Duty Cycle of Radio Mode Feedback

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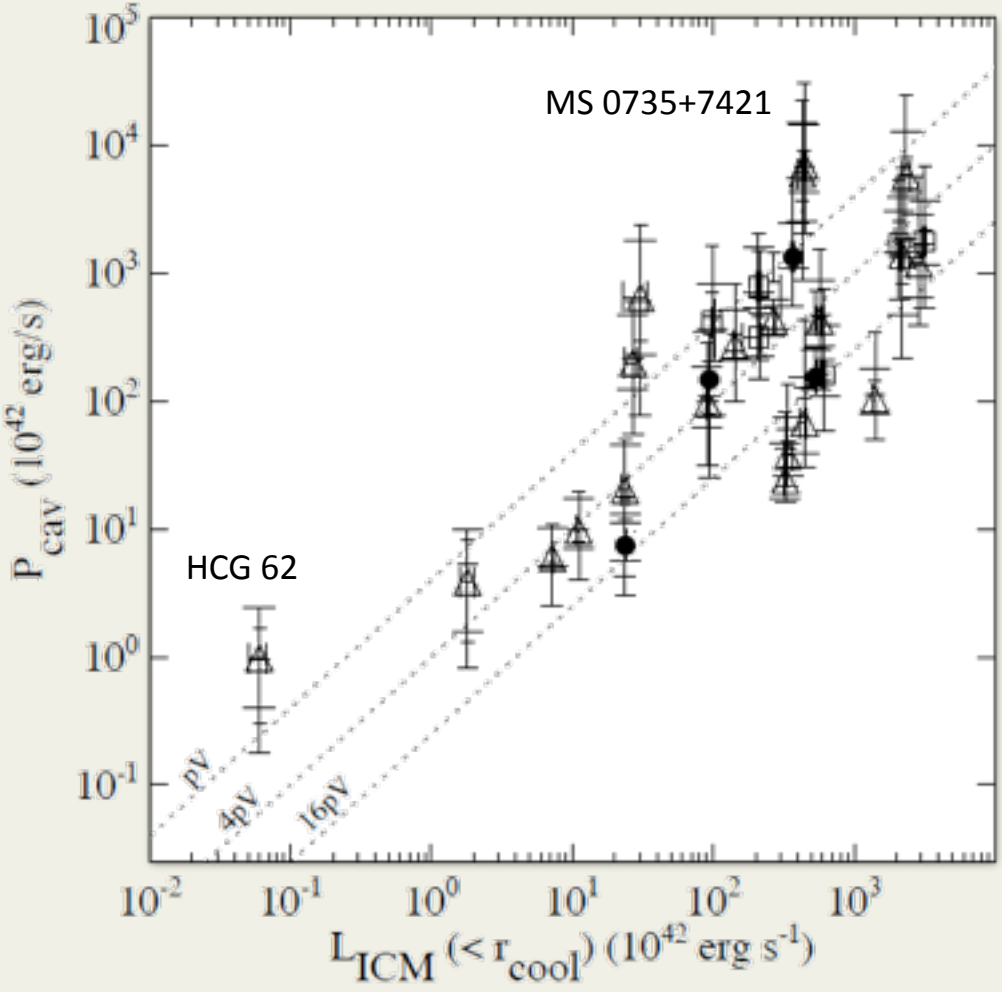
Balancing Cooling with Cavities



- Bîrzan et al. 2004; Dunn et al. 2004, 2005; Rafferty et al. 2006
- >50% of the systems with cavities can balance cooling, considering the enthalpy (Rafferty et al. 2006).

