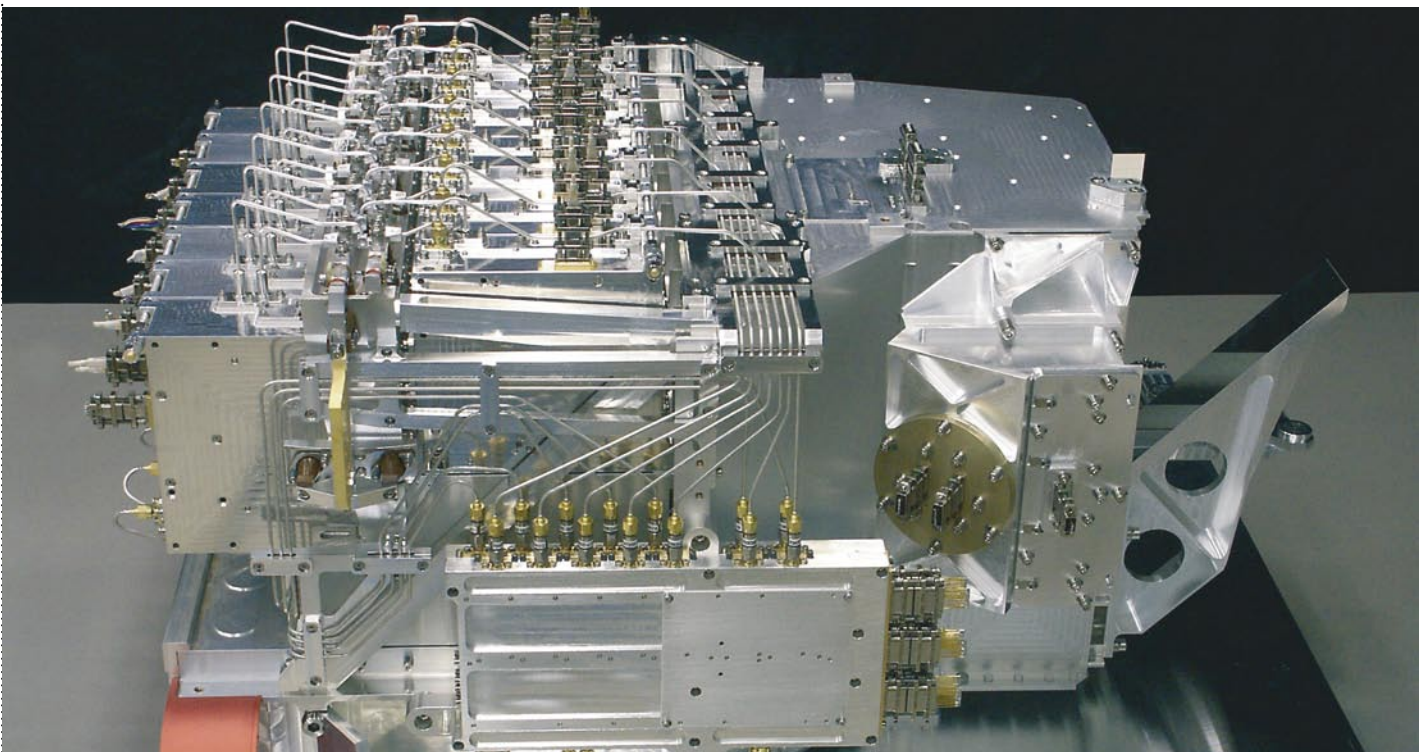


6.2 Swiss commercial applications of technology developed for astronomy

Development of major astronomy-related satellites or ground-based instrumentation are usually undertaken in collaboration between scientific research institutes and industry. This provides the scientific drive, the technological advance and the reliability of the construction that are needed to make a world class instrument. ESO and ESA thus provide Swiss industry opportunities to compete for the development and building of parts of the research infrastructure. As examples, CONTRAVES built the mechanical structure of the INTEGRAL payload module while ETEL has been responsible for significant VLT elements. Other firms like APCO, CSEM, FISBA and several others have been active in instrument and infrastructure developments.

