Astr 5465 Wed., Feb. 5, 2020

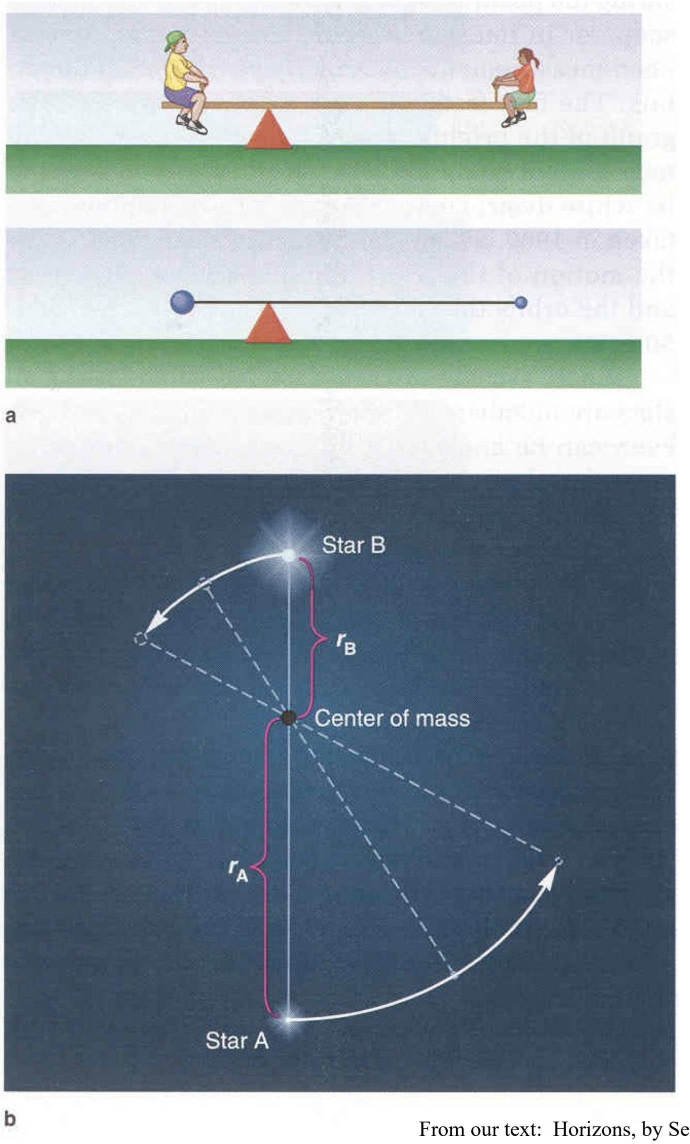
Today's Topics

- Stars: Binary Stars
    - Determination of Stellar Properties via Binary Stars
  - Classification of Binary Stars
    - Visual Binaries
      - Both stars visible
      - Only one star visible
    - Spectroscopic Binaries
      - Radial Velocity Curves
      - Mass Function
    - Eclipsing Binaries
      - Light Curves
      - Stellar Radii
      - Contact Binaries
  - Interferometic Stellar Diameters and Effective Temperatures
    - Lunar Occultations
    - Stellar Interferometers

Importance of Binary Stars

- Binary stars provide the primary means for determining the physical properties of stars.
  - Masses
  - Radii
  - Temperatures
  - Luminosities
- Classification of Binary Stars
  - Visual Binaries
    - Visible motion of the stars
  - Spectroscopic Binaries
    - Radial velocity variations of the star(s)
  - Eclipsing Binaries
    - Brightness variations of the stars

Motion of Binary stars



From our text: Horizons, by Seeds

Newton's form of Kepler's 3rd law for planets:

$$P^2 = \frac{4\pi^2}{GM} a^3$$

Modified form when mass of "planet" gets very large

$$P^2 = \frac{4\pi^2}{G(M_A + M_B)} a^3$$

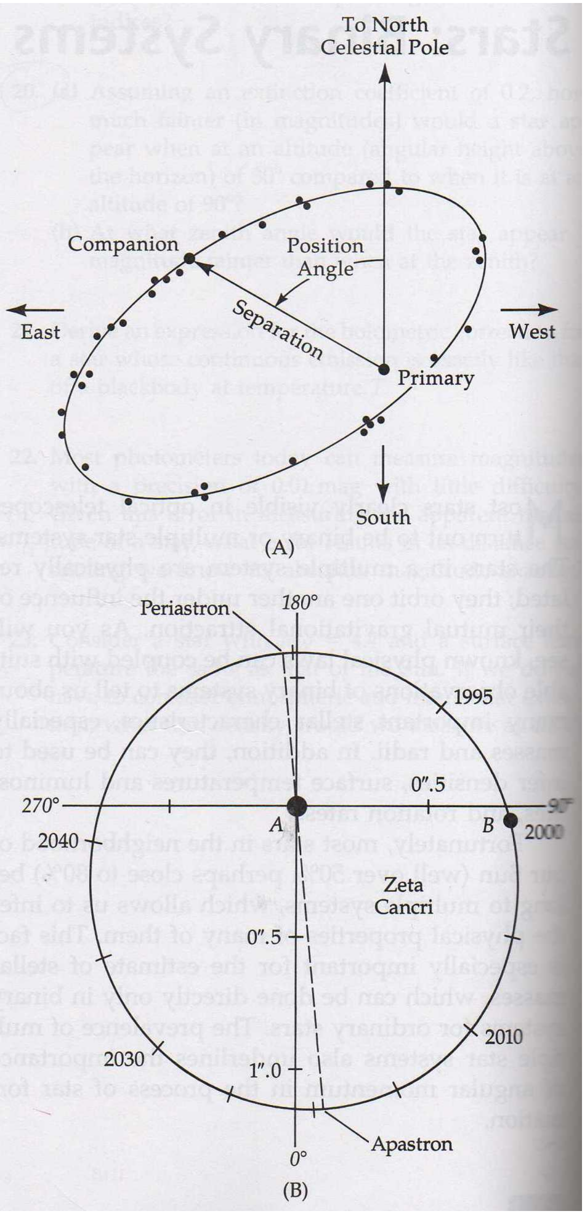
$$M_A + M_B = \frac{4\pi^2}{G} \frac{a^3}{P^2}$$

For binary stars we consider the motion of both stars about the center of mass. Note that the period and semi-major axis alone only give the sum of masses.

