Science In the Era of the 30m With the Brightest Lensed Galaxies In the Observable Universe

Matthew Bayliss
Colby College and the MIT Kavli Institute

The Thirty Meter Telescope Science Forum - Kyoto, Japan - May 26, 2016

Collaborators

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Kate Whitaker (UMASS-Amherst)

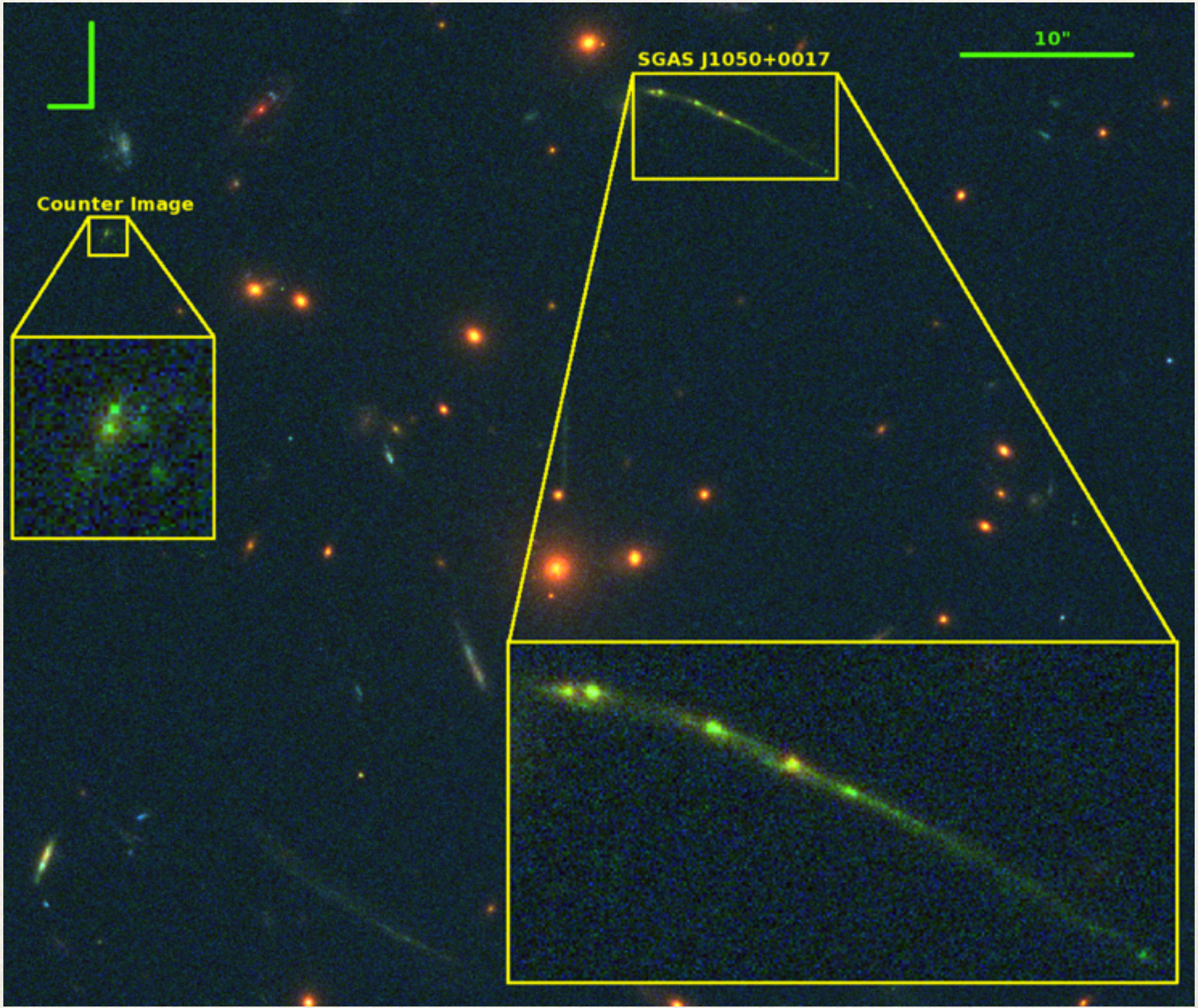
Rangoon Bordoloi (MIT)

Eva Wuyts (MPE & the non-profit world)

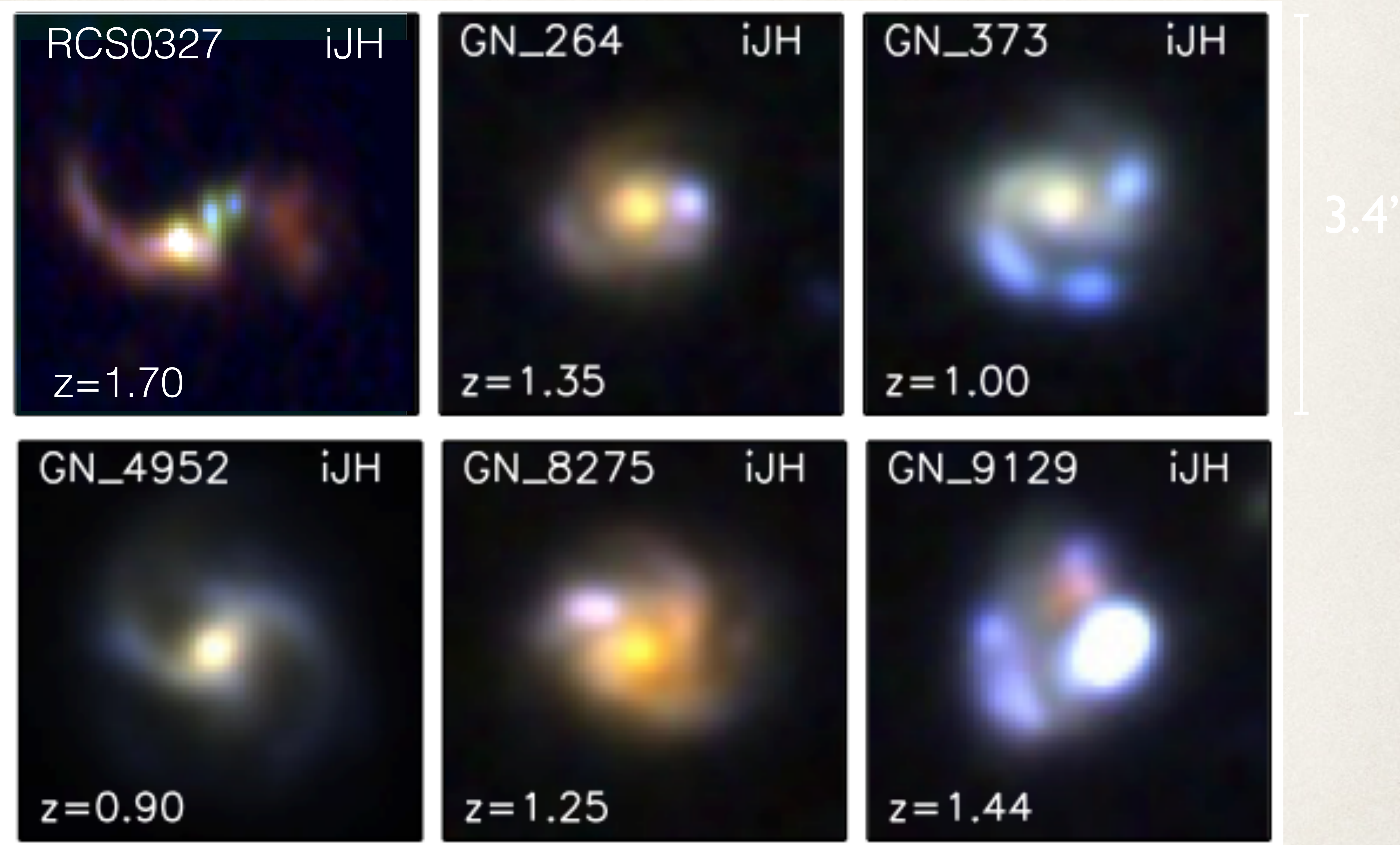
Why Strong Lensing?

Why Strong Lensing?

Because it lets us cheat and preview 30m era science now

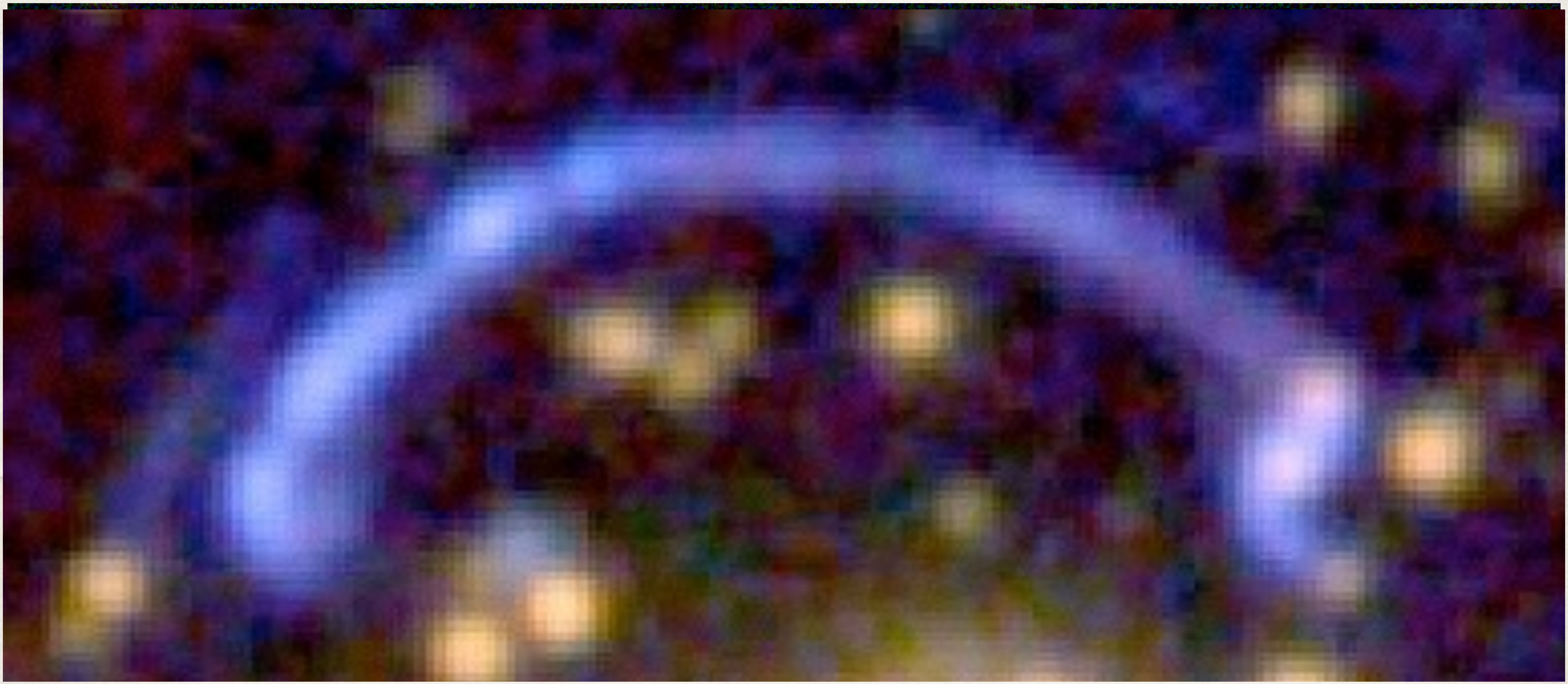


z ~ 1-2 Galaxies As Seen By HST



S. Wuyts et al. 2013, CANDELS + 3D-HST

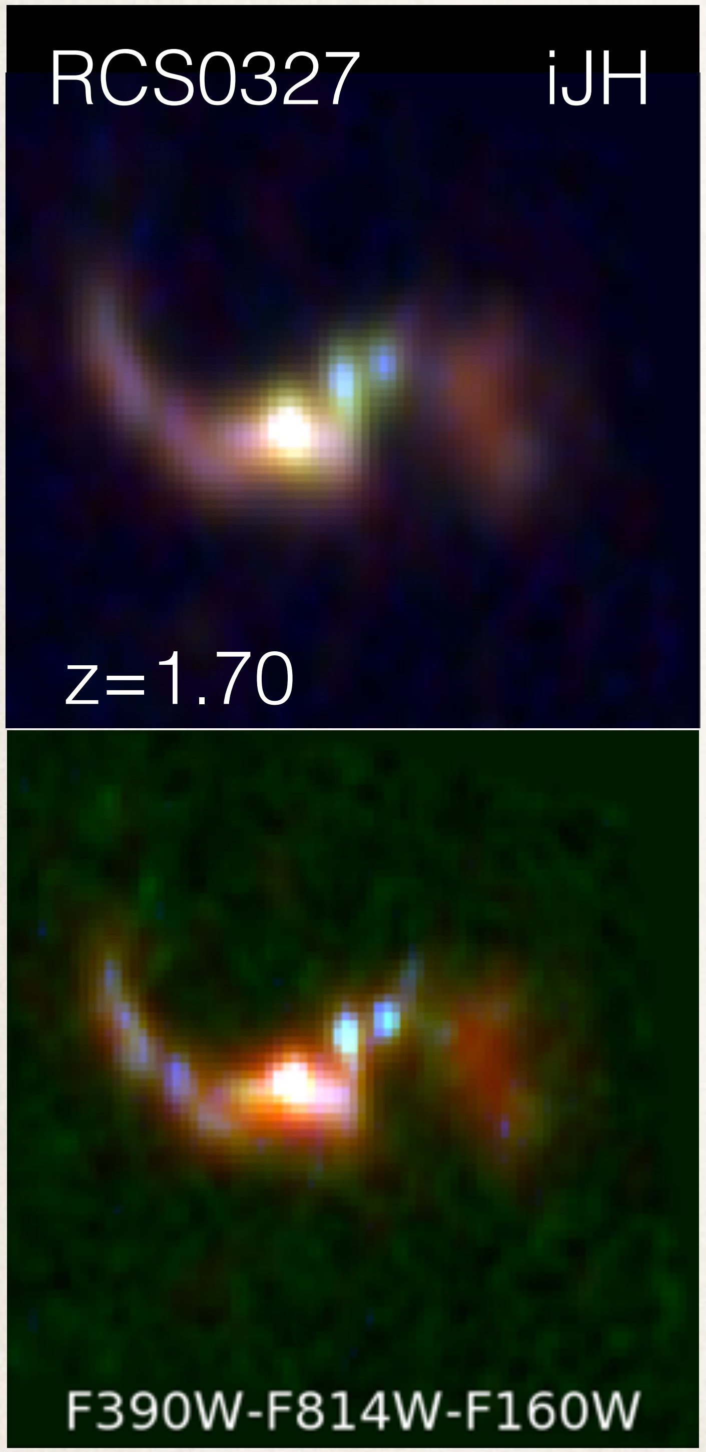
Why Strong Lensing?



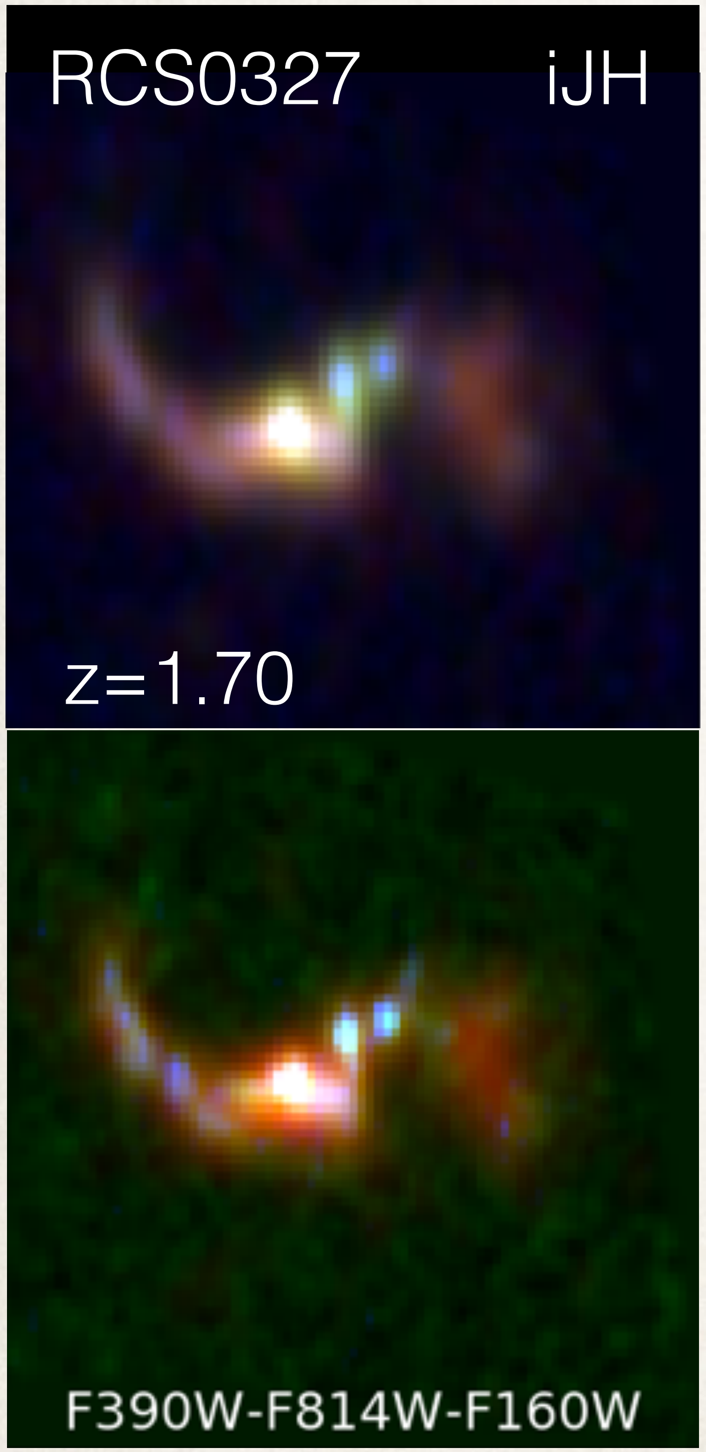
Why Strong Lensing?

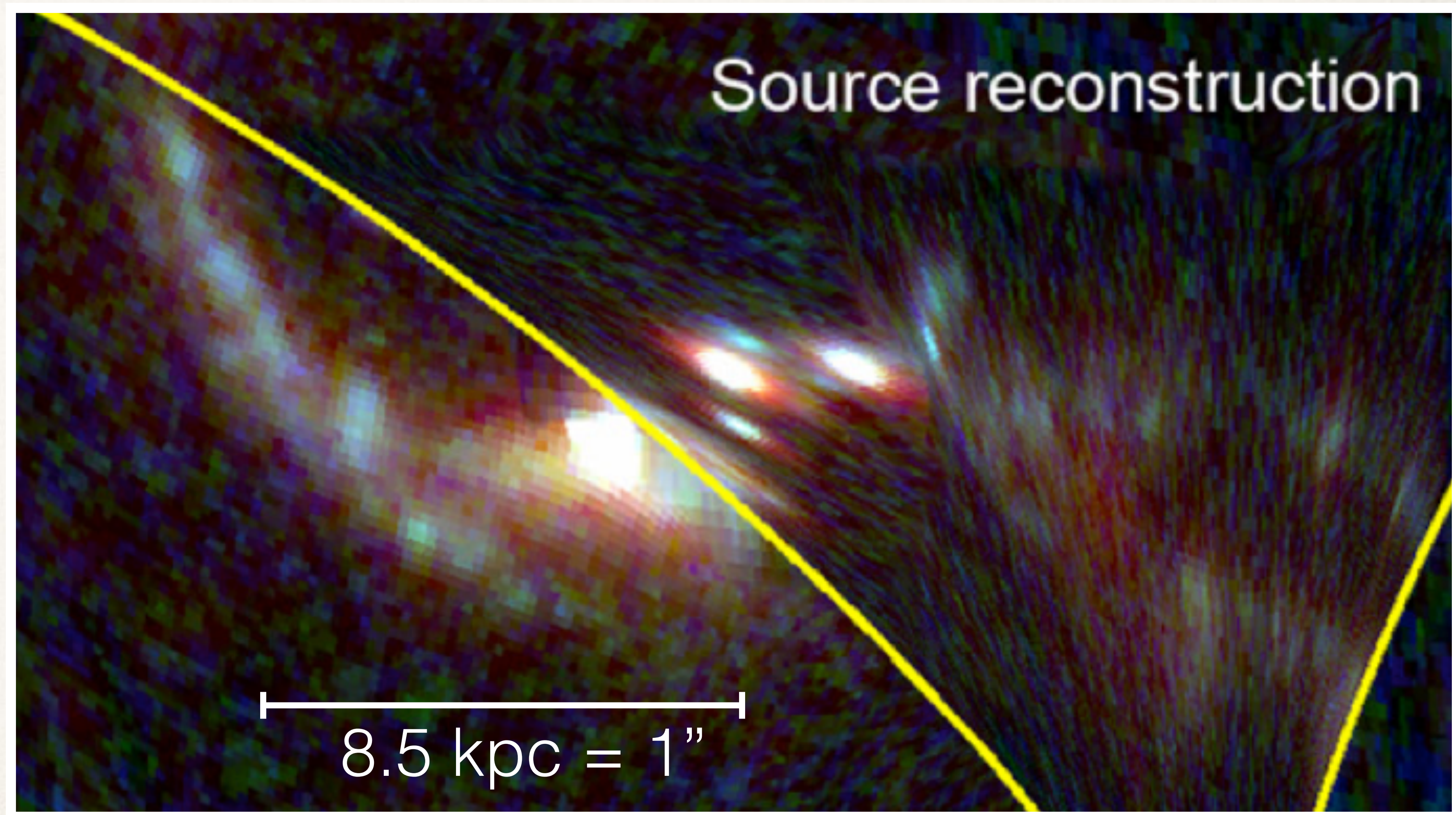
RCSGA 0327-1326

RCSGA 0327 at z = 1.7 Galaxies As Seen By HST + Strong Lensing



RCSGA 0327 at z = 1.7 Galaxies As Seen By HST + Strong Lensing

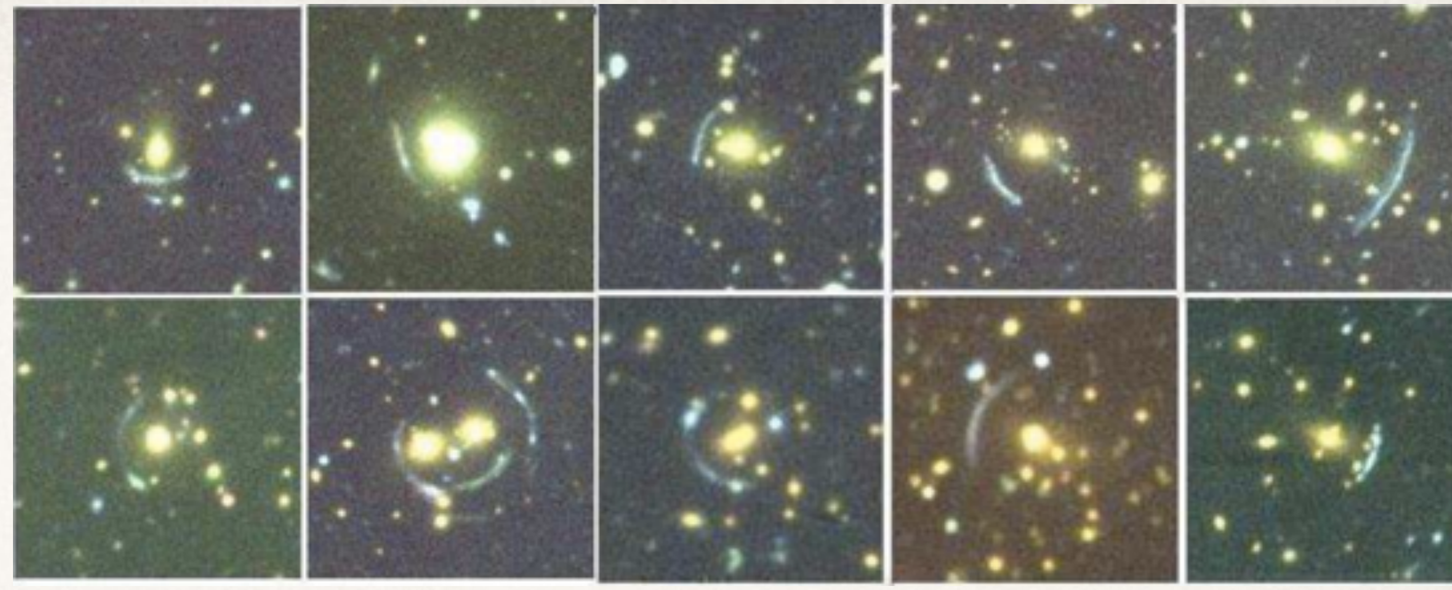





Sloan Giant Arcs Survey (SGAS)
~200 strong lensed galaxies

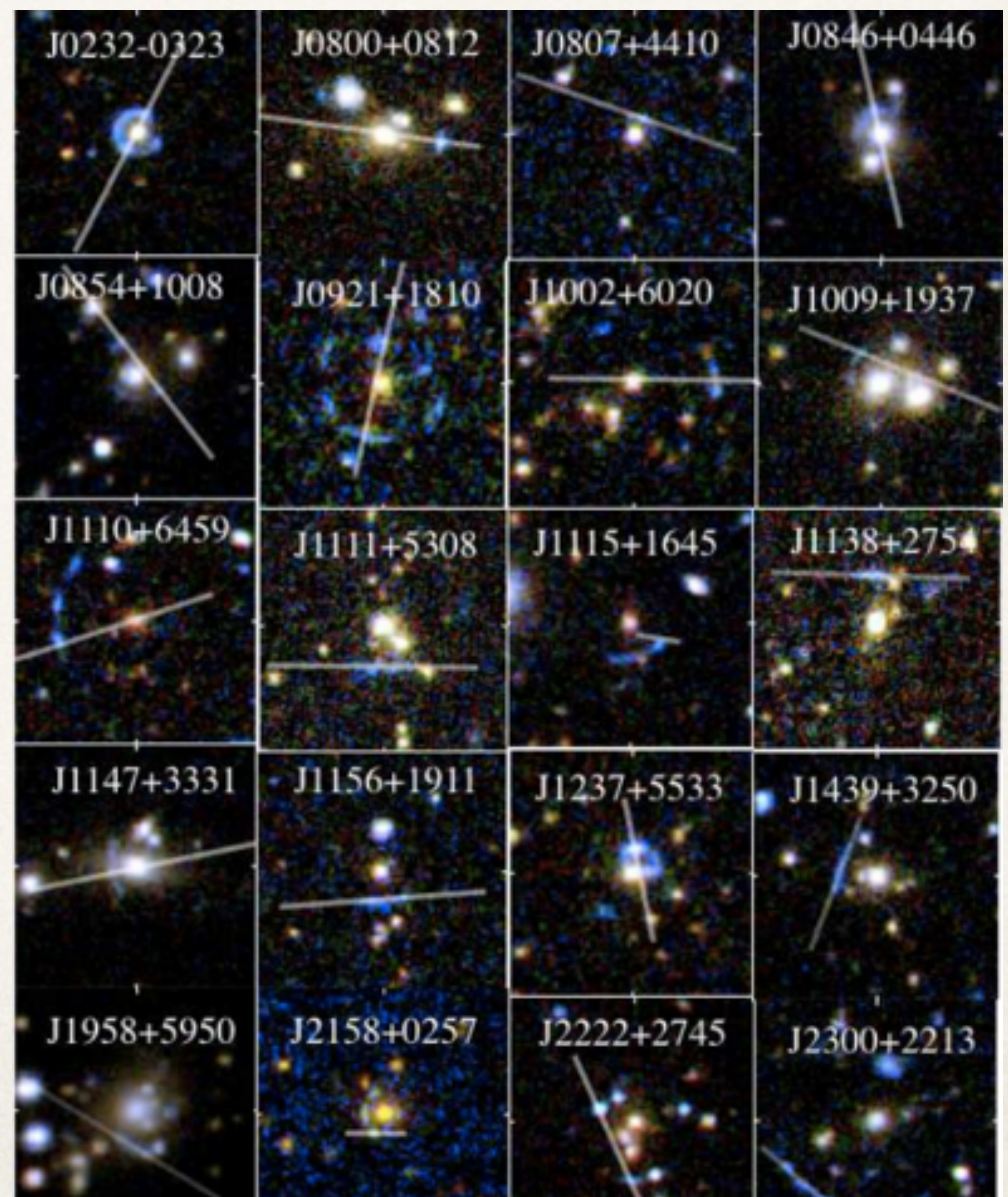
The Sloan Bright Arcs Survey

~30 Lensed Galaxies; Allam et al. 2008; Kubo et al. 2008,2009; Lin et al. 2009



The CASSOWARY Strong Lens Sample

~80 Lensed Galaxies; Belokurov et al. 2007, Stark et al. 2013

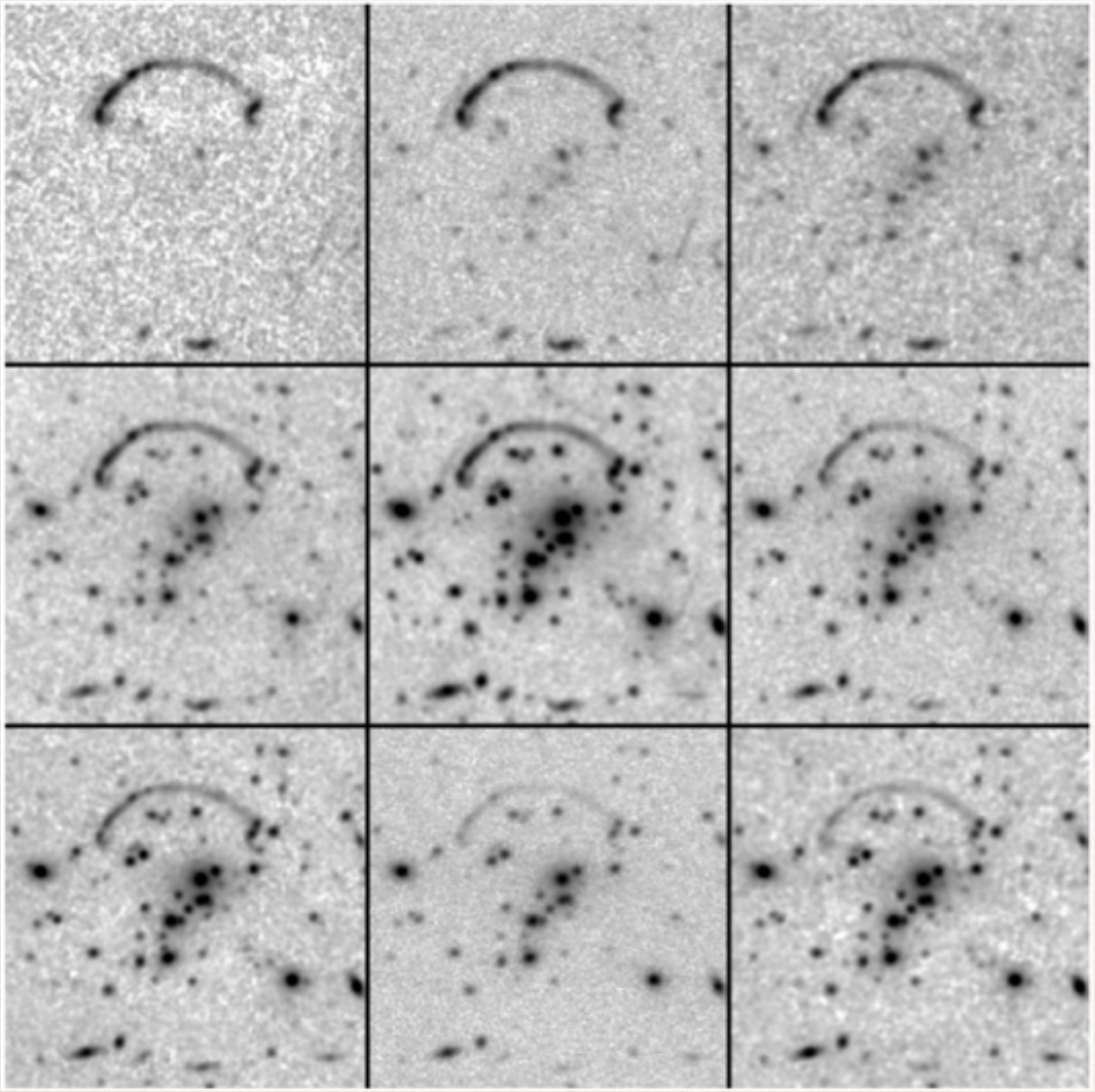


Sloan Giant Arcs Survey (SGAS)

