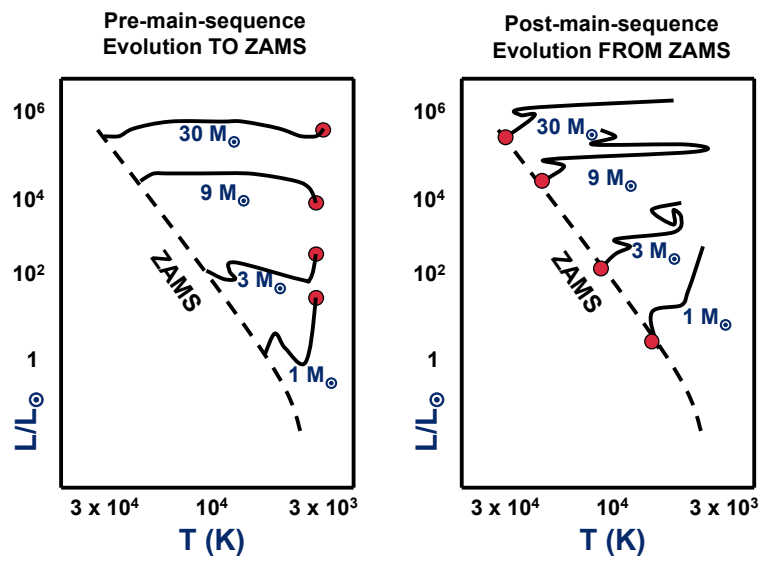
Evolutionary Tracks



Standard Candles

$$F = \frac{L}{4\pi d^2}$$

$$m_1 - m_2 = -2.5 \log L_1 / L_2$$

$$v = M_v + 5\log_{10} d - 5 + A_v$$

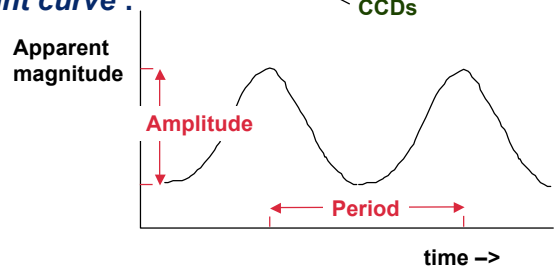
- Intrinsic: Luminosity (Watts), absolute magnitude
- Measure: Flux (Watts/Area), apparent magnitude
- e.g., lightbulbs of known wattage(luminosity)
  - green=100W, blue=200W, red=500W
  - measure flux, get distance
- Astronomy: need some object where its intrinsic luminosity can be determined…

Variable stars and their use as distance indicators

- **Vast majority of stars are stable**
  - no changes in luminosity etc.
- **A small fraction do vary in brightness. Important for 2 reasons:**
  - 1. Easily recognized; some have clearly defined absolute magnitudes; hence use as distance indicators.
  - 2. Use in astrophysics: understanding the physics of stars.

Detection of variable stars

- **Mostly by *photometry***
  - visual
  - photographic surveys
  - photoelectric
  - CCDs
- ***Light curve* :**



- **General Catalogue of Variable Stars (1985)**
  - lists 28450 known variable stars
- **Three main groups:**
  - pulsating (~ 70%)
  - eruptive (~ 10%)
  - eclipsing (~ 20%)

Pulsating variable stars

- **Surfaces oscillate radially**
  - **Radius changes (ΔR / R) ~ 0.1**
- **Simultaneous changes in surface temperature**
  - **hottest at max. brightness**
  - **coolest at min. brightness**
- **Cause of oscillations is <u>specific location</u> of certain *ionization zones* (H and He) in stellar envelope**
  - **act as valves which alternately dam-up and release the flow of radiation from the stellar interior.**
  - **Hence the *instability strip* in the HR diagram.**
- **Obey a period – mean density relationship:**

$$P(\bar{\rho}/\bar{\rho}_{\odot})^{1/2} \approx 0.04 \text{ days}$$

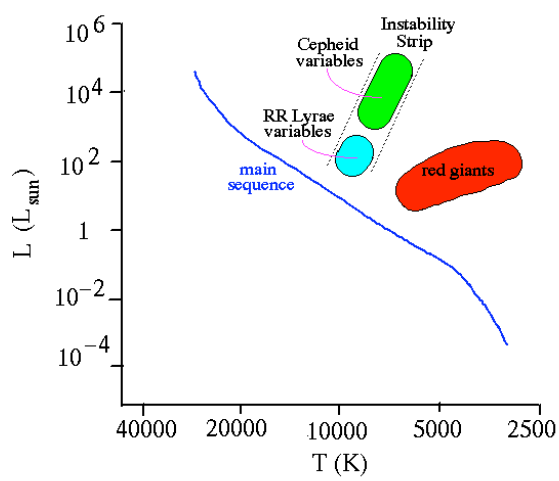
- **For ordinary stars, mean densities lie in range:**

