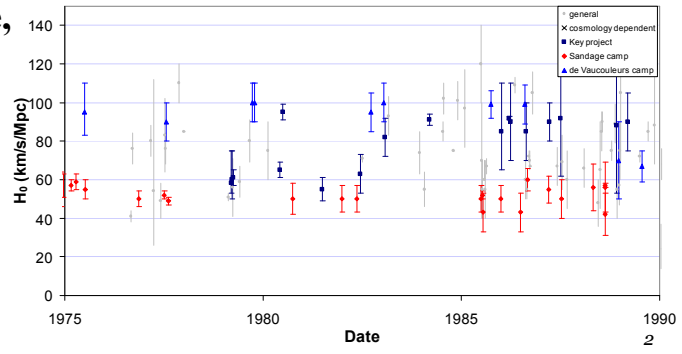
Modern cosmology 1: The Hubble Constant

- **Extragalactic distance measurements**
- **Classical Cepheid calibration**
- **HST Key Project results**
- **Independent measurements**

Measuring H_o

- **From measurements in 1970s and 80s safe to assume that $40 < H_0 < 100$ km/s/Mpc**
- **Typical motions of galaxies in clusters ~1000 km/s**
- **Therefore, for 10% precision need $d \sim$ 100 Mpc**



Distance scales

- **At $d \sim 100$ Mpc, $m - M \sim 35$**
  - **therefore no chance of using ordinary stars**
  - **must use objects of brightness comparable to whole galaxy**
    - galaxy brightness
    - galaxy angular diameter
    - supernovae
- **Few primary distance indicators at this range**
  - **gravitational lensing, Sunyaev-Zeldovich effect**
  - **rest require calibration**

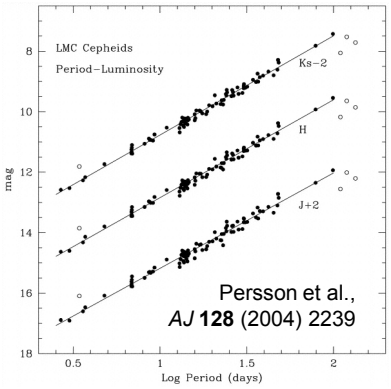
Calibration

- **Ideal calibrator would have**
  - **no systematic errors**
    - e.g. geometric methods such as parallax
  - **good statistics**
    - calibrator object reasonably common
  - **long enough range to overlap with methods it's being used to calibrate**
    - i.e. out to at least several Mpc
    - so, definitely not parallax!

→ ***classical Cepheids***

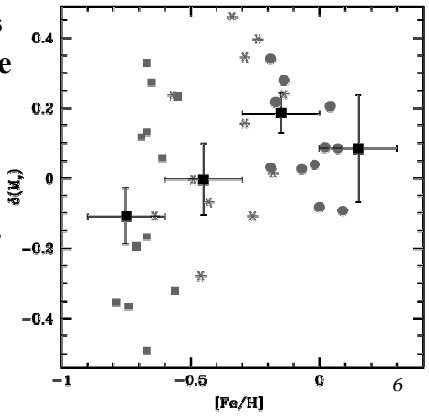
Classical Cepheids

- **Advantages as calibrator:**
  - **bright: $M \sim -4$, so at 10 Mpc $m \sim 26$**
    - **faint but not impossible**
  - **easy to identify**
  - **reasonably common in spiral and irregular galaxies**
    - **not in elliptical galaxies, because massive stars**
  - **period-luminosity relation is very good (little spread)**
  - **well understood theoretically**



Classical Cepheids

- **Disadvantages as calibrator:**
  - **young massive stars, therefore likely to be found in dusty regions**
    - **use infra-red wavelengths**
  - **calibration may be sensitive to metallicity**
    - **model theoretically**
    - **use period-luminosity-colour relationships**
  - **only a few close enough for good parallaxes**
    - **use other geometric distance indicators**

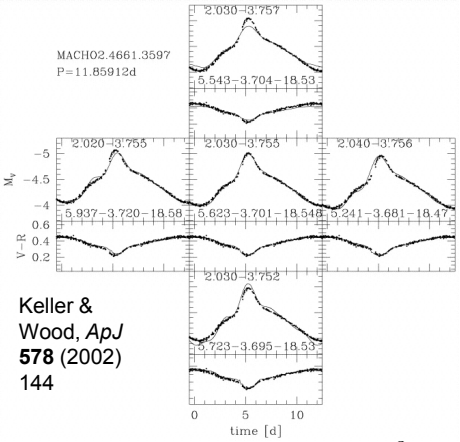


Cepheid Pulsation Mechanism

- **Cepheids contain a layer of ionised helium (He II)**
  - **if star is accidentally compressed, this layer is further ionised, trapping energy**
  - **this pushes layer outward: star expands and surface cools**
  - **reduced density reduces opacity: pressure is reduced, ionisation layer falls inward again**
  - **collapse overshoots equilibrium and cycle repeats**
- **efficiency of this mechanism strongly dependent on depth of He II ionisation layer**
  - **hence existence of instability strip**