~200 strong lensed galaxies; **~50 brighter than g~21**

Bayliss et al. 2011a,b; Gladders et al. (in prep)

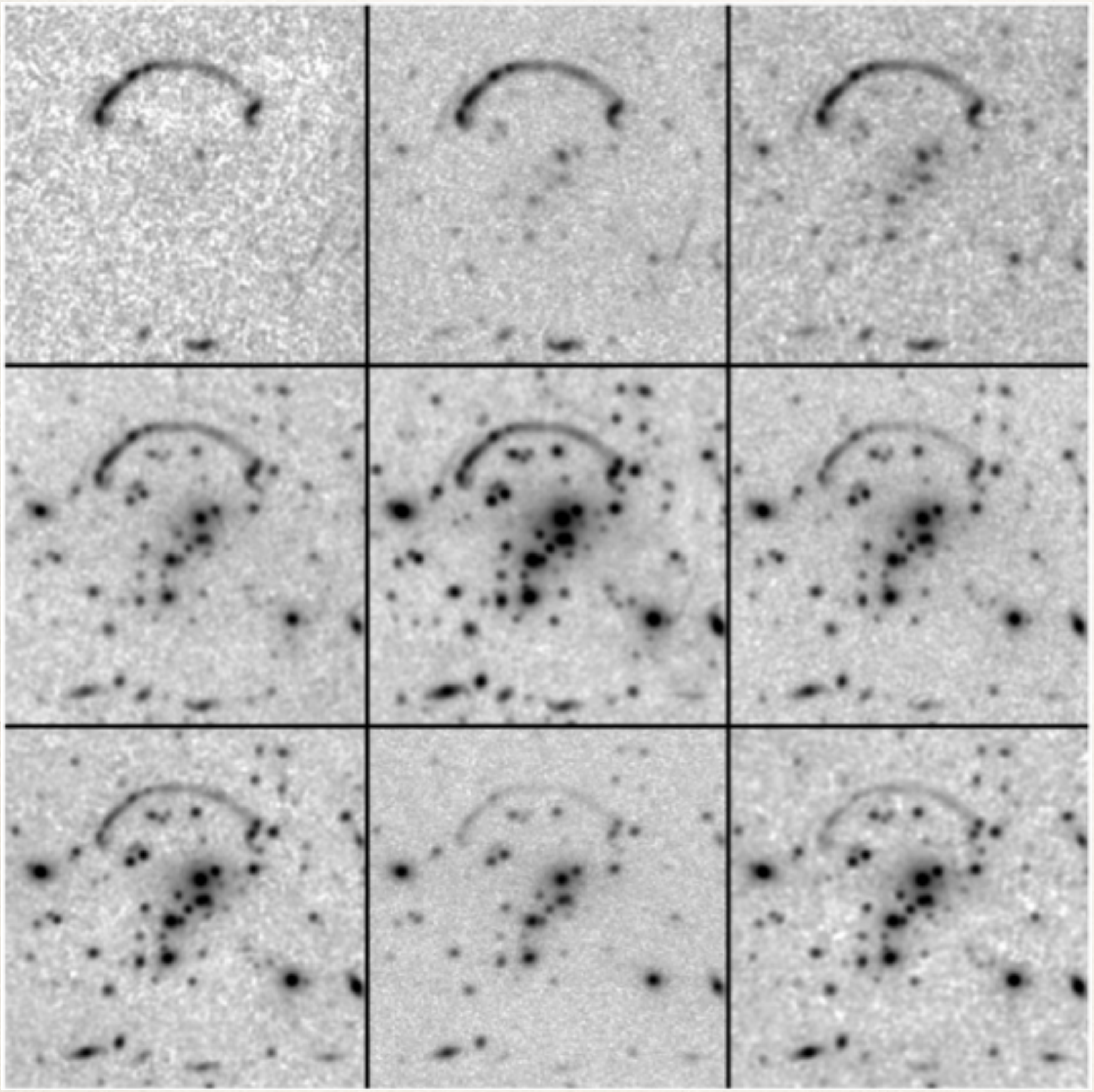
Extraordinary Sources, Courtesy of Strong Lensing

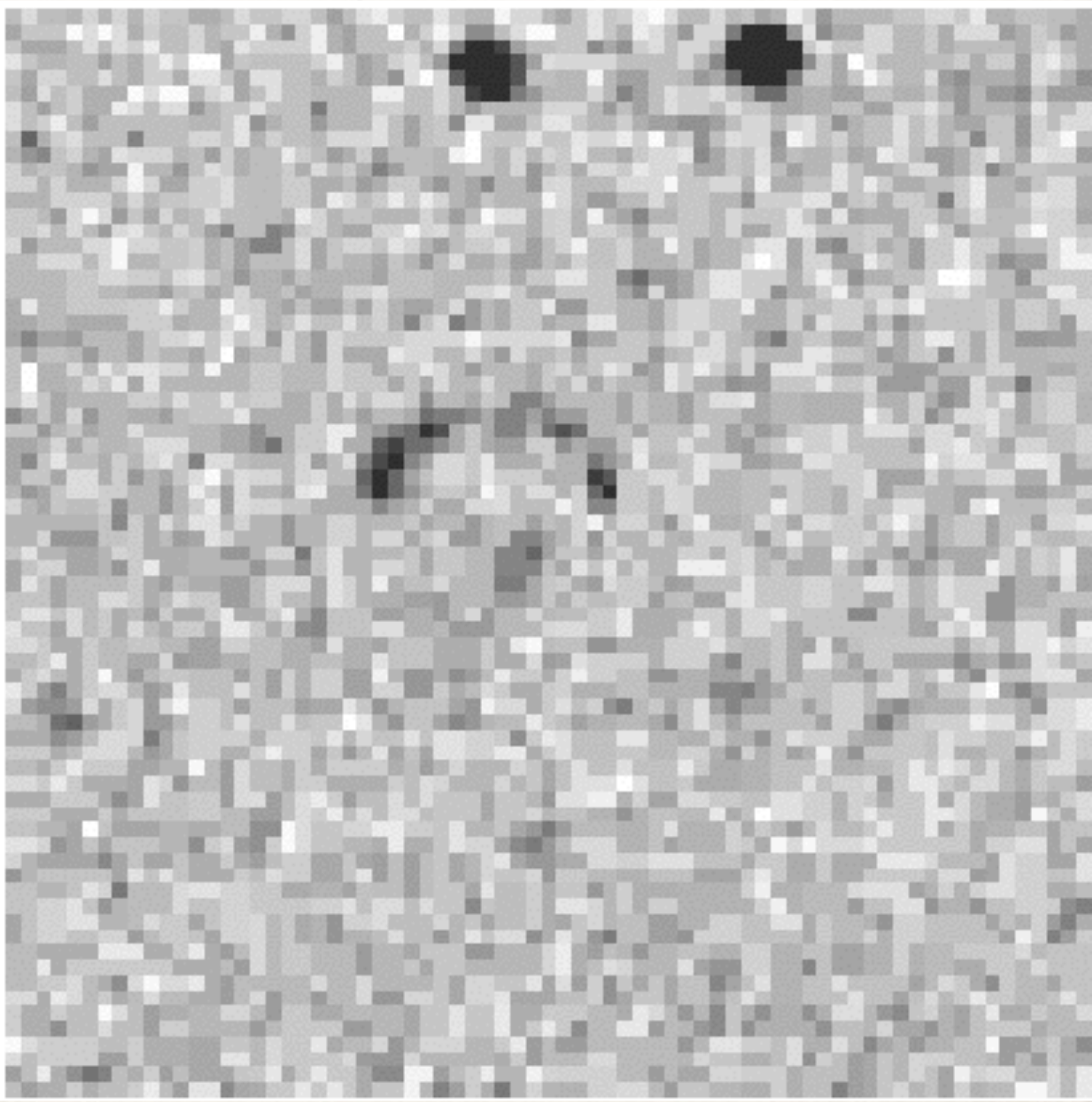


Galaxy at z=1.703, lensed by a foreground cluster (E. Wuyts et al. 2010).

Bright contiguous arc is 19th magnitude in g and r and 38" long

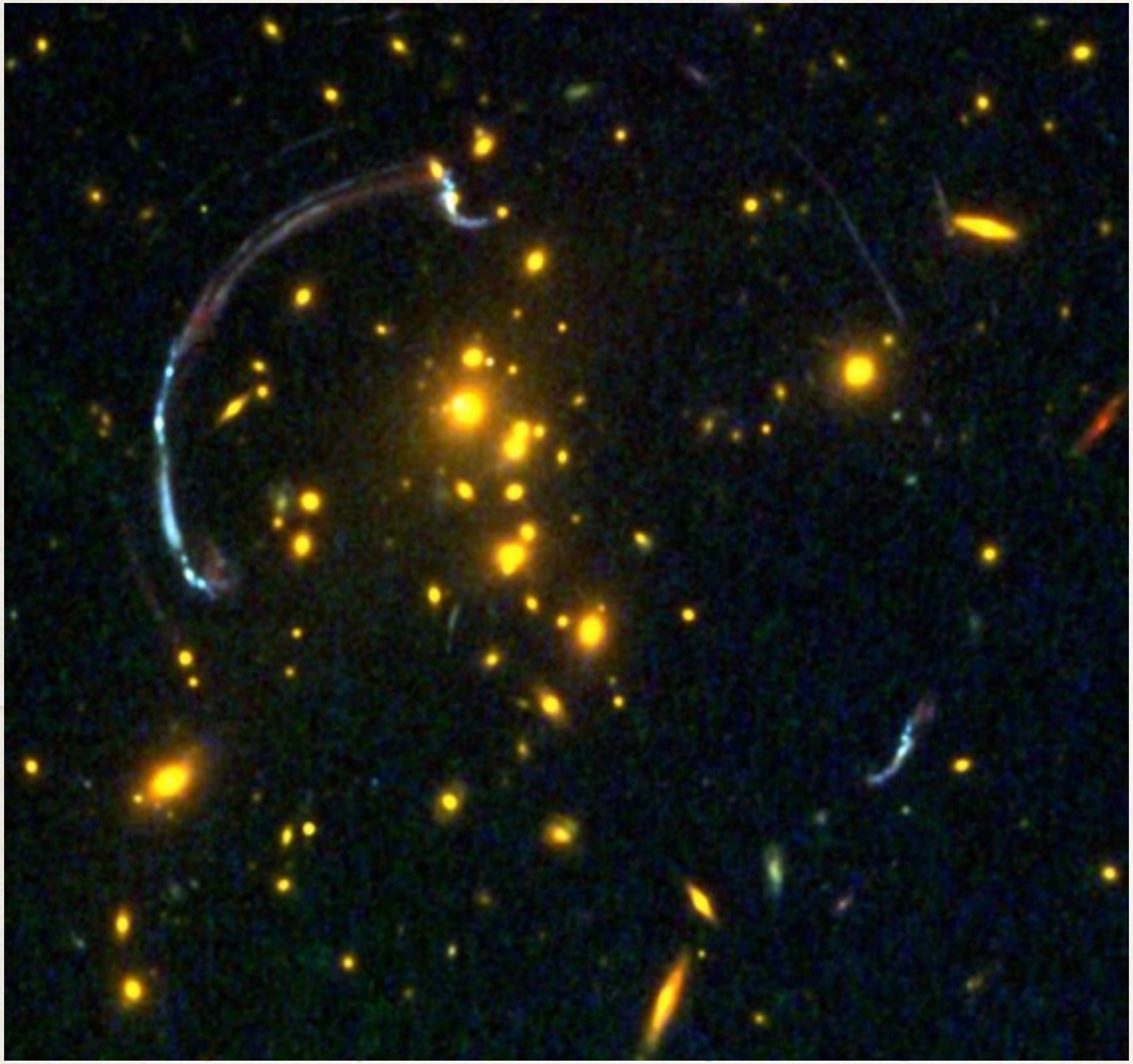
Extraordinary Sources, Courtesy of Strong Lensing

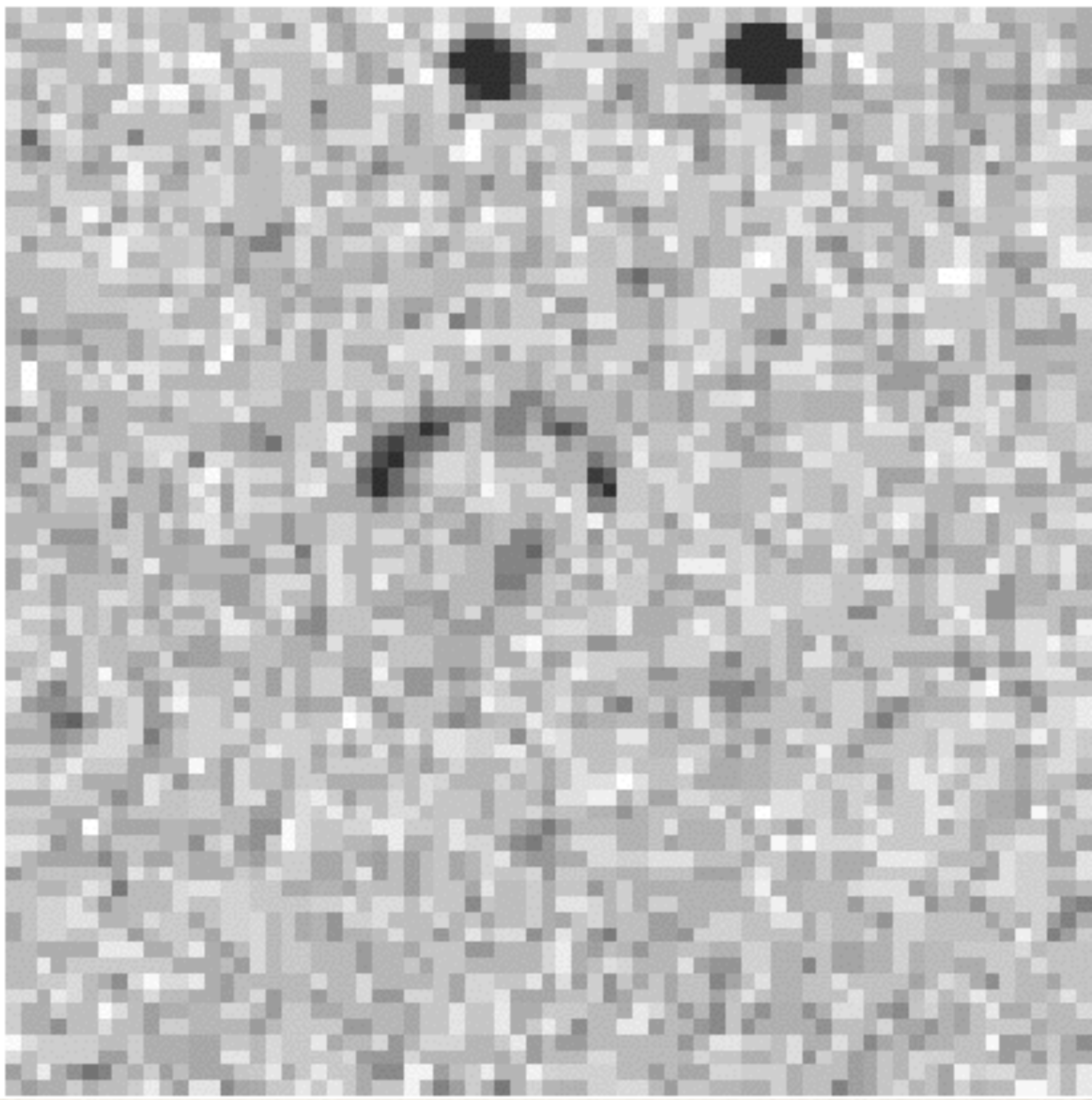




POSS

Extraordinary Sources, Courtesy of Strong Lensing





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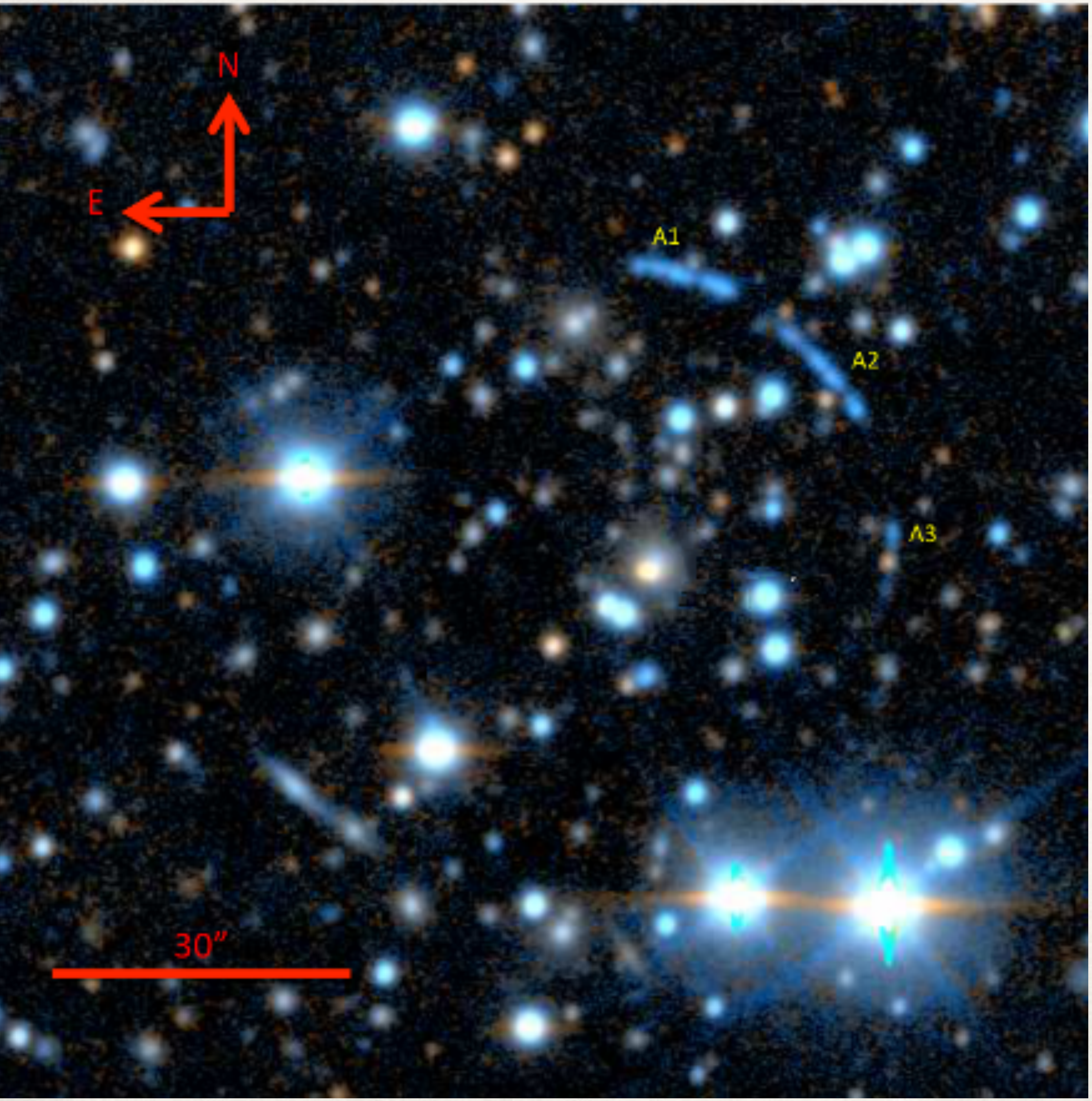
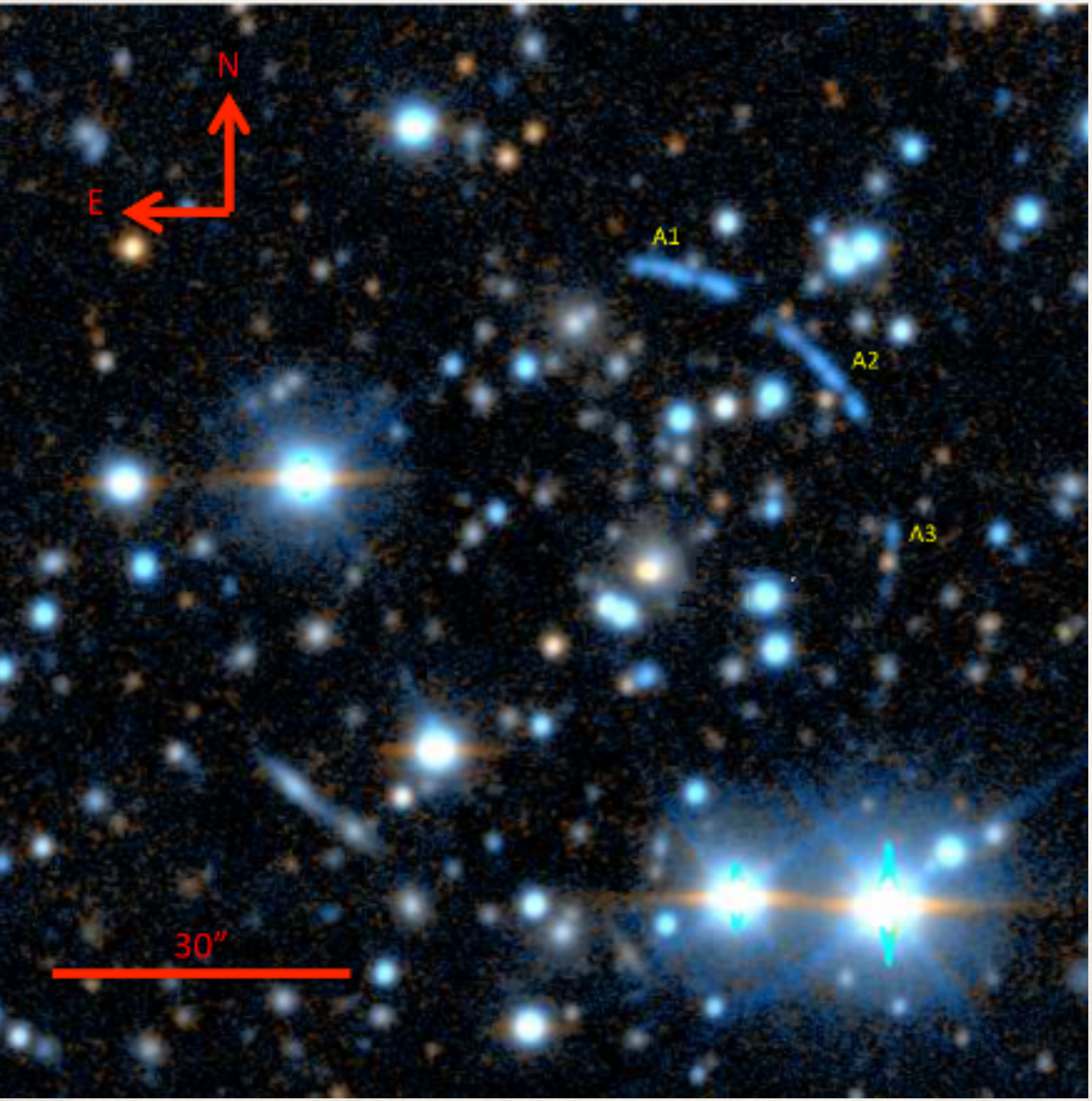
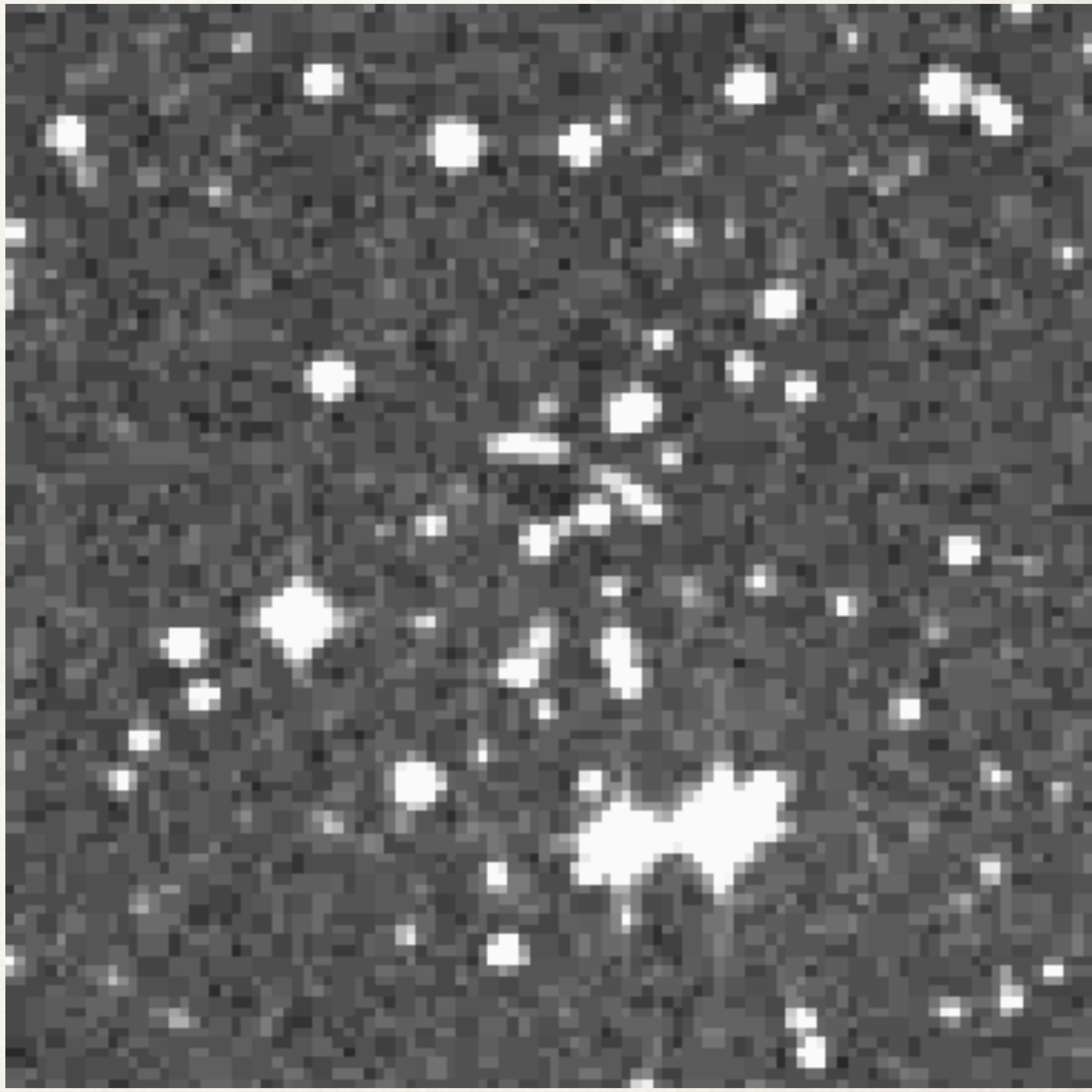


Galaxy at z=2.39, lensed by a foreground cluster (Dahle et al. 2016).

Bright contiguous arc is 17th magnitude in r and ~35″ long.

