Modelling type I quasar SEDs at UV/optical/NIR wavelengths

Templates are **important for** QSO identification, redshift determination, mock catalog simulations, investigation of physical properties

Phenomenological approach, based on **SDSS DR16Q**: catalog of spectroscopically confirmed QSOs plus NIR photometry (UKIDSS & WISE)

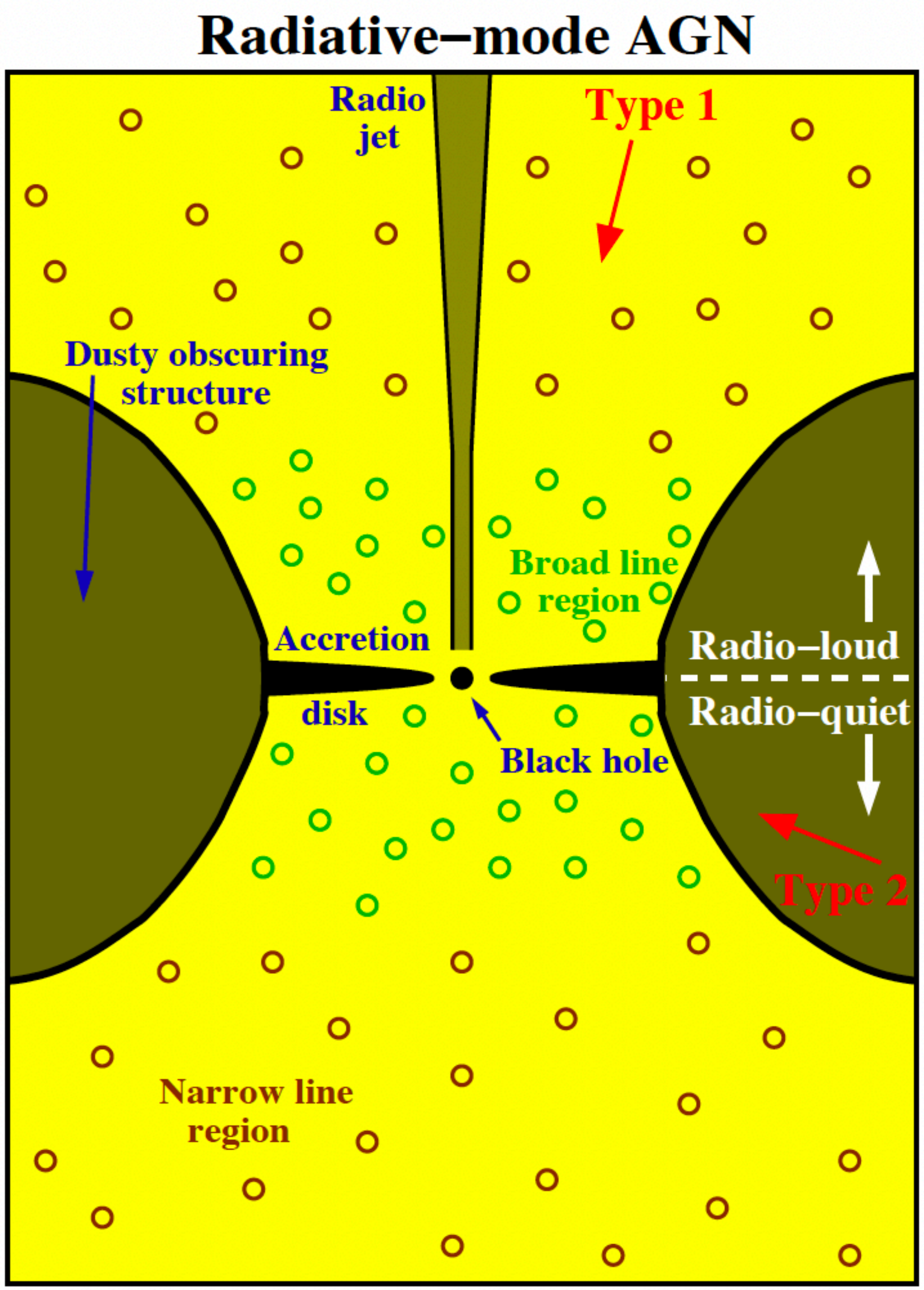
Simple physical modelling of QSO SEDs that could **account for observed variety** of QSOs

Marco Tucci

Ecogia Science Meeting, 6-Feb-2023

Introduction: QSO central engine

- **Extreme powerful** objects, due to the accretion of material onto a supermassive black hole
- **UV/optical continuum** emerges from accretion disk
- Unobscured/blue (**Type I**) and obscured/red (**Type II**) QSOs
- **Broad/Narrow emission lines** from gas clouds heated and ionised by disk
- **Dusty torus-like structure** absorbed and re-emits at IR



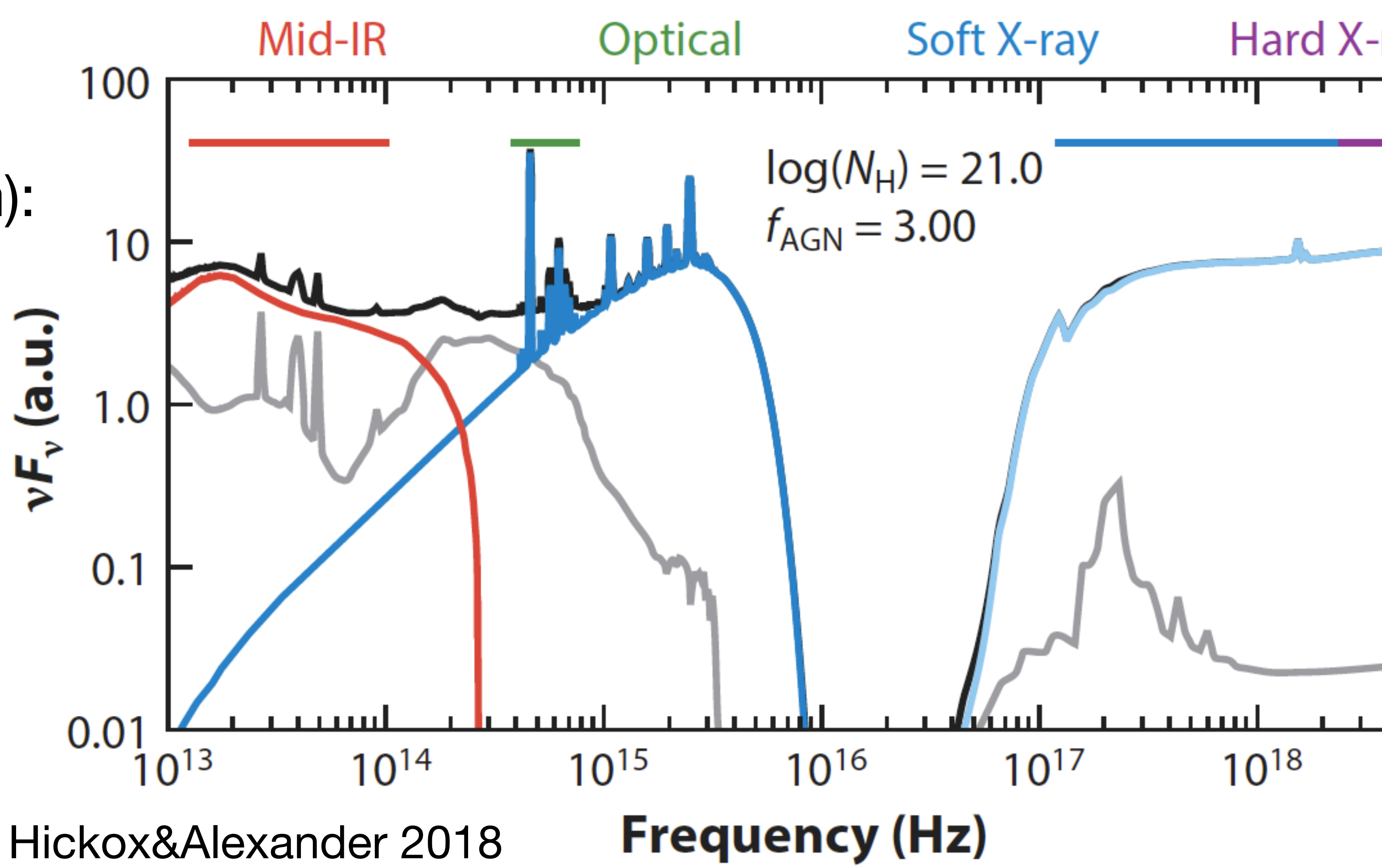
Heckman&Best 2015

Introduction: QSO SED components

- **UV-optical Continuum** (900A-1μm): single/multiple power laws
- **Emission Lines** (both broad and narrow)
- **Hot Dust** (1<λ<3μm): thermal emission with T~1000-1700K

but also

- **Host Galaxy** (4000A-2μm):
  - early-type
  - star-forming
- **Dust Reddening** (internal/host galaxy)



Hickox&Alexander 2018

QSO SED templates

Different approaches:

- **Empirical templates** based on observations (e.g., composite spectra, library of individual AGN)

- **Theoretical templates** based on physical models

Templates: Composite Spectra

Combine spectroscopy and/or photometry of many objects, covering large range of redshifts

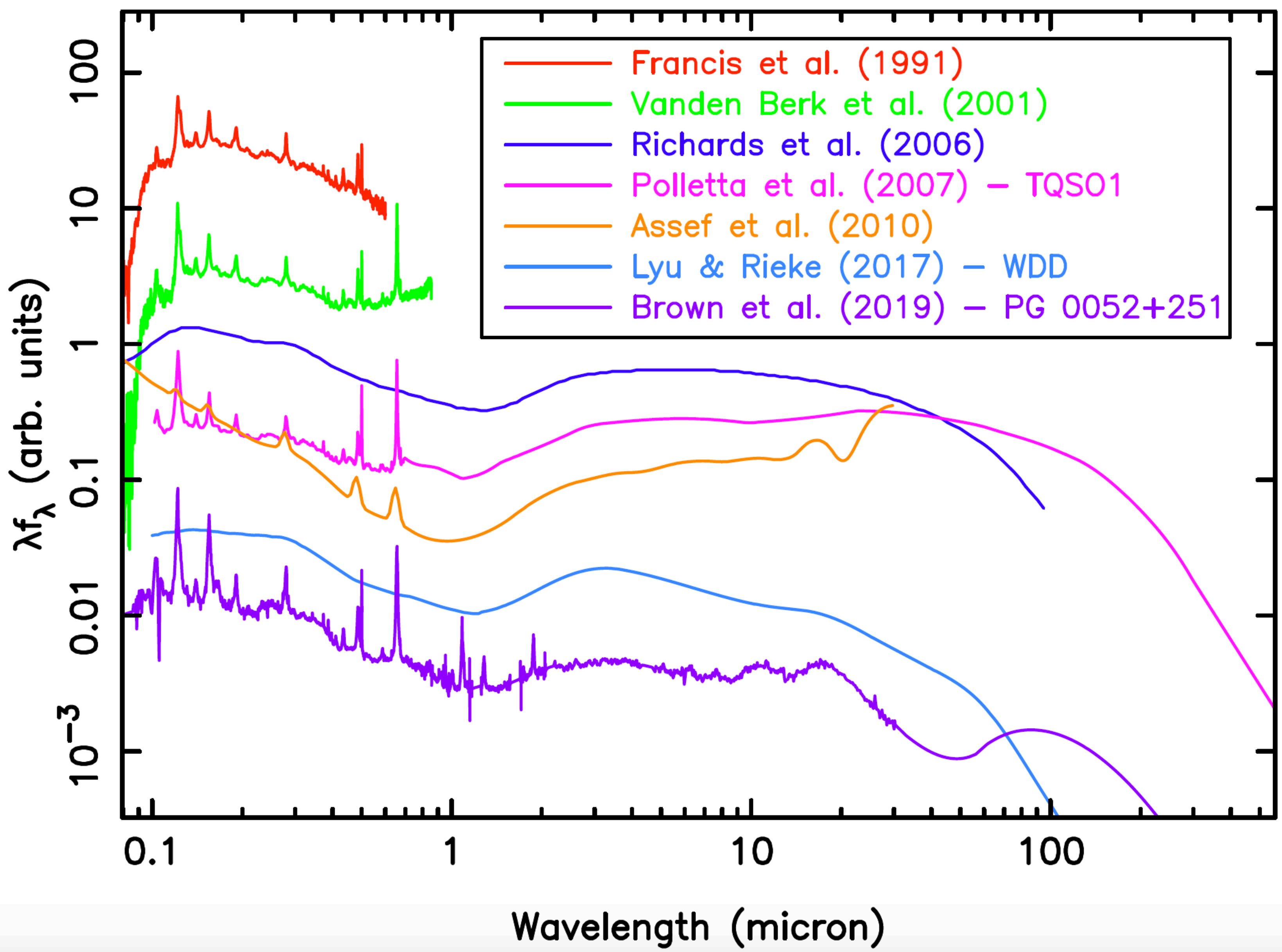
Brown+19

Pros:

- high S/N spectra
- *average* behaviour

Cons:

