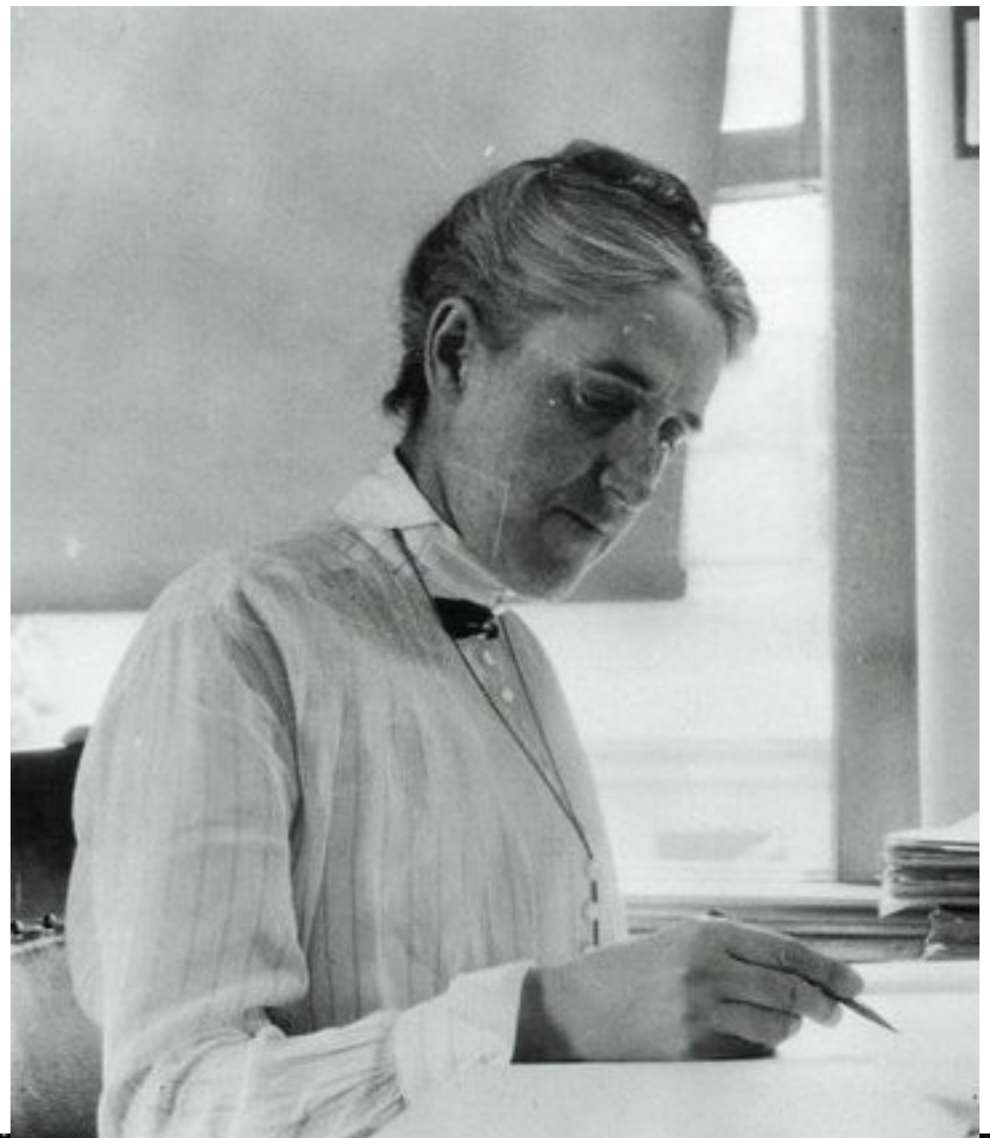
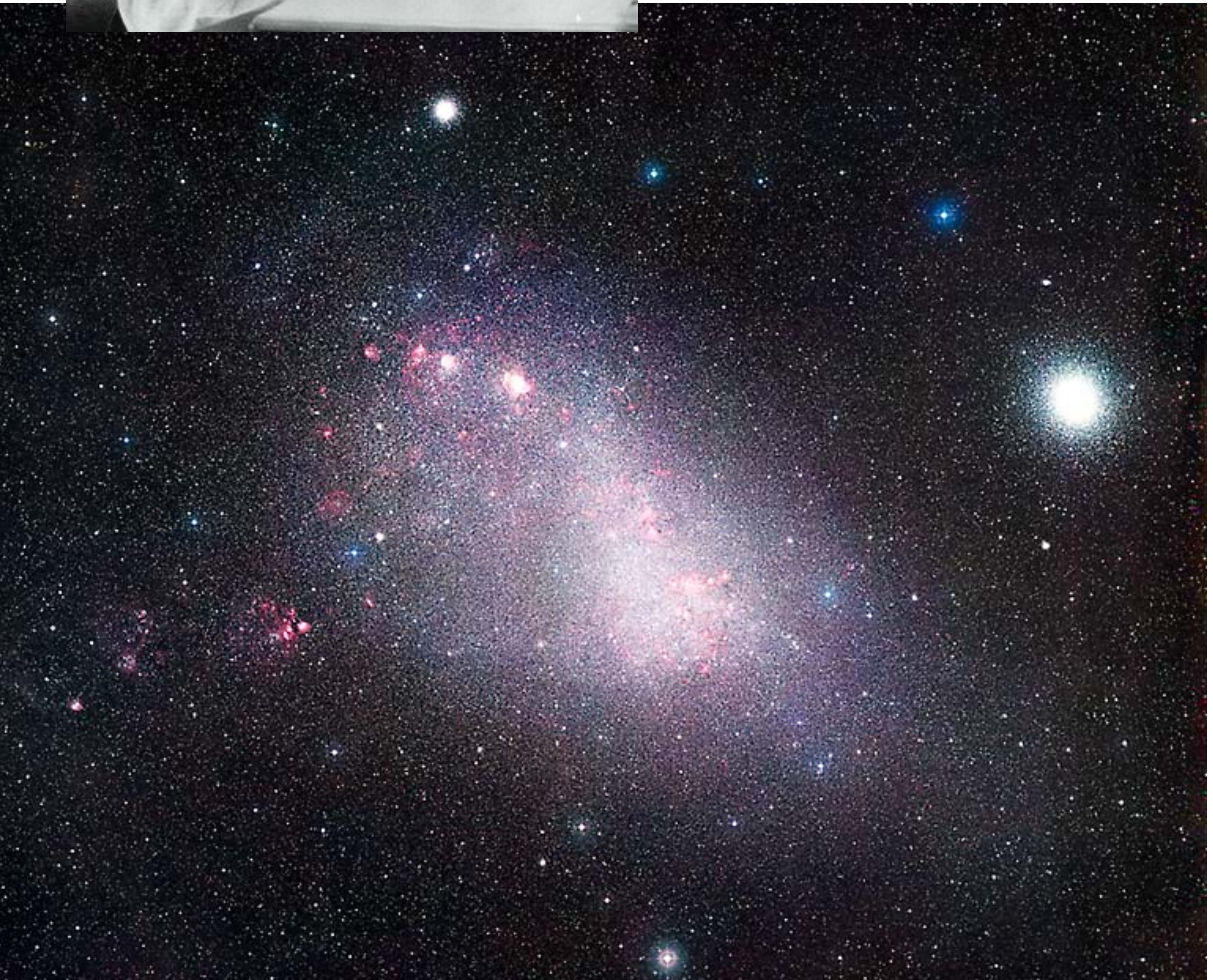