Visual Binaries

- Both stars visible:
  - Ideal but rare
  - Modeling to de-project orbits
  - mass ratio from each orbit
  - sum of masses from period.
  - Two equations, two unknowns yield both masses
  - Brightnesses + parallax give luminosities

- One star visible:
  - More common
  - Only sum of masses



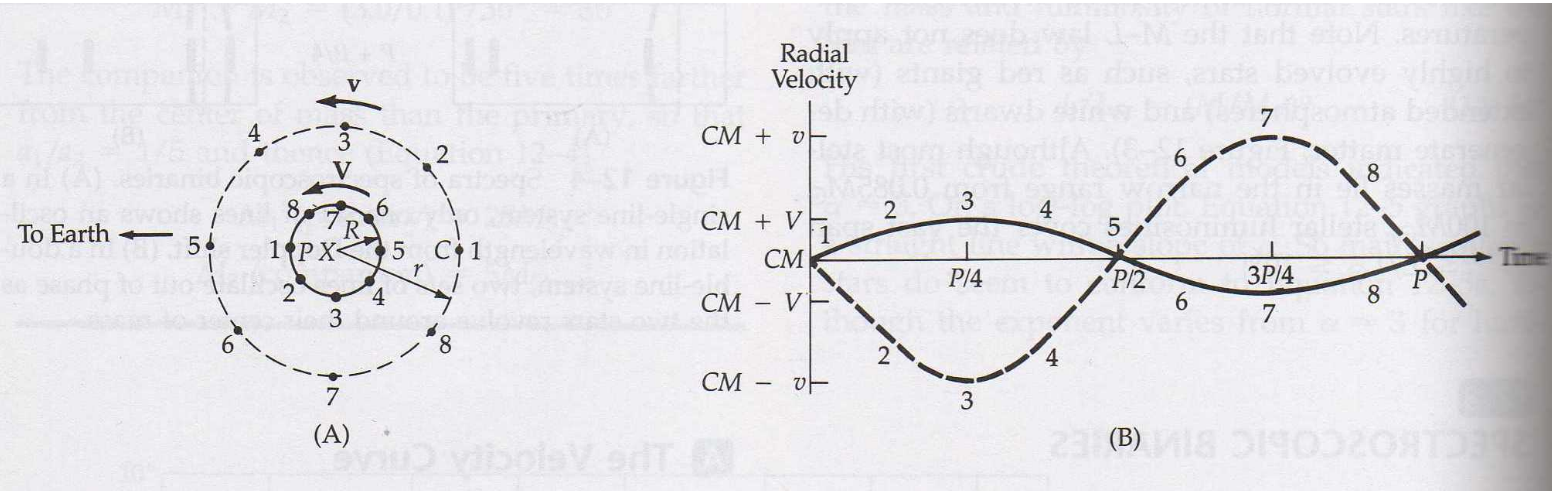
Spectroscopic Binaries

- Only combined light visible
  - Spectra reveal radial velocity variations
  - Orbital projection is generally unknown but in principle:
    - One set of lines yields sum of masses.
    - Two sets of lines yields mass ratio:

$$m_1v_1 = m_2v_2$$

$$m_1/m_2 = v_2/v_1$$

  - If also eclipsing (see below) the orbital inclination is ~ 90^o



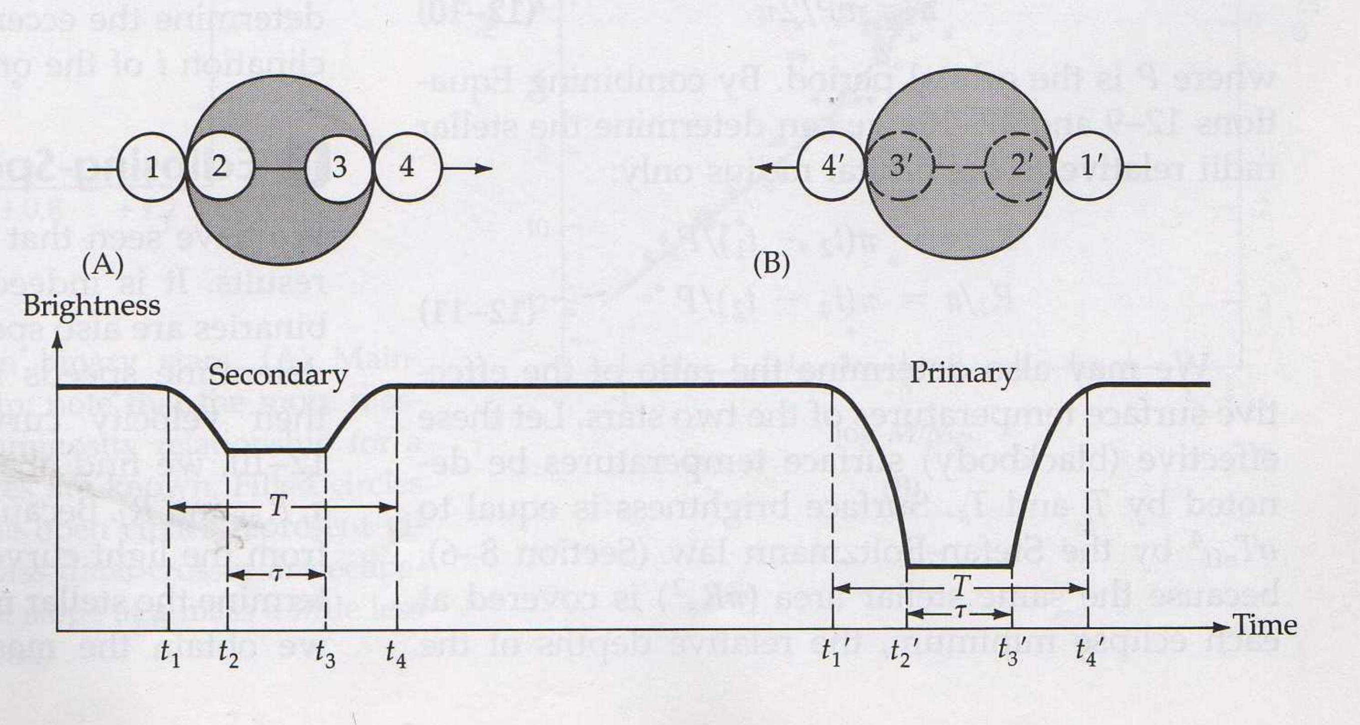
(A)

(B)

Eclipsing Binary Stars

- **Eclipses place strong constraint on orbital inclination**
- **All eclipsing binaries are also spectroscopic binaries**
- **Additional Info. Obtained:**
  - **Radii of stars (relative to orbit, see text)**
  - **relative "surface brightness"**
    - **area hidden is same for both eclipses**
    - **drop bigger when hotter star hidden**

      $\Delta L = \sigma T^4$



Measuring Stellar Diameters - I

- **Lunar Occultations**
  - Shape of diffraction pattern can be modeled to reveal stellar angular diameters
  - Rare since star must be occulted and be close enough for parallax

