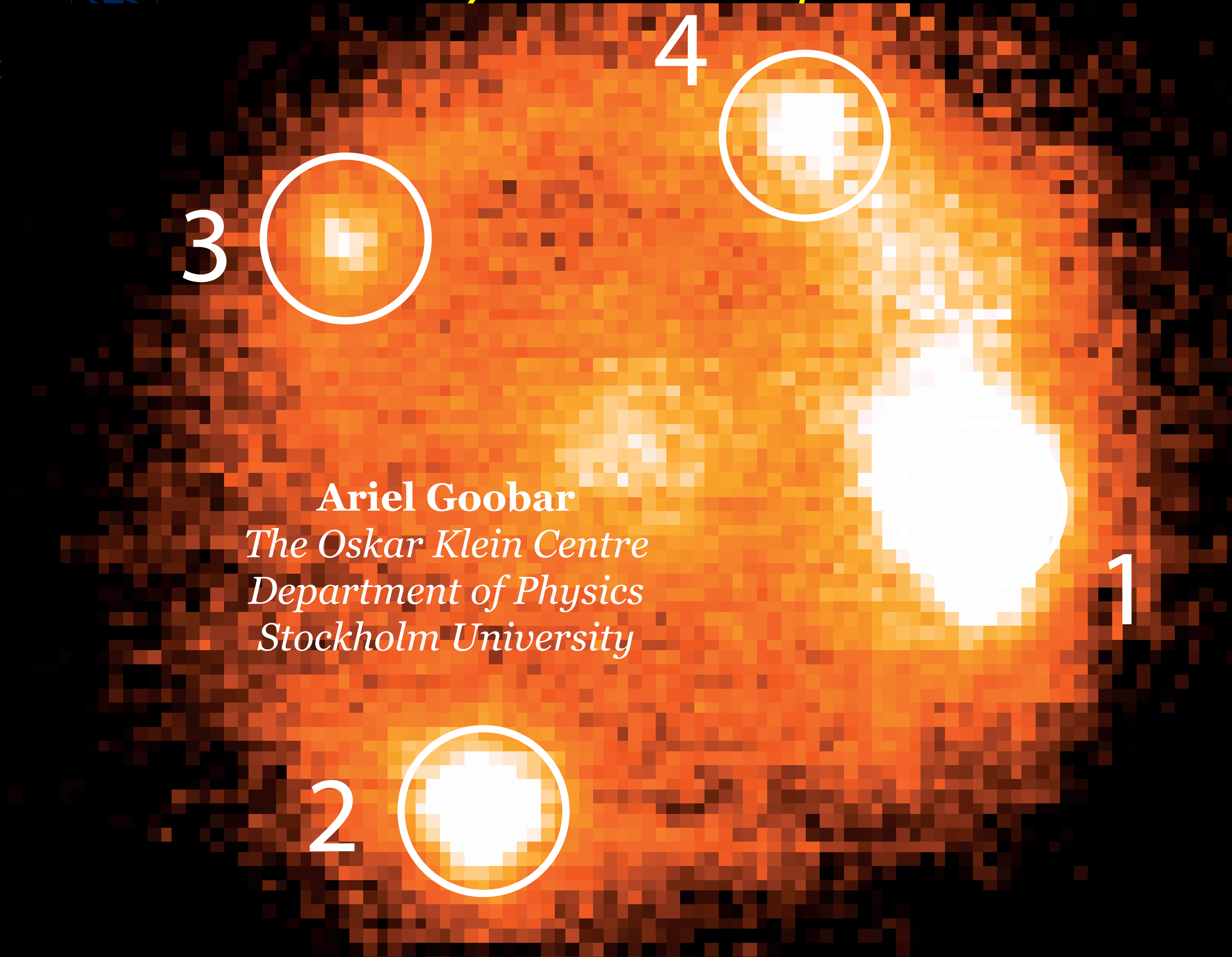
Gravitationally Lensed Supernovae



Ariel Goobar
The Oskar Klein Centre
Department of Physics
Stockholm University

gLSNe science

1) ***Tests of standard model of cosmology and beyond***

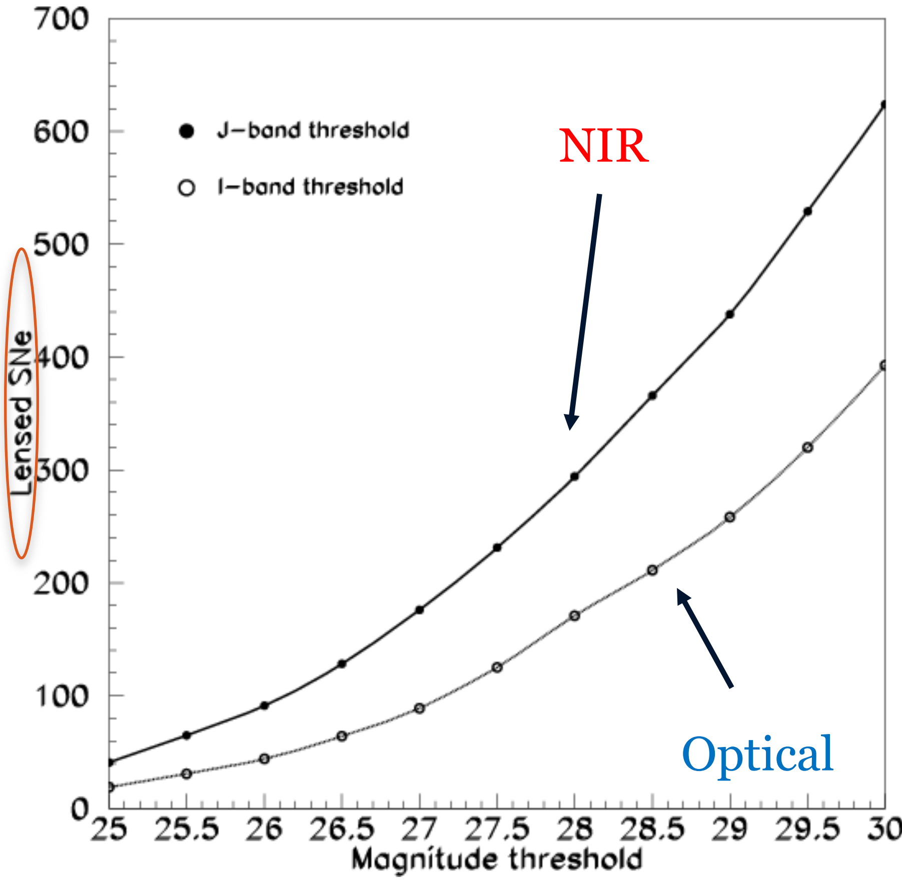
- Time-delay cosmography: H_0 + Dark Energy
- Galaxy mass distribution and small scale substructures: tests of CDM, incl. density of compact objects