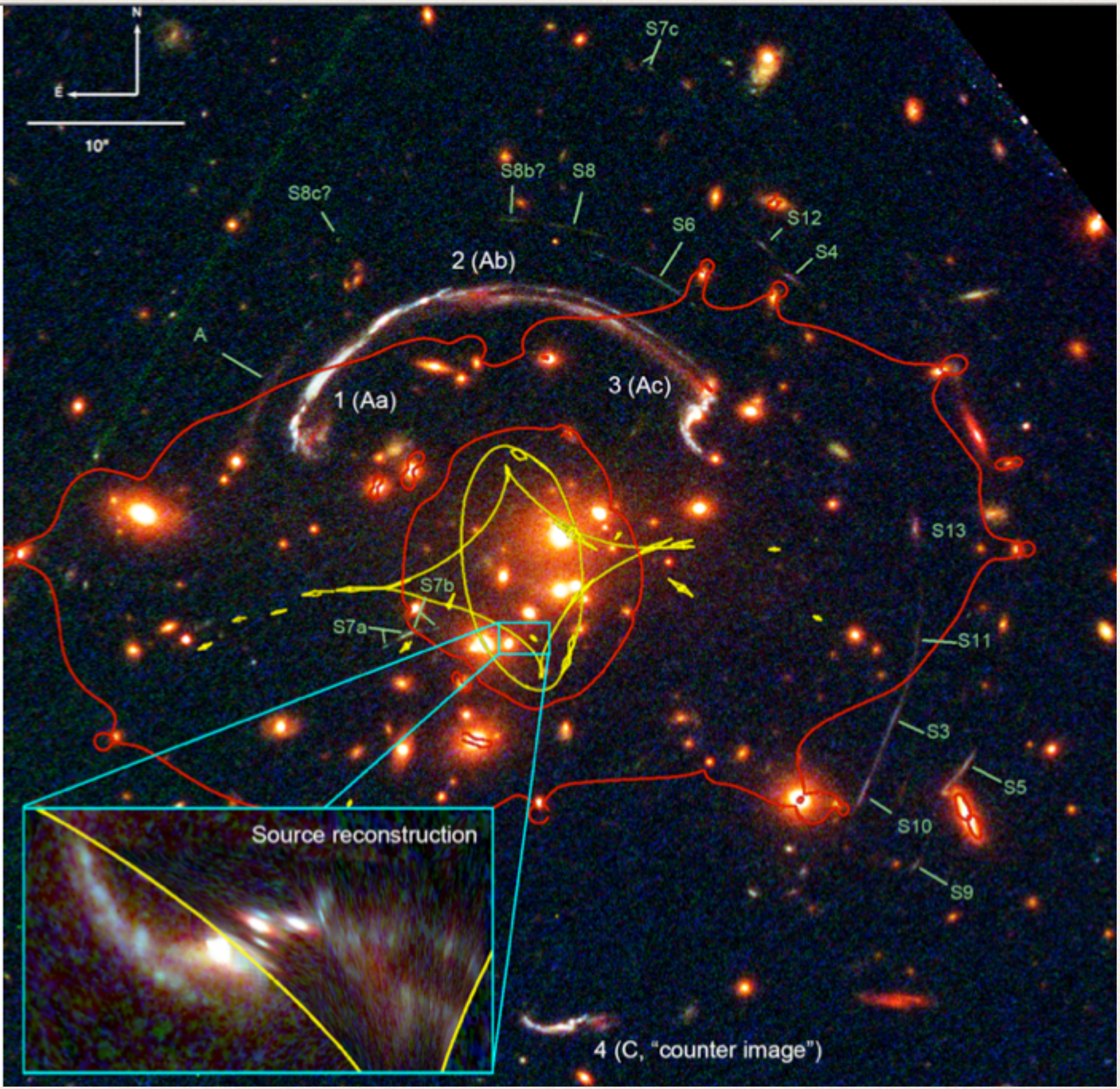
Extraordinary Sources, Courtesy of Strong Lensing





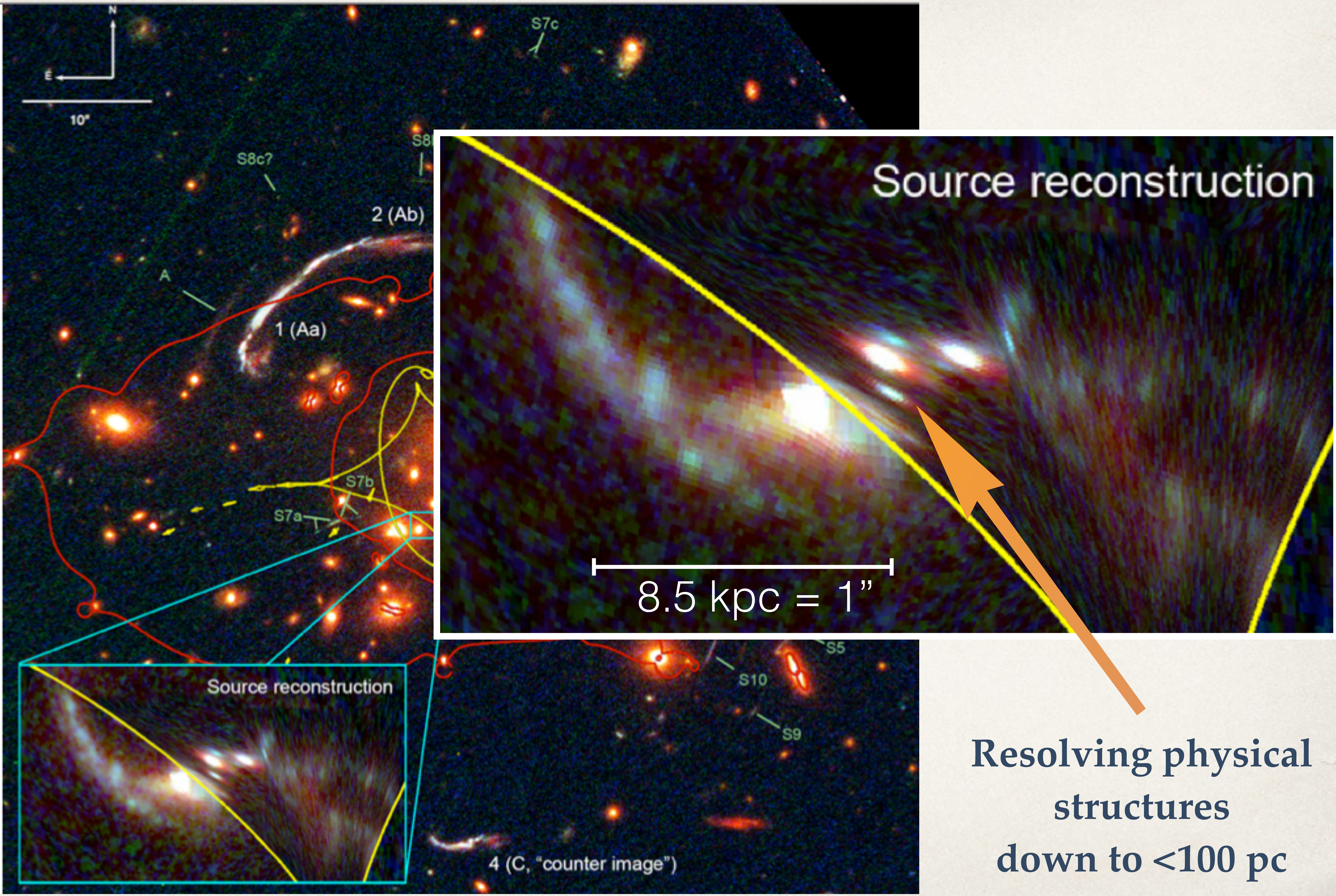
POSS-II

RCSGA 0327-1326



Sharon et al. (2012)

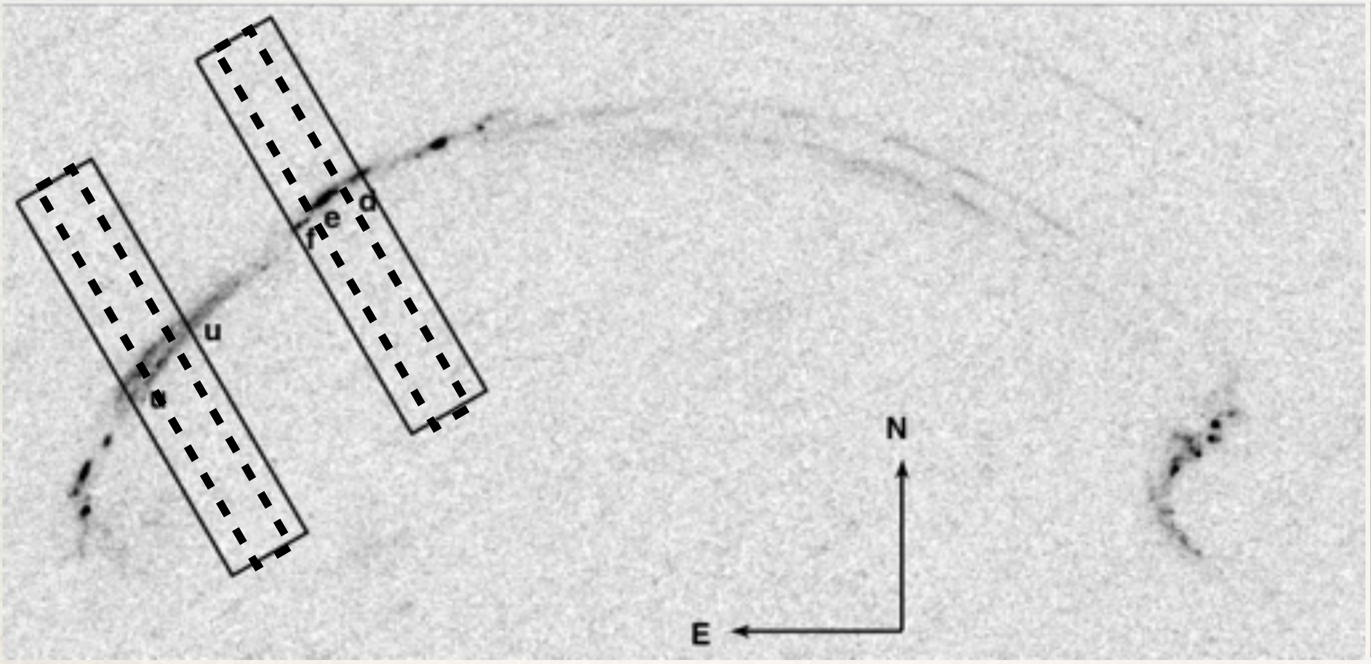
RCSGA 0327-1326

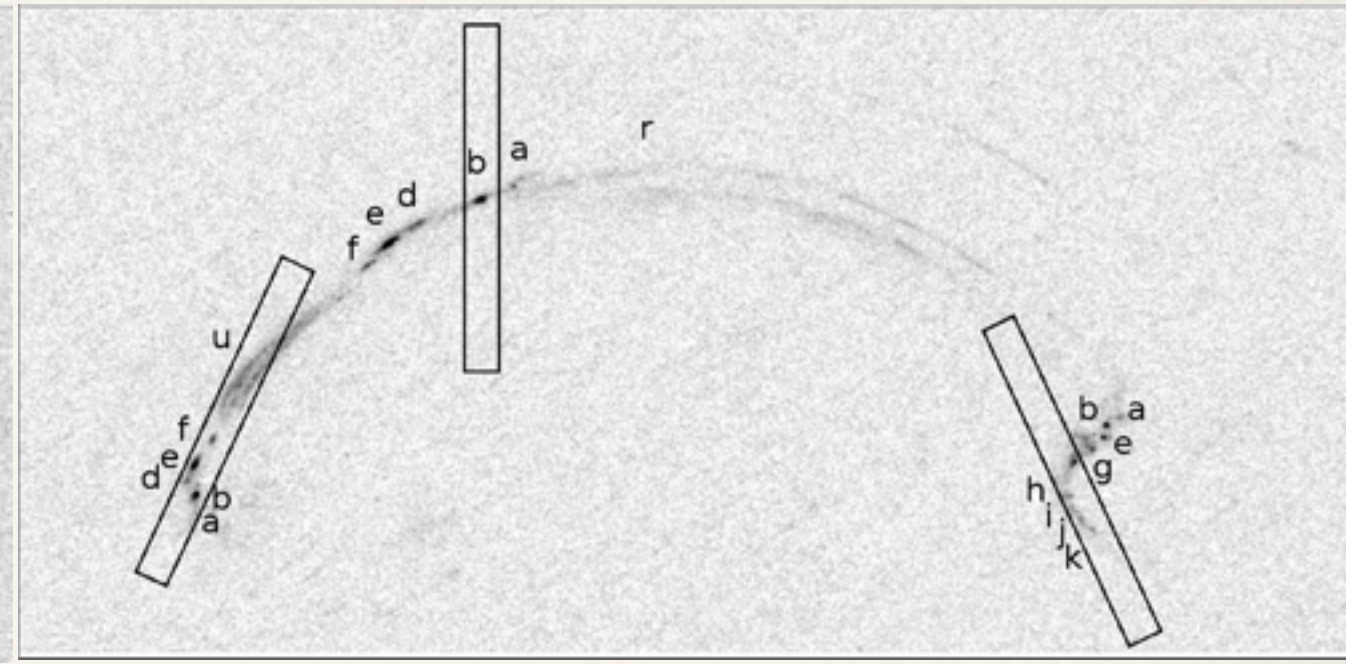


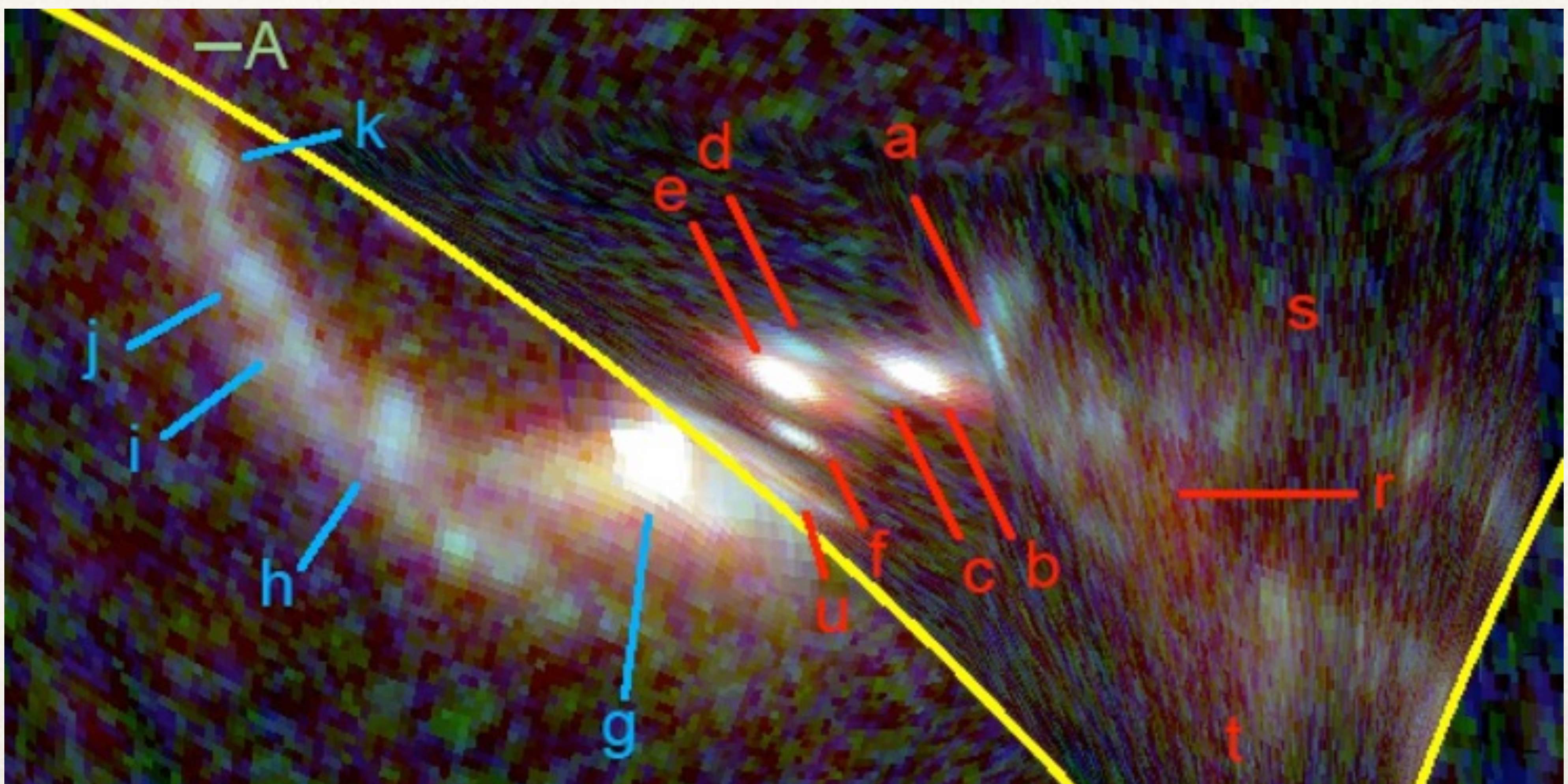
Sharon et al. (2012)

Resolving physical structures down to <100 pc

Mapping Slits Into the Source Plane







Bayliss et al. (2015a, IAU Proc.)

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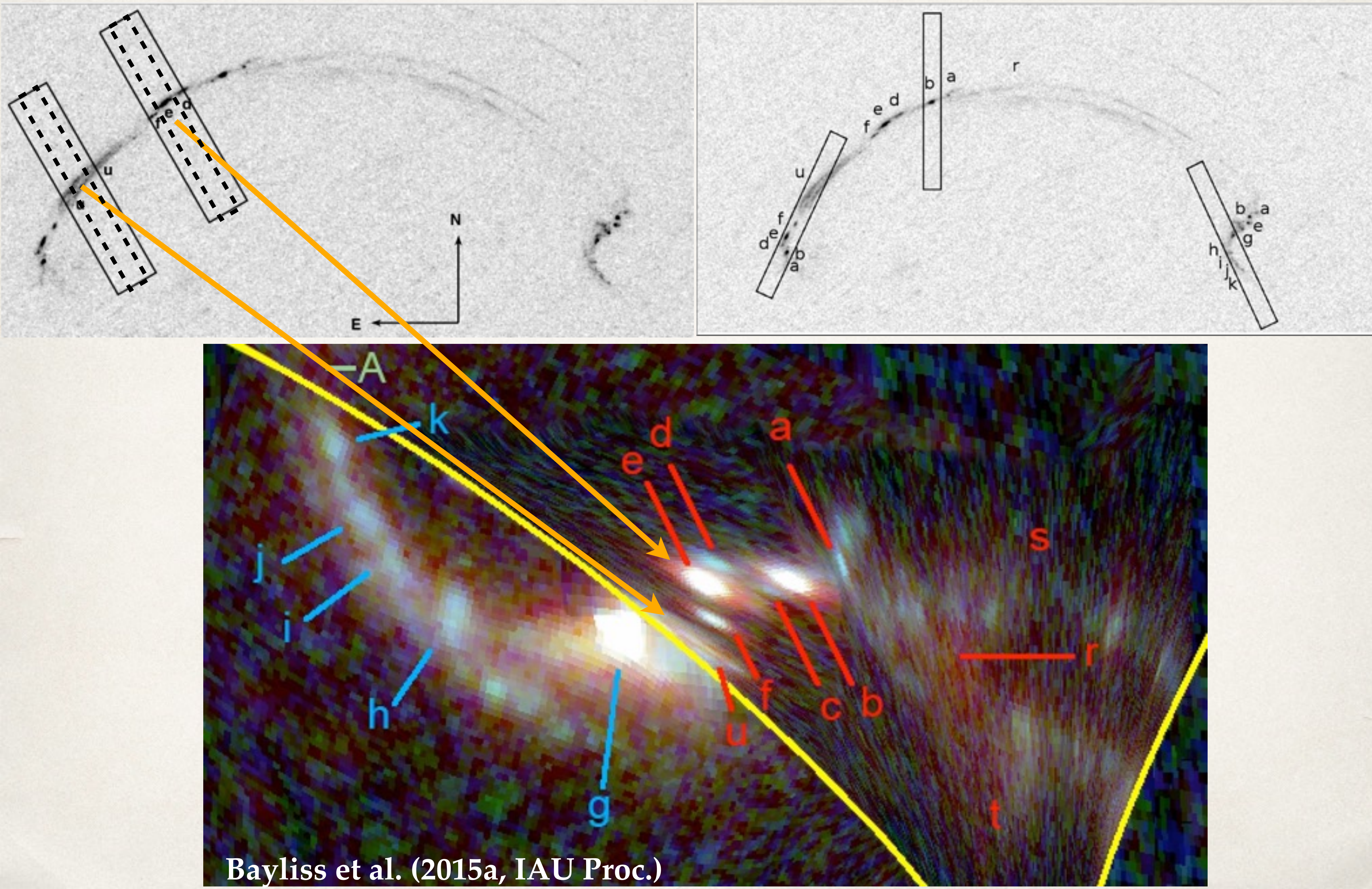

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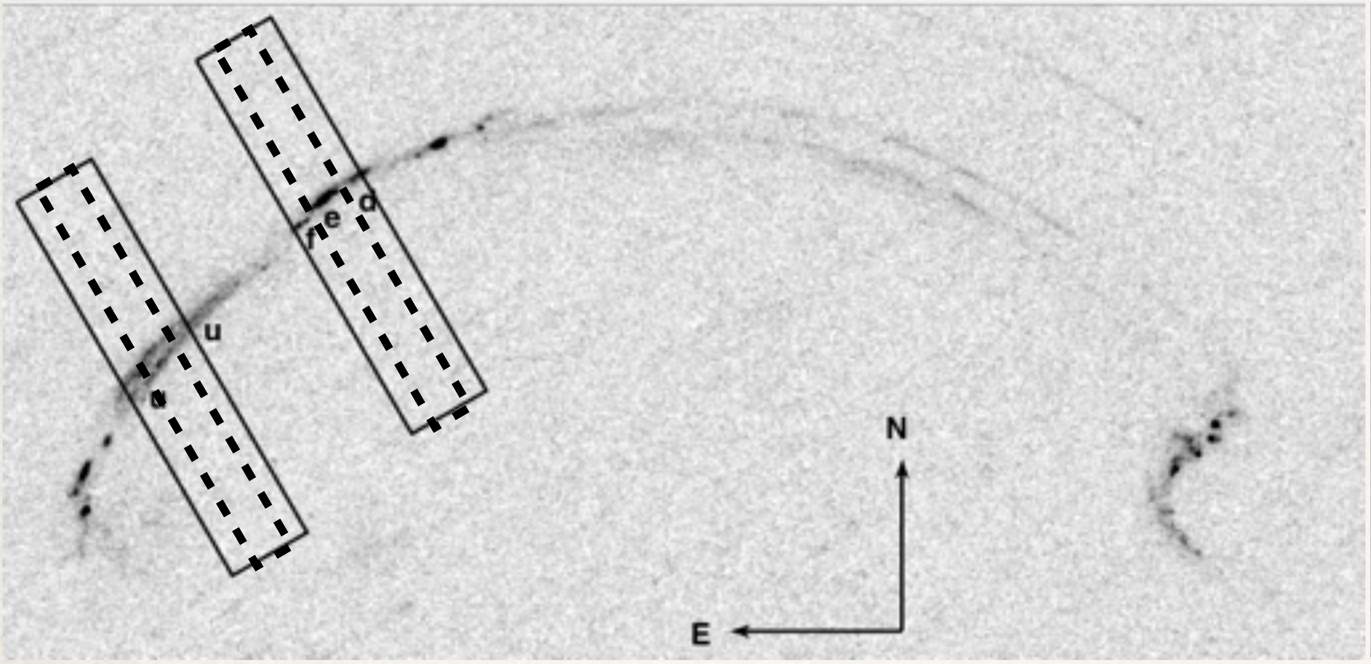

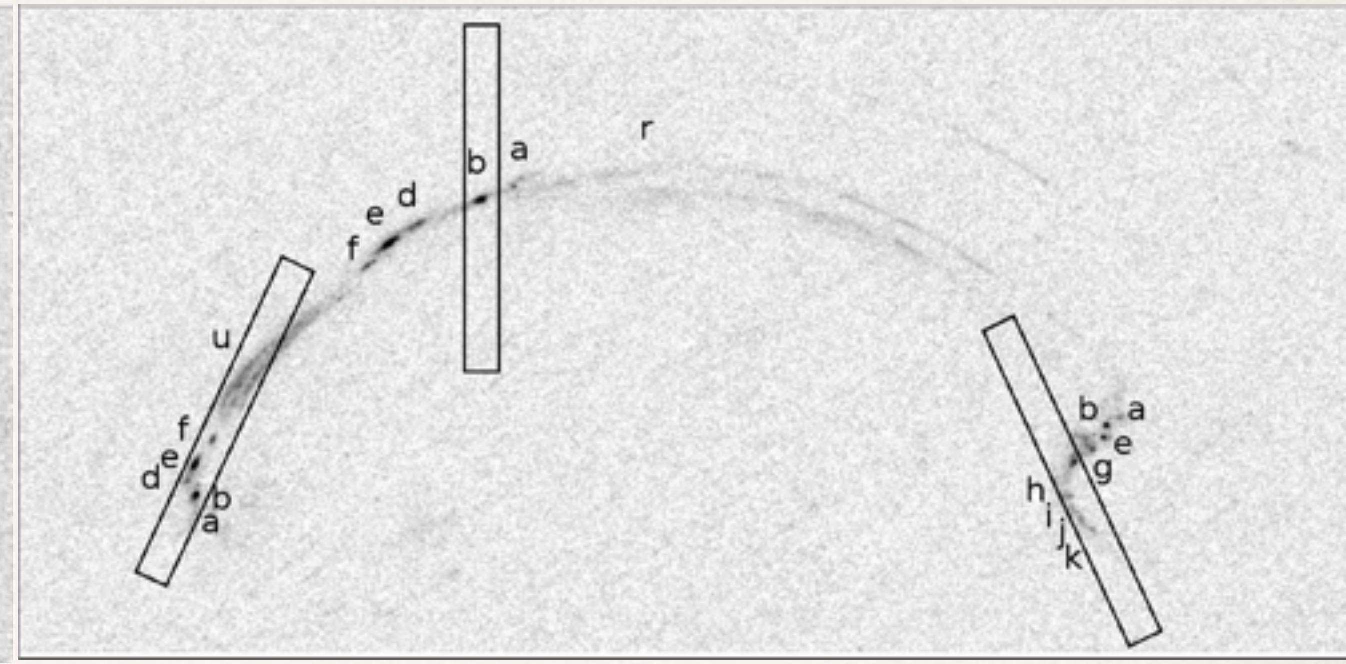

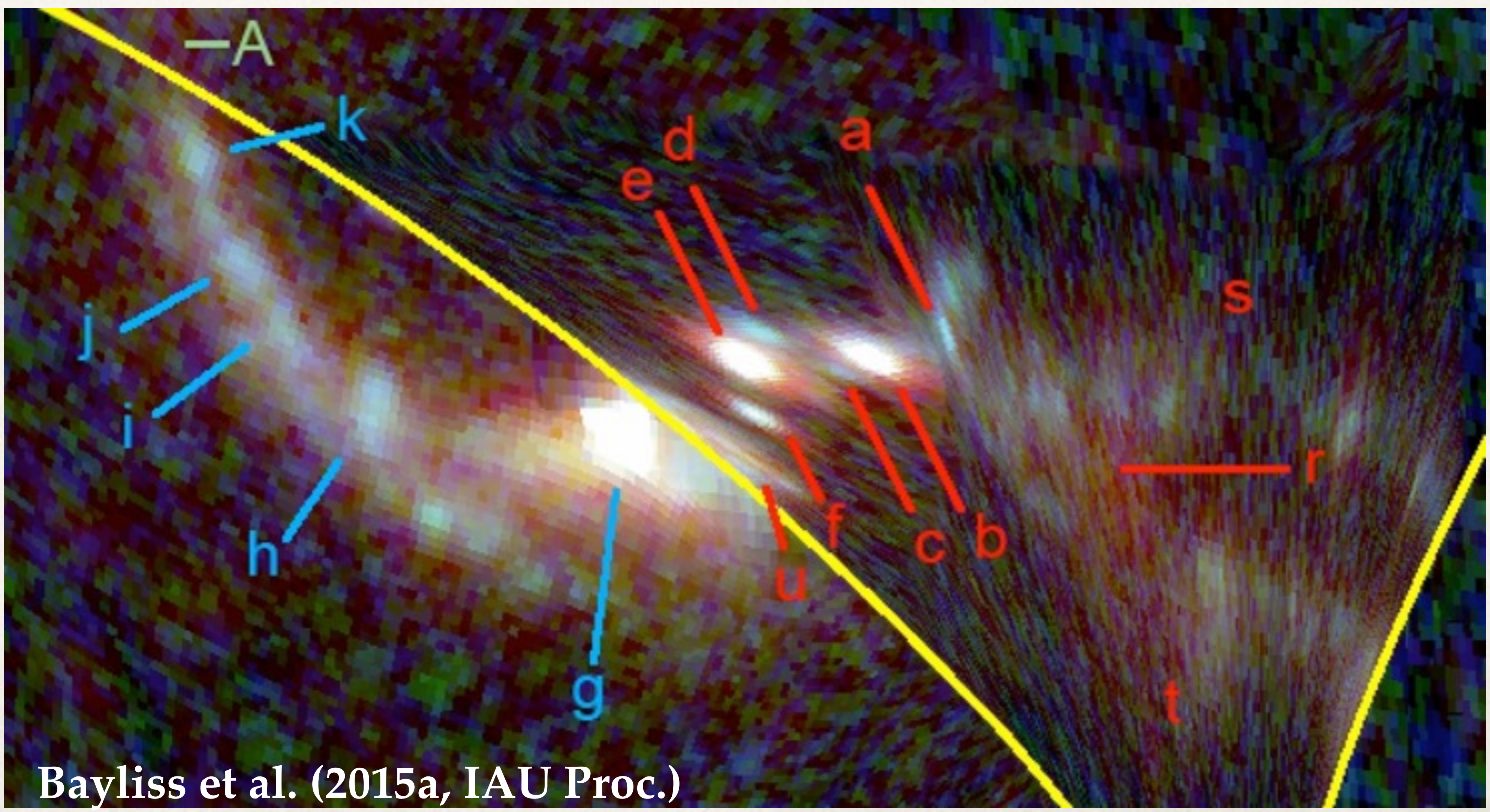

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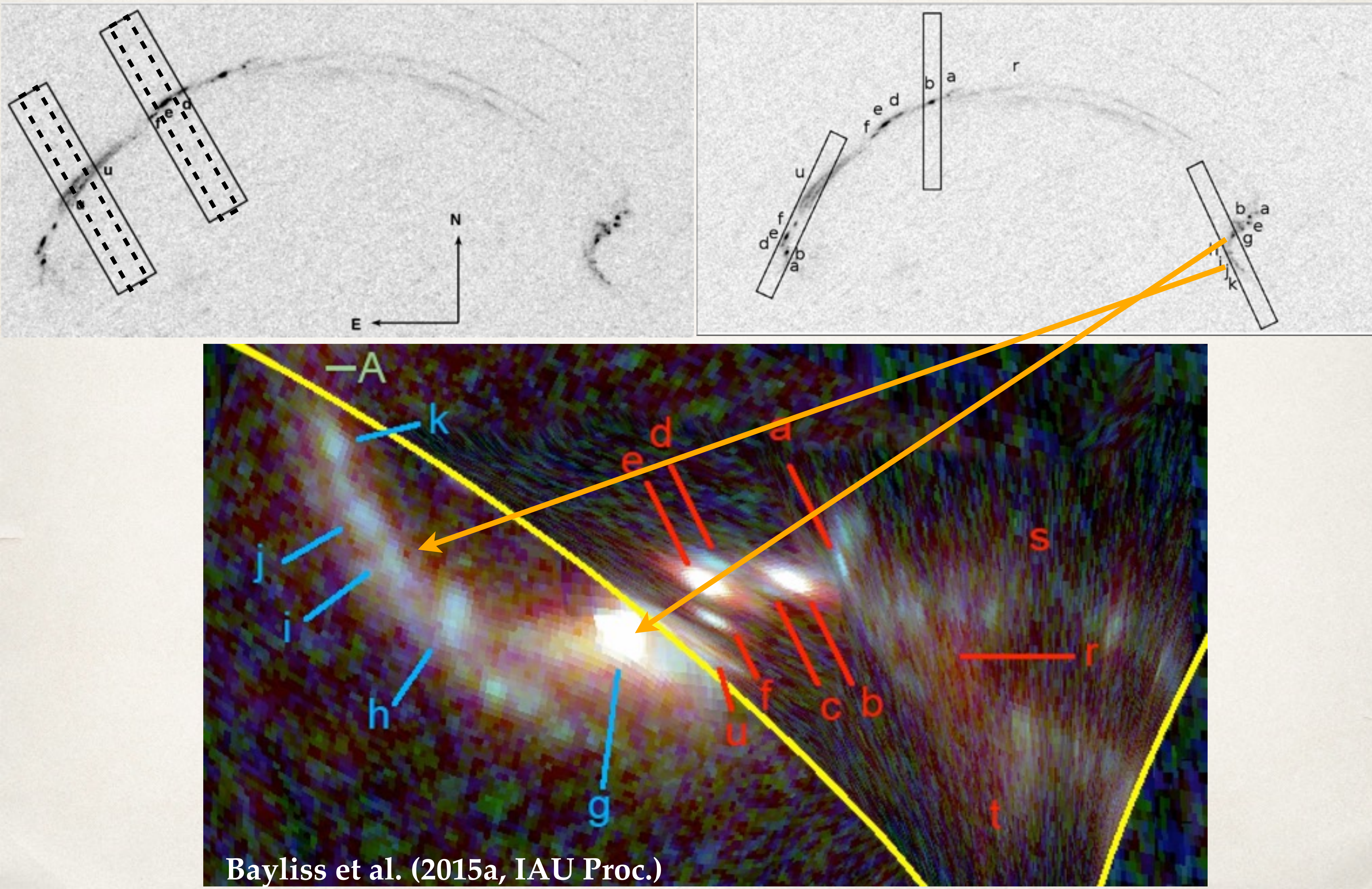

