Near-IR through UV SEDs in SDSS Quasars

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Outline

- Introduction
- Cross-matching
- Mean SEDs
- Dust reddening
- Future work
- Conclusions

Introduction

- What are quasars?
  - Bright point source objects at high redshift
  - Emission comes from an AGN (super massive black hole)
  - Radiate light in all wavelengths

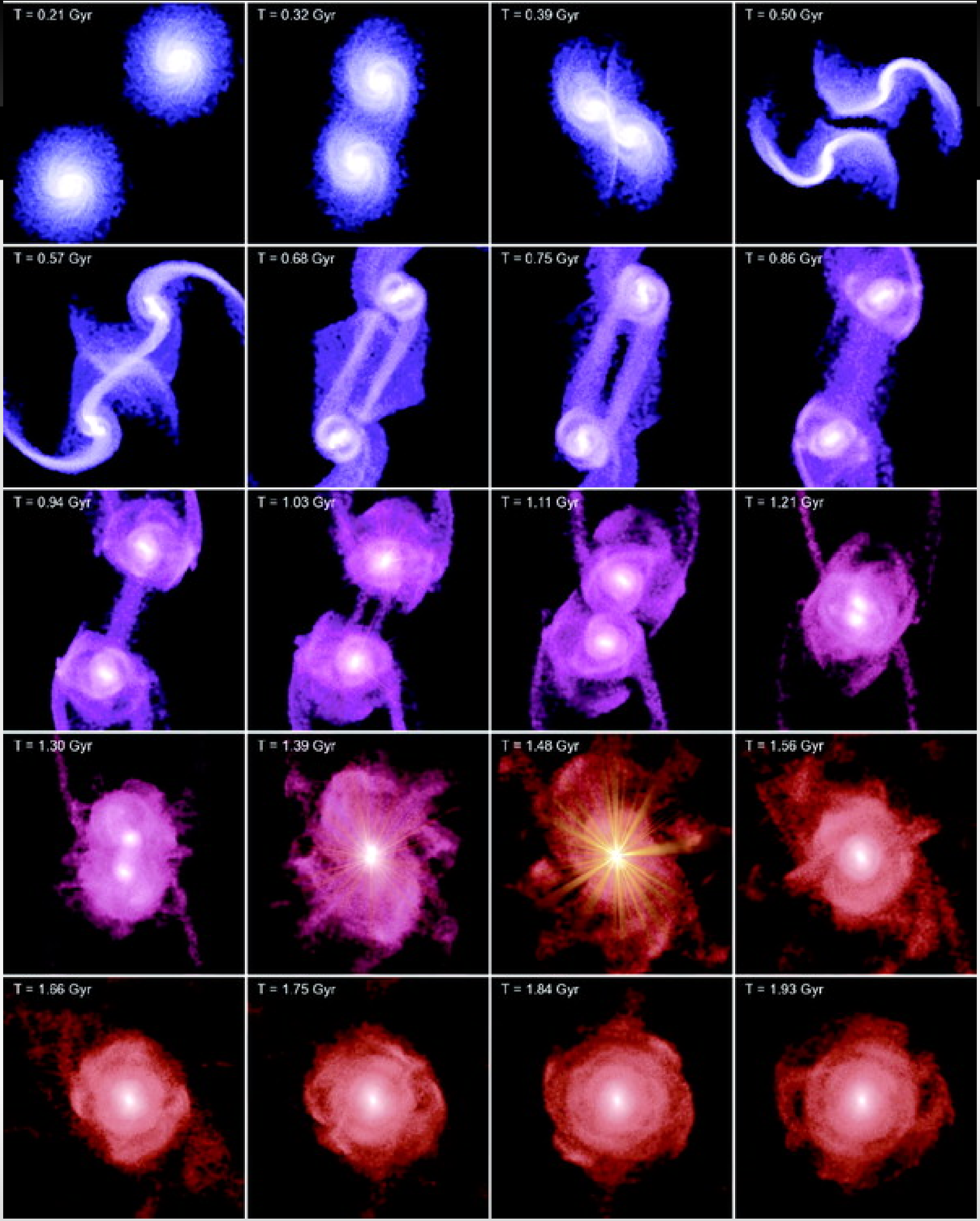
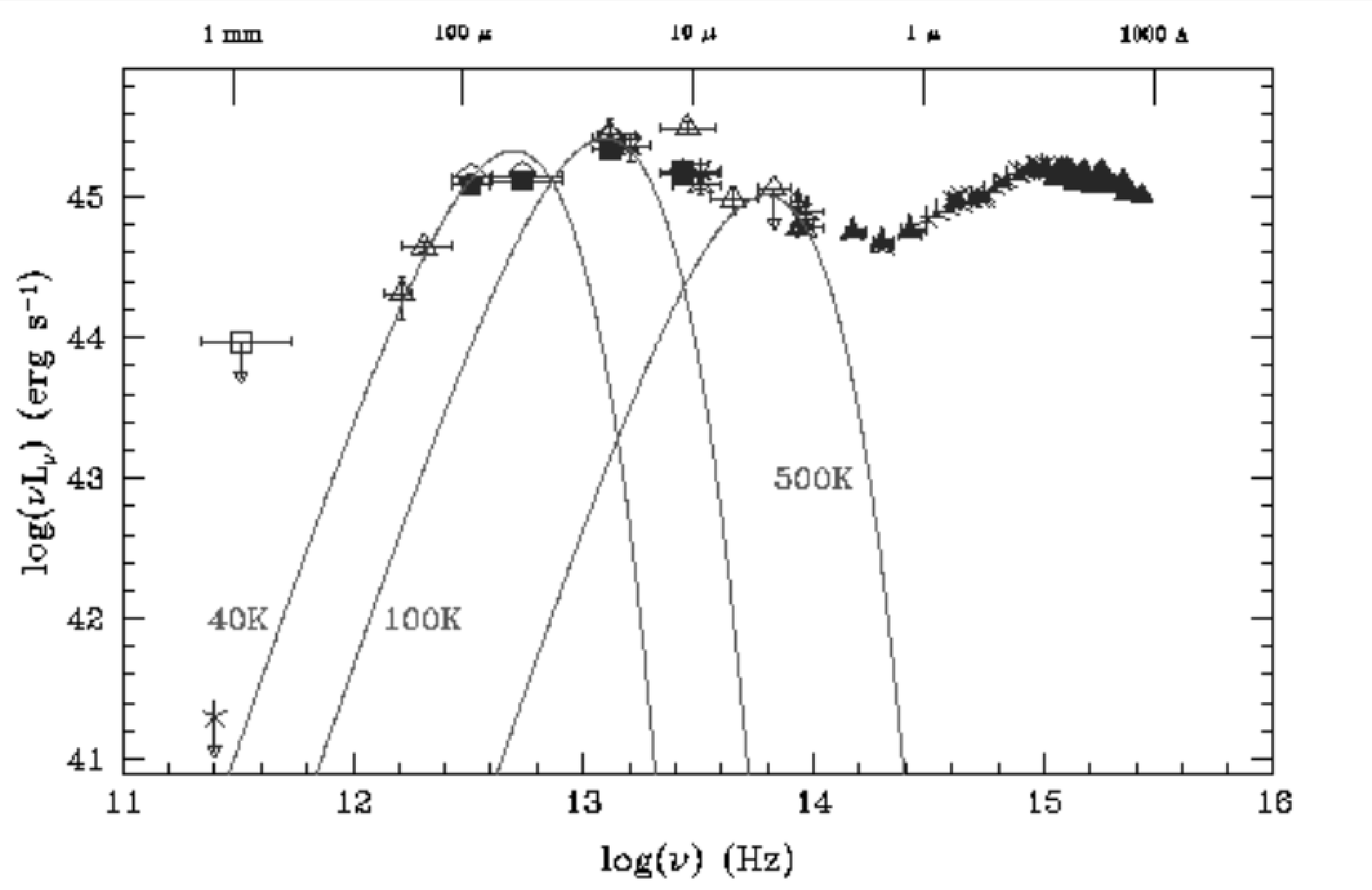


Image taken from Hopkins et al. 2006

Spectral Energy Distribution

- The SED is a plot of luminosity vs. frequency of light
  - This can give us clues into what happens in quasars
- So far components of a typical SED have determined physical drivers in each frequency regime:
  - Jets (radio)
  - Dust (IR)
  - Accretion disks (optical, UV, soft X-Ray)
  - X-ray corona (hard X-Ray)