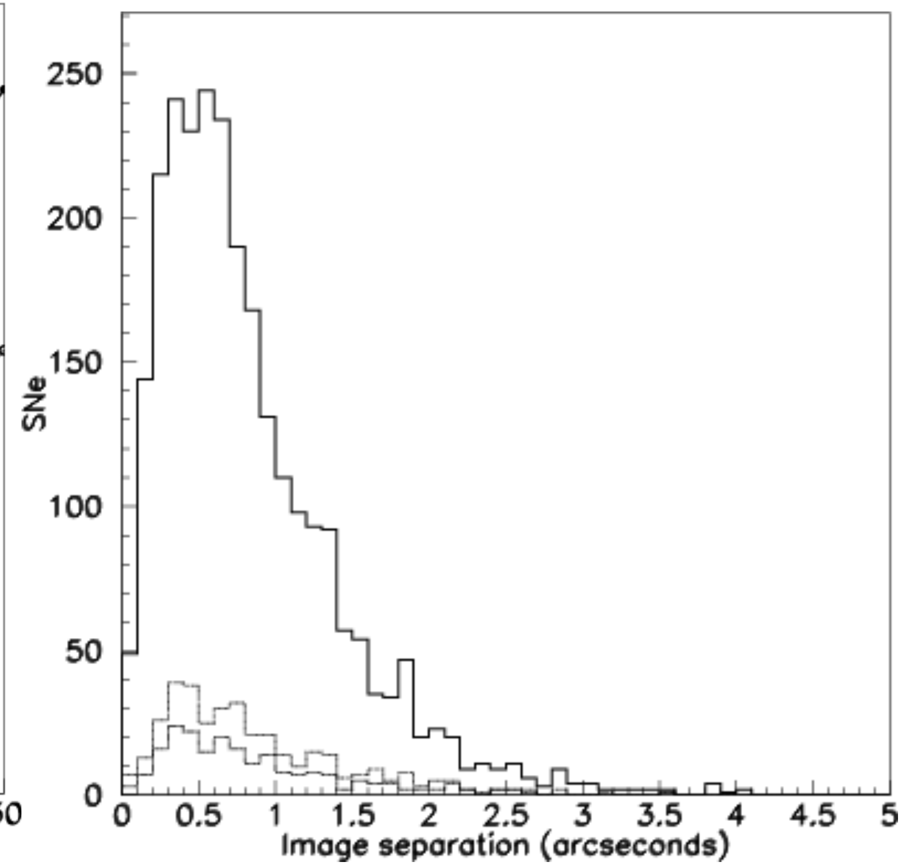
2) ***Observations through Gravitational telescopes***

- Spectroscopic scrutiny of *high-z* SNIa "standard candles"
- Window to the highest redshift SNe, a window to the first generation of core-collapse and pair-instability SNe

Why Roman?

- **Survey area**
- **Cadence**
- **Depth**
- **NIR sensitivity**
- **Spatial resolution**





Goobar et al 02 (SNAP satellite forecast!)

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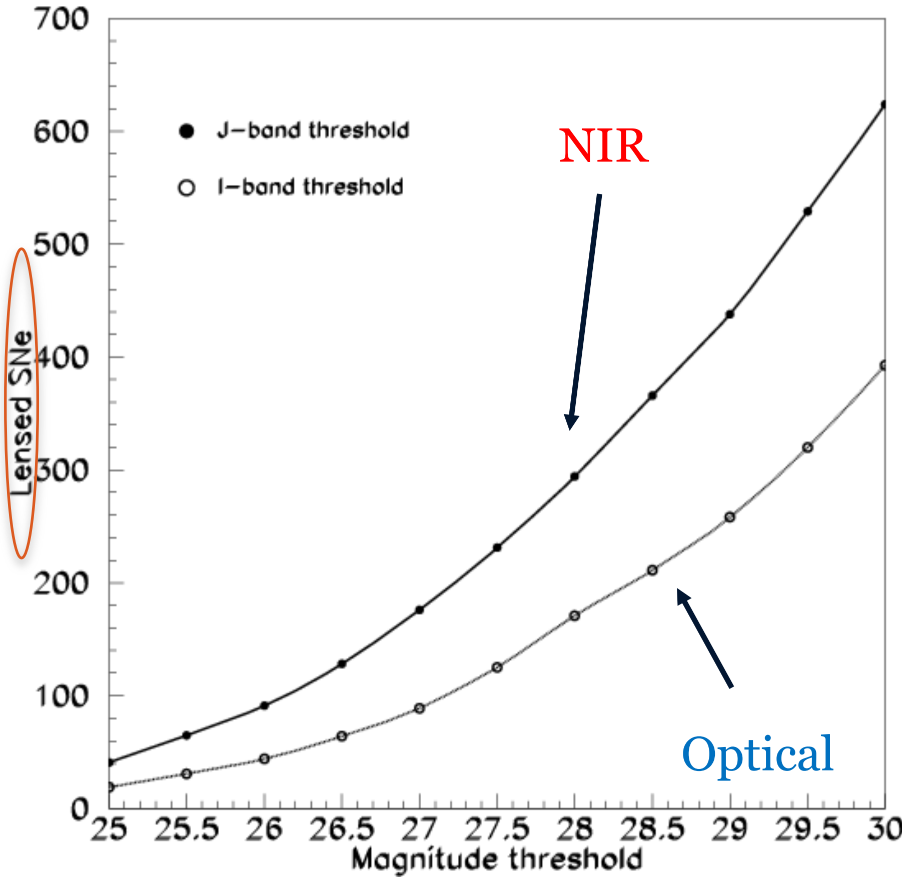
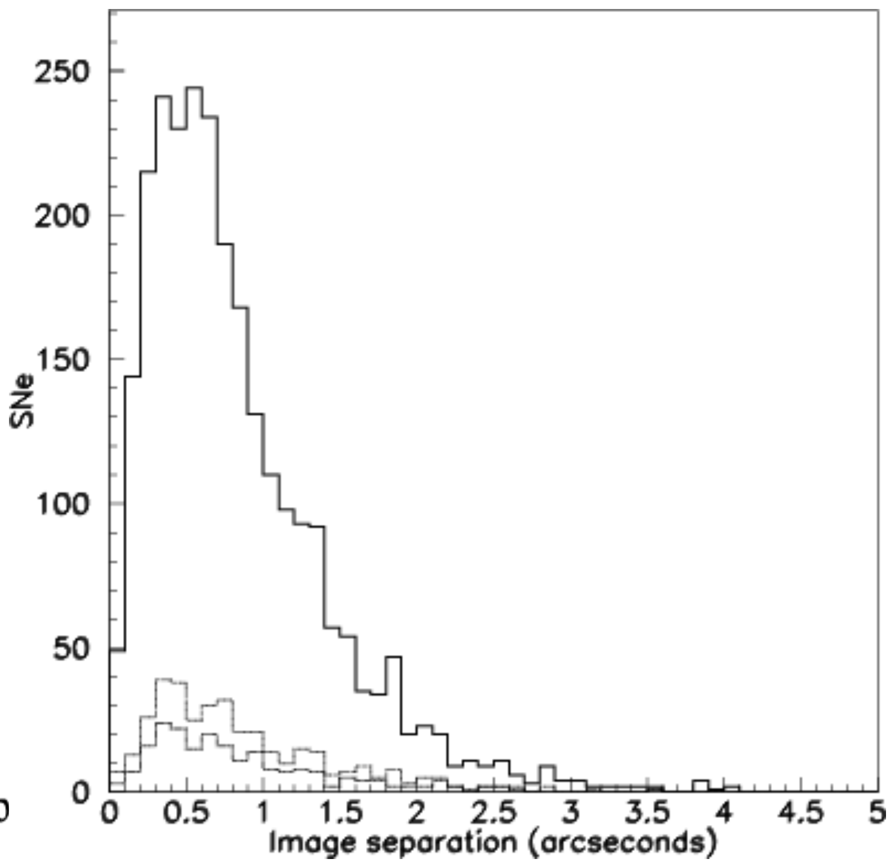
\+ synergies/complementarity with shallower/wider LSST survey





