Type Ia Supernovae diversity

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- The first results of cosmology with type Ia supernovae (Riess *et al.* 1998, Perlmutter *et al.* 1998) were obtained thanks to a normalization of supernovae taking into account the 'brighter/slower' and 'brighter/bluer' empirical relations between the absolute luminosity at maximum and other parameters of the lightcurves.

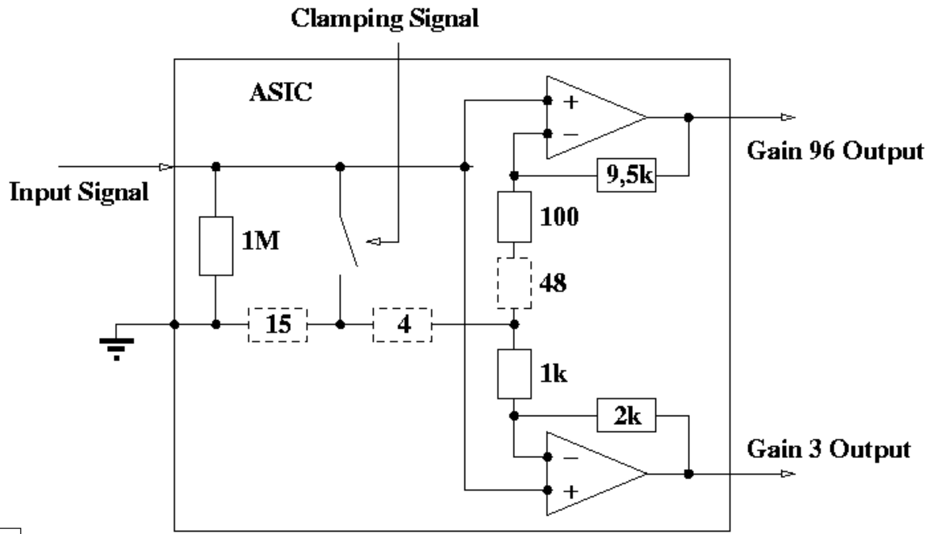
- Current experiments (SN Factory, SNLS, and similar projects) are obtaining more precise and larger samples of nearby and distant supernovae (up to a redshift of ~ 1), to make the normalizing relations as accurate as possible. This data should allow to study quantitatively the diversity of type Ia supernovae.

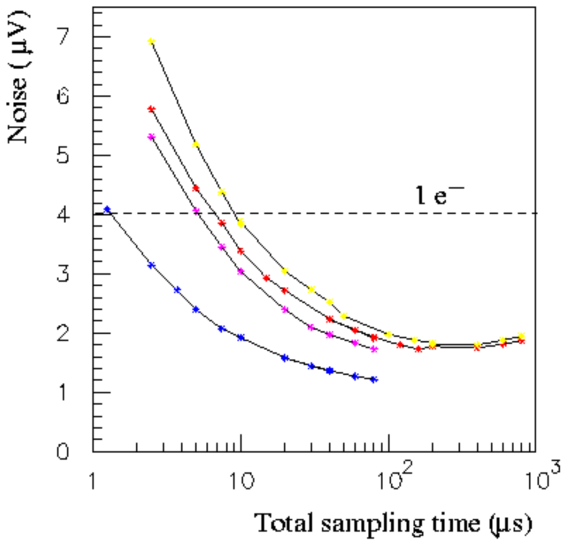
- A reccurrent doubt about supernovae cosmological results comes from the possible evolution of supernovae with time. The only way to lift that doubt is to obtain a 'sufficient' (to be determined) amount of data in several redshift bins, and to control the possible biases resulting of the evolution of type Ia supernovae with the age of host galaxies. This will be the task of next generation experiments.

- Several projects for next generation surveys (ground-based : PanSTARRS, DES, LSST, or space-based : SNAP, DUNE) will include a supernovae search component. Those projects aim for a wide coverage of the sky, using wide field cameras (1 to 10 square degrees) including a large number of CCD and/or IR pixel detectors.

