Strongly Lensed Supernovae

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with: LSST DESC + iPTF/ZTF Cosmo WG

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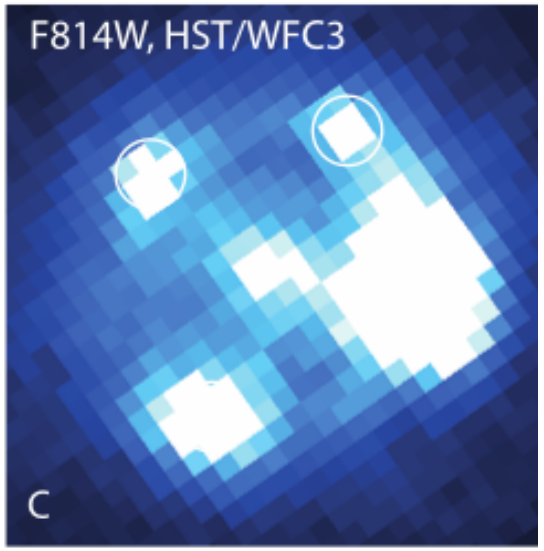
Outline

HST image of iPTF16geu



Motivation

First resolved Lensed SN Ia

SD+20b; Mortsell, **SD** et al., 2021; Johansson, .. **SD**, et al. 2021

SN Zwicky: First discovery by ZTF

Goobar,.. **SD**, et al., Nat. As, 2023; Johansson, **SD**, et al. in prep

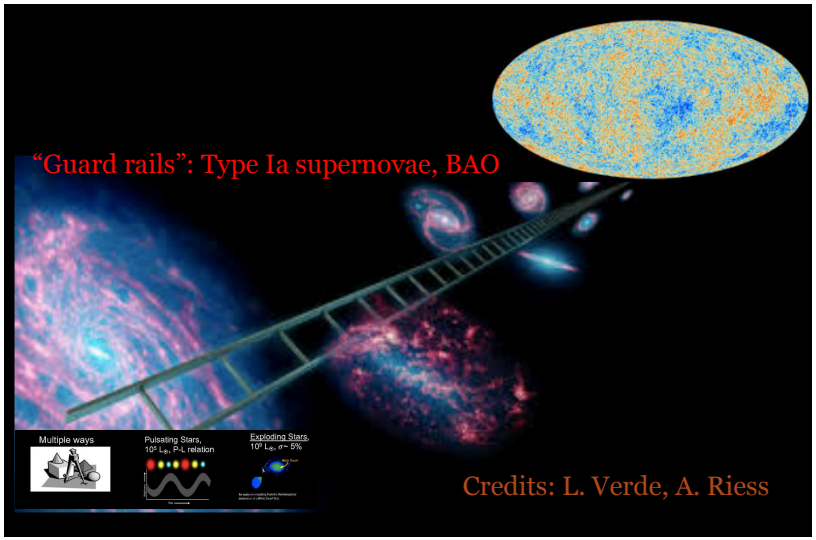
Towards precision cosmology with LSST

Arendse,**SD**, et al. in prep., Birrer, **SD**, Shajib, 2022

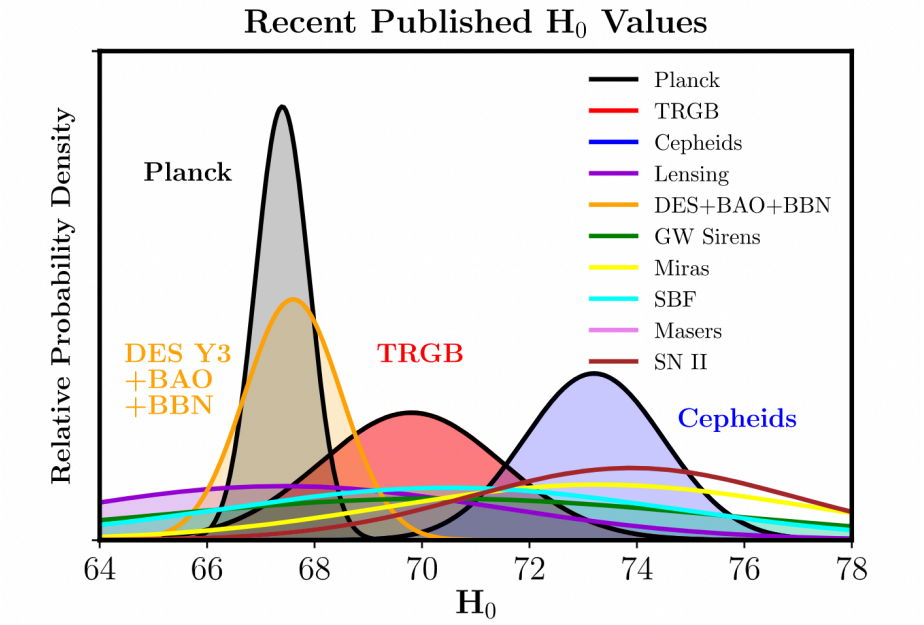
SN H0pe: Recent discovery with JWST

Motivation

- H_0: Absolute scale of the universe
- End-to-end test of background expansion



Credits: Freedman 2021

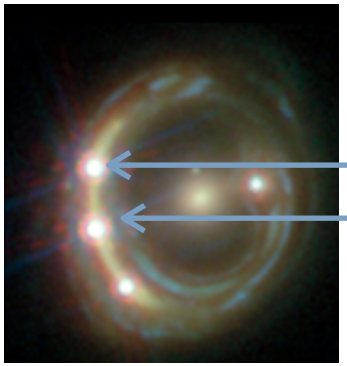


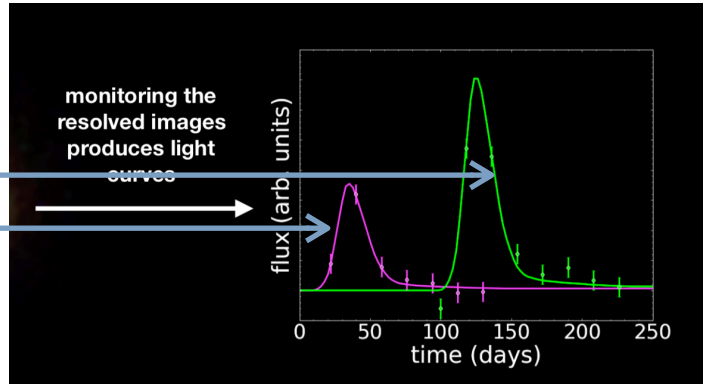
