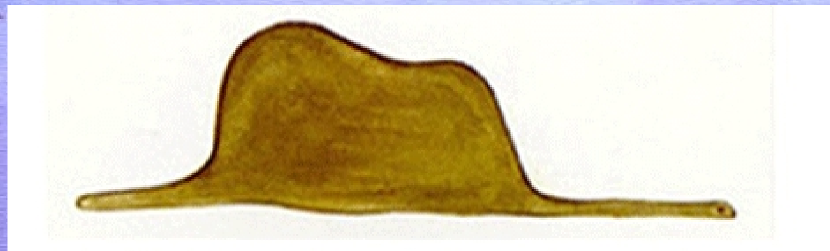
The Rise-Time of Type II Supernovae

MNRAS,451,221,2015



S. González-Gaitán, N. Tominaga, J. Molina, L. Galbany, F. Bufano, J. P. Anderson, C. Gutierrez, F. Förster, G. Pignata, M. Bersten, D. A. Howell, M. Sullivan, R. Carlberg, T. de Jaeger, M. Hamuy, P. V. Baklanov,S. I. Blinnikov

Accepted to MNRAS

STEPS, July 10, 2015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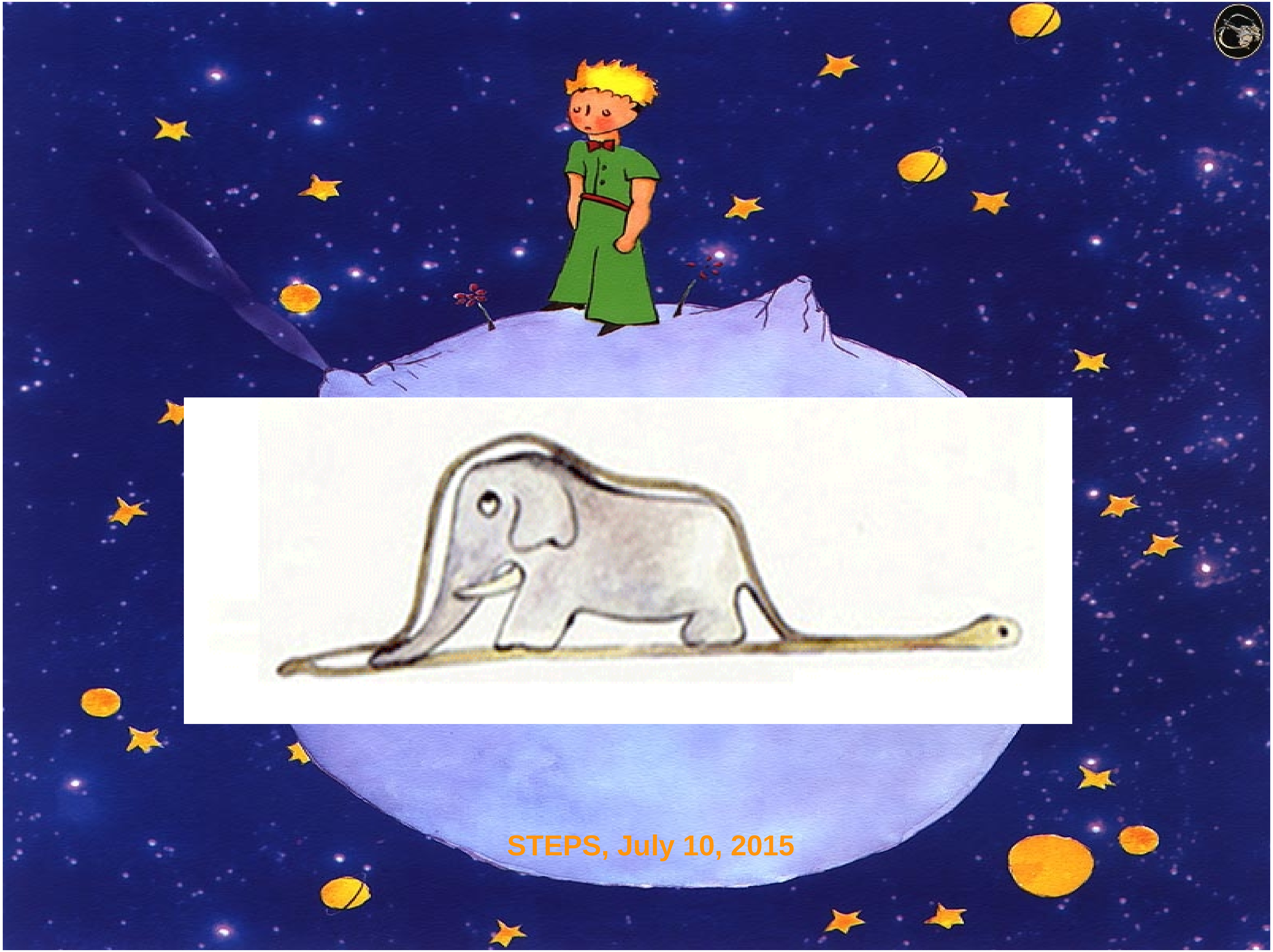
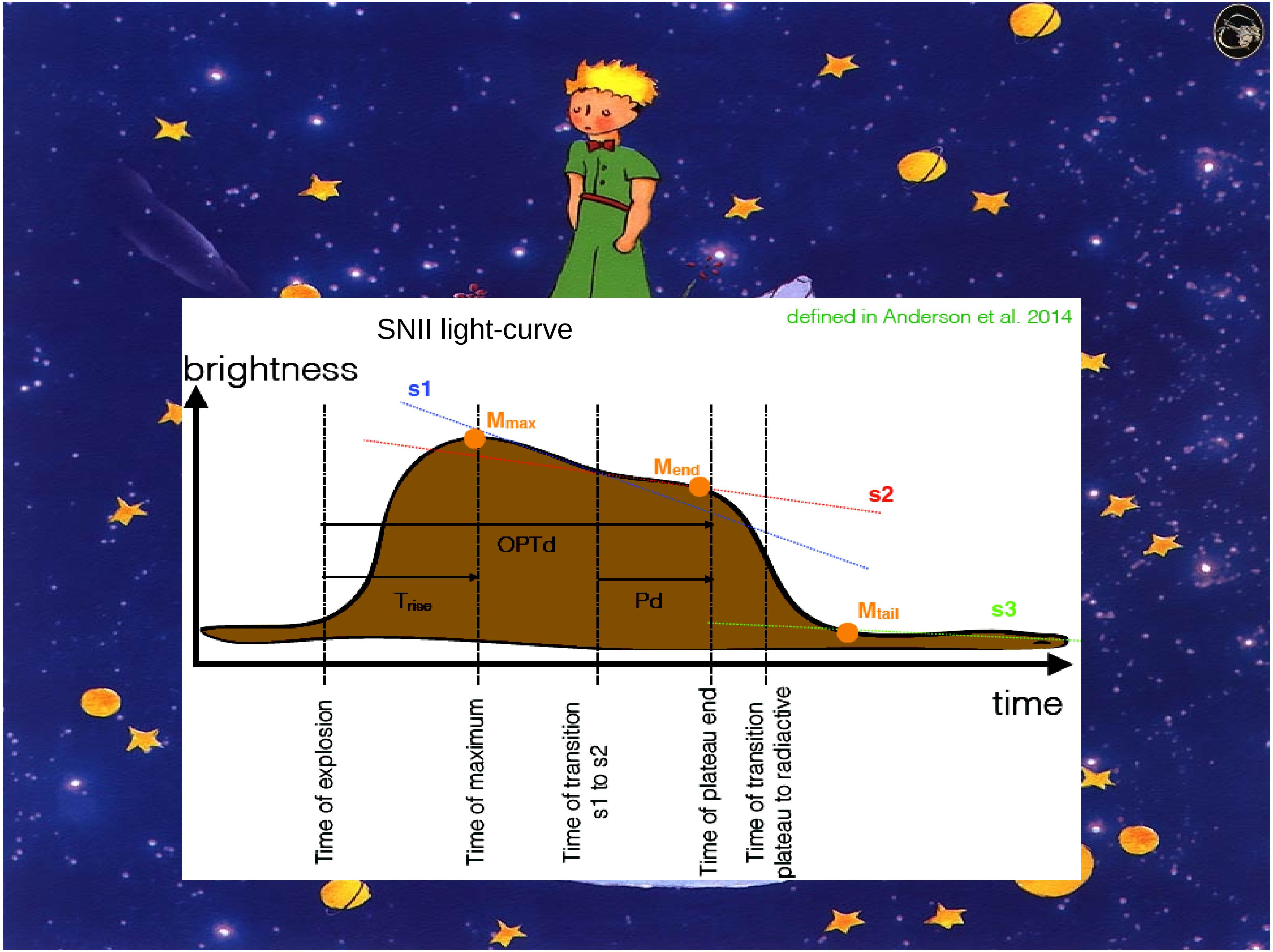
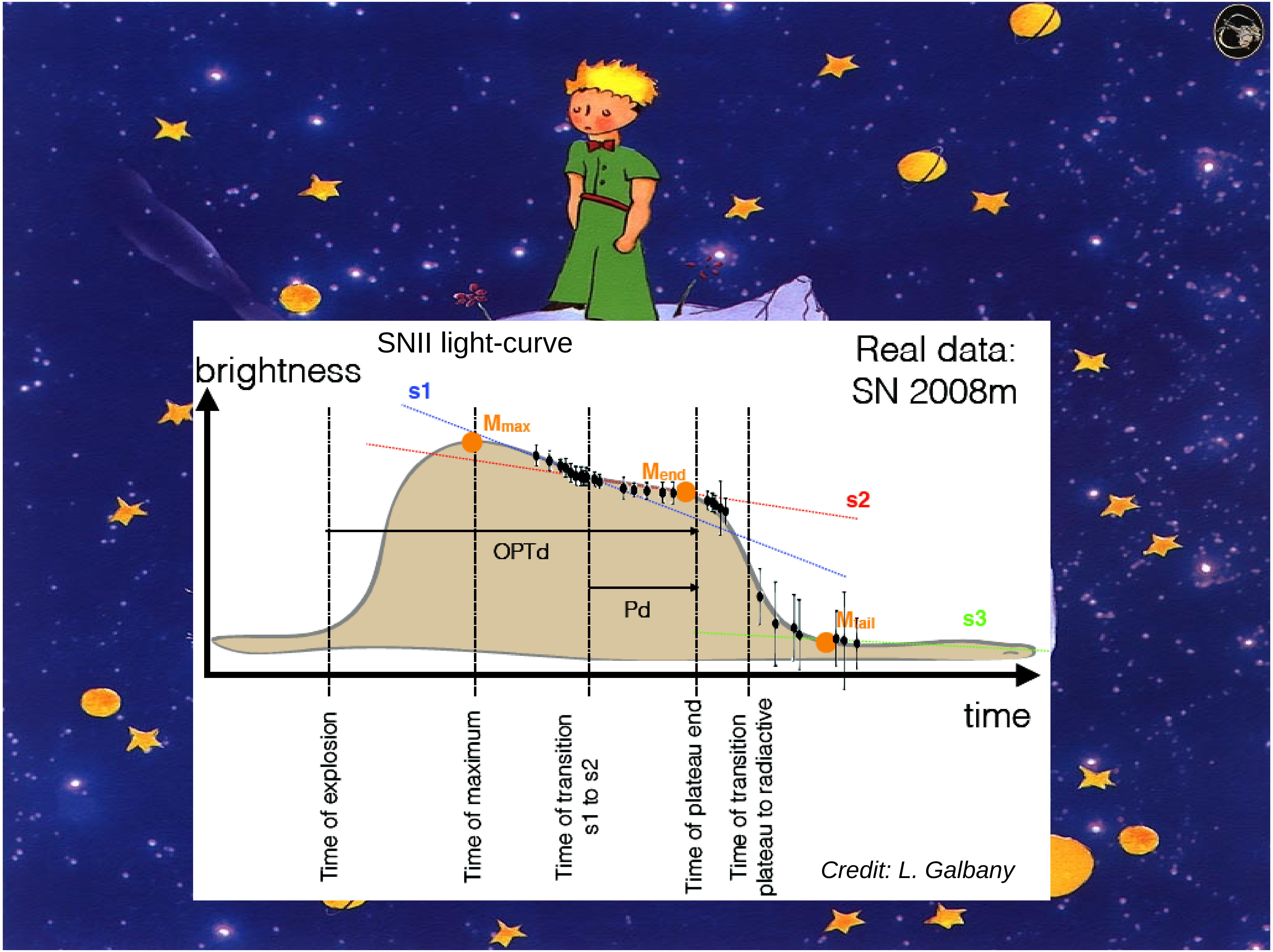

