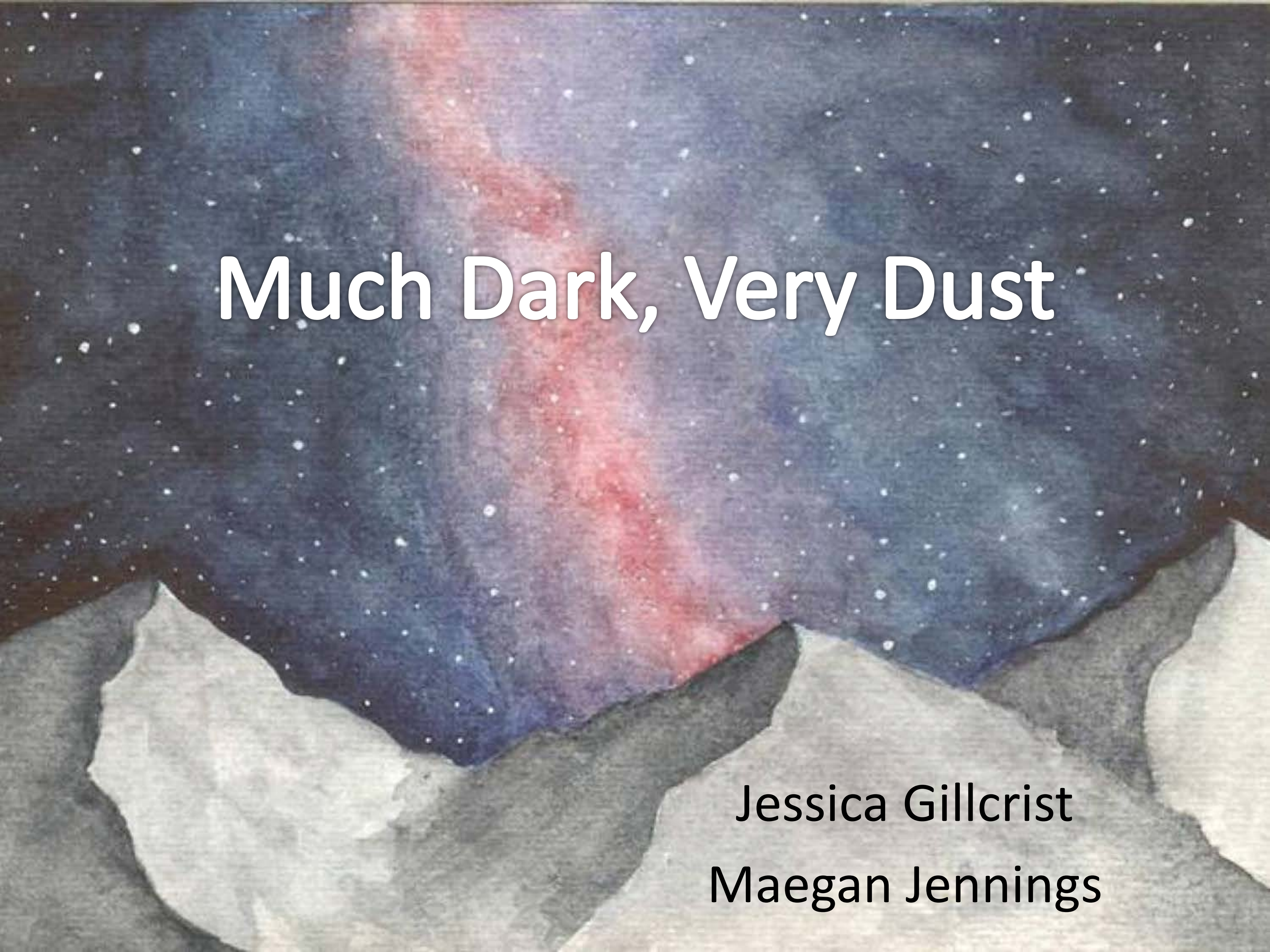
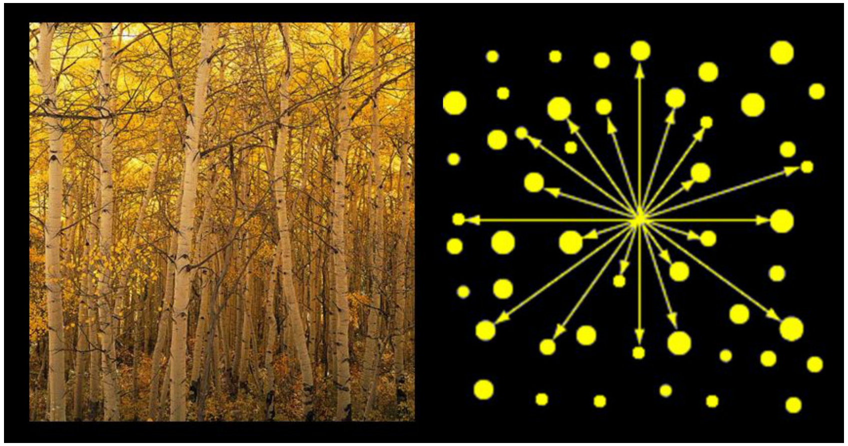


