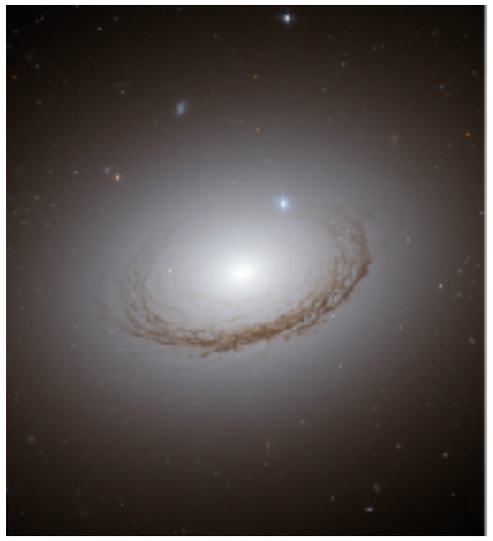
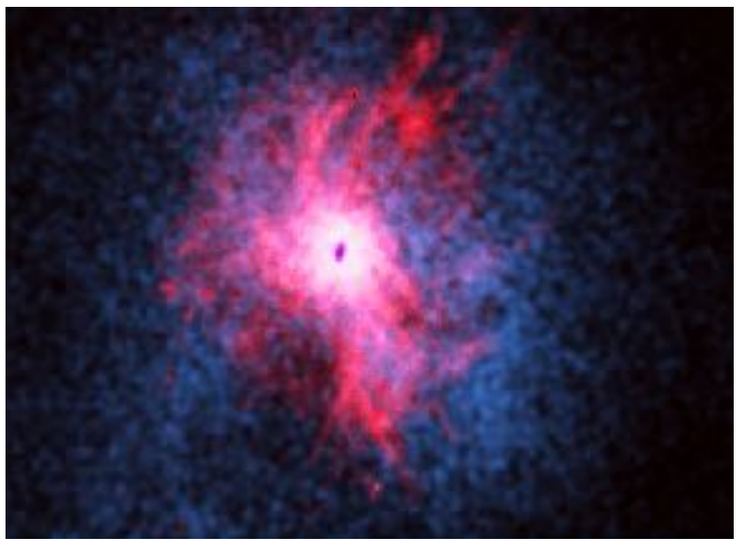
The Origin of Cold Gas in Giant Ellipticals and Its Role in Fueling Radio-mode AGN Feedback

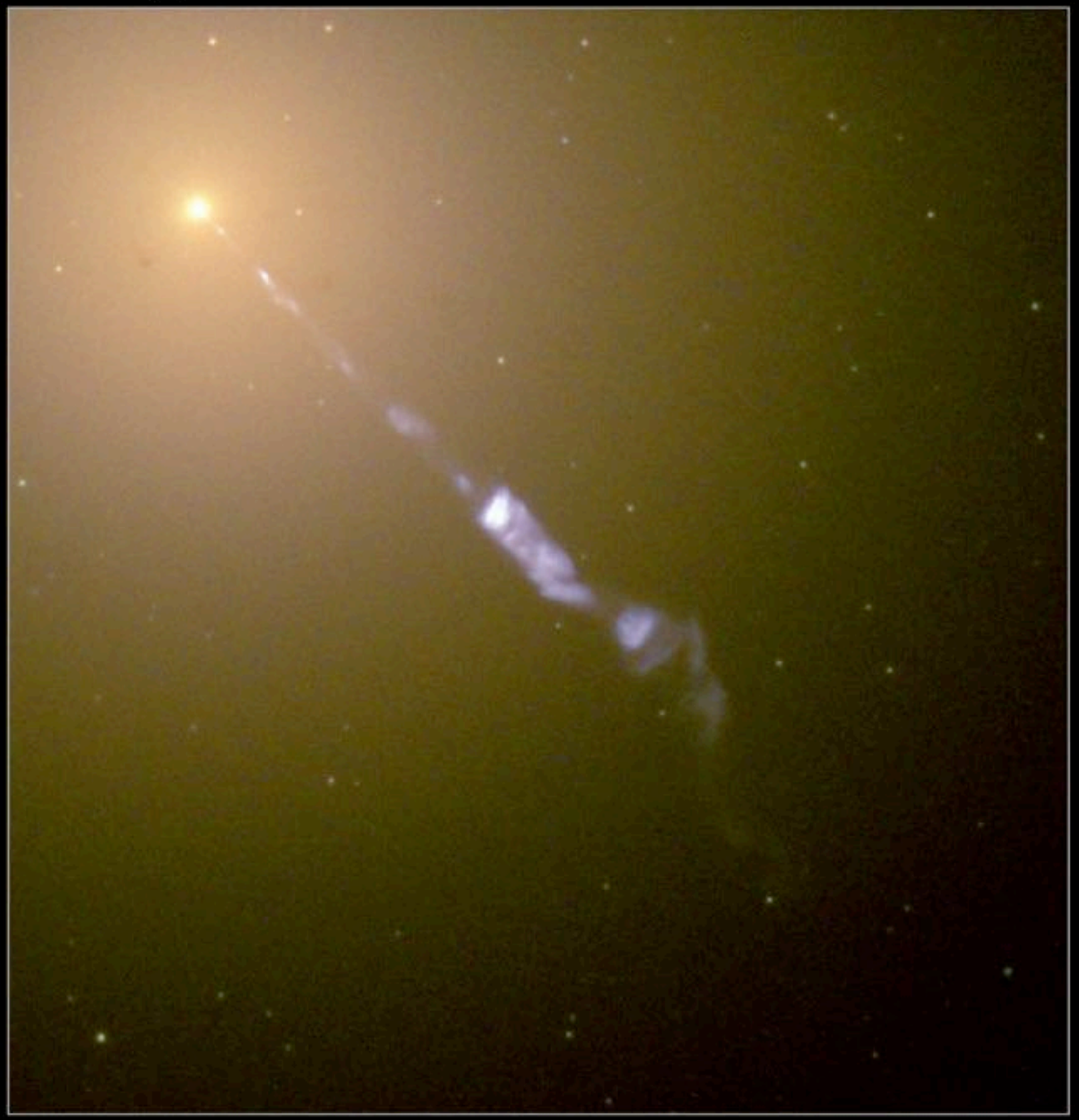





Norbert Werner

Eötvös University, Budapest

RED AND DEAD GIANT ELLIPTICAL GALAXIES

The M87 Jet



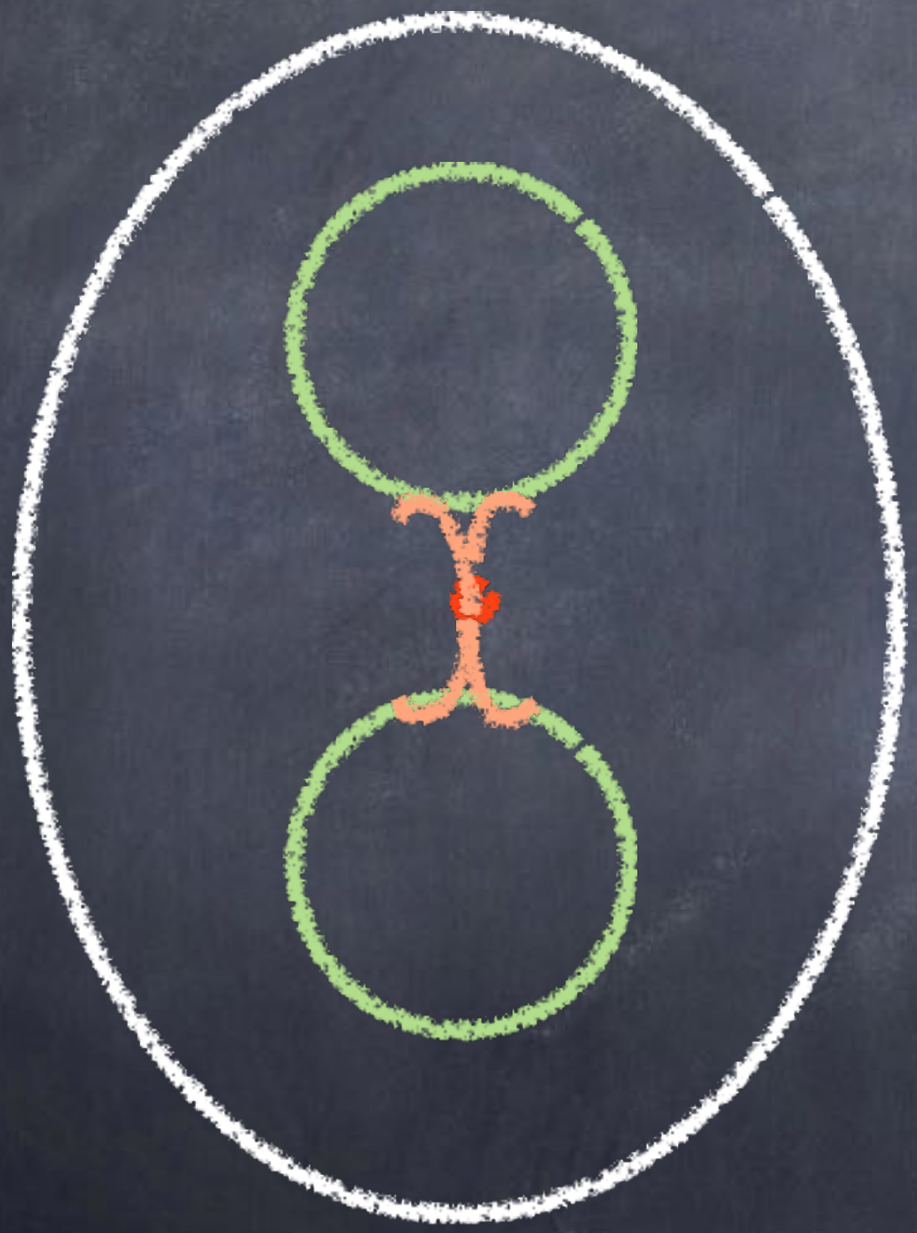
NASA, ESA, Hubble Heritage (STScI/AURA)

