Triggering of AGN Feedback

The Plan

1 The Threshold for Triggering

2 Multiphase Gas & Feedback

3 Bimodality & Regulation

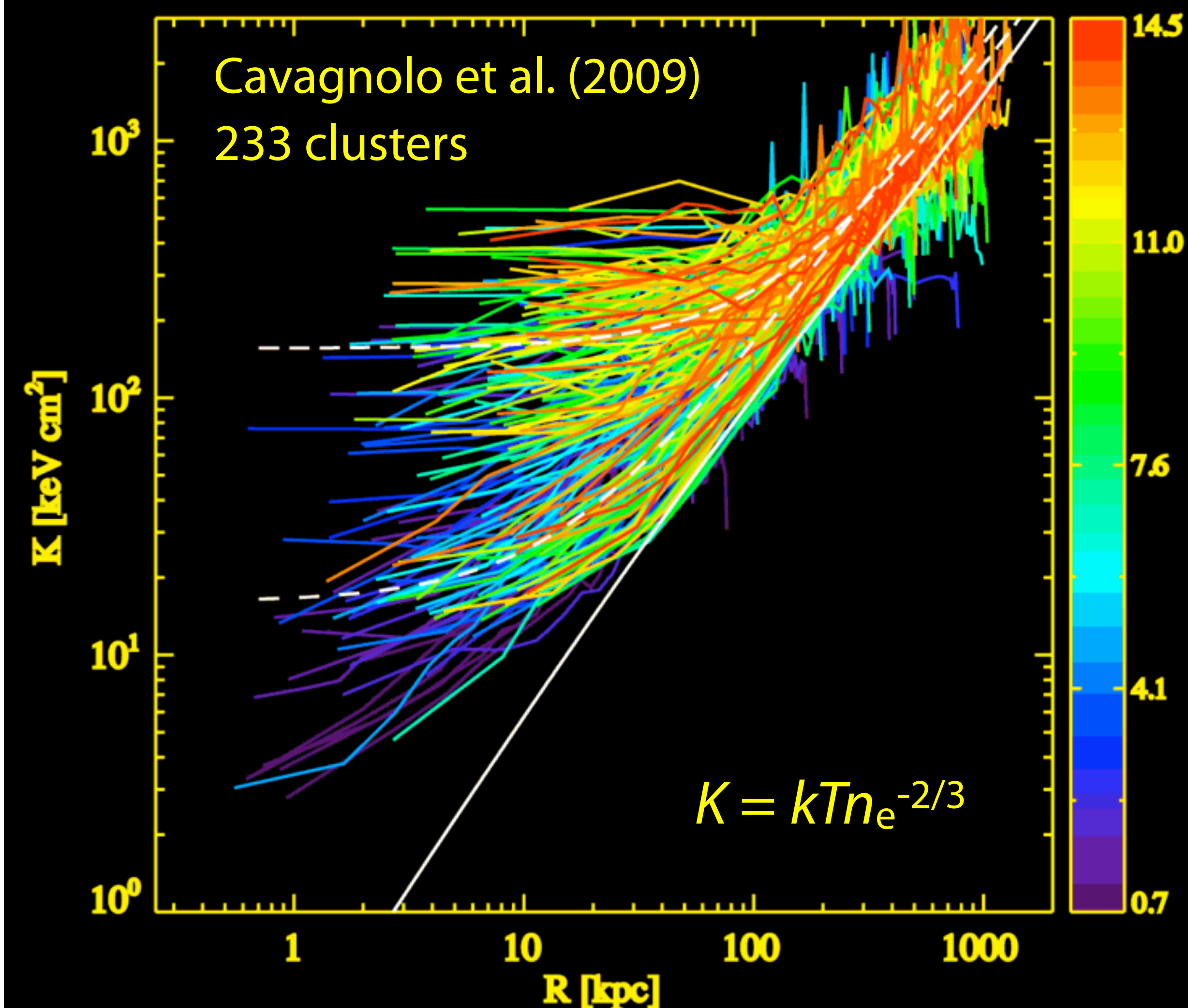
1

The Threshold for Triggering

1 *Message*

- AGN feedback, star formation, & multiphase gas all appear in cluster cores at the same threshold in central entropy & cooling time.
- AGN feedback & star formation probably share a common trigger.

Chandra Entropy Profiles



Most profiles are well fit with:

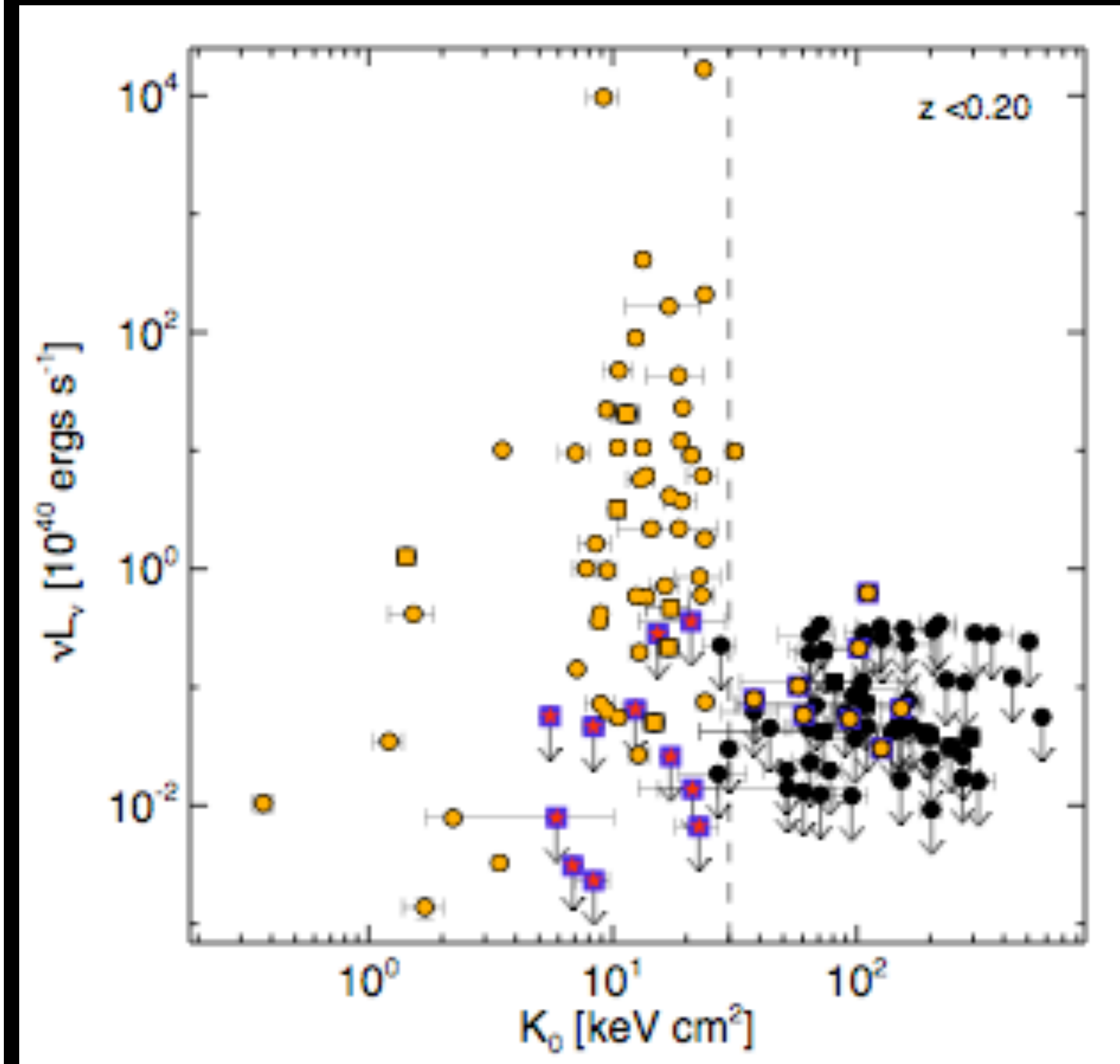
$$K(r) = K_0 + K_{100}\left(\frac{r}{100\text{ kpc}}\right)^{\alpha}$$

$K_{100} \sim 150$ keV cm^2

$\alpha \sim 1.2$

Pure cooling model is lower limit to observed profiles

K_0 and Radio Power



Central galaxy of a $z < 0.2$ cluster can be a strong radio source only if

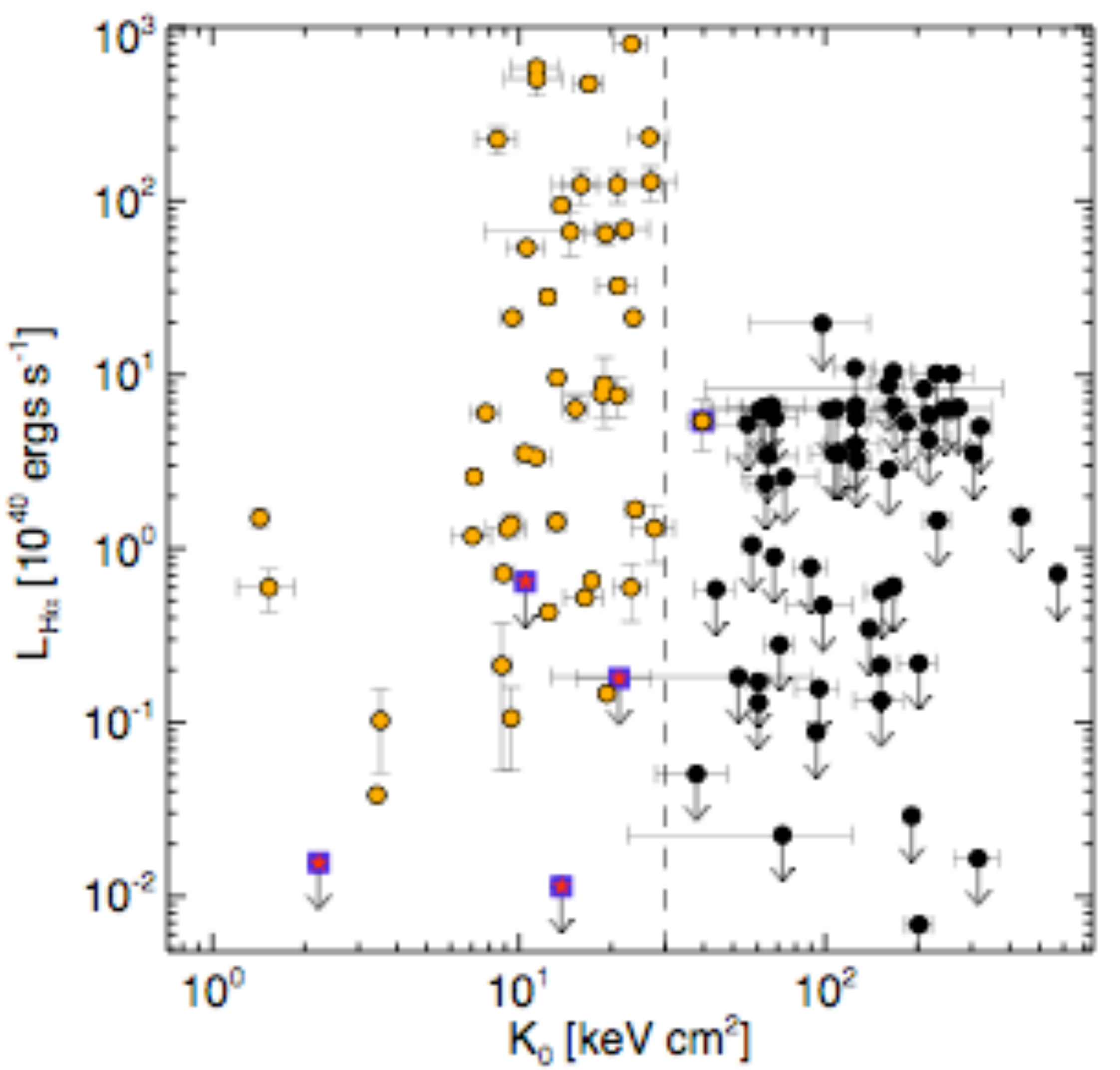
$K_0 < 30$ keV cm^2

Radio data from NVSS +SUMMS within 20″ of X-ray peak

Cavagnolo et al. (2008)

