GRB Central Engines within Superluminous Supernovae?

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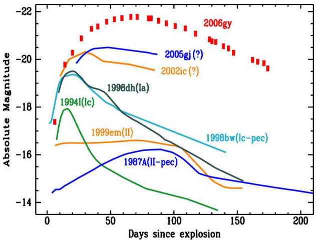
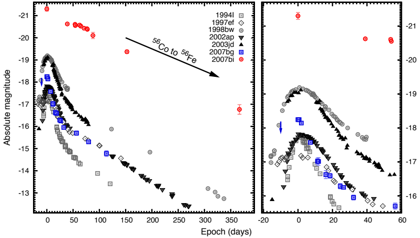
Prague, June 2017

First Superluminous Supernova (SLSN) is discovered in 2006



Superluminous SN of type II



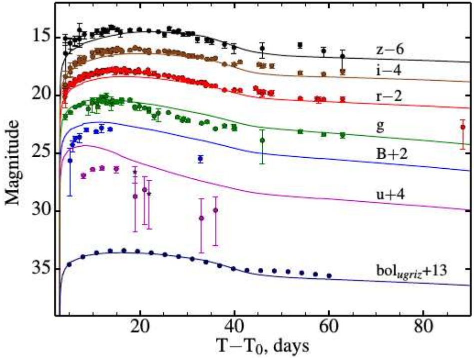
Superluminous SN of type I

SN2006gy used to be the most luminous SN in 2006, but not now.
Now many SNe are discovered even more luminous.

The number of Superluminous Supernovae (SLSNe) discovered is growing. The models explaining those events with the minimum energy budget involve multiple ejections of mass in presupernova stars. Mass loss and build-up of envelopes around massive stars are generic features of stellar evolution. Normally, those envelopes are rather diluted, and they do not change significantly the light produced in the majority of supernovae.

SLSNe are not equal to Hypernovae

Hypernovae are not extremely luminous, but they have high kinetic energy of explosion.



Alina Volnova, et al. 2017. Multicolour modelling of SN 2013dx associated with GRB 130702A. MNRAS 467, 3500.

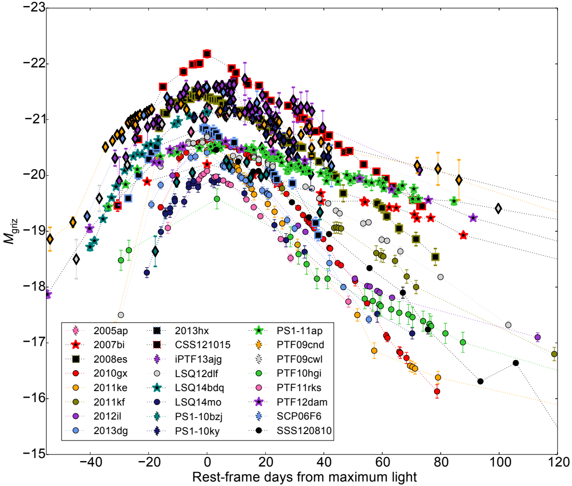
See poster S11.15 .

First year light $\sim$ 0.03 foe (Bethe) while for SLSNe it is an order of magnitude larger.

Hydrogen-poor super-luminous supernovae

M.Nicholl et al. 2015

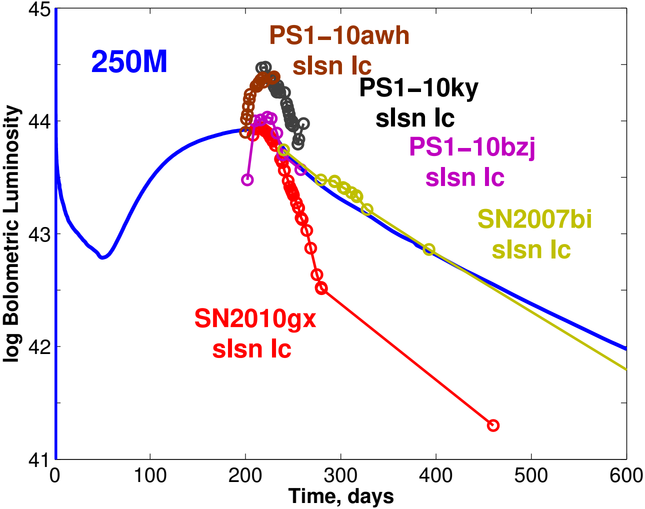
griz pseudobolometric light curves



Three scenarios proposed for SLSNe-I

- Pair instability Supernovae, **PISN**
- **"Magnetar"** pumping (BUT observed magnetars are slowly rotating, and here millisecond periods are needed)
- ***Shock interaction*** with CSM, e.g. Pulsational pair instability, **PPISN**

PISN: e.g. A. Kozyreva, SB, Langer, Yoon, 2014



It is clear that some SLSNe are not PISN.

