Detection of Supernovae beyond z ~ 2 with *JWST*

Enikő Regős[1] and József Vinkó[1,2]

[1]*Konkoly Observatory, MTA Research Centre for Astronomy and Earth Sciences (CSFK), Hungary;*
[2]*Department of Optics & Quantum Electronics, University of Szeged, Hungary*

Motivation

The First Lights At REionization (FLARE) project (Wang et al., 2017) seeks observational answers to one of the most fundamental questions: "How did the Universe make its first stars?". It can be answered by observing the most distant, most luminous transient events: supernovae (SNe) and accretion onto the first, directly-collapsed black holes (DCBH).
This presentation focuses on the detection possibilities of high-redshift (z > 2) supernovae with the *James Webb Space Telescope* (*JWST*).

Observations with JWST

The *JWST* North Ecliptic Pole (NEP) Time-Domain Field (TDF) is a ~0.1 sq.degree area within the *JWST* northern Continuous Viewing Zone (Jansen et al., 2017). The FLARE project proposes deep (~27.4 AB mag) NIRCam observations through *F150W, F200W, F356W* and *F444W* filters with $\Delta t \sim 90$ days cadence during the mission time of JWST. These data constrain the Spectral Energy Distribution (SED) of the transients at various redshifts.

Supernovae at high redshifts

Superluminous Supernovae (SLSNe)

- the brightest known SNe (SLSN-I: H-poor, SLSN-II: H-rich)
- M < -20.5 absolute AB magnitude at peak (Quimby et al. 2013)
- UV-bright SED around maximum light
- originate from explosions of very massive stars -- no delay time
- detection with *JWST*: feasible up to z ~ 4 (Regős & Vinkó, 2019)

Pair-Instability Supernovae (PISNe)

- energetic explosion of M > 150 $M_\odot$ stars driven by pair creation
- Population III, zero metallicity, 150-250 $M_\odot$ PISNe, modeled by radiation hydrodynamics simulations incorporating Lyman absorption by the neutral environment (Whalen et al., 2013) have magnitudes below the detection limit of our survey, and colors different from Pop II models
- Population II, Z=0.07 $Z_\odot$ models of 250 $M_\odot$ (Chatzopoulos et al, 2019) can be detected at z ~ 2-4 and have colors shown in Figure 1 (Regős & Vinkó in prep., in relation to comparison with DCBH)

Thermonuclear Supernovae (Type Ia SNe)

- fainter, but more abundant in the local Universe than SLSNe
- M ~ -19 ± 1 absolute AB magnitude at peak
- UV-faint SED at and after maximum light
- produced by exploding white dwarfs (WDs) via either single- or double-degenerate channel -- significant delay time after star formation
- detection with JWST: feasible up to z ~ 4 (Regős & Vinkó 2019)

