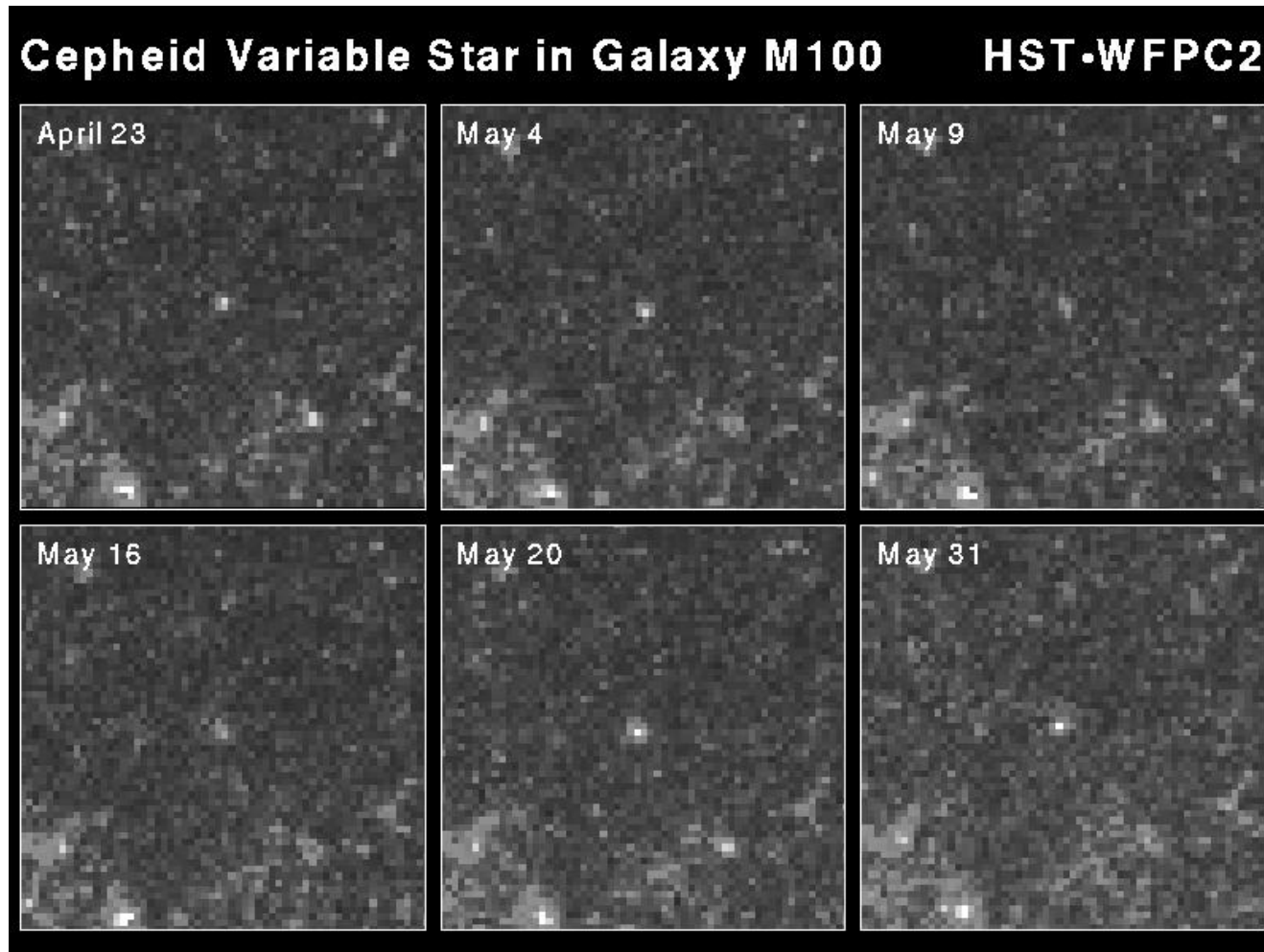


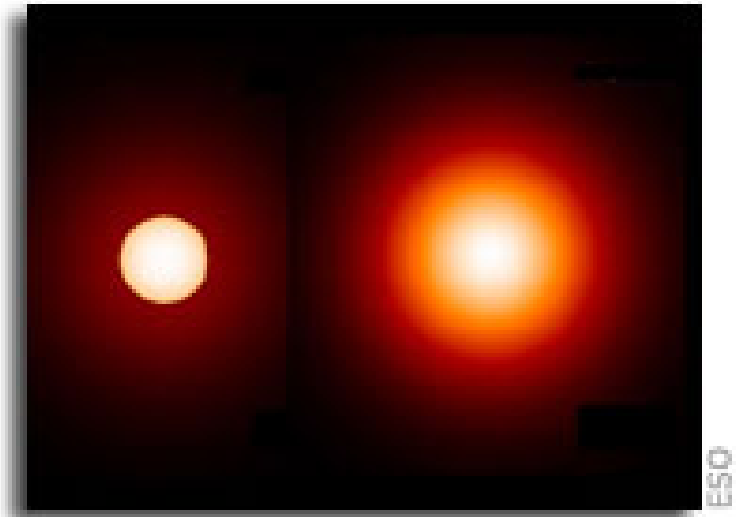
Cepheids and their historical importance