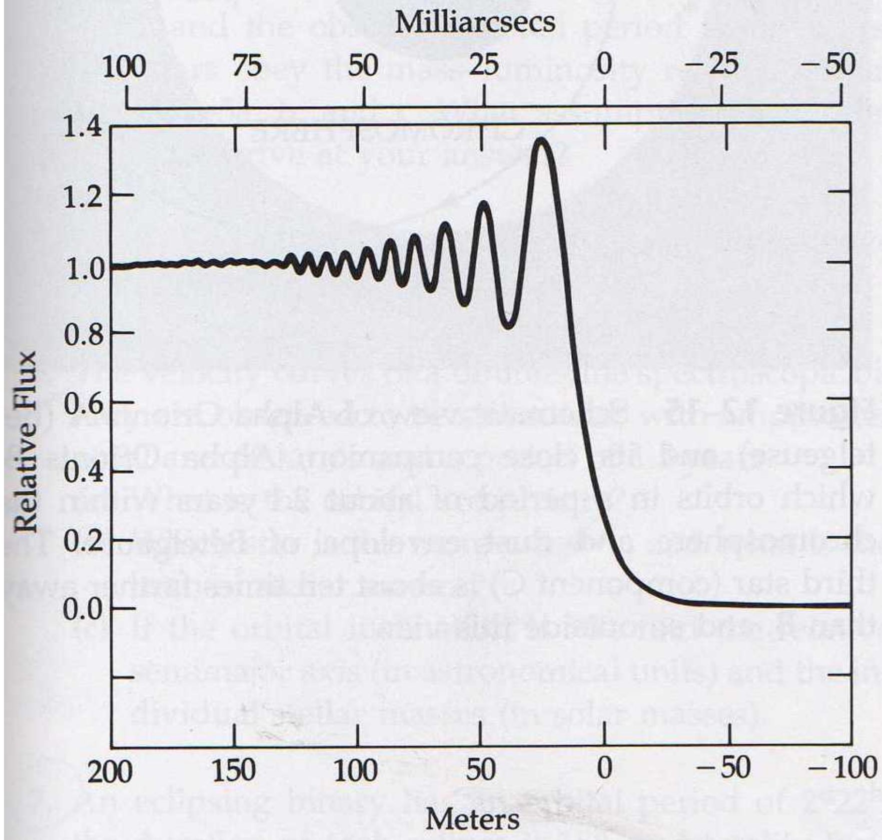


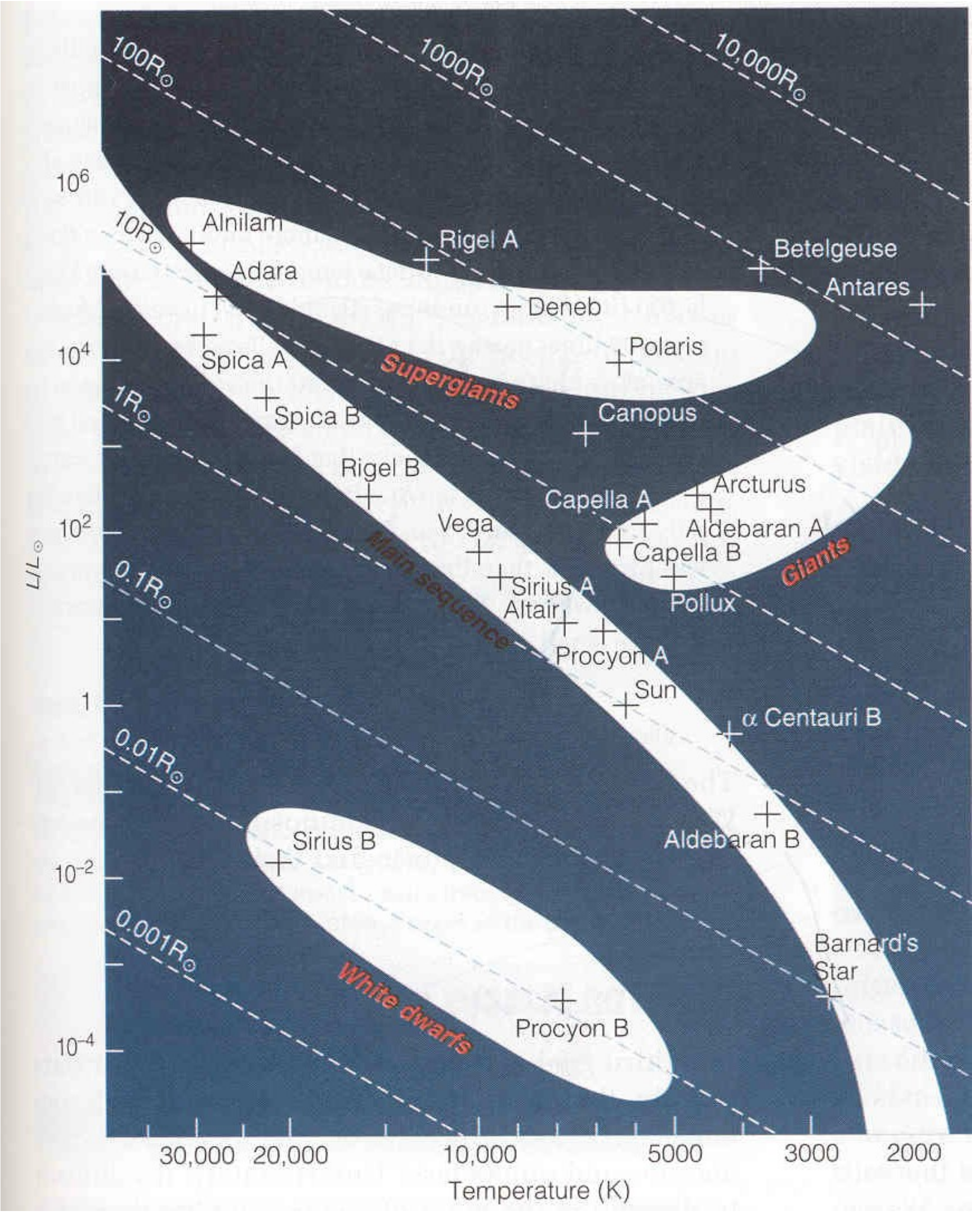
Figure 12–13 Occultation of a star by the Moon. As the limb of the Moon cuts in front of the star, a diffraction pattern appears before the light is completely cut out. The top scale is an angular one; the bottom, a linear one.

