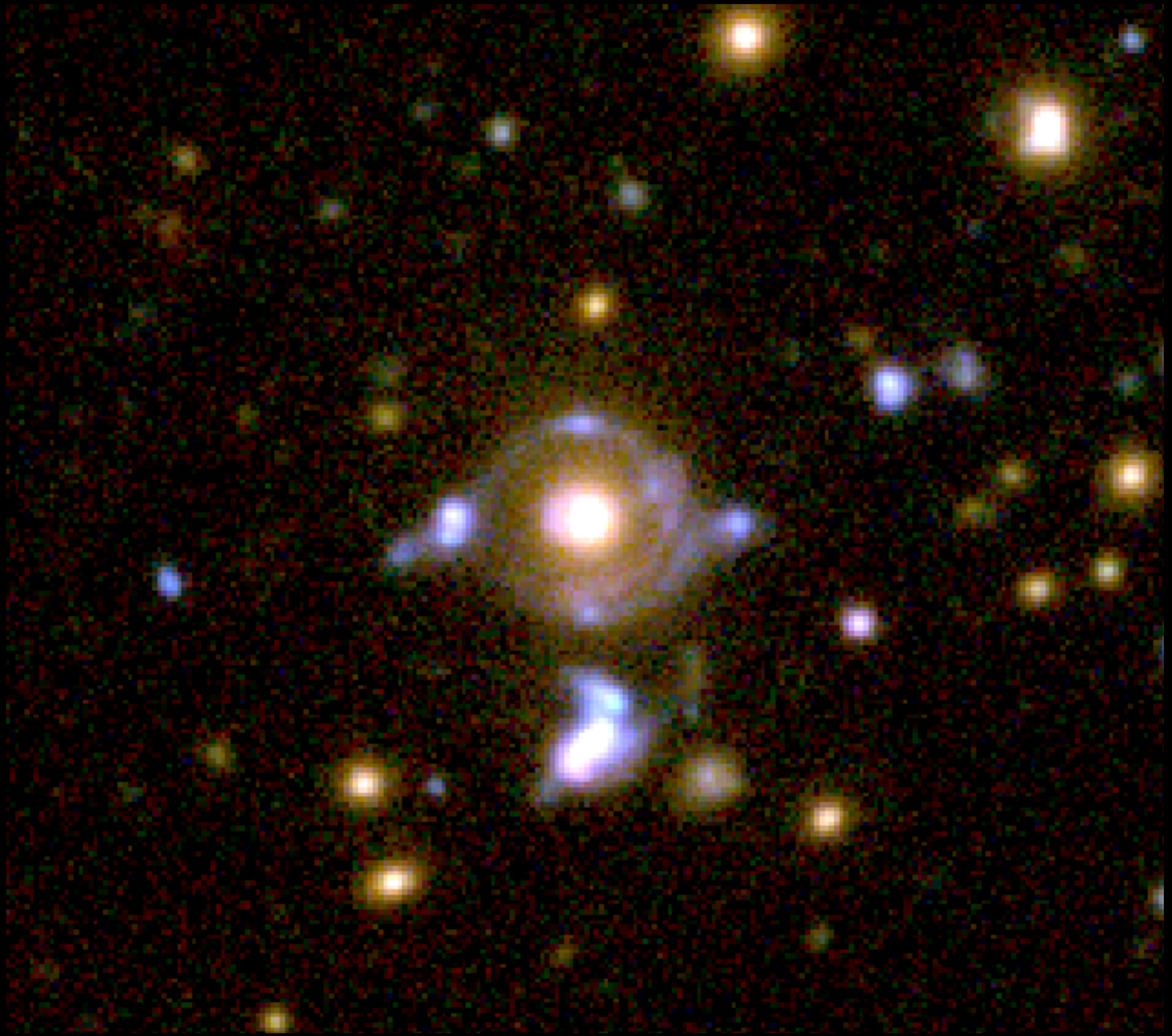
A Spectroscopically-Confirmed Double Source Plane Lens in the HSC SSP

Tanaka, Wong, et al. 2016, ApJ, 826, L19



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Subaru Users' Meeting FY2016
NAOJ
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East Asia Core Observatories Association

Strong Gravitational Lensing

- Background object (source) magnified by foreground object (lens)
- Multiple images → create lens model
- What can we learn from lensing?
  - total mass (within Einstein radius)
  - mass profile slope
  - ellipticity/orientation
  - substructure (both luminous and dark)
  - intrinsic (unlensed) source flux
  - detect/resolve source features by taking advantage of magnification
  - cosmology from time-delay lensed quasars (e.g., Suyu+2016, Wong+2016, Bonvin+2016)
- Surveys to build statistical samples of lenses (e.g., SLACS, SL2S, BELLS)
  - Mostly $z \lesssim 0.4$, up to $z \lesssim 0.8$
  - need deep, wide-area, high-resolution surveys to improve statistics, especially at higher z

