CHARACTERIZING DUST ATTENUATION IN LOCAL STAR FORMING GALAXIES

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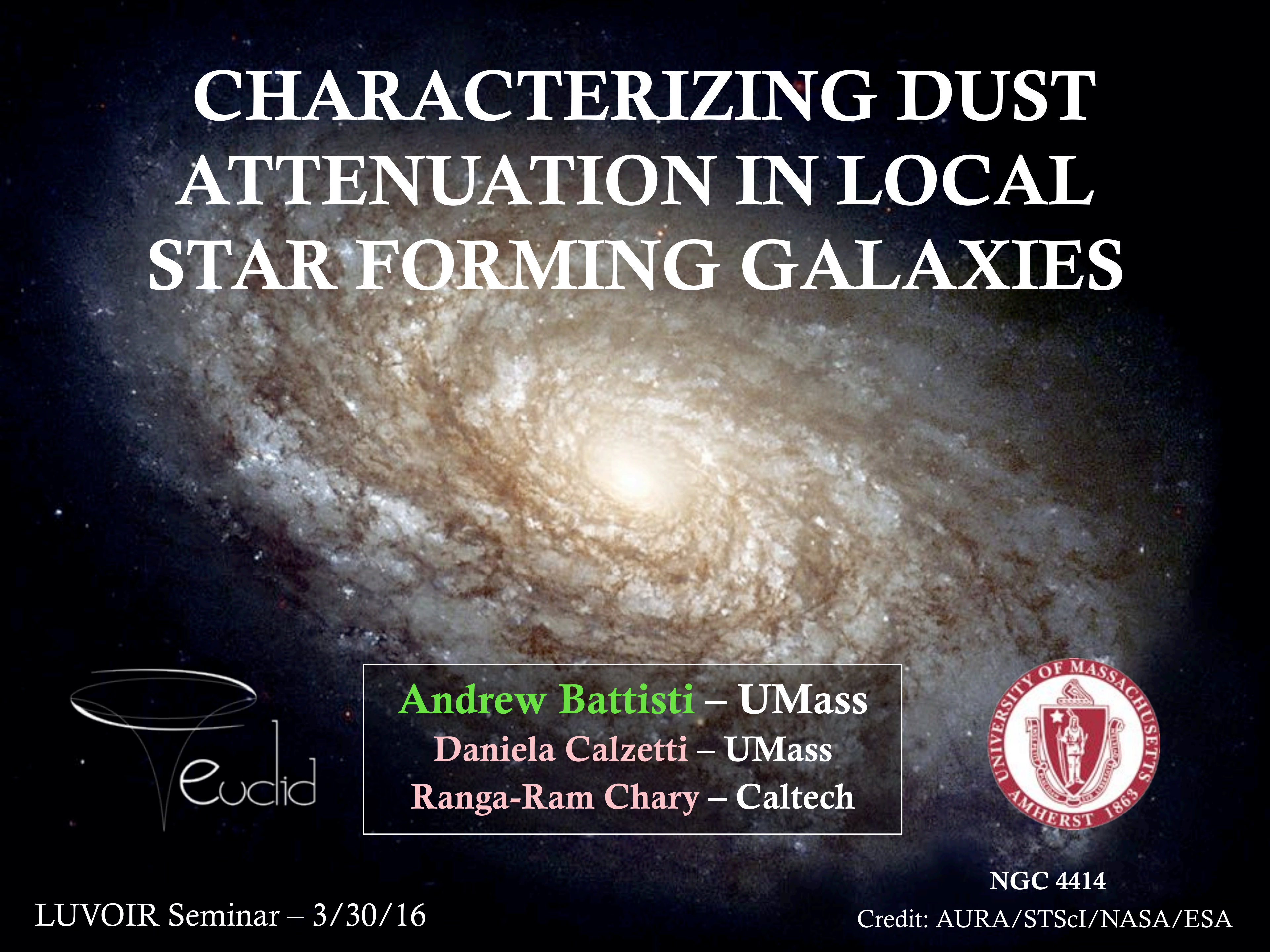


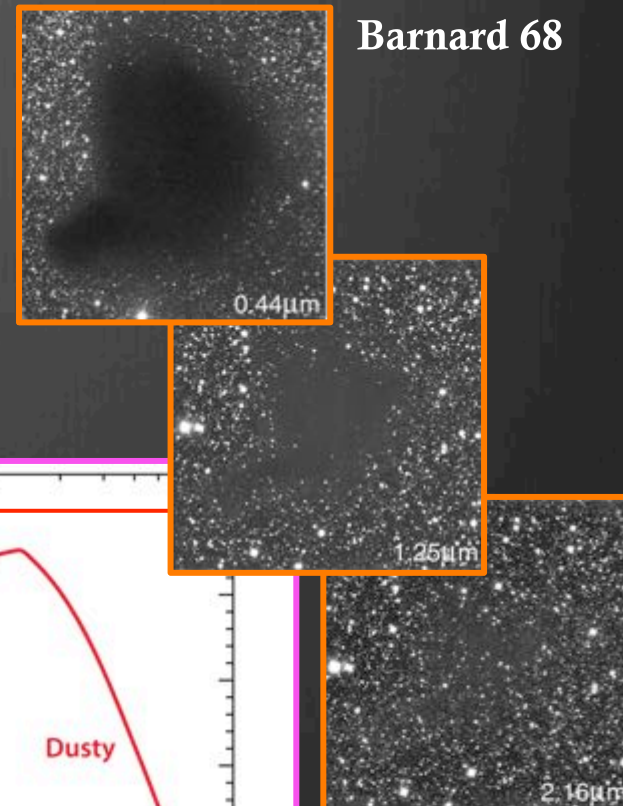
NGC 4414
Credit: AURA/STScI/NASA/ESA

LUVOIR Seminar – 3/30/16

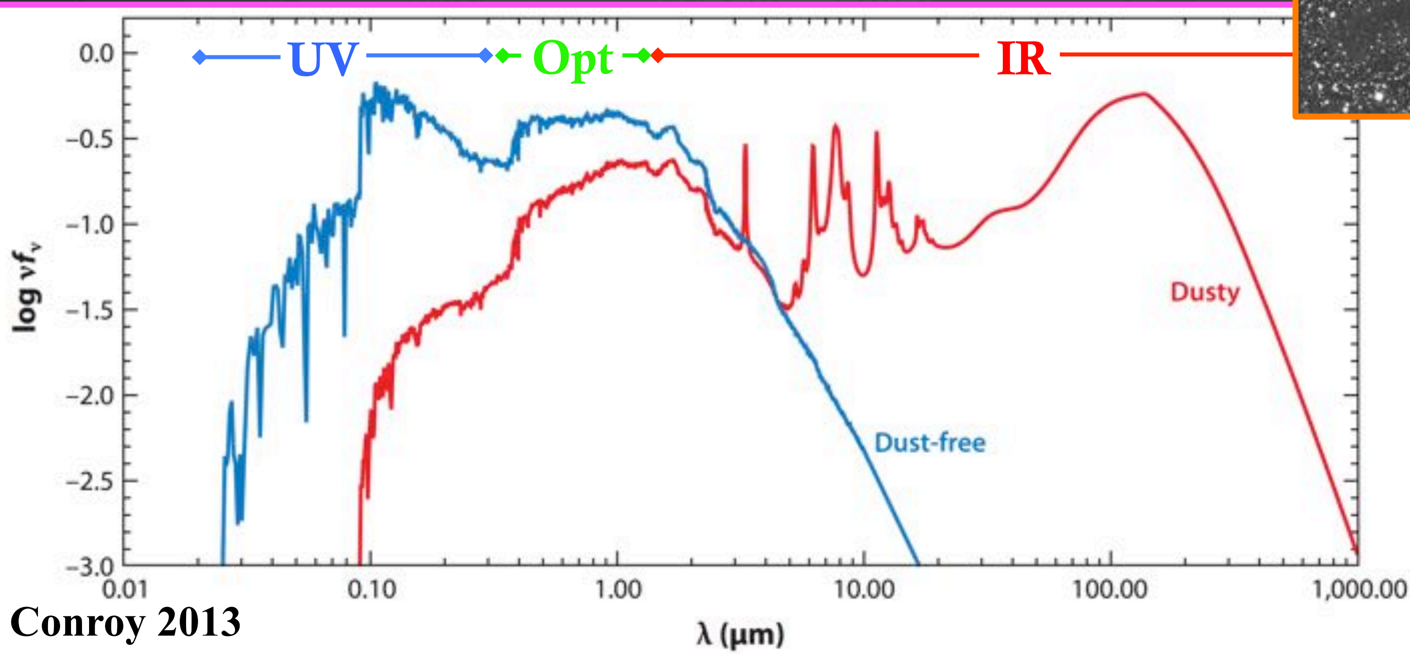
Impact of Dust on Science

- Dust alters spectral energy distributions (SEDs)
  - Wavelength dependent, blue affected more
- Galactic impact: star classification, distance measurements, etc.
- Extragalactic impact: photo-z, galaxy properties (e.g., M_*, SFR), SNe measurements, etc.