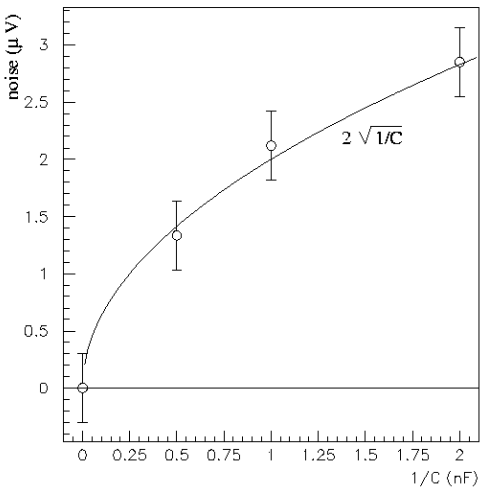
Preparing next generation experiments

- The challenge for the next generation of wide field cameras is to read out the CCD pixels at the high rate imposed by survey goals without sacrificing the dynamic range (between 2 and 250,000 electrons per pixel) or the precision because of readout noise.
- LPNHE has developed two test benches for CCD and IR detectors, and low noise electronics (ASIC).



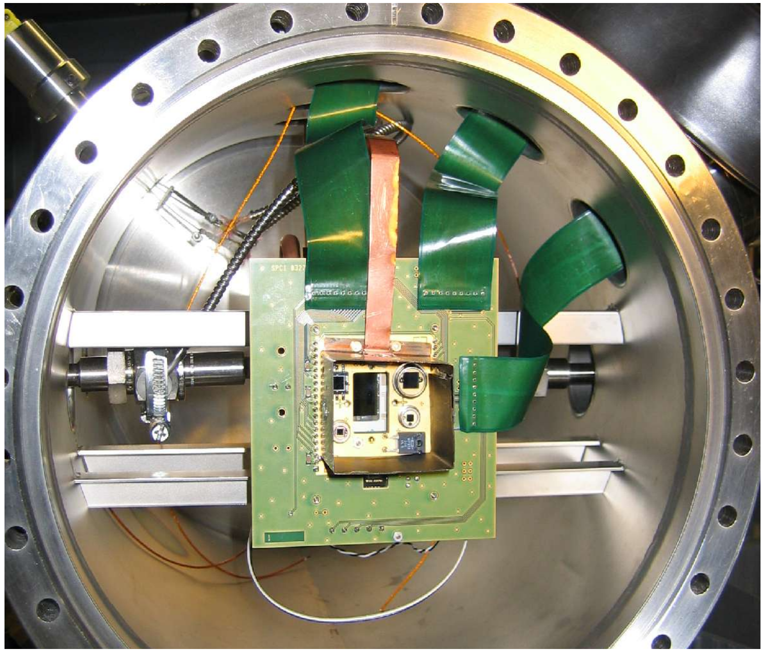


'Noise corner' : correlated double sampling (3 top lines) and single sampling



Measured kT/C noise versus 1/C, compared to theoretical curve

Inside view of the CCD test bench



Radioactive decay and deposition

The (not so) consensual model for type Ia supernovae explosions :

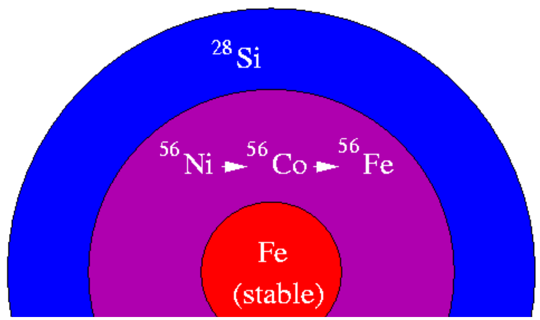
- A C+O white dwarf accretes matter from a companion star up to Chandrasekhar mass. It may also contain some neutron-rich elements like ^{22}Ne.

