RefleX 3.0 and beyond

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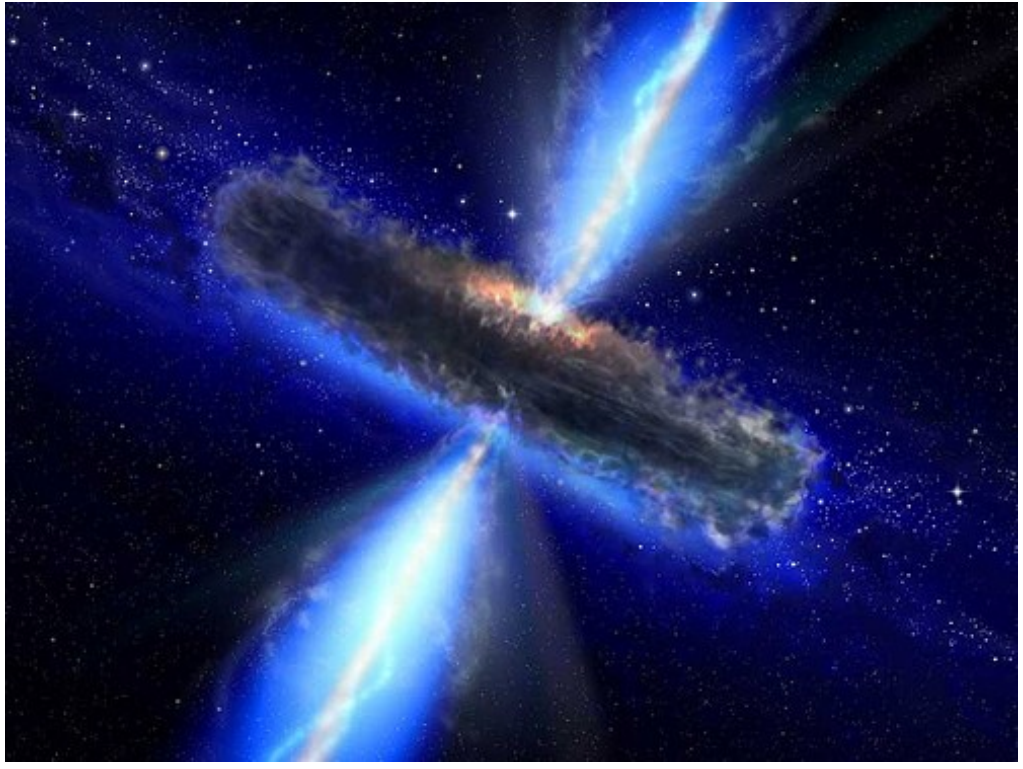
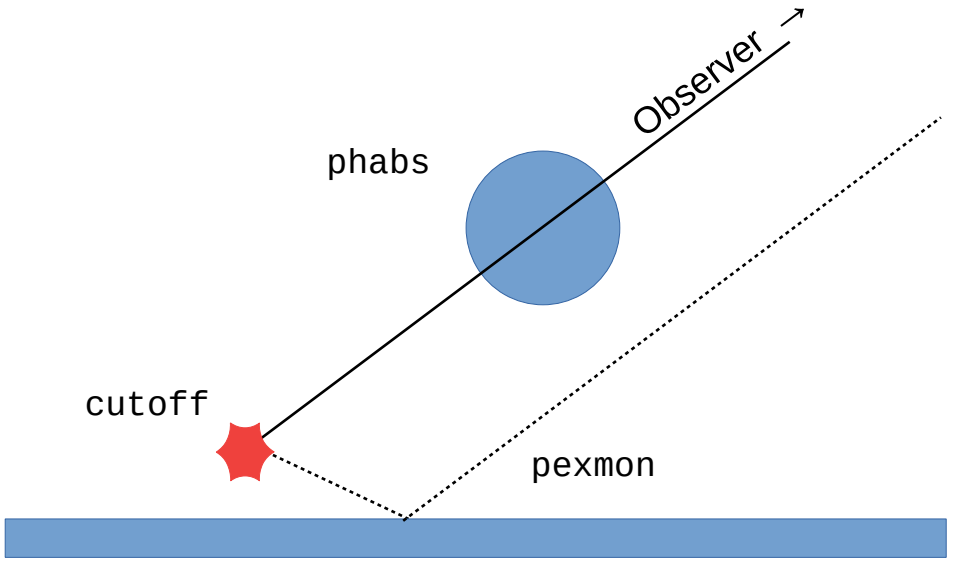
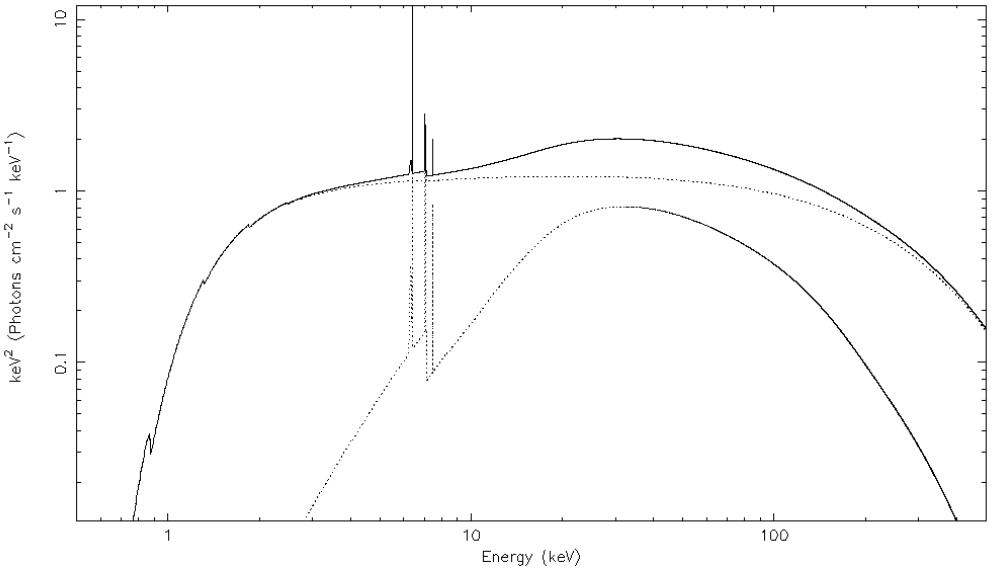
Active Galactic nuclei



- Supermassive black hole
- Surrounded by complex distribution of matter
  - Accretion disk
  - (Dusty?) torus
  - Radial/Polar structures?
  - Broad-line region
  - Warm scattering medium
- X-rays are an important probe of the matter distribution

Modeling AGN X-ray Emission

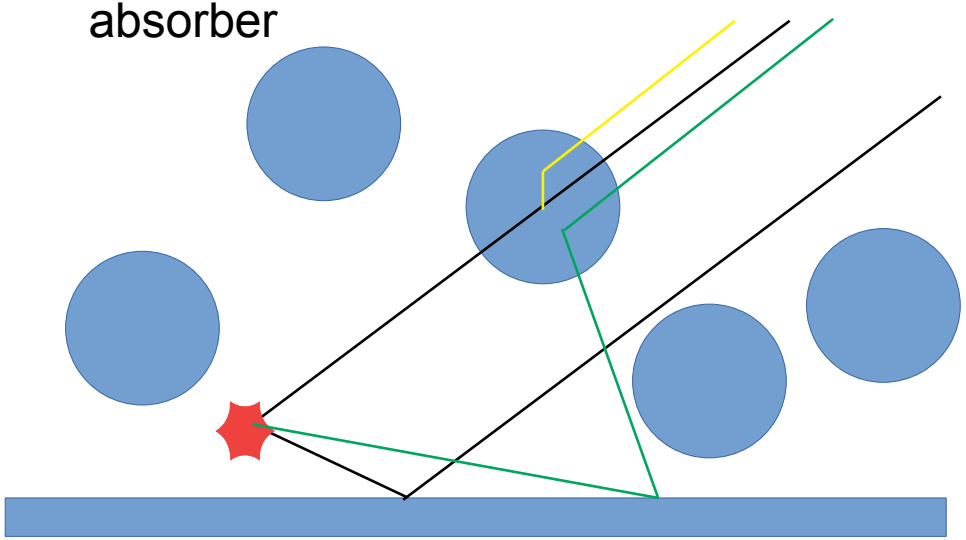




Cut-off power law, neutral absorber, thick reflector

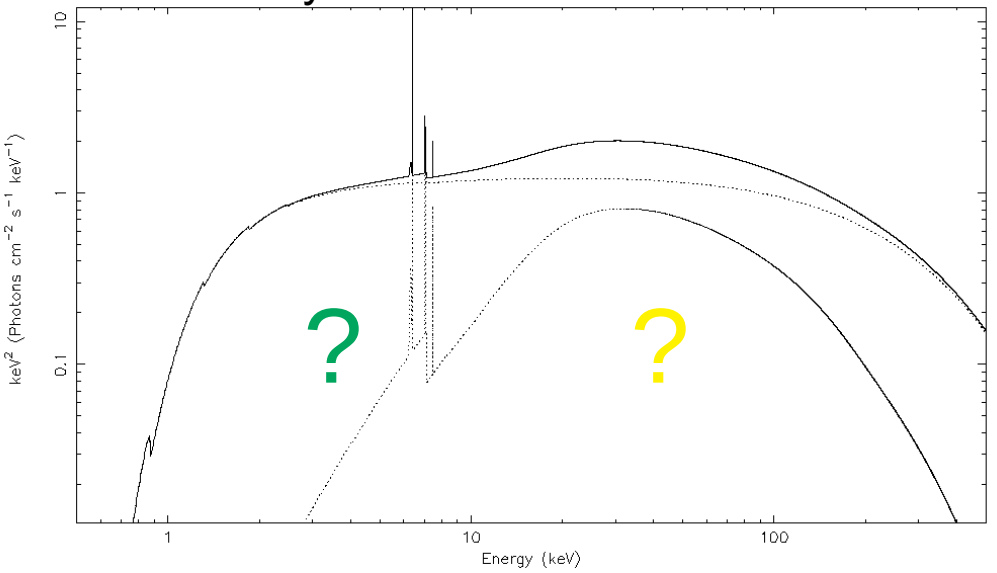
Modeling AGN X-ray Emission

- Scattering and reflection in the absorber
- Interactions between reflector and absorber