Barnard 68



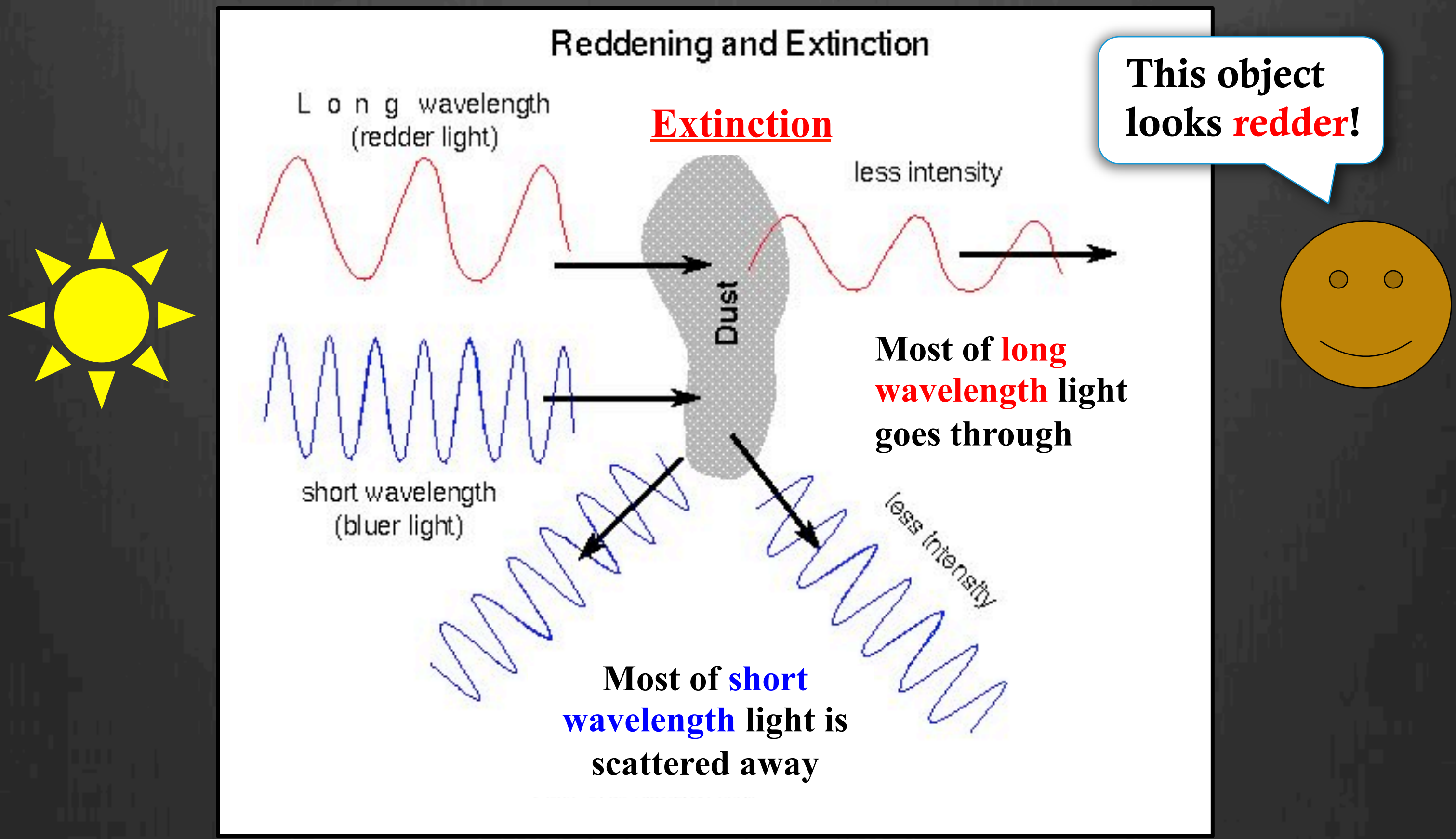
Credit: ESO



Conroy 2013

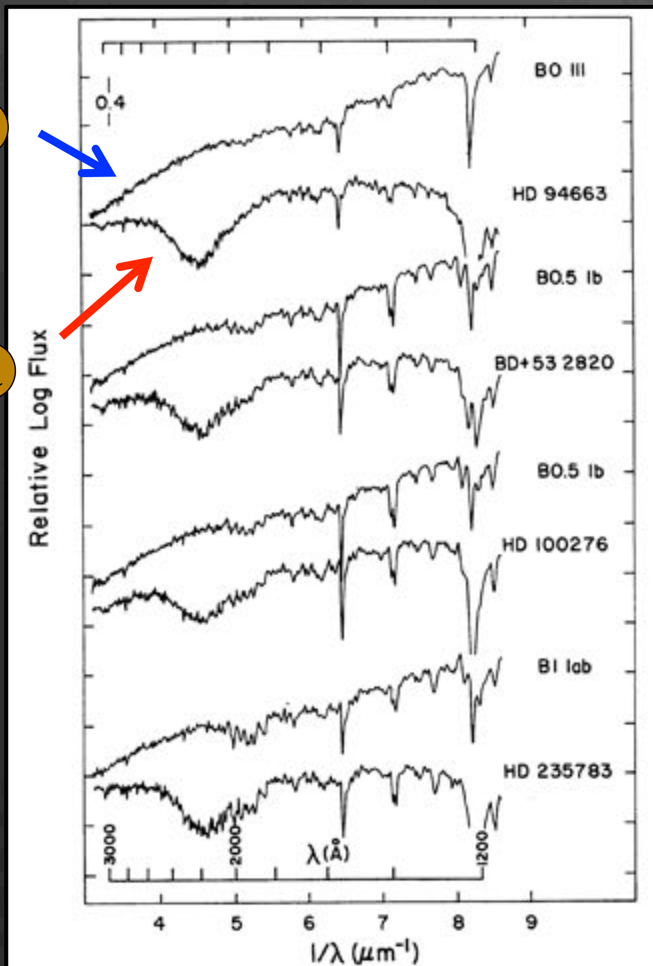
Dust in the Milky Way

- Extinction = Absorption + Scattering out of line-of-sight
  - Wavelength dependence influenced by size distribution and composition



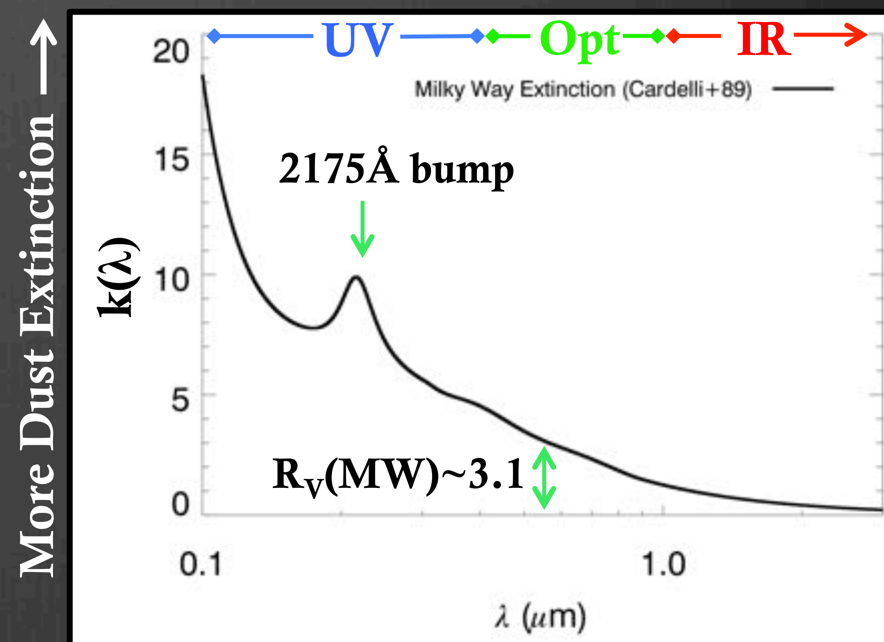
Dust in the Milky Way

- Ideal Study: use object with known spectrum
  - Stars have well understood SEDs



Cardelli+1992

$$k(\lambda) = \frac{A(\lambda)}{E(B-V)}$$



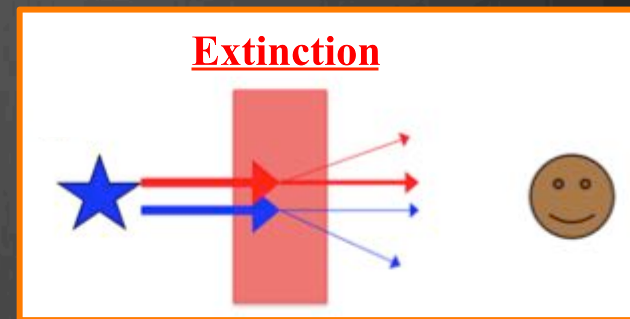
Dust in Distant Galaxies

- Unable to resolve stars, must use diffuse light
  - Diffuse light can scatter into line of sight

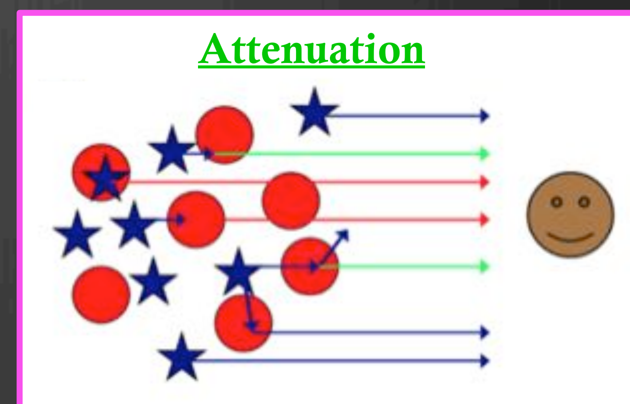
Attenuation = Absorption + Scattering out of line-of-sight + Scattering into line-of-sight