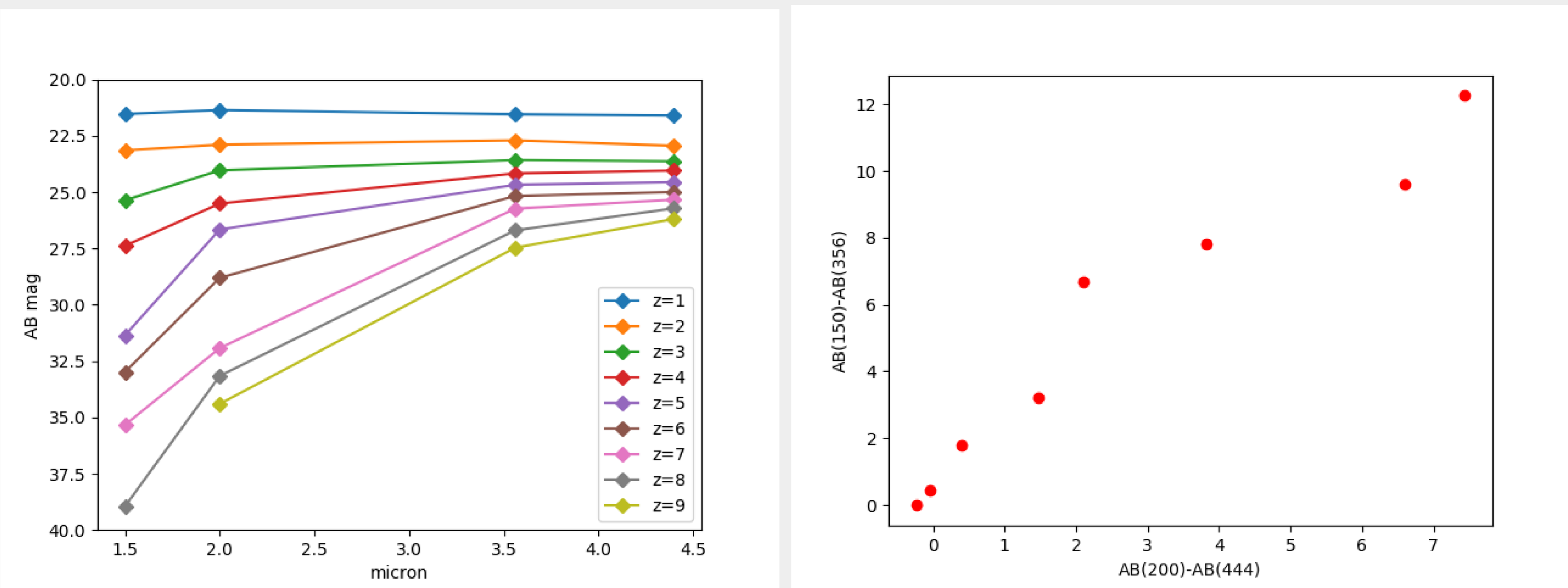

Fig.1: Peak magnitudes of Pair-Instability Supernova (PISN) models at various redshifts (left panel); position of PISNe around maximum light on the JWST color-color plot (right panel).

Rates of SNe at high redshifts

Current models for the cosmic Star Formation Rate (SFR) predict ~ 2 - 3 SLSNe between 2 < z < 4 (Fig. 2 left panel) during *JWST* mission time (~ 5 years). The actual number of SLSNe detected with *JWST* will provide a critical test of the high-z SFR.