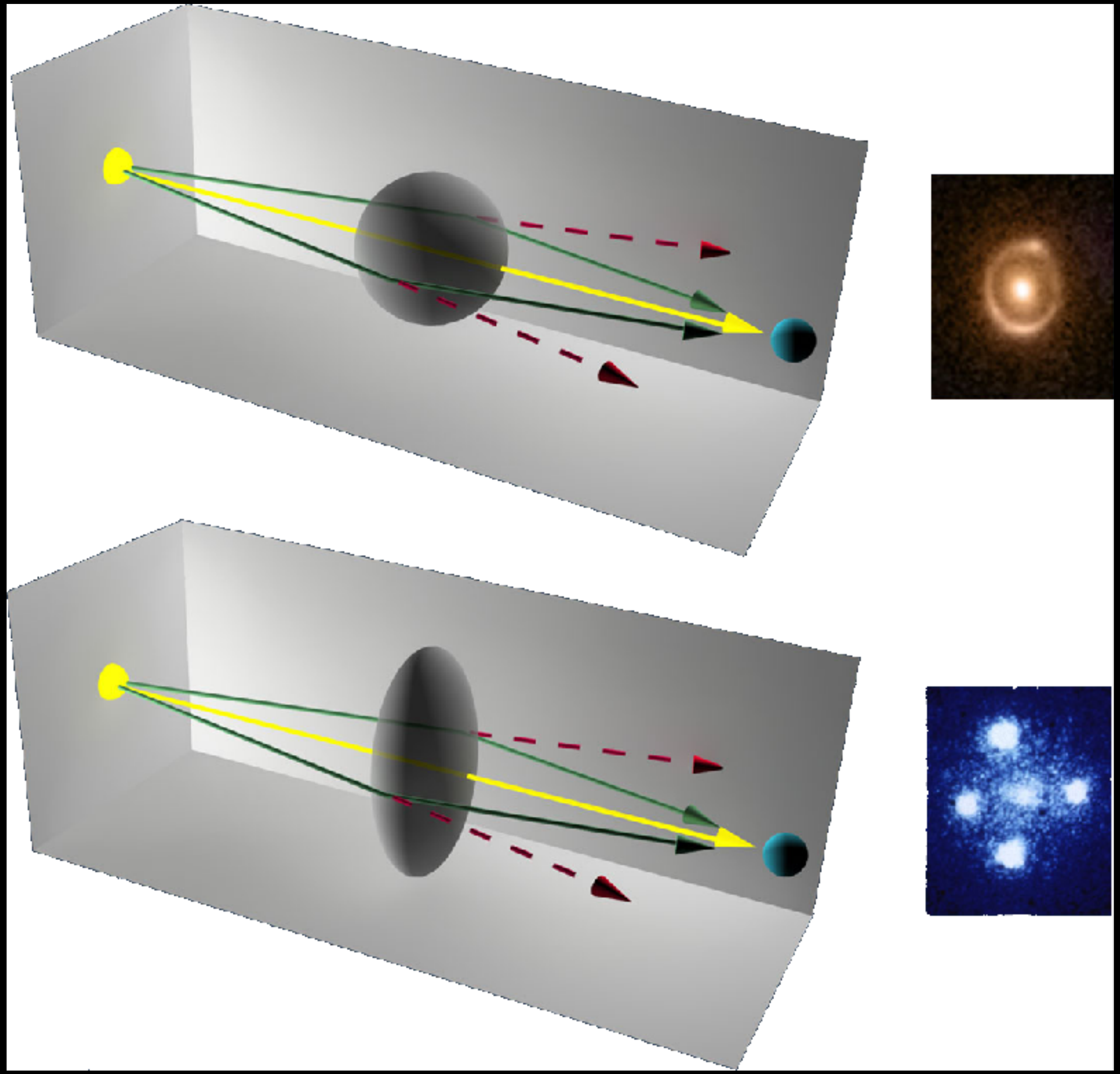
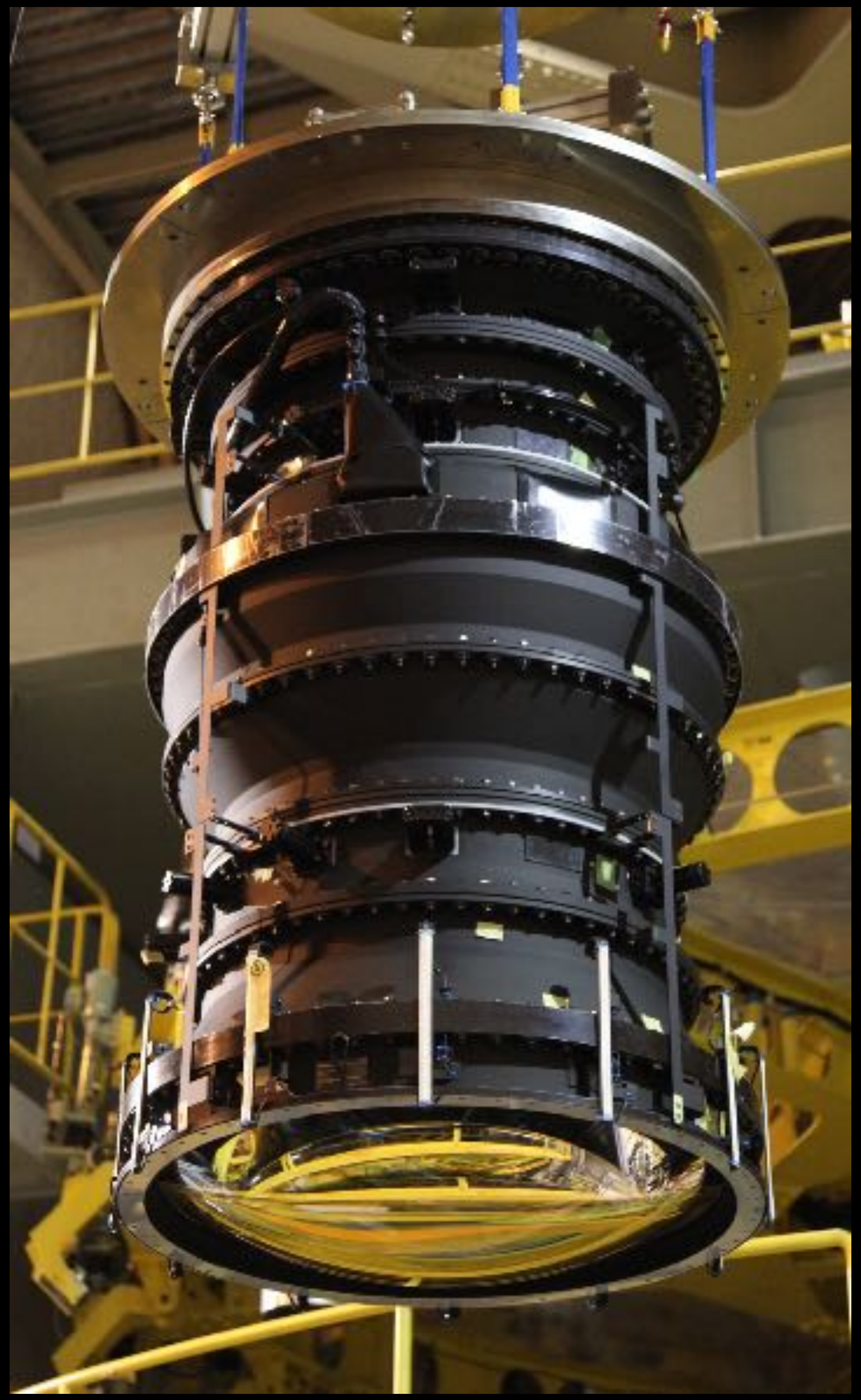
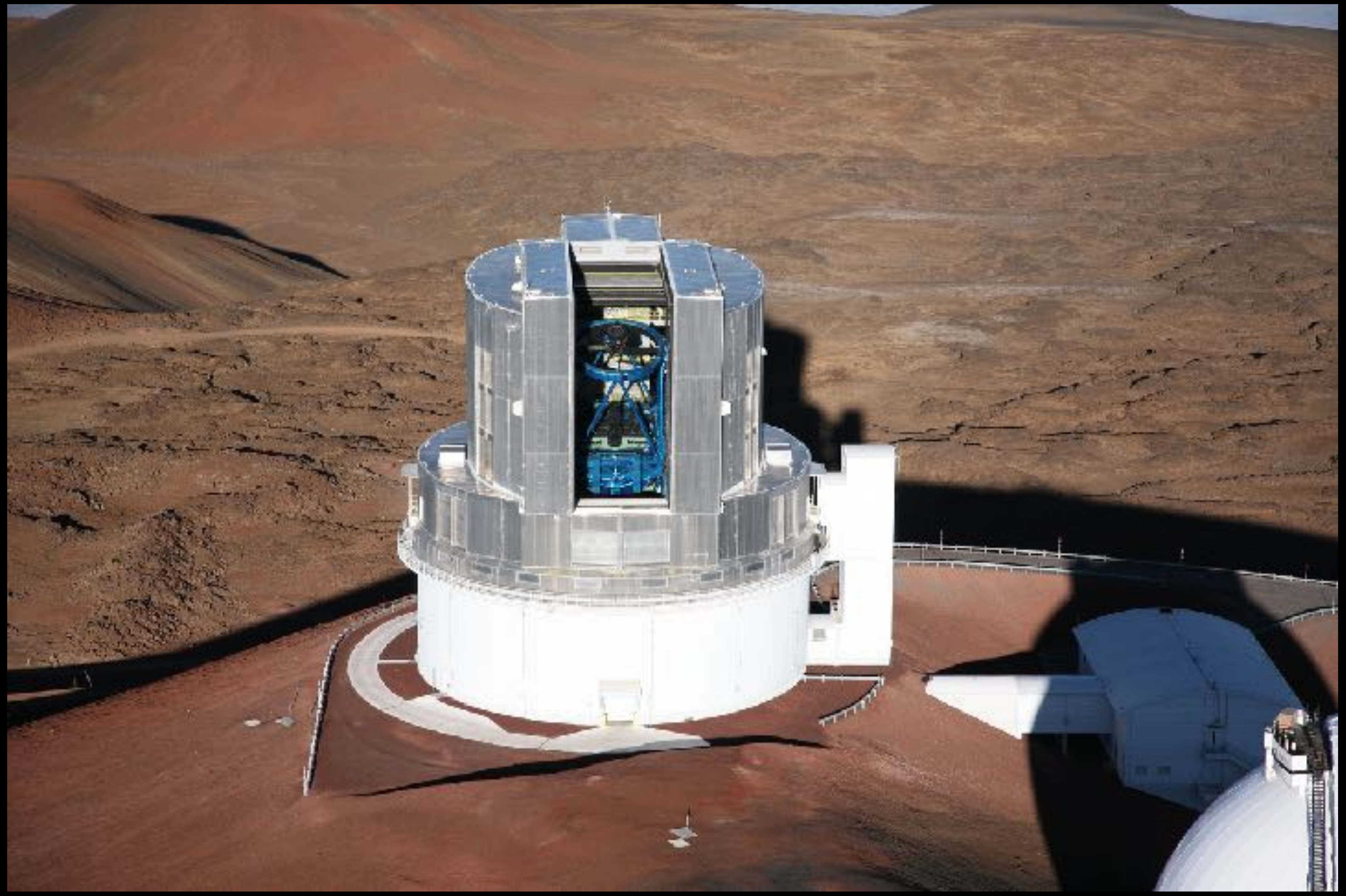


