Astro 210
Lecture 4
Sept. 4, 2013

Announcements:

- PS 1 available online and hard copies in class
  due at start of class this Friday, Sept 6
  in question 1 and 2(b): assume Sun's mass $M_\odot \gg m_{\text{planet}}$
  Typo in question 4(e): use an **M6** star rather than M7
- Instructor office hours: today 1–2pm, or by appt
  TA office hours: tomorrow (Thurs) 1–2pm
- iClicker GO app should work for this course
- ASTR 401: email me for appointment

Last time:

▷ apologies for technical difficulties!

▷ blackbody radiation

Q: what's a blackbody? what objects emit BB radiation?

Q: what sets surface flux from a BB?

Q: how is BB color related to temperature?

Stars: Brightness

to naked eye, in clear sky:
about 6000 (!) stars visible over celestial sphere
⇒ about 3000 at any one night
...but this is just the "tip of the iceberg"

directly measure **flux**
Q: for old time's sake, remind me–what is flux?

ex: Sun: $F_\odot = 1370\ \mathrm{W\ m^{-2}}$
Sirius ("dog star")

$$\frac{F_{\text{Sirius}}}{F_\odot} = 7.6 \times 10^{-11}$$

tiny, but had to be–we know stars are much dimmer than Sun

iClicker Poll: Getting Sirius

flux comparison: Sirius vs the Sun

$F_{\text{Sirius}}/F_{\odot} = 7.6 \times 10^{-11}$

Does this mean that Sirius is less luminous than the Sun?

- A yes
- B no
- C can't tell from this information alone

Luminosity

recall: apparent brightness $\neq$ luminosity!

- luminosity = power emitted from star: “wattage”
  units: energy/time, e.g., Watts
- flux = power per unit area (at some observer location)
  units: power/area, e.g., Watts/m^2

apparent brightness and luminosity related by

$$\text{observer-dependent } F = \frac{L}{4\pi r^2} \quad \frac{\text{observer-independent}}{\text{observer-dependent}} \tag{1}$$

inverse square law!
farther $\leftrightarrow$ dimmer
hence brightness is “apparent” – depends on observer
but L *is* intrinsic fundamental property of a star

Q: how can we determine a star’s L?

To find $\star$ luminosities

1. Measure flux F

   sadly, usually expressed in *magnitudes*

   see Director's Cut Extras bonus tracks below

2. Measure distance d
3. solve: $L = 4\pi d^2 F$

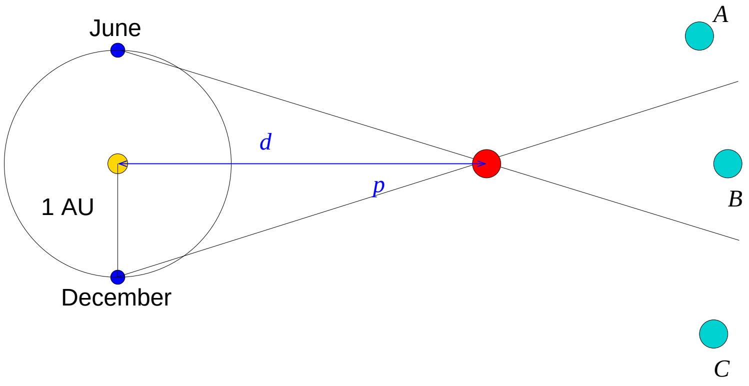
ergo: to compare wattage of stars, need **distances**!

Distances to Stars

a difficult, longstanding (ongoing!) problem
today many techniques exist
but technology good enough in last 2 centuries

Parallax – the "gold standard" of stellar distances
Demo: thumb's up–arm's length, halfway

as Earth orbits, our viewpoint shifts (slightly!)
⟶ nearby $\star$s appear to move w.r.t. background $\star$s
measure: angular shift p



Q: diagram is top view–what is sky view over 1 year?
Q: how are 1 AU, d, and angle p related?

Distances: Geometry and Units

trig technology: $d \tan p = 1$ AU
$\Rightarrow$ distance $d = 1$ AU$/ \tan p$
but p tiny! ($\leq$ 1 arc sec $\sim 10^{-5}$ rad $\ll 1$)
$\longrightarrow$ $\tan p_{\rm rad} \approx p_{\rm rad}$, so
$d = 1$ AU$/p_{\rm rad}$, or

$$d = \frac{1 \text{ pc}}{p_{\rm arcsec}} \tag{2}$$

where $p_{\rm arcsec}$ is p in arc sec
and 1 pc = 1 **parsec** = 1 AU$/(1\,\text{arcsec})_{\rm rad} = 3.086 \times 10^{16}$ m
$\longrightarrow$ distance to a star with $p = 1$ arcsec

occasionally use **light year** = distance light travels in 1 yr
lyr = $c \times 1$ yr $= 9.5 \times 10^{15}$ m
note: 1 pc = 3.26 lyr

Distances: Observations

typical parallactic shift is tiny (if observable at all!)

all less than 1 arc**sec** $= \frac{1}{3600}$ deg $= 5 \times 10^{-6}$ radian!!

Sirius: $p = 0.366$ arcsec

$d = \frac{1}{0.366}$ pc $= 2.65$ pc $\simeq 5 \times 10^{5}$ AU

nearest star: α Centauri system
three-star system at 1.3 pc = 4 lyr
note: even from nearest star, light takes 4 *years* to get here!

Lessons:

- 1 pc $\sim$ typical distance between neighboring stars
  in our Galaxy (and others) `www: 100 nearest stars`
- parallax p tiny at best
  → measureable only for nearest stars
  Q: what to do for more distant objects?

