

Galaxies and Cosmology in Light of Strong Lensing
Kavli IPMU, November 18, 2014

**Subaru Telescope Adaptive Optics
Observations of SDSS Gravitationally
Lensed Quasars**

Rusu Cristian Eduard

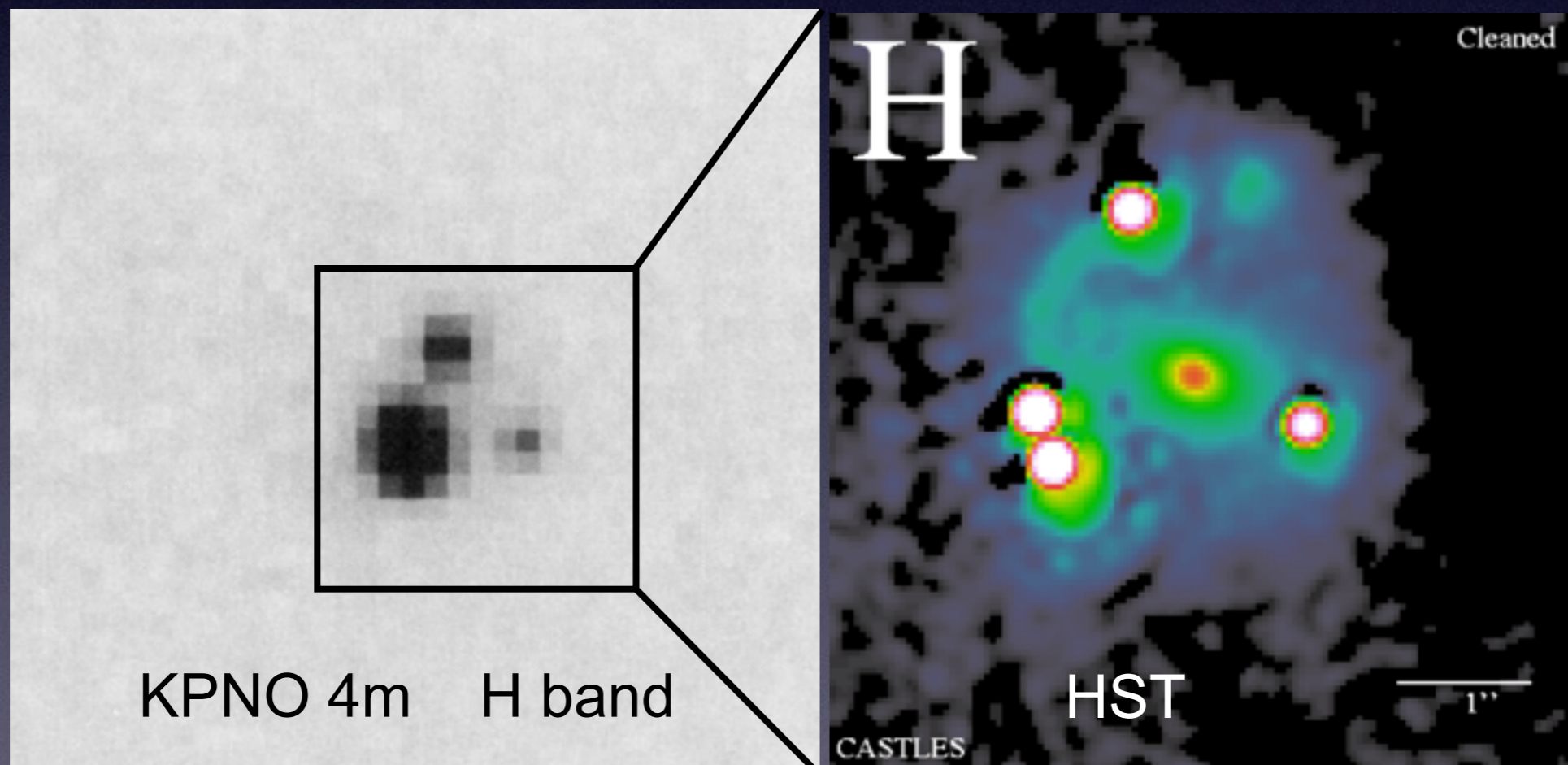
Masamune Oguri

Iye Masanori

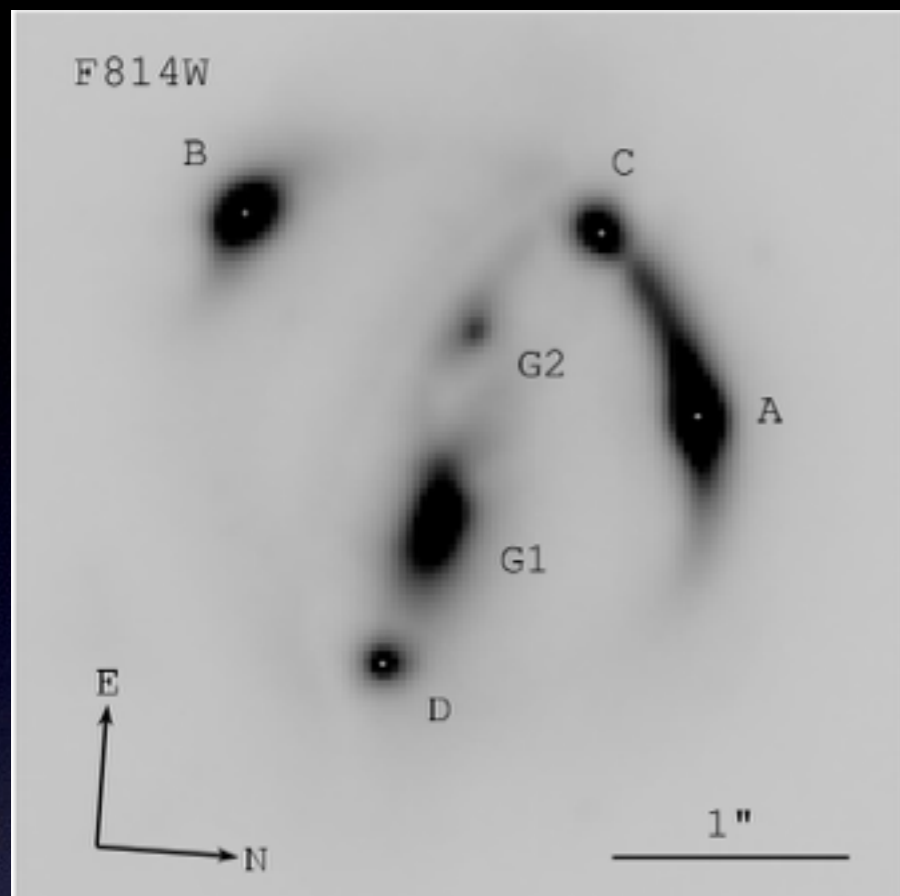
The importance of high-resolution

Typical image separation $1'' - 2'' \sim$ seeing size

HST typically used: CASTLES contains 100 lenses

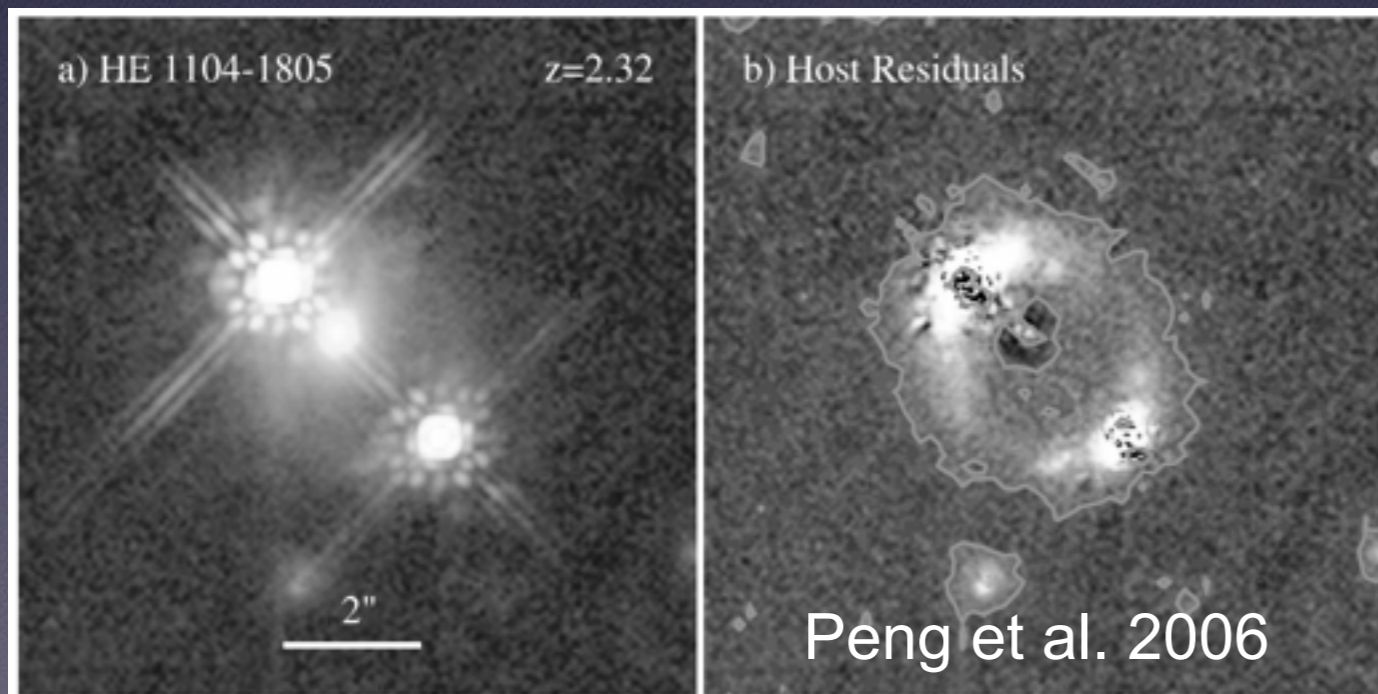


