Astro 321: Stellar Structure & Evolution

textbook: "An Introduction to Modern Astrophysics,"
Bradly Carroll & Dale Ostlie

Material: Part II; chapters 7-18 (and some of 3-5)

Basic Properties of Stars (chapters 7-9)

(I) "Normal Stars"

a) Bound by self-gravity; supported by pressure

b) radiates energy as supplied by an internal energy source

general implications

① if not rotating, non magnetic ⇒ only gravity acts and since gravity is a central force (spherically symmetric force field) ⇒ such stars are spherical

② ✱s evolve: radiate ⇒ lose energy ⇒ need energy source (nuclear reactions ⇒ n changes ⇒ P changes ⇒ contracts : gravitational release ⇒ R↓ to decrease U_g ⇒ evolution)

We will consider ✱ formation ⇒ normal lifetime ⇒ endstates (stellar remnants)

(II) How do we study ✱s?

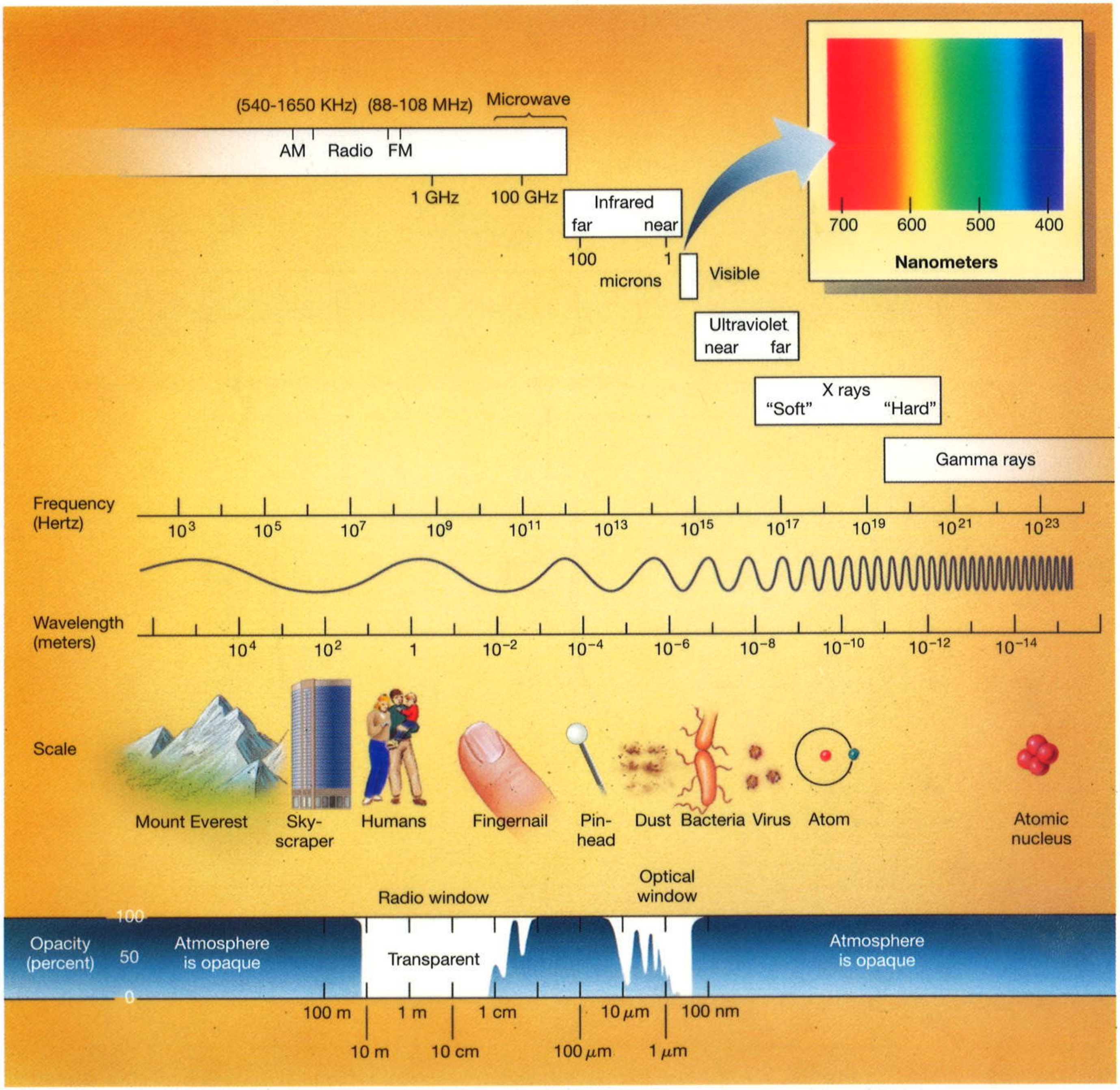
a) electromagnetic radiation

b) particle emission (ν_es from ⊙ and SN)

