OBSERVING THE FRONTIER CLUSTERS WITH CHANDRA

C. JONES FOR THE CHANDRA FRONTIER CLUSTERS TEAM

Special thanks to Reinout van Weeren - lead for radio studies
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Primary Goals

- improve understanding of merger process
- map gas temperature and pressure and identify shocks
- compare radio relics and halos with cluster merger properties to understand particle acceleration
- understand merger effects on galaxy evolution
- characterize dark matter halos to 10^{13} M_{sun}

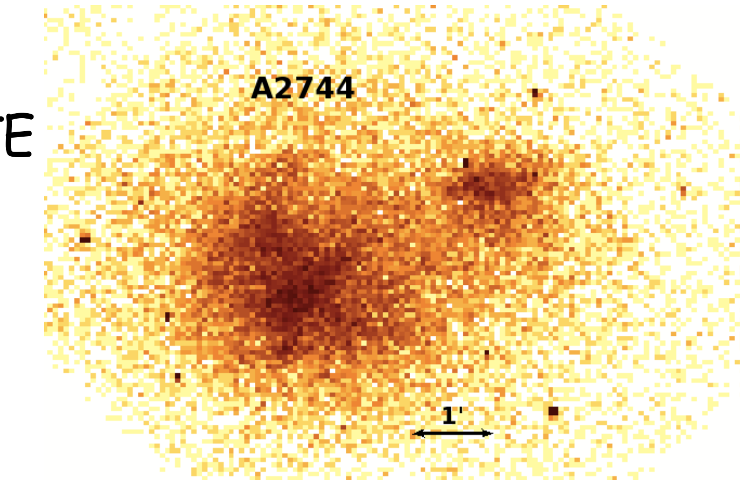
Observation Status

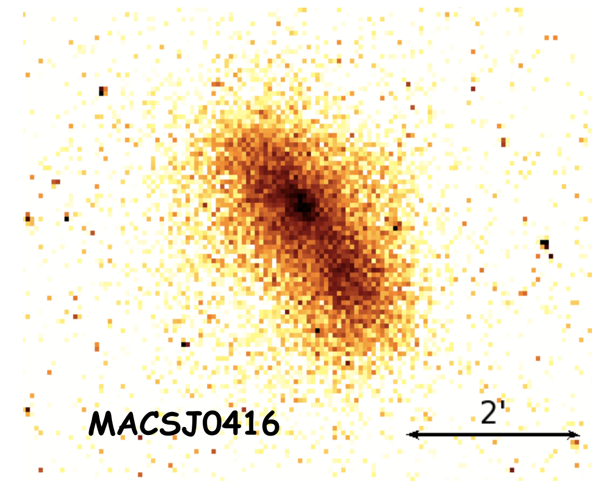
Results

- A2744 mergers and jellyfish (Owers et al. 2011, 2012)
- MACSJ0717 lensed radio and X-ray sources (van Weeren et al. 2014 in prep)

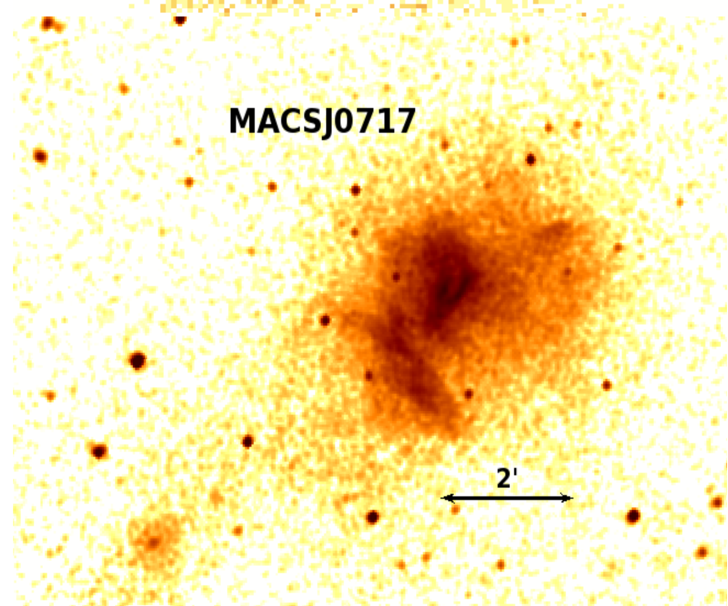
Chandra Observing Status

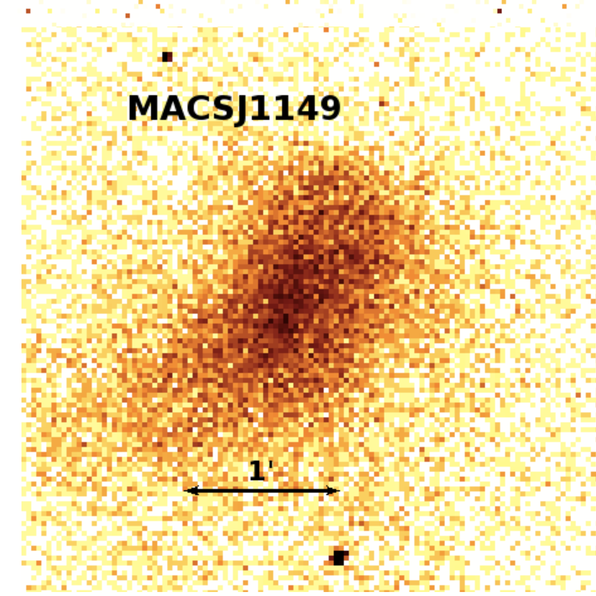
Abell 2744 (z=0.308) - 125 ks COMPLETE





MACSJ0416.1-2403 (z=0.396)
193 ks done; 107 ks (Dec 2014)



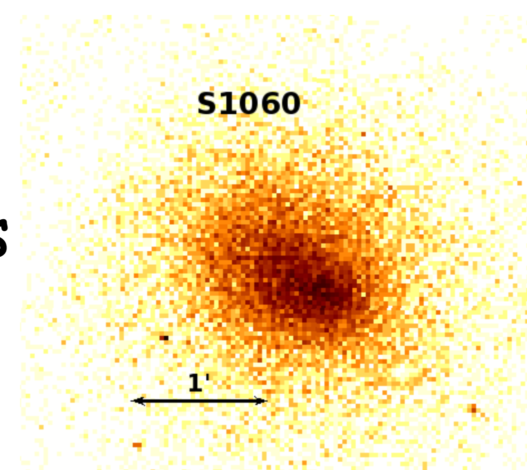


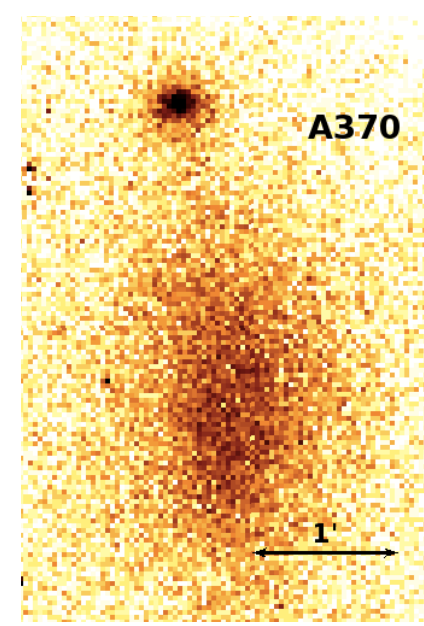
MACSJ0717.5+3745 (z=0.545)
243 ks COMPLETE

MACSJ1149.5+2223 (z=0.543)
140 ks done; 232 ks (Jan 2015)

