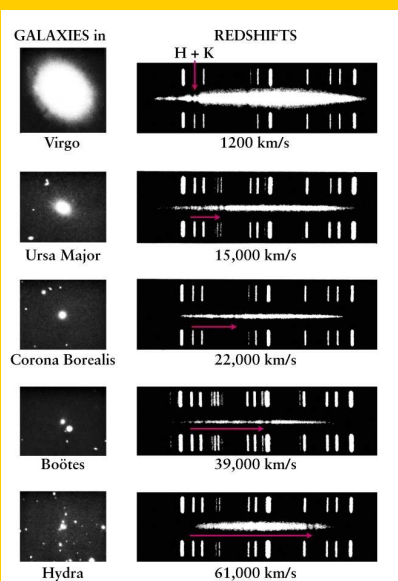


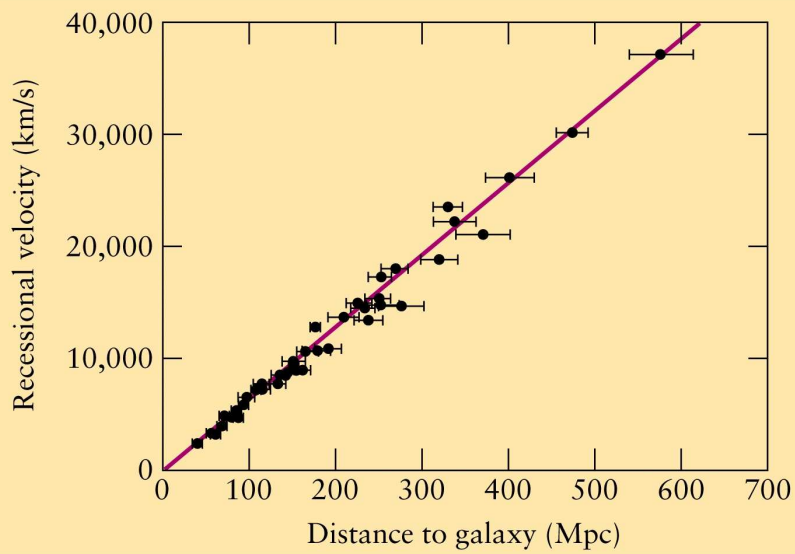
PHAS 1102, Section 2 part 2:
THE EXTRAGALACTIC
DISTANCE SCALE



Edwin Hubble

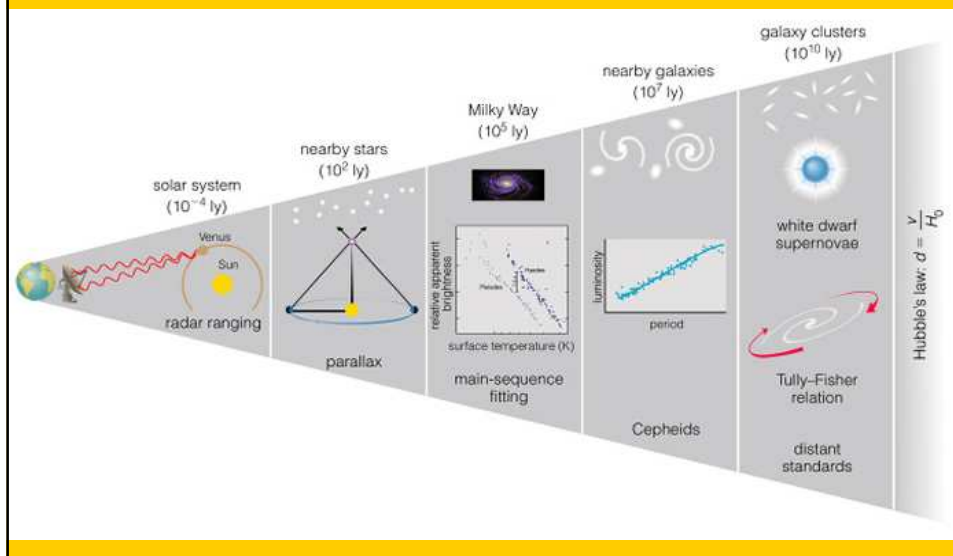
All distant galaxies are receding;
their spectra are *red shifted*



