Strategies to identify strongly lensed type Ia supernovae in the Rubin LSST

Prajakta Mane [1], **Anupreeta More*** [2,3], Surhud More [2,3]

[1]Indian Institute of Science Education and Research Mohali, India, [2]Inter-University Centre for Astronomy and Astrophysics, India, [3]Kavli IMPU, Japan, *Presenter

1. Background

- The time delay between two images of a lensed source is inversely proportional to the Hubble Constant (H_0), providing an independent method to constrain H_0.
- Gravitationally lensed multiply-imaged type Ia supernovae (SNe Ia) are uniquely suited for such measurements. However, they are extremely rare.

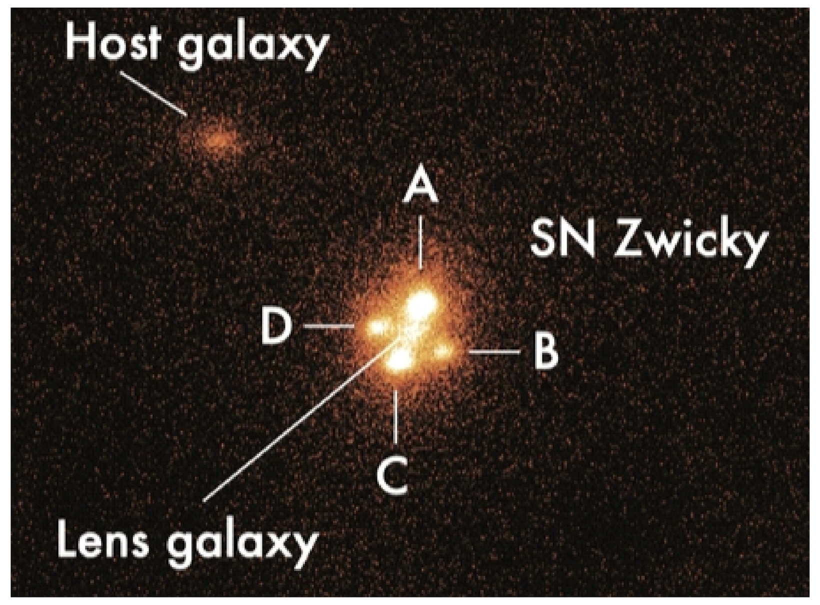

Figure 1. Quadruply imaged SN Zwicky

- Vera Rubin Observatory's Legacy Survey of Space and Time (LSST) will improve the current sample of lensed SNe Ia by order of magnitude, providing percent-level constraints on H_0 in the LSST era. **Thus, it is essential to devise effective methods to identify lensed SNe Ia from the LSST data.**

2. Objectives

- **Objective 1:** Construct and test difference imaging (DI) pipeline to identify strongly lensed supernovae within the LSST Stack framework.
- **Objective 2:** Devise early identification criteria for lensed SNe Ia by analyzing the colour-magnitude diagram[1] (CMD) of supernovae.

3. Study methodology

- Injected the simulated lensed SNe Ia into the real CCD images from the Subaru telescope. Performed DI on the science images to study the recovery of the injected information.
- Studied the simulated photometric data in the CM space for supernovae to set the red limit for unlensed SNe and (un-)lensed CC SNe at a given magnitude.

4. Results: Difference imaging

DI compares two images of the same sky area taken at different times and does pixel-by-pixel subtraction to identify sources that have varied in brightness.