Badjin, Barkov, SB, Khangulyan, in prep.: Why the primitive "magnetar" does not work?

Supernova pumping by a ms pulsar with high B is an old idea (Shklovskiy 1971, 1975).

Detailed simulations show that the spin-down energy of a magnetar is converted into relativistic plasma pressure and the work it makes upon a forming shell, and therefore into the shell kinetic energy.

Not into luminosity! Details in http://wwwmpa.mpa-garching.mpg.de/hydro/NucAstro/PDF_16/Badjin.pdf

A third path to SLSN – Double explosion: an old idea for SNIIn

Grasberg & Nadyozhin (1986)

Models were proposed for SLSNe with the explosion energy tens times higher than in usual SNe, and presupernovae were suggested ten times more massive, with a huge amount of radioactive ^{56}Ni produced in the explosion. This is possible in pair-instability SNe, **PISNe**.

However, in many cases those extreme parameters are not needed. Our Lagrangian 1D code STELLA with multigroup radiative transfer allows us to get more economical models

The latest papers with our results are

Sorokina, Blinnikov, Nomoto, Quimby, Tolstov 2016, ApJ 829, 17 "Type I Superluminous Supernovae as Explosions inside Non-hydrogen Circumstellar Envelopes",

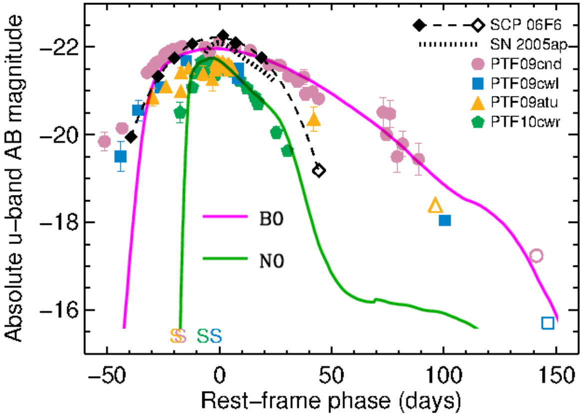
Tolstov+2017, ApJ 835, 266 "Pulsational Pair-instability Model for Superluminous Supernova PTF12dam: Interaction and Radioactive Decay"

Repeated explosions: a mechanisms for Superluminous Supernovae

In some cases, large amounts of mass are expelled just a few years before the final explosion. Then the slowly expanding envelopes around supernovae may be quite dense. The **shock waves** produced in collisions of supernova ejecta and those dense shells may provide the required power of light to make the supernova much **more luminous** than a “naked” supernova without pre-ejected surrounding material.

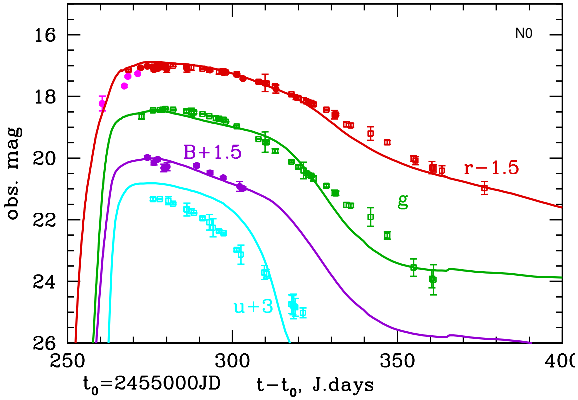
This class of the models is referred to as **“interacting” supernovae**. We show in a detailed radiation hydro modelling (E.Sorokina, S.Blinnikov, K.Nomoto, R.Quimby, & A.Tolstov - ApJ 829, 17, 2016) that the interacting scenario is able to explain both fast and slowly fading SLSNe, so the large range of these intriguingly luminous objects can in reality be almost ordinary supernovae placed into extraordinary surroundings.

STELLA reproduces the range of SLSN in shock model: 2 extreme cases



Explosion energy is just 2 - 4 foe (2 - 4 B).

