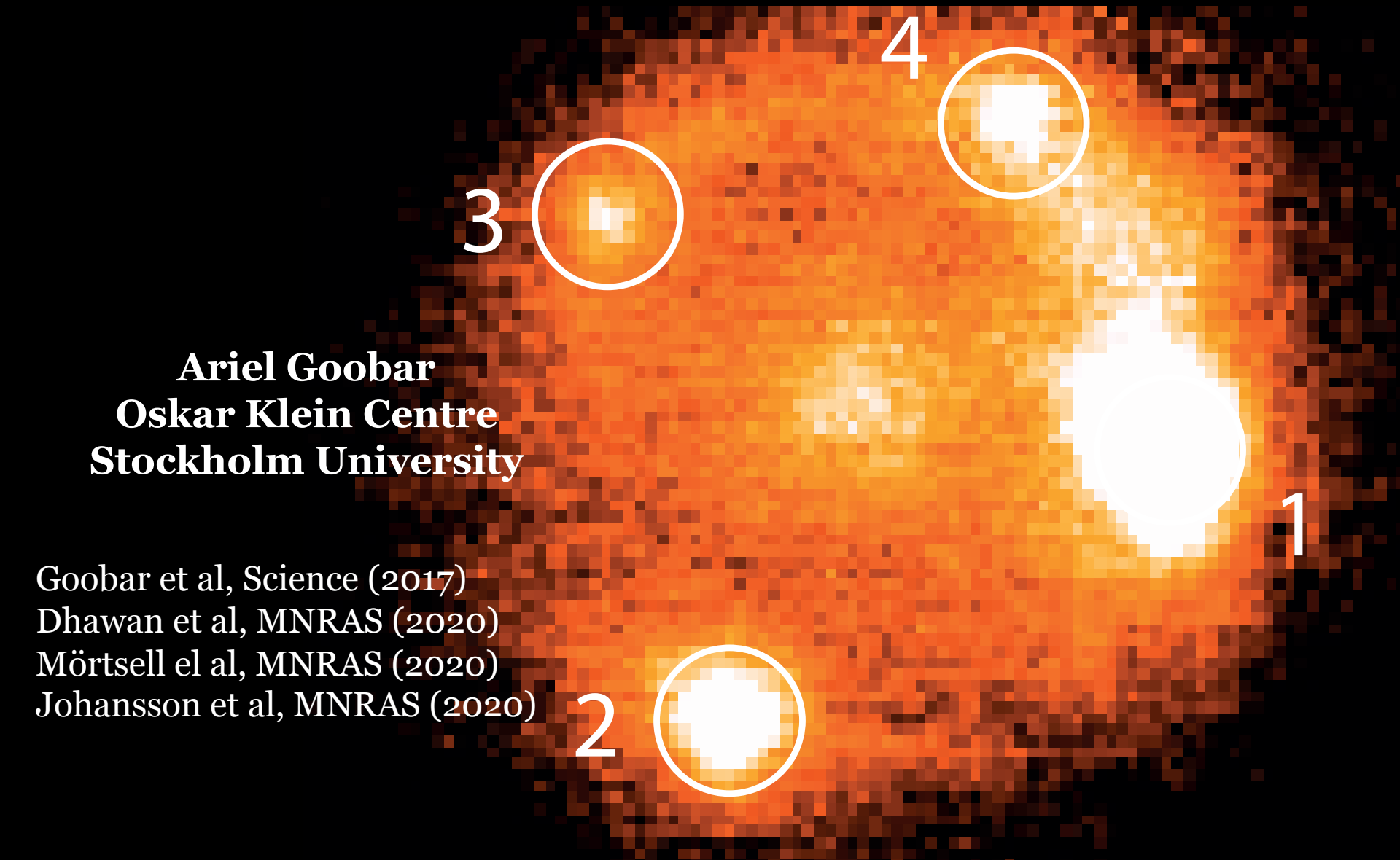
Lessons learned from iPTF16geu

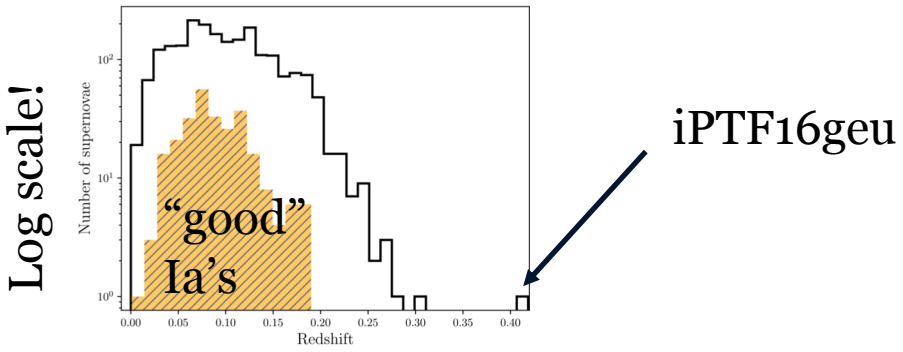


Ariel Goobar
Oskar Klein Centre
Stockholm University

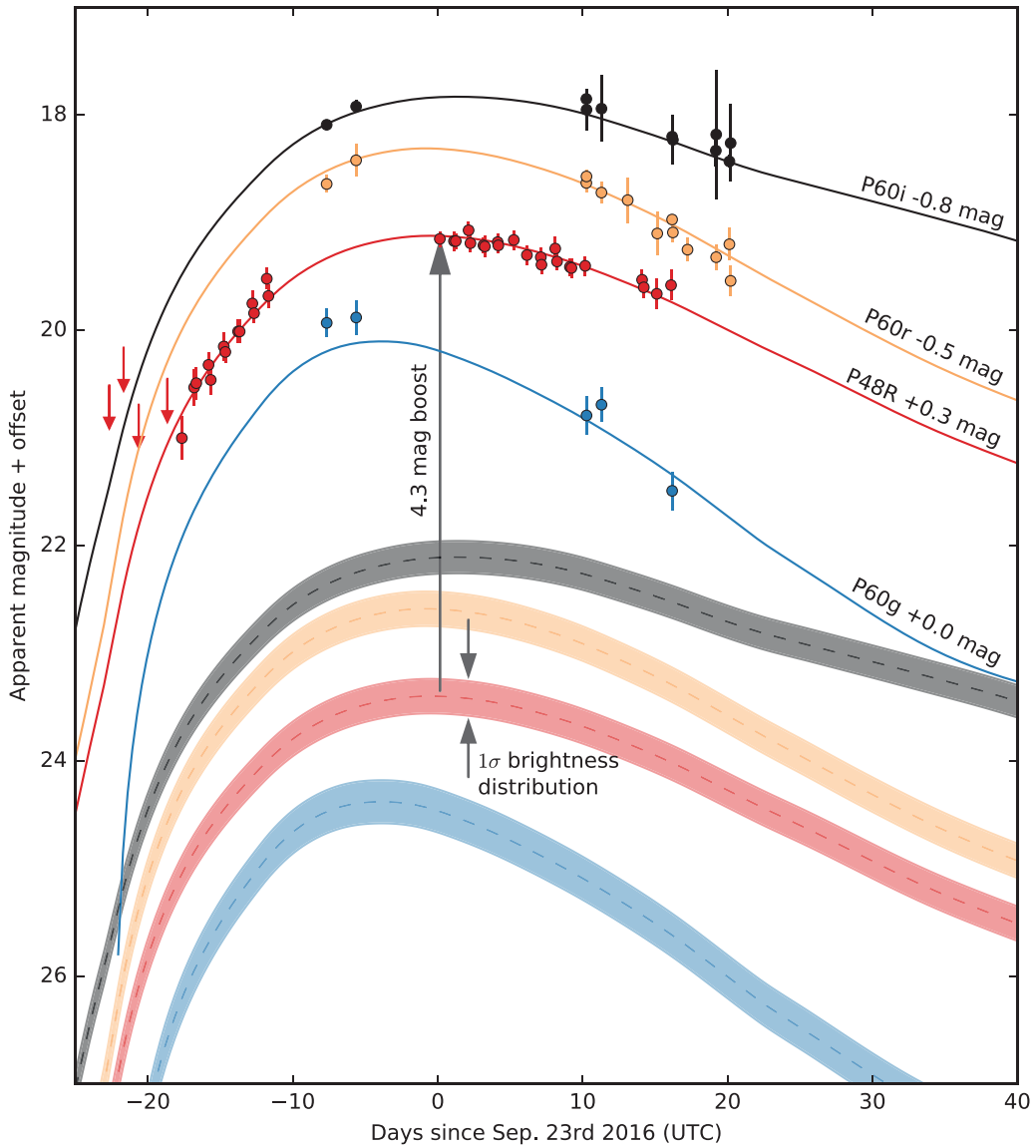
Goobar et al, Science (2017)
Dhawan et al, MNRAS (2020)
Mörtsell el al, MNRAS (2020)
Johansson et al, MNRAS (2020)

