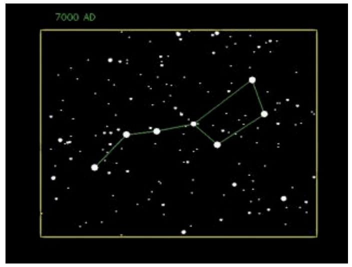
Reading: Chapter 17, section 17.3; Chapter 18: section 18.2 & 18.4; Chap. 22, through 22.3

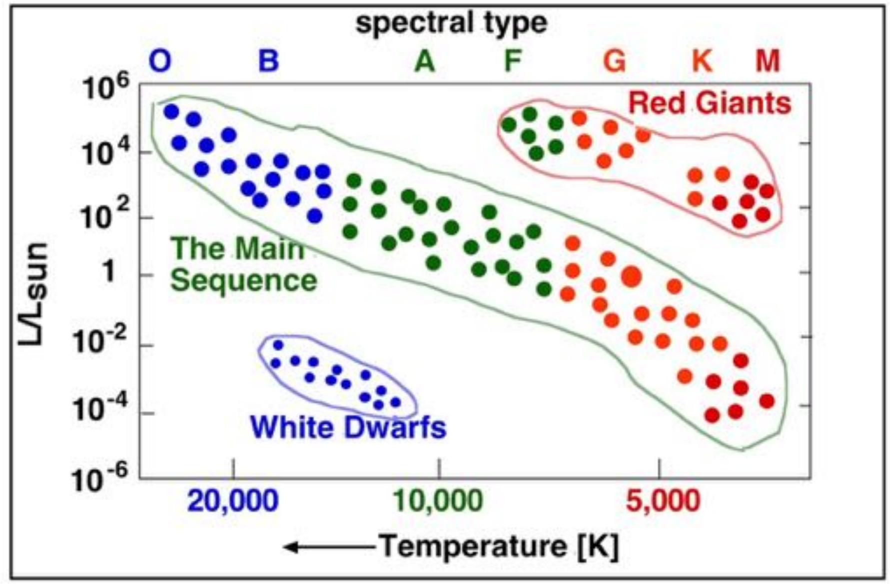
OBAFGKM Contest: a better mnemonic for OBAFGKM?
- written (or e-mail) entries due Tuesday, February 28
- judging by an "independent" panel
- prizes!

Brief review of last time: **Distances and the H-R Diagram**

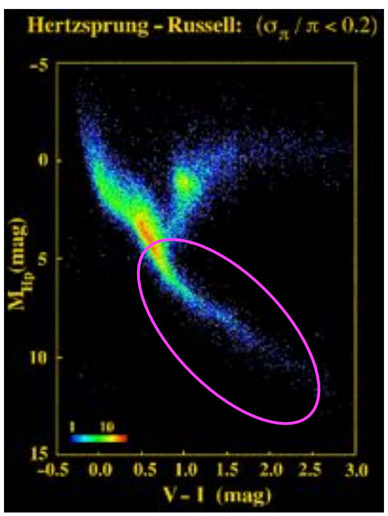
- Distance as a pivotal quantity
- Stellar Motions
  - Proper motion and tangential velocity
  - Radial Velocity via the Doppler Effect
- Statistical Parallax:
  motion of the sun for a bigger baseline
- Uses of the Doppler Effect
- The Hertzsprung-Russell (H-R) Diagram
  - classification tool: luminosity plotted vs. temperature
  - radius on the H-R diagram
- H-R Diagram Features:
  - The Main Sequence, Red Giants, and White dwarfs
  - 90% of stars are on the Main Sequence



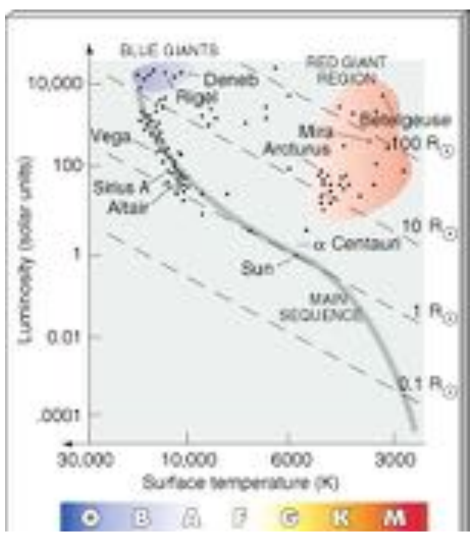
Features on the H-R Diagram



An H-R diagram for all stars with Hipparcos (space) parallaxes (distance limited)



An H-R diagram for the brightest stars in the sky (brightness limited)



