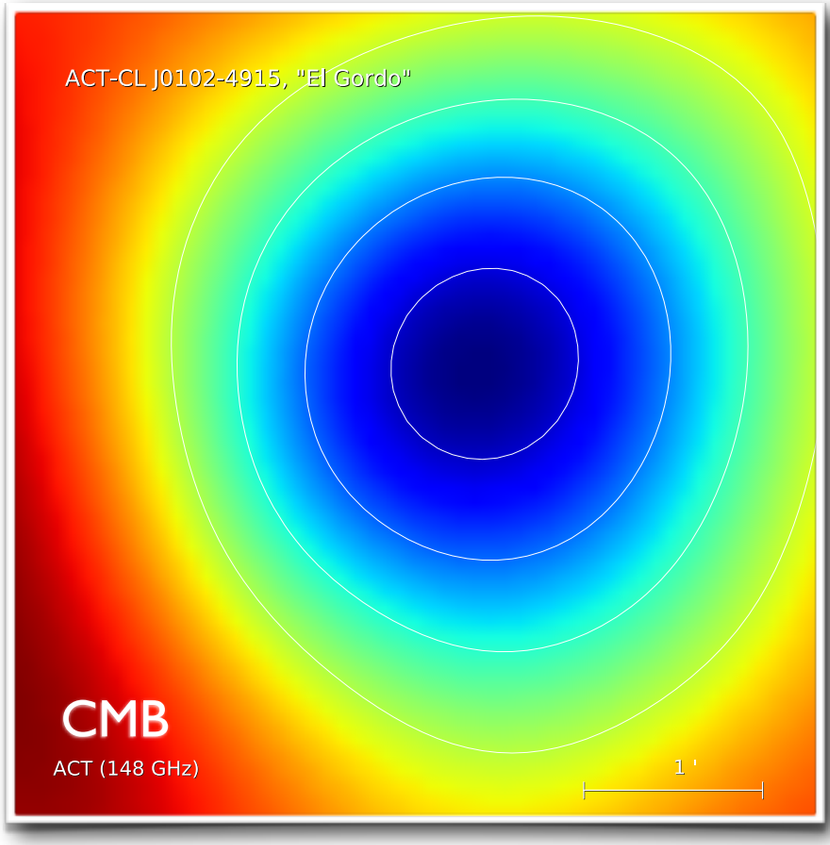
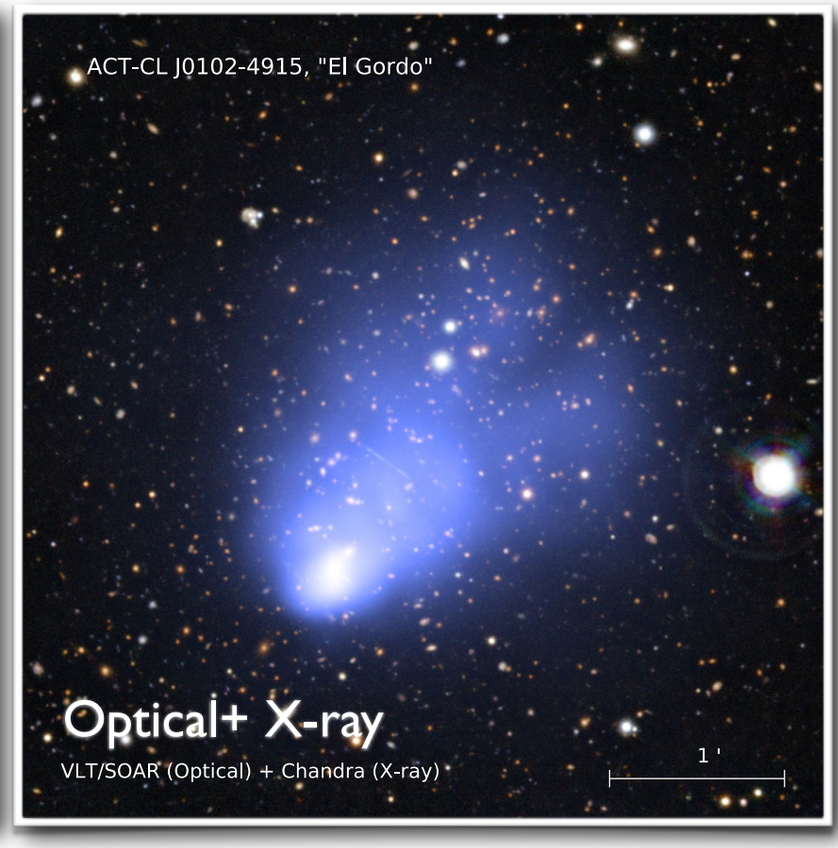
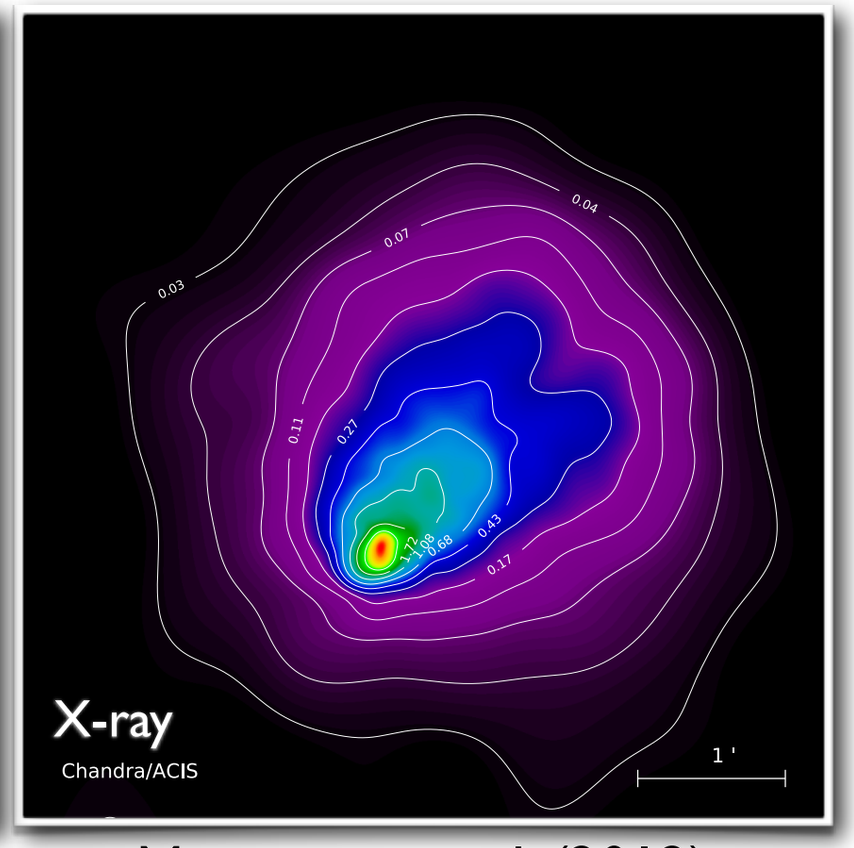
"El Gordo," Multi-wavelength Observations







Menanteau et al. (2012)

- Detected in 2008 ACT maps of Southern Strip (Menanteau et al. 2010, Marriage et al. 2011)
  - Strongest SZ decrement over 755 deg^2 (South + Equator)
- Optical follow-up: **89 redshifts!**
  - Imaged (*griz*) at SOAR/SOI (9-12 Dec 2009)
  - VLT/FORS2 MOS (10-hrs) + Imaging (2 hrs) in Jan 2011

- *Chandra* X-ray Observations
  - ACIS-I, 60 ks, observed 27 Jan 2011
- Spitzer IRAC warm-phase follow-up
  - Imaged at 3.6 μm and 4.5 μm

The well-known Bullet Cluster

Clowe et al.(2006)

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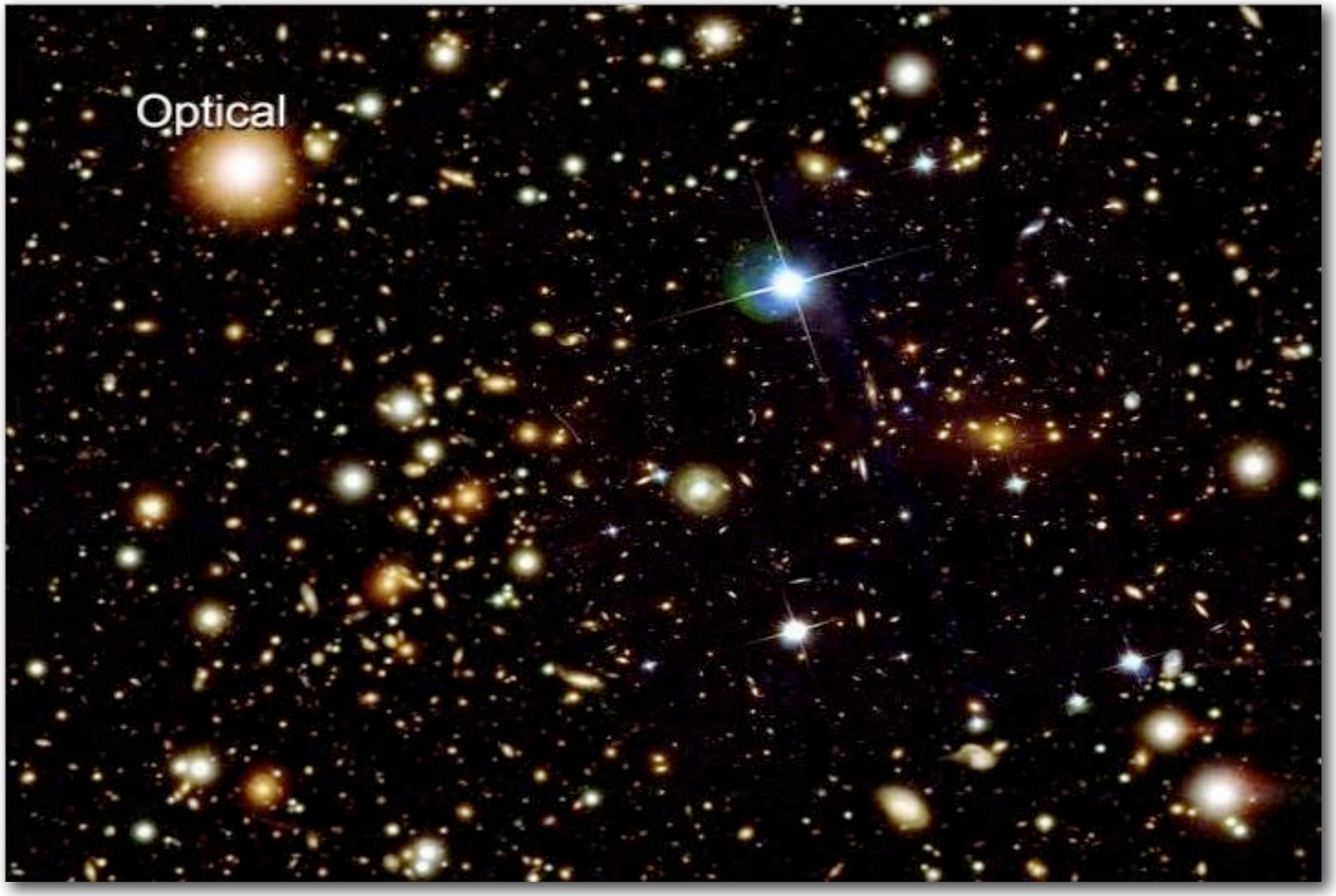

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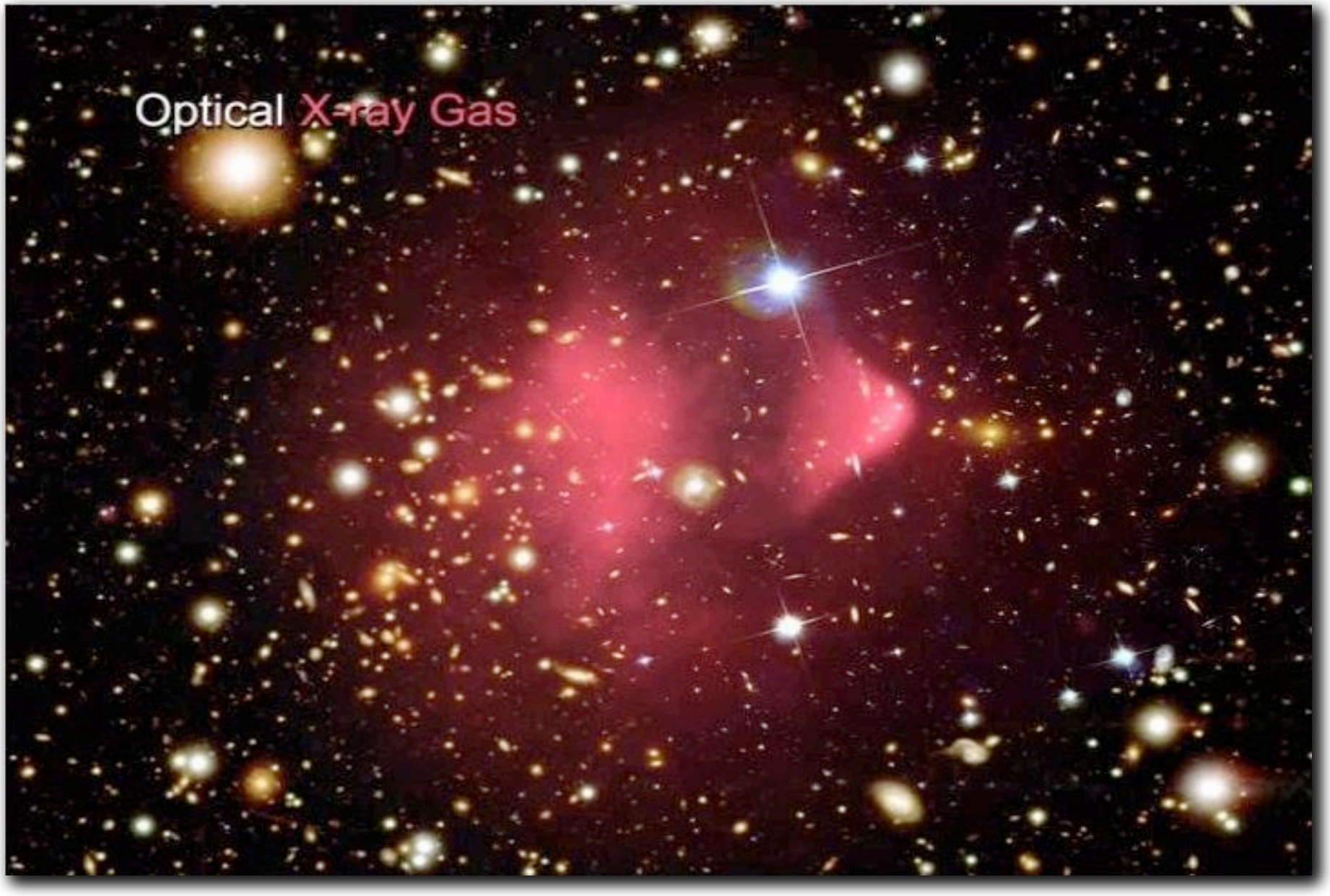

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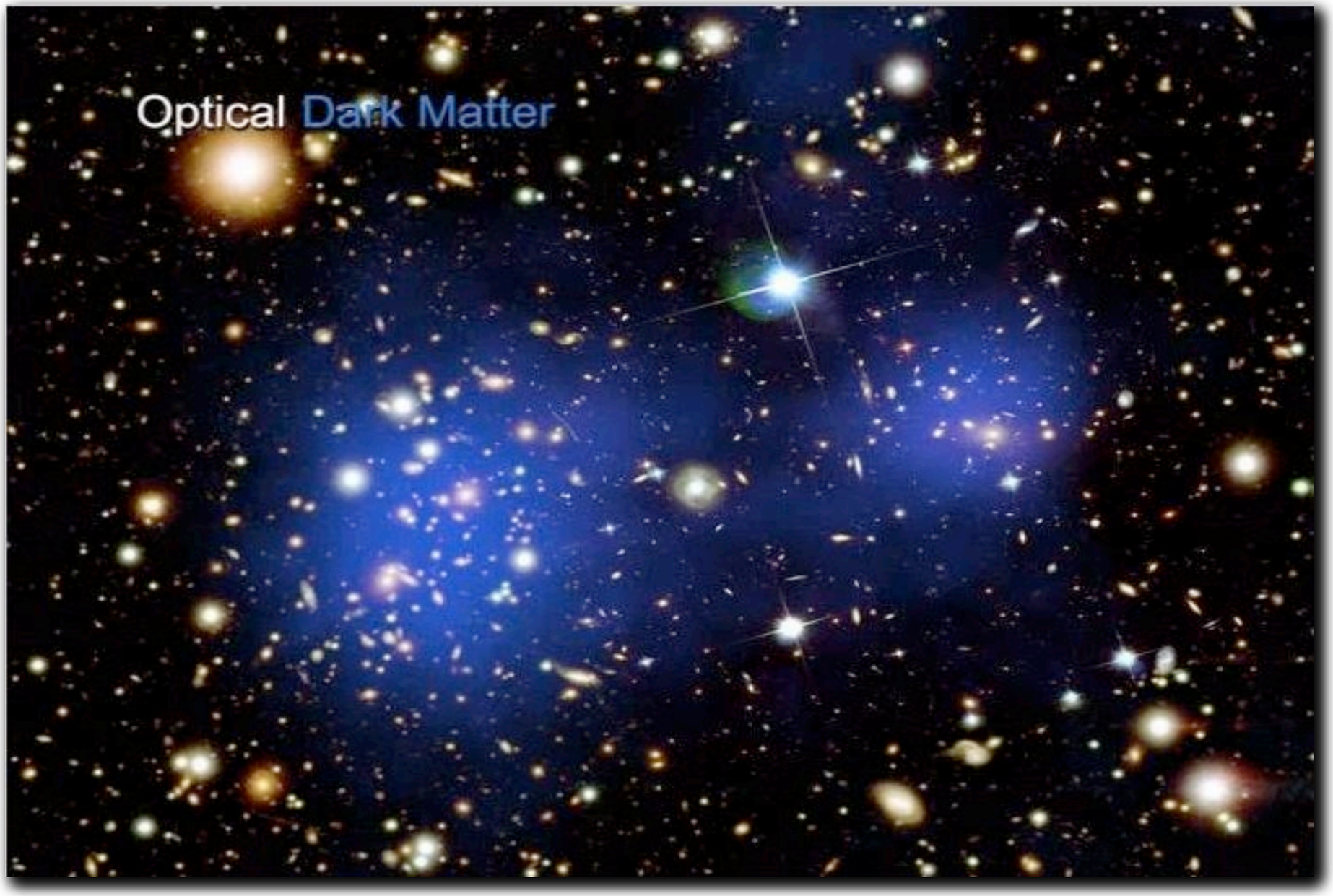