Light curve model for SN2010gx

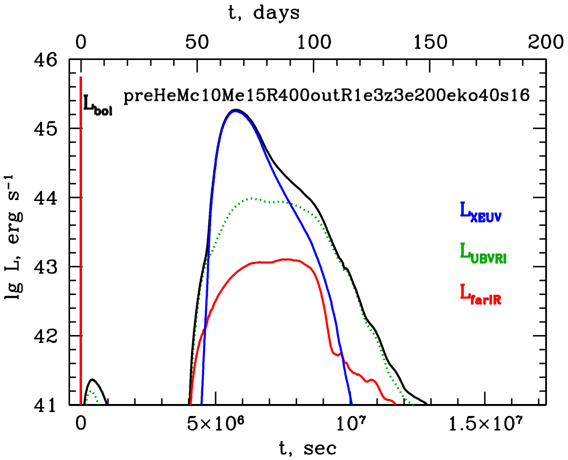


Synthetic light curves for the model N0, one of the best for SN 2010gx, in *r*, *g*, *B*, and *u*.

Problems with high photospheric velocity in SLSNe

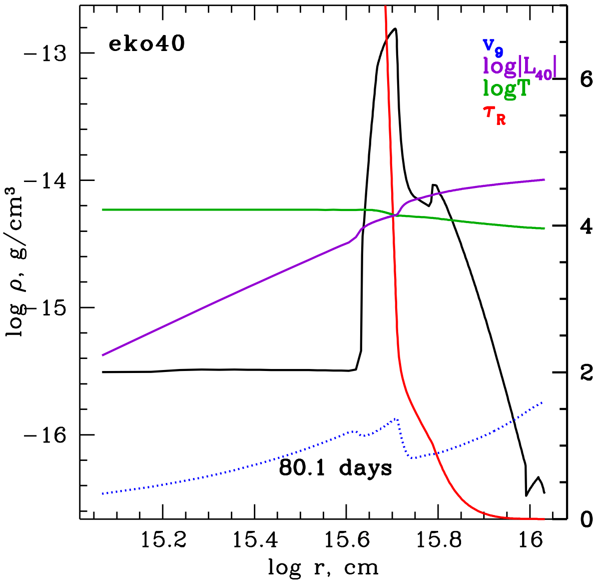
Many SLSNe-I have photospheric velocity of order 10^4 km/s which is hard to explain in interacting models with modest energy of explosion. Our new set of radiation hydro models demonstrates that a strong explosion (on the observed hypernova scale) within a dense envelope produced by previous weaker explosions explains naturally both high luminosity and high photospheric velocity of SLSNe. Observed hypernovae are associated with GRBs. We conclude that the main features observed in SLSNe near maximum light are explained by a GRB-like central engine, embedded in a dense envelope and shells ejected prior the final collapse of a massive star.

High energy of explosion is needed for explaining high velocity

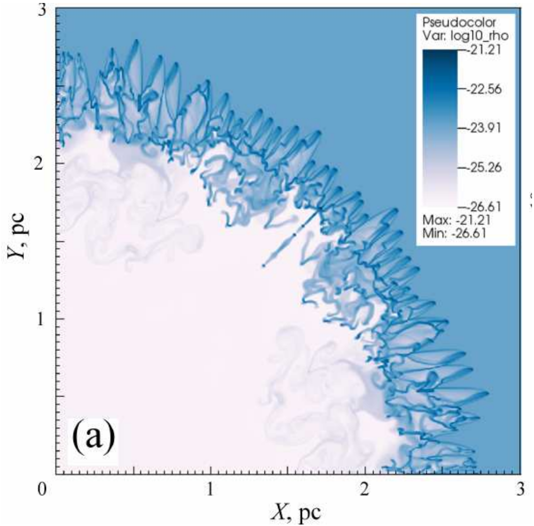


1st explosion is modelled with a kinetic bomb $E = 4$B, then a thermal bomb with $E = 20$B for producing high photospheric velocity: bolometric and quasi-bolometric LC

Radiation hydro profiles for high velocities



3D developments in our group



Badjin, Glazyrin, Manukovsky, SB, MNRAS 2016

Fore more results see poster SS11.1 by Dmitriy Badjin.

Conclusions

- Models for Superluminous Supernovae involving interaction with circumstellar matter are able to reproduce a broad class of SLSN light curves, but photospheric velocities are rather low for $E < 4$ B.
- High photospheric velocities can be explained for $E \gtrsim 20$ B, i.e. on the energy scale of hypernovae and GRBs.
- One should expect different behaviour in X-rays for low and high velocity SLSNe.

Thank you!