Ultraviolet-Bright Type IIP Supernovae and Extensive Mass Loss of Red Supergiants

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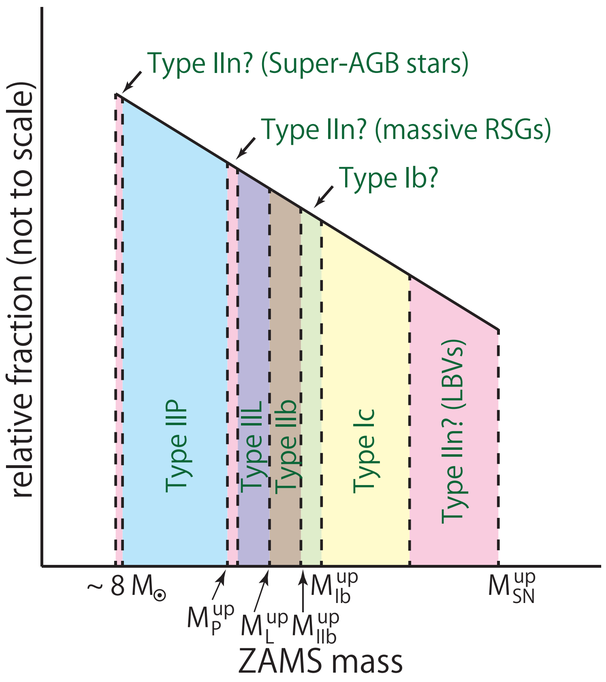
Massive red supergiants (RSGs) can experience a mass loss with a very high mass-loss rate due to the dynamical instabilities caused by the partial ionizations of hydrogen (e.g., Yoon & Cantiello 2010). It is suggested that the mass-loss rates of massive RSGs can be as high as 0.01 Msun/yr. Because of the mass loss, massive RSGs can have very dense circumstellar matter (CSM) around them. If a supernova (SN) explosion occurs soon after the extensive mass loss of RSGs, the SN ejecta will collide the dense CSM. Due to the collision, the kinetic energy of the ejecta is converted to radiation energy and such SNe with collision can be brighter , especially in ultraviolet, than the usual SNe of RSGs. By performing one dimensional multi-group radiation hydrodynamical calculations, we investigate the effects of the collision on SN LCs. We also compare our models with the ultraviolet-bright Type IIP SN 2009kf and show that the progenitor of SN 2009kf can be a massive RSG which experienced an extensive mass loss just before its explosion.

Unknown Mass Loss of Massive RSGs



Which Stars Become Which Supernovae? - We still do NOT know exactly!

Big **discrepancy** in observations and theoretical predictions from stellar evolution:

The upper mass of Type IIP SN progenitors (M_P^{up})

- Observations: $M_P^{up} \simeq 17\ M_\odot$ (Smartt et al. 2009)
- Theories : $M_P^{up} \simeq 25\ M_\odot$ (e.g., Heger et al. 2003)

Why? Another Mass-Loss Mechanism?

This discrepancy can be from **uncertainties in mass loss** used in stellar modeling.

Possible additional mass-loss mechanism of massive RSGs

- Pulsation of H envelope due to dynamical instability (Heger et al. 1997; Yoon & Cantiello 2010)
  Timescale is not resolved in usual stellar evolution modeling.
- Nuclear flash (Weaver & Woosley 1979)

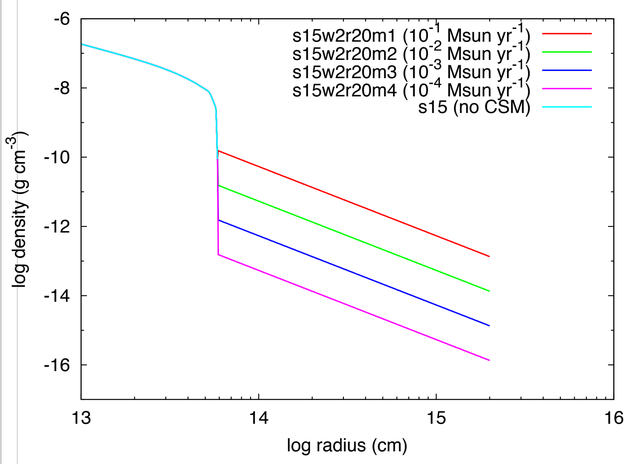
This mechanisms can induce extensive mass loss, up to $\sim 10^{-2} M_\odot\ \mathrm{yr}^{-1}$

Effect on their Supernovae?