The discovery of the lensed SN iPTF16geu

- PTF+ iPTF discovered and ***classified*** ~3000 low-z SNe (2050 Ia's) over 8 years, m_{lim} < 21 mag in R-band
- During routine *spectroscopic classification* of iPTF transients, one high SNR transient turned out to be a Type Ia SN at z=0.4, much higher z than all others…

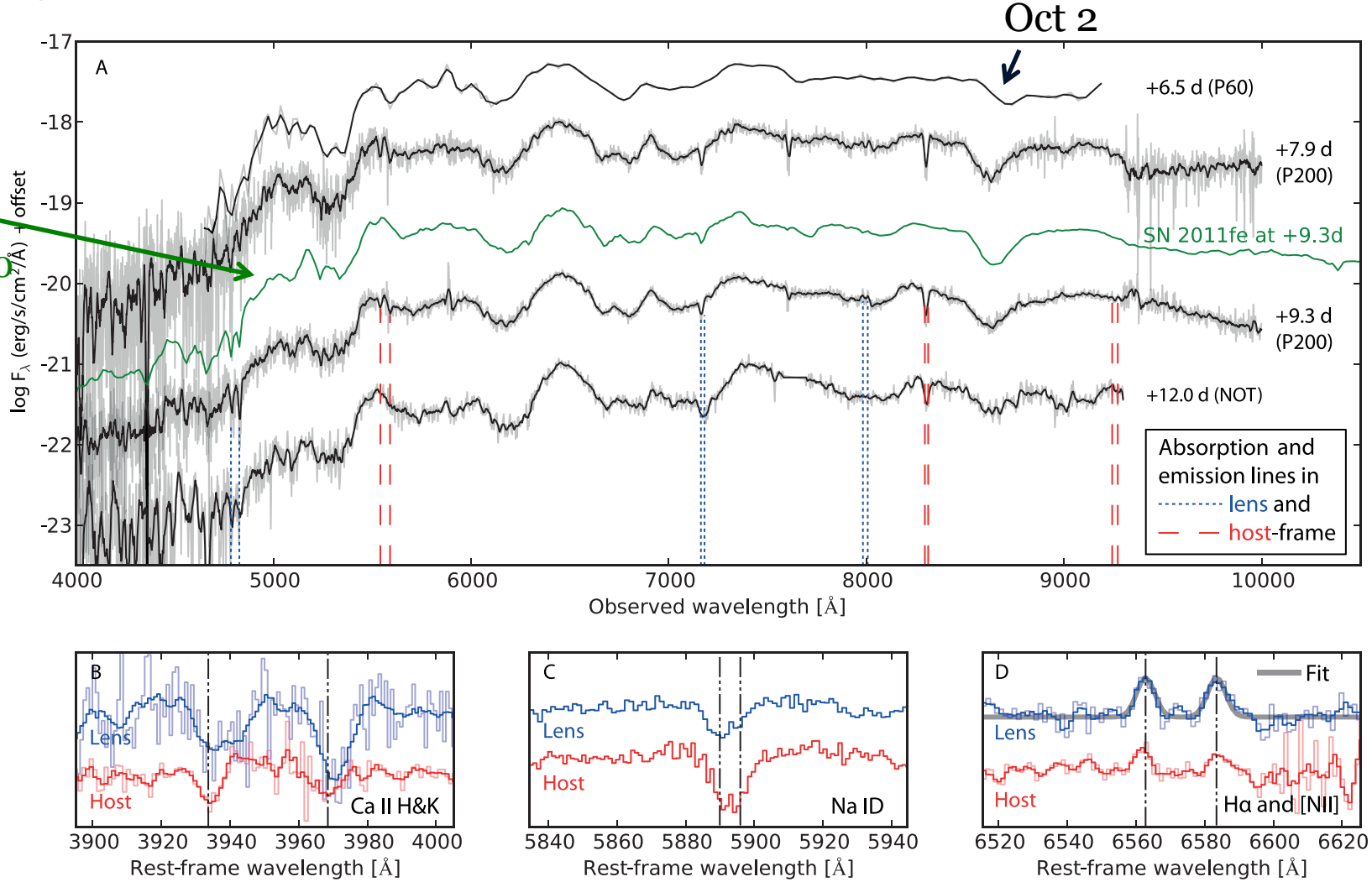


>50 times brighter than normal SNIa at z~0.4: >30σ outlier!



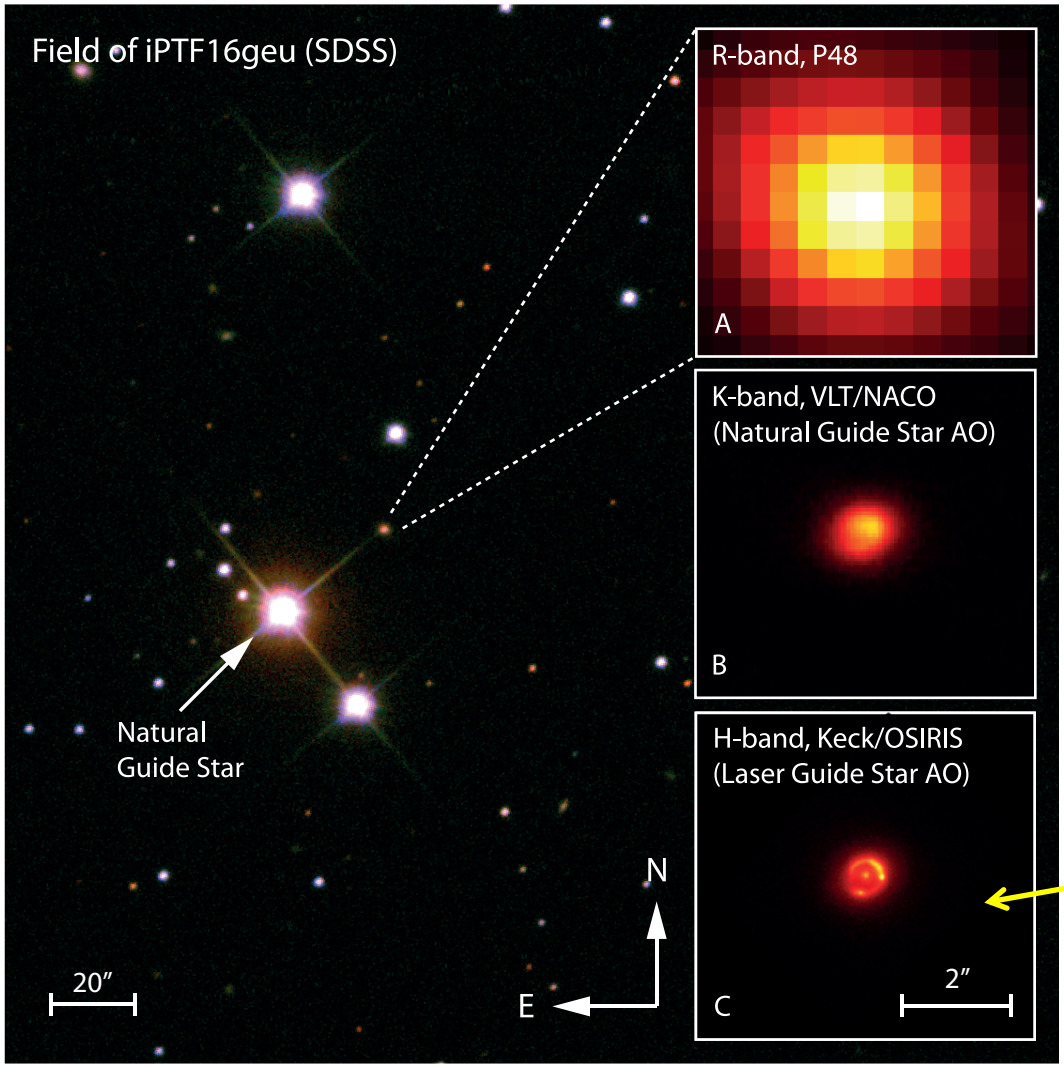
Perfect match to a z=0.409 SN Ia + intervening galaxy at z=0.216

