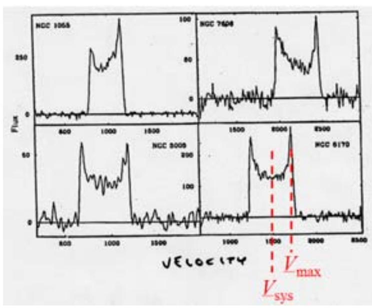
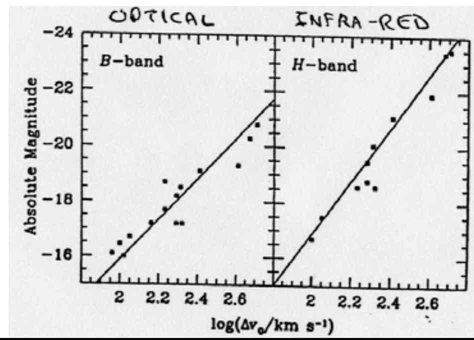
Tully-Fisher relation

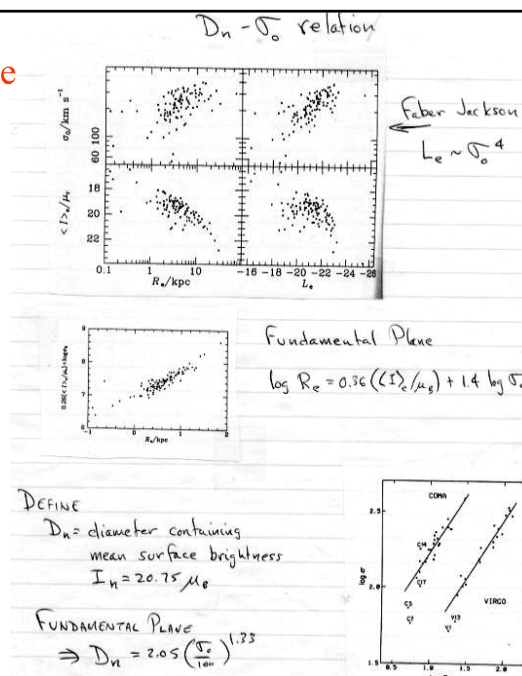
- virial theorem: $v^2 \sim GM/r$
- assume $L \propto M$ ==> L-v correlation expected
- for spiral galaxies, L - v correlation easily measured using H I 21cm profiles, optical/IR photometry.
- must apply sin i correction
- infrared Tully-Fisher: IR measurements minimize scatter due to absorption ==> tighter correlation





E galaxy fundamental plane

- another L-v correlation due to M-L correlation.
- Faber-Jackson relation is first approximation
- fundamental plane gives best precision, but D_n - σ_0 is used more often.
- σ_0 ➔ D_n
- angular size = D_n/distance
- 15% scatter in resulting distance to any one galaxy.



Linear Size - σ_o relation ➔ distance

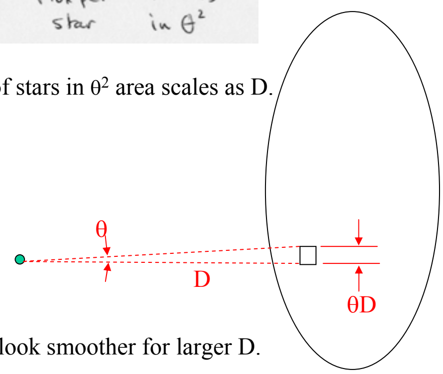
Surface brightness fluctuations

- same galaxy seen at any distance will have same surface brightness.
  N = number of stars in angular area θ^2
  n = number of stars per unit absolute area

Surface brightness $= I = \left(\frac{L}{4\pi D^2}\right) N = \underbrace{\left(\frac{L}{4\pi D^2}\right)}_{\text{flux per star}} \underbrace{n (D\theta)^2}_{\#\text{ stars in } \theta^2} = \frac{Ln\theta^2}{4\pi}$

- But standard deviation of number of stars in θ^2 area scales as D.

$$N = n(D\theta)^2$$
$$\sigma_N = \sqrt{N} = \sqrt{n}\, D\theta$$
$$\sigma_I = \left(\frac{L}{4\pi D^2}\right)\sigma_N = \frac{L n^{1/2}\theta}{4\pi D}$$
$$\frac{\sigma_I^2}{I} = \frac{\langle L \rangle}{4\pi D^2}$$

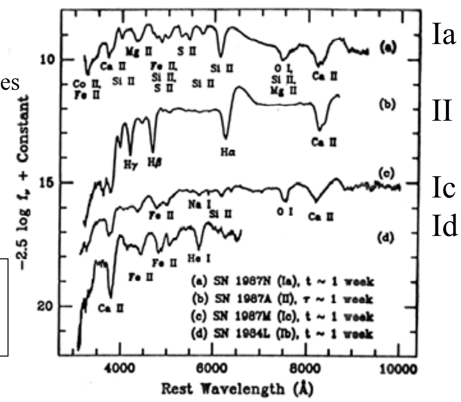


- So surface brightness distributions look smoother for larger D.