- Estimate the Hubble constant from time delays

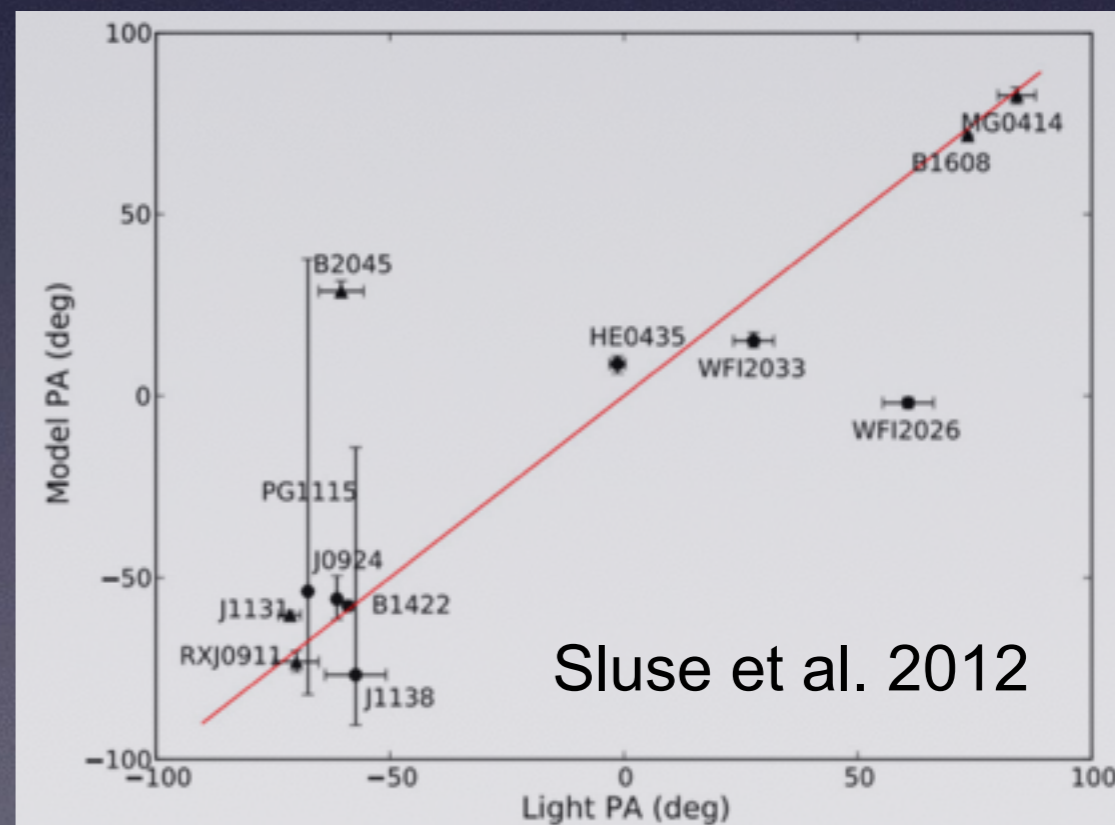


B 1608+656
Suyu et al 2010

- Quasar hosts & M_{BH} - L_{host} correlation

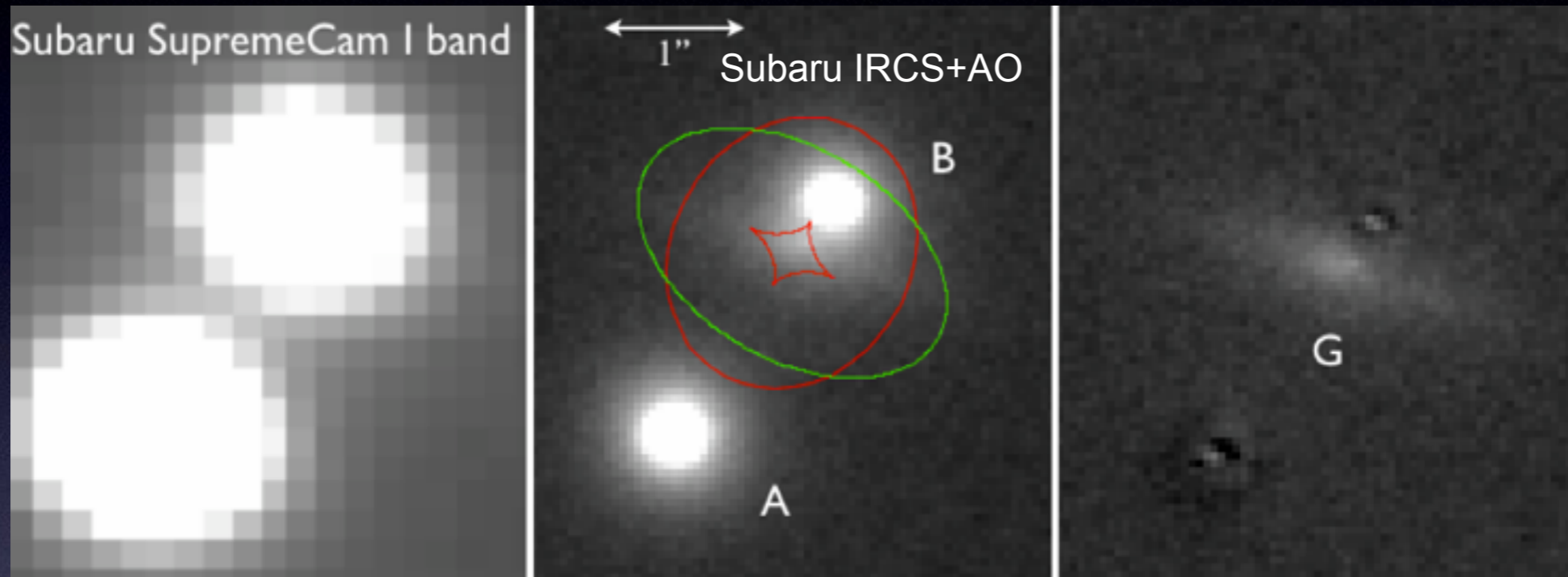


- The mass and light profile of lenses



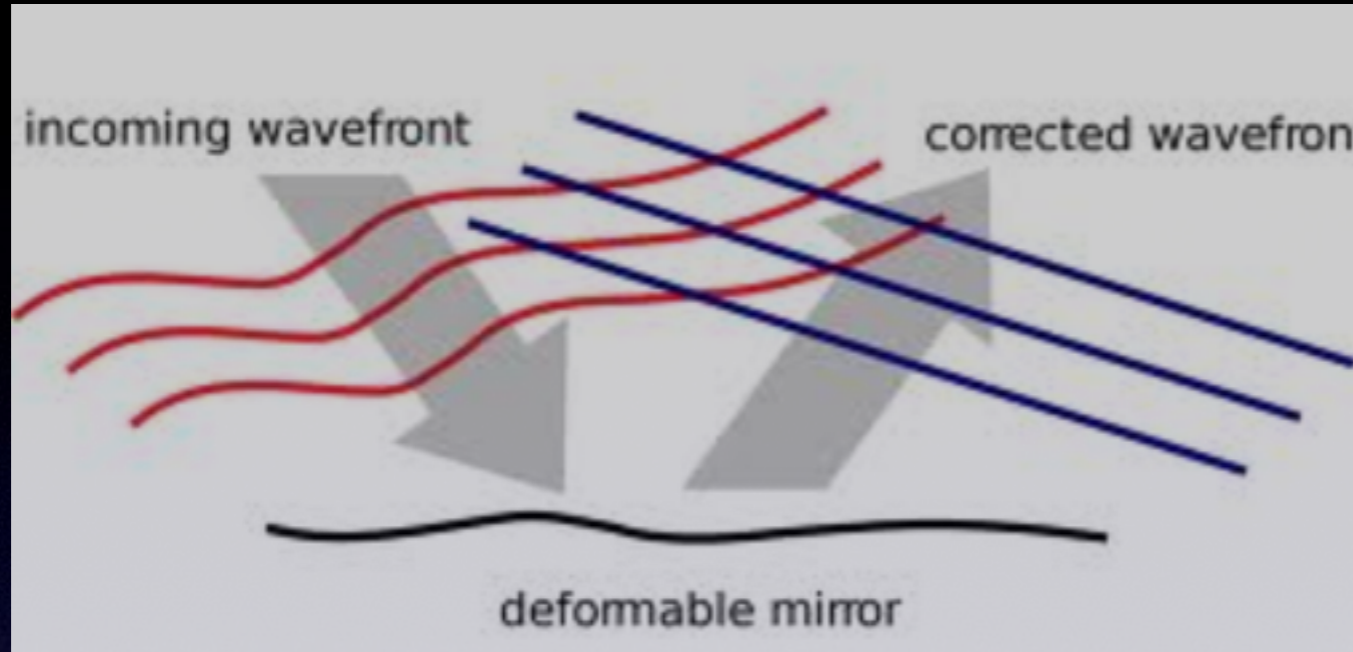
High-resolution imaging with AO

- AO: high resolution imaging possible from ground



- Few lensed quasars observed with AO so far (e.g. Sluse 2008, Suyu 2010)
→ conduct the first dedicated AO campaign, as an alternative to HST/CASTLES

