AGN Feedback: Are Radio AGN Powered by Accretion or Black Hole Spin?

Brian McNamara

University of Waterloo

Perimeter Institute for Theoretical Physics
Harvard-Smithsonian Center for Astrophysics

P. Nulsen (CfA), M. Wise (ASTRON), C. Carilli (NRAO), D. Rafferty, L. Birzan (Leiden)
M. Rohanizadegan, C. Kirkpatrick, K. Cavagnolo (UW), A. Edge (Durham), and others.

Durham, July 29, 2010

Mechanical feedback
in cooling X-ray halos

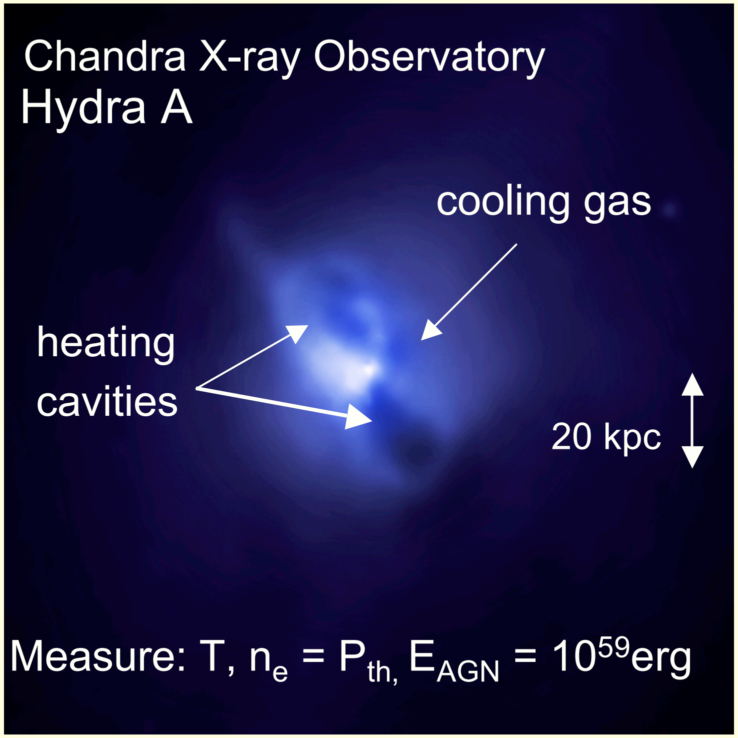
"*radio mode*" feedback

Radiative cooling - AGN heating of hot gas

thermostatically controlled accretion

==> *feedback loop*

described in talks by Merloni, Best, Bower, Croton



McN+00

Key evidence:

-AGN mechanical power matched to cooling rates

Birzan+04, Rafferty+06

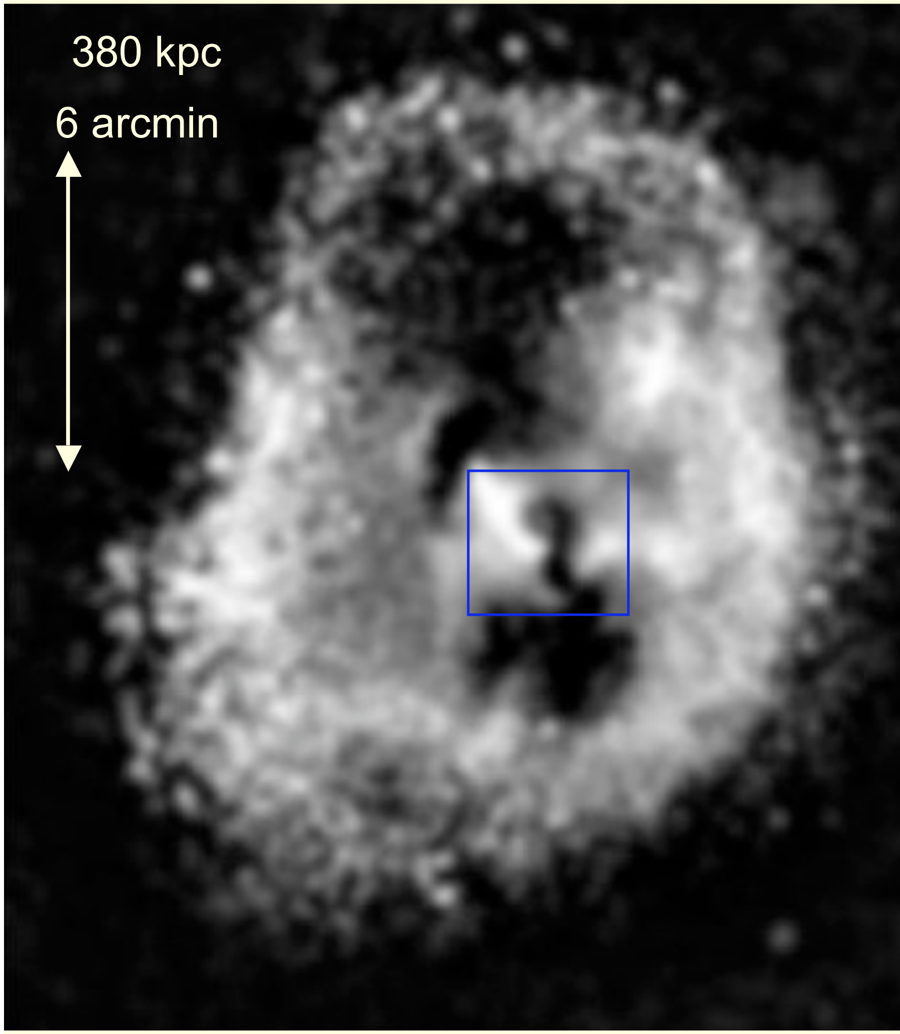
-Short ($<10^9$yr) cooling times in *all* systems

