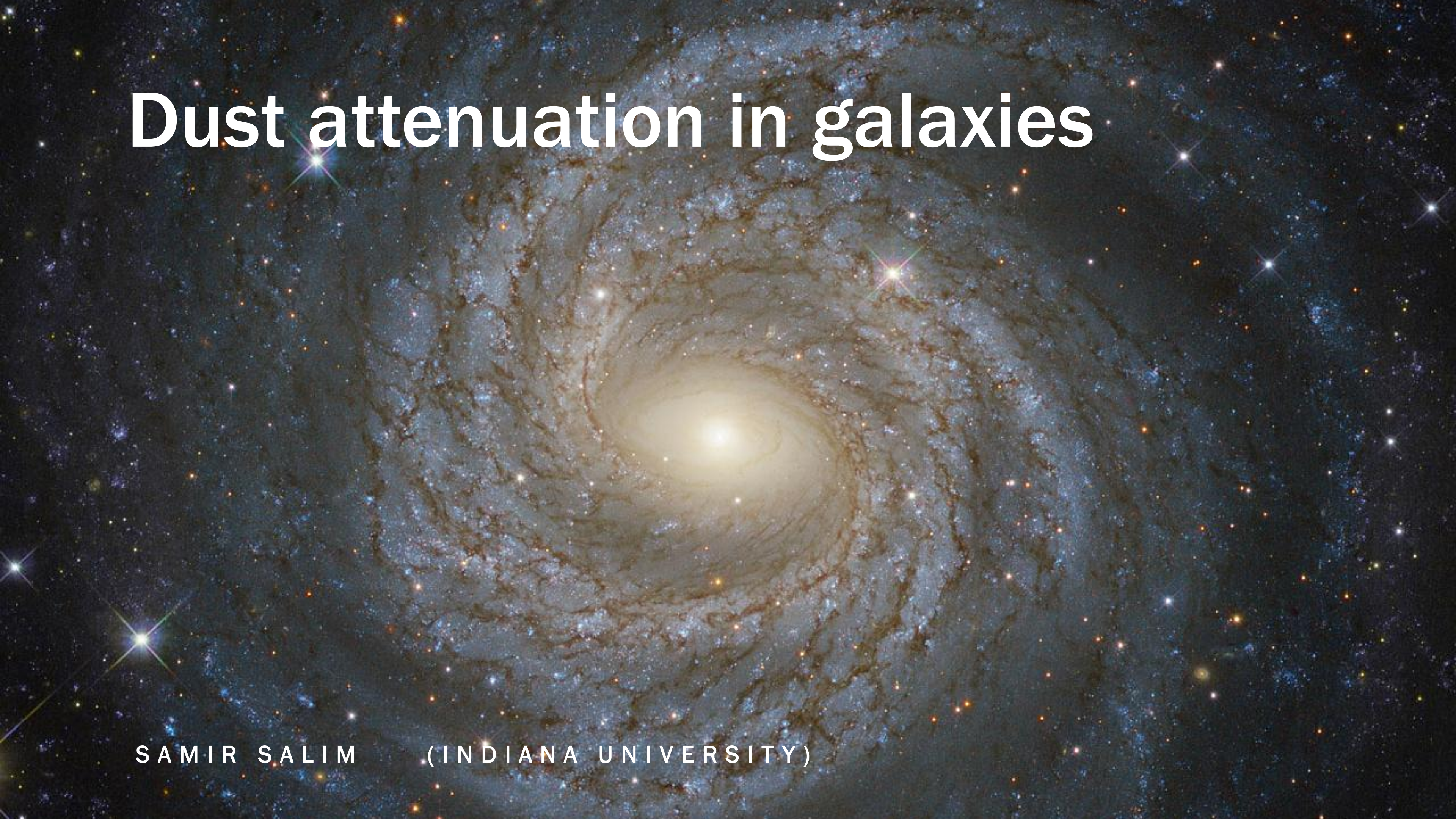
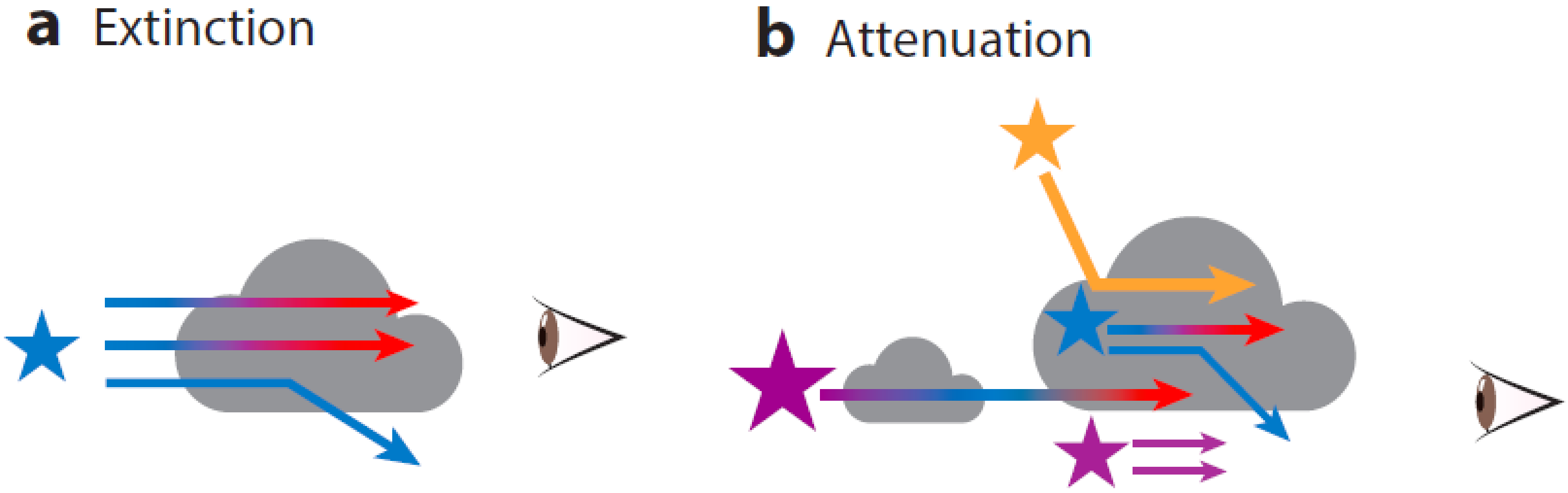
Dust attenuation in galaxies



SAMIR SALIM (INDIANA UNIVERSITY)

Extinction vs. attenuation

- Extinction = absorption + scattering **out** of line of sight
- Attenuation = the above + scattering **into** line of sight



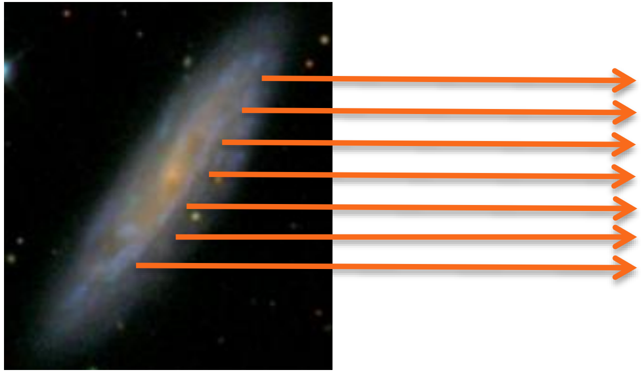
Salim & Narayanan (2020)

Extinction vs. attenuation

- Extinction = point source in a galaxy (SN, GRB)
- Attenuation = extended sources (parts or entire galaxy)
  - dust is near sources (sources must see dust with significant solid angles)
  - distant galaxies affected by MW dust = extinction (solid angle very small)

EXTINCTION – POINT SOURCE

ATTENUATION – EXTENDED SOURCE



Quantifying attenuation A_λ

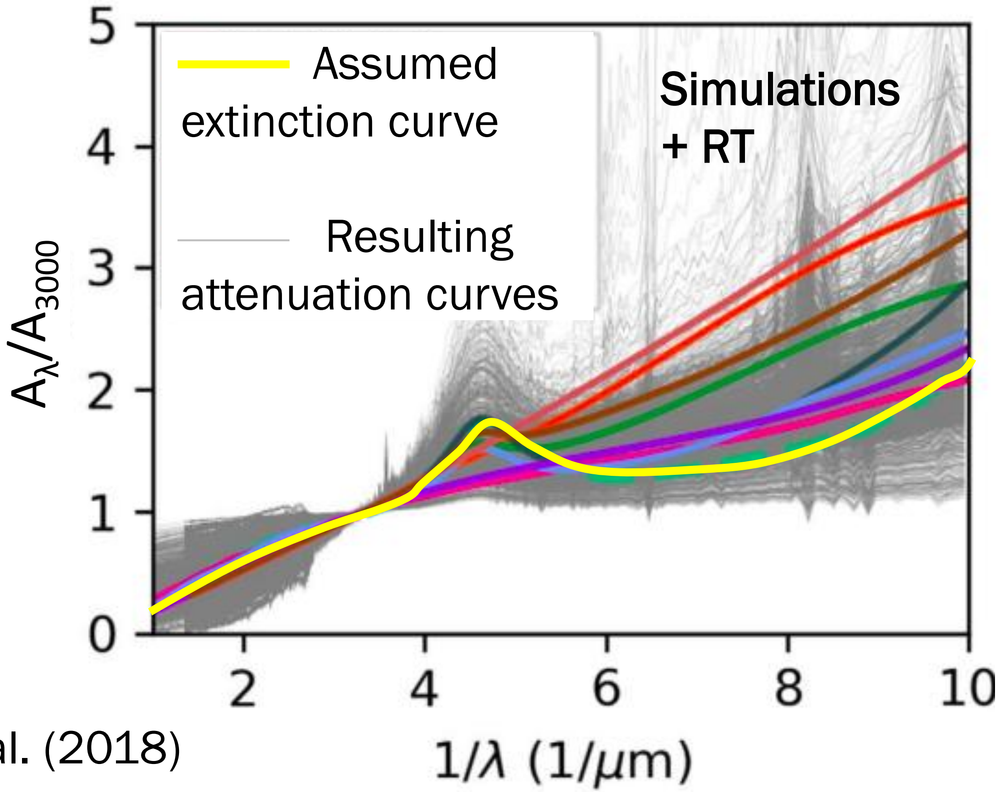
- Attenuation = light with dust – light without dust
  - same concept as for extinction

$$A_V = V - V_0$$

Attenuation curves vs extinction curves

- Assume different galaxies with the **same extinction curve**
- Scattering leads to a wide range of attenuation curves

- Both steeper and shallower than the underlying extinction curve

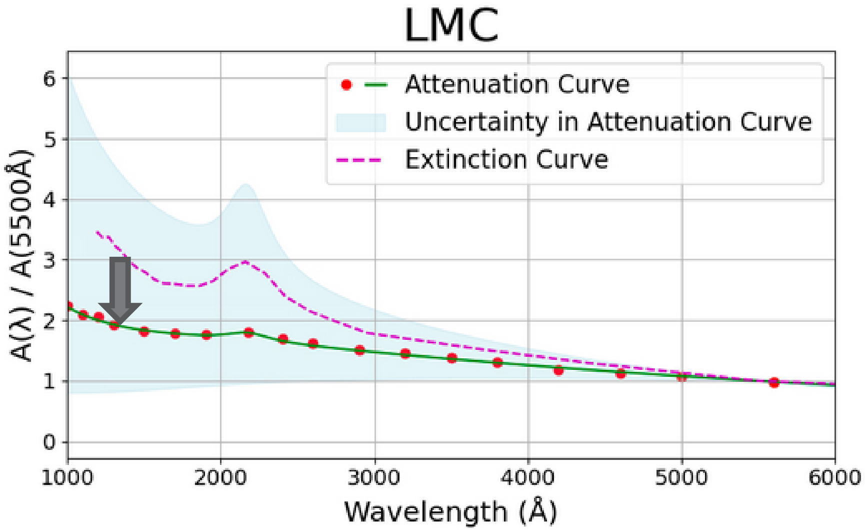


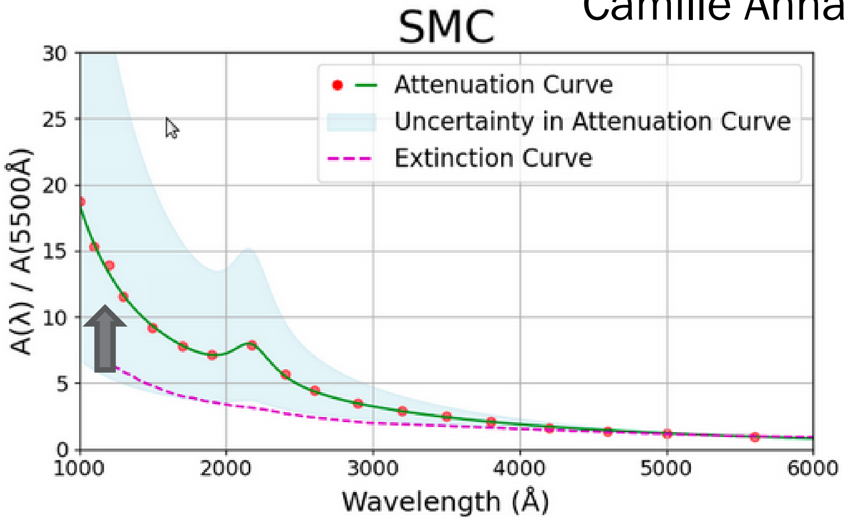
Narayanan et al. (2018)