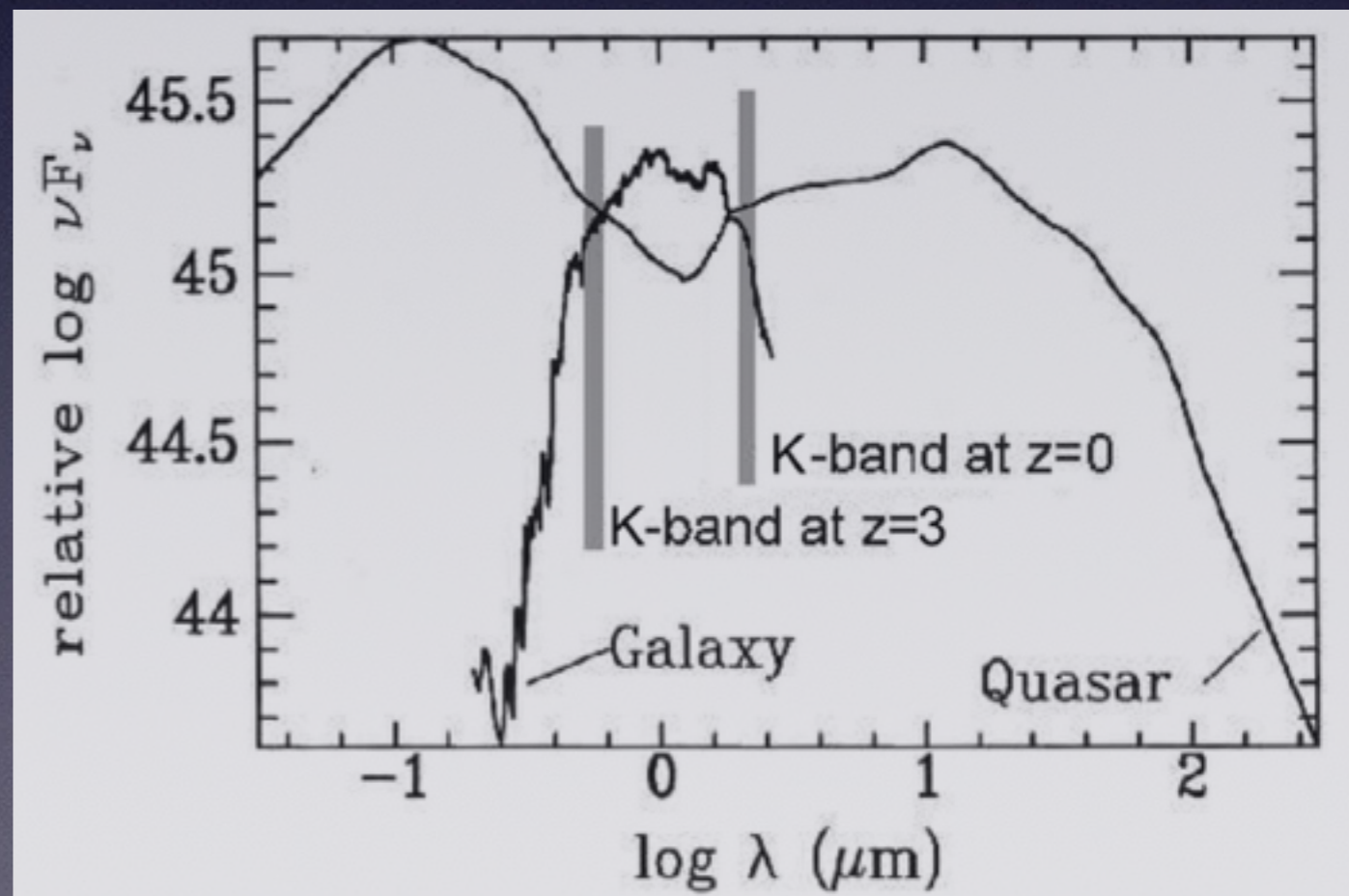
Adaptive Optics



LGS greatly increases sky coverage: tip-tilt star $R < 18$ mag, dist. $< 90''$

K' band:

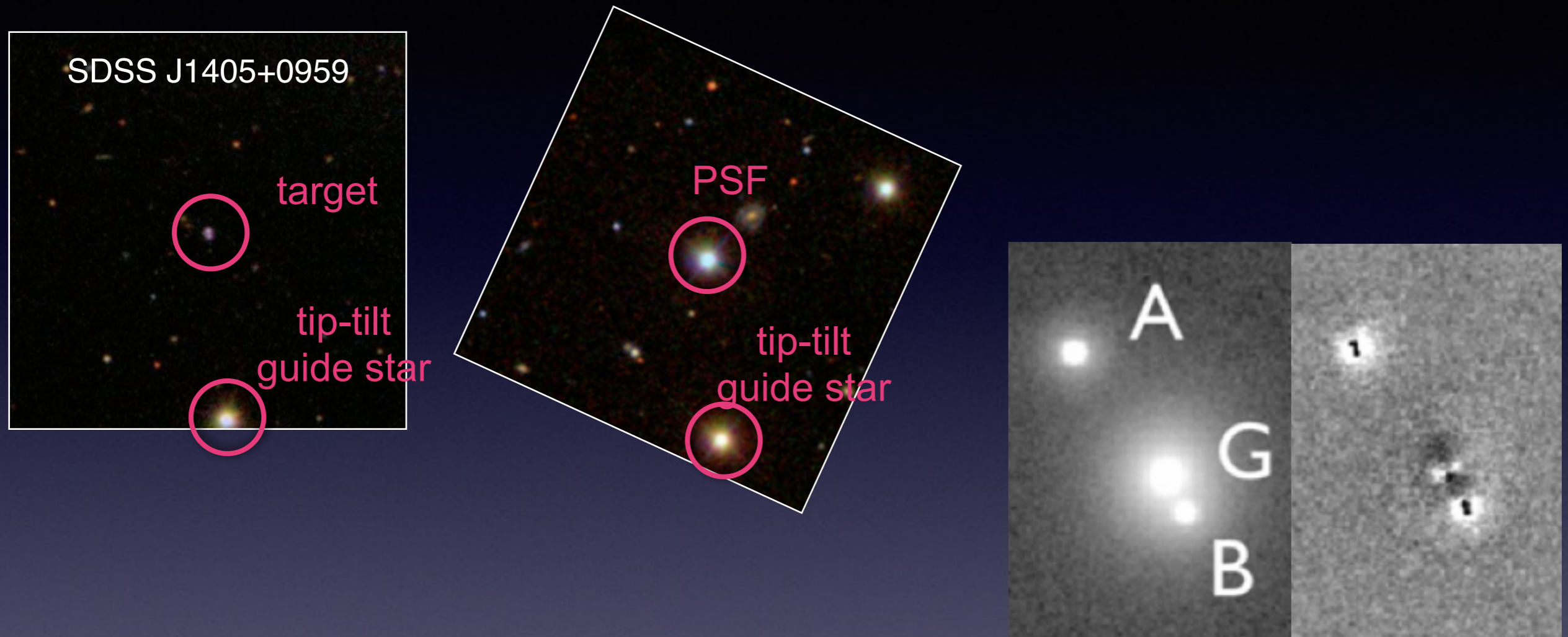
- better AO correction
- less microlensing, intrinsic variability, reddening
- host galaxy more prominent



Subaru AO imaging campaign

- SQLS: contains 62 lensed quasars discovered from SDSS (Oguri et al. 2006)
- 54/62 SQLS systems are accessible to Subaru LGSAO
(~40 Keck, ~5 Gemini North)
- ~1h/target imaging (with overhead) with Subaru IRCs+(LGS)AO188
- Campaign started in Feb. 2011 (Rusu et al. 2011)
→ ~2-3 nights usable data
- 25 (AO) objects observed:
 - 1 quad, 1 triple (?), the rest doubles;
 - 5 detected host galaxies
 - Strehl ratio < ~10%; PSF FWHM 0.15"-0.20"
 - 52"×52" field of view - no PSF stars

- Observed PSF stars with same configuration (TT-star R mag, distance)

