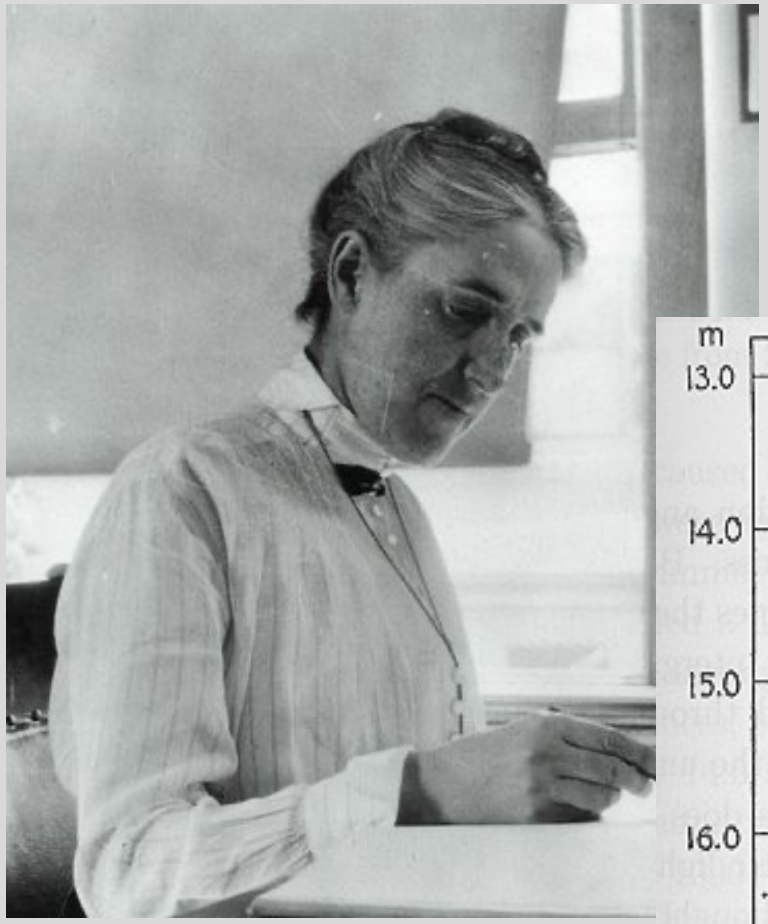
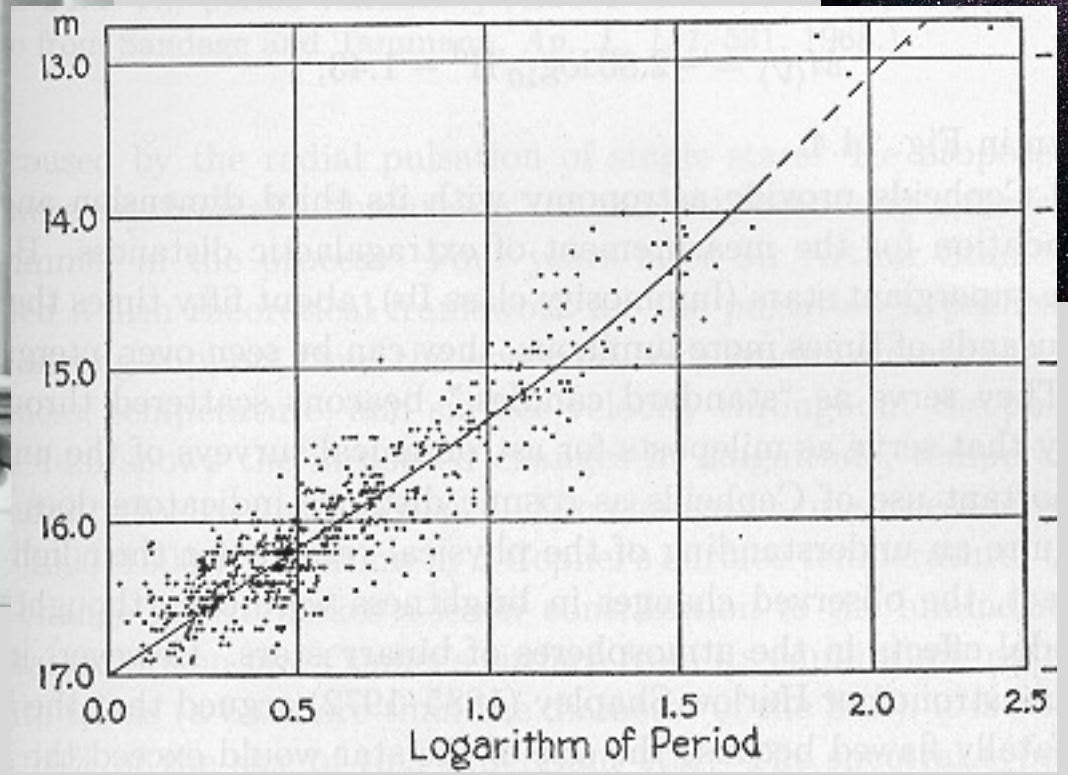
Pulsating Variables: Cepheids and RR Lyraes

