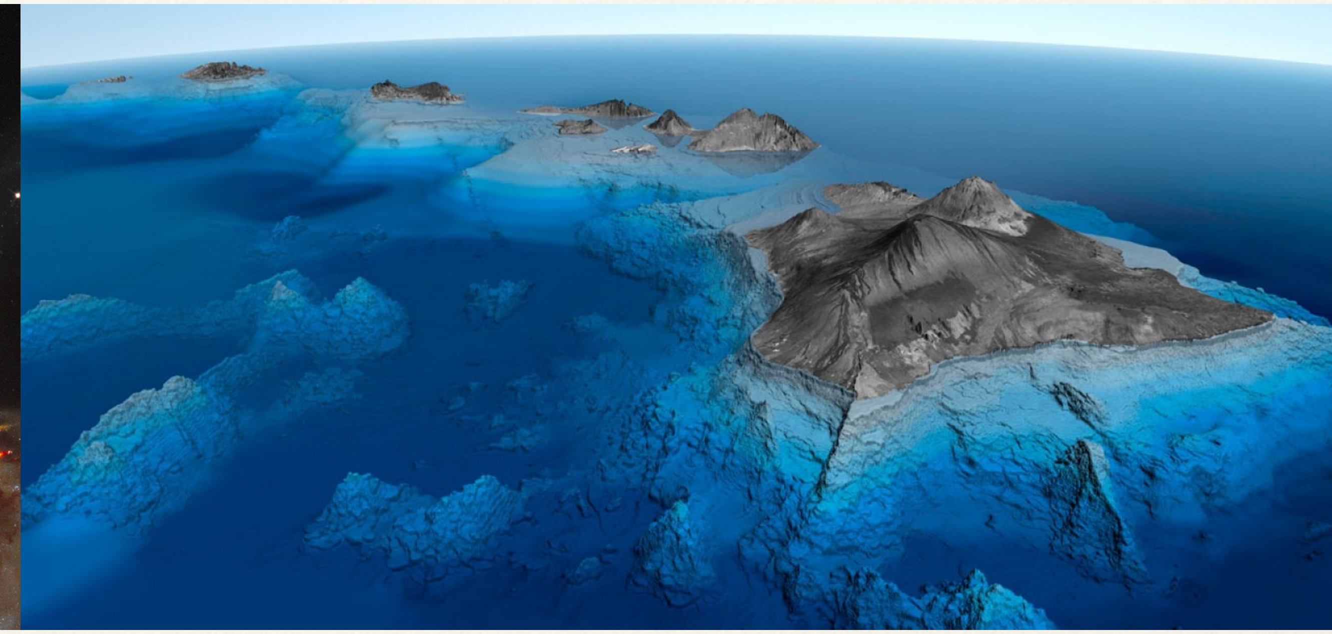


*Getting to know the "island universes" out there.*

# Galaxies I

ASTR 555
Dr. Jon Holtzman

# Outline for Today

- Building Blocks - Dust:
  - Extinction
  - Emission

# Building Blocks - Dust

- Dust is <1% of the interstellar medium by mass, yet it can have important observational effects:
  - Obscures light from stars & gas
  - Emits radiation (mostly IR)
  - Affects ISM chemistry, e.g., creation of $H_2$
  - Contributes to ISM heating & cooling

**Image Credit:** Ignacio de la Cueva Torregrosa (Capturandoeluniverso, A.A.E.)

# Building Blocks - Dust

- **Extinction —**
  - Scattering + Absorption
  - Causes decrease in flux:

$$A_\lambda = -2.5 \log \frac{F_\lambda}{F_{\lambda,0}}$$

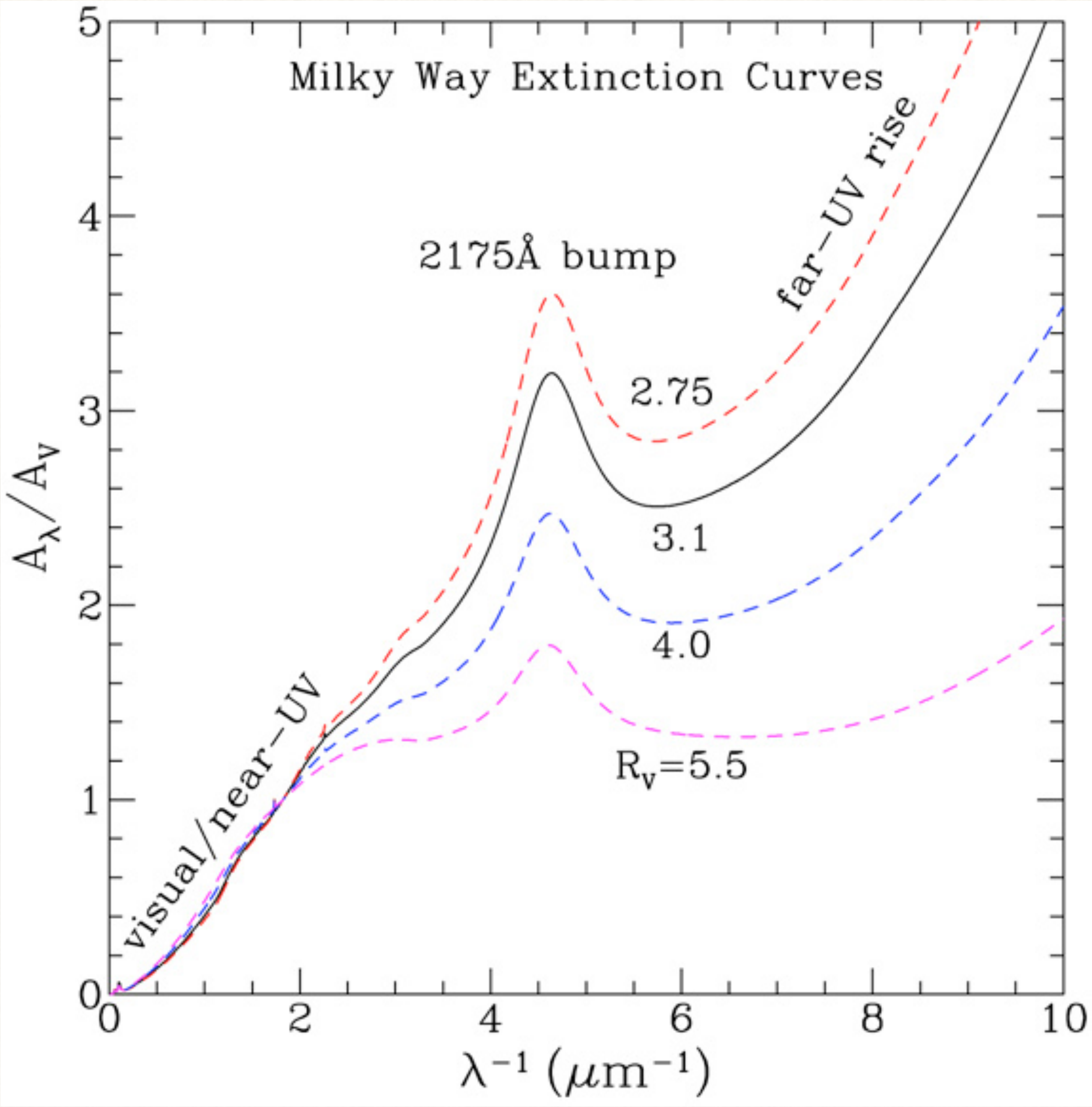
  - Varies with wavelength, causes change in color, i.e., "reddening":

$$E(\lambda - V) = A_\lambda - A_V$$

NGC1999 reflection nebula and Bok globule
(Image credit: NASA and The Hubble Heritage Team, STScI)

# Building Blocks - Dust

- **Extinction Curve**:
  - escribes spectral shape of extinction
  - Derived from objects with known SEDs
  - Rises to shorter wavelengths, with bump at ~2200Å
  - Encodes properties of the dust, e.g., composition, grain size distribution
    - Grains absorb/scatter most effectively at wavelengths ~ grain size