Goobar et al 02 (SNAP satellite forecast!)

Key points:
time-delay cosmography

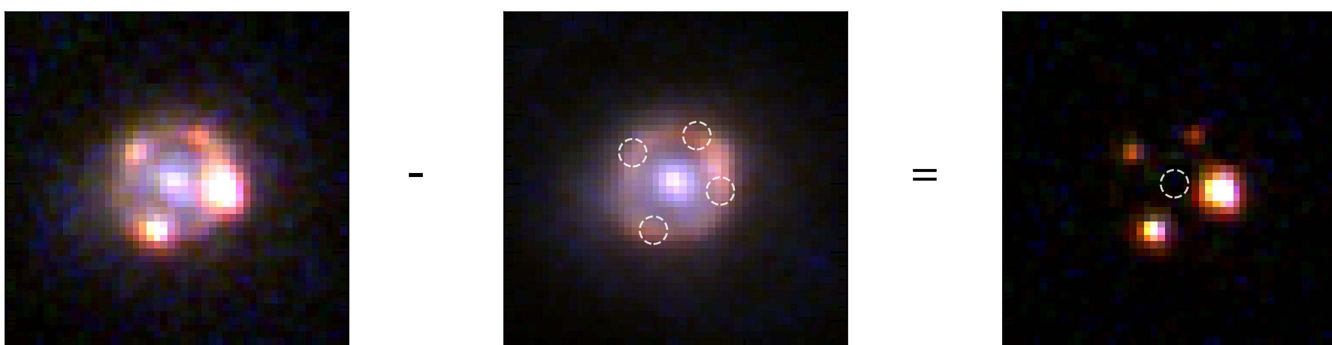
- Precise time delay between SN images
- Precise SN image positions
- Deep images of host galaxy for lens modeling
- Deep images of lens + surroundings to infer structures in the line-of-sight

"undisturbed" view of host + lens

Clean view of transient SN

HST images of iPTF16geu

Dhawan et al 2020



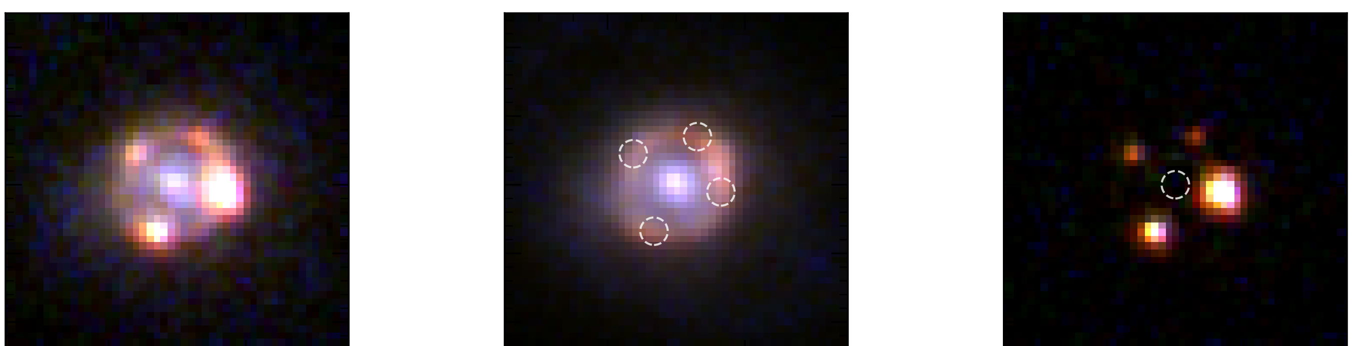
2016 2018 Difference

Key points:
time-delay cosmography

- Precise time delay between SN images
- Precise SN image positions
- Deep images of host galaxy for lens modeling
- Deep images of lens + surroundings to infer structures in the line-of-sight
- Accurate redshifts and stellar velocity dispersion in lensing galaxy can be obtained from supporting observations

