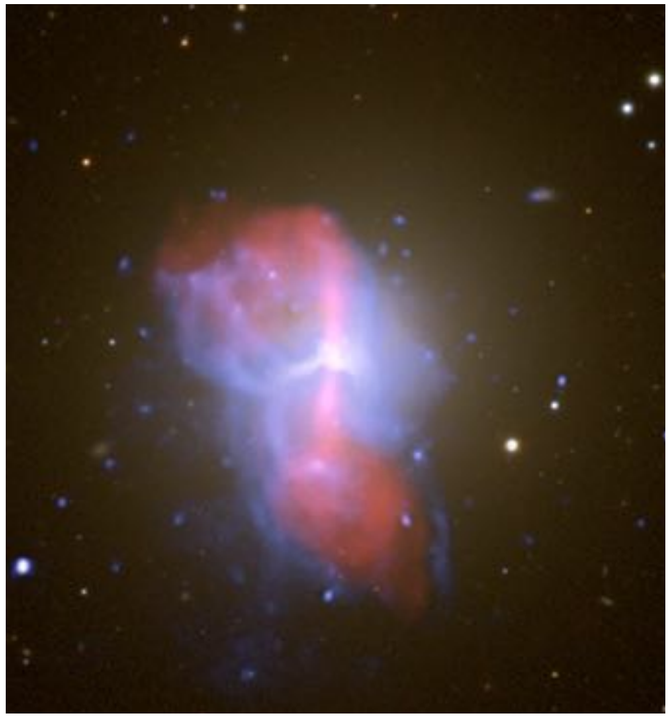
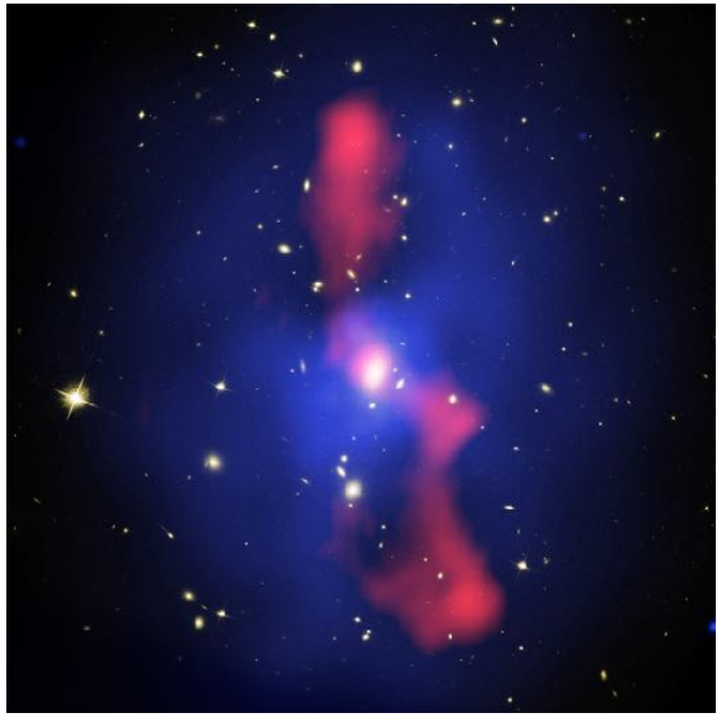
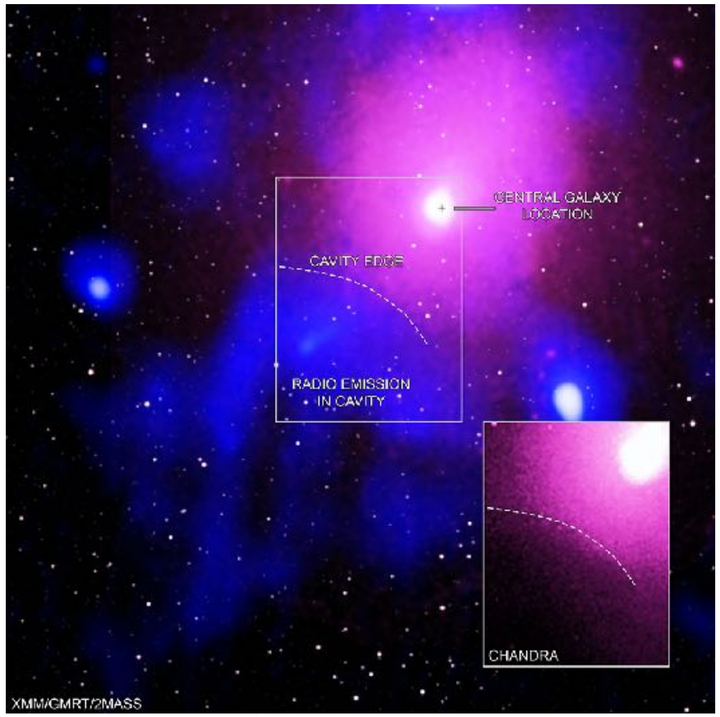
Cosmic bubble-blowers and the baryons that do not form stars

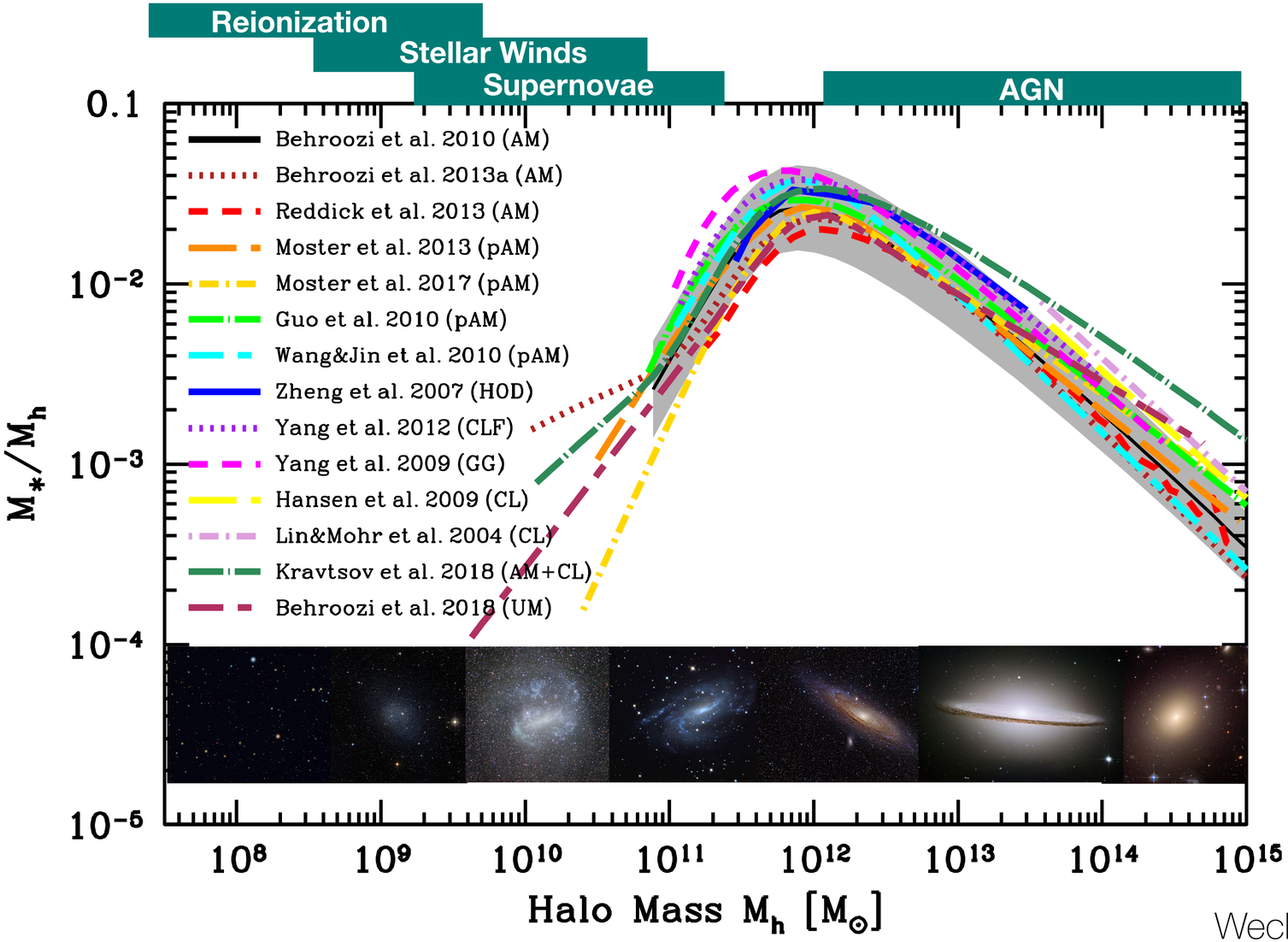






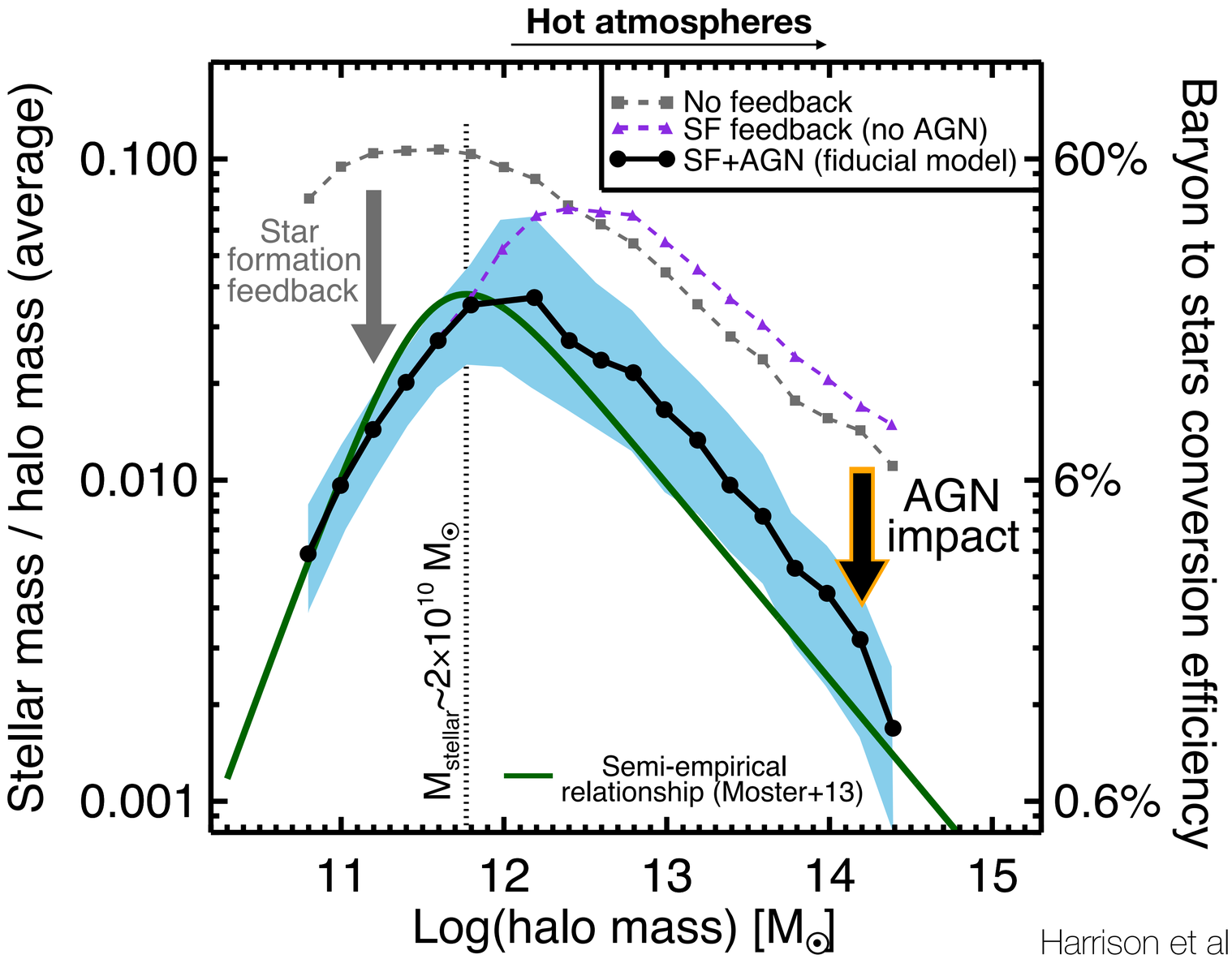
Norbert Werner
Masaryk University

Why so Much Gas and so Few Stars?

