Strongly Lensed Supernovae in the LSST era

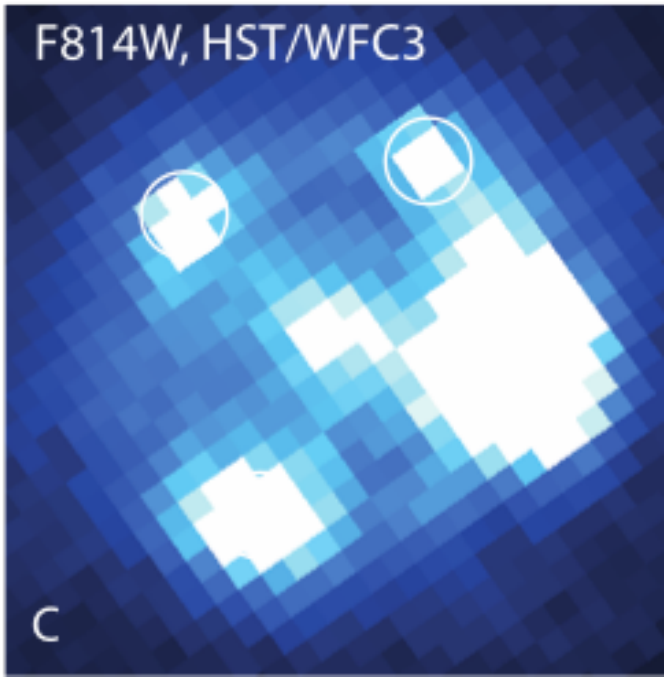
Suhail Dhawan

Marie Sklowdowska Curie Fellow,
Institute of Astronomy
+ Research Fellow, Lucy Cavendish College, Cambridge

with: LSST DESC + iPTF/ZTF Cosmo WG

OKC@15, October 18 2023

Outline



Motivation

Recent discoveries

SD+20b; Mortsell, **SD+** 2021; Johansson, .. **SD**,+2021; Goobar+, Nat. As, 2023

Towards precision cosmology with LSST

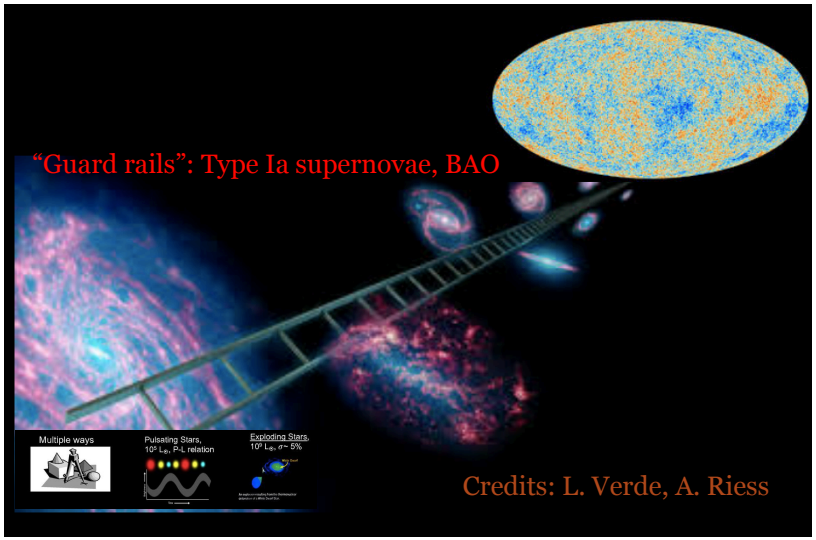
Birrer, **SD**, Shajib, 2022, Dhawan + Pierel in prep.

New time-delay inference method

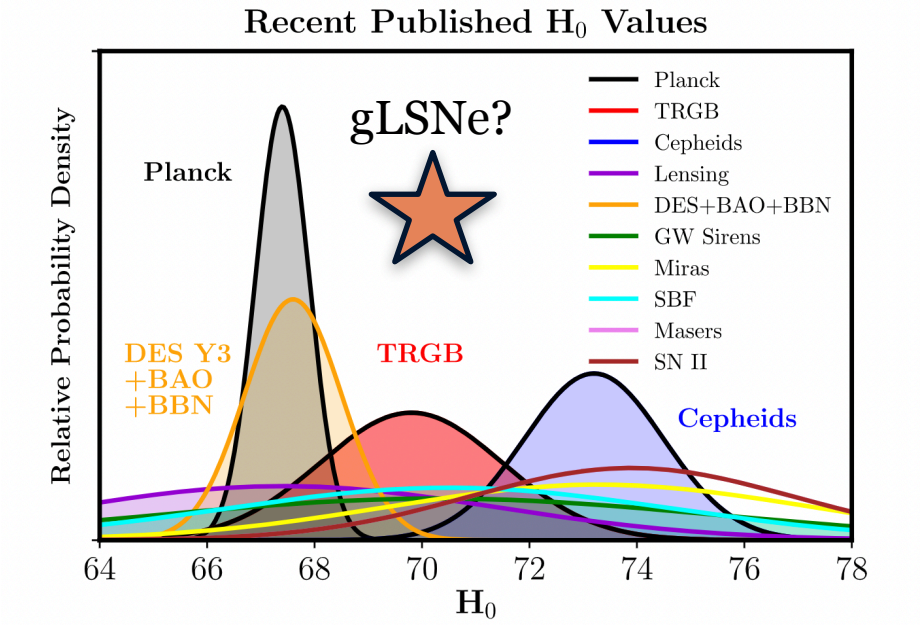
Crascall-Kennedy,**SD**,+ in prep.

Motivation

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



Credits: Freedman 2021

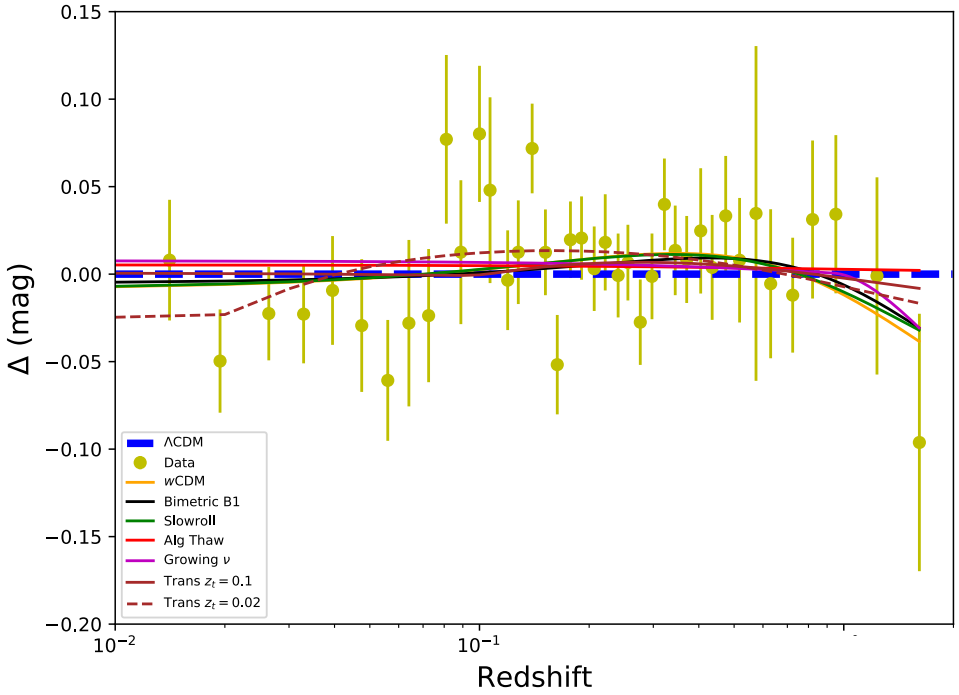


- New physics?
- Unknown Systematics?

