- How far does a supernova remnant travel over a million years

$$r = vt = 100 \times 10^3 \times 1 \times 10^6 \times 3 \times 10^7$$

$$= 3 \times 10^{18} \text{ m}$$

$$= 100 \text{ pc}$$

Interstellar Dust

- Interstellar extinction
- Interstellar reddening
- Dust emission

Interstellar Extinction

- The presence of interstellar dust is inferred from the dark extinction lanes seen in our Galaxy and other galaxies
- Background starlight or nebular light is blocked out
- The dust is made of small grains mixed with the interstellar gas
- Grain size ~5 to 500 nm, i.e. ~ λ of light

M64: Credit: NASA and The Hubble Heritage Team (AURA/STScI)

M104: Credit: NASA and The Hubble Heritage Team (AURA/STScI)

NGC5866: Credit: NASA and The Hubble Heritage Team (AURA/STScI)

Visual Extinction

- The dust along the line of sight causes objects to appear dimmer
- This amount of dimming is measured in magnitudes and is called total extinction
- In the V-band this is called A_V

$$\mathrm{A_V} = m_V(\text{observed}) - m_V(\text{intrinsic})$$

- In terms of absolute magnitude

$$m_V - M_V = 5\log d - 5 + A_V$$

Class Example

- By what factor would you get the distance wrong if a total visual extinction of 1 magnitude was not taken in to account?

$$m_V - M_V = 5\log d - 5 + A_V$$

$$\log d = \frac{1}{5}\left(m_V - M_V + 5 - A_V\right)$$

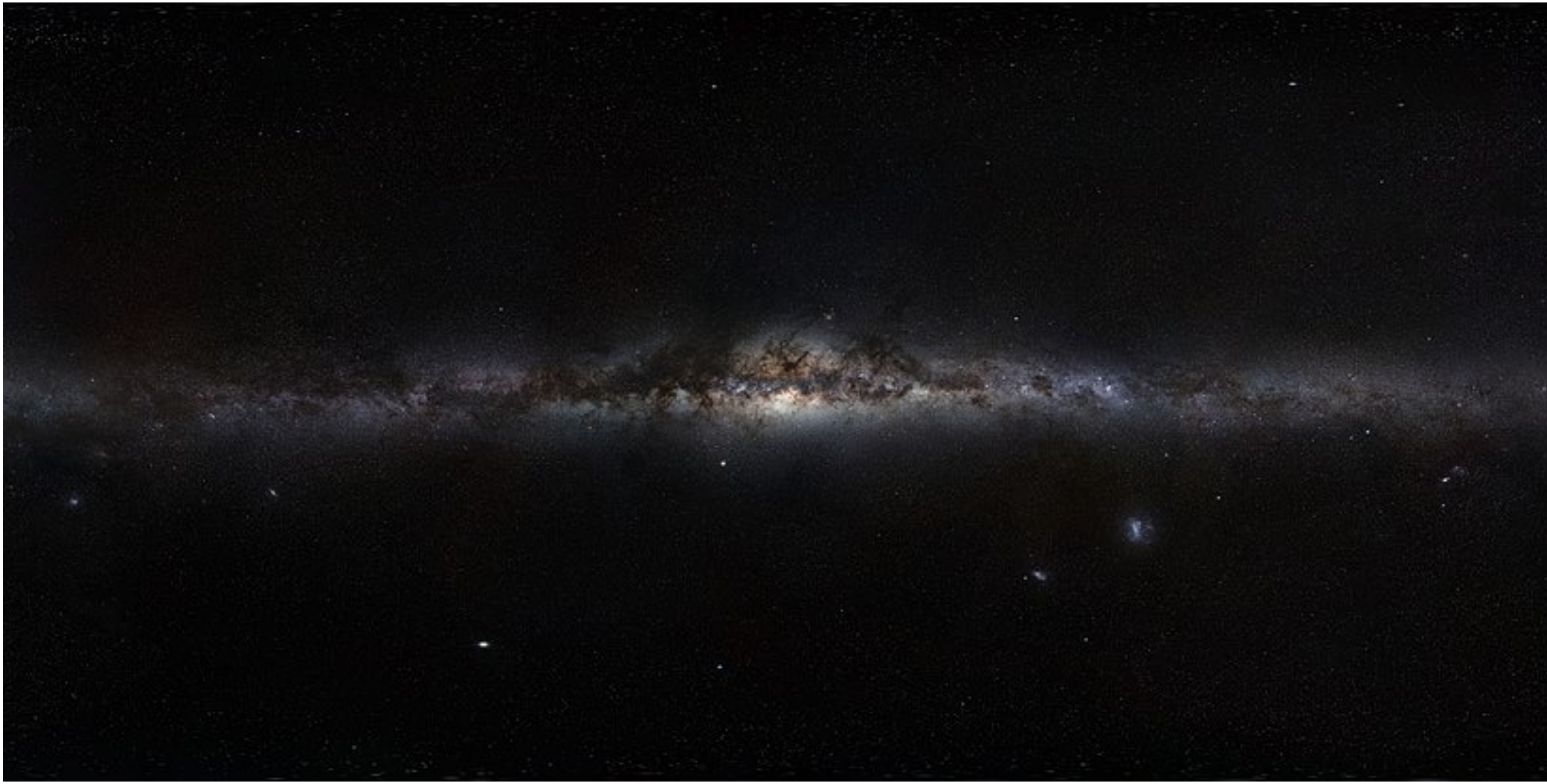
$$\log d' = \frac{1}{5}\left(m_V - M_V + 5\right)$$

