

1. ASTRONOMY CONCEPTS

Matthew Baring – Lecture Notes for ASTR 360, Spring 2025

1 Preliminaries: Stellar Magnitudes

The awareness that some stars are brighter than others dates back to the Greeks, who devised an **apparent magnitude** scale:

**C & O,
Sec. 3.2**

- * $m = 1$ (bright) \Rightarrow 6 (faint)
- In the 19th century, astronomical developments enabled determination that such a range corresponded to a factor of 100 in brightness or **flux** \mathcal{F} .
 - * \mathcal{F} = energy in photons/area/time at detector.
- The flux differs from **luminosity** L , which is the total radiated power of a star or source:
 - * L = energy in photons/time.

Hence, the inverse square law of photon dilution establishes

$$\boxed{\mathcal{F} = \frac{L}{4\pi d^2}} \tag{1}$$

for a source at distance d from Earth. For the sun, the mean distance is $d = 1 \text{ AU} = 1.496 \times 10^{13} \text{ cm}$, the **astronomical unit**.

Accordingly,

$$\mathcal{F}_\odot = \frac{L_\odot}{4\pi(1\text{AU})^2} = 1.36 \times 10^6 \text{erg sec}^{-1} \text{cm}^{-2} \quad (2)$$

is the solar flux at Earth and is called the **solar constant**.

* Note the cgs to SI unit conversion: $1 \text{erg} = 1 \text{g cm}^2 \text{sec}^{-2} = 10^{-7} \text{kg m}^2 \text{sec}^{-2} = 10^{-7} \text{Joules}$.

The flux and luminosity both depend on the waveband under consideration.

• Observational equivalents of \mathcal{F} and L are the **apparent magnitude** m and the **absolute magnitude** M . Using the Greek scale as a guideline led astronomers to the *definitions*

$$\mathcal{F} \propto 10^{-2m/5} \quad \text{and} \quad L \propto 10^{-2m/5} d^2 \propto 10^{-2M/5} \quad (3)$$

The constants of proportionality were “benchmarked” by setting $m = M$ for sources at a distance of $d = 10pc$, a typical distance scale for nearby stars. Hence,

$$\boxed{m - M = 5 \log_{10} \left(\frac{d}{10pc} \right)} \quad , \quad (4)$$

and we call this quantity a source’s **distance modulus**.

* Observe that for the sun, the brightest object in the sky, $m_\odot = -26.81$, however its absolute magnitude is $M_\odot = 4.76$, typical of other main sequence stars. The moon has an apparent magnitude of $m = -12.5$, and Venus has $m = -4.4$ at inferior conjunction.

• It is appropriate to now define the distance scale of a **parsec**, abbreviated **pc**. It is the distance at which 1 AU on the sky subtends 1 arcsec, i.e. the distance at which the parallax of a star is $\pi = 1''$:

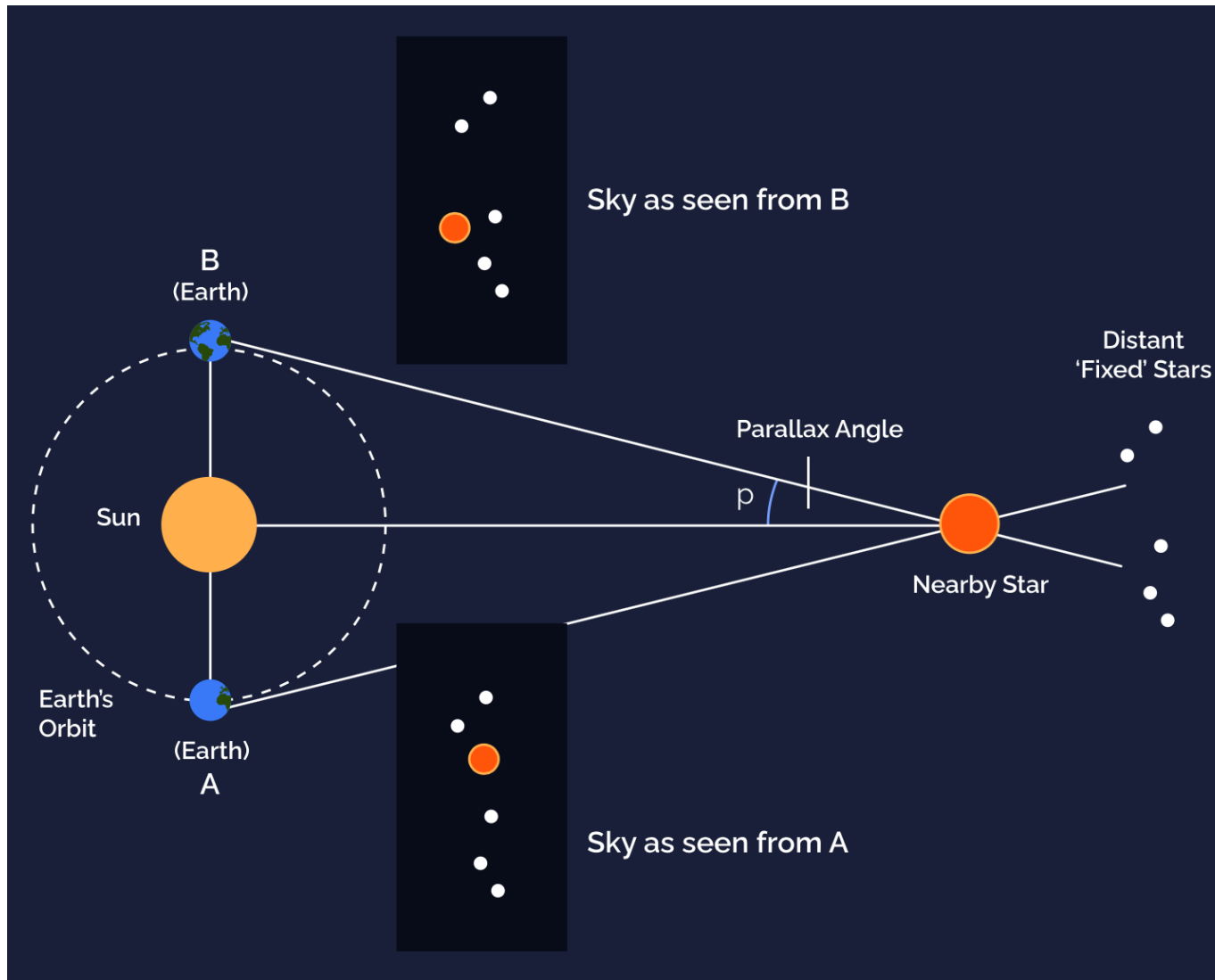
**C & O,
Sec. 3.1**

$$1pc = \frac{1.496 \times 10^{13} \text{cm}}{\pi/180/3600} = 3.09 \times 10^{18} \text{cm} = 3.26 \text{lt yr.} \quad (5)$$

Astrometry missions aim to measure the parallaxes of many nearby stars. *Hipparcos* was an important advance in the 1990s, and now *Gaia* has increased the pool of stars with accurate distances to the 1 billion level.

Plot: Stellar parallax

Stellar Parallax Distance Determination



- Schematic geometry of stellar parallax and associated distance measurement. From *Omni Calculator* web page.

2 Recap: Blackbody Radiation

Blackbody radiation is the principal continuum spectrum that is inherently thermal in nature.

- A blackbody absorbs all light incident upon it and re-radiates it with a characteristic spectrum that is determined by quantum mechanics.

2.1 Wien and Stefan-Boltzmann Laws

- The blackbody spectrum peaks at a wavelength λ_{\max} that is given by **Wien's displacement law**:

**C & O,
Sec. 3.4**

$$\lambda_{\max}T = 0.290 \text{ cm } K \quad . \quad (6)$$

e.g. for $T_{\odot} = 5.77 \times 10^3$ as the surface solar temperature, Wien's law gives $\lambda_{\max} = 0.290/5.77 \times 10^3 \equiv 5030 \text{ \AA}$ (Angstroms).

- * Hence, hot stars are blue, and cool stars are red.

Plot: Blackbody spectrum

The total luminosity of a blackbody was shown by Stefan in 1879 to obey

$$L = A\sigma T^4 \quad , \quad (7)$$

for A being the surface area of the blackbody. Eq. (7) is known as the **Stefan-Boltzmann Law**, and

$$\sigma = 5.67 \times 10^{-5} \text{ erg sec}^{-1} \text{ cm}^{-2} \text{ K}^{-4} \quad (8)$$

is the Stefan-Boltzmann constant.

