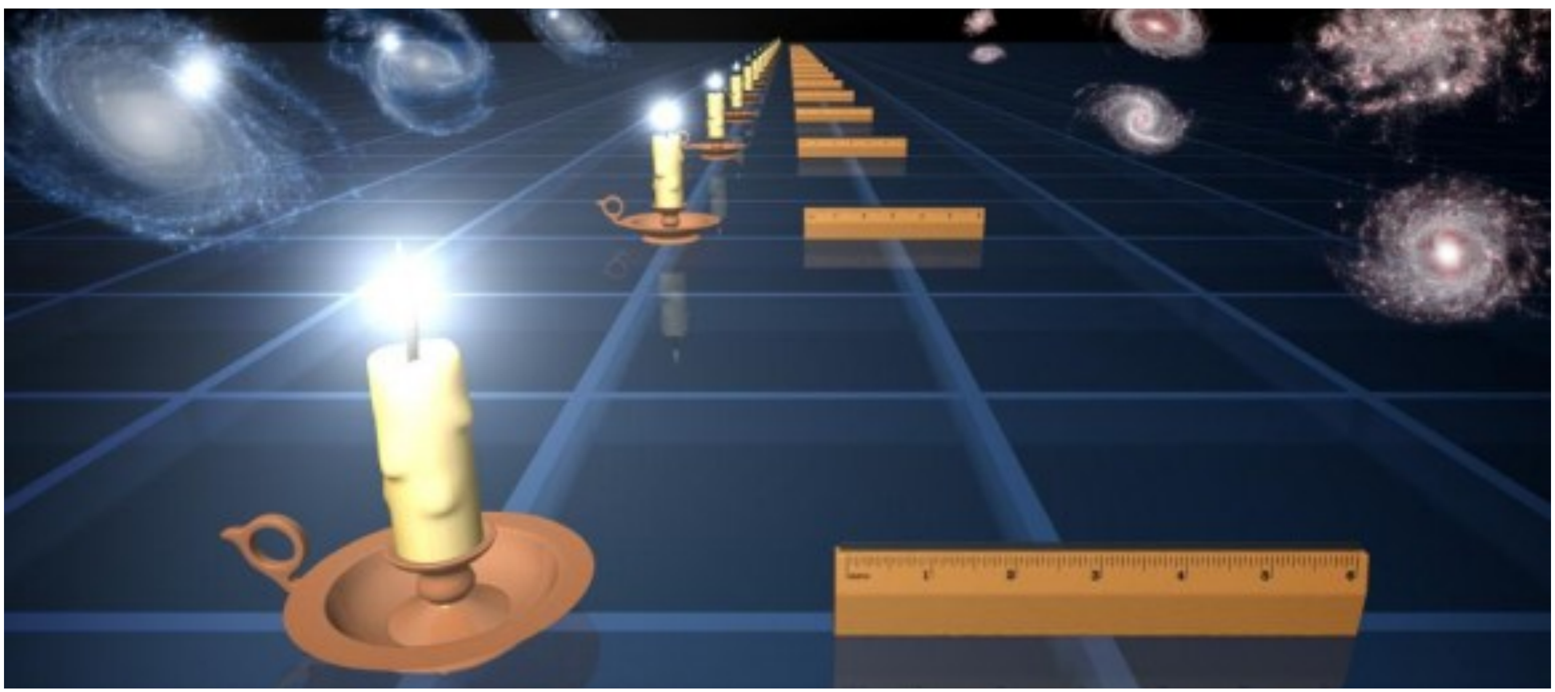

Supernova
Standard
Candles

The Basic Concept

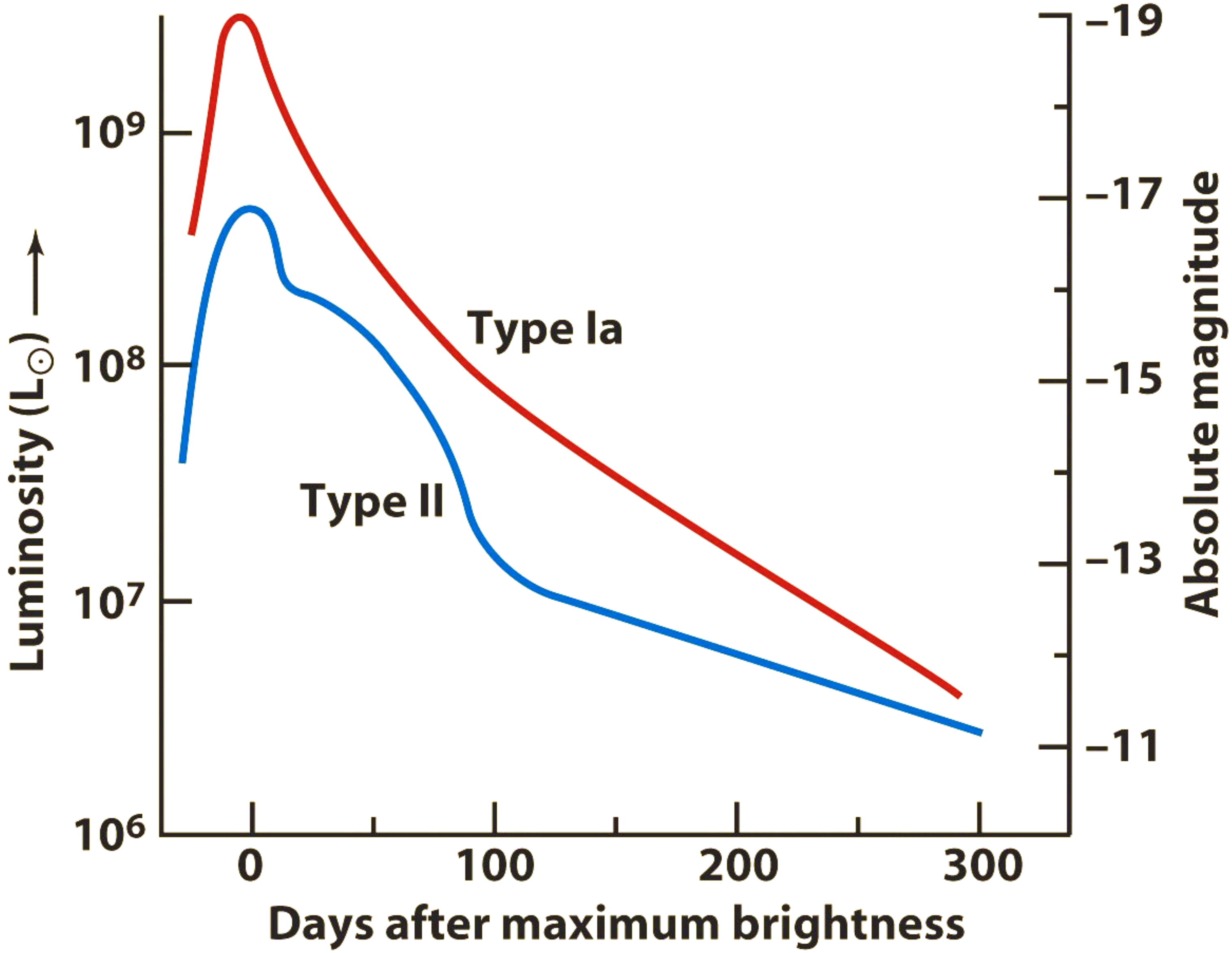
- If two sources have the same intrinsic luminosity (“standard candles”), from the ratio of their apparent brightness we can derive the ratio of their luminosity distances
- If two sources have the same physical size (“standard rulers”), from the ration of their apparent angular sizes we can derive the ratio of their angular diameter distances