- New physics?
- Unknown Systematics? → Need independent methods

- Unaccounted for systematics
- Independent distance ladder
- **Novel absolute distance measurement (e.g. lensed transients, standard sirens)**

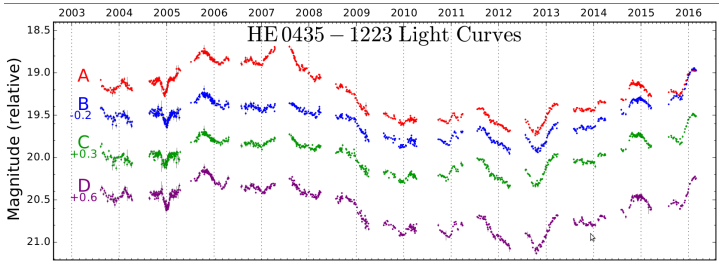
Targeting Planck precision (0.5 km/s/Mpc)
Not yet close with distance scale

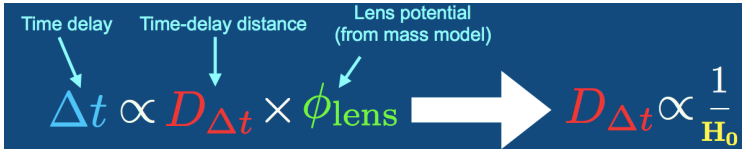
Time-delay cosmography





Typical lensed SN and QSO light curves





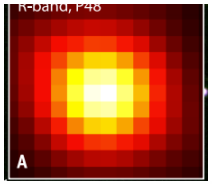
- Independent discovery method to lensed quasars
  - glSNe => “standardisable candle”

- First proposed in Refsdal 1964 (for SNe, used for QSOs)

Advantages of glSNe Ia

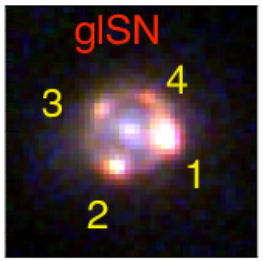
- Much less monitoring required
- “Standardisable” luminosity => break modelling degeneracies (e.g. Birrer, SD, Shajib, 22)
- Lower impact of microlensing systematics