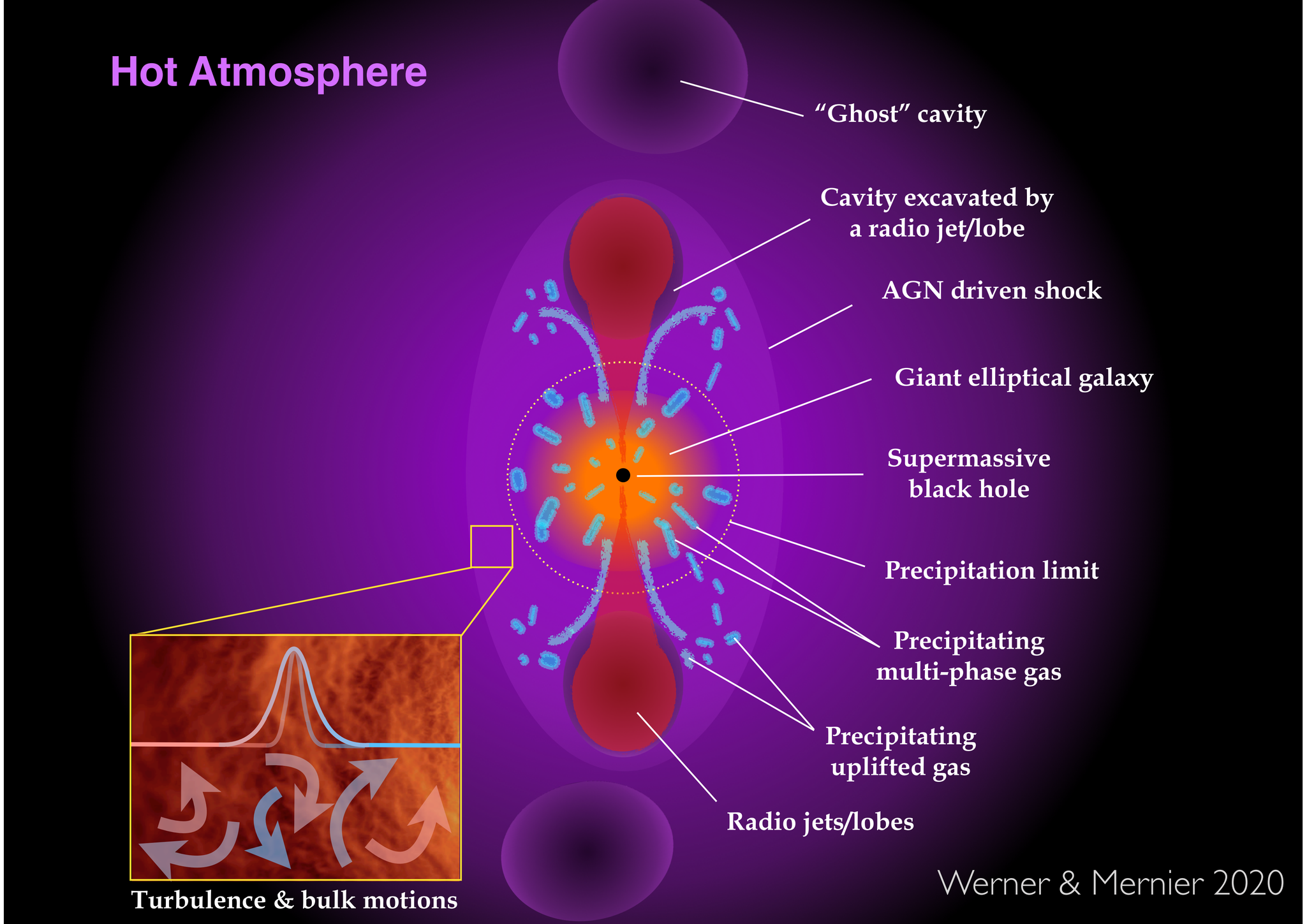


Wechsler et al. 2018

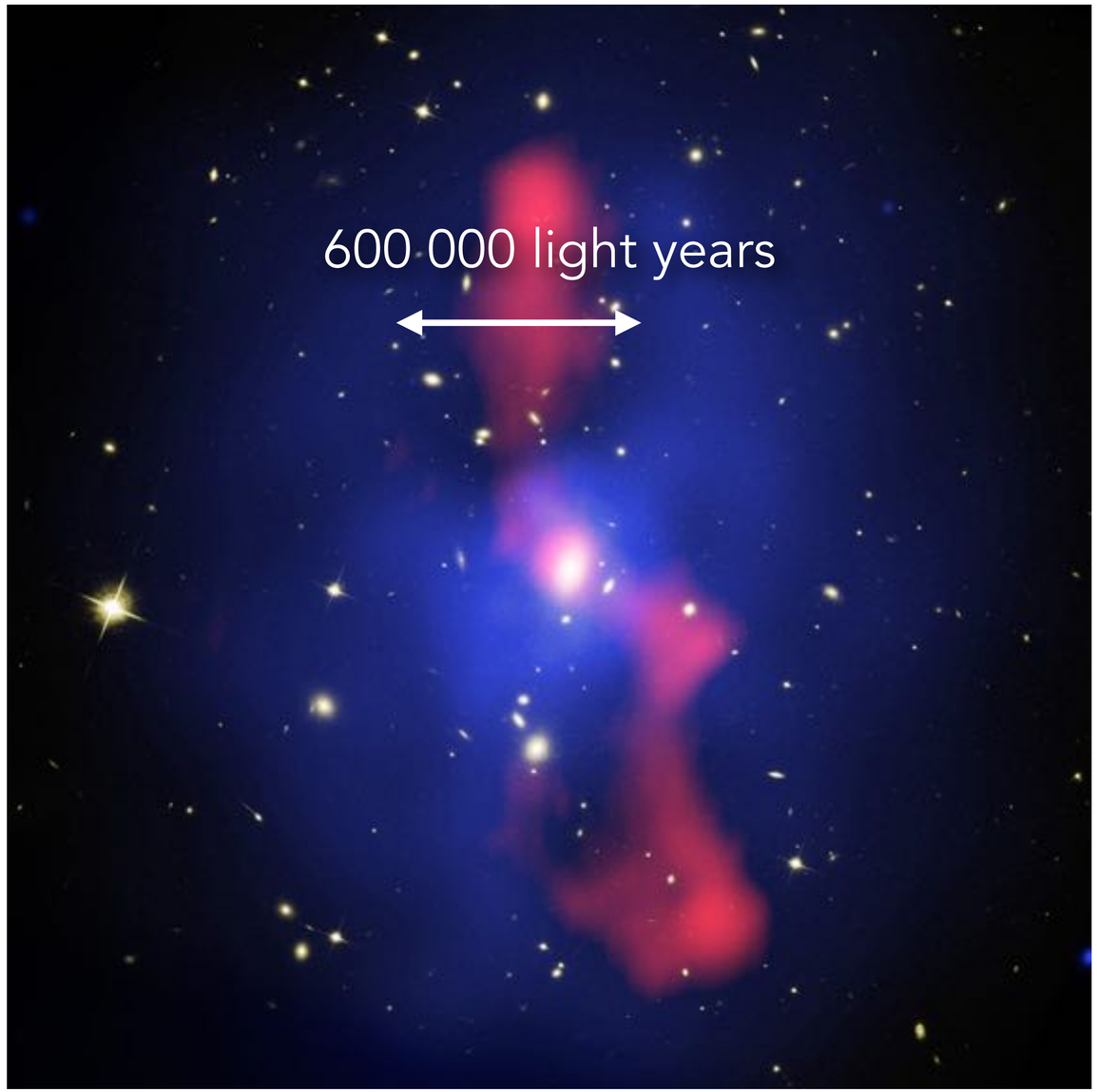
Why so Much Gas and so Few Stars?

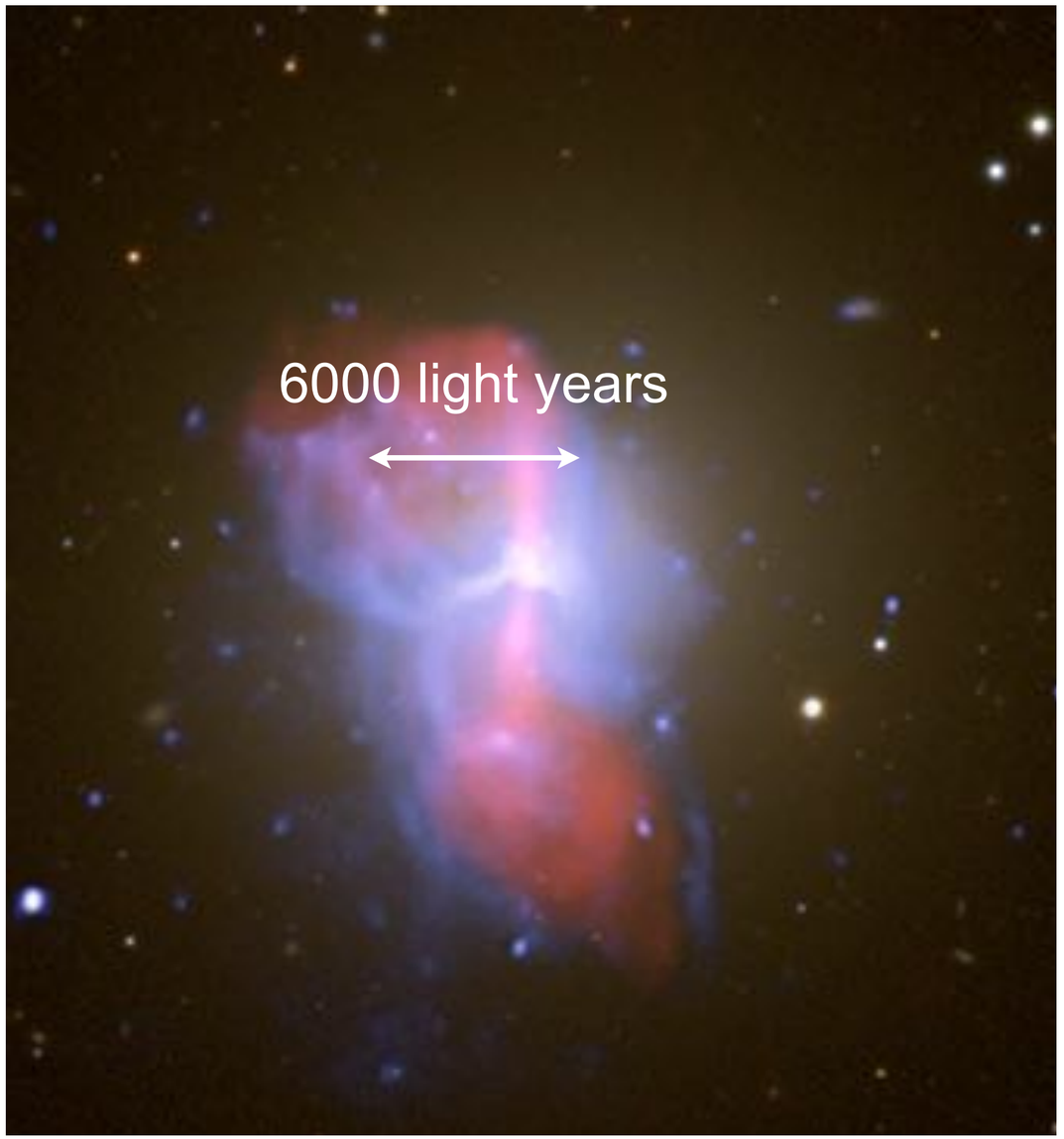


Harrison et al. 2017

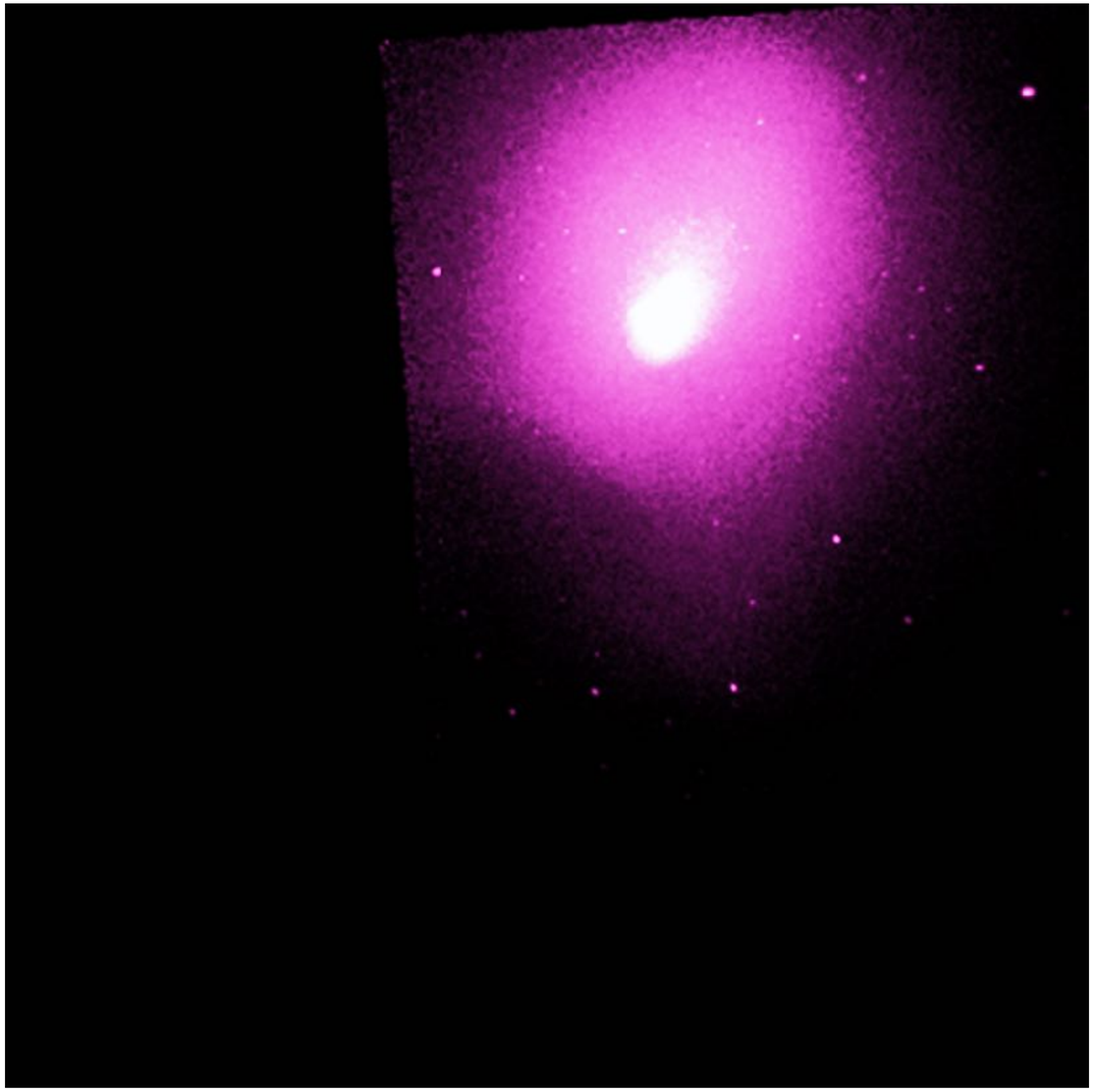

Hot Atmosphere
"Ghost" cavity
Cavity excavated by a radio jet/lobe
AGN driven shock
Giant elliptical galaxy
Supermassive black hole
Precipitation limit
Precipitating multi-phase gas
Precipitating uplifted gas
Radio jets/lobes
Turbulence & bulk motions
Werner & Mernier 2020

Black Hole Blown Bubbles in Clusters and in Galaxies



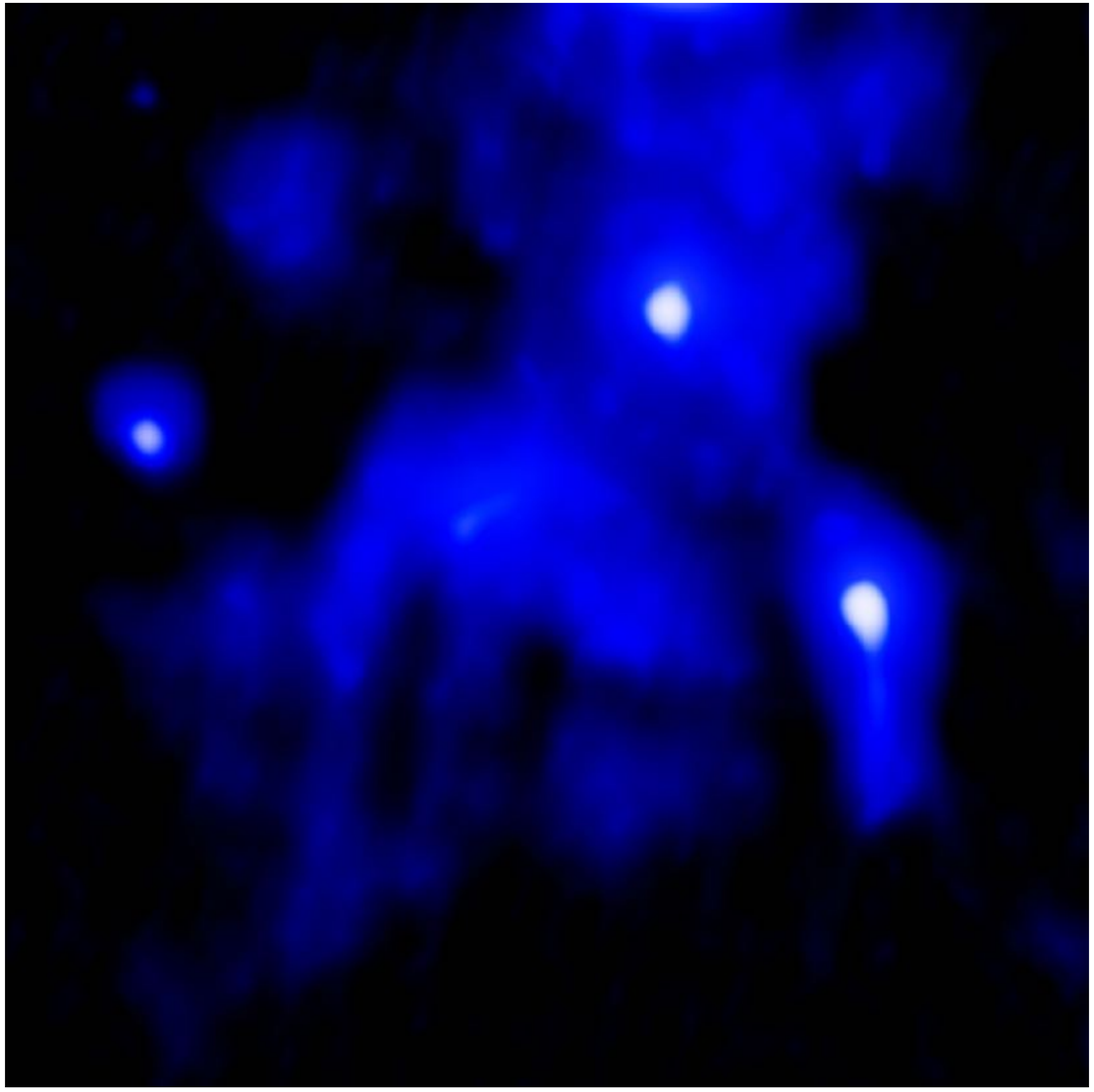


The biggest black hole outburst in the Universe?