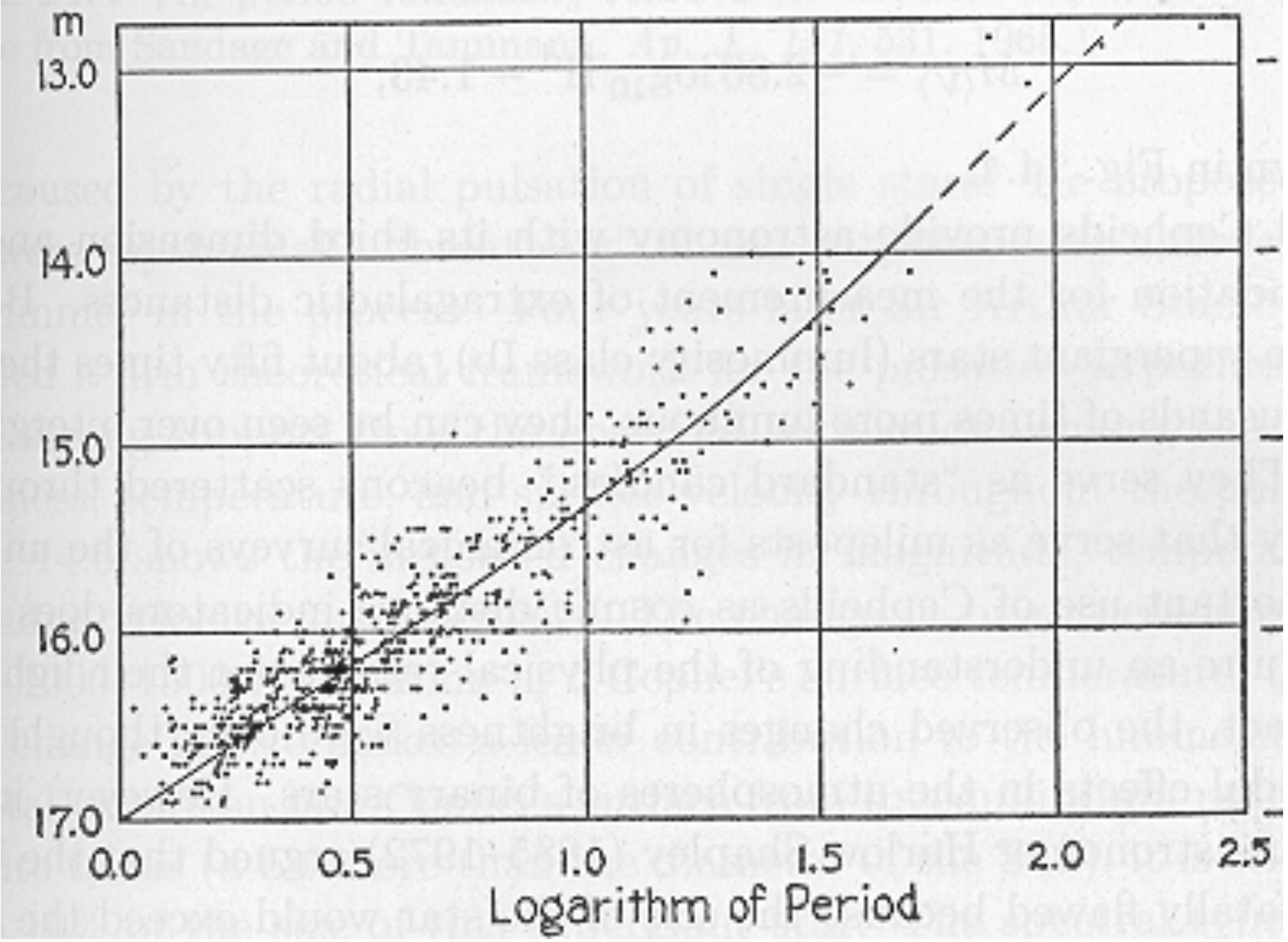
Pulsating Variable Stars