Hubble Heritage

NASA/CXC/A.Hobart

NASA/CXC/A.Hobart

AGN feedback

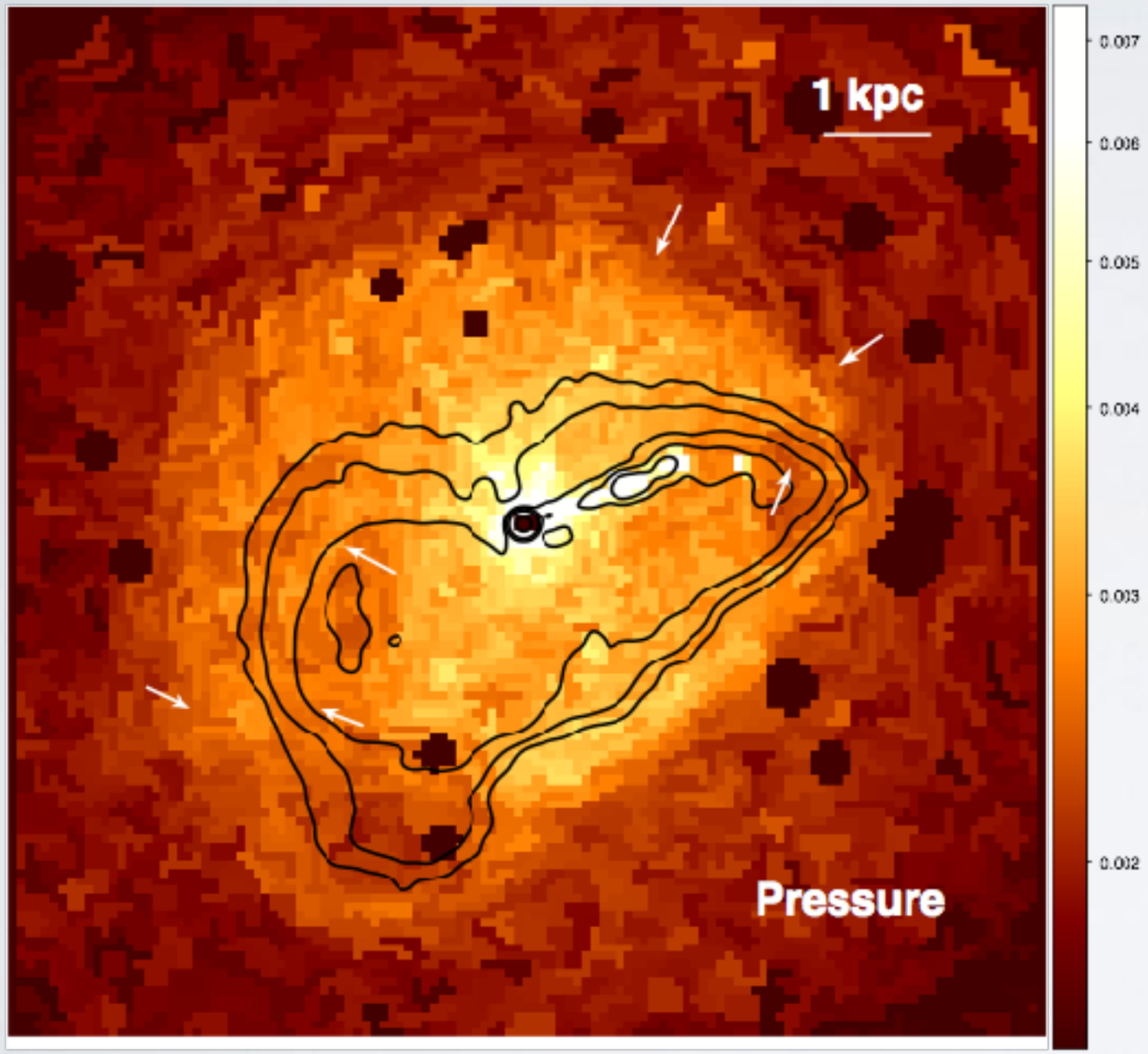


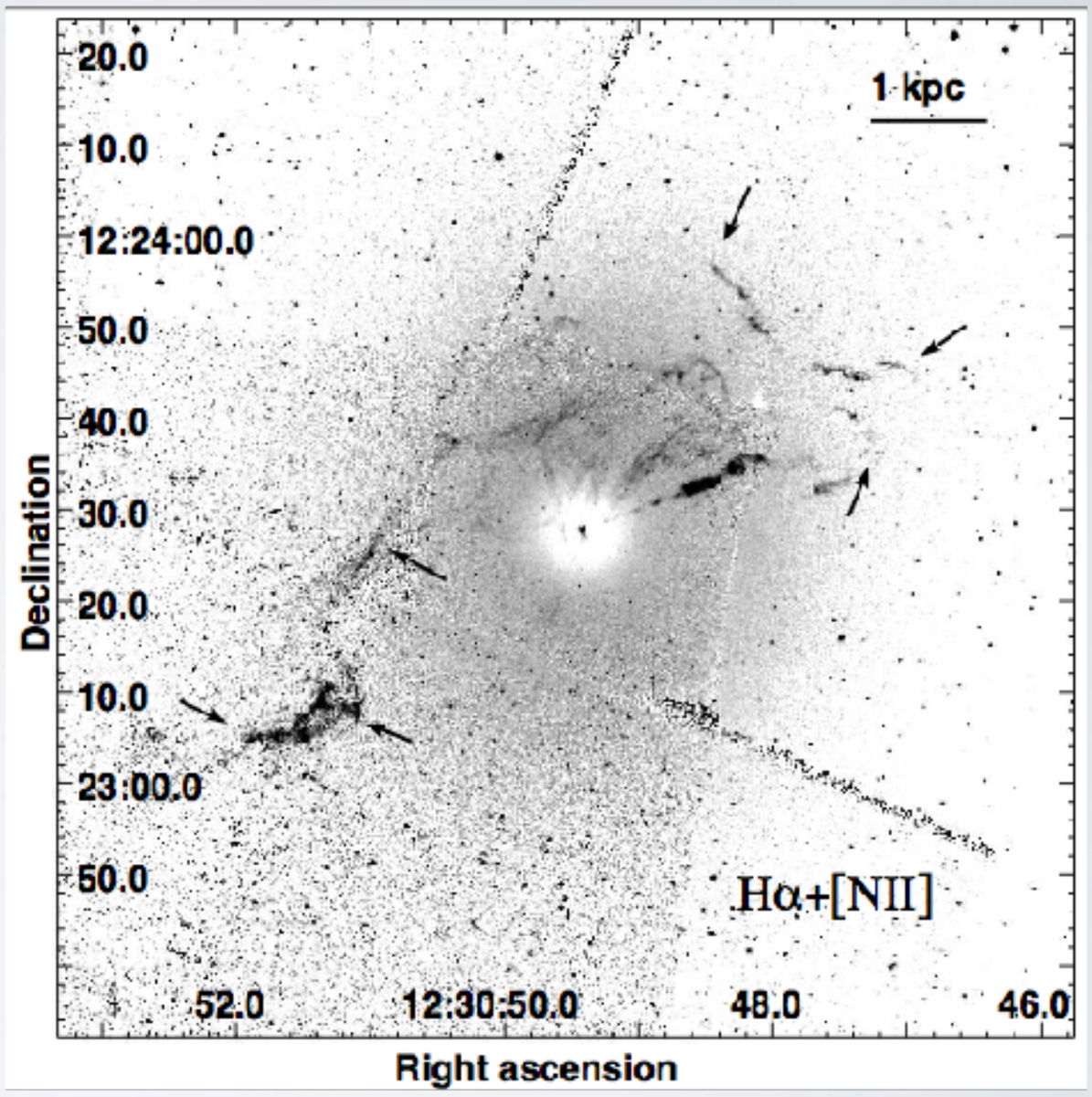
shocks: high temperature; high pressure

cavities: radio bright; X-ray faint

filaments: X-ray bright; low temperature; metal rich

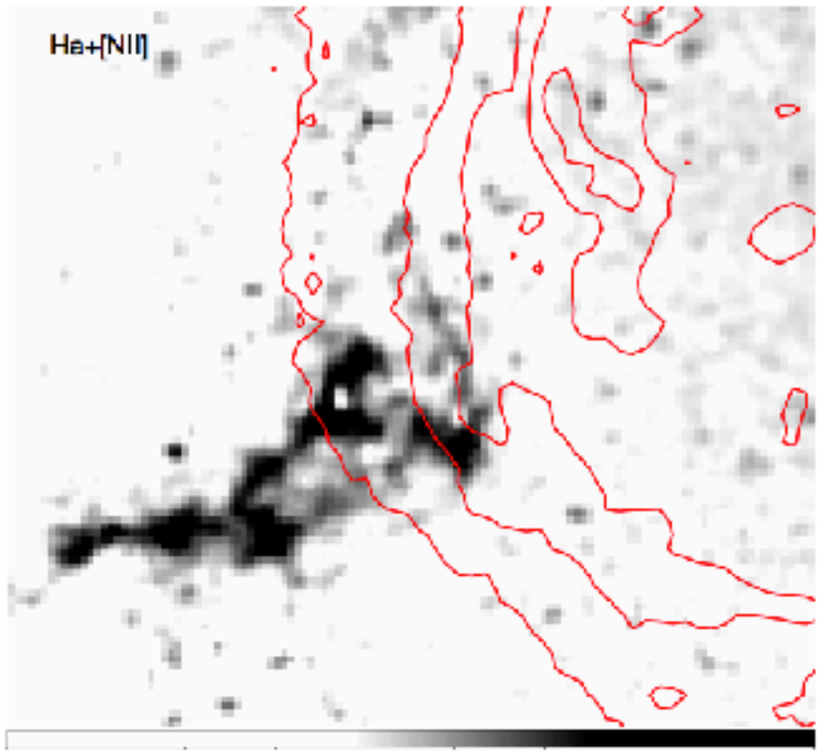
Cold gas in M87



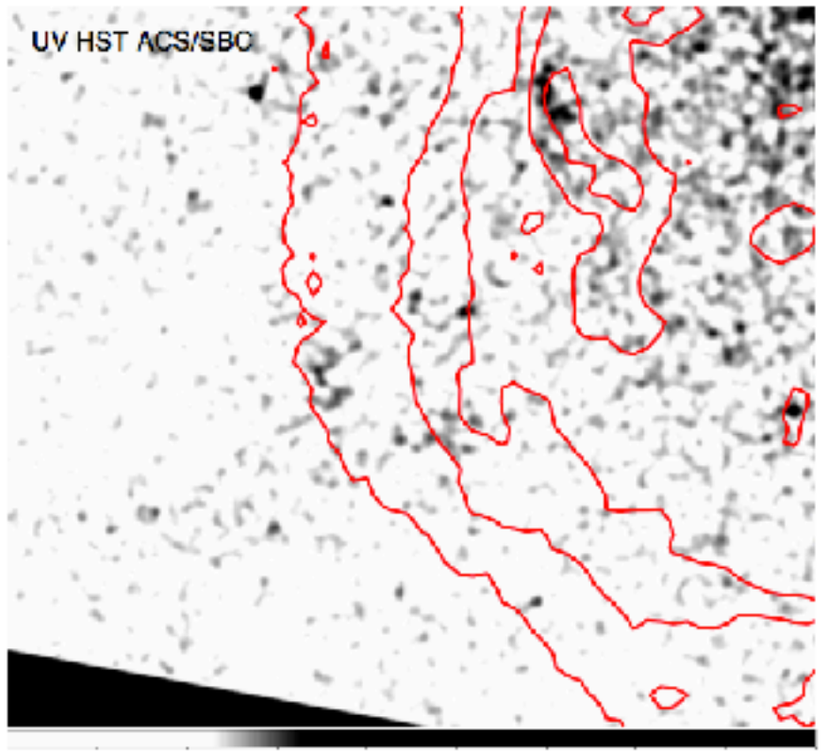


Werner et al. 2010

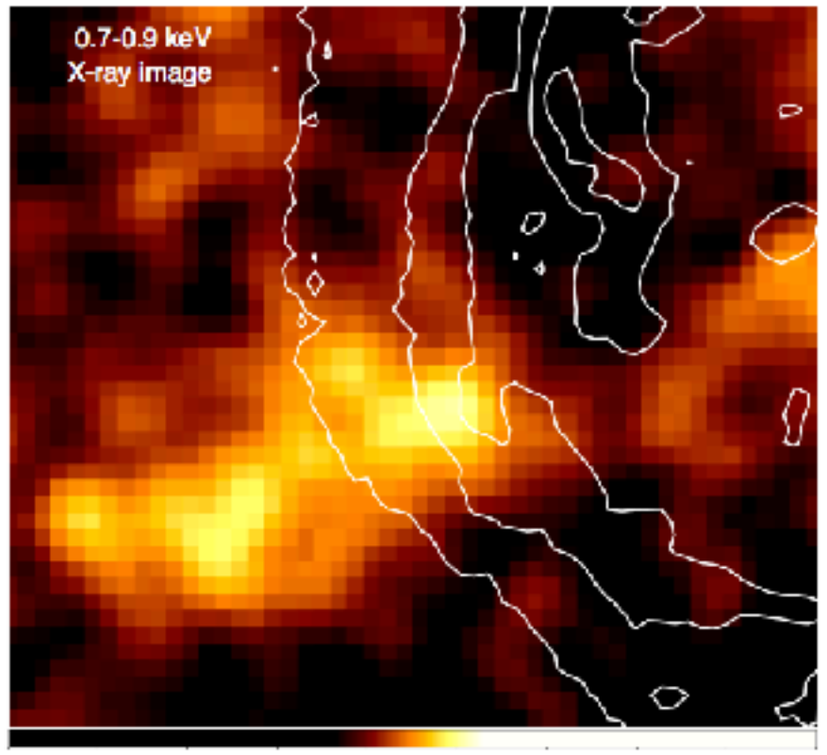
- Filaments contain multi-phase gas spanning a large temperature range
- Consist of many narrow (narrower than 32 pc) strands with very small volume filling factors
- No starformation
- The thermal pressure of the 10^4 K phase is lower than that of the surrounding ICM, indicating the presence of additional turbulent and magnetic (B ~ 30 – 70 μG) pressure. They also contain dust.



Hα emitting 10^4 K gas

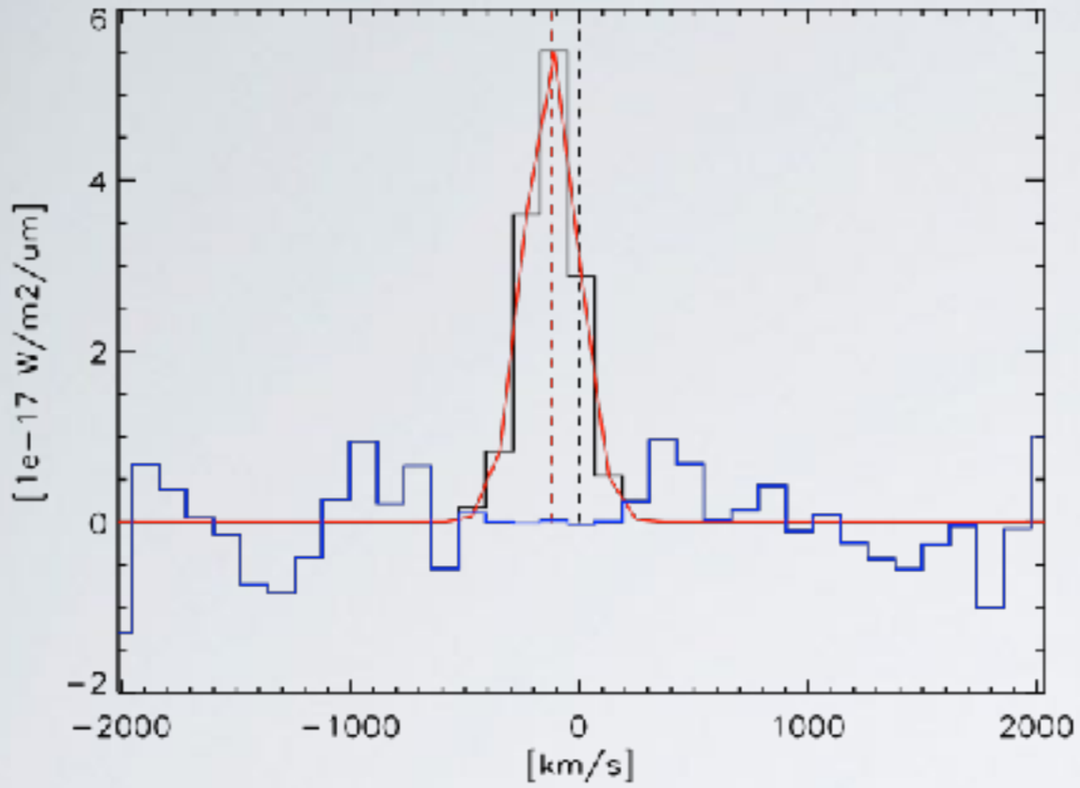


CIV emitting 10^5 K gas

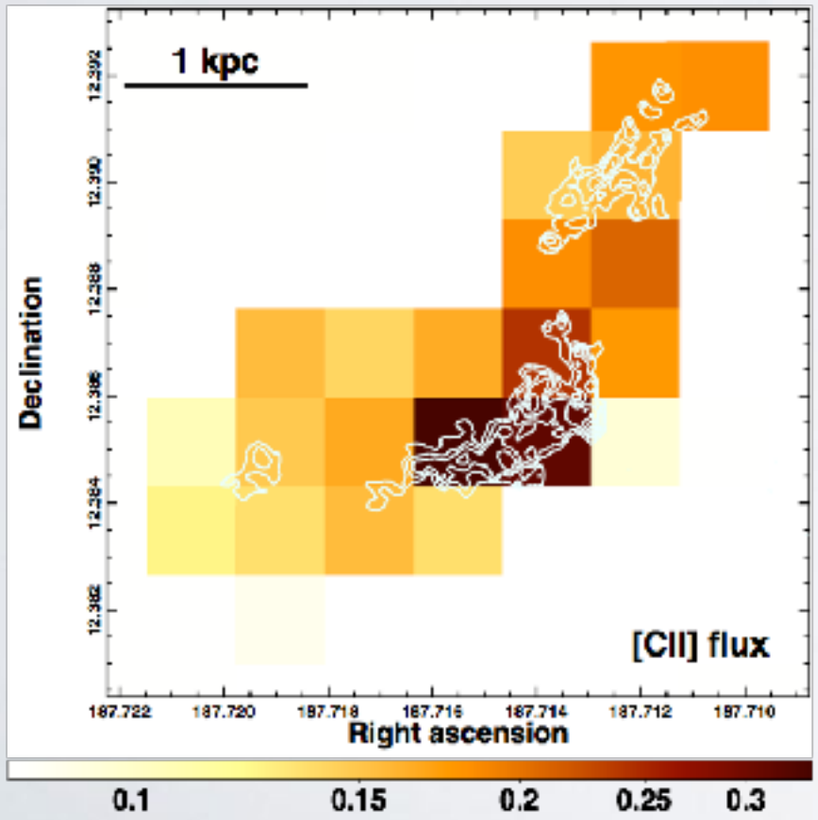


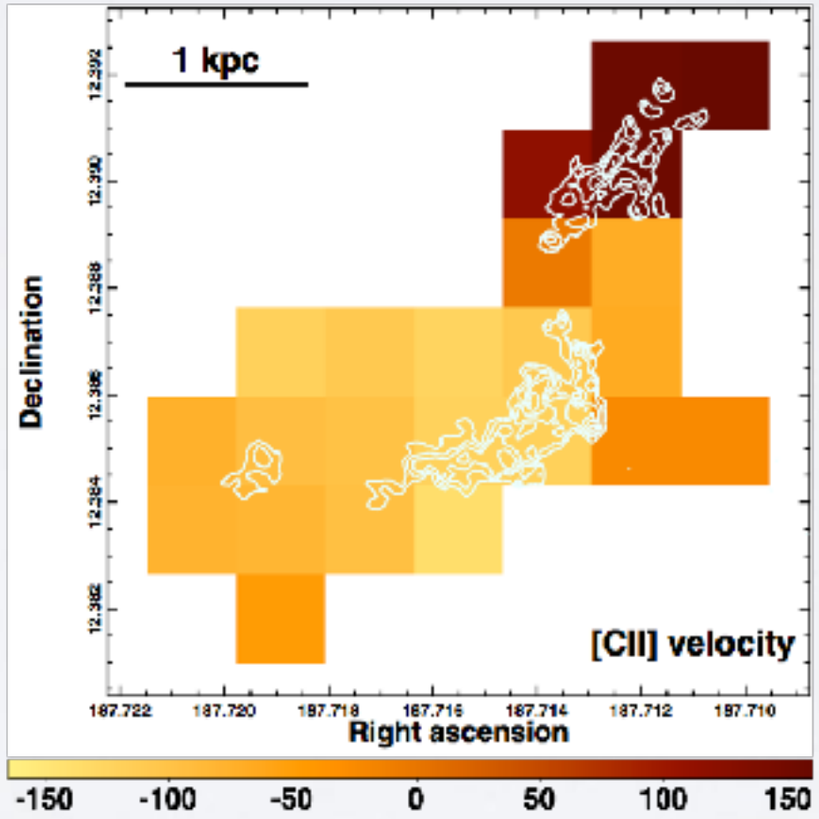
X-ray emitting
0.6-2x10^7 K gas

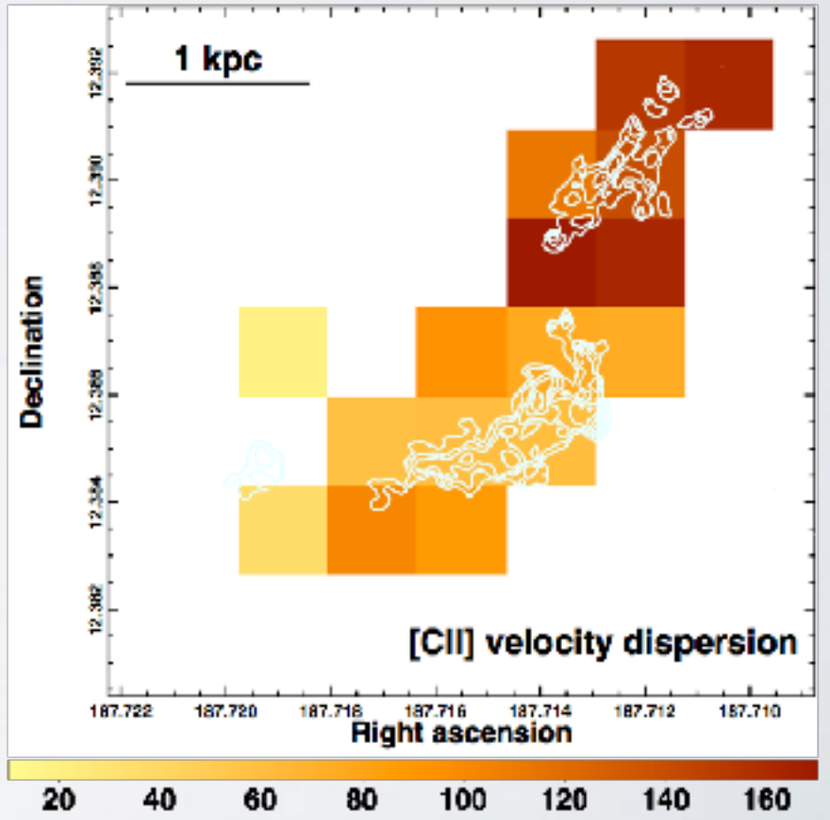
Werner et al. 2013



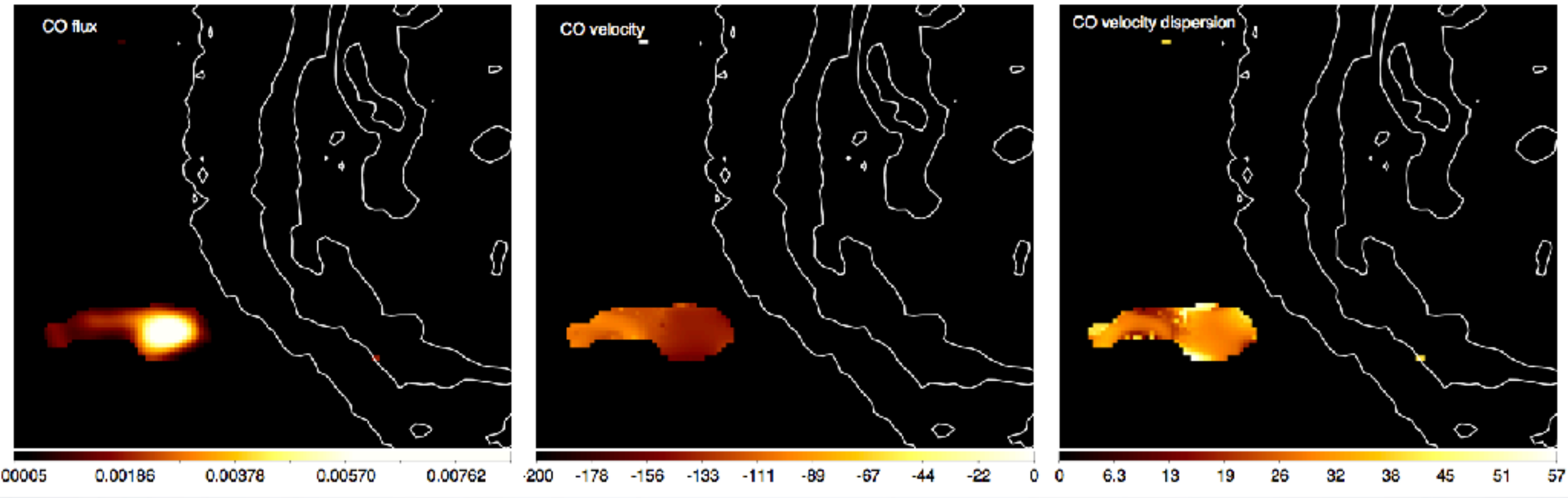
- we observed the cooling lines of [CII], [OI] with ***Herschel***
- [CII] an excellent tracer of 100 K gas, its flux is usually a few thousand times stronger than CO





