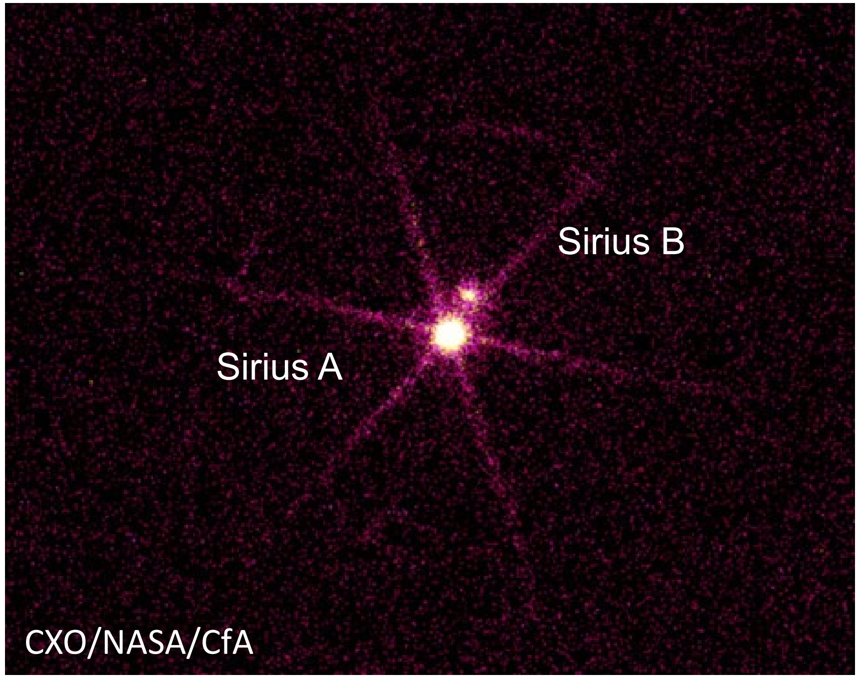
Today in Astronomy 241: normal binary stars

Review from ASTR 142:

- Measurement of the physical properties of stars.
- Stellar mass: the special role of binaries.
- The data: stellar luminosity, effective temperature, and radius *vs.* mass.
- **Groupwork**: derivation of formulas important in binary-star kinematics.

Reading:

- Carroll & Ostlie, chapter 7
- Mandel & Agol 2002, the current standard work on eclipsing stellar and exoplanetary systems.



Sirius, α CMa: at once the brightest, most famous, and most fruitful binary star system. One component isn't normal, though.

Stellar luminosity, mass and radius

Astrophysics is of course a fact-based discipline. What can we **measure**, to test theories of stellar structure?

- **Luminosity**: measure total flux at Earth at “all” wavelengths, and distance to star, *via* trigonometric parallax (e.g. from Gaia), or expanding cluster parallax.
- **Temperature**, from spectrum, which is more subtle than it sounds.
- **Radius** of isolated stars: Michelson-style stellar interferometry, e.g. at the Center for High Angular Resolution Astronomy (CHARA).
- **Mass**: measure speeds, sizes and orientations of orbits in multiple star systems, most helpfully in close **binary** star systems.
- Observations of **eclipsing** binary star systems can provide radius and temperature rather directly. So binary stars play a very special role in stellar astrophysics.
- For single stars: observation of stellar pulsation – **asteroseismology** – can be combined with good stellar structure models to yield radius and temperature. We’ll discuss this later in the course.

Binaries from which one gets useful mass measurements

Most normal stars turn out to be members of binary systems.