Henrietta Leavitt



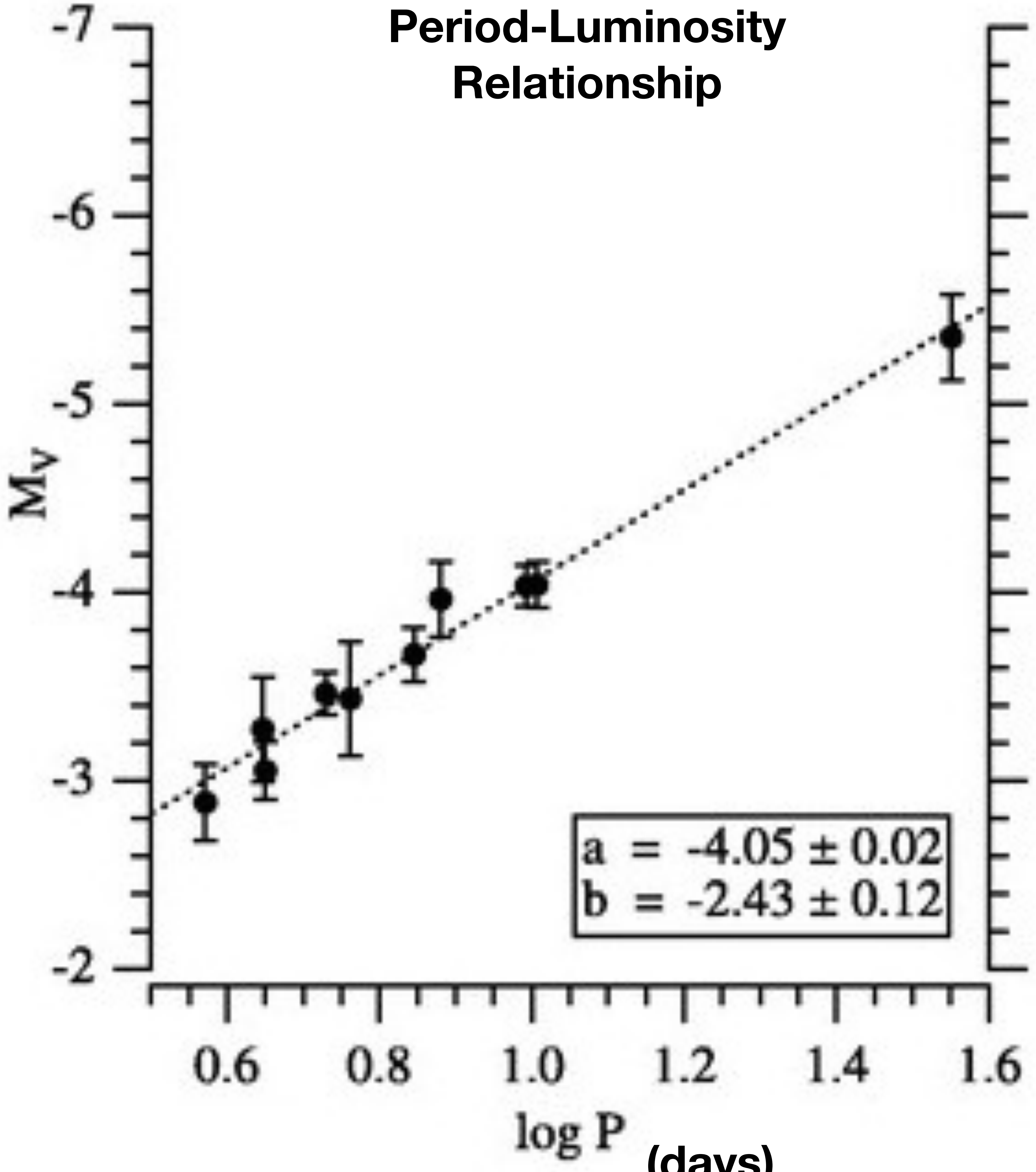


Why might this relationship be useful for measuring distances?

