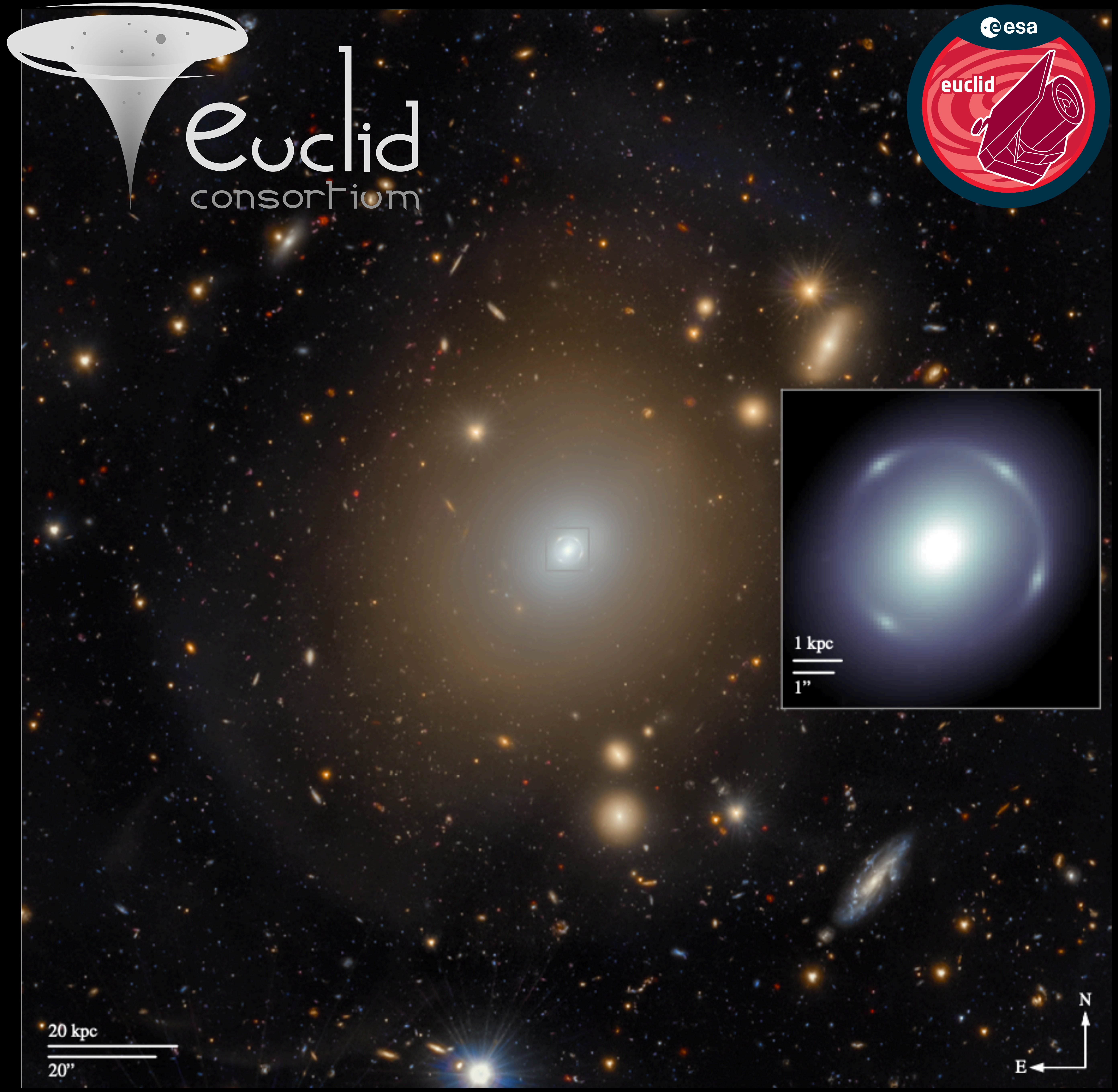



# Finding galaxy strong lenses in Euclid data
# and
# what we can do with them

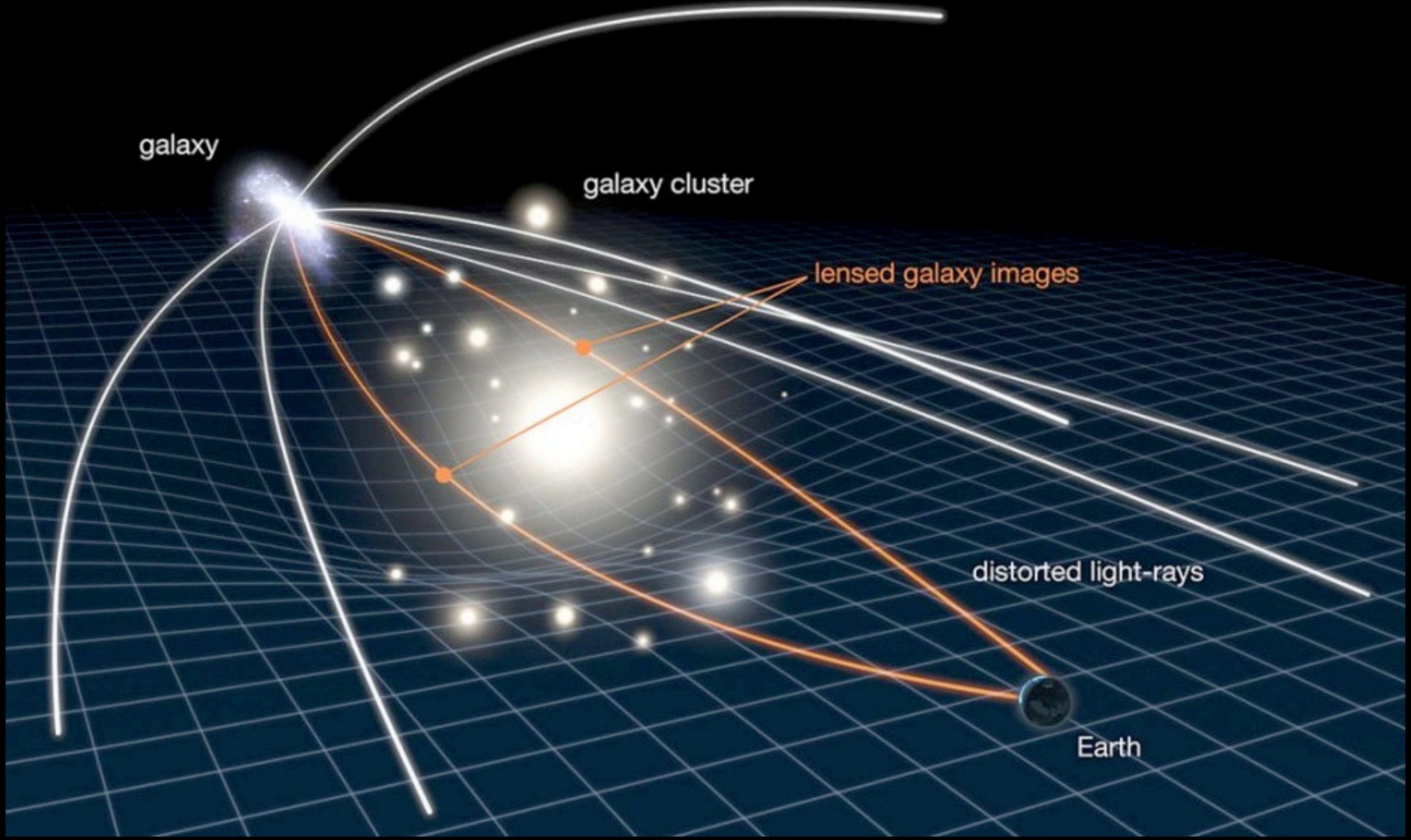
Giulia Despali

University of Bologna

## First results from the galaxy SL KP

**KP Coordinators:**
**GD, Tom Collett, Stefan Schuldt**

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA




- the shape of the image is heavily affected by the lensing
- <u>small</u> angular separation between the source and the lens position, i.e. almost aligned
- occurs in the central regions of galaxies and galaxy clusters where the density is super “critical”
- <u>**multiple images**</u> of background sources, such as bright QSO
- extended sources may be heavily distorted in <u>**gravitational arcs**</u>

# STRONG LENSING

## galaxy-galaxy lensing

J1148 - By ESA/Hubble NASA


Euclid consortium
STRONG LENSING
galaxy-galaxy lensing
Foreground lens galaxy:
Luminous Red Galaxy
z=0.444
J1148 - By ESA/Hubble NASA


Euclid
consortium
STRONG LENSING
galaxy-galaxy lensing
Foreground lens galaxy:
Luminous Red Galaxy
z=0.444
Background galaxy:
blue
star forming ~100M/yr
z=2.38
J1148 - By ESA/Hubble NASA


euclid
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STRONG LENSING
galaxy-galaxy lensing
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J1347
Red ruggets
(Oldham+2017)
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galaxy-galaxy lensing
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ESA/Treu/Schmidt
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Euclid consortium
STRONG LENSING
galaxy-galaxy lensing
SHARP Keck data
(Kyatta et al. in prep.)
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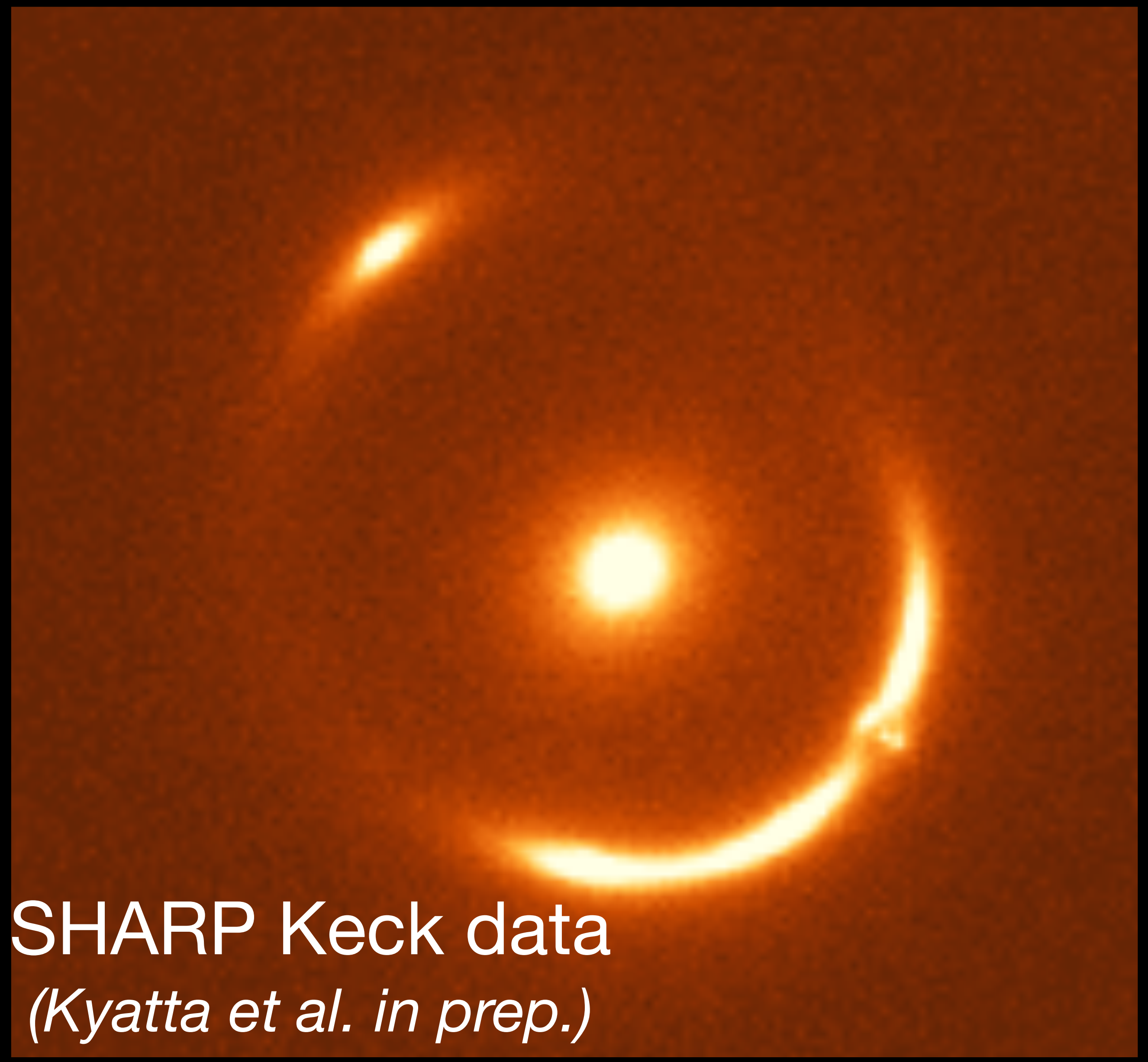
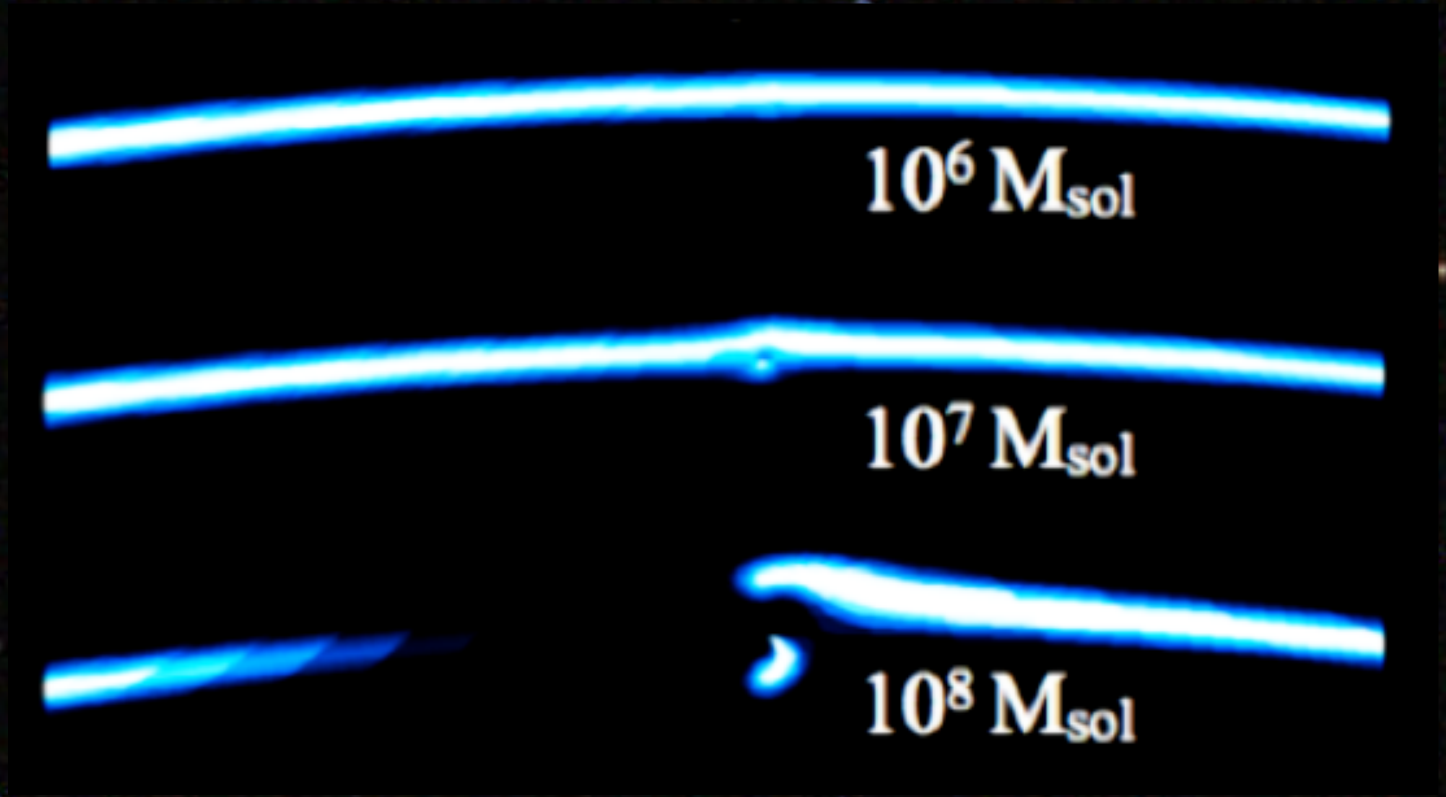
# STRONG LENSING

galaxy-galaxy lensing



SHARP Keck data

*(Kyatta et al. in prep.)*




ESA/Treu/Schmidt

Lensed quasars

Foreground lens galaxy:
Luminous Red Galaxy
z=0.444

Background galaxy:
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star forming ~100M/yr
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Red ruggets

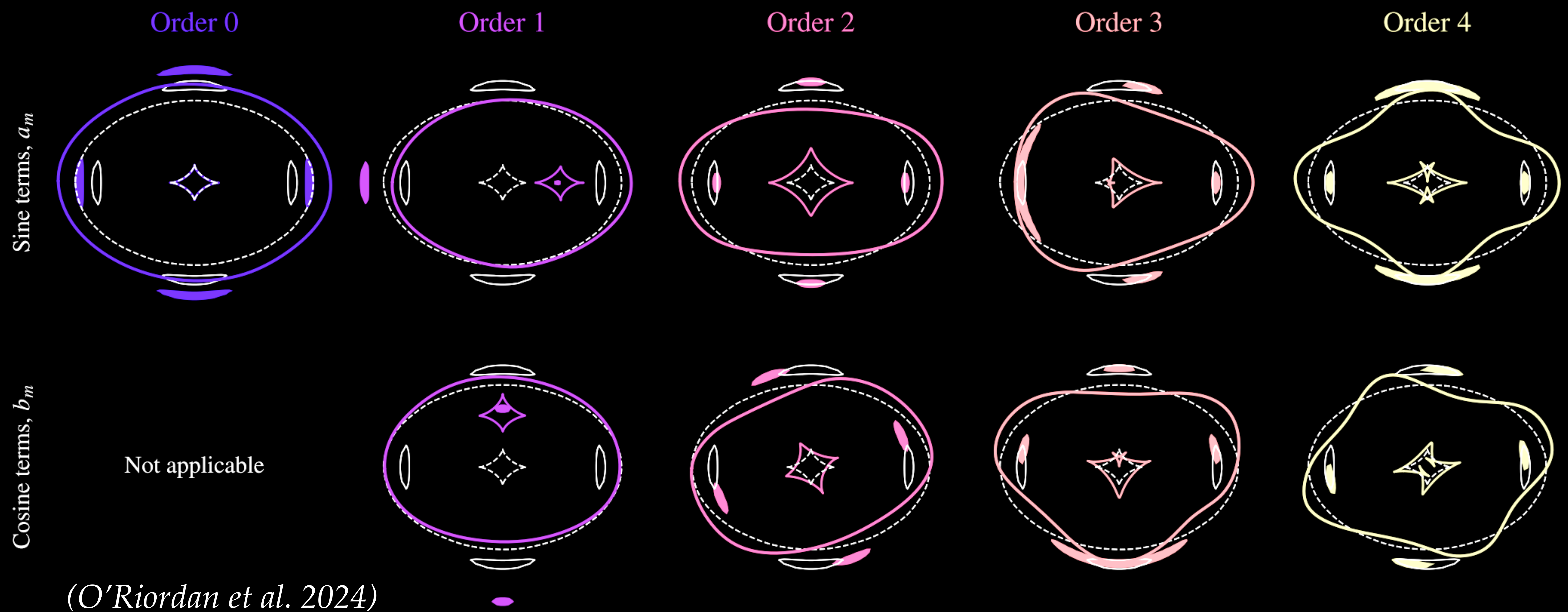
*(Oldham+2017)*

J1148 - By ESA/Hubble NASA

# KEY ASPECT: MASS MODELING

Bayesian codes

1. model the lens light (usually with a Seršič profile)
2. model the lens projected mass: ellipsoidal power-law +external shear +multipoles
3. model the subhalos: analytical profiles (NFW, power-law)