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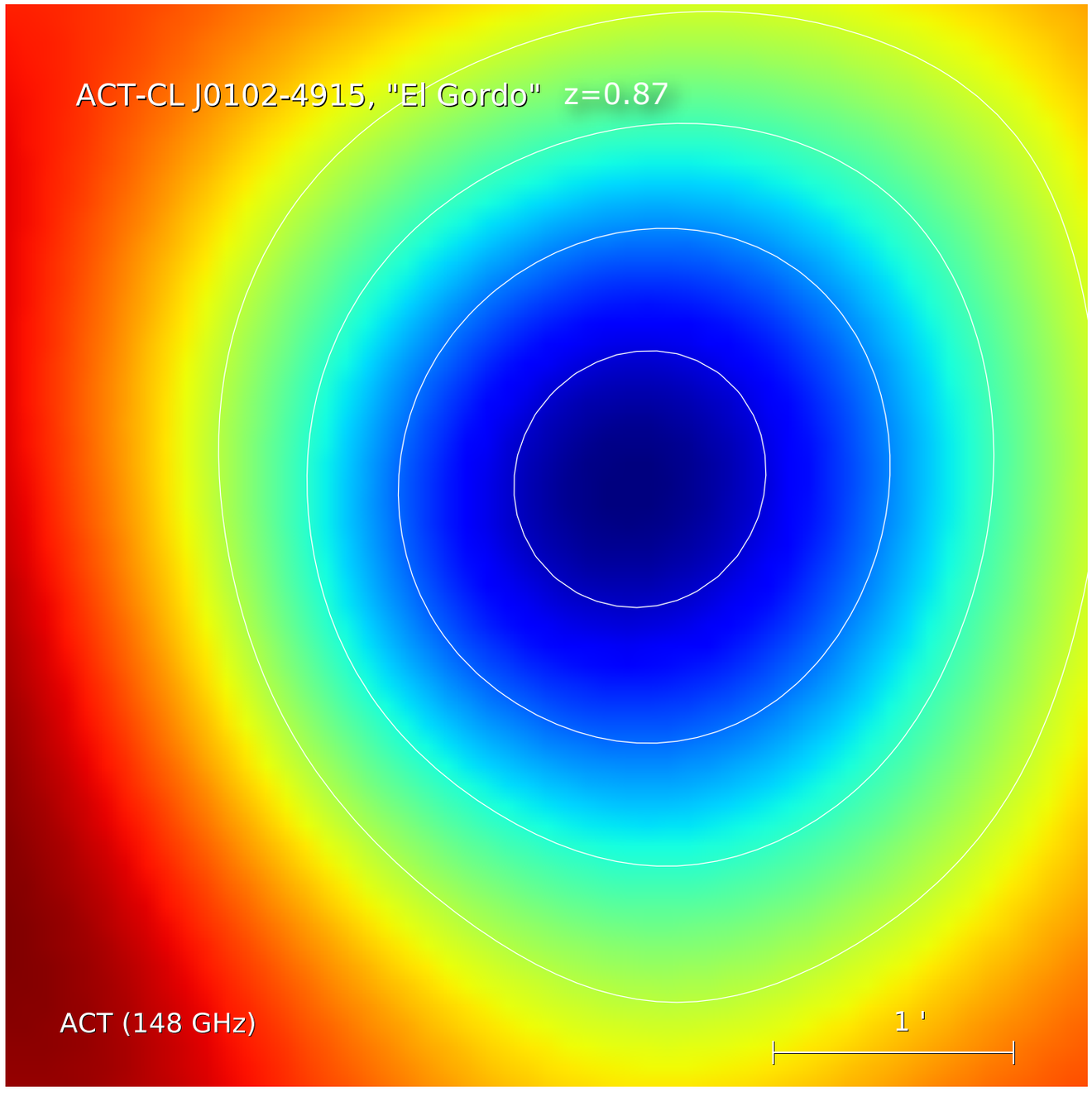
A Violent Merger in “El Gordo”



Menanteau et al. (2012, ApJ, 748,7)

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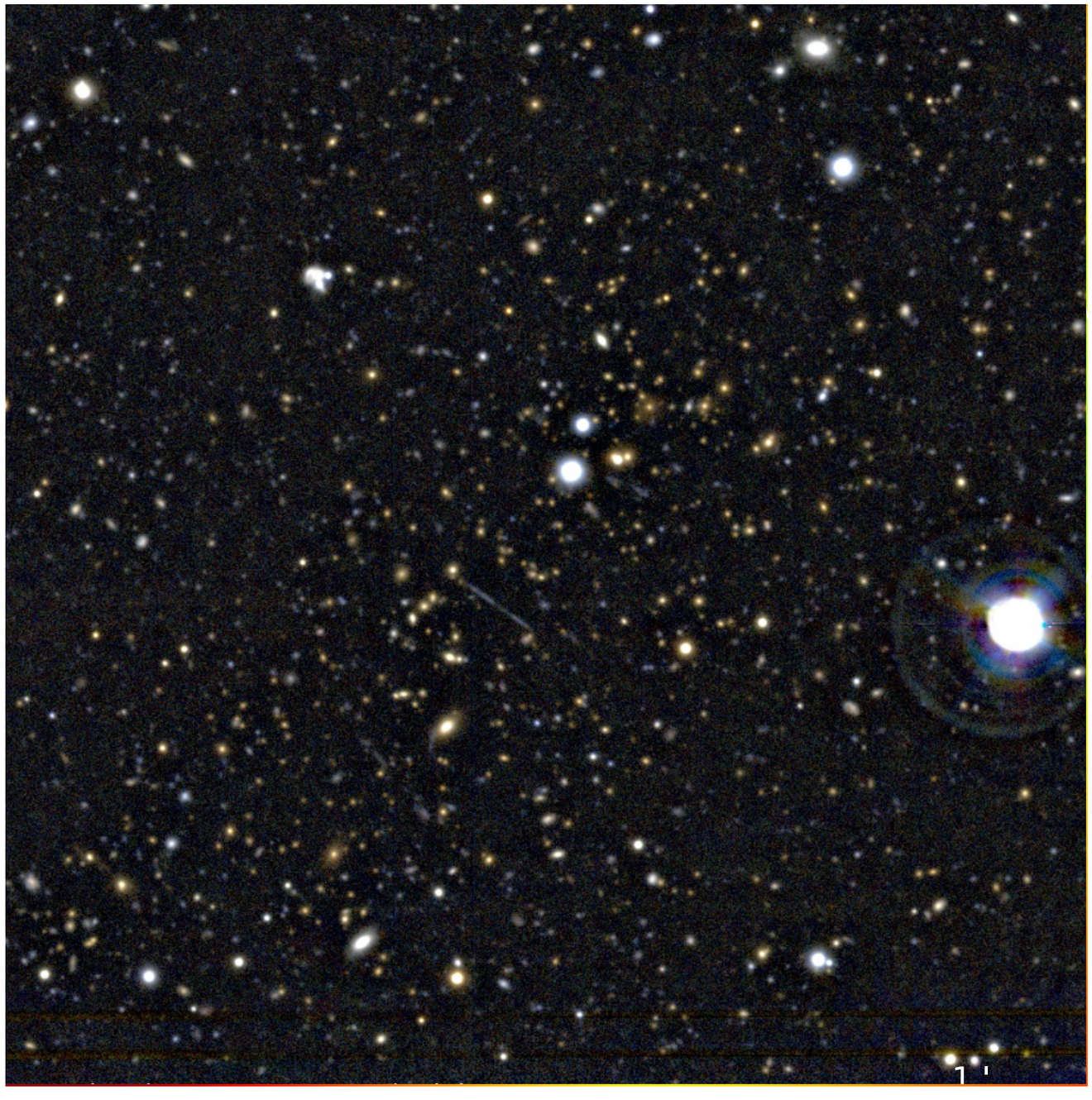

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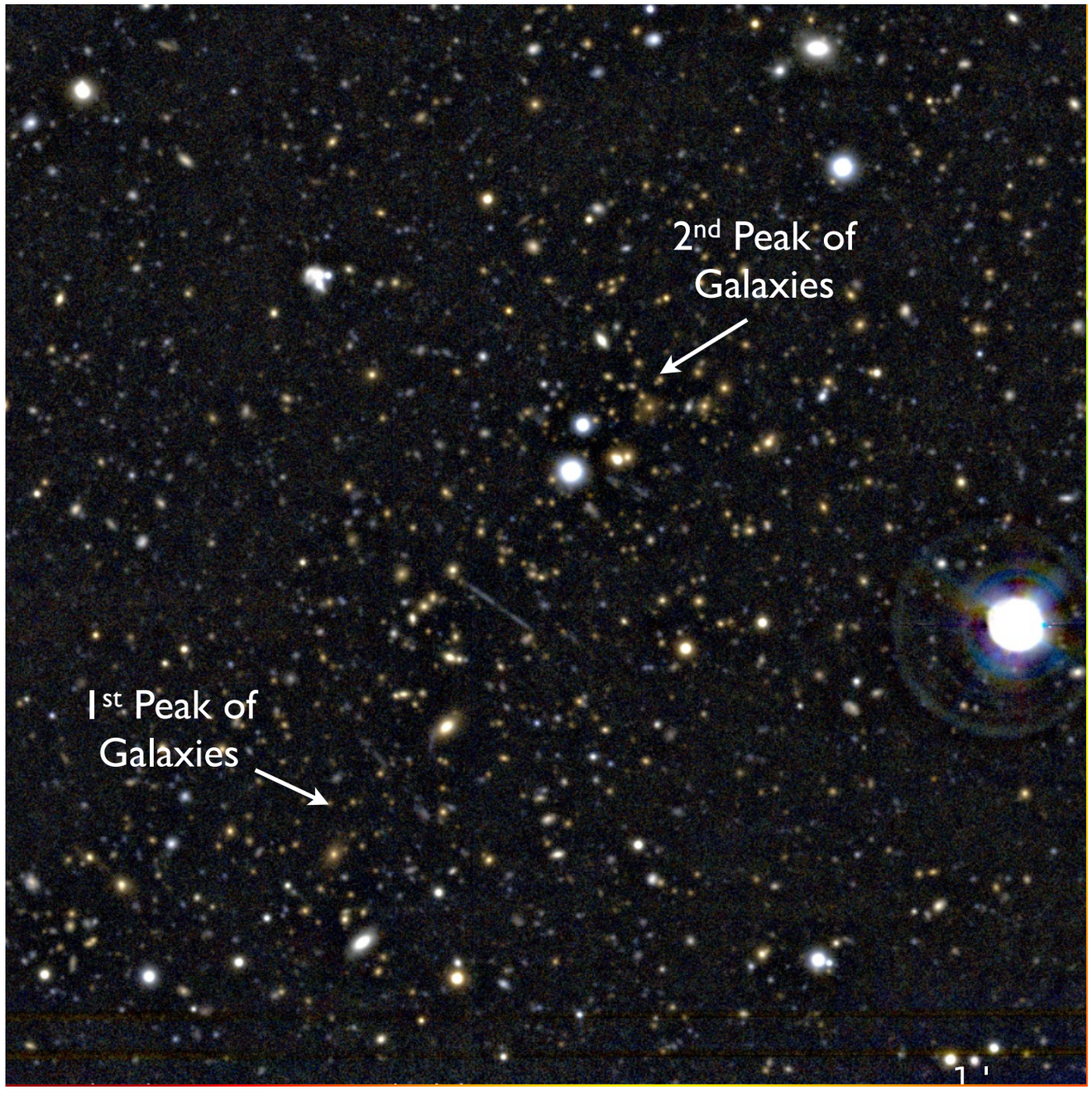
A Violent Merger in "El Gordo"

The galaxies in "El Gordo" mostly lie in two distinct groups



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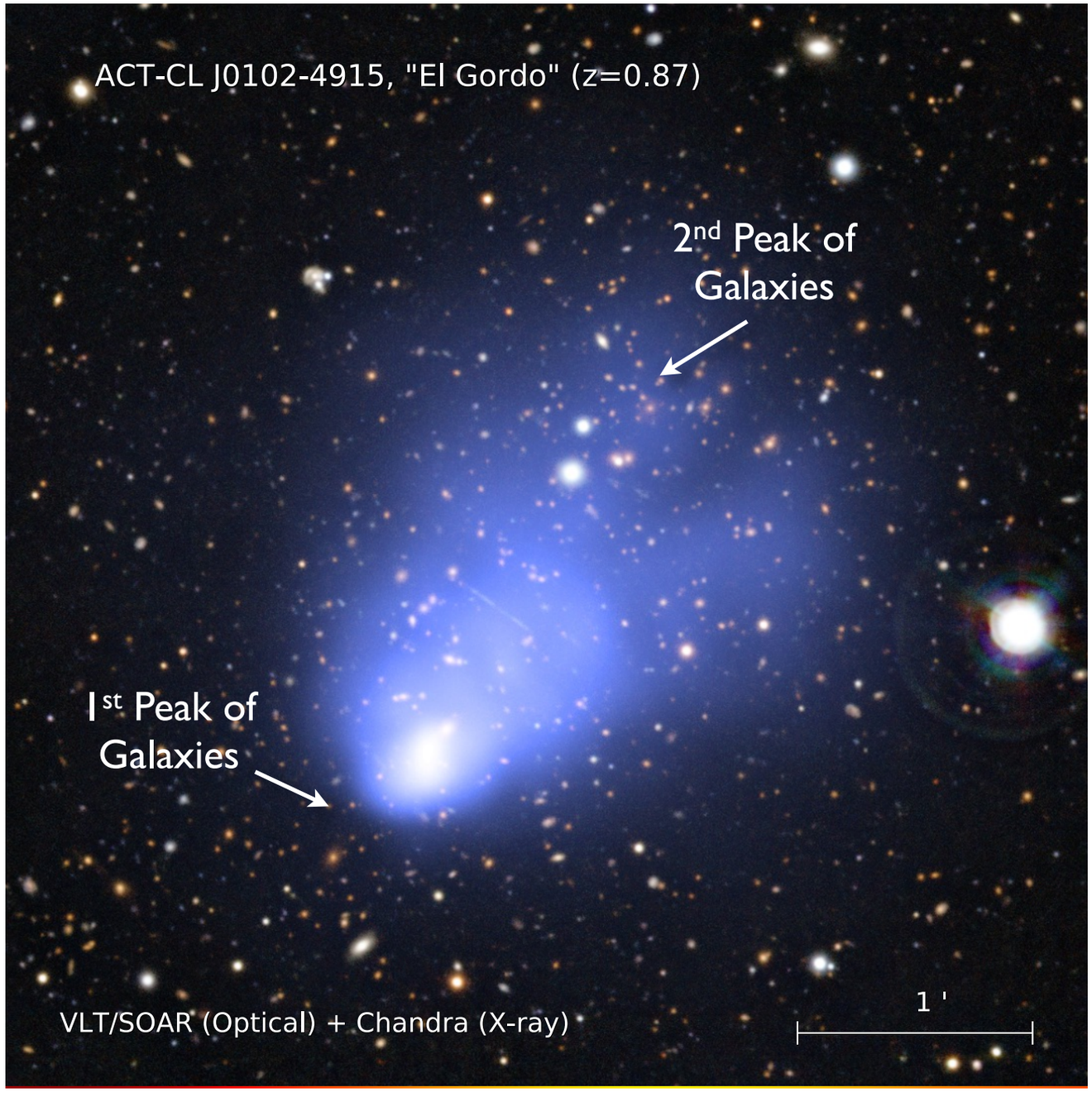

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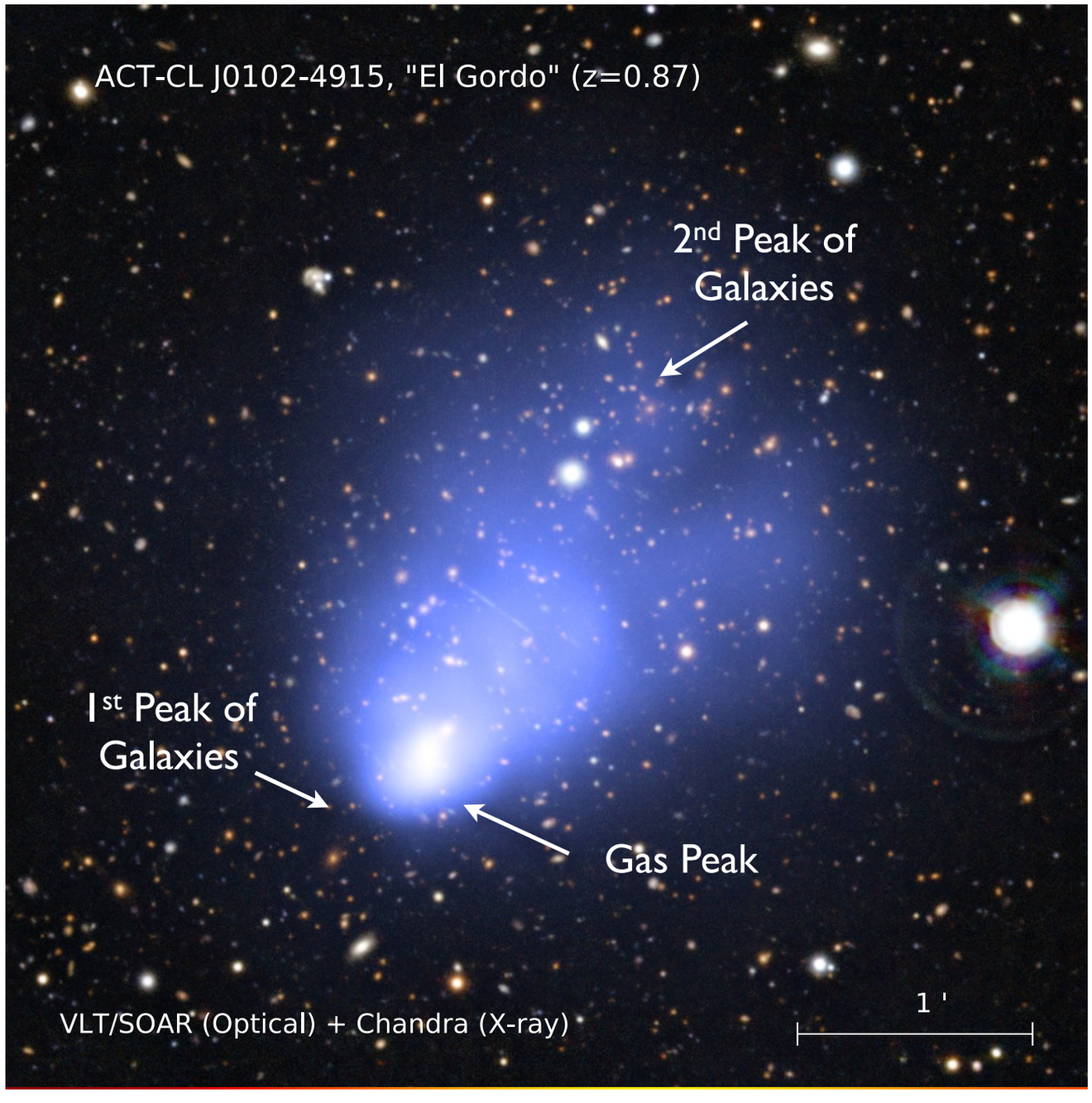

