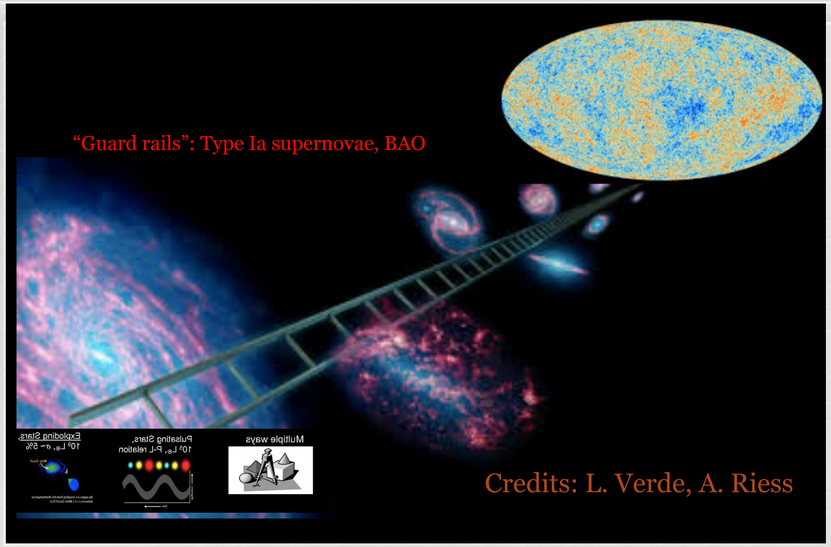
Gravitationally Lensed Supernovae

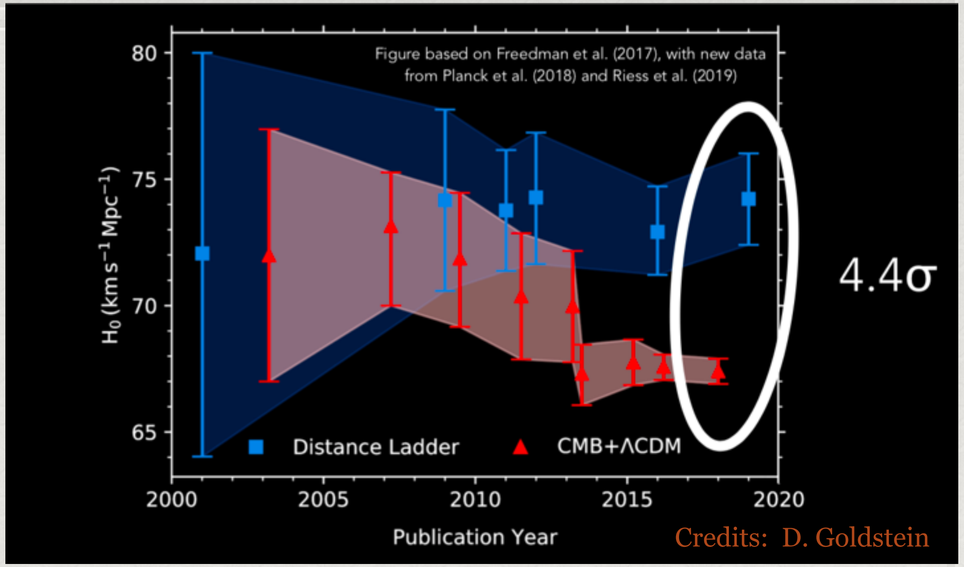
Suhail Dhawan

(+ ZTF Cosmology and Lensing WG)

KICC Science Day, 30 September 2021

Motivation





H_0 tension: New Physics or Systematics?

No clear cosmological solution
(see Knox & Millea 2019 for a review)

Need independent checks

- Unaccounted for systematics
- Independent distance ladder
- Novel absolute distance measurement

(e.g. lensed transients, standard sirens)

Why Lensed Supernovae?