- not representative of all QSOs
- low resolution, if based on photometry



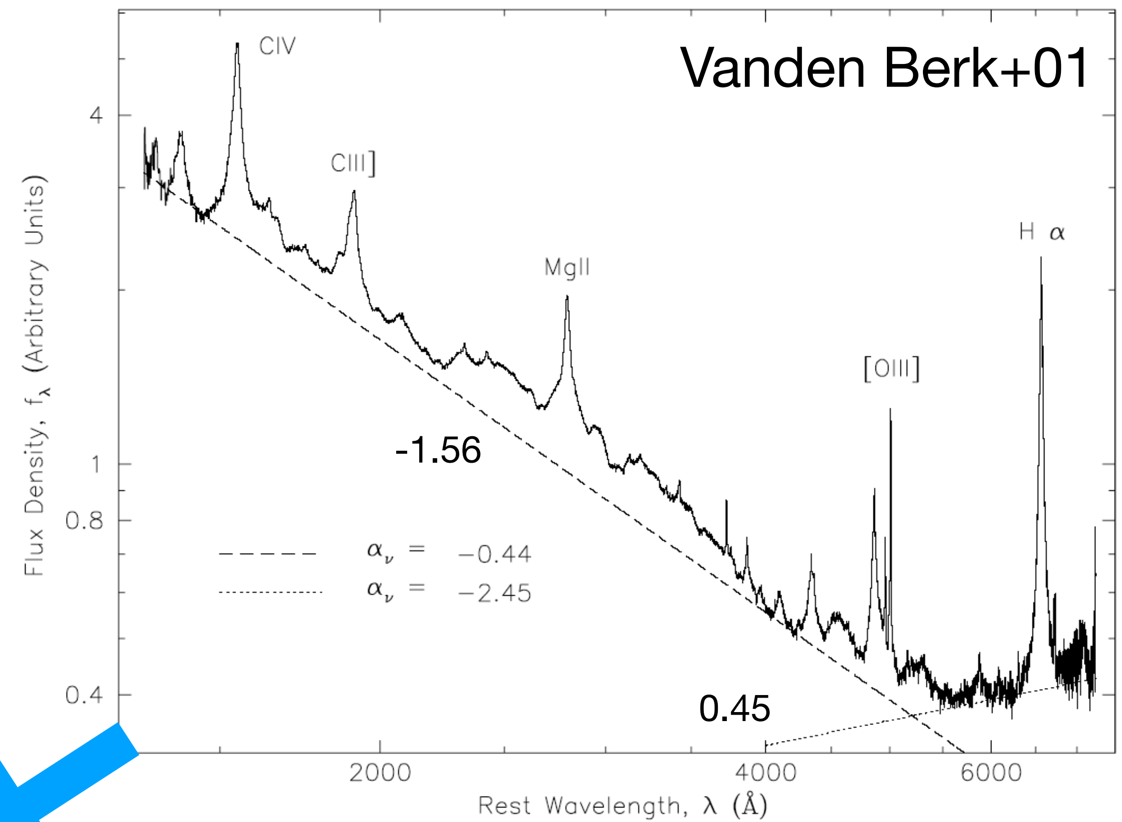
Templates: Composite Spectra

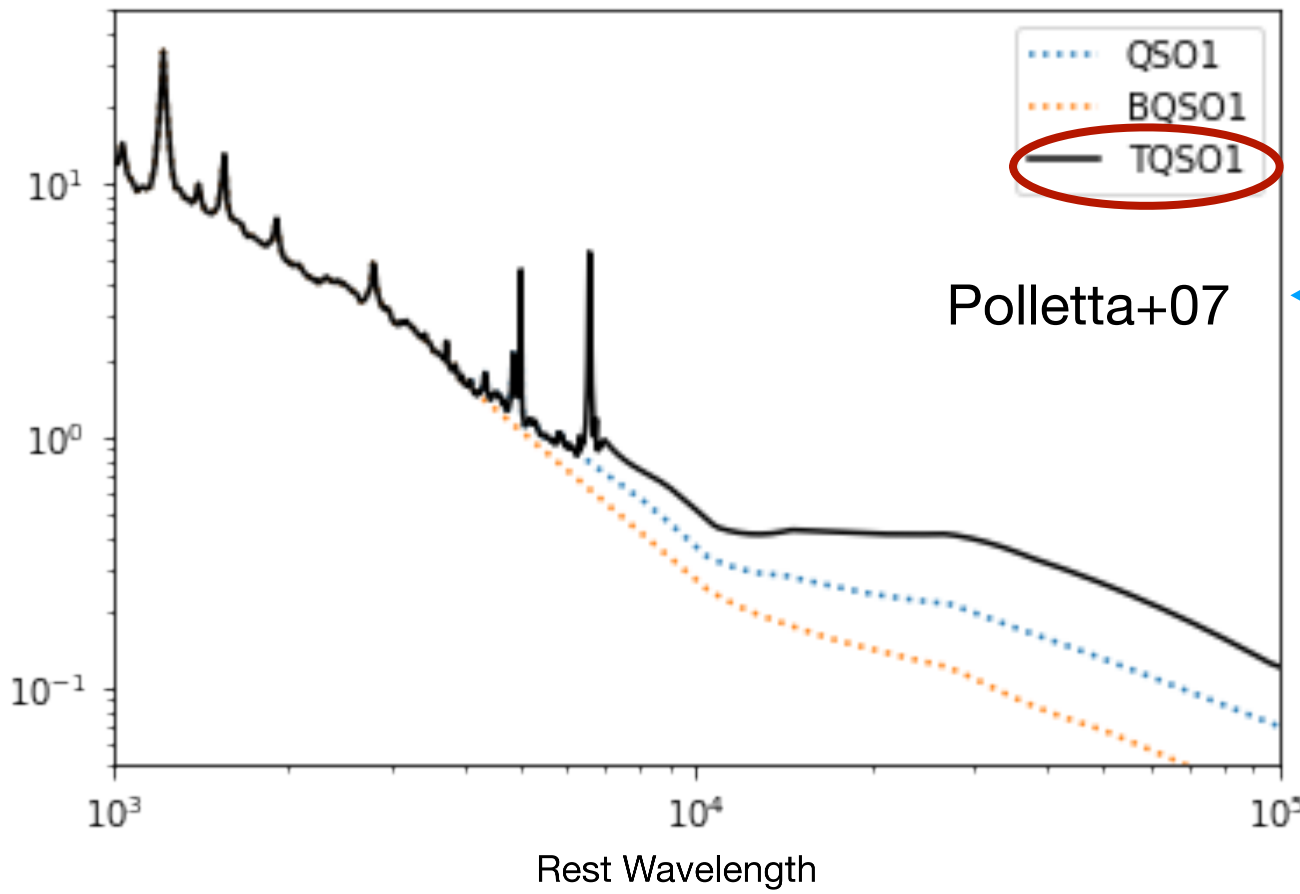
<u>Vanden Berk+01:</u>

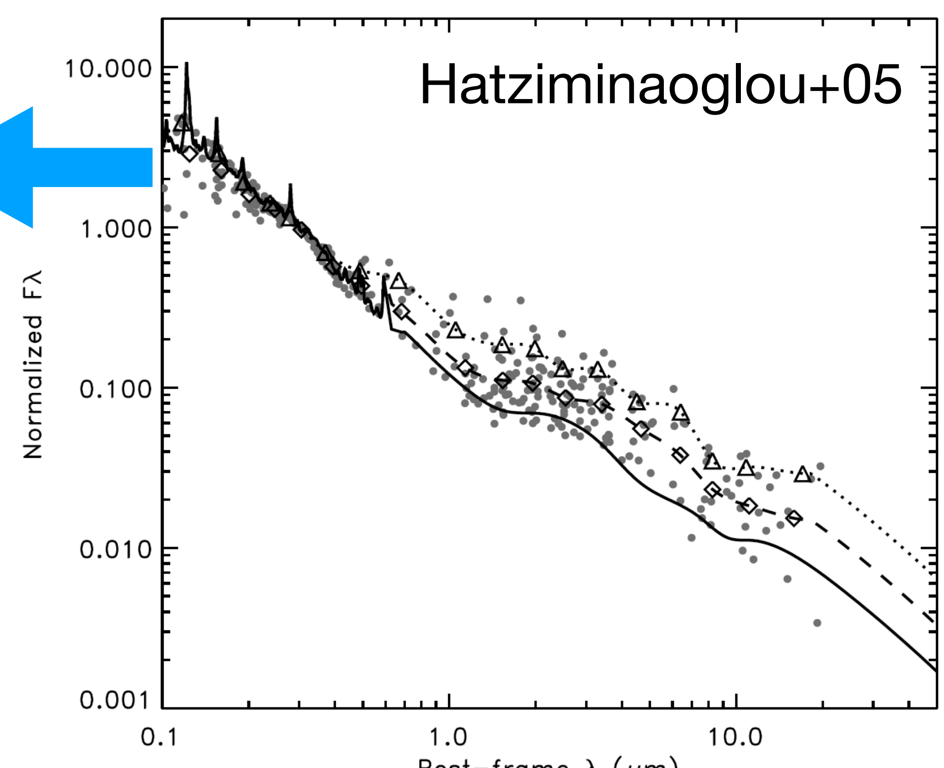
2200 high S/N spectra from SDSS,
rest-wavelength range = 800-8555A
(most at 1500-3500A)

<u>Polletta+07:</u>

extend SDSS composite spectra to IR,
using 35 SWIRE-SDSS quasars
(Hatziminaoglou+05)







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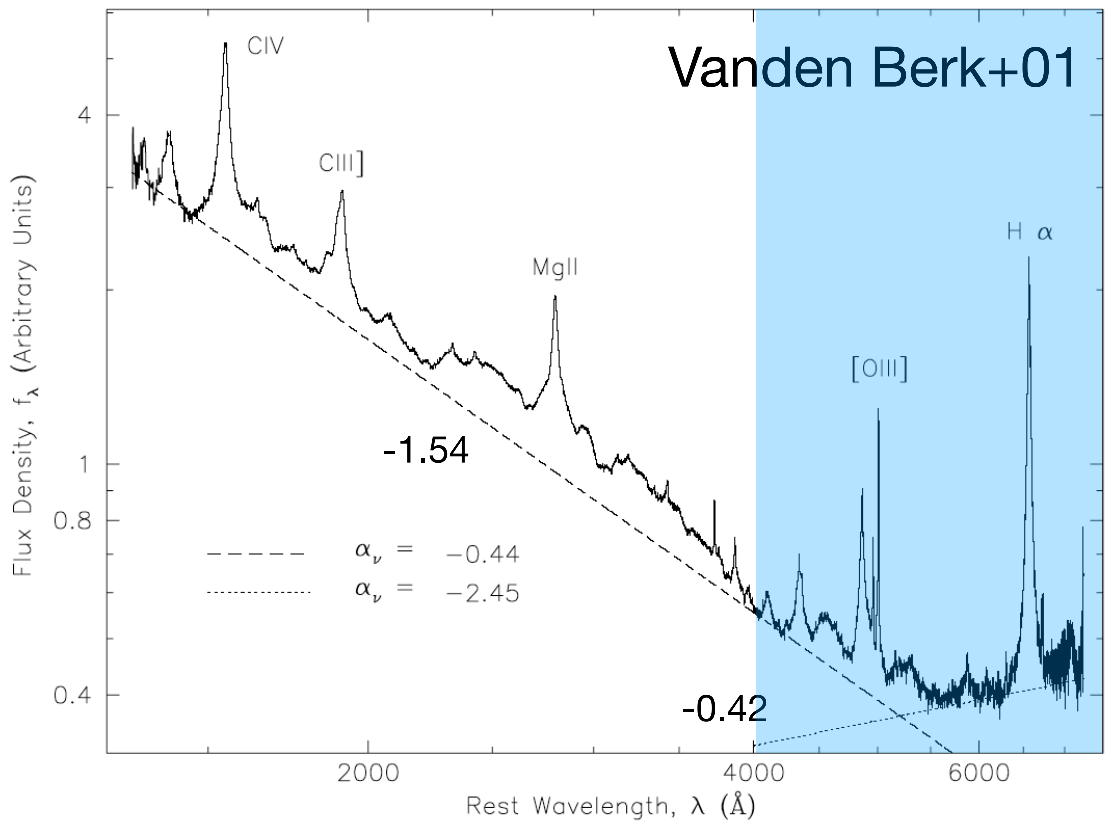

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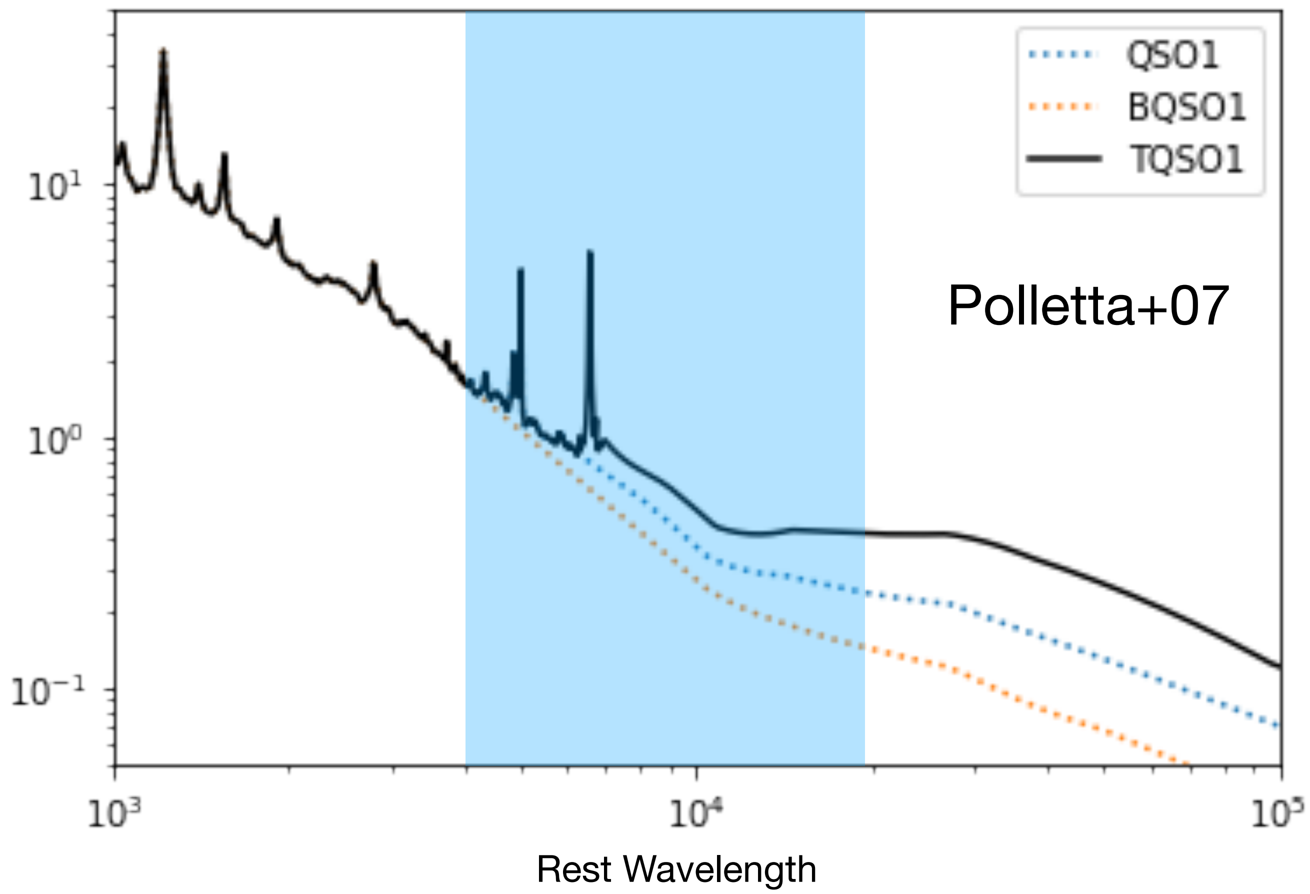