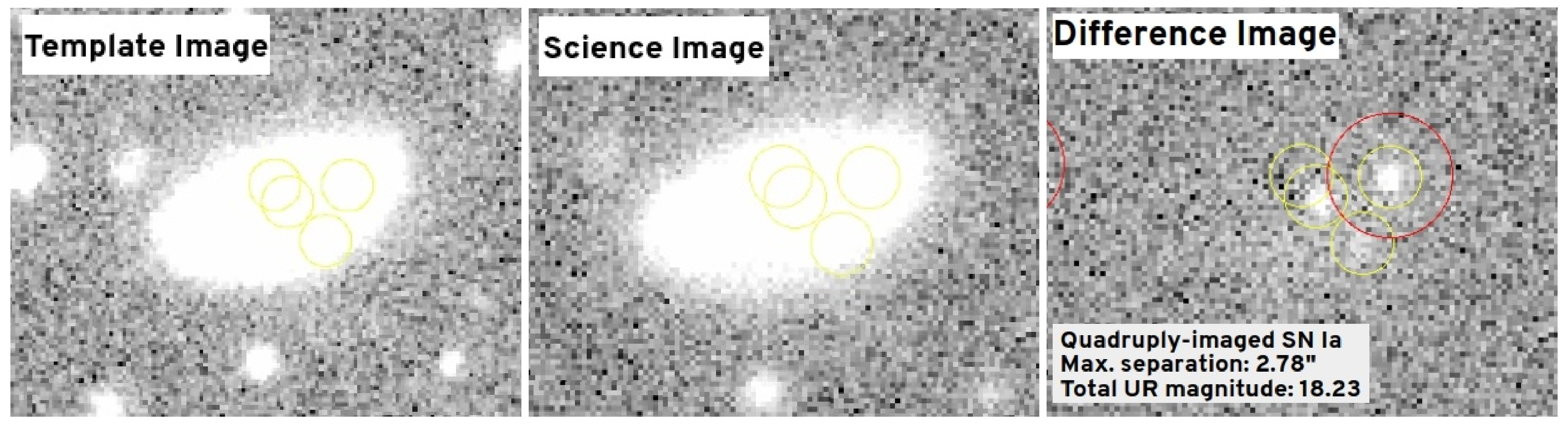

Figure 2. The coadded template (left) before the SN Ia goes off shows the foreground lensing galaxy, and the science exposure (middle) shows the injected four images of lensed SN Ia (yellow circles of radius 1"). **Difference image (right) shows recovered lensed SN Ia image (unresolved; red circle of radius 2") by the DI pipeline.**

	Injected	Detected	% recovery
Total	74143	51520	**70**
Doubles	70050	48300	70
Quads	4093	3220	78

Table 1. Detection details of the injected information in difference imaging.

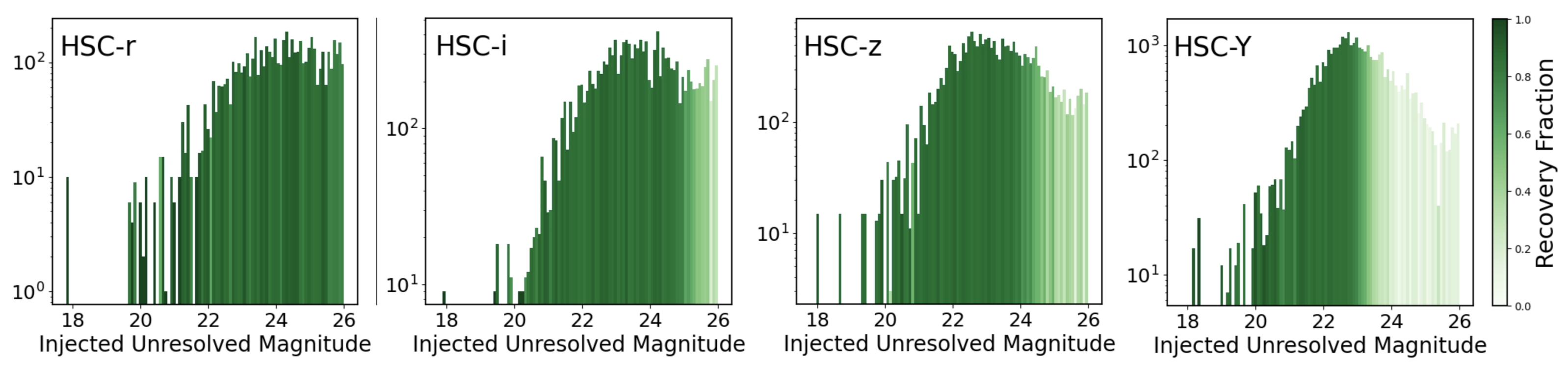

Figure 3. Variation of the recovery fraction of injected information with the brightness of the injections for HSC *rizy* bands. **The recovery fraction decreases gradually for the fainter injections. The magnitude limit at which the recovery fraction drops drastically decreases for higher wavelengths.**

[1] Quimby R. M., et al., "Detection of the Gravitational Lens Magnifying a Type Ia Supernova," Science, vol. 344, pp. 396–399, Apr. 2014.

