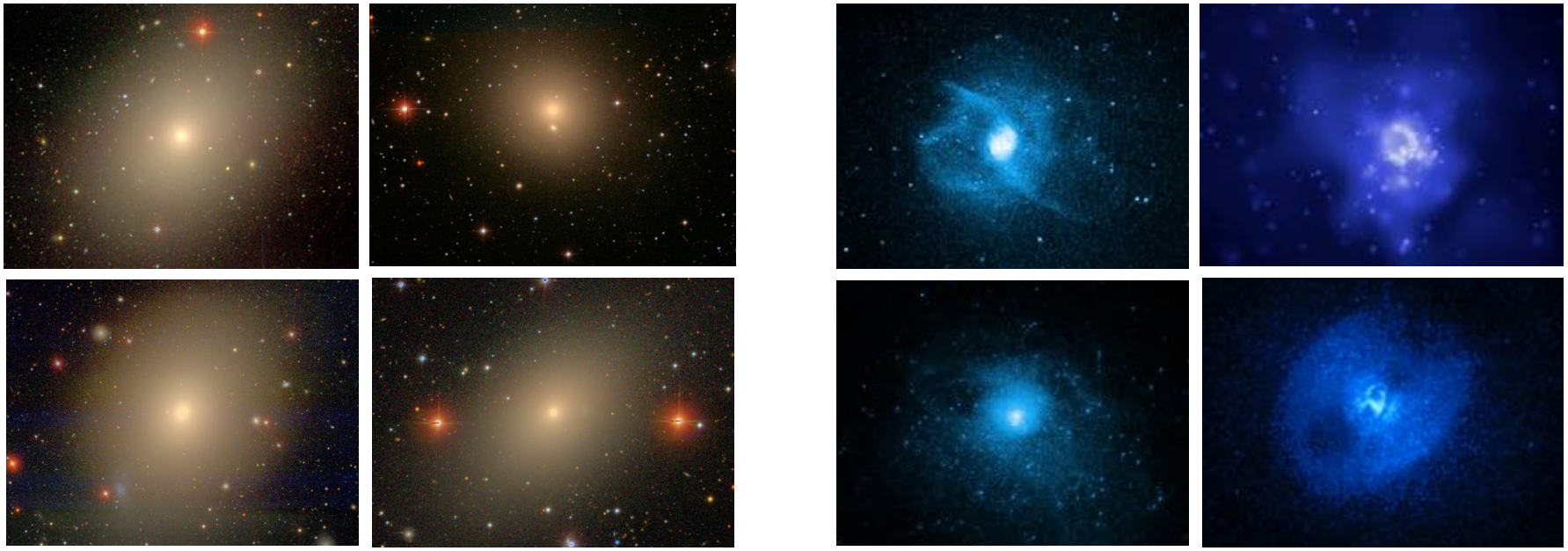


Becky Canning (Stanford University/KIPAC)

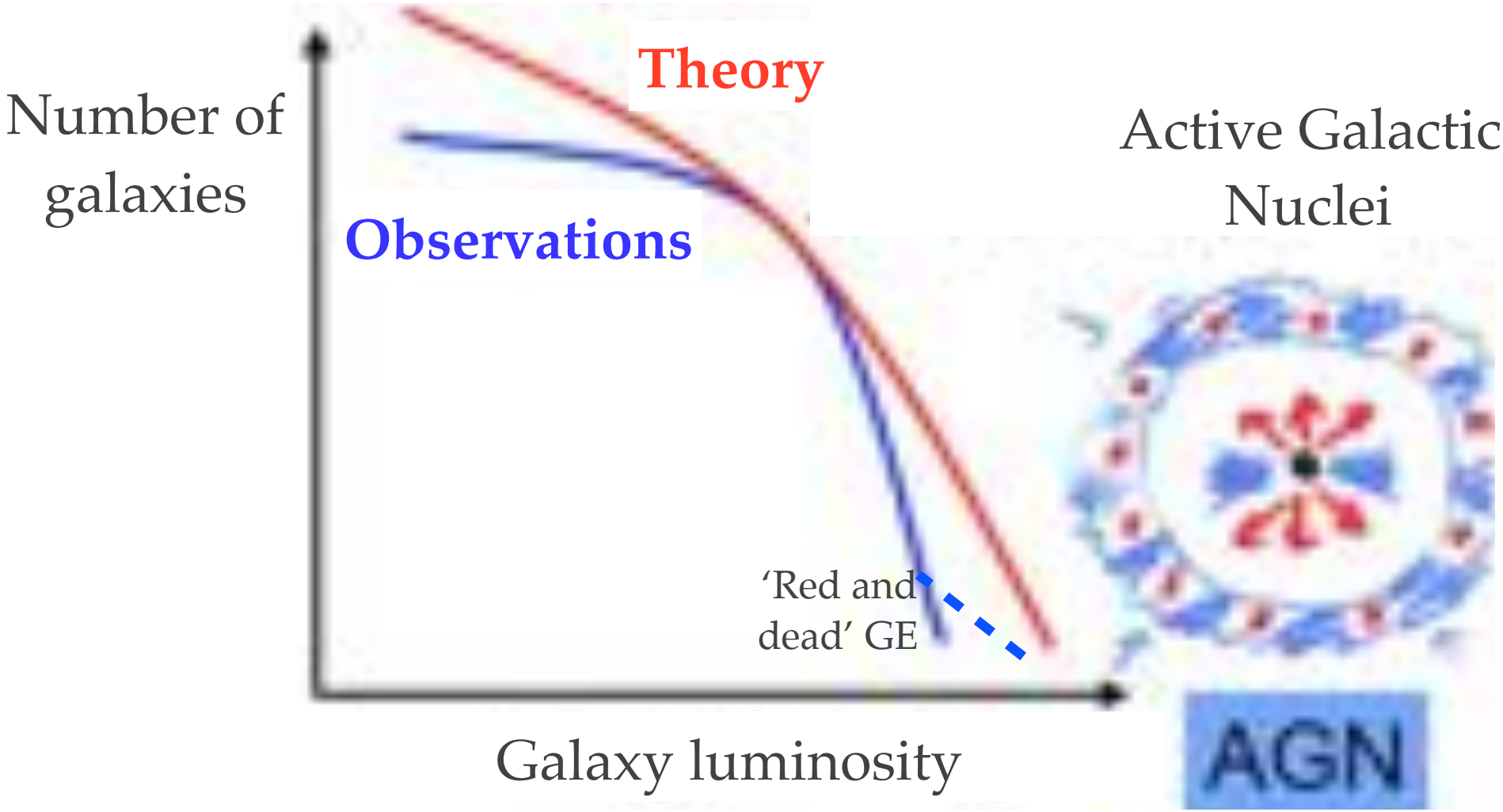
The evolution of Early-Type Galaxies: An X-ray perspective

