Kosmička prašina u galaksijama

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Cosmic dust

Origin

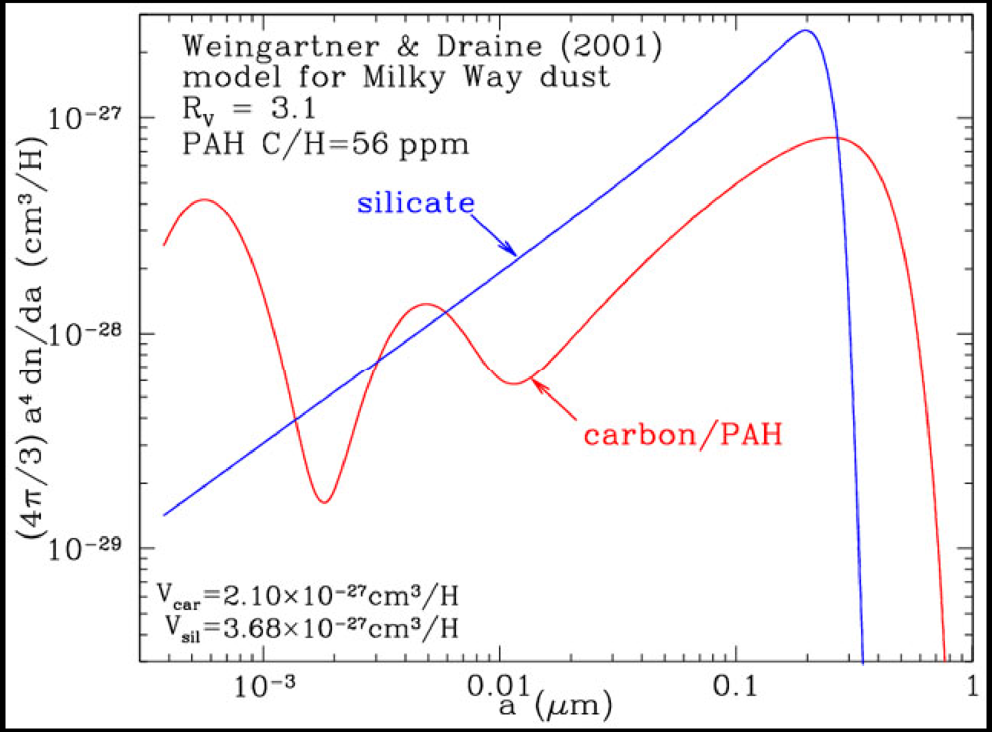
- Stellar evolution

Evolution

- Formation and destruction
- New theoretical models

Composition

- Grains of different sizes (~smoke)
- Silicates
- Carbonaceous
  - graphite
  - amorphous C
  - PAH (Polycyclic aromatic hydrocarbon)



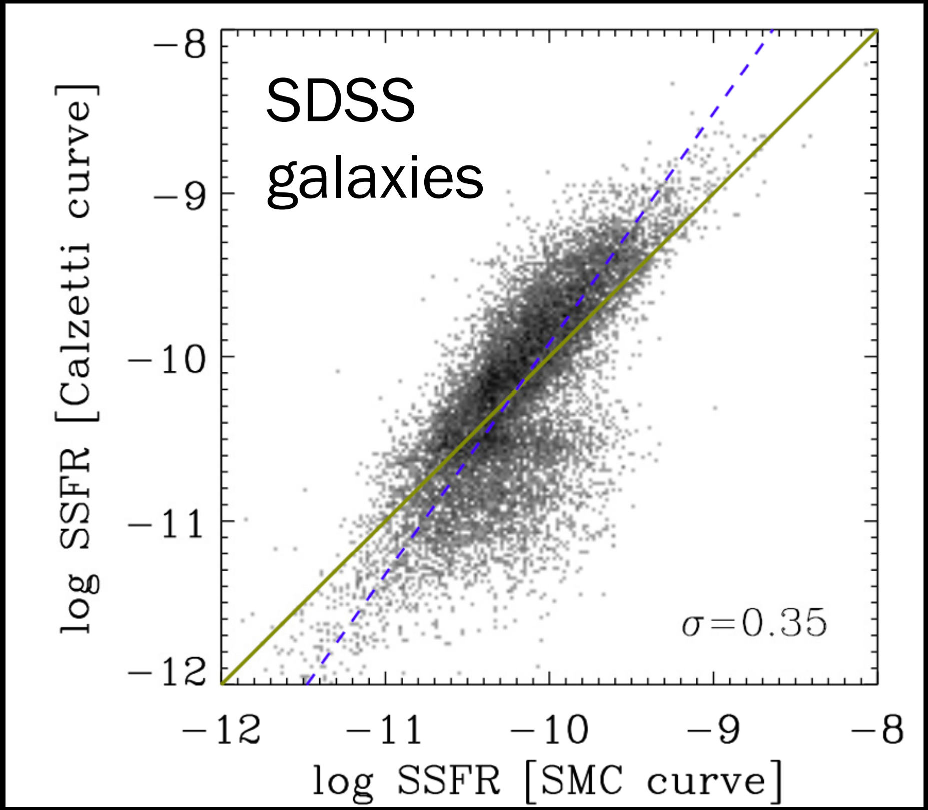
Dust grain size

Dust in galaxies

Why study?

- Intrinsic nature; evolution

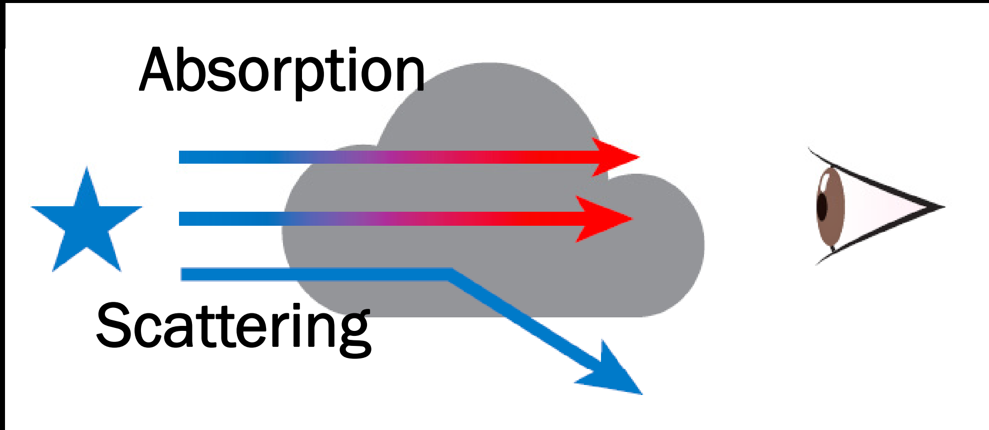
- Effect on UV-NIR light
  - must be corrected
  - systematics in physical parameters important for galaxy evolution
- Open Qs



Optical effects of dust

Extinction

- For a point source



Salim & Narayanan (2020)

$$A_\lambda = m_\lambda - m_{\lambda,0}$$

- Wavelength dependent (not gray)
  => reddening
  - E(B-V) = $A_B - A_V$ a dust column measure
  - A_V also as dust column measure

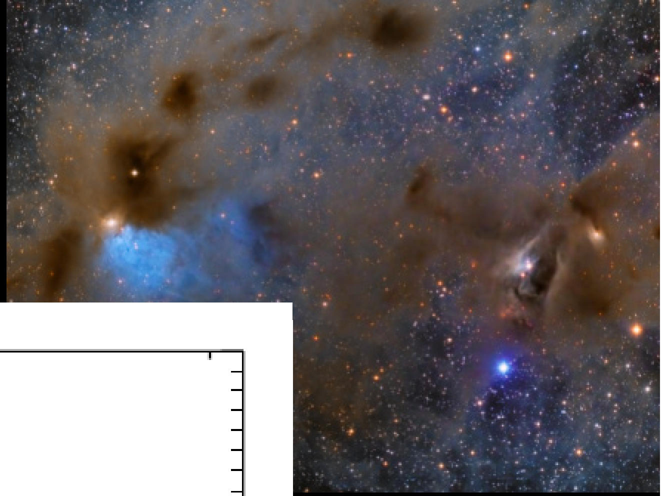
Extinction

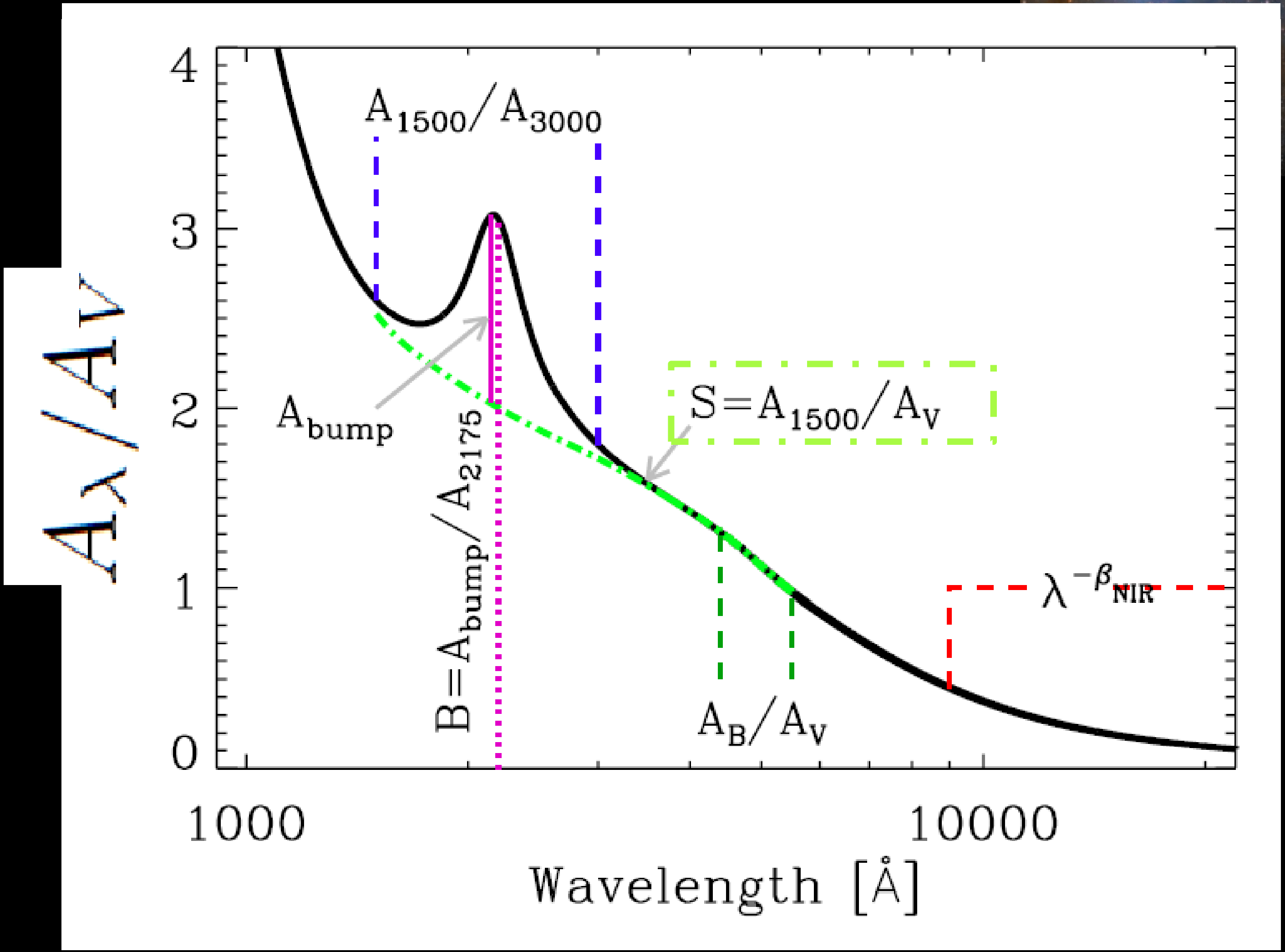
Extinction curve (AKA “law”)

- Normalized
- Shape
  1. UV/optical slope (S)
  2. Bump (B)
- Rv = optical slope

$$A_B/A_V = 1/R_V + 1$$

- Well measured:
  - MW, LMC, SMC





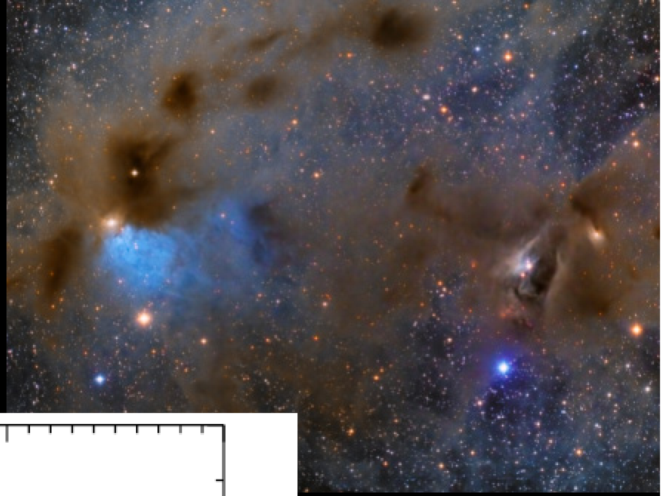
Salim & Narayanan (2020)

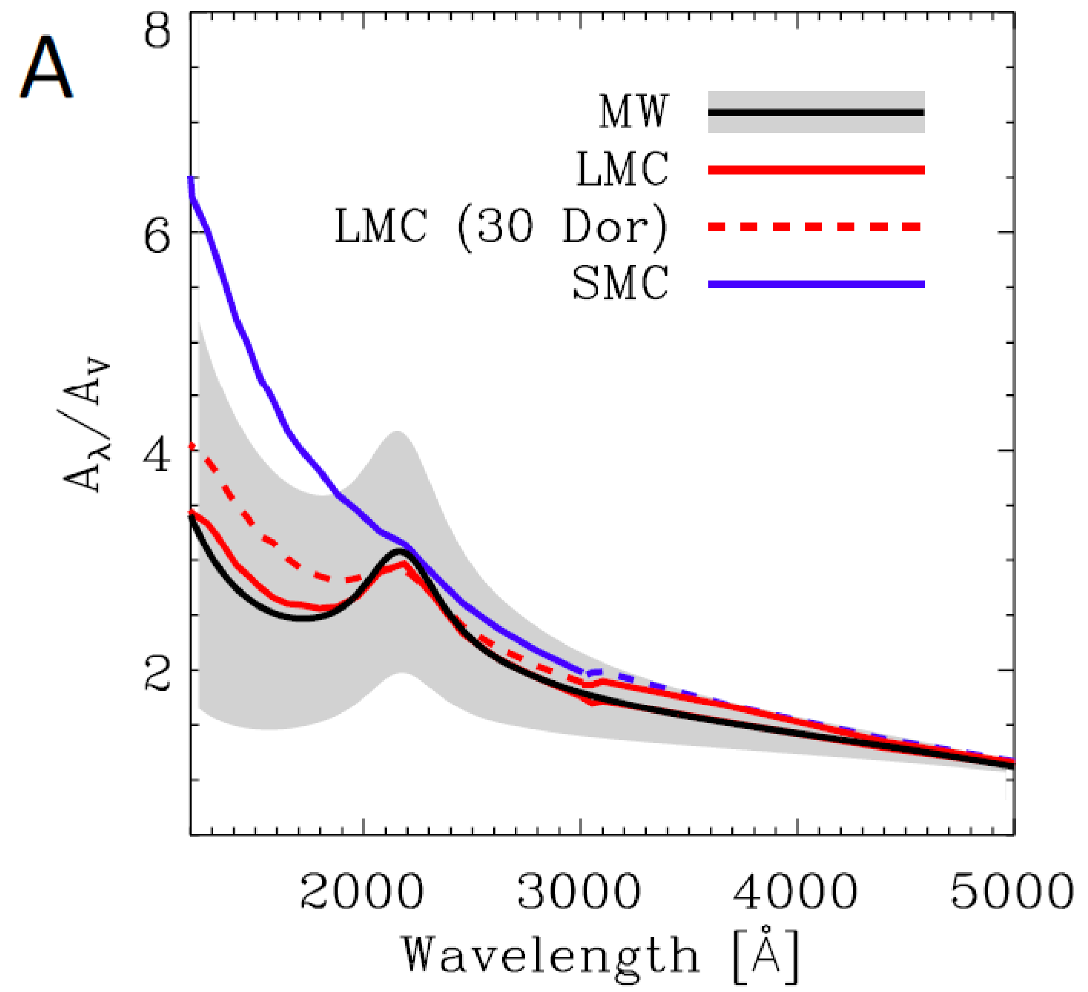
Extinction

Diversity

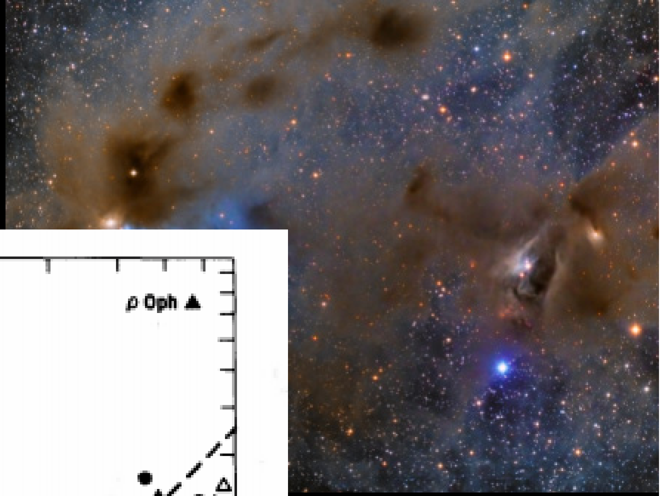
1. Average extinction curves differ among MW, LMC, SMC
2. Individual sightlines differ
   - MW: 1 < S < 3 (2.5 < Rv < 5)