Image credit: ASIAA EPO

Discovering New Lenses with HSC

- Hyper Suprime-Cam SSP
  - 1400 deg^2 *grizy* imaging to r_{AB}~26
- ~30 group/cluster lens candidates
  - found through inspection of CAMIRA clusters (Oguri 2014)
- ~10 lensed quasar candidates
  - CHITAH algorithm (Chan+2015)
- Survey of Gravitational lens Objects in HSC Imaging (see talk by A. Sonnenfeld)
- Many lenses found serendipitously
  - potential to discover exotic lenses





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More et al. (in prep)

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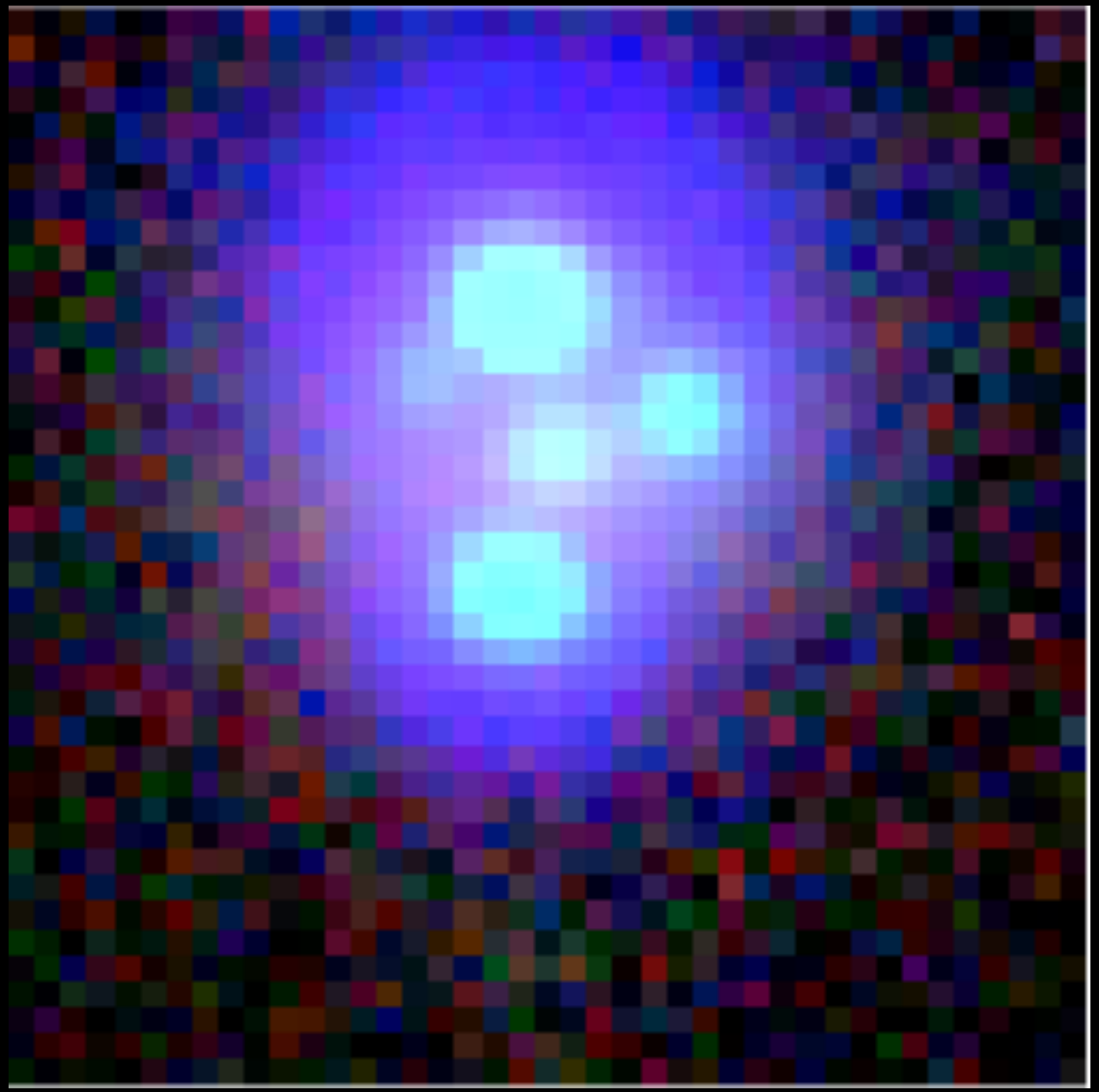
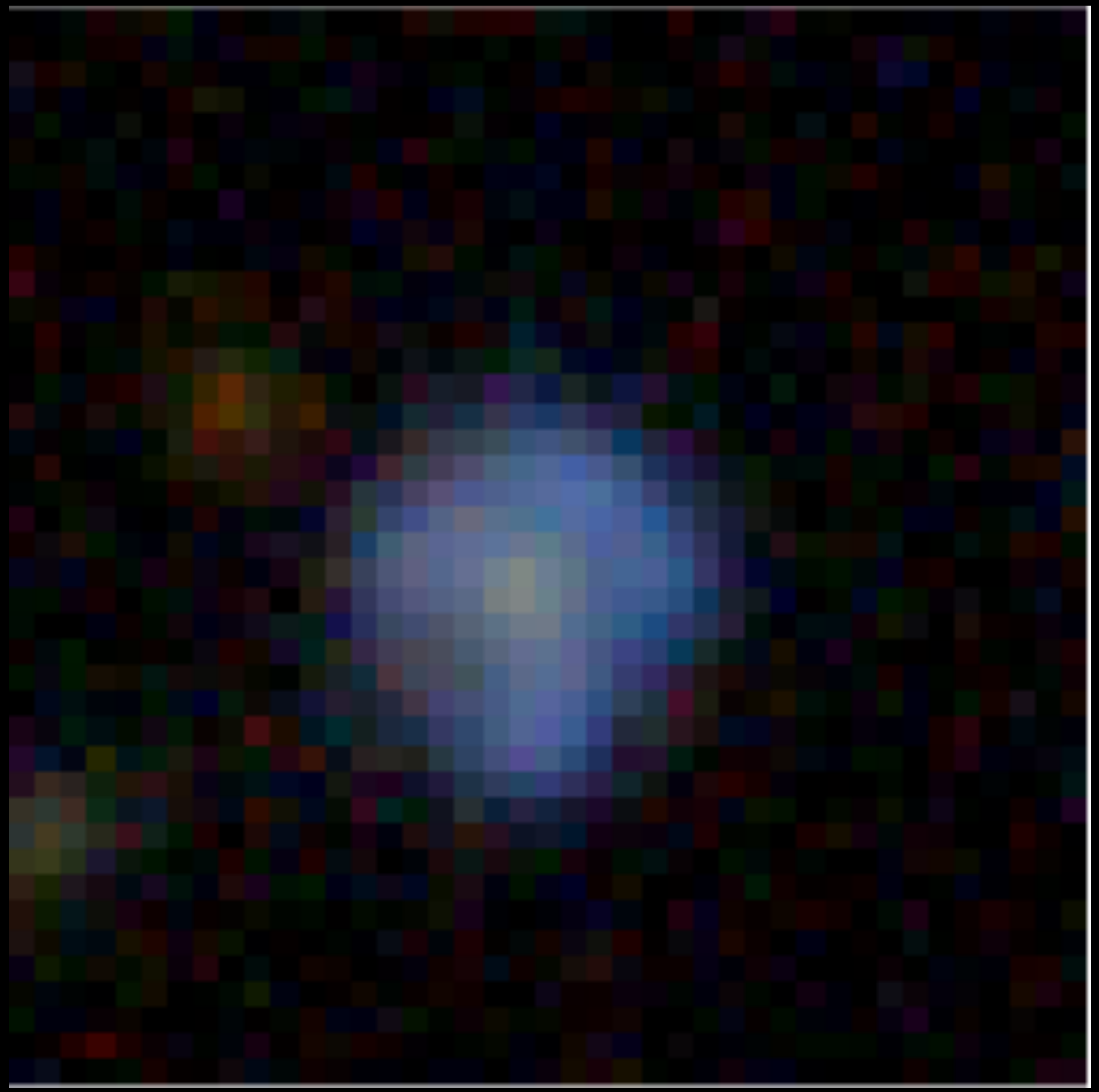
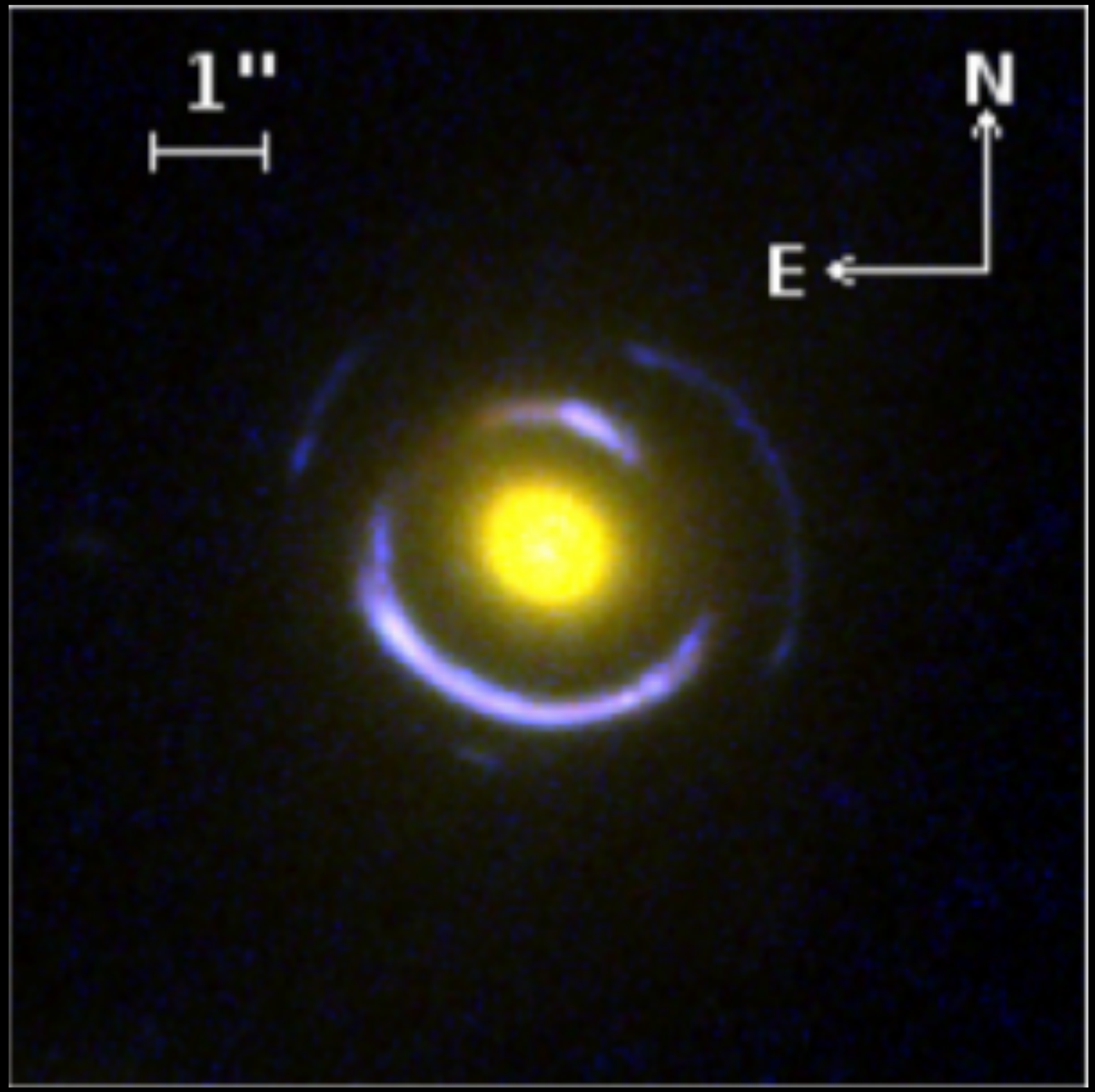