Overview

1. Why an X-ray perspective?

2. The interplay of cold and hot gas in massive elliptical galaxies

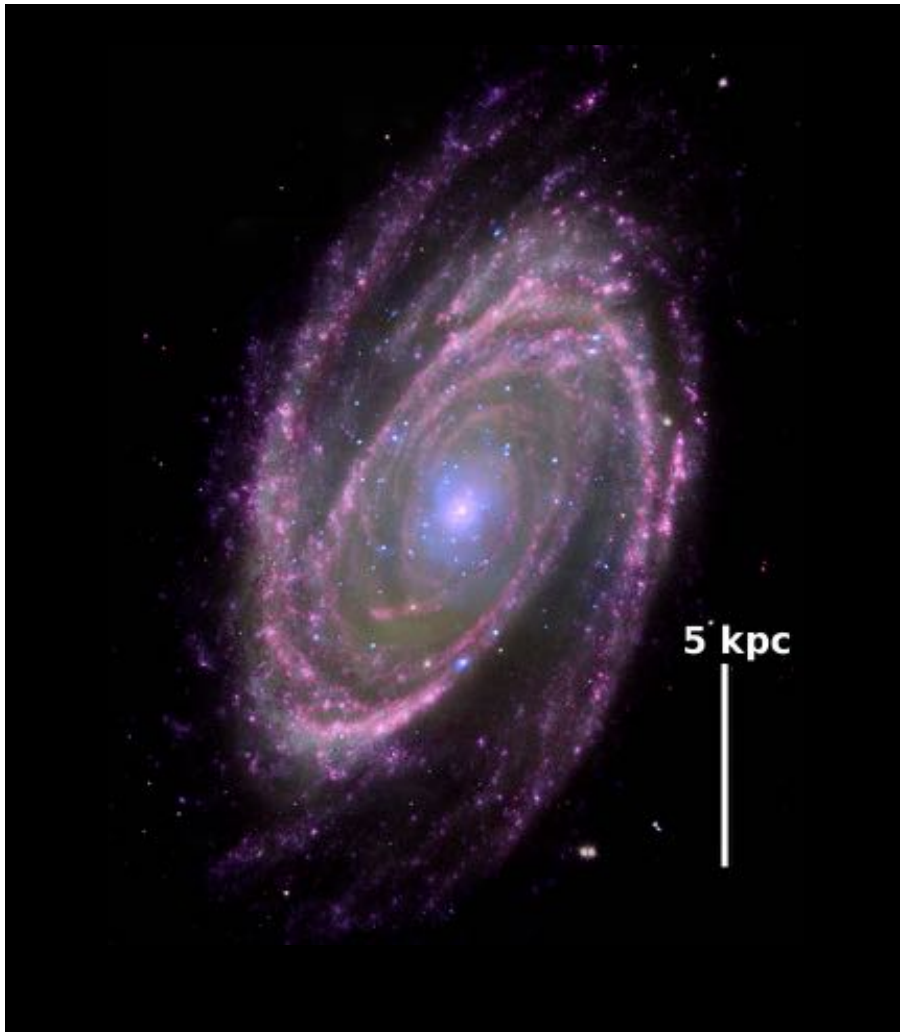
Why an X-ray perspective?



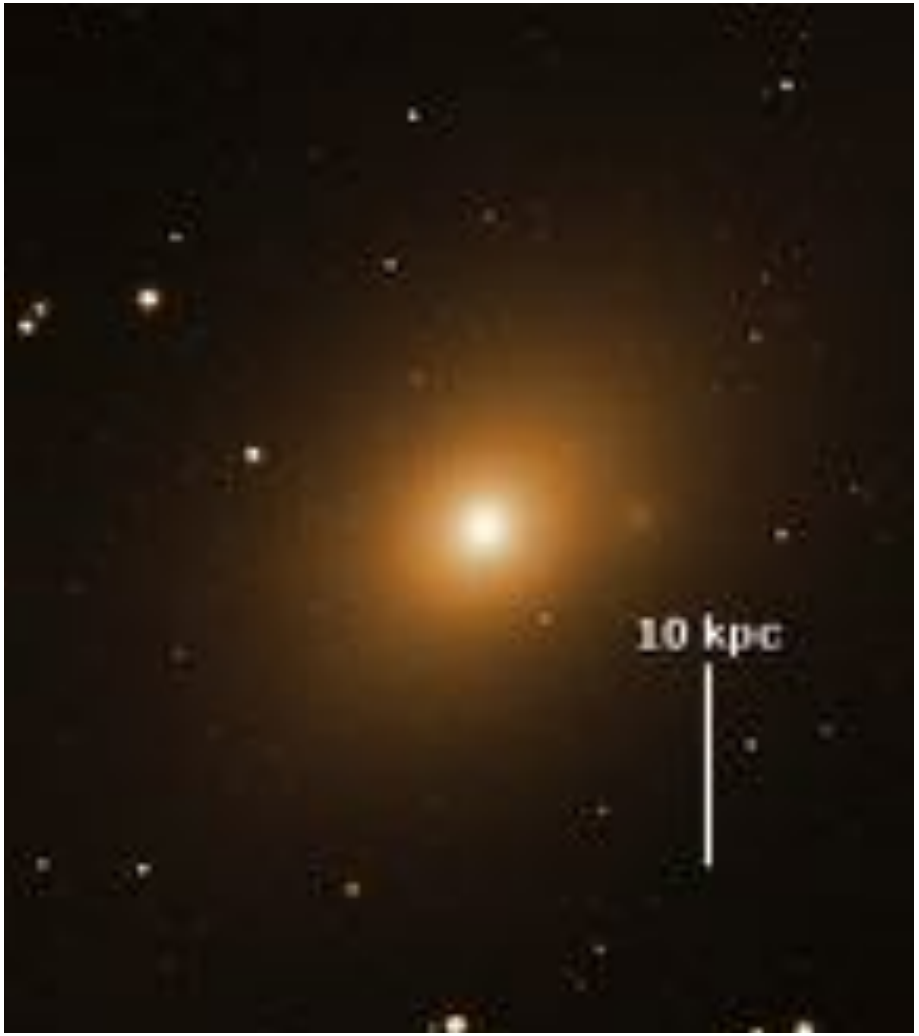
Silk & Mamon 2012

Why an X-ray perspective?