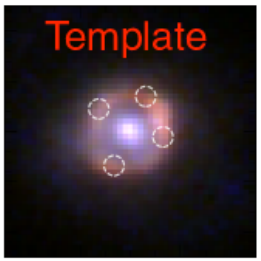
First Resolved lensed SN Ia

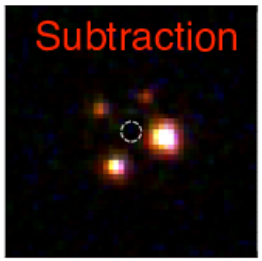


Discovery in unresolved data

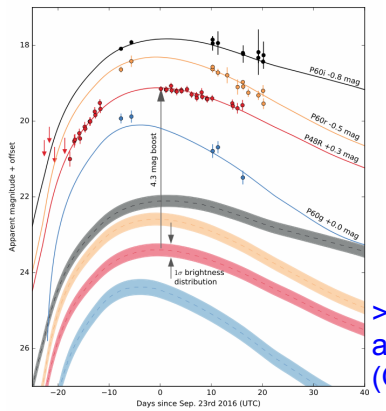
Follow-up: HST / AO





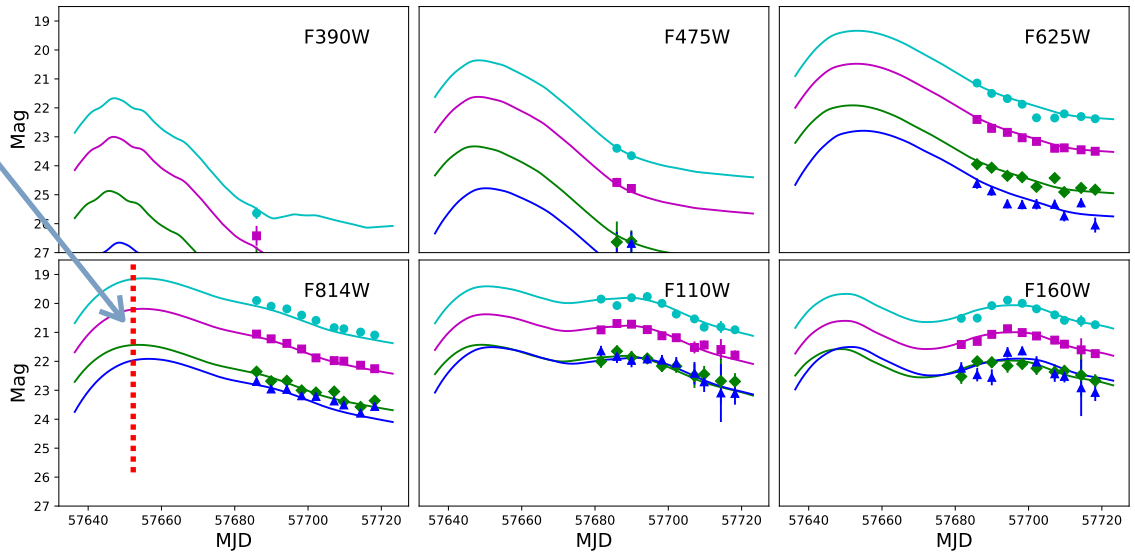


HST/WFC resolved image, template and subtraction => not possible for QSOs!



>50 times brighter than normal SNIa at z~0.4: a 30σ outlier! (Goobar+2017)

SD+20b



Very small time-delays (~ 1 day):
Not ideal for measuring H_0

Max. light simulations
=> five times smaller error

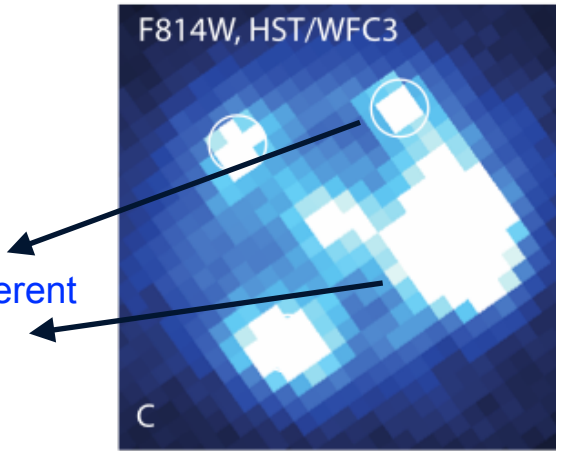
Long wavelength lever arm for extinction constraints