c) gravitational radiation (binary pulsar)

Comment: all methods are passive; we observe, we do not "experiment" and we obtain snapshots of ✱s at single stages of their evolution (we do not follow single ✱s through their life cycles)

Figure 3.9 Electromagnetic Spectrum



(III) What do we know about $*$s?

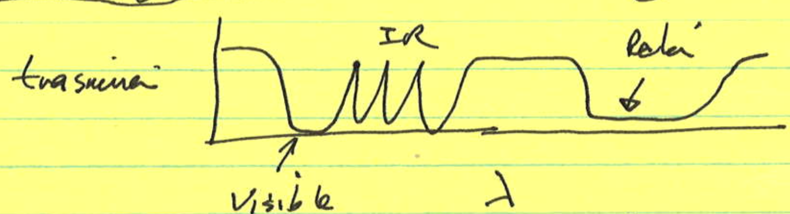
EM radiation:

① spectrum, $I(\lambda)\,d\lambda$ or $I(\nu)\,d\nu$
② polarization
③ temporal properties
④ power ("luminosity")

(i) Unfortunately, what we observe is the apparent brightness, I_{obs}, the light incident at the $\oplus$ per unit area per unit time, not the luminosity, L_*.

Ideally, we measure

$$\boxed{I_{obs} = \int_0^\infty I_{obs}(\lambda)\,d\lambda} \Rightarrow \text{ we already see issues,}$$



$\Rightarrow$ we must get above the atmosphere to measure the total apparent brightness, bolometric brightness.

(ii)