$$\log d' - \log d = \frac{1}{5}A_V$$

$$\log\frac{d'}{d} = \frac{1}{5}$$

$$\frac{d'}{d} = 1.6$$

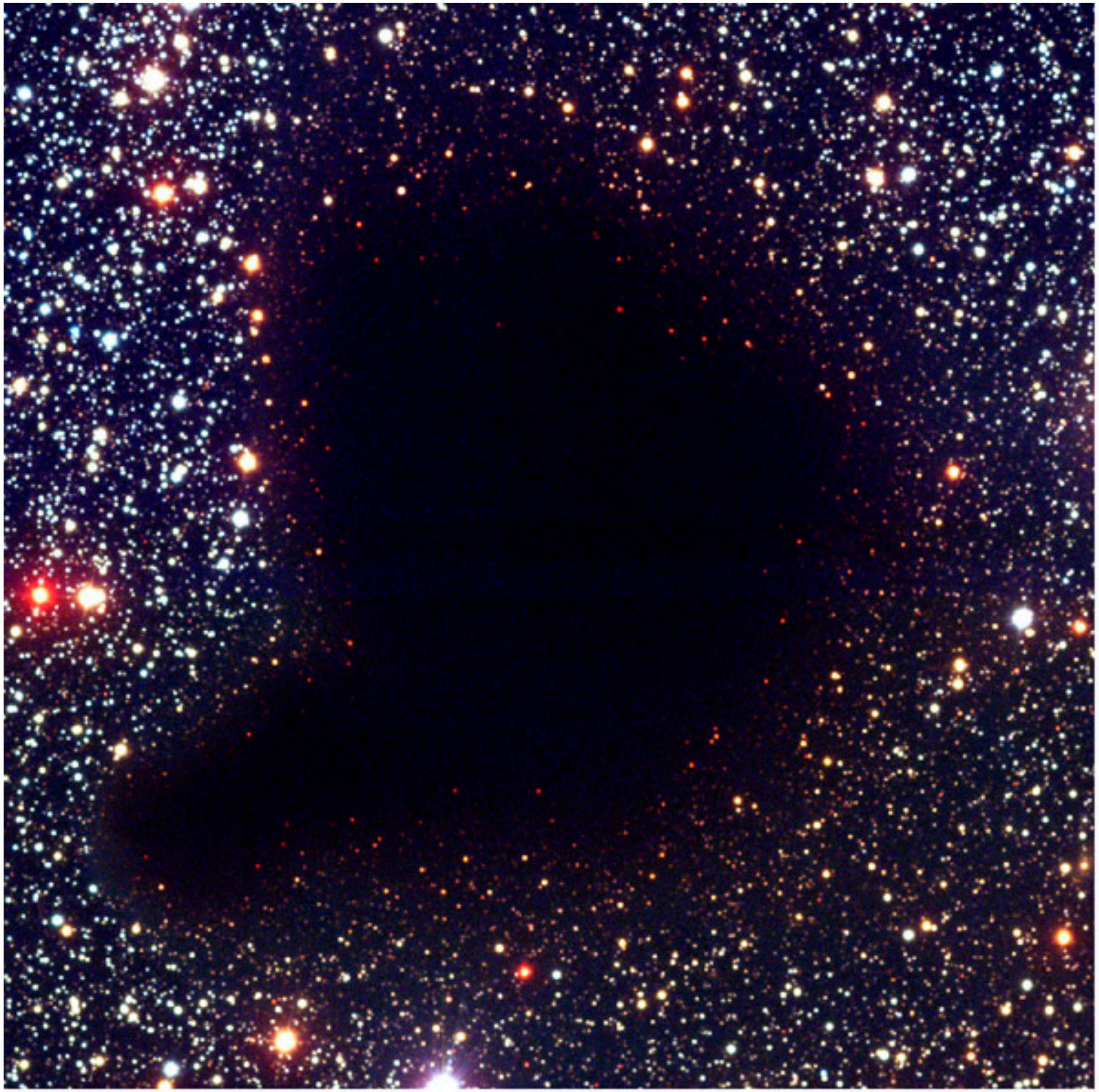
- Ignoring 1 magnitude of extinction would make you think the star is 60% further away