Supernovae (SNe) as Standard Candles

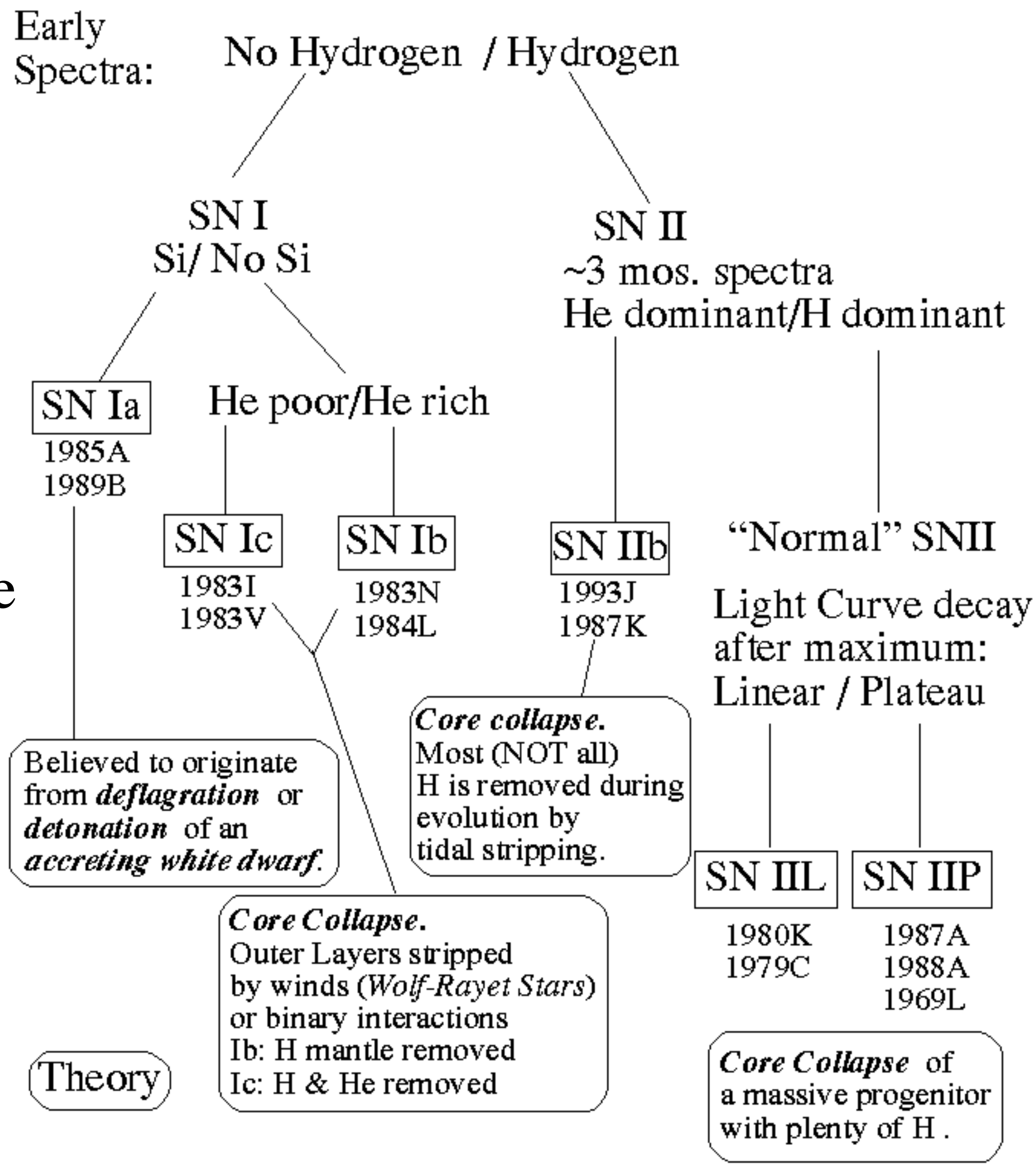
- Bright and thus visible far away
- Two different types of SNe are used as standard candles:
  - **Type Ia** from a binary white dwarfs accreting material and detonating
    - Pretty good standard candles, peak $M_V \sim -19.3$
    - There is a diversity of light curves, but they can be standardized to a peak magnitude scatter of ~ 10%
  - **Type II** from collapse of massive stars (also Type Ib)
    - Not good standard candles, but we can measure their distances using the "Expanding Photosphere Method" (EPM), essentially the Baade-Wesselink method of measuring the expansion of the outer envelope
    - Not as bright as Type Ia's

