X-ray tails of cluster late-type galaxies

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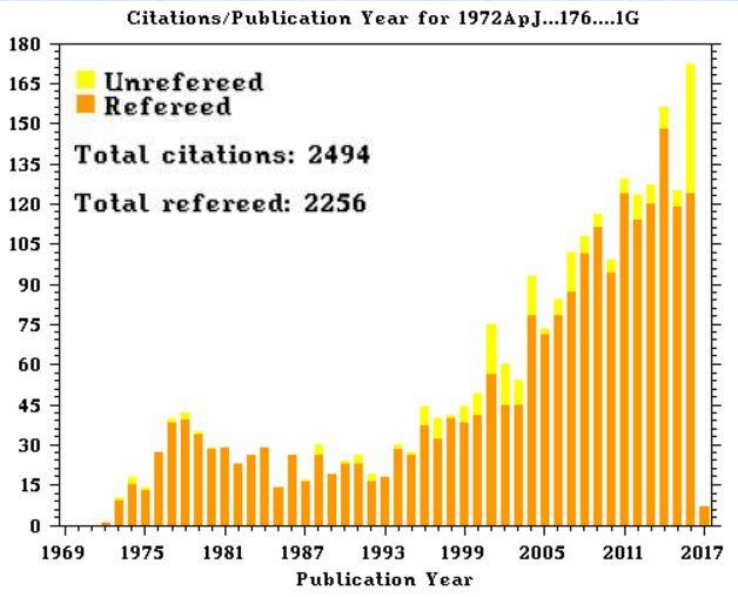
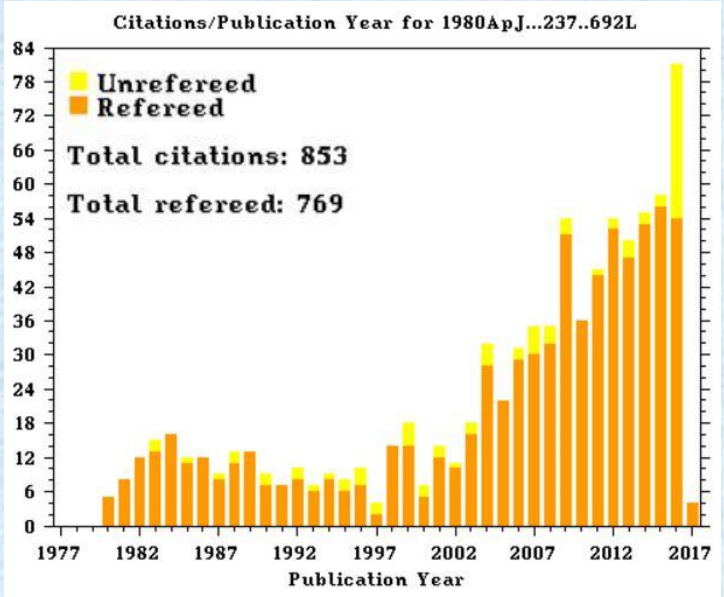
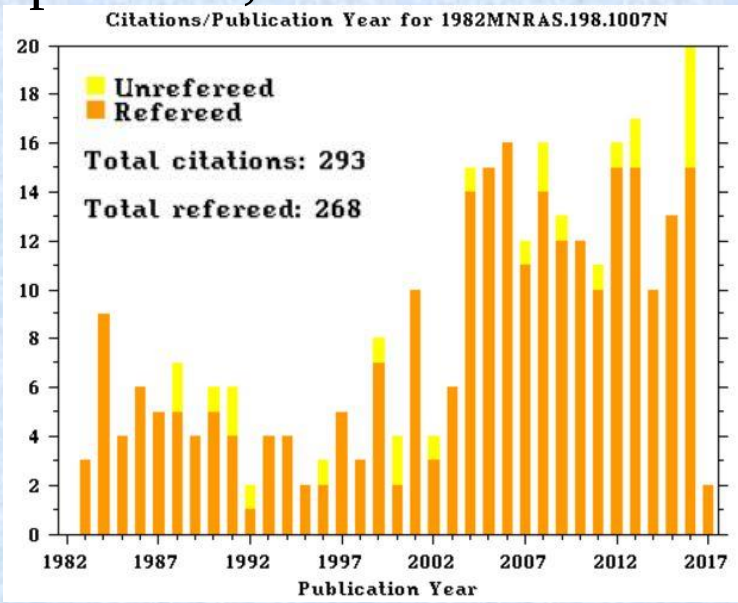


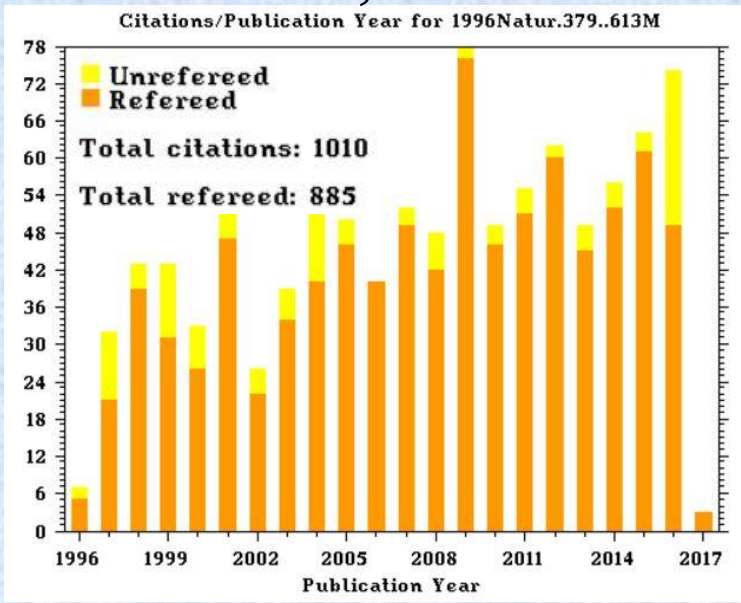
Ram pressure, Gunn & Gott 1972



Starvation, Larson+ 1980



Viscous, turbulent stripping, Nulsen 1982



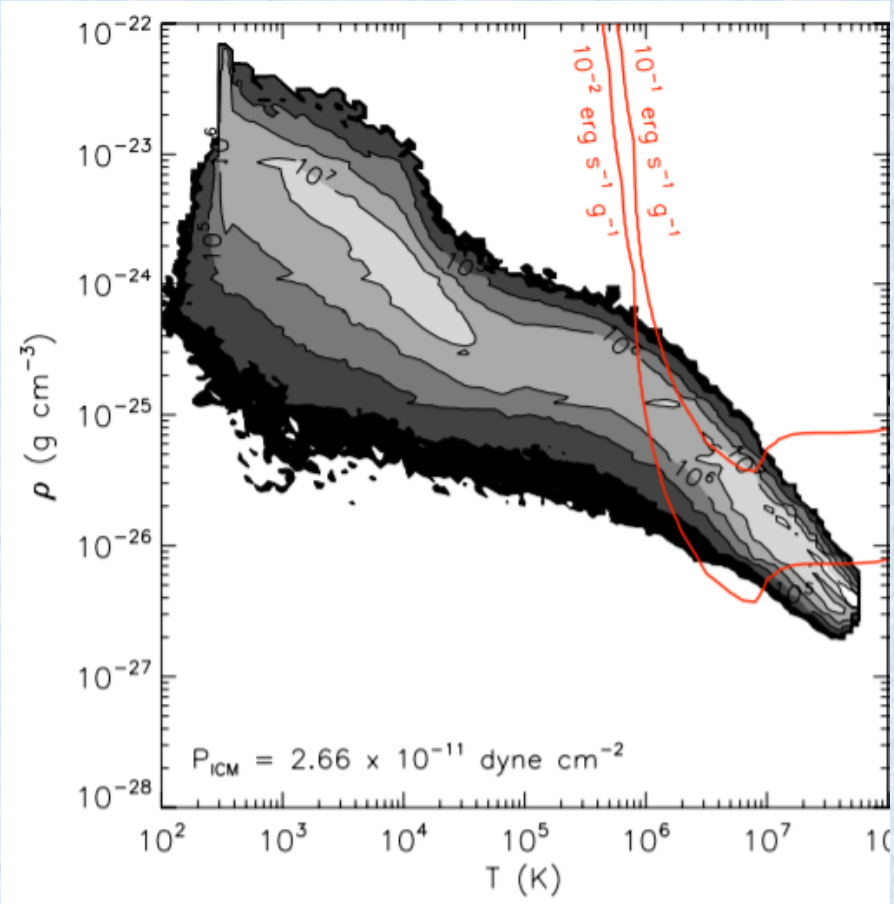
Harassment, Moore+ 1996

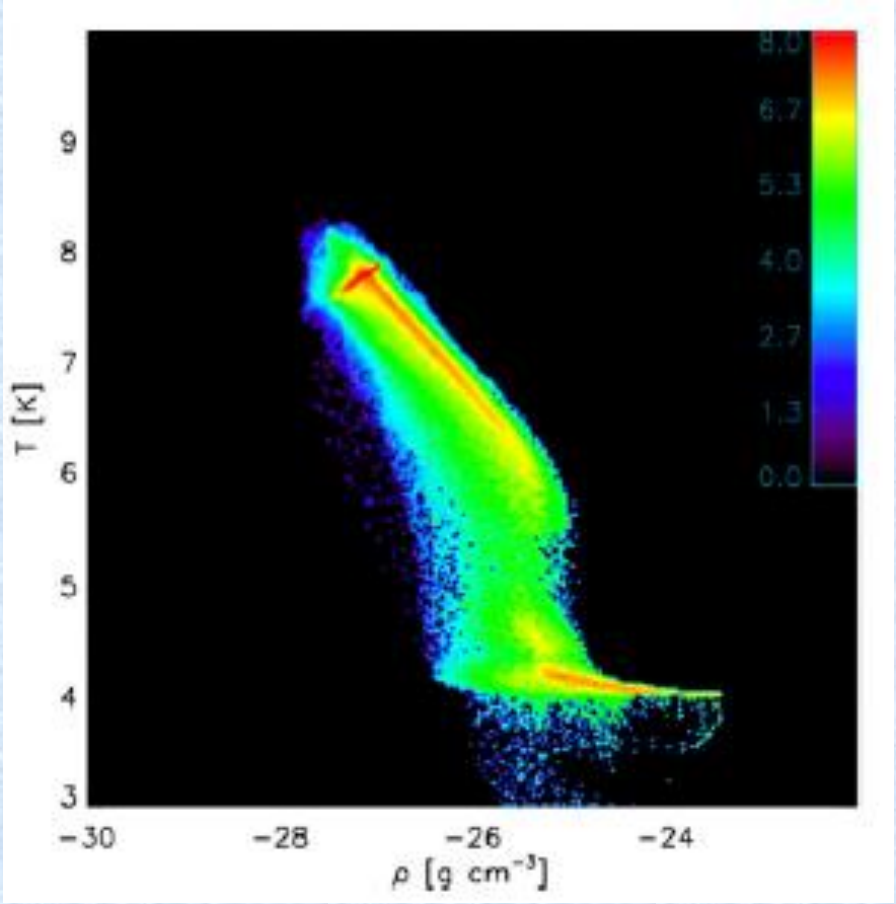
(original idea from Davor Krajnovic)

Ram pressure stripping

- Galaxy evolution (need realistic RPS model)
- A general process in astronomy (NAT radio galaxies, pulsar/stellar winds, heliosphere …)
- Clumping in the intracluster medium (ICM)
- Ideal targets to study ICM plasma physics (heat conduction and viscosity > 10 – 20 X suppression but the flow is probably not very turbulent)
- Stripped gas --- a great environment to study multi-phase medium and star formation

An era of multi-wavelength studies !



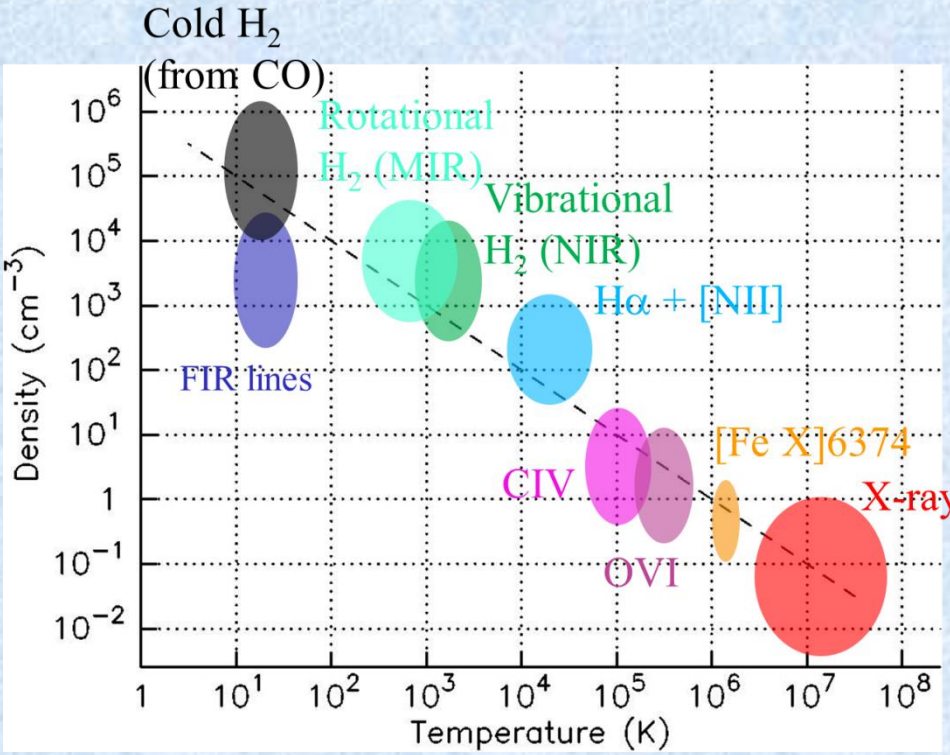


Tonnesen + 2011

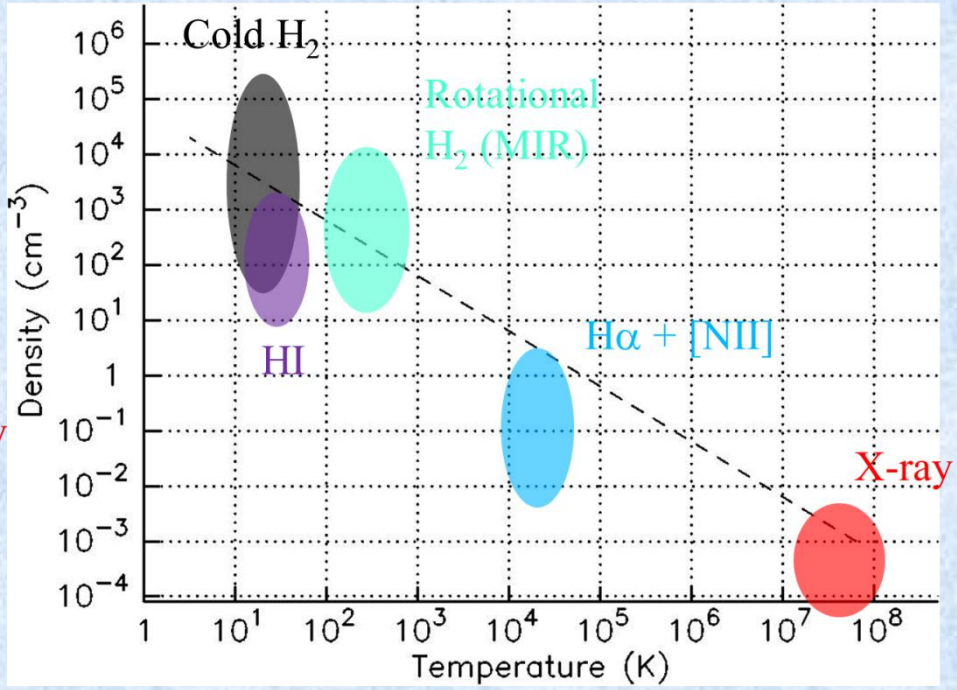
Ruszkowski + 2014

Phase diagram

cool core



stripped tail



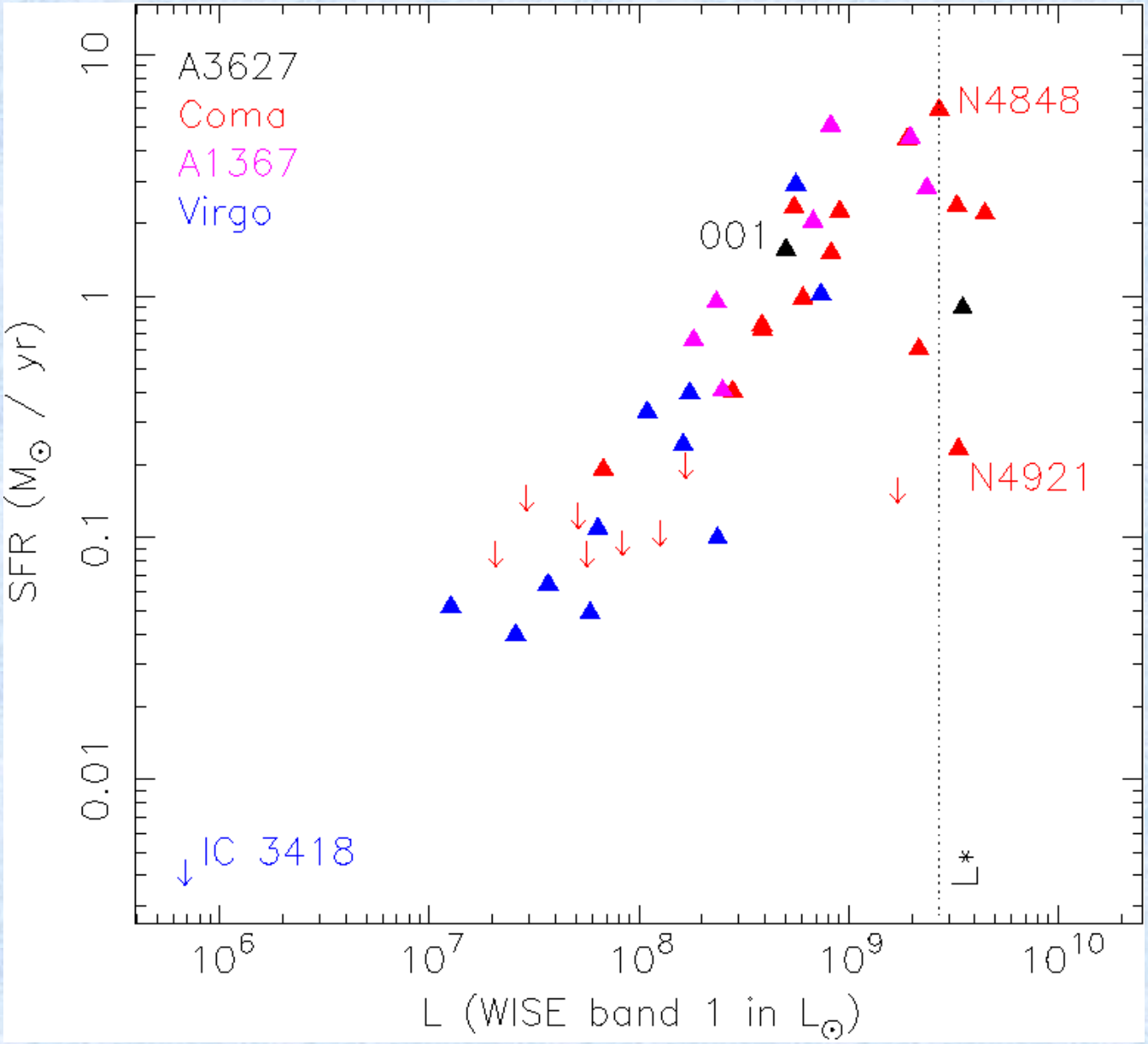
- Stripped tails have become nice objects to study multiphase medium and SF conditions / efficiency, along with cool cores
- Several tracer of kinematics