See also Dunn & Fabian

K_0 and Hα Emission



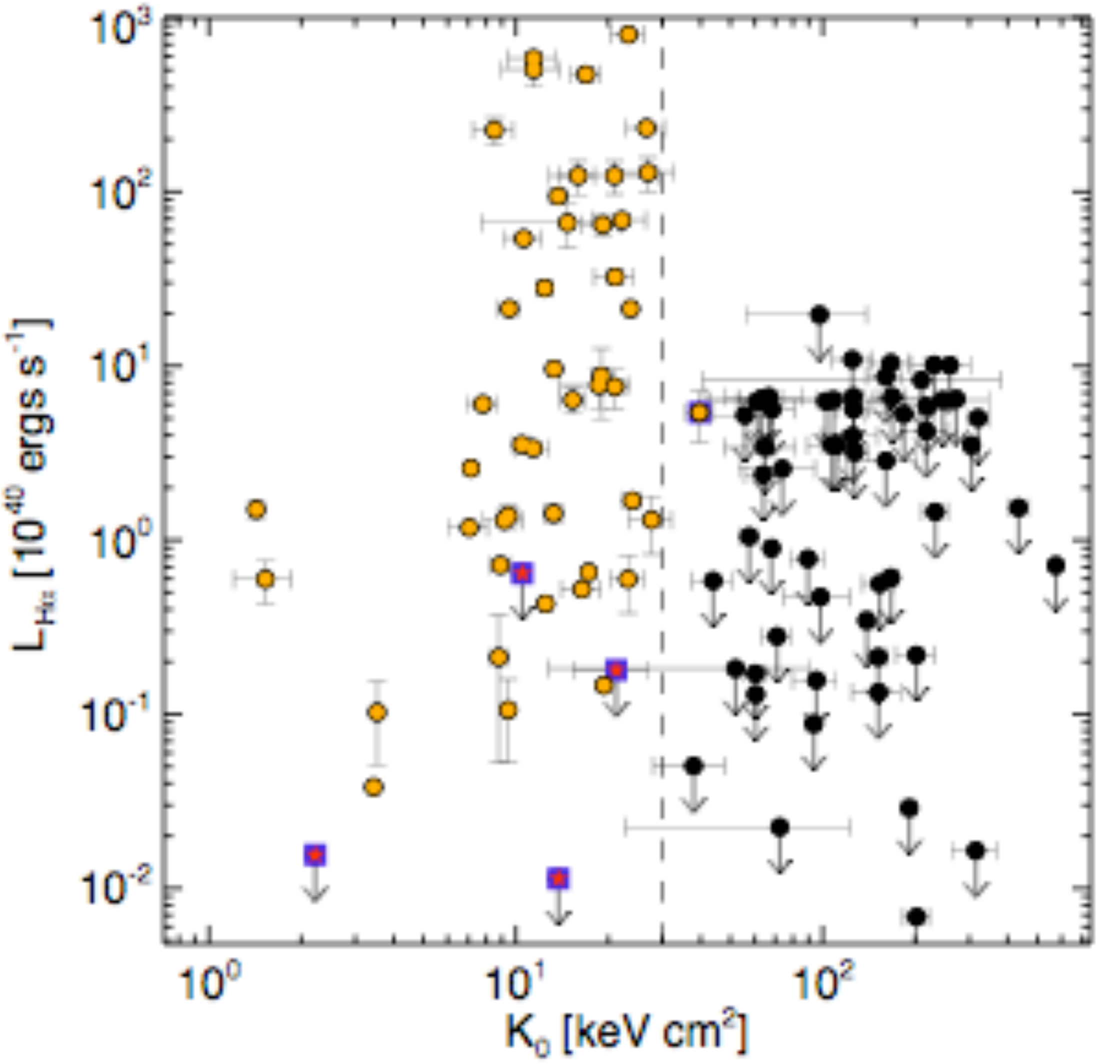
Central galaxy can have emission-line nebulosity only if

$K_0 < 30$ keV cm^2

Hα data from many diverse sources

Cavagnolo et al. (2008)

K_0 and Hα Emission



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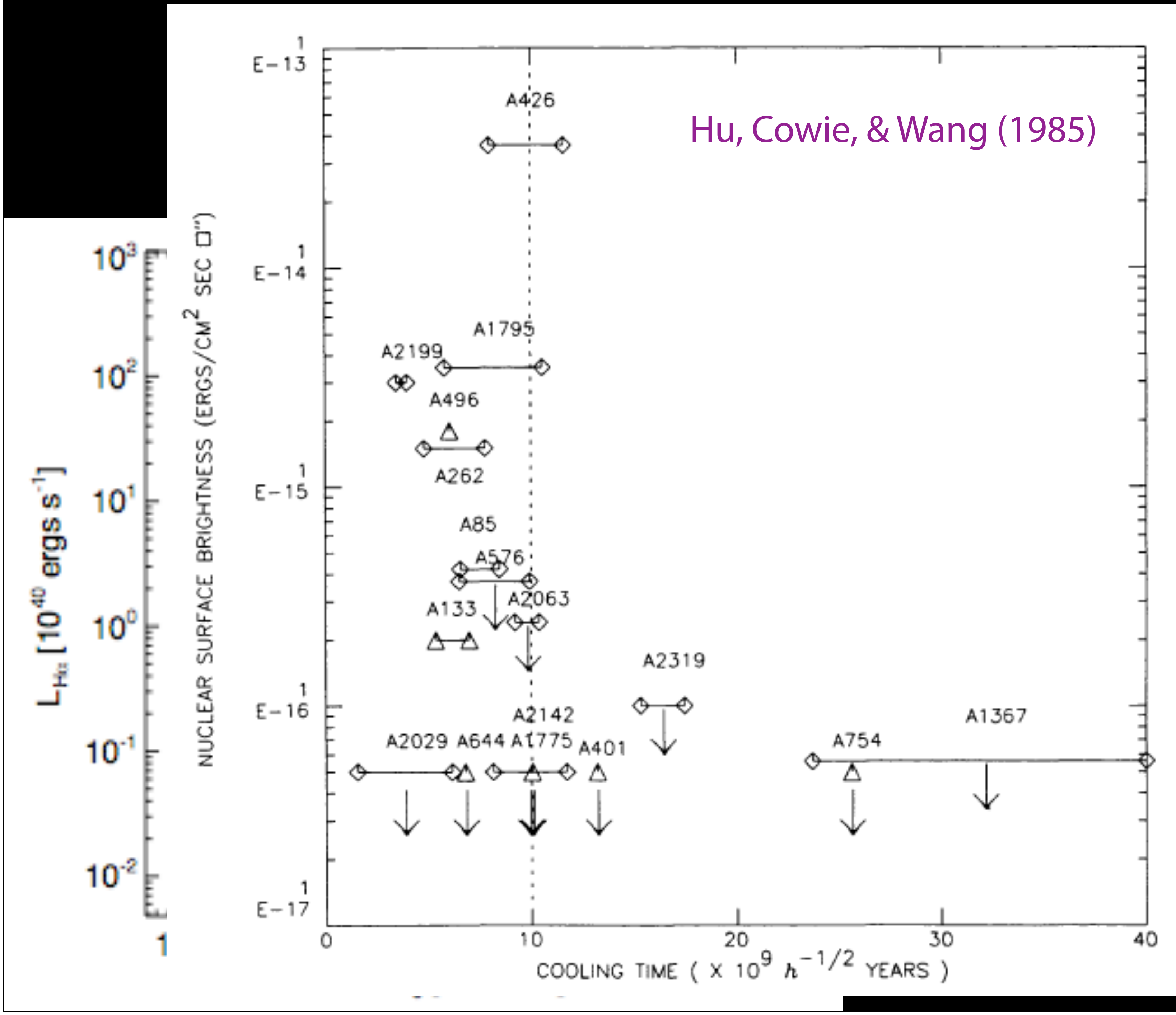
Hα data from many diverse sources

Cavagnolo et al. (2008)



