Powering the Powerful MS0735.6+7421: Testing the Infall and Spin Paradigms

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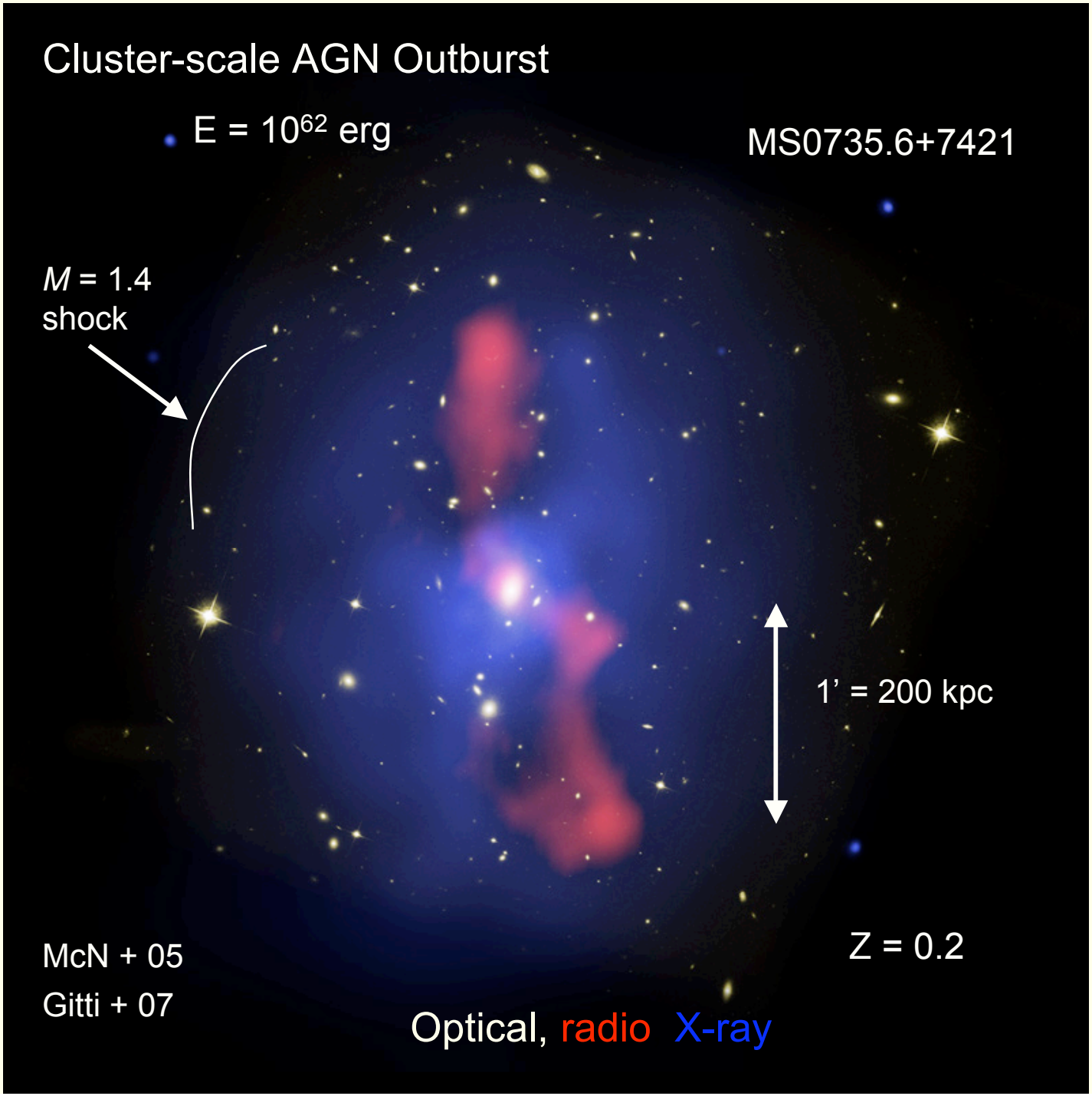
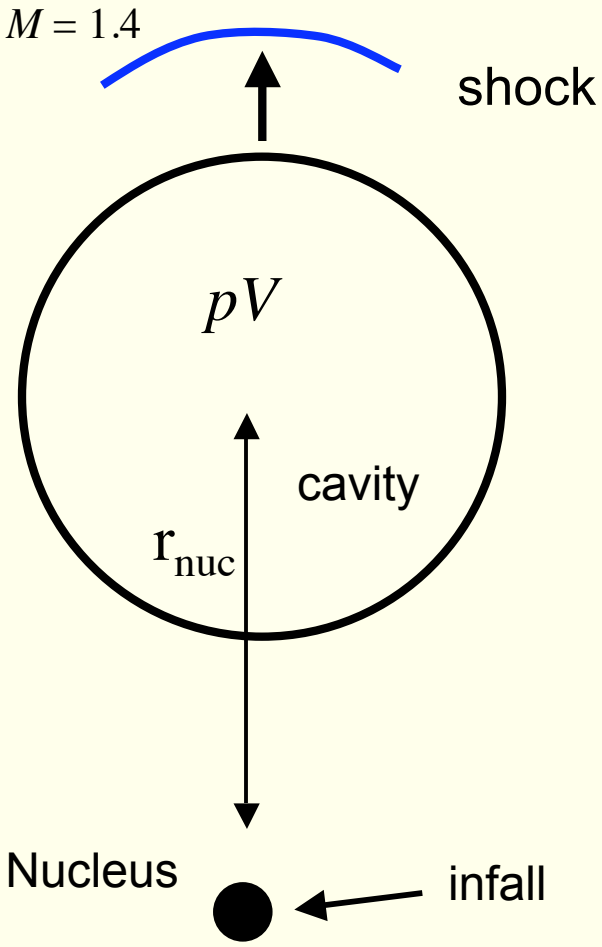
Outline:

- Cluster Scale AGN Outbursts: strain models of jet power & BH growth
- X-ray cavities, shock fronts: gauges of AGN power
- problem with MS07: too much power, not enough fuel
- testing spin power vs accretion power: X-ray constraints on power & energy
- problems with and virtues of the spin hypothesis

Radio Galaxies in the Chandra Era, Cambridge, MA. July 9, 2008


Cluster-scale AGN Outburst
E = 10^62 erg
MS0735.6+7421
M = 1.4
shock
1' = 200 kpc
Z = 0.2
McN + 05
Gitti + 07
Optical, radio X-ray

Measuring Jet Power with X-ray Cavities



- *energy & age measured independently*
- measure total (not synchrotron) power

1) cavity

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

2) shock

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

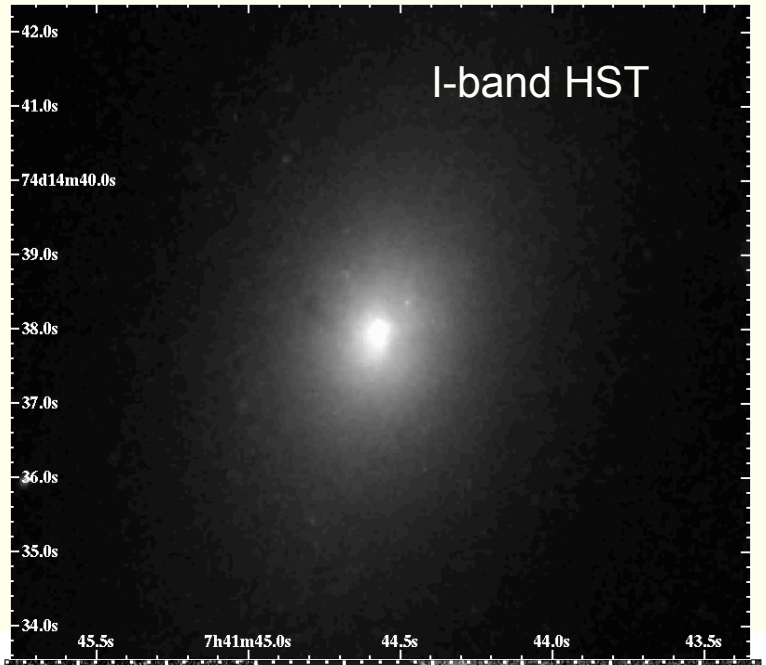
$$E_{tot} = E_{cav} + E_{shock} = 1.2 \times 10^{62} erg$$

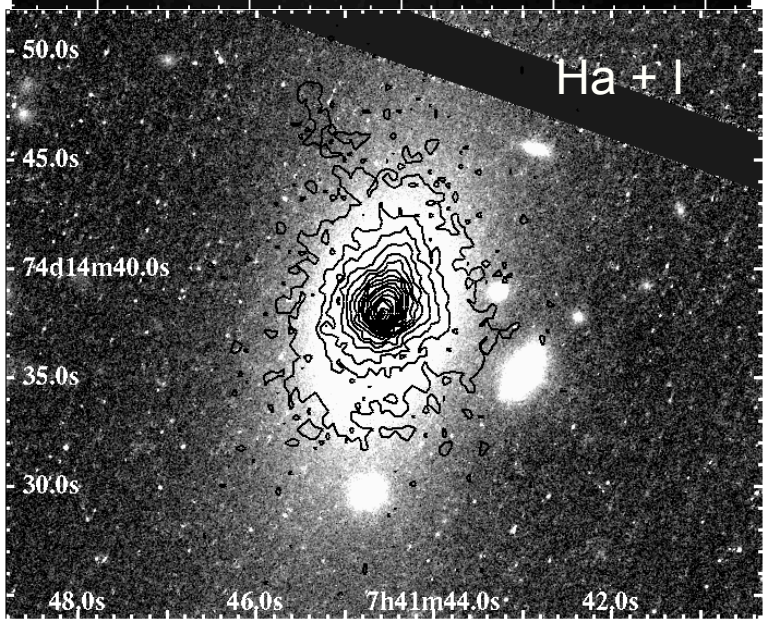
$$\Delta M_{BH} = \frac{(1-\varepsilon) E_{tot}}{\varepsilon c^2} = 6 \times 10^8 M_{\otimes}$$