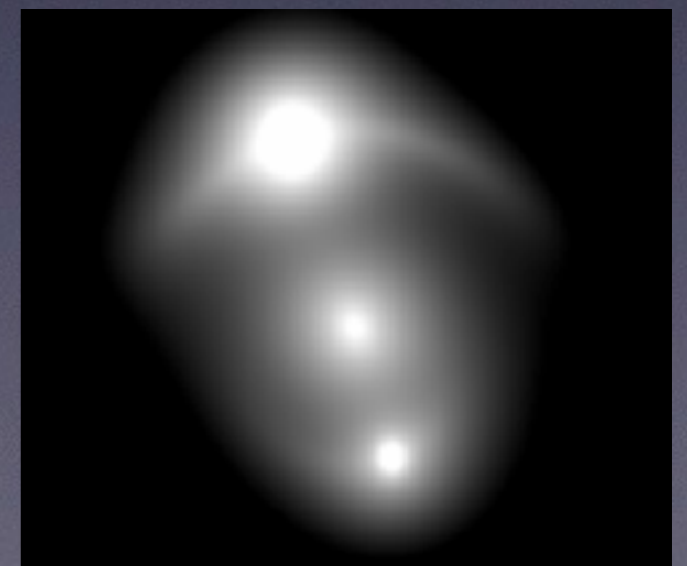
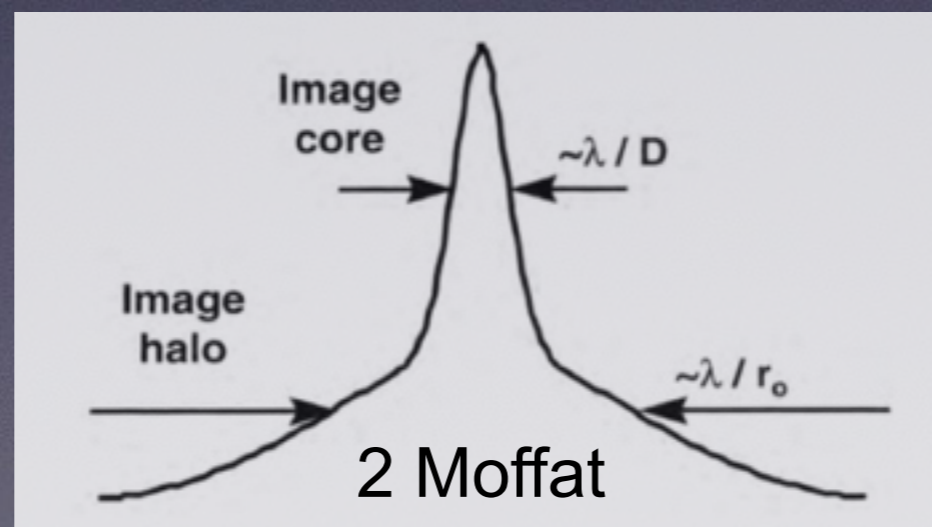
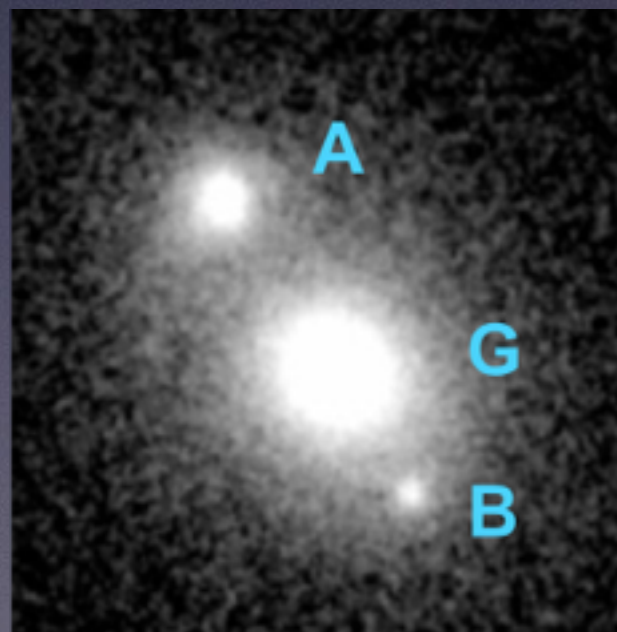


Traditional approach generally does not work with AO

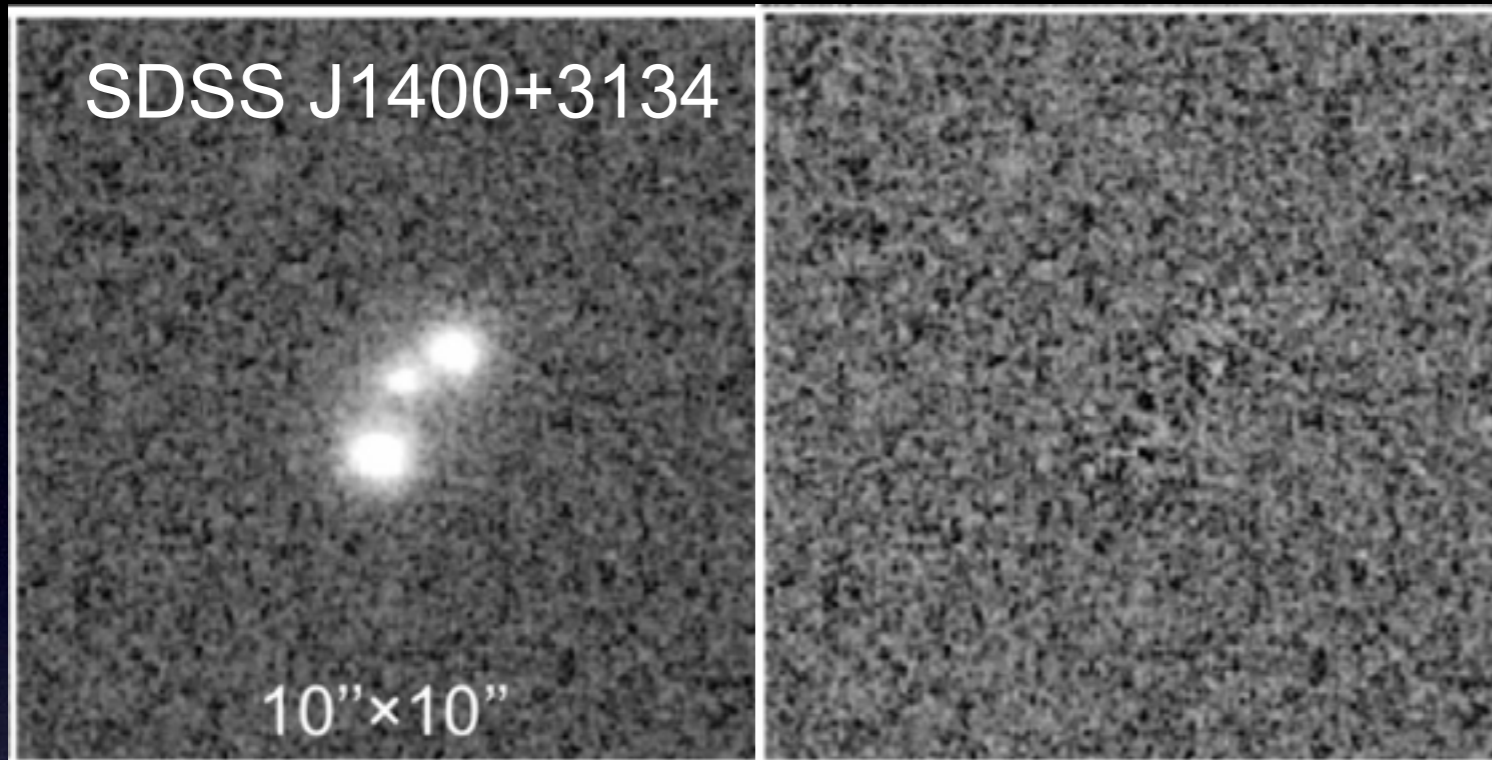
Use the information included in each system to construct the PSF on target

Morphological modeling technique

- Fit an analytical PSF and model A, B, G simultaneously
A & B: PSF G: PSF*Sersic
chi² minimization with HOSTLENS (M. Oguri) : galfit meets gravlens/glafic
- Are there visible non-analytical residuals? (high S/N)
use hybrid PSF: core (center of image A) + wings (analytical model)
- Are there host galaxy detections?
use SIS+shear lens model, fit host with de Vaucouleurs
- Simulations with noise, using the separately-observed PSF stars