*(O'Riordan et al. 2024)*

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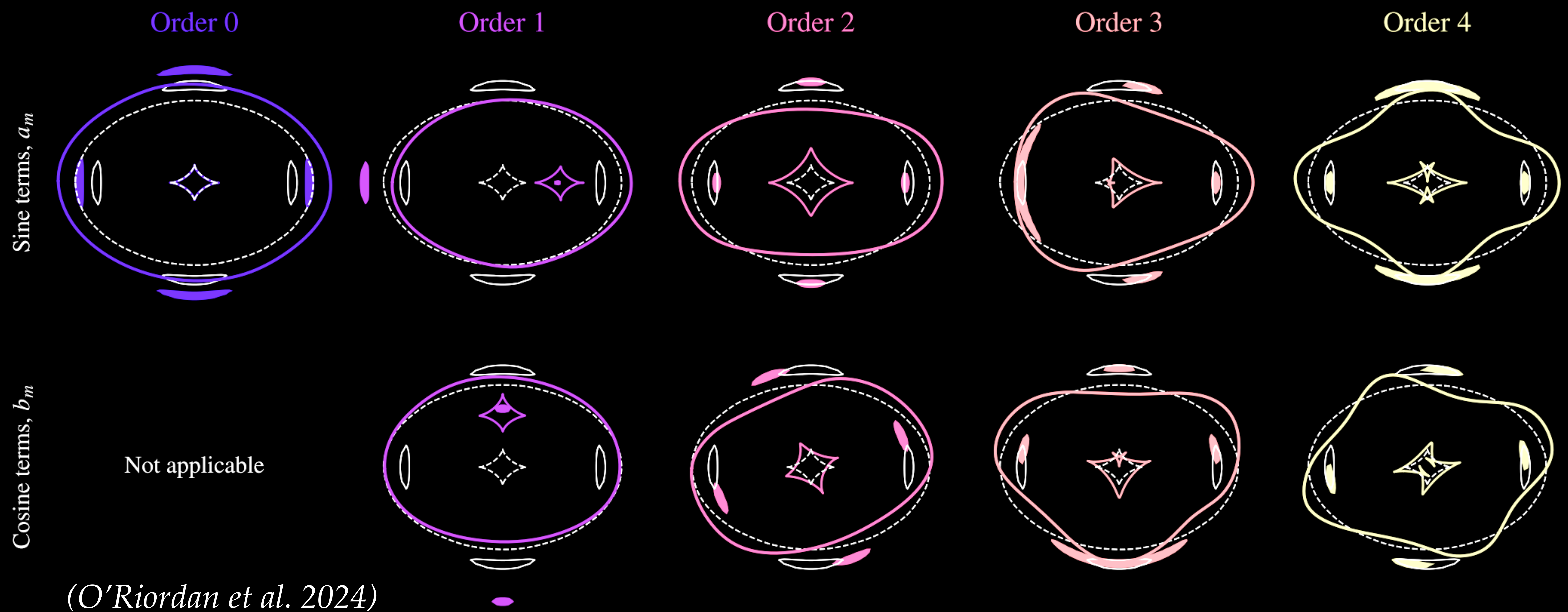


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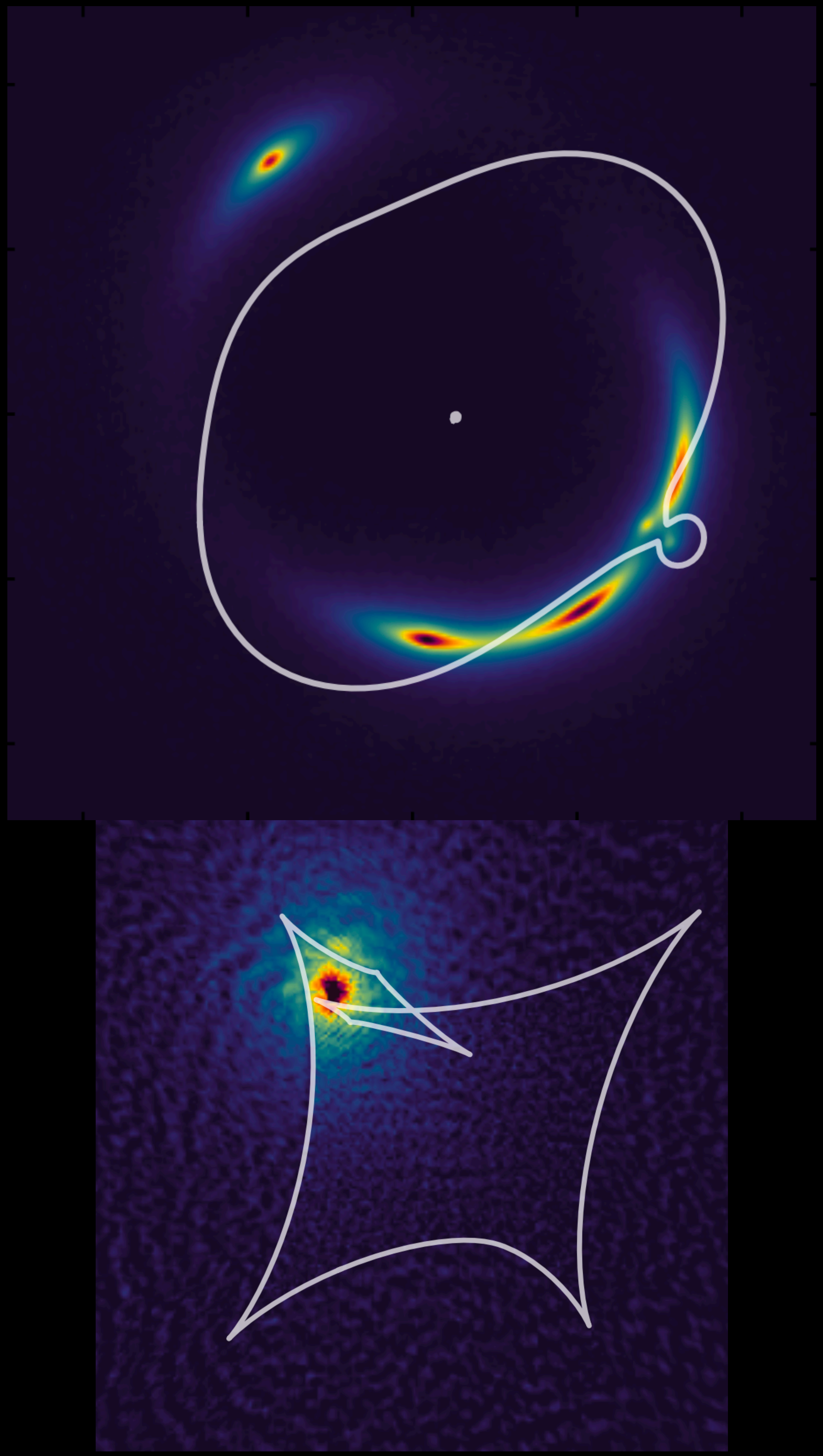

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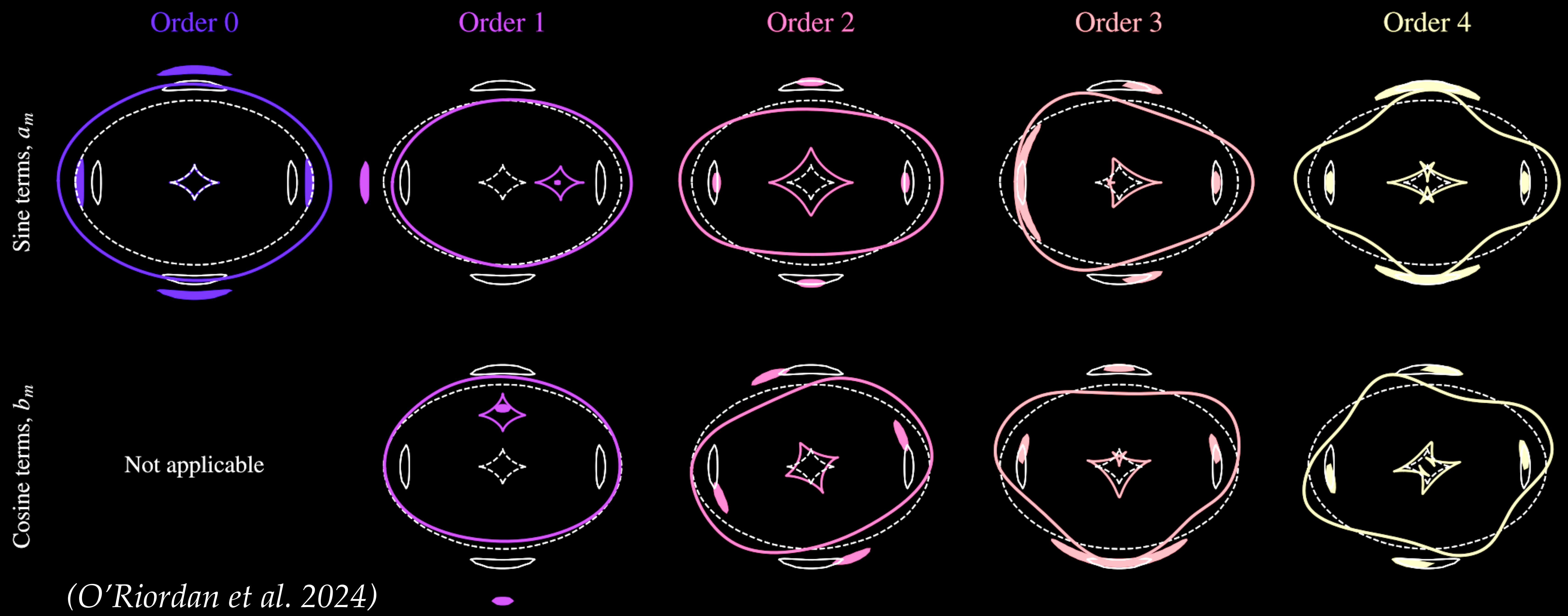


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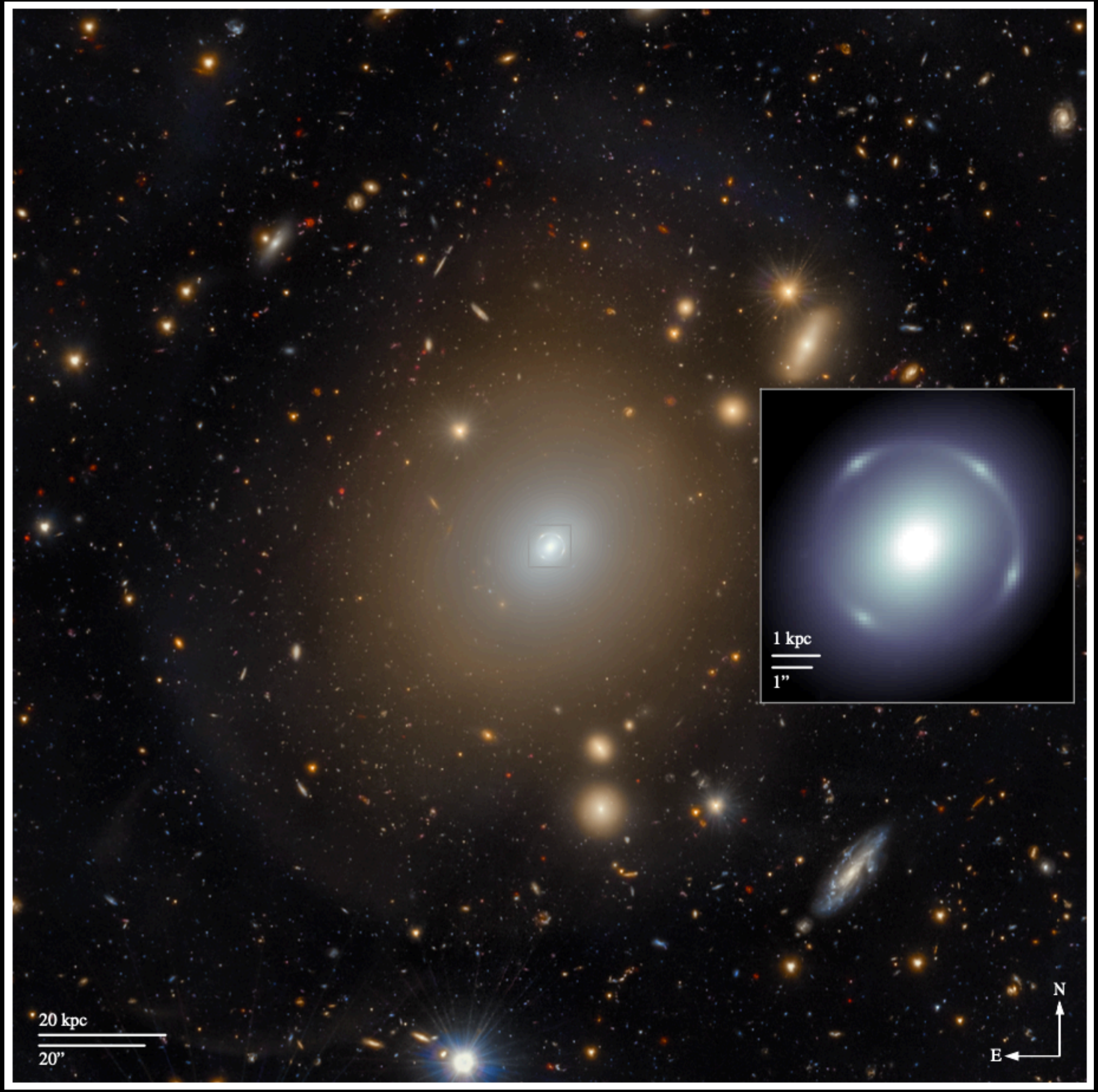
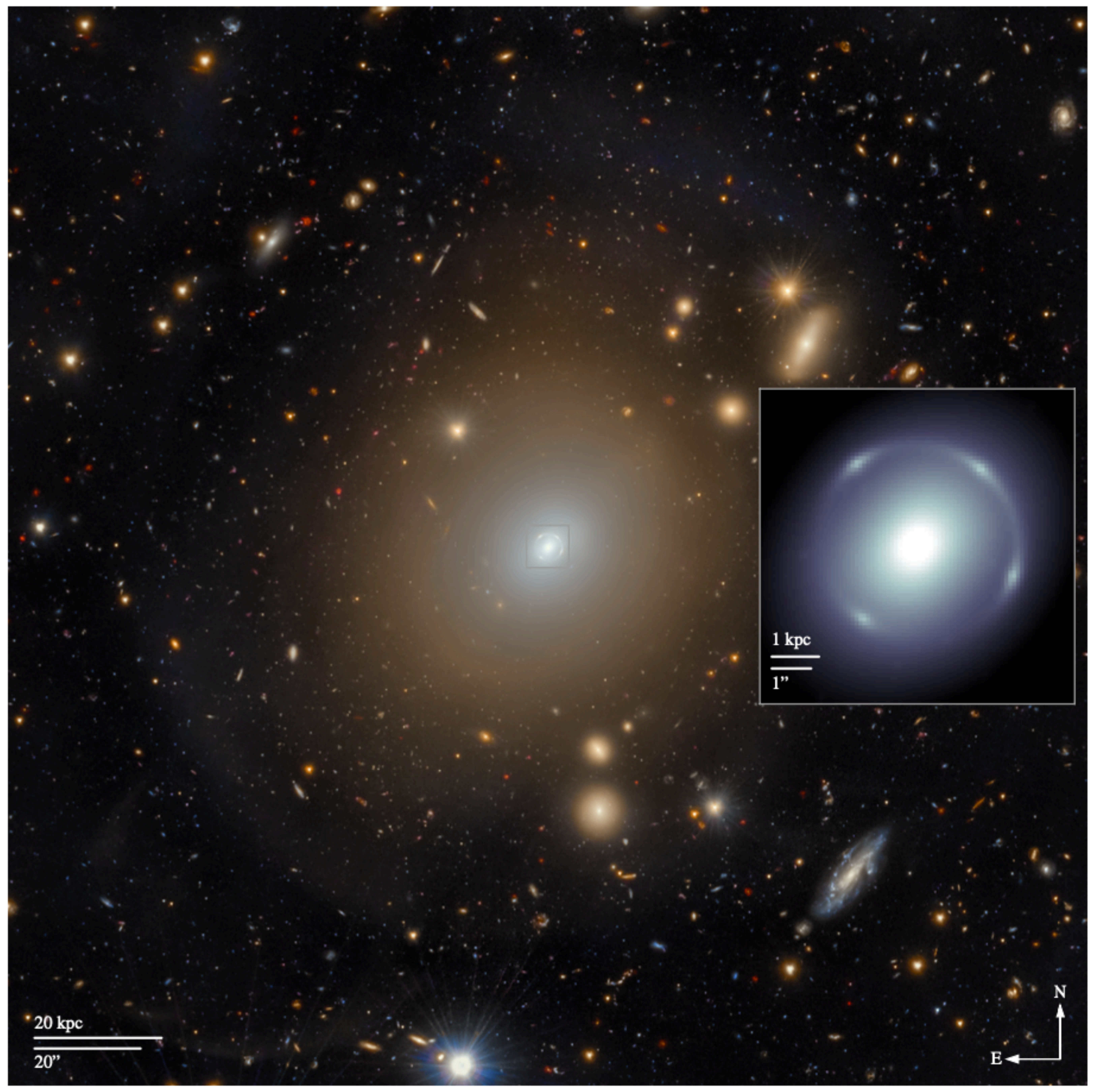



# *Euclid*: A complete Einstein ring in NGC 6505*

C. M. O'Riordan[1,**], L. J. Oldham[2], A. Nersesian[3,4], T. Li[2], T. E. Collett[2], D. Sluse[3], B. Altieri[5], B. Clément[6,7], K. G. C. Vasan[8], S. Rhoades[8], Y. Chen[8], T. Jones[8], C. Adami[9], R. Gavazzi[9,10], S. Vegetti[1], D. M. Powell[1], J. A. Acevedo Barroso[6], I. T. Andika[11,1], R. Bhatawdekar[5], A. R. Cooray[12], G. Despali[13,14,15], J. M. Diego[16], L. R. Ecker[17,18], A. Galan[11,1], P. Gómez-Alvarez[19,5], L. Leuzzi[13,14], M. Meneghetti[14,15], R. B. Metcalf[13,14], M. Schirmer[20], S. Serjeant[21], C. Tortora[22], M. Vaccari[23,24,25],