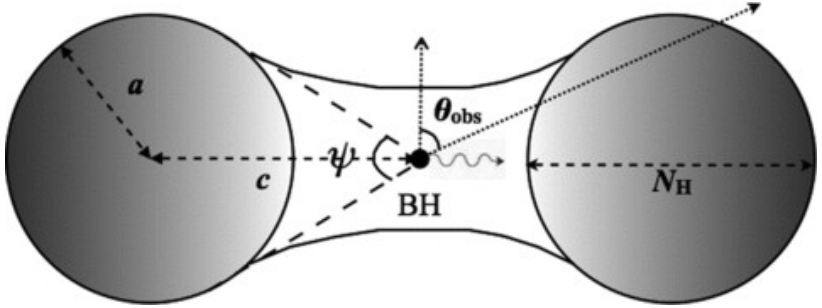
More generally:

- Absorber not only on the line of sight
- Absorber and reflector must treated consistently



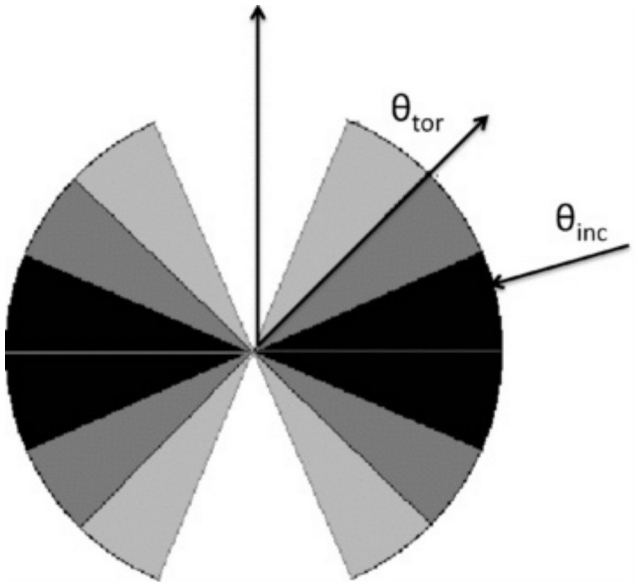
Cut-off power law, neutral absorber, thick reflector

Self-consistent Models of Absorption and Reflection



MYTorus (Murphy & Yaqoob 2009)

Torus geometry; c=2a



BNTorus (Brightman & Nandra 2011)

Spherical-toroidal geometry
Variable opening angle

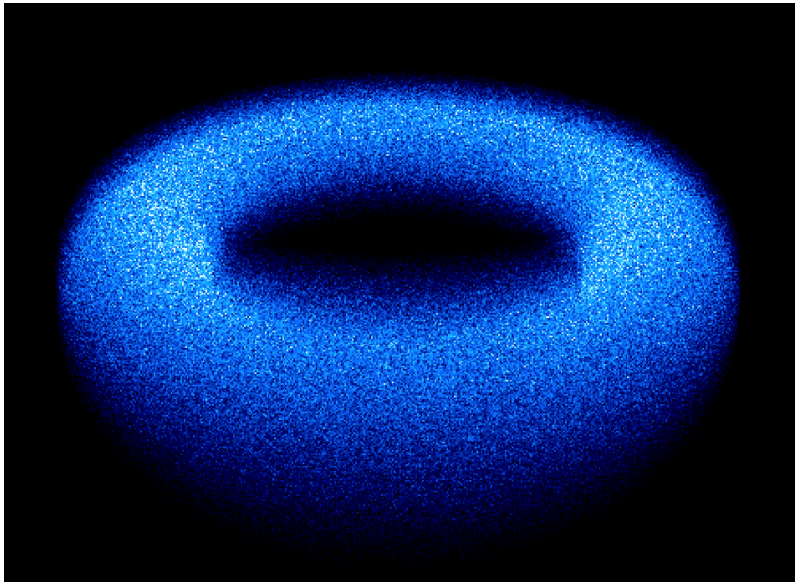
+ Variable cut-off and [Fe/H] (Baloković et al. 2018)

+ Clumpy torus (Liu & Li 2014)

+ MONACO (Okada et al. 2011)

Still quite limited geometries

RefleX 1.0

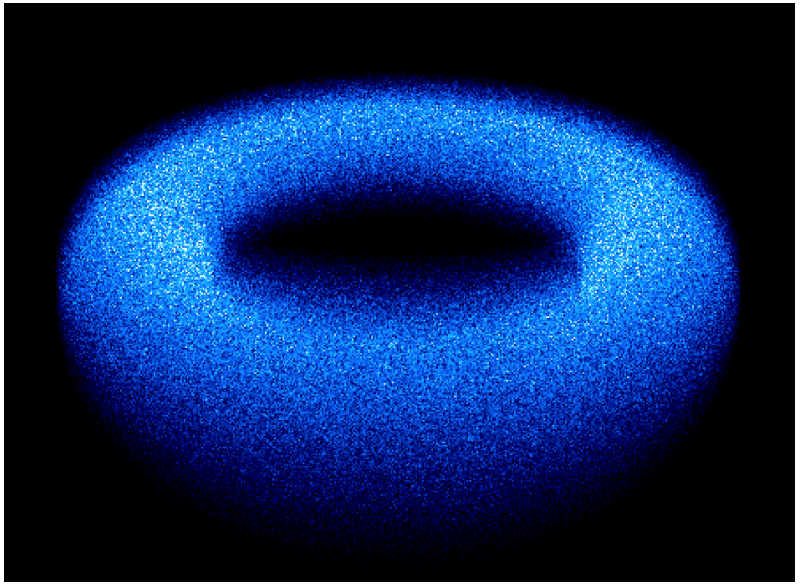


Paltani & Ricci 2017

RefleX is freely available at:
https://www.astro.unige.ch/reflex/

- Ray-tracing code
- Implements all usual physics (photo-electric, Compton scattering, fluorescence), plus Rayleigh scattering
- Several X-ray source geometries and spectra
- Several geometries for X-ray emitter and absorbing material, combined like building blocks
- Very simple configuration
- K and L fluorescence lines up to Z=30
- Produces photon lists, spectra, images
- Polarization of reflected component (not validated)

RefleX



Paltani & Ricci 2017

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LENGTH Parsec
MATTER lodd
TEMPERATURE 1
DENSITY 2e23
OBJECT WORLD  1e8
OBJECT TORUS torus 0.0 0.0 0.0 7.5 2.5
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IMAGE ENERGY > 6380
IMAGE ENERGY < 6404
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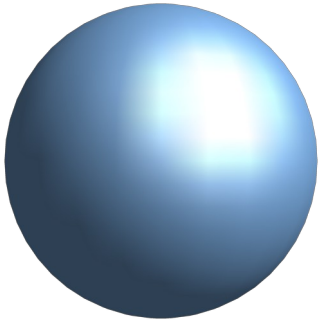
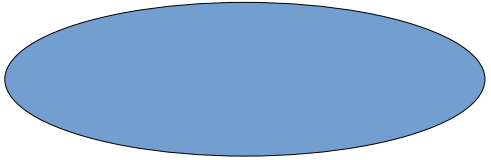
Source and Spectral Shapes



Sphere

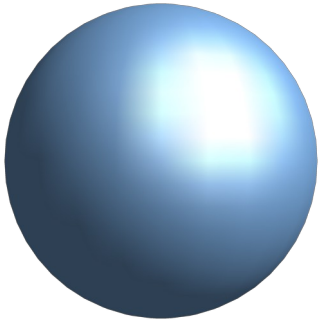


Disc
Annulus

Point source

Spectra
- Monoenergetic
- Gaussian
- Power law
- Cut-off power law
- Black body
- Wien

Object Shapes



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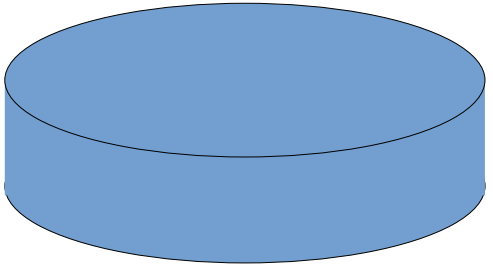
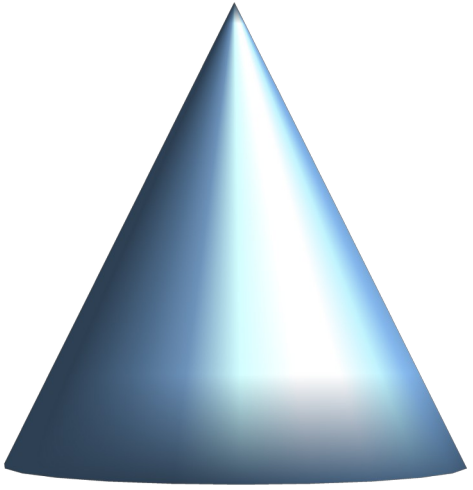
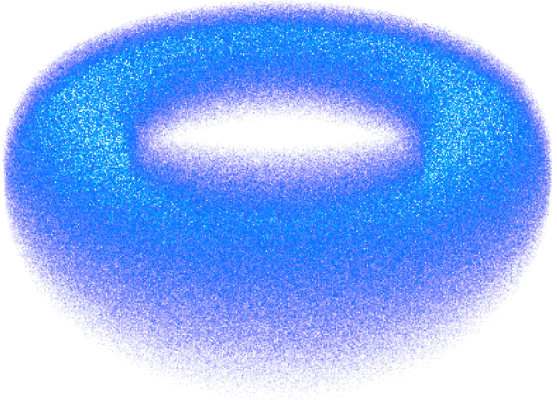