HST images of iPTF16geu

Dhawan et al 2020

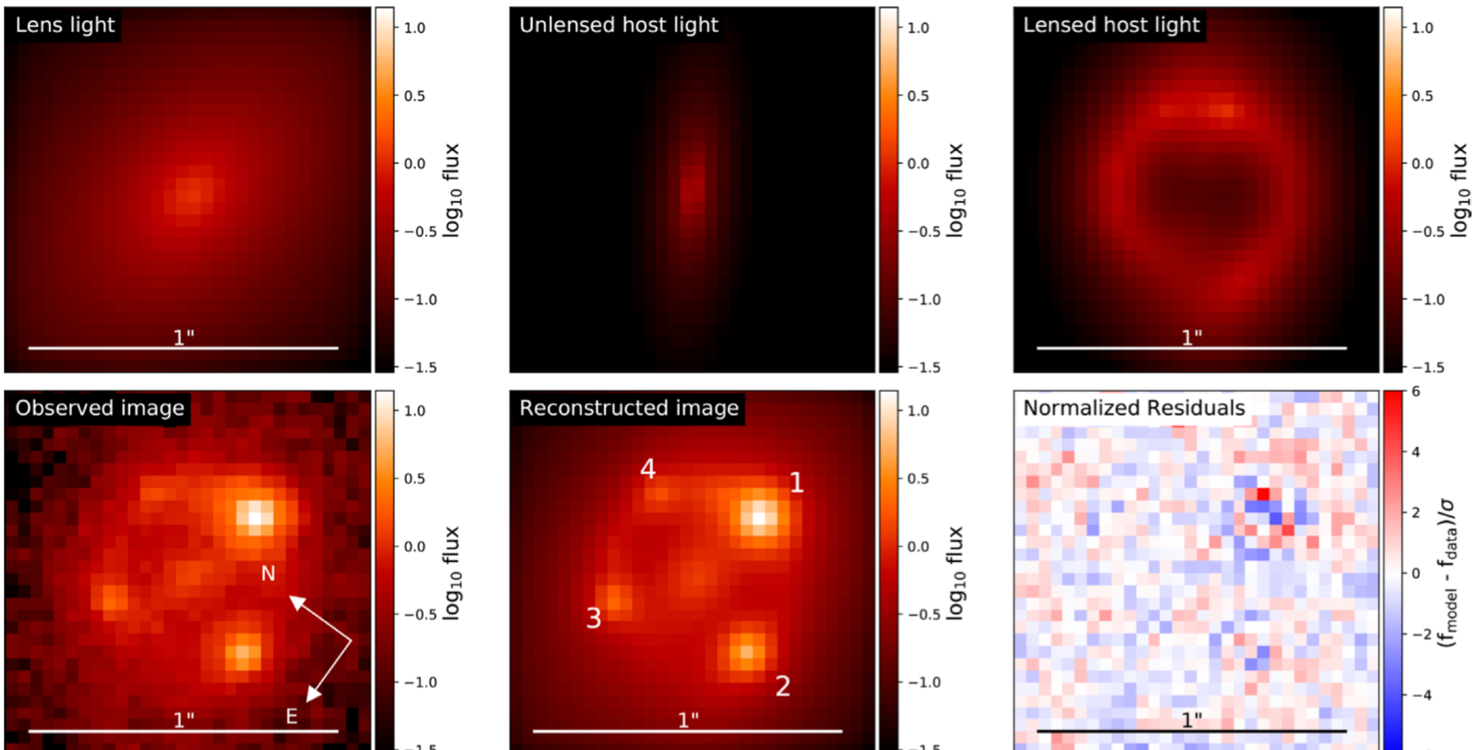


2016 2018 Difference

Key points:
Galaxy mass profile

- Galaxy central profiles (core/cusp) is an important diagnostic for the nature of DM

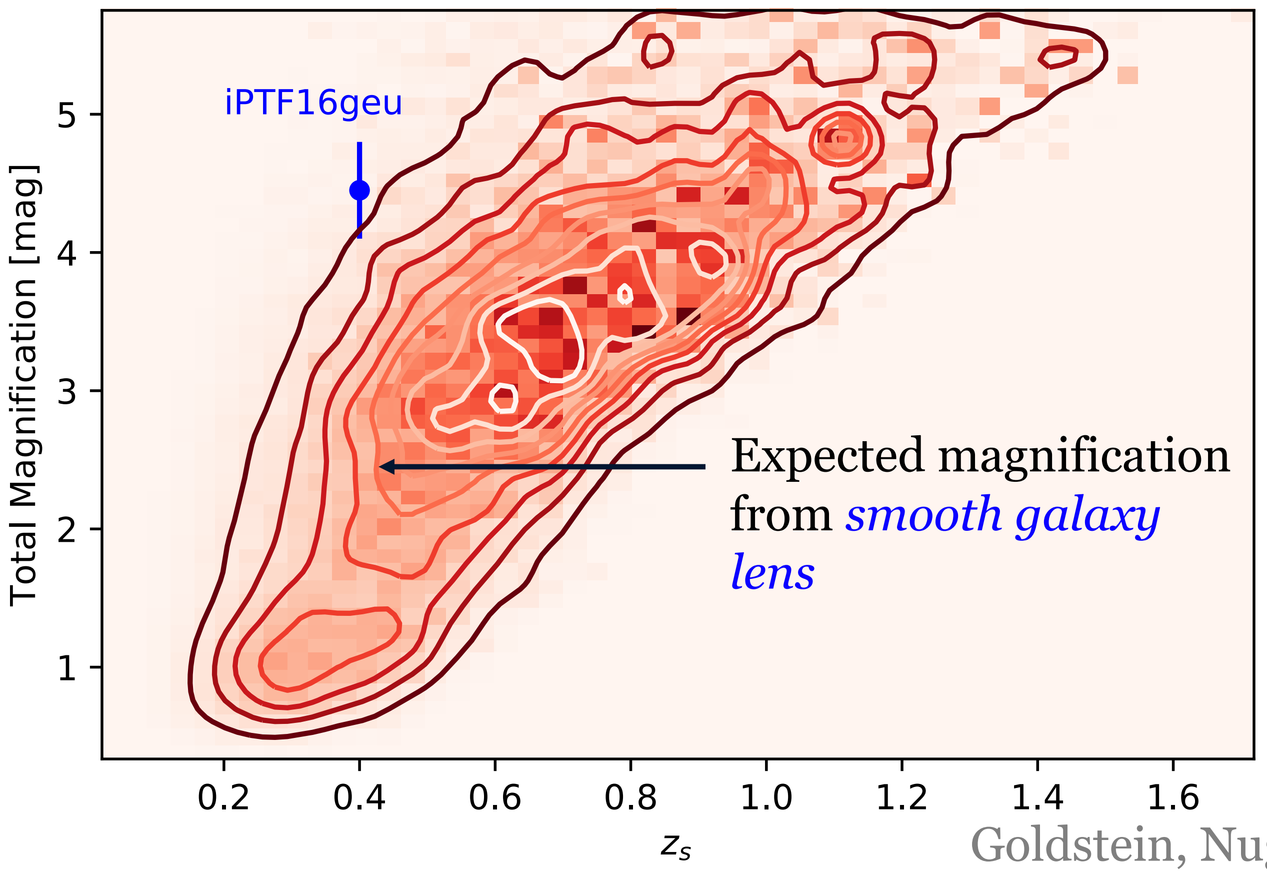
- Lens model limiting factor in QSO time-delay cosmography



