INVESTIGATING ^{56}Ni DISTRIBUTION IN TYPE IA SUPERNOVAE

KELVIN LEONG[1], Supervised by Dae-Sik Moon [1]

[1] David A. Dunlap Department of Astronomy & Astrophysics, University of Toronto

1. INTRODUCTION

- **Type Ia Supernovae** is a type of supernova that results from unstable thermonuclear ignition of degenerate matter in a white dwarf from mass transfer in binary system.
- Despite extensive research, we are still uncertain of the most prevalent progenitor systems for Type Ia Supernovae and its explosion mechanism.
- Early Type Ia Supernovea light curves, which are powered by **radioactive decay** of ^{56}Ni (^{56}Ni $\rightarrow$ ^{56}Co $\rightarrow$ ^{56}Fe) synethesized during explosion, provides unique information for identifying its progenitors.
- With recent programs like the KMTNet Supernova Program, Type Ia Supernovae are now discovered within hours after their explosions. Previous proposed ^{56}Ni models cannot describe the **"infant phase"** at ∼0-1 days post-explosion.
- **Goal of the project:** To investigate what ^{56}Ni distribution models can explain the entire early phase (∼0-7 days post-explosion) light curves for various Type Ia Supernovae.

2. MODELS

How do we parametrize the ^{56}Ni mass fraction X_{56} distribution?

- Previous model: Piro & Nakar logistic model [1] :

$$X_{56}(x) = \frac{X'_{56}}{1 + \exp(-\beta(x - x_{1/2}))}$$

- We modified the logistic model to include N-shell (i.e. isolated ^{56}Ni clumps each with different constant mass fractions) at ejecta surface to probe the X_{56} in early phase, e.g. for our 3-shell model:

$$X_{56}(x) = \begin{cases} X_{s1} * X'_{56} & , x < x_1 \\ X_{s2} * X'_{56} & , x_1 < x < x_2 \\ X_{s3} * X'_{56} & , x_2 < x < x_3 \\ \frac{X'_{56}}{1+\exp(-\beta(x-x_{1/2}))} & , x > x_3 \end{cases}$$

- x = Depth coordinate in units of diffusion time (t/t_{diffu})
- X'_{56} = Normalization constant

*Fitting parameters:

- t_{diffu} = Time required for the thermal diffusion wave to travel back through all ejecta material in the expanding supernova
- β = Describes how fast the logistic distribution rises
- $x_{1/2}$ = Locates the depth where the logistic distribution is at half-maximum
- x_N = Depth where each shell ends
- X_{sN} = (Unnormalized) mass fraction of ^{56}Ni in each shell

3. METHOD

- We used the `emcee` package to implement the MCMC algorithm to fit our models with the BVi bands data simultaneously.
- We also integrated the BVi bands data to construct the "BVi luminosity", and compared it to the luminosity prediction integrated from the BVi best fit.