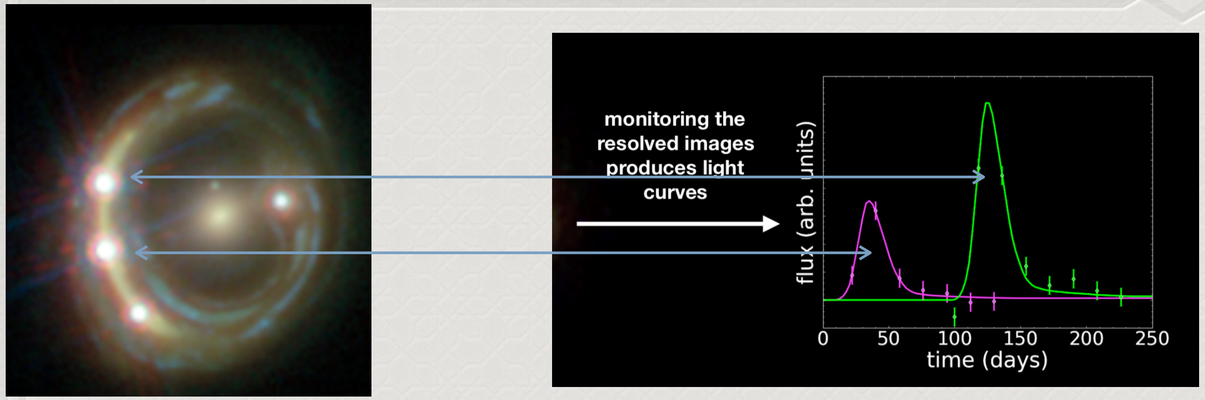
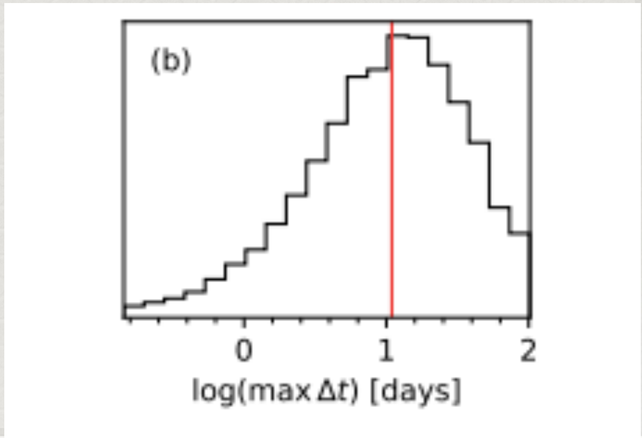


Illustration of the idea from Refsdal 1964

Advantages of glSNe Ia

- Well-understood light curves + SEDs
- Much less monitoring required (few weeks compared to years for QSOs)
- "Standardisable" luminosity => improve systematics (e.g. Birrer, SD, Shajib, 21)
- Lower impact of microlensing

Expected distribution of time delays for ZTF glSNe Ia (Goldstein+2019)