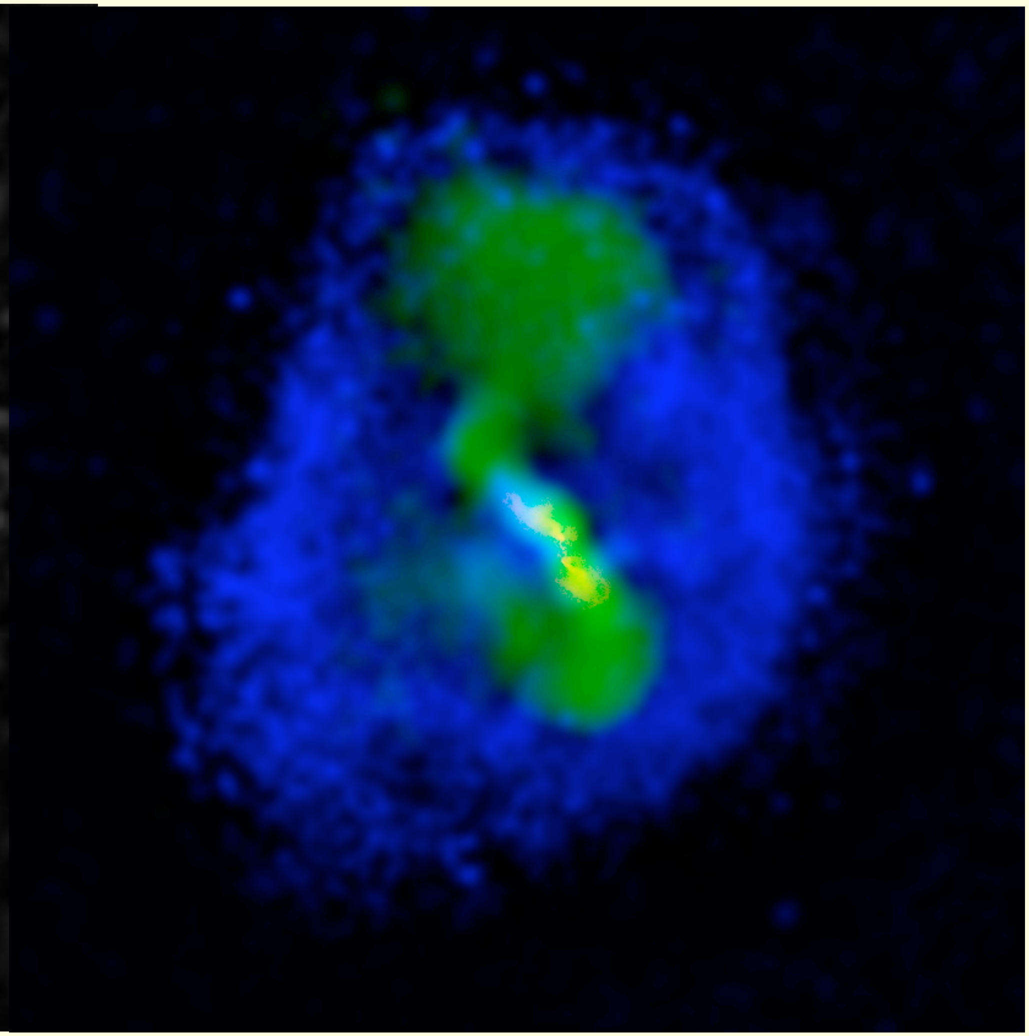
(see Siemiginowska poster) Voigt & Fabian 04

