Strong gravitational lenses in the 2020s

Masamune Oguri
University of Tokyo

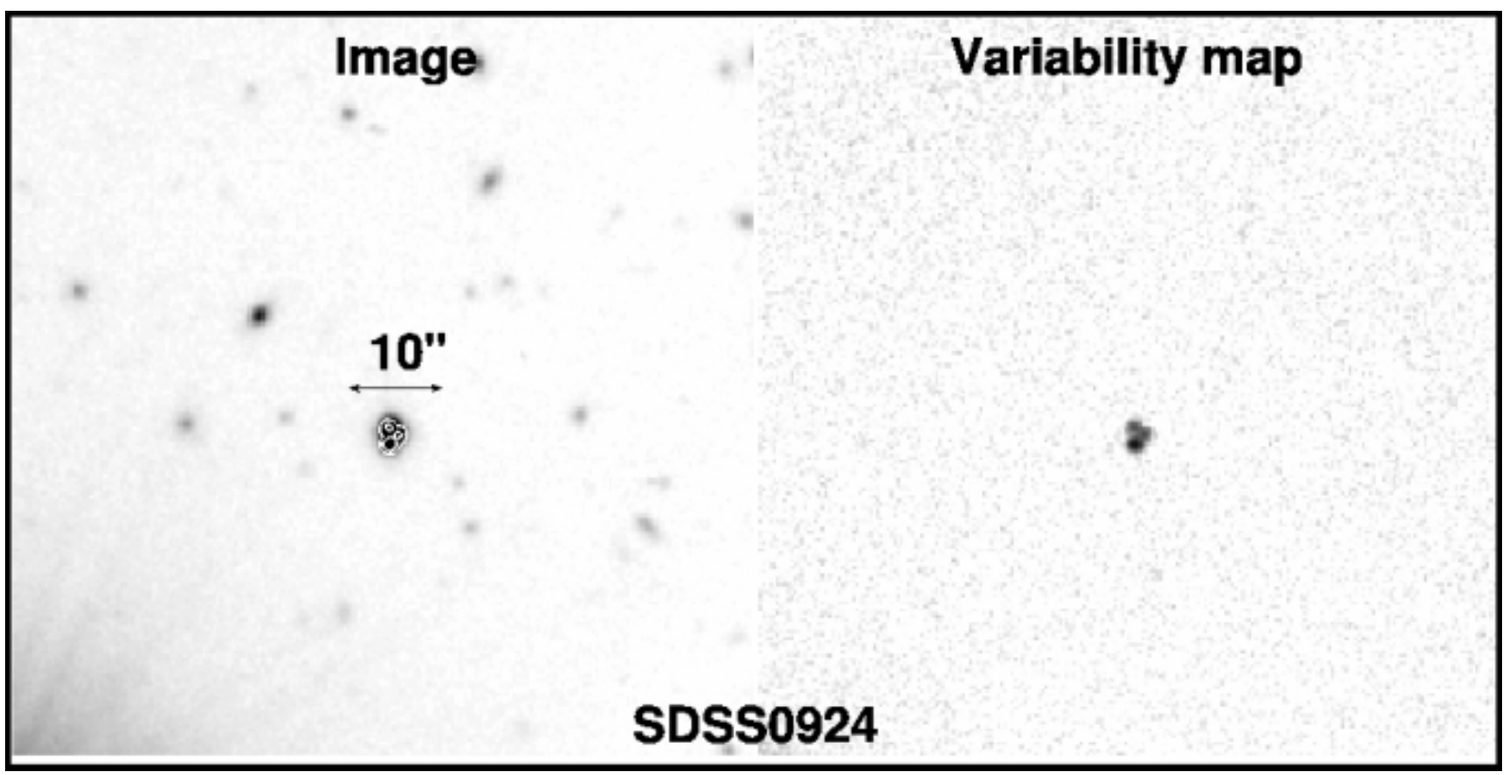
2014/7/18 TMT science forum @ Tucson

Strong gravitational lenses are rare

- wide-field surveys find strong gravitational lenses
- high spatial resolution follow-ups at TMT will be essential for better characterizing them
- an example of excellent synergy between TMT and survey telescopes
- future surveys emphasize time domain (e.g. LSST), enabling a new approach for strong lens surveys

Future direction: variability search

- close pairs of time-variable sources are very rare
- in most cases they are strong gravitational lenses, enabling very efficient search of strong lenses!
- time-variable sources → time delays