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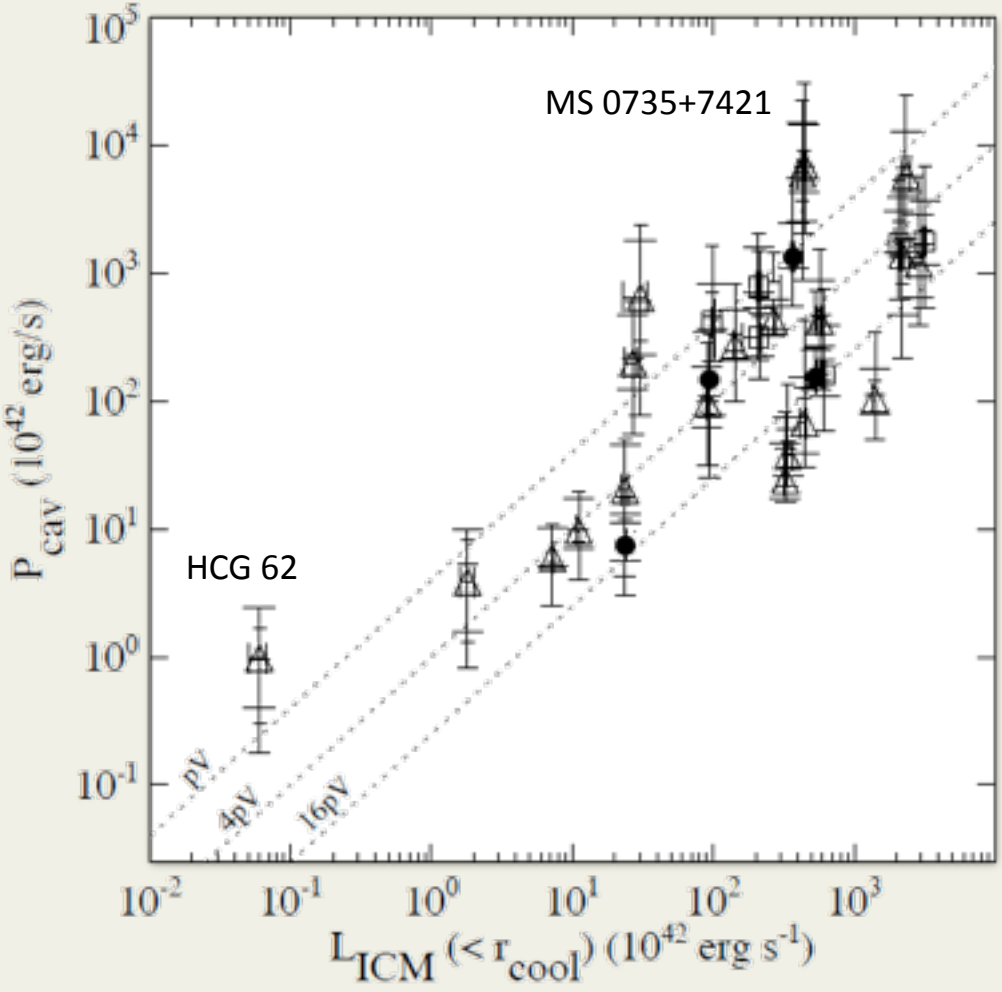

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Cooling Flow Clusters

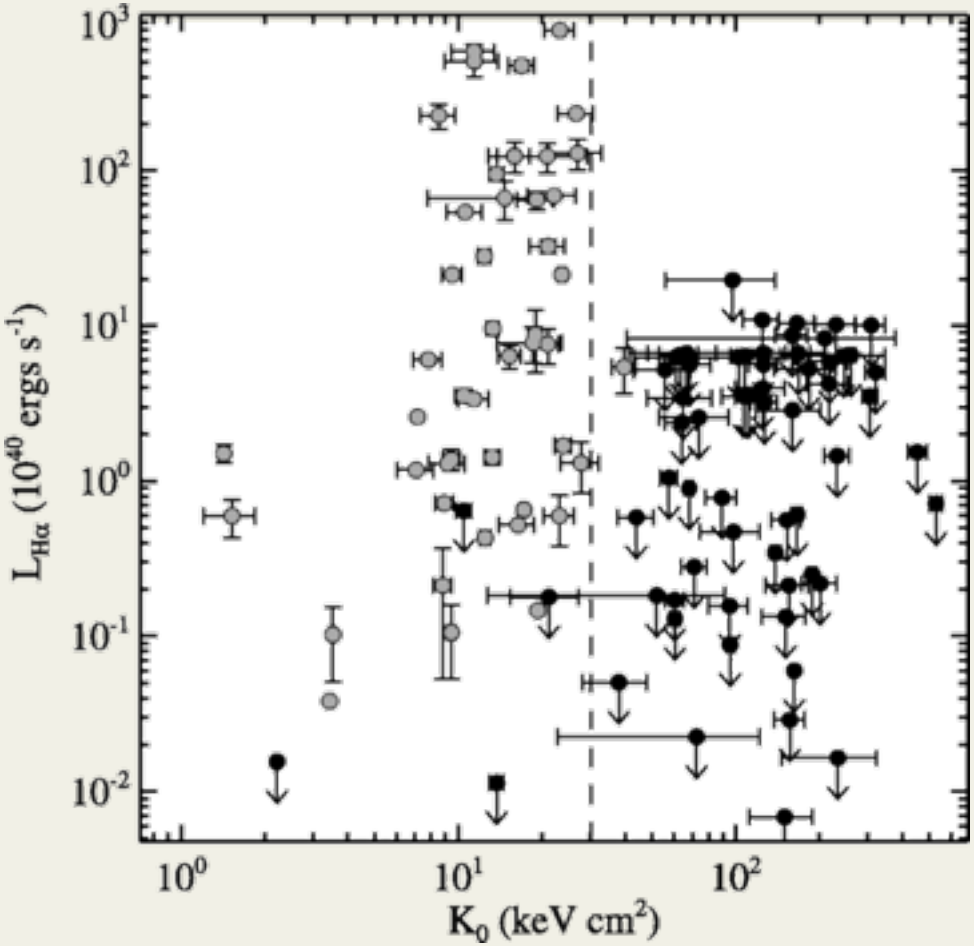
- We do not find cavities in all cooling flow clusters
  - Some clusters may not have cavities (e.g., A1650, Donahue et al. 2005):
    - Heating from “sloshing” (Zuhone et al. 2010)
    - In a cooling stage (e.g., A1068, McNamara et al. 2004)
    - Location and orientation (Ensslin & Heinz 2002; Bruggen et al. 2009)
    - Depth of the observation
- Goal: To understand the biases/selection effects in the detectability of current X-ray cavity samples