iPTF16geu: Magnification + extinction

Important probe of dust in lens galaxy
LoS Rv < Milky Way values

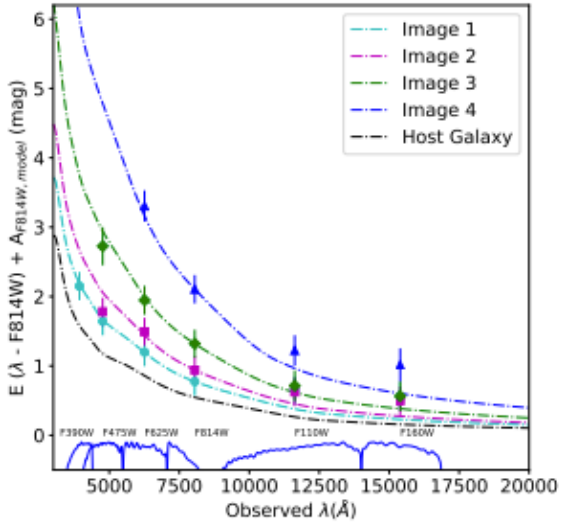
Model independent lensing magnification

Flux ratios can probe compact object dark matter

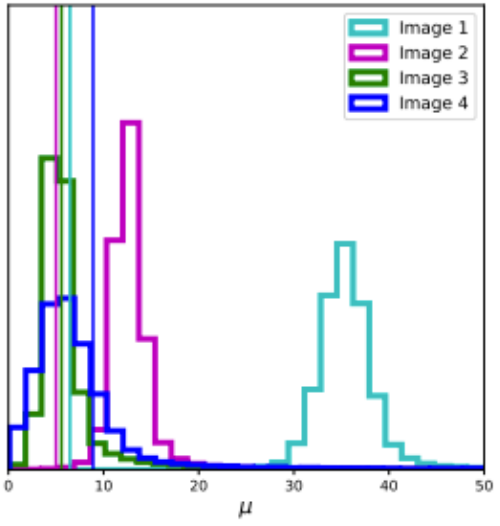


Surprisingly different brightness?

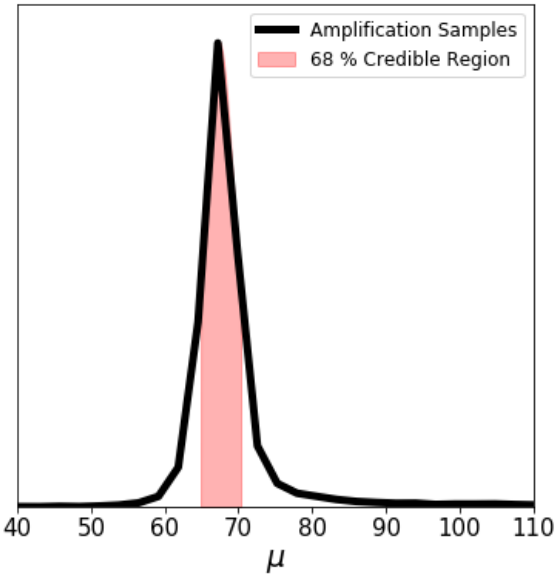
Preliminary magnification (μ) ~ 52
With extinction correction 67+/-3



Spectroscopy in Johansson,.., SD, +'21



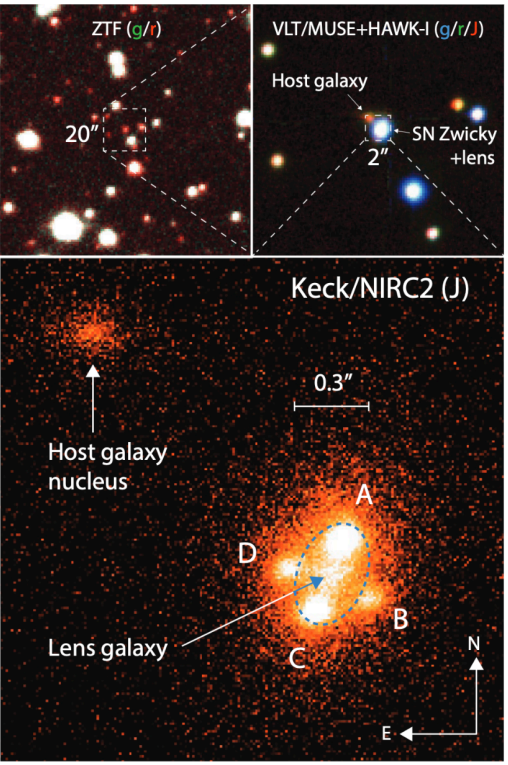
Modelling details in Mortsell,.., SD,+'21



SN Zwicky!