The know-how gained in these frontier projects can be applied to many other activities. Space and ground-based astronomical research projects help Swiss industry to fully exploit the technological potential existing in universities and technical institutes, e.g. in micro- and nano- technologies, optoelectronics, microwave technology, detector and cryogenic technology, etc.. It encourages and supports the creation of spin-off companies in the space and non-space market and it fosters the global competitiveness of Swiss equipment suppliers.

The HIFI Focal Plane Unit for the ESA Herschel Space Observatory, to be launched in 2008. ETH Zurich.



6.3 Future Requirements

The scientific program described in Chapter 4 requires continued key technology development in Swiss laboratories and industry, including:

Ground-based Astronomy instrumentation for the VLT, VLTI and E-ELT projects.

ESO's VLT comprises four 8-meter telescopes that work independently or in a combined mode with four movable 1.8-meter auxiliary telescopes (the VLTI) as the world's most advanced optical interferometer. The next major project for ESO is a single aperture telescope in the 40-m class, called the E-ELT.

Switzerland (UniGE, EPFL, Haute Ecole Arc St. Imier and CSEM) leads the development of the second-generation VLTI instrument, PRIMA (Phase-Referenced Imaging and Micro-arcsecond Astrometry). It represents a formidable advance in technological innovation and opens access to completely new domains of astronomy.

UniGE and ETHZ collaborate in the development of SPHERE, an adaptive-optics system for direct imaging of extra-solar planets. We expect that the E-ELT first-light instrumentation will include updated versions of SPHERE and MUSE as well as an ultra-high precision spectrograph developed from those built at UniGE.

Space projects

Several Swiss teams will respond to ESA's Cosmic Vision 2015-2025 "A call for missions" in 2007.

A Jupiter mission needs radiation-hardened components, laser altimetry, thermal infrared imaging spectroscopy, sub-millimeter heterodyne receivers, and low-mass high-resolution mass spectrometers. Conceptual design work on novel low mass infrared and Raman spectrometers has already been initiated in preparation for such a mission.

The Laser Interferometer Space Antenna (LISA) will detect gravitational waves emitted by supernovae and more exotic events like neutron star and black hole mergers. Three spacecraft flying approximately 5 million kilometers apart in an equilateral triangle comprise an interferometer that measures the distortion of space by gravitational waves. Swiss institutes are participating in the 2009 LISA Pathfinder mission, an ESA Technology Demonstra-

tor Mission to test new drag-free and attitude control technology. The ambitious Darwin mission proposes a flotilla of four space telescopes operating as an interferometer to search for Life on Earth-like planets. Adaptive optics and interferometry over such a long baseline presents many technological challenges in common to LISA and Darwin.

Survey space telescopes like DUNE that will observe a billion galaxies require new approaches to data handling, as well as high data transmission rates to the ground.

For future missions, Swiss institutes and industry will provide expertise in key technologies: 1) adaptive optics, 2) advanced optical components, 3) detector technology over a wide wavelength range, 4) metrology combined with nanotechnology, 5) low-power radiation-hard electronics, 6) cryogenics systems, and 7) precision mechanics.

Information Technology

Swiss astrophysicists will advance the state of the art commodity supercomputers to meet their computing needs. The UniZH is currently building a storage system which is the only one in the world with both failover NFS and information life-cycle management. Investments at a national level need to balance money put into large commercial systems and the cheaper commodity clusters.

6.4 Future infrastructure and programs

6.4.1 A national center or network for astronomical technology

Effective development of technology for complex and long-term ground-based and space-borne missions requires significant technical expertise, infrastructure and, in many cases, close ties to industry for final development and production. As instruments become larger and more complex, with longer development cycles, there is a need for the efficient management of the major technical resources of the community.