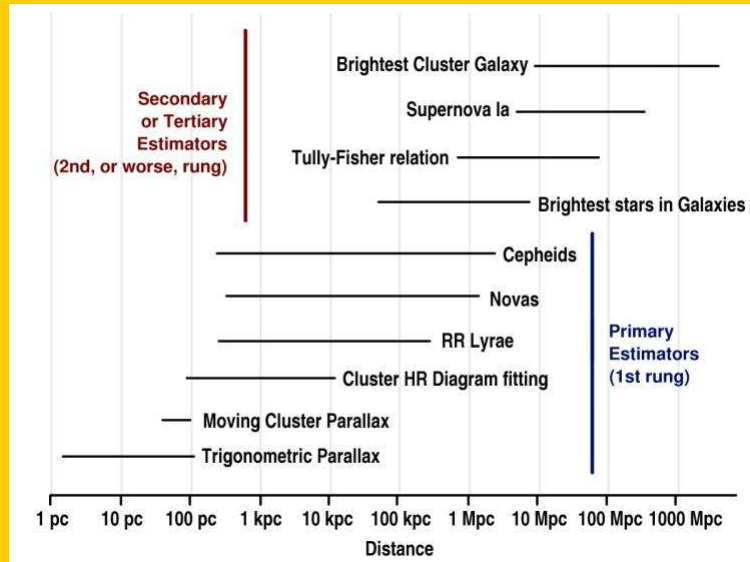


Hubble's Law (published 1929): velocity proportional to distance.
 Constant of proportionality (Hubble's Constant) $H_0 = 72 (+/-5)$ km/s per Mpc

The 'distance ladder'



An alternative version of the 'distance ladder'

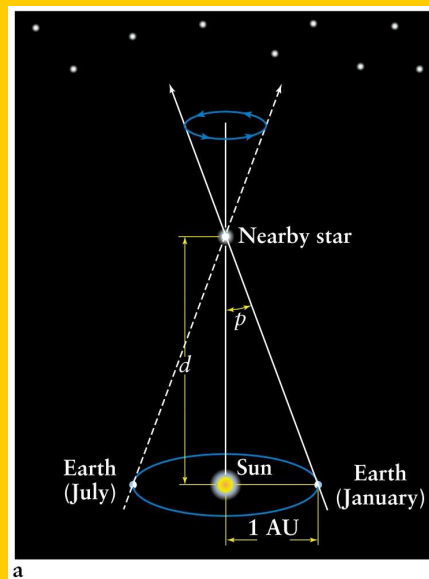


Recall distances are measured in parsecs:

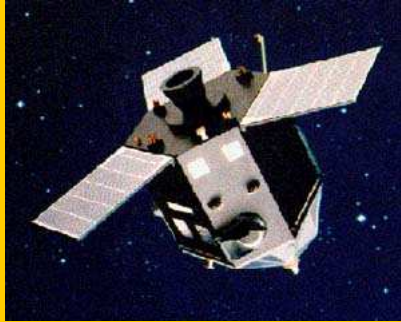
A star at 1 parsec has a parallax of 1 arcsecond

$d(\text{pc}) = 1/\text{parallax}$
(bigger parallax = nearer star)

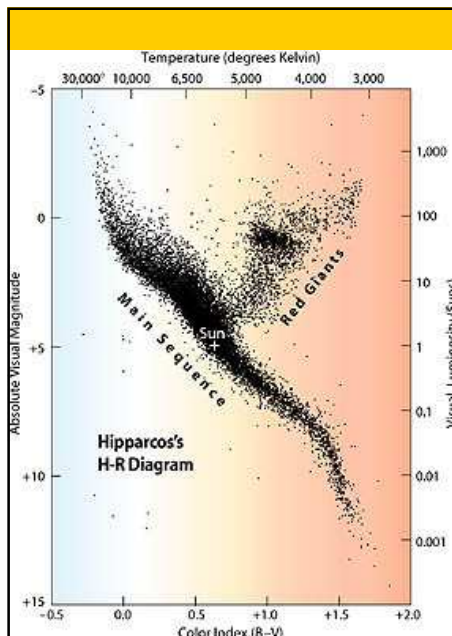
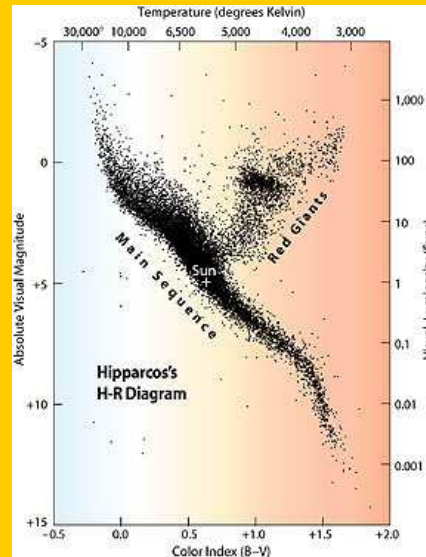
atto = 10^{-18} ; apc = 3cm