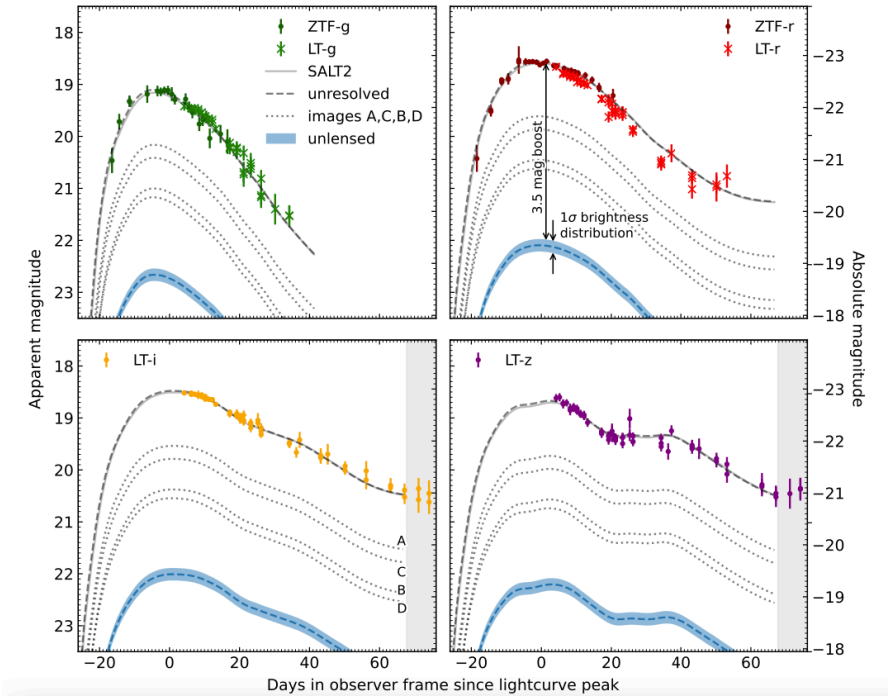
Multiband P48+ LT data
Accurate extinction constraints
PI: Dhawan, Perley

1”



~ 0.3”

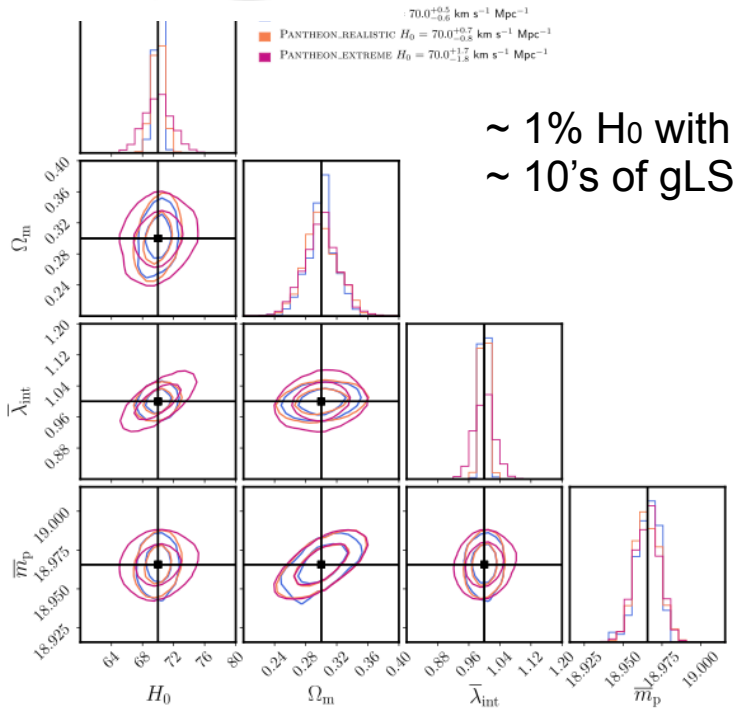
0.01”



Discovered via magnification in ZTF
~ 3.5 mag > SN Ia at z_s =0.354
Compact system θ_E < 0.2”: study central stellar IMF

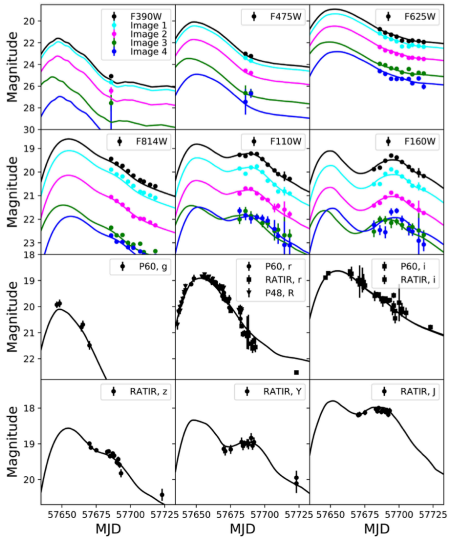
(Goobar,…, **SD** +, Nat. As., submitted)