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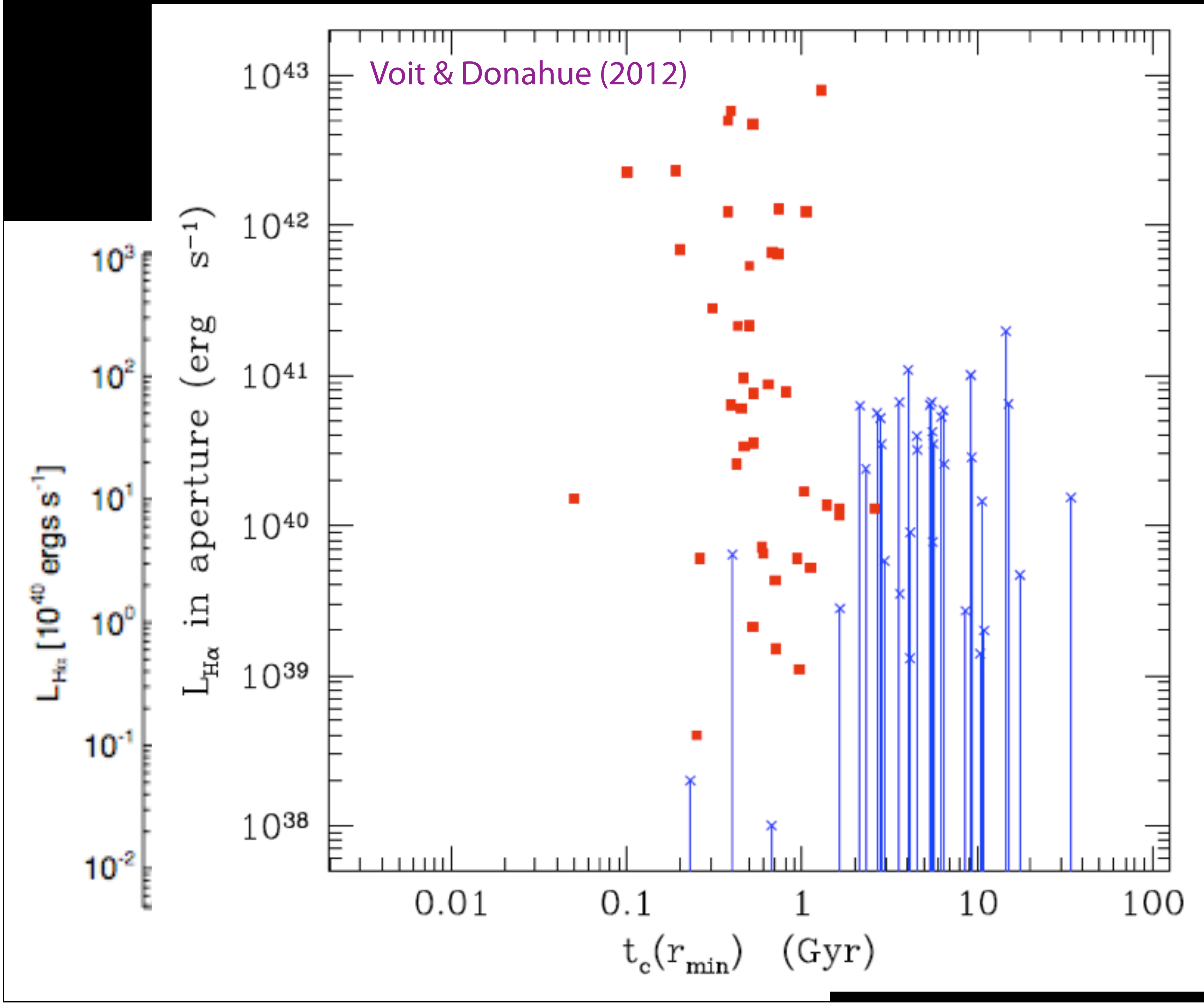
Voit & Donahue (2012)
$L_{H\alpha}$ in aperture (erg s^{-1})
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
0.01
0.1
1
10
100
$t_c(r_{min})$ (Gyr)
$L_{H\alpha}$ [10^{40} ergs s^{-1}]
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}

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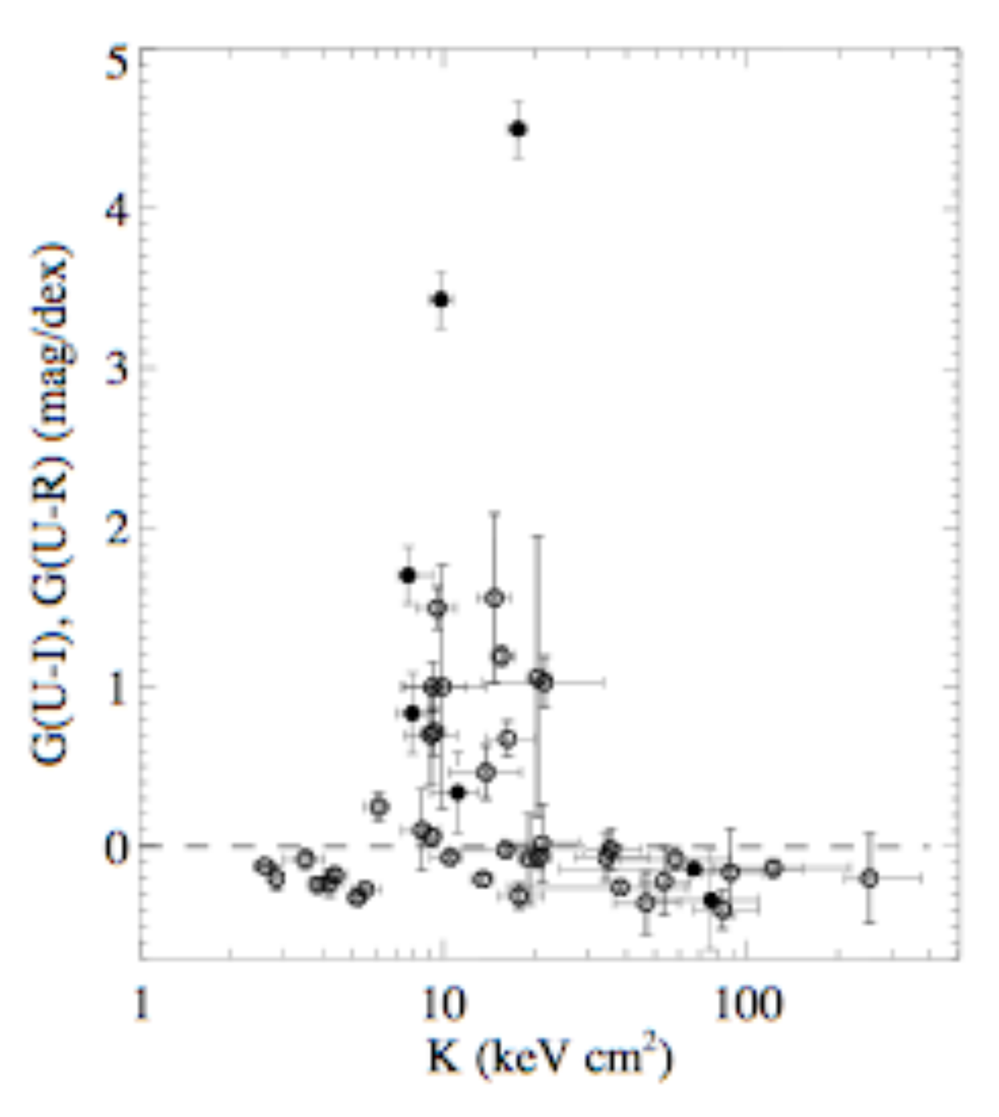
K_0 and Star Formation