Attenuation curves vs extinction curves

- LMC and SMC global *attenuation* curves

Camille Annan

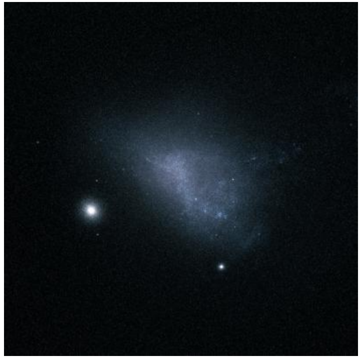




Annan & Salim (in prep)

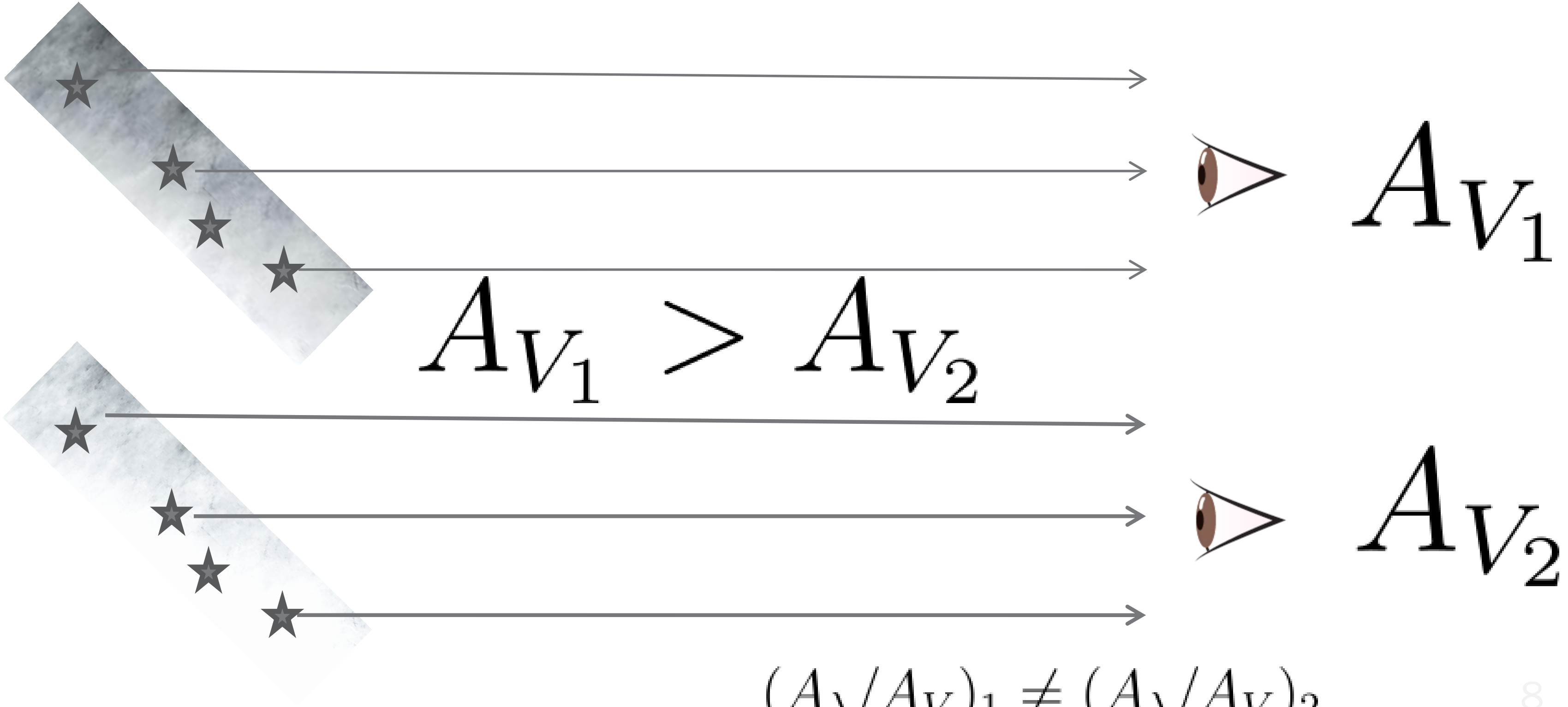
Factors affecting attenuation A_λ

- Dust content



Factors affecting attenuation A_λ

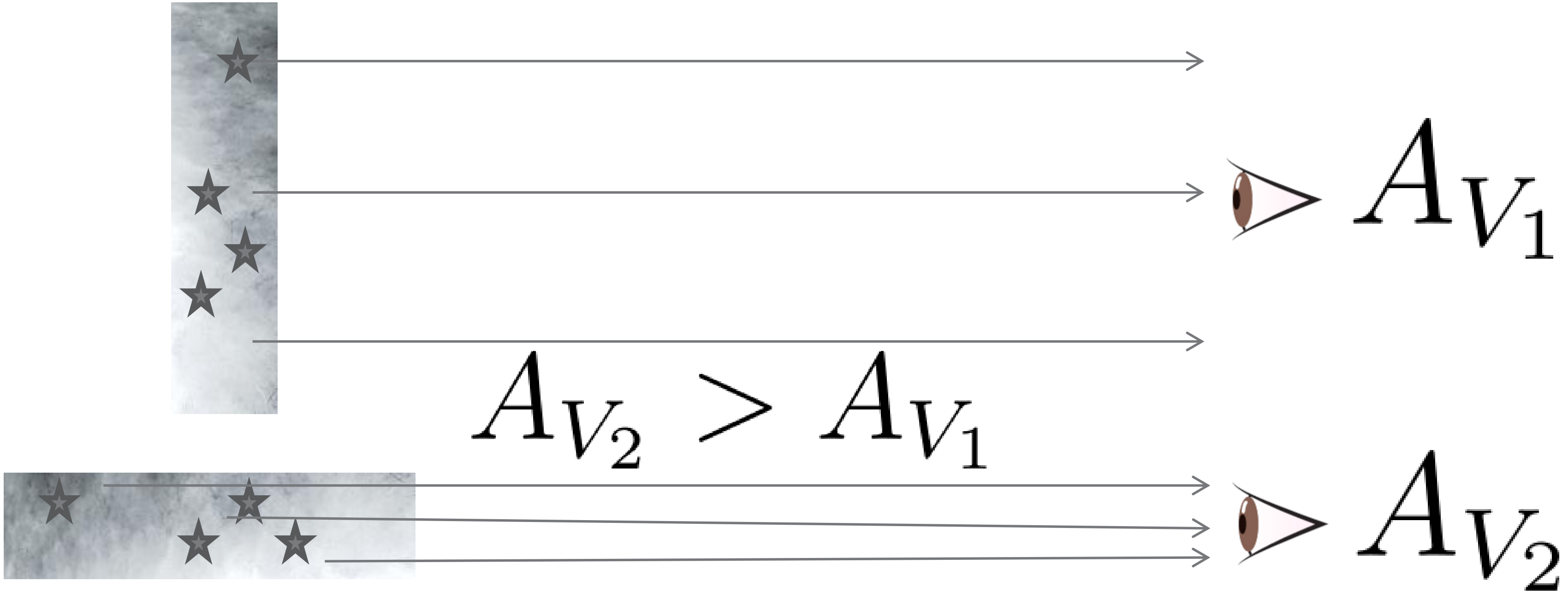
- Vary dust content



$$(A_\lambda/A_V)_1 \neq (A_\lambda/A_V)_2$$

Factors affecting attenuation A_λ

- Vary viewing angle (without changing dust content)