Hydra A

Chandra X-ray Observatory

10^{61} erg





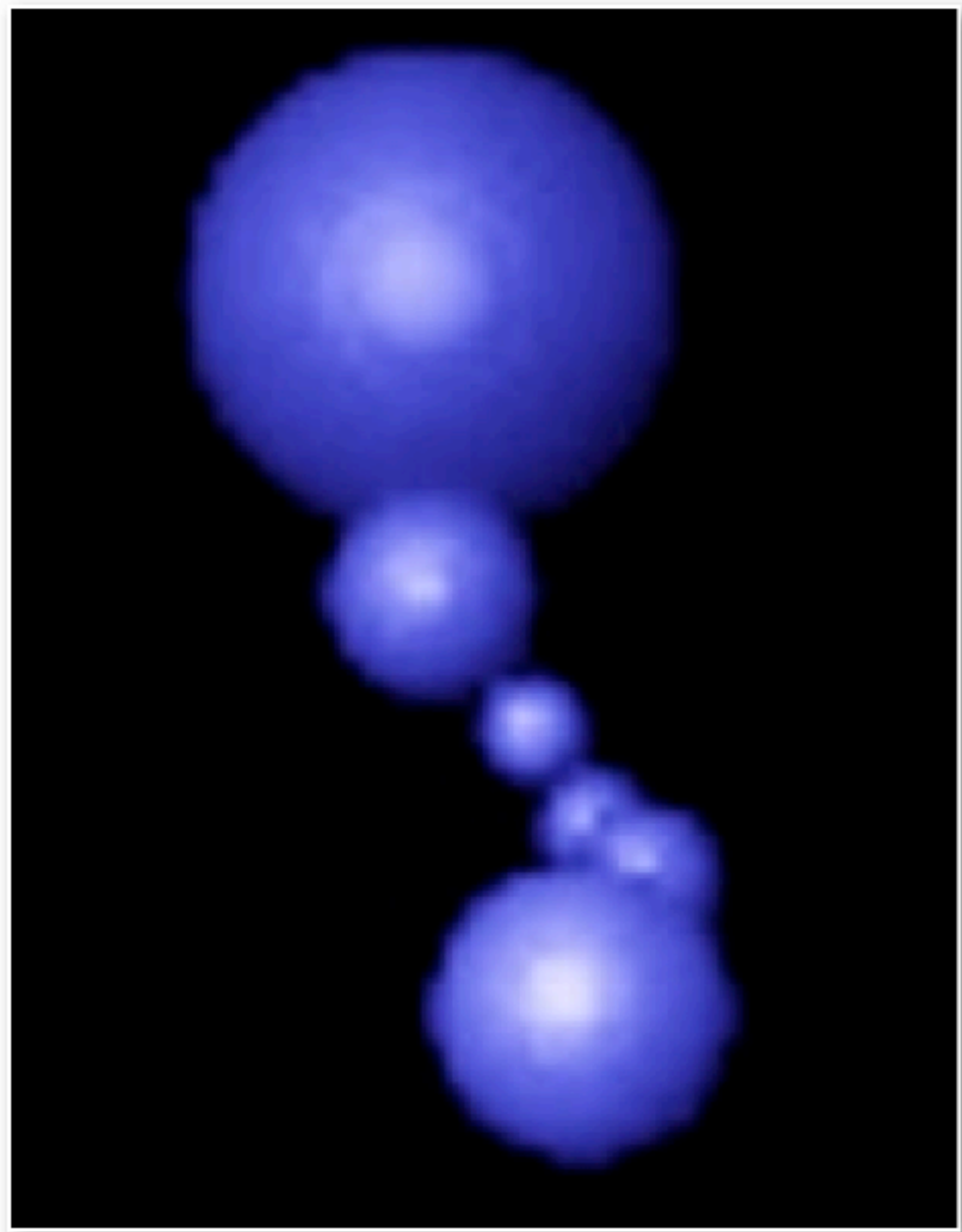
Wise + 07

Nulsen + 05

McN + 00

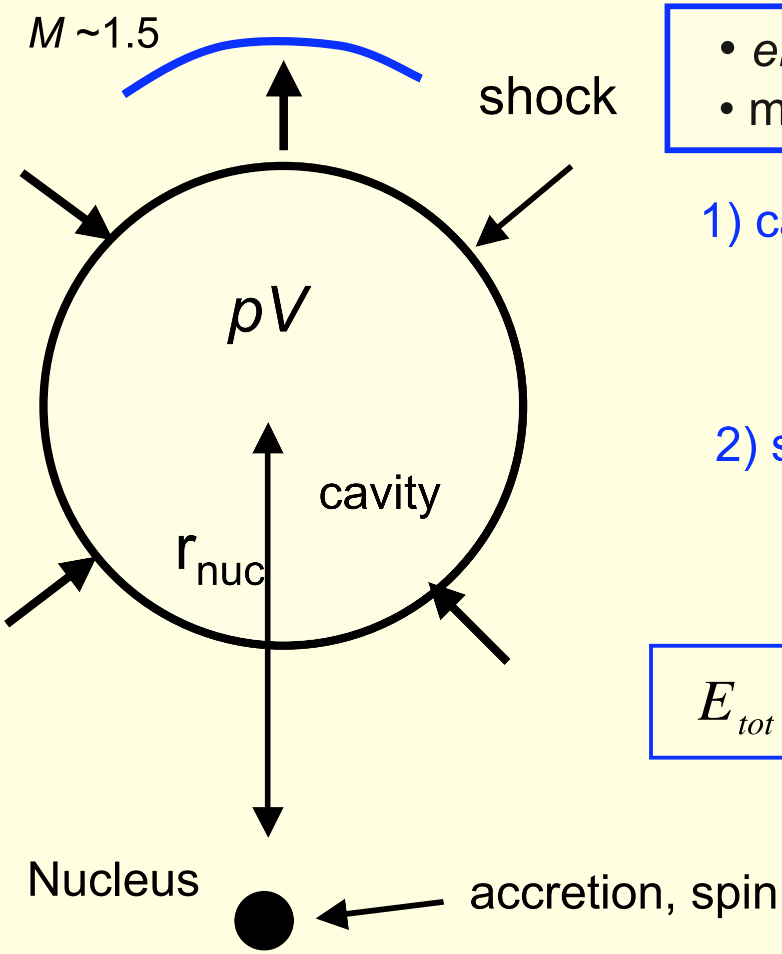
320 MHz + 8 GHz

Hydra A



Buoyancy

Measuring Jet Power with X-ray Cavity Dynamics



- *energy & age measured directly*
- measure mechanical (not synchrotron) power

1) cavity

$$E_{cav} = \frac{\gamma p V}{\gamma - 1} = 2.5\,pV - 4\,pV \qquad t_{cav} = r_{nuc} / v_{buoy}$$

2) shock

$$E_{shock} \approx \Delta p V \qquad t_{shock} \approx r_{shock} / c_s$$

$$E_{tot} = E_{cav} + E_{shock} + (E_{photon}) = 10^{55} - 10^{62}\,erg$$

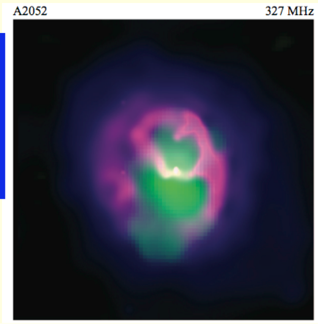
McNamara + 00,01; Birzan + 04
Churazov + 01

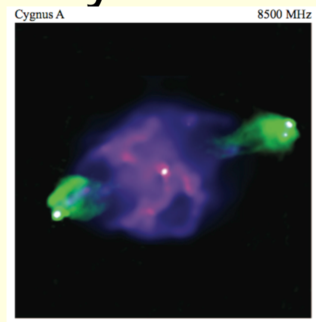
Theory: Ruszkowski, Heinz, Bruggen, Begelman, Voit, Churazov, T. Jones, etc.

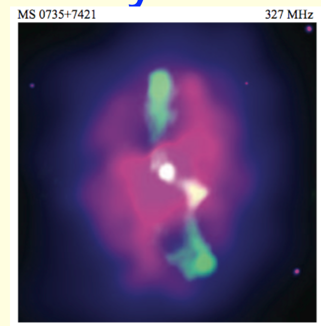
slow gas motions < $c_{s,}$ gentle heating

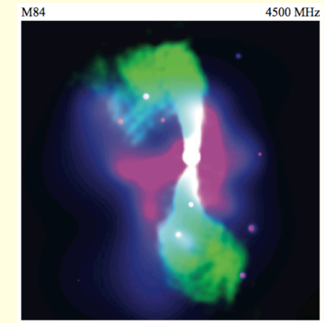
Low radiative efficiency: Mechanically Dominated