STEPS, July 10, 2015



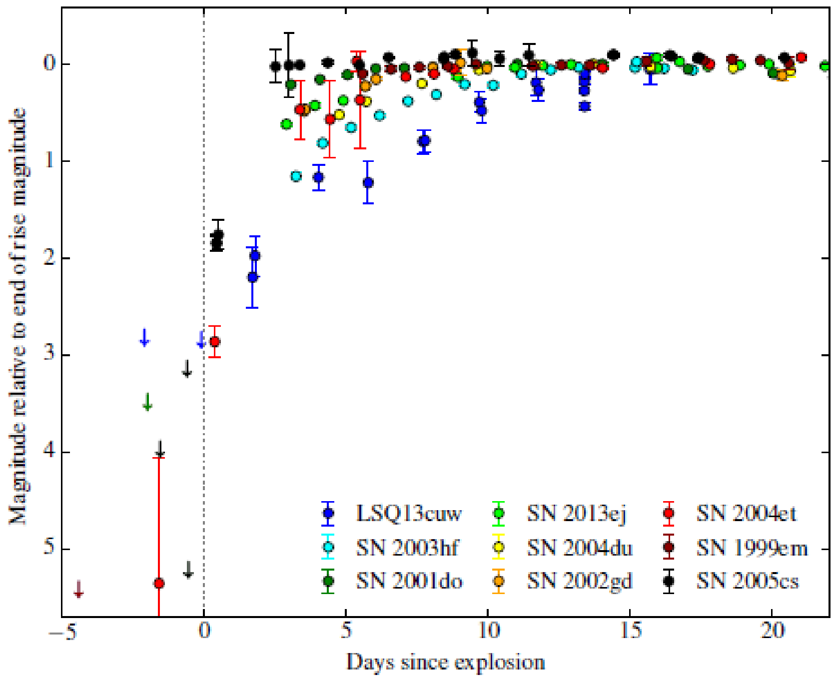
SNII light-curve
defined in Anderson et al. 2014
brightness
time
s1
s2
s3
Mmax
Mend
Mtail
OPTd
Trise
Pd
Time of explosion
Time of maximum
Time of transition s1 to s2
Time of plateau end
Time of transition plateau to radiactive



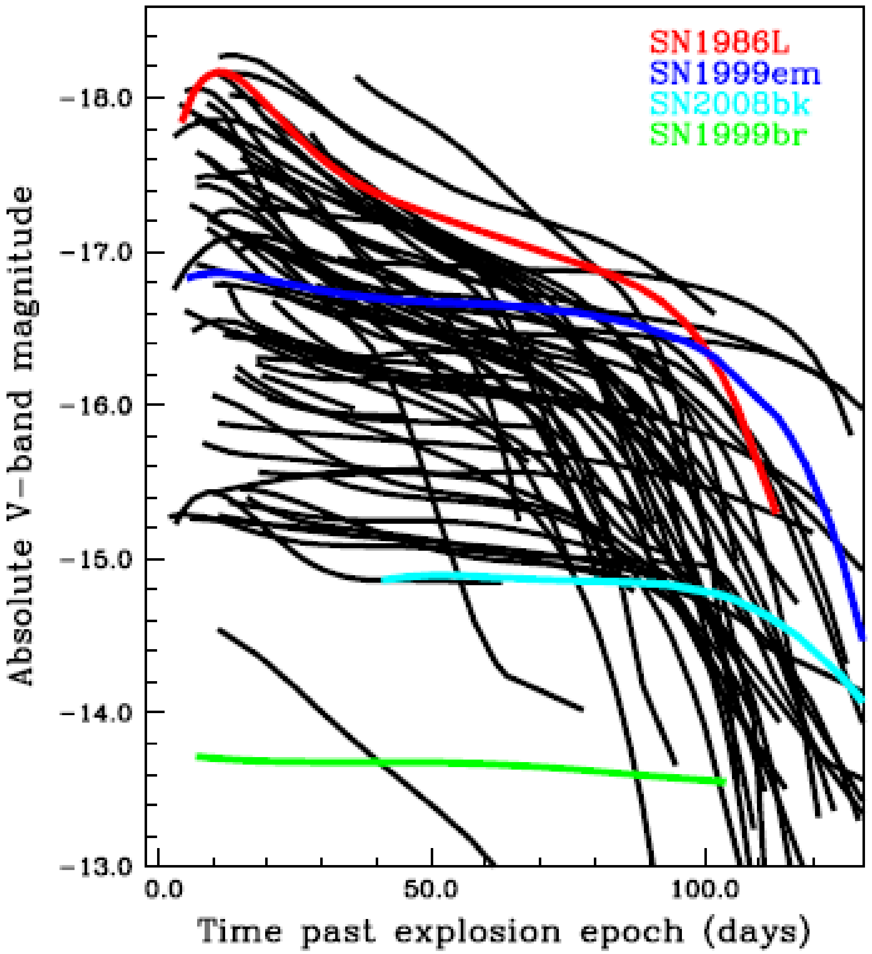
SNII light-curve
Real data:
SN 2008m
brightness
s1
Mmax
Mend
s2
OPTd
Pd
Mtail
s3
time
Time of explosion
Time of maximum
Time of transition
s1 to s2
Time of plateau end
Time of transition
plateau to radiactive
Credit: L. Galbany