Much Dark, Very Dust

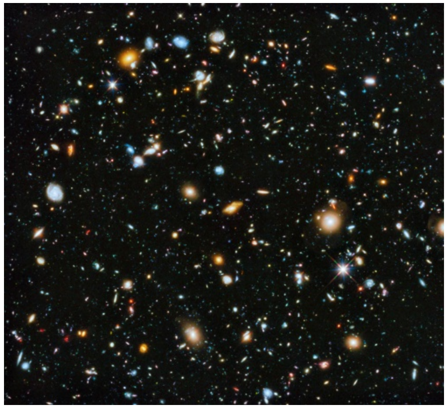
Jessica Gillcrist
Maegan Jennings

Olbers' Paradox



- History
  - See Kayleigh's poster
- Accepted Resolution
  - Age of the Universe
  - Expansion
- Not Accepted Resolution
  - Absorption (Olbers, de Chéseaux)
  - Cannot *eliminate* background light

    --- but can *shift it* out of optical!



Hubble Ultra Deep Field (2014)

Extragalactic Background Light (EBL)

- In general relativity, given as a function of wavelength λ_0 by:

Galaxy formation redshift

Number density

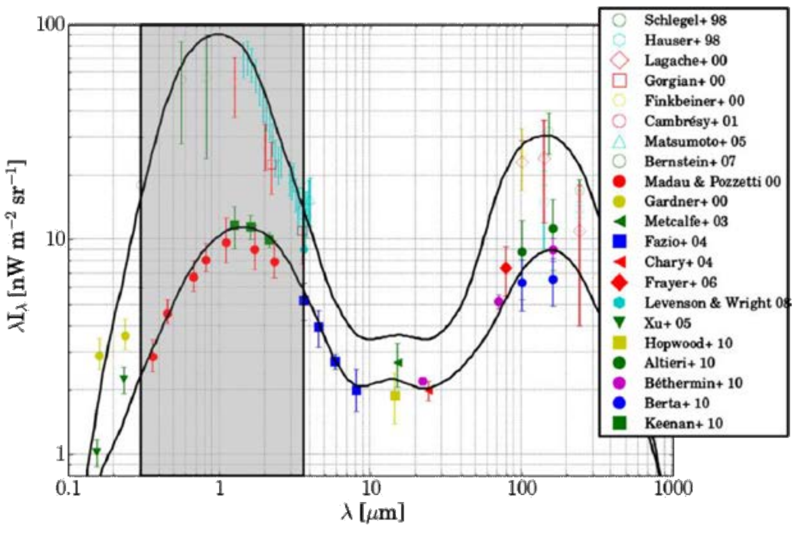
Spectrum

Optical depth in the Intergalactic Medium (IGM)

$$I_\lambda(\lambda_o) = \frac{c}{4\pi}\int_0^{z_f} \frac{n(z)F(\lambda,\ z)}{(1+z)^3 H(z)} e^{-\tau(\lambda,z)} dz$$