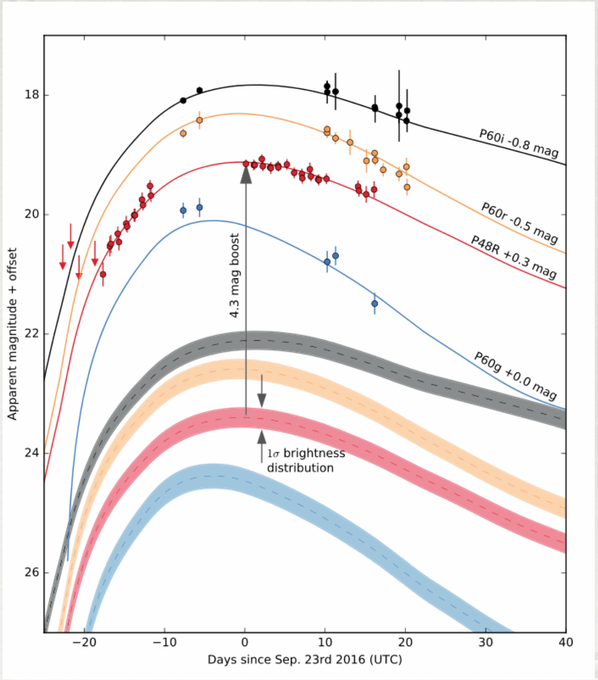


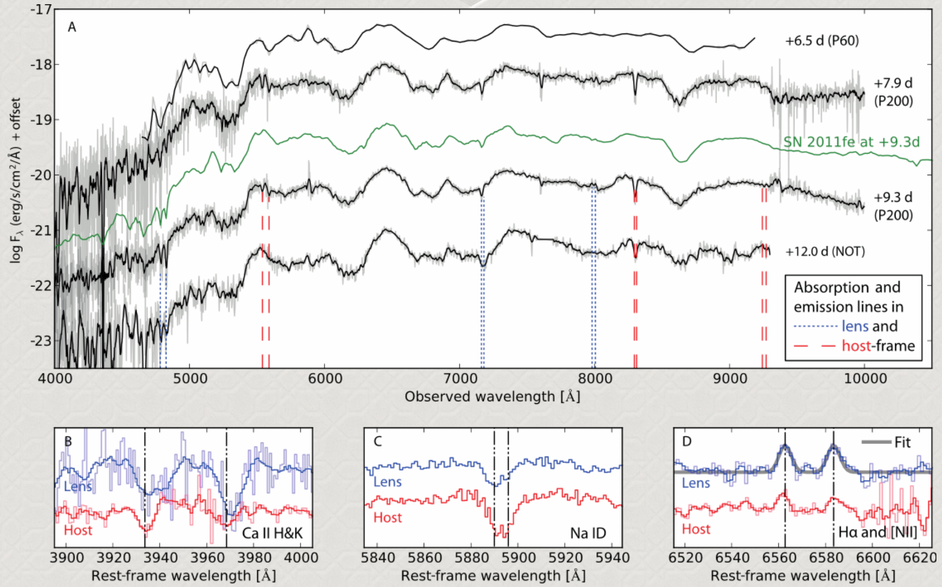
- Rubin Observatory ~ 100s of events
  - + Millions of unlensed supernovae (contaminants)
- Zwicky Transient Facility ~ 1 -2 per year (g,r depth of 20.5 mag)

First resolved gLSN Ia: iPTF16geu

>50 times brighter than normal SNIa at z~0.4: a 30σ outlier!

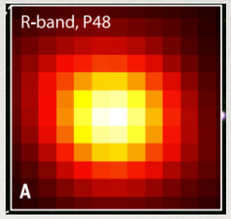
Goobar+ 2017





Perfect spectral match to z=0.409 SN Ia
+ intervening galaxy at z=0.216

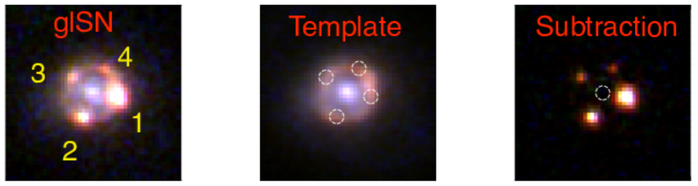
Dhawan+2020a



Discovery in unresolved data

⟷

Follow-up: HST / AO



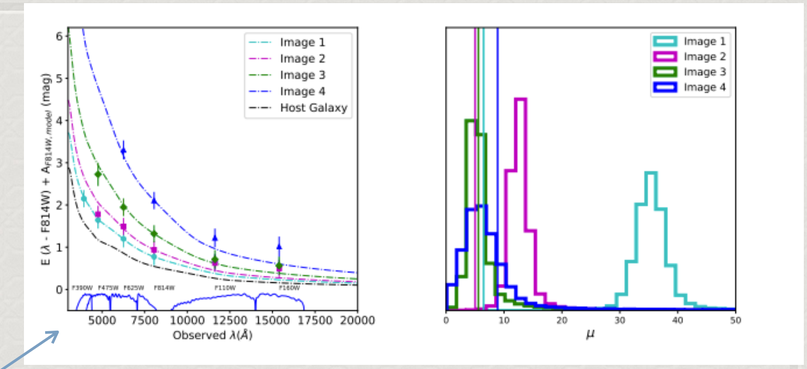
HST/WFC resolved image, template and subtraction

Time delays and Magnifications

Extremely high magnification (μ)

Important to get multi-band, resolved photometry
-> preliminary μ ~ 52, now precisely measured to μ = 67 +/- 3

