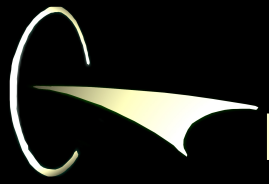

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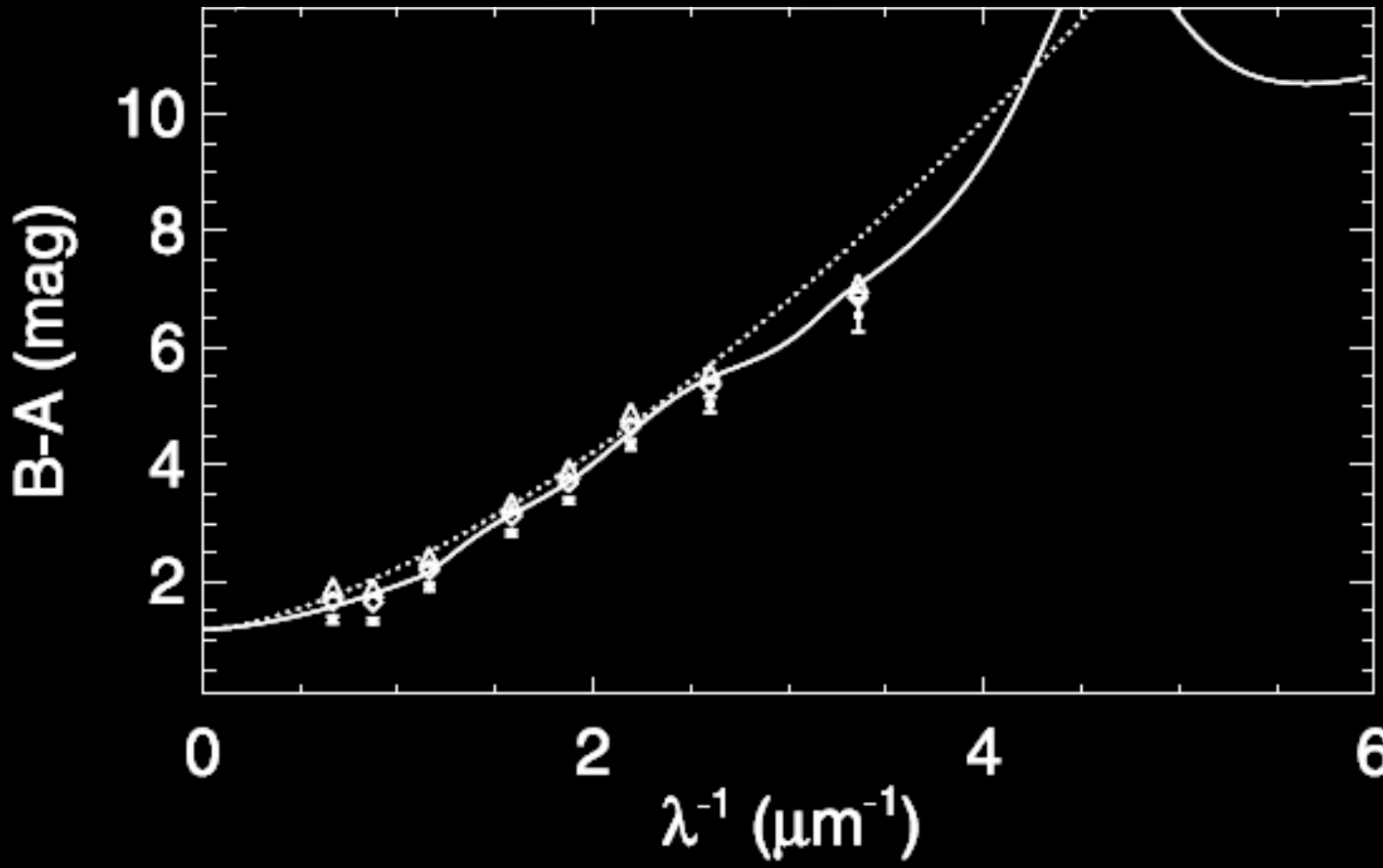
Danmarks Grundforskningsfond
Danish National Research Foundation

DUST EXTINCTION IN HIGH-REDSHIFT QUASARS

Jens Hjorth
Dark Cosmology Centre (DARK)
Niels Bohr Institute
University of Copenhagen

Measuring cosmic extinction: multiply imaged QSOs



Elíasdóttir et al. 2006

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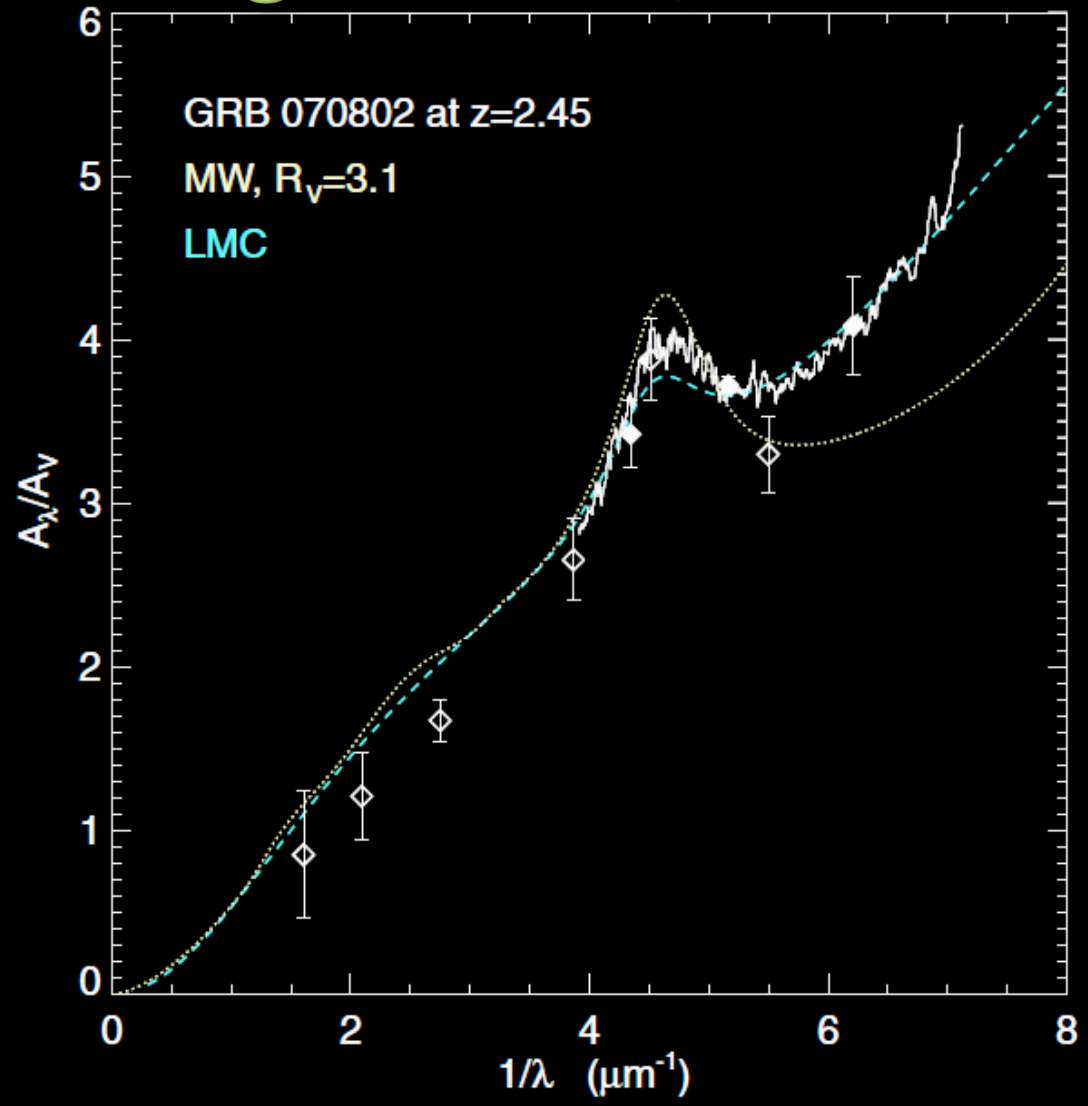
Measuring cosmic extinction: gamma-ray bursts



