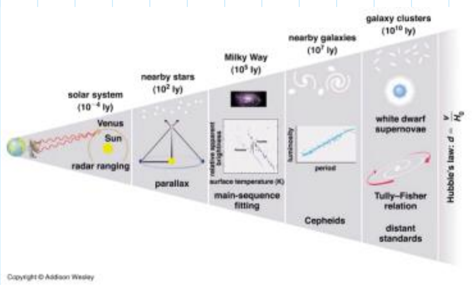
Distance Determination

We want to know H_0, the Hubble constant

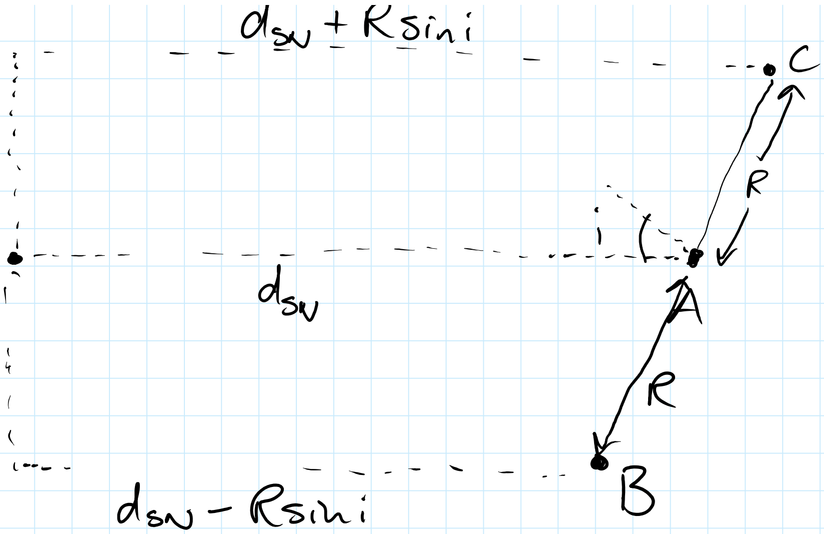
Use Hubble's law, $v = H_0 d$

Need to move to distances where expansion velocity > peculiar velocity (beyond the Virgo cluster ~16 Mpc)

To measure distances that far away, use a distance ladder.



Lowest rung in extragalactic distance ladder is the LMC. SN1987A illuminates a nearly perfectly elliptical ring that consists of material that was once ejected by the stellar winds of the projenitor star. Since the intrinsically circular ring is inclined wrt the line of sight, the distance to SN1987A can be derived from watching the ring light up.



$$t_A = \frac{d_{SN}}{c}, \quad t_B = \frac{R}{c} + \frac{d_{SN} - R\sin i}{c}, \quad t_C = \frac{R}{c} + \frac{d_{SN} + R\sin i}{c}$$

$$t_B = \frac{d_{SN}}{c} + \frac{R}{c}(1 - \sin i), \quad t_C = \frac{d_{SN}}{c} + \frac{R}{c}(1 + \sin i)$$

or

$$t_B - t_A = \Delta t_0 = \frac{R}{c}(1 - \sin i)$$

$$t_C - t_A = \Delta t_{max} = \frac{R}{c}(1 + \sin i)$$

From obs. of Δt_0 & Δt_{max} find $i = 42.^\circ8 \pm 2.^\circ6$

and $R = (1.27 \pm 0.07) \times 10^{18}$ cm

$\Theta = \frac{R}{d}$; $\theta_R = 1.''66 \pm 0.03$

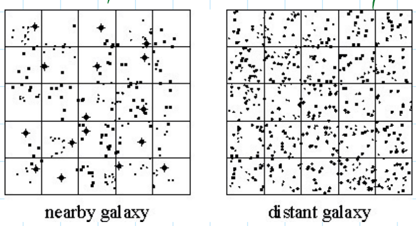
$\rightarrow d = 51.8$ Kpc $\pm 6\%$

Assuming the extent of the LMC along the los is small, this is taken to be distance to LMC.

Surface Brightness Fluctuations

Consider a small CCD camera. Each pixel subtends a fixed solid angle $d\omega$, so the area subtended at some galaxy 1 is $dA_1 = d_1^2 d\omega$; area subtended at galaxy 2 is $dA_2 = d_2^2 d\omega$

Galaxy 1 Galaxy 2



d_1 d_2

Mean # of stars per pixel is proportional to area

$\bar{n}_1 \propto d_1^2 d\omega$; $\bar{n}_2 \propto d_2^2 d\omega$

Suppose each star has mean luminosity $\bar{L}$

$\therefore$ flux/star from galaxy 1 is $\dfrac{\bar{L}}{4\pi d_1^2}$

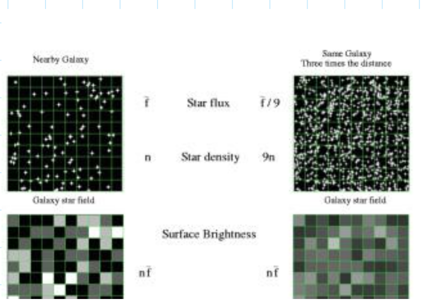
flux/star from galaxy 2 is $\dfrac{\bar{L}}{4\pi d_2^2}$

