Keck LGSAO Imaging and Spectroscopy of Massive Passively Evolving Galaxies at z ~ 2.5

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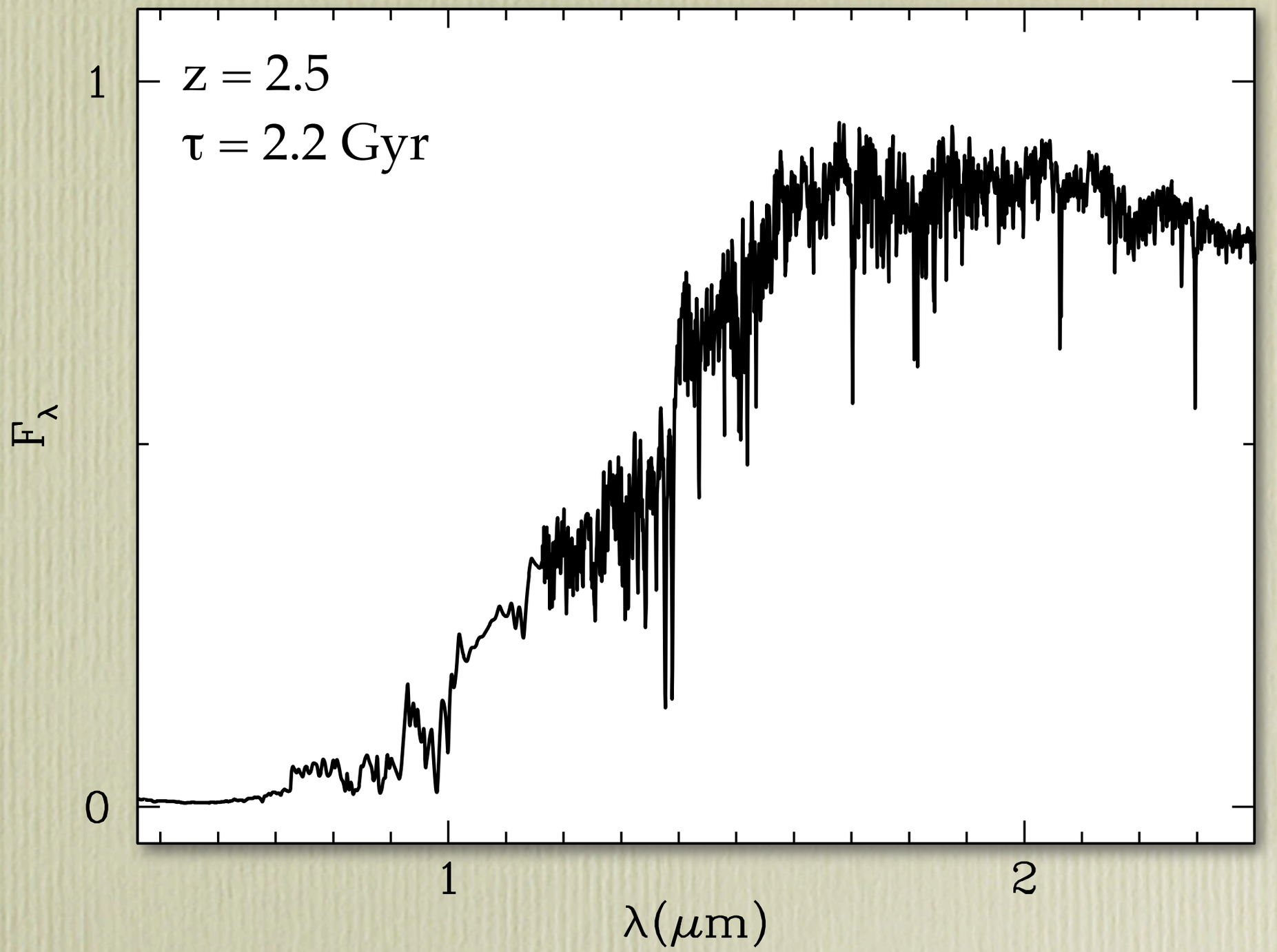
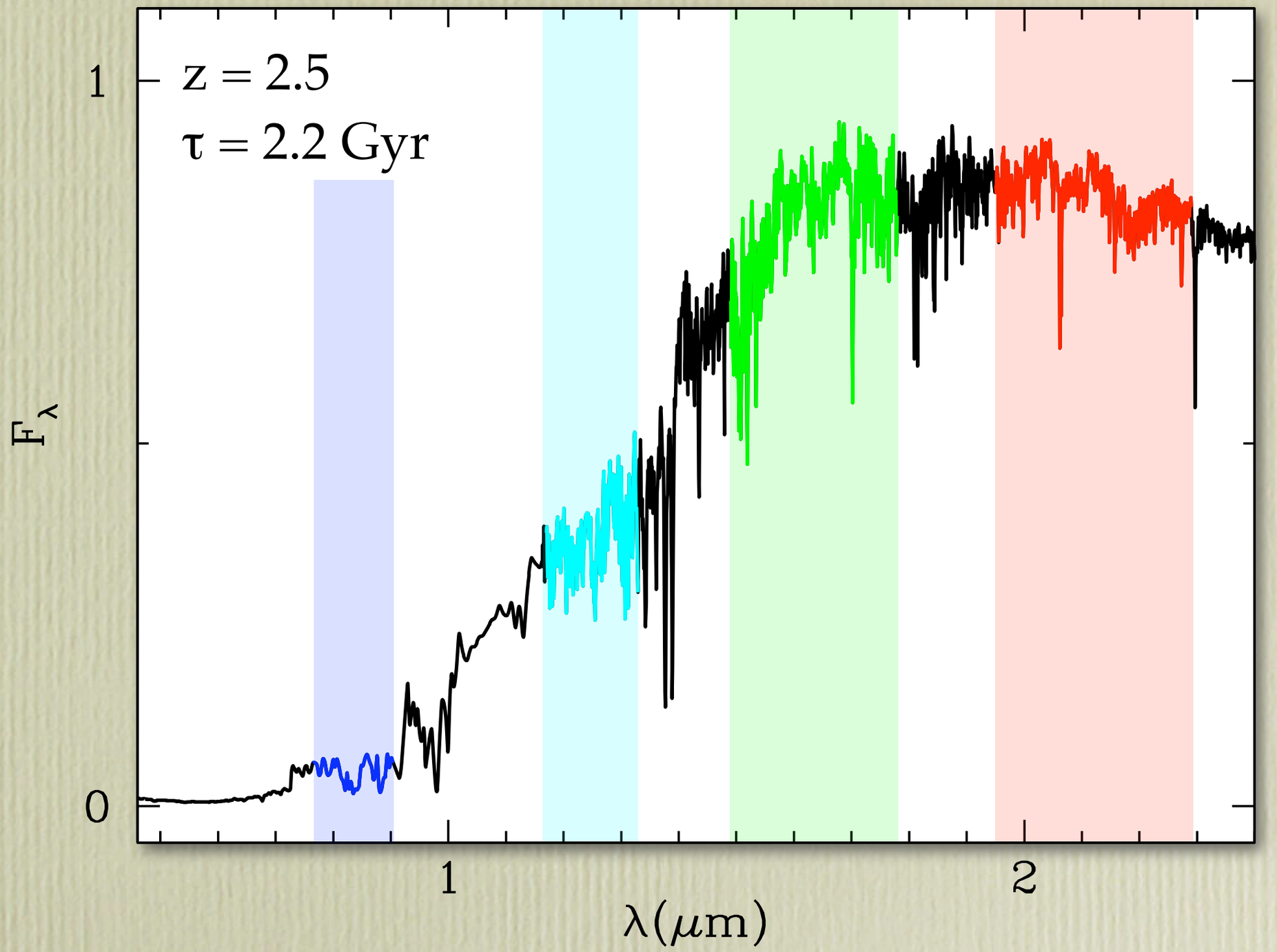
...and thanks to the Keck AO team!

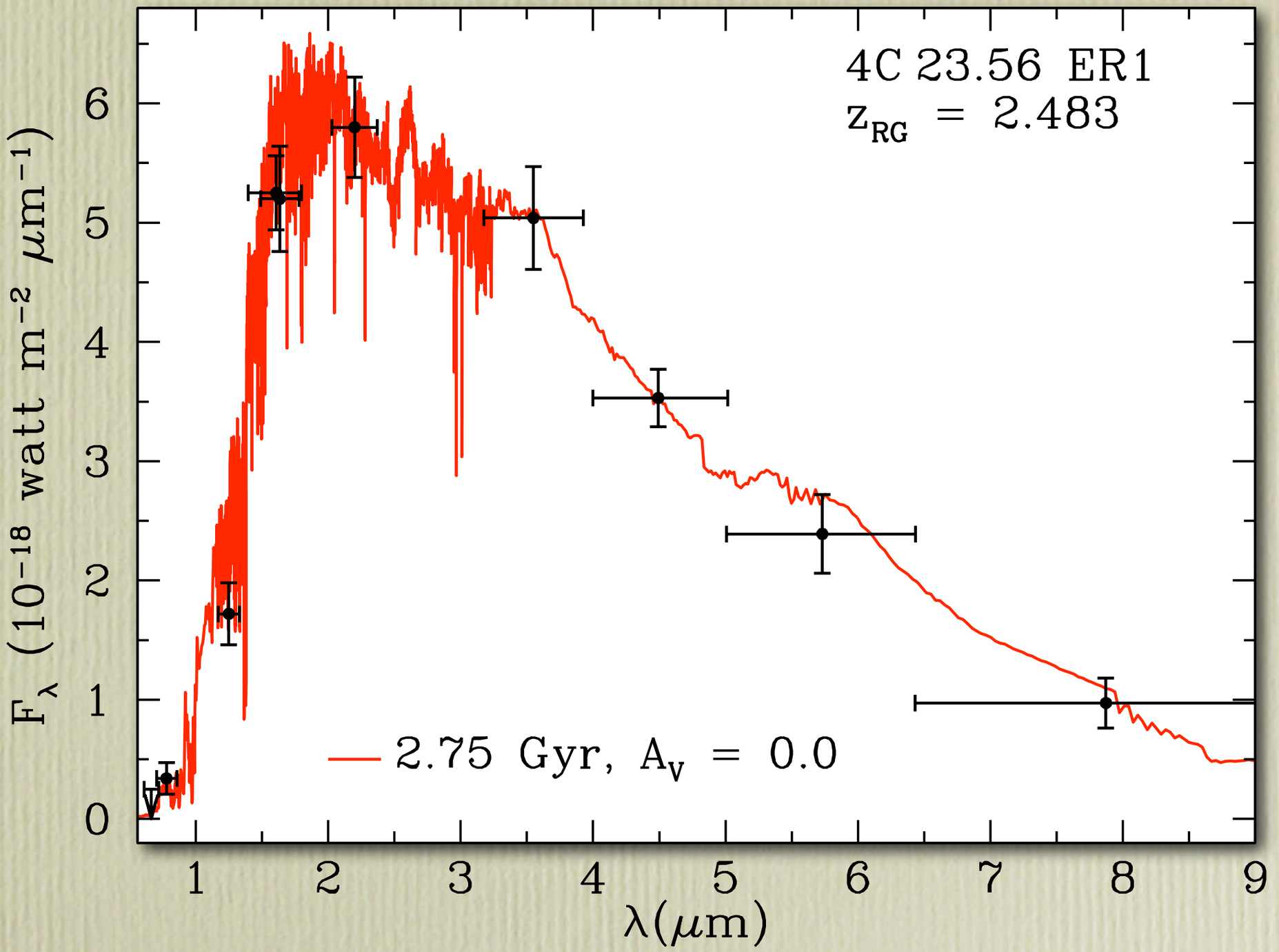
Passive Galaxies in Radio-Source Fields at High Redshifts

- Radio-sources signpost some of the highly overdense regions in the early universe, in which the first massive galaxies are expected to have formed.

- Because we know the radio-source redshifts, we can target redshift ranges that allow the best separation of galaxies with old stellar populations from highly reddened star-forming galaxies.


z = 2.5
τ = 2.2 Gyr
1
0
F_λ
1
2
λ(μm)

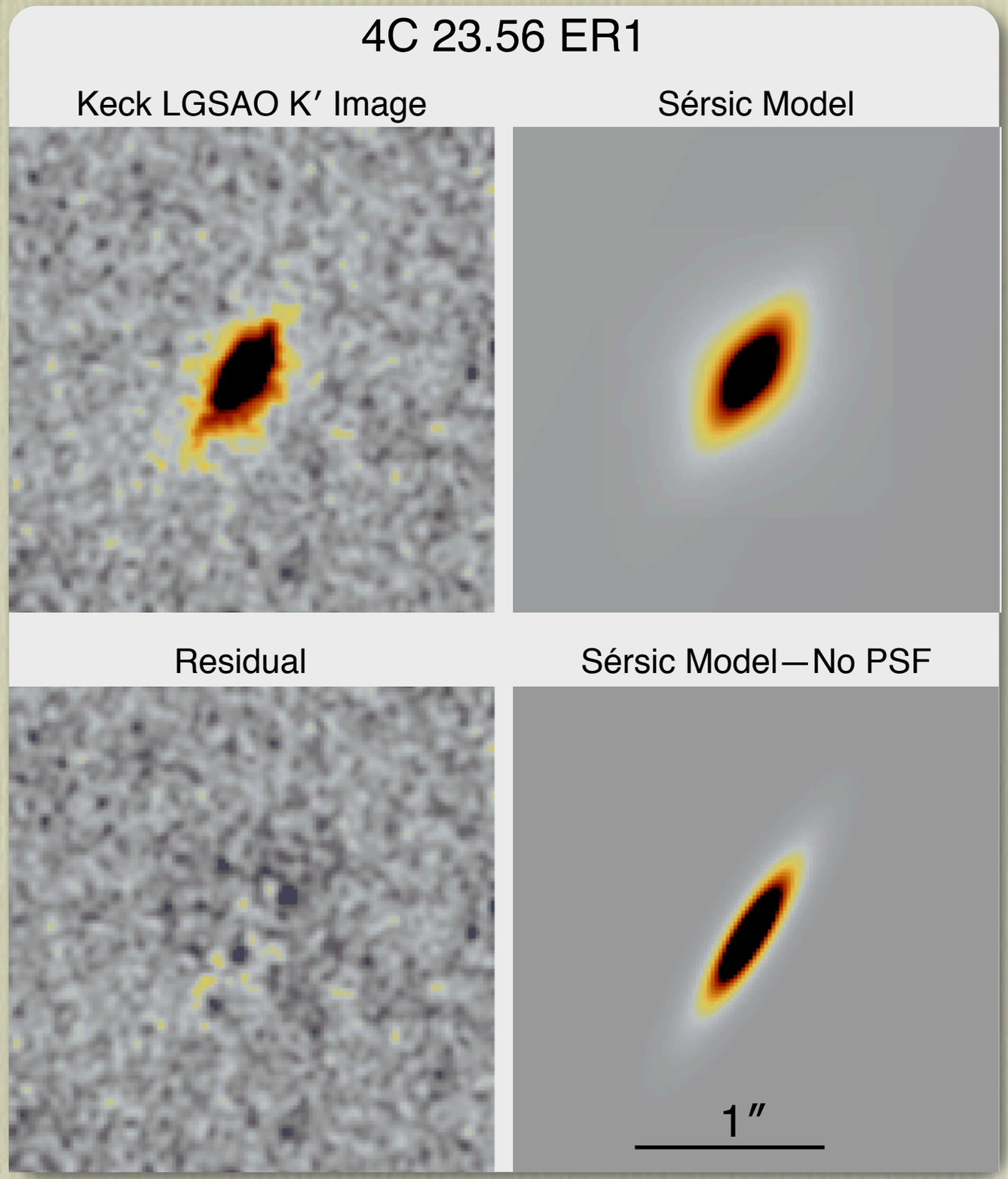

z = 2.5
τ = 2.2 Gyr
1
0
F_λ
1
2
λ(μm)