Gilles Otten

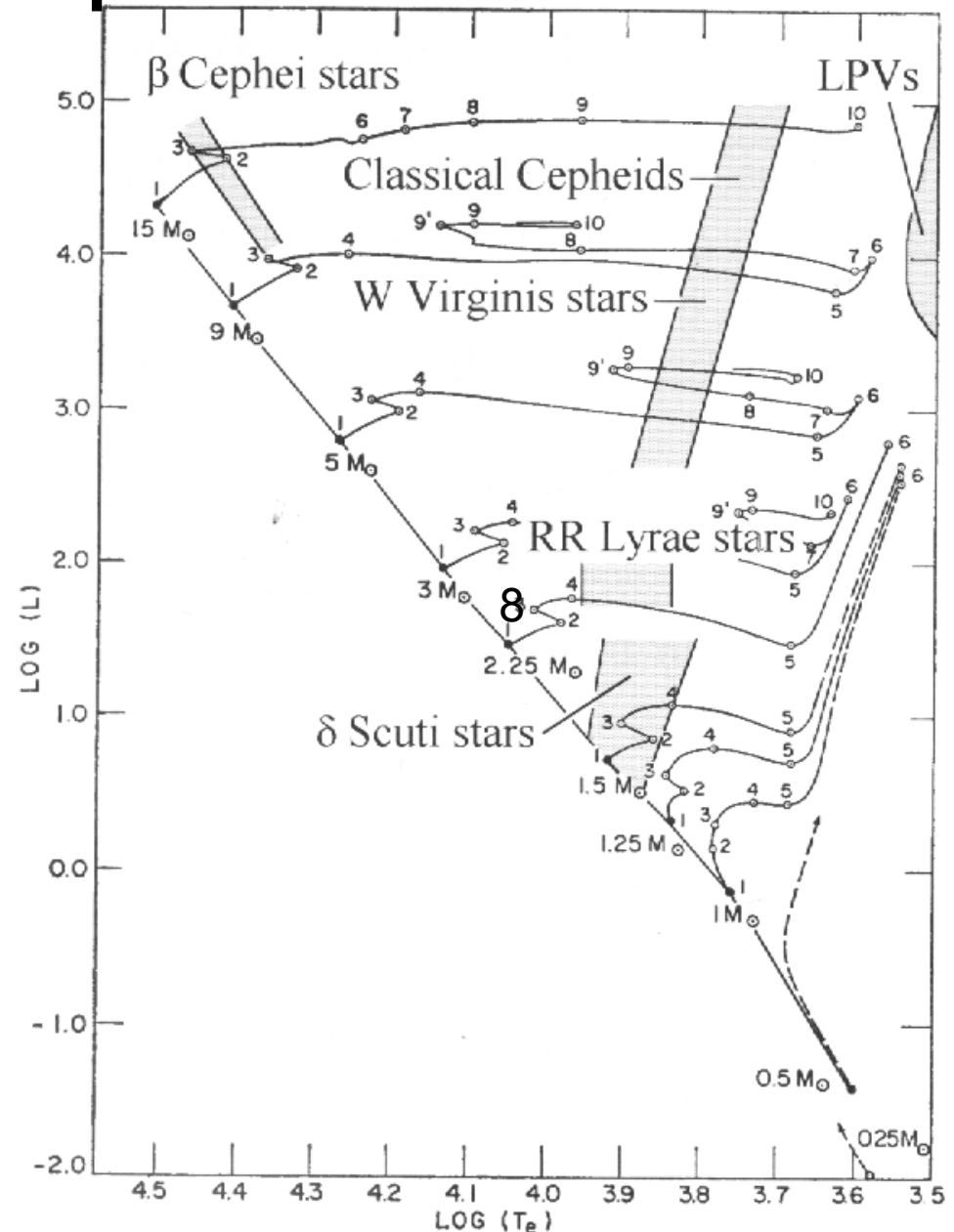
Outline

- what are Cepheids?
- pulsation mechanism
- period-luminosity relation
- history
- importance of Cepheids
 - recognition of other galaxies
 - usage in distance ladder
 - determining the Hubble constant