DLA
Reddening
2175 Å
C I absorber

Elíasdóttir et al. 2009

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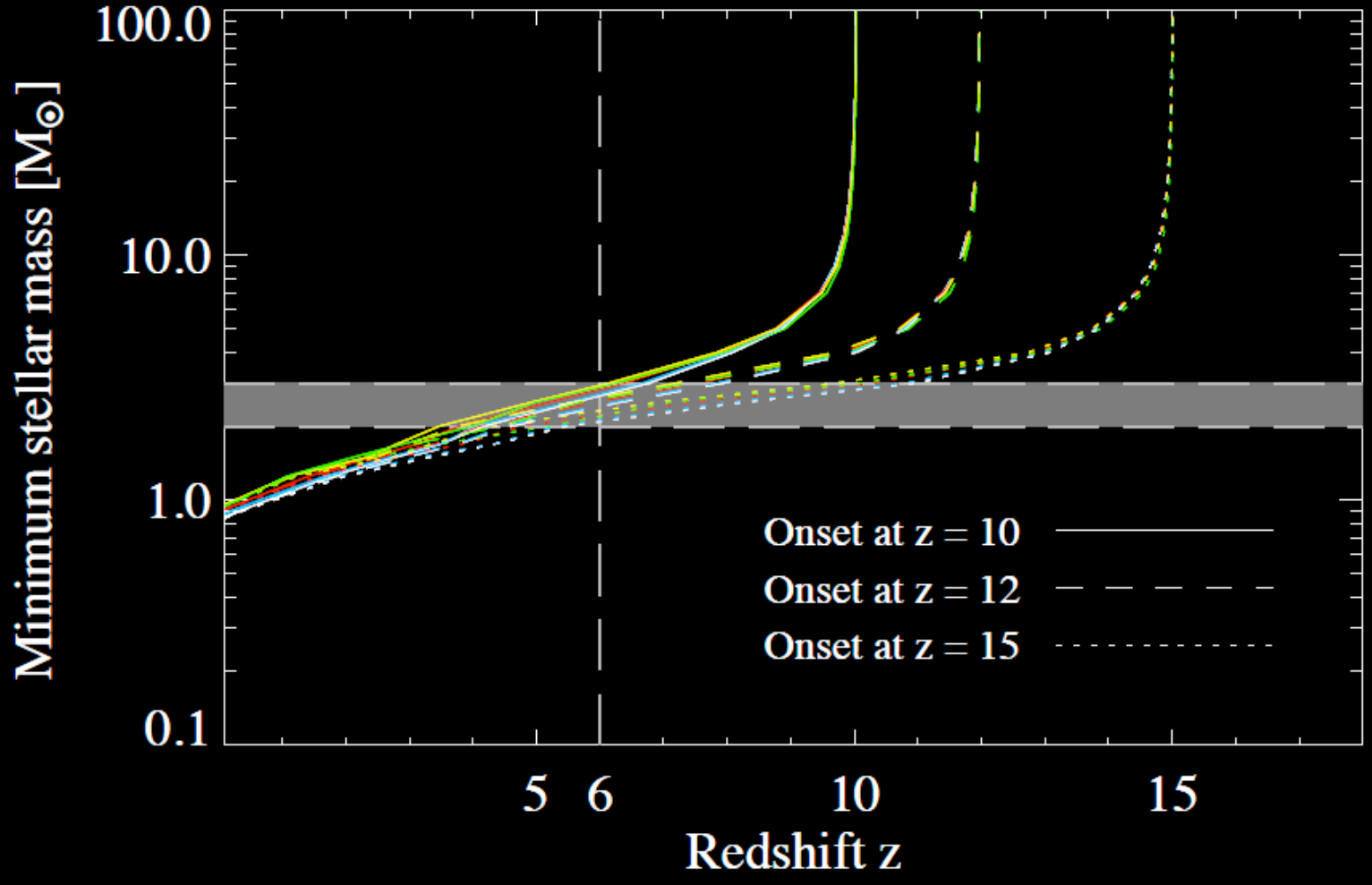
The quest for a rapid process

- At z ~ 6 the Universe was young (< 1 Gyr)
- Luminous quasars at high redshift
  - Large black-hole masses ($10^{9\text{-}10}\ M_\odot$)
  - Large stellar masses ($10^{10\text{-}11}\ M_\odot$)
  - Large dust masses ($10^{8\text{-}9}\ M_\odot$)
- How was all this dust produced so quickly?
  - Dwek, Gall, Foyle, Valiante,…

AGB stars live too long!



Gall et al. 2011

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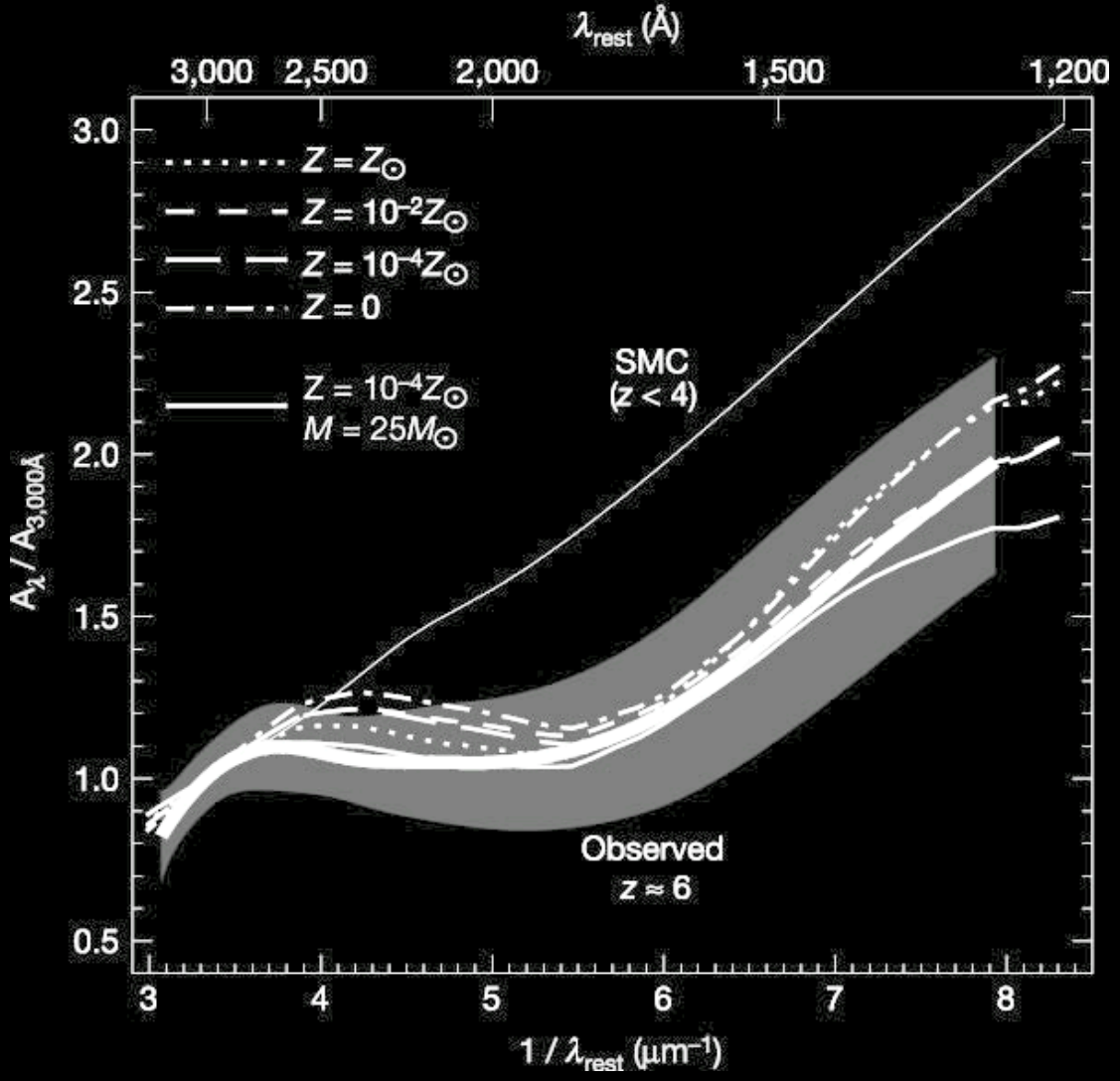
Supernovae?

- Massive stars evolve fast and there is some evidence that they produce dust (progenitor, supernova itself, remnant)
  - Rho, Matsuura, Dwek, Gall, …
- Look for special signatures in the extinction curves of high-redshift quasars, which could be indicative of supernova dust

Supernova dust extinction?



Todini & Ferrara 2001; Maiolino et al. 2004

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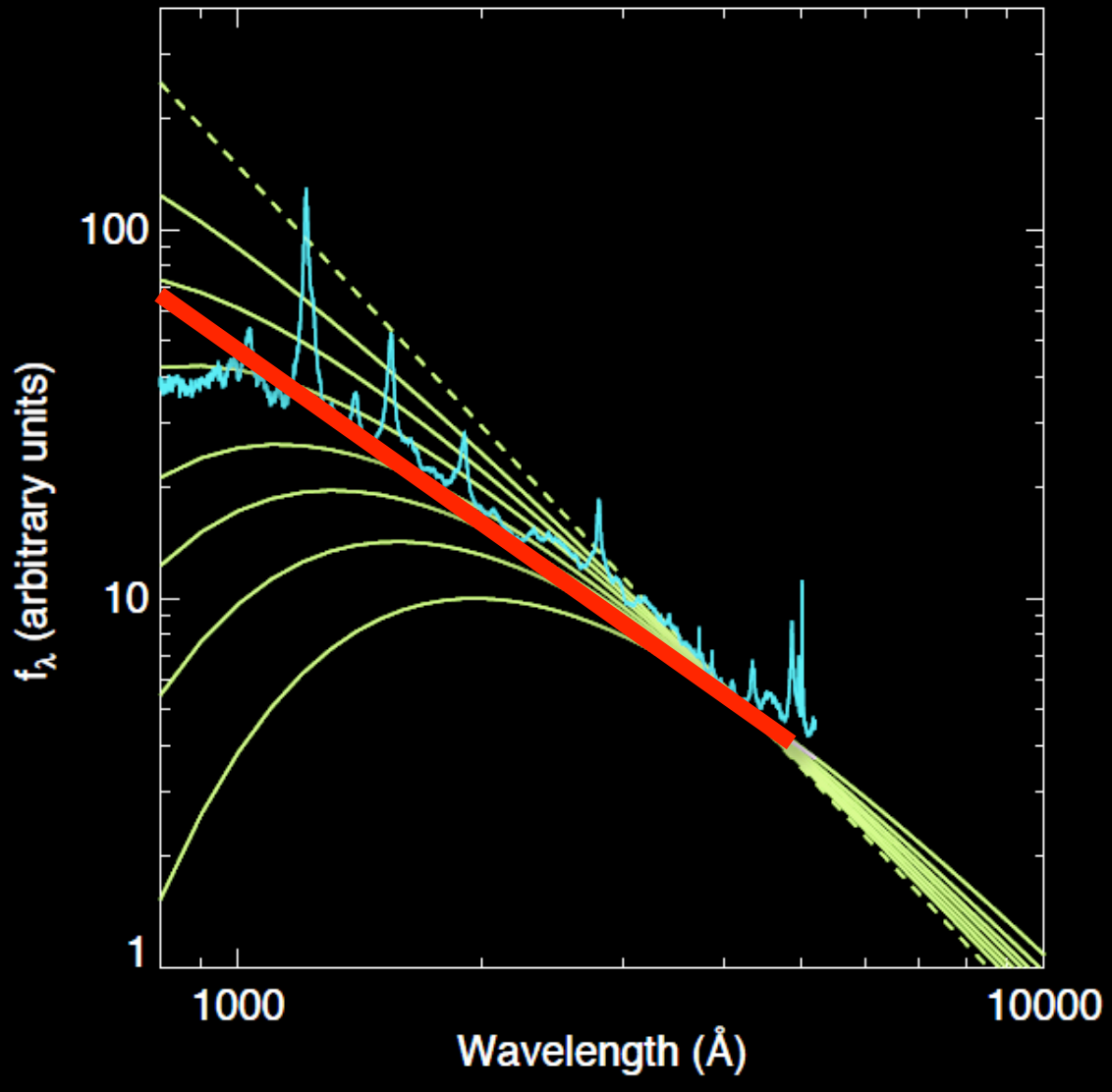
Intrinsic quasar spectrum: Assume power-law continuum!