$$m - M = 5 \log d - 5 + A$$

Cepheid Variable Stars

Cepheid Period-Luminosity Relationship



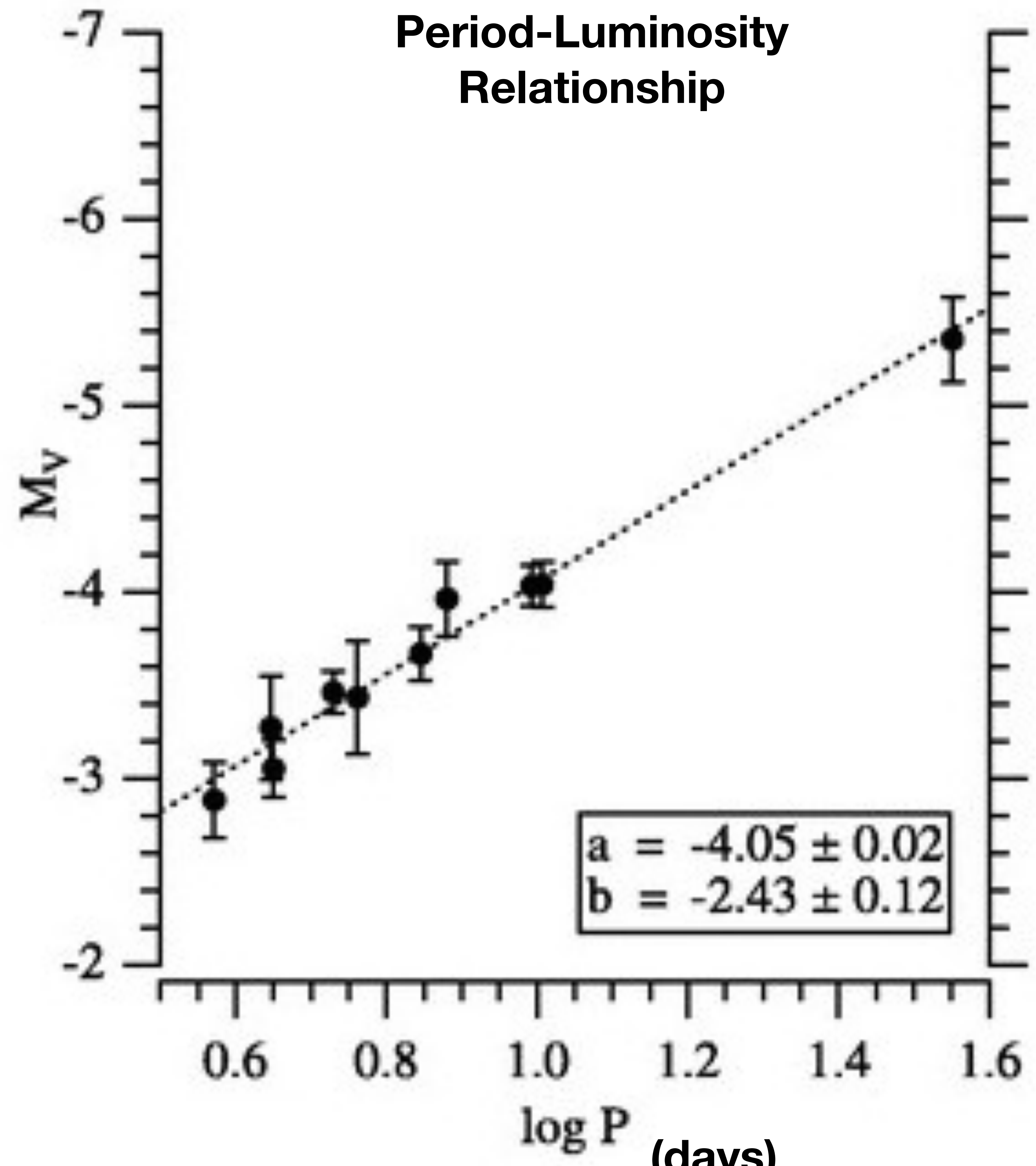
$$M_V = -2.43 \log P - 1.62$$

Cepheid variables in Milky Way

How do we get absolute magnitude to calibrate this relationship?

Cepheid Variable Stars

Cepheid Period-Luminosity Relationship



(days)