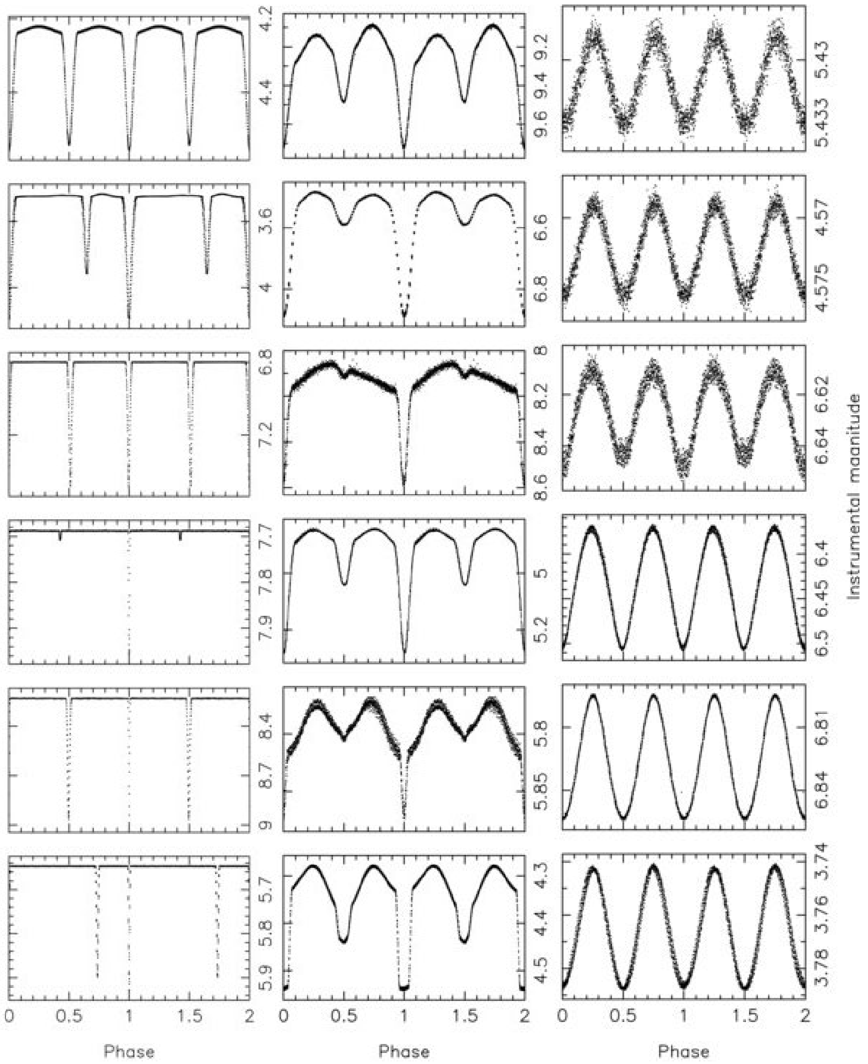
- Resolved **visual binaries**: see stars separately, measure orbital axes and speeds directly. There aren't very many of these.
- **Astrometric binaries**: only brighter member seen, with periodic wobble in the track of its proper motion.
  - This is a growing industry, driven by the results from Gaia.
- **Spectroscopic binaries**: unresolved (close) binaries told apart by periodically oscillating Doppler shifts in spectral lines. Periods = days to years.
  - Spectrum binaries: orbital periods longer than period of known observations.
  - Eclipsing binaries: orbits seen nearly edge on, so that the stars eclipse one another. (Most useful.)
  - Binaries for which the separation is clearly larger than the stars are called **detached**. In **semidetached** or **contact** binaries, mass transfer may have modified the stars.

Binaries (continued)

Kepler **light curves** – observed fluxes as functions of time – for eclipsing binaries:

- detached (left column),
- semidetached, (center), and
- contact (right).

From Prša et al. 2011.



Stellar masses determined for binary systems

- If orbital major axes (relative to center of mass) or radial velocity amplitudes are known, so is the ratio of masses:

$$\frac{m_1}{m_2} = \frac{a_2}{a_1} = \frac{v_{2r}}{v_{1r}}$$

- If the period, *P,* and the sum of major axis lengths, $a = a_1 + a_2$, are known, Kepler's third law can give masses separately:

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

Stellar masses determined for binary systems

- If only radial velocities are known, the sum of masses is too, from Kepler's third law:

$$m_1 + m_2 = \frac{P}{2\pi G}\left(\frac{v_{1r} + v_{2r}}{\sin i}\right)^3$$

- If orientation angle of orbit, *i*, is known, this allows separate determination of the masses.
    - That's why eclipsing binaries are so important: sin *i* is close to unity in such cases, so the stellar masses one derives from the measurements are very insensitive to the precise value of *i*.