M 81

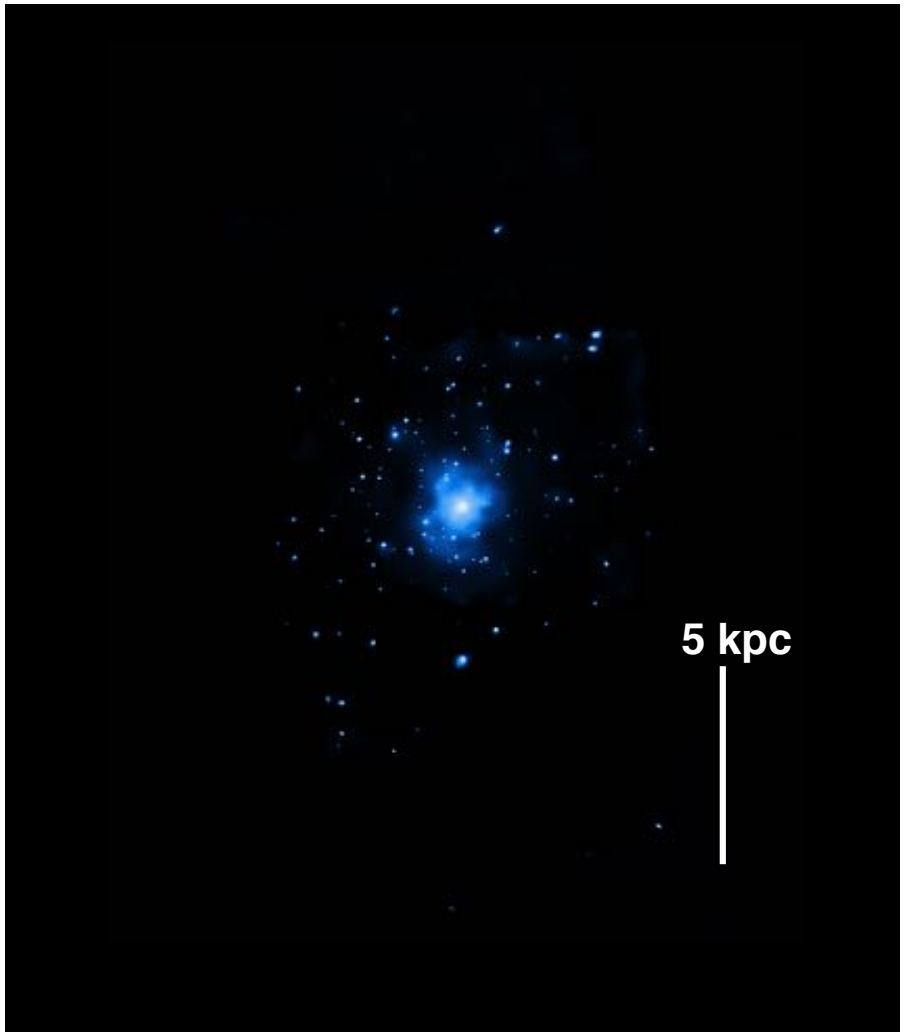


NGC 5813

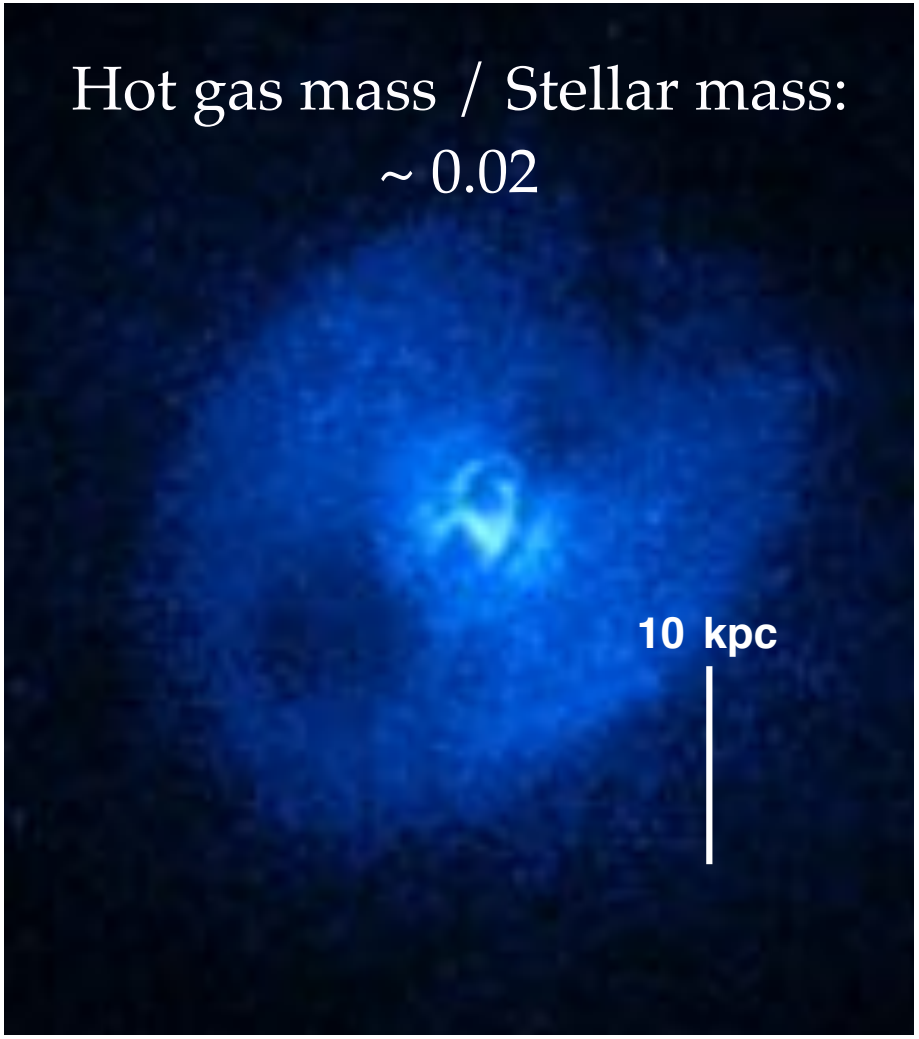


Why an X-ray perspective?

M 81



NGC 5813



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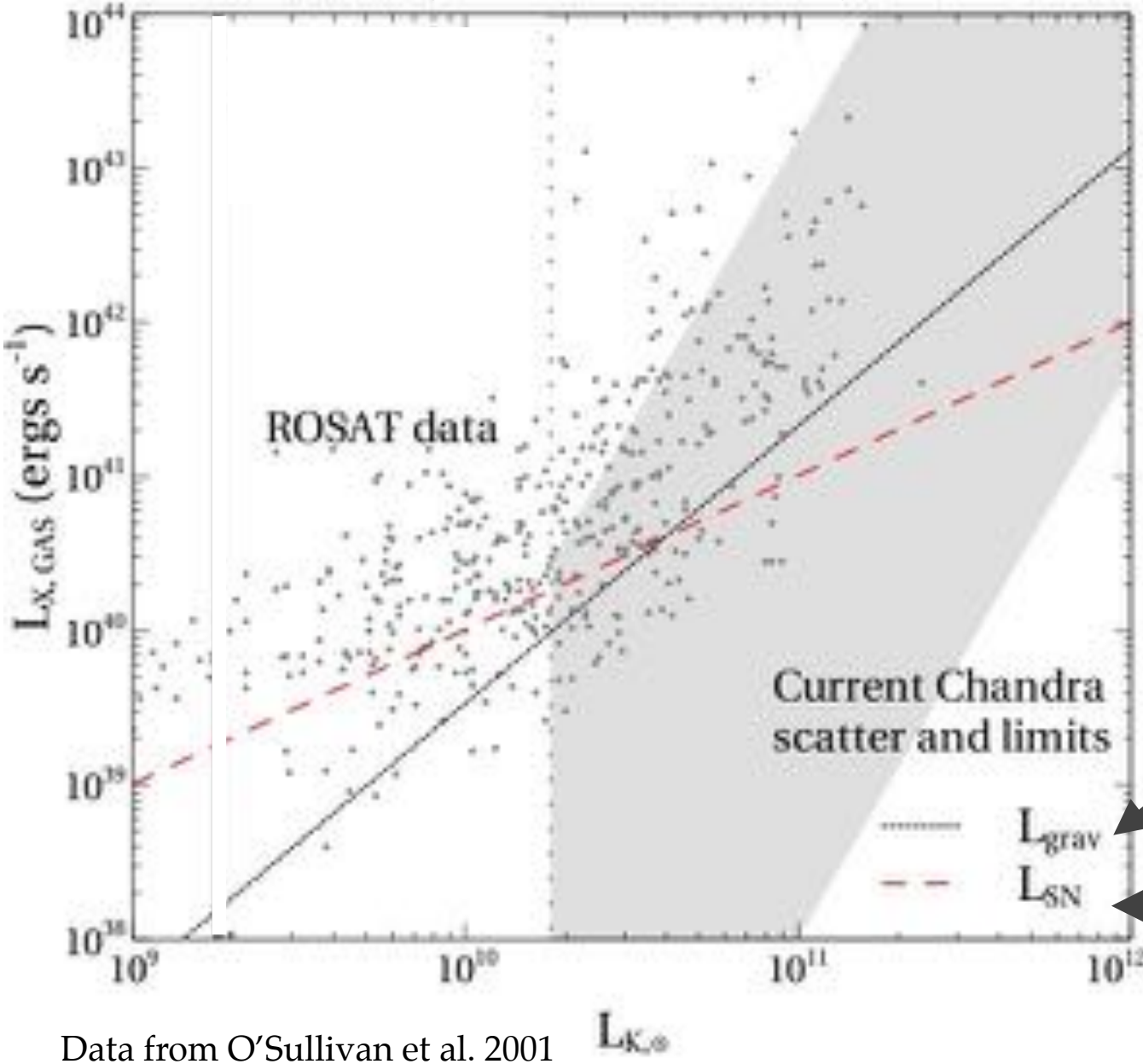


