Observations and modelling of SNe associated with GRBs

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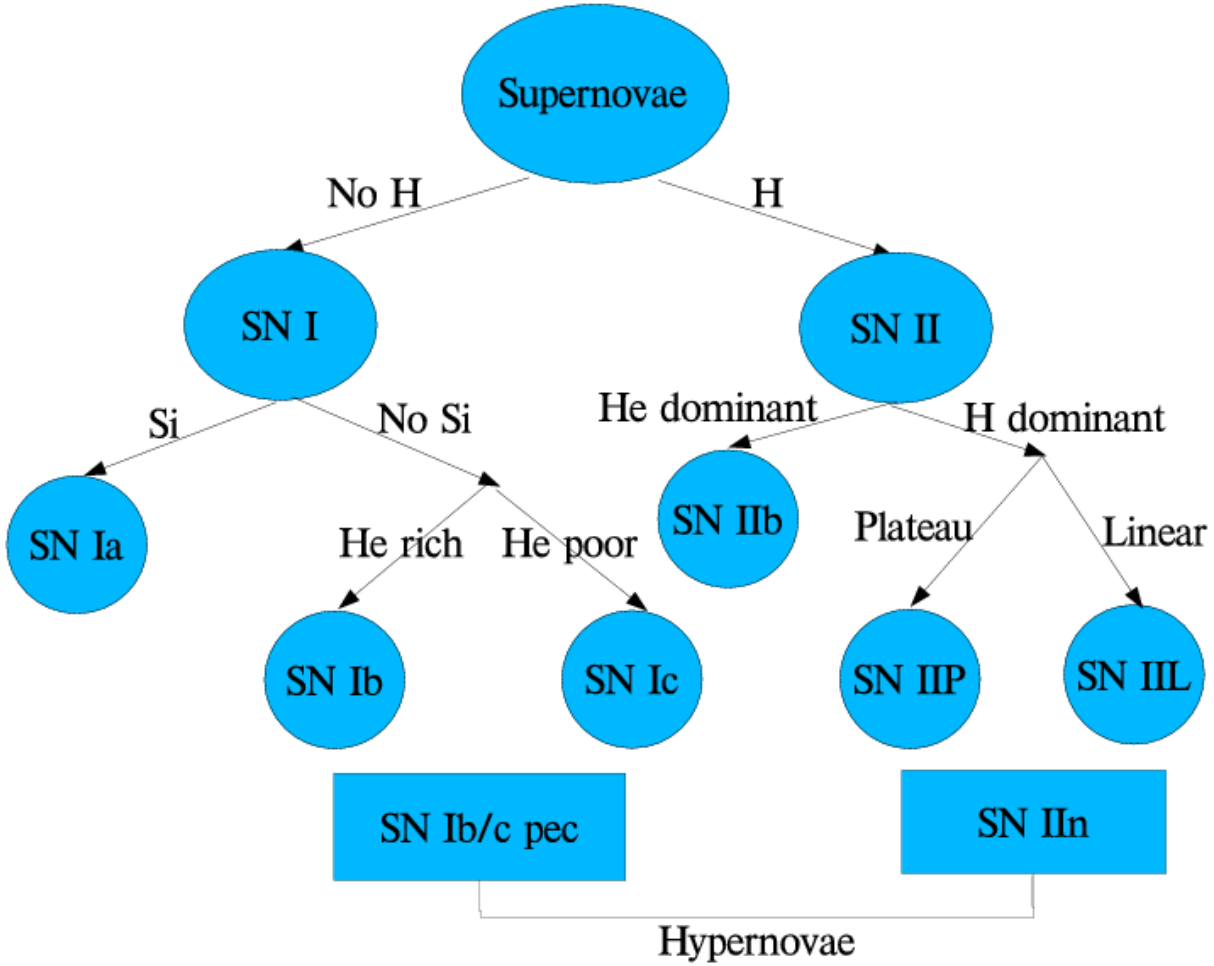
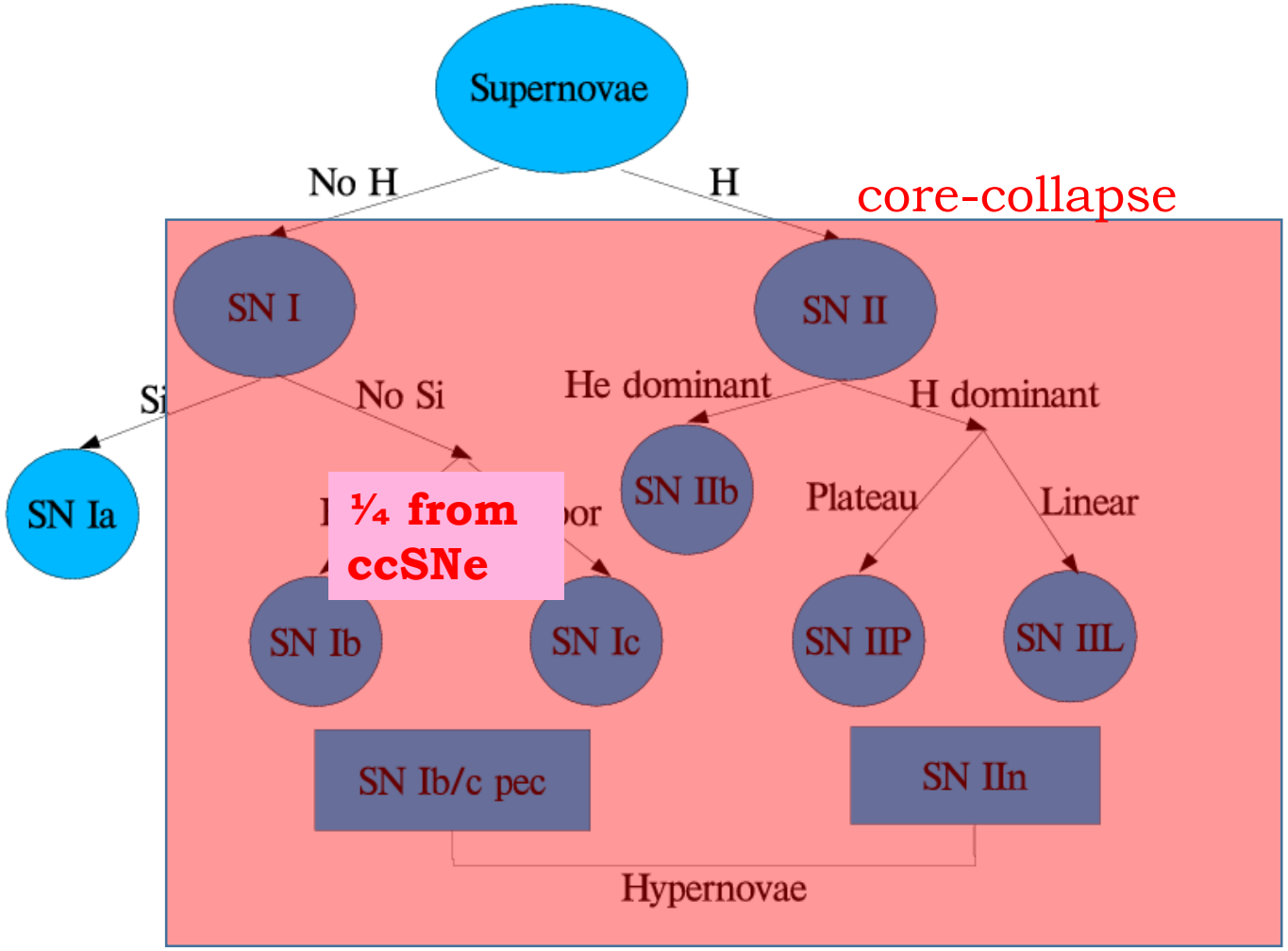
Context