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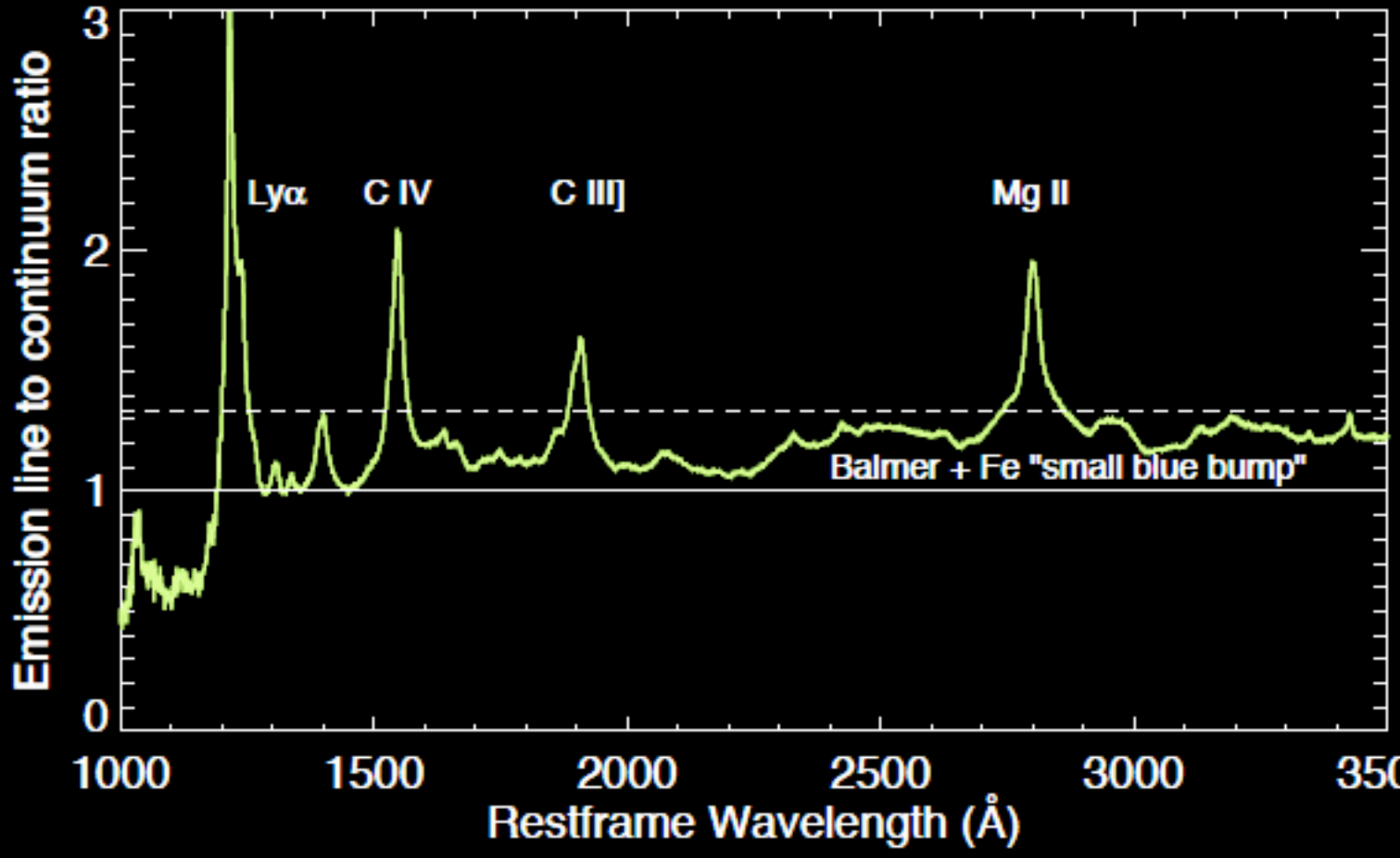
Emission-line-to-continuum ratio



Vanden Berk et al. 2001

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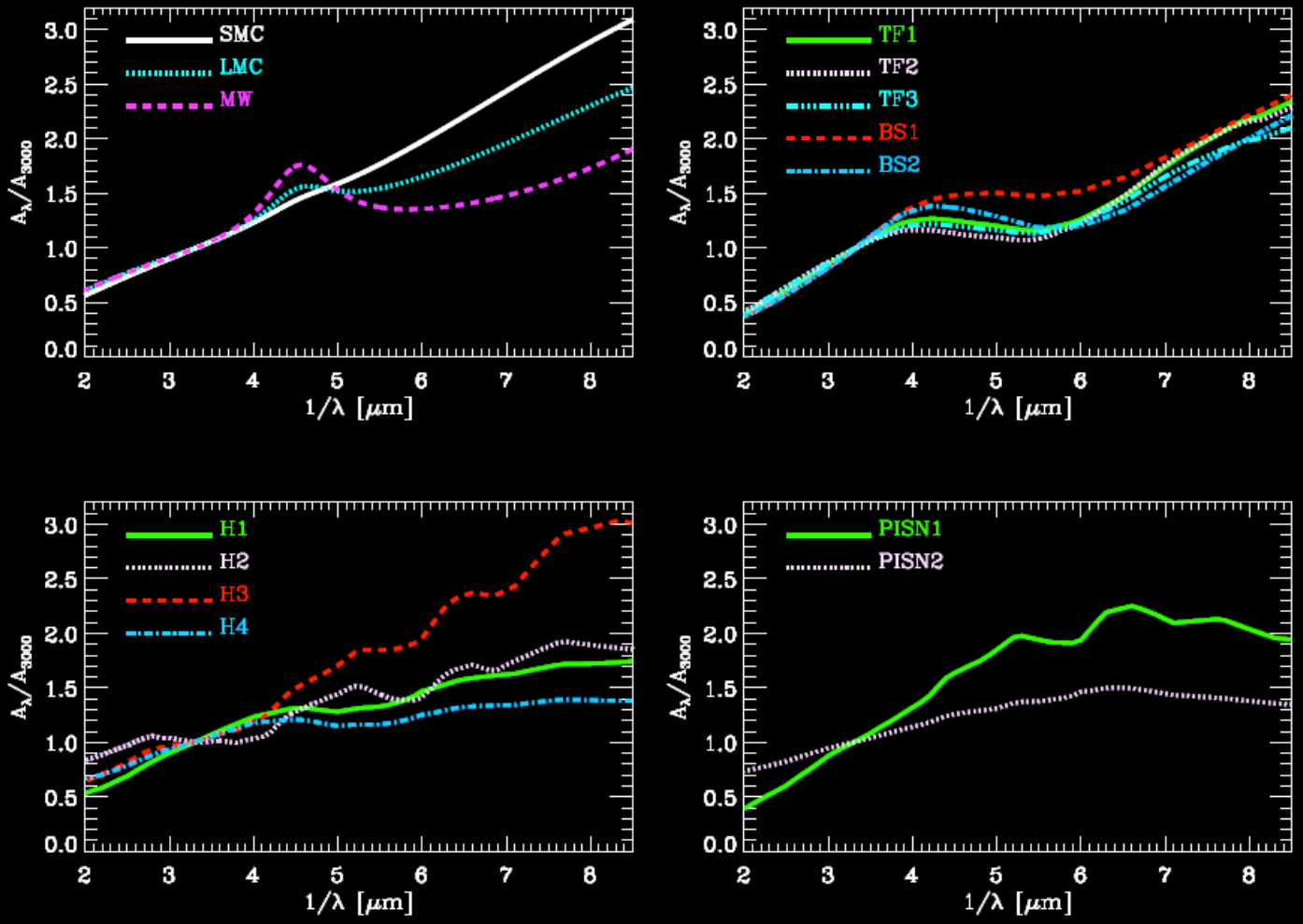
Plethora of theoretical extinction curves