Need independent methods

- **Novel absolute distance measurement (e.g. lensed transients)**

Cosmological Solutions?



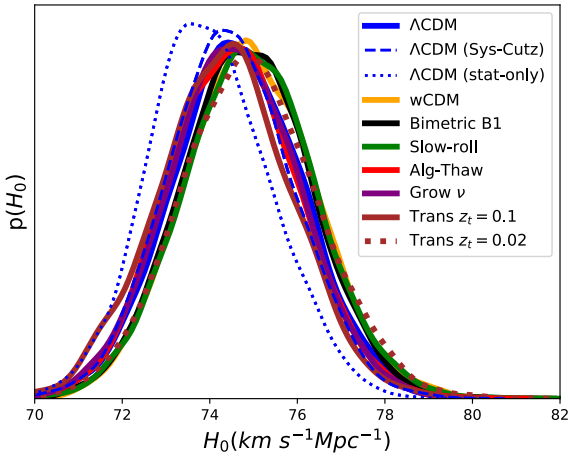
SD+20c

Simultaneous dark energy + H_0 constraint

Exotic models, including late-time transition

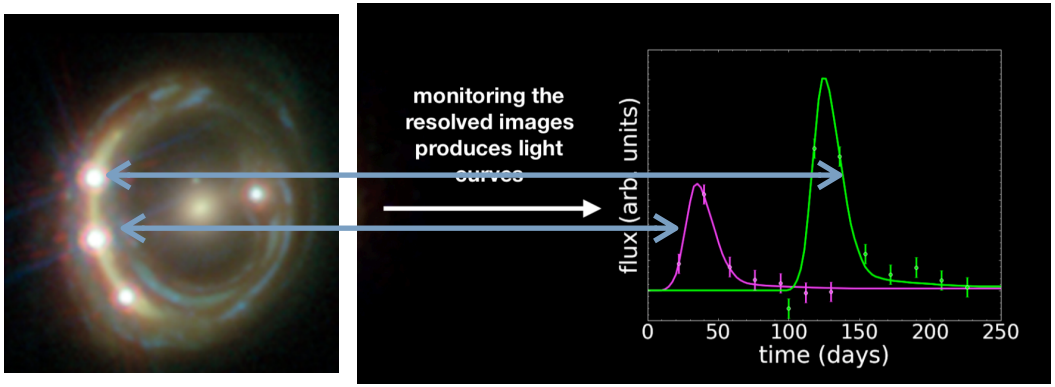
No model deviates from smooth-Λ

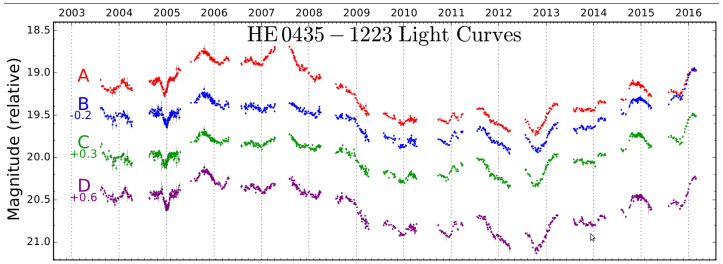
No transition seen in M_B (Lovick, SD, Handley in prep.)

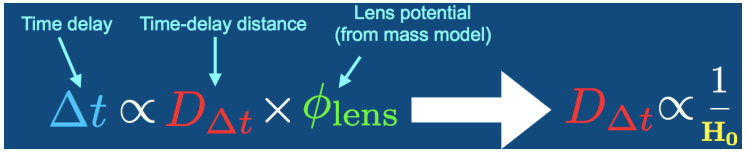


Time-delay cosmography

Typical lensed SN and QSO light curves





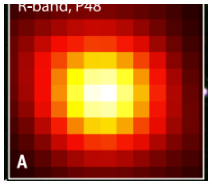


Independent of SN distance scale!

- Independent discovery method to lensed quasars
  - glSNe => “standardisable candle”
  - Much less monitoring required

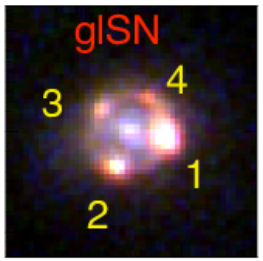
- First proposed in Refsdal 1964 (for SNe, used for QSOs)