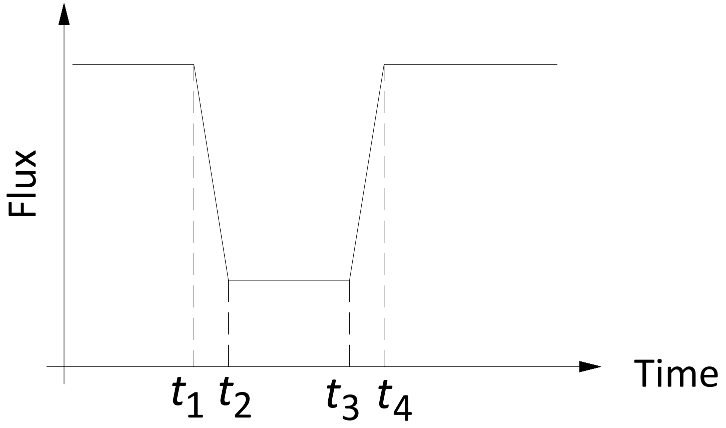
Radii and effective temperatures determined for eclipsing binary systems

The duration and shape of eclipse light curves can be used to determine the stars' radii. Thereby, *via* luminosity, one also gets the ratio of the stars' effective temperatures.

- **Very crudely**, assuming uniformly bright stellar disks, as in C&O chapter 7:

$$R_s = \frac{v_1 + v_2}{2}(t_2 - t_1) \quad \textbf{s}\text{maller star}$$

$$R_\ell = \frac{v_1 + v_2}{2}(t_3 - t_1) \quad \ell\text{arger star}$$

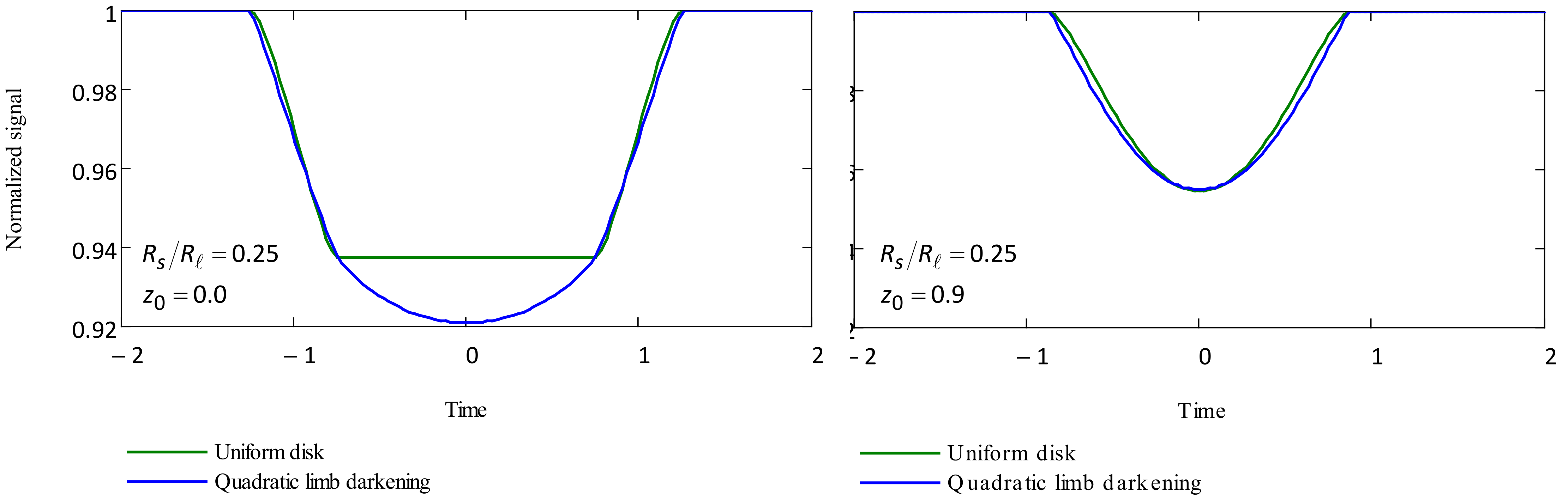


- Also **very crudely**, from the relative depth of primary (deepest) and secondary brightness minima of eclipses,

$$\frac{F_0 - F_{\text{primary}}}{F_0 - F_{\text{secondary}}} = \left(\frac{T_{e,s}}{T_{e,\ell}}\right)^4 \quad .$$