Hubble expansion rate

$$H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}$$

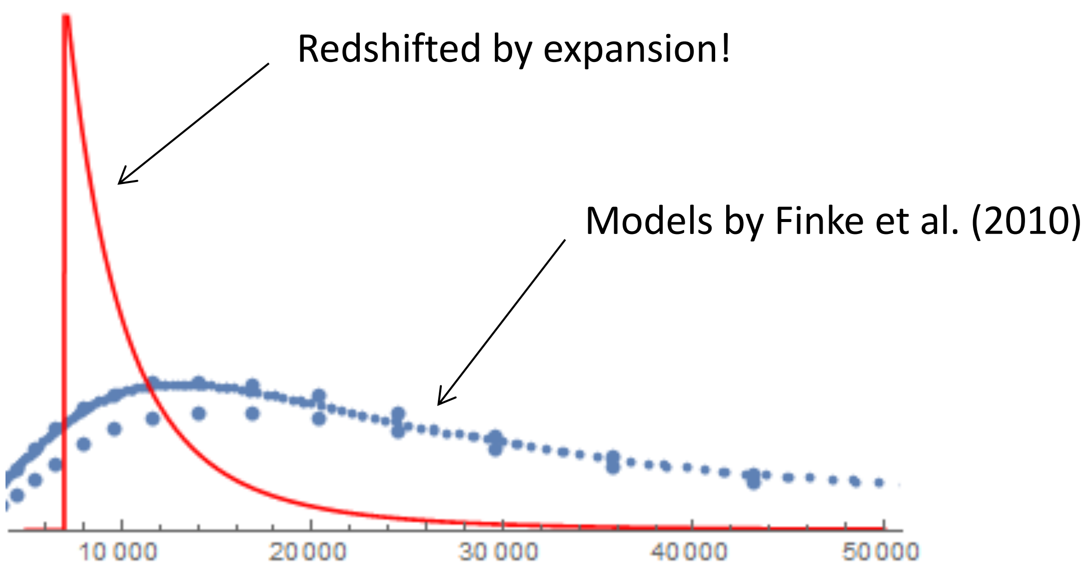


(Vavryčuk 2017)