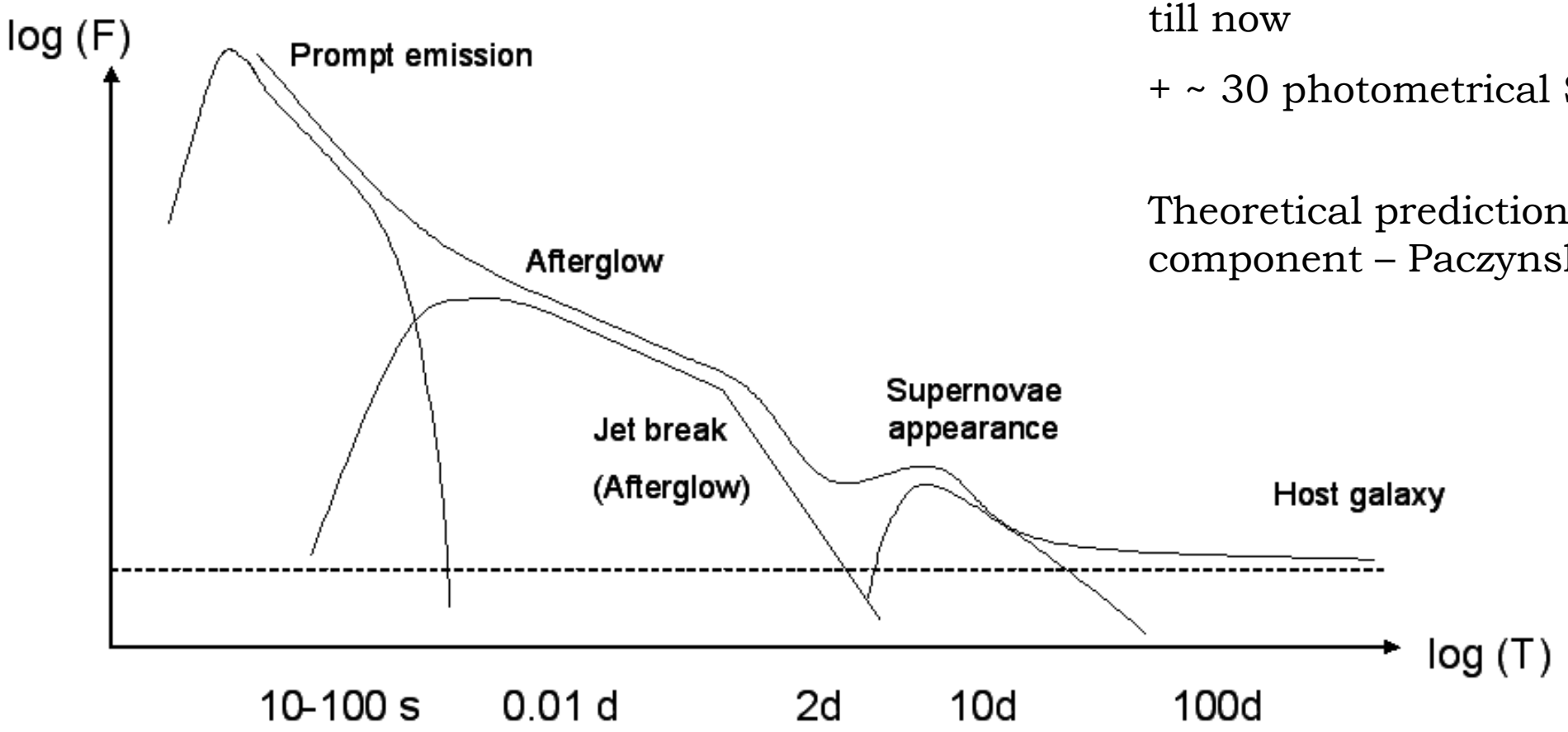
Modern SNe classification



Modern SNe classification



GRB Optical Afterglow



25 spectroscopical GRB-SNe till now

+ ~ 30 photometrical SN-GRB

Theoretical prediction of SN component – Paczynski 1986

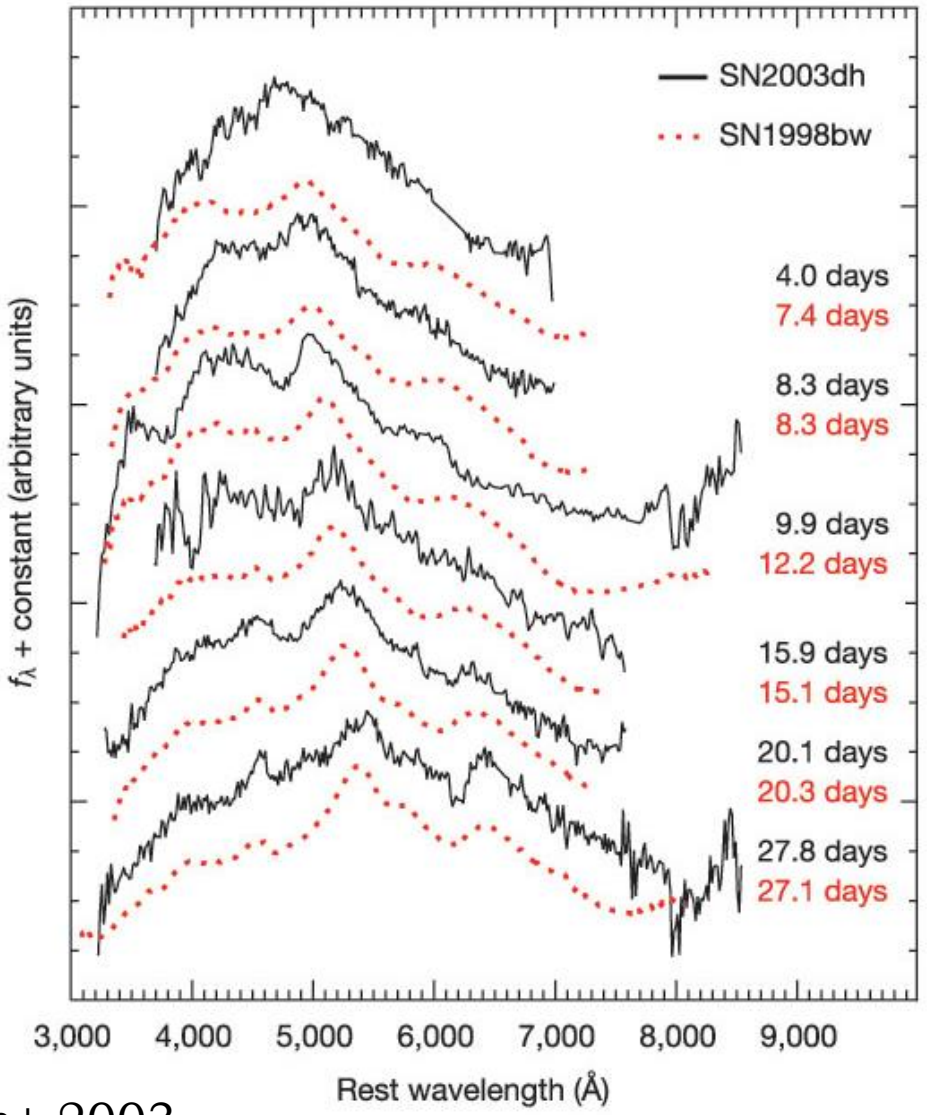
Spectroscopical GRB-SNe

- GRB 980425 / SN 1998bw z = 0,0085
- GRB 011121 / SN 2001ke z = 0,36
- GRB 021211 / SN 2002lt z = 1,01
- GRB 030329 / SN 2003dh z = 0,168
- GRB 031203 / SN 2003lw z = 0,105
- GRB 050525A / SN 2005nc z = 0,606
- GRB 060218 / SN 2006aj z = 0,0331
- GRB 081007 / SN 2008hw z = 0,5295
- GRB 091127A / SN 2009nz z = 0,49
- GRB 100316D / SN 2010bh z = 0,059
- GRB 101219B / SN 2010ma z = 0,55
- GRB 111209A / SN 2011kl z = 0,677
- GRB 120422A / SN 2012bz z = 0,283
- GRB 120714B / SN 2012eb z = 0,3984
- GRB 130215A / SN 2013ez z = 0,597
- GRB 130427A / SN 2013cq z = 0,3399
- GRB 130702A / SN 2013dx z = 0,145
- GRB 130831A / SN 2013fu z = 0,4791
- GRB 140606B / iPTF14bfu z = 0,384
- GRB 150818A / SN z = 0,282
- GRB 161219B / SN 2016jca z = 0,1475
- GRB 171010A / SN 2017htp z = 0,3285
- GRB 171205A / SN 2017iuk z = 0,0368
- GRB 180728A / SN z = 0,117
- GRB 190829A / SN z = 0,08

z_{med} = 0,33

All type Ic!