A possible solution would be the implementation of a Swiss Center for Experimental Astrophysics and Astronomy. Such centers exist in many countries such as the United Kingdom (RAL and the ATC), the Netherlands (SRON), Germany (MPI's), Belgium (CSL), and France (many different institutes). Such a center can act as a nucleus for the technical participation of research institutes in technically demanding missions. One model would be to embed such a center within a large technical laboratory for effective matrix management of different areas of expertise. PSI's heritage in space astronomy missions (XMM/Newton, RHESSI and JWST/MIRI) is a clear model, but the decision to close the PSI Astrophysics Laboratory may make such a concept impractical.

Another model would be to build a network of technological expertise across Switzerland. Given the convergence of overall science goals of the Swiss community described elsewhere in this Report, the goal would be to effectively pool complementary laboratory expertise to build up a joint, national participation in large high profile projects undertaken at ESO and ESA. This model is difficult as the projects are large, but few in number, and will require a lot of technical expertise as would be available at a larger National laboratory. In addition, as Switzerland is small, there are not a lot of laboratories of this sort to choose from.

Finding 7

While the space research group at Bern provides a centre for solar system research missions, the equivalent for astronomical space projects is missing. The Swiss astronomy community will not be able to participate effectively in future space astrophysics projects if it does not contain the necessary technical expertise with whom strong collaborations can be developed by groups for particular projects.

Recommendation 7

The SER should ensure that Switzerland retains a capability in space astrophysics instrument development. The SER and CHAPS should jointly develop an implementation plan. This capability should be based on a full-time development core team, ideally embedded within a larger technical and engineering organisation, and should be located in close proximity to an active astrophysical research environment.

6.4.2 Seed funding for concept studies and prototyping

The early exploratory development phase of a technical project is crucial, since the competence must be demonstrated in the study phase to compete competitively to a Call for Proposals or Announcement of Opportunity from ESA or ESO. If the instrument is selected, then there is a need to make a long-term commitment for financial and technological support to deliver sophisticated instruments or components in time.

One of the key issues in the development of future experimentation is a funding mechanism for

new concepts. Groups that have new instrument concepts must rely on inadequate internal funding to achieve the proof of the concept needed for competitive selection by ESA or ESO, when and only then, the project is eligible for PRODEX or FINES funds. Without short-term funding for proof of concept, Swiss astronomers lose competitiveness in this crucial phase. The US have an “instrument incubator” program; our community needs one to compete.

6.4.3 The FINES program

FINES provides support for Swiss participation in instrumentation projects approved by ESO. This program is currently set to expire in 2007 and it is critical that it be renewed.

The number of eligible projects is small and the current mechanism for competitively assessing them has been problematic because the funding envelope is so tight that future funding can easily be over-committed.

Finding 2

The FINES program provides critical support for ESO instrumentation projects. This enables high impact science using new observational capabilities and the large amounts of associated “guaranteed observing telescope time” (GTO). The existing and projected demand for FINES support of ESO-approved programs will continue to grow with the implementation of the VLT 2nd generation, VLT-I, and E-ELT programmes.

Recommendation 2a

The SER's FINES fund must be continued in 2008-2011 to ensure completion of the 2nd generation instruments for the ESO VLT (SPHERE and MUSE) and the instrumentation for the VLTI (PRIMA). The detailed future investment required from FINES in 2008-2011 is summarized in Table X

on p. X: Swiss participation in future E-ELT instrumentation development should be supported through an augmented continuation of the FINES fund at a level of CHF 1.5M in 2012 and beyond.

Recommendation 2b

A small instrument incubator program should be established to fund technological development of instrument concepts for ESO instrumentation, through to a proof of concept prototype. Support for this should come from FINES. Awards should be based on both the scientific case and the potential for a successful ESO-approved project.

Recommendation 2c

In managing the cash-flow of the FINES program, the SNF needs a system of “pre-proposals” to gain information on instrumentation programs as they progress through the earliest phases of development and not only after they have been approved by ESO and the need for FINES funding becomes urgent. The Swiss representatives at ESO should also be charged with maintaining a running overview of potential Swiss participation in ESO instrument projects so as to brief the SNF.

6.4.4 PRODEX and the Mesures d'accompagnement

In the last two decades, Switzerland has provided funds to the PRODEX programme to support experiments and instruments for ESA's scientific missions. PRODEX has supported major programmes such as the UniBe mass spectrometers, and the XMM-Newton spectrometer and JWST/MIRI instruments by PSI, as well as part of the funding for ISDC.