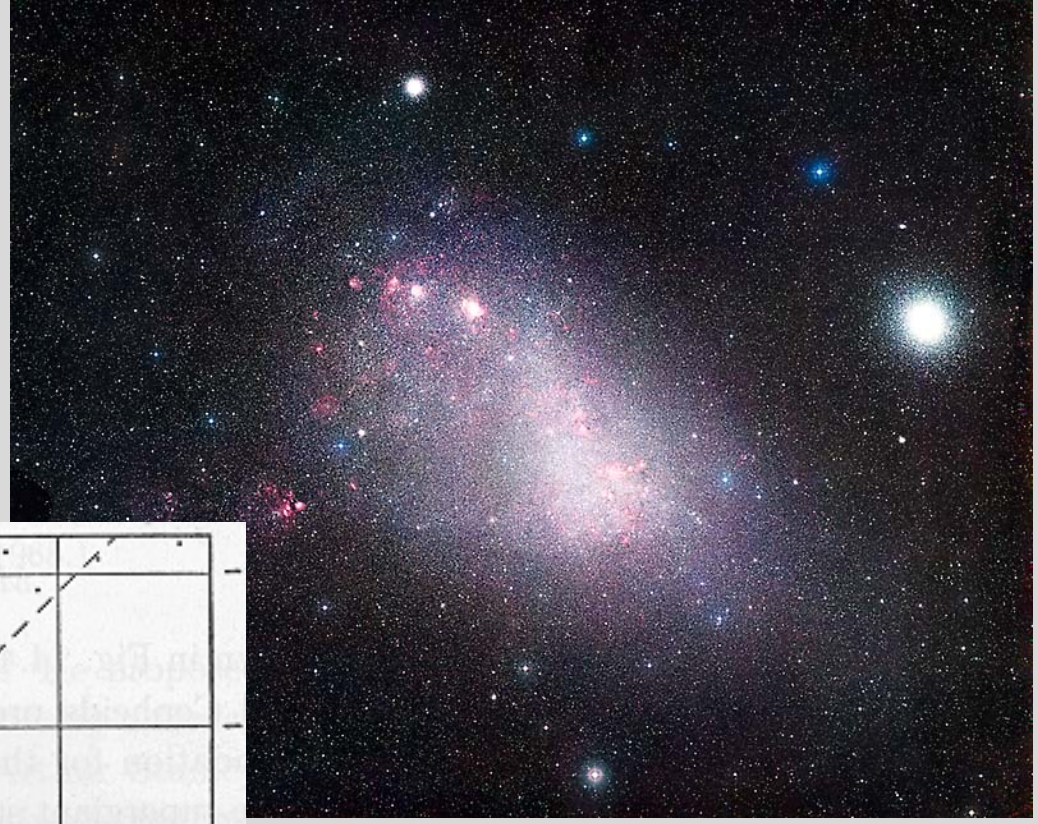


Henrietta Leavitt (1868-1921)

Cepheids in the SMC



apparent mag (m_{pg}) versus log(P)



Small Magellenic Cloud

Since all these stars are at roughly the same distance, this must be a period-luminosity relationship.

If we can calibrate it. We need absolute distances.

Pulsating Stars

As stars evolve off the main sequence, at certain phases their internal structure (temp, pressure, density) makes them unstable to radial oscillations.

