Quasar search with S-PLUS
Hands-on session

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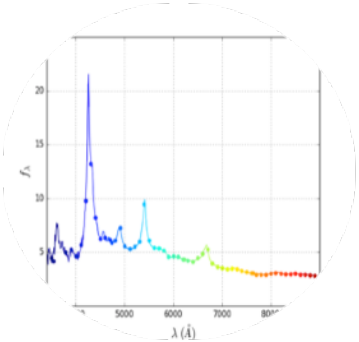
Structure

Theory ↔ **Exercises**

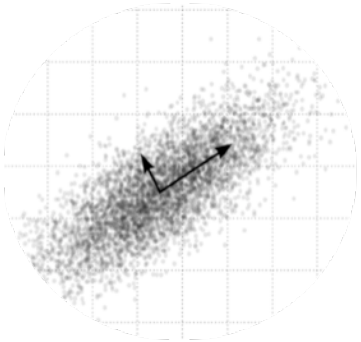
Overview

why study quasars?

quasars as tracers of the large-scale structure



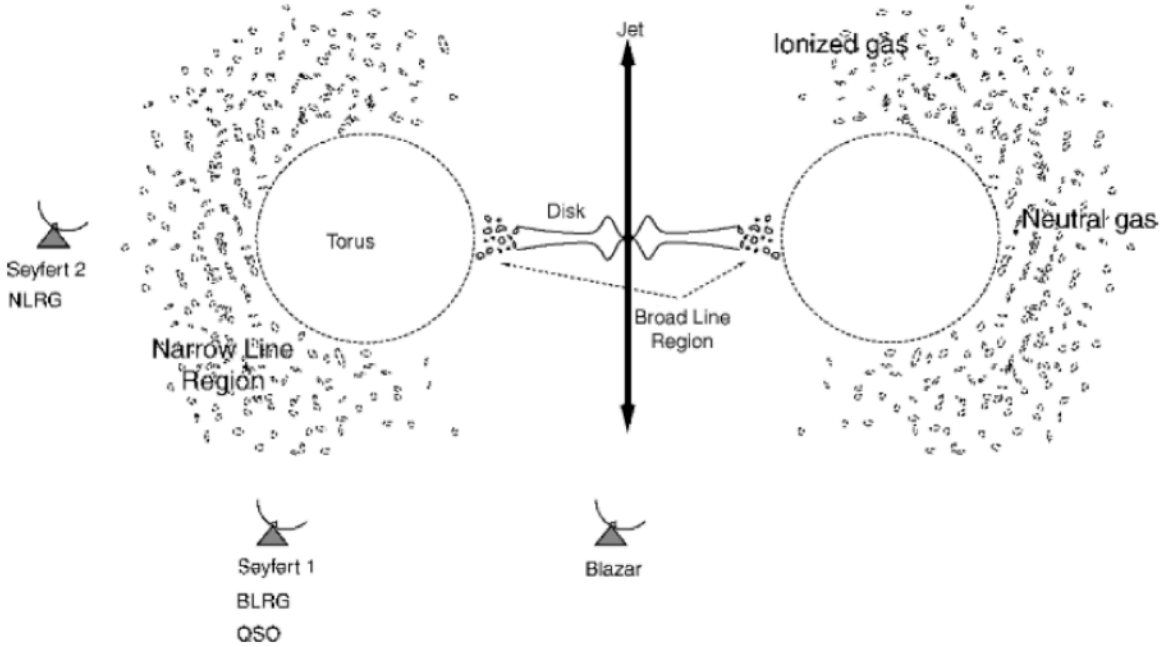
mapping the Universe with 12 colors



fitting quasar spectra with eigenspectra/ templates

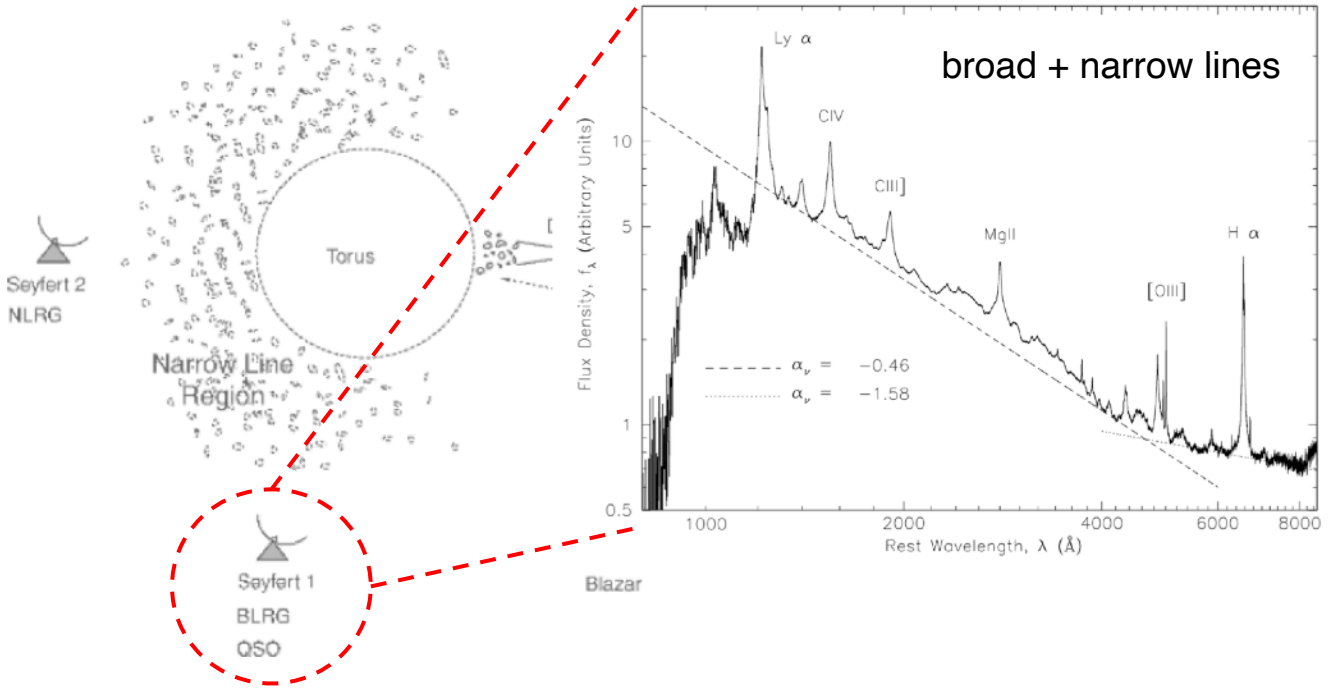
[Urry & Padovani 1995]