Likely contaminated by host galaxy at λ≳4000A
(e.g., Shen16, Temple+21)

Templates: Physical Models

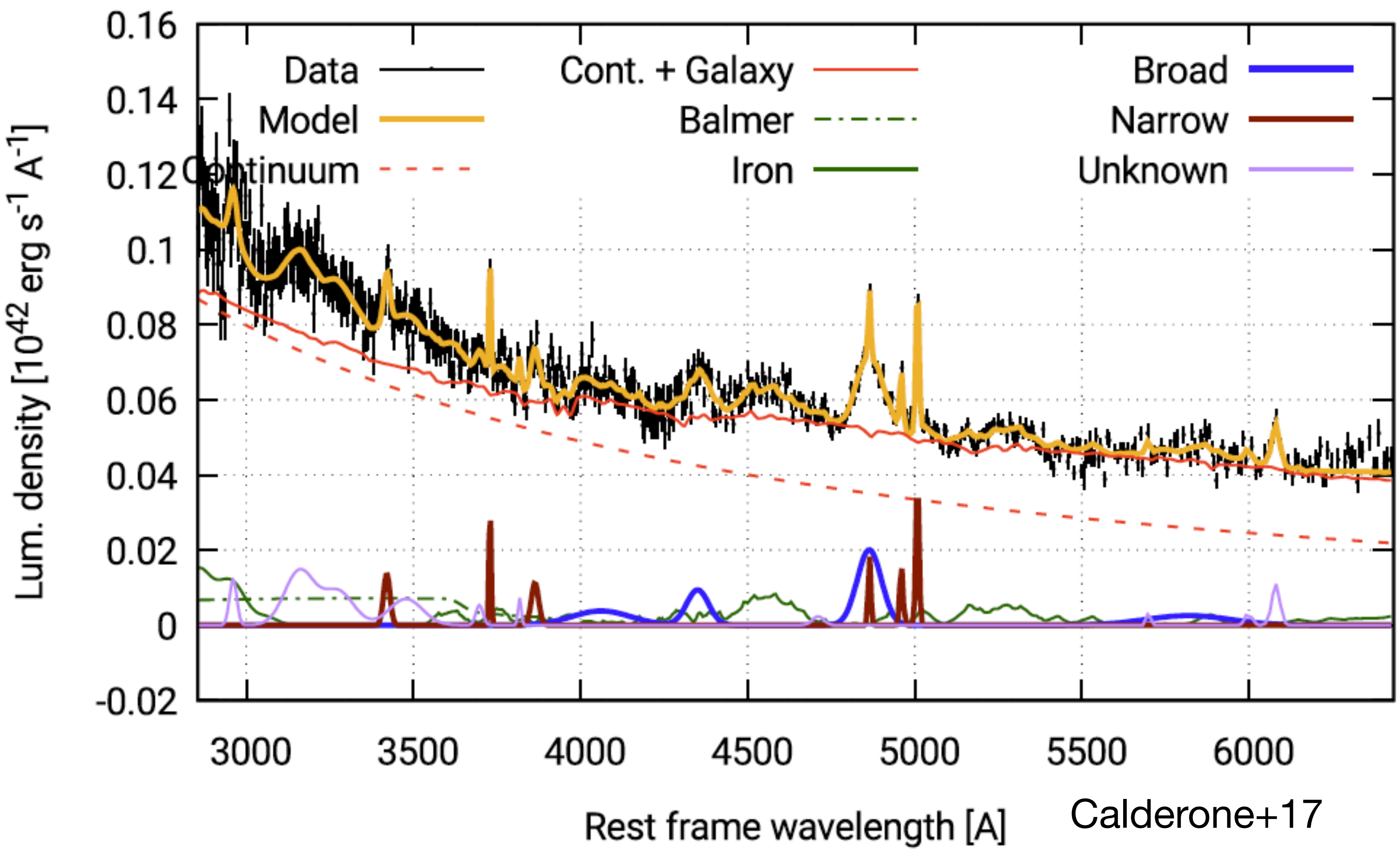
SED-fitting approach, modelling the different AGN emissions.
Several codes available in literature, e.g., AGNFITTER (Calistro Rivera+16), QSOFit (Calderone+17), CIGALE (Boquien+19)

Pros:

- good description of individual SEDs
- studying physical properties of QSOs

Cons:

- large number of free parameters
- difficult to constrain using photometry alone



Calderone+17

Templates: Temple+21

Empirical QSO SEDs obtained by:

- modelling AGN emission with a small number of parameters (9)

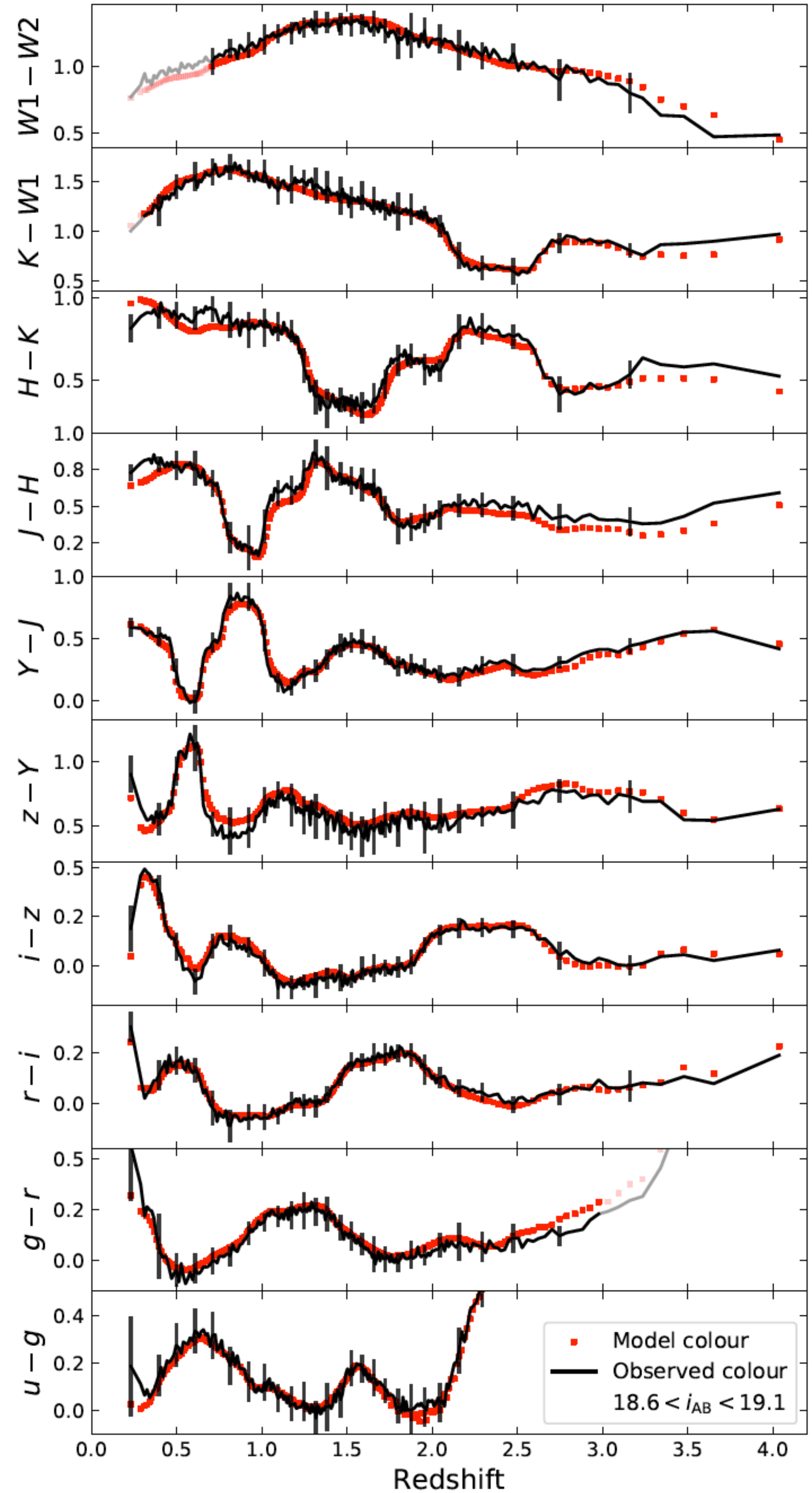
- reproducing average colours from SDSS, UKIDSS, WISE photometry; 15K objects with $18.6 < i_{AB} < 19.1$)

To note:

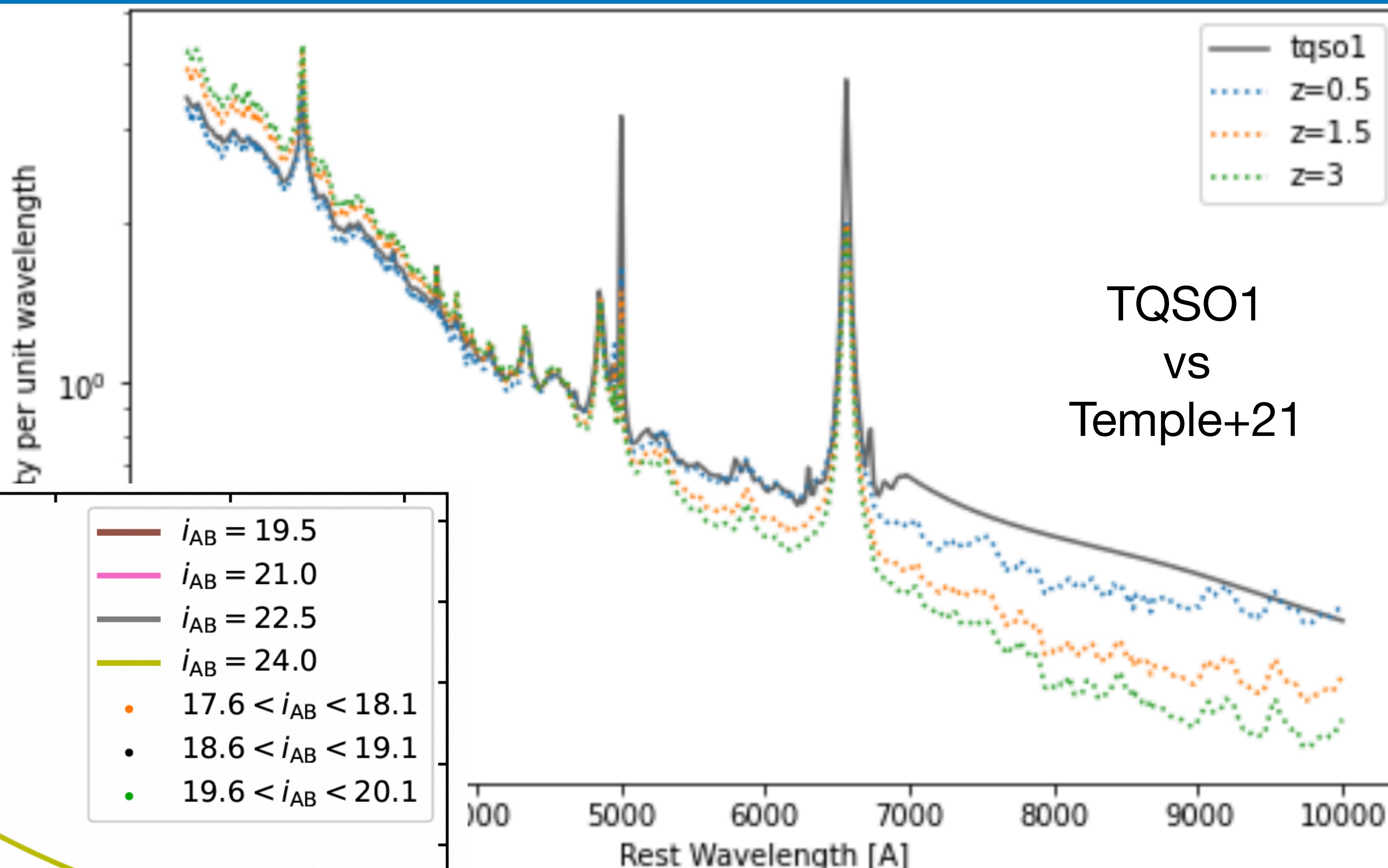
1) extinction considered negligible

2) Host Galaxy SED = S0 and

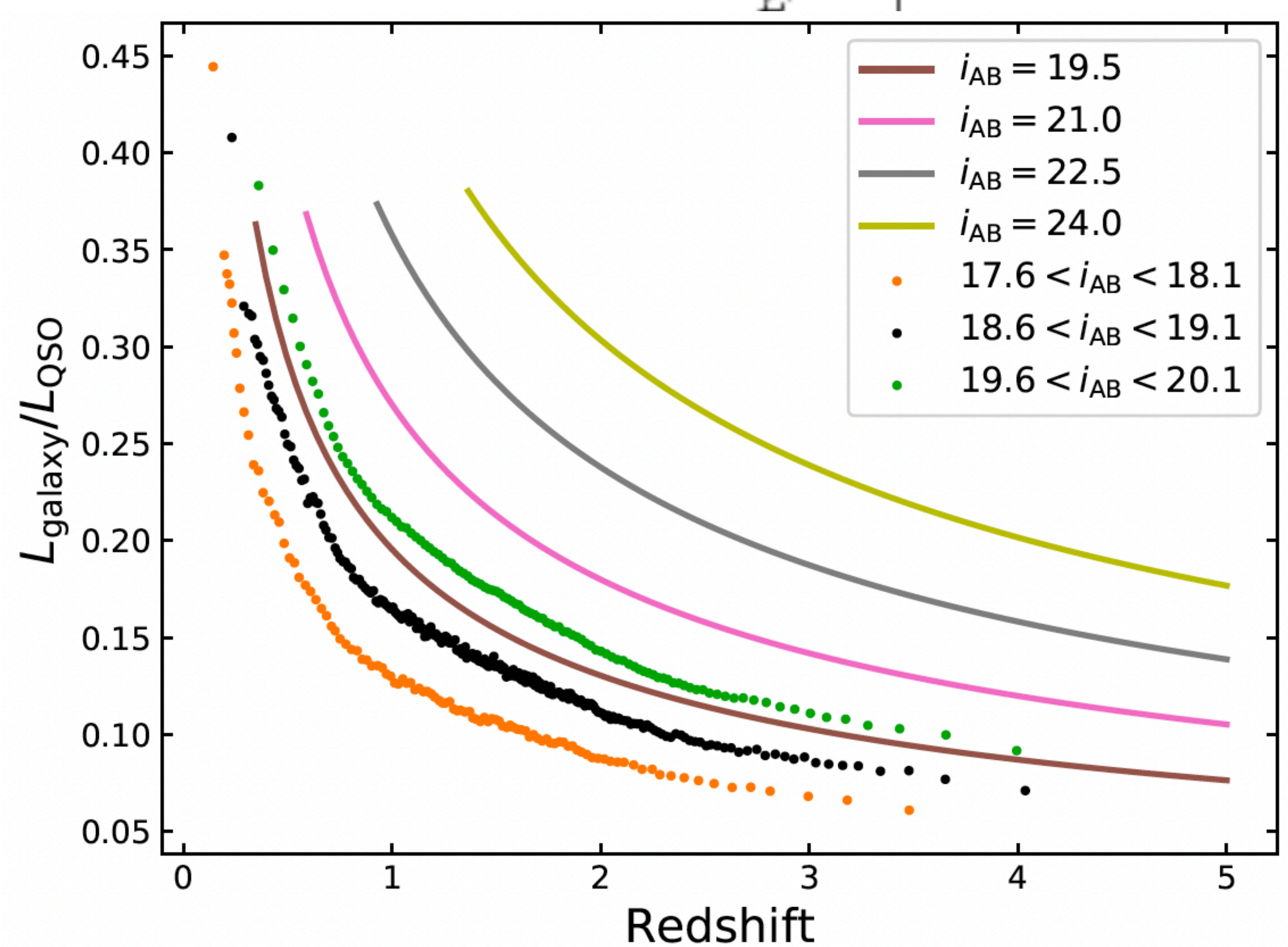
$$L_{gal} \propto (L_{QSO})^{\alpha}$$



Templates: Temple+21



TQSO1
vs
Temple+21



New Model: Objectives

Simple model able to reproduce observed SEDs of type I quasars, using a ***mixed* approach** of previous methods

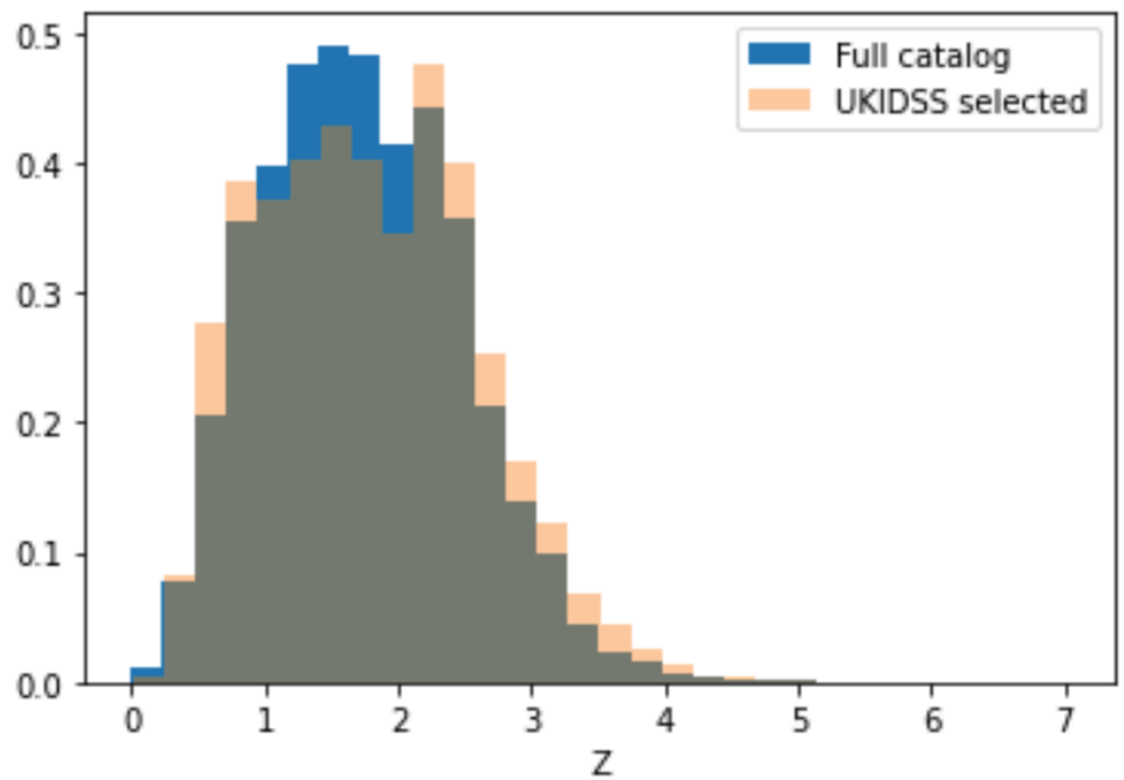
- **Composite spectra** but only for objects with similar colours (in same redshift bin) —> high S/N, keeping the SED diversity
- Modelling composite SEDs with a small number of physical parameters (2-4):
  - ✦ **UV/optical: reference Template (TQSO1)** + intrinsic extinction + host galaxy emission
  - ✦ **NIR:** power law + hot dust emission

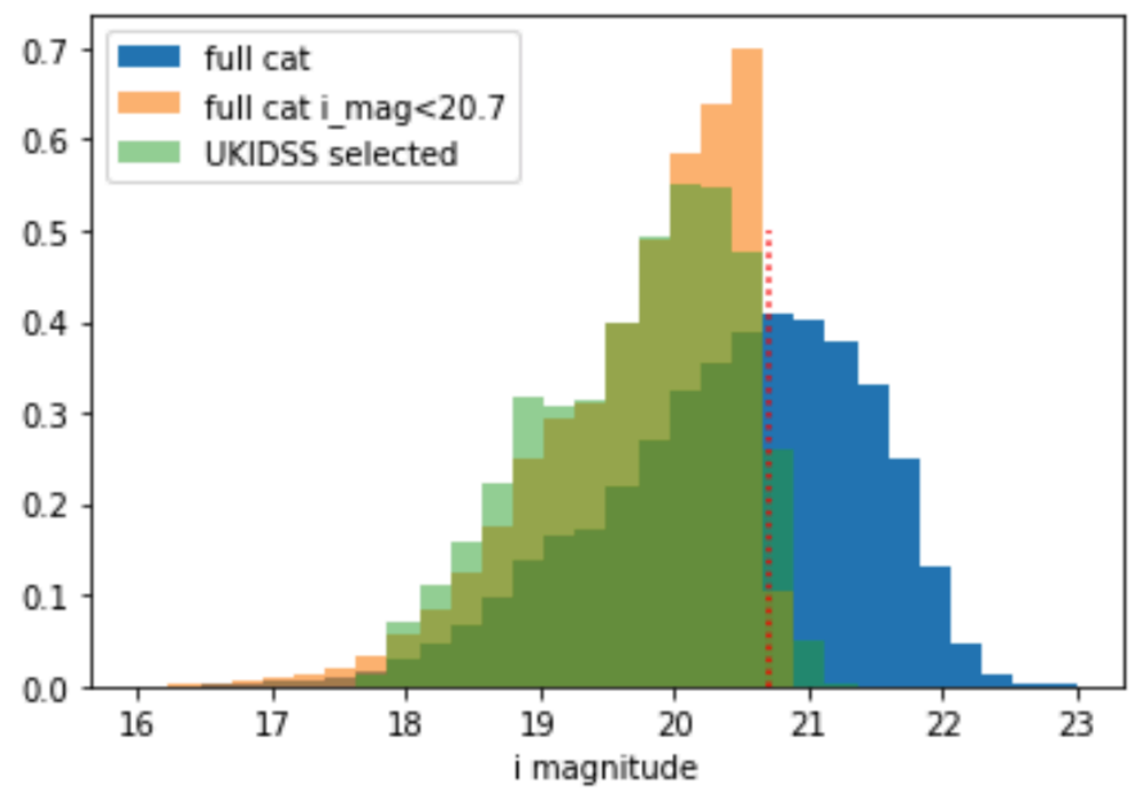
Data: SDSS DR16Q

SDSS DR16Q: catalog of ~750K spectroscopically confirmed quasars (Lyke+20)

—> optical spectra between 3800—9100A

- Match objects with **UKIDSS (*Y,J,H,K*)** & **WISE (*W1,W2*)** surveys
- Select objects with i_{AB} SNR > 20, z<2.5: **~80K** QSOs



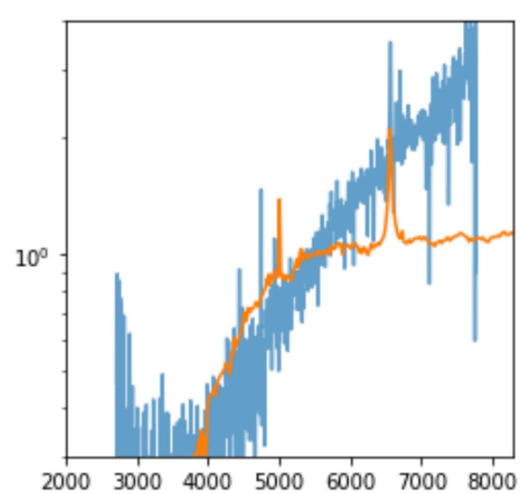


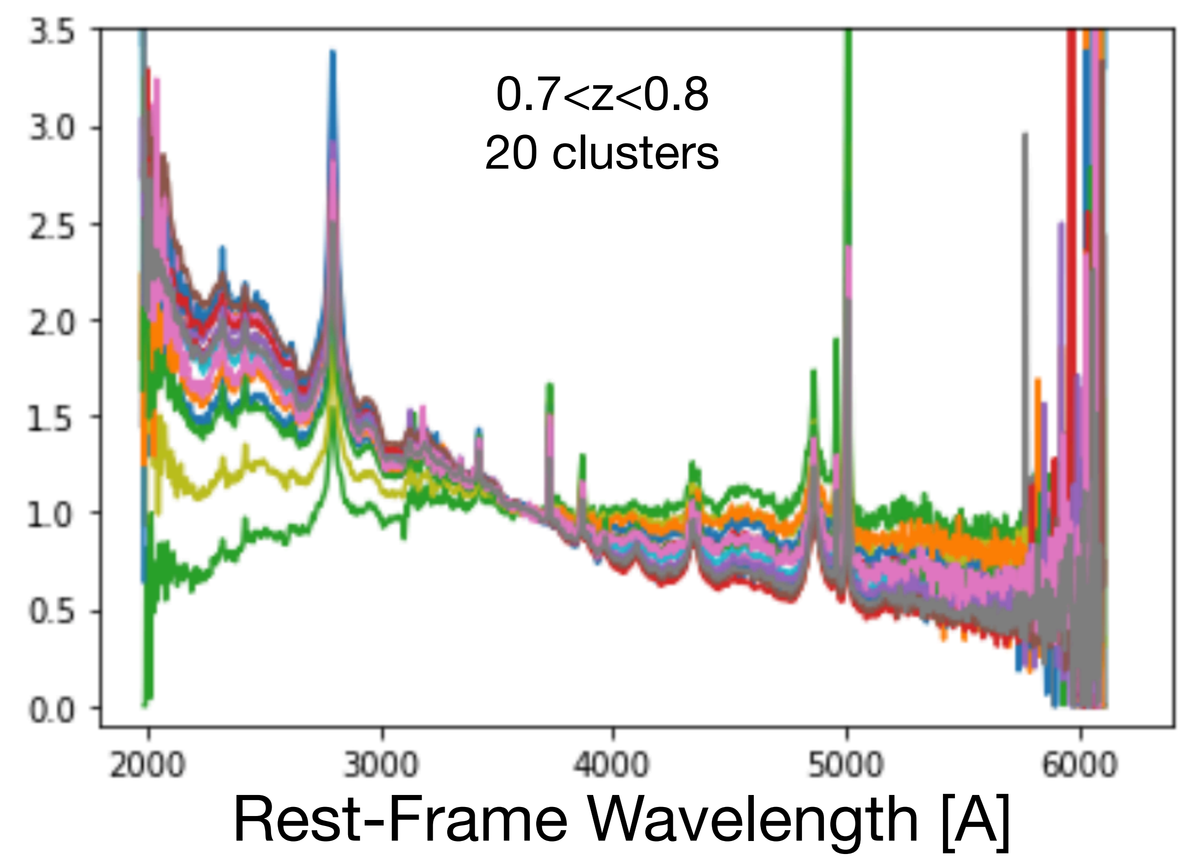
Composite SEDs vs Colours and Redshift

- Divide **QSOs in redshift bins** (Δz=0.1, 0.1≤z≤2.5)
- Compute colours in UV-optical (*u,g,r,i,z)* bands and **cluster** objects **based on colours** using a *k-means* method (*k*=10-25)
- **Combine** (geometrical mean) spectra belonging to the same cluster (normalised & at rest frame)