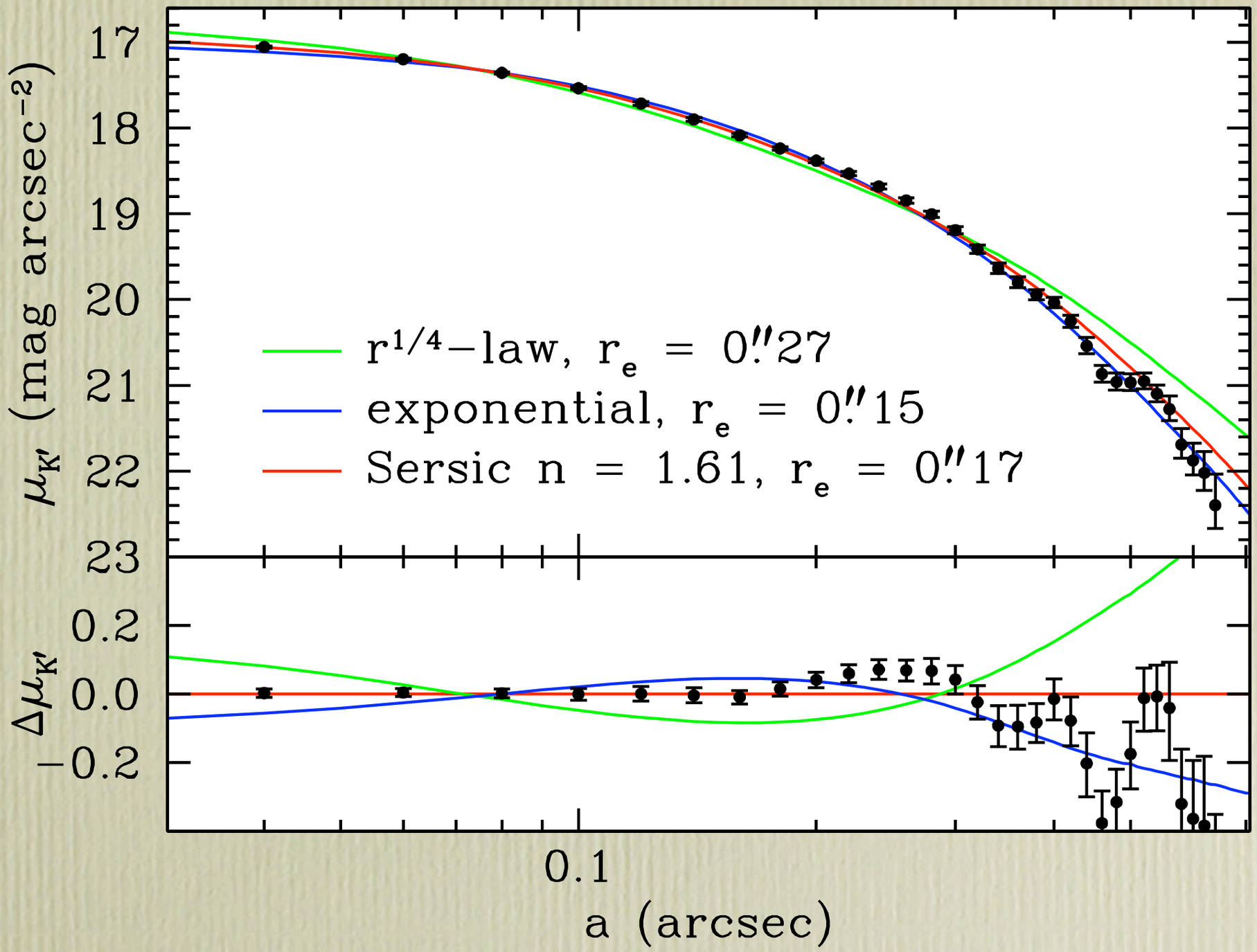

4C 23.56 ER1
z_{RG} = 2.483
2.75 Gyr, A_V = 0.0
F_λ (10^{-18} watt m^{-2} μm^{-1})
$\lambda(\mu m)$
0
1
2
3
4
5
6
7
8
9

Sérsic n = 1.61

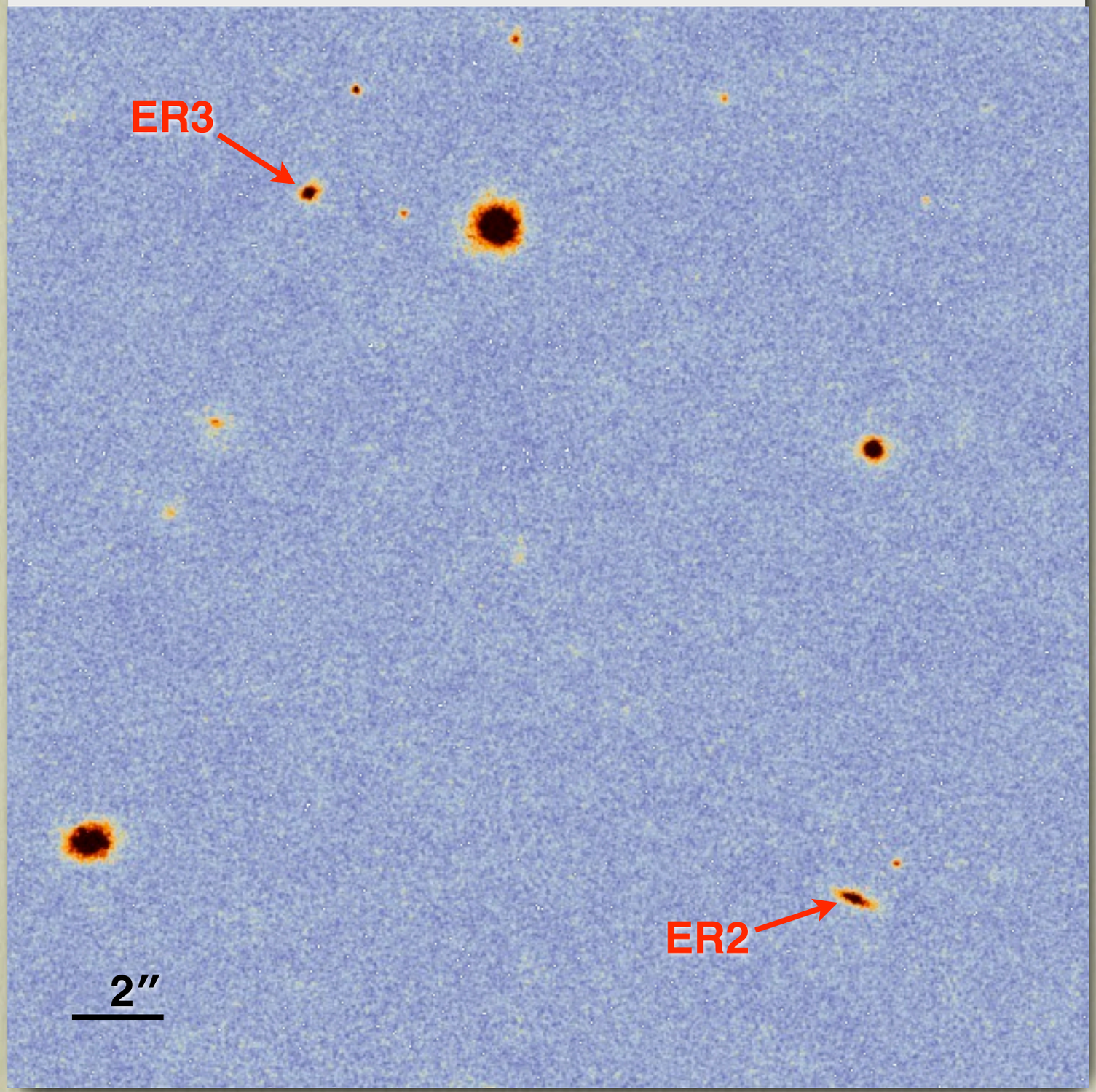
R_e = 0.17″

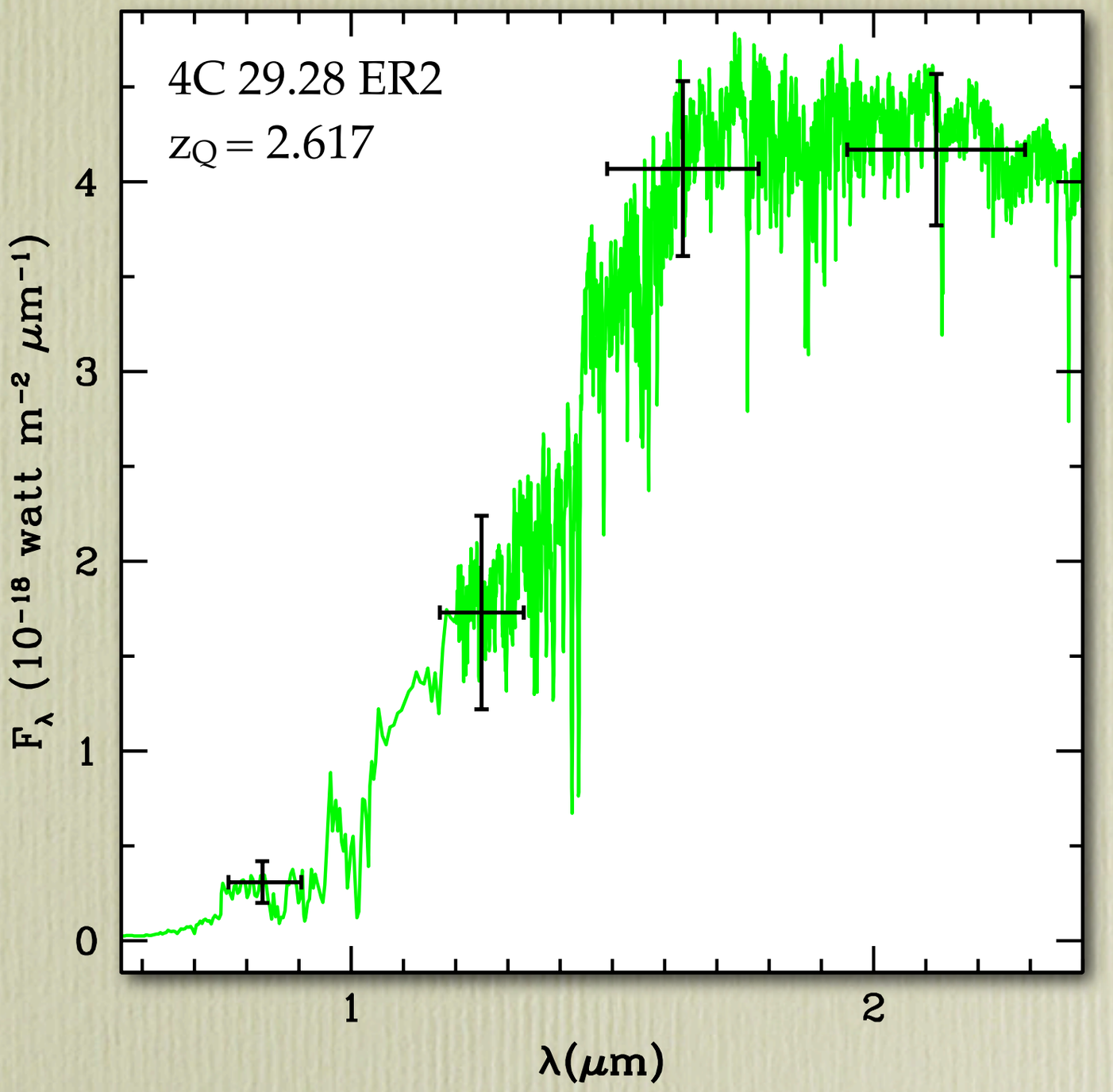
= 1.4 kpc




17
18
19
20
21
22
23
$\mu_{K'}$ (mag arcsec^{-2})
$r^{1/4}$–law, r_e = 0.″27
exponential, r_e = 0.″15
Sersic n = 1.61, r_e = 0.″17
0.2
0.0
−0.2
$\Delta\mu_{K'}$
0.1
a (arcsec)