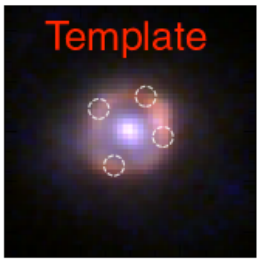
First Resolved lensed SN Ia

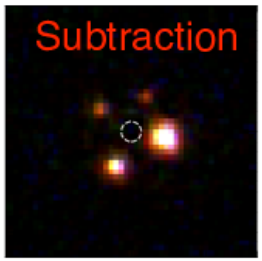


Discovery in unresolved data

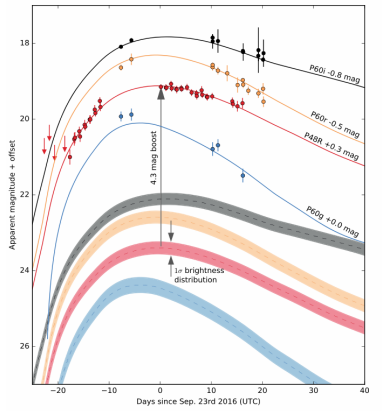
Follow-up: HST / AO







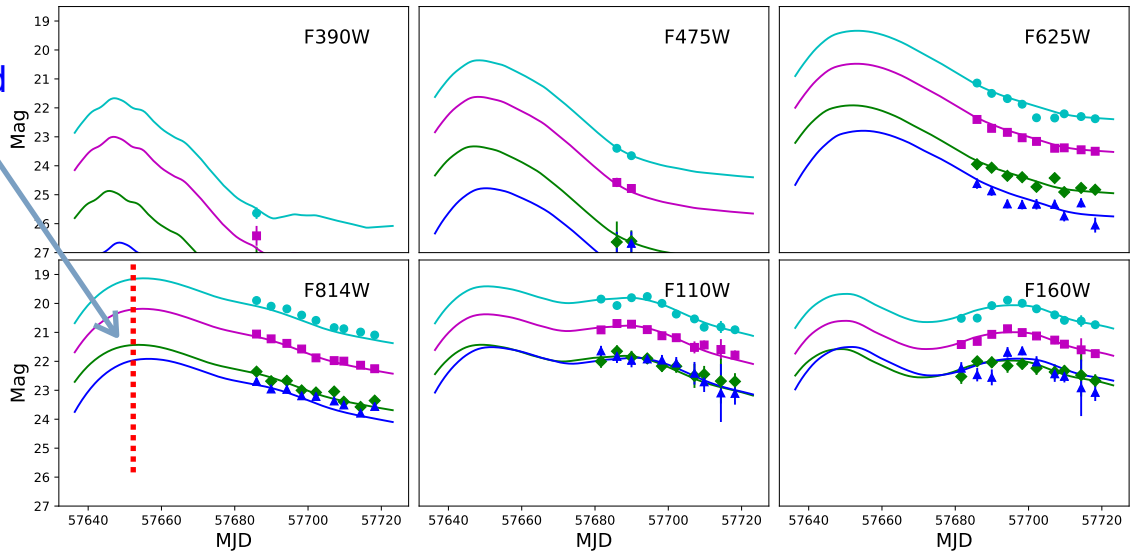
HST/WFC resolved image, template and subtraction => not possible for QSOs!



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

SD+20b

Just a few orbits: errors ~ 1d



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

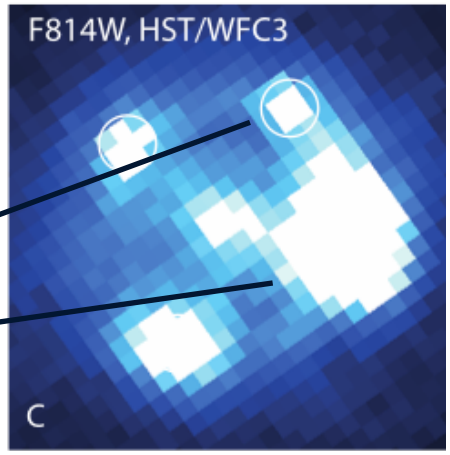
Max. light simulations
=> five times smaller error

Long wavelength lever arm for
extinction constraints

iPTF16geu: Magnification + extinction

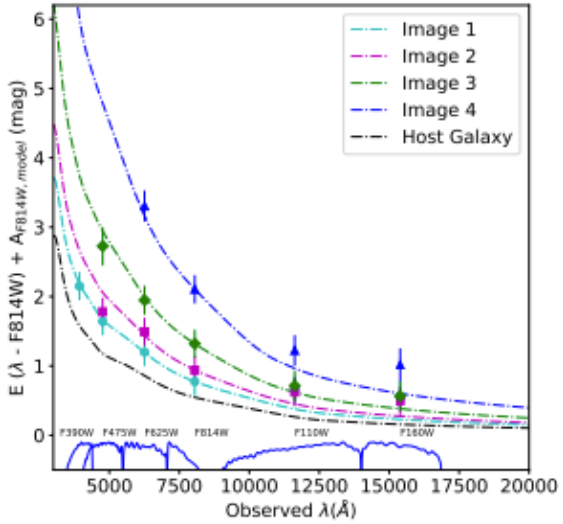
Important probe of dust in lens galaxy
LoS Rv < Milky Way values

Model independent lensing magnification

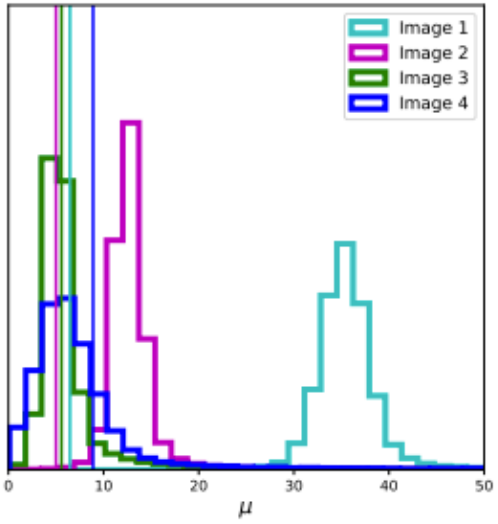


Surprisingly different brightness?

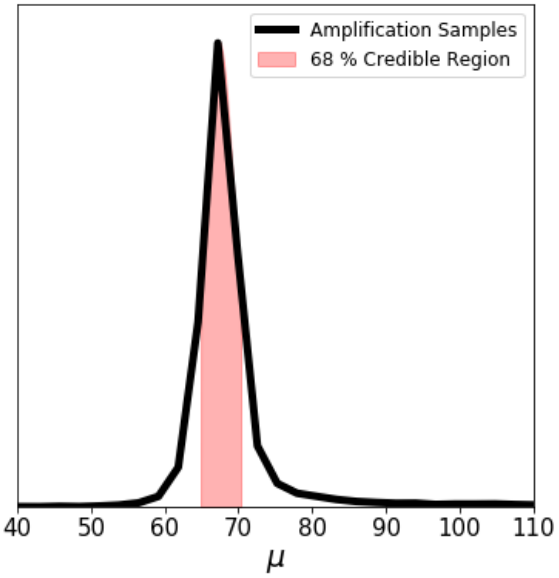
Preliminary magnification (μ) ~ 52
With extinction correction 67+/-3



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

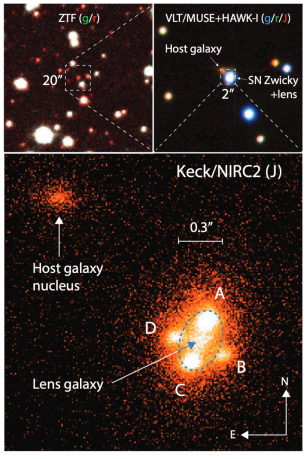


Modelling details in Mortsell,.., SD,+'21



SN Zwicky!

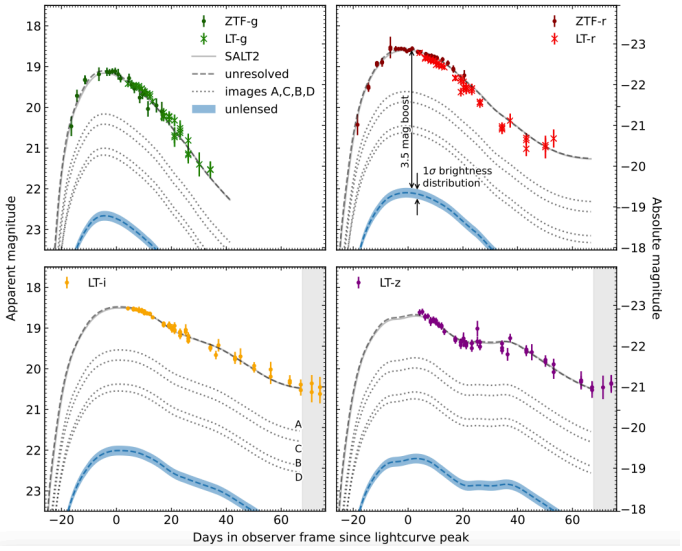
1”



~ 0.3”

0.01”