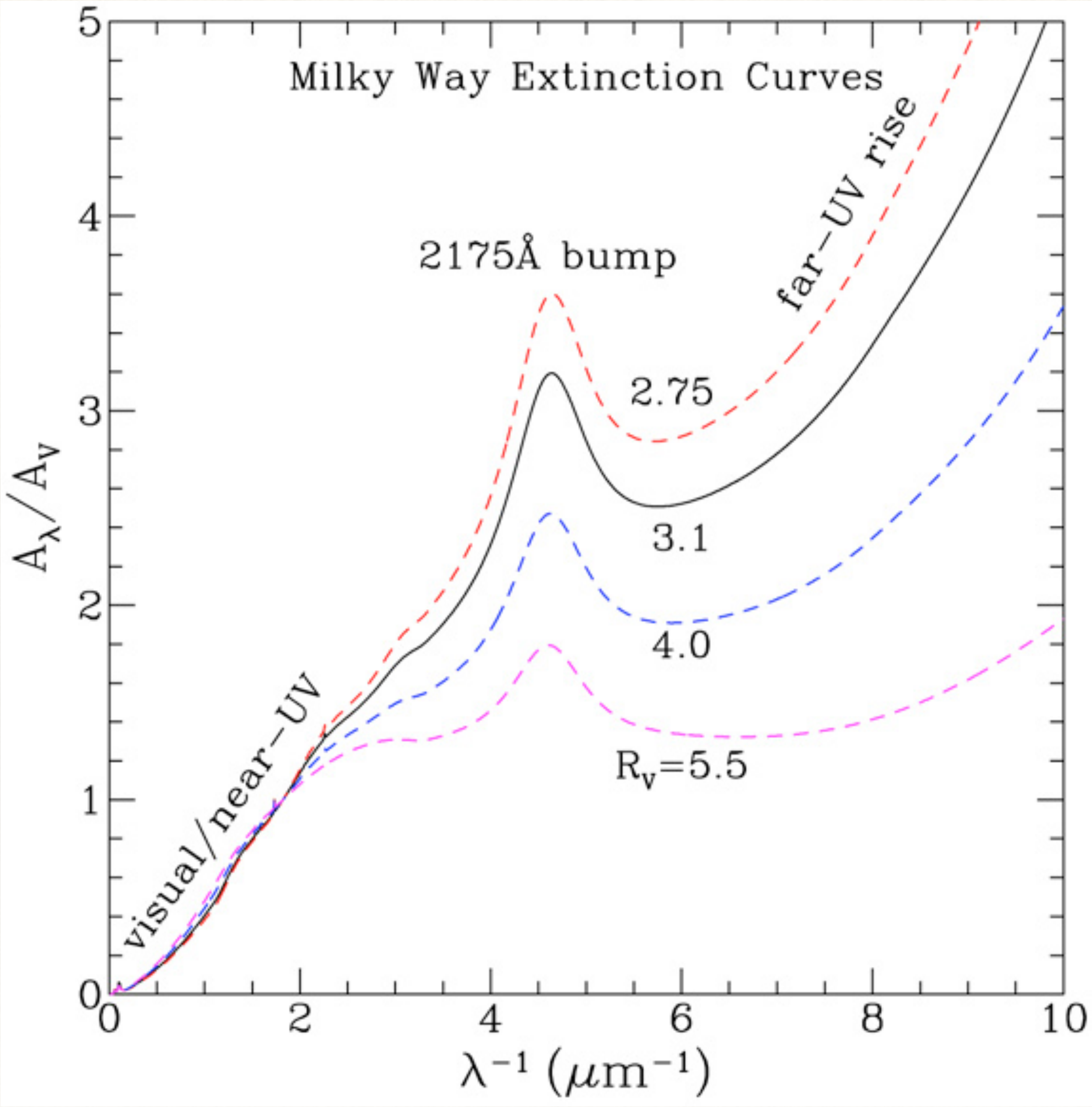
Li 2007

# Building Blocks - Dust

- **Extinction Curve**:
    - Reddening E(B-V) and total extinction $A_V$ parameterized by a factor $R_V$ that depends on dust properties:

$$R_V \equiv A_V/E(B-V)$$

        - e.g., "Standard" Milky Way extinction curve has $R_V = 3.1$




Li 2007

# Thought Questions

We discussed correcting Halpha fluxes in HII regions for extinction using the Hbeta flux (to use the Halpha flux to estimate star formation rate)