Mörtsell et al 2020

Key points:
small-scale substructures (I)

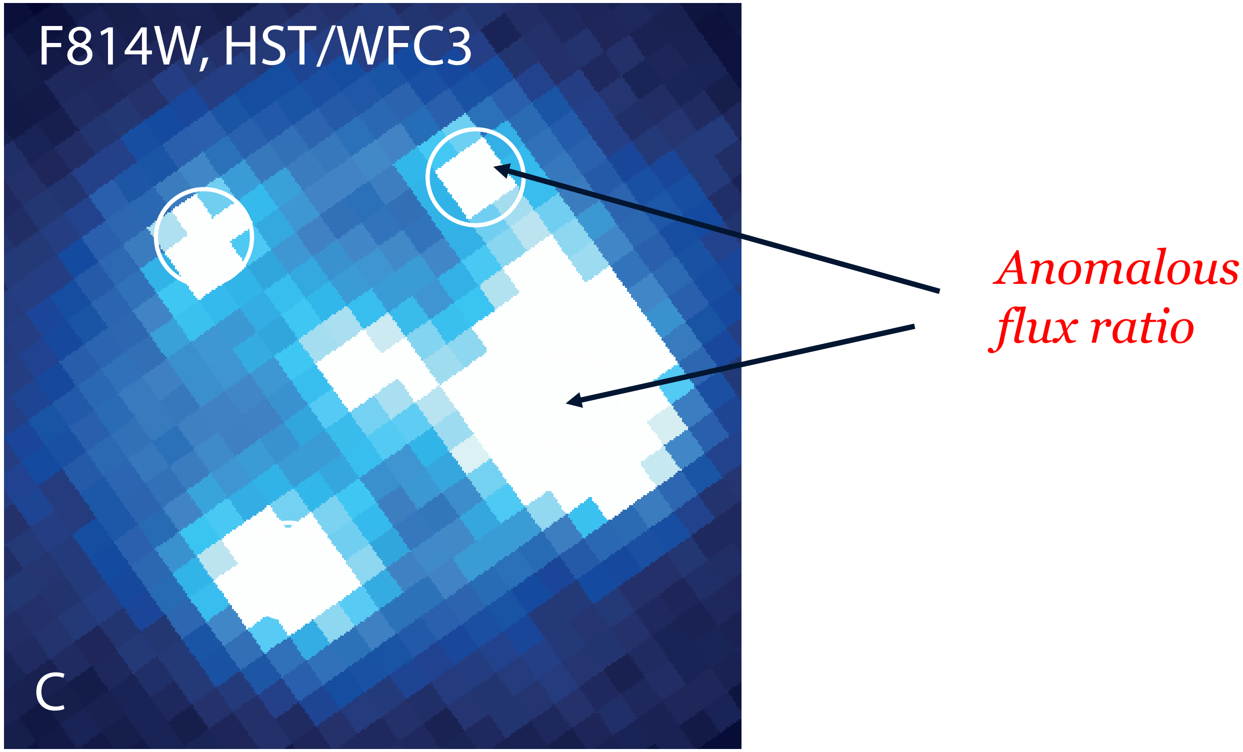
- *Precise magnification measurements possible for SNIa*, can be used to test lens model assumptions



Goldstein, Nugent & Goobar 2019

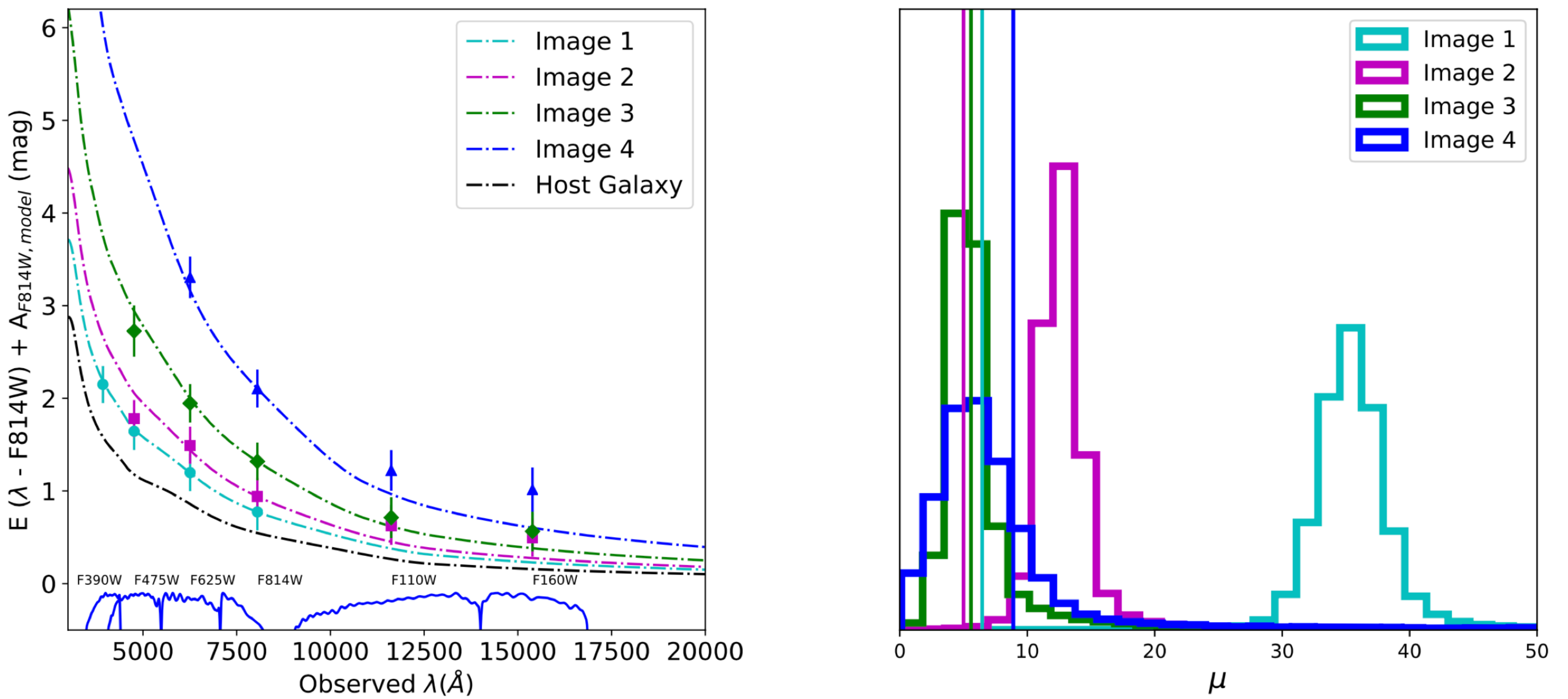
Key points:
small-scale substructures (II)