Dust lanes in the Milky Way Credit: ESO

Interstellar Reddening

- The amount of extinction varies with wavelength
- Extinction is larger at blue wavelengths than red wavelengths, i.e. $A_B > A_V$
- Therefore interstellar dust causes background objects to appear redder as well as dimmer



B, V, I

ESO PR Photo 02c/01 (10 January 2001)

Credit: NASA, NOAO, ESA and The Hubble Heritage Team (STScI/AURA)

Colour Excess

- The amount of reddening is also measured in magnitudes and is the difference between the observed and intrinsic colour

$$E(B-V)=(B-V)_{\text{observed}}-(B-V)_{\text{intrinsic}}$$

- This is called the colour excess

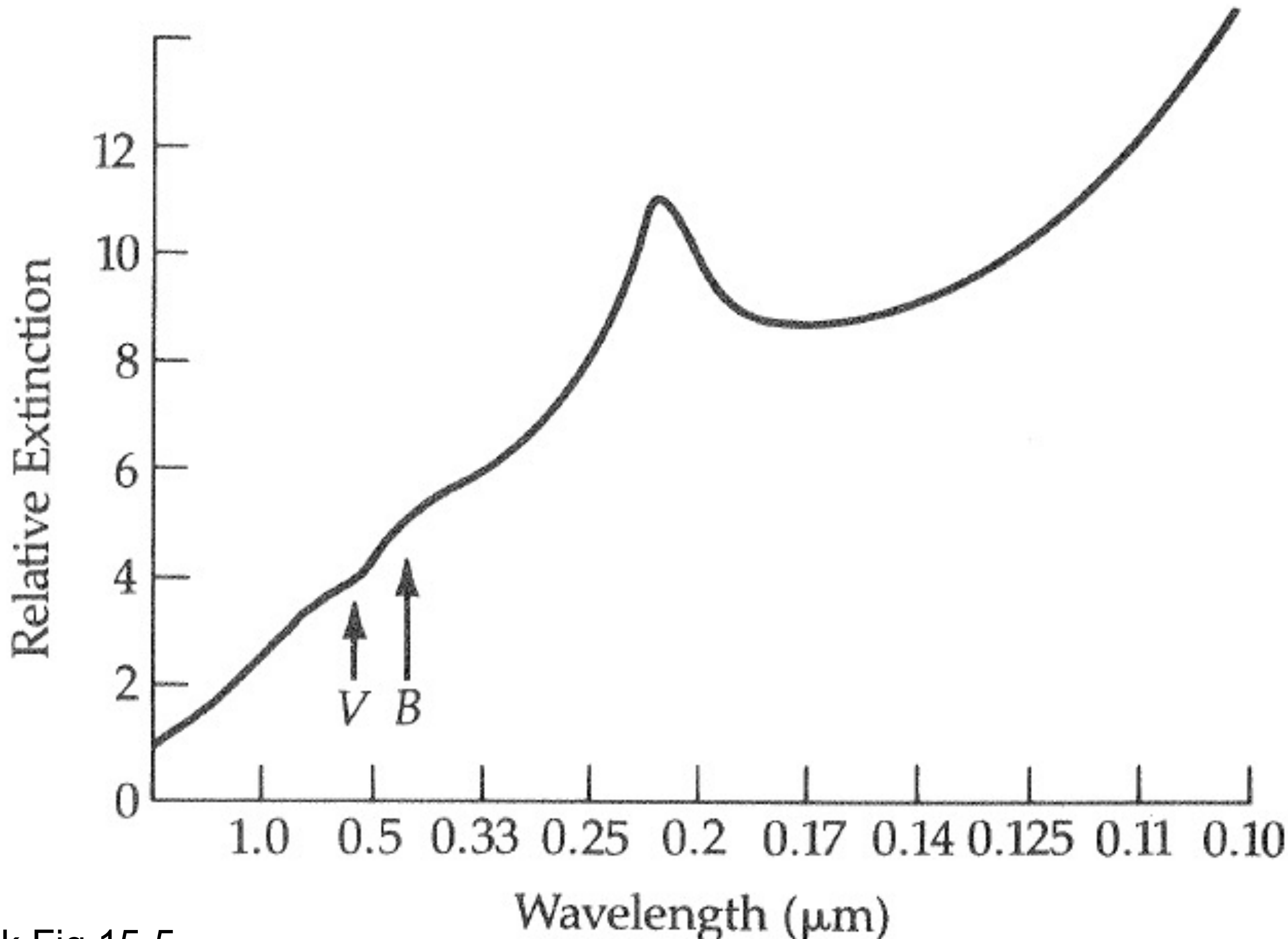
Extinction Law

- How the extinction varies with wavelength is called the extinction law
- The slope of the law allows the visual extinction to be related to the colour excess

$$A_V \approx 3E(B-V)$$

- If the intrinsic colour of a source is known, then the extinction can be measured

Interstellar extinction law



Zeilik Fig 15-5

Class Example

- A star has a spectral type such that its absolute visual magnitude, M_V = -0.8, and its intrinsic colour, B-V = -0.1. It is observed to have an apparent visual magnitude, m_V = 8.5, and a colour, B-V = +0.4. How far away is it?