Future

Abell S1060 (RXCJ2248.7-4431) (z=0.348) 27 ks
Abell 370 (z=0.375) 95 ks



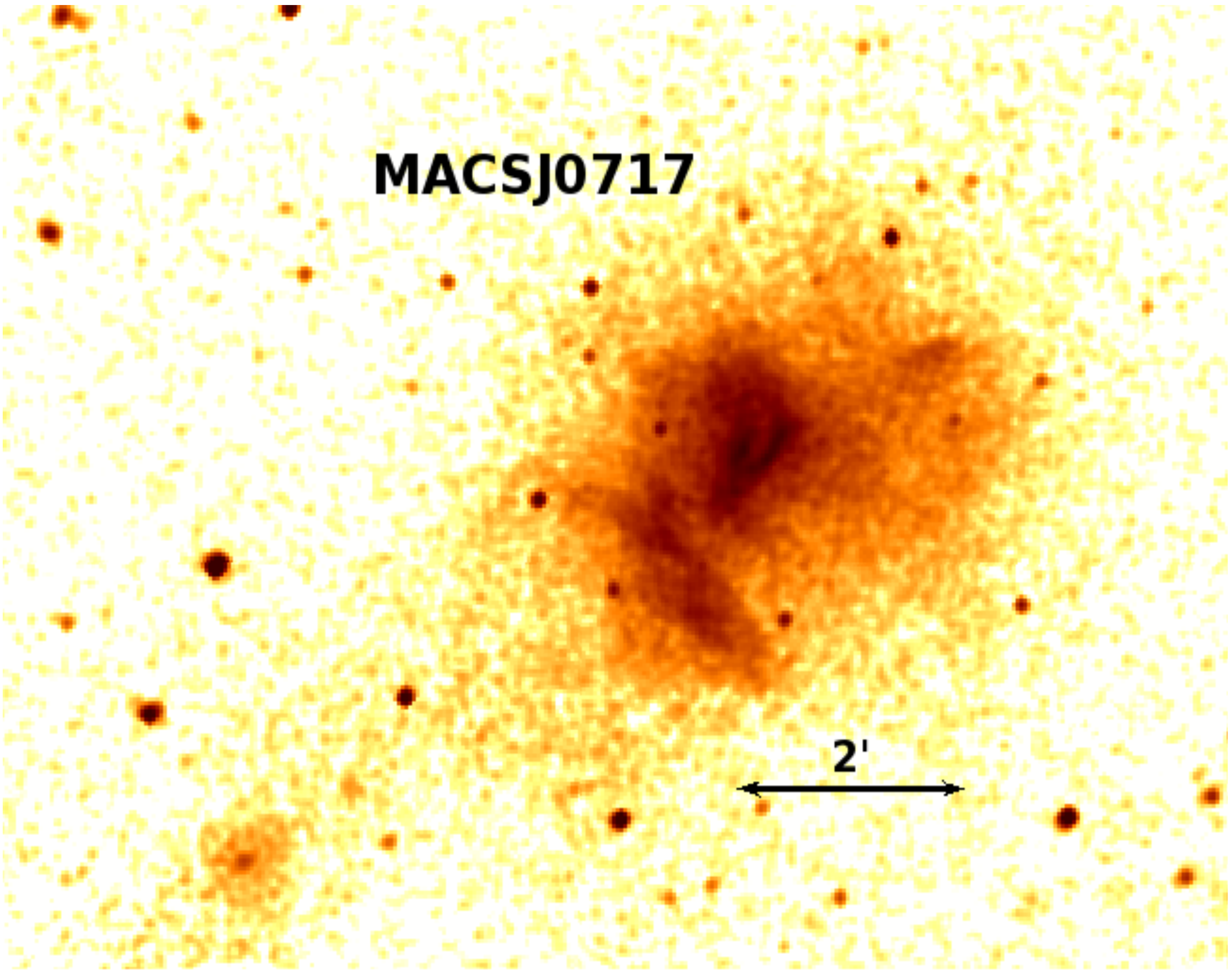


Deep radio observations lead by R. van Weeren

Cluster growth through mass accretion

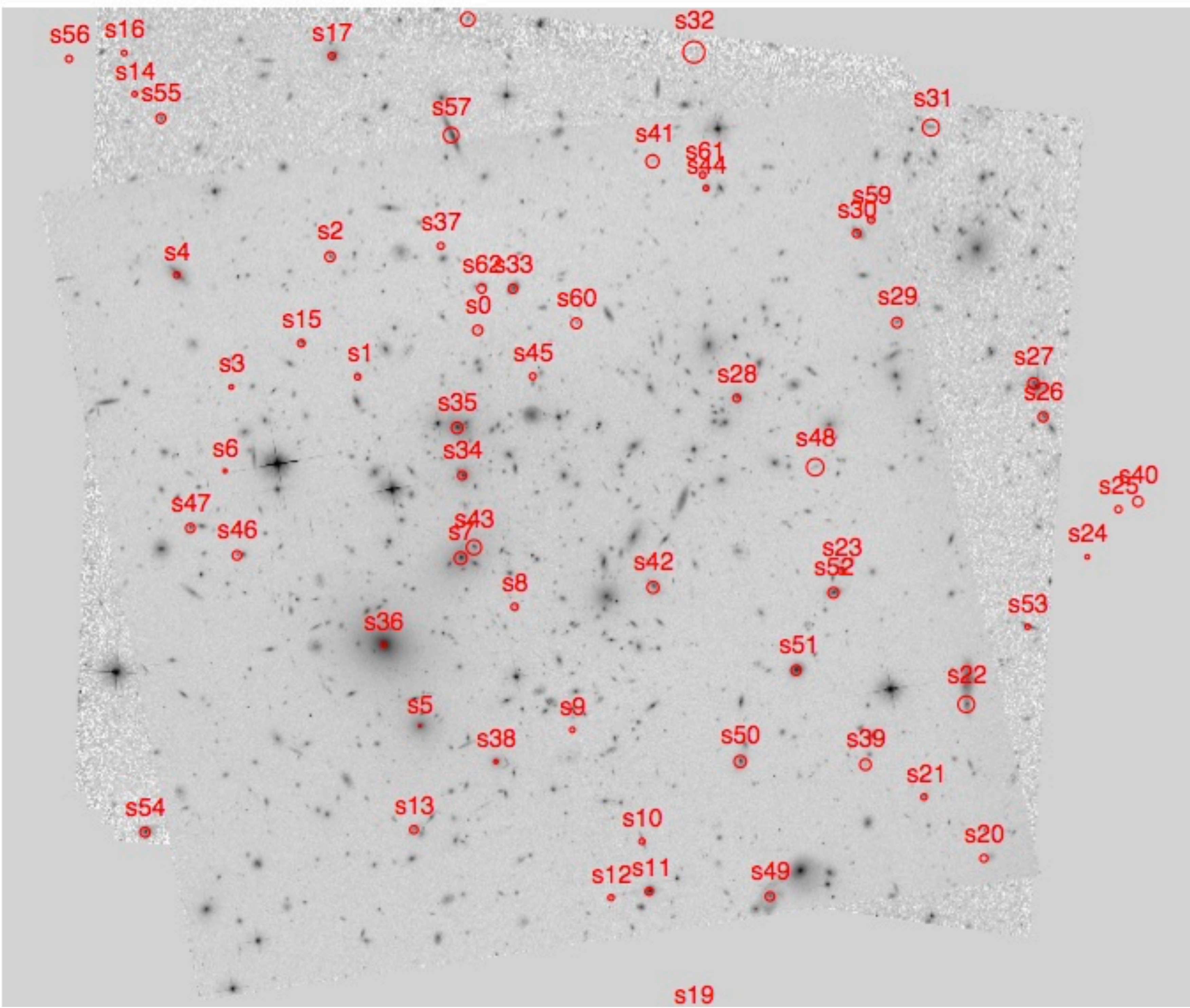
1) "Steady" infall of matter from filaments
2) Infall of groups
3) Major mergers

In MACS0717 all of the above- Talk by Felipe Andrade-Santos



Clusters as cosmic telescopes

MACS J0717.5+3745 - Radio sources



Deep JVLA observations

1.0-6.5 GHz in A and B configurations

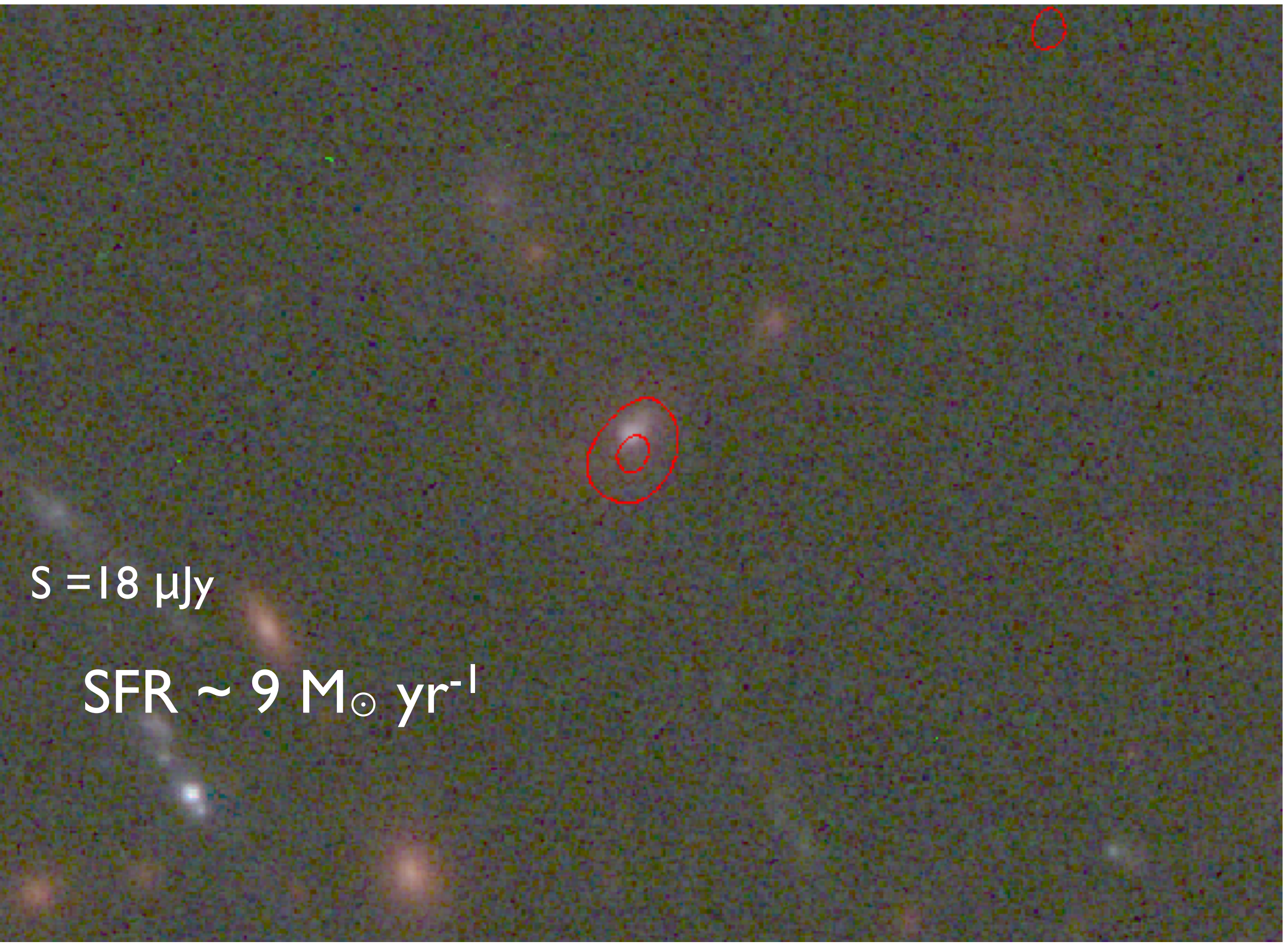
8 sources with multiplication factors >2

Most are likely star forming galaxies

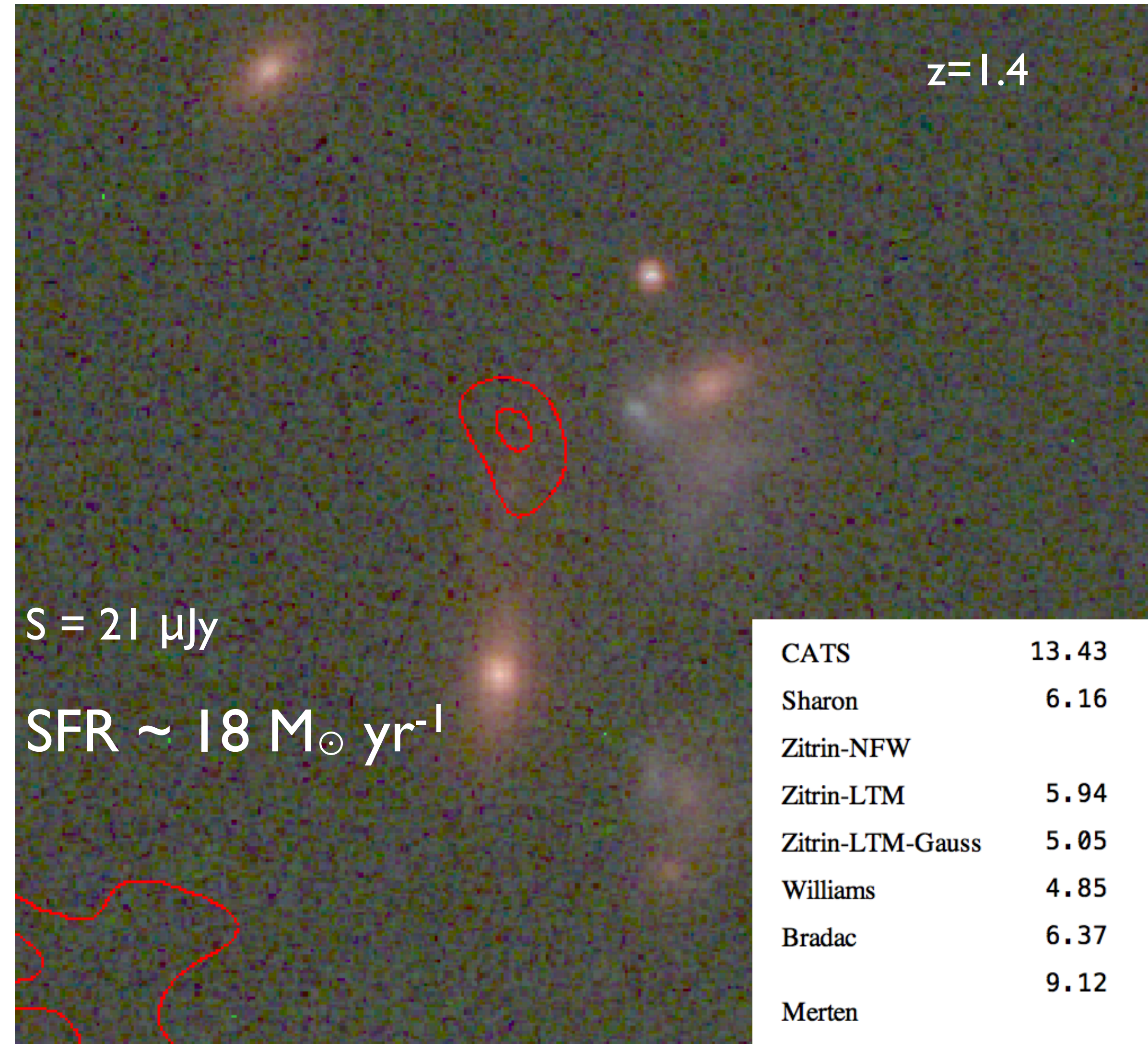
R. van Weeren et al 2014 (in prep)

MACS0717 z>1 lensed radio sources

van Weeren et al. 2014 (in prep)



z=1.1



CATS	13.43
Sharon	6.16
Zitrin-NFW	
Zitrin-LTM	5.94
Zitrin-LTM-Gauss	5.05
Williams	4.85
Bradac	6.37
Merten	9.12