- Consequence:
  - $A_\lambda \neq$ const Av





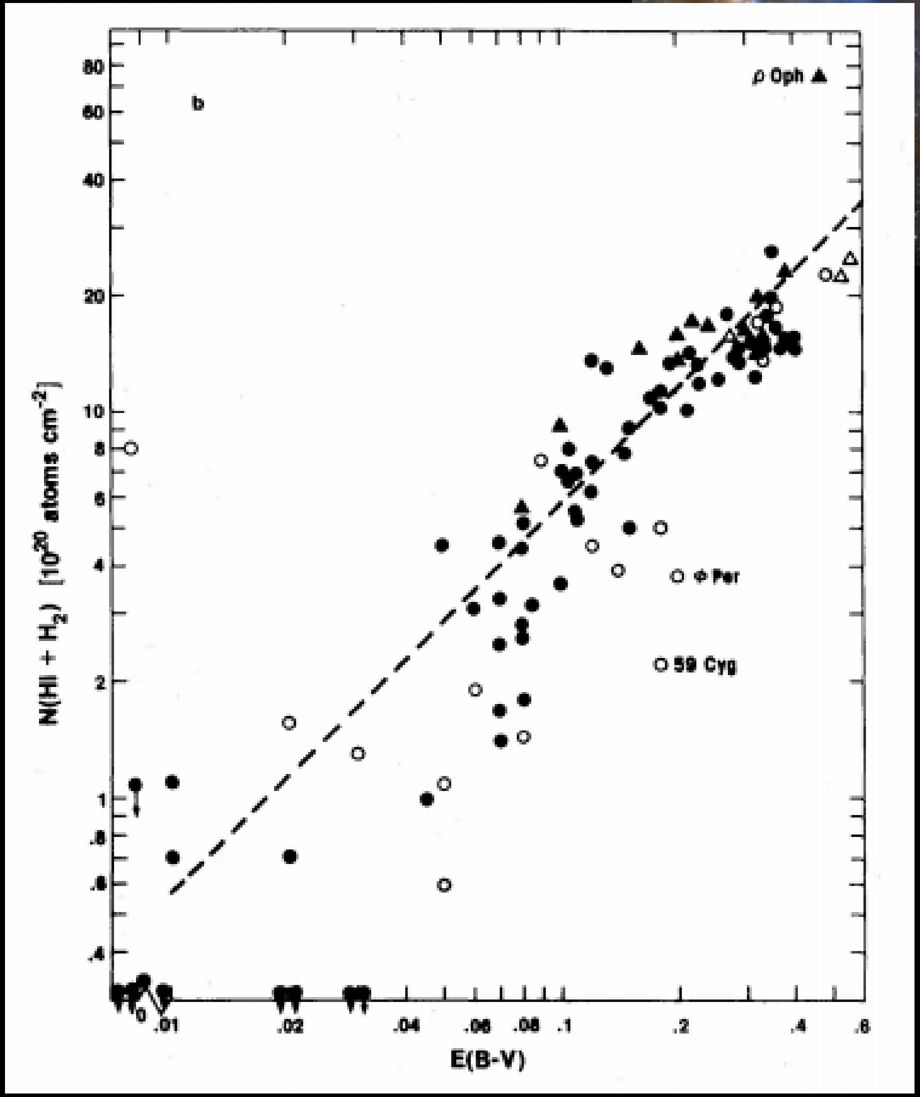
More fundamental measure of dust?



Extinction related to H column density

- E(B-V) or Av as a proxy for dust column density
- Fixed curve (e.g., Rv = 3.1):
  - Av = Rv E(B-V)
  - A_λ = const Av
- Which is the most fundamental measure of dust?
  - $A_\lambda \neq$ const Av
  - Av ?
  - A_{NIR} ?
  - E(B-V) ?
  - A_λ?

Hydrogen column density



Dust reddening

Bohlin et al. (1978)

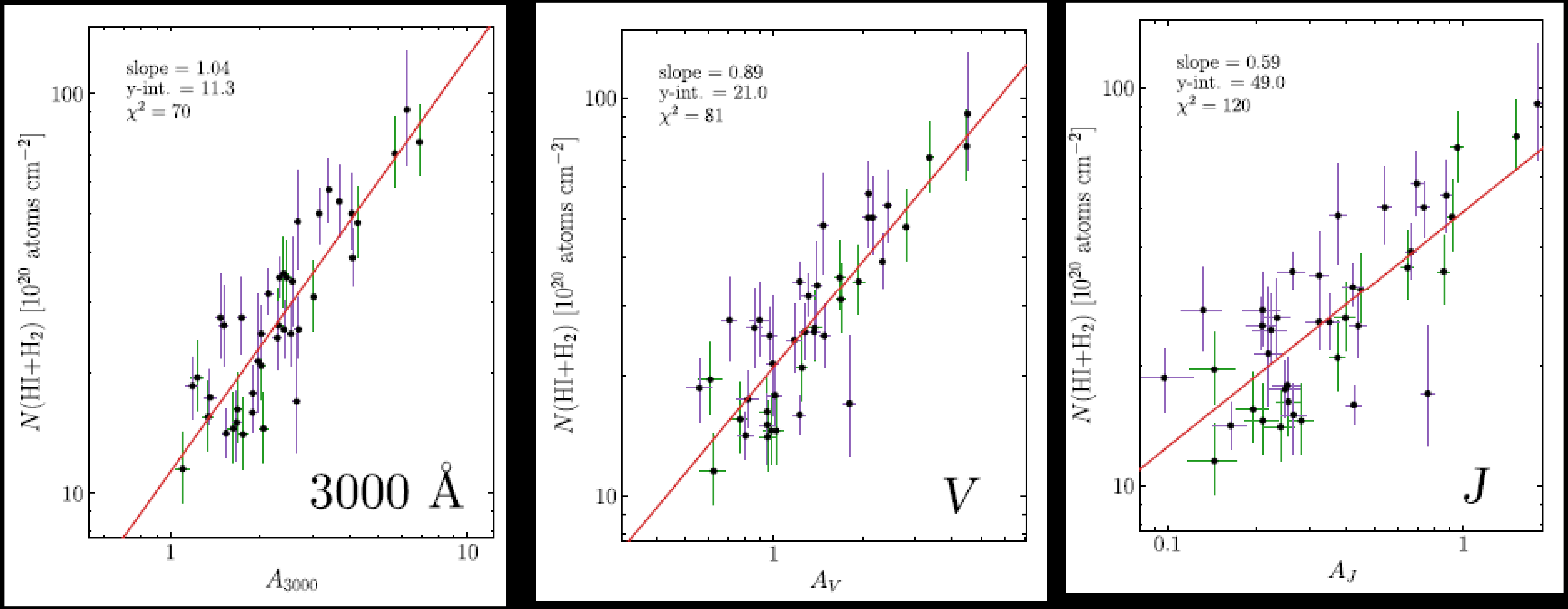
More fundamental measure of dust?

Empirical test using MW sightlines

- Only 300 sightlines w/ full extinction curves (OB stars)
  - get continuous A_λ
  - 50 stars with N(H)

Butler & Salim (2021)

Hydrogen column density

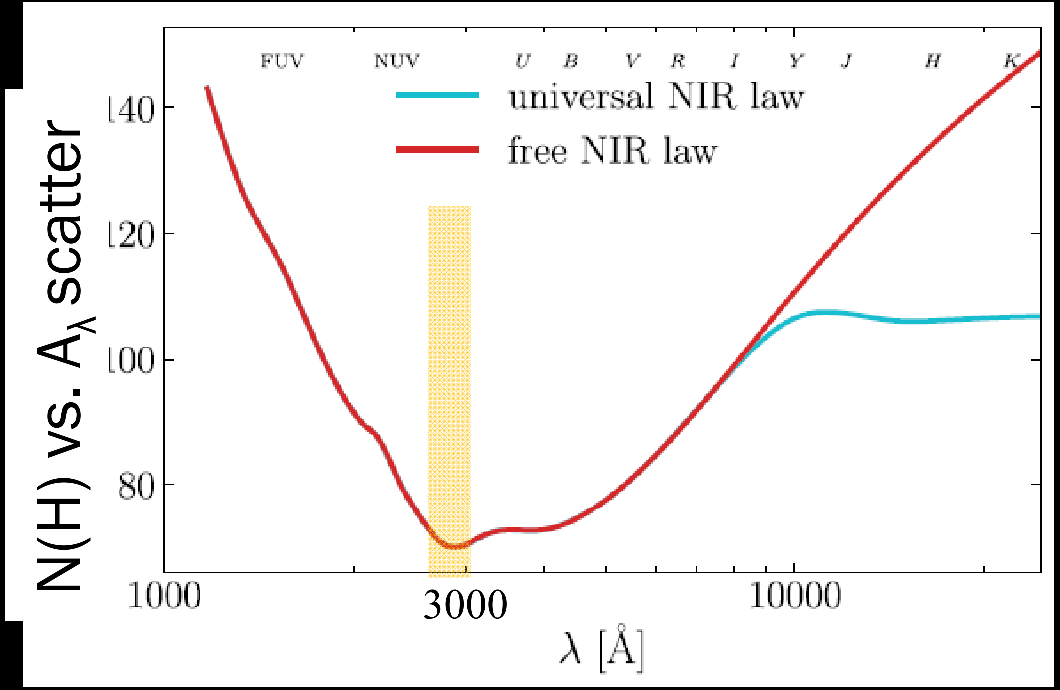


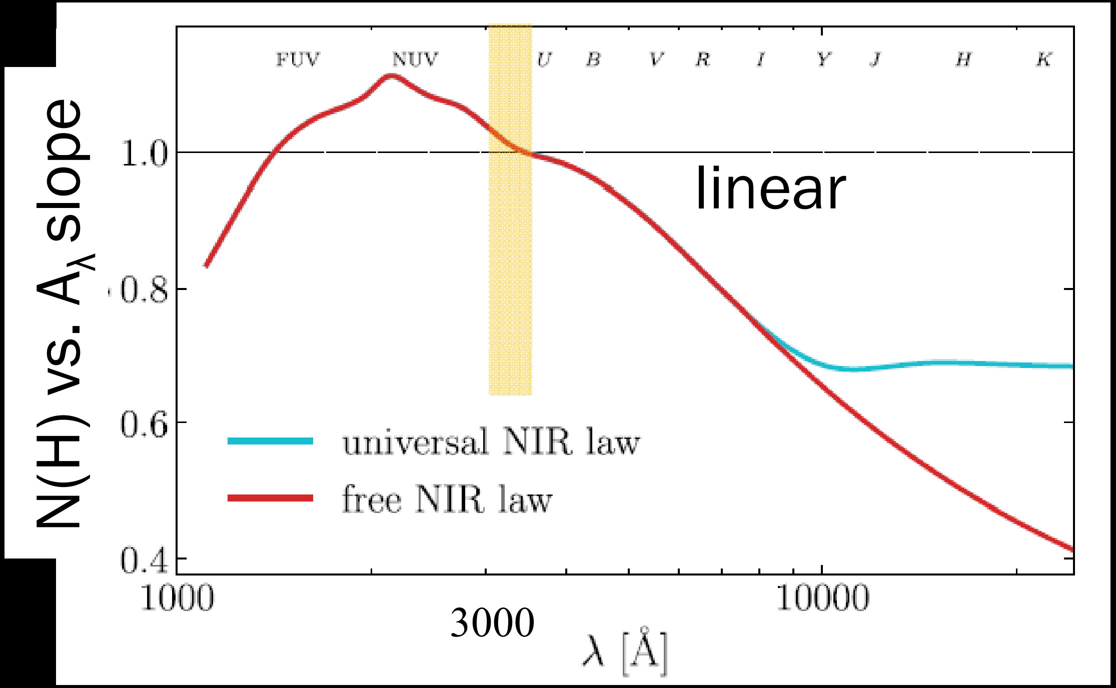
More fundamental measure of dust?

Empirical test

- Near-UV correlation correlates the best with N(H)
- Near-UV correlation with N(H) is linear

Takeaway: UV extinction is a more fundamental measure of dust than Av (or E(B-V))





Butler & Salim (2021)

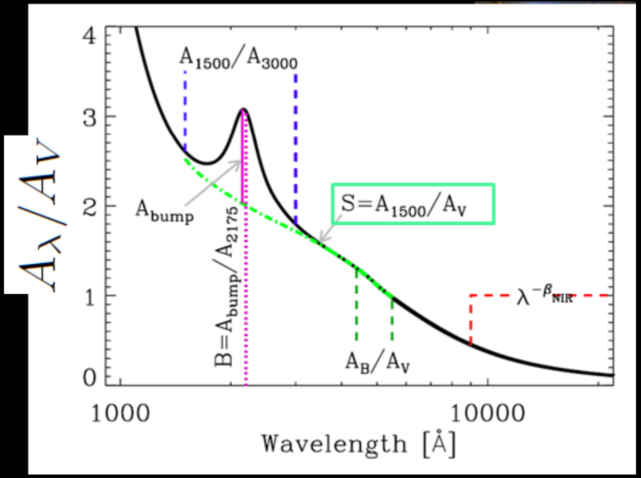
Why extinction curves vary?