Plotting..~~World Domination~~ Graphs

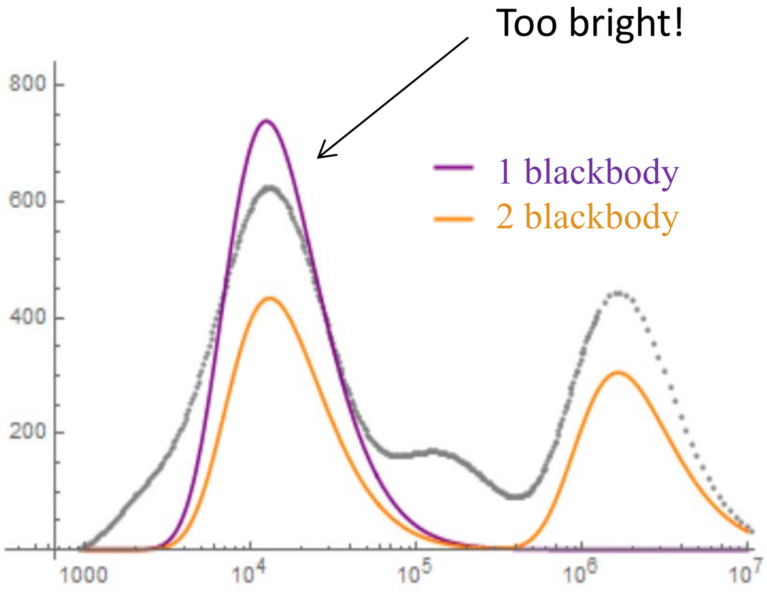
Test case: delta-function spectrum

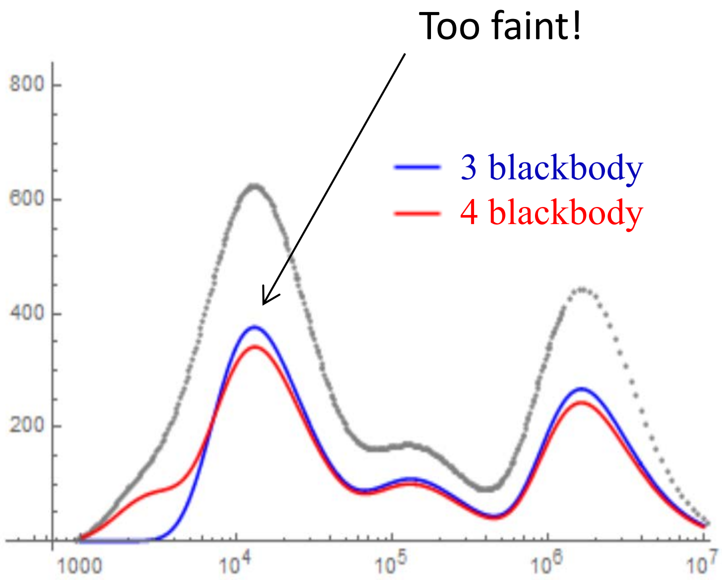
- As a test case, model galaxy spectrum with a Dirac delta function $F(\lambda) = \frac{L}{\lambda_p}\delta\left(\frac{\lambda}{\lambda_p} - 1\right)$ where $\lambda = \frac{\lambda_0}{1+z}$
- Normalize via $\int_0^\infty F(\lambda)d\lambda \equiv L$, take λ_p=7000 Å
- And take $n(z) =$ constant for simplicity
- Result:



Blackbody spectra

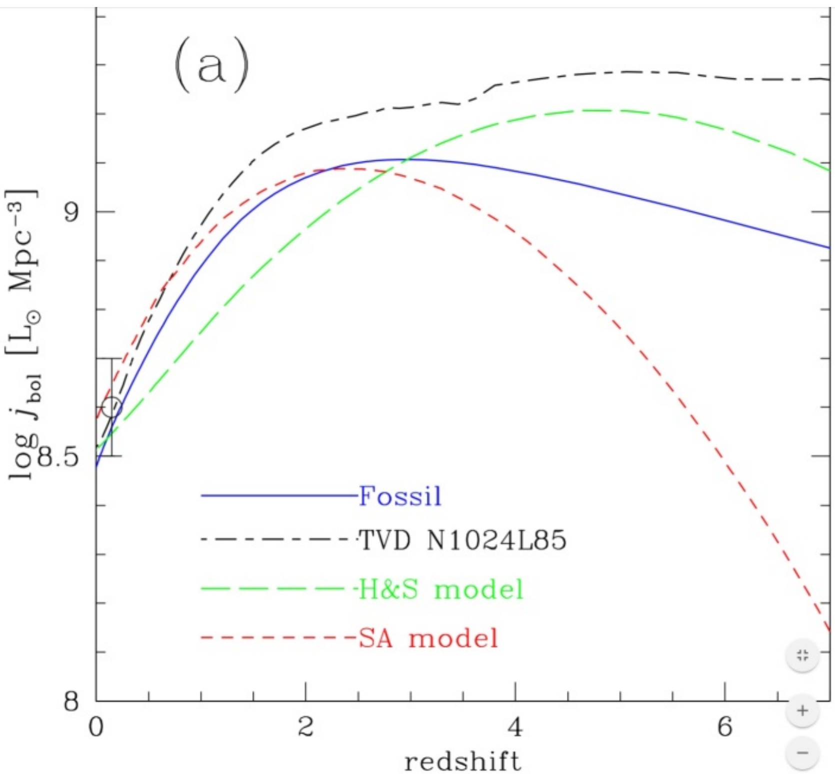
- Now try blackbody spectrum $F(\lambda) = 15\left(\frac{hc}{\pi k}\right)^4 \frac{C/\lambda^5}{e^{hc/kT\lambda}-1}$
- Normalization $\int_0^\infty F(\lambda)d\lambda = CT^4 \equiv L$ so $C = L/T^4$
- For multiple blackbodies, $L = f_1T_1^4 + f_2T_2^4$+…
- Results!