Unified model of Active Galactic Nuclei

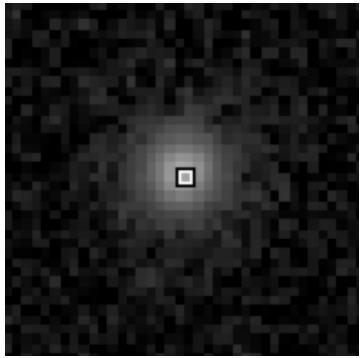


[Urry & Padovani 1995, Vanden Berk 2001]

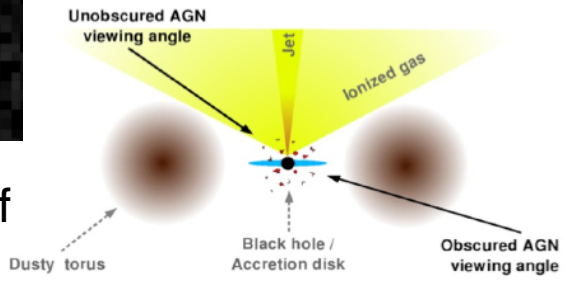
Unified model of Active Galactic Nuclei



Why quasars?



r-band image of an S-PLUS quasar



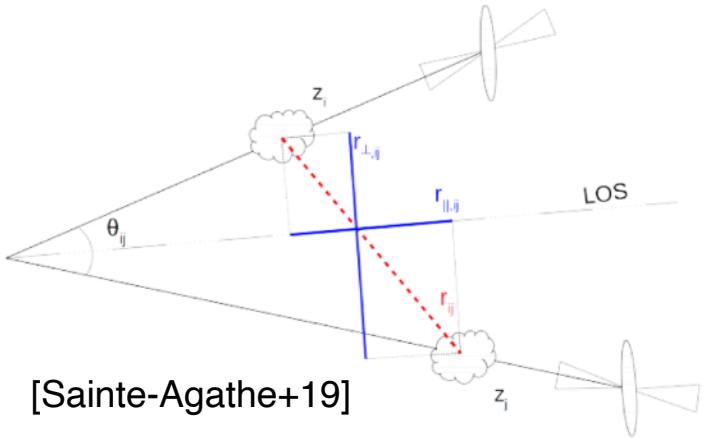
[Spinoglio & Fernández-Ontiveros19]

1. Probe **large distances**, up to *z*~7 (Wu+15,Mortlock+11,Bañados+17;
2. active phase may be present in the history of every galaxy lifetime: estimate the **mass** of the central **SMBH**; study the **coevolution** of the host galaxy and the SMBH (Ferrarese&Merritt2000,Heckman+14);
3. serve as **light sources** to map the intervening neutral hydrogen (Weinberg+03).

[Abramo+12; Riebe+13; Abramo+16; Voivodic+19]

1. Quasars as tracers of large-scale structure

- Quasars are believed to inhabit the centers of very massive DM halos.
- Include quasar redshift probability distributions in simulations (e.g. ExSHalos, MultiDark) to study the formation of structures in the largest scales using multi-tracers.