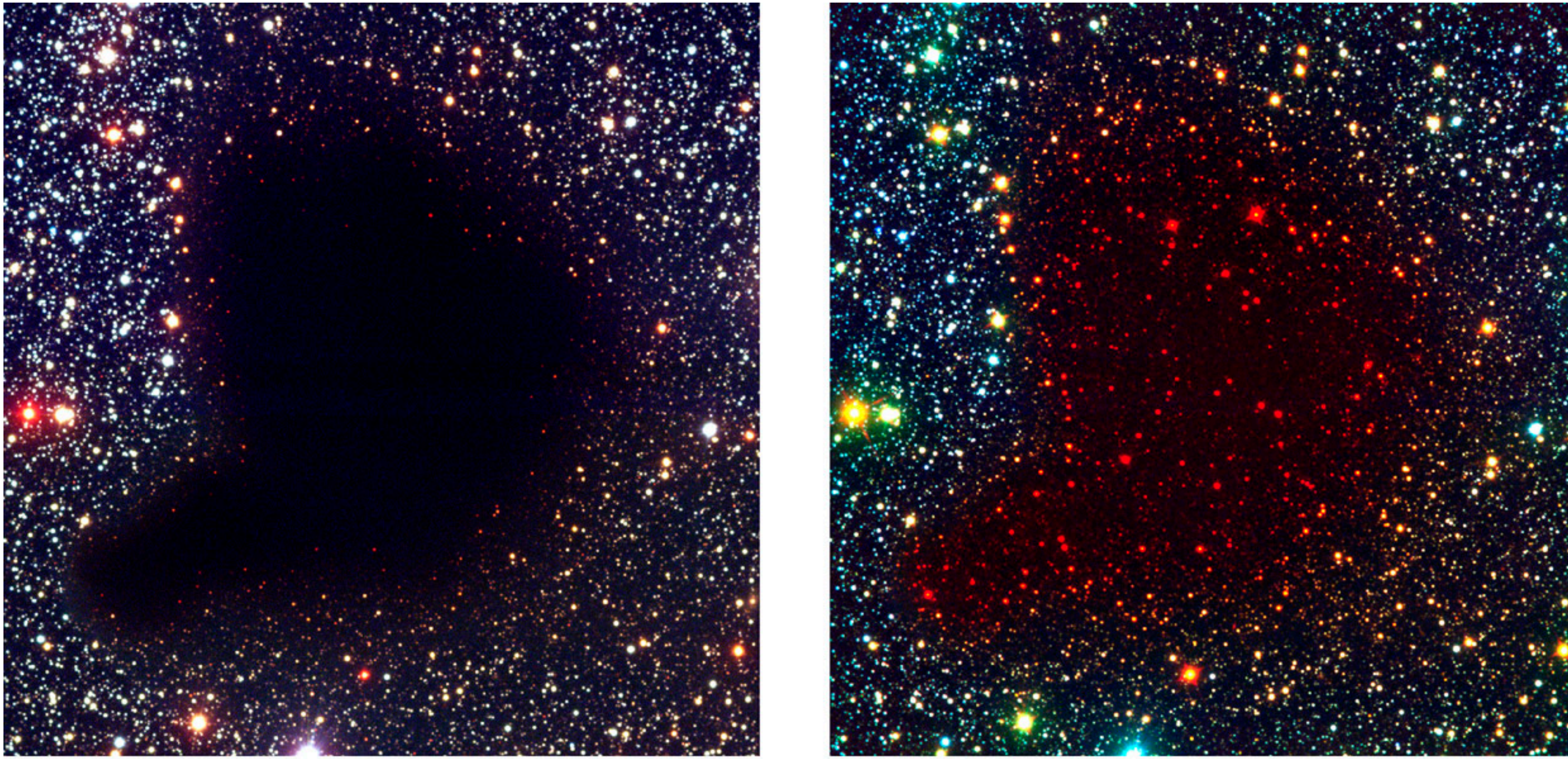
$$E(B-V) = (B-V)_{\text{observed}} - (B-V)_{\text{intrinsic}}$$
$$= +0.4 - (-0.1)$$
$$= 0.5$$

$$A_V \approx 3E(B-V)$$
$$= 3 \times 0.5$$
$$= 1.5$$

$$m_V - M_V = 5\log d - 5 + A_V$$
$$\log d = \frac{1}{5}(m_V - M_V + 5 - A_V)$$
$$= \frac{1}{5}(8.5 - (-0.8) + 5 - 1.5) = \frac{12.8}{5} = 2.56$$
$$d = 10^{2.56} = 360 \text{ pc}$$

Near-infrared Observations

- The extinction drops as the wavelength increases
- Therefore observations at near-infrared wavelengths are good for seeing through dust obscuration
- Near-infrared wavelengths are 1-3 μm (J,H & K filters)



B, V, I

B, I, K

Pre-Collapse Black Cloud B68 (comparison)

(VLT ANTU + FORS 1 - NTT + SOFI)

ESO PR Photo 02c/01 (10 January 2001)