Data from O'Sullivan et al. 2001

Three key features…

1. Bright end slope - mass, AGN

2. Faint end slope - SNe

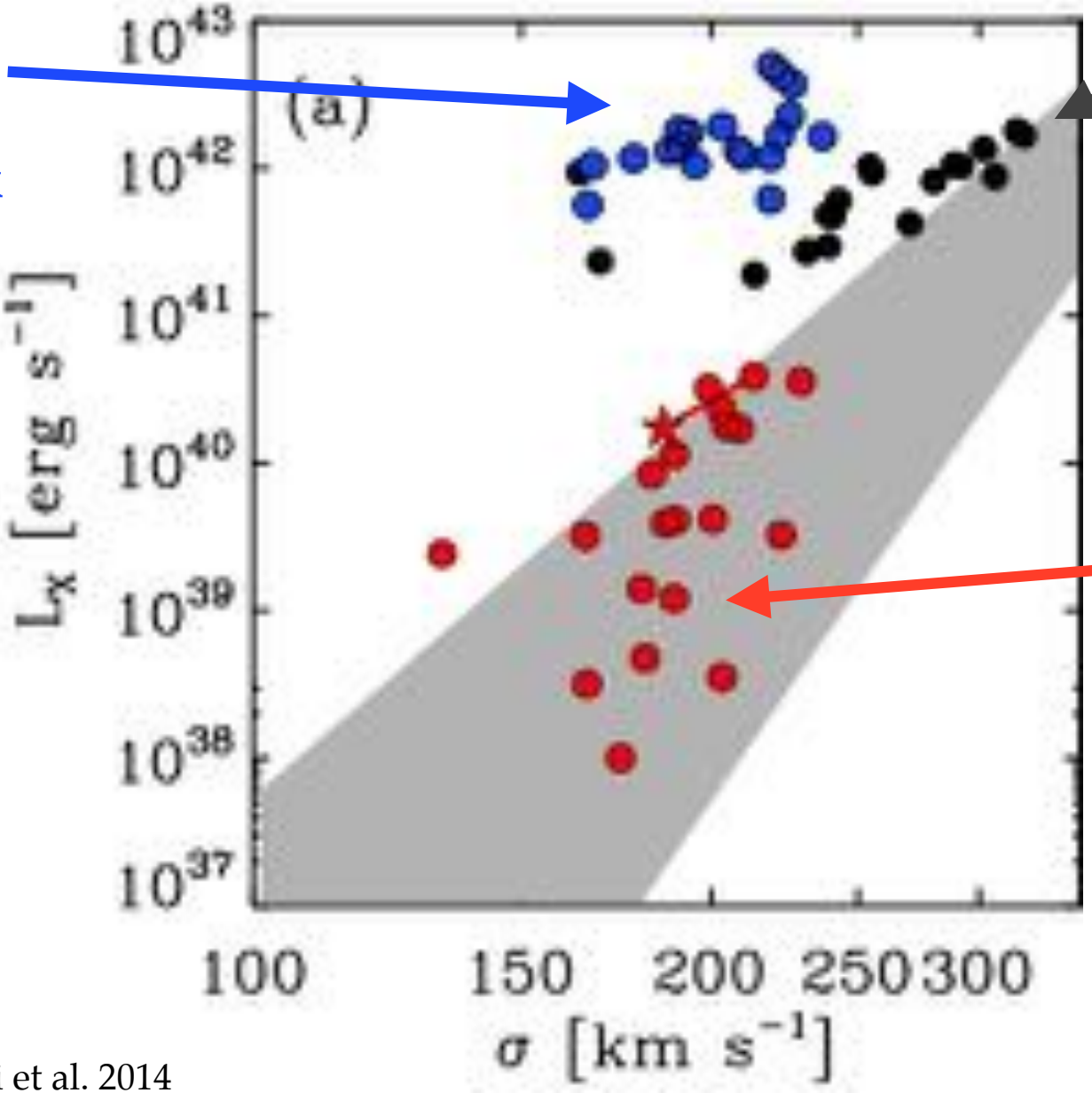
3. Critical luminosity - mass at which SNe winds dominate over AGN and gravitational processes

…can test feedback models

E required to unbind gas

E input from SNe

Why an X-ray perspective?