Since 2003 the mesures d'accompagnement has also funded space projects directly in Switzerland, including those also that are outside of ESA's programmes.

It is important that these programmes be further developed to ensure the continued strong participation by Swiss institutes in scientific space instrumentation and data processing. It is foreseen that the mesures d'accompagnement programme will be continued. It is essential that scientists participate in mission definitions, long before their approval, so as to position Swiss institutes and industries in the competition for their most fruitful elements. The Mesures d'accompagnement should take over the largest part of the ISDC operations and the development of ISDC participation in other missions. PRODEX and the mesures d'accompagnement should therefore be funded at levels commensurate with the ambitions of the Swiss astronomers and space scientists.

Recommendation 6a

The PRODEX and the "Mesures d'accompagnement" programmes must be maintained at a combined inflation-adjusted level of approximately CHF 19M (€13M) per year over the next 10 years, so as to fund Swiss participation in the current ESA missions (Bepi-Colombo, EXOMARS, Solar Orbiter, Gaia, LISA), as well as future missions undertaken by ESA in "Cosmic Vision" and non-ESA missions. The anticipated investment required from these two funds is summarized in Table 5, and is expected to be in the ratio 2:1 for PRODEX/Mesures d'accompagnement.

Recommendation 6b

A small instrument incubator program should be established to fund technological development of space instrument concepts, through to a proof of concept prototype. Support for this should come from Mesures d'accompagnement funds. Awards should be based on both the scientific case and the potential for a successful PRODEX project.

Sharing the excitement Public education and outreach

Switzerland has a scientific and technical competence and leadership that is the envy of the world. A key element to continuing such leadership is a well-educated and scientifically literate public.

Astronomy captures the popular imagination by addressing some of the oldest and deepest questions about our origins and place in the cosmos. UniGE Astronomers are *primo loco* in planet discovery, while those in UniBe, UniZH and ETHZ are at the top of the field in understanding how planets form and the future fate of our own solar system. Cosmological research at ETHZ and UniGE/EPFL looks back in time to the first billion years of the Universe to witness the formation and early evolution of galaxies like our own, while theoretical cosmology contemplates the Universe when it was a tiny fraction of a second old.

Swiss professional astronomers are at the forefront of the global research community in many of the most rapidly developing research areas in astrophysics, particularly those that are most accessible and appealing to the general public. This is a remarkable position for such a small number of Professors in a nation with a population that is barely 1% of the combined Western World.

Despite its small size, the Swiss astronomical community has the potential to strengthen the nation's science educational system and improve public scientific literacy. Astronomy is increasingly interdisciplinary and has a natural link to new technology, putting it in a position to contribute to the health of the technical work force in the coming century. To enhance the professional training at the graduate level, we must embrace new technology to work collectively.

Effective public outreach programmes to explain and share the excitement of scientific advances are a unique opportunity that must be grasped by a technologically-driven civilization such as ours. Astronomy has a unique ability to inspire and to draw the brightest young minds into the physical sciences.

Advances in information technology have offered unprecedented opportunity for educators and learners to access scientific data and information, as well as expanding the opportunities for participation in scientific learning. As part of its em-

brace of technology, astronomy is establishing itself as a leading application in the grid-enabled world. The International Virtual Observatory will deliver vast amounts of astronomical data to any desktop. While this will change the way we do science at our premier research institutions, it may have even greater impact for astronomical education and outreach.

Our strategic goals are:

- To share the excitement of astronomical and space discoveries with the public
- to use this interest to enhance the effectiveness of science, mathematics and technology education
- to contribute to the creation of a 21st century technical and scientific workforce
- to prepare the next generation of Swiss astronomers who can continue with all aspects of this roadmap

The keys to an impact from our small community will be partnerships and the use of new technologies to make our efforts collective.

Astronomy captures the popular imagination by addressing some of the oldest and deepest questions about our origins and place in the cosmos.