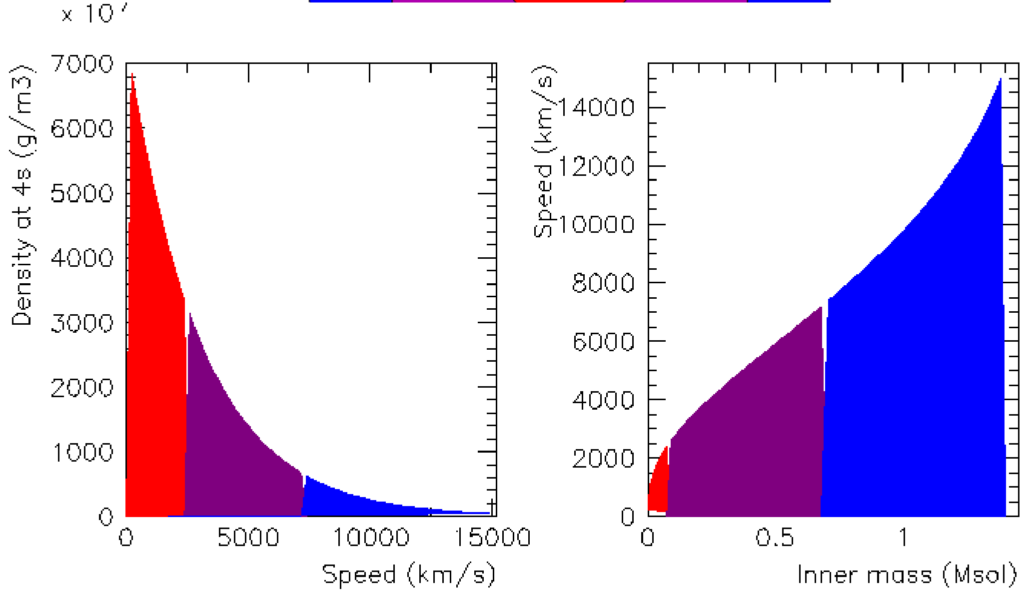
- During the explosion, C and O fuse into the most stable isotopic elements (mainly ^{56}Ni) and various intermediate mass elements. Most of the thermonuclear energy is converted to kinetic energy : all the matter is expelled at high speed (up to 20,000 km/s).

- The luminosity of the supernova comes from the radioactive decay of ^{56}Ni into ^{56}Co (half-life : 6.1 days), then into ^{56}Fe (77.1 days). Therefore the quantity of synthesized ^{56}Ni is supposed to be the key parameter controlling the absolute luminosity of the supernova at maximum.

The simulation :

- A Chandrasekhar-mass sphere in homologous expansion, with a multi-layered structure, for example :





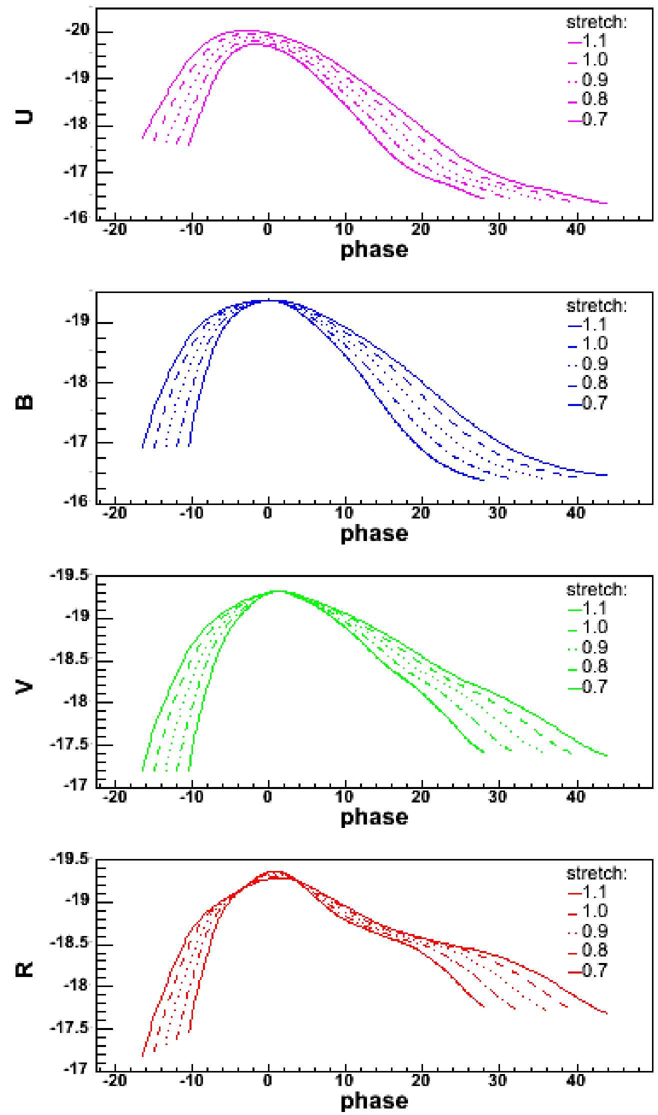
Density distribution here : $\rho(v) = \rho_0 \exp(-5\, v / v_{max})$