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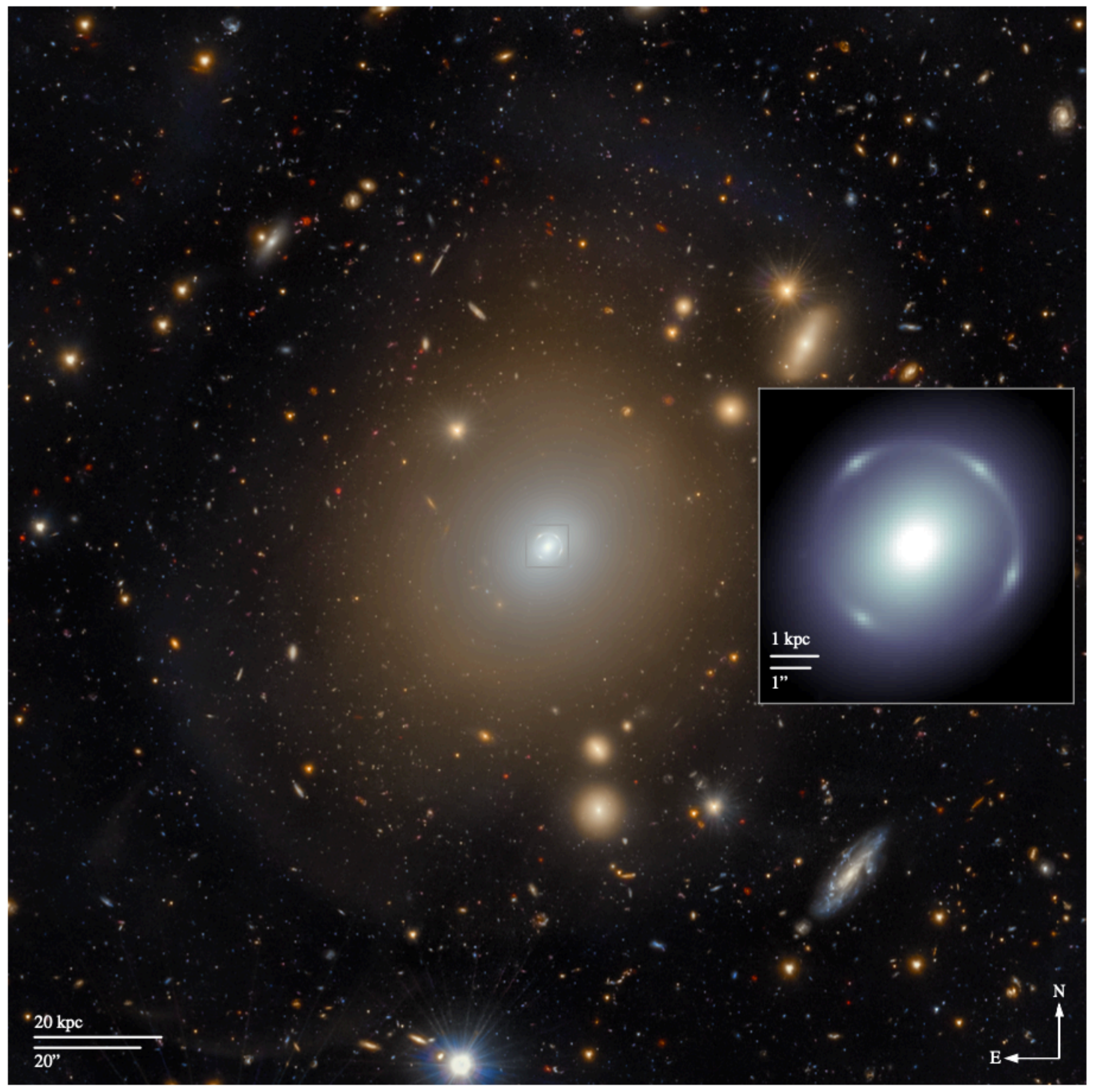
- z (lens) = 0.04, z (source) = 0.4
- extremely rare configuration

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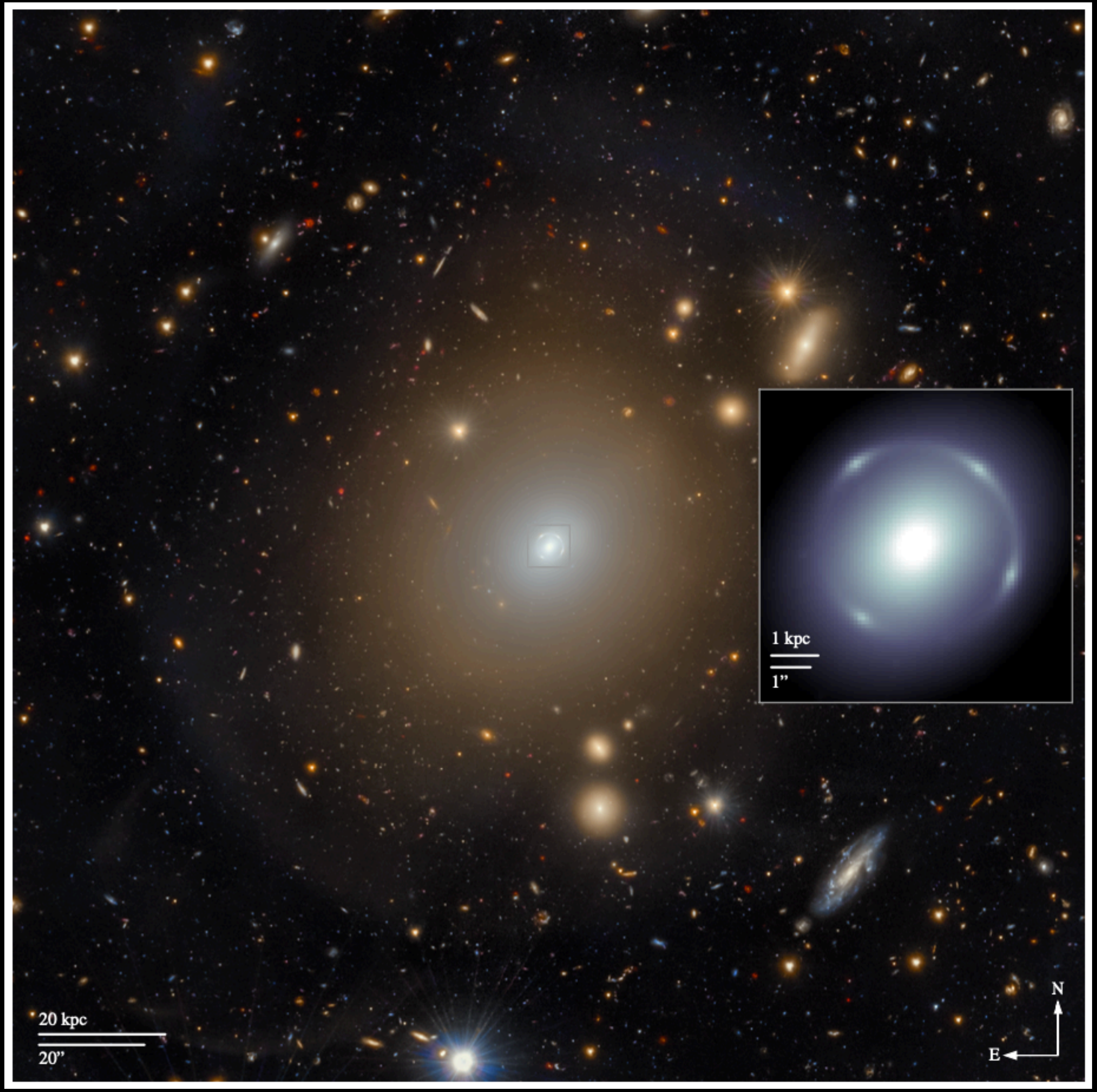


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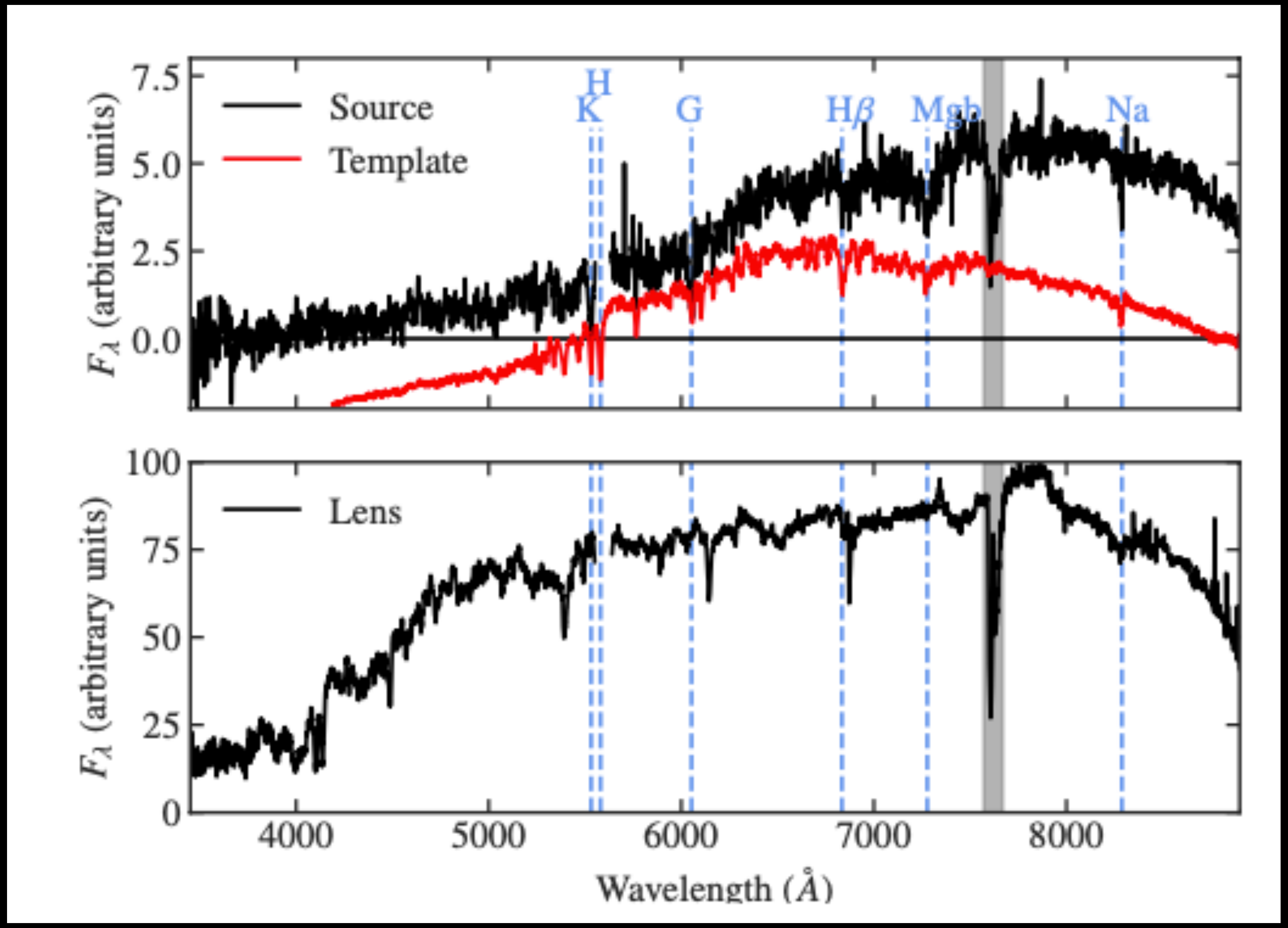
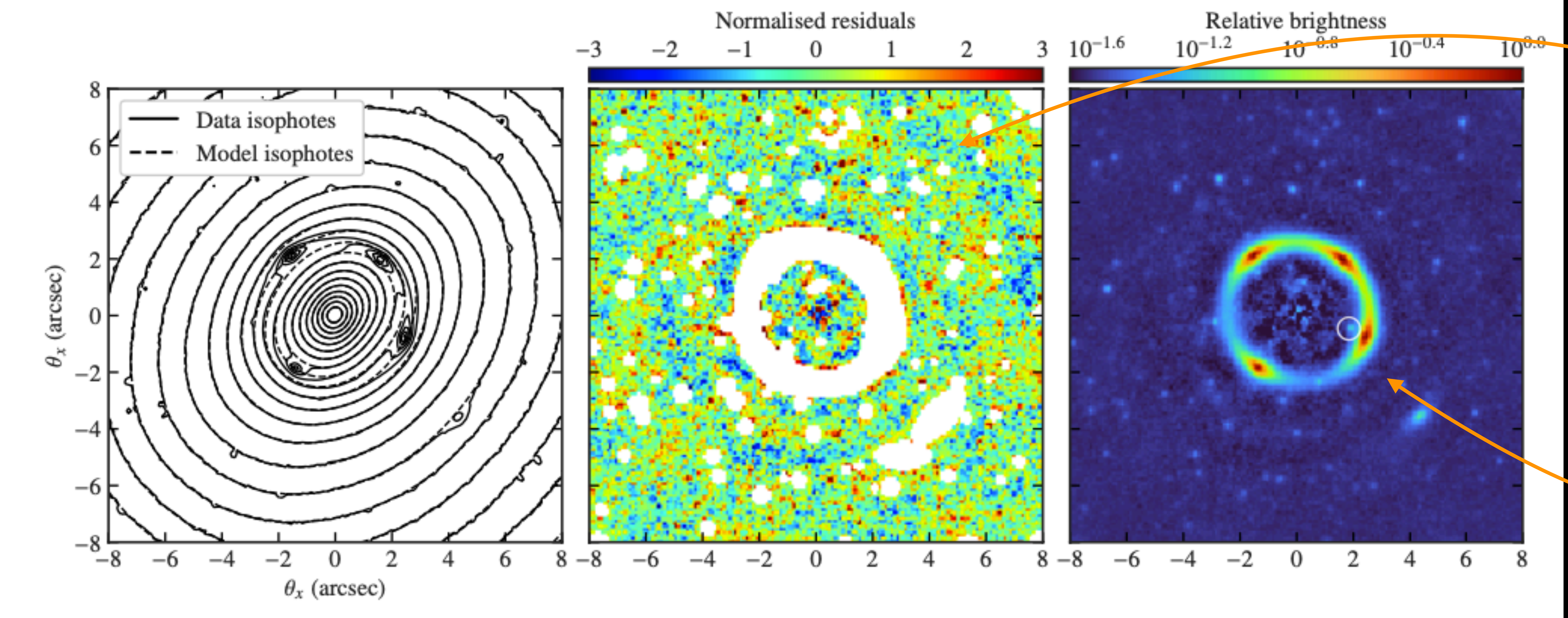
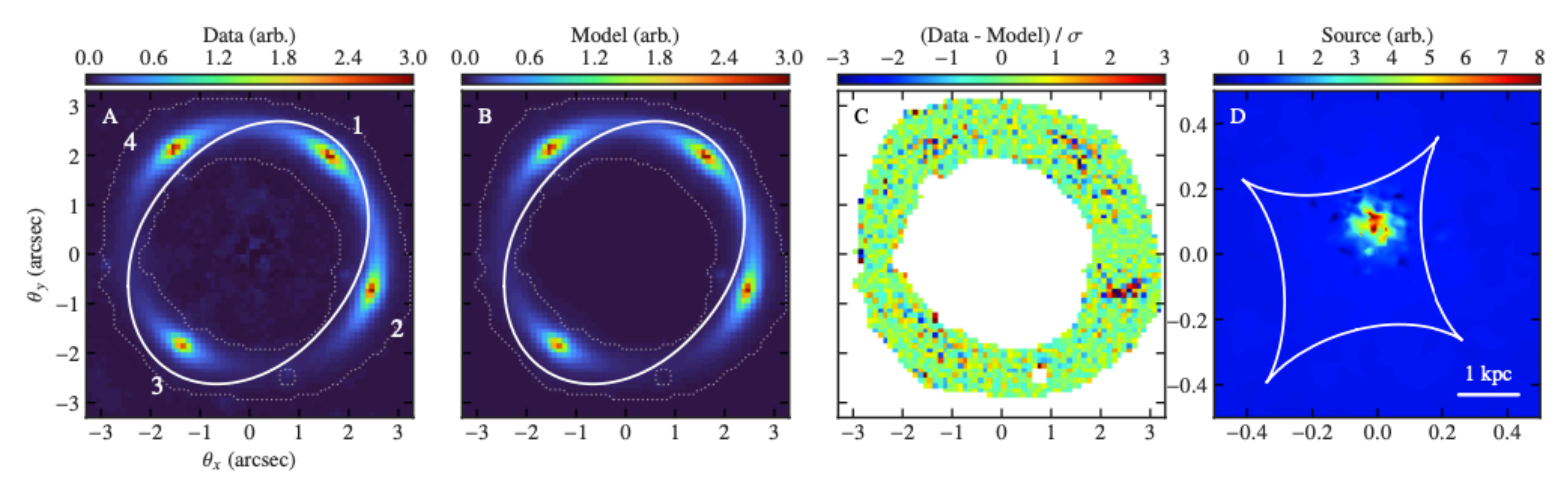
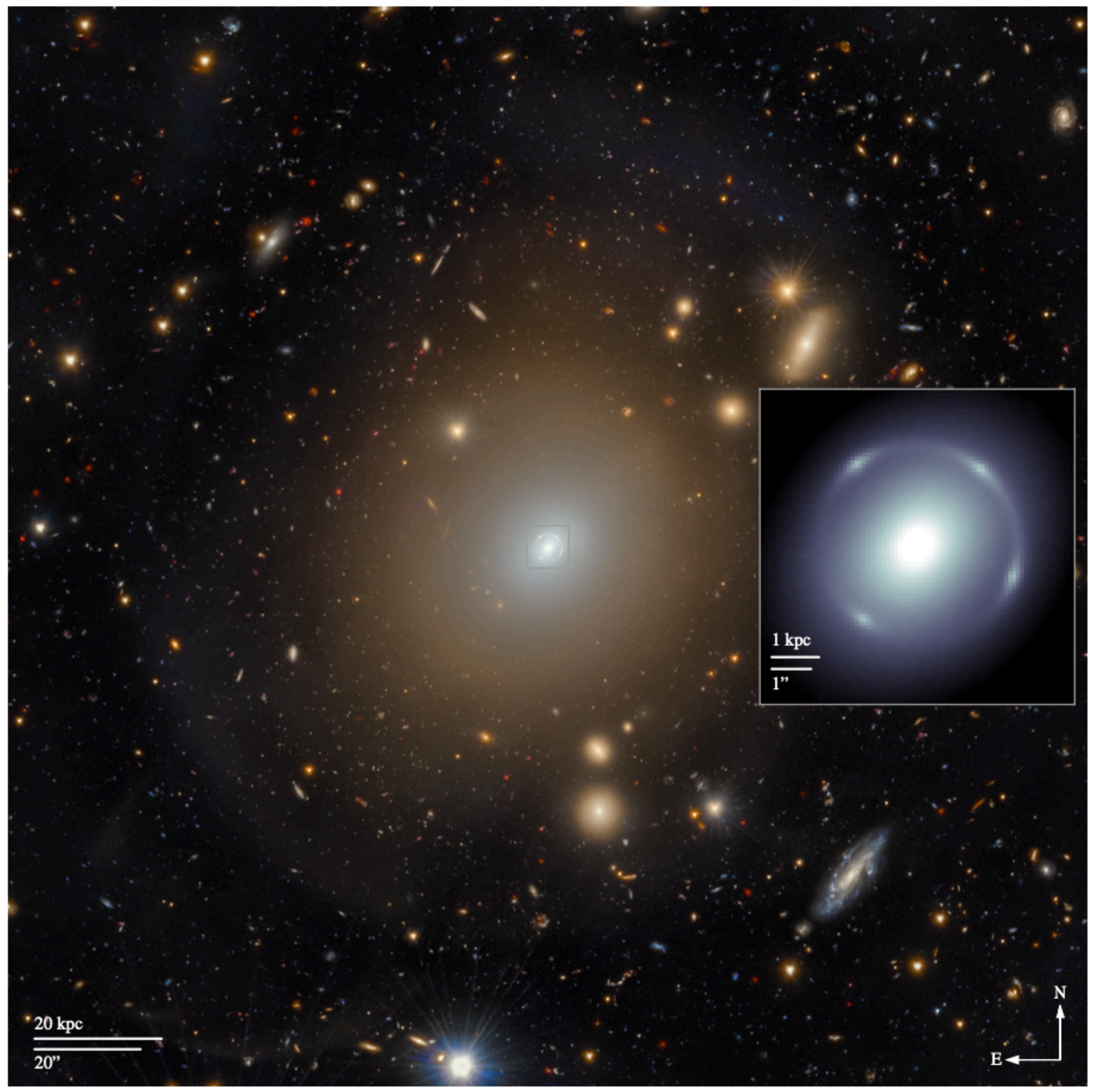