Modified Blackbody



SED from PG1351+640 (Belinda J. Wilkes, 2004)

SDSS

- SDSS uses a CCD camera on a dedicated 2.5m telescope in New Mexico
- Obtains images in five optical bands, u, g, r, i, z (354nm, 475nm, 622nm, 763nm, 905nm)
- Covers over 10,000 deg^2 of high Galactic latitude sky
- From the 7th data release ~100,000 quasars have been identified

Cross-matching

- In order to construct SEDs that cover the entire spectrum the SDSS quasars must be matched to other surveys

- So far we have matched to two other surveys
  - 2MASS in the near-IR
  - *GALEX* in the near and far UV

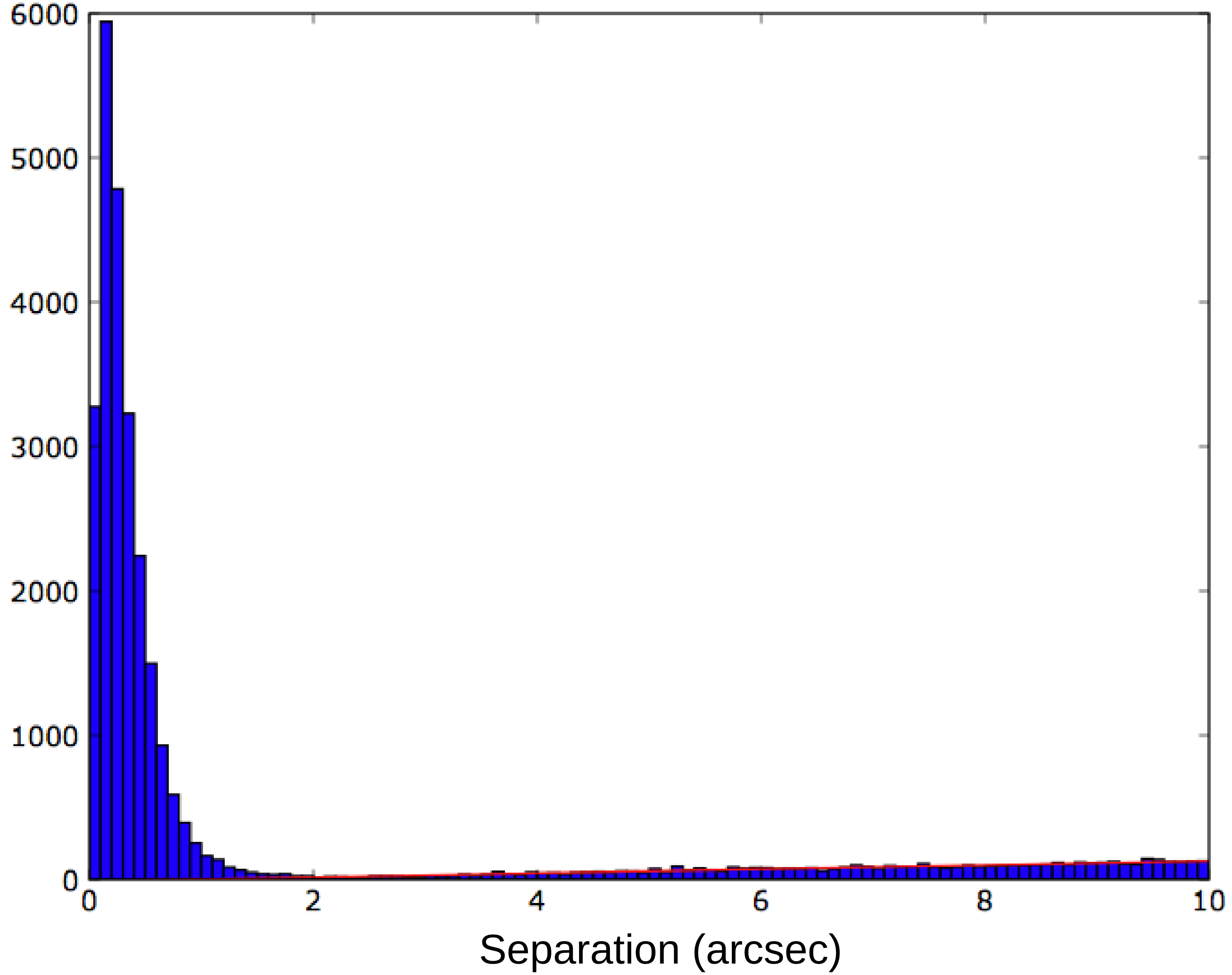
2Mass

- 2Mass used two dedicated 1.3m telescopes, one in Arizona the other in Chile
- It covered 99.998% of the celestial sphere in three near-infrared bands, J, K, H (1.25μm, 1.65μm, 2.16μm)
- All point sources with a S/N>5 were compiled into a single searchable online catalog

Nearest Neighbor Matching

- Idea: take any point source whose position falls within some matching radius of the SDSS quasar as a match
- This works well if the angular resolution and flux limits are similar in the two surveys
- To find the ideal matching radius we make a histogram of separation distances between objects in the two surveys

Separation Histogram



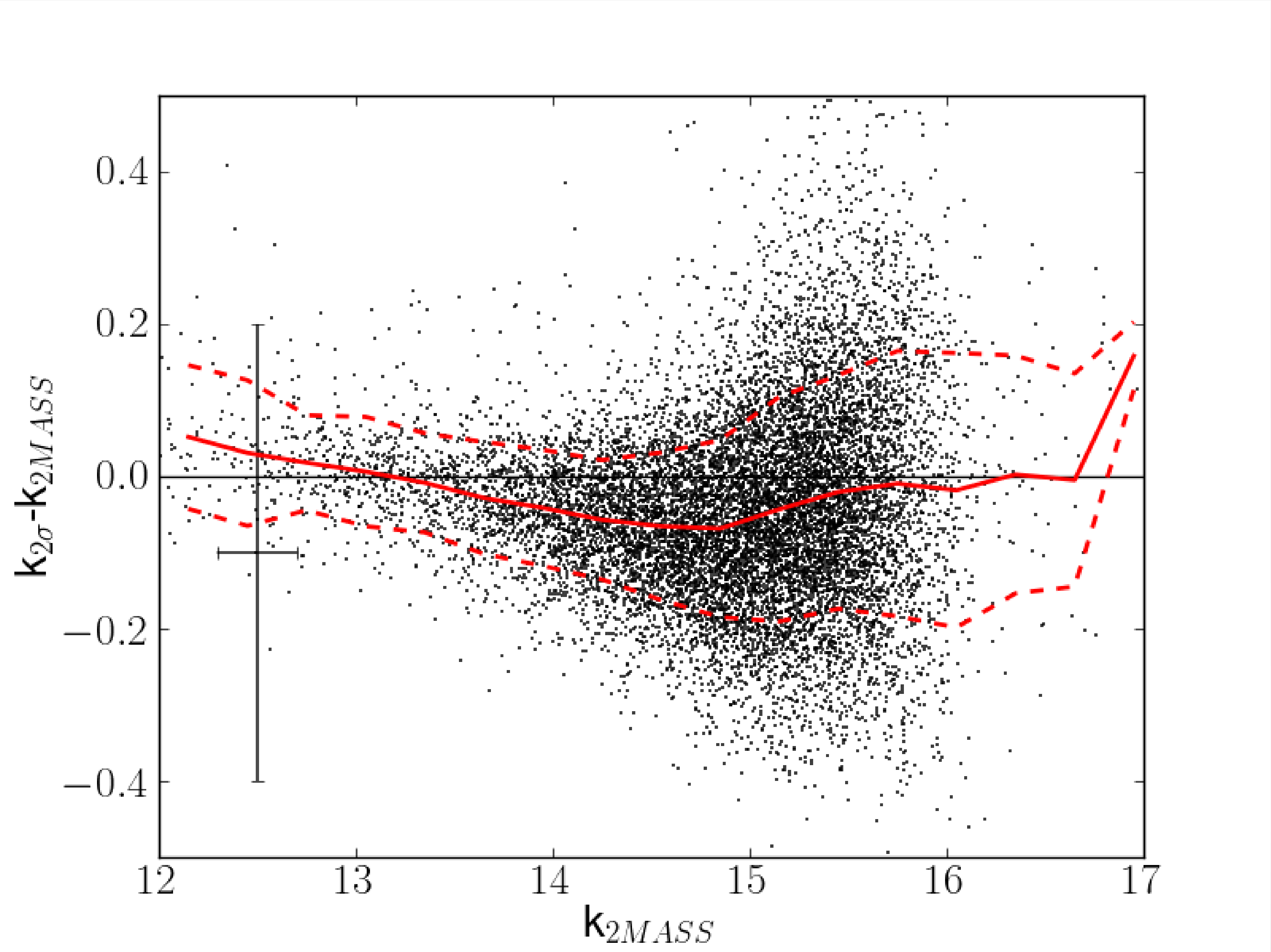
Matches

- Using a matching radius of 2” resulted in 13,930 matches
- The 2MASS catalog only contains objects with a S/N > 5, but since accurate positions are already known for the quasars, it was possible to extract photometric data down to S/N ~ 2