Gallerani et al. 2010

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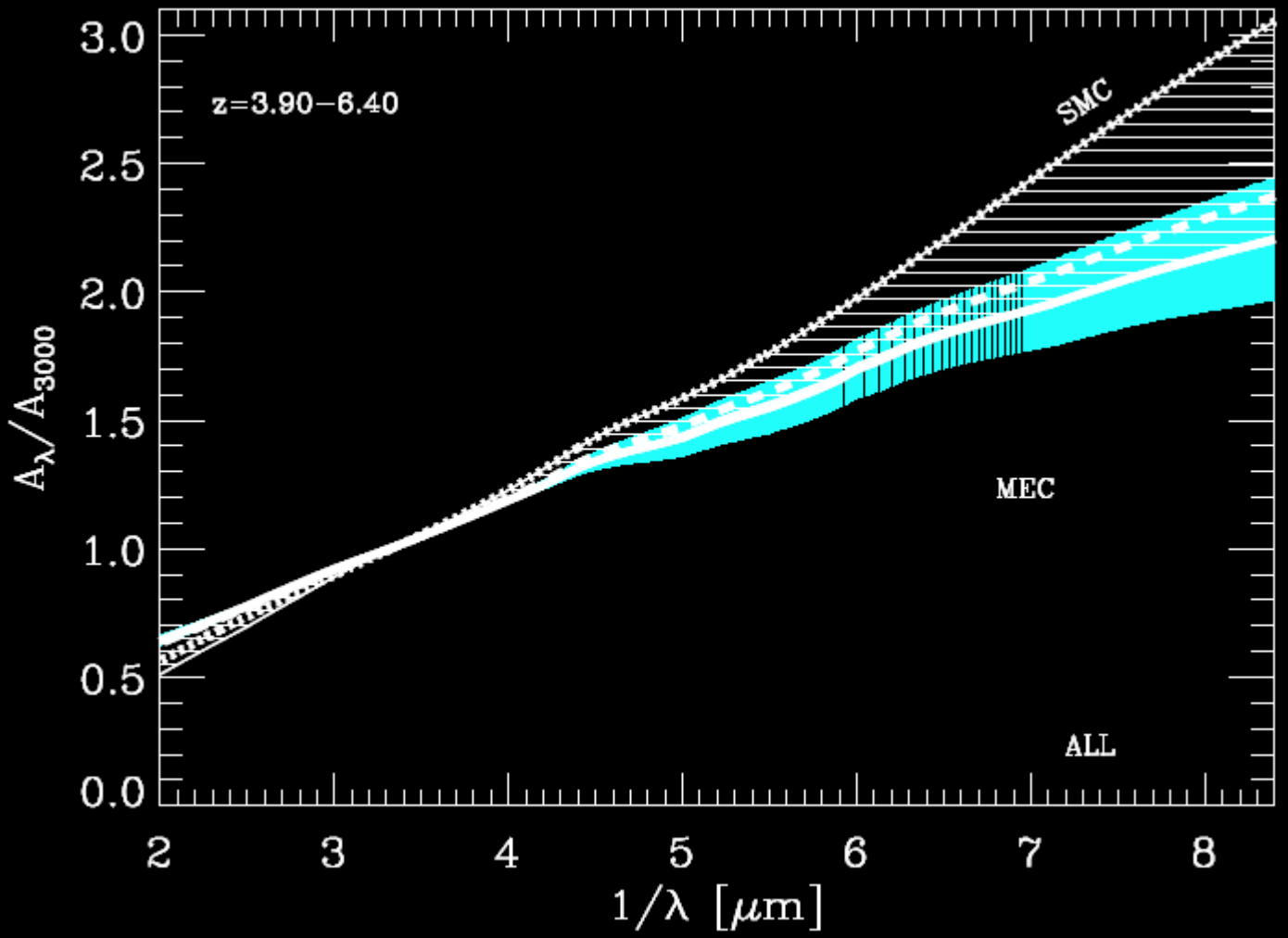
Mean extinction curve for hi-z QSOs



Gallerani et al. 2010

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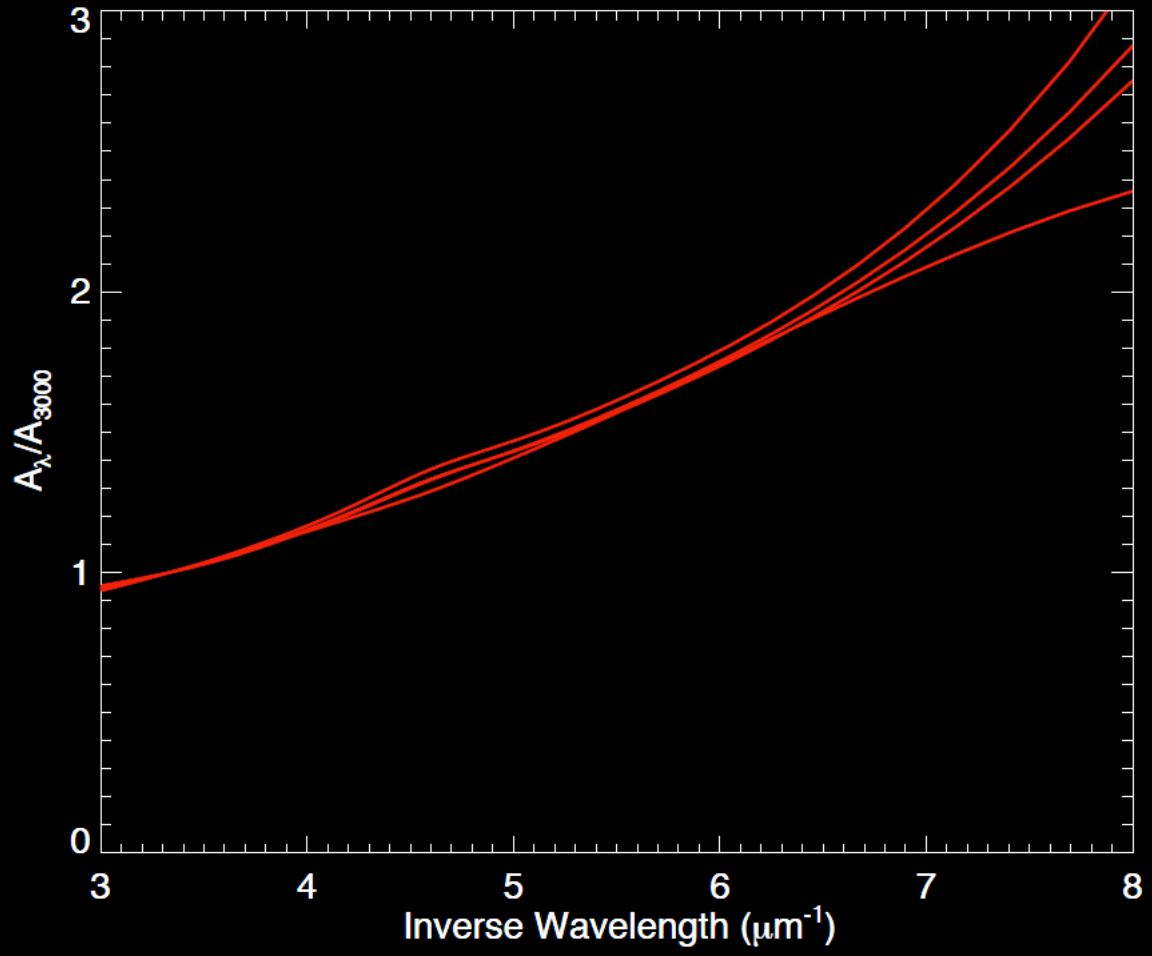
Diversity in the SMC Bar



Gordon et al. 2003

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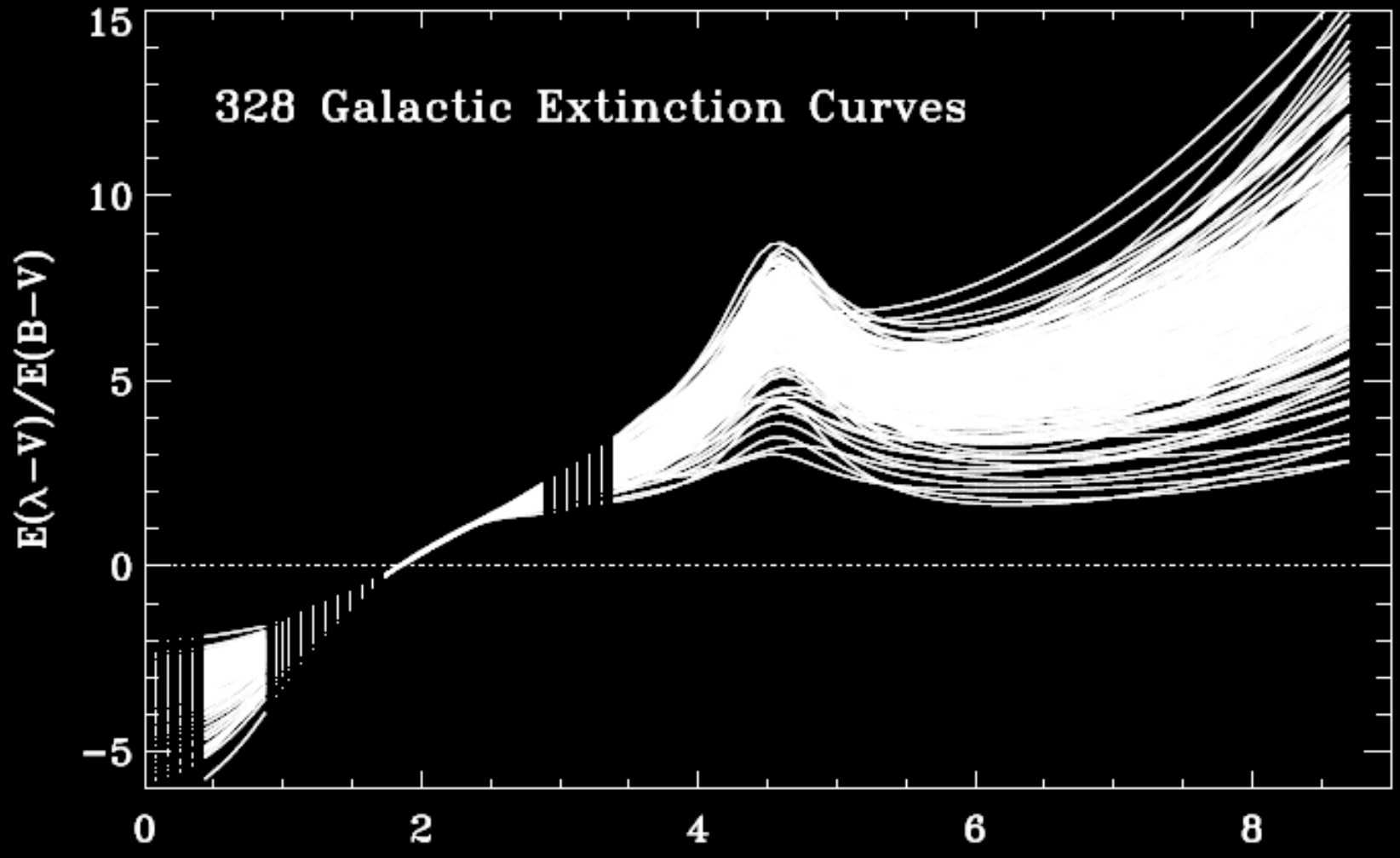
Diversity in the Milky Way