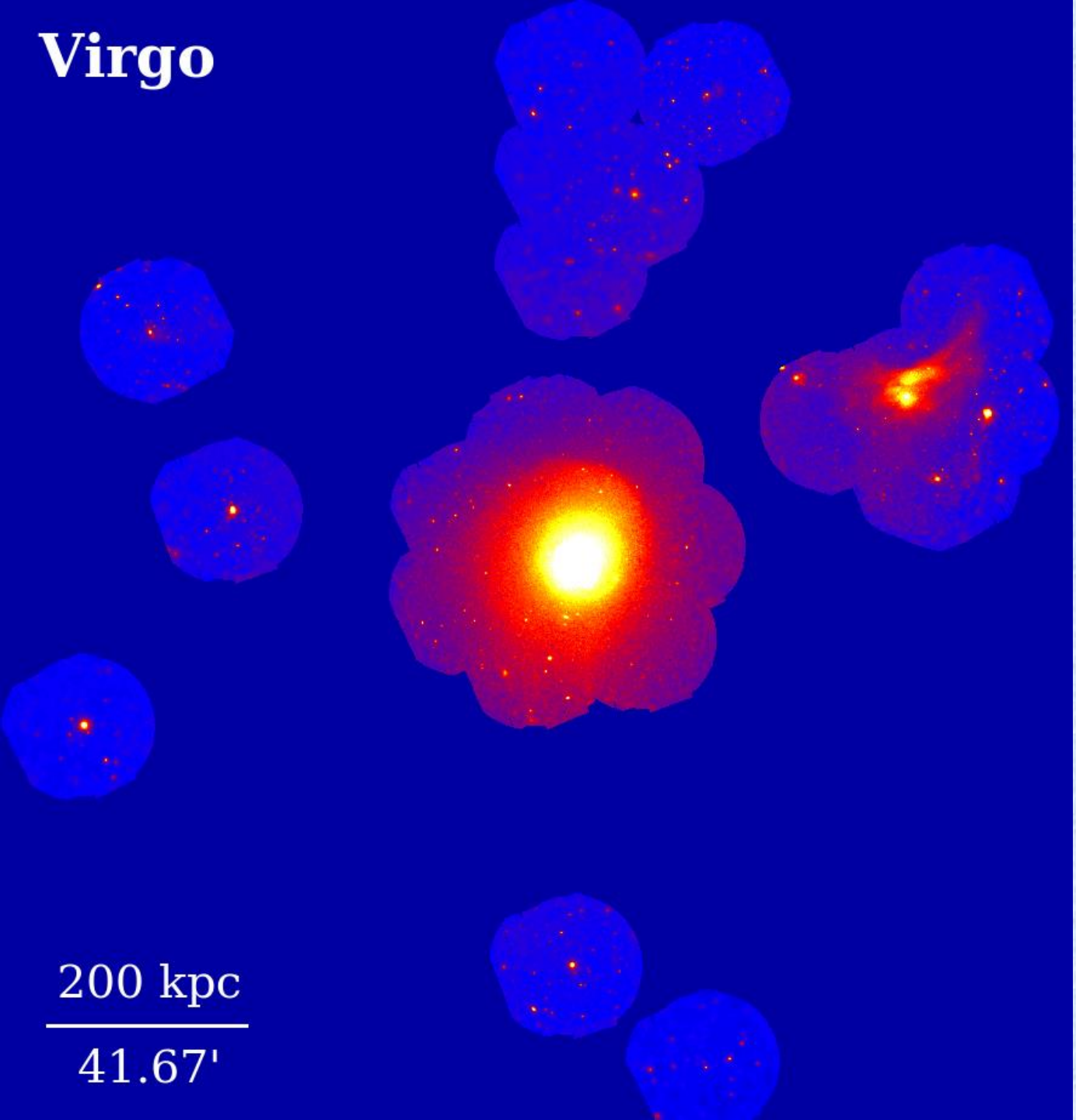
Wake of creation

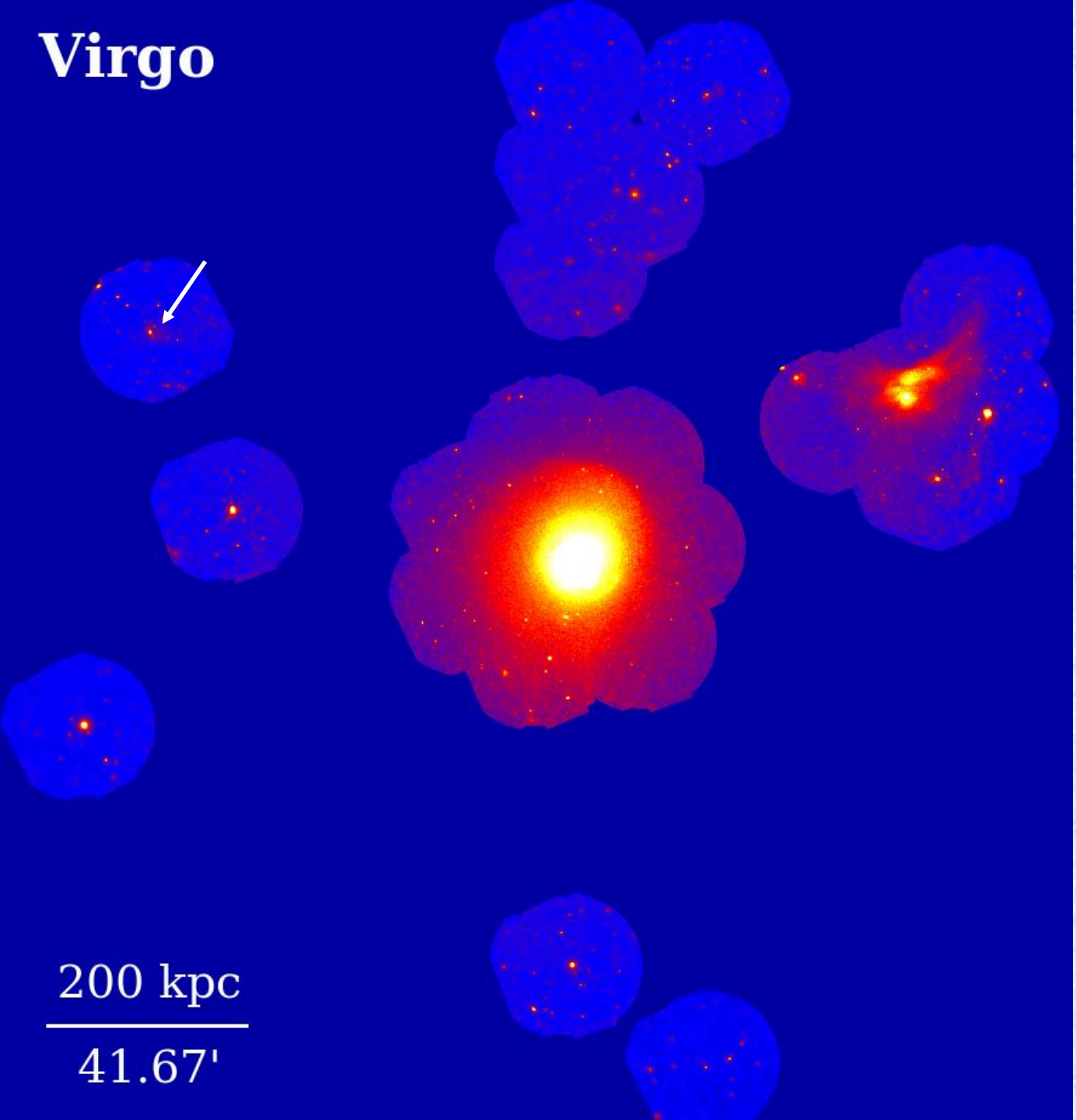
instead of

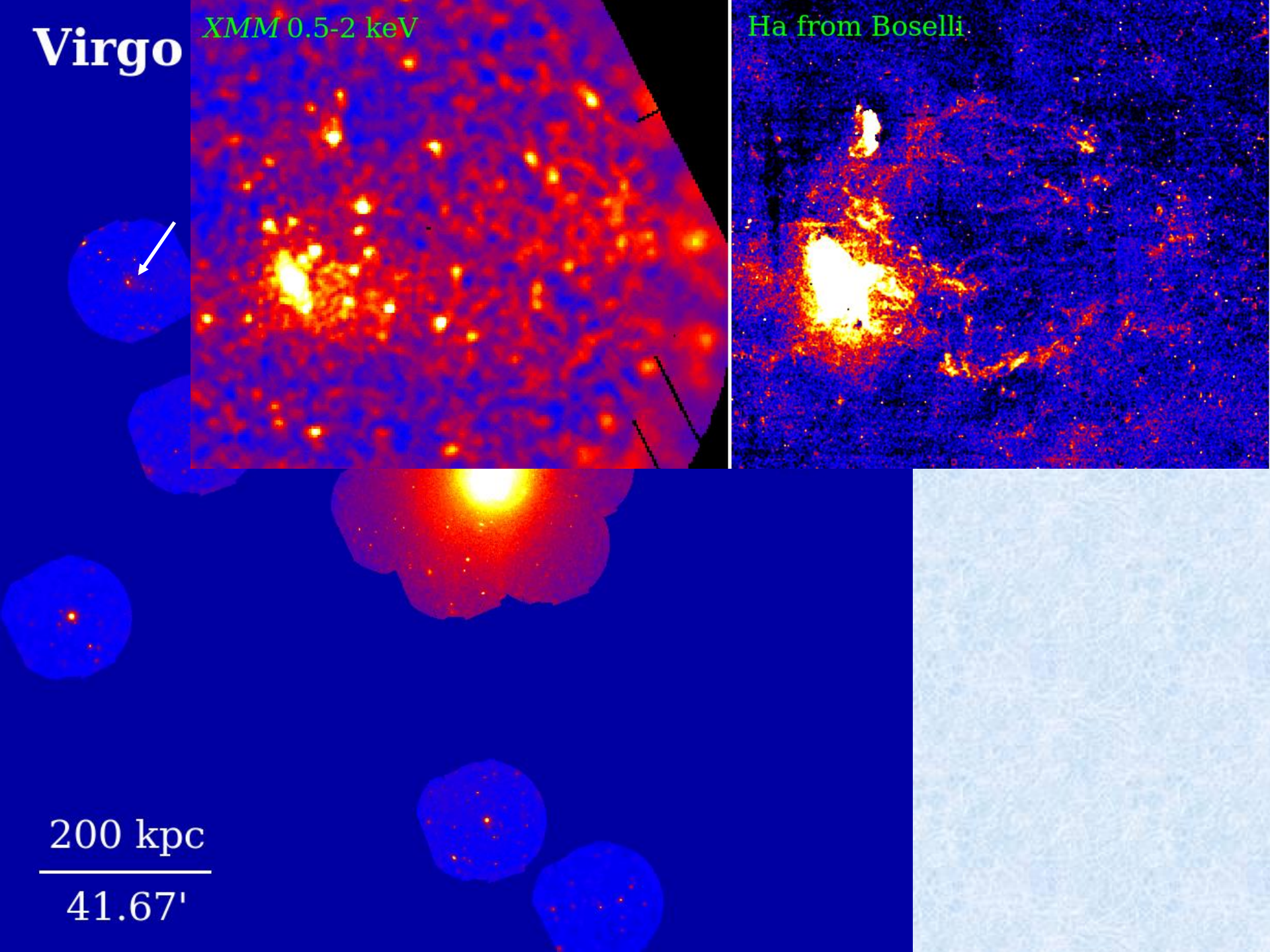
Wake of destruction

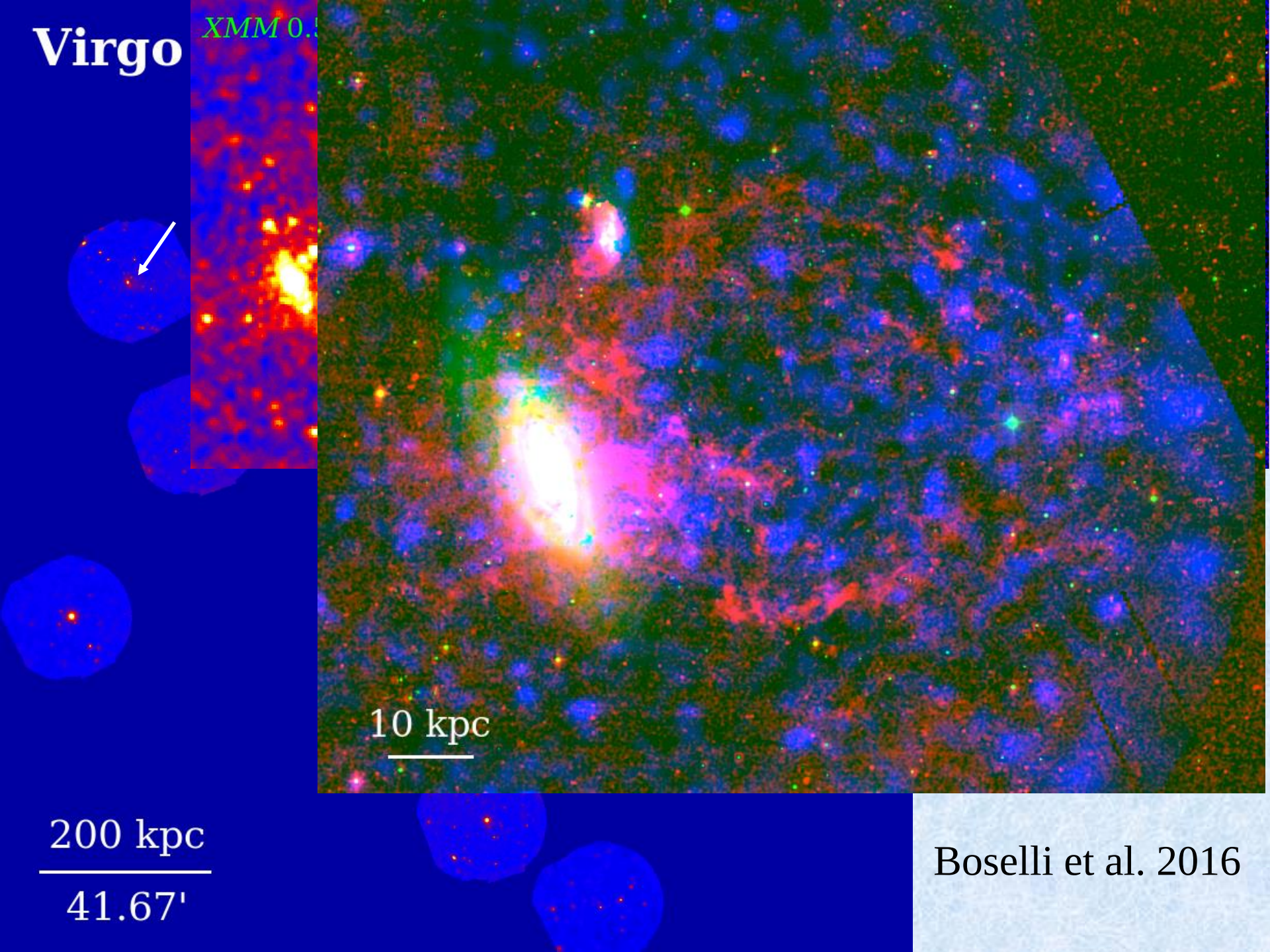
Nearby galaxies with gaseous tails

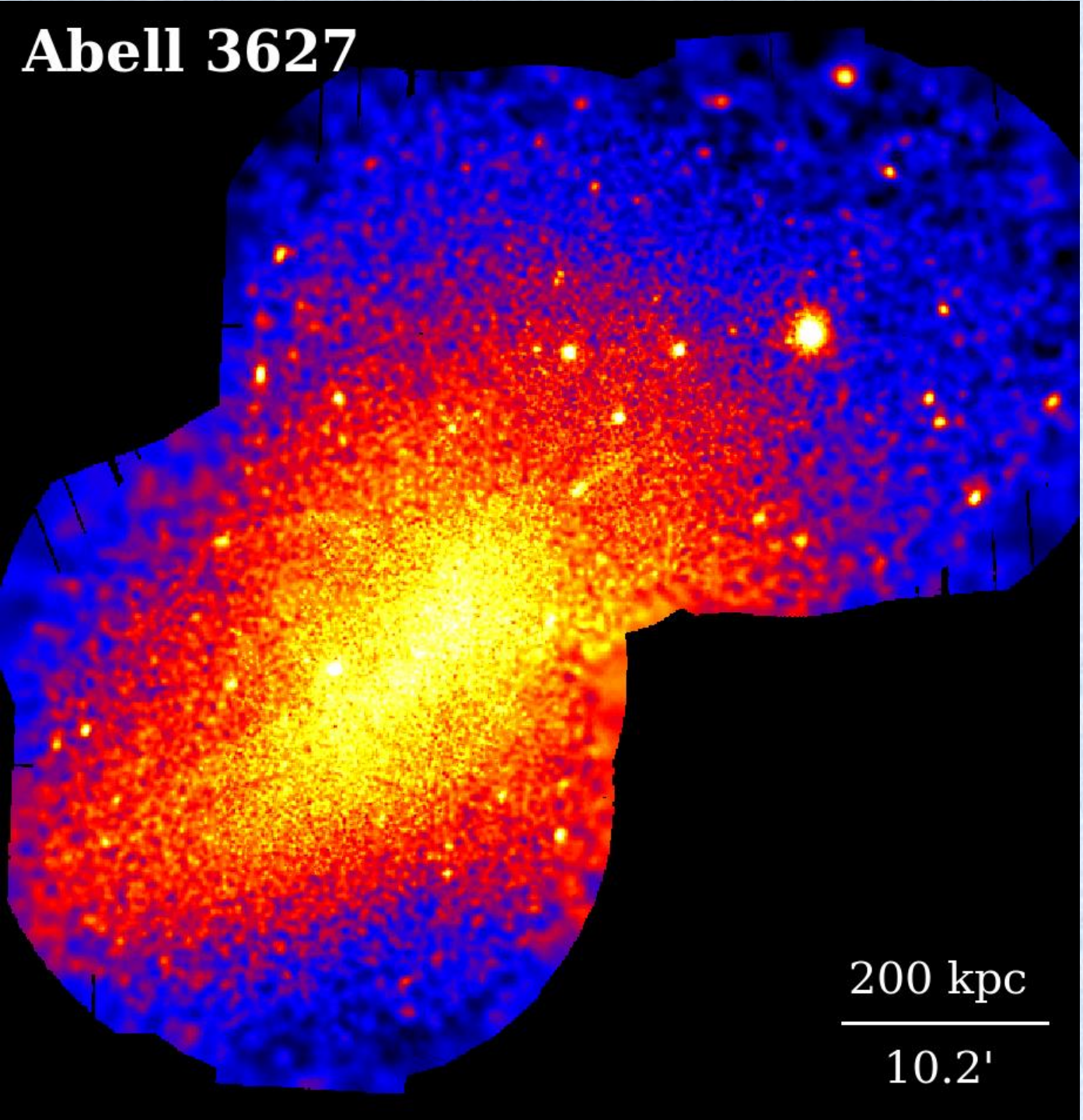


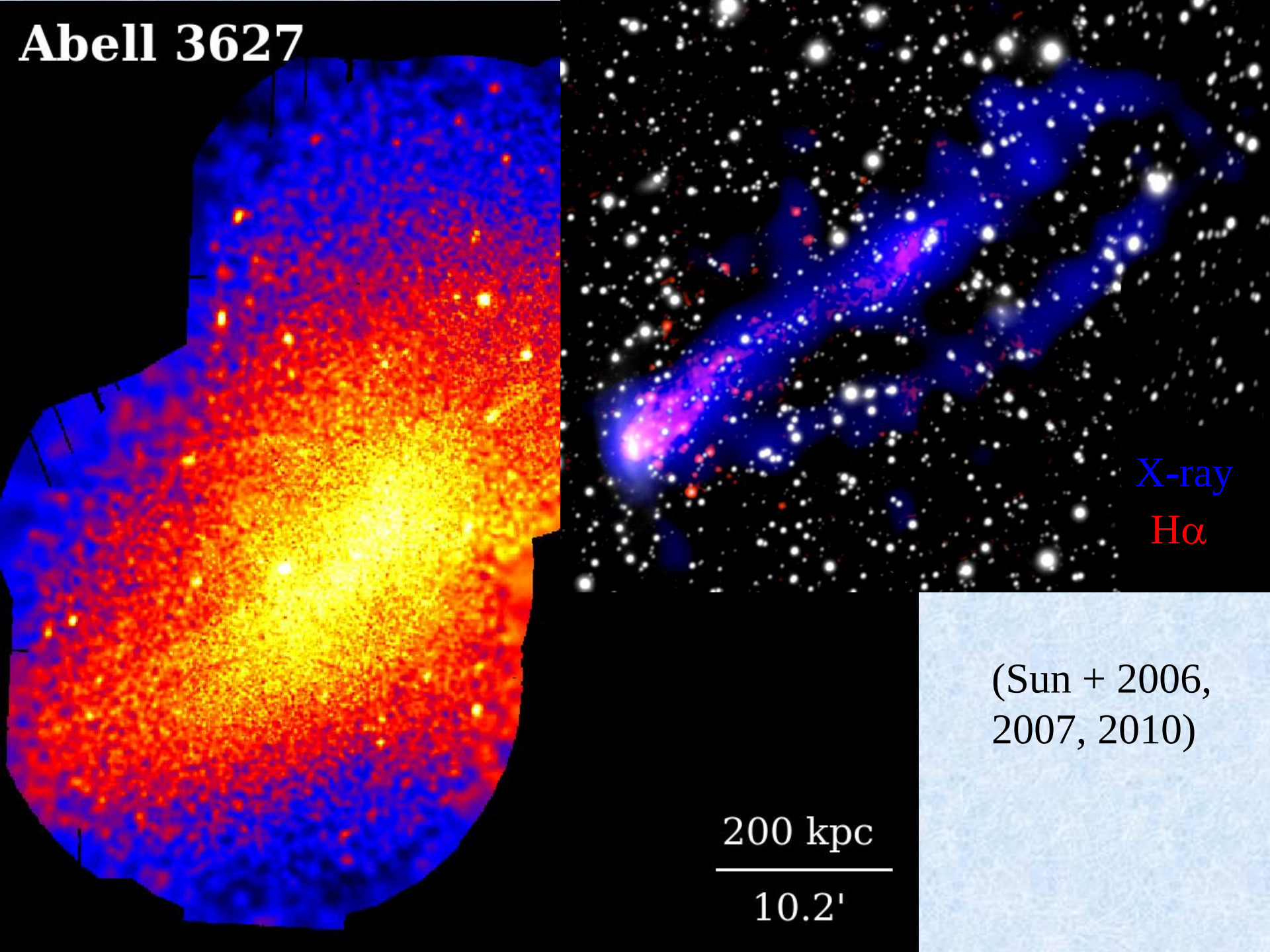

Virgo
200 kpc
41.67'


Virgo
200 kpc
41.67'