SN Types: Light Curve Differences



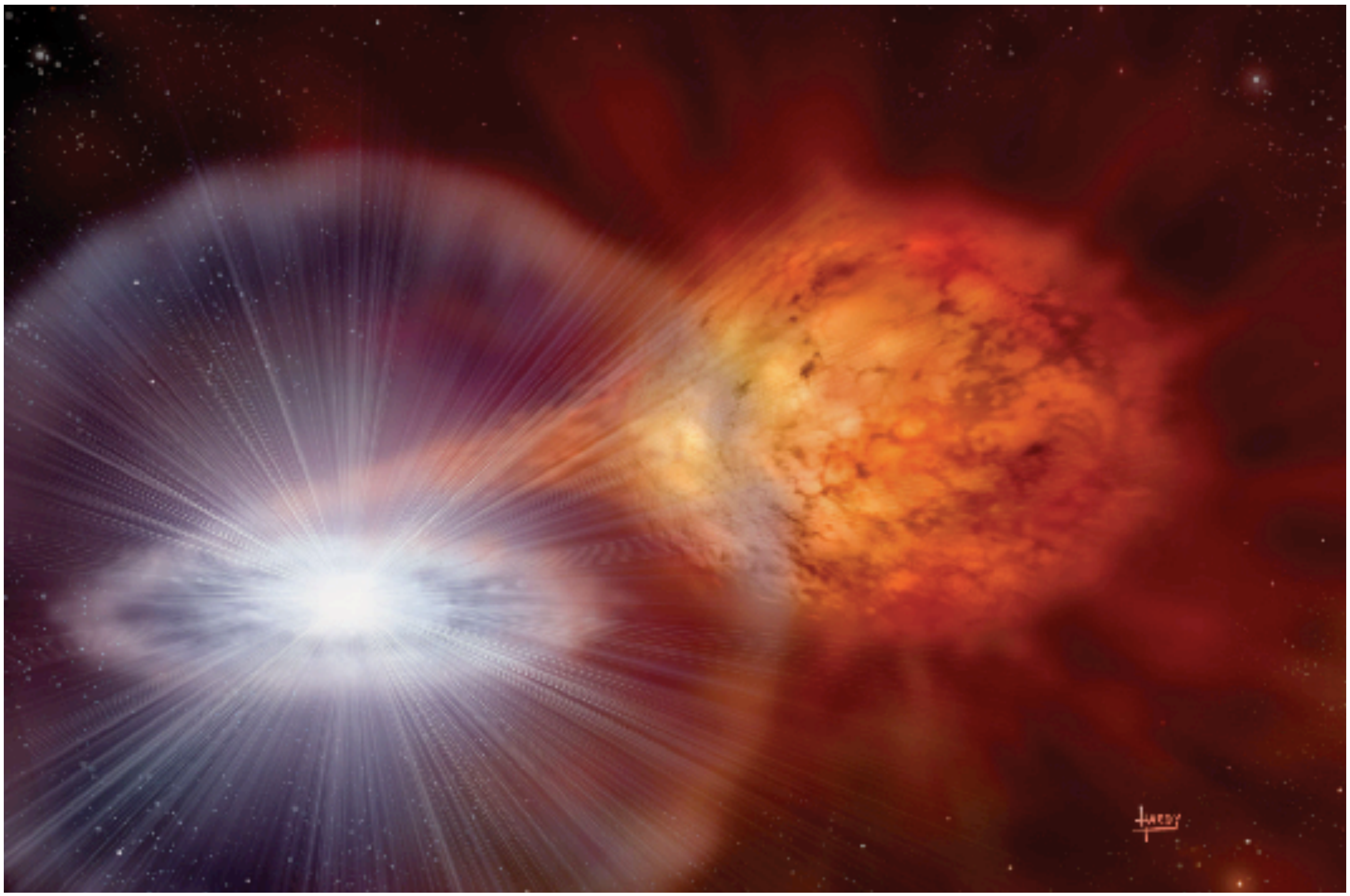
Supernova Classification

There are two basic mechanisms, but a variety of the possible evolutionary paths



Type Ia Supernovae

Believed to be caused by an accretion of material from a