Type II light-curves

- At low-z SNe II are discovered near or after maximum in B
- Very few SNe with pre-maximum data



Gall et al 2015

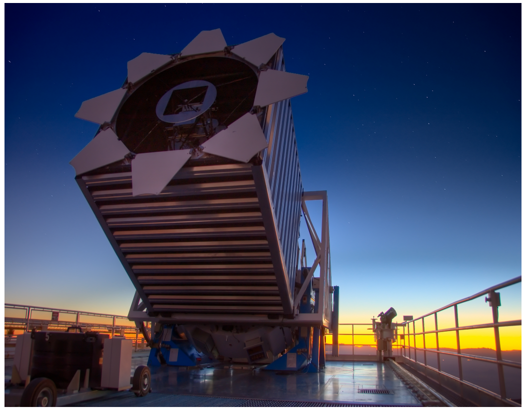


Anderson et al 2014

DATA: rolling searches

Sloan Digital Sky Survey-SDSSII

- 2005-2007 aimed mostly at SNe Ia
- Sloan-2.5m with *ugriz* filters

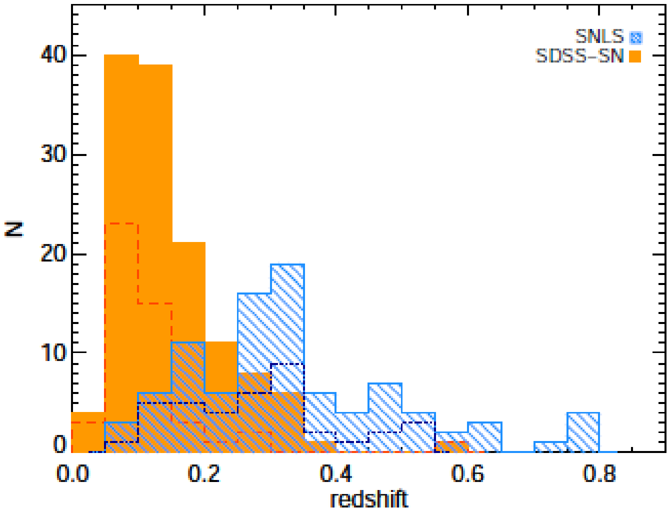


Supernova Legacy Survey-SNLS

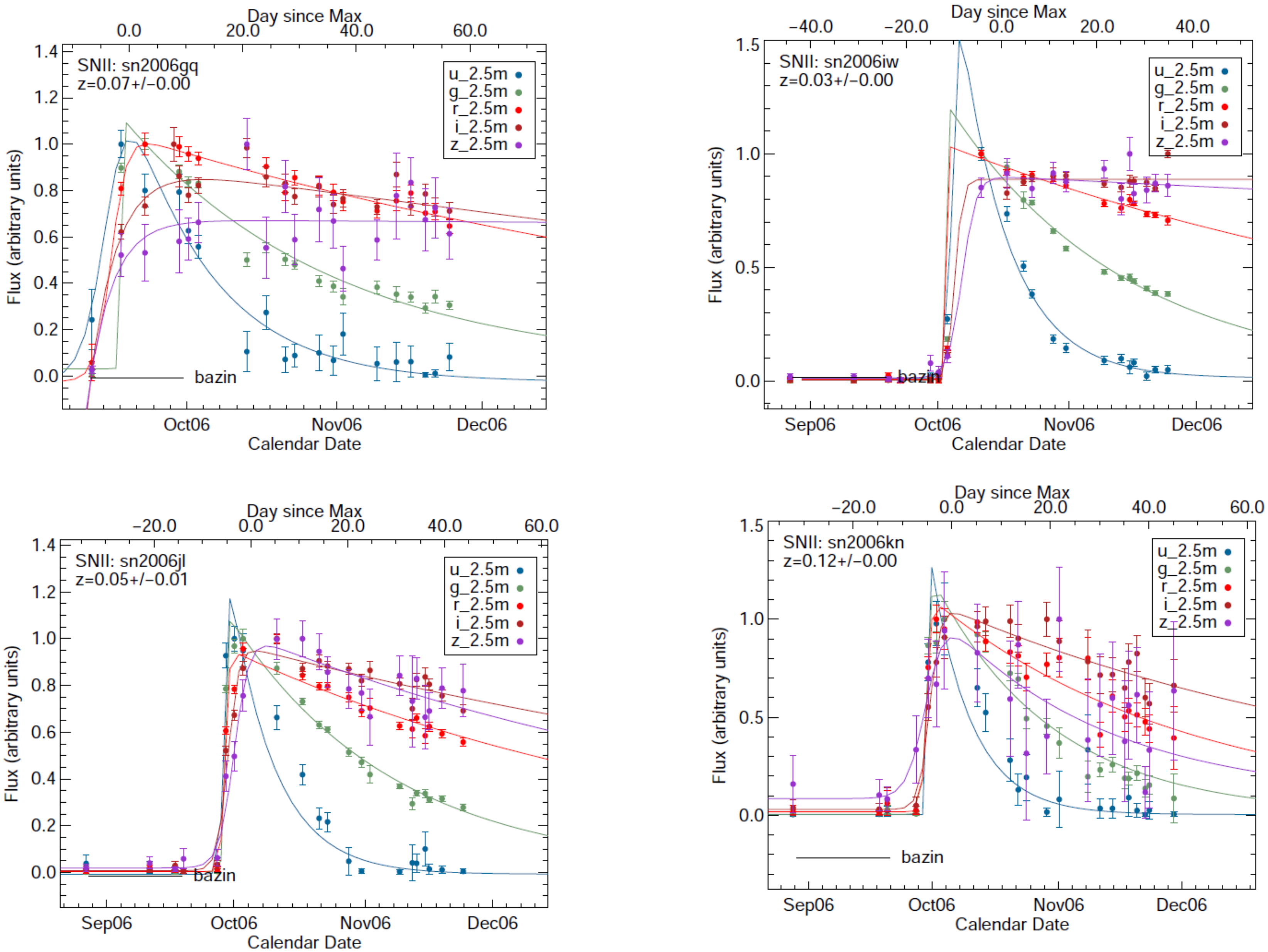
- 2003-2008 aimed mostly at SNe Ia
- CFHT with *griz* filters

Total sample

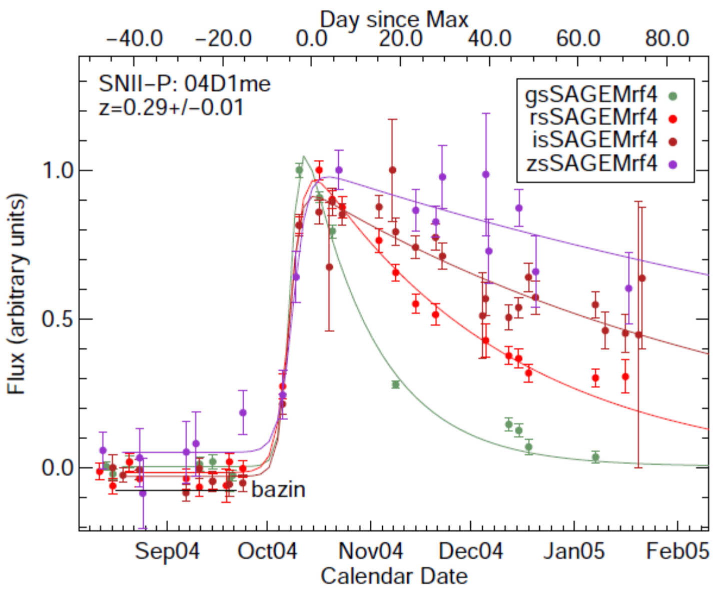
- 223 type II supernovae
- 94 spec-z with early data
- At 0.1<z<0.8