Disc
Cylinder
Annulus



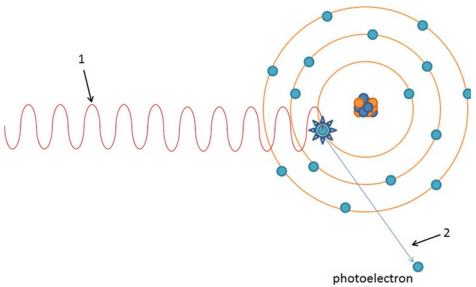
Cone
Hollow Cone



Torus

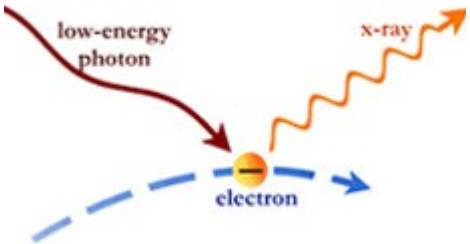
Physical Processes

Photo-ionization and Fluorescence

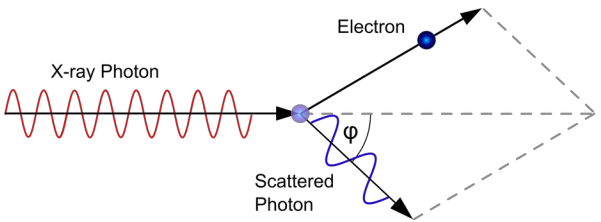


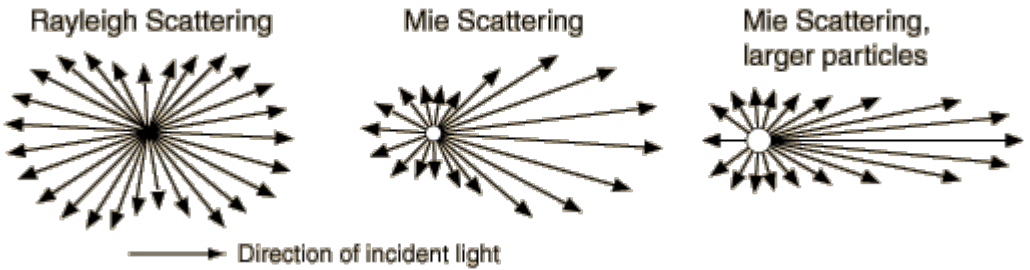
K- and L-shell fluorescence

Inverse Compton scattering



Compton Scattering





Free electrons – bound electrons

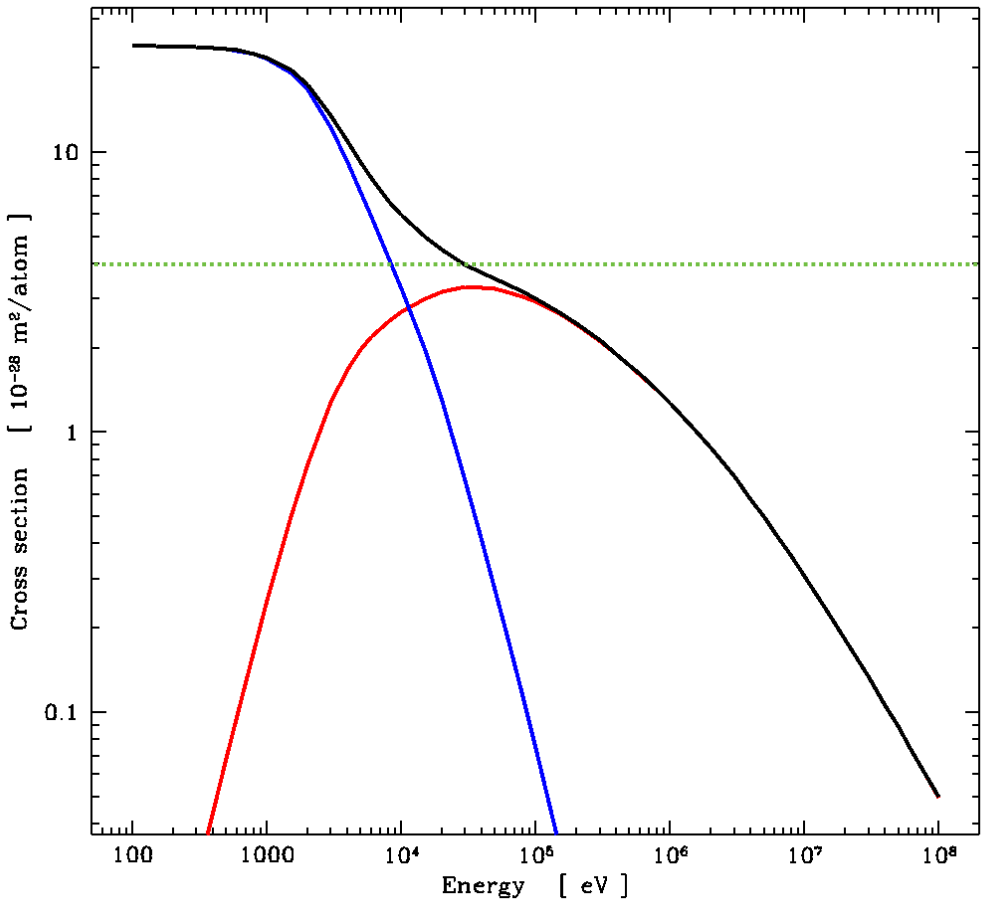
Bound electrons

Dust

Any composition (→ Zn), molecular Hydrogen H_2