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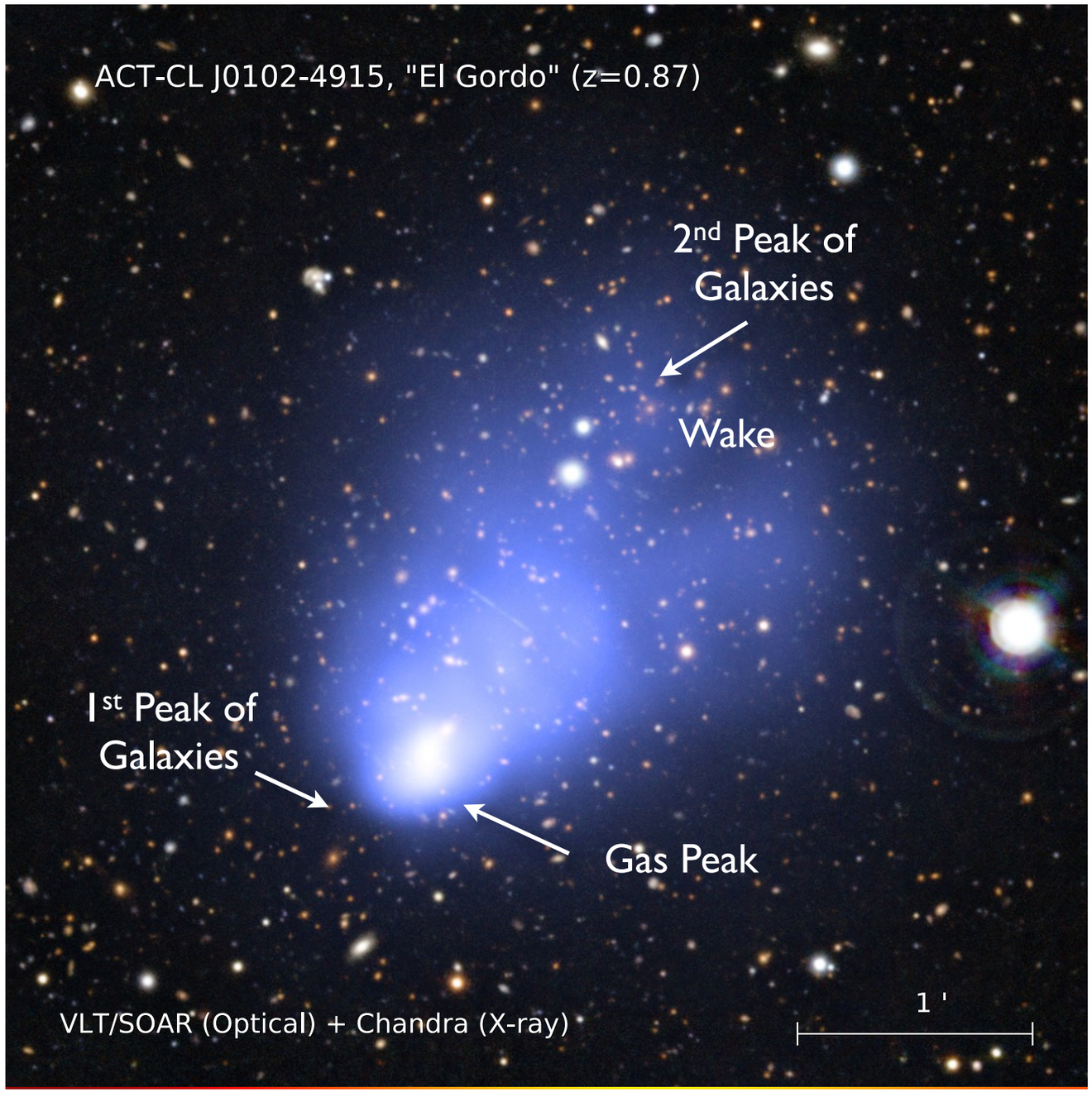

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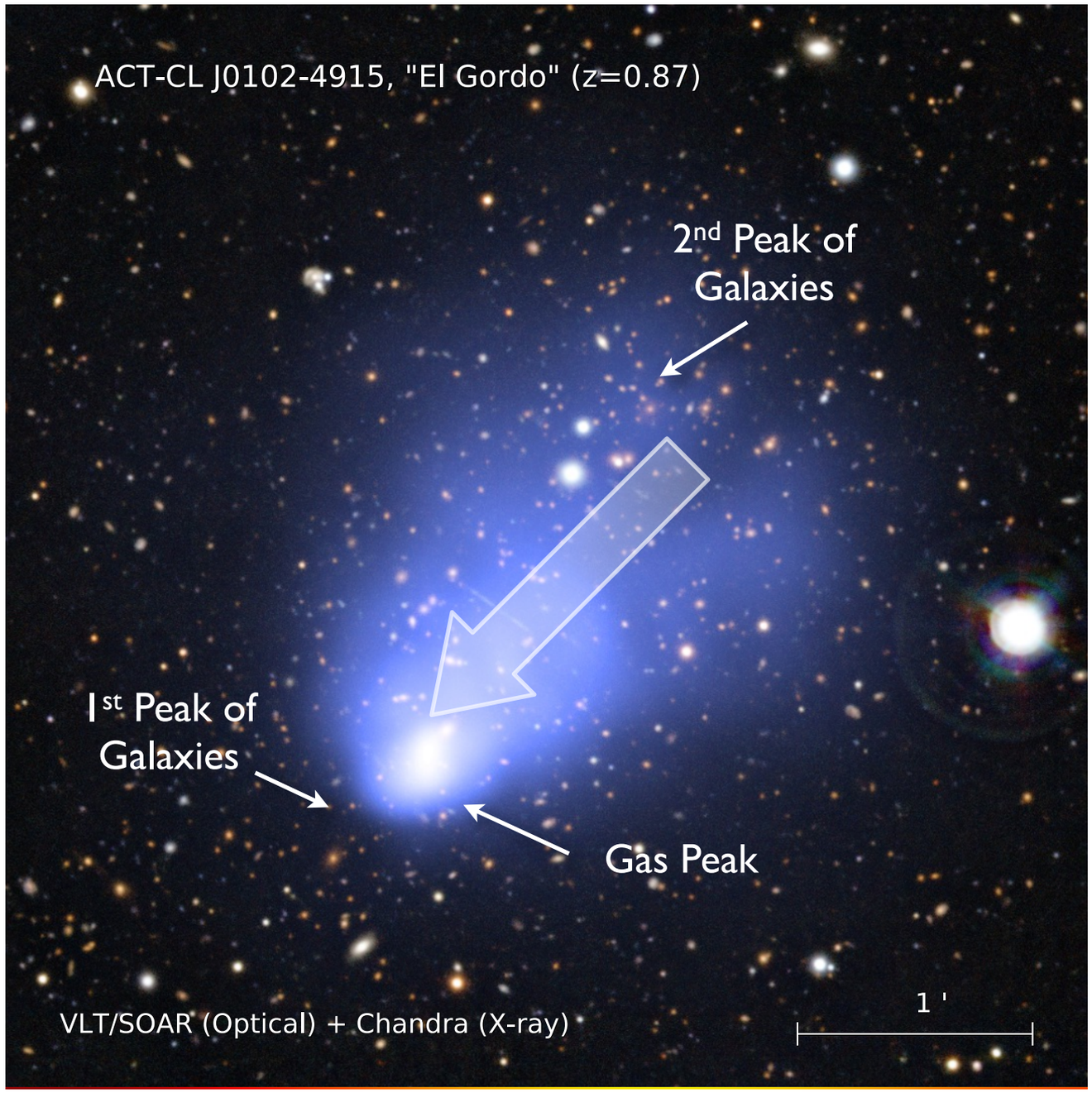

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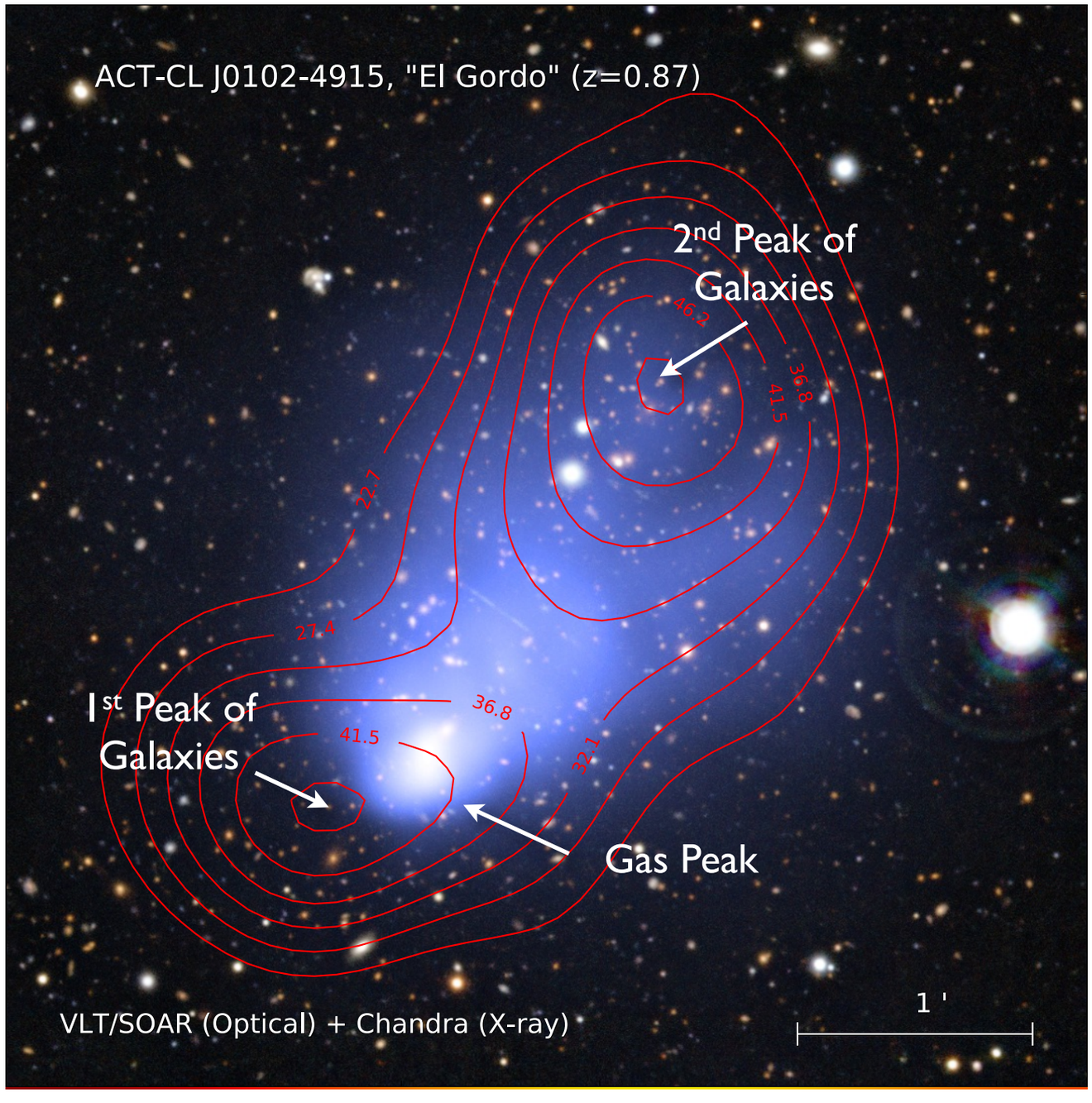
The peak of the Galaxy distribution precedes the Gas Peak in the direction of the merger – a spatial separation like that seen in the Bullet Cluster.



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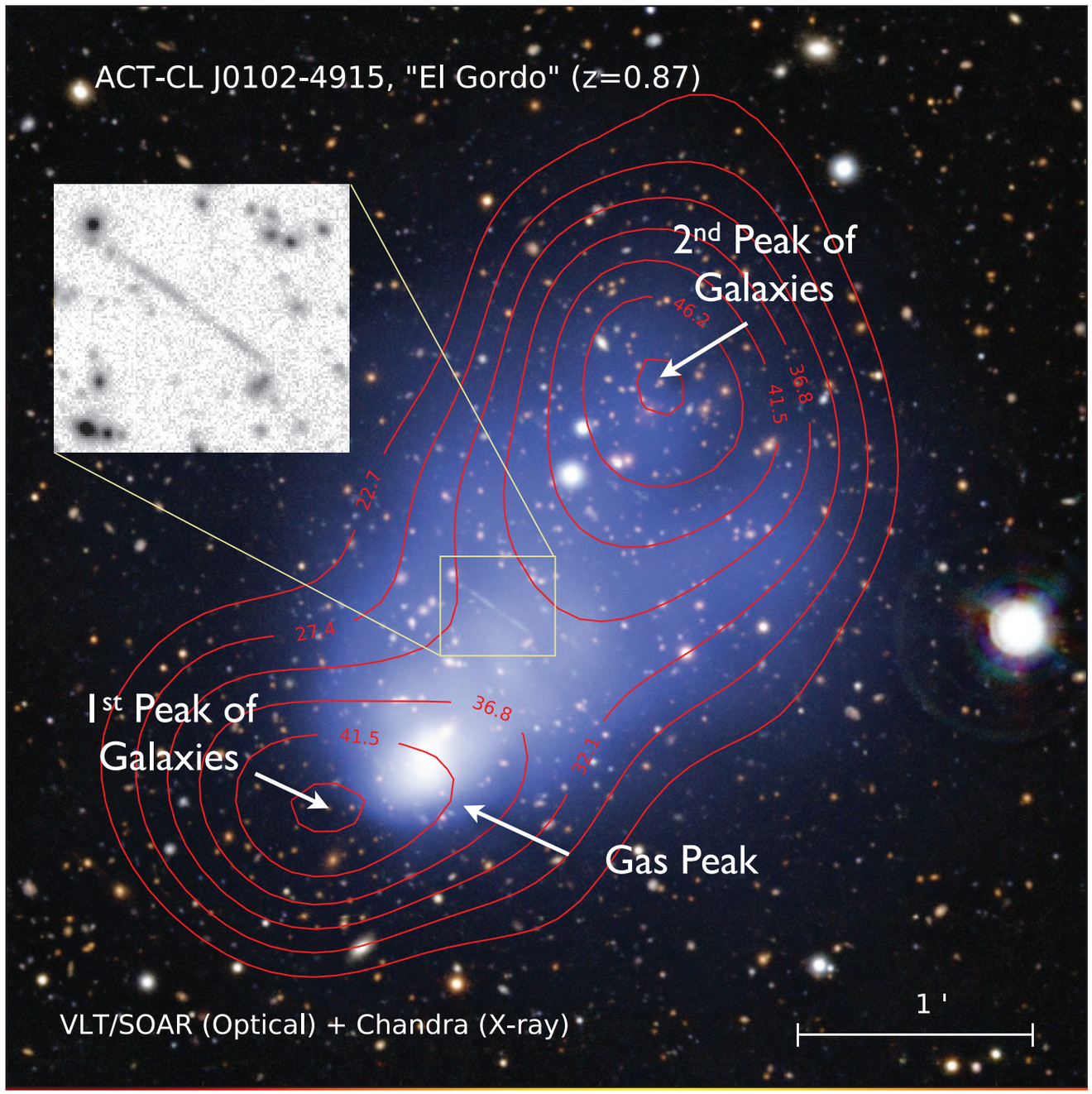
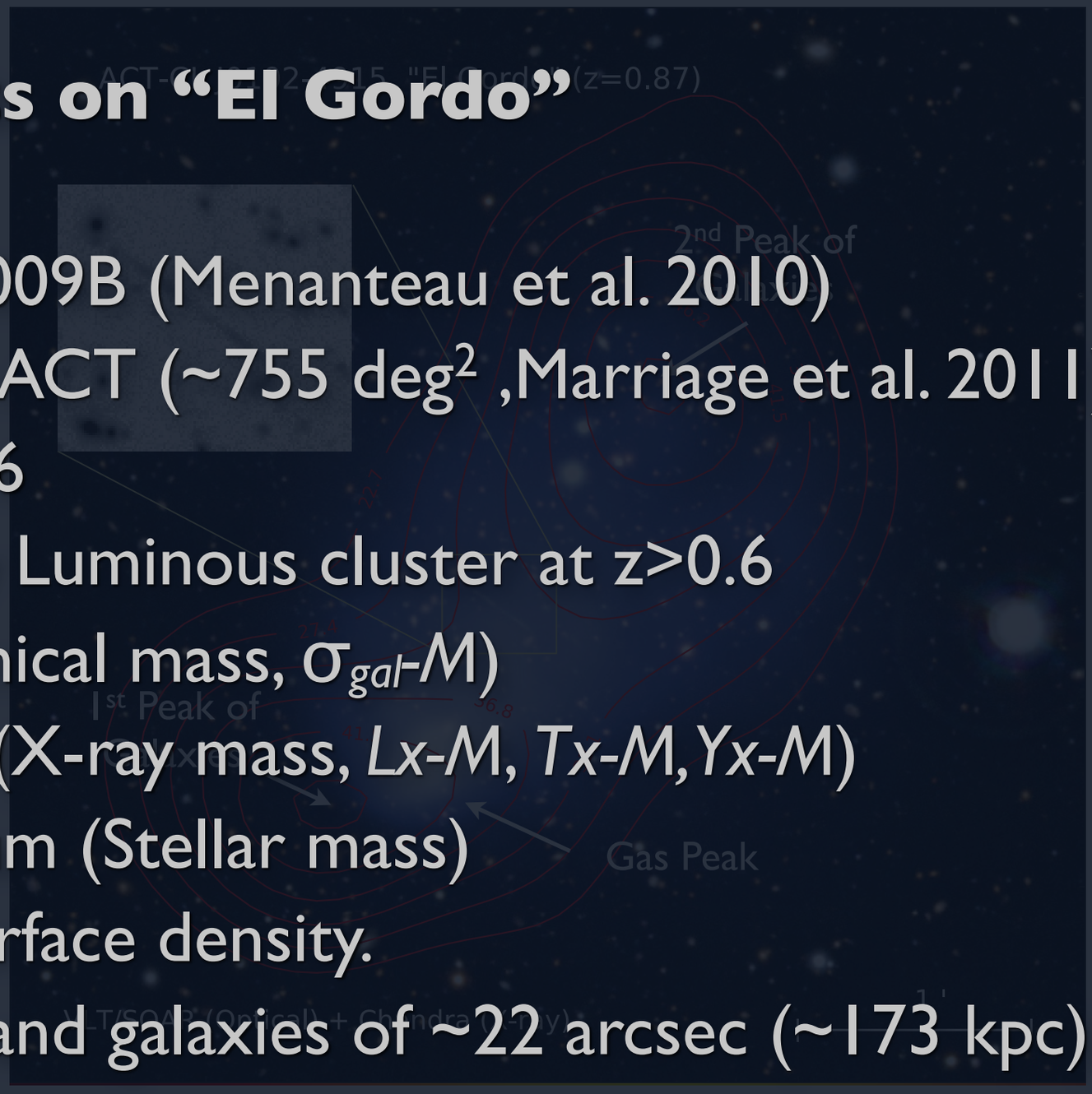


Menanteau et al. (2012, ApJ, 748,7)

A Violent Merger in "El Gordo"

Highlights on "El Gordo"