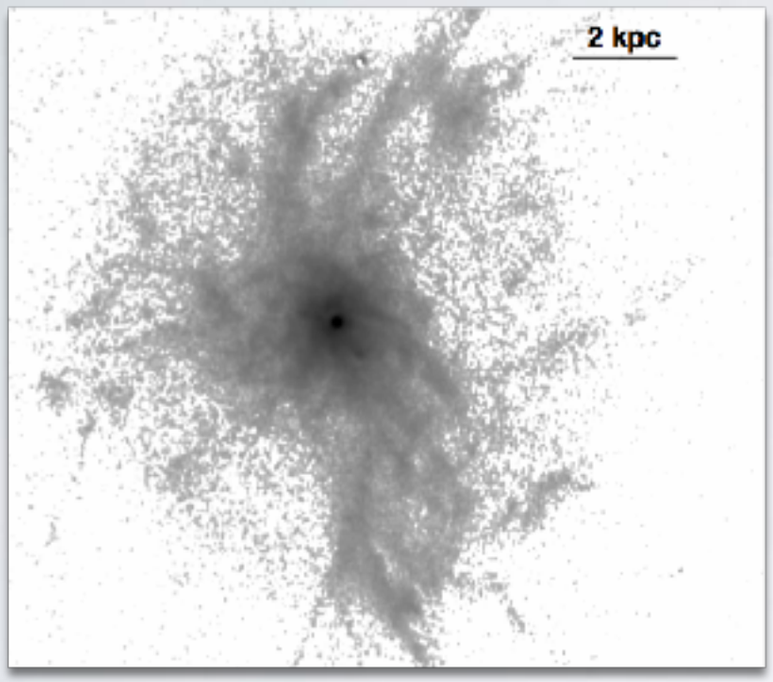


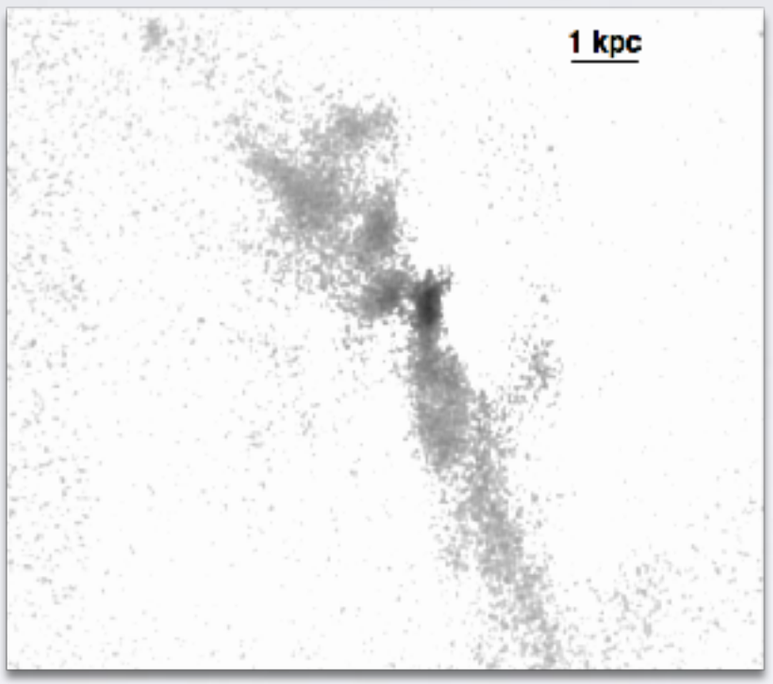
Werner et al. 2013

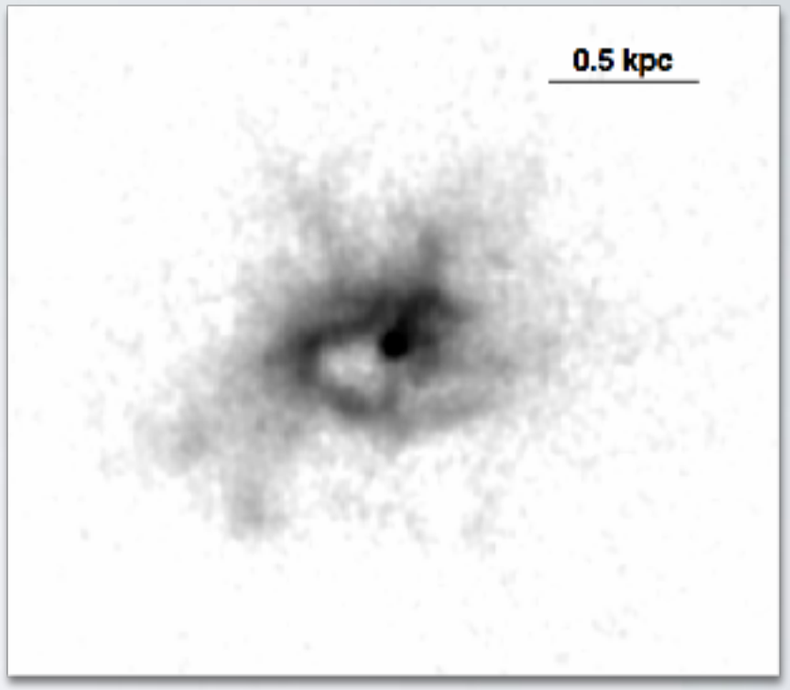


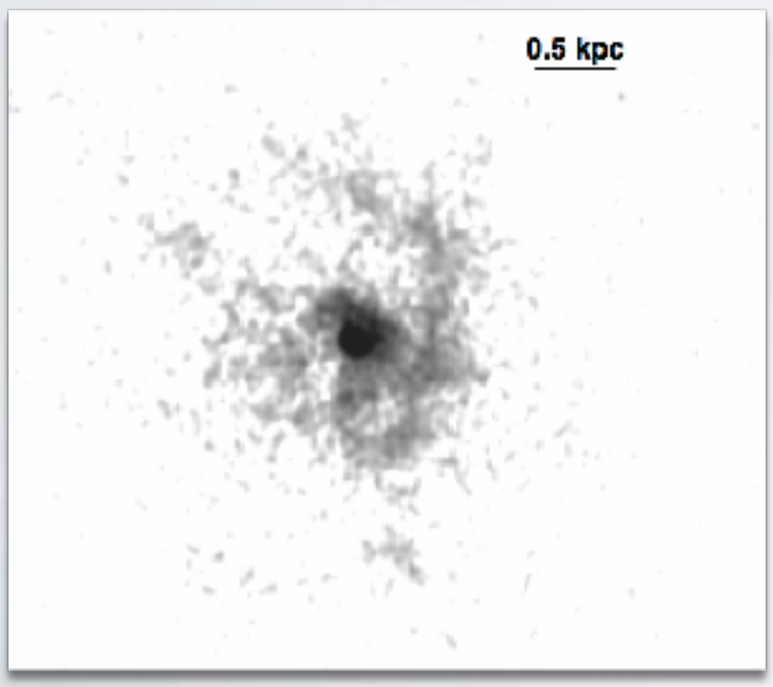
Simionescu et al. in prep.

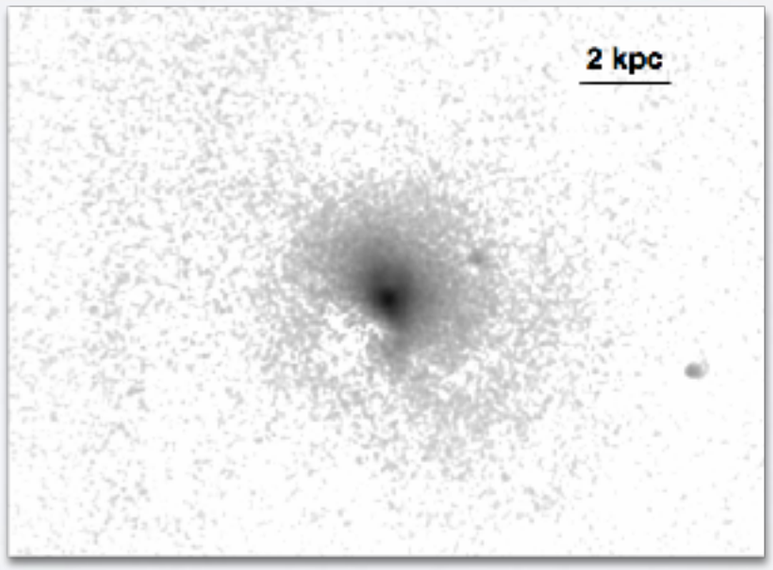
Hα+[NII] IMAGING WITH THE SOAR TELESCOPE

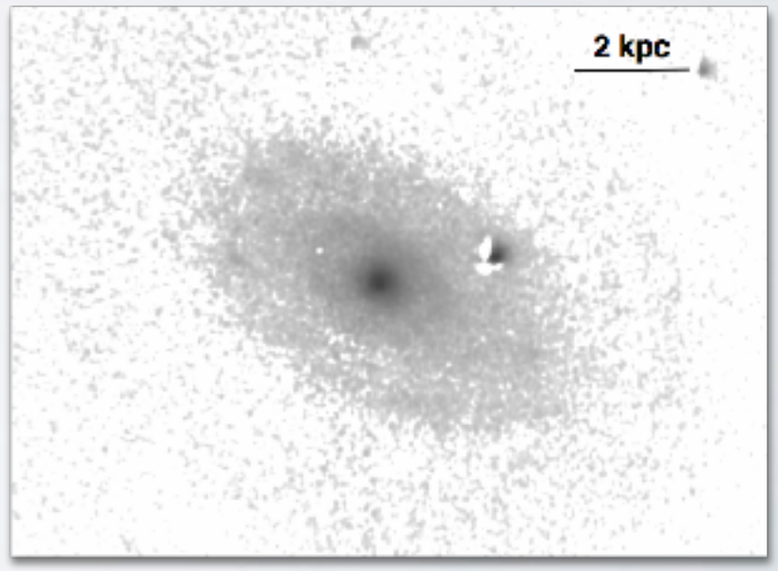






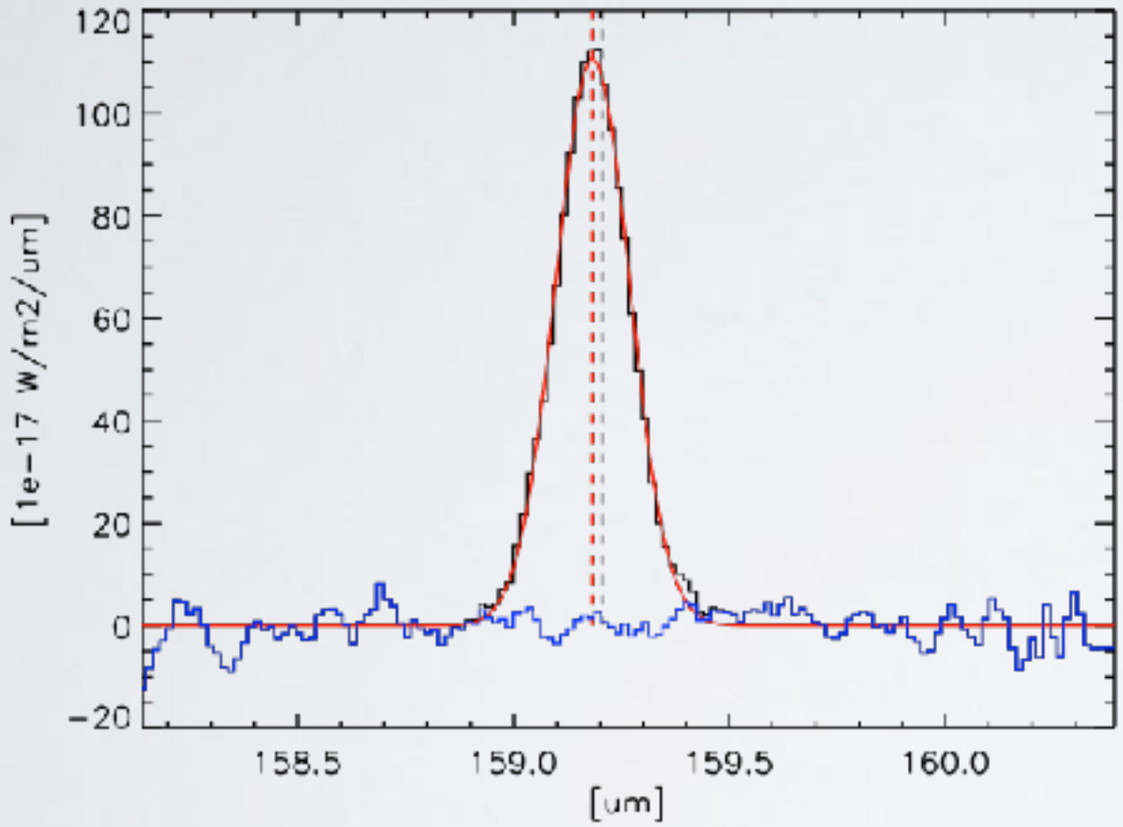






Werner et al. 2014

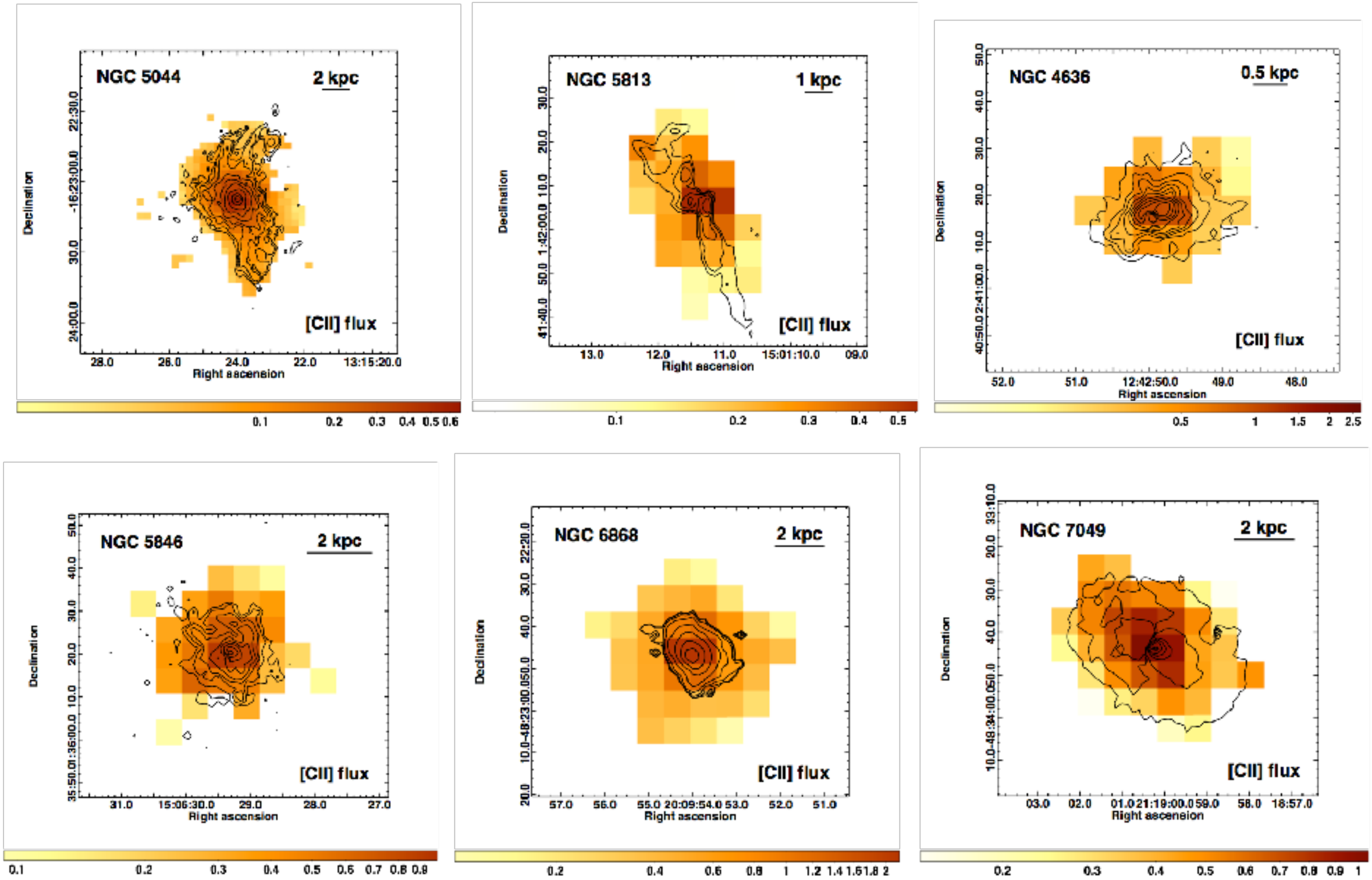
FAR-INFRARED LINE DETECTIONS IN GIANT ELLIPTICALS