SALT empirical template

- The SALT model developed by the SNLS group :
  - A spectral 'template'
  - A sum of two polynomials as a correction function depending on phase, wavelength, and two empirical parameters : 'stretch' and 'color'
- 'Training' on a sample of nearby type Ia supernovae
- For a supernova with $m*_B$, *s* and *c* derived from the lightcurves, the distance estimator is : $\mu_B = m*_B - M + \alpha\cdot(s-1) - \beta\cdot c$
- To minimize the residuals in the Hubble diagram, including a sample of nearby supernovae and the SNLS first year sample :

$$M = -19.3 \pm 0.03 + 5\log(h_{70})$$
$$\alpha = 1.52 \pm 0.14$$
$$\beta = 1.57 \pm 0.15$$

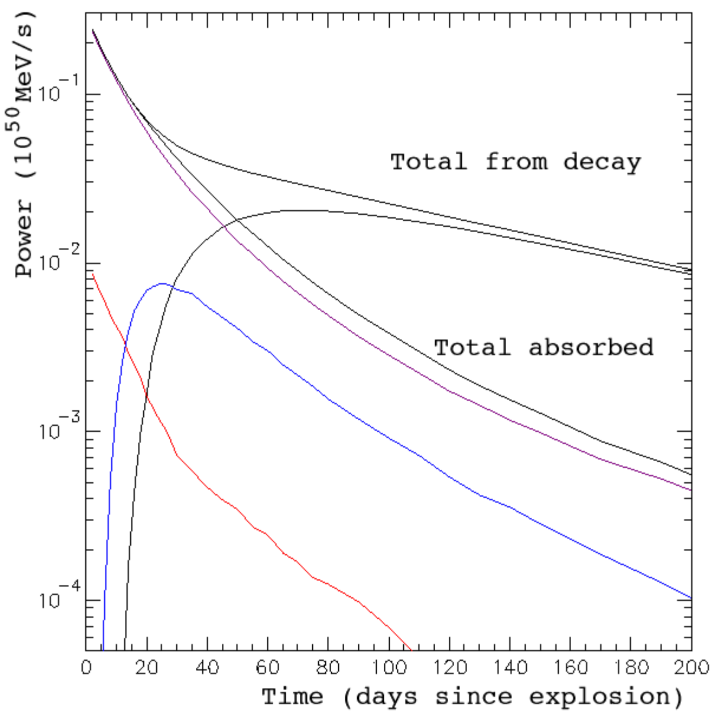
From Astier *et al.*, SNLS collaboration, 2005