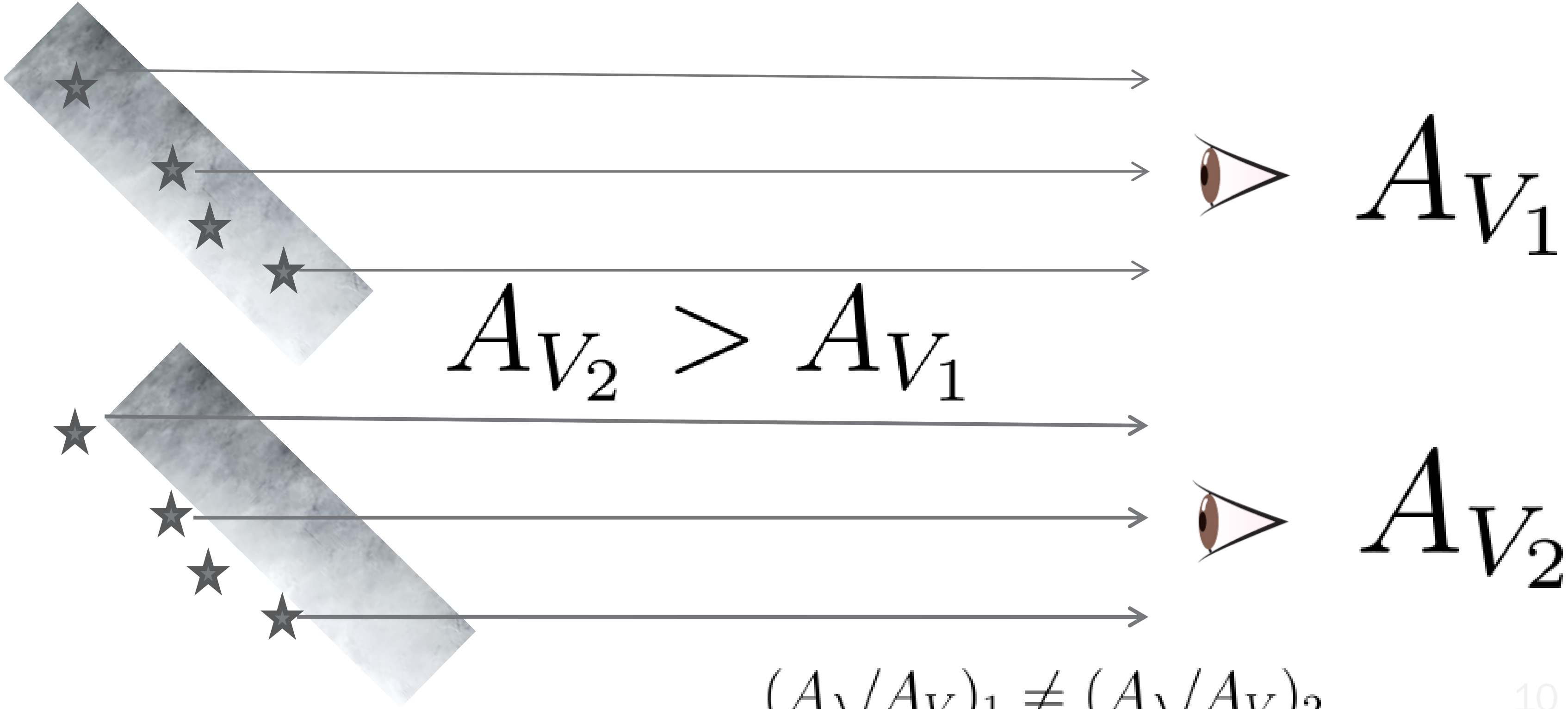


$$A_{V_2} > A_{V_1}$$

$$(A_\lambda/A_V)_1 \neq (A_\lambda/A_V)_2$$

Factors affecting attenuation A_λ

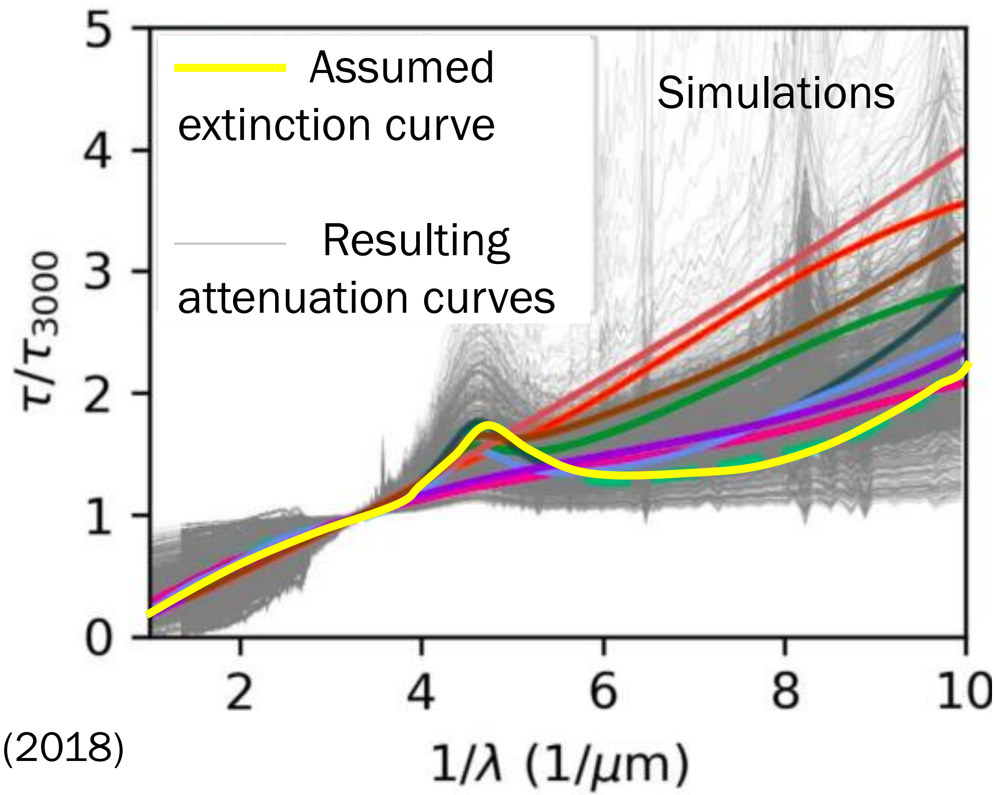
- Vary relative distribution of dust and stars (local geometry)



$$(A_\lambda/A_V)_1 \neq (A_\lambda/A_V)_2$$

Attenuation curves vs extinction curves

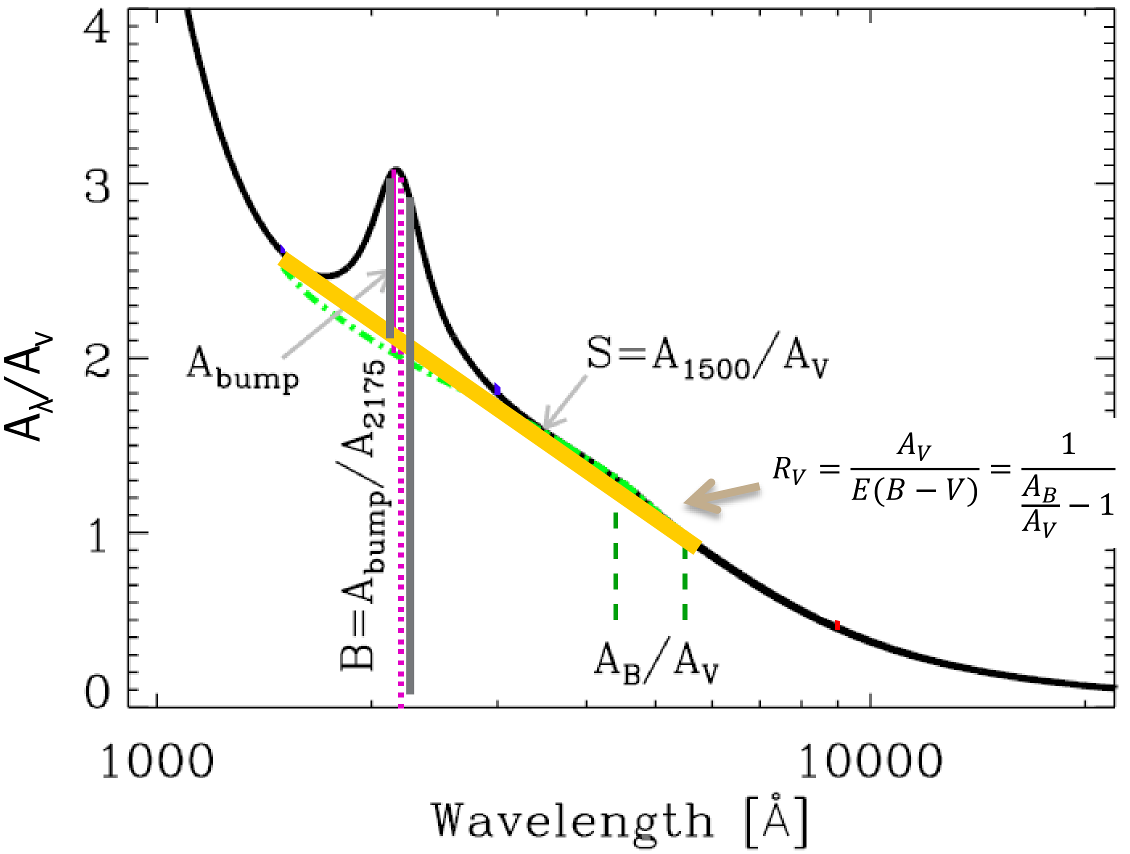
- RT effects due to differences in “geometry”:
  - dust content
  - viewing angle
  - local star-dust distribution



Narayanan et al. (2018)

Attenuation curve parameterization

- Analogous to extinction curve
- Usually normalized to Av rather than E(B-V)
- Rv = optical slope
  - not commonly used
- **UV-optical slope (S)**
  - **$S = A_{1500}/Av$**
- **2175 A bump strength**
  - **$B = A_{bump}/A_{2175}$**

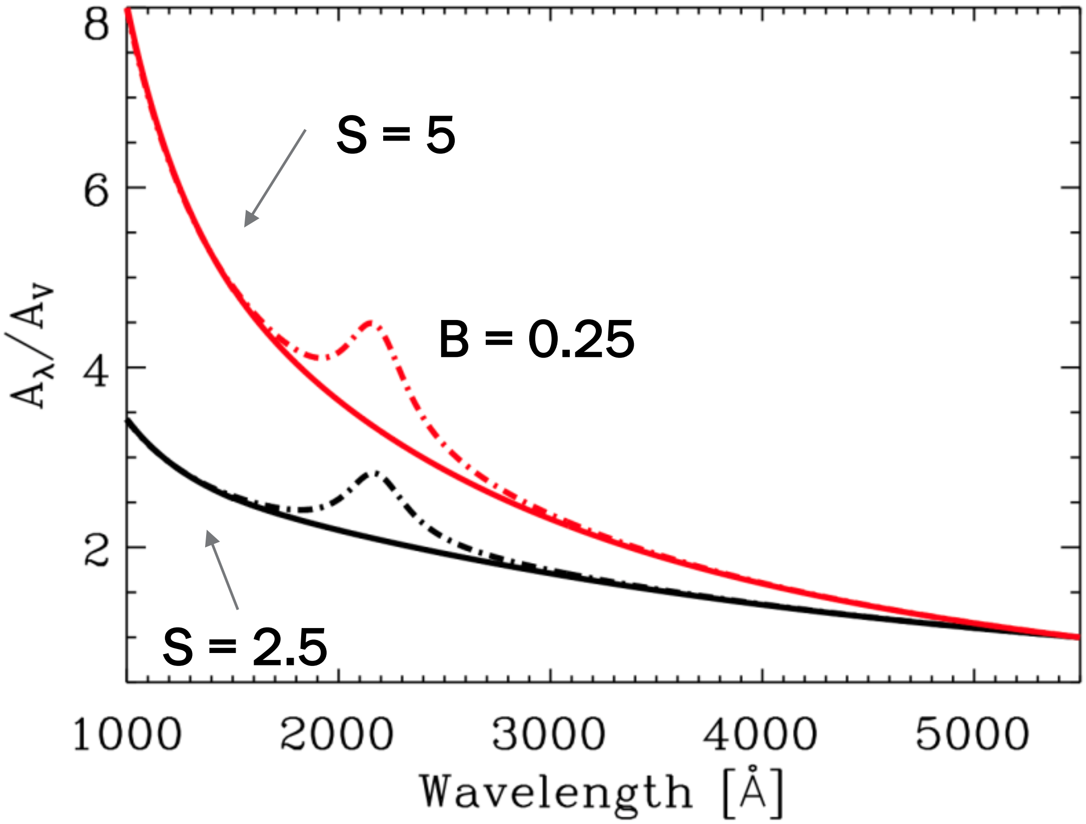


Attenuation curve parameterization

- $S = A_{1500}/Av$
- $B = A_{bump} / A_{2175}$

Useful split:

S<3 shallow
S>5 steep

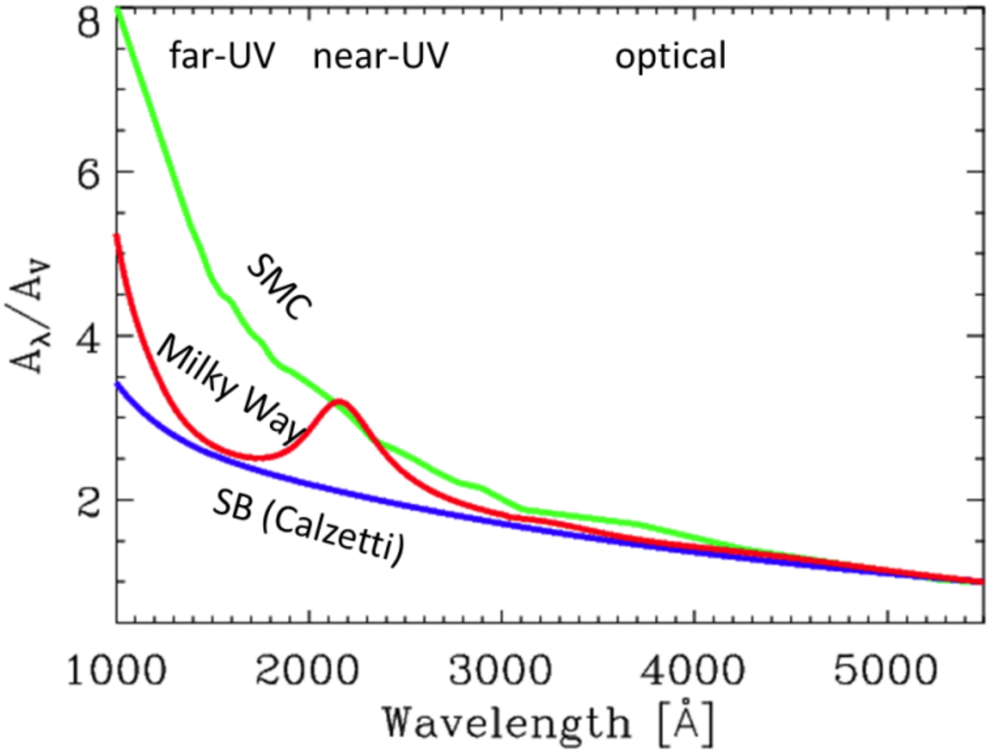


Attenuation curve parameterization

- $S = A_{1500}/Av$
- $B = A_{bump} / A_{2175}$

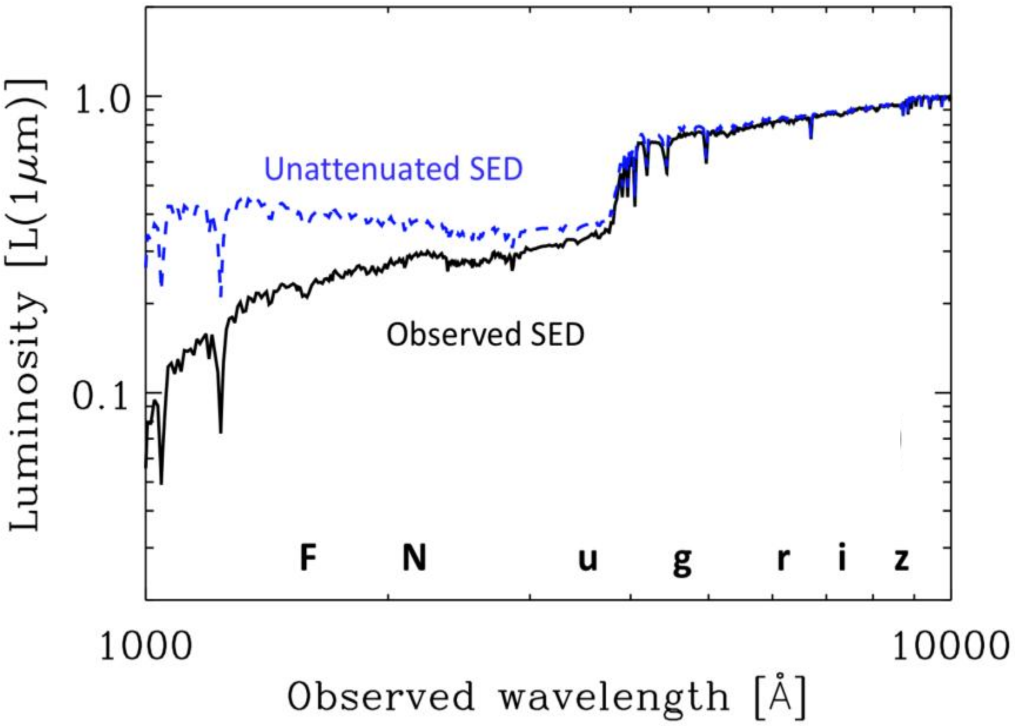
- Calzetti et al. (1994, 2000)
  - first determined attenuation law
  - aggregate of local starbursts