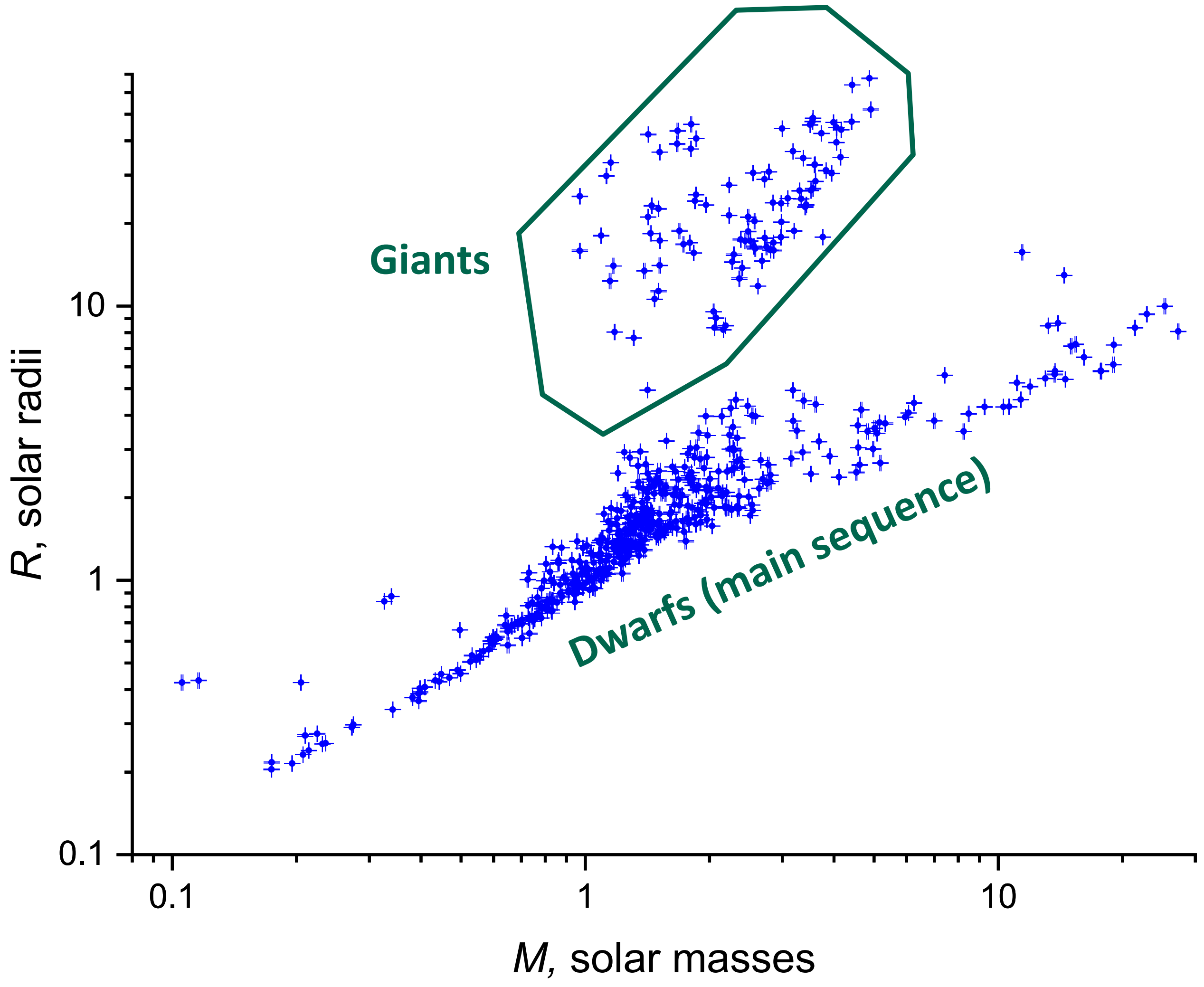
Radii and effective temperatures determined for eclipsing binary systems (continued)

- Crude won't do for very long here in ASTR 241. We will return to this topic when we have discussed the elements of radiative transfer in stellar atmospheres, and the topic of stellar **limb darkening**.