Fitzpatrick & Massa 2007

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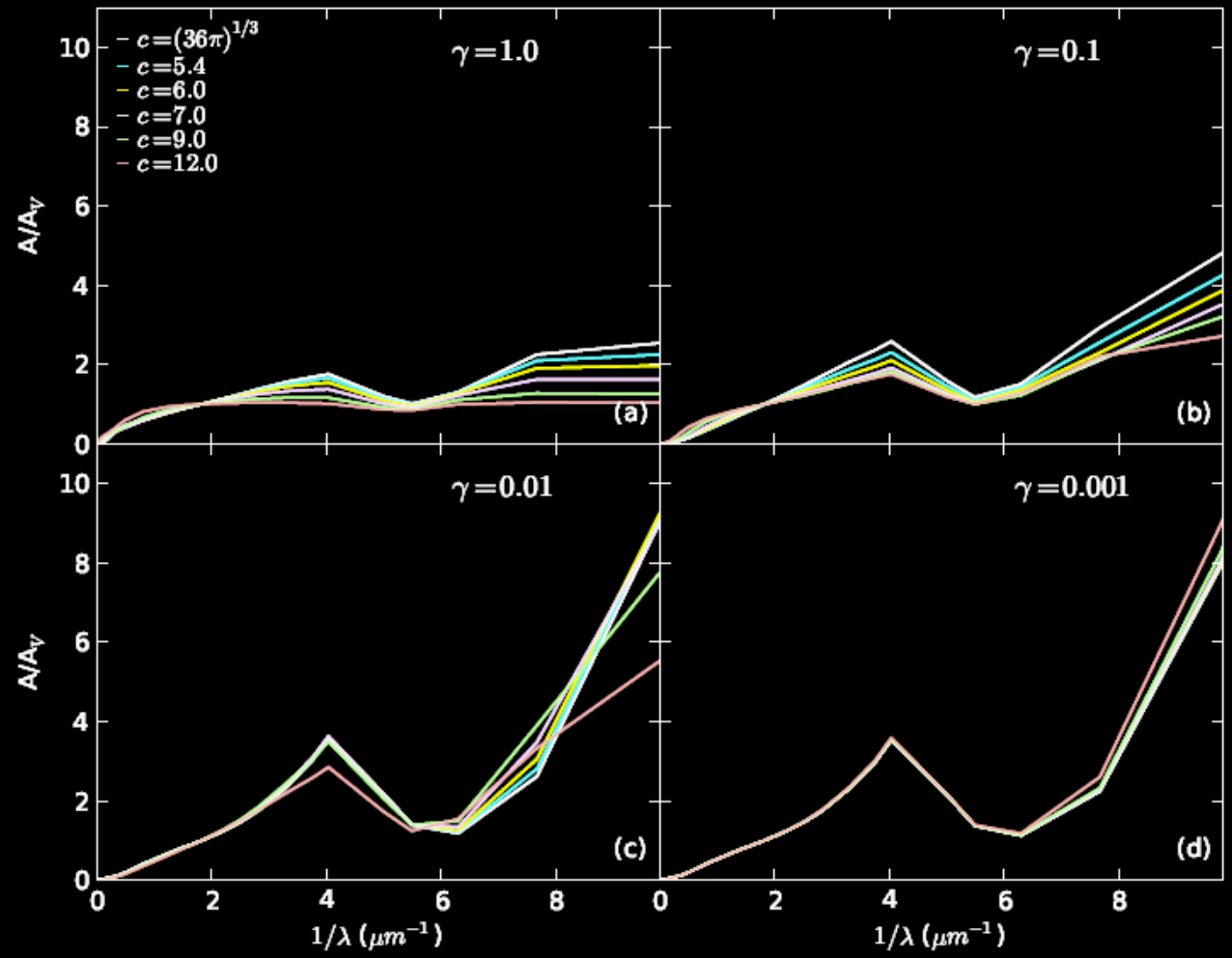
Dependency on sticking probability and shape



Fallest et al. 2011

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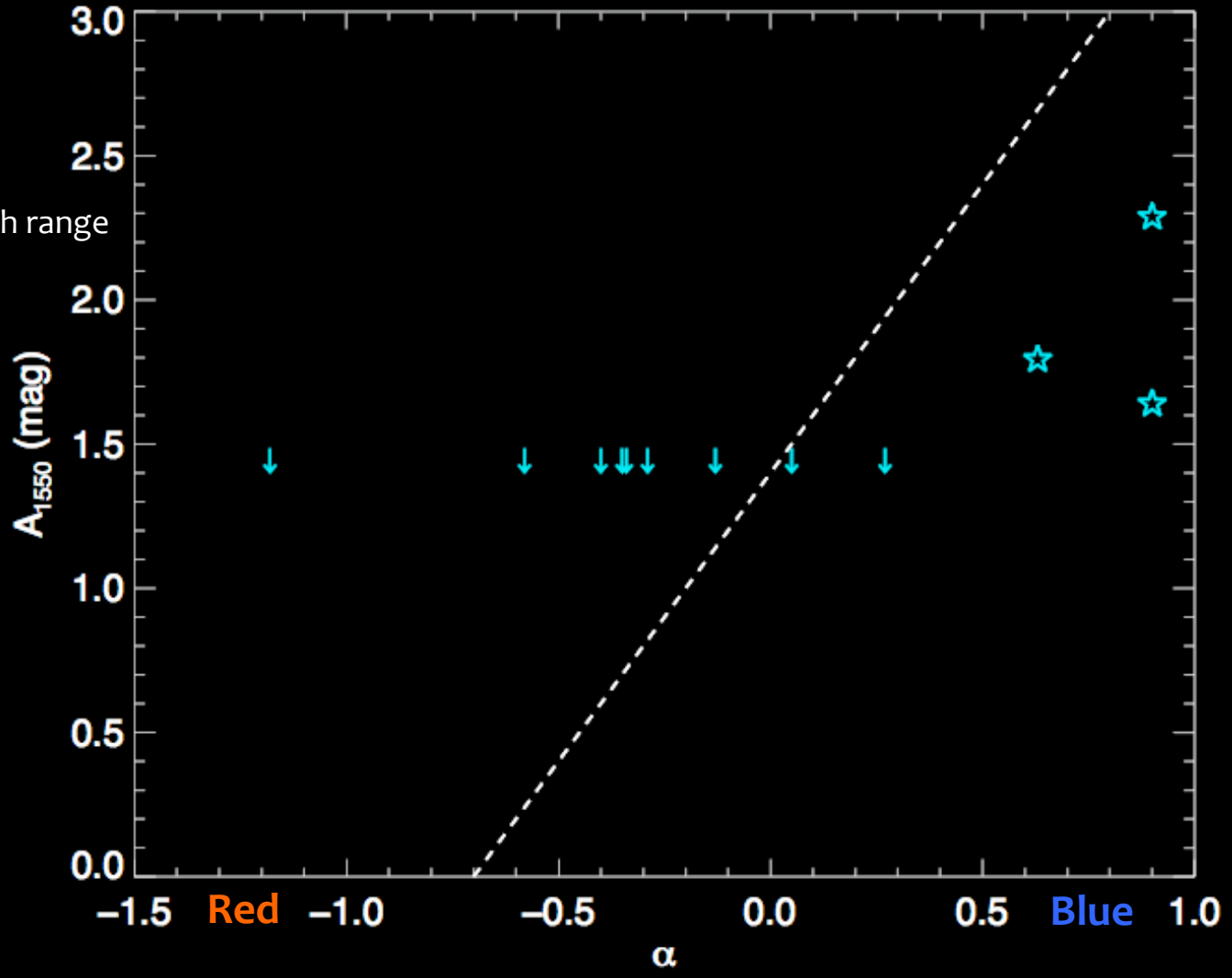
Reddened hi-z QSOs are extremely blue