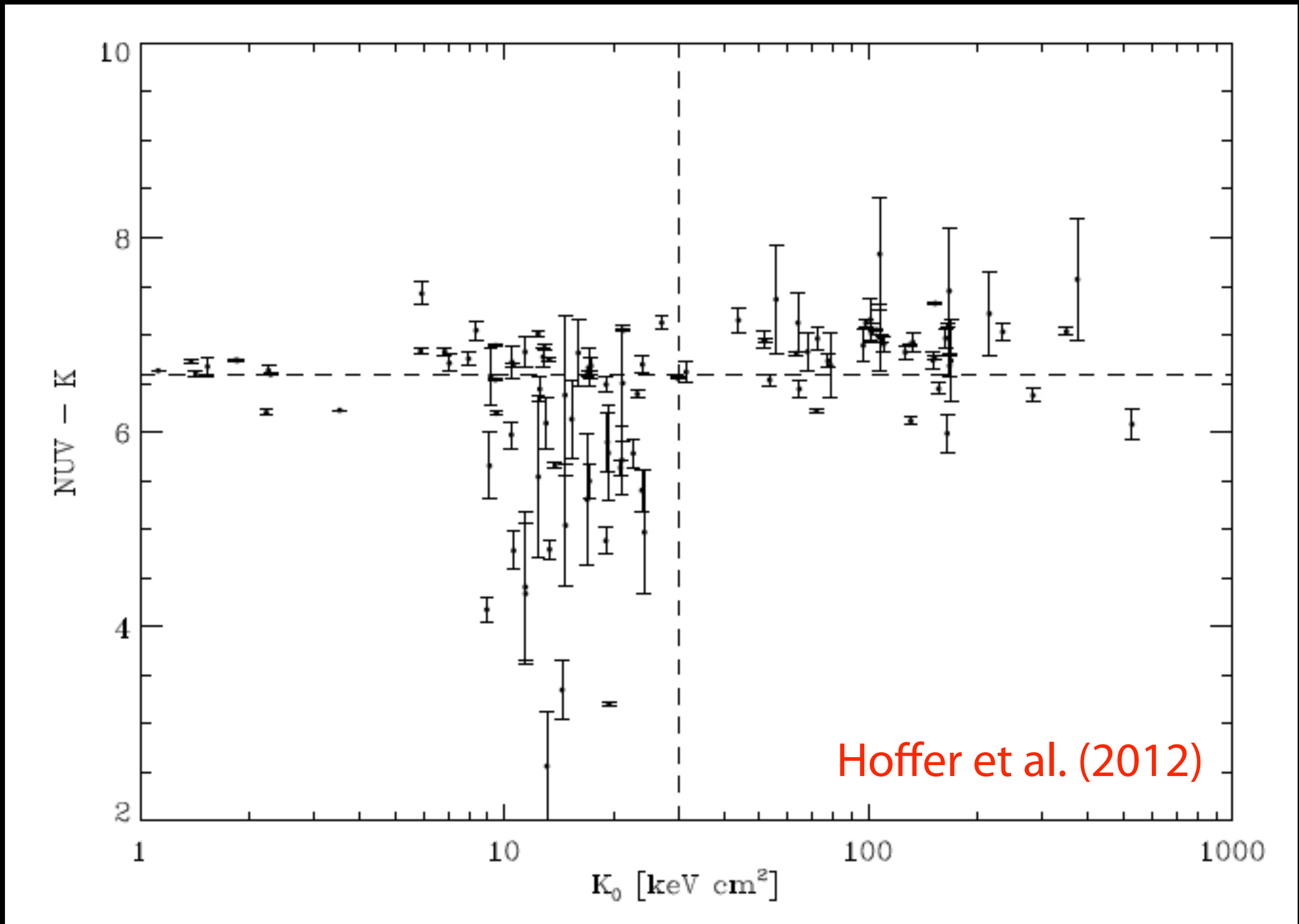


Central galaxy has blue core indicative of star formation only if

$K_0 < 30$ keV cm^2

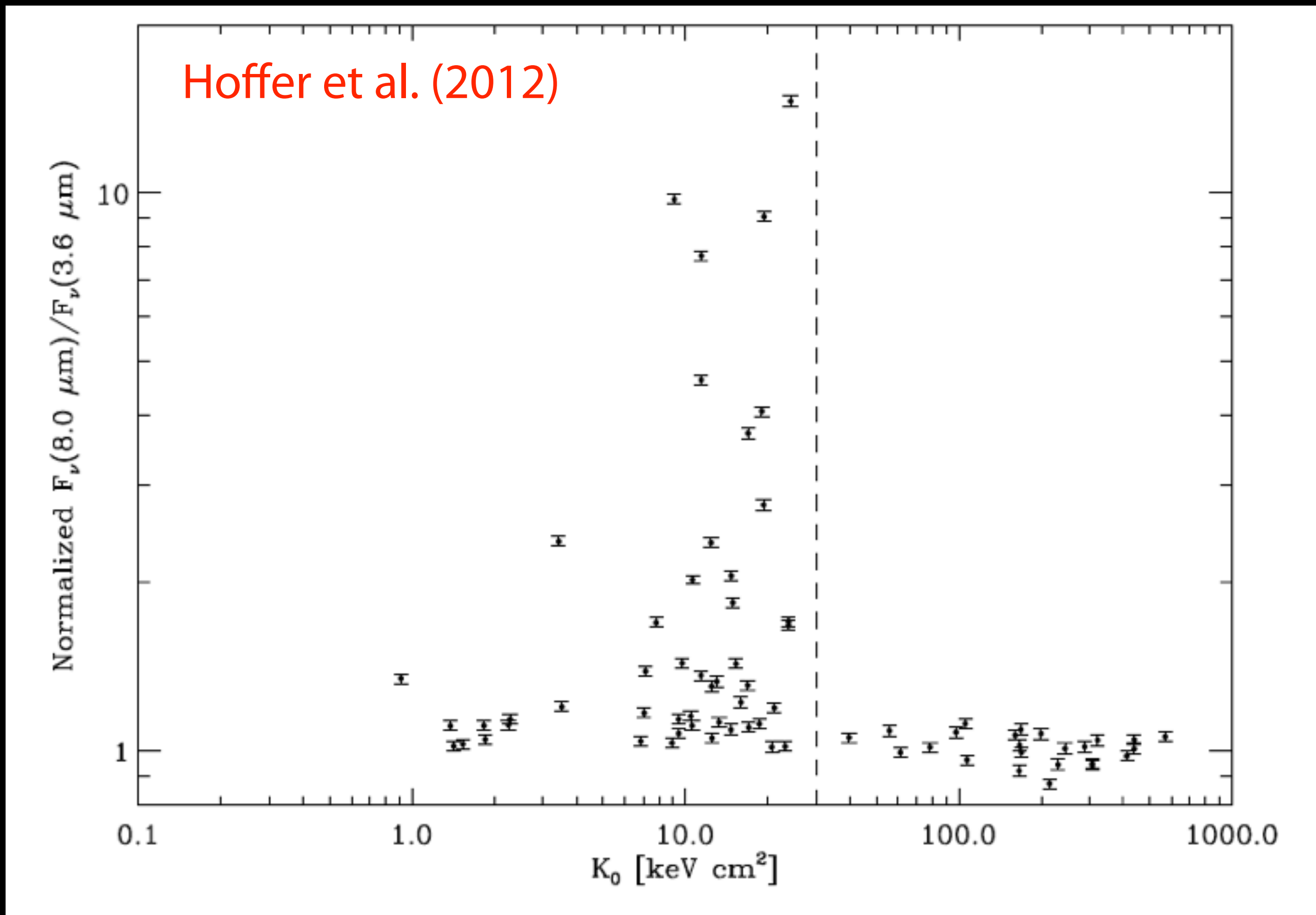
Rafferty+ 2008

K_0 and Star Formation



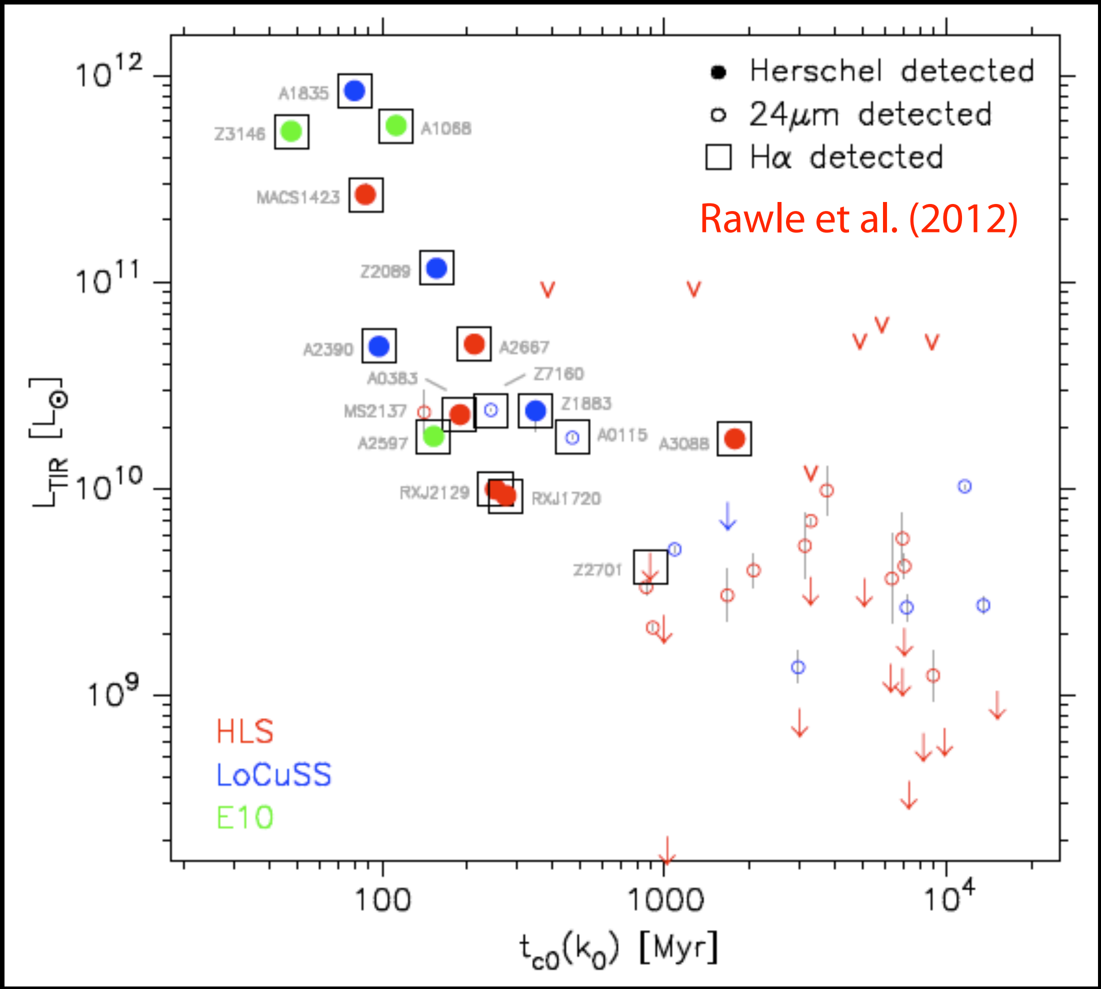
Central galaxy has excess UV emission only if $K_0 < 30$ keV cm^2

K_0 and Star Formation



Central galaxy has strong dust emission only if $K_0 < 30$ keV cm^2

K_0 and Star Formation



Central galaxy has strong dust emission only if $K_0 < 30$ keV cm^2

2

Multiphase Gas & Feedback

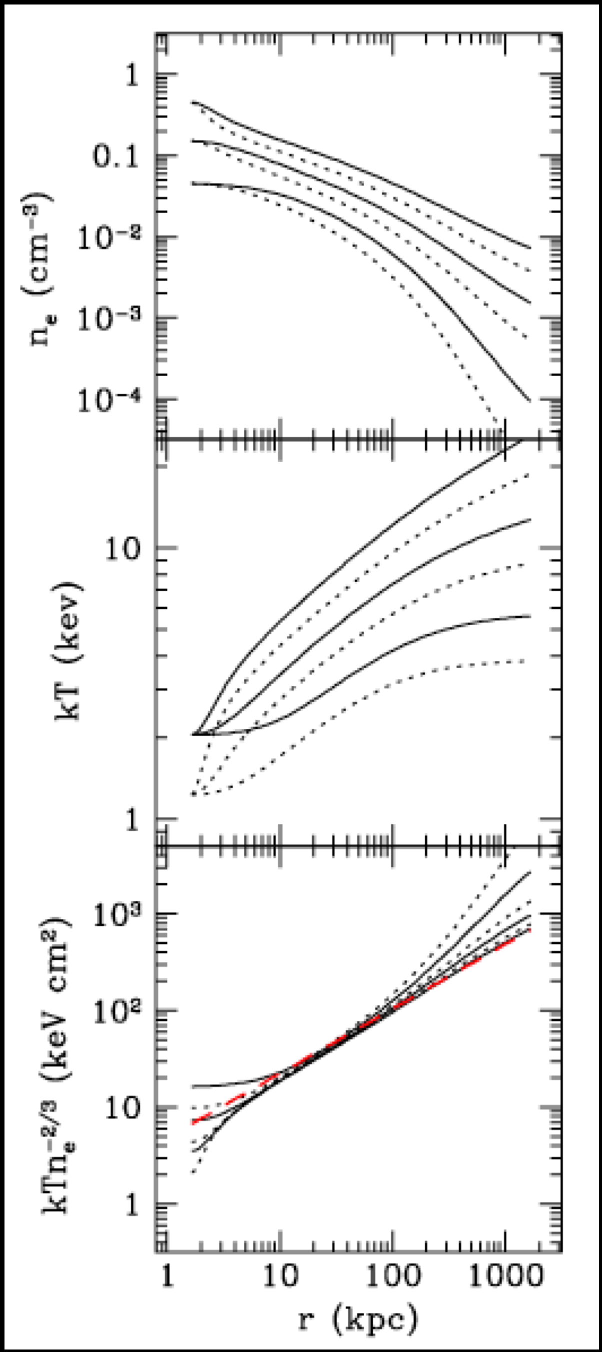
2 *Message*

- Conduction may prohibit multiphase medium in high-entropy cores.
- Short cooling times promote accumulation of cold gas.
- Dust implicates stellar mass loss as a source of cold gas.

Hypothesis 1

Thermal conduction determines whether a multiphase medium can develop at the centers of galaxy clusters.

(Voit+ 2008)

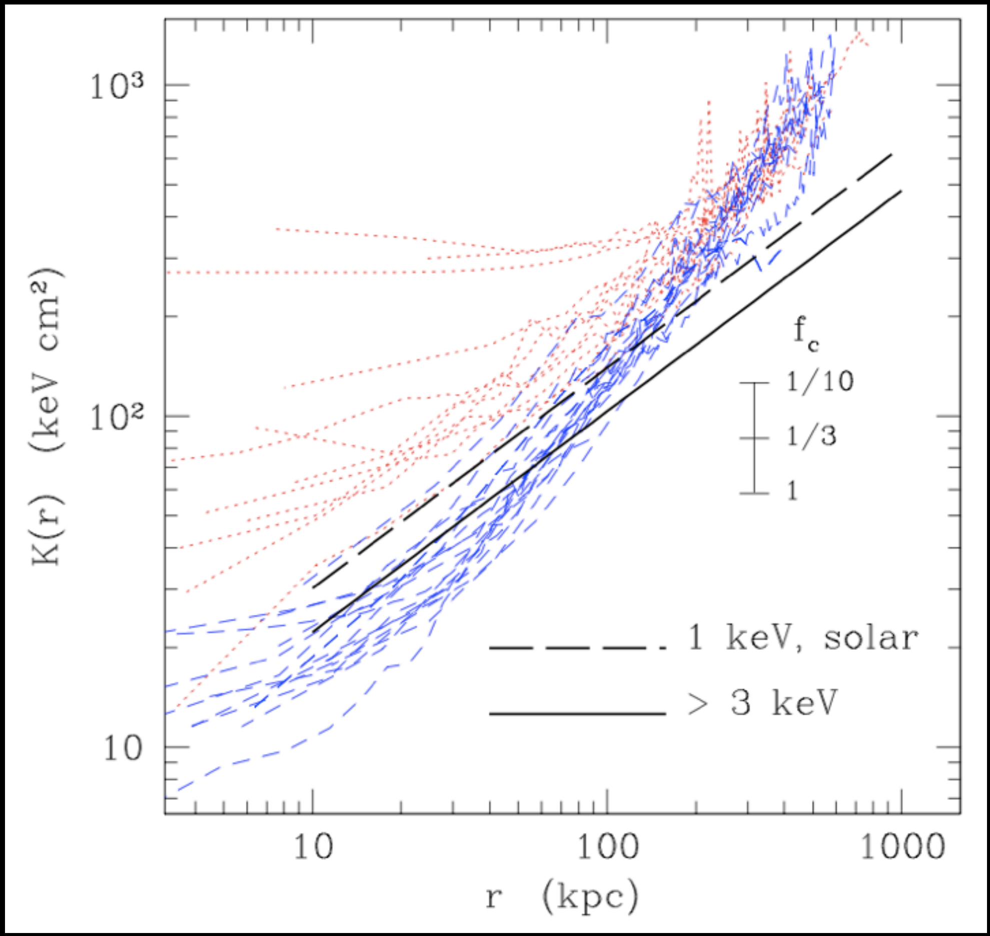


Conduction & Cooling

ICM configurations in which (isotropic) thermal conduction balances radiative cooling all follow same locus in the *r*-*K*(*r*) plane.