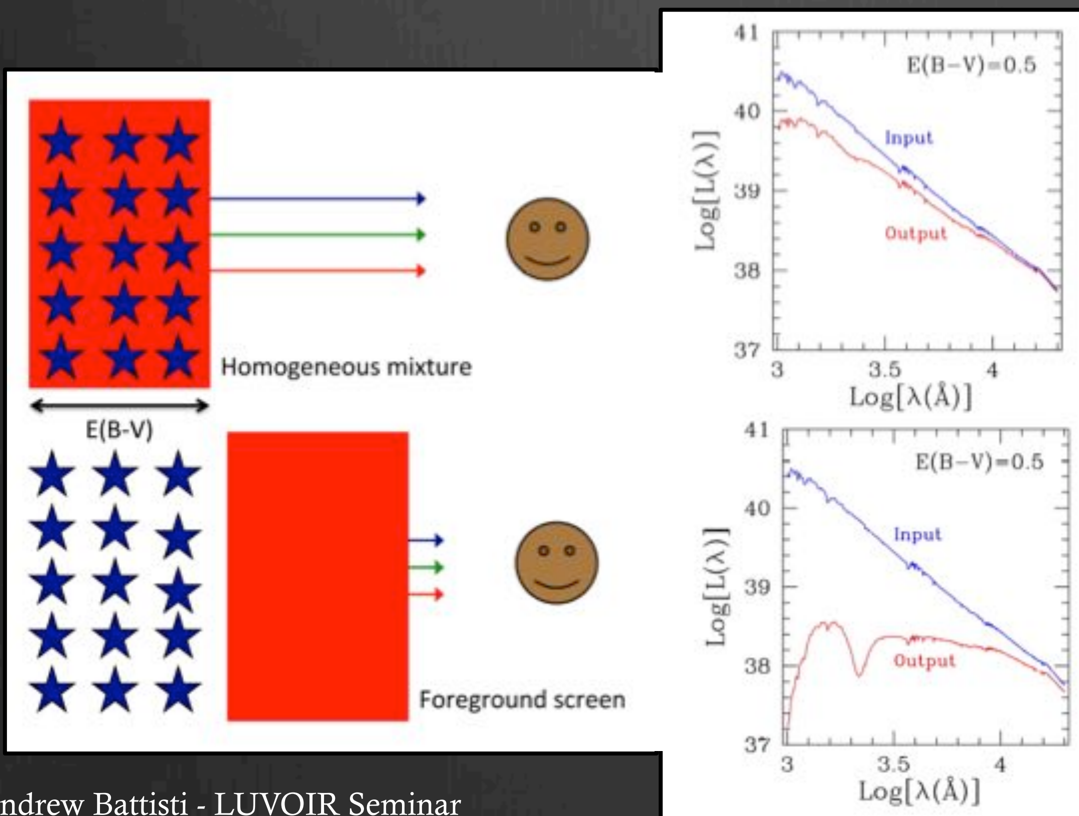
  - Strongly dependent on star/dust geometry

Galactic



Extragalactic

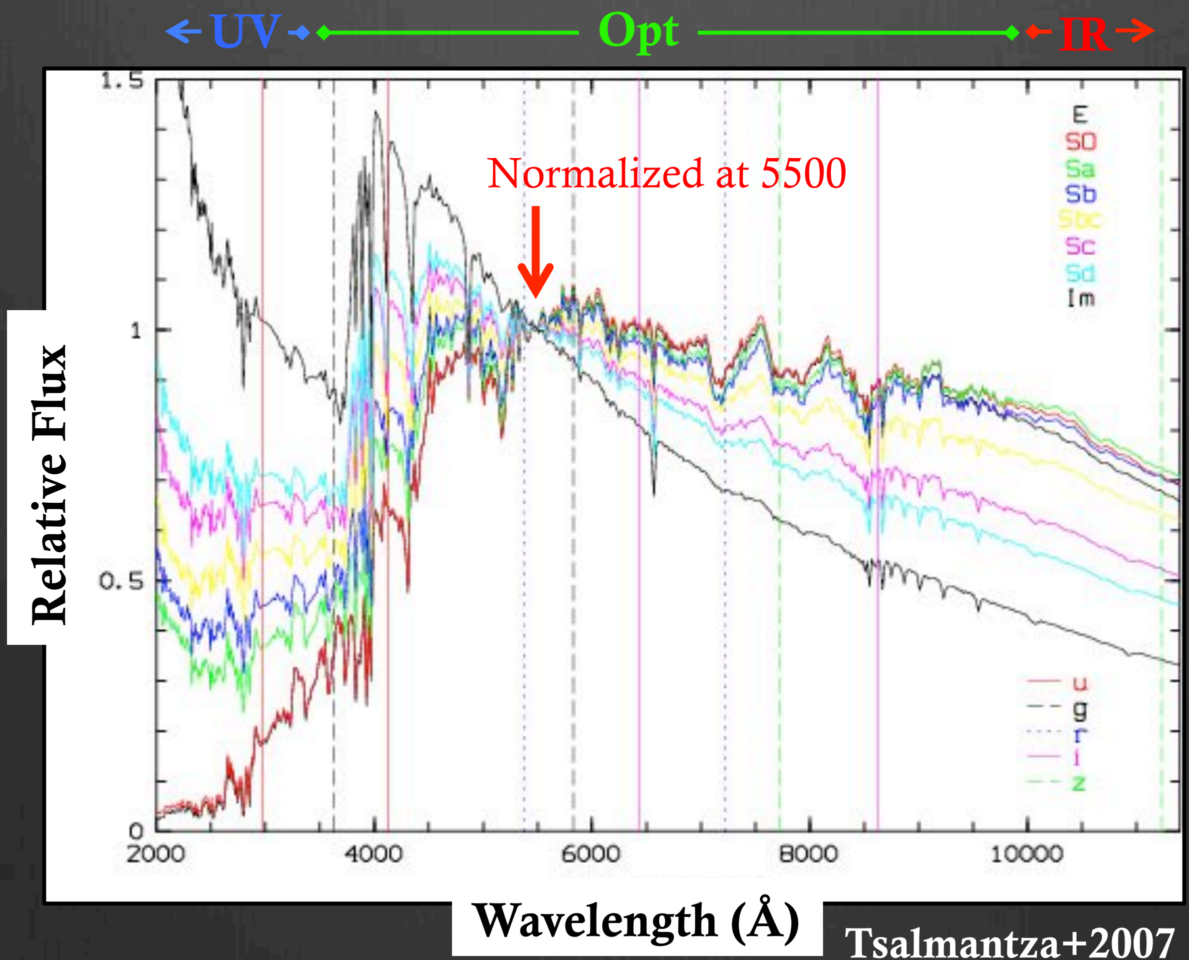




Calzetti 2013

Dust in Distant Galaxies

- Galaxy = Collection of many stars with different ages
  - No "intrinsic" galaxy SED → More difficult to characterize dust



Tsalmantza+2007

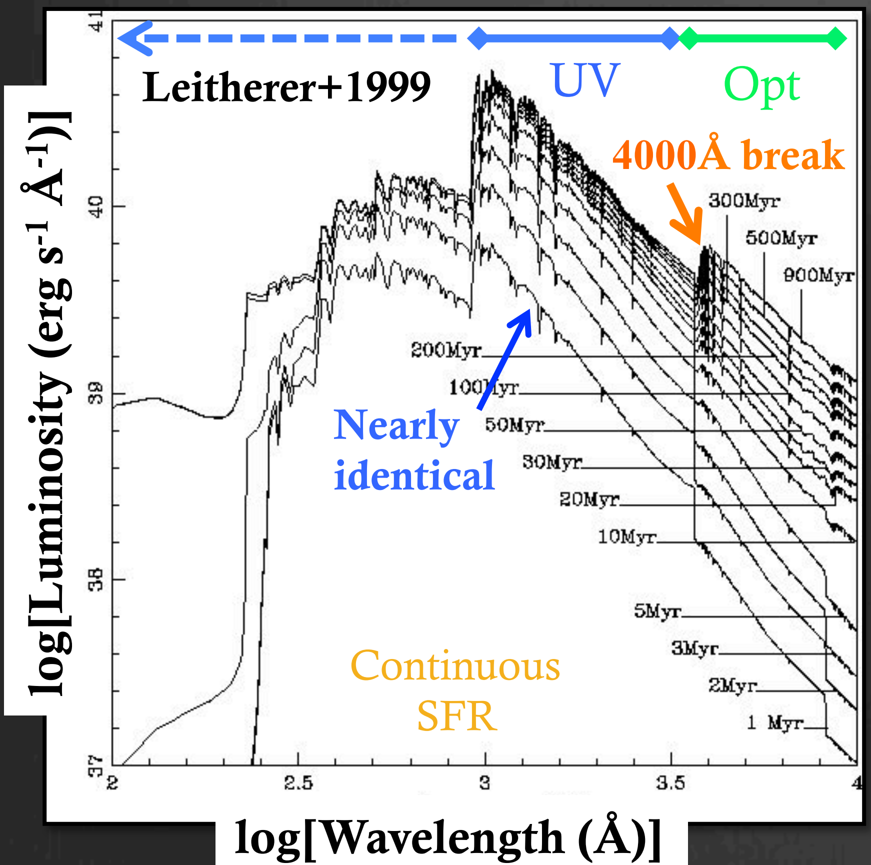
Attenuation or Age?

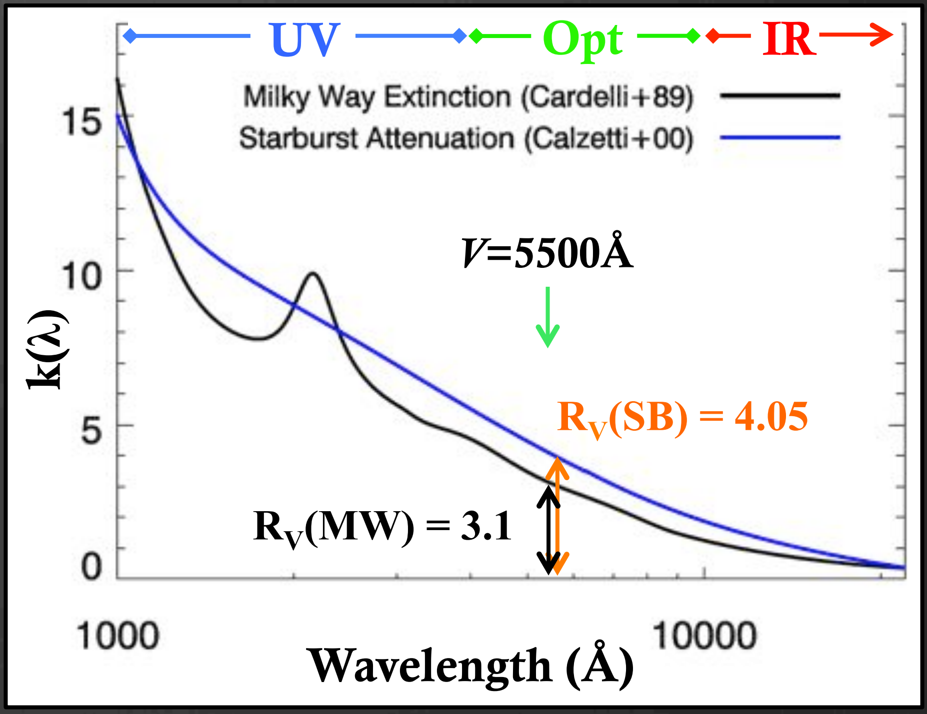
- Need to limit the variables
  - Choose a particular type of galaxy (limit age range)
  - Actively star-forming galaxies share similar UV SEDs