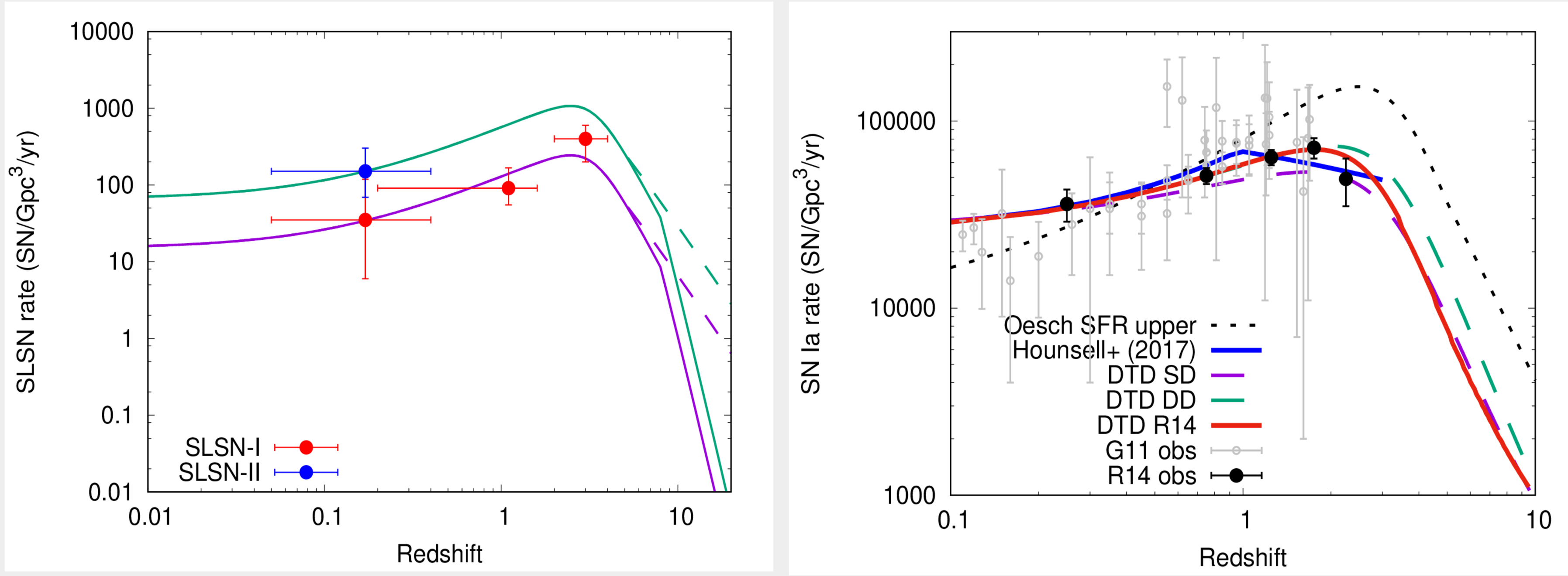

Fig.2: The expected rates for different types of supernovae (left panel: SLSN, right panel: SN Ia), compared to the observed rates in the local Universe.

For SNe Ia, population synthesis models predict universal Delay-Time Distribution (DTD) shapes (Strolger et al. 2004):

exponential: $\Psi_{DTD} \propto \exp[-t/\tau]/\tau$ with τ = 0.5, 1.0, 2.0, 3.0, 4.0 Gyr

Gaussian: $\Psi_{DTD} \propto \exp[-(t-\tau)^2/2\sigma^2]$ with $\sigma = 0.5\tau$ ("wide") and $\sigma = 0.2\tau$ ("narrow")

Depending on the assumed DTD, current models (Fig. 3) predict ~ 50 - 60 SNe Ia per year in the *JWST* TDF between 2 < z < 5. The observed SNe Ia will give valuable constraints on their real DTD.

Fig. 4 shows the results from a simulation of SN Ia observations using SNCOSMO (Barbary et al. 2016). The photometric redshifts derived from SEDs taken with JWST NIRCam filters are plotted in the left panel. The right panel contains the Hubble-diagram from the simulated data as well as the recovered peak magnitudes and photometric redshifts (see Regős & Vinkó 2019).

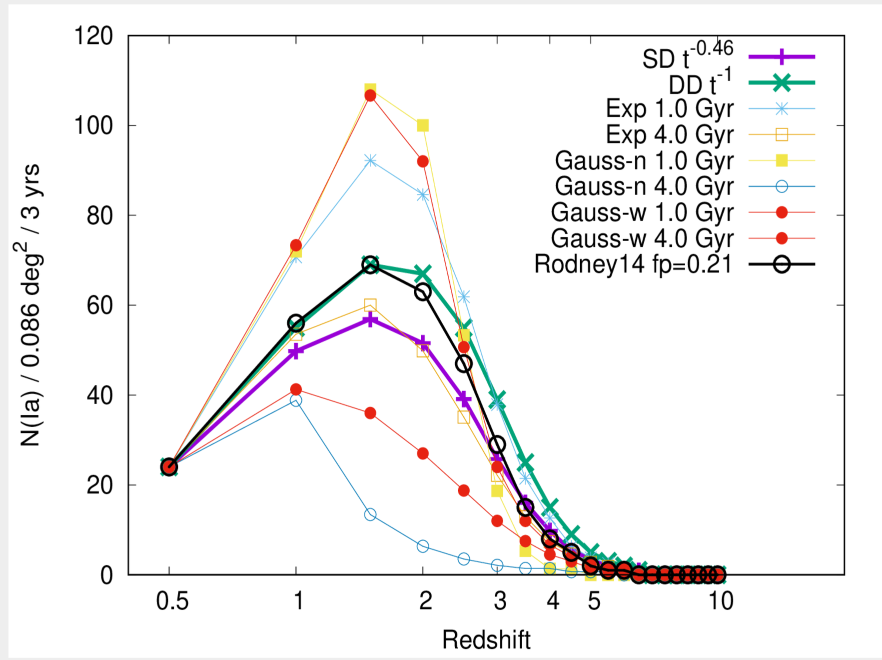

Fig.3: The expected number of SNe Ia in 3 years in the JWST TDF from various progenitor scenarios.