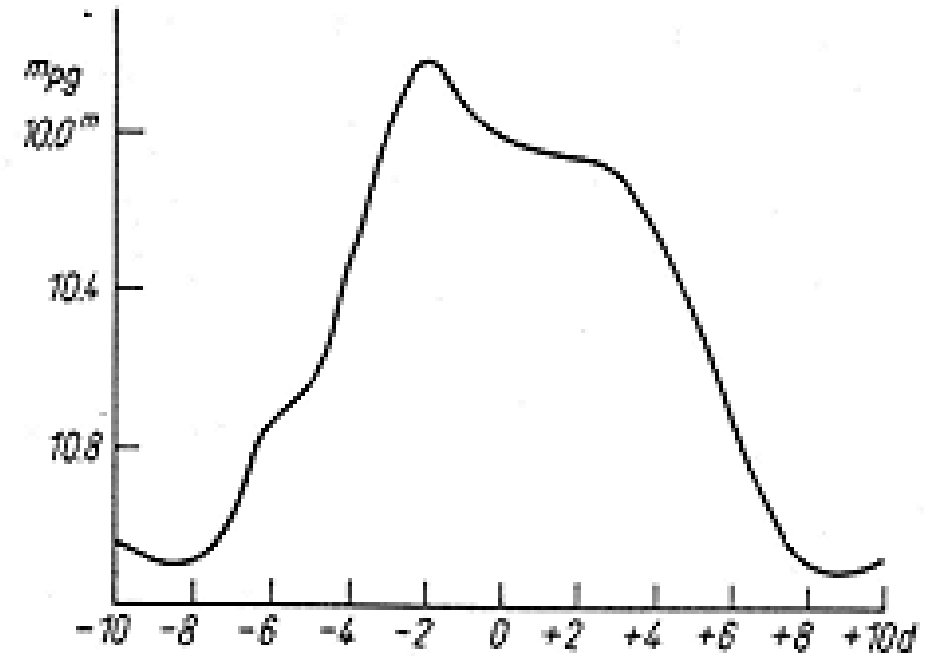
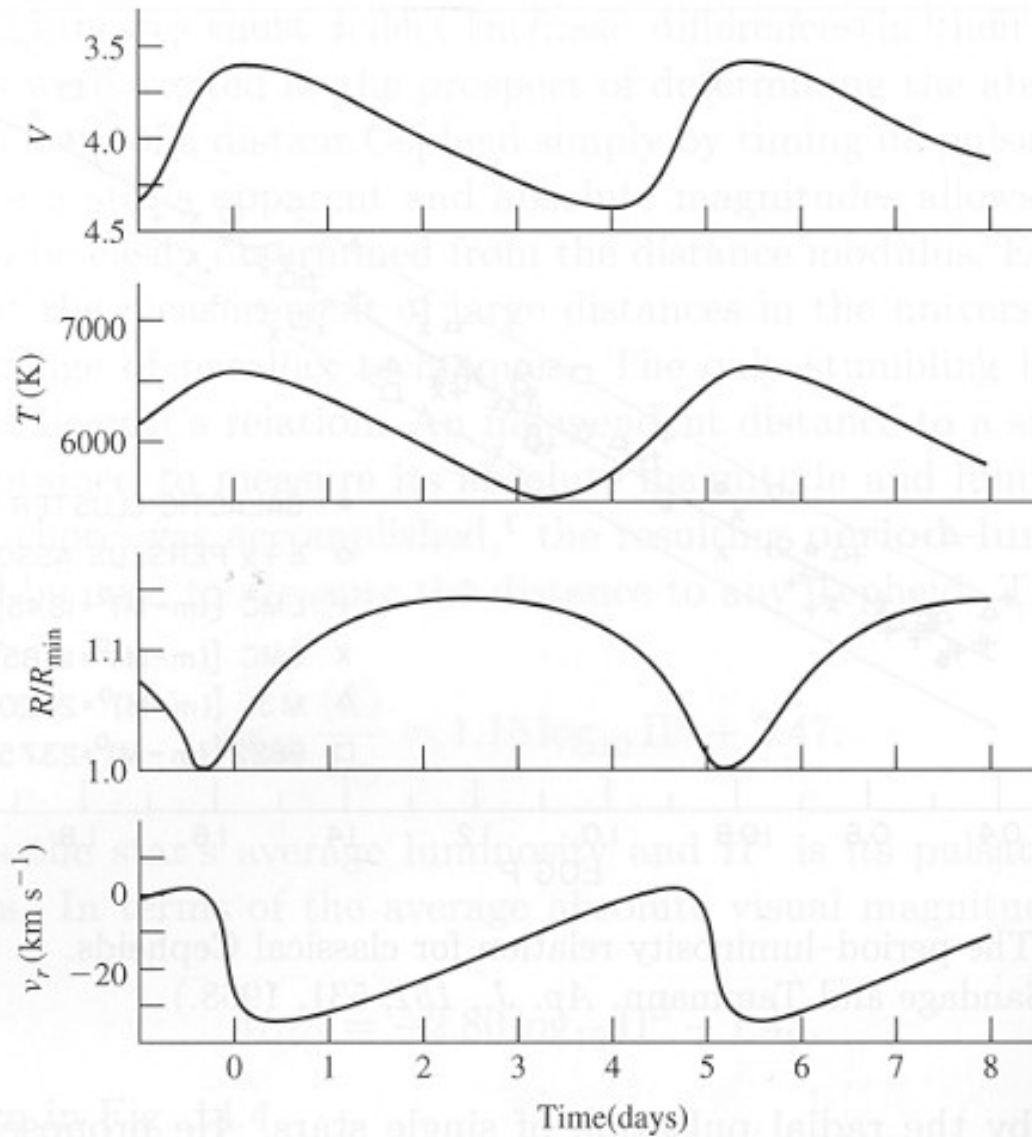


What are cepheids?

- post-main sequence variable stars
 - Type I: *Delta Cepheids*
 - Metal rich
 - Type II: *W Virginids*
 - Metal poor
- $P = 0.8-135$ days
- F-G-K Spectral type
(3500-7500K)
- $0,5-30 M_{\odot}$



Cepheid lightcurves



Hoffmeister et. al., 1985, Variable Stars, chapter 2

Figure 14.5 Observed pulsation properties of δ Cephei.