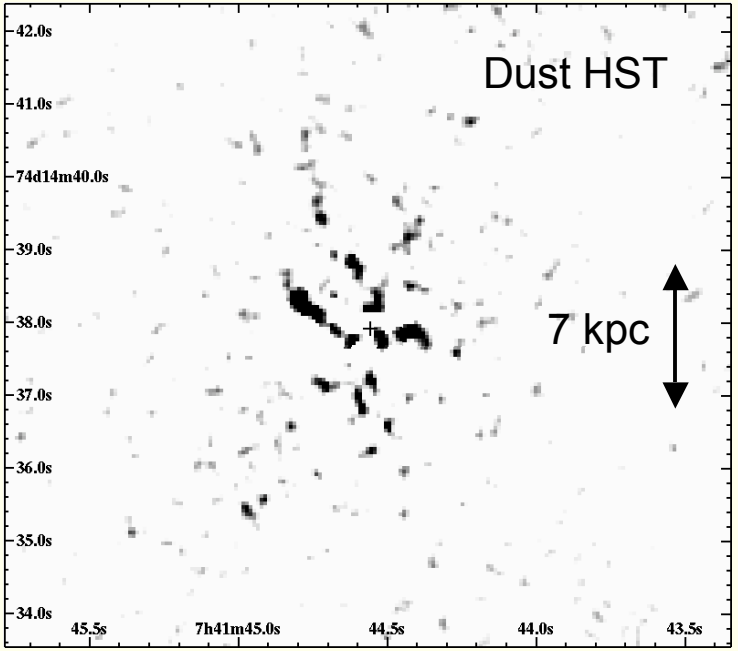
$$M_{BH}(Magorrian) \sim 8 \times 10^8 M_{\otimes}$$

SMBH ~ doubled in size!!

Gas and Dust in the Nucleus







$L_{Ha} = 1.2 \times 10^{42}$ erg s^{-1}

$M_{ion} = 4.5 \times 10^{6}\ M_o$

$M_{gas} \sim 4.9 \times 10^{7}\ M_o$ (from dust)

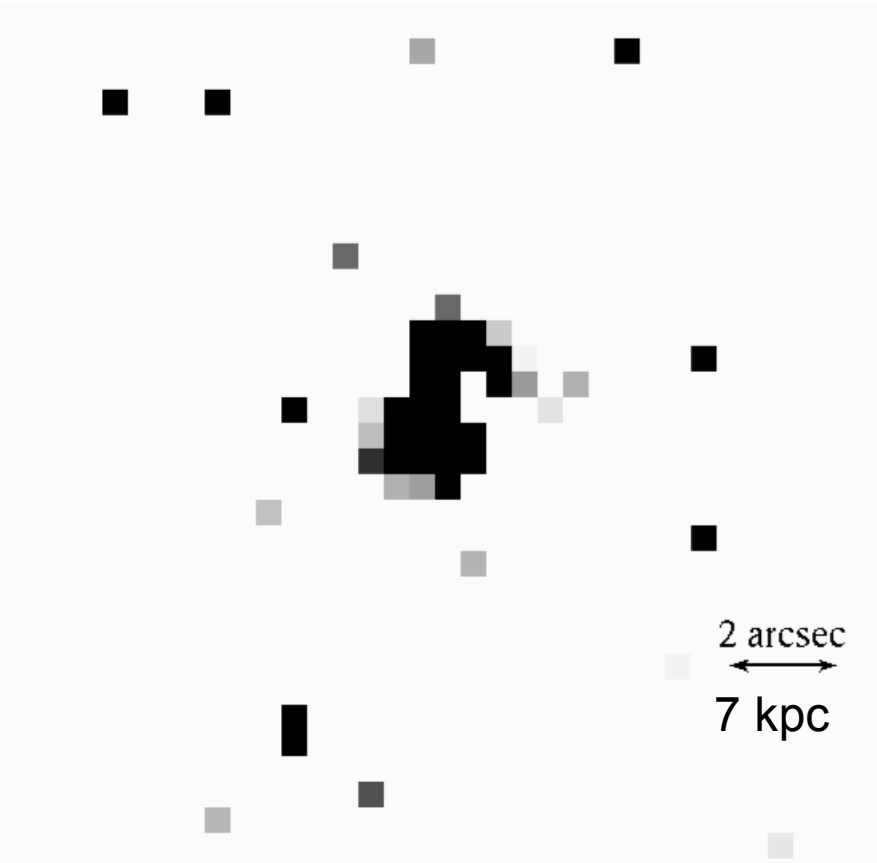
$M_{CO} < 10^{9}\ M_o$ (Salome & Combes 08)

