Discovering Supernovae at Epoch of Reionization with Nancy Grace Roman Space Telescope

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High-redshift supernova survey with Roman

- Type Ia supernova survey for cosmology
- up to $z \sim 3$ (Rose et al. 2021)

$N = 12471$ (recovered)
High-redshift supernova survey with Roman

- some supernovae become much brighter than Type Ia supernovae
  - superluminous supernovae (SLSNe)
  - a kind of massive star explosions (core-collapse supernovae)
High-redshift supernova survey with Roman

- some supernovae become much brighter than Type Ia supernovae
- pair-instability supernovae (PISNe)
- hypothetical thermonuclear explosions of very massive stars

Kasen et al. (2011)
Discovering SLSNe/PISNe at Epoch of Reionization

- SLSNe and PISNe are probes of massive stars
  - direct identification of massive star properties at EoR
    - top-heavy IMF?
  - constrain massive star contribution to reionization
- confident PISNe have not been identified
  - fundamental prediction of stellar evolution
    - BH mass distributions, etc…
  - PISNe preferentially exist at low metallicity
  - high-redshift SN survey is needed
- etc!

We investigated survey strategy to discover SLSNe/PISNe at $z > 6$. 
Light curves with the Roman filters
Light curves with the Roman filters

no severe requirements for survey cadence!

every 0.5 - 1 year observation is fine
Single-epoch candidate screening with CMD

- rare PISN and SLSN candidates need to be identified among other SNe
- color information is essential for the efficient identification

**color-magnitude diagram (CMD) of possible filter combinations**

- SNe Ia at $z > 1.5$
- SNe II at $z > 1.5$
- SLSN at $z > 6$
- PISN at $z > 6$

**F213 is a must!**

(SN Ia cosmology survey doesn’t use F213)
Single-epoch candidate screening with CMD
Survey limiting magnitudes

\[ F_{158} > 27.0 \text{ mag} \]
\[ & F_{213} > 26.5 \text{ mag} \]

will identify PISNe/SLSNe
Survey simulations

- $F_{158} = 27.0$ mag & $F_{213} = 26.5$ mag limits
- 10 deg$^2$, 5 year baseline
- PISN rate based on the SFR density and Saltpeter IMF
- SLSN rate extrapolated based on the local rate and SFR density

| Cadence | $t_{\text{total}}$ | $z > 5.0$ | $z > 6.0$ | $z > 6.2$ | $z > 6.4$ | $z > 6.6$ | $z > 6.8$ | $z > 7.0$ |
|---------|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| PISN    |                     |           |           |           |           |           |           |           |
| 0.5 yr  | 877 hr              | 78.9 ± 8.5| 24.2 ± 3.3| 17.7 ± 2.3| 12.1 ± 1.6| 7.3 ± 1.0 | 3.5 ± 0.5 | 1.2 ± 0.1 |
| 1.0 yr  | 525 hr              | 76.1 ± 8.2| 22.5 ± 2.8| 16.0 ± 2.1| 10.5 ± 1.4| 5.9 ± 0.7 | 2.1 ± 0.2 | 0.62 ± 0.08|
| 1.5 yr  | 385 hr              | 64.1 ± 6.9| 18.4 ± 2.2| 13.0 ± 1.7| 8.3 ± 1.1 | 4.5 ± 0.5 | 1.5 ± 0.1 | 0.40 ± 0.06|
| SLSN    |                     |           |           |           |           |           |           |           |
| 0.5 yr  | 877 hr              | 12.0 ± 1.2| 4.4 ± 0.5 | 3.4 ± 0.4 | 2.7 ± 0.3 | 2.0 ± 0.2 | 1.5 ± 0.1 | 1.1 ± 0.1 |
| 1.0 yr  | 525 hr              | 9.1 ± 0.9 | 3.1 ± 0.3 | 2.4 ± 0.2 | 1.8 ± 0.2 | 1.3 ± 0.1 | 1.0 ± 0.1 | 0.76 ± 0.09|
| 1.5 yr  | 385 hr              | 5.9 ± 0.6 | 1.9 ± 0.2 | 1.5 ± 0.2 | 1.1 ± 0.1 | 0.8 ± 0.1 | 0.6 ± 0.1 | 0.45 ± 0.09|

~ 20 PISNe and ~ 3 SLSNe at $z > 6!$
Survey simulations

\[ \text{SN discovery number density (redshift}^{-1}) \]

- PISN
- SLSN

- \( F_{158} = 27.0 \text{ mag limit} \)
- \( F_{213} = 26.5 \text{ mag limit} \)

10 deg\(^2\), 1.0 year cadence

\(~ 20 \text{ PISNe and } ~ 3 \text{ SLSNe at } z > 6! \)
Discovering PISNe & SLSNe at $z > 6$ are essential for understanding reionization and stellar evolution.

In order to discover PISNe & SLSNe at $z > 6$, we suggest:
- long-term (5 year) yearly observations of ~ 10 deg$^2$ field
- with $F_{213} > 26.5$ mag and $F_{158} > 27.0$ mag
- quick and reliable candidate identification to trigger follow-up observations with, e.g., JWST
- total required time is ~ 525 hours

~ 20 PISNe and ~ 3 SLSNe at $z > 6$ will be discovered!

See arXiv:2108.01801 for more details.