Astro 210

Lecture 31

November 8, 2010

Announcements

- HW 9 due in class Friday

Solar Observing last-chance raindates:

today, 10am-2pm

tomorrow, 10am-2pm

▷ schedule, report form online

Last time: how the Sun shines

and how we know this for sure

The Stars as Suns

We've proved that that Sun is nuclear reactor
but (we'll see that) the Sun is a typical star
$\Rightarrow$ **all** stars run by thermonuclear fusion

The Night sky, the Universe lit up ultimately by nuclear power

How do we know Sun is typical?
Compare!

`www: big picture cartoon`

STARS

iClicker Poll: Naked-Eye Stars

Vote your conscience!

On a clear night, outside of a city,
about how many stars can you see with the naked eye?

A More than the number of people in a packed movie theater

B More than the number of people at a UI football game

C More than the population of Illinios

Stars: Brightness

to naked eye, in clear sky:
about 6000 (!) stars visible over celesital sphere
$\Rightarrow$ 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: $F_\odot = 1370 \text{ W m}^{-2}$
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

Apprent 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 measure star L?

To find $\star$ luminosities

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

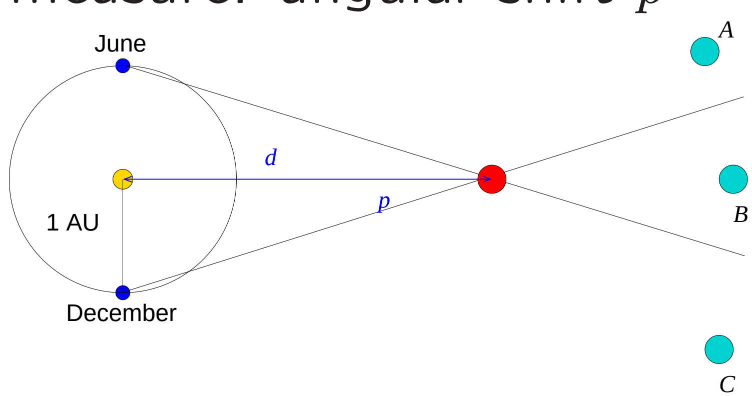
ergo: to compare wattage of stars, need **distances**!

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!)
$\rightarrow$ nearby $\star$s appear to move w.r.t. background $\star$s
measure: angular shift p



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 $\ll 1$)
$\rightarrow \tan p_{\rm rad} \approx p_{\rm rad}$, 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$/(1'')_{\rm rad} = 3.086 \times 10^{16}$ m
$\rightarrow$ distance to a star with $p = 1$ arc sec

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!)
none even a large as 1 arc **sec**!!
Sirius: $p = 0.366''$
$d = 1/0.366$ pc $= 2.65$ pc $\simeq 5 \times 10^5$ AU

nearest $\star$ is α Centauri
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
  $\rightarrow$ measureable only for nearest stars
  Q: what to do for more distant objects?

Star Brightness: Magnitudes

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

Magnitudes use a logarithmic scale:

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

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

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

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, $L_1 = 100\mathrm{Watt}$, $L_2 = 50\mathrm{Watt}$?

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 $m_{\text{Sirius}} = -1.45 \to$ 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?*

⋆ 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

$\rightarrow$ a stellar "police lineup"

$\rightarrow$ then differences in F only due to diff in L

$\rightarrow$ 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

Distance Modulus

take ratio of actual star flux vs "lineup" flux
at abs mag distance $d_0 = 10$ pc:

$$\frac{F}{F_0} = \frac{L/4\pi d^2}{L/4\pi d_0^2} = \frac{d_0^2}{d^2} \tag{3}$$

so we have

$$m - M = -2.5 \log \left(\frac{F}{F_0} \right) = -2.5 \log \left(\frac{d_0}{d} \right)^2 = 5 \log \left(\frac{d}{10 \text{ pc}} \right) \tag{4}$$

- depends only on distance d, not on luminosity!
  can use as measure of distance
- $m - M \equiv$ "distance modulus"