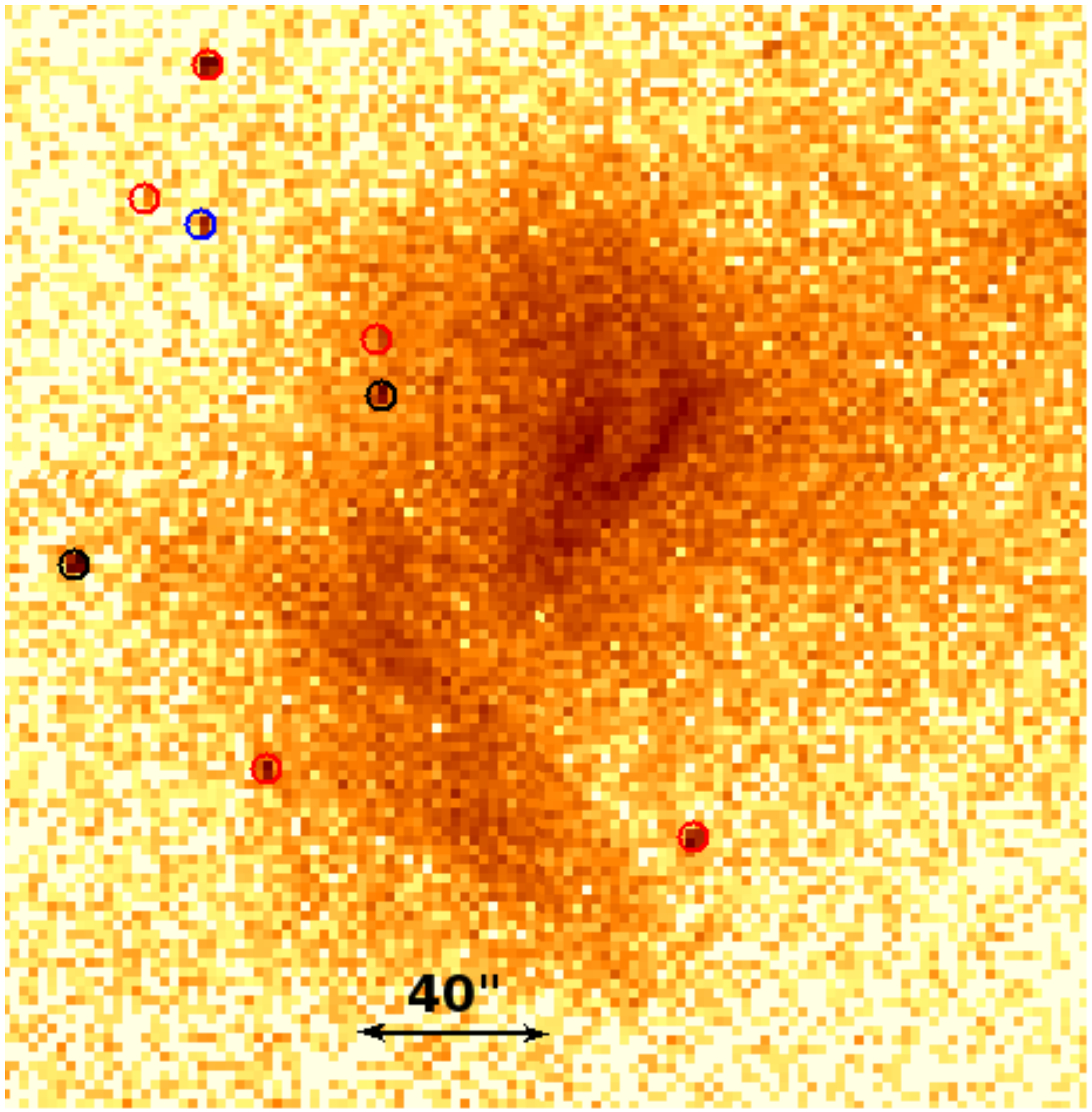
Factor > 7 magnification
Most detected sources have lower magnification

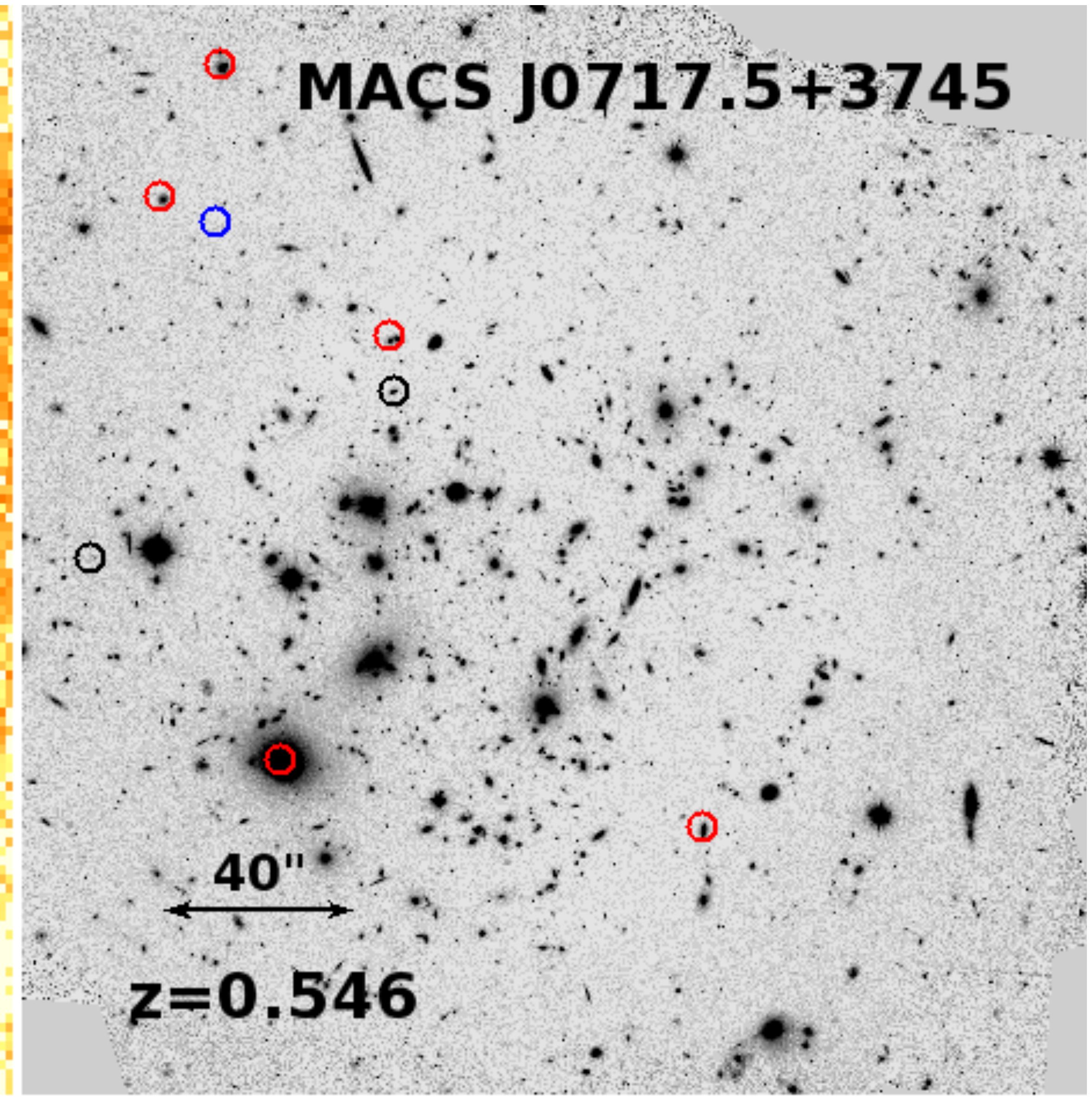
$$\frac{\dot{M}_*}{M_\odot \mathrm{yr}^{-1}} \approx 4.5 \left(\frac{\mathrm{GHz}}{\nu}\right)^{-\alpha} \frac{L_\nu}{10^{22}\,\mathrm{W\,Hz^{-1}}}.$$

Clusters as cosmic telescopes –
study the faint radio source population at the level otherwise only possible with the SKA

MACS J0717.5+3745

243 ks
80K source counts

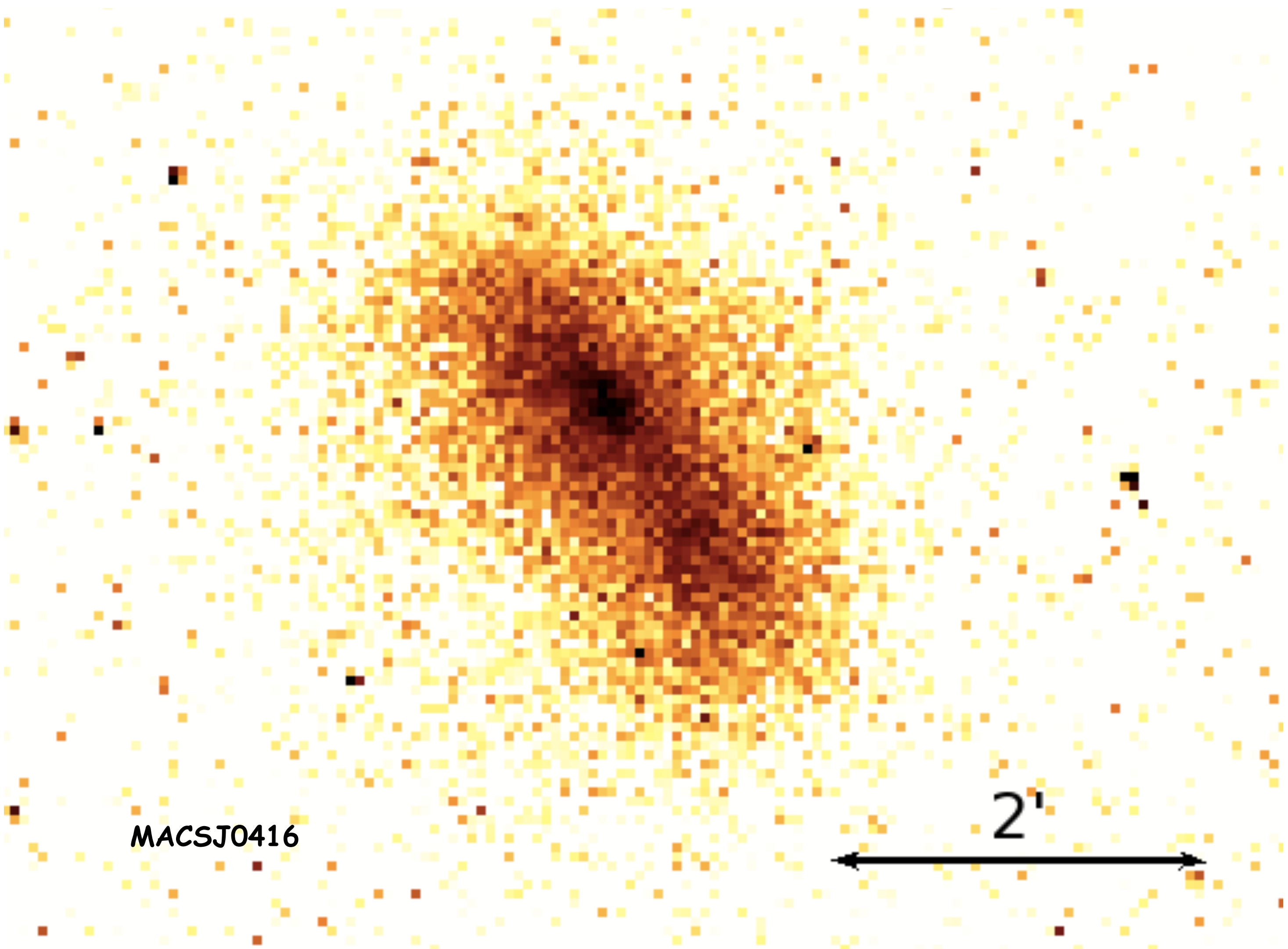




Red = X-ray/optical
Black = X-ray/radio/optical
Blue = X-ray

R. van Weeren, C. Jones, W. Forman, F. Andrade-Santos, S. Randall, S. Murray, A. Bonafede, E. Roediger, R. Kraft, E. Bulbul