Carbon grains + Silicate $MgFeSiO_4$

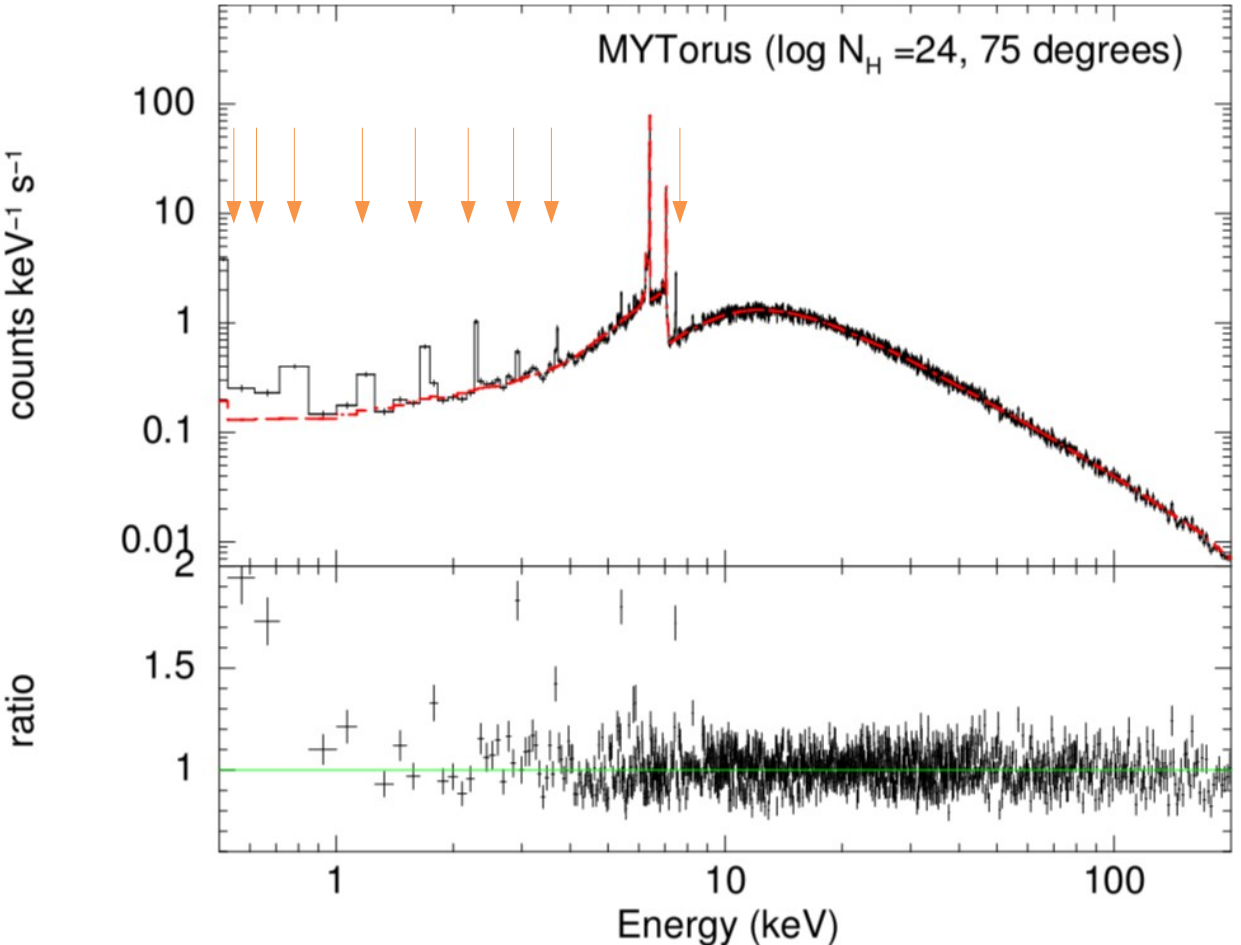
Rayleigh vs Compton Scattering

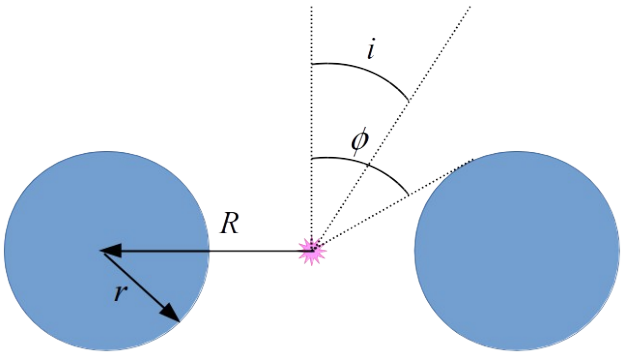


Carbon ^{6}C

TOTAL
Rayleigh
Compton
Thomson

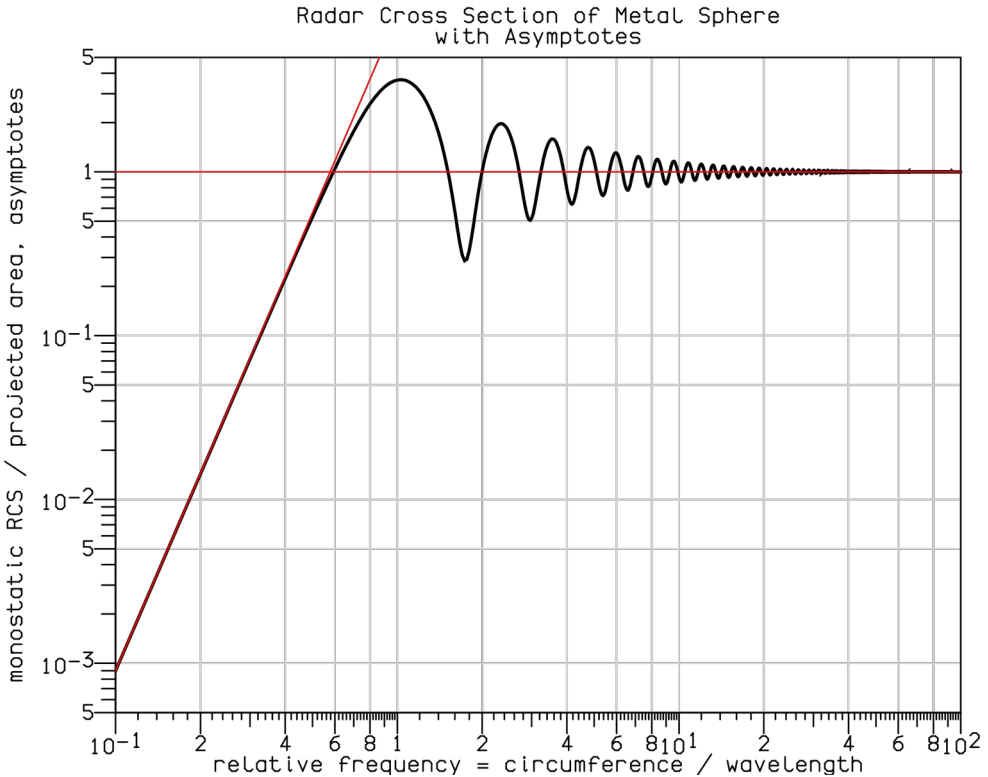
RefleX vs MYTorus

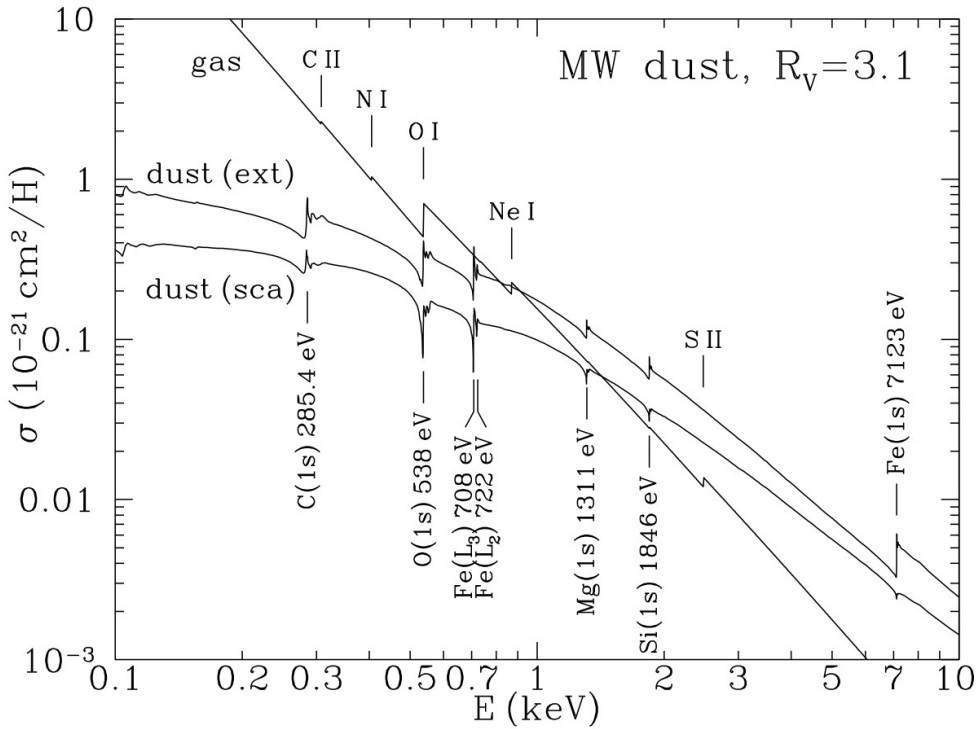




Murphy & Yaqoob 2009

Dust



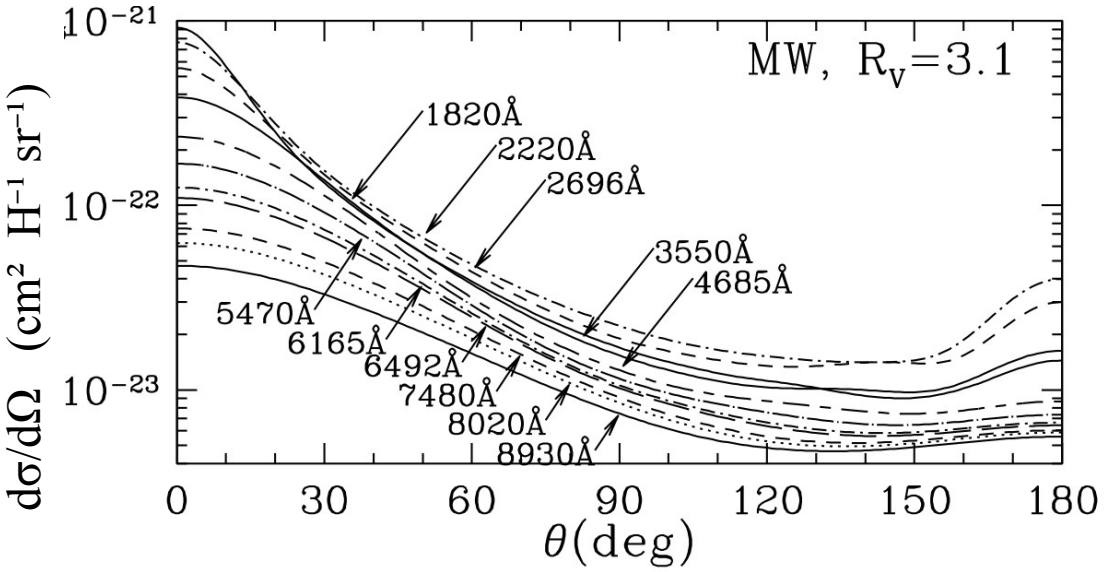


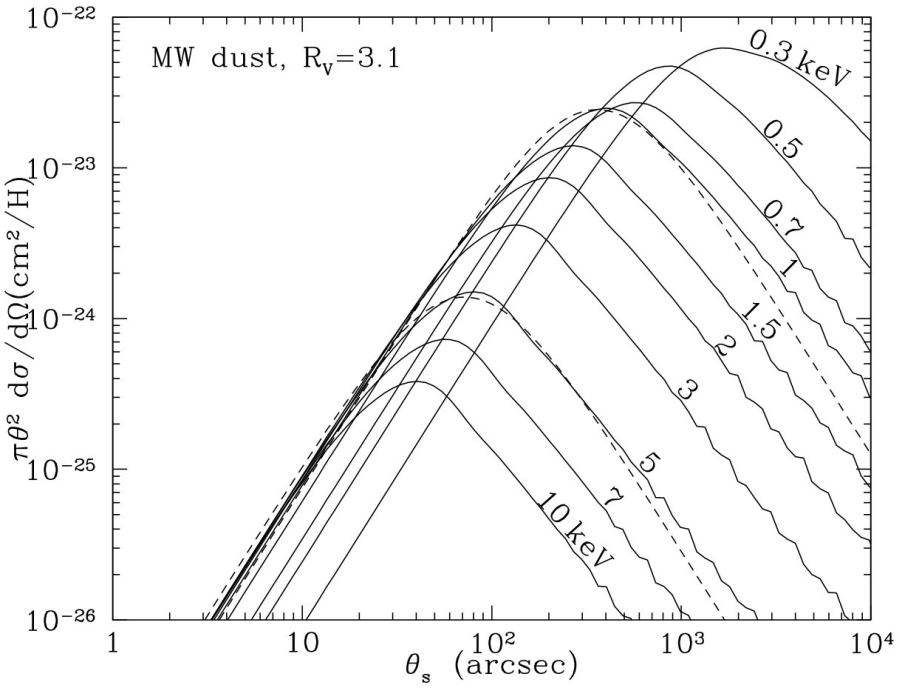
Composition: Carbon grains and Silicates $MgFeSiO_4$
Grain size distribution: 0.5 nm – 0.5 μm