individual “blobs” from GC had to be subtracted from the image

or modeled separately



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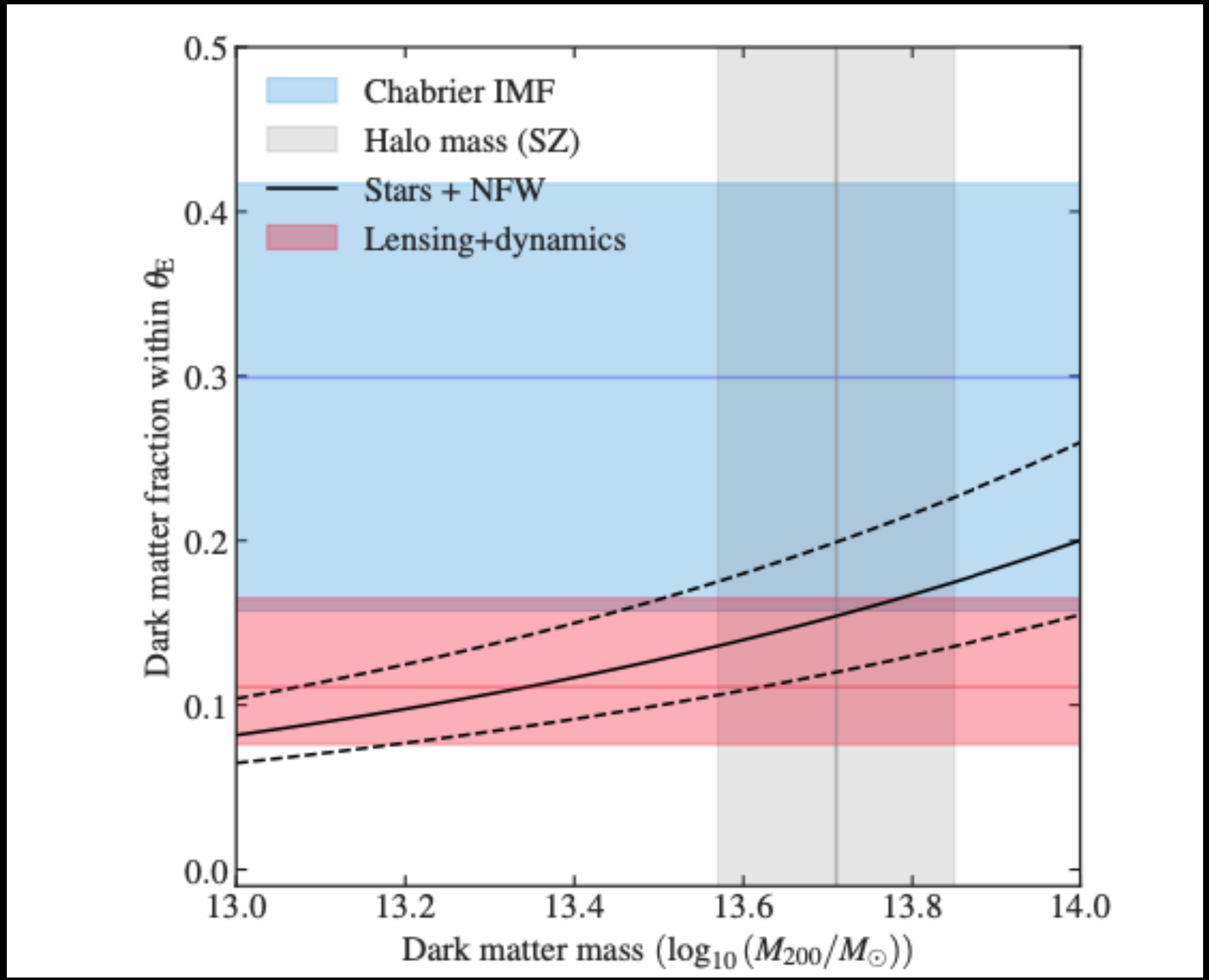

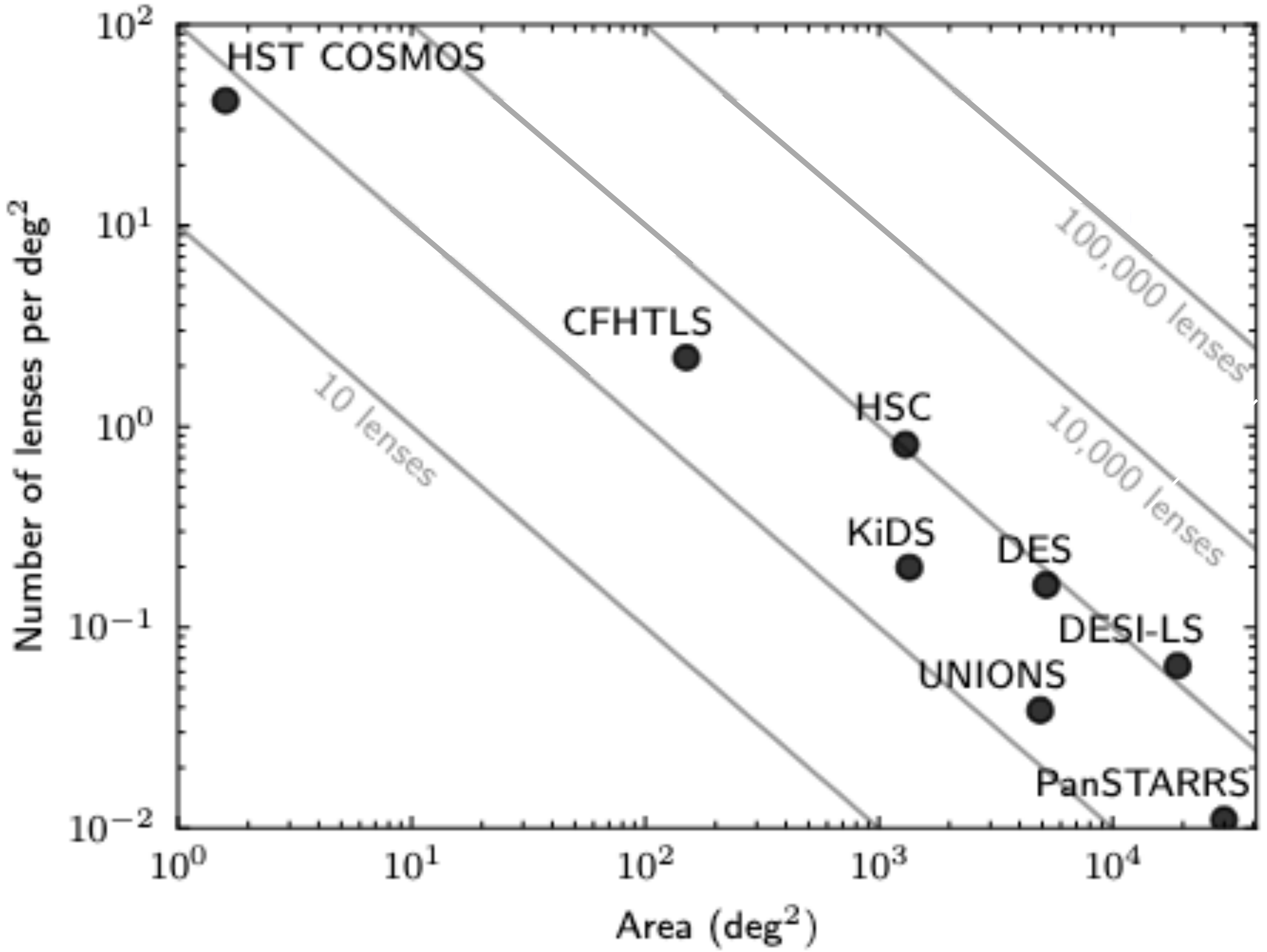

HST COSMOS
CFHTLS
HSC
KiDS
DES
DESI-LS
UNIONS
PanSTARRS
10 lenses
10,000 lenses
100,000 lenses
Number of lenses per deg$^2$
Area (deg$^2$)
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
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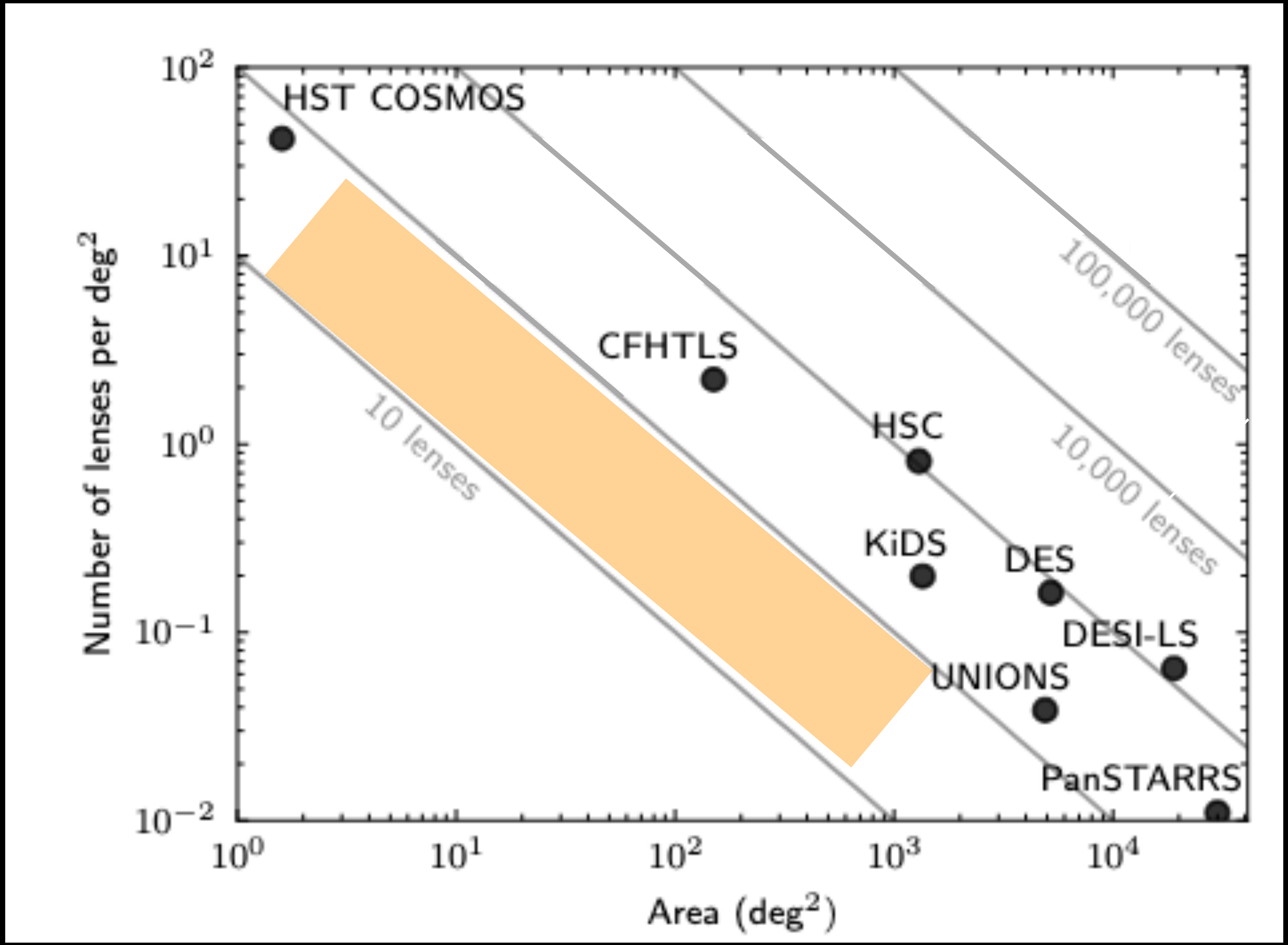
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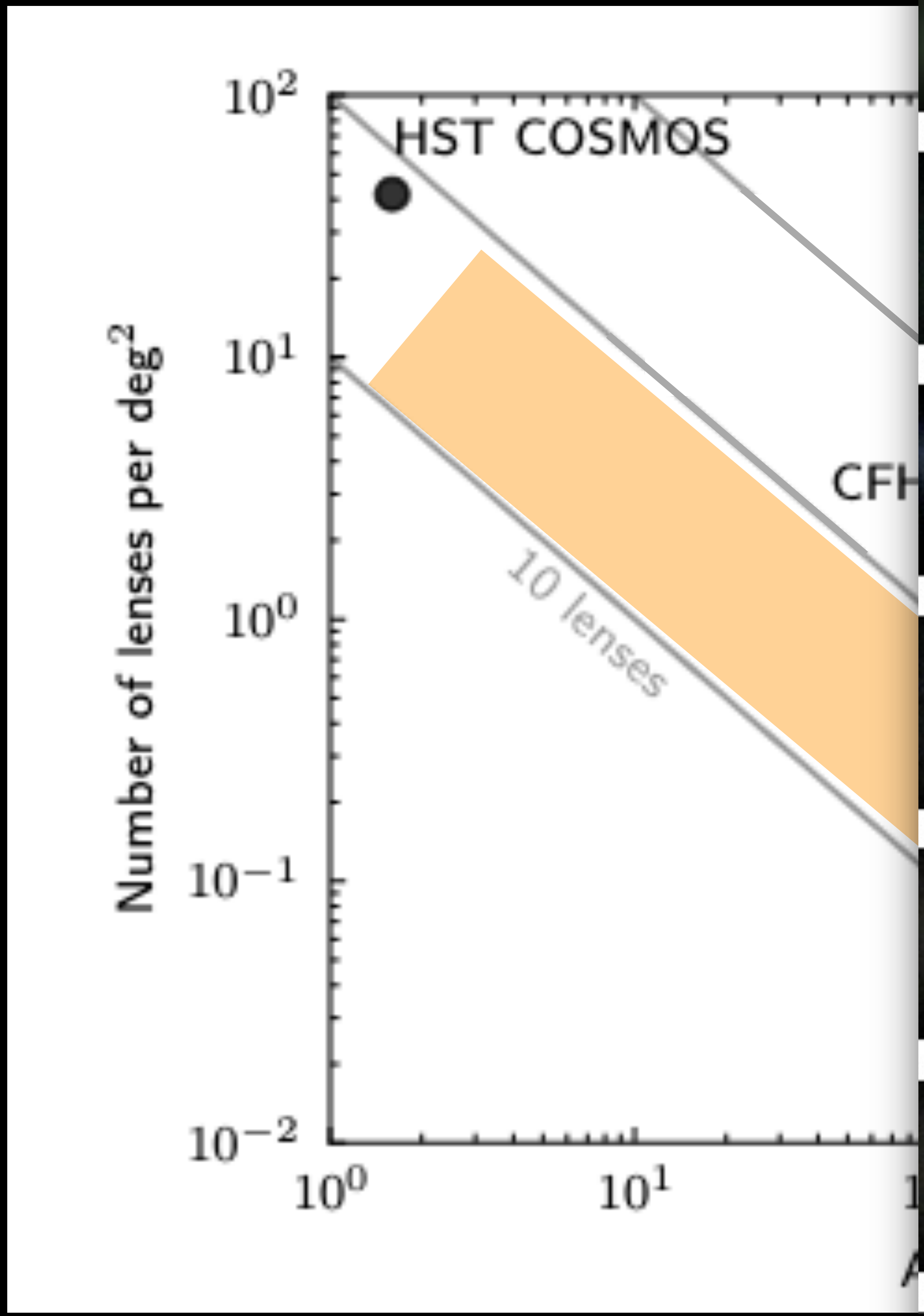
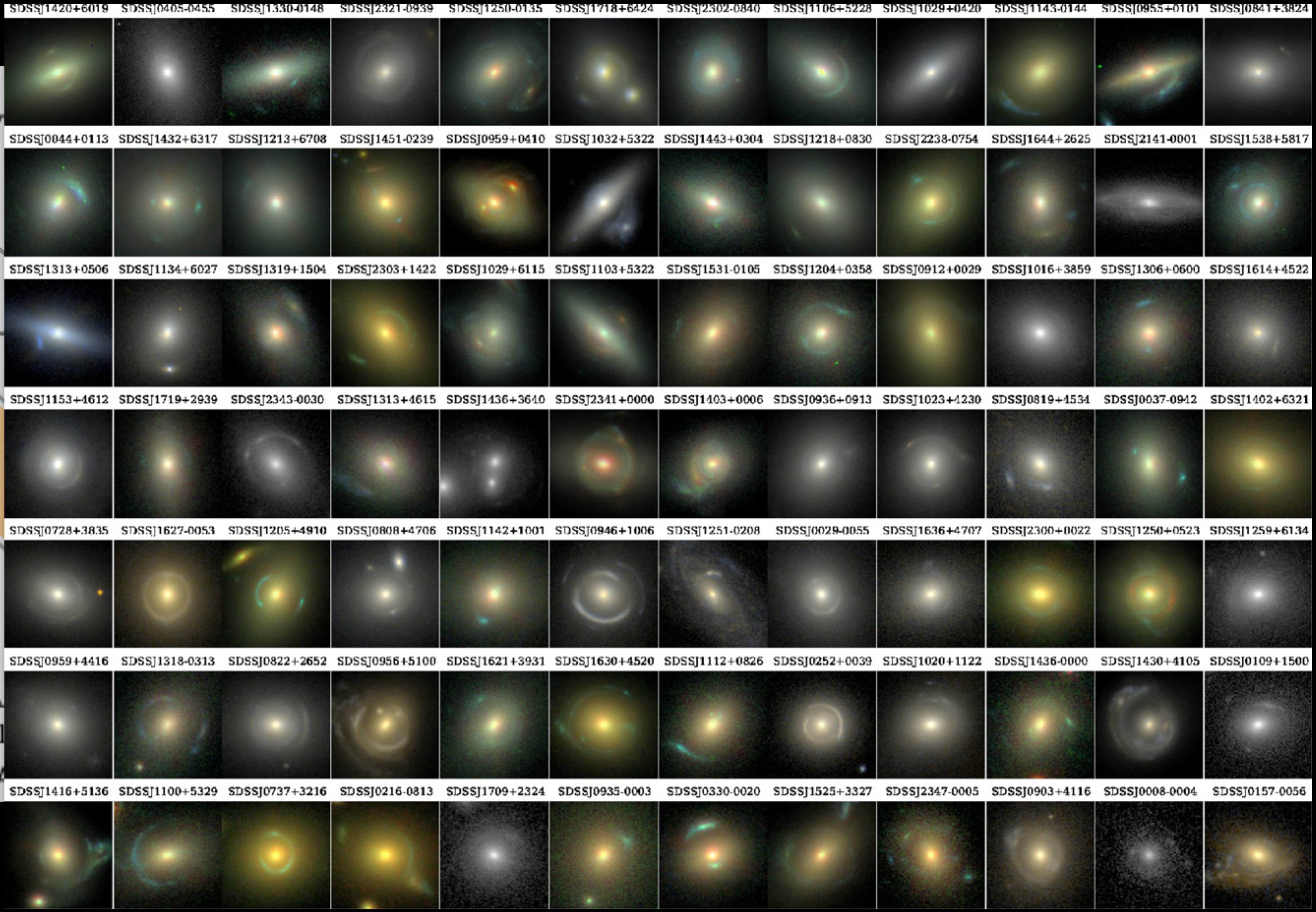
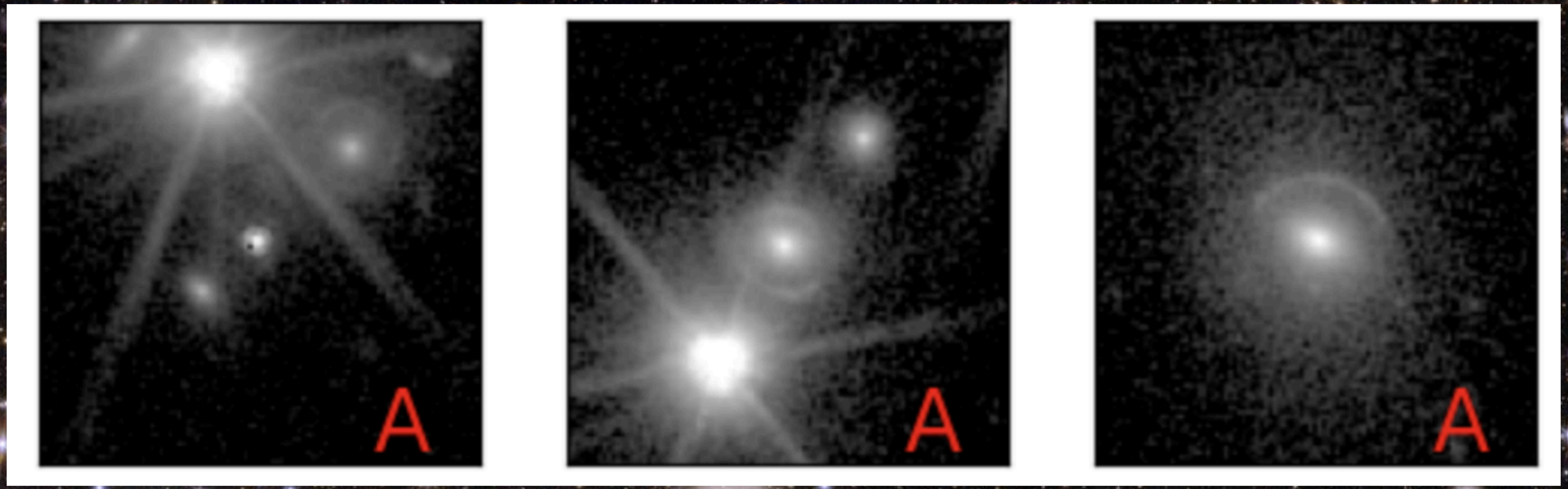