4C 29.28 Field

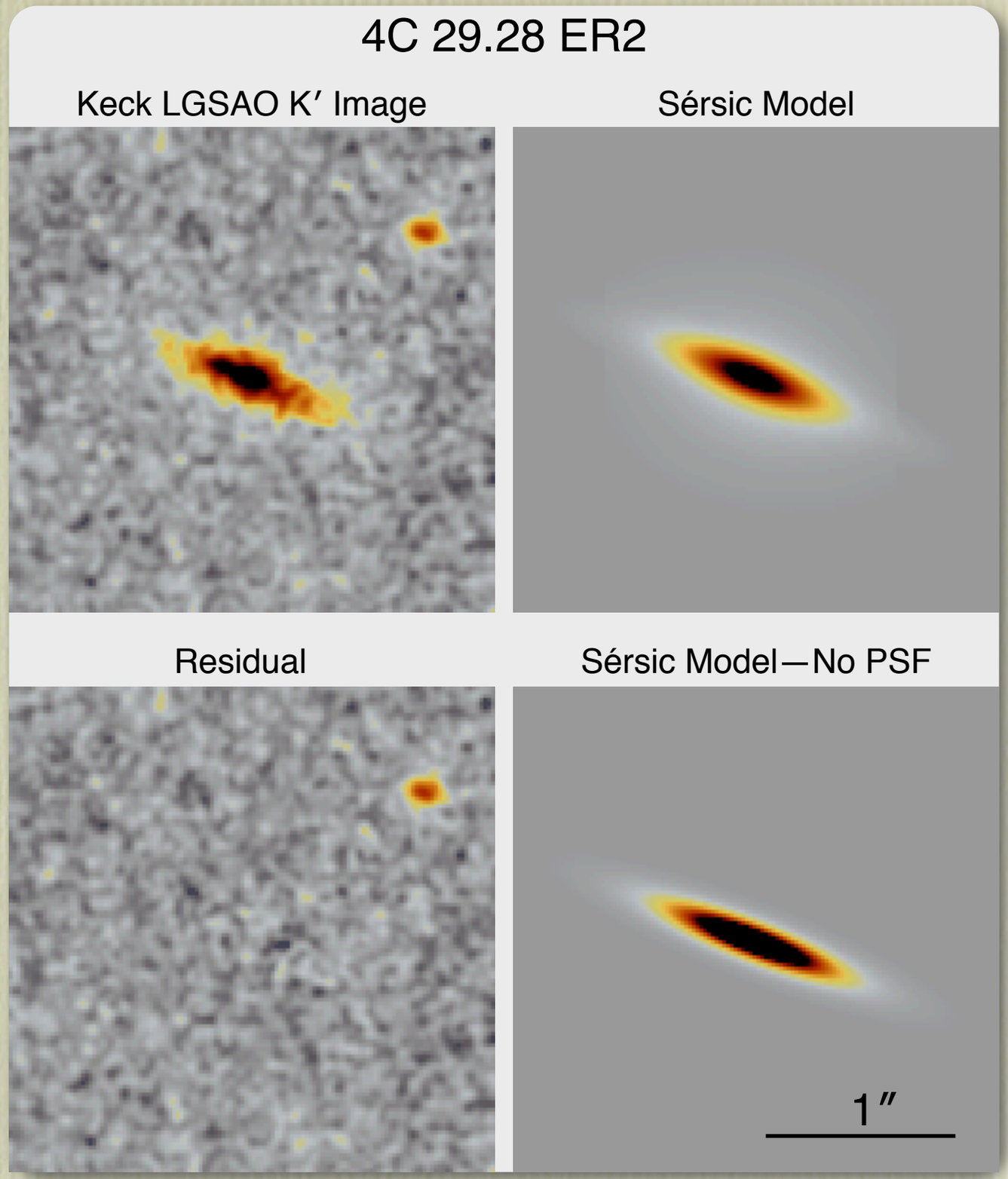



4C 29.28 ER2
$z_Q = 2.617$
F_λ (10^{-18} watt m^{-2} μm^{-1})
0
1
2
3
4
1
2
λ(μm)