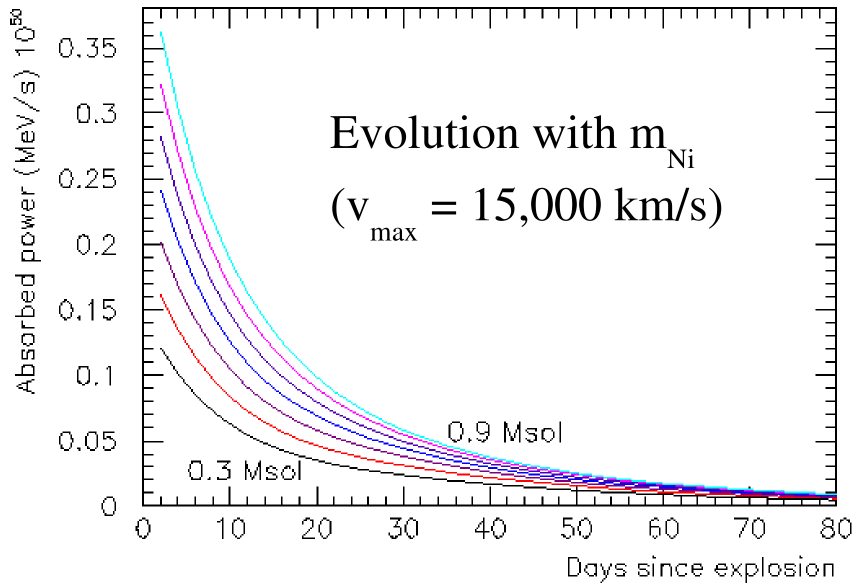
Guy *et al.*, 2005

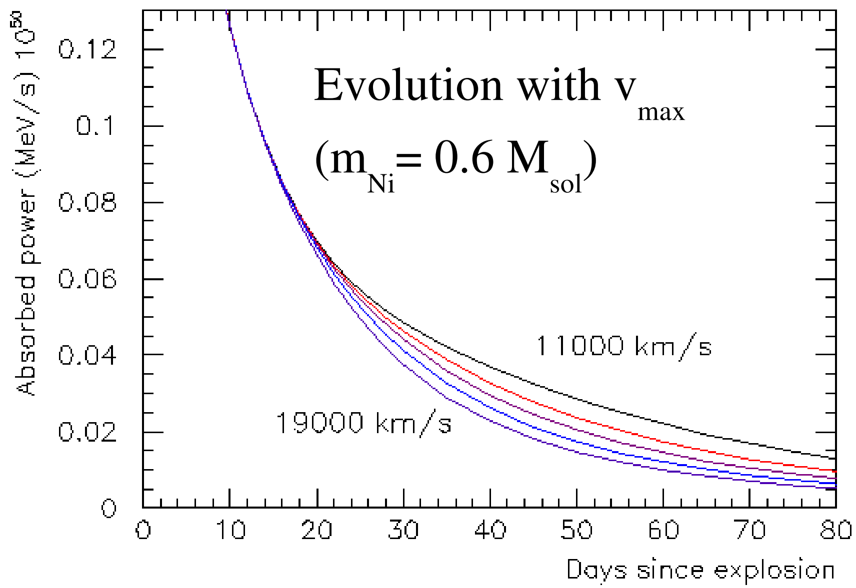
Energy deposition from simulation

- The propagation of the gamma rays produced by radioactive decay is simulated by Monte-Carlo, with interactions by Compton or photo-electrical effect.
- The positron kinetic energy is entirely transferred to the medium.



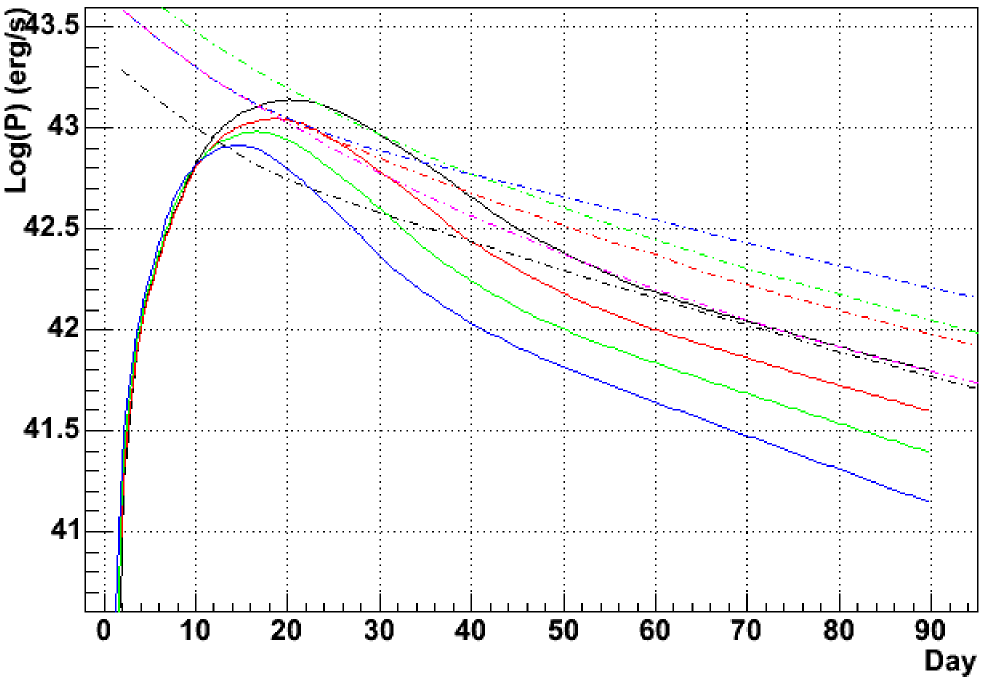
Typically : $m_{Ni} = 0.6\ M_{sol}$, $v_{max} = 15{,}000$ km/s