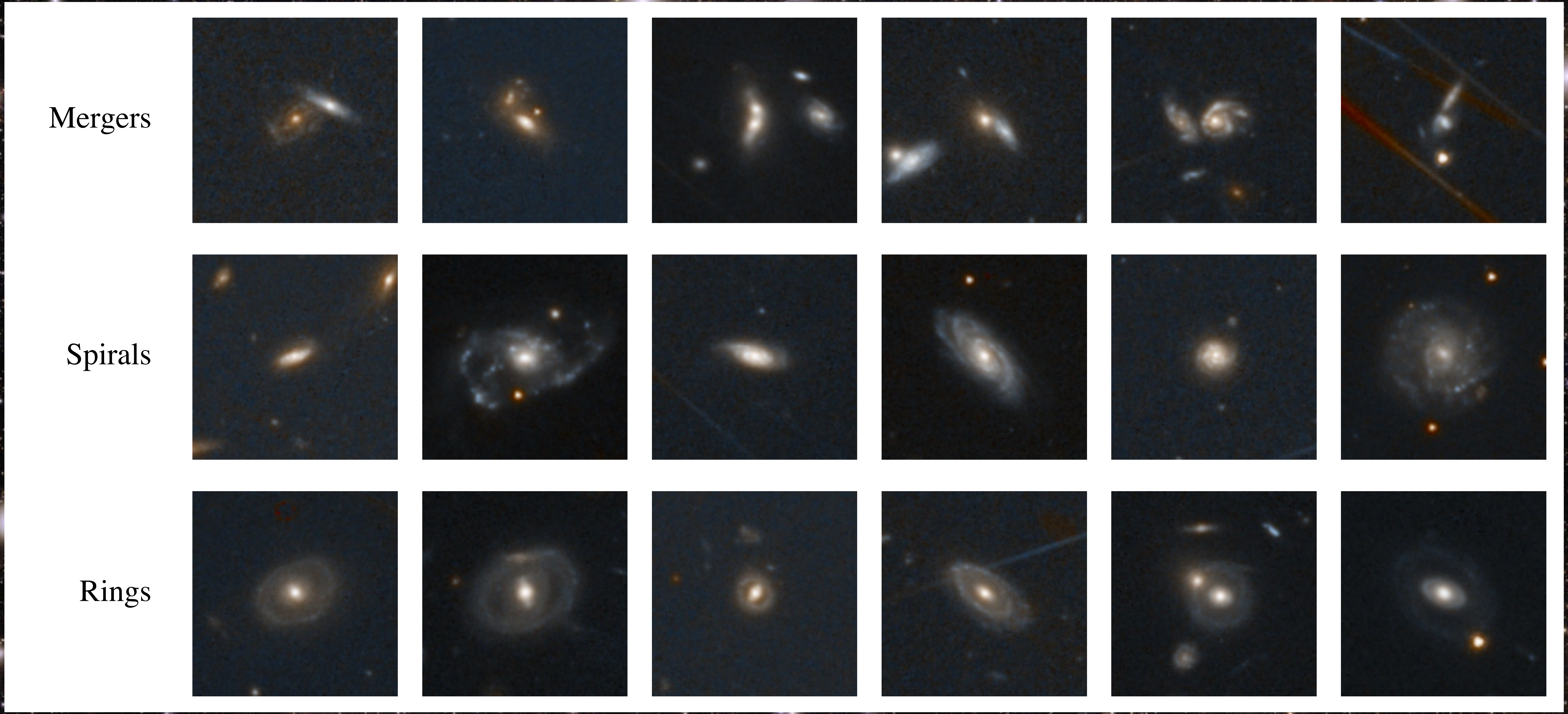

SLACS lenses *(Bolton+06)*


euclid
consortium


Euclid
consortium
A
A
A
Acevedo-Barroso et al. 2025




Acevedo-Barroso et al. 2025



## serie of 5 Q1 papers: " The Strong Lensing Discovery Engine "

A: Walmsley et al. "System overview and lens catalogue"
B: Rojas et al. "Early strong lens candidates from visual inspection of high velocity dispersion galaxies"
C: Lines et al. "Finding lenses with machine learning"
D: Li et al. "Double source plane lens candidates"
E: Holloway et al. "Ensemble classification of strong gravitational lenses: lessons for Data Release 1"

**Initial selection of candidates:**

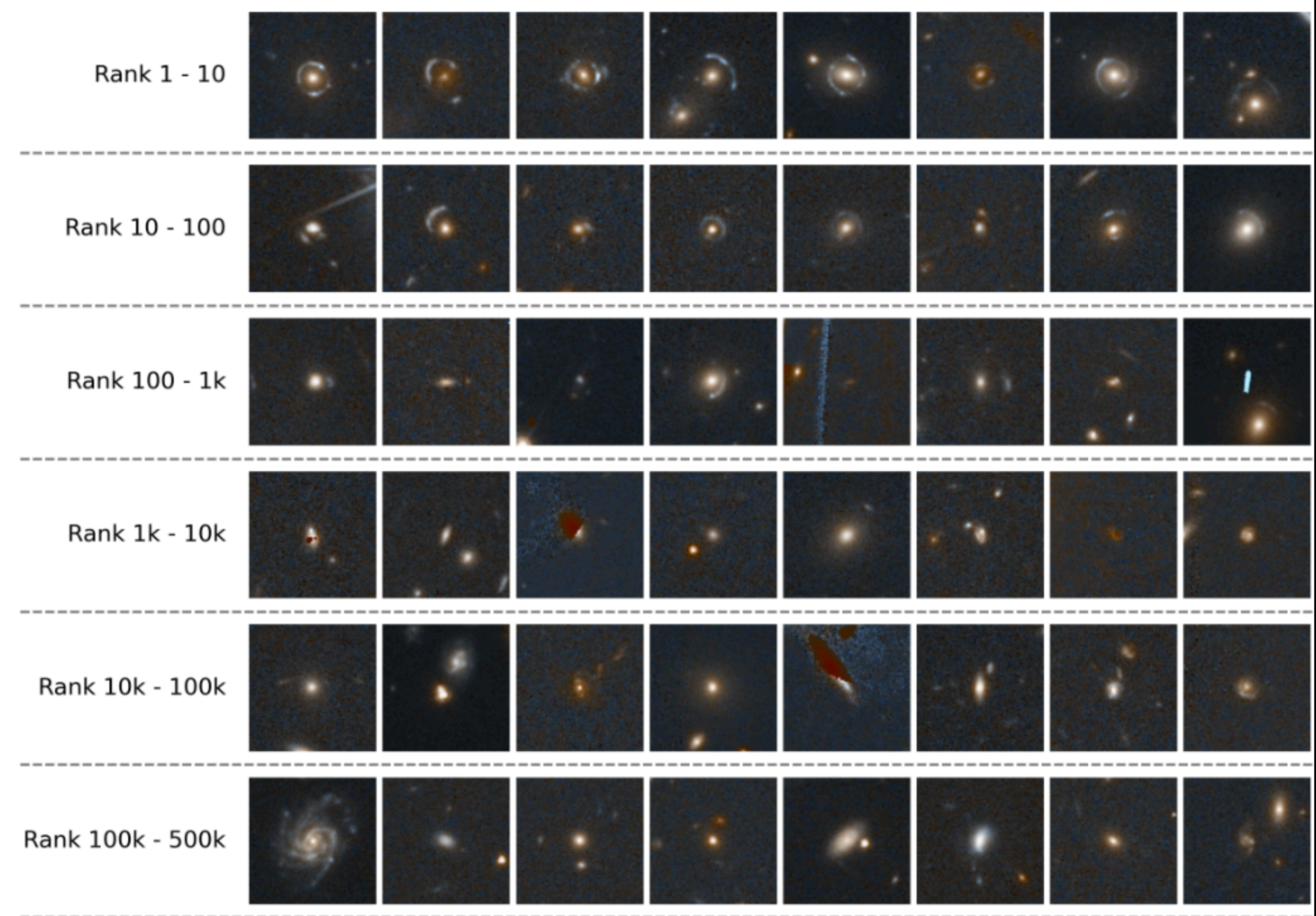
- bright sources in Q1 ($I_E \leq 22.5$ AB)
- detected in VIS
- removed artifacts
- 15" fov cut-outs

**1086556 sources**

**Machine learning models:**

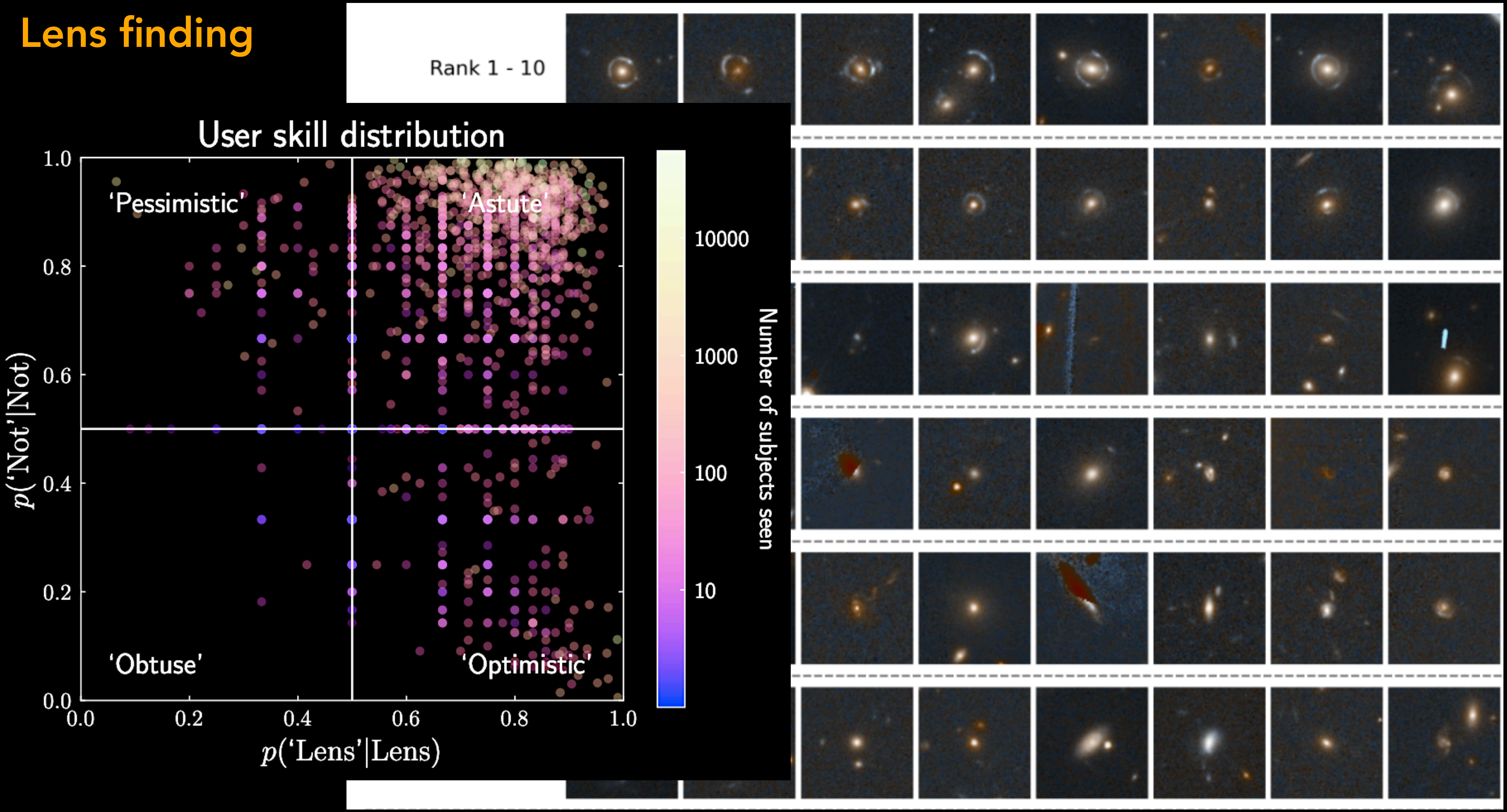
- 5 networks applied to the candidates
- top 10-20k objects from each network
- passed to citizen science & expert inspection

# Lens finding




https://www.zooniverse.org/projects/mikewalmsley/galaxy-judges/classify

# Lens finding

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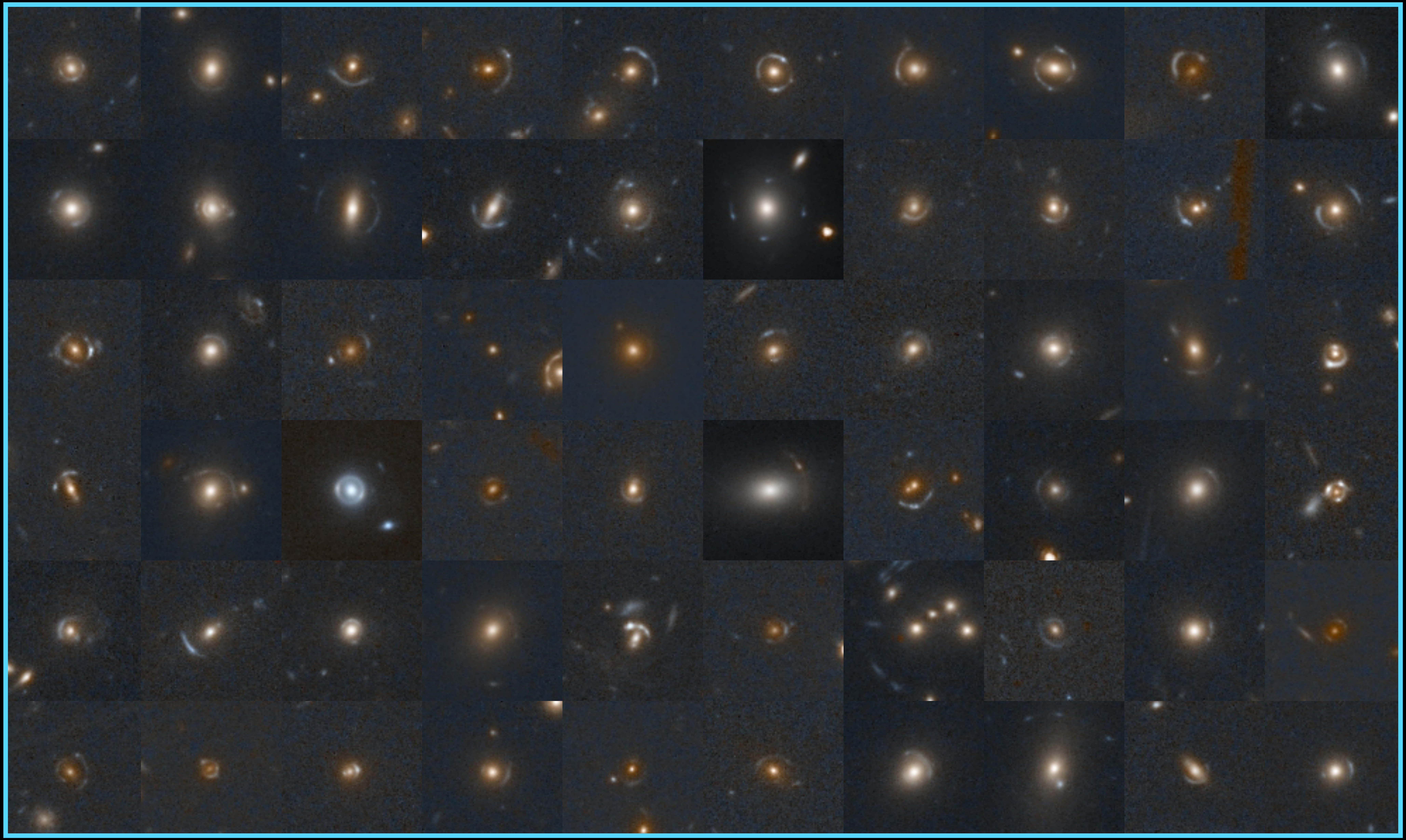
# Galaxy-galaxy lensing in Euclid

A: Welmsley et al.
"System overview and lens catalogue"

