Observations and modelling of SNe associated with GRBs

<u>Volnova Alina (IKI RAS)</u>, Pozanenko Alexei (IKI RAS), Pruzhinskaya Maria (SAI MSU), Blinnikov Sergei (ITEP), Minaev Pavel (IKI RAS), Mazaeva Elena (IKI RAS), Belkin Sergei (MITP, IKI RAS) *et al.*

Context

Modern SNe classification



Modern SNe classification



GRB Optical Afterglow



Spectroscopical GRB-SNe

SN 2003dh

GRB 980425 /	SN 1998bw	z = 0,0085							
GRB 011121 /	SN 2001ke	z = 0,36							
GRB 021211 /	SN 2002lt	z = 1,01	All type Ic!		ma			<u> </u>	N2003dh
GRB 030329 /	SN 2003dh	z = 0,168		, MM	m			••• S	N1998bw
GRB 031203 /	SN 2003lw	z = 0,105		Martin		mm			0
GRB 050525A /	SN 2005nc	z = 0,606		-	m.				
GRB 060218 /	SN 2006aj	z = 0,0331		- Martin	w wy.		my		4.0 days
GRB 081007 /	SN 2008hw	z = 0,5295	ts)	- N.	···· m	my .	·'		7.4 days
GRB 091127A /	SN 2009nz	z = 0,49	rui,	- 1. mm	. <u>M</u> .	To bend as			
GRB 100316D /	SN 2010bh	z = 0.059	ary (w h		your		8.3 days _
GRB 101219B /	SN 2010ma	z = 0,55	bitra	- Marine		my.		. 1	8.3 days
GRB 111209A /	SN 2011kl	z = 0,677	(ar	- Intil Mann	month.	m	m	M. M	-
GRB 120422A /	SN 2012bz	z = 0,283	ant	i k MJ	A.M AP	hy	·.	2. M.	9.9 days
GRB 120714B /	SN 2012eb	z = 0,3984	nst	[]	M	myth	M		12.2 days
GRB 130215A /	SN 2013ez	z = 0,597	8	[min m	w 1	·	mm		-
GRB 130427A /	SN 2013cq	z = 0,3399	ť, +	- Marine		mon	·. /		15.9 days -
GRB 130702A /	SN 2013dx	z = 0,145		f . M		·	mymus		15.1 days .
GRB 130831A /	SN 2013fu	z = 0,4791		- W A	Mar 1	my my	hun		20.1 days -
GRB 140606B /	iPTF14bfu	z = 0,384		- Mannan	1.1	. W	My		20.3 days _
GRB 150818A /	SN	z = 0,282		- M"			human	the M	27.8 days -
GRB 161219B /	SN 2016jca	z = 0,1475		- M				1 M	27.1 days
GRB 171010A /	SN 2017htp	z = 0,3285						1	
GRB 171205A /	SN 2017iuk	z = 0,0368			mhum	mhum	mulum	l	սոկոսոս
GRB 180728A /	SN	z = 0,117	3	.000 4.000	5.000	6.000	7.000	8.000	9.000
GRB 190829A /	SN	z = 0.08		,	Dee	t wovele	nath (Å)	-,	-,
,		z _{med} = 0,33	Hjorth+	2003	ries	a wavele	ngth (A)		
	GRB 980425 / GRB 011121 / GRB 021211 / GRB 030329 / GRB 031203 / GRB 050525A / GRB 060218 / GRB 060218 / GRB 091127A / GRB 100316D / GRB 100316D / GRB 101219B / GRB 120422A / GRB 120422A / GRB 120714B / GRB 120714B / GRB 130215A / GRB 130427A / GRB 130831A / GRB 130831A / GRB 140606B / GRB 150818A / GRB 161219B / GRB 161219B / GRB 171010A / GRB 171205A / GRB 180728A / GRB 180728A /	GRB 980425 / SN 1998bw GRB 011121 / SN 2001ke GRB 021211 / SN 2002lt GRB 030329 / SN 2003dh GRB 031203 / SN 2003lw GRB 050525A / SN 2005nc GRB 060218 / SN 2006aj GRB 081007 / SN 2008hw GRB 091127A / SN 2009nz GRB 100316D / SN 2010bh GRB 101219B / SN 2010ma GRB 111209A / SN 2011kl GRB 120422A / SN 2012bz GRB 120714B / SN 2012eb GRB 130215A / SN 2013ez GRB 130427A / SN 2013cq GRB 130702A / SN 2013dx GRB 130831A / SN 2013fu GRB 