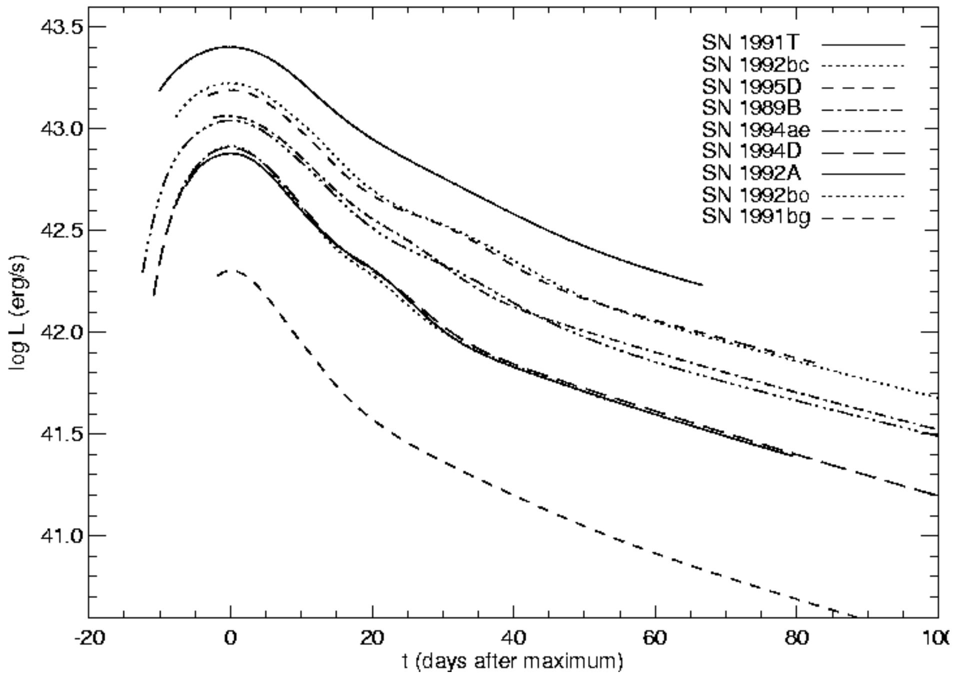


Bolometric lightcurves from SALT

- 'Bolometric' range is supposed to cover the whole spectrum ; to compare to other authors, we take a range of 3,000 to 10,000 Å.
- The absolute calibration of the lightcurve is done thanks to the cosmological fit : the best fit for the distance estimator gives the absolute magnitude at maximum in B band (with reference to Vega) for a supernova at 10 pc. This gives the calibration factor to get the power emitted by the supernova.