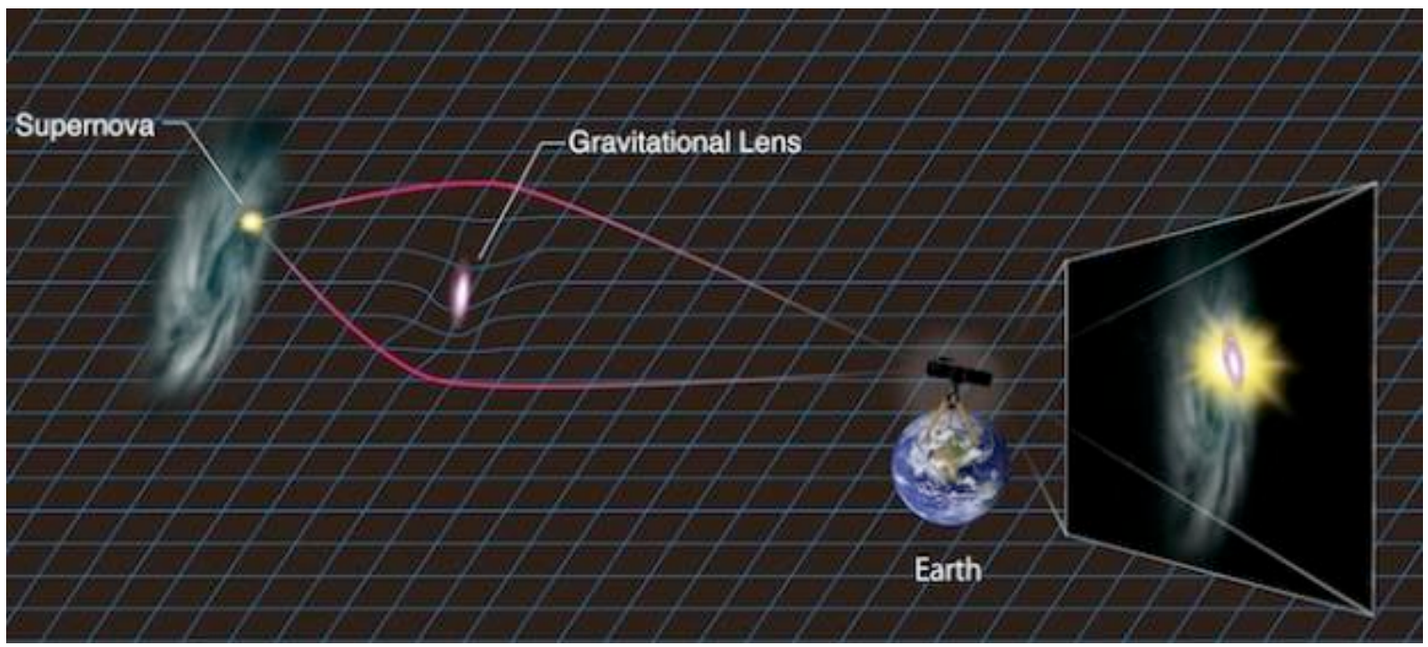


Kochanek et al. (2006)

Oguri & Marshall MNRAS **405**(2010)2579

Time variable lenses in future surveys

- gravitationally lensed quasars
  ~8000 discovered in LSST, ~3000 of them have well-measured time delays
  (cf. ~120 quasar lenses discovered to date)
- gravitationally lensed supernovae
  much rarer, but potentially more interesting!



credit: Kavli IPMU

Why is lensed SNIa interesting?

- standard candle
  direct measurement of the magnification factor, breaking various (e.g., mass-sheet) degeneracy
  (Oguri & Kawano 2003)

- known light curves
  accurate and robust measurements of time delays
  (but notice microlensing; Dobler & Keeton 2006)

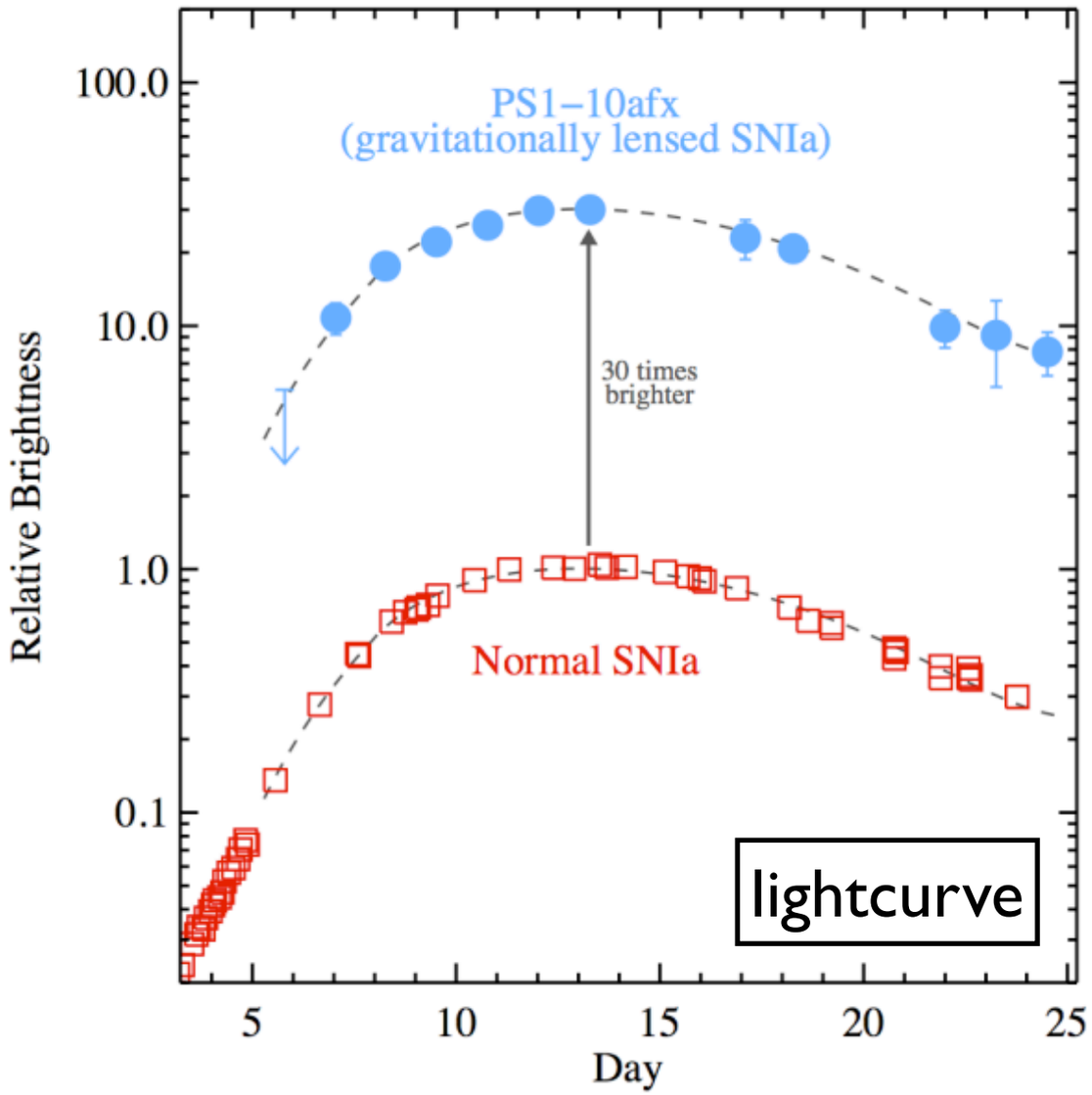
- better use of host galaxy
  better measurement of detailed morphology of lensed host galaxy after SNIa fades away