Dust Emission

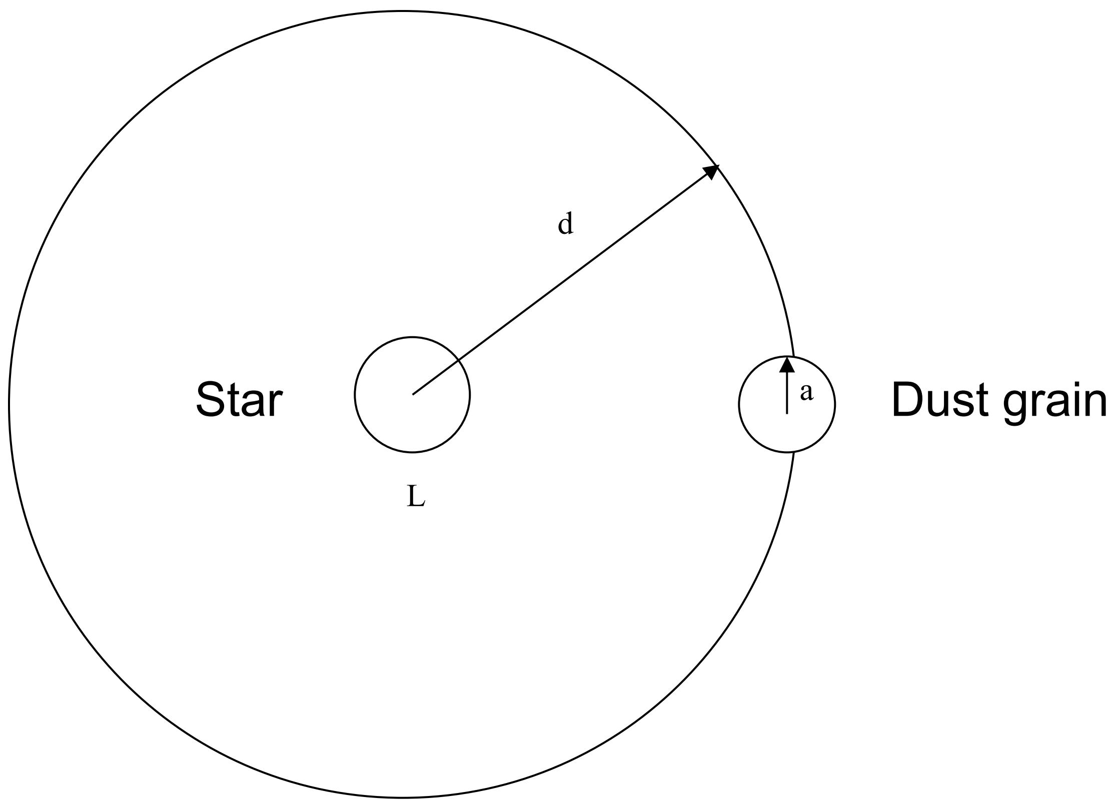
- Dust grains in interstellar space are usually at a temperature of about 30 K
- Hence, they emit at around 100 μm which is at far-infrared wavelengths
- If dust grains are near a hot star then they can get heated up to around 300 K
- Then they emit at mid-infrared wavelengths, i.e. ~10 μm