Draine 2003

Mie Scattering

- Mie scattering is essentially “forward-scattering”, especially in the X-rays

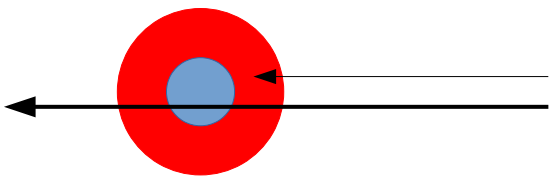


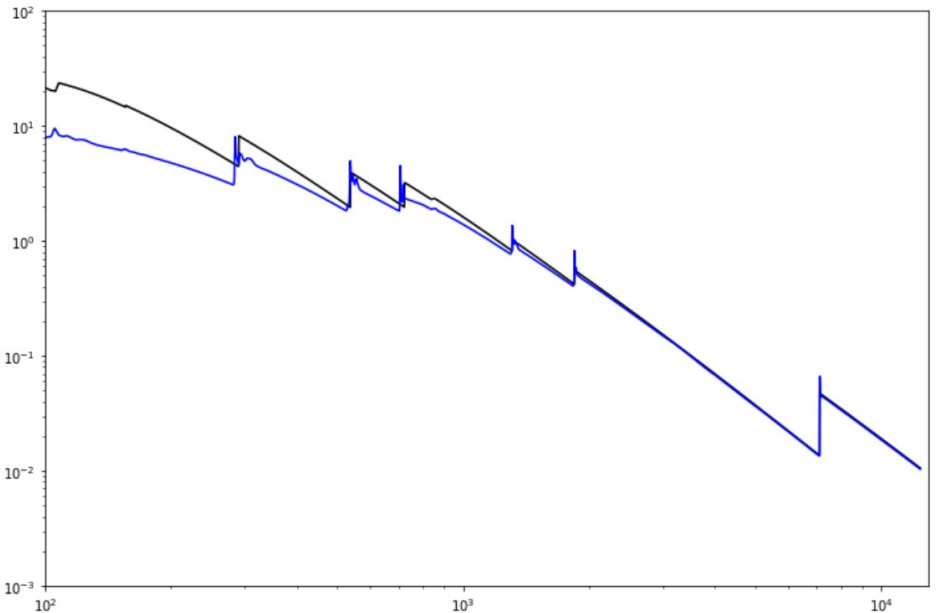


Draine 2003

Absorption by Dust

- Screening: at low energies, photons that hit a grain never reach the center of the grain
- Absorption cross-section decreases

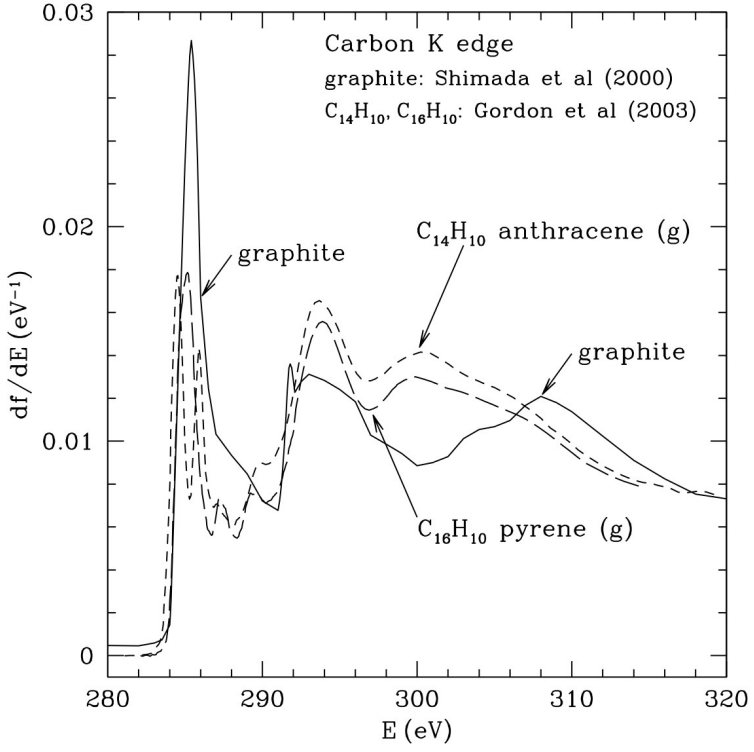




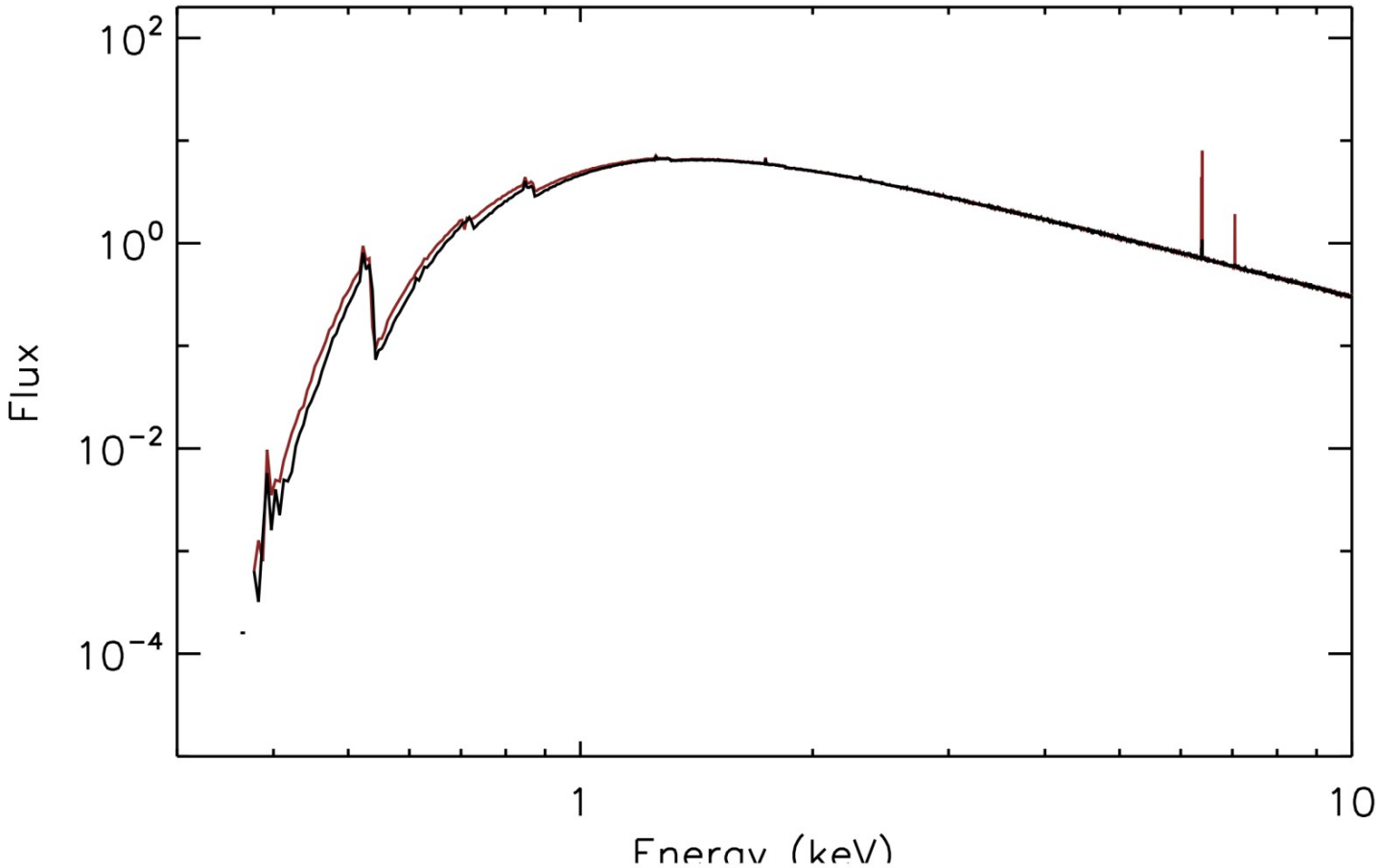
NEXAFS

- Dust photoelectric cross-section is modified by cristalline structure: Near-Edge X-ray Absorption Fine Structure
- Direct dust diagnostic in X-rays. Detectable with Athena?

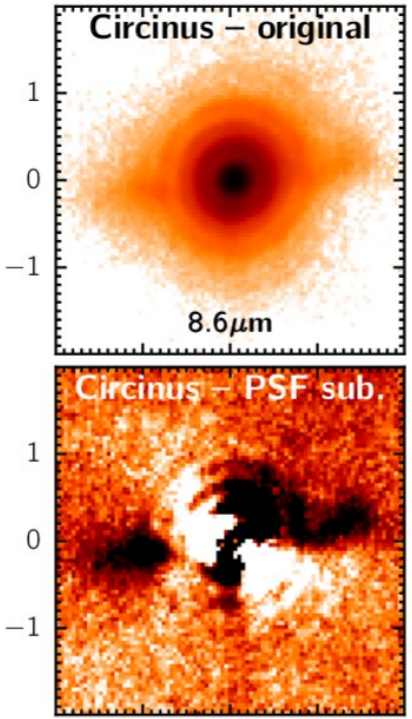
Oscillator strength (linked to σ) for different Carbon dusts



Slab, $N_H=10^{22}$ cm^{-2}



A multiwavelength-motivated X-ray model for the Circinus Galaxy

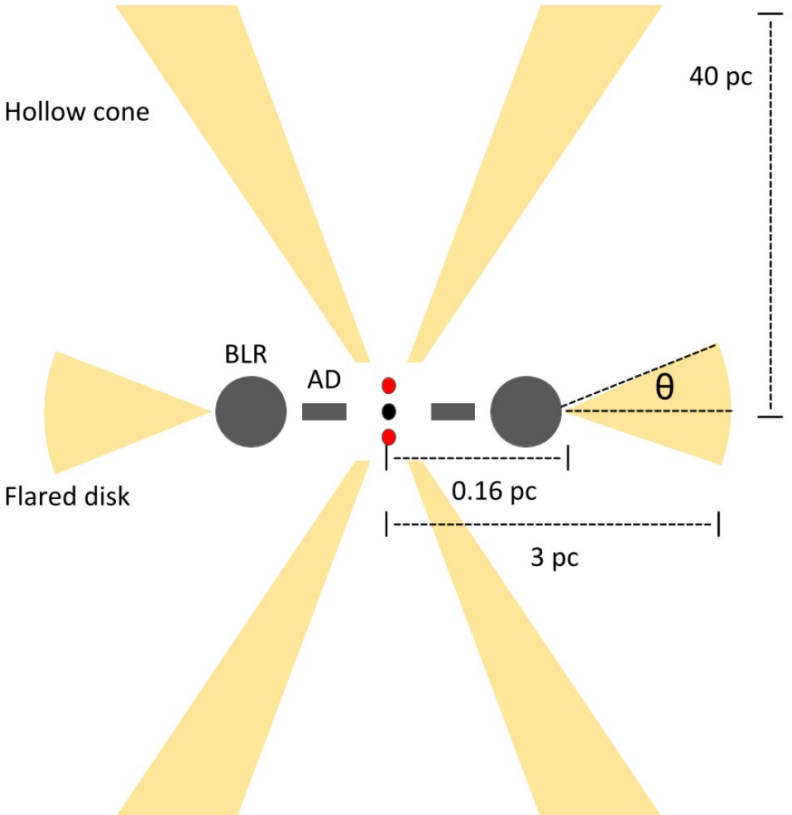


Stalevski et al. (2017)