This occurs on the instability strip on the HR diagram. (grey shaded regions)

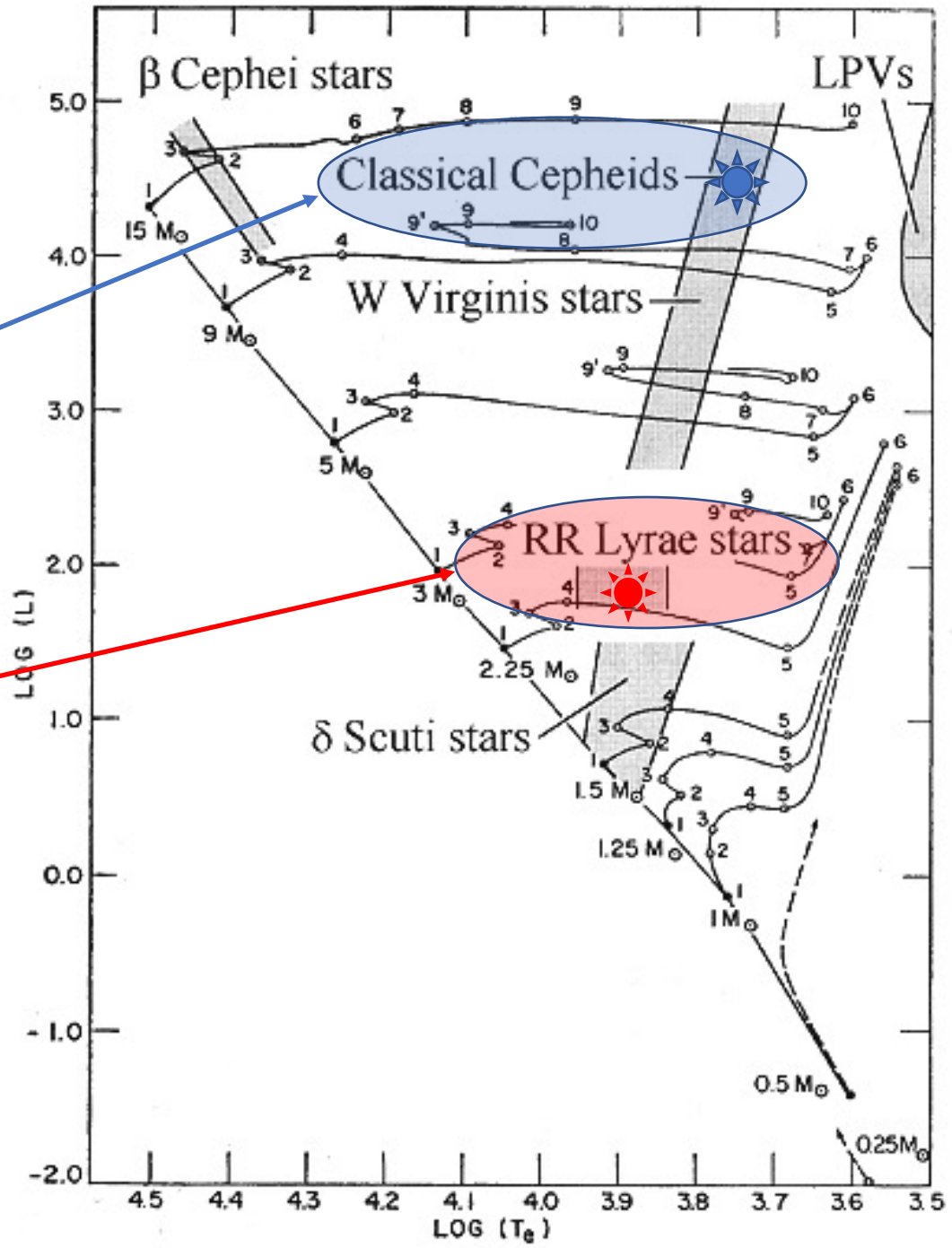
Cepheids: high mass stars ($\gtrsim$8–10 $M_\odot$)

Luminous, easy to see. But rare. Traces young populations.

RR Lyraes: low mass stars ($\approx$ few $M_\odot$)

More common, but fainter. Traces old populations.

Very challenging to get direct distances to these kinds of stars. Because they are rare, there aren't many nearby, so hard to get parallaxes to work out distances and absolute mags.



Getting Distances

We see Cepheids and RR Lyraes in large numbers in the LMC and SMC. If we had distances to those galaxies, we could then calibrate the P-L relationship and have a powerful distance estimating tool.

But:

- Metallicity effects (it may actually be a period-luminosity-metallicity relation for these stars)
- Uncertain reddening (particularly for Cepheids which may still be near their original star-forming region)
- Rare objects means none are close enough to get ground-based parallaxes, which makes it hard to calibrate their absolute magnitudes.