REFERENCES

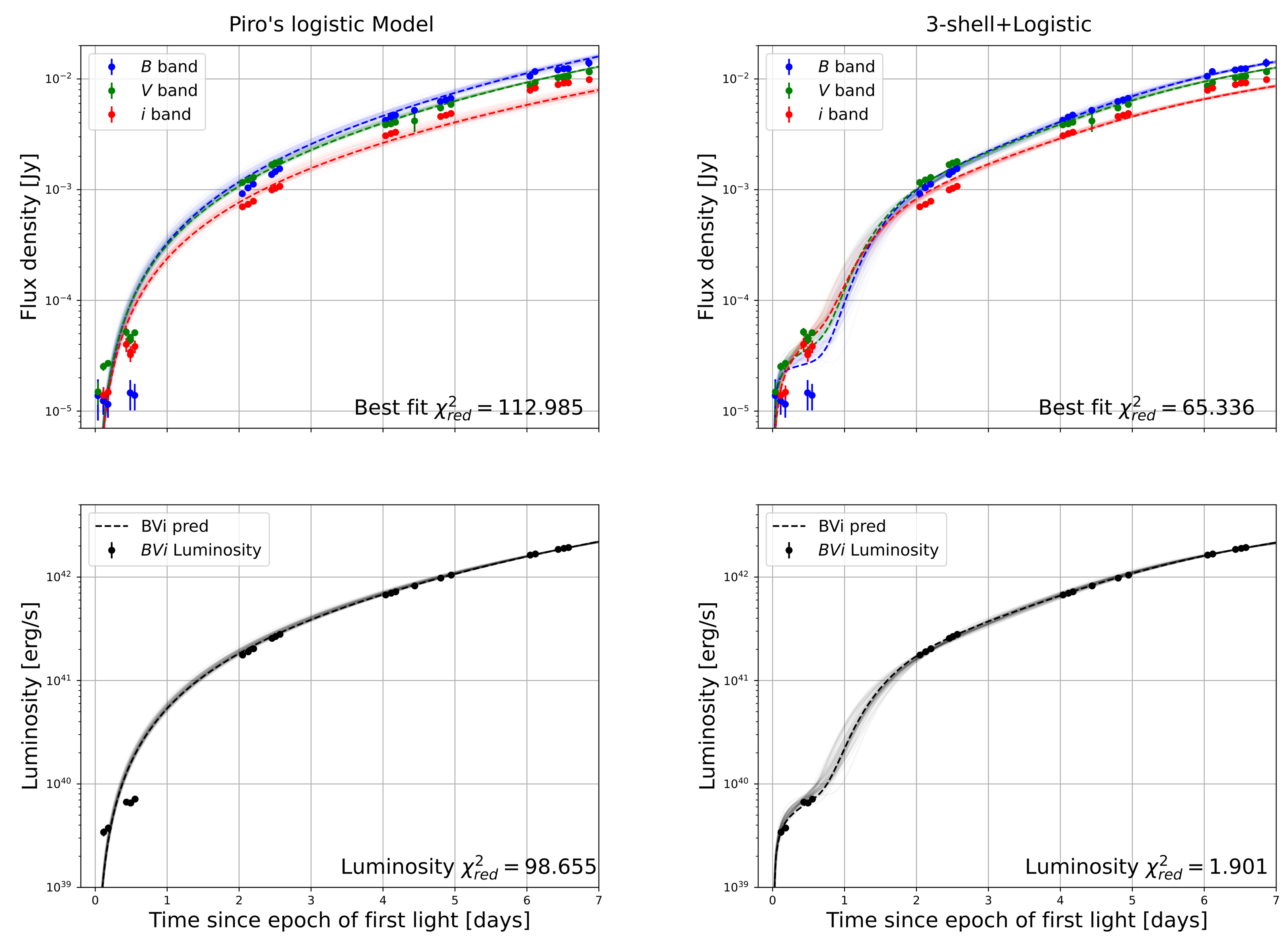
[1] A. L. Piro and E. Nakar, "CONSTRAINTS ON SHALLOW Ni56 FROM THE EARLY LIGHT CURVES OF TYPE ia SUPERNOVAE," *ApJ*, vol. 784, p. 85, mar 2014.

[2] Y. Q. Ni, D.-S. Moon, M. R. Drout, and et al., "Infant-phase reddening by surface fe-peak elements in a normal type ia supernova," *Nature Astronomy*, vol. 6, pp. 568–576, feb 2022.

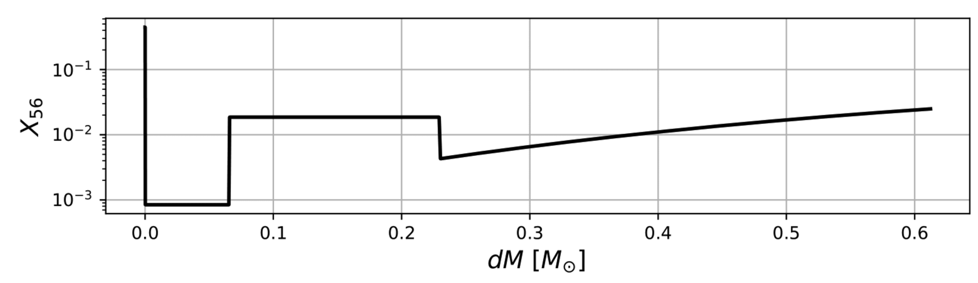
[3] Y. Q. Ni, D.-S. Moon, M. R. Drout, and et al., "Origin of high-velocity ejecta and early red excess emission in the infant type ia supernova 2021aefx," 2023.

4. FITTING FOR SN2018AOZ

- Features of SN2018aoz [2]:
  - Discovered within 1 hour after epoch of first light; earliest detection of Type Ia Supernovae ever.
  - B-band flux nearly constant during the infant phase, while Vi bands rises rapidly during this period.