- Precise magnification measurements for SNIa, can be used to test lens model assumptions
- Anomalous flux ratios between images indicate *secondary - lower mass- lenses* (micro or millilensing)



Goobar et al 2017

Key points:
extinction corrections

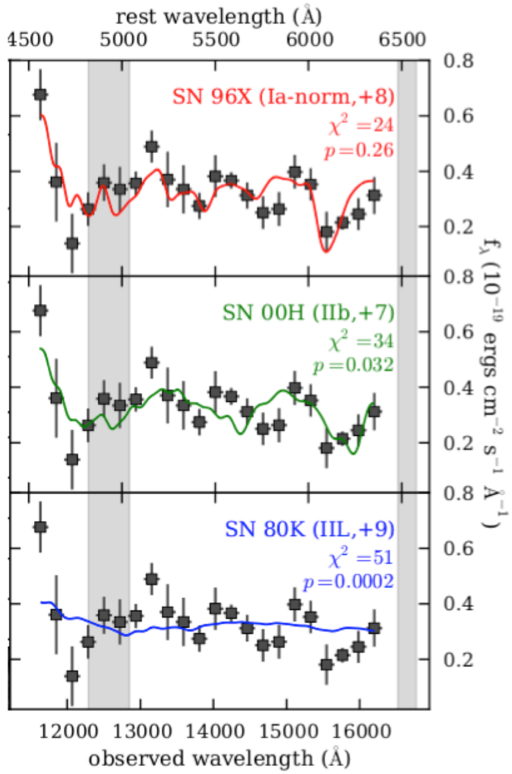


Dhawan et al 2020

Figure 6. (Left) The observed colour excess for the resolved images in each filter relative to $F814W$ plus the model absorption in the $F814W$ filter compared to the best fit model absorption in each filter assuming the CCM89 dust law. The absorption from the host galaxy dust is plotted in black. For Image 1 we can see that the host galaxy is the dominant source of extinction, and for images 2,3,4 there is a progressively larger contribution from the dust in the lens galaxy. (Right) magnification distribution for the individual images for the fiducial case of host and lens R_V fixed to 2 compared to the predictions from the model assuming the lens to be a single isothermal ellipsoid (dashed-dotted lines; see Mörtsell et al in prep for details. The model prediction for μ of Image 2 has been shifted down by 0.5 so that it can be distinguished from the value for Image 3).

Key points: GT's *verifying accuracy of SNIa as distance indicators*

Unlensed at z=1.5 (6 hs HST)



Rodney et al 2012

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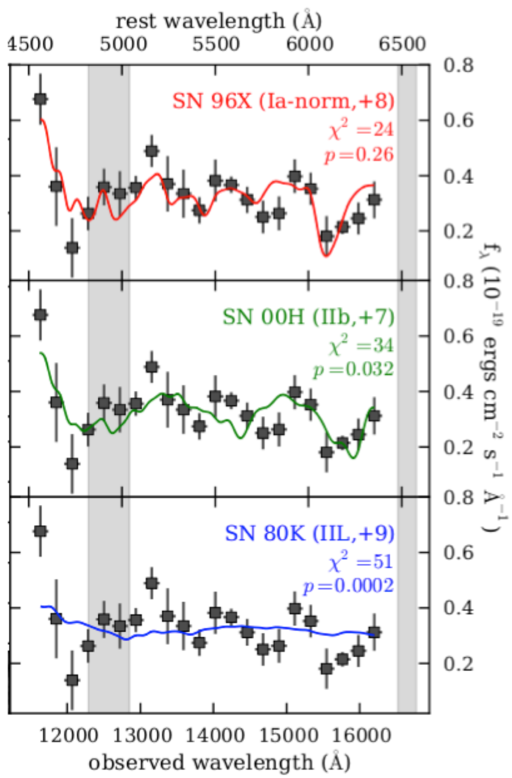
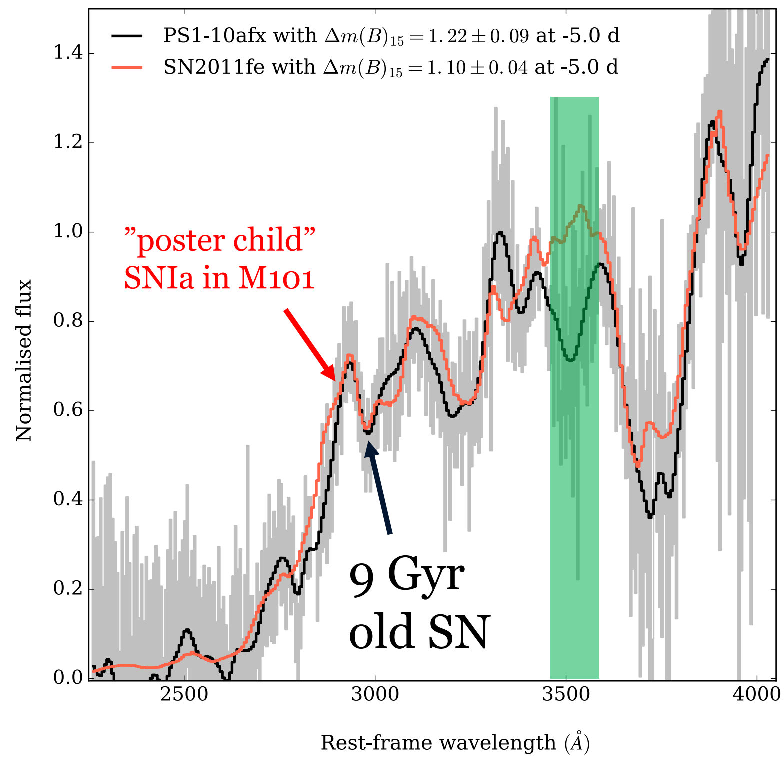


