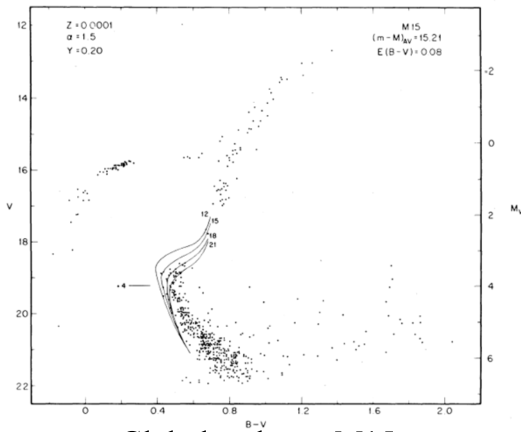
Lifetime of Stars/ Fusion powers the stars—11 Oct

- Big questions
  - Does the sun have a finite life or does it last forever?
  - What powers the sun?
  - Where does carbon come from?
  - How long does the sun live?
  - What happens to the sun when it dies?
- Clues
  - H-R diagram of star clusters
- Fusion
  - $4H \rightarrow {}^4He$



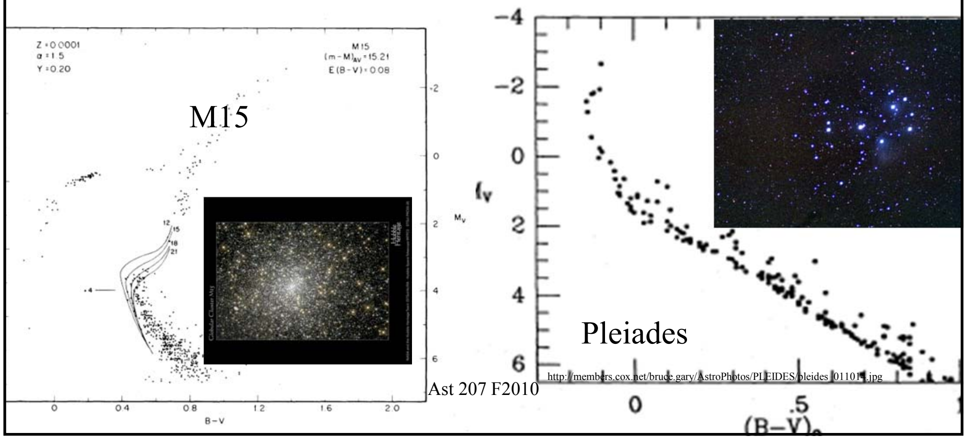
Ast 207 F2010 Globular cluster M15

- Test 2 is Wed, Oct 20.
  - Covers material though HR diagram of star clusters (today). Does not cover energy production.
  - Covers homework 5.
  - Mostly on material since first test.
  - One cheat sheet.
  - See practice test on angel.
- Homework 5 is due at start of class on Mon, Oct 18. No late papers.

Pleiades & M15

- Stars in a cluster were born at the same time. They are at the same distance.
  - Study a cohort of thousand-tuplets. How are they different? What is their lifetime?

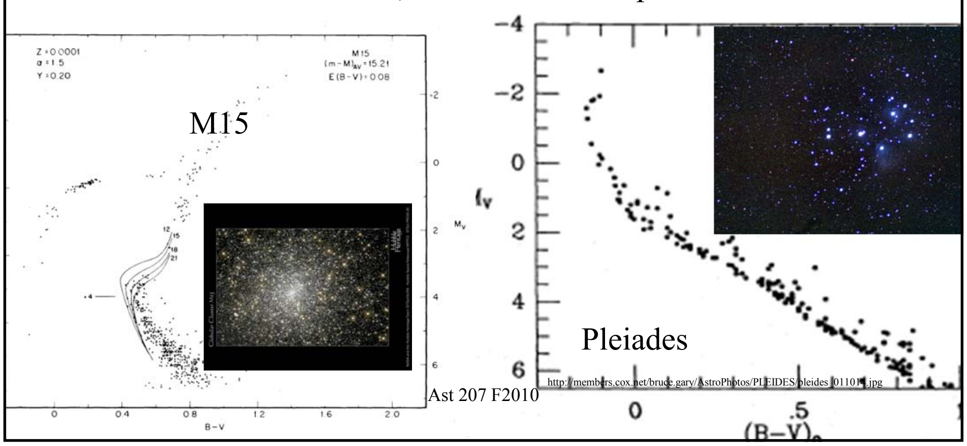
1. Are there any MS stars with abs mag $M_{\mathrm{v}} = 2$ in M15 & Pleiades? A. YY. B. YN. C. NY. D NN.



Pleiades & M15

1. Are there any MS stars with abs mag M_v=2 in M15 & Pleiades?

- Very hot stars were born in both clusters. Hotter stars died and disappeared.
- Pleiades is the younger cluster. Stars with $M_{\mathrm{V}} = 2$ formed when cluster formed. In M15, these stars used up their fuel and died.



Lifetime of Stars

- Lifetime = Amount of fuel/Rate of consumption
  - Lifetime of a tank of gas for a car
  - For a star
    - Amount of fuel = mass
    - Rate of consumption = luminosity
- Lifetime = mass / luminosity
- Stars have a finite life. The sun will not live forever!

Spectral Class	Abs Mag	Luminosity [Lsun]	Mass [Msun]	Lifetime [Tsun]
O3	-6	25000	40	1/600
G2 (sun)	5	1	1	1
M0	10	1/100	0.3	30

Lifetime of Stars

- Lifetime = mass / luminosity
- Stars have a finite life.
- The sun will not live forever!
  - Life of sun is 10Byr
- O3 stars
  - Lifetime is 1/600 of sun's
  - O stars have a lot more mass than the sun. Why is their life so short?
- M0 stars have a long life.