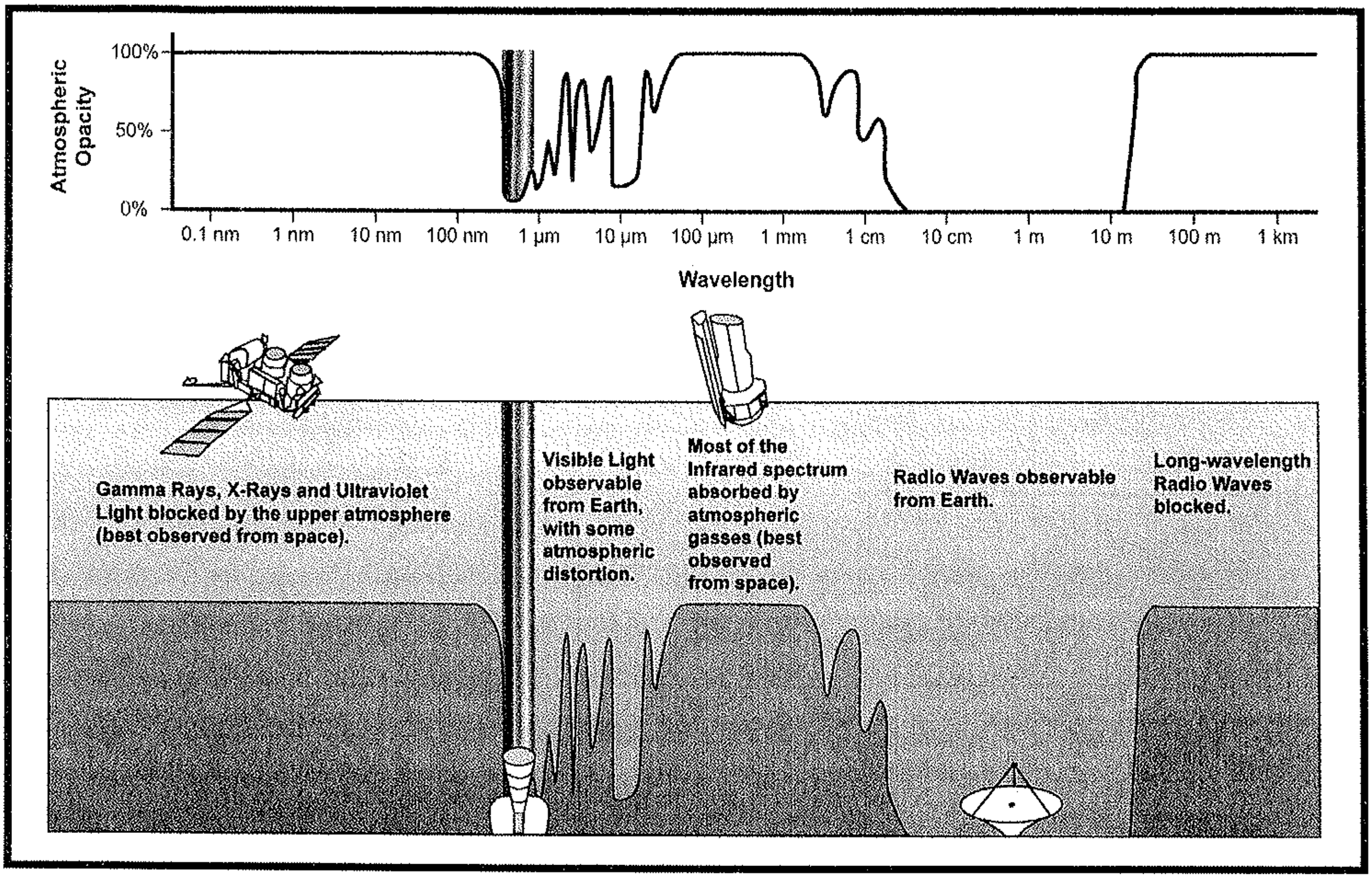
$$\boxed{I_{obs} = \frac{\text{Luminosity}}{4\pi r^2} = \frac{L_*}{4\pi r^2}}$$
inverse square law