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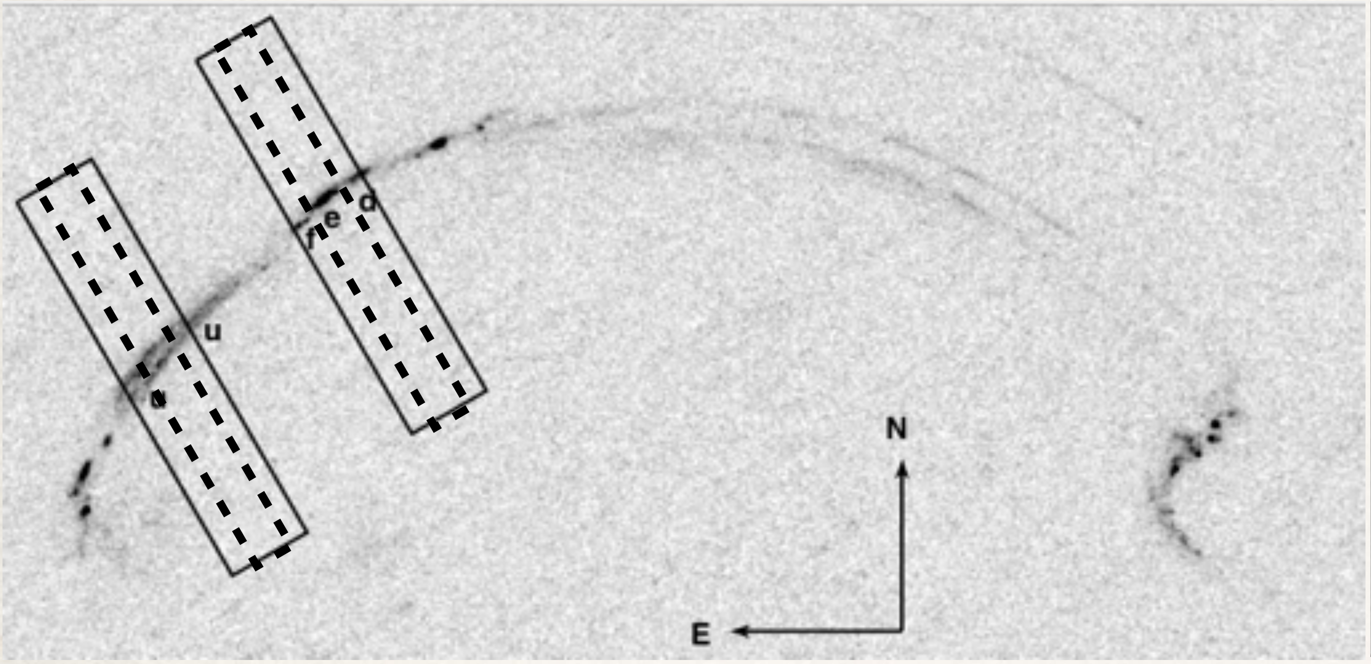

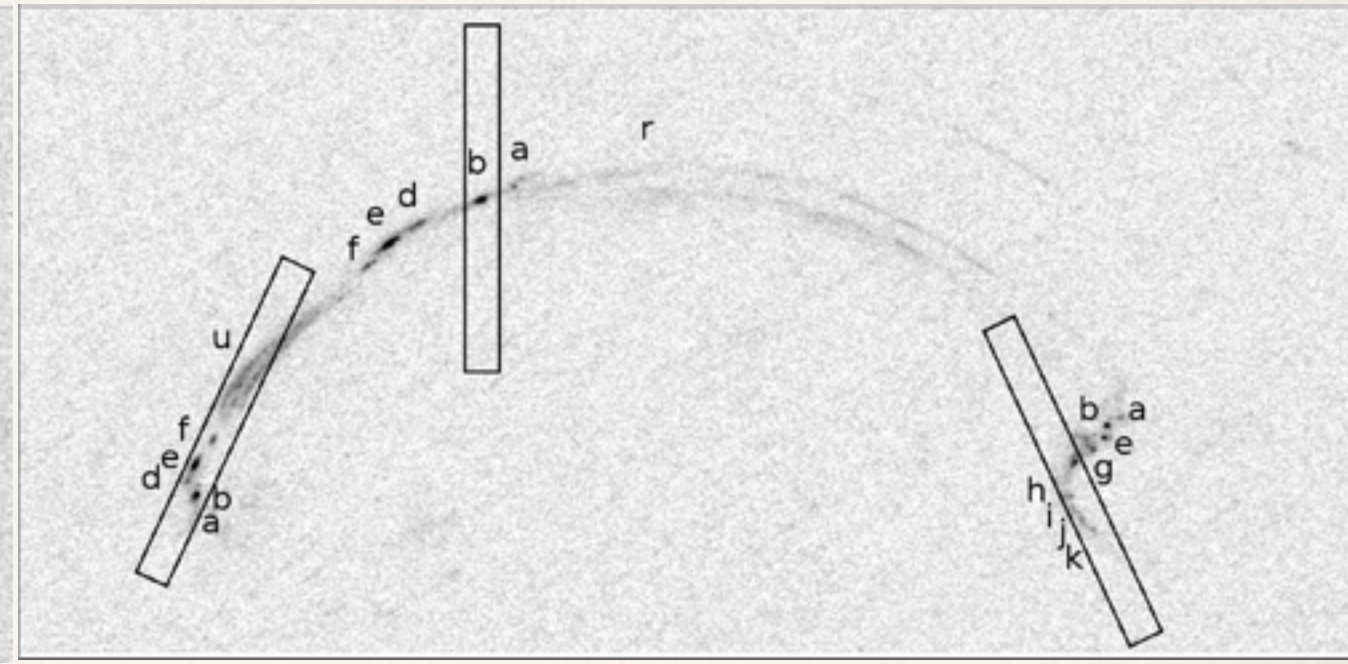

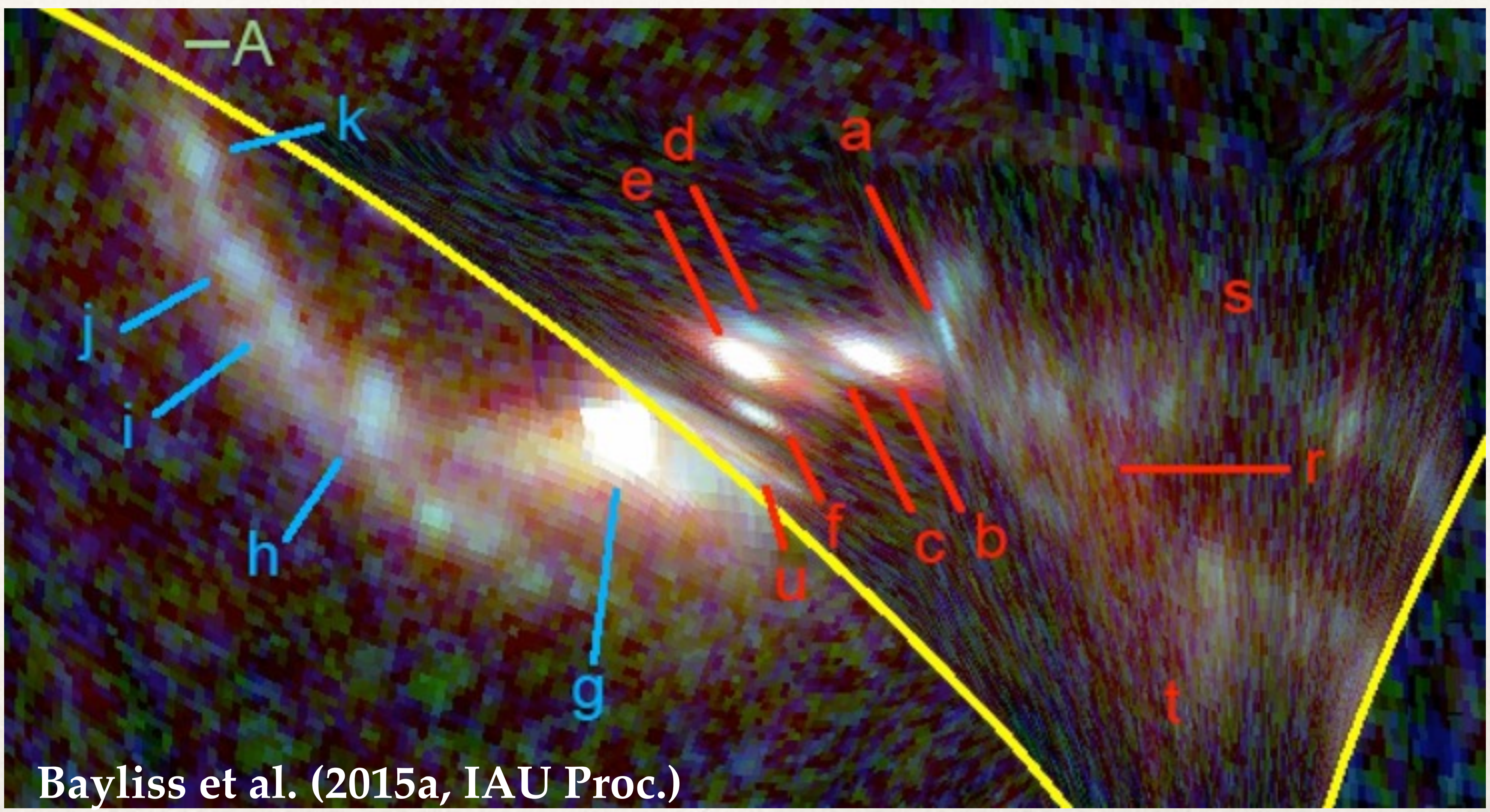

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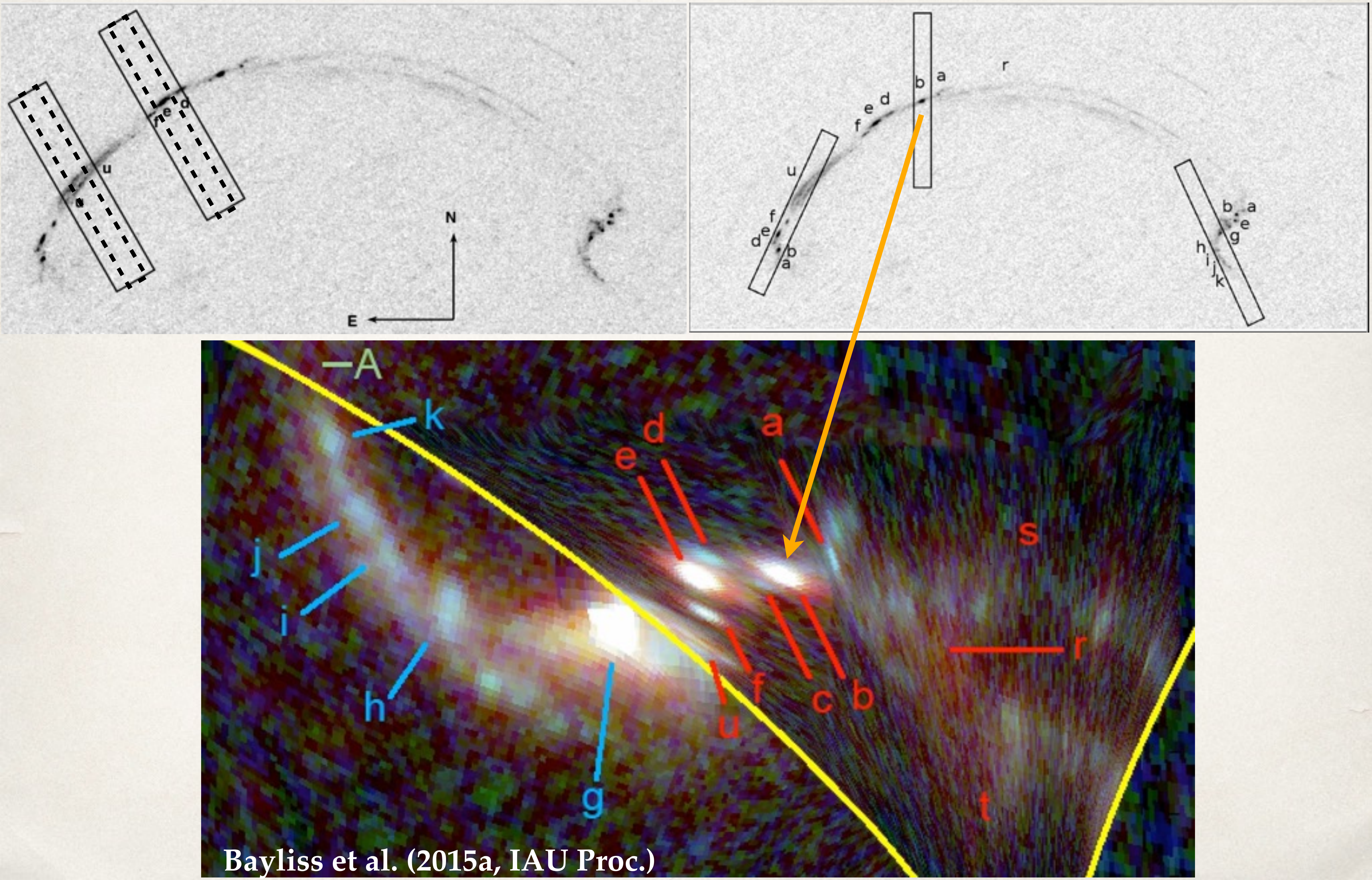

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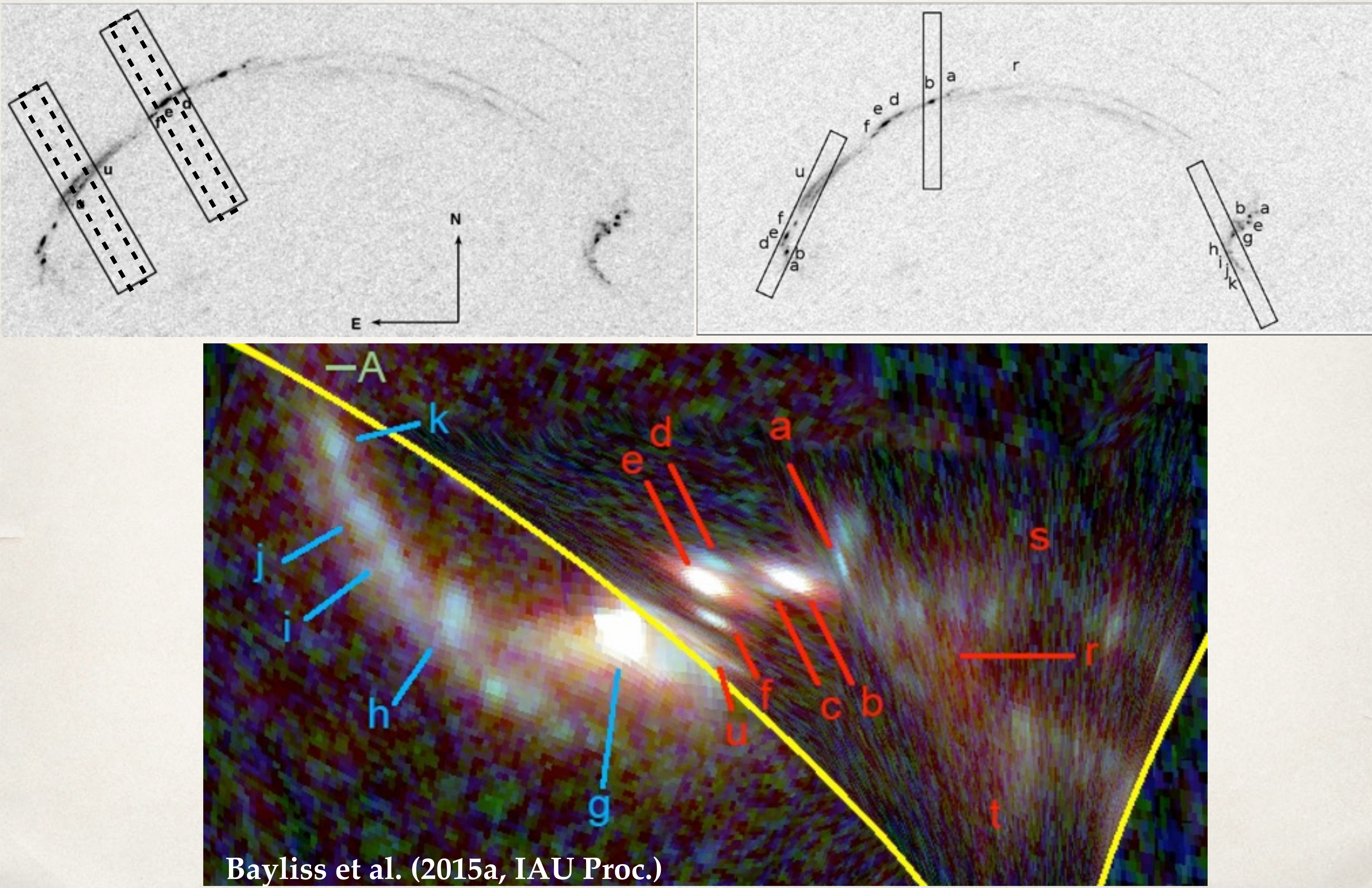

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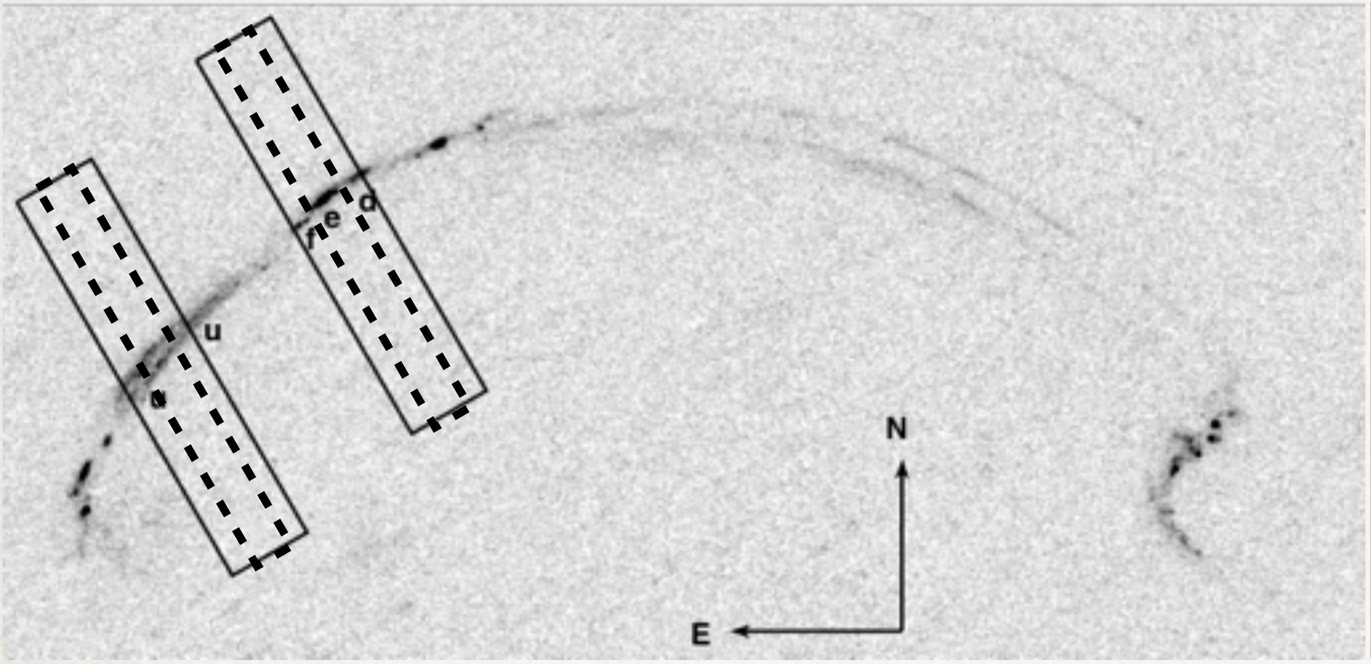

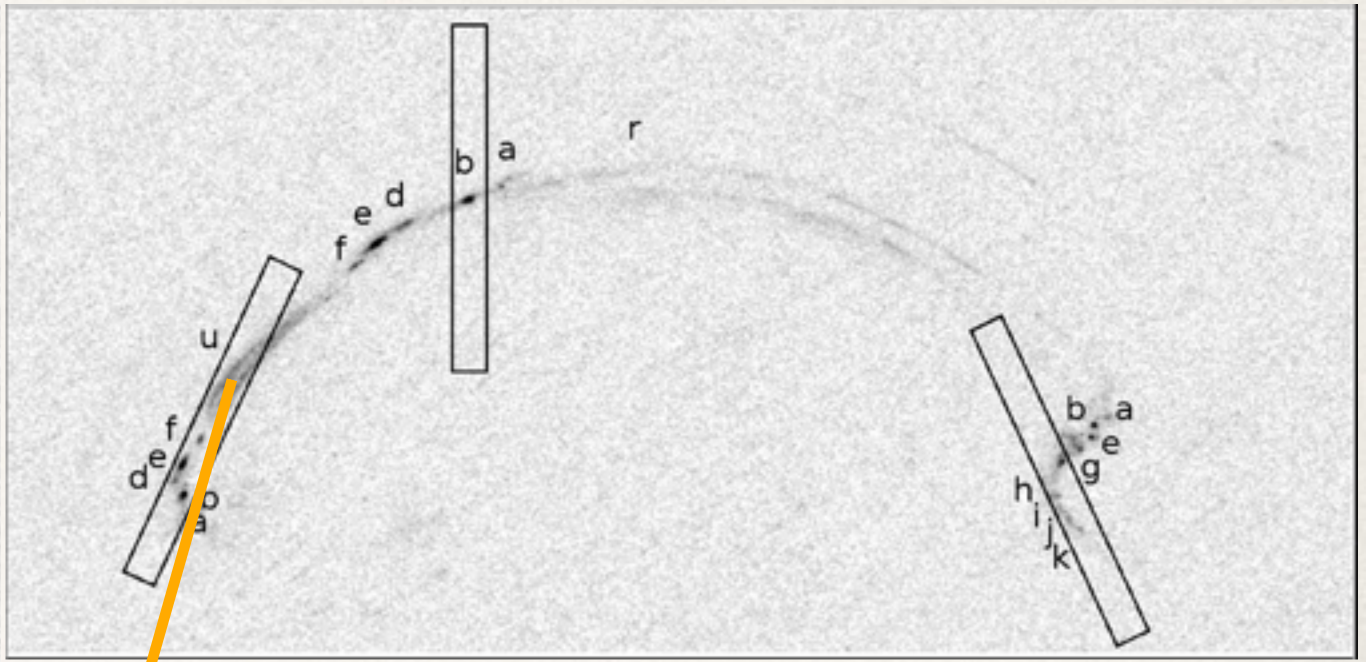

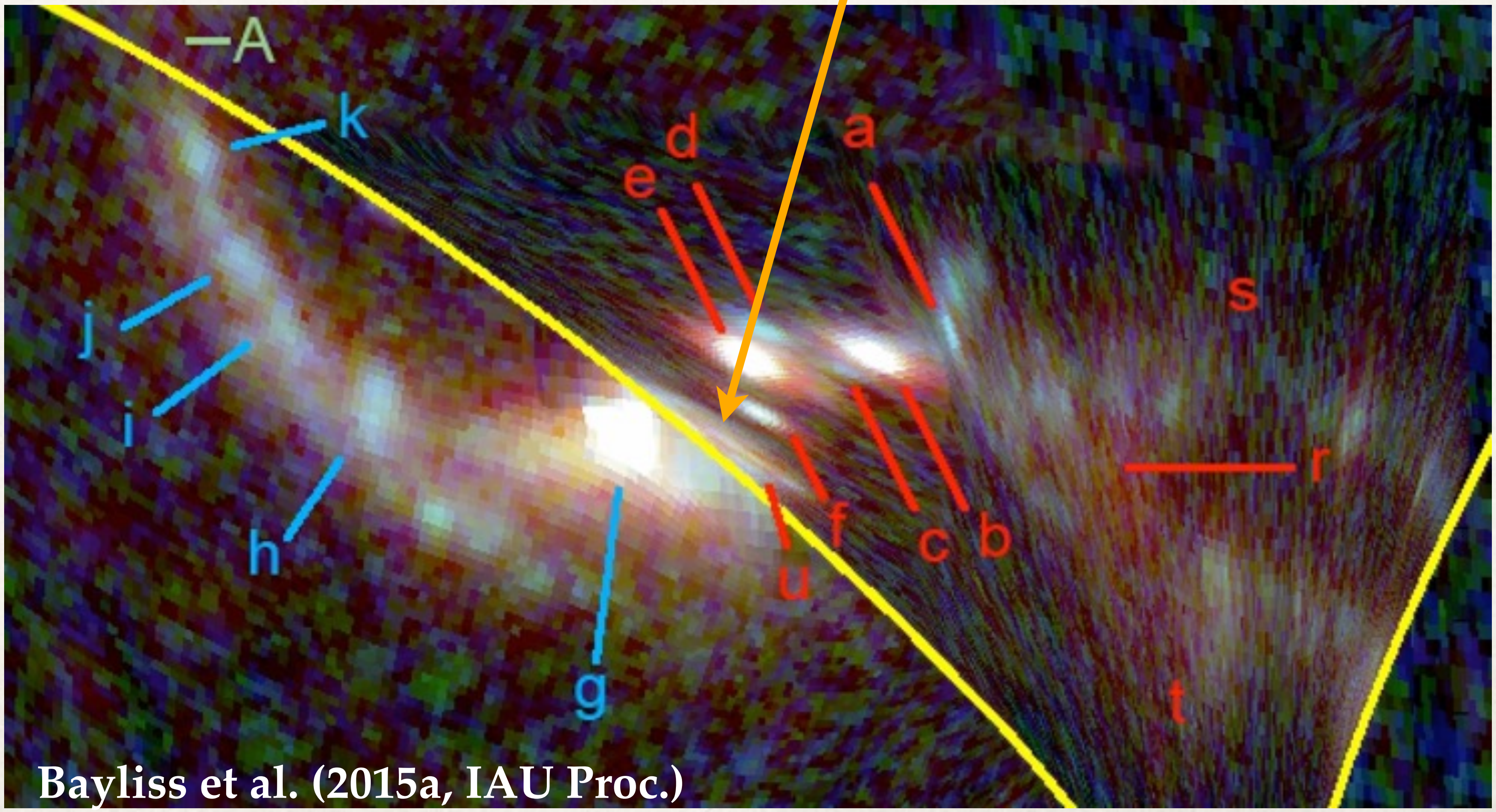

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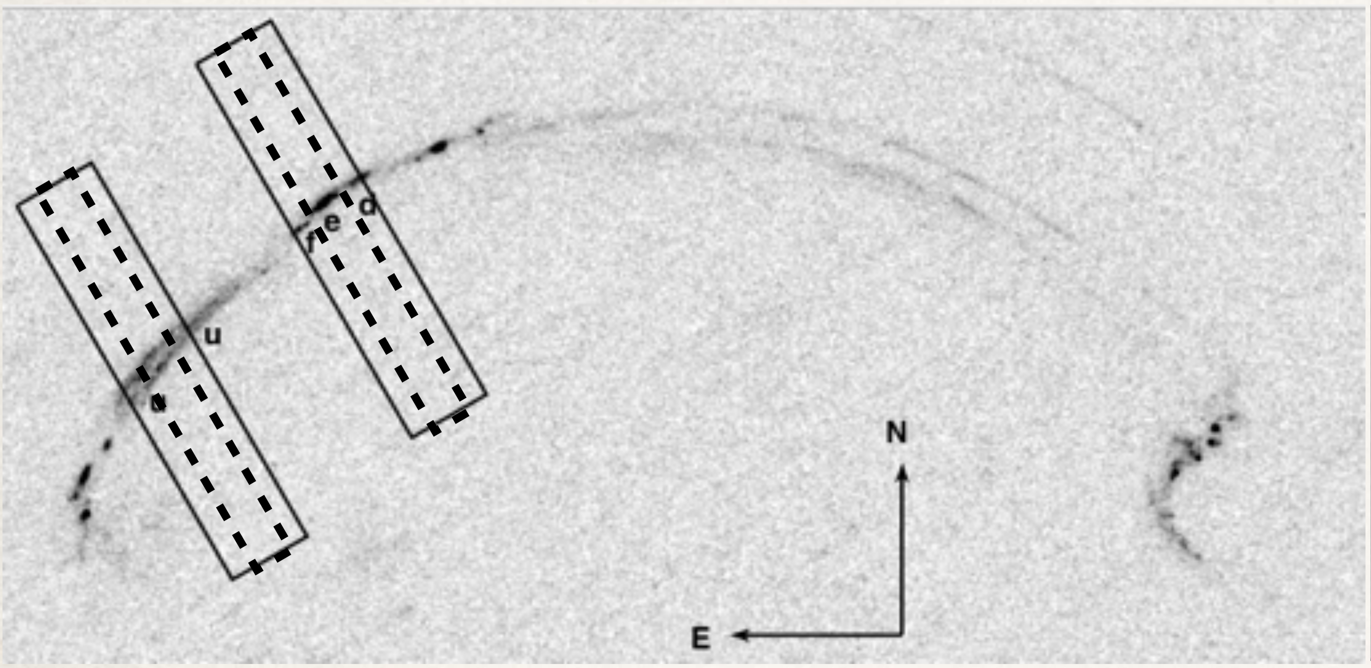