$$10^{6} \geq \bar{\rho}/\bar{\rho}_{\odot} \geq 10^{-9}, \text{ so 3 seconds } \leq P \leq 1000 \text{ days}$$

dense white dwarfs | red supergiants | ZZ Ceti stars | long-period variables

Instability Strip

- **Gap in HR diagram: stars in it are variable**

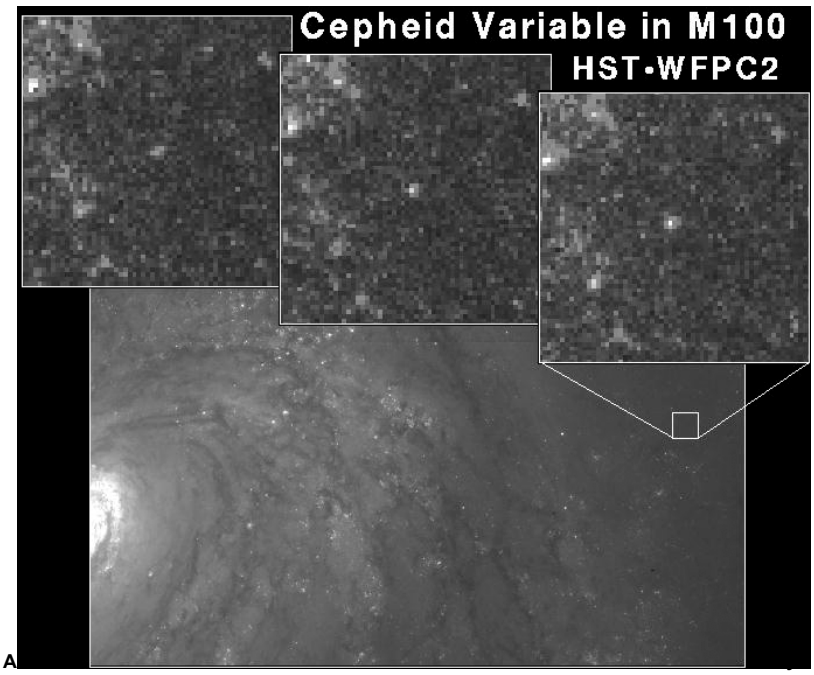


Cepheid variables

- ***Classical Cepheids*** **: Prototype: δ Cephei**
- **F-G type supergiants**

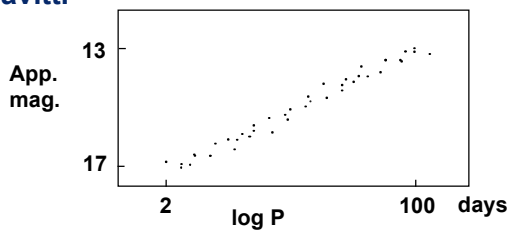
- **Established as population I, massive stars**
  - **in core He-burning phase,**
  - **i.e. crossing instability strip in blue-red loops (~10^7 years old)**

- **N.B. Characteristic light-curve shape + large (~ 1 mag) amplitude + high intrinsic luminosity => *easily recognised* at large distances.**
  - **~ 700 known in MW Galaxy**
  - **many in nearby galaxies: LMC, SMC, M31, M33 + (recently with HST) Virgo cluster galaxies**



The Period-Luminosity Relationship

- **First established (1912) from many photographic observations of Cepheids in LMC, SMC by Henrietta Leavitt.**



- **Period - apparent mag. relation:**
  - Cepheids in a galaxy are at approx. the same distance
  - Hence infer a period-luminosity law of form:

$$M_V = a \log P + b$$

  - where a, b are constants to be found from observations.

Calibration of P-L relationship

- **Modern calibration methods use Cepheids at known distances**
  - members of open clusters
  - Cepheids with known angular diameters.
- **Hence get:**
  - range of M_V: -2 to -6 mag
  - corresponding to periods: 2 to 100 days.
- **Hence for a distant Cepheid:**
  - use photometry to determine pulsation period P and mean apparent magnitude V
  - use P-L relationship to find M_V and hence distance via:

$$\boxed{V - M_V = 5 \log d - 5 + A_V}$$

- **Classical Cepheids used as distance indicators in MWG (spiral-arm regions) and for nearby galaxies:**
  - M31: V ~ 19 to 23 mag
  - Virgo cluster: V ~ 25 to 27 mag

Type II Cepheids and RR Lyrae variables

- **Type II Cepheids:**
  - found in globular clusters and galactic halo
  - hence very old stars (> 10^{10} years)
  - Light curves similar in shape to classical Cepheids BUT:
  - period range 10 to 30 days
  - M_V values ~ 1.4 mag fainter at same period

- **RR Lyrae variables**
  - very common in globular clusters and galactic halo
  - old horizontal-branch stars in instability strip
  - period range: 0.3 to 1 day
  - light curve amplitude ~ 1 mag
  - $M_V \simeq$ +0.6 mag for all RR Lyraes
  - Now observed in M31 (V ~ 24 - 25 mag)