Gearing up for LSST



~ 1% H0 with LSST
~ 10's of gLSNe

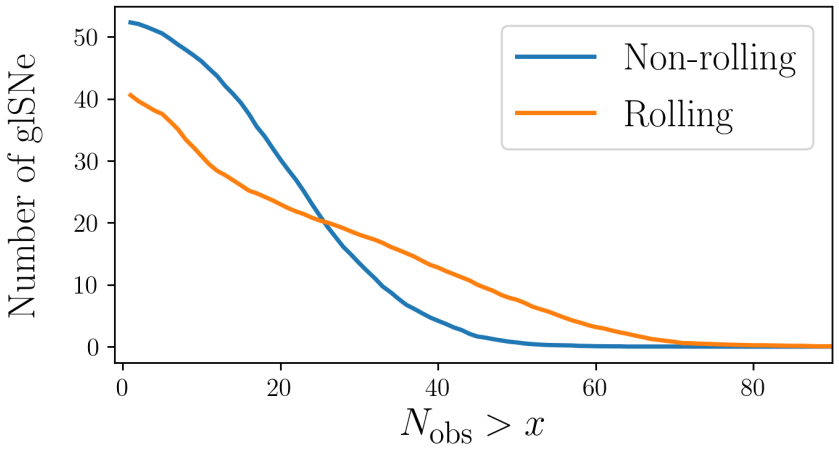
Birrer, **SD**, Shajib, 2022

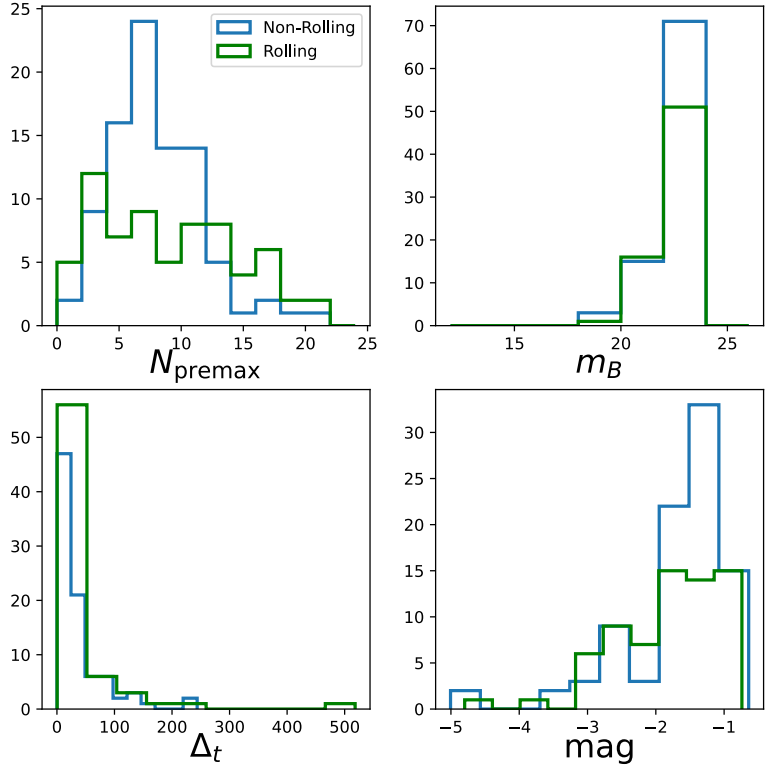


Robust combination of
Unresolved + resolved data
(LSST + HST/JWST/Roman;
SD + Pierel in prep.)

Detectability in LSST

Simulated realistic cadence
Many 10's expected per year
Rolling has fewer -> denser sampling





Several with early sampling for discovery
Bright for 4m spec classification
Long time delays for cosmology