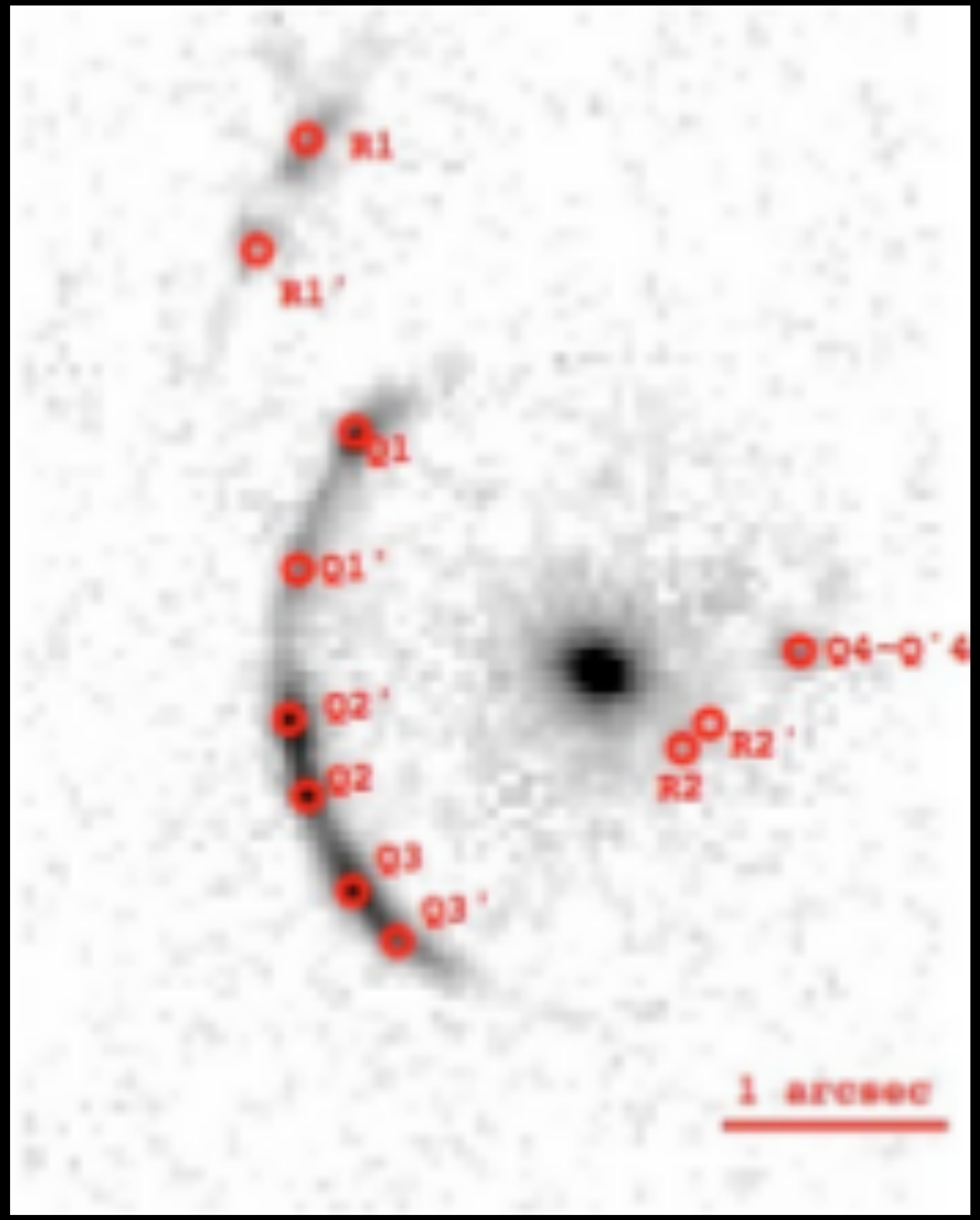
Chan et al. (in prep)

Double Source Plane Lenses

- Double source plane (DSP) lenses
  - two sources at distinct redshifts being lensed by the same galaxy
  - extremely rare, only a handful known (e.g., Gavazzi+2008, Tu+2009)
- Constraints from DSP lenses
  - can constrain Ω_m and w, independent of H_0 (e.g., Collett+2012,2014)
  - can break model degeneracies (although see Schneider 2014), constrain mass structure, IMF (e.g., Sonnenfeld+2012)