Selective Attenuation

Normalization

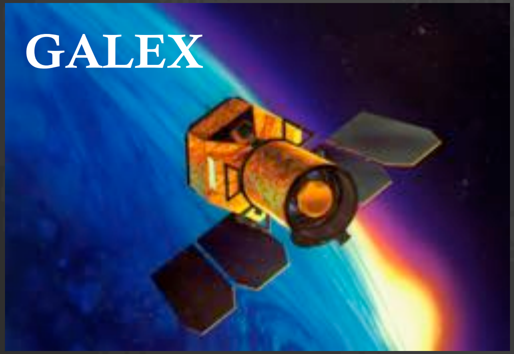
$$k(\lambda) = fQ(\lambda) + R_V$$





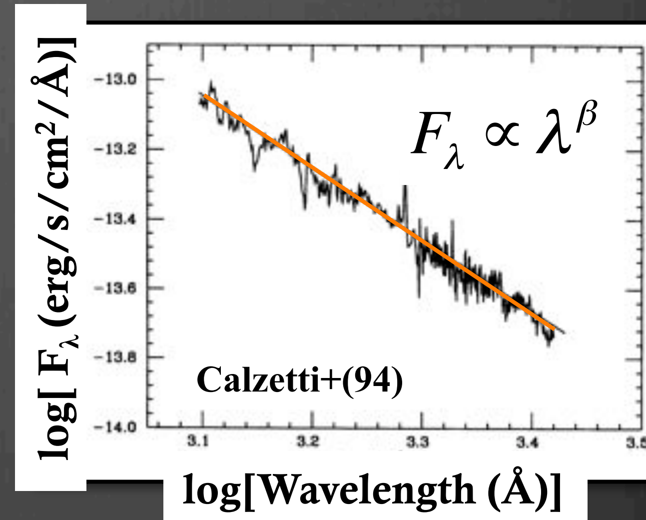
Expanding the Sample

- Nearly all studies use starburst attenuation curve (only 39 galaxies!)
  - How appropriate is this for less active galaxies?
  - Does attenuation curve vary with galaxy properties?
- Need a large sample of galaxies to address these questions
  - Large Area Surveys: GALEX (UV), SDSS (Optical+spectroscopy)
  - Select SFGs from optical emission line diagnostics
  - Aperture match UV & optical data (4.5'')
  - Final sample – 9,813 star-forming galaxies ($z < 0.1$)

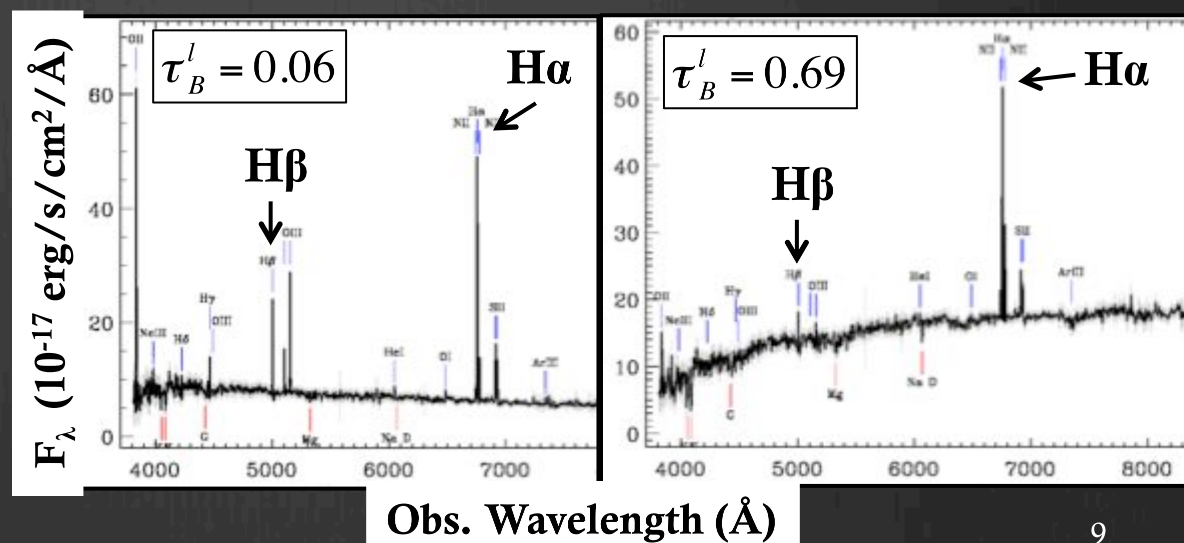


Characterizing Attenuation

- UV slope, β (1250–2600Å)
  - Reddening of stellar continuum
  - Influenced by stellar age
- Balmer optical depth, τ_B^l
  - Reddening of ionized gas
  - Not influenced by stellar age
  - Proxy for dust content

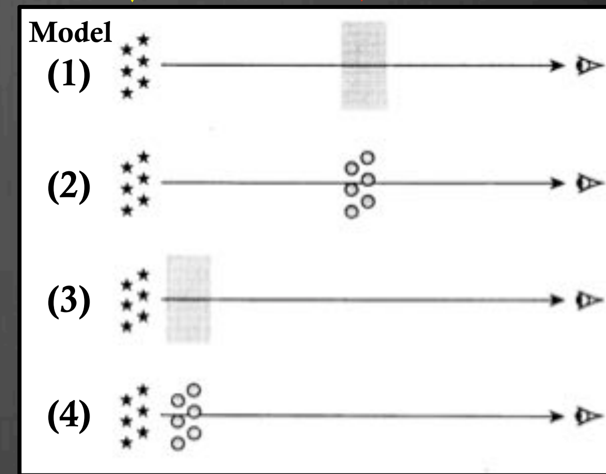


$$\tau_B^l = \ln\left(\frac{F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)}{2.86}\right)$$

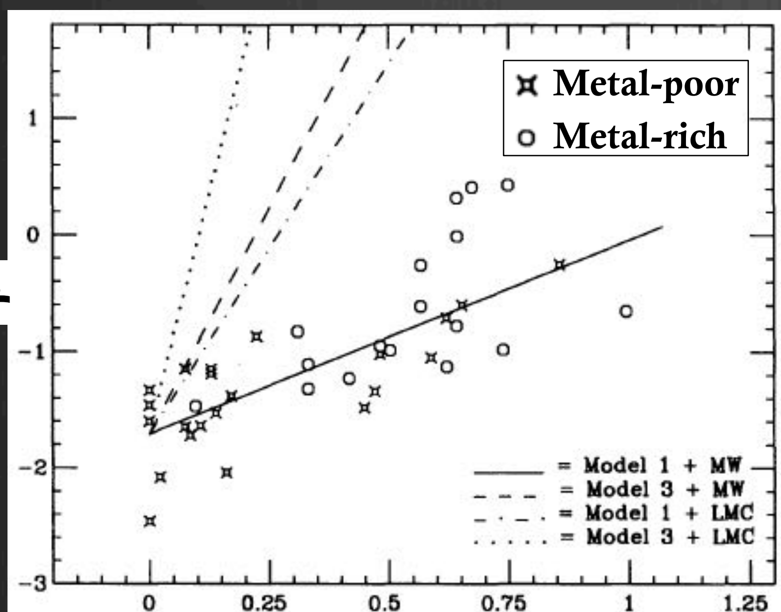


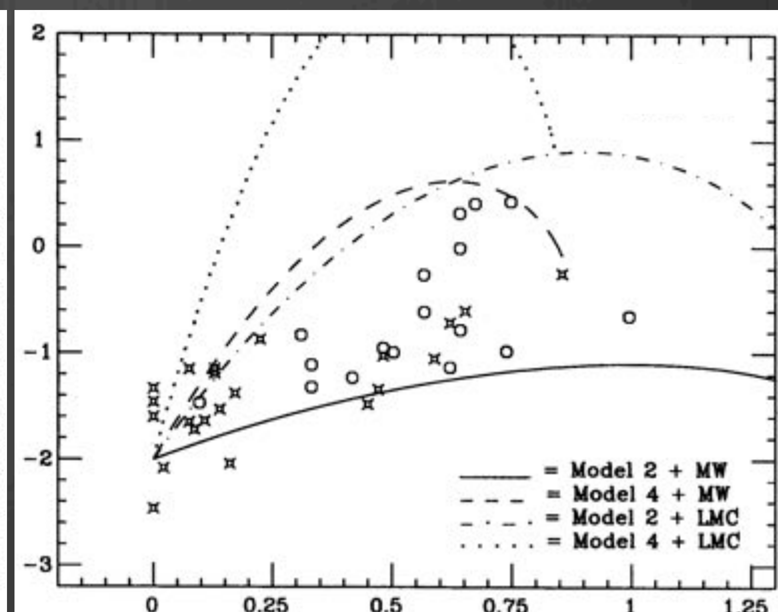
Constraining Geometry
(Stars/Dust)

- Expect different trends between $\beta - \tau_B^l$
- Case Study: Starburst galaxies
  - Linear behavior → foreground dust dominates



Redder ionized gas
(More Dust)