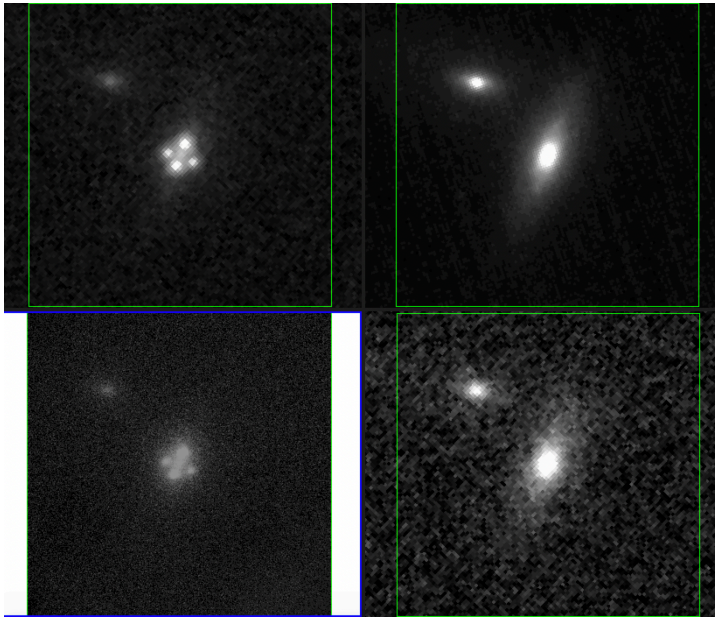
(Goobar+2023)



Small telescopes also vital for bright lensed SNe

JWST NIRCam obs
(Compared to HST live + template)

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

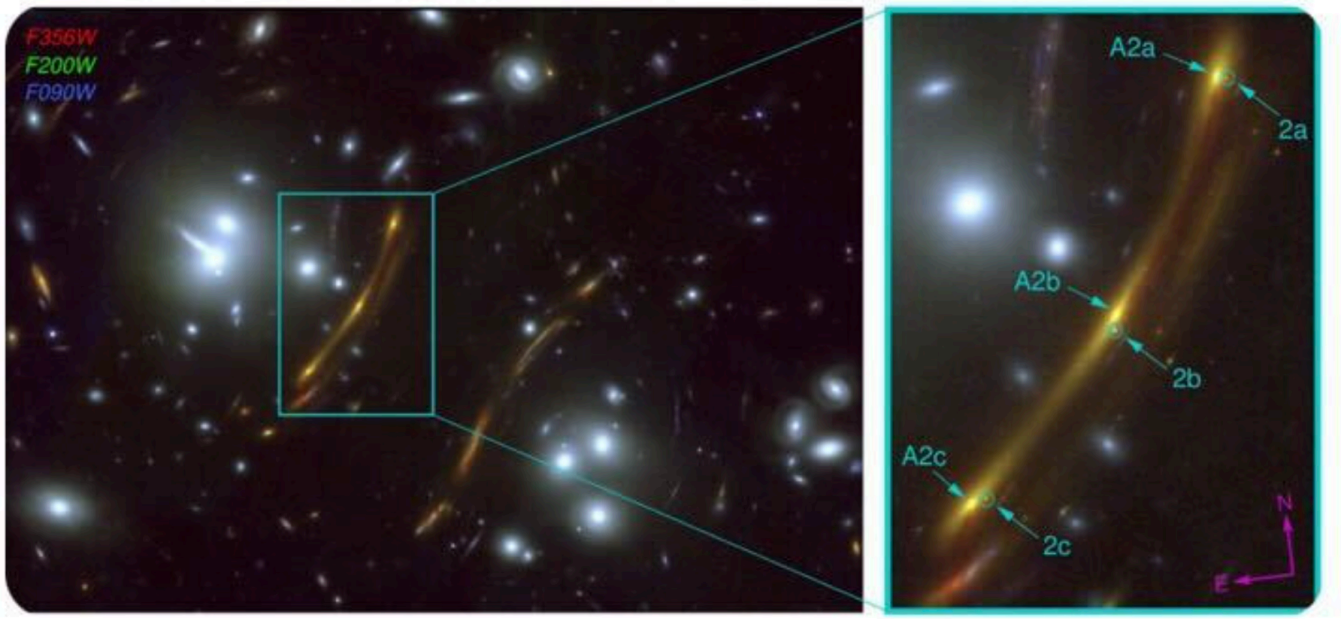


~ 3.5 mag > SN Ia at z_s =0.354

Low extinction in host + lens

Compact system θ_E < 0.2”: study central stellar IMF

SN H0pe



Discovery in NIRCAM obs of PLCK G165.7+67

Triply imaged SN Ia at z =1.78

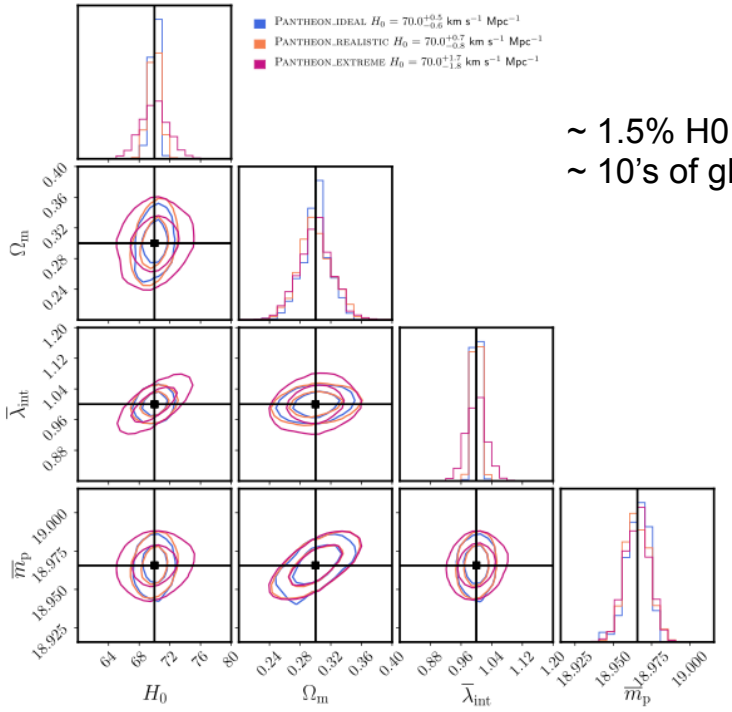
Cluster lens, long expected time-delay

Multiband follow-up with NIRCam (F090W-> F444W)

Expected H_0 at 10% -> 7% with reference epochs

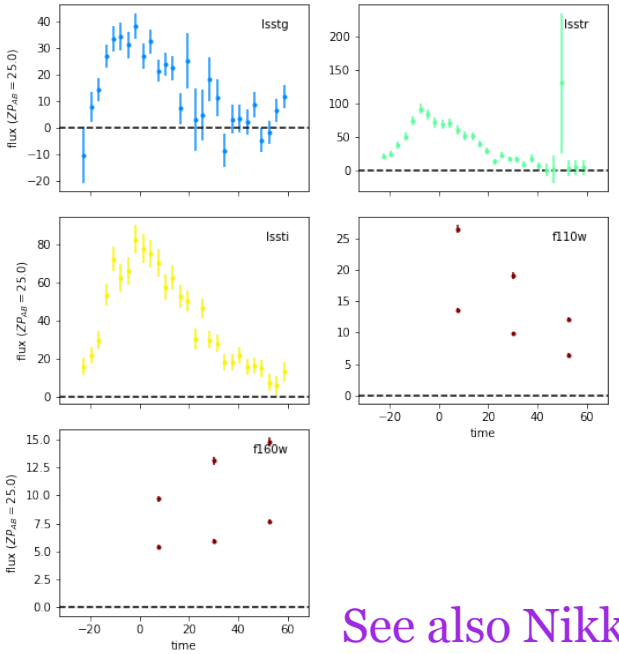
Pierel,., SD, et al. in prep.