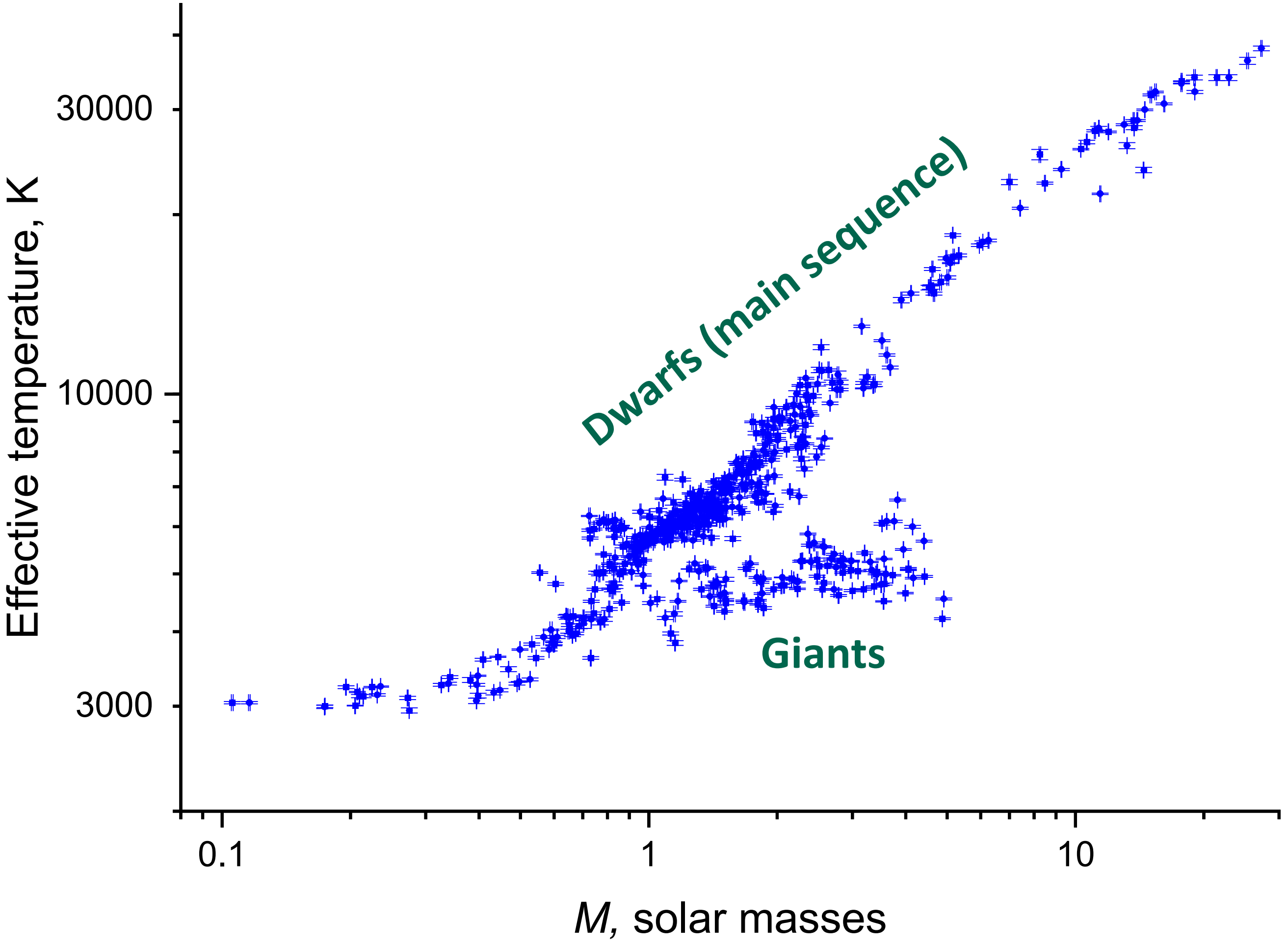
Primary eclipse light curves, comparing "crude" to quadratic limb darkening as in Mandel & Agol 2002.