SN 2003dh

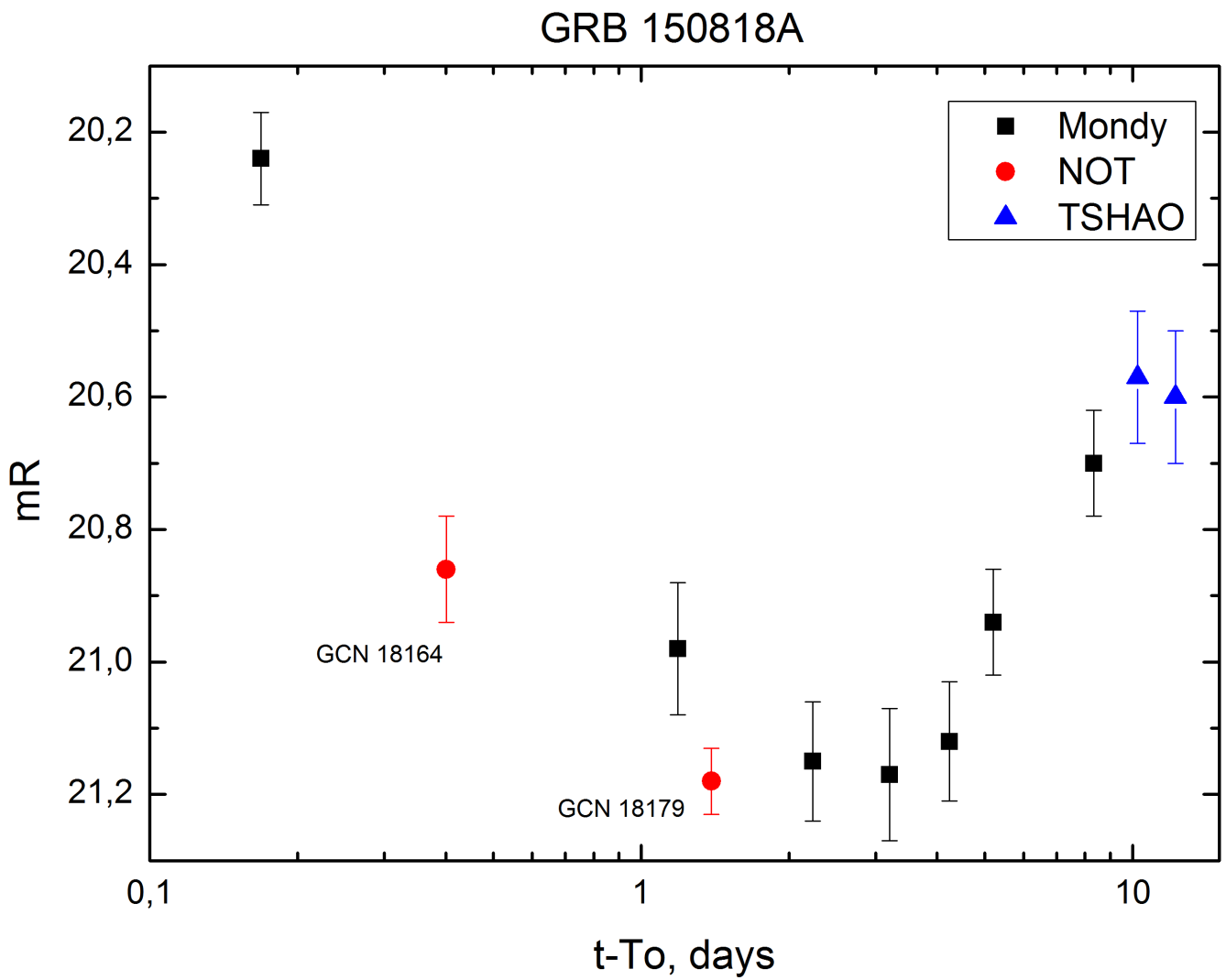


Hjorth+ 2003

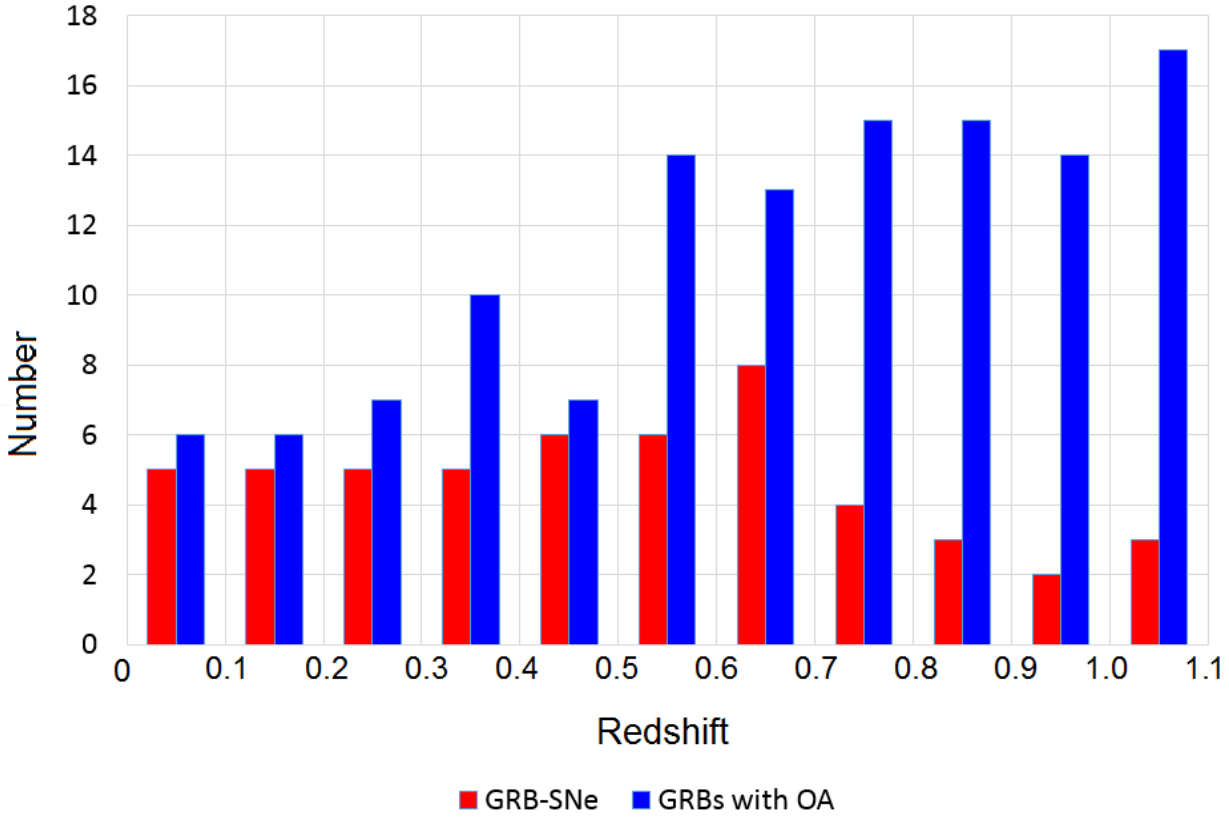
Photometrical GRB-SNe

- GRB 970228 z = 0,695
- GRB 980326 z = 1 (?)
- GRB 990712 z = 0,434
- GRB 991208 z = 0,706
- GRB 000911 z = 1,058
- GRB 020305 z = 0,2 (?)
- GRB 020405 z = 0,69
- GRB 020410 z = ?
- GRB 020903 z = 0,25
- GRB 030723 z = ?
- GRB 040924 z = 0,859
- GRB 041006 z = 0,716
- GRB 050416A z = 0,6535
- GRB 050824 z = 0,83
- GRB 060729 z = 0,54
- GRB 060904B z = 0,703
- GRB 070419A z = 0,97
- GRB 080319B z = 0,937
- GRB 090618A z = 0,54
- GRB 100418A z = 0,6235
- GRB 111211A z = 0,478
- GRB 111228A z = 0,714
- GRB 120714B z = 0,3984
- GRB 120729A z = 0,80
- GRB 141004A z = 0,573
- GRB 150518A z = 0,256
- GRB 180720B z = 0,645
- GRB 181201A z = 0,45
- GRB 190114C z = 0,42

z_{med} = 0.67

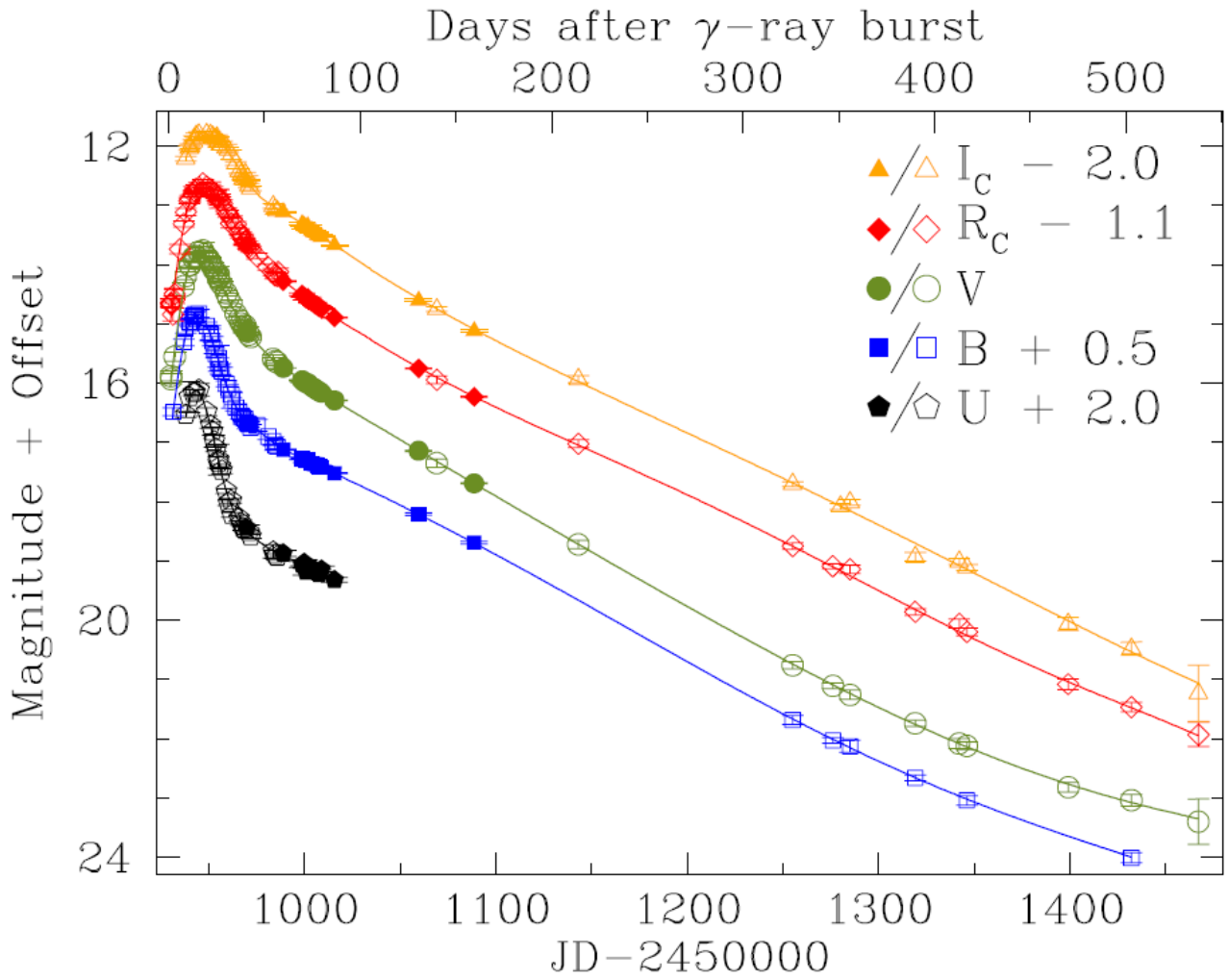


Some SNe/GRBs statistics



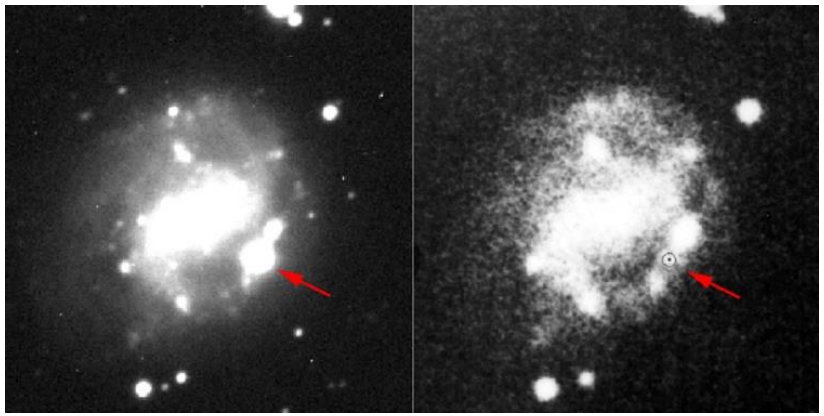
- The farthest LGRB-SN has z = 1,1
- There are 124 LGRBs with discovered OA at z < 1,1
- At z < 0,3 (almost) all LGRBs have an association with SNe
- At z < 1,1 ~40% of LGRBs (52 out of 124) have an association with SNe