Extraction

- Standard aperture photometry was performed on all SDSS quasar positions
  - A 2” radius aperture was used, following the procedure outlined in Gallagher et al. (2007)
- This resulted in an additional 39,646 matches
- To test the accuracy of our algorithm, the photometry was also performed on the matched quasars

Extraction vs. Catalog



GALEX

- The *Galaxy Evolution Explorer* is a space based telescope
- It collects photometric data in two UV wave bands
  - NUV 153.9 nm
  - FUV 231.6 nm
- Cross matching was performed by Budavári et al. (2009)
  - This contains 36,251 clear matches

Definitions

- Flux:
  - Number of photons per unit time per unit frequency per unit area received at detector
- Luminosity:
  - Number of photons per unit time leaving the source per unit frequency
- Magnitude:
  - $m = -2.5*\log(f/f_0)$
- Color:
  - Difference in two magnitudes

Distance correction

- What is measured is a magnitude and what we want is a luminosity, to convert we use:

$$f = \frac{L}{4\pi D_L^2(z)}$$

- D_L = luminosity distance to source

Move to log space

- Quasar SEDs are plot as log(vL) vs. log(v)
  - In the quasars rest frame
- To move to the rest frame:

$$\nu = \nu_{obs}(1+z)$$

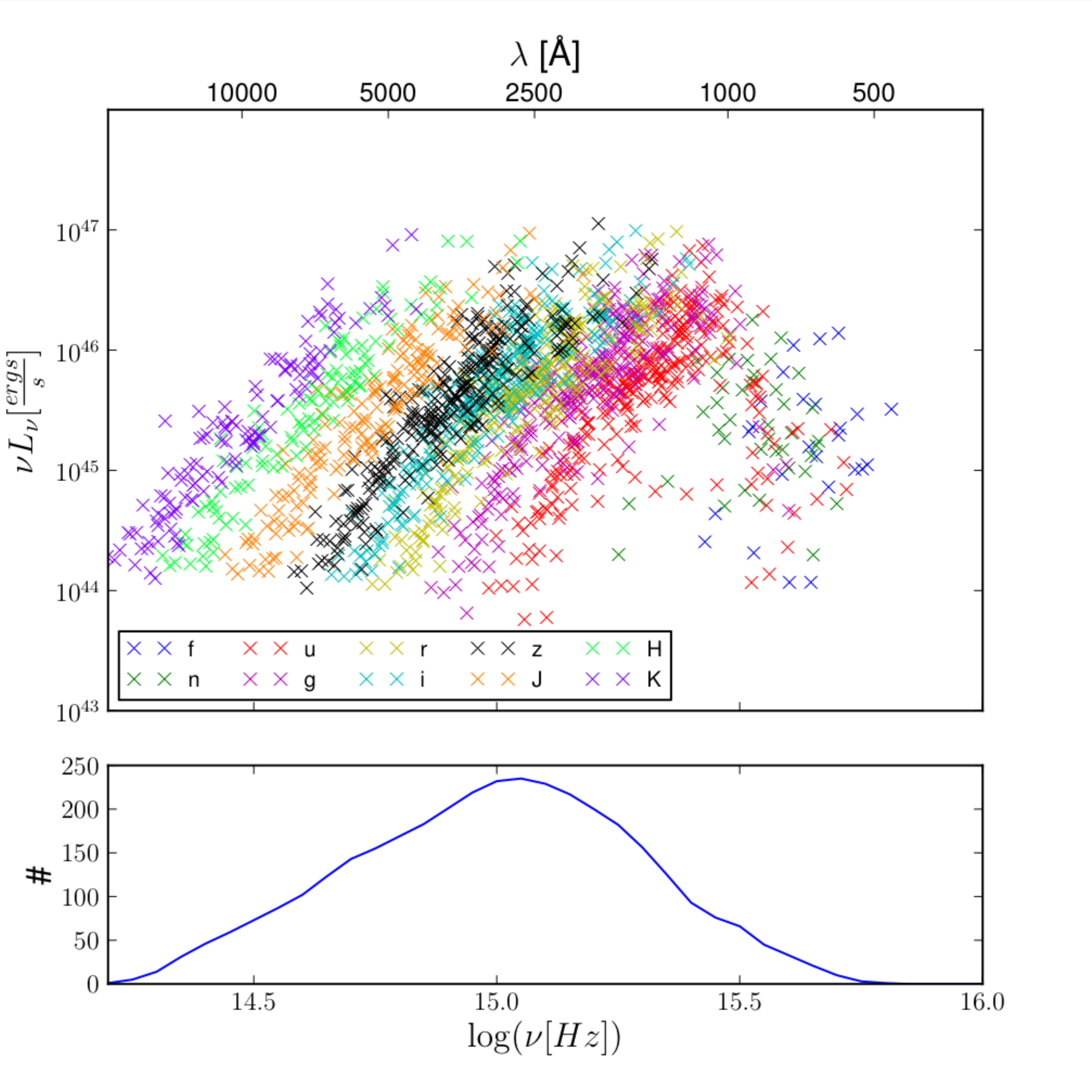
- Rearranging the luminosity equation:

$$\log(\nu L_\nu) = \log(4\pi D_L^2) + \log(\nu_{obs}) + \log(f)$$

- Or convert to magnitudes

$$\log(\nu L_\nu) = \log(4\pi D_L^2) + \log(\nu_{obs} f_0) - \frac{m}{2.5}$$

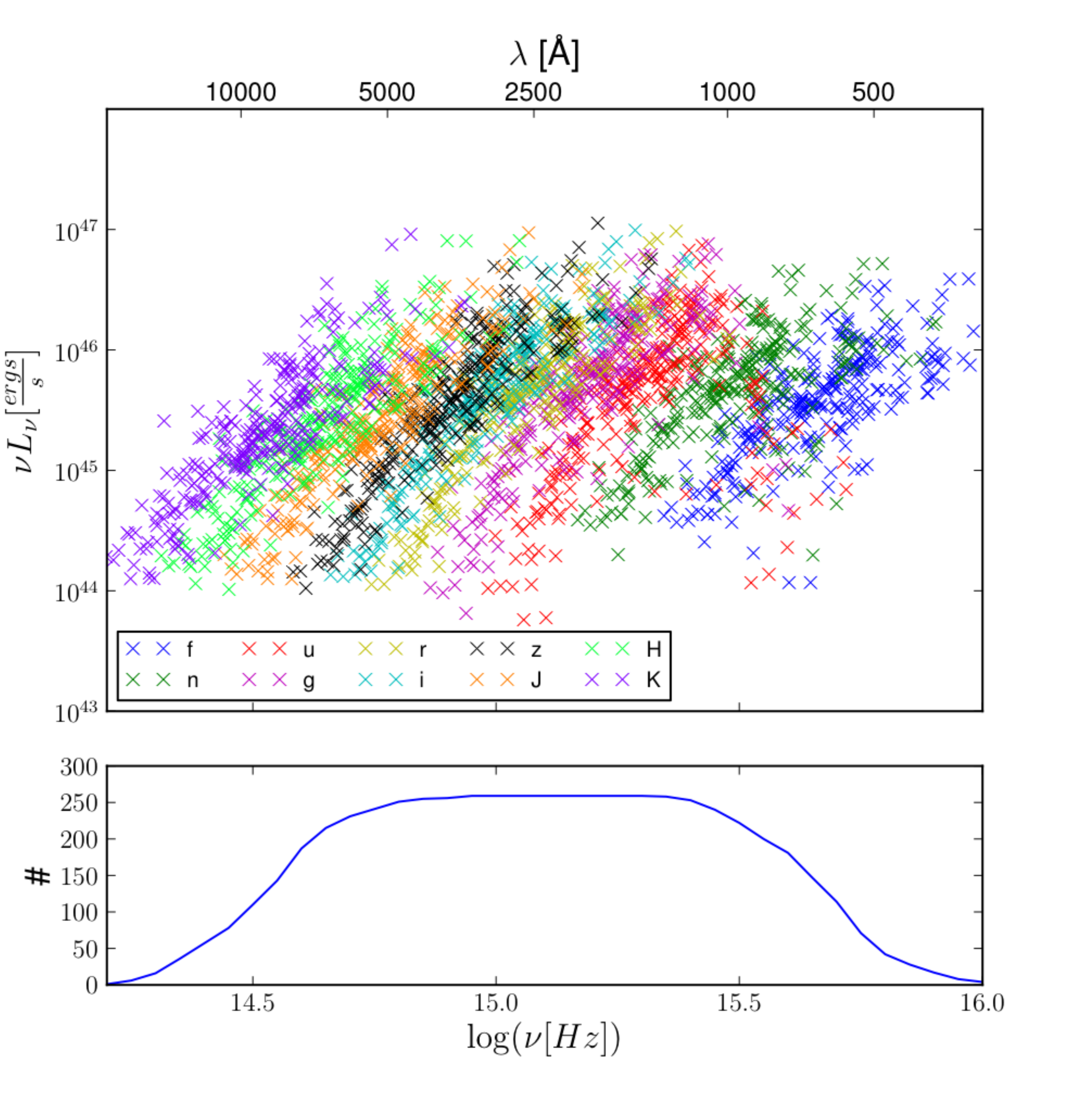
SEDs for 259 Quasars



Gap filling

- To compare this data with that of Richards et al. (2006) we perform gap filling
  - First we find the best fit model
    - Model used: Elvis 1994
  - Then we fill in any filter that had no detection with the model's value