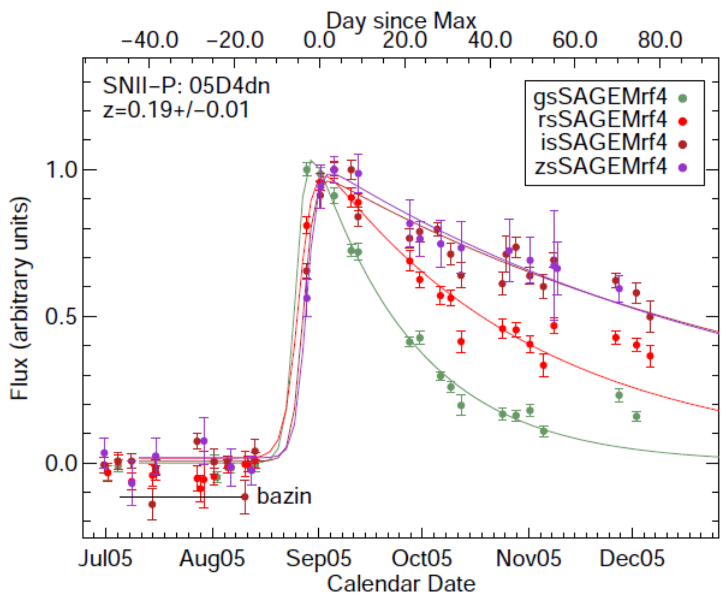


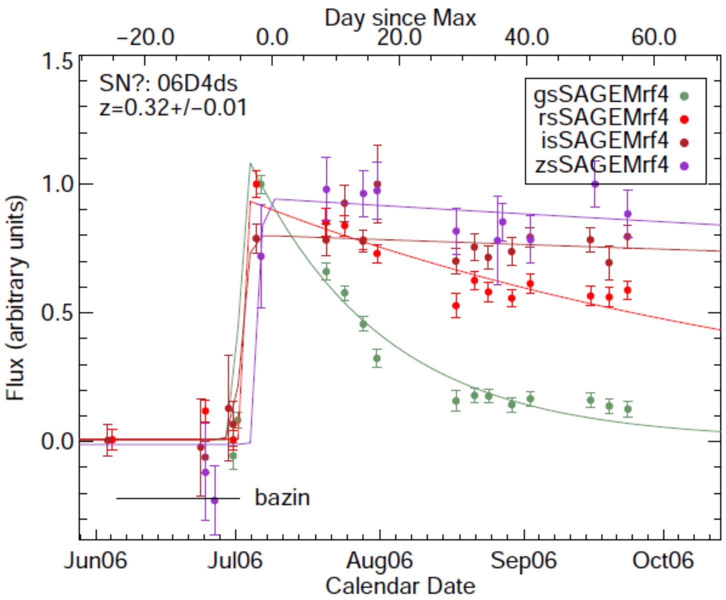
SDSS: examples

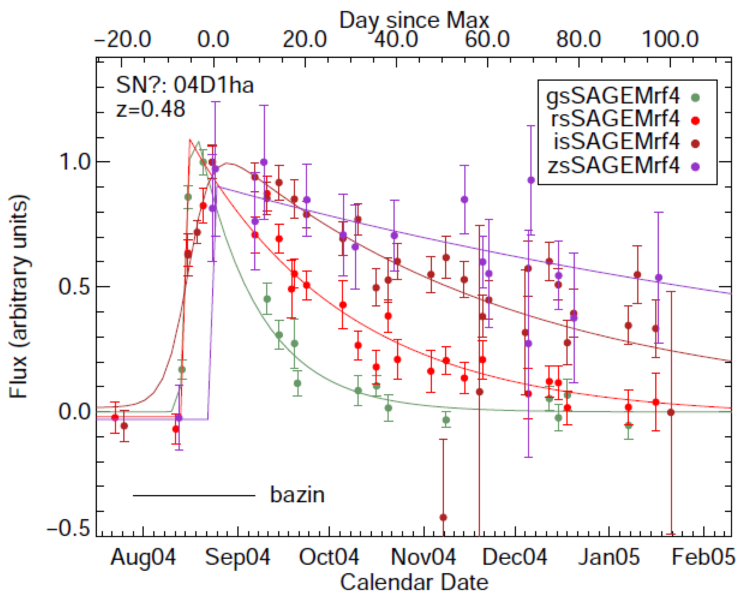


SNLS examples









Light-curve fits and rise-times

Starting dates (explosion)

- Midpoint between last non-detection and first detection
- **Power rise fit**:

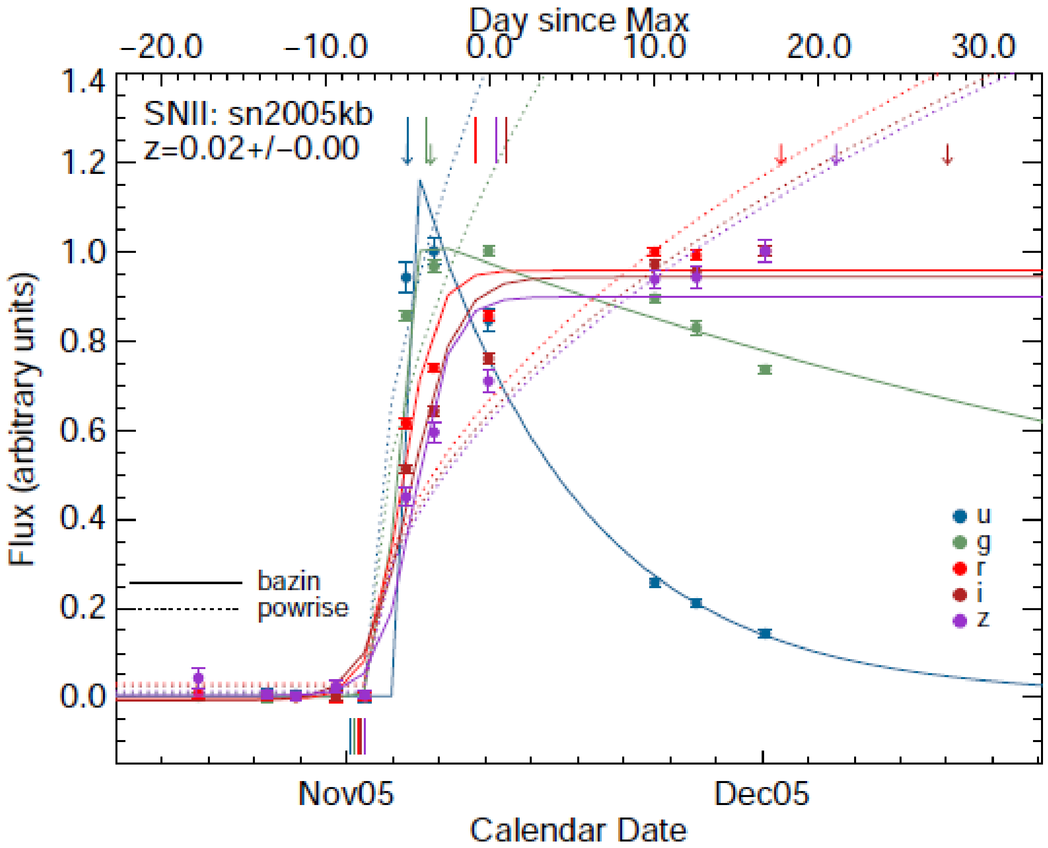
$$f(t) = \begin{cases} a(t - t_{\text{exp}}^{\text{pow}})^n & \text{if } t > t_{\text{exp}}^{\text{pow}} \\ 0 & \text{if } t < t_{\text{exp}}^{\text{pow}} \end{cases}$$

End dates

- Maximum data point
- Bazin fit:

$$f(t) = A\frac{e^{-(t-t_0)/\tau_{fall}}}{1 + e^{(t-t_0)/\tau_{rise}}} + B$$

- **Derivative less than 0.01mag/d**



Rise-time in g: 4.4±0.4 and i: 10.1±1.7d

Light-curve fits and rise-times

Starting dates (explosion)

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- **Power rise fit**:

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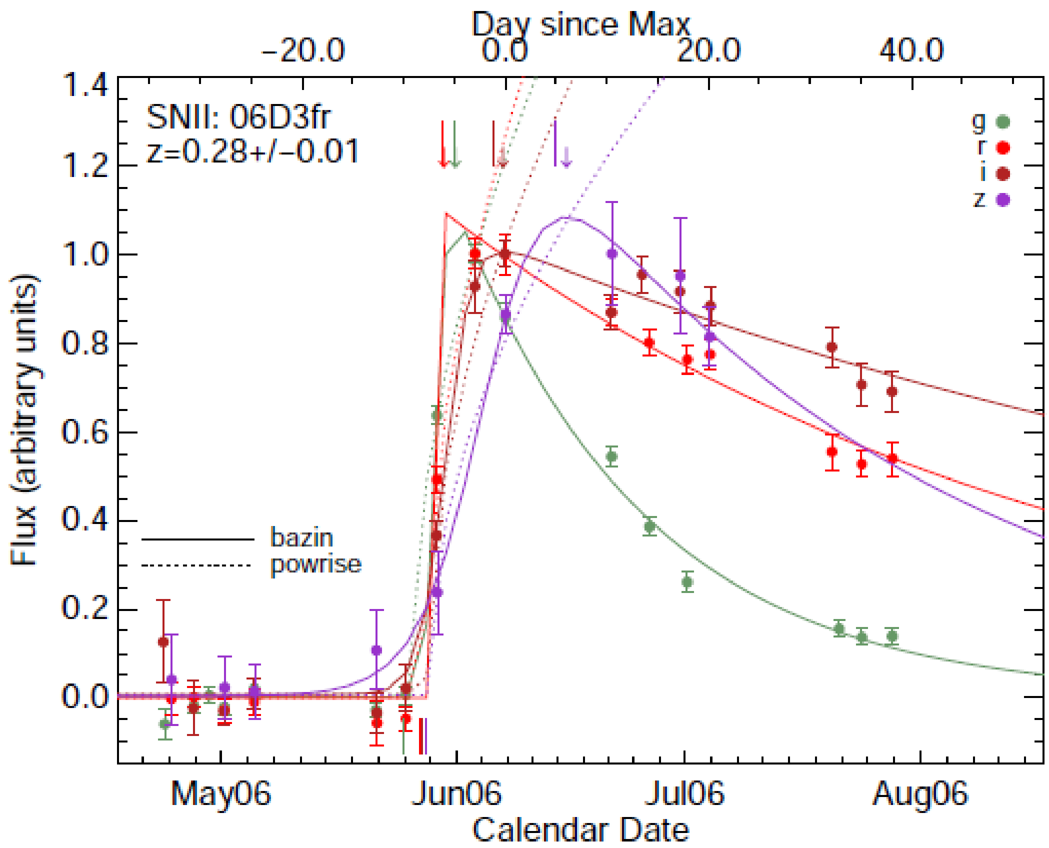
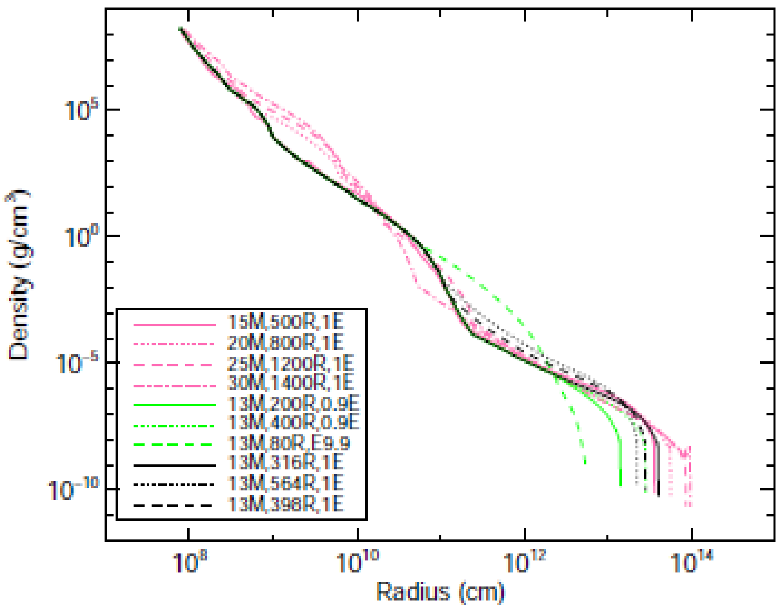


Rise-time in g: 4.4±1.2 and i: 6.9±1.2d

Theoretical models

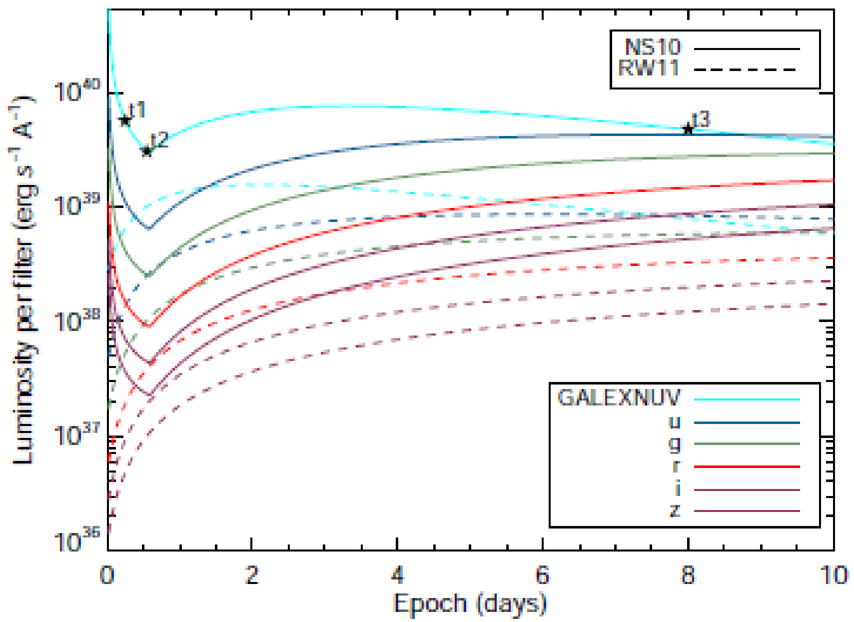
- Hydrodynamical

Models by Tominaga et al. 2009, 2011 with pre-SN evolutionary non-rotating models (Umeda & Nomoto 2005) and radiation hydrodynamics with STELLA (Blinnikov et al. 1998,2006)