Voit 2011

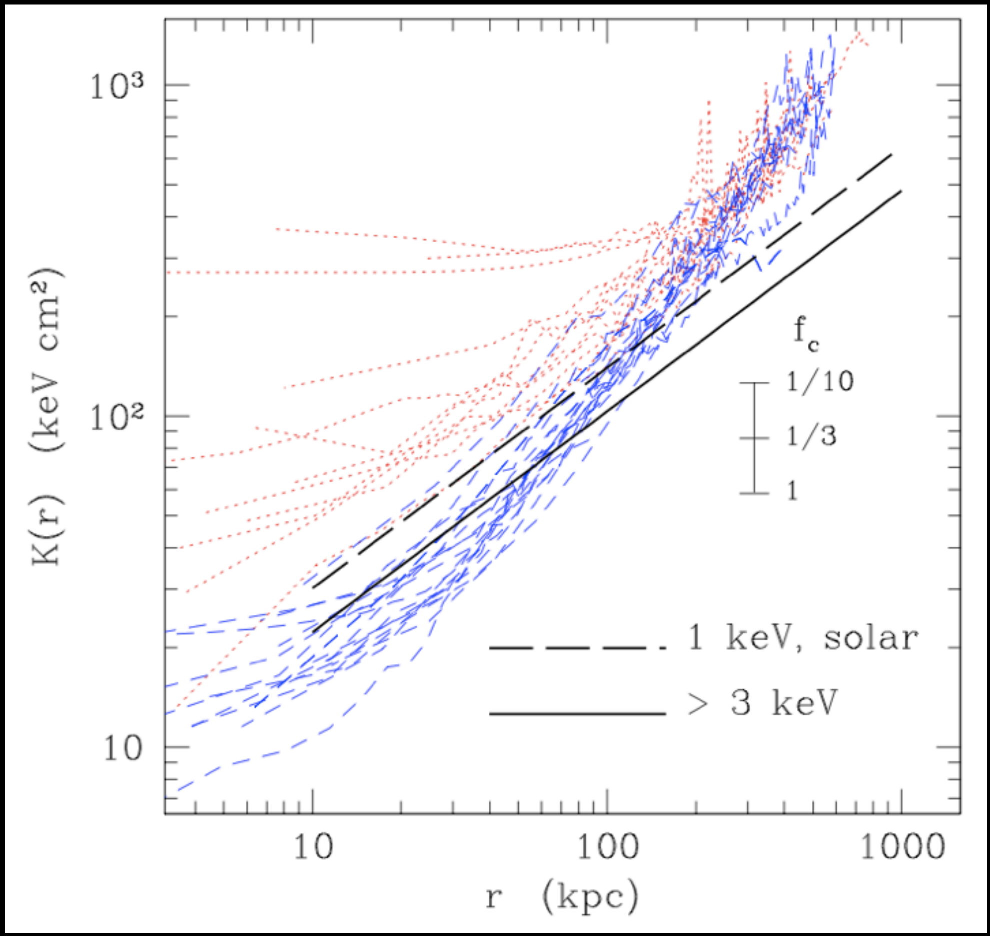
Conduction & Triggering



Voit 2011

Clusters with entropy profiles above the conductive locus with $f_c = 1/3$ are free of multiphase gas, plausibly because of conduction (and/or turbulent heat diffusion).

Conduction & Triggering



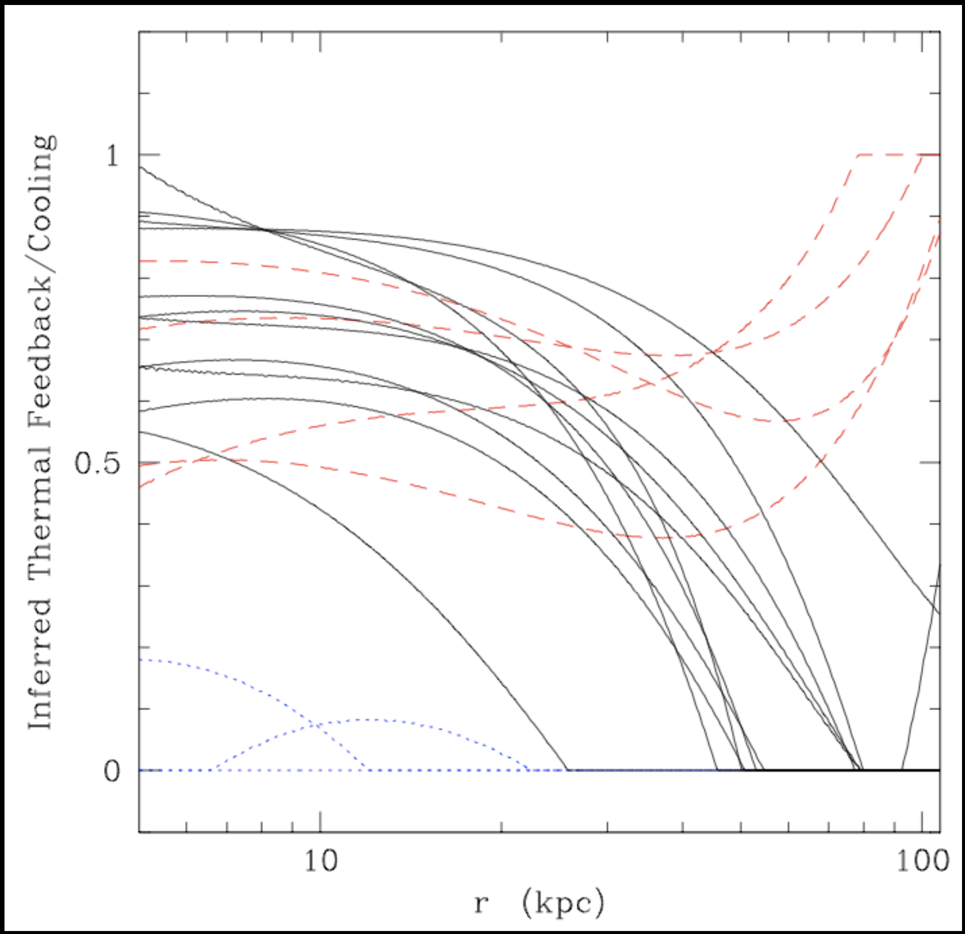
Voit 2011

Could the failure of conduction to prevent cooling in clusters below this locus be the switch that turns on AGN feedback?

See also:

Ruszkowski & Begelman 2002
Voigt & Fabian 2004
Guo+ 2008

Radial Distribution of AGN Heating



Voit 2011

If so, conduction may also be supplying most of the core heating at greater than ~30 kpc.

See also:

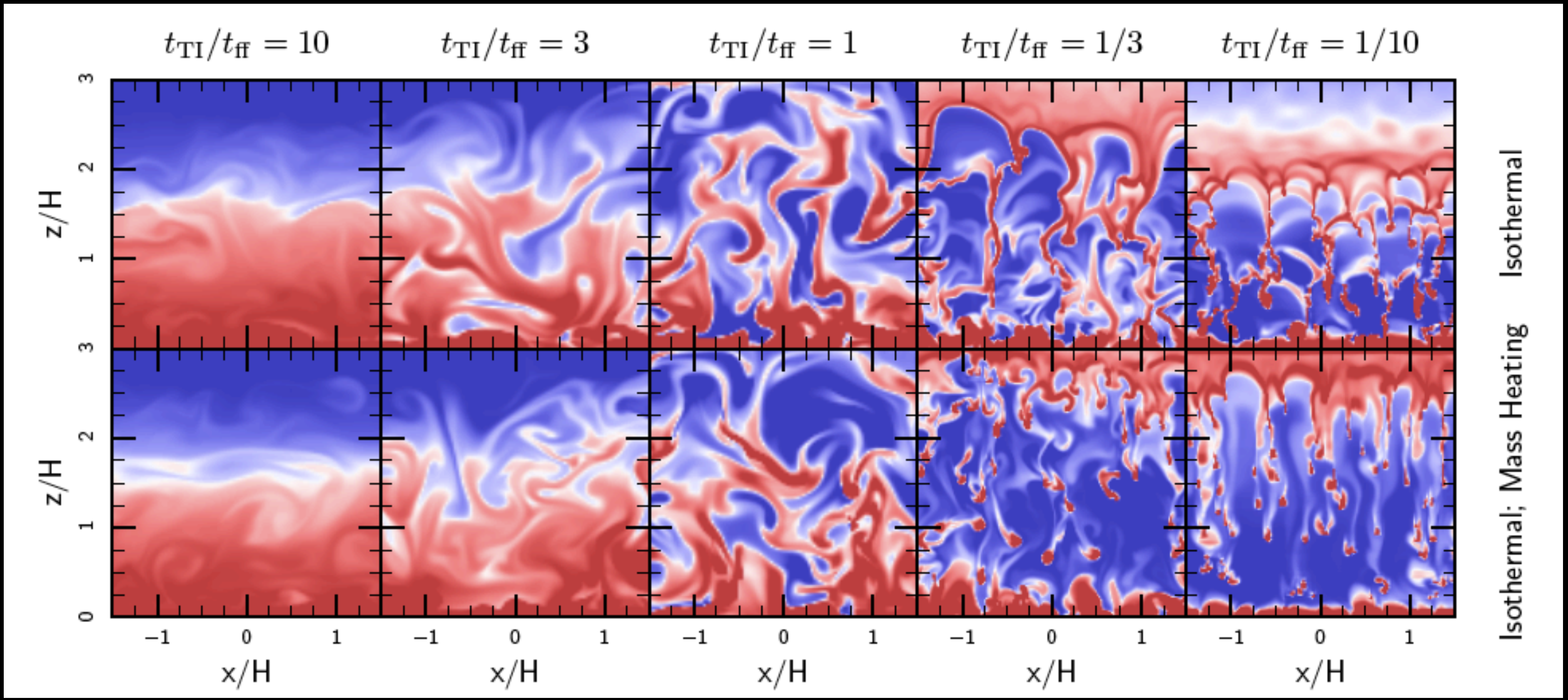
Ruszkowski & Begelman 2002
Voigt & Fabian 2004
Guo+ 2008

Hypothesis 2

Condensation of hot gas produces a multiphase intracluster medium when the ratio of cooling time to free-fall time becomes small enough.