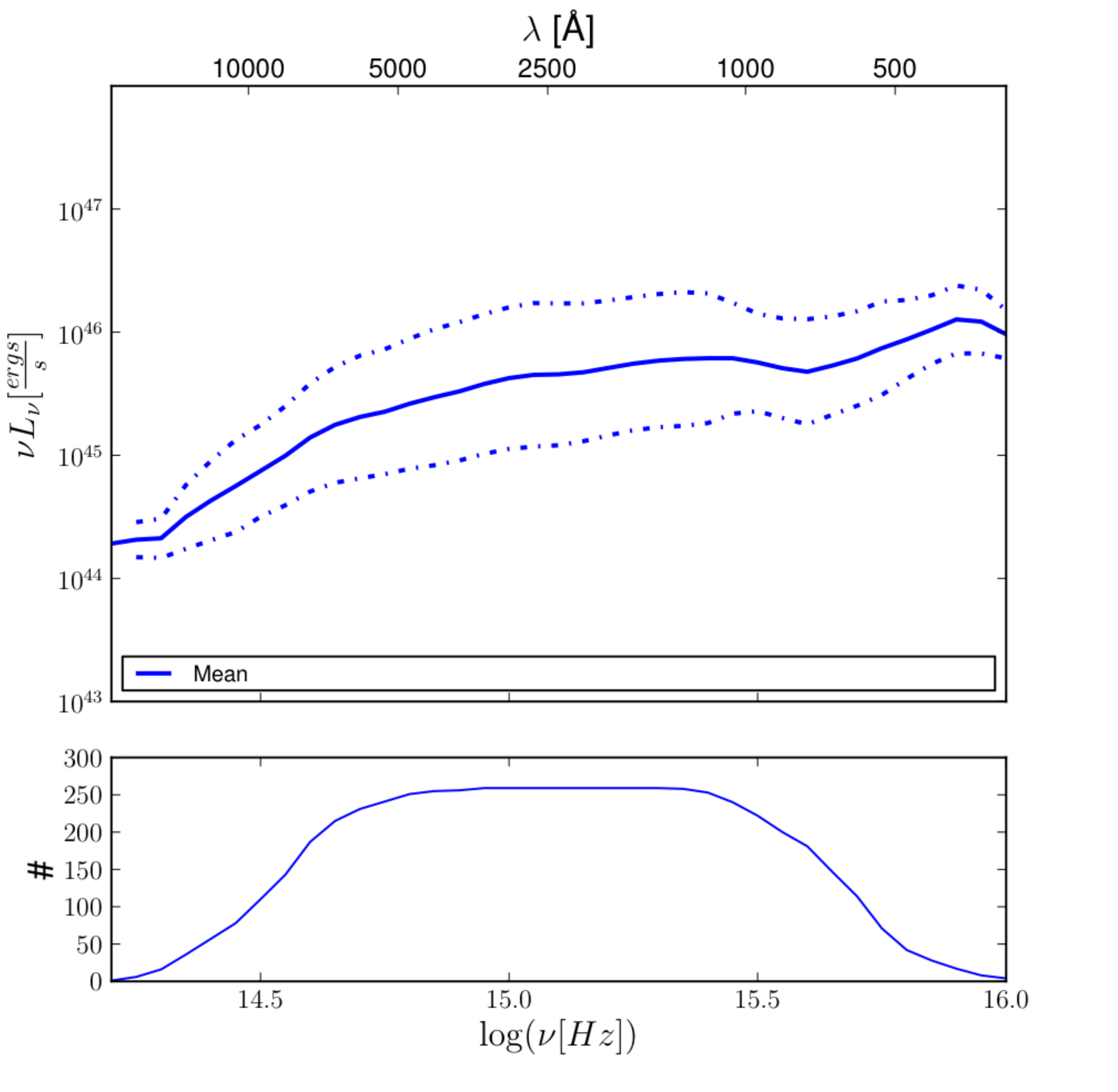
SEDs for 259 Quasars Gap Filled



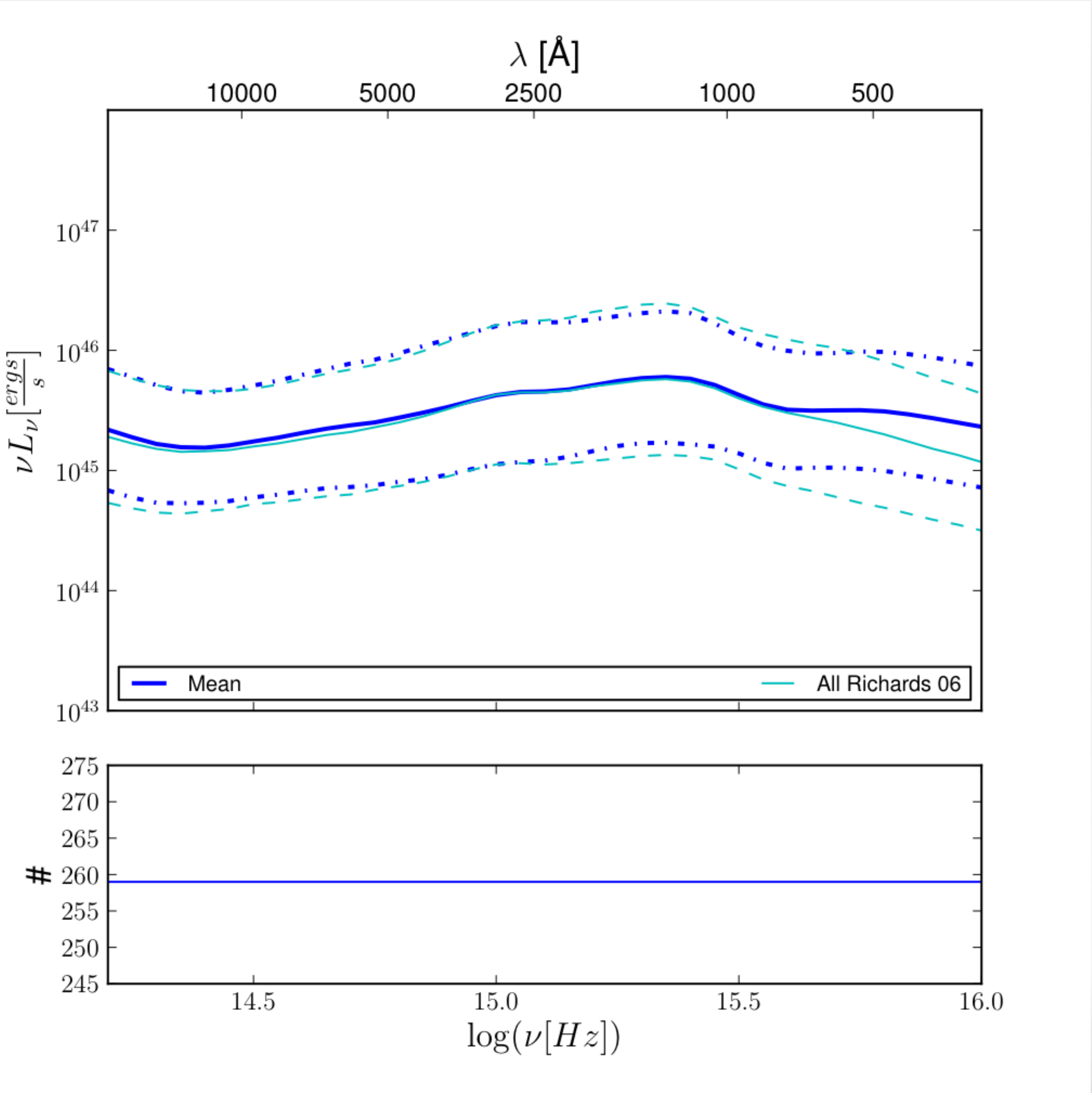
Extrapolation

- The quasars with the highest luminosities also have the highest redshifts
  - This causes the mean SED to have kinks
  - At low frequencies it will be too low
  - At high frequencies it will be too high
- To Fix this the Elvis model is again used to fill in the SEDs over then entire range of frequencies

Mean Before Extrapolation



Mean After Extrapolation



Lyα Forest

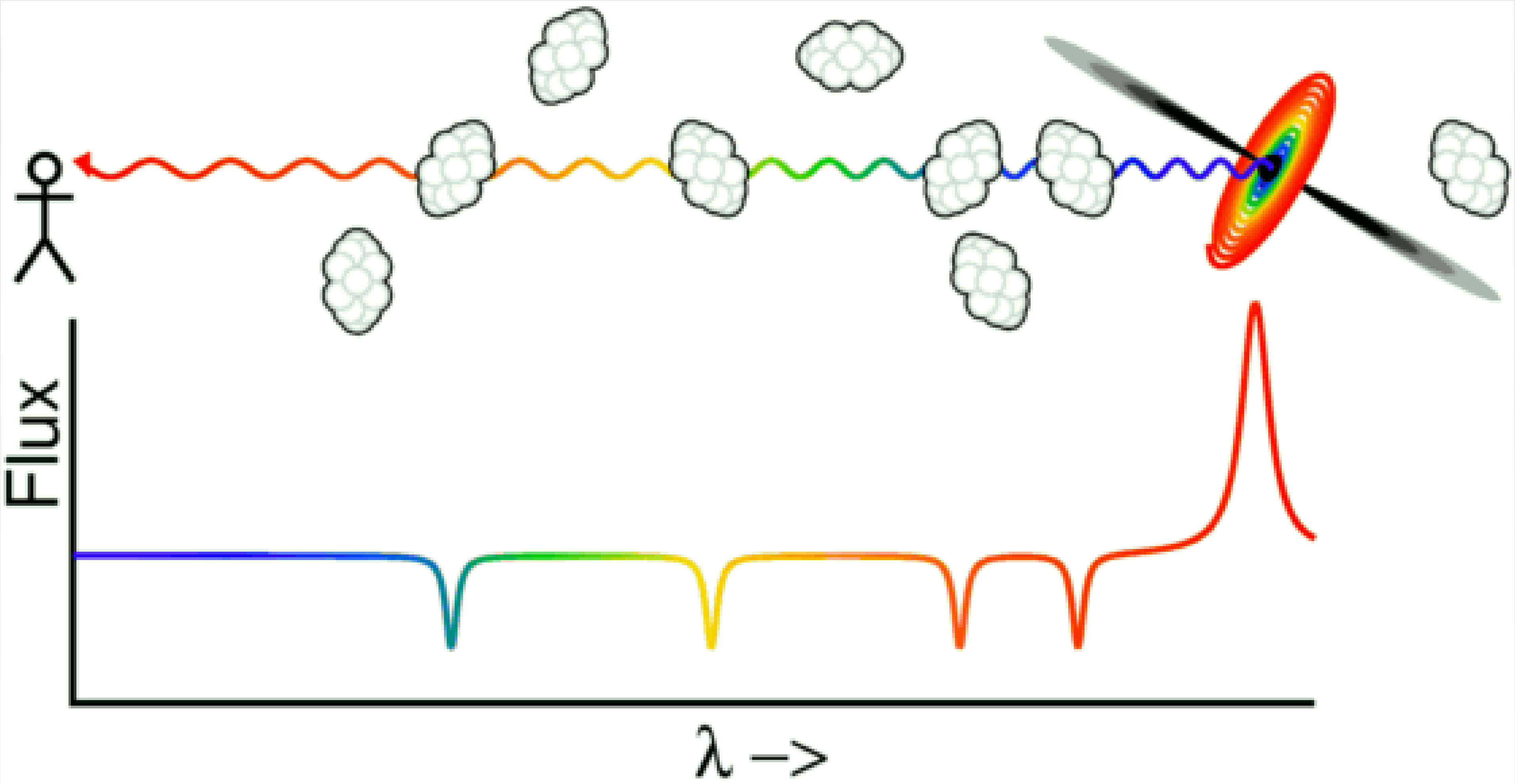


Image made by Edward L. Wright:
http://www.astro.ucla.edu/~wright/Lyman-alpha-forest.html

