EMISSION FROM ROTATING PAIR INSTABILITY
SUPERNOVAE

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PAIR-INSTABILITY SUPERNOVAE (PISNe)

Very massive stars (ZAMS mass > 130 M_☉) form large C/O cores (> 60 M_☉) that are of high T but relatively low ρ a thermodynamical parameter space that favors the rapid creation of electron-positron pairs. -> Once rate of e-e+ creation exceeds average nuclear reaction rate the gamma-rays produced are absorbed by the pairs therefore leading to a pressure deficit (Γ_{ad} < 4/3). -> Initiation of collapse and explosive C/O burning and production of large amounts of radioactive ^{56}Ni, in the most massive cases.
WHY PISNe?

Super-Luminous Supernovae (SLSNe)
- SN 2007bi
- PTF 10nmn
- Some SLSN-I?

Primordial Explosions
- Pop III stars > 100 M☉
- Reduced mass-loss
WHY ROTATION?

Some observed massive stars rotate (Dufton et al. 2011)

Larger CO cores for smaller ZAMS mass compared to zero rotation due to mixing (Chatzopoulos & Wheeler 2012; Yoon, Dierks & Langer 2012)

Massive Pop III stars can be rapid rotators (Greif et al. 2011; Stacy et al. 2013)
1. MESA stellar evolution with rotation from ZAMS to pre-PISN

2. Map MESA pre-SN profile to the AMR hydrodynamics code FLASH. Follow explosion and nuclear burning

3. Map FLASH pre shock break-out profile into RAGE for radiation hydrodynamics

4. Map post break-out profiles into the LTE radiative transfer code PHOENIX for model LCs and spectra
SUITE OF MODELS

- ZAMS Mass Range: 90 - 300 M
- ZAMS Metallicity Range: 0 - 0.1 Z
- ZAMS Rotation Rate Range: 0 - 0.5 \(\Omega_{\text{crit}}\)

- Pre-PISN Radii: 4-4000 x 10^{10} \text{ cm}
- Pre-PISN CO-core Masses: 60 - 112 M
- Ni-56 Production: 60 - 112 M
- Nickel to SN Ejecta ratio (%): 0.2 - 20
- Peak Bolometric Magnitudes: -16 to -21.5
RA GE SHOCK BREAK-OUT LCs AND SEDs

SEDs peaking in the hard X-rays, at shorter wavelengths than RSG/BSG progenitors (1-100 keV)

Bolometric LCs peaking at $10^{45} - 10^{46}$ erg/s
Spanning large luminosity range yet still not super-luminous
PHOENIX LTE LCs AND SPECTRA
Zero Metallicity 90 - 140 M_

-64 d
-84 d
0 d
0 d
+204 d
+184 d

☆ Strong metallic blends in near-UV dominated by Mg/Ca/Ti/Cr.

☆ Mg/Si/Ca in the optical.

☆ OI lines for model 90 M_

☆ Cr/Fe/Co line-blends in later spectra.

☆ Red colors compared to SLSN (B-V, V-I > 0.5).
PHOENIX LTE LCs AND SPECTRA
Different Rotation Rates

- No robust differences in spectra due to rotation.
- Most differences attributable to different surface composition and SN ejecta temperature and velocity.
Two events are super-luminous!

Differences due to ZAMS metallicity wiped out after explosion.

Artificial addition of metal content prior to radiative transfer leads to suppressed near-UV flux and differences in Ca H&K absorption (Kasen et al. 2011)
Reasonable agreement modulo differences in progenitor models and different numerical treatments
WAS SN 2007bi a PISN? 
(Data from Gal-Yam 2009)

Agreements found in terms of LC (Gal-Yam 2009, Kasen et al. 2011, Kozyreva et al. 2014) but...

...Spectra are quite different at contemporaneous epochs (agreement with Dessart et al. 2014).

No PISN model fit spectra of SN 2007bi or any other SLSN. The implied colors are also very red compared to observed SLSN events.
SUMMARY

✴ Most PISN are NOT super-luminous: low Ni-56 to SN ejecta mass ratio.
✴ Rotating PISN SBO SEDs peak at hard X-rays.
✴ The pre-SN rotation and metallicity properties cannot be deciphered from observed spectra.
✴ The primary factors controlling the PISN spectroscopic characteristics are initial surface composition (affected by pre-SN mass-loss..) and the temperature and velocity of the SN ejecta.
✴ Models of PISNe consistent across different codes.
✴ SN 2007bi was not a PISN, neither was any other SLSN. -> Difficulty in forming massive pre-SN CO-cores at high metallicity.
✴ PISNe are still relevant within the context of early Universe environments. Potential targets for JWST and WFIRST.
THANK YOU!!!