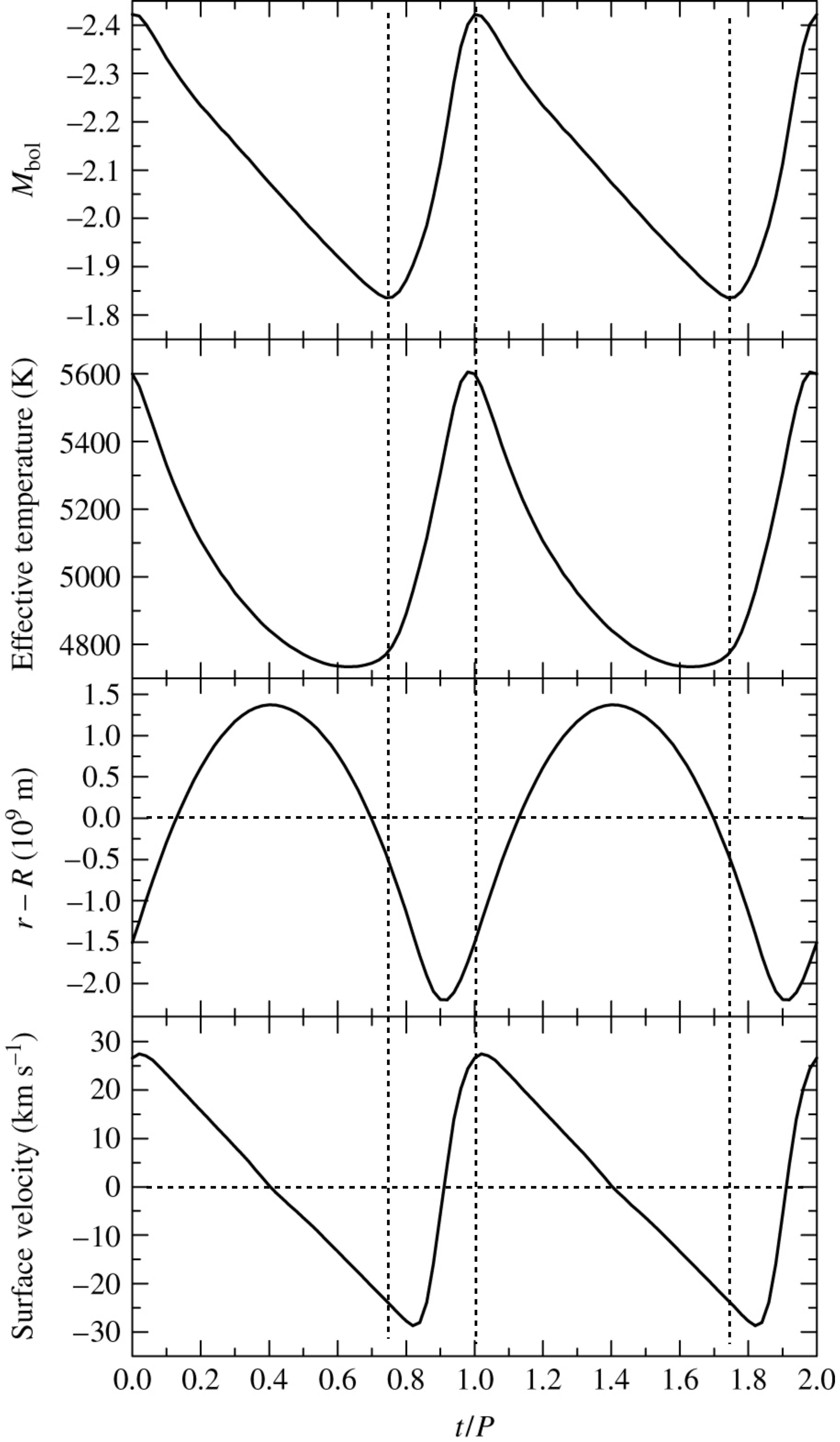
$$M_V = -2.43 \log P - 1.62$$

Cepheid variables in Milky Way

How do we get absolute magnitude to calibrate this relationship?

Pros:
- Cepheids are 1000x brighter than the Sun
- Underlying physics pretty well understood

Cons:
- Massive stars, so short-lived -> rare
- Period also dependent on chemical composition