- The closest Seyfert 2 (absorbed AGN) galaxy: 4.2 Mpc
- Compton-Thick: $N_H=(6-10)\times10^{24}$ cm^{-2}
- 2 components in the IR at parsec scale:
  - Torus-like component in the equatorial plane of the system
  - Large structure elongated in the polar direction
- Stalevski et al. (2017) proposed for the dusty emitting regions:
  - A flared disk for the torus-like component
  - A cone/hyperboloid shell for the elongated emission

Andonie et al. submitted

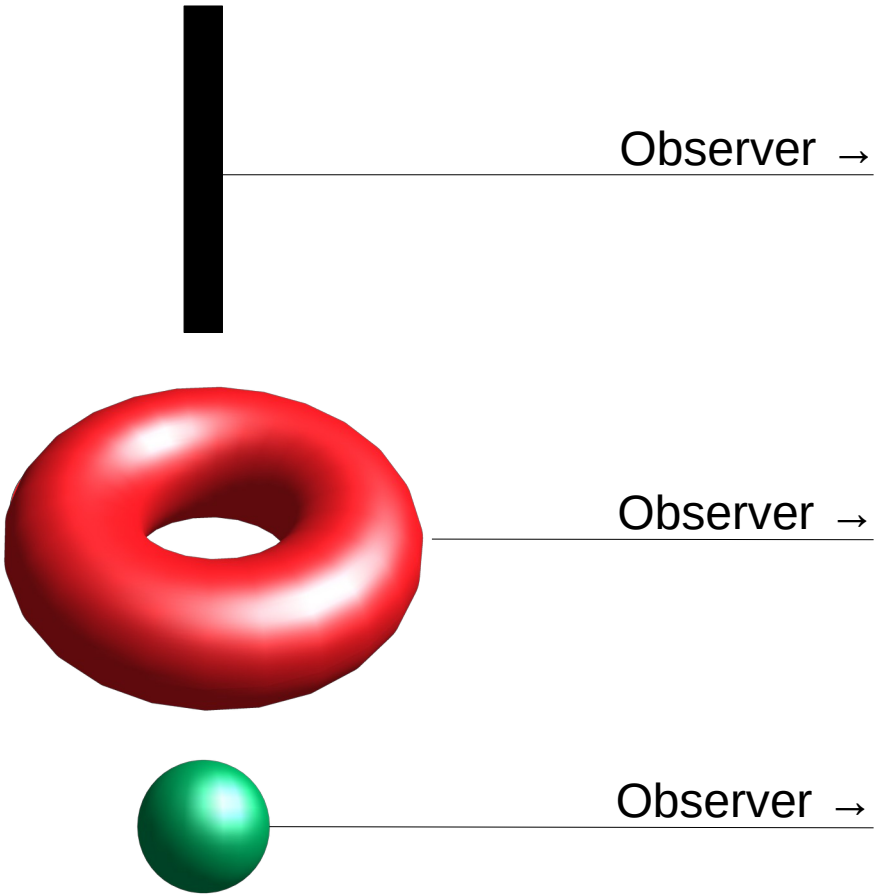
The Circinus Galaxy

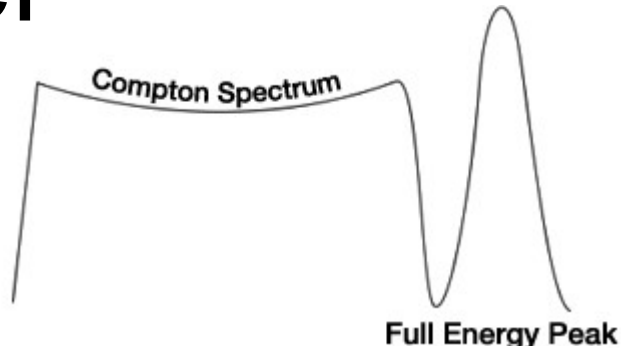


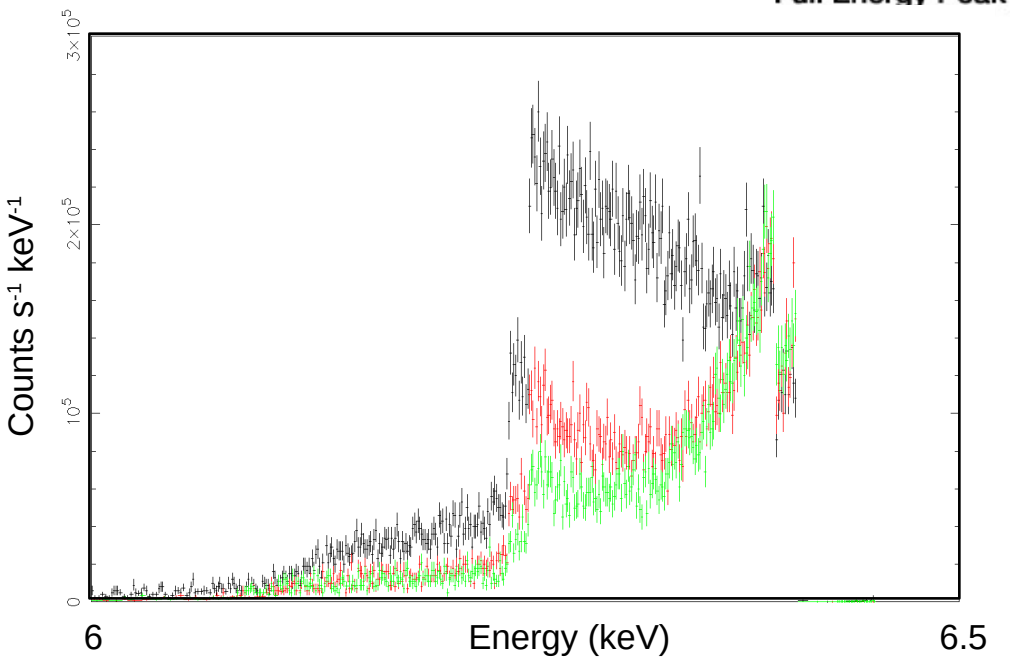
Stalevski et al. (2017)