Measuring Stellar Diameters - II

- Michaelson Interferometer
  - Visibility of fringes falls as the interferometer resolves the star
  - Only a few stars near enough for ground-based measurements
  - Future space-based interferometers may provide considerably more
- Intensity Interferometer
  - Two “telescopes” used to correlate fluctuations in the number of photons.
  - Correlation falls if separation resolves star
  - Many stellar diameters have been measured via this technique

The Hertzsprung-Russell Diagram

- Stellar Atmospheres
  - Physical Characteristics
  - Temperatures
  - Spectral Line Formation
- Classifying Stellar Spectra
  - Spectral Classification Sequence
  - Temperature Sequence
- Hertzsprung-Russel Diagram
  - Magnitudes vs. Spectral Type
  - Magnitude vs. Color
  - Luminosity Classification
  - Elemental Abundance Effects
  - Distances and the H-R Diagram



Stellar Atmospheres

- Radiative Transfer of photons from deeper layers must be modeled
  - Scattering effects complicated
  - Given density profile temp, pressure vs. depth
- Spectral Line Formation
  - Given physical properties vs. depth Solve Boltzman and Saha Equations
    - Most of the atomic elements
      - » Requires huge list of ionization energies
      - » Requires huge list of spectral lines and transition probabilities
  - Compute strength and broadening for each line
  - Result is a model stellar atmosphere:
    - Fe and Fe+ line strength temperature sensitive.

What Causes the Stellar Spectral Sequence?

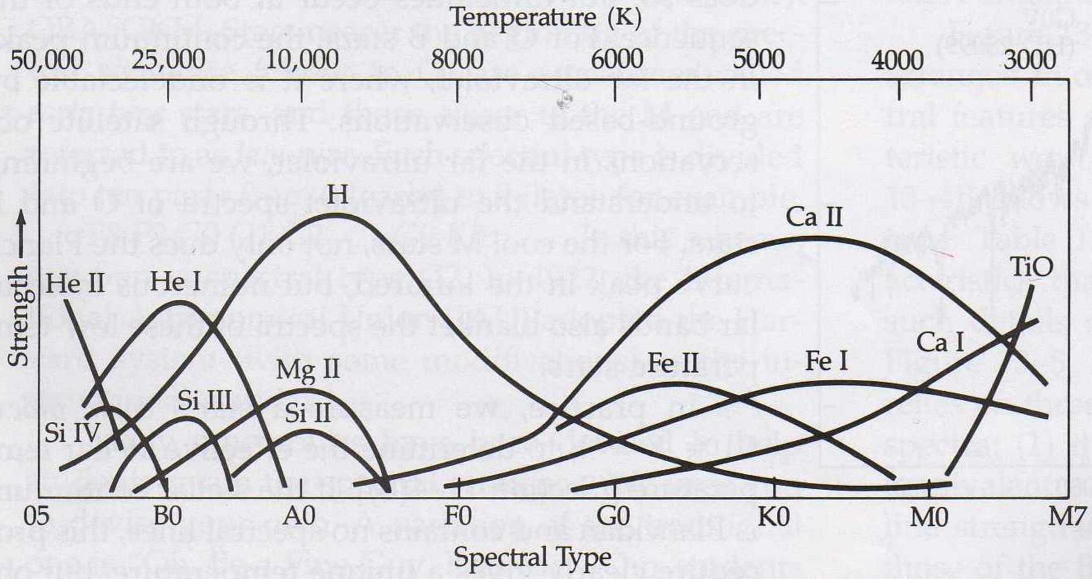


Figure 13–6 Absorption lines and temperature. The strengths (equivalent widths) of the absorption lines for various ionic species are shown as a function of stellar temperature. These changes result in ionization–excitation equilibria as described by the Boltzmann-Saha equation.

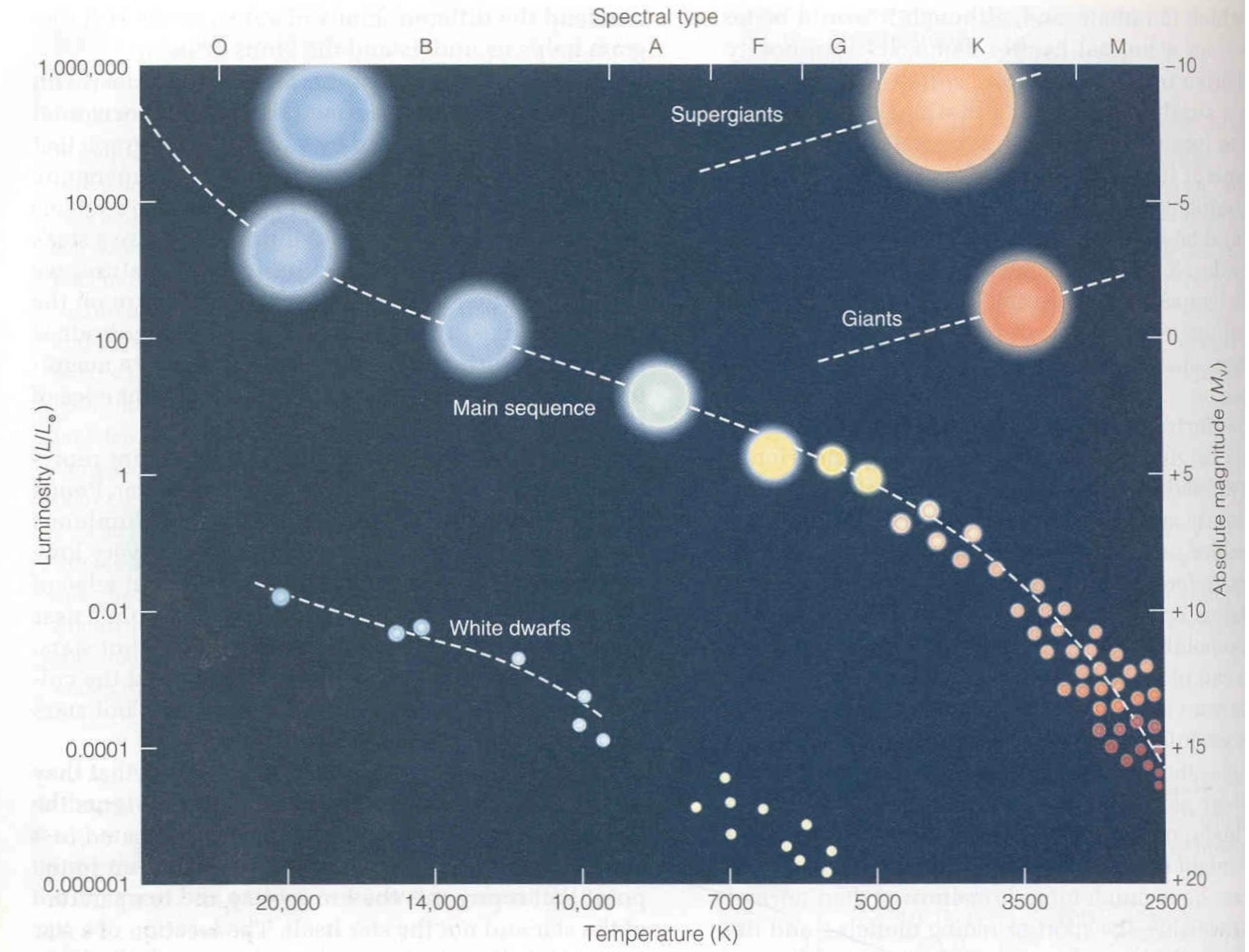
- Saha Equation models the ionization state of the atomic elements.
- Boltzman Equation describes the collisional excitation of each element/ion. Both depend on temperature and pressure.
- Atomic Physics describes the transition probabilities of each atomic level and strength of the corresponding spectral line.