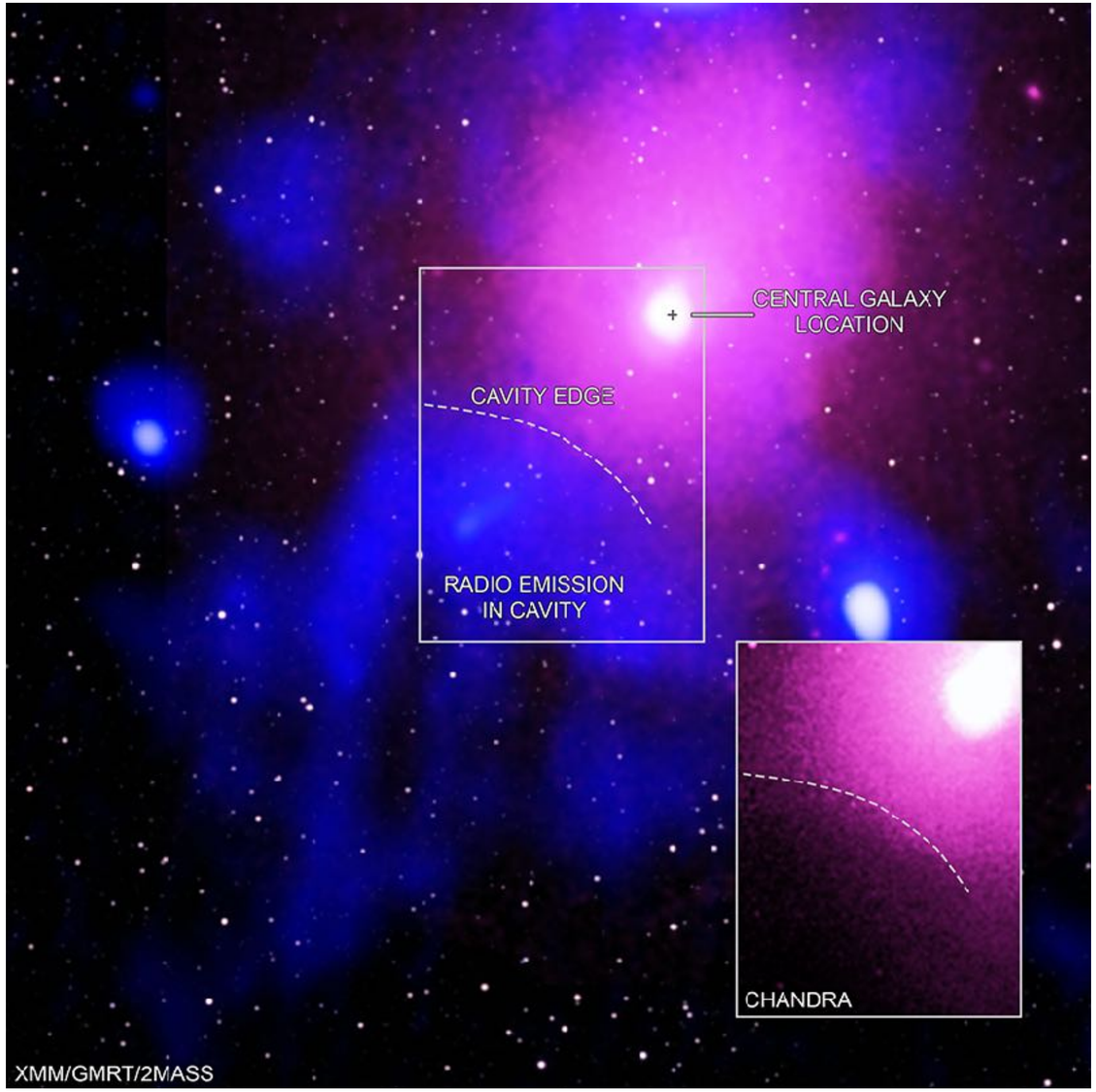
Werner et al. 2016
Giacintucci et al. 2020

The biggest black hole outburst in the Universe?

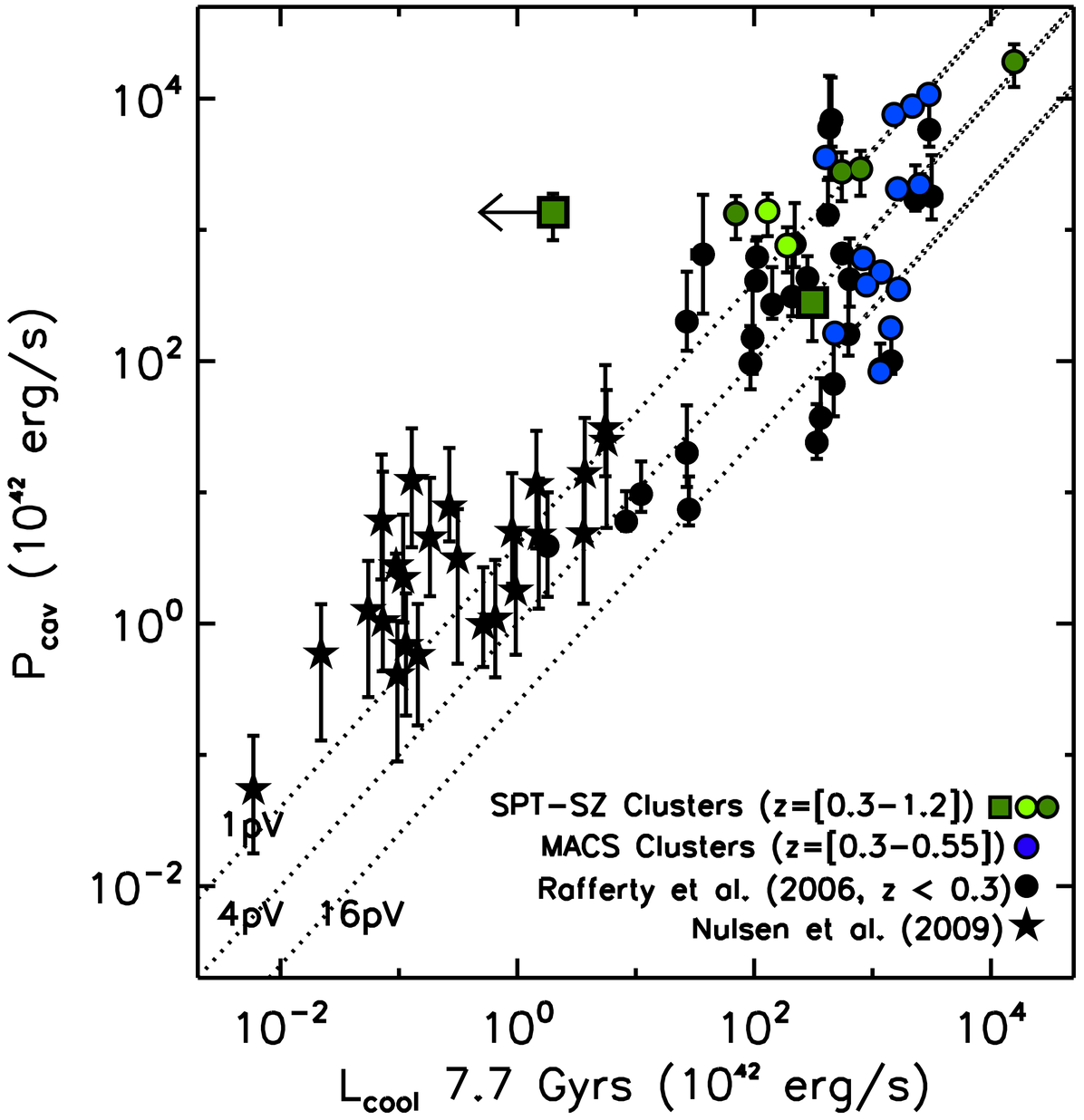


Giacintucci et al. 2020

THE BIGGEST BLACK HOLE OUTBURST IN THE UNIVERSE?

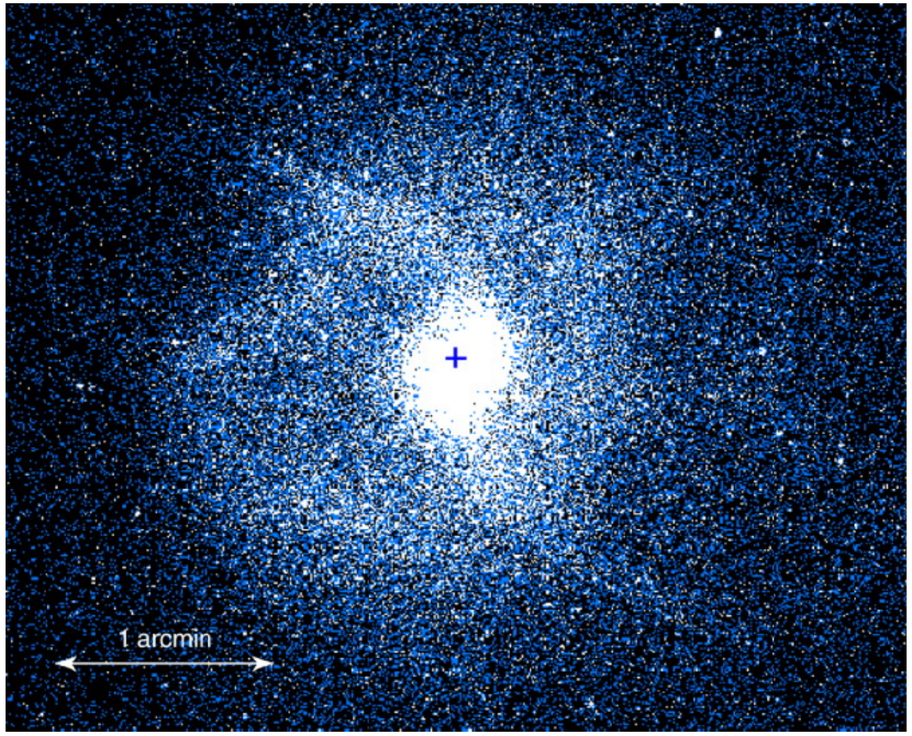


Giacintucci et al. 2020

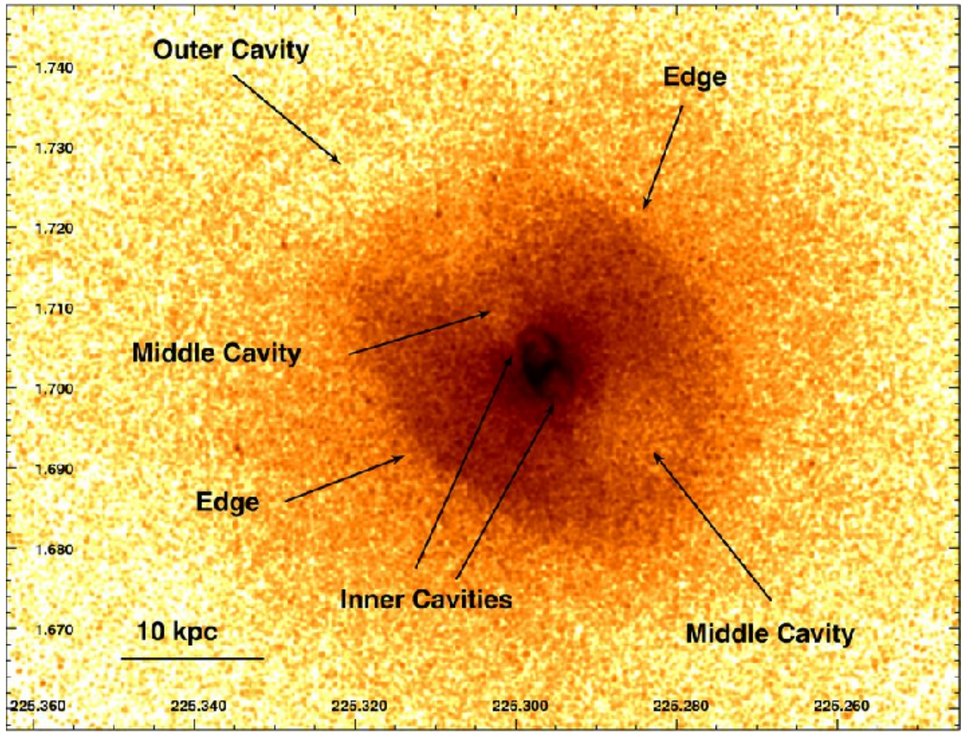


Hlavacek-Larrondo et al. 2015


NGC 1399
NGC 4472
NGC 4636
NGC 5044



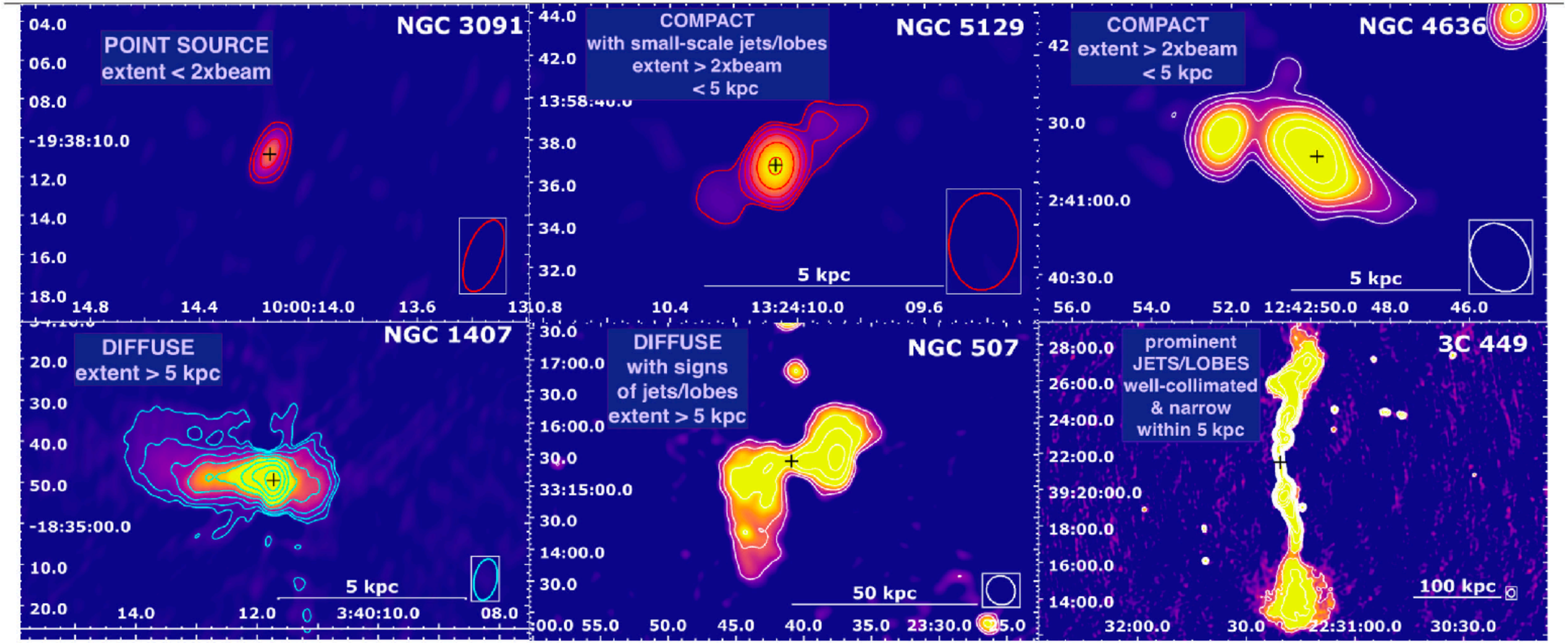
Jones et al. 2002
Baldi et al. 2009



Randall et al. 2015

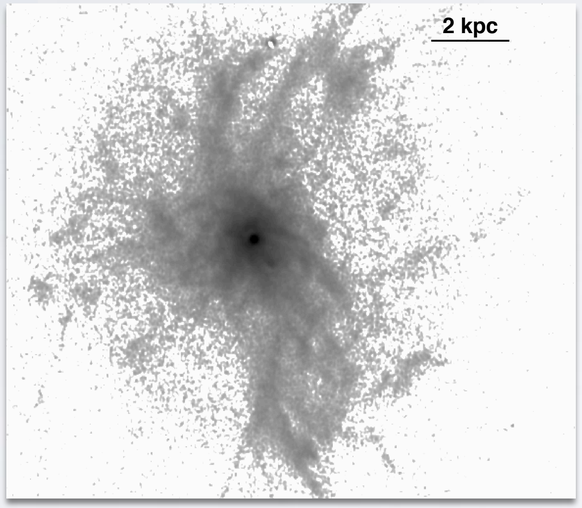
HIGH DUTY CYCLE

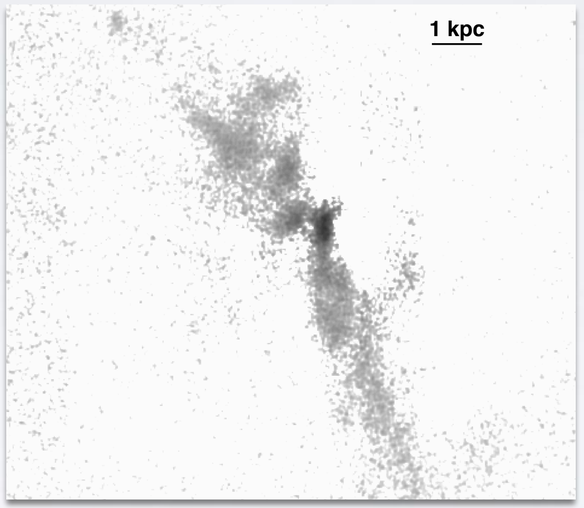
- 41(42)/42 have a central radio sources
- 27/42 have an extended radio source
- 34/42 show cavities
  - 7/14 galaxies with point-like radio emission show cavities
  - 5 radio sources appear offset from the center