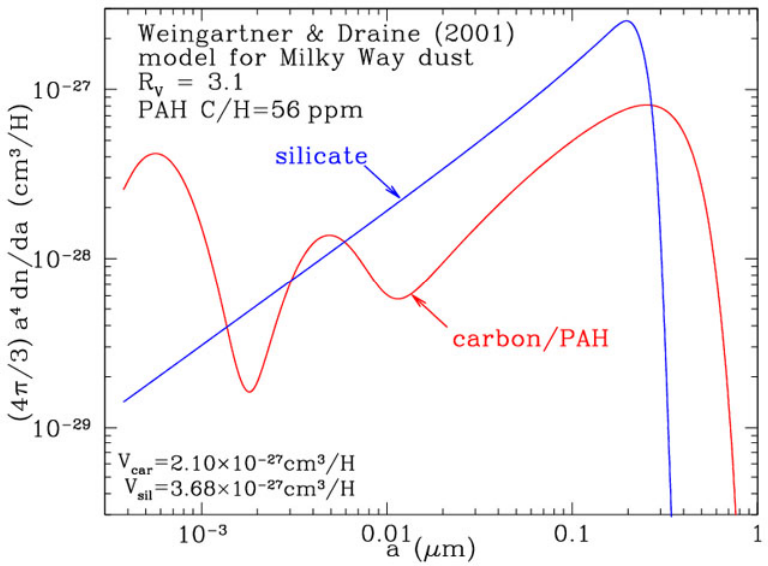
Models

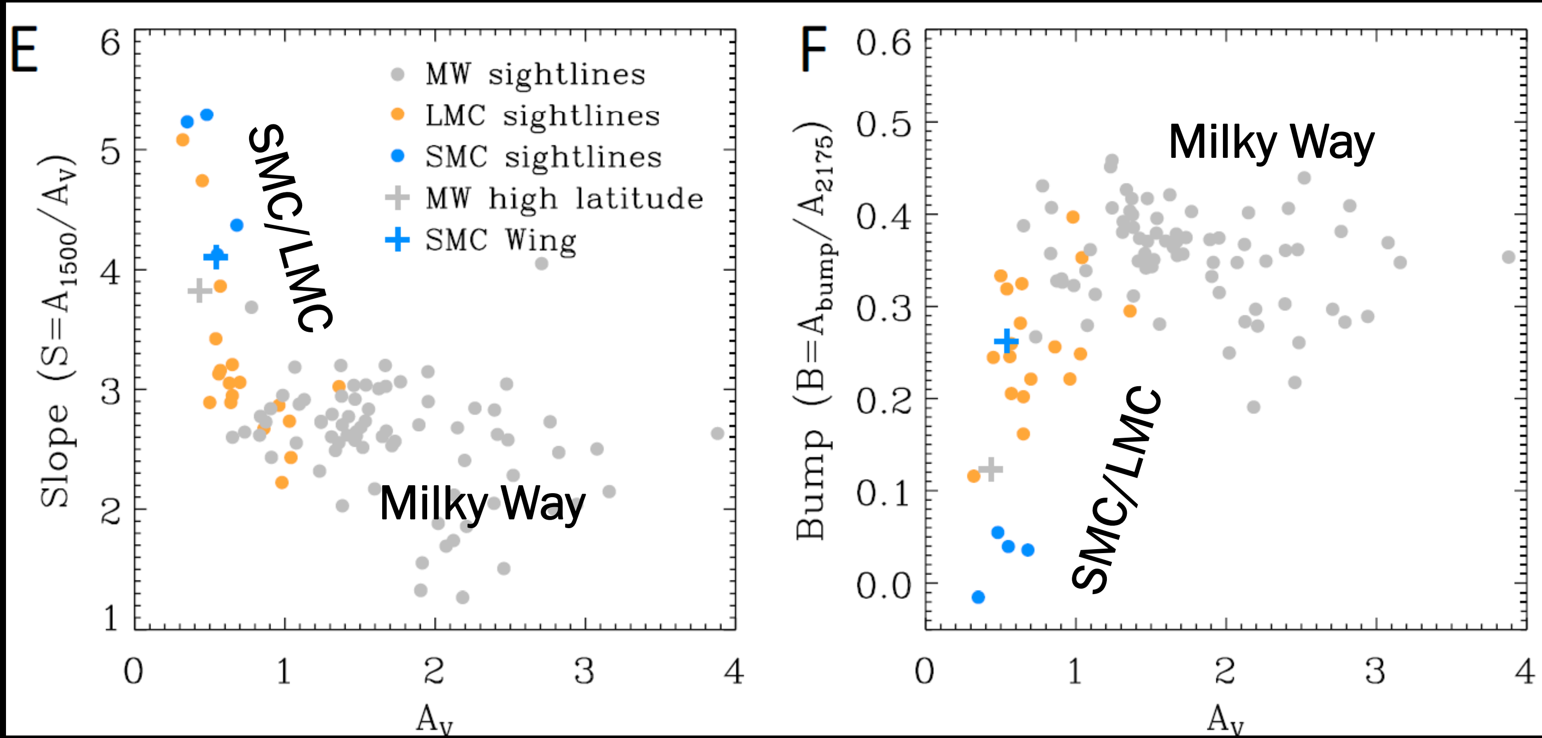
- Extinction curves slope and bump depend on:
  - composition
  - grain size distribution
  - not on dust density

MW standard curve

- OB stars
  = low latitude
  = high extinction
- MW/MC opt curve ~
- High-latitude UV curve not well known
  - challenging







Salim & Narayanan (2020)

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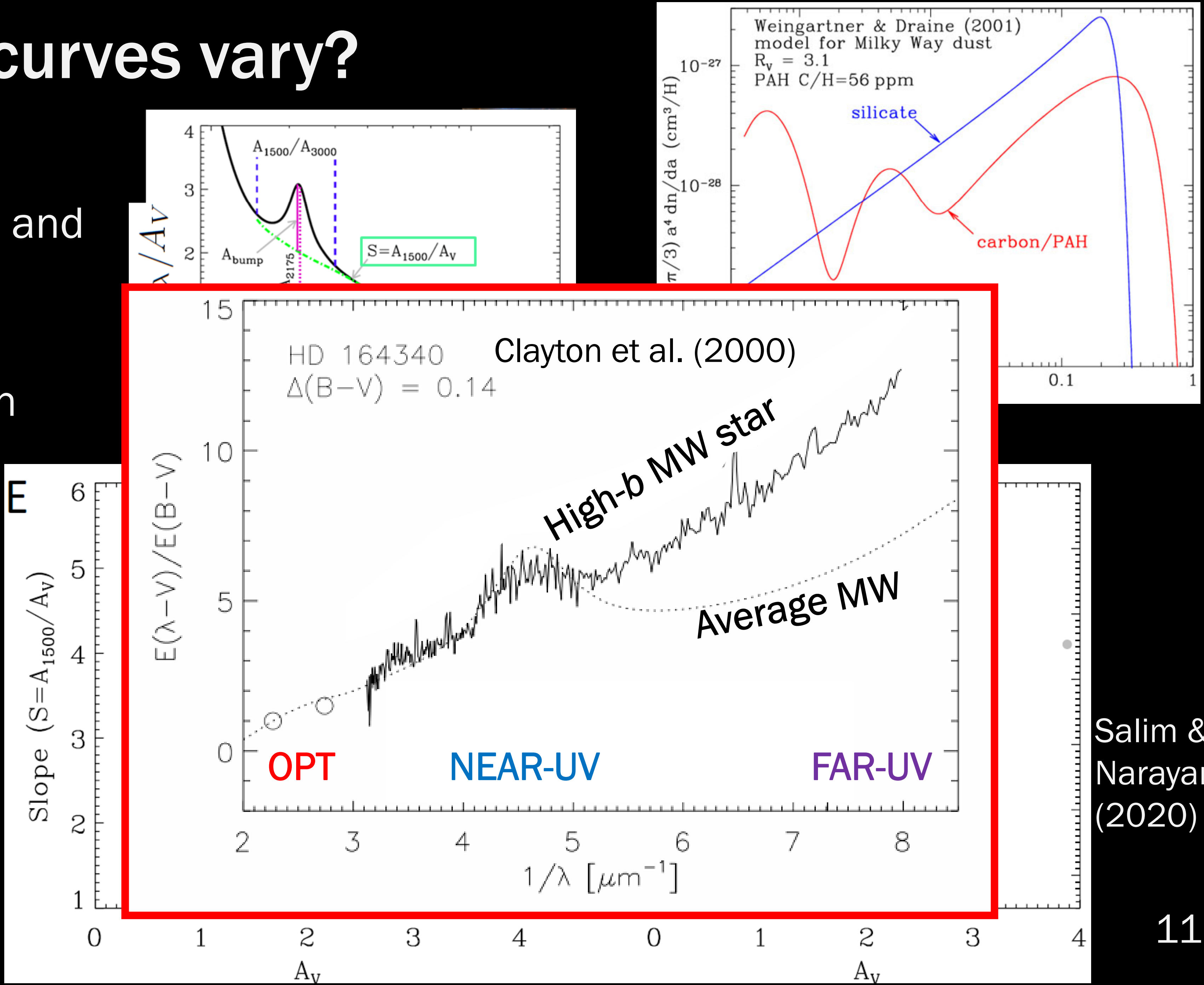


Salim & Narayanan (2020)

Diversity of extinction curves

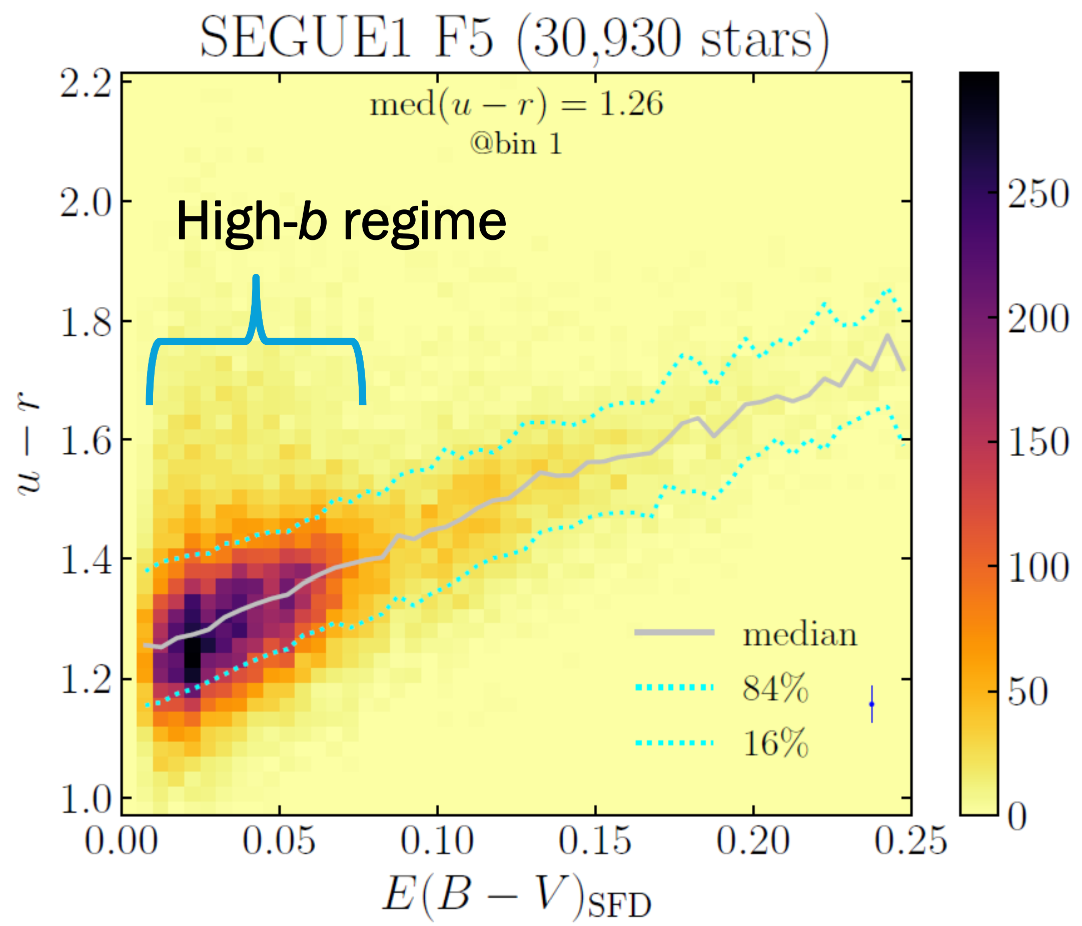
High-latitude UV/optical curve

- Use extensive SDSS spectroscopy
  - 500,000 stars
- Spectral type + stellar par known
  - intrinsic
  - average
- + GALEX, 2MASS, WISE

MW dust correction for external galaxies

- E(B-V) -> A(3000A)
- Non-standard (low-latitude) curve

Takeaway: Extinction curve may be more like LMC at high latitude

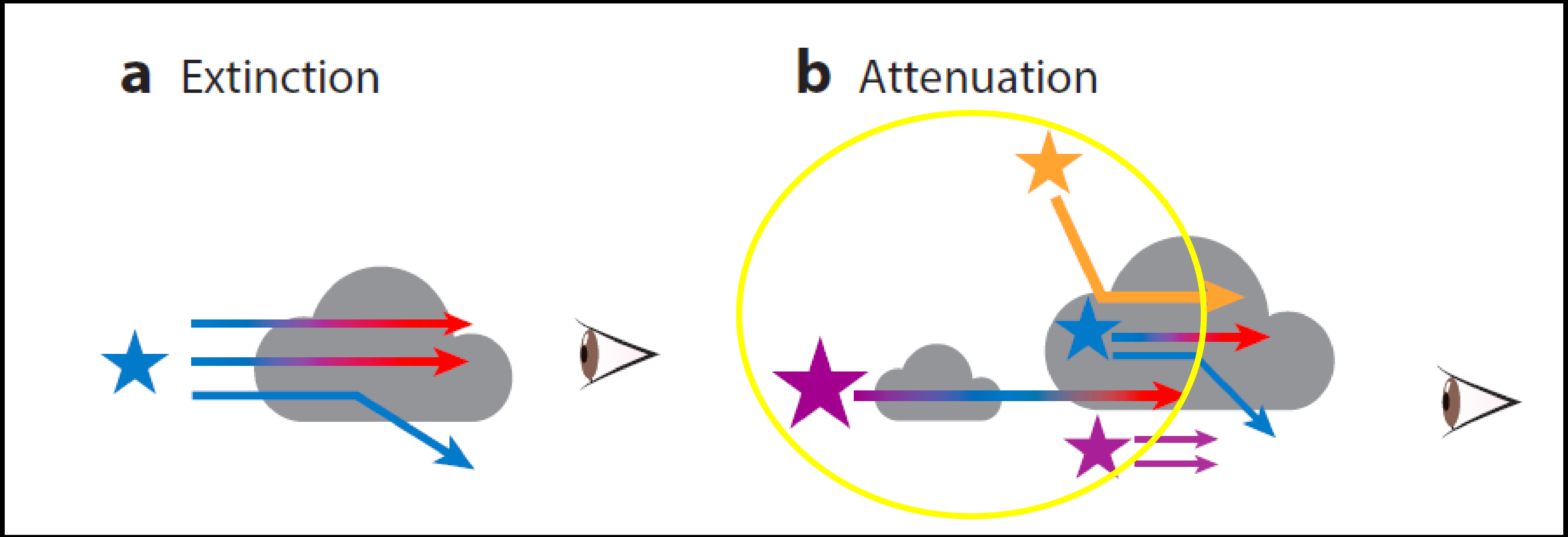


Butler (in prep)

Attenuation

Attenuation vs .extinction

- Integrated light loss for extended objects
- Extinction + scattering into line of sight
  - local geometry (dust/stars distribution)
  - global geometry (viewing angle)



Salim & Narayanan (2020)

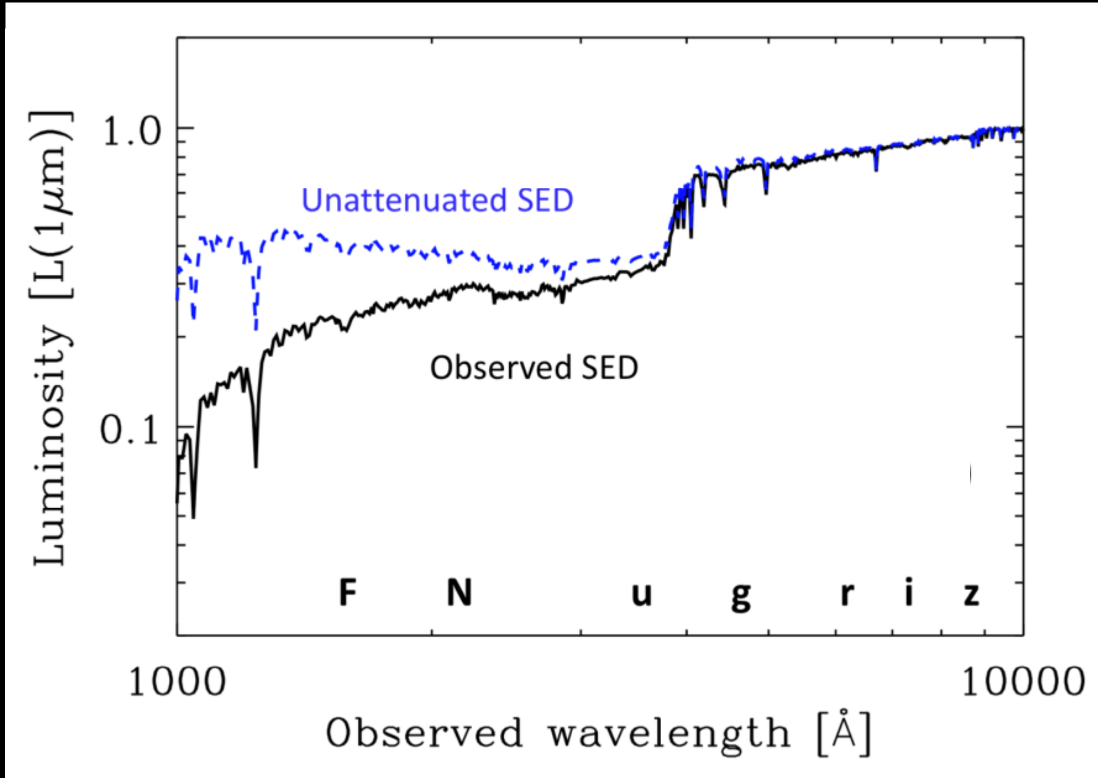
Dust attenuation curves

Dust attenuation curve

- Dust attenuation as a function of λ normalized to V

Challenge

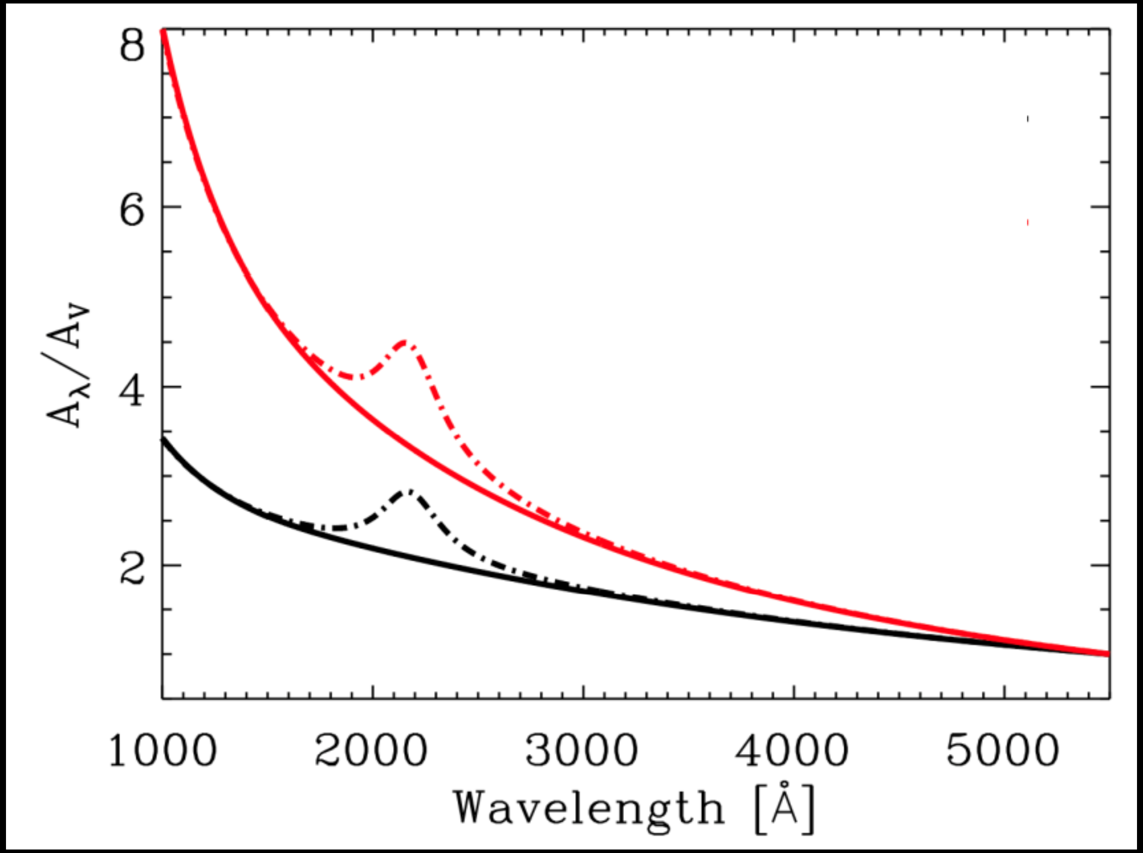
- What is the dust-free SED of a galaxy? Use models