Selection effects

Limited wavelength range
Model dependent



$f_\nu \sim \nu^\alpha$

Gallerani et al. 2010

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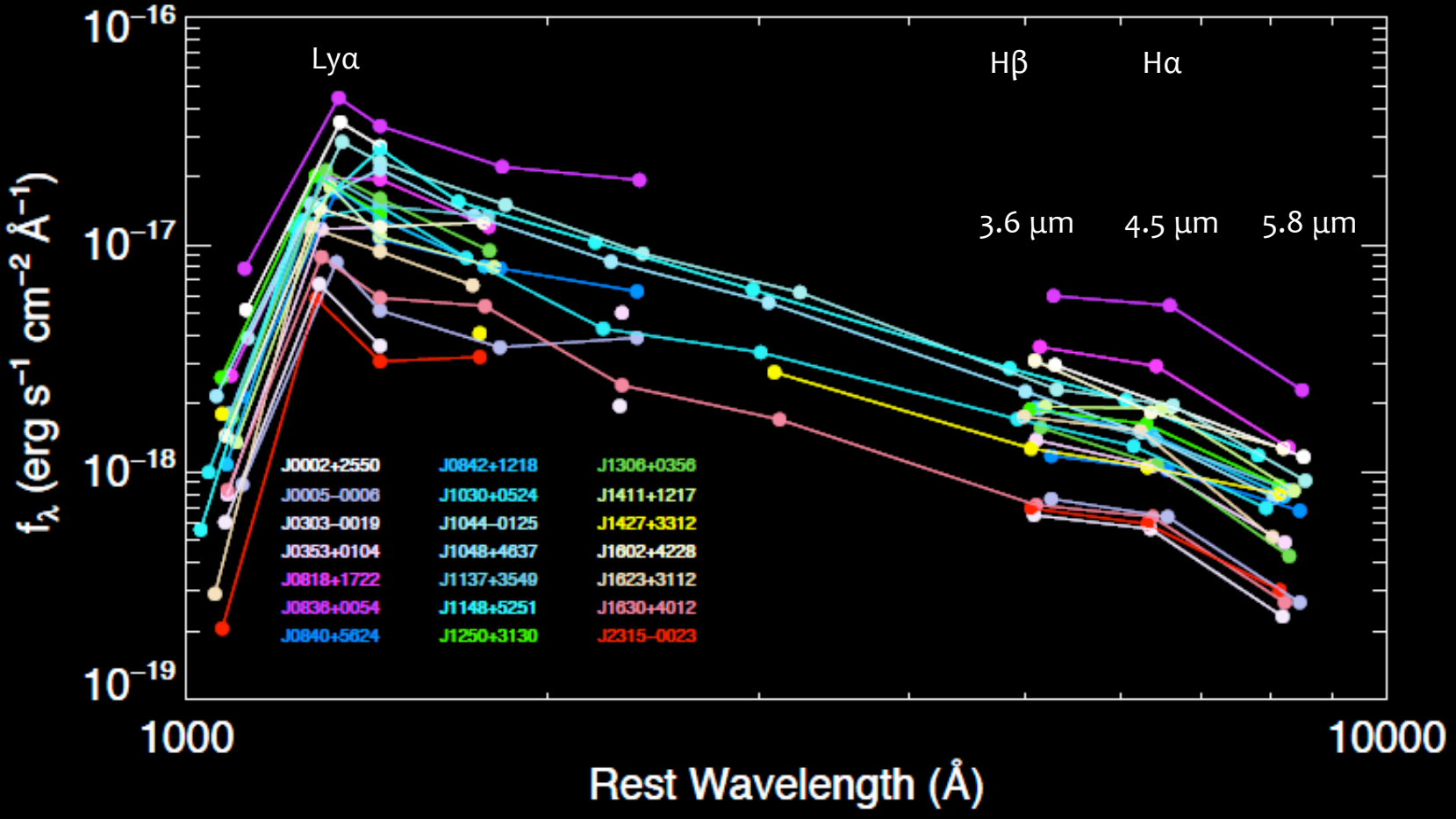
Motivation for this work: status

- High-redshift quasars with detected dust extinction are required to be extremely blue
- Only one example of Todini-Ferrara supernova extinction curve known (and not confirmed)
- Parametric models

21 z ~ 6 QSOs with optical+NIR+MIR broad-band photometry



Jiang et al. 2006, 2010

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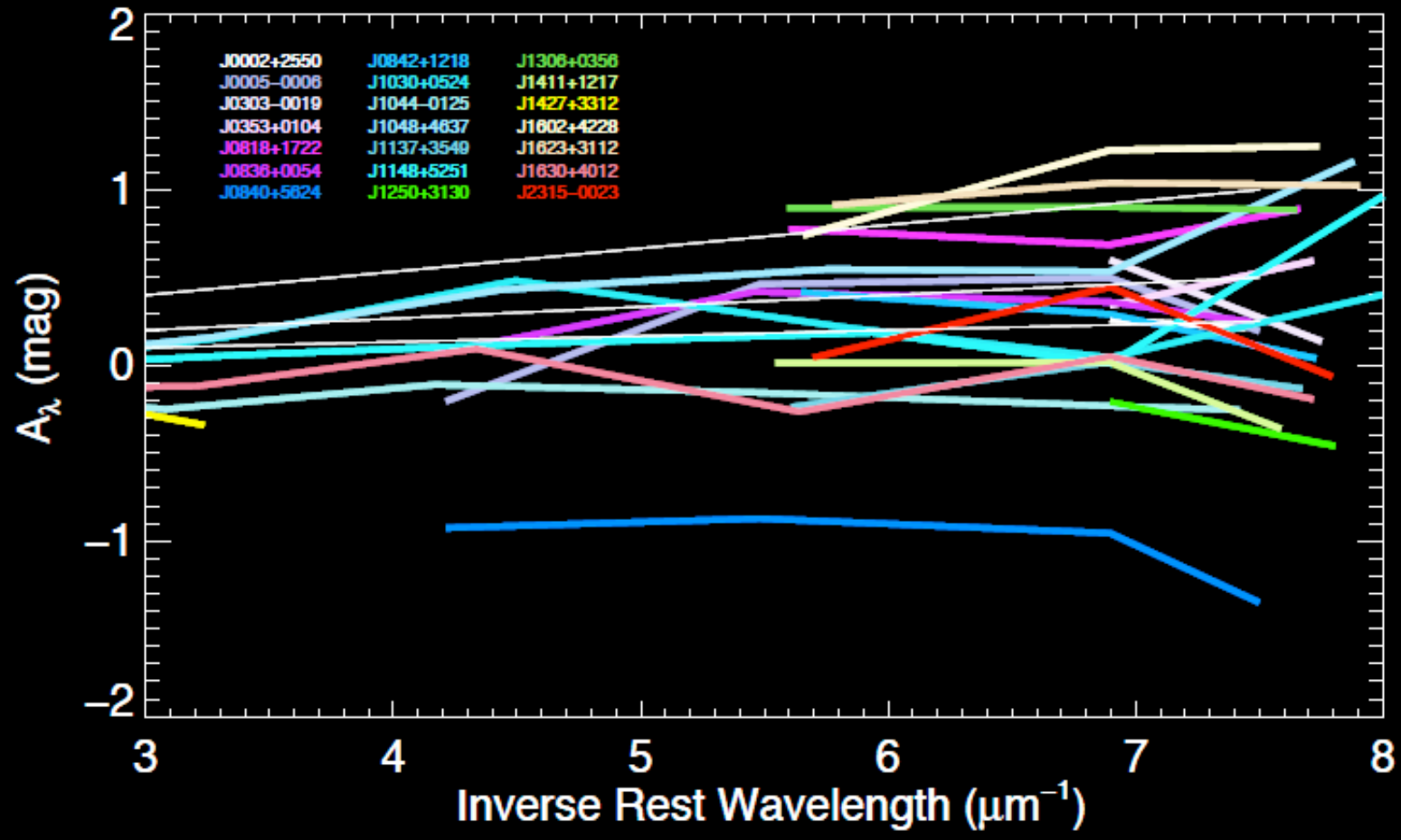
Extinction curves from Spitzer spectral index



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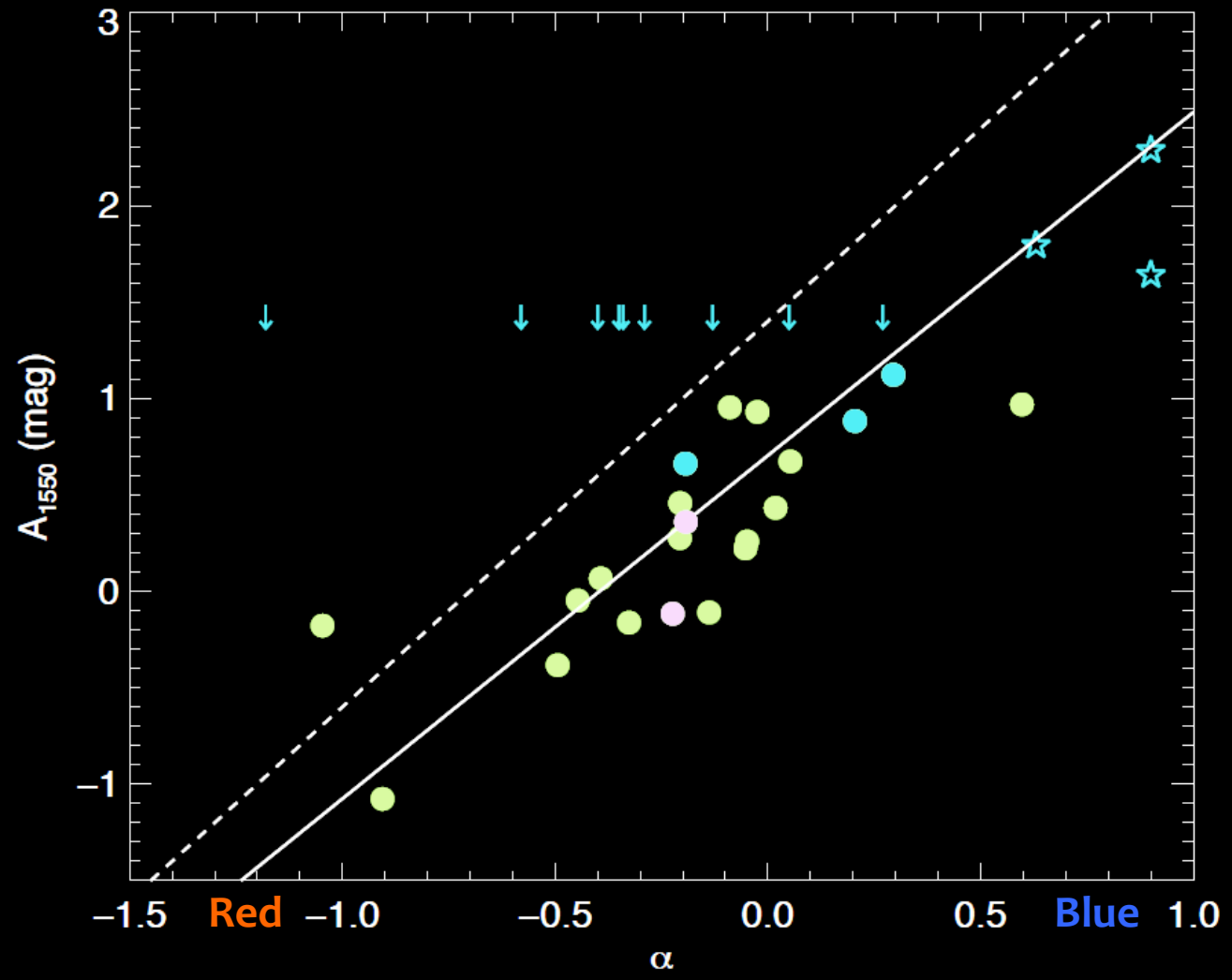
Extinction – spectral slope degeneracy