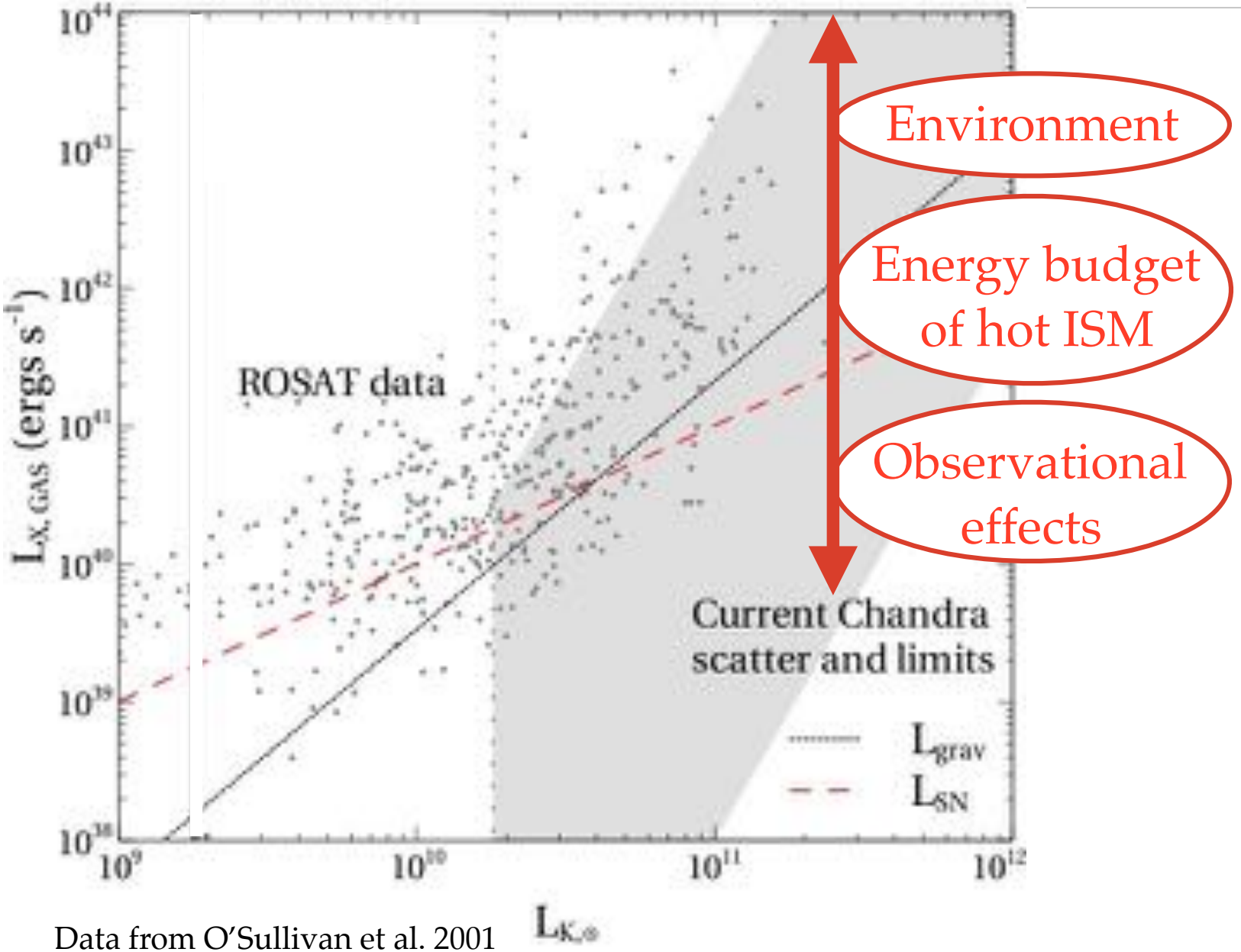
Thermal AGN feedback

No AGN feedback

Momentum AGN feedback

Choi et al. 2014

Why an X-ray perspective?



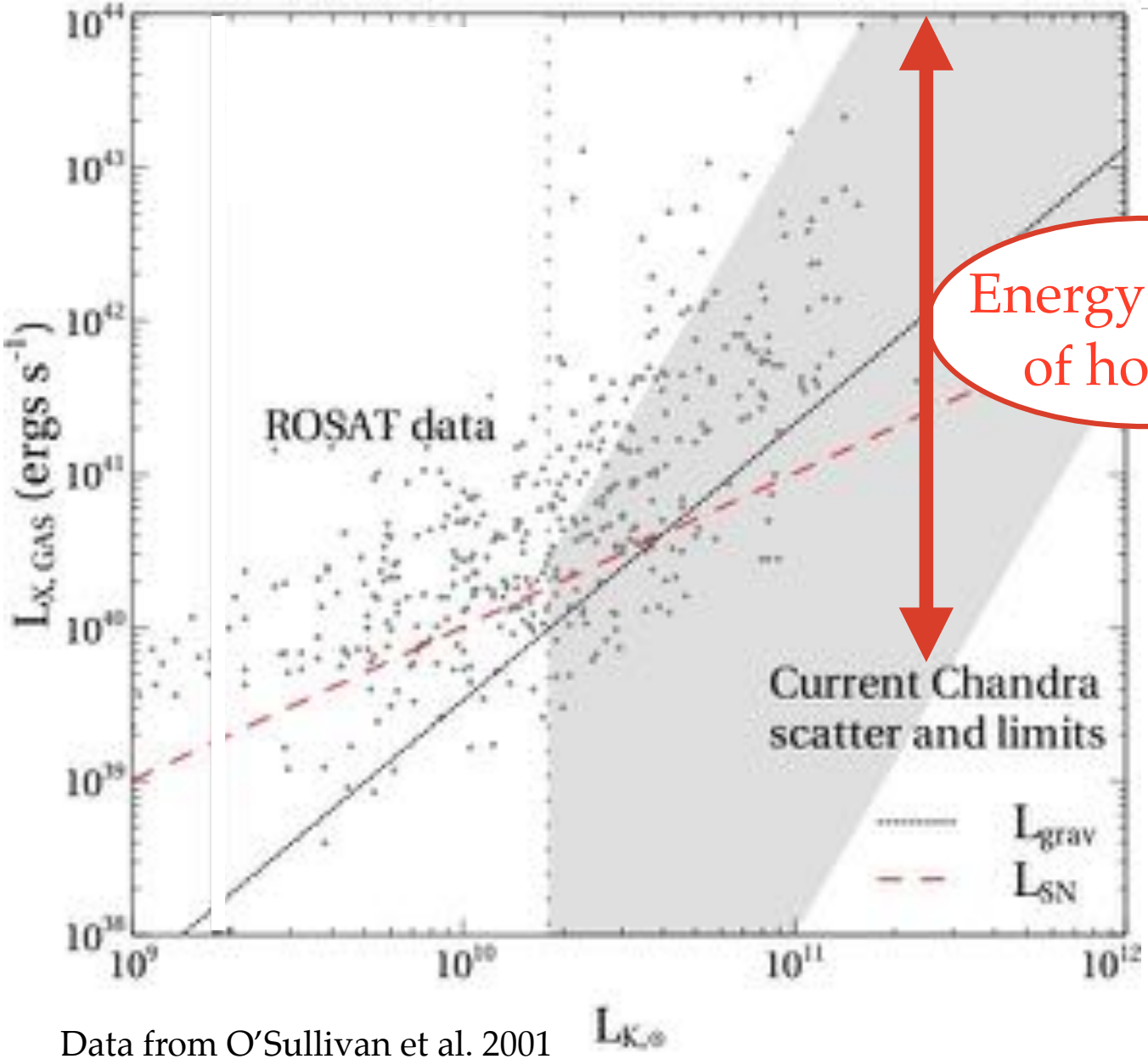
Environment

Energy budget of hot ISM

Observational effects

Data from O'Sullivan et al. 2001

Why an X-ray perspective?