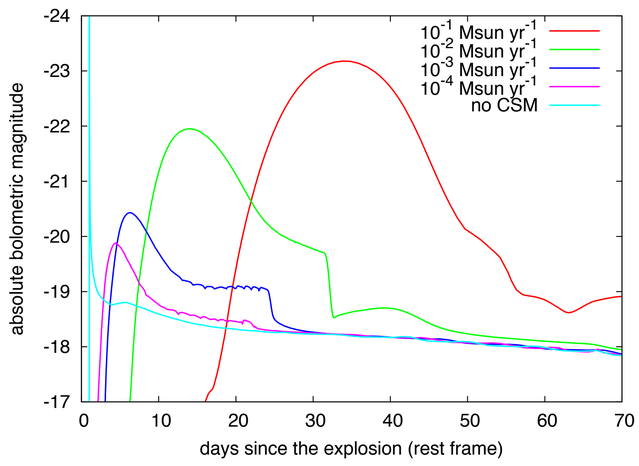
RSGs become Type IIP SNe. If dense CSM due to extensive mass loss exists at the time of explosion, it may affect LCs of SNe.

This work: Investigate the effect of dense CSM on Type IIP SN LCs and compare the LCs to observation

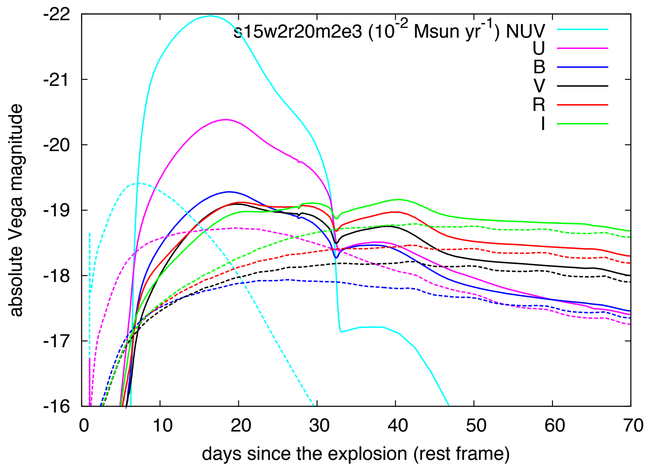
Explosions of RSGs in dense CSM (Explosion energy: 3e51 erg)



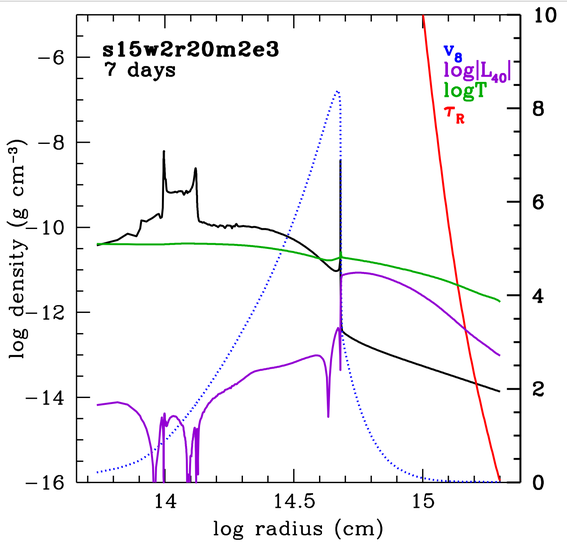
Pre-SN models:
15 Msun Woosley RSG + dense CSM



Bolometric LCs: calculated by radiation hydrodynamics code



Multi-color LCs: calculated by radiation hydro code, dashed lines are LCs w/o CSM