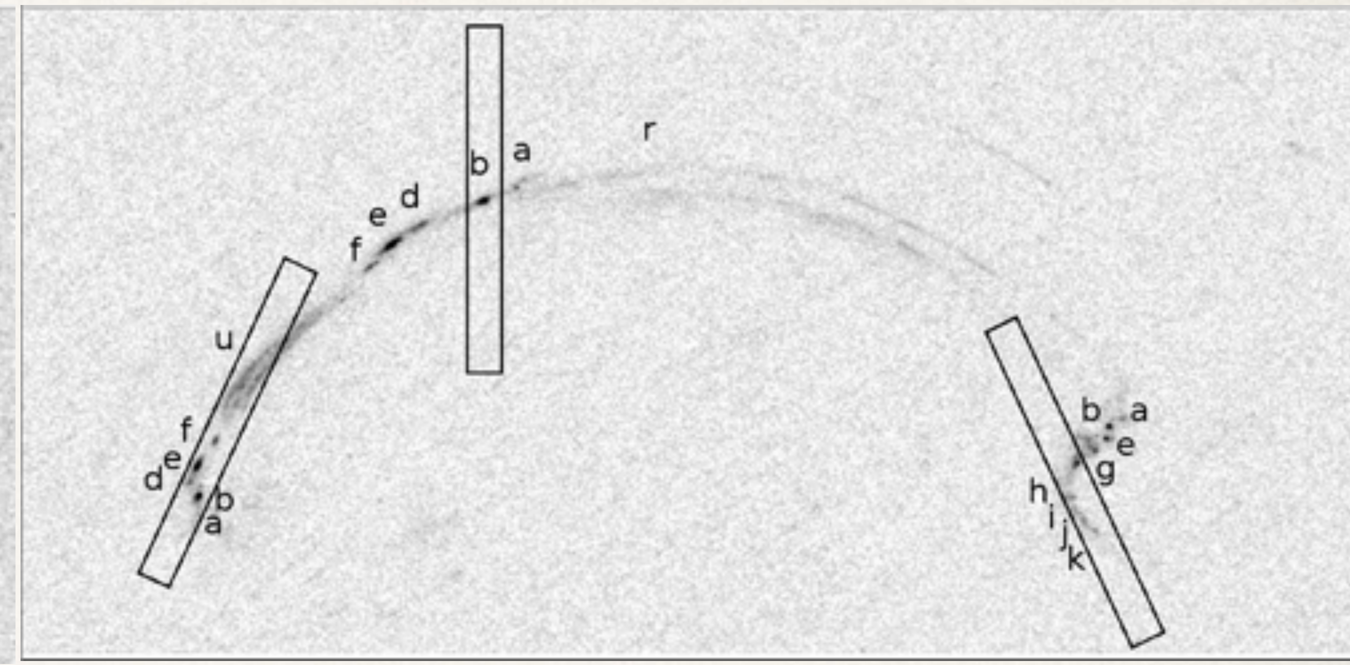

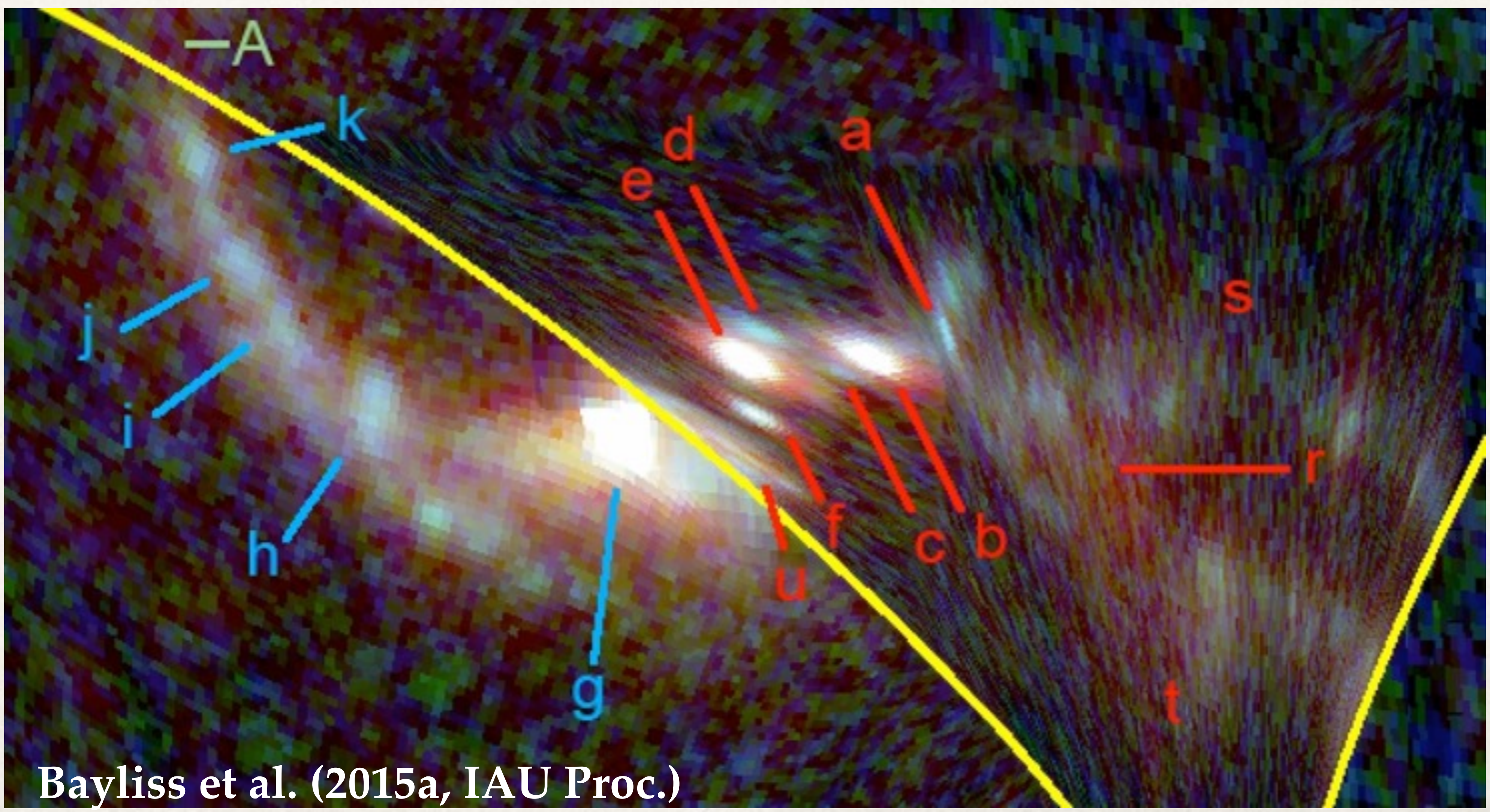

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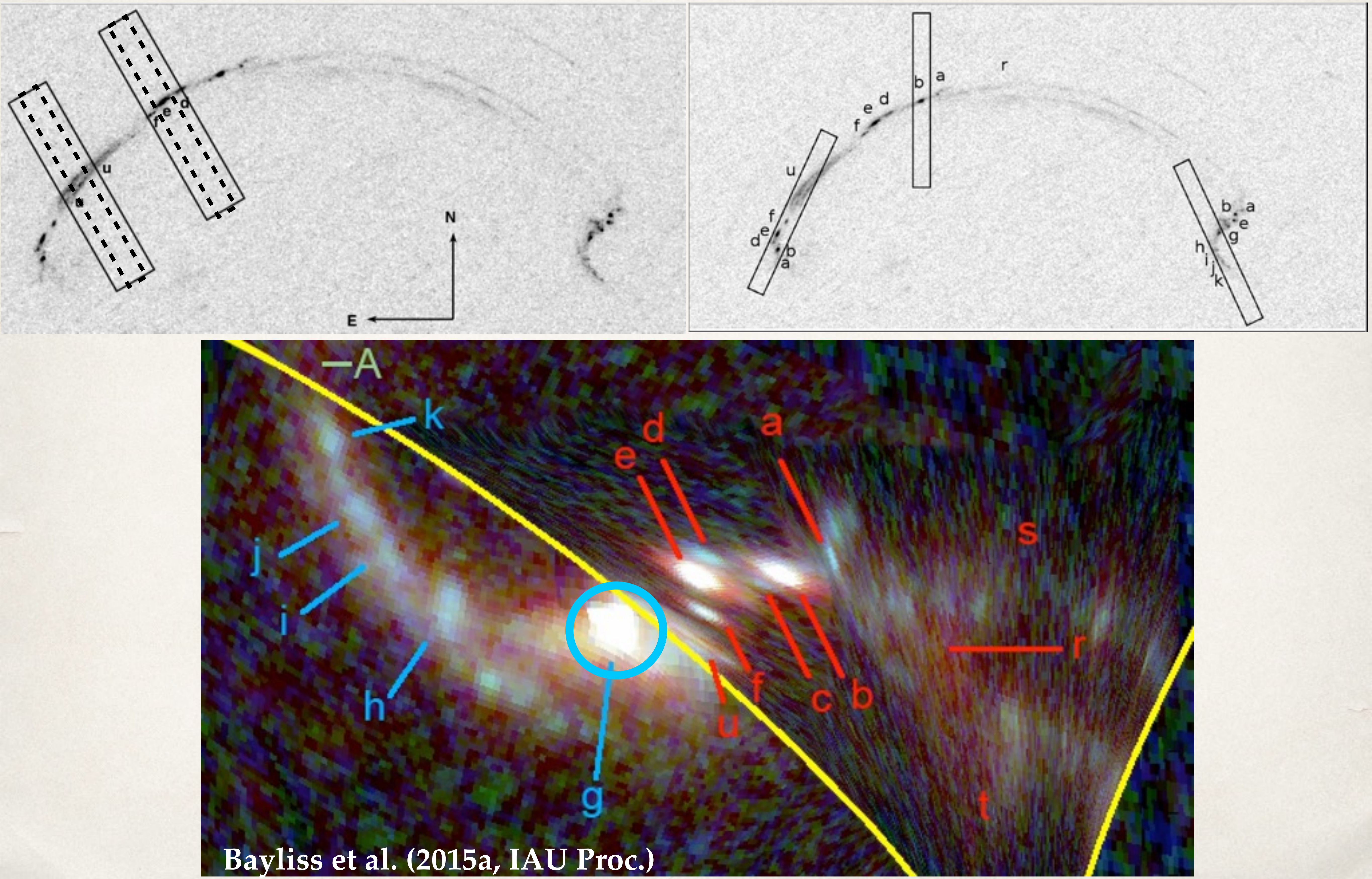

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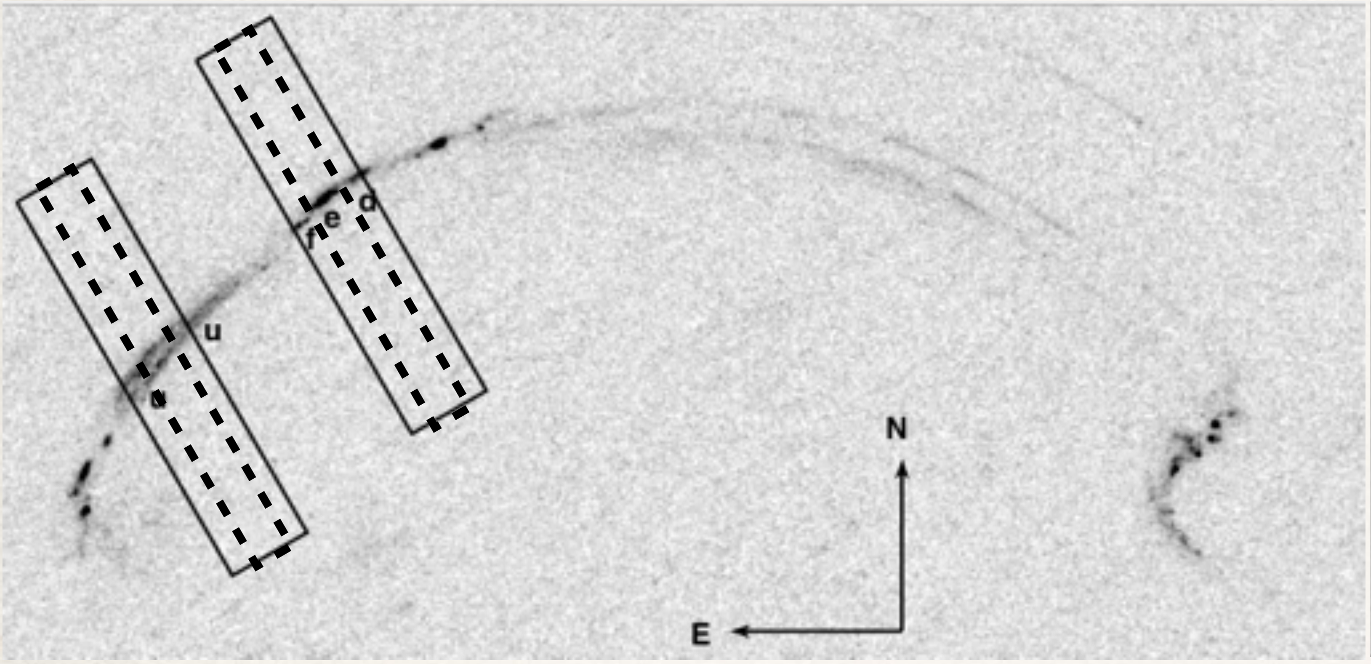

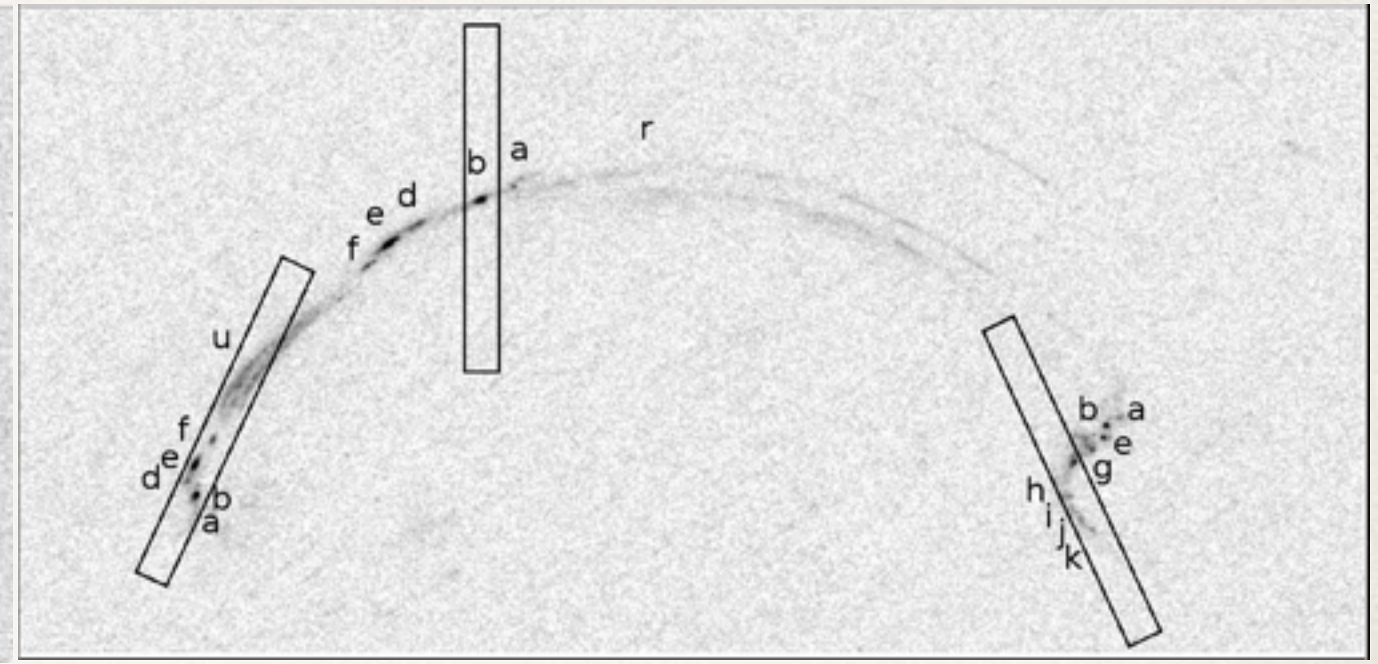

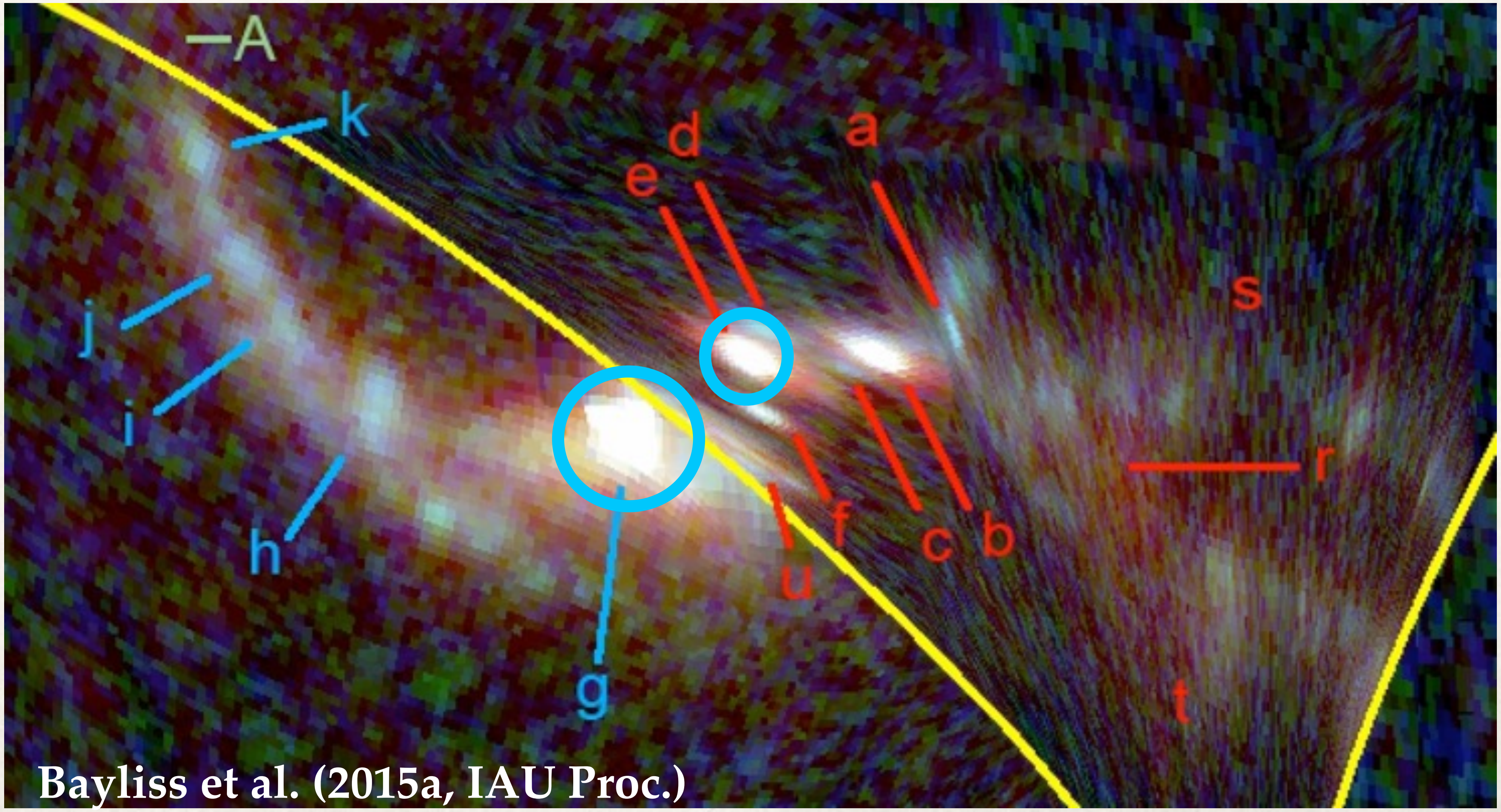

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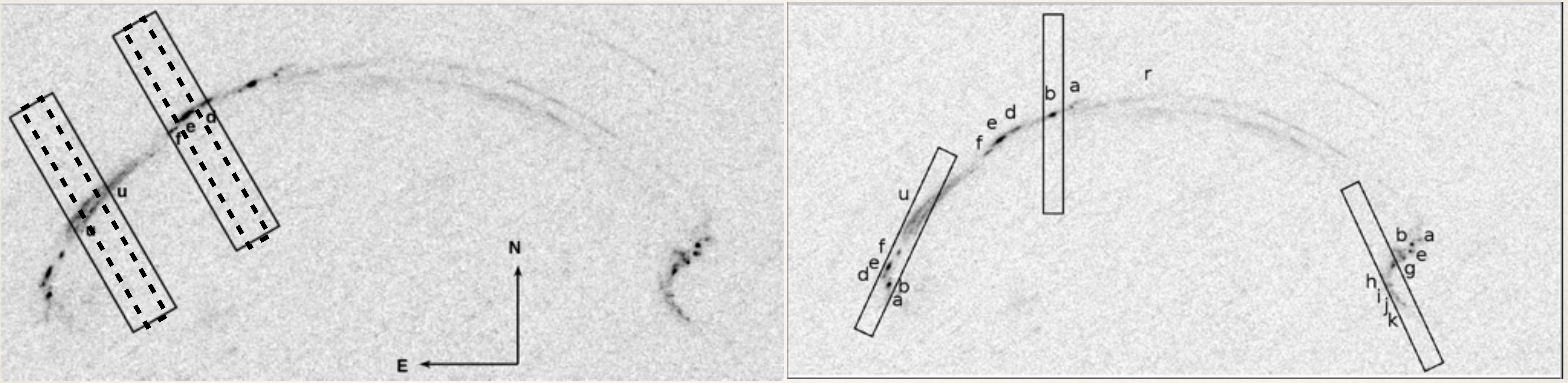

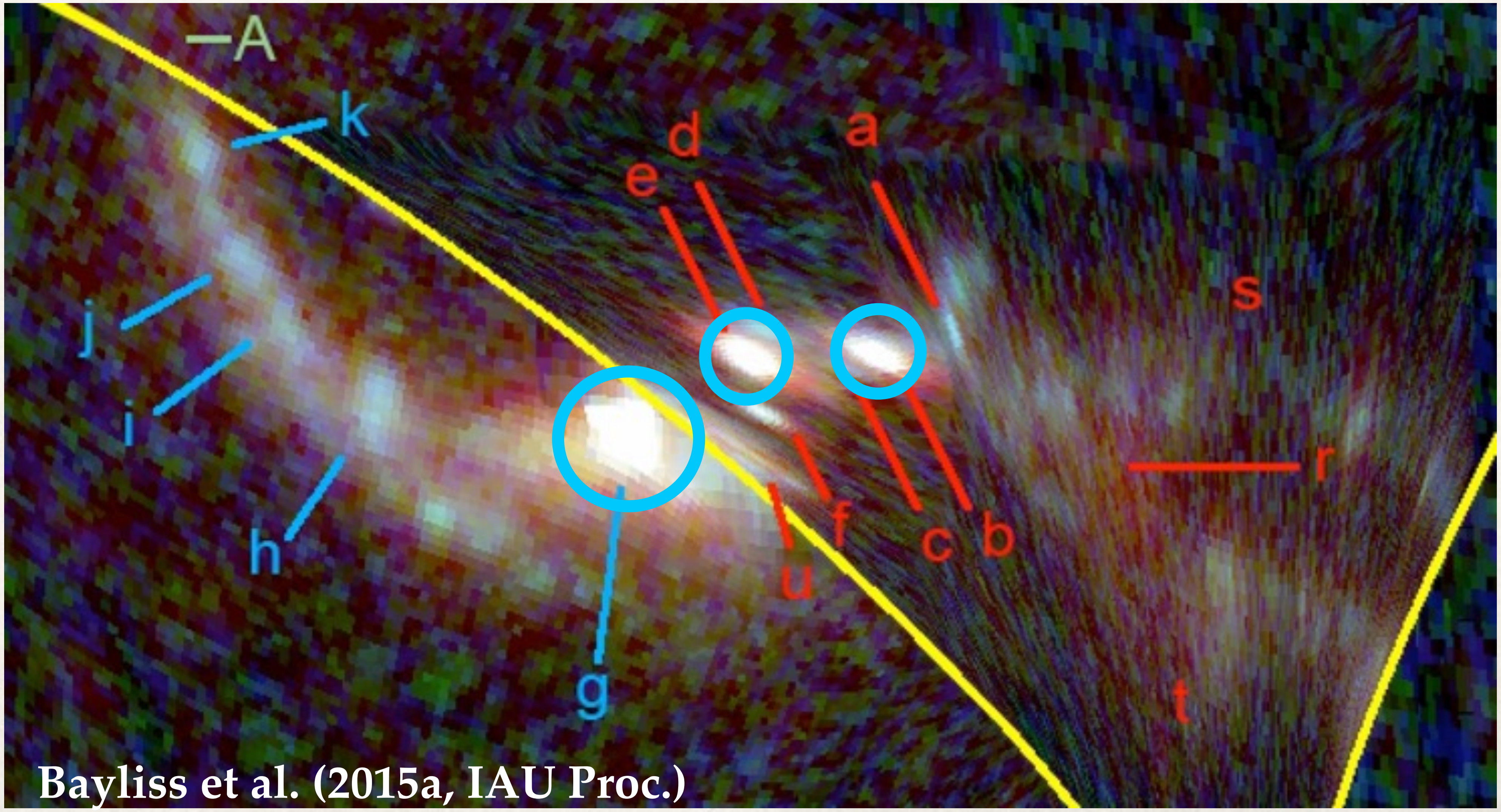

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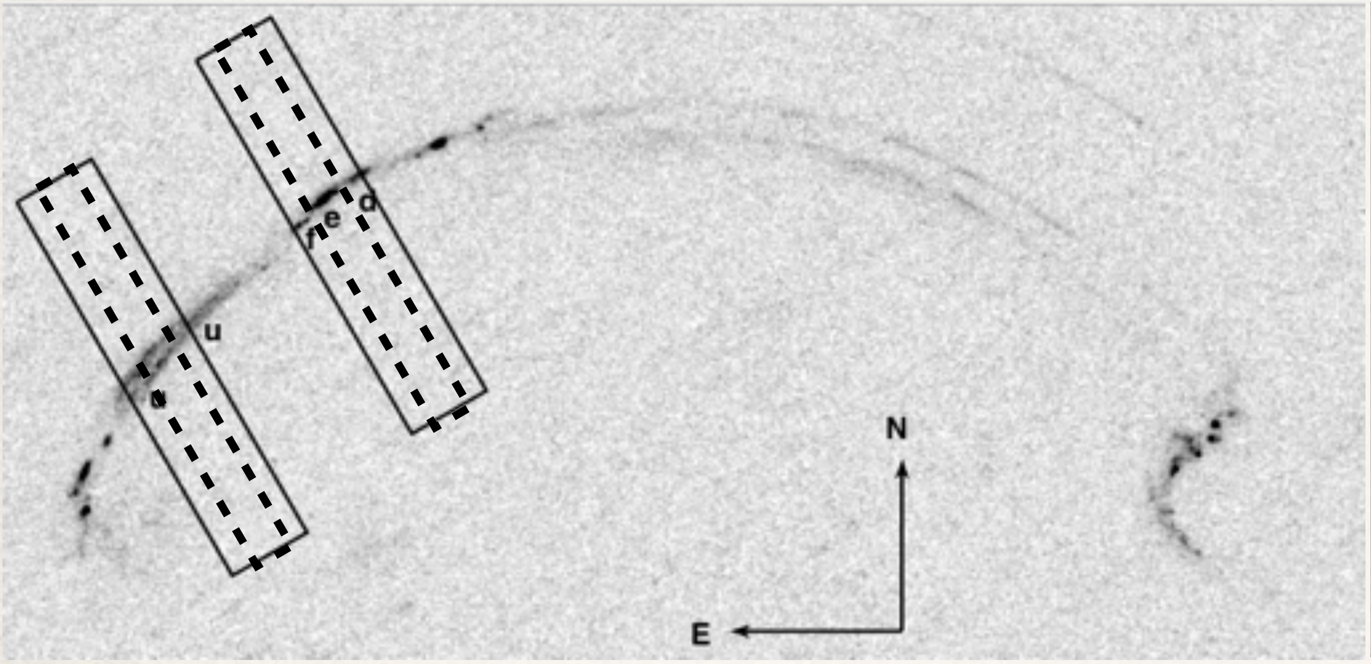