Sérsic n = 0.90

R_e = 0.30″

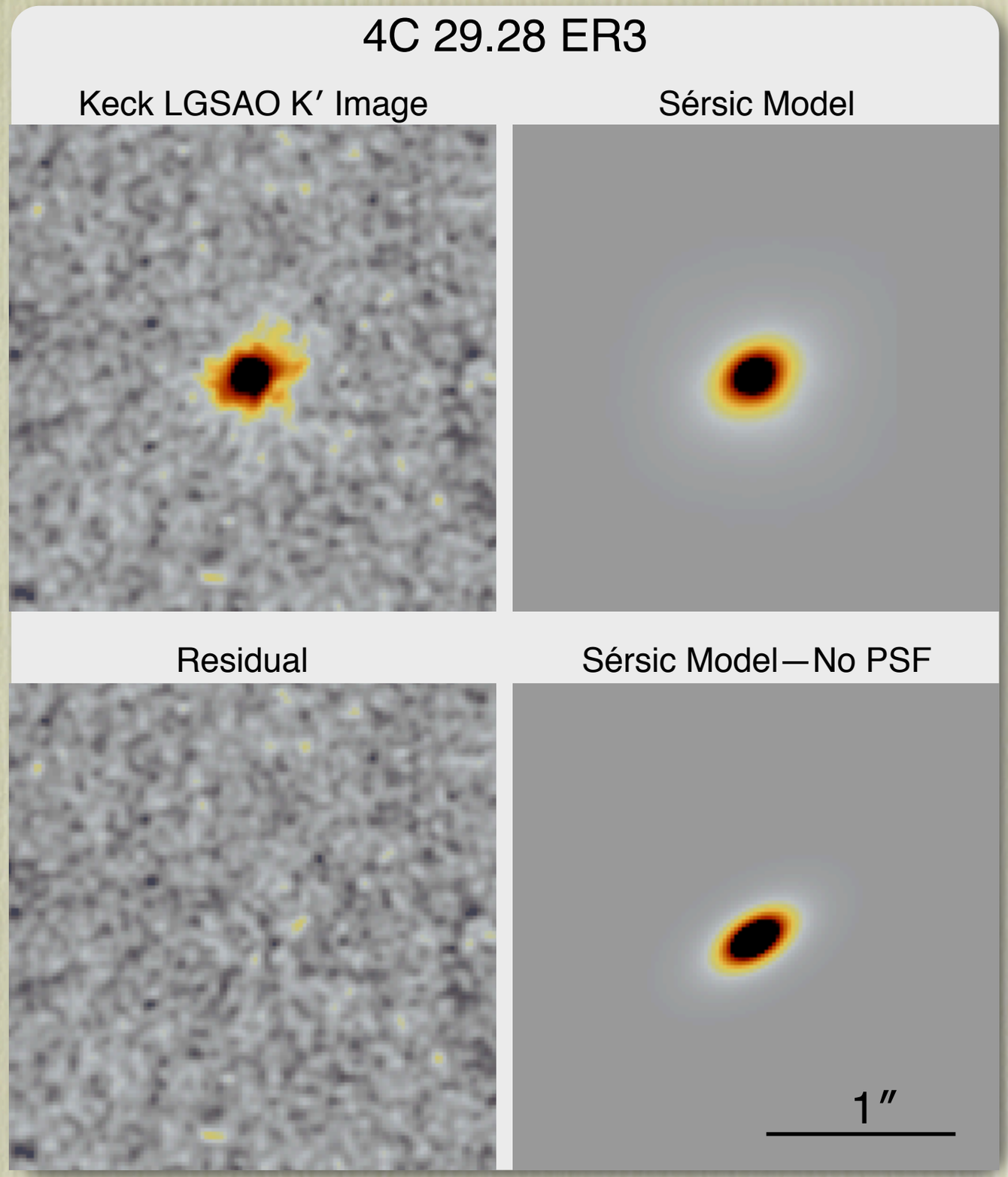
= 2.5 kpc

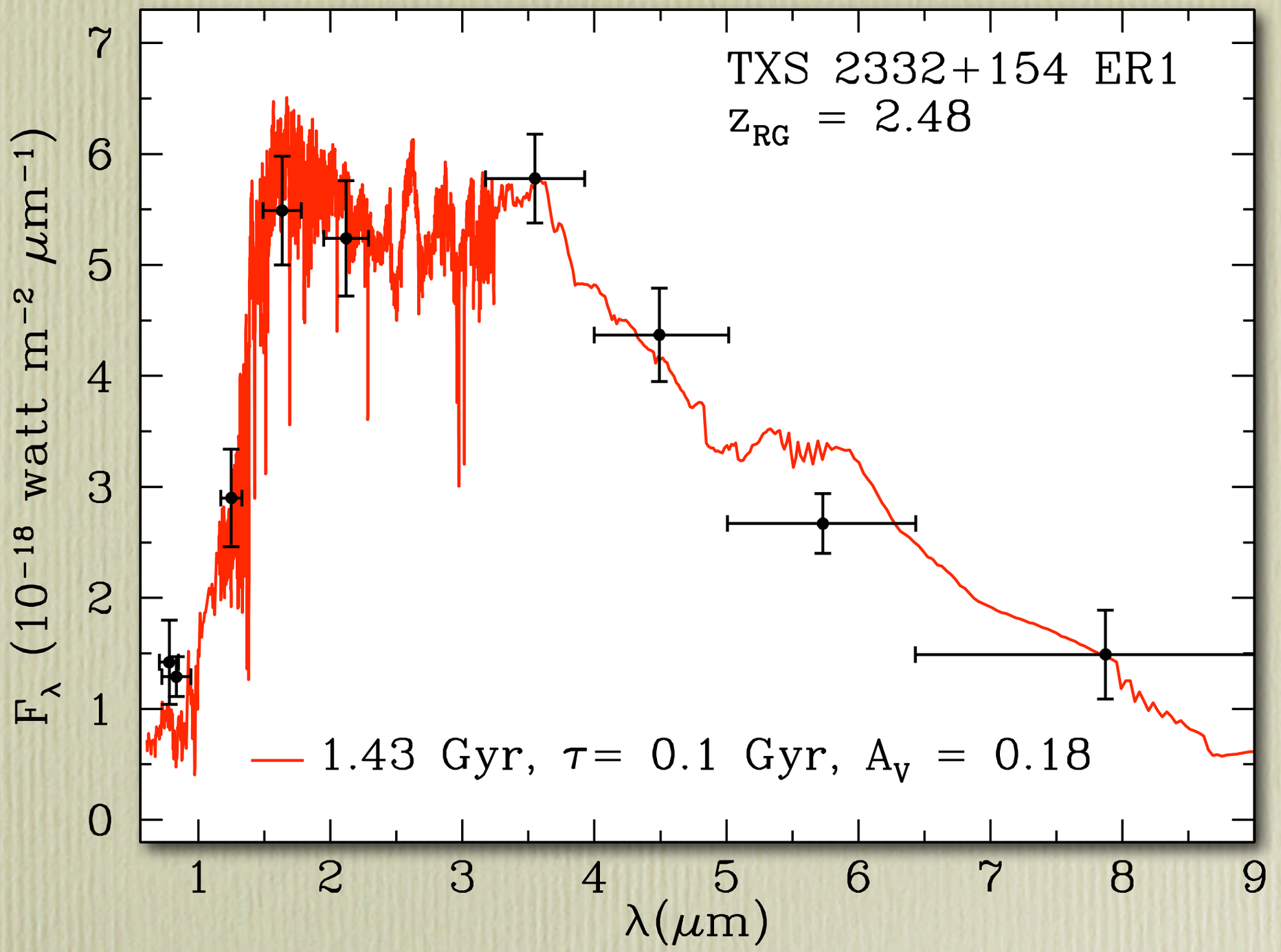


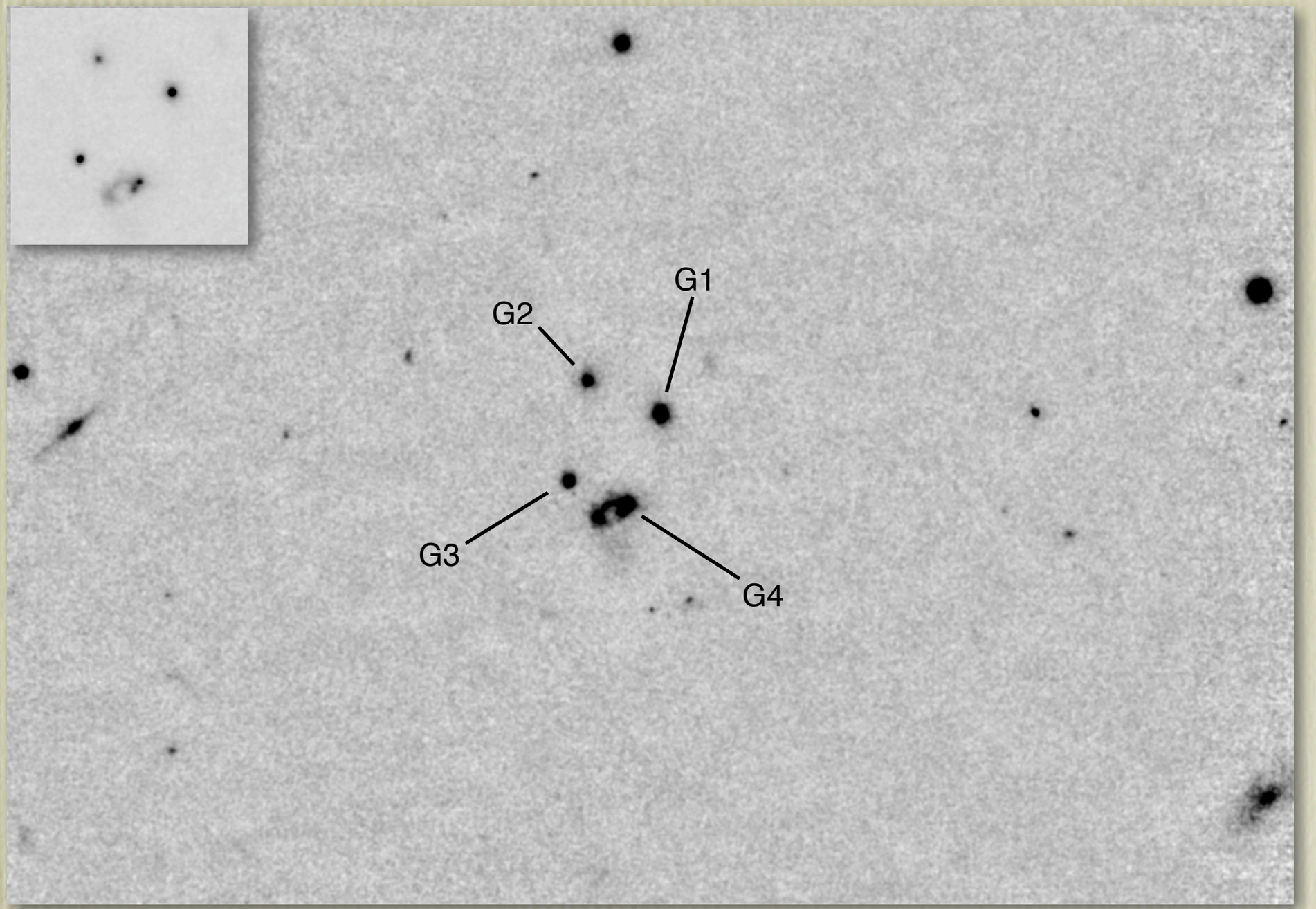
Sérsic n = 1.83

R_e = 0.105″

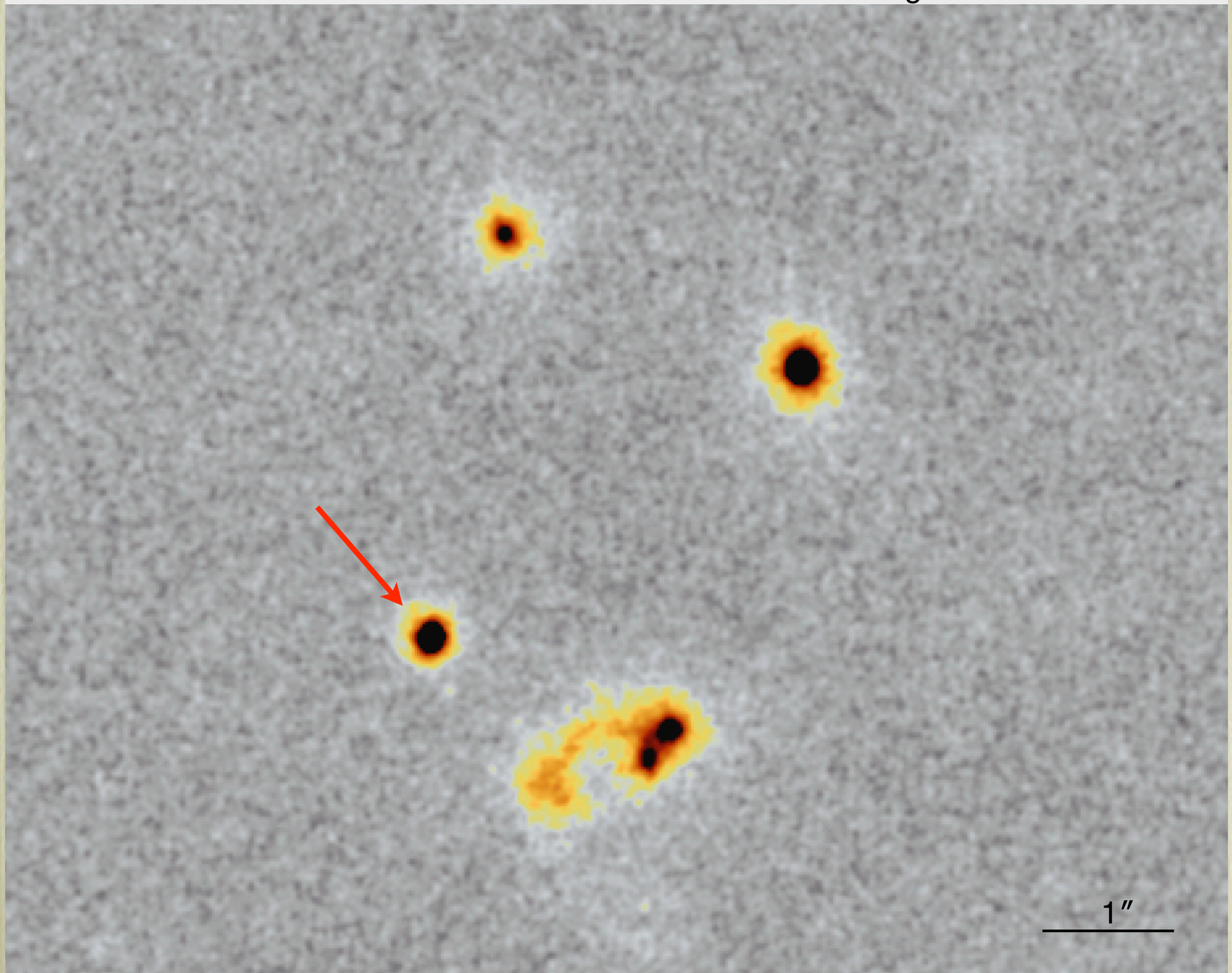
= 870 pc



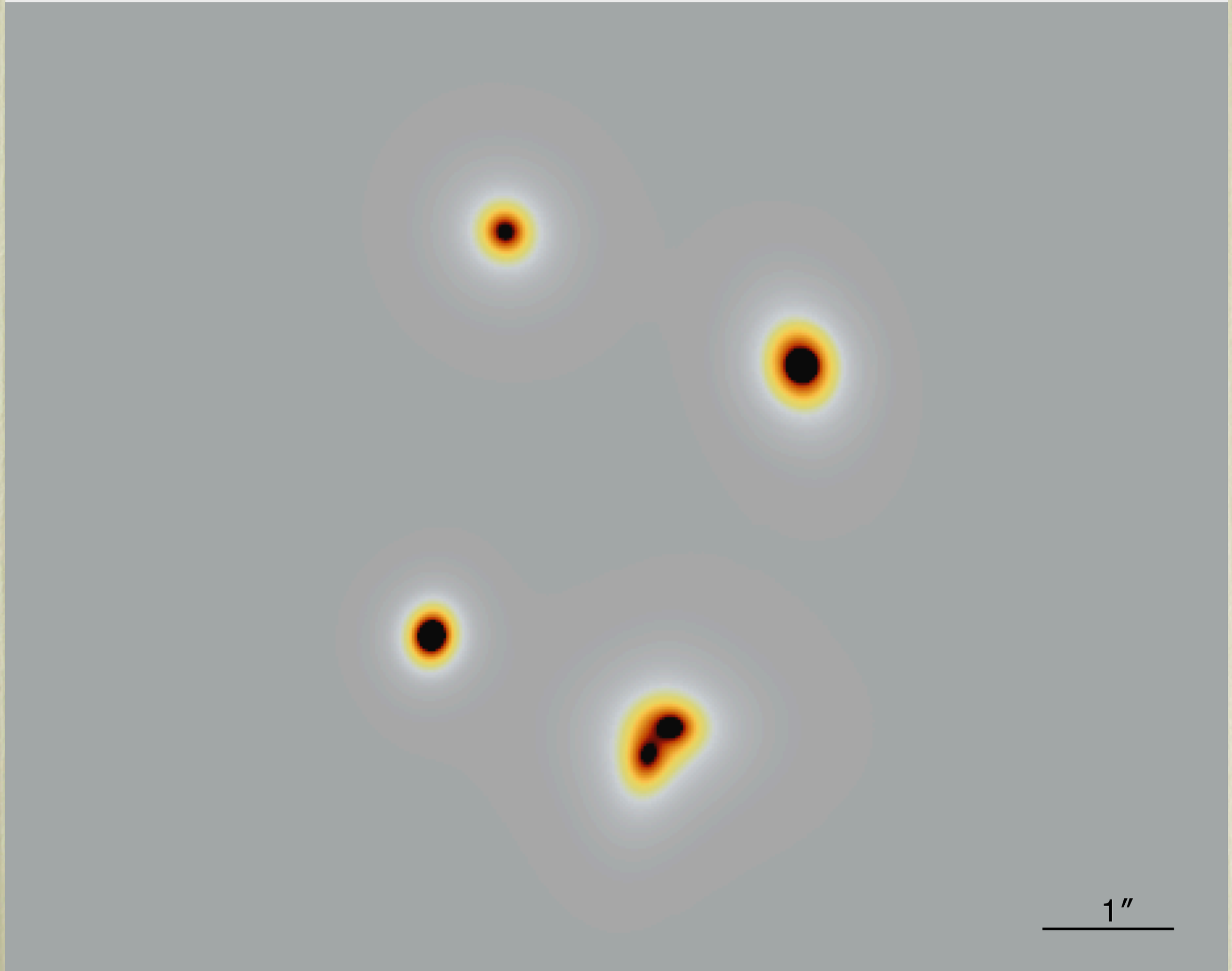

TXS 2332+154 ER1
z_{RG} = 2.48
1.43 Gyr, τ= 0.1 Gyr, A_V = 0.18
F_λ (10^{-18} watt m^{-2} μm^{-1})
$\lambda(\mu m)$
0
1
2
3
4
5
6
7
8
9