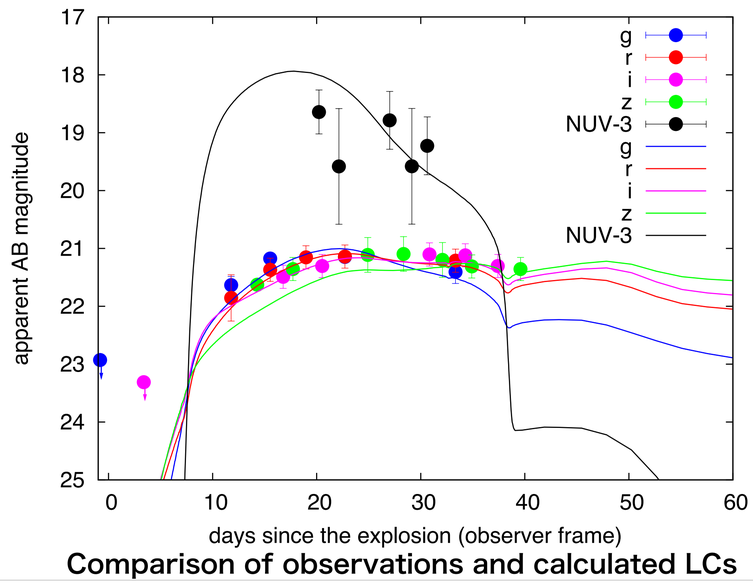


Hydro structure: calculated by radiation hydrodynamics code

Comparison to ultraviolet-bright Type IIP SN 2009kf

SN 2009kf was discovered by Pan-STARRS and observed by GALEX. It is found to be a Type IIP SN but **very bright in ultraviolet** at early epochs (Pastorello et al. 2010). We compared the observed LCs with our models and found that the UV brightness can be explained by **the existence of dense CSM** (Moriya et al. 2010). Mass-loss rate just before the explosion is estimated to be $\sim 10^{-2} M_\odot\ \mathrm{yr}^{-1}$. What is more, SN 2009kf is found to be one of the most energetic Type IIP SN and this indicates that **the progenitor of SN 2009kf is a very massive RSG**.

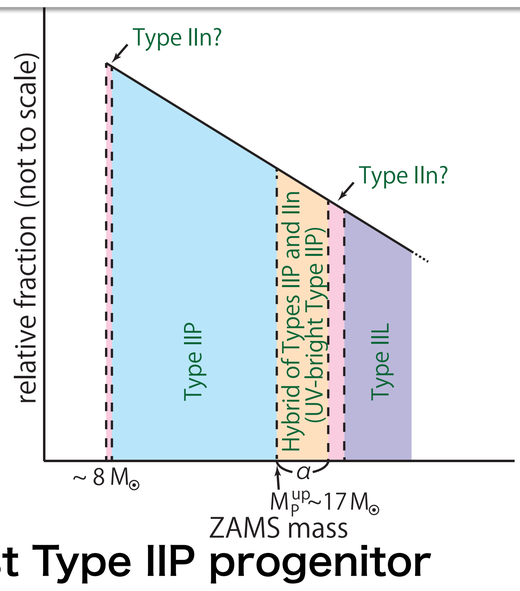
→ **Massive RSGs do experience extensive mass loss!**

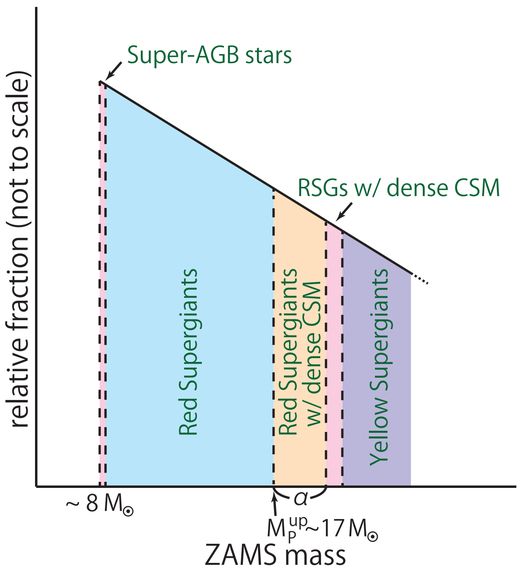


Comparison of observations and calculated LCs

Possible Interpretations

Pulsations of H envelope are suggested to occur RSGs whose ZAMS mass heavier than 17 Msun (Yoon & Cantiello 2010). As this mass corresponds to the upper mass of Type IIP SNe, this mechanism may determine the mass range of Type IIP SNe. Then, there can be a small mass range where Type IIP SNe are exploded with dense CSM and become bright in UV.





Conclusions

- **SN 2009kf is an explosion of a massive RSG with dense CSM**
- **Existence of extensive mass loss can be what determine the heaviest Type IIP progenitor**