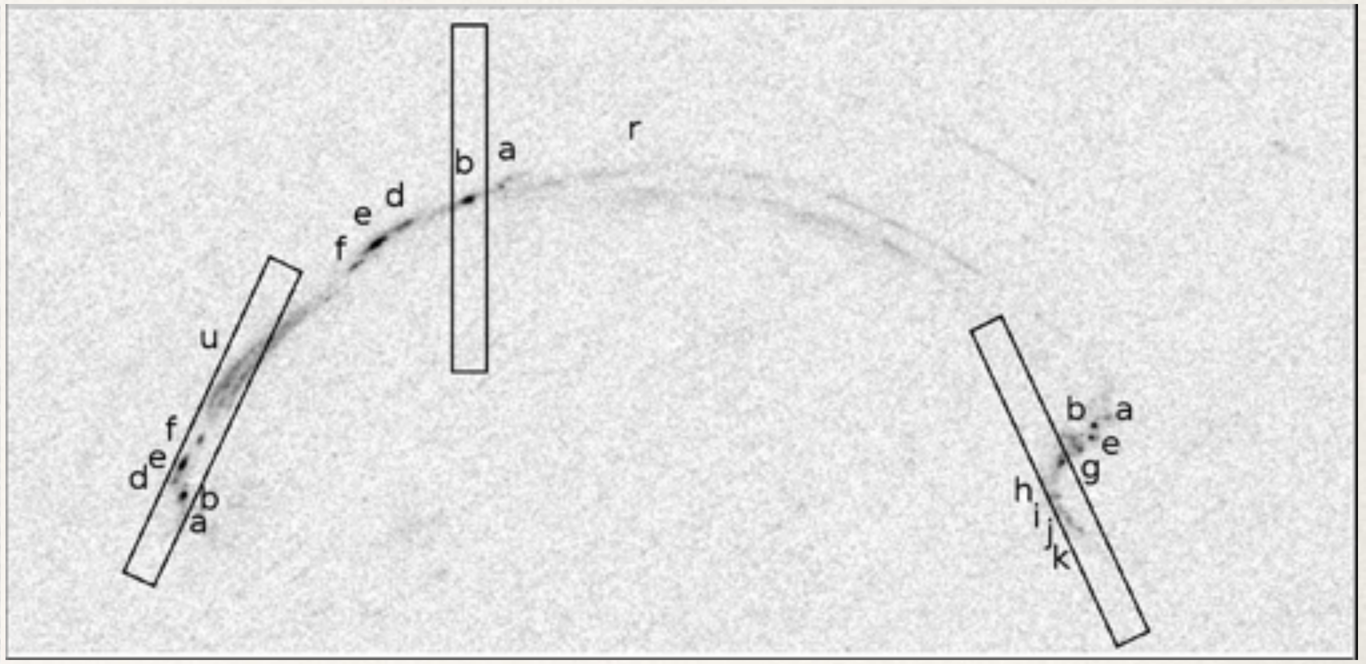

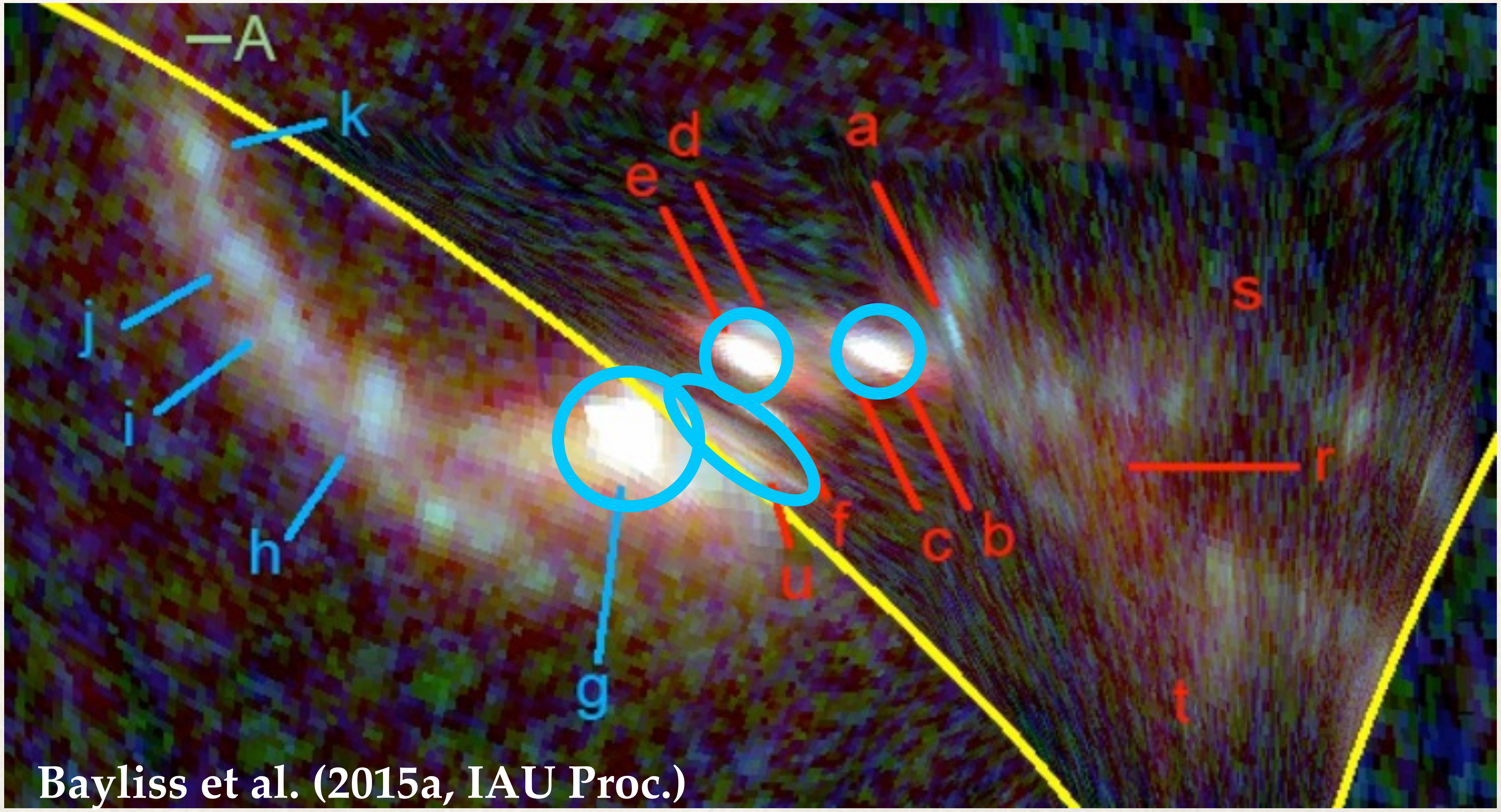

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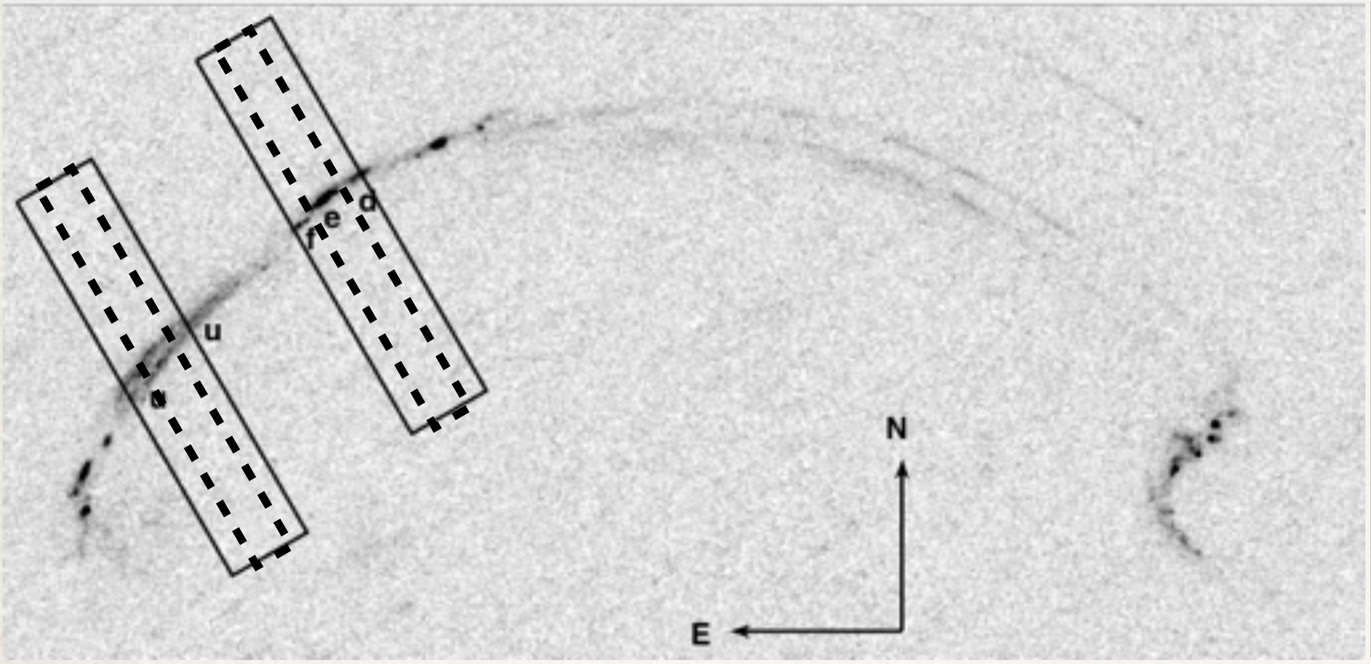
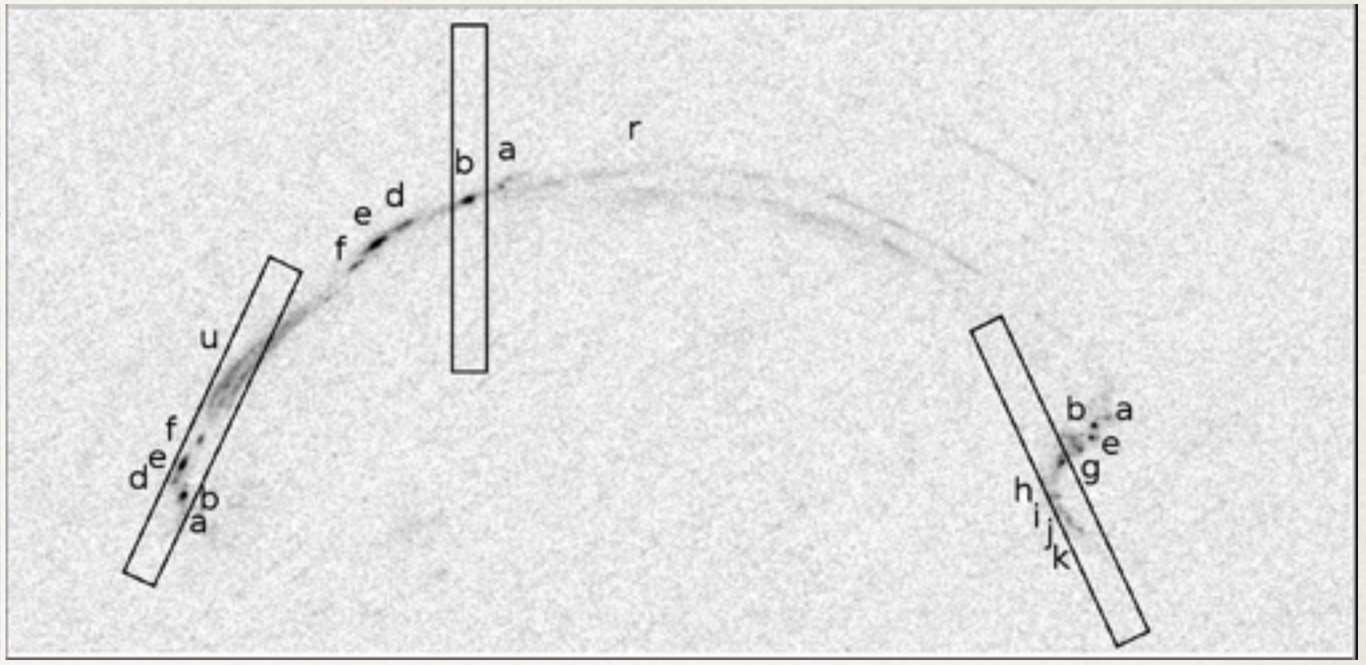
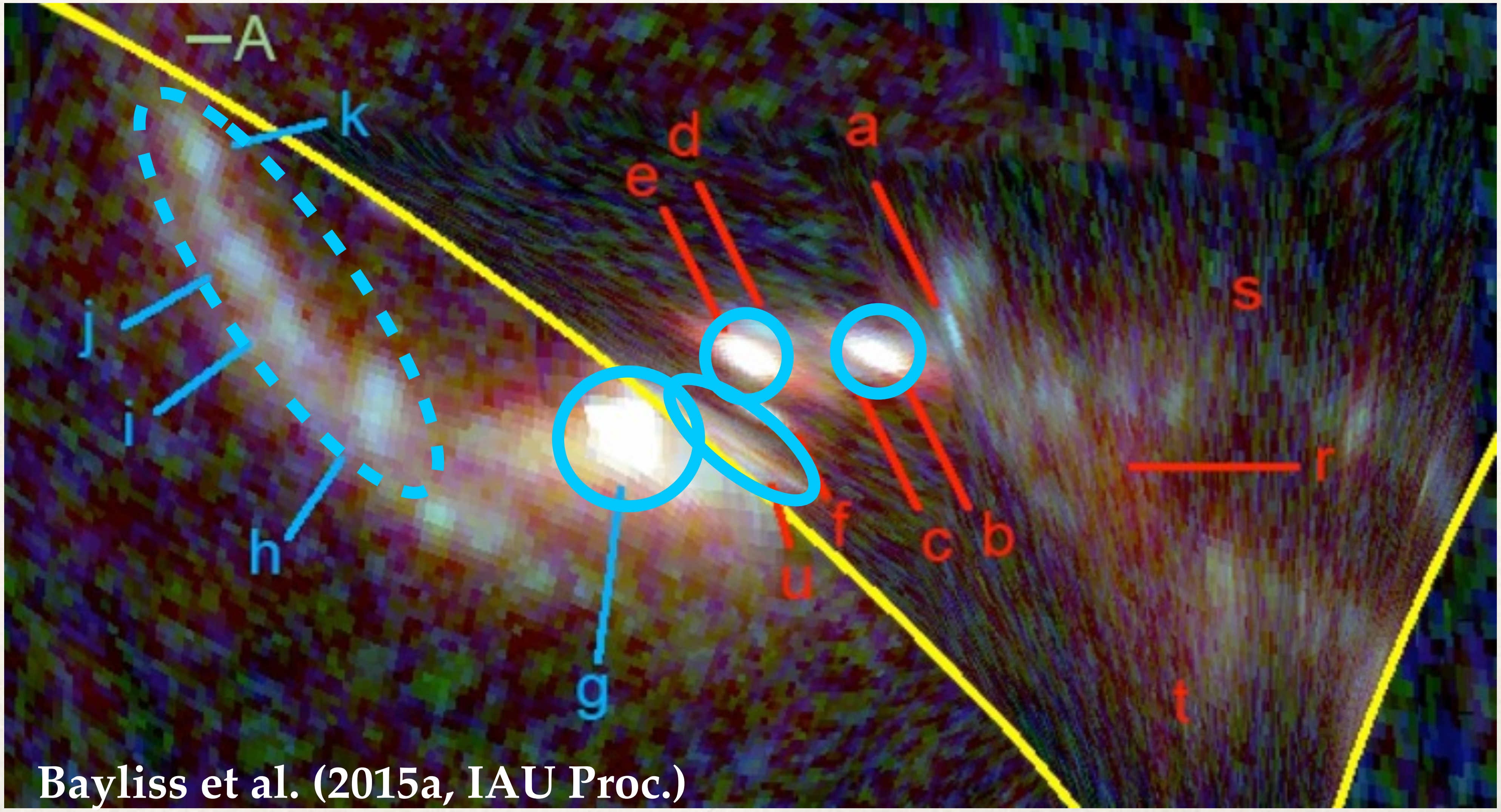
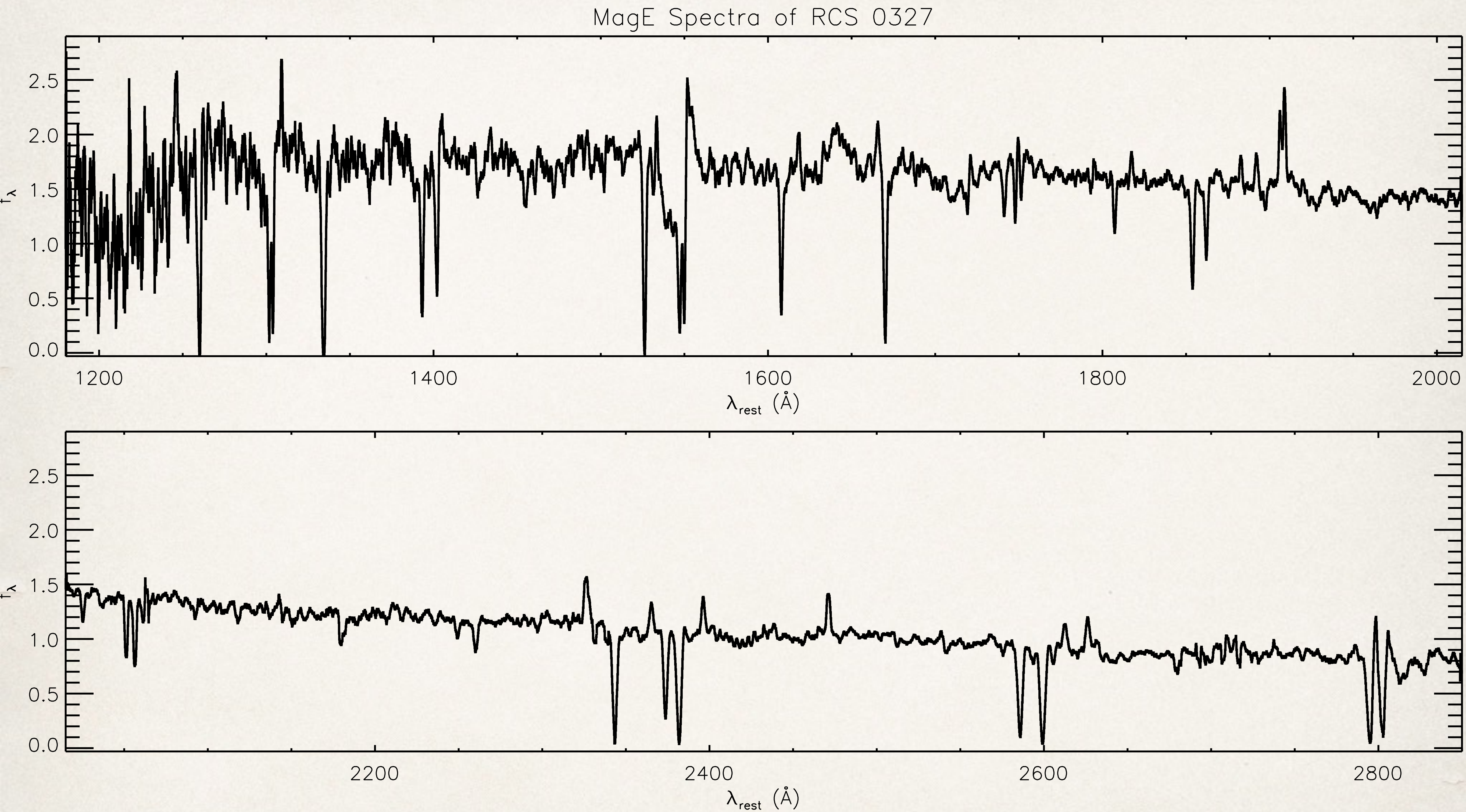


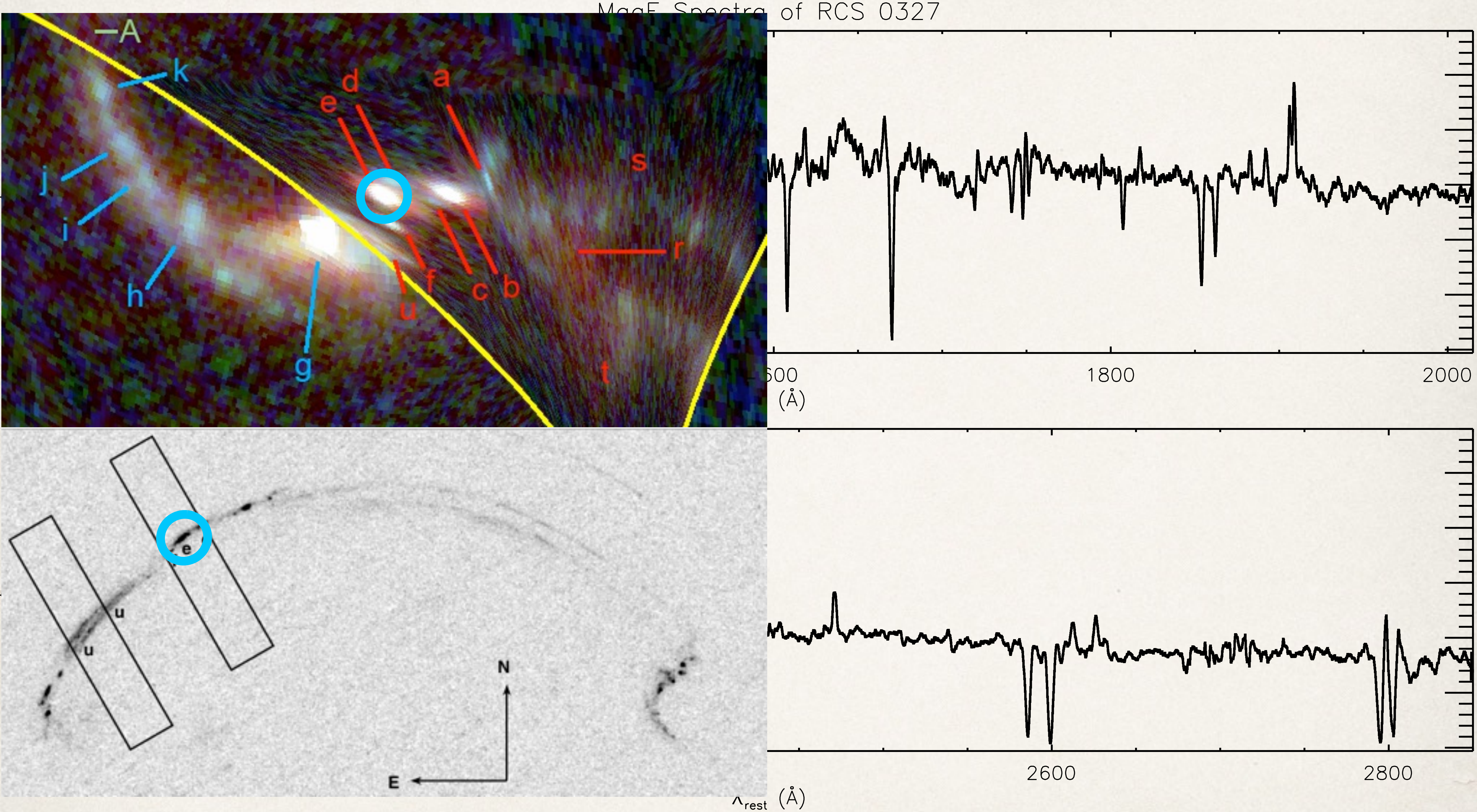


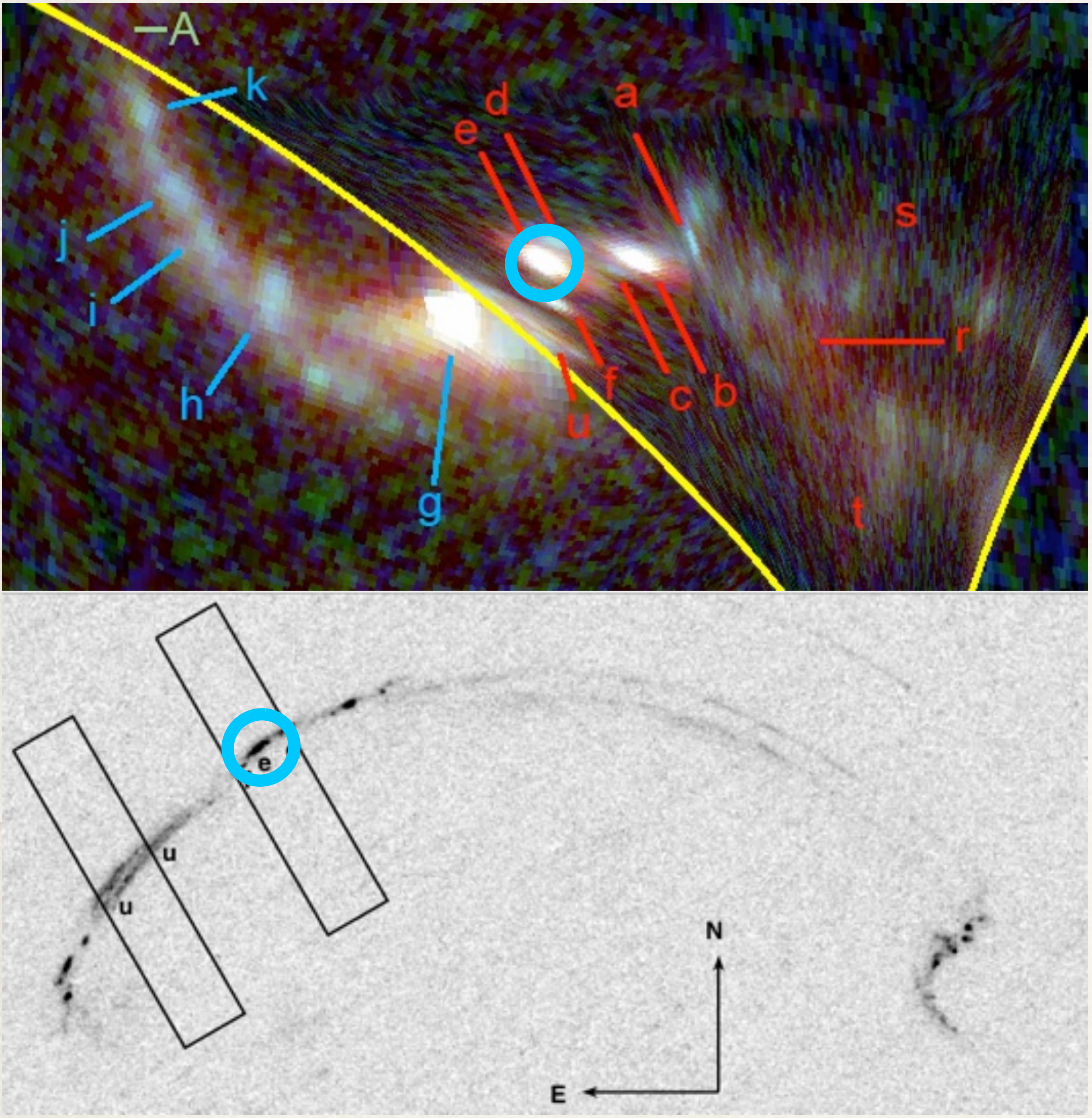




MagE Spectra of RCS 0327
f_λ
0.0
0.5
1.0
1.5
2.0
2.5
1200
1400
1600
1800
2000
λ_{rest} (Å)
2200
2400
2600
2800
λ_{rest} (Å)

MagE Spectra of RCS 0327

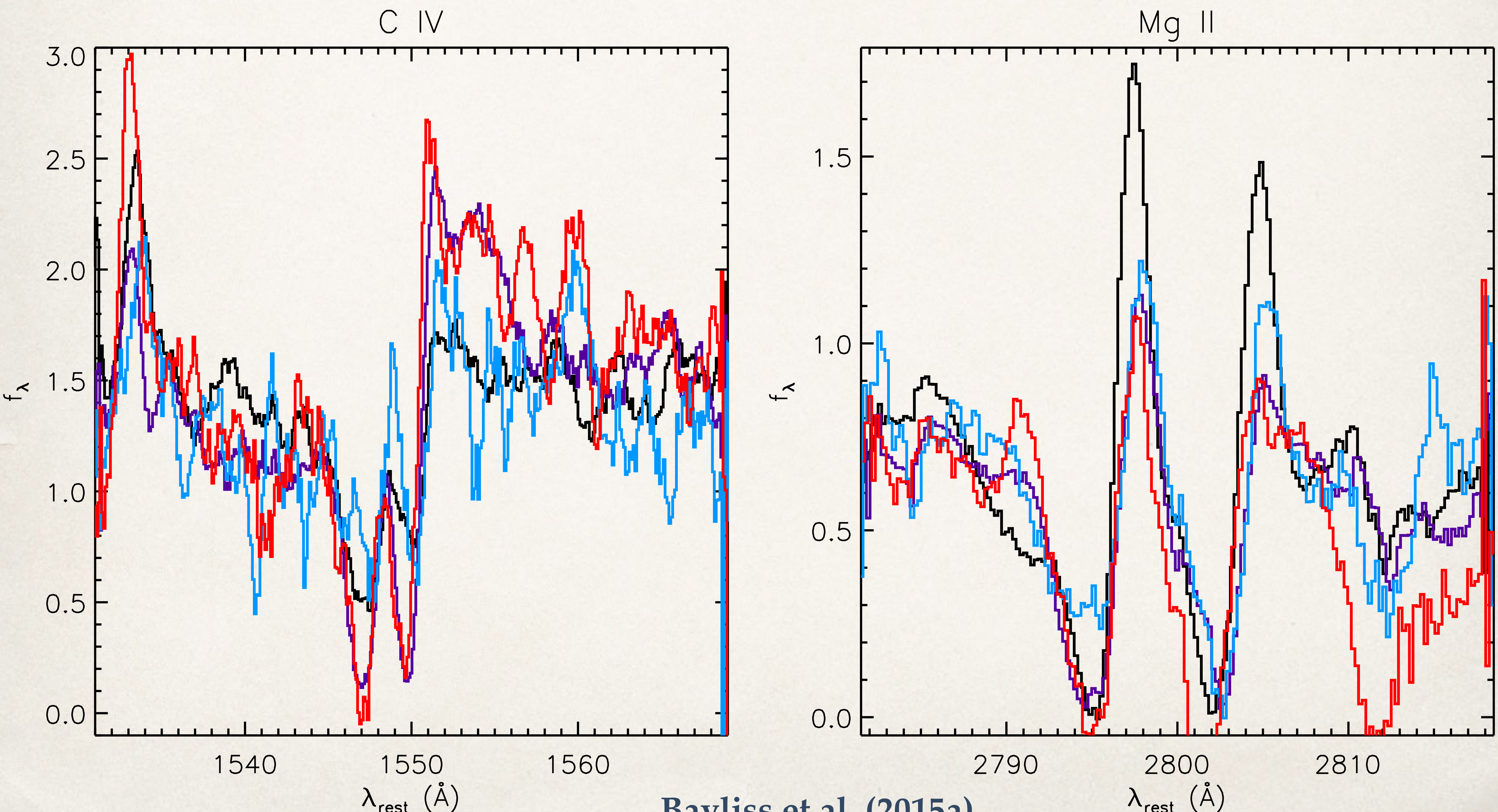




In *each knot*, can constraint each of:

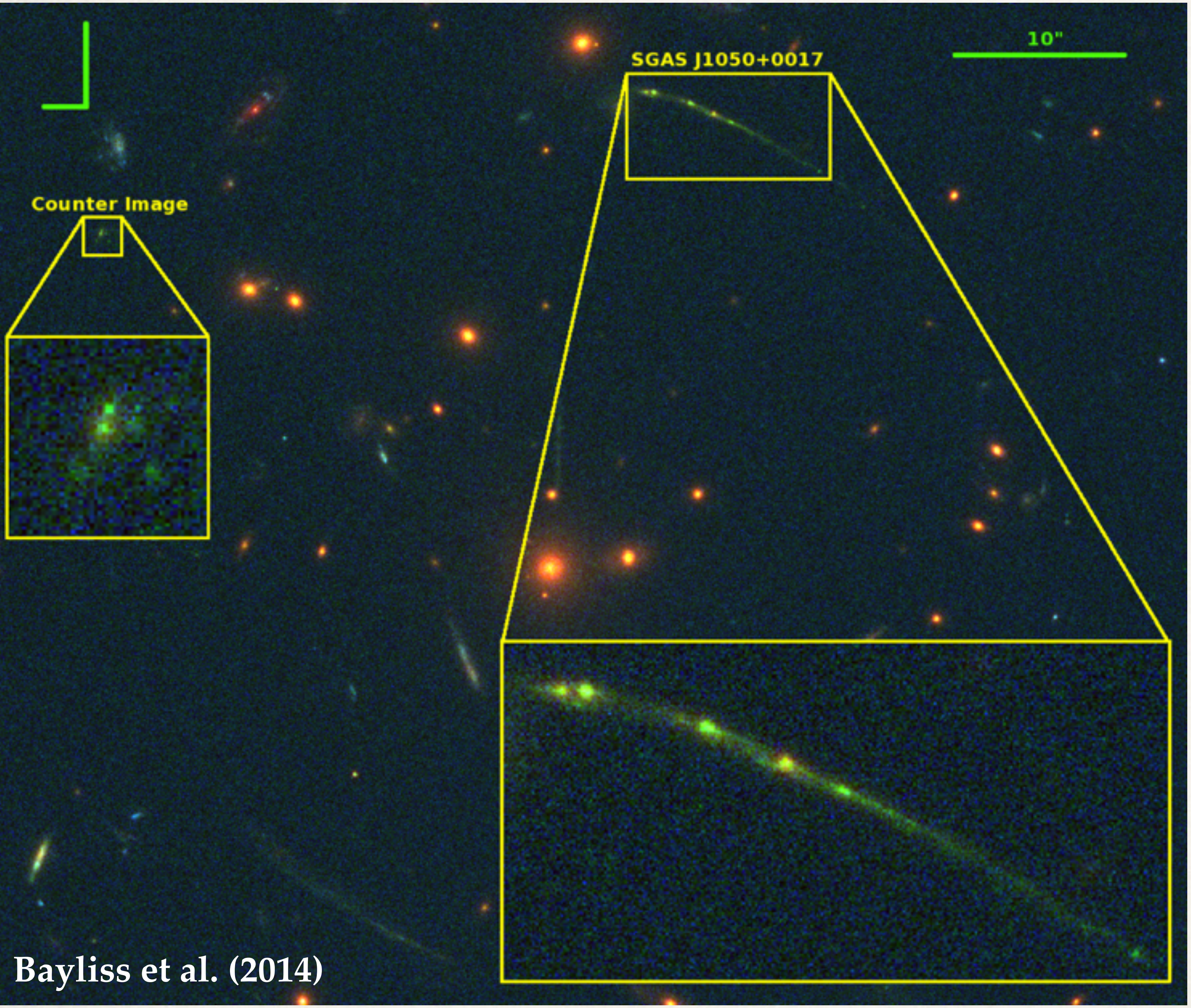
- metallicity
- ionization parameter
- electron temperature/density
- abundance ratios (C/O, Si/O, N/O
- Massive Stars and Wolf-Rayet winds
- Galaxy-scale outflows

P Cygni Profiles Within Different Star Forming Regions/Lines of Sight



Bayliss et al. (2015a)

SGAS1050+0017



Bayliss et al. (2014)

Galaxy at z = 3.625, can resolve individual star forming regions on scales of ~200 pc. A 2-hr optical spectrum of this arc reveals >20 lines that constraint each of:

- metallicity
- ionization parameter
- electron temperature
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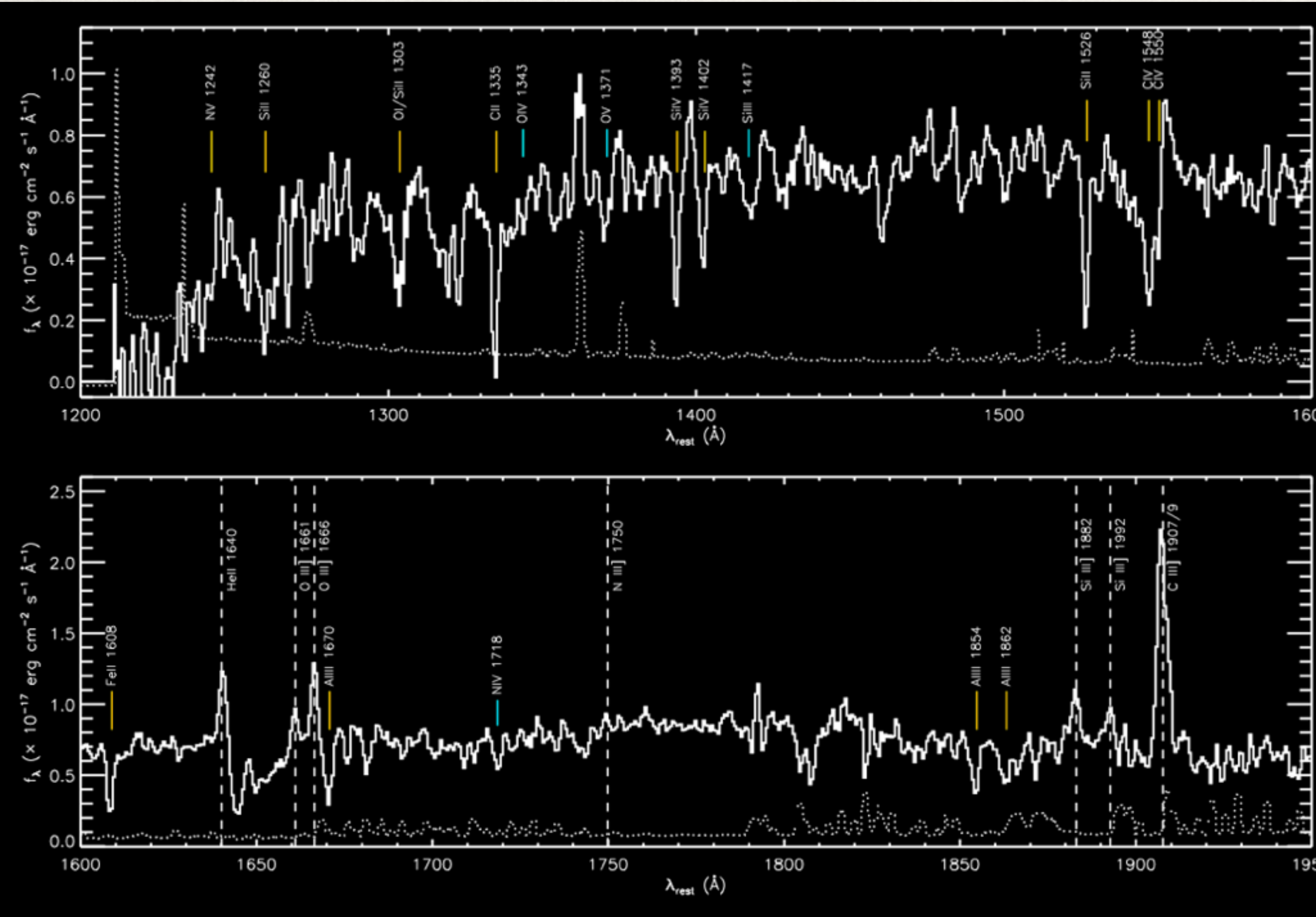
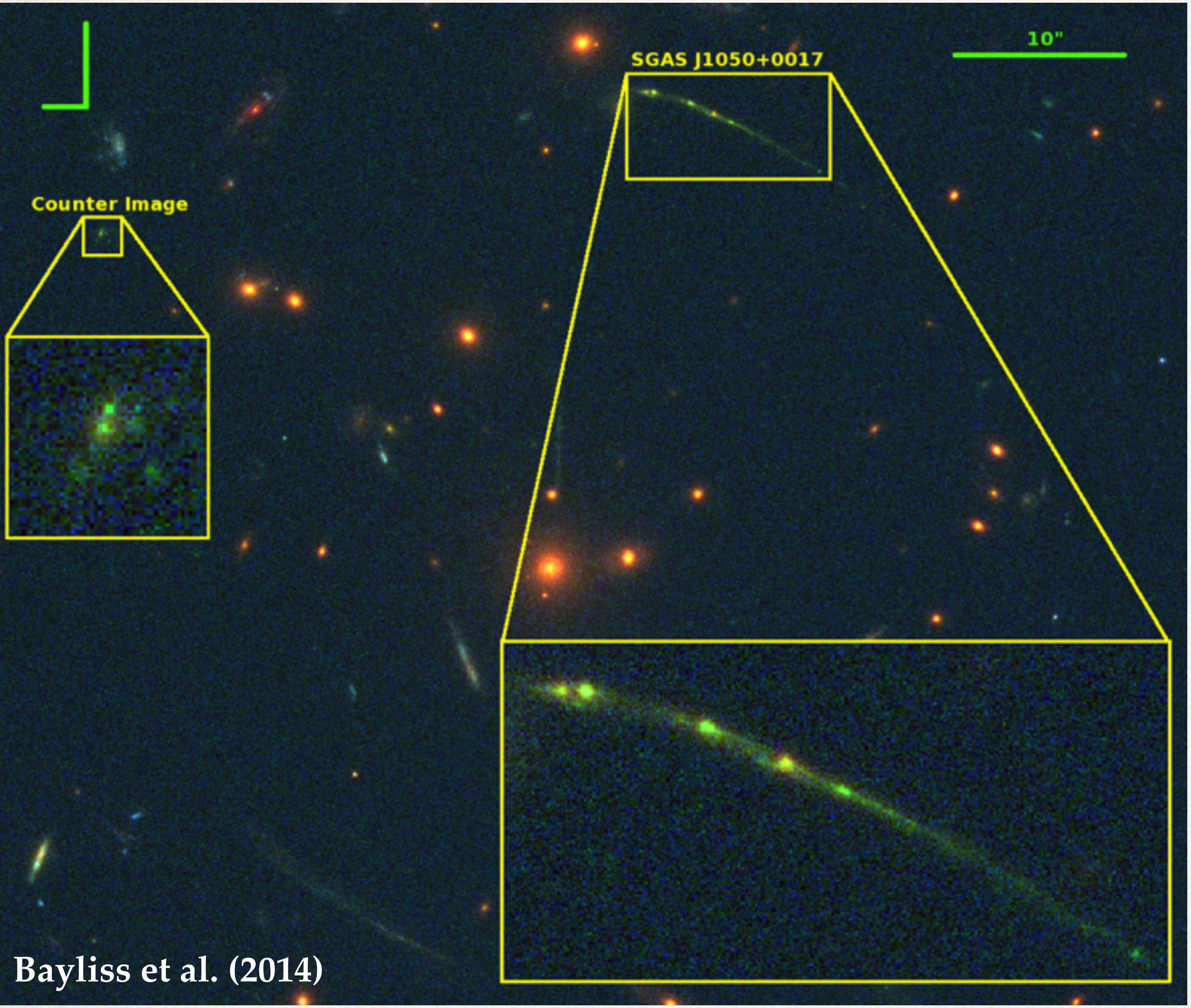


NV 1242
SiII 1260
OI/SiII 1303
CII 1335
OIV 1343
OV 1371
SiIV 1393
SiIV 1402
SiIII 1417
SiII 1526
CIV 1548
CIV 1550
f_λ ($\times 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1})
0.0
0.2
0.4
0.6
0.8
1.0
1200
1300
1400
1500
λ_{rest} (Å)
FeII 1608
HeII 1640
O III] 1661
O III] 1666
AlIII 1670
NIV 1718
N III] 1750
AlIII 1854
AlIII 1862
Si III] 1882
Si III] 1992
C III] 1907/9
f_λ ($\times 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1})
0.0
0.5
1.0
1.5
2.0
2.5
1600
1650
1700
1750
1800
1850
1900
λ_{rest} (Å)

SGAS1050+0017



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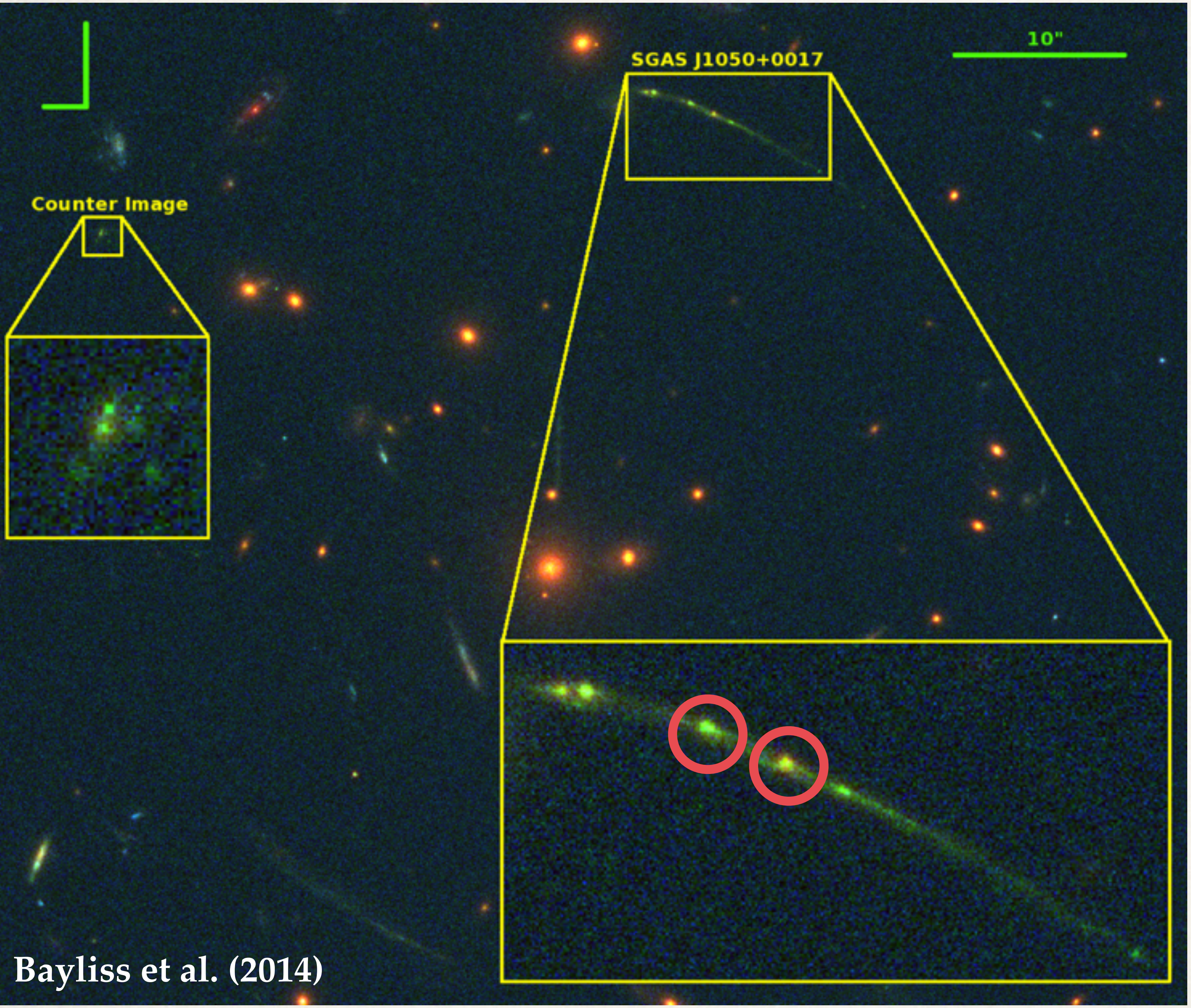

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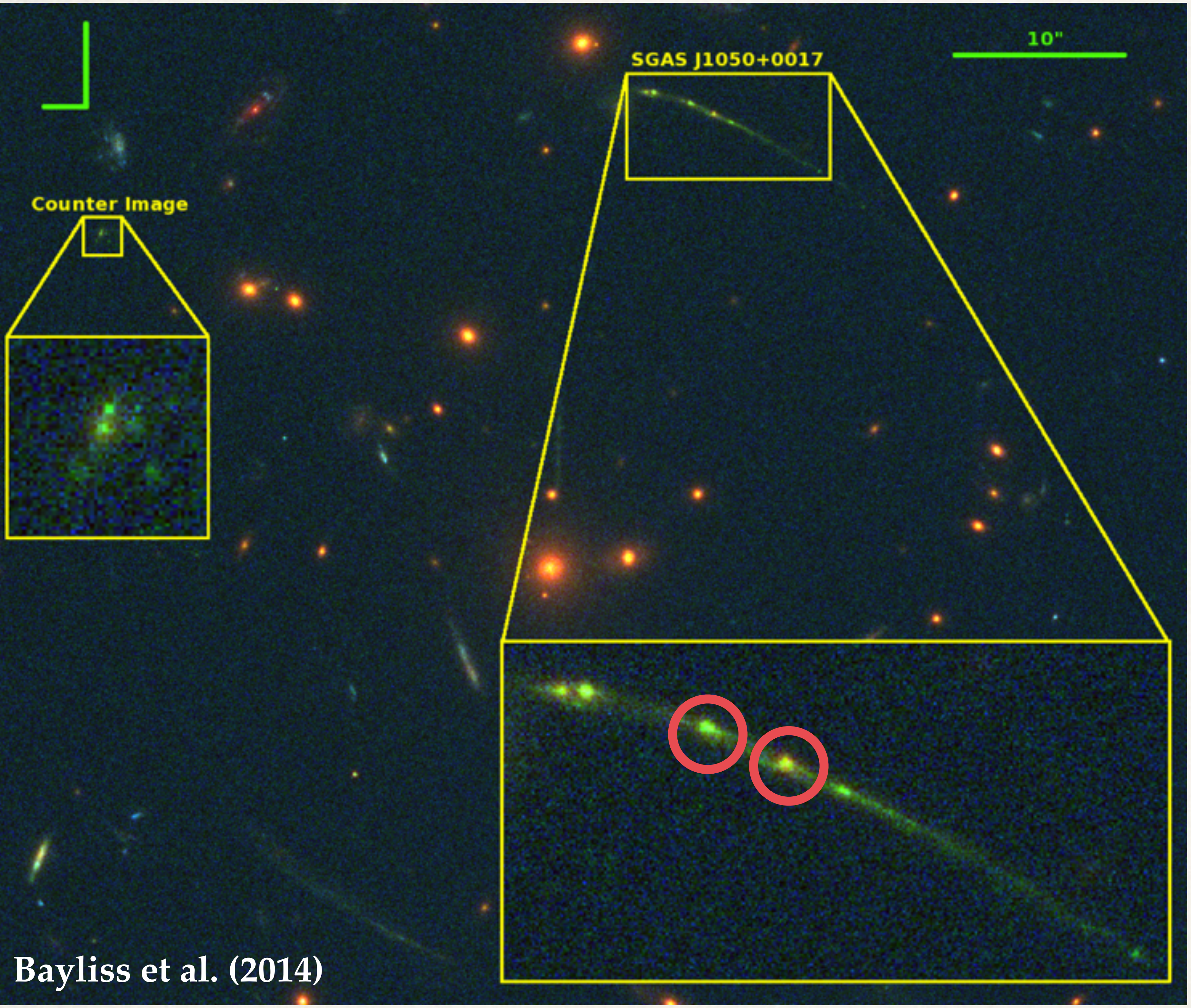
Take, for example, C IV & He II lines from two separate star-forming regions.

SGAS1050+0017



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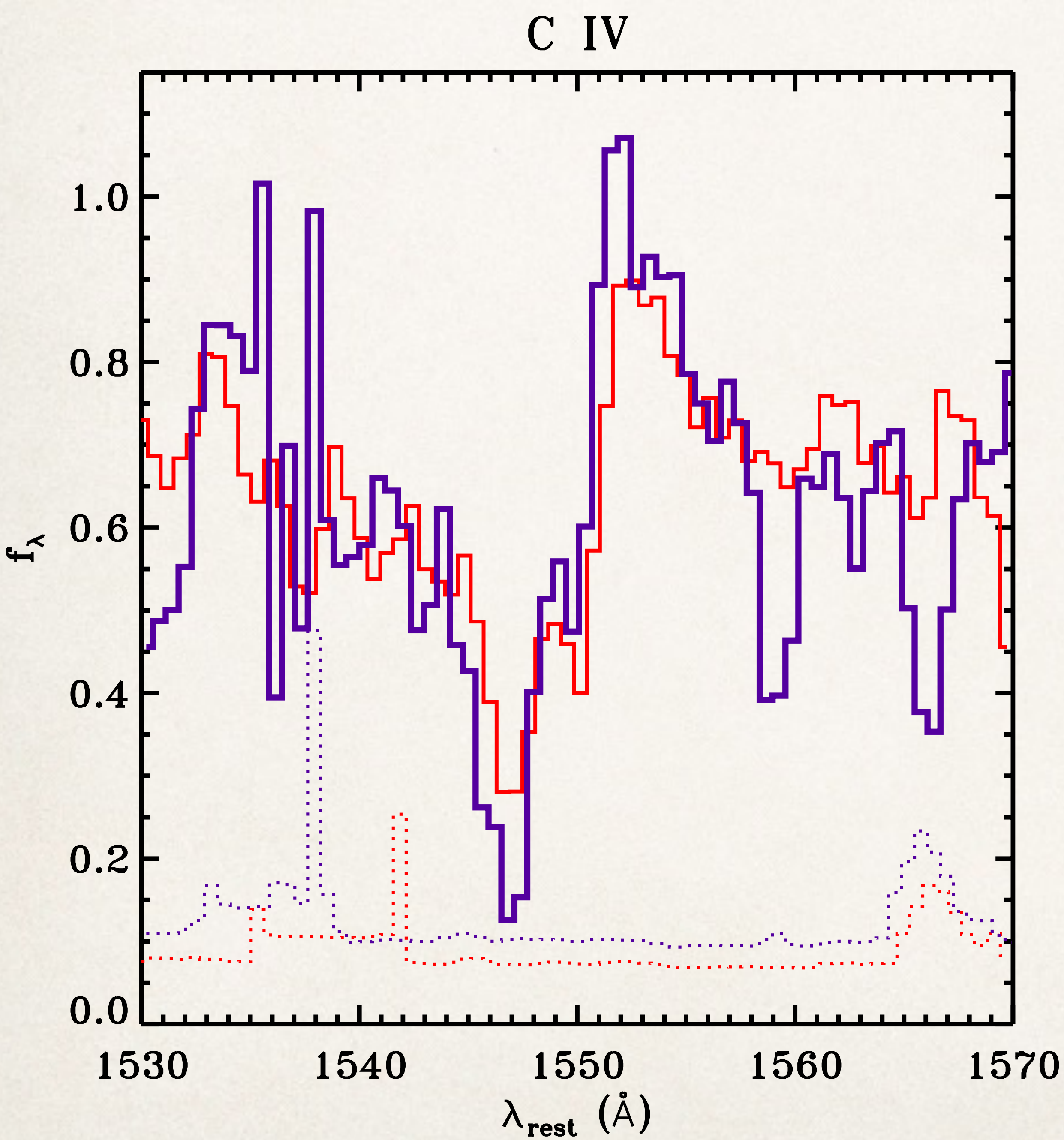
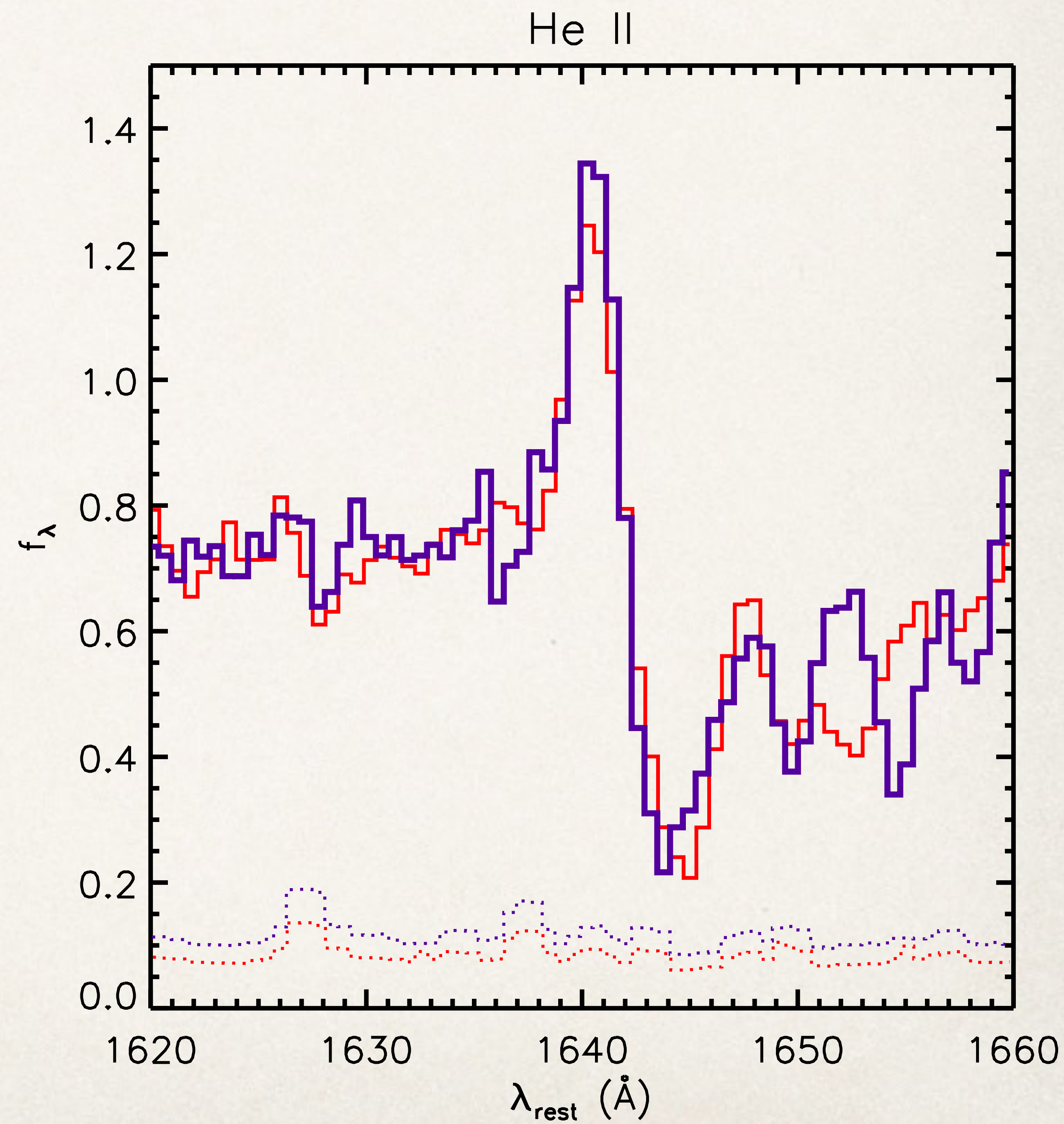
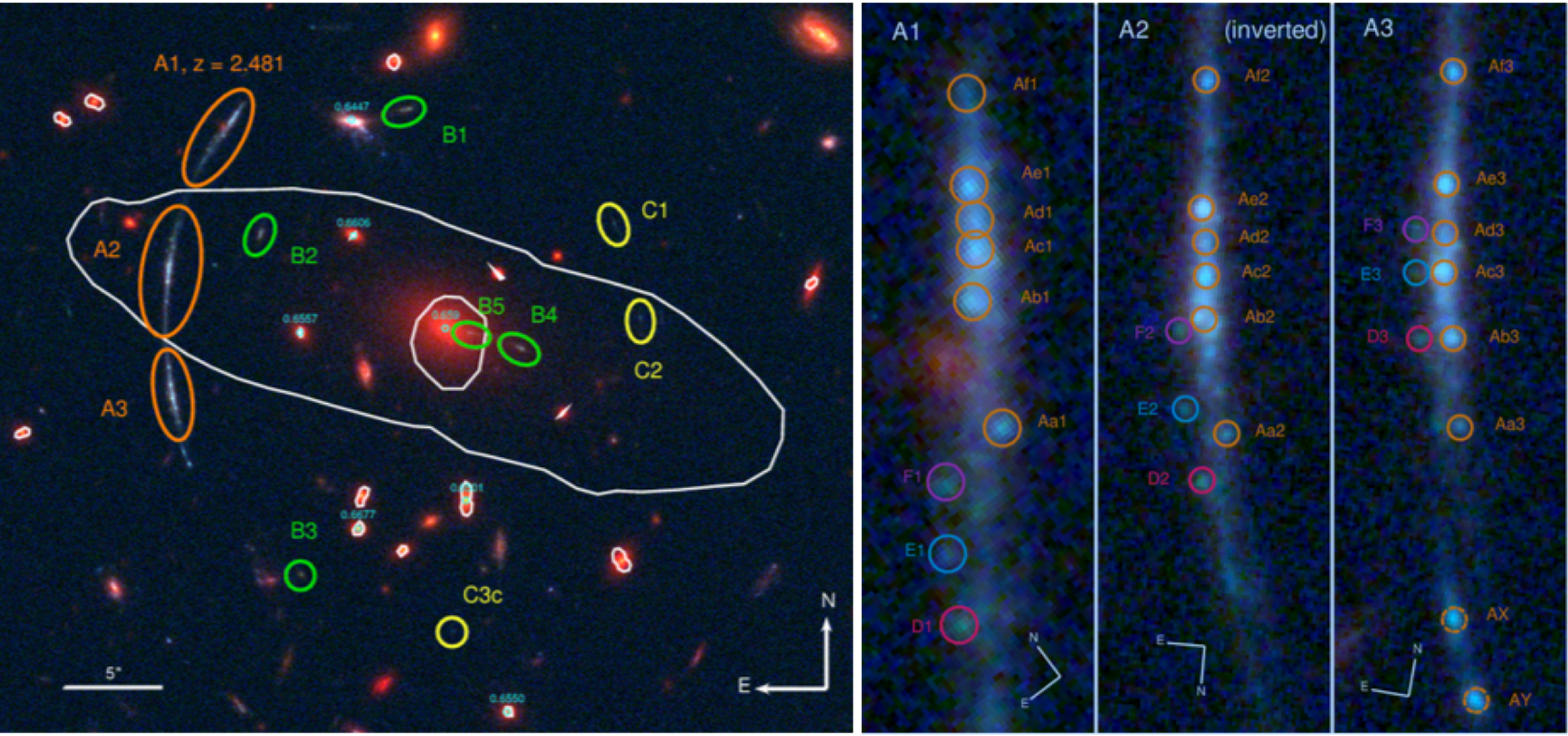
C IV & He II Line Profiles Within Different Star Forming Regions