Two ways to get direct distances to these stars and do the absolute magnitude calibration!

Small Magellenic Cloud

Large Magellenic Cloud

Pulsating Stars

How we know they pulsate: we *see* the velocity of absorption lines in the photosphere changing across the cycle.

When the star is smaller, it is hotter.

Since $L = 4\pi R^2 \sigma T^4$, the temperature increase ($\nearrow T^4$) beats the radius decrease ($\searrow R^2$), and so it is more luminous when it is smaller.

Properties along the pulsation phase

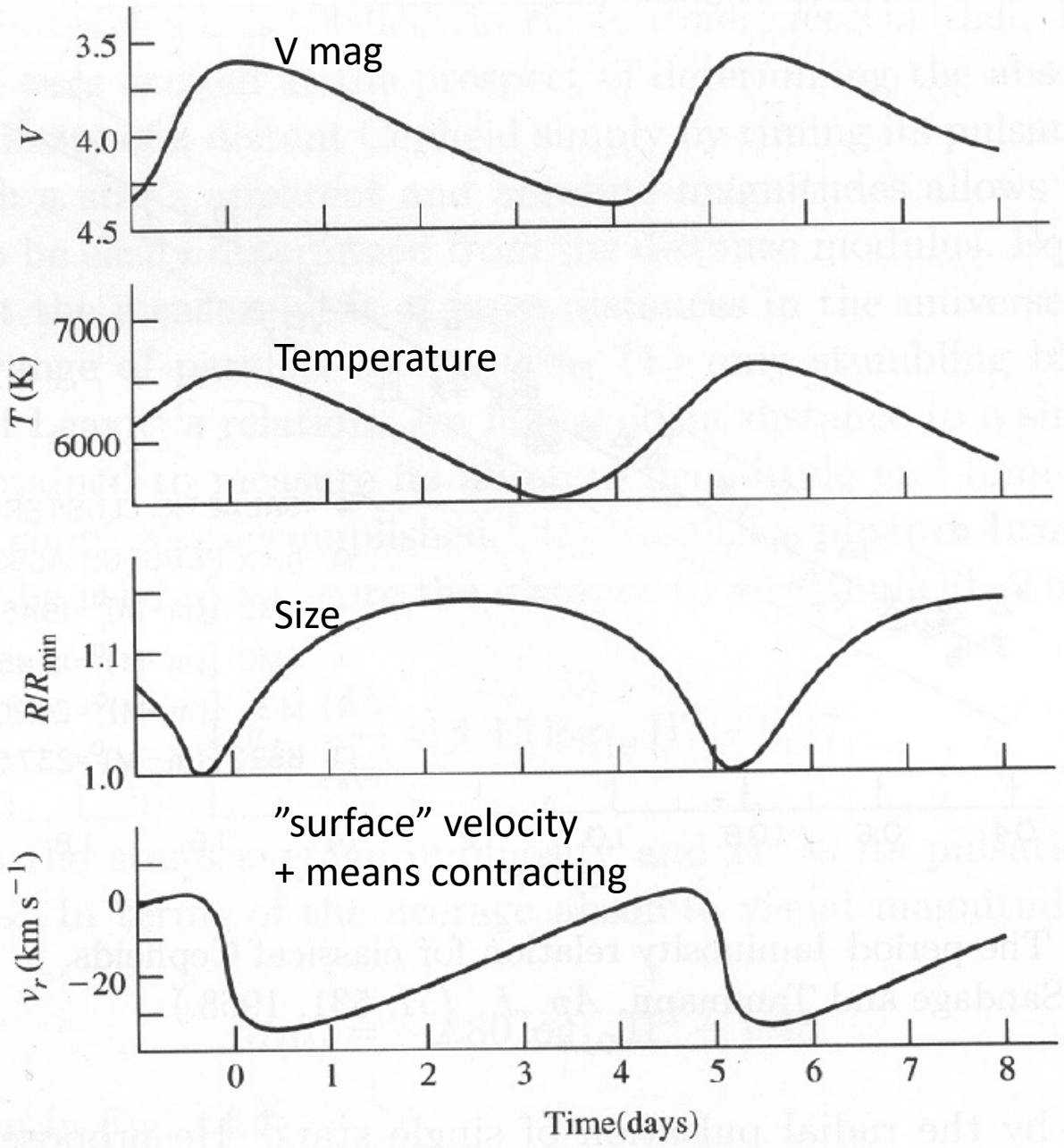


Figure 14.5 Observed pulsation properties of δ Cephei.