7.1 Public outreach

Astronomy captures the public imagination. Fewer than 1% of all scientists are astronomers, yet astronomical stories take more headlines and television specials than any discipline other than medicine. Astronomy is the focus of numerous publications, foundations and amateur associations. Planetariums and astronomical exhibits are among the most popular at museums that showcase science.

There are activities that have been started and should be promoted in the coming decade. We will address here what is needed to take them to the next level. A key issue is scale. If they were all collocated, the 20 Swiss astronomy professors would be comparable in size to a large US astronomy department, but small compared to the top 129 US physics departments. The largest concentration of astronomers is at the Astronomical Center UniGE-EPFL. This gives them a critical mass to engage in many of the activities that it would be desirable to take to a national level.

Public visits and open houses of the institutes are becoming routine annual events. These should be considered as part of a sustained effort that transforms our buildings into more interesting places for students and the general public as corridors and entrance halls become permanently decorated with pedagogic posters and demonstrations. The Astronomical Center UniGE-EPFL, the UniBe Astronomical Institute and the Specola Solare at Locarno have been effective at this and are now visited by more than 5,000 people each year. Last year, “Nacht der Physik” events at ETHZ and UniBe to celebrate the Einstein Centenary attracted a total of 15,000 visitors in a single evening.

Press officers have proven enormously valuable in communicating discoveries. This activity needs to be strengthened at most Universities in partnership with the astronomical community. Regular contributions of monthly chronicles written by professional astronomers appear in Basel, Bern, Geneva, and Zurich publications.

The Swiss Astronomical Society is a joint effort of professional and amateur astronomers; the keen interests of amateurs helps astronomy reach a far larger number of lay people. Their journal

ORION is edited by professional astronomers at UniBe and UniGE with contributions from all parts of the society. Nearly 3,000 copies of each issue are sold.

Public astronomical viewings stimulate the interested public. The Urania Observatory in Zurich and UniGE are probably the best known, but there are further opportunities at UniBas and UniBe as well as the François-Xavier Bagnoud Observatory operated by amateur astronomers at St-Luc (Wallis).

Special events associated with particular phenomena can also have high impact. Comets such as Hale-Bopp always have great appeal, but even the Mars oppositions of 2003 and 2005 were able to attract thousands of people.

Adult Education Courses of Astronomy open to the public are highly desirable. These are currently offered at UniGE which draws 100-150 students each year, the “Saturday morning physics” lecture series aimed at high school students at UniBe, and under the auspices of the “studium generale” at UniBas.

Planetariums and science museums provide venues to engage the public. The largest planetarium in Switzerland is located in Luzern. If the number were equal on a per capita basis to the ~1100 North American planetaria, we would have 25 comparably large ones. The new generation of digital planetariums offer a wide range of presentations at a cost that is less than a traditional planetarium. Developing additional sites for these should be a priority. In addition, our community needs greater involvement with the Swiss Technorama and the other science museums that are in a planning stage.

We advocate promotion of these activities and several new ones that will build new partnerships with teachers and educators. It will require such partnerships to make the step from informing the public to positively impacting education.

7.2 Pre-University Astronomy education

Switzerland, like the rest of Europe, is undergoing a crisis in science education. While astronomy holds great fascination for young people, it plays a comparatively small role in primary and secondary education. In the last decade, its role has diminished owing to educational reforms at various levels that have standardized curricula.

To reverse this trend, the astronomical community must take a proactive role to ensure that the educational advantages of using astronomy as a gateway into science are not abandoned. However, we still have a lot to learn about how to gain enough leverage to take a significant role. There are certainly three areas that hold great promise:

- (a) building teacher-astronomer partnerships,
- (b) using technology to provide interesting materials to both teachers and directly to young web-surfers,
- (c) making it more attractive for teachers to acquire astronomical knowledge through continual training opportunities as well as attractive astronomy courses during their original training years.