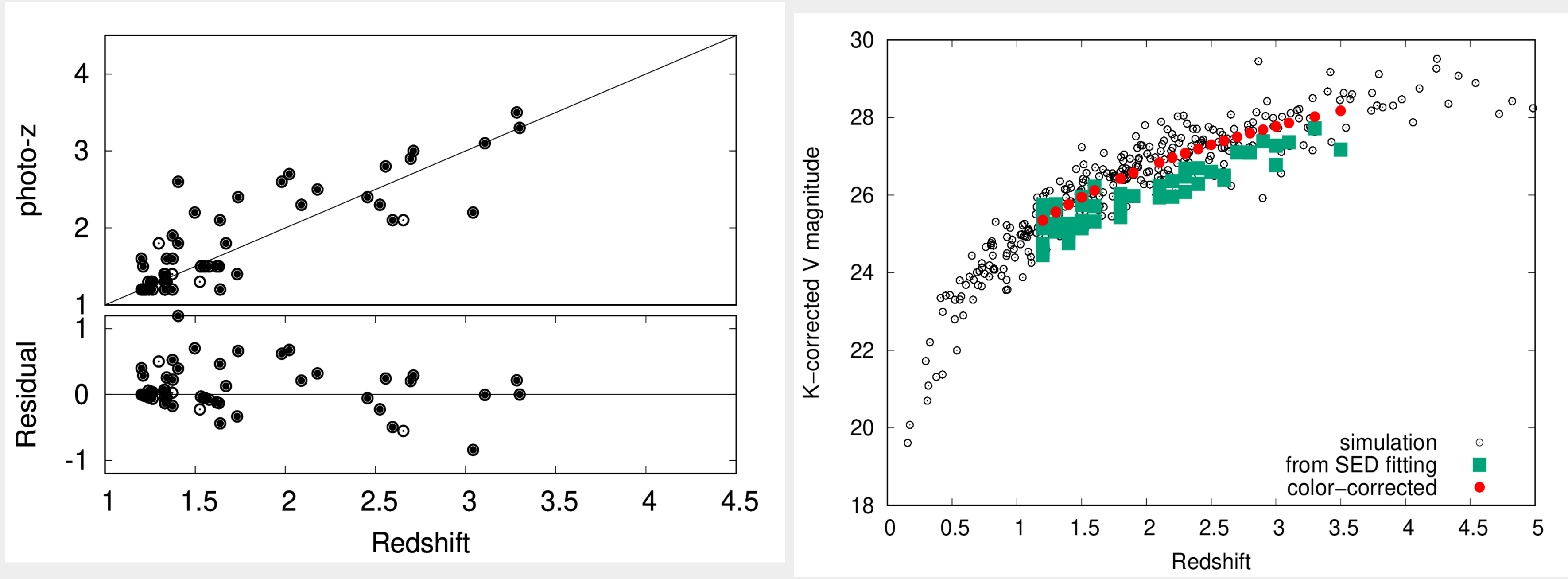

Fig.4: A simulated sample of SNe Ia using SNCOSMO designed for SEDs and light curves at any redshift. Left panel: photo-z of the simulated SEDs in JWST NIRCam color bands (F150W, F200W, F356W, F444W). Right panel: the Hubble-diagram of the simulated and the "observed" sample. The scatter is decreased by correcting for the differences in peak absolute magnitudes by fitting model SEDs, computed from SALT2 templates for SNe Ia, to the "observed" fluxes.

References

Barbary, K. et al. Astrophysics Source Code Library ascl:1611.017
Chatzopoulos, E. et al. 2019, 875, 140
Jansen, R. A., Webb Medium Deep Fields IDS GTO Team, & the NEPTDS-Chandra Team, 2017, AAS Meeting Abstracts Vol. 230, 216.02
Quimby, R. et al. 2013, MNRAS 431, 912
Regős, E., Vinkó, J. 2019, ApJ 874, 158
Strolger, L-G. et al. 2004, ApJ 613, 200
Wang, L. et al., 2017 arXiv:1710.07005
Whalen, D. et al. 2013, ApJ 777, 110

Acknowledgement

This work has been supported by the project "Transient Astrophysical Objects" **GINOP 2.3.2-15-2016-00033** of the National Research, Development and Innovation Office (NKFIH), Hungary, funded by the European Union.

SZÉCHENYI 2020

Hungarian Government

European Union
European Social Fund

INVESTING IN YOUR FUTURE