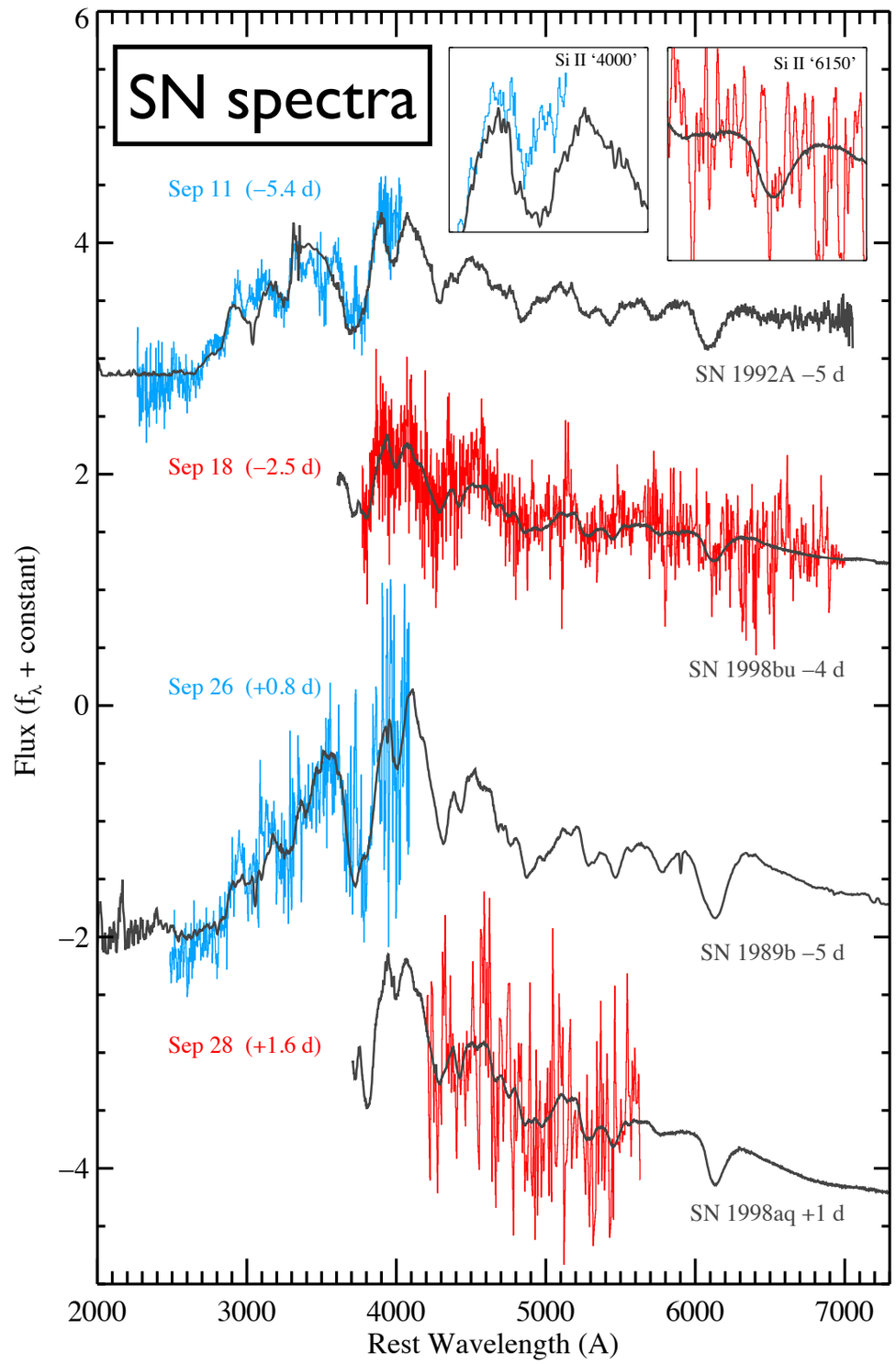
First strongly lensed SNIa

- PS1-10afx is a very peculiar transient (z=1.388) discovered in Pan-STARRS1 Medium Deep Survey
- PS1 team concluded that this is a new class of super-luminous SN, with much redder color and much faster light-curve evolution than any SLSN (Chornock et al. 2013)
- but we find that PS1-10afx is actually strongly lensed normal SNIa!

