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MACS

An introduction to the Massive Cluster Survey

Keywords: cosmology, large-scale structure, gravitational lensing, bulk flows, galaxy evolution...

Summary

(1) Containing vast amounts of dark matter, gas, and galaxies, *clusters are key* to our understanding of the Universe

(2) *X-ray selection is crucial* to defeat projection effects

(3) Clusters are probes, tools, and catalysts for a *huge range of extragalactic processes* from kpc to Gpc scales, from the dawn of the Universe to the present day

Collaborators

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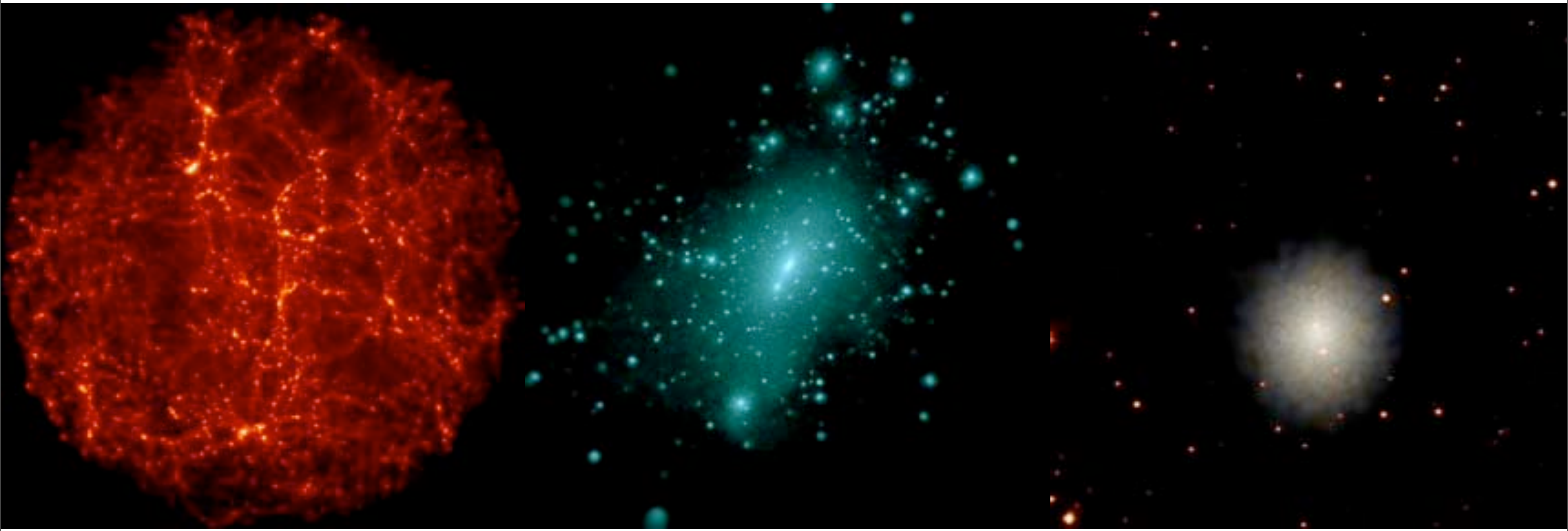
Sasha Kashlinsky *GSFC*
Fernando Atrio-Barandela *Santander*
Gabriele Giovannini *Bologna*
Leon van Speybroeck (†) *SAO*

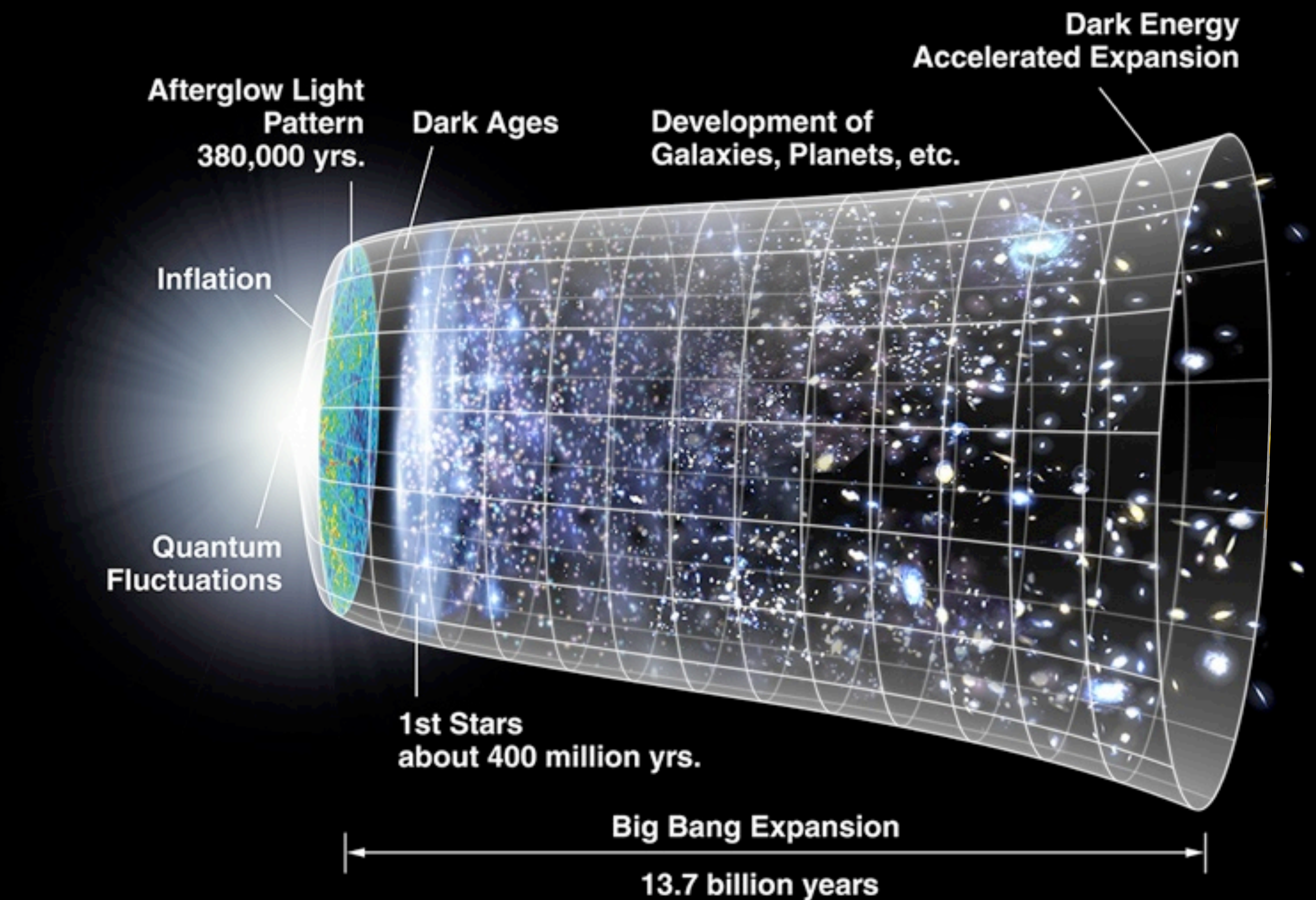
Study physics of structure formation/evolution over a vast range of scales

in space...



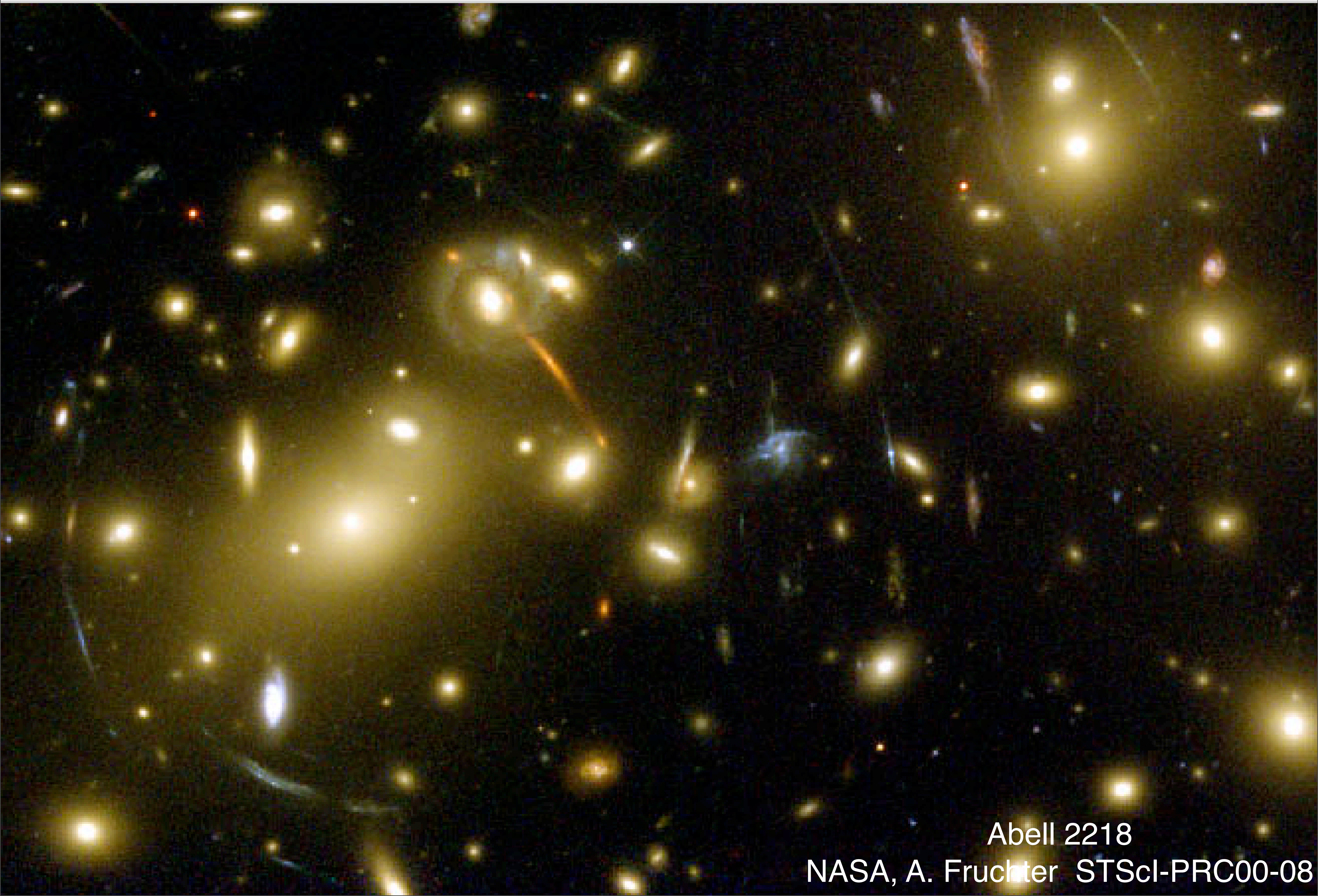
Credit: Volker Springel, MPA

... and time



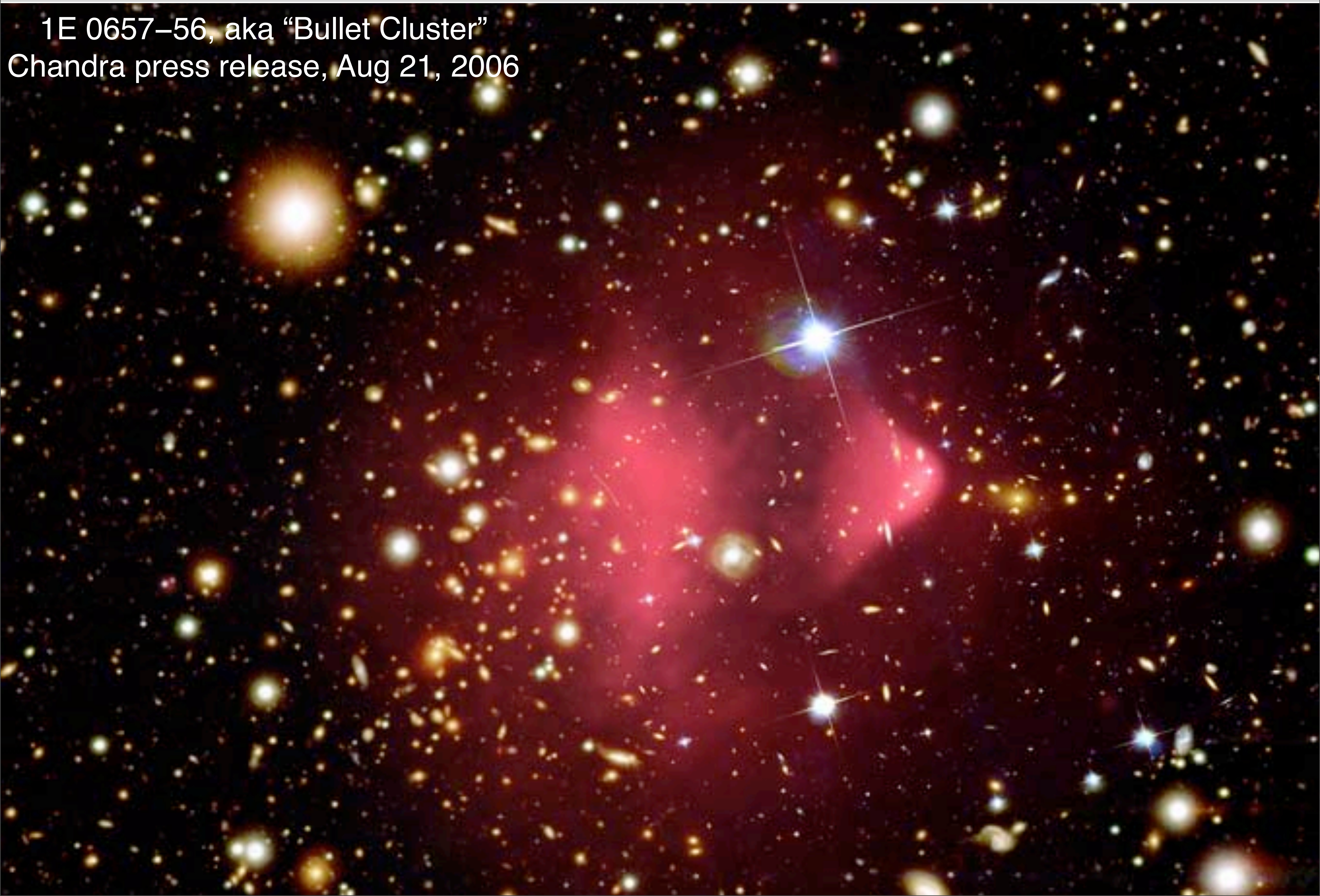
Credit: NASA / WMAP

X-ray vs optical selection



X-ray vs optical selection

X-ray vs optical selection



1E 0657–56, aka “Bullet Cluster”
Chandra press release, Aug 21, 2006

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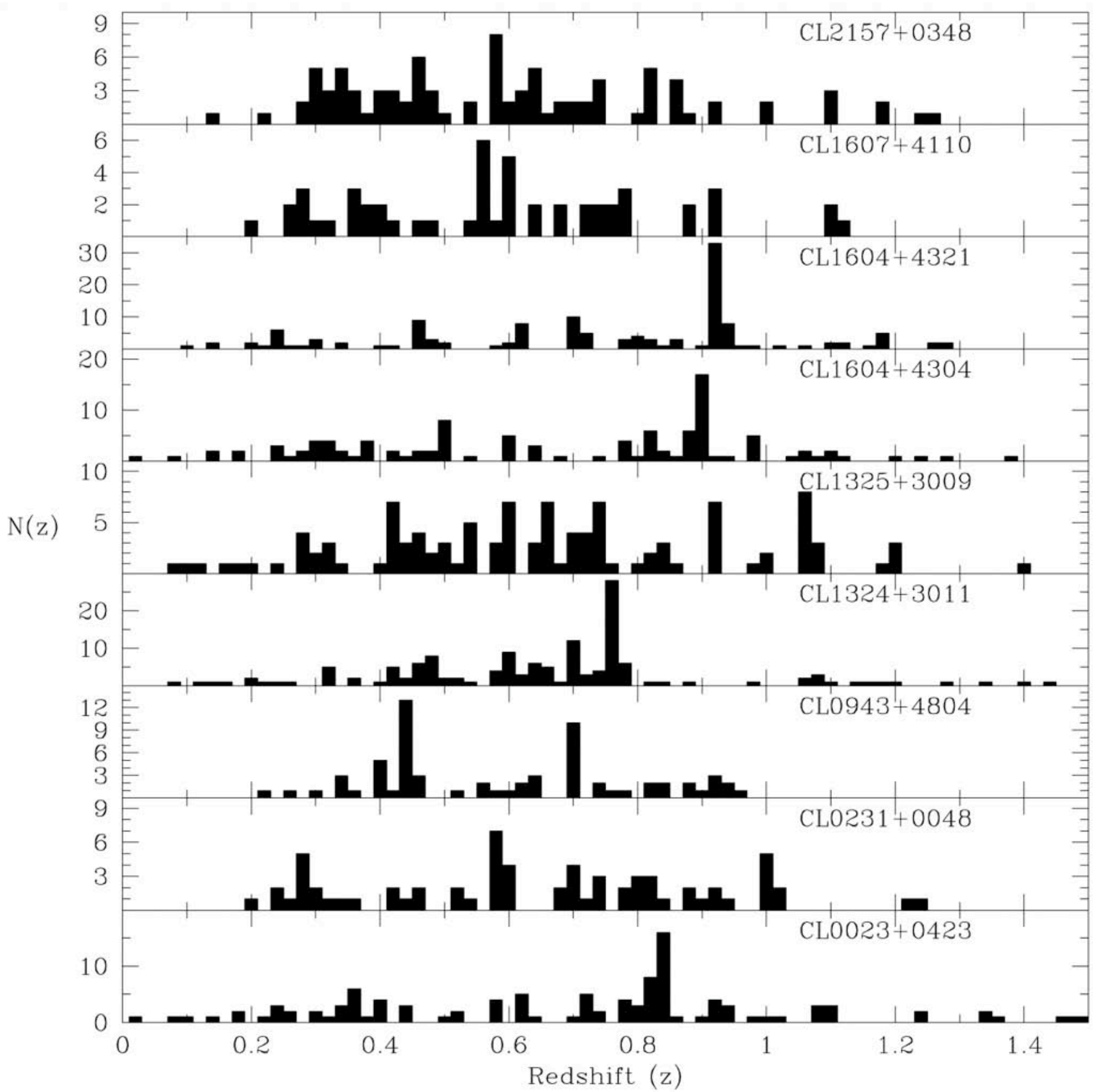
X-ray vs optical selection

X-ray vs optical selection



Oke, Postman & Lubin, 1998

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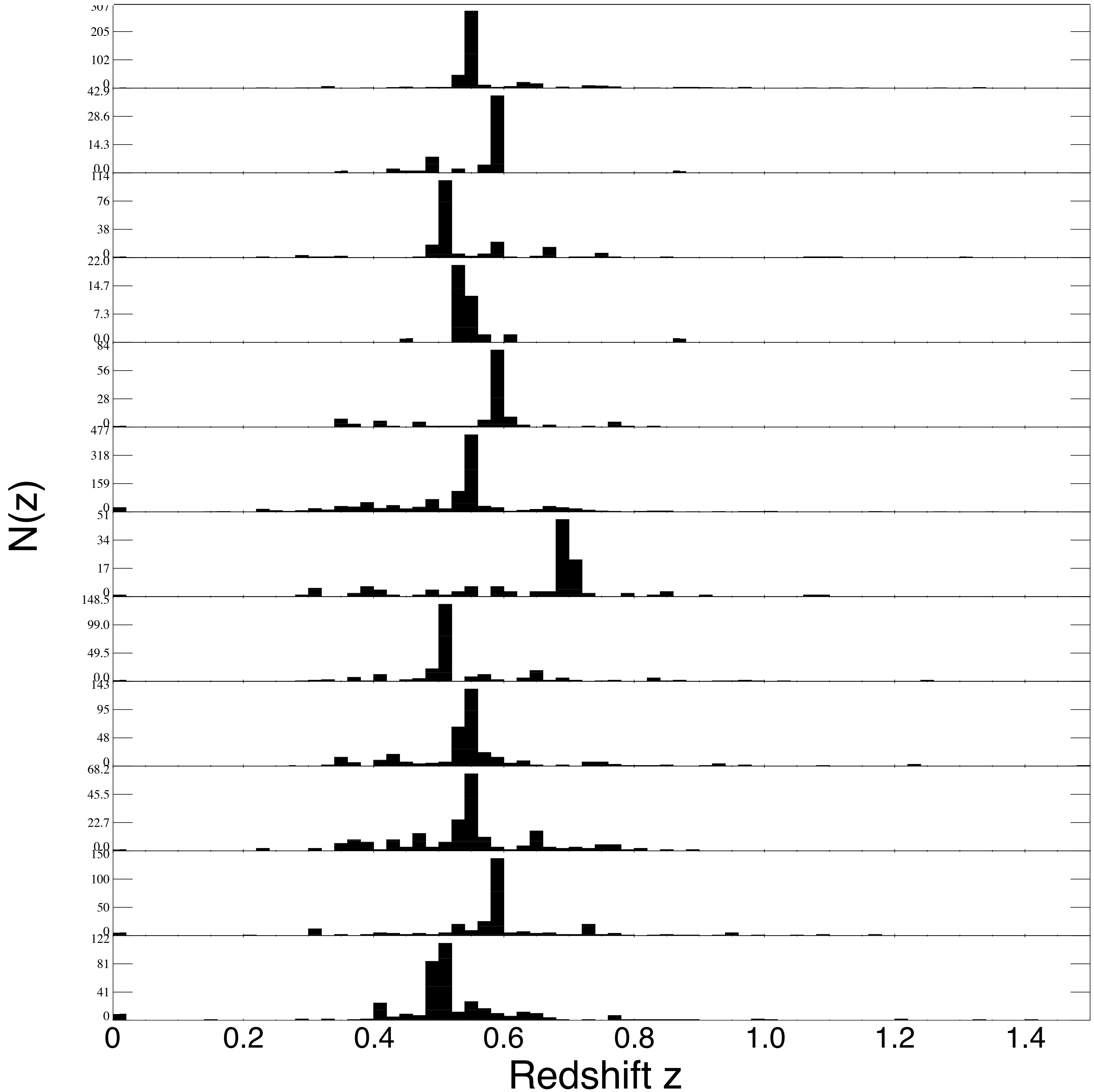
X-ray vs optical selection