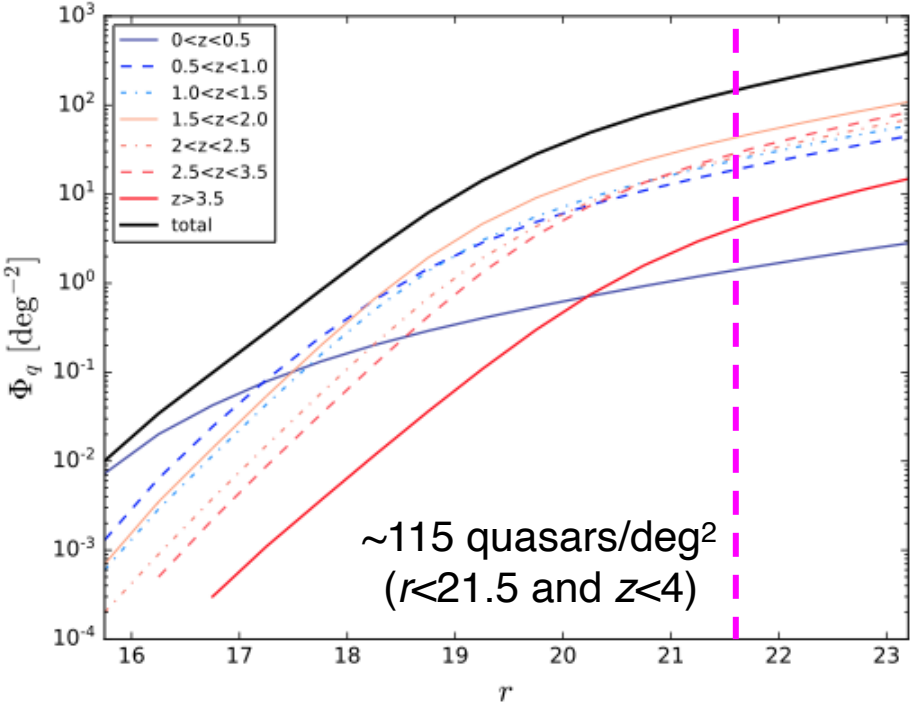


[Sainte-Agathe+19]

BAO, H_0, non-Gaussianities (f_{NL}).

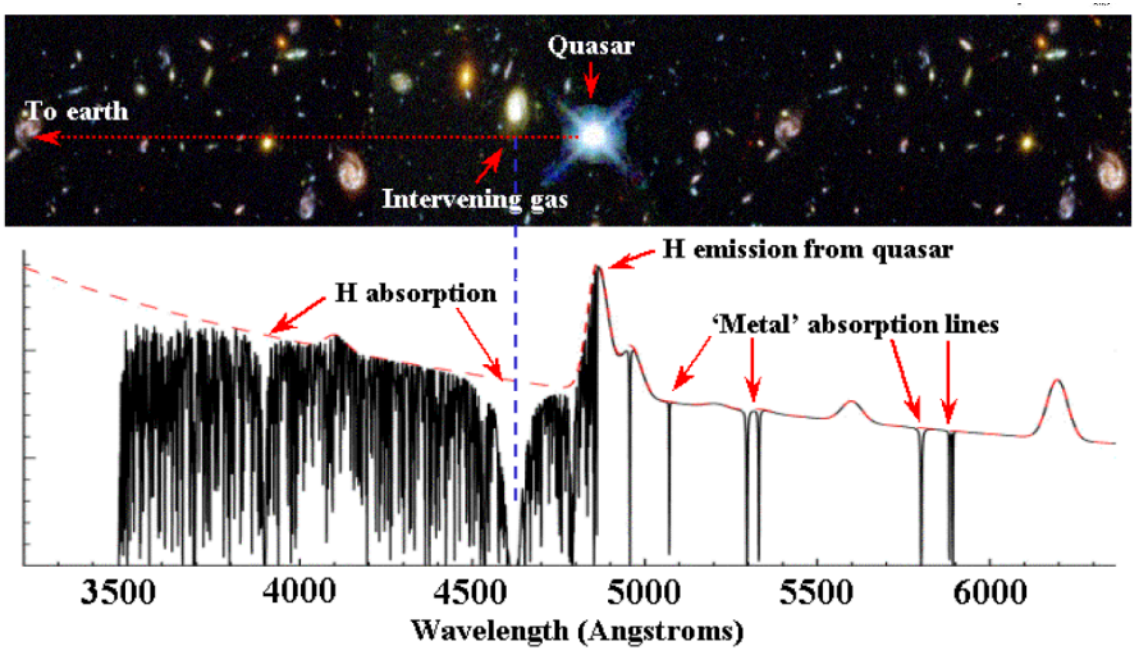
[Richards+06; Croom+09; Ross+13; **Palanque-Delabrouille+15**]

2. Luminosity function for quasars



Crucial point for understanding assembly history of black holes

3. Lyman-α forest



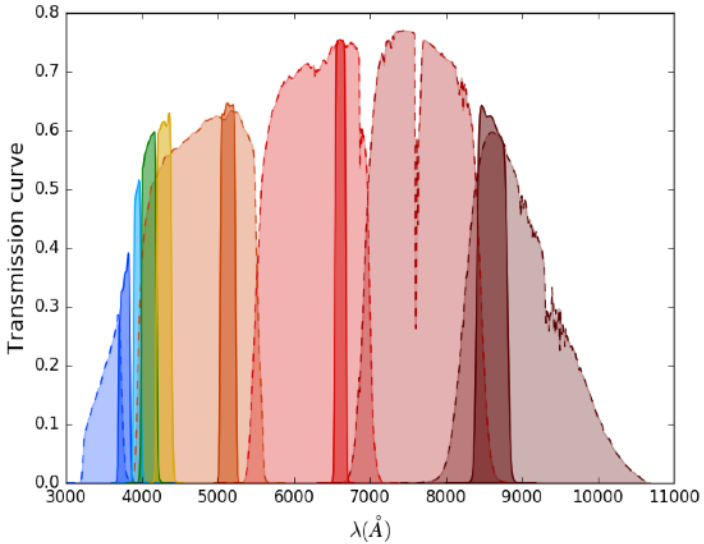
EXERCISE 1. Quasars are so distant and luminous sources that they appear as point-like objects in the sky. If you were going to perform a classification to identify quasars by using one of the methods taught during the classes, with which kinds of sources should you worry about?