Andonie et al. submitted

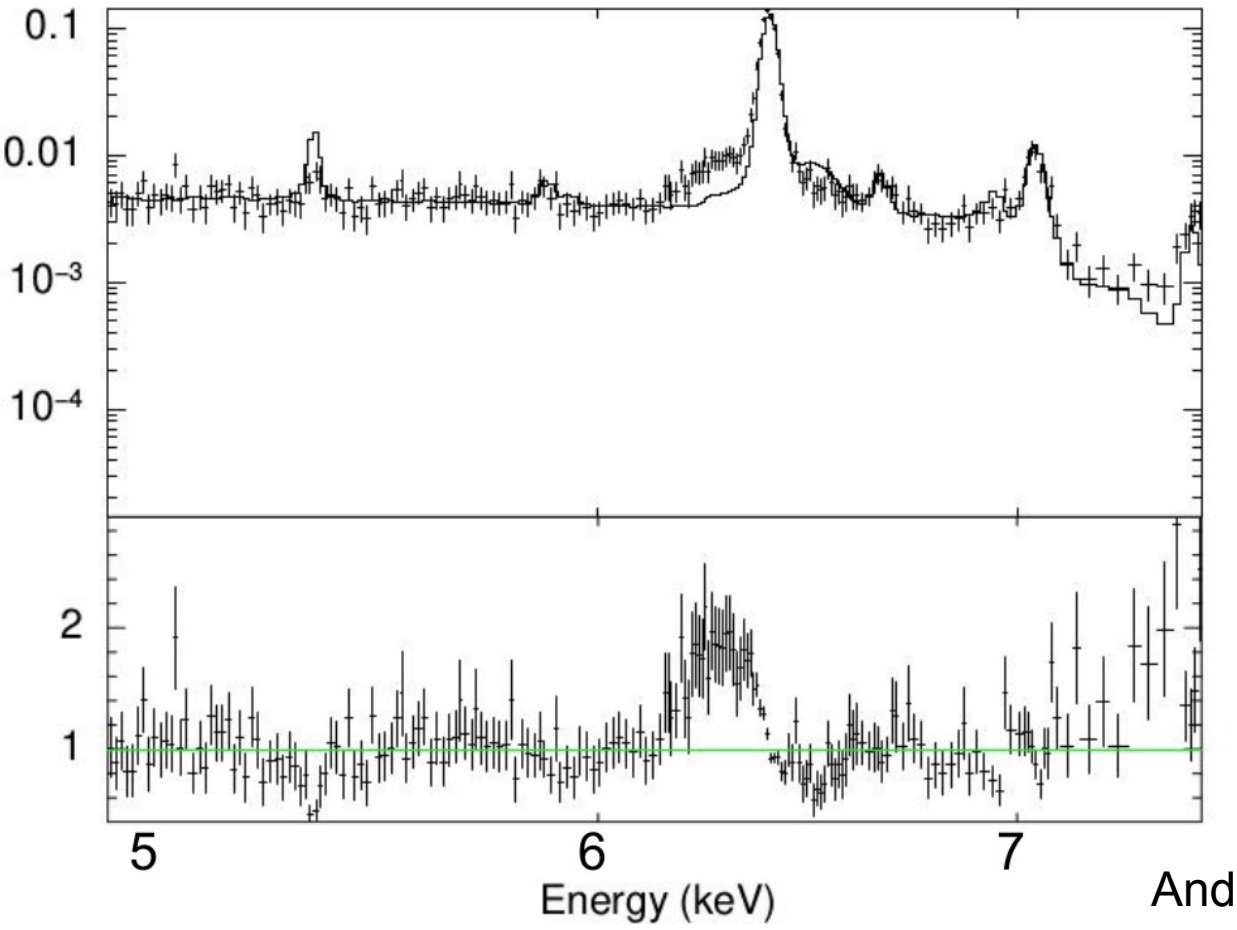
Compton Shoulder





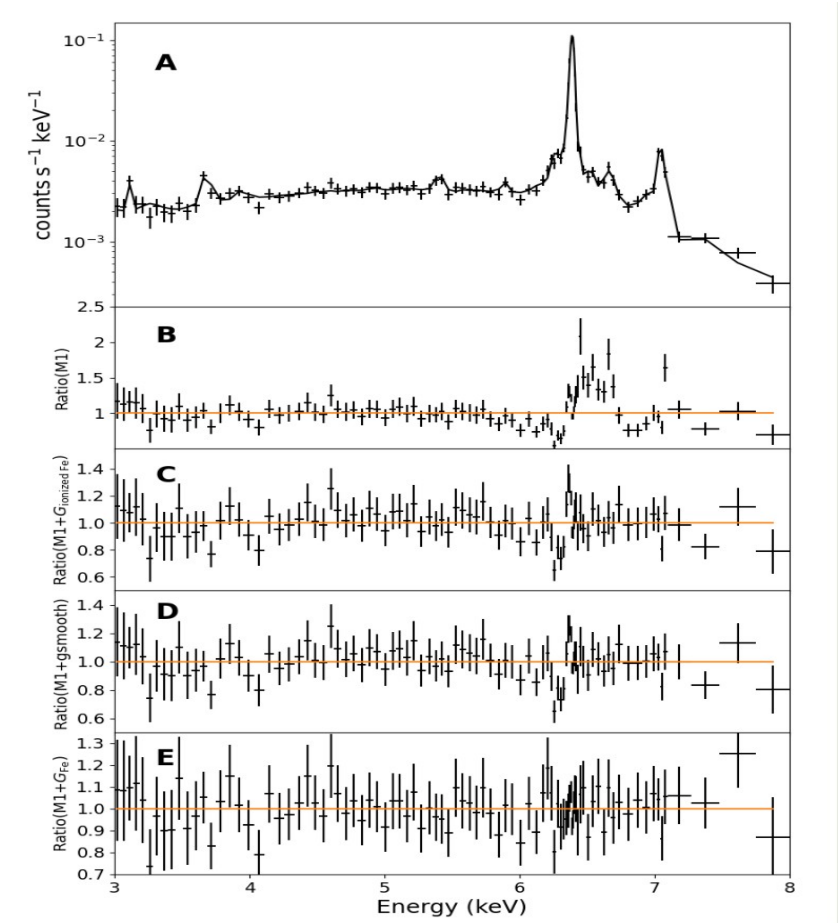


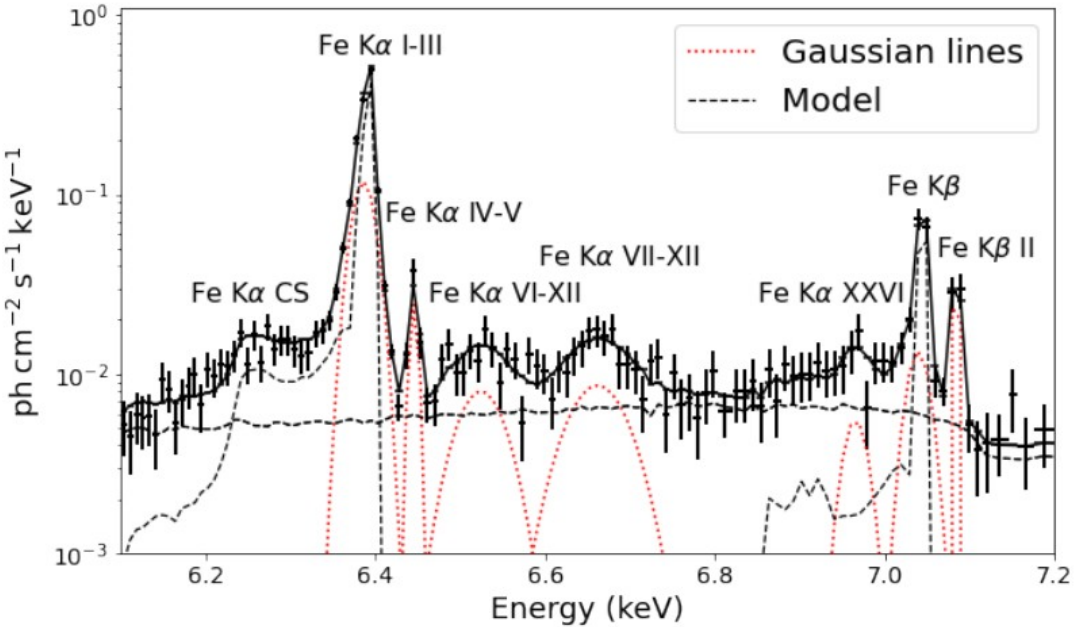
Chandra HEG Spectrum



Andonie et al. submitted

Chandra HEG Spectrum

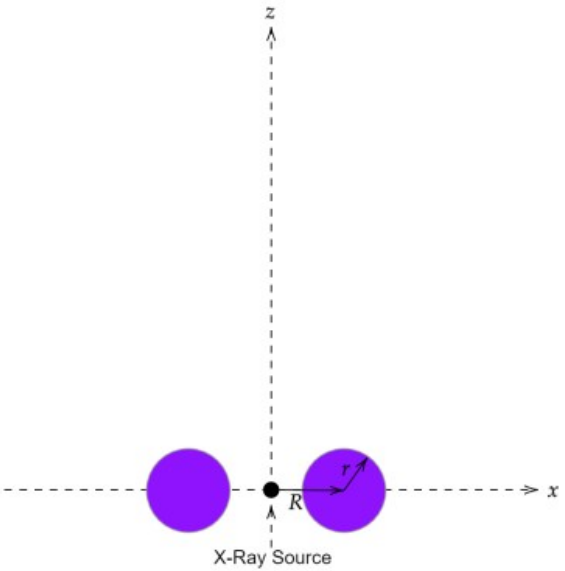


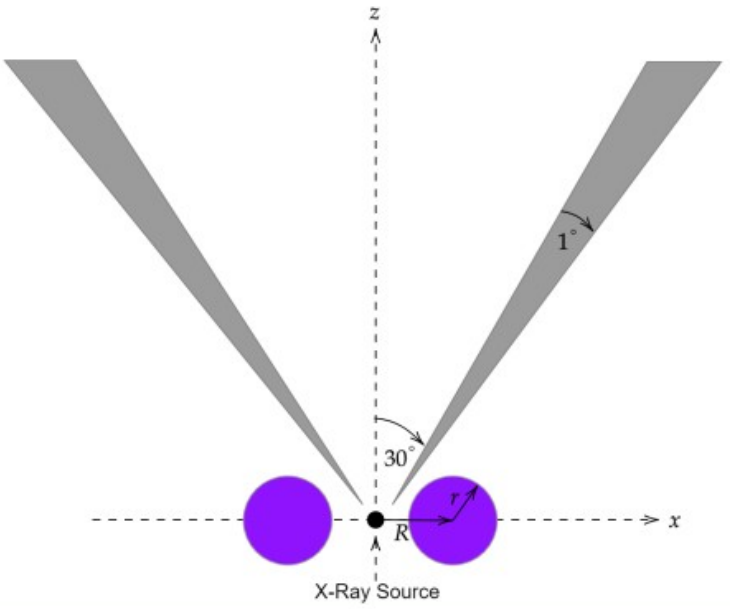


Very good fit of the CS, but requires broad Fe Kα and Kβ lines (1300 km s^{-1}; BLR?) + mildly ionized lines

Andonie et al. submitted

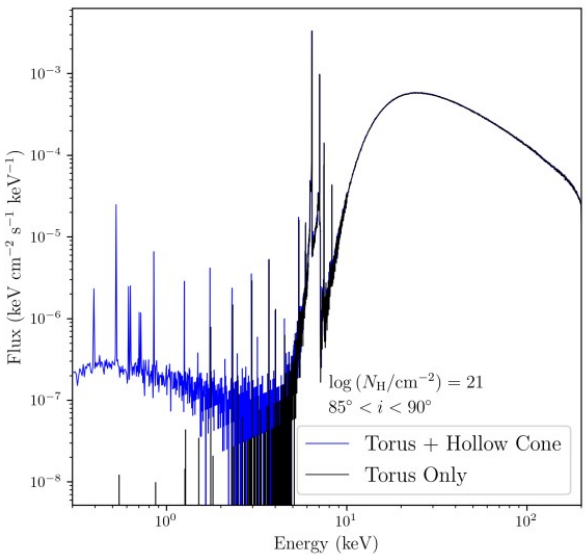
X-ray Simulations of Polar Gas in Accreting Supermassive Black Holes