Ebeling et al. 2007

- The most massive clusters grew from the rarest, largest fluctuations in the primordial density field ➜ their numbers depend sensitively on the properties of the density field
- Massive clusters evolve fastest in all cosmological models ➜ tight constraints can be obtained already at moderate redshifts
- Massive clusters are easier to detect and less susceptible to contamination (optical, X-ray,...) than poor clusters
- Massive clusters contain more galaxies, more gas, more dark matter ➜ in-depth studies of the properties and interactions of all three cluster components are greatly facilitated

Survey design

- X-ray selected from 5798 spectrally hardest ROSAT All-Sky Survey sources
- $|b| > 20°$, $-40° > \delta > +80°$
- solid angle: 22,735 square degrees
- X-ray flux limit: 1×10^{-12} erg s^{-1} cm^{-2} (0.1–2.4 keV)
- *lower* redshift limit: $z = 0.3$
- $\Rightarrow$ $L_{X,median}$: 1.3×10^{45} erg s^{-1} (0.1–2.4 keV)

Ebeling, Edge & Henry, ApJ, 2001

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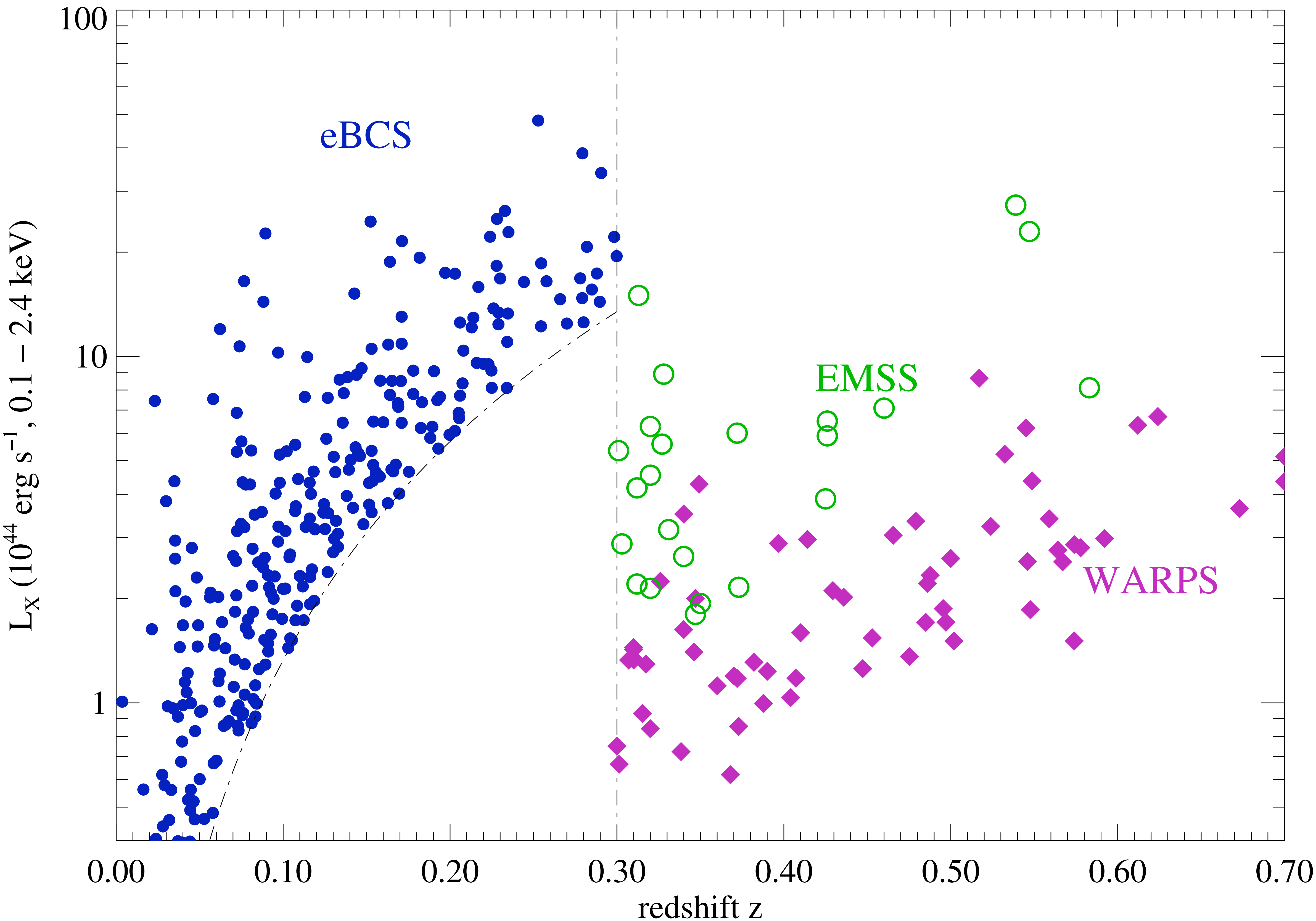
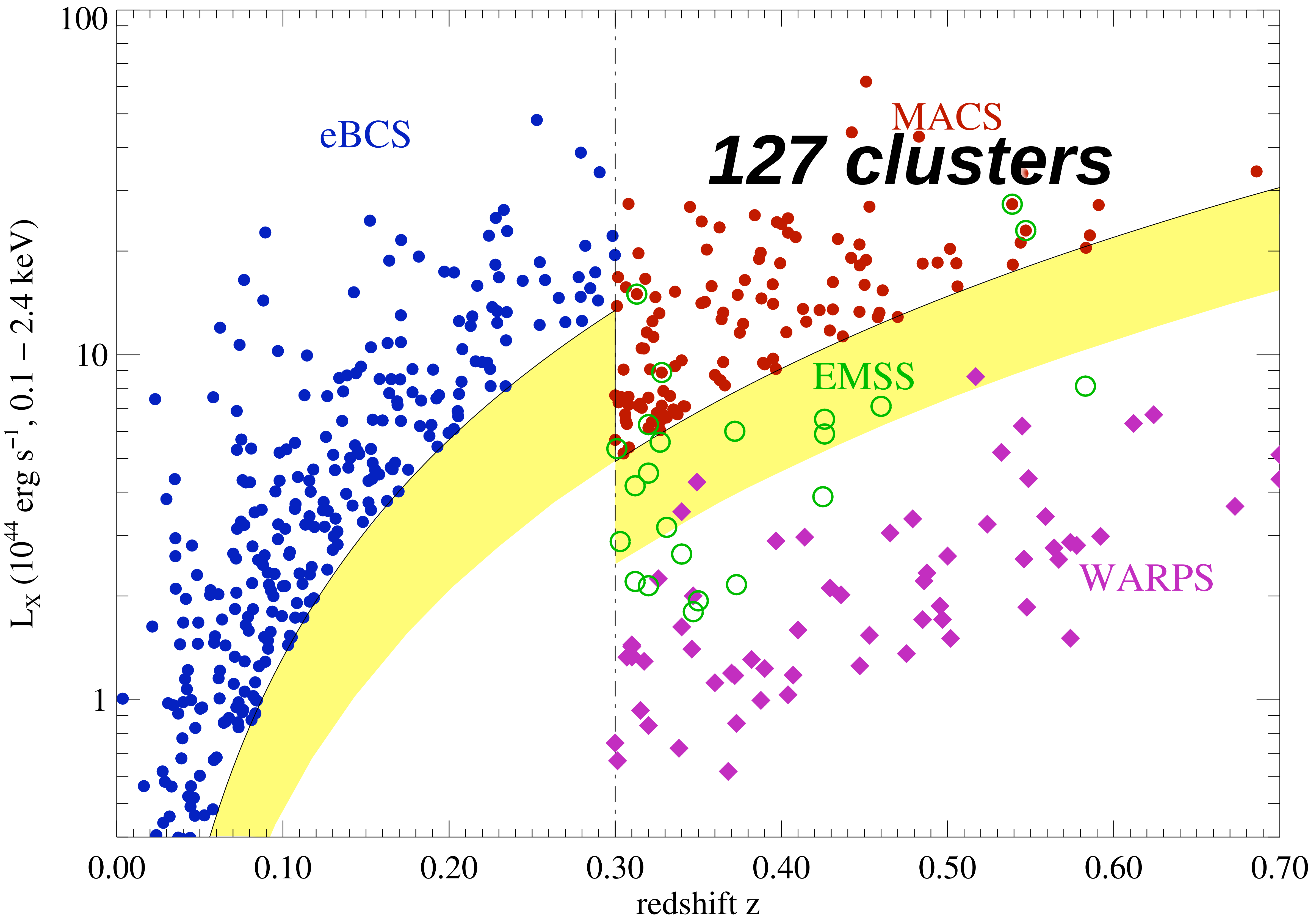
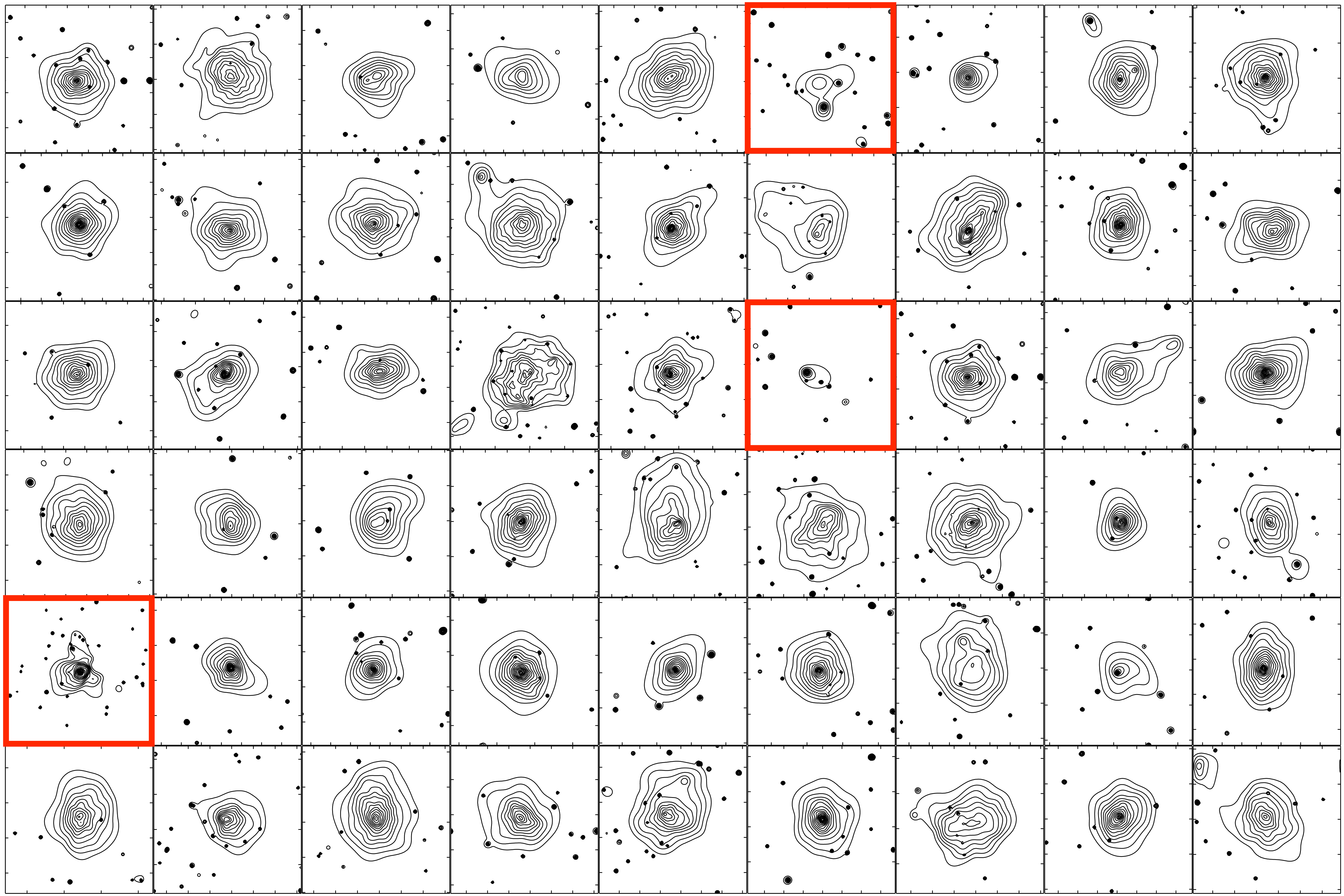



100
10
1
L_X (10^{44} erg s^{-1}, 0.1 – 2.4 keV)
eBCS
MACS
127 clusters
EMSS
WARPS
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
redshift z


UH2.2m, Keck-2 10m: spectroscopic confirmation
Keck-1 10m, Gemini 8.1m, CFHT 3.6m: MOS spectroscopy
Subaru 8.3m: wide-field, multi-colour imaging

Chandra/ACIS images of MACS clusters



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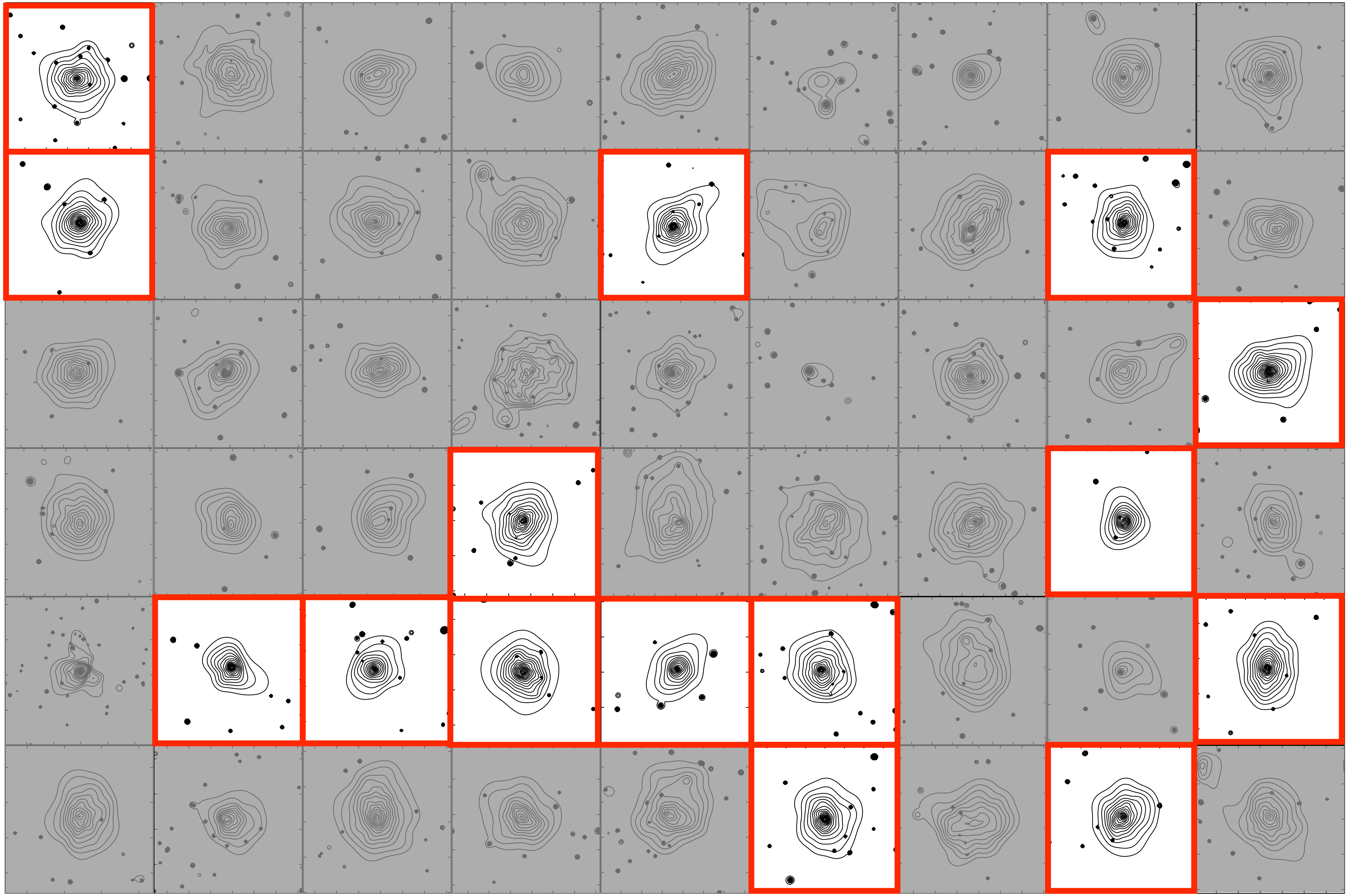