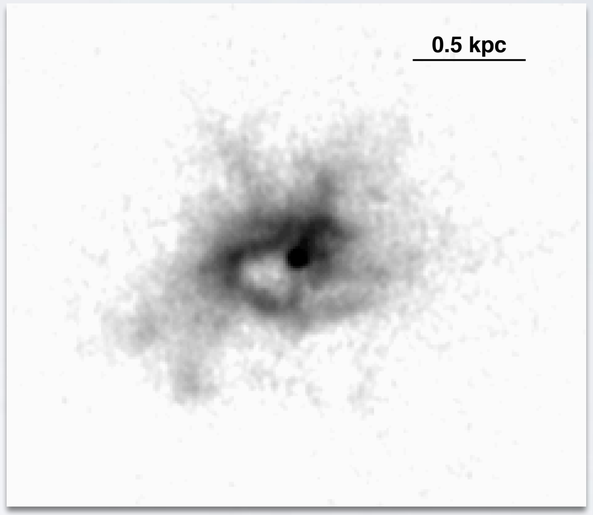


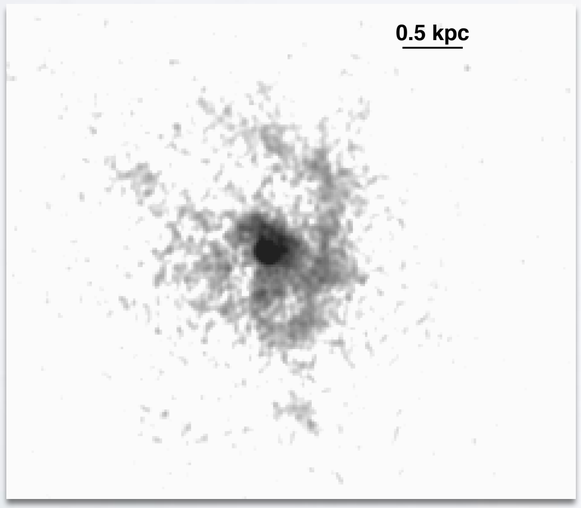
Grossová, Werner, et al. 2021

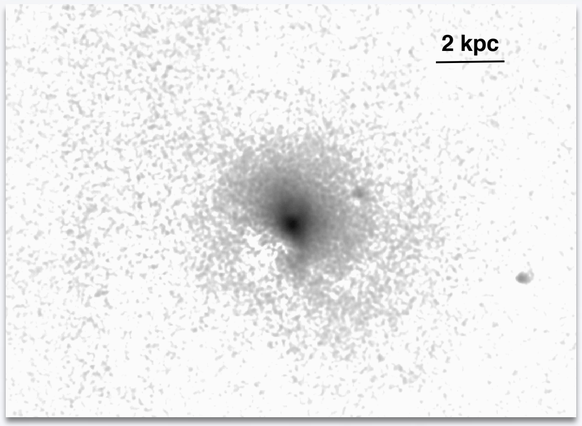
Hα+[NII] IMAGING WITH THE SOAR TELESCOPE

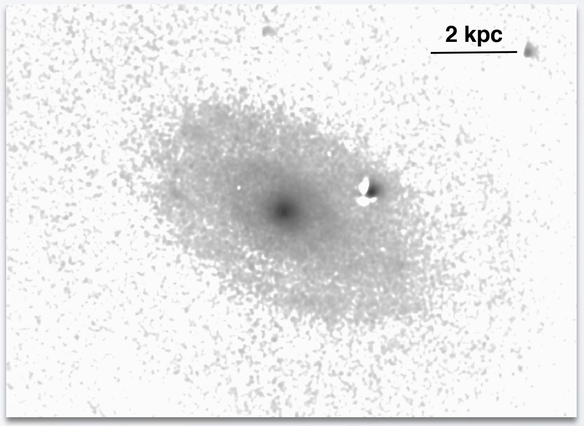






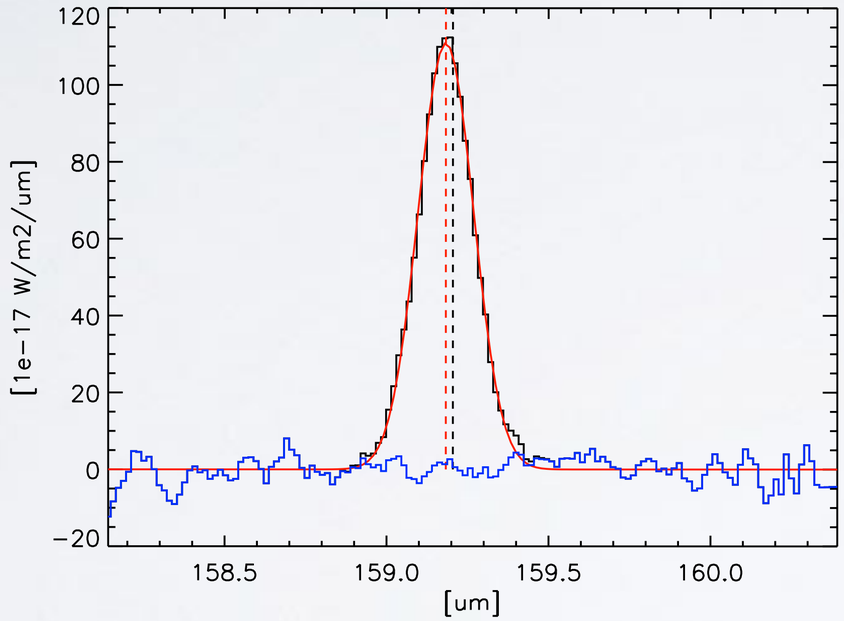






Werner et al. 2014

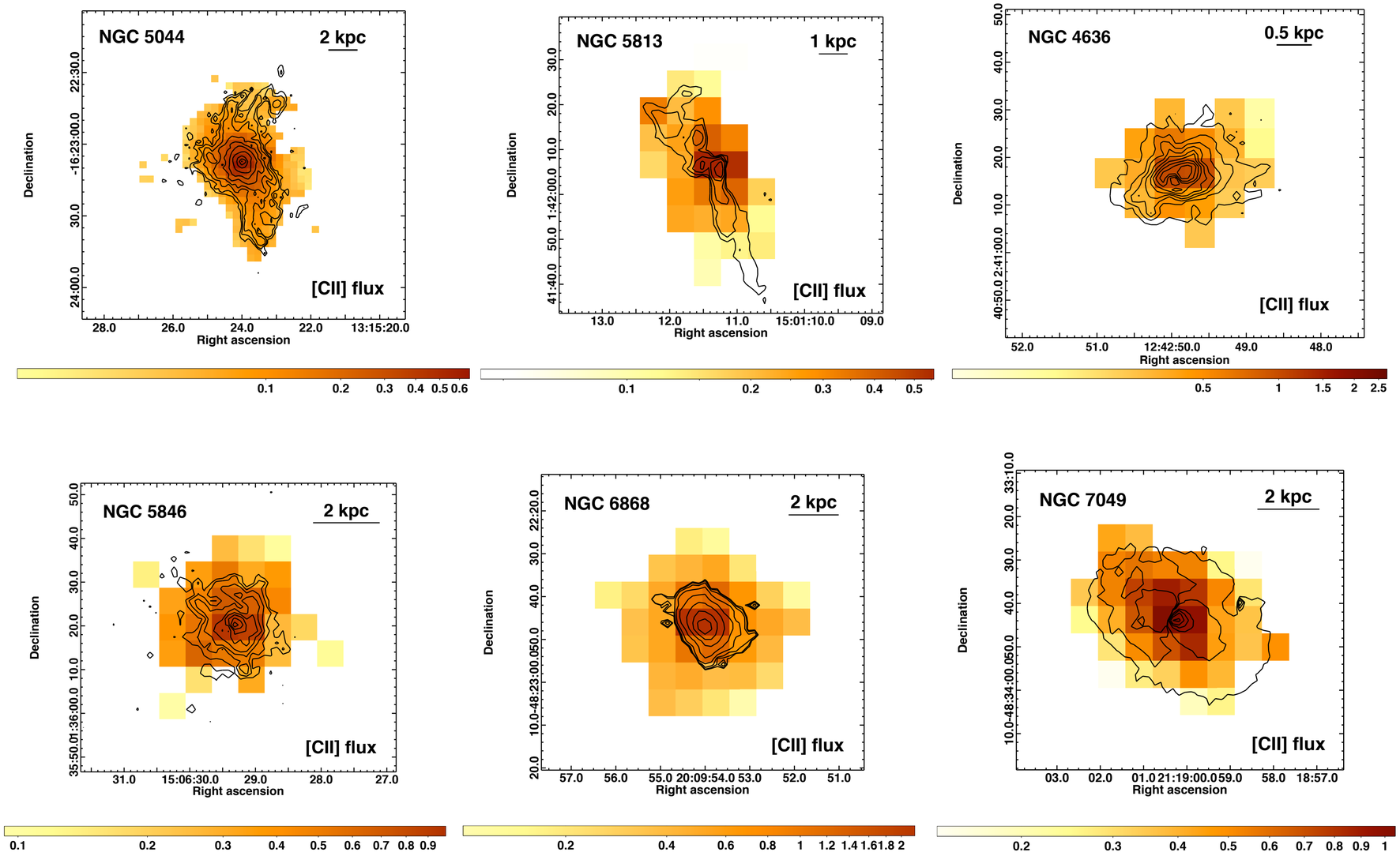
FAR-INFRARED LINE DETECTIONS IN GIANT ELLIPTICALS



- [CII] detected in every single galaxy (6/8) with extended Hα line emitting nebulae
- in 4/8 systems also detected the [OI] line and in 3/8 the [OIb] line