Arendse, **SD**, et al. in prep

Conclusions

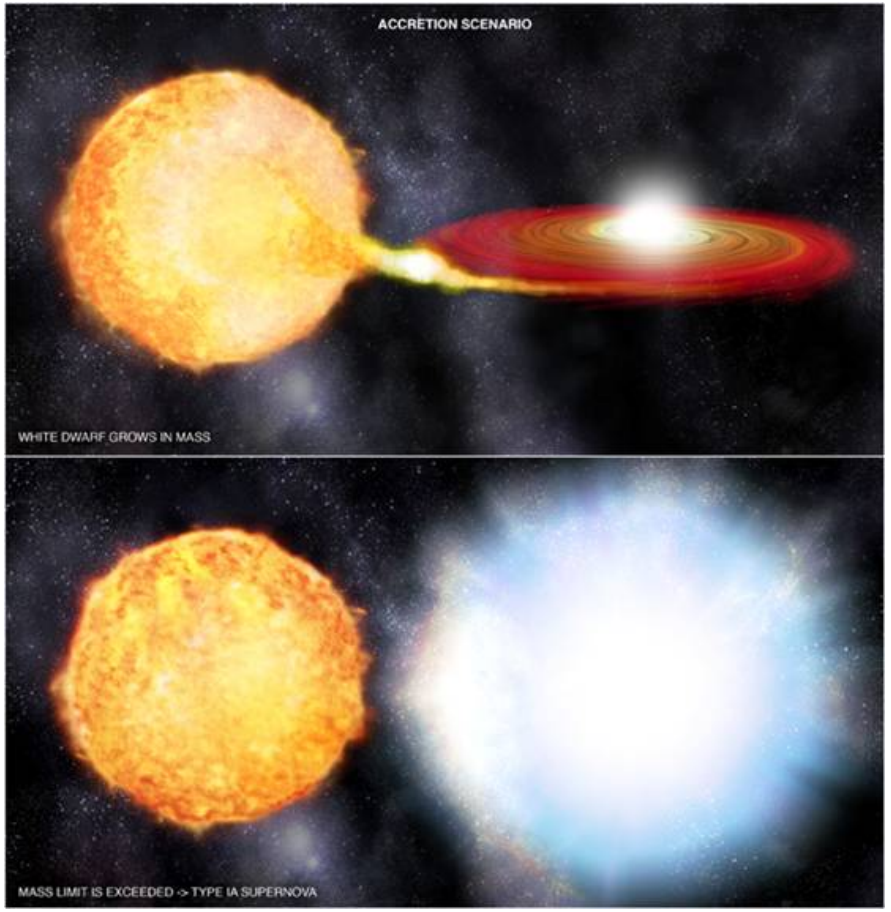
- Current survey discoveries
  - 16geu: short time delays, extreme magnification
  - Important to study extinction, deviation from MW
  - SN Zwicky: Most compact galaxy lens to date
  - Excellent laboratory for spectroscopic studies

- Forecasts for cosmology
  - Independent H_0 at 1.5% with LSST
  - Detect a large sample with feasible spectroscopy

- SN H0pe
  - Serendipitous discovery, long time-delay
  - Potential for H_0 measurement

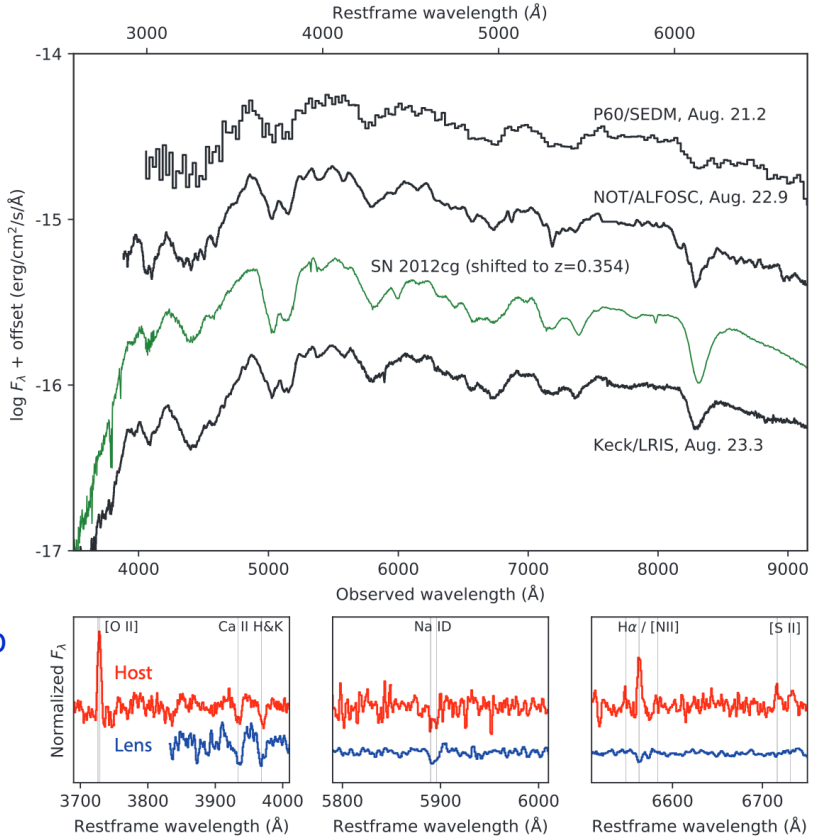
What are Type Ia supernovae?