Dust attenuation curves

Questions

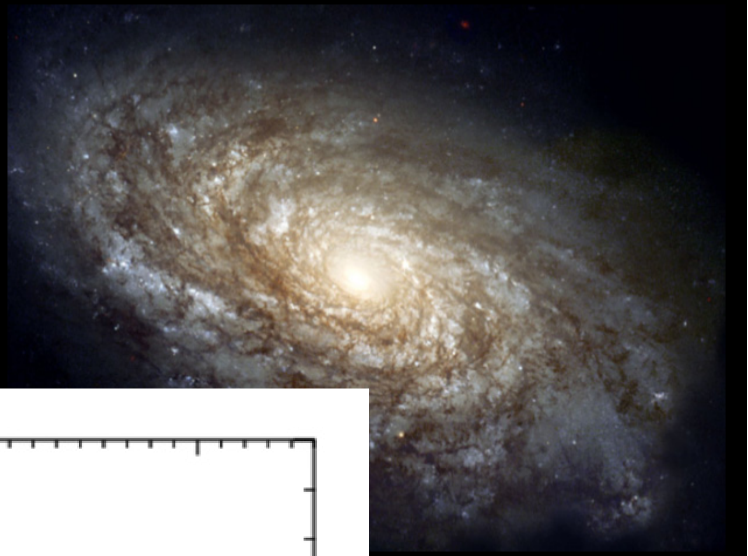
- Shape of the typical curve (“law”)
- Diversity? Dependence on xyz?
- Evolution?

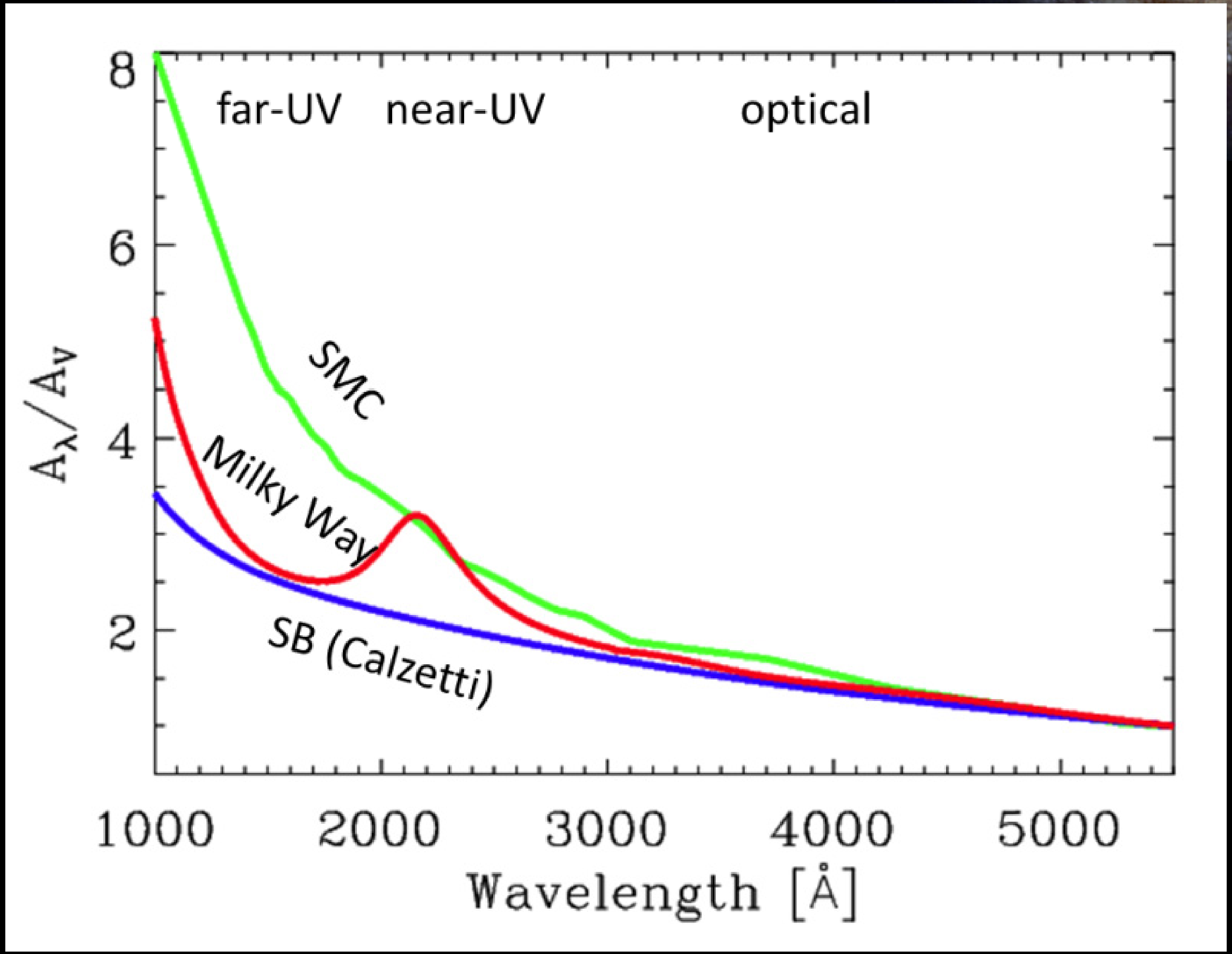


Dust attenuation curves

Physical parameters from SED fitting

- Usual approach: assume a curve
  - Calzetti
  - MW
  - SMC
- MW, SMC are not attenuation curves
- Is Calzetti curve universal?





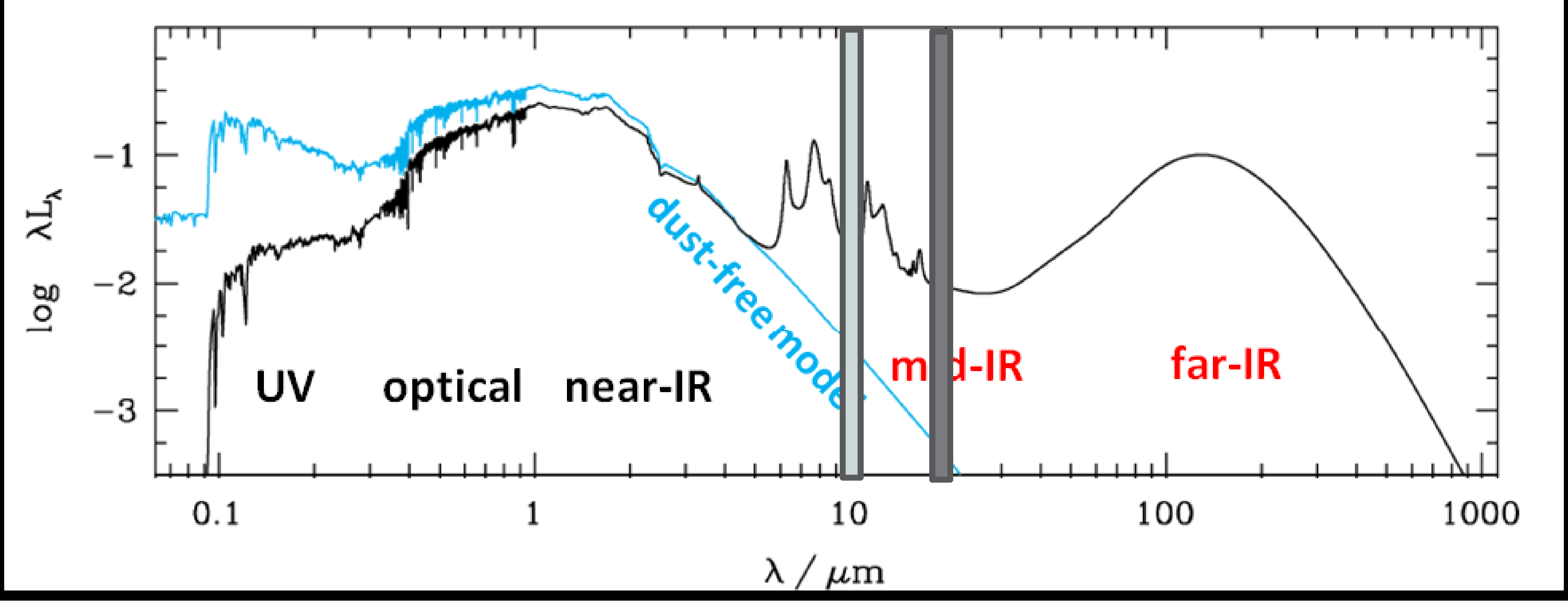
Attenuation curve from SED fitting?

Attenuation curve can be constrained rather than assumed if IR is available

- Energy balance argument
- WISE 12 and 22 um converted to L(TIR) using templates

SED+LIR fitting with free curve parameters

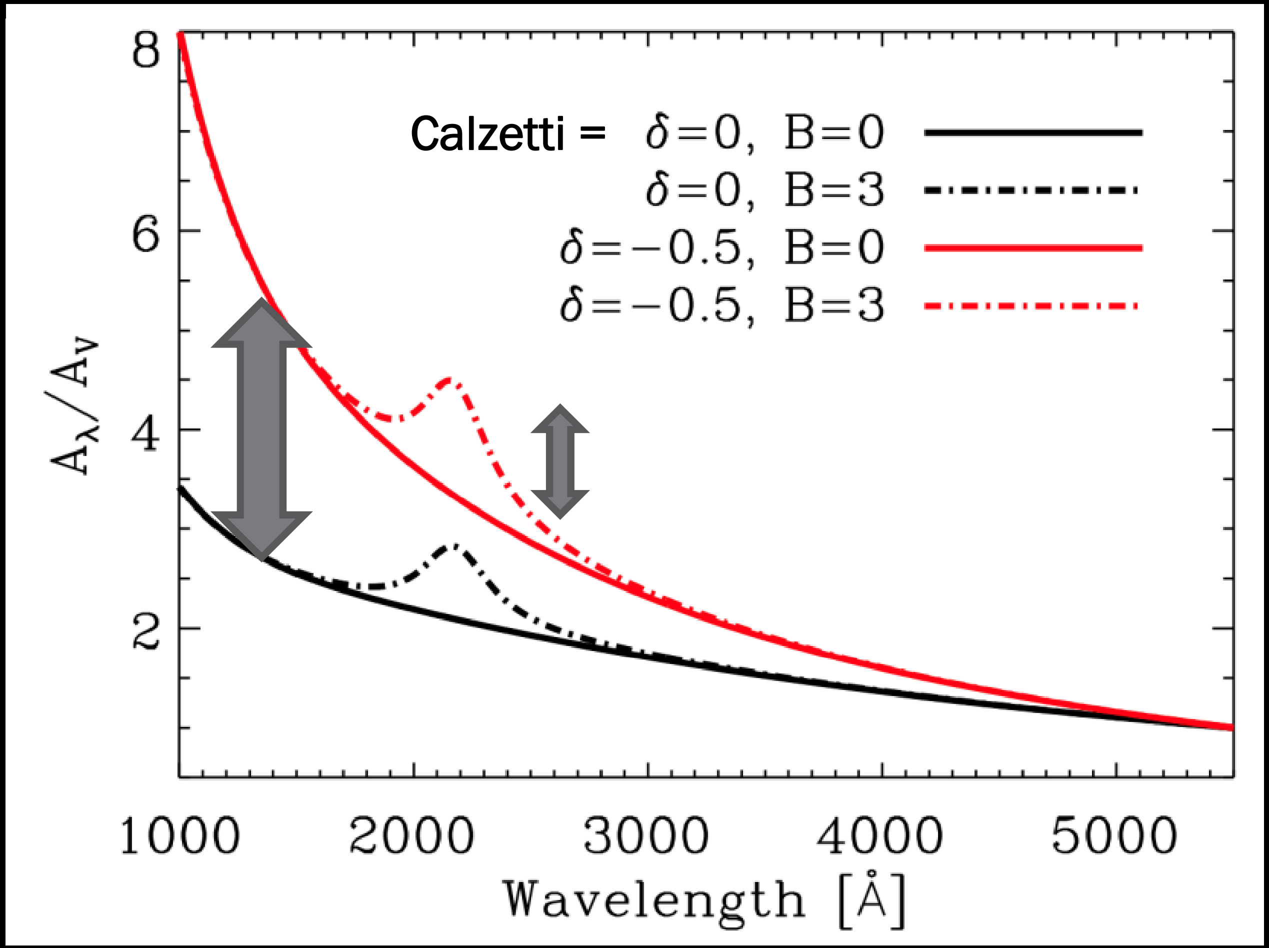
- FUV, NUV, ugriz + LIR



Attenuation curve from SED fitting?