Quimby, Werner, Oguri, et al. ApJ **768**(2013)L20

Type Ia interpretation of PS1-10afx

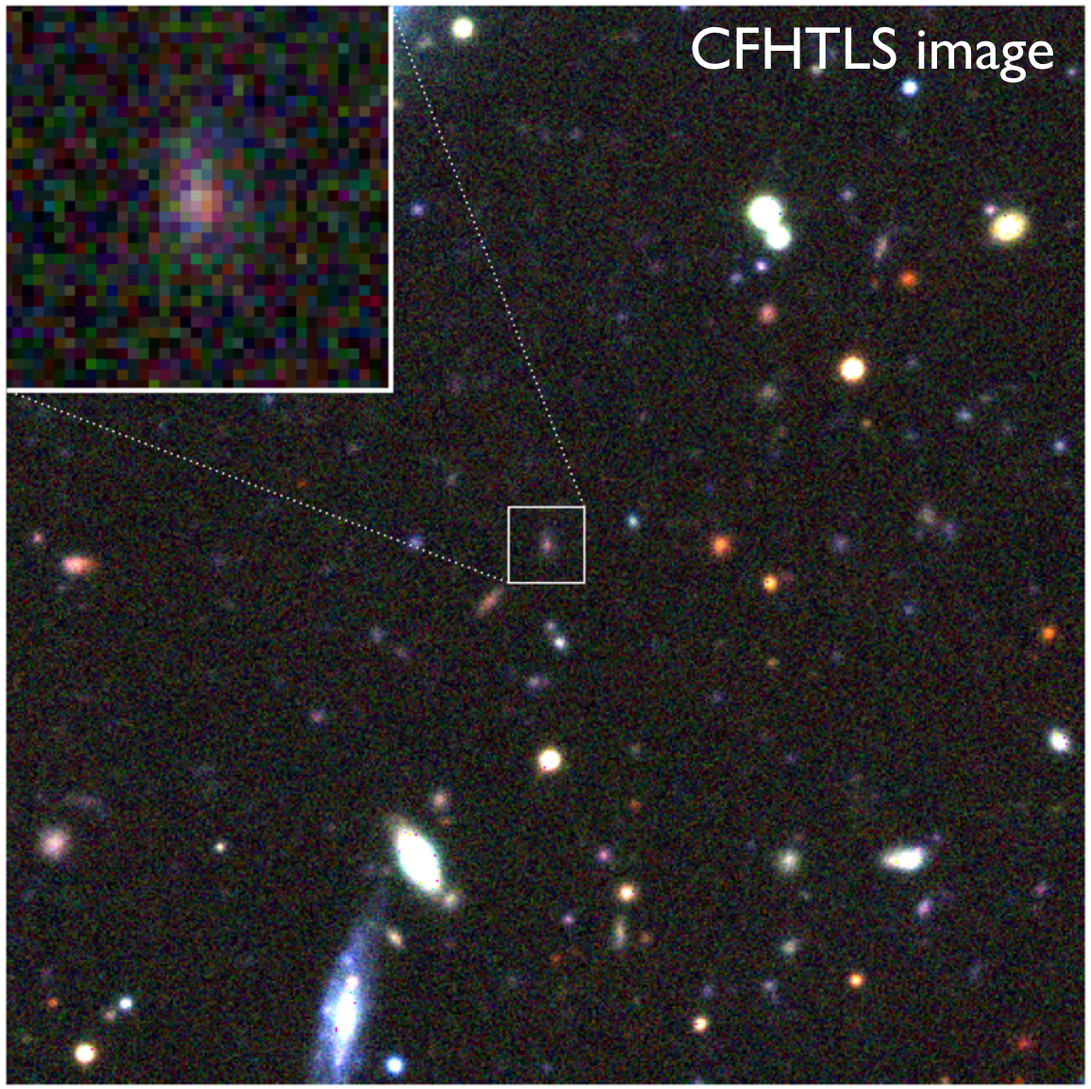




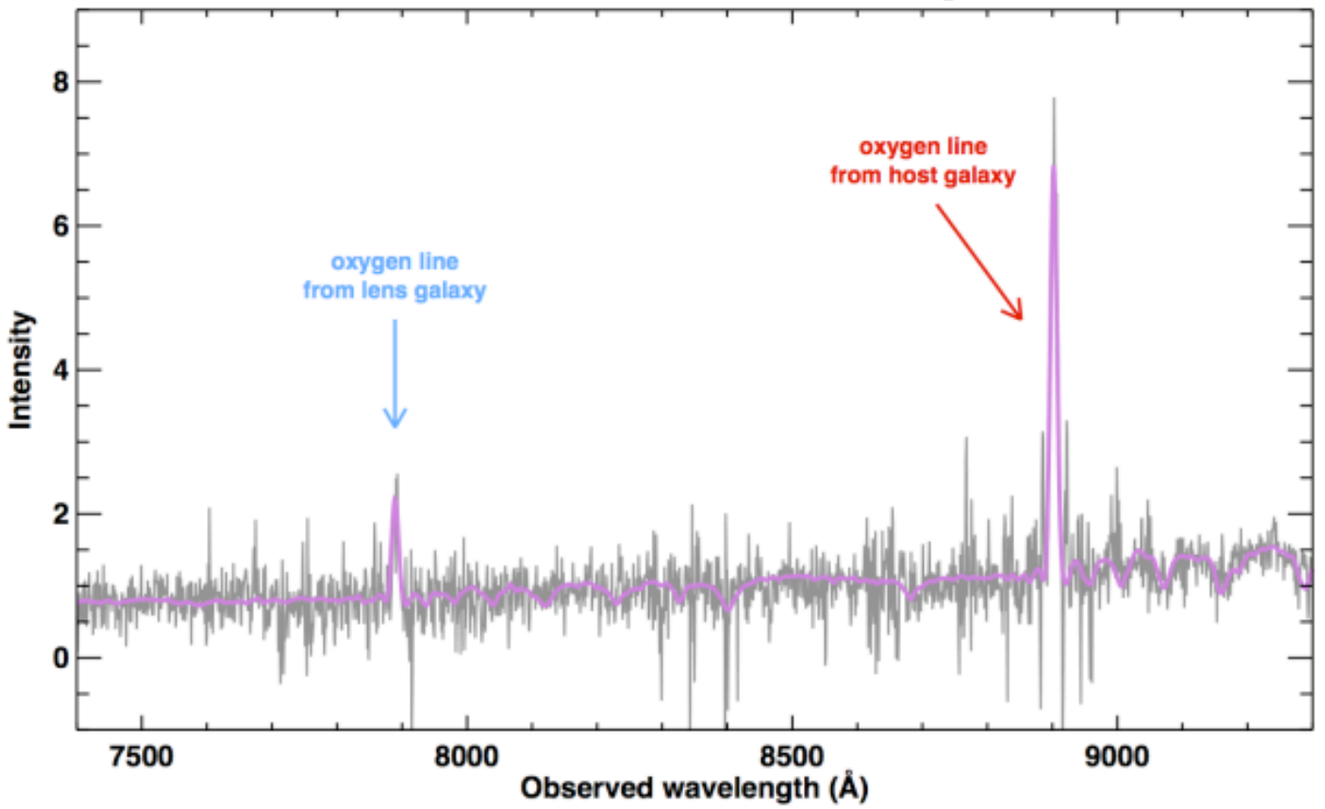
lightcurve and spectra consistent with 30x magnified type Ia SN