Sonnenfeld+2012



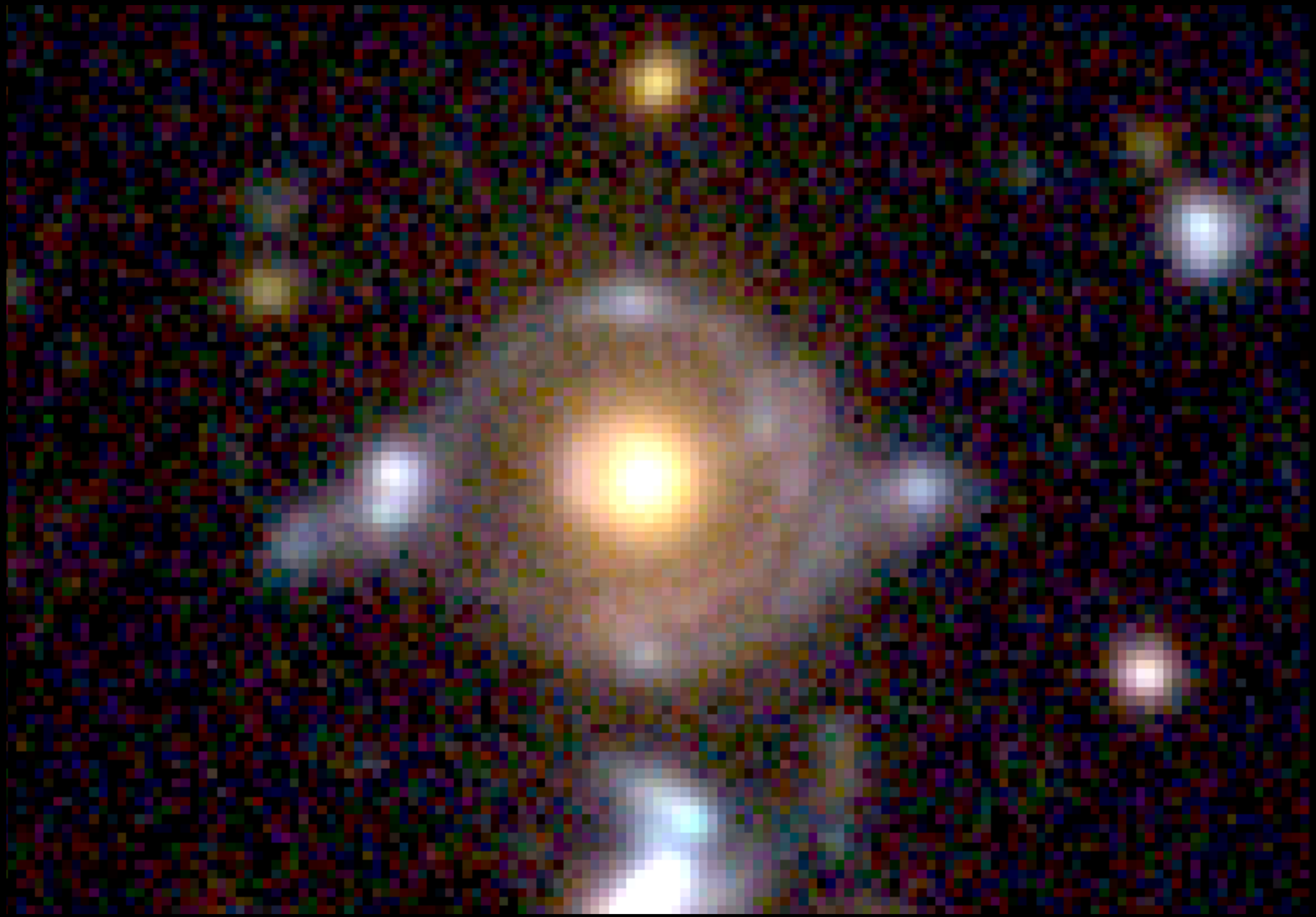
Tu+2009

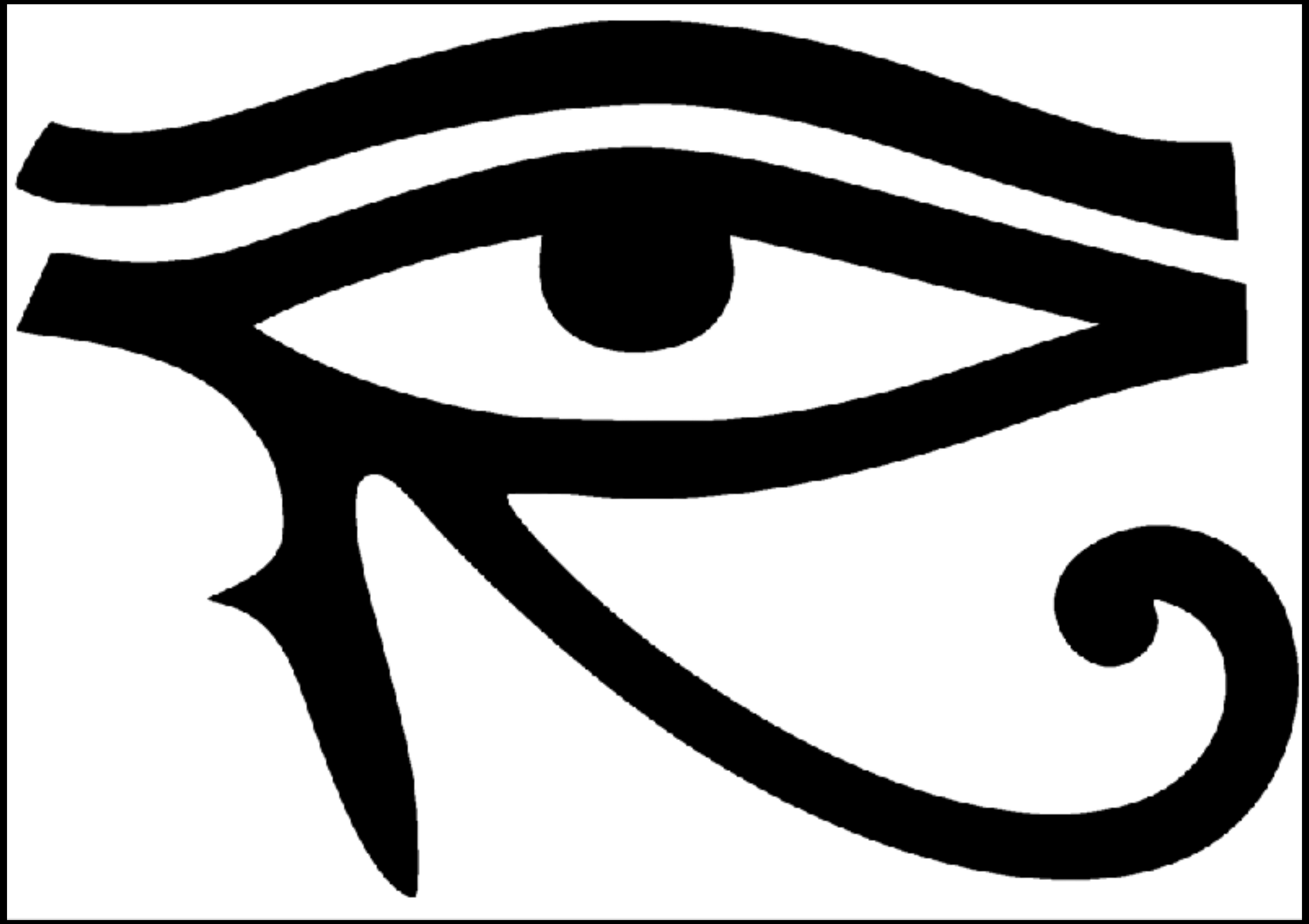
Discovery of the First DSP Lens in the HSC SSP

Tanaka, Wong, et al. (2016)

- Double source plane (DSP) lens serendipitously discovered in HSC SSP
  - inner arc and counterimage (S1)
  - outer Einstein ring with central knot (S2)
- All redshifts spectroscopically confirmed from Magellan/FIRE observations
  - $z_L = 0.795$
  - $z_{S1} = 1.30$
  - $z_{S2} = 1.99$
  - first known DSP lens with both source redshifts spectroscopically confirmed
- Press release: naoj.org/Pressrelease/2016/07/25/index.html

The “Eye of Horus”





Kenneth Wong (NAOJ)