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

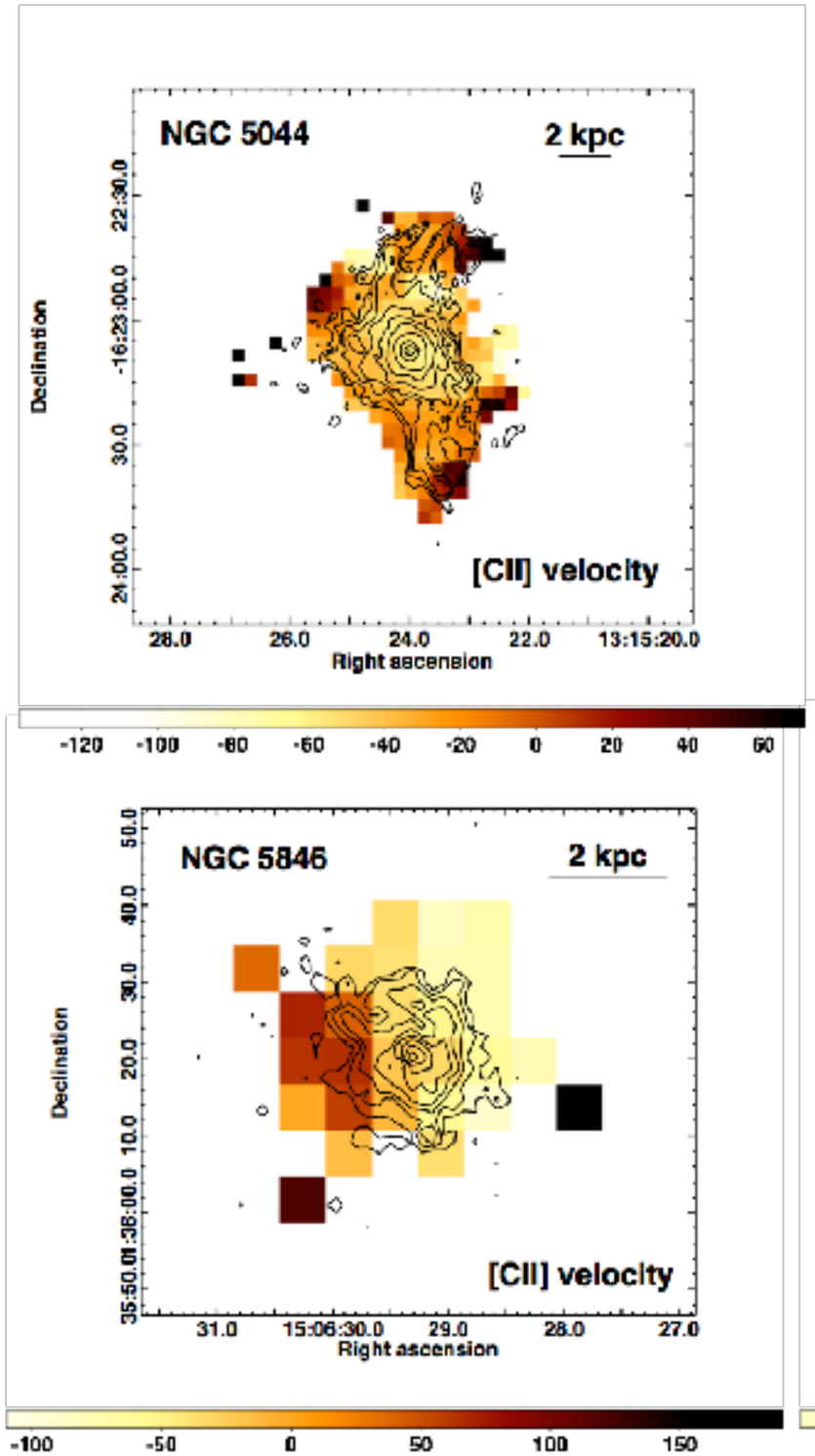
Werner et al. 2014

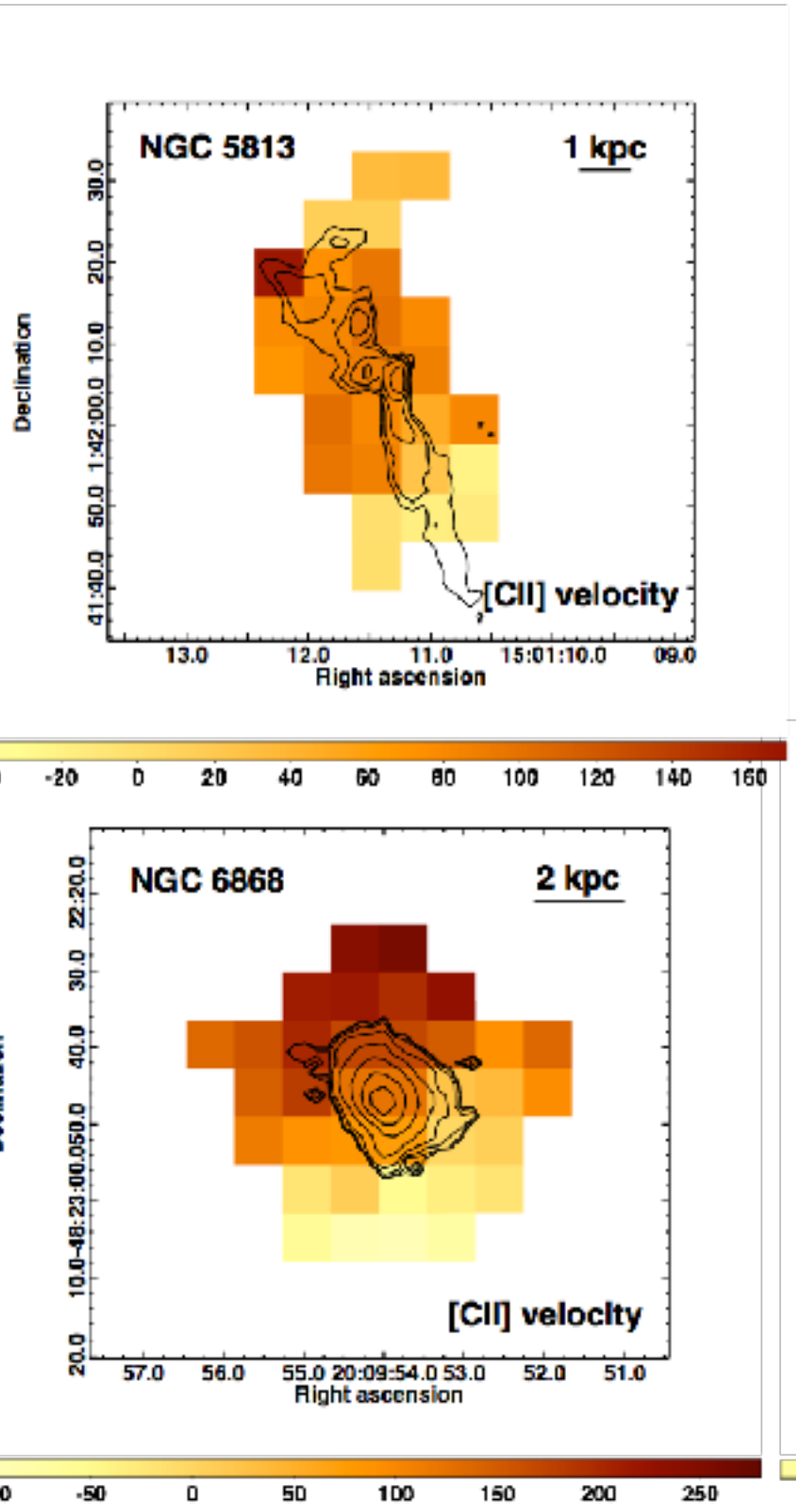
[CII] EMISSION FOLLOWING Hα

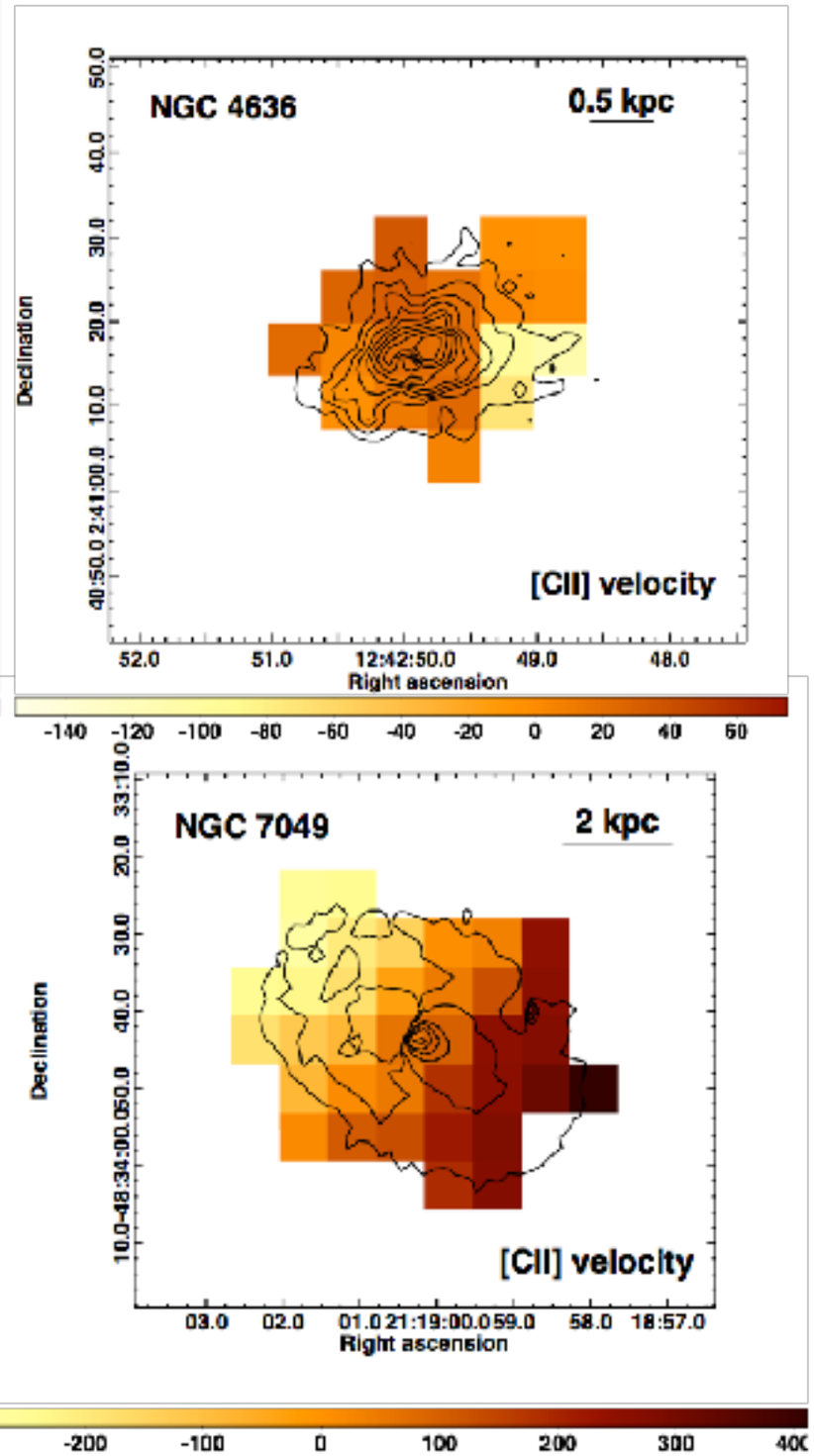


Werner et al. 2014

VELOCITIES OF THE COLD ISM

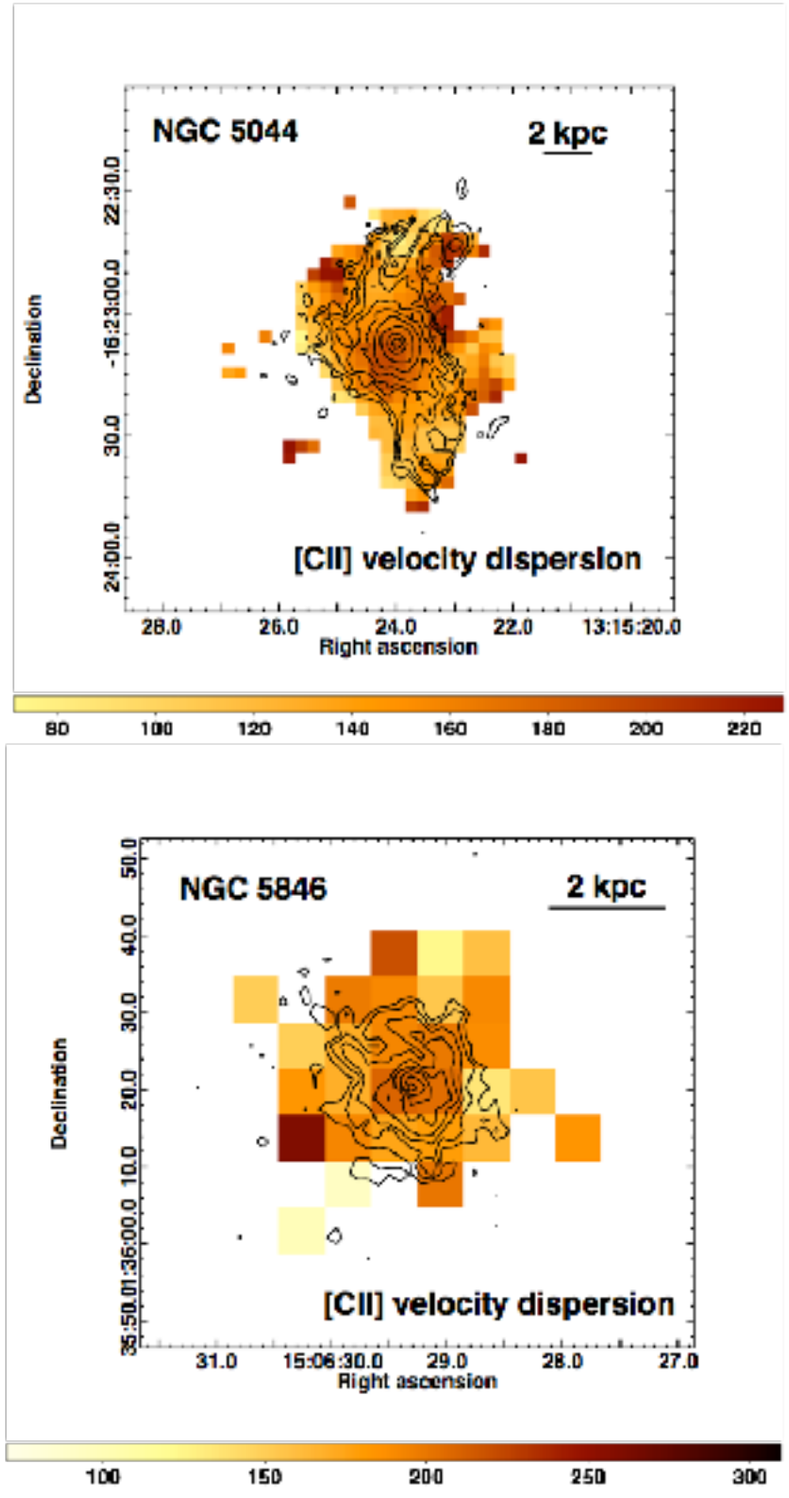


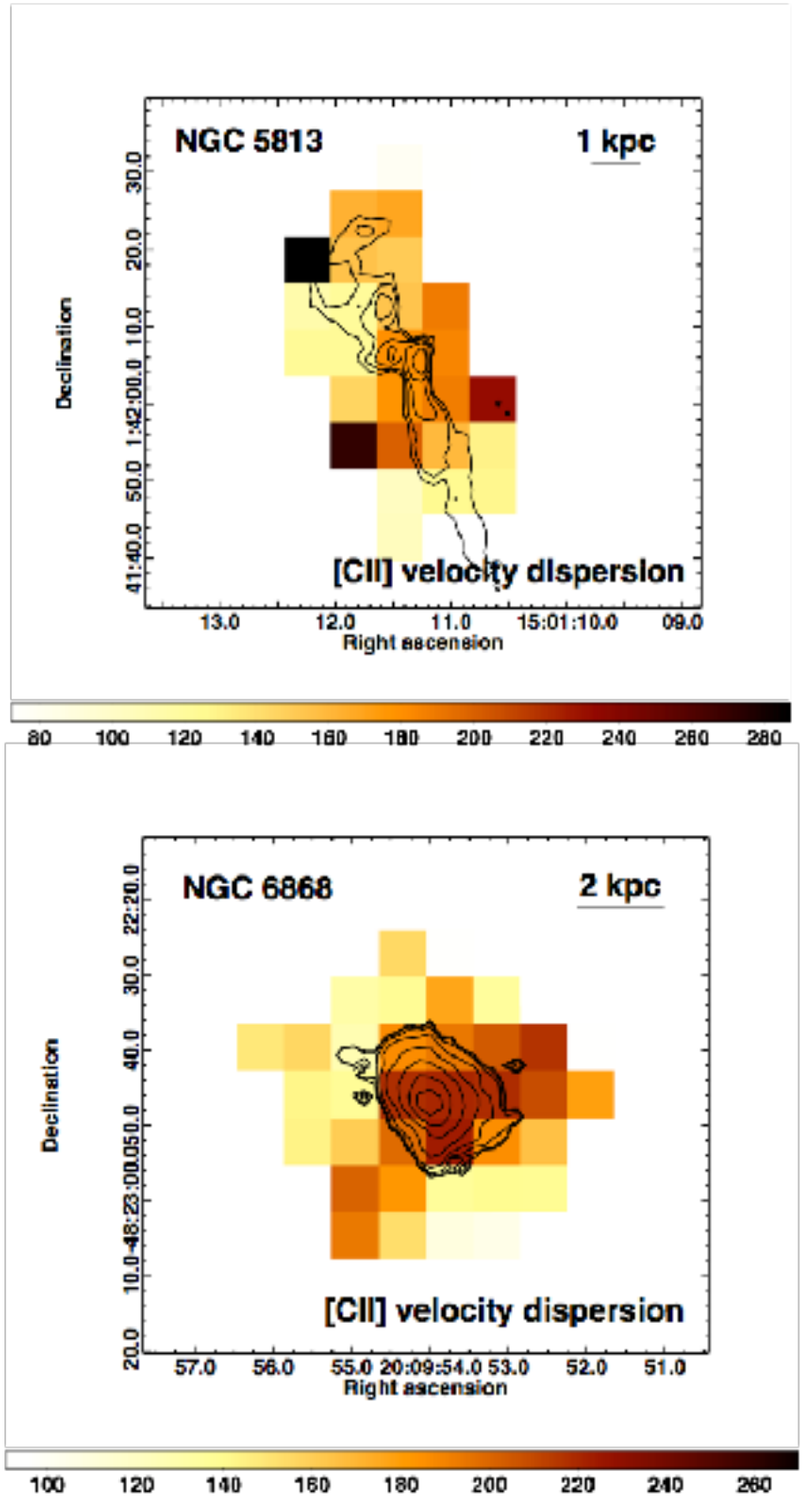


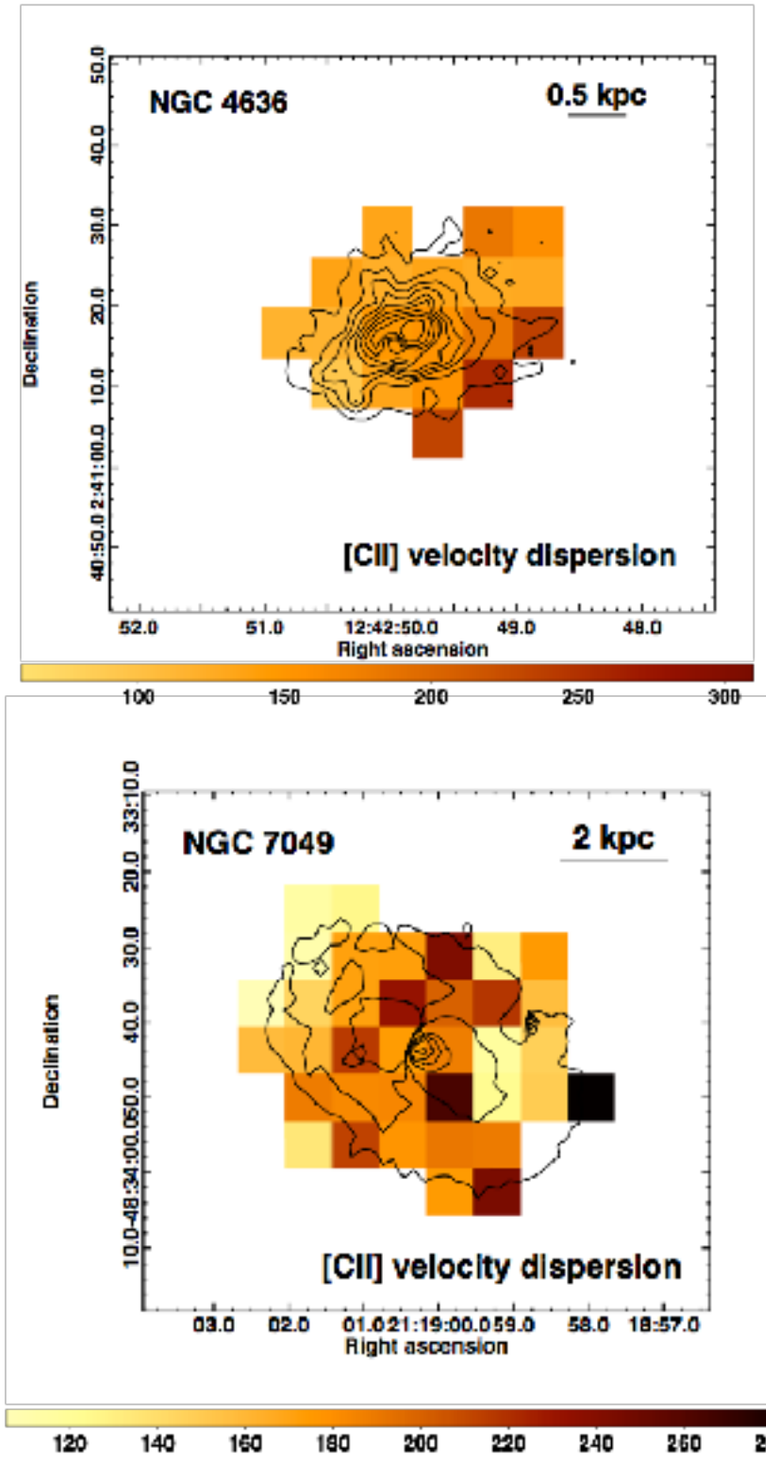


Werner et al. 2014

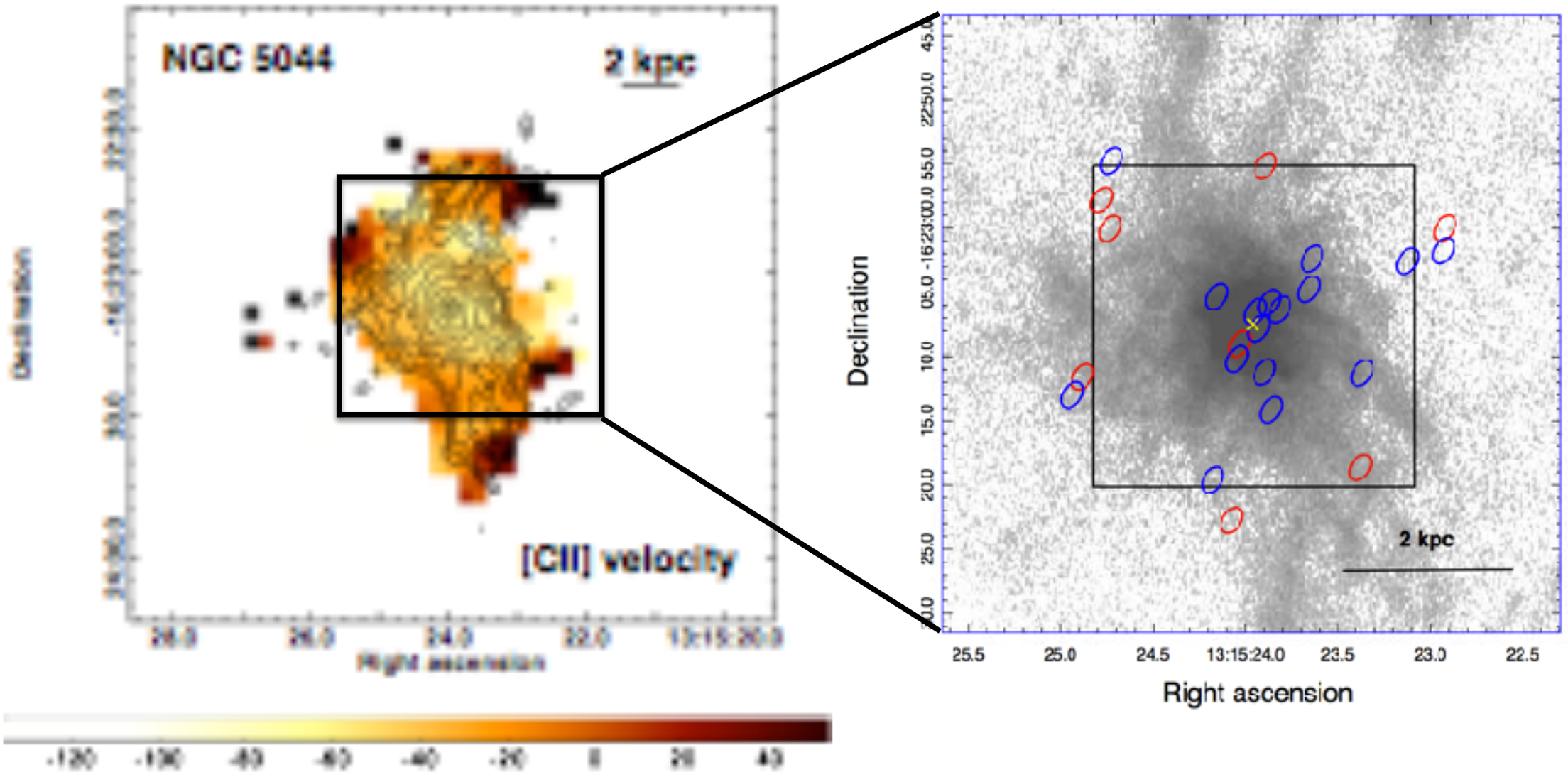
VELOCITY DISPERSIONS IN THE COLD ISM