Quimby, Oguri, et al. Science **344**(2014)396

Detection of the lensing galaxy



Keck spectrum after the SN faded away



- foreground lensing galaxy at z=1.117 discovered by deep Keck spectroscopy

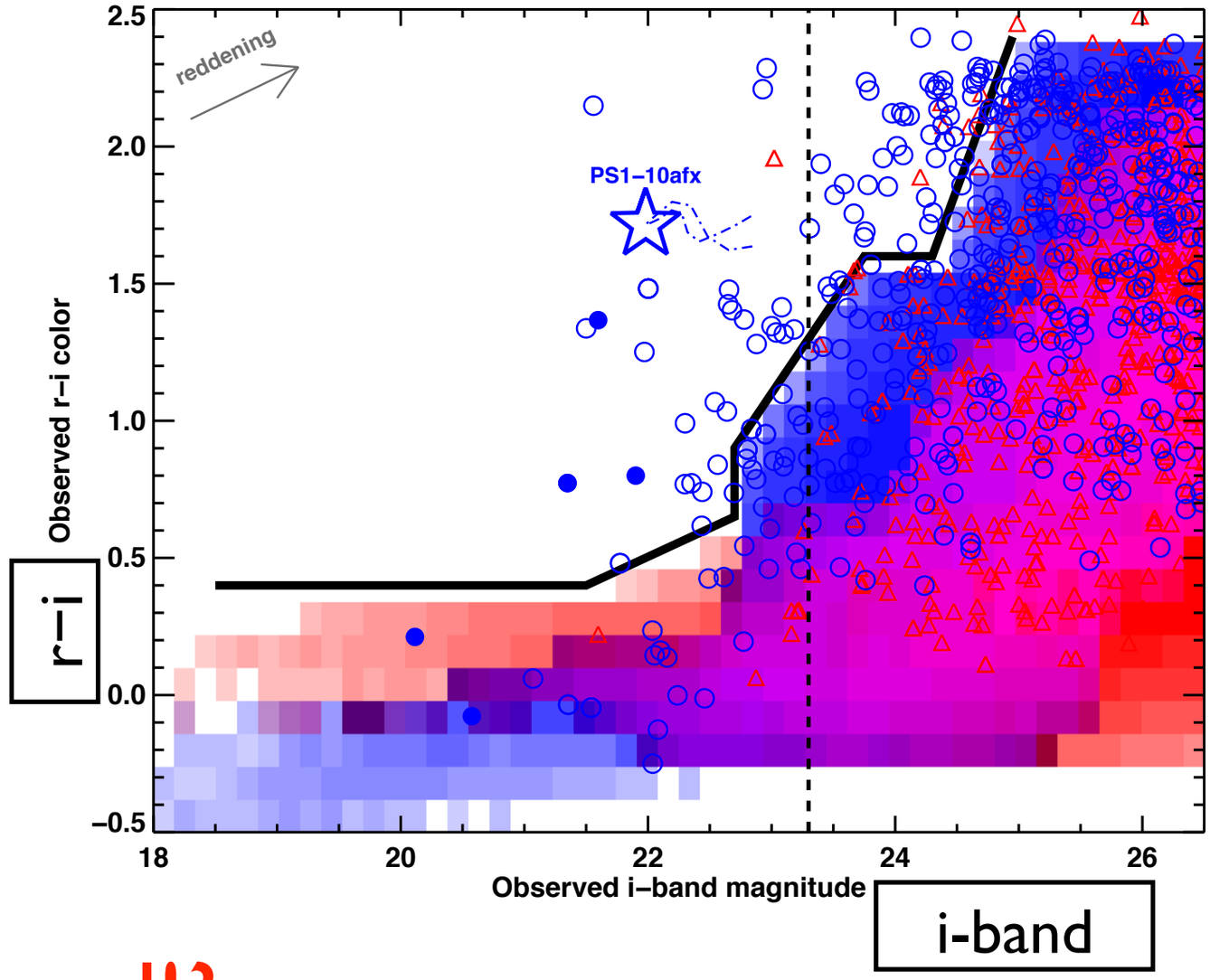
→ PS1-10afx is indeed first strongly lensed SNIa!

Quimby, Oguri, et al. Science **344**(2014)396

Expected number of lensed SNe?