Star Color

Recall: color related to Temperature

Dr. Wien's amazing law says colder: redder; hotter: bluer

`www: objective prism spectra`

very useful to *quantify* color!

- could try spectrum peak λ_{max} – but often, absorption lines → non-blackbody spectrum
- also: full spectrum from spectrometer “expensive” → have to collect more light since spread out

Q: what's a cheaper way to get color information from an image?

Note: imaging detectors are CCDs

→“democratically” count all photons they see equally regardless of wavelength

To get color information without a spectrometer:
$\Rightarrow$ use **filter** which accepts light
only in a *range* of wavelengths: “passband”

`www: filter wheel`

$F_B \rightarrow m_B = B$: blue band, centered around $\lambda \approx 440$ nm
$F_V \rightarrow m_V = V$: “visual”, yellowish, $\lambda \approx 550$ nm
response roughly similar to naked eye
...and many others
`www: filter` λ `ranges`

images in multiple filters ↔ crude spectrum

Star Luminosity

from star color → surface temperature T

stellar luminosity depends on T
but also on star's radius R:
since surface flux $F = L/\text{area} = \sigma T^4$

$$L = 4\pi R^2 \sigma T^4 \tag{3}$$

so for fixed T (same color), $L \propto R^2$
→ bigger stars → bigger emitting surface → higher L

iClicker Poll: Star Temperature and Luminosity

Vote your conscience!

For large sample of stars, measure L and T for each
plot points on diagram of L vs T
What will the data show?

A random scatter: stars have large range of L, and of T, and in any combination

B tight clump of points: stars are nearly identical, all with very similar L and T

C a clear trend: stars have large range of L and of T but the two vary together (correlated)

D none of the above

A Stellar Census: Hertzsprung-Russell Diagram

Hertzsprung-Russell: plot L vs$T$ for lotsa stars
really, abs mag M_V vs spectra type
but these are equivalent to L and T

`www: H-R diagram`

Q: what patterns do you notice?
Q: where are most stars?
Q: where is the Sun?
Q: how does the Sun compare to other stars?

Hertzsprung-Russell Diagram

for a "fair sample" of stars
(i.e., not a specially picked cluster)
trends emerge

most stars ($\sim 90\%$) fall on curve: "main sequence"
  (including the Sun!); "dwarfs"
most of the rest: cooler but more luminous: "giants"
  Q: how do we know they are giant?
a rare few: hot but luminous: "supergiants"
not rare but dim and hard to find:
  very hot but very low-L objects: "white dwarfs"
  Q: how do we know they are teeny?

Q: what does the HR diagram tell us about the Sun?

H-R and the Sun

The Sun on H-R diagram:
- found on the main sequence
- position is in the middle of the curve

but the main sequence is where most stars are found!

thus: *the Sun is a typical star!*
- lies in heart of main sequence L vs T trend
- neither most nor least luminous, not hottest or coolest

Other questions arise:
- *why* do stars lie on the main sequence?
- what controls their position on the diagram?
- what's up with the giants, supergiants, and white dwarfs?

...stay tuned

Director's Cut Extras

Star Brightness: Magnitudes

star brightness measured in **magnitude** scale
magnitude = "rank" : **smaller** $m \rightarrow$ **brighter**
Sorry.

Magnitudes use a logarithmic scale:

- difference of 5 mag is factor of 100 in flux:

$\boxed{m_2 - m_1 = -2.5 \log_{10} F_2/F_1}$ (definition of mag scale!)

- mag units: dimensionless! (but usually say "mag") because mags are *logs* of *ratio* of two dimensionful fluxes with physical units like W/m^2

What is mag difference $m_2 - m_1$:
Q: if $F_2 = F_1$*?*
Q: what is sign of difference if $F_2 > F_1$*?*
Q: for equidistant light bulbs, $L_1 = 100\text{Watt}$, $L_2 = 50\text{Watt}$*?*

Apparent Magnitude

a measure of star flux = (apparent) brightness

- no distance needed
- arbitrary mag zero point set for convenience:
  historically: use bright star Vega: $m(\text{Vega}) \equiv 0$
  then all other mags fixed by ratio to Vega flux

- ex: Sun has **apparent** magnitude $m_\odot = -26.74$
  i.e., $-2.5 \log_{10}(F_\odot / F_{\text{Vega}}) = -26.74$
  so $F_{\text{Vega}} = 10^{-26.74/2.5} F_\odot = 2 \times 10^{-11} F_\odot$
- ex: Sirius has $m_{\text{Sirius}} = -1.45 \rightarrow$ brighter than Vega

so: $F_{\text{Sirius}} = 3.8 F_{\text{Vega}} = 8 \times 10^{-11} F_\odot$

- ex: $m_{\text{Polaris}} = 2.02$ *Q: rank Polaris, Sirius, Vega?*

$\star$ if *distance* to a star is known
can also compute Absolute Magnitude

abs mag $M \equiv$ apparent mag if star placed at $d_0 = 10$ pc

Q: what does this measure, effectively?

Absolute Magnitude

absolute magnitude M = apparent mag at $d_0 = 10$ pc

places all stars at constant fixed distance
→ a stellar "police lineup"
→ then differences in F only due to diff in L
→ absolute mag effectively measure **luminosity**

Sun: abs mag $M_{\odot} = 4.76$ mag
Sirius: $M_{\text{Sirius}} = +1.43$ mag
Vega: $M_{\text{Vega}} = +0.58$ mag
Polaris: $M_{\text{Polaris}} = -3.58$ mag
ϵ Eridani: $M_{\epsilon\text{Eri}} = +6.19$ mag (nearest exoplanet host; $d = 3.2$ pc)
Q: rank them in order of descending L?

Immediately see that Sun neither most nor least luminous star around