	S	B
MW	2.5	0.35
SMC	**5**	**0**
Calzetti	2.5	0



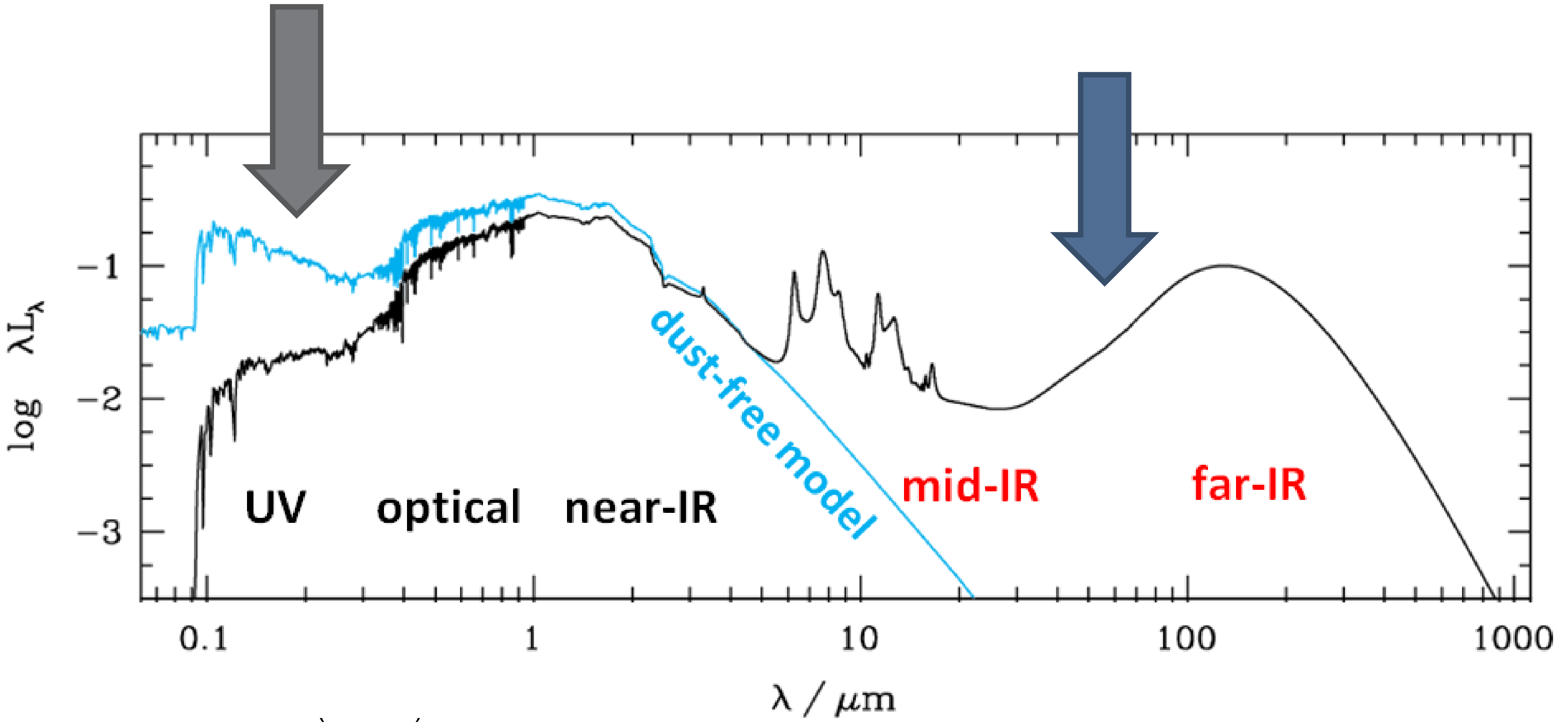
How do we determine attenuation curves?

- UV/optical SED fitting
  - Dust-free SED known from models
  - Allow slope and bump to vary
- Dust-age-metallicity degeneracy
  - older age of stars or
    higher metallicity
    also produce reddening
- Degeneracy can be broken with
  - good sampling of bands
  - IR dust emission data



How do we determine attenuation curves?

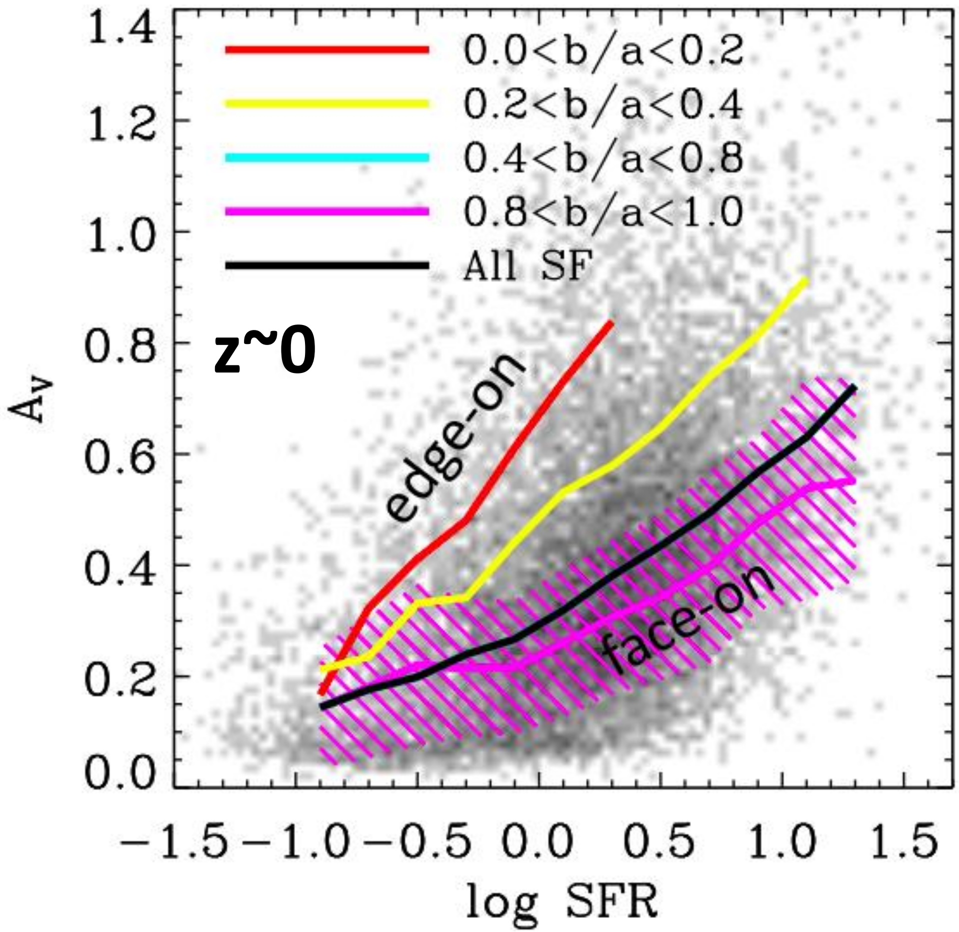
- Energy balance constraint: energy absorbed in UV+optical = energy emitted in IR



Observational results

Scaling relation for Av

- Attenuation (Av)
  = dust content + viewing angle + mixed local geometry
  - dust content scales with SFR (star formation rate) or M* (stellar mass)
- Low-z data: 10^5 galaxies
  - z < 0.3
  - GALEX UV
  - SDSS optical
  - WISE mid-IR
  - CIGALE SED fitting code



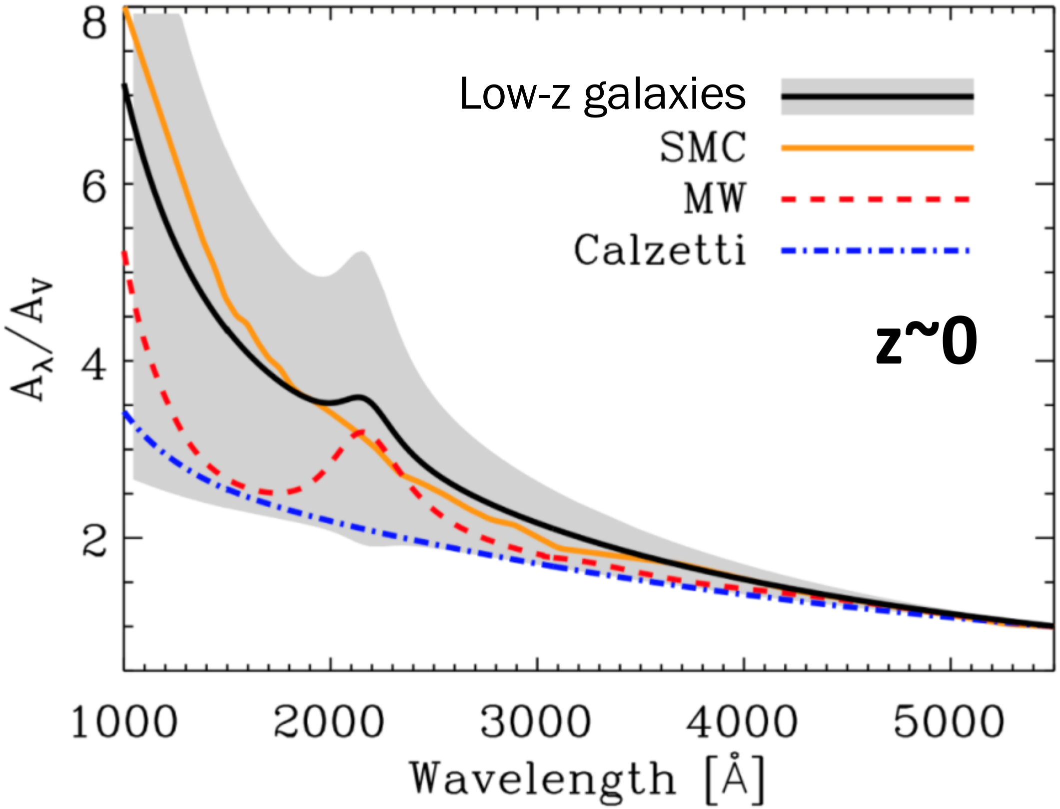
Salim & Narayanan (2020)