abs mag

temperature

star radius

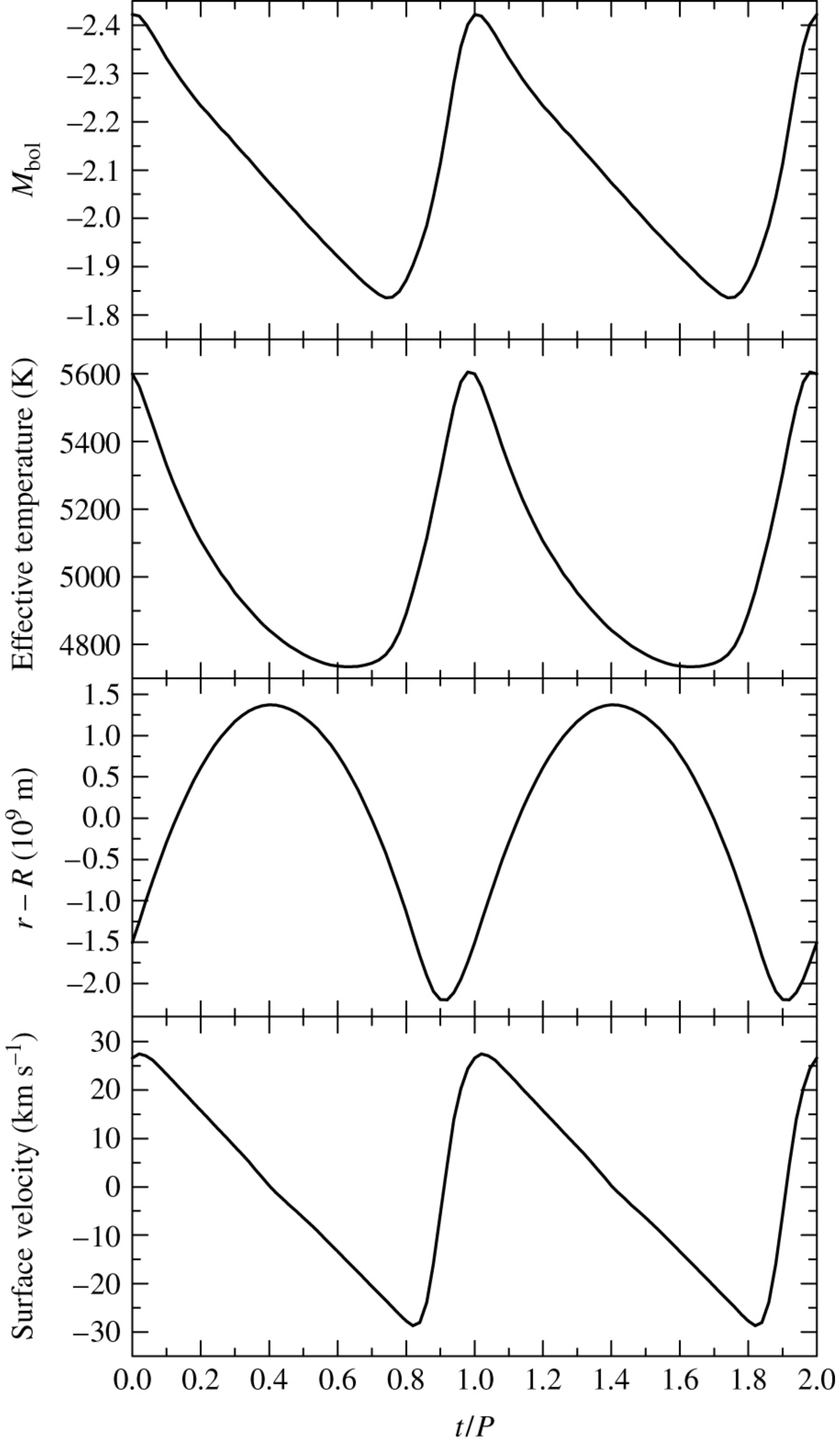
radial velocity

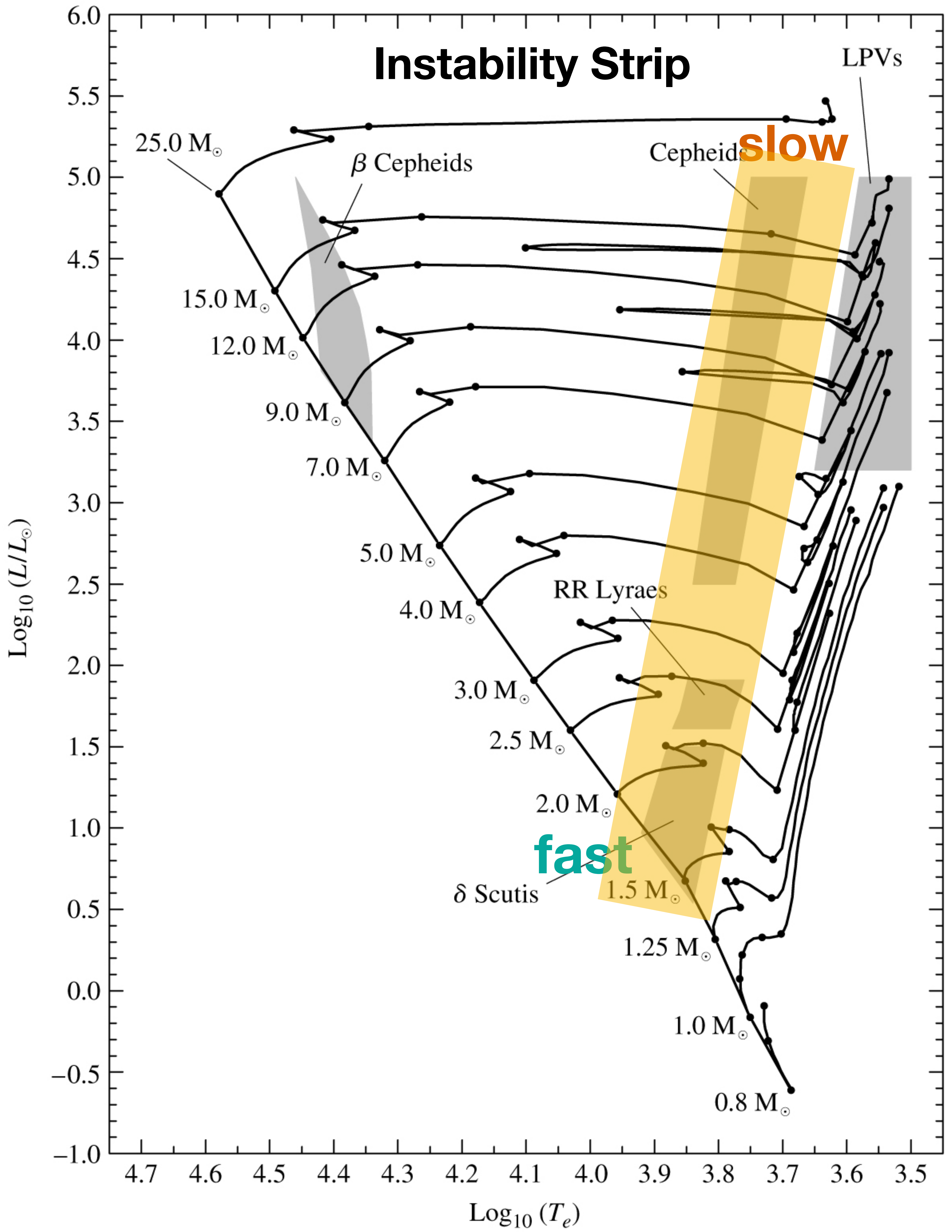
abs mag

temperature

star radius

radial velocity



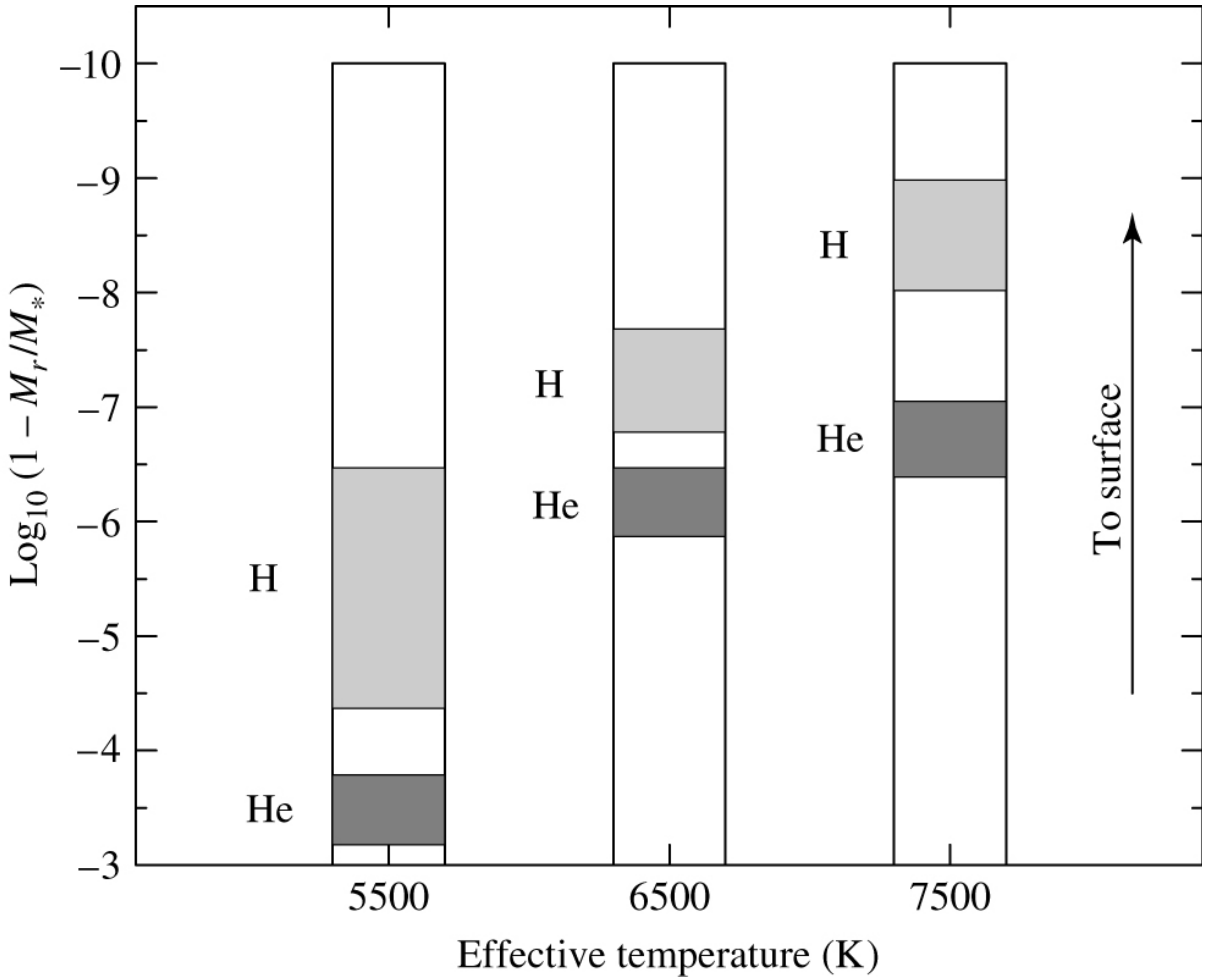


Why do stars pulsate?

Let's look at a normal star and squeeze it (a radial perturbation)
- density and temperature and pressure increase
- star "rebounds" and expands. But it will overshoot (like a swing) and go past equilibrium
- now density and temperature and pressure are too low, so the star will fall back
- etc

Okay, but we have ignored the role of opacity. In a normal star, when temperature increases, opacity decreases. So when we squeeze the star and it heats up, more of the stars heat can flow out of the star, relieving the excess pressure. Similarly when the star expands and temperature drops, more of the heat gets bottled up inside the star keeping it from collapsing back to far.

Opacity stabilizes stars against radial oscillations.



Under special conditions, however, opacity can work in the opposite direction.

Take a portion of a star where Helium is singly ionized. If the temperature rises, the Helium can become doubly ionized. So a temperature increase results in much of the radiative energy being absorbed during ionization. In a helium ionization zone, opacity rises as temperature rises.