$\therefore$ total flux/pixel for galaxy 1 is $\bar{n}_1 \dfrac{\bar{L}}{4\pi d_1^2} = \dfrac{d_1^2 d\omega \bar{L}}{4\pi d_1^2}$

for galaxy 2, $\dfrac{d_2^2 d\omega \bar{L}}{4\pi d_2^2}$

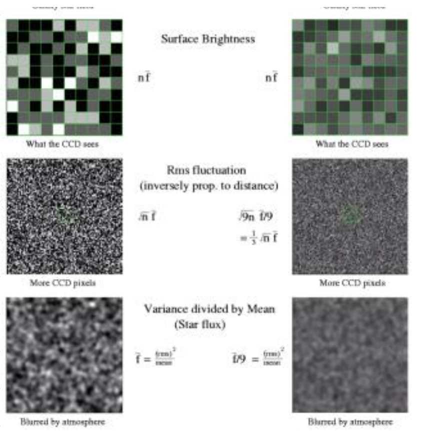
SB is independent of distance

pixel-to-pixel variations $= \sqrt{n} = \sigma_n$



pixel-to-pixel variations for galaxy 1 $= \dfrac{d_1 (d\omega)^{1/2} \bar{L}}{4\pi d_1^2} \propto \dfrac{1}{d_1}$

pixel-to-pixel variations for

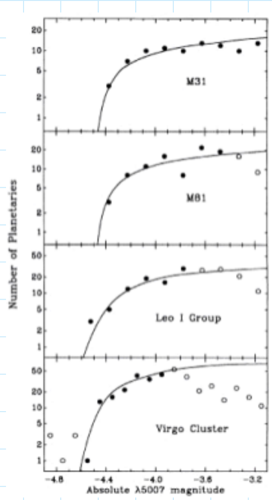


pixel-to-pixel variations for galaxy 2 $= \dfrac{d_2 (d\omega)^{1/2} \bar{L}}{4\pi d_2^2} \propto \dfrac{1}{d_2}$

So, if $\bar{L} \simeq$ same for both galaxies then the ratio of the SB fluctuation is prop. to ratio of distances

Planetary Nebula LF

The brightness dist'n of PN in a galaxy seems to have an upper limit which is nearly the same for each galaxy.

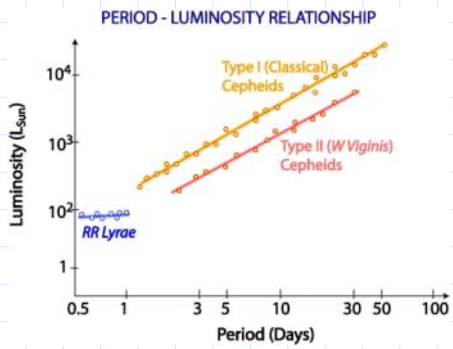


If enough PN are observed to measure the max. app. mag. can calc. absolute mag. and obtain distances.

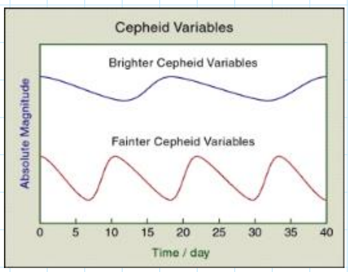
Cepheid Variables

Stars that exhibit a period-luminosity

relationship. Many in LMC which allows relationship to be calibrated.



The existence of a relation b/w L & P is expected from simple theoretical considerations.



Pulsations are essentially radial density waves inside a star that propogate at c_s

$$P \sim \frac{R}{c_s} \quad \text{(sound crossing time)}$$

c_s is usually ~ thermal velocity of gas particles → $kT \sim mc_s^2$

From the virial theorem, the grav. binding energy of a star is about 2x the kinetic (thermal) energy

$$\frac{GMm_p}{R} \sim k_B T$$

$$\therefore P \sim \frac{R}{c_s} \sim \frac{R\sqrt{m_p}}{\sqrt{kT}} \sim \frac{R^{3/2}}{\sqrt{GM}}$$

From stellar evol. theory $L \propto M^3$. If we now consider stars of equal effective temp. T_{eff} (where $L \propto R^2 T_{eff}^4$)

$$P \propto \frac{R^{3/2}}{\sqrt{GM}} \propto L^{7/12}$$

These Cepheid stars are young, v. luminous & HST can pick them out of galaxies out to the Virgo cluster (Hubble Key Project)

Best to look in near IR to minimize effects of extinction.

Mechanism of pulsation: a zone of He^+ in the stellar interior increases the opacity, raises the Temp., increase the rate of energy generation, swells the star, lower the T, He^+ recombine