SGAS: Clumpy Star-formation On 10's of Parsec Scales



T. Johnson et al. (in prep)

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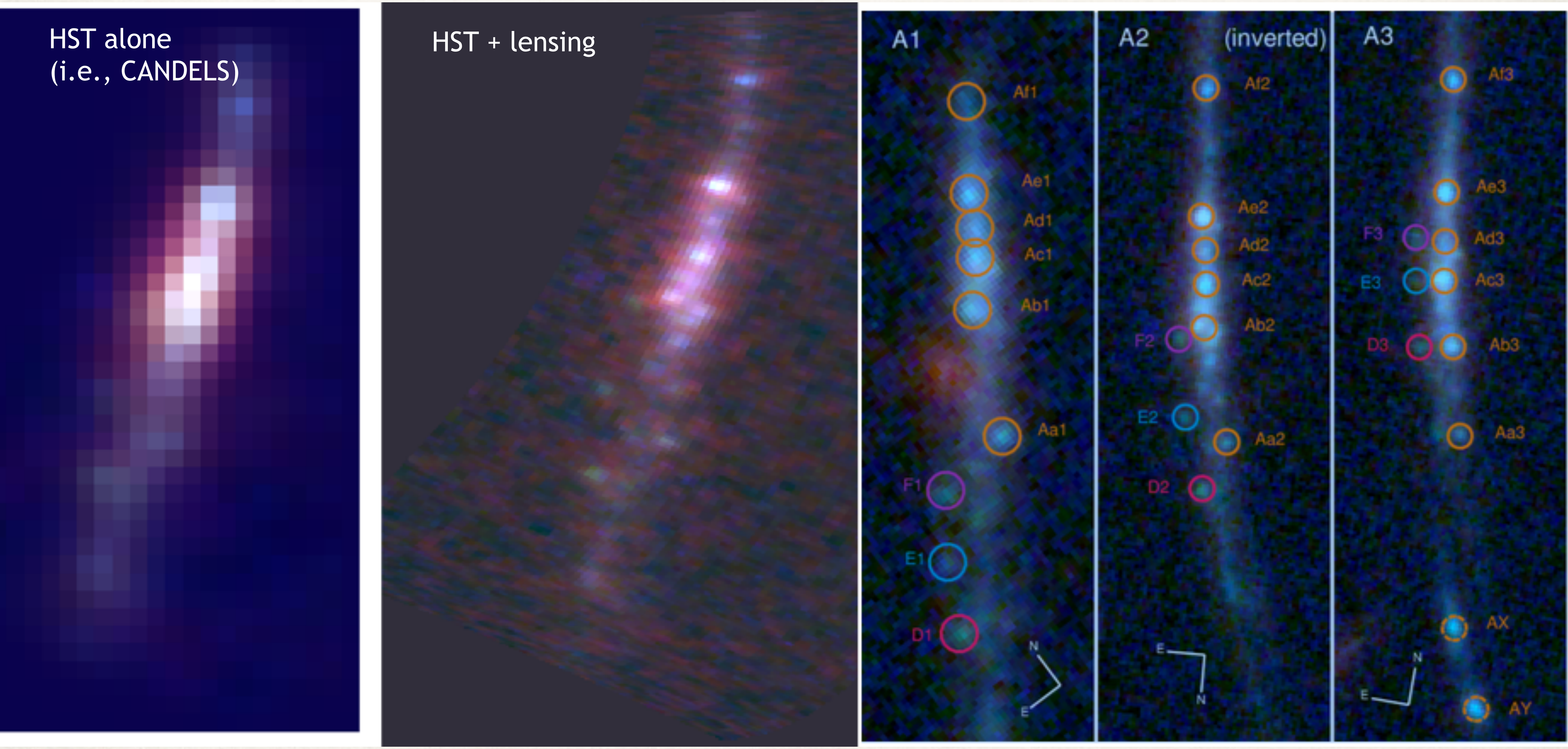

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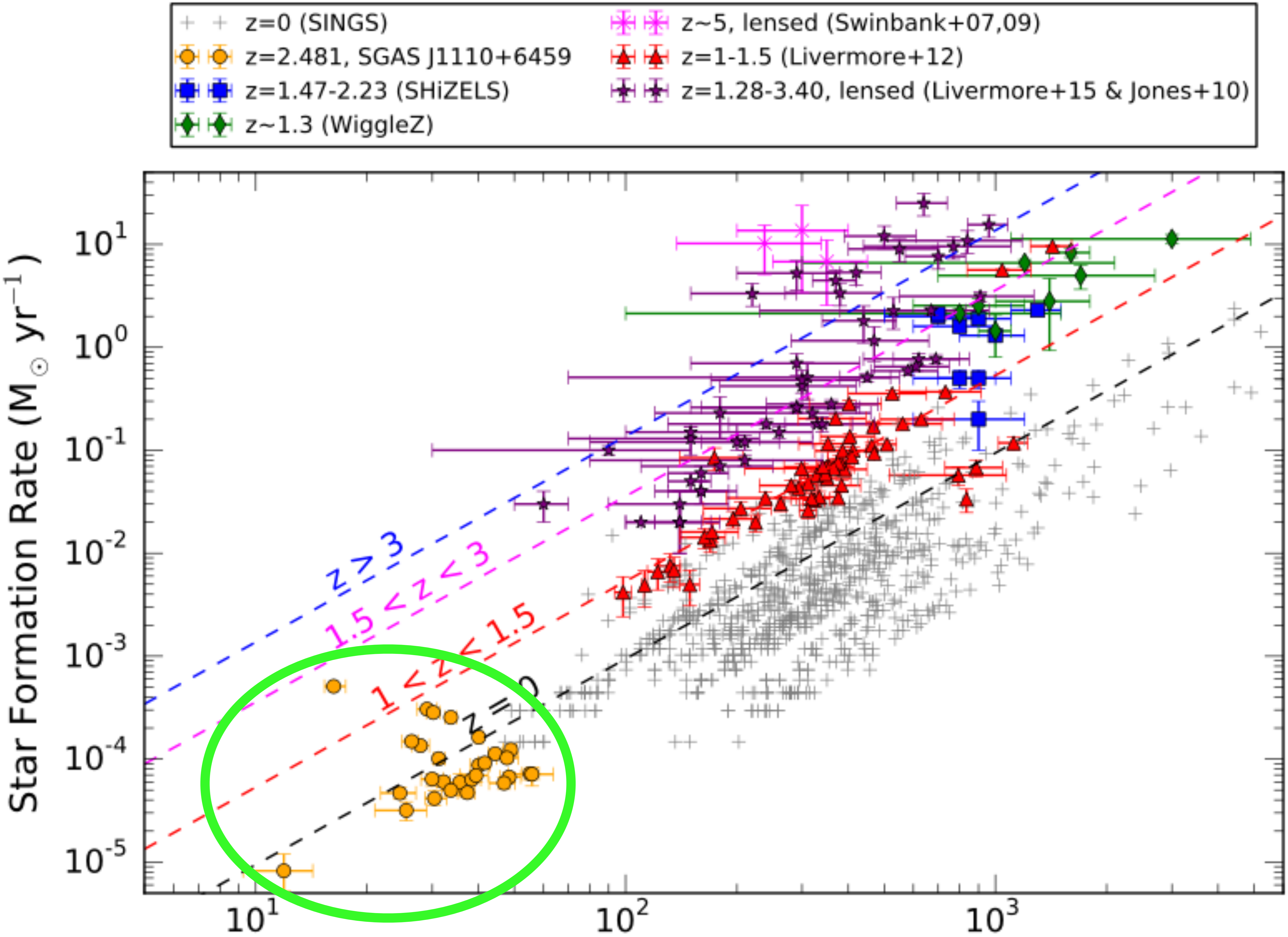
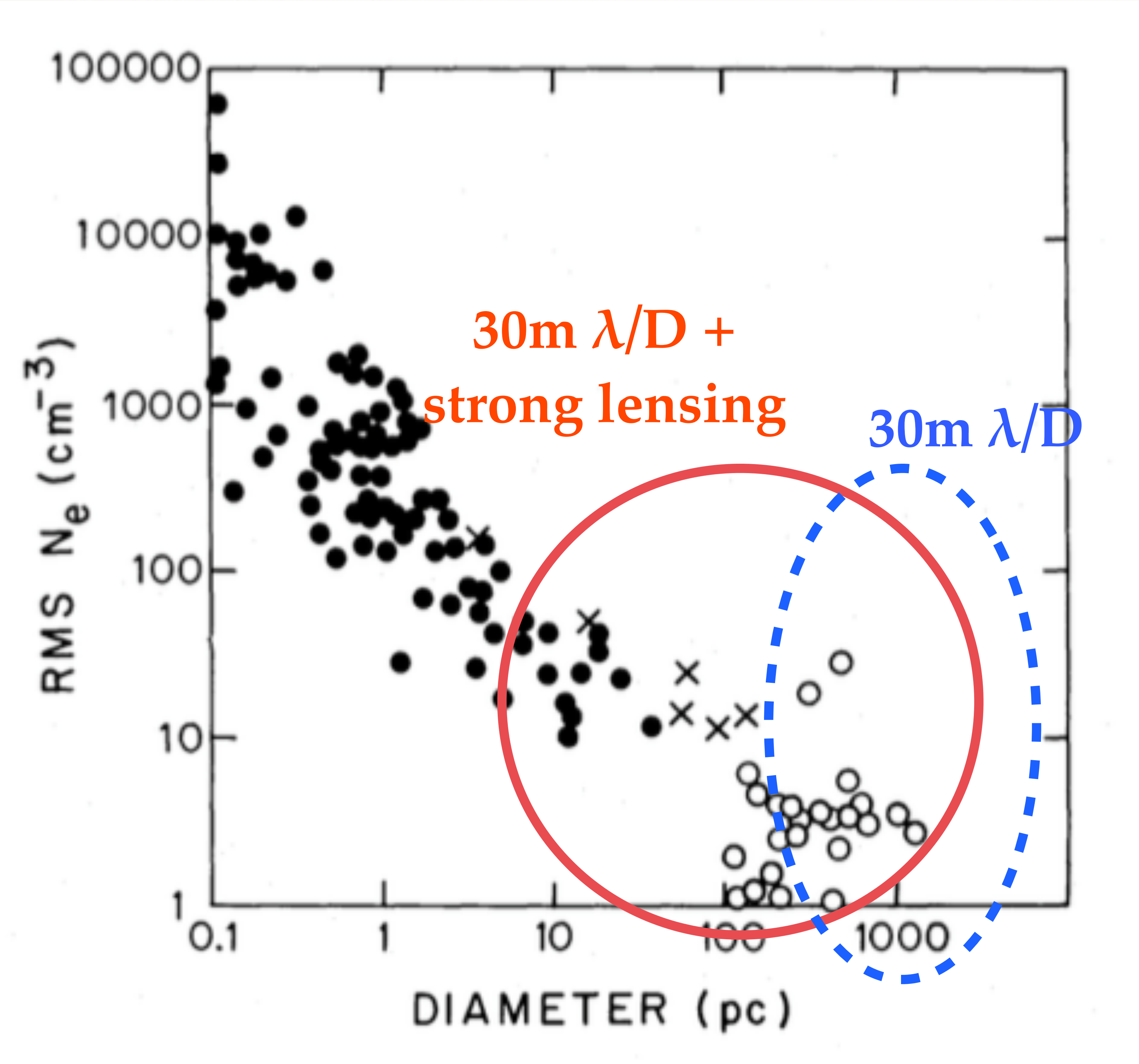


T. Johnson et al. (in prep)

What Can We Do With 30m Telescopes?

Now moving from real science to projected science.



Properties of local HII regions (Kennicutt 1984)

At z~3, diffraction limit of a 30m telescope in the NIR corresponds to physical scales of ~100's of parsecs. Highly magnified lensed galaxies let you do >10x better (<10's of parsecs).

Spatially resolved spectroscopy on these scales is equivalent to resolving the internal structure of the largest Milky Way star-forming regions such as W49 and Carina, or 30 Doradus in the LMC.

For comparison, the Orion nebula is ~8 pc across.

What Can We Do With 30m Telescopes?

Dream scenario: R ~ 5000+ optical IFU with AO-assisted angular resolution.

This would allow us to obtain rest-UV through rest-optical spectra of individual star forming clumps down to ~10 pc scales (i.e., we could "cheat" and do 300m telescope science with 30m telescopes).

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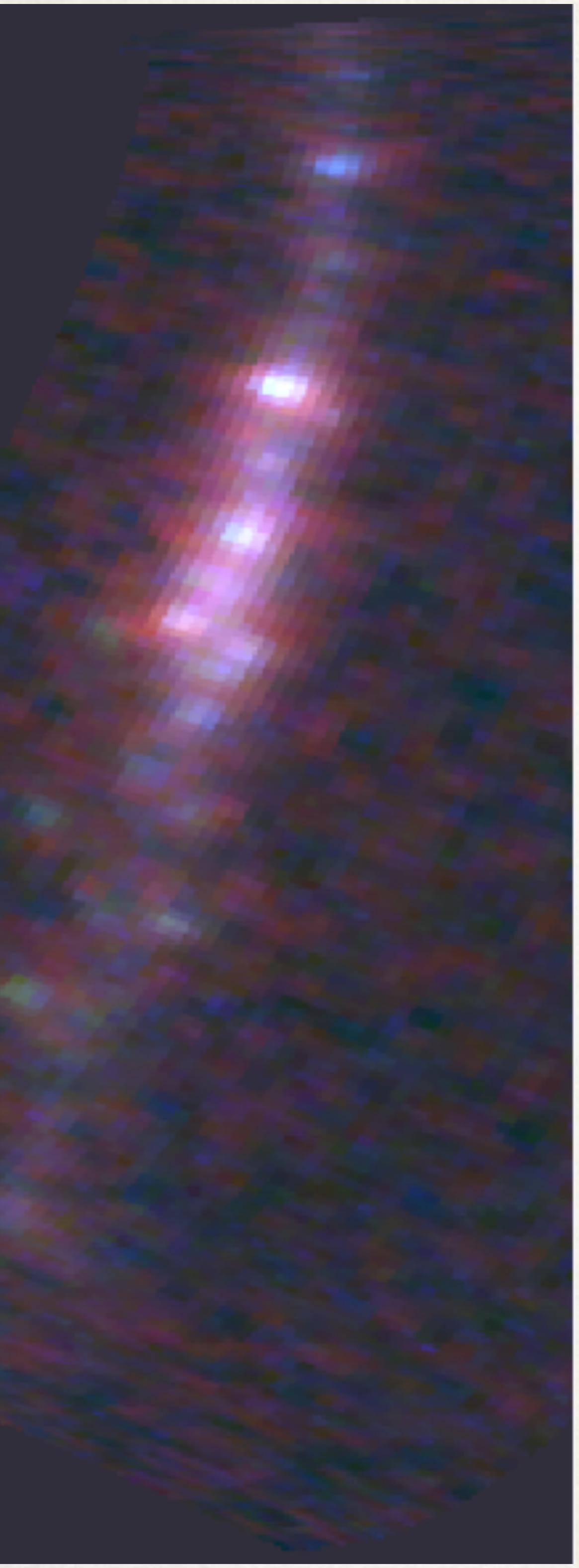
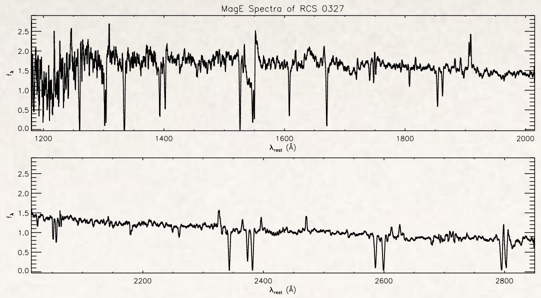
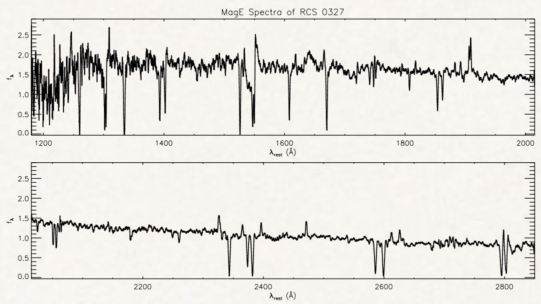
Worst-case Scenario: R ~ 5000+ natural seeing optical IFU.

Could obtain rest-UV through rest-optical spectra of individual star-forming clumps down to ~100 pc scales, including clumps ~10x fainter than can be achieved with current facilities.




MagE Spectra of RCS 0327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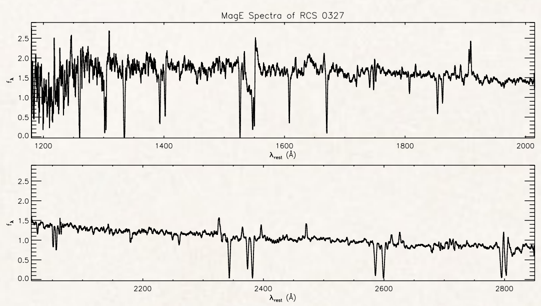
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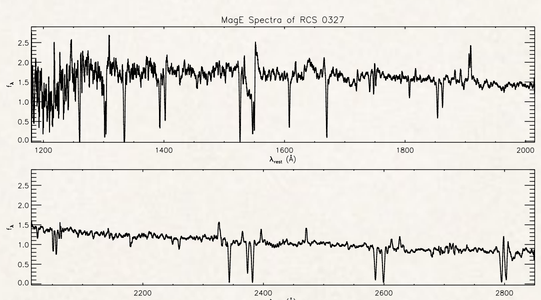
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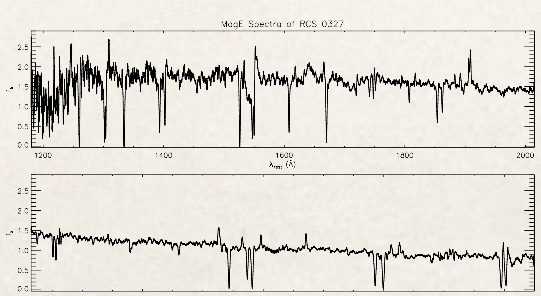
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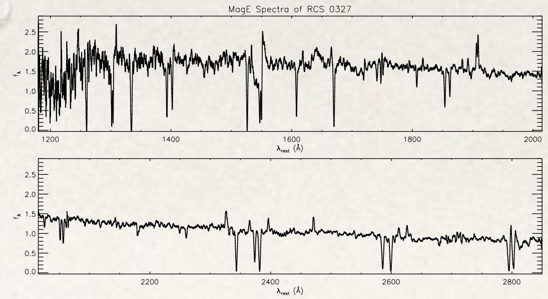
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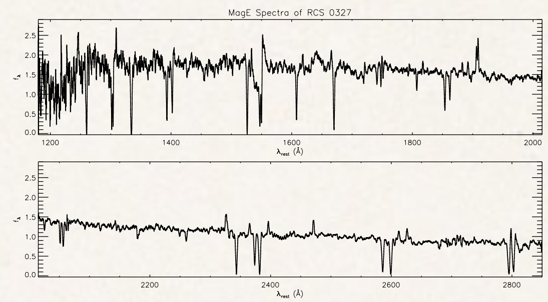
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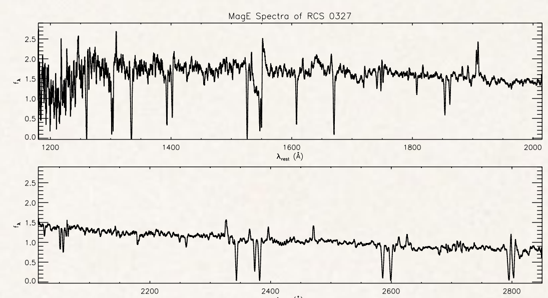
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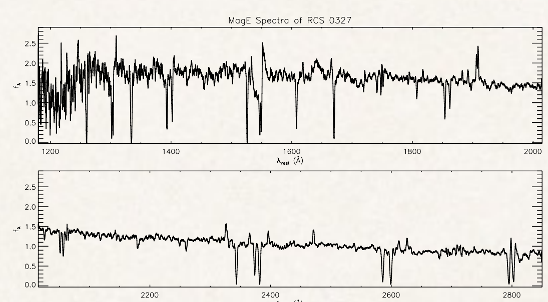
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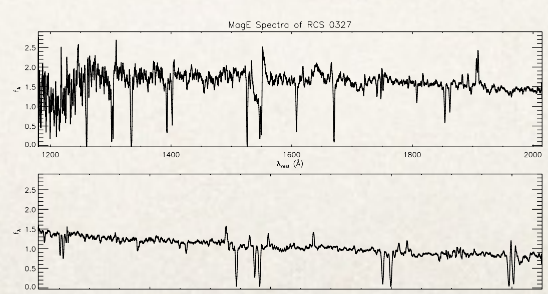
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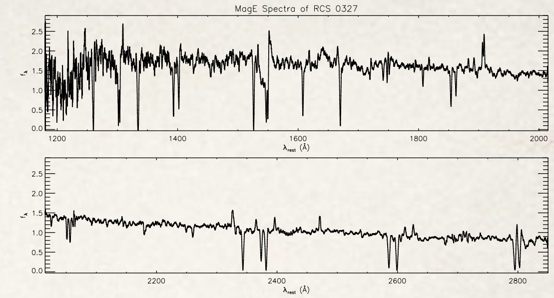
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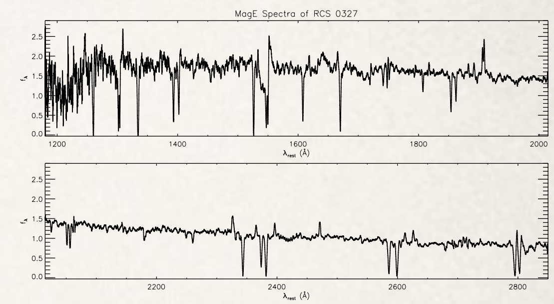
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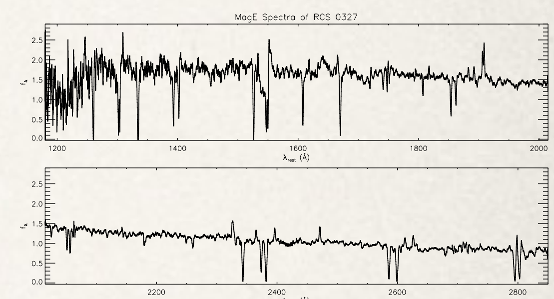
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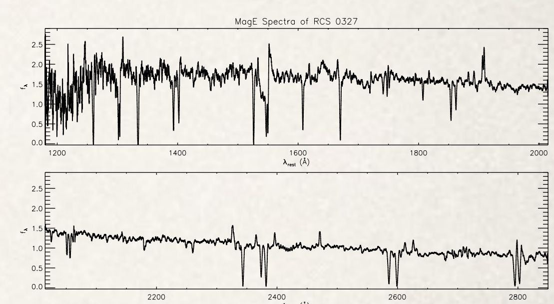
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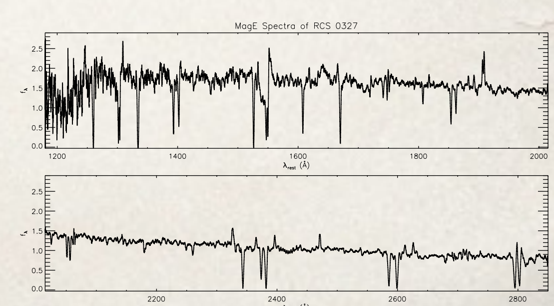
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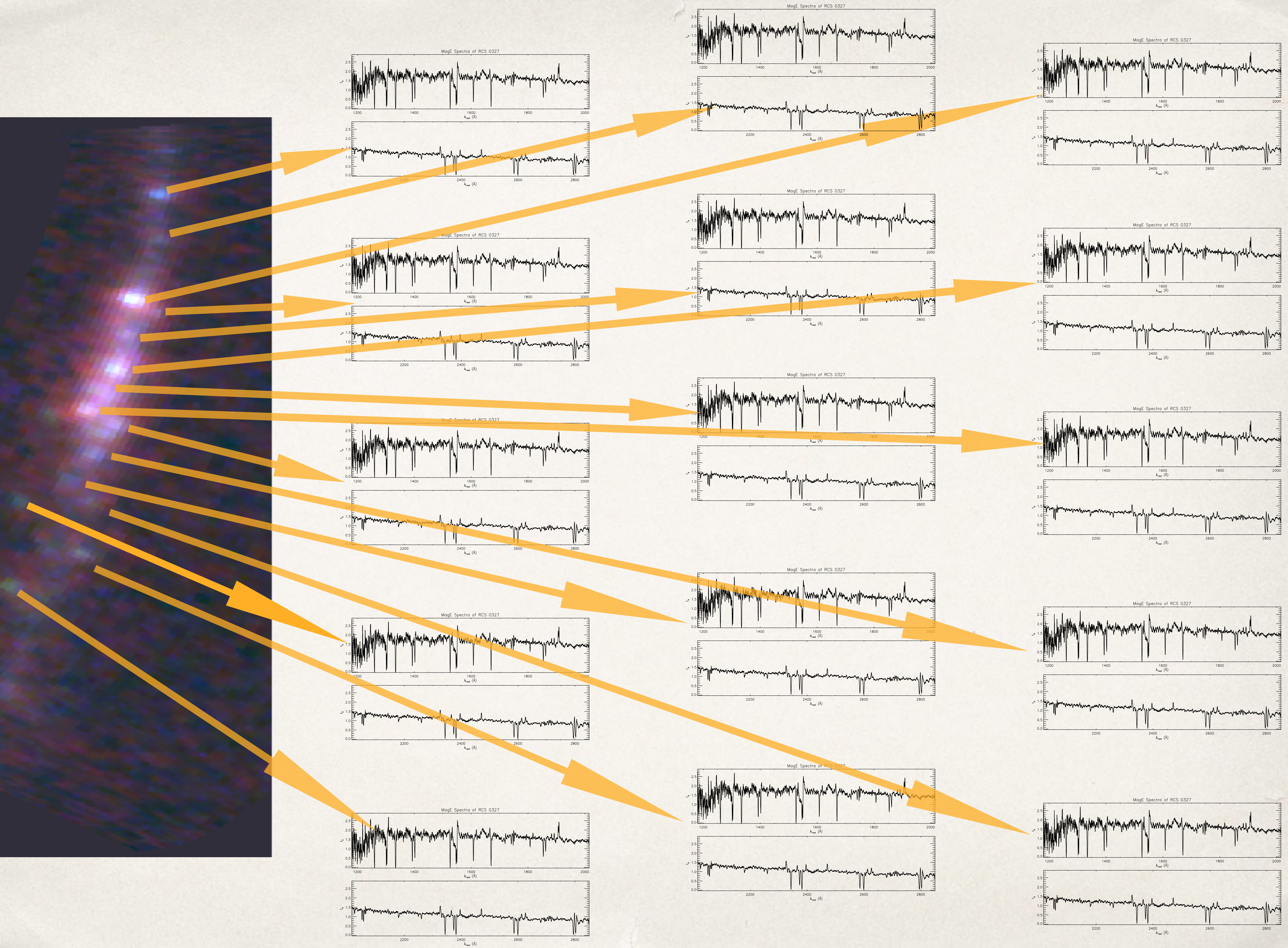
MagE Spectra of RCS 0327

End

Work to date with spectra of gravitationally lensed galaxies overcomes the limits of current telescopes, and previews 30m science, including:

-detect faint diagnostics
-obtain much higher signal-to-noise,
- resolve much smaller physical regions (down to 100pc).

Diagnostics and physical conditions:

C III] emission	Rigby, Bayliss et al. 2015, ApJL
C,N,O, Si abundance at z=3.6	Bayliss, Rigby et al. 2014, ApJ
Outflows from Mg II, Fe II	Bordoloi, Rigby et al. MNRAS 2016; Rigby, Bayliss et al. 2014
Outflows, kinematics of Hα	Wuyts, Rigby et al. 2014, ApJ
Physical conditions	Rigby, Wuyts et al. 2011; Bayliss, Rigby et al. 2014
Winds & Massive Stars	Bayliss, Rigby et al. 2015; Rigby et al. in prep