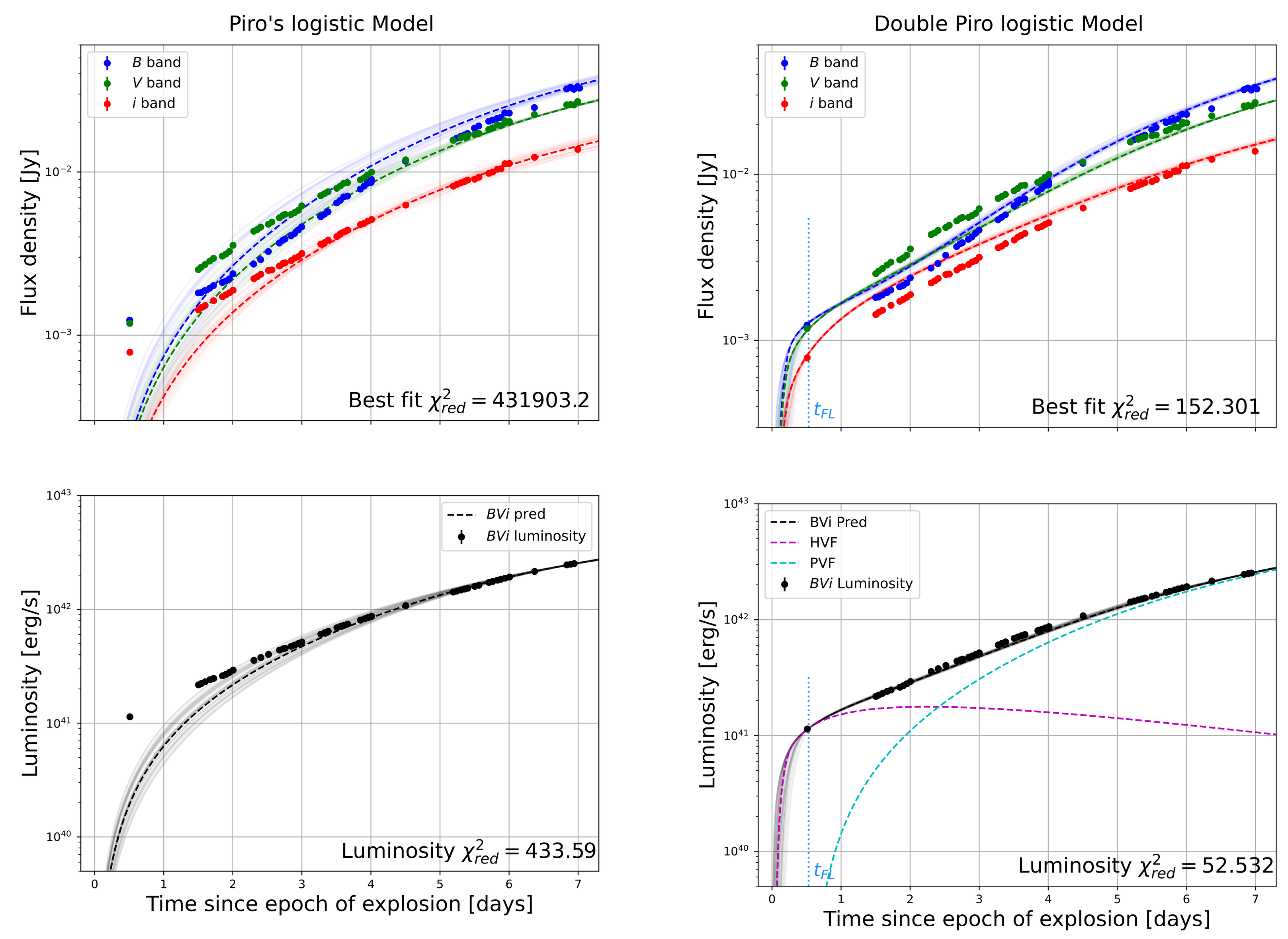


- The logistic model (left) can't explain infant phase data.
- 3-shell+logistic model (right) is most optimal to explain the light curve.
  - 45% of ^{56}Ni in the first 0.1% ejecta mass
  - ∼ 0.1% of ^{56}Ni in the next 7% ejecta mass
  - 2% of ^{56}Ni in the following 16% ejecta mass
  - Logistically distributed peaked toward ejecta center



5. FITTING FOR SN2021AEFX

- Feature of SN2021aefx [3]:
  - Discovered at 0.5 hours before epoch of first light (t_{FL}), indicating presence of additional power source.
  - Observed "high-velocity feature" (HVF) in addition to the typical photospheric-velocity feature (PVF).
- A potential explanation: the pre-first light observation is powered by ^{56}Ni decay from HVF. We attempted to use 2 different logistic distributions ("Double Piro logistic model") to model rise of light curve of HVF and PVF separately and sum their light curves subsequently.



- The logistic model (left) is only able to fit data well from day 4 post-explosion onward.
- The double logistic model (right) is adequate to explain the BVi luminosity, but each individual band is not fitted well during day 1-4, which could be a limitation on our model which assumes blackbody radiation.

6. CONCLUSION & FUTURE WORK

- The investigation for these 2 supernovae indicates that their ^{56}Ni are not distributed logistically toward ejecta surface, which suggests the possibilities of subsonic mixing of ejecta material, asymmetric explosion, etc.
- Applying these models and our framework in studying all other Type Ia supernovae can help us understand better their ^{56}Ni distribution and potentially their progenitor systems.