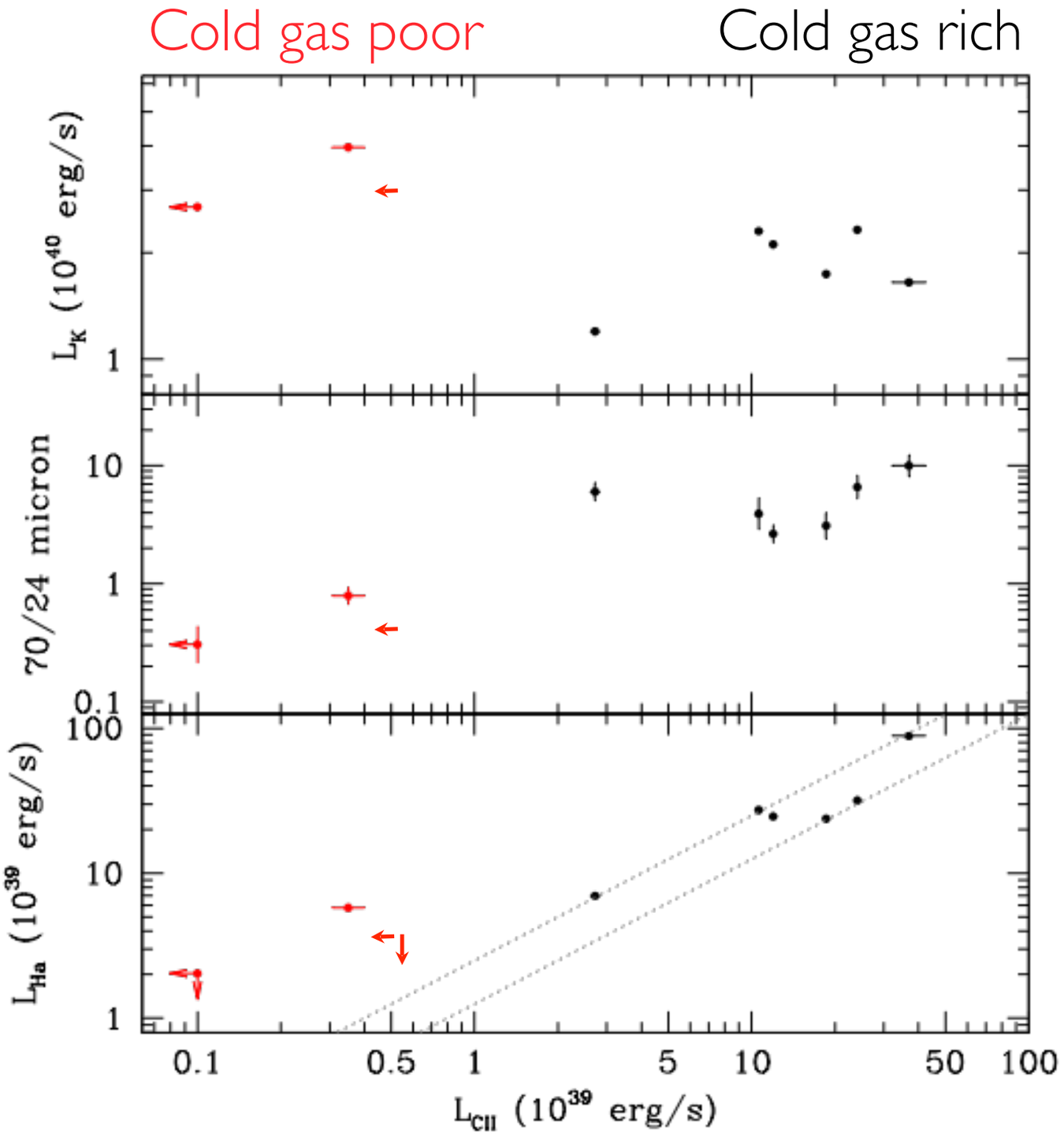


Werner et al. 2014



David et al. 2014

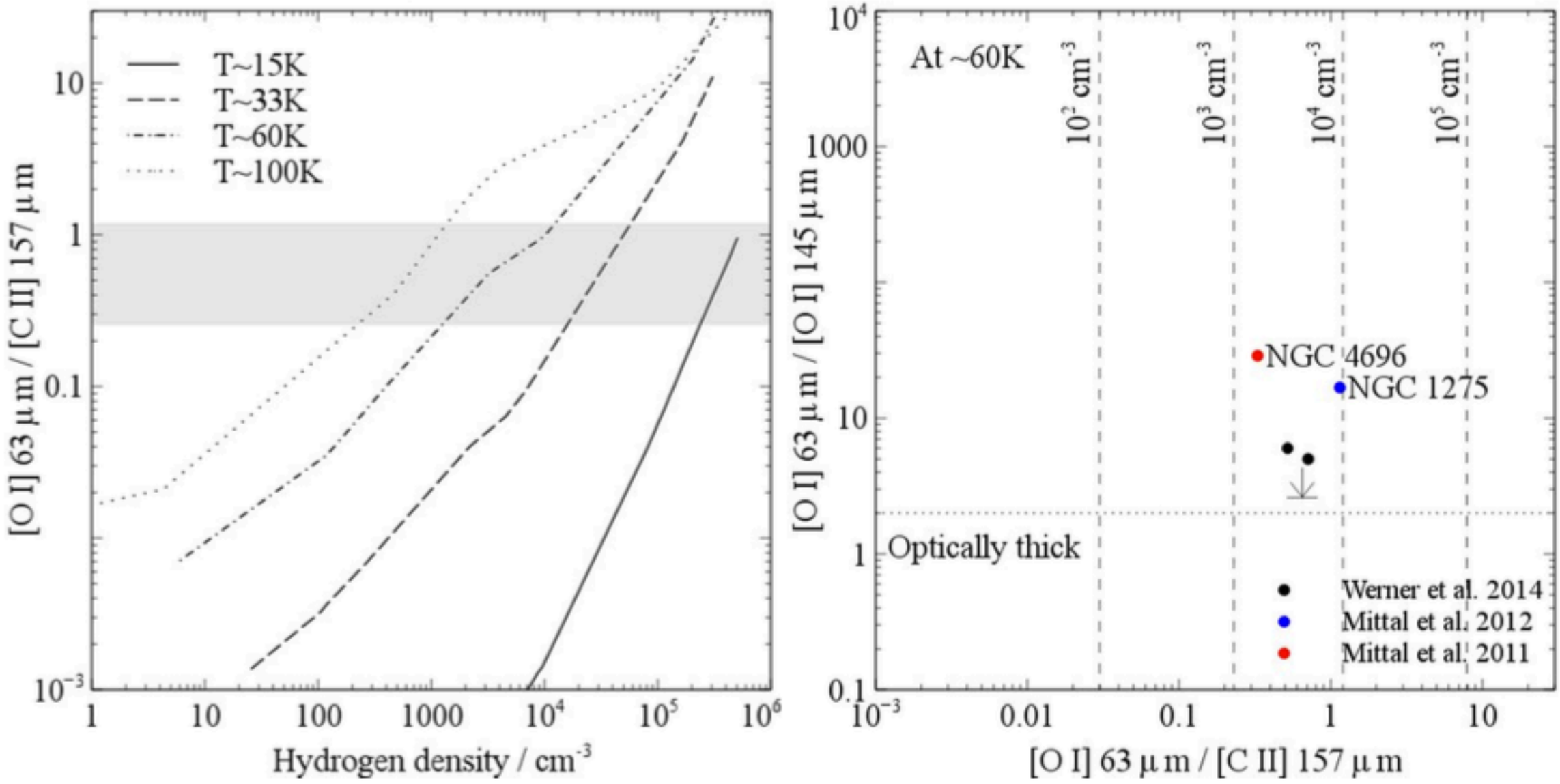
Properties of the filaments



- No correlation between the stellar mass and cold gas
- The extended nebulae are dusty and contain PAHs
- [C II]/Hα ratios similar (~0.4-0.8) in all systems with extended Hα emission
- Filaments collisionally ionized by the surrounding hot particles (Ferland et al. 2009, Canning et al. 2015)
- The filaments are bright in thermal soft X-ray emission (FeXVII and Fe XVIII lines)