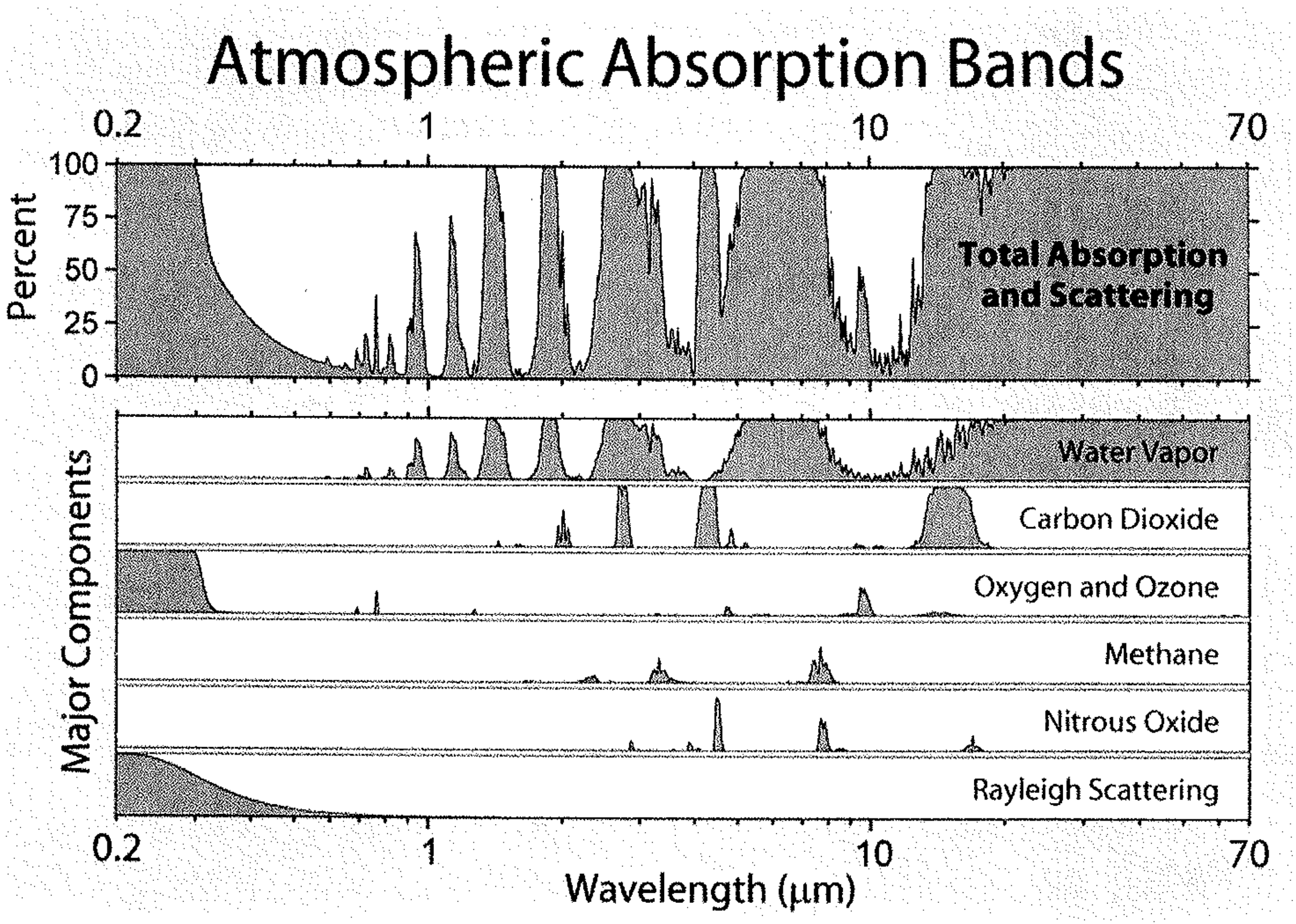
$$\Rightarrow I_{obs} = \int_0^\infty I(\lambda)\,d\lambda = \frac{L_*}{4\pi r^2} \Rightarrow \boxed{L_* = 4\pi r^2 I_{obs}}$$

to find intrinsic power, need r, distance & I_{obs} the bolometric brightness

characteristic L_* is $L_\odot = 3.85 \times 10^{26}\ \mathrm{J\,s^{-1}}$; normal $*$s have a range of