(McCourt+ 2012; Sharma+ 2012; see also Soker 2008)

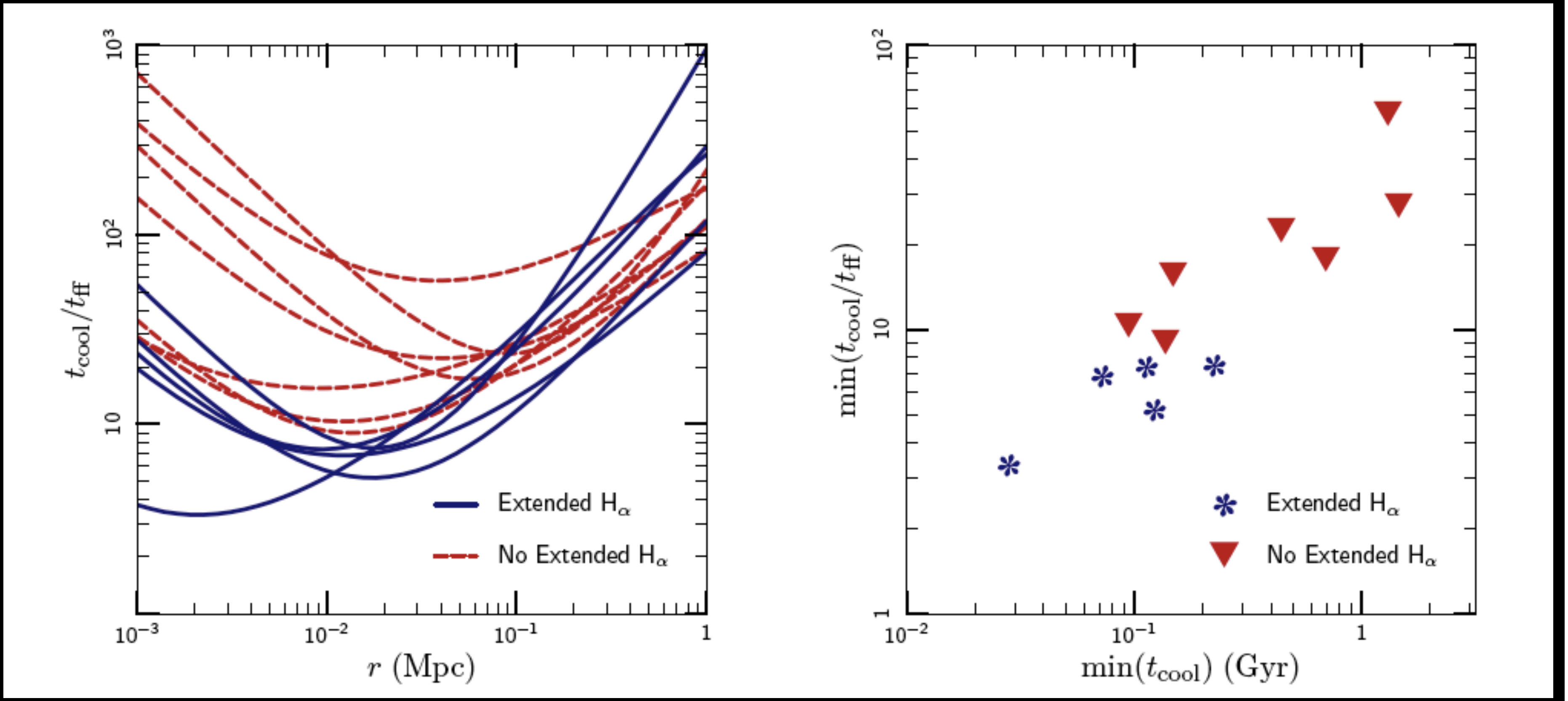
Instability & Multiphase Structure



McCourt+ (2012), Sharma+ (2012)

Feedback that maintains global balance can promote thermal instability if t_{cool}/t_{ff} is sufficiently small.

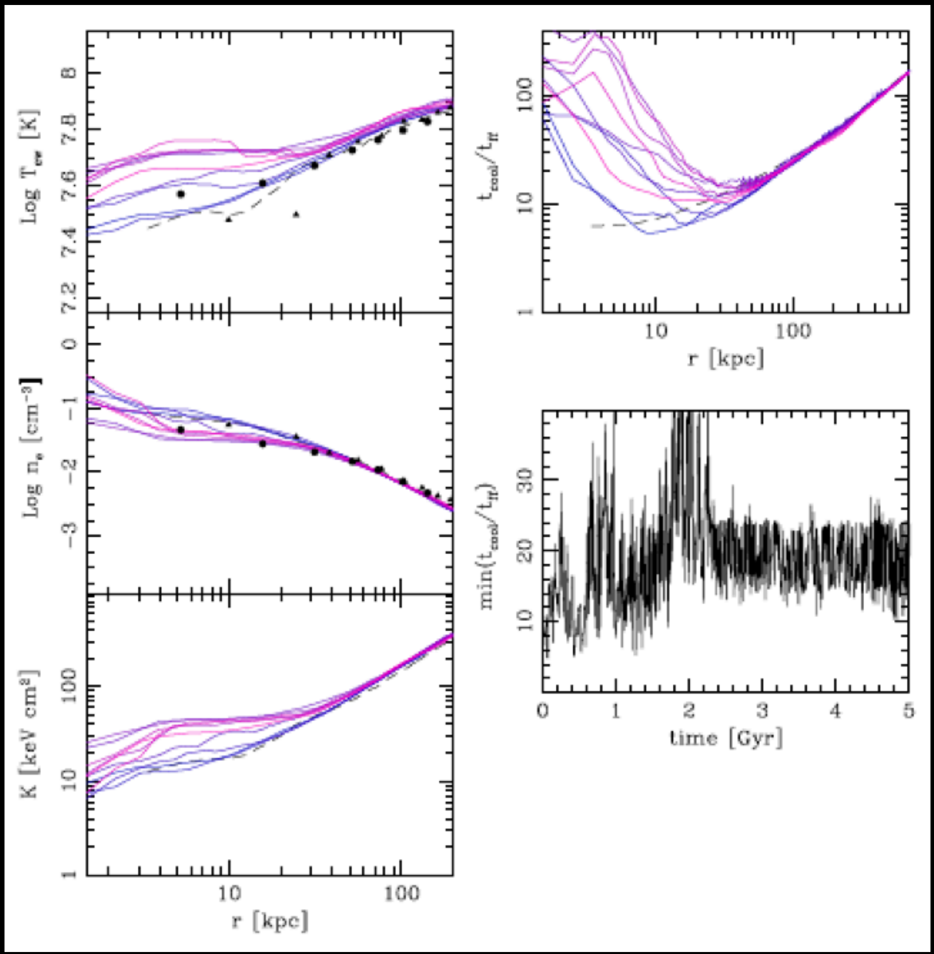
Instability & Multiphase Structure



McCourt+ (2012), Sharma+ (2012)

Threshold for thermal instability seems to be $t_{cool}/t_{ff} \sim 10$.

Simulations of Cold Feedback

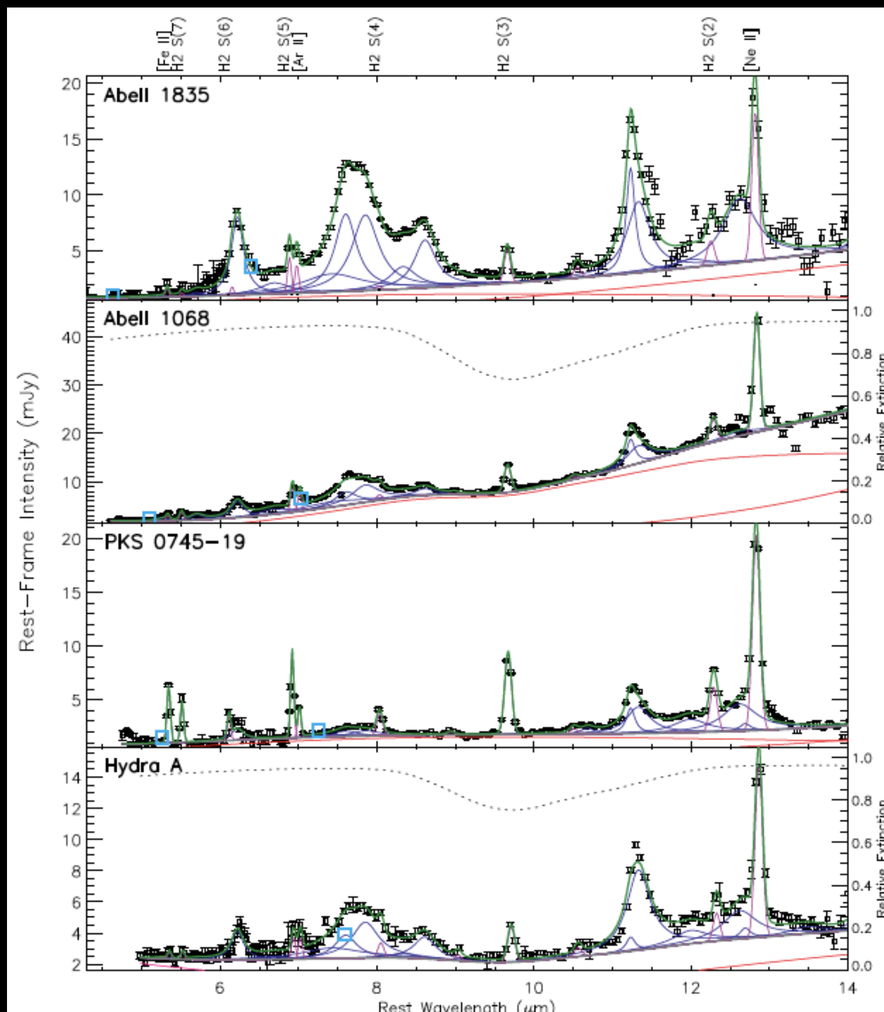


Gaspari+ (2012)

Simulations that feed AGN with condensed multiphase gas can naturally reproduce the observed structure of cluster cores.

But what about the dust?

