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

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RED AND DEAD GIANT ELLIPTICAL GALAXIES
The M87 Jet
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 star formation

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 ($B \sim 30 - 70 \mu G$) pressure. They also contain dust.

Werner et al. 2013
• we observed the cooling lines of [CII], [OI] with \textit{Herschel}

• [CII] an excellent tracer of 100 K gas, its flux is usually a few thousand times stronger than CO
Simionescu et al. in prep.
Hα+[NII] IMAGING WITH THE SOAR TELESCOPE

Werner et al. 2014
[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 [OIIb] line

FAR-INFRARED LINE DETECTIONS IN GIANT ELLIPTICALS

Werner et al. 2014
[CII] EMISSION FOLLOWING $\text{H}\alpha$

Werner et al. 2014
VELOCITIES OF THE COLD ISM

Werner et al. 2014
VELOCITY DISPERSIONS IN THE COLD ISM

Werner et al. 2014
No correlation between the stellar mass and cold gas

The extended nebulae are dusty and contain PAHs

$[\text{C II}]/\text{H}\alpha$ ratios similar (~0.4-0.8) in all systems with extended H$\alpha$ 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)

Properties of the filaments

Cold gas poor

Cold gas rich

Werner et al. 2014
Properties of collisionally ionized clouds

Canning et al. 2015
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 $t_{\text{cool}}/t_{\text{ff}} \lesssim 10$, 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.

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Voit et al. 2015
GALAXIES WITH NO COLD GAS

Werner et al. 2014
GALAXIES WITH NO COLD GAS
- RADIO JETS

NGC 4472

NGC 1399

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

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

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

Werner et al. 2014
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