5. Results: Colour-magnitude analysis

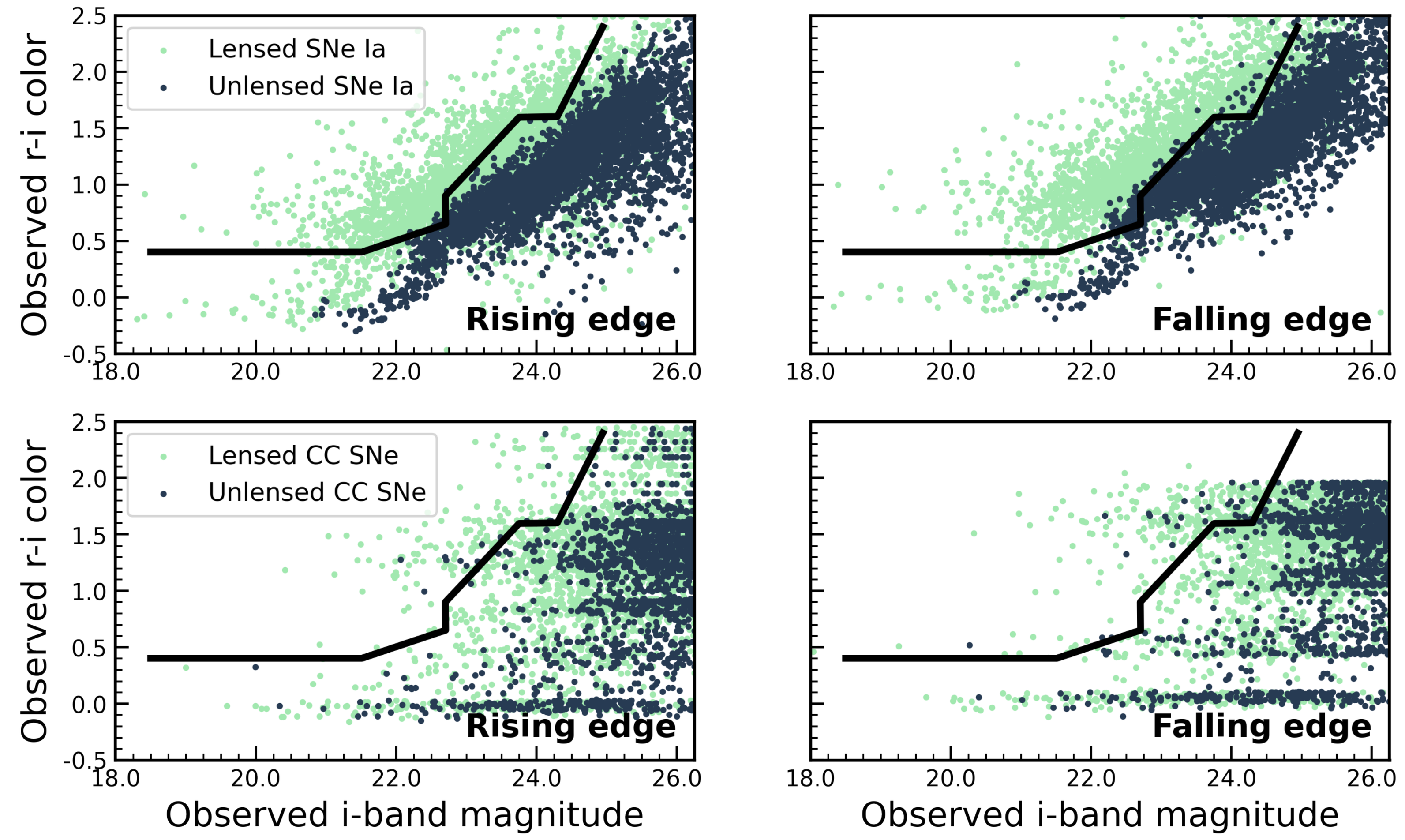

Figure 4. CMD for simulated unlensed (dark blue) and lensed (green) SNe Ia (upper panel) and core-collapse (CC) SNe (lower panel). **The proposed bold black curve, the "red" limit, allows demarcation of the CM space between the lensed and the unlensed SNe Ia and (un-)lensed CC SNe both in the rising (left panels) and falling (right panels) phases.**

6. Conclusions

- In the first run, the DI pipeline recovers $\sim$ 70% of the injected lensed SNe Ia data. The recovery fraction decreases for fainter injected systems. It is slightly higher for quads and decreases significantly for HSC y-band.
- The pipeline fails to resolve a majority of the recovered systems, resulting in a very low resolved fraction. The resolved fraction is found to be weakly correlated with the angular separation of the system for doubles.
- Colour-magnitude-based demarcation effectively selects lensed SNe Ia for simulated and observed (un-)lensed SNe Ia till redshift 2.4, both on rising and falling edge. Contamination from unlensed CC SNe is low. Primary contaminants are found to be lensed CC SNe Ib and Ic.

7. Further work

- Study if extendedness can be used as a marker for unresolved systems.
- Incorporate LSST cadence in this analysis.
- Test the DI pipeline on the LSST-like DC2 dataset.