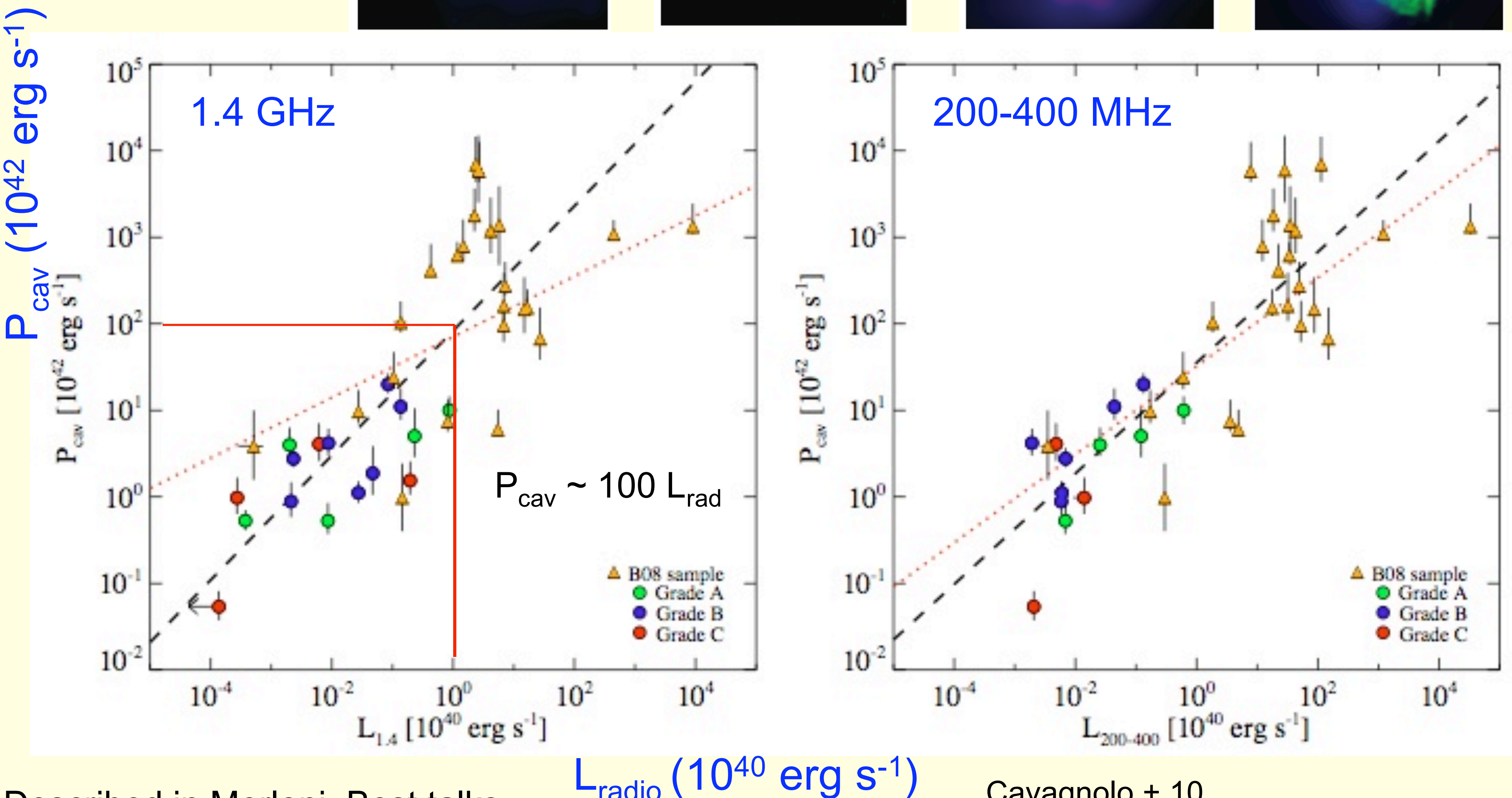
$$P_{cavity} \propto L_{radio}^{0.7}$$









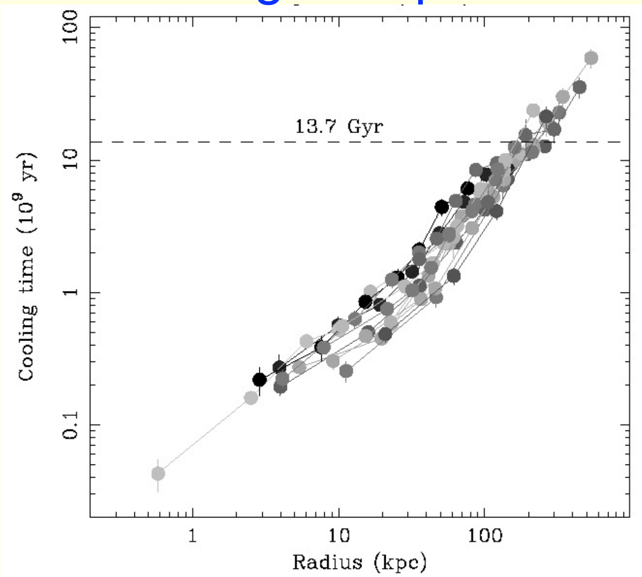


Described in Merloni, Best talks

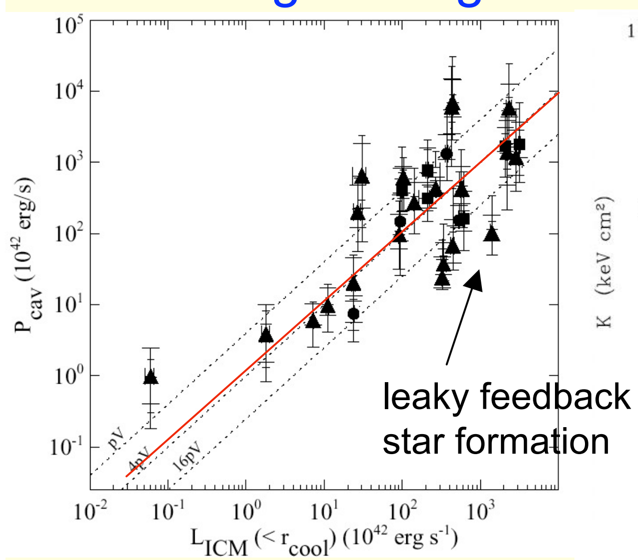
Cavagnolo + 10
Birzan + 04,08

Conditions for AGN-Regulated Feedback Loop

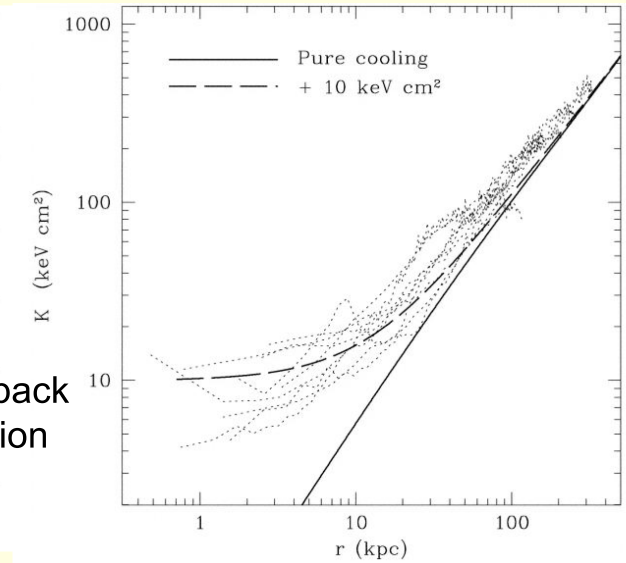
cooling time profiles



heating/cooling



entropy profiles



Voigt & Fabian 04

Rafferty et al. 06
Birzan et al. 04

Voit & Donahue 05
Donahue et al. 06
Voit 05

1) $t_{cool} \sim t_{cav} \sim 10^8$ yr

2) $L_{AGN} \sim L_x$

3) Entropy floors

See Voit & Donahue 05, Peterson & Fabian 06, McNamara & Nulsen 07 ARAA

This talk: How are Radio AGN Fueled and Powered?