Examples

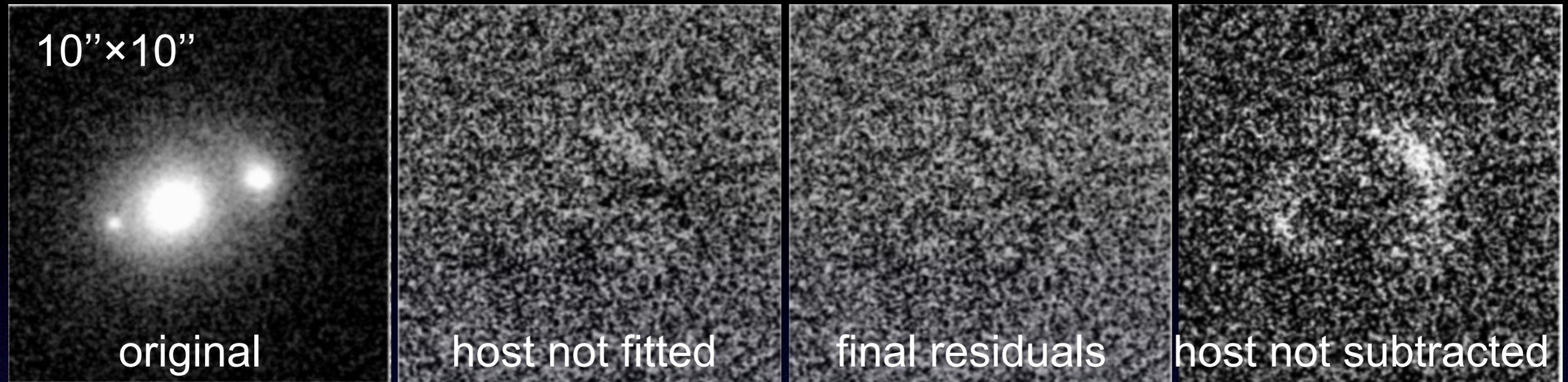


Fitting with analytical PSF

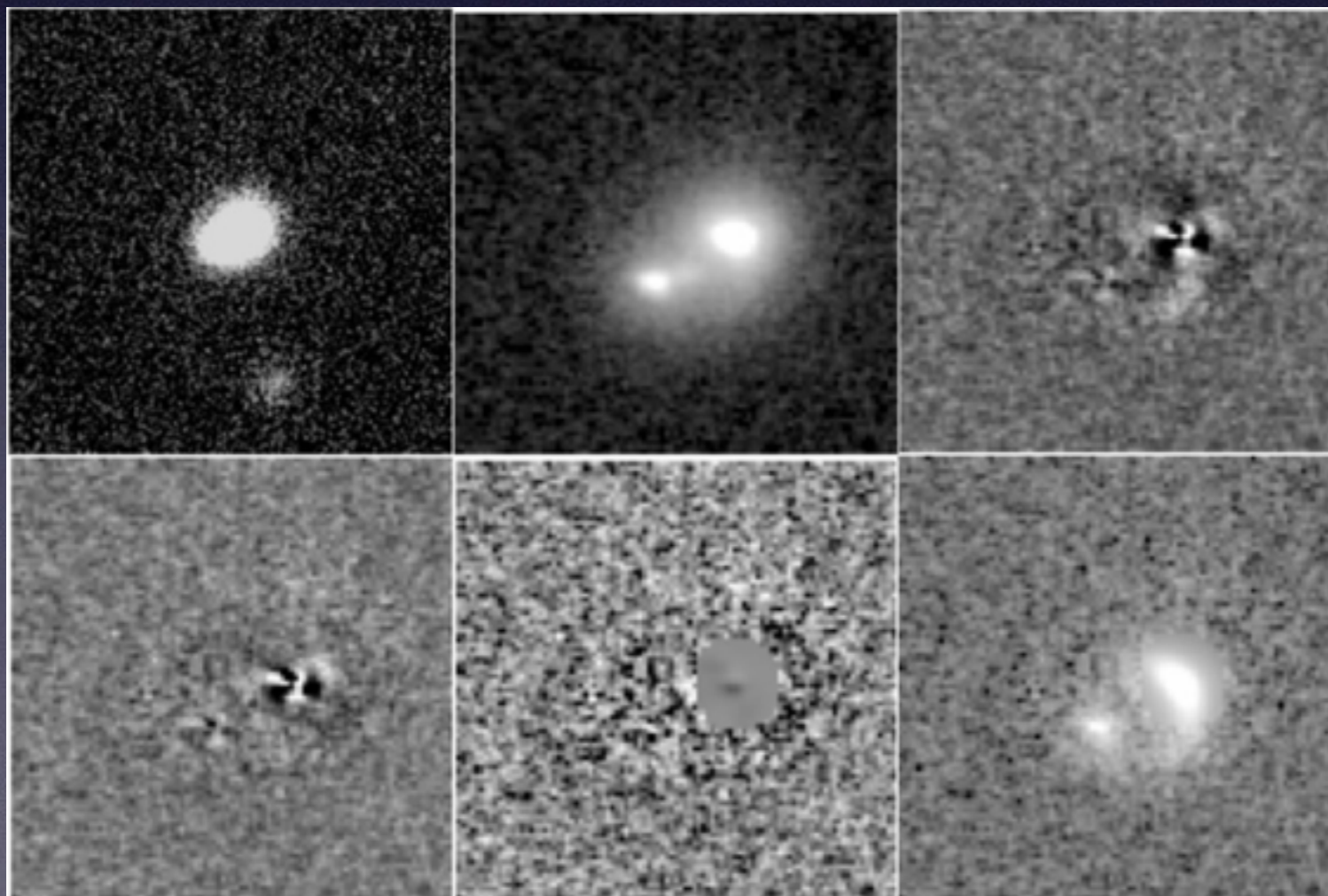


Fitting with hybrid PSF

SDSS J0819+5356: host fitted with analytical PSF $z_{\text{quasar}} = 2.24$

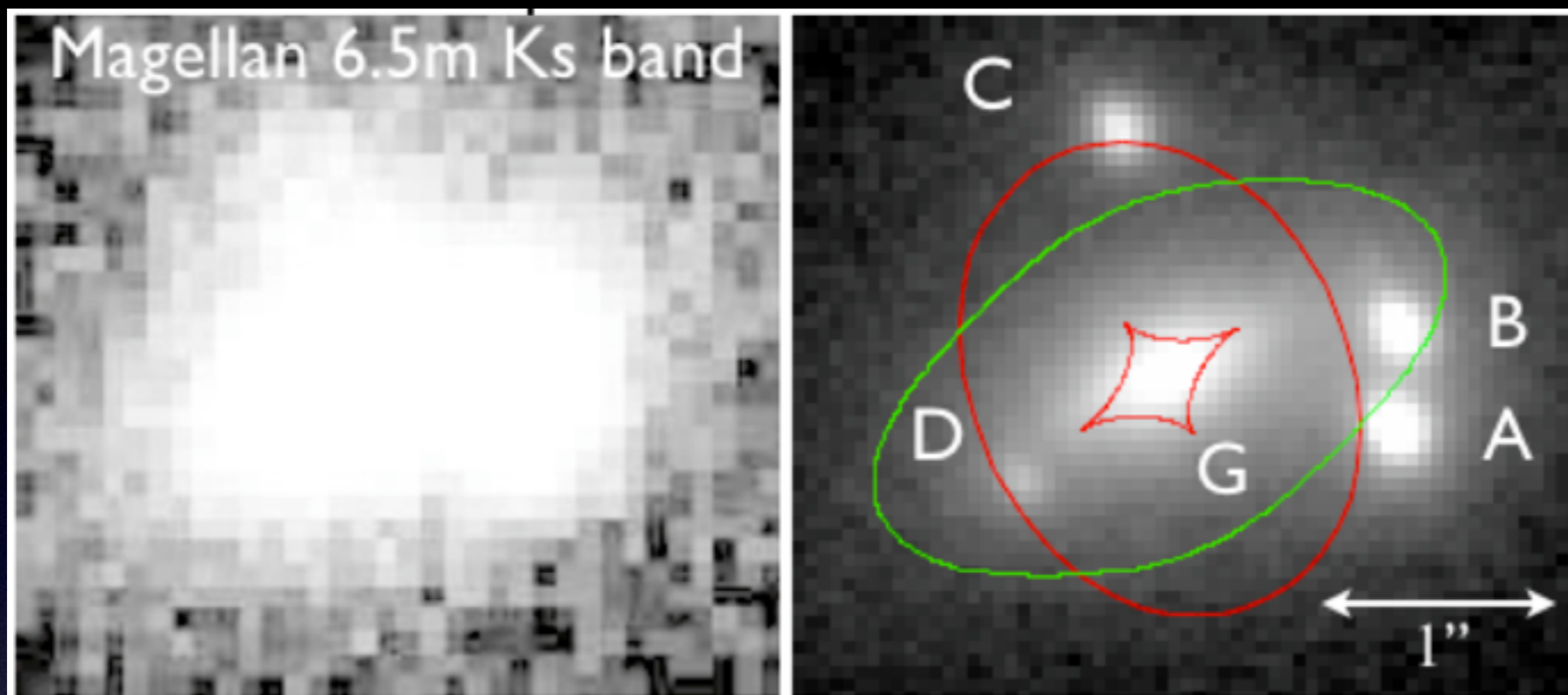


SDSS J0904+1512: host fitted with hybrid PSF $z_{\text{quasar}} = 1.83$



- using analytical PSF fit, subtract the host
- build hybrid PSF on A
- refit the original system using the hybrid PSF
- iterate until minimum χ^2 is reached