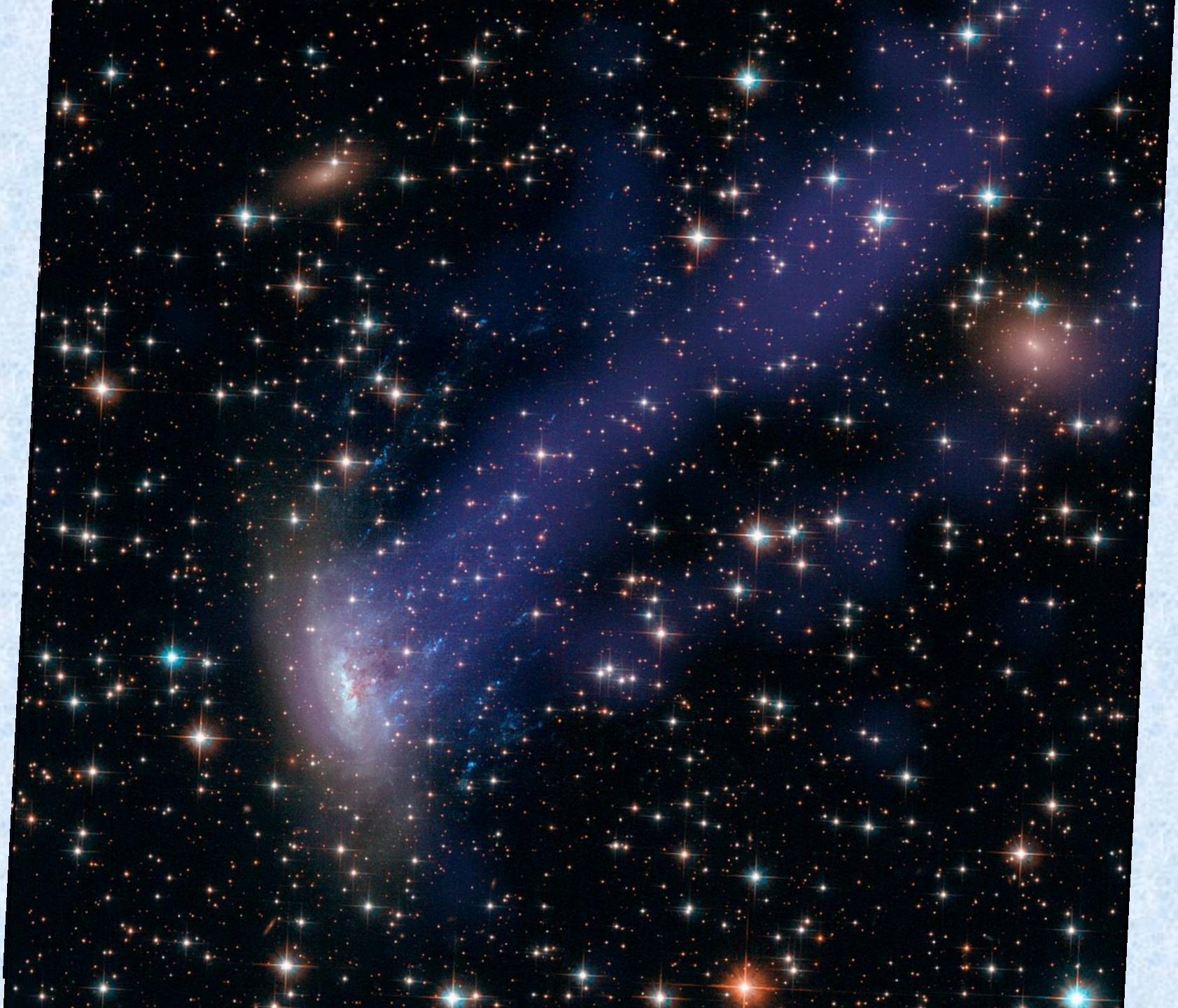

Virgo
XMM 0.5-2 keV
Ha from Boselli
200 kpc
41.67'

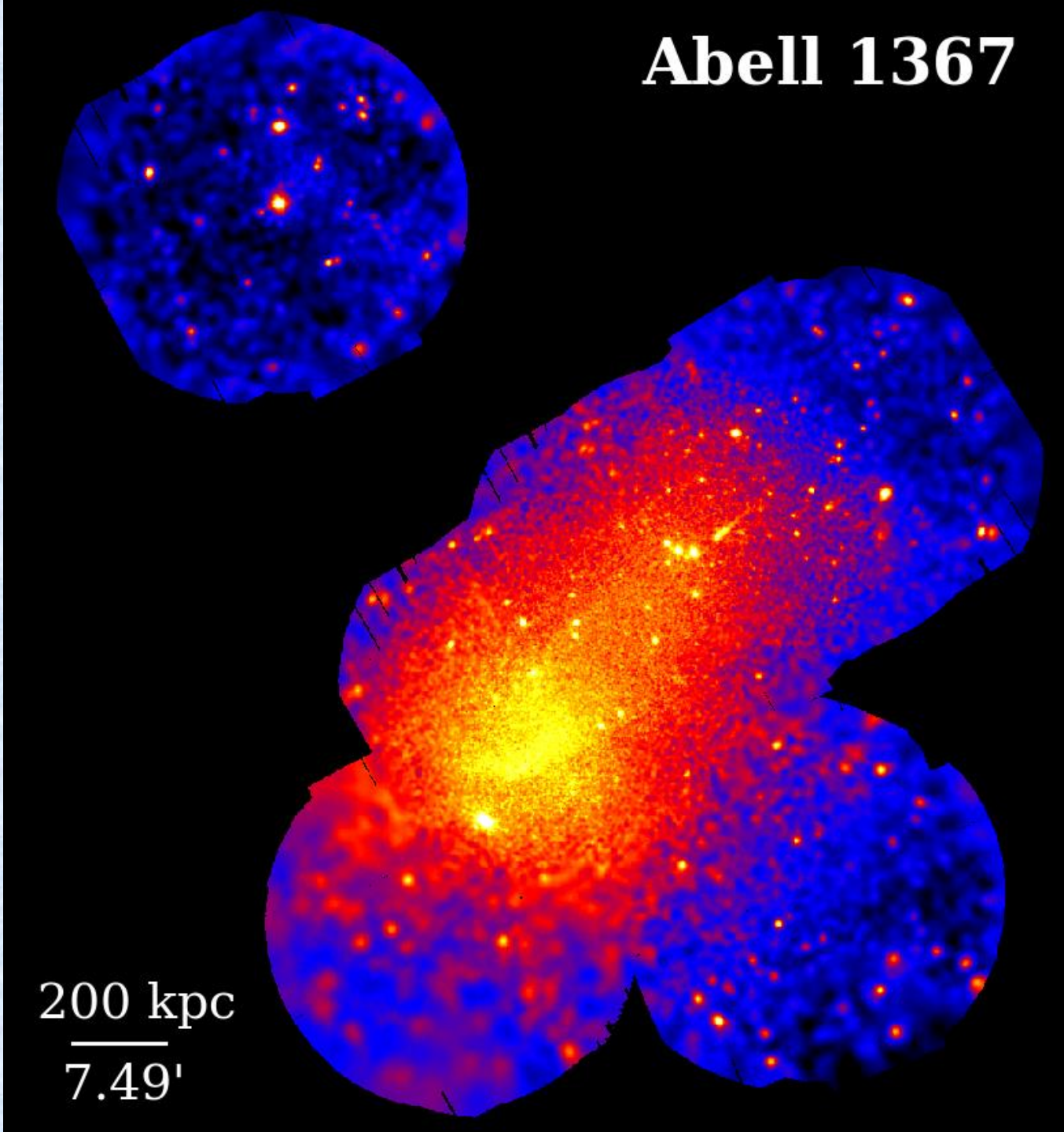

Virgo
XMM 0.5
10 kpc
200 kpc
41.67'
Boselli et al. 2016

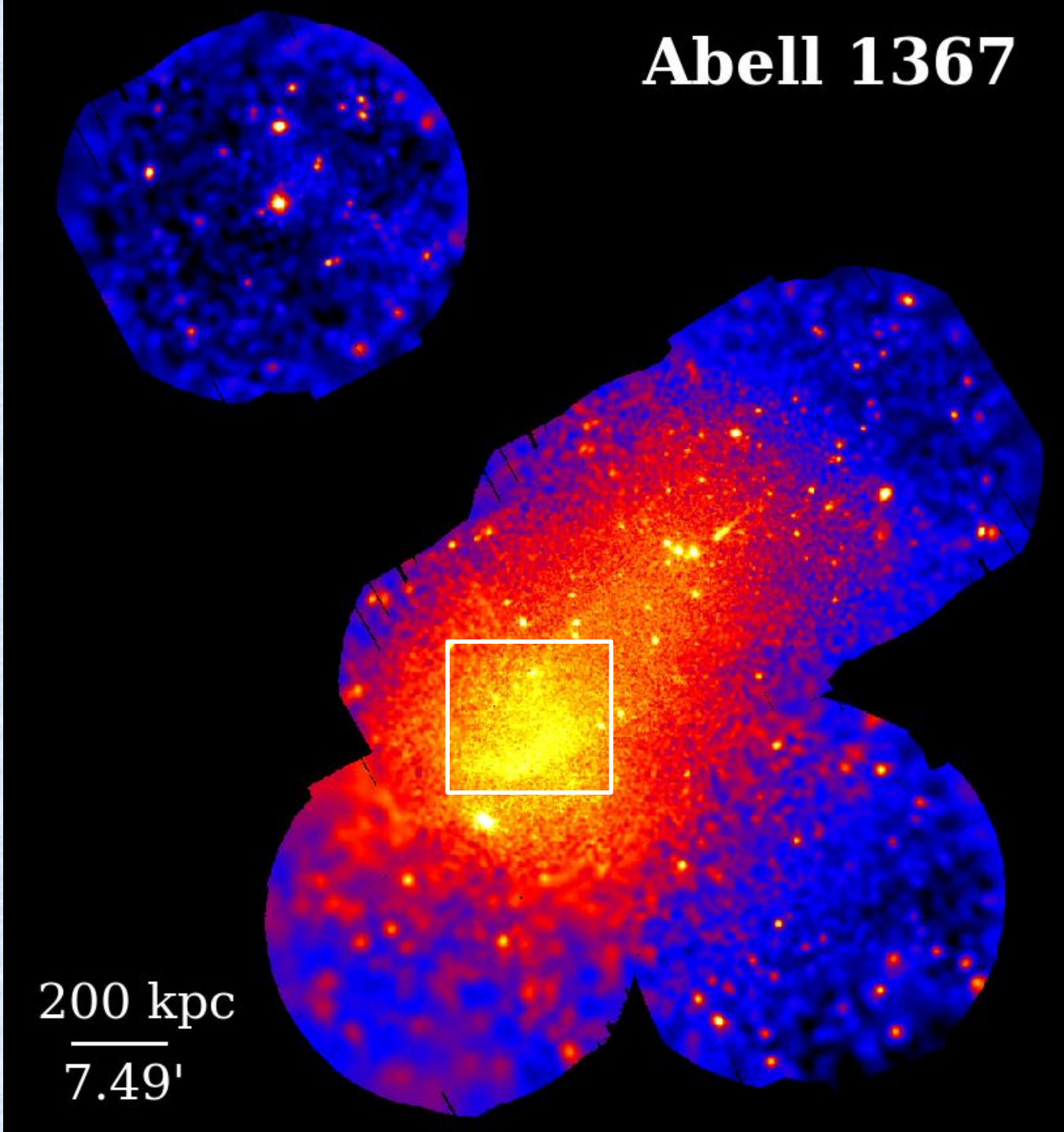

Abell 3627
200 kpc
10.2'

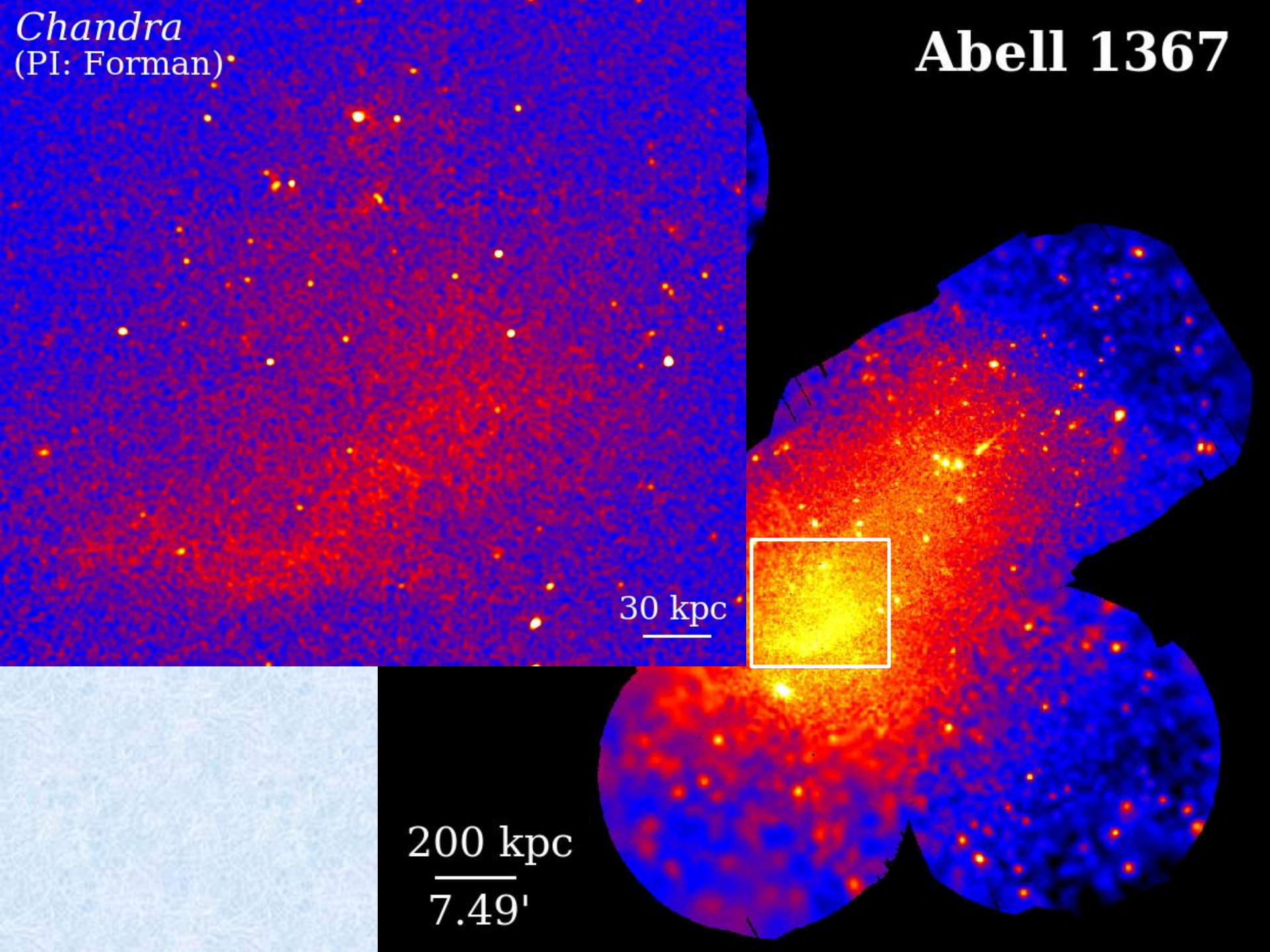


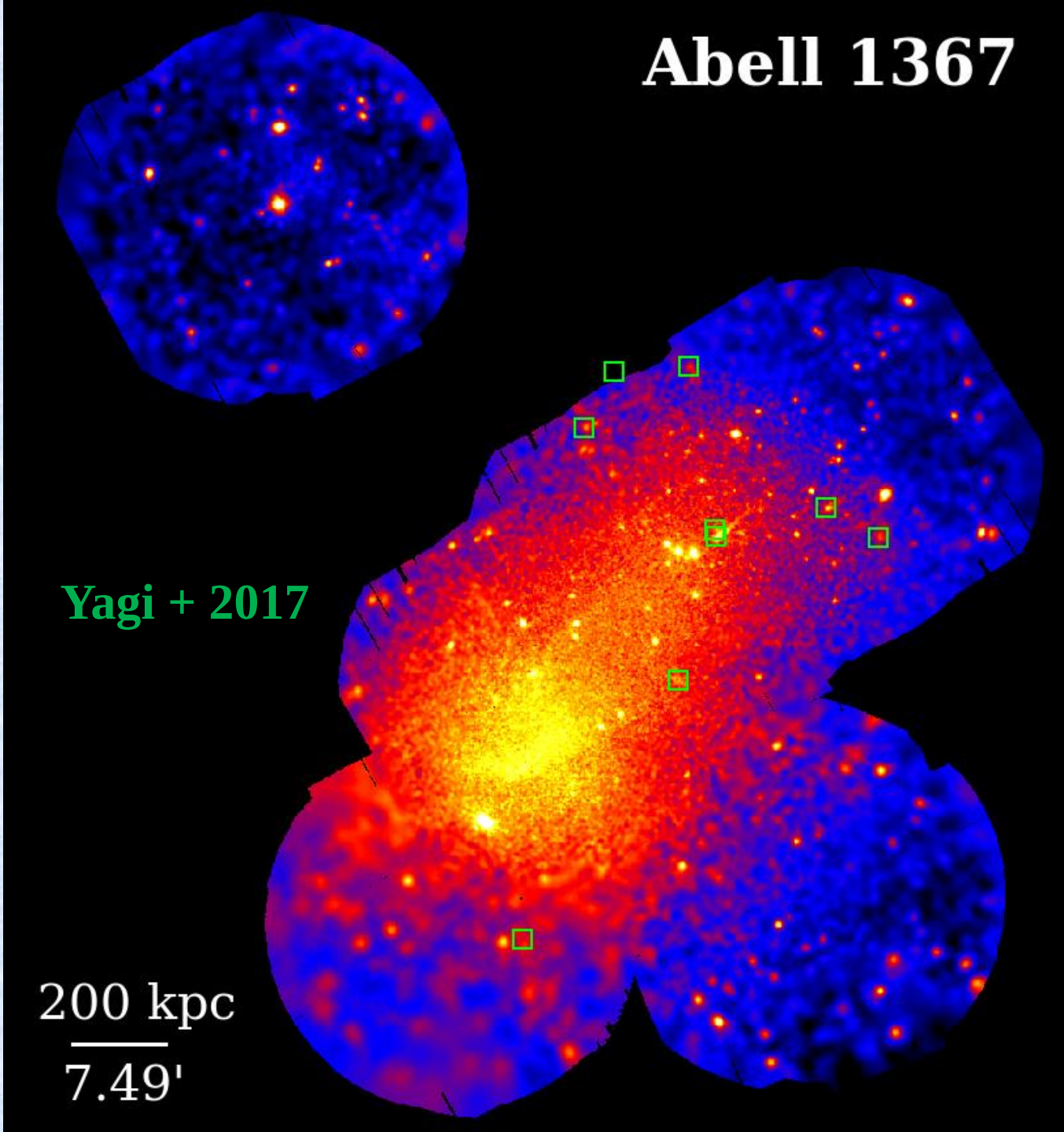
(Sun + 2006, 2007, 2010)