Type Ia Supernovae

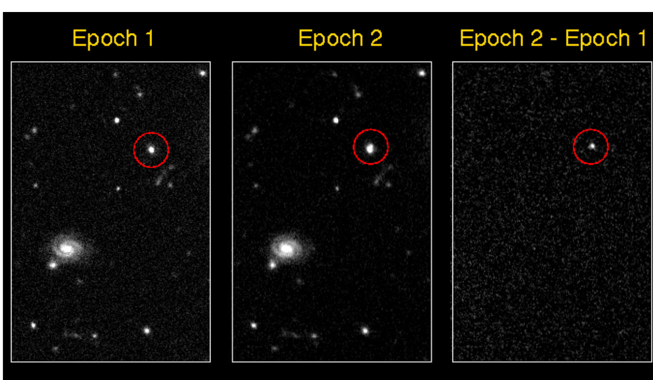
Type Ia Supernovae

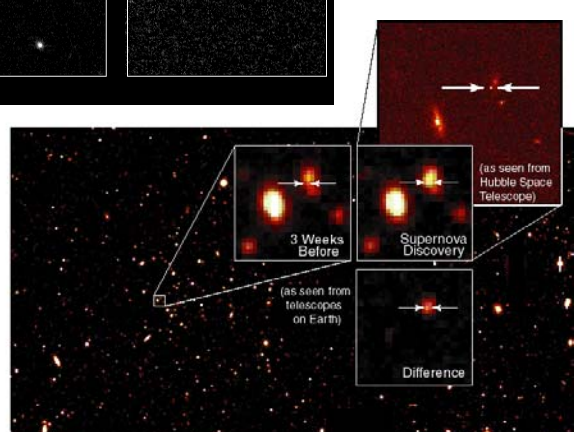
- Type I - no H in spectra
  - Type Ia – strong Si, S, Ti, Ca Mg lines
  - Type Ib/c – strong He, Na, Ca
- Type II - strong H lines



Spectra taken 1 week after maximum.

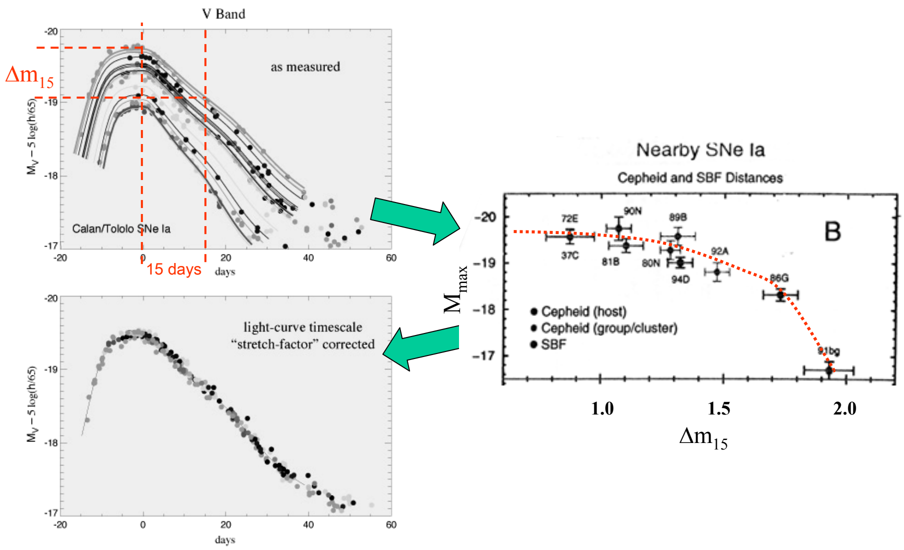
- Types II, Ib, Ic: core collapse & explosion of $M > 10M_\odot$ star.
- Type Ia: thermonuclear detonation of massive ($\sim 1.4M_\odot$) white dwarfs.
  - Great uncertainty about details.