MACSJ0416.1-24.3 z=0.397 193 ks Chandra



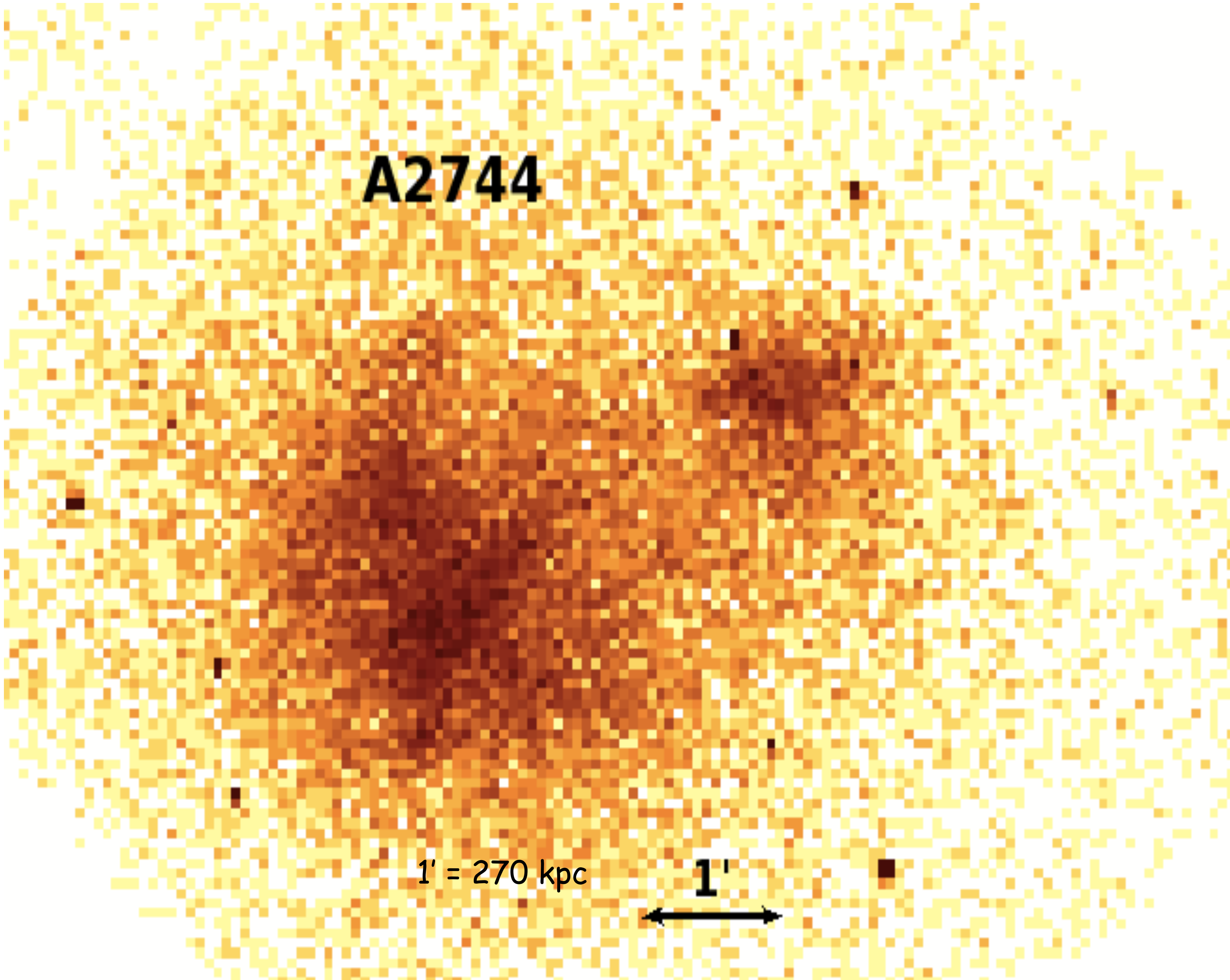
Classed as actively merging, after the primary collision, based on 16 ks Chandra (Mann & Ebeling 2012)

Determined to be either pre-merger or post-merger based on 53 ks Chandra, plus galaxy spectroscopy and lensing analysis (Jauzac et al. 2014)

Merger state determined from our deep Chandra observations (talk by Georgiana Ogrean)

Also CLASH Cluster (Postman et al.)

Abell 2744 (z=0.308) 125 ks Chandra Complete

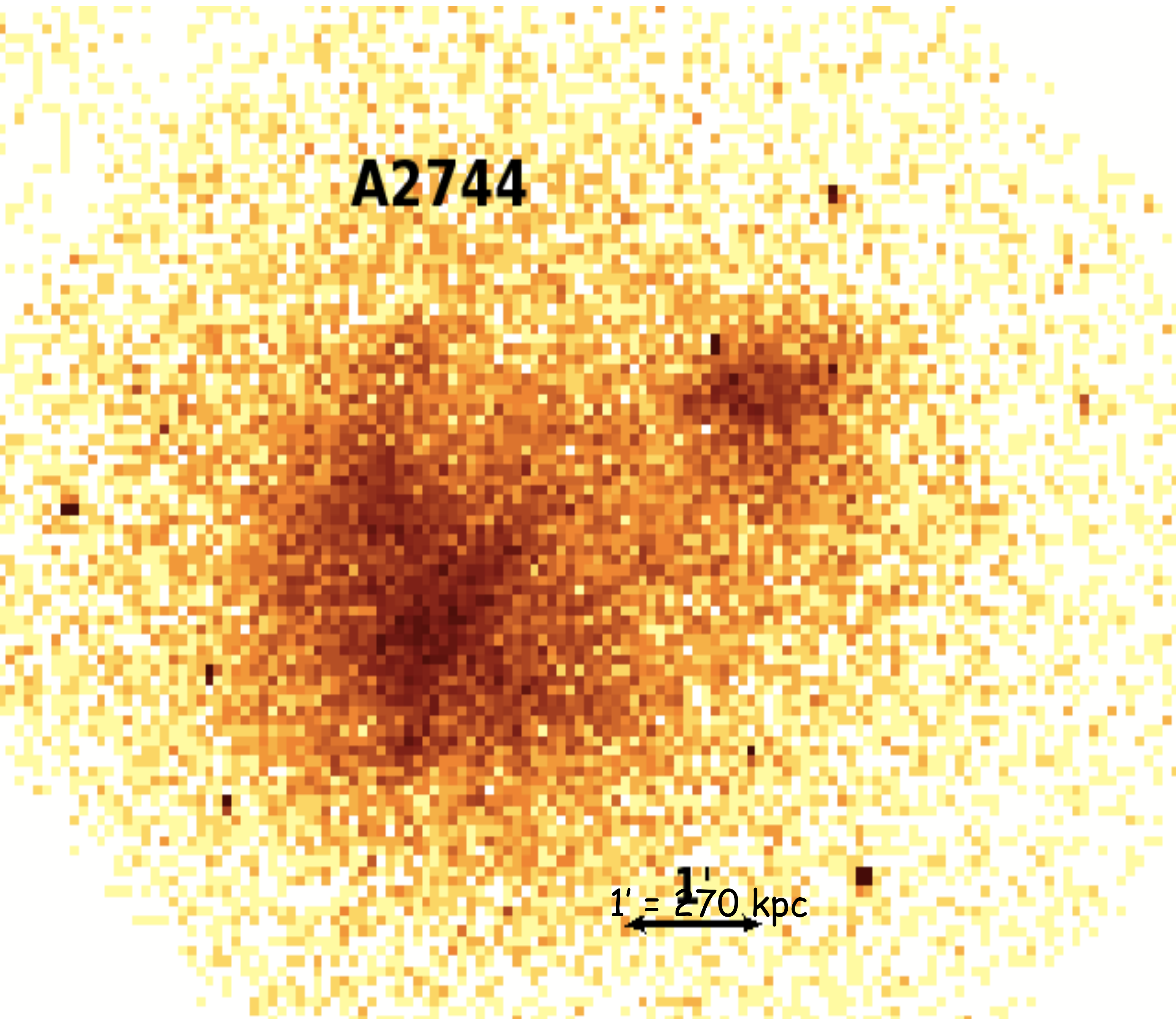


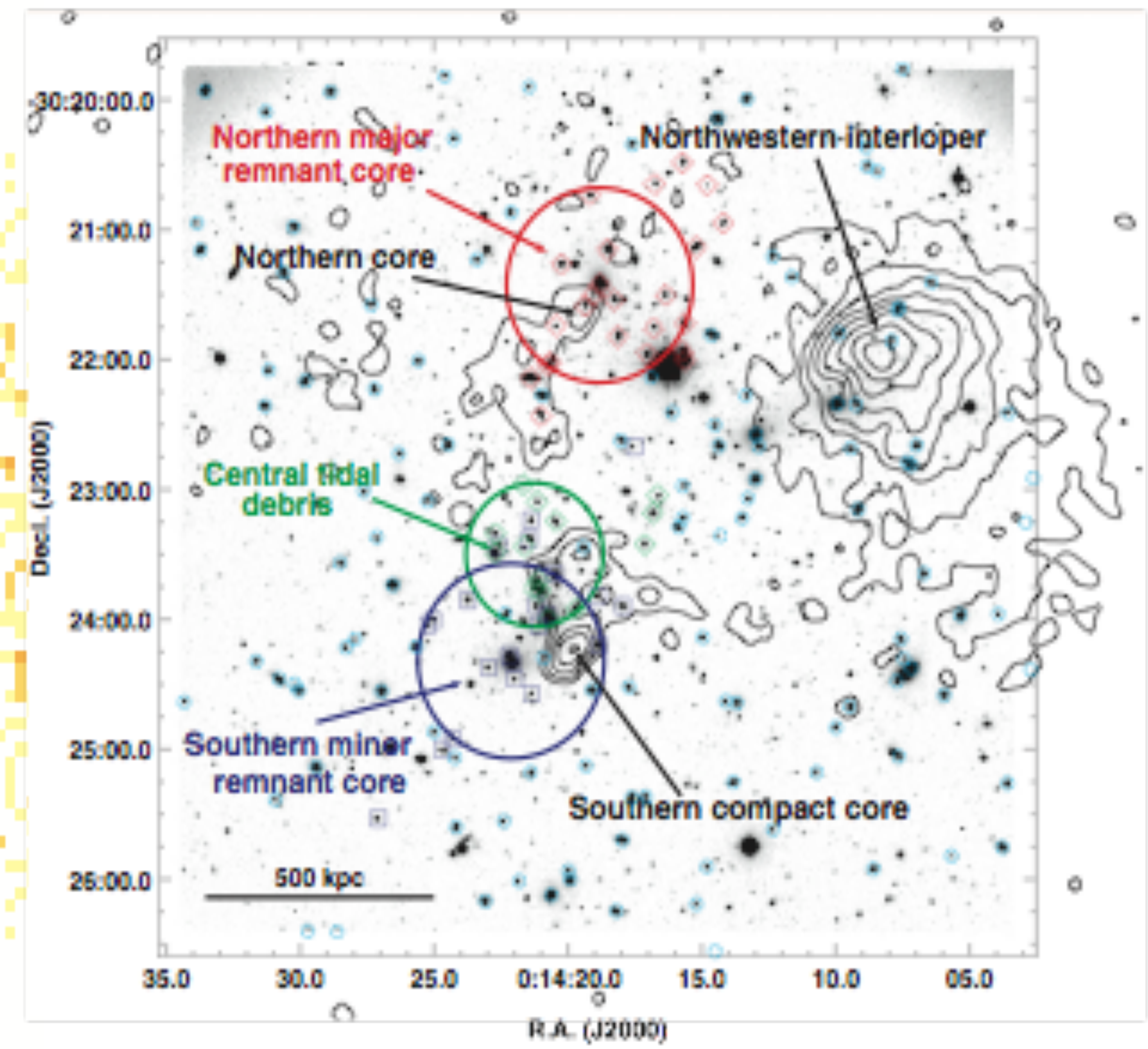
X-ray luminous (10^{46} erg/s and hot (9 keV)