+15:46:00
55
50
45
+15:45:40
G1
G2
G3
G4
23:34:59
58
57

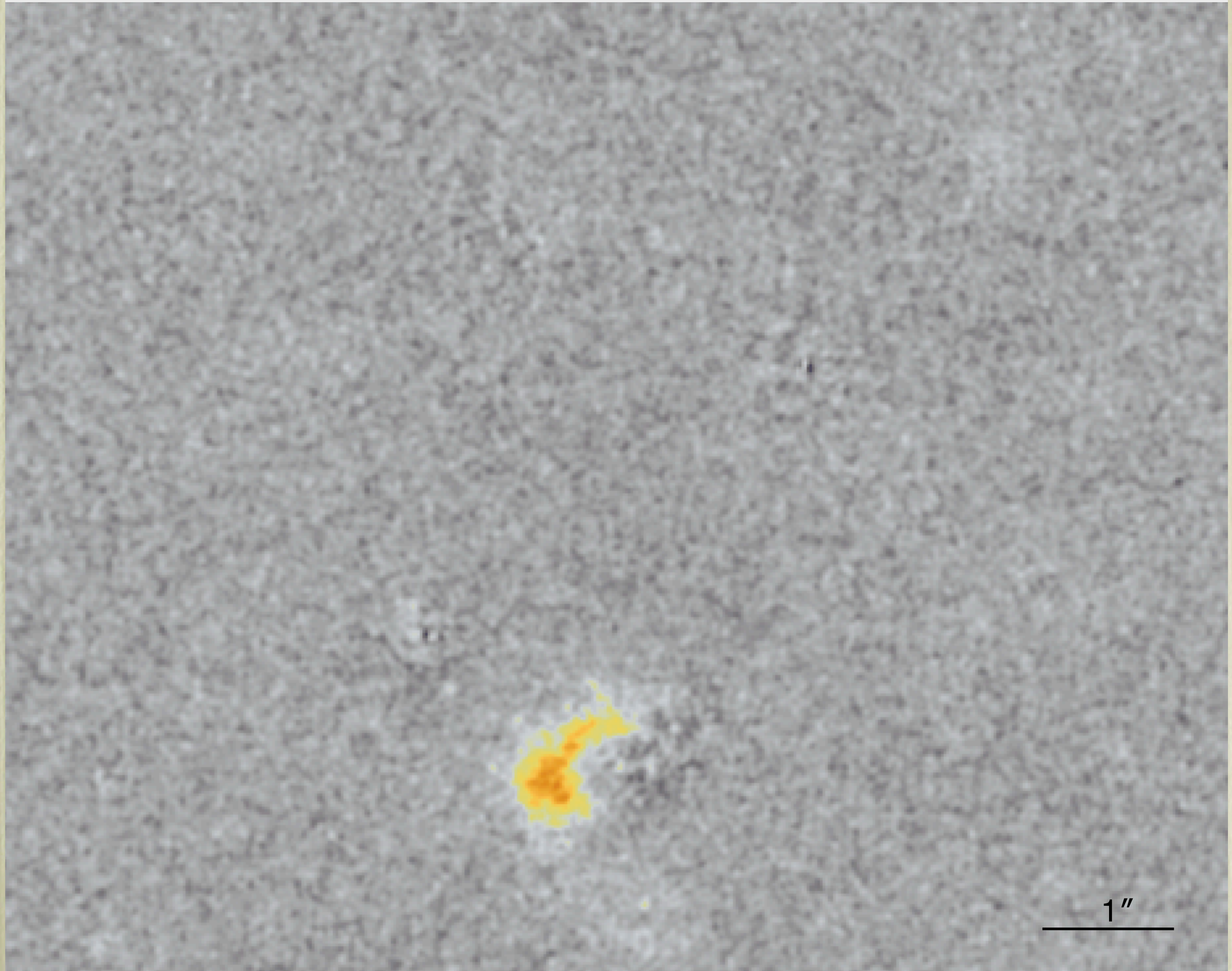
TXS 2332+154 Field—Keck LGSAO K′ Image



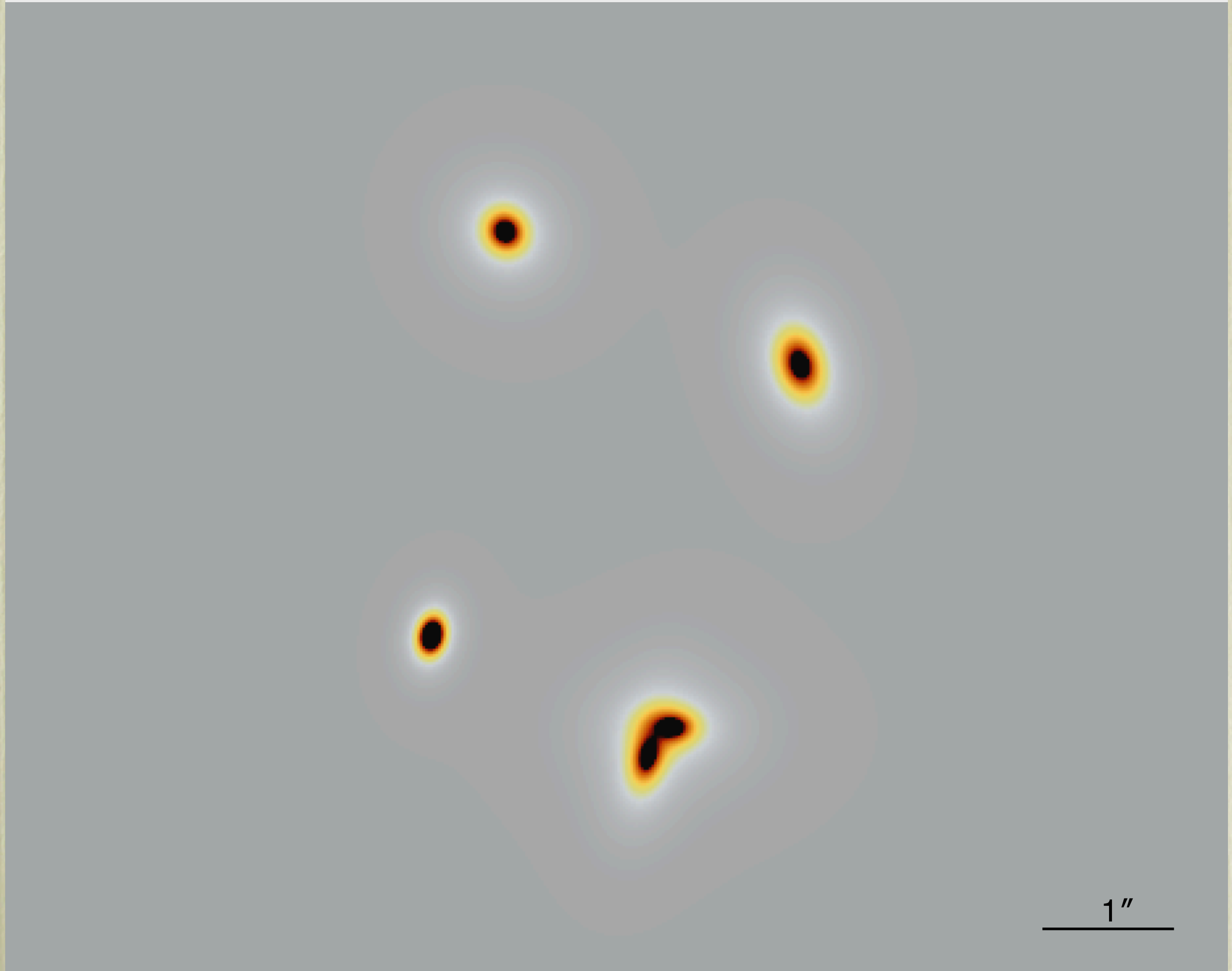
TXS 2332+154 Field—Galfit Sérsic Models



TXS 2332+154 Field—Residuals



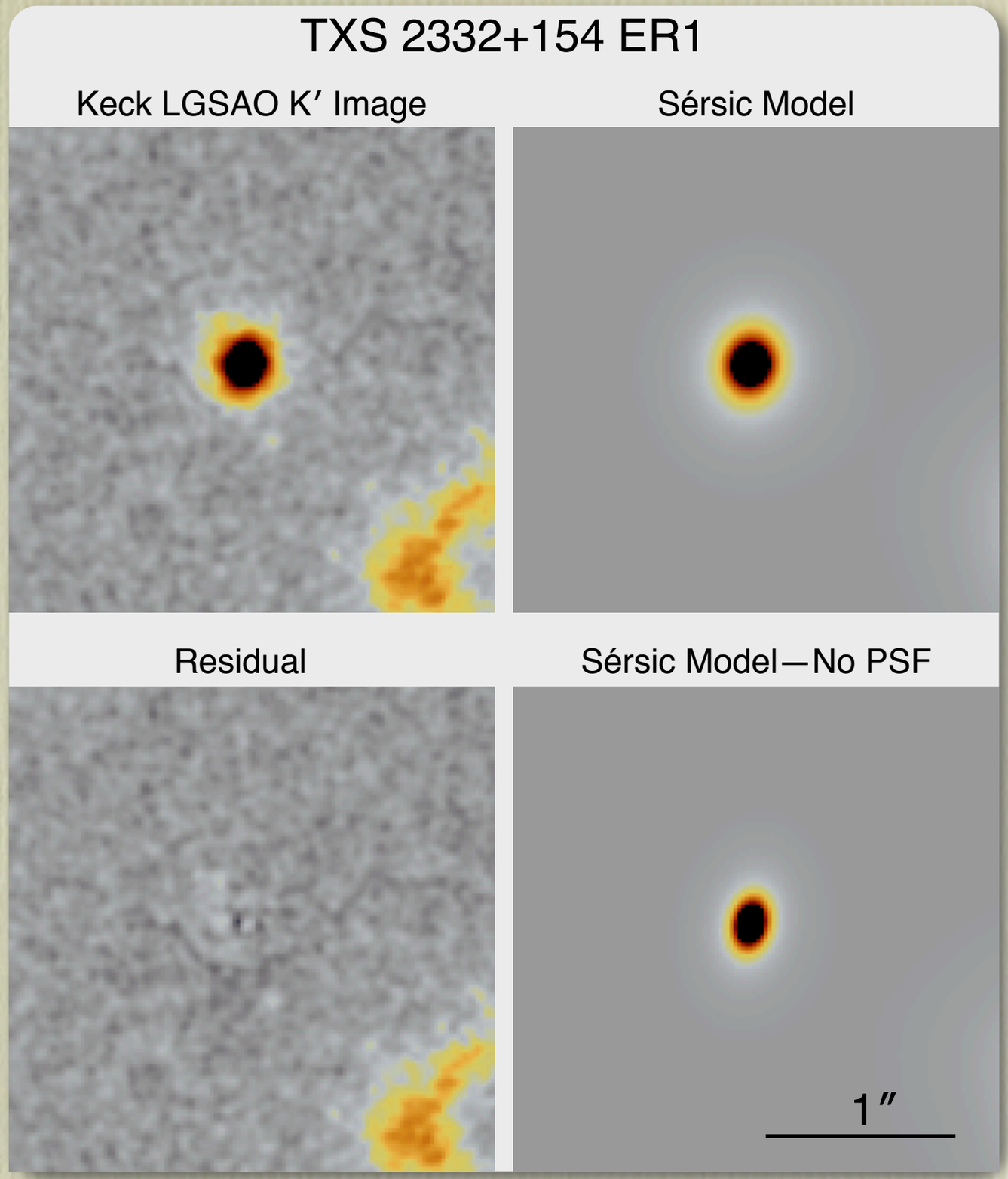
TXS 2332+154 Field—Galfit Sérsic Models—No PSF



