Astro 210
Lecture 29
April 6, 2011

Announcements

- Good news: instructor still out of town!
- Guest: Prof. Myers–real observer, better jokes, better accent
- HW 8 due next time
  erratum posted, sign error fixed: $\mu = -5 + 5\log_{10} d$
- **Solar Observing** today and tomorrow
  open 10:30am to 3:30 pm; allow about 30min
  info, report form online

Last time: Stars

- parallax *Q: what's that? what's it good for? limitations?*

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:

$\boxed{m_2 - m_1 = -2.5 \log_{10} F_2/F_1}$ (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 $m_{\text{Sirius}} = -1.45 \to$ 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?*

$\star$ 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

Distance Modulus

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

$$\frac{F}{F_0} = \frac{L/4\pi d^2}{L/4\pi d_0^2} = \frac{d_0^2}{d^2} \tag{1}$$

so we have

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

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

Star Color

Recall: color related to Temperature

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
...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"
$B - V = 2.5 \log F_V / F_B + const$ → ratio of fluxes
Fix const: $B - V = 0$ for star with $T = 10,000$ K (e.g., Vega)
index measures T!
`www: color and spectra`

ex: `www: Orion`
Betelgeuse reddish, $B - V = 1.5$; $T \sim 3300$ K
Rigel bluish, $B - V = -0.1$; $T \sim 12,000$ K

Stars: Temperatures and Spectral Types

Note: color index is useful but crude measure of star T

in today's Director's Cut Extras:
how to use full spectrum of star to get accurate temperatures

this procedure classifies star "spectral types"
which correspond to different temperatures
hotter → cooler: **OBAFGKMLT**

how to remember?
classic mnemonic: "Oh be a find girl/guy kiss me"
HW9: make your own mnemonic for bonus points and prizes!

Star Luminosity

color and/or Spectral type → temperature T

stellar luminosity depends on T
but also on 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 spectral type), $L \propto R^2$
→ 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-Russel 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?

Hertzsprung-Russel 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"
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: what does the HR diagram tell us about the Sun?

H-R and the Sun

The Sun on H-R diagram:
- 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

Stellar Temperatures

instead of broadband colors, take full stellar *spectrum*
→ contains much more information

roughly ("zeroth approximation"): stars are blackbody emitters
▷ spectrum roughly Planckian, $\lambda_{\rm max} \to T$ (Wien's law)

more realistically: stars are not perfect blackbodies
Q: why? hint–what does the Sun's spectrum look like?
Q: how can we make use of the non-blackbody aspects?

Stars: Spectral Types

solar & stellar photospheres cooler than underlying material

→ observed spectrum shows *absorption lines*

- "barcode" of elements in star, but also
- distorts spectrum from blackbody

Annie Jump Cannon, Harvard ~ 1900:

studied many stellar spectra, and found patterns:

- different atomic lines show different *relative* strength in different stars *Q: meaning?*
- linestength variations not random: follow pattern

★ can *classify* stars accoring to spectrum

→ spectral types: originally named ABC...

Physical Origin: What Spectal Types Mean

first consider one atom's lines:

Balmer series in hydrogen: $n = 2 \rightarrow n \geq 3$

diagram: Balmer line strength vs $\star$ *atmosphere temperature* T

as T increases, strength increases → max → decreases

Q: why this pattern?

What's going on?

Balmer needs $n = 2$ H atoms:

$\rightarrow$ need neutral atoms, but in 1st excited state

temperature "fine tuning" required

too cold: most in ground state $n = 1$

hot: most ionized ($n = \infty$)

Balmer → intermediate T!

similar issues with other lines

→ each has "favorite" temperature where strongest

Q: so what sets spectral types?

Q: M, L, T types include molecular lines–what does this mean?

Q: O stars have singly ionized He, doubly ionized carbon
what does this mean?

Key point:

spectral type $\Leftrightarrow T$

- a better, finer scale than color index
- gold standard for temperature
- when sorted by temperature, spectral types un-alphabetical
  hotter → cooler: **OBAFGKMLT**

how to remember?

classic mnemonic: “Oh be a find girl/guy kiss me”

HW9: make your own mnemonic for bonus points and prizes!

OBAFGKMLT

Spectra types → spectral features → temperature

e.g., Sun is G-type star:
most elements neutral, some heavier elements singly ionized
→ intermediate temperature: 4900-5700 K

compare: O stars have high ionization states
→ very high $T > 30,000$ K!
MLT stars not only neutral atoms, but even molecules
→ molecule survival → very low $T < 3800$ K