Galaxy Evolution

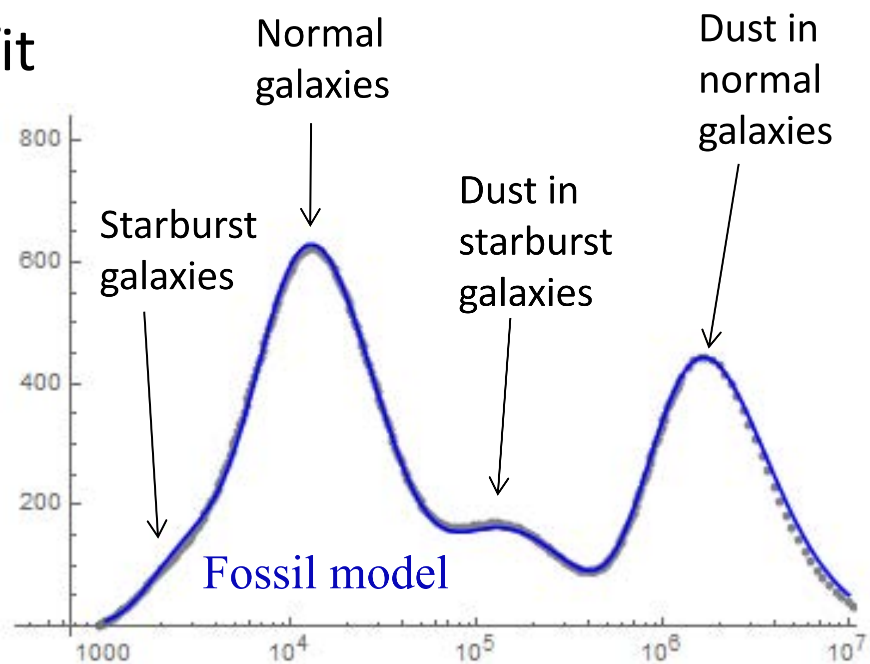
- Universe was much brighter at higher redshifts!
- Model with an evolving galaxy luminosity density $L * n(z) \to \mathcal{L}(z)$
- Four different models (Fossil, TVD, H&S, SA)

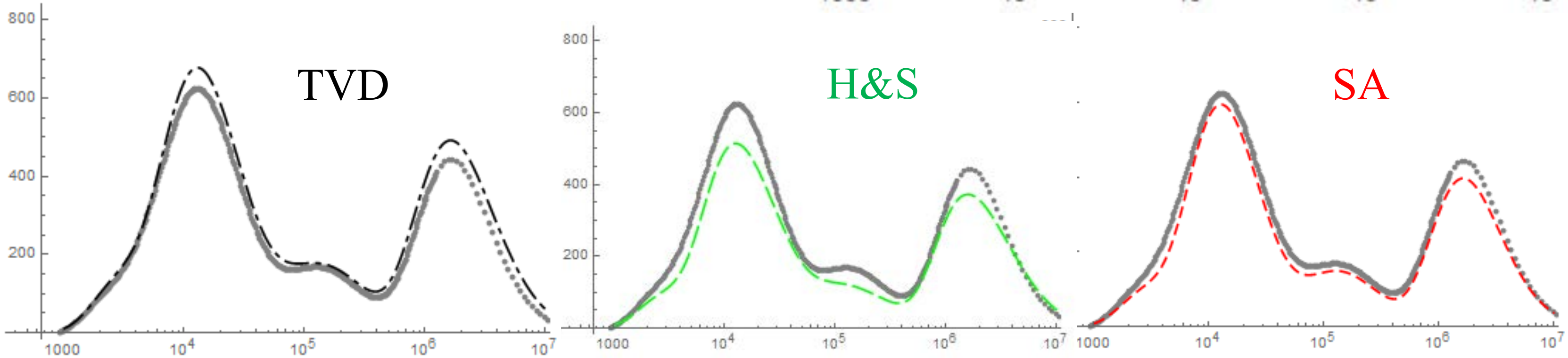


(Nagamine et al. 2006)

EBL with Galaxy Evolution

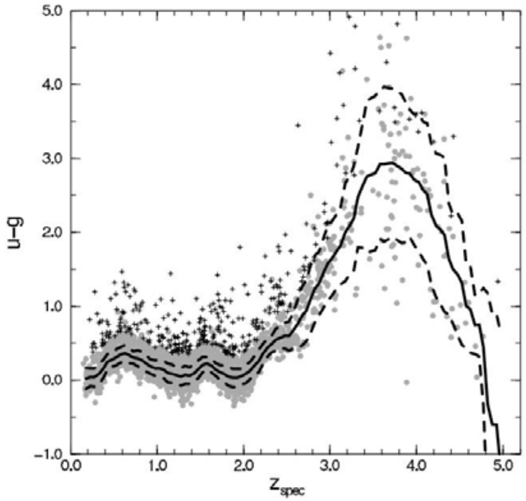
- Results – an almost perfect fit with 4 blackbodies!
- Possible physical interpretation of peaks
- *Significant* IGM absorption is clearly not needed