➡ Need complete samples of cooling flows

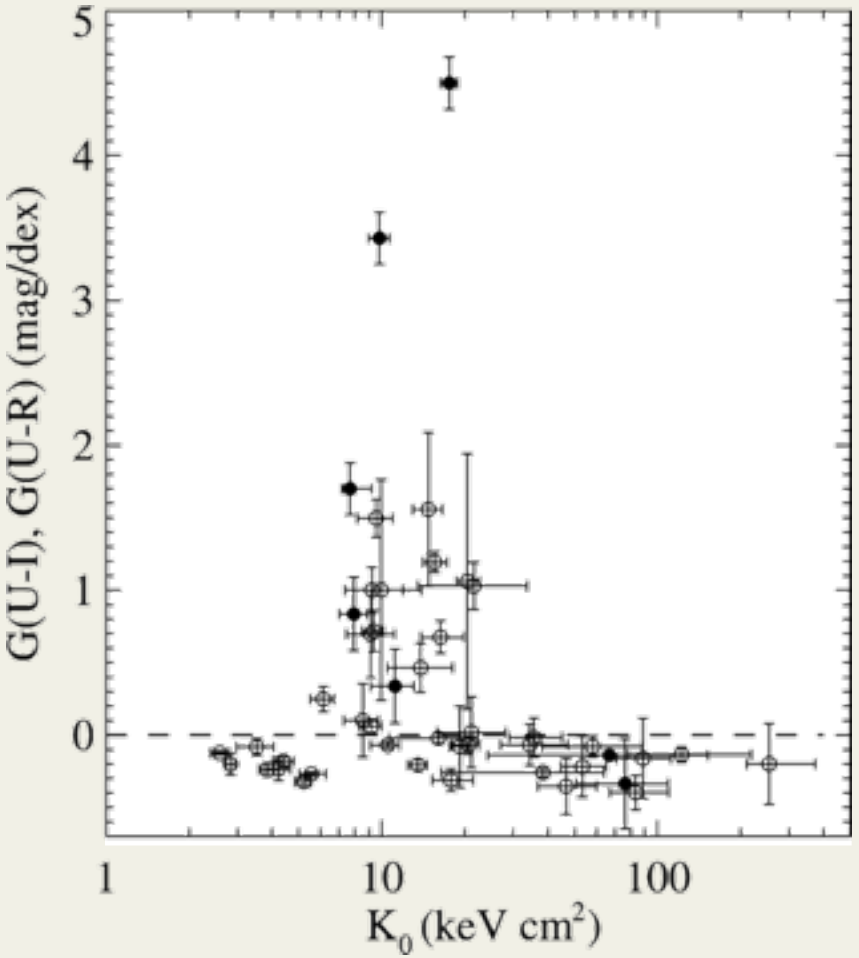
Subsamples of Cooling Flow Clusters

- Complete samples (flux limited): B55 and HIFLUGCS
- Identify cooling flow systems (Chen et al. 2007, Sanderson et al. 2006, 2009; Cavagnolo et al. 2009, etc.)
- Underling origin for the CF/NCF dichotomy:
  - Separation occurs early on in the cluster evolution (pre-heating; e.g., McCarthy et al. 2008):
    - Heating from mergers (Poole et al. 2008, Burns et al. 2008),
    - Heating from TeV gamma rays from blazars (Pfrommer et al. 2011)
  - Separation occurs late:
    - Destruction of CF due to merger (Rossetti & Molendi 2010, 2011)
    - Destruction due to powerful AGN (Guo & Oh 2009)
    - ➡ Both are improbable? (Poole et al. 2008, Pfrommer et al. 2011)

CF/NCF Separation (continued)



Cavagnolo et al. (2008)



