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 $\lambda_0$ by:

$$I_\lambda(\lambda_0) = \frac{c}{4\pi} \int_0^{z_f} \frac{n(z)F(\lambda, z)}{(1 + z)^3 H(z)} e^{-\tau(\lambda, z)} \, dz$$

where:
- $c$ is the speed of light,
- $n(z)$ is the number density spectrum,
- $F(\lambda, z)$ is the spectrum,
- $\tau(\lambda, z)$ is the optical depth in the Intergalactic Medium (IGM),
- $H(z) = H_0 \sqrt{\Omega_m (1 + z)^3 + \Omega_\Lambda}$

(Vavryčuk 2017)
Plotting.. World Domination Graphs

IM GONNA NEED THAT GUYS LEG
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 $\lambda_p = 7000 \text{ Å}$

- And take $n(z) = \text{constant for simplicity}$

- Result:

Redshifted by expansion!

Models by Finke et al. (2010)
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, \( L = f_1 T_1^4 + f_2 T_2^4 + \ldots \)

• Results!

Too bright!

Too faint!
Galaxy Evolution

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

(15' x 15')
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:

Maryland Space Grant – For *granting* us this opportunity
Towson University Fisher College of Science and Mathematics
Dr. Overduin
Dr. Storrs