140606B / iPTF14bfu GRB 150818A / SN GRB 161219B / SN 2016jca GRB 171010A / SN 2017htp GRB 171205A / SN 2017iuk GRB 180728A / SN GRB 180728A / SN	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 091127ASN 2009nz $z = 0,49$ GRB 100316DSN 2010bh $z = 0,059$ GRB 101219BSN 2010ma $z = 0,677$ GRB 120422ASN 2012bz $z = 0,283$ GRB 120714BSN 2012eb $z = 0,3984$ GRB 130215ASN 2013ez $z = 0,3984$ GRB 130702ASN 2013dx $z = 0,4791$ GRB 130831ASN 2013fu $z = 0,4791$ GRB 140606BiPTF14bfu $z = 0,384$ GRB 150818ASN $z = 0,282$ GRB 161219BSN 2016jca $z = 0,1475$ GRB 171010ASN 2017htp $z = 0,3285$ GRB 180728ASN $z = 0,117$ GRB 190829ASN $z = 0,08$ Zmed = 0,33 $z = 0,33$	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	GRB 980425 / SN 1998bw $z = 0,0085$ GRB 011121 / SN 2001ke $z = 0,36$ GRB 021211 / SN 2002lt $z = 1,01$ GRB 030329 / SN 2003lw $z = 0,168$ GRB 031203 / SN 2003lw $z = 0,105$ GRB 050525A / SN 2005nc $z = 0,606$ GRB 060218 / SN 2005nc $z = 0,606$ GRB 06127A / SN 2009nz $z = 0,6331$ GRB 101219B / SN 2010bh $z = 0,5295$ GRB 101219B / SN 2010bh $z = 0,677$ GRB 11209A / SN 2012bz $z = 0,3984$ GRB 130215A / SN 2013cz $z = 0,3984$ GRB 130215A / SN 2013cz $z = 0,3399$ GRB 130215A / SN 2013cz $z = 0,3399$ GRB 130427A / SN 2013cz $z = 0,384$ GRB 130702A / SN 2013fu $z = 0,145$ GRB 161219B / SN 2017htp $z = 0,3285$ GRB 171010A / SN 2017htp $z = 0,3285$ GRB 17010A / SN 2017htp $z = 0,08$ GRB 190829A / SN $z = 0,08$ GRB 190829A	GRB 980425 / SN 1998bw $z = 0,0085$ GRB 011121 / SN 2001ke $z = 0,36$ GRB 021211 / SN 2002lt $z = 1,01$ GRB 03329 / SN 2003dh $z = 0,168$ GRB 031203 / SN 2003lw $z = 0,105$ GRB 050525A / SN 2003m $z = 0,0331$ GRB 060218 / SN 2008hw $z = 0,059$ GRB 081007 / SN 2008hw $z = 0,5295$ GRB 100316D / SN 2010bh $z = 0,677$ GRB 101219B / SN 2012bz $z = 0,334$ GRB 120422A / SN 2012eb $z = 0,3399$ GRB 130215A / SN 2013cq $z = 0,3399$ GRB 1302015A / SN 2013cq $z = 0,384$ GRB 1302015A / SN 2013cq $z = 0,384$ GRB 130831A / SN 2013cq $z = 0,384$ GRB 161219B / SN 2017iuk $z = 0,3285$ GRB 17100A / SN 2017iuk $z = 0,038$ GRB 171205A / SN 2017iuk $z = 0,08$ Zmed = 0,33 Hjorth+ 2003	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 050525A / SN 2005nc $z = 0,606$ GRB 060218/ SN 2006aj $z = 0,5295$ GRB 011219A / SN 2009nz $z = 0,5295$ GRB 100316D / SN 2010bh $z = 0,5295$ GRB 101219B / SN 2010bh $z = 0,659$ GRB 102129A / SN 2012bz $z = 0,677$ GRB 120422A / SN 2012bz $z = 0,3984$ GRB 130215A / SN 2012eb $z = 0,3984$ GRB 130427A / SN 2013cq $z = 0,3399$ GRB 130831A / SN 2013fu $z = 0,797$ GRB 130831A / SN 2013fu $z = 0,797$ GRB 161219B / SN 2010ba $z = 0,384$ GRB 130831A / SN 2013fu $z = 0,797$ GRB 161219B / SN 2016jca $z = 0,1475$ GRB 171010A / SN 2017hup $z = 0,3285$ GRB 171205A / SN 2017iuk $z = 0,0368$ GRB 171205A / SN 2017iuk $z = 0,0368$ GRB 17028A / SN $z = 0,0177$ GRB 180728A / SN $z = 0,0177$ GRB 190829A / SN $z = 0,028$ GRB 190829A / SN $z = 0,038$	GRB 980425/ SN 1998bw $z = 0,085$ GRB 011121/ SN 2001ke $z = 0,36$ GRB 021211/ SN 2002lt $z = 1,01$ GRB 030329/ SN 2003dk $z = 0,168$ GRB 050525A/ SN 2005nc $z = 0,0031$ GRB 060218/ SN 2006aj $z = 0,0331$ GRB 060218/ SN 20008hw $z = 0,039$ GRB 011219/ SN 2009nz $z = 0,039$ GRB 100316D/ SN 2010bh $z = 0,059$ GRB 101219B/ SN 2010bh $z = 0,677$ GRB 11209A/ SN 2012bz $z = 0,283$ GRB 120422A/ SN 2012bz $z = 0,283$ GRB 130215A/ SN 2013cq $z = 0,797$ GRB 130215A/ SN 2013cq $z = 0,797$ GRB 130215A/ SN 2013cq $z = 0,797$ GRB 130702A/ SN 2013dx $z = 0,74791$ GRB 130831A/ SN 2013fu $z = 0,74791$ GRB 161219B/ SN 2017htp $z = 0,3285$ GRB 17100A/ SN 2017htp $z = 0,3285$ GRB 17100A/ SN 2017htp $z = 0,0368$ GRB 17100A/ SN 2017htp $z = 0,08$ Cmd B 190829A/ SN $z = 0,08$ Zmd $= 0,33$ Hjorth+ 2003	GRB 980425 / SN 1998bw z = 0,085 GRB 011121 / SN 2001ke z = 0,36 GRB 02111 / SN 2002lk z = 1,01 GRB 031203 / SN 2003lw z = 0,168 GRB 031203 / SN 2003lw z = 0,031 GRB 050525A / SN 2003lw z = 0,031 GRB 060218 / SN 2006aj z = 0,0331 GRB 091127A / SN 2009nz z = 0,49 GRB 101219B / SN 2010bh z = 0,555 GRB 101219B / SN 2012bz z = 0,283 GRB 120714B / SN 2012eb z = 0,3984 GRB 130215A / SN 2012eb z = 0,3984 GRB 130215A / SN 2013cq z = 0,3399 GRB 130215A / SN 2013cq z = 0,3384 GRB 130831A / SN 2017htp z = 0,3285 GRB 171205A / SN 2017htp z = 0,3285 GRB 171205A / SN 2017htp z = 0,3285 GRB 180728A / SN z =

Photometrical GRB-SNe

z = 0,695• GRB 970228 z = 1 (?) GRB 980326 GRB 990712 z = 0,434GRB 991208 z = 0,706GRB 000911 z = 1,058GRB 020305 z = 0,2 (?) GRB 020405 z = 0.69GRB 020410 z = ?GRB 020903 z = 0,25GRB 030723 z = ? GRB 040924 z = 0,859 GRB 041006 z = 0.716GRB 050416A z = 0,6535 GRB 050824 z = 0.83GRB 060729 шR z = 0.54GRB 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 $z_{\rm med}$ = 0.67 GRB 181201A z = 0,45 GRB 190114C z = 0,42



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 $M_{\rm R} = -19.36 \pm 0.05 \text{ mag}$ $M_{\rm Ni56} = 0.42 \pm 0.02 \text{ M}_{\rm Sun}$ $M_{\rm Ej} = 6.80 \pm 0.57 \text{ M}_{\rm Sun}$ $E = 2.19 \pm 0.17 \times 10^{52} \text{ erg}$



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)



Modelling

Templates



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)

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

time stretch and luminosity scaling

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



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 presupernova.
- 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
 - = <u>modelled light curve</u>

SN 2013dx



Volnova+ 2017

22

Some non-correlations



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