GRB 980425 / SN 1998bw



Galama+ 1998
Clocchiatti+ 2011
Zhang+ 2012

$z = 0.0085$
$M_R = -19.36 \pm 0.05$ mag
$M_{Ni56} = 0.42 \pm 0.02\ M_{Sun}$
$M_{Ej} = 6.80 \pm 0.57\ M_{Sun}$
$E = 2.19 \pm 0.17 \times 10^{52}$ erg



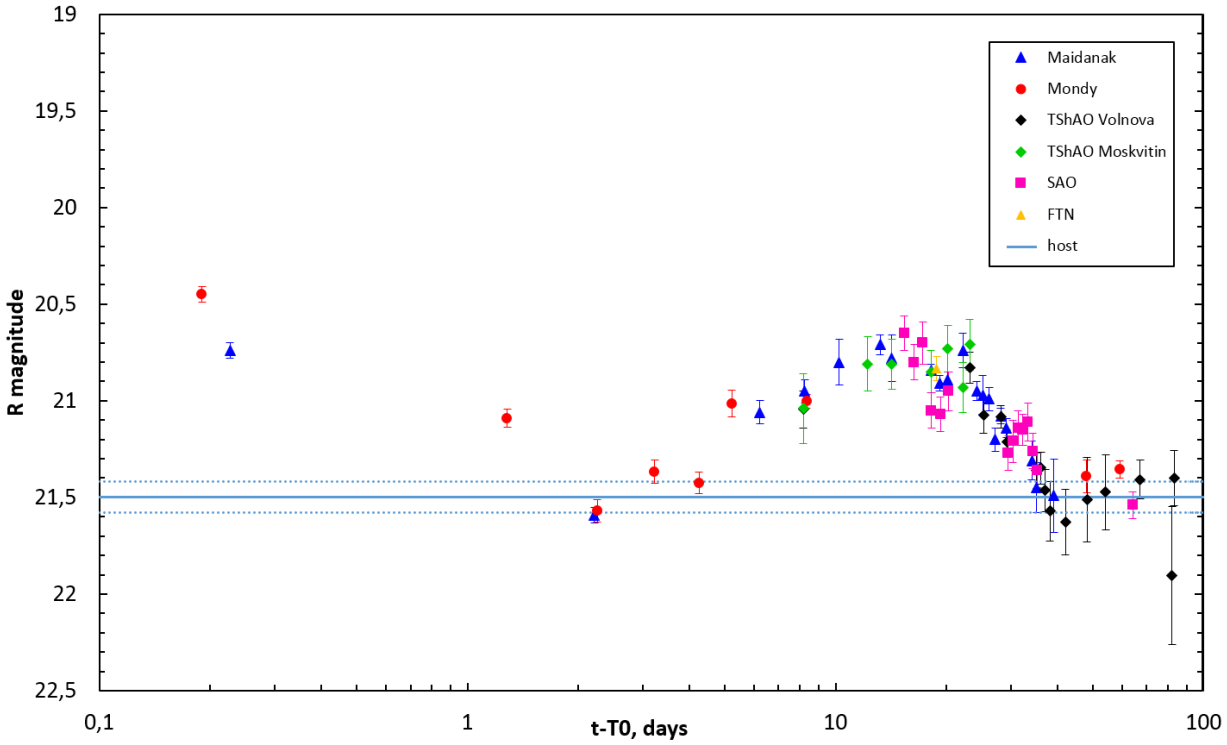
Observations

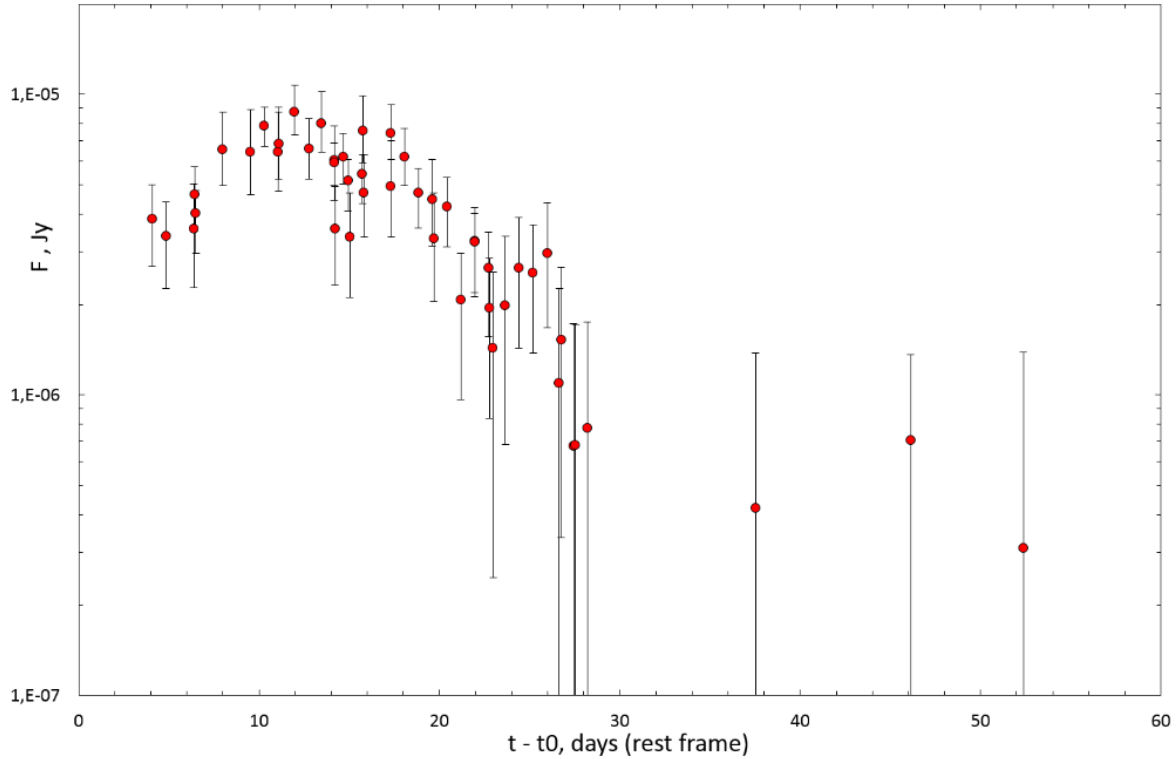
IKI GRB Follow-up Network (IKI-GRB-FuN)

- Crimean Astrophysical Observatory – ZTSh (2,6), AZT-11 (1,25), AZT-8 (0,7), Ziess-1000 Mt. Koshka
- Sayan Observatory near Mondy (ISTP SB RAS) – AZT-33IK (1,5)
- Tein-Shan Astronomical Observatory (Kazakhstan) – Zeiss-1000 East, Zeiss-1000 West
- Assy-Turgen Observatory (Kazakhstan) – AZT-20 (1,5)
- Maidamak Astrophysical Observatory (Uzbekistan) – AZT-22 (1,5)
- Burakan Observatory (Armenia) – ZTA (2,6)
- Abastumani Observatory (Georgia) – AS-32 (0,7)
- Hureltogoot Observatory (Mongolia) – ORI-40 (0,4)
- ISON-Kislovodsk – K-800 (0,8)
- Special Astrophysical Observatory of RAS – Zeiss-1000
- Mt. Terskol Observatory – Zeiss-600, Zeiss-2000
- Caucasian Mountain Observatory of SAI MSU – KGO 2,5-meter
- CHILESCOPE (Chile, Ovalle) – RC-1000, Newtonian-50
- SAAO (South Africa) – SALT (10) – spectrum!!! + 40inch (1,0)
- ARIES (India) – DOT (3,6), HCT (2)
- PROMPT (Australia, Chile) – 1 and 0.4 meter