Leave attenuation curve free

- 2 parameters:
- slope of modified Calzetti curve
- UV bump



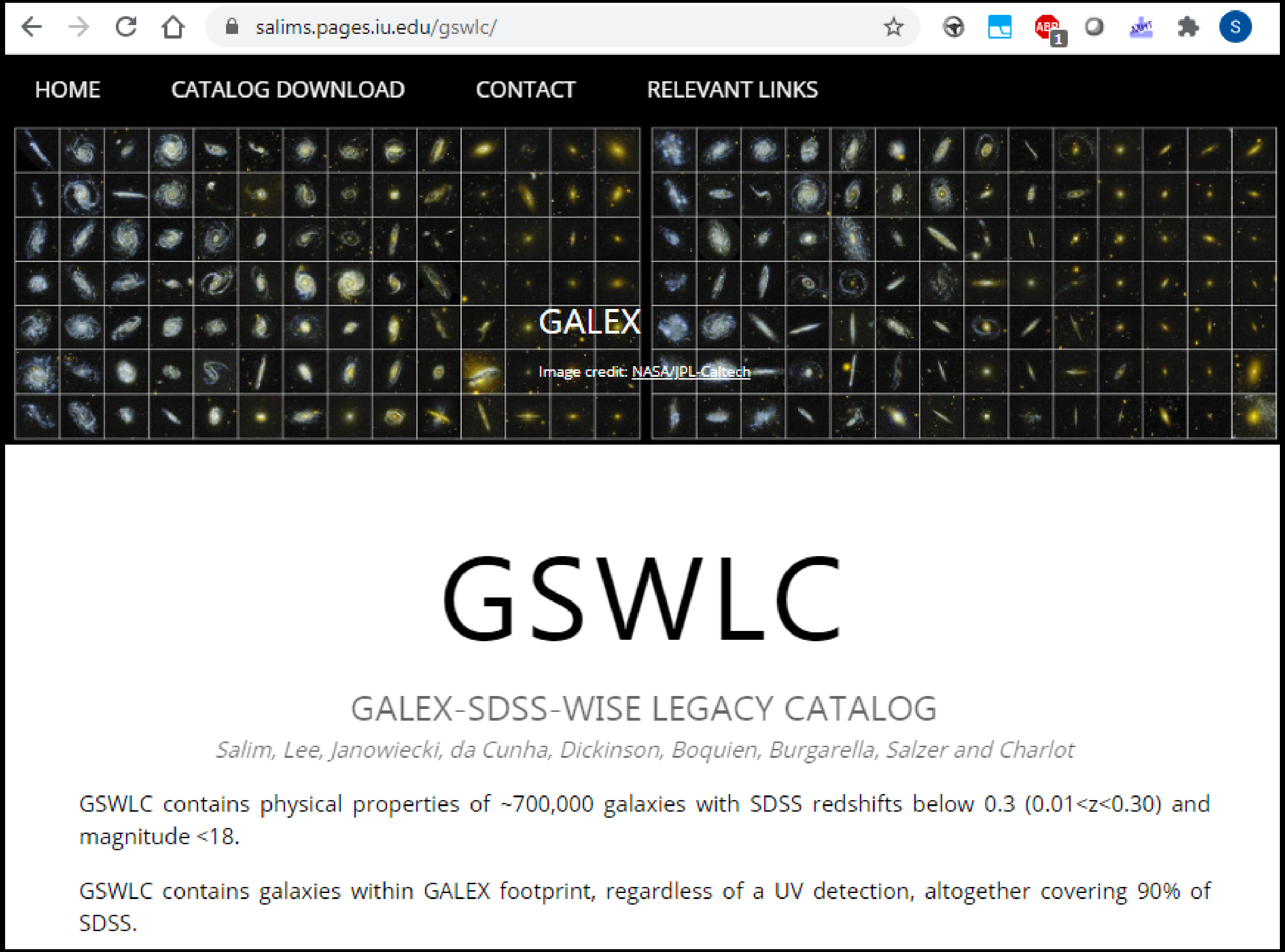
SDSS-based sample

230,000 galaxies with WISE data

- z < 0.3
- GALEX UV
- SDSS
- WISE mid-IR

GALEX-SDSS-WISE Legacy Catalog (GSWLC; Salim+ 206)

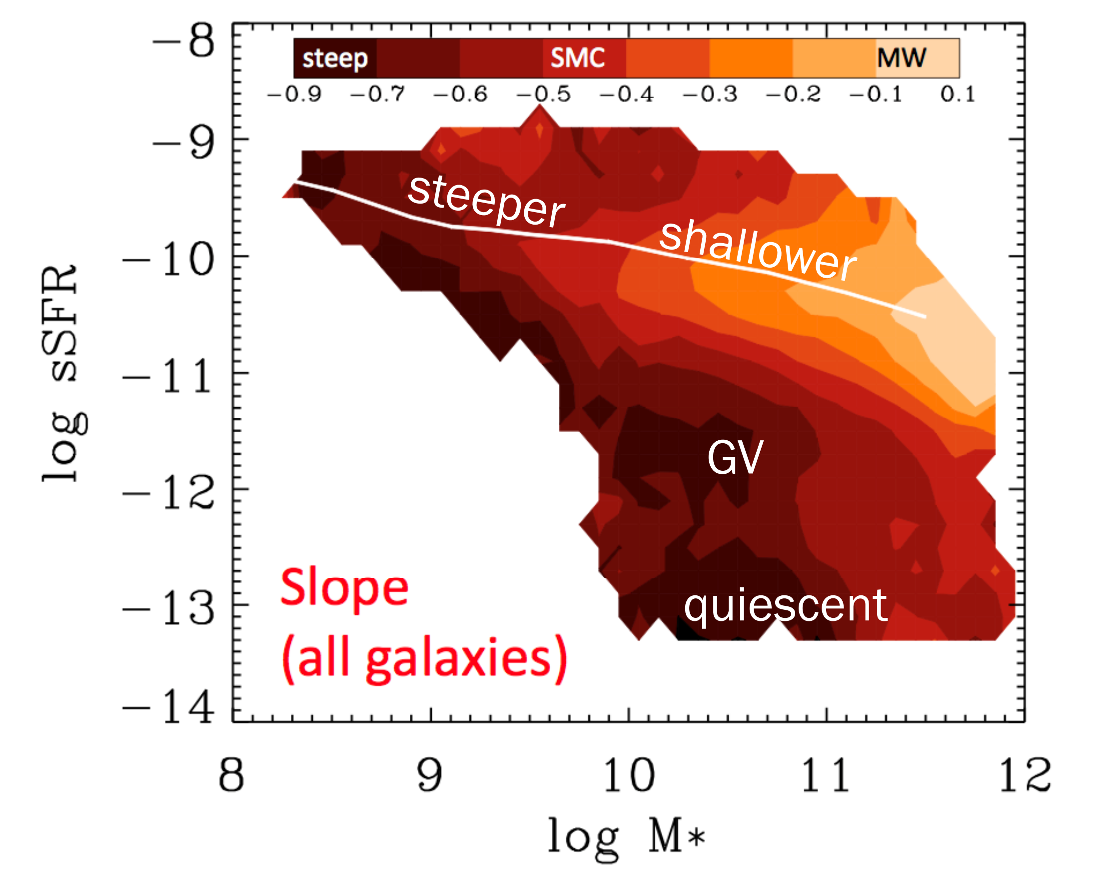
- 700,000 galaxies
- SED fitting M*, SFRs, attenuations
  - SFR accuracy: up to 0.1 dex

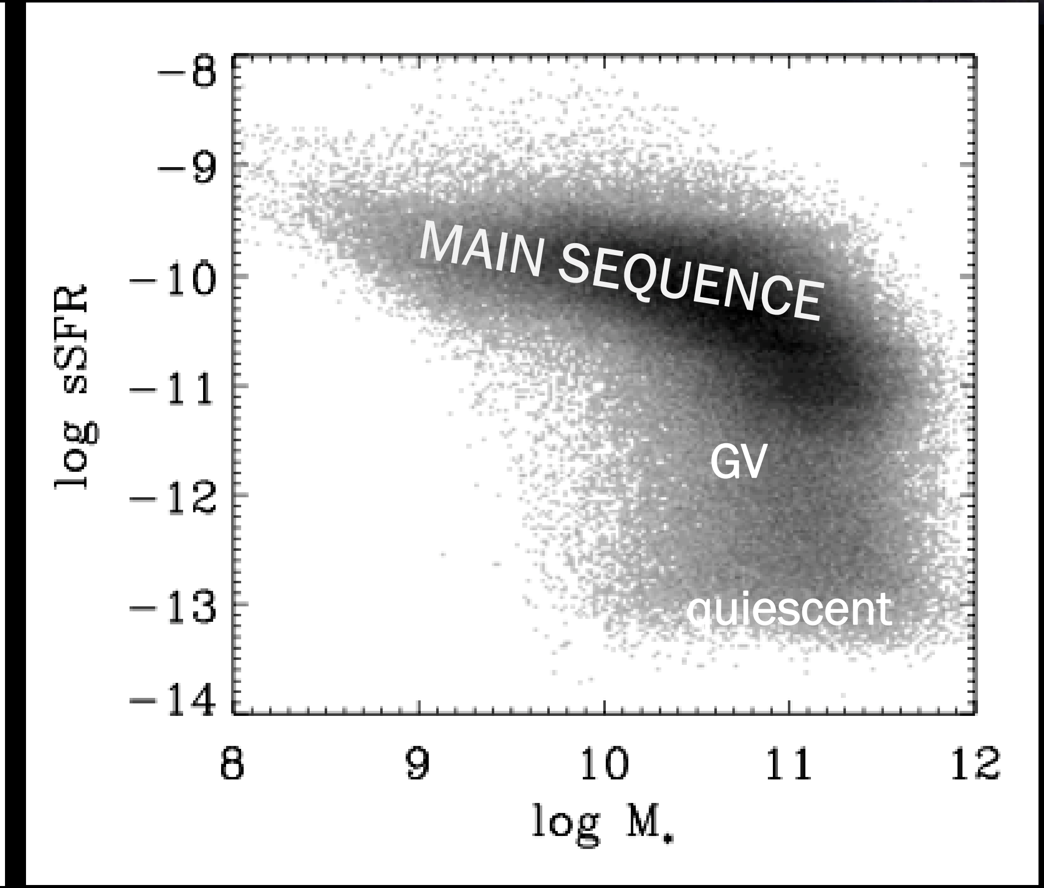


Attenuation curve slopes

Maps of average slopes

- Takeaway: Very large range of slopes; steep on average





Salim , Boquien and Lee (2018)

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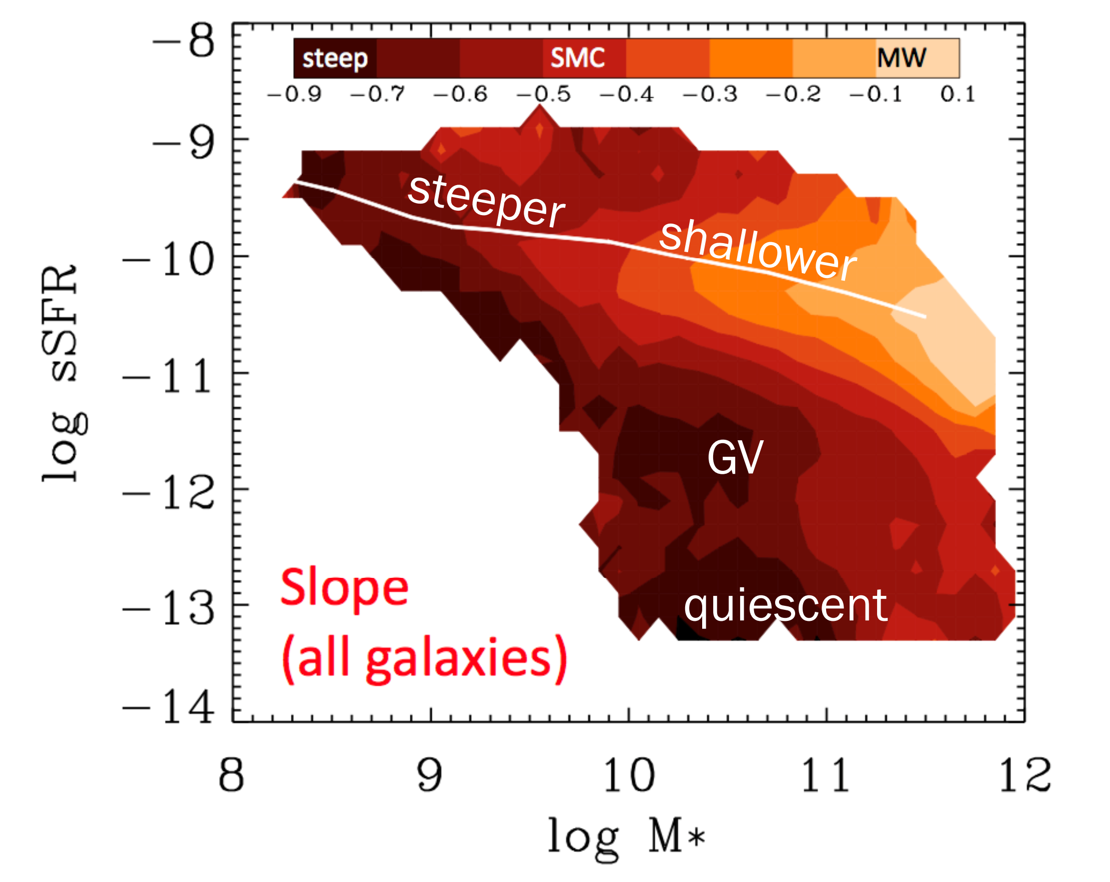
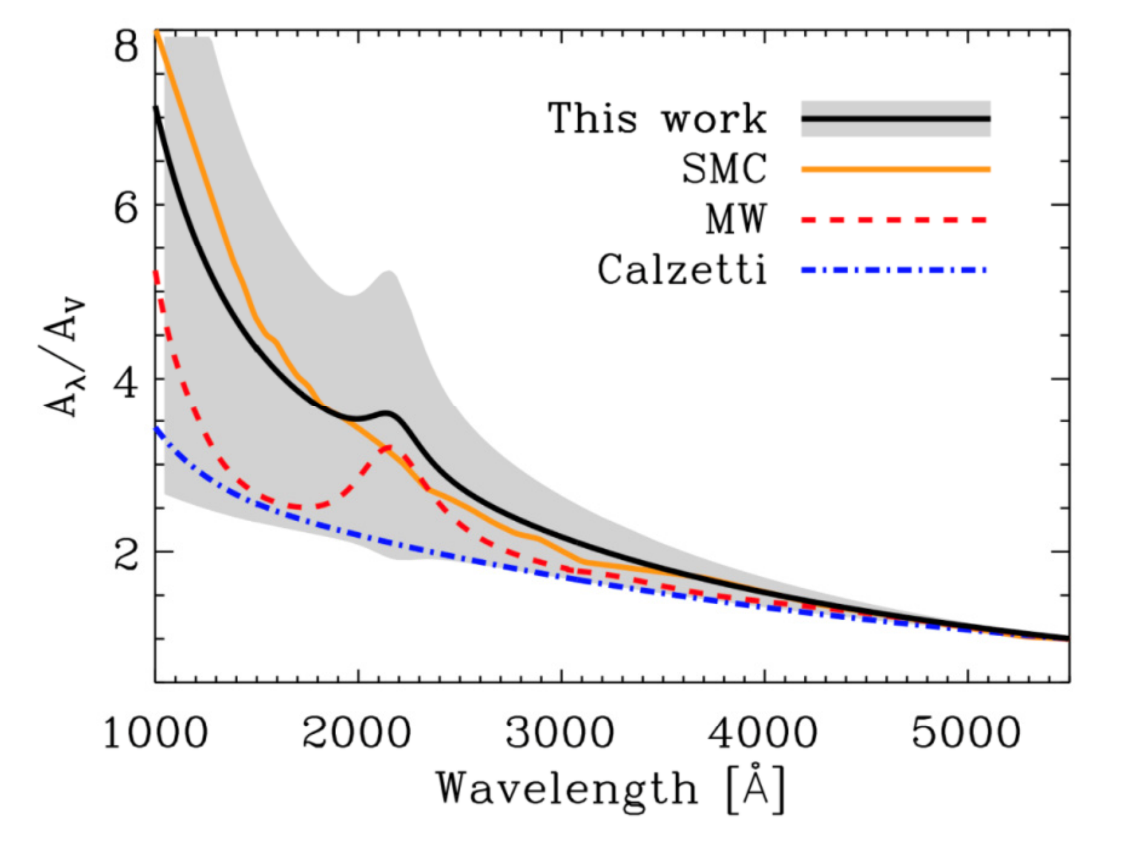
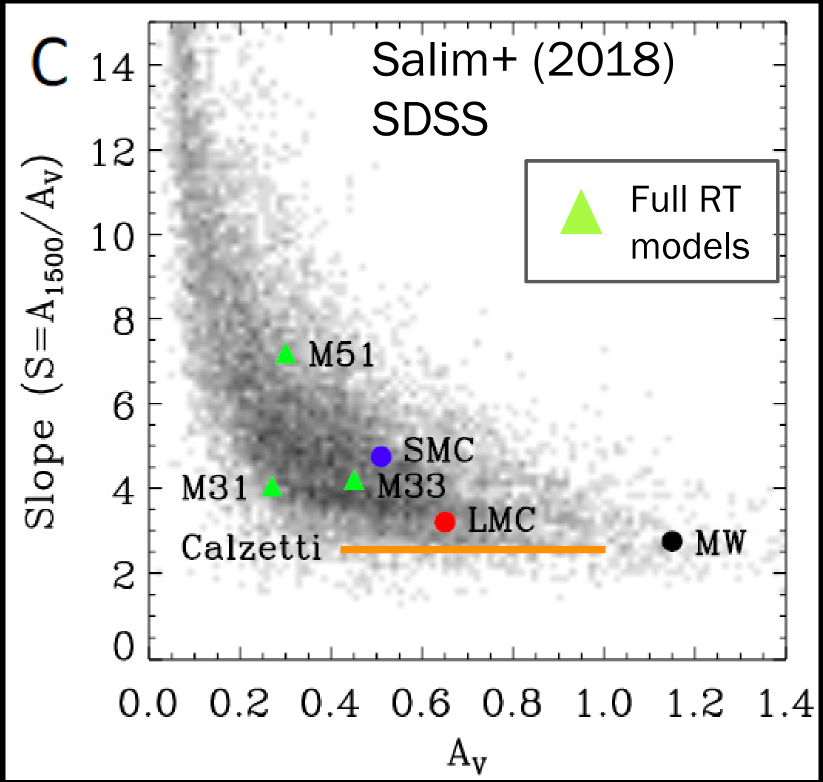