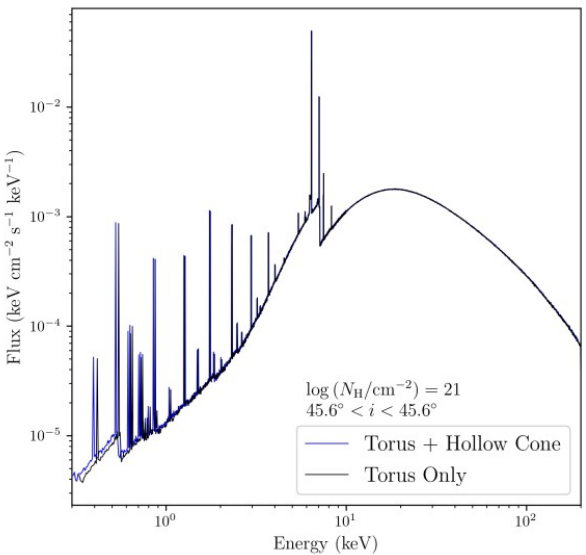


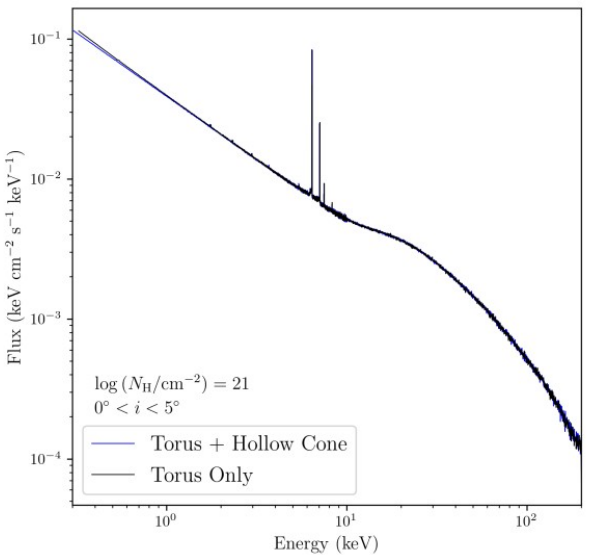


McKaig et al. submitted

X-ray Simulations of Polar Gas in Accreting Supermassive Black Holes







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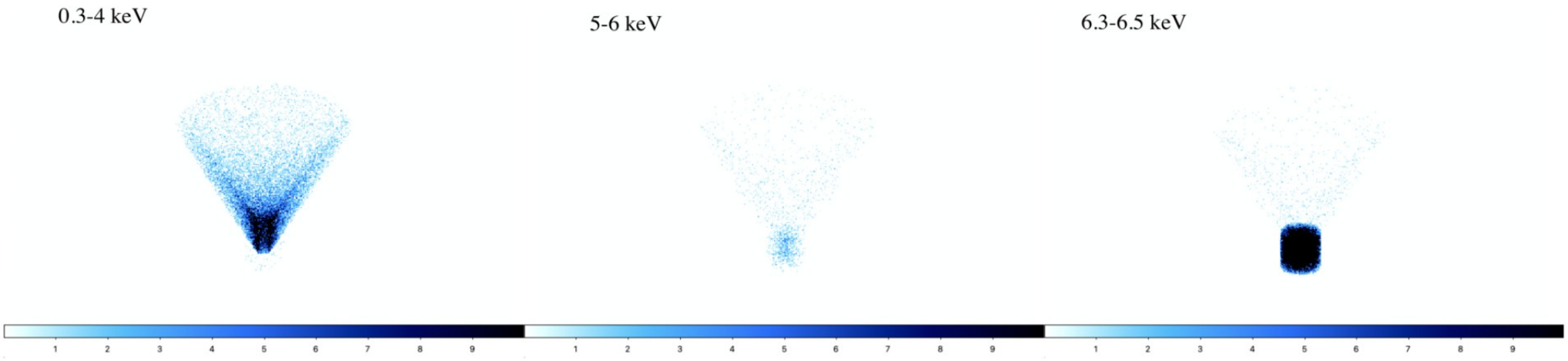
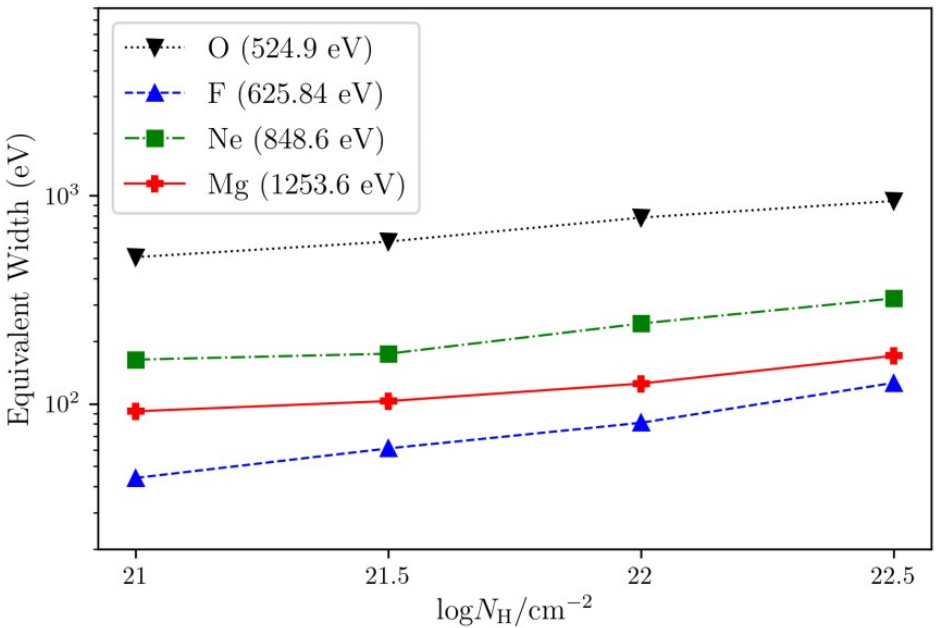
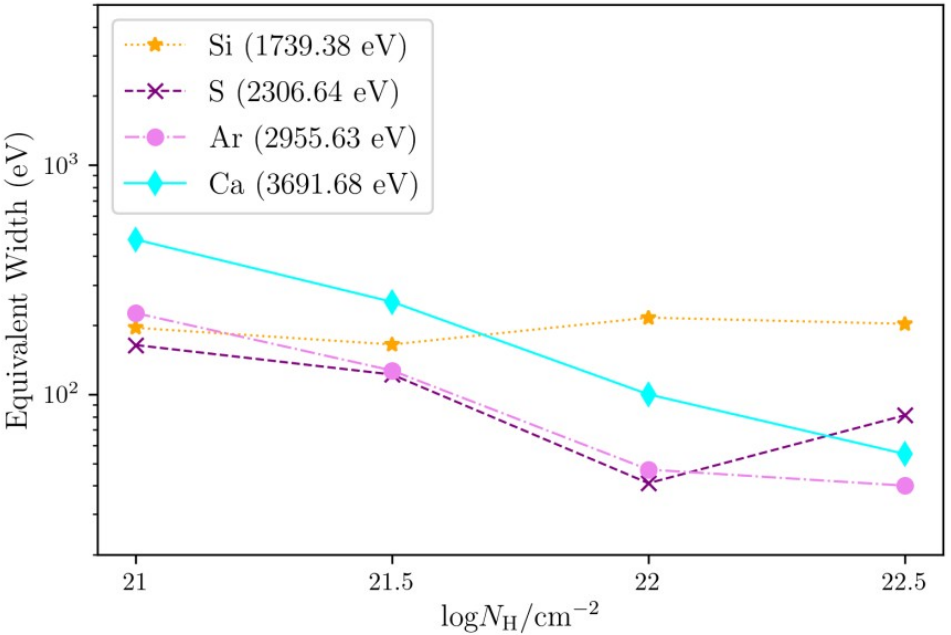
X-ray Simulations of Polar Gas in Accreting Supermassive Black Holes



McKaig et al. submitted

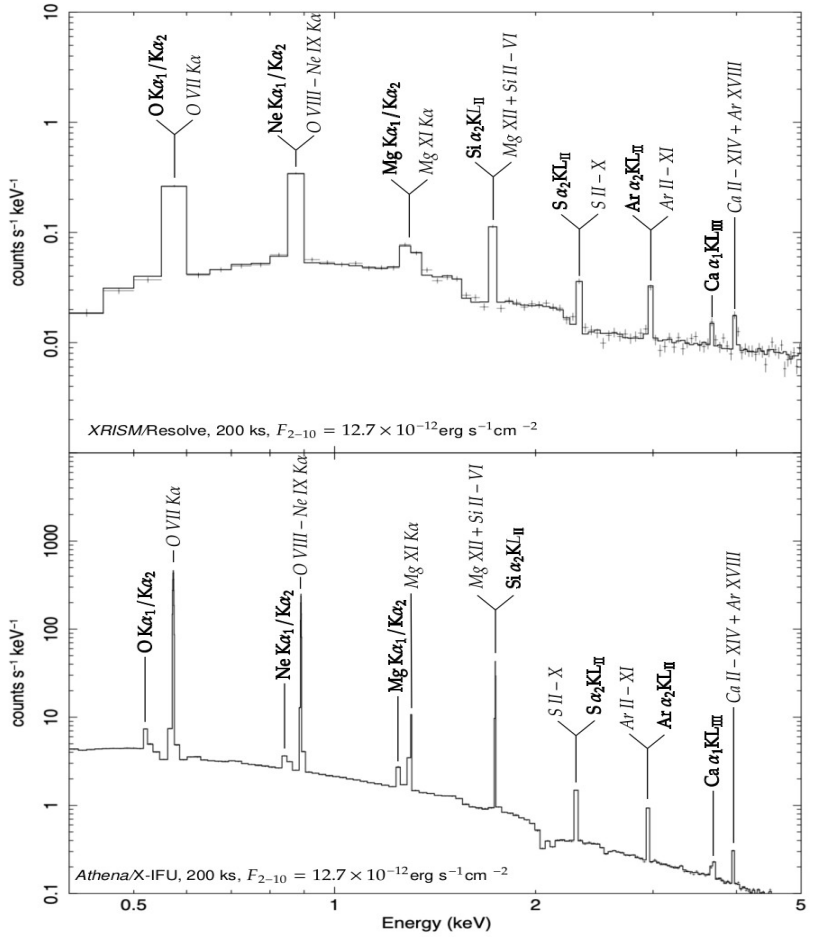
Evolution of Fluorescence lines EW





McKaig et al. submitted

Detectability



McKaig et al. submitted

New RefleX Features since V1.0

- 2.0/2.1
  - Speed: about 5x faster (mostly precomptation of cross-sections)
  - Wien spectrum
  - Cone and hollow cone geometry
  - Arbitrary rotation and location for any object
  - Multi-threading
- 3.0
  - Rayleigh scattering now treated element per element
  - Dust scattering and absorption
  - Annulus geometry emission
  - Solved issue of stuck photons due to numerical imprecision
  - Spectrum of a single object
  - Variables passed on the command lines

RefleX 4.0 and beyond

- 4.0
  - Temperature
  - Turbulence
  - Translations
  - Keplerian rotations (will be hard)
- 5.0
  - Photon trajectories in Schwarzschild and Kerr metrics
- 6.0
  - Ionized media