Gearing up for LSST



~ 1.5% H0 with LSST
~ 10's of gLSNe

Birrer, **SD**, Shajib, 2022



See also Nikki's talk for rates and parameters

High-Cadence LSST + sparse space-based follow-up (SD + Pierel in prep.)

Spectroscopic Time-Delay

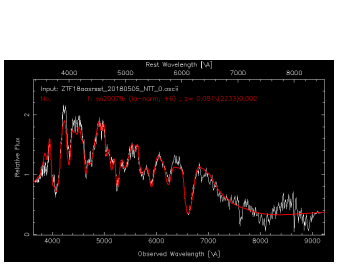
Spectroscopic time-delay: “one-shot” method (Johansson+2021 for 16geu)

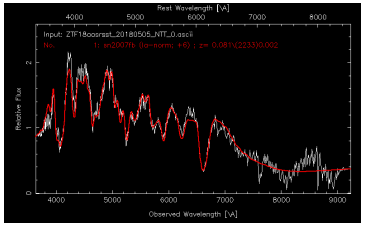
Cross-correlate against template spectra

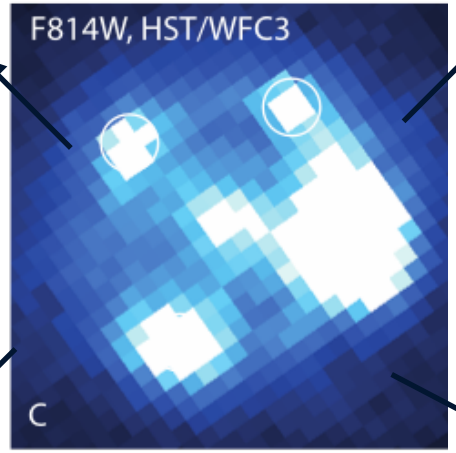
Small errors (< 2d) near maximum light

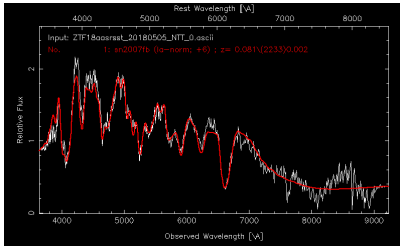
Works similarly well for core-collapse SNe

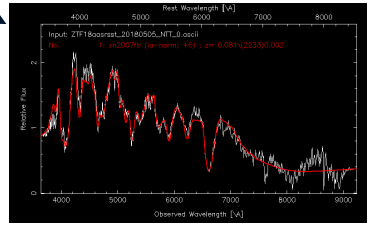
Example SNID fit for a typical low-z SNIa spectrum

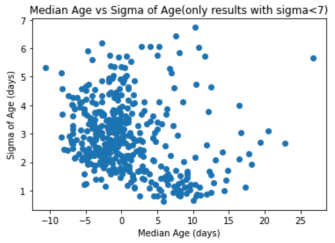


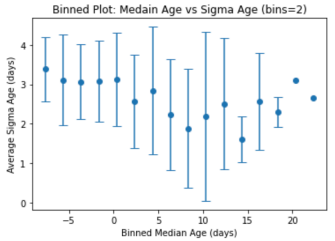












Crascall-Kennedy, SD+ in prep.

Conclusions

- Current survey discoveries
  - 16geu: short time delays, extreme magnification
  - 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

- New inference methods
  - Spectroscopy is a promising alternative

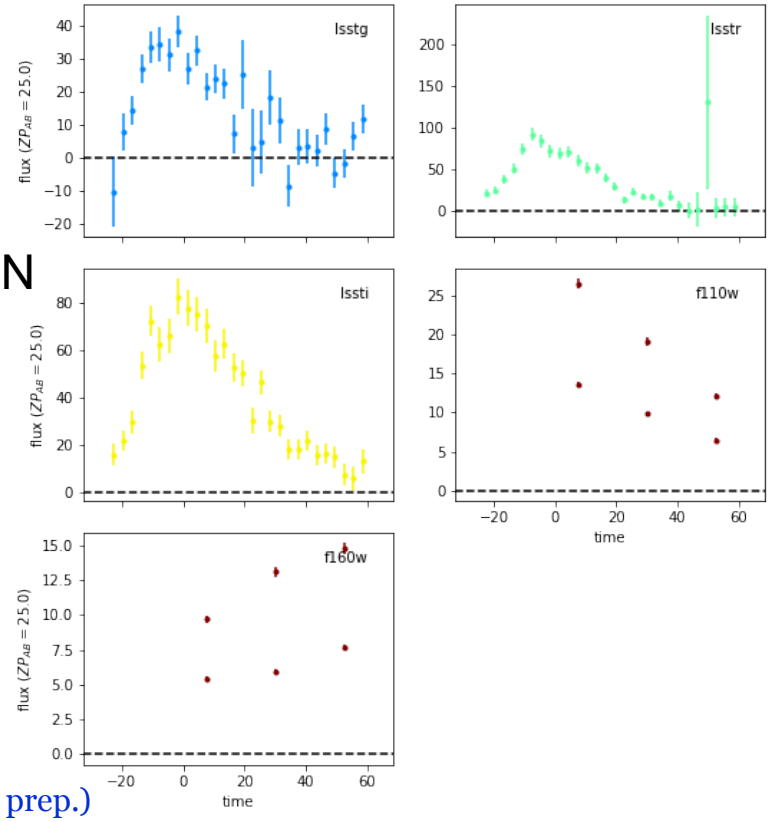
High-resolution observations

LSST lightcurves (mostly) unresolved

Lensing parameter constraints require follow-up

Combine with space based photometry
- Phase for triggering
- Number of observations

Preliminary results suggest 5 observations per gLSN



High-Cadence LSST + sparse space-based follow-up (SD + Pierel in prep.)

Spatial Curvature Constraints

Spectroscopic Follow-up!