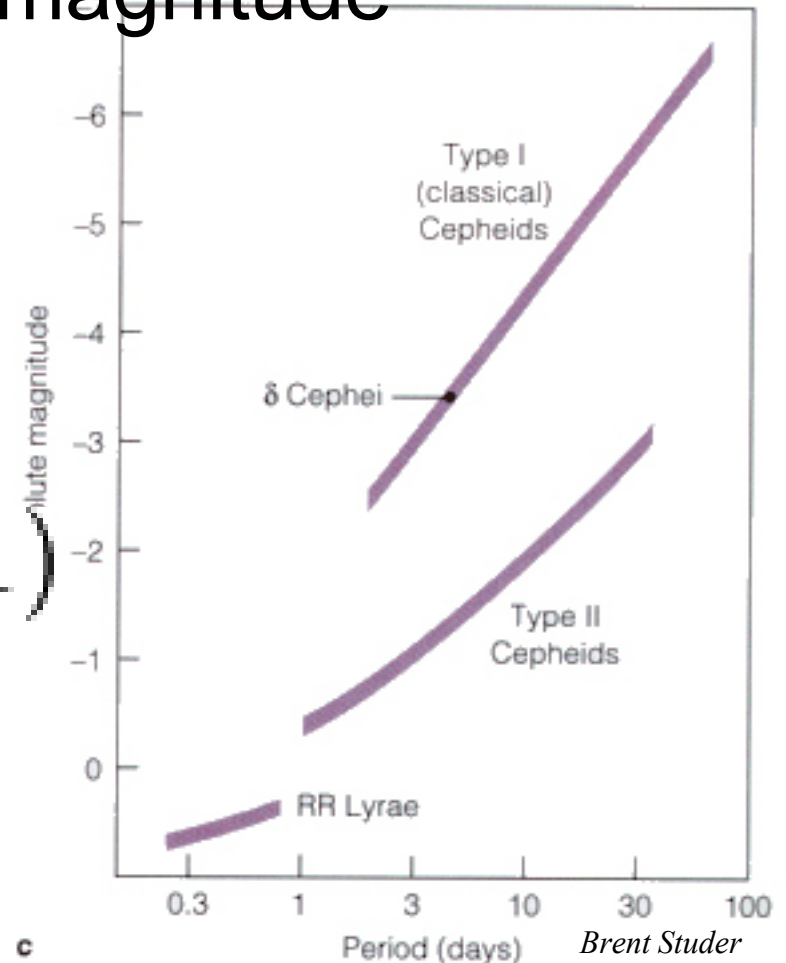
Pulsation mechanism

- pulsating stars (*Eddington*)
 - gravity \leftrightarrow pressure
 - small imbalance \rightarrow star grows
 - growing star lowers pressure
 - gravity acts as restoring force
- opacity drives dampened pulsation (*k-mechanism*)
 - heat makes He^+ below surface He^{++} (opaque)
 - He^{++} blocks heat \rightarrow pressure increase \rightarrow expands
 - $\text{He}^{++} \rightarrow \text{He}^+$ (transparent) \rightarrow pressure decrease

Period-Luminosity relation

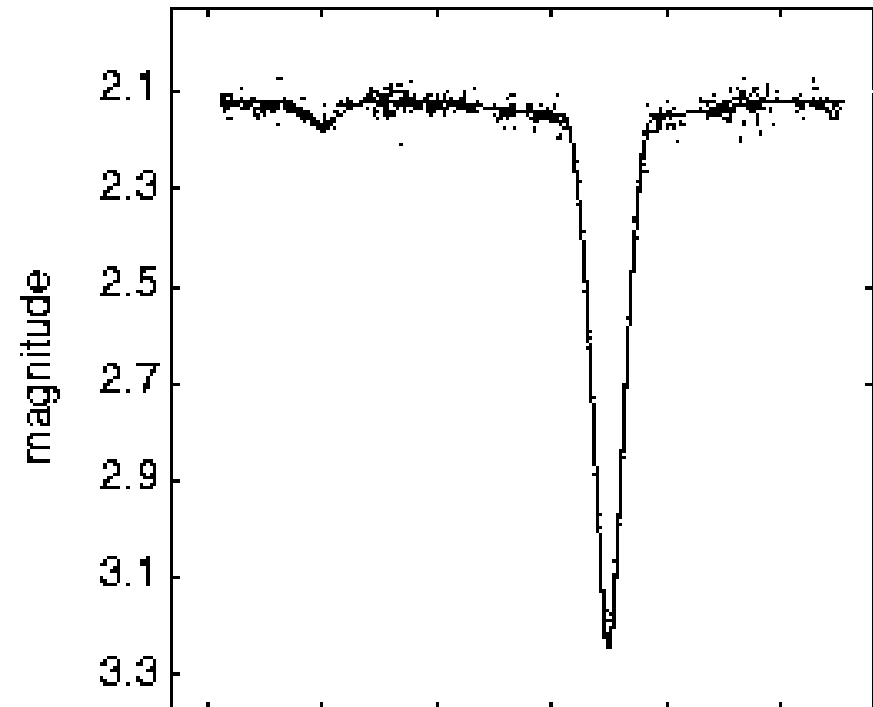
- P-L relation of Type I & II are well defined
- RR Lyrae have a 0.6 mean magnitude

$$M_v = -2.76 \log(P) - 1.4$$
$$M = m - 5(\log_{10} D_L - 1)$$



History

- John Goodricke (1782-1784): Algol, Delta Cep
- Edward Pickering (1895): cluster-Cepheids (RR Lyrae)



Henrietta Leavitt (1912)