binary companion star to a white dwarf (WD), pushing it over its Chandrasekhar limit, causing its collapse



Type Ia Supernovae

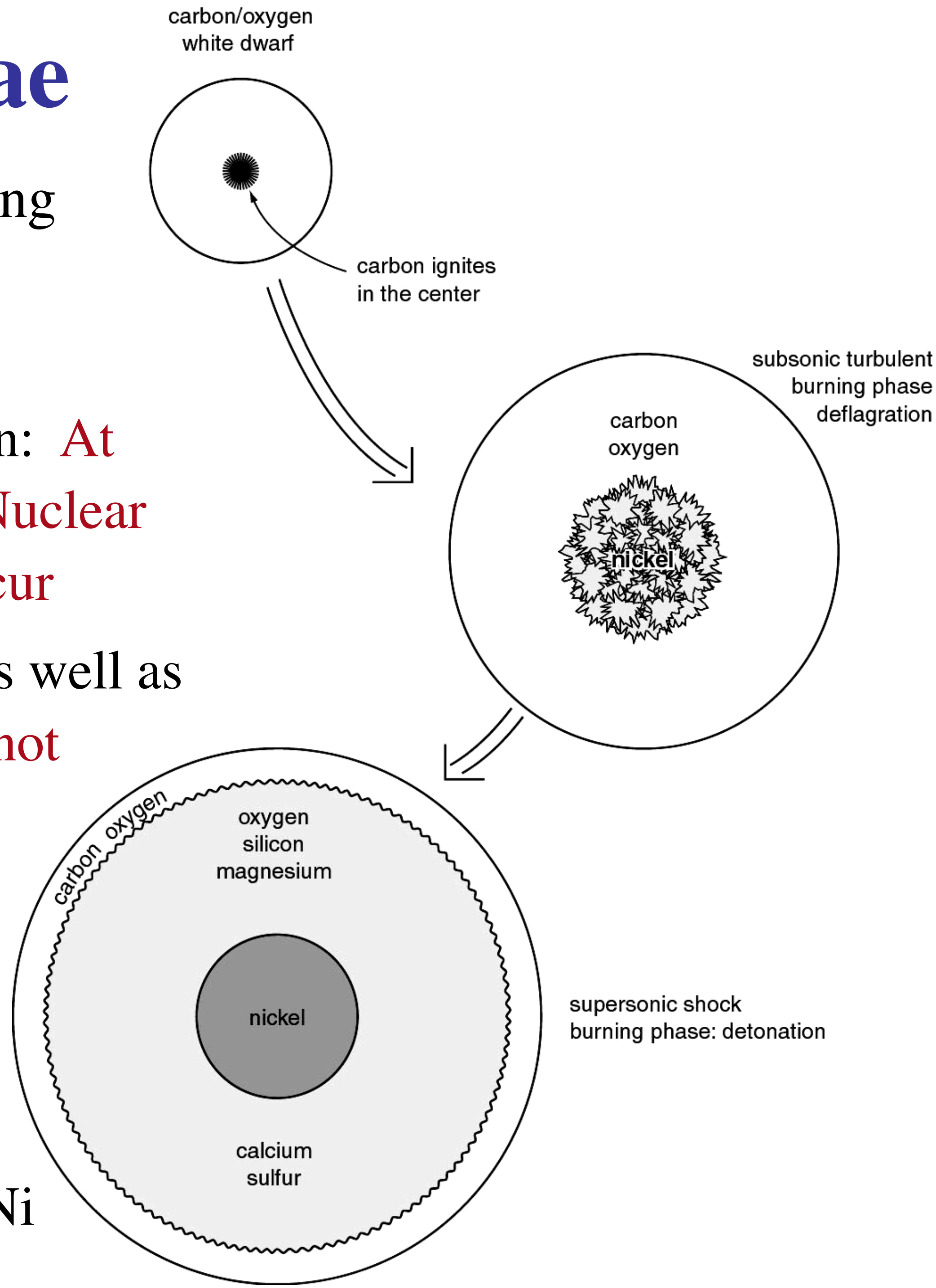
Their identification with exploding white dwarfs is still somewhat circumstantial, but strong:

• No H lines, Si lines in absorption: At most ~ 0.1 $M_{\odot}$ of H in vicinity. Nuclear burning all the way to Si must occur

• Observed in elliptical galaxies as well as spirals: Old stellar population – not from young massive stars

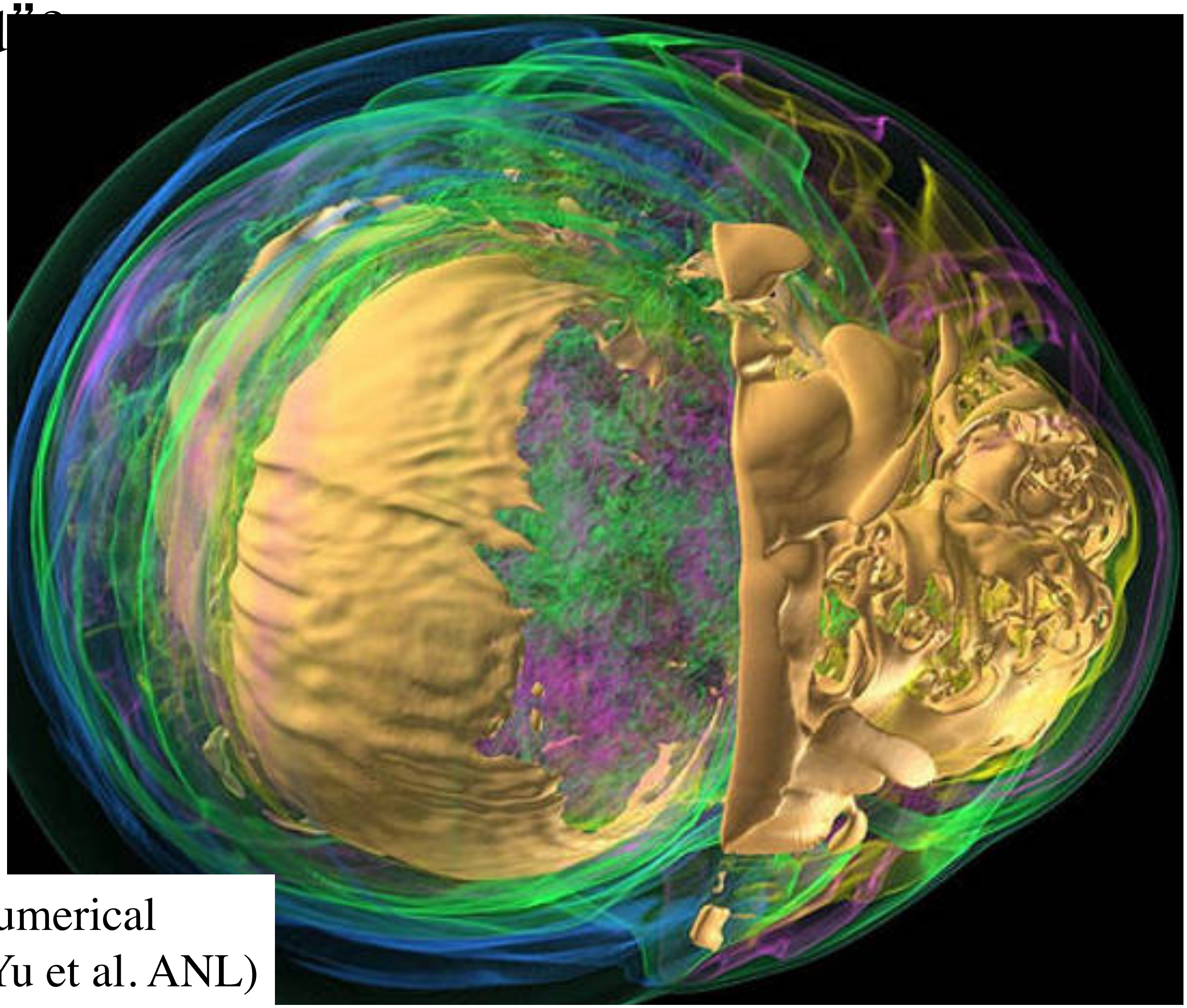
• Remarkably homogenous properties: Same type of an object exploding in each case