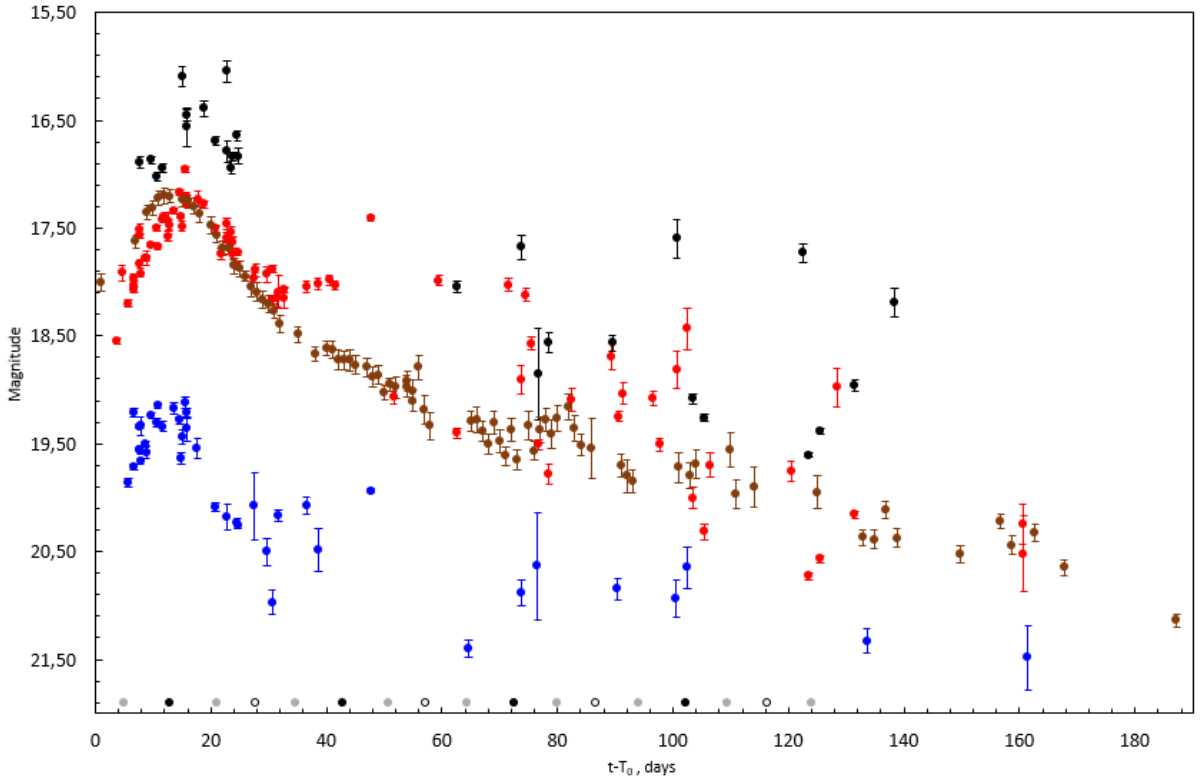
IKI-GRB-FuN map

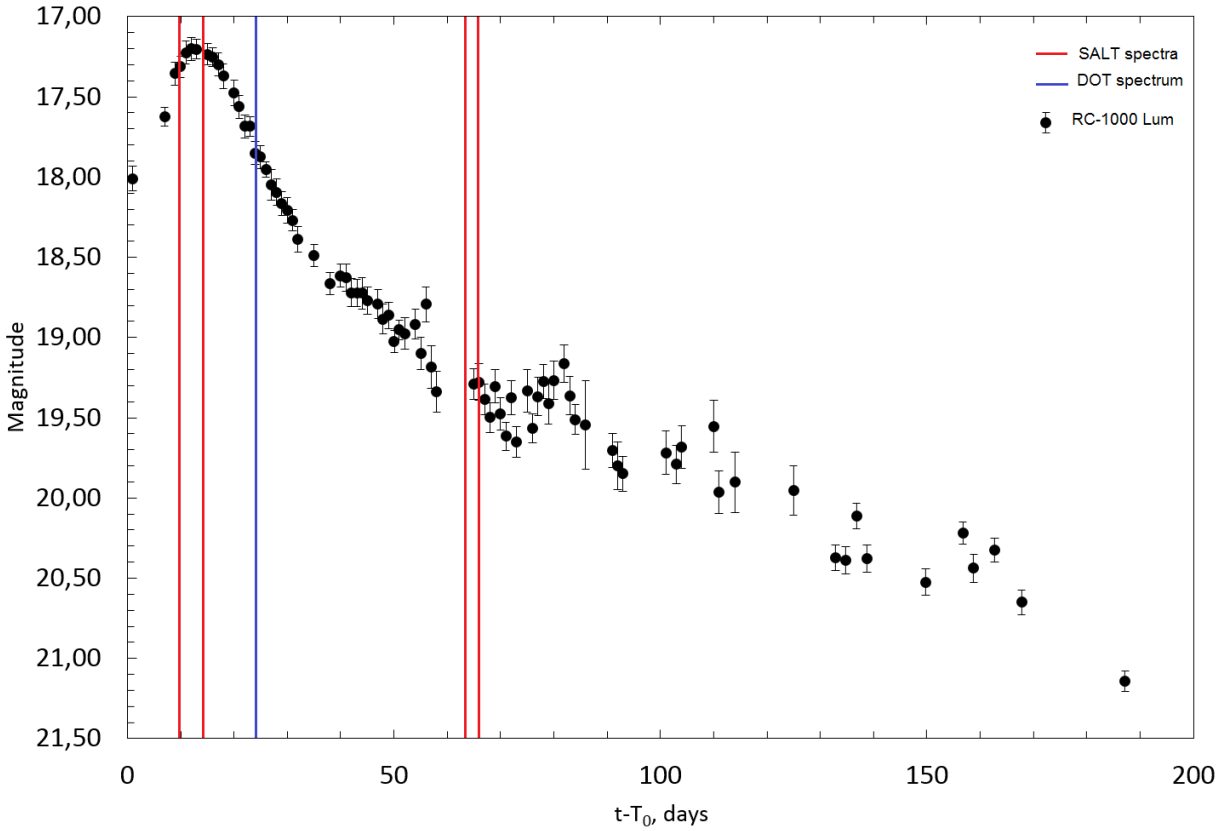
GRB/SN 150818A (z = 0.282):



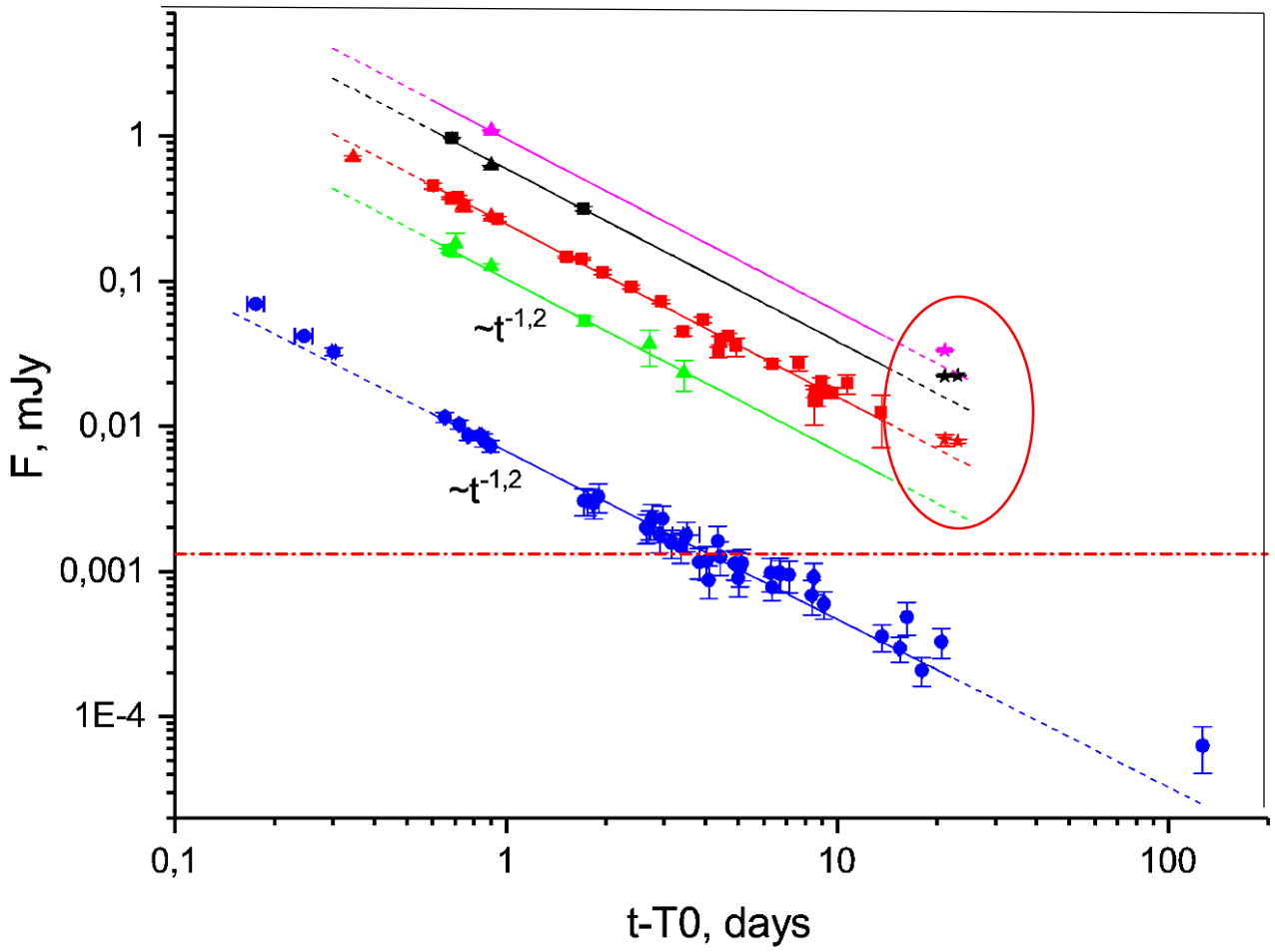


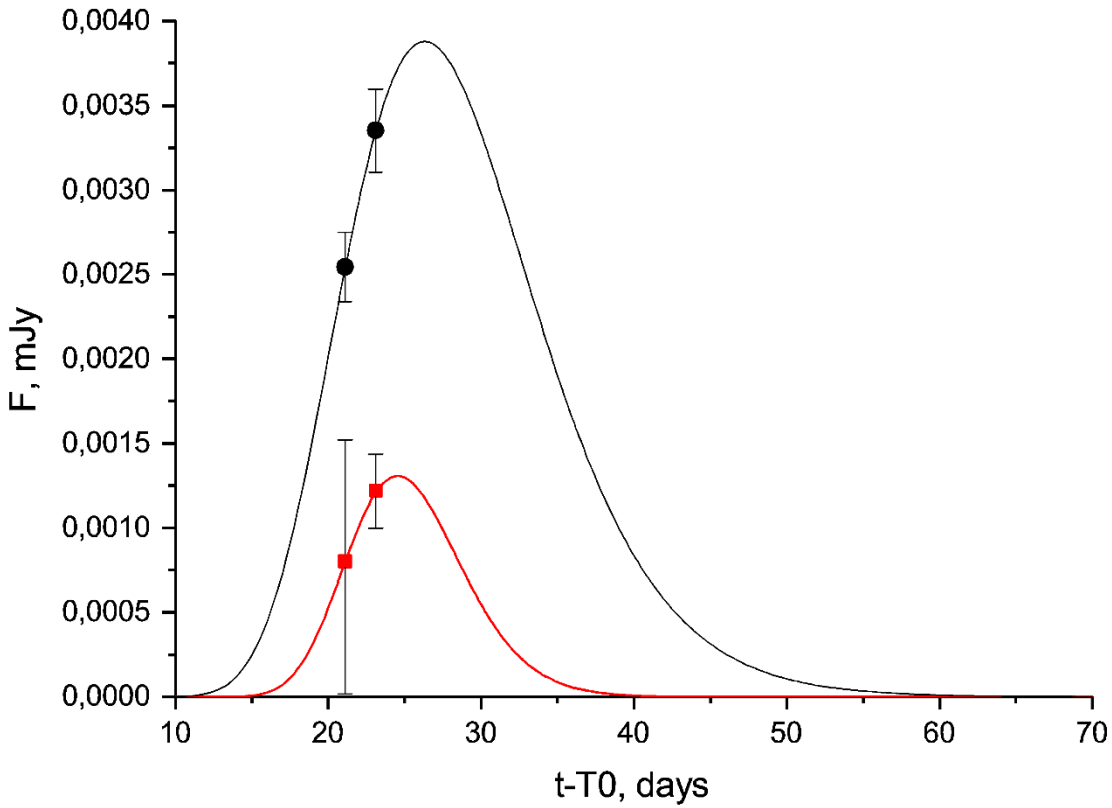
GRB 171205A / SN 2017iuk (z = 0,0368)