Quasar Reddening

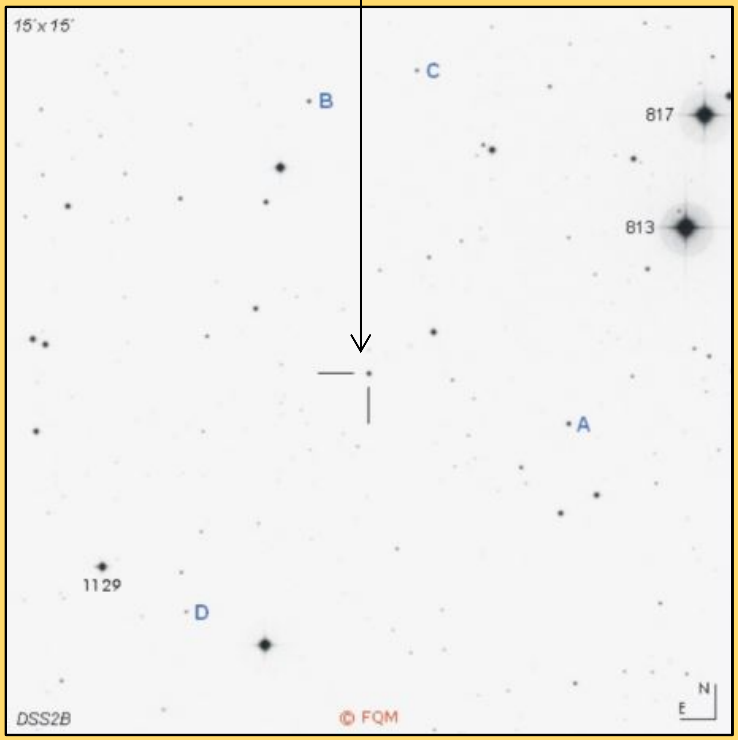
- Dust in the IGM reddens the spectra of quasars beyond $z \sim 2$:



(Weinstein et al. 2004)

- But there cannot be *too much* dust or we would not see quasars at all!

(Quasar PG1634+706 at z =1.337, m =14.5, observed using the MDSGC telescope on July 18, 2018)

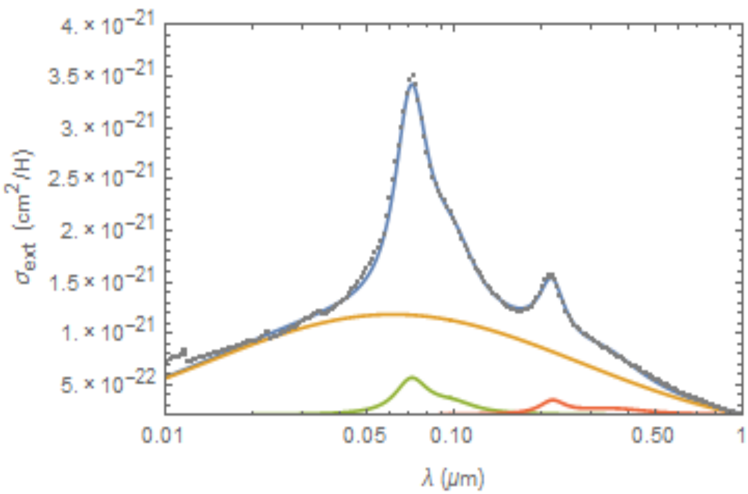


(That's a look-back time of *9 billion years!!!*)

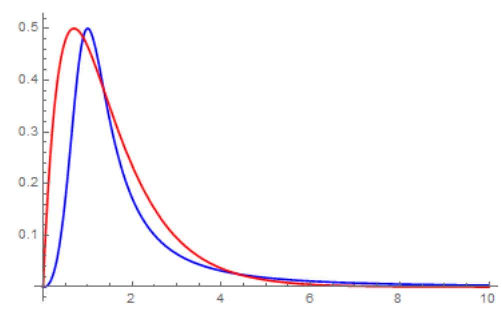
Opacity of the dusty IGM

- Given by $\tau(\lambda_o, z) = \int_0^z \xi\left(\frac{\lambda_o}{1+z'}\right) \tau_*(z') \frac{(1+z')^2}{H(z')/H_0} dz'$