Major post core crossing merger

Owers et al. 2011

Abell 2744 (z=0.308) 125 ks Chandra Complete

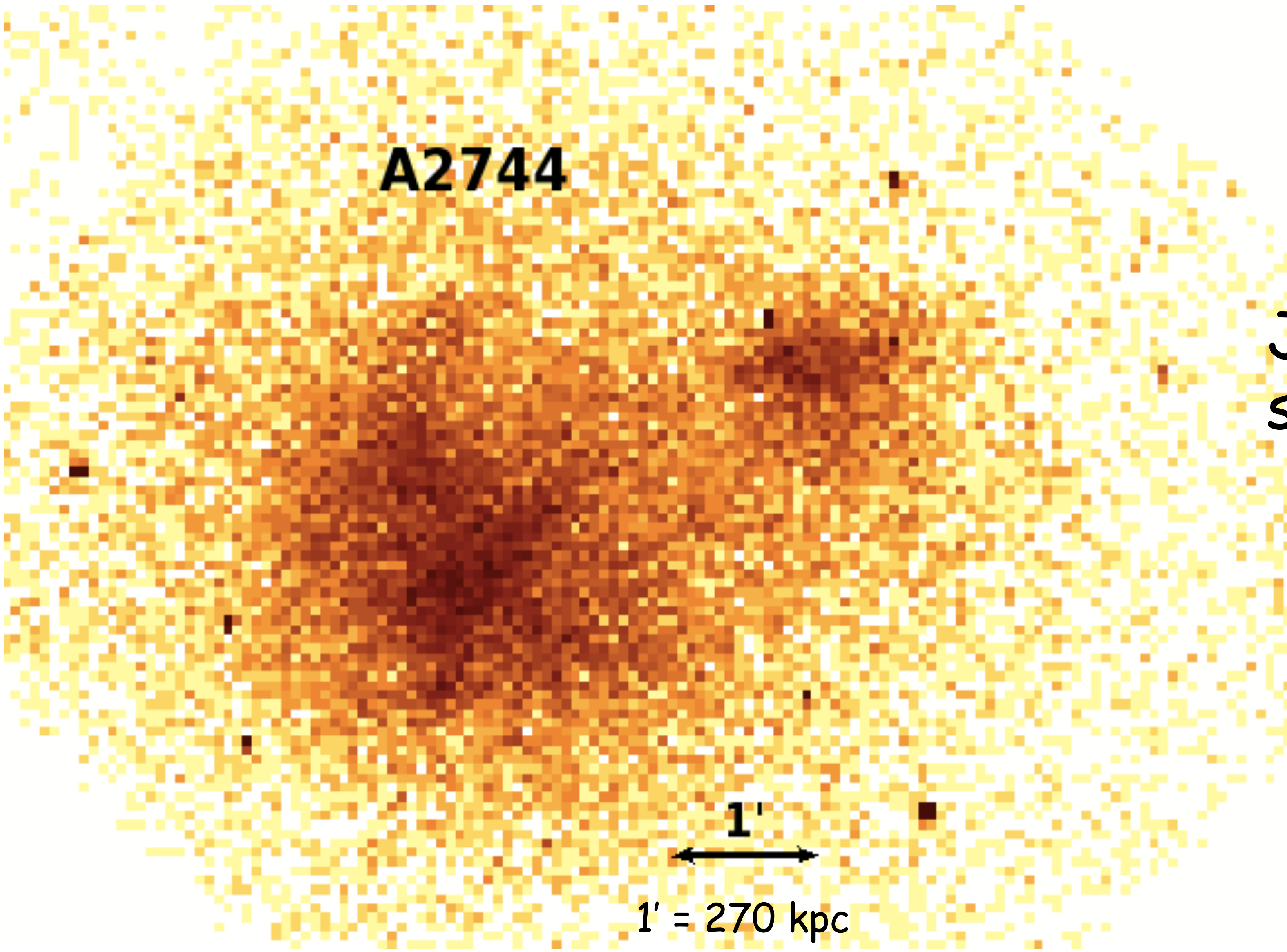




- Major post core crossing merger
  - North and south cores plus debris
    X-ray cores fully disrupted
    X-ray peak has no major galaxy concentration
- Northwestern interloping merger