$$10^{-5} L_\odot \lesssim L_* \lesssim 10^{5} L_\odot$$


Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

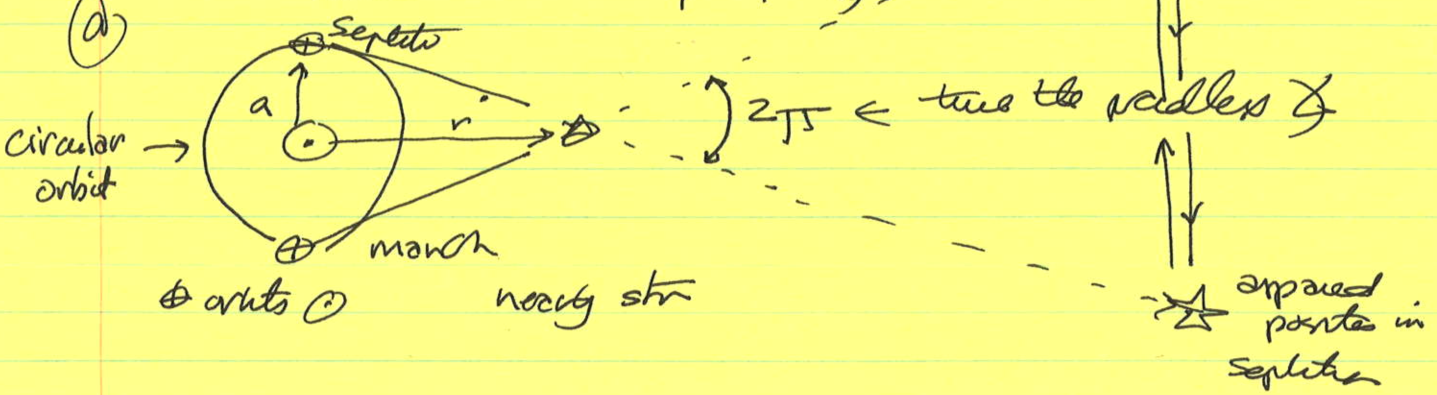


Atmospheric Absorption Bands
0.2
1
10
70
100
75
50
25
0
Percent
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

there are only 2 "direct ways" to find r

parallax (in ecliptic plane)

(a)



r then follows from $\tan\pi = \frac{a}{r}$

for small π ⇒ $\tan\pi = \frac{\sin\pi}{\cos\pi} \simeq \frac{\pi}{1-\frac{1}{2}\pi^2} \simeq \pi + \frac{1}{2}\pi^3$

and $\boxed{r \simeq \frac{a}{\pi}}$

outside of the ⊙, closest ∗ is Proxima Centauri, $r \simeq 4.3$ l.year

1 l.year $= 9.46\times10^{15}\,m \Rightarrow r \simeq 4.3\times9.5\times10^{15} \simeq 4.1\times10^{16}\,m$

$a = 1.50\times10^{11}\,m \Rightarrow \pi_\alpha = \frac{1.5\times10^{11}}{4.1\times10^{16}} \simeq 3.7\times10^{-6}$ Radians

(i) 2π Radians $= 360^\circ \Rightarrow 1$ Radian $= \frac{360^\circ}{2\pi} = 57.3^\circ$

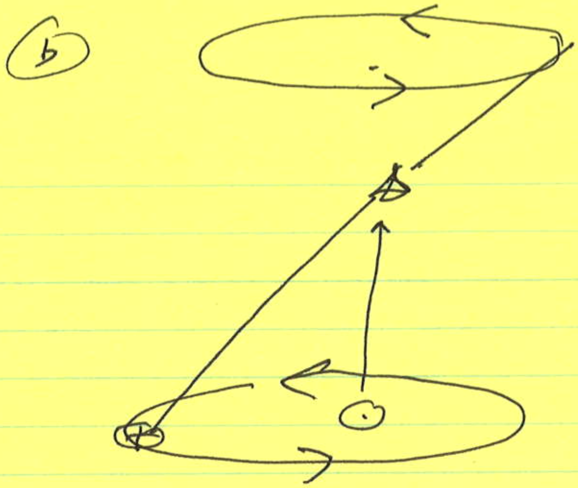
(ii) $1^\circ = 60'$ & $1' = 60'' \Rightarrow 1^\circ = 3600''$

$\Rightarrow \boxed{\pi_\alpha \simeq 0.76'' \ll 1^\circ \ll 1 \text{ Radian}}$

def^n 1 parsec is r for which $\pi = 1''$

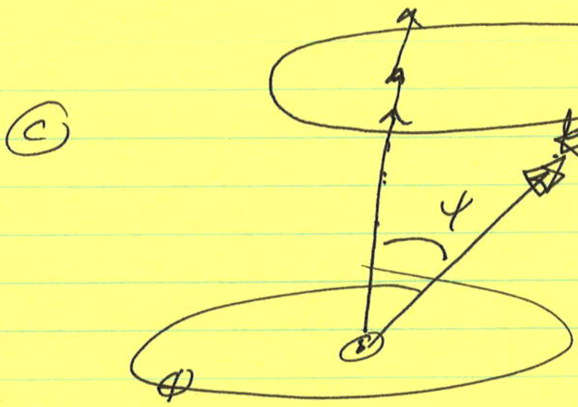
or $\boxed{r_p = 3.08\times10^{16}\,m} = 3.26$ light years