"Typical" SNIa redshifted to z=0.409



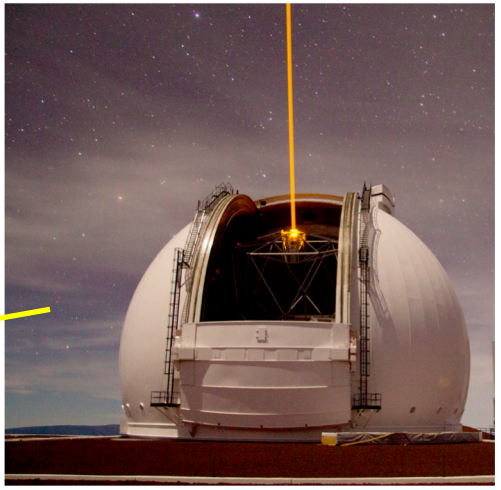
AG+17

Palomar vs AO images

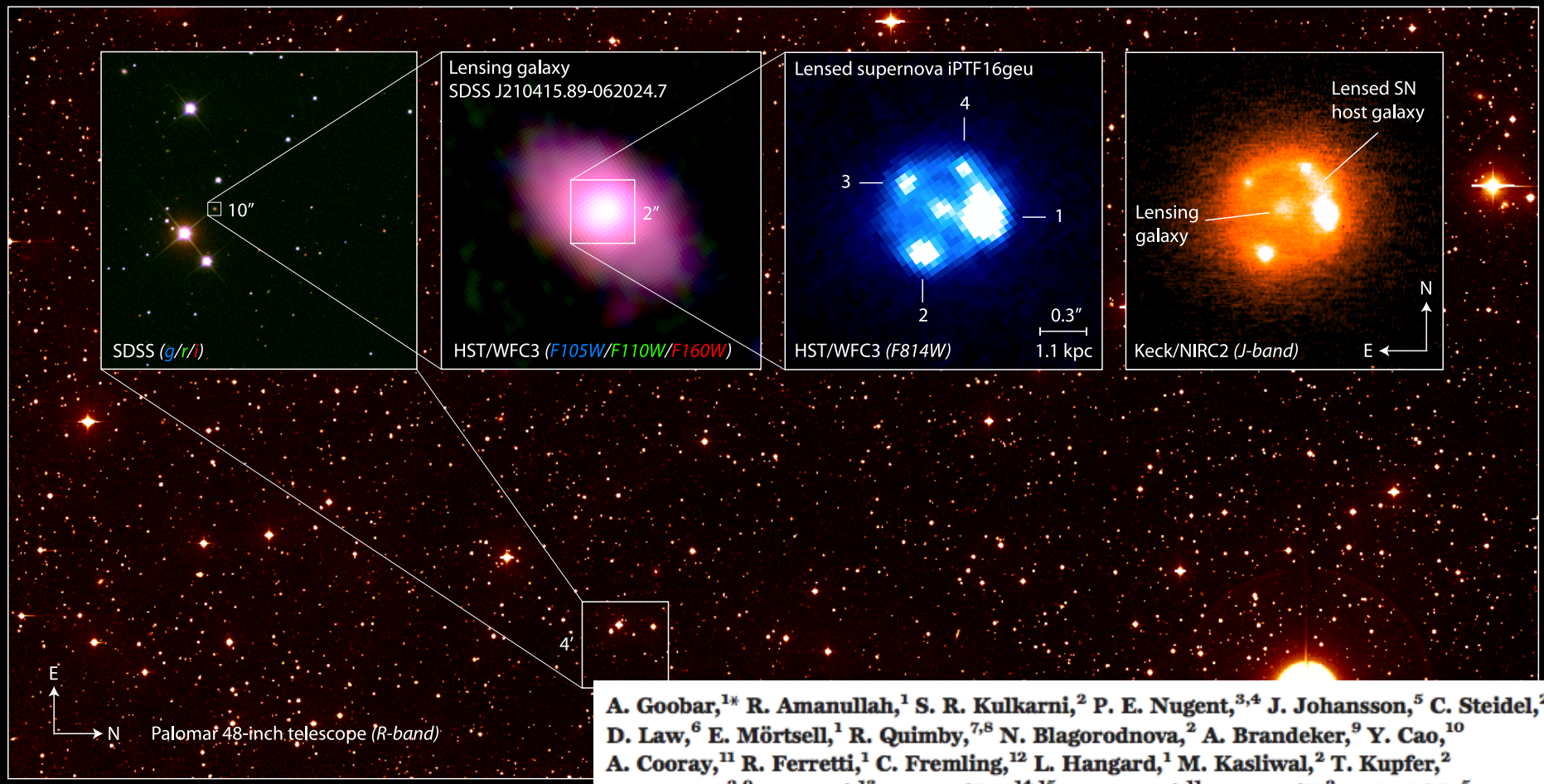


~2” seeing
1” pixels

Laser Guide Star
Adaptive Optics



....+Hubble



A. Goobar,[1*] R. Amanullah,[1] S. R. Kulkarni,[2] P. E. Nugent,[3,4] J. Johansson,[5] C. Steidel,[2] D. Law,[6] E. Mörtsell,[1] R. Quimby,[7,8] N. Blagorodnova,[2] A. Brandeker,[9] Y. Cao,[10] A. Cooray,[11] R. Ferretti,[1] C. Fremling,[12] L. Hangard,[1] M. Kasliwal,[2] T. Kupfer,[2] R. Lunnan,[2,9] F. Masci,[13] A. A. Miller,[14,15] H. Nayyeri,[11] J. D. Neill,[2] E. O. Ofek,[5] S. Papadogiannakis,[1] T. Petrushevska,[1] V. Ravi,[2] J. Sollerman,[12] M. Sullivan,[16] F. Taddia,[12] R. Walters,[2] D. Wilson,[11] L. Yan,[2] O. Yaron[5]

Why care about lensed SNe Ia?

1. Detection of lensed SNe is based on ***flux*** and *not* angular separation (typically >1”), thus *complementary set of lens systems* and important for probing matter/gravity close to galaxy center

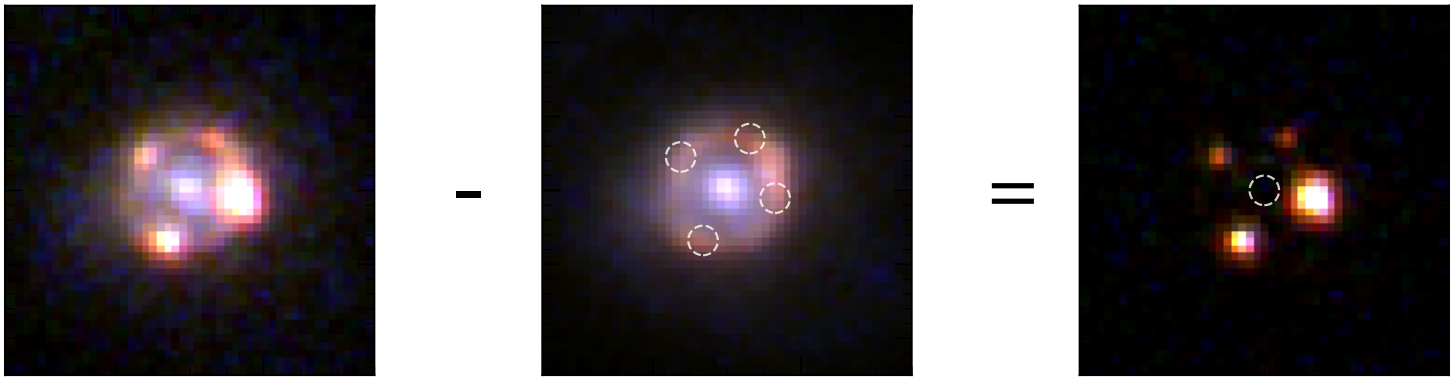
2. Model independent lensing magnification, since “standard candles”

3. Time-delay between images can be measured in just a few weeks (compared to many years for QSOs), thanks to the smooth and fast time evolution of SN light

4. When the SN fades, the *host* and the *lens* galaxy can be studied without confusion from the (sometimes) very bright lensed QSOs

5. …and a central image may be looked for

Revisited field with Keck and HST,
2 years after the SN explosion to get a
”clean shot” of the host + lens galaxies



2016 | 2018 | Difference

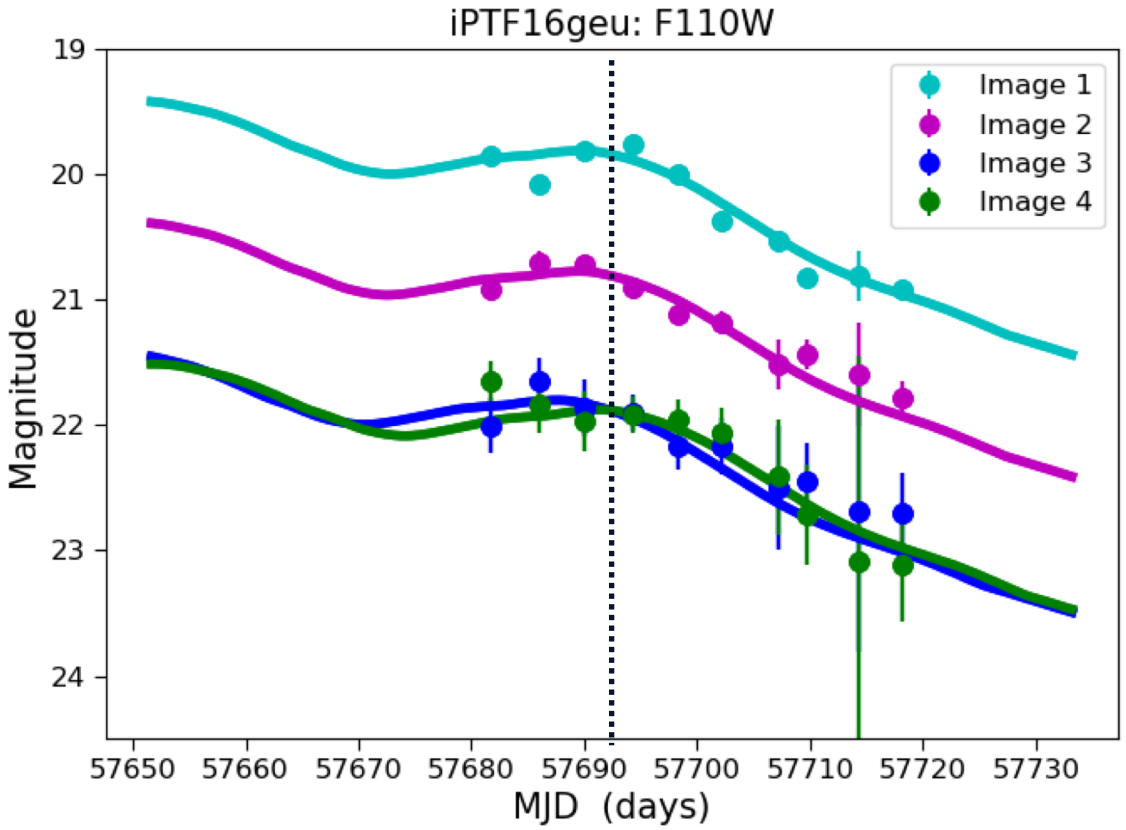
SN + host galaxy + lens | host galaxy + lens | SN