- Optically confirmed in the 2009B (Menanteau et al. 2010)
- The **highest** SZ signal from ACT (~755 deg^2 ,Marriage et al. 2011)
- The **hottest** cluster at z>0.6
- The ***most*** massive and X-ray Luminous cluster at z>0.6
- 89 redshifts from VLT (dynamical mass, σ_{gal}-M)
- Chandra/ACIS observations (X-ray mass, Lx-M, Tx-M, Yx-M)
- Spitzer/IRAC 3.6um and 4.5um (Stellar mass)
- Clear "wake" in the X-ray surface density.
- Separation between hot gas and galaxies of ~22 arcsec (~173 kpc)



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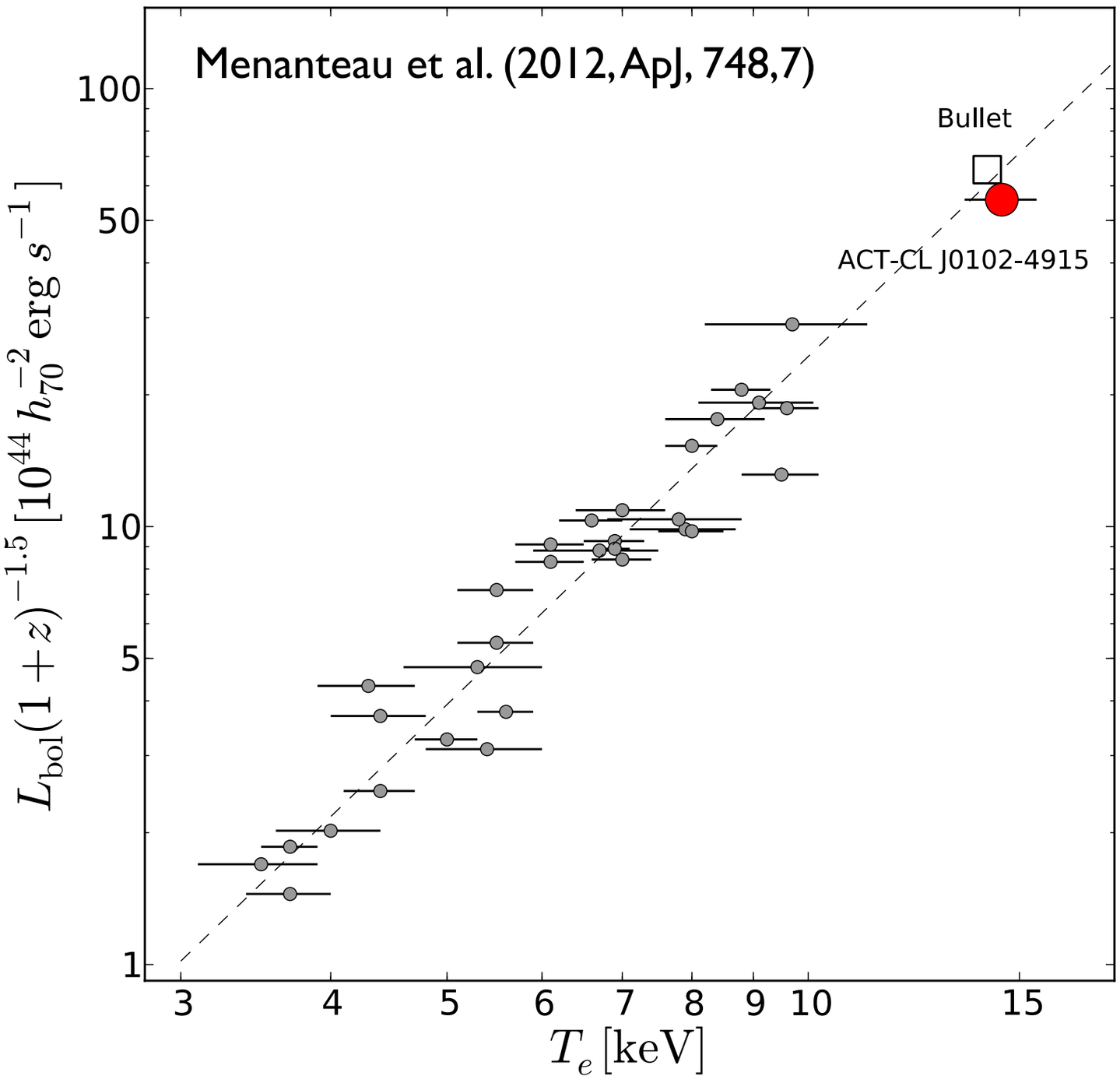
“El Gordo” is Hot and Luminous!!



Compared with Markevitch et al. (1998)

Core-excised Integrated spectrum

$$kT = 14.5 \pm 0.1 \text{ keV}$$
$$L_X = 2.19 \times 10^{45} \text{ erg s}^{-1}$$
$$L_{\mathrm{bol}} = 1.36 \times 10^{46} \text{ erg s}^{-1}$$

Combined measurements for the Most Massive Cluster at z>0.6

Menanteau et al. (2012, ApJ, 748,7)

Combined measurements for the Most Massive Cluster at z>0.6

- VLT FORS2 (Jan 2011, 10hrs), redshifts for 89 members:

$$z = 0.8701 \pm 0.0001$$

$$\sigma_{\rm gal} = 1321 \pm 106 \ {\rm km \ s^{-1}}$$

$$M_{200,{\rm dyn}} = 1.86^{+0.54}_{-0.49} \times 10^{15} \, h_{70}^{-1} \, M_{\odot}$$

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- *Chandra*/ACIS (Jan 2011, 60 ks exposure):

$$T_X = 14.5 \pm 1.0 \ {\rm keV}; f_{\rm gas} = 0.133$$

Kravtsov, Vikhlinin & Nagai (2006)
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$$M_{200,Y_X} = 2.88^{+0.78}_{-0.55} \times 10^{15} \, h_{70}^{-1} \, M_\odot$$

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- ACT/SZ decrement, yT_{CMB} - *Mass*

$$yT_{\rm CMB} = 490 \pm 60 \mu K$$
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- Combined (χ^2 combined) optical+X-ray+SZ:

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CL J1226+3332 (z=0.89)
$M_{200} = (1.38 \pm 0.20) \times 10^{15} \, h_{70}^{-1} \, M_\odot$

SPT-CL J2106-5844 (z=1.14)
$M_{200} = (1.27 \pm 0.21) \times 10^{15} \, h_{70}^{-1} \, M_\odot$

- Combined (χ^2 combined) optical+X-ray+SZ:

$$M_{200} = (2.16 \pm 0.32) \times 10^{15} \, h_{70}^{-1} M_\odot$$

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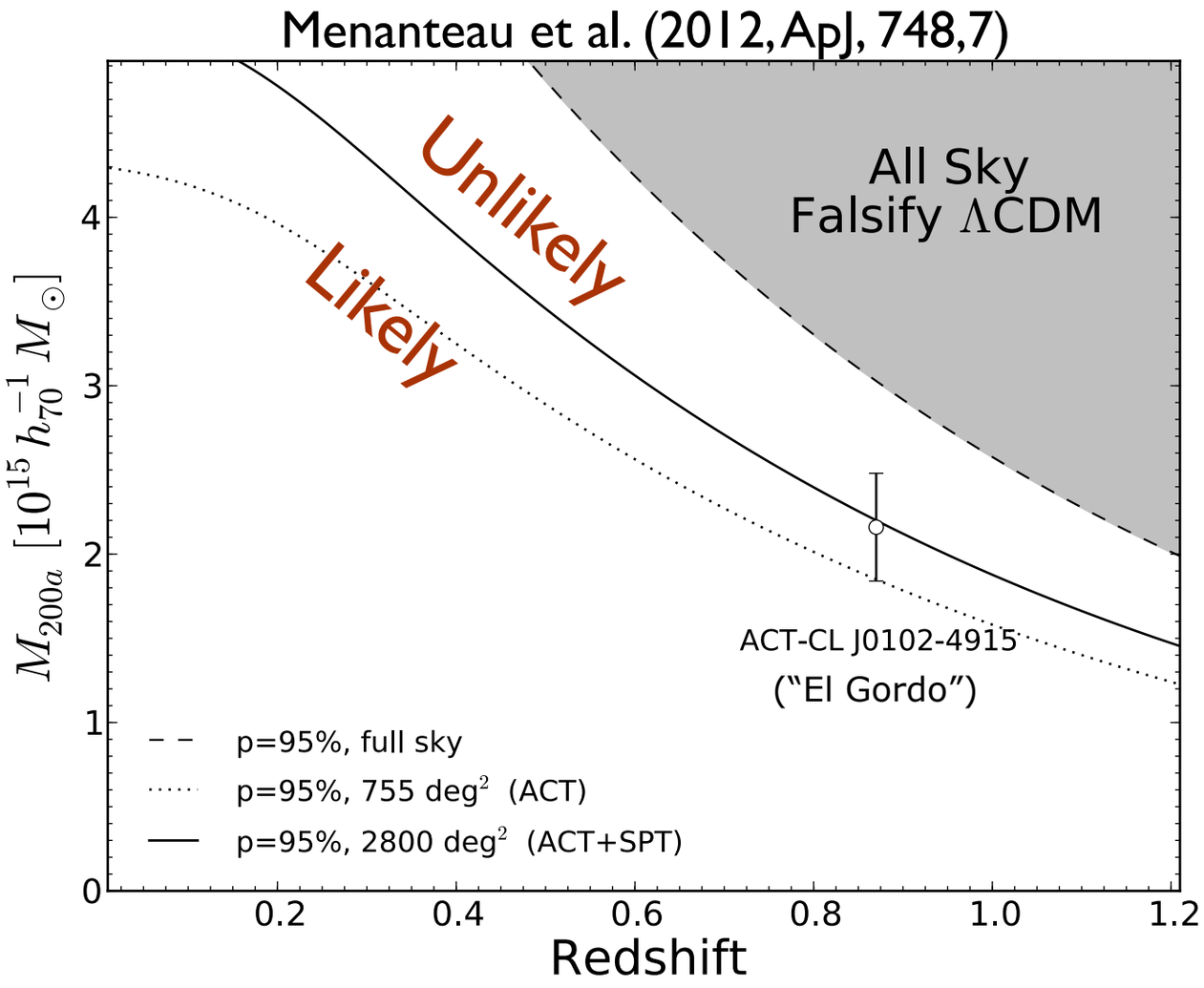
Rarity of "El Gordo" (Based on its exceptional mass)

- Combined Mass from optical +X-ray+SZ:

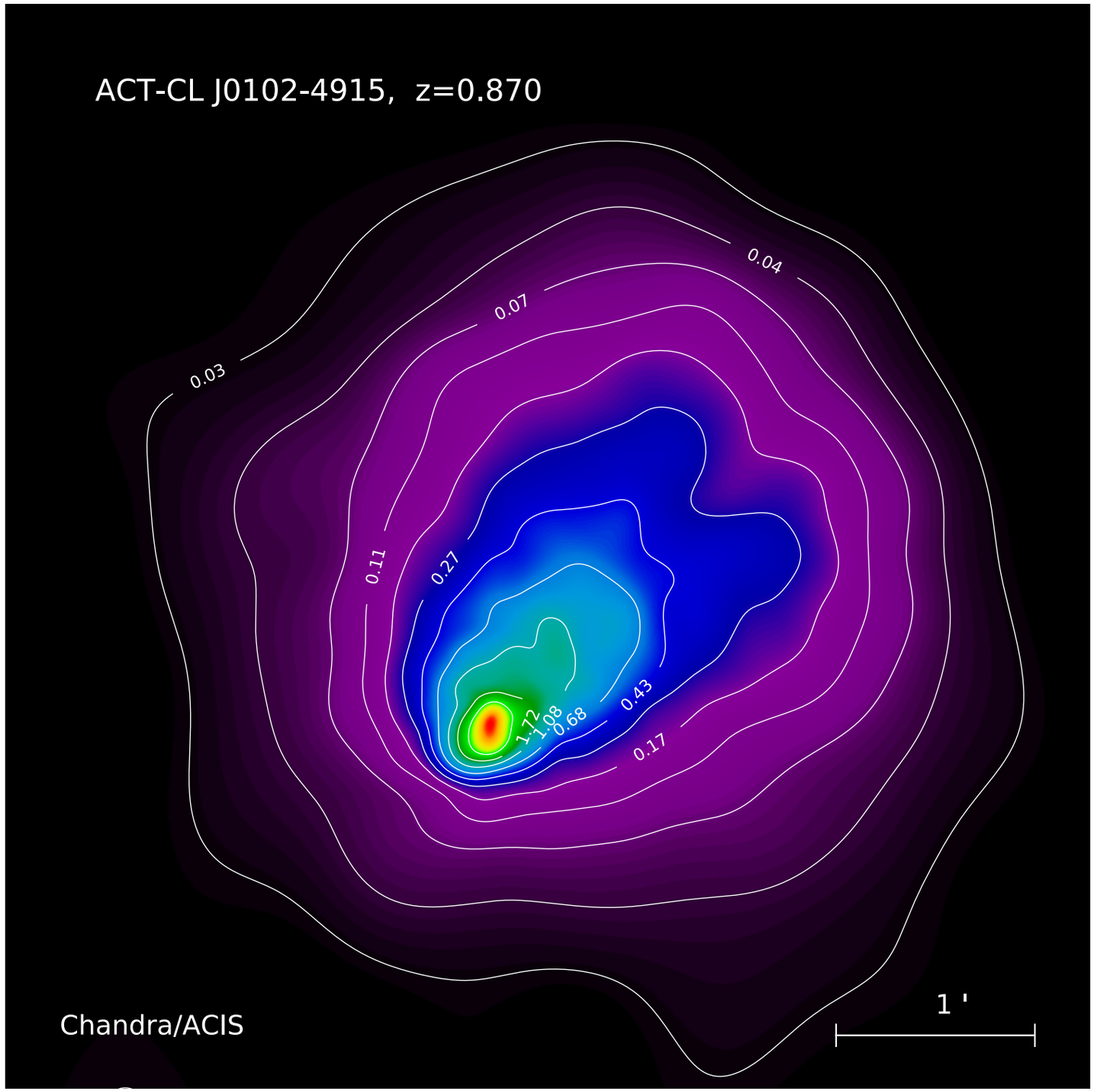
$$M_{200} = (2.16 \pm 0.32) \times 10^{15}\, h_{70}^{-1} M_\odot$$

- Area of survey:
  - ACT: 755 deg^2
  - ACT+SPT: 2800 deg^2
- Mortonson et al. (2011) exclusion curves for ΛCDM and quintenssence parameter distribution.



- Cluster is very unlikely in the ACT survey area alone (3σ), but still allowed in the ACT+SPT sky region if its mass is 1-σ or more below the nominal mass.

“El Gordo,” *Chandra* Imaging



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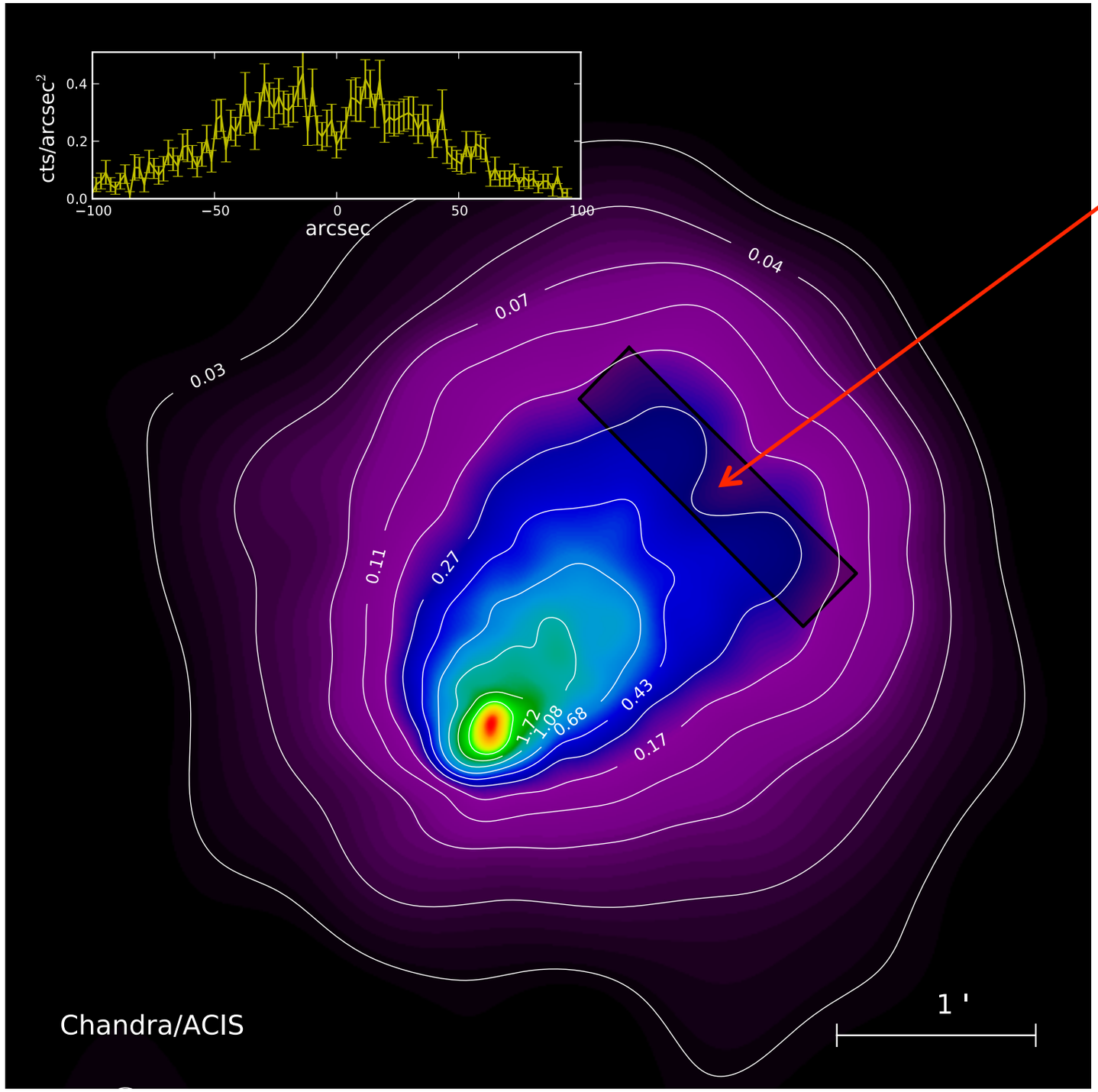

Wake! Cometary shape (even 2 tails!) 20-40% surface brightness suppression ≈35”x60”