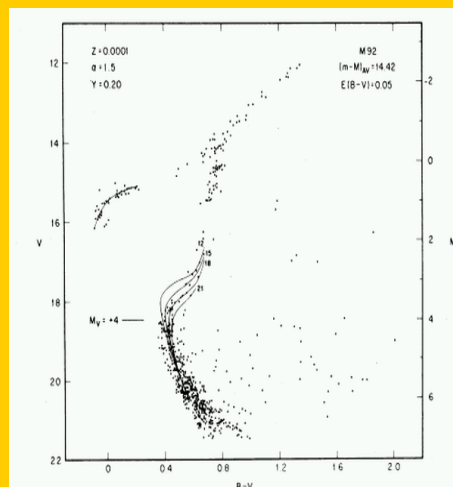
Hipparcos: High Precision PARallax Collecting Satellite (not “Hipparchus”!)



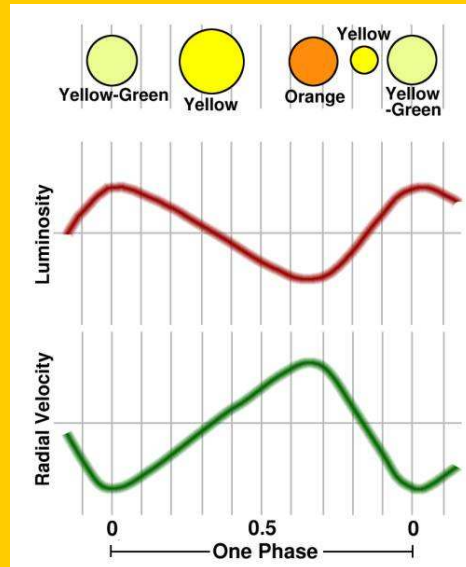
120,000 stars to a few mas
(i.e., distances to a few hundred
parsec) => HR diagram



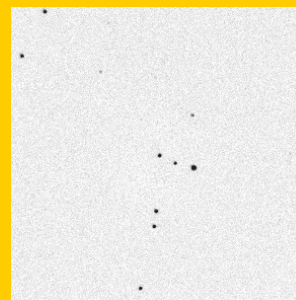
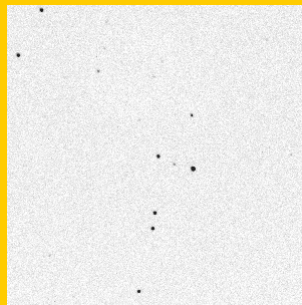
Main-sequence fitting (& spectroscopic pllx)



Cepheid variables are pulsating stars:



Roughly speaking,
small but hot when bright
big but cool when faint



Henrietta Swan Leavitt (ca. 1912), studying stars in the Magellanic Clouds, found a number of Cepheid Variables



Leavitt |

| Cannon

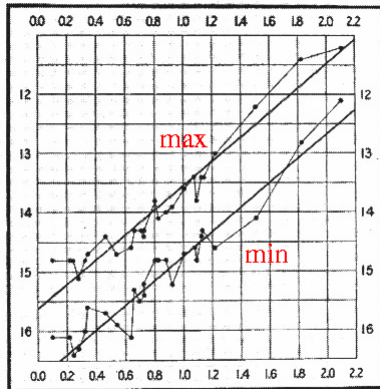
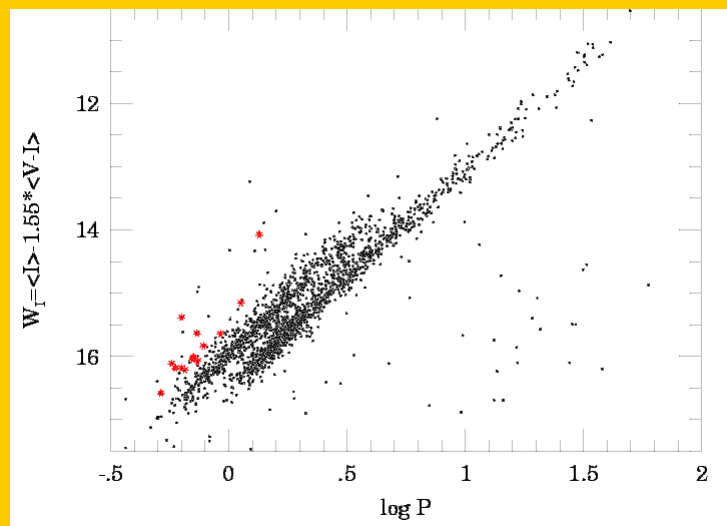


FIG. 2.

