Astro 210

Lecture 28

April 4, 2011

Announcements

- Good news: instructor away today
- Guest: Prof. Myers–real observer, better jokes, better accent
- HW 8 due Friday
  erratum posted, sign error fixed: $\mu = -5 + 5\log_{10} d$
- **Solar Observing** this week Mon–Thurs
  open 10:30am to 3:30 pm; allow about 30min
  info, report form online

Before exam: began the Sun

What is the Sun's "Surface"?

the Sun made of gas
cannot have a sharp, hard surface, has no edge

but does not look hazy; instead, do *see* sharp boundary:
Sun appears to have surface!
`www: Sun in white light`

so: what's going on?

The Solar Photosphere

observed surface $\rightarrow$ visible light emitted from
thin region/layer: "photosphere"
but why does light only come from this surface?
what defines the location of this surface?

Key idea: **photon scattering**
in Sun, photons *scatter* off electrons, ions
each photon scattered many ($\gg$ millions!) times
outward progress erratic: "random walk"
diagram: γ trajectories
less scattering as move outwards and gas ρ decreases
until finally γs escape $\rightarrow$ we see them

Q: so what sets photosphere location?

scattering frequency/probability increases with
higher gas $\rho \to$ more "targets" to hit
can define mean free path $\ell_{\rm mfp}$:
average γ pathlength ("stepsize") between scatterings

iClicker Poll: Mean Free Path and Density

Does photon mean free path $\ell_{\rm mfp}$ depend on
the *density* ρ of the medium?
Which of these is most physically reasonable?

A $\ell_{\rm mfp} \propto \rho$

B $\ell_{\rm mfp} \propto 1/\rho$

C $\ell_{\rm mfp}$ independent of ρ

turns out: $\ell_{\mathrm{mfp}} \propto 1/\rho$

not crazy: if no medium at all, then no scattering:

so stepsize infinite $\ell_{\mathrm{mfp}} \to \infty$

and $\rho \to 0$ gives right answer

but if ultradense medium, many scatterers:

$\rho \to \infty$ means $\ell_{\mathrm{mfp}} \to 0$

Apply to photons in the Sun:

- at center: highest ρ, smallest $\ell_{\mathrm{mfp}} \sim 1$ cm (!) $\ll R_\odot$
  guaranteed scattering before leaving
- but as move outwards, $\rho \downarrow$ and so $\ell \uparrow$
- until ρ so low that $\ell_{\mathrm{mfp}} > R_\odot$
  $\to$ scattering finally "turns off"

Fun fact: the sunlight we see from the photosphere
took millions of years to come from the Sun's core!

So: photons from Sun come from “last scattering” surface

this is the photosphere: region where $\ell_{\text{mfp}} \rightarrow \infty$

- $\delta r_{\text{photosphere}} \sim few$ 100’s of km thick
- $T_{\text{photosphere}} \sim 6400$ K at base, ~ 4200 K at “top”

$\Rightarrow$ we see T “mixture” – not perfect single-T blackbody

can see deeper at center than at edge (“limb”):

photons at edge come from higher, cooler region

“limb darkening”

Sun’s surface shows activity!

in photosphere, gas motion:

hot rises, cool sinks: convection

Demo: lighter, show on screen

granulation

Sunspots

dark regions on photosphere
`www: today's sun in white light`
`www: sunspot seething`

spots transient, last $\sim$ 2 weeks
#, location of sunspots varies
periodic: 11-year "sunspot cycle"
`www: sunspot counts` – we're on the upswing to a maximum

sunspots move: reveal solar spin
`www: real time Sun movie`

sunspots created by magnetism
strong mag. field "locks" plasma in place
keeps hot gas from rising
cooler gas $\rightarrow$ dark spot

The Sun as a Star?

You've heard the Sun is a star
  that is, the Sun is like other stars

But how do we know?

Q: How can we go about comparing the Sun to the stars?

Q: What will be easy to compare? what will be challenging?

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
⇒ 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

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

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: $L = 4\pi d^2 F$

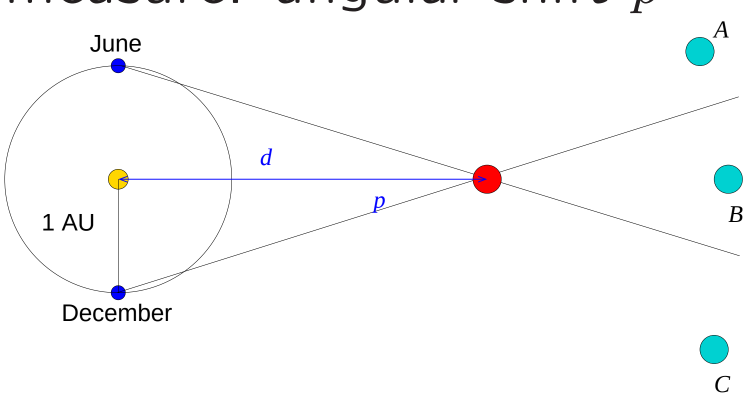
ergo: to compare wattage of stars, need **distances**!

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



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! (≤ 1 arc sec $\sim 10^{-5}$ rad $\ll 1$)

$\rightarrow$ $\tan p_{\text{rad}} \approx p_{\text{rad}}$, so

$d = 1$ AU$/p_{\text{rad}}$, or

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

where p_{arcsec} is p in arc sec

and 1 pc = 1 **parsec** = 1 AU$/(1\,\text{arcsec})_{\text{rad}} = 3.086 \times 10^{16}$ m

$\rightarrow$ 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

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?