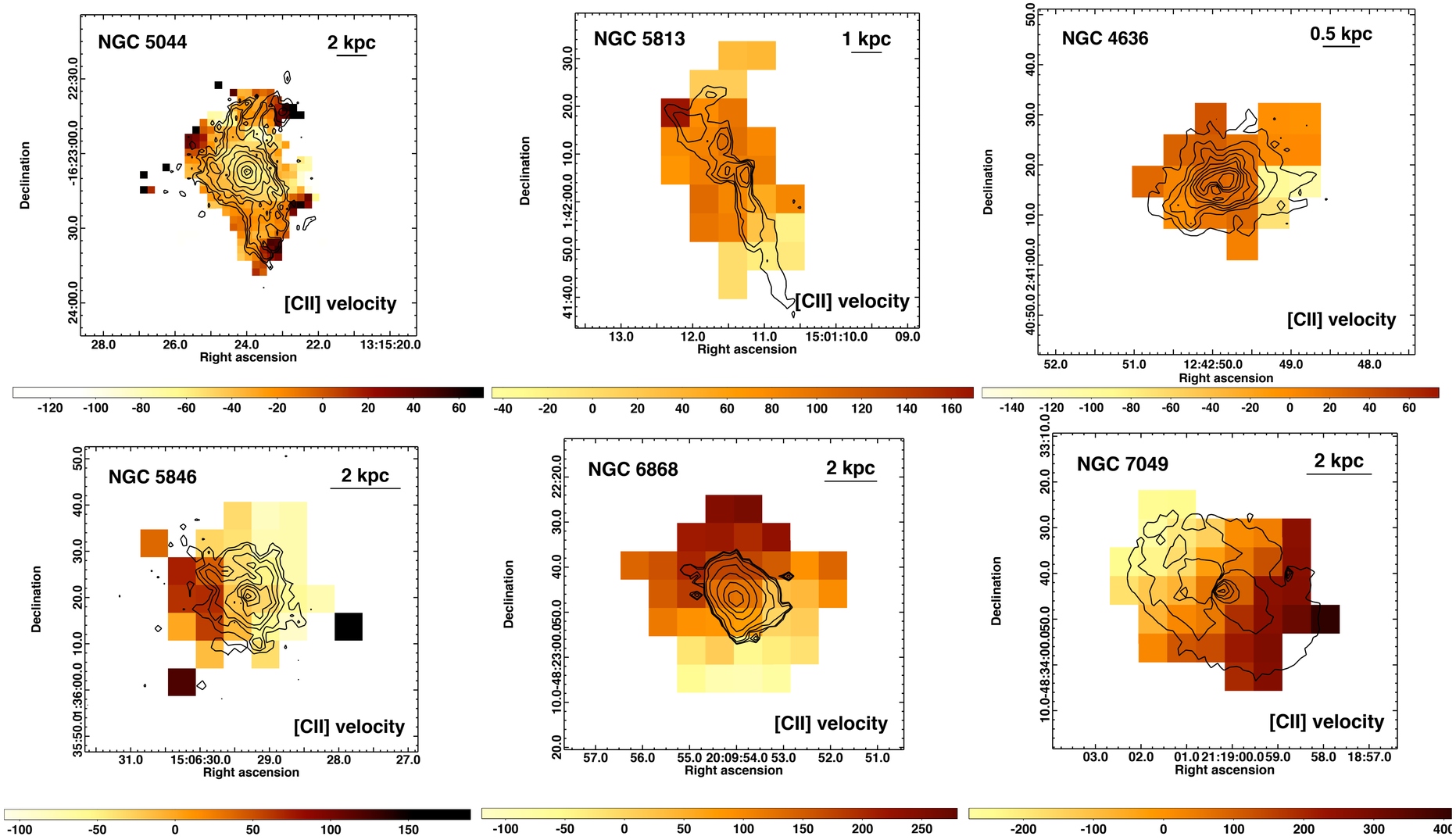
Werner et al. 2014

[CII] EMISSION FOLLOWING Ha



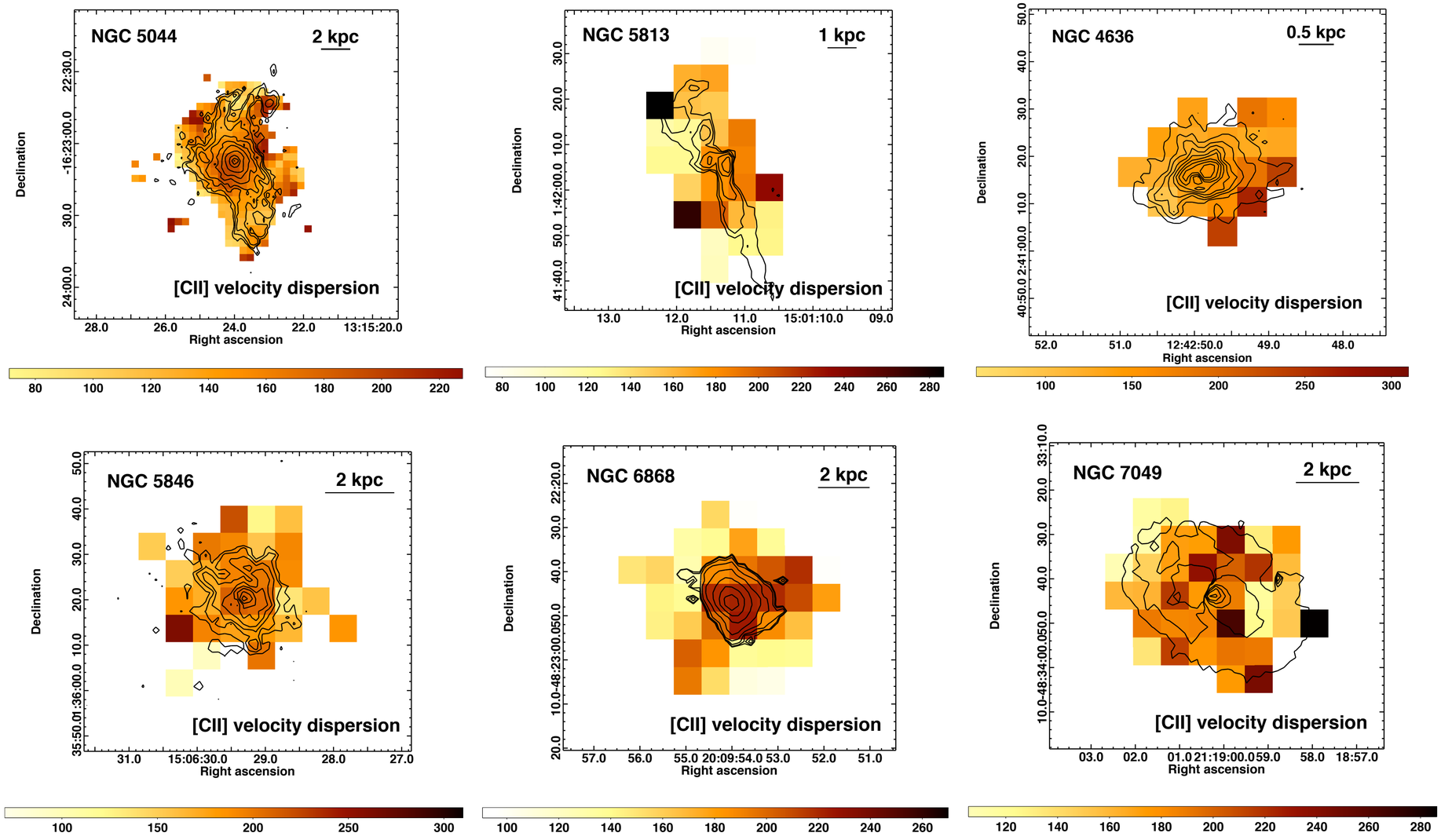
Werner et al. 2014

VELOCITIES OF THE COLD ISM

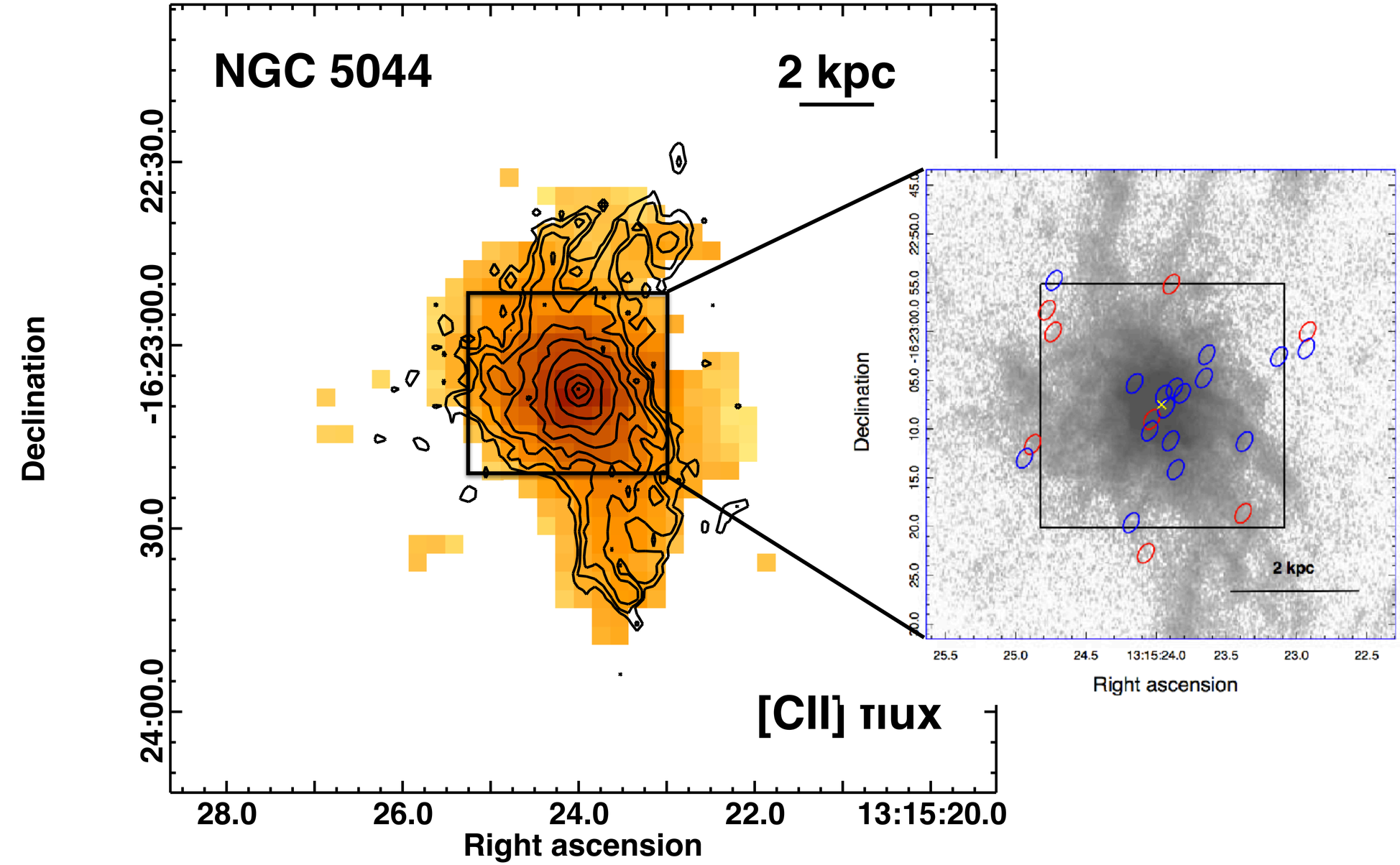


Werner et al. 2014

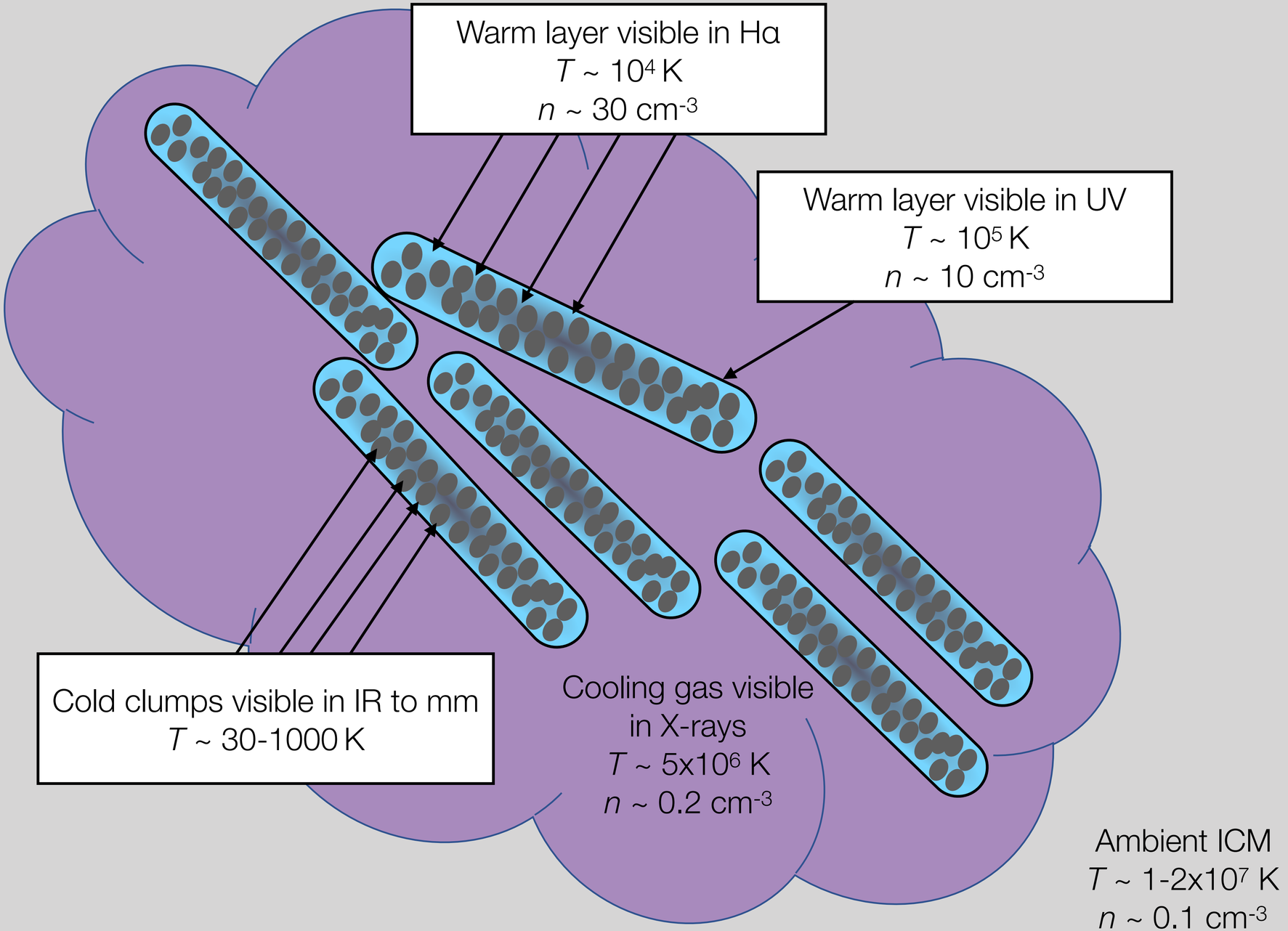
VELOCITY DISPERSIONS IN THE COLD ISM

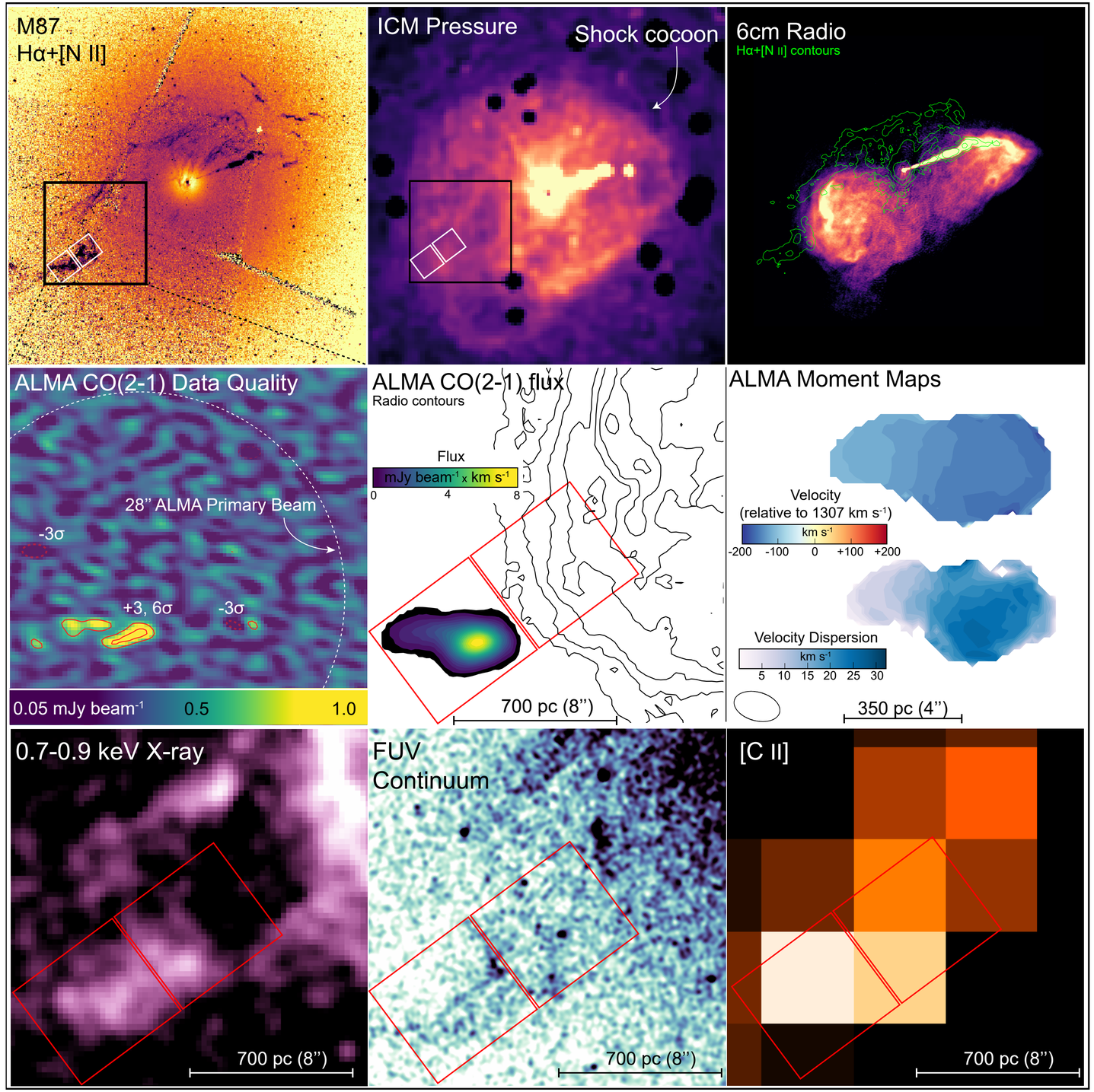


Werner et al. 2014



David et al. 2014

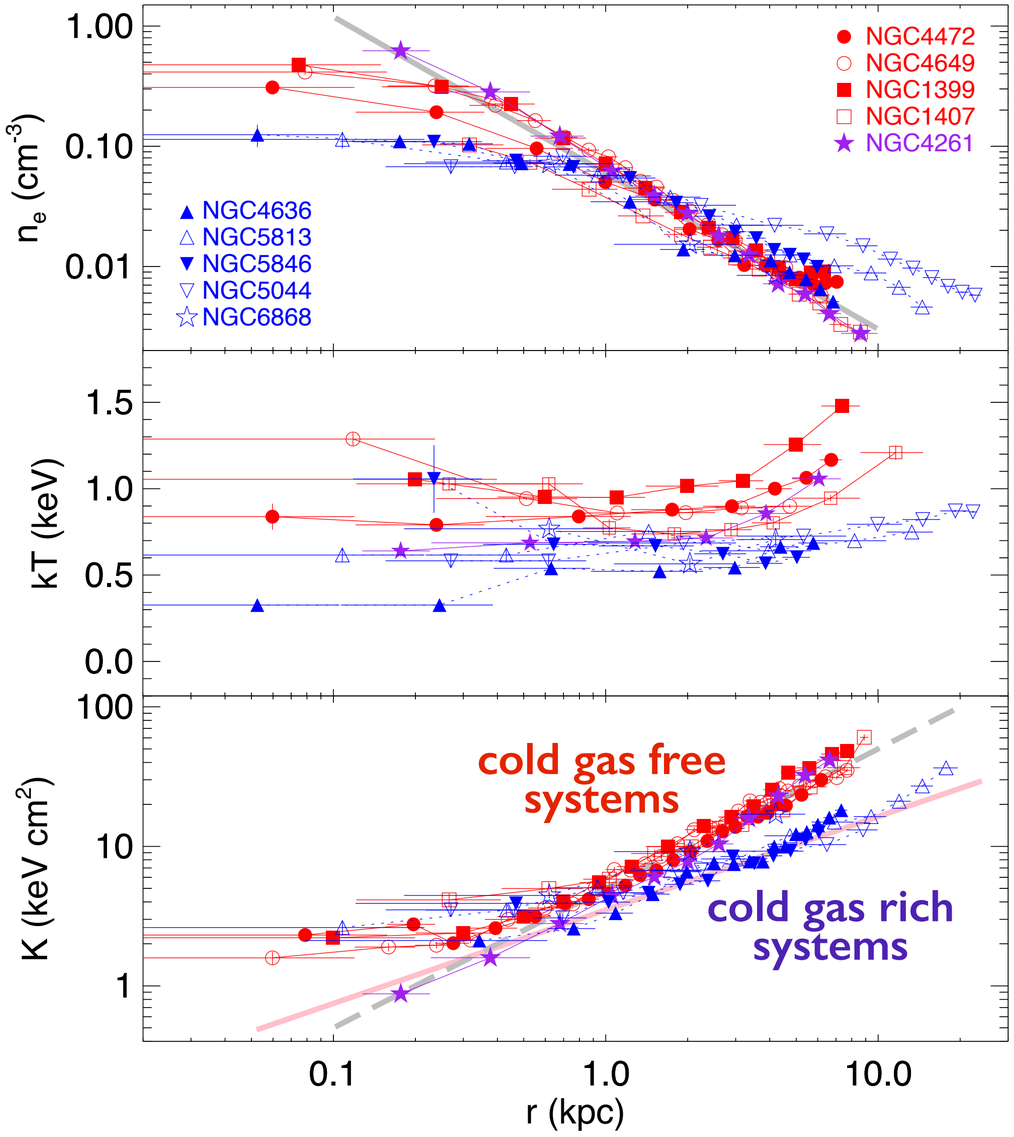

Warm layer visible in Hα
T ~ 10^4 K
n ~ 30 cm^{-3}
Warm layer visible in UV
T ~ 10^5 K
n ~ 10 cm^{-3}
Cold clumps visible in IR to mm
T ~ 30-1000 K
Cooling gas visible
in X-rays
T ~ 5x10^6 K
n ~ 0.2 cm^{-3}
Ambient ICM
T ~ 1-2x10^7 K
n ~ 0.1 cm^{-3}