$f_\nu \sim \nu^\alpha$

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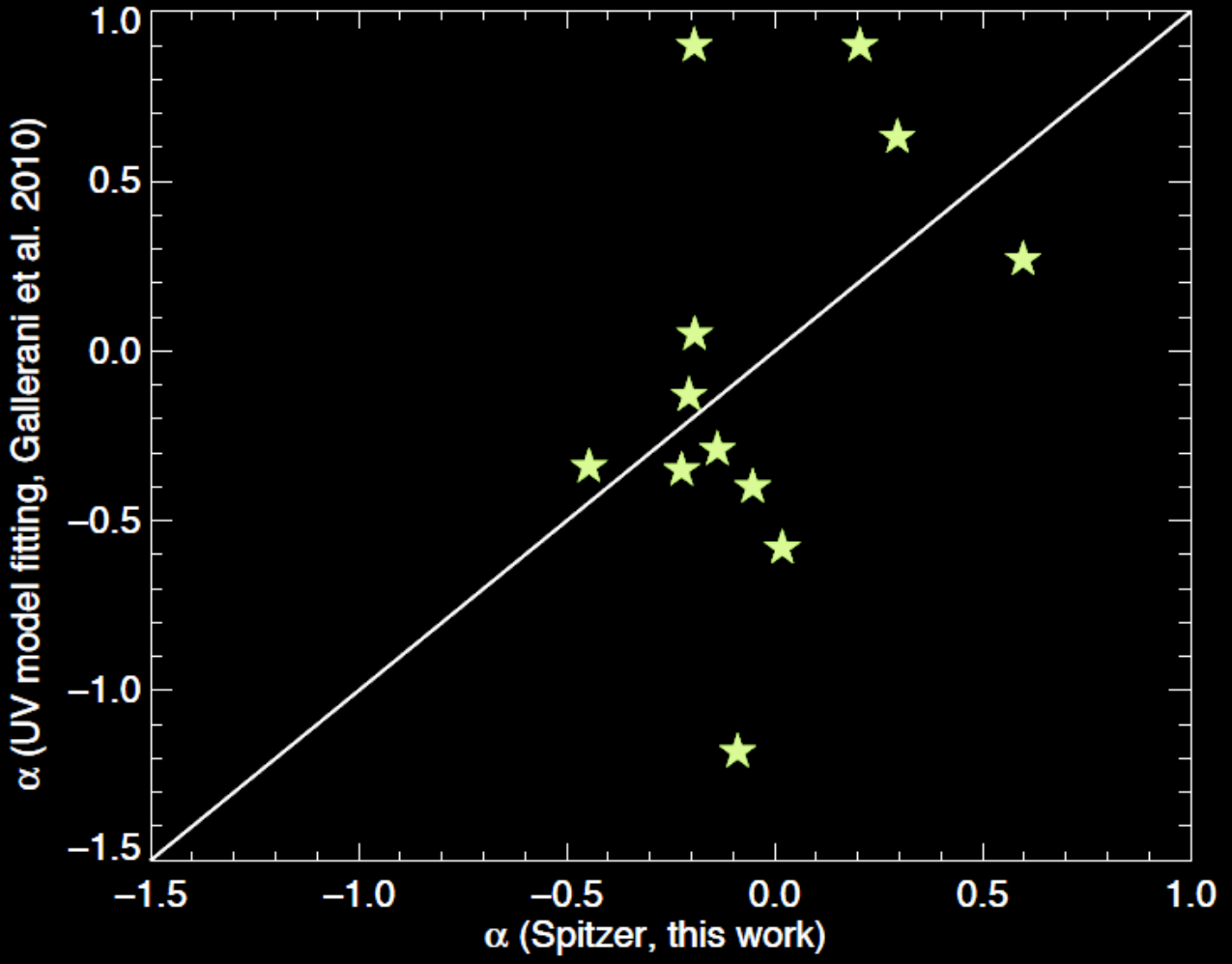
Difficulty in determining α



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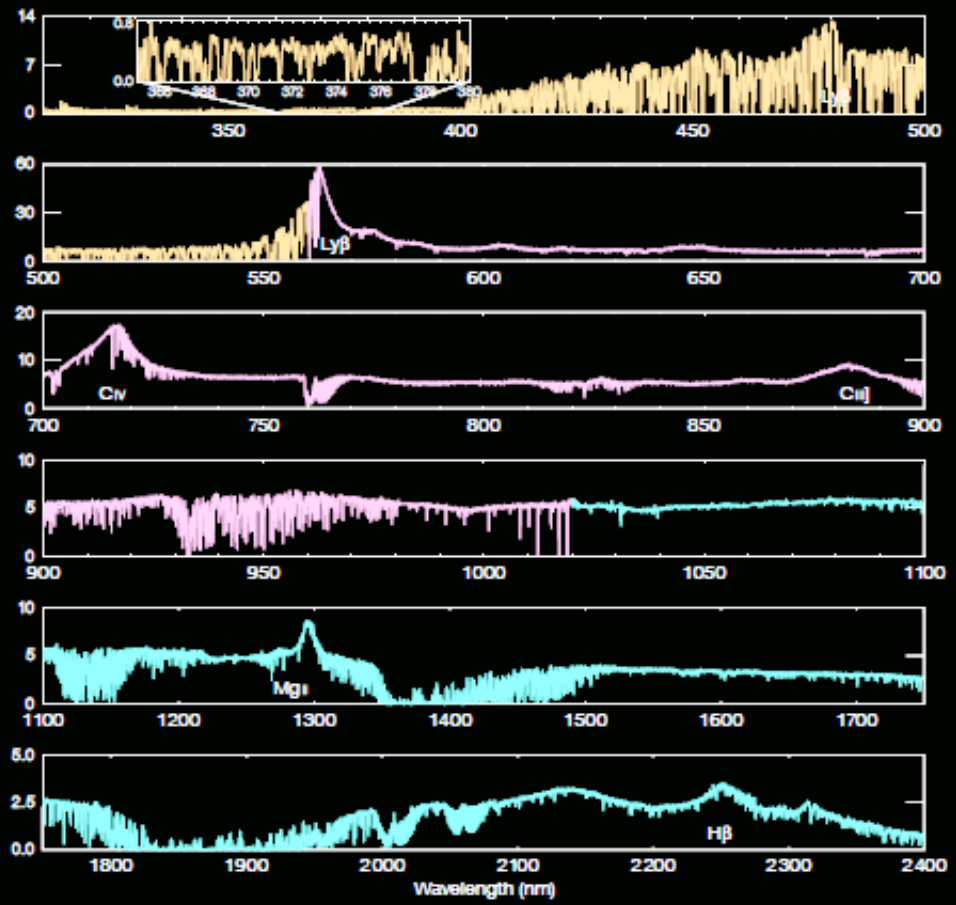
Results from broad-band data alone

- Alternative method of fixing the intrinsic spectral slope of quasars
- Clear detection of UV extinction
- Minimum (not absolute) values
- Degeneracy between α and A_{1550}, primarily due to uncertainties in correcting for Hβ and [O III] 4959,5007 flux in the 3.6 μm IRAC band
- Need wide-band spectra for accurate calibration and elimination of effects of emission lines etc.

X-shooter@VLT

- Medium resolution spectrograph
- 0.3 – 2.5 μm
- With Paul Vreeswijk



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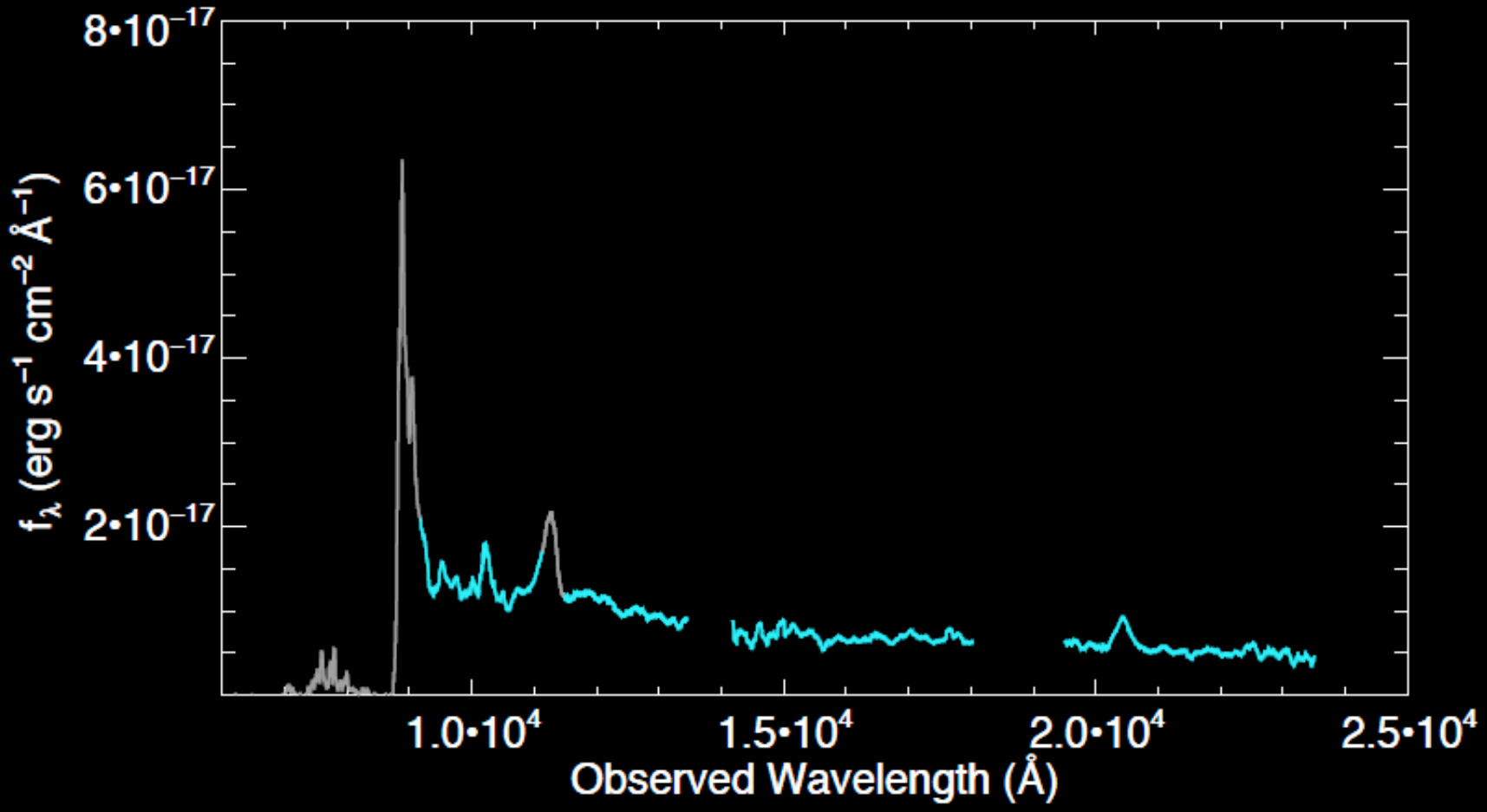
SDSS J1030+0524 (z=6.31)