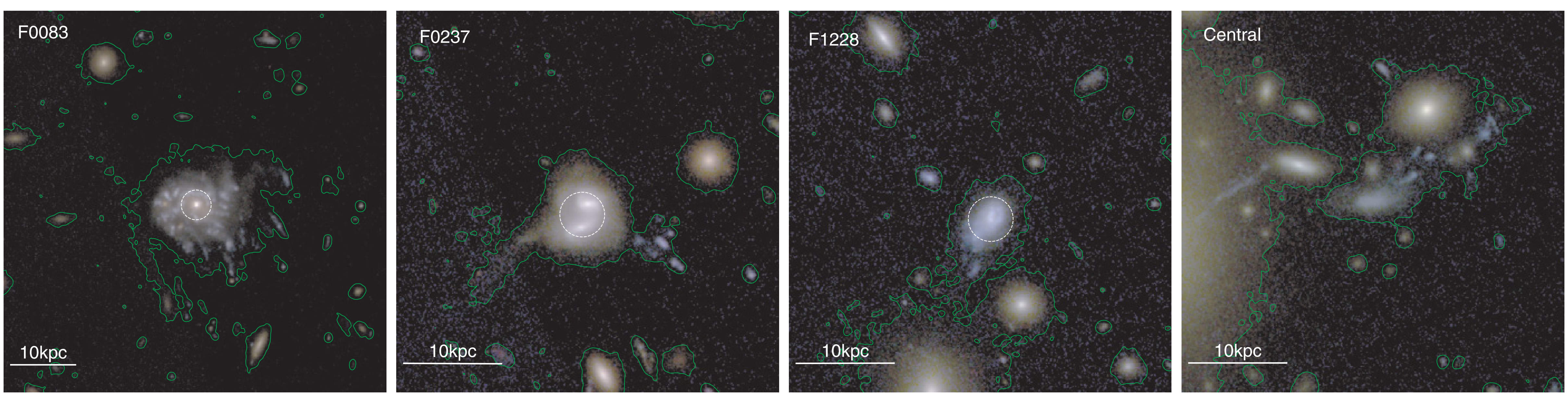
Owers et al. 2011

Abell 2744 (z=0.308) 125 ks Chandra Complete

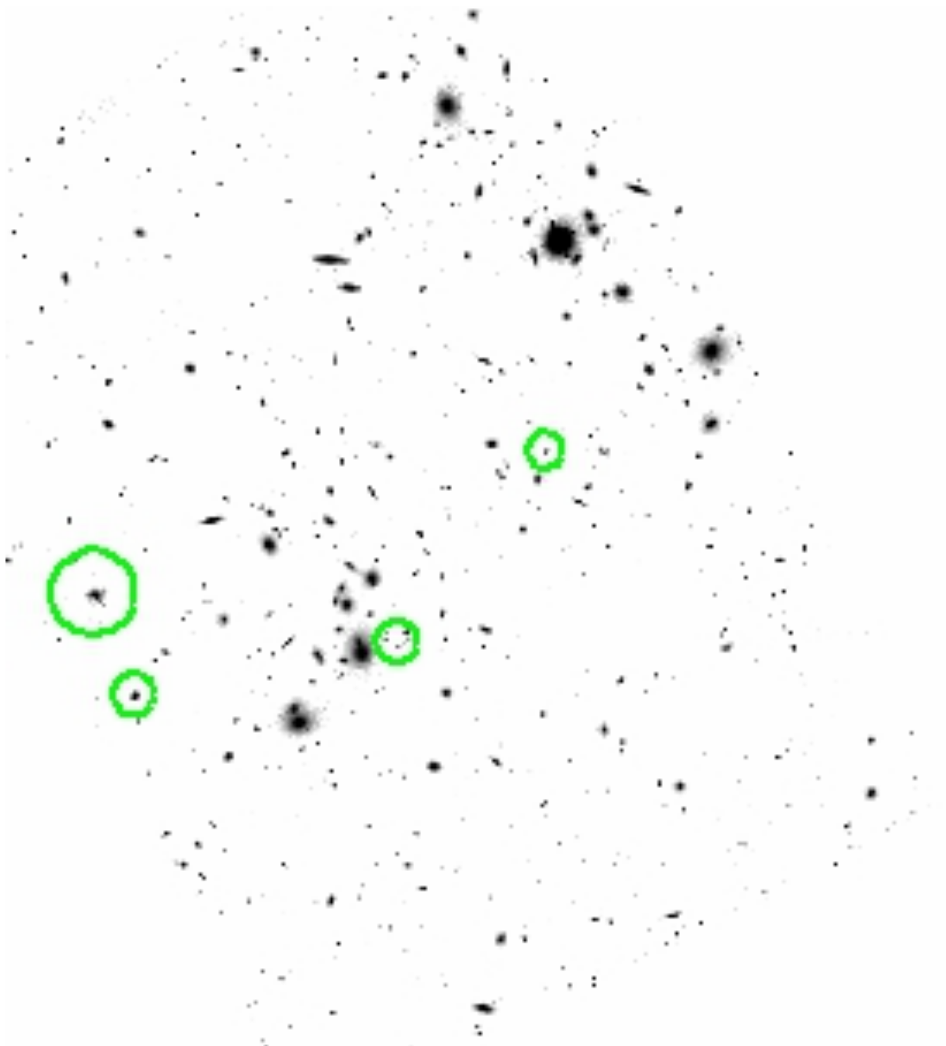


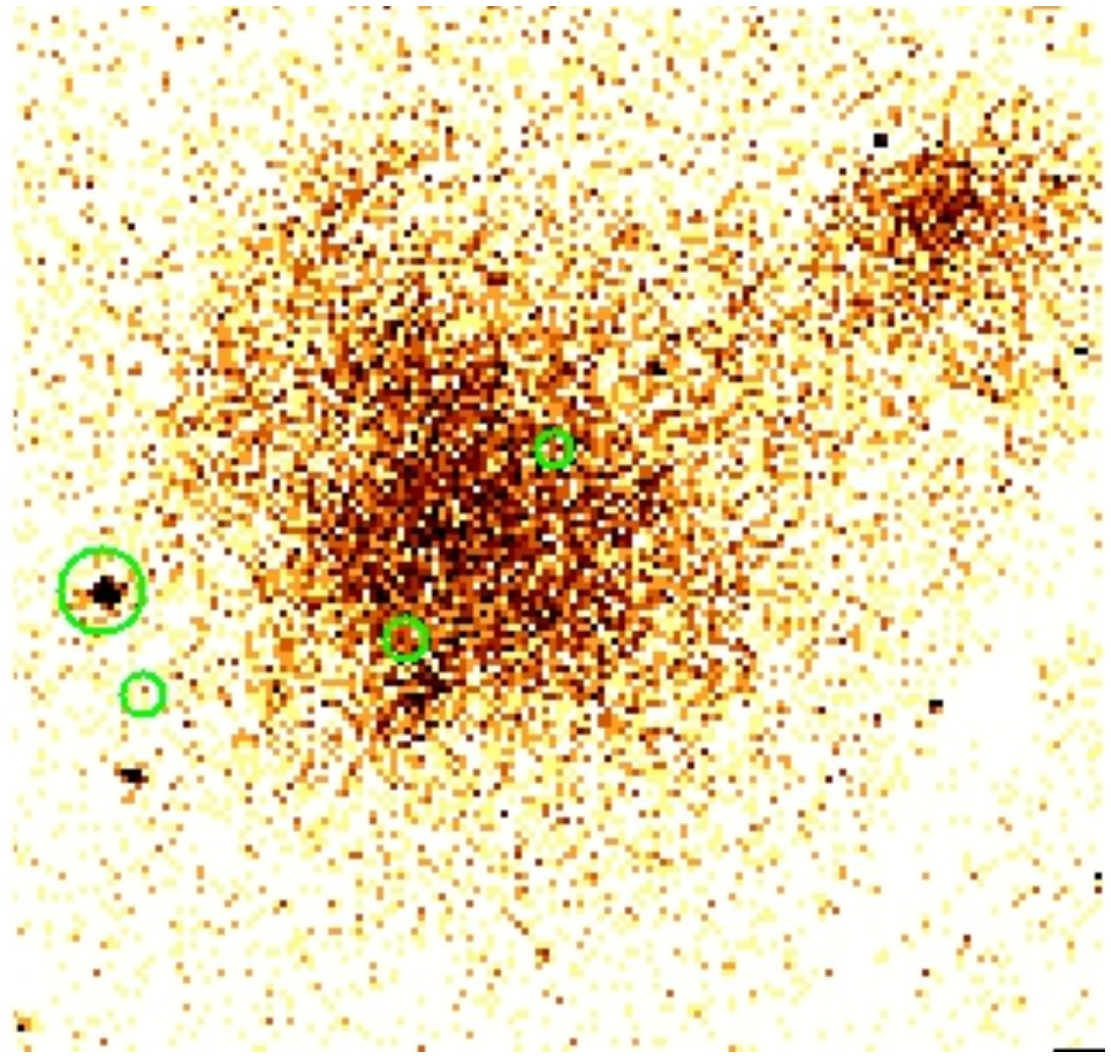
Jellyfish galaxies with induced star formation from high pressure environment

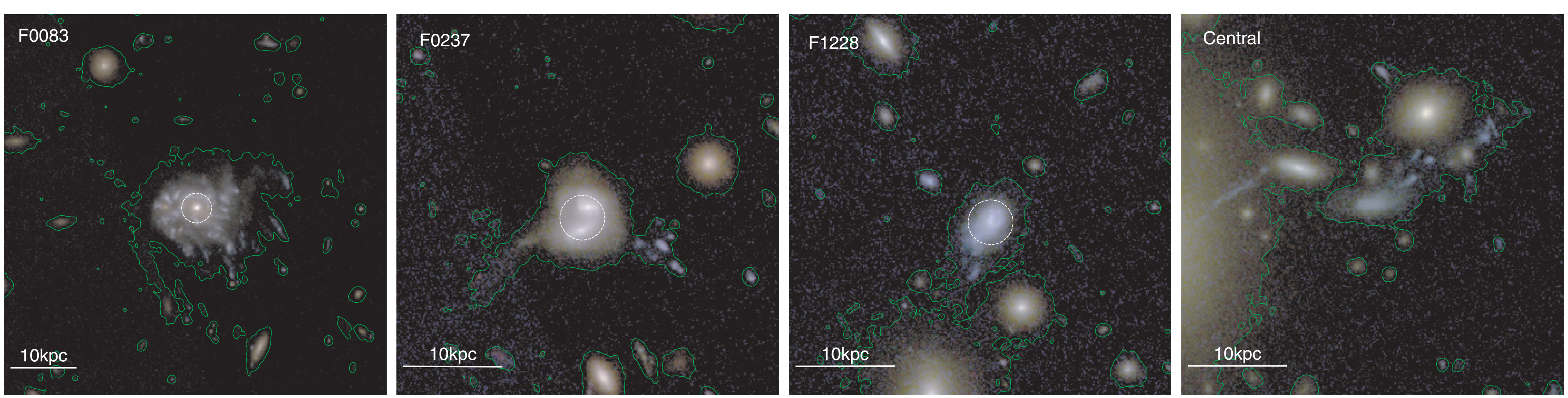
Owers et al. 2012

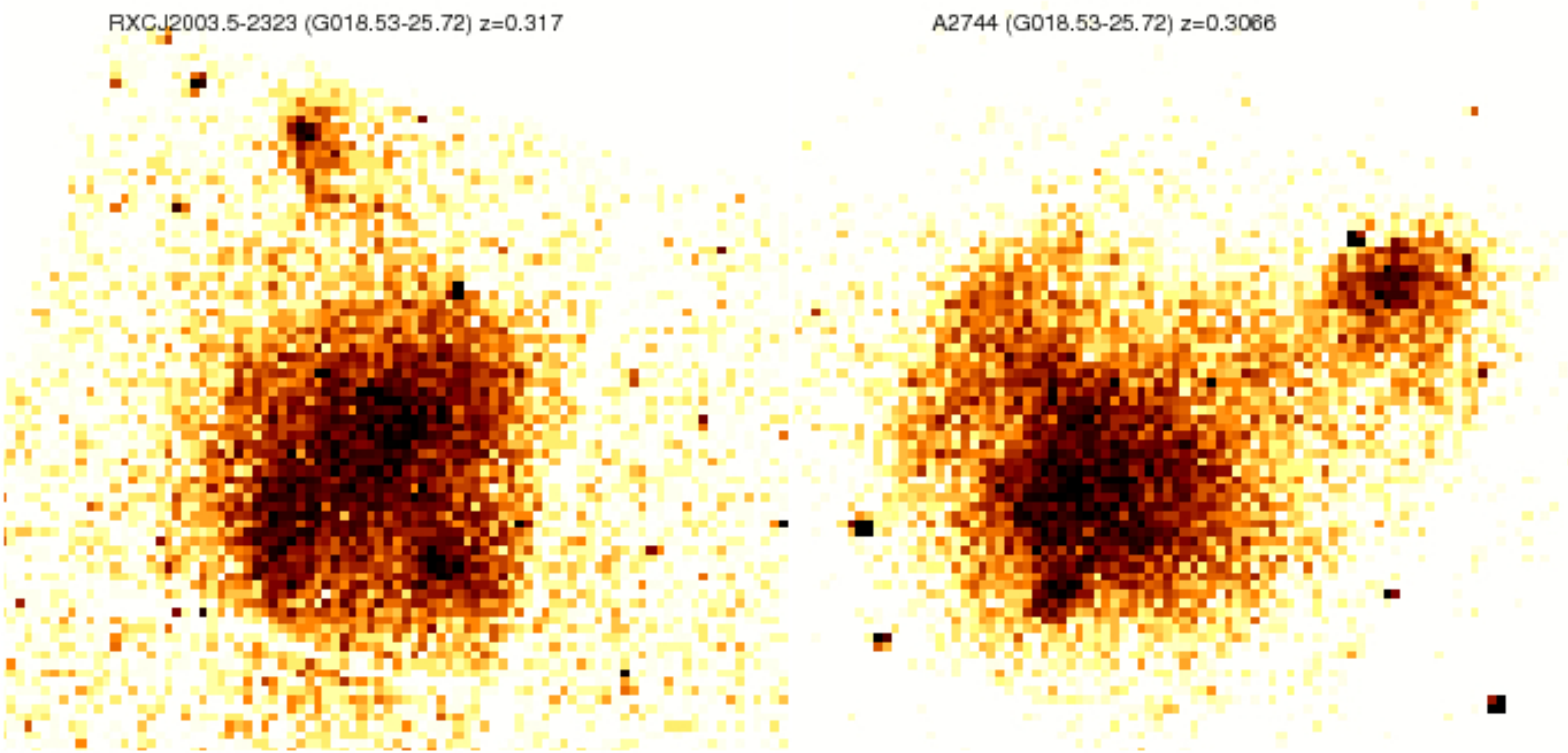


Abell 2744 - Jellyfish galaxies (Owers et al. 2012)









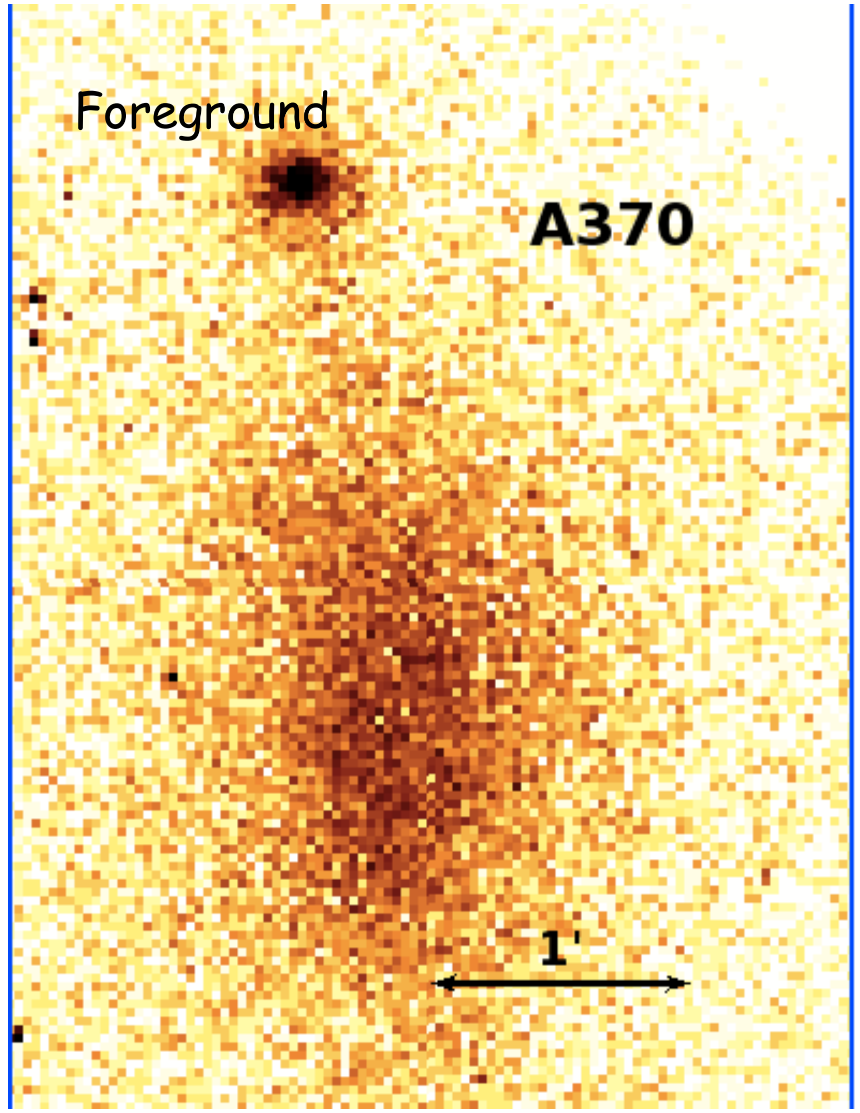
A "TWIN" TO A2744 ?