Subaru Users’ Meeting
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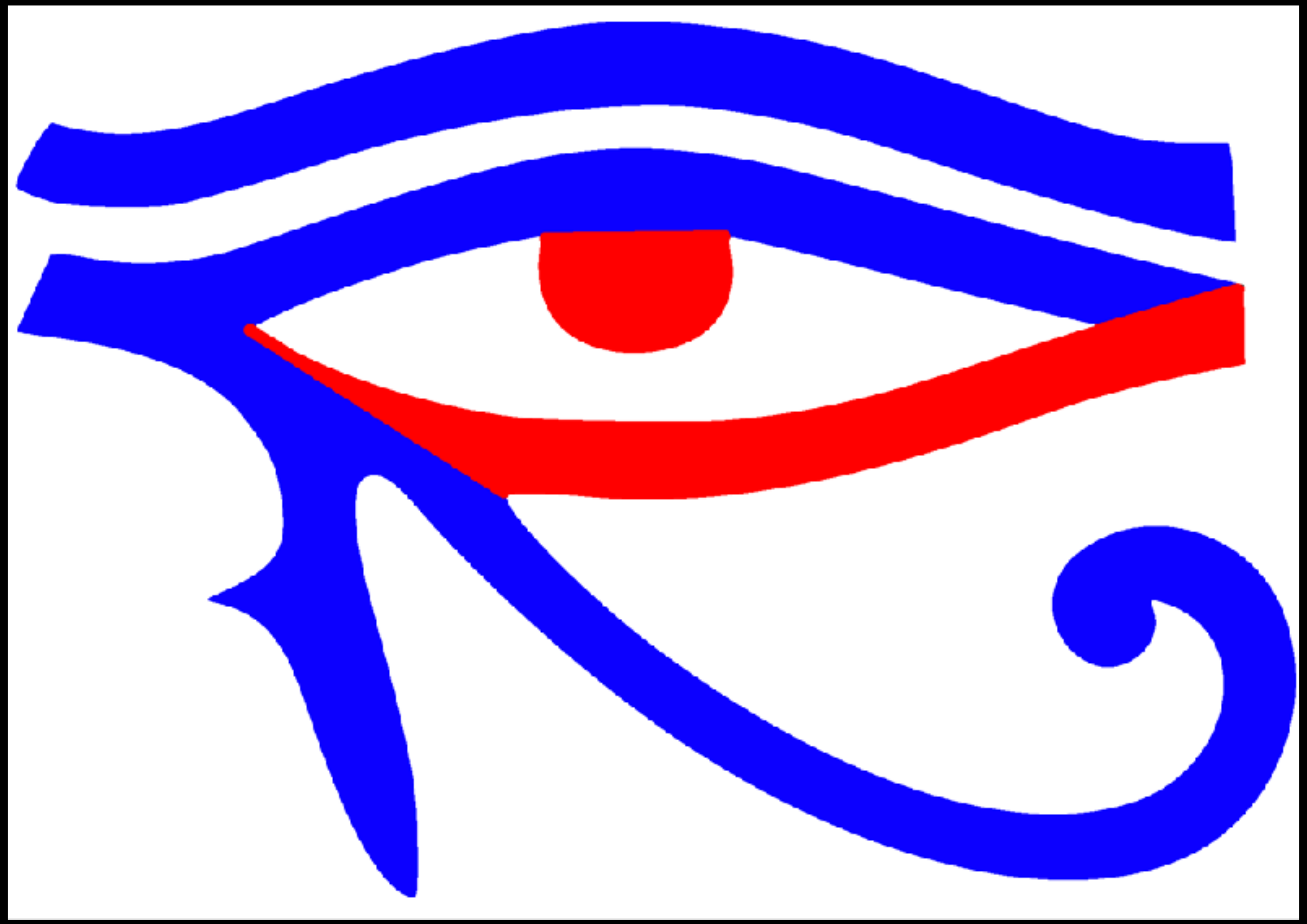
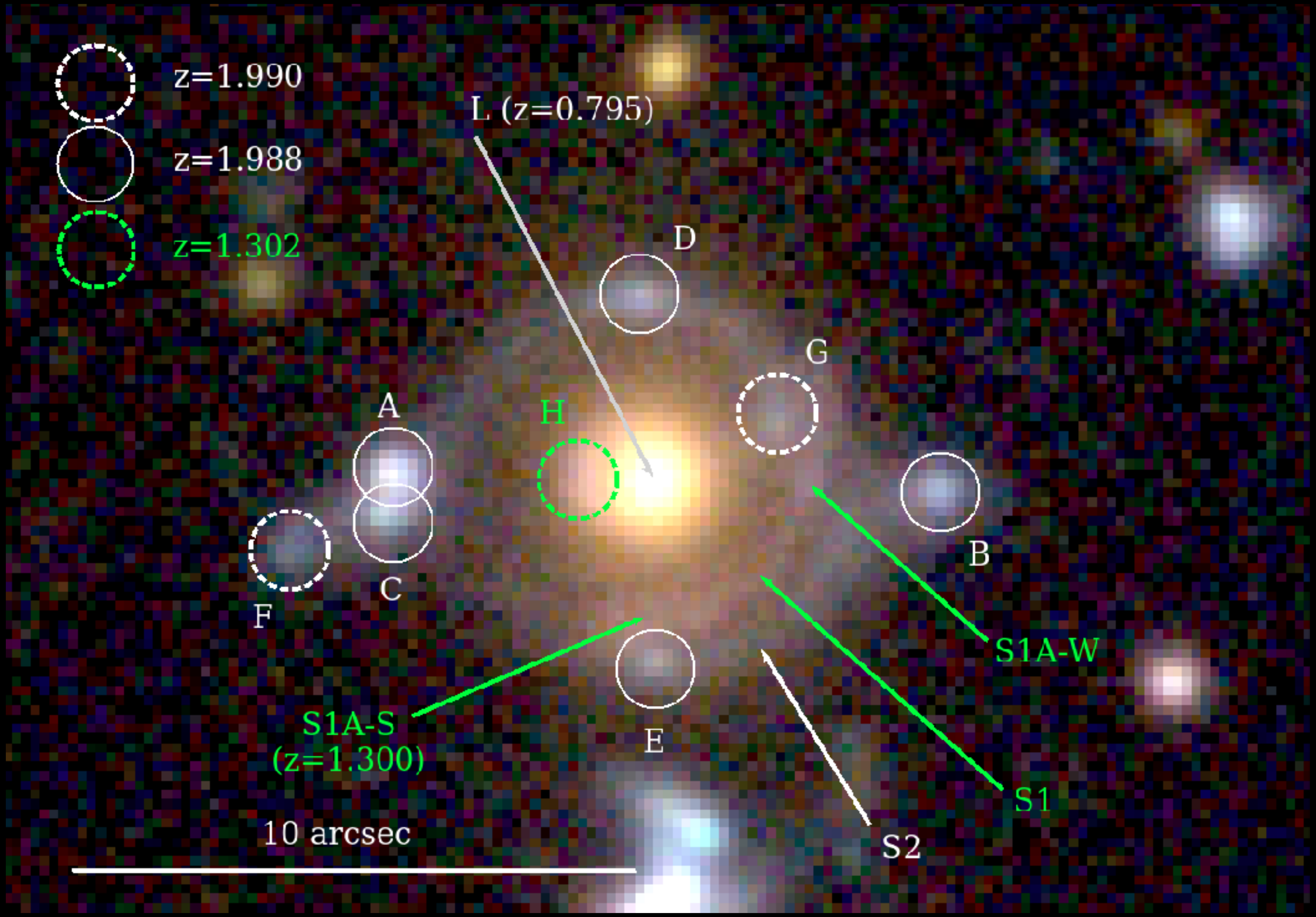