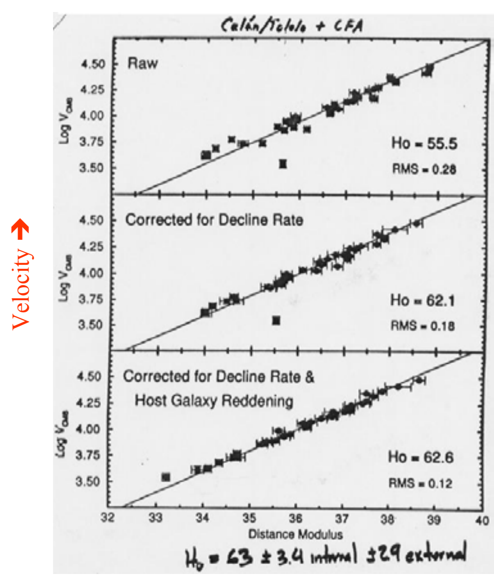


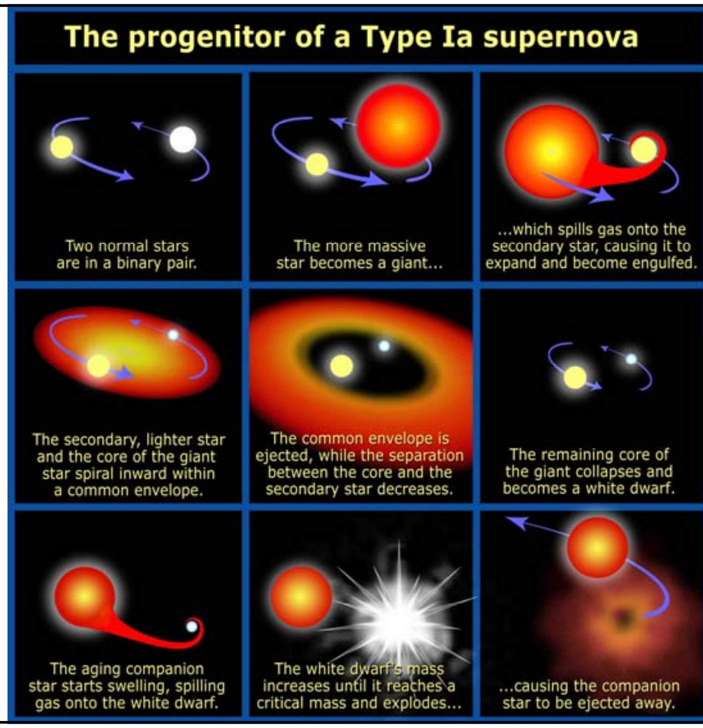


SN Ia as Standard Candles

Low Redshift Type Ia Template Lightcurves

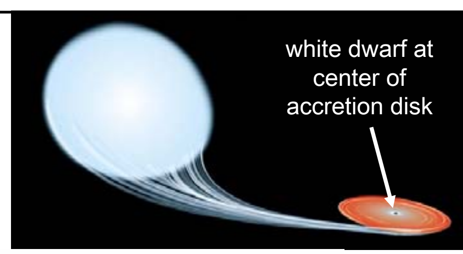


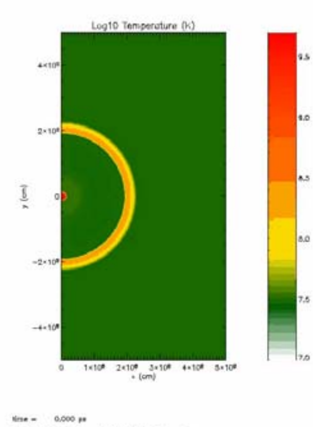




Type Ia Supernovae

- Neighbor star dumps too much mass onto a white dwarf.
- Increased density ➔ runaway heating through C + C burning
  - Overwhelms γ ➔ $\nu + \bar{\nu}$ cooling
- Heating rate faster than dynamical timescale
  - White dwarf interior cannot peacefully respond to pressure increase.
- *Deflagration*
  - leading to *detonation*?





Deflagration simulation

Type Ia Supernovae as "standard candles".

- Always happens when mass goes just past limit for heating-cooling balance.