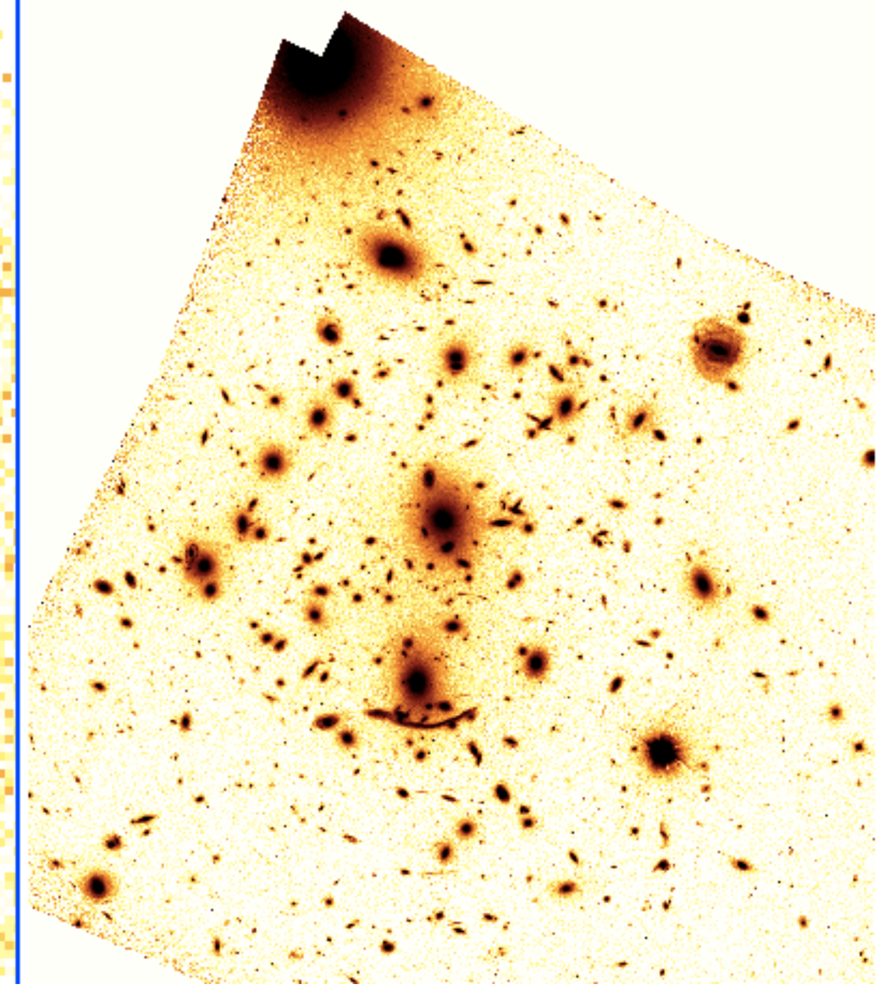
G018.53-25.72 from the Chandra – Planck sample

ABELL 370 (Z=0.375) 95 KS CHANDRA

- A Frontier cluster for HST cycle 3
- Two primary BCGs
- N-S Orientation

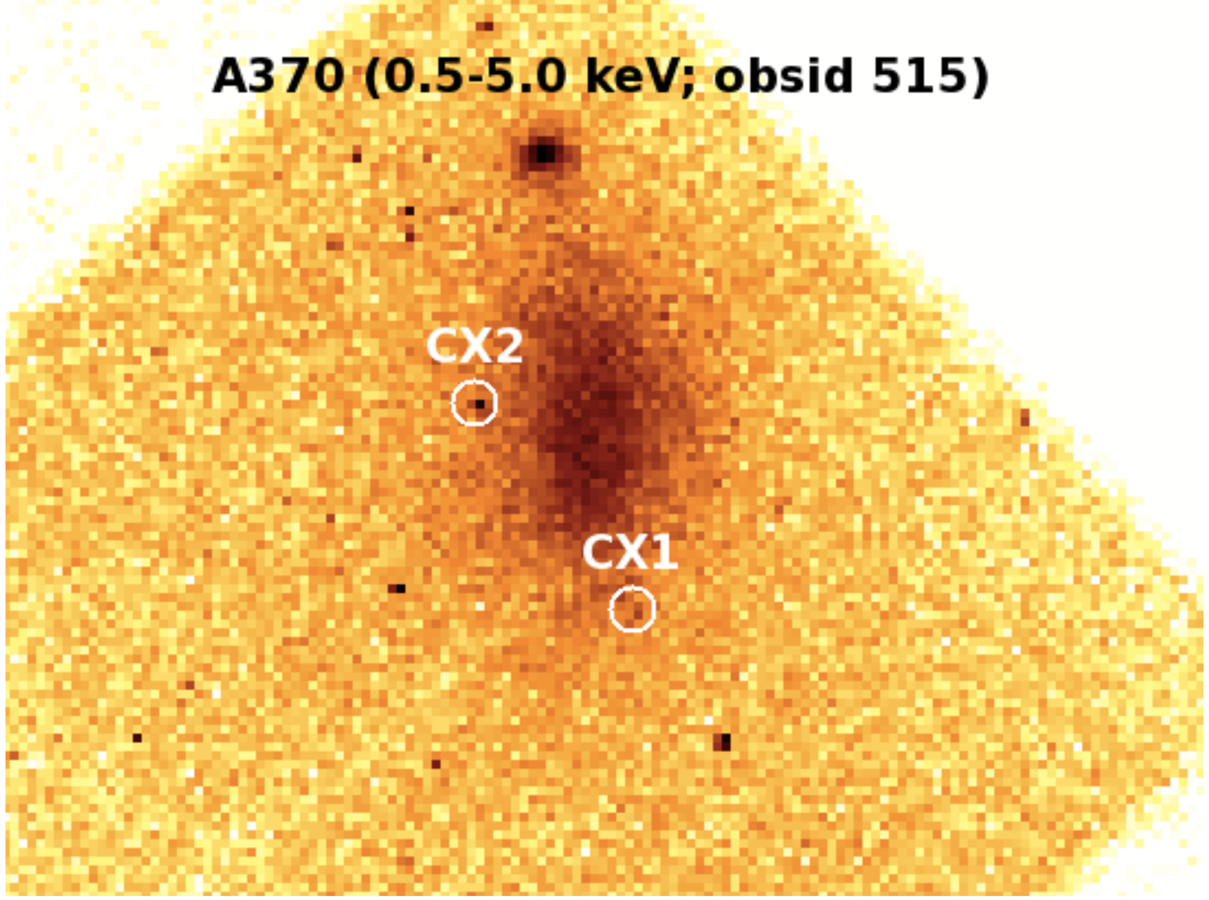
- Studied by Bautz et al. (2000)
  - Studied triaxiality
  - Detected submm galaxies

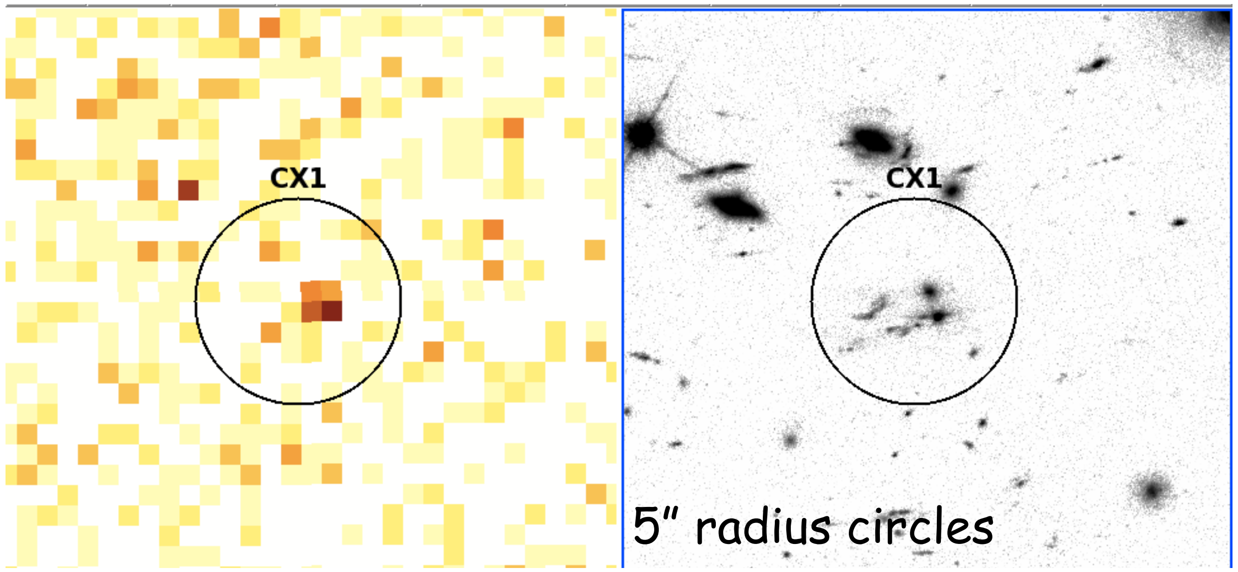


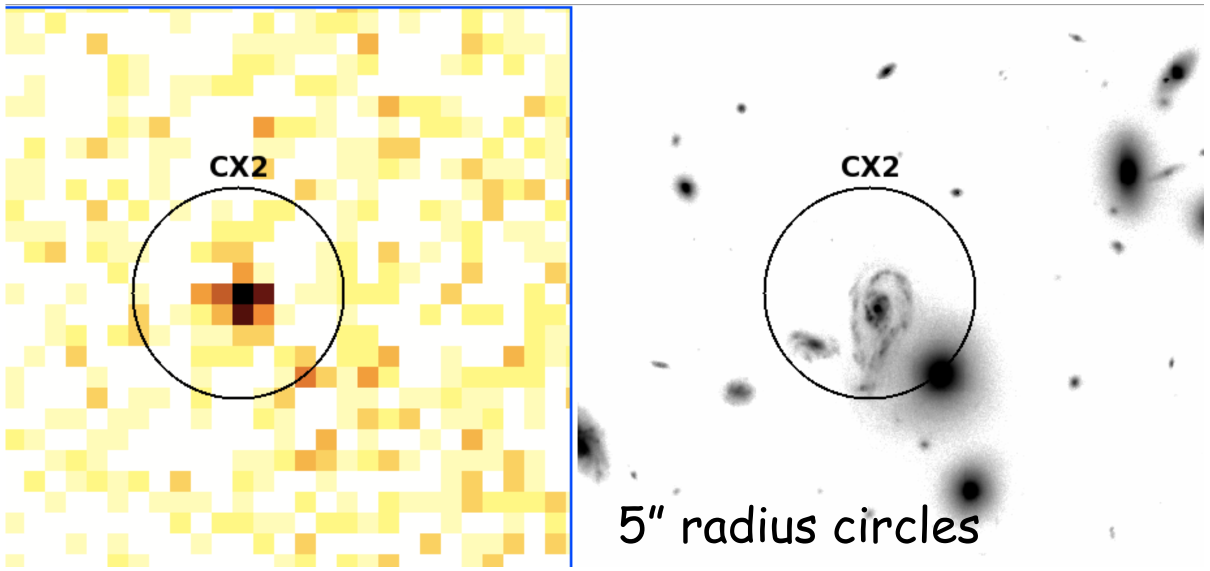


ABELL 370 - TWO LENSED SUBMM GALAXIES

M. Bautz+ 2000







CX1
z=1.06

Magnification ~ 2.5 (Kneib+93, Ivison+98, Soucail+99)
L_x (observed) > 10^{43} erg/sec
Hard X-ray spectra — $n_H > 2\times10^{23}$ cm^{-2}

CX2
z=2.81

L_x (unabsorbed) > 10^{44} erg/sec
AGN emission — not starburst

Summary and the Future

- Chandra and JVLA observations underway

- New insights for cluster mergers and Frontier field structures
- Talks by Andrade-Santos on MACSJ0717 and Ogrean on MACSJ0416

- Just beginning study of lensed radio and X-ray galaxies (e.g. MACSJ0717
  - Primarily modest magnifications (1-3)
  - Two magnification > 7 X-ray/radio sources
  - Radio emission usually consistent with SFR~10-20 M_{sun}/yr (also few AGN)

- Multi-wavelength comparisons/analyses will provide the greatest insights
  - Combine X-ray/radio/optical
  - Study faint populations, as well as high redshift, starbursts and AGN
  - Resolve X-ray sources, if from star formation and sufficient magnification