Spitzer Spectroscopy of BCGs



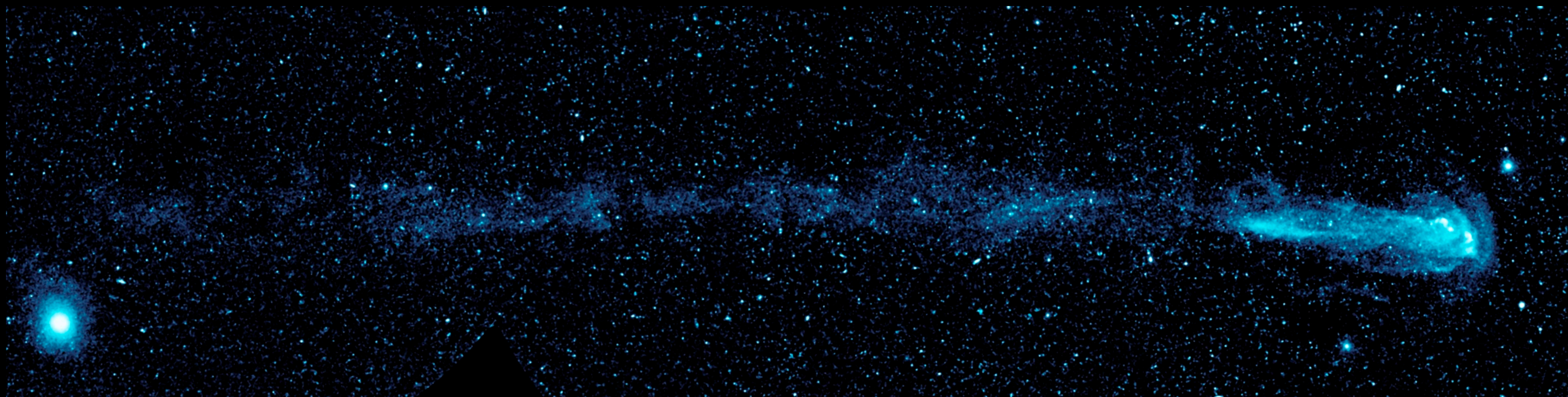
Donahue+ 2011

Dust emission from star-forming BCGs, including PAHs (!), resembles that of normal star-forming galaxies.

Can stripped cold clouds survive the ICM?

Could stellar mass loss be the main source of cold gas?

Mira GALEX Image

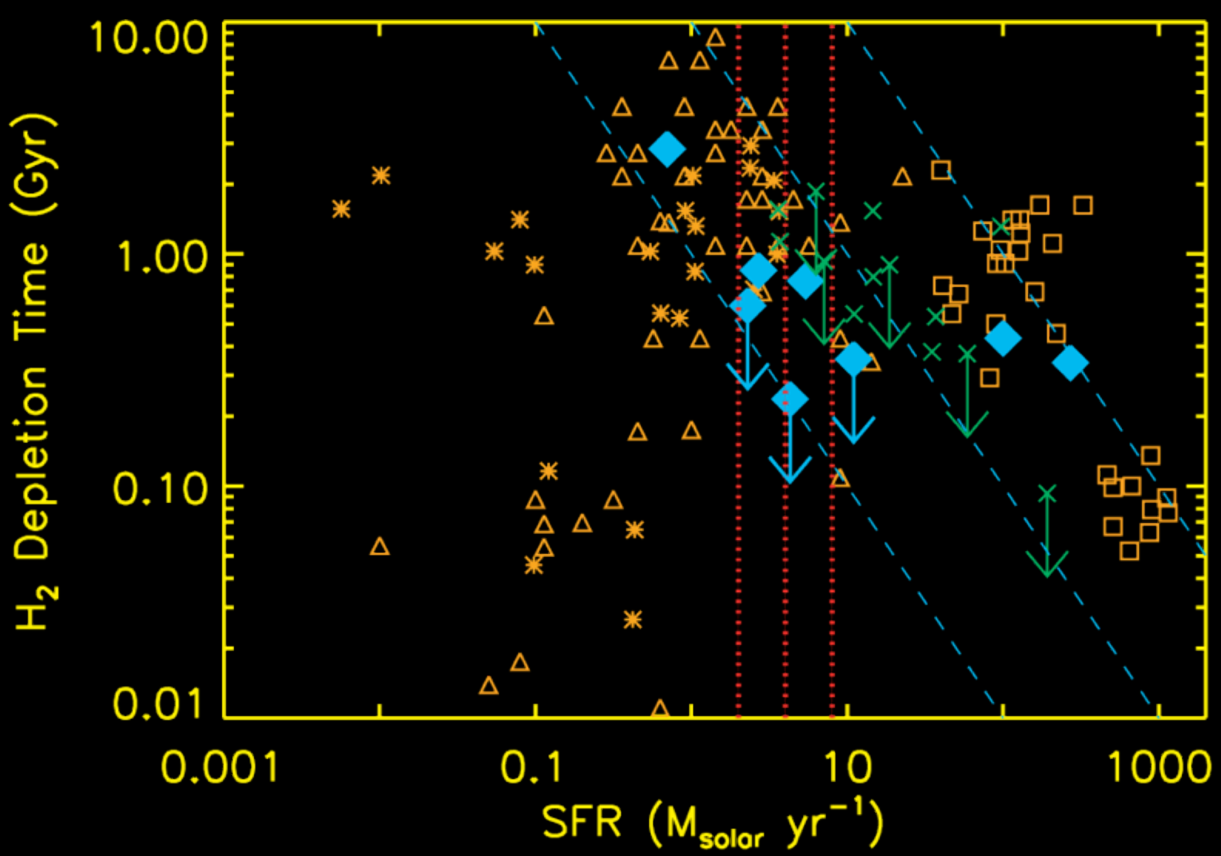


Martin+ 2007

Nearby mass-losing star Mira has an extended tail apparently made of molecular hydrogen.

Can gas lost by a central galaxy's stars remain cold for many Myr?

Stellar Mass Loss from BCGs



In most BCGs the star-formation rate does not exceed the stellar mass-loss rate — could it be an important source?

Voit & Donahue (2011)

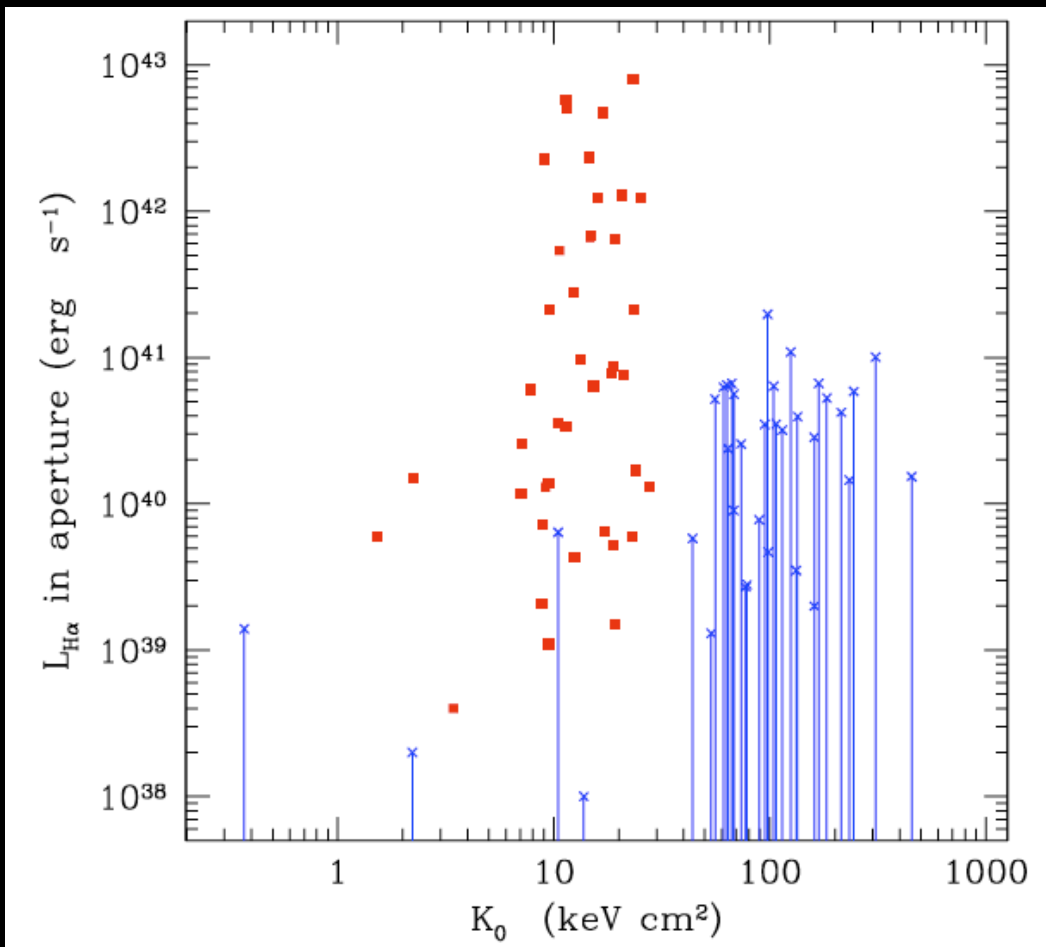
3

Bimodality & Regulation

3 *Message*

- K_0 more closely related to bimodality.
- Thermal instability more closely related to strength of feedback.

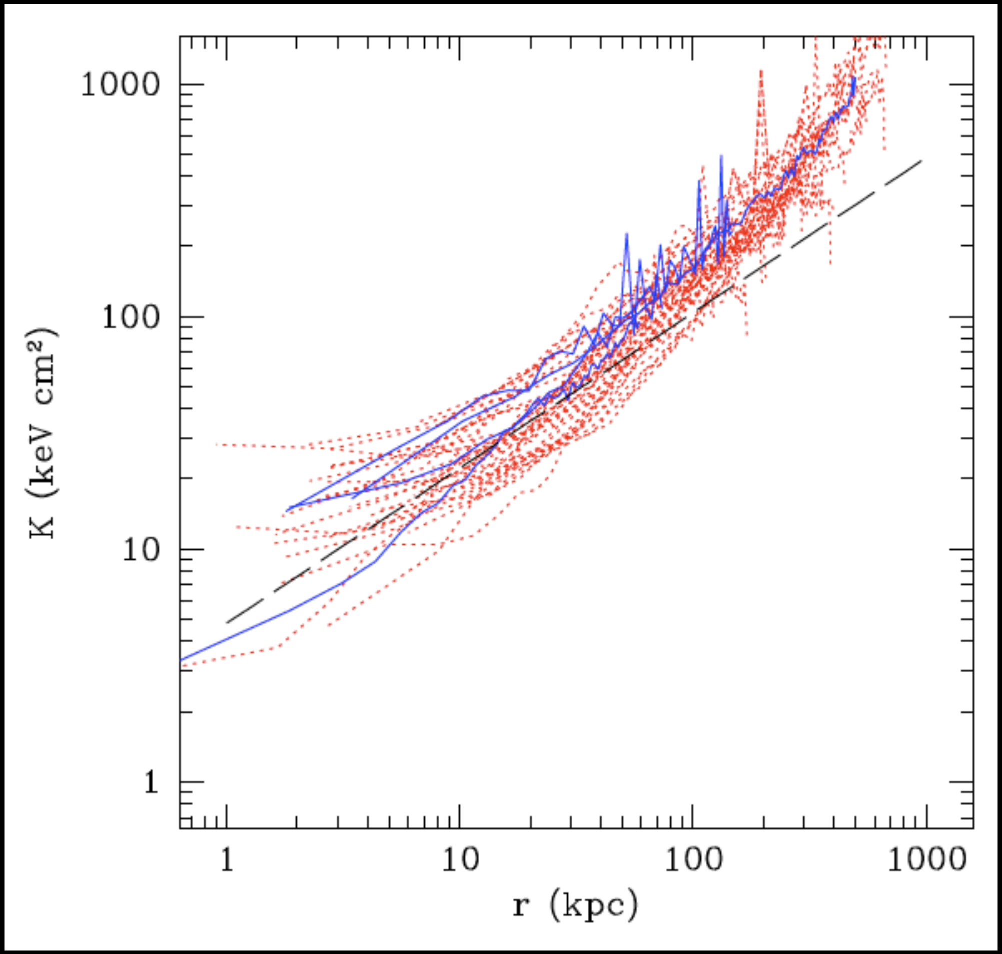
Core Entropy & Bimodality



Voit & Donahue (2012)

Presence of multiphase gas in *ACCEPT* clusters is directly related to K_0, with few exceptions.