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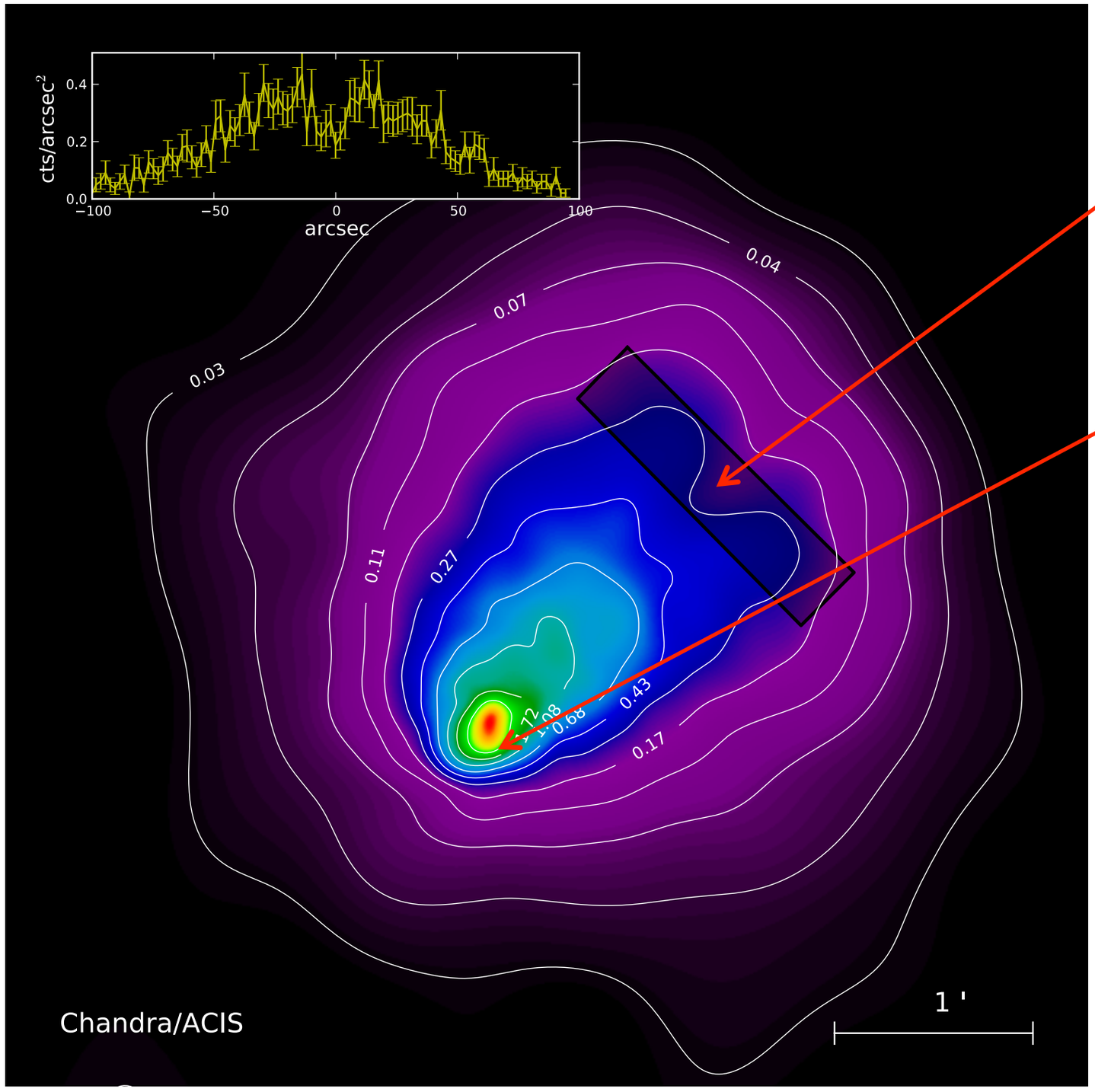

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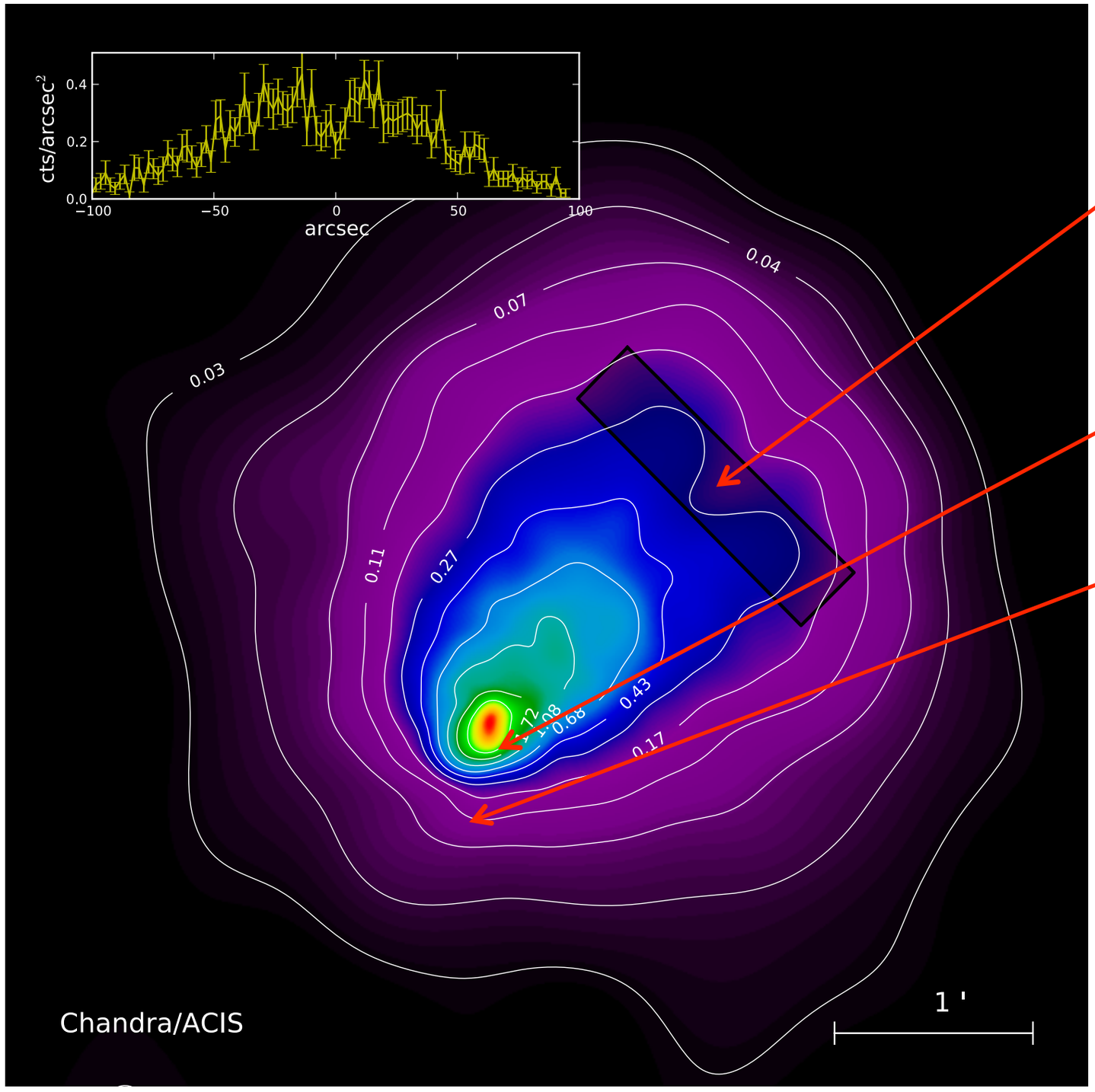

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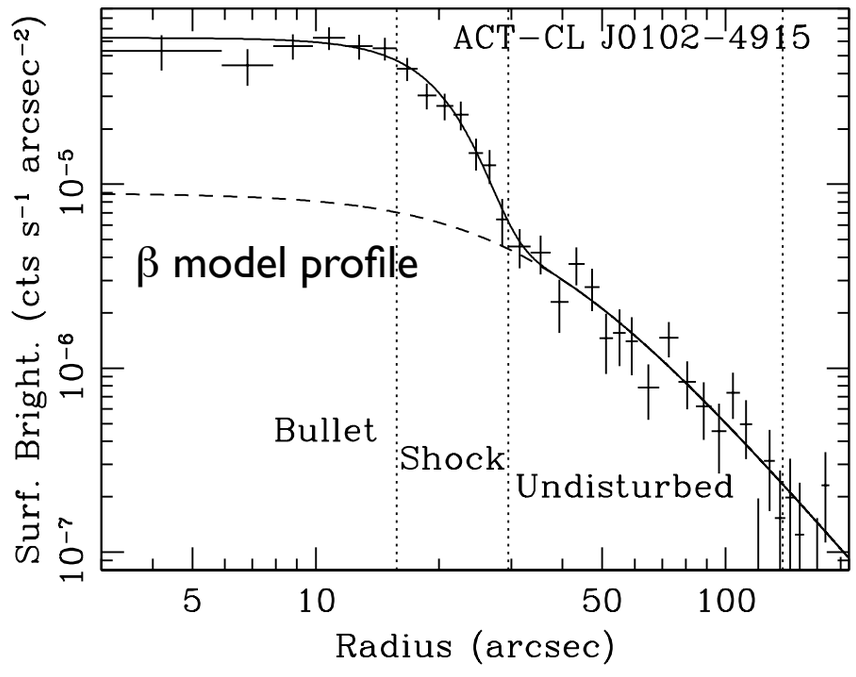
Low entropy, bright, offset peak

Steep brightness gradient



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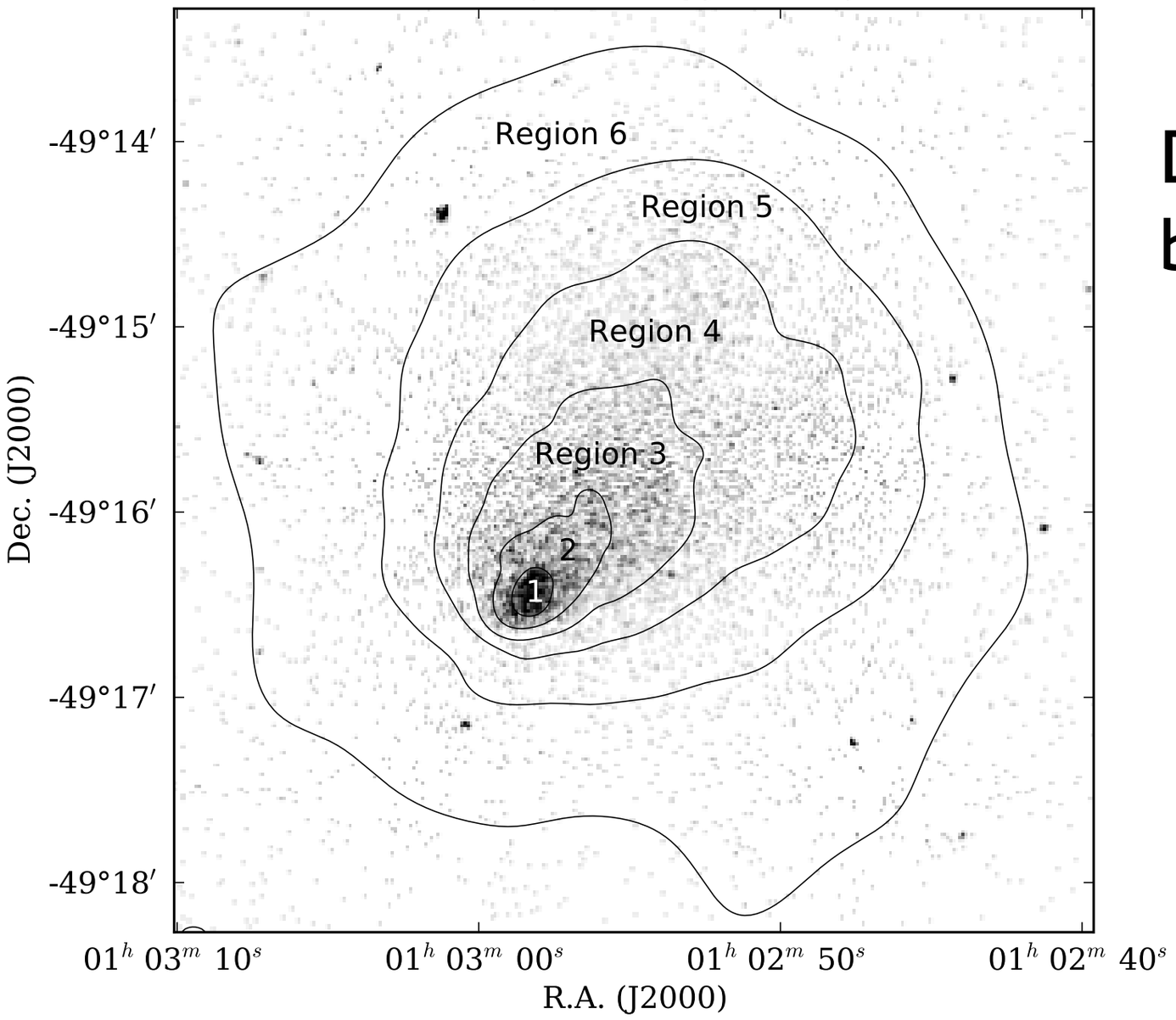
Chandra Spectro-Imaging Analysis

Menanteau et al. (2012, ApJ, 748,7)



Divide cluster in six regions based on surface brightness

Region 1 : 1000 cts

Region 4 : 4300 cts

Others : 2000 – 3600 cts

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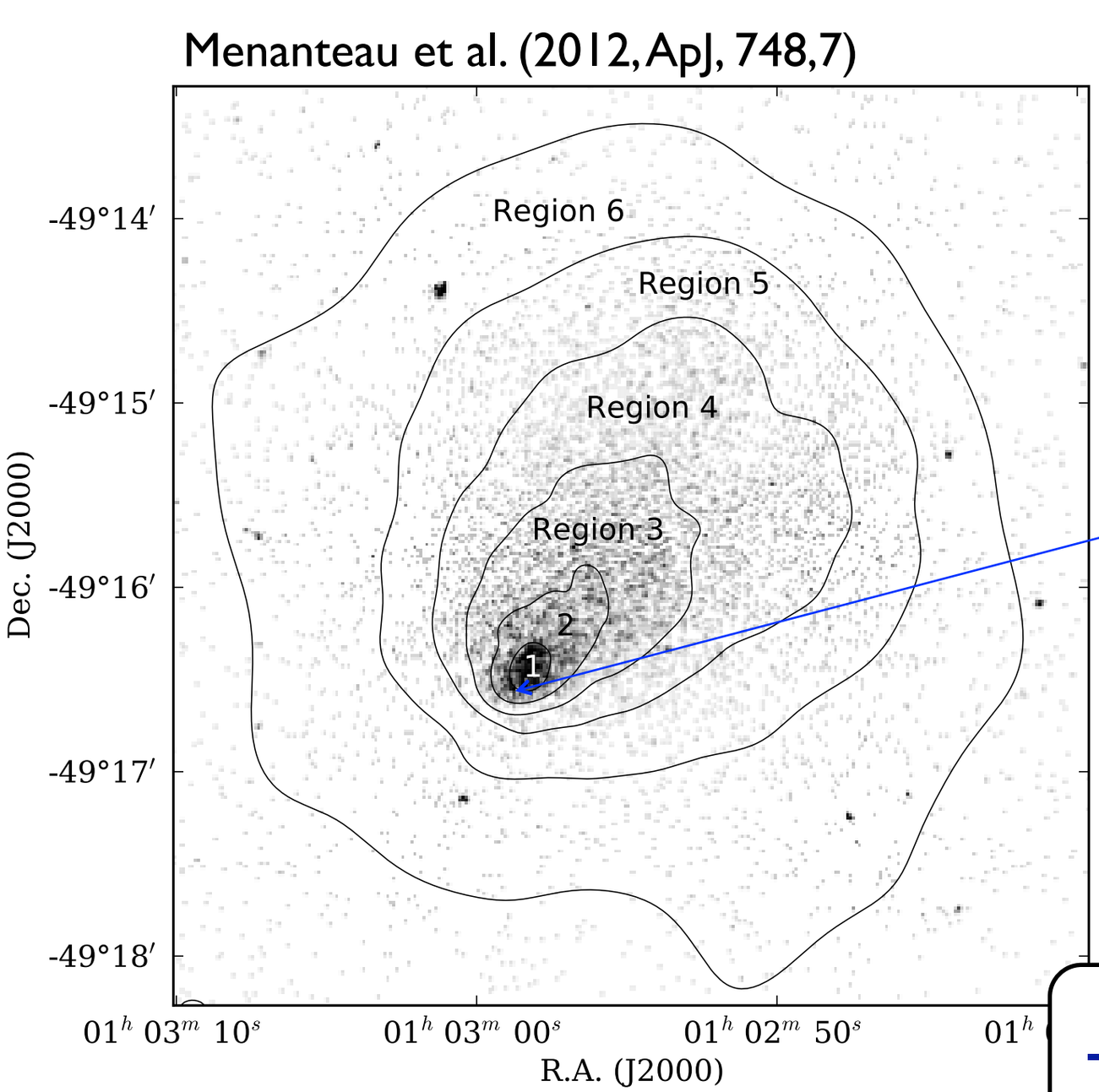

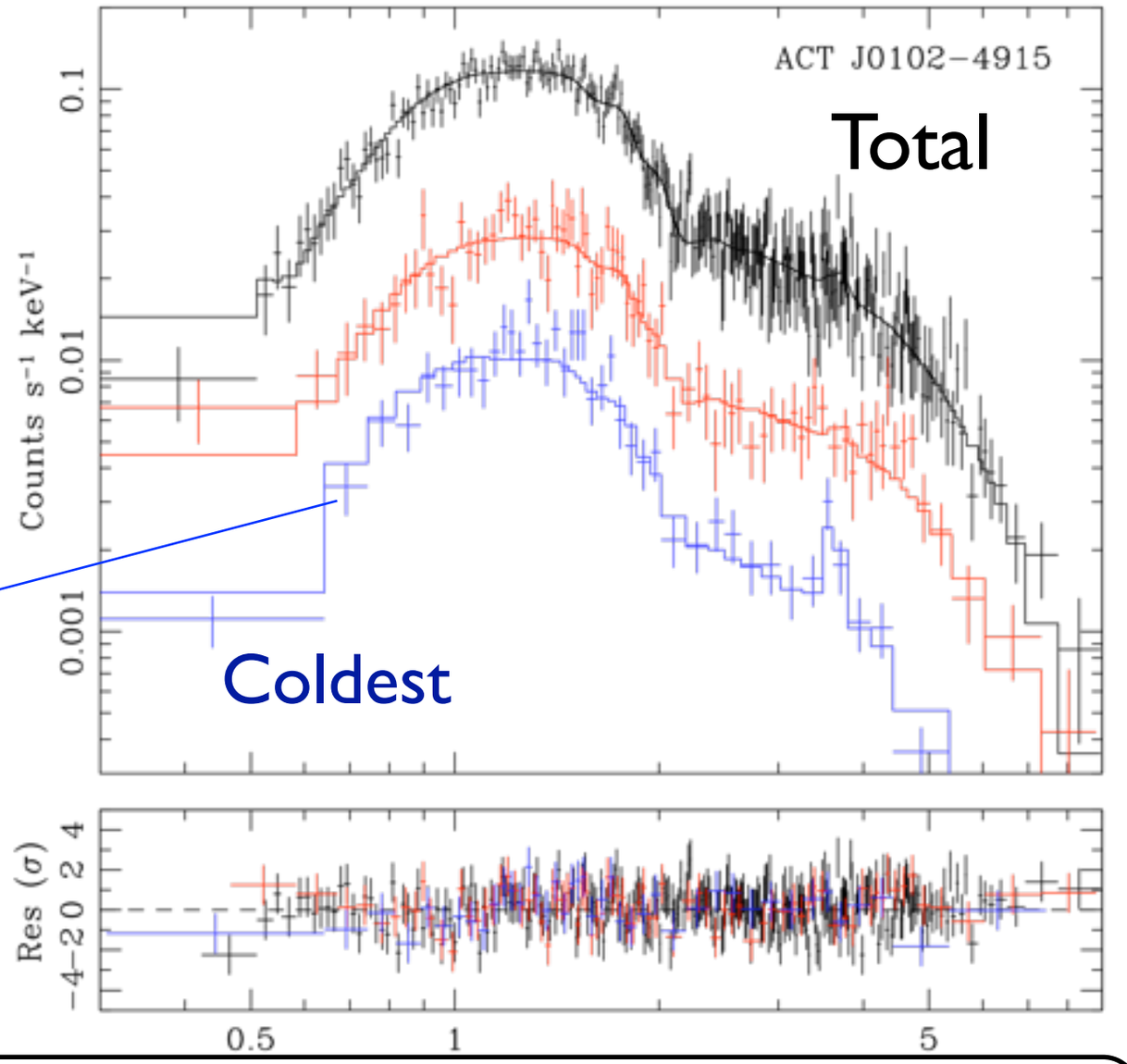

- X-ray peak is cold (kT=6.6±0.7 keV)
- Highest Fe abundance (Z=0.57±0.20)
- low entropy bullet, i.e., the cool core of a merging cluster