➡ Keep SED variety

➡ Detect outliers





Modelling Composite SEDs

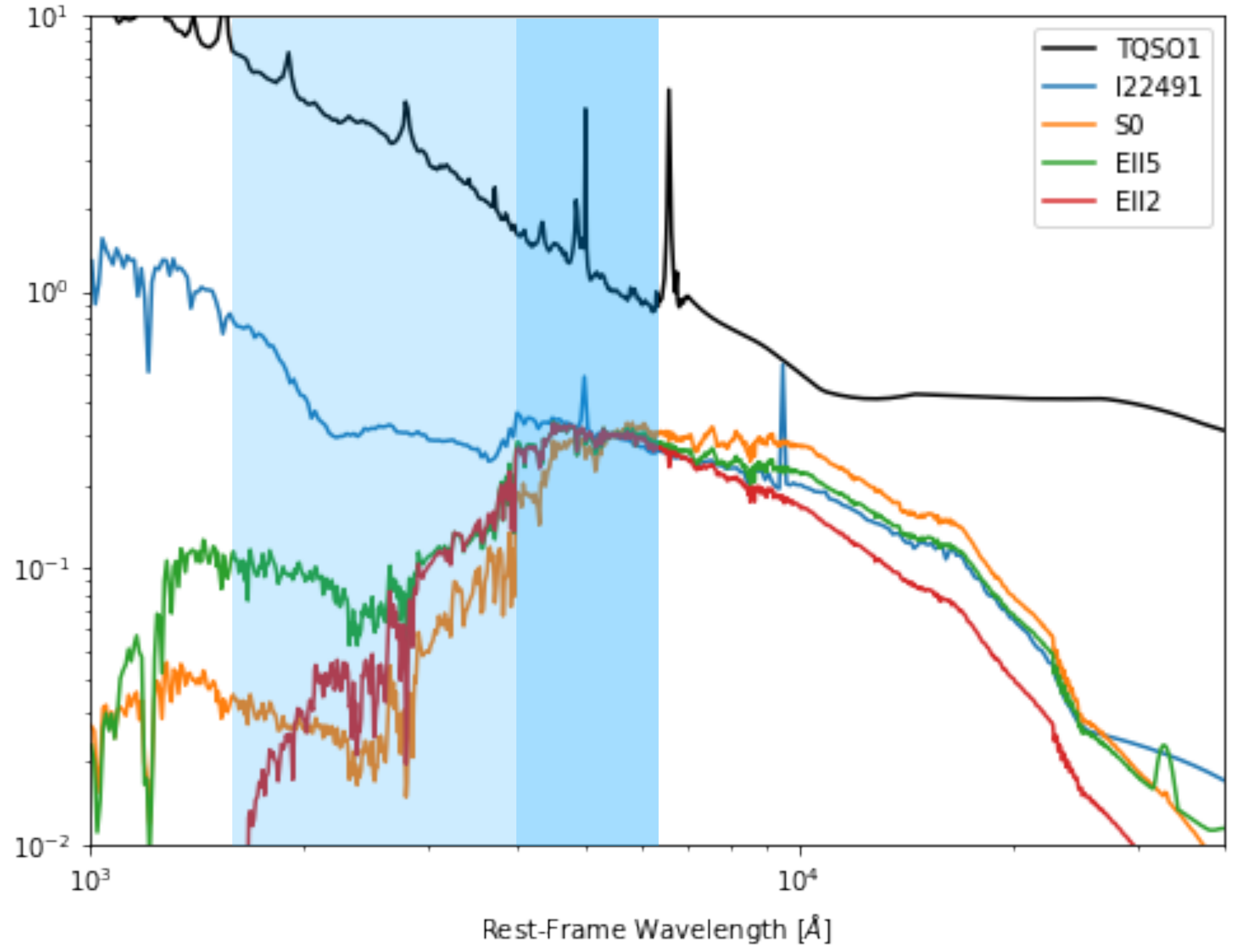
TQSO1 template (Polletta+07, Vanden Berk+01) is a good description of the *average* SED for SDSS QSOs

➡ Fit composite spectra (focused on continuum) by:

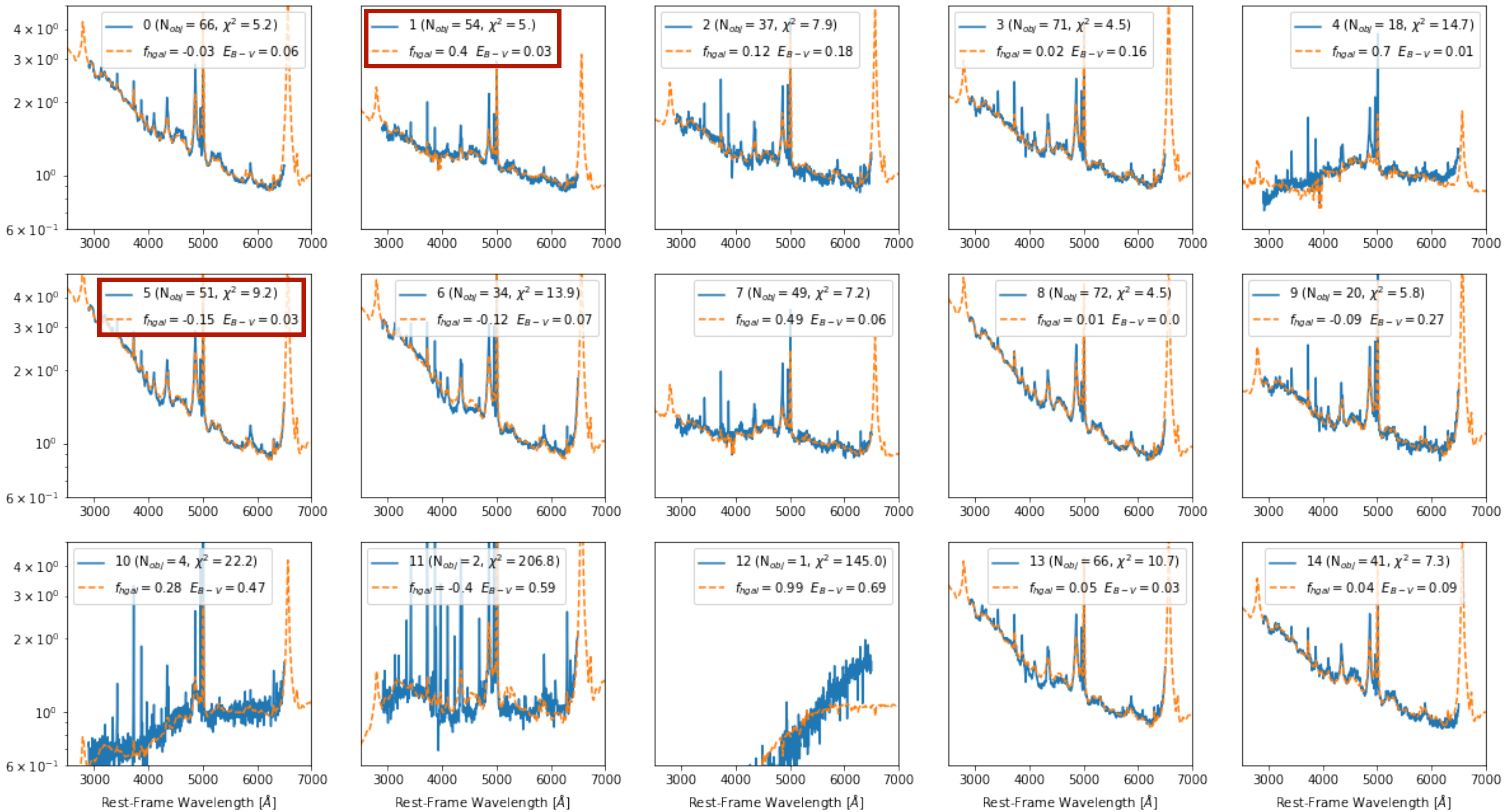
- Adding **host galaxy contribution** (only for z<1.3)
- Applying **reddening**

free
- **E(B-V)**: [-0.4, 0.7]
- **Host galaxy fraction**: [-0.4, 1]

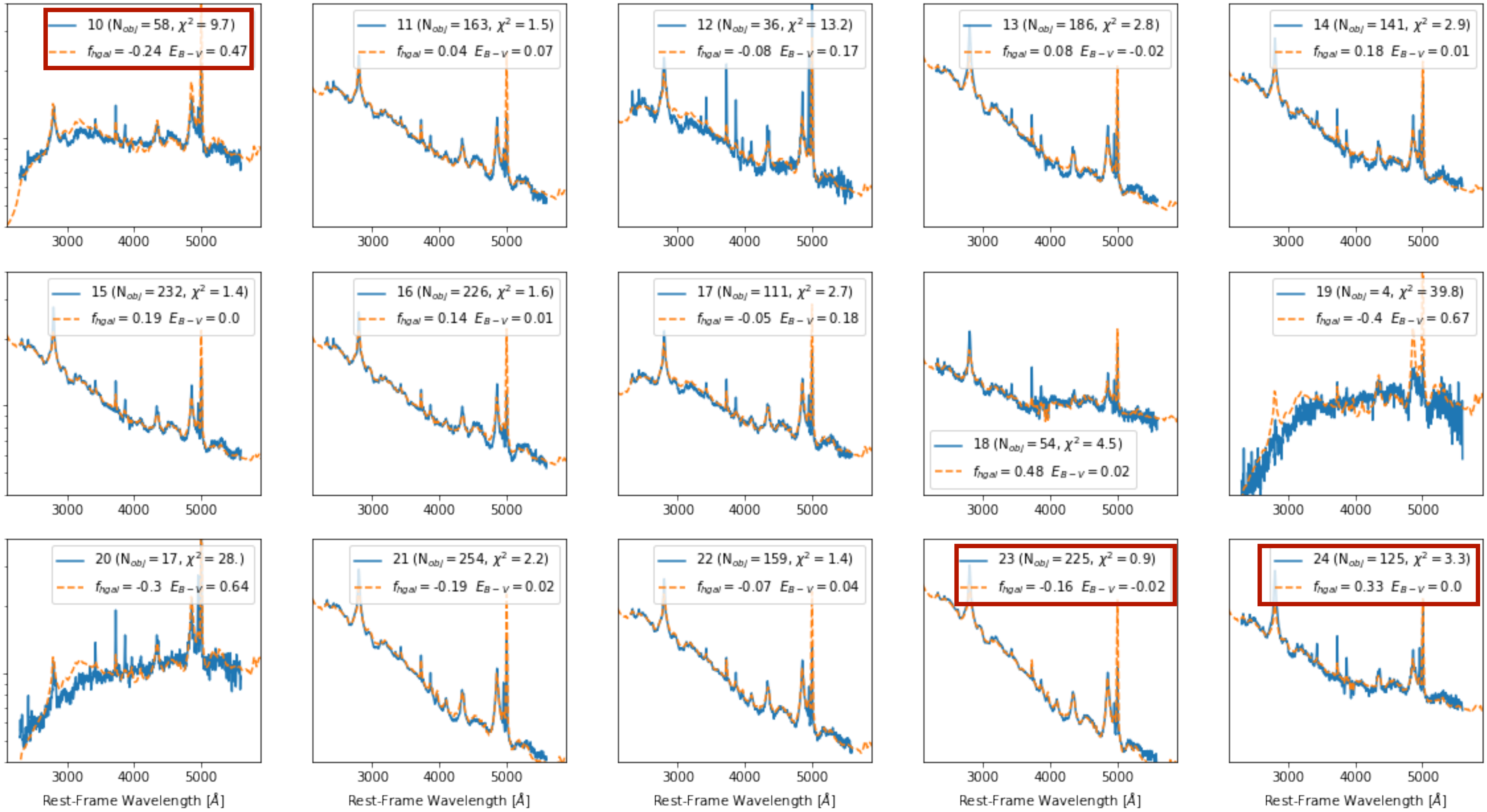
fixed
- **Reddening curve:** SMC
- **Host galaxy spectrum: Ell2** (also S0, I22419, Ell5)