• Lightcurve fit by radioactive decay of about a Solar mass of ^{56}Ni



Stellar Explosions are a Messy Business

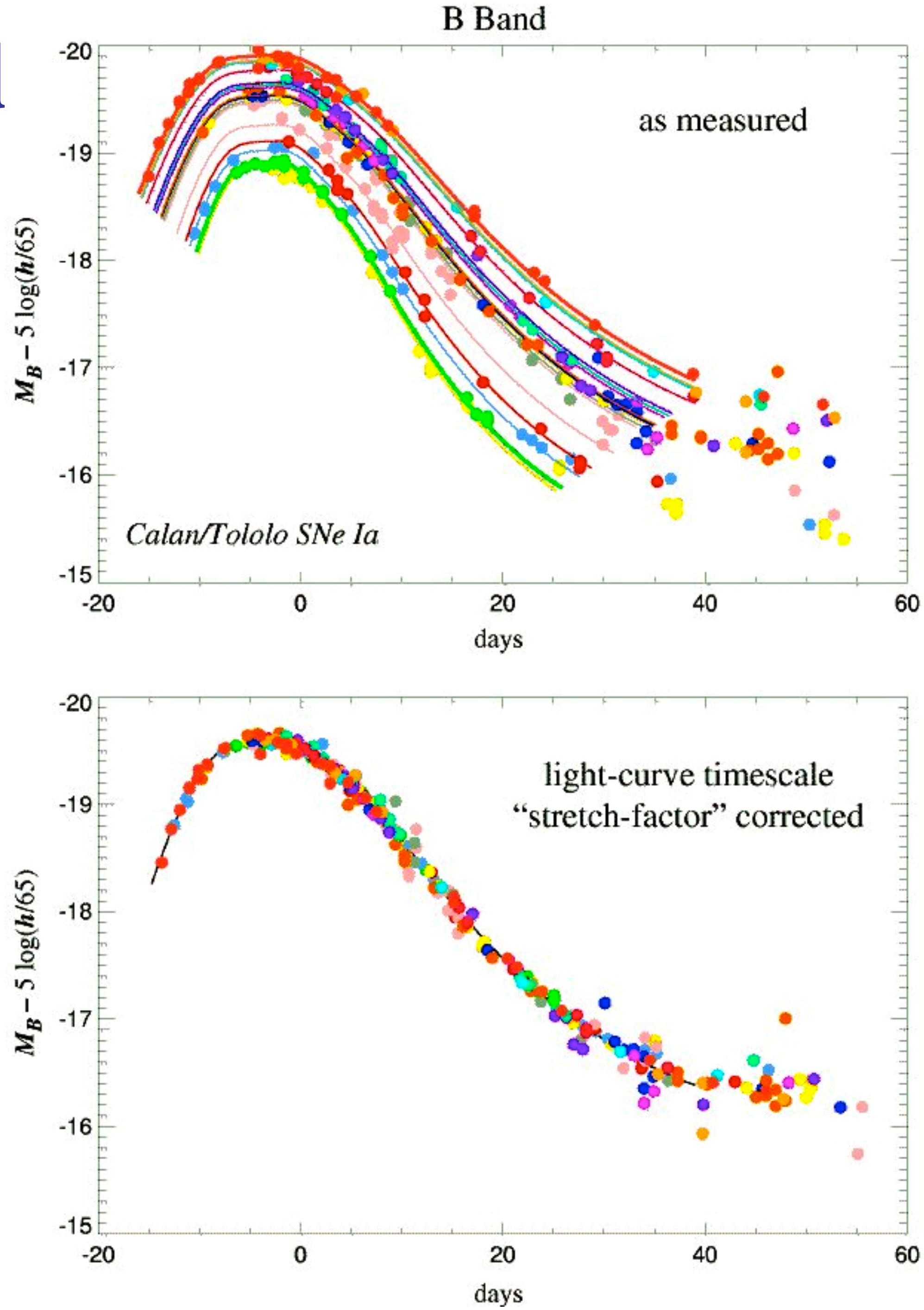
… and hard to model theoretically. How can they be “standard”?