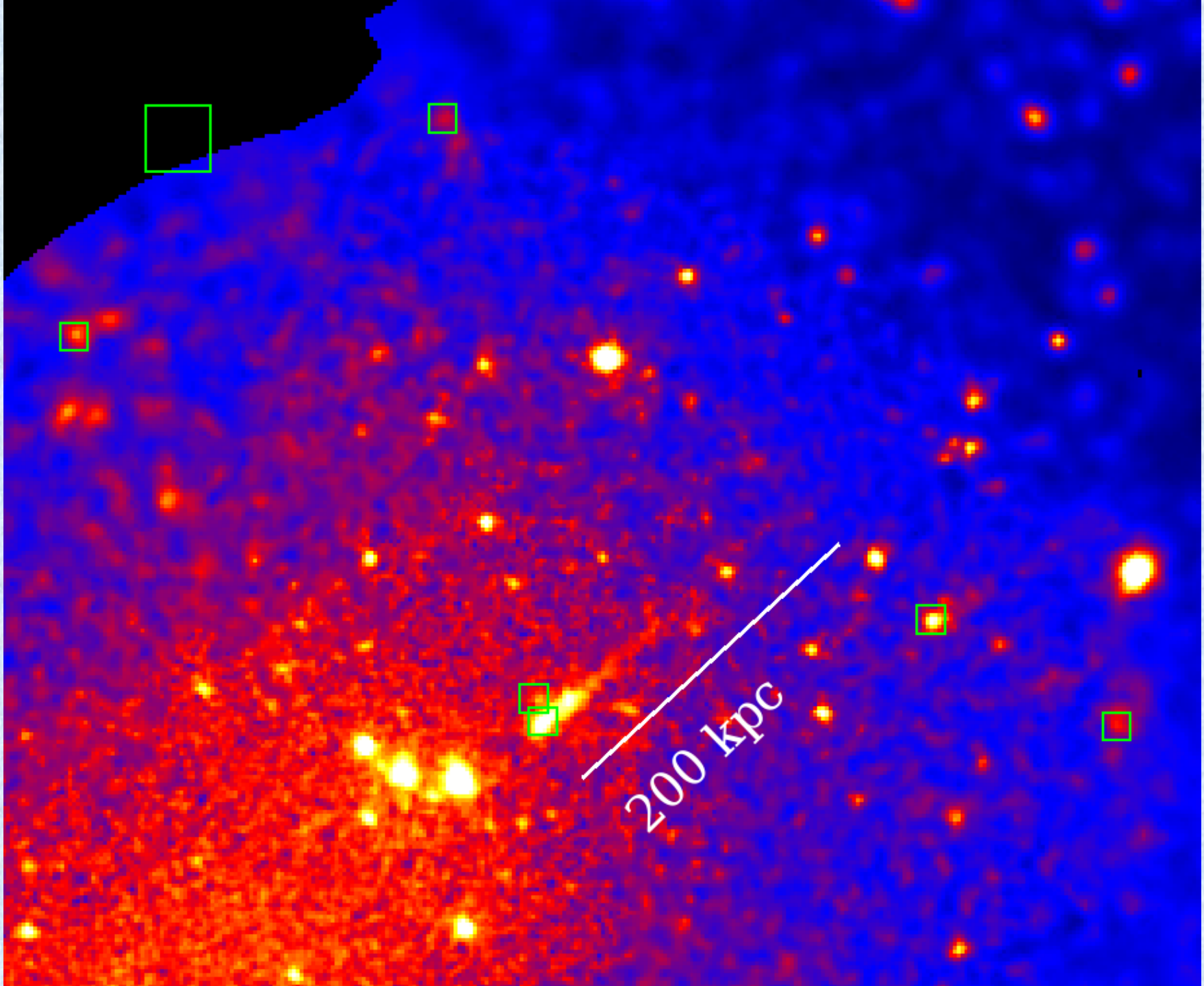


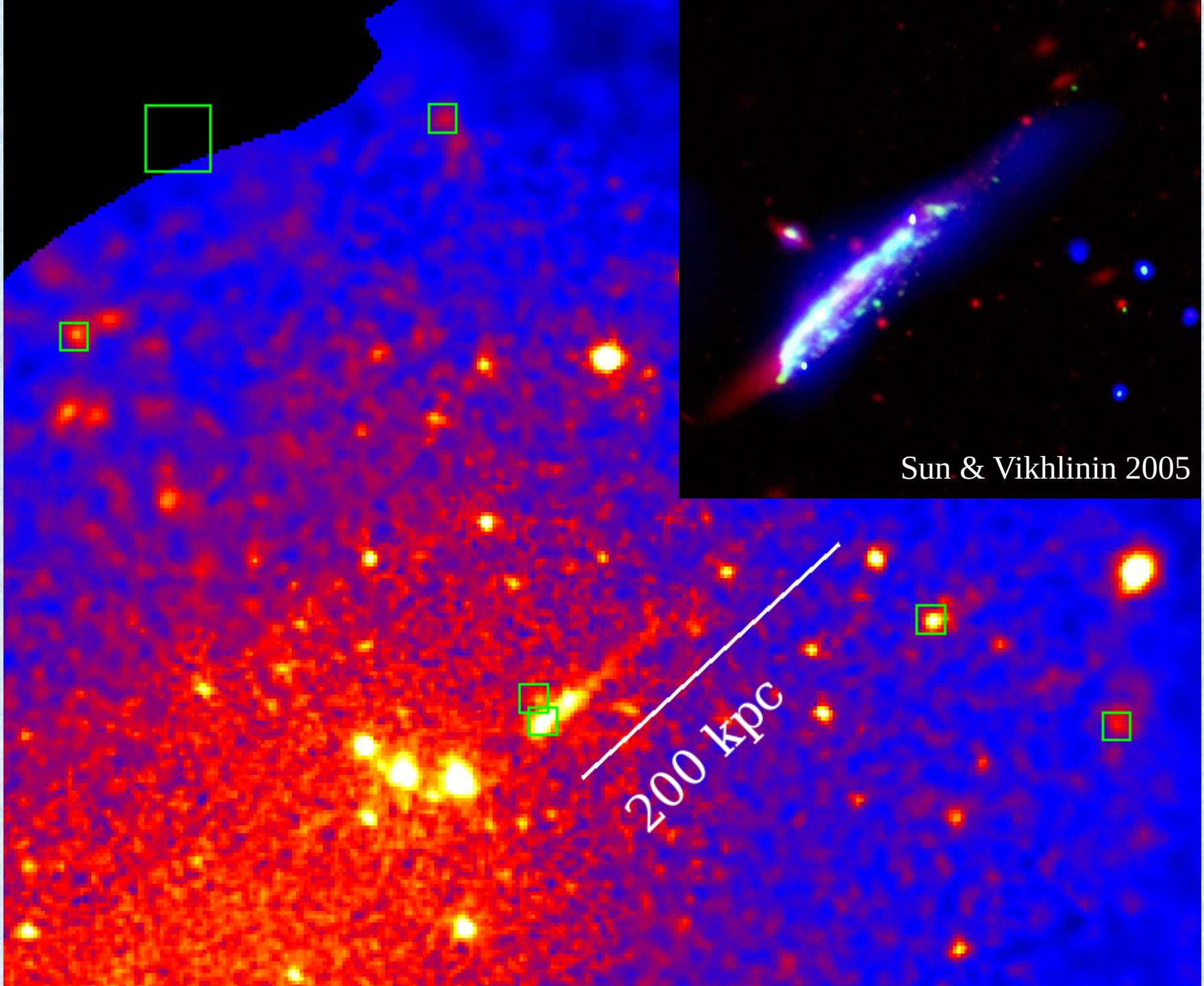

Abell 1367
200 kpc
7.49'

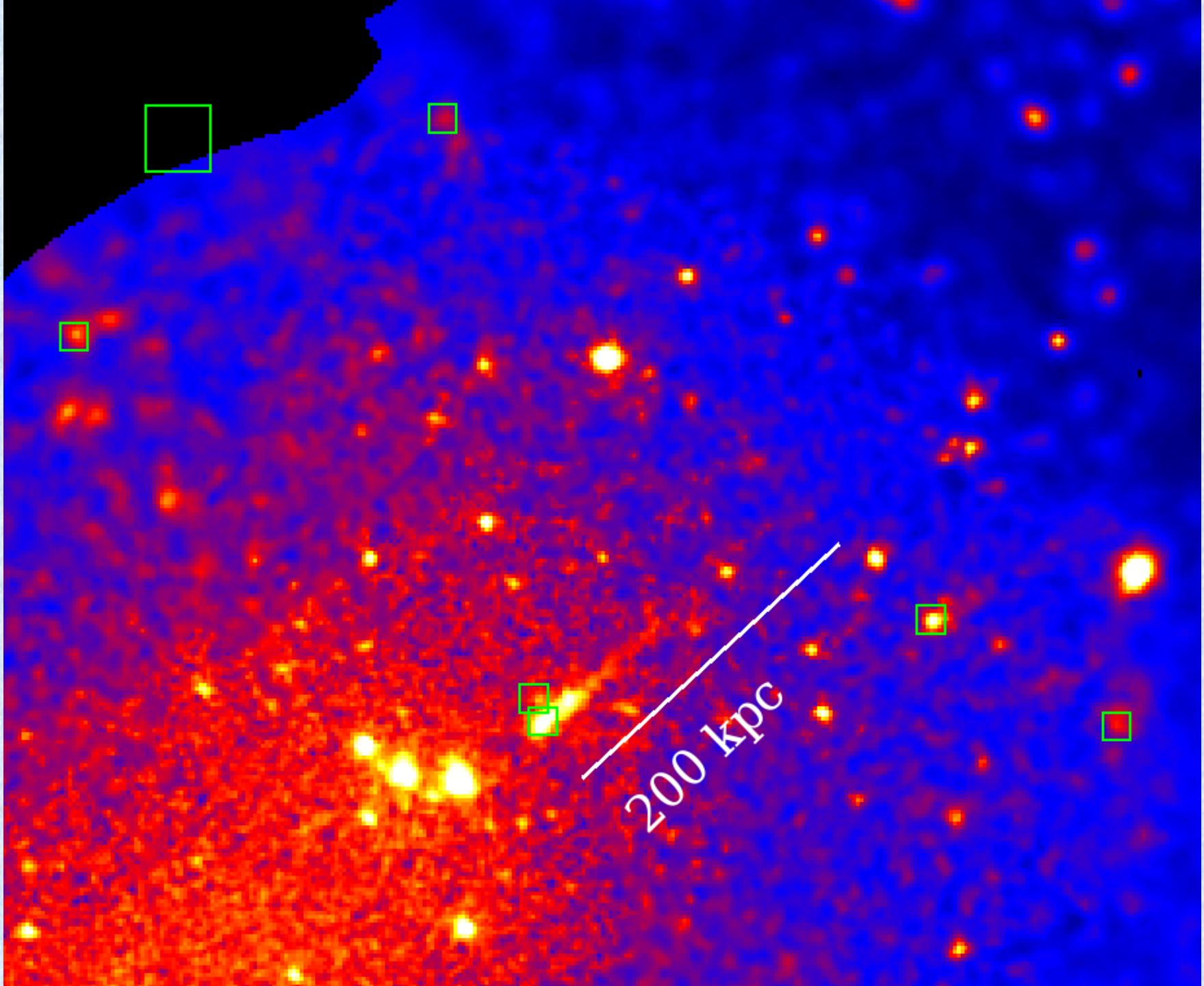

Abell 1367
200 kpc
7.49'

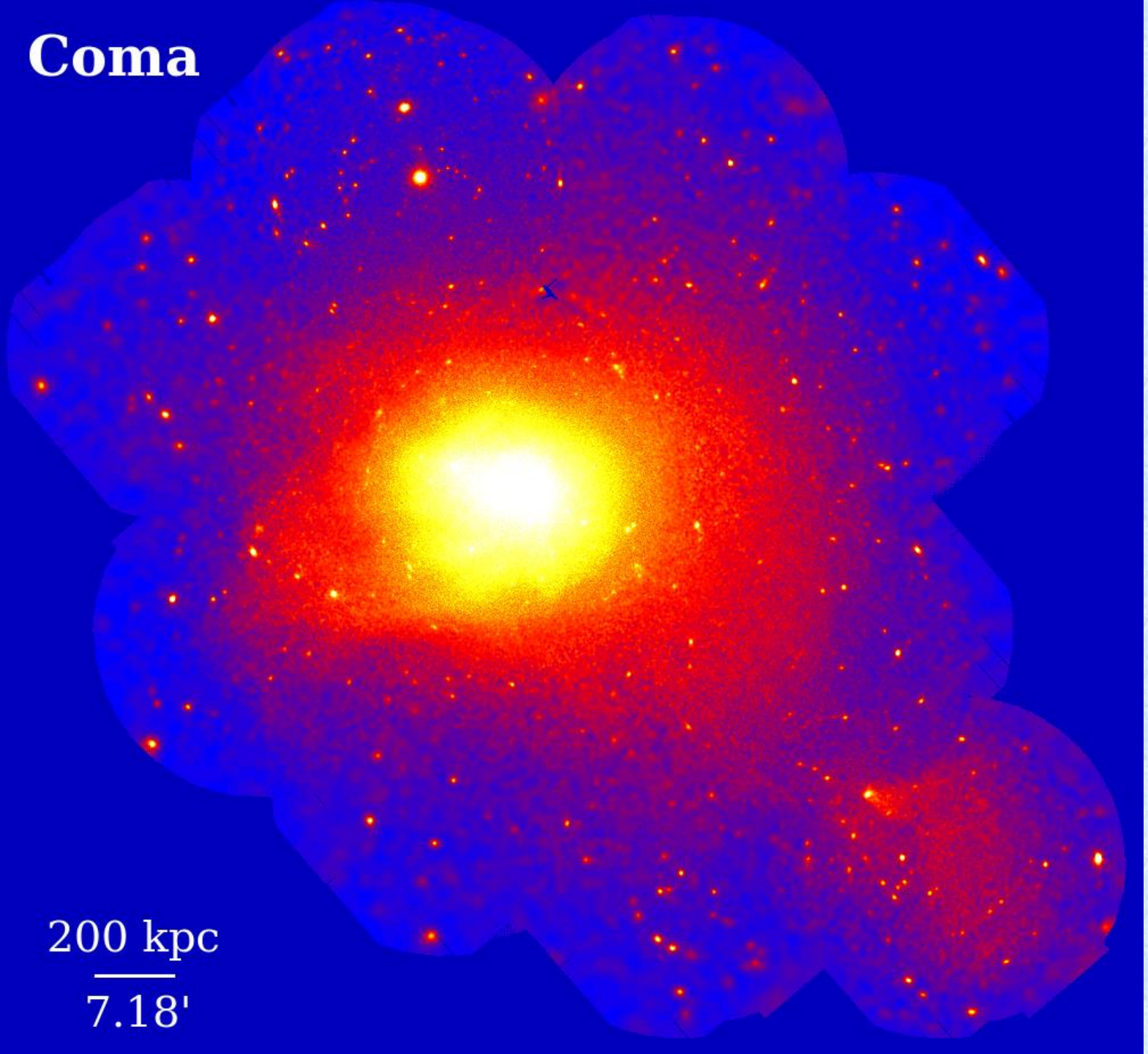

Chandra
(PI: Forman)
Abell 1367
30 kpc
200 kpc
7.49'

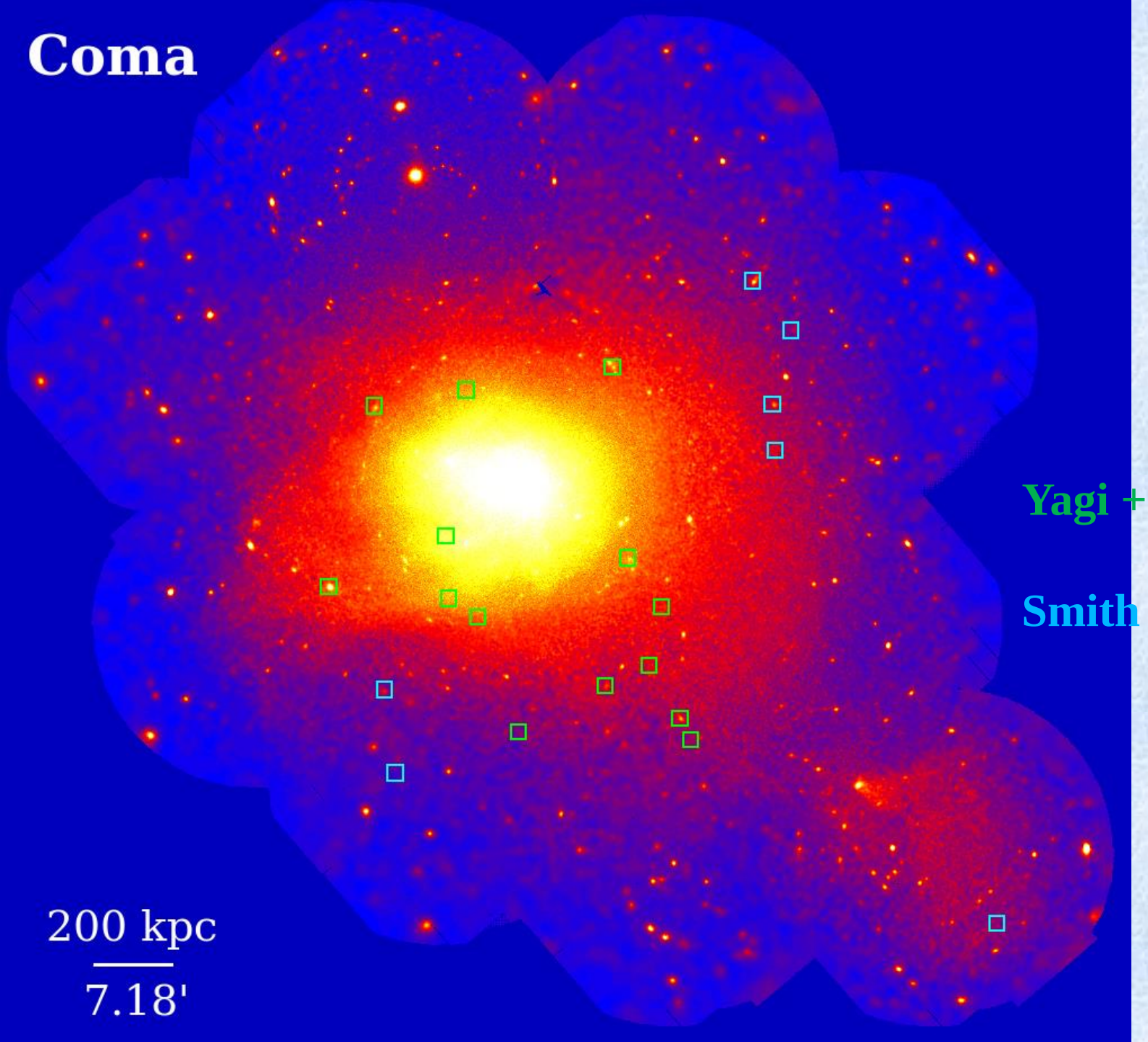

Abell 1367
Yagi + 2017
200 kpc
7.49'


200 kpc


Sun & Vikhlinin 2005
200 kpc

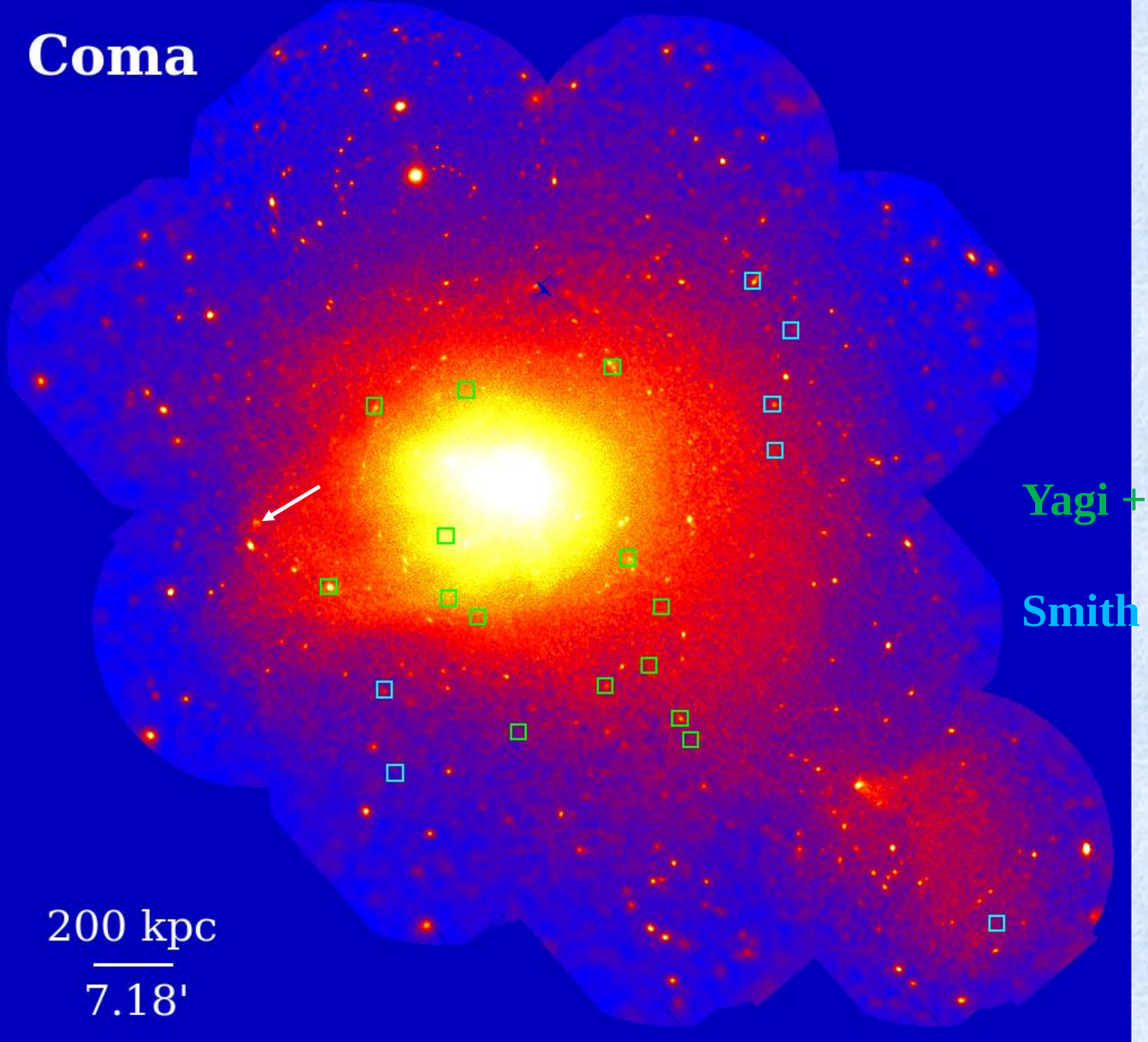

200 kpc


Coma
200 kpc
7.18'



