Astro 404

Lecture 8

Sept. 10, 2021

Announcements:

- **Problem Set2 due today Friday 5:00pm**
  two problems use the SIMBAD online database

- **Problem Set 3** posted today, due next Friday

Last time:

- masses of main sequence stars: *Q: trend with L? implications?*
- HR diagram: *Q: role of mass?*

for **main sequence stars**

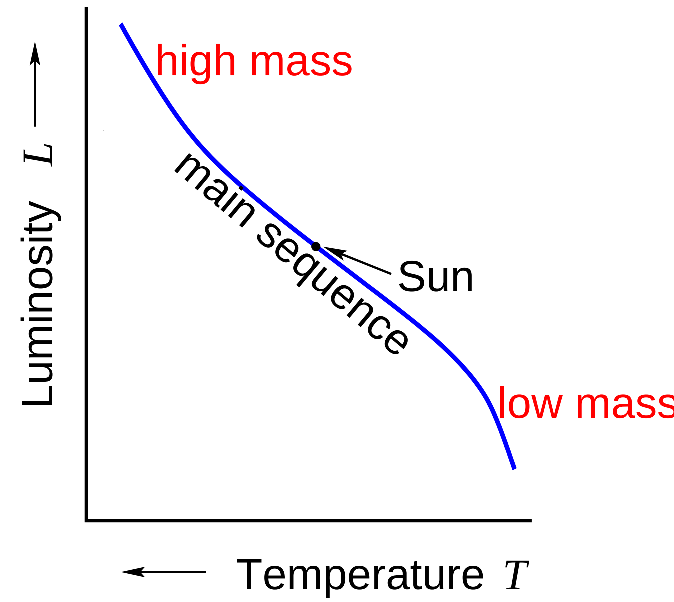
mass–luminosity relation is roughly a power law

$$L \approx \left(\frac{M}{M_\odot}\right)^{\nu} \ L_\odot \tag{1}$$

where $\nu \approx 3.5$ for masses near $1 M_\odot$

HR diagram shows:

on main sequence, L and T correlated



but now we see L and M are correlated

each L corresponds to a particular M

Lesson:

main sequence is a sequence in mass

Stellar Energy

main sequence luminosities span roughly $(10^{-4}L_\odot, 10^4 L_\odot)$
huge range in power output

but energy conservation requires luminosity power to be generated by a "fuel" of some kind

$$\left(\frac{dE}{dt}\right)_{\text{emitted}} = L = \left(\frac{dE}{dt}\right)_{\text{fuel}} \tag{2}$$

so *total energy requirement* for fuel
over a star's main sequence lifespan τ is

$$E_{\text{fuel}} = \int_0^\tau L\ dt \approx L\ \tau \tag{3}$$

Q: should available fuel depend on star mass? how?
Q: implications for lifespan?

Main Sequence Lifespans and Mass

it stands near to reason (and turns out to be right)
that *more mass* $\leftrightarrow$ *more available fuel*

simplest such relation (also turns out right): linear proportionality

$$E_{\text{fuel}} \propto M \tag{4}$$

and since we have $E_{\text{fuel}} \approx L\ tau$
predict *main sequence lifespan* depends on mass:

$$\tau(M) \approx \frac{E_{\text{fuel}}(M)}{L(M)} \sim M^{1-\nu} \tag{5}$$

so for masses near $1 M_{\odot}$: $\tau \sim M^{-2.5}$
Q: how can this be? doesn't more mass mean more fuel?

Q: implications for HR diagram?
Q: how can we test this?

Prediction: MS Lifespan Depends Strongly on Mass

main sequence lifespan: expect $\tau \sim M^{1-\nu} \sim M^{-2.5}$
- strong dependence on mass!
- *high mass* $\leftrightarrow$ *short lifespan*
- *low mass* $\leftrightarrow$ *long lifespan*

to test:
- *find clusters of stars that were born together*
- plot on HR diagram, and compare main sequences
- prediction: young clusters $\rightarrow$ entire MS populated
  old clusters $\rightarrow$ no upper MS (high L, T), but full lower MS

Q: analogy in mosquito/human fable?