DESTRUCTION OF MOLECULAR GAS BY RADIO LOBES

Simionescu et al. 2018

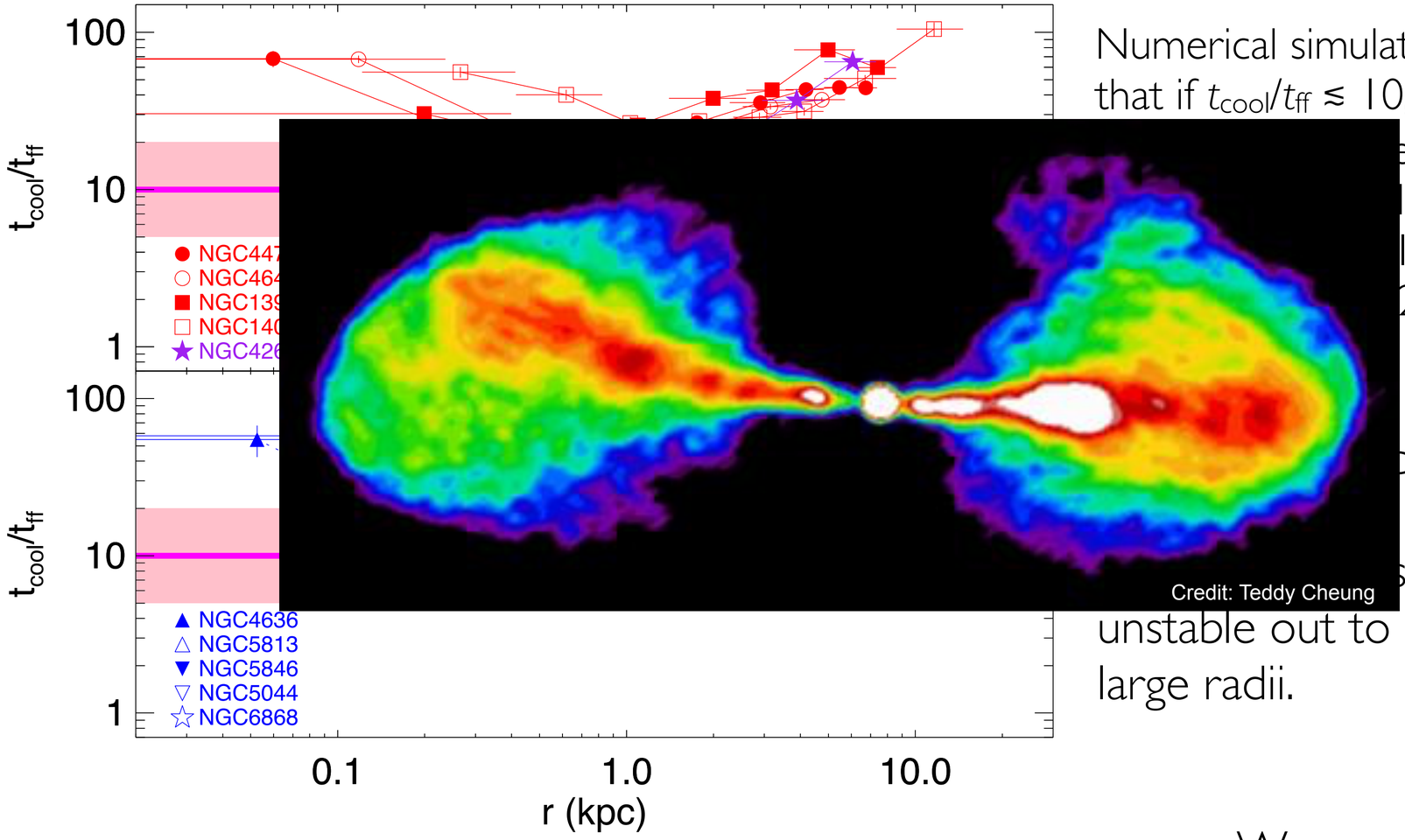
PROPERTIES OF THE HOT ISM



Outside of the innermost core, the entropy and temperature of systems containing cold gas is lower

Werner et al. 2014
Voit et al. 2015

COLD GAS RICH SYSTEMS PRONE TO COOLING INSTABILITIES

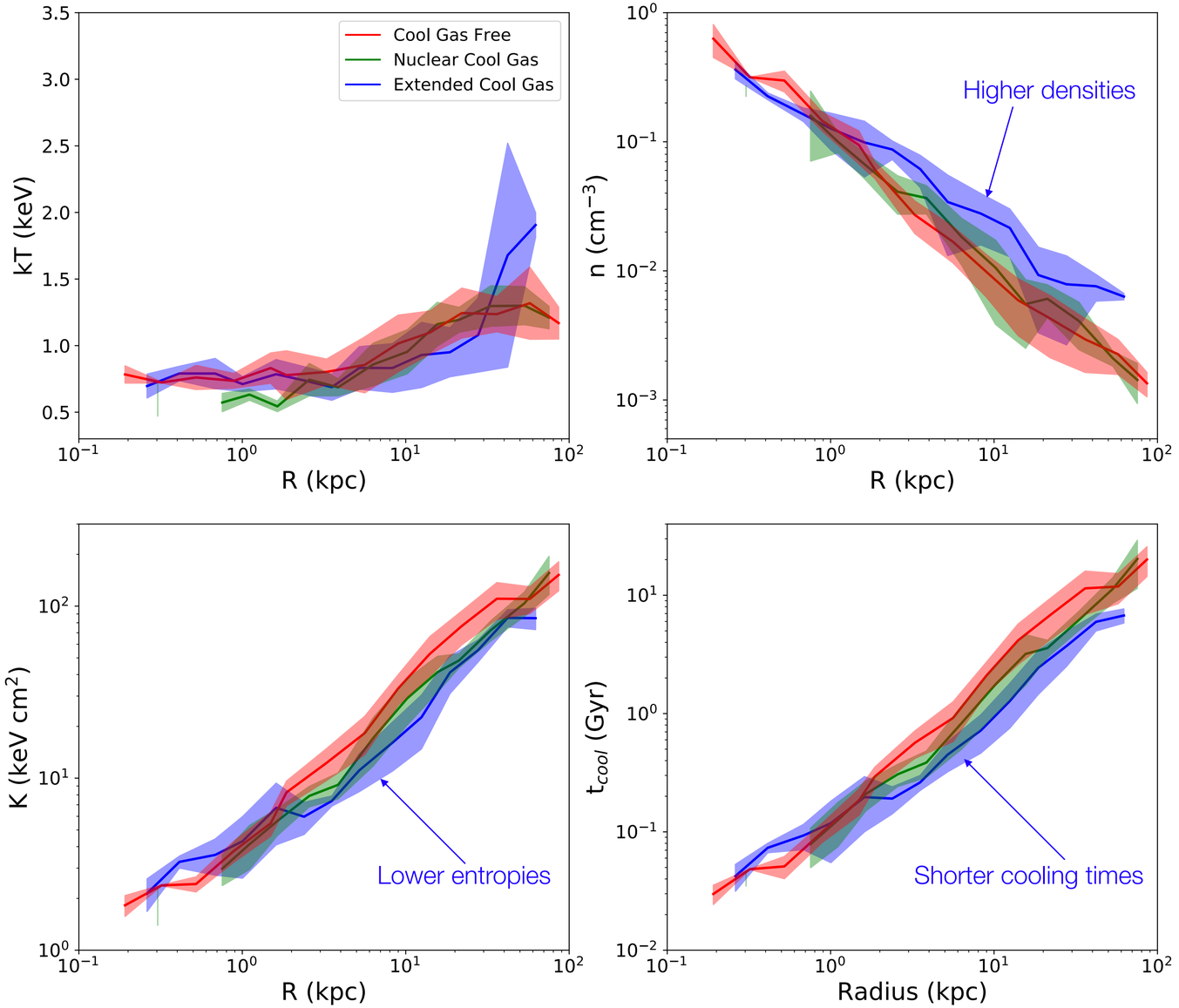


Numerical simulations predict that if $t_{cool}/t_{ff} \lesssim 10$, local
es will create
ium
12, 2013,
2, McCourt

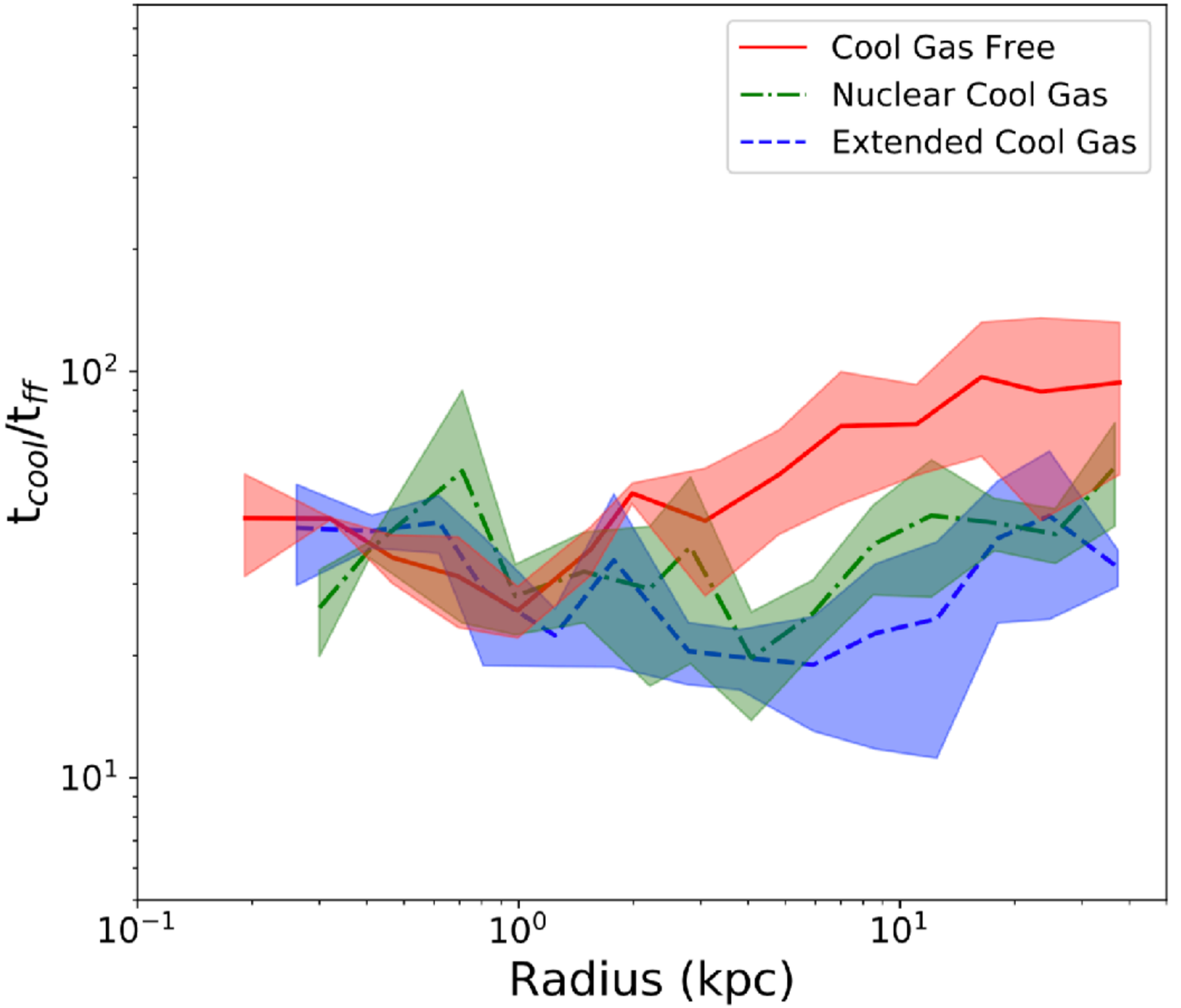
lear
the cold-
s remaining
unstable out to relatively large radii.