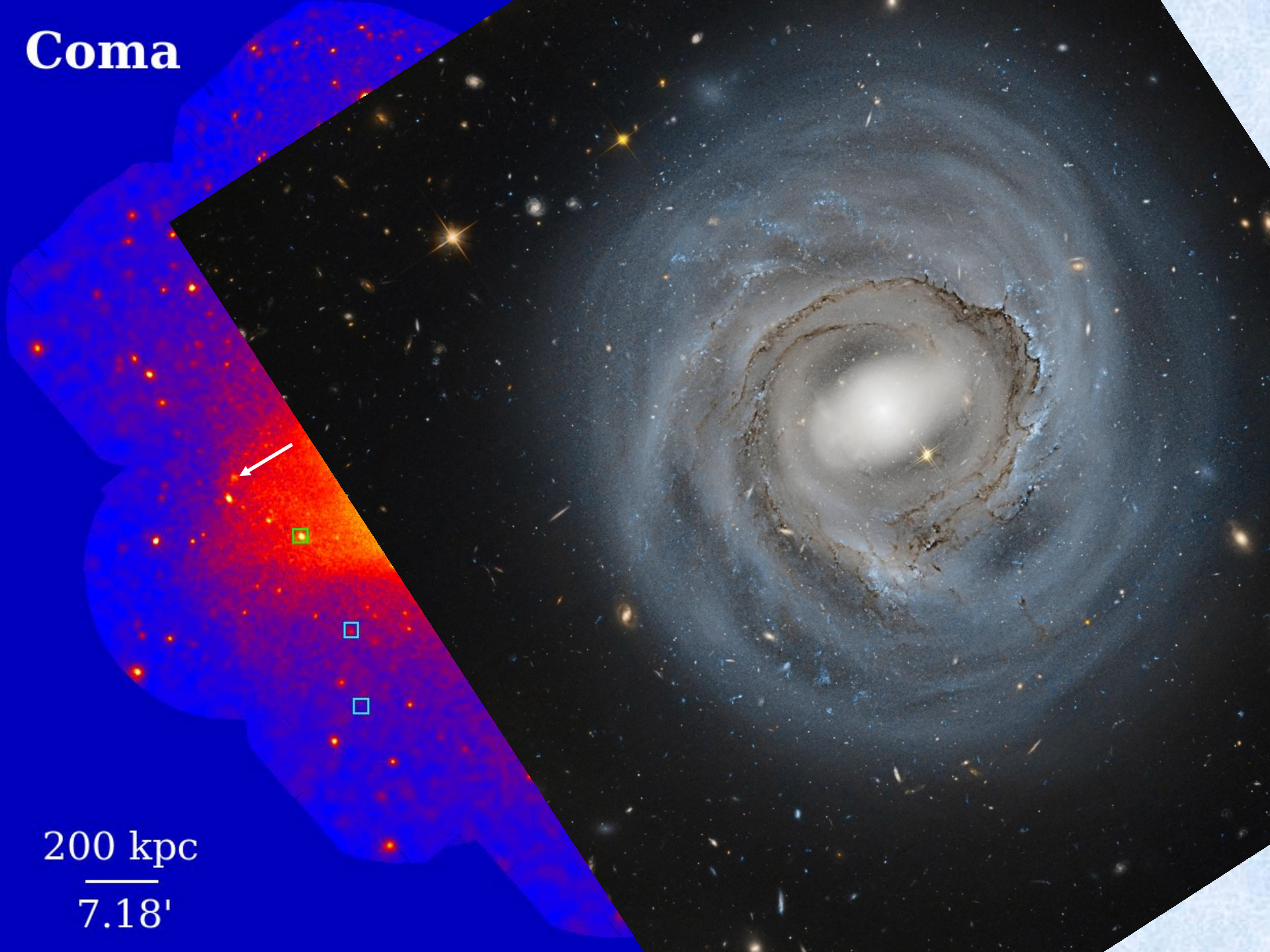
Yagi + 2010

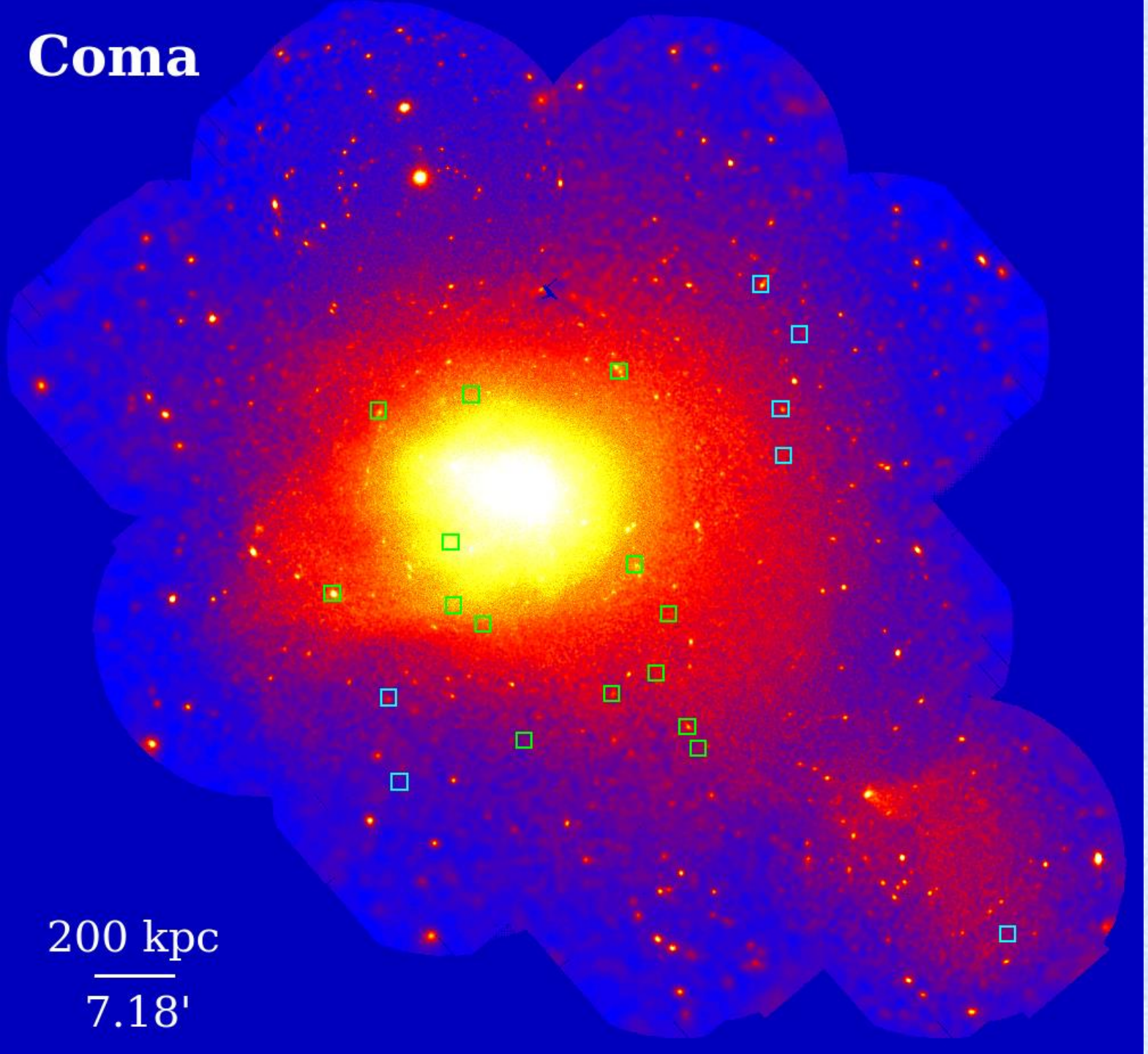
Smith + 2010

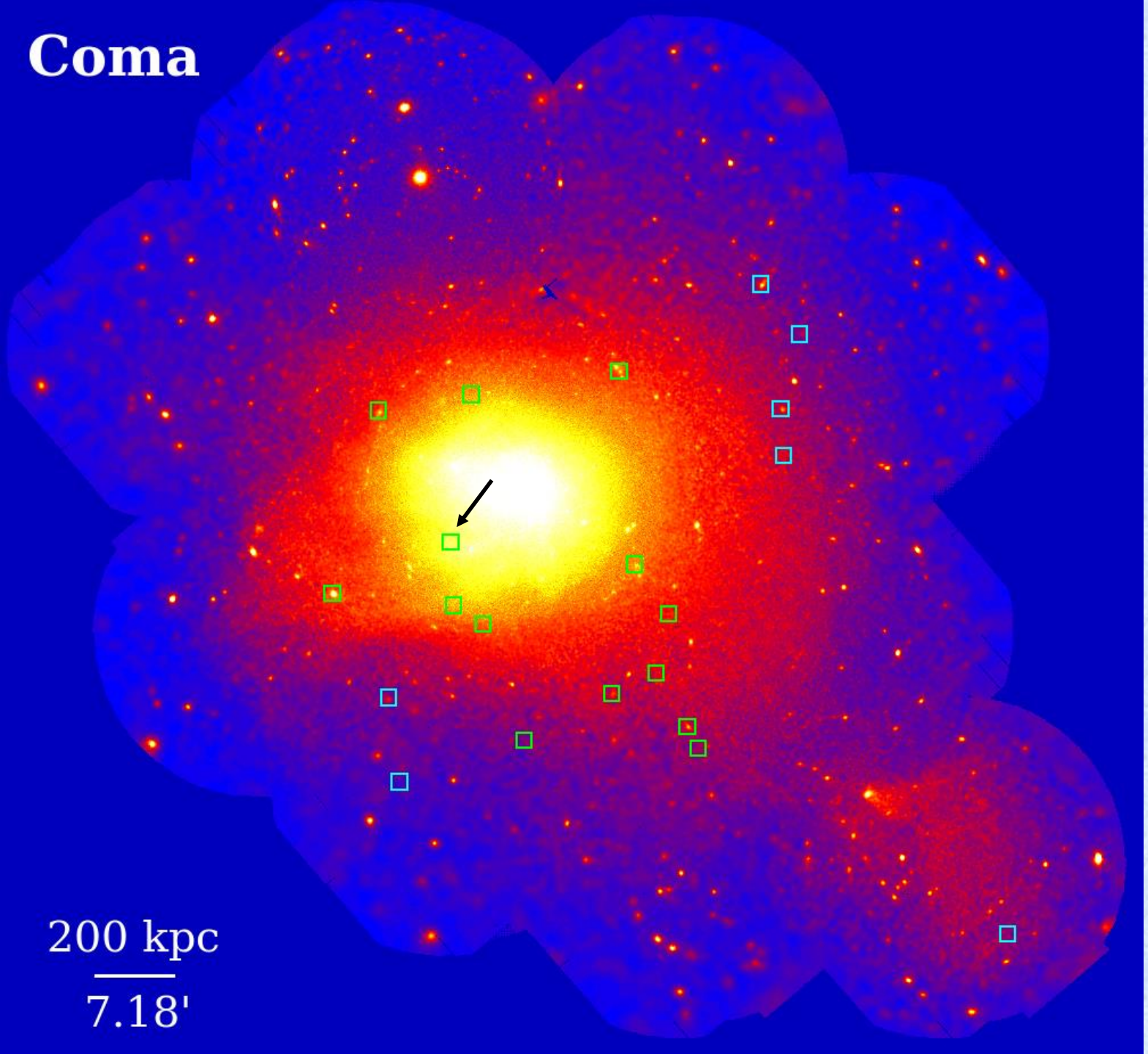


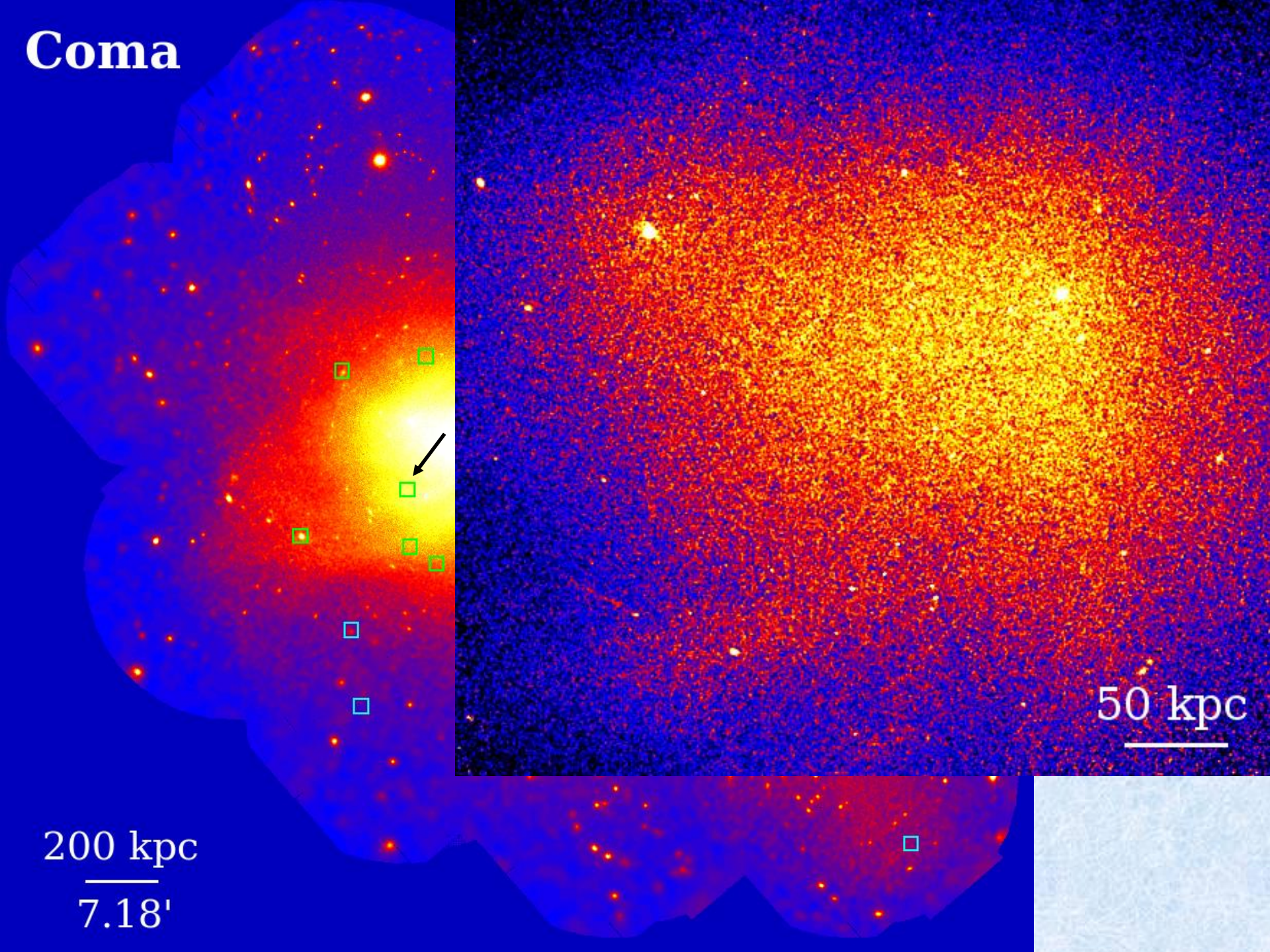
Yagi + 2010

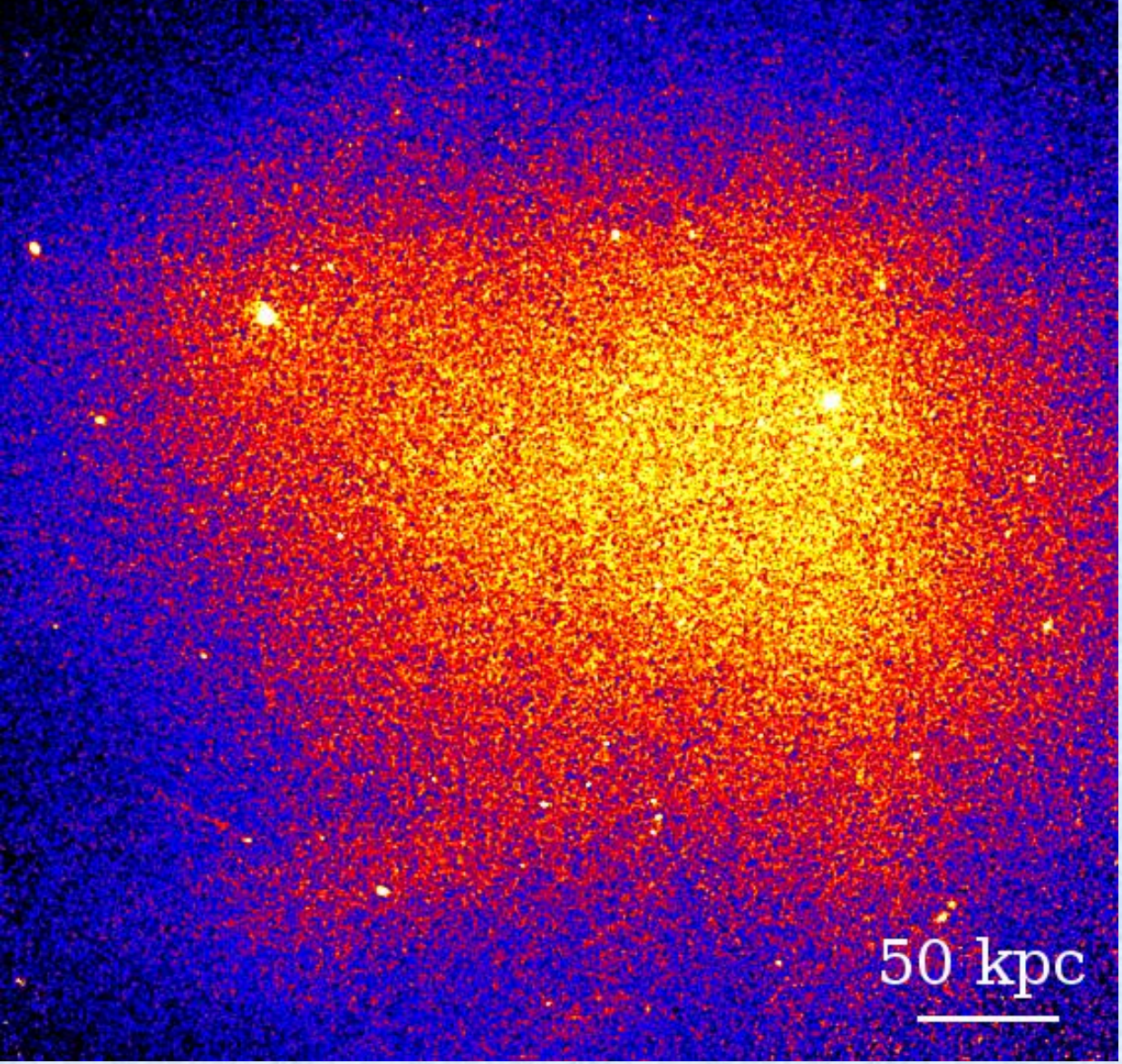
Smith + 2010

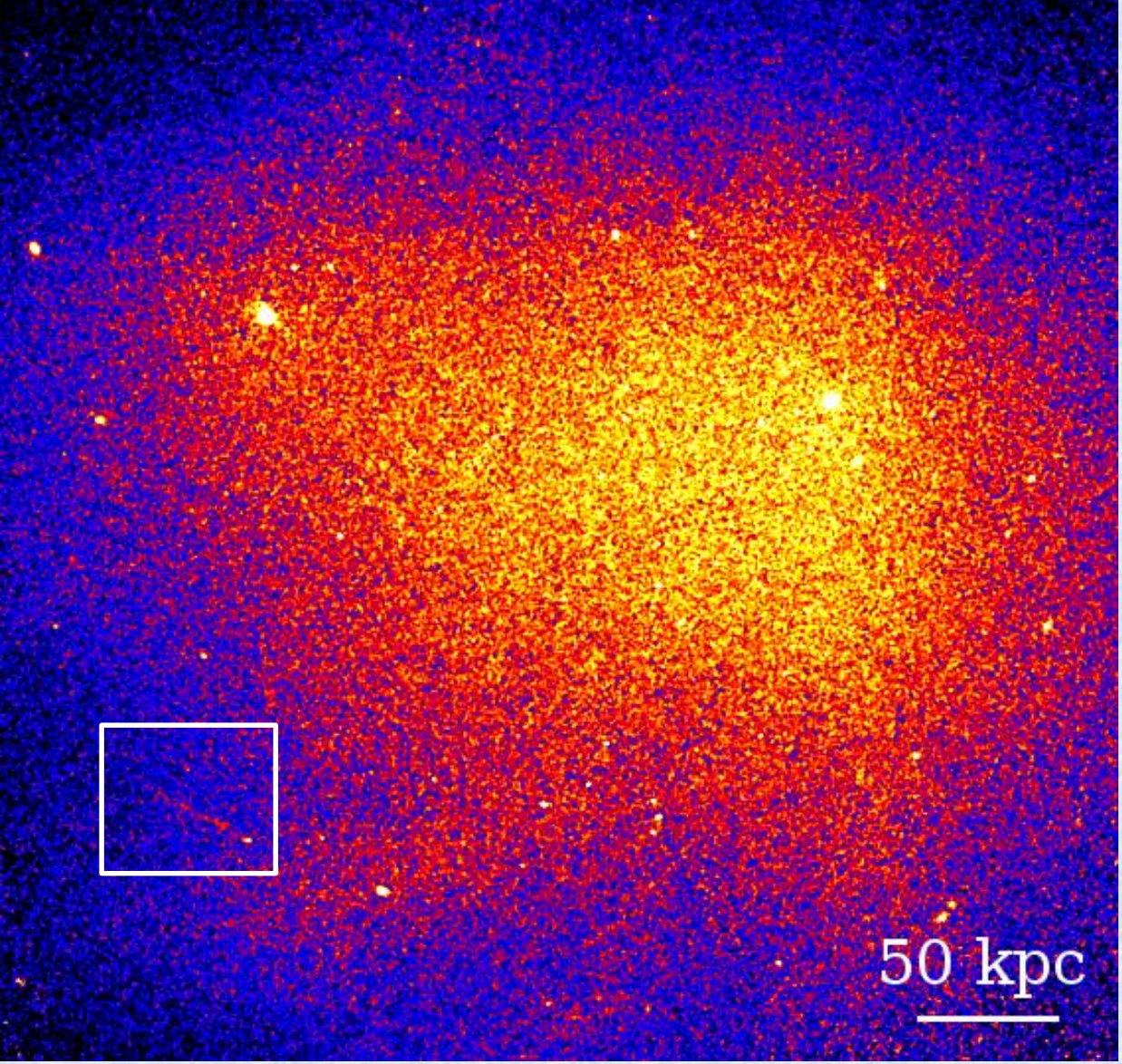

Coma
200 kpc
7.18'

