Astro 404

Lecture 3

Aug 30, 2019

Announcements:

- **Problem Set 1** posted today on Compass
  due **on Compass in pdf**, next Friday Sept 6 at 5:00pm
- Note: problem sets are non-trivial
  but usually not as bad as they look
  wordy writeups are to help guide you and get the punchlines
- you may speak to me, the TA, and other students
  but you must *understand* your own answers
  and write them *yourself* and *in your own words*

- Syllabus available
- note: yesterday LIGO detected *two different* BH/BH mergers!

Last Time: Electromagnetic Radiation

Q: why electromagnetic? why radiation?

Q: why so important for stellar astrophysics?

Q: definition of flux? units? everyday experience?

Stellar Astronomy

geometry of the sky: spherical
stars appear “fixed” (on human timescales)
to a vast *celestial sphere*

star locations: angular coordinates on celestial sphere

offical celestial sphere divided into 88 regions: *constellations*
cover the sky like states on a map
so each point on sky lies in exactly one constellation

brightest star in night sky: *Sirius* in constellation Canus Major
officially: α Canis Majoris (αCMa)
unofficially: the “dog star” `www: Canus Major`

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 population of Great State of Illinois

Stellar Flux Observed

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

Sun: $F_\odot = 1370$ W m^{-2}
Sirius, brightest star, has

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

faintest stars observed with modern telescopes:
$F_{\text{faintest}}/F_{\text{Sirius}} \lesssim 2 \times 10^{-13}$!
more than 1 trillon times fainter–a huge range in stellar fluxes!
Q: what does this suggest for how we quantify flux?

Stellar Flux Quantified

huge range in stellar fluxes suggests we focus on exponent
that is, take *logarithm* of flux
so: convenient to express measured flux as $m \propto \log F$

also: *human eye has logarithmic response to brigtness*
ancient Greeks quantified stellar brightness
each star given "**apparent magnitude**" (1st, 2nd, 3rd, etc)
due to log sensitivity of naked eye:
apparent magnitude differences correspond to *flux ratios*

$$m_2 - m_1 \ \propto \ \log F_2 - \log F_1 = \log \frac{F_2}{F_1} \tag{1}$$

very convenient! that's the good news.

Q: units of apparent magnitudes?
Q: what's the bad news?

Apparent Magnitude Scale for Flux

good news: logarithms convenient for star fluxes
this is built into magntiude scacle
mag units: dimensionless! (but usually say “mag”)
because mags are *logs* of *ratio* of two
dimensionful fluxes with physical units like $\mathrm{W/m^2}$

bad news: historically, mag conceived as “rank”
brightest stars are 1st magnitude: top dog
next dimmer stars are 2nd magnitude, etc.
so $m \propto -\log F$: smaller flux ↔ larger magnitude

to match historic system, modern fluxes set by:
- $m_2 - m_1 = 5$ mag corresponds to $F_1/F_2 = 100$

• magnitude "zero point" set by star Vega: $m_{\text{zp}} = 0 = m_{\text{Vega}}$

PS 1: show this gives magnitdue m vs flux F relation

$$m = -\frac{5}{2} \log_{10} \left(\frac{F}{F_{\text{zp}}} \right) \tag{2}$$

Living with Magnitudes

stellar fluxes tabulated as magnitudes. sorry.

$$m = -\frac{5}{2}\log_{10}\left(\frac{F}{F_{\text{zp}}}\right) \tag{3}$$

• ex: Sirius has $m_{\text{Sirius}} = -1.45 \rightarrow$ brighter than Vega
so: $F_{\text{Sirius}} = 3.8 F_{\text{Vega}}$

• ex: Polaris (α Ursae Minorus = αUMi) *Q: what's this? why name?*
$m_{\text{Polaris}} = 2.02$
Q: rank brightness of Polaris, Sirius, Vega?

Star Color

stars have colors! and they are different!

`www: objective prism spectra`

very useful to *quantify* color!
could try spectrum peak $\lambda_{\rm max}$ – but often,
  absorption lines $\longrightarrow$ spectrum not smooth
  also: full spectrum from spectrometer "expensive"
  $\longrightarrow$ 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
$\longrightarrow$"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`

flux $F_B \rightarrow m_B = B$ mag: blue band, centered at $\lambda \approx 440$ nm

flux $F_V \rightarrow m_V = V$: "visual", yellowish, $\lambda \approx 550$ nm
response roughly similar to naked eye

...and many others

www: filter λ ranges

images in multiple filters $\leftrightarrow$ crude spectrum

Q: how to quantify color based on filter data?

Color Index

measure color by comparing flux at different λ bands

"**color index**" is *magnitude difference*, e.g.,

$$B - V = 2.5 \ \log\left(\frac{F_V}{F_B}\right) + \text{const} \tag{4}$$

$\longrightarrow$ measures ratio of fluxes in two bands

ex: `www: Orion`

Betelgeuse reddish, $B - V = 1.5$

Rigel bluish, $B - V = -0.1$

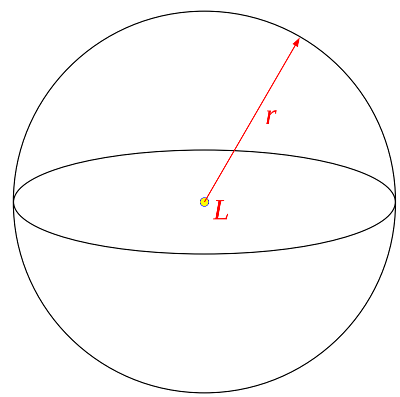
Flux from a Point Source

consider spherical source (hint: it's a star!) of size R
emitting light isotropically (same in all directions)
with constant *power* L (“**luminosity**”)

at radius $r > R$ (outside of source)
area $A = 4\pi r^2$, and flux is

$$F = \frac{L}{4\pi r^2}$$

inverse square law
Q: what principle at work here?
Q what implicitly assumed?



for we observers to infer luminosity (star wattage)
need *both flux* F *and distance* r

Inverse Square Law

Ultimately relies on *energy conservation*

$\longrightarrow$ energy emitted $d\mathcal{E}_{\rm emit} = L\ dt_{\rm emit}$ from source
is same as energy observed $d\mathcal{E}_{\rm obs} = F\ A\ dt_{\rm obs}$

Thus: inverse square derivation assumes

- no emission, absorption, or scattering outside of source
  we will revisit these
- no relativistic effects (redshifting, time dilation)
- Euclidean geometry–i.e., no spatial curvature,
  usually fine unless near strong gravity source

Luminosity

Warning! 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

$$\text{observer-dependent } F = \frac{L}{4\pi r^2} \quad \frac{\text{observer-independent}}{\text{observer-dependent}} \tag{5}$$

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 ⋆ luminosities

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

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

Q: what about color–how does that depend on distance?