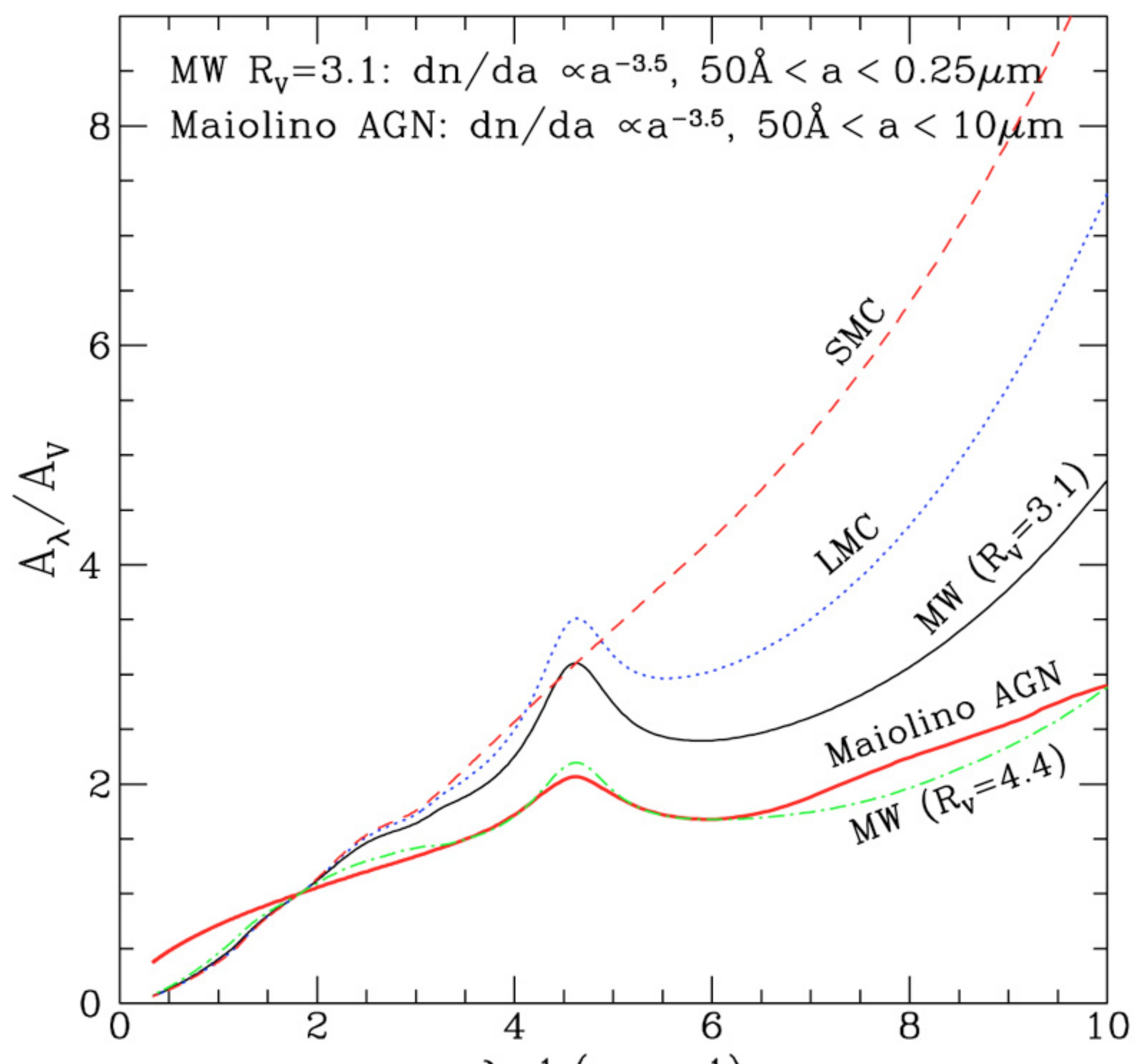
- The Halpha/Hbeta flux ratio in the absence of extinction has a value close to 3.
- Imagine you observe a ratio of 4. What is the inferred extinction E(Hbeta - Halpha)?
- If $A_{Hbeta}/A_V = 1.2$, and $A_{Halpha}/A_V=0.8$ (i.e., from an extinction law), then what is $A_V$ and $A_{Halpha}$ for your observation?
- How much do you have to correct your Halpha flux by?