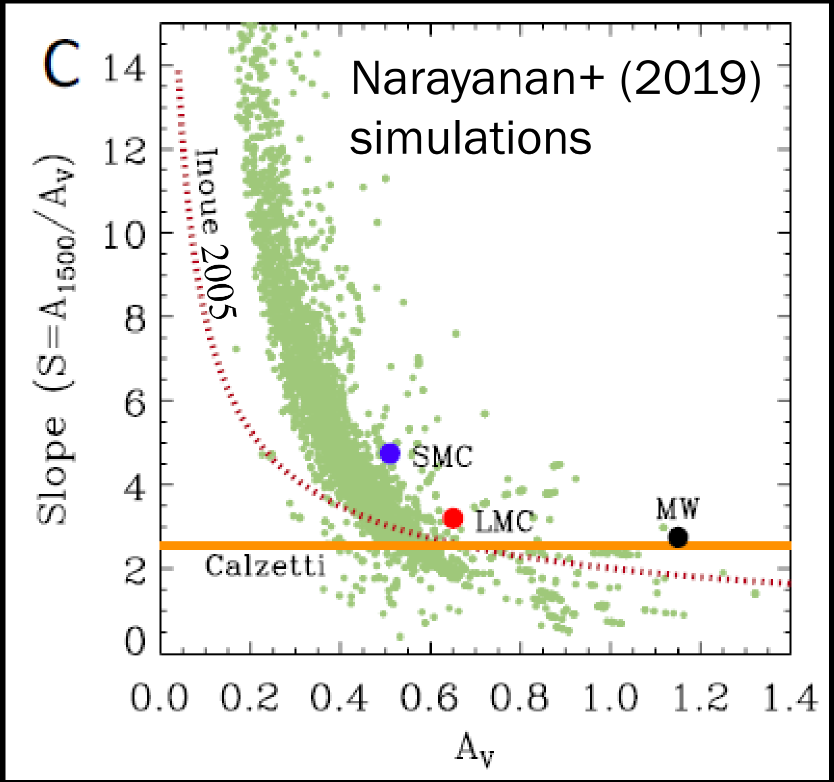


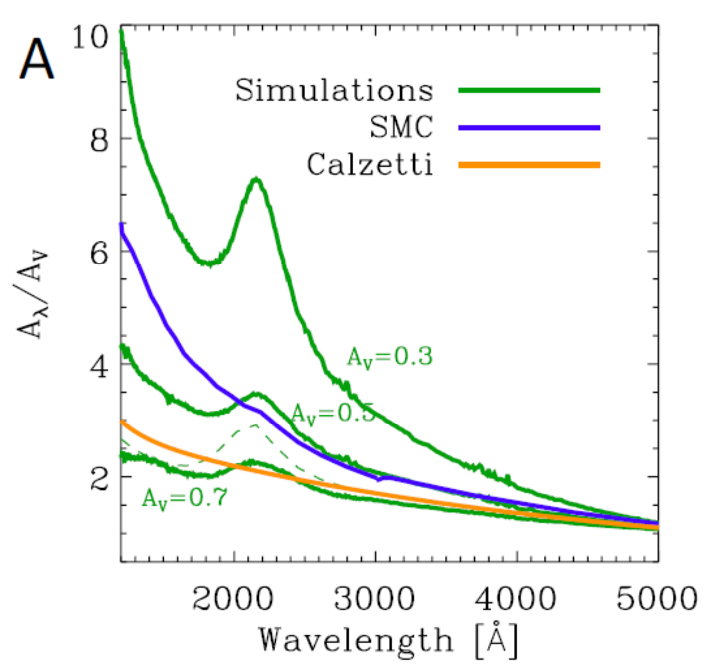
Salim , Boquien and Lee (2018)

What drives attenuation curve slopes?

- Predicted by RT models (Pierini et al. 2004; Seon & Draine 2016)
  - Low opacity: scattering dominates (highly λ dependent)
  - High opacity: absorption dominates (grey)
  - Takeaway: attenuation curve slope correlated with the amount of dust



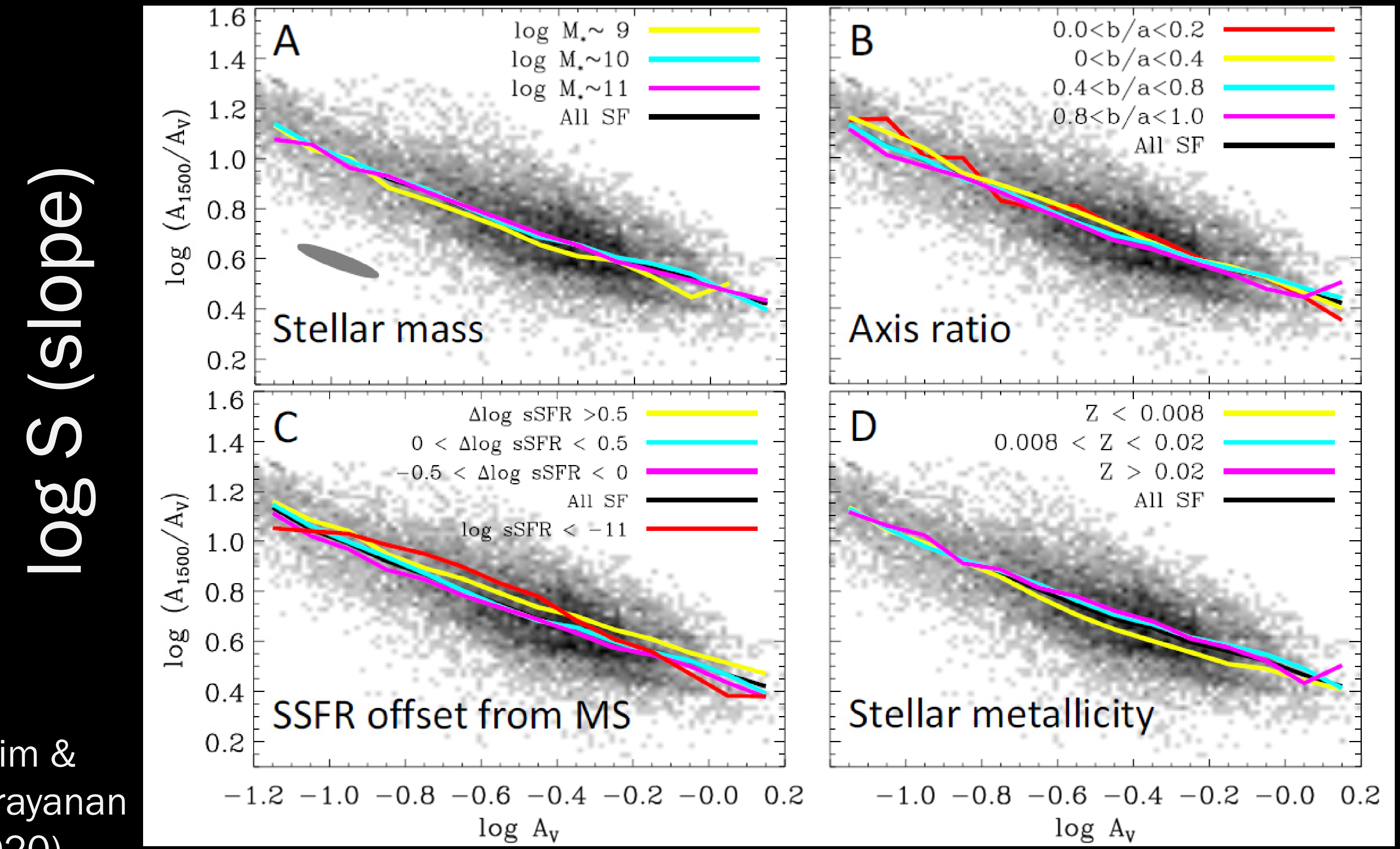




Salim & Narayanan (2020)

What drives attenuation curve slopes?

Residual dependence on other parameters



Takeaway: Slope does not depend directly on SFH, global geometry; only through dust column density

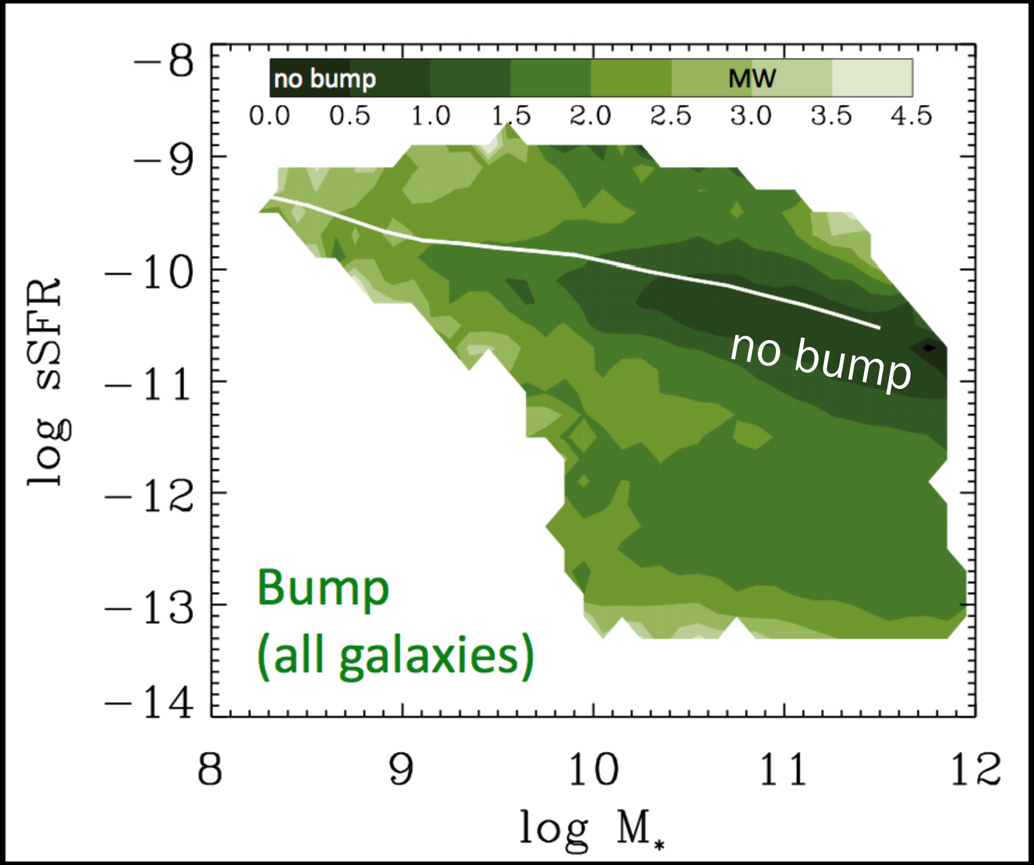
Residual scatter – different dust compositions?

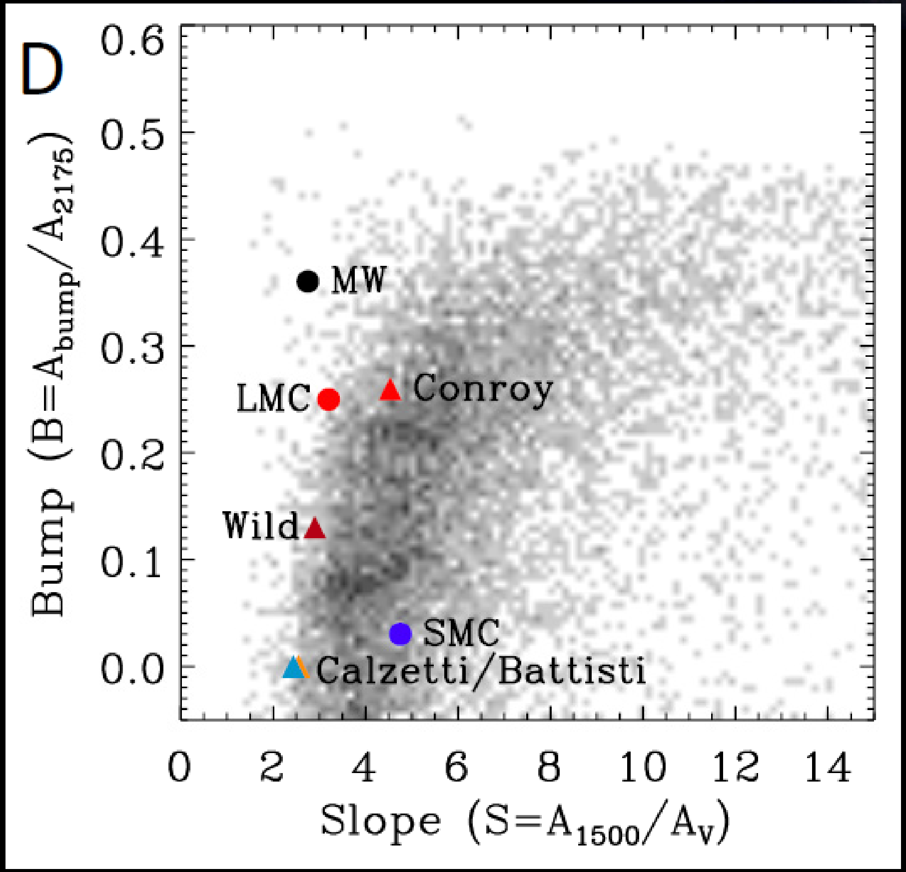
Salim & Narayanan (2020)

Attenuation curve UV bump

Wide range of UV bump strengths

- Stronger bump in steeper curves (also Kriek and Conroy 2013)
  - opposite from the MW-SMC “trend” for extinction curves





Salim, Boquien & Lee (2018)

Salim & Narayanan (2020)

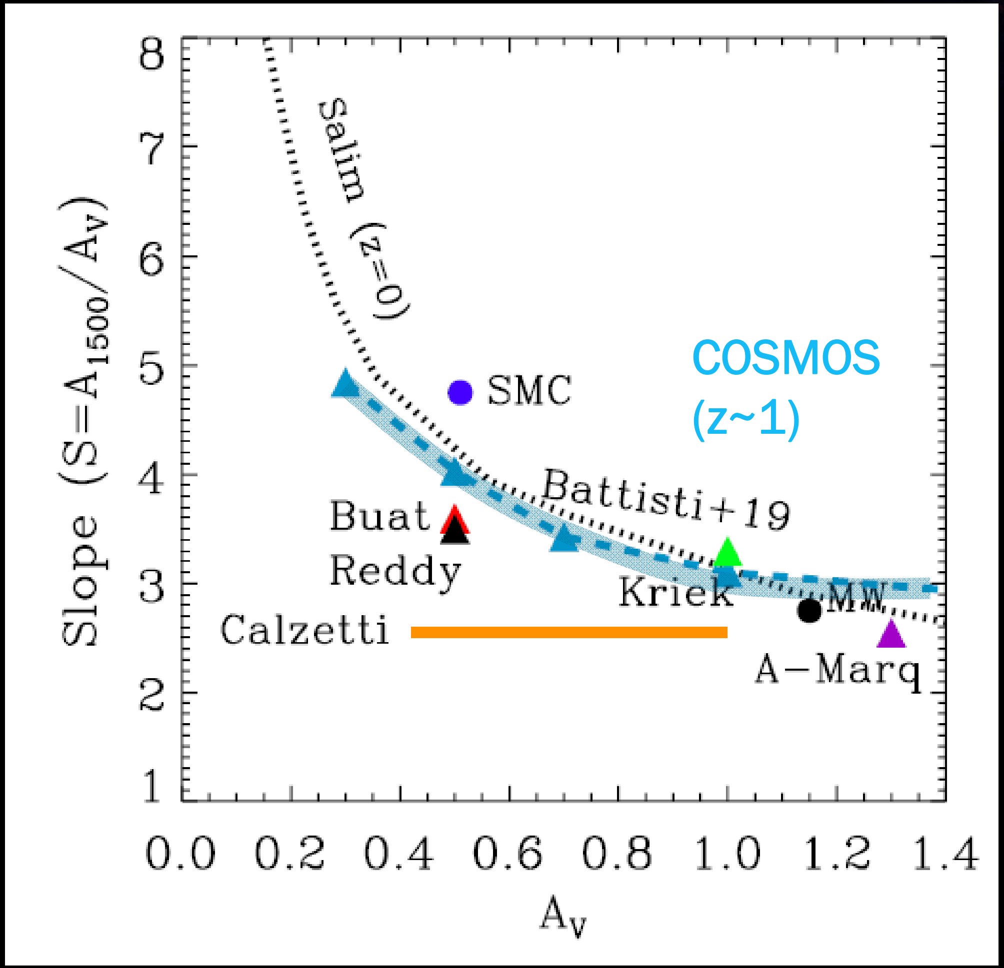
Evolution of the attenuation curve?