Diversity of attenuation curves at z~0

- Wide range of slopes
- 2 < S < 15

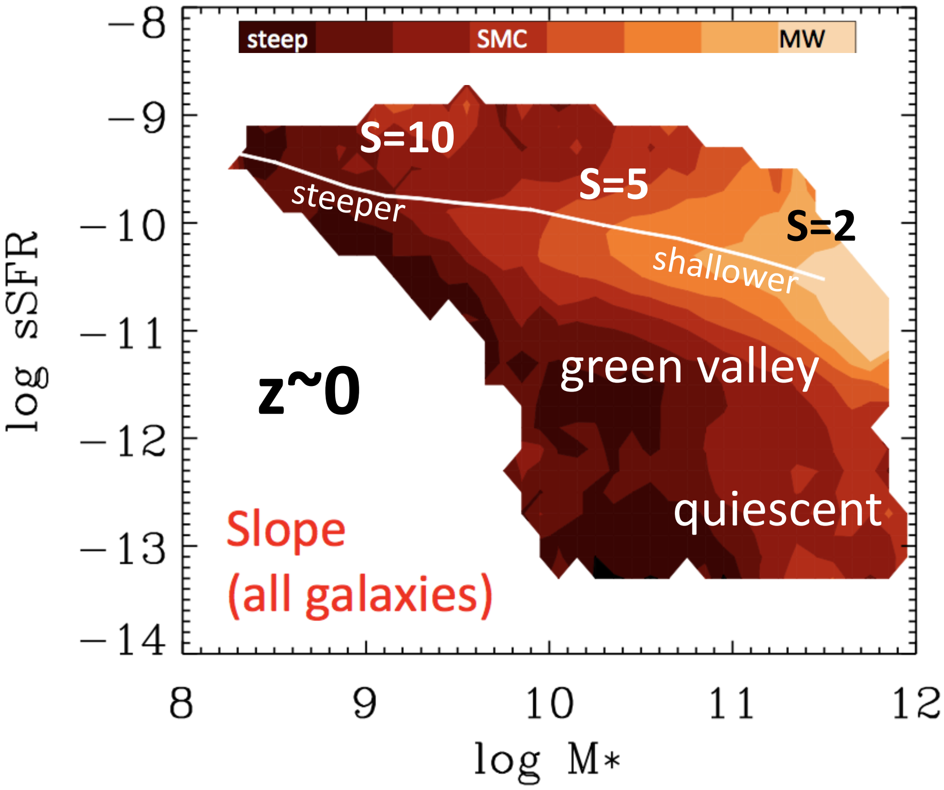
- Average slope steep

- Average bump ~1/2 MW

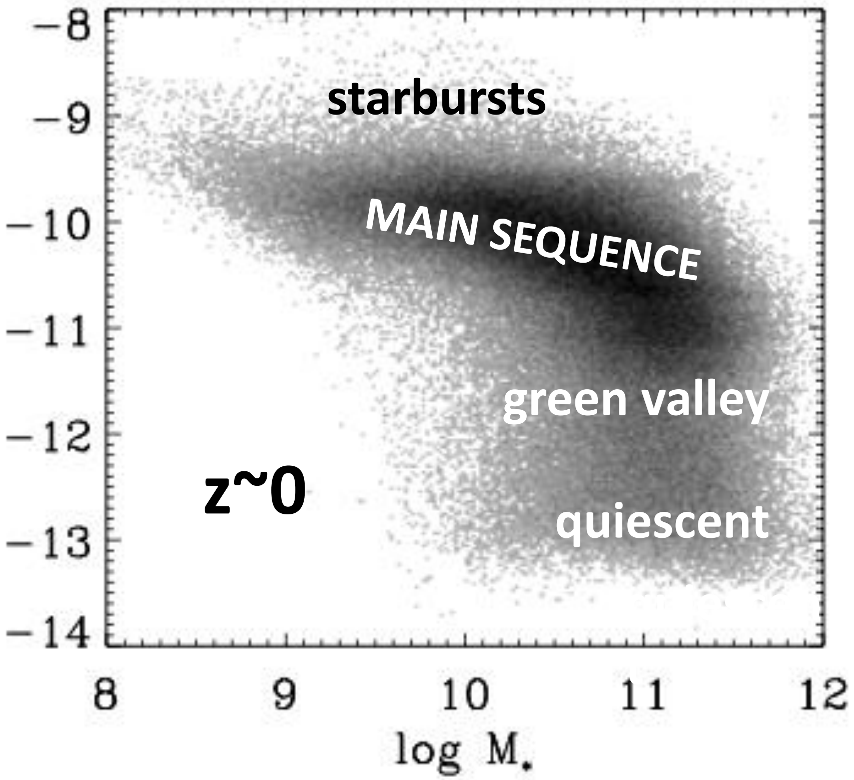


Salim et al. (2018)

Diversity of attenuation curves at z~0



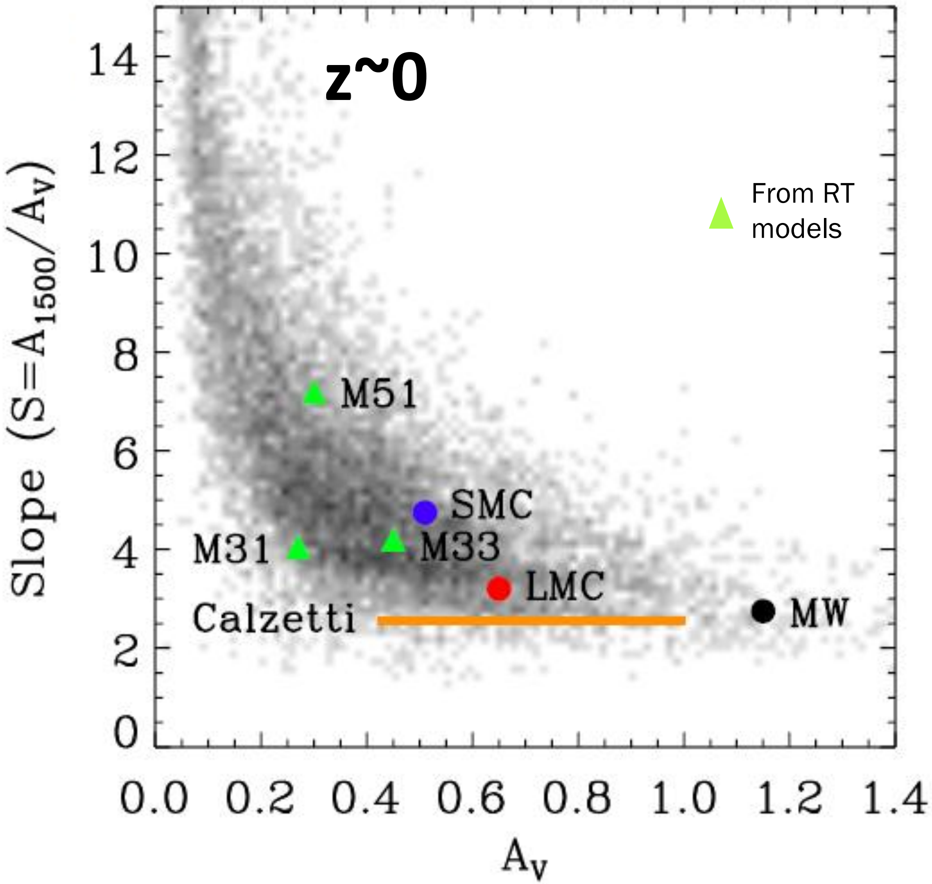
230,000 galaxies in SDSS



Salim et al. (2018)

Slope vs Av relation

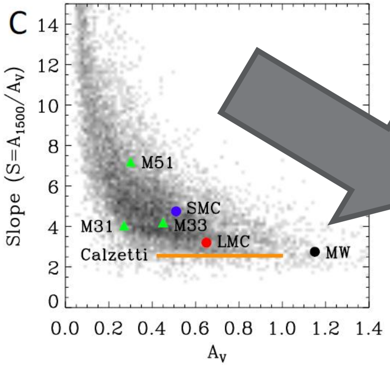
- Galaxies with higher effective attenuation have shallower curves

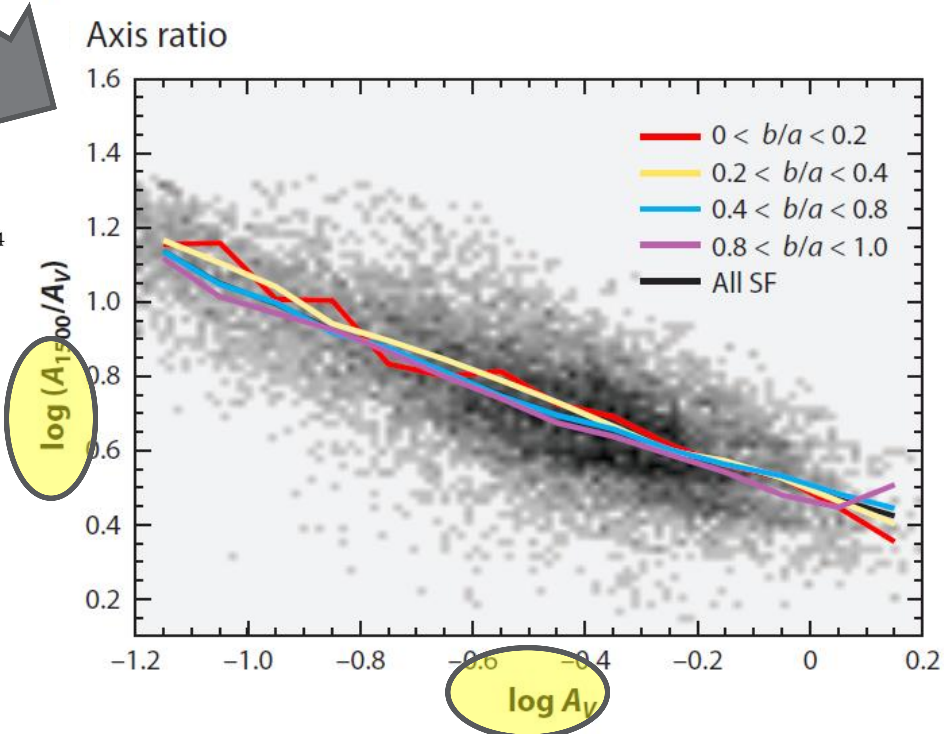


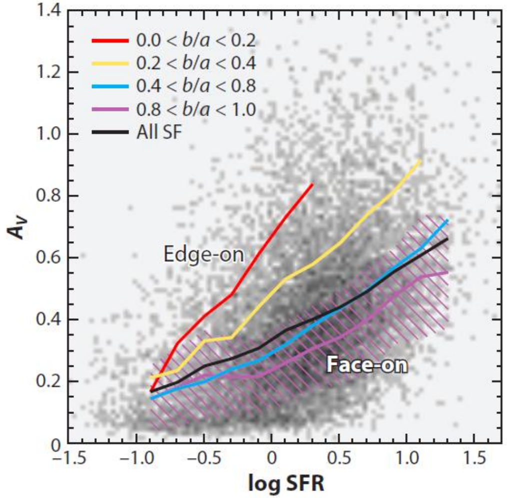
Salim & Narayanan (2020)

Slope vs Av relation

- At fixed Av, slope does not depend on the viewing angle





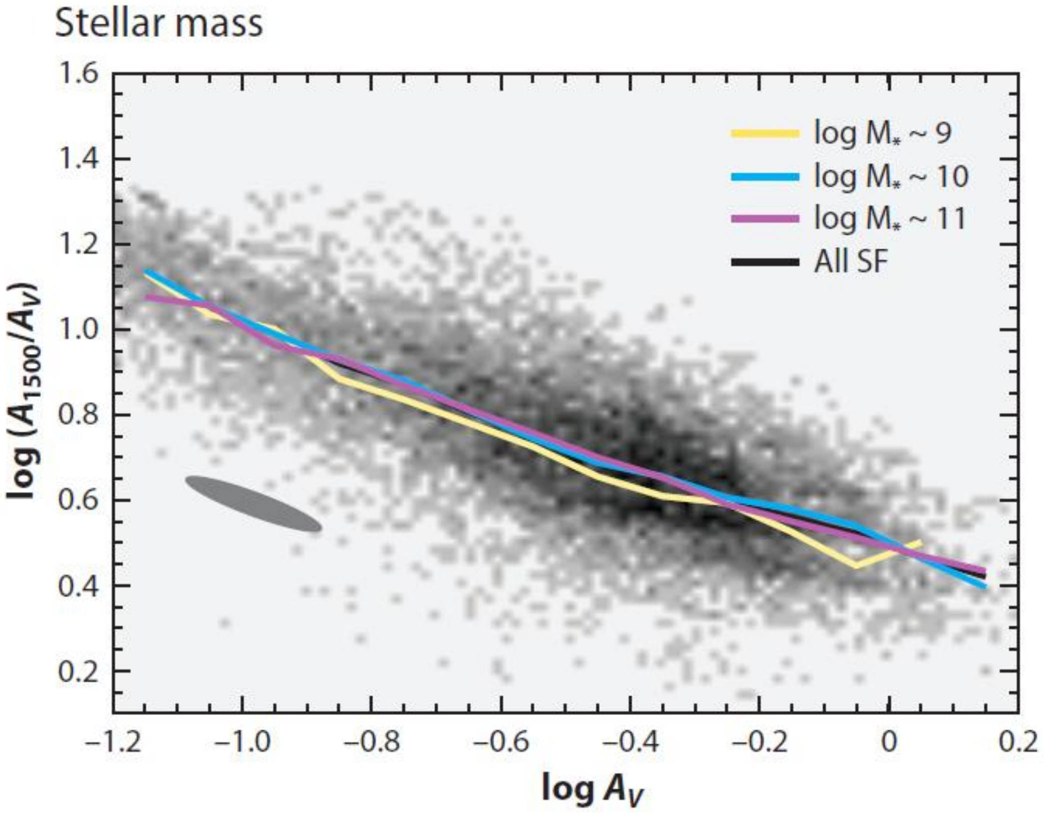


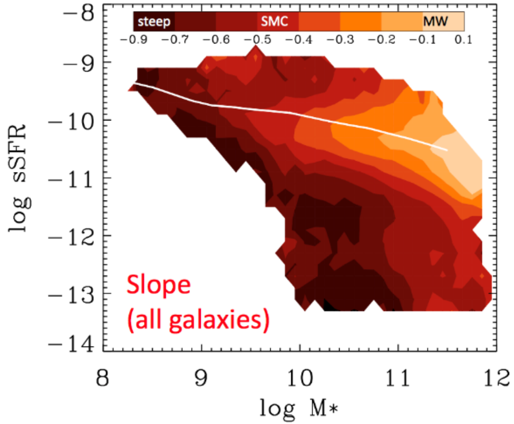
Salim & Narayanan (2020)