Radio AGN are mechanically dominated and powerful

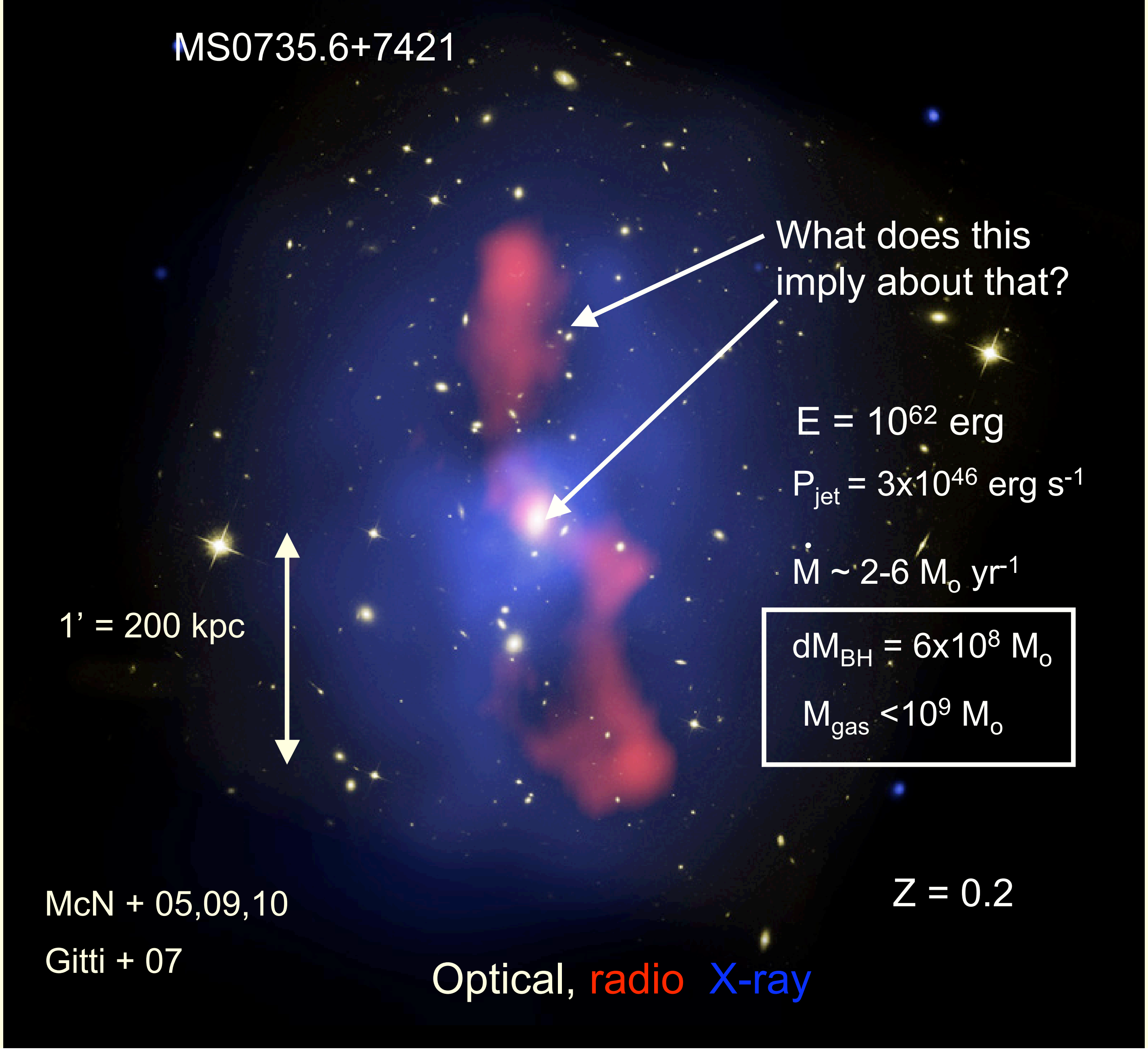
-- Accretion?
  cold gas
  hot gas (Bondi Accretion)

-- Black hole spin
  requires accretion to tap

Need for accretion at some level key to feedback loop

Star formation starves the nucleus

Good Candidate for Spin Powering



Hot gas phase Bondi Accretion

$$\dot{M}_{\mathrm{B}} \propto n_e(kT)^{-3/2} M_{BH}^2$$

$$P = \eta \epsilon \dot{M} c^2$$

$\eta << 1$ Benson & Babul 09, Merloni & Heinz 08

$0.06 \leq \varepsilon \leq 0.42$ efficiency depends on spin

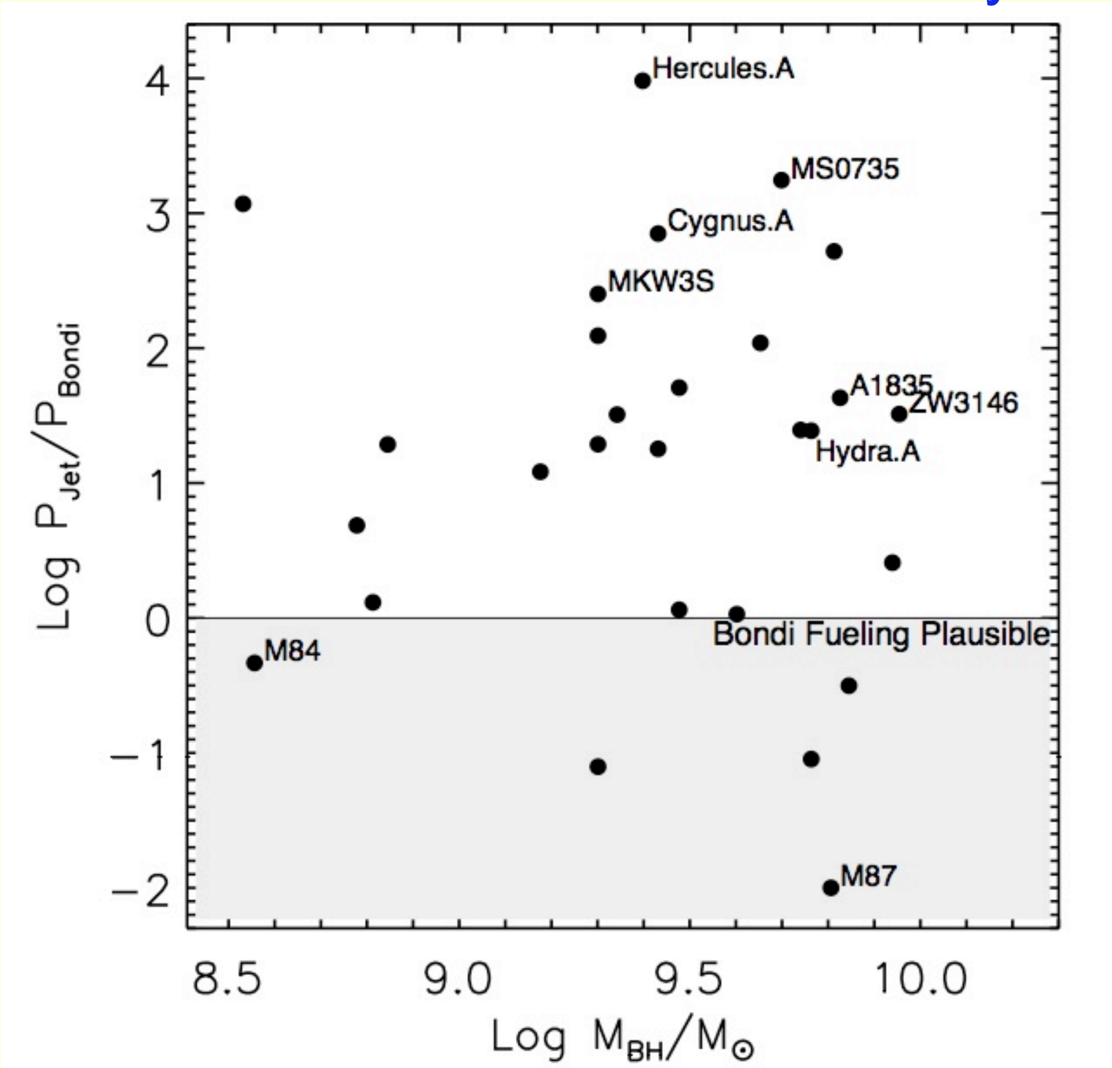
If at all, only in low power AGN

Unlikely to be a broadly significant fuel source

(see justification in McN + 10, Rafferty + 06)