Stellar Abundances

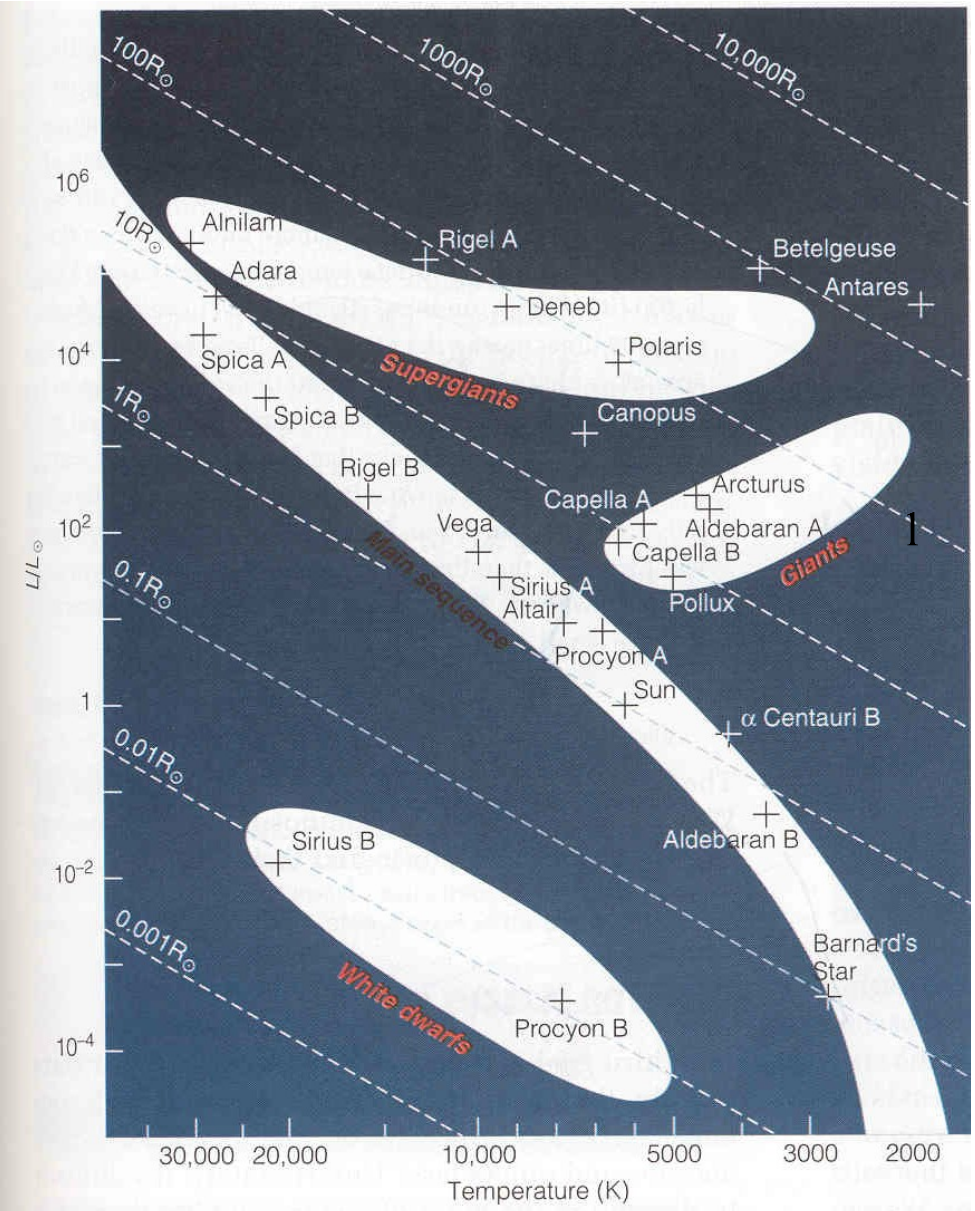
- Given an accurate stellar atmosphere model
  - Lines of individual ions are matched in a self-consistent way (Boltzman Equation).
  - All ionization states of an element summed to yield elemental abundance.
  - Abundance varied and the atmospheric model recomputed until lines are reproduced to yield elemental abundance.
  - Interpolation of grid of models (temp. vs. log g)

Hertzsprung-Russell (H-R) Diagram

- **Plot of Luminosity and Temperature of Nearby Stars Reveals H-R Diagram**
- **Most stars found on the main sequence.**
- **Giants and Supergiants**
- **White dwarfs**

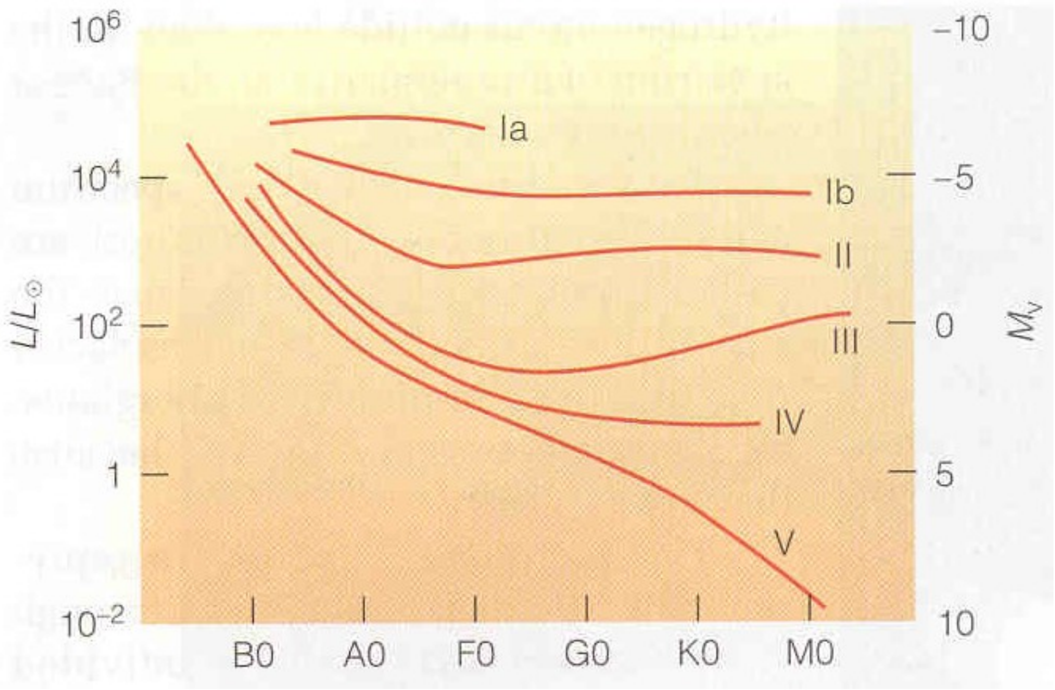


Lines of constant Radius in the H-R diagram



- Main sequence not quite constant R
  - $L = 4\pi R^2 \sigma T^4$
  - B stars: $R \sim 10\ R_{Sun}$
  - M stars: $R \sim 0.1\ R_{Sun}$
- Betelgeuse: $R \sim 1{,}000\ R_{Sun}$
  - Larger than 1 AU
- White dwarfs: $R \sim 0.01\ R_{Sun}$
  - A few Earth radii
- What causes the "main sequence"?
  - Why "similar" size, with R so tightly related to T?
  - Why range of T?
- Mass Sequence!