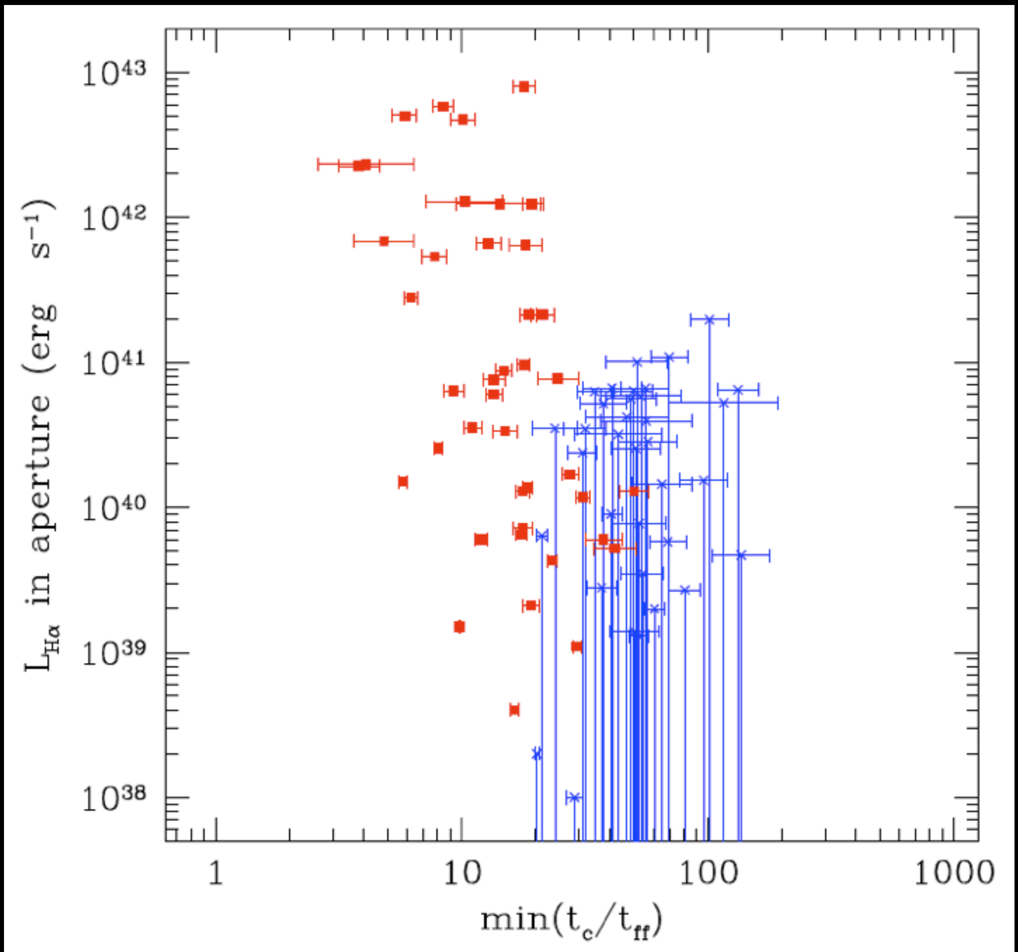
Core Entropy & Bimodality



Three of the four exceptions to the K_0 threshold have $K(r)$ profiles that remain in the conductively heated domain.

Voit & Donahue (2012)

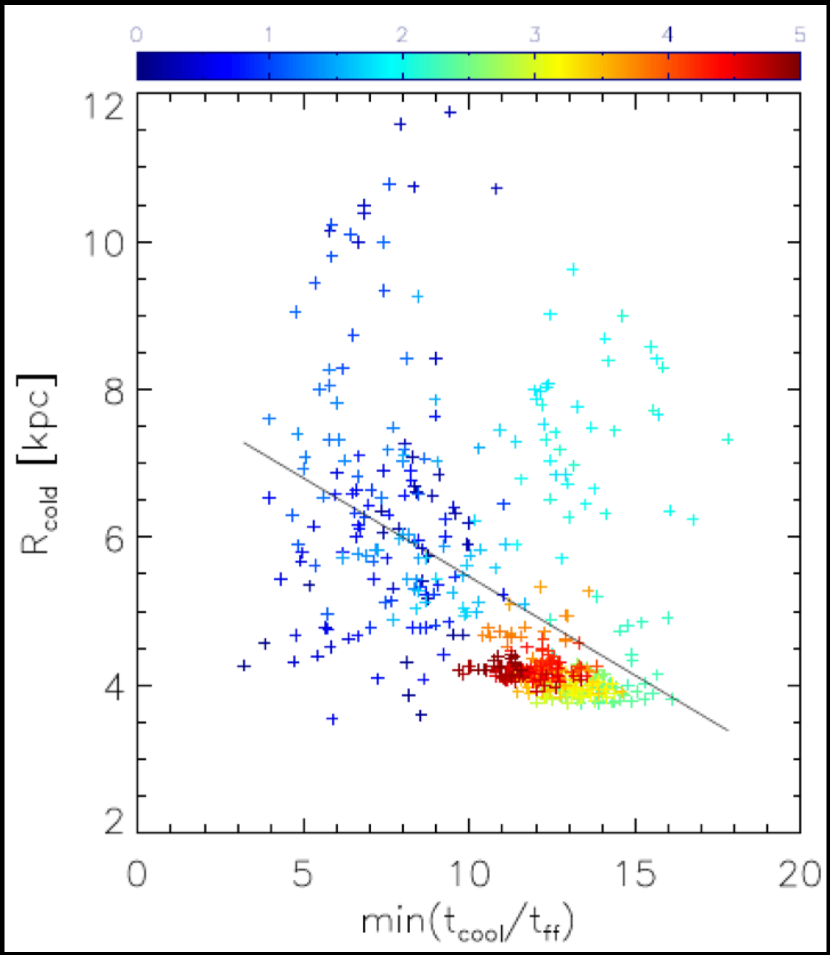
Thermal Instability & Feedback



Voit & Donahue (2012)

Prominence of line emission a strong function of susceptibility to thermal instability.

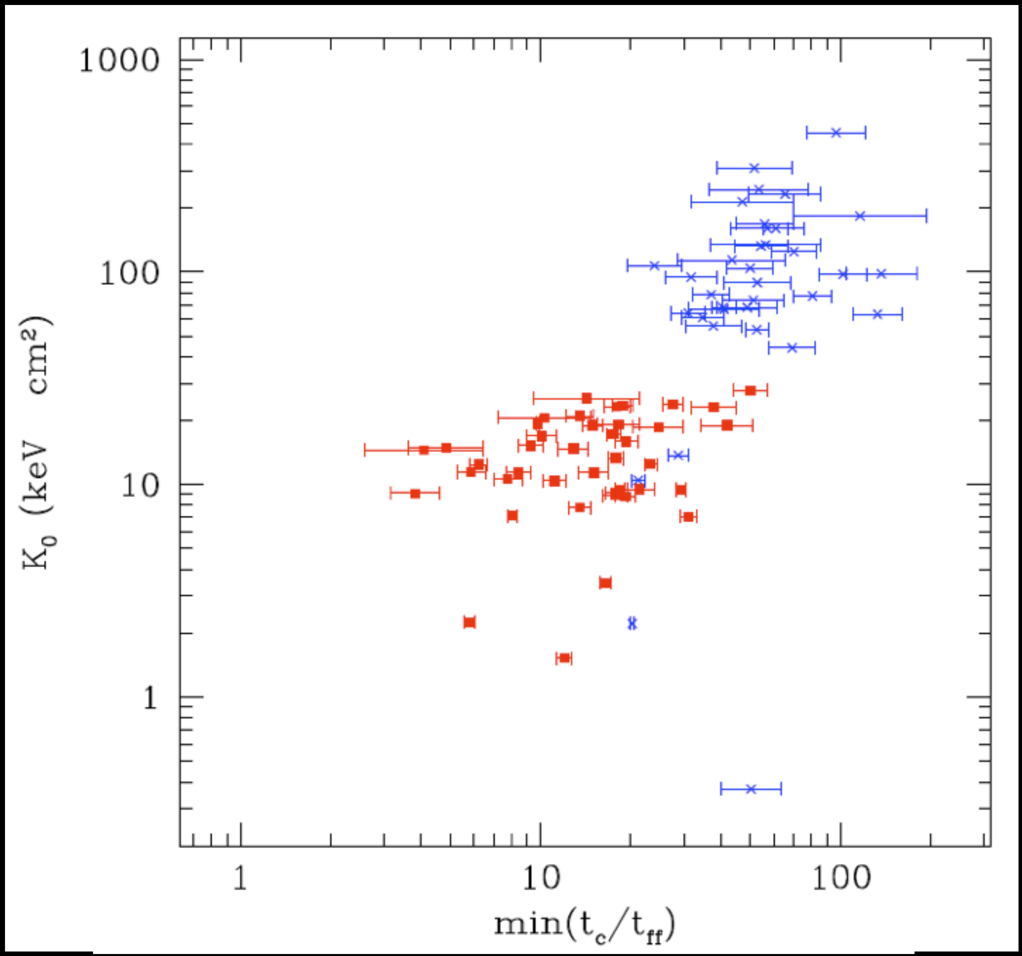
Thermal Instability & Feedback



Gaspari+ (2012)

Values of min(t_c/t_{ff}) in a simulated cluster stabilized by cold feedback span a range similar to that seen in the *ACCEPT* clusters with multiphase gas.

Thermal Instability & Feedback



Voit & Donahue (2012)

Data suggest:

(1) bimodality hinges on K_0 criterion, implicating conduction

(2) thermal instability regulates feedback.