Result: ~500 new lenses,



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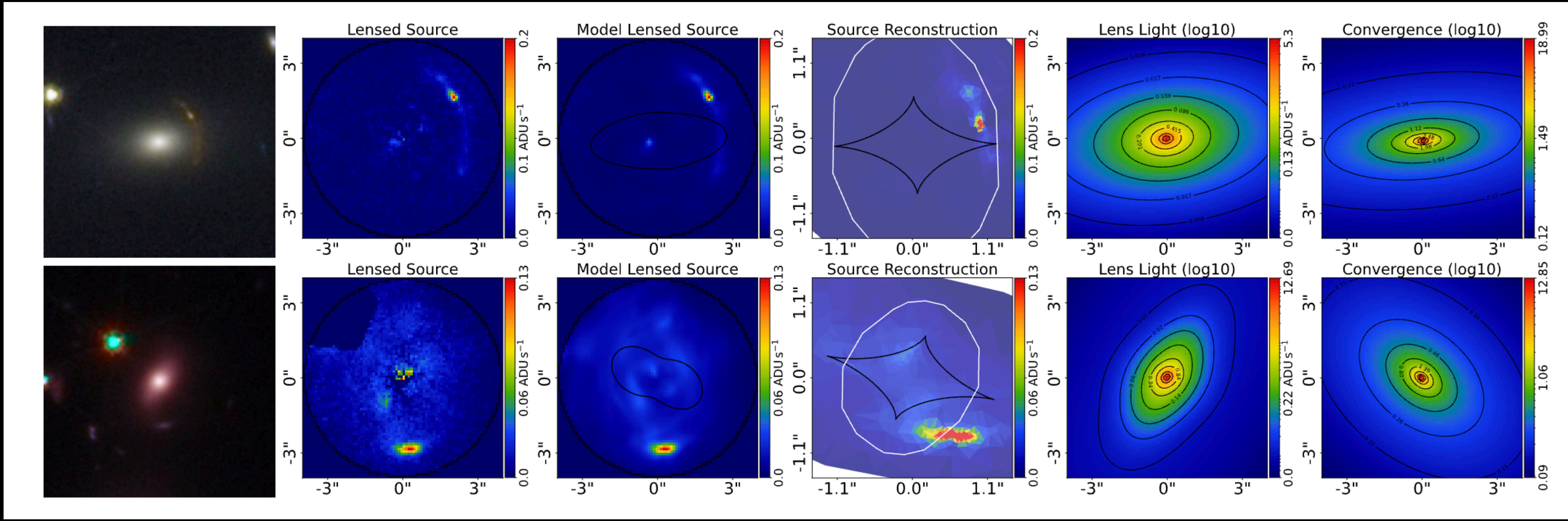


Lenses automatically modeled with PyAutoLens

developed by James Nightingale (Newcastle)
integrated in the Euclid Pipeline

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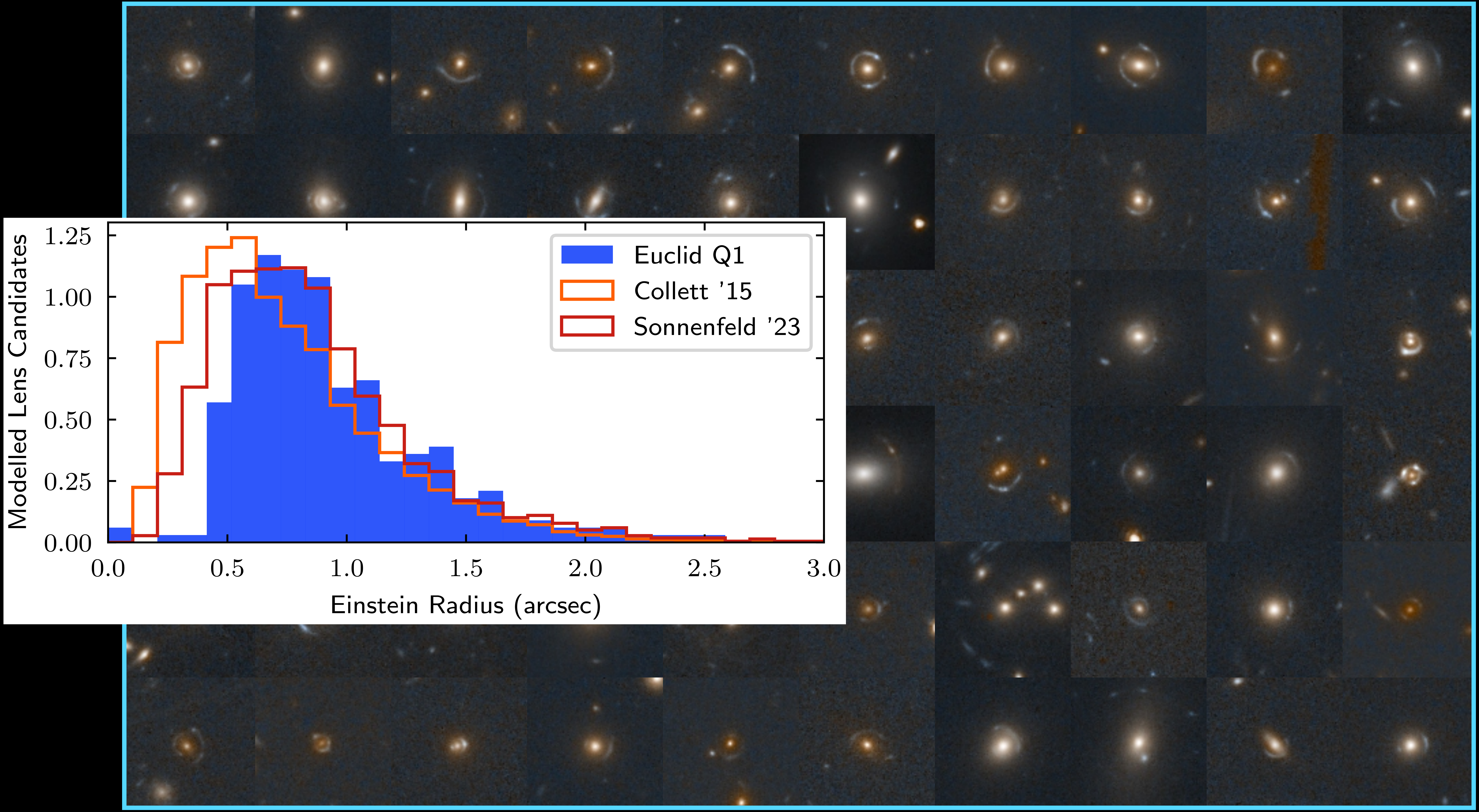

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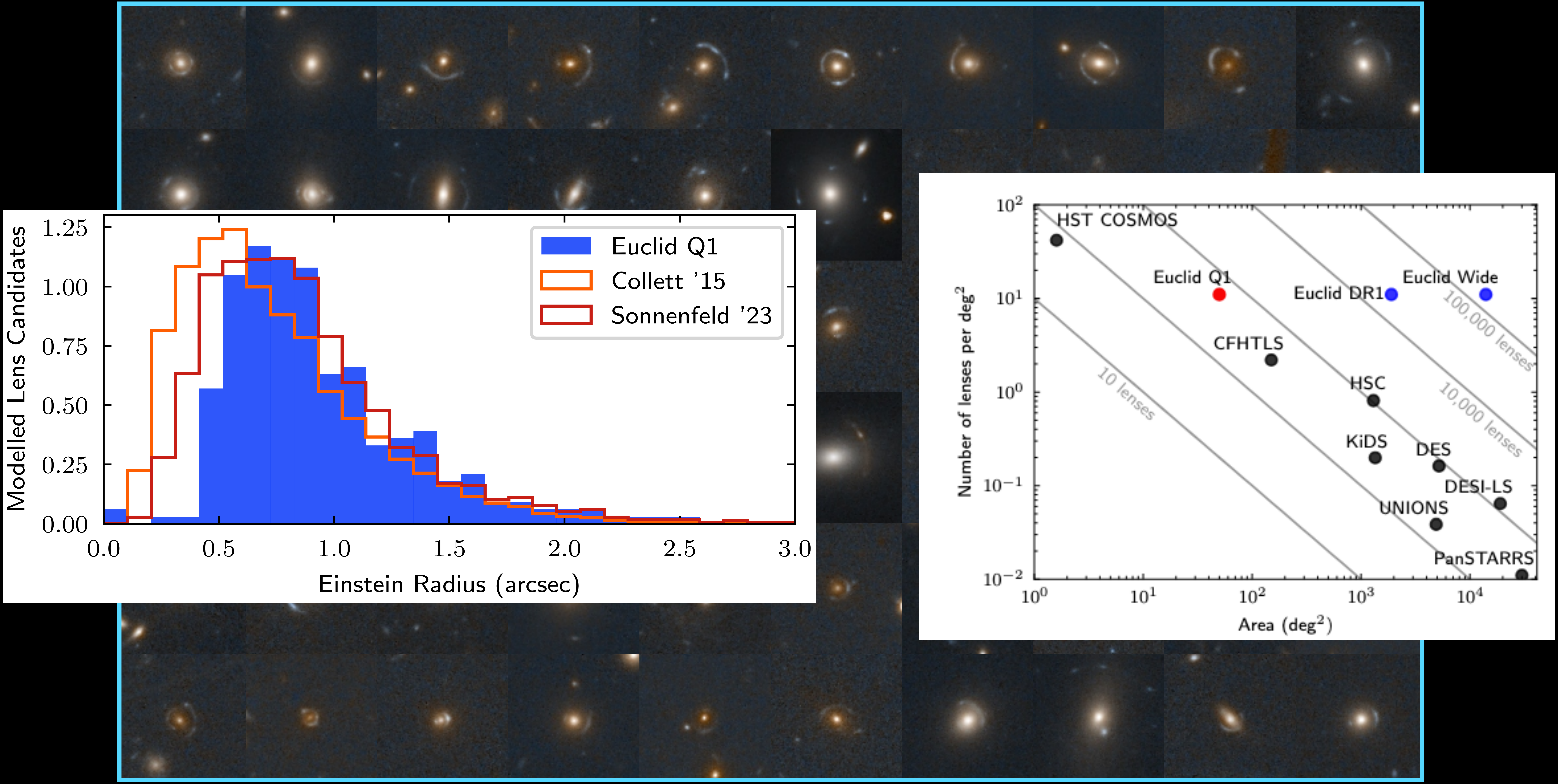
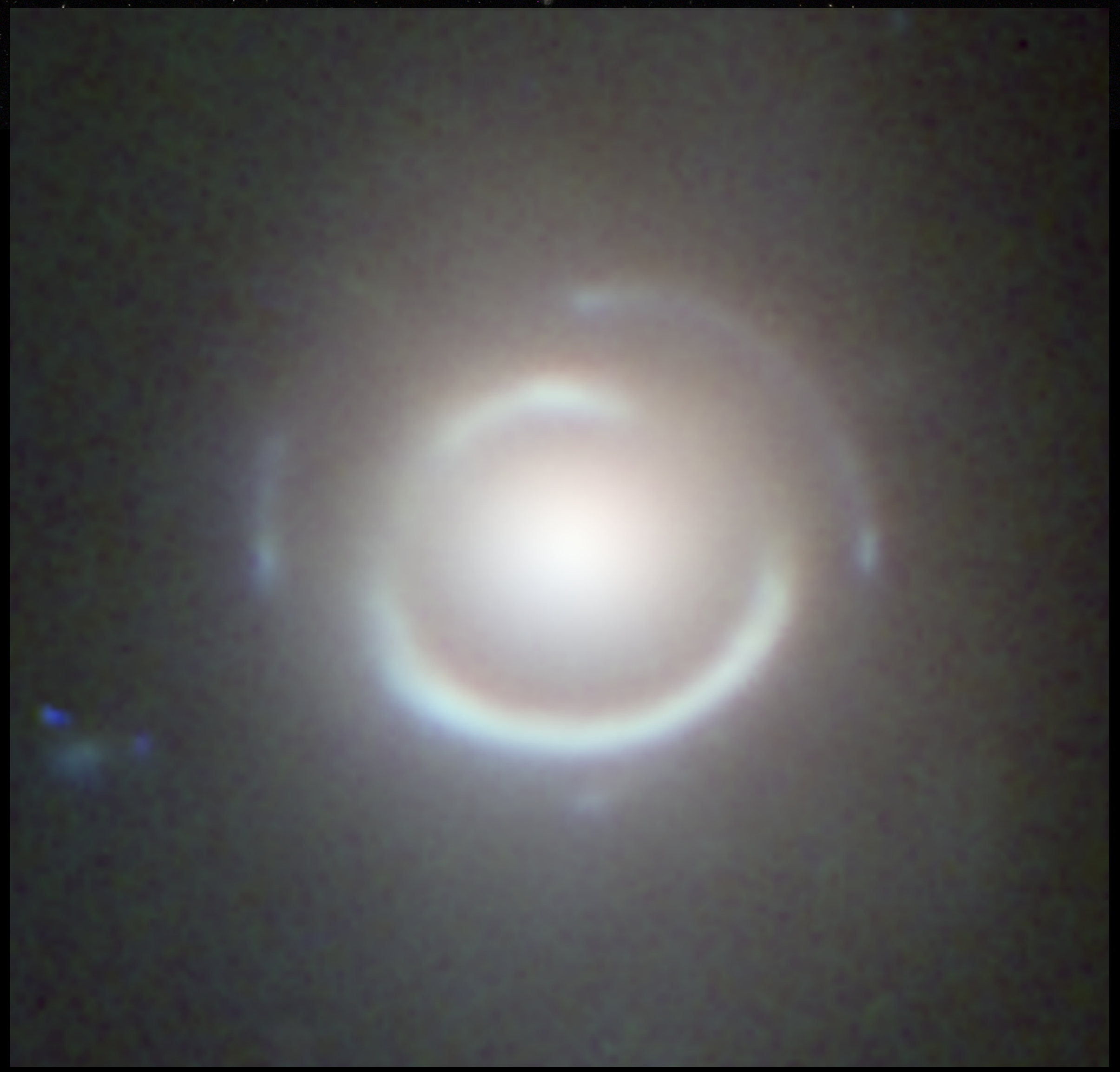
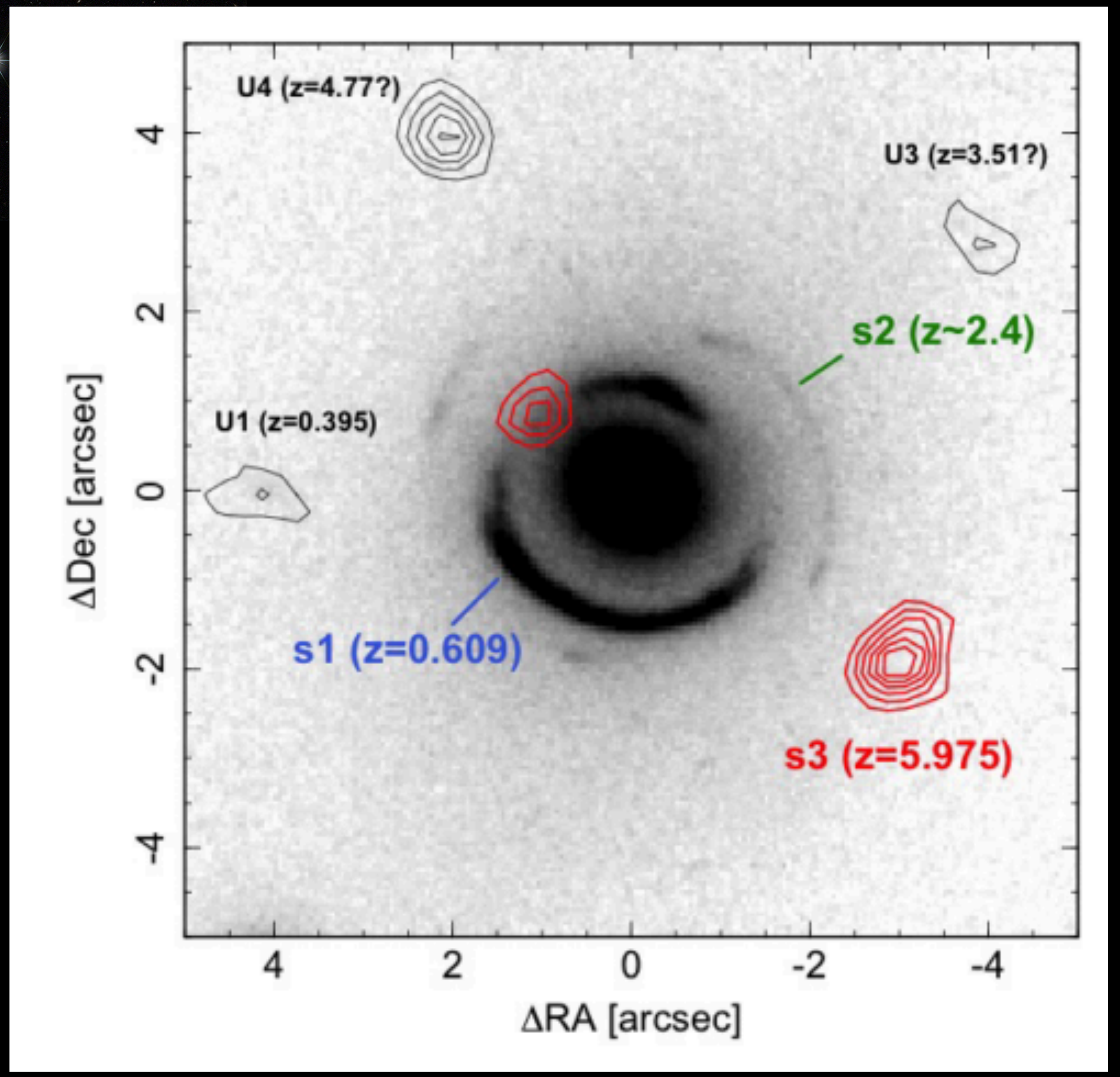


# Compound lenses: a tool for cosmology

A lens system with multiple source galaxies at different redshifts
(with multiple Einstein rings with different Einstein radius)






- Galaxy mass profile (second ring)
- Cosmography (different redshift plane)