Important issue: Bondi underpins nearly all feedback models

Bondi Accretion: most unlikely



McN+ 10
Rafferty+06
Hardcastle, Evans +07

Bondi Accretion: basis for most feedback models/simulations

See Soker + 10 for cold alternative

Cold Gas Accretion

$$P_{jet} = \varepsilon \dot{m} c^2$$

$$\varepsilon \approx 0.06 - 0.42$$

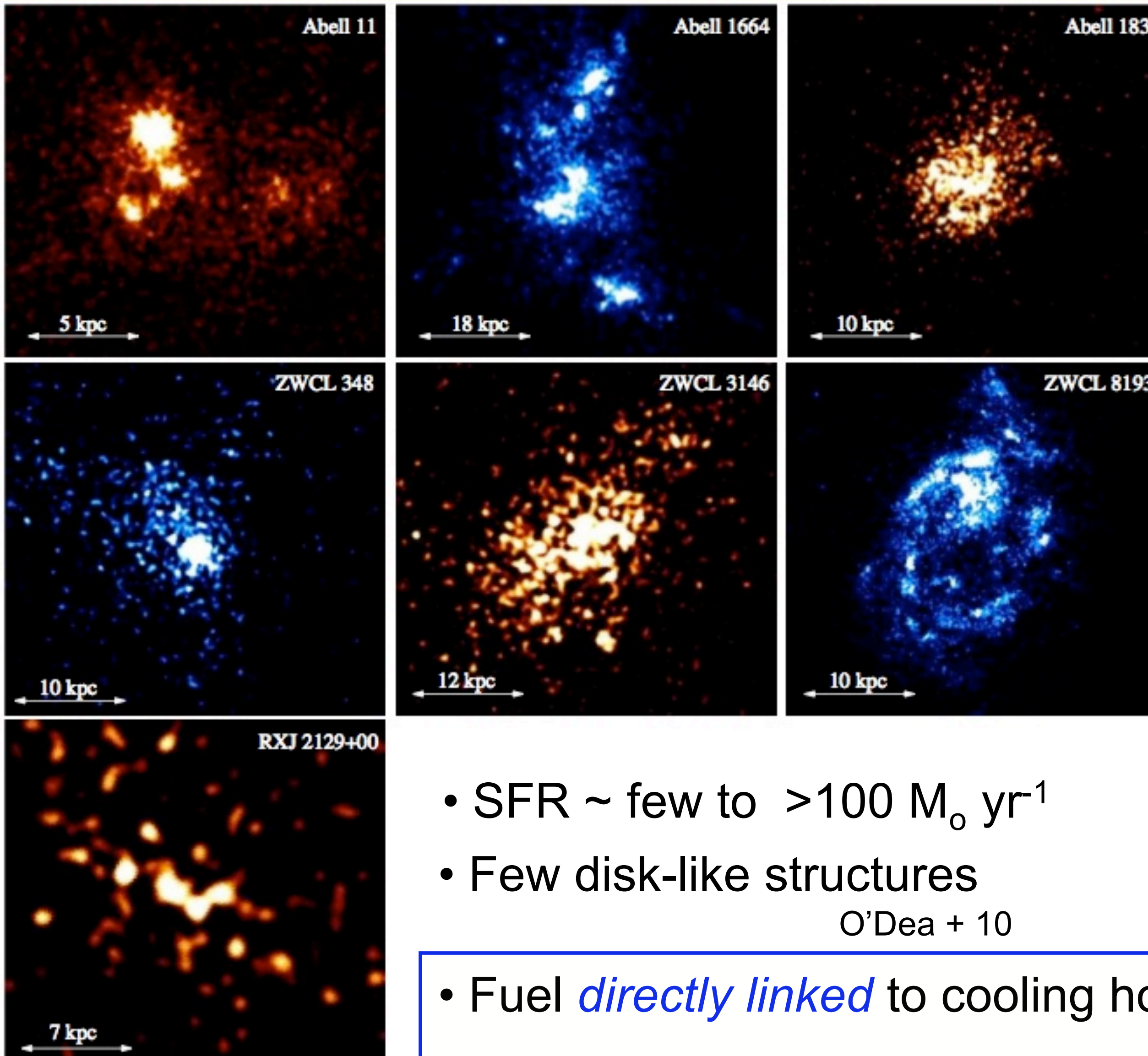
Mass to energy conversion efficiency depends on spin

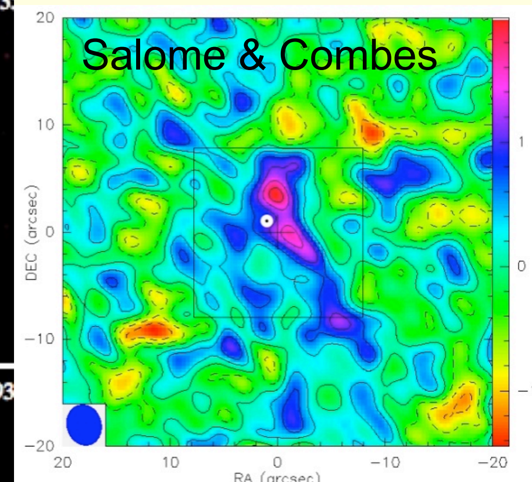
BCGs in cooling flows can harbor 10^9 - 10^{11} M_o of molecular gas

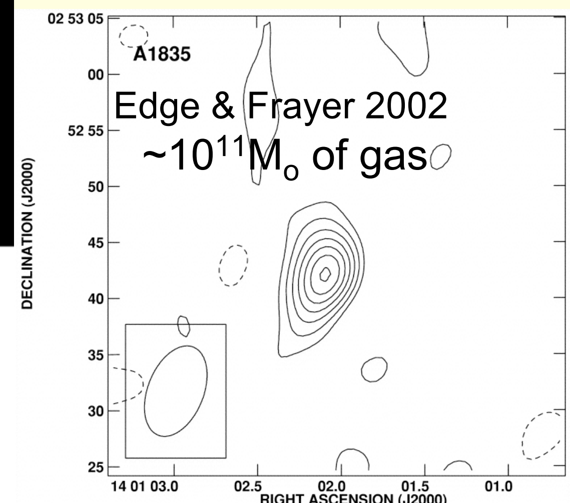
Molecular gas masses from Edge, Salome & Combes