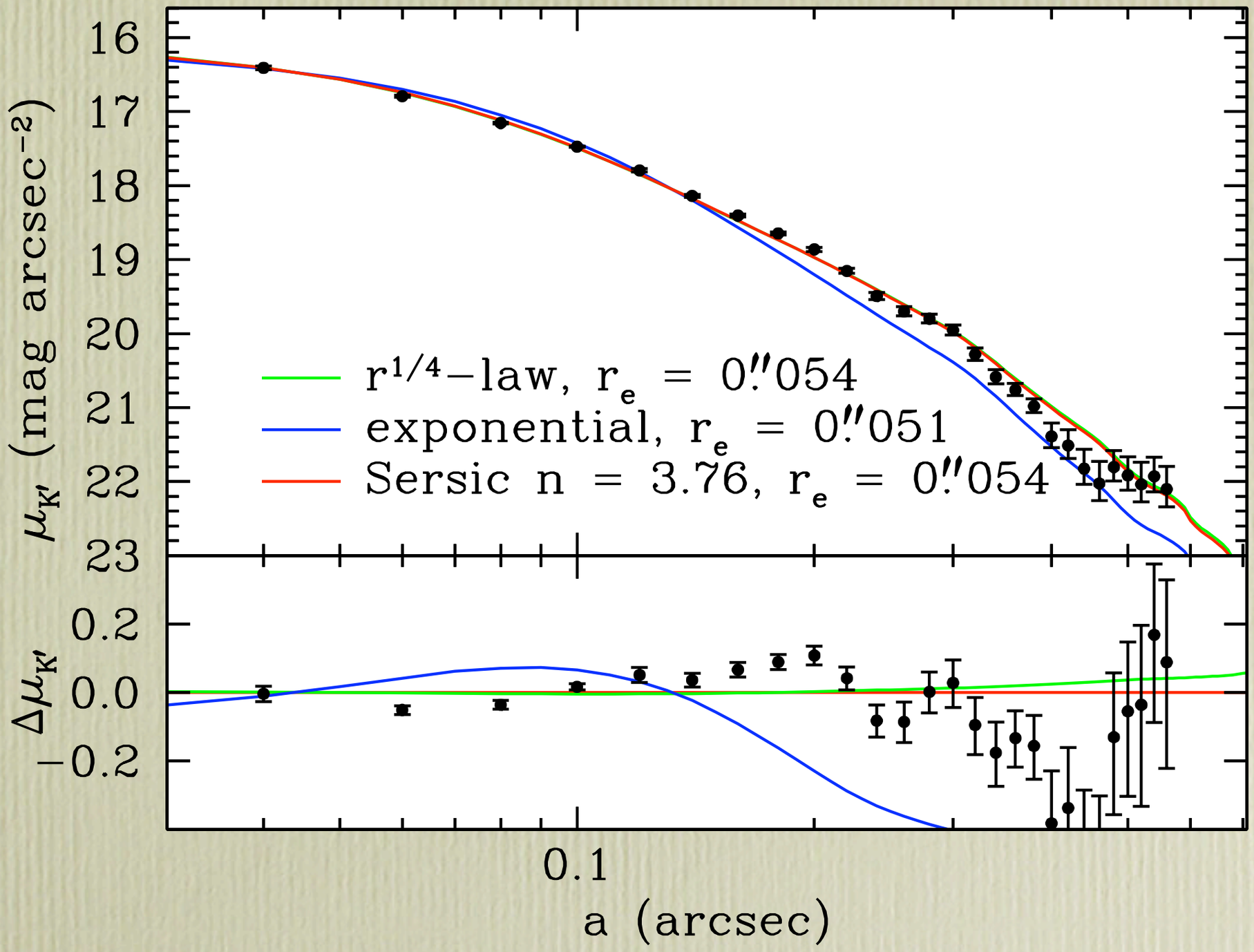
Sérsic n = 3.76

R_e = 0.054″

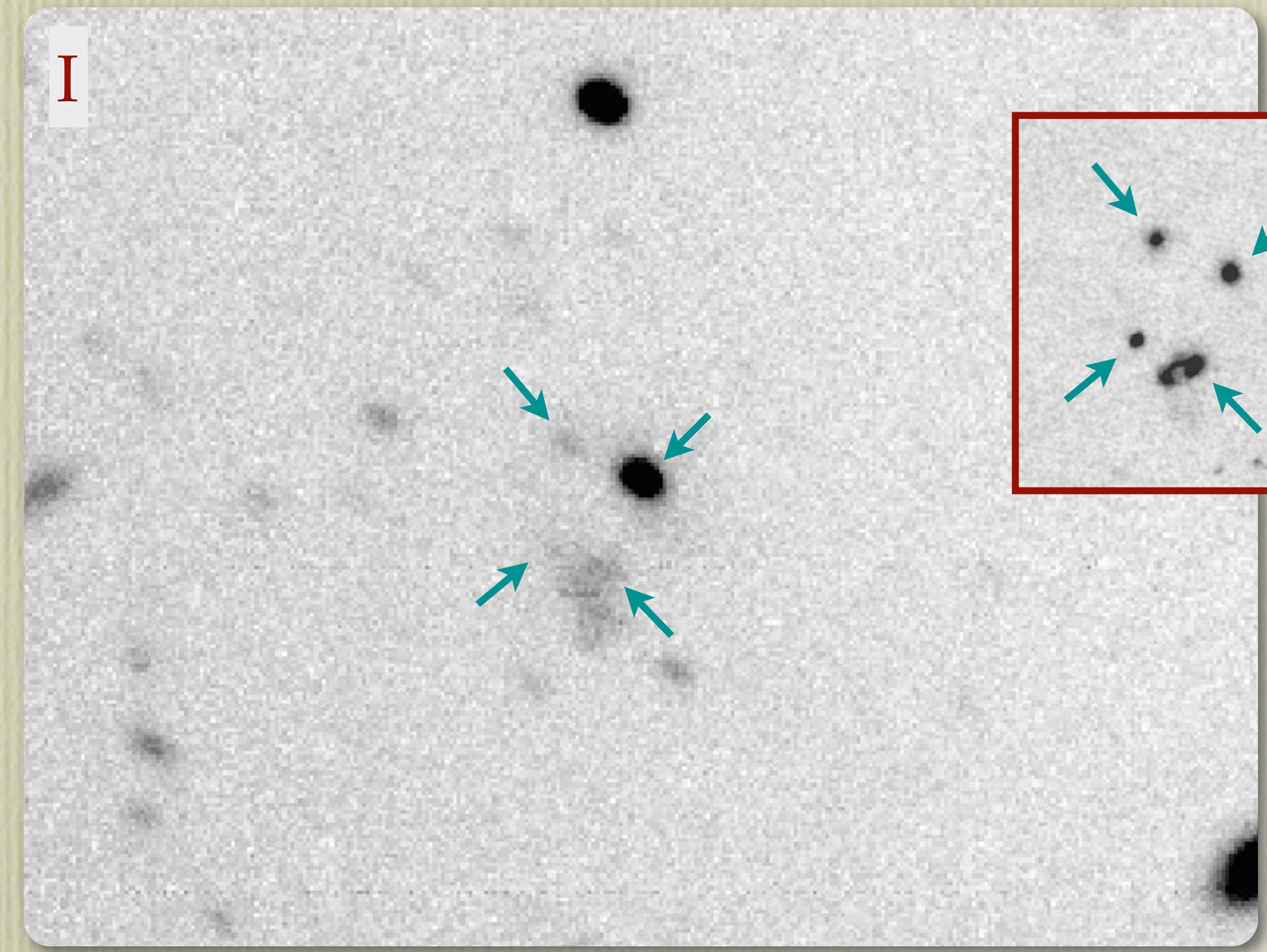
= 450 pc

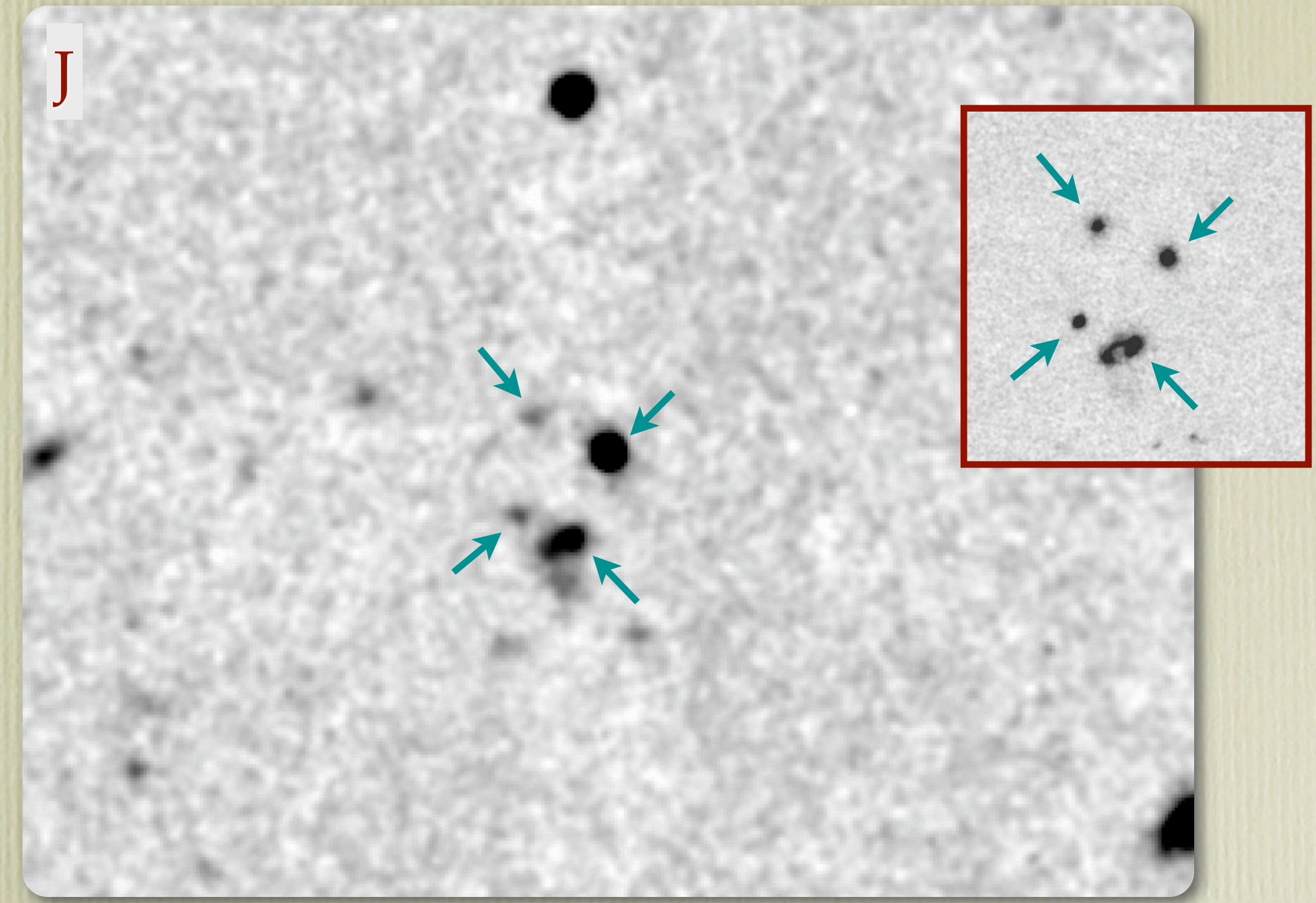


1″

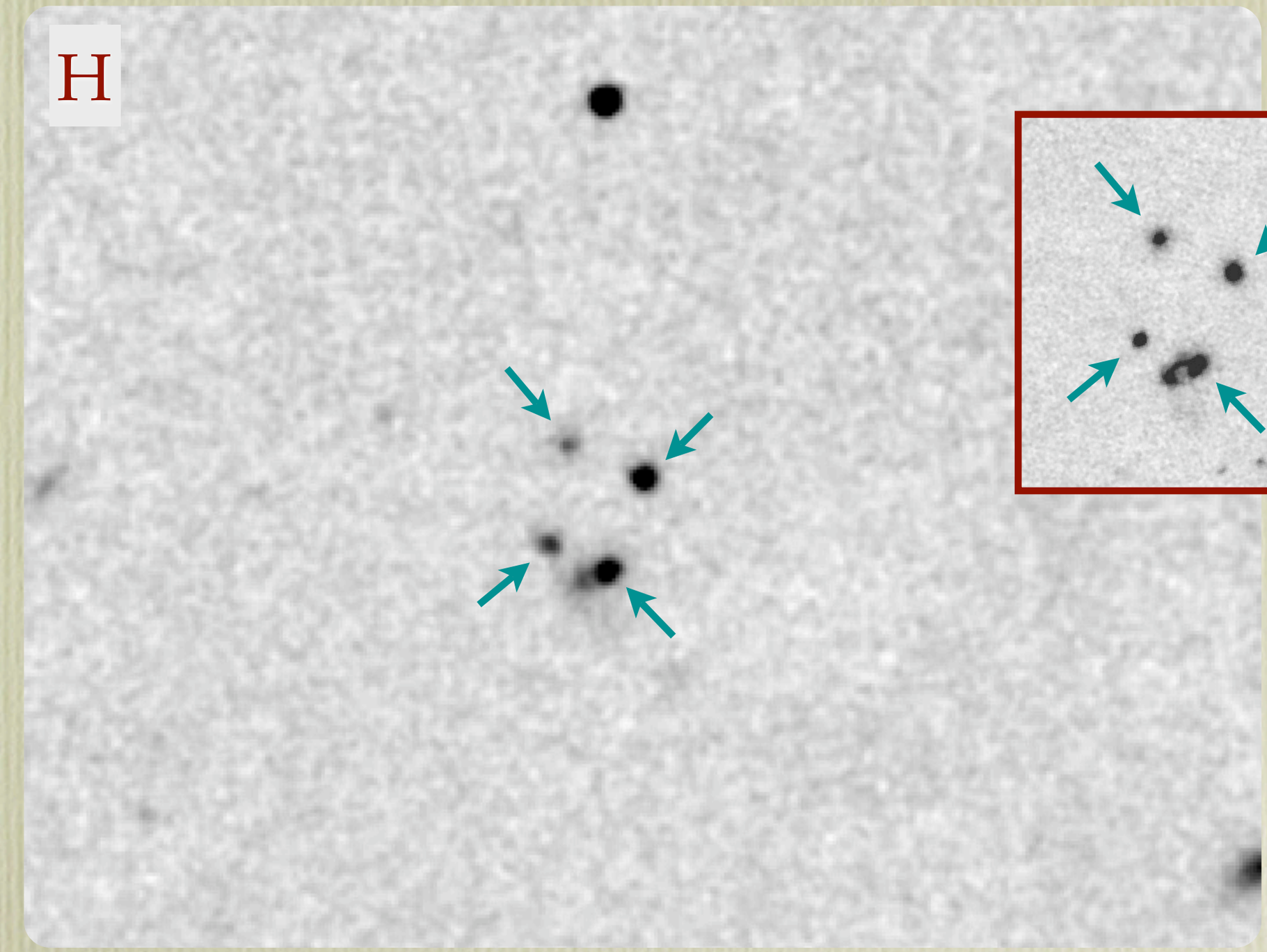

16
17
18
19
20
21
22
23
$\mu_{K'}$ (mag arcsec^{-2})
$r^{1/4}$–law, r_e = 0.″054
exponential, r_e = 0.″051
Sersic n = 3.76, r_e = 0.″054
0.2
0.0
−0.2
$\Delta\mu_{K'}$
0.1
a (arcsec)