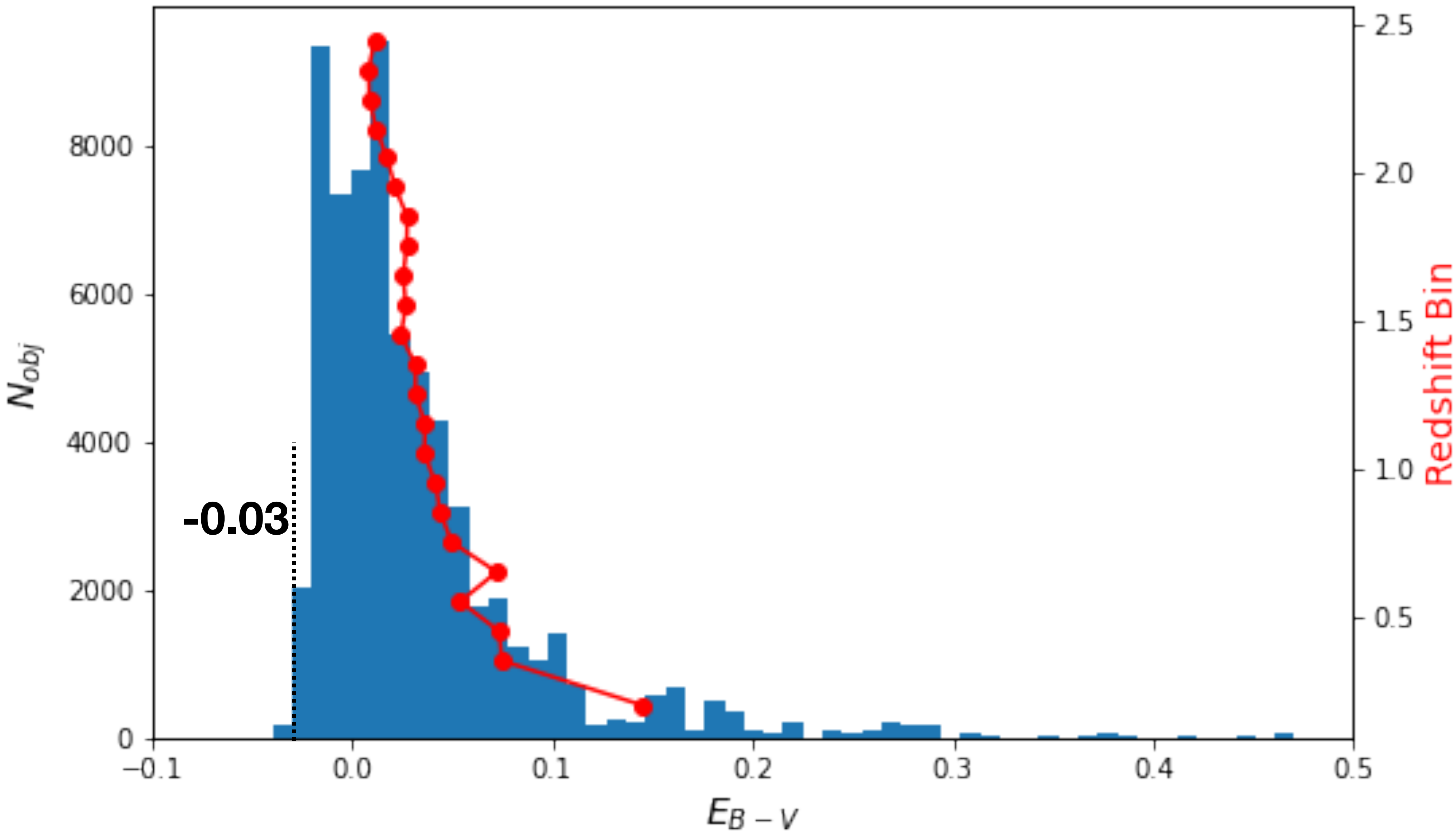
Results: fit for z=[0.3,0.4)



Results: fit for z=[0.7,0.8)



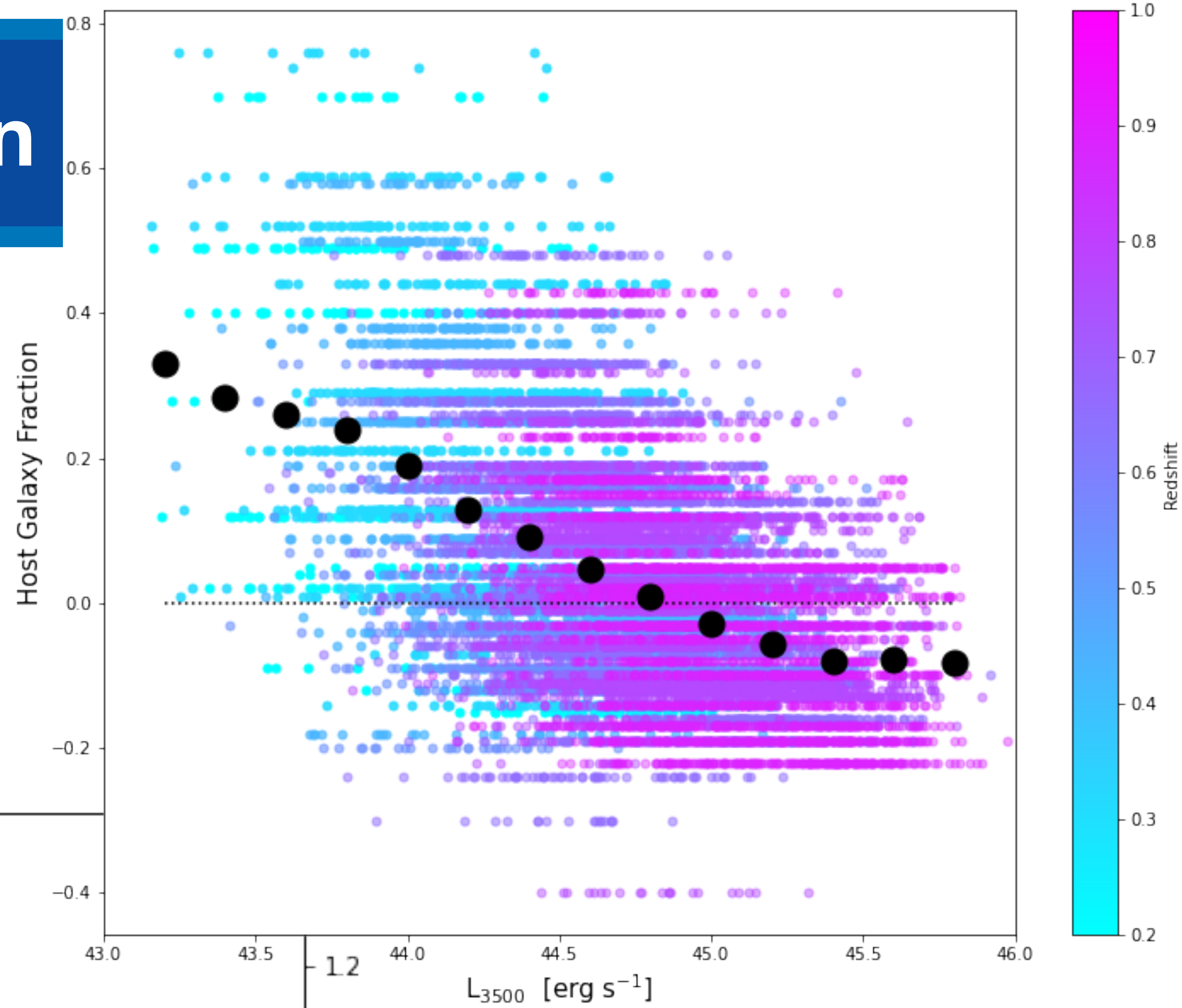
Results: Reddening E(B-V)

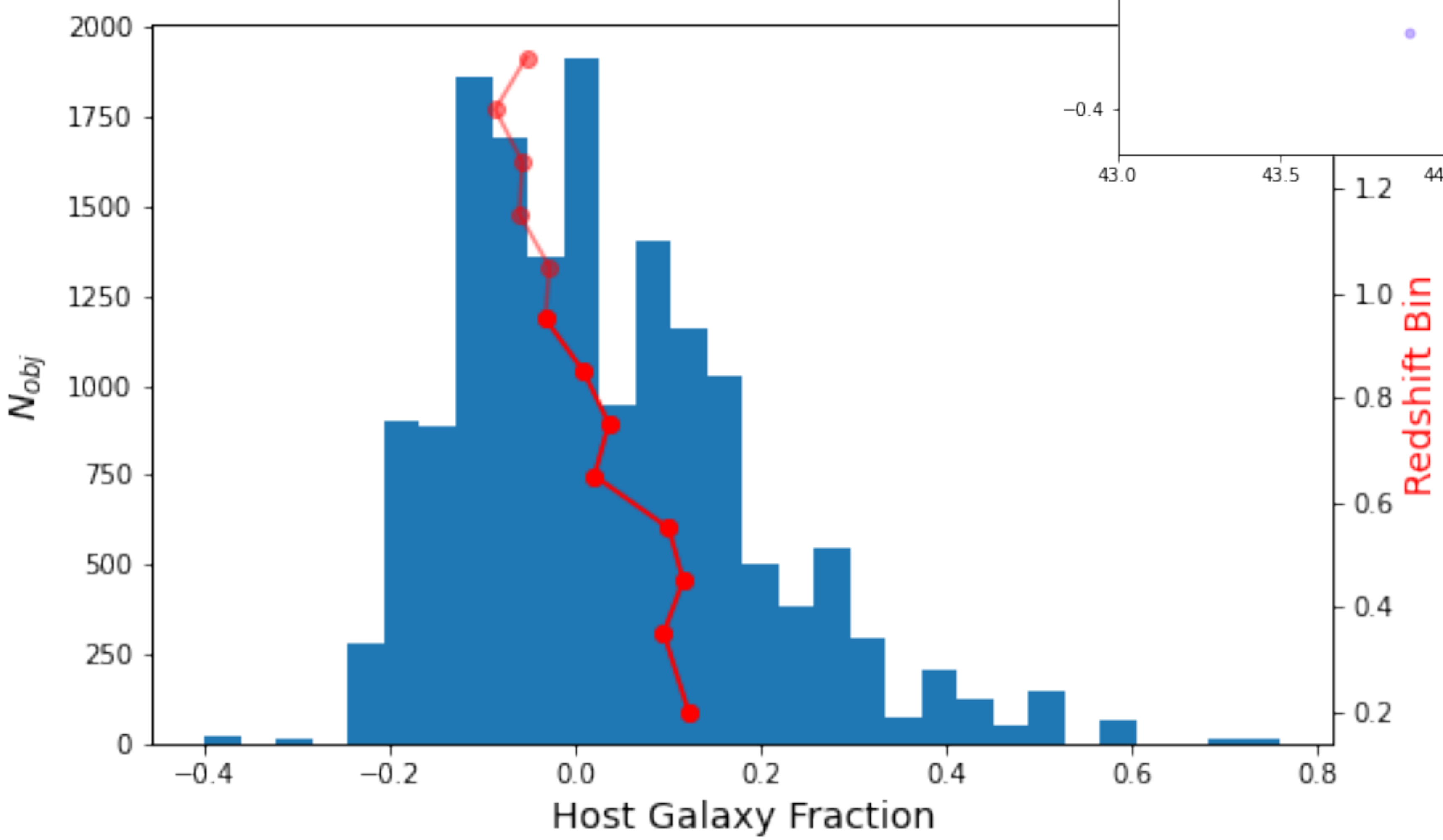


~30% with negative values

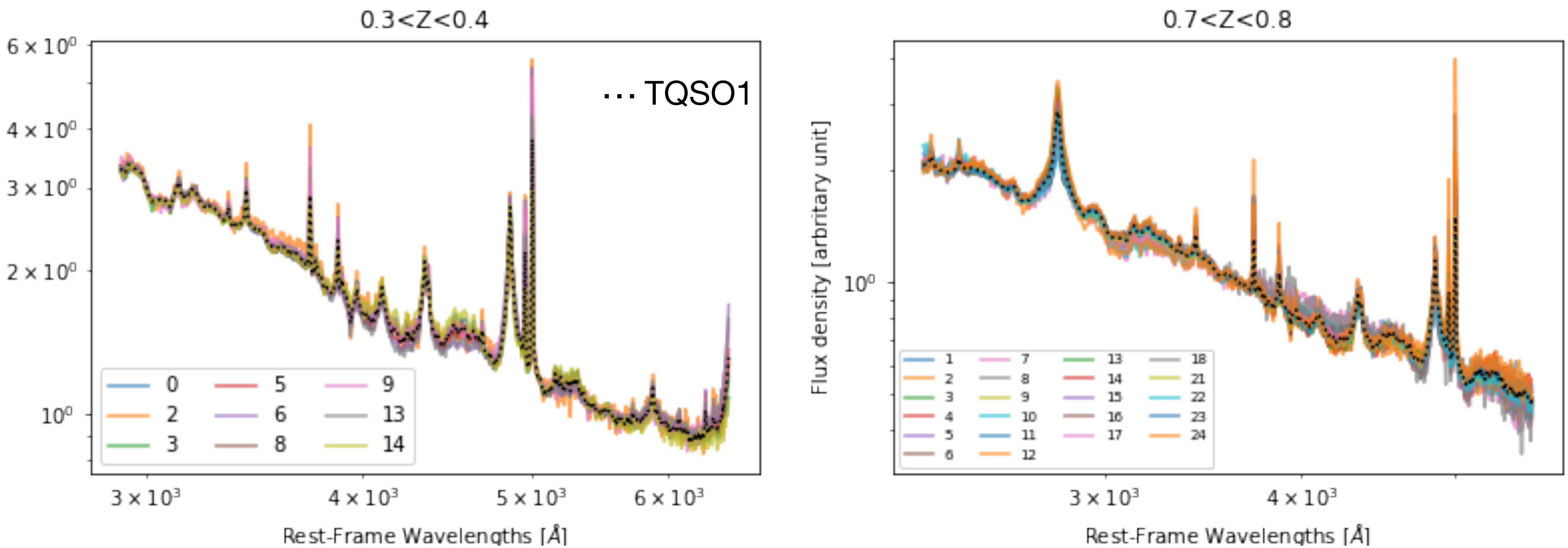
Host Galaxy Fraction

- Mostly $-0.2 \lesssim F_{gal} \lesssim 0.3$
- $\langle F_{gal} \rangle = 0.15$ $z<0.6$
- $\langle F_{gal} \rangle \lesssim 0$ $z>0.8$