Rodney et al 2012

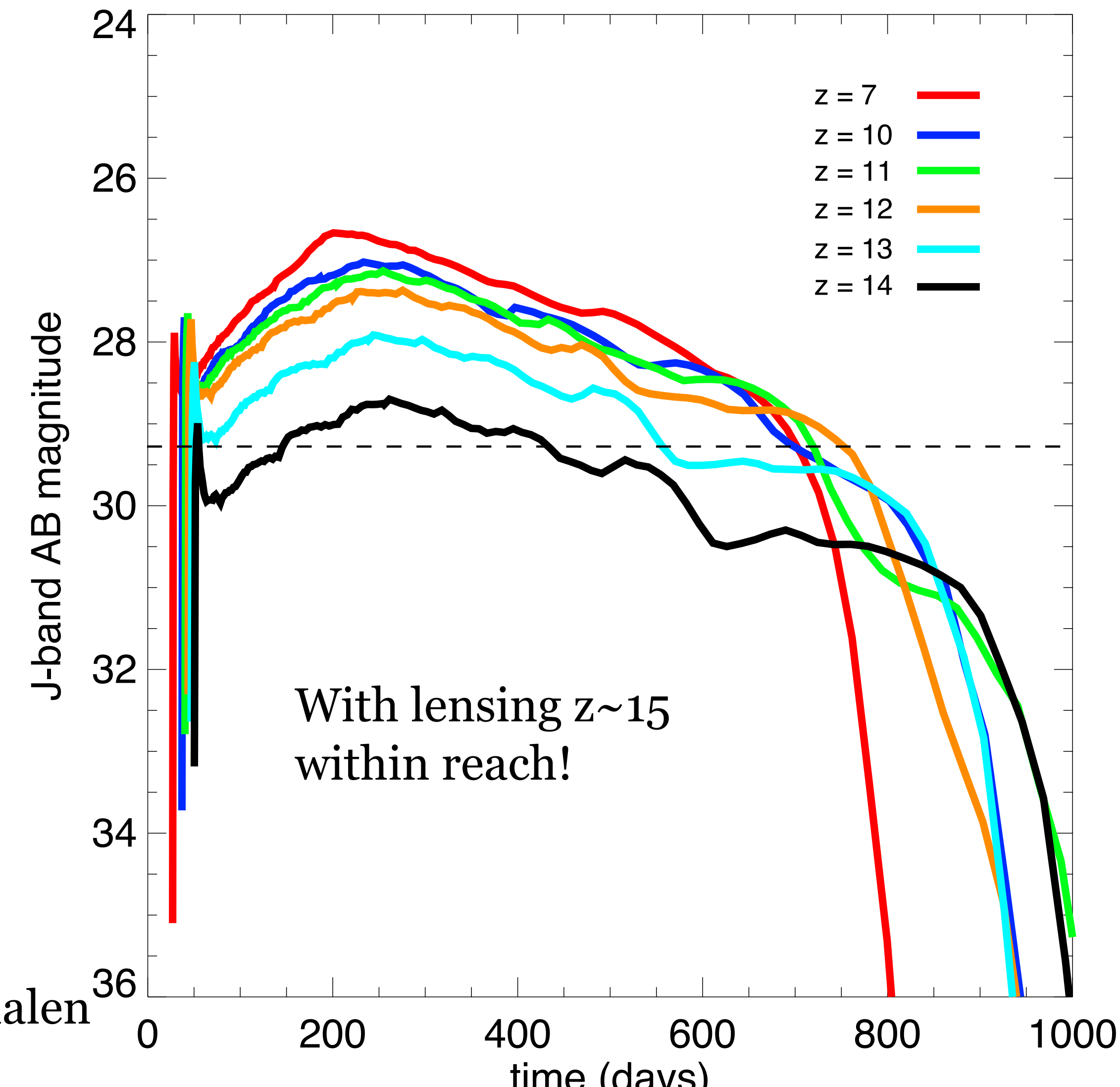
Petrushevska+17



Shown to have similar matches in the low-z universe. "Standard candle" nature OK – at least in this case!

Key points: GT's

First generation of supernovae may be detected with lensing magnification



Courtesy of Dan Whalen

Summary

- Cadenced observations with Roman are arguably the best strategy to find and study lensed SNe.
- The science is rich, involves many hot topics in cosmology and astrophysics
- ESA led effort in this direction?

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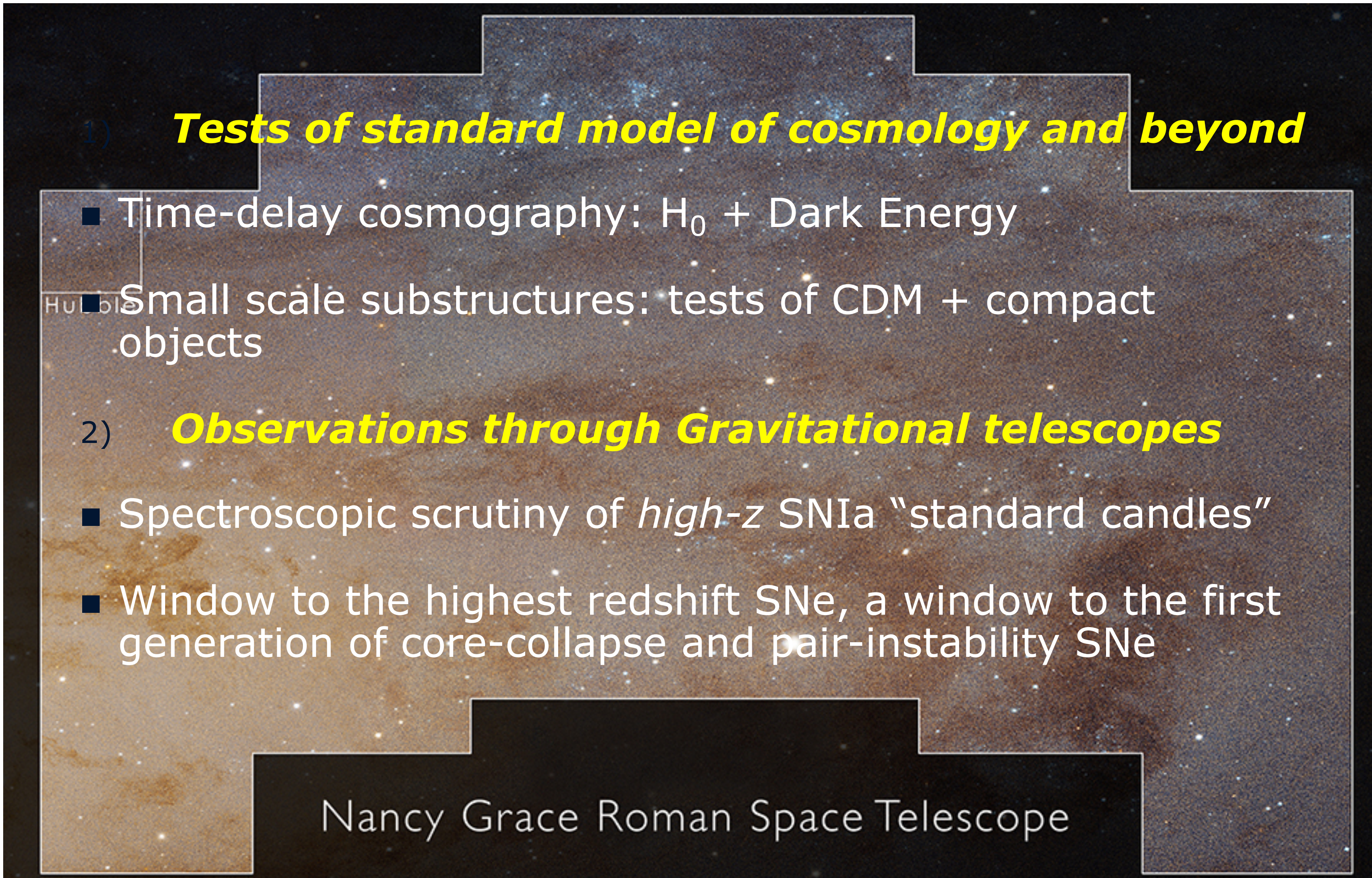
Thank You