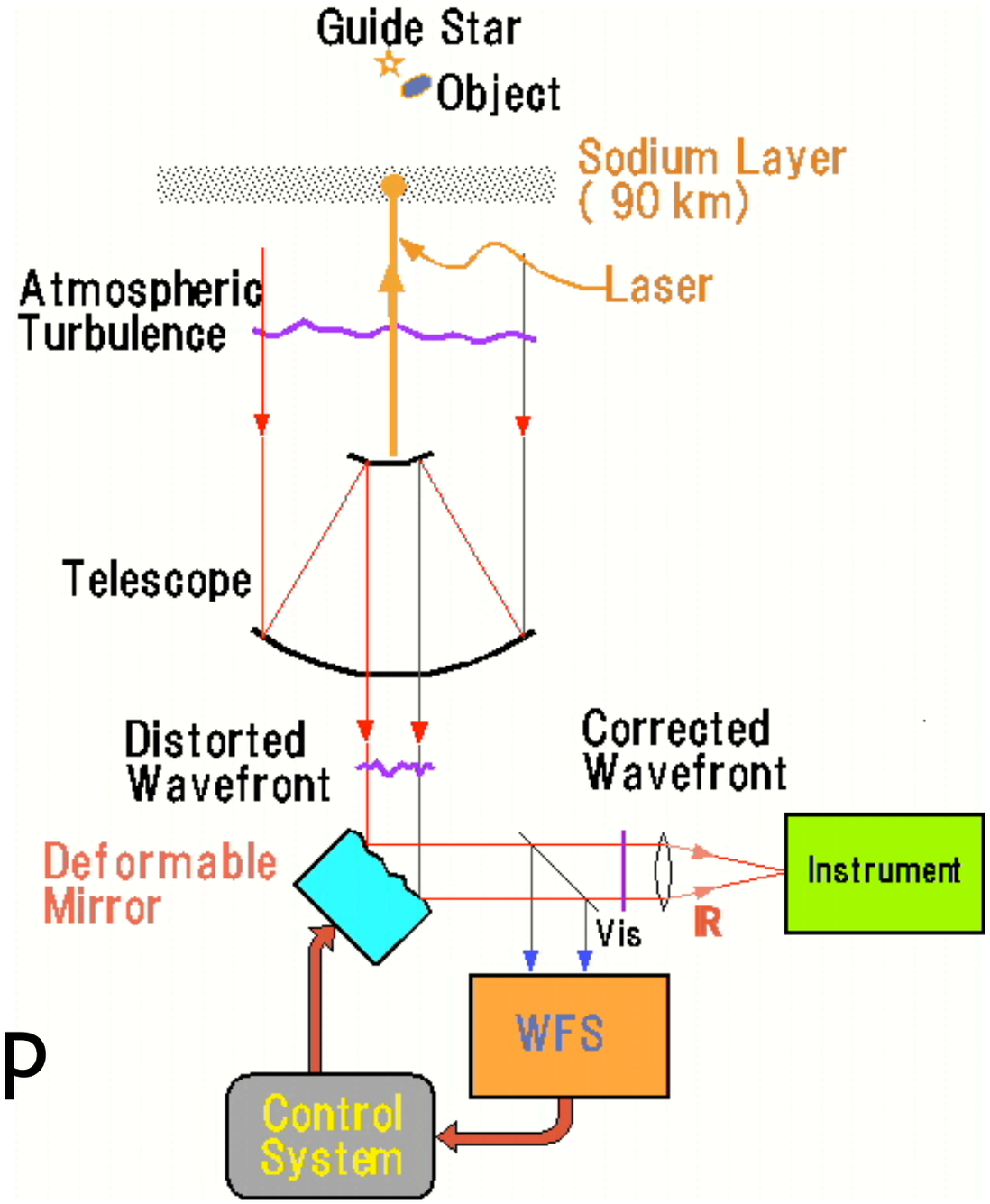
- predicted to ~100 in LSST (Oguri & Marshall 2010), assuming multiple SN images to be resolved
- we find we can locate lensed SNe in color-mag space, without resolving SN images

→ 10x more lensed SNela can be discovered!?



- quick follow-ups at TMT to resolve them and measure time delays

Laser guide star adaptive optics

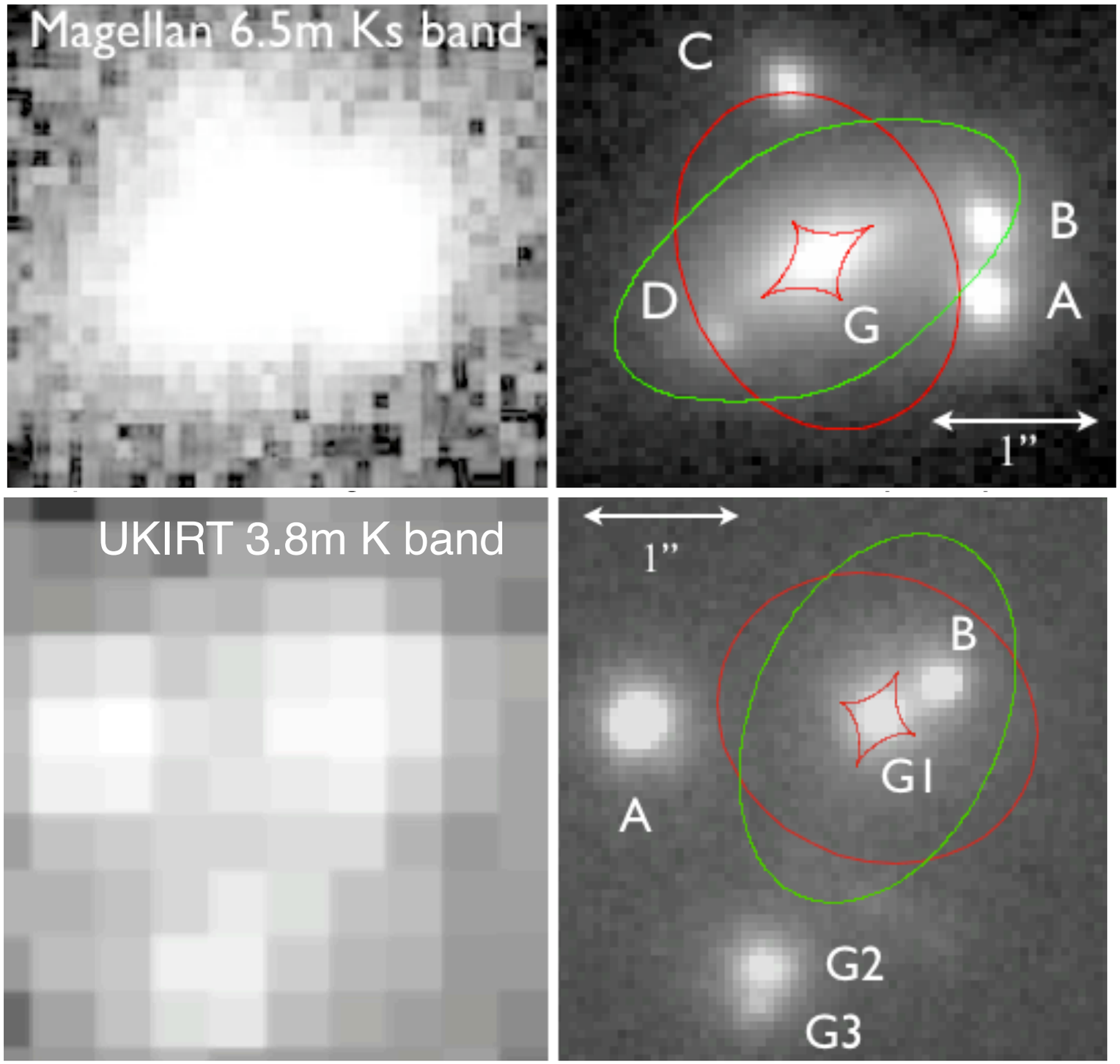


- key element of follow-up observations at TMT

Subaru webpage

Rusu, Oguri, Minowa, Iye, et al.