- Period-Luminosity relation of Cepheids in SMC

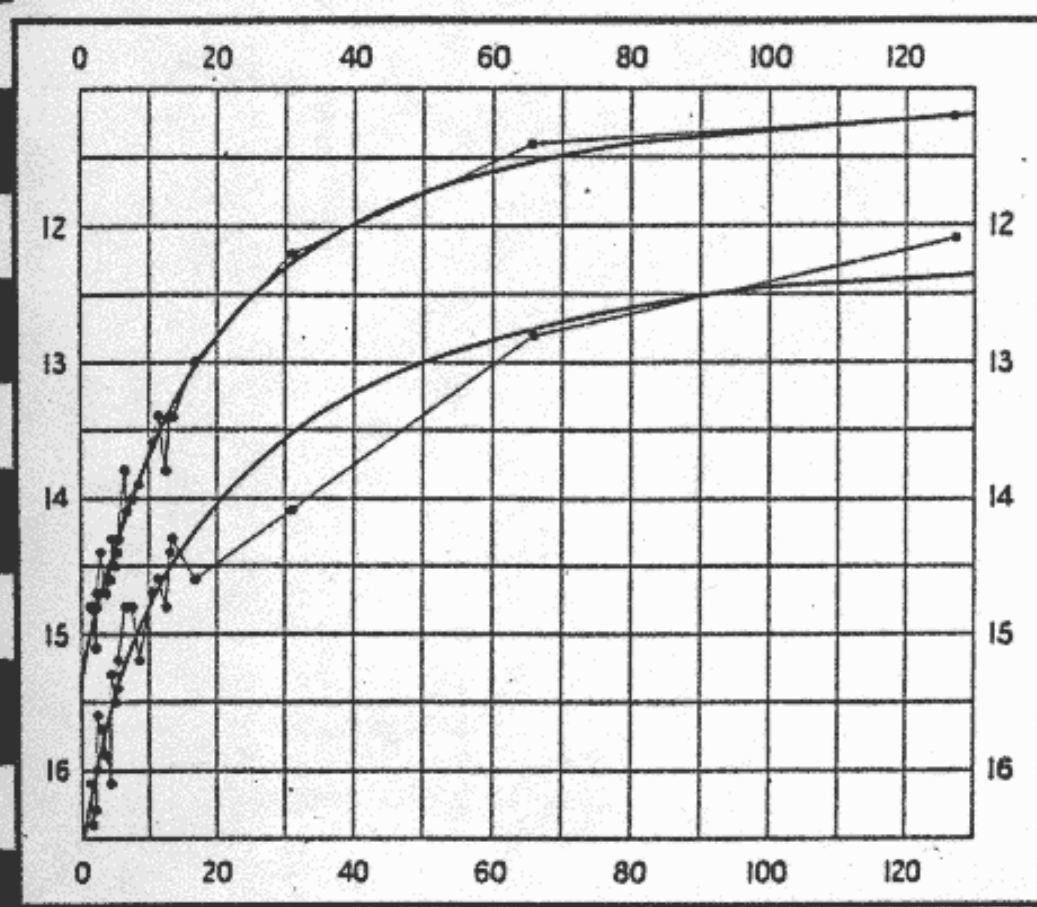


FIG. 1.

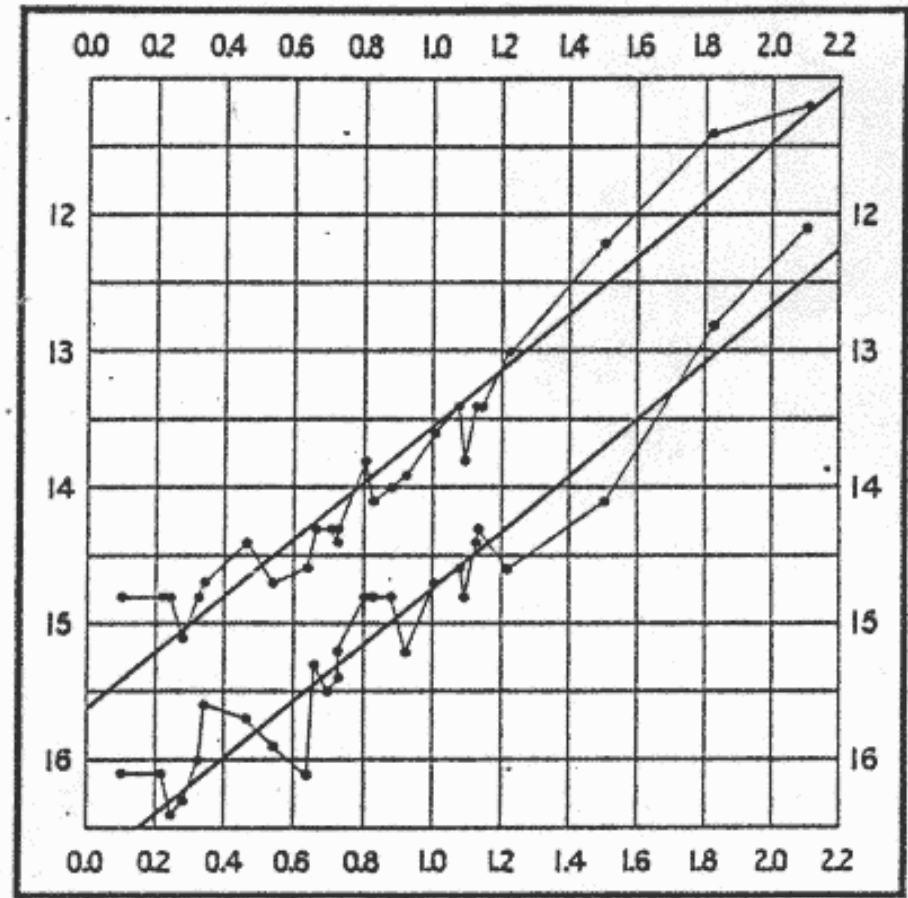
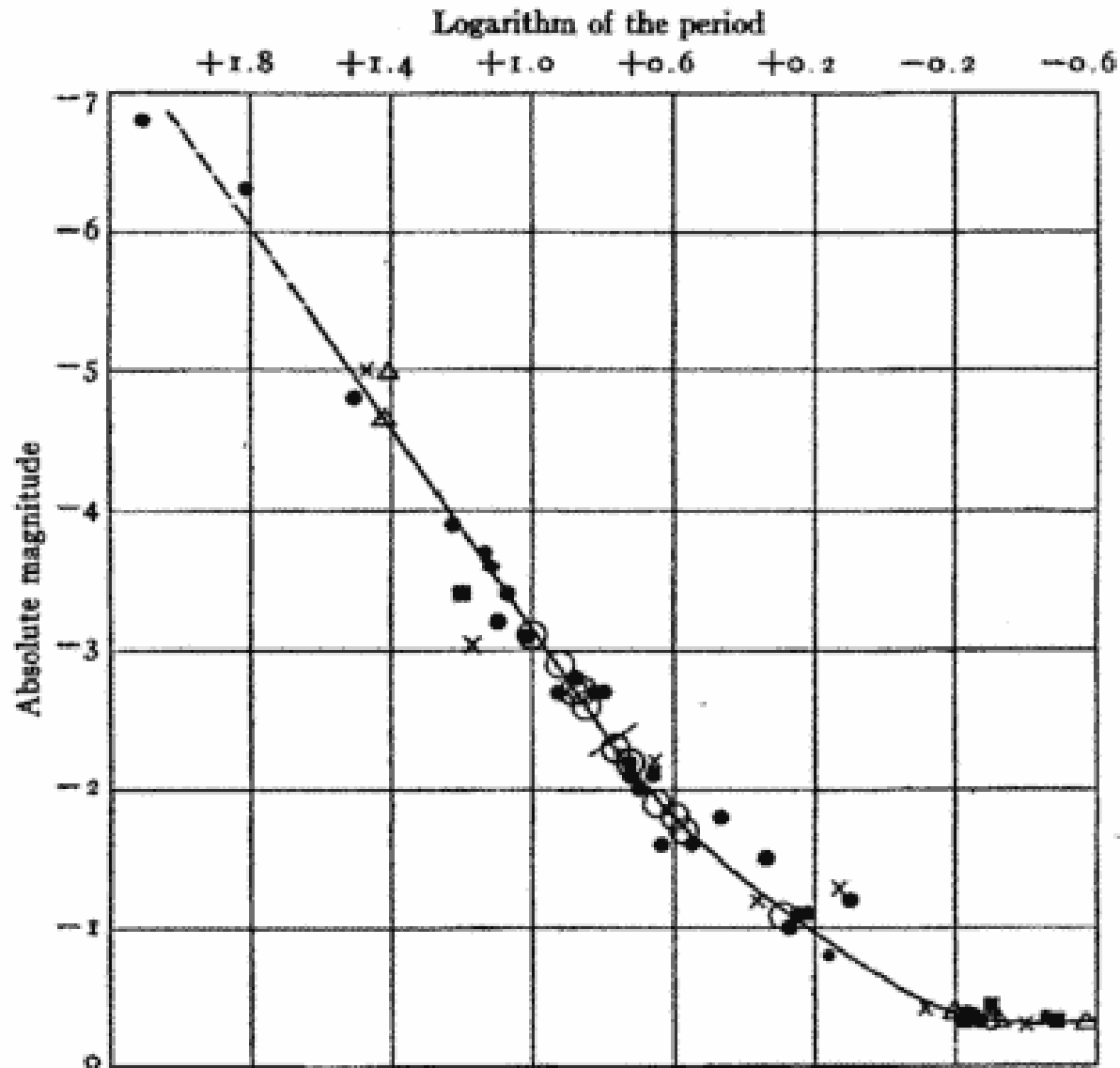