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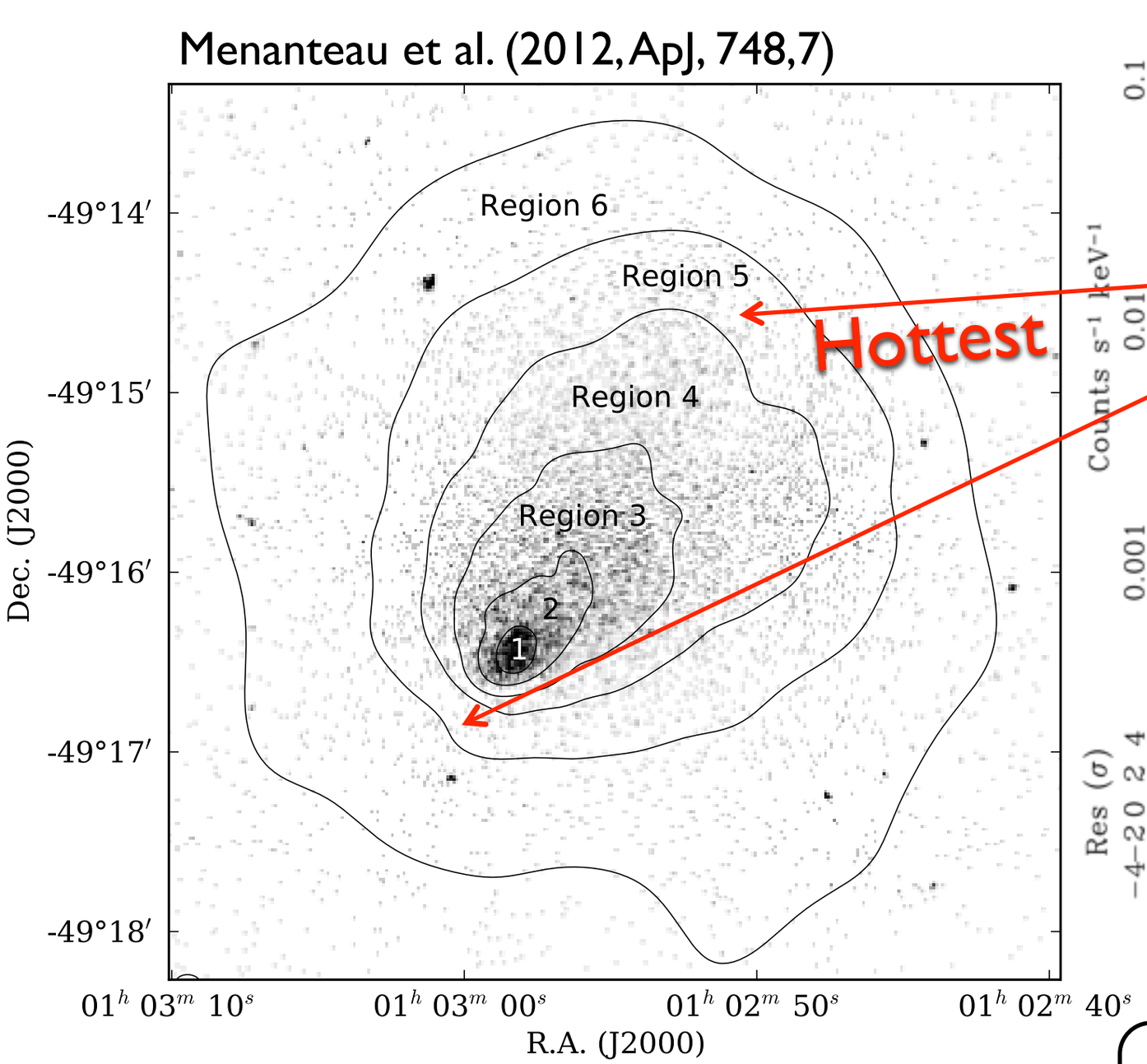
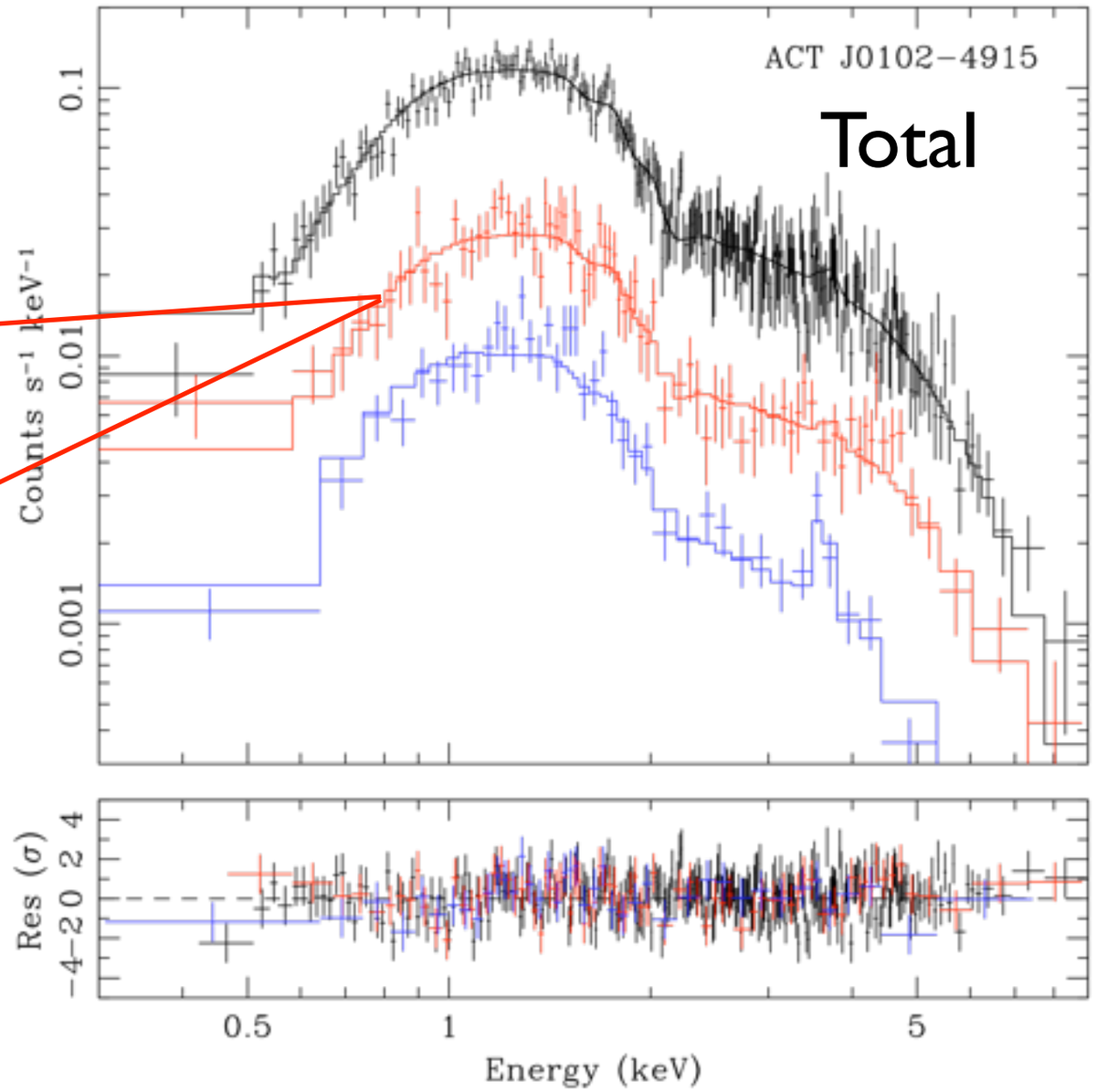


Hottest



Hottest region is kT=22(+6,-5) keV (source frame) – shock heating?

Chandra Spectro-Imaging Analysis

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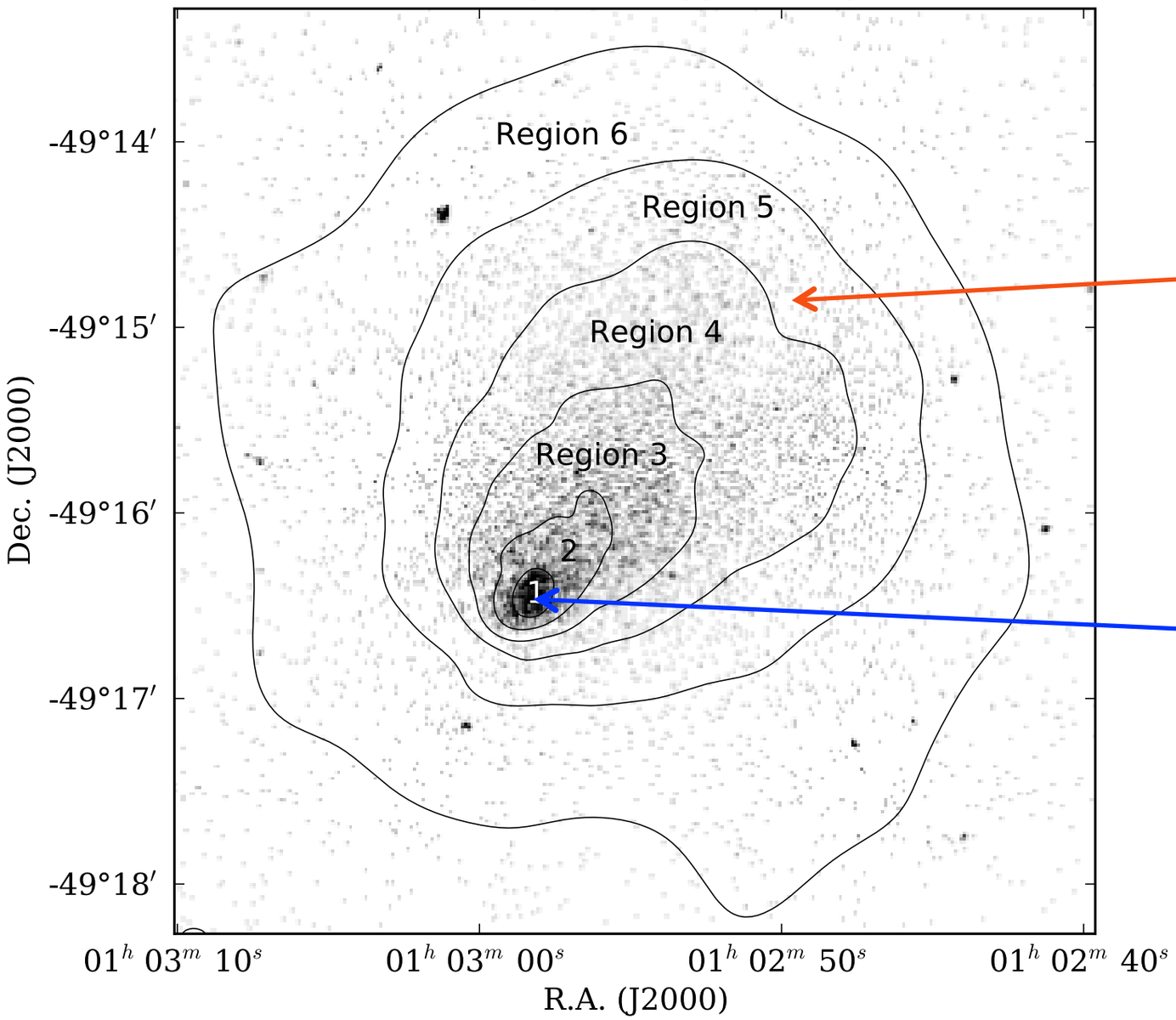
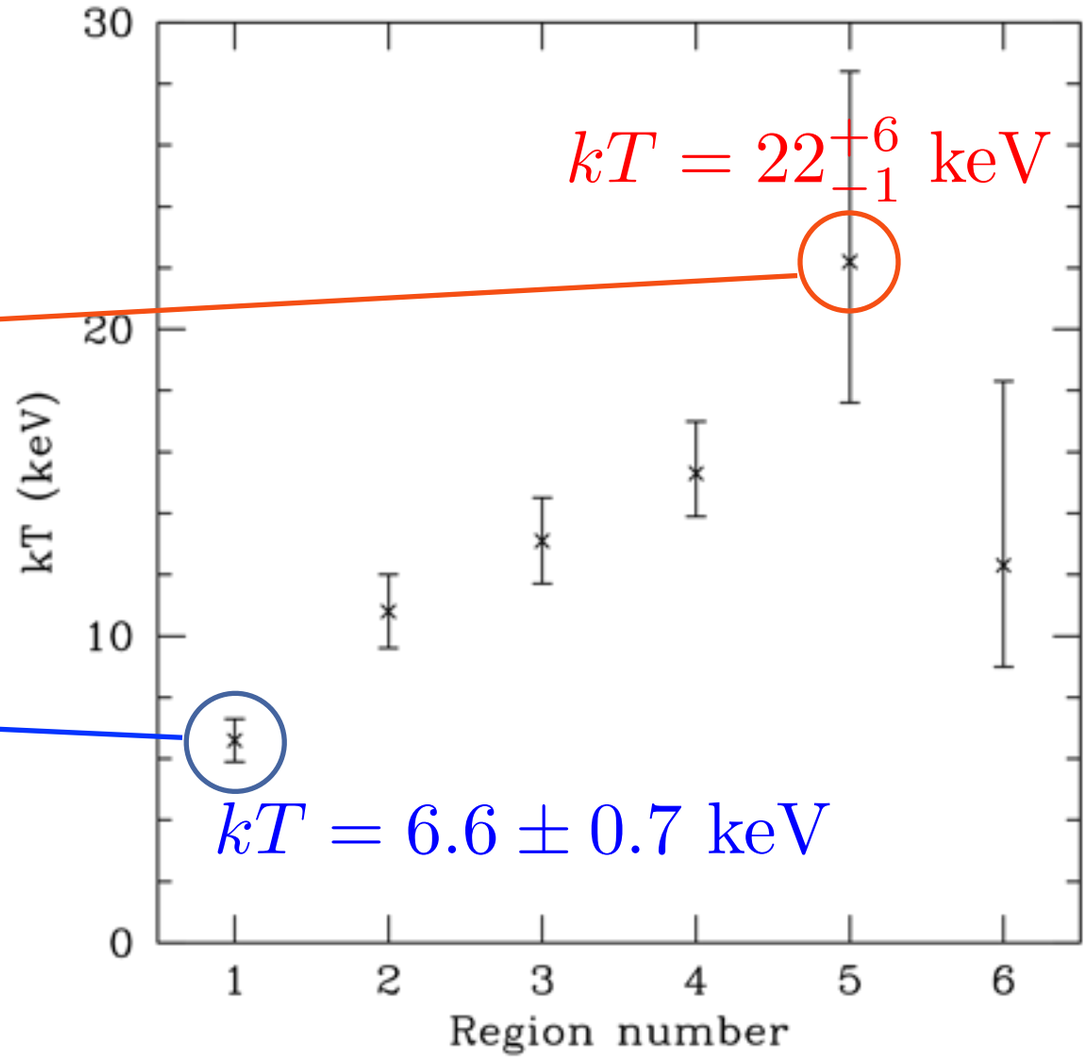
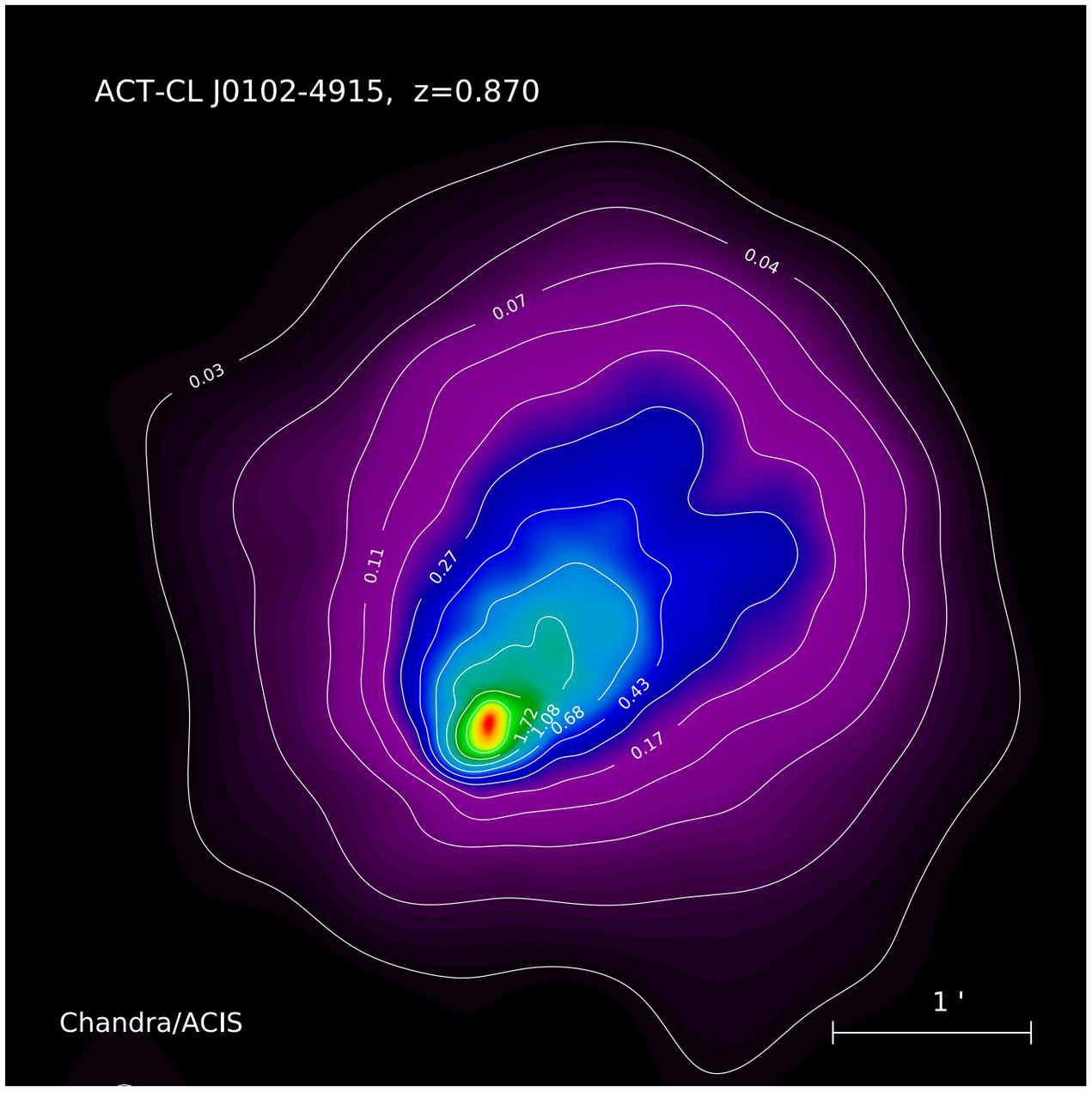




A new bullet at z=0.87?