A Closer Look Into the Eye of Horus

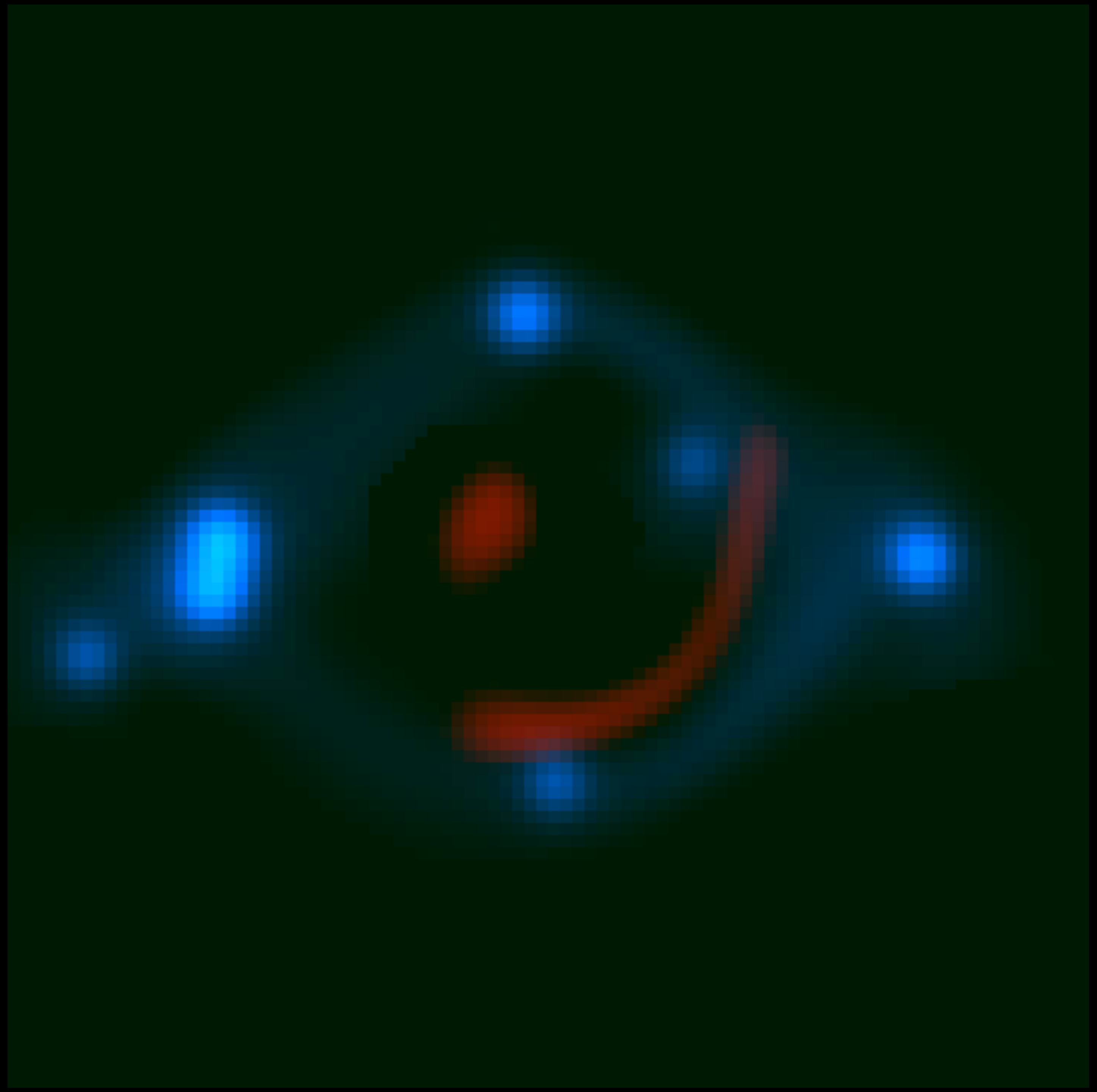
- S1A has slight velocity offset
  - rotating disk?
- Features F and G at z≈1.99, but slightly offset from rest of S2
  - S2 could be interacting galaxy pair
- One of the images of S2 is split into two distinct peaks (A+C)
  - suggests mass structure causing image splitting
  - no evidence of a galaxy between A and C from ground-based data, need higher resolution

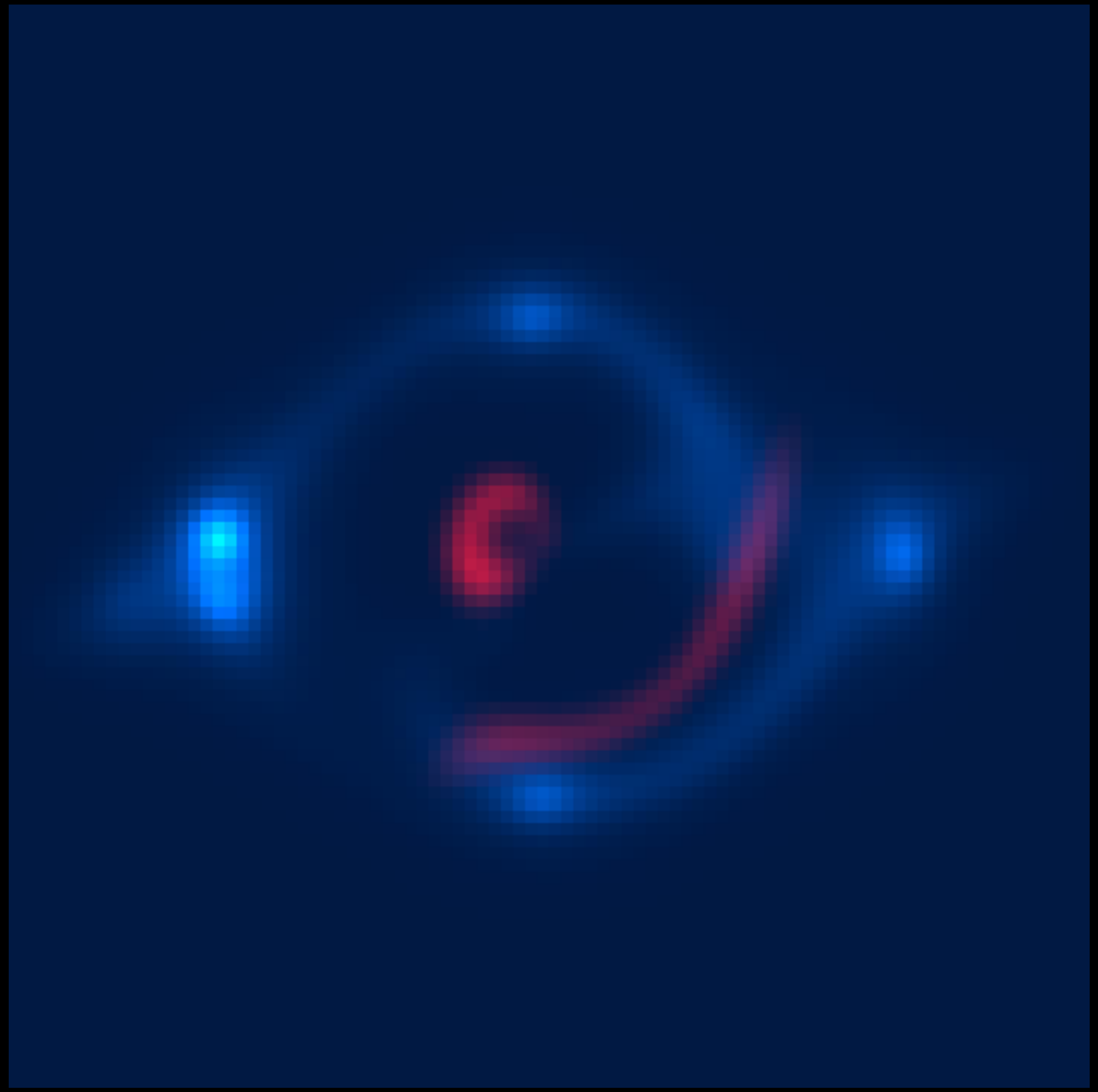


Tanaka, Wong, et al. (2016)

Modeling the Eye of Horus

- Eye of Horus is a “compound” lens
  - S2 is being lensed by both the main lens galaxy and by S1
  - recursive multi-plane effects
- Preliminary models using HSC data
  - broadly reproduce main features
  - require additional mass component to split A+C into two images
- Need higher-resolution data (e.g. *HST*, ALMA, AO) for better constraints
  - ALMA Cycle 4 observations scheduled
  - Subaru/IRCS+AO188 observations in 2017A
- Lens might be in a cluster, need to include environment effects
  - existing multi-object spectroscopy of nearby galaxies
  - upcoming X-ray observations with XMM to probe cluster environment





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Science Goals

- Cosmological constraints, complementary to CMB, BAO, time-delay lenses
- Mass structure of lens
  - constrain stellar IMF of early-type galaxy at z~0.8
  - structure of satellite galaxy from analysis of high-resolution imaging
- High-resolution studies of source galaxies with ALMA
- Expect to find ~10 DSP lenses in HSC survey