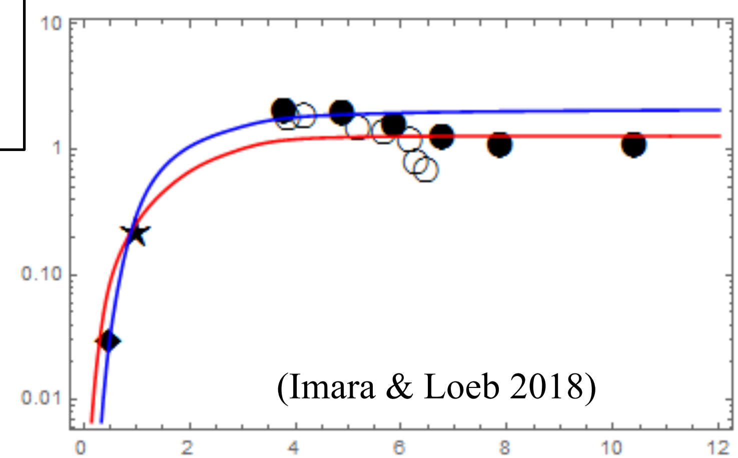
Raw dust extinction (fit to ISM model of Draine)



Dust evolution models



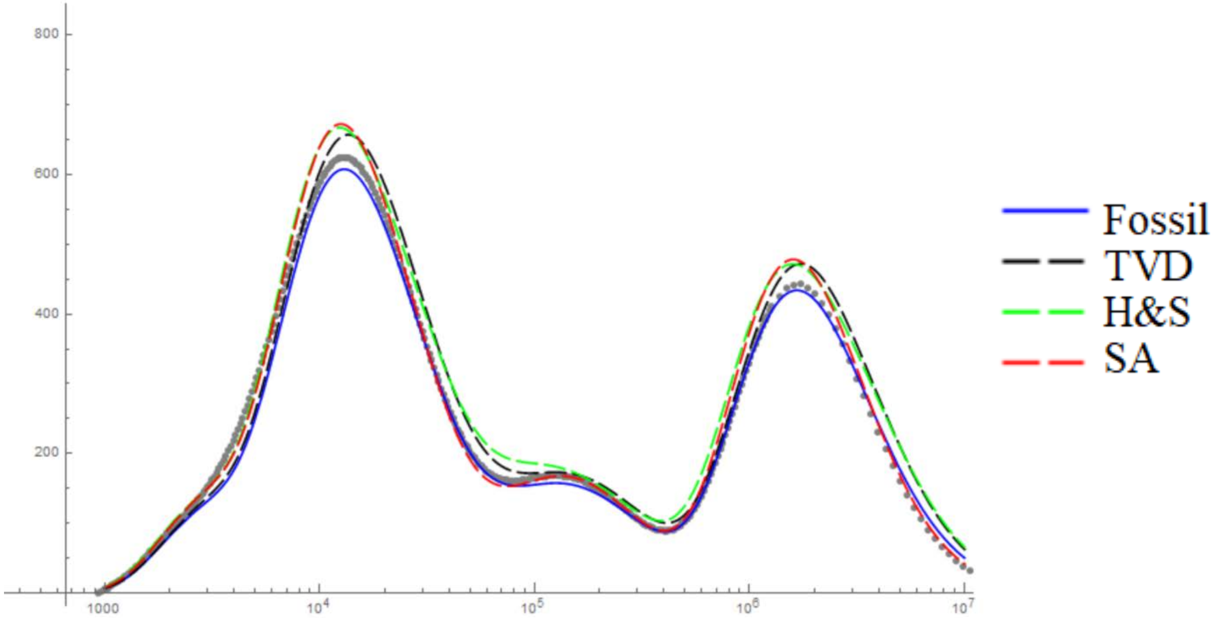
- Resulting opacity is a good match to observational data at 3000 Å:



(Imara & Loeb 2018)

Preliminary Results!

- Spectral EBL intensity including IGM opacity for all four galaxy evolution models:



- Each model takes 10-20 minutes to run
- IGM opacity reduces intensity of first peak **by about 3%**
- Olbers was not so wrong after all!

Thank you to:

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Dr. Storrs