# Thought Questions

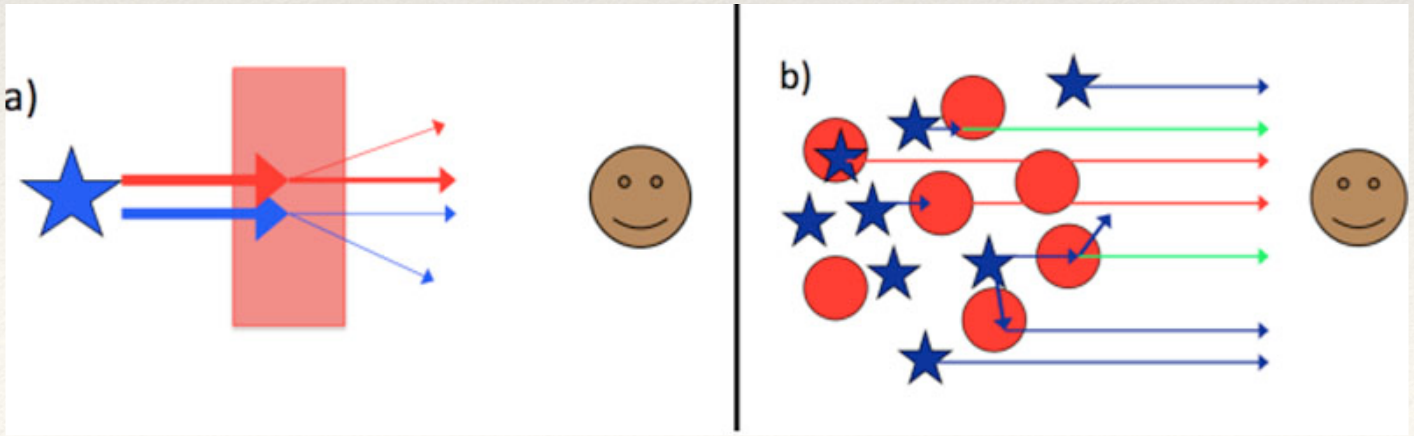
- The Halpha/Hbeta flux ratio in the absence of extinction has a value close to 3.
- Imagine you observe a ratio of 4. What is the inferred reddening E(Hbeta - Halpha)?
  E(Hbeta-Halpha) = -2.5 log 0.75 = 0.3
- If $A_{Hbeta}/A_V$ = 1.2, and $A_{Halpha}/A_V$=0.8 (based on extinction law), then what is $A_V$ and $A_{Halpha}$ for your observation??
  0.3 = 0.4 $A_V$: $A_V$ = 0.75, $A_{Halpha}$ = 0.6 $A_{Hbeta}$= 0.9
- How much do you have to correct your Halpha flux by?
  10.**(0.4*0.6) = 1.73

# Building Blocks - Dust

- **Extinction Curve Complications:**
  - Regional Variations
  - Dust Geometry
    - Simple "Foreground screen"?
    - Integrated galaxy light often more complicated




Li 2007




Calzetti 2012

- **Attenuation** — extinction + photons scattering back into line of sight

# Building Blocks - Dust

- How much dust is there?
  - Well-correlated with HI:

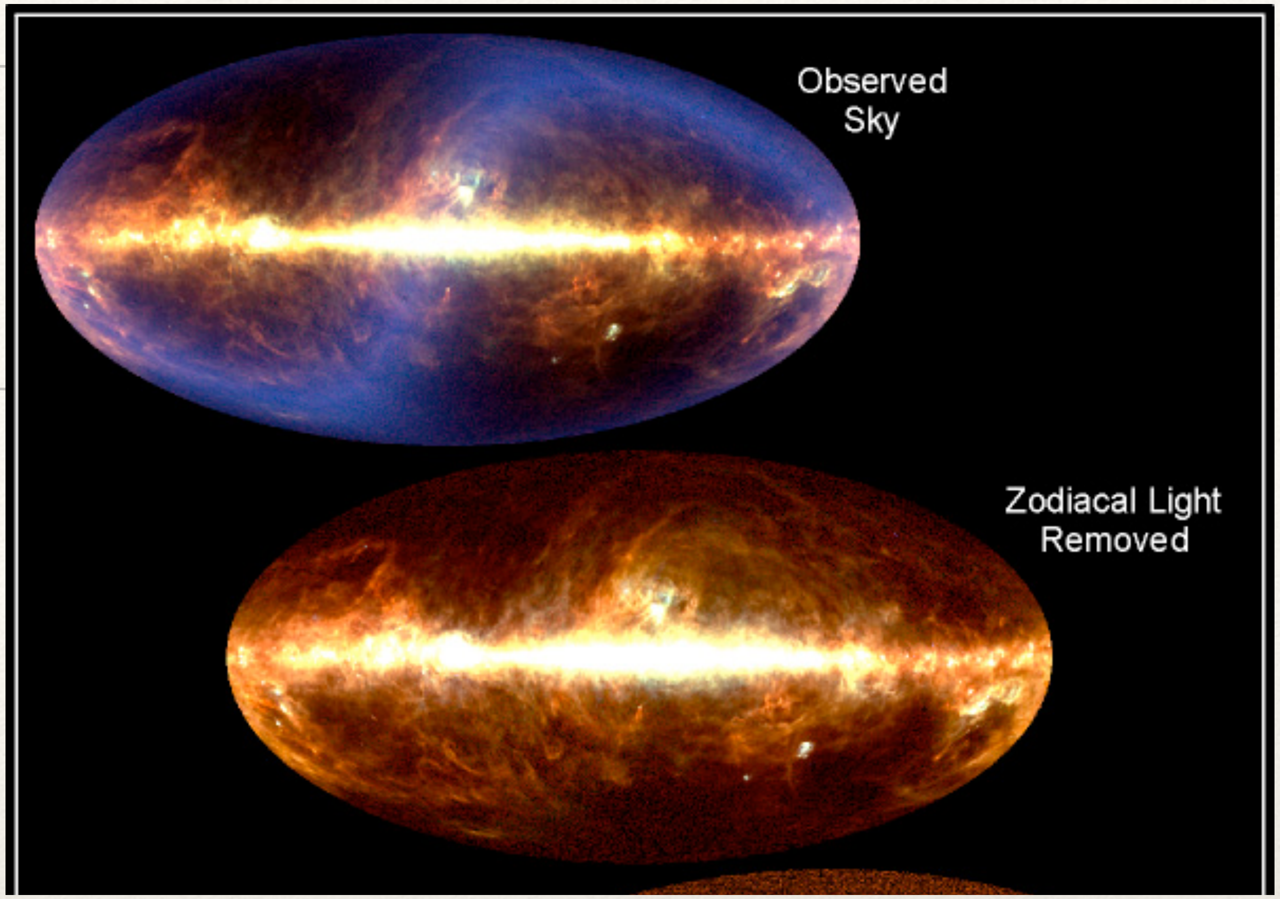
$$N(H) = 5.8 \times 10^{21} E(B-V) cr$$

    - Dust-to-gas ratio may depend on metallicity and star formation
  - Direct probe using observations of "overlapping" galaxies — extinction is non-negligible!
  - Likely patchy: galaxies are both opaque and transparent

NGC 3314 — NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and W. Keel (University of Alabama)

# Building Blocks - Dust

- **Dust Emission:**
  - Heated predominantly by radiation from stars and AGN
  - <u>Approximated</u> as a blackbody in far-IR
  - Sharp emission features at ~10 microns from PAH molecules
  - Forming dust is hard : much thought to be formed in envelopes around cool stars