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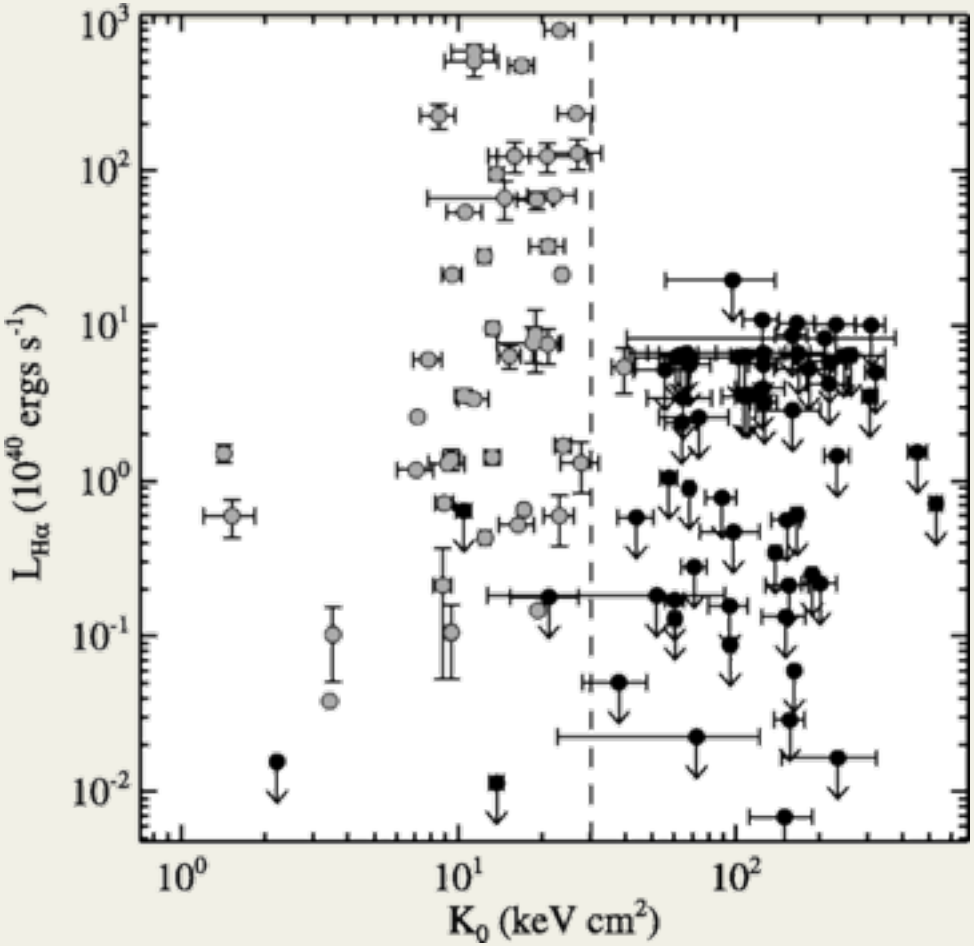

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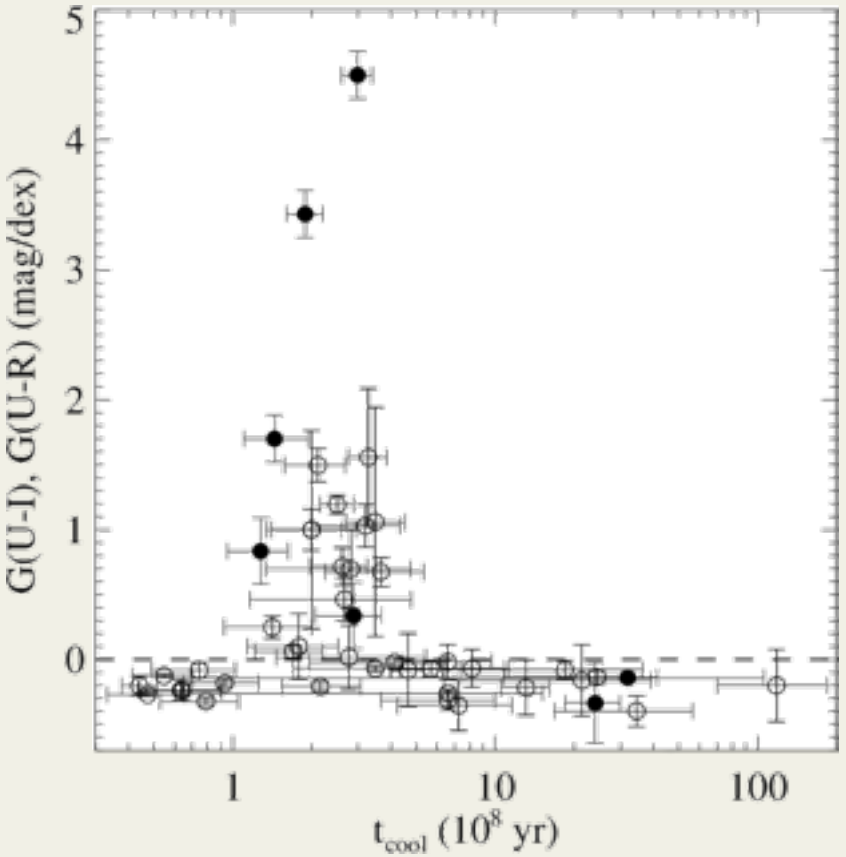

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CF/NCF Separation (continued)