Nebular phase (~ 1 year post explosion) observations

Four filter photometry + spectra (NIRCam + NIRSpec IFU)

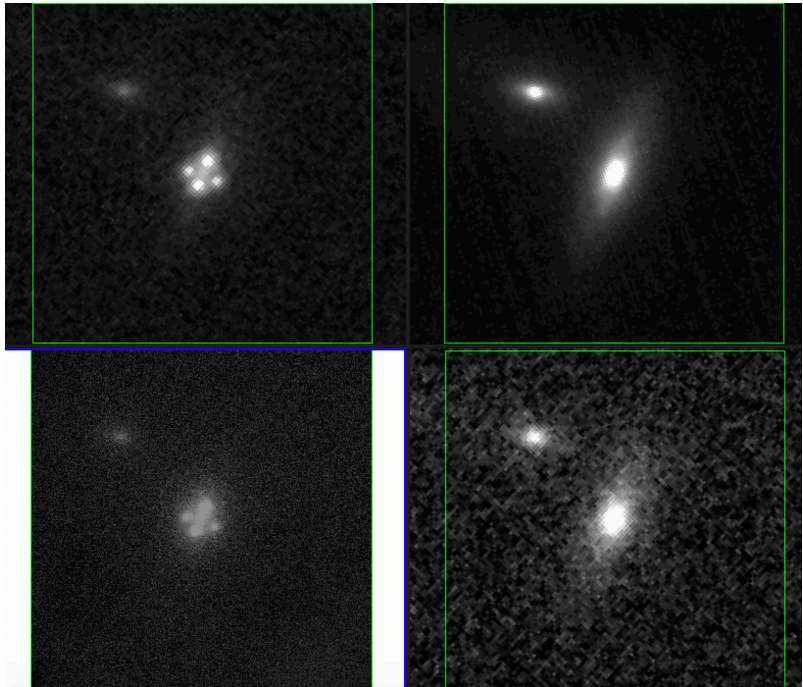
Faint SN, important constraints on lens light

Important for post-explosion host + lens modelling

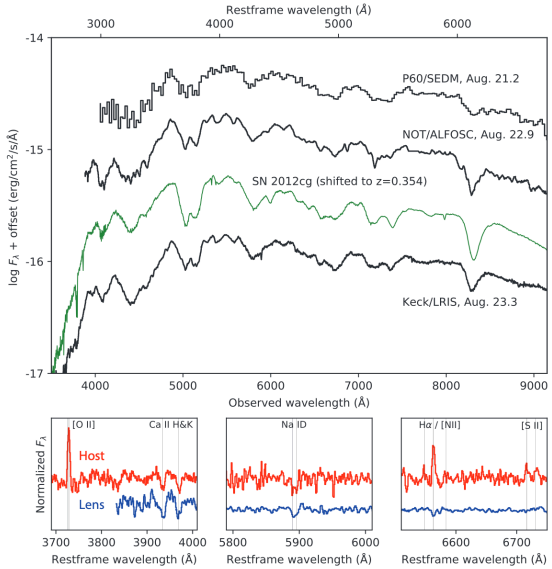
Nebular spectra -> shed light on progenitors

Photospheric spectra from the ground

NIRCam image of host +lens

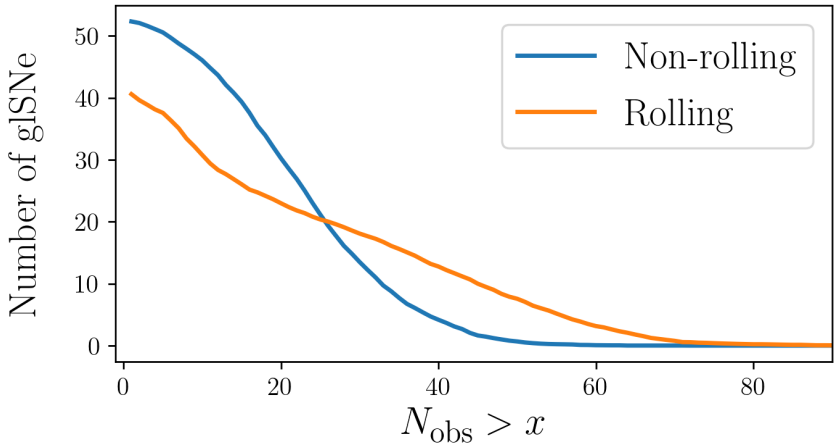


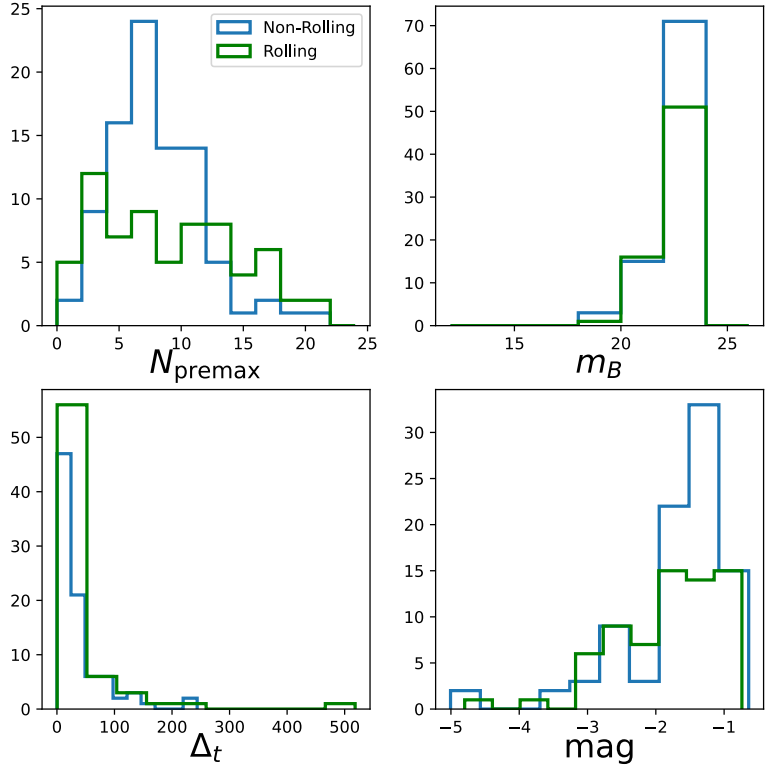
SN Zwicky spectra compared to local SN 2012cg



Detectability in LSST

Baseline v3.0 cadence
Many 10's expected per year: ~ 20 with large Δt
Rolling has fewer -> denser sampling



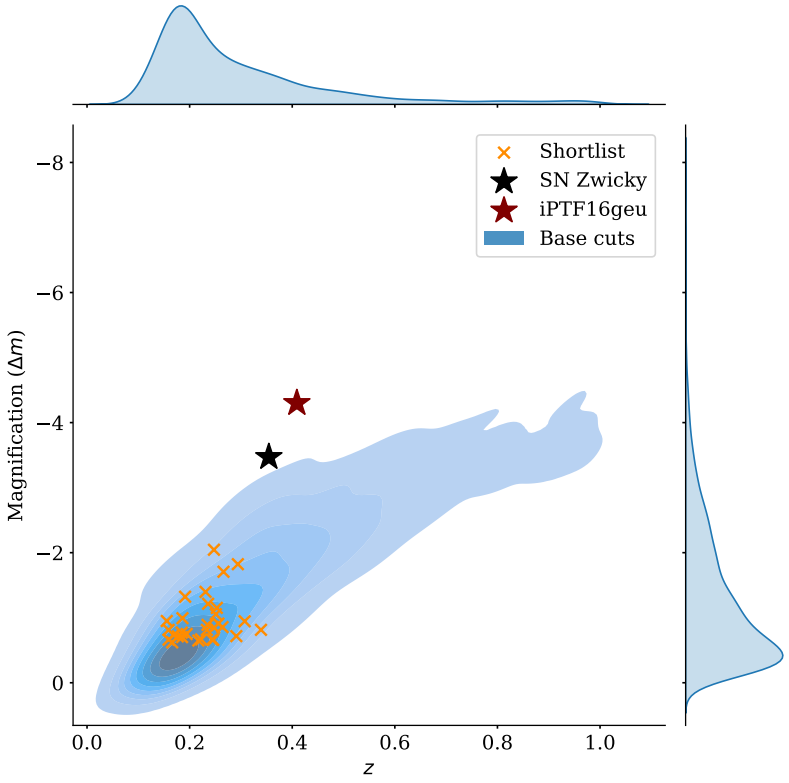


Several with early sampling for discovery
Bright for 4m spec classification
Long time delays for cosmology