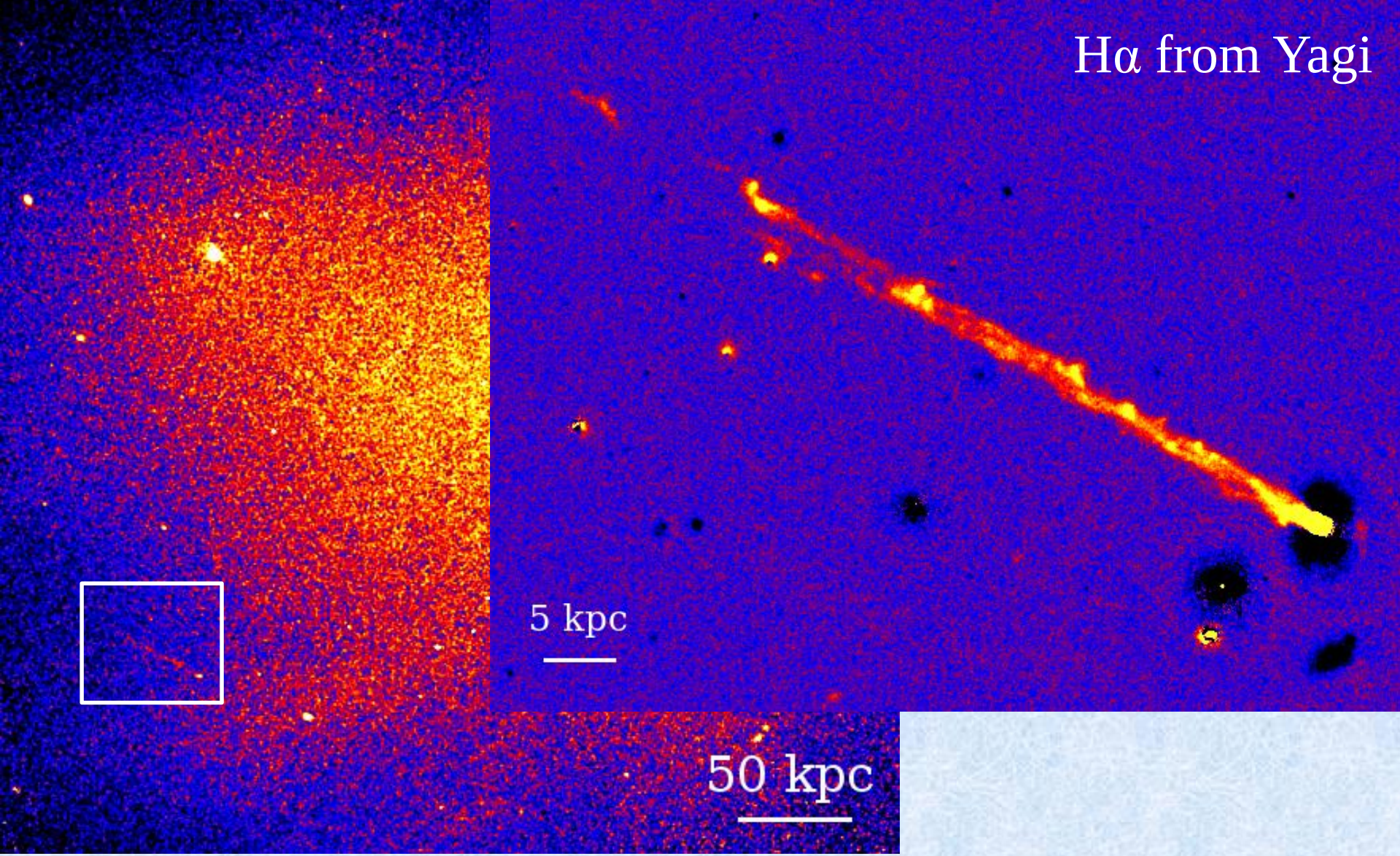

Coma
200 kpc
7.18'


Coma
200 kpc
7.18'

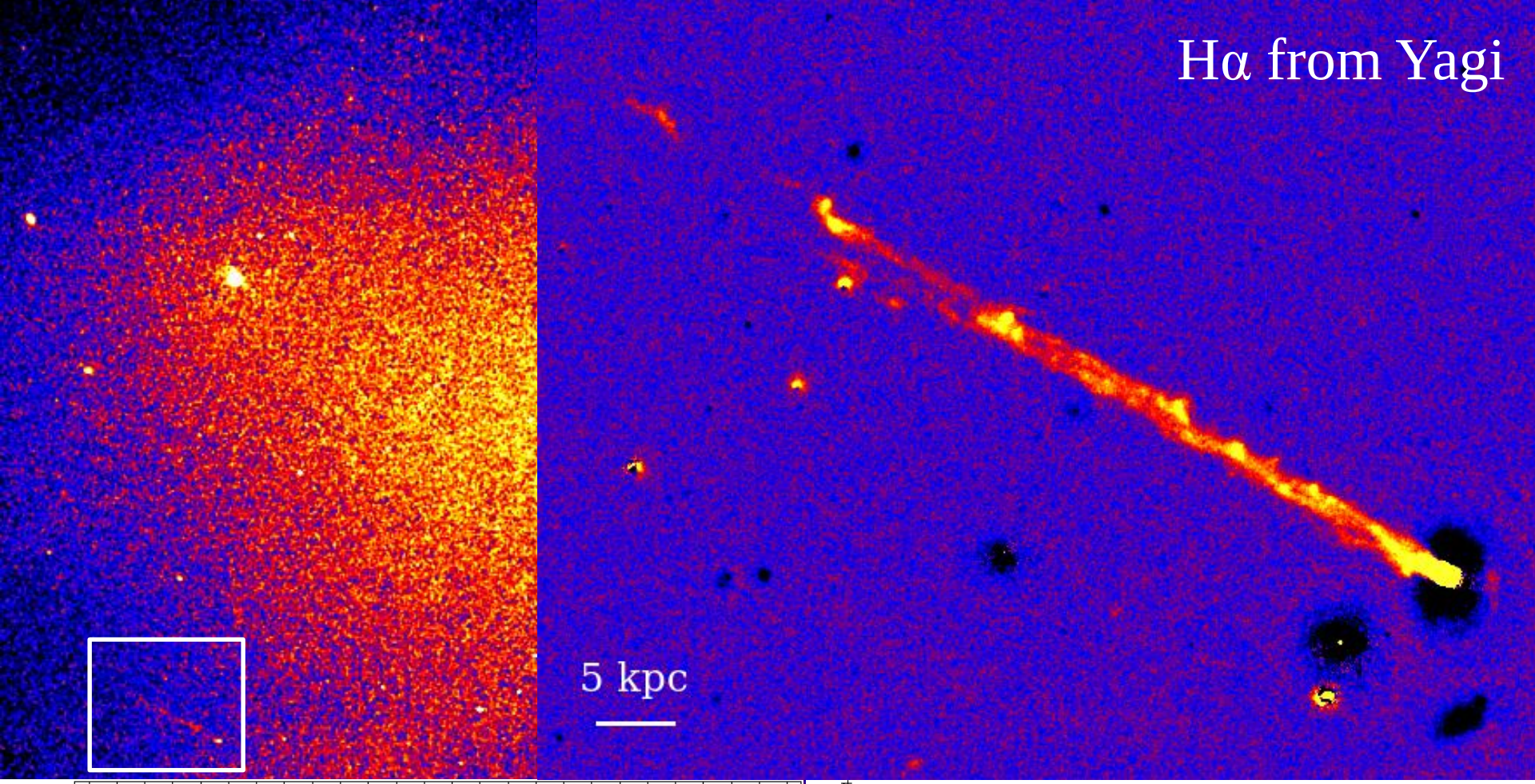

Coma
50 kpc
200 kpc
7.18'

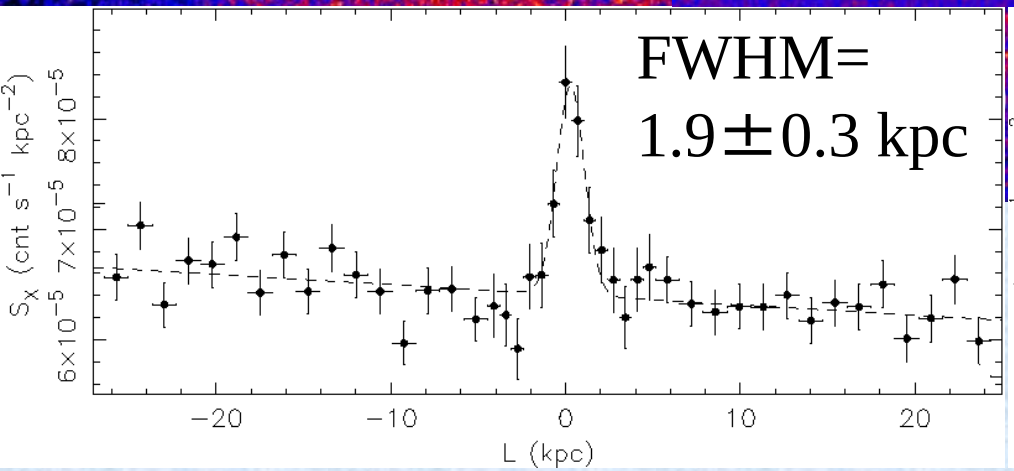

50 kpc

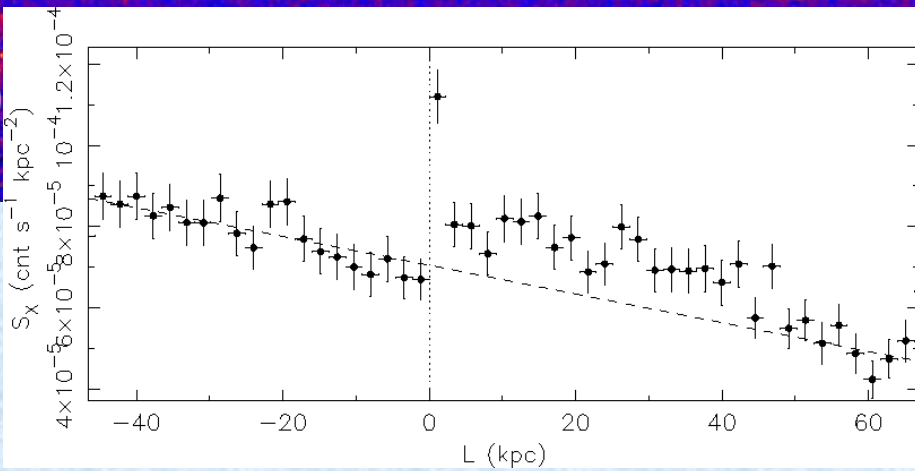

50 kpc

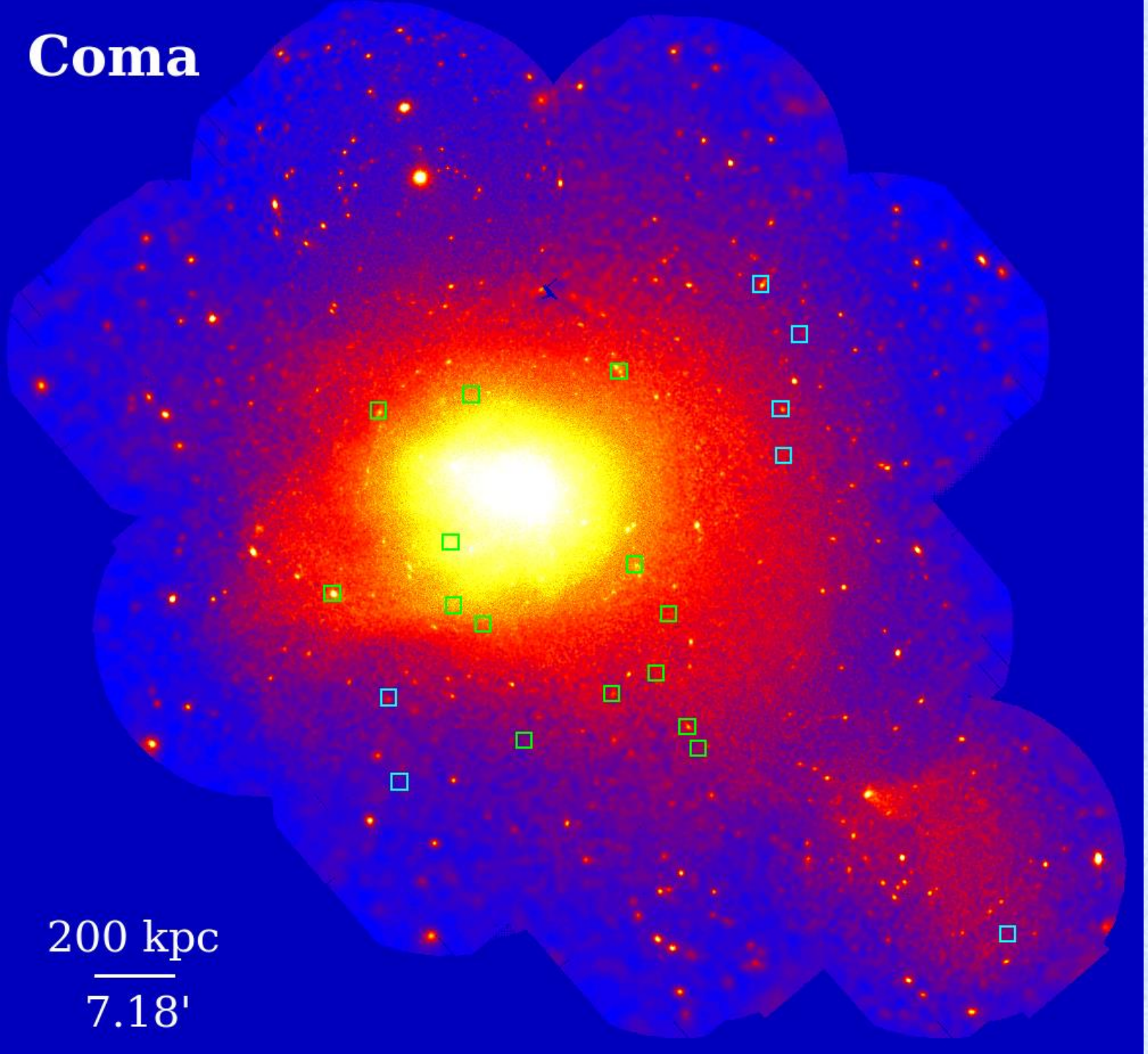

Hα from Yagi
5 kpc
50 kpc

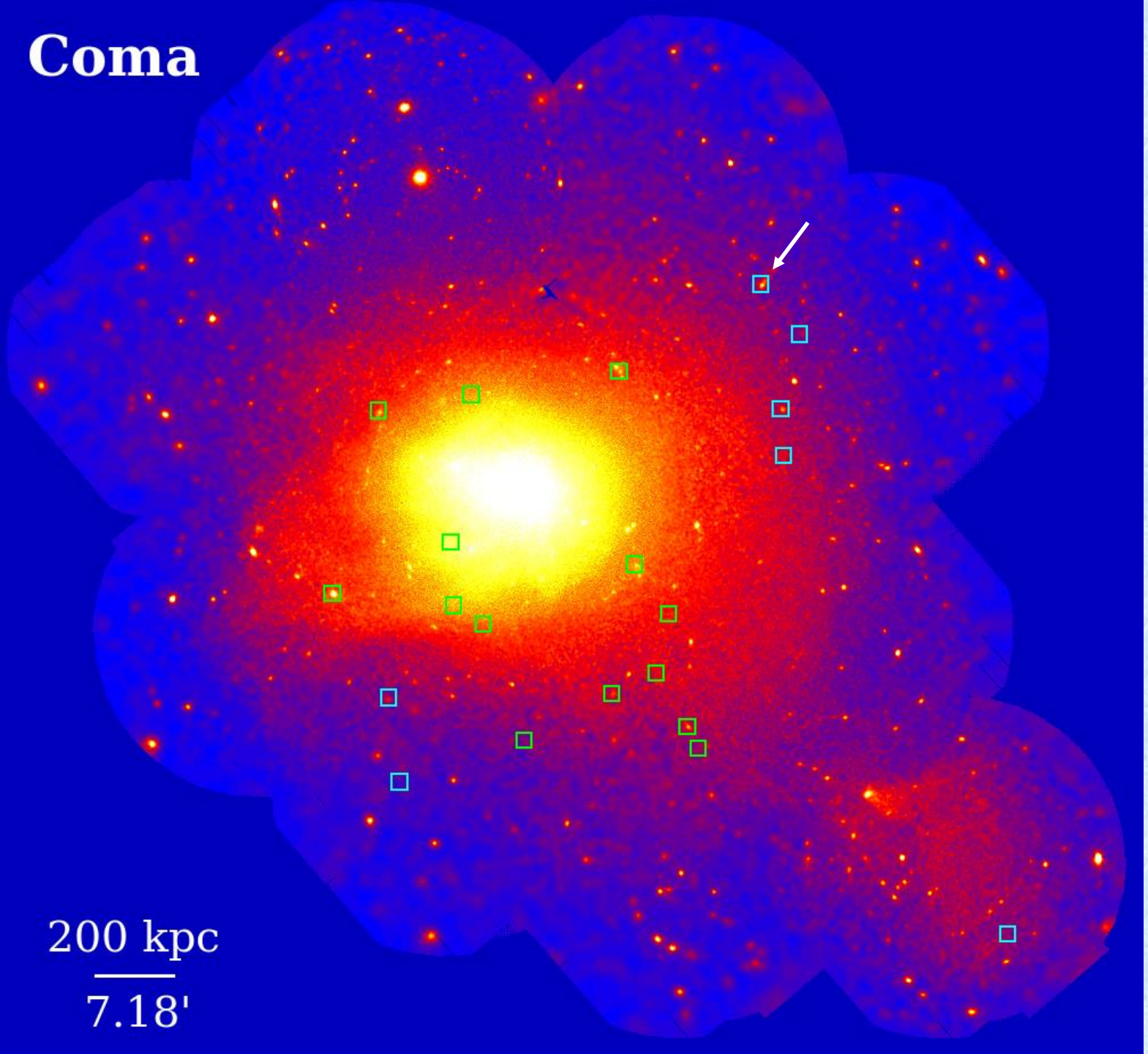
Hα from Yagi


5 kpc

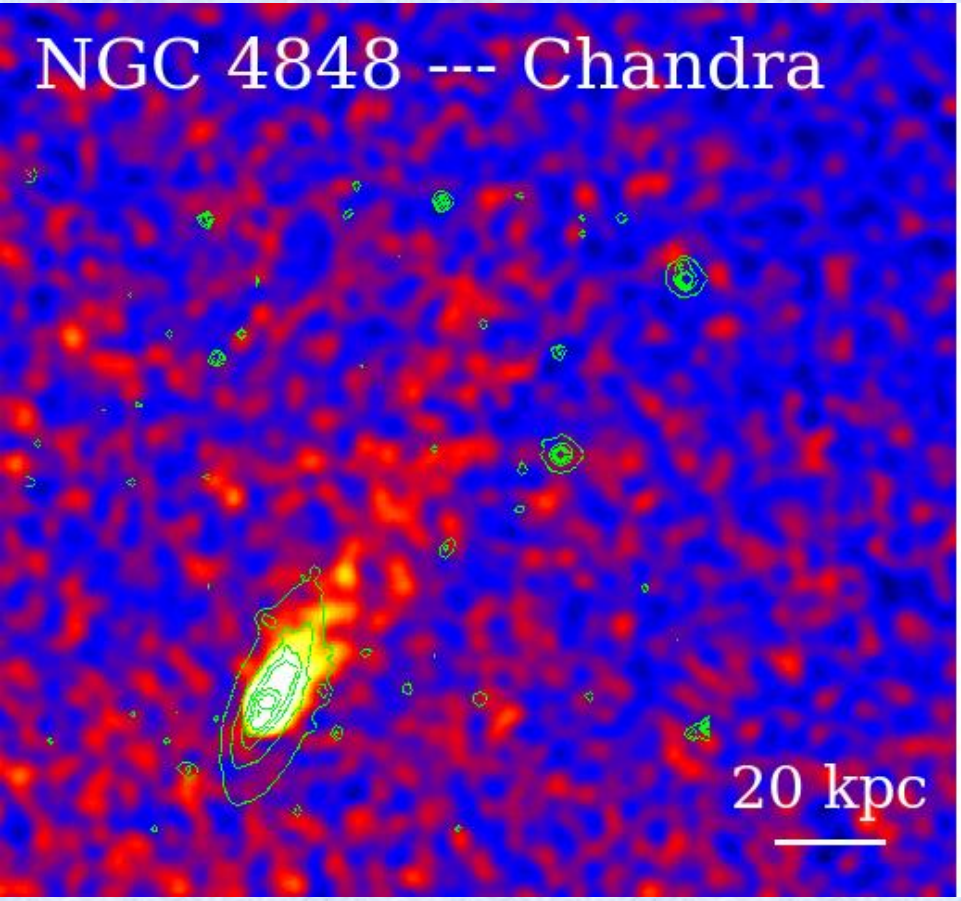

FWHM=
1.9±0.3 kpc
S_X (cnt s^{-1} kpc^{-2})
6×10^{-5}
7×10^{-5}
8×10^{-5}
−20
−10
0
10
20
L (kpc)