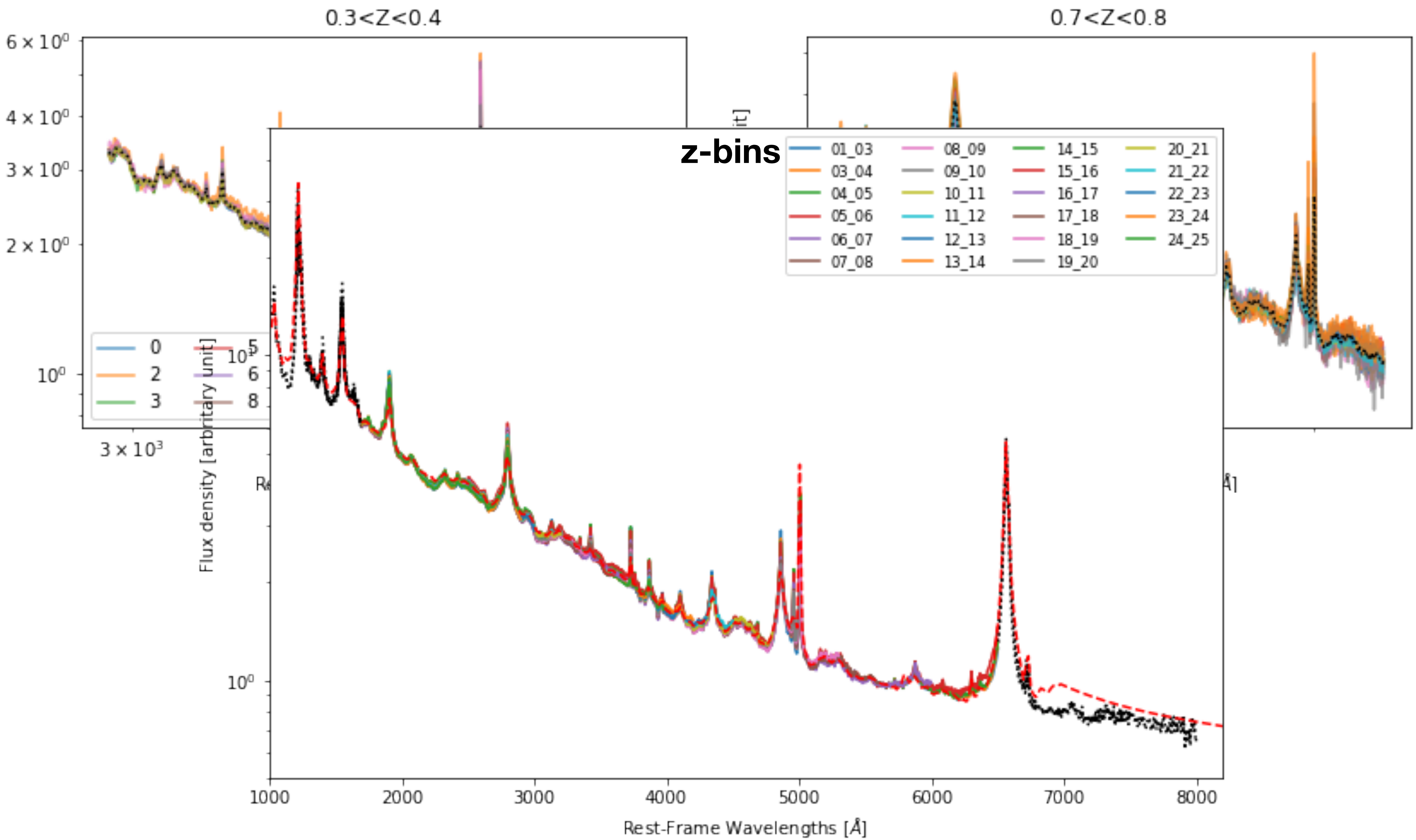
Mean Template at UV/optical



Correct composite spectra for extinction and for the host galaxy contribution

Mean spectra for each redshift bin

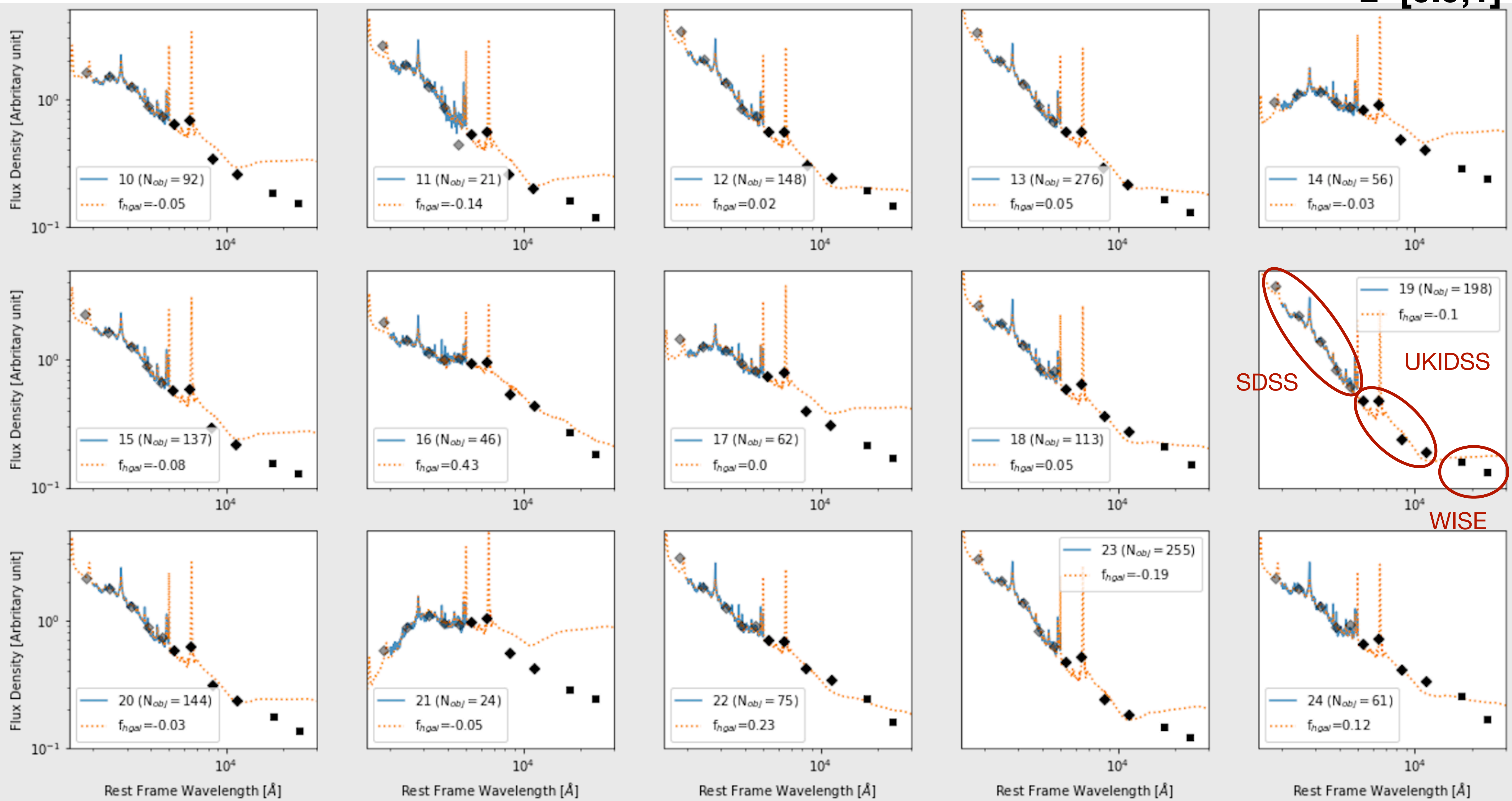
Mean Template at UV/optical



QSO SED at near-infrared wavelengths

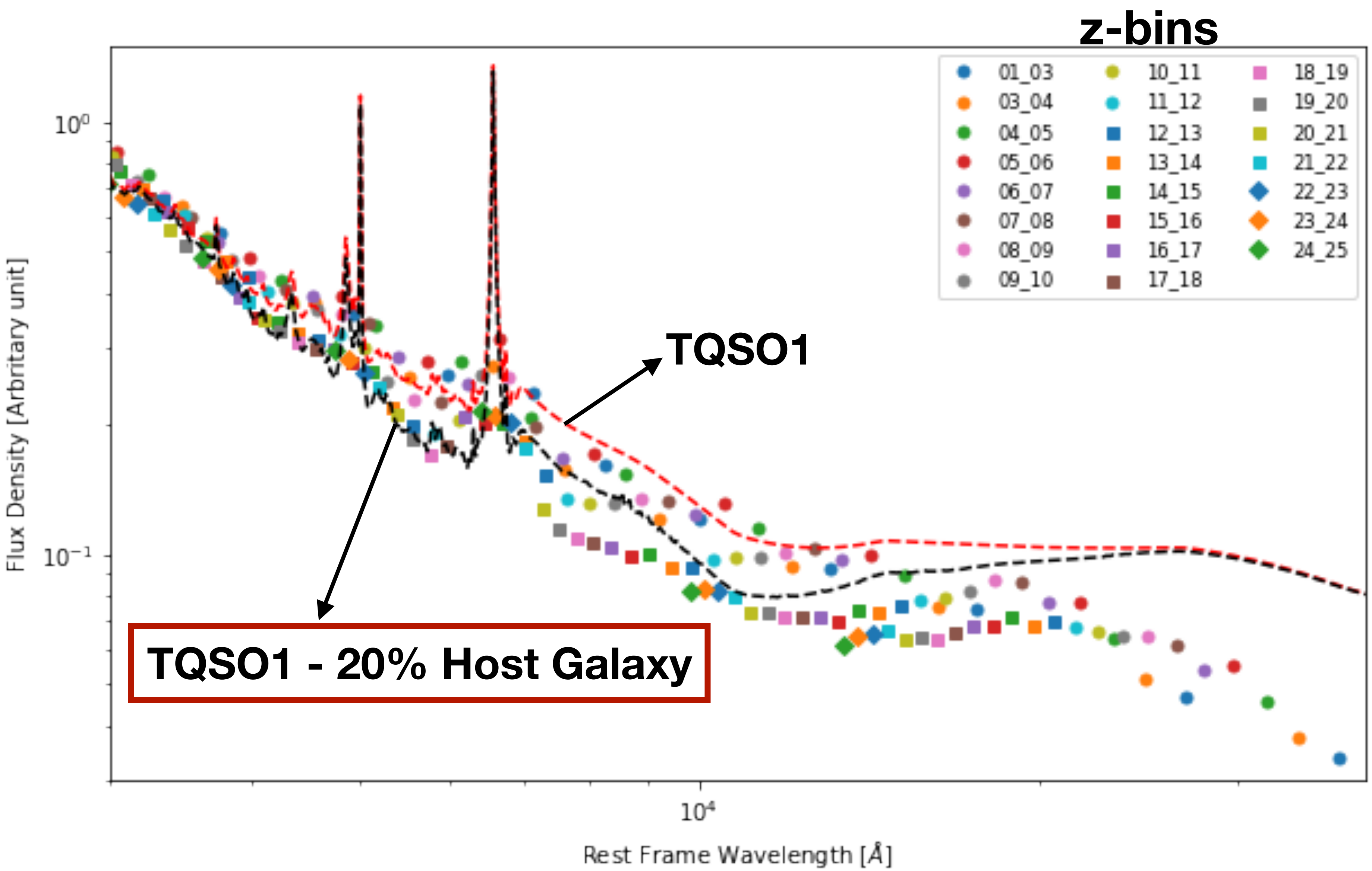
- Based on **UKIDSS (YJHK)** and **WISE (W1W2)** photometry

z=[0.9,1]



QSO SED at near-infrared wavelengths

Constrain the NIR QSO SED using the **mean photometry in redshift bins** (after correction for reddening)



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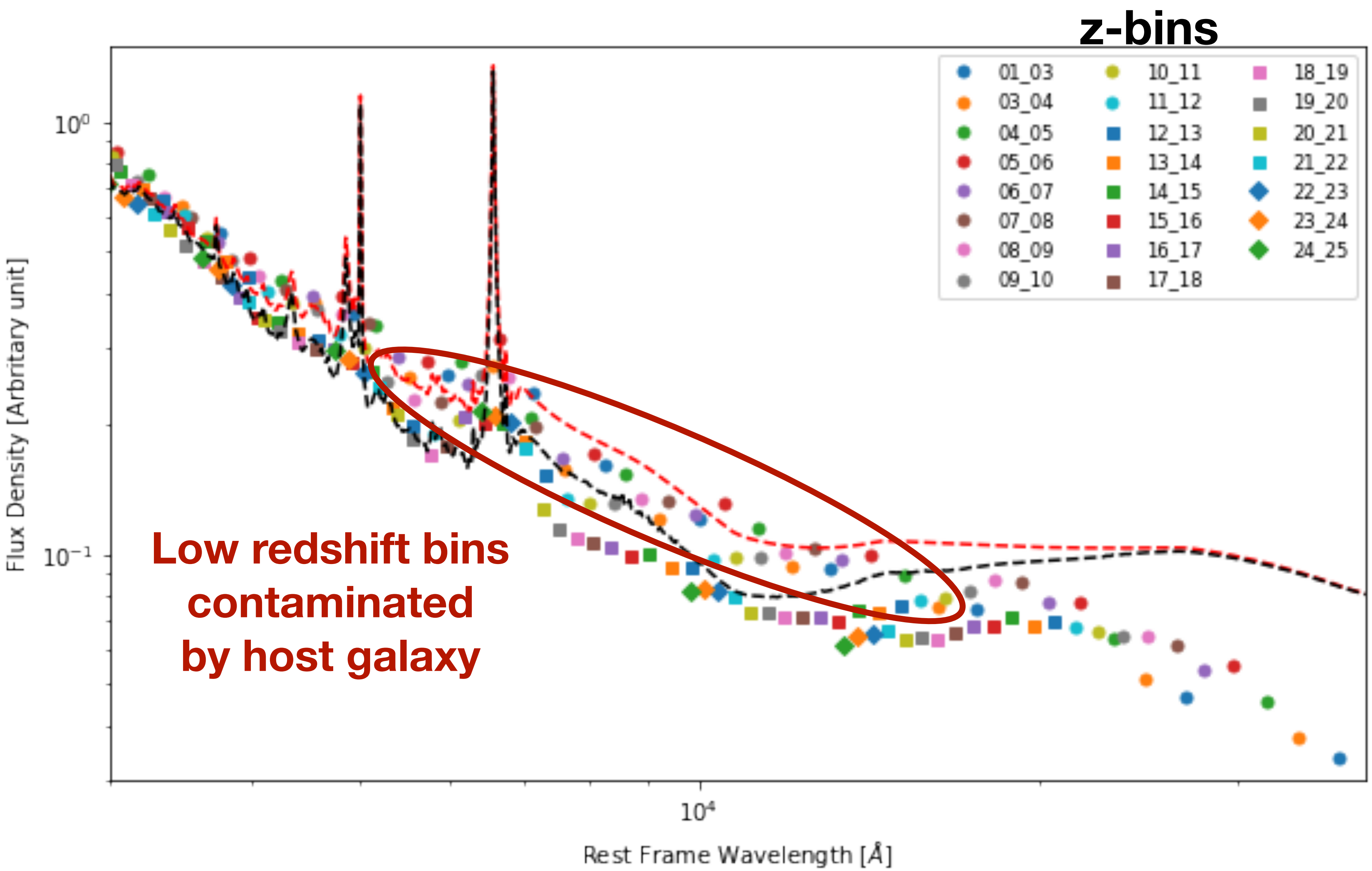
Constrain the NIR QSO SED using the **mean photometry in redshift bins** (after extinction correction)