Supernova numerical simulation (Yu et al. ANL)

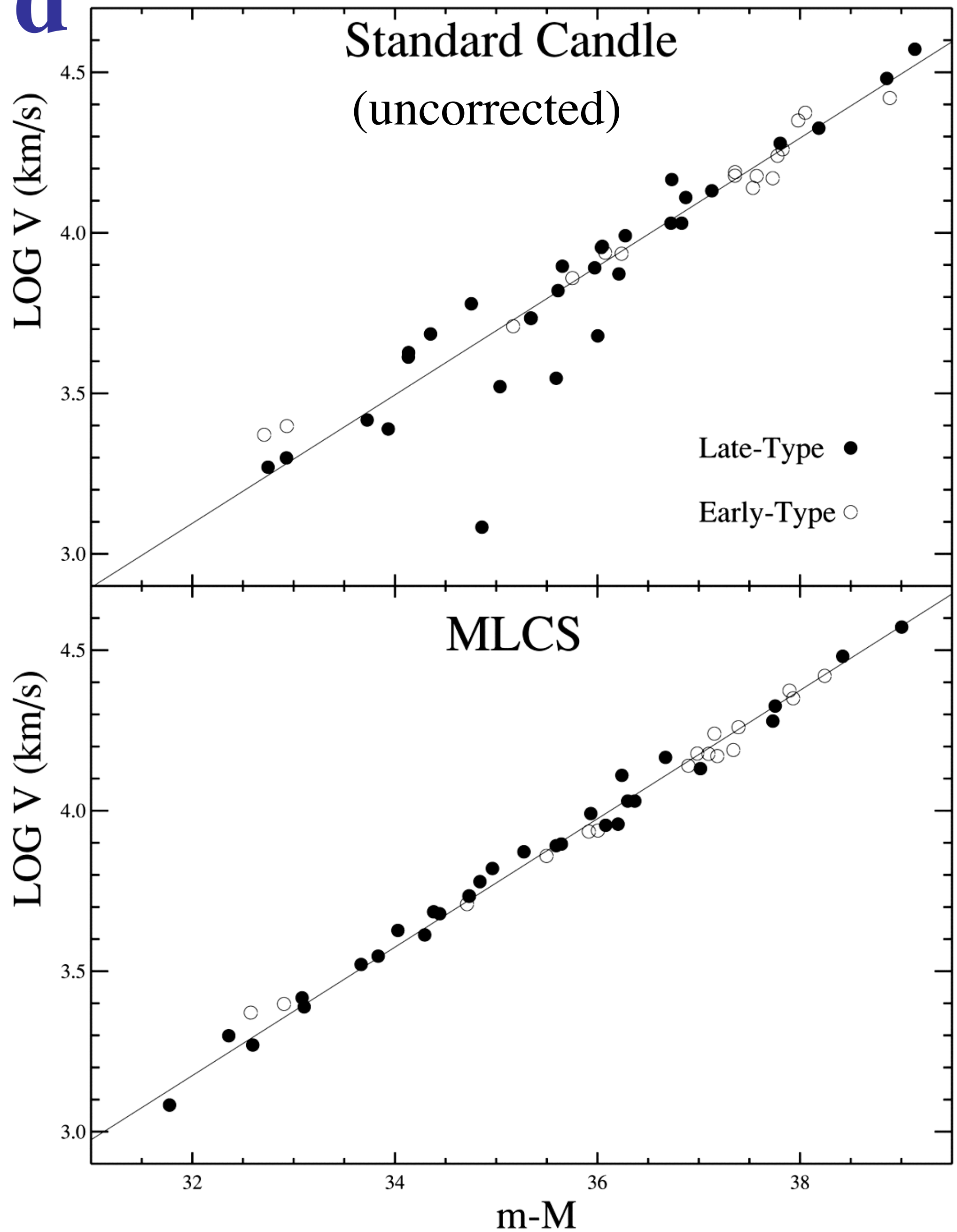
SNe Ia as Standard Candles

- The peak brightness of a SN Ia correlates with the shape of its light curve (steeper → fainter)
- Correcting for this effect standardizes the peak luminosity to ~10% or better
- However, the absolute zero-point of the SN Ia distance scale has to be calibrated externally, e.g., with Cepheids