[Mendes de Oliveira+19; Molino+19; Costa-Duarte+19; Barbosa+20]

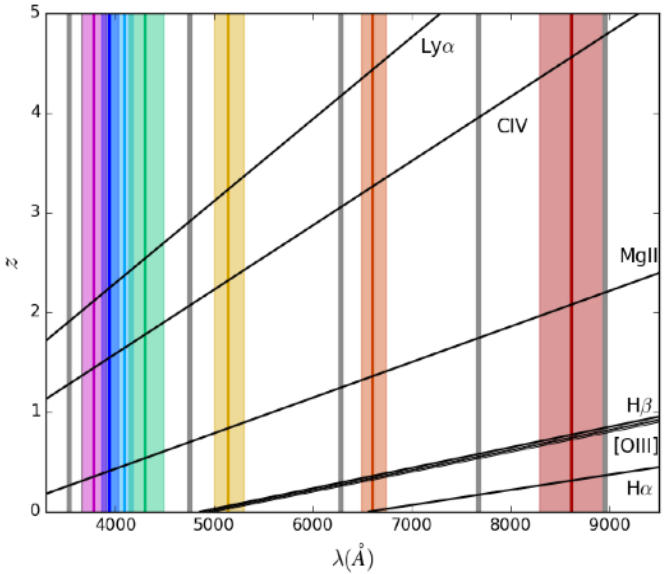
PART I. S-PLUS observations

[Mendes de Oliveira+19]

S-PLUS quasars: Stripe-82 as a test case



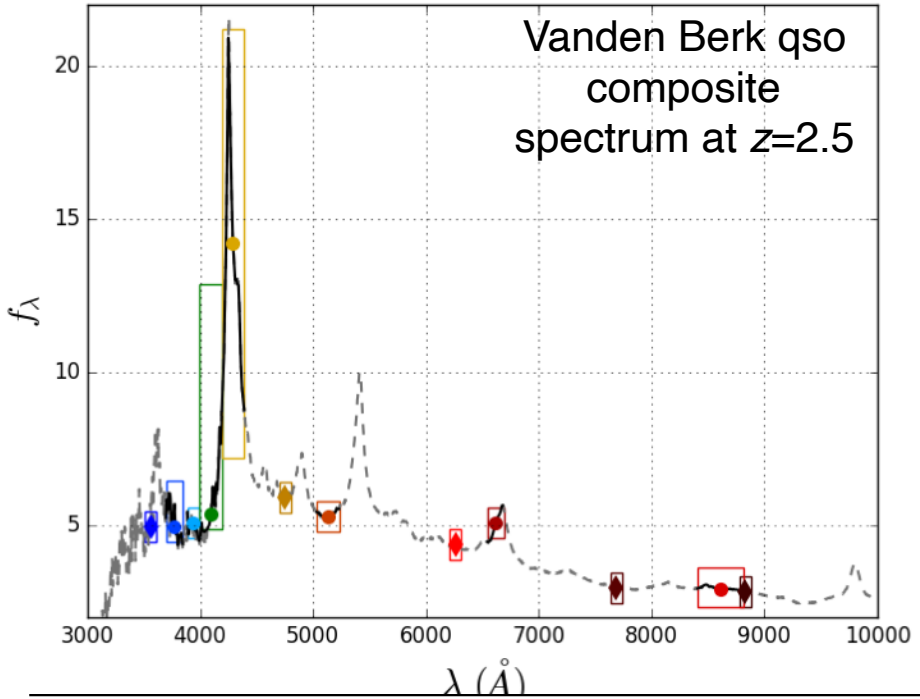
S-PLUS filter system



Main quasar emission lines at different redshifts

[Vanden Berk 2001; Mendes de Oliveira+19]

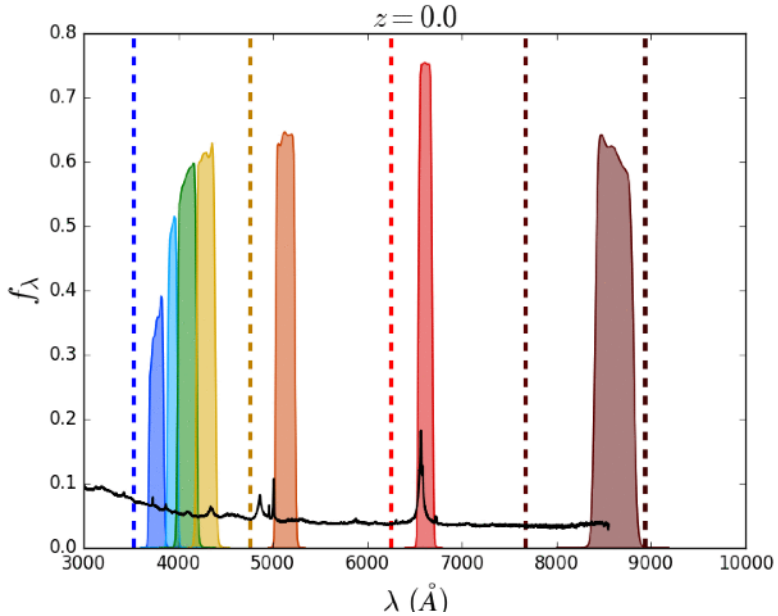
Quasar at different z's in the S-PLUS filters