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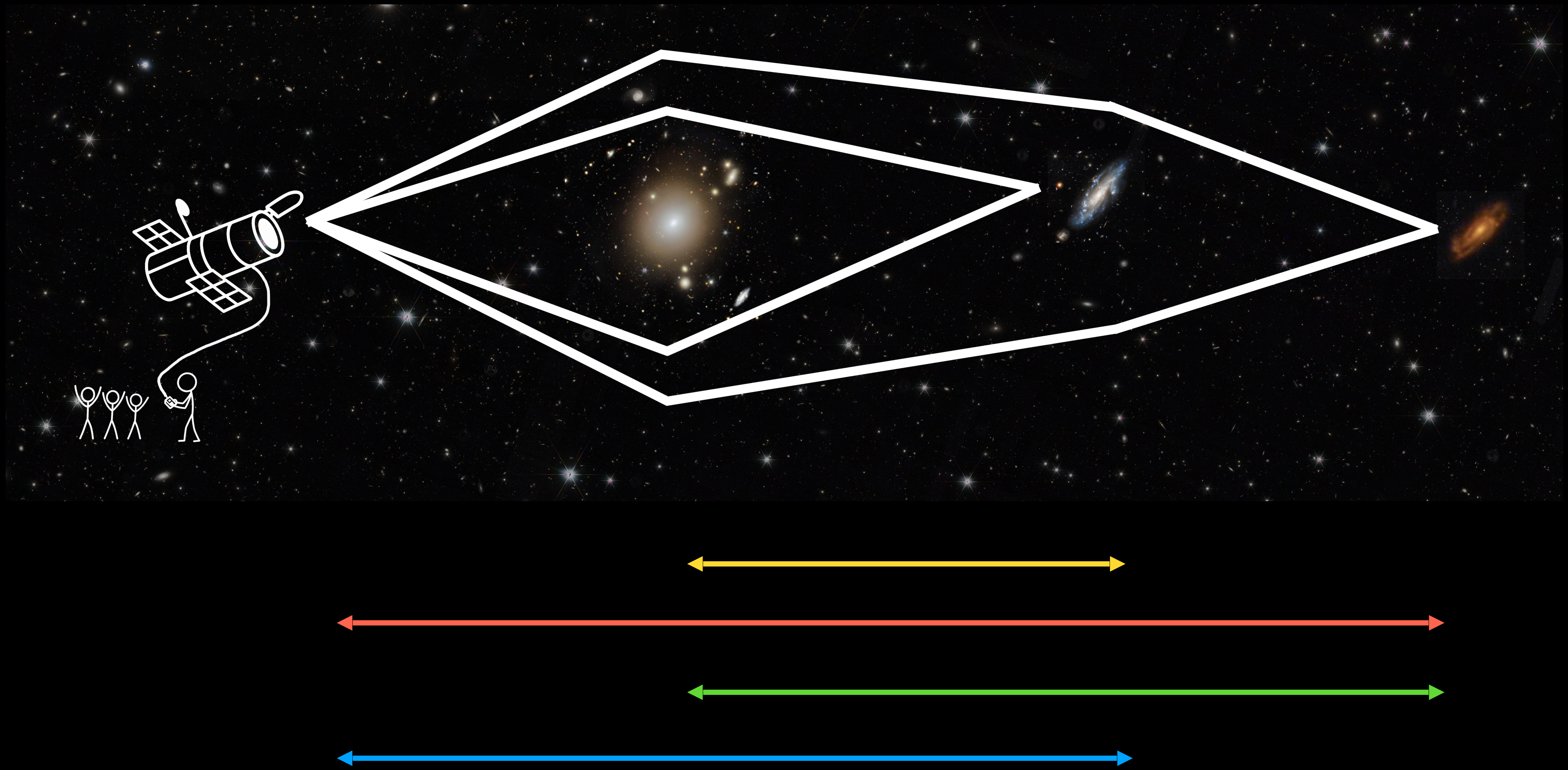


$$\beta = \frac{D_{ls1} D_{s2}}{D_{s1} D_{ls2}}$$

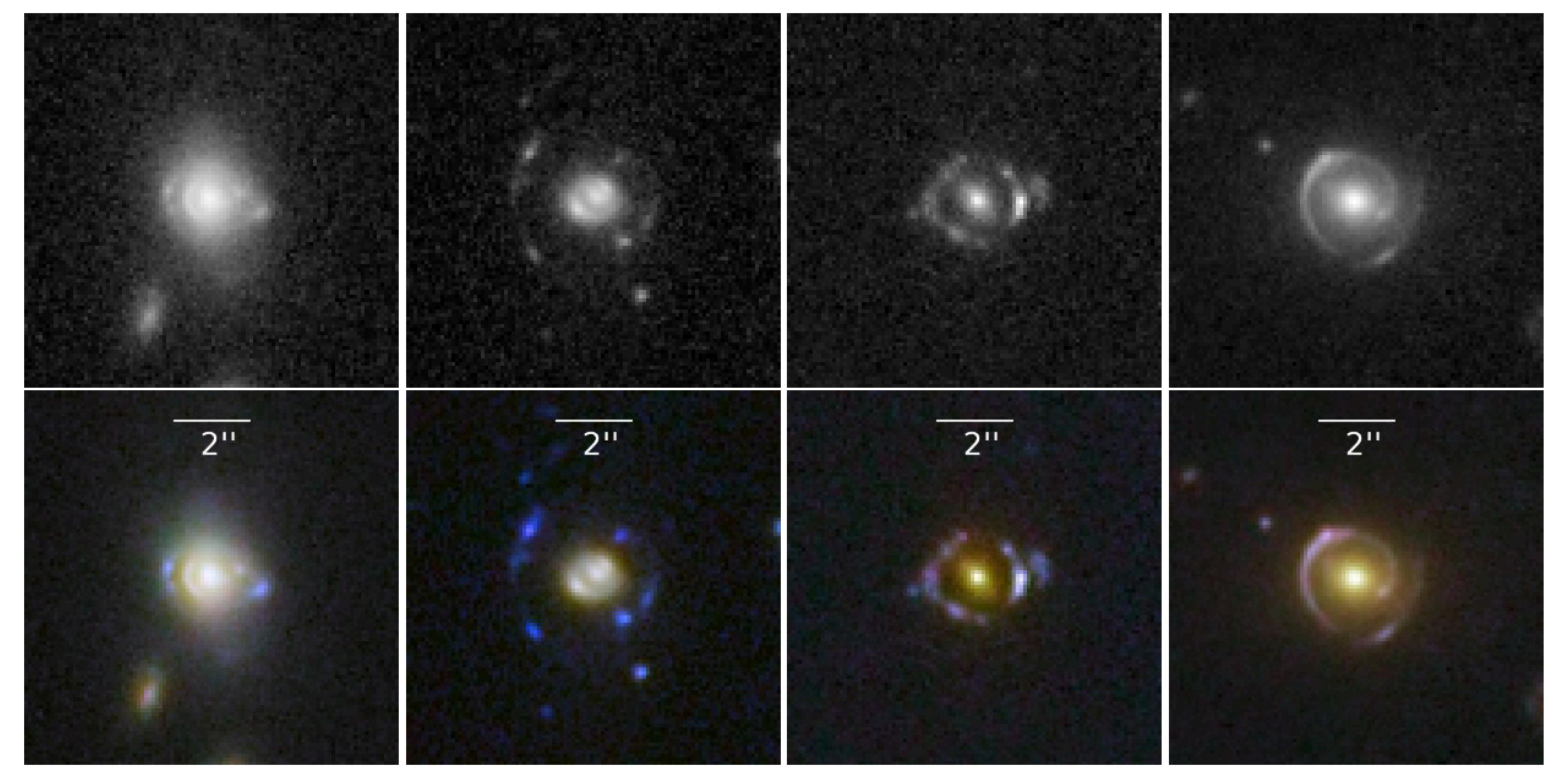
The ratio of the deflection angles is the ratio of angular diameter distances

$$D_{ij} = \frac{c/H_0}{(1+z_j)} \left( \frac{\mathrm{sinn}\left(\sqrt{|\Omega_k|} \int_{z_i}^{z_j} \frac{dz}{E(z)}\right)}{\sqrt{|\Omega_k|}} \right)$$

# Compound lenses: a tool for cosmology

D: Li et al.
"Double source plane lens candidates"

Result: 4 new candidates



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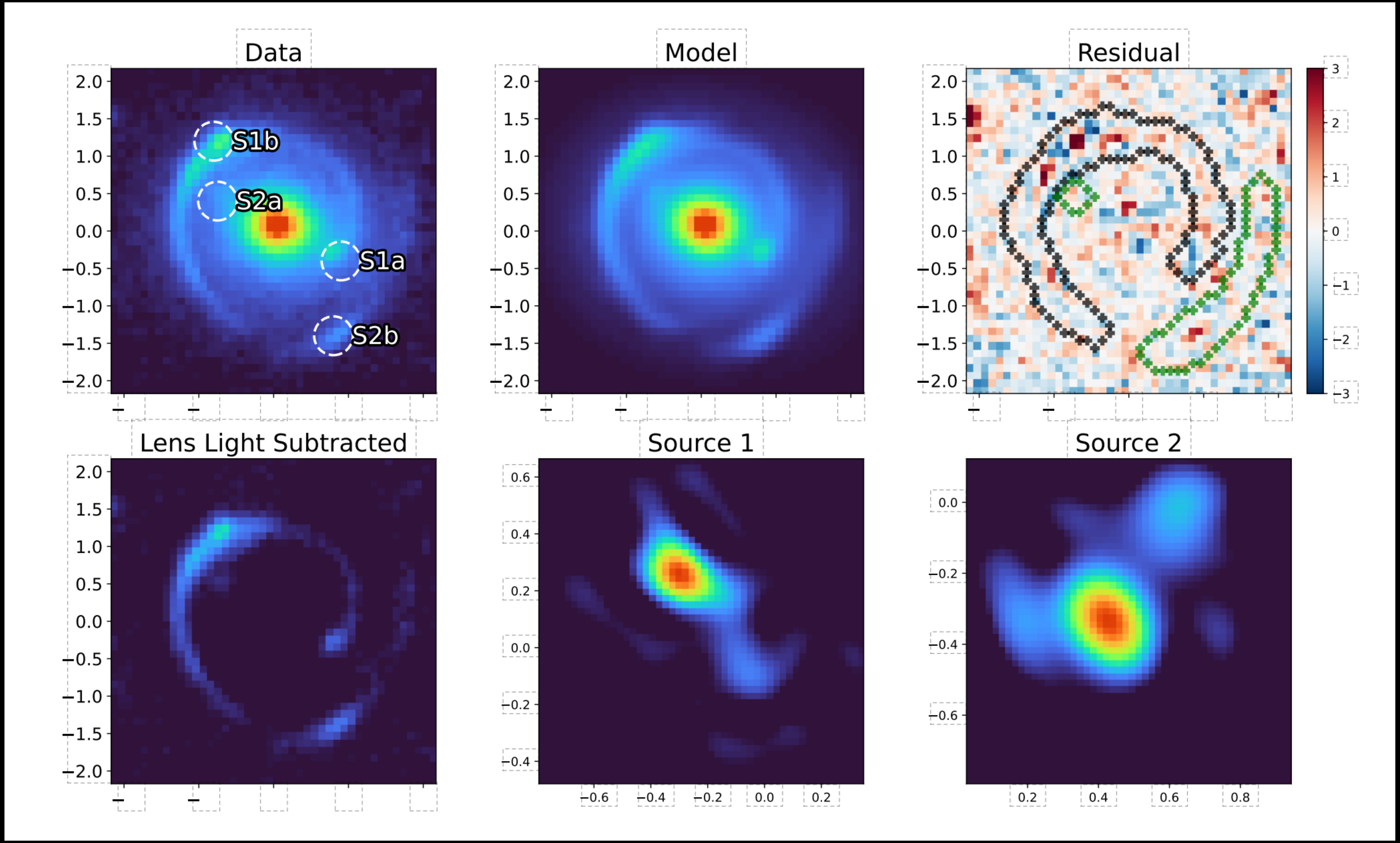
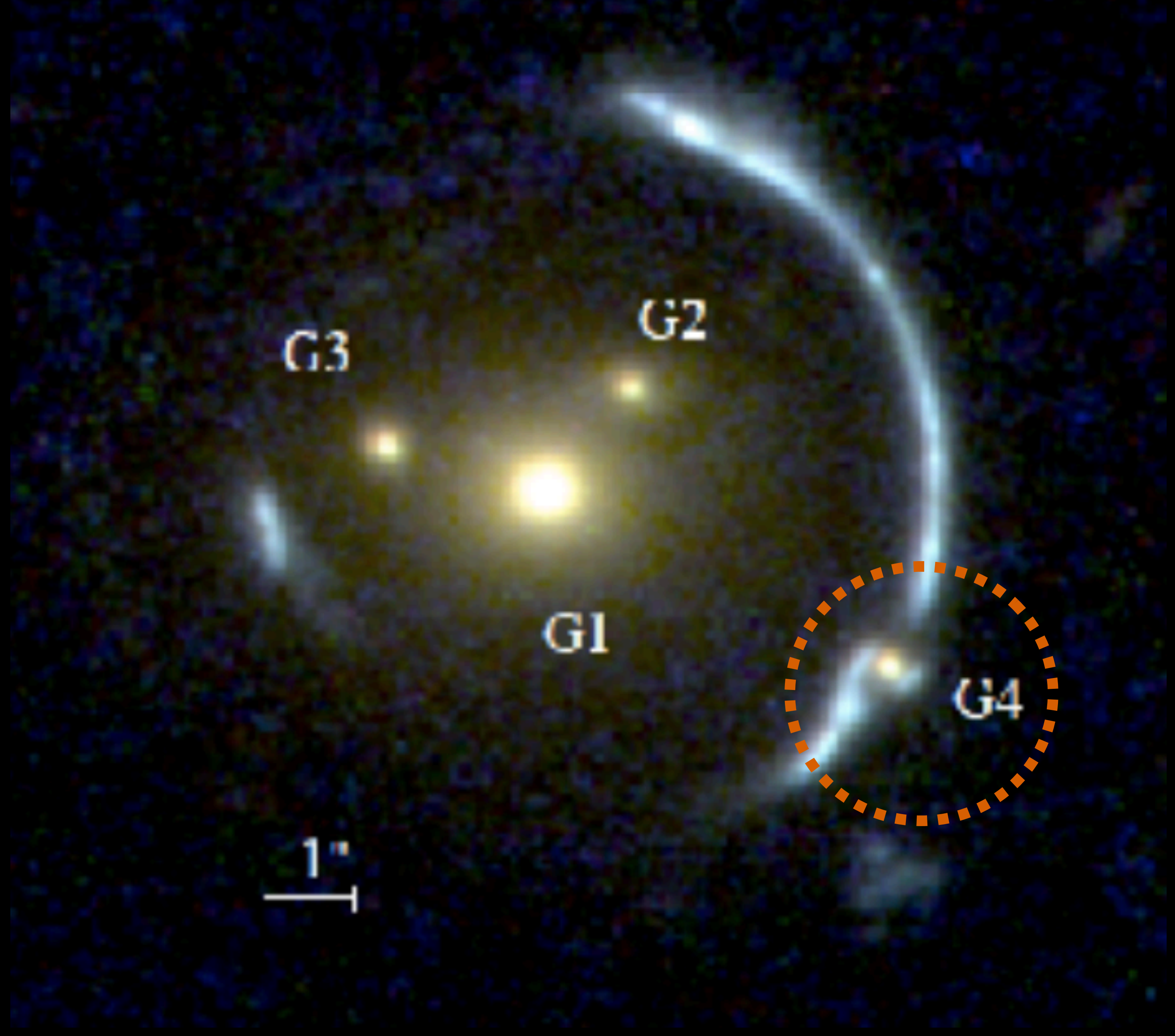