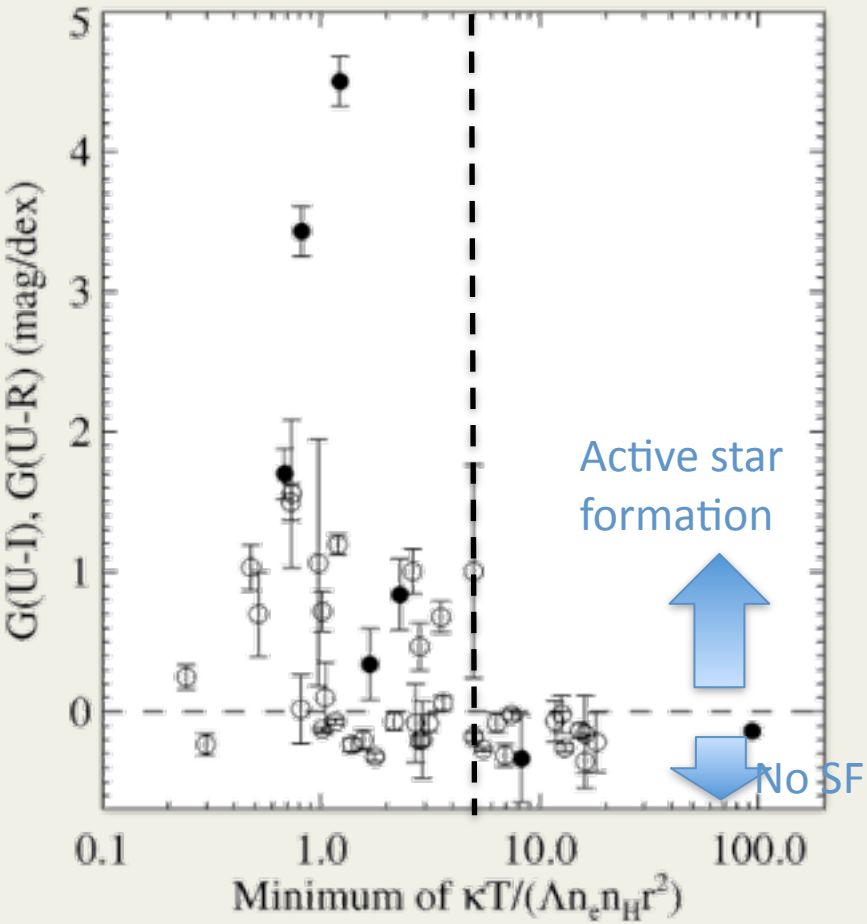
- Star formation and H-α (and hence cooling) seems to occur if

$$\eta_{\min} = \min\left(\frac{\kappa T}{\Lambda n_e n_H r^2}\right) \sim \frac{1}{f_c} \leq 5$$

(Voit et al. 2008)

- Similar to Sharma et al. (2011) criterion:

$$\min\left(t_{\rm cool}/t_{\rm ff}\right) \lesssim 10$$

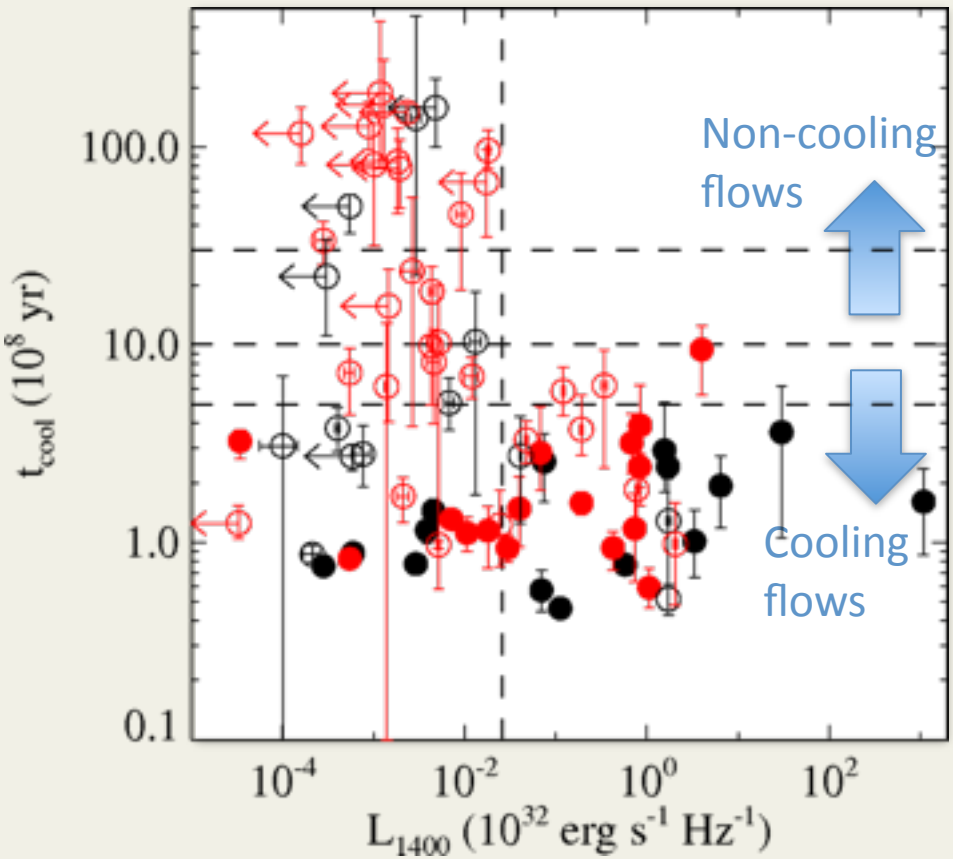


Voit et al. (2008)

CF vs NCF

- CF systems also separate based on radio luminosity of BCGs (from Mittal et al. 2009):
  - All high-radio-luminosity systems are consistent with $t_{cool} \lesssim 5 \times 10^8$ yr
- *And projected optical--X-ray separation*
- *Mergers are randomly distributed:*

  ➡ *mergers are not primary means of quenching cooling*



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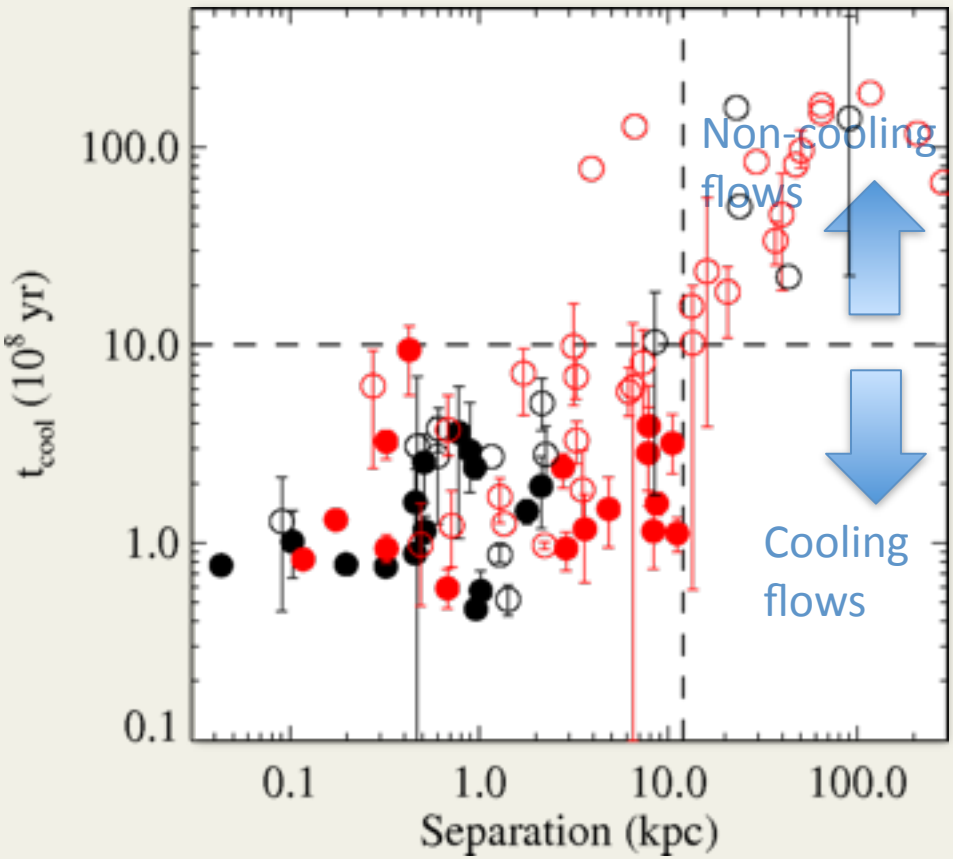