Main Sequence stars are the most numerous

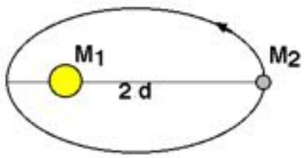
BUT

The most prominent stars in our sky are the rare but luminous blue main sequence, giants and supergiants

- **Why such variety?**
- **What makes stars so different from one another?**
- **What are we missing? MASS!**

Measuring Stellar Masses: Binary Stars

- <u>Kepler's Third Law</u> - for binary stars

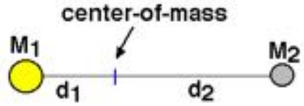


$$\frac{d^3}{P^2} = M_1 + M_2$$

orbital period [yrs]

- <u>The See Saw Law</u>

$$\frac{M_1}{M_2} = \frac{d_2}{d_1}$$



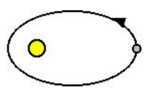
- sum *and* ratio of masses allows determination of the individual masses of each star

Reflex Orbital Motion

Credit: R. Pogge, OSU

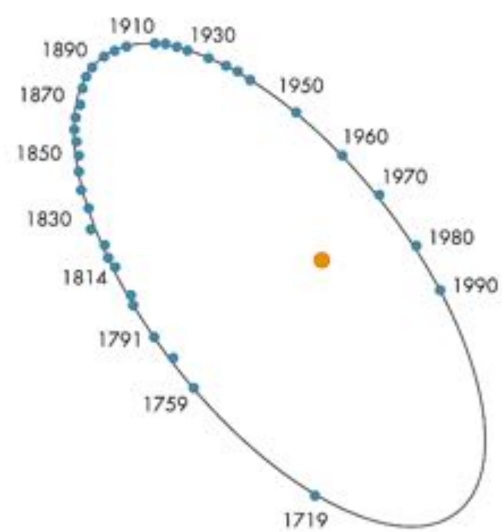
Types of binary stars

- **Visual**
  - widely separated (10-100 a.u. and more)
  - know d_1+d_2, d_2/d_1, P (sometimes)



- **Spectroscopic**
  - spectral lines show periodic Doppler shifts
  - too close to see individual stars
  - know d_2/d_1 (from velocities), P
- **Eclipsing**
  - brightness variations as stars eclipse one another
  - know P , shapes of stars, light distribution
- **Eclipsing spectroscopic - rare**
  - provide d_1+d_2, d_2/d_1, P and so masses
  - radii from eclipses and orbital velocities
- **Astrometric**
  - stars that "wiggle"
  - bright star orbiting an unseen compa
  - provides d_2, P

Castor - a visual binary



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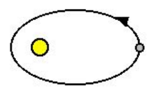

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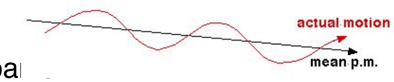

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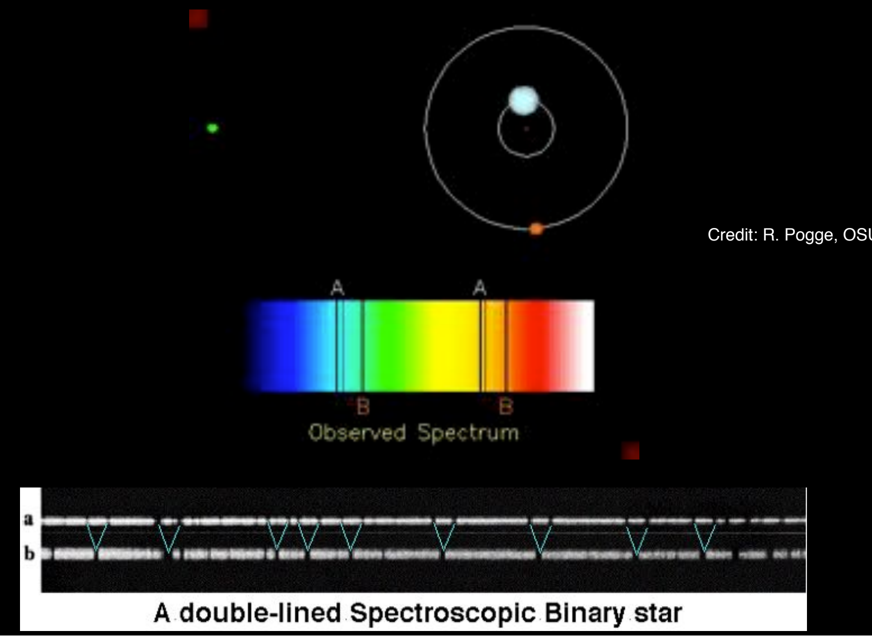
Reflex Orbital Motion - Spectroscopic Binary