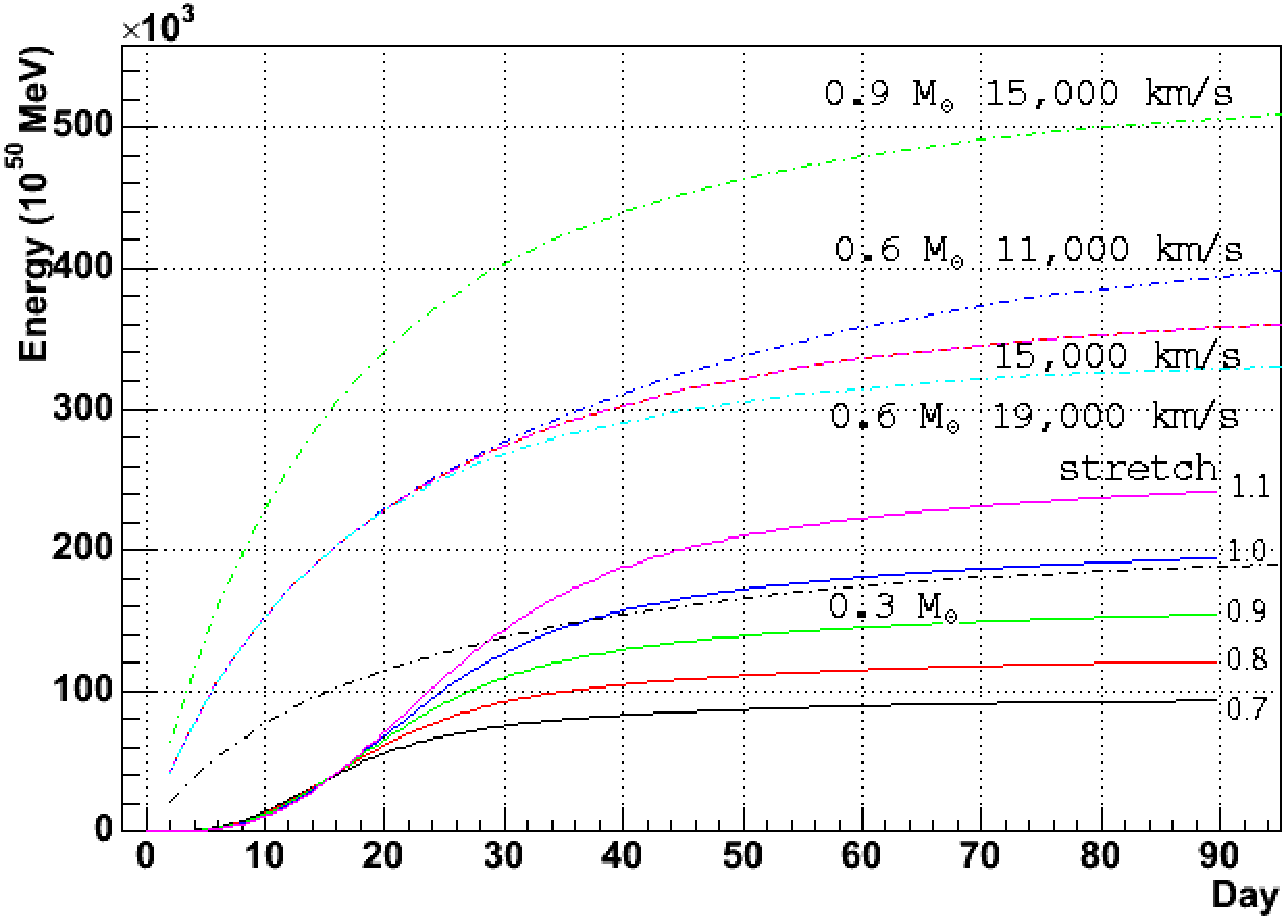
Filled : SALT with *s* and *c* from real supernovae
Dashed : simulation for several m_{Ni}/v_{max}



Contardo *et al.*, 2000

Cross-correlations between sets of parameters

- The goal is to find relations between the empirical parameters from SALT and the physical parameters injected into the simulation.
- A first example : if we had truly bolometric lightcurves, the luminosity integrated as a function of time should equal the total absorbed decay energy.
- Studying the distributions of this or other empirical quantities should give some insights into the distributions of physical parameters.

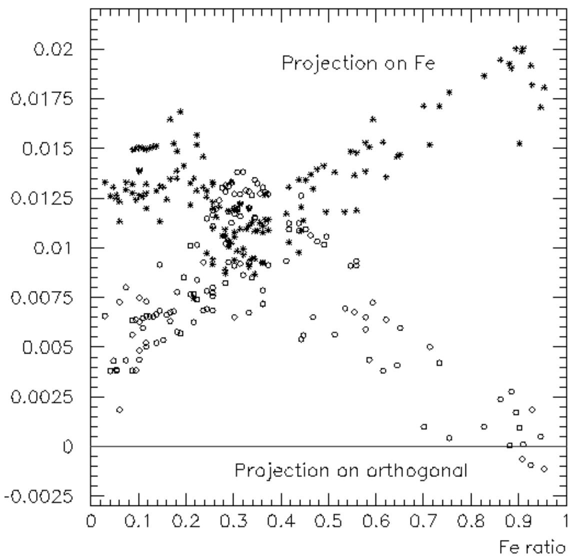


$$I_{\infty} = 3.33\left[(0.093 + m_{Ni}) + \frac{10^4}{v_{max}}(0.057 + 0.967\, m_{Ni})\right]10^{55}\, MeV$$