Small angular separation; probing the inner kpc of the lens



Multiband photometry for extinction in each image

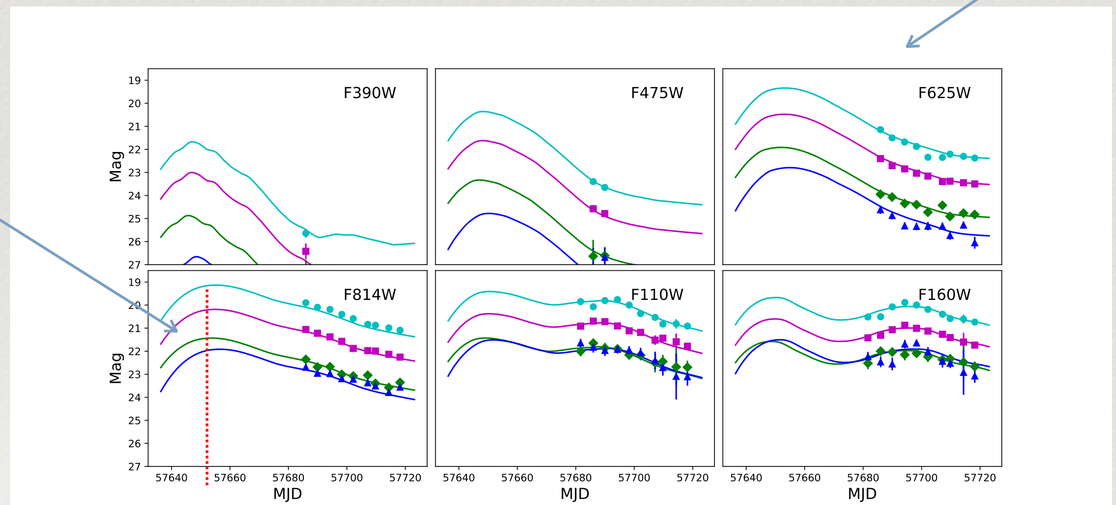
Dhawan+2020a

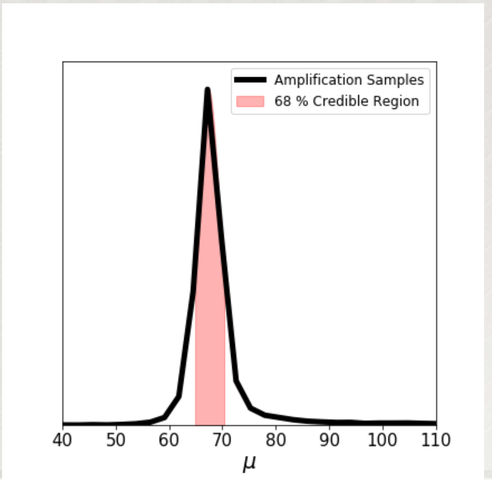
Very small time-delays (~ 1 day):

Coverage began post-maximum
=> large errors (~ 0.7 - 1 day)