Subaru LGSAO imaging campaign



no-AO images　　Subaru LGSAO images

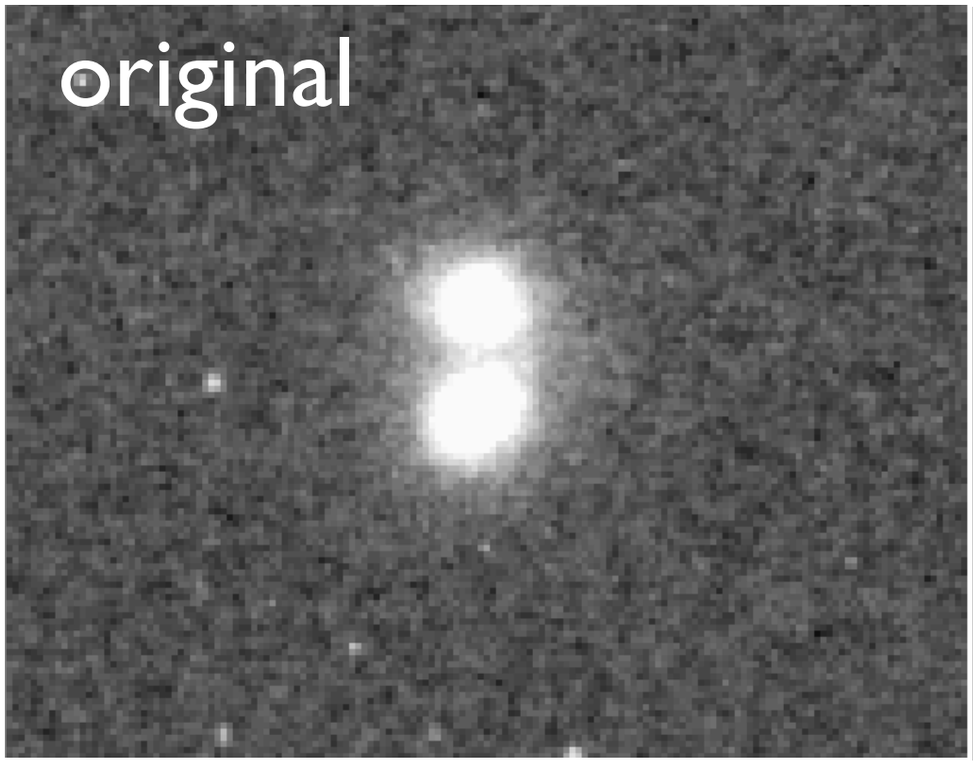
- high-resolution is essential for analysis of quasar lens systems
- LGSAO imaging drastically improve spatial resolution
- we have observed ~20 SQLS quasar lenses with LGSAO