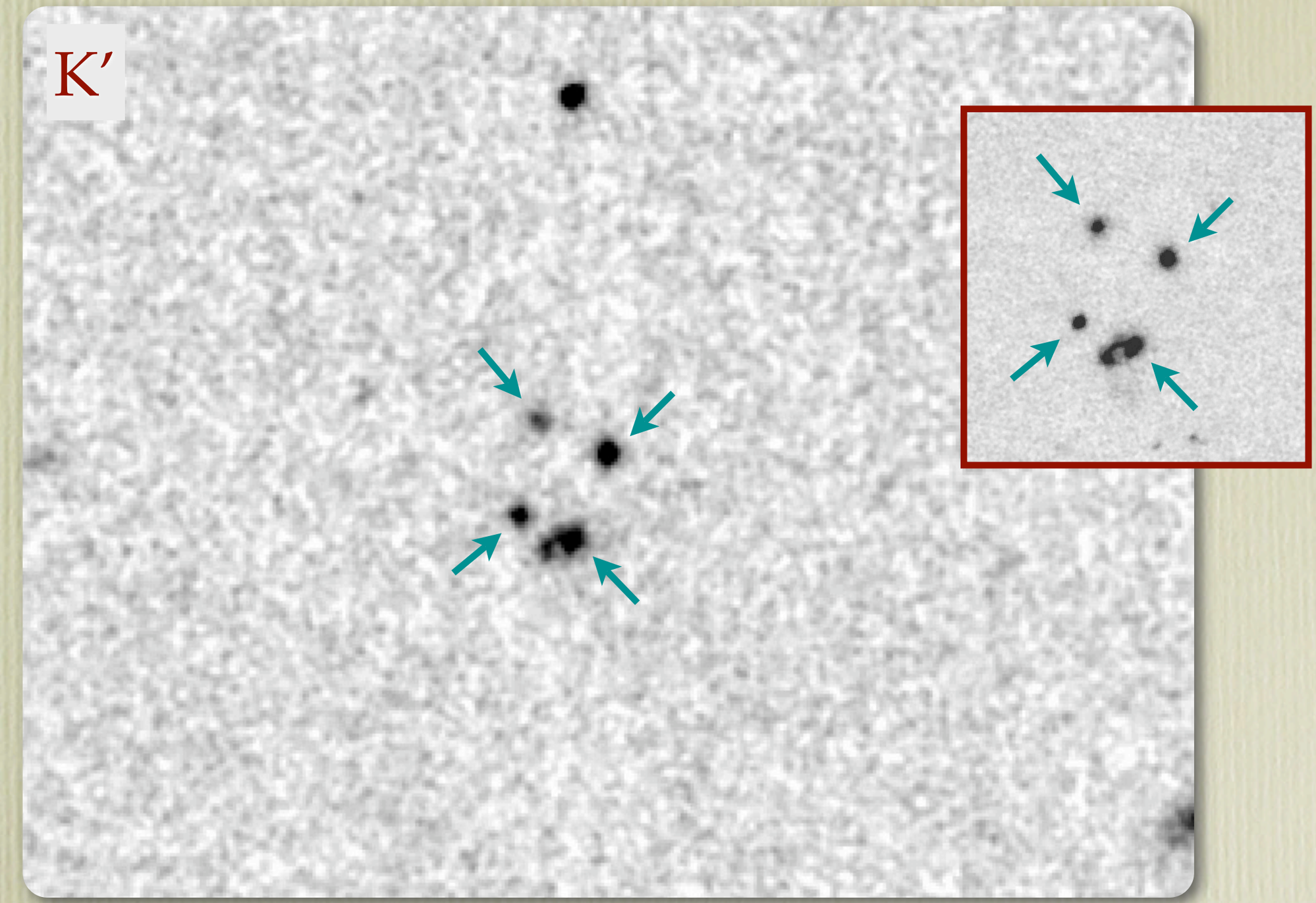
I



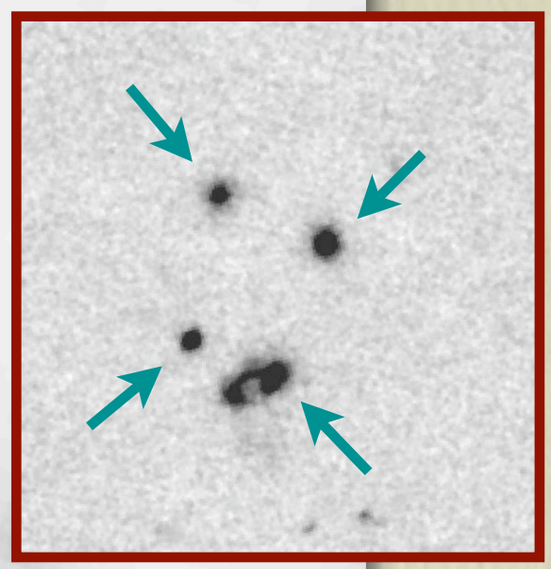

J

H

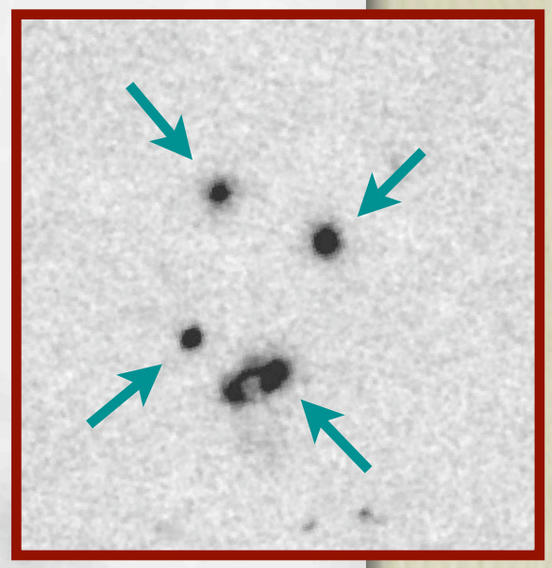



K′

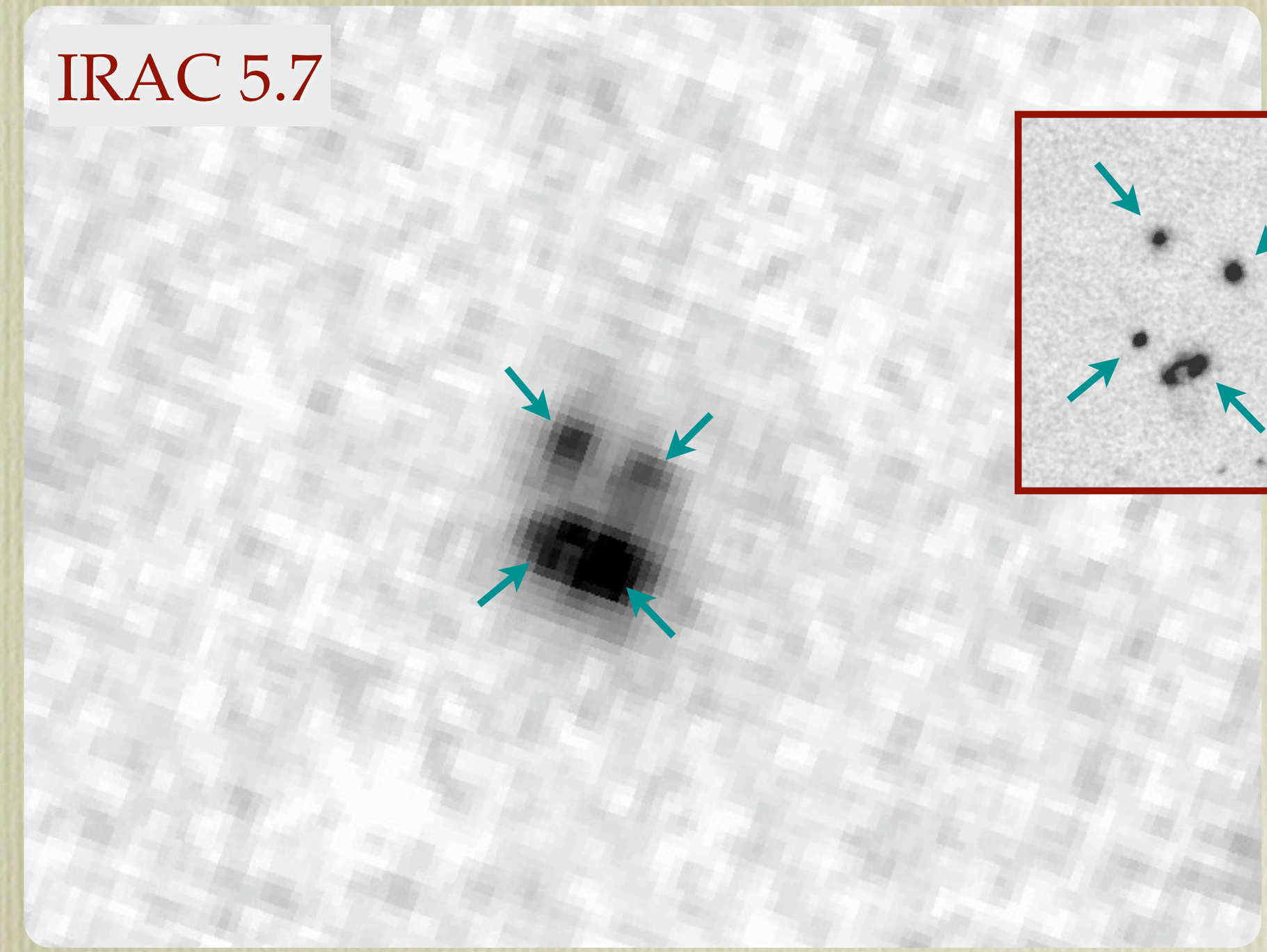
IRAC 3.6



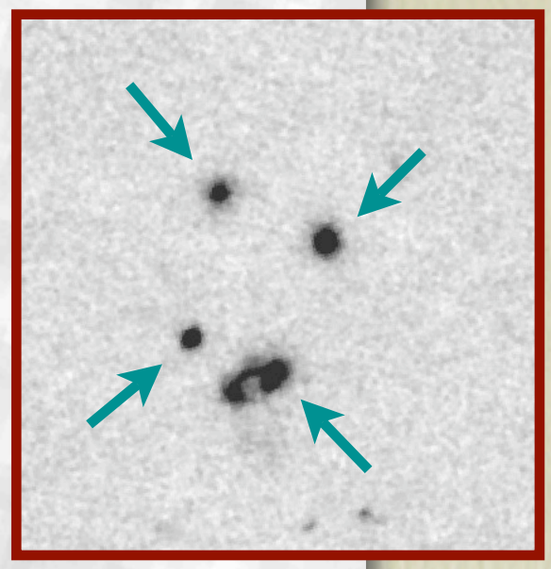
IRAC 4.5



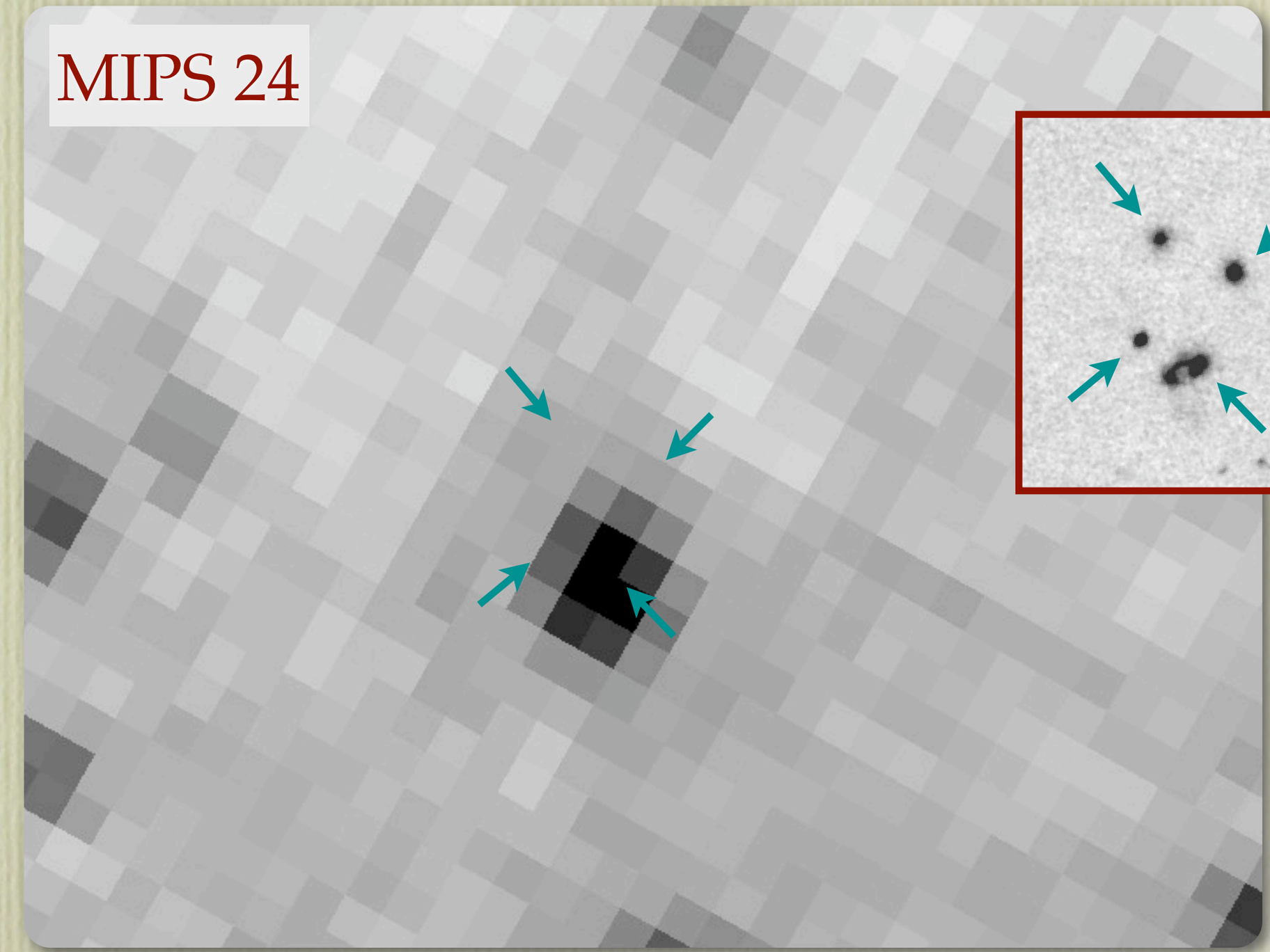
IRAC 5.7

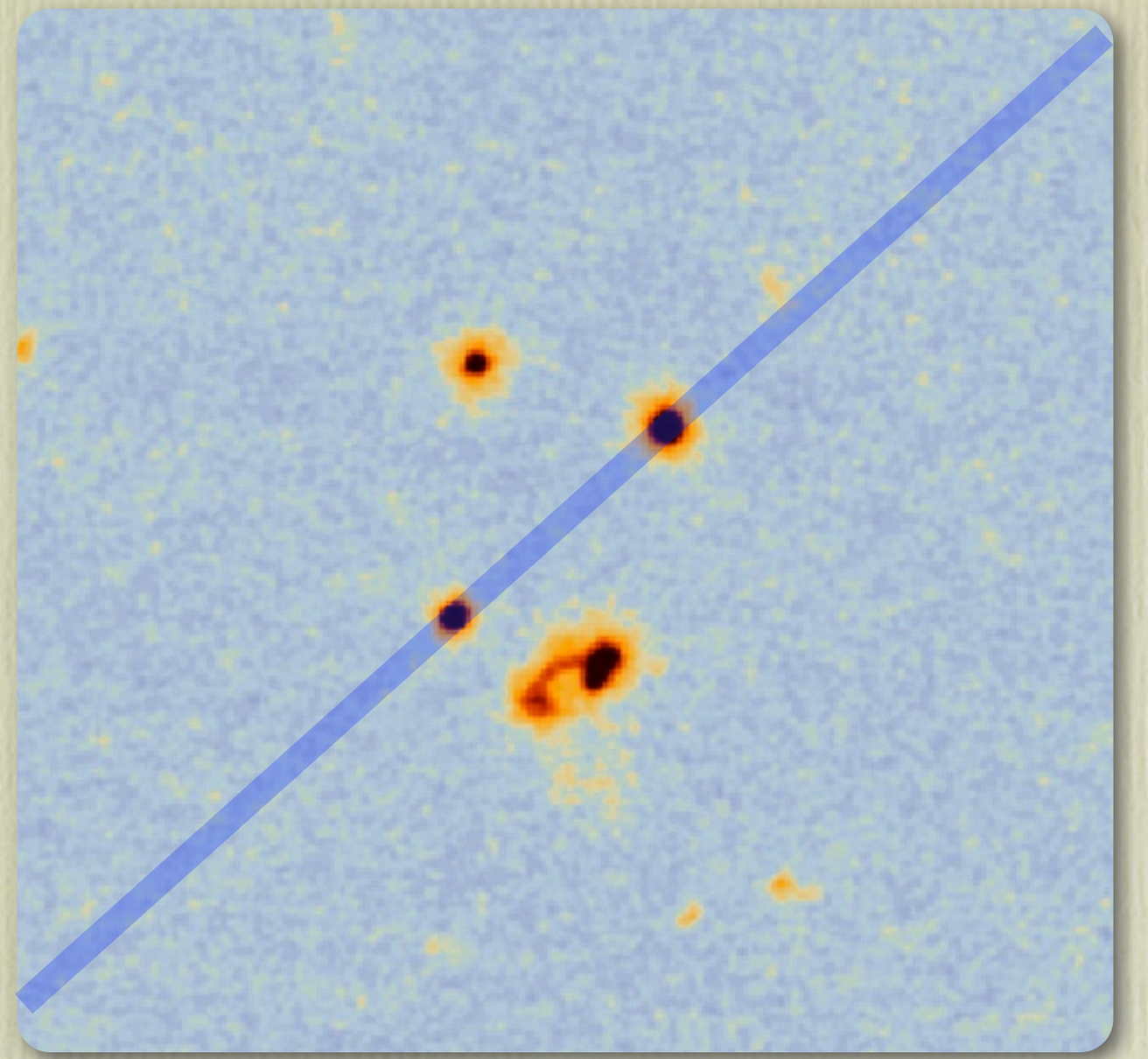


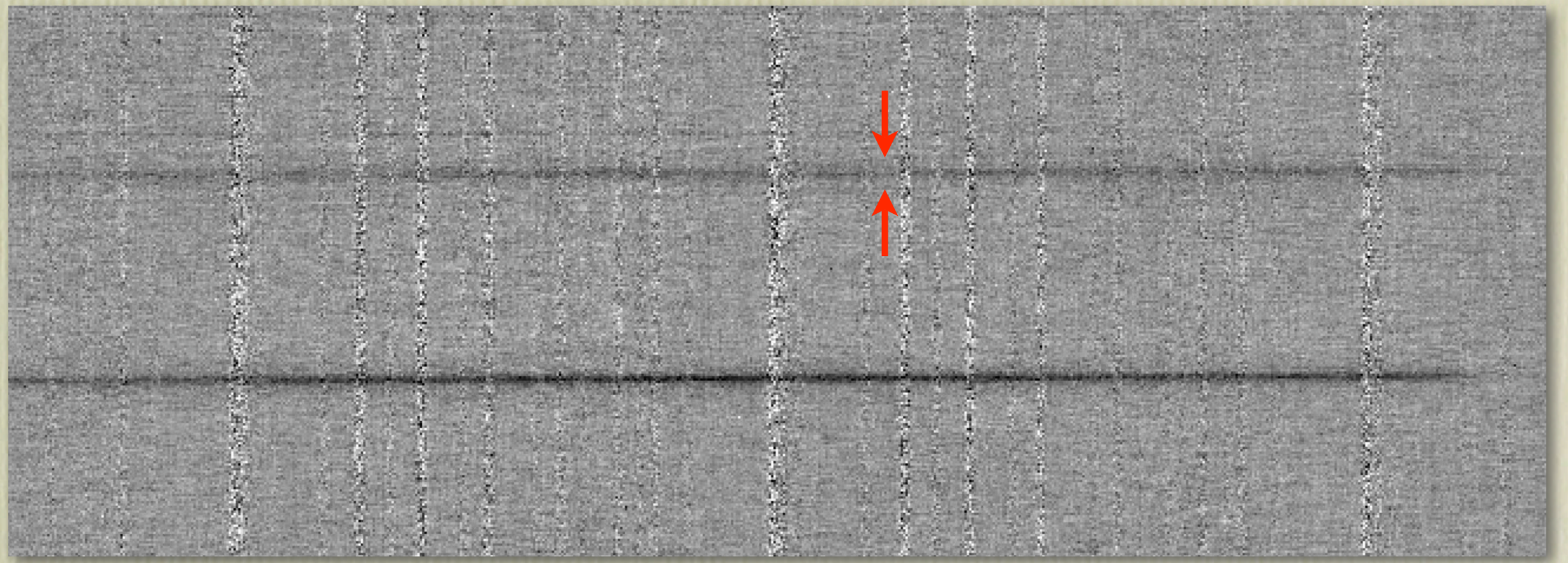
IRAC 7.9

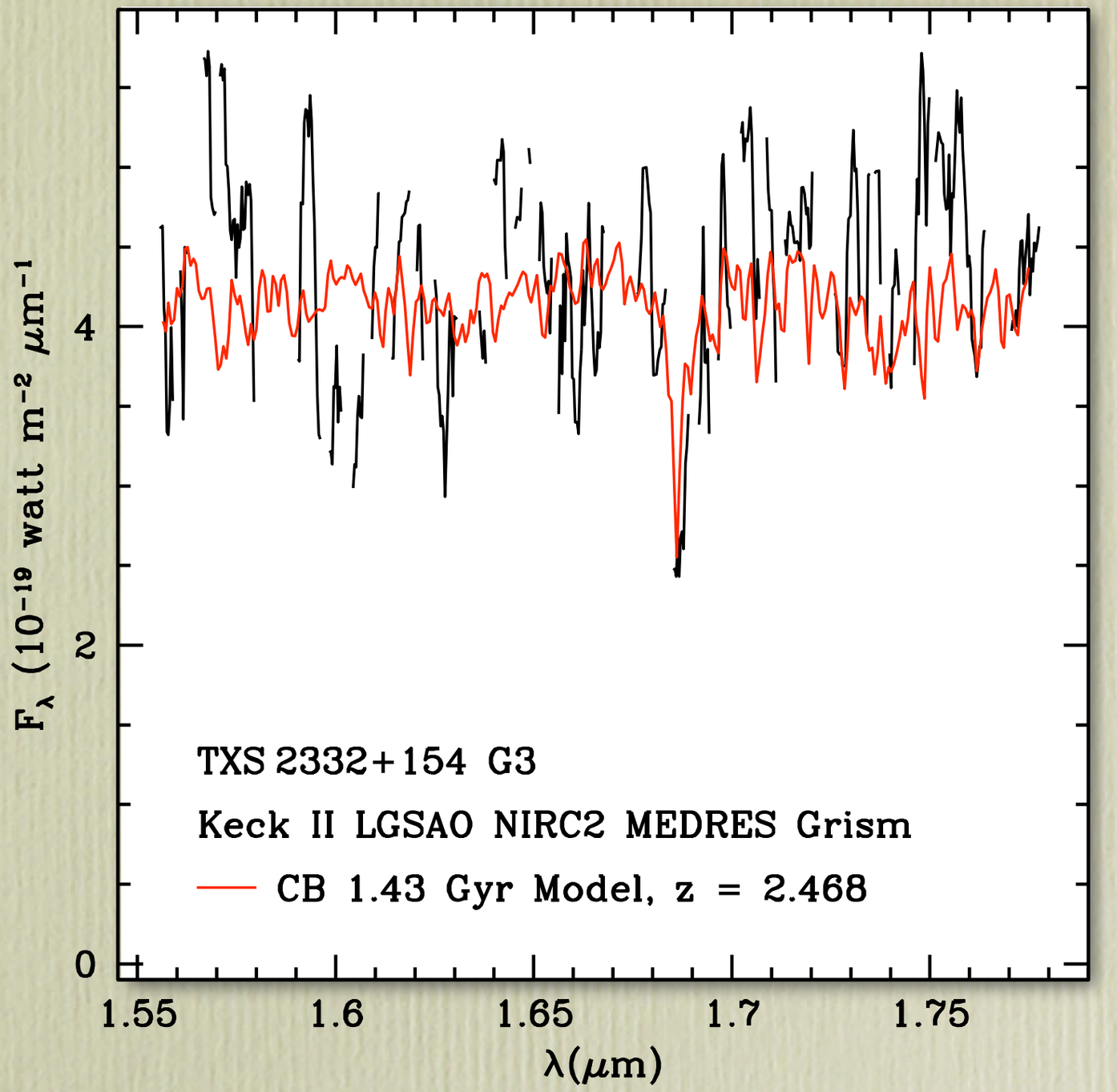


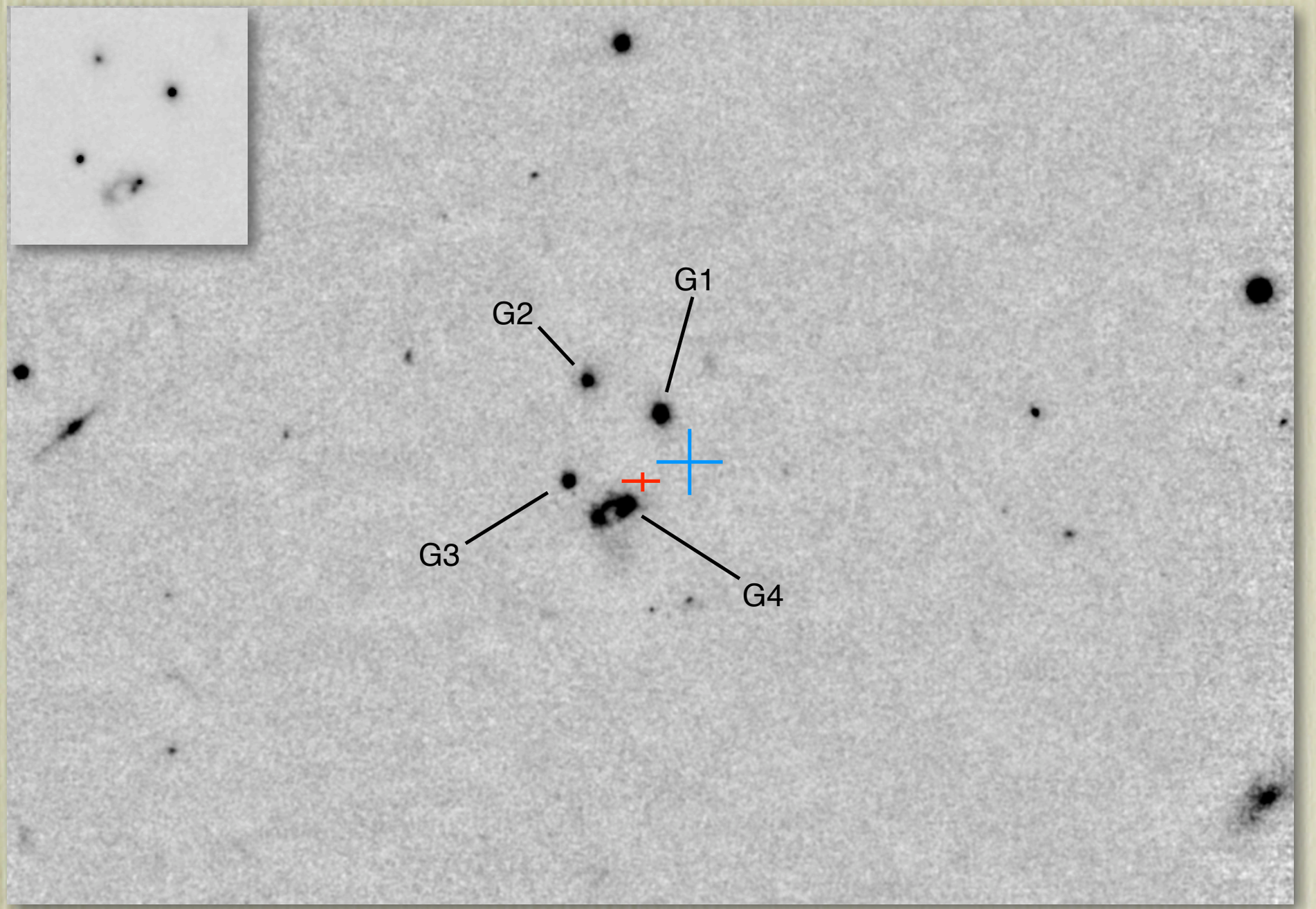
MIPS 24



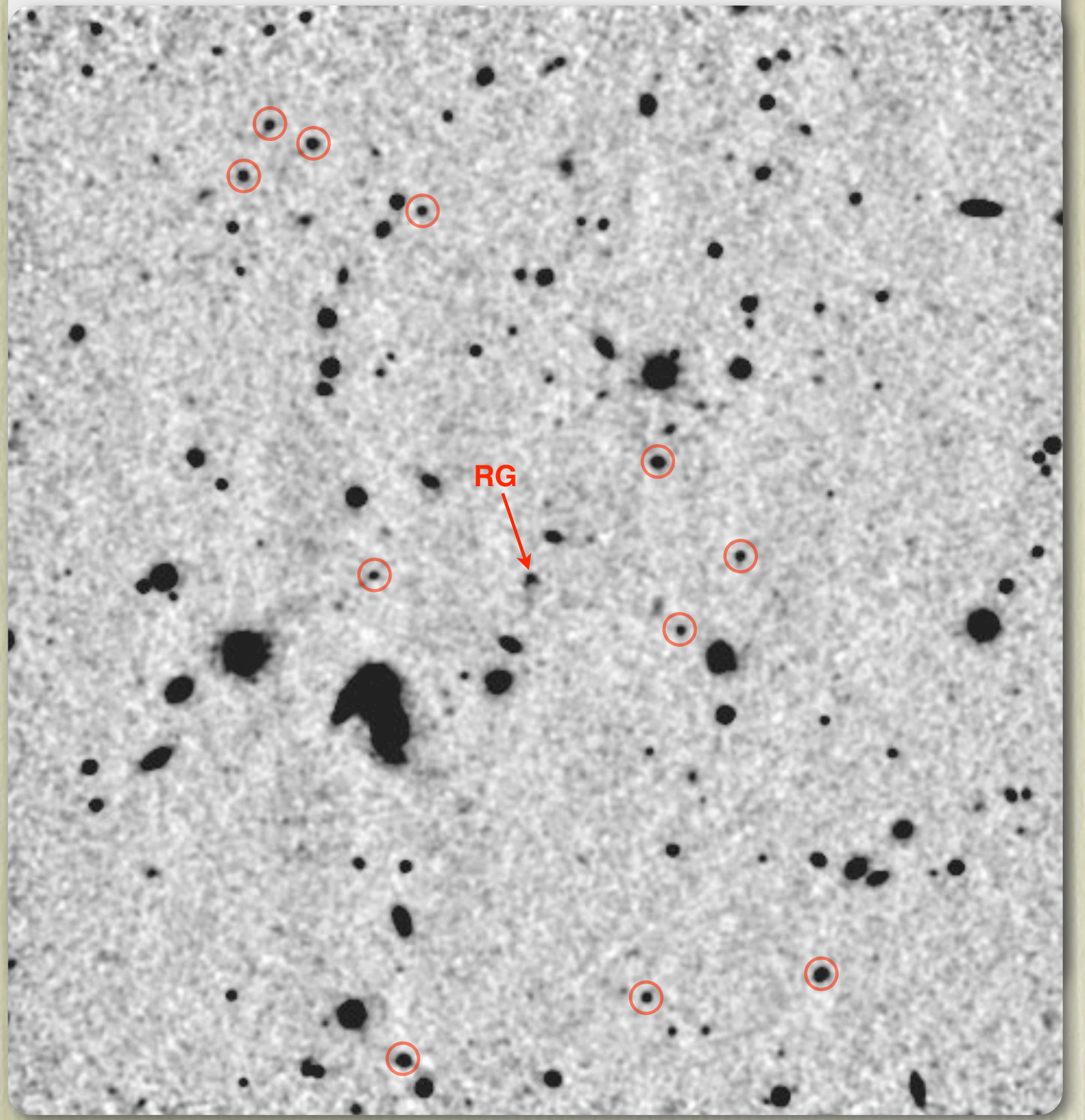


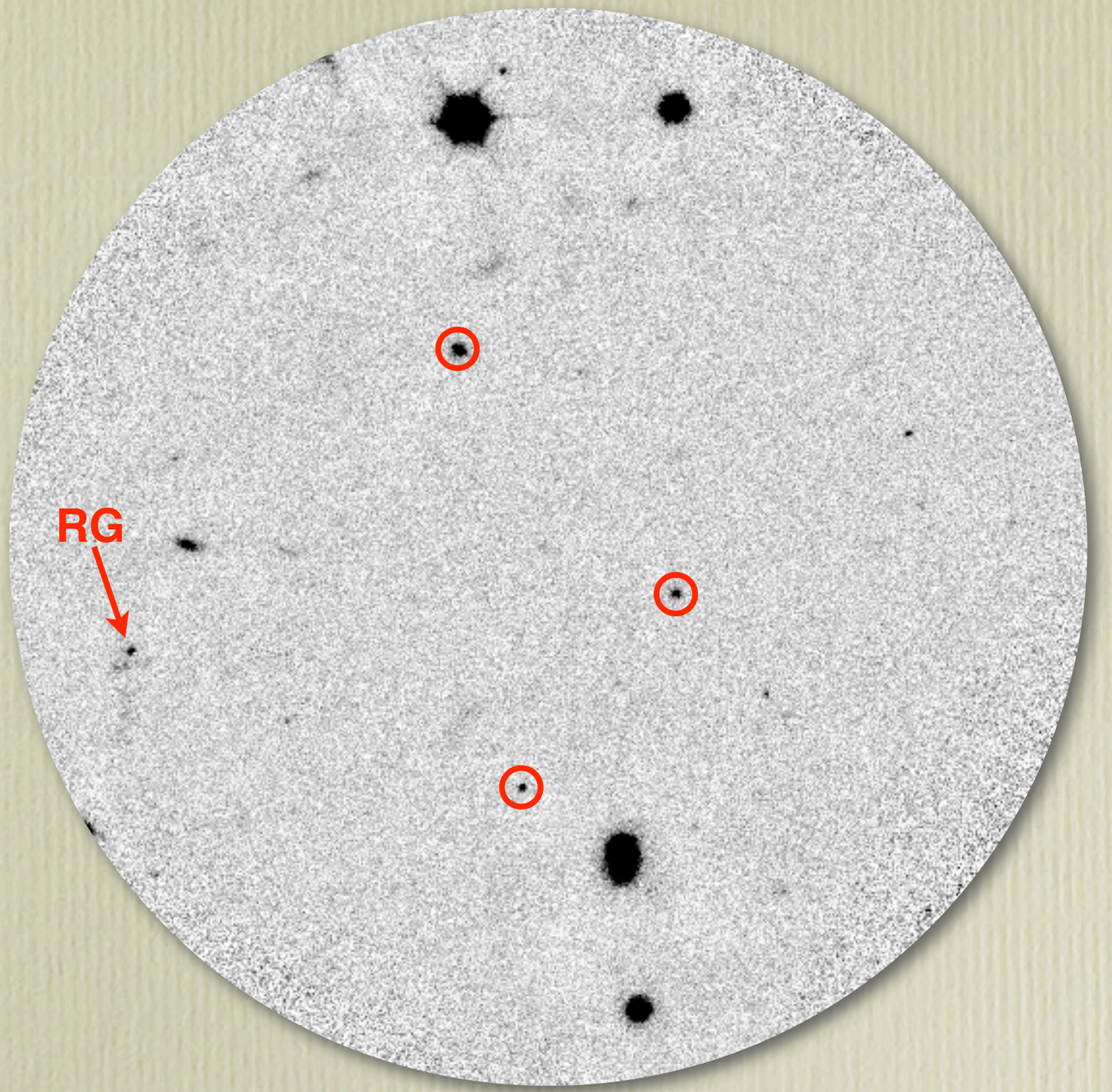



F_λ (10^{-19} watt m^{-2} μm^{-1})
4
2
0
TXS 2332+154 G3
Keck II LGSAO NIRC2 MEDRES Grism
CB 1.43 Gyr Model, z = 2.468
1.55
1.6
1.65
1.7
1.75
λ(μm)


+15:46:00
55
50
45
+15:45:40
G1
G2
G3
G4
23:34:59
58
57

4C 19.71 Field (z_{RG} = 3.594)




RG

Results

- LGSAO imaging can give good results for determining morphologies of high-redshift galaxies.
- Some quite massive ($\gtrsim 2 \times 10^{11}$ $M_\odot$) galaxies were able to form virtually all of their stars very early, likely by ~ 500 Myr after the Big Bang, and apparently essentially directly from gas flows.
- These galaxies are compact, in extreme cases packing their ~ 2×10^{11} $M_\odot$ or so of stars into systems with R_e = 500 pc or less.
- The slightly less compact galaxies with old stellar populations generally have disk-like morphologies.

Questions and Future Prospects

- Are we over-estimating the masses? There are some reasons for believing that the IMFs for early generations of stars may be top-heavy. However, it is not clear that this will be a large effect for $> 10^{11}\,M_\odot$ of stars.
- By what physical mechanisms did these extremely dense configurations form?
- How have these early massive galaxies been incorporated into the galaxies we see in the local universe?
- Is there any evolutionary relationship between the disk-like galaxies with $R_e \sim 2$ kpc and the very compact galaxies with $R_e \sim 500$ pc?