Max. light simulations
=> five times smaller error

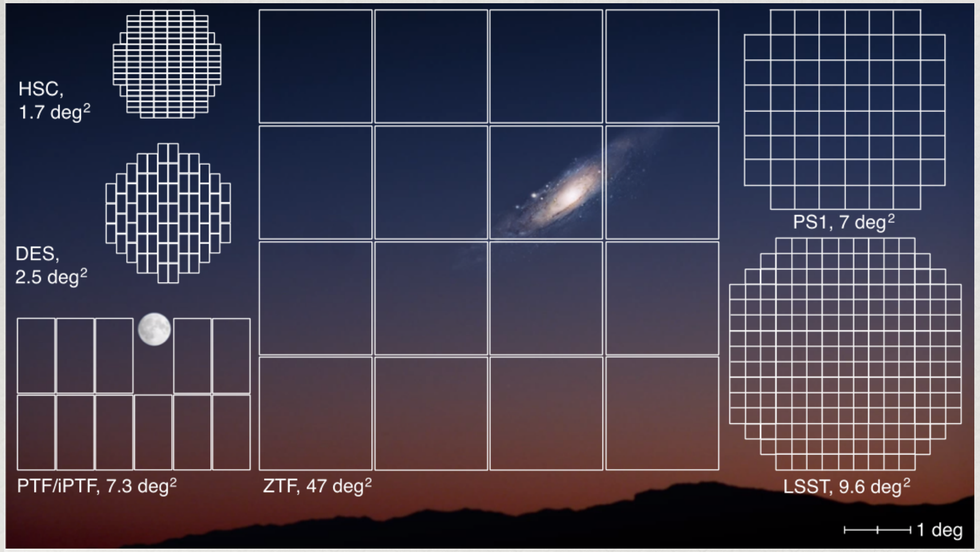
10 day delay measurable at ~ 2%





Search with the Zwicky Transient Facility

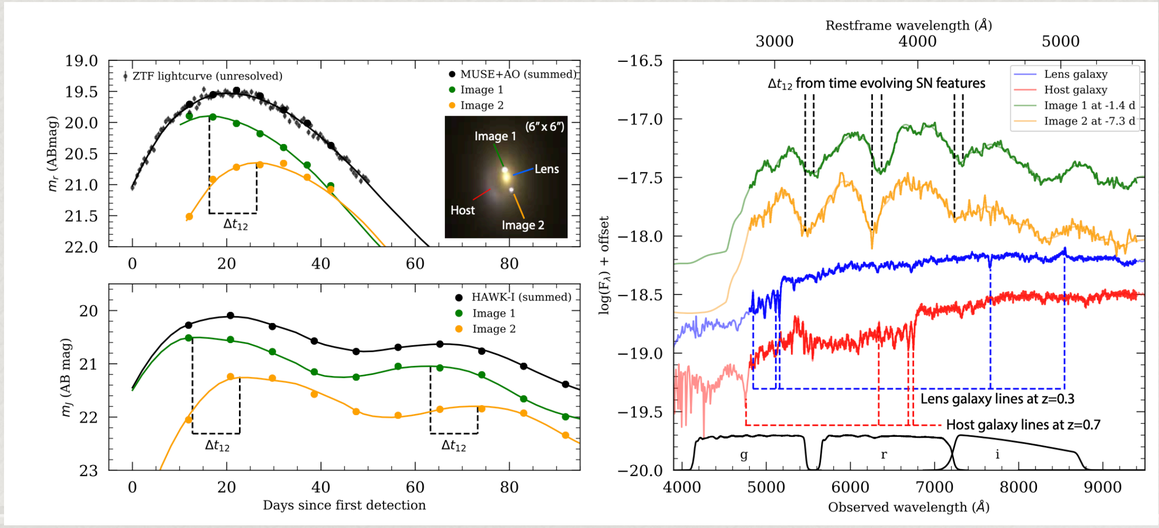
P48: 1.2m discovery Schmidt telescope



Improving filters for AMPEL broker (one of LSST brokers)

Spectroscopic classification @ fainter than 19 mag

High-resolution spectrophotometry time at VLT

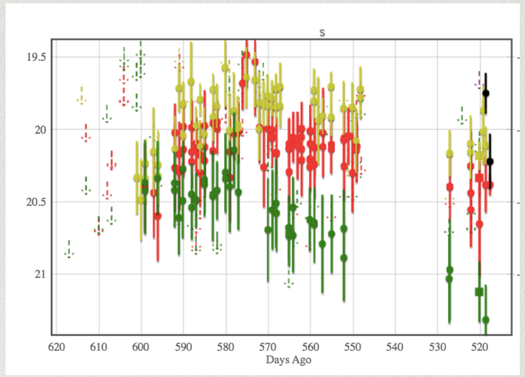


Dedicated classification with P60: SEDm

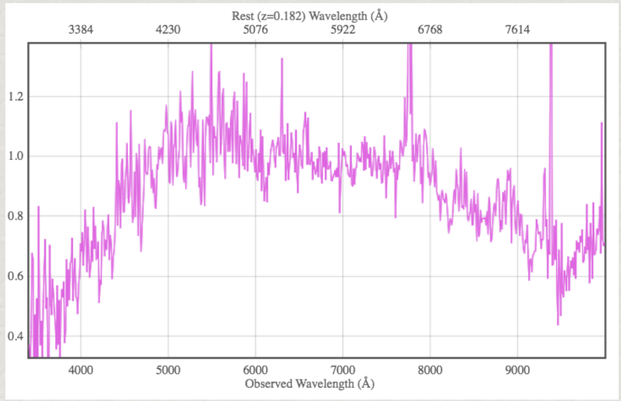
- Depth ~<18.5 mag
- Most lensed SN candidates are fainter