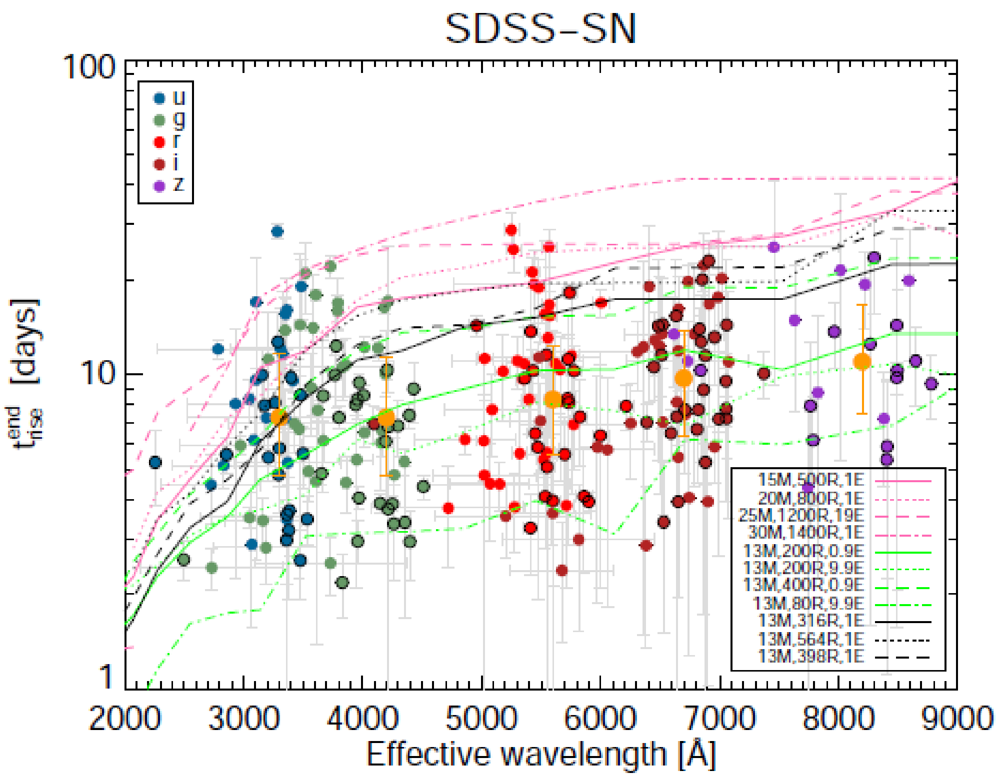


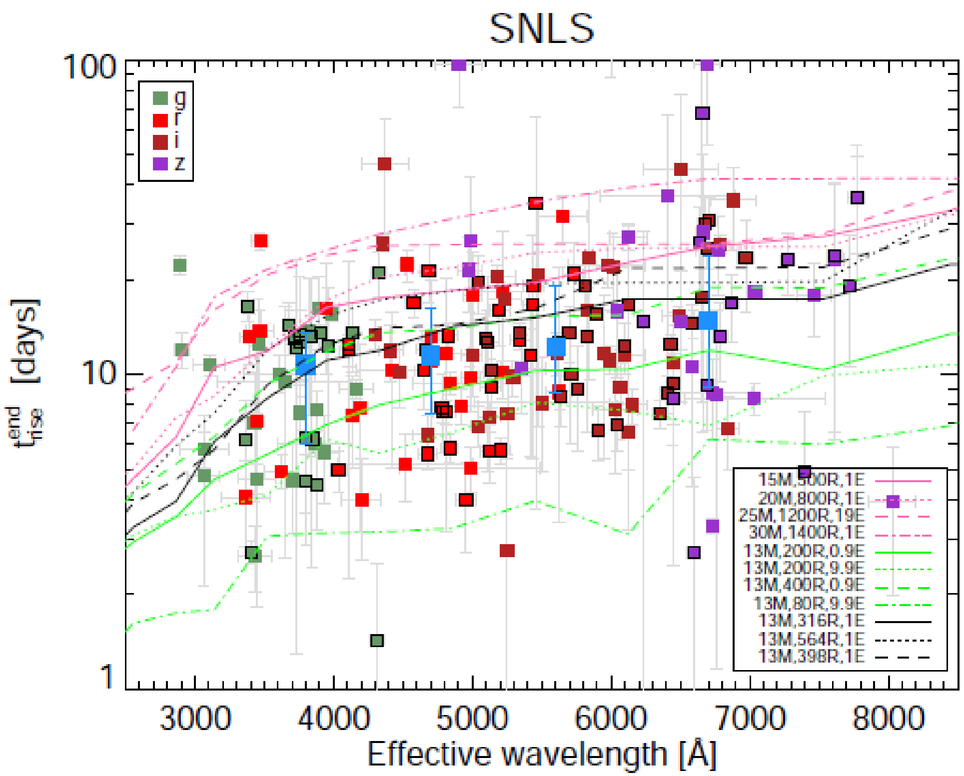
- Analytical

Models by Nakar & Sari (2010) and Rabinak & Waxman (2011) with polytropic profiles which can be used until recombination/radioactive decay



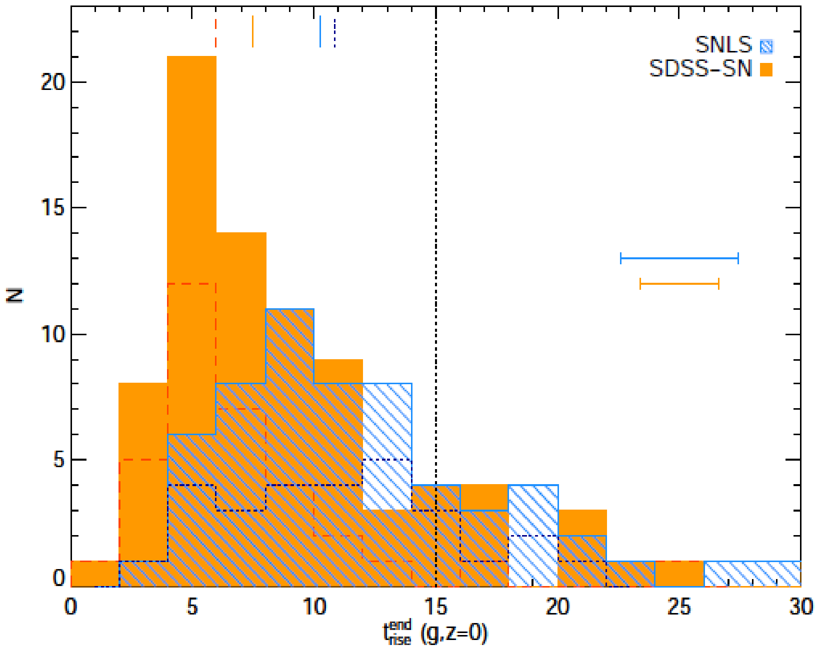
Results: Rise-time vs wavelength



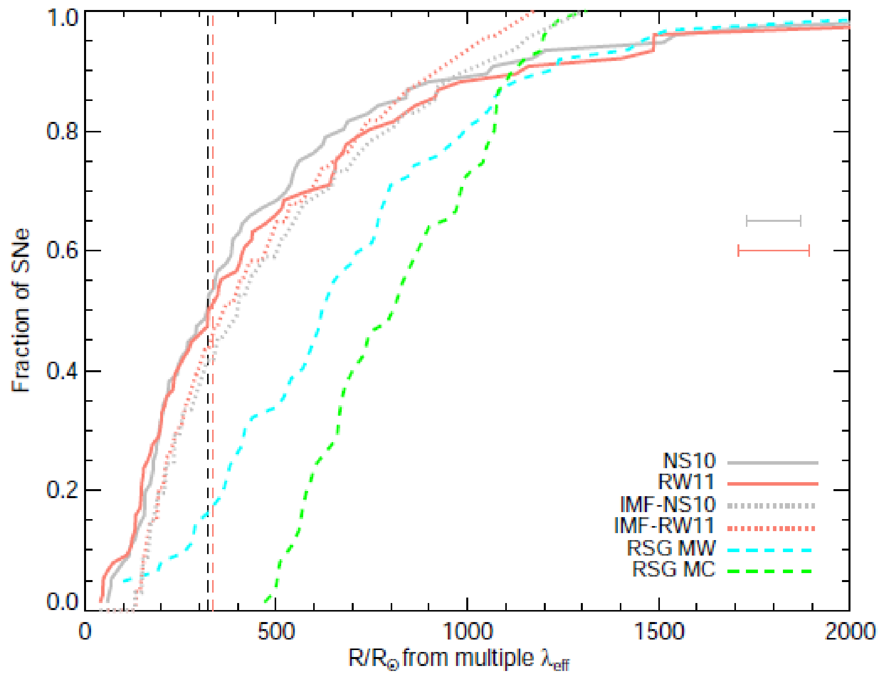


- Increase of rise-time with wavelength
- Fast rise-times compared to other SNe and with typical theoretical models of typical red supergiants (RSG)