Pulsating Stars: Baade-Wesselink Distances

Since $L = 4\pi R^2 \sigma T^4$, the difference in apparent magnitude and temperature along the phase gives us the ratio of radii: R_{max}/R_{min}.

But if we integrate the radial velocity curve over time, we know the difference in size:

$$R_{max} - R_{min} = \int_{t_{min}}^{t_{max}} v_r \, dt$$

Having both R_{max}/R_{min} and $R_{max} - R_{min}$ means we can solve for radius.

Then $L = 4\pi R^2 \sigma T^4$ gives us luminosity, and the combination of luminosity and apparent magnitude gives us distance.

Properties along the pulsation phase

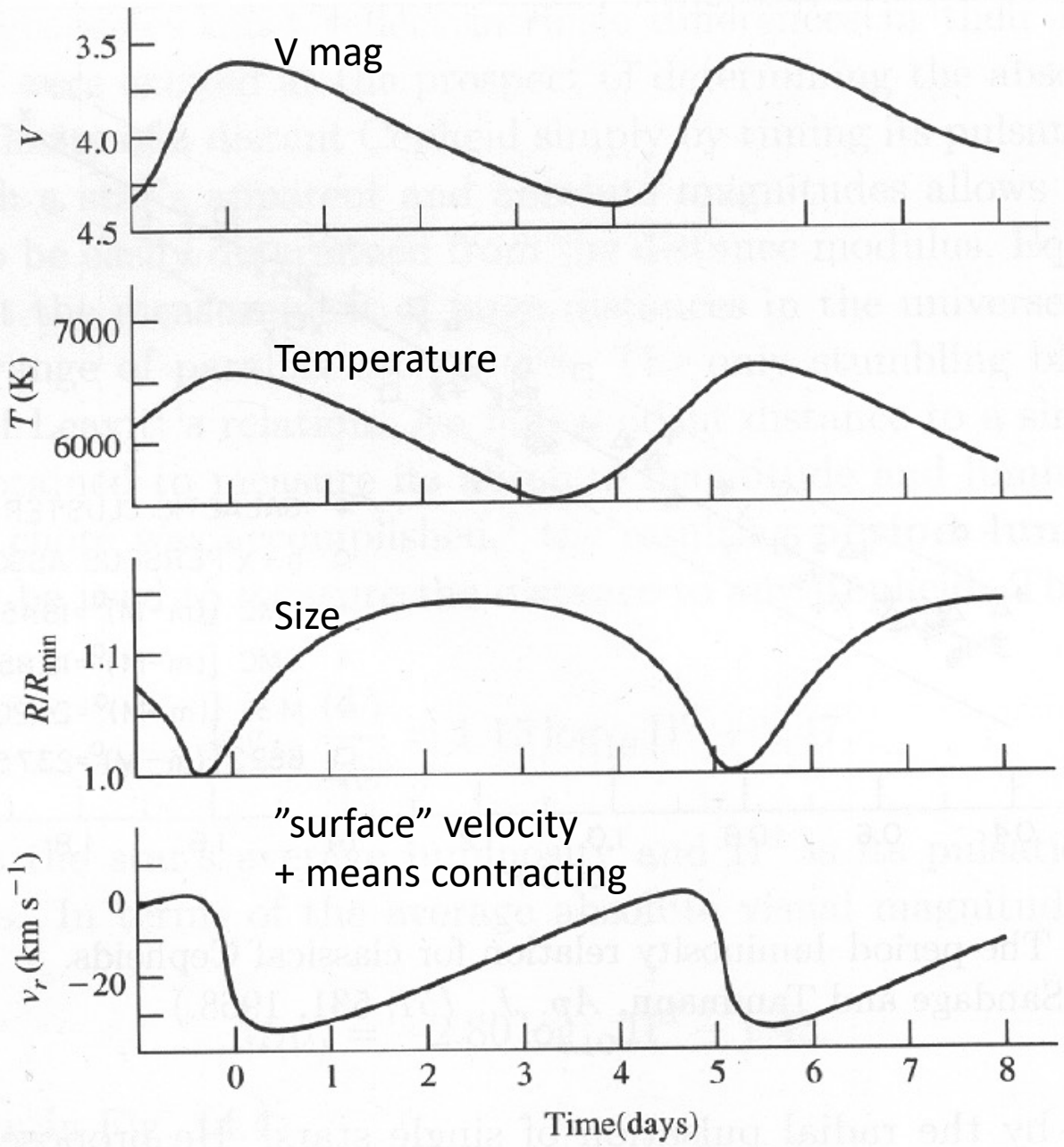
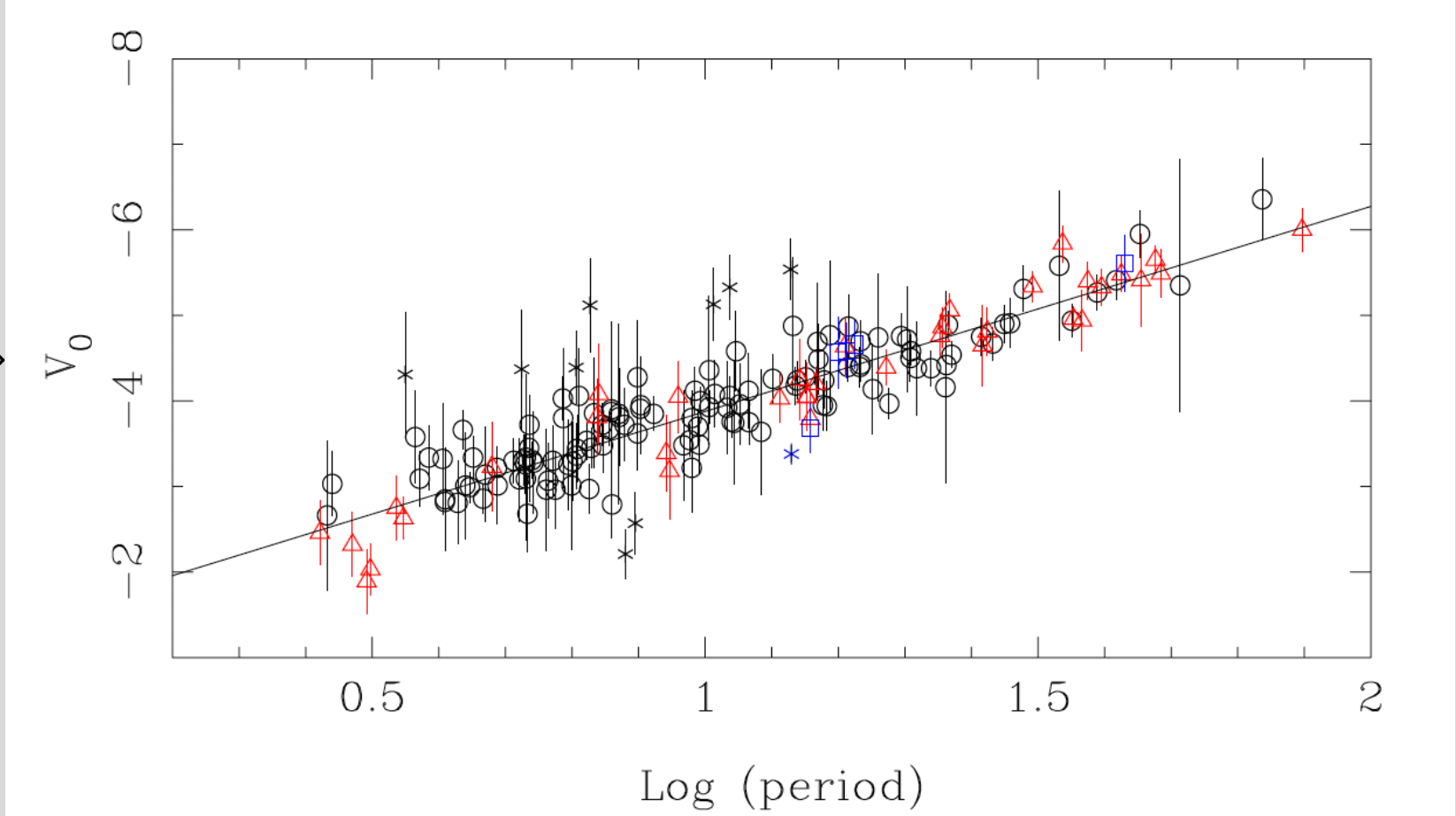


Figure 14.5 Observed pulsation properties of δ Cephei.