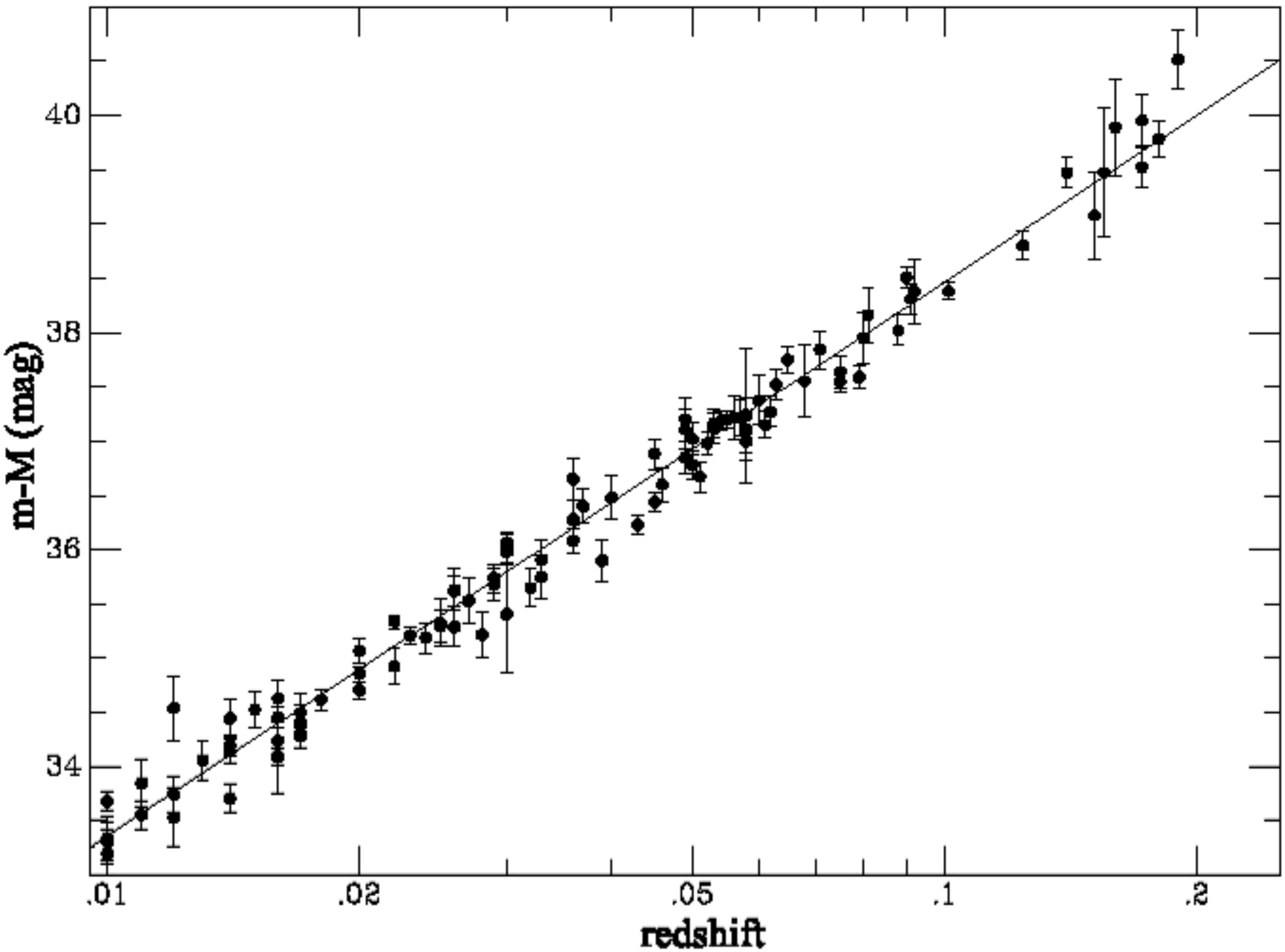


SNe Ia as Standard Candles

- A comparable or better correction also uses the color information (the Multicolor Light Curve method)
- This makes SNe Ia a superb cosmological tool (note: you only need relative distances to test cosmological models; absolute distances are only needed for the H_0)



The Low-Redshift SN Ia Hubble Diagram



The Expanding Photosphere Method (EPM)

- One of a few methods for a direct determination of distances; unfortunately, it is model-dependent
- Similar to the Baade-Wesselink method for pulsating variables
- Uses Type II SNe - could cross-check with Cepheids
- Based on the Stefan-Boltzmann law, $L \sim 4\pi R^2 T^4$

If you can measure T (which is distance-independent), understand the deviations from the perfect blackbody, and could determine R, then from the observed flux F and the inferred luminosity L you can get the distance D

The Expanding Photosphere Method (EPM)

EPM assumes that SN photospheres radiate as dilute blackbodies:

$$\theta_{ph} = \frac{R_{ph}}{D} = \sqrt{\frac{F_\lambda}{\zeta^2 \pi B_\lambda(T)}}$$

Apparent Diameter

Fudge factor to account for the deviations from blackbody, from spectra models

Determine the radius by monitoring the expansion velocity

$$R_{ph} = v_{ph}(t - t_0) + R_0$$

And solve for the distance!

$$t = D\left(\frac{\theta_{ph}}{v_{ph}}\right) + t_0$$


Next:
The Hubble Space Telescope
Distance Scale Key Project
and Beyond