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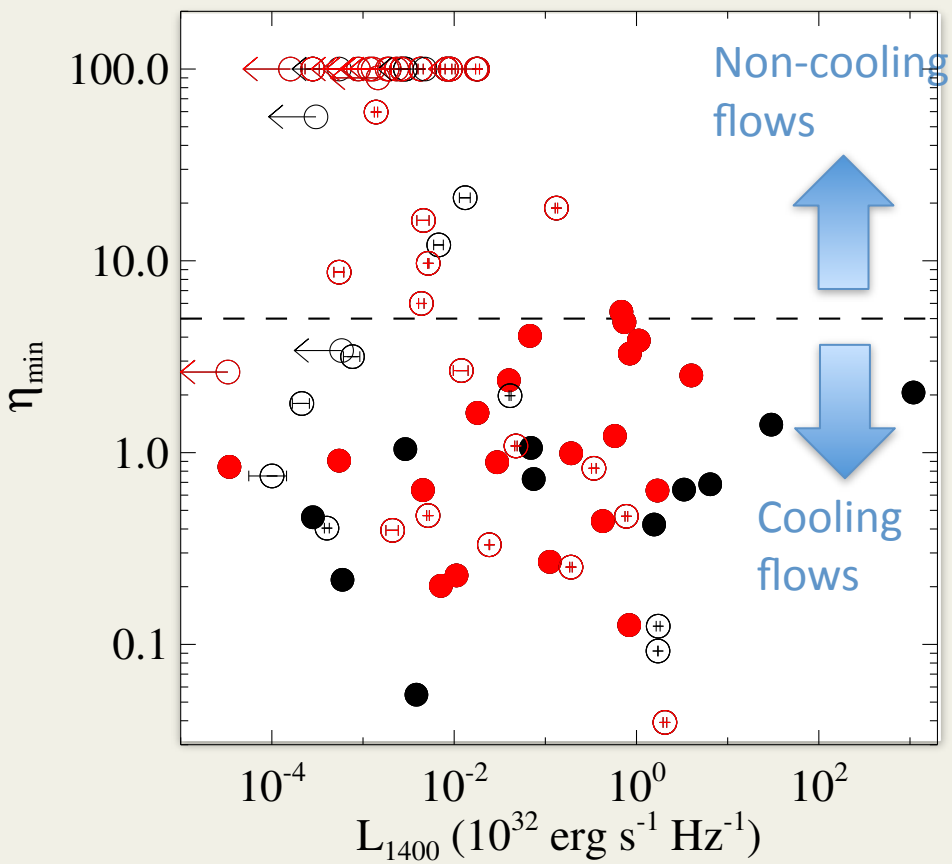
Cooling Flow Samples

- $\eta_{\rm min}$ of 5 ≈ Central cooling time of 5 × 10^8 yr (only 1 object is different: A2065)
- ➡ 49 systems require heating: 31 have detected cavities
- For 18 systems without detected cavities, we perform simulations to place limits on how much energy may be present but undetected



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Simulation Parameters

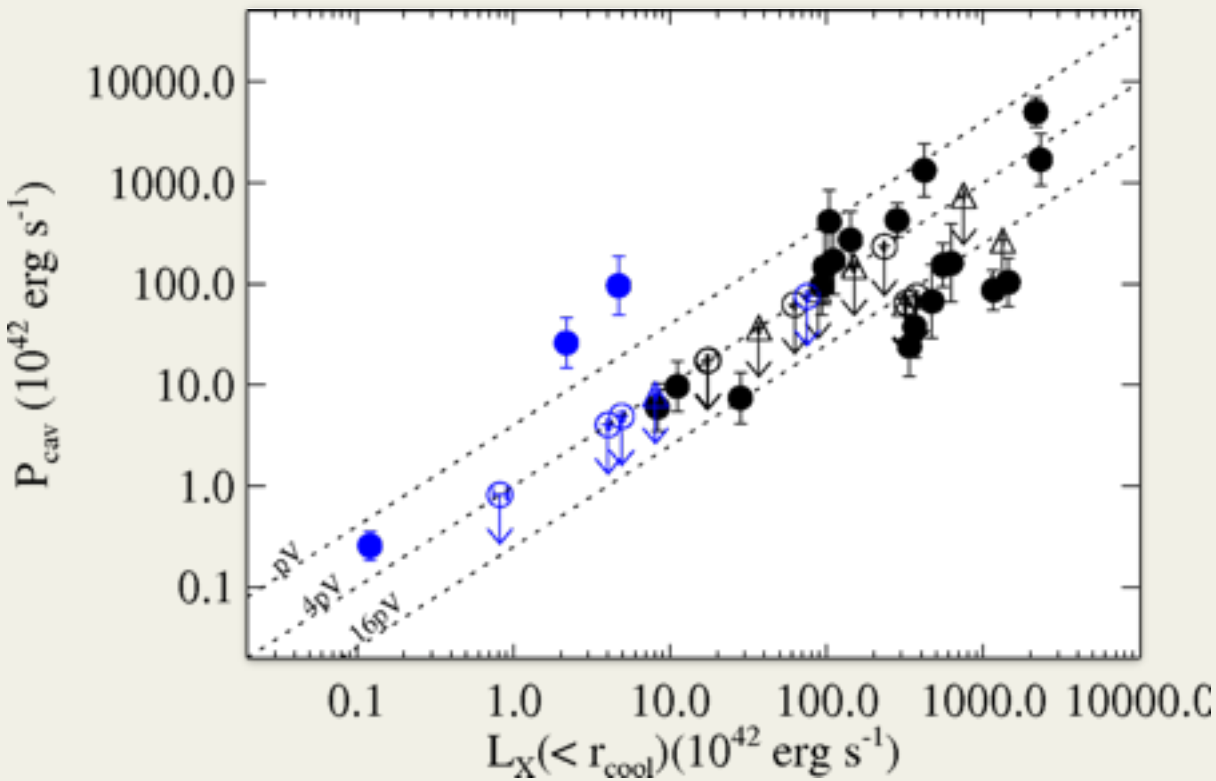
- Double-β model ➤ 3D emissivity ➤ 2D SB ➤ MARX ➤ Sim. image
- Assuming adiabatic expansion (to place limits on bubble sizes and locations) and buoyancy velocity (to calculate ages)
- Calculate the injection radius assuming:

$$4\,pV \sim P_{\rm cav}\,t \sim L_{\rm X}\,t$$

where t is the time between the outbursts (≈10^8 yr)