Cepheids: Baade-Wesselink PL-relation

Calibrated P-L relationship

Absolute V magnitude! ⇒



Milky Way Cepheids (black)
Large Magellanic Cloud Cepheids (red)
Small Magellanic Cloud Cephedis (blue)

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Cepheids: Hubble Parallaxes

Since Cepheids are typically pretty distant, ground based parallax is impossible.

But then the Hubble Space Telescope came along.

Direct calibration of Galactic Cepheids ⇒

Absolute mag vs log(P)

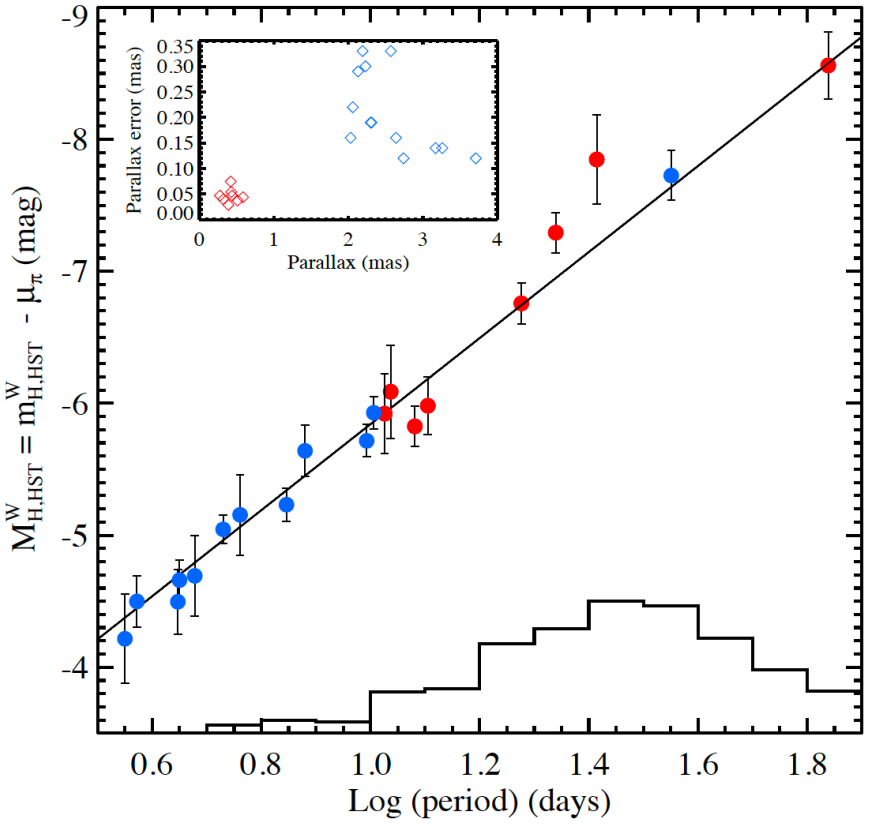
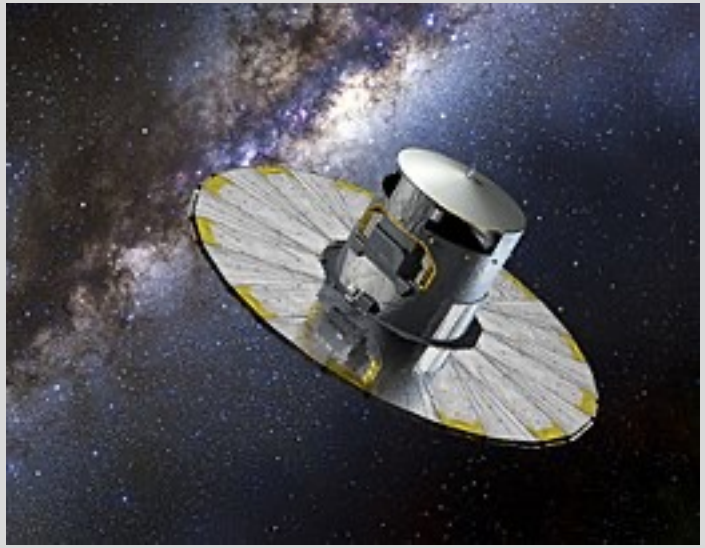


Figure 13. The P–L relation of Milky Way Cepheids based on trigonometric parallax measurements. The points in blue were measured with the *HST* FGS (Benedict et al. 2007) and *Hipparcos* (van Leeuwen et al. 2007) and are all within 0.5 kpc, and the points in red are presented here from spatial scanning of WFC3 and are in the range of $1.7 < D < 3.6$ kpc. The inset shows the uncertainties in the measured parallaxes.