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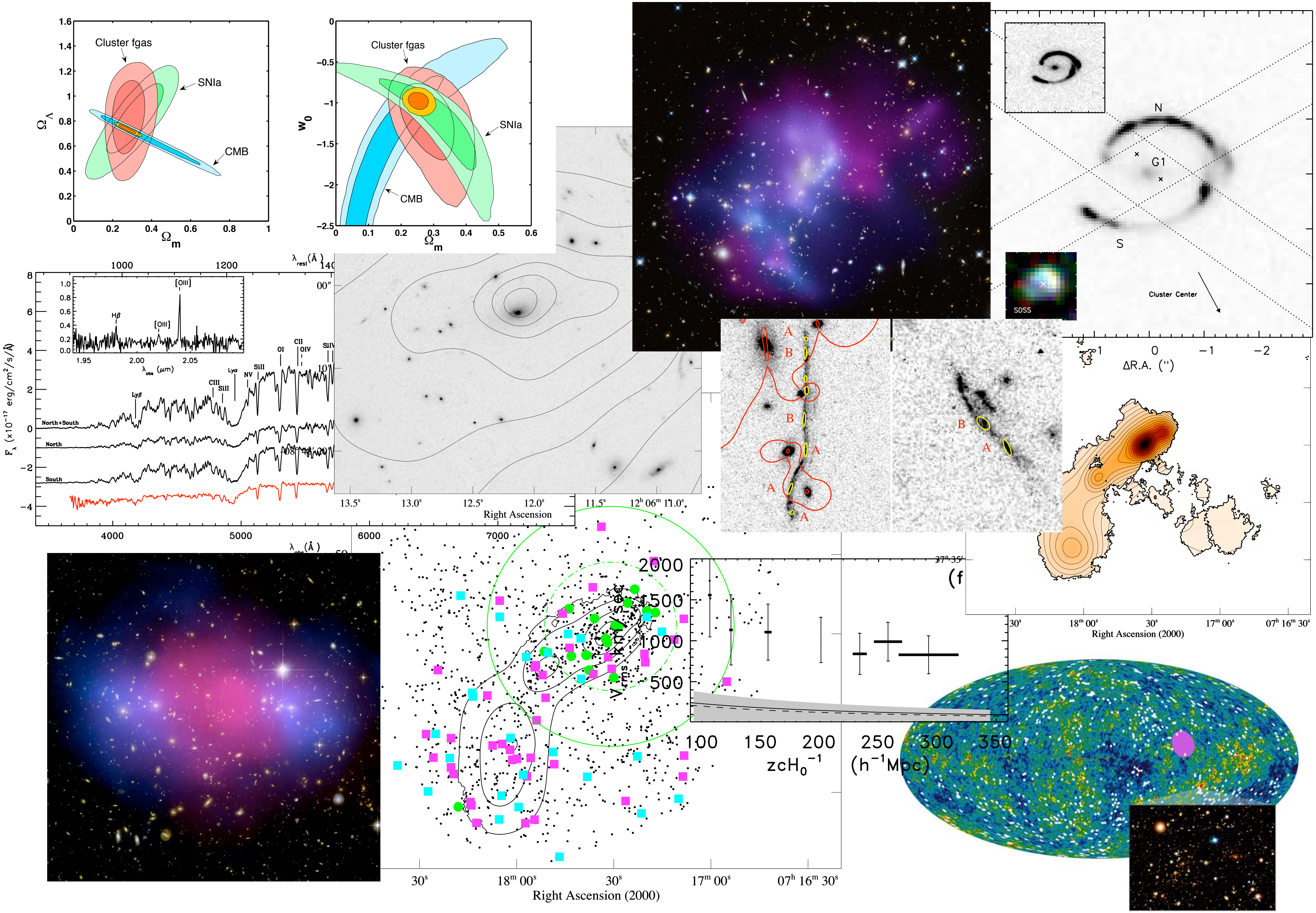
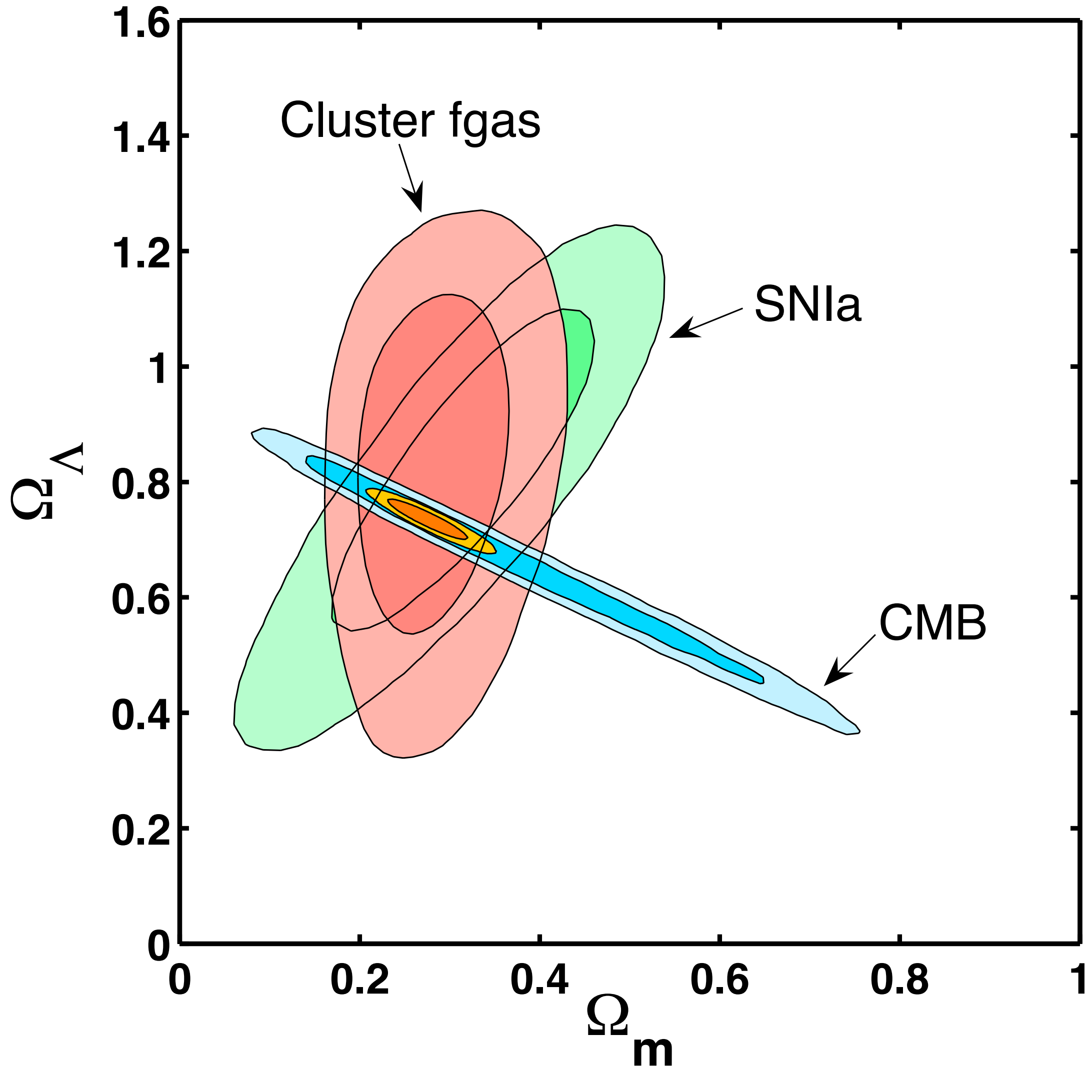
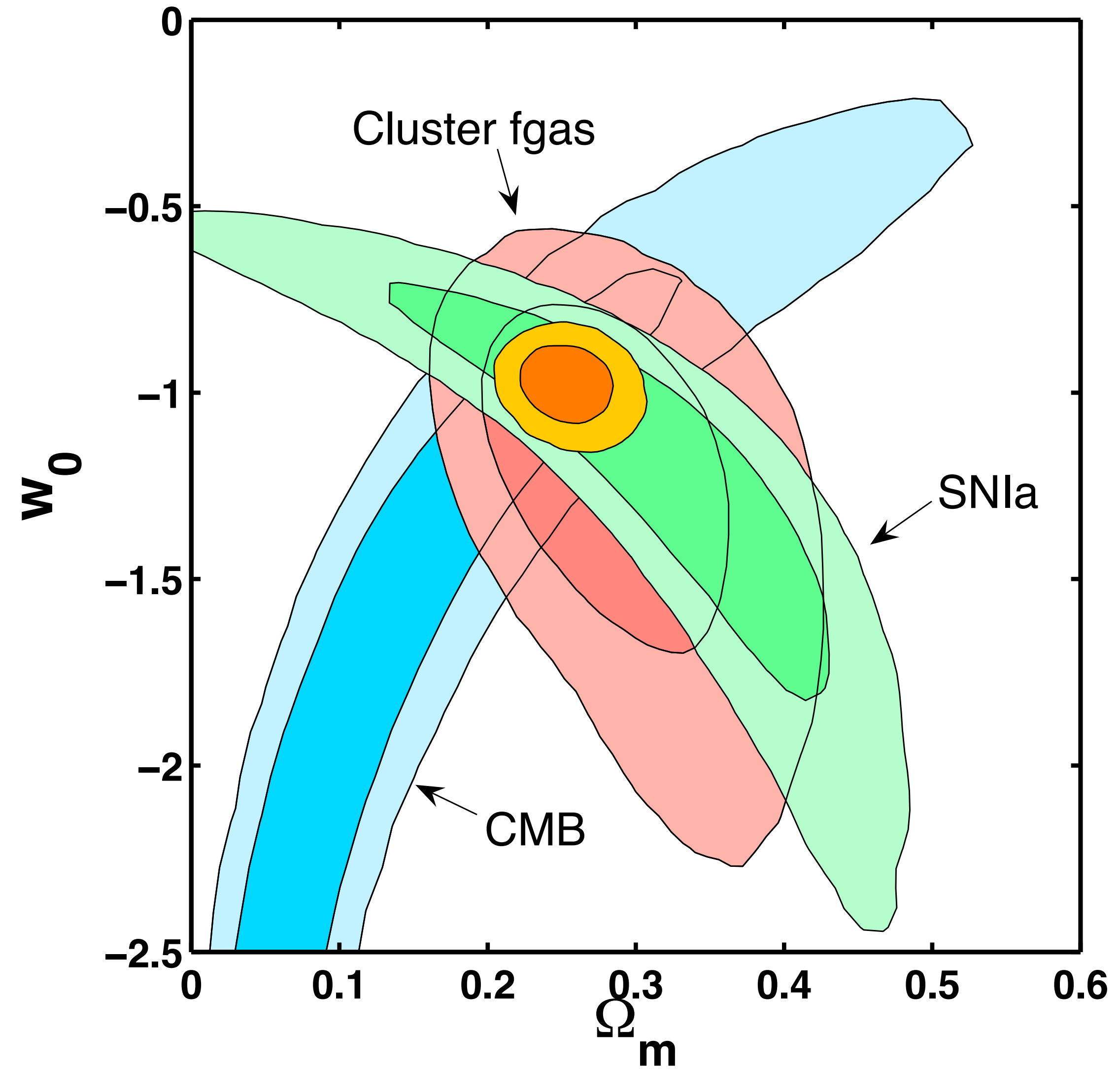
Selected, recent MACS results



Cosmological constraints





Measurements of the gas-mass fraction in clusters as well as of the redshift evolution of the cluster abundance lead to greatly improved cosmological constraints

Allen et al. (2007, 2008)
Mantz et al. (2008)
Rapetti et al. (2009)

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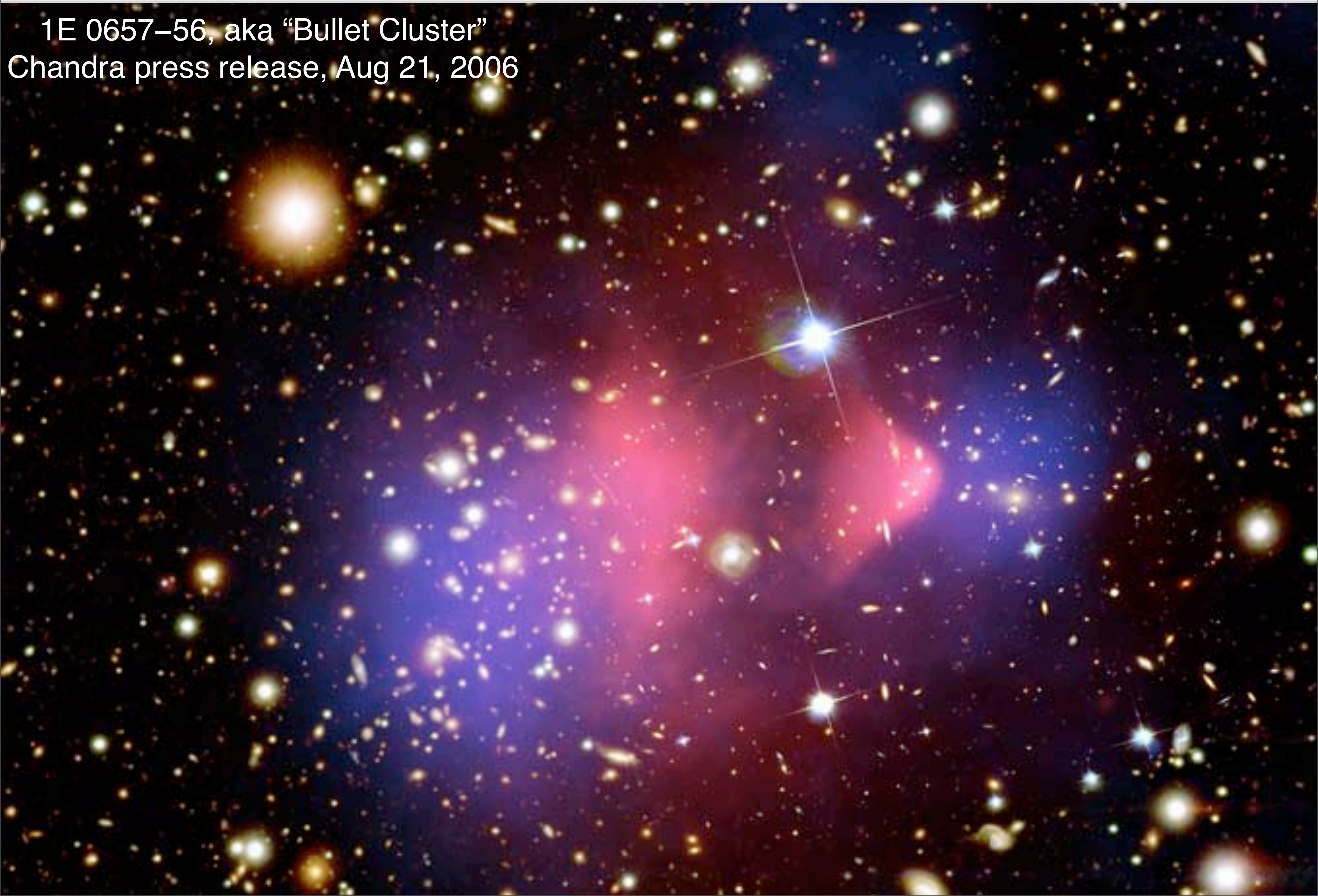
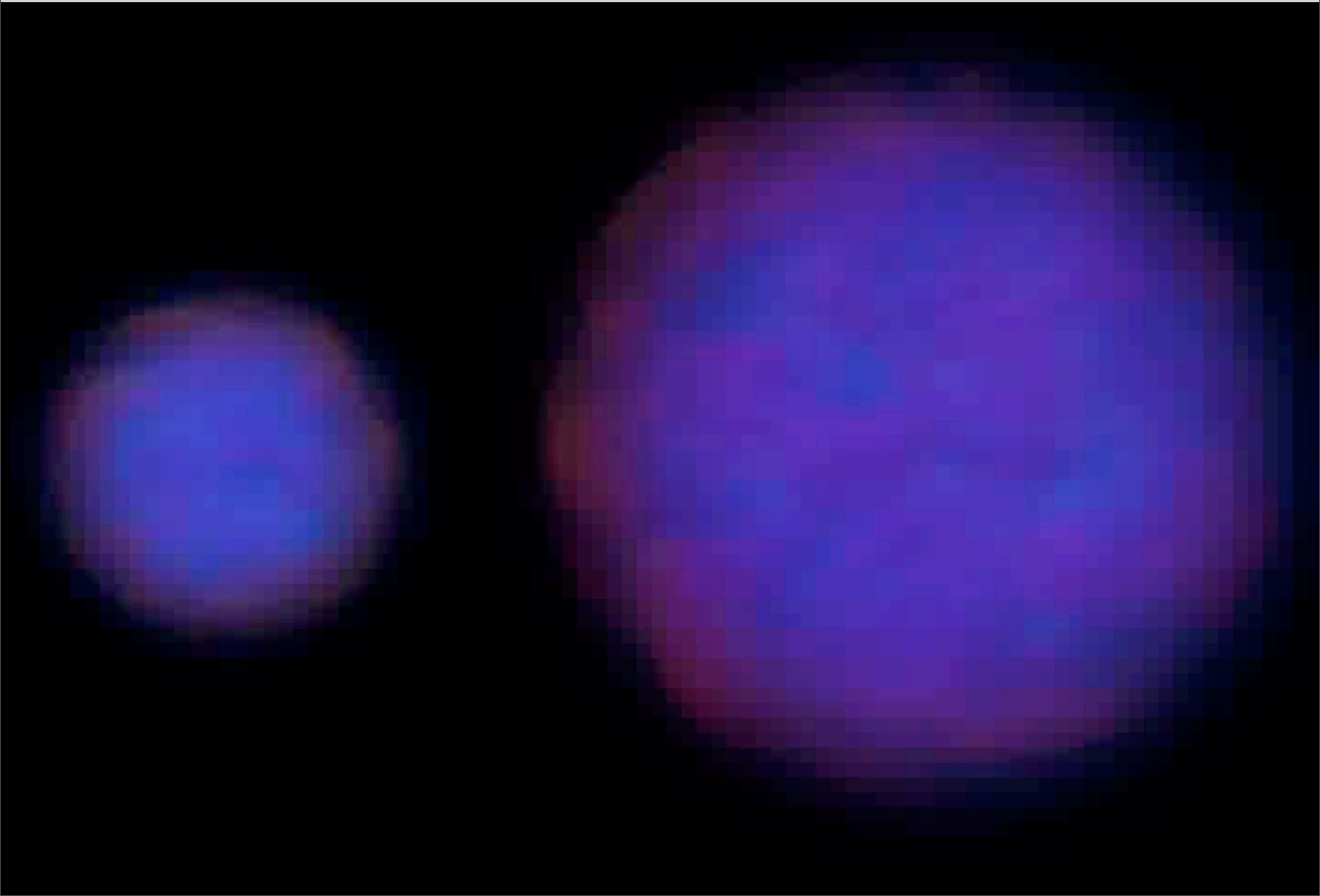
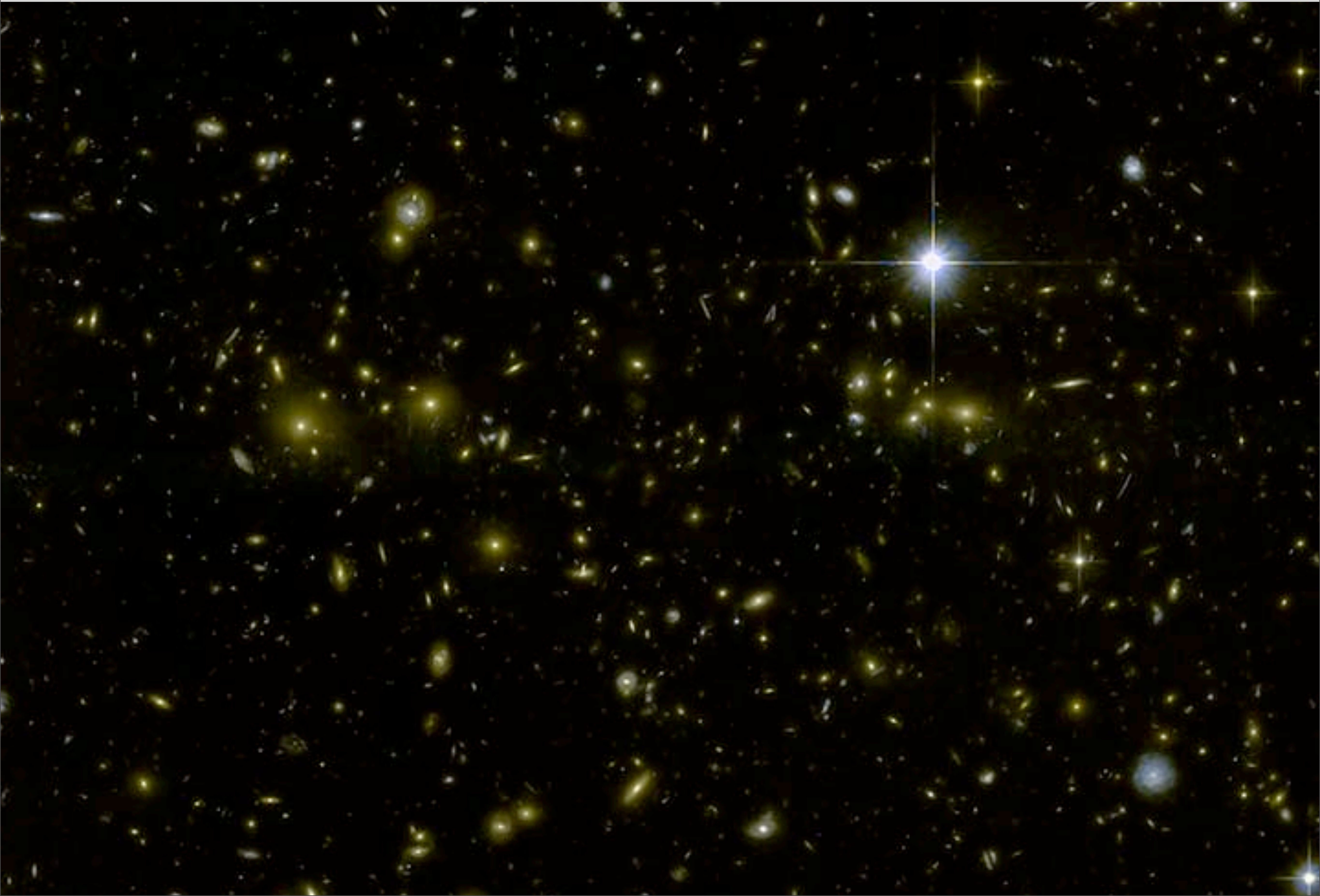