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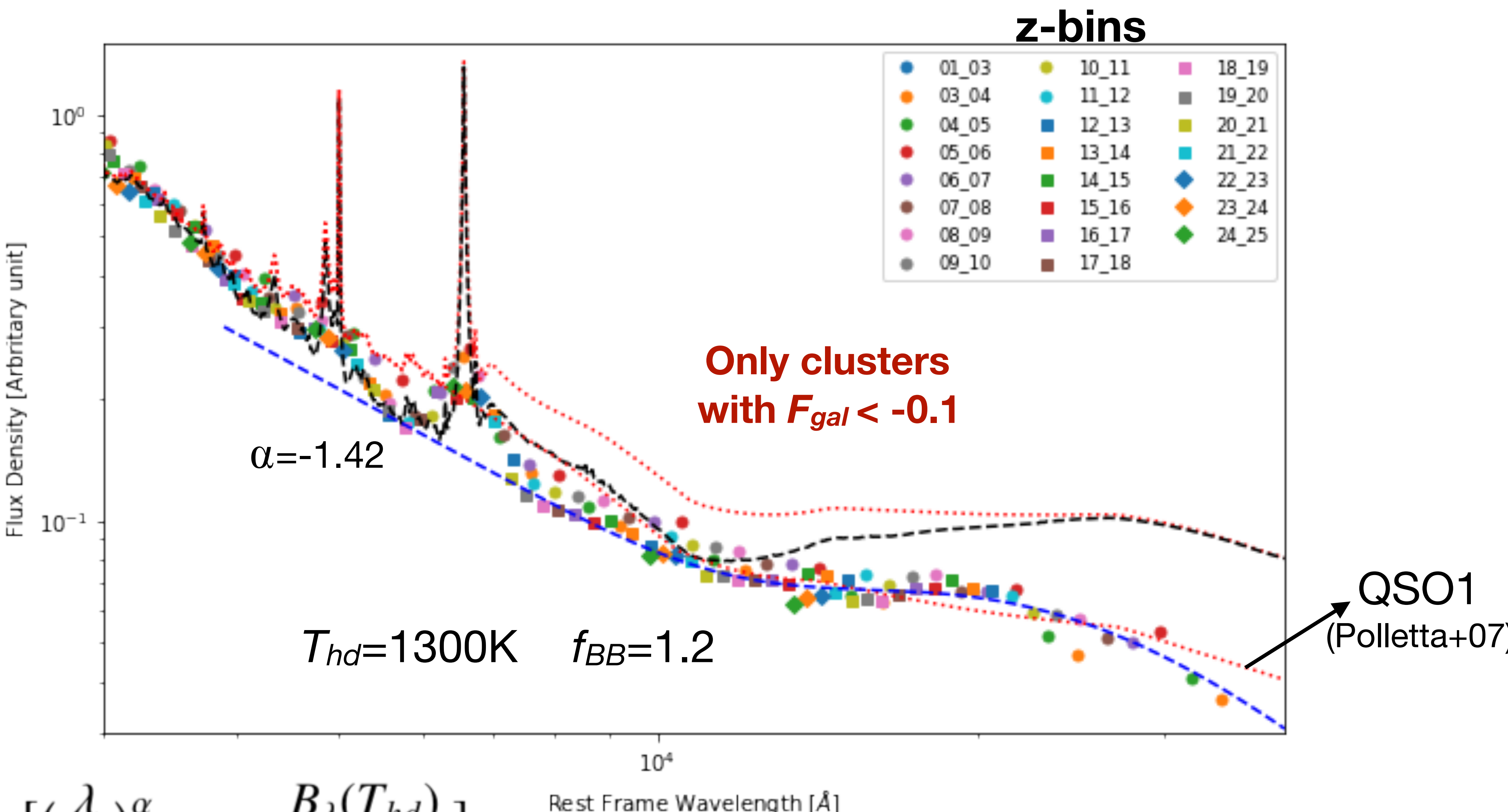
Constrain the NIR QSO SED using the **mean photometry in redshift bins** (after extinction correction)



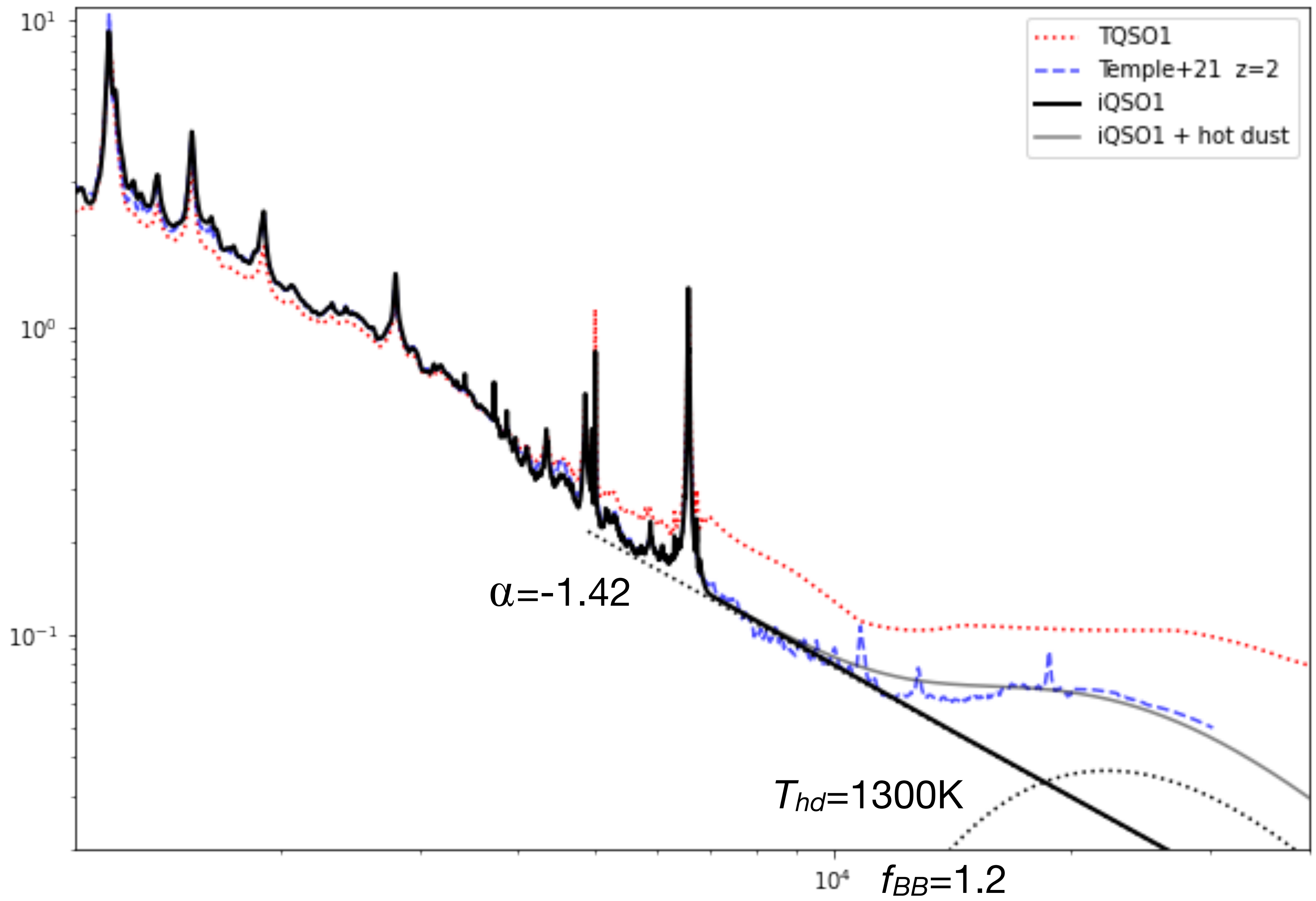
$$F(\lambda) = A_n\Big[\Big(\frac{\lambda}{\lambda_0}\Big)^{\alpha} + f_{BB}\frac{B_\lambda(T_{hd})}{B_{\lambda_0}(T_{hd})}\Big]$$

$$\lambda_0 = 2\mu\mathrm{m}$$

Template of intrinsic QSO SED (iQSO1)

Intrinsic SED: TQSO1-like but corrected for

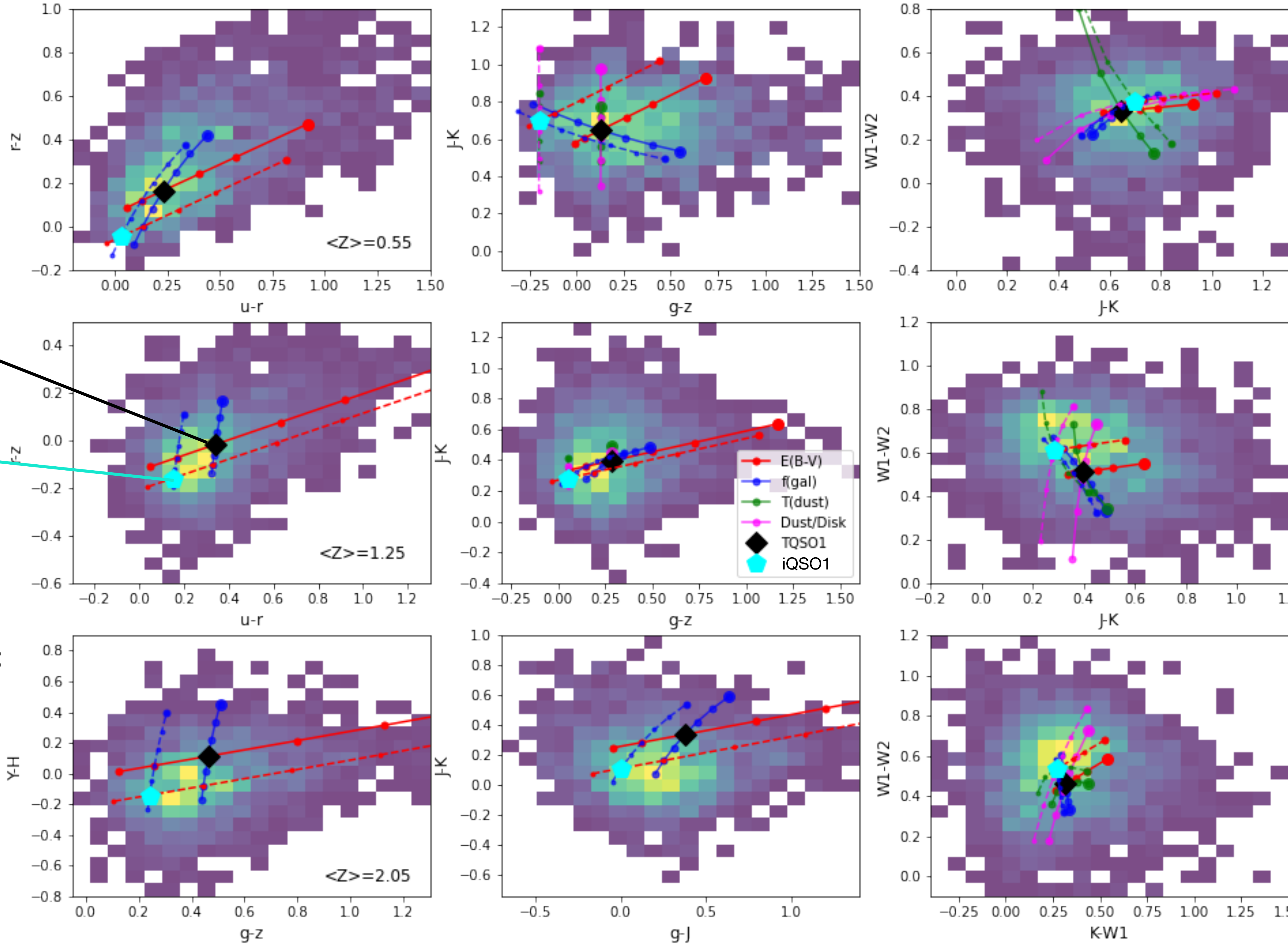
- residual extinction (E_{B-V} = 0.03)
- host galaxy contamination (20%)



Modelled vs Observed Colours

Reference SED: TQSO1

Intrinsic SED: iQSO1



Parameters Range:

E(B-V)=[-0.05,0.3]

Fgal=[-0.3,0.3]

T(dust)=[900,1700]

f_{BB}=[0,3]

Conclusions

- Most of **SDSS QSO spectra** can be well described by a **single template** (TQSO1-like), taking into account extinction and host galaxy contribution

- We produce an ***intrinsic* SED template** by de-reddening the TQSO1 template and by subtracting residual galaxy emission

- **Galaxy contamination** become small at $z>1$ (typically $<20\%$)

- At NIR, a **hot dust** ($T\sim1300K$) component is needed to fit observed photometry (relevant for Euclid only at $z<1$)

- Good match in colours between model and data