Slope vs Av relation

- At fixed Av slope does not depend on stellar mass

slope

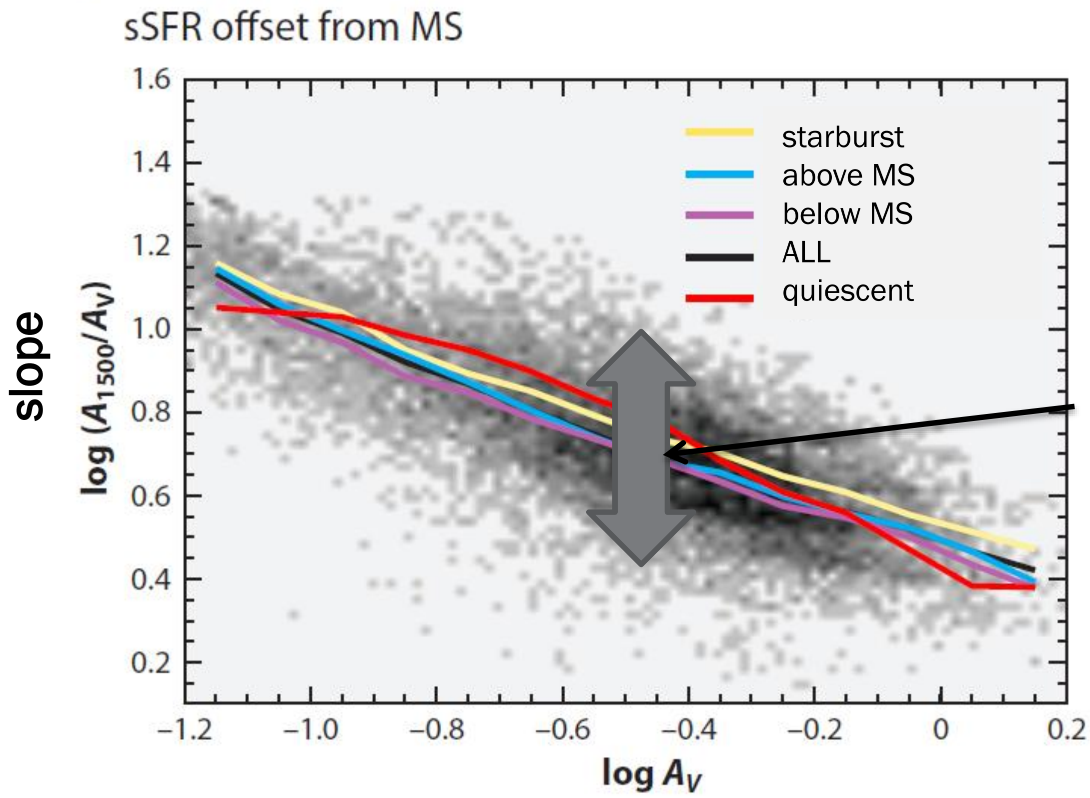


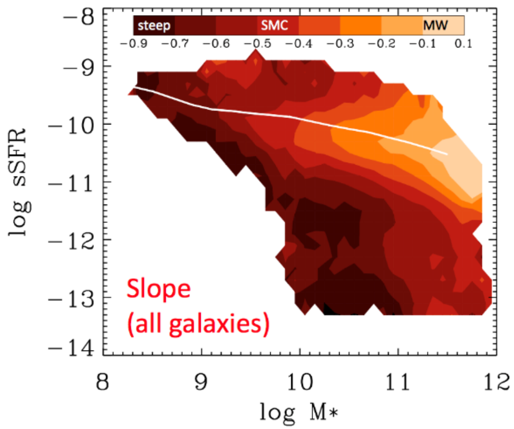


Salim & Narayanan (2020)

Slope vs Av relation

- At fixed Av, slope does not depend on SFR



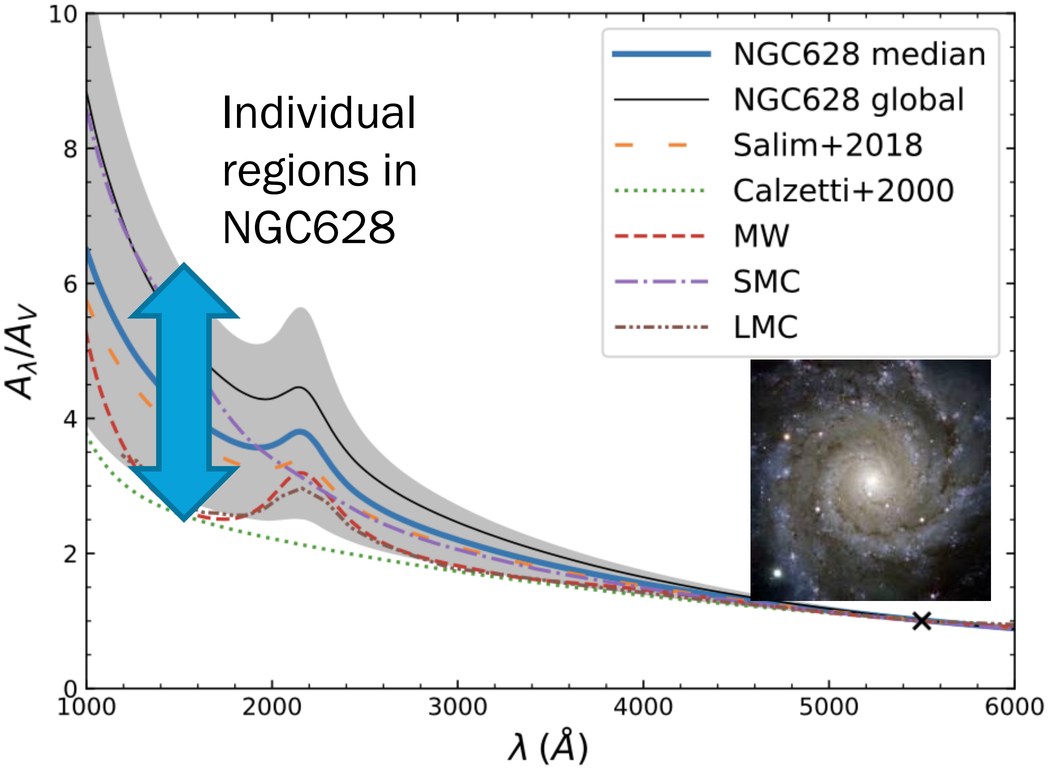


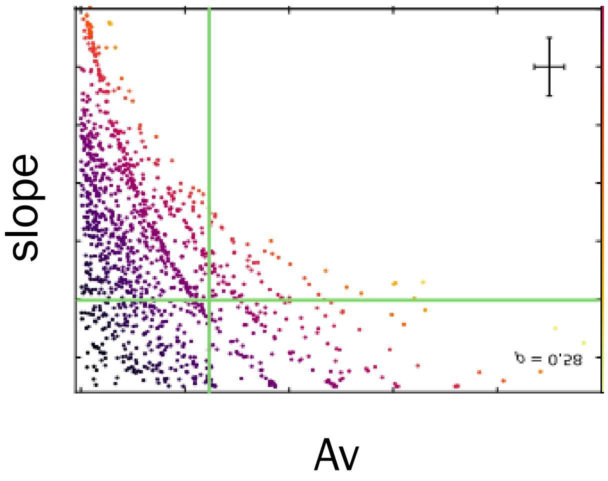
scatter = diversity in dust properties (**extinction** curve)

Salim & Narayanan (2020)

Slope vs Av relation

- Slope-Av relation holds for resolved regions in individual galaxies

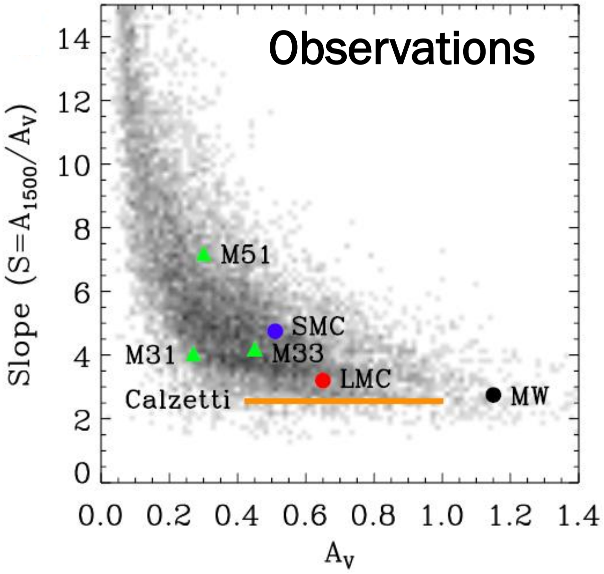


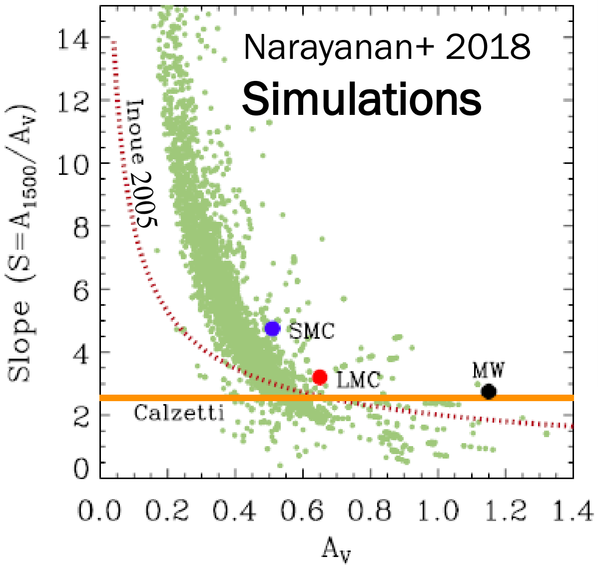


Decleir et al. (2019)

Slope vs Av relation

- Predicted by radiative transfer models
  - Low Av: scattering dominates (highly λ dependent)
  - High Av: absorption dominates (grey)





Salim & Narayanan (2020)

Av dependence was predicted before it was found in observations:

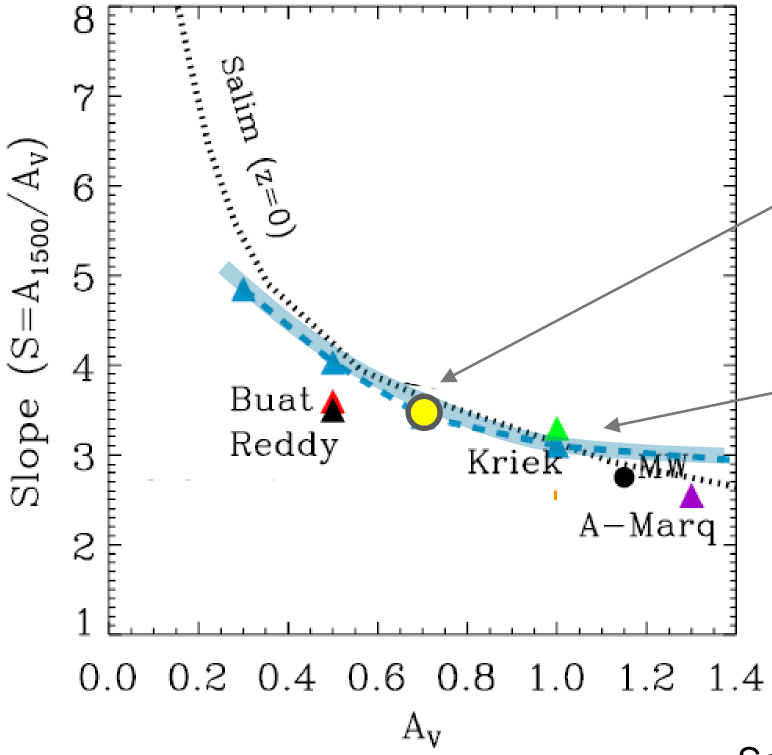
Witt & Gordon (2000)
Baes & Dejonghe (2001)
Pierini (2004)
Inoue (2005)
Chevallard et al. (2013)
Seon & Draine (2016)

Evolution of the Slope-Av relation?