1E 0657−56, aka "Bullet Cluster"
Chandra press release, Aug 21, 2006



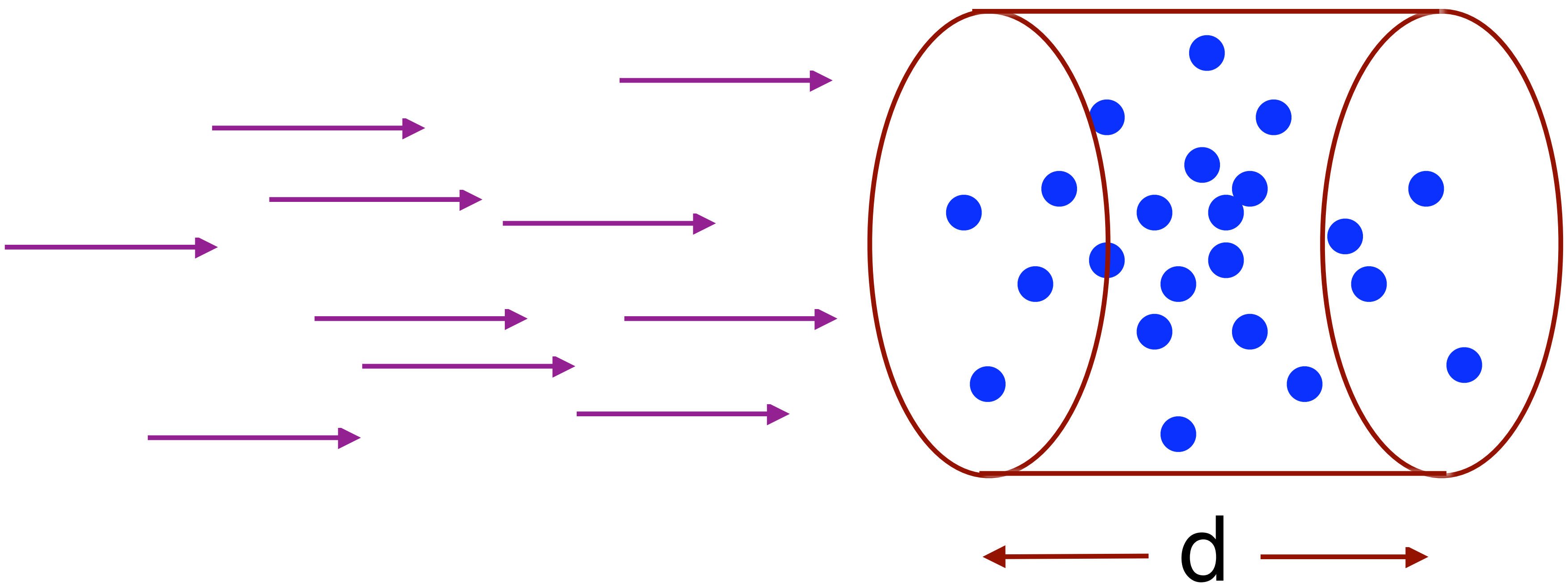


MACSJ0025.4−1222, Bradač et al. (2008), joint CXO/STScI press release

Clusters as astrophysical laboratories

- if dark matter did not exist and all observational evidence of it was in fact caused by deviations from the Newtonian r^{-2} law, the gravitational potential in merging clusters should follow the gas distribution: this is in conflict with observations
- the most stringent constraints on the self-interaction cross section of dark matter are obtained when the relative velocities of the merging clusters are known: $\sigma/m < 1\ \mathrm{cm^2\ g^{-1}}$ (1E0657–56)
- a significant offset between gas and dark matter can be used to constrain σ/m through the requirement that $\tau < 1$: $\sigma/m < 4\ \mathrm{cm^2\ g^{-1}}$ (MACSJ0025.4–1222)

optical depth: $I/I_0 = e^{-\tau}$



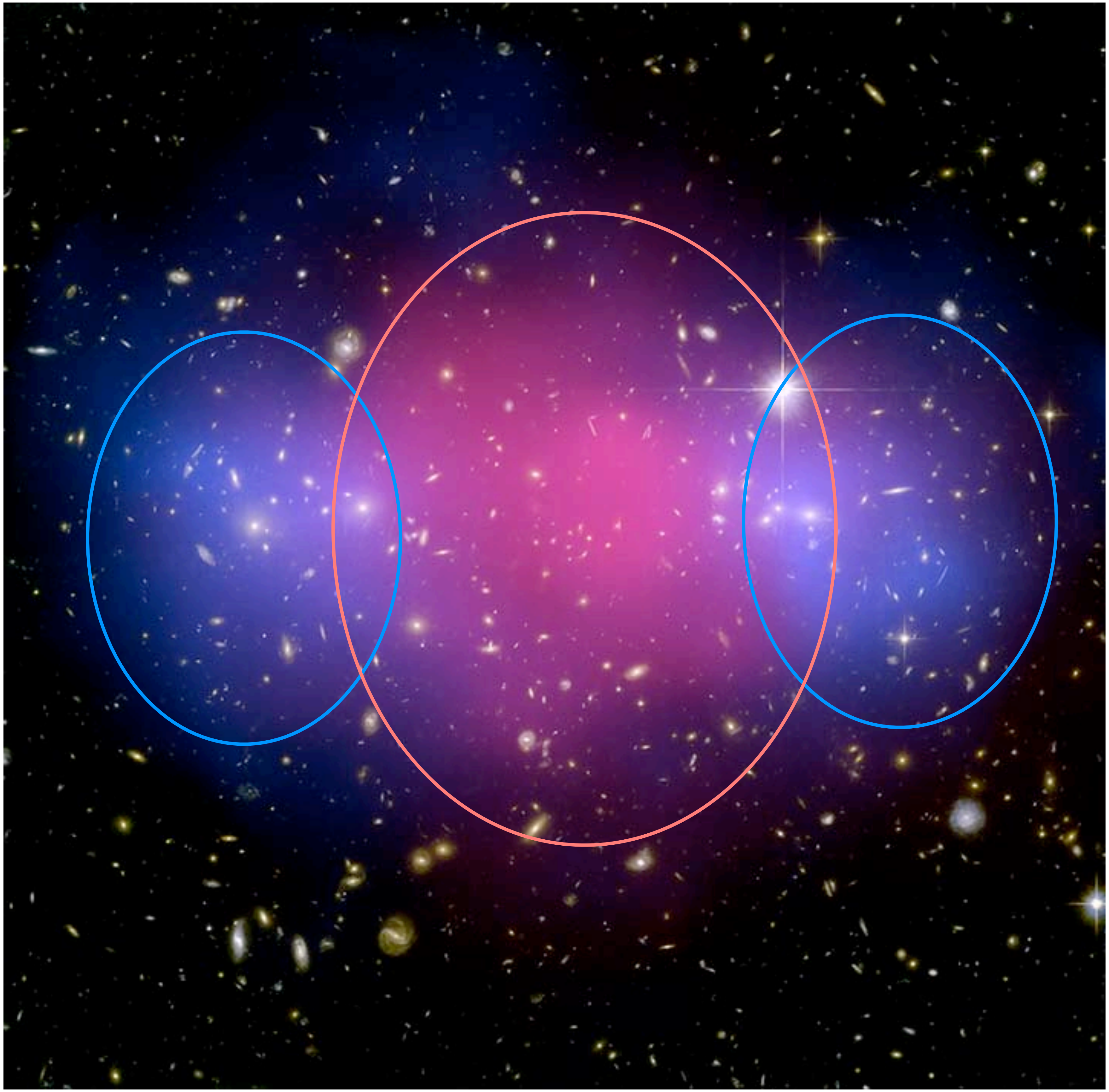
$\tau = n\sigma d$

scattering depth: $\tau_s = \Sigma_s\,\sigma/m$

The self-interaction cross section of dark matter

- gas-dark matter offset:
  $\tau = \Sigma\, \sigma/m < 1 \;\Rightarrow\; \sigma/m < 4\ \mathrm{cm^2\, g^{-1}}$
- post-collision bullet velocity (no drag): $\sigma/m < 7\ \mathrm{cm^2\, g^{-1}}$
- survival of dark-matter halos: $\sigma/m < 1\ \mathrm{cm^2\, g^{-1}}$
- A520: $\sigma/m = 3.8\ \mathrm{cm^2\, g^{-1}}$

1E0657–56: Clowe et al. 2004, ApJ, 604, 596
Markevitch et al. 2004, ApJ, 606, 819
Clowe et al. 2006, ApJ, 648, L109
MACSJ0025.4–1222: Ebeling et al. 2007, ApJ, 661, L33
Bradač et al, 2008, ApJ, 687, 959
A520: Mahdavi et al. 2007, ApJ, 668, 806



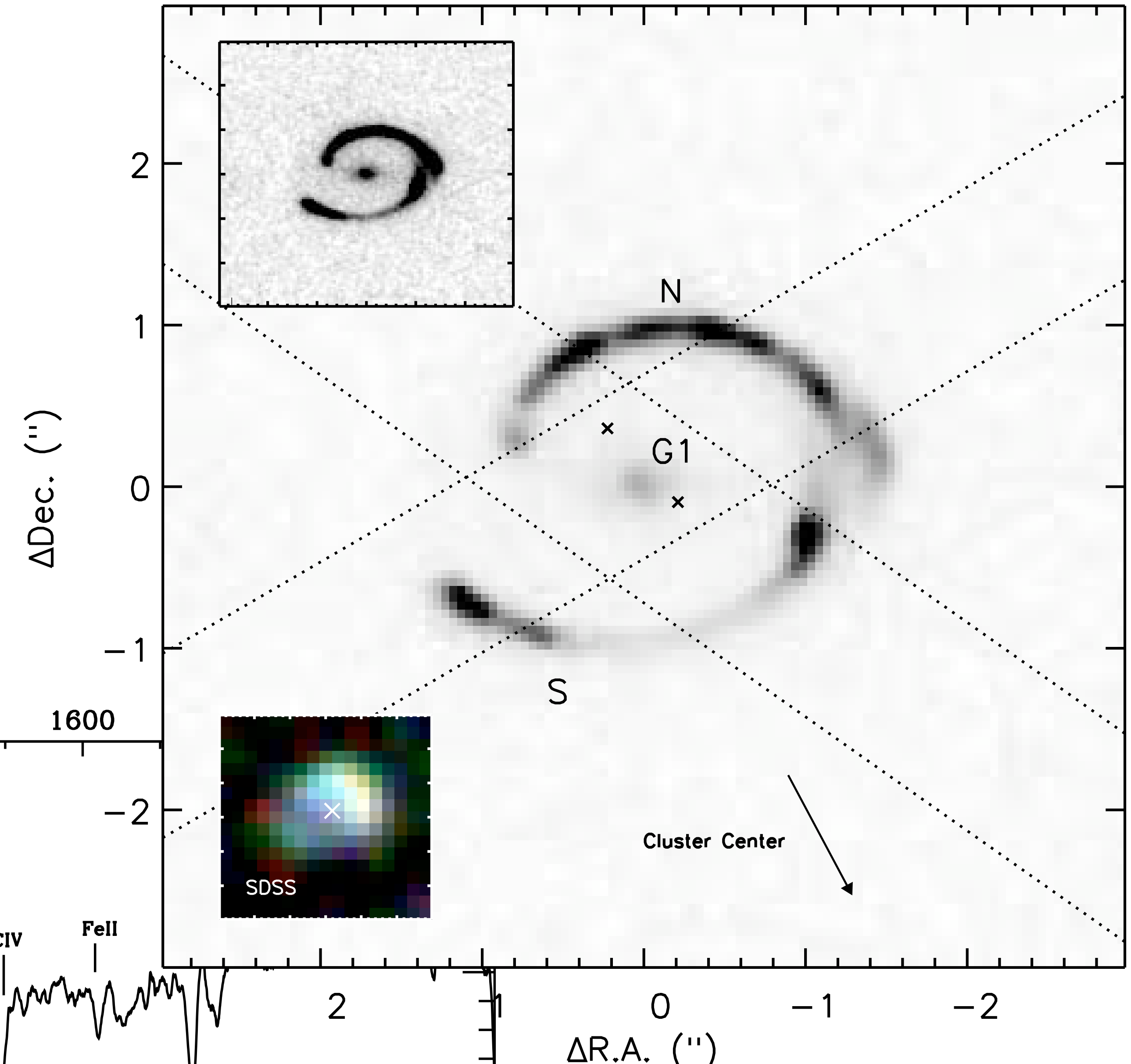
The nature of dark matter

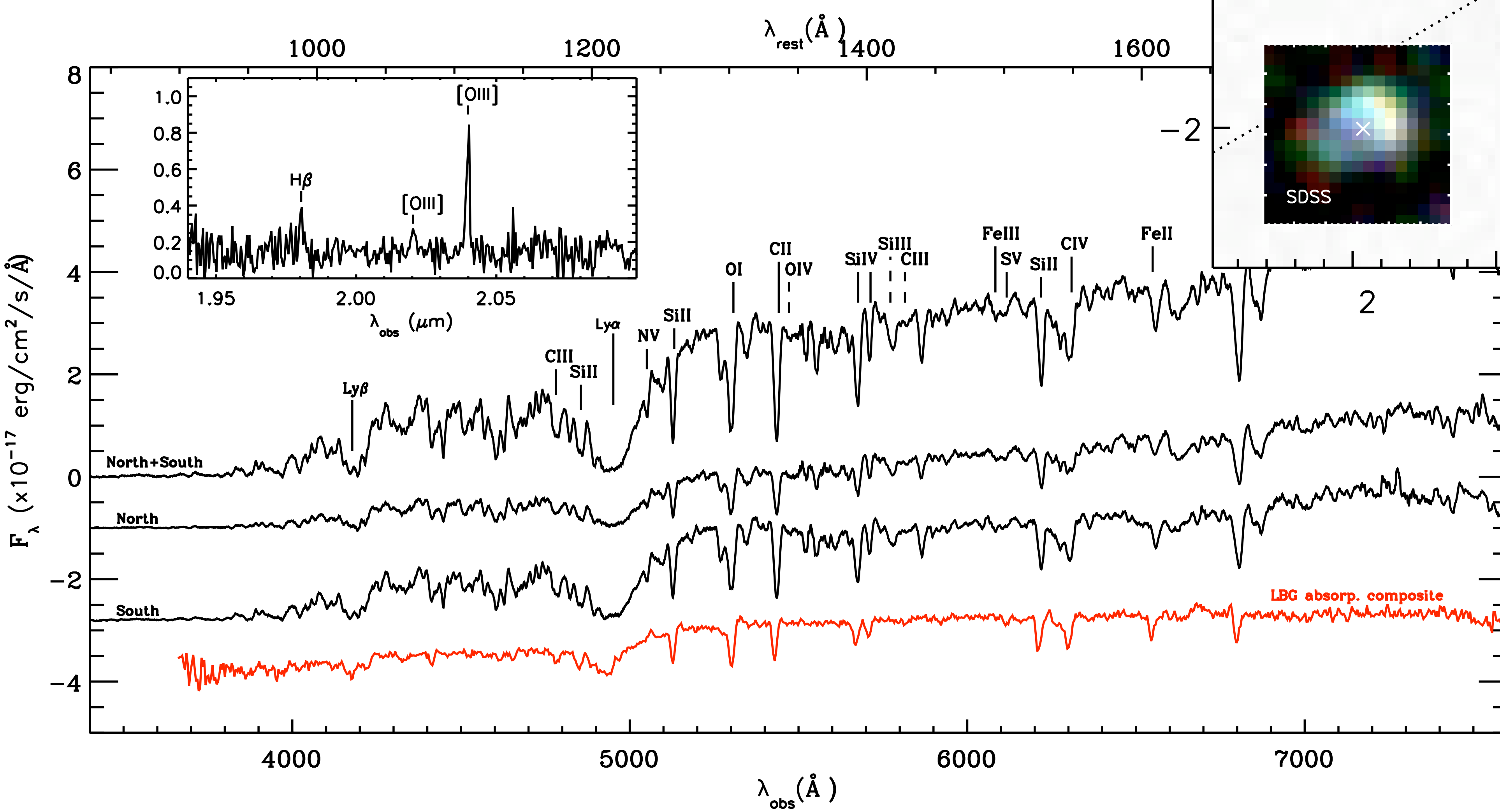
The spatial segregation of intracluster gas and dark matter in MACSJ0025.4–1222 places a new upper limit on the self-interaction cross section of dark matter

Bradač et al. (2008)
joint CXO/STScI press release

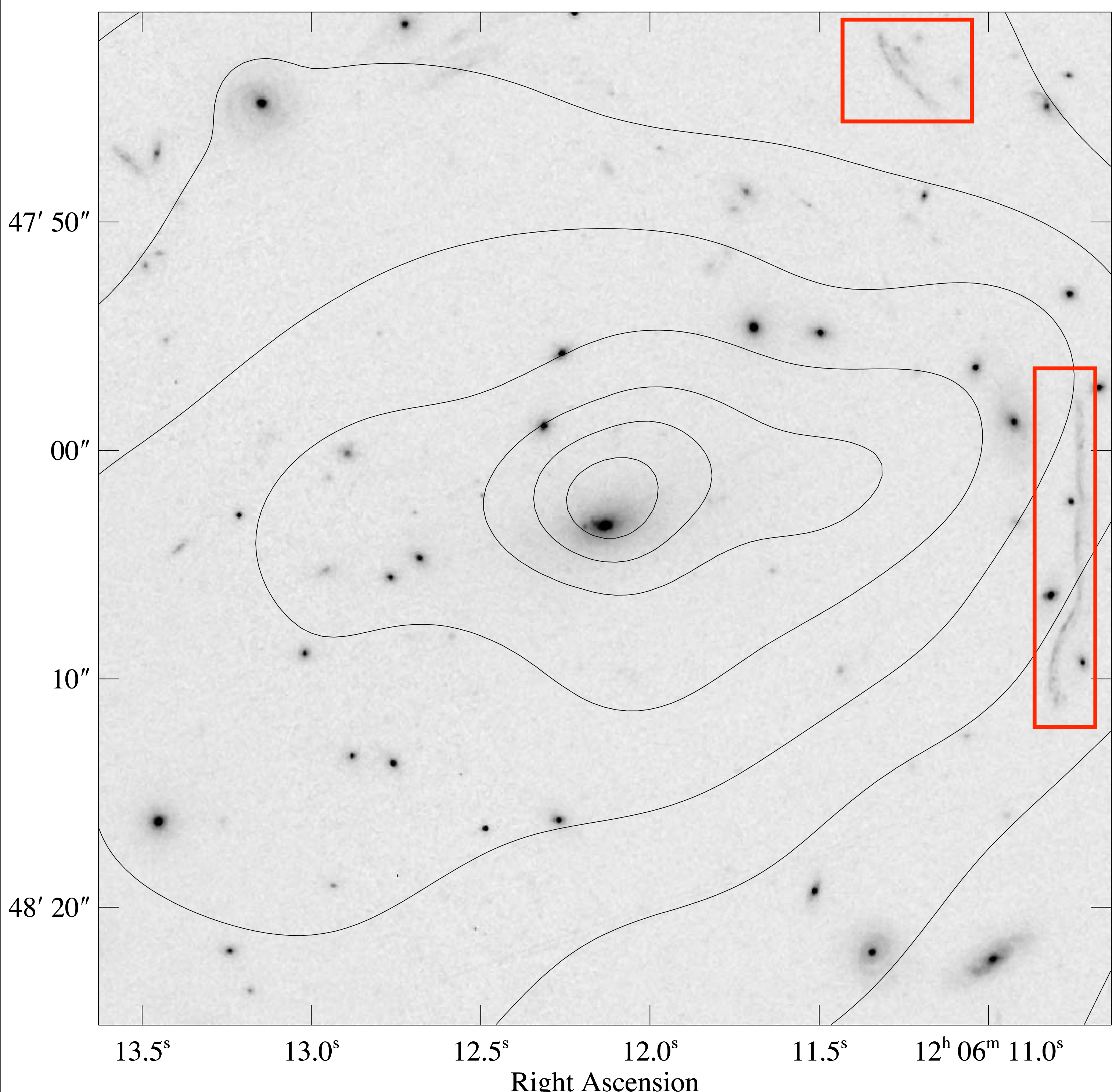
Background galaxies

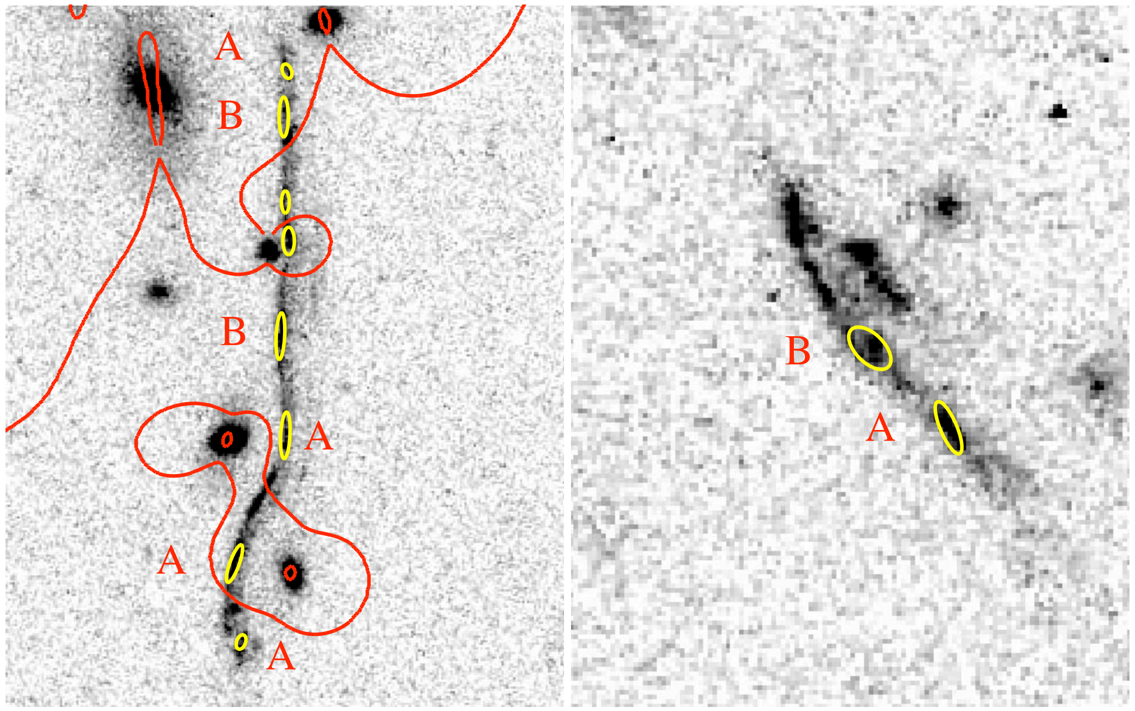
The "cosmic eye", a serendipitiously discovered galaxy-galaxy lens in the field of MACSJ2135.2–0102, allows an in-depth study of the properties of a Ly-break galaxy at z=3.01, thanks to gravitational amplification.