[Vanden Berk 2001; Mendes de Oliveira+19]

Quasar at different z's in the S-PLUS filters

$$(1+z) = \frac{\lambda_{obs}}{\lambda_{em}}$$



Ly-α: 1215 Å
CIV: 1549 Å
MgII: 2799 Å
Hβ: 4862 Å
[OIII]: 4932-4960-5008 Å
Hα: 6564 Å

***Not taking into account Baldwin effect! [Baldwin 1977]**

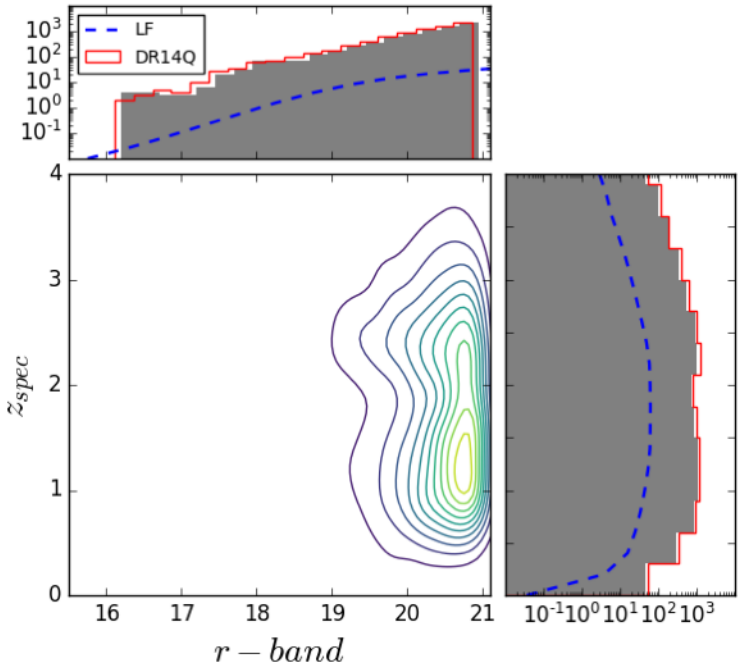
EXERCISE 2. Are the emission lines the same for all quasars? Is there a relationship between redshift and emission lines?
Identify suitable redshift ranges to observe quasar emission lines with the S-PLUS filters.

[Mendes de Oliveira+19; Palanque-Delabrouille+15; Pâris+18]

S-PLUS quasars: Stripe-82 as a test case

DR1: ~330 deg^2

1. DR14Q (Pâris+18): 526,356 qso spectra
2. 16,261 qsos in the S82 region with r<22
3. Cross-match with S-PLUS DR1 within 1 arcsec (e.g. Topcat): 15,582 quasars
4. PhotoFlag=0 & zWarning = 0: **8,042** quasars



PART II. Generating mock catalogs

Visual inspection!!!

Downloading spectra from SDSS: quick tutorial

- SDSS spectrum(*) identifiers: **plate - mjd - fiberID**
- Spectroscopic Query Form *([flux]=10^{-17} erg/s/cm^2/Å)
- SDSS Object Explorer : look for RA/dec; plate-mjd-fiberID
- SDSS SciServer/CasJobs : perform queries

http://dr14.sdss.org/sas/dr14/eboss/spectro/redux/v5_10_0/spectra**/lite/**4225/spec-4225-55455-0800.fits

EXERCISE 3. Plot the three given spectra and identify the quasar(s).

/exercises/exercise3.py

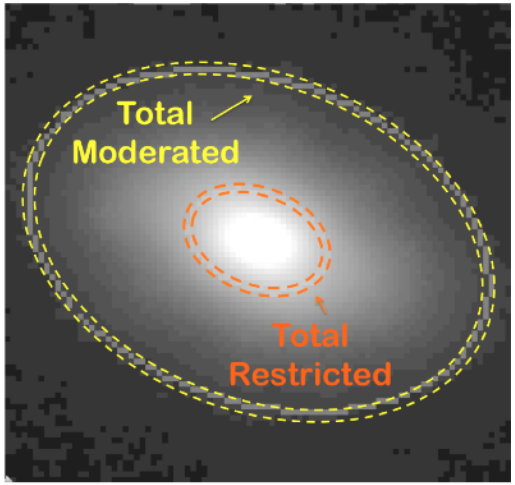
Creating mock catalogs

$$f_{a_q} = \frac{\int T_a F_q d\lambda}{\int T_a d\lambda}$$

- Useful even when we have observations: calibrate your data, test the performance of methods, increase training set for machine learning algorithms
- Standard approach: **(i)** convolve real spectra with transmission curves, **(ii)** find the expected noise in the catalog of observations (data set), **(iii)** add noise when necessary
- Important points: **(1)** # of objects; **(2)** realistic magnitude/redshift distribution

[Credit: Molino+17]

Creating mock catalogs: highlights



- Errors coming from a catalog with sorted observed mags

  select point-like sources from S-PLUS DR1 (CLASS=6)

  mag_aper (Circular-3arcsec-Diameter)

- **Important!** Shift the magnitude distribution to have realistic mocks

  e.g. luminosity function for quasars, Besançon model for stars

EXERCISE 4. Create a mock catalog of quasars in the S82 region, by convolving SDSS spectra with the S-PLUS filters. Assume that the quasars are distributed as in the DR1 catalog.