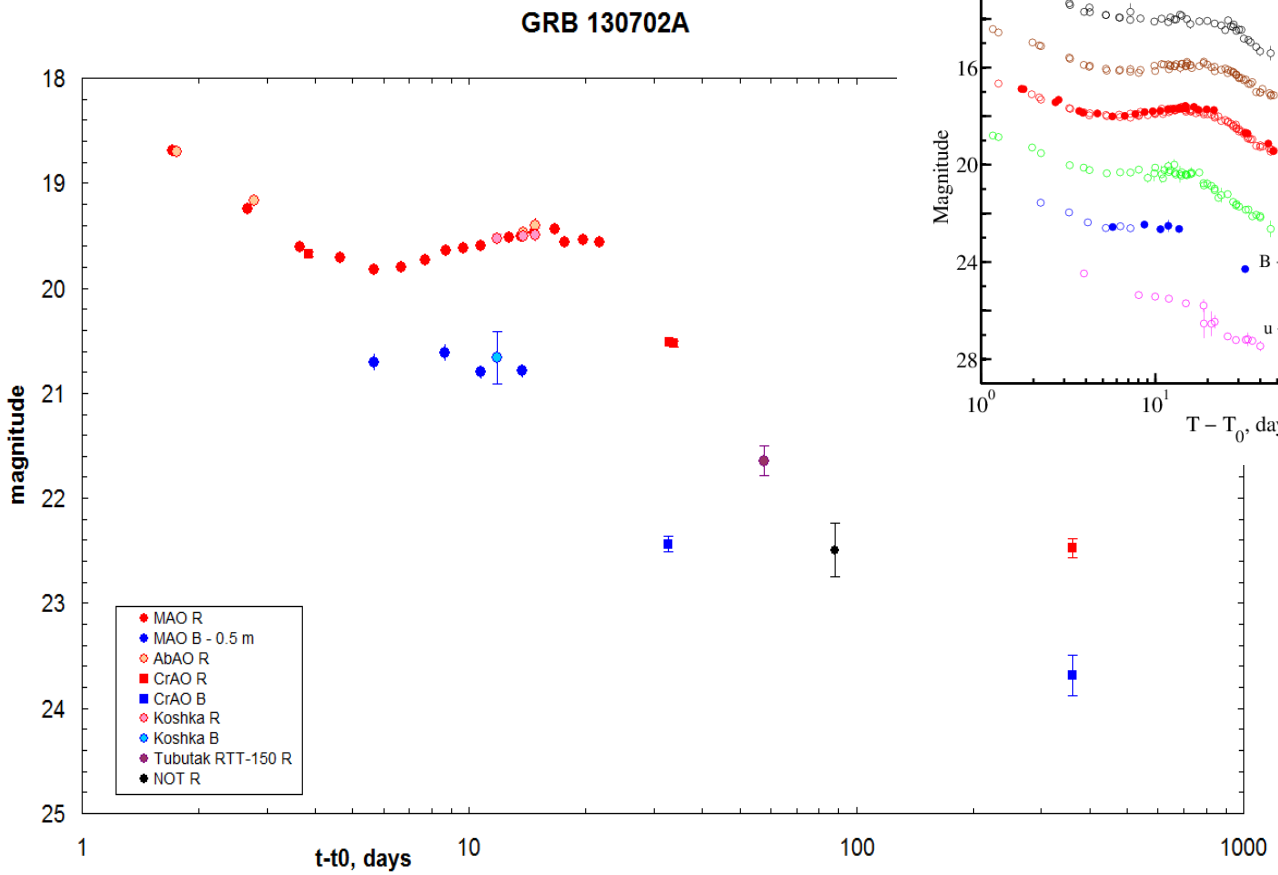


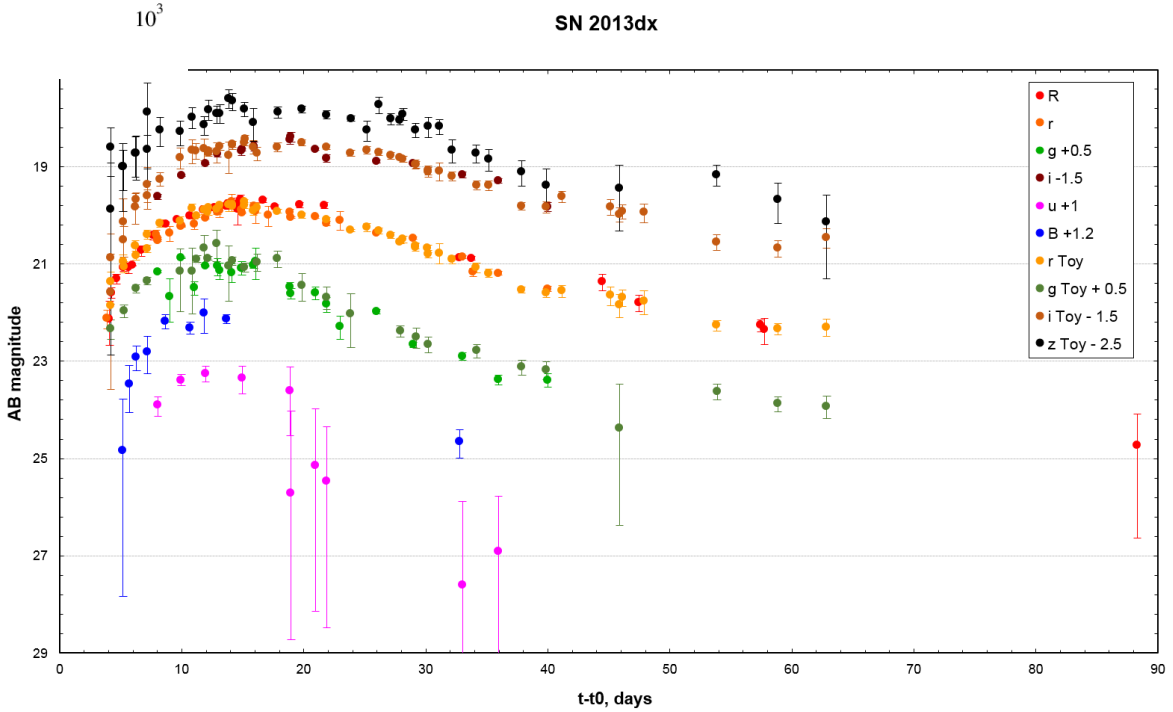
GRB / SN 181201A (z = 0.45)





GRB 130702A / SN 2013dx (z = 0,145)