FIG. 2. *Leavitt 1912*

Harlow Shapley (1917)



- PL relation applied to all Cepheids

Other galaxies

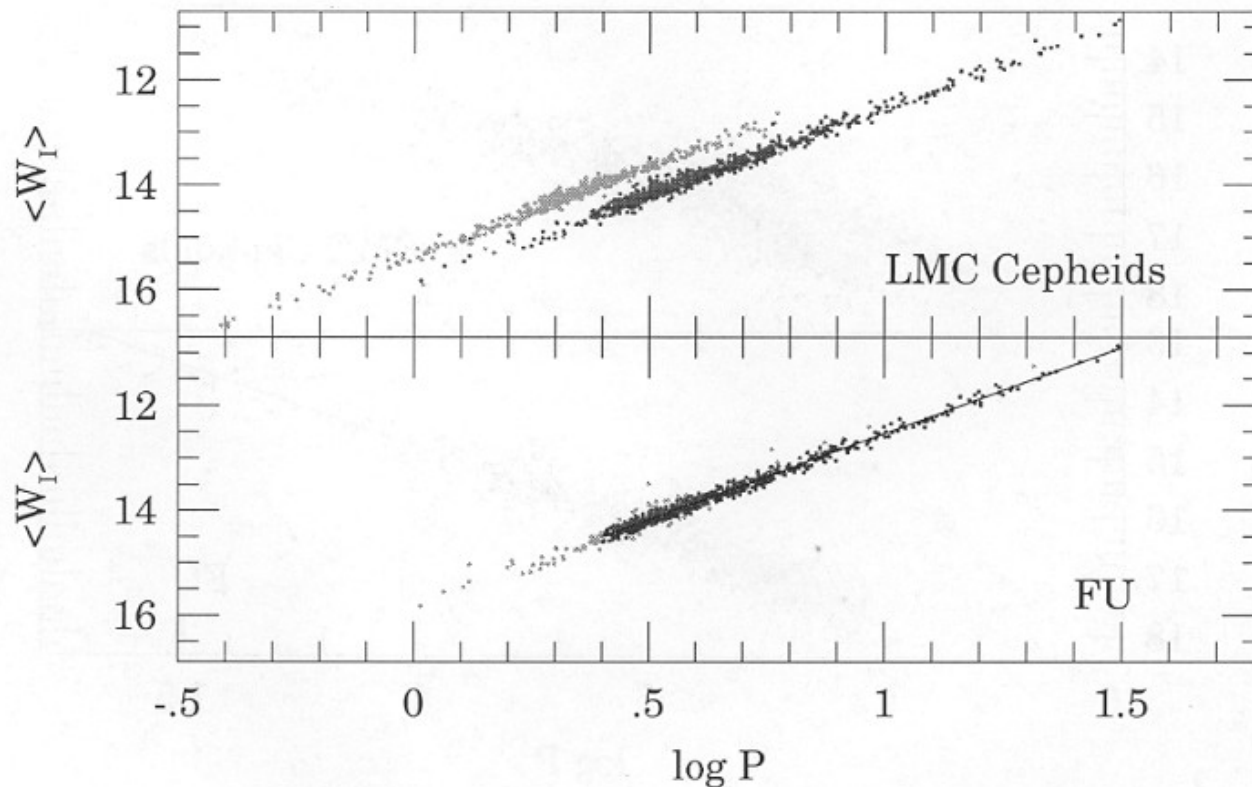
- Great Debate: spiral nebulae, local?
- Hubble (1923): M31 = another galaxy
- Baade (1944): Type I & II 1.5 magnitudes apart