Luminosity Classes

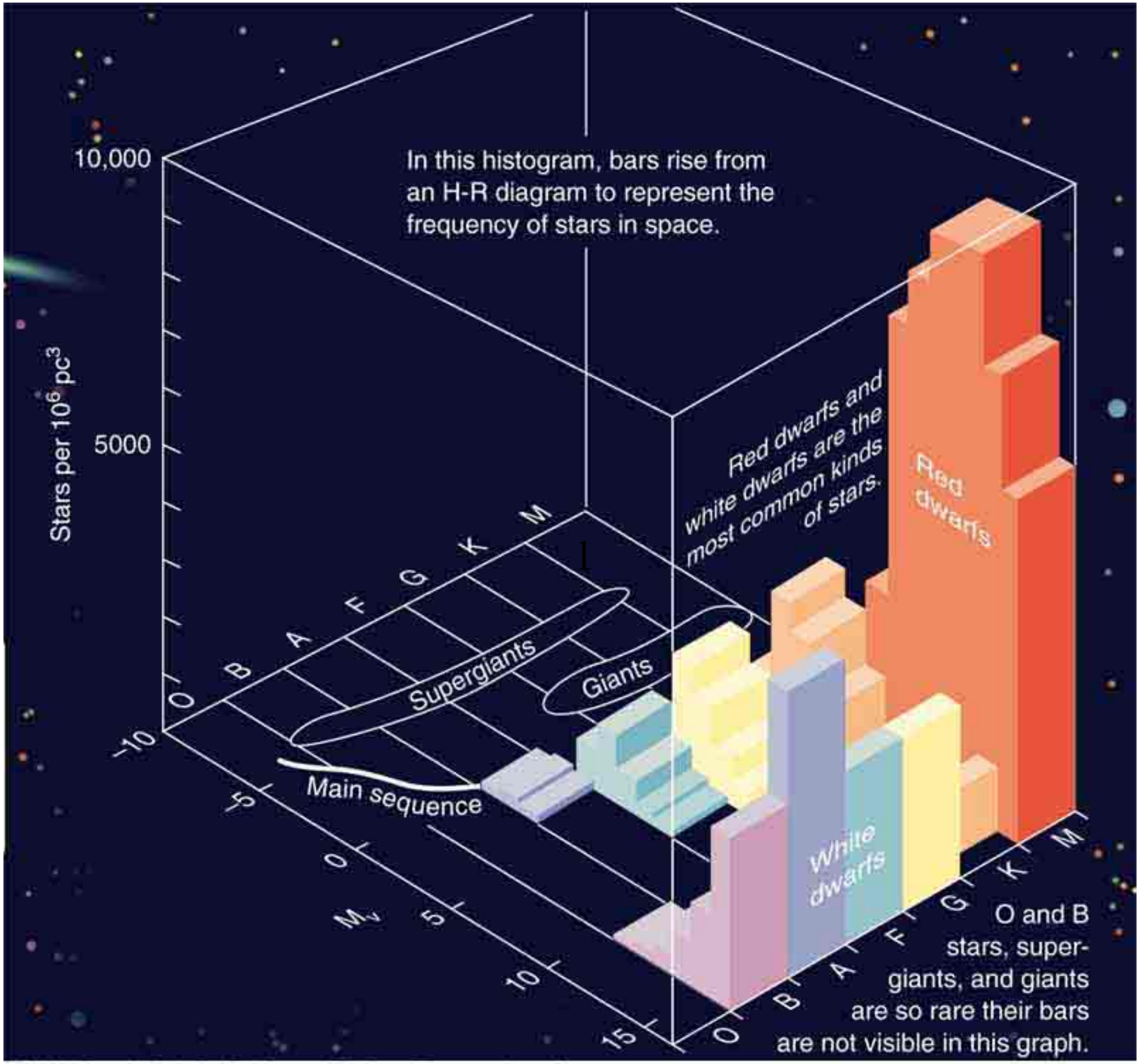


All Stars of Given Temp. Don't Have Same Luminosity

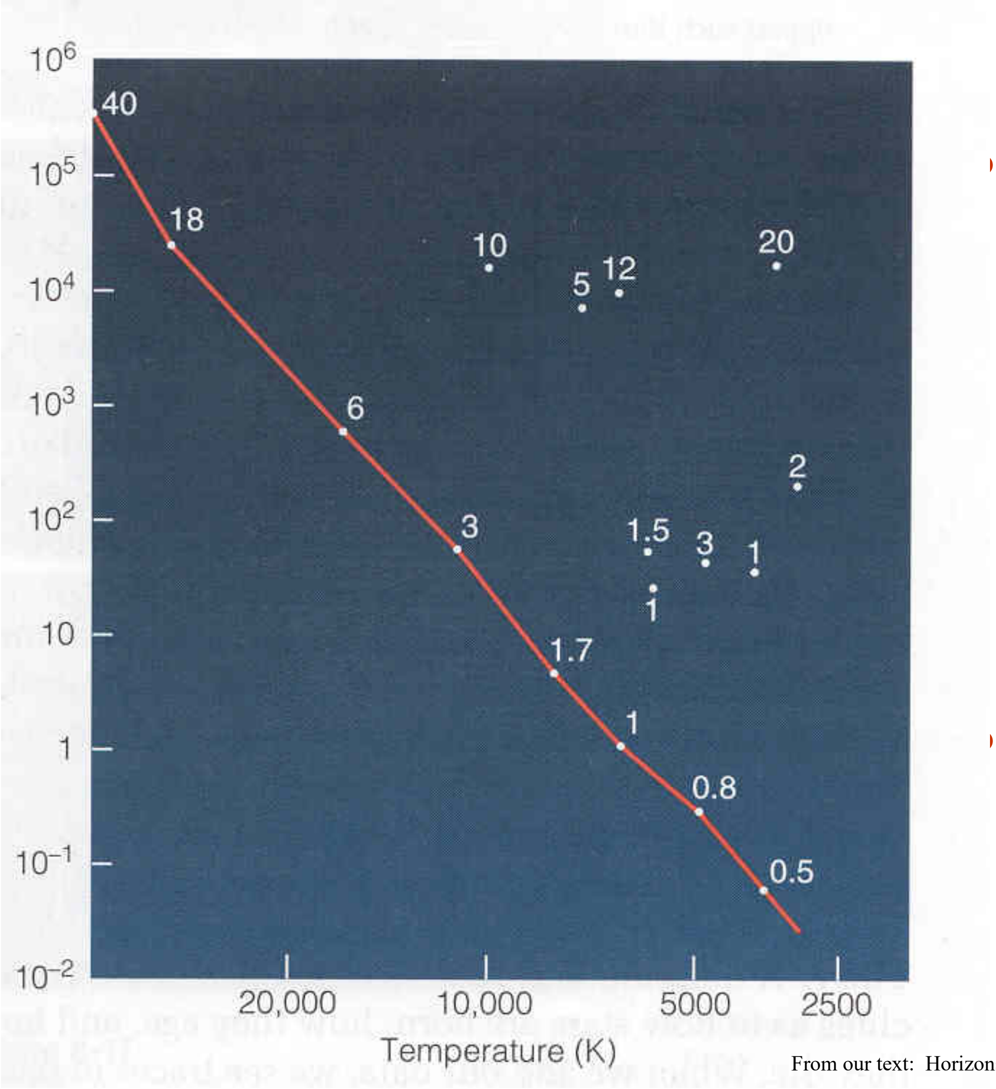
- Ia Bright supergiant
- Ib Supergiant
- II Bright giant
- III Giant
- IV Subgiant
- V Main sequence star