M8 nebula in the mid-infrared at 8-20 microns

Courtesy NASA/JPL-Caltech

Temperature of a dust grain

- Consider a grain with radius, *a,* at distance, *d,* from a star of luminosity, *L.*



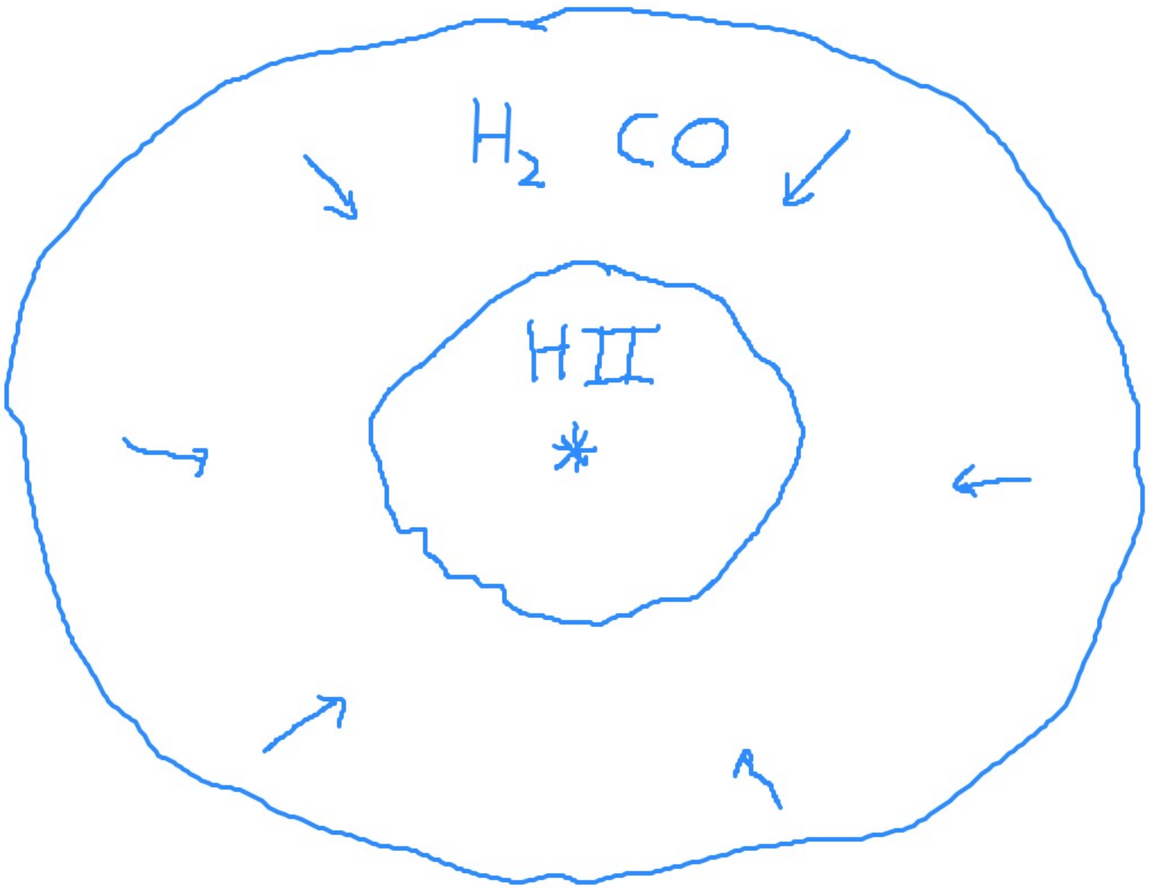
- Equate fraction of star's luminosity absorbed by grain with blackbody emission from the grain