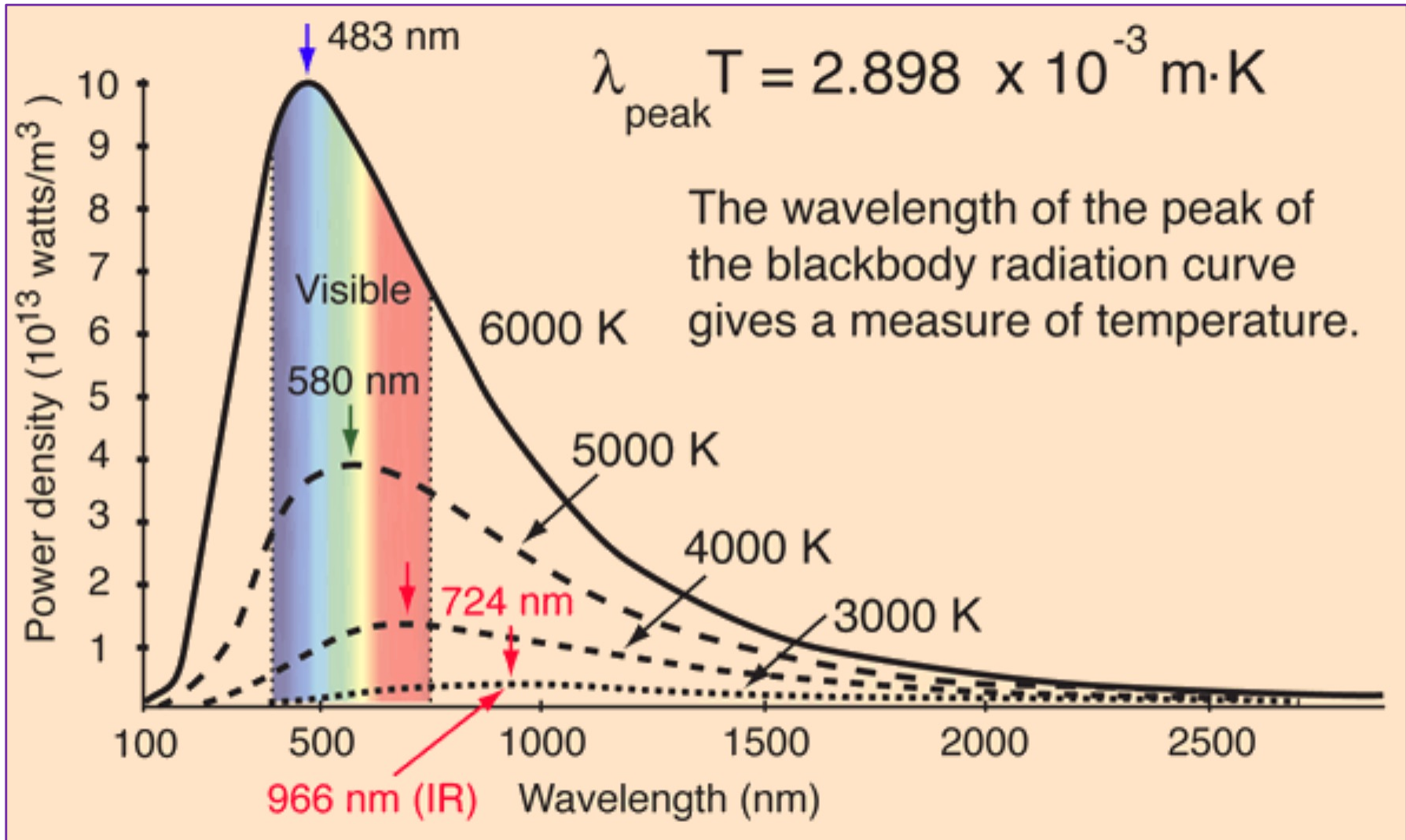
- Boltzmann explained Stefan's experimental determination in terms of thermodynamics and electromagnetism.

e.g. For a sphere like the sun, with a radius $R_{\odot} = 6.96 \times 10^{10} \text{ cm}$,

$$L_{\odot} = 4\pi R_{\odot}^2 \sigma T_{\odot}^4 = 3.826 \times 10^{33} \text{ erg/sec} \Rightarrow T_{\odot} = 5770 \text{ K} \quad (9)$$

is the effective temperature of the solar surface.

The Blackbody Spectrum



- Planck spectrum in the UV/optical/IR band, with example temperatures typical of those for main sequence stars. Courtesy of *Georgia State University*.