/exercises/exercise4.py

PART III. Photometric redshifts

Photometric quality

$$\sigma_z = \frac{\text{median}(\Delta z)}{1 + z_{spec}}$$

$$\sigma_{nmad} = 1.48 \times \text{median}\left|\frac{\Delta z - \text{median}(\Delta z)}{1 + z_{spec}}\right|$$

$$\eta(\%) : \left|\frac{\Delta z}{1 + z_{spec}}\right| > 2\ \sigma_{nmad}$$

$$b_z = \langle z_{photo} - z_{spec} \rangle$$

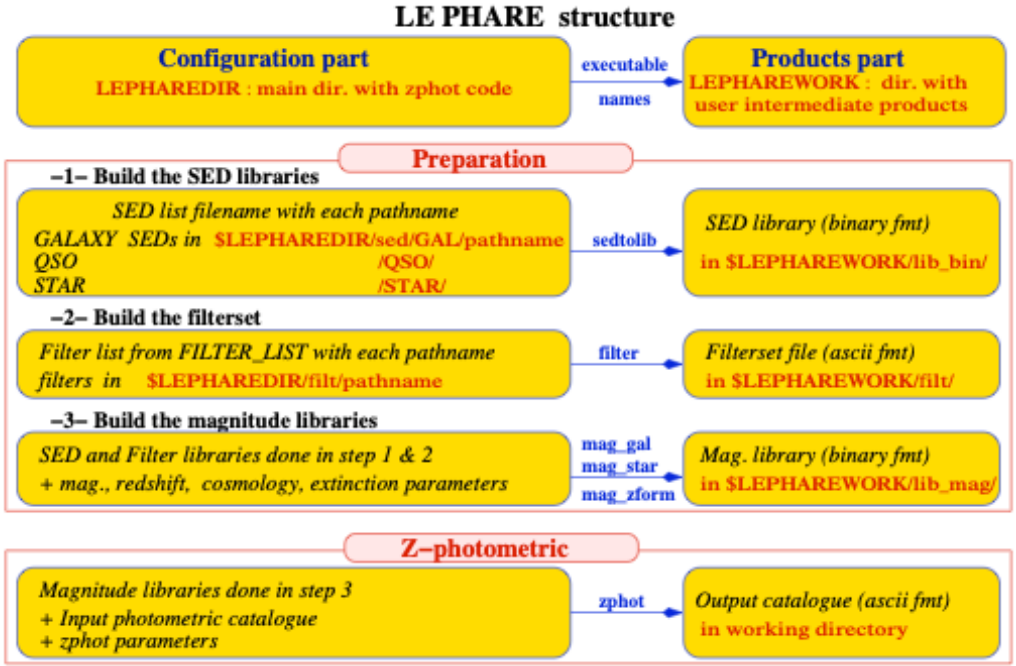
[Arnouts+99; Ilbert+06]

LePhare: photo-z's and SED fitting

- Spectroscopy vs. photometry
- Template fitting vs. machine learning
- LePhare: set of template SEDs (stars, galaxies, quasars) + filter set = model of magnitudes to determine the photo-z's using a chi-square minimization.

[Arnouts+99; Ilbert+06]

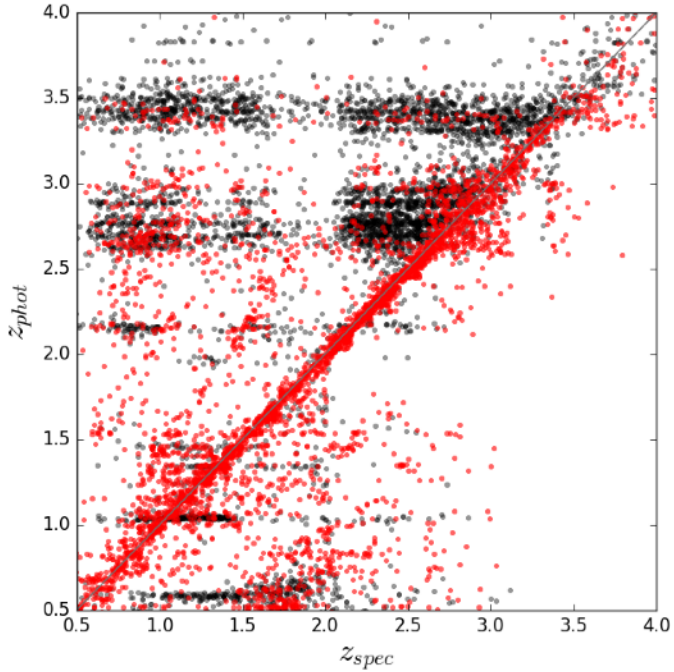
LePhare: photo-z's and SED fitting

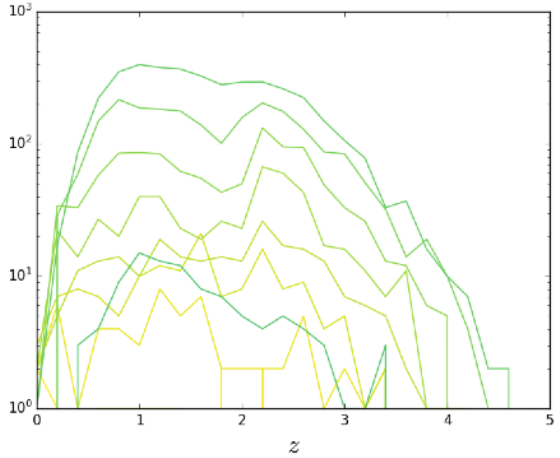


Adapted from Fig1 in LePhare documentation file

EXERCISE 5. As a quick start to photo-z codes, download and install LePhare. Try to run the example in $LEPHAREDIR/test.