Advances in X-ray and optical telescopes

3 inch diameter solar X-ray telescope mirrors

First imaging solar X-ray telescope about the same diameter as Galileo's 1610 telescope

380 years after Galileo, Hubble is **100 million** times more sensitive

In ~40 years X-ray telescopes have comparable increase in sensitivity with launch of Chandra

At 15 years, Chandra is operating very well

Final Release Over Earth
Image Credit: NASA, 2009

ATHENA APPROVED BY ESA FOR 2020'S
SMART-X UNDER STUDY FOR THE 2020'S

SMART-X team at SAO, PSU, MIT, GSFC, MSFC, JHU, Stanford, Waterloo, Rutgers, NIST, Dartmouth

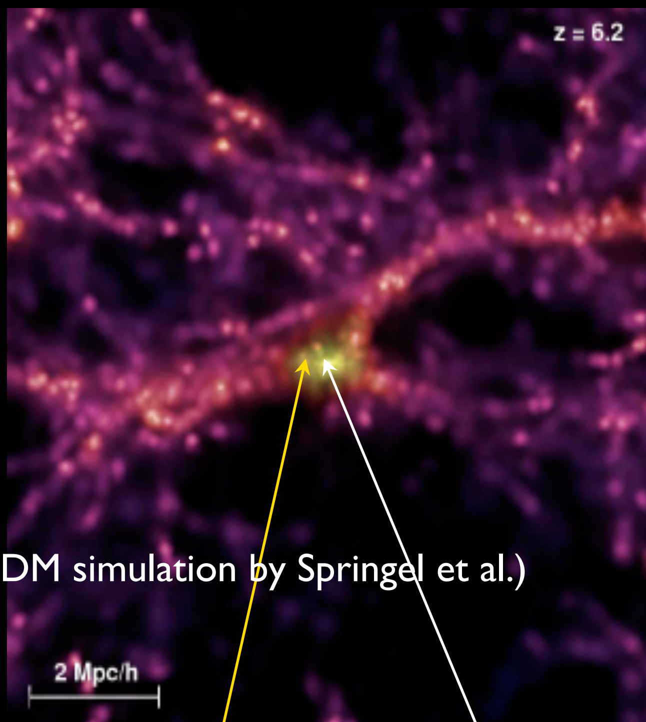
- 3 m aperture with high angular resolution
- 30 x Chandra (A_{eff} = 2.3 m^2 at 1 keV)
- sub-arcsec imaging in the inner 8′ (diameter) FOV
- Piezo-electric material on back of thin glass shells shapes figure
- Useful FOV ~ 20′ (diameter); 4″ imaging at the edges

- Science Instruments:
  - 5×5′ microcalorimeter with 1″ pixels (XMIS)
  - 22×22′ CMOS imager with 0.33″ pixels (APSI)
  - insertable gratings with R = 5000 (CATGS)

see Vikhlinin et al. 2011 "High Resolution, High Throughput X-Ray Observatory with Adjustable Optics"

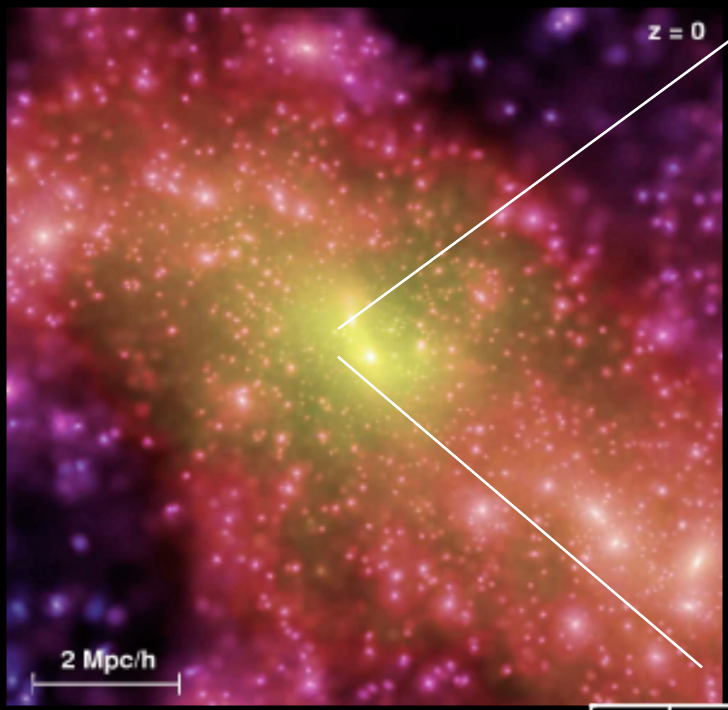
M87's youth - Growth of galaxy groups and 10^9 $M_\odot$ black holes from $z = 6$ to the present

Sloan quasar at z=6

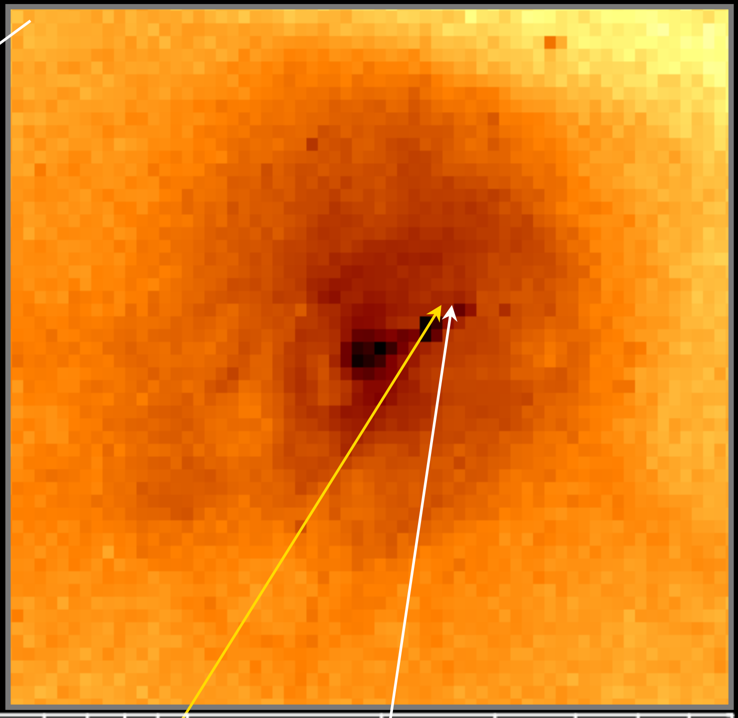


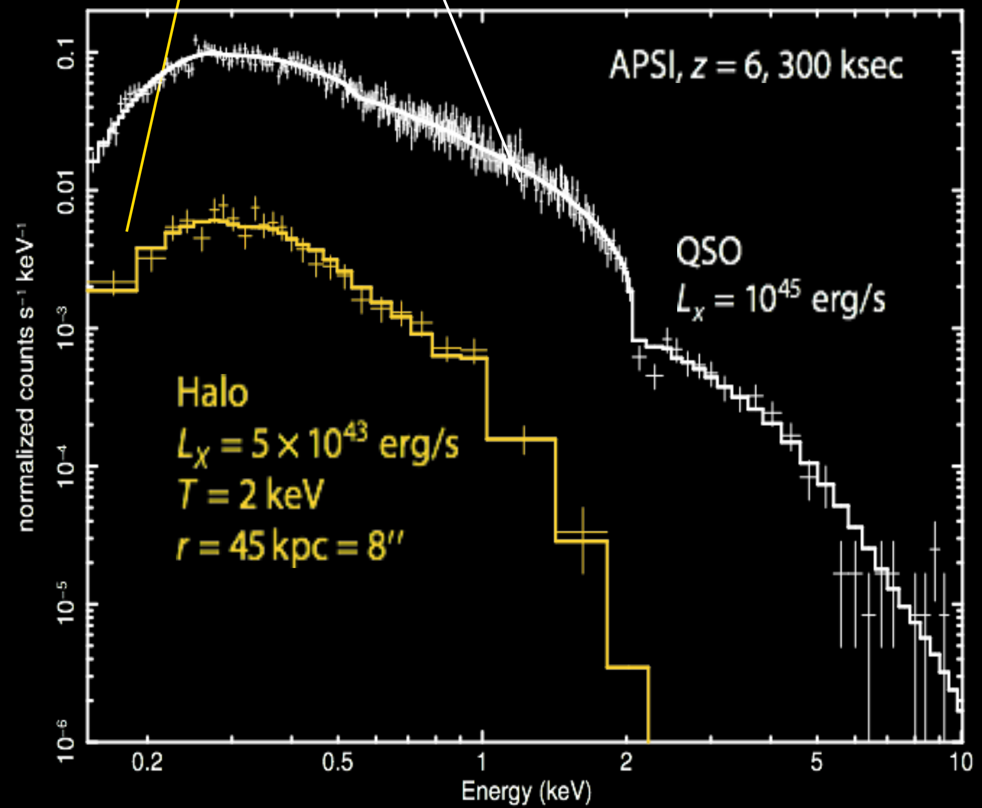
(DM simulation by Springel et al.)

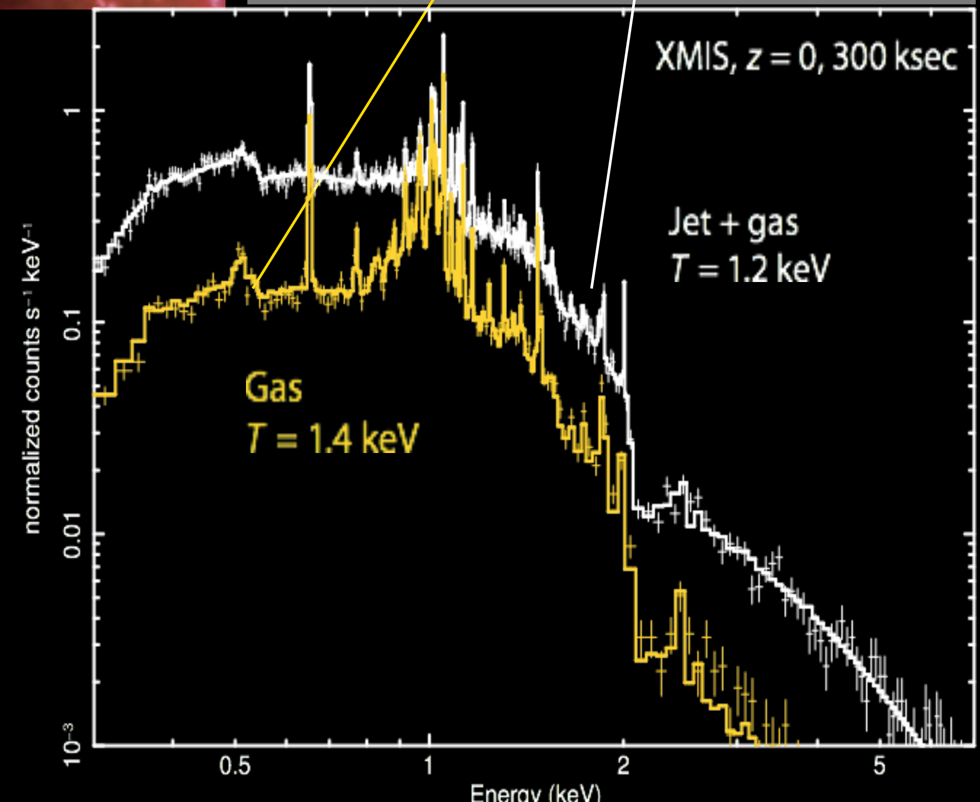
"nursing home" at z=0



M87, *Chandra*, 1″ pixels







✓ *Sensitivity + angular resolution — detect and resolve quasar host halos and galaxy groups at z=6*

✓ *High-res spectroscopy on 1″ scales — feedback and physics in clusters, galaxies, SNRs*

THANKS