Smail et al. (2007)
Dye et al. (2007)
Coppin et al. (2007)
Stark et al. (2008)

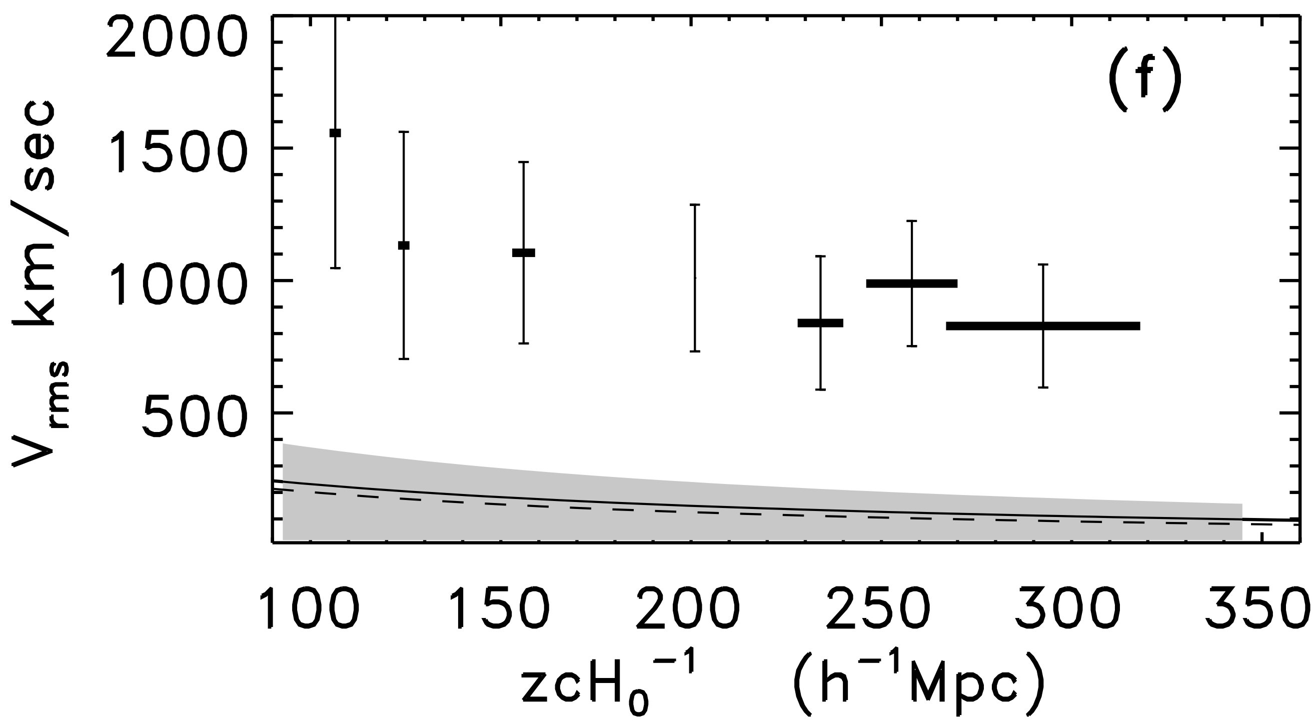


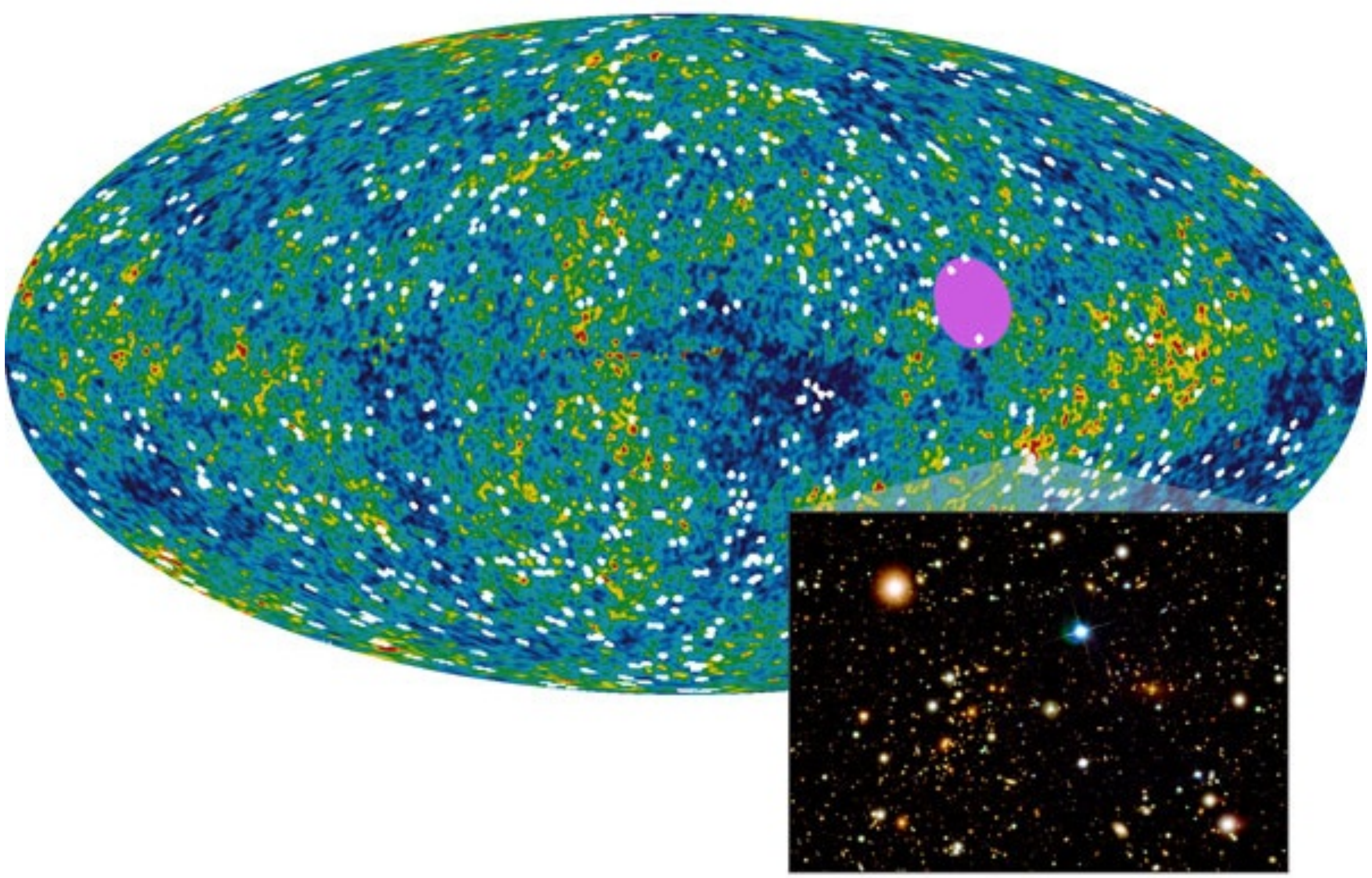


Cluster mass modeling

The discovery of a giant gravitational arc in the massive cluster MACSJ1206.2–0847 enables detailed mass modeling and reveals a discrepancy of over a factor of two between the X-ray and lensing mass estimates, pointing to pronounced substructure in a line-of-sight merger

Ebeling et al. (2009)





Large-scale flows

Based on WMAP CMB data, measurements of the kinematic Sunyaev-Zel`dovich effect in the direction of 700 X-ray luminous galaxy clusters from an all-sky sample find a net dipole in the clusters' peculiar-velocity field, possible across the entire visible Universe. If confirmed, this "Dark Flow" could be a way to probe the geometry of the pre-inflationary Universe.

Atrio-Barandela et al. (2008)
Kashlinski et al. (2008)
NASA press release

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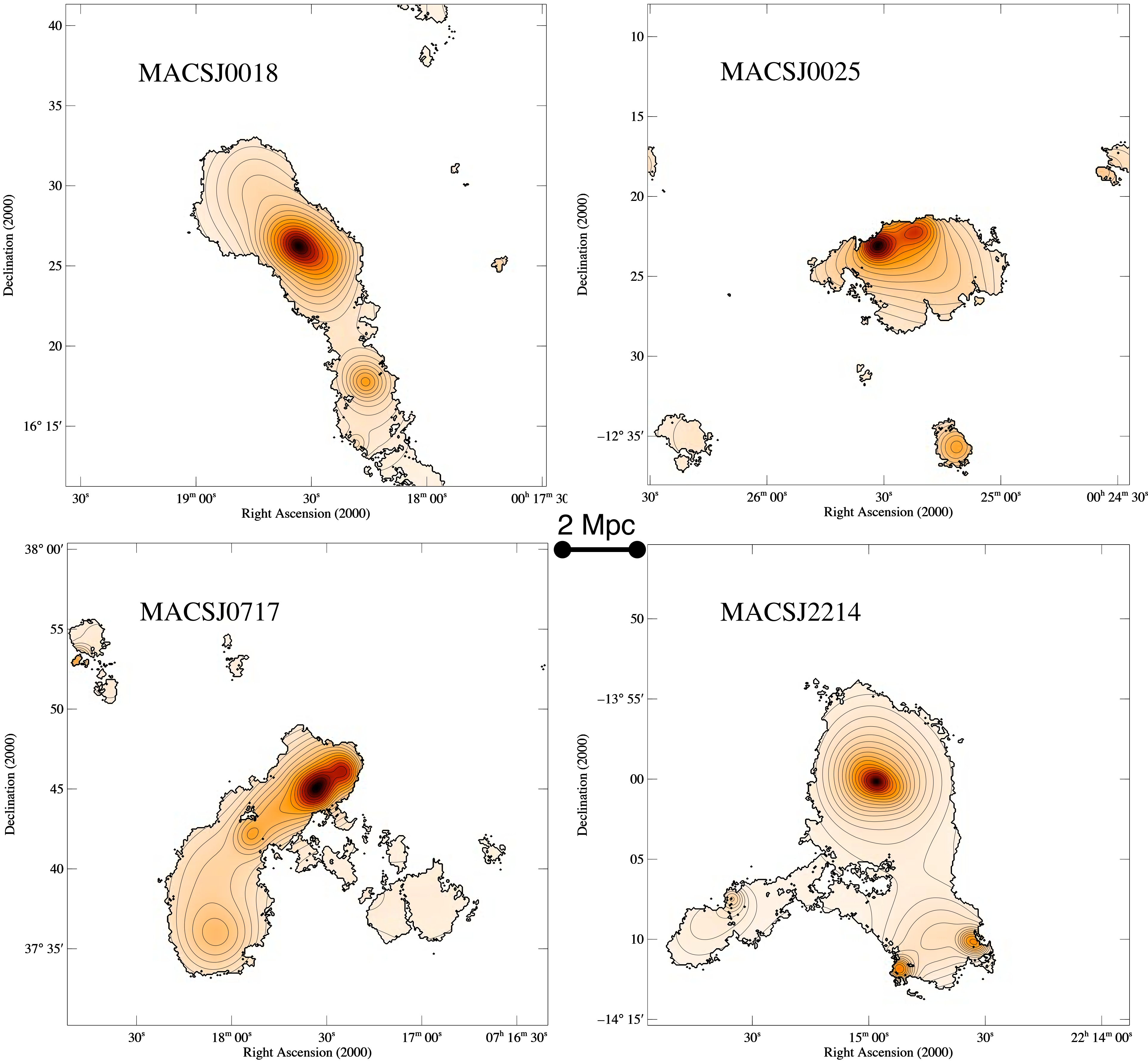
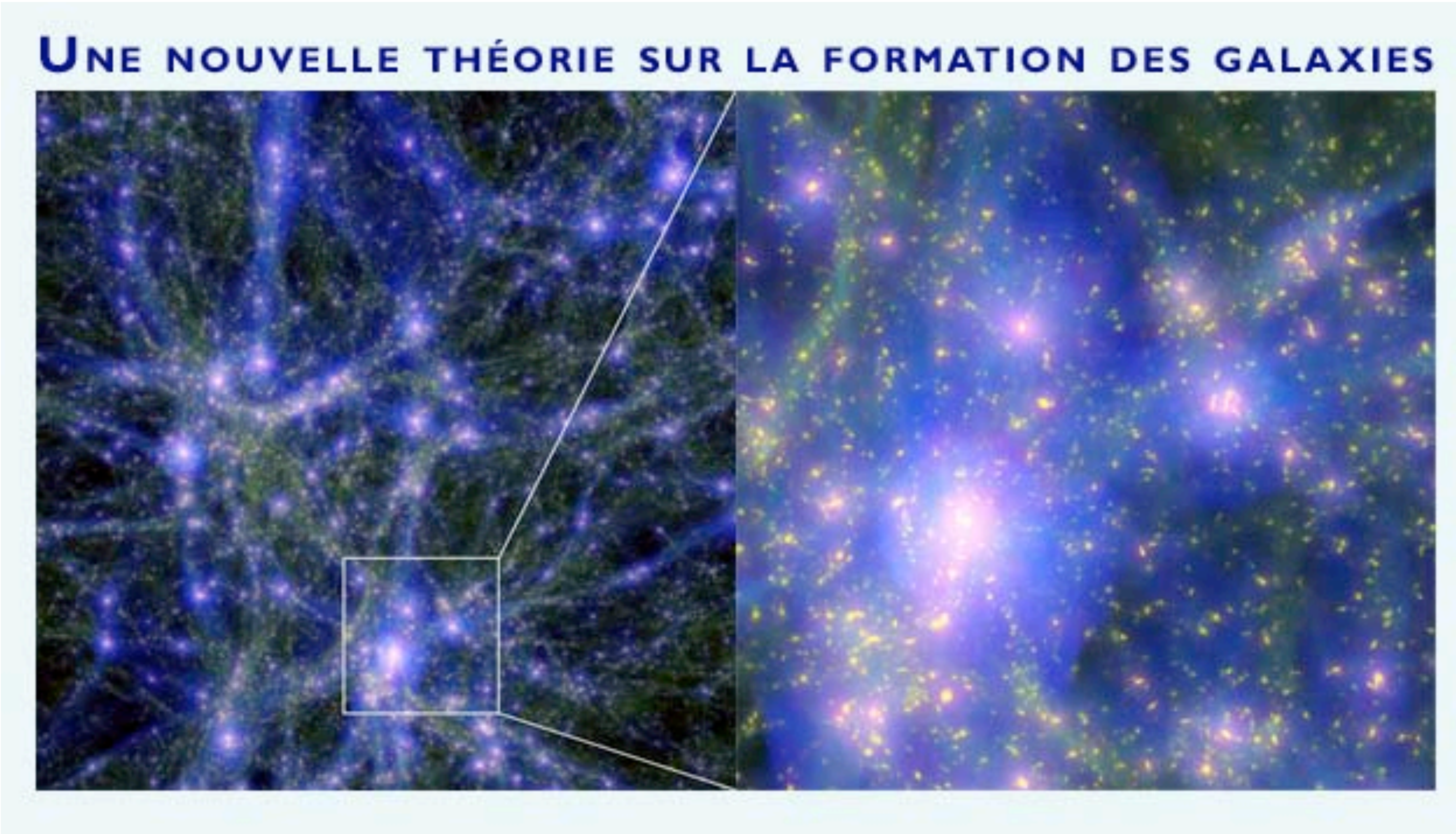
Selected, recent MACS results



Large-scale structure

The galaxy-density distribution around massive clusters reveals large-scale structure on scales of 2-8 Mpc consistent with the predictions of numerical simulations

Kartaltepe et al. (2008)



credit: IAP (Pichon, Teyssier)


How do we get from here...


to there?

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Galaxies NGC 2207 and IC 2163

Hubble Heritage

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Galaxy evolution

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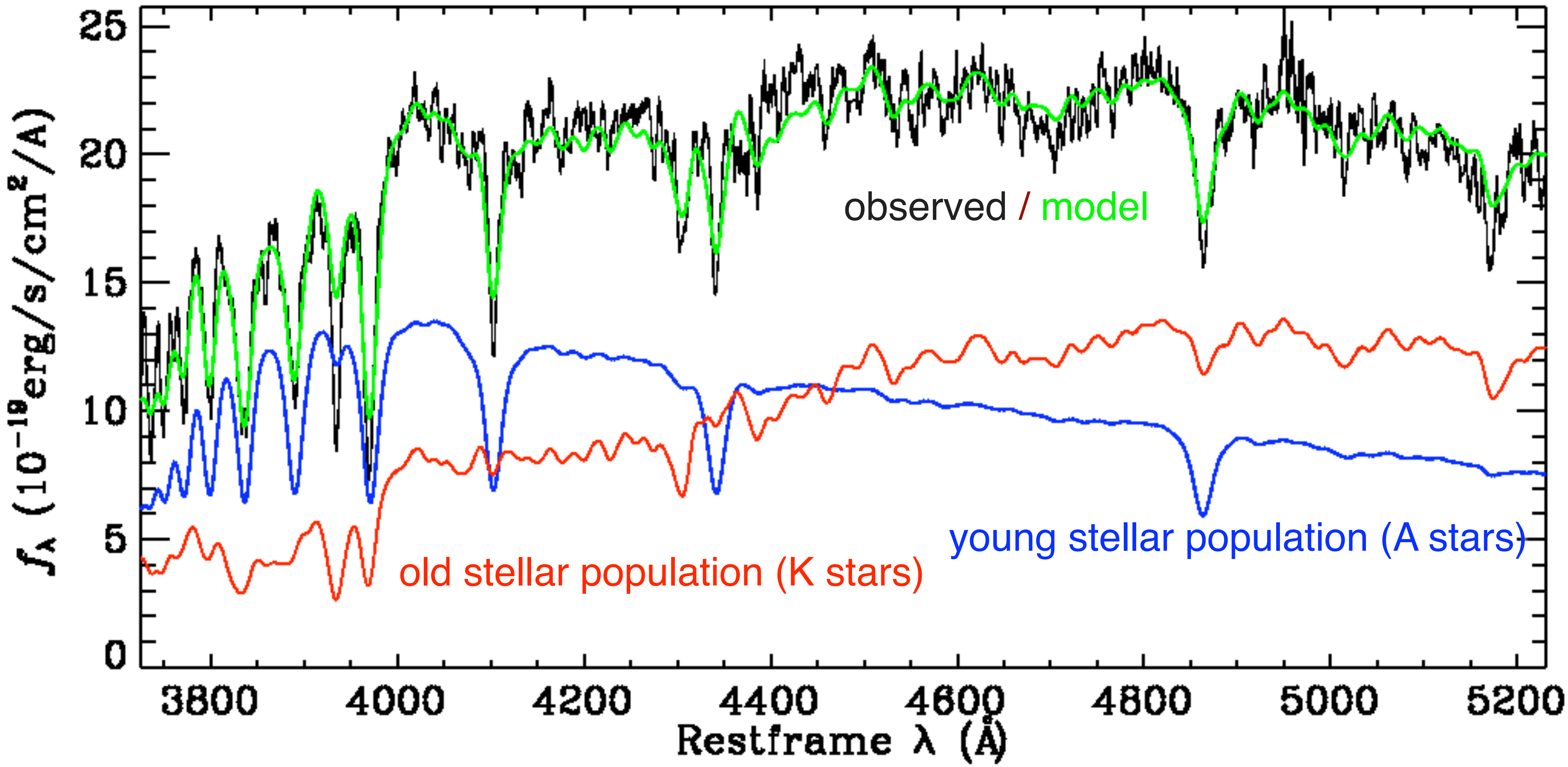
Galaxy evolution