NOT standard but calibratable -> small scatter, reduce lensing uncertainties



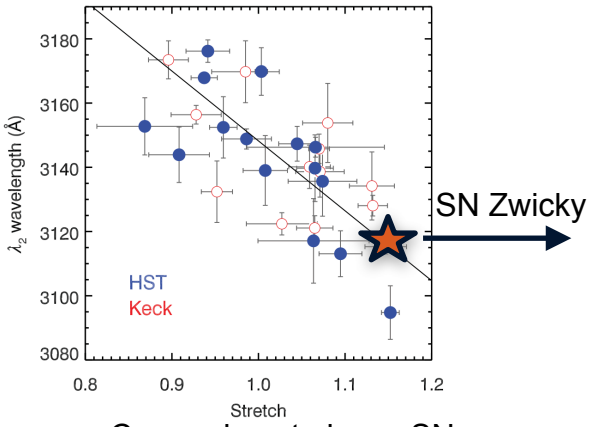
dark energy systematics -> lensing helps study high-z SN physics

Spectroscopy of lensed SNe



SN Zwicky spectra compared to local SN 2012cg

Johansson, **SD+**, in prep

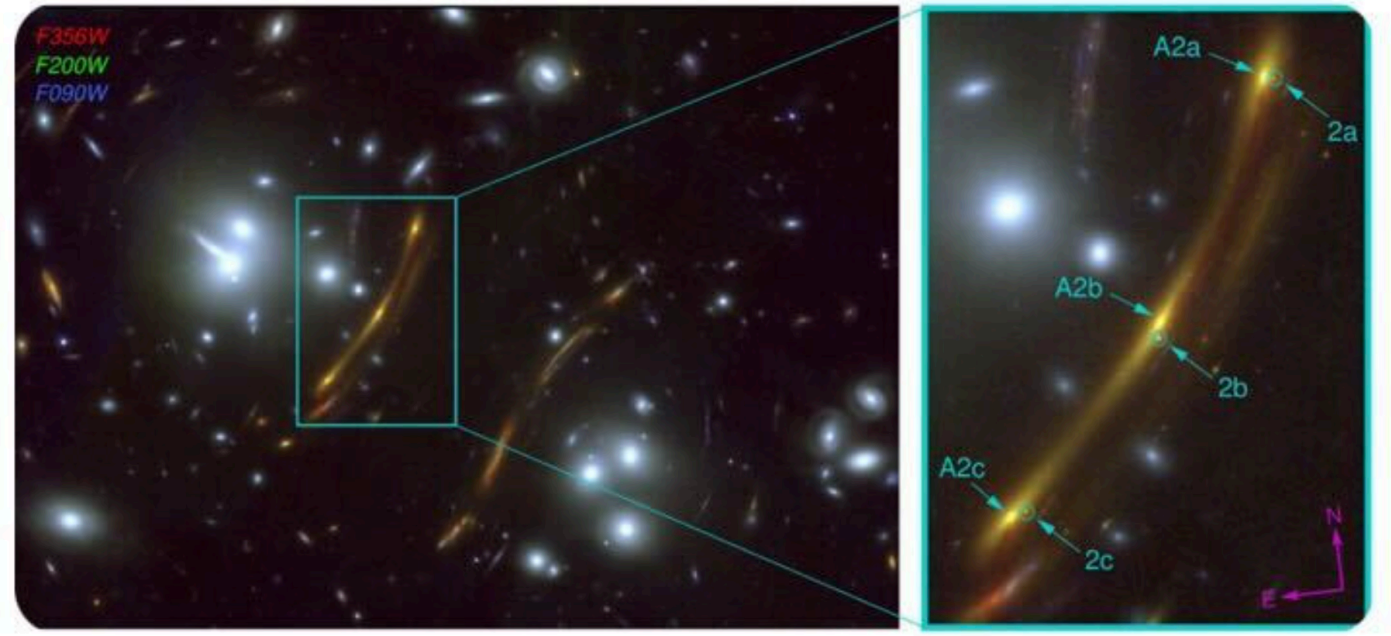


Comparison to low-z SNe sample from Maguire +2012

No signs of cosmic spectroscopic evolution!

JWST Cycle 2 NIRCam + NIRSpec proposal
Nebular observations of SN Zwicky

SN Hope



Discovery in NIRCAM obs of PLCK G165.7+67 ; PEARLS program

Cluster lens, long expected time-delay

Triply imaged SN Ia at z ~ 2; Follow-up with DDT ongoing