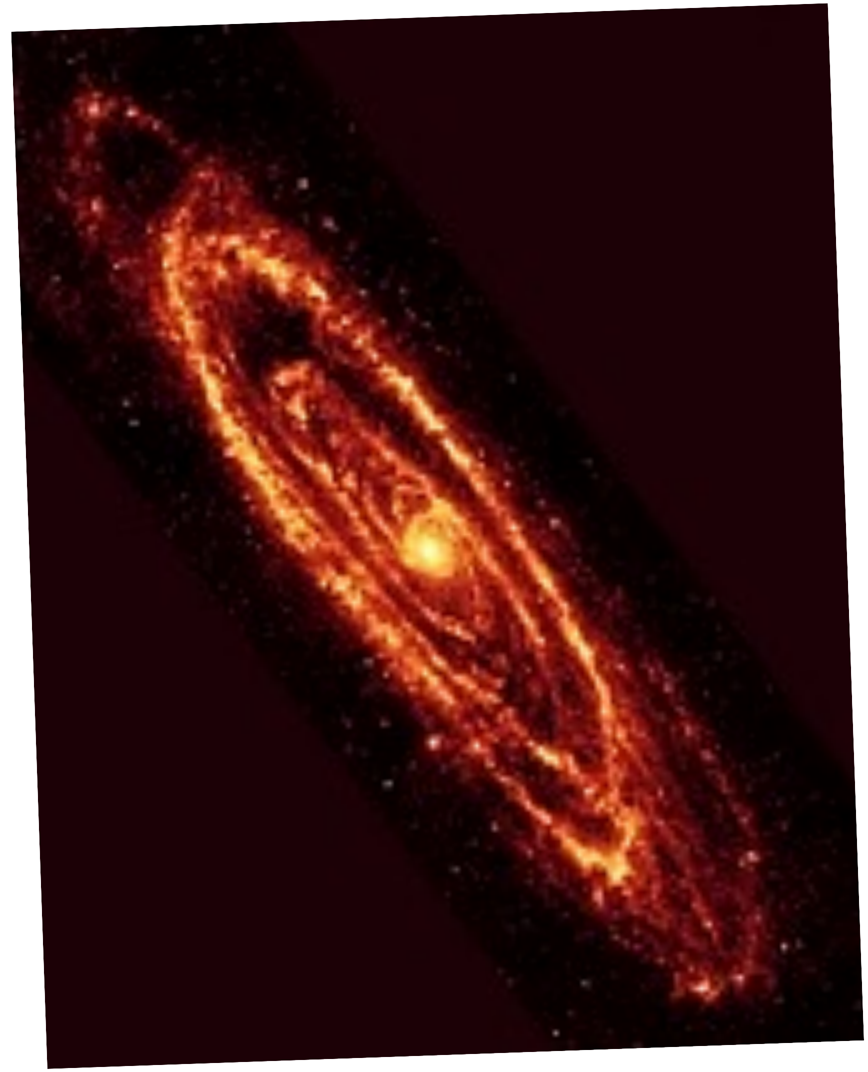
$$\frac{\pi a^2}{4\pi d^2} L \approx 4\pi a^2 \sigma T^4$$