High-z results often inconsistent

- Important: compare all studies at the same Av

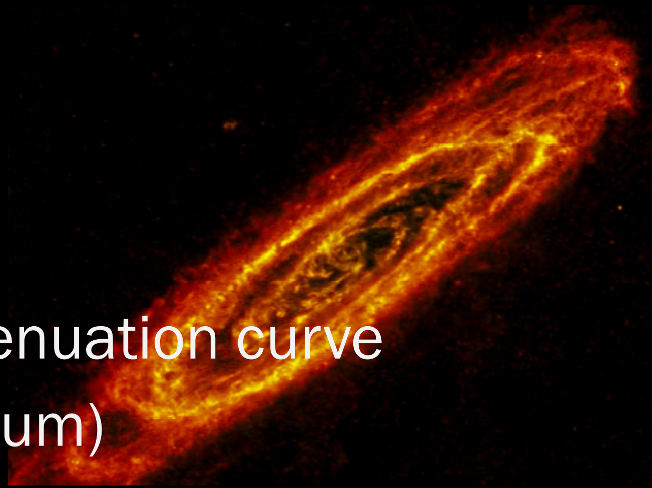
Takeaway: At a given Av attenuation curve (slope) may not evolve much

Comparing LBGs, DSFGs, z>6, etc requires caution



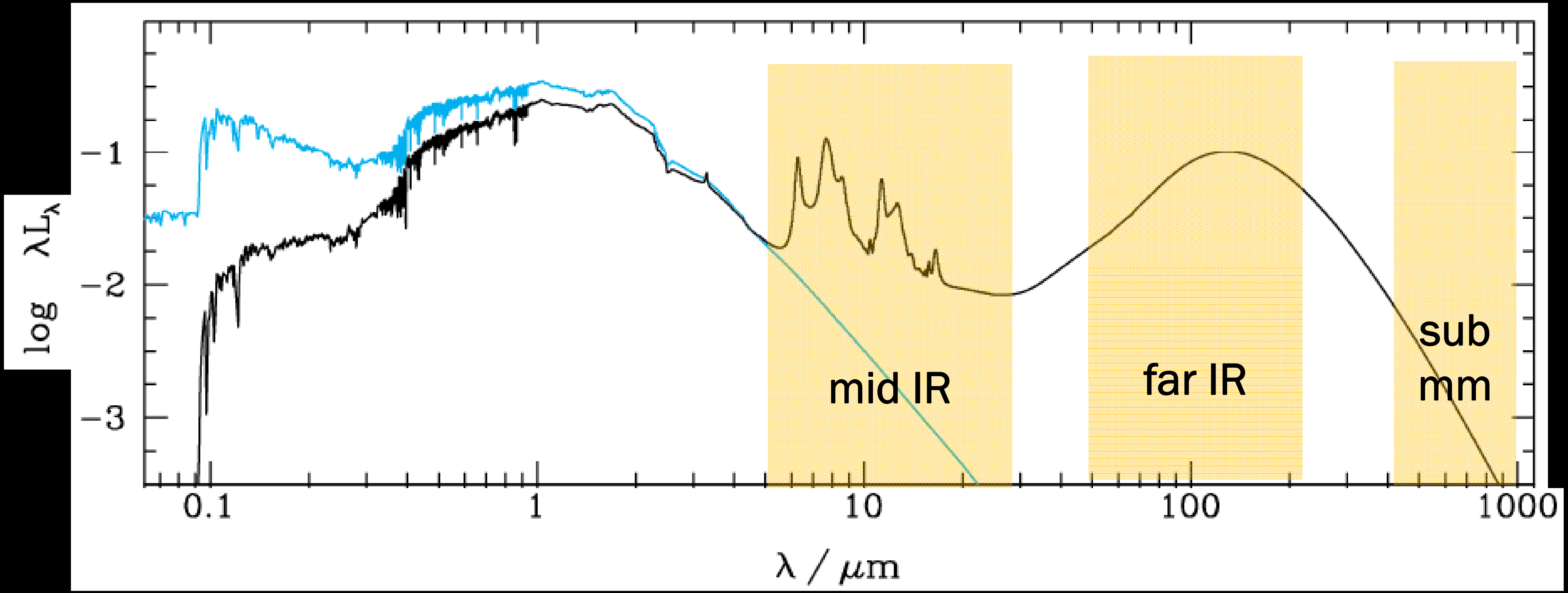
Salim & Narayanan (2020)

Dust emission in IR



Total IR luminosities and SFR from IR

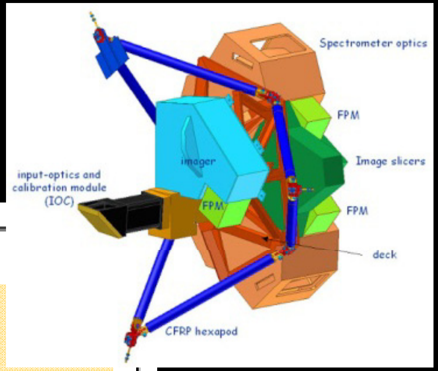
- Total IR luminosity (L(TIR)) circumvents the need to know the attenuation curve
  - SFR = Unobscured SFR (=UV lum) + Obscured SFR (=total IR lum)
- L(TIR) – need wavelength sampling in mid-IR, far IR and sub-mm

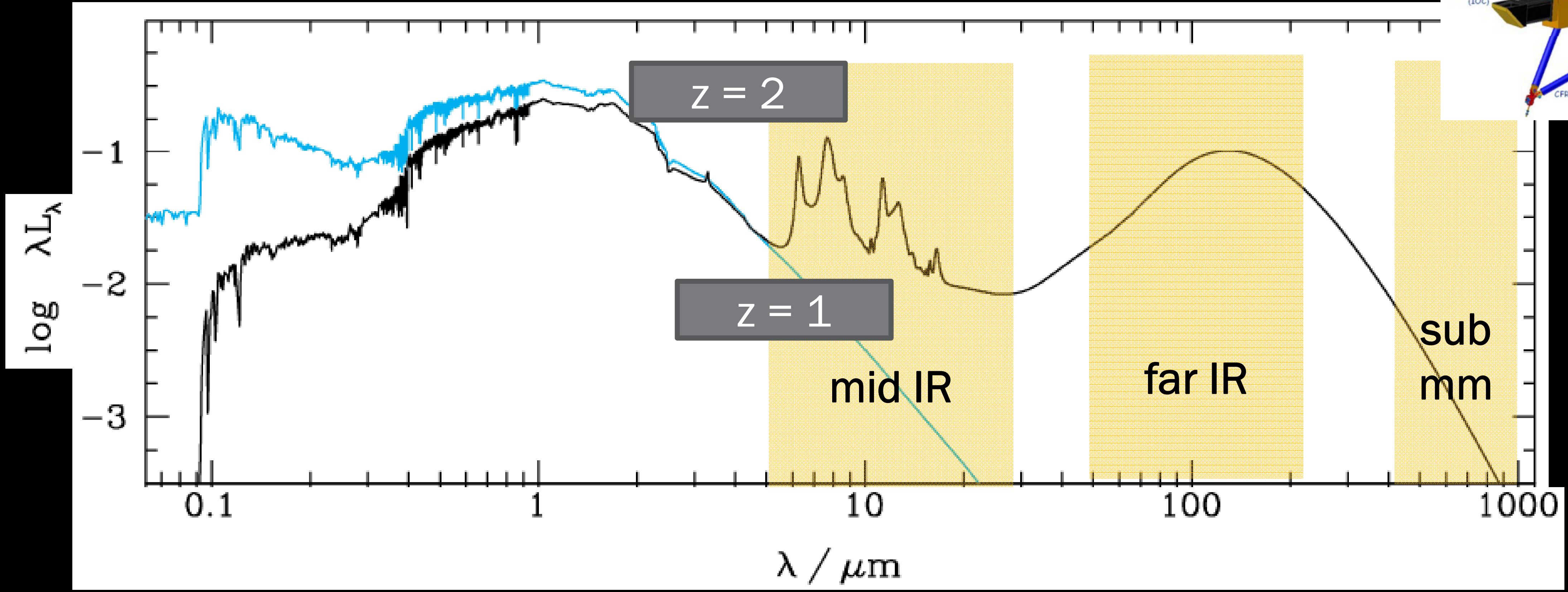


Dust emission in IR

JWST MIRI = mid IR

- Extrapolation to get L(TIR) requires templates
- Templates (dust spectra) reduce range of possible shapes



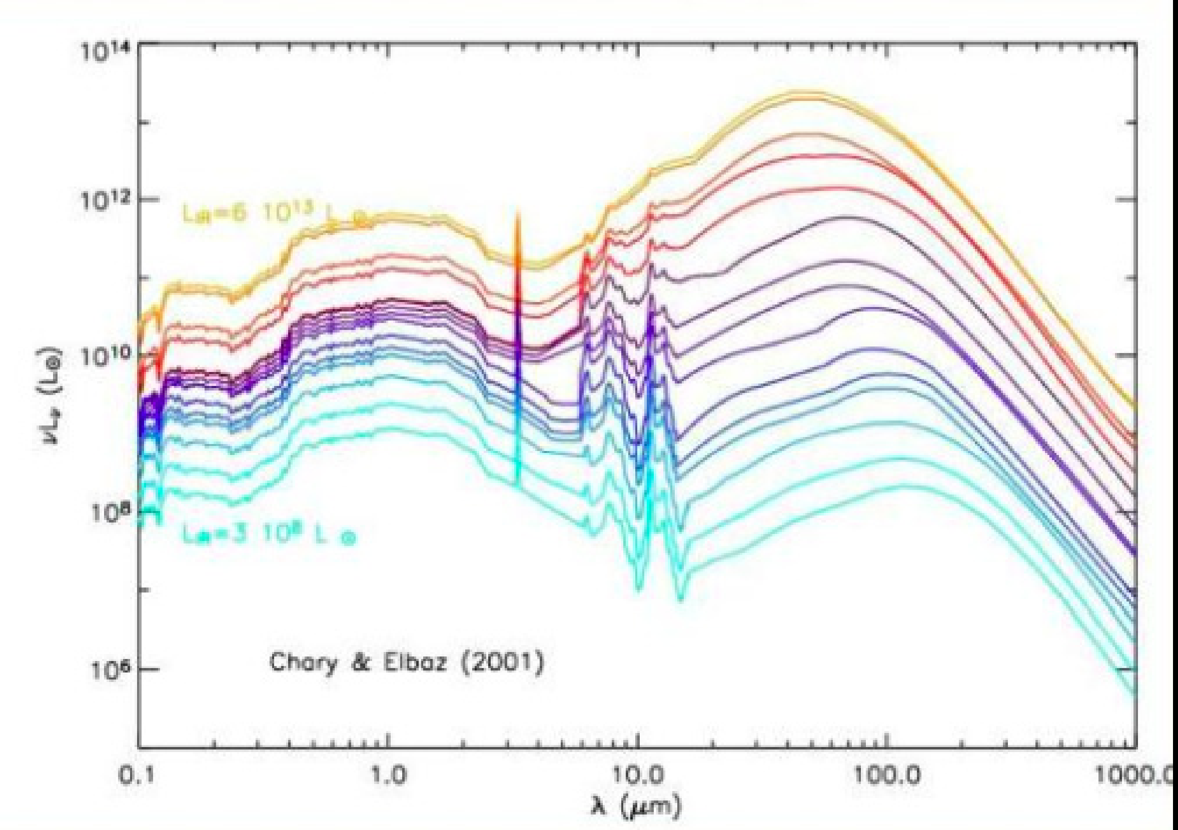


Dust emission in IR

Existing templates

- Local templates
  - small samples (~100)
  - parameterized on L(TIR)
  - IRAS selected
  - not appropriate for normal SF galaxies of same L(TIR)
- High-z templates
  - require stacking
  - AGN removal difficult
  - redshift parameterized

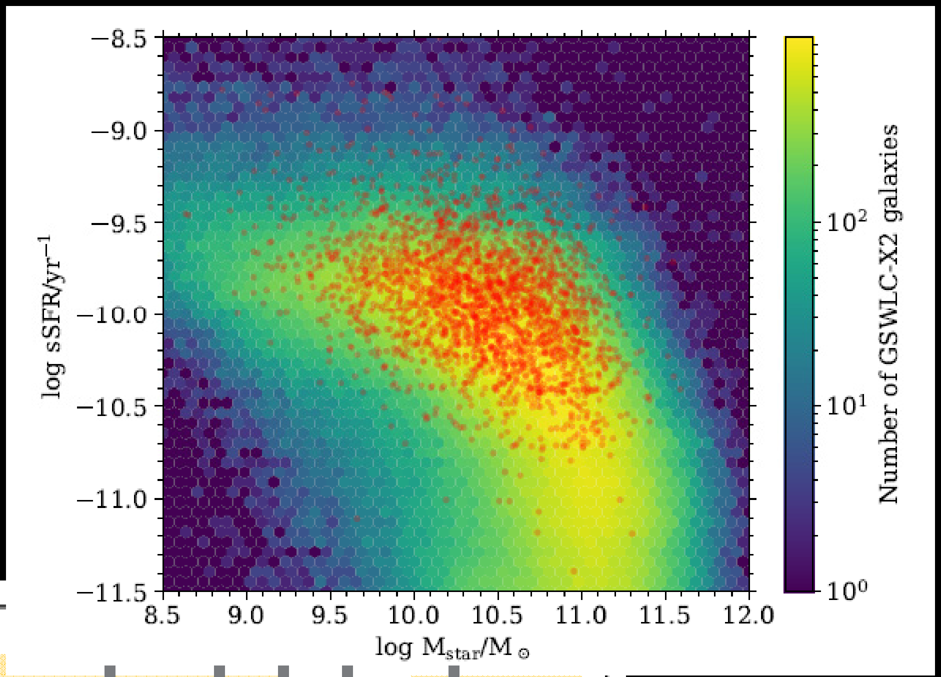
Templates for wide range of z and gal types?

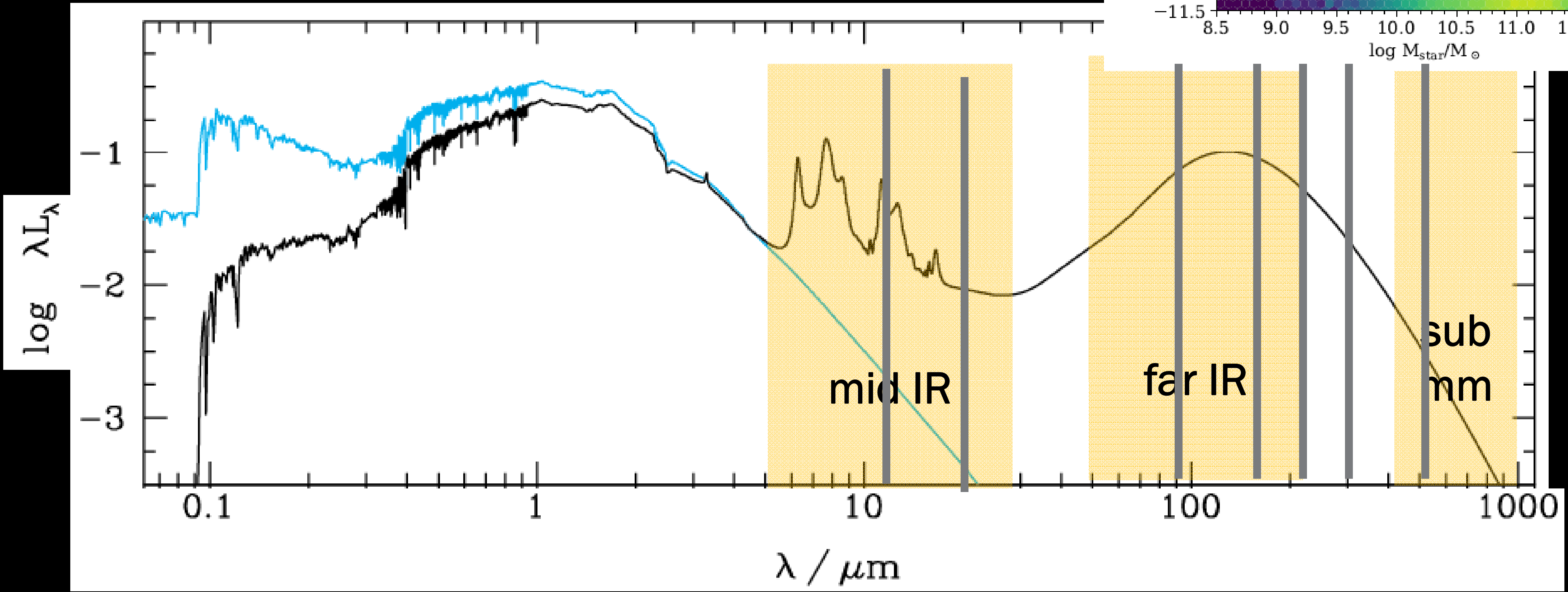


Dust emission in IR

WISE + Herschel –ATLAS (400 sq deg)