The first comprehensive vision of Nature and the human environment is acquired during the critical early years of primary school. Analytical skills are developed by a child's early engagement in science. The working group "Penser avec les mains" analysed primary schools of the Cantons of Geneva, Vaud and Neuchâtel and concluded that a special effort should be made to improve the teacher training in the natural sciences with a particular emphasis in astronomy (Hulo S., Penser avec les mains, rapport d'activité, Passerelle Science-Cité, UniGE, 2004).

Very little astronomy is presented in the current secondary curriculum. Typically, a geography course includes "the place of the Earth in the cosmos" with the introduction of a few hours of general astronomical information. Astronomy is also used to illustrate a physical law (e.g. gravitation), or to explain the historical evolution of a scientific concept. We need to develop ways that help teachers exploit and develop the inherent interest that students have for astronomy.

An extremely successful model is the Astronomical Society of the Pacific's Project Astro (see www.astrosociety.org/education/astro/project_astro.html). This project pairs teachers and astronomers (professors, graduate students, amateurs) with the latter committing to give some informal discussions and 4-10 visits per year to the classroom. Starting in San Francisco in 1993, there are now 13 regional centres, serving 20,000 students annually.

Finding 12

The development of individual partnerships between astronomers and high school educators has proved very successful in Switzerland and elsewhere.

Recommendation 12

CHAPS should co-ordinate the creation of a center for developing and strengthening these astronomer-educator partnerships across the country. Sustainability should be given greater emphasis in this effort than innovation.

7.3 Enhancing the Technical Workforce of the 21st Century

Astronomy's need for cutting edge technology has had many interesting by-products. Rapid development of CCD cameras owed to investments by planetary exploration missions. For a long time, astronomers were the only scientists interested in image processing with error analysis. As a result, scientists trained in astronomy have developed much of imaging science from automated cleanup of images in consumer cameras to the acquisition and analysis of data in transcriptomics and proteomics. While that is a specific example, scientists trained in astronomy are found throughout the high technology workforce including such diverse areas as banking, actuarial risk assessment, data-mining and Earth-observation.

Our Masters and Ph.D. programs must be guided by the knowledge that the PhD is a versatile advanced degree in science and that well over half of the successful students will pursue careers that will take them outside of astronomical research into the general labour-force.

As a community, we should try to provide more specific options in Master's programs. For example, UniZH is about to introduce a Master's program in Computational Astrophysics. It would also be desirable to have Master's programs that focused on Astronomical Instrumentation, Data Processing and Astronomical Education.

Young visitors ETH Zurich



This Roadmap for Astronomy in Switzerland 2007-2016 outlines a plan drawn up by the 24 members of CHAPS during a series of highly interactive meetings in 2005-2006, in which a consensus vision emerged for research, education and public outreach, and of technical development and industrial co-operation.

It builds on the strong foundations of current excellence within Swiss astrophysics to secure continued leadership in key research areas. On the experimental/observational side, it draws heavily on Switzerland's membership of ESO and ESA, and on the future exploitation of the current and next generation of facilities at ESO – the VLT, VLT-I, ALMA and the future E-ELT – and in participation in future ESA missions – already approved and those to be proposed under the ESA Cosmic Vision program. We advocate the strengthening of the financial position of ESO and of the Science Directorate of ESA so that these future programs at the European level will proceed in a timely and globally competitive way.

The detailed plan calls for a continued increase in the number of personnel engaged in Swiss astrophysics of about 5% per year for the next five years. The FINES fund will be fully utilised for the next five years, and should be increased thereafter to accommodate Swiss participation in E-ELT instrumentation. The anticipated demands on the PRODEX and Mesures d'accompagnement

funds will be heavy – although it is in this part of the program that the precise investments and timescales thereof are less certain as Cosmic Vision is implemented.

SNF support for Swiss astrophysics is crucial and we call for continued support of both data analysis and for theoretical work, noting that support for the latter must keep pace with the investments in observational facilities and space missions.

A healthy and vigorous astrophysics research community within Switzerland will educate and inspire young people from primary school to the universities. The technical development that is essential to scientific advances in astrophysics will benefit Swiss companies in the global marketplace.