(b)

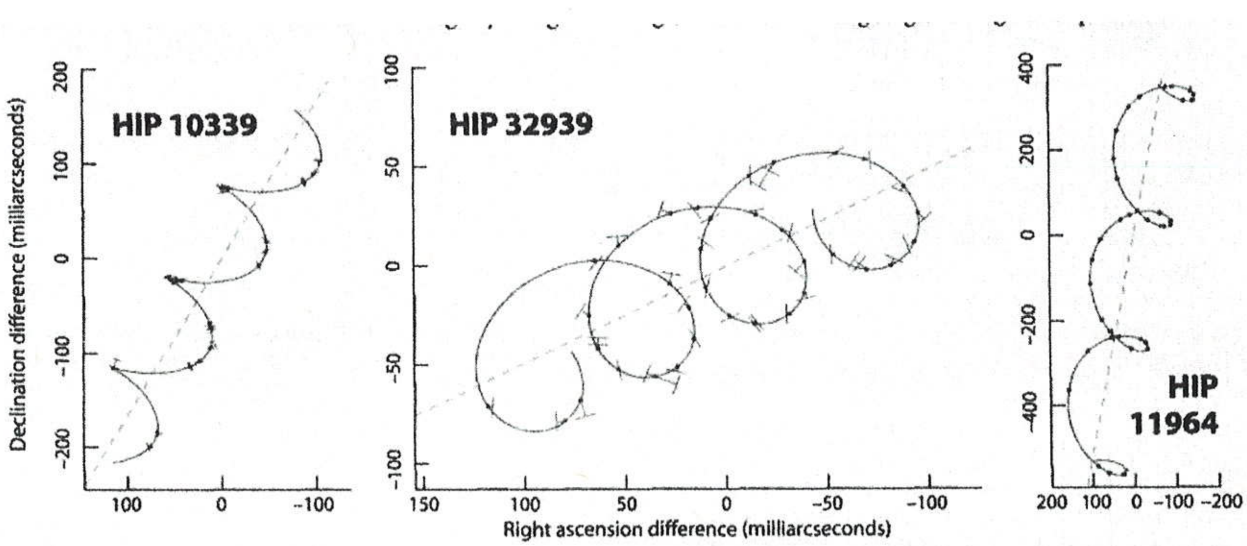


makes a circle only if ✡ ⊥ to ecliptic plane

(c)