Galaxy evolution

E+A (K+A) post-starburst galaxies



credit: Renbin Yan

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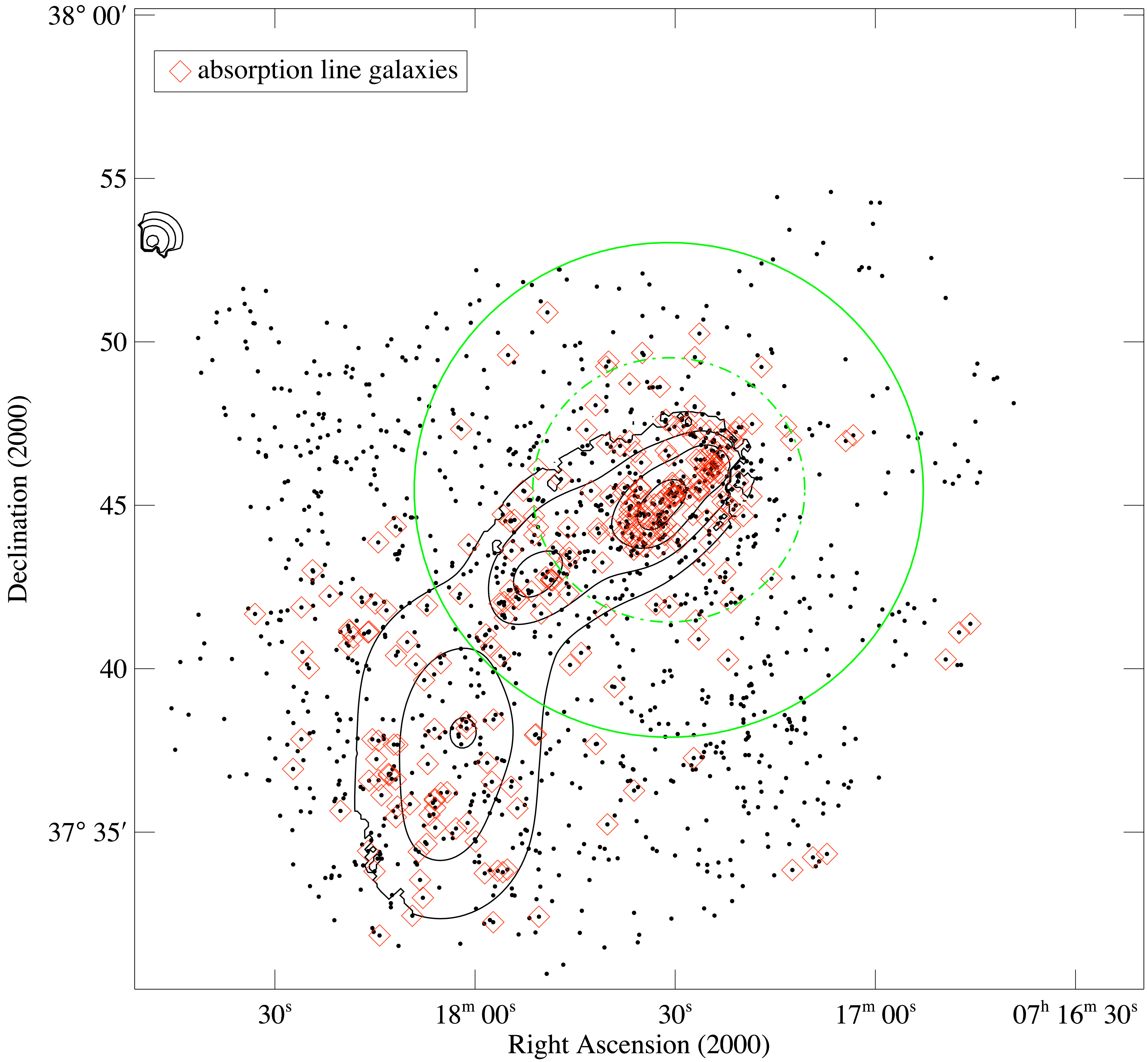
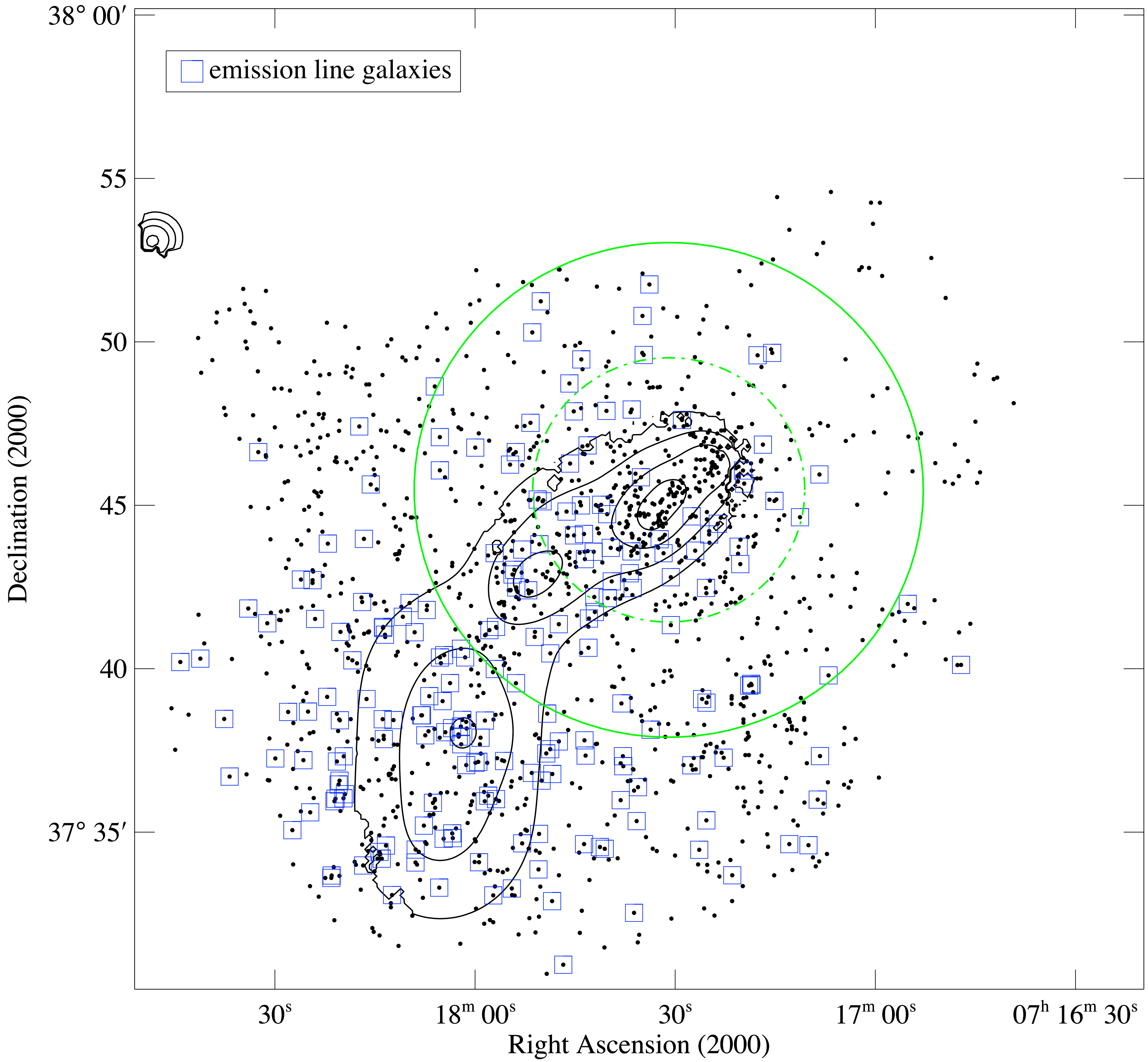


Ma et al., 2008

Selected, recent MACS results



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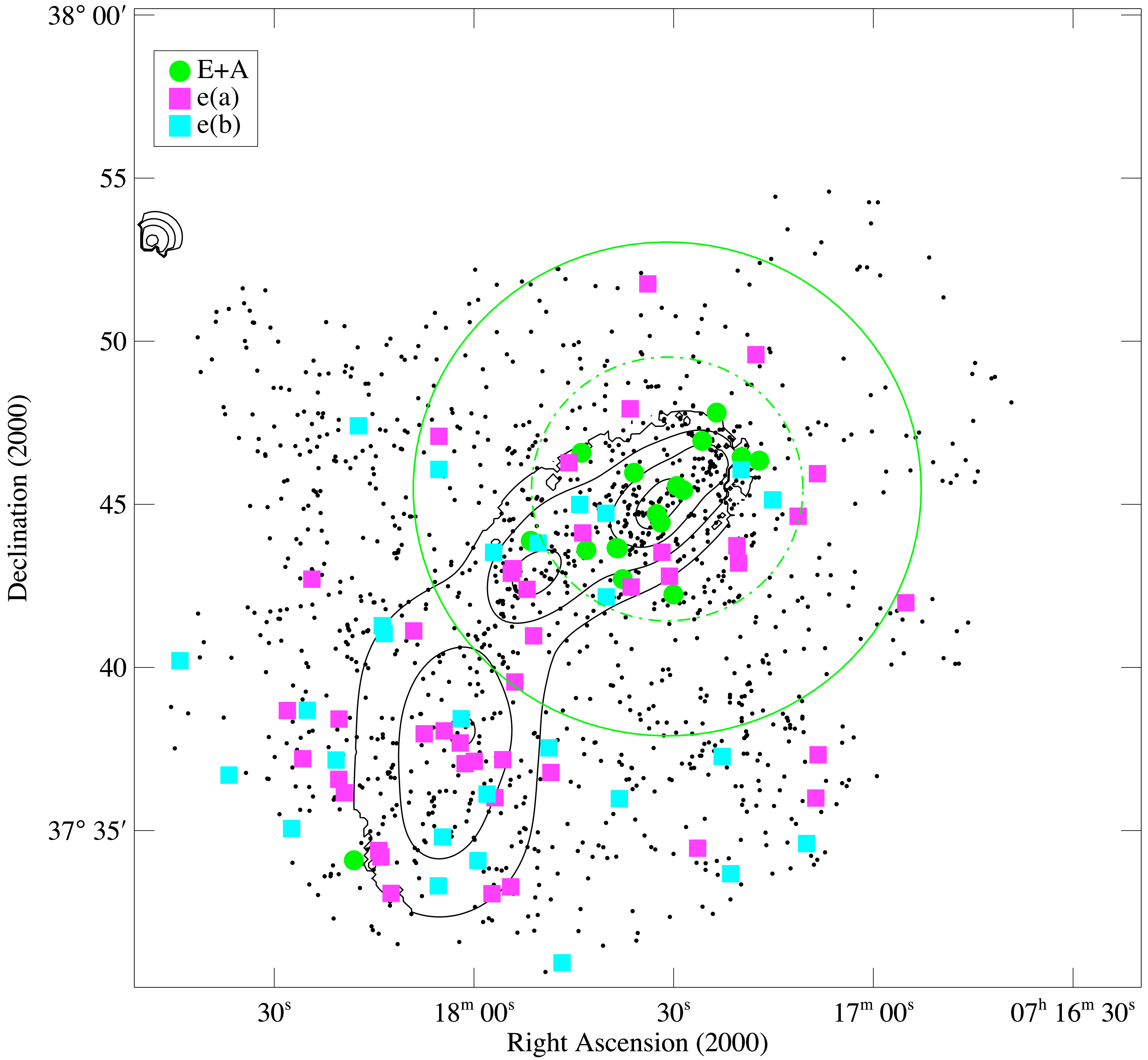

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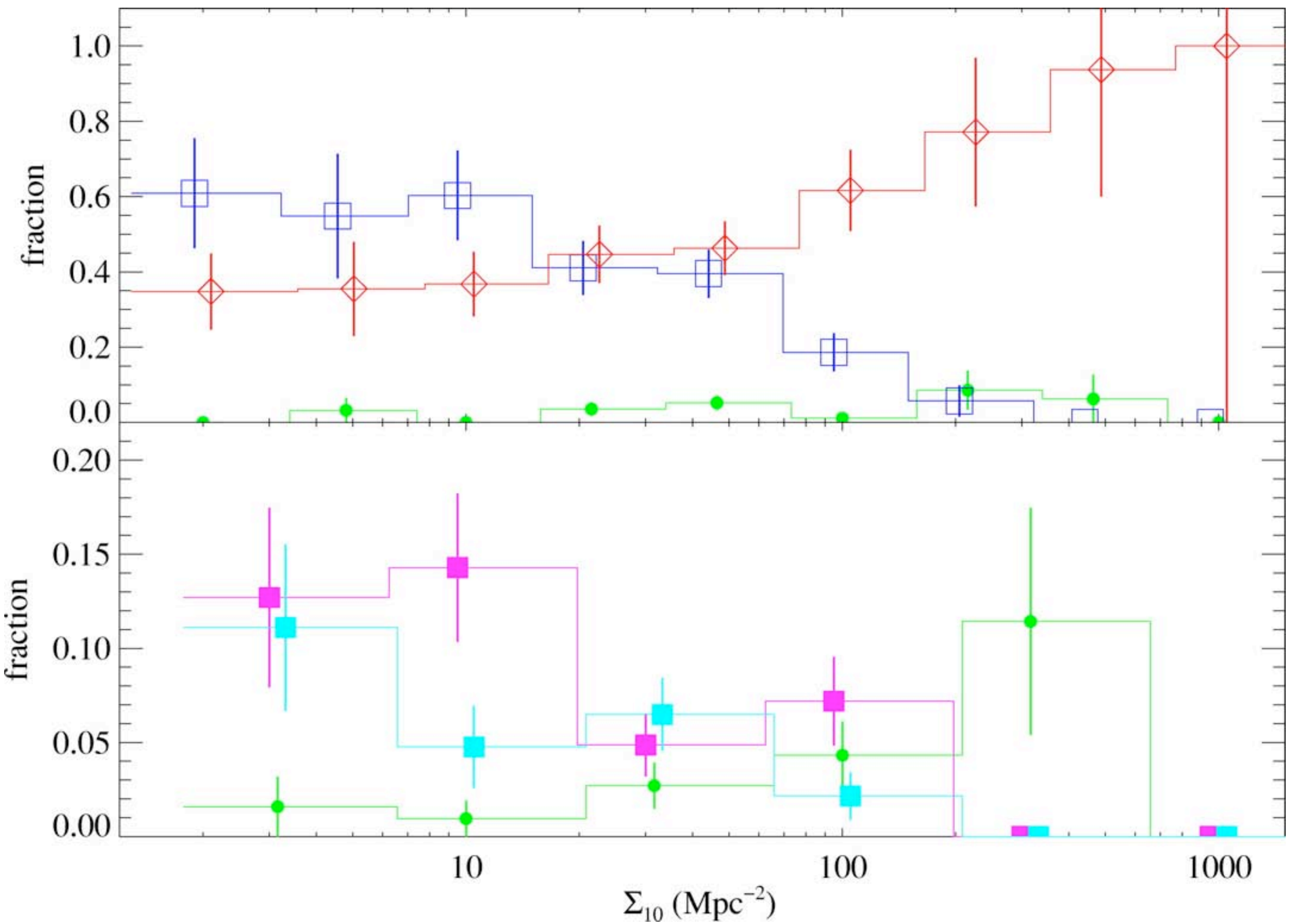

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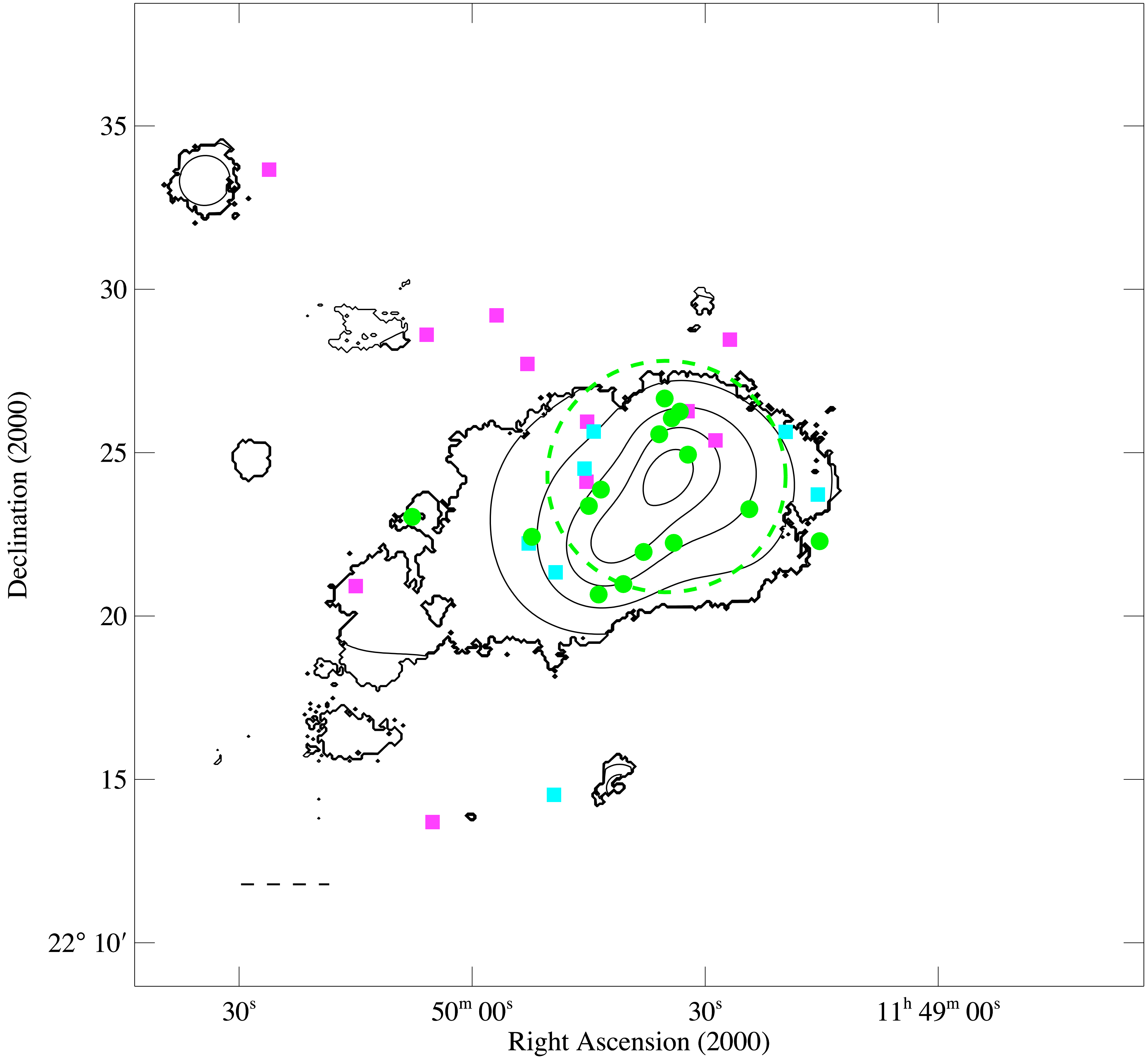
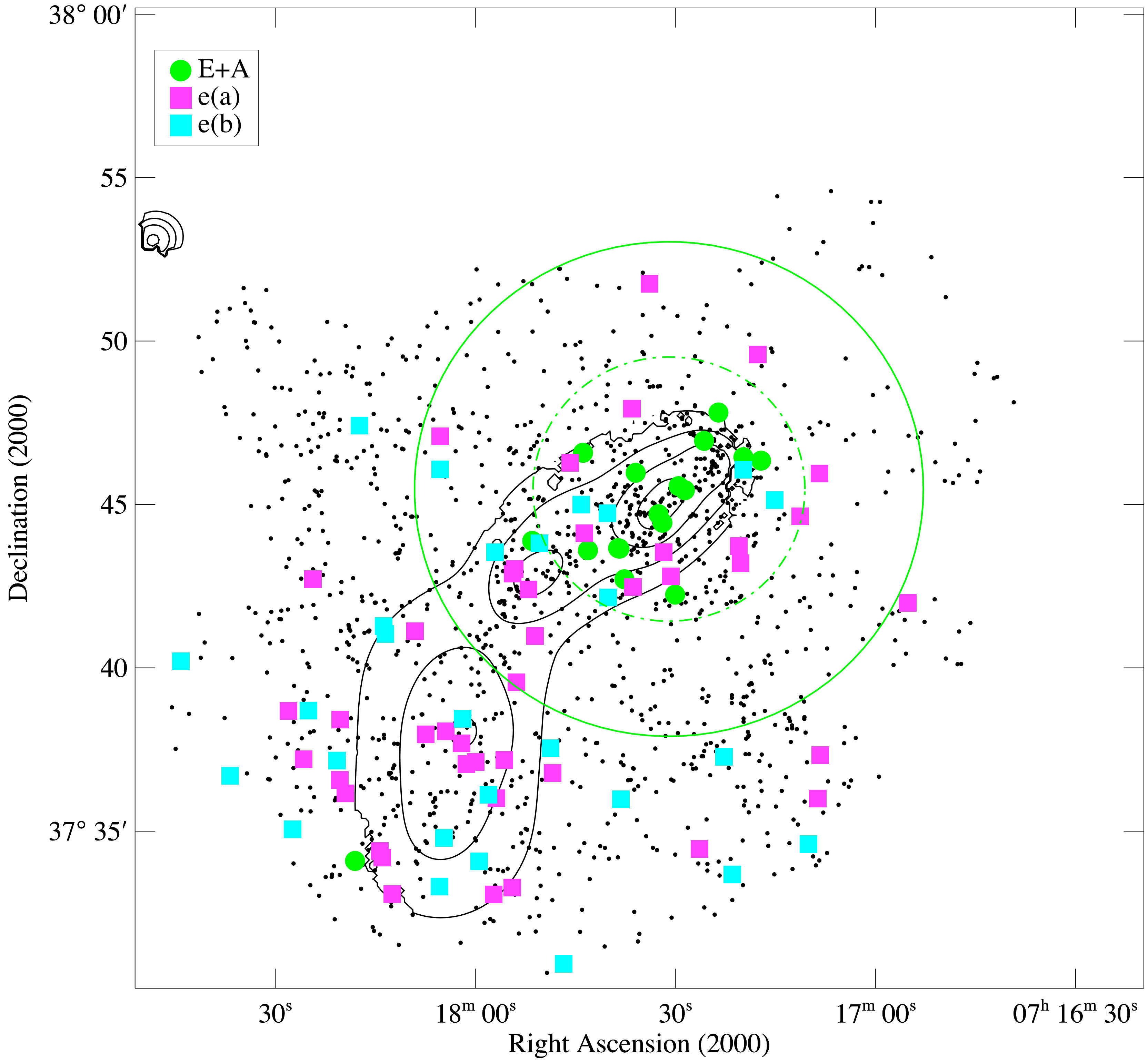