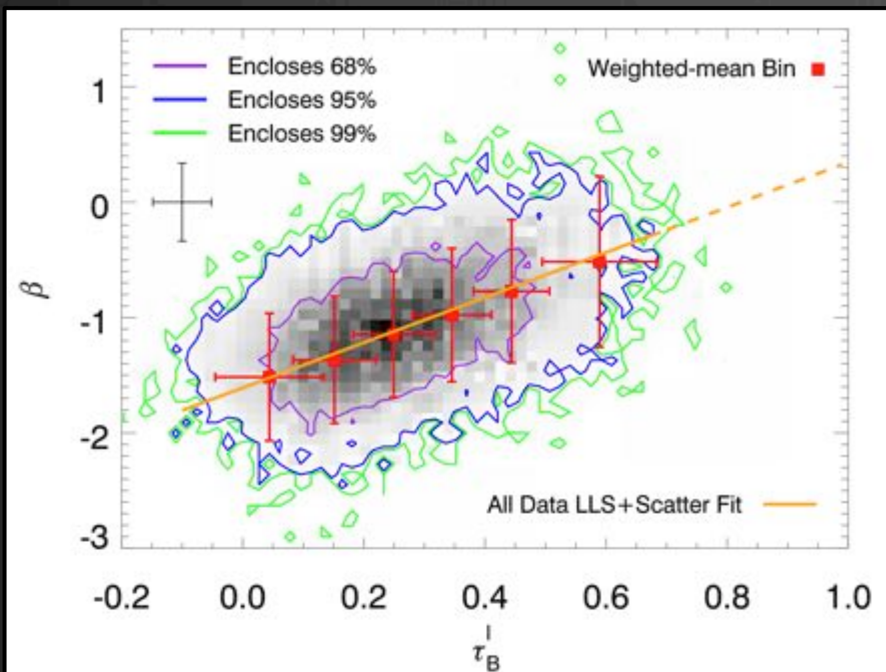


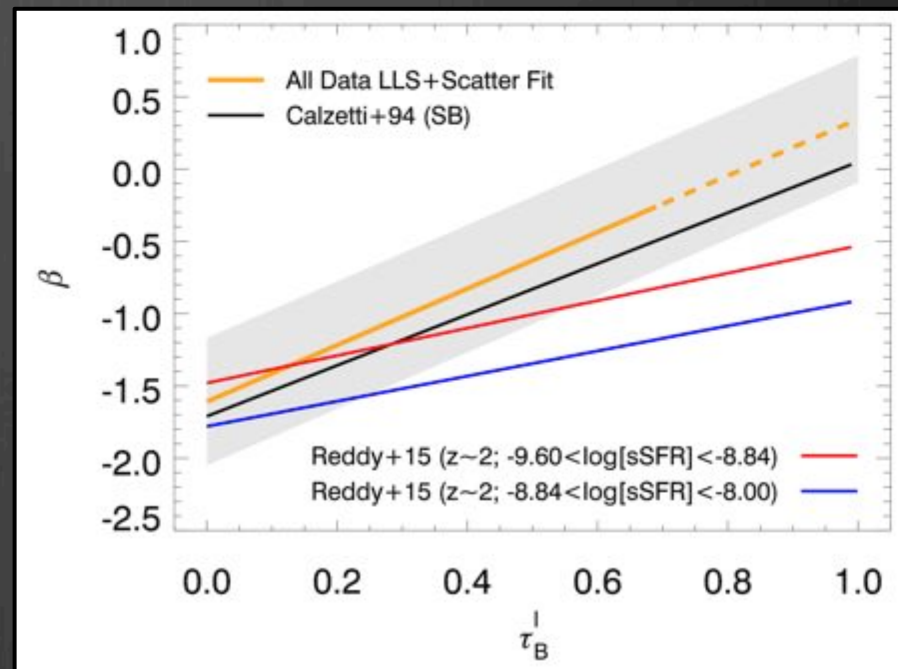
Calzetti+1994

Constraining Geometry: SFGs

- SFGs also have linear relation
  - Scatter is large: $\sigma_{int} = 0.44$
  - $\beta - \tau_B^l$ consistent with foreground dust as dominant component

Redder UV



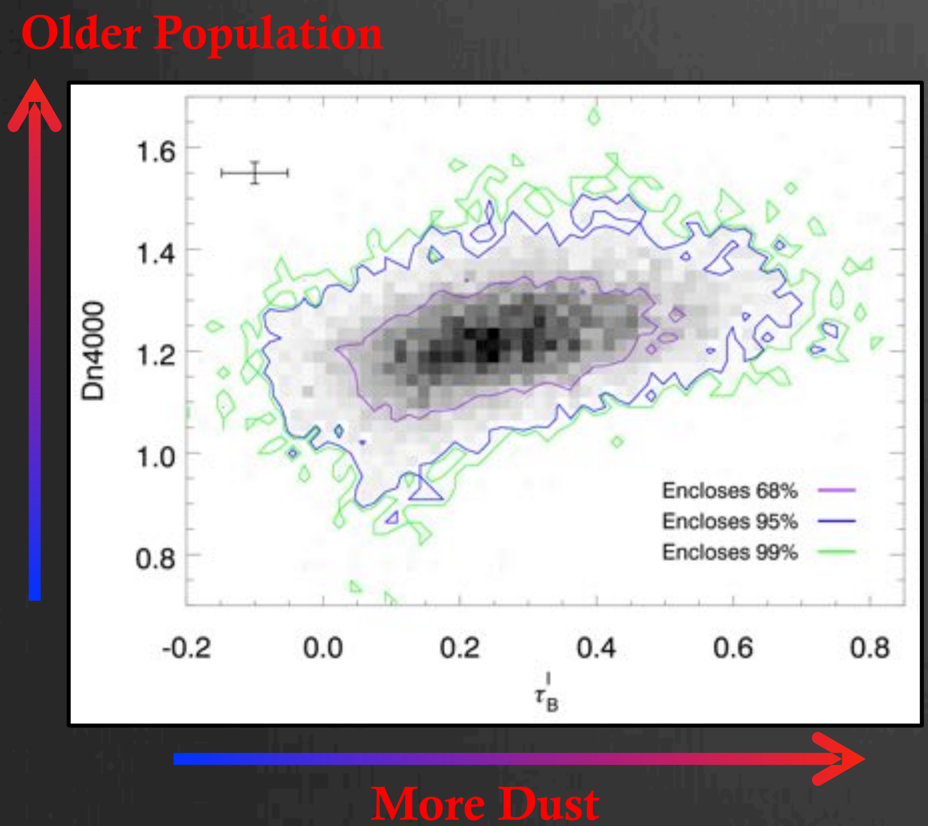


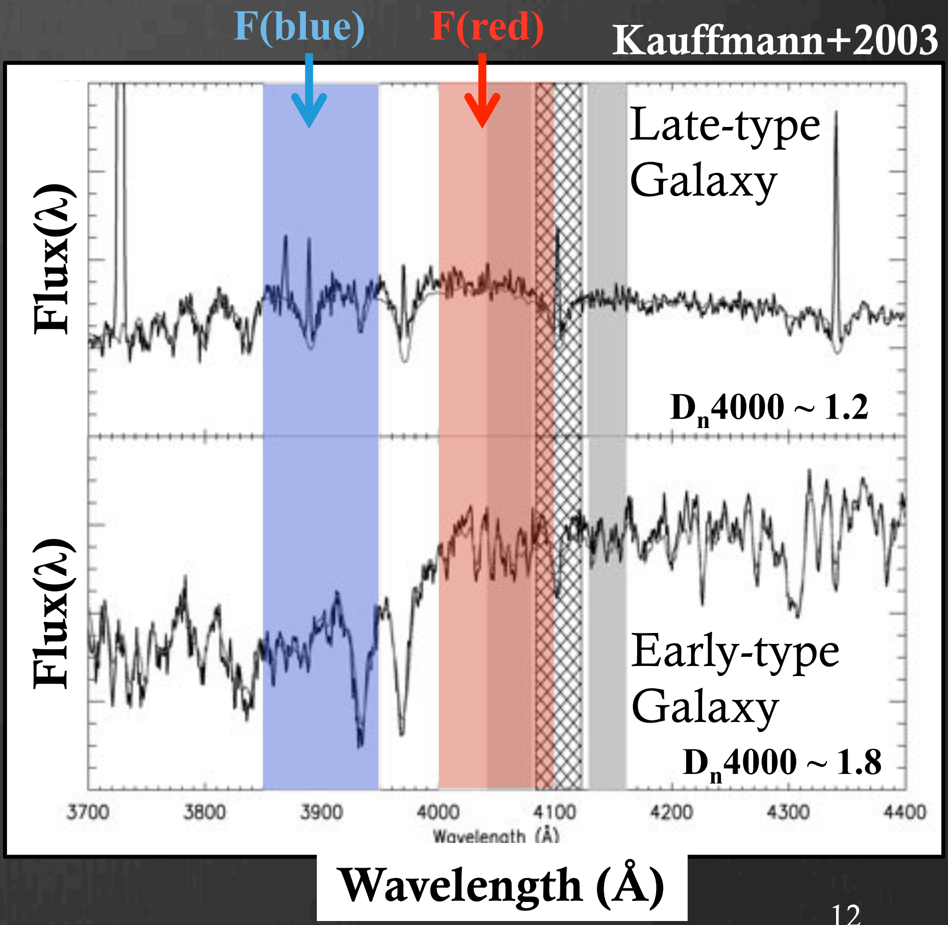
More Dust

Battisti+2016

Derive Attenuation Curve

- Want similar average stellar population with τ_B^l (dust proxy)
- Need to limit stellar age effects:
  - Use 4000Å break; D_n4000 = F(red)/F(blue)