Arendse, **SD**, et al. internal review

ZTF archive search for lensed SNe

- Systematic search for strongly lensed SNe Ia in the ZTF archive.
- Applying cuts based on simulations.
    - Cuts on photo-z, distance to host, peak absolute magnitude, SN and host colours.
- 31 930 alerts —> 30 candidates.
- Paper out this year!

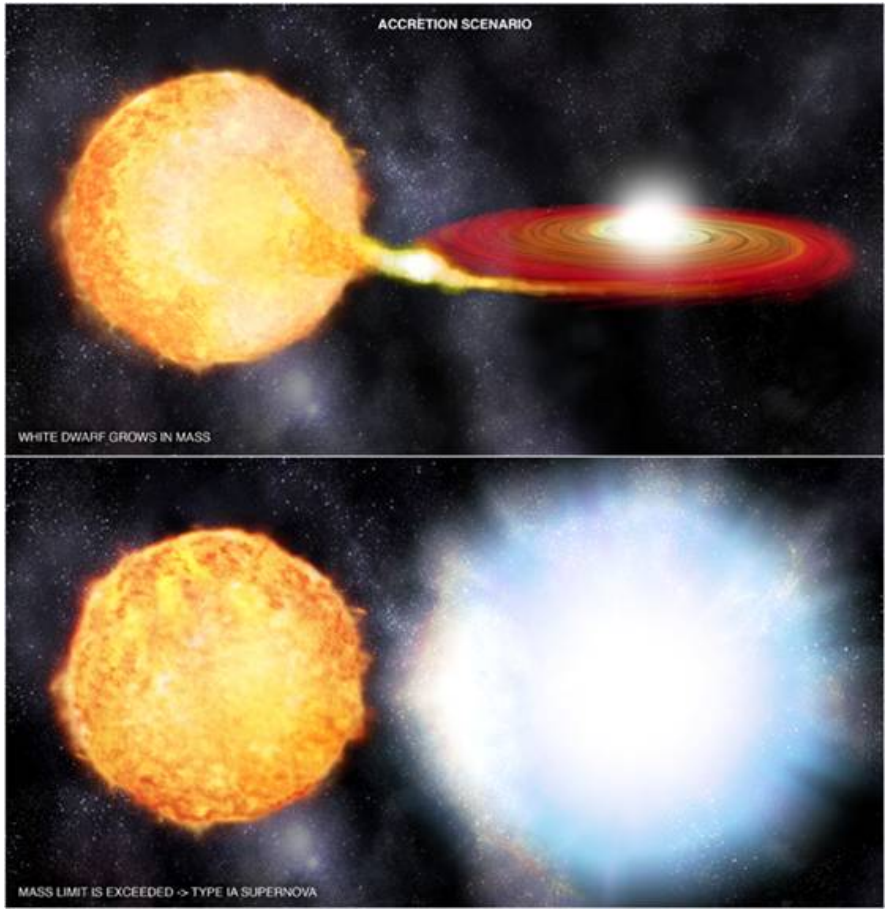


Magnification vs. z for the best 7000 candidates (base cuts), and the shortlist candidates.

A. Townsend, J. Nordin (HU Berlin), A. Goobar, A. Sagas Carracedo, J. Johansson, N. Arendse, B. S. Schulze, E. Mörtsell (OKC), S. Dhawan (Cambridge)

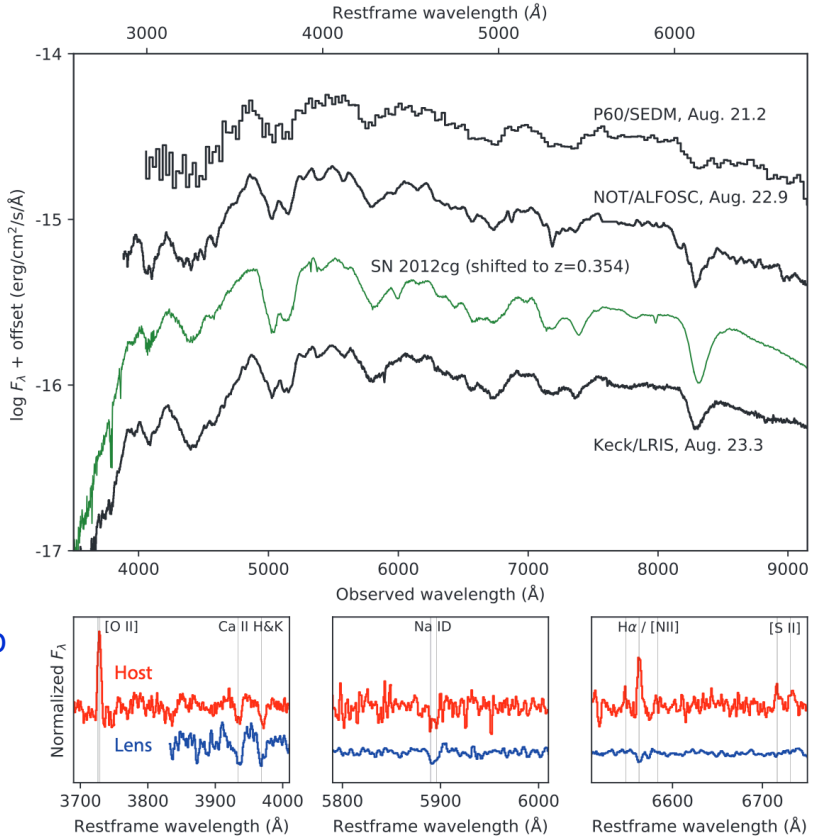
What are Type Ia supernovae?