Dhawan+20

Brief summary of lessons learned

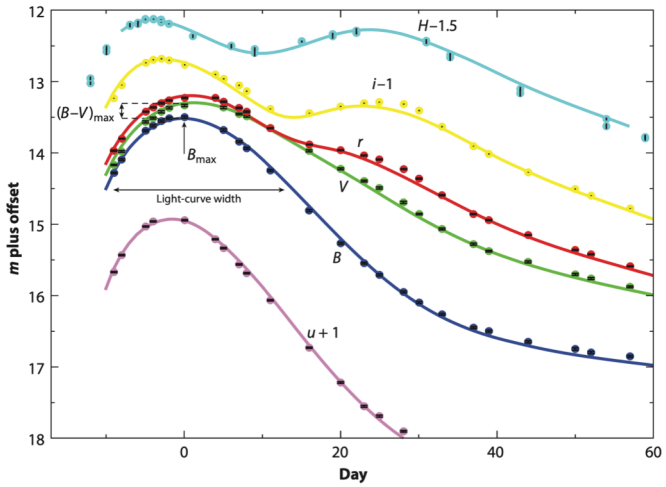
Takeaway (I)

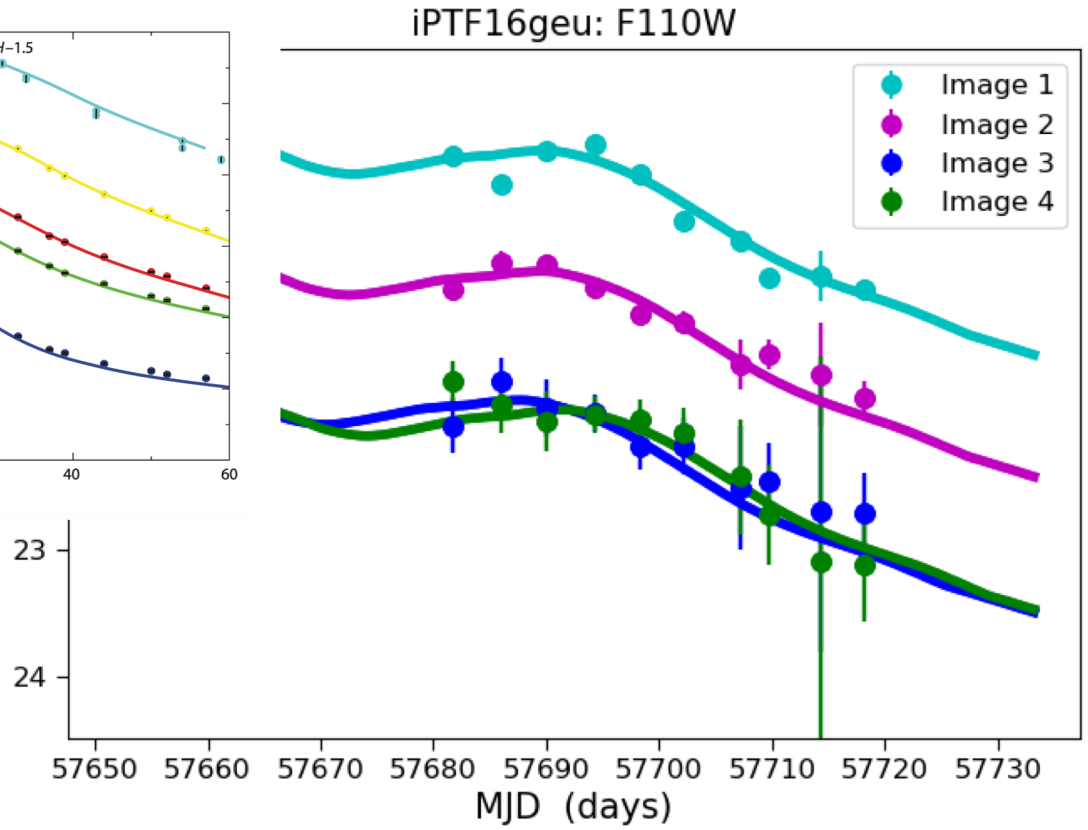
Dhawan+20



Sadly, time-delays very short for this system, ~1 day. For future systems >10 days and 5% measurements of Δt expected

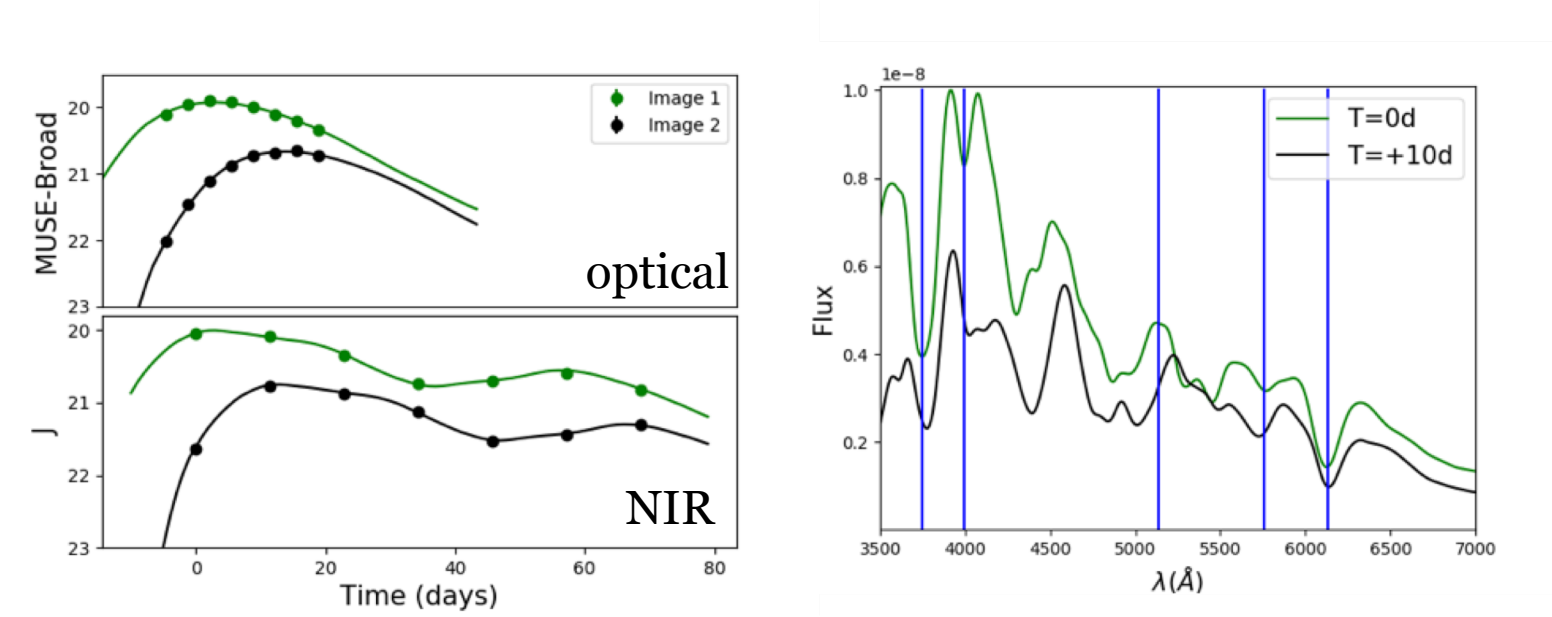
Takeaway (II)





On the plus side, demonstrated that time-delays can be measured with *secondary* maximum in the SNIa near-IR lighcurves: gives "extra" time to get on the target, crucial for space observations in non-disruptive mode with HST and JWST

Takeaway (III)