Werner et al. 2014
Voit et al. 2015

Cooling vs. Heating in galactic atmospheres

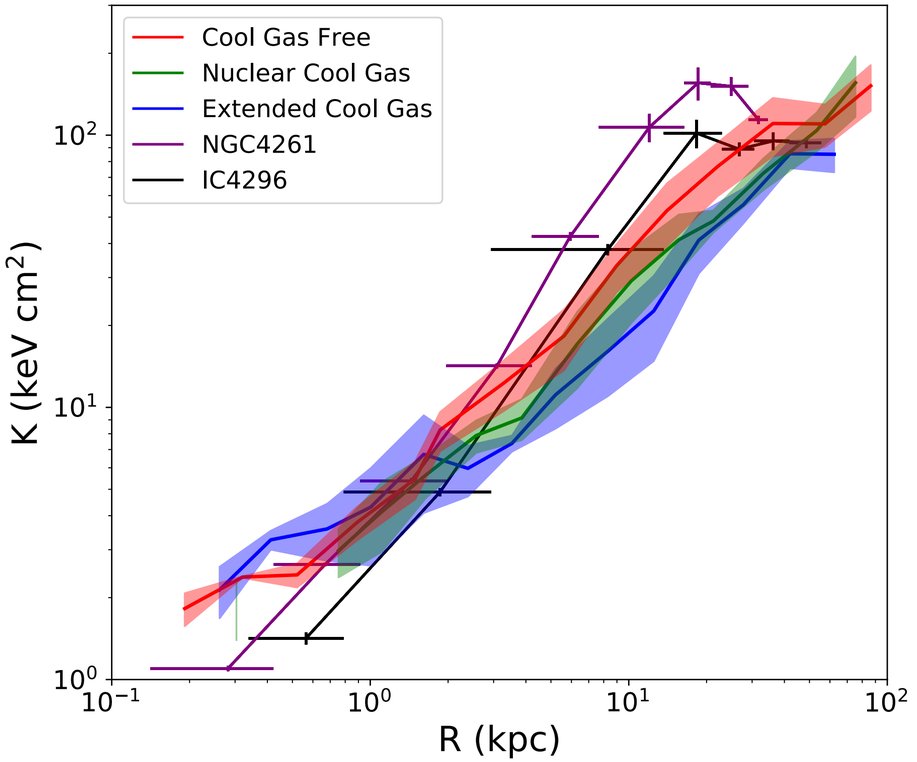


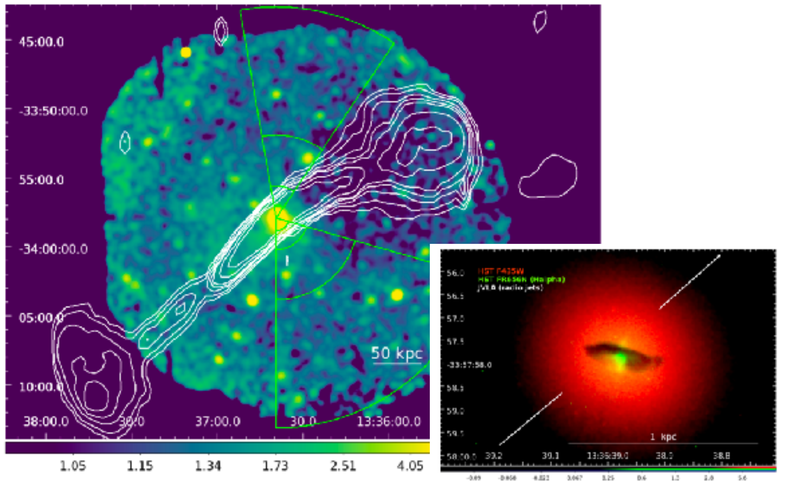
Lakhchaura et al. 2018

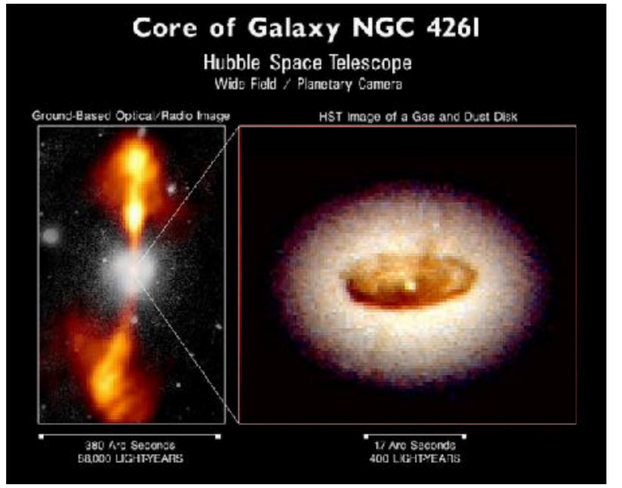


Lakhchaura et al. 2018

Unusually steep entropy profiles in systems with powerful jets

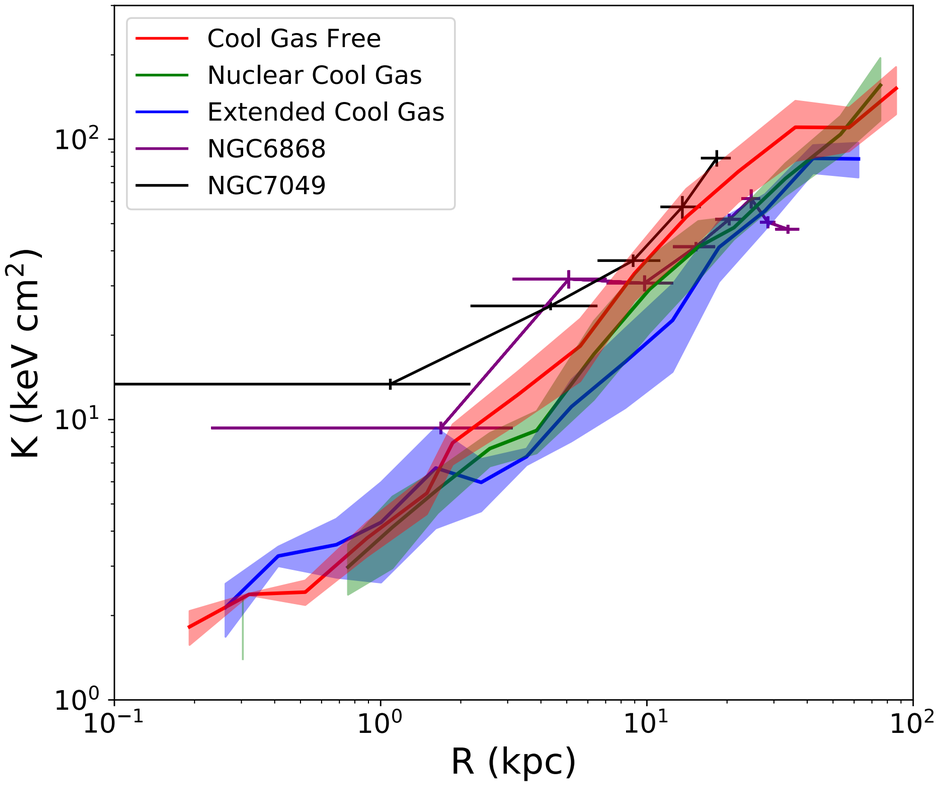






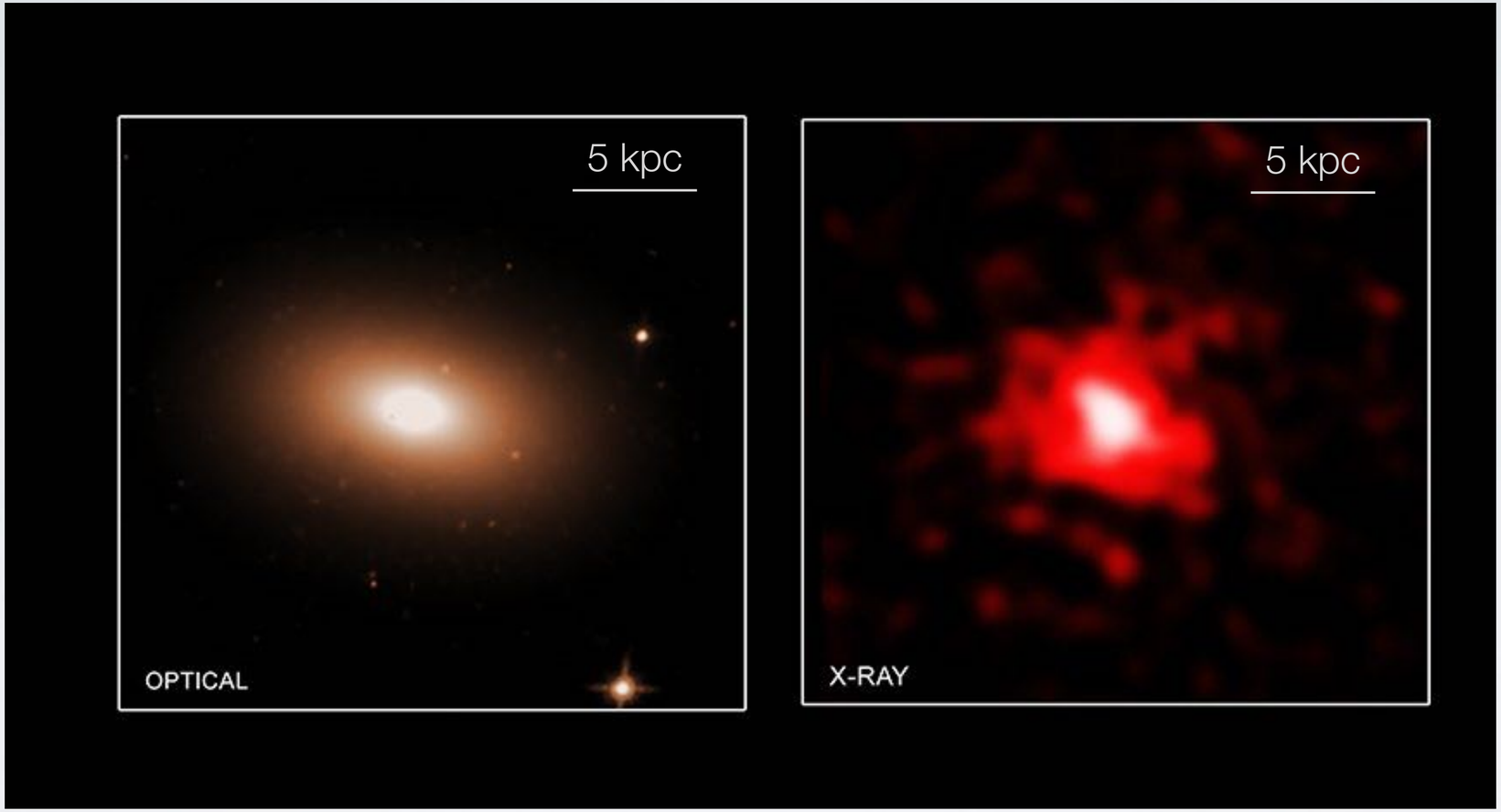
Grossova et al. 2018.

Cooling in a rotating X-ray atmosphere



Juráňová et al. 2018.

MRK 1216 A RELIC RED NUGGET



$M_{stellar} = (2.0 \pm 0.8) \times 10^{11}\ M_{\odot}$

$R_e = 2.3 \pm 0.1$ kpc

Age = 12.8±1.5 Gyr

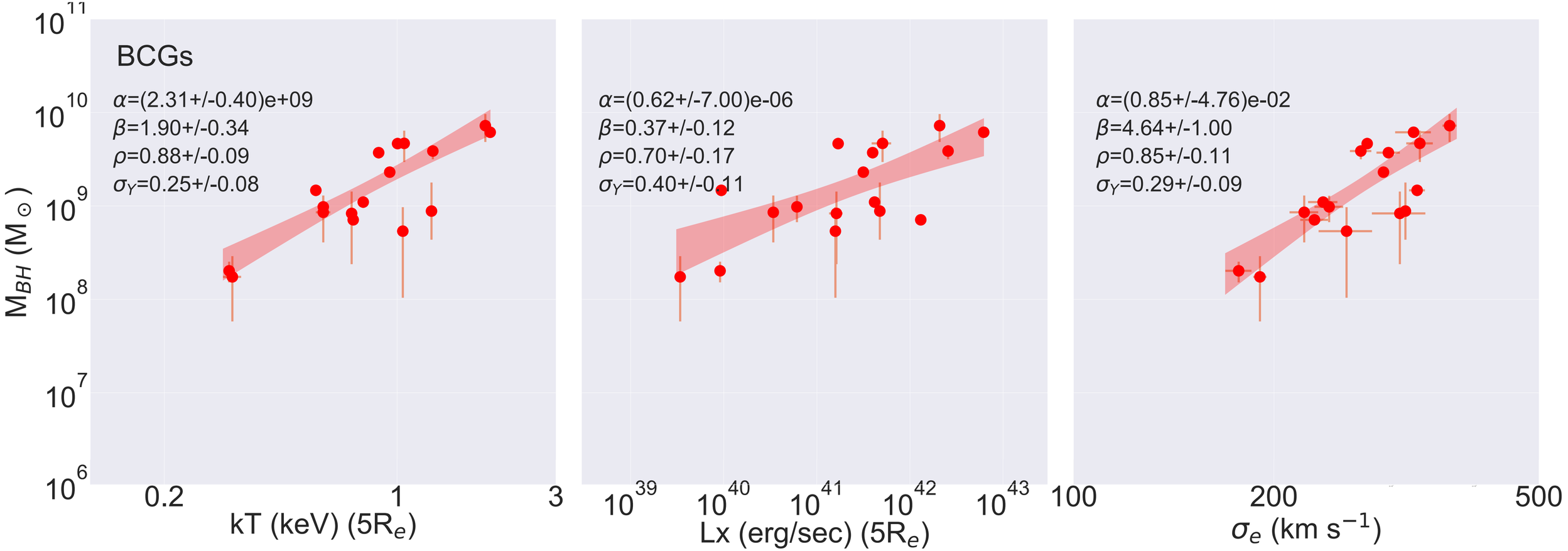
$M_{BH} = (4.9 \pm 1.7) \times 10^{9}\ M_{\odot}$

$D = 97$ Mpc (Ferre-Mateu et al. 2017)