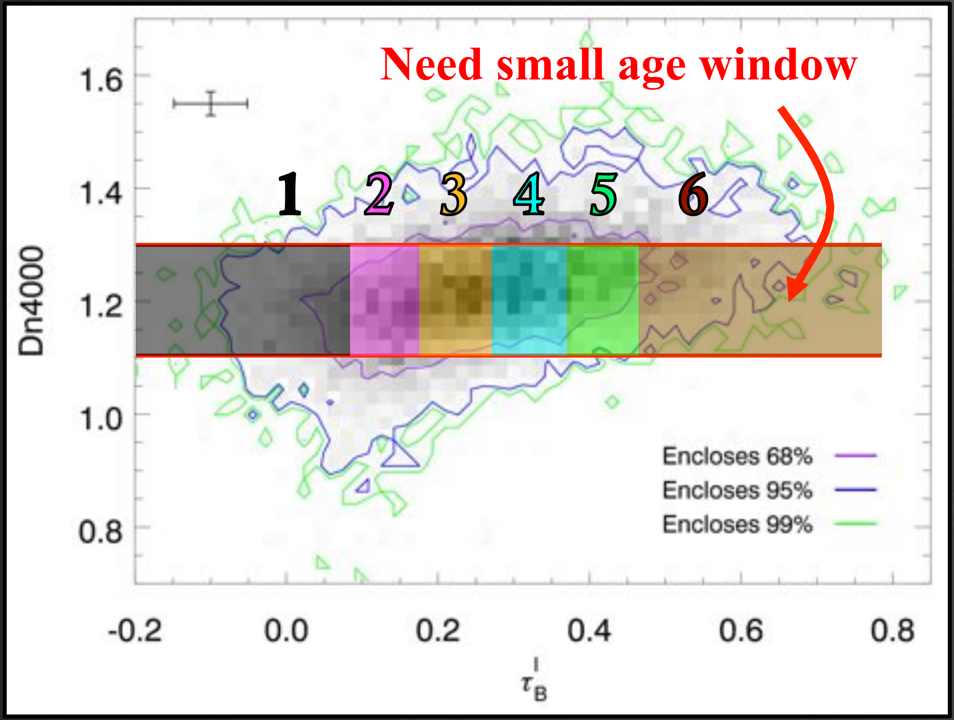


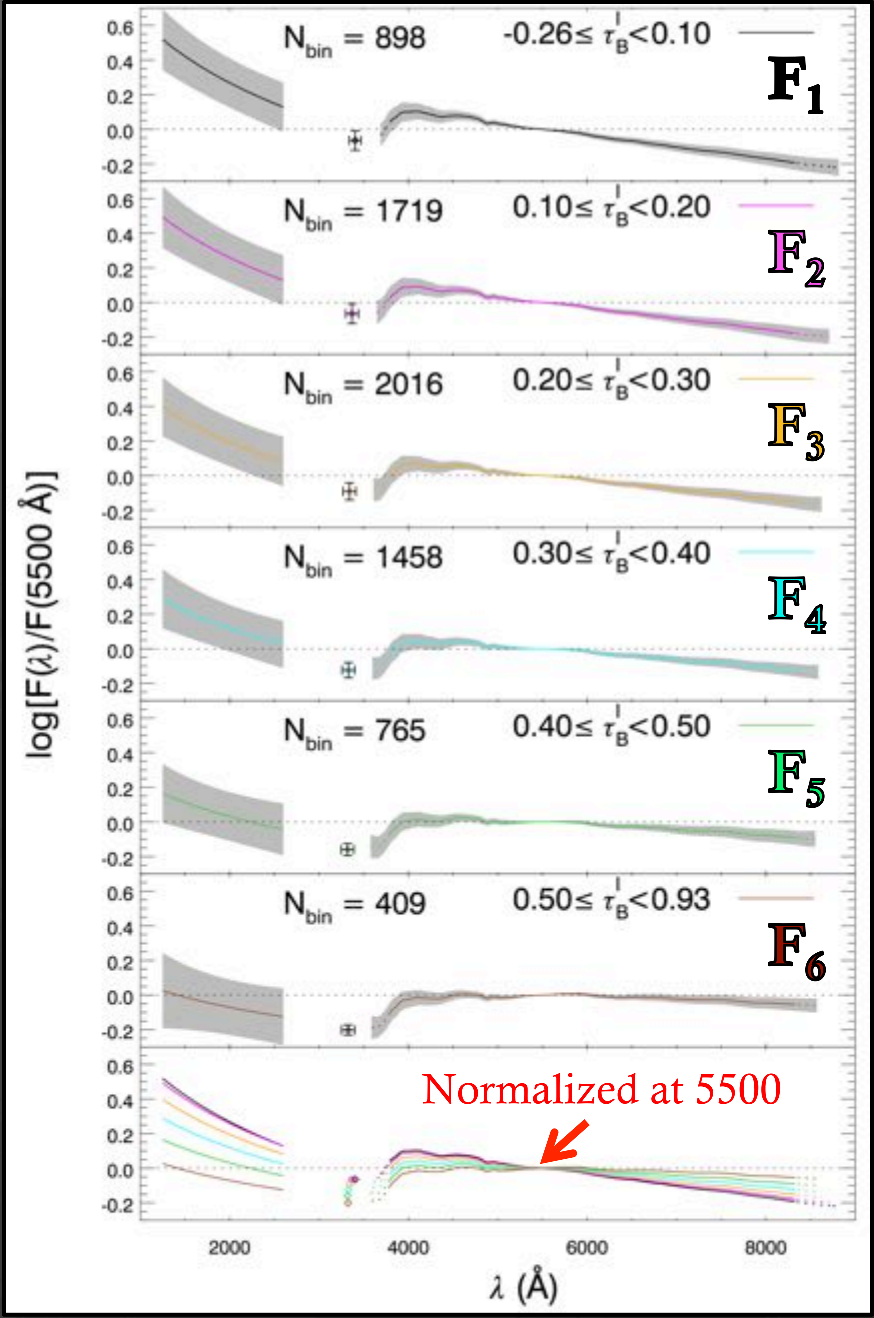


Derive Attenuation

- Create templates as function of τ_B^l

N(1.1<D_n4000<1.3) = 7265

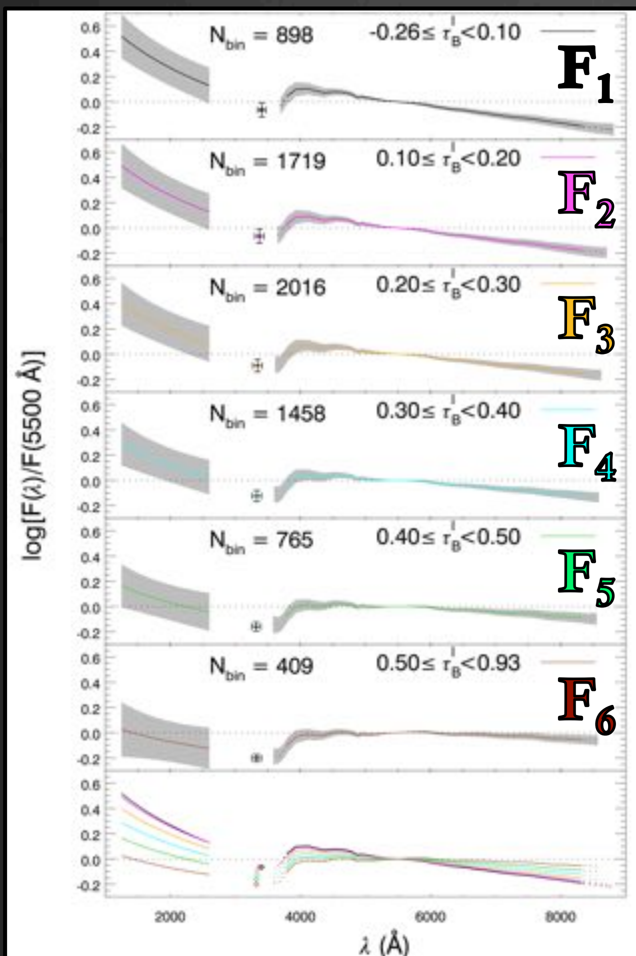


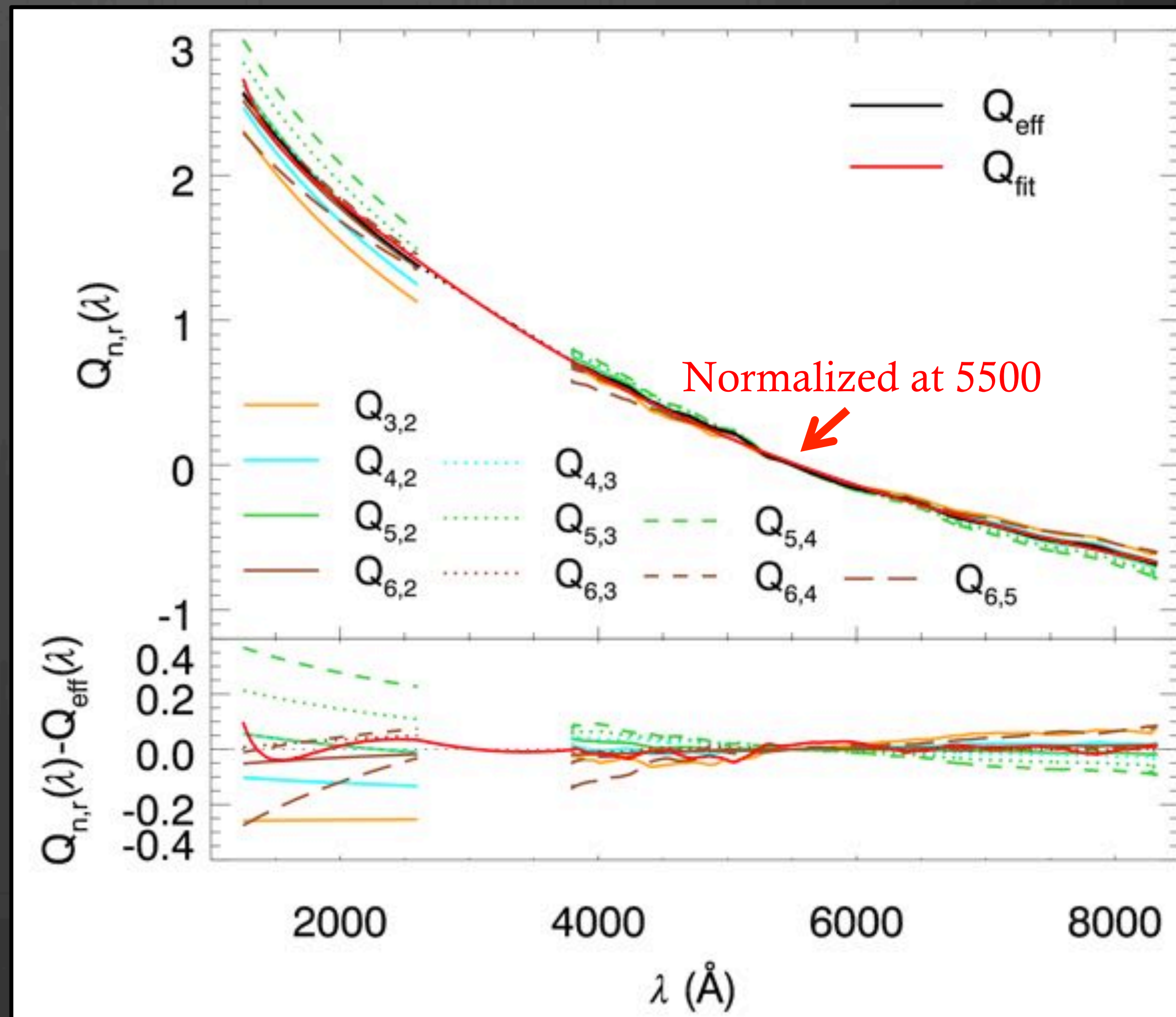


Selective Attenuation Curve

$$Q_{n,r}(\lambda) = \frac{-\ln\left(F_n(\lambda)/F_r(\lambda)\right)}{\tau^l_{Bn} - \tau^l_{Br}}$$