- Important: compare slopes from different studies/redshifts at the same Av

Pre JWST:

Not much evolution at 0<z<2



Shivaei et al. (2020)
MOSDEF z~2.2

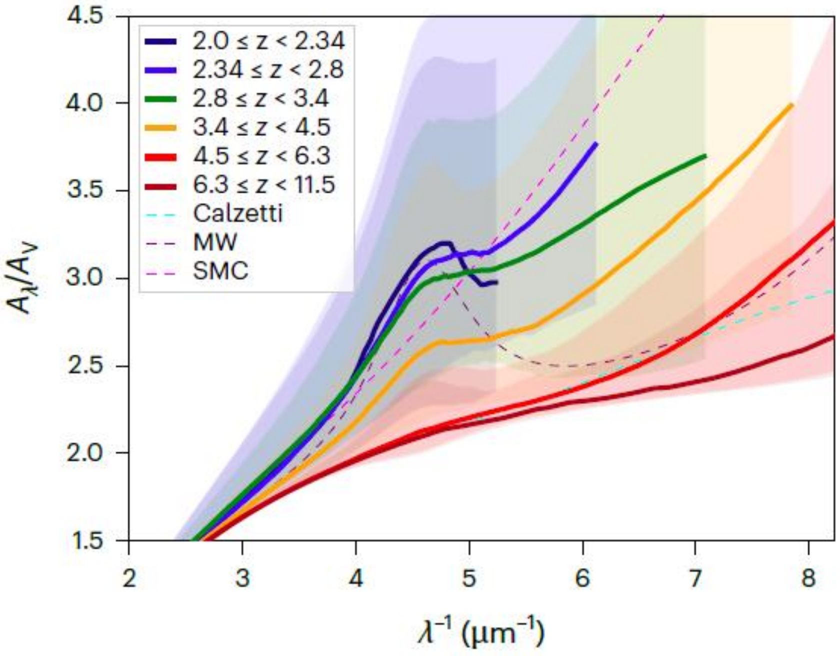
Battisti et al. (2020)
COSMOS z~1

Salim & Narayanan (2020)

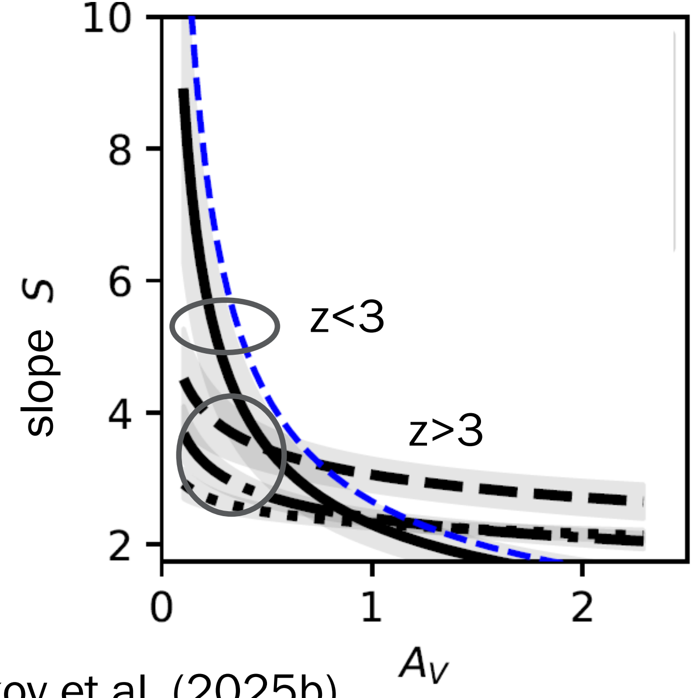
Evolution of the S-Av relation?

- Important: compare slopes from different studies/redshifts at the same Av

JWST NIRSpec 2<z<12



higher z



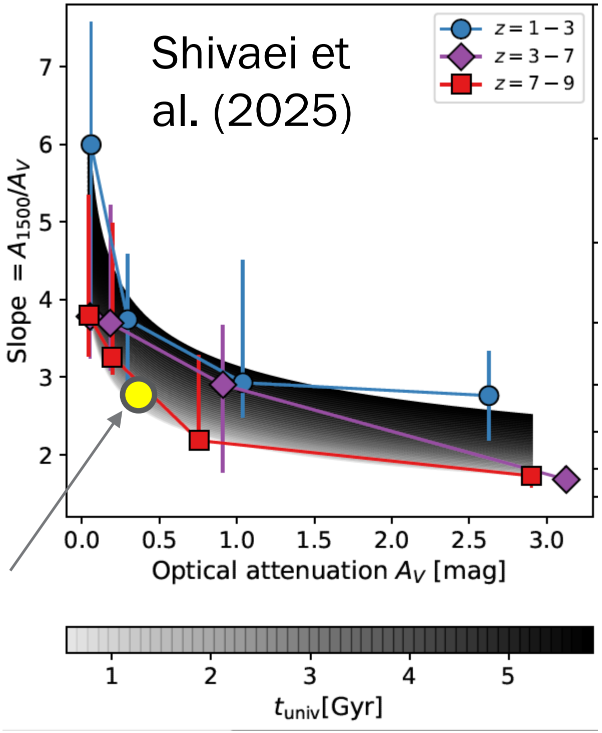
Markov et al. (2025a)

Markov et al. (2025b)

Evolution of the S-Av relation?

- Important: compare slopes from different studies/redshifts at the same Av

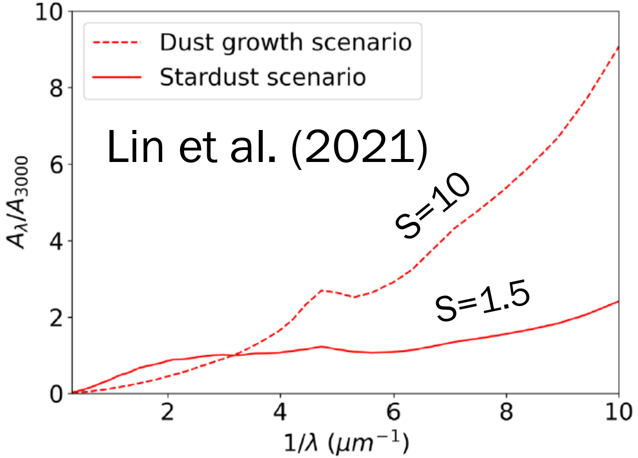
JWST NIRCam grism 1<z<9



Ormerod et al. (2025)

Grains bigger in the early universe (SN dust, aka “stardust”)

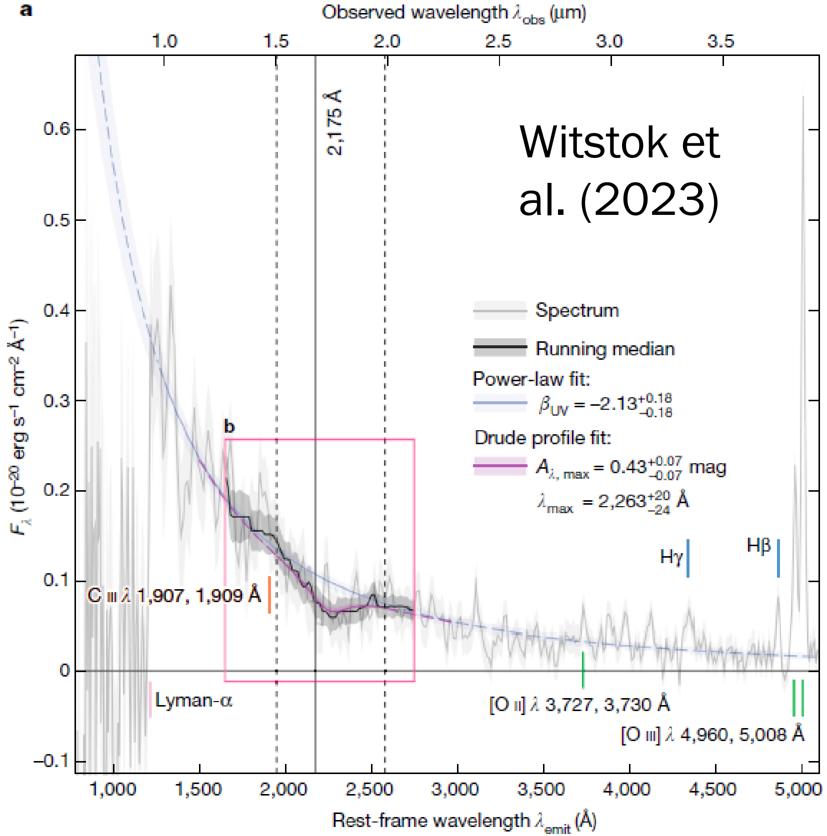
Theoretical *extinction* curves

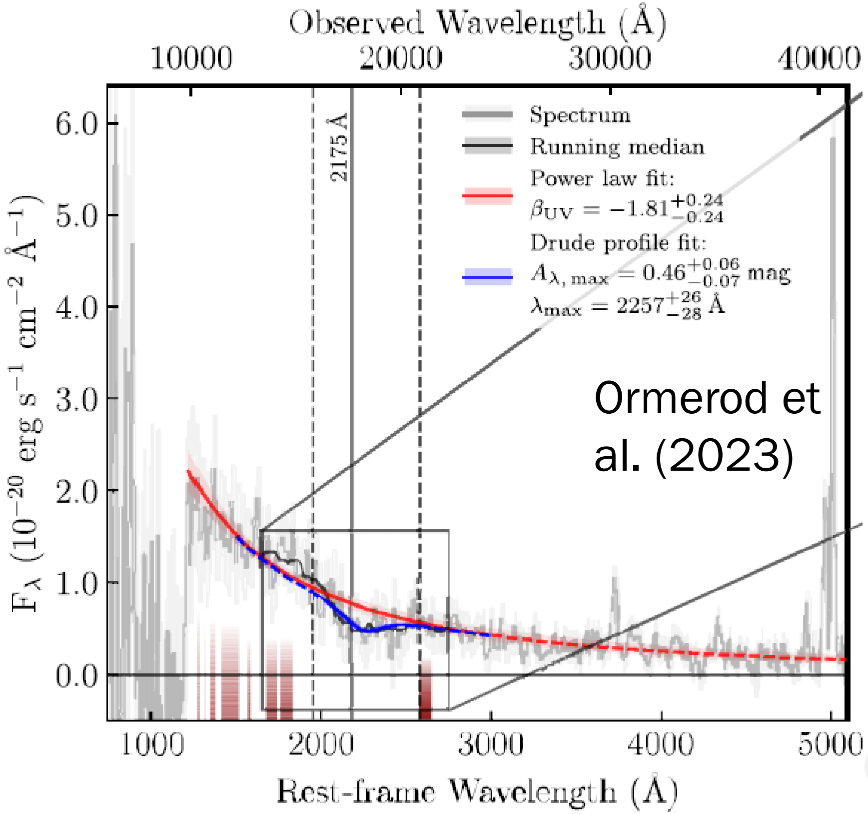


McKinney et al. (2025): Shallow curve provides better SED fit

Evolution of the UV bump

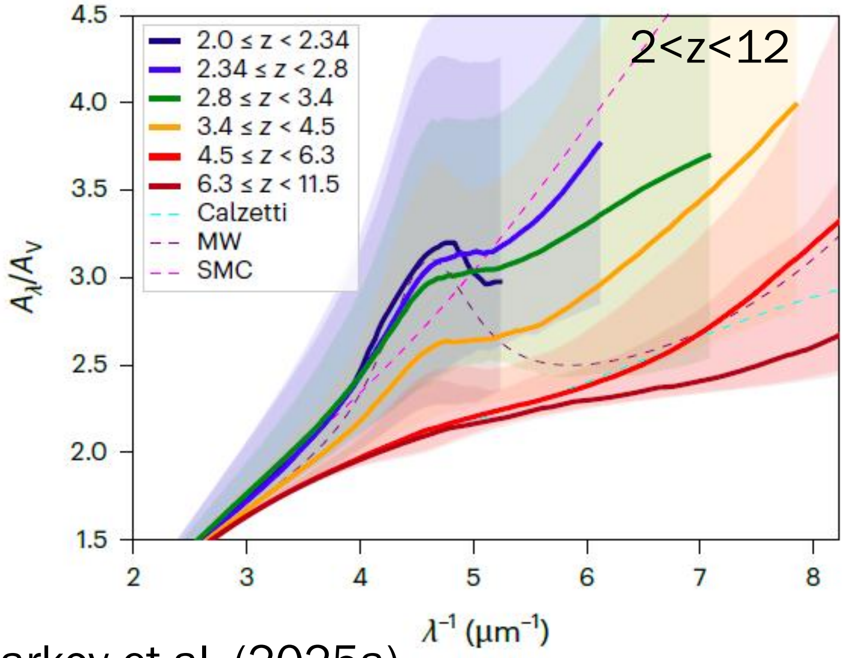
- Bump found in spectra of individual z~7 galaxies (at 2260A)