Data from O'Sullivan et al. 2001

Mass

Energy budget of hot ISM

Heating and cooling

SNe Feedback
AGN Feedback
Metallicity of gas

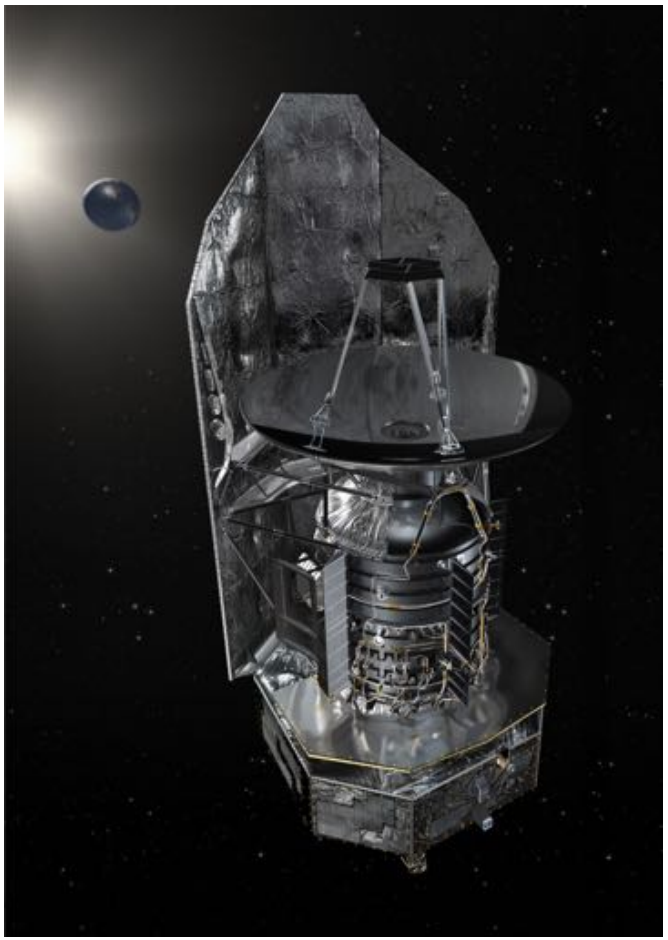
Galaxy Structure and kinematics

Overview

1. Why an X-ray perspective?

2. The interplay of cold and hot gas in massive elliptical galaxies

Cold and hot gas in elliptical galaxies



Credit NASA

Herschel [C II] (100 K) observations of 8 nearby 'red and dead' giant elliptical galaxies

Parent Sample: The 18 optically and X-ray brightest nearby galaxies

$$d < 100\ Mpc$$

Stellar mass: $\sim 10^{11}\ M_{\odot}$

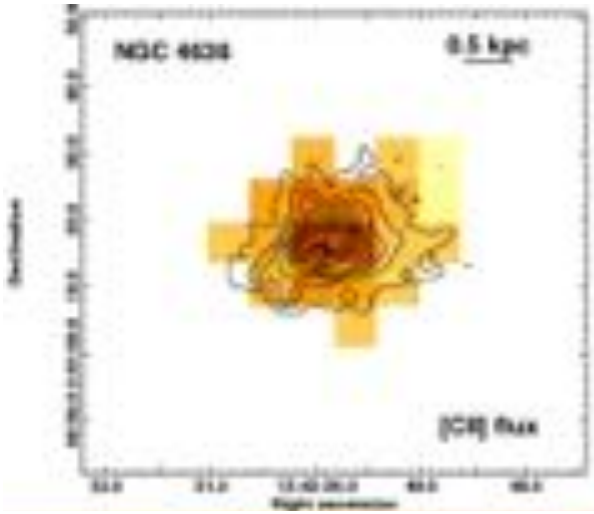
X-ray gas mass: $\sim 10^{9}\ M_{\odot}\ in\ 10\ kpc$

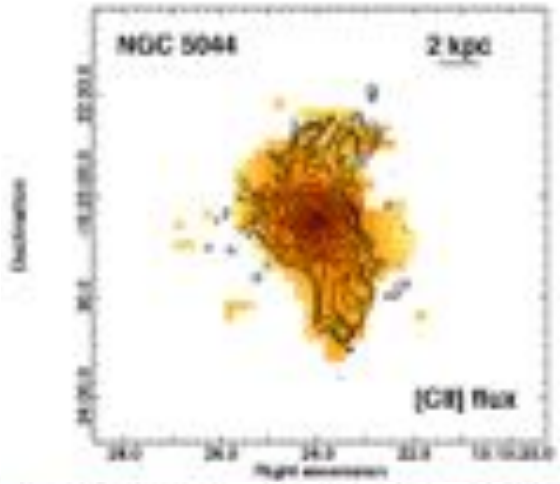
Whilst these galaxies lack SF 6/8 systems have extended ionized gas detections