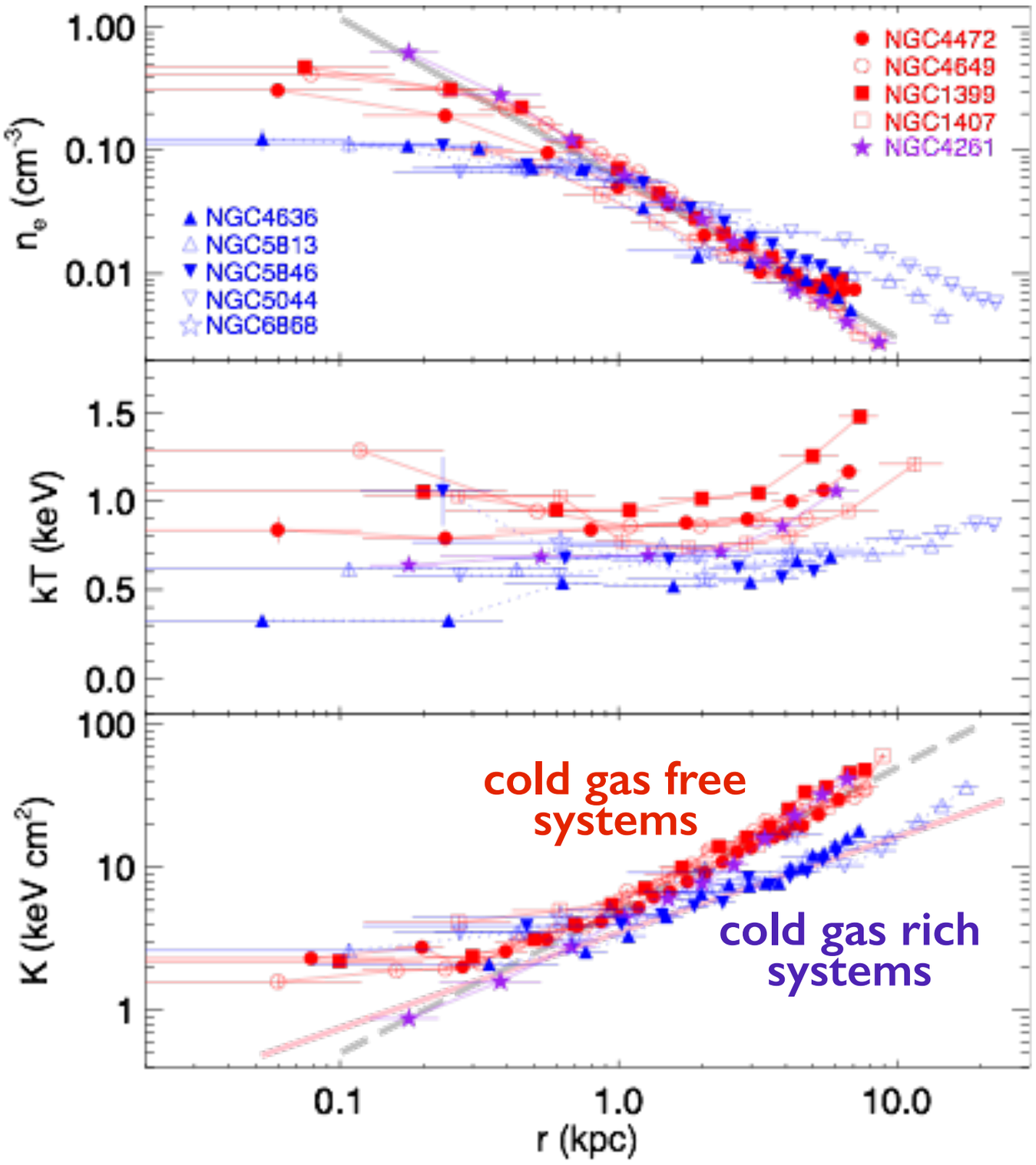
Werner et al. 2014

Properties of collisionally ionized clouds



Canning et al. 2015

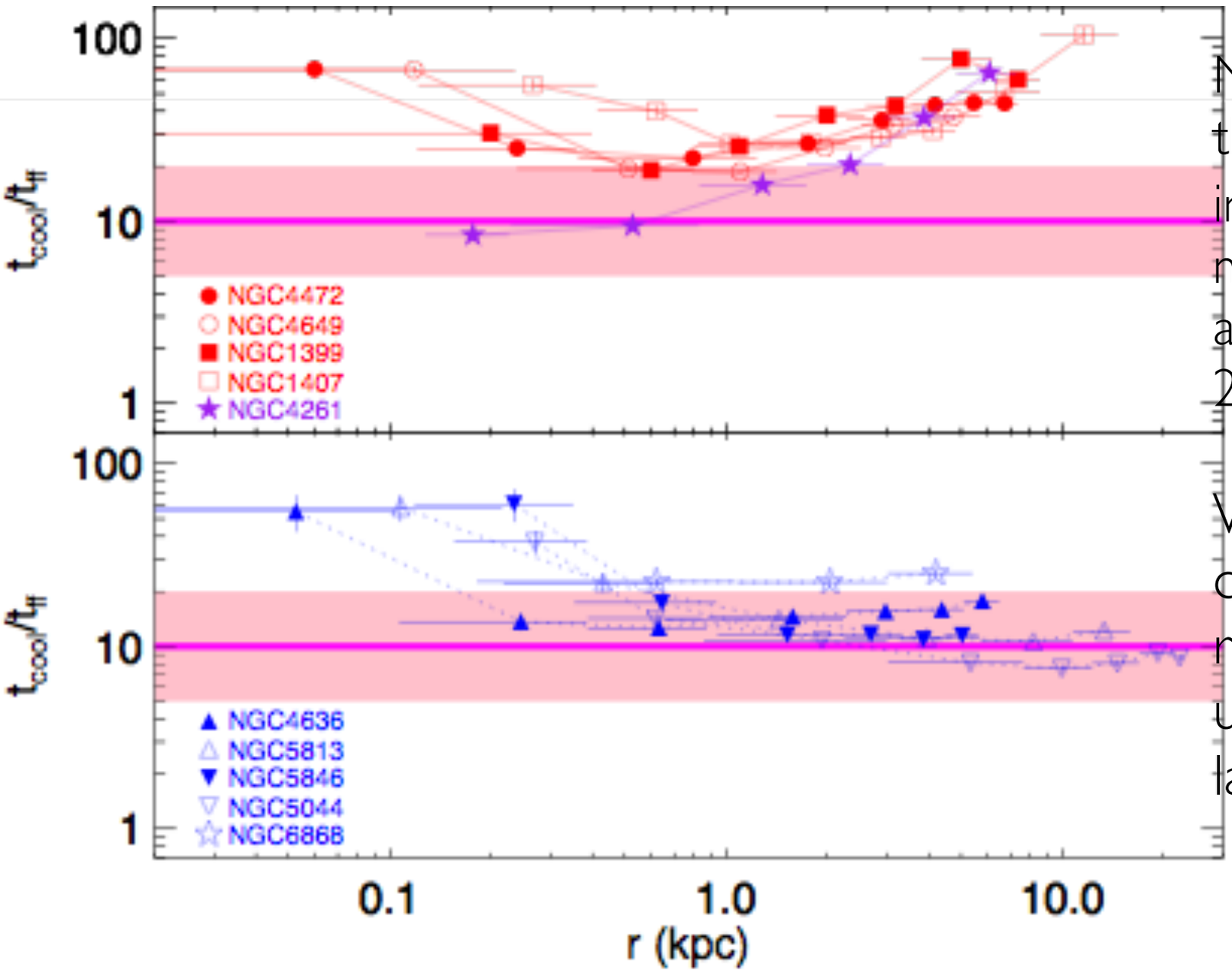
PROPERTIES OF THE HOT ISM



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

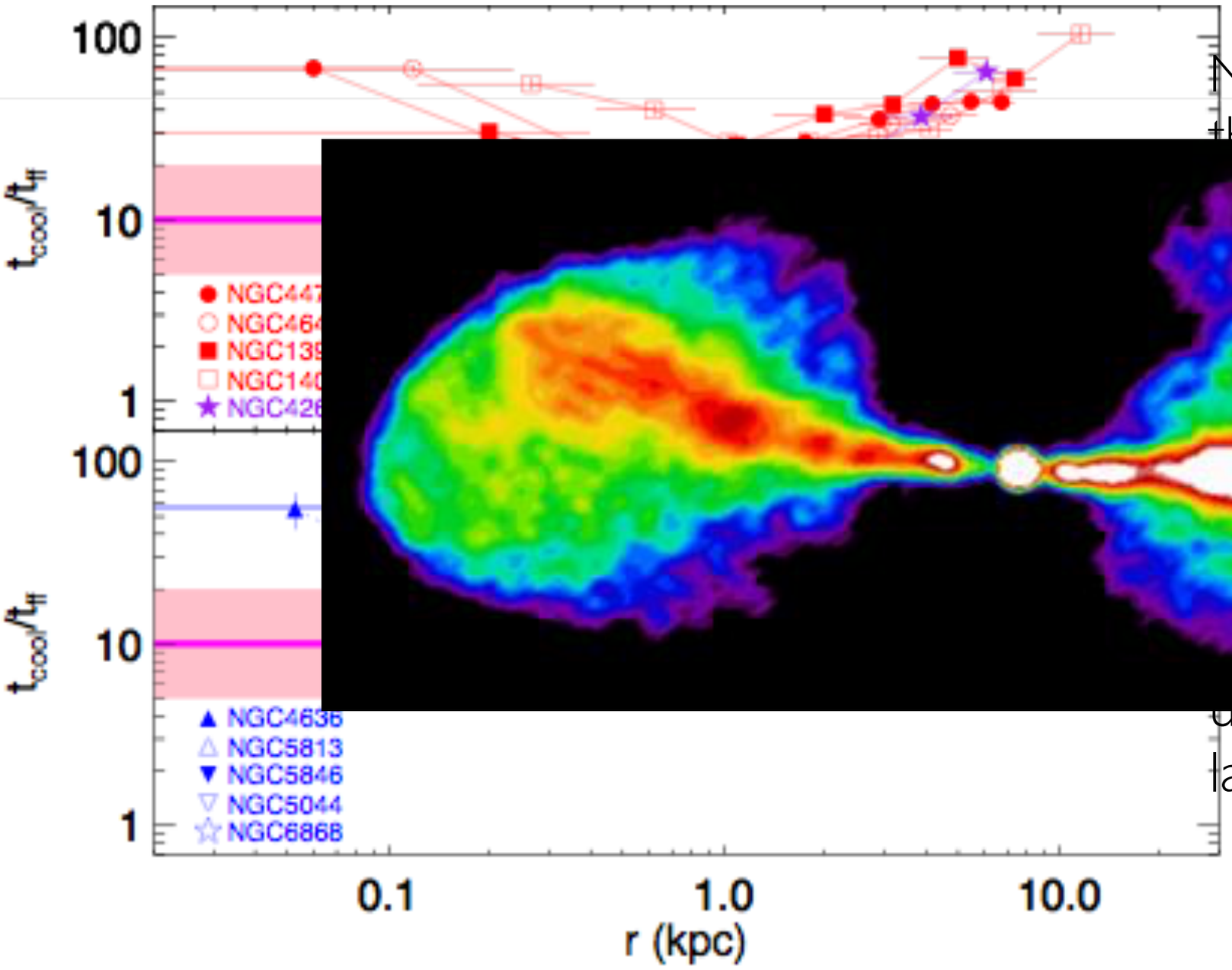


Numerical simulations predict that if $t_{cool}/t_{ff} \lesssim 10$, local thermal instabilities will create a multiphase medium (Sharma et al. 2012, Gaspari et al. 2012, 2013, McCourt et al. 2012)

We observe a clear dichotomy with the cold-gas-rich systems remaining unstable out to relatively large radii.

Werner et al. 2014
Voit et al. 2015

COLD GAS RICH SYSTEMS PRONE TO COOLING INSTABILITIES



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Werner et al. 2014
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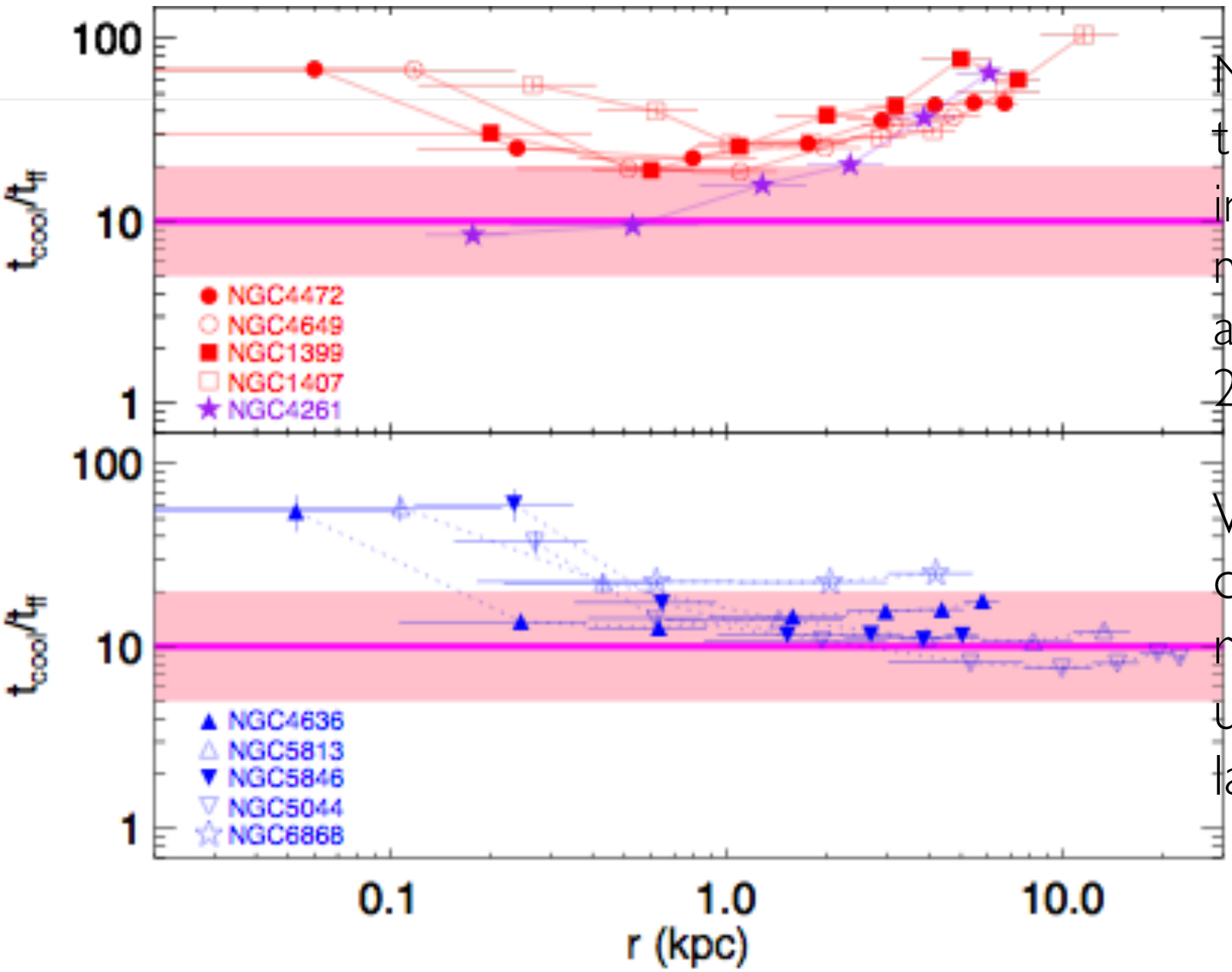

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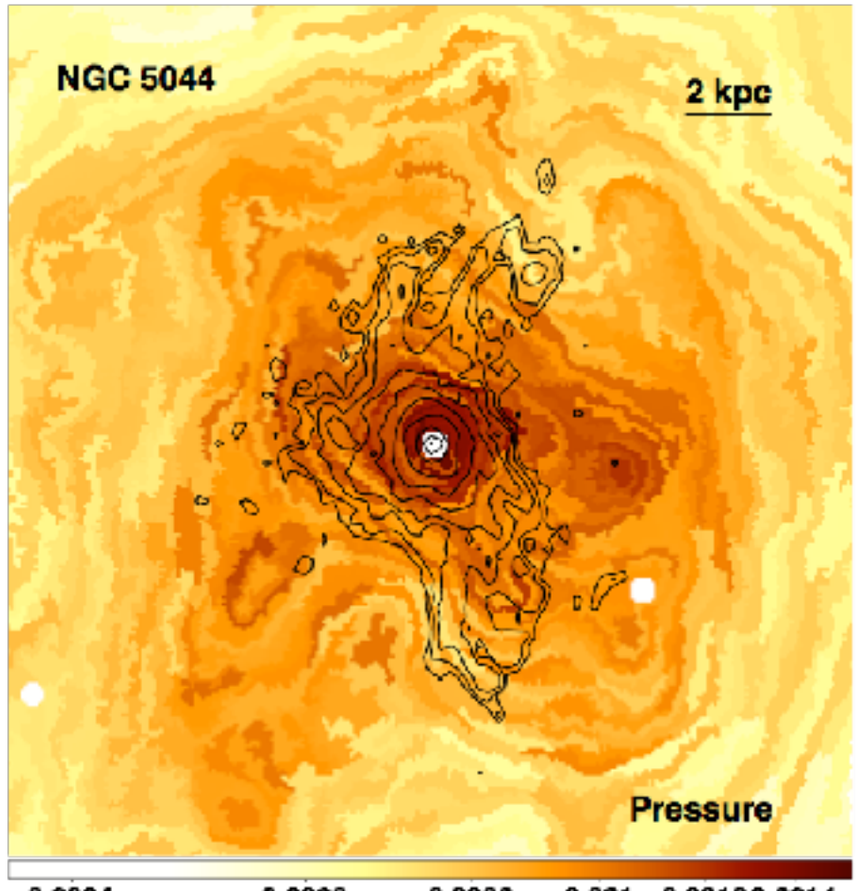
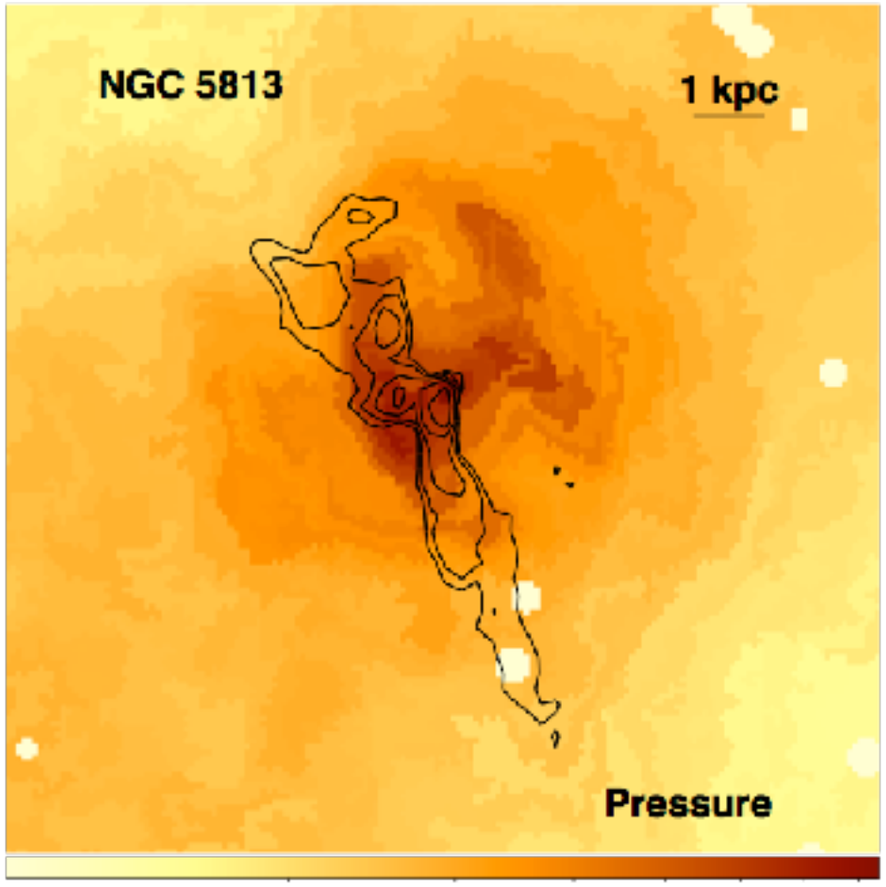
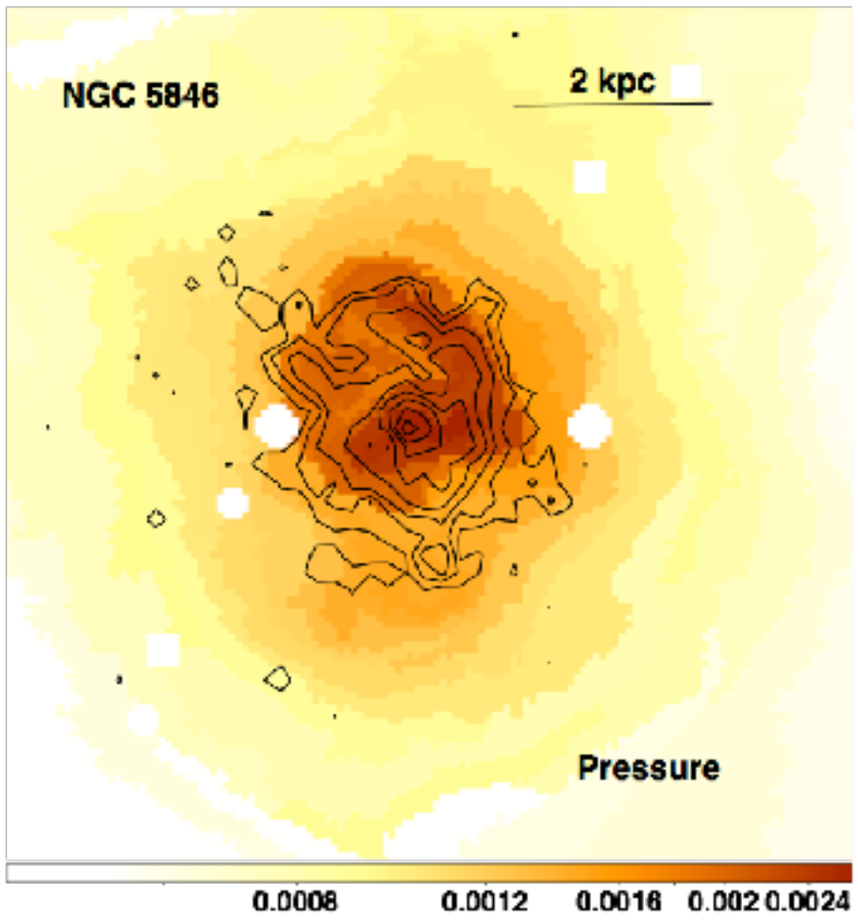
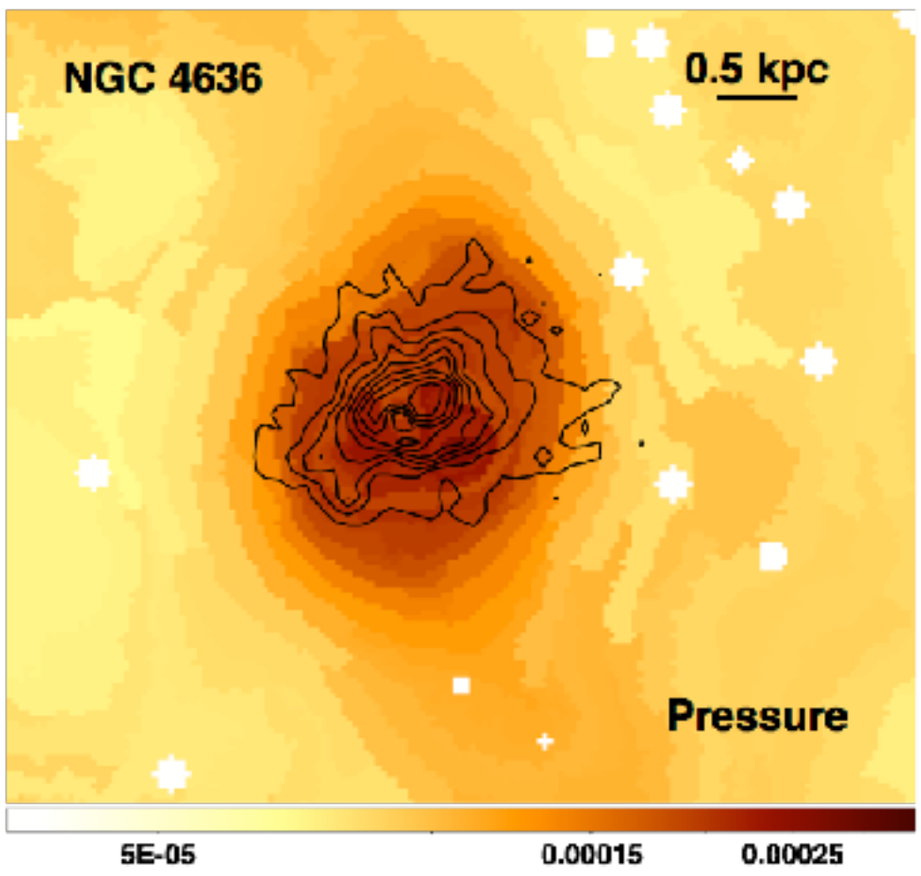
Werner et al. 2014
Voit et al. 2015