- 2500 non-AGN galaxies
- Low-z, but with wide range of sSFR
  - high-z “analogs”





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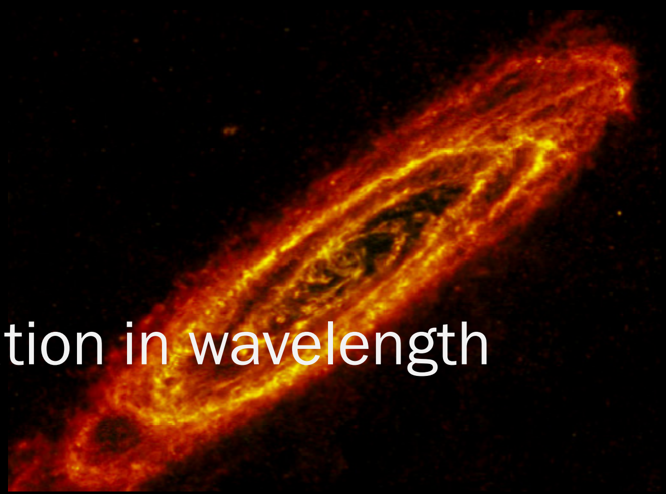
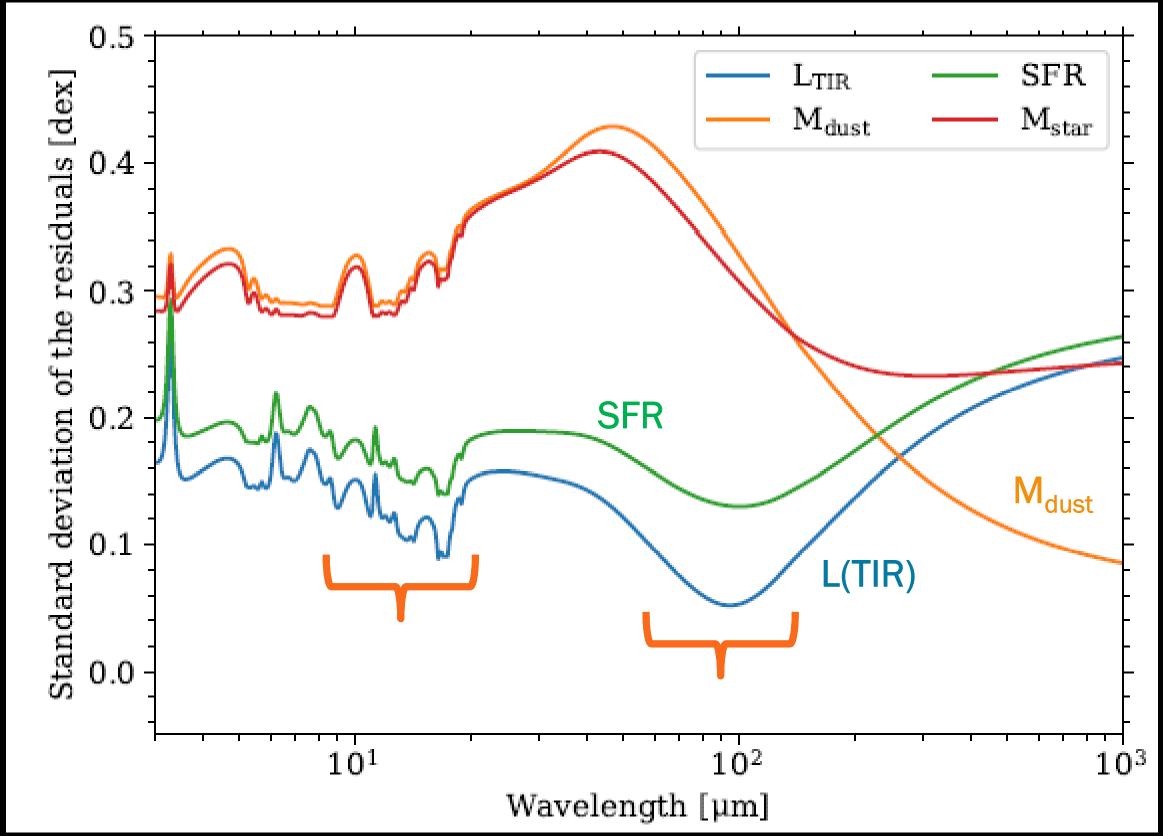


Approach

- Fit flexible models Draine & Li models to 7 IR points => interpolation in wavelength
- SED+LIR fitting to get M*, total SFR
- What IR range best constrains L(TIR)

Takeway: Best monochromatic tracer of L(TIR) or total SFR is mid-IR and ~peak

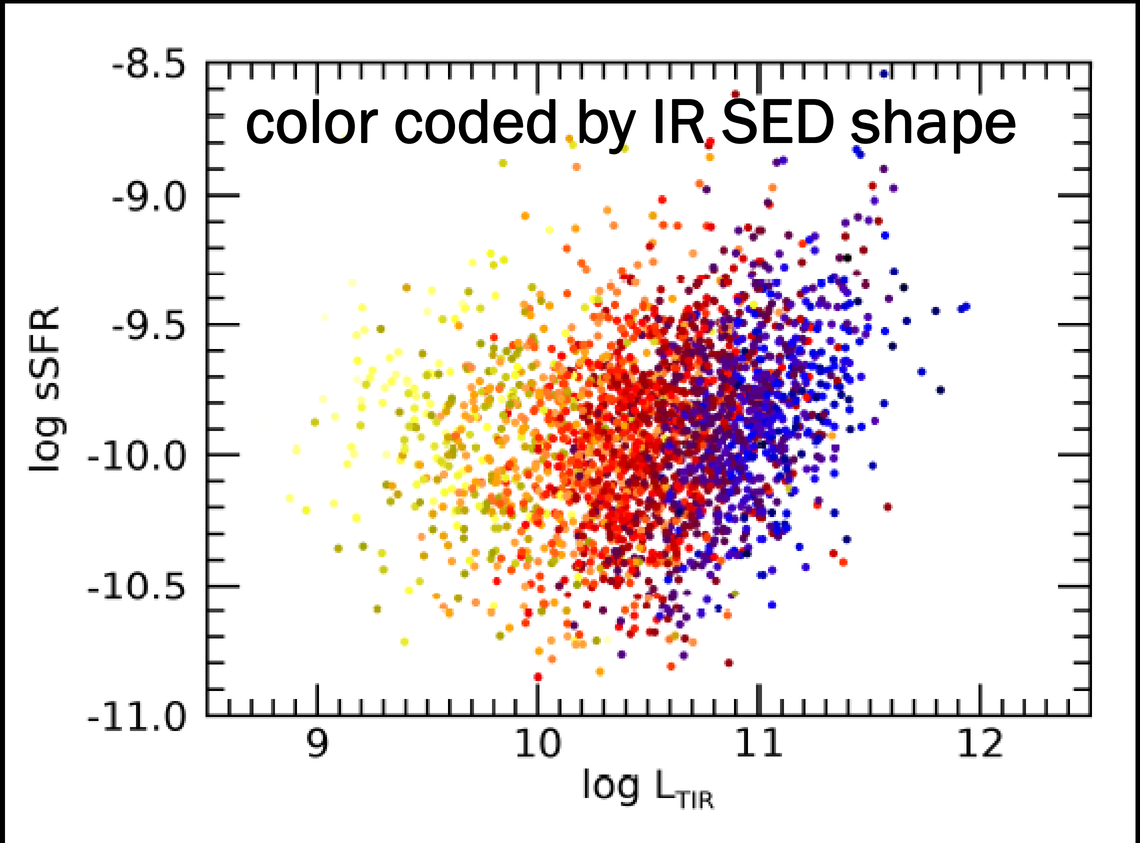


Boquien & Salim (in prep)

Dust emission in IR

Parameterization

- Dependence both on L(TIR) and sSFR
- Important for monochromatic estimates

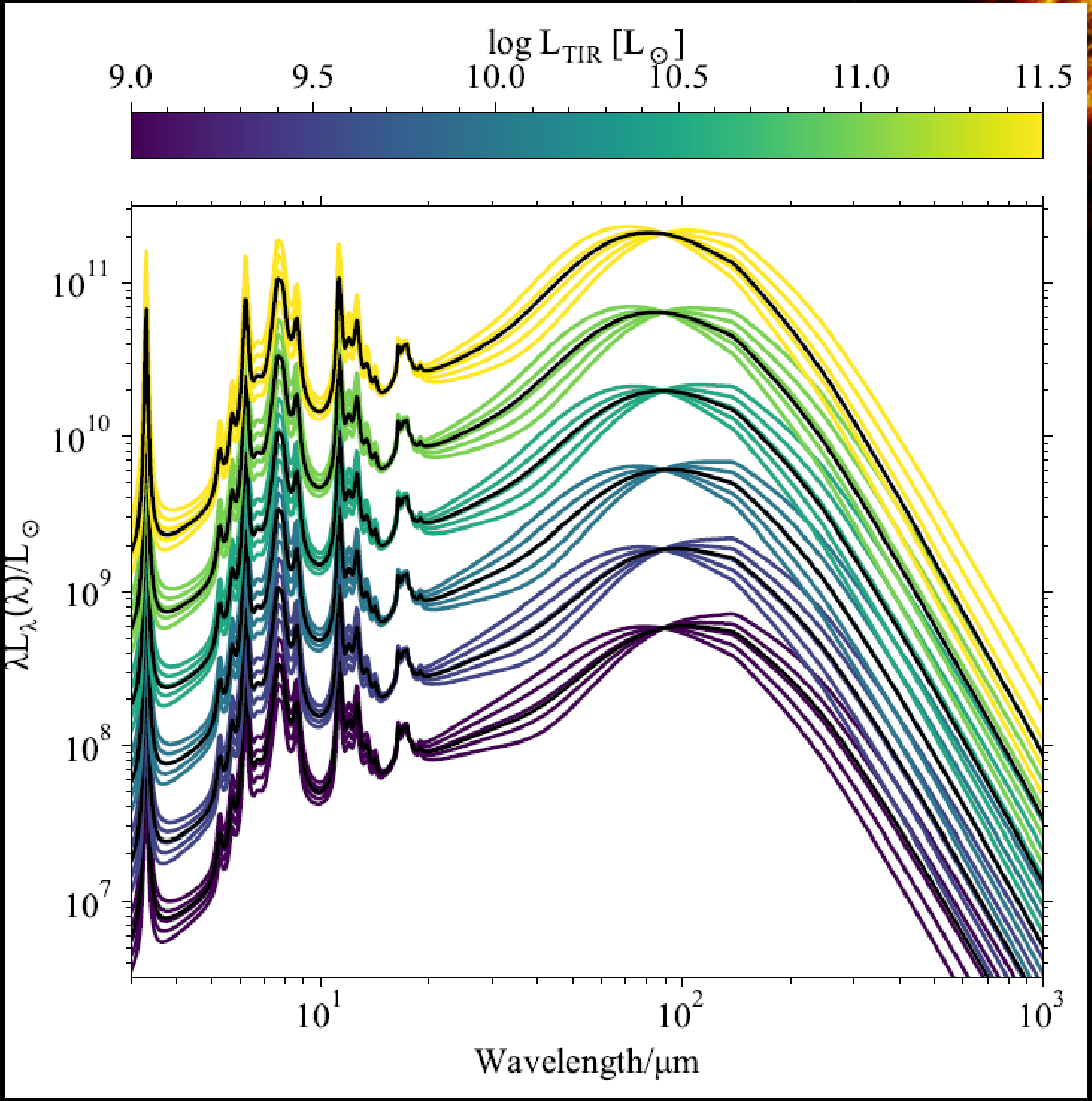


Boquien & Salim (in prep)

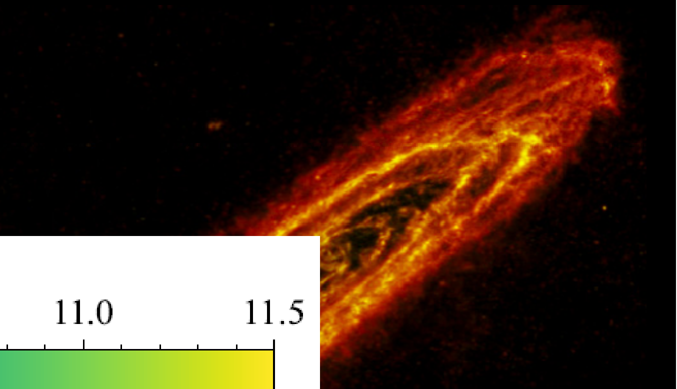
Dust emission in IR

New templates

- Redder peak than existing local templates
- + sSFR dependence



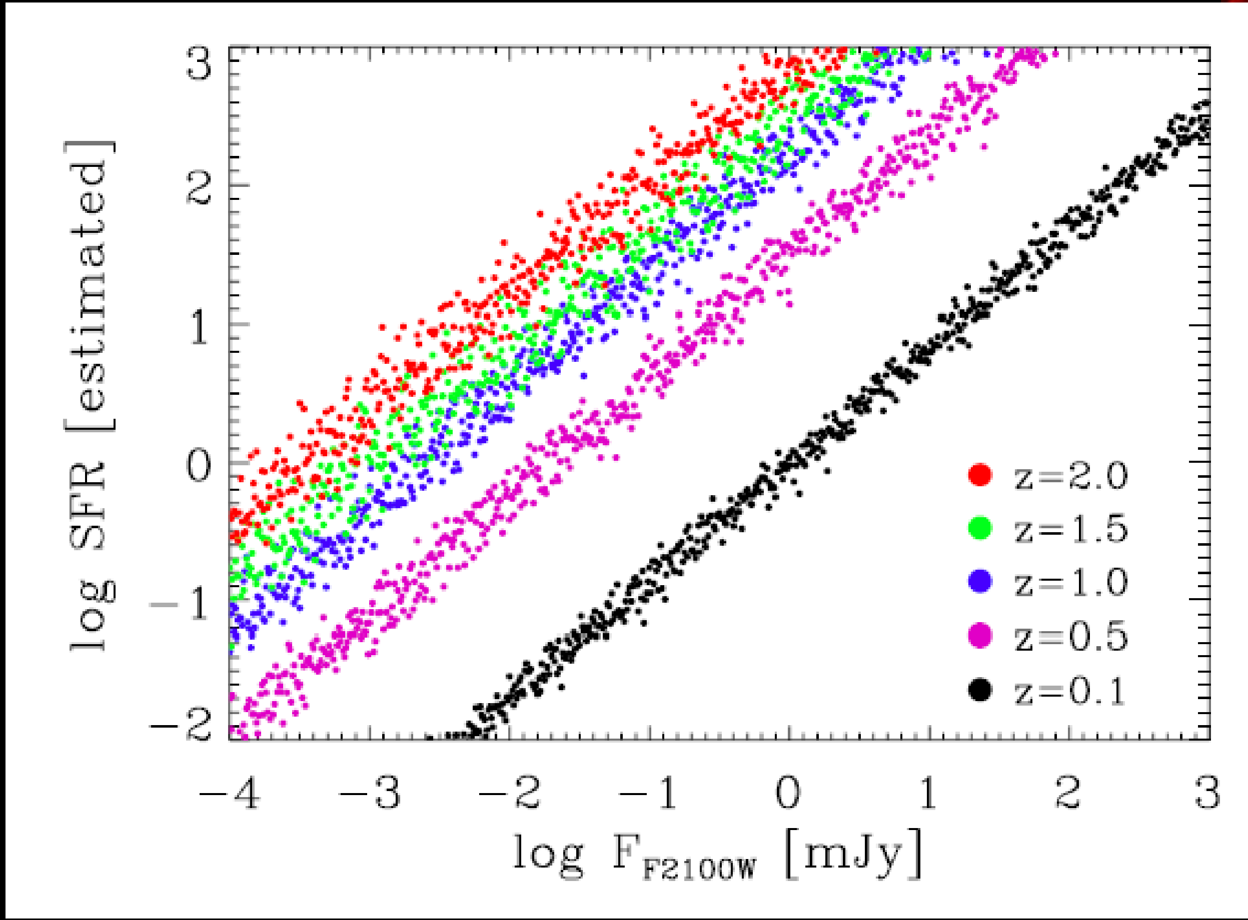
Boquien & Salim (in prep)



Dust emission in IR

New templates

- Estimating L(TIR) or SFR from JWST 21 um
- Software tools for fitting 1-4 IR bands -> L(TIR) and total SFR



Boquien & Salim (in prep)

Summary

Dust extinction

- What is the most fundamental measure of dust?
- How well do we know the MW extinction curve?

Dust attenuation

- Is there a diversity of attenuation curves?
- What is the average curve?
- What does the slope depend on?
- What does it not depend on?
- What is the meaning of IRX-β relation?

Emission

- What IR range best constrains IR luminosity (SFR)?
- Do we need new templates?