Radii of eclipsing, detached binary stars



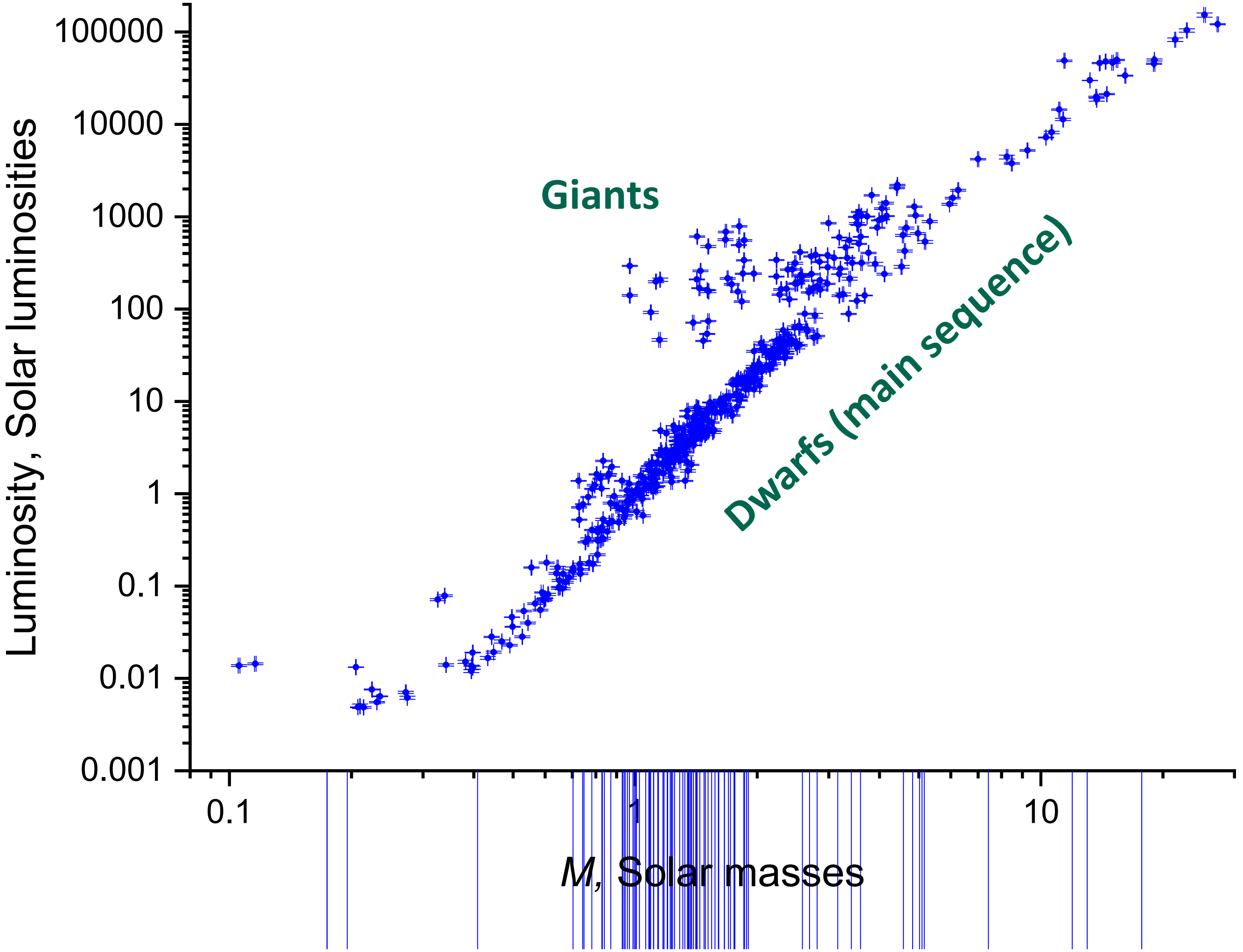
Data from John Southworth's online database.