Lyα Forest

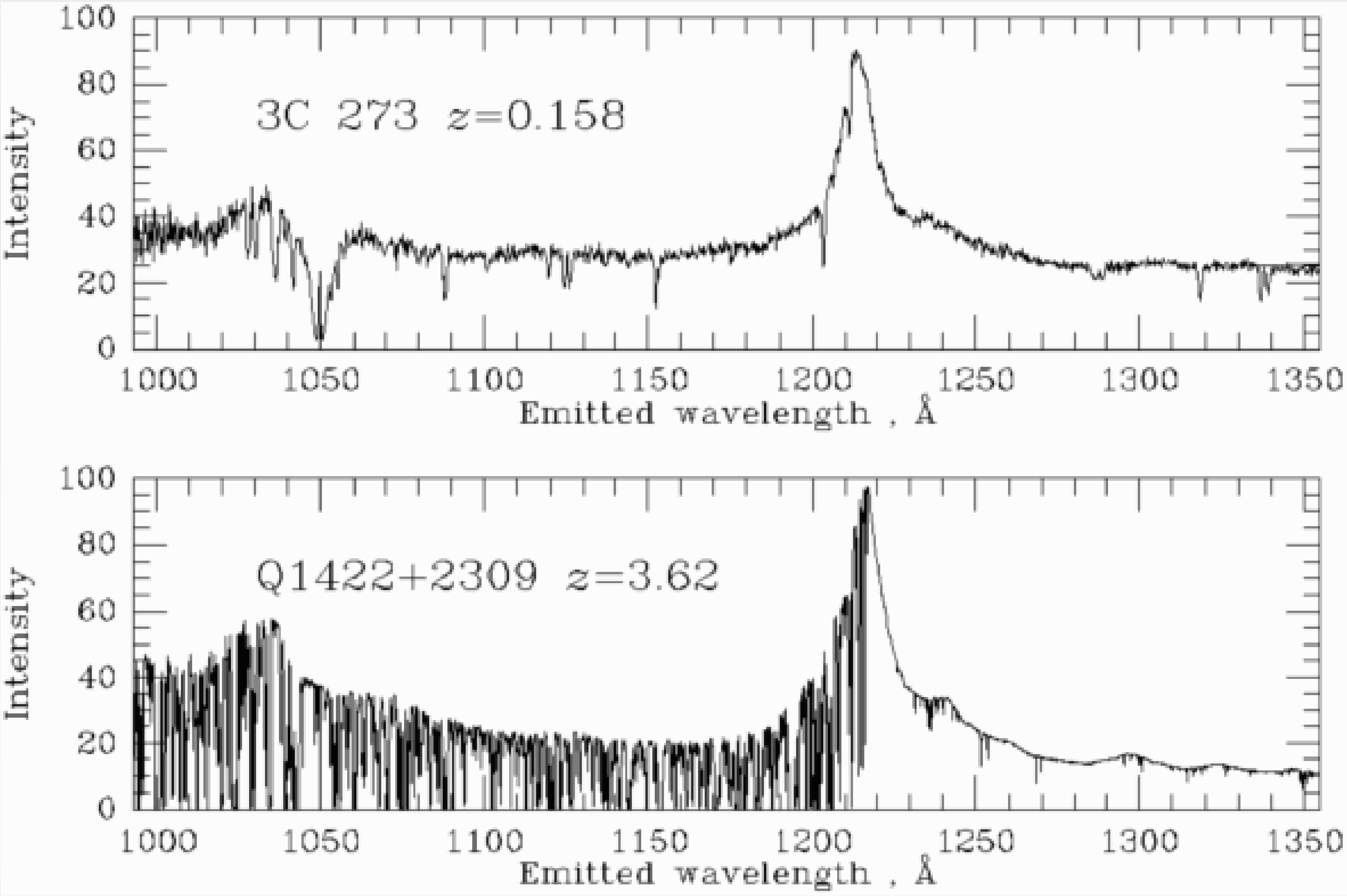
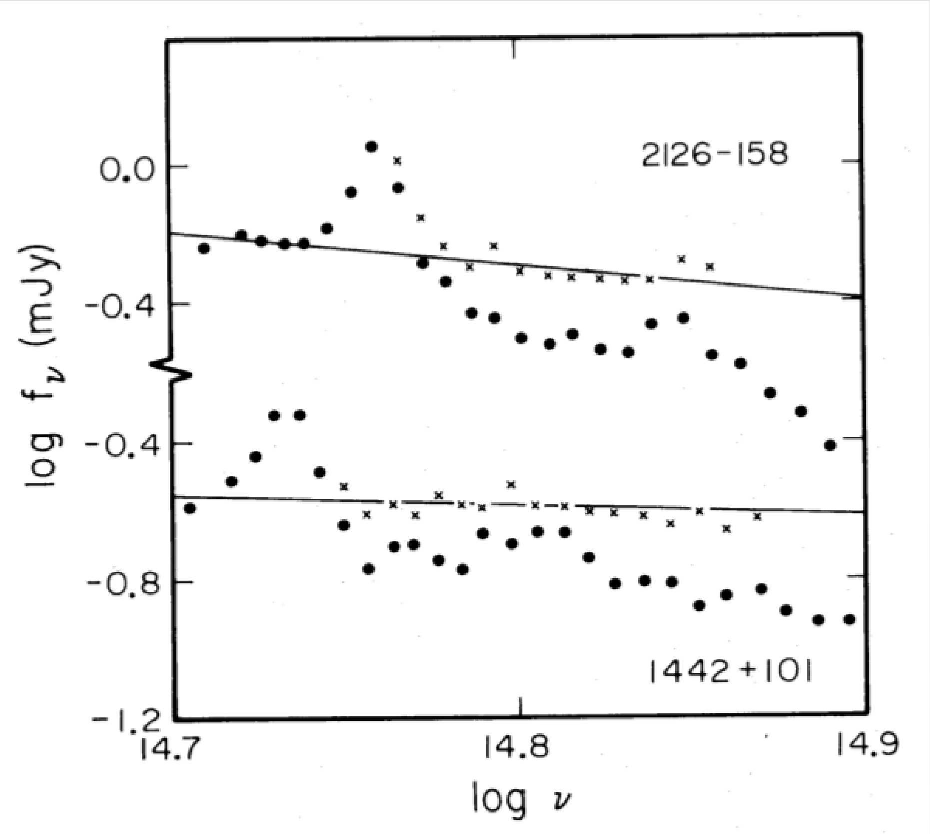


Image made by Edward L. Wright:
http://www.astro.ucla.edu/~wright/Lyman-alpha-forest.html

Lyα Forest Correction



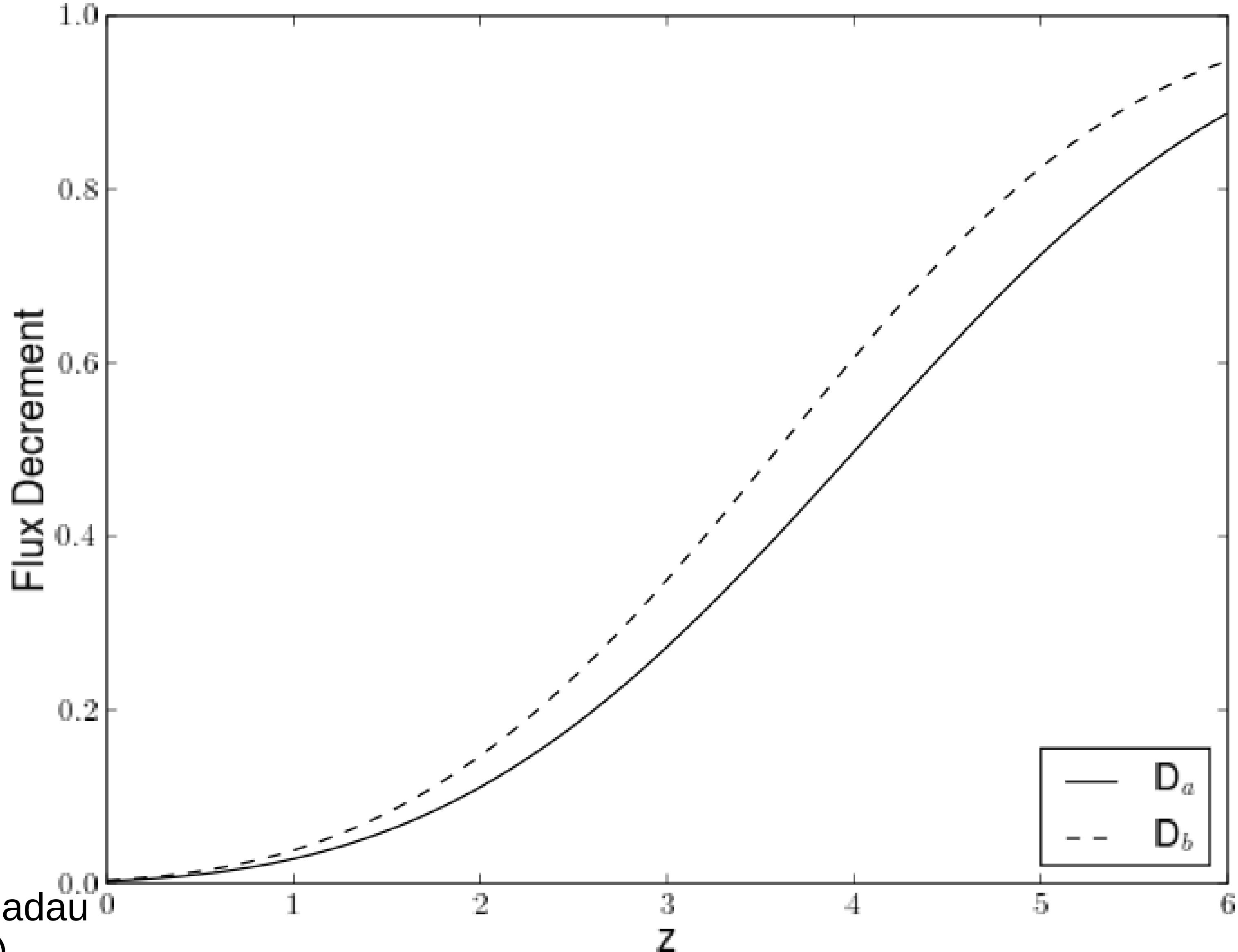
Oke et al. 1982

- This can be corrected using D_a:

$$D_a = \langle 1 - \frac{f_{obs}}{f_{cont}} \rangle$$

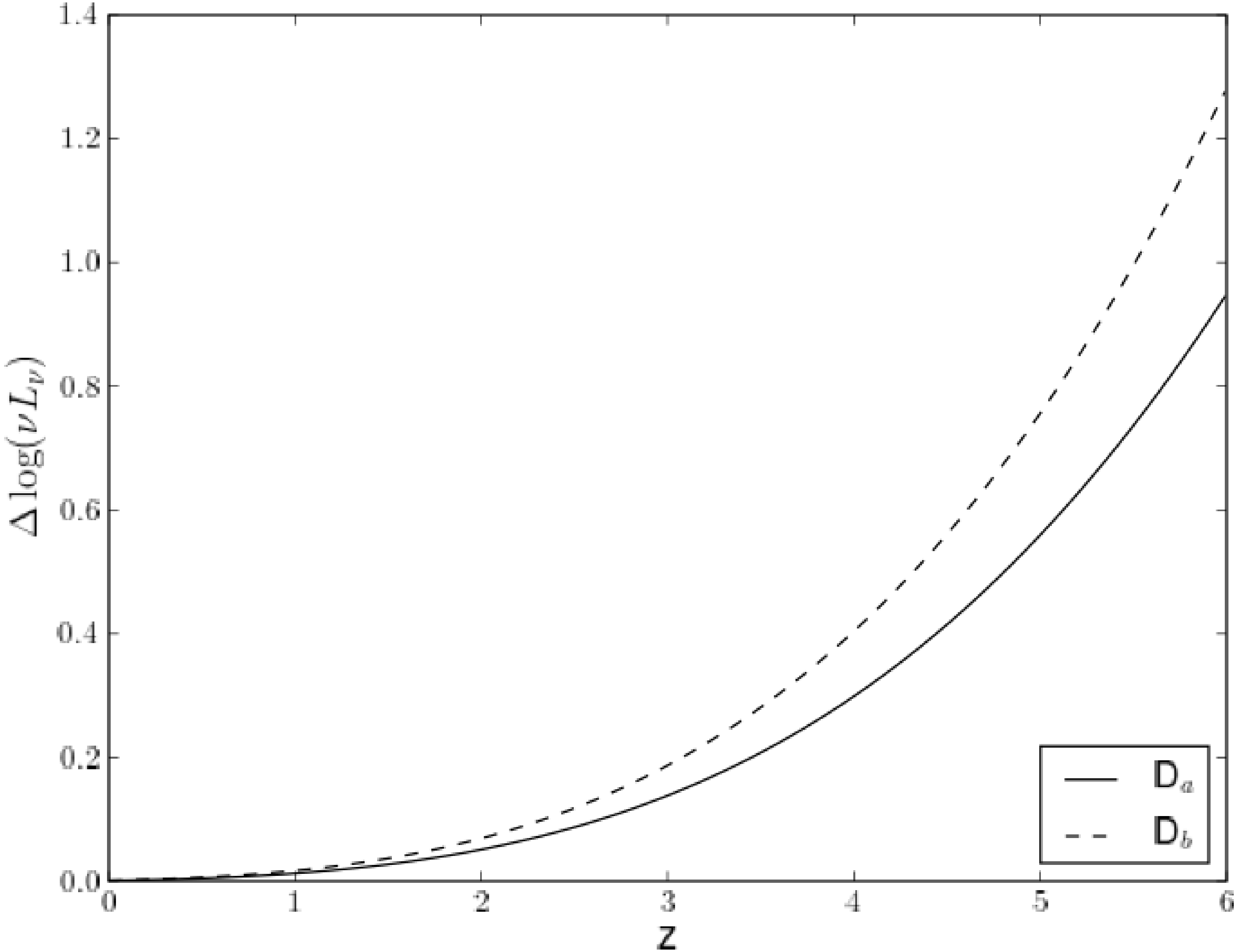
- This is used between Lyα and Lyβ
- D_b is used between Lyβ and the Ly limit

D_a and D_b Models



Model by Madau et al. (1995)

How this Changes SEDs



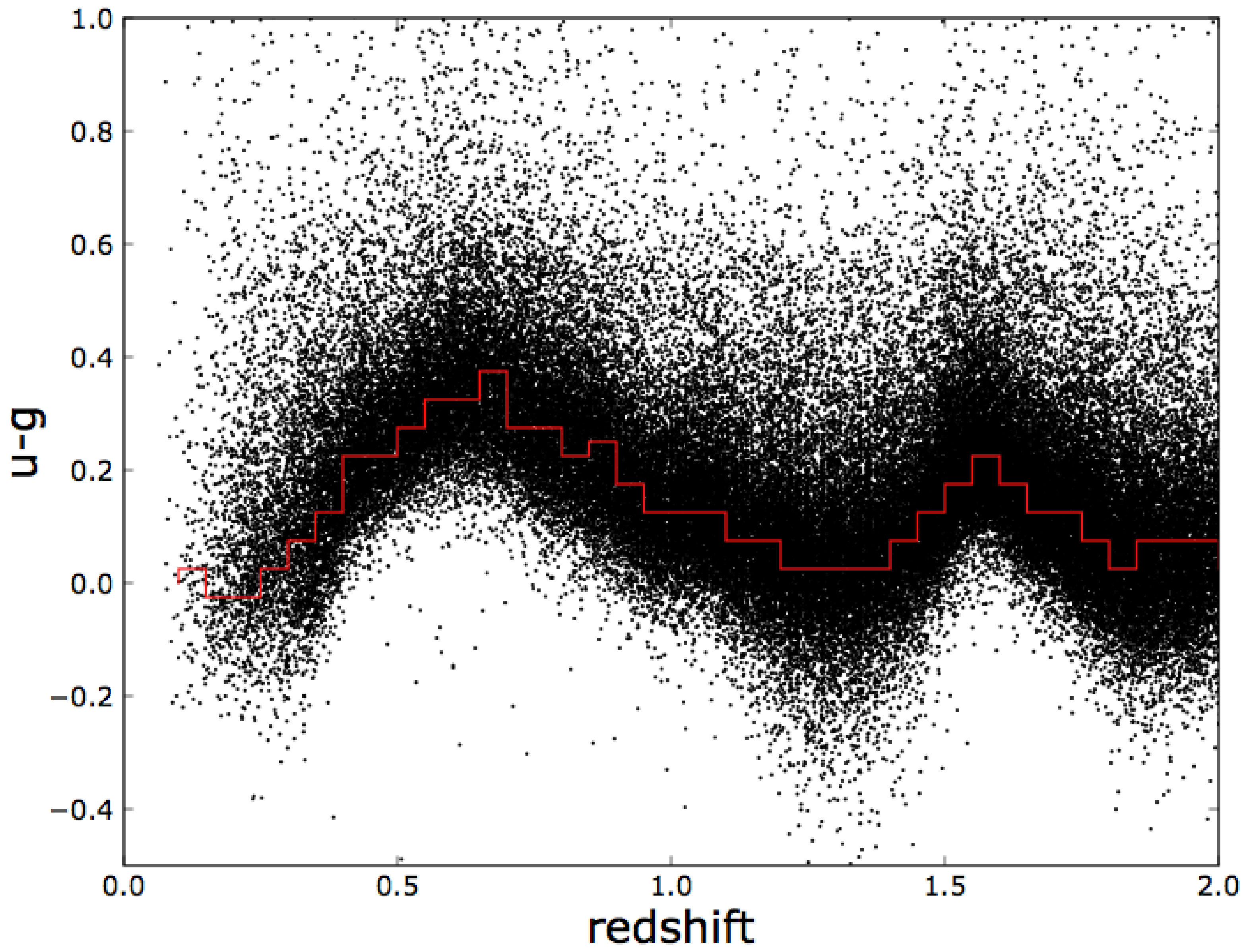
Dust reddening

- To be able to compare quasar feedback models to data it is important to know how much of the color variation is intrinsic and how much is due to dust
- This is done by comparing a relative SED to a power-law
  - Intrinsically red quasars will be well fit by a line
  - Dust reddened quasars will be well fit by a quadratic

Relative Colors

- Because of spectral lines being redshifted into the different filters quasar colors will show a trend as a function of redshift
- The mode of this trend is found and subtracted off of the SED
  - This makes the typical quasar SED be zero in all filters
  - These relative SEDs are then fit and the slope and curvature are found