We will discover more than 1000 DSPLs in DR3

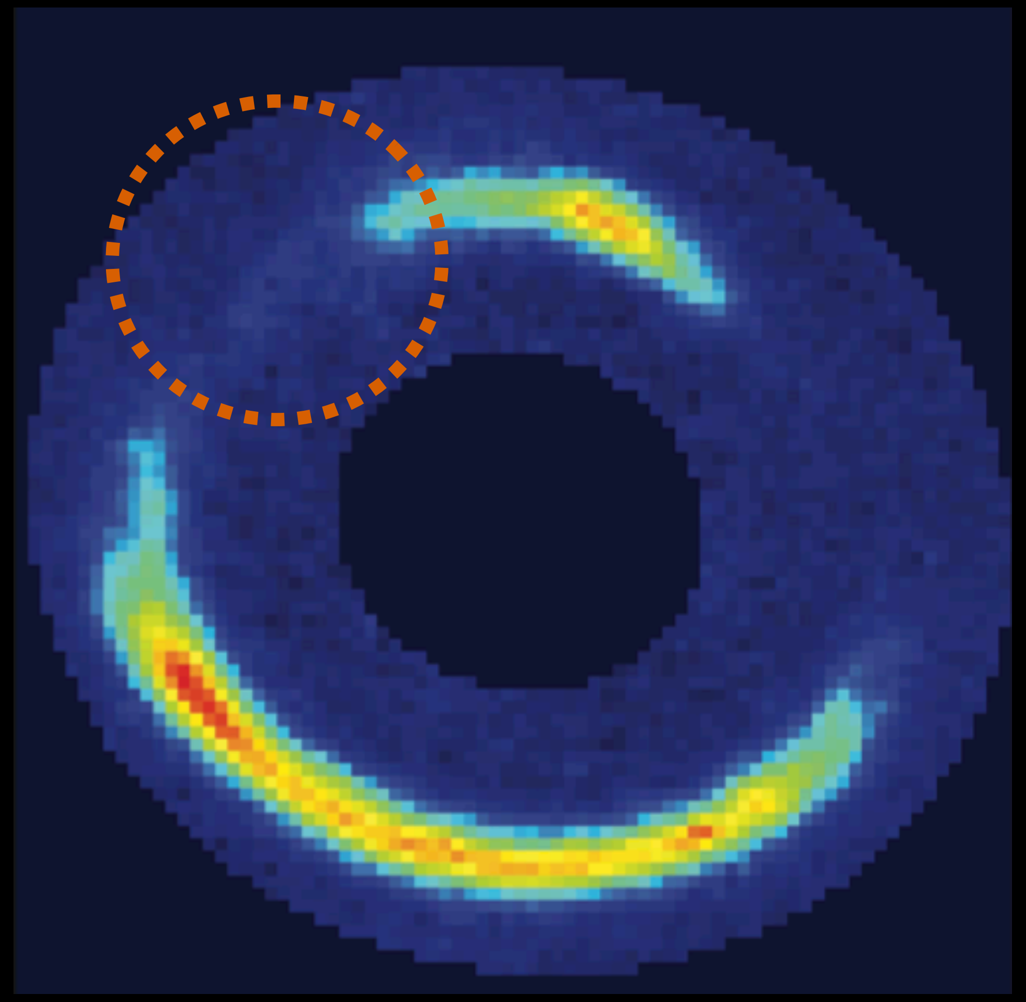
# edge-on galaxies as lenses


*Ecker et al in prep.*

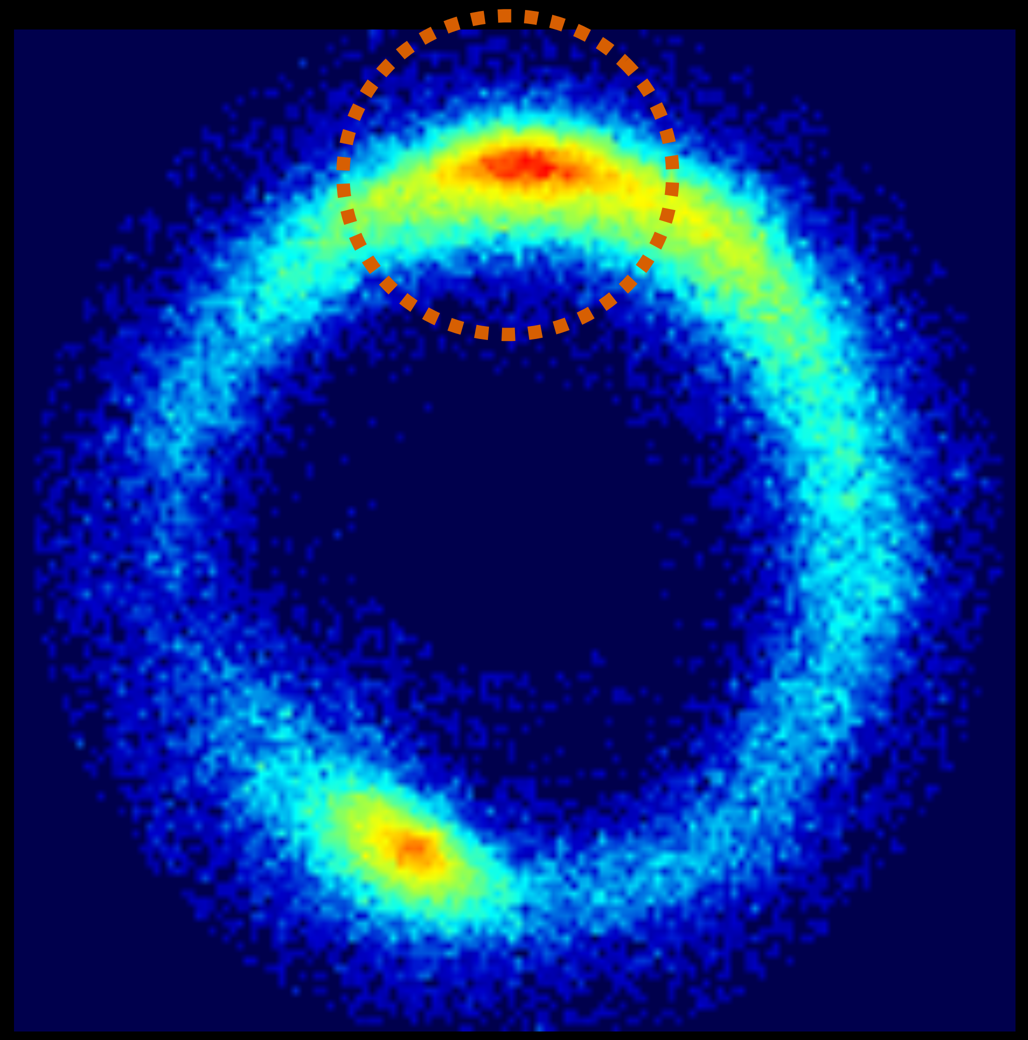
# DETECT DARK MATTER SUBSTRUCTURES



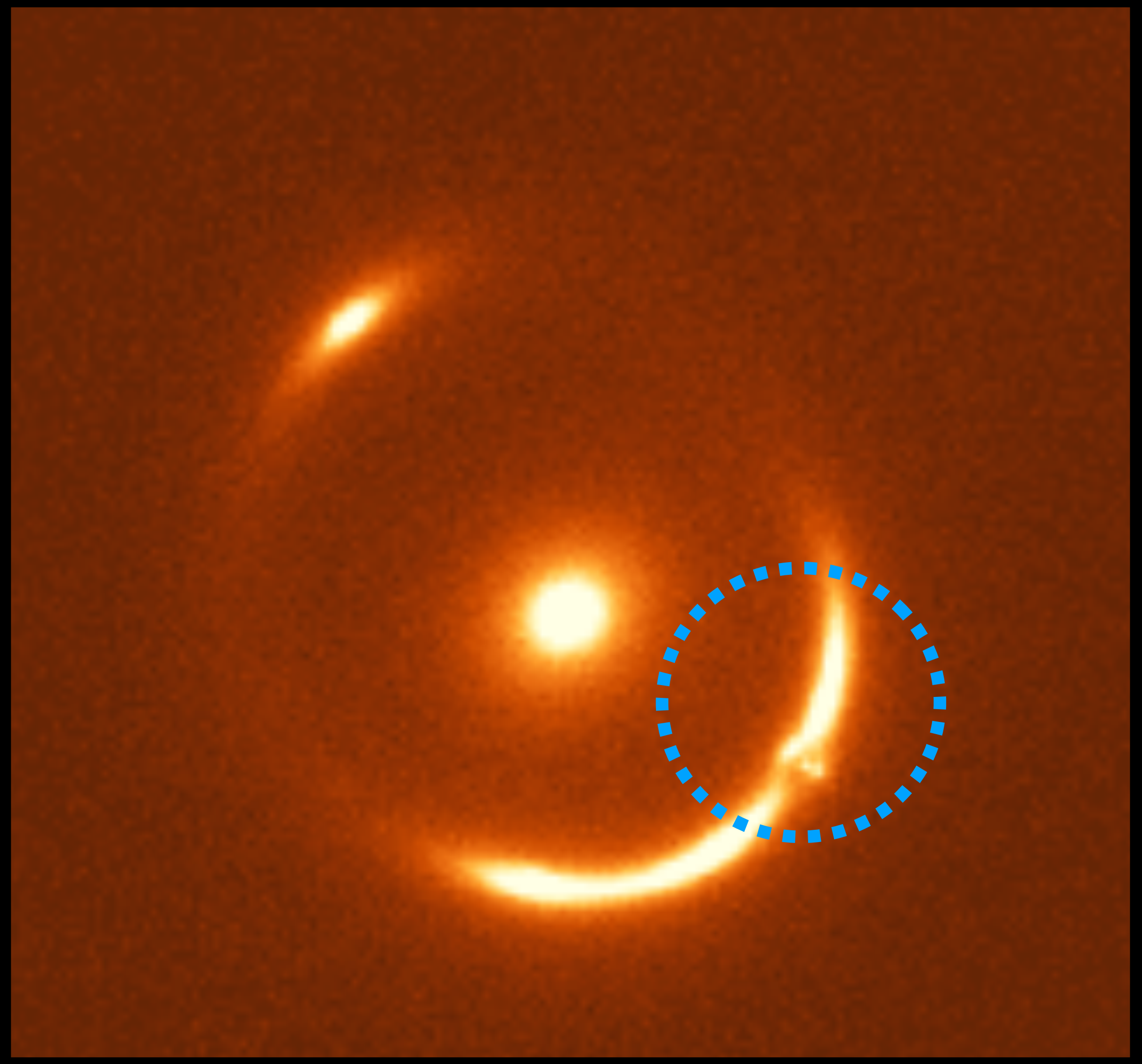

*"The clone"*



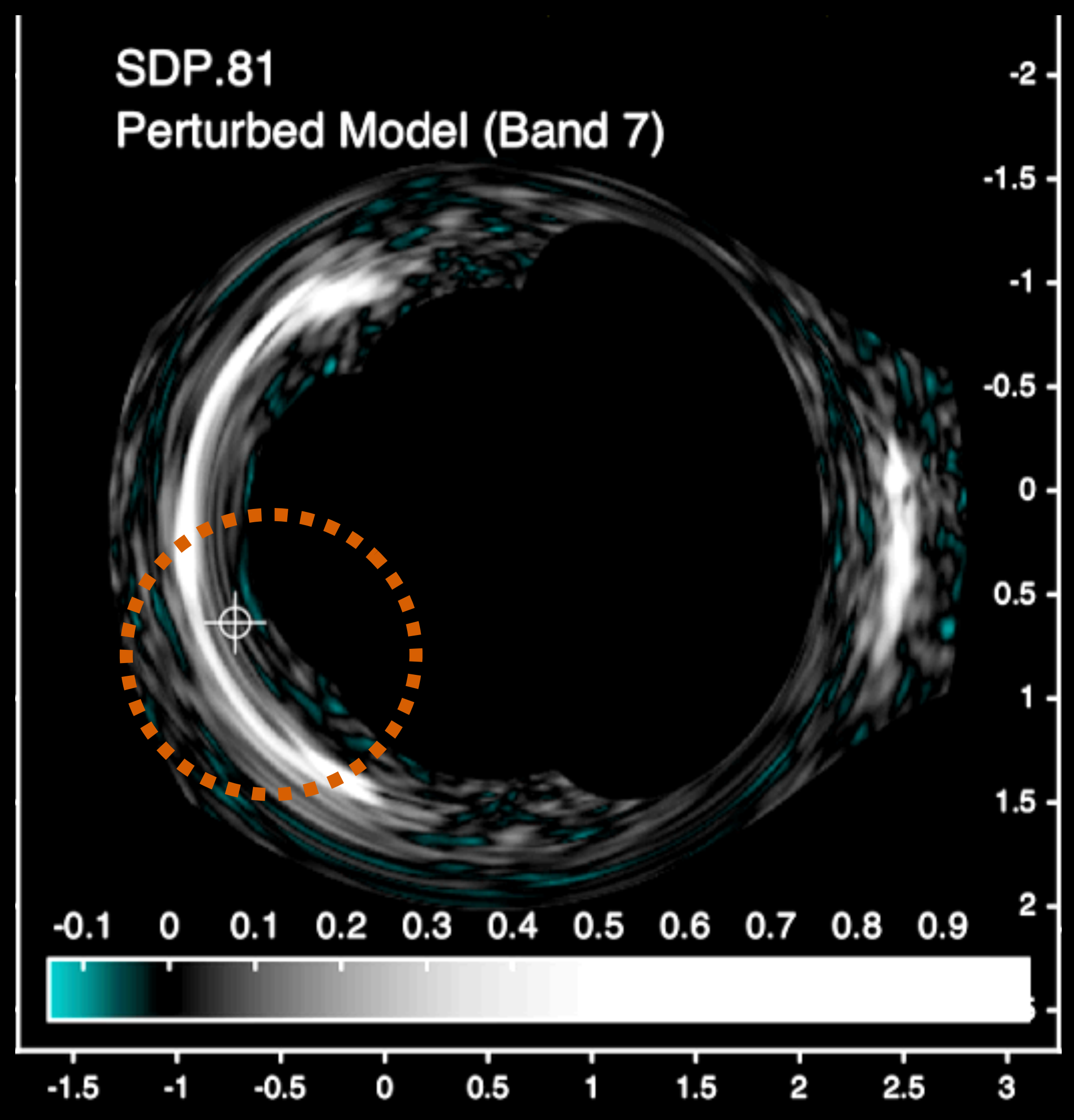
J0946 - Vegetti+2010



B1938 - Vegetti+2012



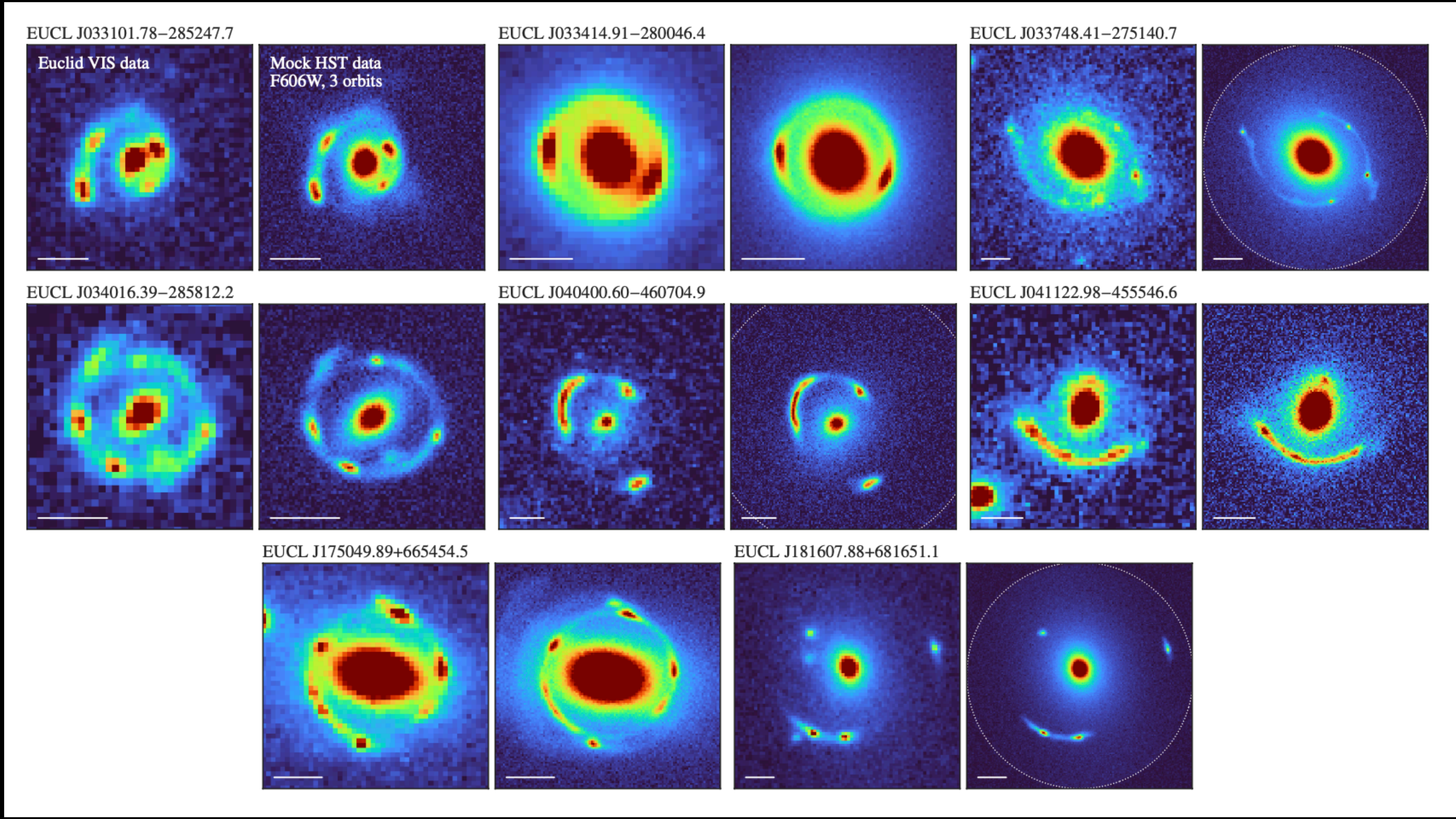
new SHARP lens
(in prep)




SPD81 - Hezaveh+2016

# DETECT DARK MATTER SUBSTRUCTURES

Euclid ⟶ HST




forecast:

>1 detection

per lens

*O'Riordan et al in prep.*

## Proposals and accepted programmes – Spectroscopy

*Please add date with mm.yyyy and add the proposal PDF to the title column.*
*If your proposal is eventually not accepted, please remove it from the list.*
*The contact person should be aware of the targets observed and/or to be observed.*

| | Telescope/Instr. | PI | contact person email | observing period | # hours | # targets | Status | Submission/Acceptance date | Proposal | KP | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GTC/Osiris+ | Acebron | ana.acebron@unican.es | 2025B–2027A | 270 | 135 | pending | 04.2025 | CELESTE: A gtC spEctroscopic Legacy programme of Euclid STrong lEnses | KP1 | |
| 2 | SALT RSS | Serjeant | stephen.serjeant@open.ac.uk | 2025 – 1 | 2.6 | 1 or 2 from Euclid SLDE paper D | Guaranteed time | 04/2025 | UKSC GTO request | KP1 | |
| 3 | Palomar/NGPS | Stern | daniel.k.stern@jpl.nasa.gov | 2025B | 5/n | 40 | Pending | 04.2025 | Euclid Strong Lenses and Distant Quasars | KP1 | |
| 4 | VLT x-shooter | Tian | tian.li@port.ac.yk | 2024 | 2 | 1 DSPL | finished | 10.2024 | DSPL | KP1 | |
| 5 | HET LRS2 | Ecker | ecker@usm.lmu.de | 2025 | 10 | 11 | Guaranteed time | 04.2025 | | KP1 | |
| 6 | LBT | Ecker | ecker@usm.lmu.de | 2025 | 12 | 6 | Guaranteed time | 04.2025 | | KP1 | |
| 6 | VLT X-shooter | Ecker | ecker@usm.lmu.de | 2025 | 56 | 24 | pending | 04.2025 | https://euclid.roe.ac.uk/attachments/150262 | KP1 | |
| 7 | VLT MUSE+FORS2 | Bergamini | pietro.bergamini@unimi.it | 2025 | 12 MUSE + 8 FORS2 | 2 clusters from Q1 paper | pending | 03.2025 | https://euclid.roe.ac.uk/attachments/150324 | KP4 | |
| 8 | OHP/MISTRAL | R. Gavazzi | raphael.gavazzi@lam.fr | 2025 | | 4 | EXECUTED | 03.2025 | | KP4 | No detections (low S/N, poor sensitivity) |
| 9 | Gemini GMOS | H. Srivastava | hsrivast@student.ubc.ca | 2025A | 3.18 | 1 | Guaranteed time | 05.2025 | Spectroscopic follow-up of a bright double source-plane lens discovered by Euclid | KP1 | |

## Proposals and accepted programmes – Photometry

*Please add date with mm.yyyy and add the proposal PDF to the title column.*
*If your proposal is eventually not accepted, please remove it from the list.*
*The contact person should be aware of the targets observed and/or to be observed.*

| | Telescope/Instrument | PI | contact person email | observing period | # hours | # targets | Status | Submission/Acceptance date | Proposal | KP |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | HST WFC3/UVIS | O'Riordan | conor@mpa-garching.mpg.de | Cycle 33 | 24 orbits | 8 | Submitted | 10.04.2025 | Detecting low-mass dark matter haloes in a Euclid-selected sample of strong lenses | KP1 |
| 2 | HST | Ryczanowski | | | | | | | | |
| 3 | HST | Li | | | | | | | | |

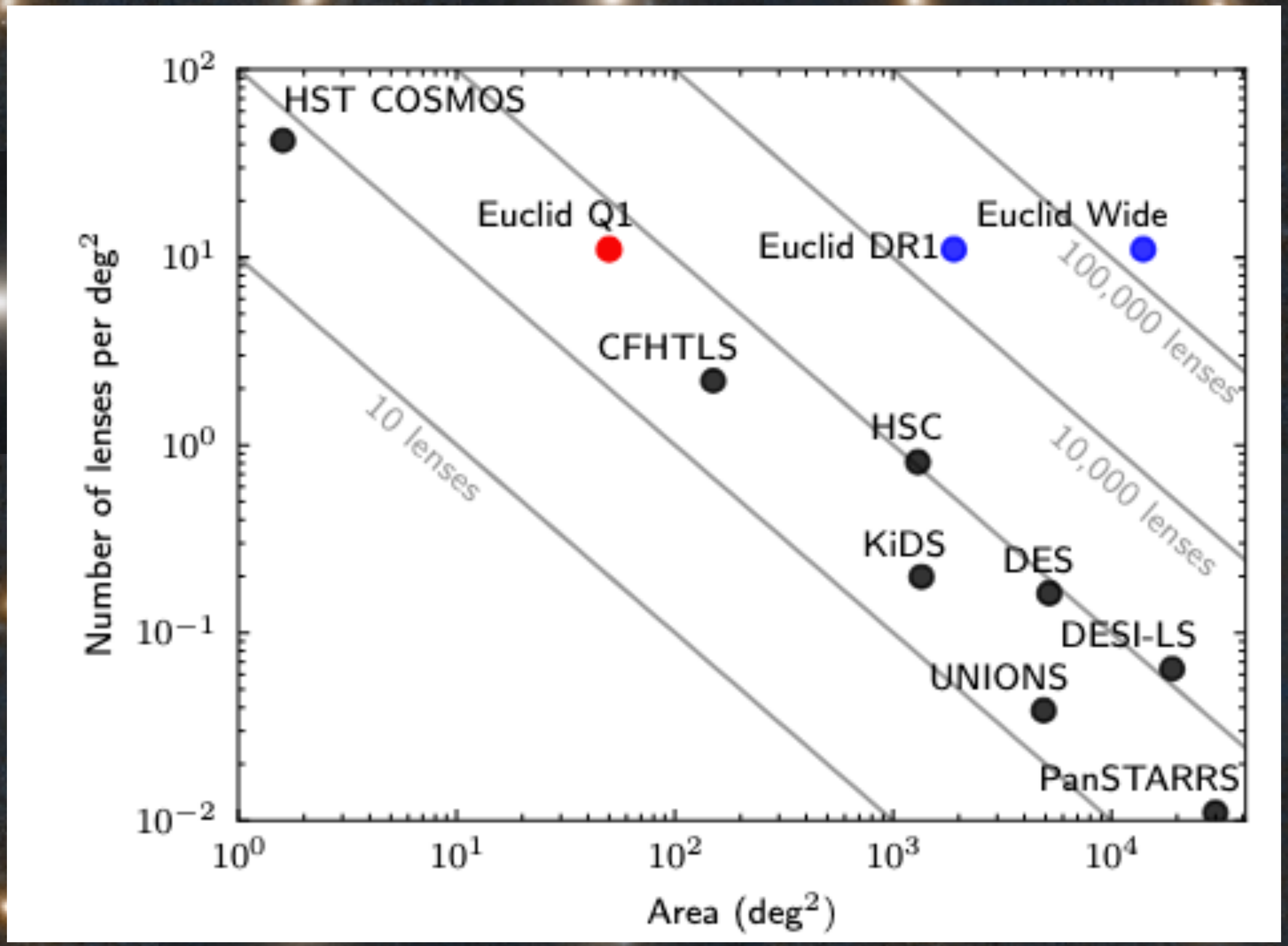
# Towards DR1

Several ML network have now been improved

& are being integrated in the Euclid Pipeline to run automatically

We will run a new citizen science project to help confirm the best lens candidates

Many science applications in progress




Euclid consortium