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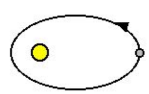

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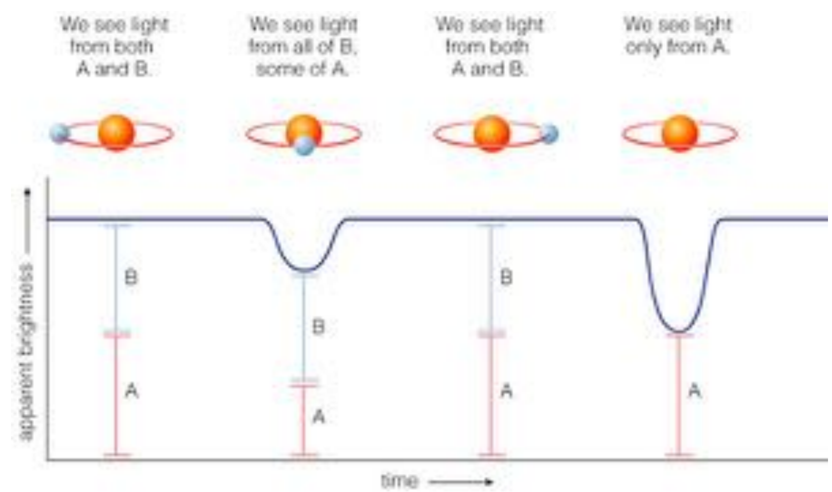
- Eclipsing binary



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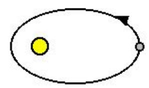

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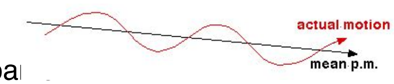

- more than 50% of stars are in binary or multiple systems
- BUT only a **few dozen** can be used to measure accurate stellar masses
- **Key Observation:**
  Stars with the same mass have the same spectral type... on the Main Sequence

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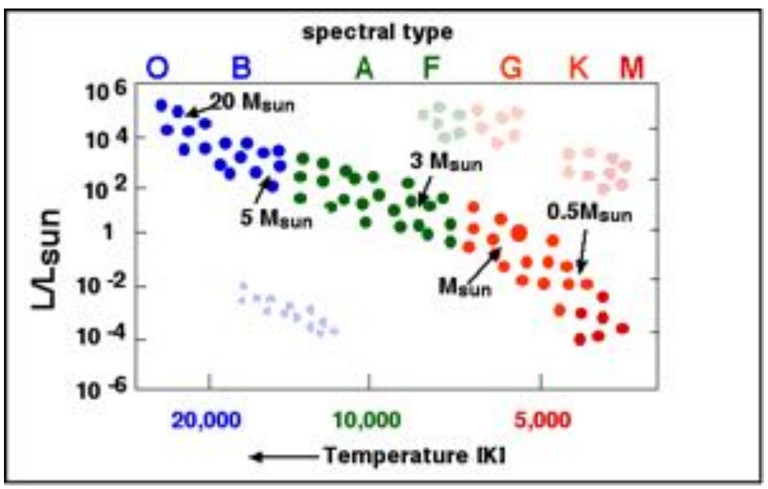


Properties of Main Sequence Stars

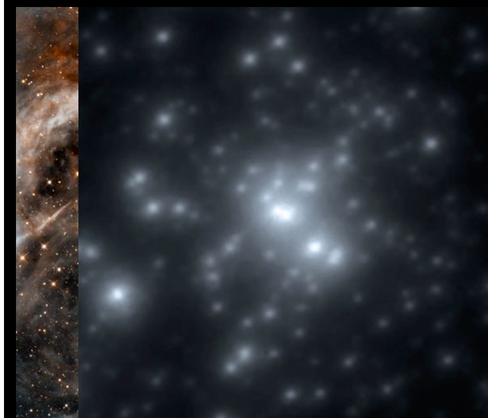
# in Galaxy for each O star	L/L_{sun}	M/M_{sun}	R/R_{sun}	Example
1	260,000	20	10	Rigel
100,000	60	3	2.5	Vega
1,000,000	1	1	1	Sun, Capella
5,000,000	0.06	0.4	0.6	Barnard’s Star

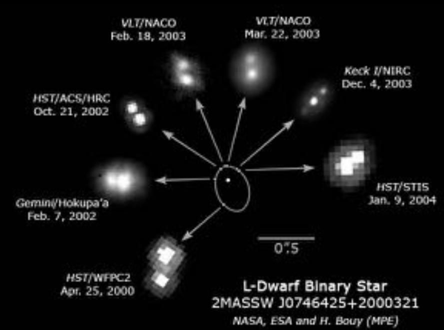
- **Lower mass limit** of Main Sequence: **$0.08\ M_{sun}$**
  - stars less massive don’t get hot enough to burn hydrogen
- **Upper mass limit**: **~ 200 M_{sun}**
  - if $M > 100\ M_{sun}$, violently unstable