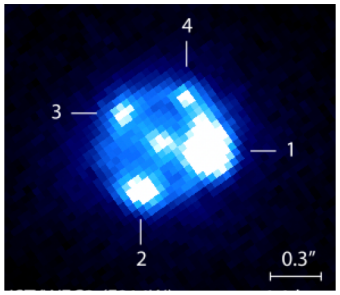


(simulated example z_{SN}=0.7 , MUSE + HAWKI)

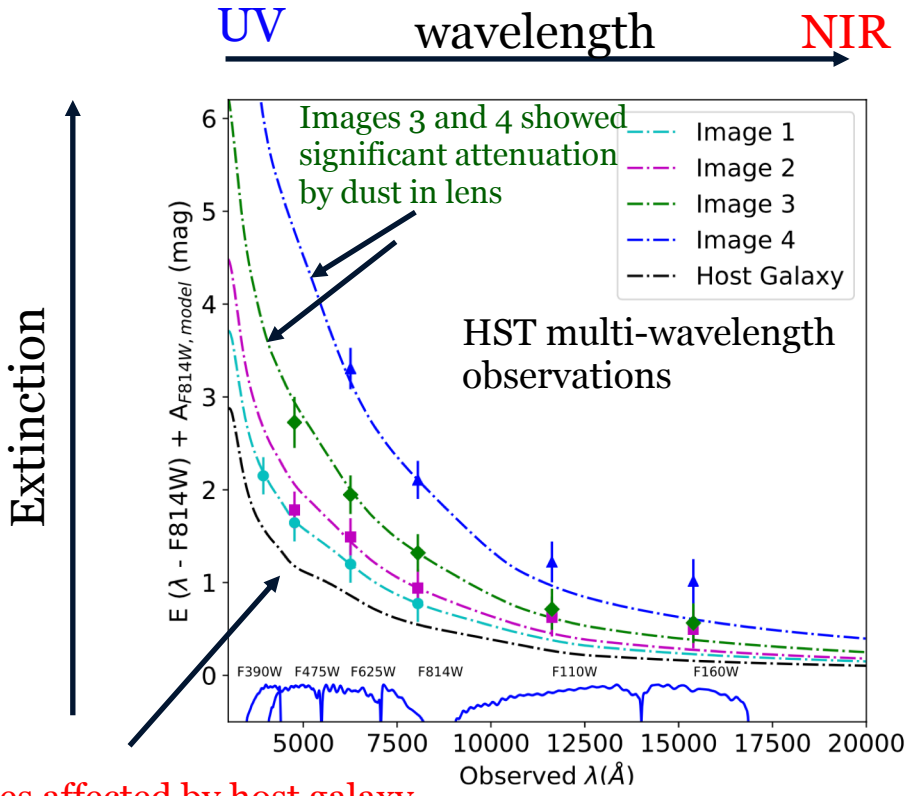
We can make competitive (independent) time-delay measurements with a *single spectroscopic observation* of the resolved system!

see Johansson+20 for demonstration with HST grism obs for iPTF16geu

Takeaway (IV)



0.3” = 1 kpc



Dhawan+20

All images affected by host galaxy extinction

Precise magnification measurements require accounting for extinction by dust in resolved images, *both in host and lensing galaxies*. Went from μ~52 to $\mu=67.8^{+2.6}_{-2.9}$

Takeaway (V)

Johansson+20

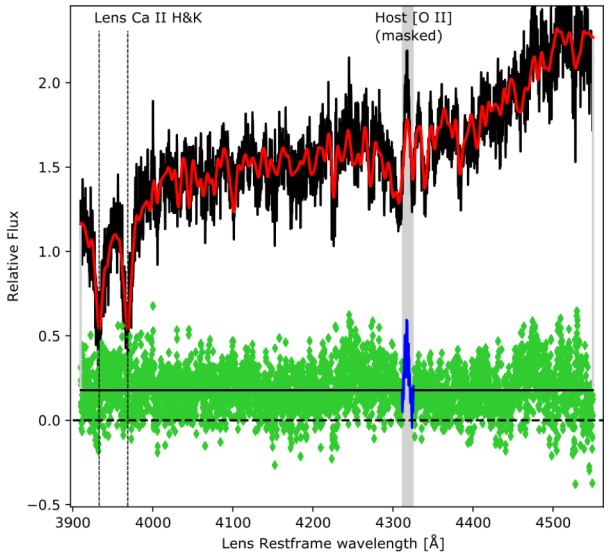
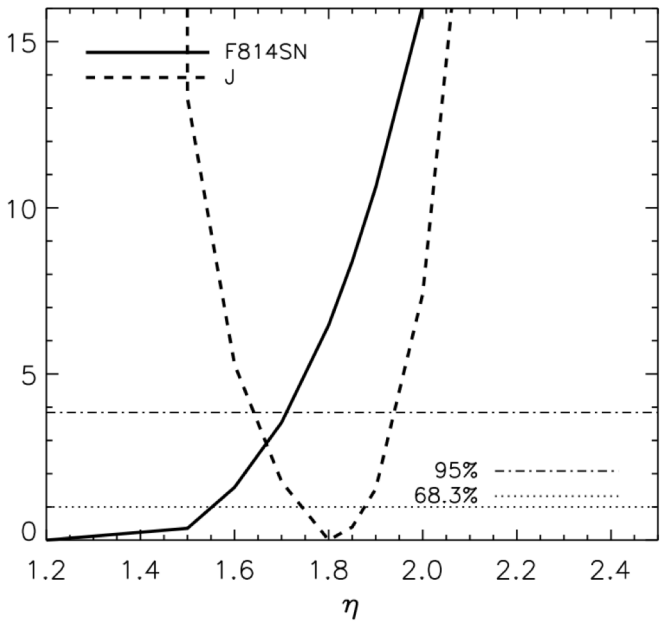


Figure 7. pPXF fit of the lens galaxy. The black line is part of the UVB-arm XSHOOTER spectrum from 2016 Oct. 30, red line is the best fit PEGASE template and green symbols show the residuals. The dashed lines indicate the lens galaxy Ca II H & K absorption lines and the gray shaded area shows the masked-out [O II] line from the host galaxy.

Projected surface density at 1 kpc

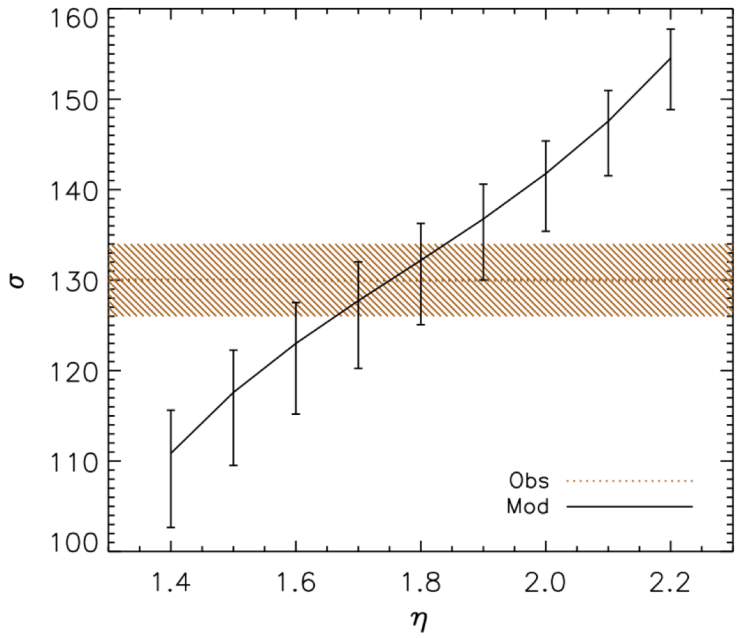
$\Sigma \propto r^{1-\eta}$



Mörtsell+20

Power-law fit of lensing profile, close to Singular Isothermal Sphere model, yields good fit to *image positions and velocity dispersion* in lens…

Takeaway (V)