Evolution of the UV bump

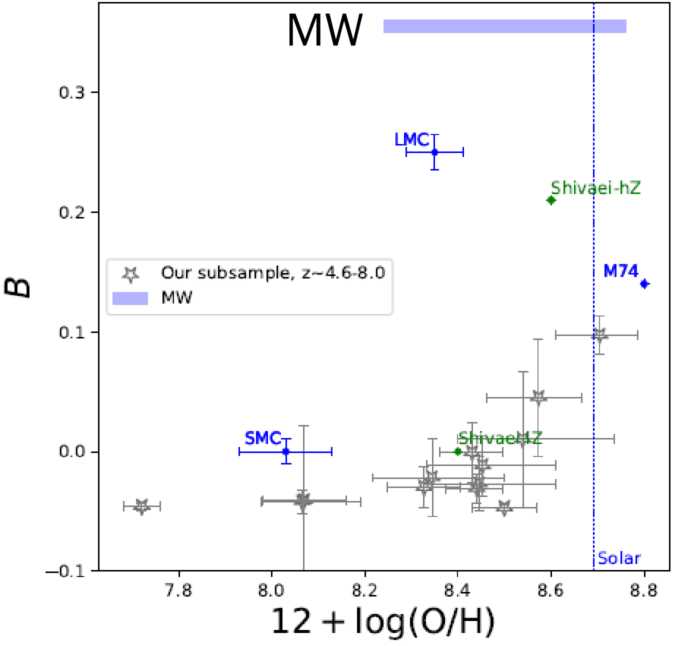
- z ~ 0: $B = B_{MW}/2$
- z ~ 1: $B = B_{MW}/3$ (Battisti et al. 2020)
- z > 4: $B \sim 0$ (Witstok et al. 2023)



higher z

Bump gets smaller

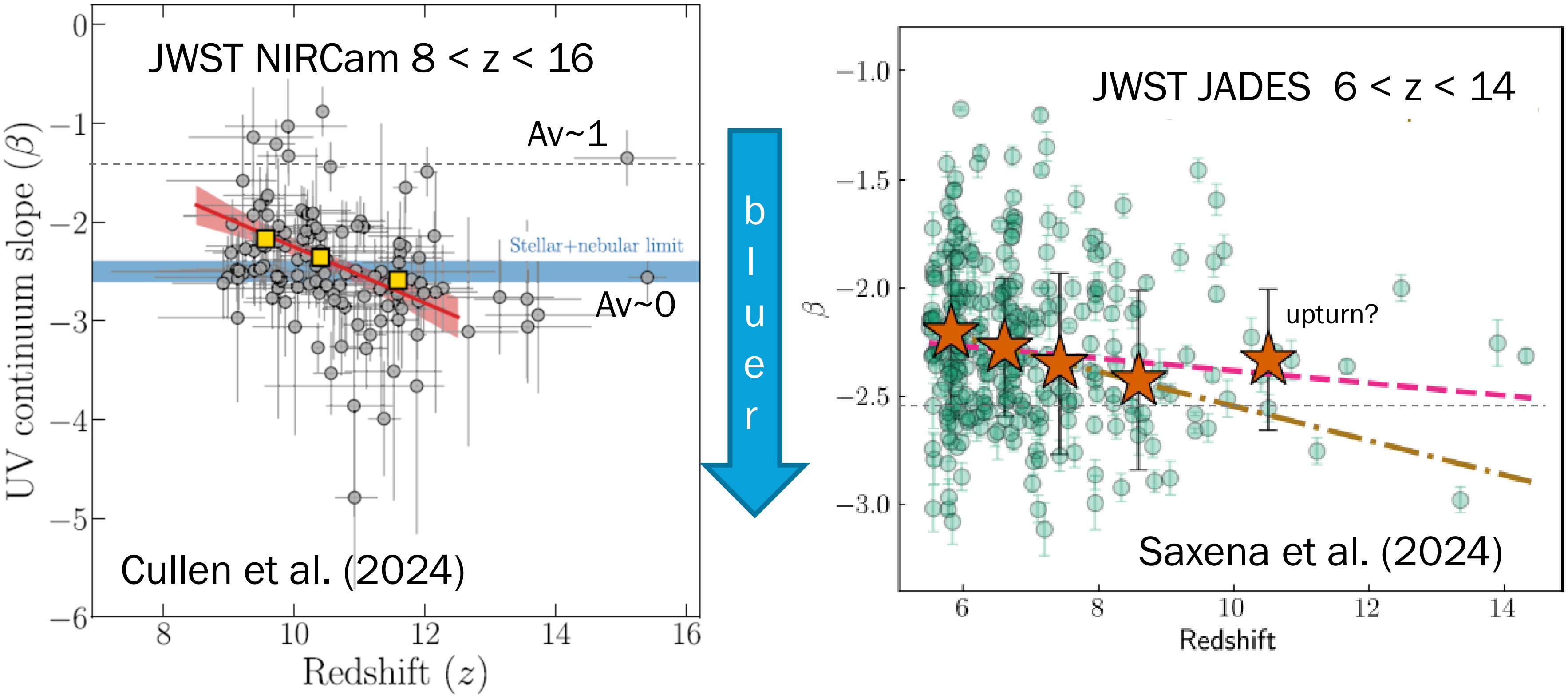
Markov et al. (2025a)



Markov et al. (2025b)

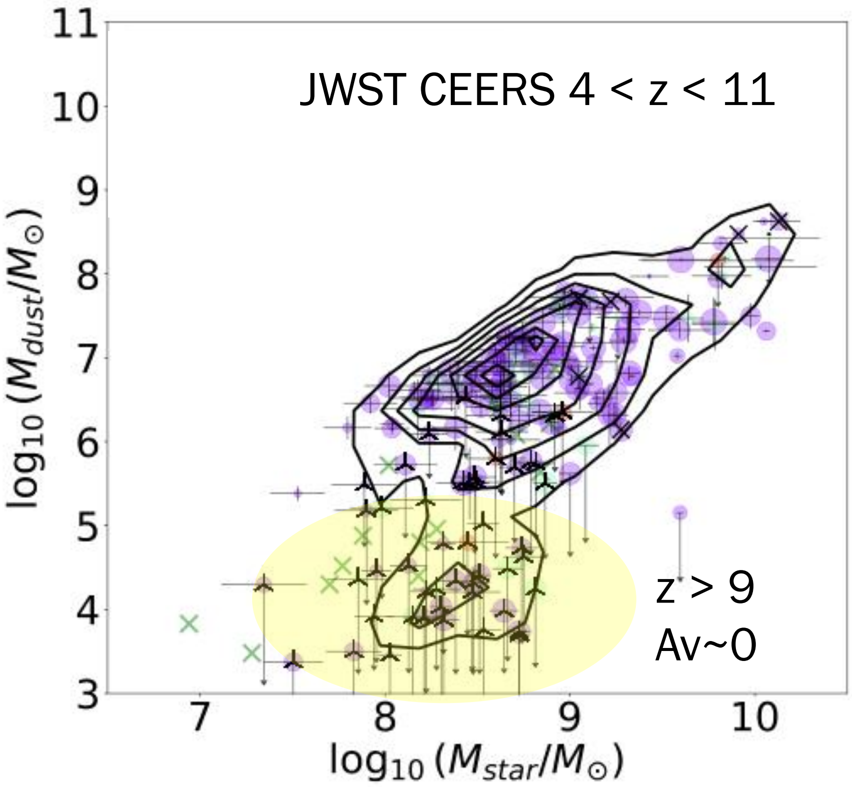
Towards dust-free galaxies?

- Rest-frame UV color (β) reaching and exceeding (?) dust-free values at high z



Towards dust-free galaxies?

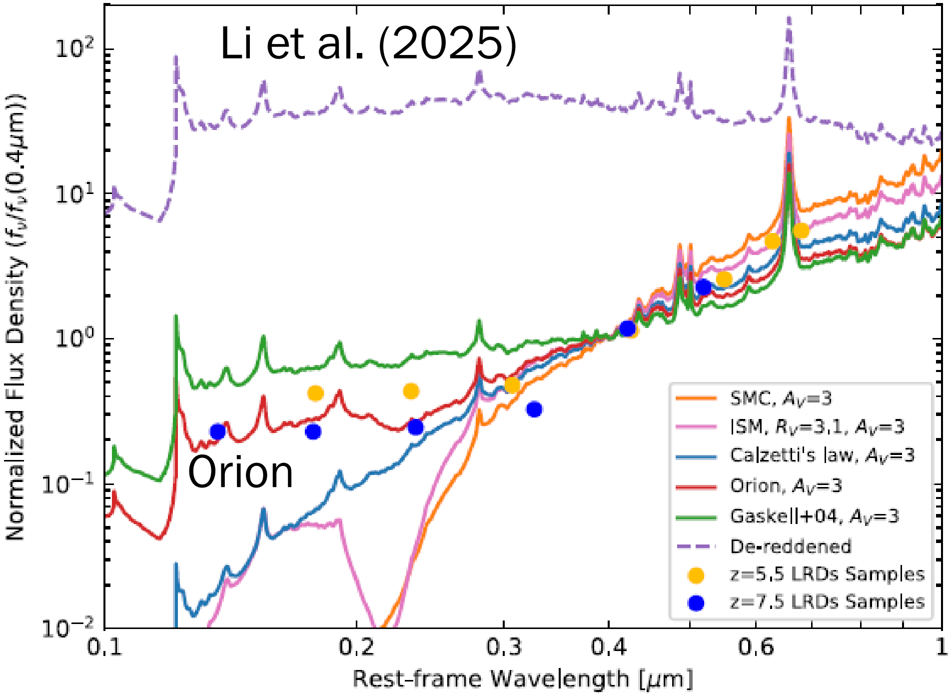
- At highest z we expect to see original SN stardust (prior to accretion) -> lower M_{dust}

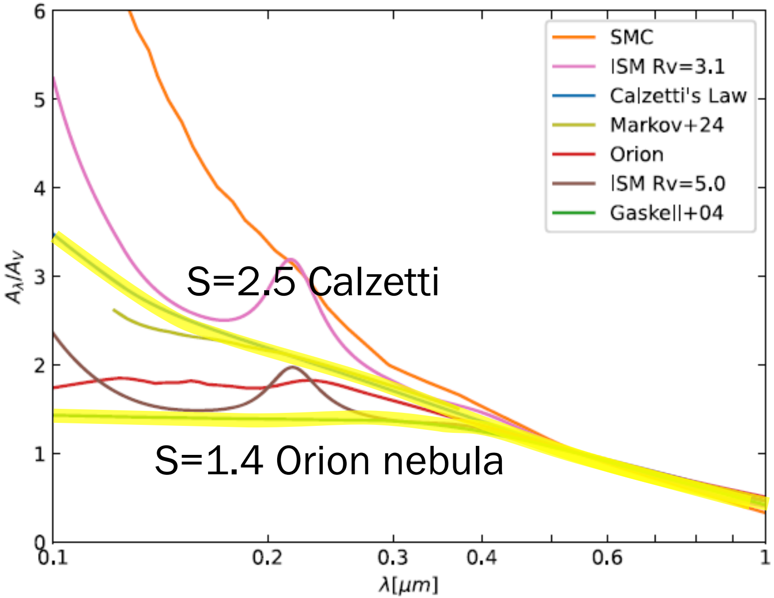


Burgarella et al. (2025)

Special dust law in Little Red Dots?

- Are LRDs dust reddened broad-line AGN or ultracompact massive galaxies?
  - AGN may destroy small grains -> extremely shallow (gray) attenuation curve -> UV does not drop as expected





Future

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

UVEX

PRIMA

VERA C. RUBIN OBSERVATORY

LSST
Legacy Survey of Space and Time

esa
euclid

Summary

- Extinction vs. attenuation
  - attenuation = extinction + RT effects (aka "geometry")
- Large diversity of attenuation curves
  - steep – on average
- Dependence of slope on Av
  - not much residual dependence on M*, SFR
  - residual scatter due to differences in dust properties