Rise-time and Radii



Rise-times: 7.5±0.3 (4.5-16.4) days

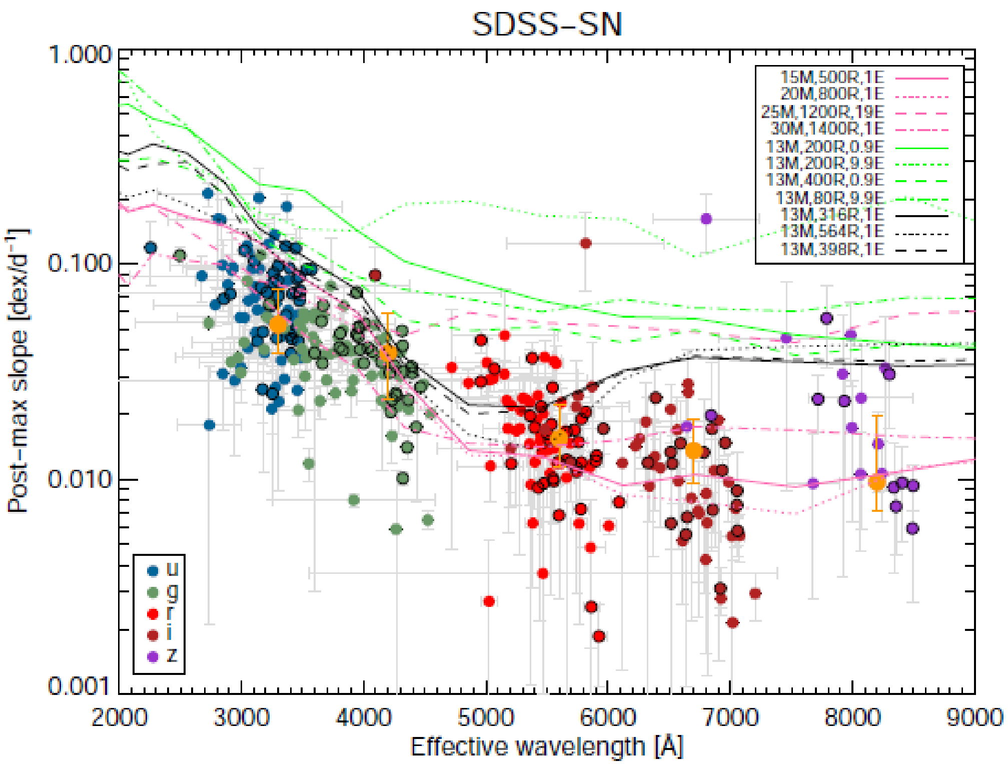


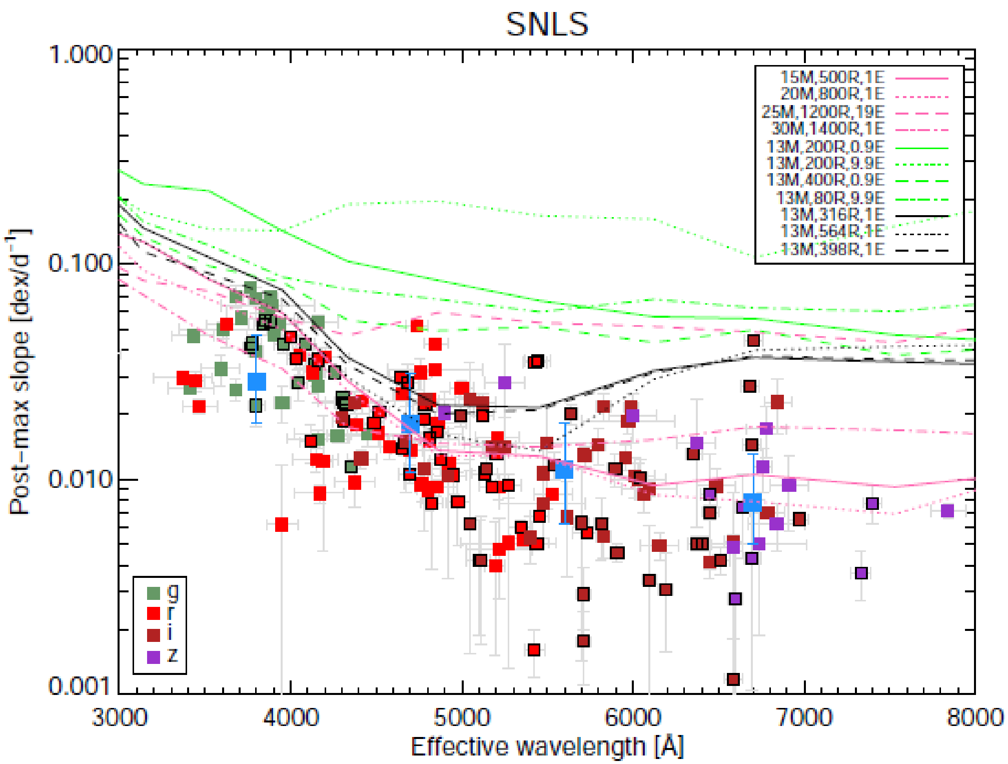
Radii: ~340 (100-900) solar radii

Inferred radii are inconsistent with observed RSG (Levesque+05,06) and interferometric data for Betelgeuse & VY Cma (Haubois+09,Wittkowski+12):

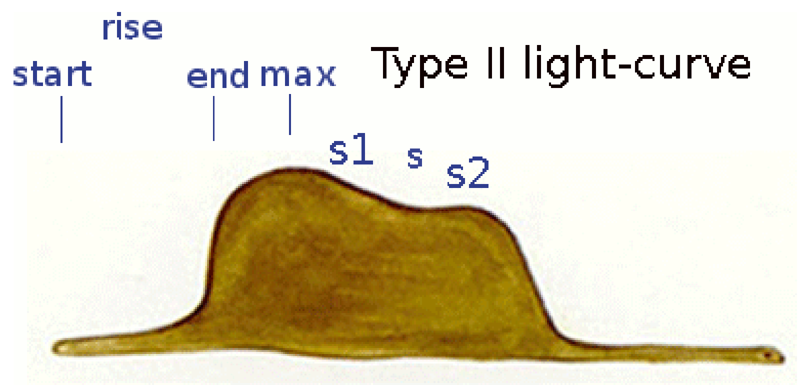
- RSG radii much smaller?
- RSG surveys incomplete?
- RSG radii are wrong (Davies+13, Dessart+13)?
- Mixing length theory uncertainties (Deng+01, Meynet+14)?

Results: Slope vs wavelength

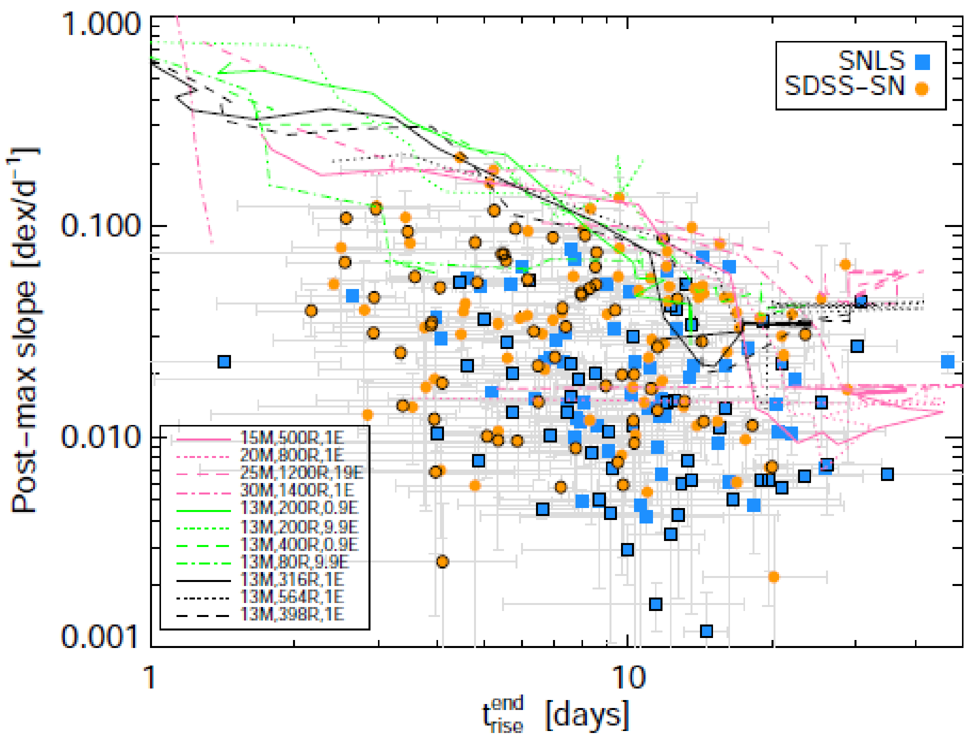




- Steeper slopes with wavelength
- Slopes are consistent with theoretical models of typical RSG.



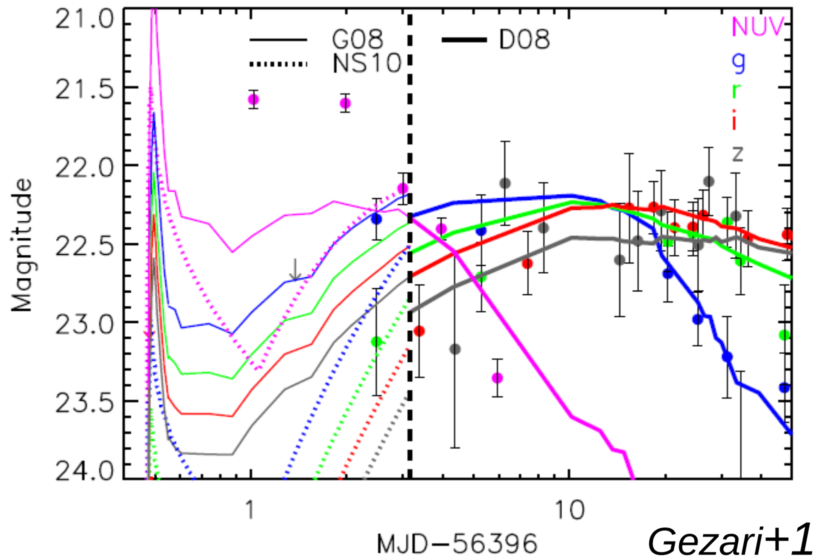
Slopes vs Rise-times



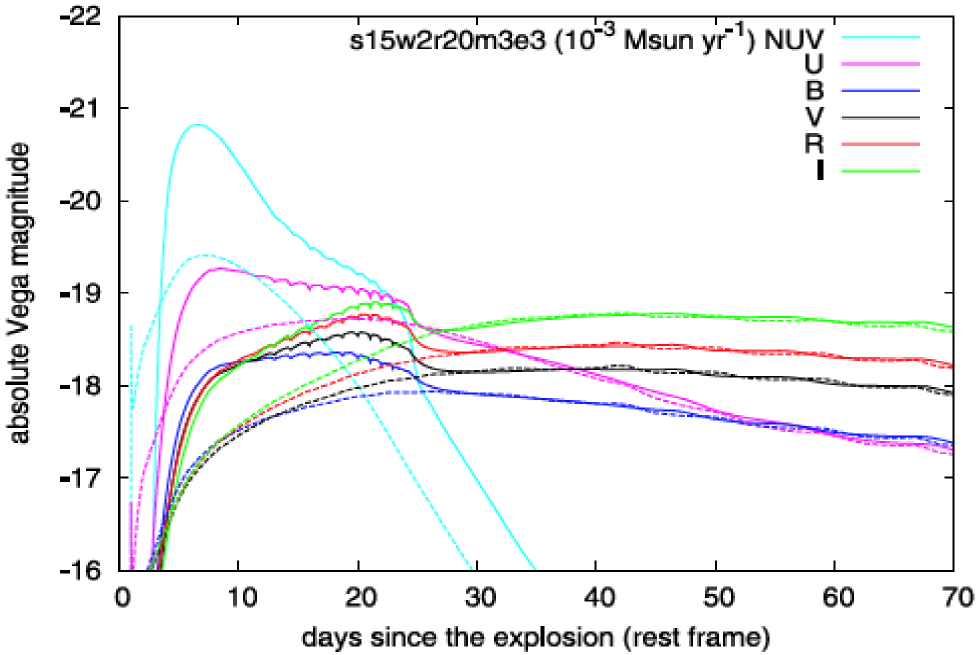
- Requirement of both: small radii for rapid rise and large/dense hydrogen envelope for shallow slopes
- No hydrodynamic model can account for both, rise-times and slopes, not even “dense” models