Interesting Candidates + way forward

Contaminant false positives: SLSNe, blazars
With stacked images: higher-z SNe Ia



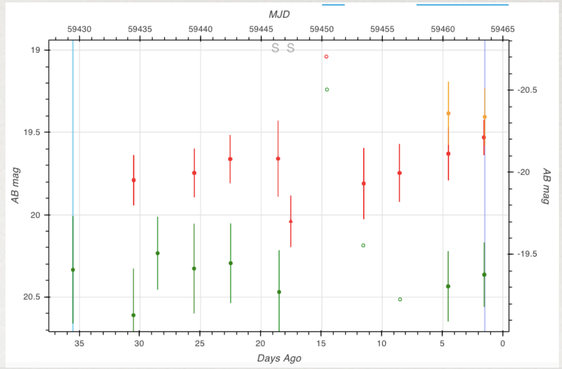
Contaminants are interesting themselves

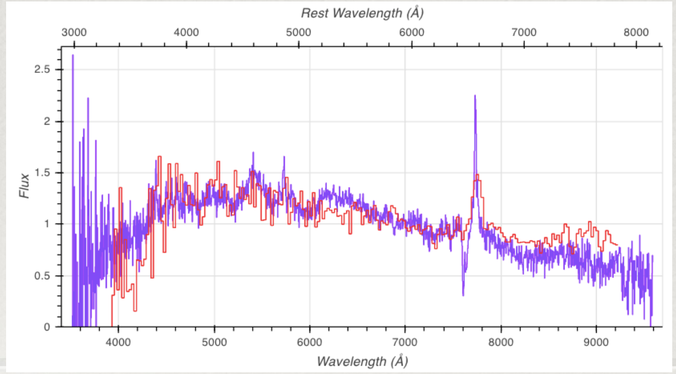


Ongoing spectroscopy campaigns
- INT, Gemini (PI: Dhawan)
- NOT (PI: Goobar)

Ongoing improvements to alert filter
Inferring from detailed survey simulations

Bright (M > -20), red Type II-P, only 4 seen in a sample of few hundred SNe (Perley+'20)





Bright (M > -20), red Ia-CSM; interacting SN

Conclusions

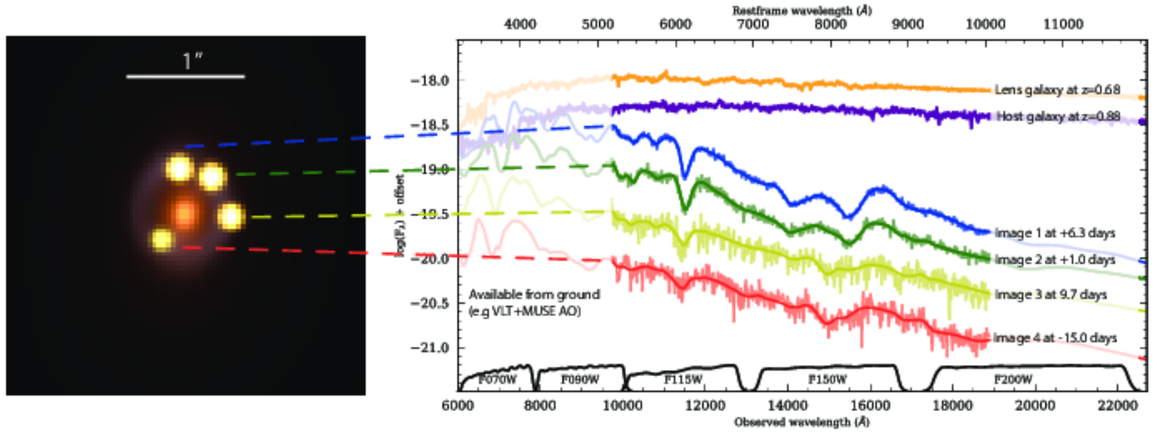
- Future glSN sample: H_0 at ~ 1-2%
- iPTF16geu: first resolved gLSN Ia
  - Highly magnified -> precisely measured
  - Extinction measurement in each LoS

- ZTF gLSN search ongoing
  - Improved filter searches
  - Need for deeper classification spectroscopy

Lensed Supernova Spectroscopy

- Spectroscopy essential for discovery
- Magnification -> high signal spectroscopy
- Independent, “one-shot” time-delays (Johansson,..SD, et al. 2021)

Forecast for high-res spectroscopy of a gLSN



Comparison to low-z SNe Ia (Petrushevska+2017)