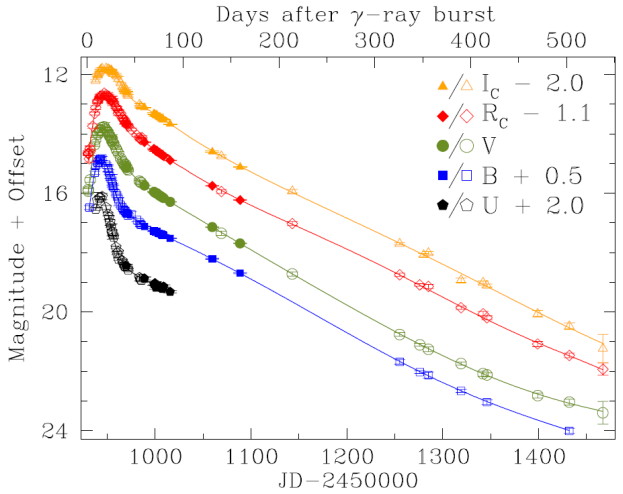




data from IKI-GRB-FuN

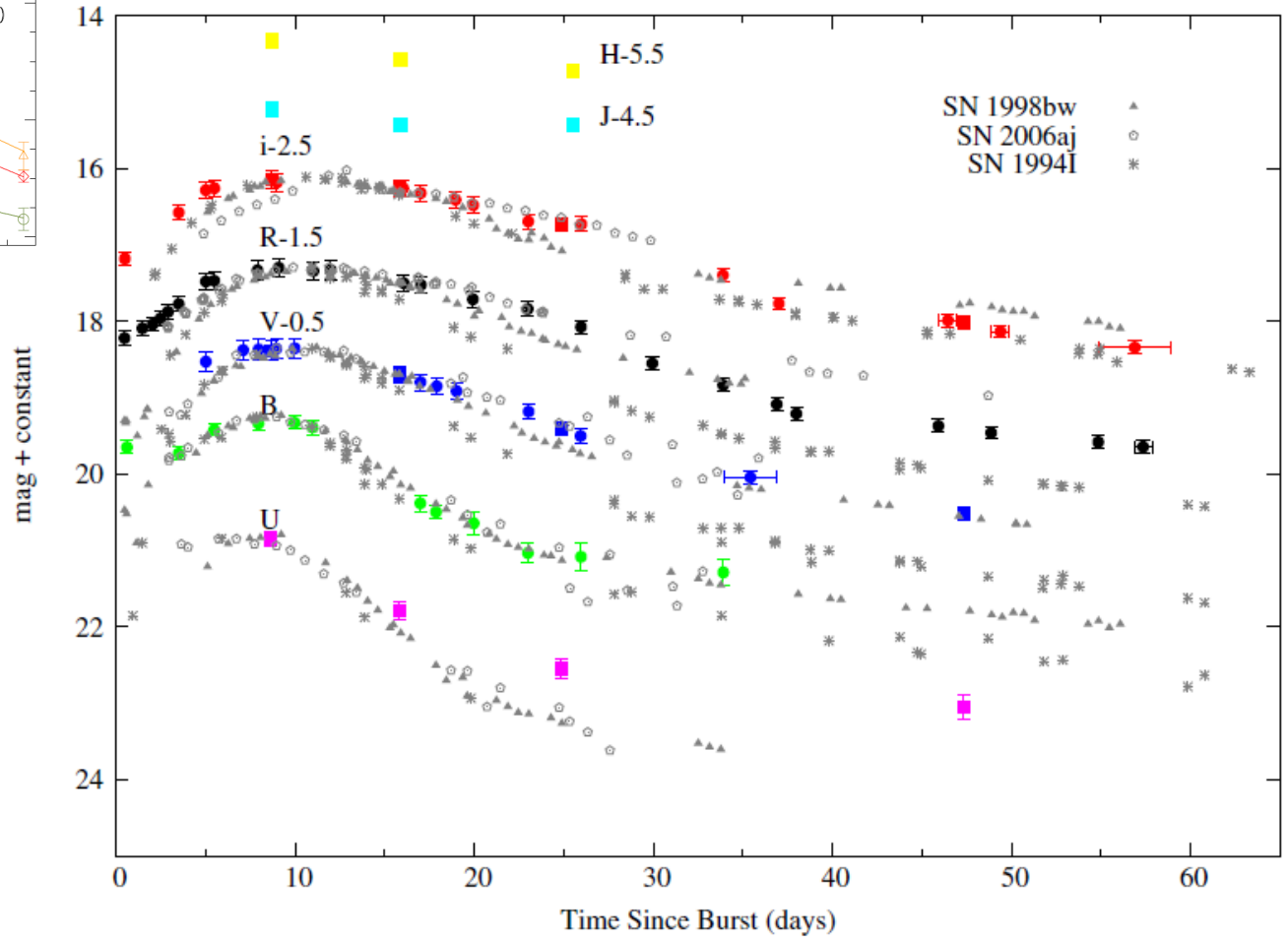
Modelling

Templates



SN 1998bw

GRB 100316D / SN 2010bh, Cano+ 2011



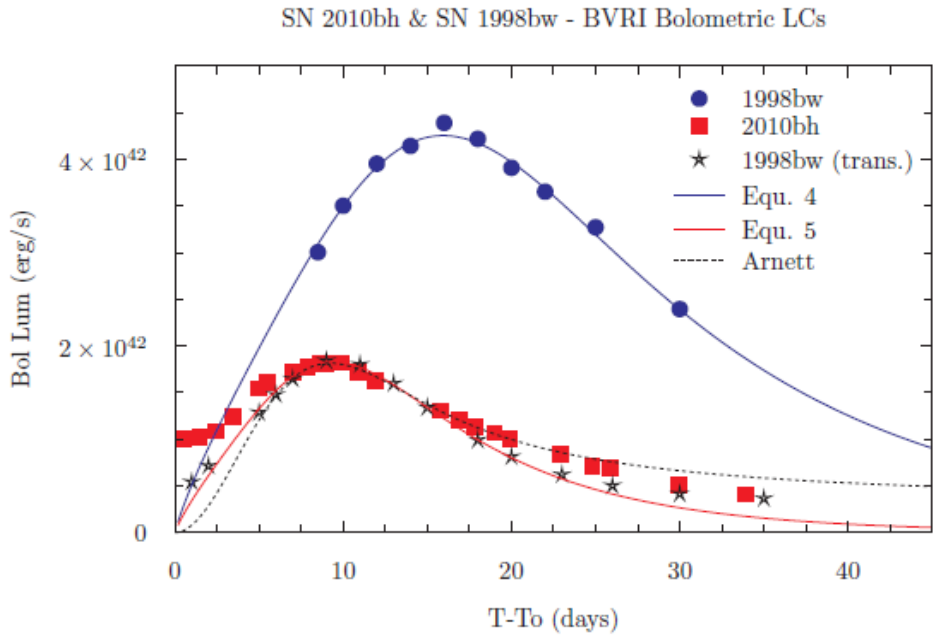
Analytical model

A homologous expansion of the ejecta
Spherical symmetry
56Ni is located at the and does not mix
Radiation-pressure dominance
A small initial radius before the explosion
The photospheric phase
(Arnett 1982)

$$U(t) = A + \lambda t \left(\frac{e^{(\frac{-t^{\alpha_1}}{F})}}{1 + e^{(\frac{p-t}{R})}} \right) + t^{\alpha_2} \log(t^{-\alpha_3})$$

time stretch and luminosity scaling

$$W(t) = k \times U(t/s)$$



Cano+ 2011, 2013

Numerical modelling - STELLA

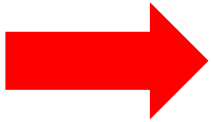
Blinnikov S. I. et al., 1998, ApJ, 496, 454
Blinnikov S. I. et al., 2006, A&A, 453, 229

- STELLA is a package of one-dimensional spherically symmetrical multi-group radiation hydrodynamics codes which treat non-equilibrium radiative transfer according to chemical composition and inner structure of pre-supernova.
- Geometry is simple, but the consideration of chemical abundances and distribution of different chemical elements inside a pre-supernova allows one to calculate radiative transfer during the explosion and to build more physically correct modelled light curve.
- STELLA is widely used for SNe modelling, but it was used for the 1st time to model a GRB-SN.

STELLA

Input

- Mass & Padius of SN progenitor
- Mass of ejecta
- Mass of a compact remnant
- Burst energy
- Abundances and initial radial distribution of chemical elements



Output

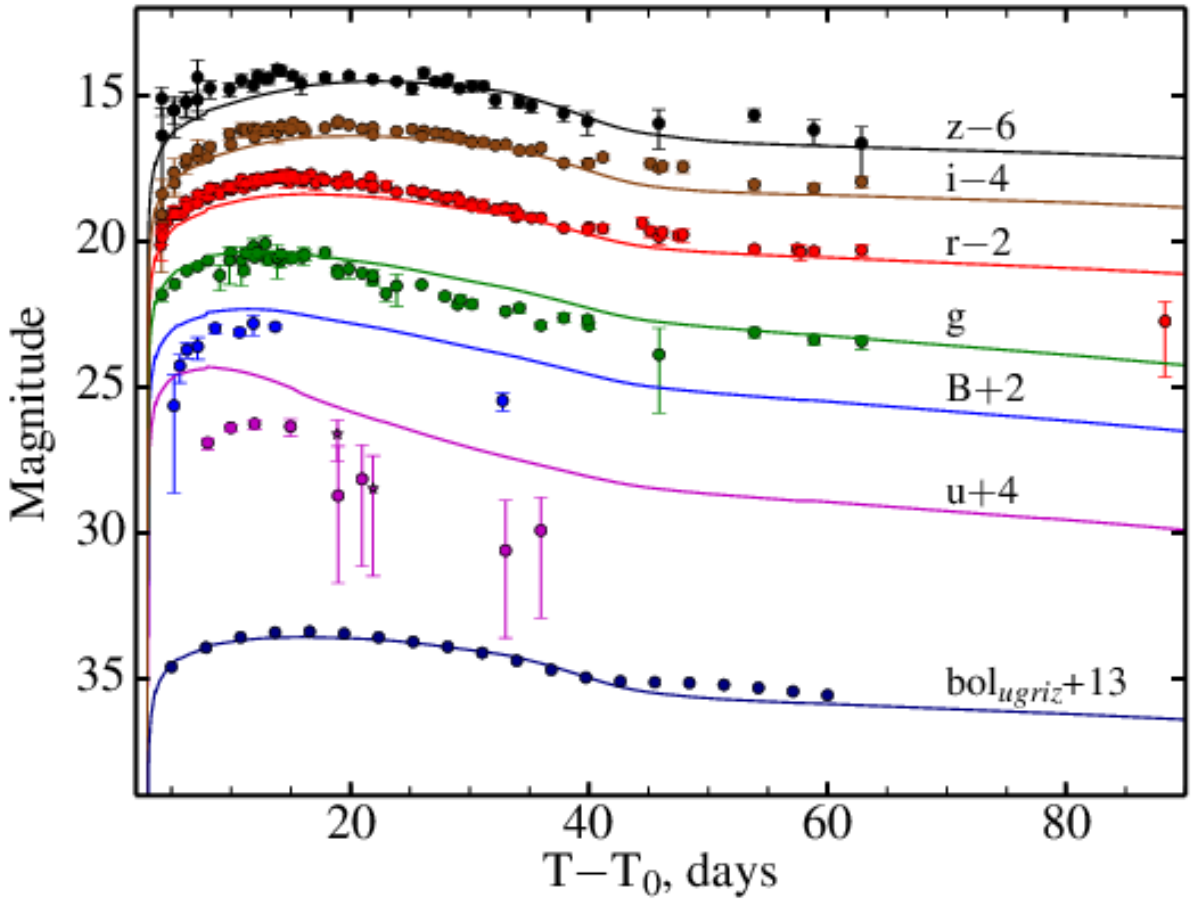
- Spectra from UV (70 eV) to IR (4.8 μm) from 1 to several 10s of days after the burst