Modelling the Pulsation

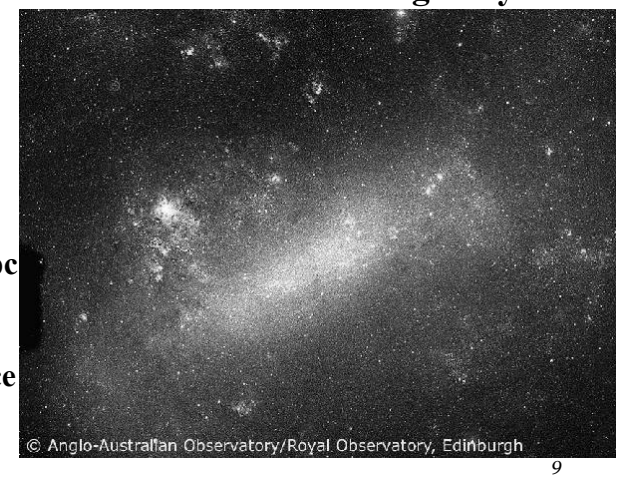
- **Pulsation is resonant (like wind instrument)**
  - **can be fundamental or first harmonic**
  - **"bump" Cepheids have both modes**
  - **model lightcurve to get mass, luminosity, effective temperature etc.**
    - excellent fits obtained
  - **compare calculated luminosity with apparent magnitude → distance**



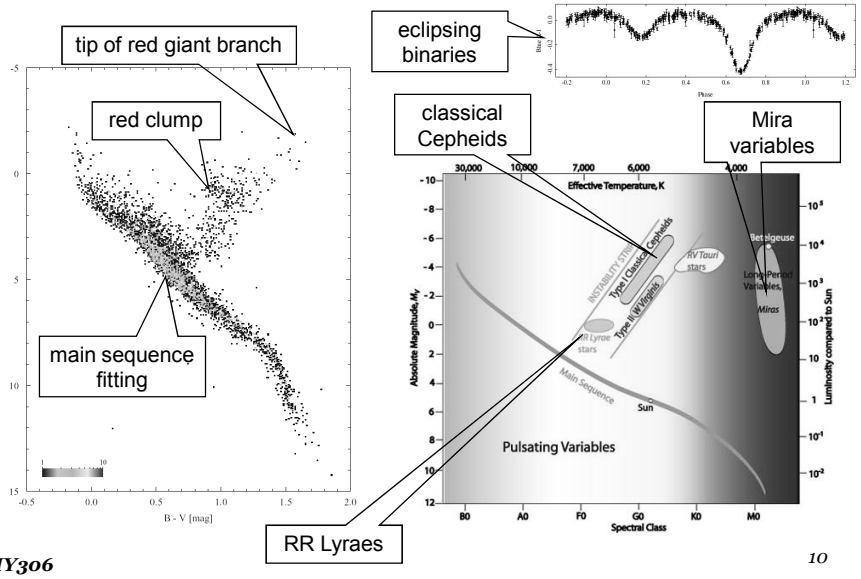
Keller & Wood, *ApJ* **578** (2002) 144

The Large Magellanic Cloud

- **The Large Magellanic Cloud is a satellite galaxy of the Milky Way**
  - **type SBm**
    - more small barred spiral than irregular, but disrupted by tidal forces
  - **distance ~50 kpc**
  - **standard first step on extra-galactic distance scale**



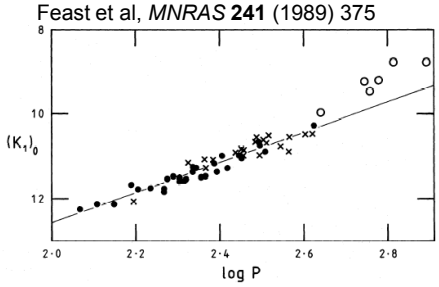
LMC distance indicators

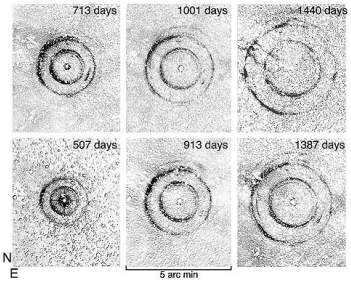


LMC distance indicators

- **Standard candles**
  - **RR Lyrae stars and red clump stars**
    - both helium core fusion
  - **tip of red giant branch**
    - helium flash
- **Period-luminosity relation**
  - **classical Cepheids**
  - **Mira variables**
- **Stellar modelling**
  - **eclipsing binaries**
- **Geometry**
  - **SN 1987A light echo**

Feast et al, *MNRAS* **241** (1989) 375

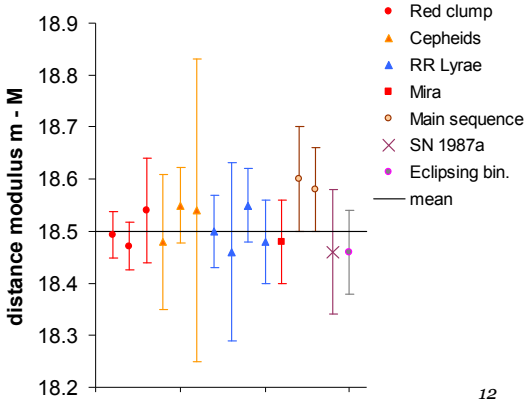




Distance of the LMC

- **Recent measurements of LMC distance show excellent consistency**
  - **weighted mean distance modulus 18.50±0.02 mag**
  - **50.1±0.5 kpc**
  - **Cepheid distances consistent with mean**

Alves, *New AR* **48** (2004) 659, compilation of measurements since 2002



Calibration summary

- **Classical Cepheids are bright enough to be seen at distances of 10-20 Mpc by HST or 10-m class telescopes**
- **Theoretical calibration agrees with parallax estimates**
- **Distance of main testbed (LMC) seems well established**