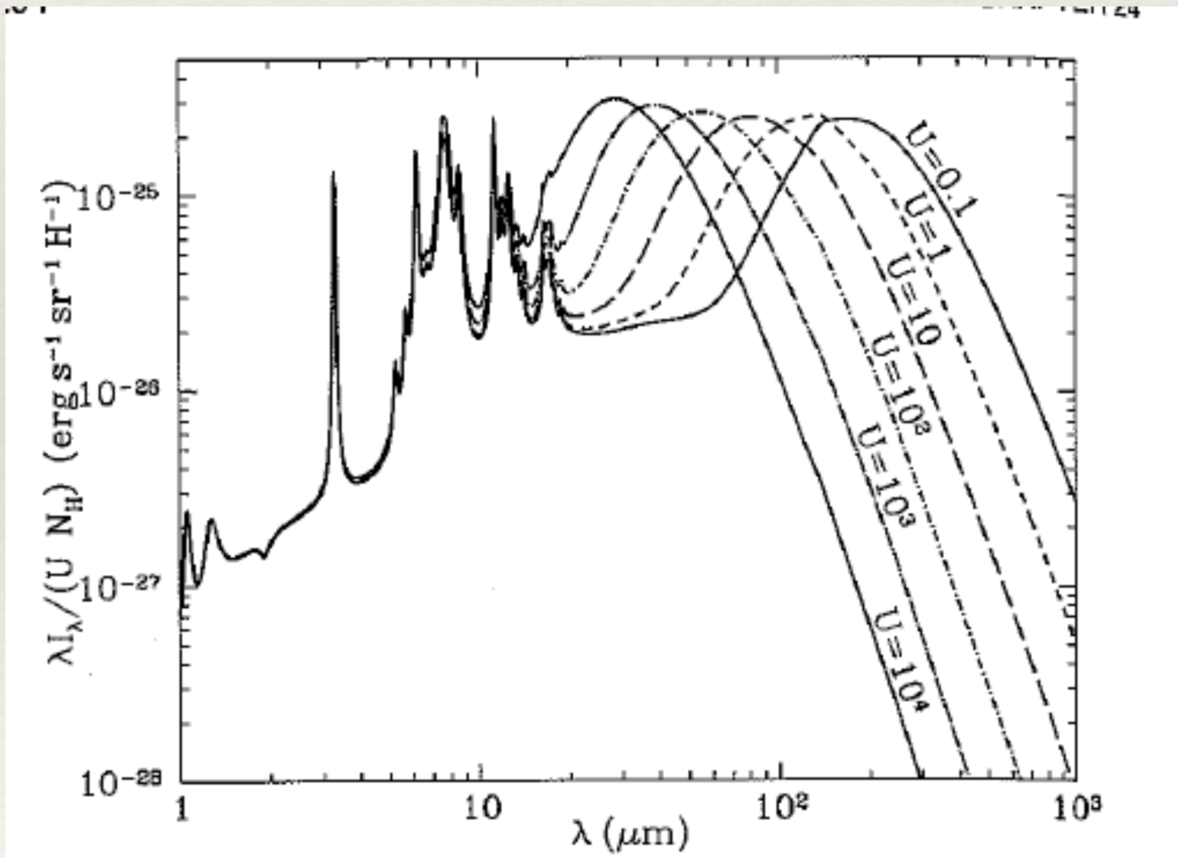
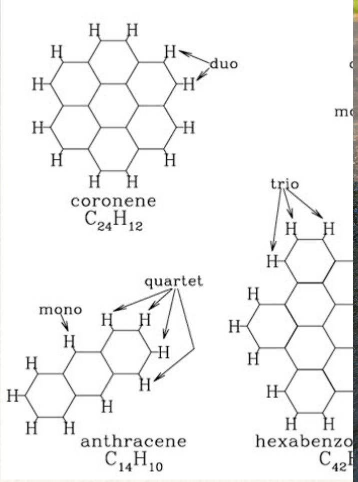




**Figure 24.7** Infrared emission spectrum for model with silicate and graphite/PAH grains in ISRF intensity scale factor $U$ from 0.1 to $10^4$ ($U$ = 1 is the local ISRF). Spectra are scaled to give power per H nucleon per unit $U$, calculated using the model of Draine & Li (2007).




https://fwwa.org/2018/03/19/pah-pollution-tar-based-sealants/

# Building Blocks - Dust

- **Dust Emission:**
    - Find galaxies with 10 -100x more IR emission than typical galaxy:
        - Luminous and Ultra-luminous IR galaxies (LIRGs, ULIRGs)
    - Dust emission traces star formation — increasingly large contribution at higher redshift
    - Note negative K-correction in sub-mm, makes dust easier to observe at higher redshift