Main Sequence Extremes

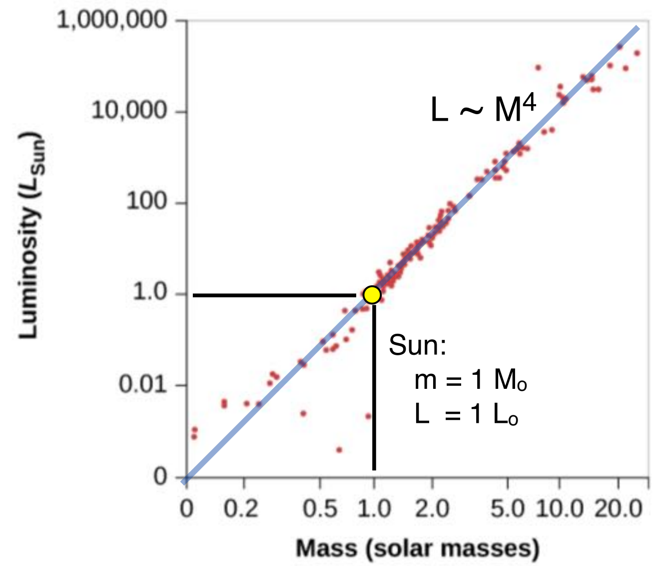
High Mass:
R136a1 at ~300 M_{sun}

Low Mass:
an ‘L’ Dwarf at 0.077 M_{sun}





The Mass-Luminosity Relation



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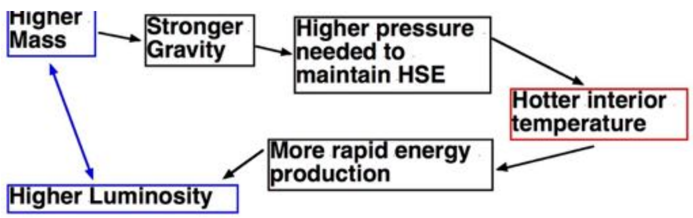


- Eddington (1926):

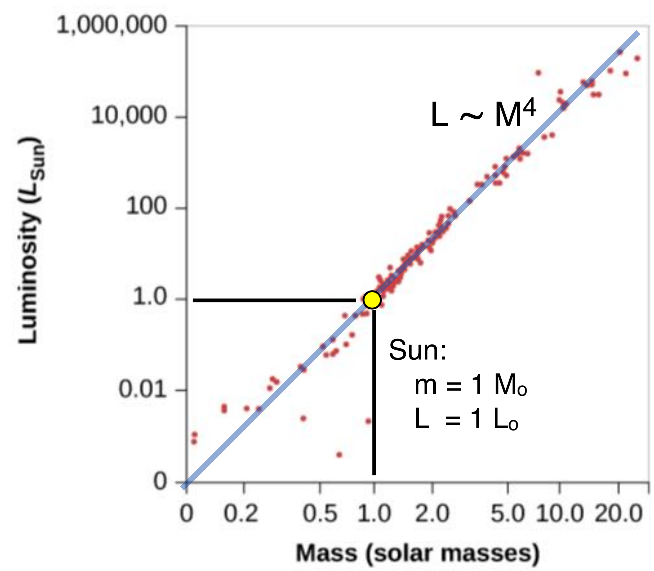
  $L \propto M^4$ for main sequence stars

- Main sequence is a sequence in MASS
  blue stars are more massive than red stars

- The Sun is a M.S. star
  - The Sun burns hydrogen in its core

- **all M.S. stars burn hydrogen in their cores**

The Mass-Luminosity Relation



The Vogt-Russell Theorem (1926):

Properties of ordinary stars are determined uniquely by mass and composition

- Mass+Composition -> position in H-R diagram
- on M.S., star burning hydrogen
- BUT: star is voluntarily changing its composition!
- V-R theorem demands:
  - star must leave M.S. when hydrogen is exhausted
  - so stars must move in the H-R diagram as they age
- **"Stellar Evolution"**

Life Expectancies for Main Sequence Stars

- available fuel supply ∝ mass
- rate of fuel consumption ∝ luminosity
- rate of consumption x lifetime = total fuel consumed
  - so... luminosity x lifetime ∝ mass

    or lifetime ∝ mass / luminosity
  - combine with luminosity ∝ mass^4 to give

$$t_{ms} \propto 1/M^3$$

$$t_{ms} = 10^{10} \text{ yr} \times (M/M_{sun})^{-3}$$

- **Massive Stars burn out faster**