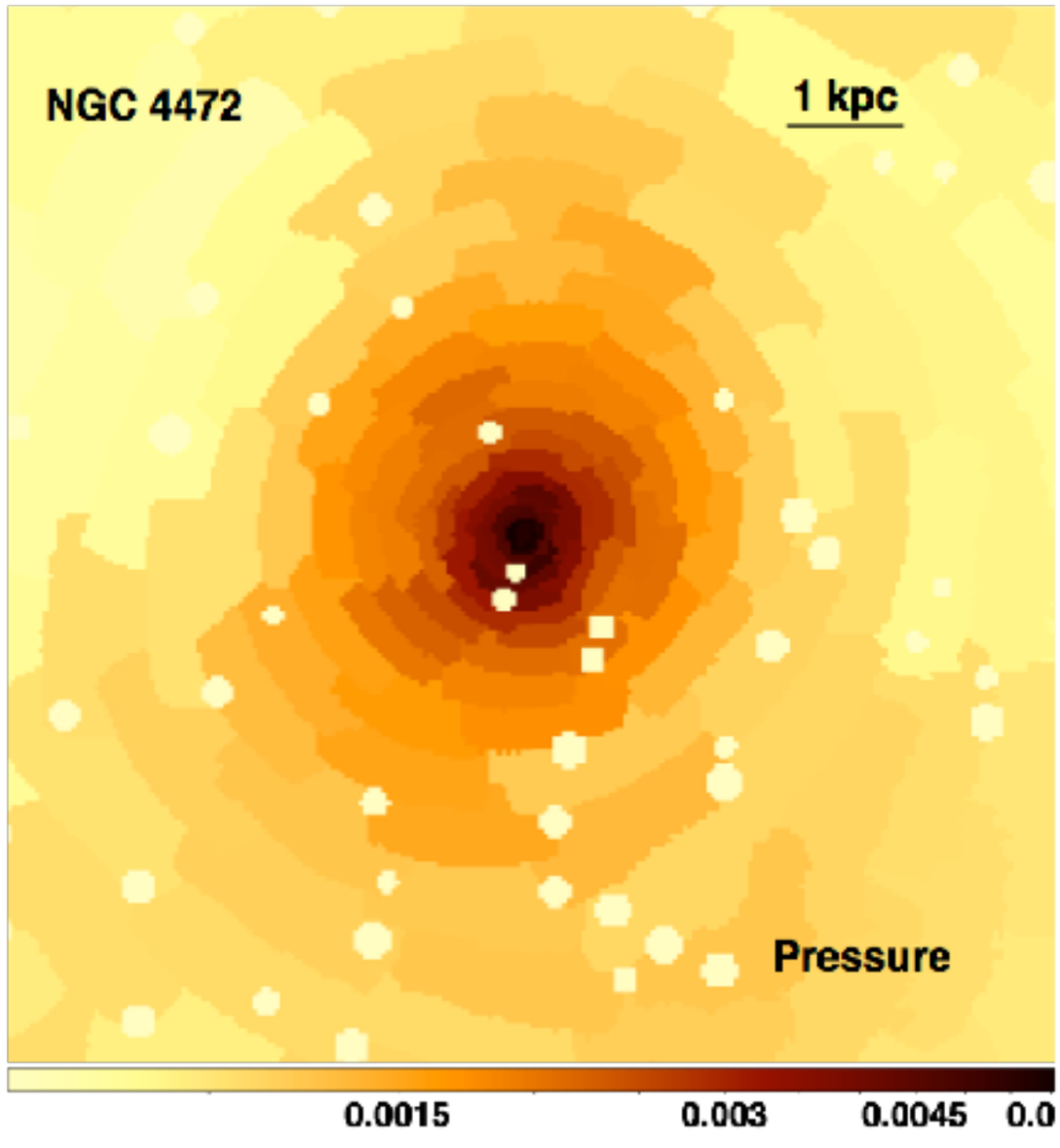

NGC 5044
2 kpc
Pressure
0.0004
0.0006
0.0008
0.001
0.0012
0.0014

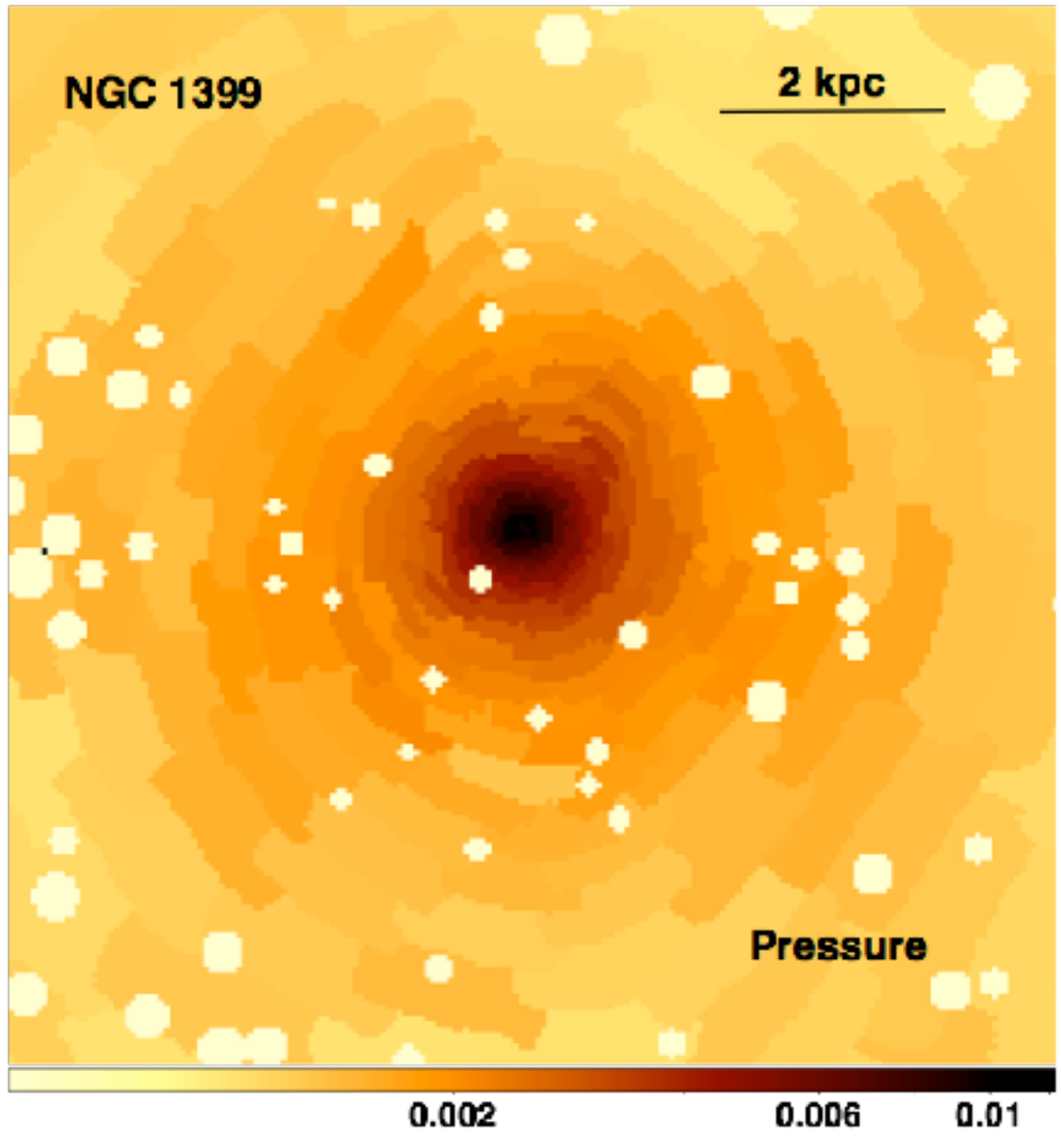

NGC 5813
1 kpc
Pressure
0.0006
0.001
0.0014


NGC 5846
2 kpc
Pressure
0.0008
0.0012
0.0016
0.002
0.0024


NGC 4636
0.5 kpc
Pressure
5E-05
0.00015
0.00025

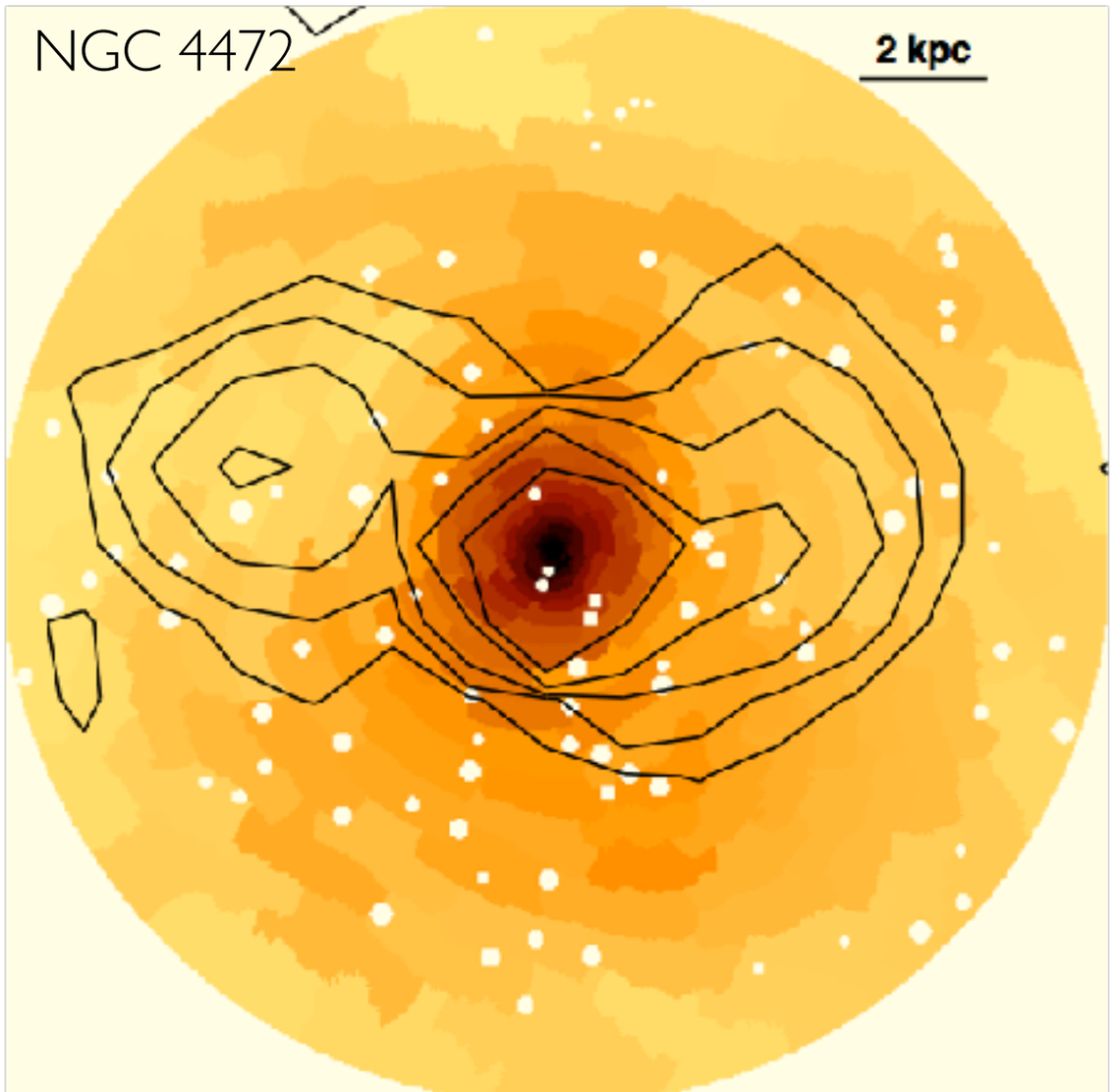
GALAXIES WITH NO COLD GAS

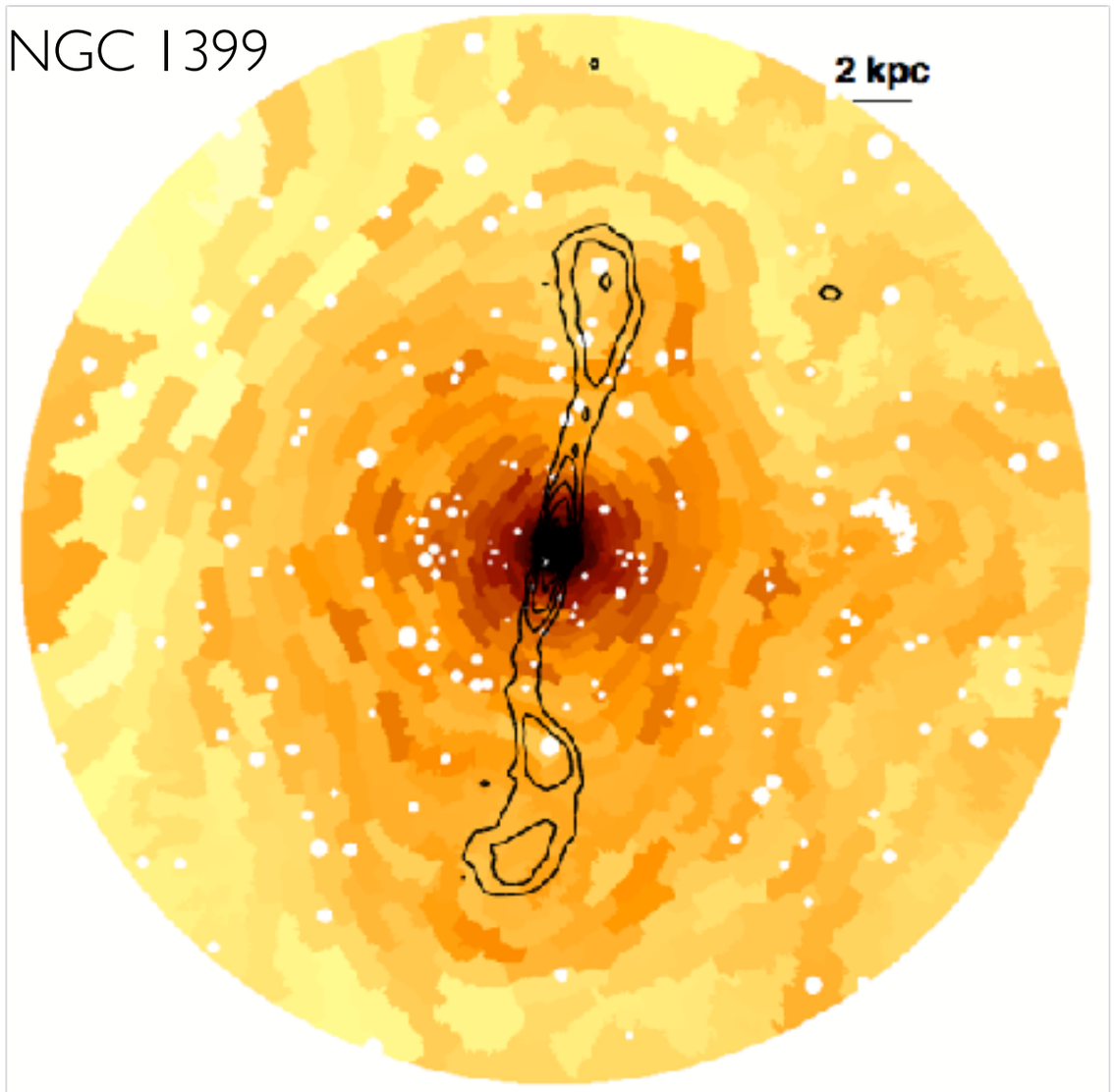




Werner et al. 2014

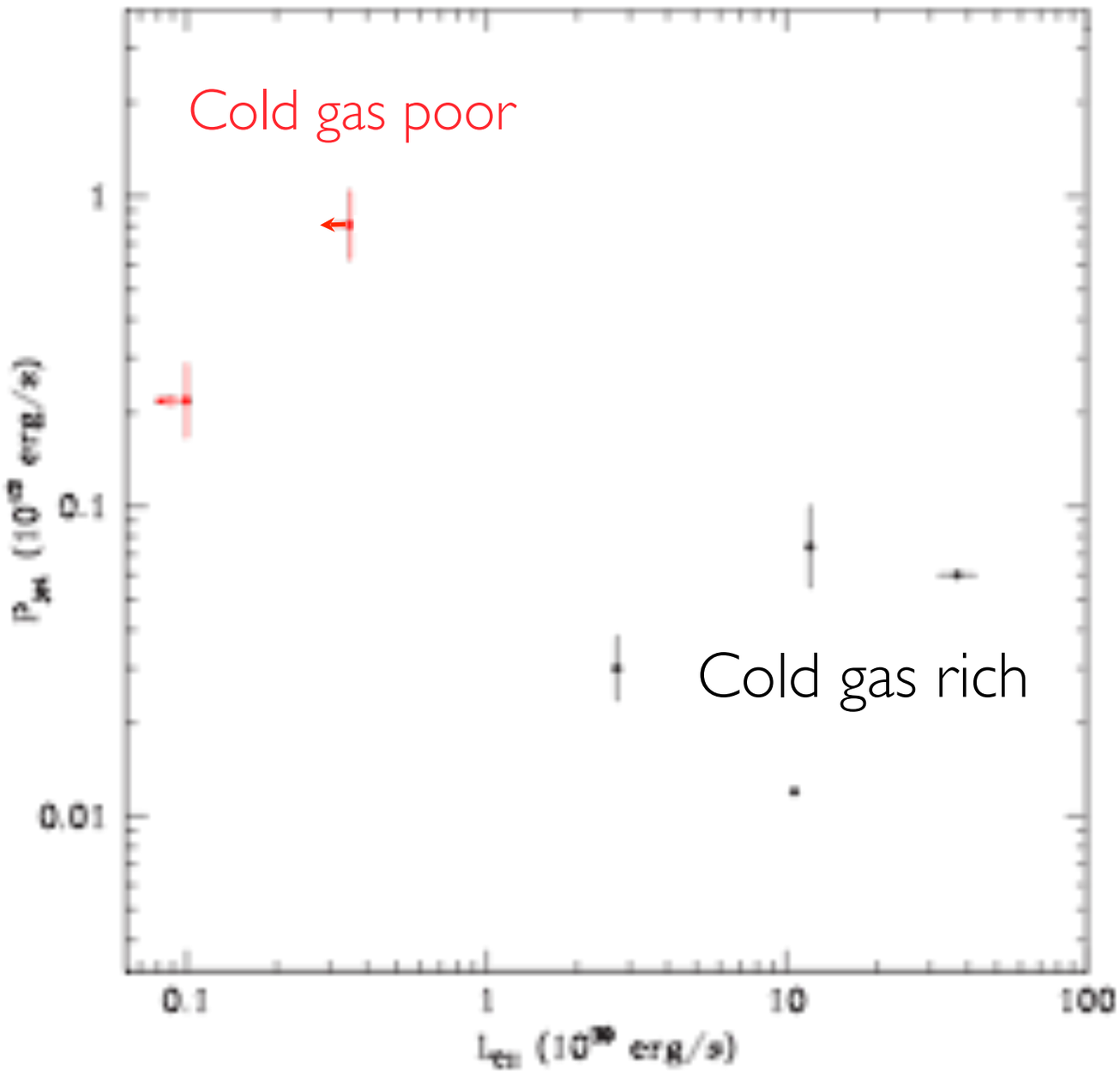
GALAXIES WITH NO COLD GAS
- RADIO JETS





Werner et al. 2014

Jet powers and cold gas

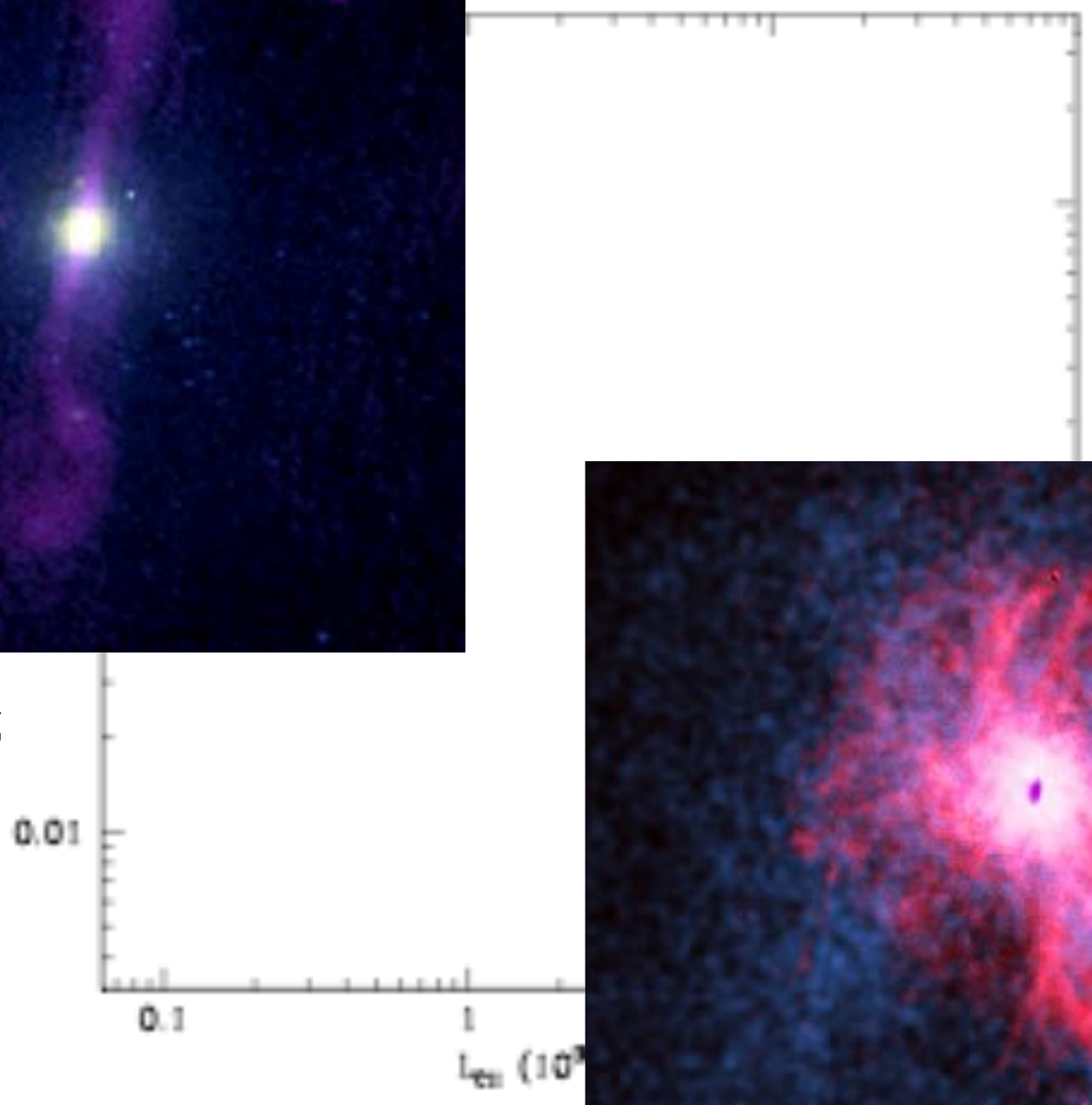


Power input (measured from X-ray cavities) into the ICM from radio mode AGN does not increase with the amount of cold gas

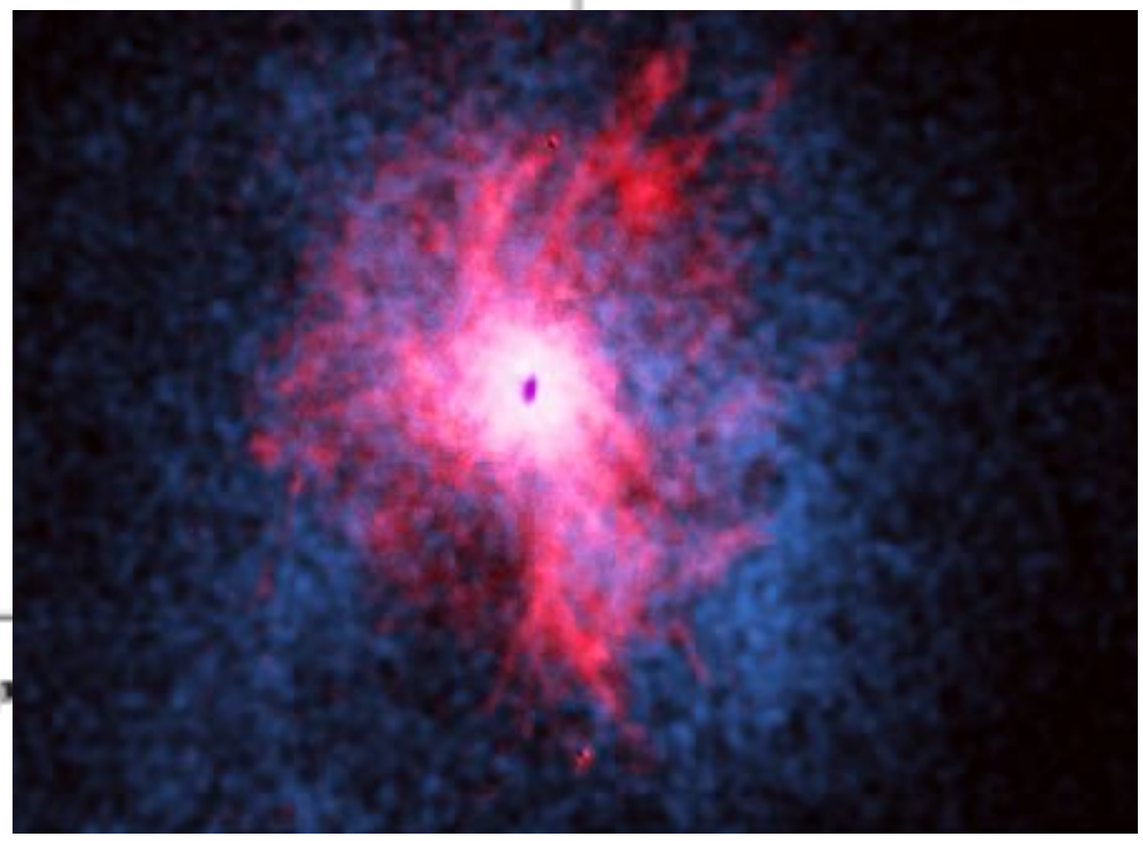
Werner et al. 2014

Jet powers and cold gas

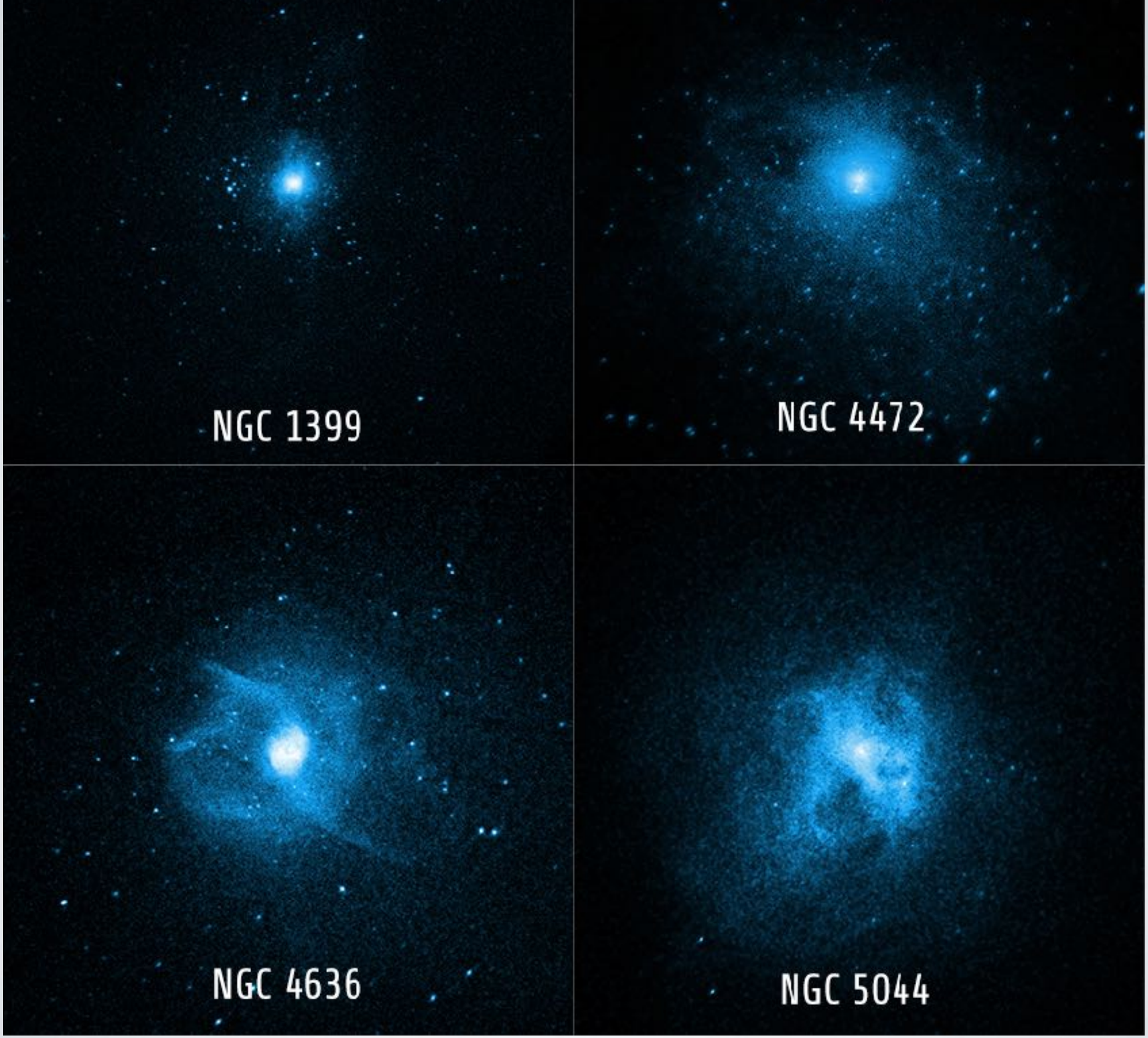
Large jet power,
no cold gas,
relaxed X-ray



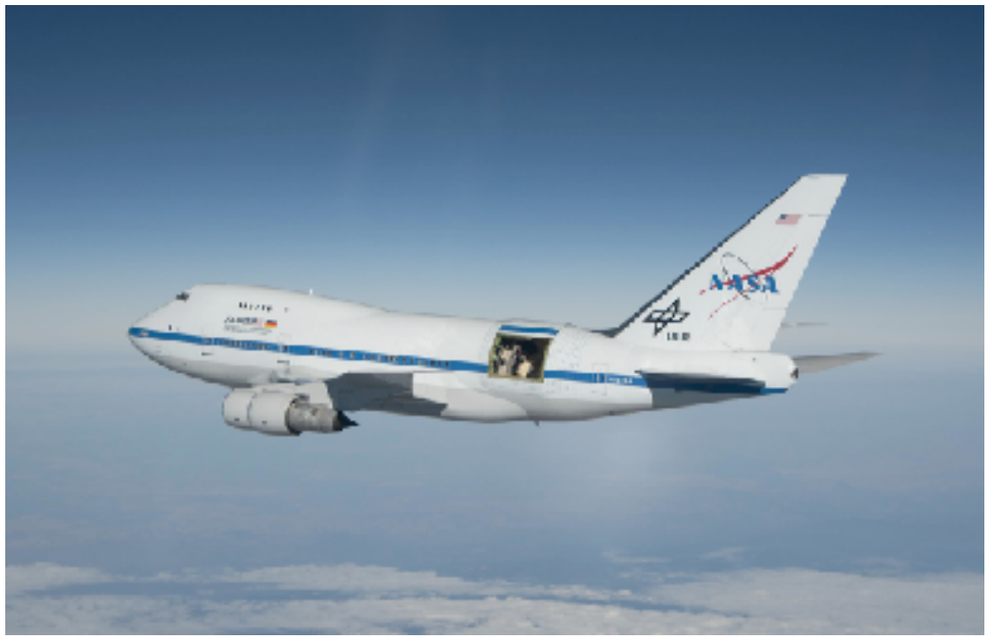
Small jet power,
many X-ray
cavities and
disturbed
morphology,
plenty of cold gas



Werner et al. 2014


NGC 1399
NGC 4472
NGC 4636
NGC 5044

Continuing the survey with SOFIA



Building a complete volume limited sample of the nearest brightest giant ellipticals

We observed 6 more galaxies at different level of morphological disturbance with SOFIA FIFI-LS

Some of them suffered strong AGN outbursts (M89, M84), other are being ram-pressure stripped (M86), while some galaxies appear very relaxed (NGC4649)

Summary:

Nearby giant ellipticals with similar SFR, stellar masses and halo masses but very different cold gas properties and X-ray morphologies.

We identify two states:

1. X-ray morphologically relaxed, $t_c/t_{ff} > 10$, - ***cold gas is not detected***

2. X-ray morphologically disturbed, $t_c/t_{ff} < 10$ - ***rich in cold gas***

The cold gas likely originates from cooling of the hot ISM

Radio mode AGN interact with both hot and cold gas in massive galaxies quenching the star formation