Other pieces of evidence

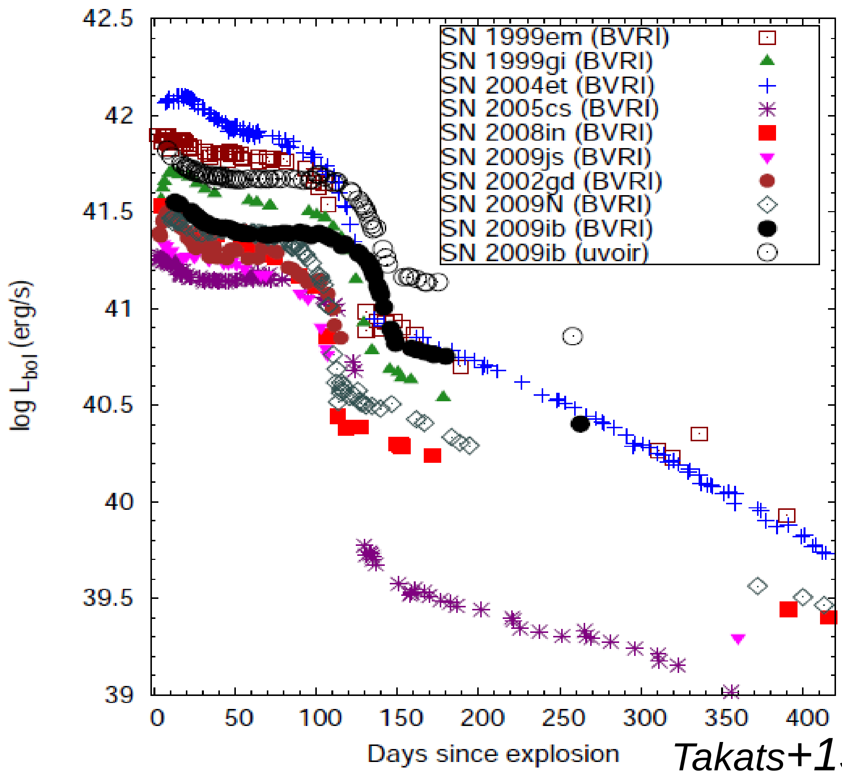
- NUV light-curve of PS13arp (Gezari+15)
- Rise-times of SNIIn models (Moriya+11, Baklanov+13)
- Bolometric LCs of low-z SNe II (Anderson+14, Bersten+12)
- Transitional objects between normal SNe II and IIn (Inserra+13,Smith+15, Valenti+15)



Gezari+15



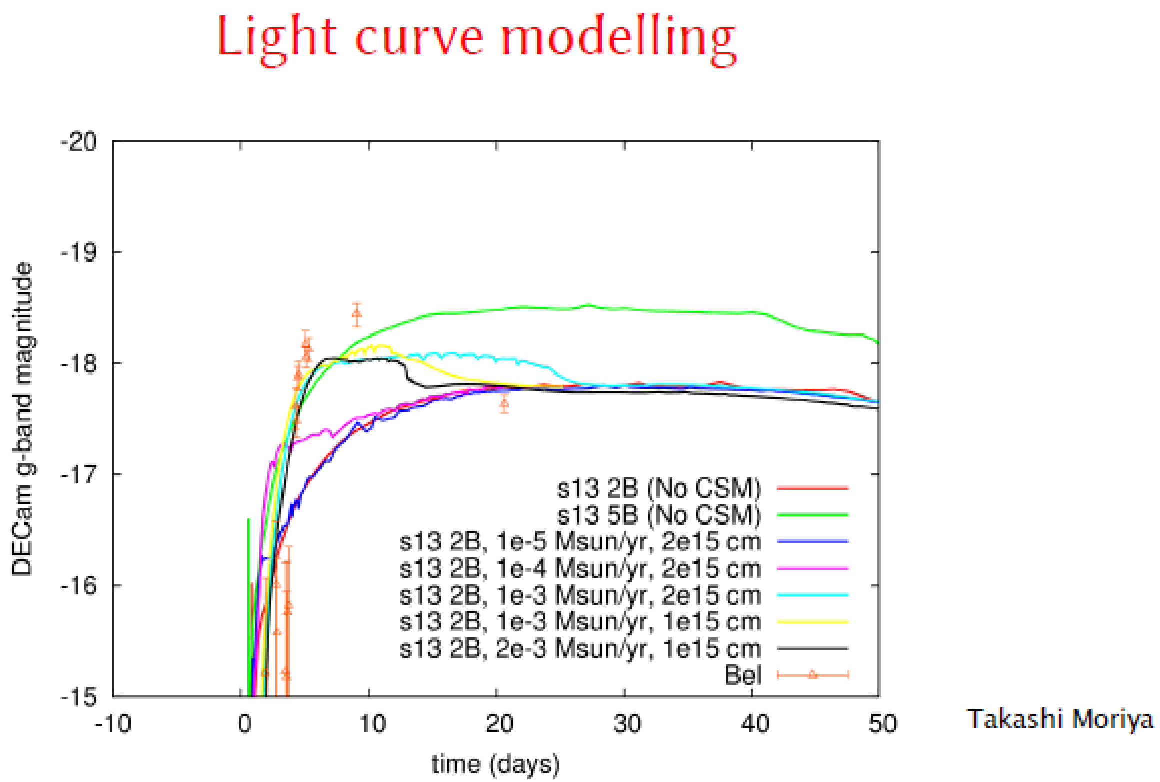
Moriya+11

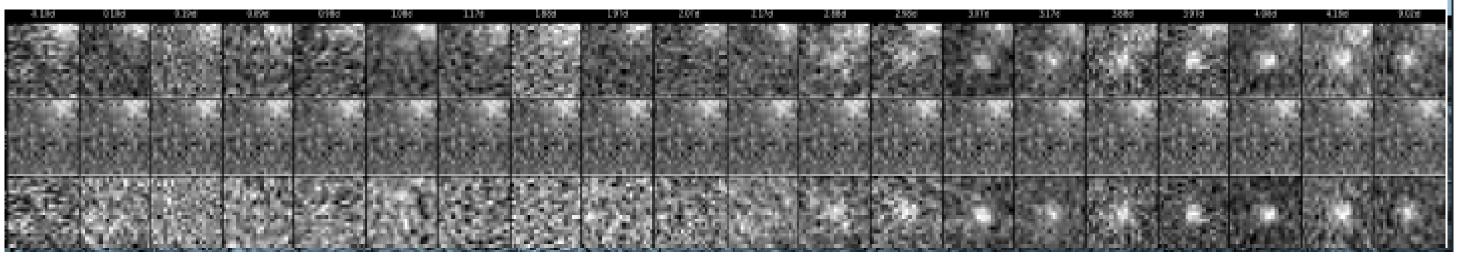


Takats+15

Other pieces of evidence

Lack of shock breakouts? In SDSS/SNLS and fast cadence surveys like HiTS...





HiTS (PI:F. Förster)

Are SNe II coming from RSG with
a) very extended atmospheres (e.g. Arroyo-Torres+15, Kervella talk); or
b) surrounded by circumstellar material (e.g. Mackey talk)
smearing the shock into the main light-curve?

Summary

- We find a **continuous** distribution of fast rise-times with median 7.5±0.3 days in g-band
- Compared to theoretical models, we find small characteristic radii of 300-400Rs.T these are inconsistent with RSG of >800 solar radii typical of observed RSG in MW and MC.
- Massive hydrogen envelopes are still required to explain shallow post-maximum slopes

  → **Rise-times are the shock cooling of exploding RSG with very small and dense hydrogen atmospheres**

  → **Rise-times are the smeared shock breakout of exploding RSG with very extended atmospheres or embedded in CSM.**