- white dwarfs not given a Roman numeral
- Sun: G2 V
- Rigel: B8 Ia
- Betelgeuse: M2 Iab

From our text: Horizons, by Seeds


10,000
5000
Stars per 10^6 pc^3
In this histogram, bars rise from an H-R diagram to represent the frequency of stars in space.
Red dwarfs and white dwarfs are the most common kinds of stars.
Red dwarfs
White dwarfs
O B A F G K M
Supergiants
Giants
Main sequence
1
−10
−5
0
M_V
5
10
15
O B A F G K M
O and B stars, supergiants, and giants are so rare their bars are not visible in this graph.

Masses and the HR Diagram



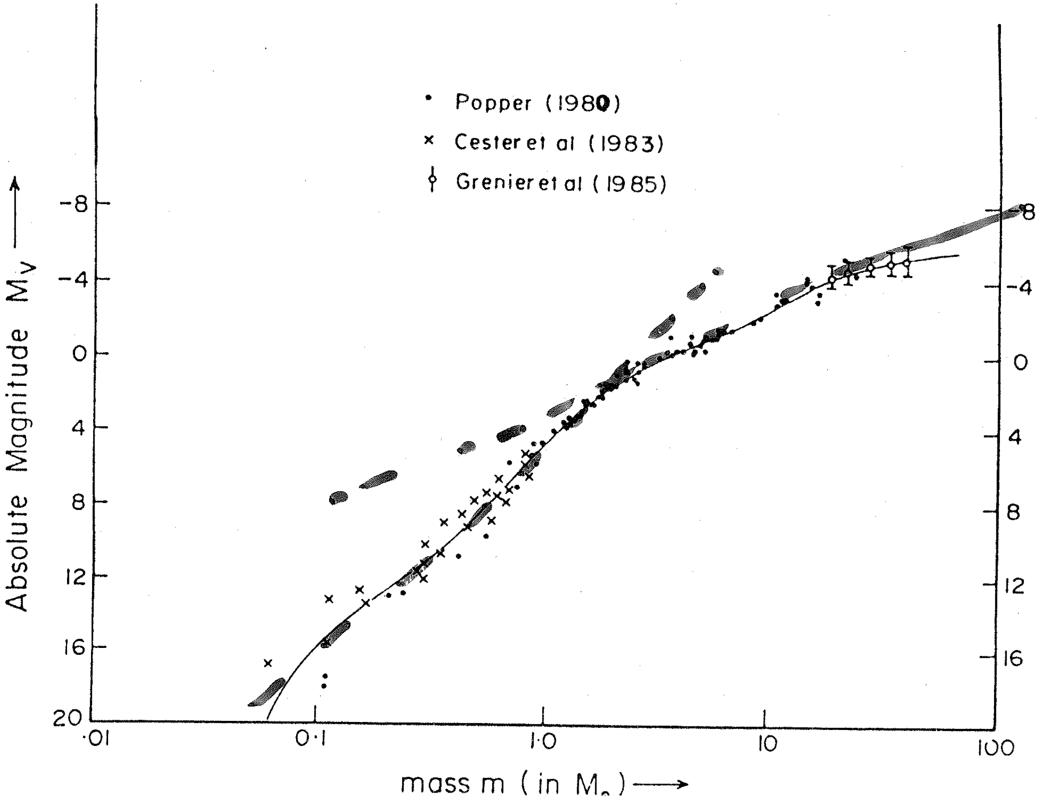
From our text: Horizons, by Seeds

- Main Sequence position:
  - M: 0.5 M_{Sun}
  - G: 1 M_{Sun}
  - B: 40 M_{sun}
- Luminosity Class
  - Must be controlled by something else

The Mass-Luminosity Relationship

- $L_{MS} = M^{3.5}$

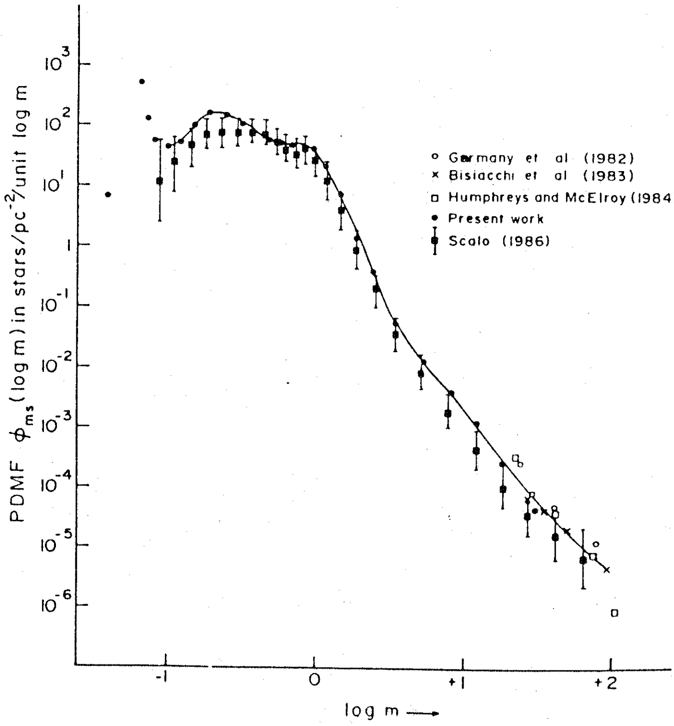
- Implications for lifetimes:
  10 M_{Sun} star
  - Has 10 × mass
  - Uses it 10,000 × faster
  - Lifetime 1,000 shorter