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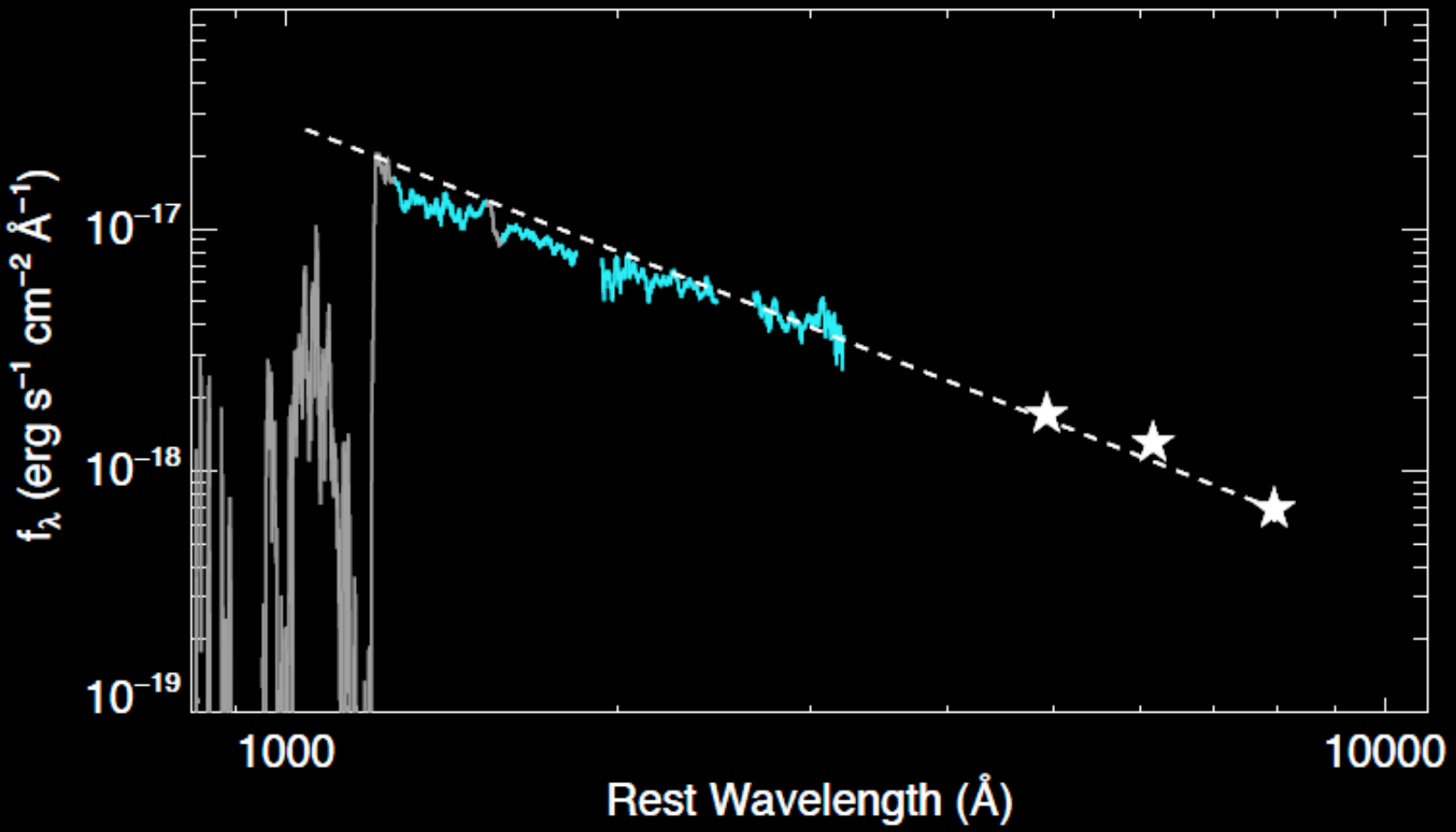
X-shooter/VLT+IRAC/*Spitzer*



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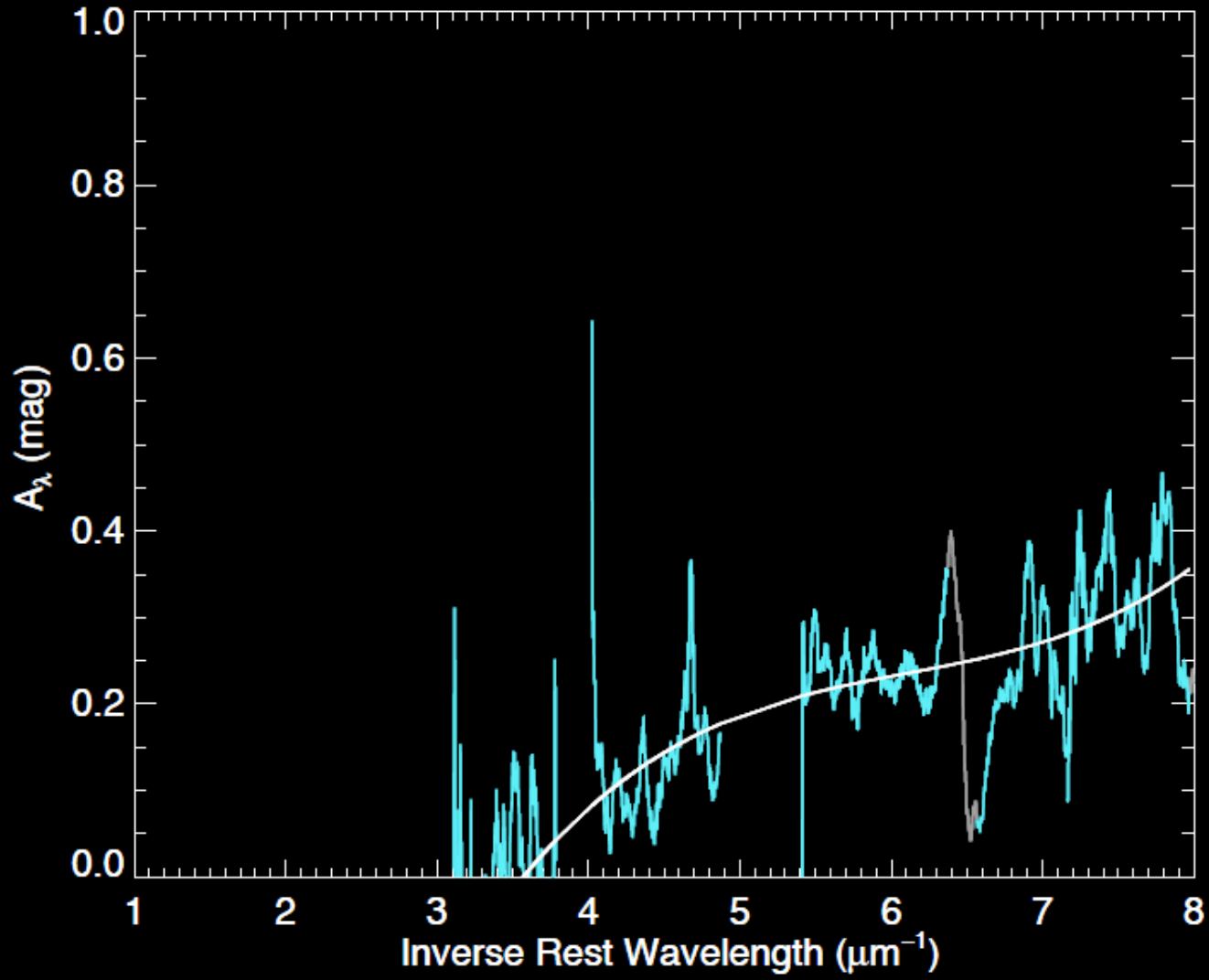
SDSS J1030+0524 (z=6.31)



noBAL

Small FIR dust mass

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Summary

- Using *Spitzer*/IRAC to fix intrinsic spectral slope:
  - Evidence for extinction in many high-redshift quasars
  - Different intrinsic spectral slopes from Gallerani et al. (no extremely blue quasars)
- X-shooter + *Spitzer*/IRAC extinction curves for moderately extinguished (normal α) high-redshift quasars (noBAL and BAL)
- No evidence for Todini-Ferrara-Maiolino feature
- Method will be applied to a larger sample of X-shooter quasars