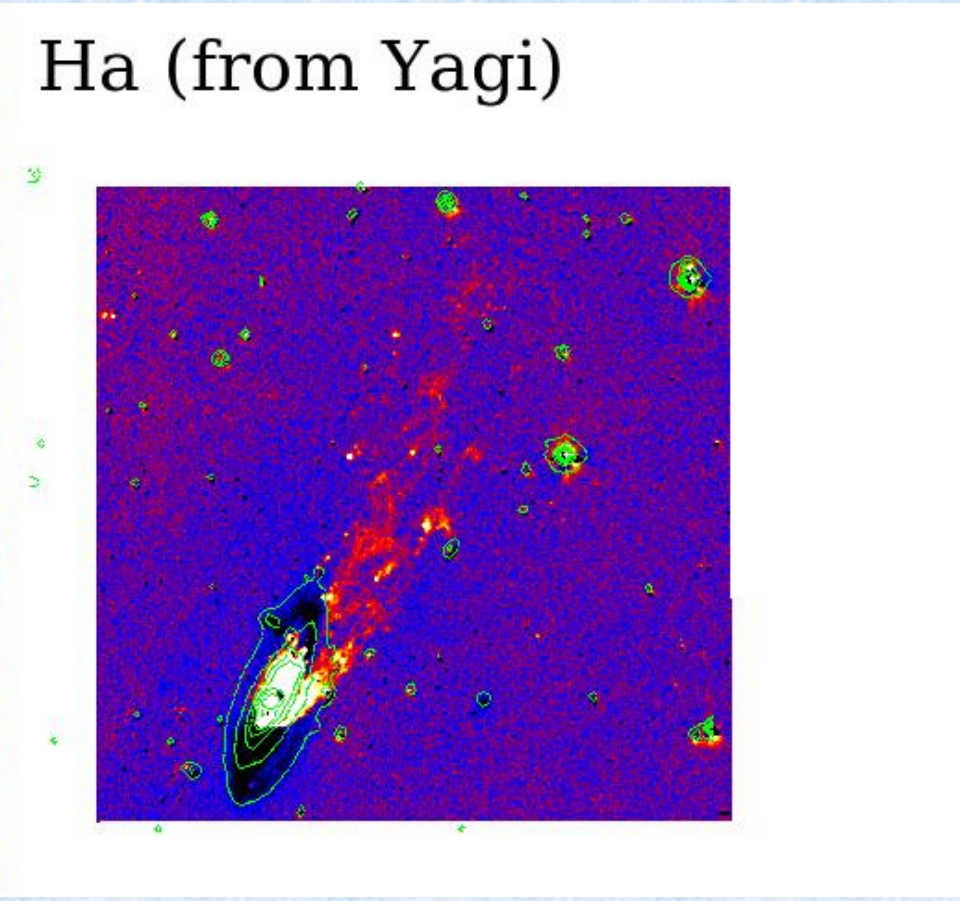

S_X (cnt s^{-1} kpc^{-2})
4×10^{-5}
6×10^{-5}
8×10^{-5}
10^{-4}
1.2×10^{-4}
−40
−20
0
20
40
60
L (kpc)


Coma
200 kpc
7.18'

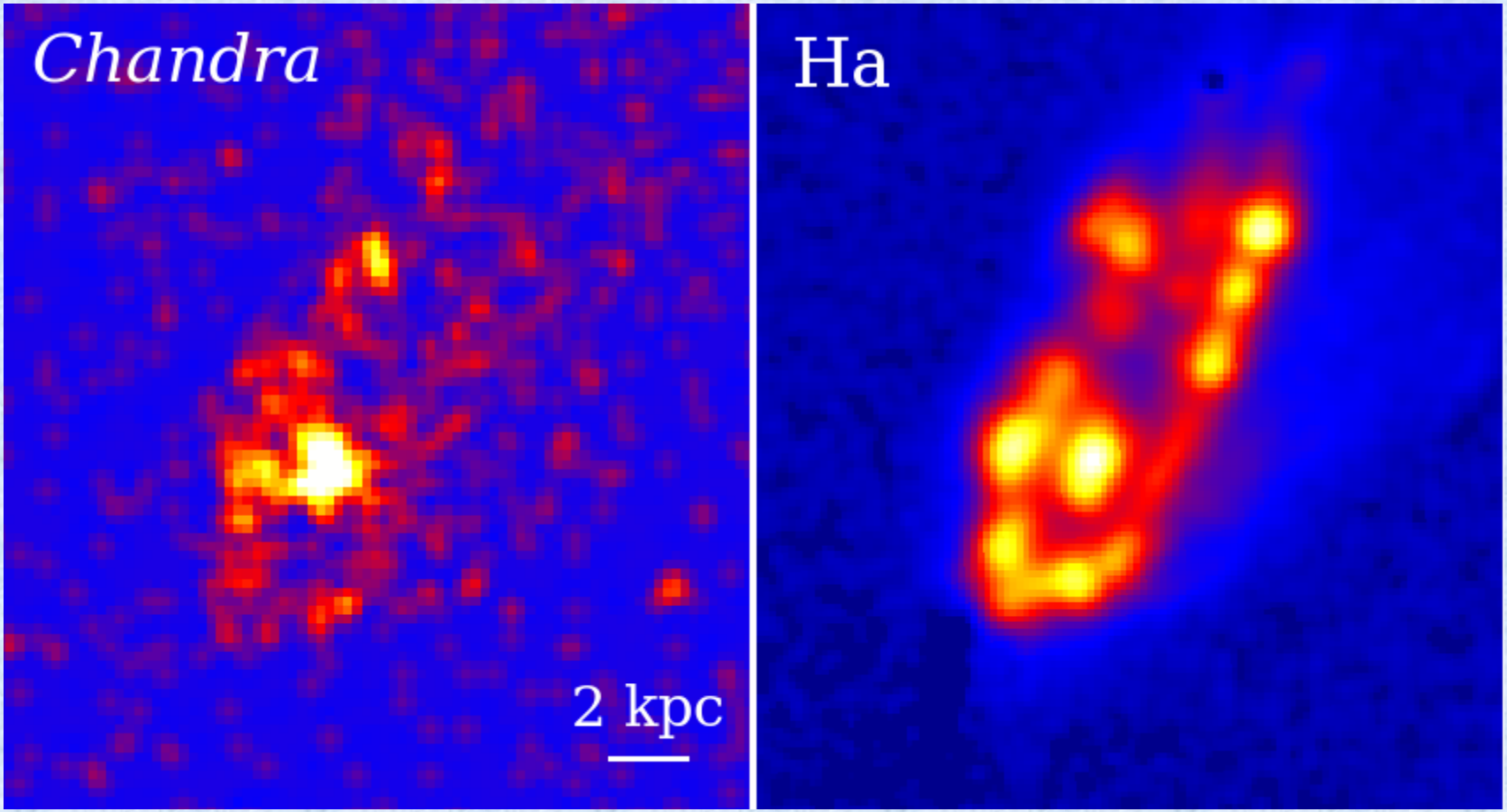

Coma
200 kpc
7.18'

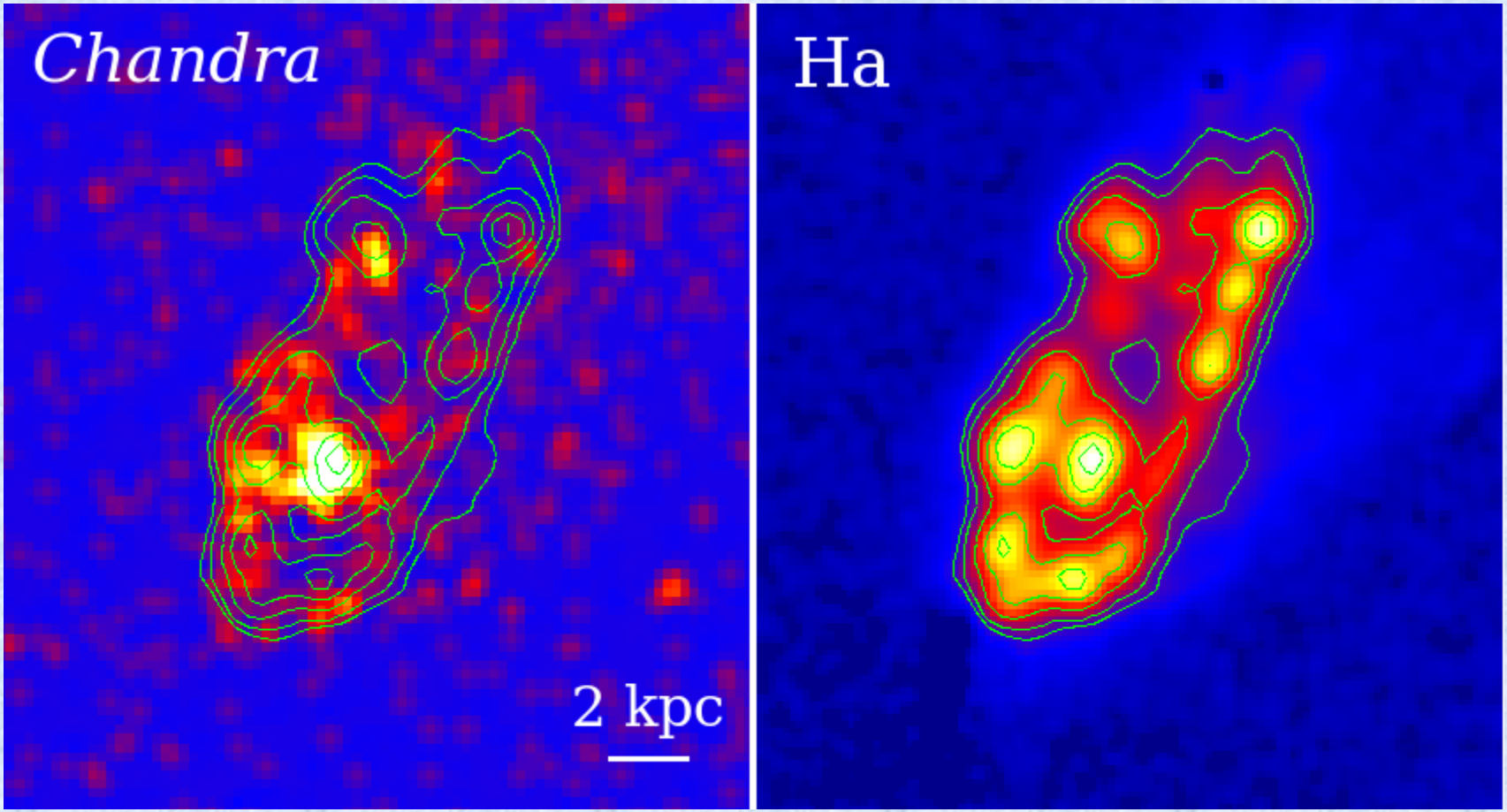
A ~ 90 kpc tail behind NGC 4848 (in Coma)





Chandra: 29 ks in 2008 + 90 ks in 2017

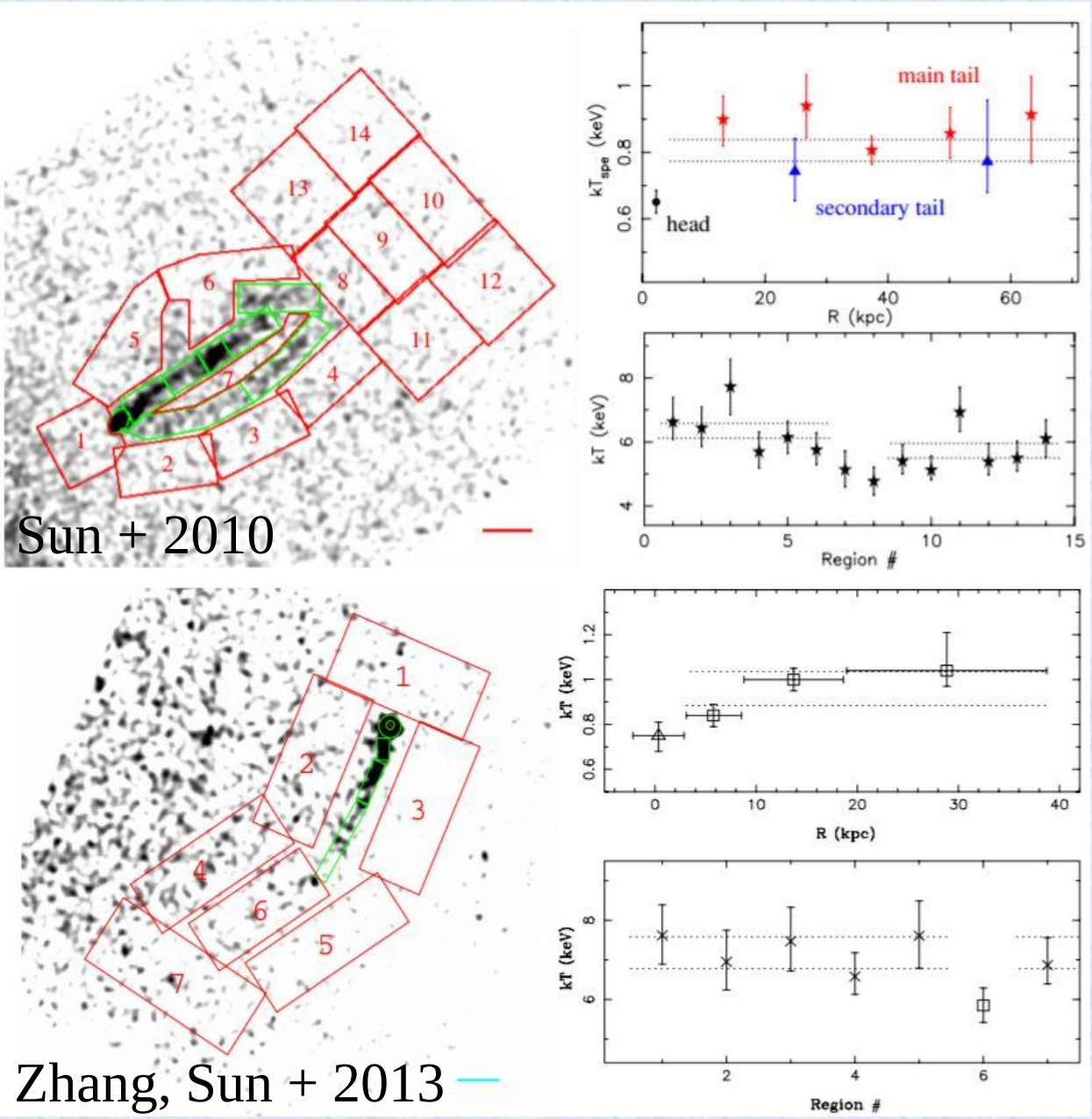

Chandra
2 kpc
Ha


Chandra
Ha
2 kpc

What do we now know about X-ray tails ?

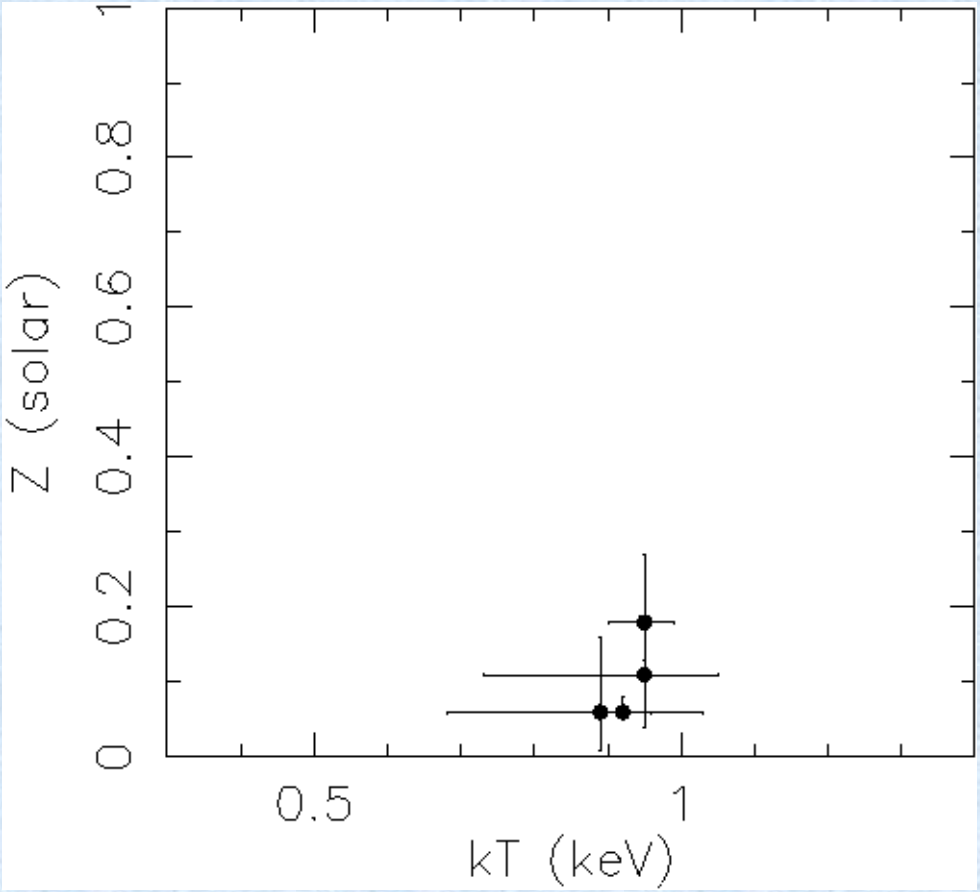
- Soft X-ray emission in tails naturally from mixing
- They are still rare since they are usually only revealed from deep *Chandra* and *XMM* observations because of a) strong local X-ray "background" from the ICM; b) their intrinsic faintness and also "contaminated" by point sources and ICM clumping.
- They appear "isothermal" with the current data --- intrinsic multi-phase gas, modelling and X-ray spectrum quality; low abundance with the single-*T* fit probably for the same reason.
- The soft X-ray gas (T ~ 10^7 K) co-exists with colder gas and the soft X-ray surface brightness correlates with the Hα surface brightness at 5 – 10 kpc scales.
- Gas mass in the hot phase likely < cold gas mass

Isothermal X-ray tails !?



- ESO 137-001 (tidal truncation radius of ~ 15 kpc), Ts with AtomDB 1.3.1
- ESO 137-002 (tidal truncation radius of ~ 23 kpc), Ts with AtomDB 2.0.1
- Also true for D100 and NGC 4848 in Coma, each with only two T bins in the tail

Mixing and multiphase !?



- Similar *kT* for the four brightest X-ray tails (ESO 137-001 and ESO 137-002 in A3627, D100 and NGC 4848 in Coma) with AtomDB 2.0.2 (hopefully add 2-3 soon)
- **Low abundance** from single-*T* fits (v.s. ~ 0.3 solar for the surrounding ICM) because of intrinsic multiphase gas from mixing ?
- Detailed X-ray spectral modelling beyond the capability of current X-ray telescopes …

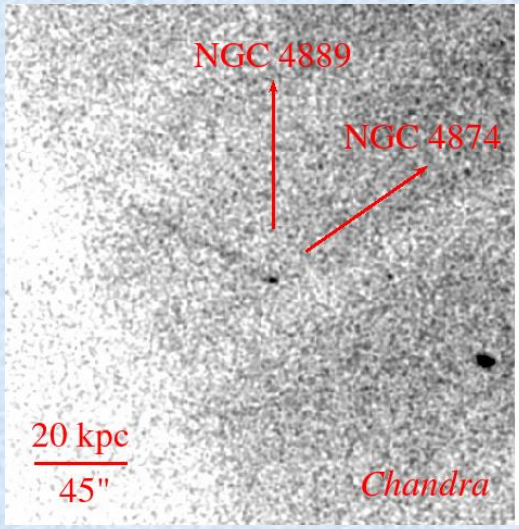
Correlation of different gas phases (X-ray vs. Hα)

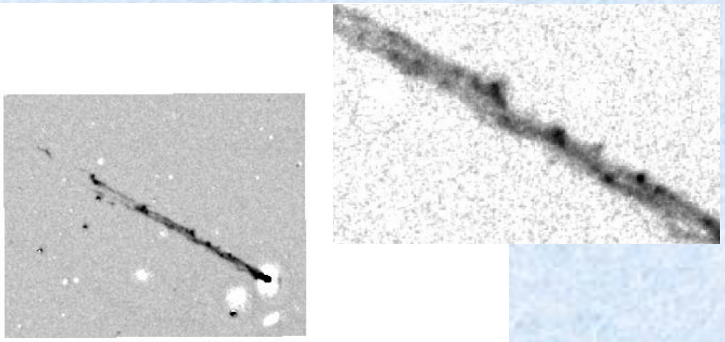
- Diffuse X-ray vs. diffuse Hα at ~ 5 – 10 kpc scales
- Not a fit ! Simply $S_X / S_{H\alpha} = 3$

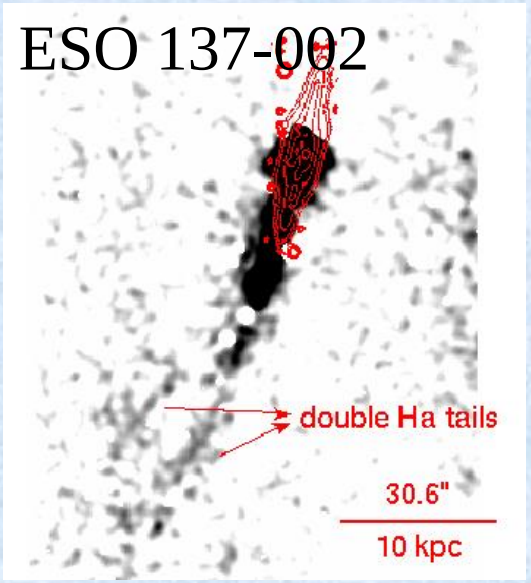
(Sun et al. 2017)

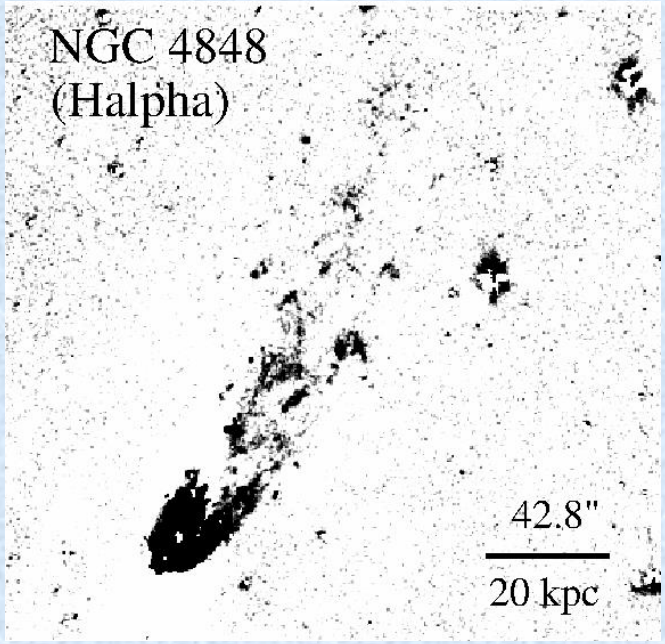
Also see Pavel's talk on Hα – CO correlation

Two tails to tell ?