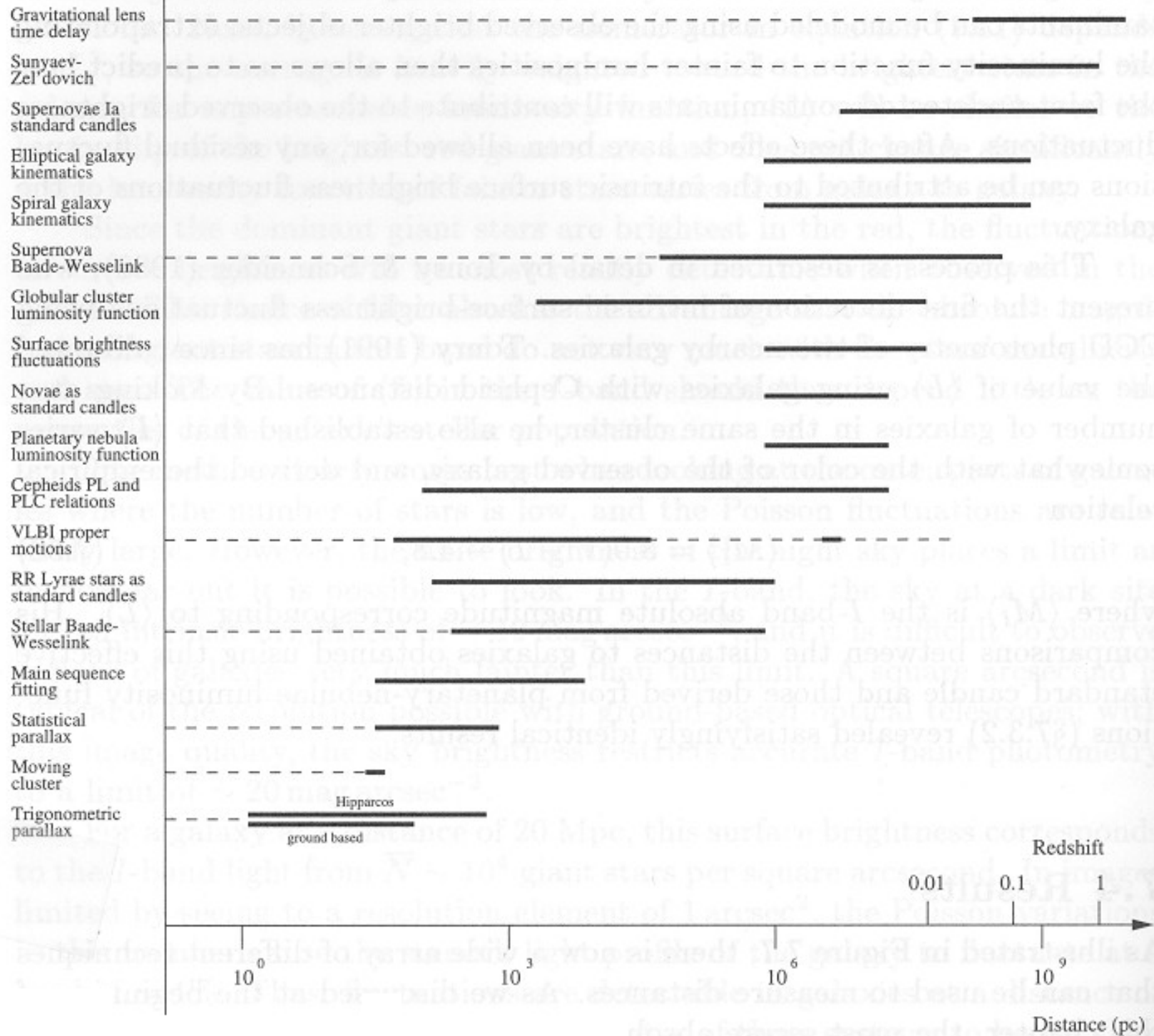
Jason Ware

Usage on distance ladder

- low scatter of magnitudes in infrared ($\pm 0.1m$)
- sawlike lightcurve are characteristic
- Cepheids are bright and numerous