Among Magellanic Cloud Cepheids, Miss Leavitt found a *Period-Luminosity* relationship

“The two resulting curves, one for maxima and one for minima, are surprisingly smooth, and of remarkable form. In Figure 2 ... a straight line can readily be drawn among each of the two series of points corresponding to maxima and minima, thus showing that there is **a simple relation between the brightness of the variables and their periods** ... Since the variables are probably at nearly the same distance from the Earth, **their periods are apparently associated with their actual emission of light**”

Modern version (two types of pulsator):



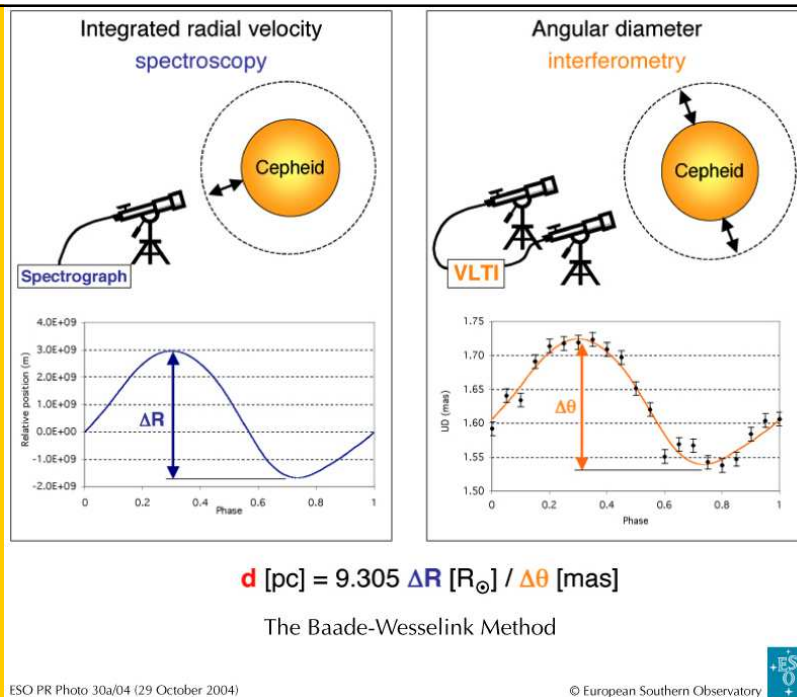
How do we calibrate the zero-point of the period-luminosity relation?

Galactic Cepheids:

- Parallaxes
- Cluster fitting
- Baade-Wesselink

Or

- Independent LMC distance determination



Distance to the Magellanic Clouds:

Calibrate Cepheids in Galactic clusters => PLC zero-point;

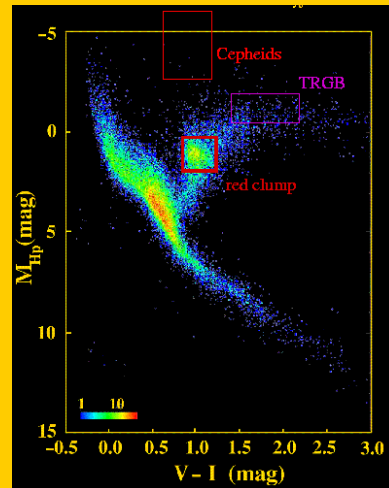
Cluster main-sequence fitting;

‘tip of the RGB’ / ‘red clump’