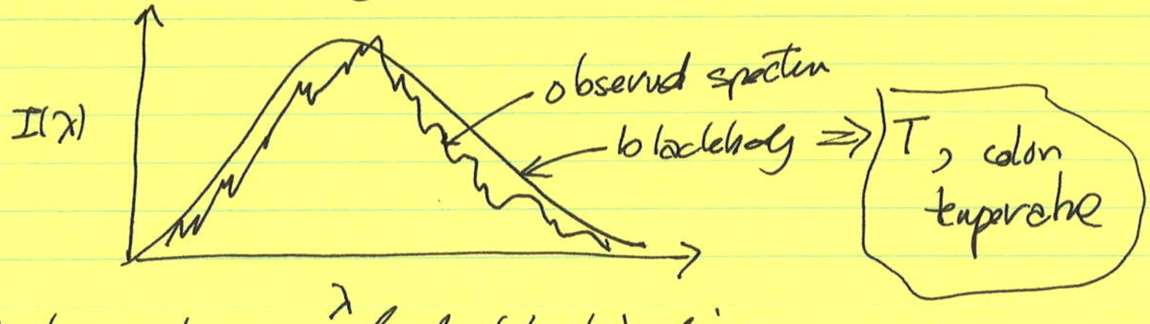


makes an ellipse only if ✡ is at $\angle\psi$ where $0<\psi<\frac{\pi}{2}$



The apparent paths of three stars across the sky during the three years of the Hipparcos mission. Each looping line shows the combination of parallax (an ellipse) and proper motion (a straight line) that best fits the data. The star's measured positions are shown by T-like intersections; these are often hidden under the dots, which mark their best-fit places on the line. Each curlicue in the 118,000-star database is different. From the Hipparcos Intermediate Data Web page.

(A) Can estimate the surface temperature of a * from $I(\lambda)$ & L_* using an important result.



Stellar spectra are similar to blackbodies,

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}, \quad \text{Planck function}$$

, $h = 6.626\times10^{-34}$ J-s

$c = 2.998\times10^{8}$ cm s^{-1}

$k = 1.381\times10^{-23}$ J K^{-1}

a) <u>Wien's law</u>

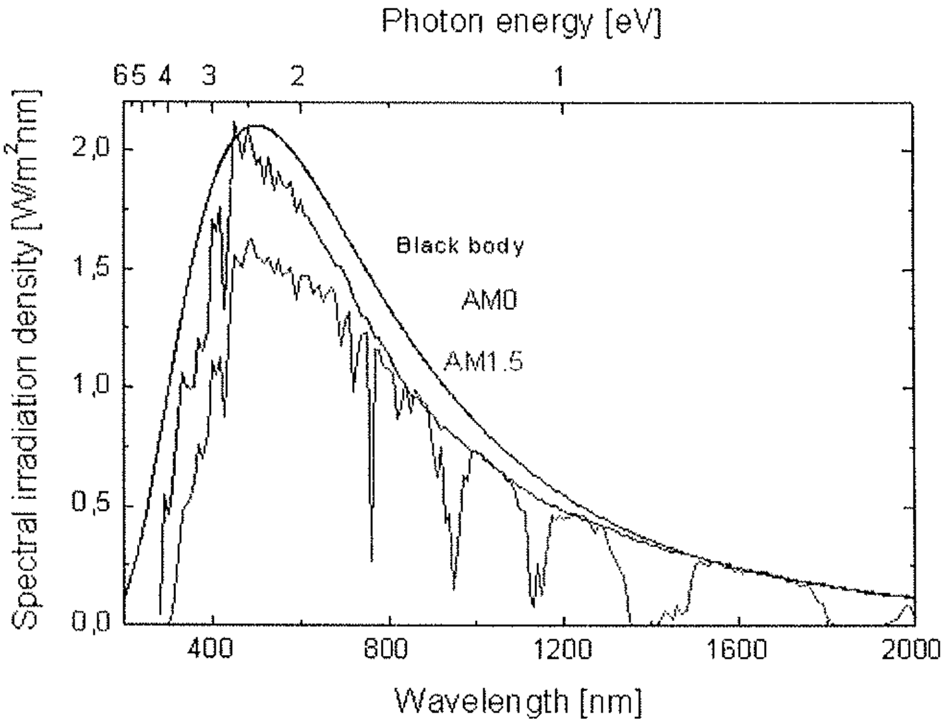
λ at which $B(\lambda)$ peaks follows from

$$\frac{dB(\lambda)}{d\lambda} = \frac{-\frac{10hc^2}{\lambda^6}}{e^{hc/\lambda kT}-1} - \frac{\frac{2hc^2}{\lambda^5}}{(e^{hc/\lambda kT}-1)^2}\left(-\frac{hc}{\lambda^2 kT}e^{\frac{hc}{\lambda kT}}\right) = 0$$

$$-\frac{10hc^2}{\lambda^6}\left(e^{\frac{hc}{\lambda kT}}-1\right) + 2\frac{h^2c^3}{kT\lambda^7}e^{hc/\lambda kT} = 0$$

$$\boxed{\left(e^{\frac{hc}{\lambda kT}}-1\right) - \frac{1}{5}\frac{hc}{\lambda kT}e^{\frac{hc}{\lambda kT}} = 0}$$

$$\Rightarrow \boxed{\begin{array}{c}\lambda_{max}T = 0.002898\,\text{m-K} \\ \text{Wien's law}\end{array}}$$