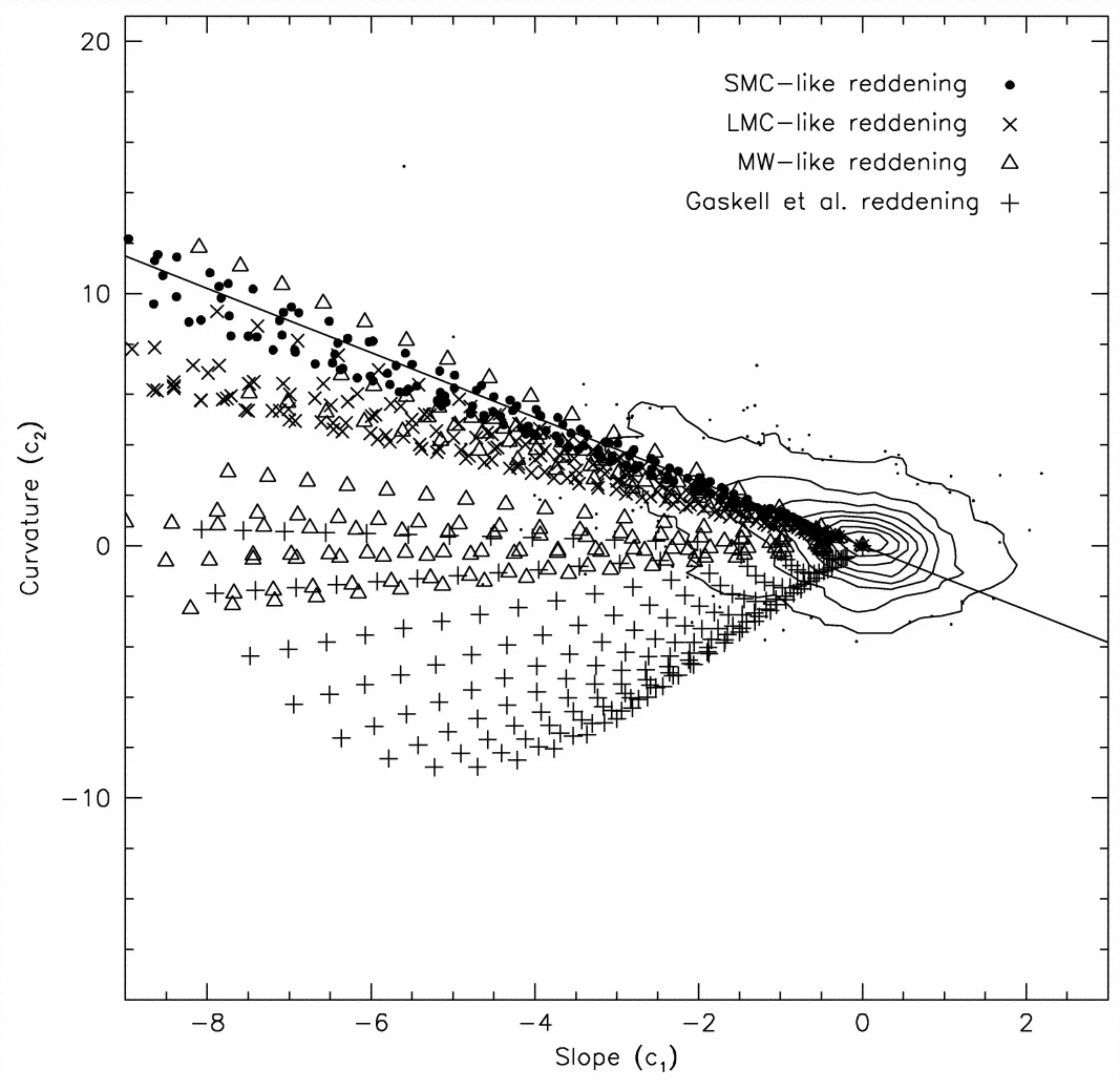
u-g Color vs. Redshift



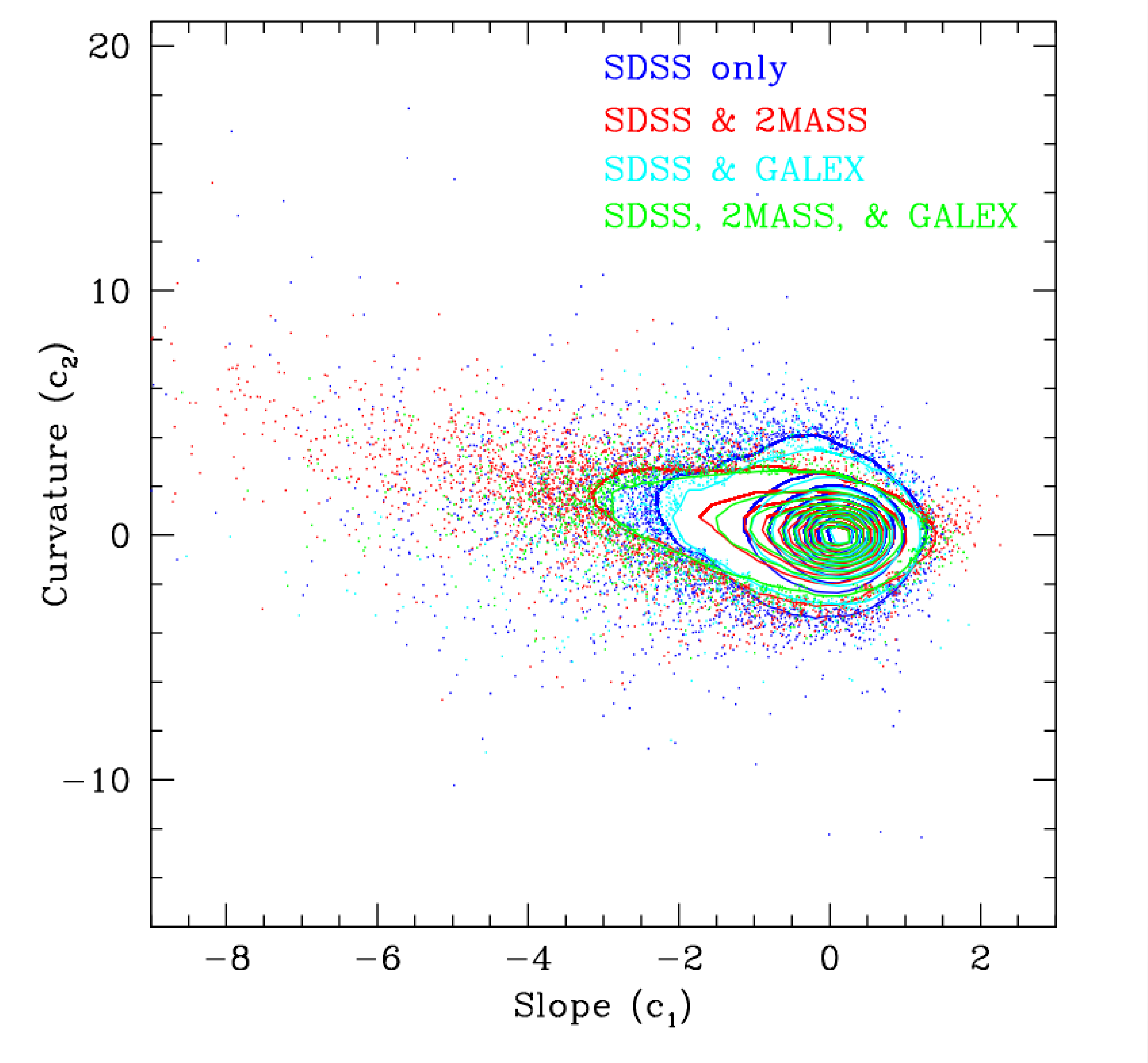
Kinds of Dust

- By plotting the slope vs. curvature the kind of dust can be determined
- Hopkins et al. (2004) did a similar study using ~2,000 quasars
- They made models for 4 kinds of dust
  - Small Magellanic Cloud-like (SMC)
  - Large Magellanic Cloud-like (LMC)
  - Milky Way-like (MW)
  - Gaskell et al. (2004)-like

What Hopkins Found



What We Found using 88,200 Quasars



Future Work

- Expand SEDs into the mid-IR using *Spitzer*
  - Remove host galaxy contribution
- Find more *GALEX* matches
  - Perform *GALEX* extraction
- Calculate bolometric corrections

Conclusions

- Cross-matching
  - 2MASS: 53,576
  - *GALEX*: 36,251
- Mean SEDs
  - Distance correction
  - Gap filled
  - Mean matches well with Richards et al. (2006)
  - Lyα correction
- Dust reddening
  - SMC/LMC-like

Thank You
Any questions?