$$T \approx \left(\frac{L}{16\pi\sigma d^2} \right)^{\frac{1}{4}}$$

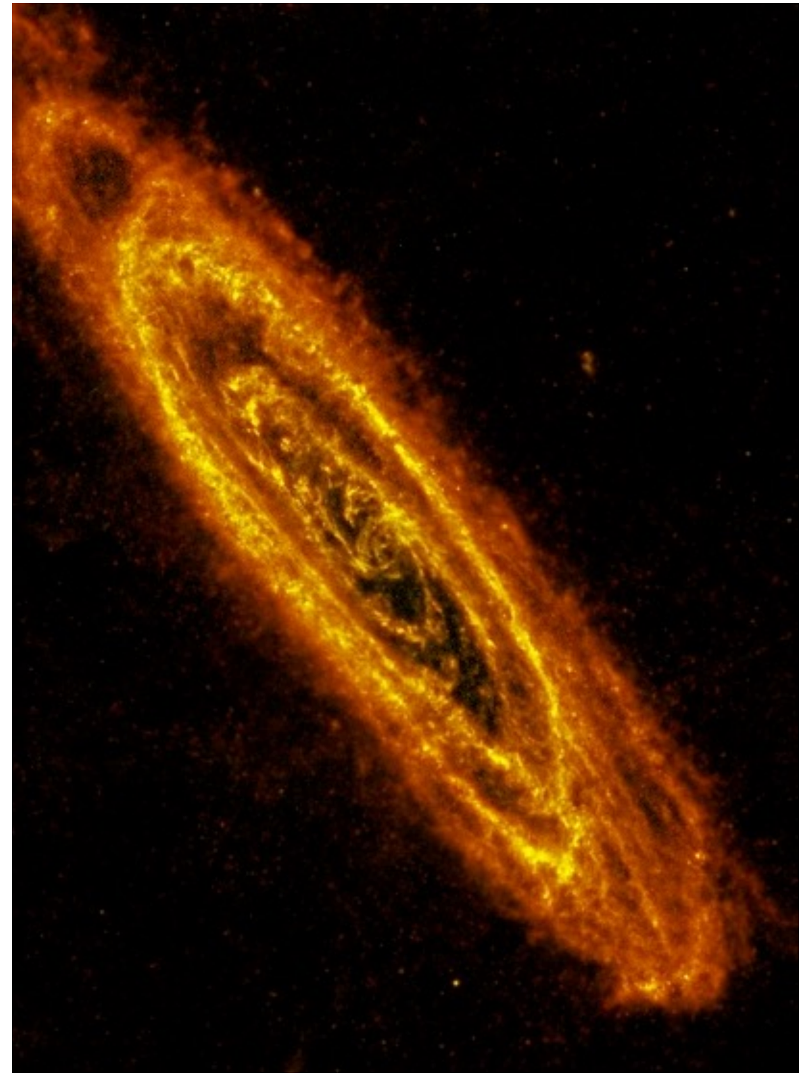
Star Forming Regions

- When stars form the dust in the molecular clouds gets heated up by the new stars
- Hence, star forming regions are bright infrared sources, in particular where massive, hot stars are being born


H2 CO
HII



NASA Spitzer 24 microns



ESA Herschel 250 microns

Summary

- Interstellar dust is responsible for extinction and reddening of starlight at optical and ultraviolet wavelengths
- Near-infrared is used to see through the dust
- Mid-infrared and far-infrared is used to see emission from warm and cool dust

Class Example

- Evaluate the temperature of a dust grain at distances of 10^{-4} and 1 pc from a massive young main sequence star with a luminosity of $10^5\ L_\odot$