SDSS J1330+1810



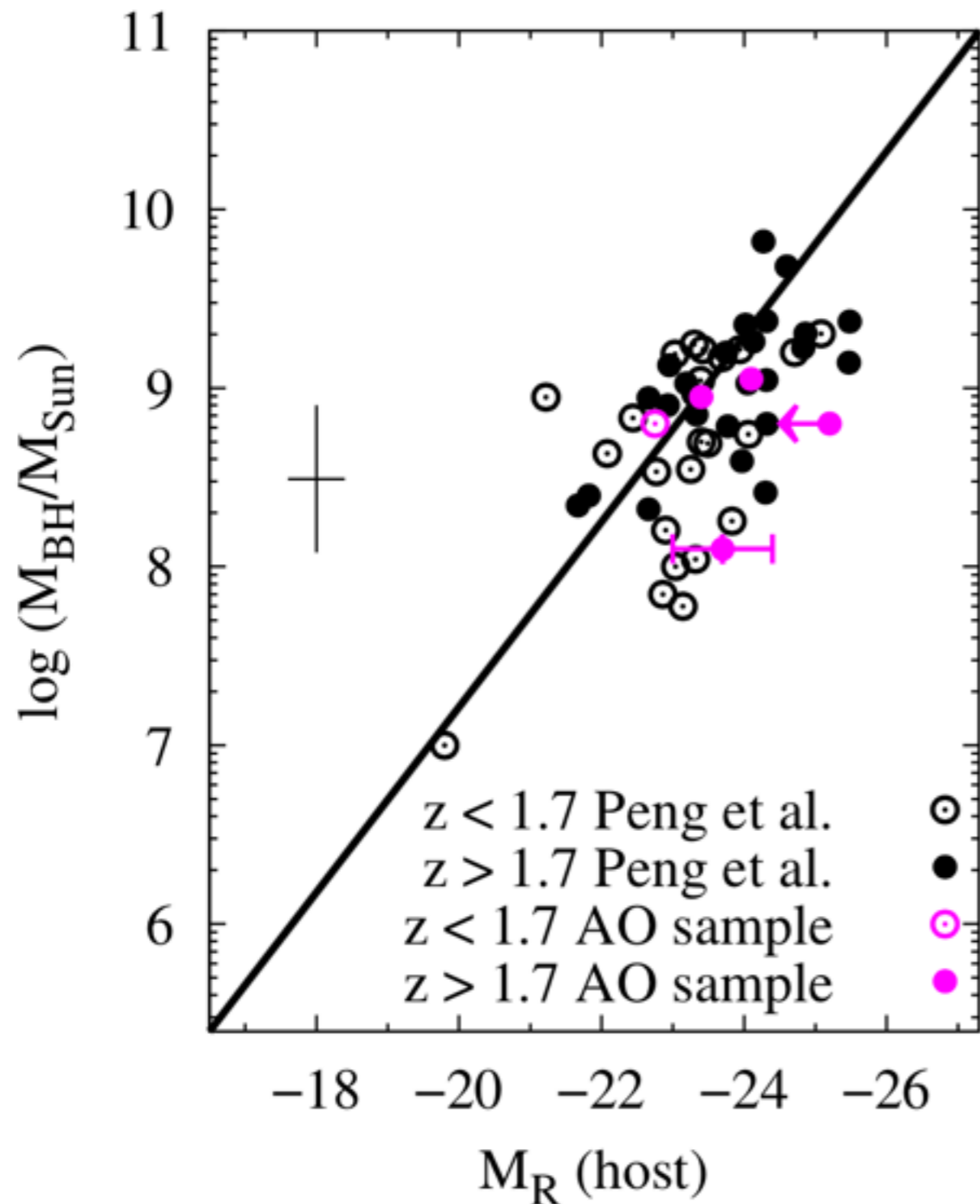
Name	x [arcsec]	y [arcsec]
A	$\equiv 0$	$\equiv 0$
B	0.42 ± 0.03	-0.01 ± 0.03
C	1.30 ± 0.03	1.19 ± 0.03
D	-0.24 ± 0.04	1.58 ± 0.04
G	0.24 ± 0.03	0.97 ± 0.03

scatter 5 bands
(Magellan 6.5m, UH88)

A	0.000 ± 0.001	0.000 ± 0.000
B	0.414 ± 0.0015	-0.013 ± 0.001
C	1.253 ± 0.003	1.163 ± 0.0015
D	-0.237 ± 0.0055	1.580 ± 0.002
G	0.225 ± 0.009	0.965 ± 0.001

scatter 2 observations
Subaru LGSAO

The $M_{\text{BH}} - L_{\text{host}}$ correlation in the detected hosts



- demagnified host & quasar luminosity K-corrected to rest-frame R-band
- BH mass measured using the virial relation (SDSS spectra, MgII)

Used for the first time lensed quasars observed with AO

SDSS J1405+0959

Rusu et al 2014

- $z_{\text{lens}} = 0.66$ $z_{\text{QSO}} = 1.98$
- new components: GX, GY
- J, H, K' imaging for photo-z

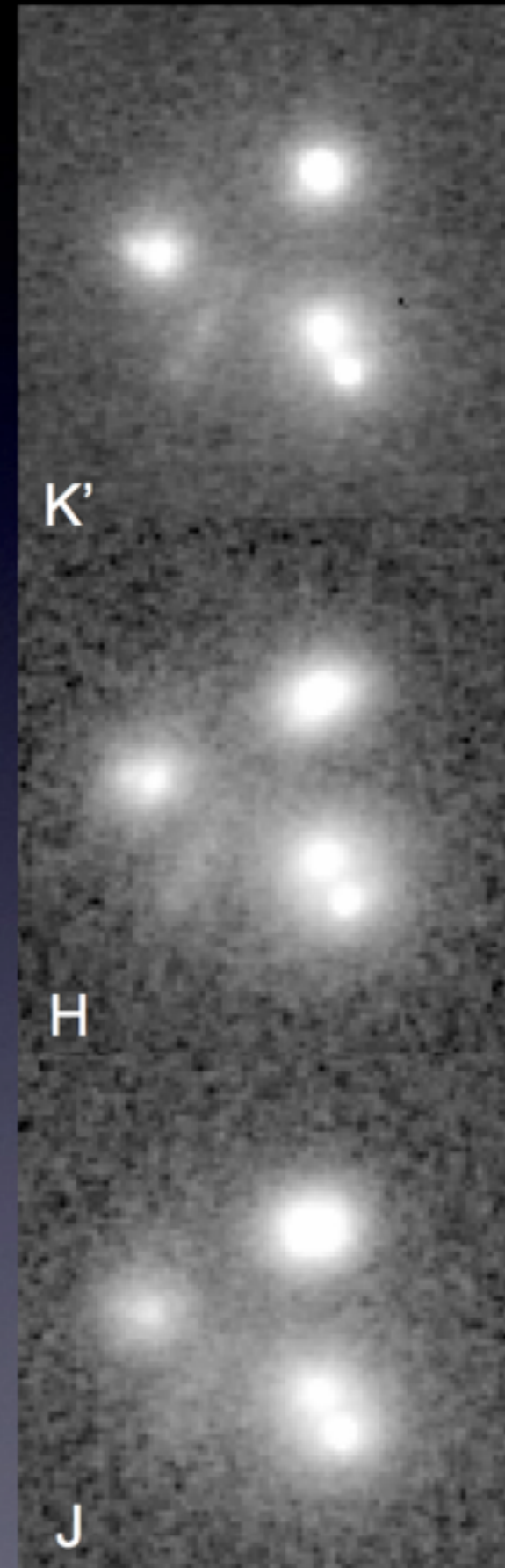
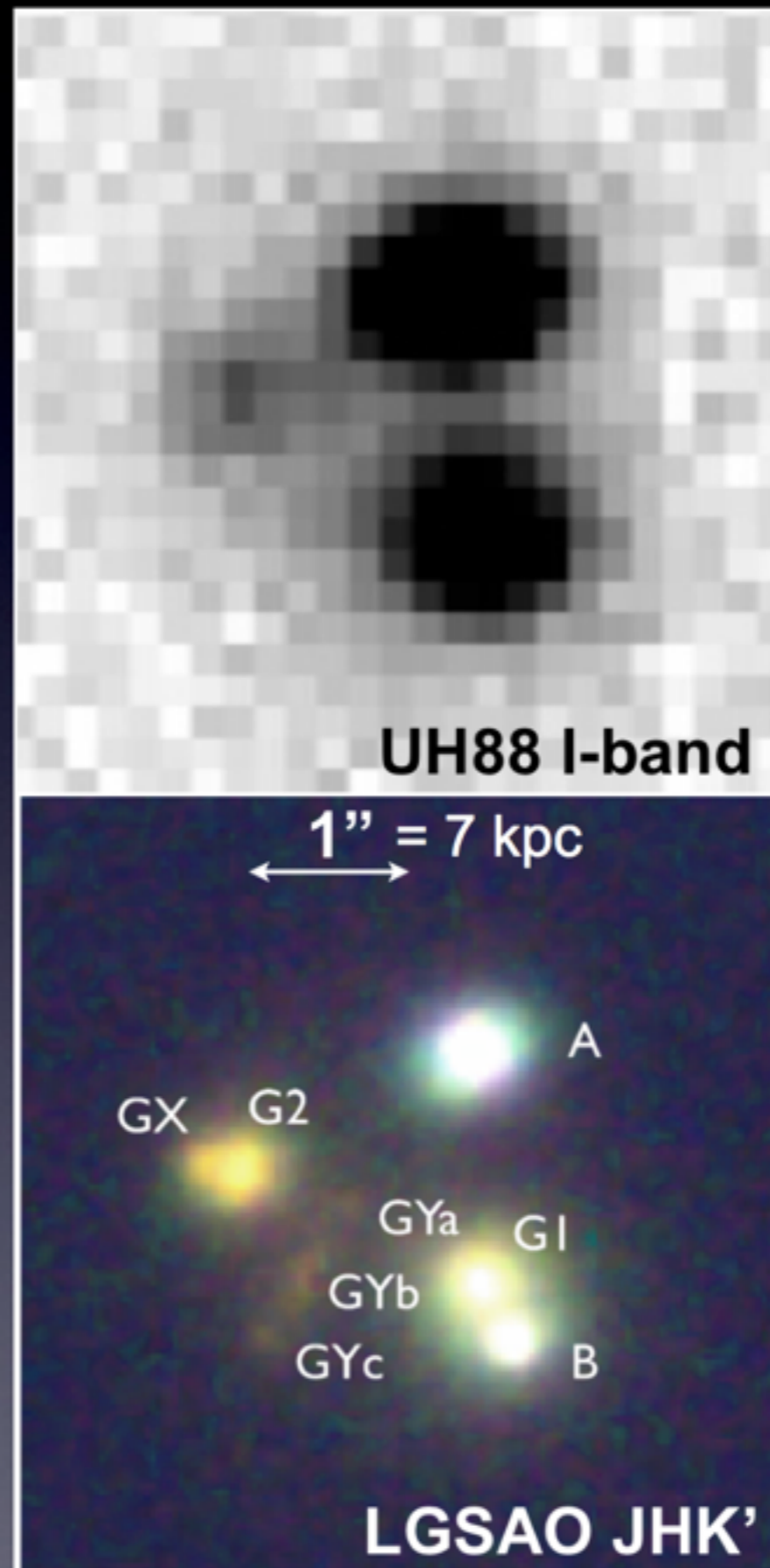