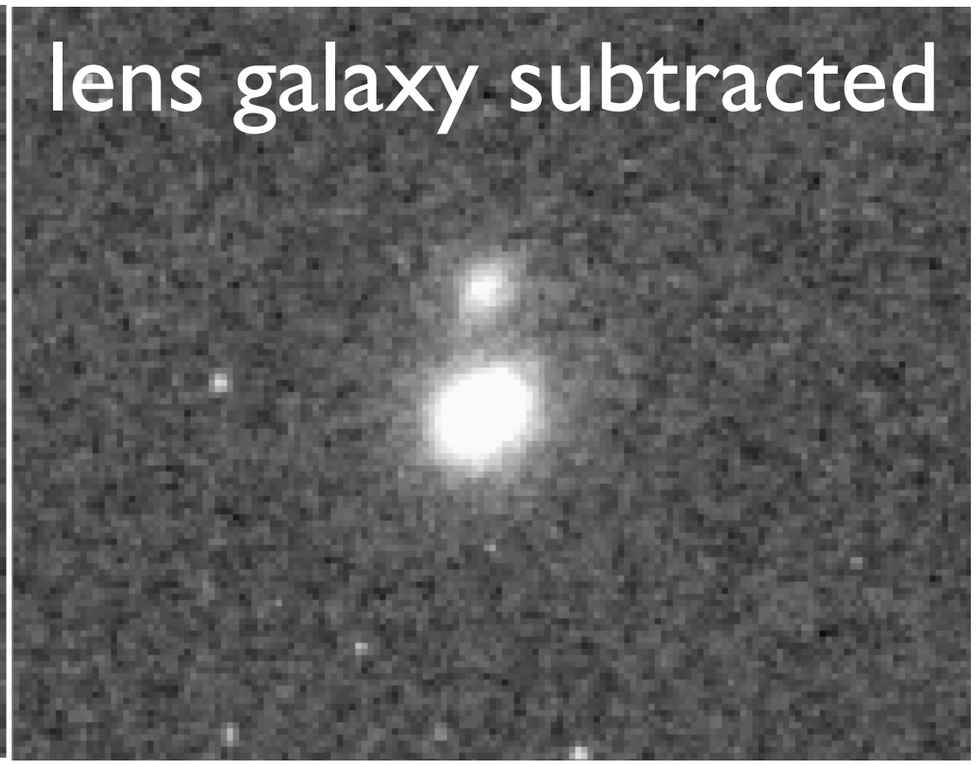
Challenge: PSF uncertainty

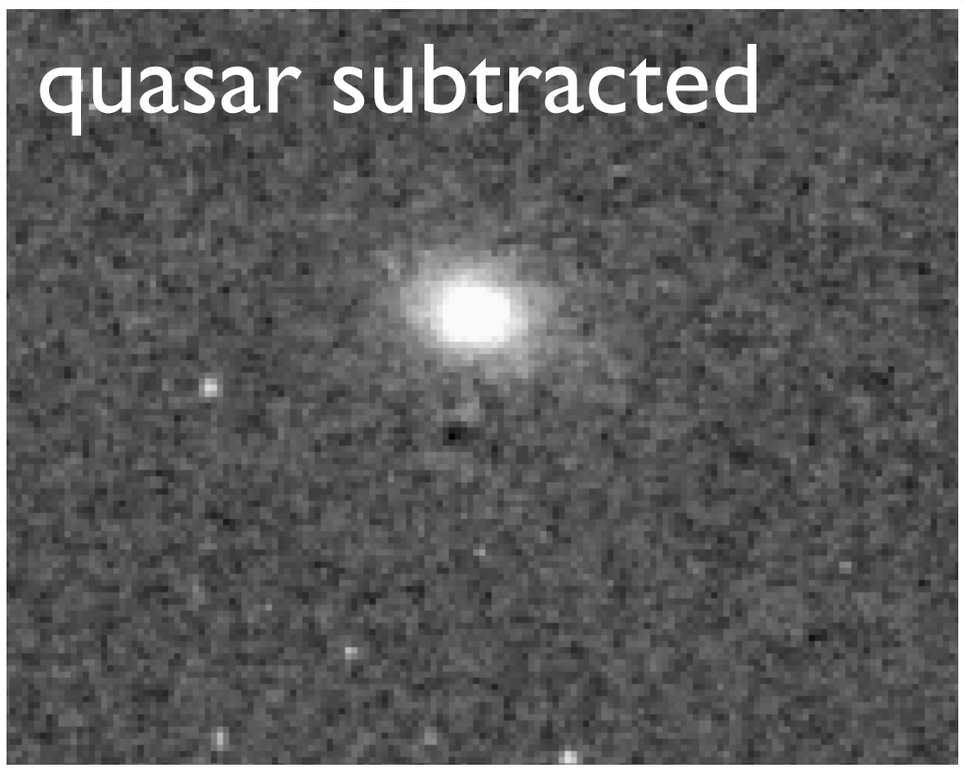
- in LGSAO observations, PSF changes very quickly with sky positions (relative to the guide star) as well as with time
- therefore PSF uncertainty is a main limitation of LGSAO observations
- we developed a new approach to constrain PSF, image configuration, and lensing galaxy morphology simultaneously, by utilizing the point-source nature of quasar images

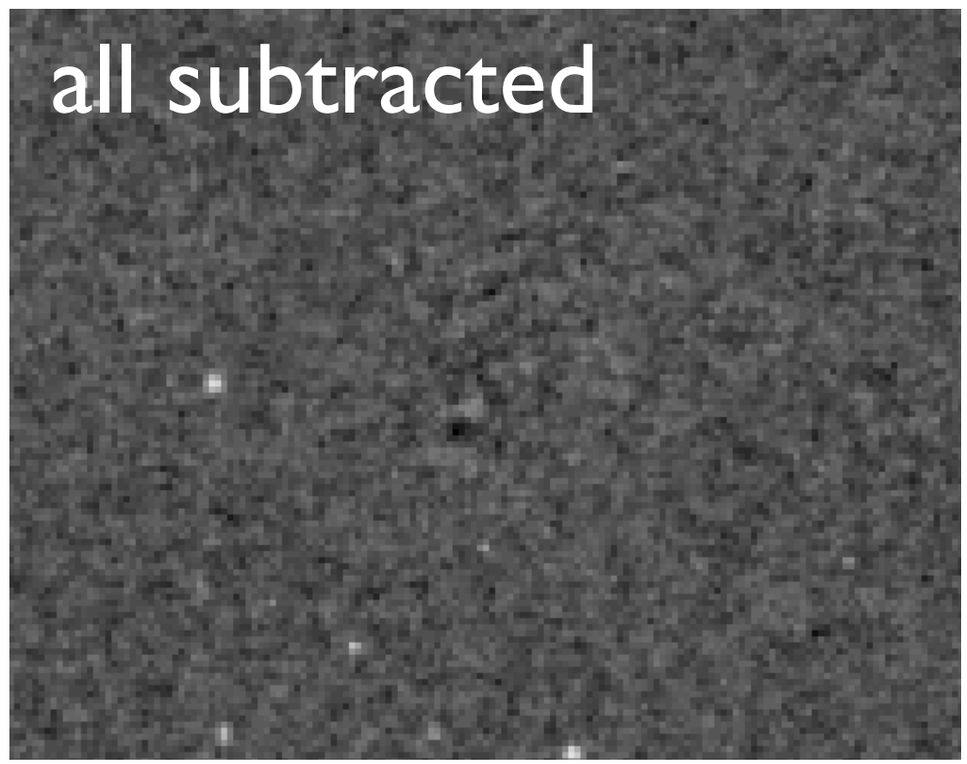
Rusu, Oguri, Minowa, Iye, et al.

Simultaneous fitting approach









PSF modeled by two Moffat profiles (9 param.)

lens galaxy by Sersic profile with the PSF convolved

Simultaneous fitting of PSF, quasar images and lensing galaxy morp.

Summary

- Strong lensing represents an example of good synergy between TMT and wide-field surveys
- particularly interesting is time-variability search of strong lenses, which will find a huge number of lensed quasars as well as lensed supernovae, interesting new probe of cosmology
  (time-domain survey at Mauna Kea? HSC? PS4?)
- ongoing Subaru LGSAO observations of lensed quasars highlight challenge of PSF estimates and a possible way to get around it