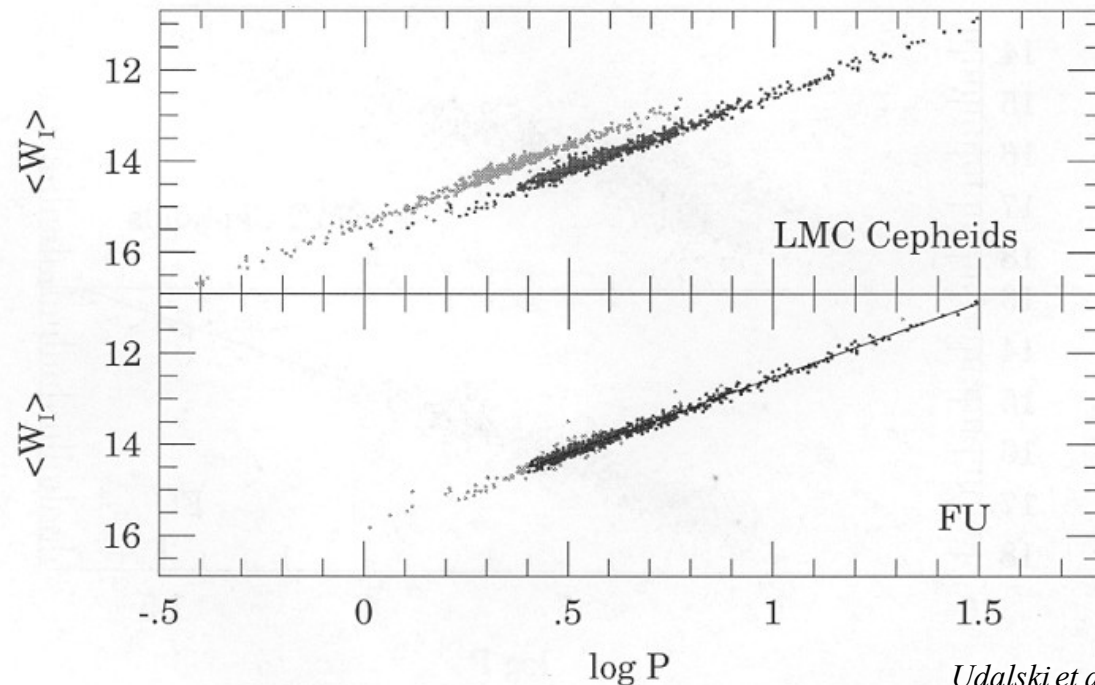


Distance Determination



Error in distances

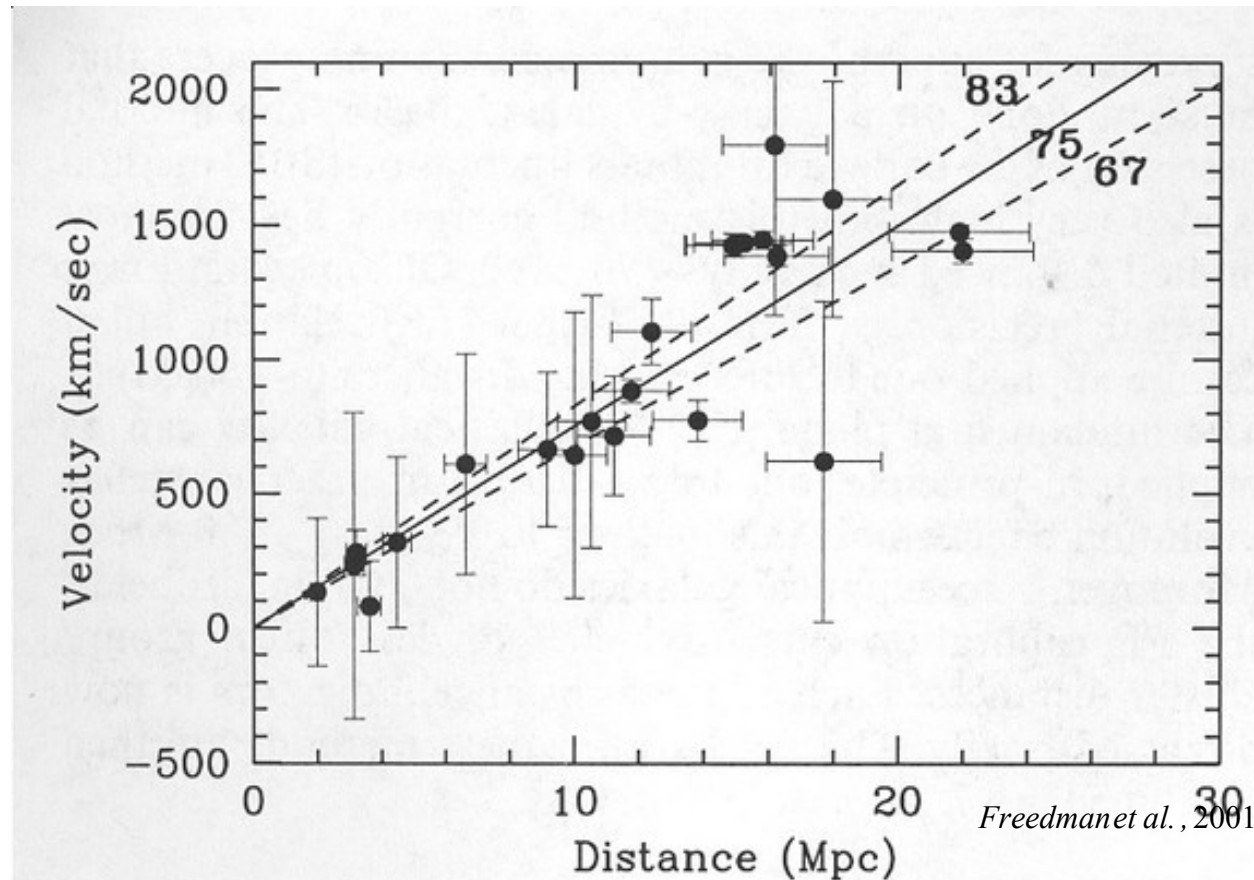
- calibration of zero-point
- interstellar reddening ($\pm 1\%$)
- fundamental and overtone pulsators ($0.73 P$)
- metallicity ($\pm 4\%$)



Udalski et al. 1999

Determining Hubble constant

- radial velocities & distances
- Cepheids visible over long range



Summary

- stars hit instability strip -> harmonic oscillators
- gravity and pressure are restoring forces
- opacity drives the oscillation
- P-L relation gives distance accurately
- broad range on ladder useful
- solved problems in large scale structures

Articles, books & links

- *Turner, JAAVSO Volume 26, 1998*
- *Freedman et al., 2001, Final Results from the Hubble Space Telescope Key Project to Measure the Hubble Constant*
- *ASPCS, volume 83, Astrophysical applications of stellar pulsation*
- *Proceedings of the IAU coll. 82, B. Madore, Cepheids: Theory and observations*
- <http://josephhall.org/ho/>
- <http://www.institute-of-brilliant-failures.com/>
- <http://www.aavso.org/vstar/vsots/0900.shtml>