How to tell old vs young clusters?
`www: open clusters` versus `www: globular clusters`
consider *shape* ("morphology") and *environment*
Q: which is likely old? which young?

Star Clusters and Ages

globular clusters

stars tightly packed in sphere

→ suggests equilibrium

isolated from other stars and gas (out of Galactic plane)

→ no raw materials, unrelated to ongoing star formation

open clusters

stars loosely grouped, with irregular shapes

→ suggests disequilibrium (not round!)

often near gas and dust clouds and many other stars

→ raw stellar materials and active star formation nearby

best available data is hot off presses: *Gaia!*

Breakout Project

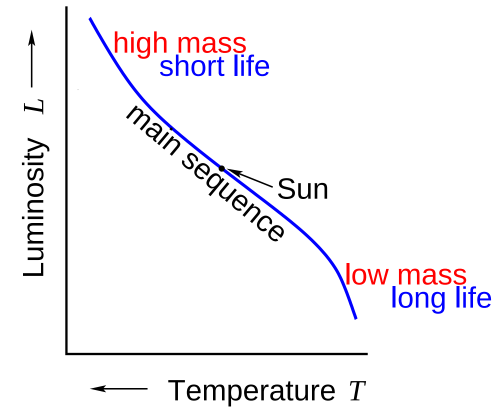
Compare Gaia HR diagrams for open and globular clusters

Q: how do they differ?

Q: for each: trends in MS? giants? white dwarfs?

`https://docs.google.com/presentation/d/1IzAka5X6iB9PJVKXe0MK8p_uP8V7u`

Star Cluster H-R Diagrams: Evolution Revealed!



our predictions confirmed!

- *young open clusters* have *full MS*
- *old globular clusters* have lower MS
  but *no stars with above* $\sim 1 M_\odot$

more clues:

- some open clusters have no giant branch!
- other open clusters lack highest masses,
  and have some (super)giants
- open clusters have very few white dwarfs
- globular clusters have no supergiants but full giant branch

Q: what does this suggest?

(Super)Giant Phase Follows Main Sequence

giant branch and white dwarf sequence emerge as clusters age at expense of ever more of upper main sequence

implications: *this is due to stellar evolution!*

- *highest mass stars quickly evolve from MS to supergiants*
- lower masses progressively evolve from MS to giants
- globular cluster MS "turnoff" near $1 M_\odot$ suggests stars with $M \lesssim 1 M_\odot$ live a very long time!
- white dwarfs also arise after MS

Decoding the H-R Diagram: Evolution Revealed!

main sequence is *ordered by mass*
and star properties do not change much during MS phase
in particular: a star does not move up or down the MS
Q: why not? what would that mean for clusters?

giants and supergiants are phase after MS
most massive MS stars $\rightarrow$ supergiants
then, ever more slowly, MS $\rightarrow$ giants
until very long MS lifespans at $M \lesssim 1 M_{\odot}$

and thus **stellar evolution is stellar transformation**

- ▷ *stars change color, temperature, luminosity, and size over time*
- ▷ these changes are modest and slow during main sequence
  but dramatic and increasingly rapid after MS ends

iClicker Poll: Stars and Galaxies

galaxies are made of billions of stars
at optical wavelengths, the light from a galaxy
is dominated by the combined light of its stars

elliptical galaxies are red in color

What does this suggest about elliptical galaxies?

A they are young and mostly made of giant stars

B they are old and mostly made of giant stars

C they are young and mostly made of white dwarfs

D they are old and mostly made of white dwarfs

The Mighty H-R Diagram

note the power of the HR diagram
and the progress we have made
still with very basic physics only

and the HR diagram has more information
which we will uncover in weeks to come

many question remain: how do stars arrive on the MS?
how and why do stars linger on the MS?
why do stars become giants? how do they leave this phase?
what is role of white dwarfs?

to make further progress – *need to develop theory of stars*