Effective temperatures of eclipsing, detached binary stars



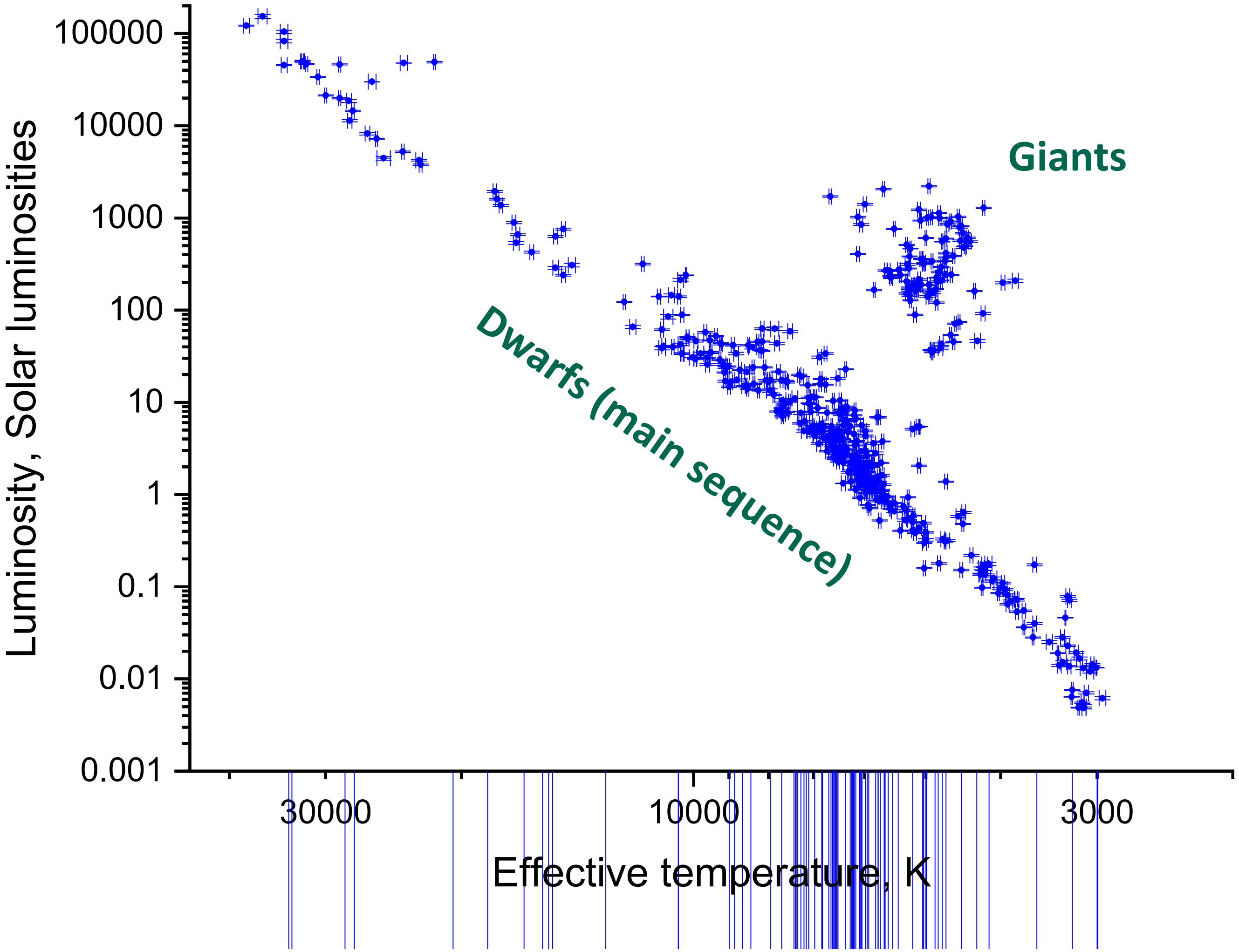
Data from John Southworth's online database.

Luminosities of eclipsing, detached binary stars



Data from John Southworth's [online database].

H-R diagram for eclipsing, detached binary stars



Data from John Southworth's online database.

Today's in-class problems

- C&O problem 7.1. Recall also the polar-coordinate expression for an ellipse, $r = a\dfrac{1-\varepsilon^2}{1+\varepsilon\cos\eta}$.

- C&O problem 7.2. You are allowed to look up the integral, but it's easy to integrate by parts.

Brief solutions provided in next class's handout.