Mörtsell+20

Projected surface density at 1 kpc

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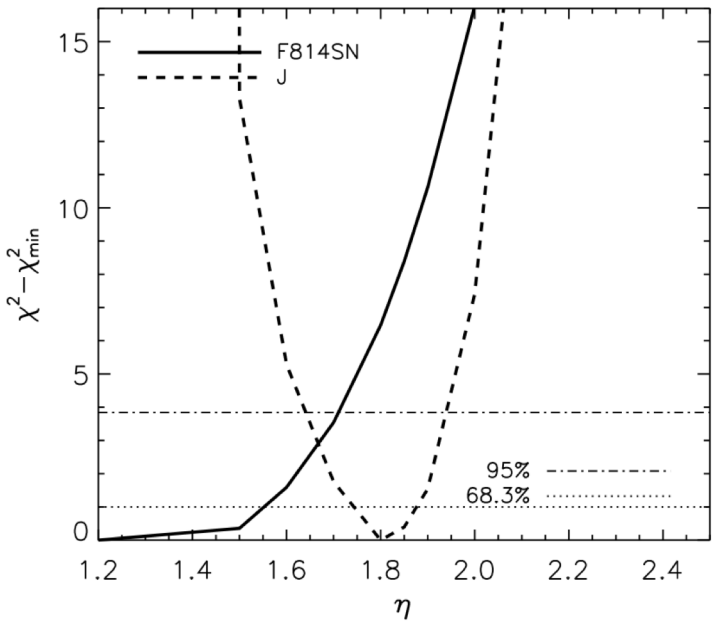
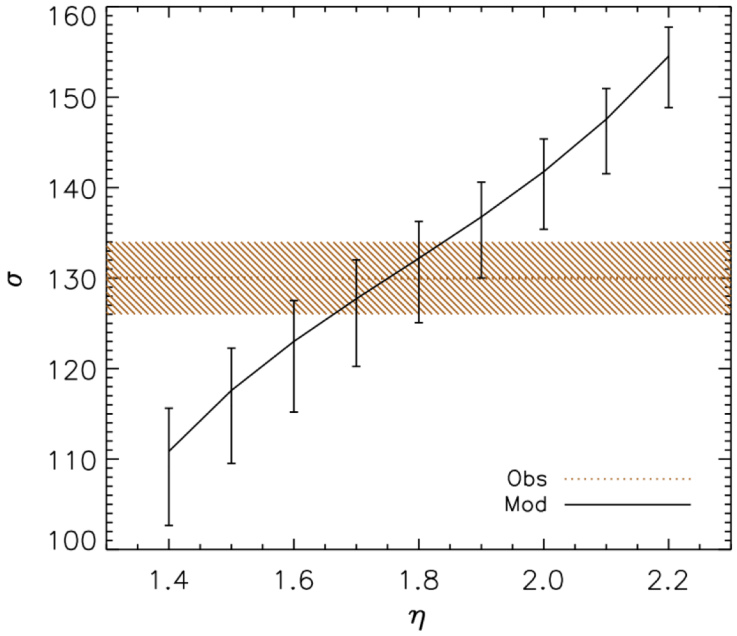


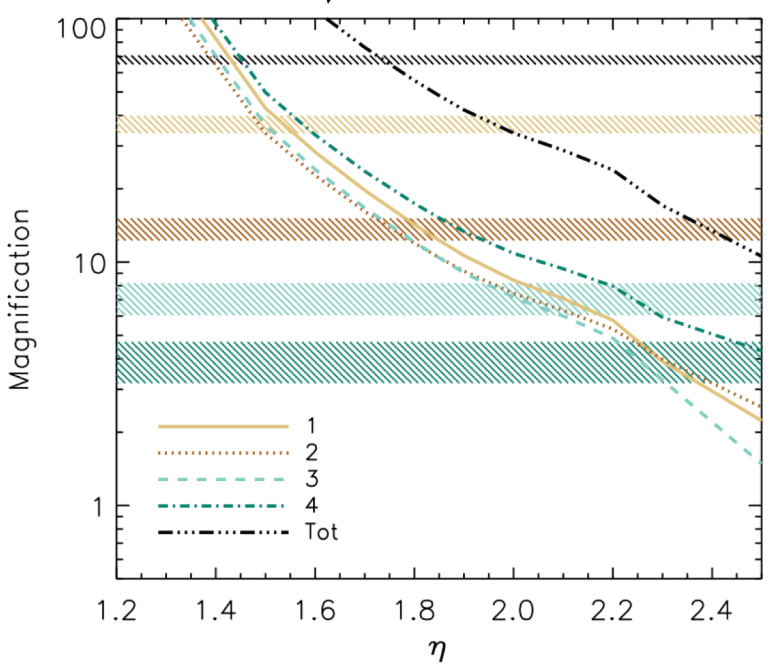
Power-law fit of lensing profile, close to Singular Isothermal Sphere model, yields good fit to *image positions and velocity dispersion* in lens…

Takeaway (VI)

Lensing model predictions from image *positions*



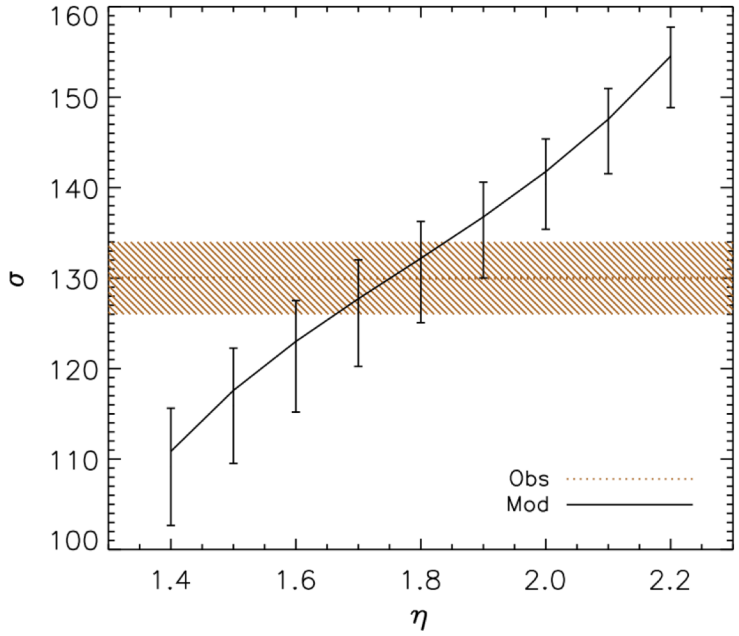
Mörtsell+20



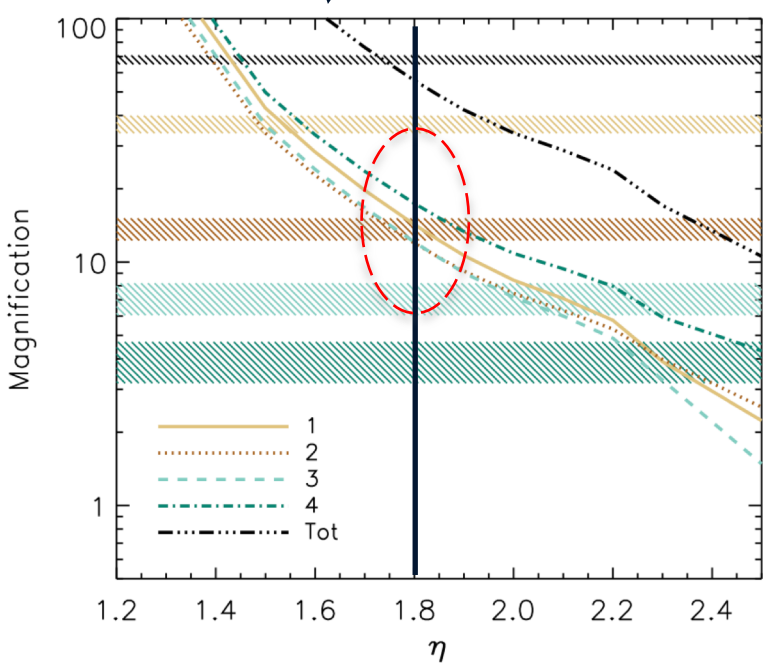
… but fails to explain the relative brightness of the 4 SN images

Takeaway (VI)

Lensing model predictions from image *positions*



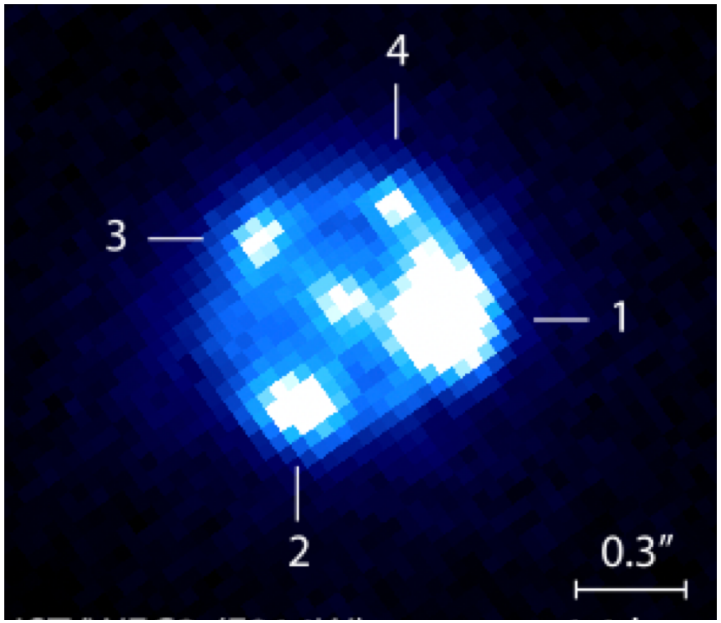
Mörtsell+20

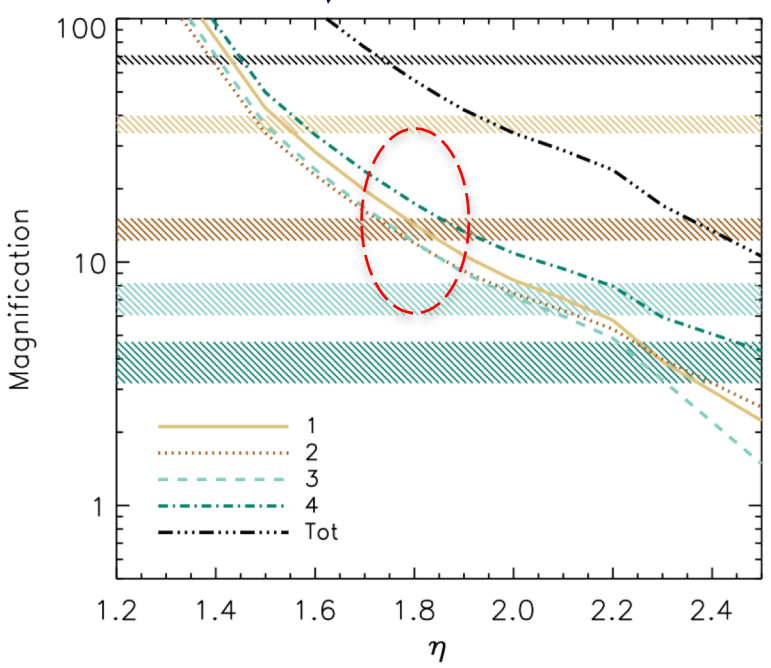


… but fails to explain the relative brightness of the 4 SN images, also after corrections for dimming by dust. This conclusion is rather insensitive to the value of η