Menanteau et al. (2012, ApJ, 748,7)



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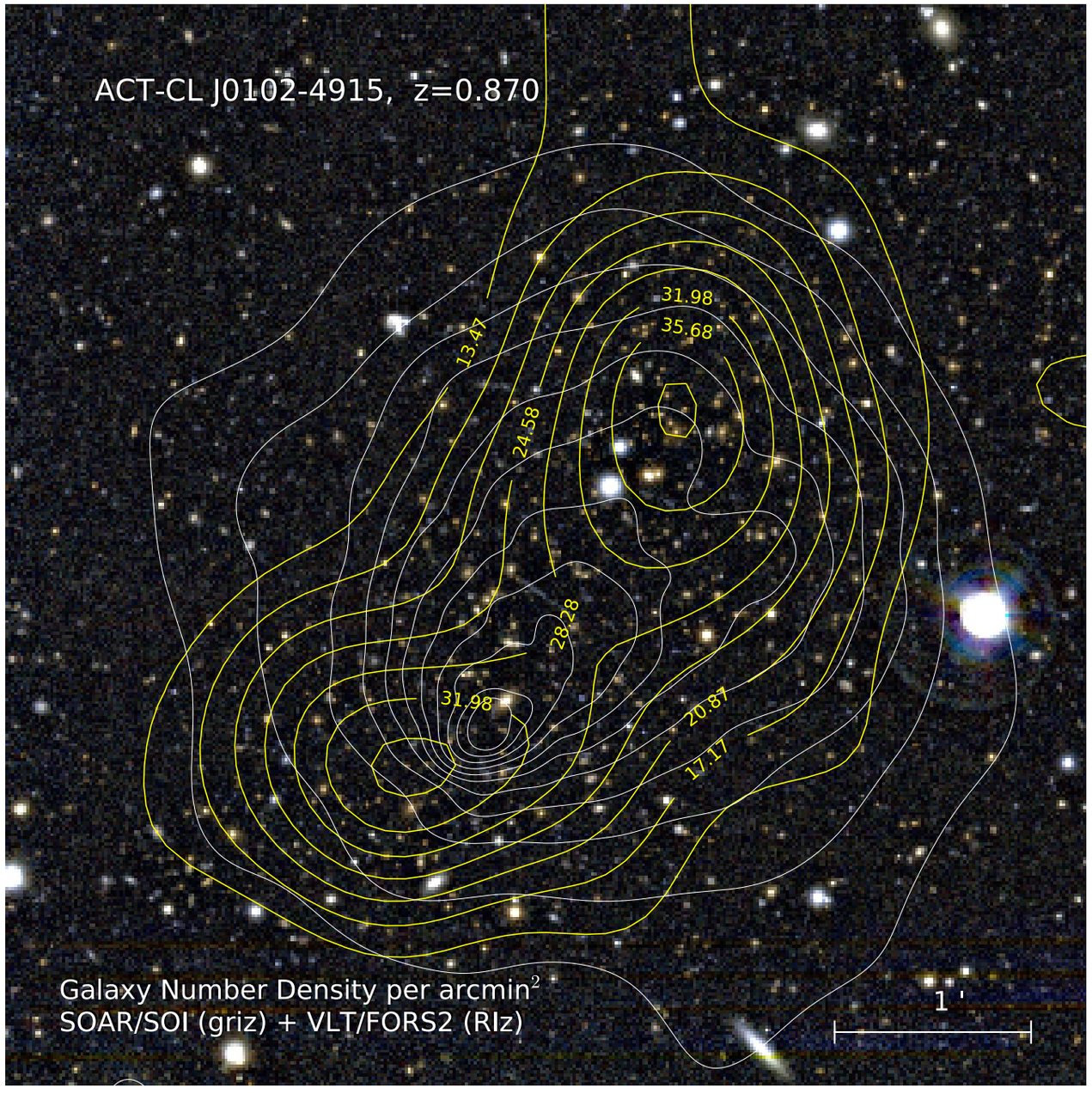

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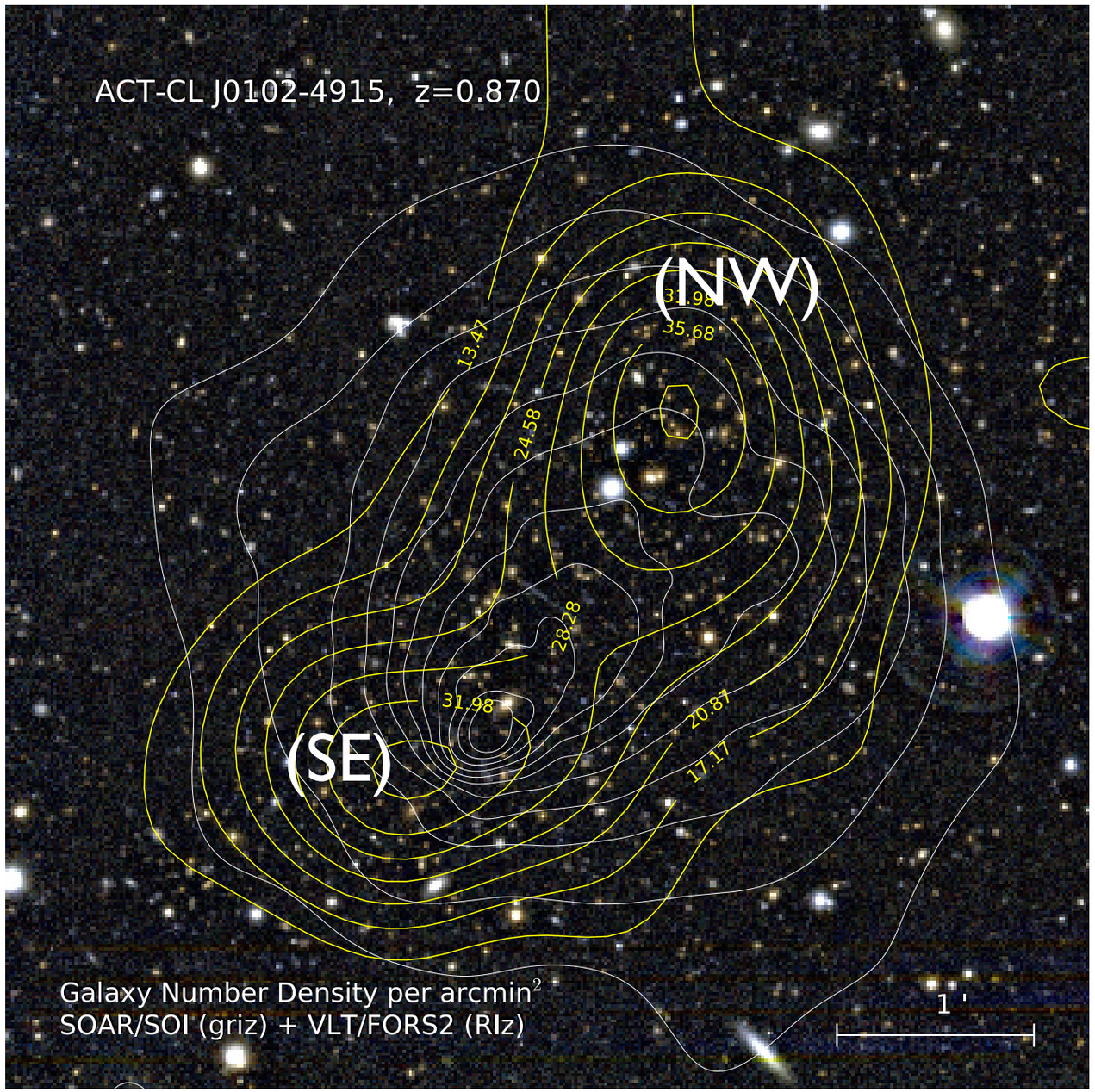
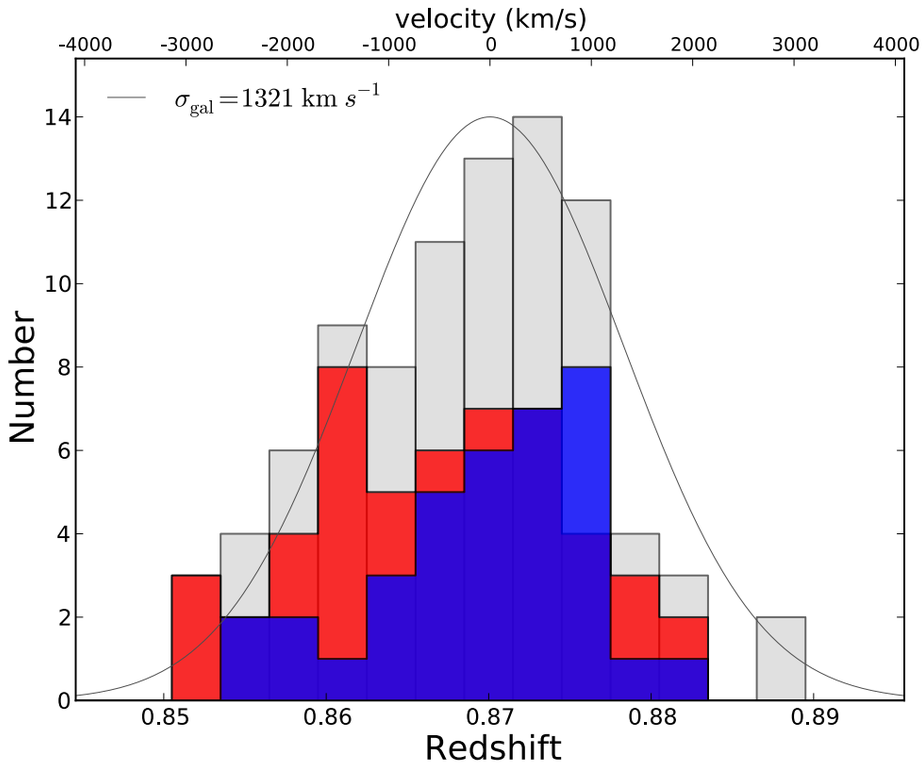




$$M_{200} = 1.76^{+0.62}_{-0.58} \times 10^{15}\, h_{70}^{-1} M_{\odot}(\mathrm{NW})$$

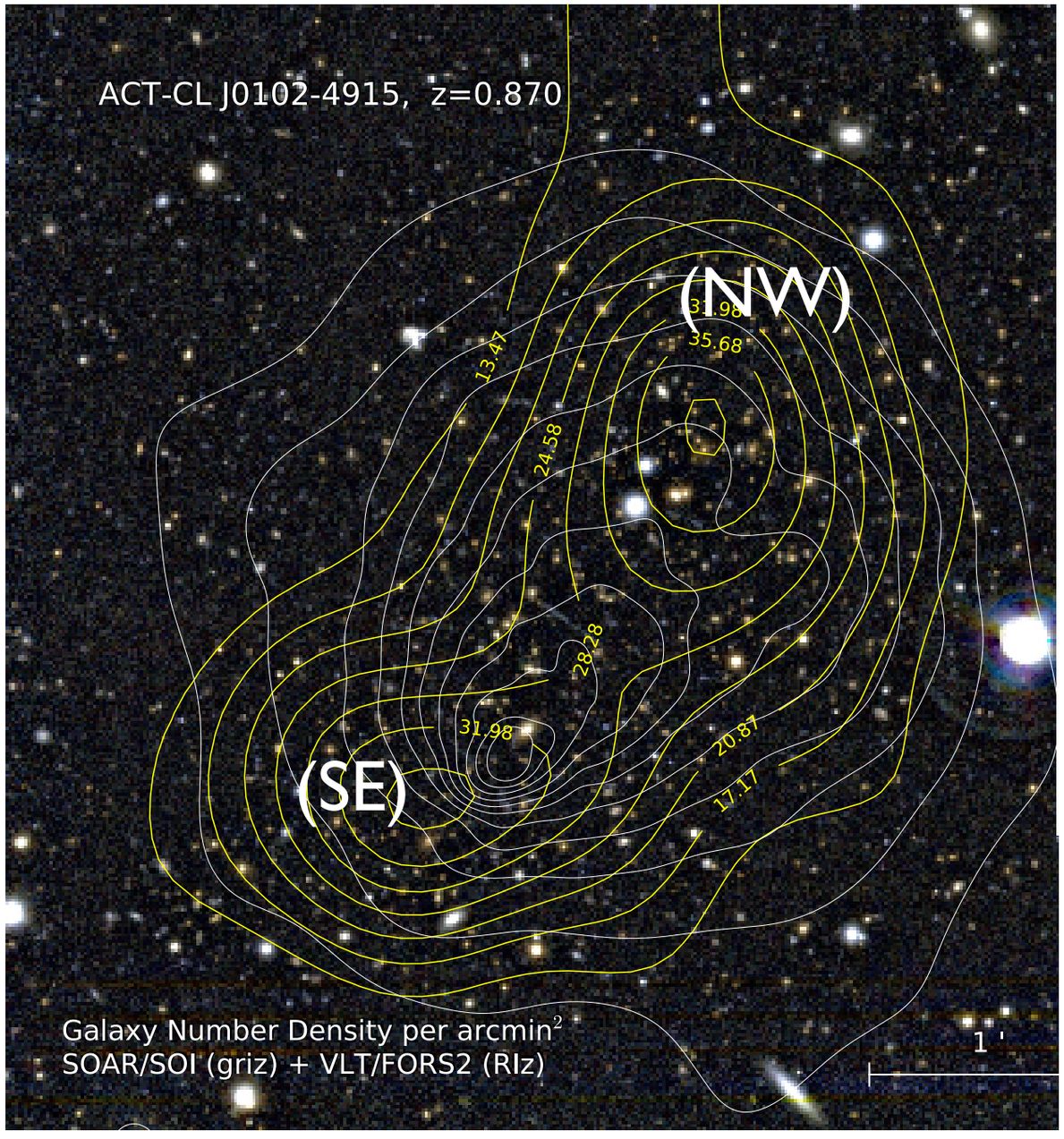
$$M_{200} = 1.06^{+0.64}_{-0.59} \times 10^{15}\, h_{70}^{-1} M_{\odot}(\mathrm{SE})$$

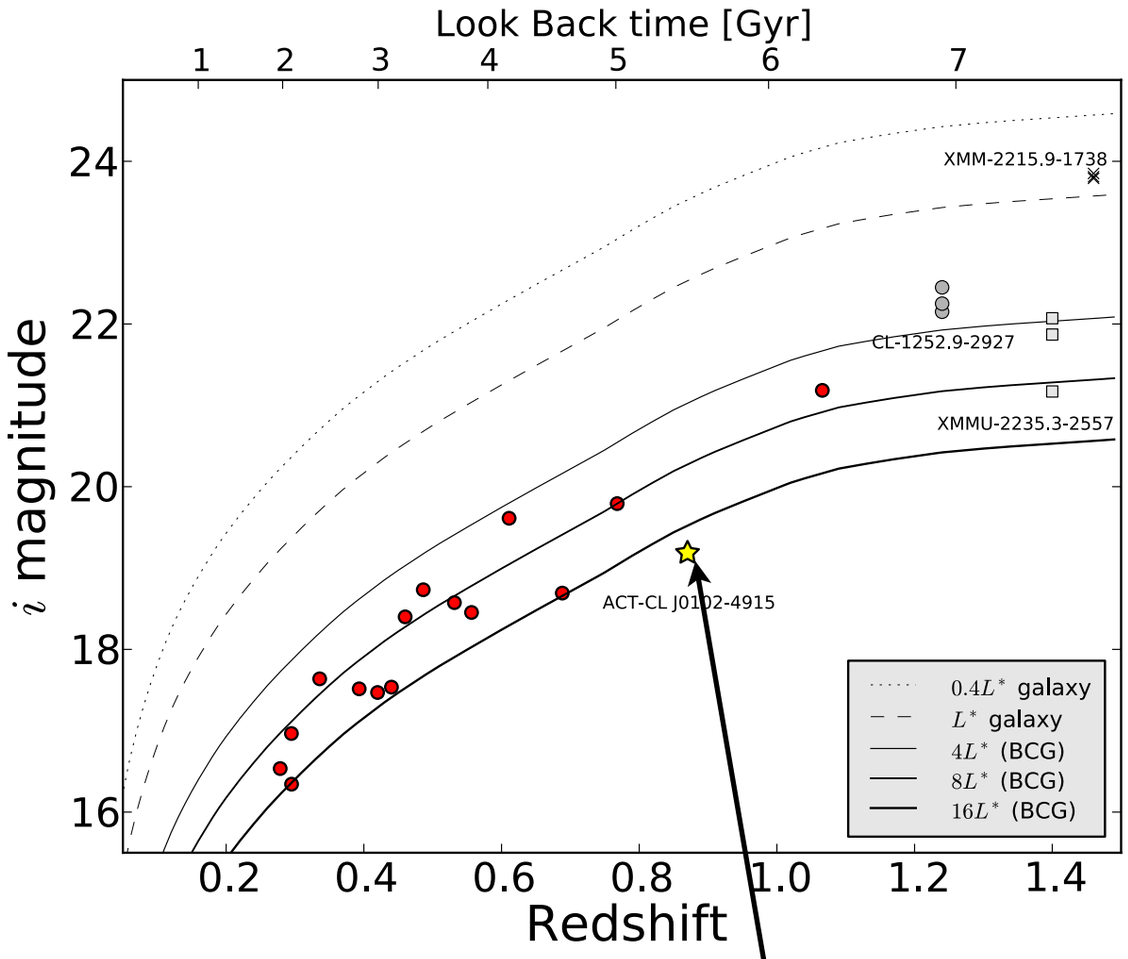
Mass ratio ~ 2 to 1

No such high-z mergers find in current large N-body Simulations (Cube3pm)

A new bullet at z=0.87?