S-PLUS: the role of the narrow-bands





Magnitude-redshift distribution as a prior

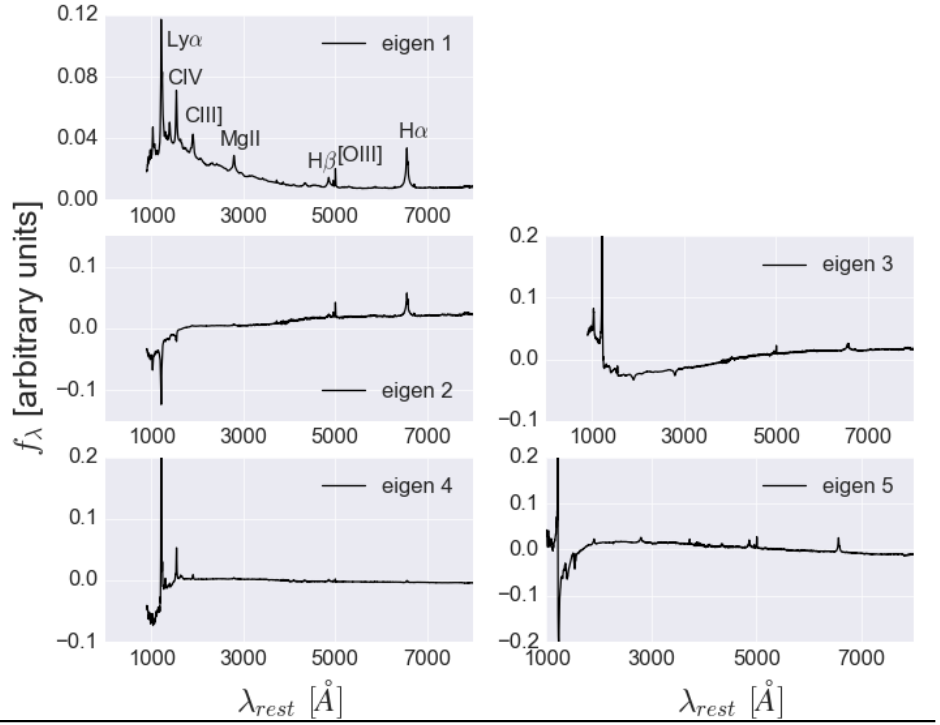
$$BB: \sigma_{nmad} = 0.50 \; ; \; \eta = 31\%$$
$$BB + NB: \sigma_{nmad} = 0.13 \; ; \; \eta = 9\%$$

[Yip+04; Abramo+12; CQueiroz et al. in prep.]

Photo-z estimation: the role of different components

Model the quasar fluxes through a linear combination of the amplitudes of the principal components of quasar spectra + reddening law:

$$F_\mu(z) = \sum_{n=1}^{5} c_n \xi_\mu^n(z) \left(\frac{\lambda_\mu}{5100}\right)^a$$



[Yip+04; Abramo+12; CQueiroz et al. in prep.]

Photo-z estimation: the role of different components

Model:

$$F_\mu(z) = \sum_{n=1}^{5} c_n \xi_\mu^n(z) \left(\frac{\lambda_\mu}{5100}\right)^\alpha$$

6D parameter space to explore

Shift eigenspec in *redshift* (up to *z*=6) and obtain

$\{c_n, \alpha\}$ at z_p that minimize:

$$\chi^2(z) = \sum_{\mu=1}^{N_f} \frac{[f_\mu - F_\mu(z)]^2}{\sigma_\mu^2}$$

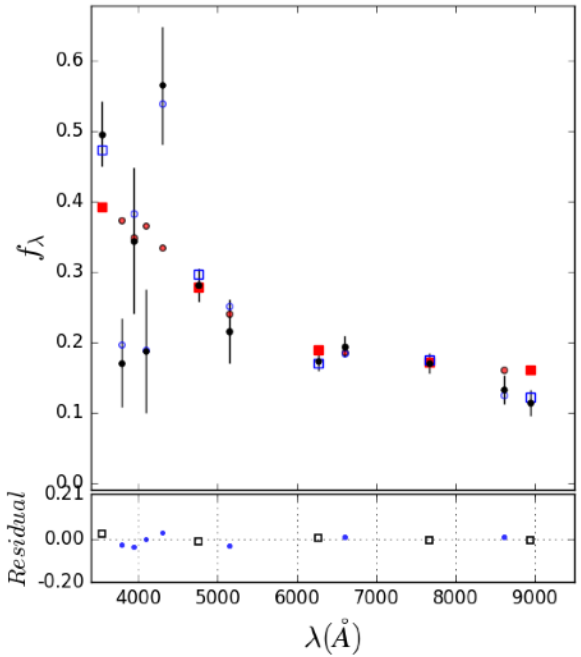
redshift probability distributions

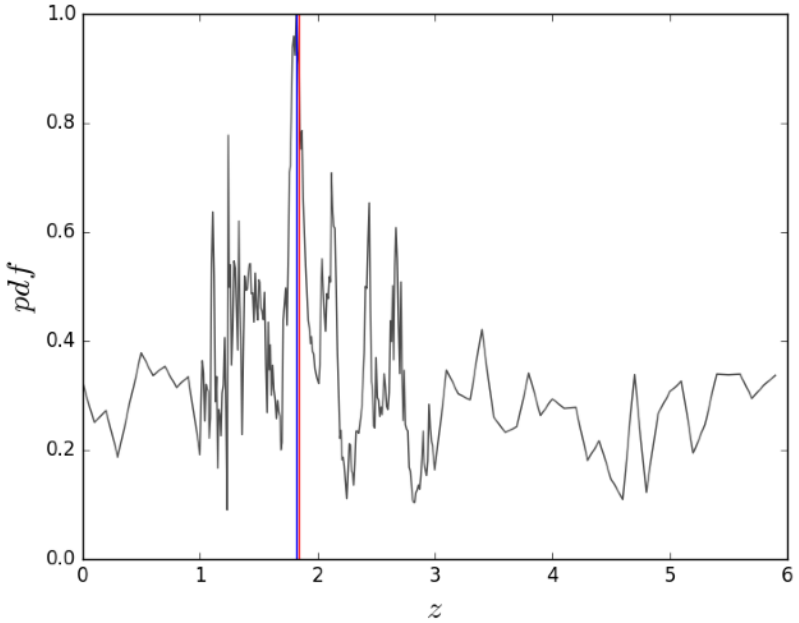
* α varies in [-1.5,1.5]; $\{f_\mu, \sigma_f\}$: observations

[Yip+04; Abramo+12; CQueiroz et al. in prep.]

Photo-z's: fitting and pdf(z)

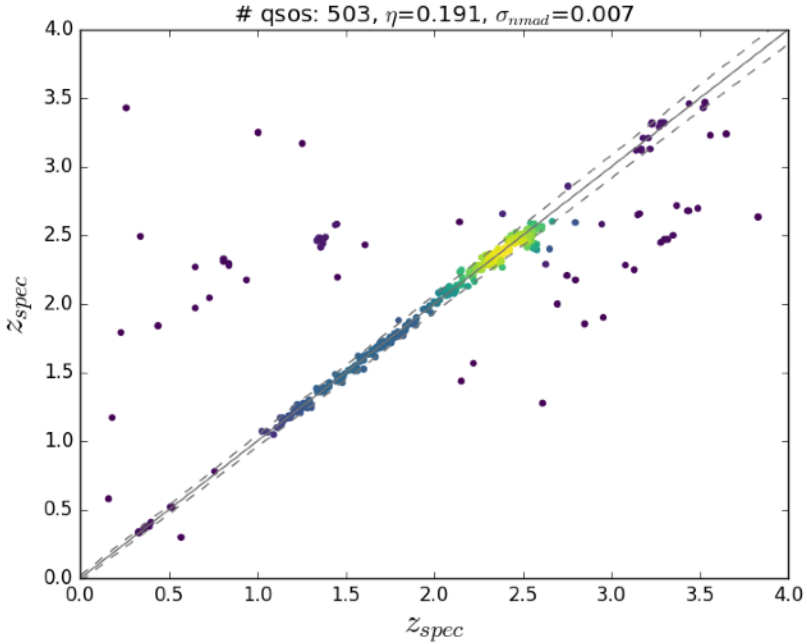
***zspec* = 2.35 / *zphot* = 2.39 / r=20.55**

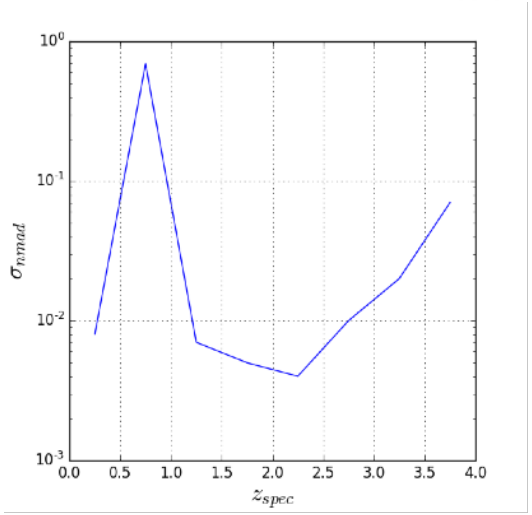




Photometric quality

$$odds = \frac{\int_{z_{peak}-1\sigma}^{z_{peak}+1\sigma} p(z)dz}{\int_{z_{min}}^{z_{max}} p(z)dz}$$





EXERCISE 6. Comparison between the photometric precision for S-PLUS quasars obtained with two different methods.

/exercises/exercise6.py

LET'S WORK!

TEST TIME

https://es.surveymonkey.com/r/J2BBGT3

FINAL REMARKS

Take-home lessons

- S-PLUS photometric system is suitable for quasar search
- Mock catalogs are a powerful tool, but it is important to take into account both the number of sources and their magnitude/redshift distribution
- Photometric redshifts are an essential tool in modern astronomy
- **This is just the DR1! Exciting future with quasar research & S-PLUS: stay tuned!**

¡Muchas gracias!