Ma et al., 2008

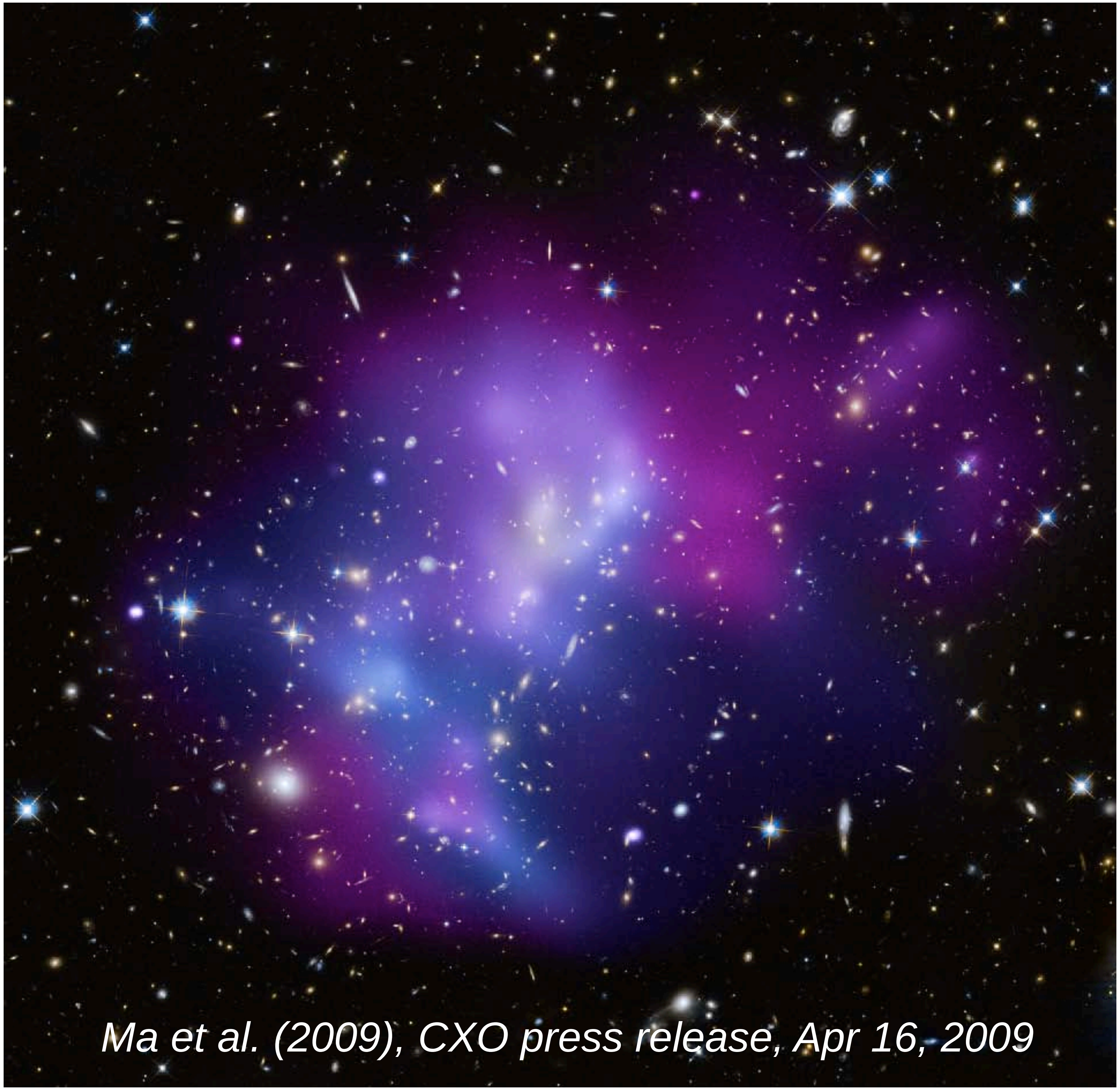


Galaxy evolution

Using spectral diagnostics of star-formation activity, an in-depth study of the galaxy population of MACSJ0717.5 +3745 finds strong evidence for ram-pressure stripping by the intracluster gas being the main physical mechanism for galaxy evolution in clusters.

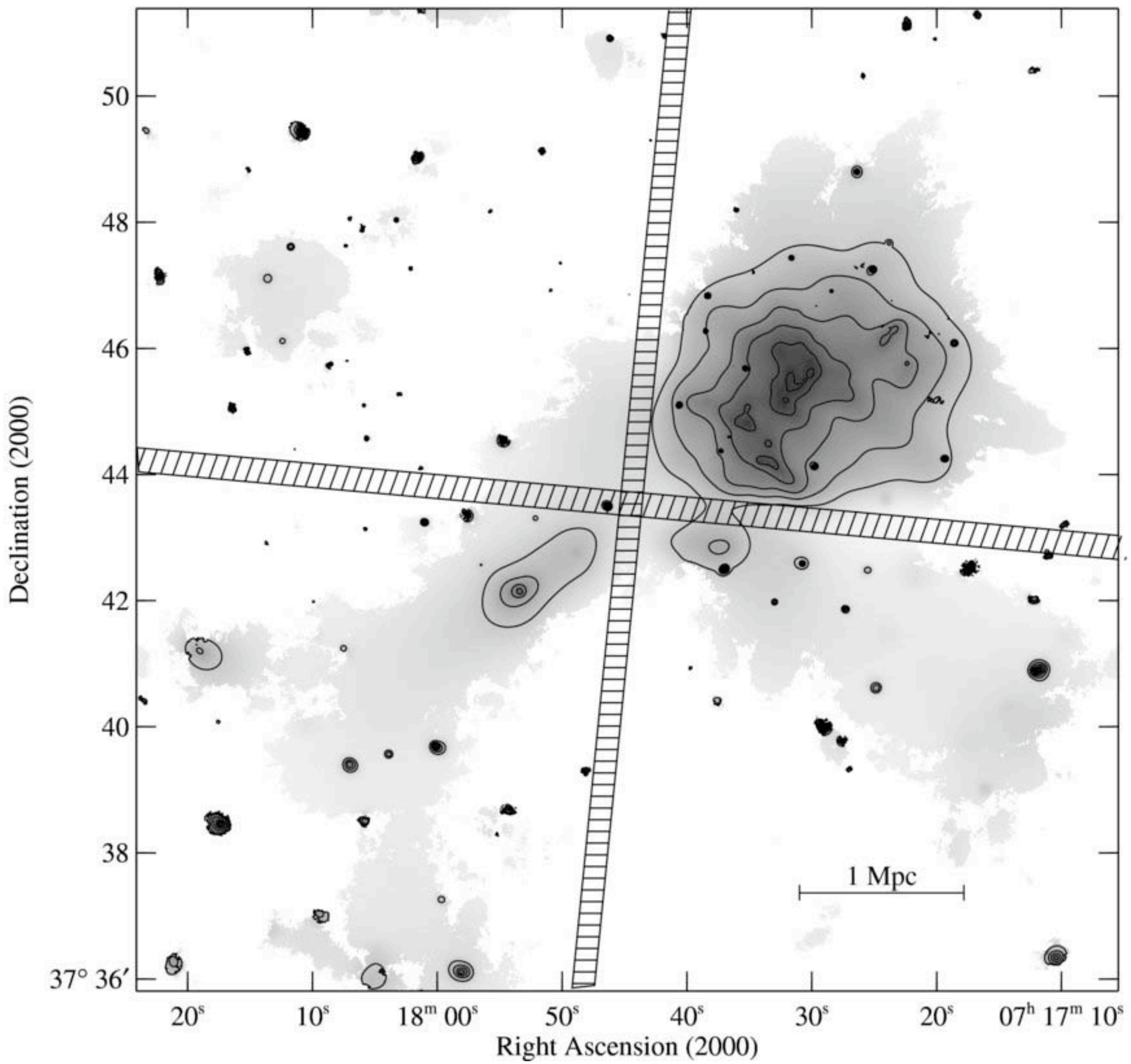
Ma et al. (2008)

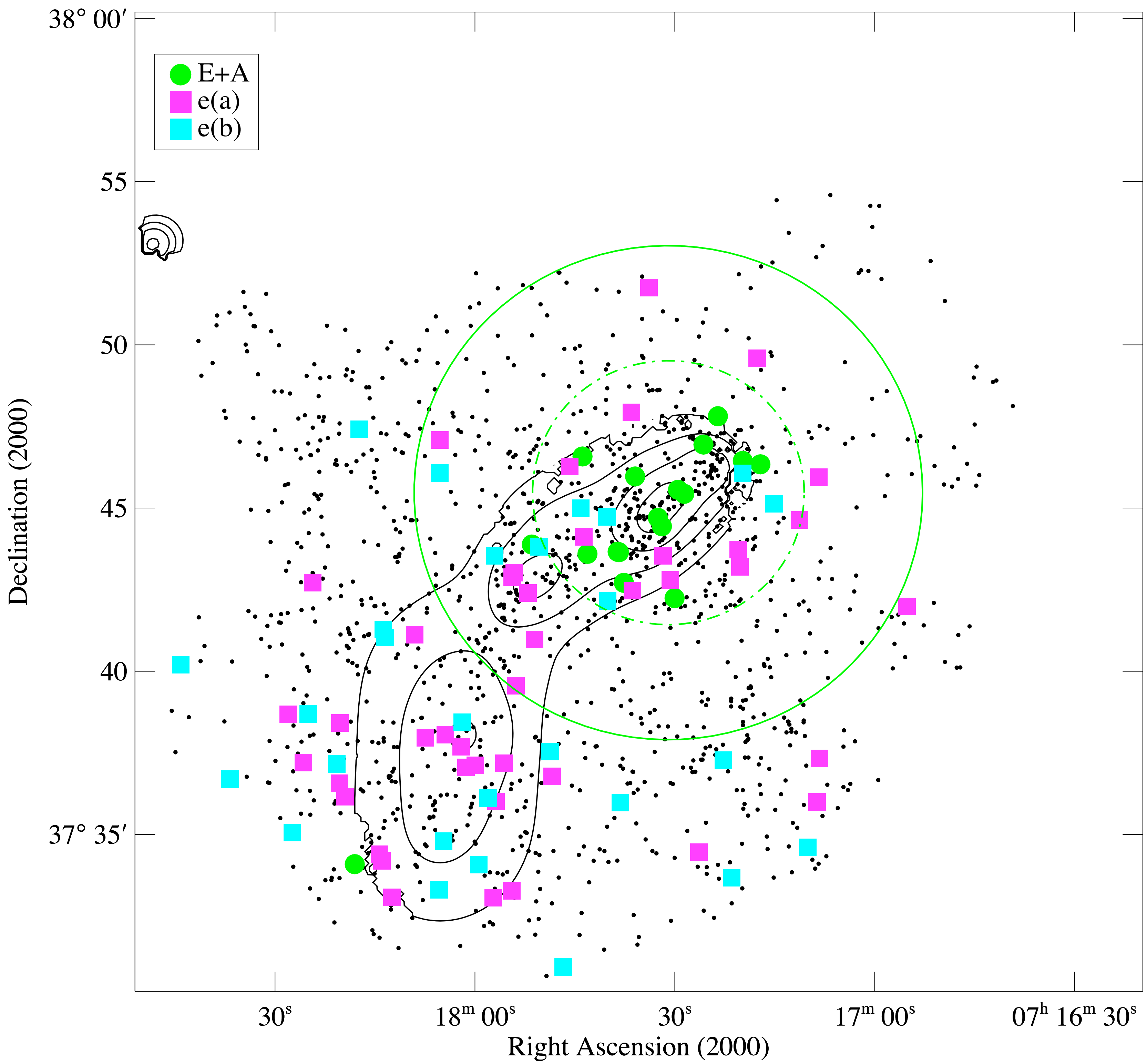
3D dynamics of cluster mergers



Ma et al. (2009), CXO press release, Apr 16, 2009

MACSJ0717.5+3745, Chandra ACIS-I, 60 ks





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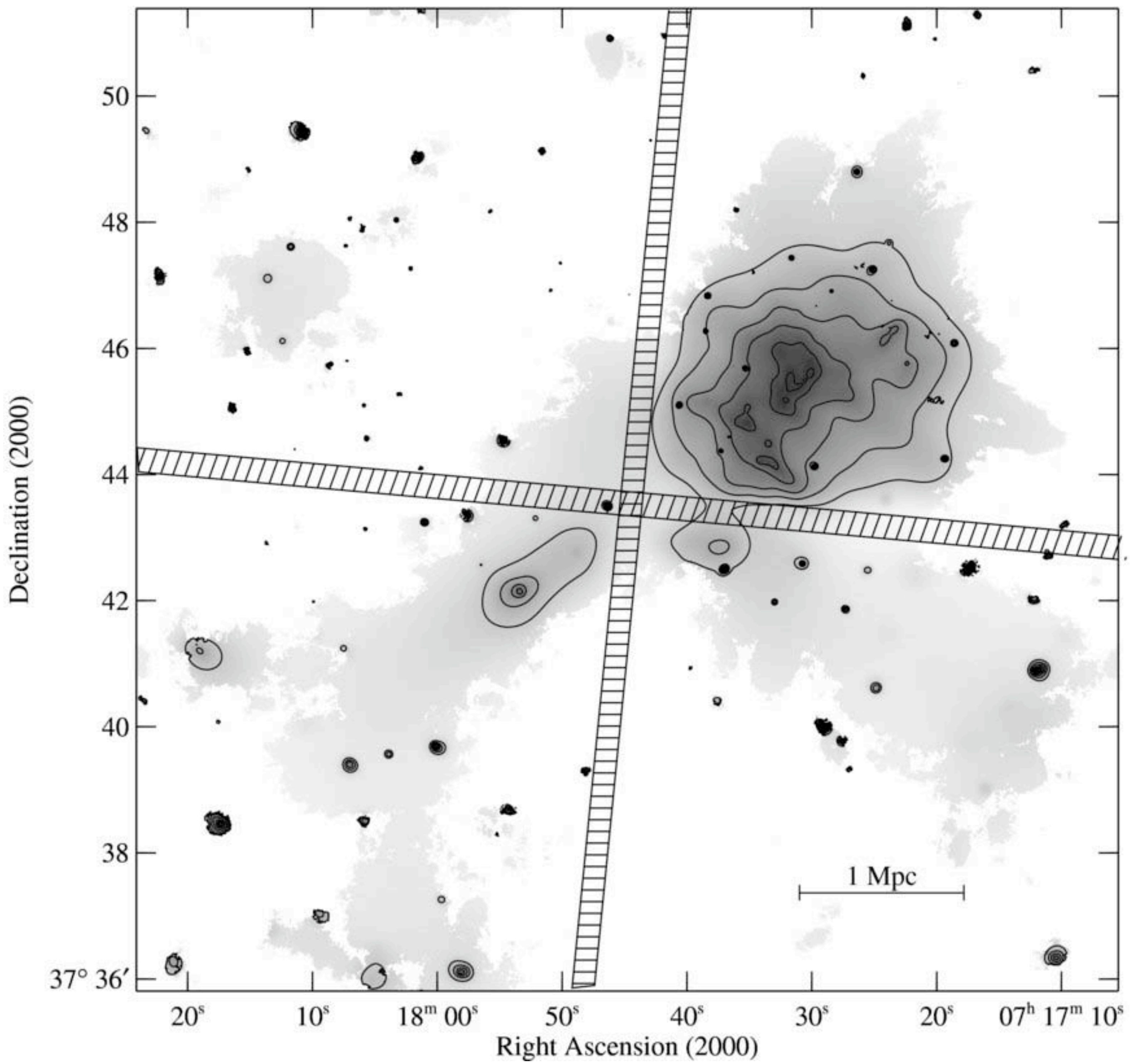

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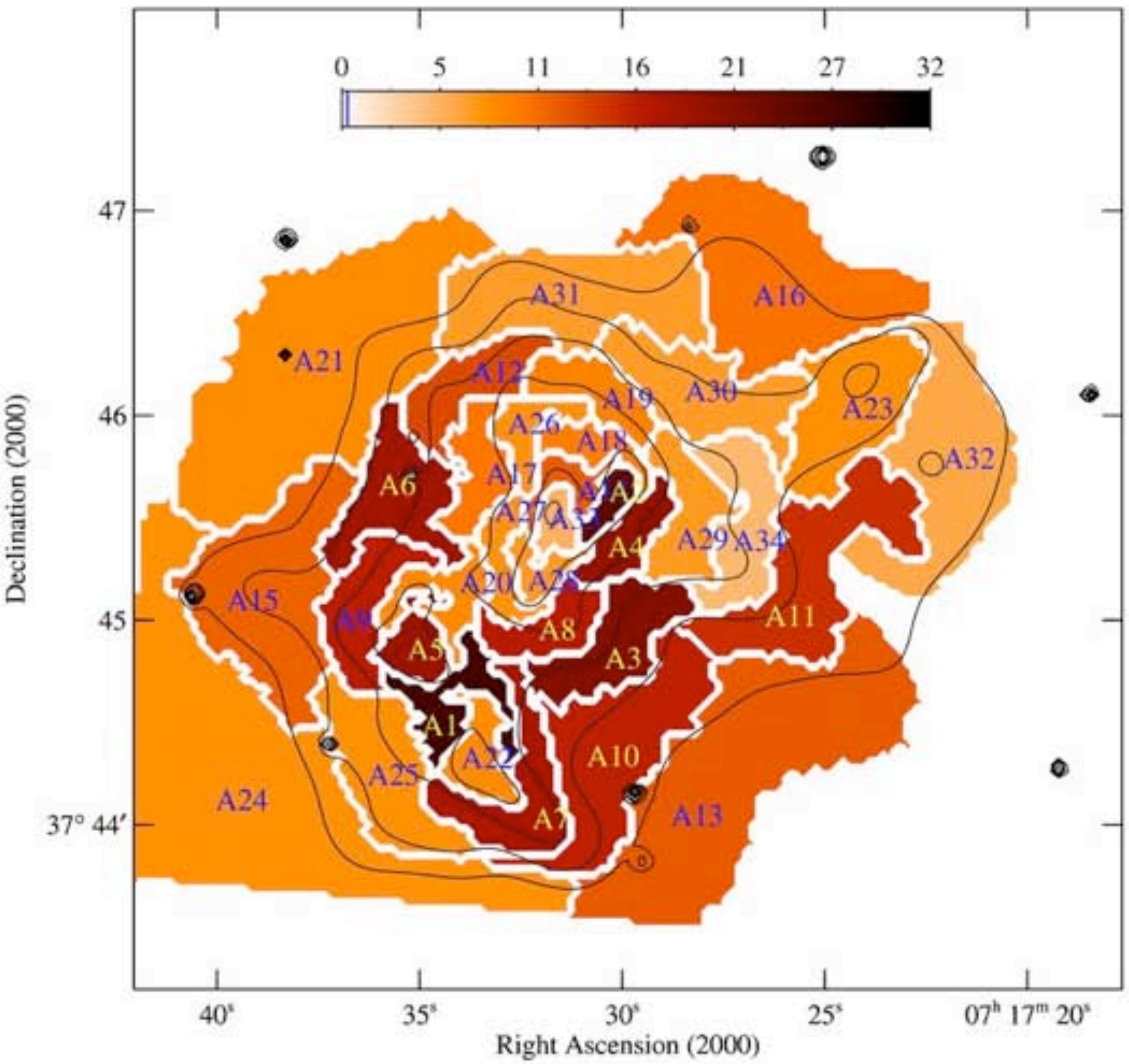