Takeaway (VI)

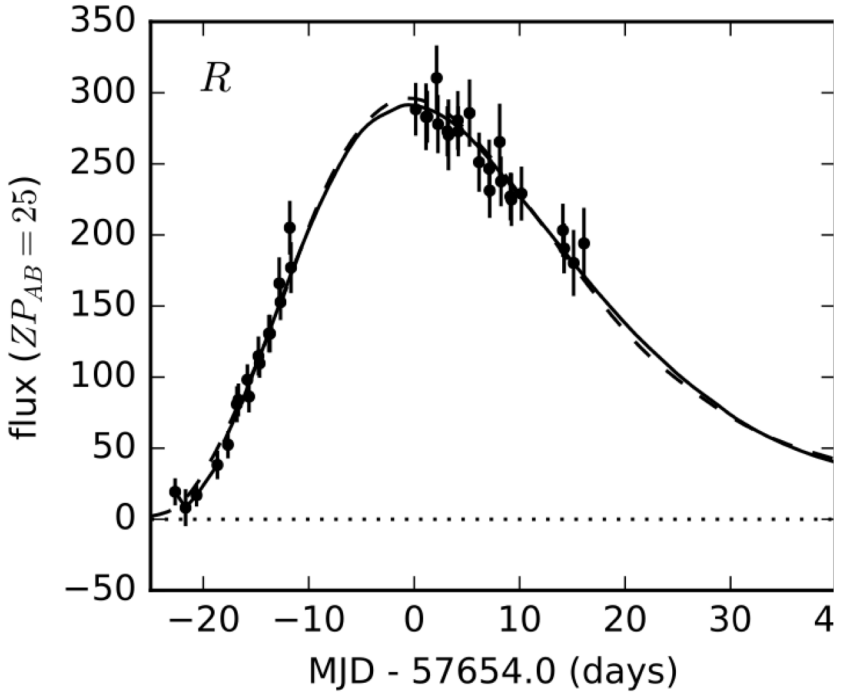
Lensing model predictions from image *positions*

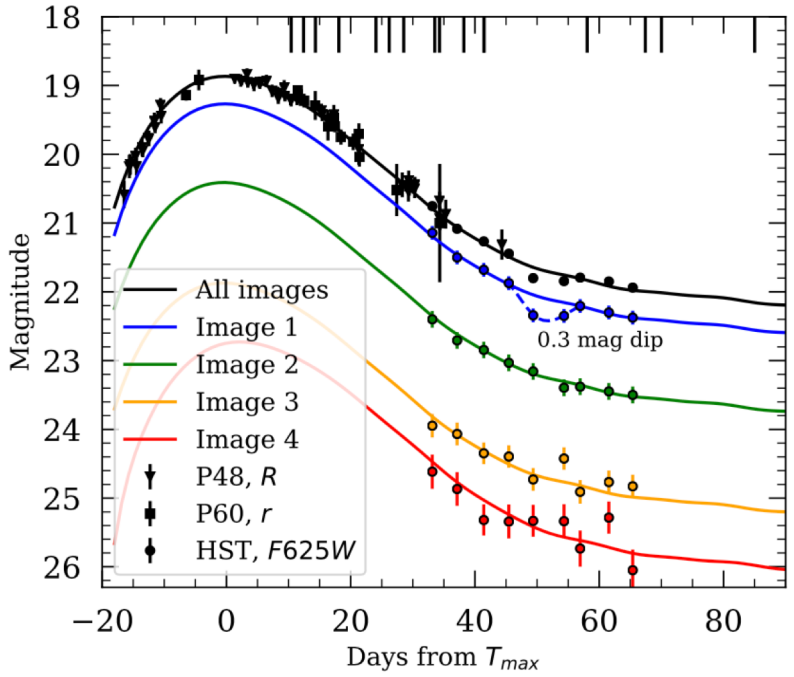




… two or more images require additional (de)magnification from substructures. E.g., stellar microlensing provides *plausible* explanation, but there is room for e.g., BHs etc. Allowed range 10^{-1}-10^{7} $M_{\odot}$

Takeaway (VII)



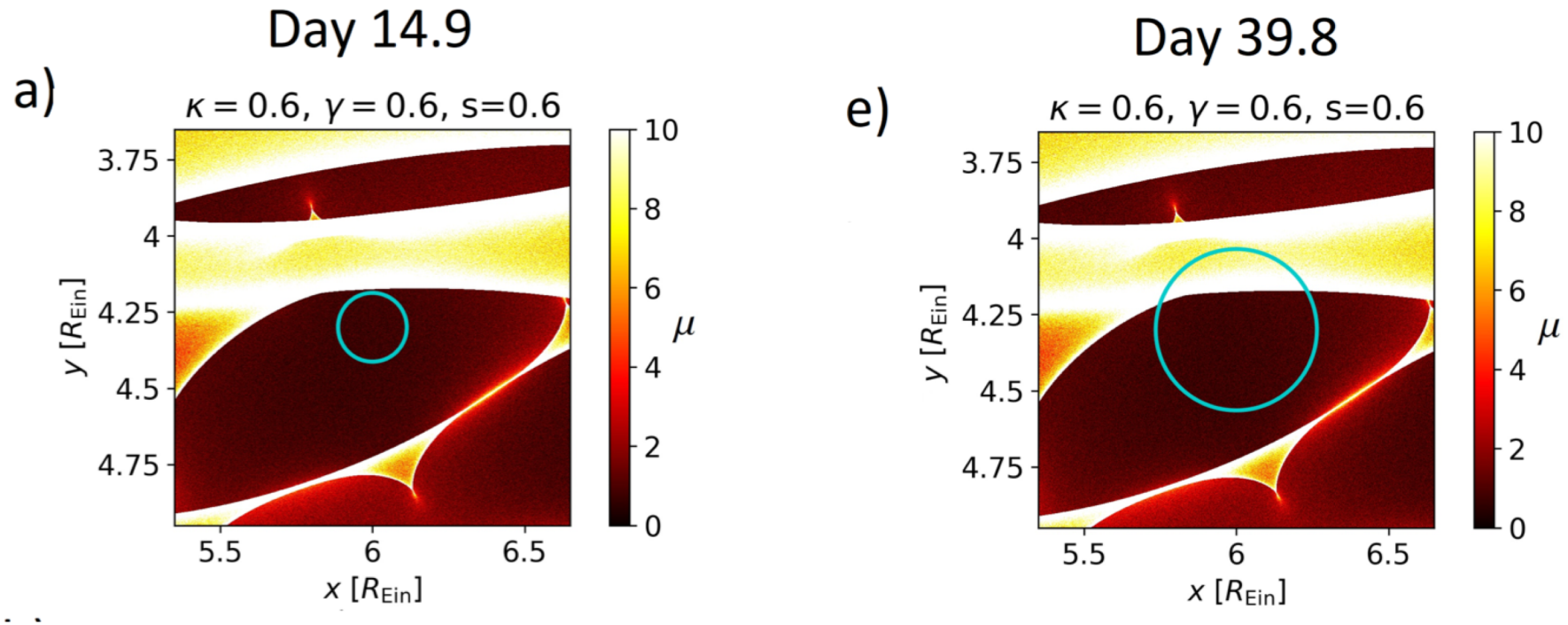


Discovery within
~5 days from explosion

...yet, no obvious signs of microlensing perturbations on lighturves nor spectra. As photosphere grows (~10^4 km/s) one could have seen the finite size effects of a stellar lens...

