The physical origins of the extreme luminosity for slowly fading Super-luminous Supernovae

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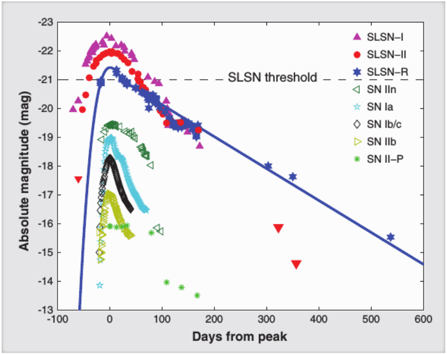
SLNSe can be classified:

- **SLSN-I** - hydrogen-poor (PTF09cnd)
- **SLSN-II** - hydrogen-rich (SN 2006gy)
- **SLSN-R** - radioactively powered by ^{56}Ni (PTF12dam)

Credit: Gal-Yam A. et. al.(2012)



Initially it was suggested what SLSN-R could be powered by radioactive decay chain ^{56}Ni $\Rightarrow$ ^{56}Co $\Rightarrow$ ^{56}Fe. The required amount of a ^{56}Ni can be synthesized in a model of pair-instability supernova (PISN).

The progenitors of PISN have C-O cores of $65 - 130\ M_{\odot}$.

PTF12dam is not PISN but magnetar-powered?

Nicholl et al. (Nature,2013): *Slowly fading super-luminous supernovae that are not pair-instability explosions.*

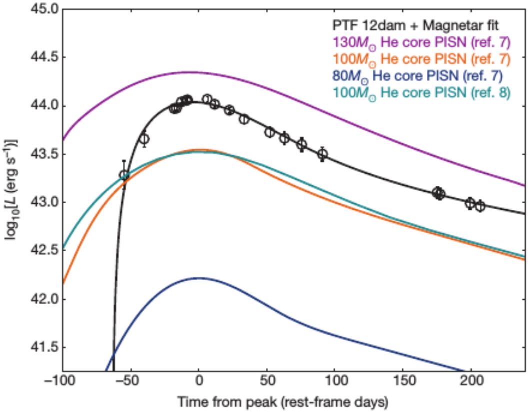
In view of:

- relatively fast rises
- blue spectra
- lacking ultraviolet line blanketing - no metal

Favor of the magnetar

The magnetar loses rotation energy, injecting the most energy to expanding dense shell.

Bolometric Luminocity & magnetar fit:



Credit: Nicholl et. al. (2013)

The magnitar model

Nicholl et al. (Nature,2013): *Slowly fading super-luminous supernovae that are not pair-instability explosions.*

The same result has been obtain for all known SLSN-R: PS1-11ap, SN 2007bi.
As a consequence Nicholl et. al. (2013) obtained a low upper limit on the rate of occurrence of super-luminous PISN.

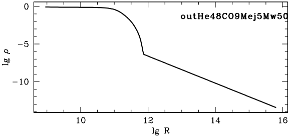
But the magnetar model works only for SLSN-R.
There is another possibility that at the same time explains SLSN-R as well as others.

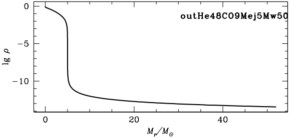
PTF12dam: the extended envelope of progenitor

Luminosity due to the collision of SN fireball with an extended envelope

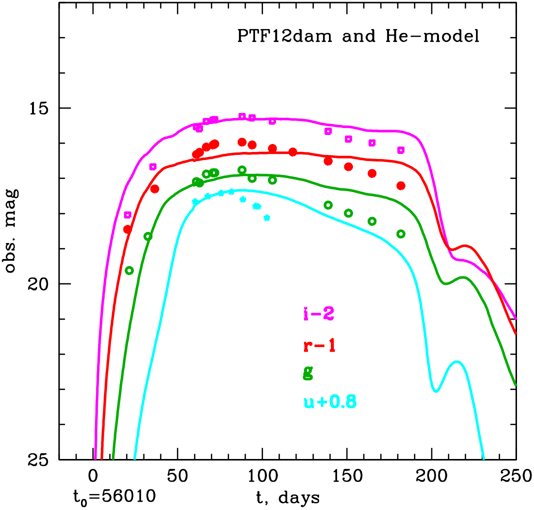
Go to frame Structure

Density structure



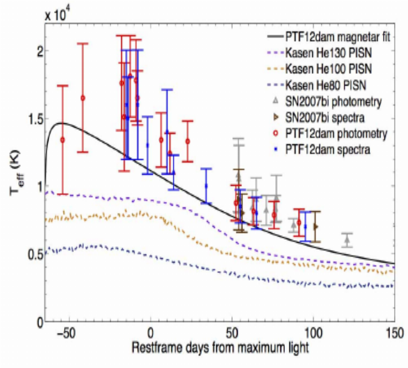


The ugri-bands the extended envelope model and observations



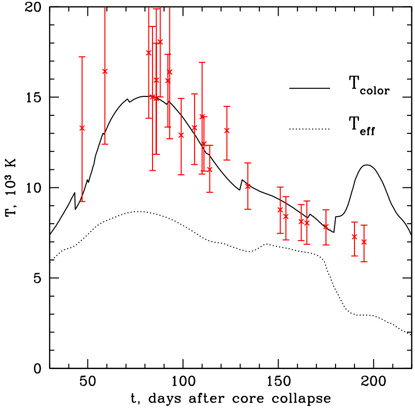
PTF12dam: $T_{color}(t)$ - color temperature versus time

The Magnetar model:



Credit: Nicholl et. al. (2013)

The model of extended envelope:



Discussions

- What is the power source for the extreme luminosity of SLSN-R: Radioactive decay of ^{56}Ni OR a magnitar OR the collision of SN fireball with an extended envelope?
- Do such extended envelopes of presupernovae exist? They should have $M_{env} \sim 30 - 100\ M_{\odot}$ and $R_{env} \sim 10^{15} - 10^{16}\ cm$
- It was a challenge to make a slower rise of the LS peak. We found a satisfactory model without H and He, but it reaches the maximum of LC a little bit quickly. Our best model requires the presence of He-envelope.
  But there is no He-lines observed in spectra.
- What is the rate of occurence for such SLSN?
- What is the contribution of SLSN-R to galactic chemical composition per event: $10 - 15\ M_{\odot}$(magnitar) OR $40 - 100\ M_{\odot}$(extended envelope) ?

SLSN: velocity structure of envelope

Nicholl (2013): *"For PTF12dam, the velocities of spectral lines are close to $10,000$ km s^{-1} at all times ".*

For PTF12dam (Nicholl, 2013):

"Before and around peak, our objects show the characteristic blue continua and O II absorptions common to super-luminous supernovae of type I/Ic, although the lines in the slowly evolving objects are at lower velocities than are typically seen in those events. "

Velocity structure for the eruption of a 110-solar-mass PISN.

(Woosley, Blinnikov, Heger, 2007)