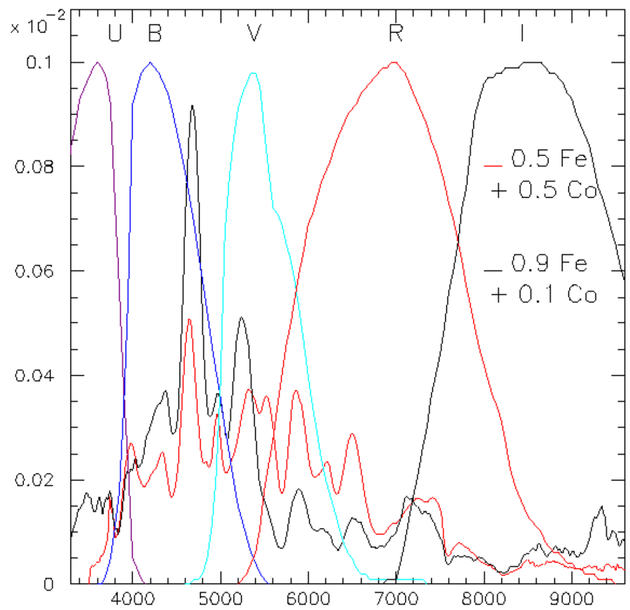
$$I_{\infty} = 2.82\,(s^2 - 0.68\, s + 0.26)\cdot(c^2 - 1.68\, c + 1.23)\,10^{55}\, MeV$$

Next steps for data analysis

- Another quantity correlated both to the empirical parameters and to the physical parameters is the rate of decrease at late times after maximum, but the SALT model focused on the lightcurves around maximum and is less reliable at those times.
- An alternative way : in the 'nebular' phase of the evolution of the supernova, the spectrum is essentially an emission spectrum of cobalt turning into iron. An analysis with two spectral components (hypothetically a 'cobalt' component and an 'iron' component) evolving as a function of the iron content yields results regarding the color evolution of supernovae at those times.

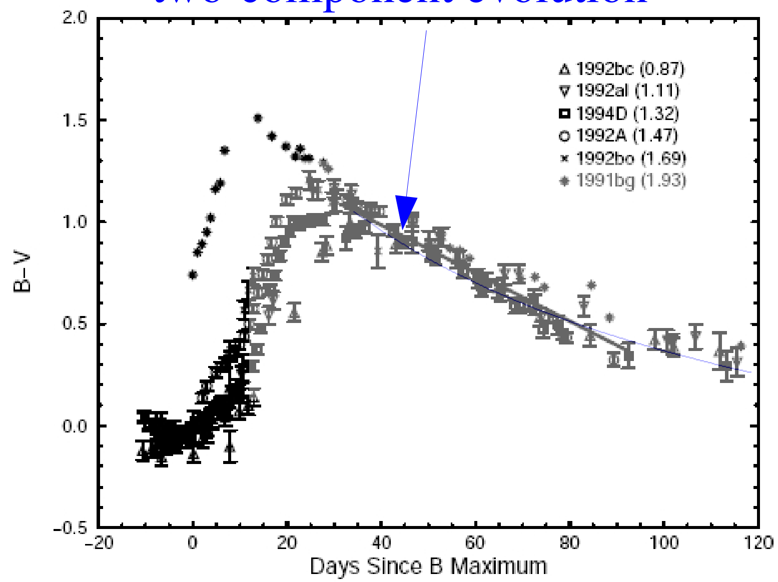


Projections of raw spectra on two orthogonal components vs. iron ratio



Reconstitutions from 'Fe' and 'Co' components + Johnson filters

B-V color synthesized from two-component evolution



Data from Phillips et al. (1998) illustrating the 'Lira' relation