Takeaway (VII)

Simulations from Huber, Suyu, et al 2019

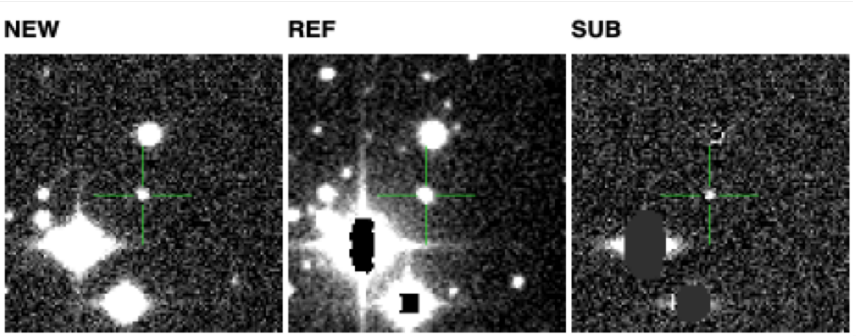


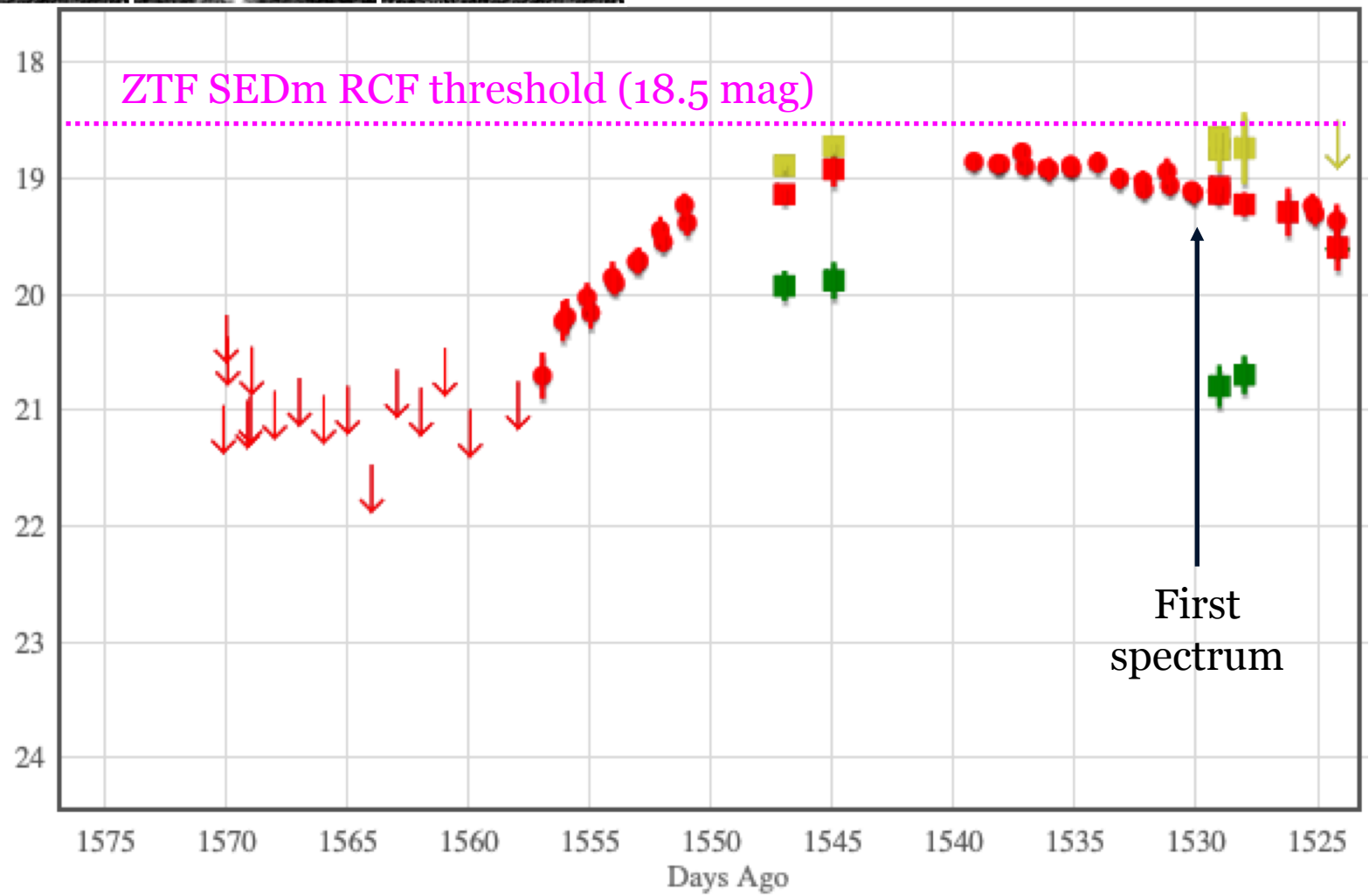
...yet, no obvious signs of microlensing perturbations on lighturves nor spectra. As photosphere grows (~10^4 km/s) one could have seen the finite size effects of a stellar lens...

The elephant in the room… - why haven't we found more lensed SNe?

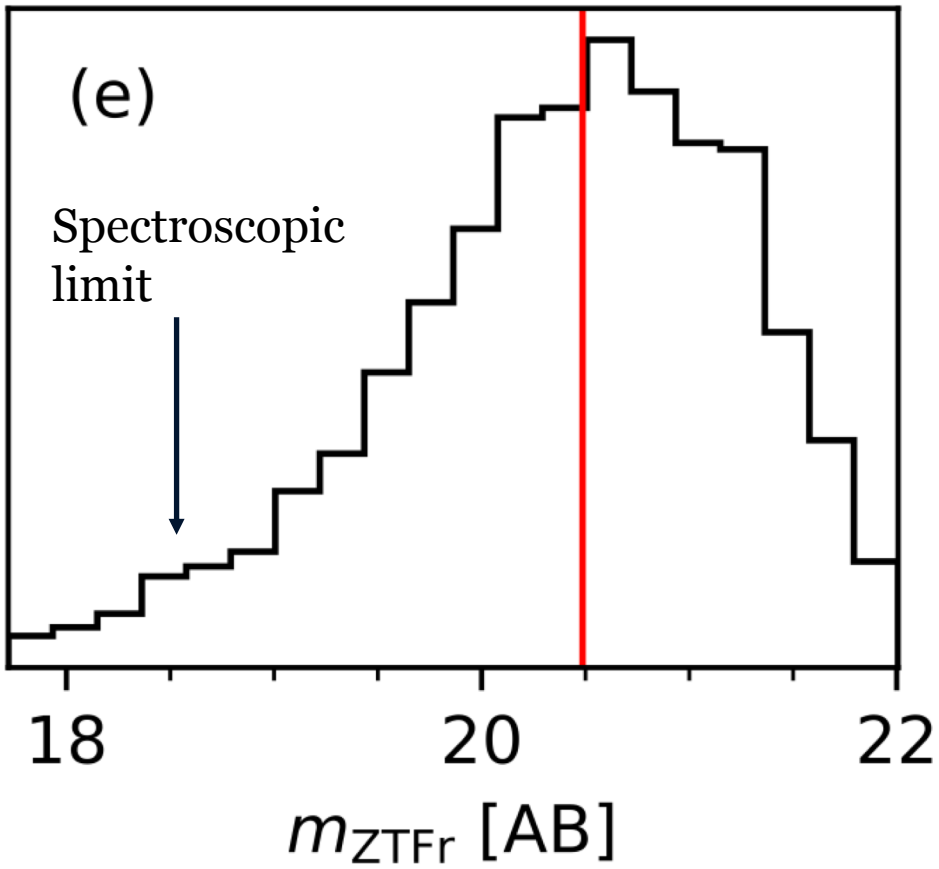
- ZTF is nearly 10x faster at scanning the sky compared to PTF/iPTF…
- So far no confirmed sequel! What is the bottle-neck? *-Spectroscopic classification!* The follow-up facilities are the same as during the iPTF era.
- Lensed SNe in ZTF will not look "special" given the spatial resolution. Only when redshift/SN type is known can we tell if it is lensed and request AO/space imaging.
- ZTF aims at a complete spectroscopic sample. Given the large number of detections and the spectrograph resources, limit is set at 18.5 mag.
  -That is too shallow to have a decent chance!

iPTF16geu


NEW
REF
SUB


ZTF SEDm RCF threshold (18.5 mag)
First spectrum
18
19
20
21
22
23
24
1575
1570
1565
1560
1555
1550
1545
1540
1535
1530
1525
Days Ago

PDF of detected lensed SN mags in ZTF



From Goldstein, Nugent & AG (2019)

The challenge…

- From 18.5 mag to 21 mag the rate of transients (false positives) increases by factor 15: need to be smart about this, *work in progress based on host/lens galaxy properties*
- Exposure length for spectroscopy with P60 at Palomar increases with up to two orders of magnitude: *non-starter. Need bigger light buckets!*
- In 2020, lined-up spectroscopic resources at biggest telescopes, for vetting candidates e.g., Palomar 5m, Keck 10m, VLT 8m, …, *cancelled due to COVID-19*
- Now open, the search resumes – but would benefit enormously from a coherent effort from the SN lensing community: resources are very scarce!

The challenge…

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Thank you for your attention!