← Behavior of foreground geometry





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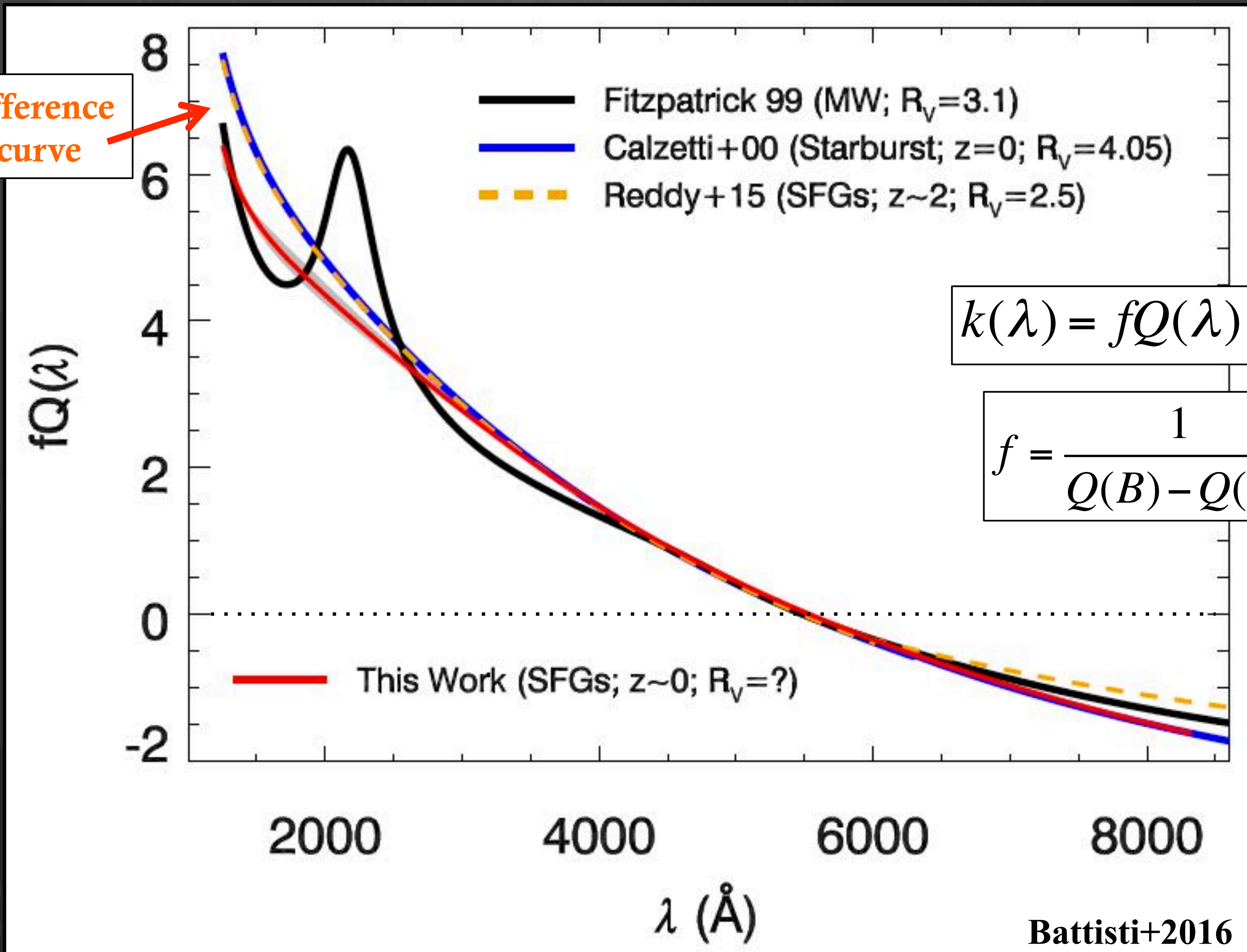
Selective Attenuation Curve

~20% difference from SB curve



$$k(\lambda) = fQ(\lambda) + R_V$$

$$f = \frac{1}{Q(B) - Q(V)}$$

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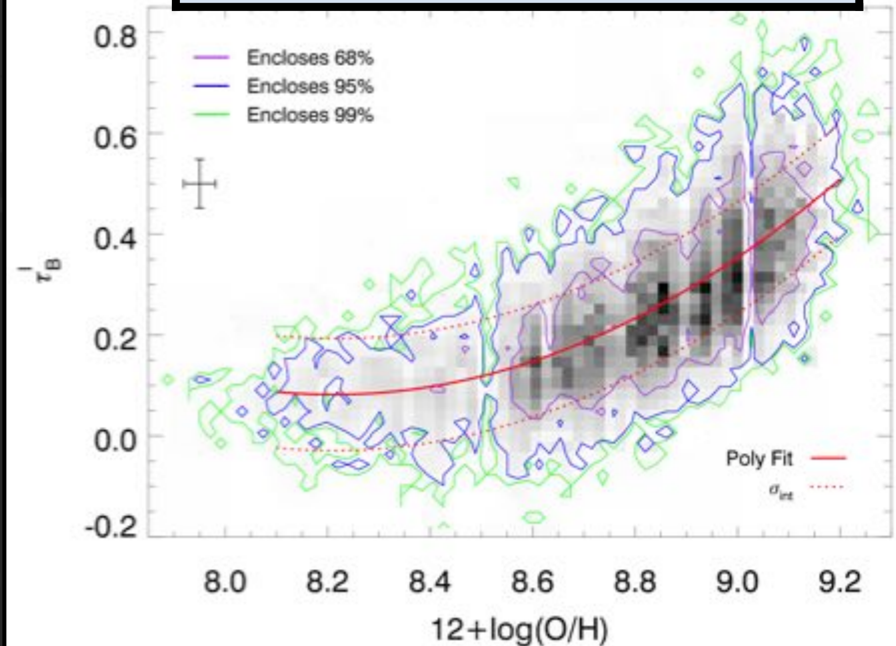
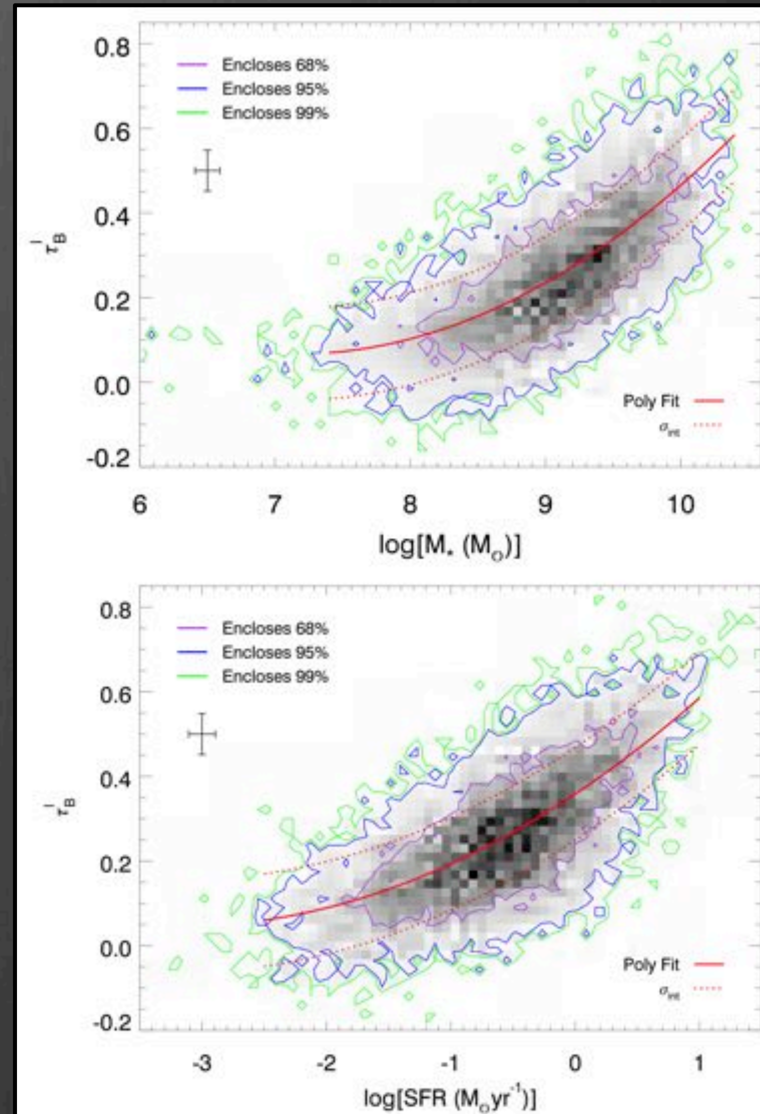
Attenuation vs. Galaxy Properties

SFG Properties (3” fiber)
$-3.7 \leq \log(\mathrm{SFR}\ [M_\odot/\mathrm{yr}]) \leq 1.6$
$6.0 \leq \log(M_*/M_\odot) \leq 10.7$
$7.7 \leq 12 + \log(\mathrm{O/H}) \leq 9.4$