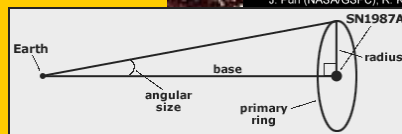
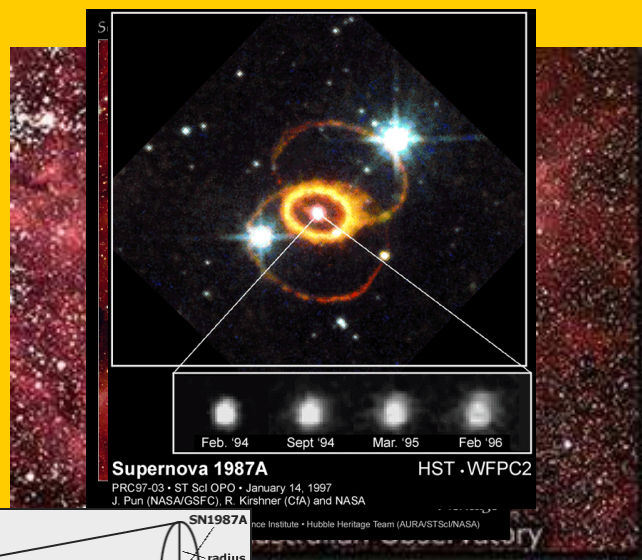
SN 1987A...

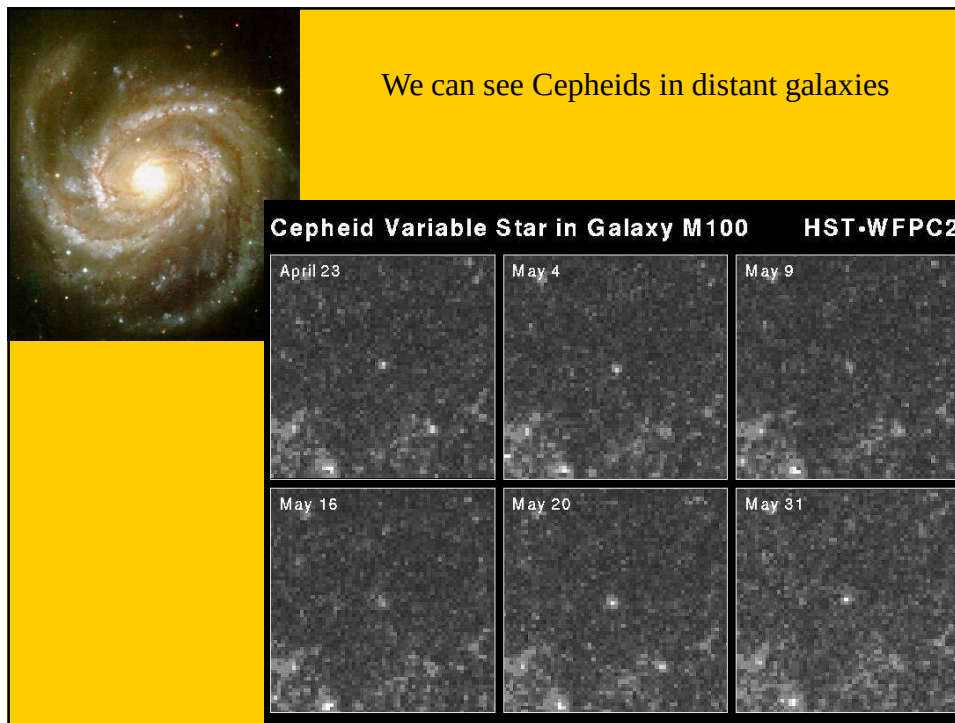
Lead to Period-Luminosity relation:

$$M_V = -2.80 \log_{10} P_d - 1.43$$



SN 1987A geometric distance

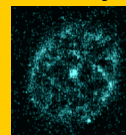




Cepheids allow distances to be determined to galaxies in which bright stars can be resolved.

Other techniques:

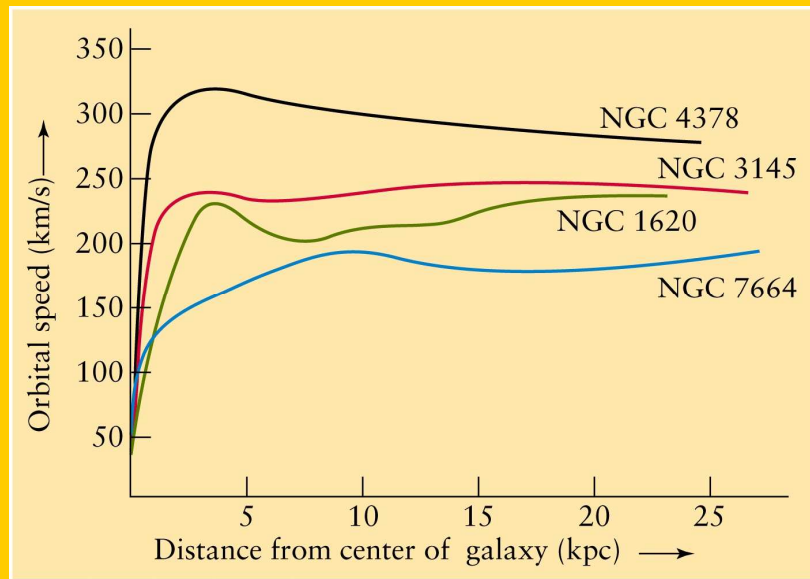
Novae (have roughly the same absolute magnitude 15 days after their peak [-5.5]; + nova-shell expansion)