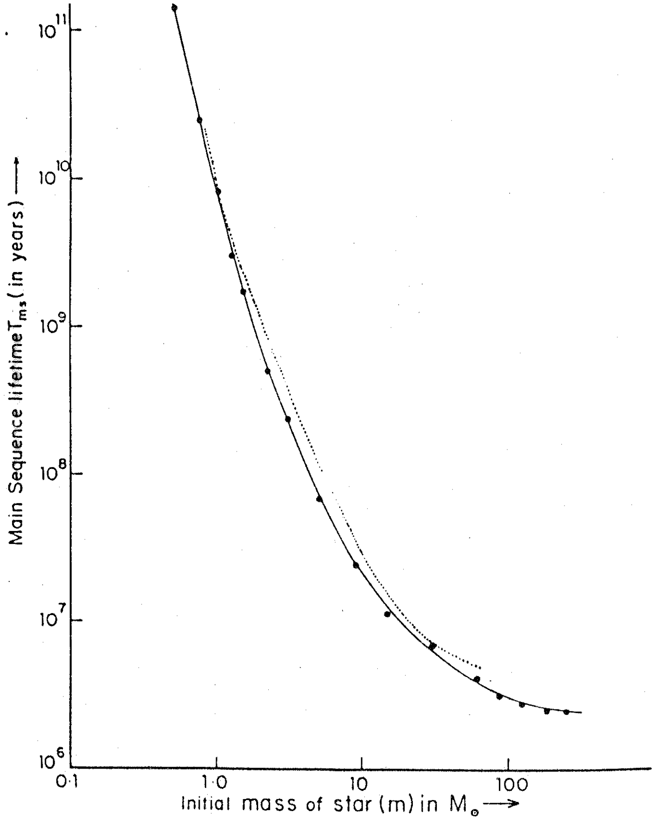


From our text: Horizons, by Seeds

Main Sequence Lifetime of Stars

- Stellar Census
  - Mass Function (# vs. Mass)
  - Luminosity Function [L vs. Mass (MS)]
- Stellar Interiors Models
  - Main Sequence Lifetime
  - Post-main sequence evolution
  - Evolutionary Tracks (cmd locus vs. time)





H-R Diagram of the Brightest vs. the Nearest Stars

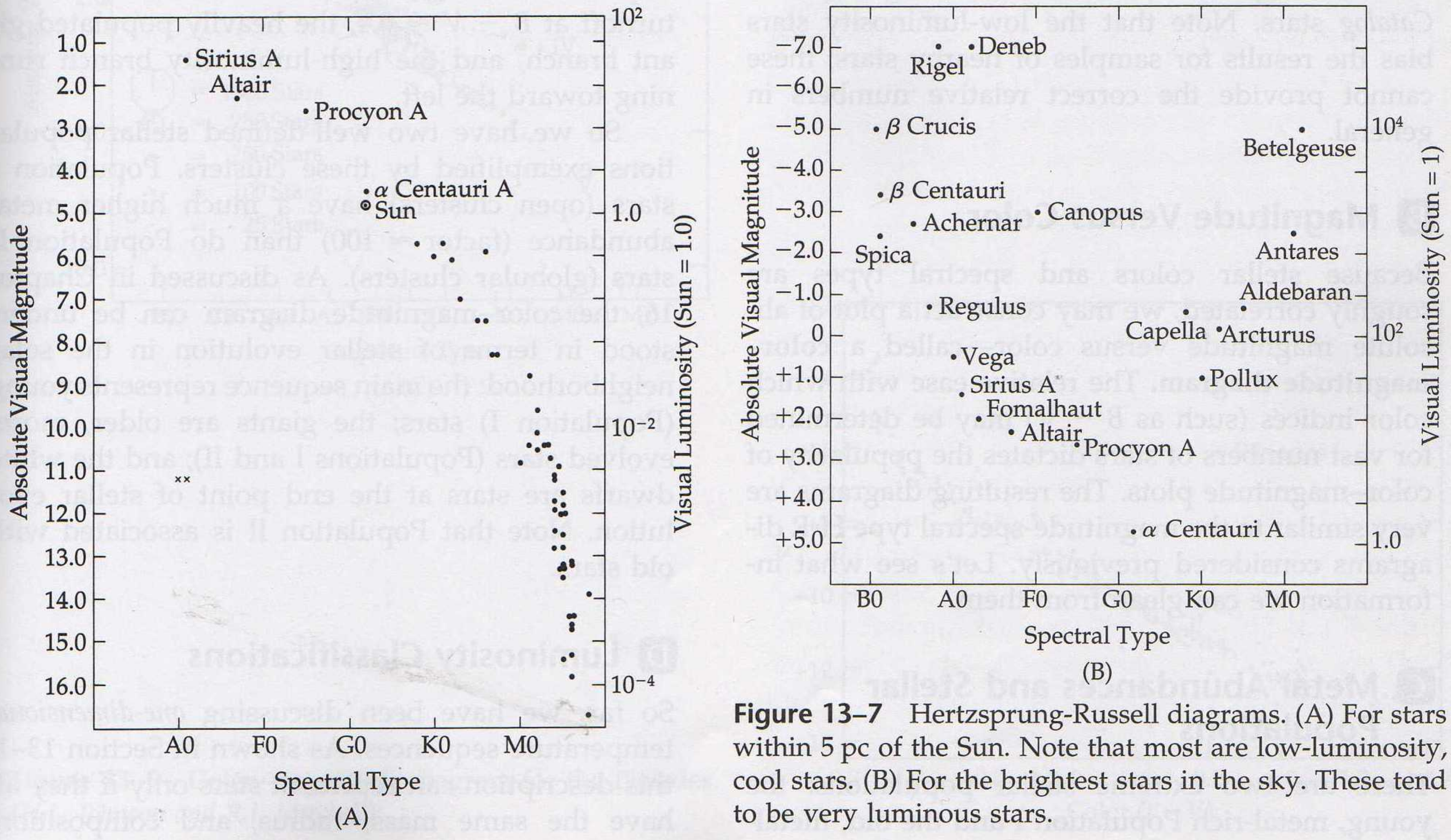


Figure 13–7 Hertzsprung-Russell diagrams. (A) For stars within 5 pc of the Sun. Note that most are low-luminosity, cool stars. (B) For the brightest stars in the sky. These tend to be very luminous stars.

References

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