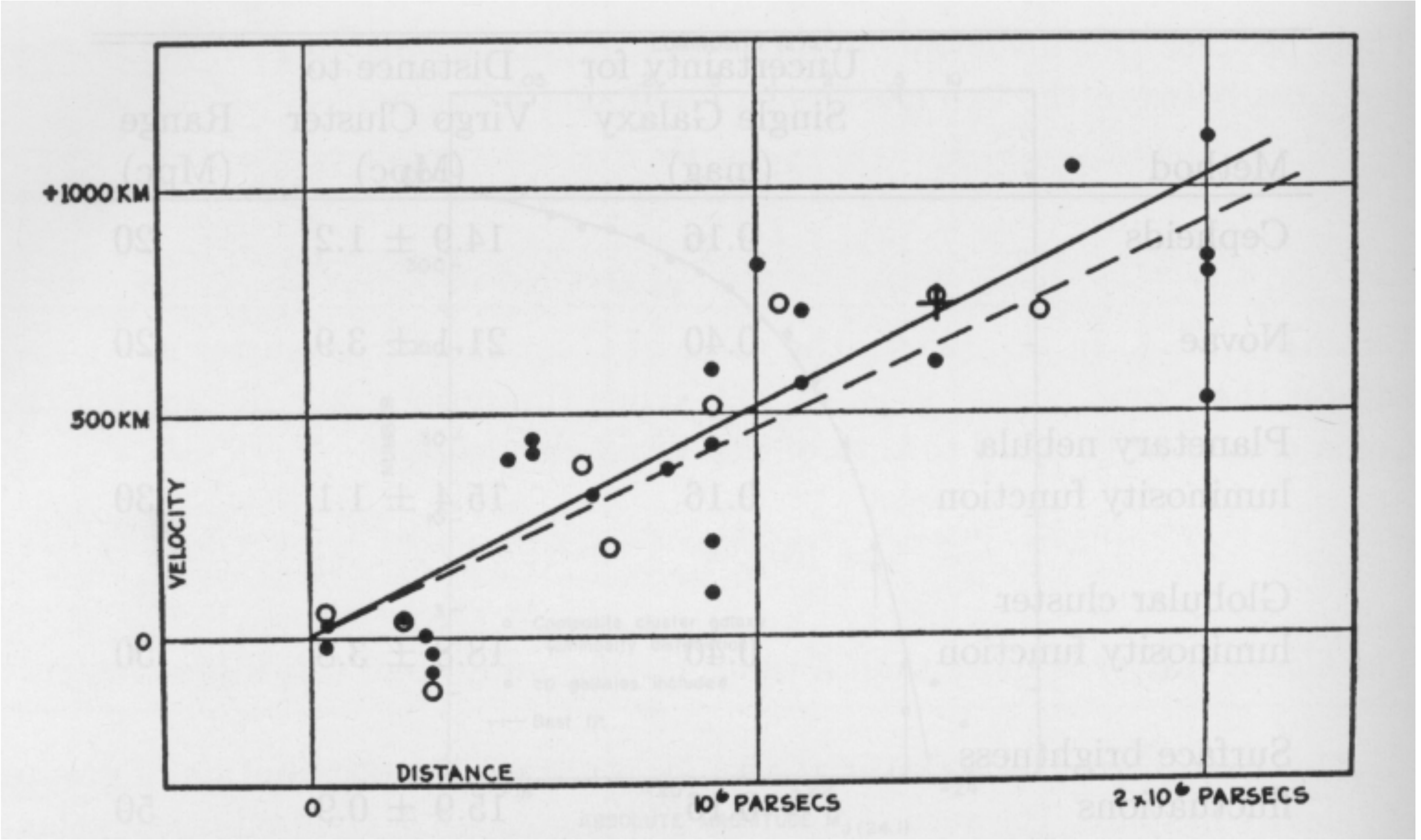
Now squeeze the star:

- density and temperature and pressure increase
- helium absorbs the energy in ionization
- excess pressure can only be relieved via expansion -- and the star will now overshoot
- density, temperature, and pressure decrease
- helium recombines, opacity decreases
- lack of thermal pressure is enhanced, as energy flows out of the star more easily.
- star falls back too far
- etc

The oscillation continues, driven by the helium ionization.

If stars are too cool, helium ionization occurs too far inside the star. If stars are too hot, helium ionization occurs too close to the surface. In the instability strip, the conditions are just right to drive the oscillation.

In the 1920s and 1930s, **Edwin Hubble** was studying the distances and velocities of galaxies. He noticed an amazing thing: distances and velocities are correlated:



In other words, *the Universe is expanding!* For now, ignore the *stupefying* physical meaning behind this, and realize that Hubble's Law can be written

$$V_r = H_0 d \text{ (for } V_r \ll c)$$

In other words, if we can determine H_0, then all we need to do is measure the radial velocity of a galaxy and we know its distance. How much simpler can you get?

Problem #1: what else (besides expansion) could affect the velocity of galaxies?
Problem #1a: For a given galaxy, how much of its velocity is really due to expansion?
Problem #1b: We live near a big galaxy cluster (Virgo).

Problem #2: we need to determine H_0 (in km/s/Mpc).
How do we do this? We need to know the absolute distances of a large sample of galaxies at large distances. This is hard! But if we can calibrate any of the previous techniques locally, and then use them to get distances to distant galaxies, it can be done.

A modern Hubble plot (from the HST Key Project team).

Best current estimate comes from using the Hubble Space Telescope to calibrate a whole set of distance indicators in more distant galaxies; these studies get H_0=72 +/- few km/s/Mpc.