H

UV emission from star formation in molecular-gas-rich BCGs







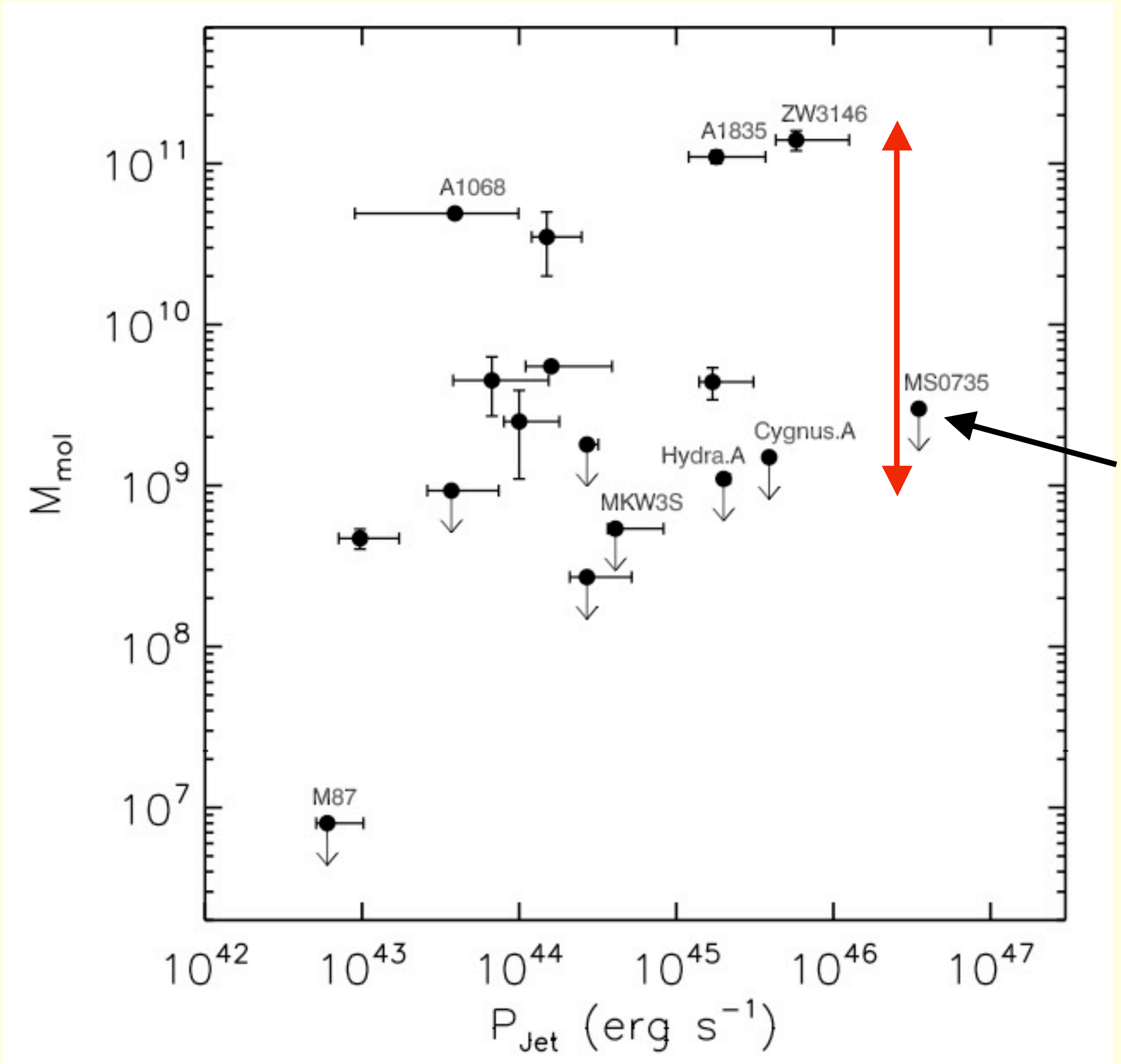
- SFR ~ few to >100 M_o yr^{-1}
- Few disk-like structures

O'Dea + 10

- Fuel *directly linked* to cooling hot halo (not mergers)

Rafferty+08, Cavagnolo+08

Jet power vs gas mass: weak trend, large scatter



Molecular gas mass

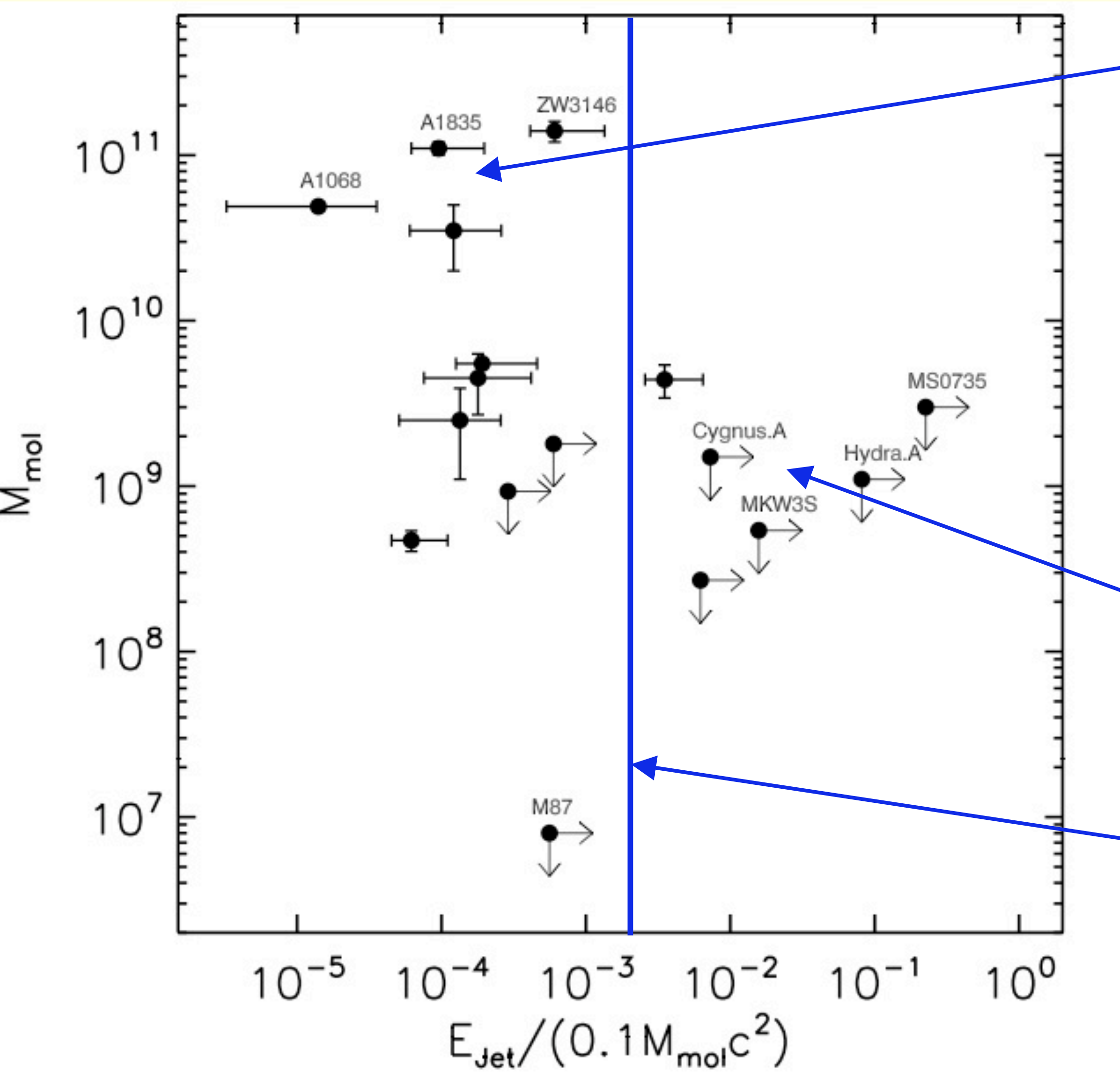
Jet Power

MS0735

McN + 10

Accretion Efficiency: gas poor/gas rich segregation

Molecular gas mass



Efficiency

Nearly 5 decades of spread in accretion efficiency

Gas-rich massive star formation

low accretion efficiency: starvation by SF or winds?