  \+ conversion with filters

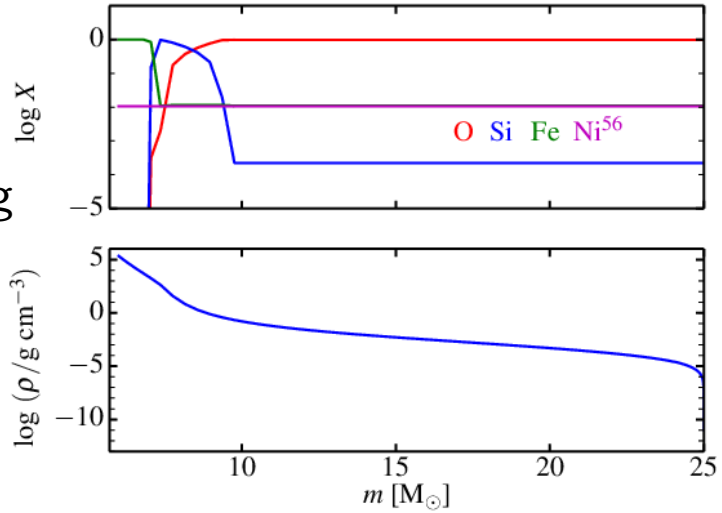
  = modelled light curve

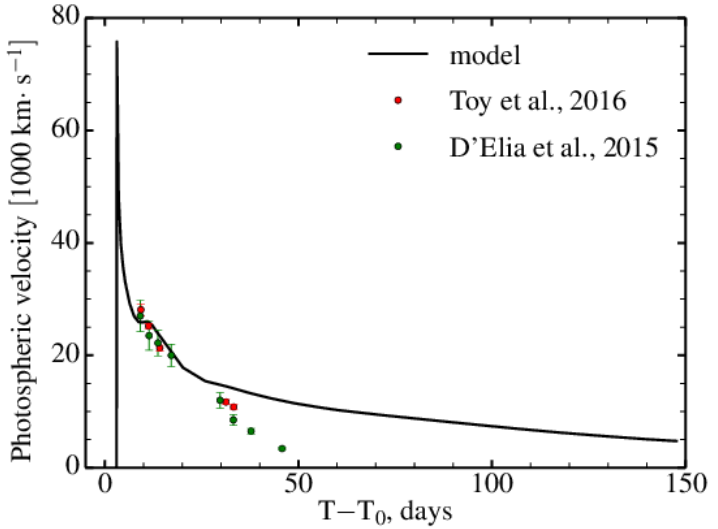
SN 2013dx

Volnova+ 2017



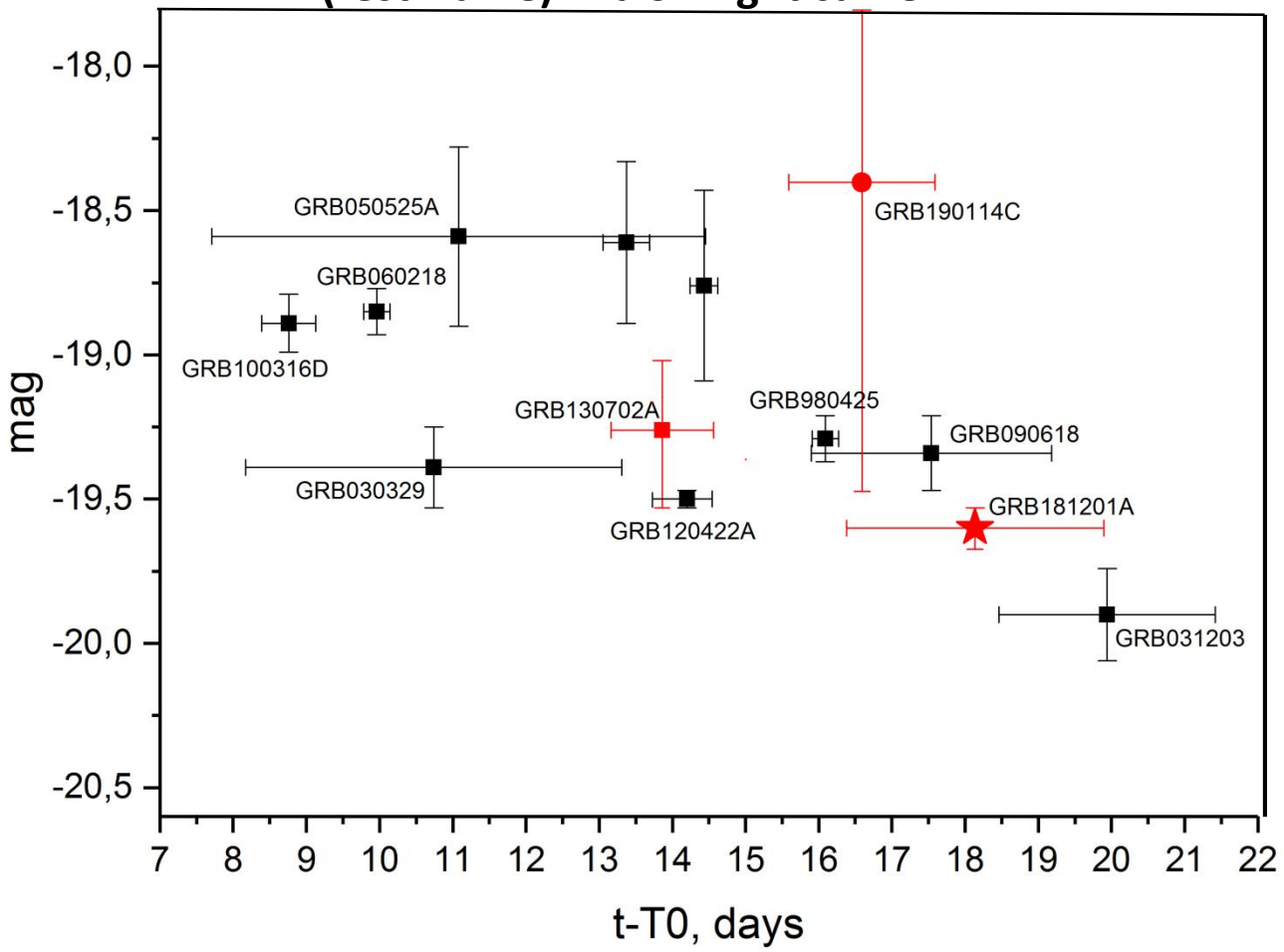
$M = 25\ M_{Sun}$
$E_{oburst} = 3.5 \times 10^{52}$ erg
$M_{56Ni} = 0.2\ M_{Sun}$, перемешан
$M_{CR} = 6\ M_{Sun}$
$M_{ej} = 19\ M_{Sun}$
$R = 100\ R_{Sun}$
$M_O = 16.6\ M_{Sun}$
$M_{Si} = 1.2\ M_{Sun}$
M_{Fe} 1.2 M_{Sun}
$E_{bol} = 3.1 \times 10^{49}$ erg
$t_{peak} = 14.35$ d
$\eta > 0.1$ %



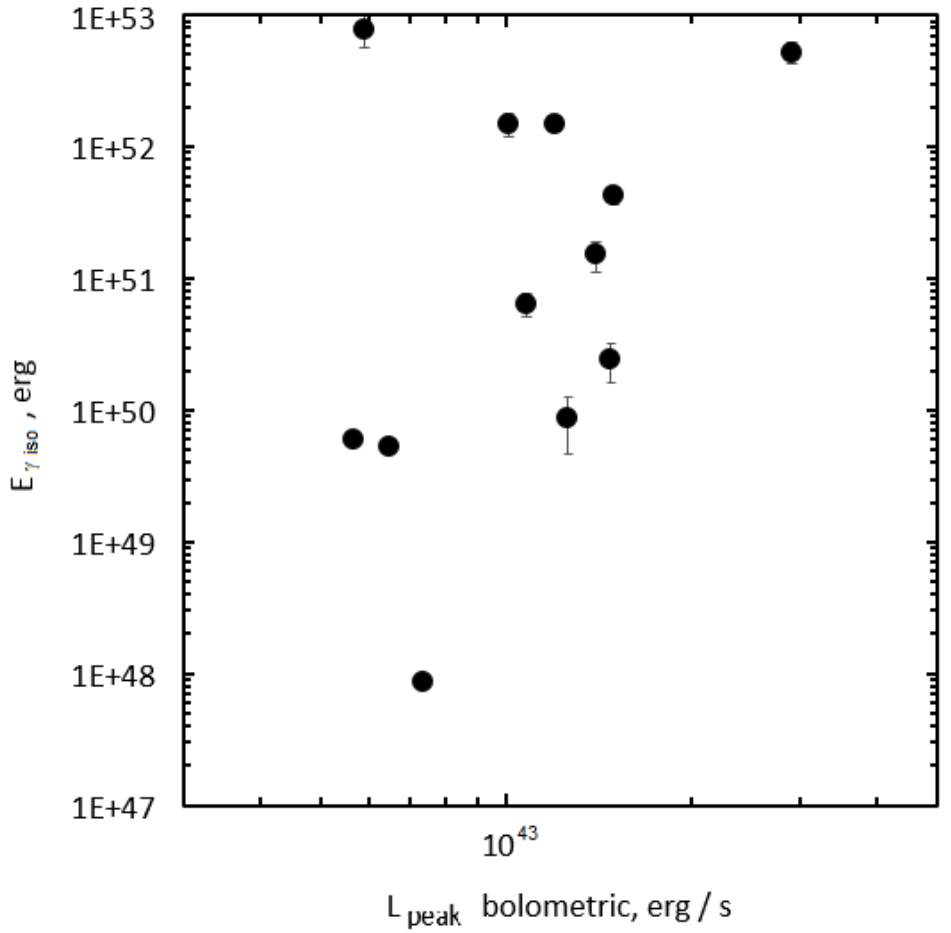


Some non-correlations

Absolute magnitude V vs. T_max (rest frame) in a SN light curve



E_iso of GRBs vs. max bolometric luminosity of SNe



Conclusions

- ~40% of long GRBs with optical counterpart at $z < 1,1$ exhibit the SN feature.
- The number of spectroscopically GRB-SNe is small (25 events), and every new GRB-SN may be crucial for the physics of the phenomena.
- Numerical modelling of the multicolour SNe light curves and photospheric velocities using radiation hydrodynamics allows direct estimation of parameters of the SN and its chemical composition. (Spectral data are necessary for evolution of photospheric velocities which are important in modeling).
- There is still no correlations between observable properties of GRB in gamma-ray domain and bolometric properties of the associated SN.

Thank you for your attention!

LC dependence of the main parameters