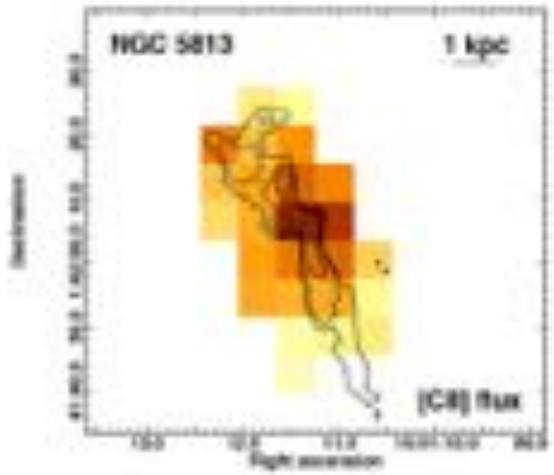
Cold gas properties

6/8 galaxies have cold gas and same 6/8 have ionized gas

Cold gas morphology and kinematics similar to ionized gas

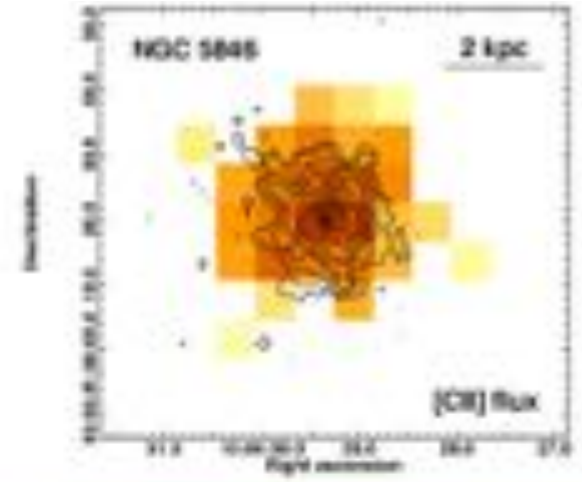


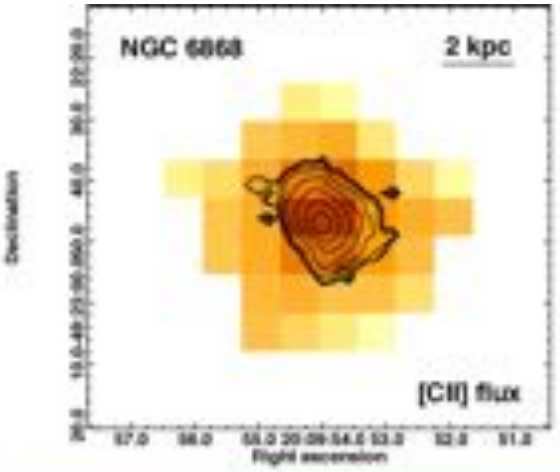


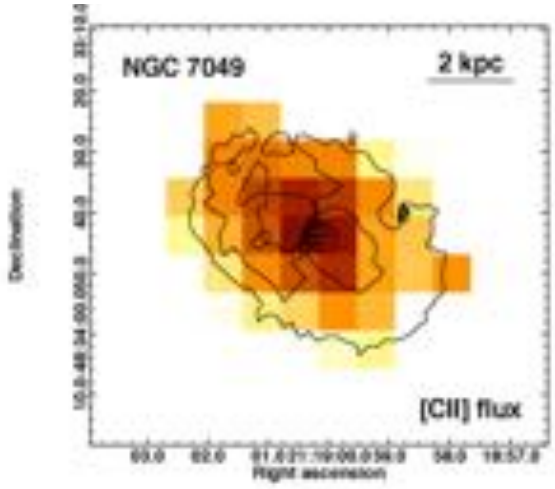


$[C\ II]\ /\ H\alpha = 0.8$

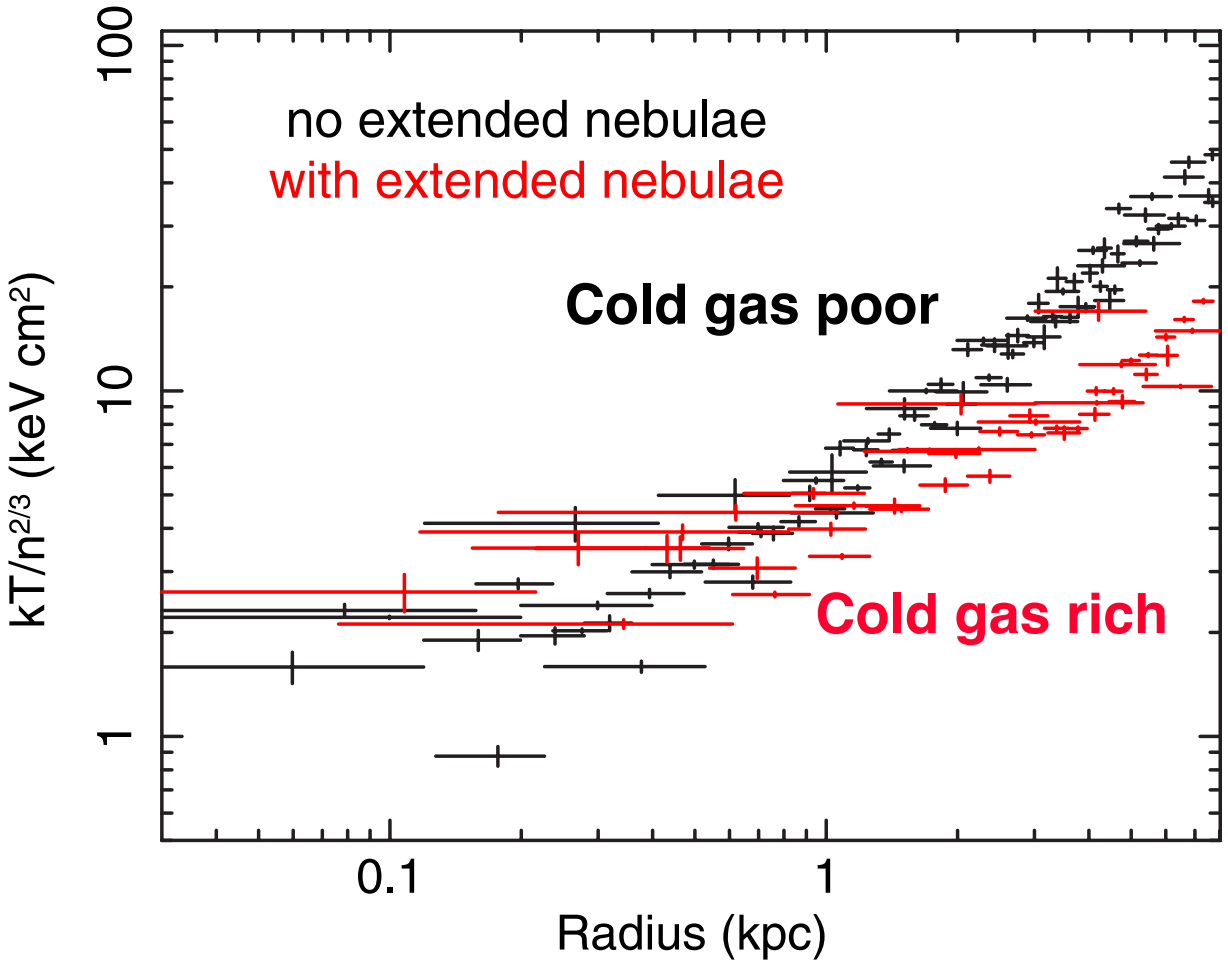
[C II] < 100 K







Hot gas properties



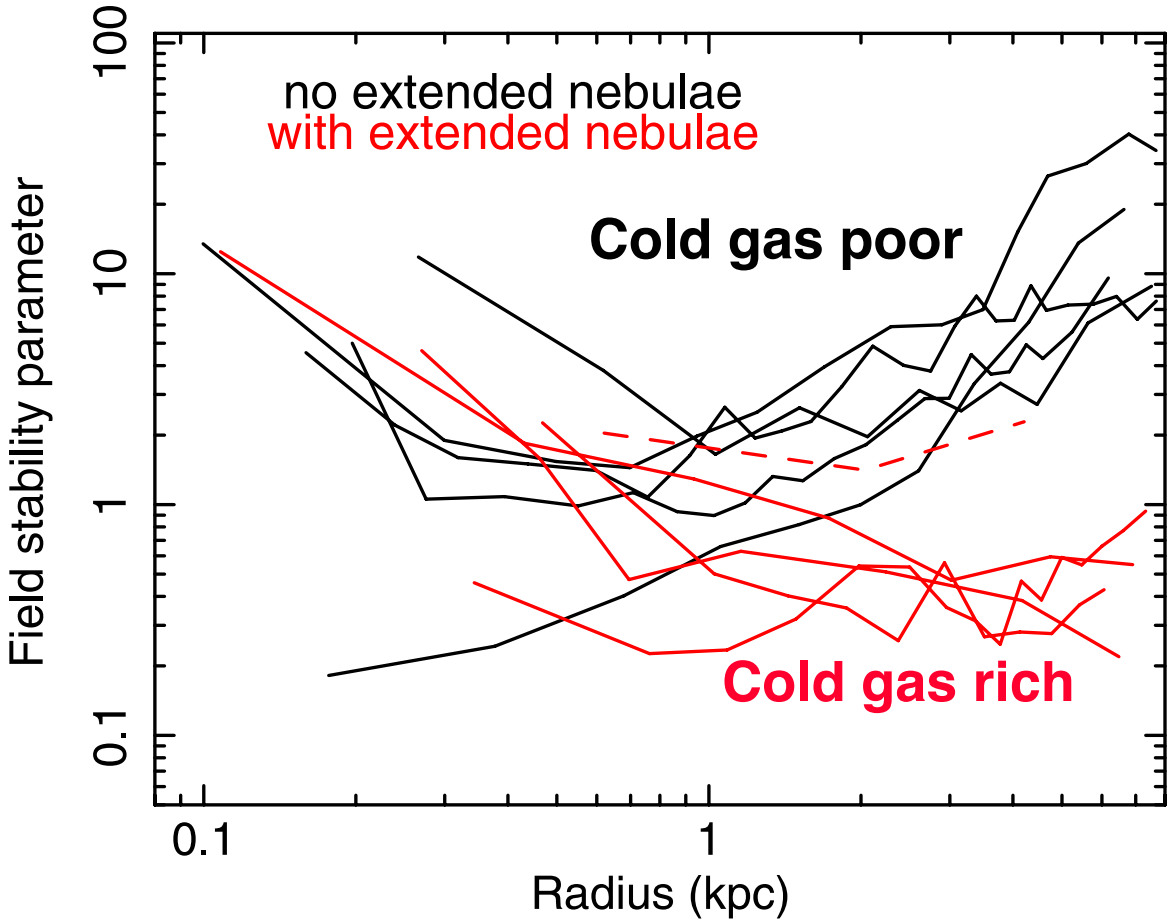
Cold gas poor - relaxed X-ray morphology - gas peak on AGN

Cold gas rich - disturbed X-ray morphology - gas peak off AGN

Outside of 1 kpc, the entropy of systems containing cold gas is lower

Werner et al. 2014

Hot gas properties



The Field stability parameter, defined as

$$\Pi_{\rm F} = \frac{\kappa T}{n_{\rm e} n_{\rm H} \Lambda(T) r^2}$$

is the ratio of the conductive heating to the radiative cooling rate.