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



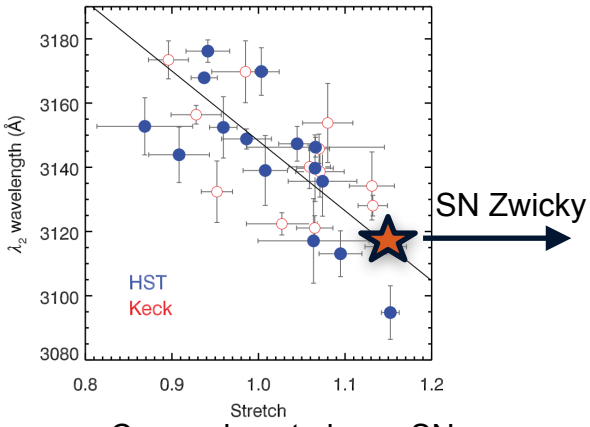
dark energy systematics -> lensing helps study high-z SN physics

Spectroscopy of lensed SNe



SN Zwicky spectra compared to local SN 2012cg

Johansson, **SD+**, in prep

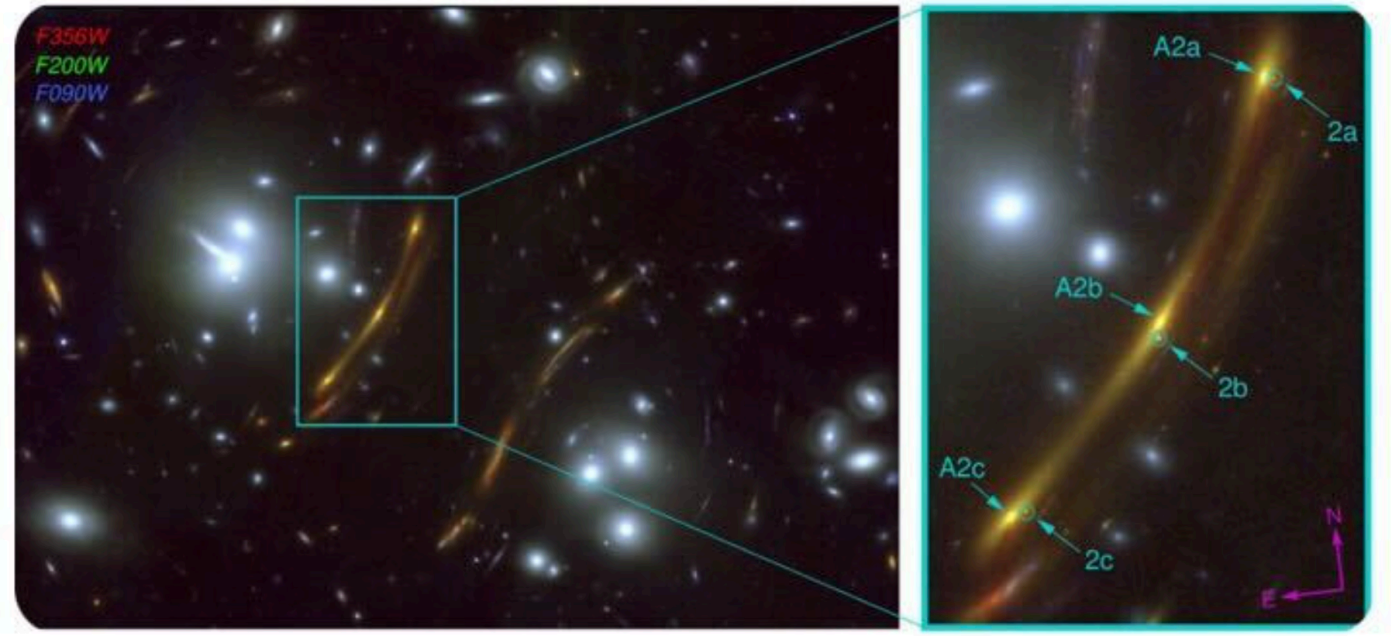


Comparison to low-z SNe sample from Maguire +2012

No signs of cosmic spectroscopic evolution!

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

SN Hope



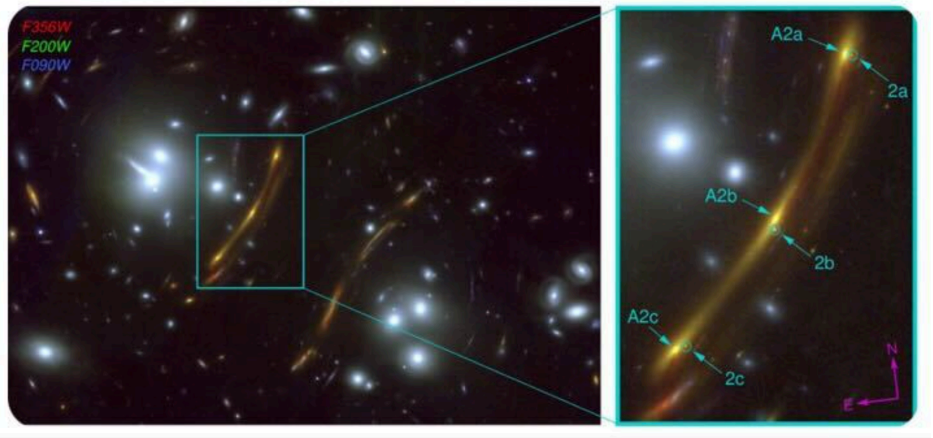
Discovery in NIRCAM obs of PLCK G165.7+67 ; PEARLS program

Cluster lens, long expected time-delay

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

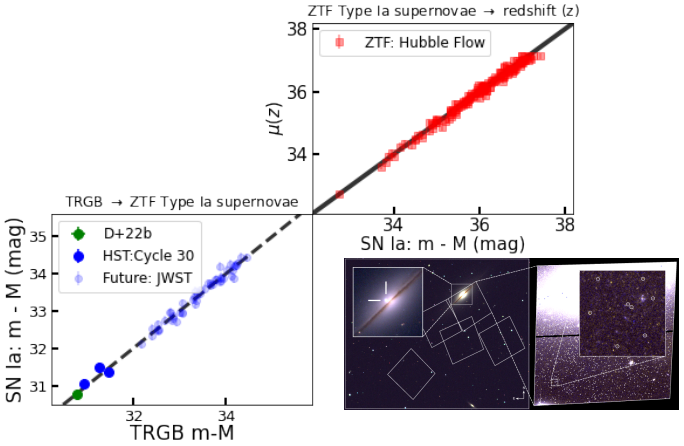
PhD in Time-Domain Cosmology

Suhail Dhawan (sd919; K01)



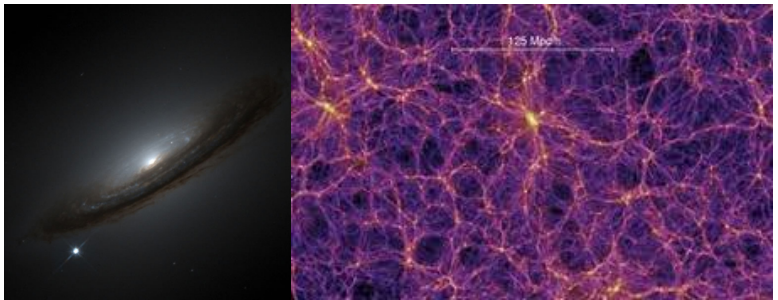
Strongly Lensed Supernovae

- Discovery with Vera C. Rubin Observatory
- Analyses with JWST IFU data
- Novel methods with current surveys



Local Hubble Constant

- Uniform, large Type Ia supernova datasets
- New distance indicators



Structure growth with SNe

- Bulk flows from local superstructures
- $f\sigma_8$ with Type Ia supernovae