Heating vs. Cooling for Complete

Bîrzan et al. (2012 in prep)



- Corona class systems (Sun et al. 2007, 2009)
- Cooling flows with detected bubbles
- Cooling flows without detected bubbles

- Roughly ~65% of cooling flow clusters have detected cavities (~80 % when we exclude the corona class)
  - Similar to the Dunn et al. (2006) finding for a sample of cooling flows (~70%)

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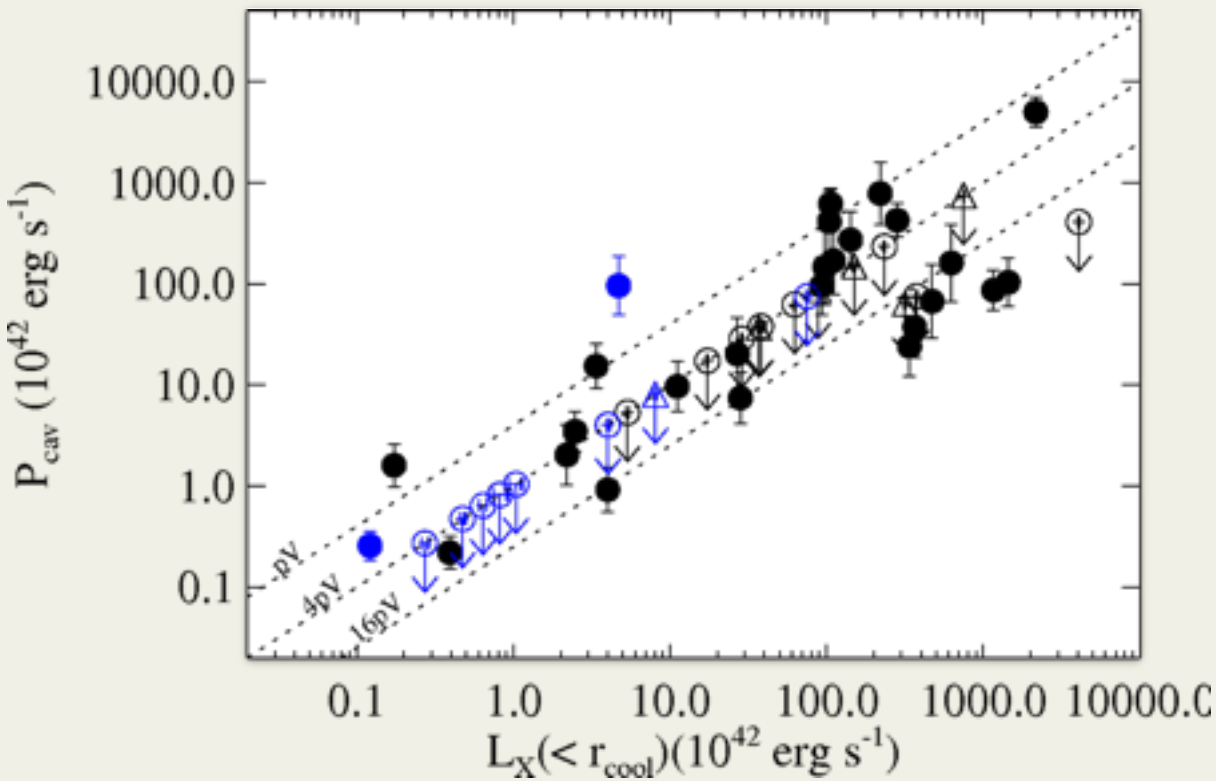

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Summary and Future Work

- Roughly 65% of cooling flows (40% of all clusters) have detected cavities
- Of the others, most could have significant cavity power yet remain undetected in existing images (under simple assumptions), or may be in a cooling stage
- Further work needed:
  - Investigate with radio images (Burns et al 1990, Mittal et al. 2009) using EVLA, GMRT, LOFAR
  - Add rims to cavities
  - Investigate different schemes for bubble evolution

What can LOFAR add?

- For NCF: search for radio halos (see Cassano talk)
  - study complete samples to understand the fraction of NCF systems with halos
- However, some CF systems might also have a halo (e.g., A1689, Vacca et al. 2011)
- For CF: mini-haloes, re-energizing of the old AGN activity by sloshing