Photon energy [eV]
6 5 4 3 2 1
Spectral irradiation density [W/m²nm]
2,0
1,5
1,0
0,5
0,0
Black body
AM0
AM1.5
400
800
1200
1600
2000
Wavelength [nm]

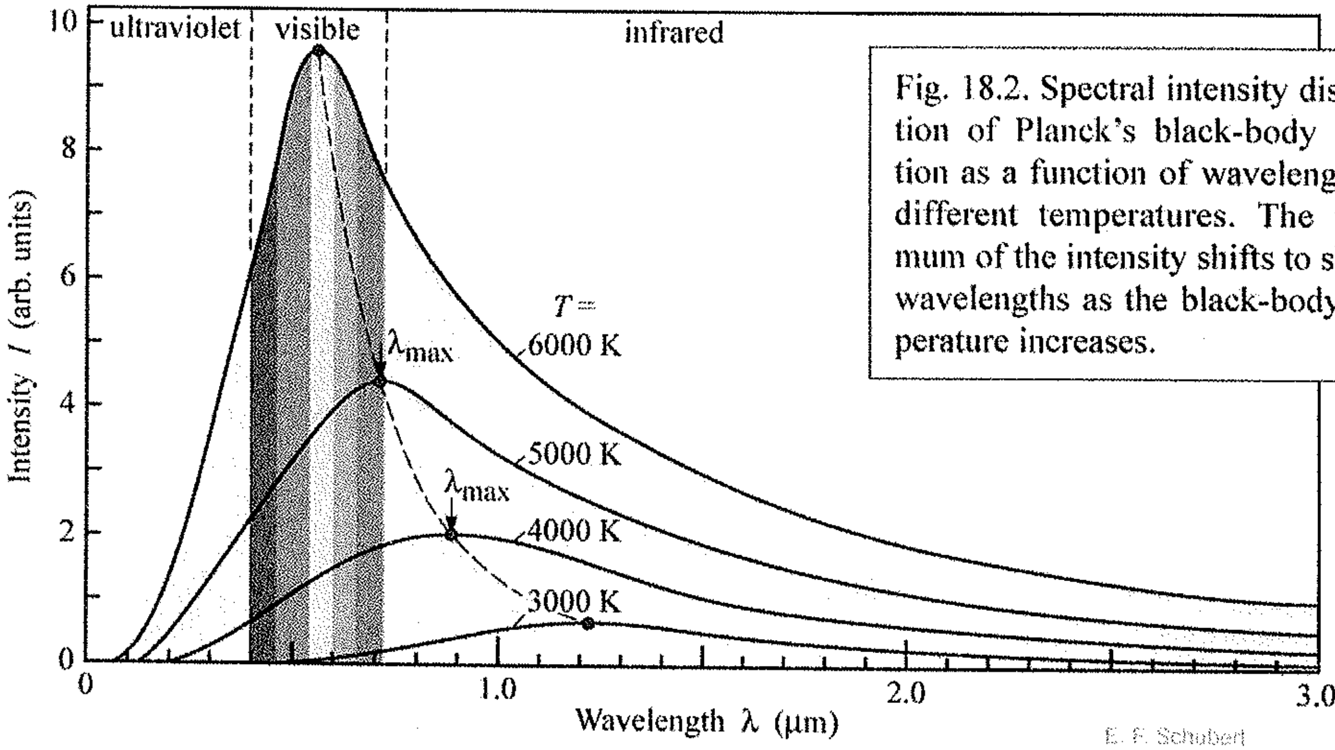


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.