Finally, the Roadmap has brought together the Professors and Heads of independent laboratories in an exercise to plan our future direction. This itself has generated a strong sense of collaboration and co-operation in meeting the challenges that lie ahead.



Eta Carinae, a region of intense star-formation in the Large Magellanic Cloud, a small satellite galaxy of the Milky Way. NASA/ESA

Research Networks

A Planetary Science Network

Mission Statement

The purpose of the network is to bring together all of the researchers in Switzerland working in the area of the formation and evolution of planets. This covers a broad range of interconnected subjects from the exploration and study of the solar system to the study of disks around young stars and the detection and/or imaging of extra-solar planets including the search for life inside and outside the solar system. The research carried out within this network is based on the development of novel instrumentation for space- and/or ground-based platforms, observational and laboratory studies, and on the development of theoretical models. The multi-disciplinary character of this research and the large number of ground- and space-based projects currently ongoing worldwide makes such a network an essential tool for preserving Switzerland's future leading role in this area of astrophysics.

www.space.unibe.ch/planet-network

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B Stellar Evolution Network

Mission statement

Stellar evolution is at the crossroad of many topical subjects in astrophysics as for instance, the first stellar generations in the Universe, the mechanism of star formation, the progenitors of the different types of supernovae and of the Gamma Ray Bursts, the origin of black holes and pulsars, the chemical evolution of the galaxies, the heating sources of the interstellar medium, the sources of dust in the Universe. The advent of new facilities such as ALMA and the E-ELT, and developments in helio- and asteroseismology, will reveal new aspects of the evolution of stars and will allow us to build stronger connections between fundamental physical processes, the evolution of stars and that of the galaxies. This network has for aim to offer a possibility for all the researchers in Switzerland working in the area of stellar physics and evolution to exchange information on their works and on the new developments in this field, to benefit from the experience acquired in Switzerland in various domains as for instance in numerical technics or in preparing observing runs, to prepare the community for the advent of future observation facilities (as for instance ALMA) and finally to offer a platform for organizing conferences, lectures in this area of research.

<http://obswww.unige.ch/senetwork/>

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C Galaxy Formation and Cosmology Network Mission Statement

The purpose of the network is to bring together all of the researchers in Switzerland working in the area of cosmology and galaxy formation. This covers a broad range of interconnected subjects from particle physics in the early universe to astrophysics of stars and galaxies. It includes topics such as dark matter candidates in particle physics, initial conditions for structure formation in the universe, structure evolution in the universe, first stars and galaxies, evolution of intergalactic gas, cosmic microwave background, galaxy clustering, gravitational lensing, galaxy formation etc. There has been a tremendous progress in these areas in the past several years and in many cases the progress in one area has only been possible due to advances in another area. There is a clear desire to connect workers in these fields to open up new channels of collaboration and to facilitate the transfer of information among them.

www-theorie.physik.unizh.ch/EXGnetwork

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D Swiss Virtual Institute for Solar Science (SVISS)

Mission statement

New ground-based and space observations of the Sun have revolutionized our understanding of solar physics and space weather. SVISS is a coordinated network of research groups and laboratories for promoting solar physics in Switzerland and for advancing national and international cooperation in solar sciences. This includes physics of the Sun and the heliosphere, their influence on the Earth's climate, and the Sun as a laboratory for studying in detail basic astrophysical processes such as scattering, convection, magnetized plasma, stellar pulsations and energy transport. The main mission of this network is to coordinate participation in large international programs and space projects, inform the community about ongoing research activities, promote interdisciplinary collaborations, and incorporate Swiss solar physics into the world-wide network of virtual solar observatories.

www.sviss.ch

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List of acronyms

Swiss research institutions

EPFL	Ecole Polytechnique Fédérale de Lausanne
ETHZ	Eidgenössische Technische Hochschule Zürich
IRSOL	Istituto Ricerche Solari Locarno
ISSI	International Space Science Institute
ISDC	Integral Science Data Center
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center
PSI	Paul Scherer Institute
UniBas	University of Basel
UniBe	University of Bern
UniGE	University of Geneva
UniZH	University of Zurich