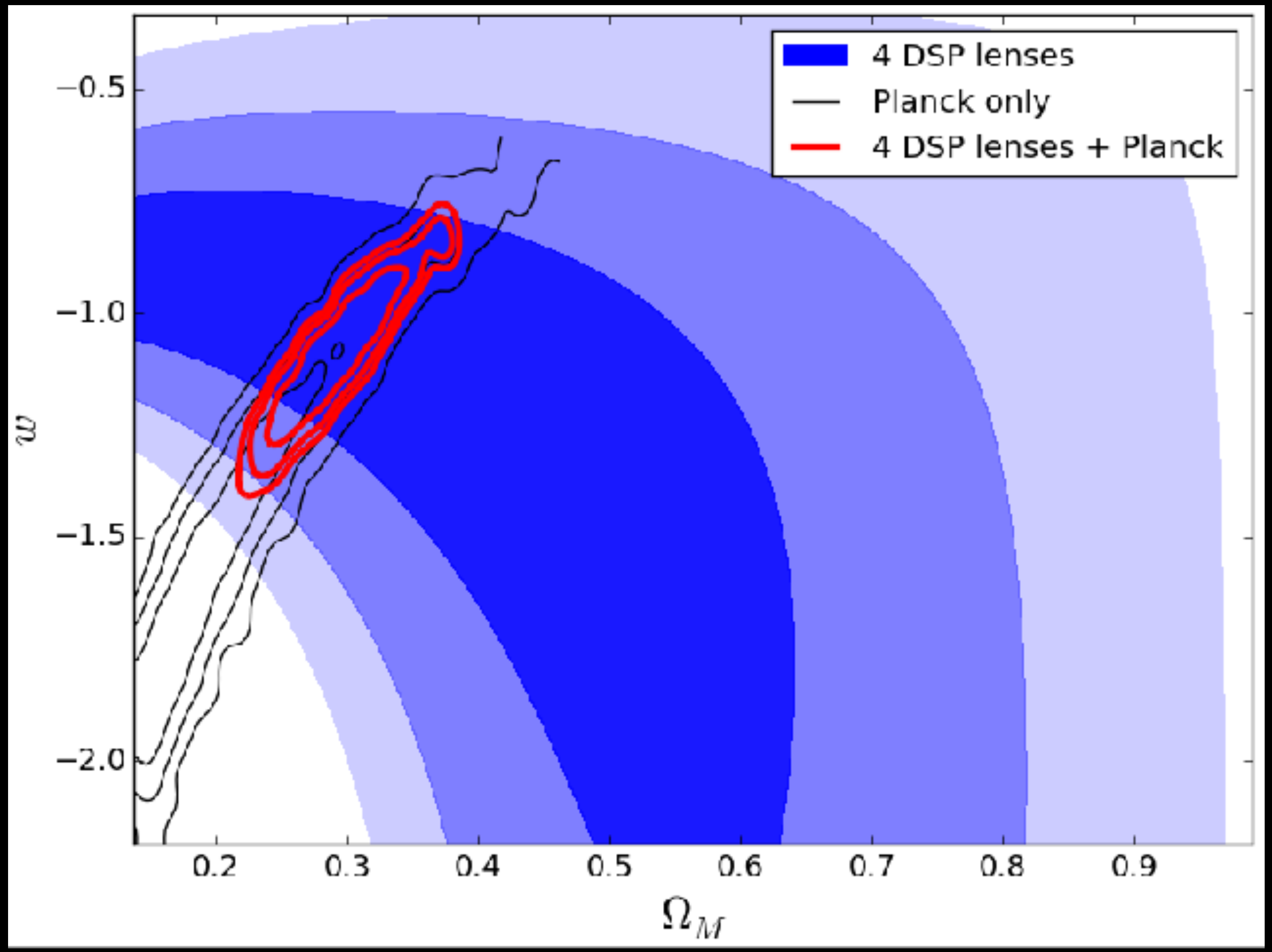

Image credit: A. Sonnenfeld

Simulated AO image

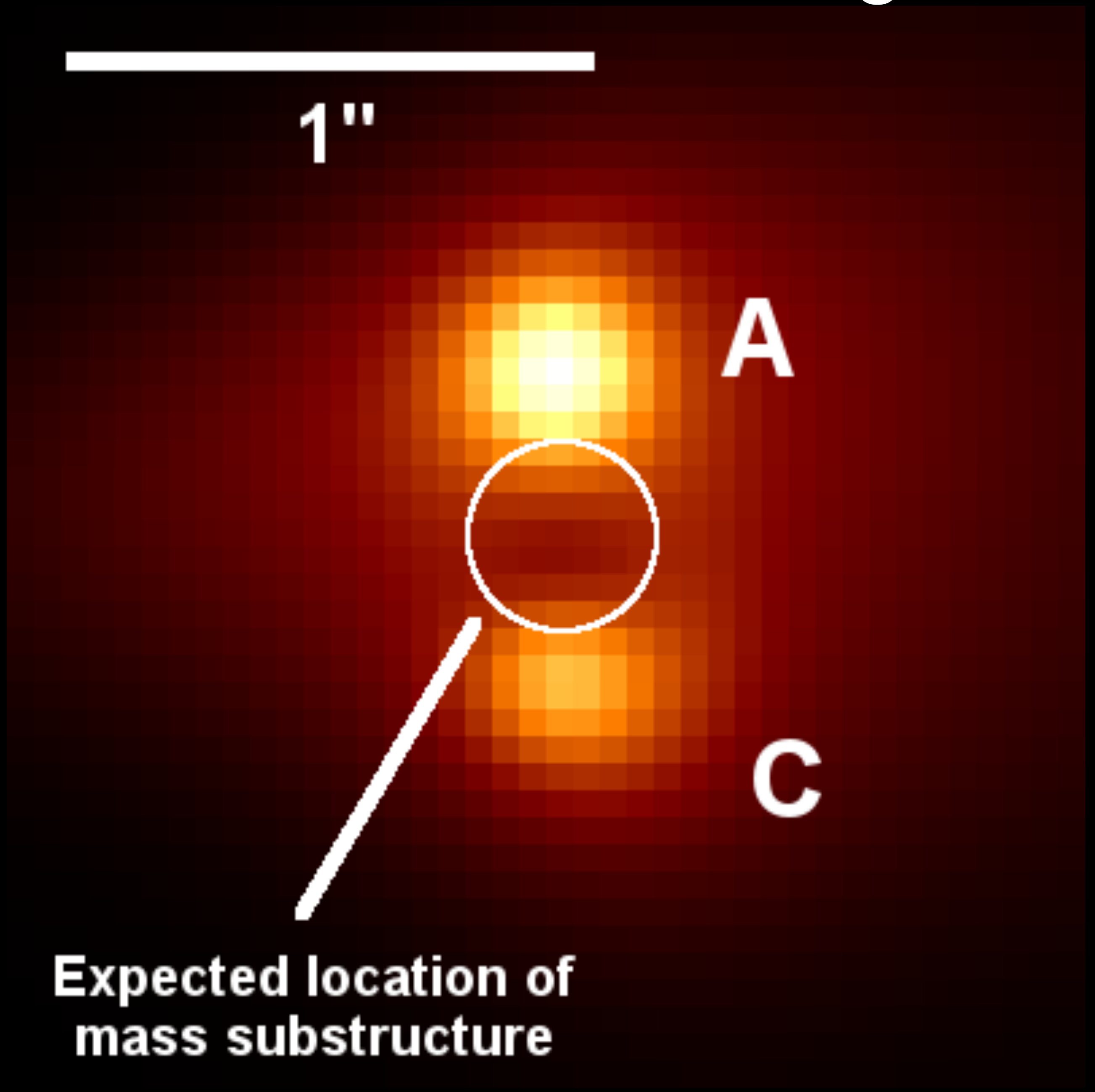

Image credit: A. More

Summary

- HSC SSP will discover hundreds of new lenses at galaxy and group/cluster scales
- Discovery of the "Eye of Horus", the first double source plane lens found in the HSC SSP (Tanaka, Wong, et al. 2016)
- Eye of Horus is the first DSP lens with all redshifts spectroscopically confirmed
  - $z_L = 0.795$, $z_{S1} = 1.30$, $z_{S2} = 1.99$
- Possible substructure causing additional image splitting of A+C
- High-resolution data (e.g., *HST*, ALMA, AO) needed for more detailed modeling
  - ALMA Cycle 4 observations scheduled
  - 2017A IRCS+AO188 observations scheduled
- Modeling efforts will make this system useful for cosmology and galaxy evolution studies