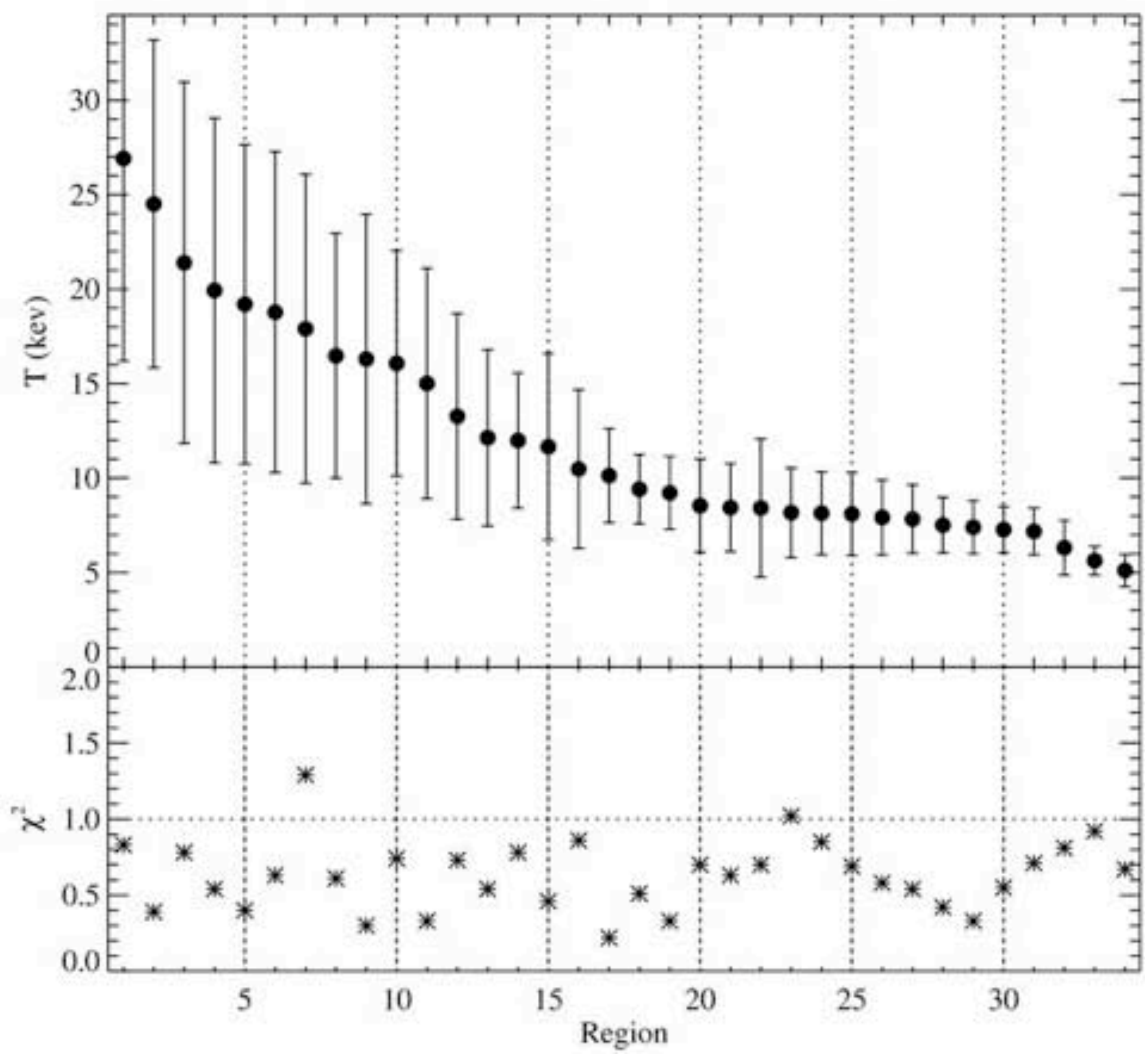

Ma et al. (2009)

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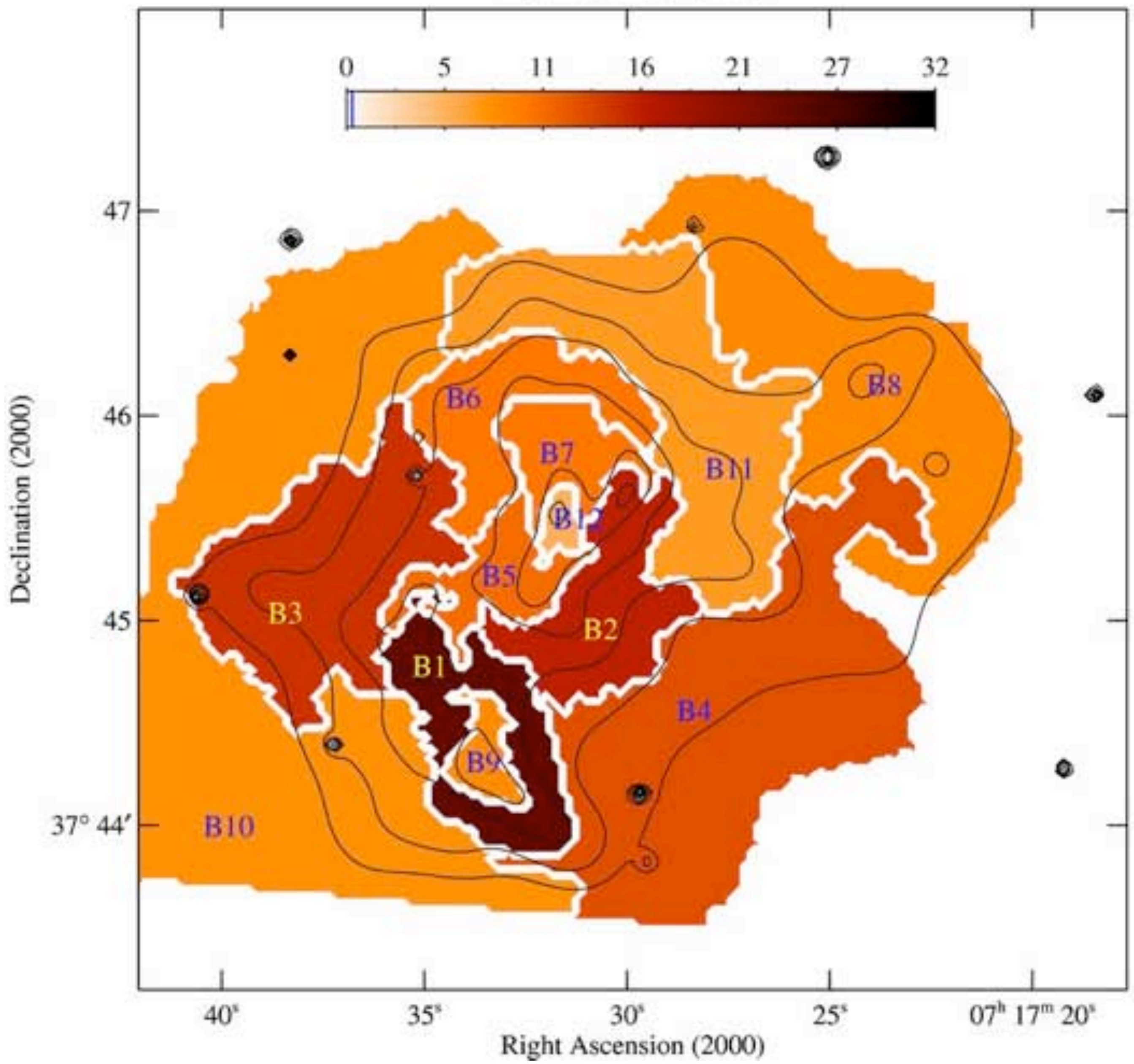

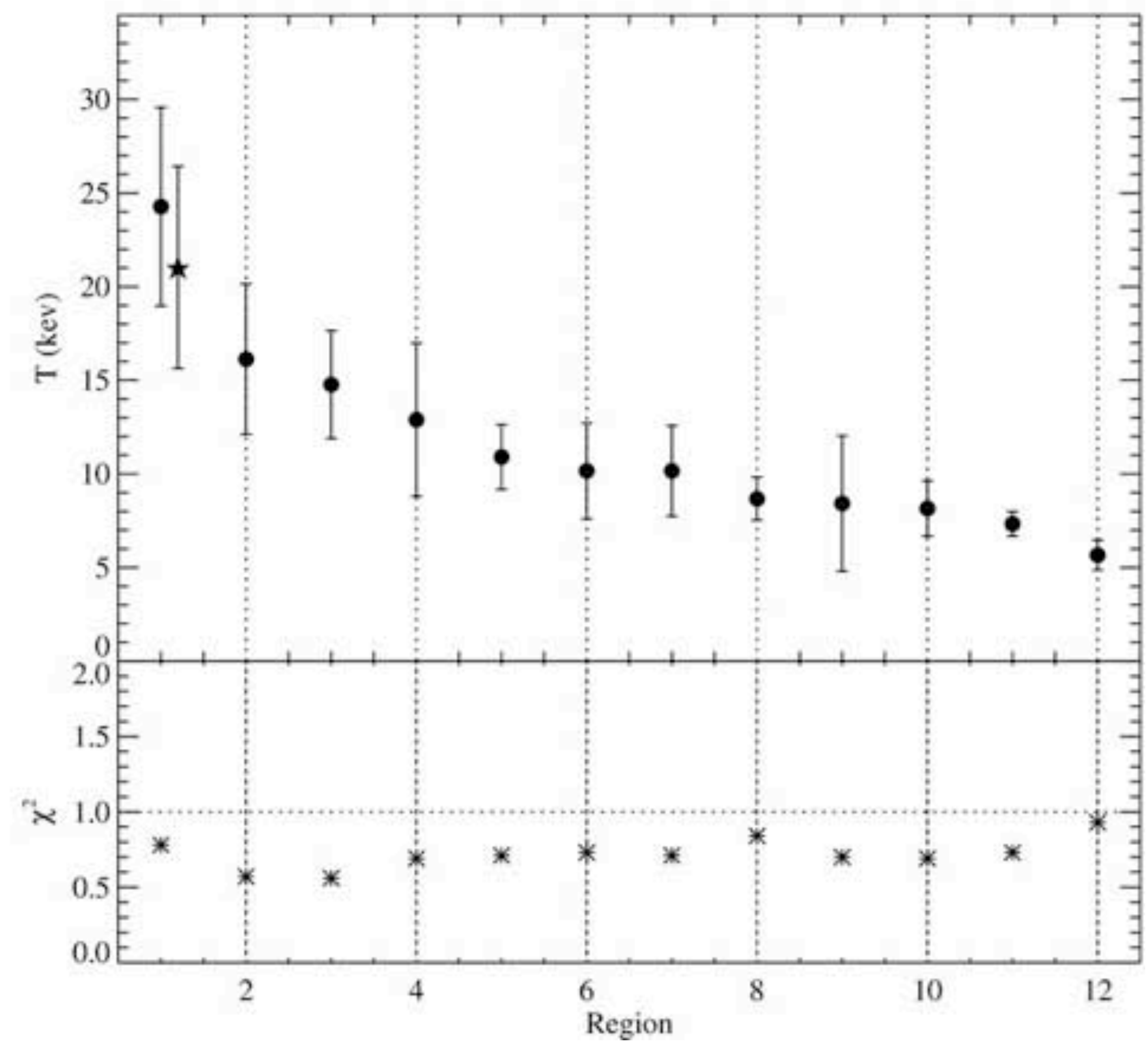

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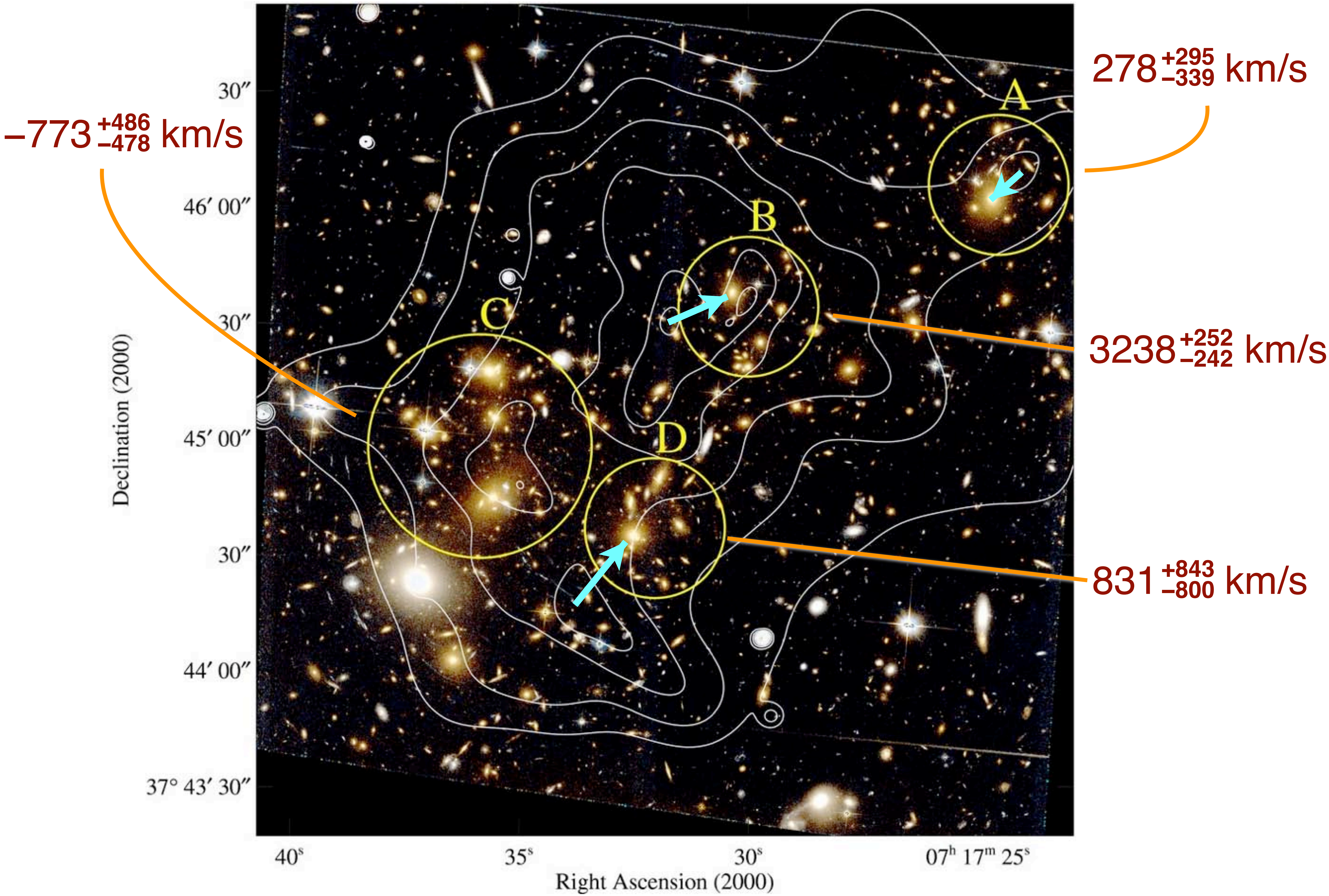

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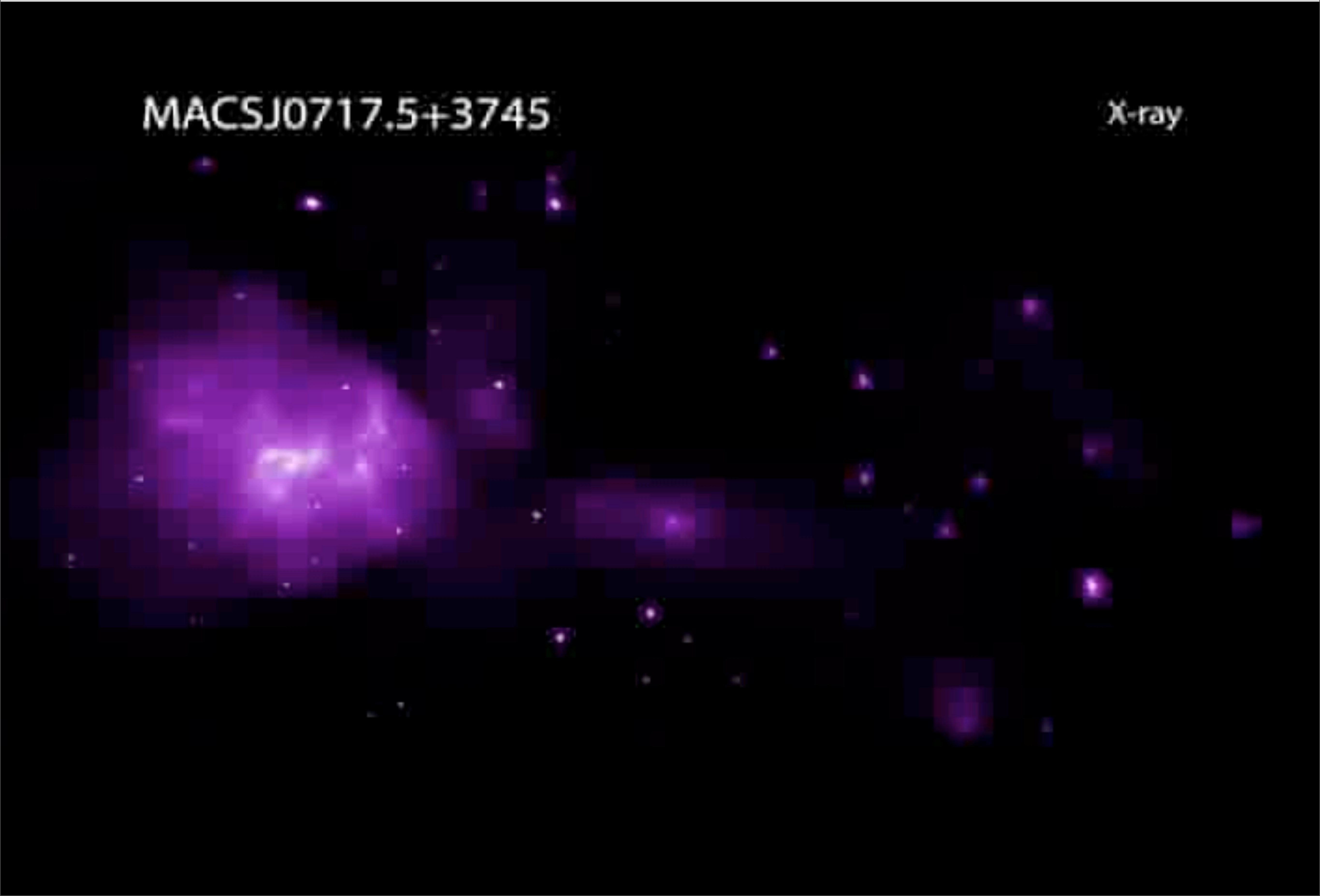

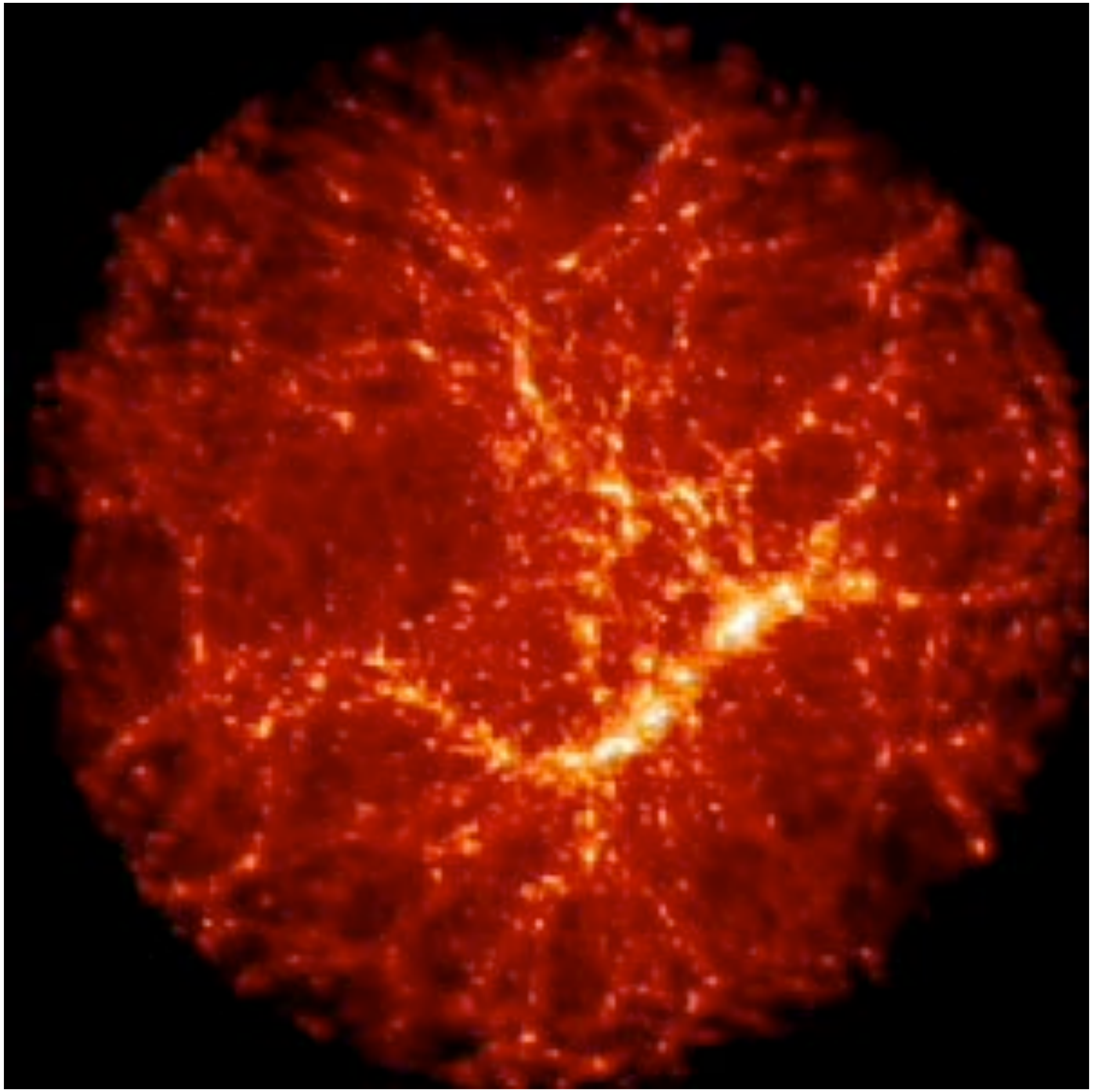

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(2) *X-ray selection is crucial* to defeat projection effects

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