There is a dichotomy with the cold-gas-rich system remaining unstable out to relatively large radii.

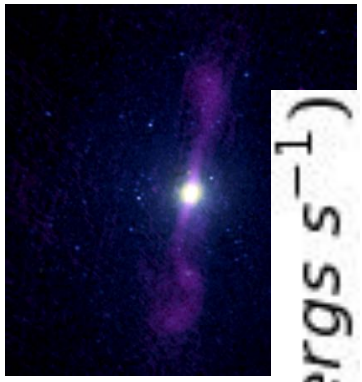
Cold gas cools unstably from hot ICM

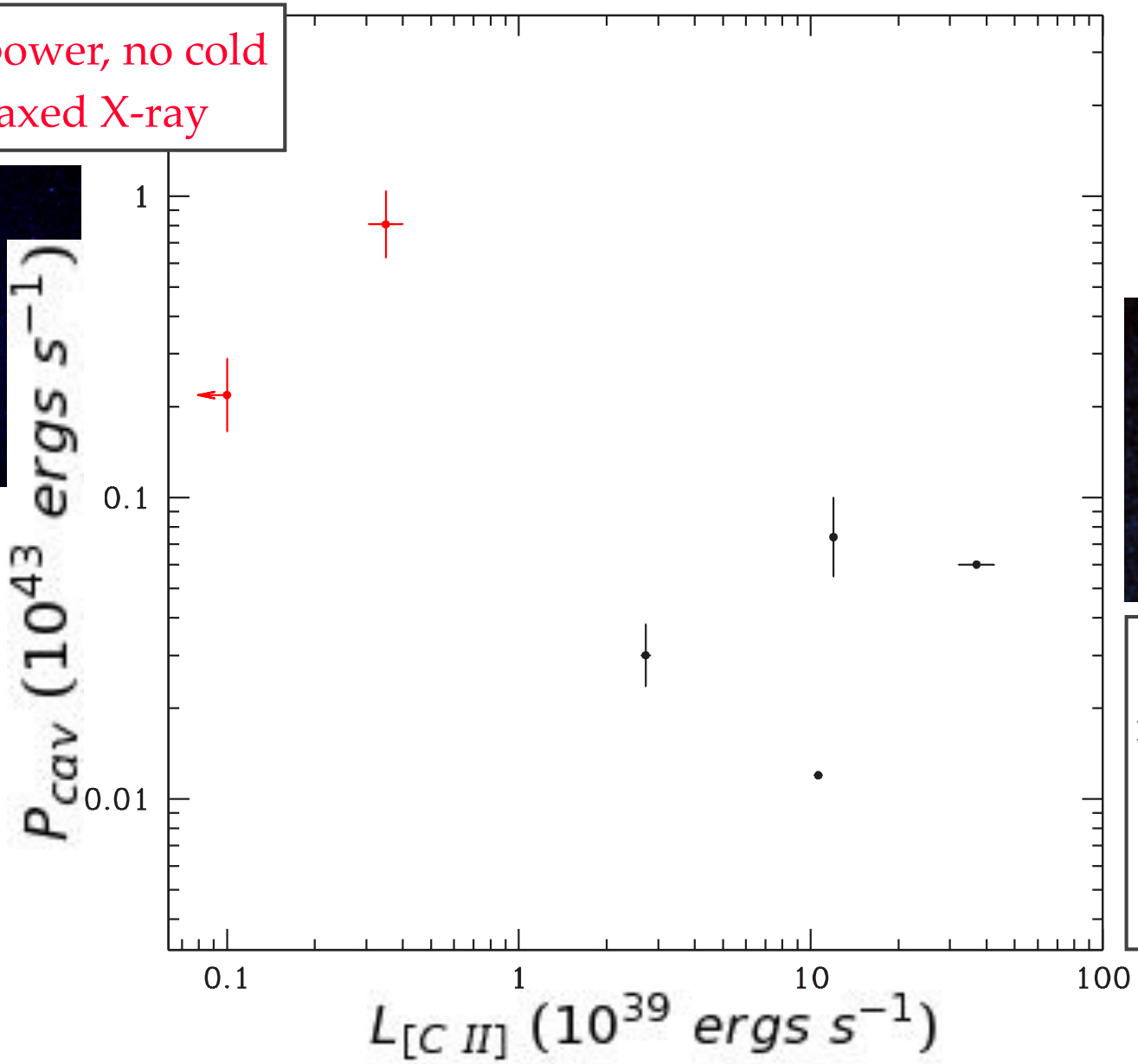
How is gas coupled?

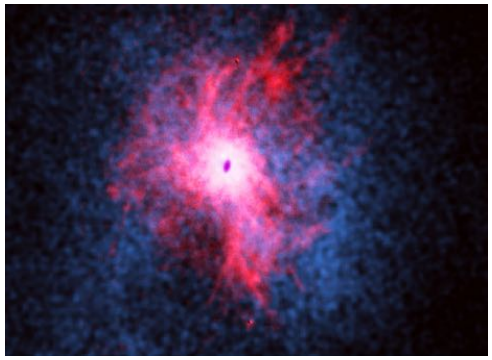
Werner et al. 2014

How is hot and cold gas coupled?

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

How is hot and cold gas coupled?

Two scenarios:

1. Relaxed -> dense X-ray gas
Stable if cavity power = X-ray luminosity
If gas is disturbed -> Jets shut off
Energy input decreases -> Gas becomes unstable and cools
Eventually system relaxes and jets switch on
-> AGN strongly coupled to hot gas - potentially stable for long periods in cold-gas-poor phase

2. Disturbed system -> Aids cooling
AGN has more cold dense fuel -> Strong jets
Jets clear out cold gas -> Jets at larger radius so energy deposited farther from BH
Hot gas able to cool again
-> AGN strongly coupled to cold gas - but must see intermediate states

Interplay of cold and hot gas in Early-Type Galaxies

Initial SOFIA proposal: 6 new systems traced in [C II]

1. Does cold gas cool from the X-ray gas?

2. Is the rate at which gas cools affected by the dynamics of the hot gas?

3. How is the AGN fed?

4. At what mass does the radio-mode feedback cycle break?

Summary

1. X-ray observations of the gaseous halos of ETGs holds information about their evolution.

2. Massive galaxies can be cold and cool gas rich, yet still lack star formation, and this gas likely originates from the hot gas.

3. Hot gas may be important in feeding the AGN and is fundamental to the feedback cycle.

Thanks!