Astro 210
Lecture 32
November 10, 2010

Announcements
- HW 9 due next time
- Solar Observing report due next time

Last time: Stars
- parallax *Q: what's that? what's it good for? limitations?*
- magnitude scale

  apparent magnitude measures flux

  $m = -2.5 \log_{10}(F/F_{\text{Vega}})$

  smaller $m \to$ *larger* F

  absolute magnitude measures luminosity

  $M = -2.5 \log_{10}[F(10\text{pc})/\text{F}_{\text{Vega}}] = -2.5 \log_{10} \text{L} + \text{const}$

  smaller $M \to$ *larger* L

Star Color

Recall: color related to Temperature

colder: redder; hotter: bluer

`www: objective prism spectra`

very useful to *quantify* color!

- could try spectrum peak $\lambda_{\rm max}$ – but often, absorption lines $\rightarrow$ non-blackbody spectrum
  also: full spectrum from spectrometer “expensive”
  $\rightarrow$ 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

$\rightarrow$ “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"

$B - V = 2.5 \log F_V / F_B + const \rightarrow$ 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

Mass

Most important parameter of a star!

Q: why is stellar mass hard to determine?

Q: when/how can mass be measured?

For single stars:
mass determination difficult, very indirect

But can find masses for **binary** systems:
two stars orbiting common center of mass
diagram: orbits

measure P, r_1, r_2
get m_1, m_2 from Newton's version of Kepler's 3rd law

$$m_1 + m_2 = \frac{4\pi^2}{G} \frac{r^3}{P^2} \qquad (1)$$

and $m_1/m_2 = r_1/r_2$

- problem: must measure r's *Q: how?*

visual binary

can see both stars!

`www: visual binary orbit`

eclipsing binary

stars pass in front of each other

can see in light curve:

diagram: light curve $\rightarrow$ get rs from timing of eclipses

spectroscopic binary

periodic Doppler shifts in spectrum

see $\Delta\lambda_1$, $\Delta\lambda_2$

$\rightarrow$ radial velocity $v_r/c = \Delta\lambda/\lambda_0$

then $v_1 = r_1\omega = 2\pi r_1/P$

can solve for r!

iClicker Poll: Stellar Luminosity and Mass

Vote your conscience!

How are a star's luminosity and mass related?

A directly: larger $M \rightarrow$ larger L

B inversely: larger $M \rightarrow$ smaller L

C no strong dependence: L nearly constant for all M

for many stars find M, $L \to$ plot!

`www: ` M `vs` L `-- beware!  logarithmic axes`

for "normal" stars ("main sequence")
i.e., in hydrogen-burning phase, not dying
there is a simple, clear correlation

mass-luminosity relation (main sequence):

$$L \propto M^4 \tag{2}$$

where M is now mass, not magnitude!
Note: this is a rough approximation, not accurate for $M \gtrsim 4M_\odot$

Q: what is L of $0.5M_\odot$ star?

iClicker Poll: Stellar Lifetime

Stars of which mass live longer–$1M_\odot$ or $0.5M_\odot$?

A $1M_\odot$: higher $M \rightarrow$ more fuel

B $0.5M_\odot$: lower $L \rightarrow$ longer to "burn out"

C effects cancel: lifetimes roughly equal

Stellar Lifespans

From M and L get lifespan τ
since energy conservation gives

$$\begin{array}{rccr} E = & L & \tau & (3) \\ \text{energy supply (fuel)} = & \text{burn rate} & \text{lifespan} & (4) \end{array}$$

thus: $\tau = E/L$

but $E \propto M$: hydrogen mass is thermonuclear fuel

- $\tau = E/L \propto M/M^4 = M^{-3}$
- using solar values $\tau_\odot = \tau(M_\odot) = 10^{10}$ yr, get

$$\tau = 10^{10}\ \text{yr} \left(\frac{1 M_\odot}{M}\right)^3 \tag{5}$$

- high mass $\leftrightarrow$ high luminosity $\leftrightarrow$ short life
- low mass $\leftrightarrow$ low luminosity $\leftrightarrow$ long life

Stellar Lifetimes: Implications

Some Facts:

- stellar ("main sequence") mass-lifetime relation:

$$\tau = 10 \text{ billion yr} \left(\frac{1 M_\odot}{M}\right)^3 \tag{6}$$

- age of Sun and solar system: $t_{\rm SS} = 4.5$ billion yr
- age of the Universe (we'll find): $t_0 = 13.7$ billion yr

Q: what's the lifespan of a $0.5 M_\odot$ *star? implications?*
Q: what's the lifespan of a $10 M_\odot$ *star? implications?*

Imagine (for simplicity) that:

- our Galaxy has formed stars at a constant rate throughout the age of the Universe (oversimplified!)

Q: what would this mean for the population of Galactic stars today?