Cepheids: Gaia Parallaxes

And then Gaia came along.

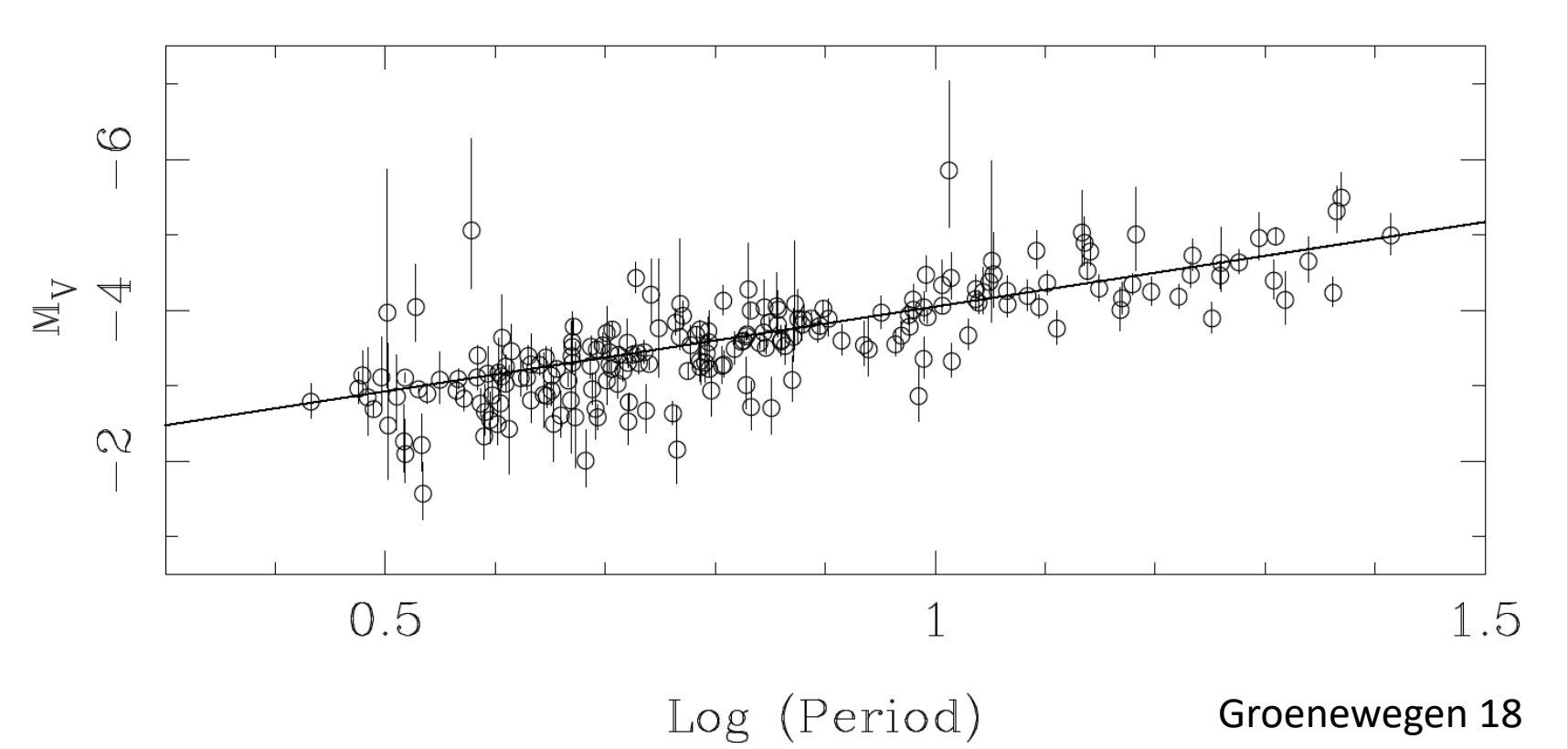


With directly calibrated period-luminosity relationships, our ability to measure distances inside and outside the Galaxy is greatly improved!

Studying pulsating stars in other galaxies

- Need young pops for Cepheids; otherwise RR Lyraes.
- Hubble: Cepheids out to ≈ 15−20 Mpc, RR Lyraes to ≈ 3−5 Mpc or so.
- Even then, these stars are rare.

Direct calibration of Galactic Cepheids ⇒



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