Photo-z estimates

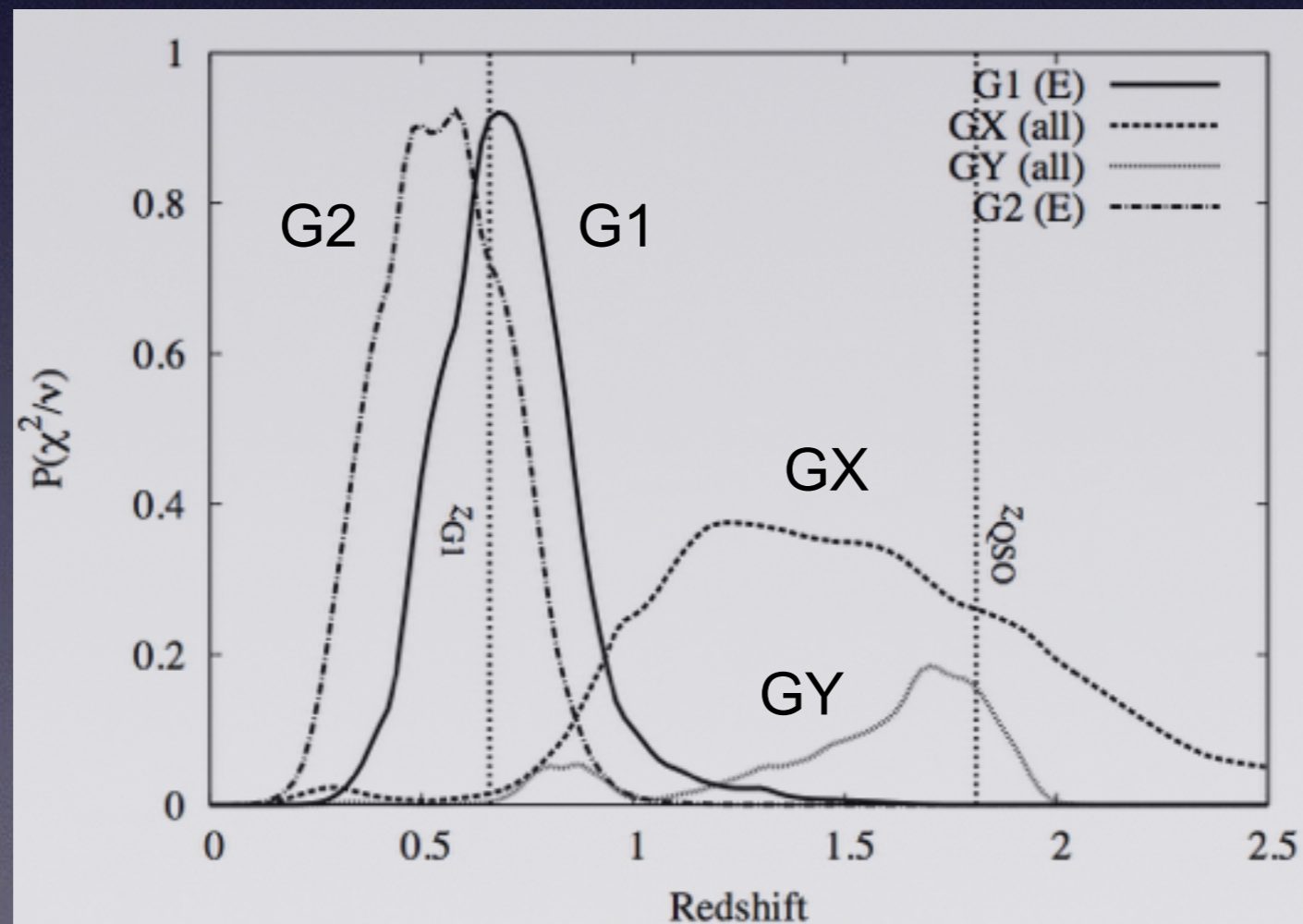


G1, G2 ellipticals consistent with same redshift

GX (assuming galaxy): larger, broad redshift

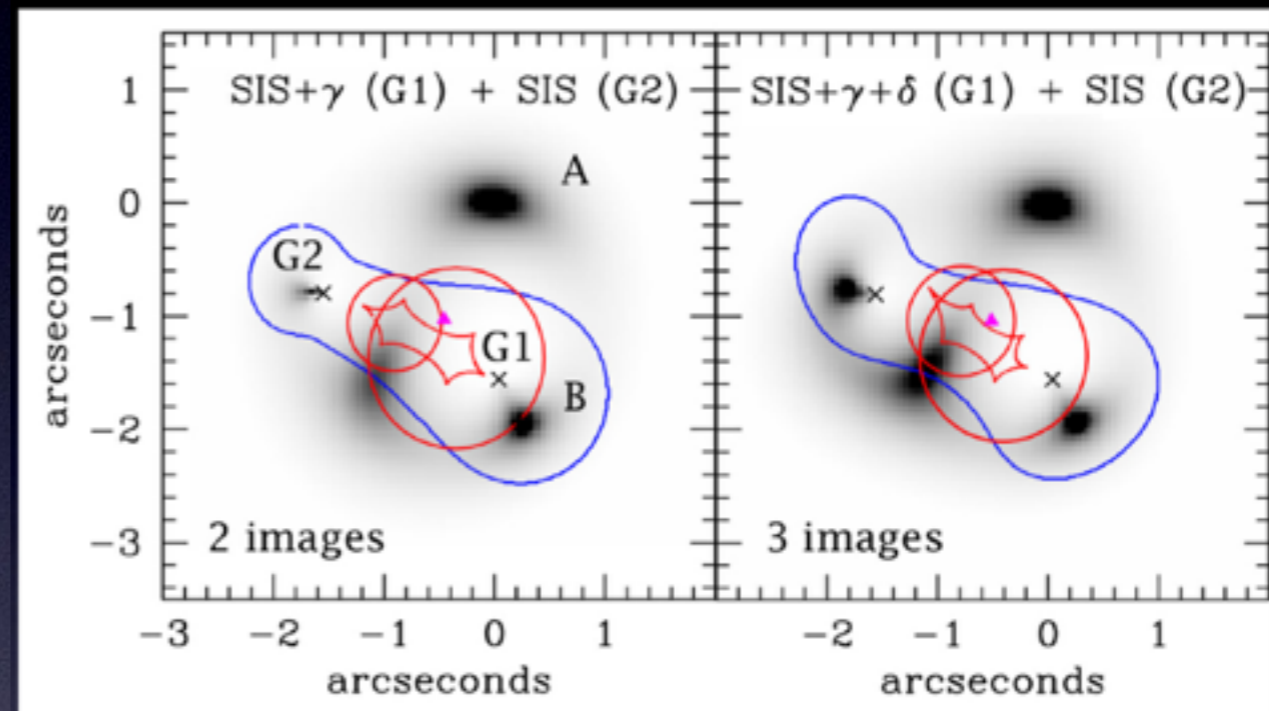
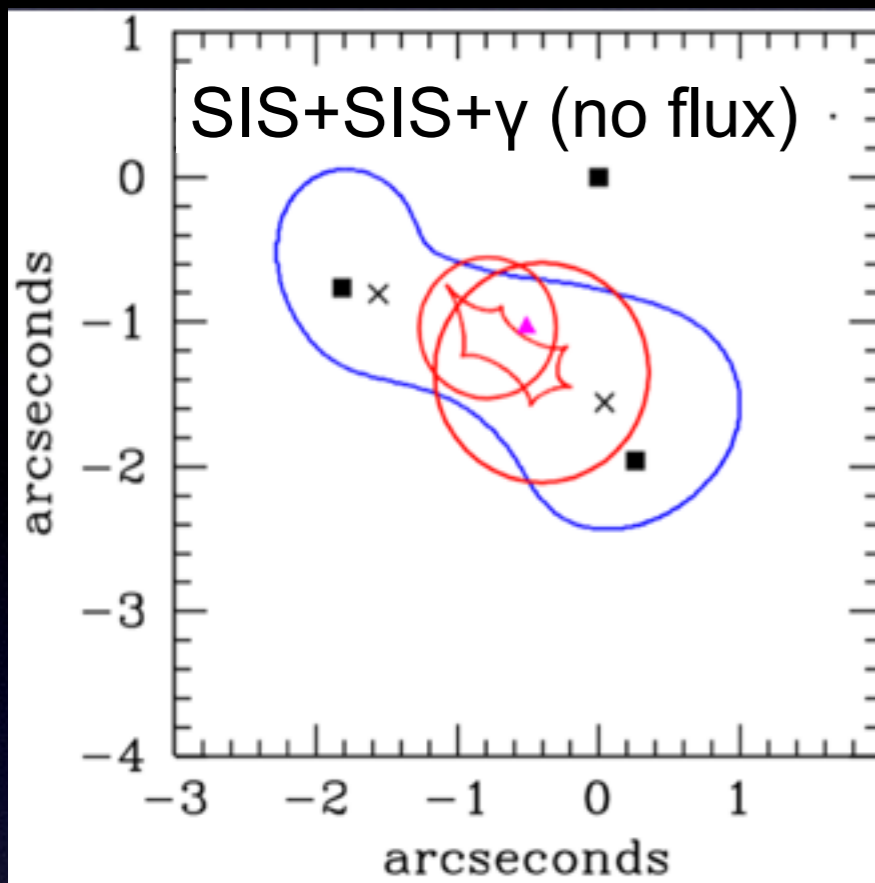
GY (aperture photometry) consistent with quasar redshift