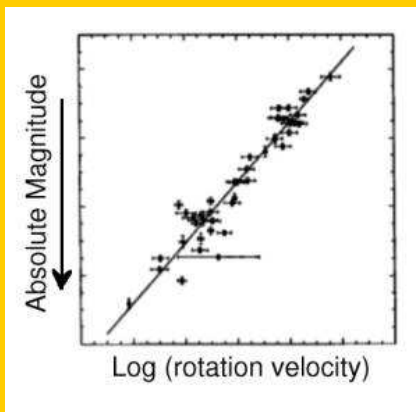
Brightest stars

Eclipsing Binaries (primary technique!!)

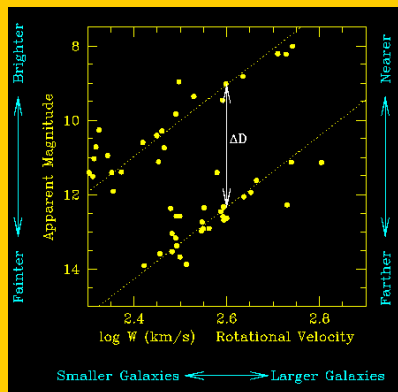
Thereafter: 'Galaxy methods' (increasingly approximate; the 'distance ladder')



Recall rotation curves for spiral galaxies; each has a characteristic rotation velocity

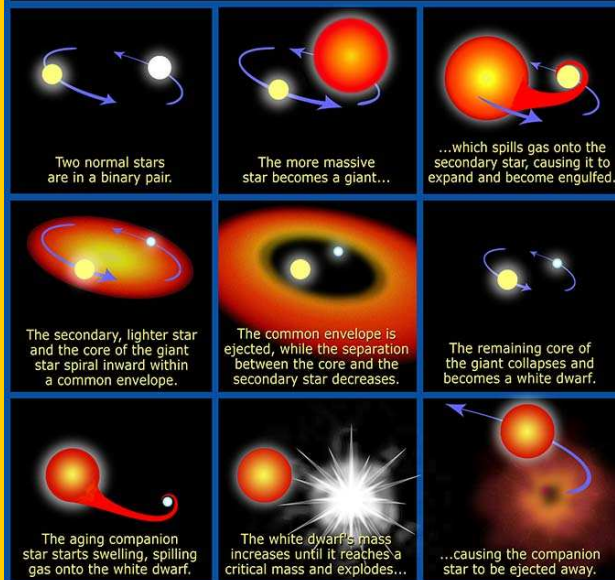


Tully-Fisher:
rotation velocity
proportional to
galaxy luminosity

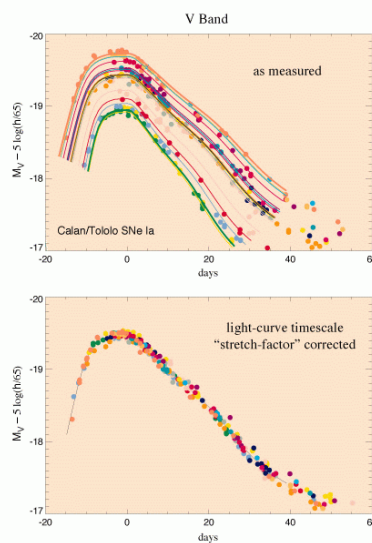


Type Ia supernovae (alone) make good 'standard candles'...

The progenitor of a Type Ia supernova



Low Redshift Type Ia Template Lightcurves



Type Ia Supernovae (SNe Ia) have become the principal distance indicator for the determination of distances in the Hubble flow and, in connection with their calibration through Cepheids, the Hubble constant



SN 1998AQ NGC 3982