  ➔ Supernova always has same luminosity.
- Get distance from $\text{Flux} = \dfrac{L}{4\pi r^2}$

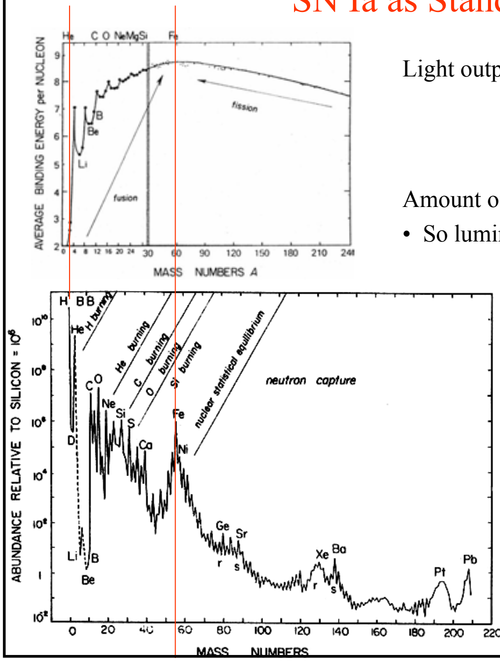
SN Ia as Standard Candles

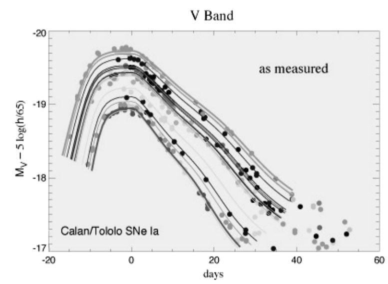
Light output powered by radioactive decay:

$^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$

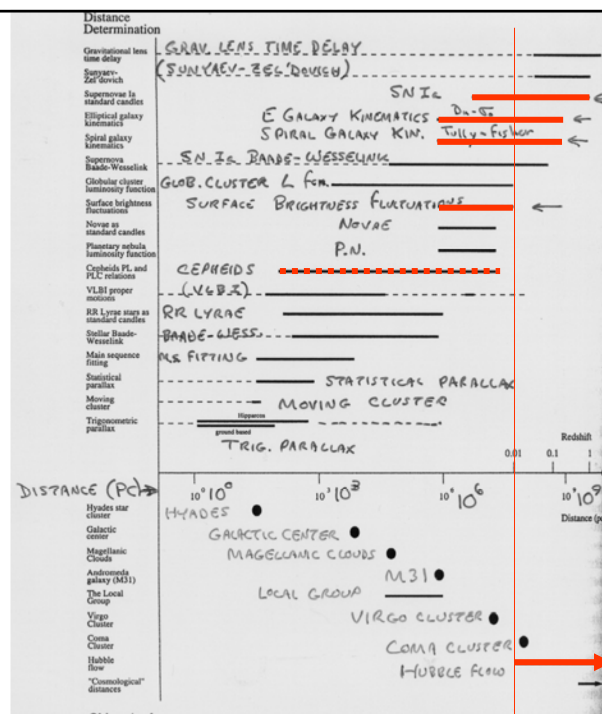
Amount of Ni determines both luminosity *and* opacity.

- So luminosity and fading timescale are correlated.

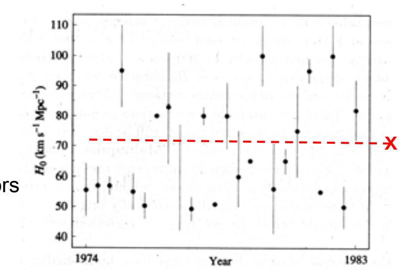




The Cosmic Distance Ladder and the HST Key Project



HST Key Project on Extragalactic Distance Scale

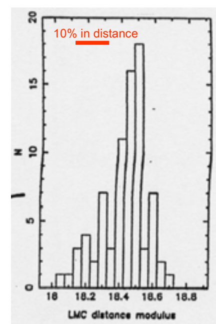


- Mould et al. 2000, ApJ 529, 786
- Measured Cepheids in 18 spirals
  - D < 25 Mpc,   v < 1800 km/s
  - also used 7 more galaxies from other sources
- Distances to Cepheids relative to LMC distance
- Used these to calibrate secondary distance indicators
  - Tully-Fisher
  - Fundamental plane
  - Surface brightness fluctuations
  - Type Ia supernovae
- Secondary distance indicators ==> coverage to 10^4 km/s
- Goal is to measure H_0

H_0 = 71 +/- 6 km/s/Mpc

TF:	71	+/- 4 (random)	+/- 4 (systematic)
FP:	78	8	10
SBF:	69	4	6
SN:	68	2	2

- Uncertainties:
  - Correction for large scale flows
  - Distance to LMC.
    Taken to be 50 kpc +/- 6.5%



Distribution of published LMC distance moduli