can it be the host?



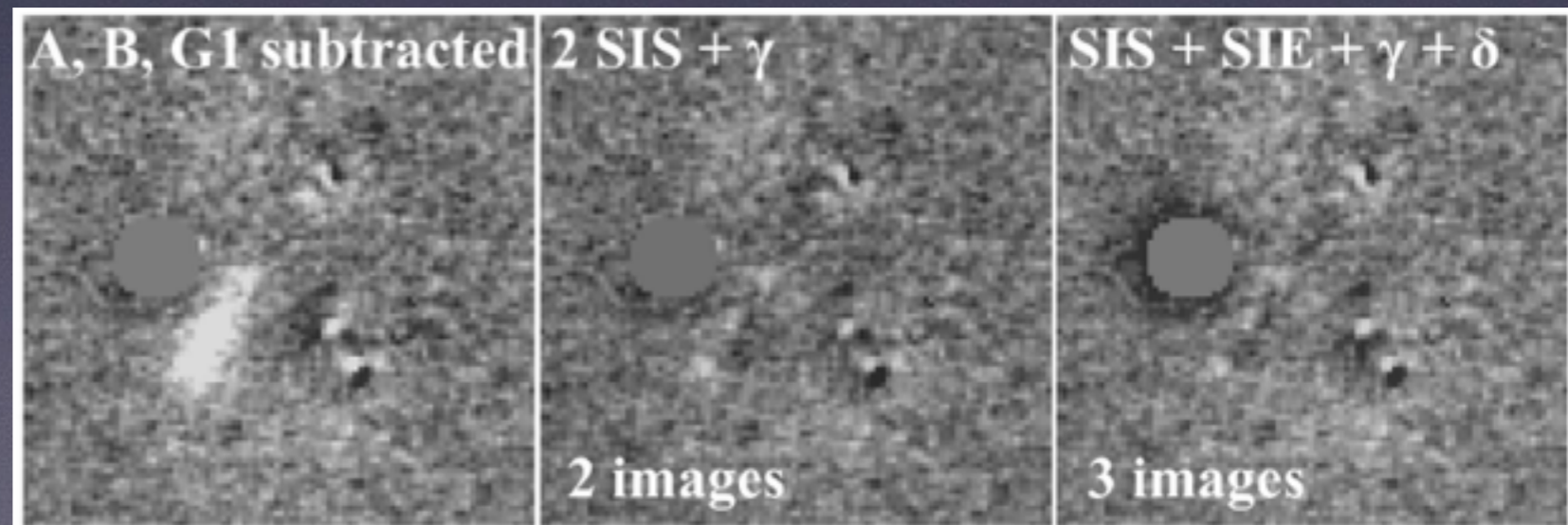
Nature of GX

- 1) galaxy at high-z: **unlikely, multiply imaged by G2**
- 2) star: **NO, different colors from any stars in near-IR**
- 3) 3rd quasar image: **lensing models with GX as the 3rd quasar image produce a good fit**



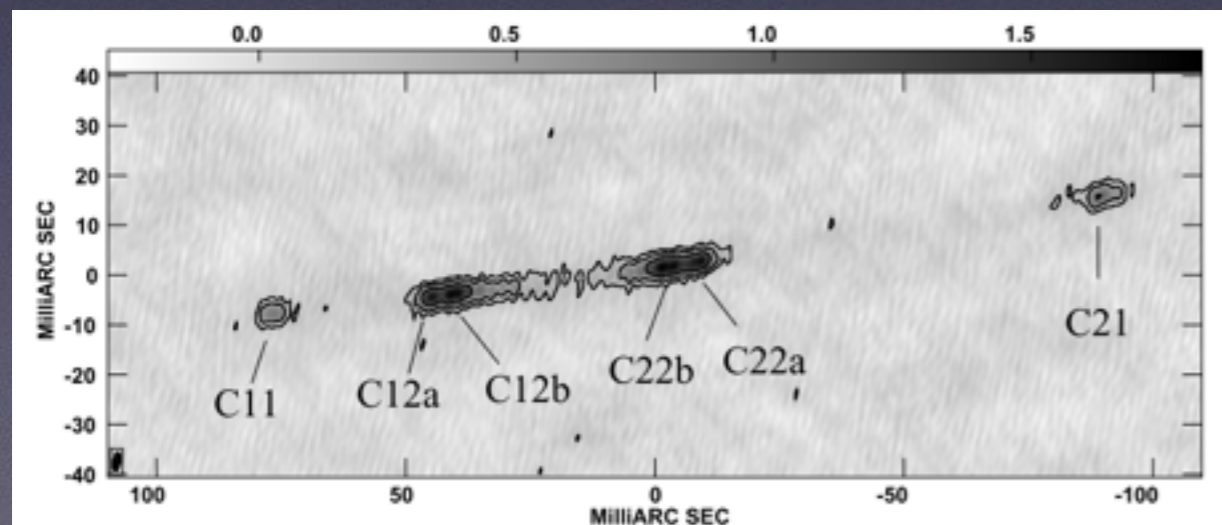
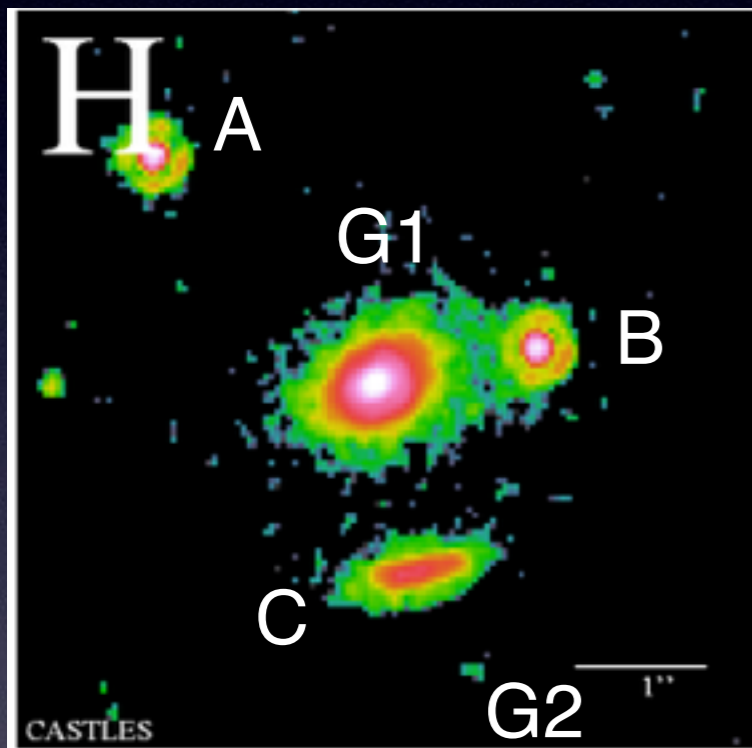
Nature of GY

Position, orientation, elongation consistent with expected host



→ SDSS J1405+0959 is the 2nd known lensed quasar with an observed quasar host galaxy arc component with no central quasar image

MG 2016+112



Conclusions and future prospects

- Conducted the first dedicated AO imaging campaign of lensed quasars
- Used the unique structure of lensed quasars to model the systems without a-priori known PSFs
- Detected several quasar hosts and modeled them without a-priori known PSFs
- Obtained relative astrometry, photometry, lens galaxy shapes comparable with HST results → vast improvement over results from low-resolution data
- Overall conclusion: AO can be used as HST alternative to model the 1000s of lenses from upcoming wide-field surveys: HSC, LSST etc.