Spectral Class	Abs Mag	Luminosity [Lsun]	Mass [Msun]	Lifetime [Tsun]
O3	-6	25000	40	1/600
G2 (sun)	5	1	1	1
M0	10	1/100	0.3	30

Cluster of Stars

- In a cluster of stars
  - All stars were born at the same time.
  - Some are massive and live a short life.
    - On a human scale: 20T if the sun scales to 100lb.
    - On a human scale: 5 wk if the sun scales to 70yr.
  - Some have little mass.

Spectral Class	Abs Mag	Luminosity [Lsun]	Mass [Msun]	Mass	Lifetime [Tsun]	Lifetime
O3	-6	25000	40	20T	1/600	5wk
G2 (sun)	5	1	1	100lb	1	70yr
M0	10	1/100	0.3	30lb	30	2000yr

Ast 207 F2010

Energy production in the sun

- Big questions
  - What powers the sun?
  - Where does carbon come from?
  - How long does the sun live?
  - What happens to the sun when it dies?
- Lifetime of the sun
  - Chemical reactions
  - Gravitational energy
  - Nuclear fusion
- Fusion

19^{th} Century "Energy Crisis"

- Luminosity of sun $L=4\times10^{26}$Watt
- Mass $m=2\times10^{30}$kg
- How long will the sun last if the energy is produced by burning coal? $C+O_2\rightarrow CO_2$
  - Life time = m×(E/m)/L
  - E/m=9MJ/kg
  - 1500 years
- Earth is much older than that.

Extract Energy from Gravity

William Thomson
Lord Kelvin
1824-1907
www-history.mcs.st-andrews.ac.uk/history/PictDisplay/Thomson.html /

- Luminosity of sun: $L=4\times10^{26}$Watt
- Mass $m=2\times10^{30}$kg
- How long will the sun last if the energy is produced by the sun contracting?
- If material falls from R_{sun} to $0.9R_{sun}$,
  - Energy = ½ m v² = m g h = $m\,(GM_{sun}/R_{sun}^2)(0.1R_{sun})$
  - Life time = m×(E/m)/L
  - 1.6 Million years
- Kelvin's calculation includes material falling not just on surface. Got 100 Myr.
  - Kelvin thought earth could be this old, but later in 19^{th} century, age of earth was shown to be much larger.

$E=mc^2$

- Crisis: No solution with physics of 19th century.
- Einstein's new theory (1906)
  - Energy can change into mass, and mass can change into energy.
  - $E = m c^2$.
  - Energy = mass × (speed of light)^2.
- Changing a little mass produces a lot of energy. Compare kinetic energy ½ m v^2 with m c^2.
  - Speed of light c = 300,000 km/s
  - Air in blast furnace moves at 0.2 km/s
- Chemical reaction $C+O_2 \rightarrow CO_2$
  - $E=m c^2/100,000,000,000$. One part in 100 billion of mass disappears and changes into energy.
- Sun contracts by 10%
  - $E=m c^2/1,000,000$. One part in a million of mass disappears and changes into energy.
- H fuses to produce He
  - $E=m c^2/140$. A part in 140 of the mass disappears and changes into energy.

Nuclear fusion

Hans Bethe
1906-2005

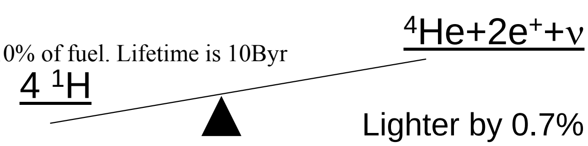
- In a nuclear reaction, converting a significant fraction of the mass to energy is possible.
- Hans Bethe figured out the nuclear physics of how this happens.
- $4\ {}^1H \rightarrow {}^4He$ + neutrinos $+2e^+$+ energy
  - 4 hydrogen nuclei fuse
  - One helium nucleus is produced

1. Which is heavier? A box of hydrogen and a box of helium, neutrinos, and positrons made from the hydrogen?
   A. Box containing H
   B. Box containing the products: He, neutrinos, and positrons
   C. The two boxes have the same mass.

Nuclear fusion

Hans Bethe
1906-2005

- In a nuclear reaction, converting a significant fraction of the mass to energy is possible.
- $4\ {}^1H \rightarrow {}^4He$ + neutrinos $+2e^+$+ energy
  - 4 hydrogen nuclei fuse
  - One helium nucleus is produced
- $4\ {}^1H$ weighs 0.7% more than ${}^4He$ + neutrinos $+2e^+$.
  - Part of the mass has been converted into energy.
  - Amount of energy is $E=0.007mc^2$. Most of mass remains.
- Life time = $m\times(E/m)/L$
  - $m \times(0.007mc^2/m)/L$
  - 100Byr
  - In reality sun uses 10% of fuel. Lifetime is 10Byr



Proton-proton chain

- Two paths for fusing hydrogen into helium
- Carbon-nitrogen-oxygen cycle (important in more massive stars)
- Proton-proton chain (main process in sun)
  - Step 1: Two protons fuse to produce a deuterium nucleus (^2H), a positive electron, and a neutrino.
    $p+p\rightarrow d+e^+ +\upsilon$
    - Deuterium is an isotope of H with one neutron.
    - A neutrino is almost massless, not charged, and interacts very weakly.

1. Did the number of nucleons change? Charge?
   A. YY
   B. YN
   C. NY
   D. NN