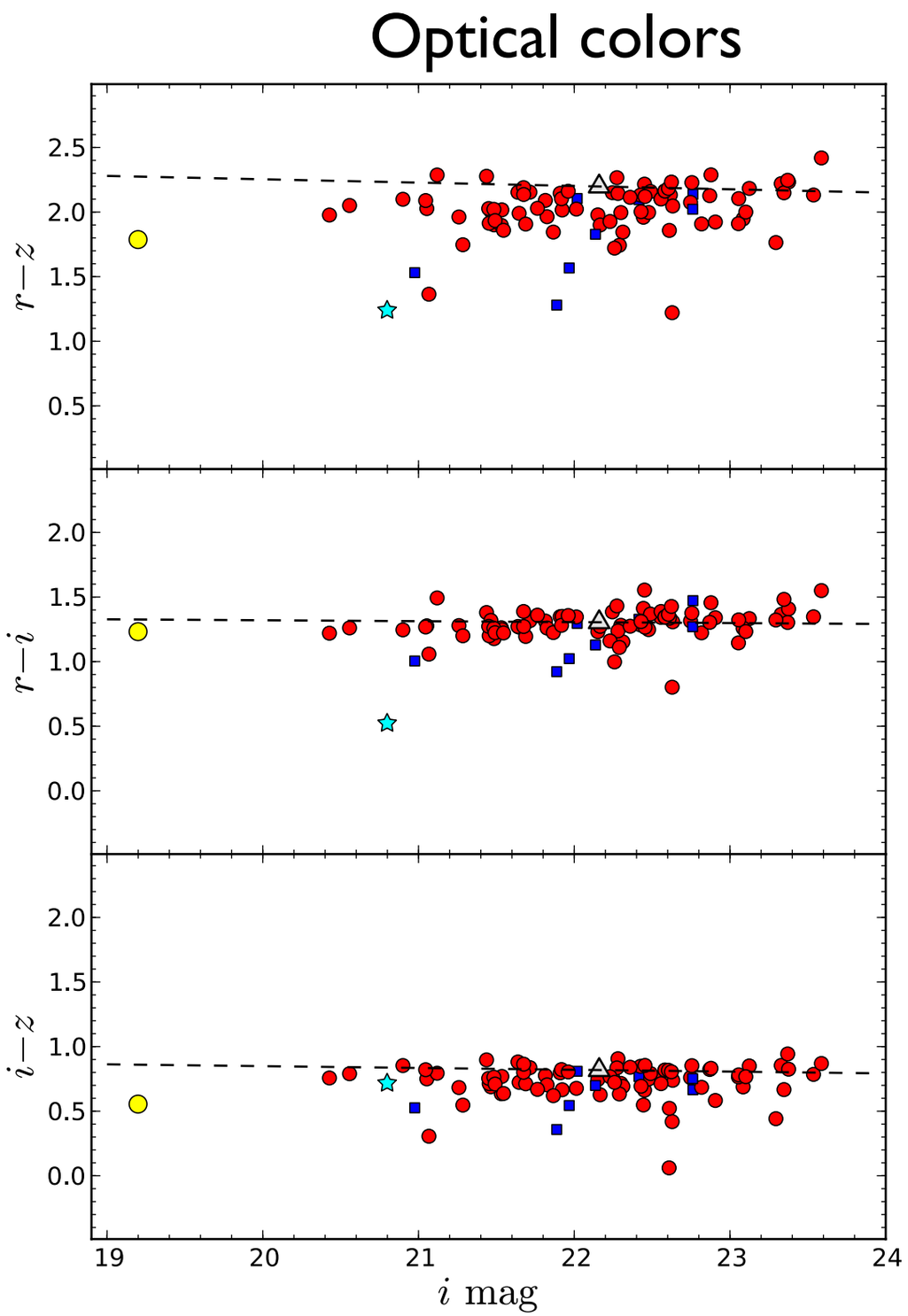
Menanteau et al. (2012, ApJ, 748,7)





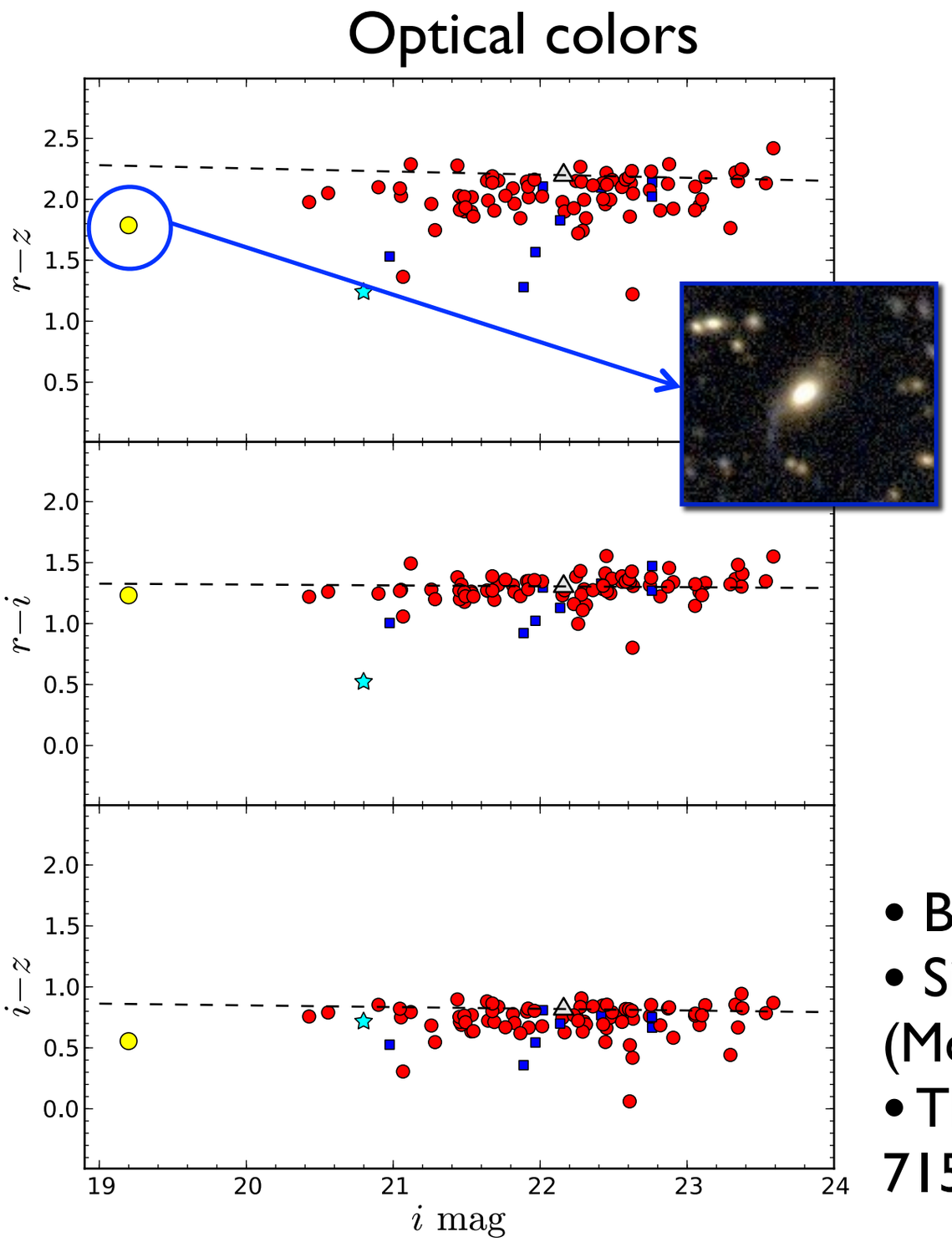
Very luminous BCG

Color-magnitude for ACT-CL J0102-4915

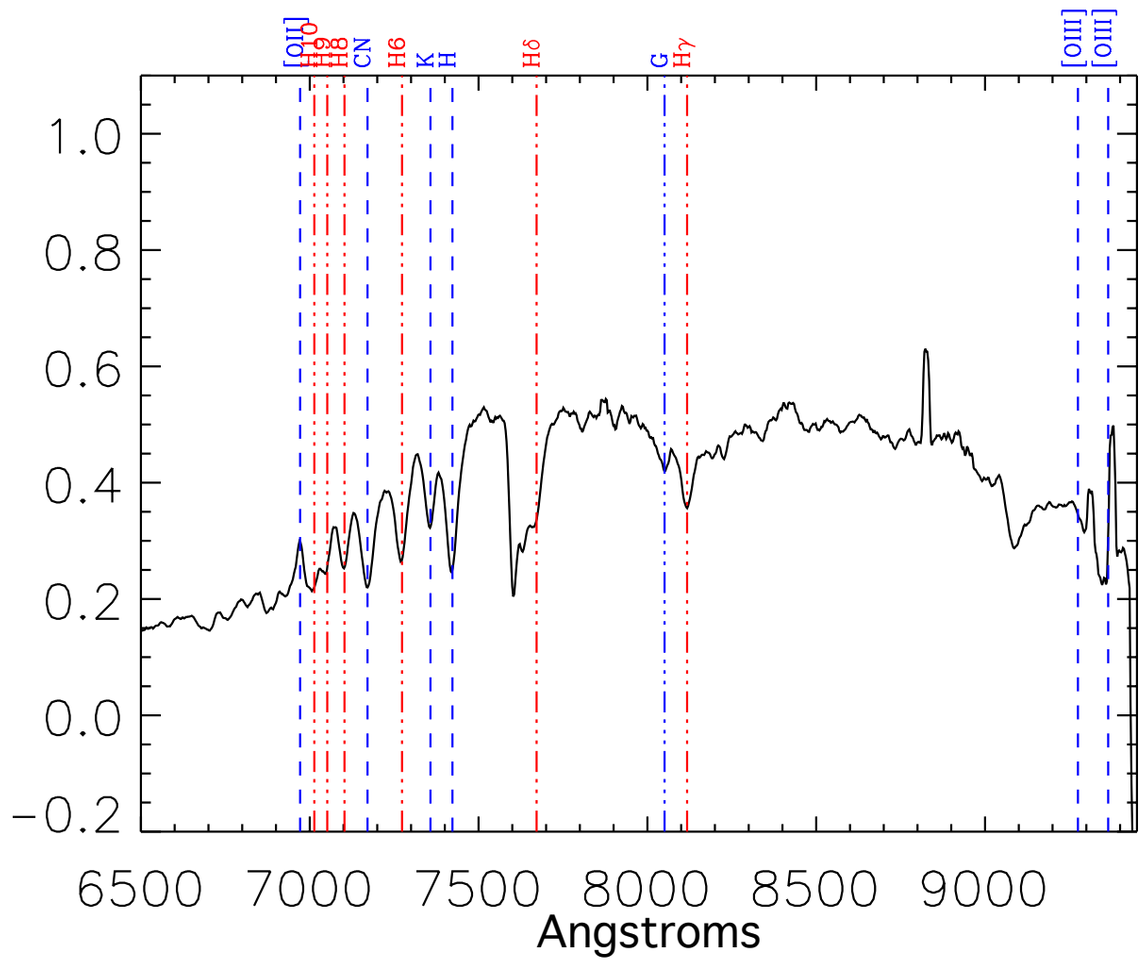


Menanteau et al. (2012, ApJ, 748,7)

Color-magnitude for ACT-CL J0102-4915

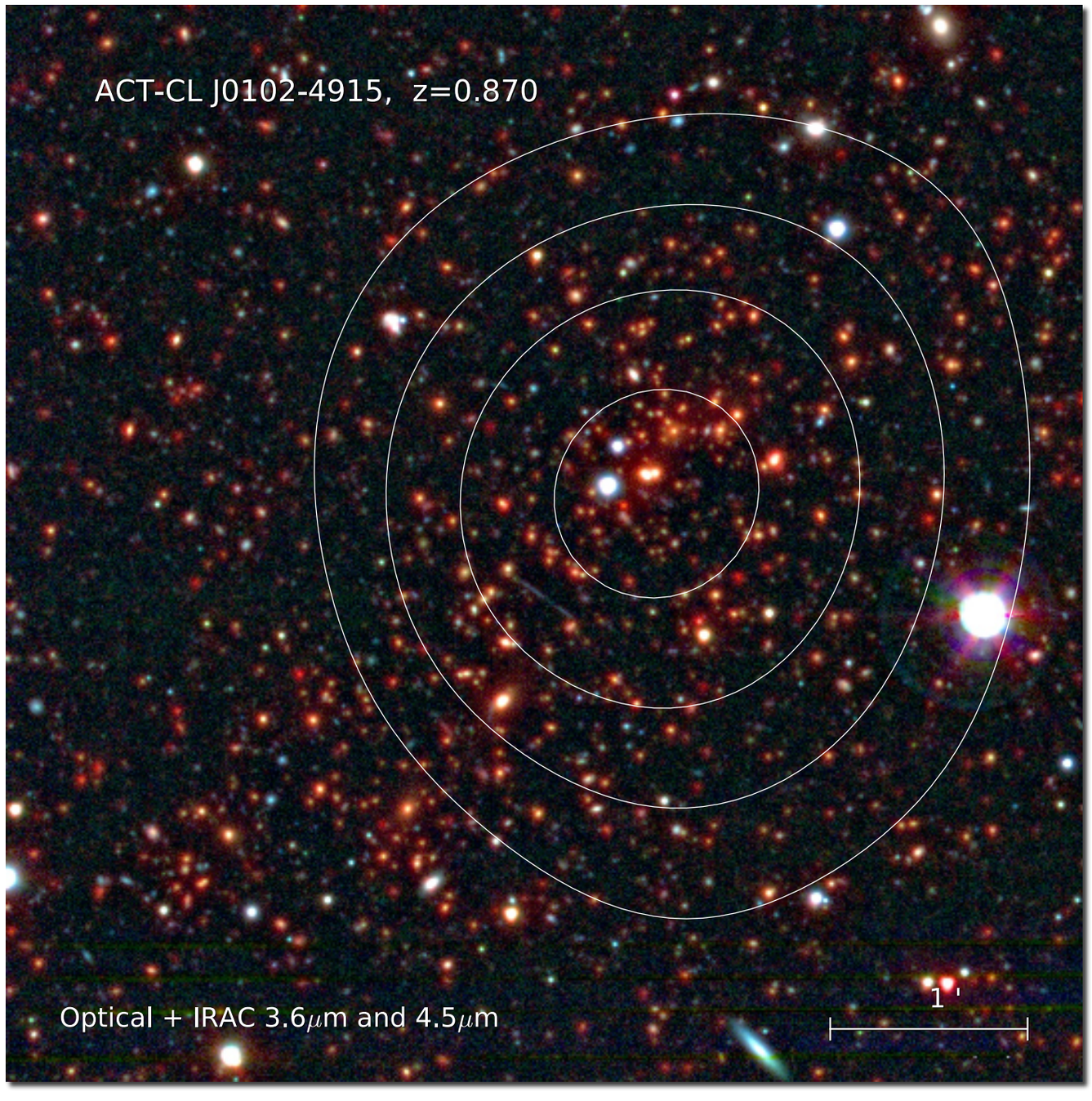


Menanteau et al. (2012, ApJ, 748,7)



- BCG is an E+A+[OII] galaxy (not red and dead)
- Similar to NGC 1275 in Perseus Clusters (McNamara 1996) and RXJ 1347 (z=0.45)
- The BCG sample in Donahue et al.(2010), ApJ 715, 881

Spitzer/Stellar Mass Content



Menanteau et al. (2012, ApJ, 748,7)

- Use g,r,i,z + Spitzer/IRAC 3.6um, 4.5um to estimate stellar mass content from SED fits (BC03)

$$M^*_{200} = (1.31 \pm 0.26) \times 10^{13} M_\odot$$

$$f^* = \frac{M^*}{M} = 0.6 \pm 0.2\%$$

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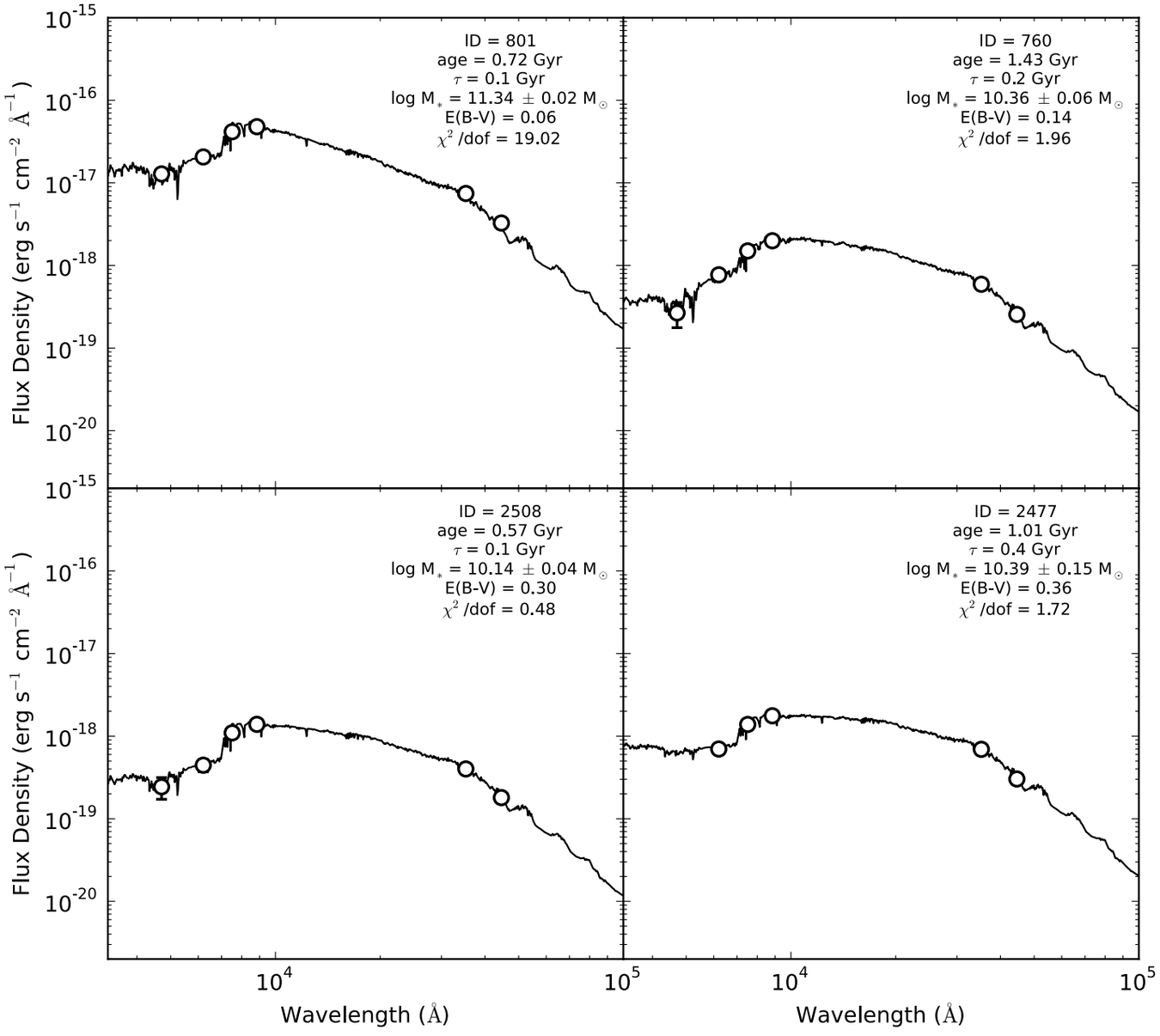

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