gLSNe: science potential



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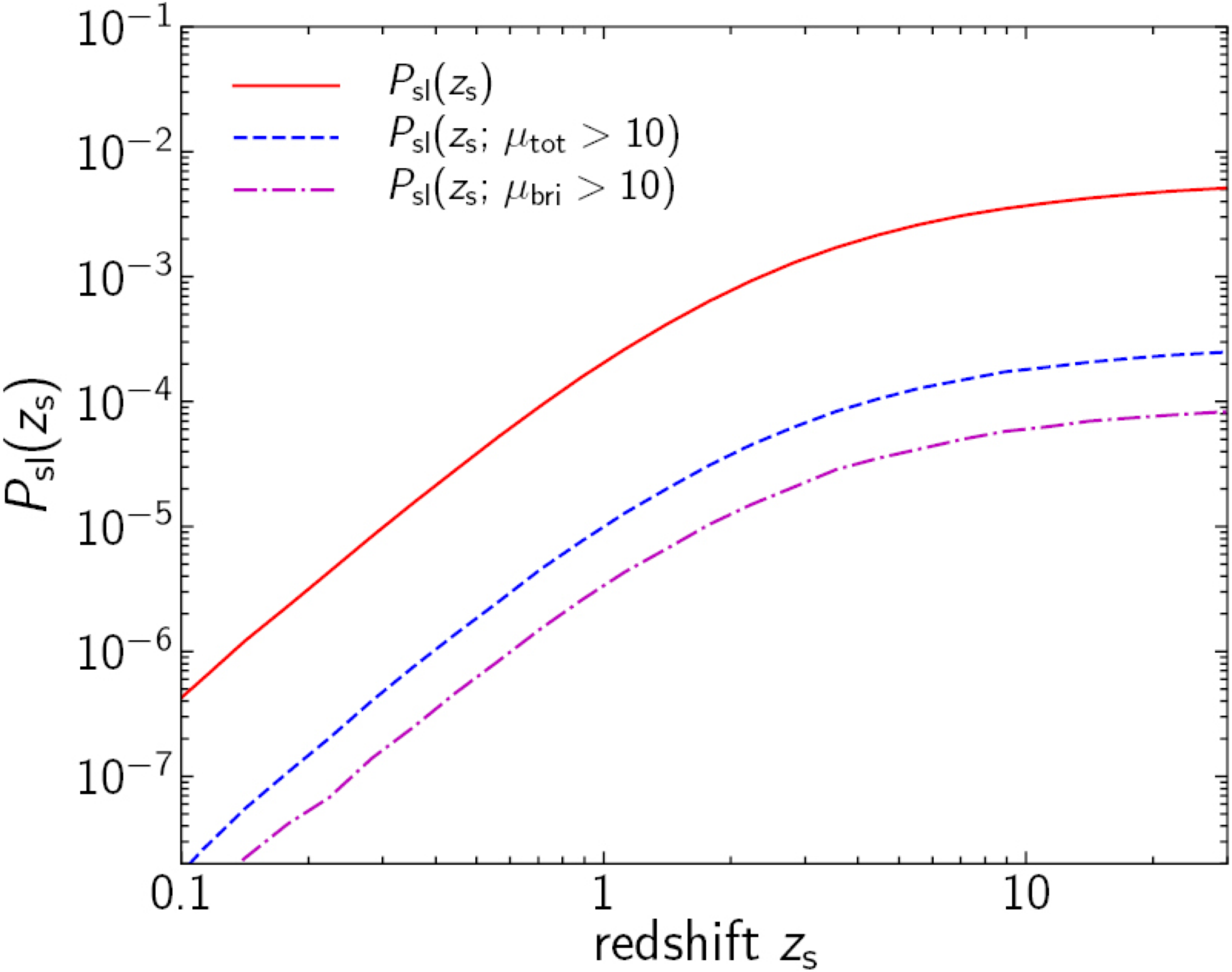
$P_{sl}(z_s)$
$P_{sl}(z_s;\ \mu_{tot} > 10)$
$P_{sl}(z_s;\ \mu_{bri} > 10)$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.1
1
10
redshift z_s
$P_{sl}(z_s)$

Oguri 2019

Roman specs

Roman Space Telescope Imaging Capabilities			
Telescope Aperture (2.4 meter)	**Field of View** (45′x23′; 0.28 sq deg)	**Pixel Scale** (0.11 arcsec)	**Wavelength Range** (0.5-2.3 μm)

Filters	F062	F087	F106	F129	F158	F184	F213	W146
Wavelength (μm)	0.48-0.76	0.76-0.98	0.93-1.19	1.13-1.45	1.38-1.77	1.68-2.00	1.95-2.30	0.93-2.00
Sensitivity (5σ AB mag in 1 hr)	28.5	28.2	28.1	28.0	28.0	27.5	26.2	28.3

Roman Space Telescope Spectroscopic Capabilities

	Field of View (sq deg)	Wavelength (μm)	Resolution	Sensitivity (AB mag) (10σ per pixel in 1hr)
Grism	0.28 sq deg	1.00-1.93	461	20.5 at 1.5 μm
Prism	0.28 sq deg	0.75-1.80	80-180	23.5 at 1.5 μm