$L_X = 6.9 \times 10^{41}$ erg s^{-1} within r<10 kpc

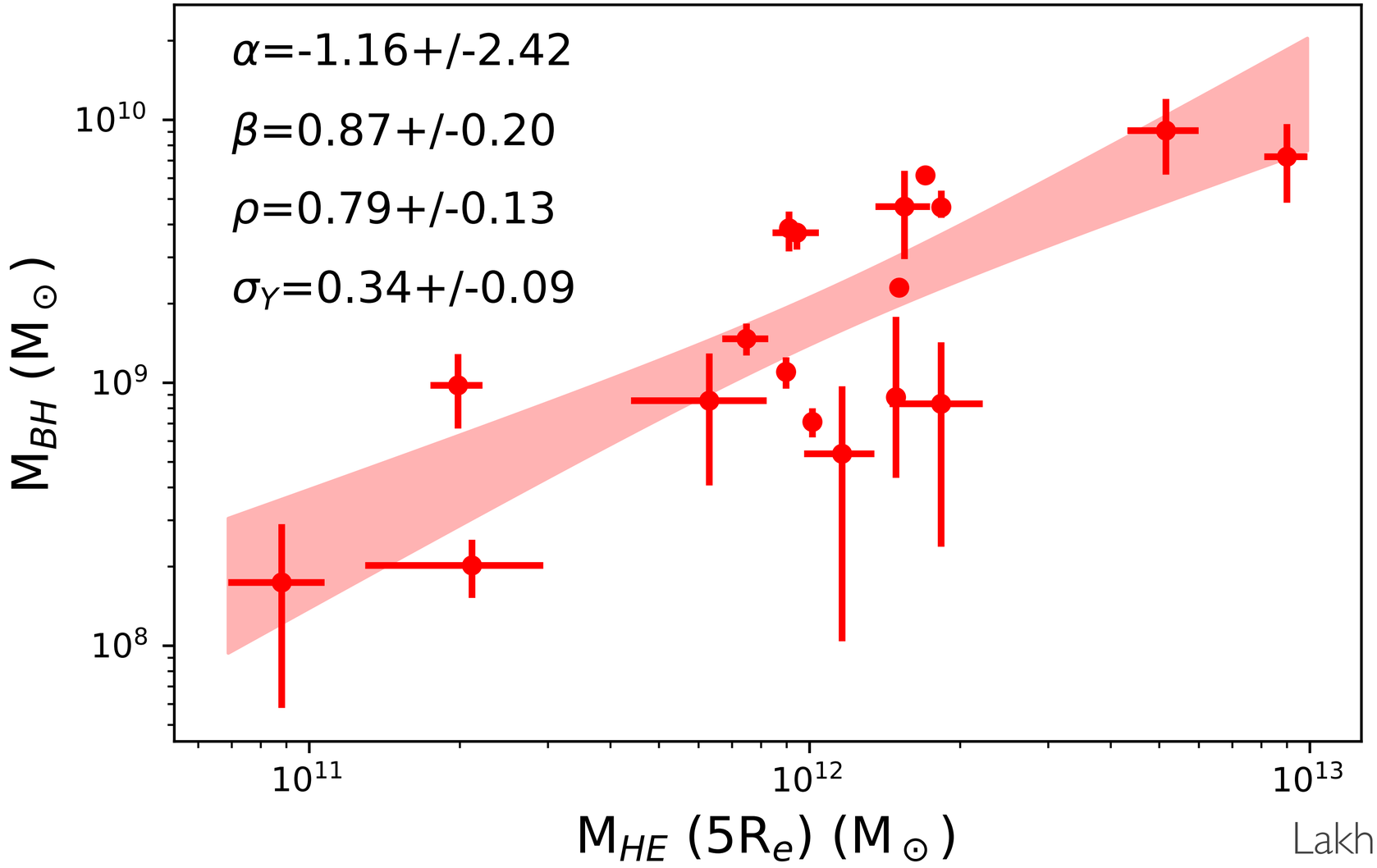
Werner et al. 2018

The Black Hole - X-Ray Atmosphere Correlation in BCGs



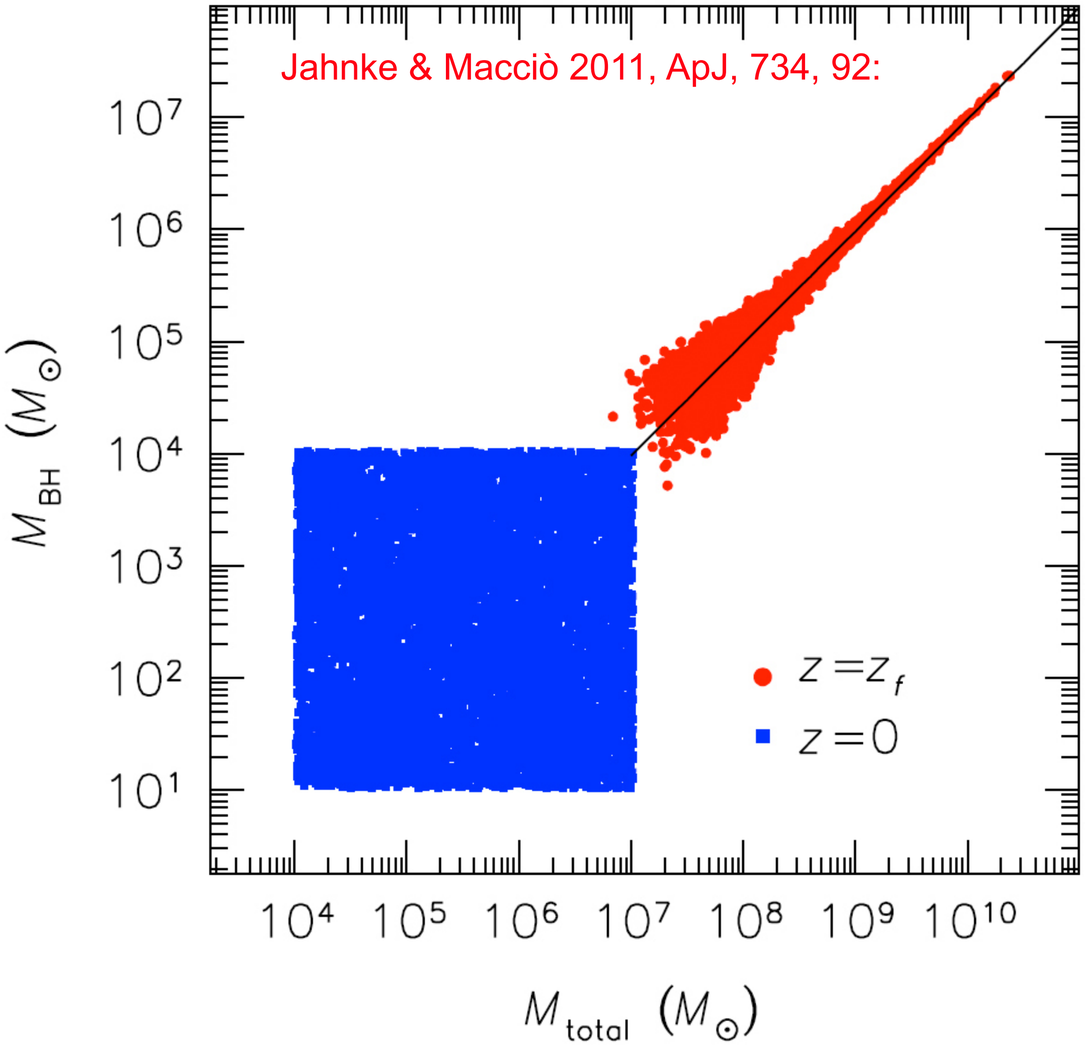
Lakhchaura, Truong, Werner 2019

The Black Hole - Dark Matter Halo Correlation

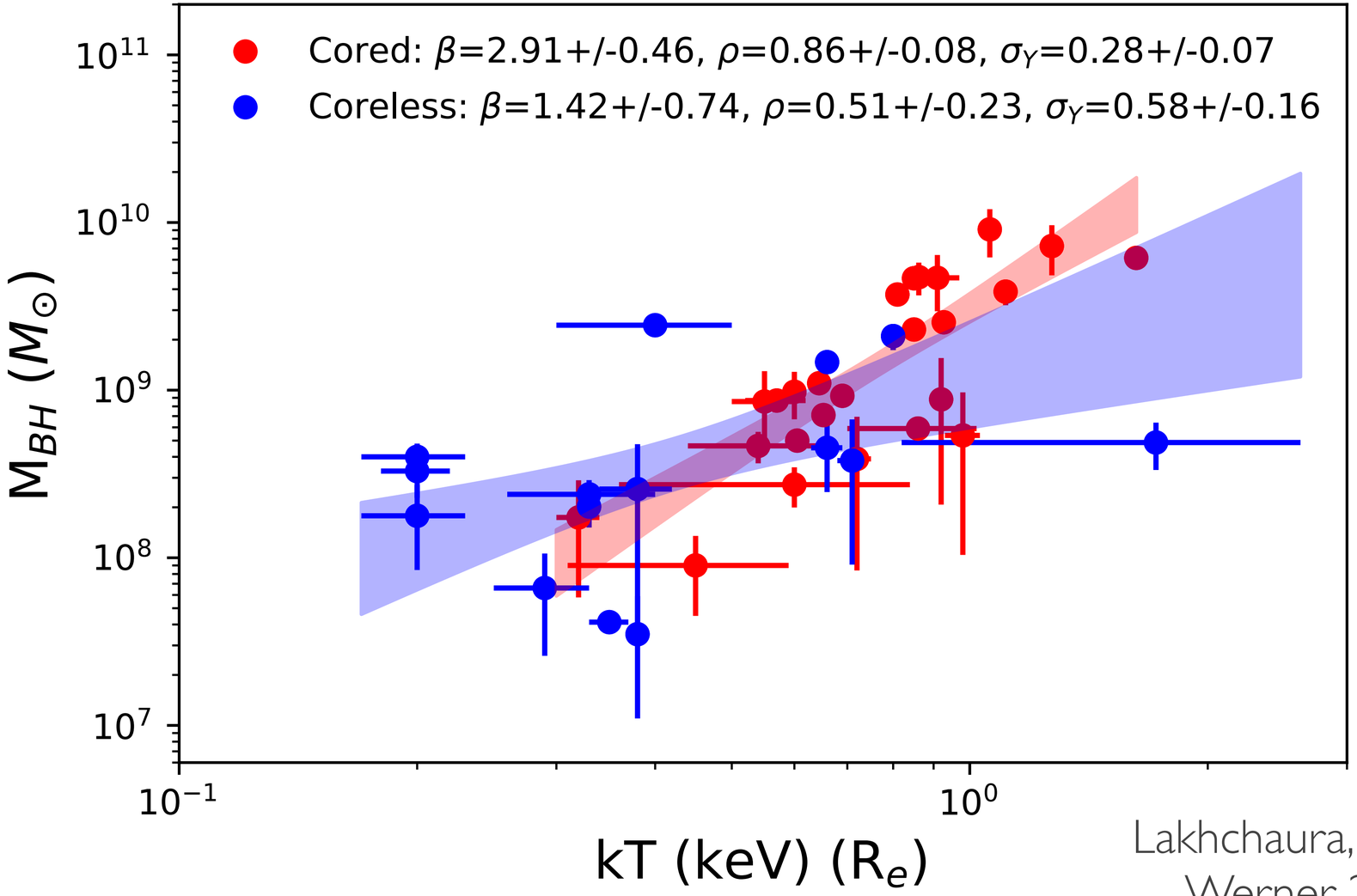


Lakhchaura, Truong, Werner 2019

Could the small scatter be the result of dry mergers and the central limit theorem?

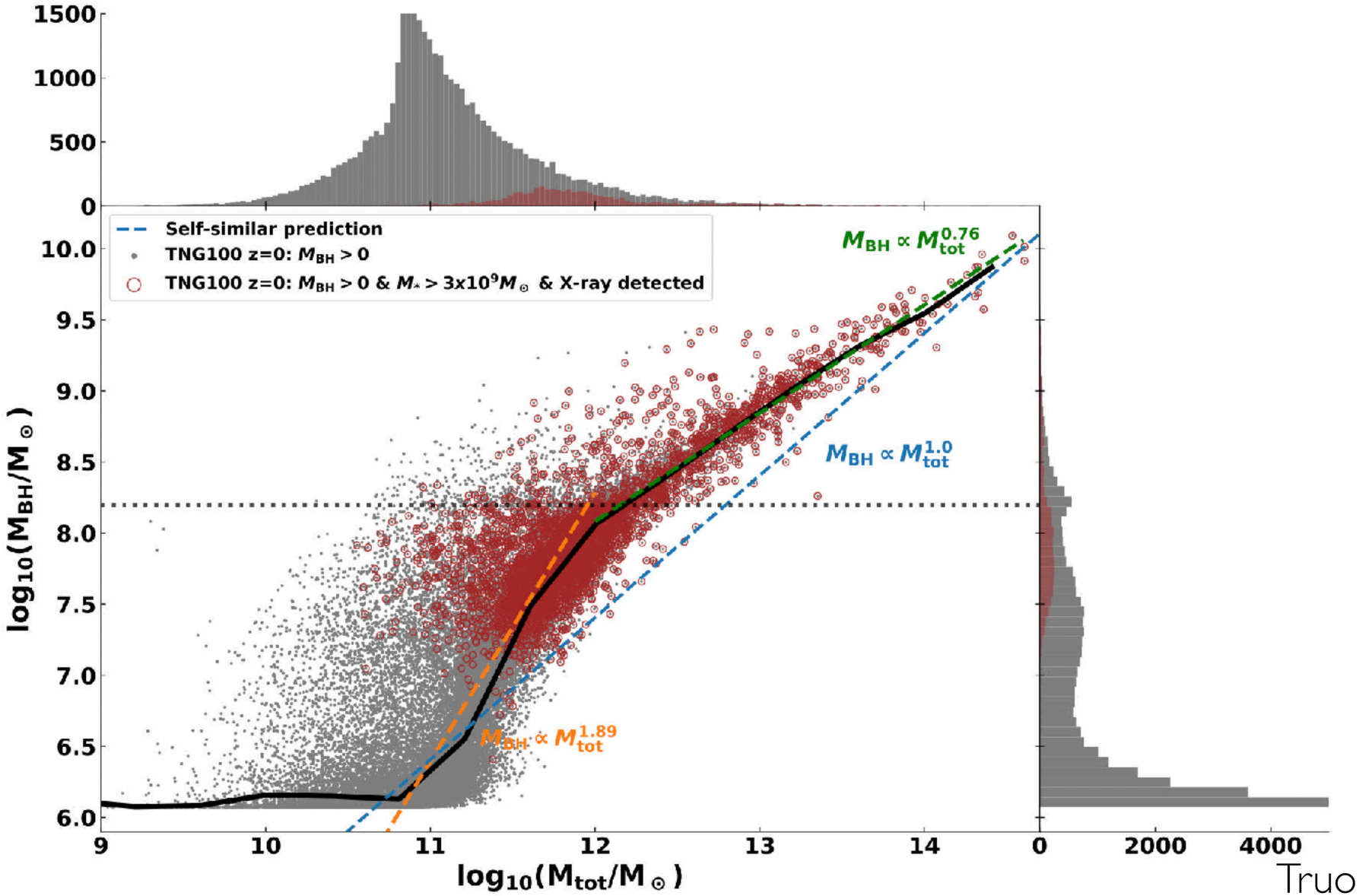


Correlation is Better for Systems that Appear to Undergo More Mergers



Lakhchaura, Truong, Werner 2019

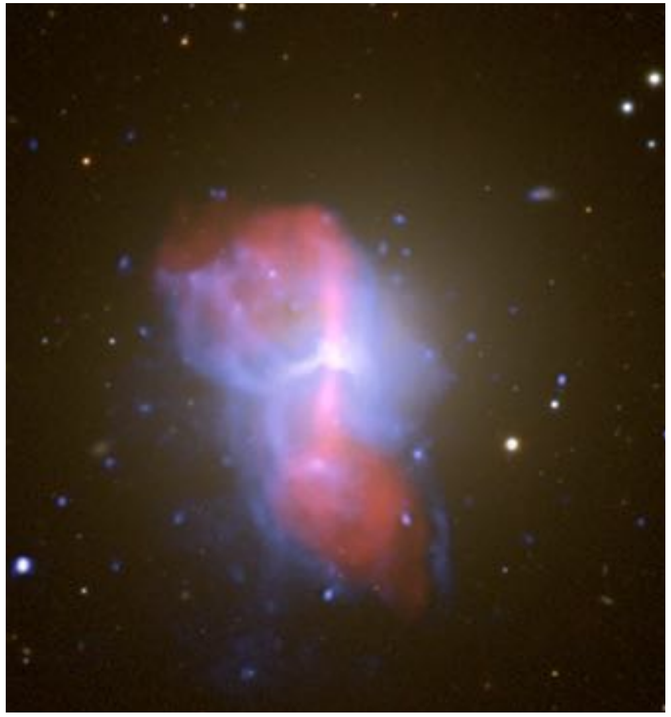
Black Hole Growth in Simulations

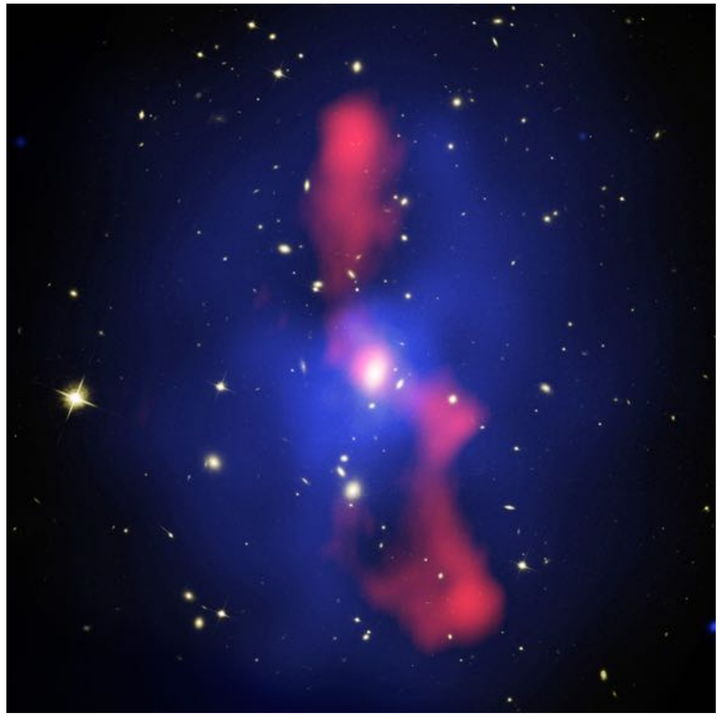


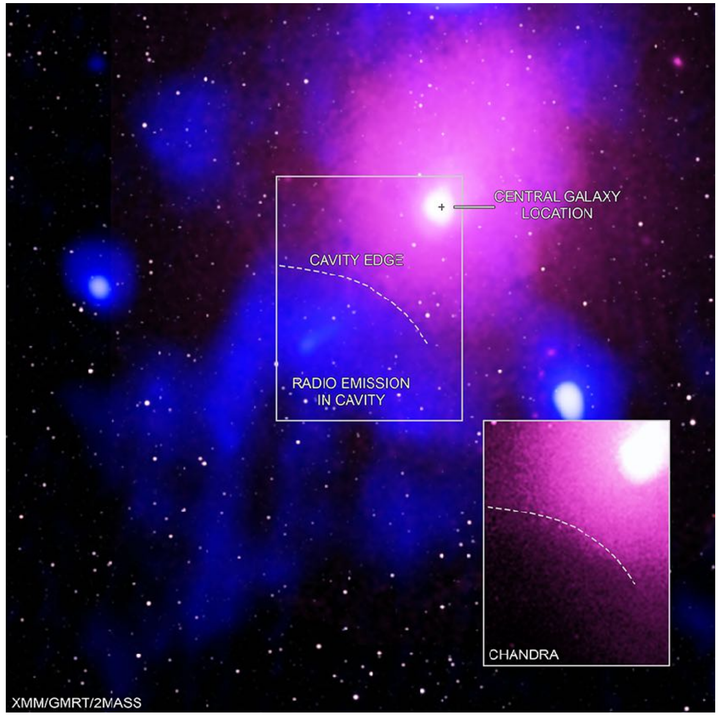
Truong, Pillepich, Werner 2021

SUMMARY

- In massive early type galaxies, radio mode AGN are mostly switched on
- Most molecular gas in giant ellipticals has likely cooled from their hot atmospheres
- The central black hole mass of massive central group/cluster galaxies correlates with the atmospheric temperature and with the total mass. *More massive systems have more massive black holes producing stronger jets*.






CENTRAL GALAXY
LOCATION
CAVITY EDGE
RADIO EMISSION
IN CAVITY
CHANDRA
XMM/GMRT/2MASS