Gas *not* stripped from galaxies (Kirkpatrick + 09)

powerful AGN gas-poor

efficient accretion, spin?

global efficiency of bulges (Haring & Rix)

McN + 10

Why Spin?

$>10^{62}$ erg in maximally spinning, $10^9\ M_o$ BH

Comparable to thermal energy of surrouding atmosphere

Can be coupled to feedback by accretion

May explain powerful AGN in gas-poor systems

McN+09,10

Accretion & Spin Paradigms

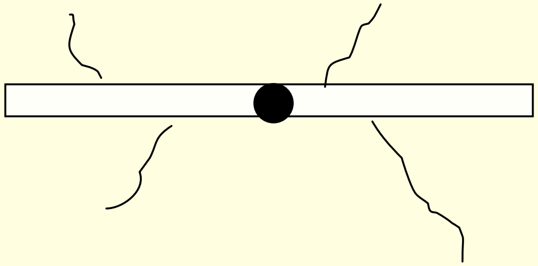
Accretion

thin disk + slowly spinning hole = radiation

$$L_{opt} \geq 1.7 \times 10^{12} L_{\otimes} m_9^{1.27} \left(\frac{\dot{m}}{0.1} \right)^{0.6}$$

Not observed

Meier 99

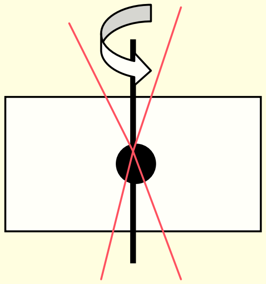


Spin

hybrid = thick disk + fast spinning hole + ADAF = powerful jet

$$L_{jet} = 10^{46} \left(\frac{B_p}{10^4 G} \right)^2 m_9^2 j^2$$

Meier 99



$B_p^2 \propto \dot{m}$ in BZ-based models

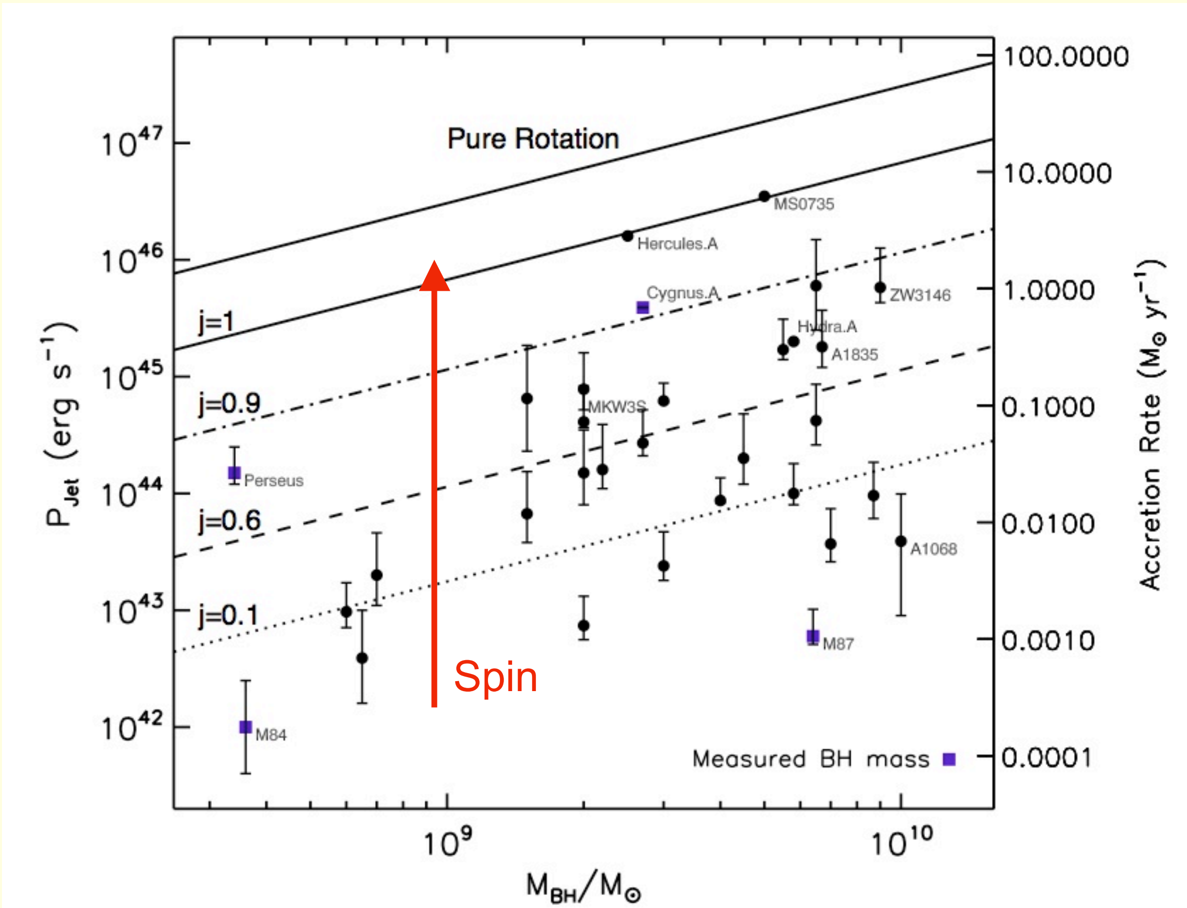
Link to feedback

Can we test this?

Problem: spin power & accretion power are coupled

Cavity constraints on Spin

Jet power



Black hole mass

(galaxy luminosity, really)

Model: Nemmen + 07

Assume: all accreting at 2% Ed

- MS0735 insufficient fuel to power by accretion alone

- Low nuclear emission likely ADAF

critical accretion

$$\dot{m}_{crit} \sim 0.02$$

McN + 09, Benson & Babul 09

$$j \rightarrow 1 \quad P_{Jet} > \dot{M}c^2$$

Summary

Most powerful AGN in clusters live in gas-poor hosts

Why? Efficient fueling mechanism, or alternative power source

BH spin energetically able:
broad range of spin parameter
broad range of accretion rate

Star formation, jets linked to central cooling time

Bondi accretion: difficulty fueling high power sources

Transition between radiative flows and RIAFs $\sim 0.02\,\dot{M}_E$