More Dust



- Galaxies with more metals, stellar mass, star formation have more dust

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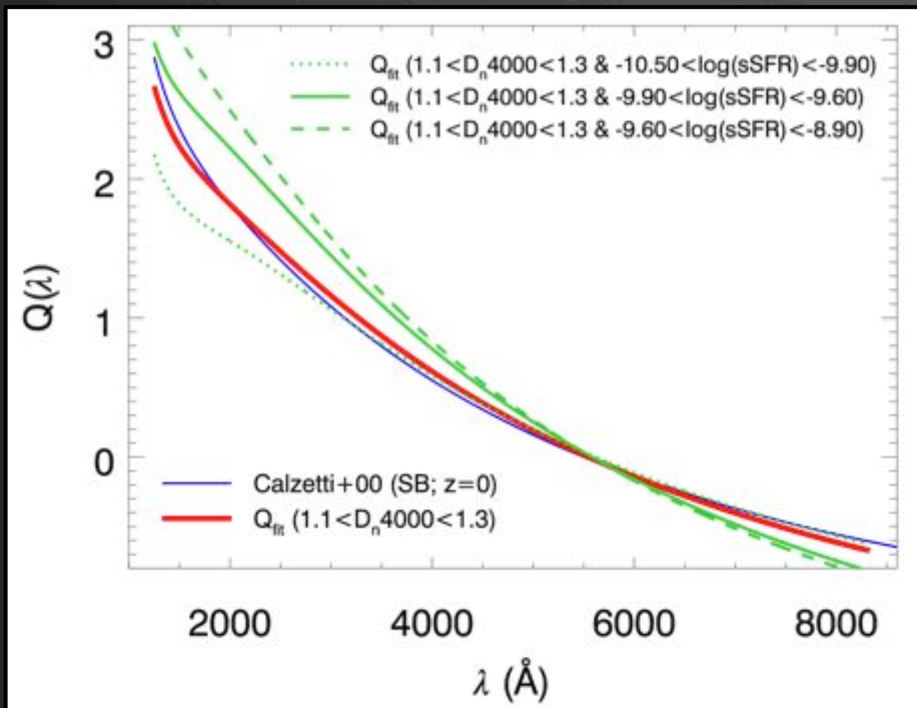
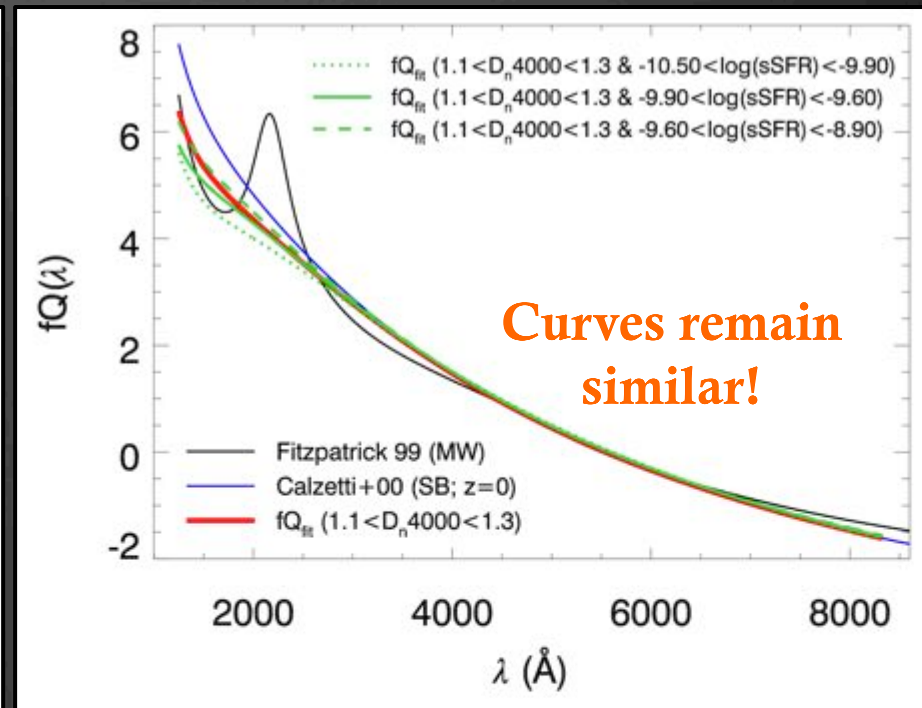
Attenuation Curve Variation

- Separate sample by various properties (ex. shown for sSFR)
  - Differential reddening (*f*) varies, but selective attenuation similar
  - Although, notable variation with inclination (work in progress)

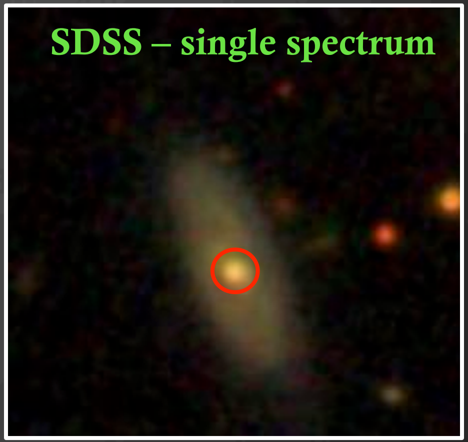


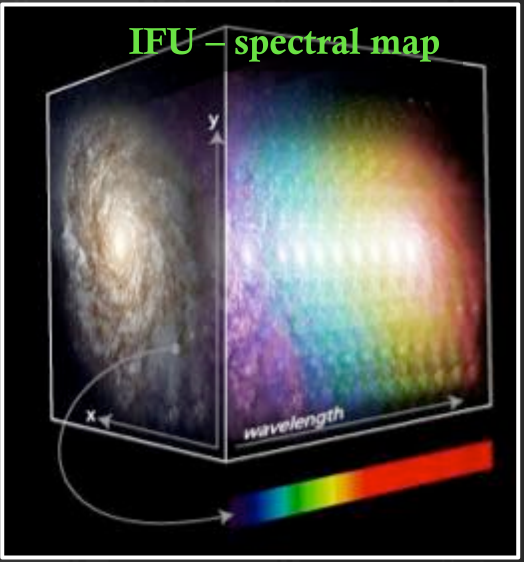


Battisti+2016

The LUVOIR Revolution

- Current limitations:
  - UV – GALEX only 2 bands, poor angular resolution
  - Optical – SDSS fiber give single measurement of dust content
- Future prospects:
  - UV – LUVOIR IFU, high angular resolution
  - Optical – Numerous IFU surveys provide spatial map of dust
- Multi-λ IFUs → Revolutionize understanding of dust attenuation in other galaxies!
- Improved resolution → Measure extinction curves out to few Mpc (how much variation?)





Credit: Marc White

Summary

- Selective attenuation, $fQ(\lambda)$, of SFGs similar to SB galaxies
  - Favors foreground dust geometry (dominant over internal dust)
  - Shallower UV (~20% in FUV)
- Majority of sample is consistent with a single selective attenuation curve

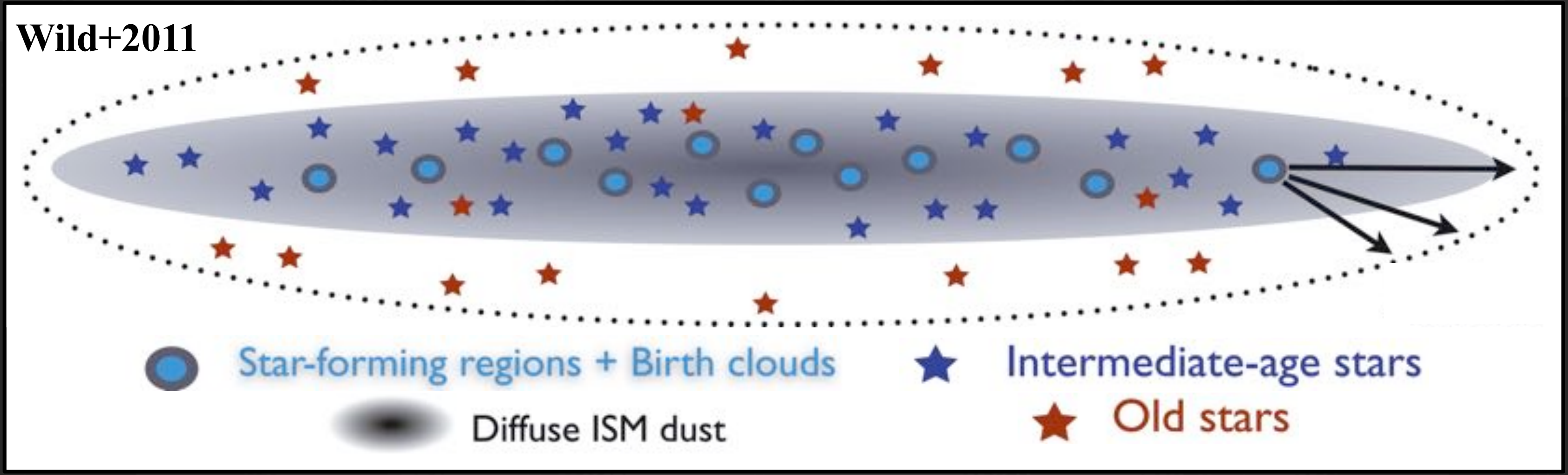
See Battisti, Calzetti, & Chary 2016 for more details

In Progress…

- Measure R_V to determine if total attenuation, $k(\lambda)$, is different
- Investigate inclination & geometry (reduce scatter?)

Differential Reddening

- Our parameters probe different regions
  - Attenuation curve (β) – reddening of stellar continuum (SF regions, Intermediate, & Old Stars)
  - Balmer optical depth (τ_B^l) – reddening of ionized gas (SF regions)



- Ionized gas ~2x redder than continuum (Calzetti+00; Kreckel+13)
- Need to correct Q(λ) shape (*f*), so that *k*(B) - *k*(V) =1

Normalizing the Curve

- Ways to get the normalization, R_V:
  - (1) Measure $Q(\lambda)$ out to NIR where $k(\lambda) \rightarrow 0$ (occurs at ~2.85 μm)
  - (2) Energy balance, $\Delta F(0.09\text{-}2.85\mu m) = F(3\text{-}1000\mu m)$

$$k(\lambda) = fQ(\lambda) + R_V$$