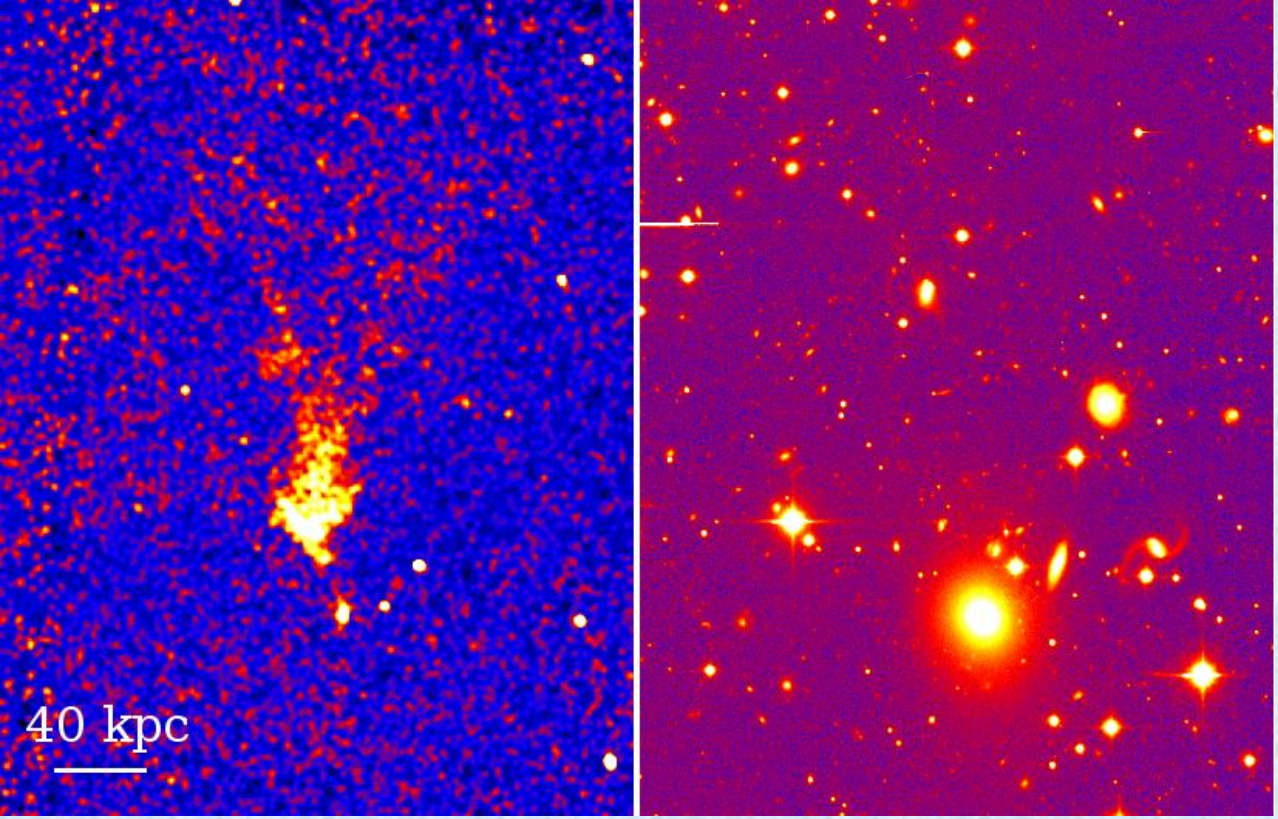


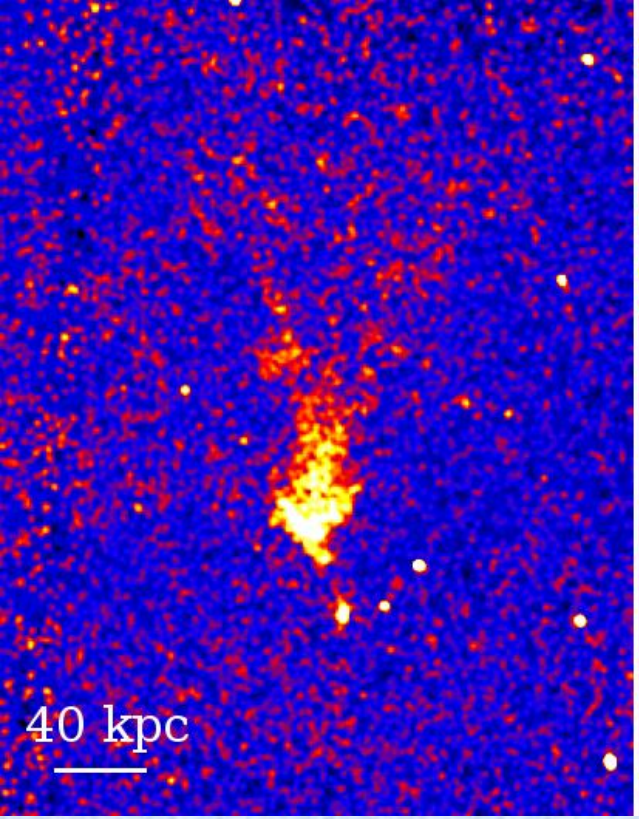
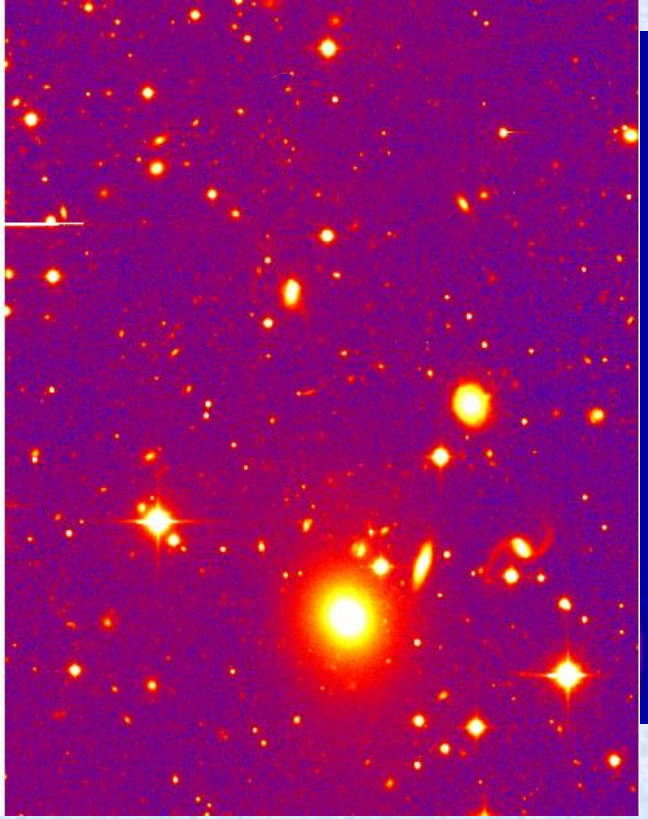
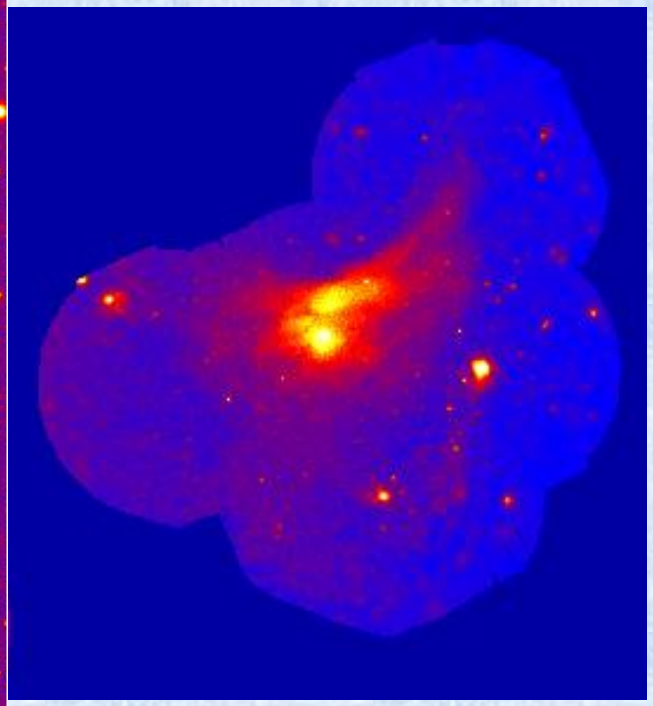


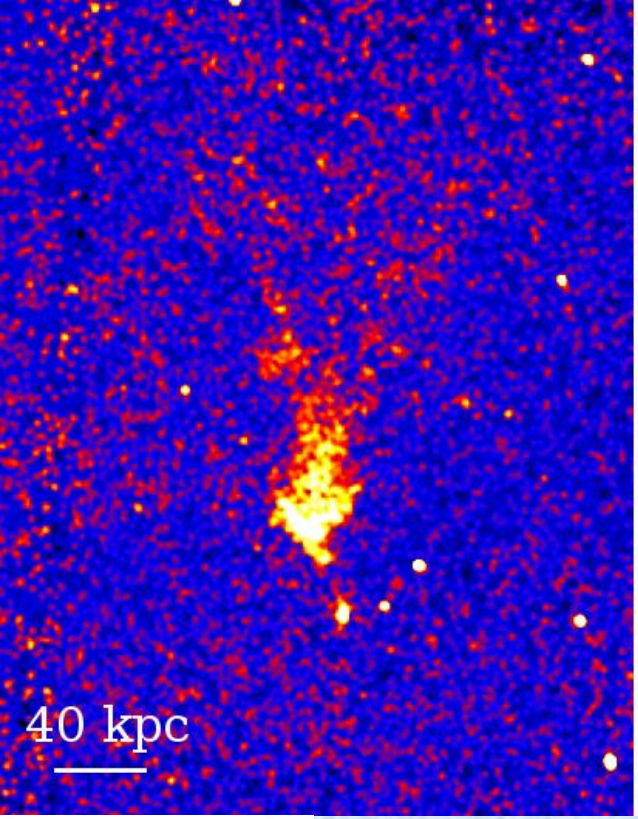


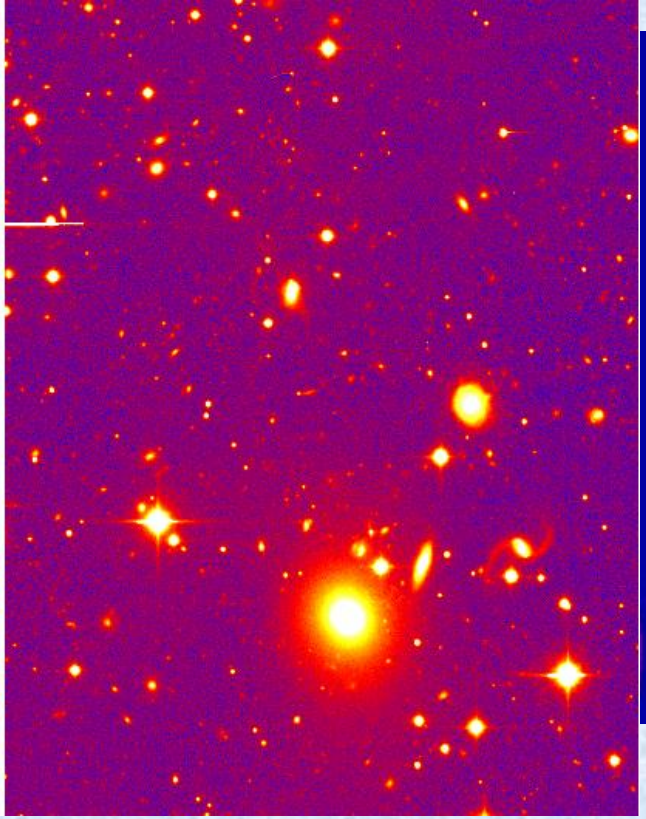


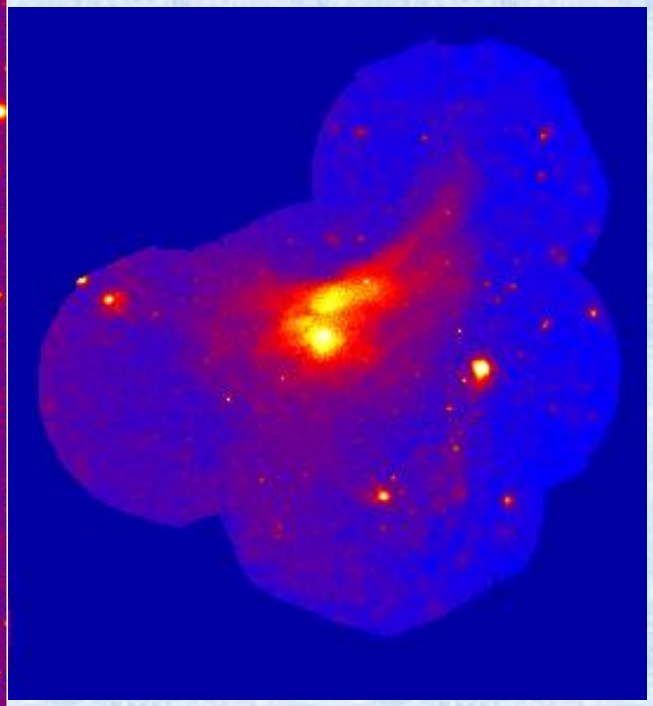
- Many examples of X-ray / H tails are double ! (ESO 137-001 / 002 in A3627; D100 and NGC 4848 in Coma (Sun+2007, 2010; Yagi+ 2007; Zhang, Sun+2013; Yagi+)
- Possible in the MHD stripping simulations by Ruszkowski+2014 from the ICM B field folding

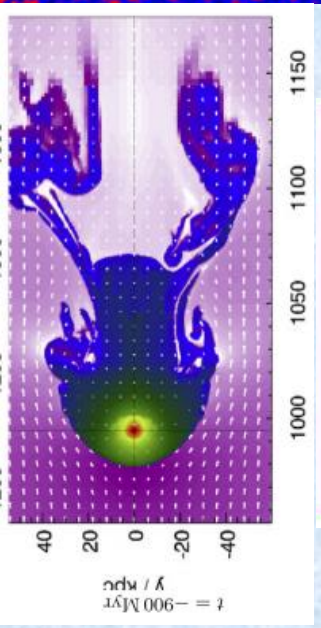

40 kpc

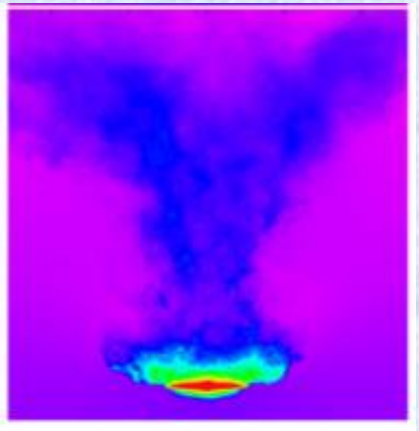

40 kpc



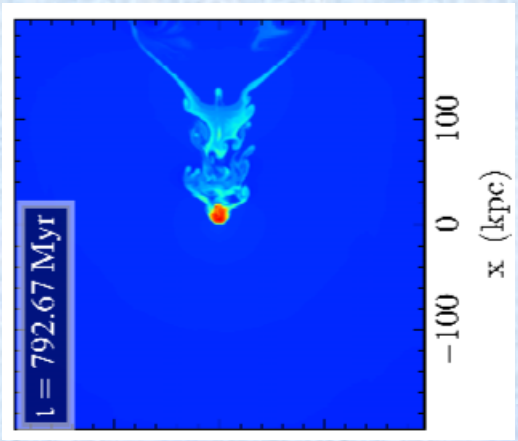






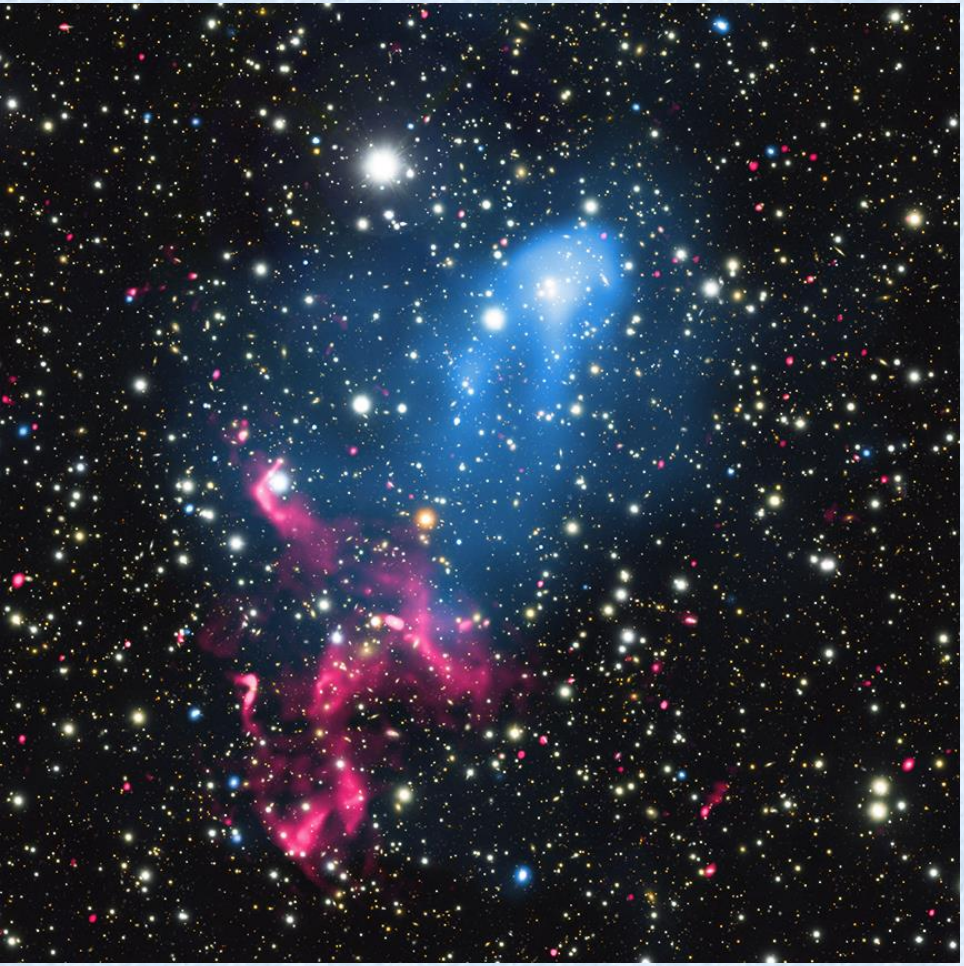






Roediger et al. 2015;
Tonnesen & Stone 2014
Vijayaraghavav &
Sarazin 2017

Abell 3411



El Gordo

~ 900 kpc & ~ 1.2 Mpc from the front edge to the end of the tail

Conclusions

1) X-ray tails start to show up with deeper, better X-ray data (unfortunately, *Chandra* is no longer good at this).

2) Stripped tails are great objects to study multi-phase medium and star formation.

3) Correlations between gas in different phases are observed (e.g., X-ray vs. Hα) and need to be examined in more detail.

4) Do we need magnetic field to explain tail bifurcation?