Others

ALMA	Atacama Large Millimeter Array A major collaboration between ESO, the US and Japan to construct and operate an array of 50 12-m millimeter-wave antenna, covering 200 km ² of the Chajnantor plateau at 5000m altitude. The project has a total budget in excess of CHF 1 billion and is scheduled for completion in 2012.
Astronet	Astronomy Network, an EC-funded ERANET.
ATST	Advanced Technology Solar Telescope, a US-led project with international partners to build a 4-m solar telescope on Haleakala (Hawaii), planned to be operational in 2014.
Bepi-Colombo	An ESA mission to Mercury
Darwin	A proposed ESA advanced space mission that will search for signatures of life on exo-solar planetary systems, by means of

DUNE

E-ELT

ESO

ESA

ExoMars

FINES

Gaia

GNSS

GTO

HARPS

HST

IBEX

Integral

interferometry between free-flying spacecraft.

Dark Universe Explorer. A proposed Cosmic Vision mission to map dark matter and characterise dark energy through weak lensing and other techniques.

European Extremely Large Telescope. ESO's medium term priority after completion of ALMA is the construction of a 40-m class optical-infrared telescope.

European Southern Observatory. A partnership of 12 nations, including Switzerland, that operates numerous state of the art telescopes in Chile, La Silla and Paranal observatories.

European Space Agency
An exo-biology mission to Mars. Its aim is to further characterise the biological environment on Mars in preparation for robotic missions and then human exploration

Fund for Developing Astronomical Instruments ESO

An ESA mission to obtain extremely accurate positions and photometry of approximately 1 billion stars in the Galaxy.

Global Navigation Satellite Systems

Guaranteed Time Observation. Awarded to instrument developers to enable them to carry out specific science investigations with their instrument.

High Accuracy Radial velocity Planet Searcher – an ultra high precision spectrometer operating on the ESO 3.6m telescope.

Hubble Space Telescope, a NASA-ESA orbiting 2.5m telescope, in operation since 1990.

Interstellar Boundary Explorer
ESA's g-ray observatory.

Appendix B

IVO	International Virtual Observatory. A global network of digital data archives that will provide data in a common, highly usable, format.	SIM	Space Interferometry Mission, a NASA mission.
JWST	James Webb Space Telescope. The 6.5m successor to the HST (and also the Spitzer Space Telescope) due to be launched in 2013. The JWST will operate primarily in the 1-28 μm waveband.	SONTEL	Solar Neutron telescope, located on the Gornegrat.
LISA	Laser Interferometer Space Antenna – a proposed ESA mission to detect gravitational waves.	Spitzer	A NASA infrared observatory.
MIRI	Mid-infrared imager. This is an instrument being built for the JWST by a European-US consortium, operating in the 5-28mm waveband and performing both imaging and spectroscopy.	SPHERE	A second-generation instrument for the ESO VLT, designed to detect large Jupiter-like planets around nearby stars.
MUSE	Multi-unit Spectroscopic Explorer, a second-generation instrument for the ESO VLT, consisting of a 90,000 channel integral field spectrograph.	STEREO	A space mission to observe the Sun.
NIRCAM	Near Infrared Camera. The primary camera to be flown aboard JWST. ETHZ is a participant.	VLT	Very Large Telescope: The four 8-m telescopes operated by ESO at Paranal Observatory.
OECD	Organisation of Economic Co-operation and Development.	VLT-I	Very Large Telescope Interferometer: The four telescopes of the VLT when linked together interferometrically to give exceptional resolution on bright sources.
PICARD	A French space experiment to measure the solar diameter, with launch 2009.	XEUS	A proposed Cosmic Vision space mission for an advanced X-ray observatory.
PRIMA	The Phase Referenced Imaging and Micro-arcsecond Astrometry project for the ESO VLT-I.PROBA2. An ESA technology demonstration space mission with launch in 2008.		
PRODEX	PROgramme de Développement d'Expériences scientifiques.		
SOHO	Solar and Heliospheric Observatory, an ESA/NASA space mission of ESA/NASA, in operation since 1995		

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