Need $6 \times 10^{8}\ M_o$ to fuel outburst

Barely enough gas to do so!

Star Formation Rate

XMM-OM Far UV ~ 2000 A



Normal red optical colors

SFR < 0.25 M_o yr^{-1}

Jet power implies:

$\dot{M}_{BH}$ = 5.6 M_o yr^{-1}

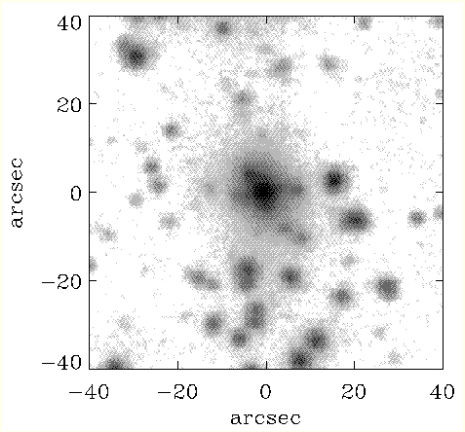
who ordered that?

Bondi accretion No
Stellar accretion No

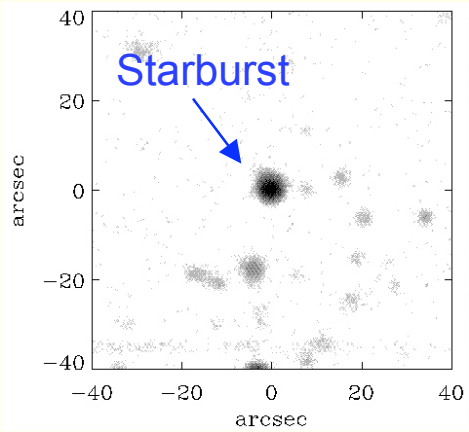
Stark Contrast: a gas-rich outburst

Abell 1835

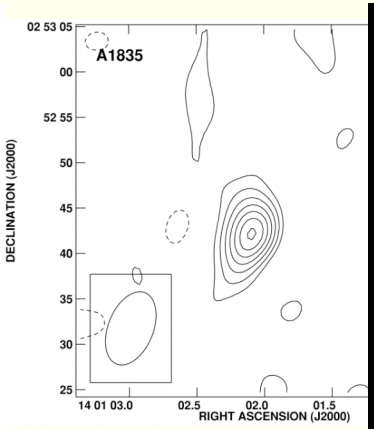
R-band



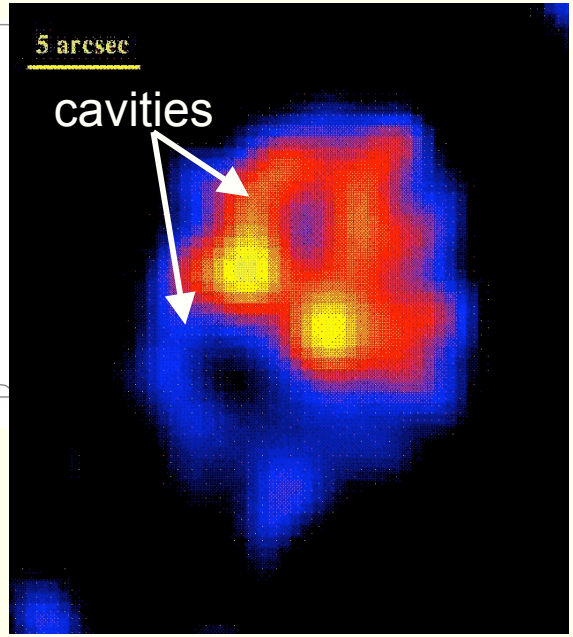
U-band



10^{11} M_o of gas



Edge & Frayer 02



SFR = 100 - 200 M_o yr^{-1}

E_{cavity} = 1.7 x 10^{60} erg

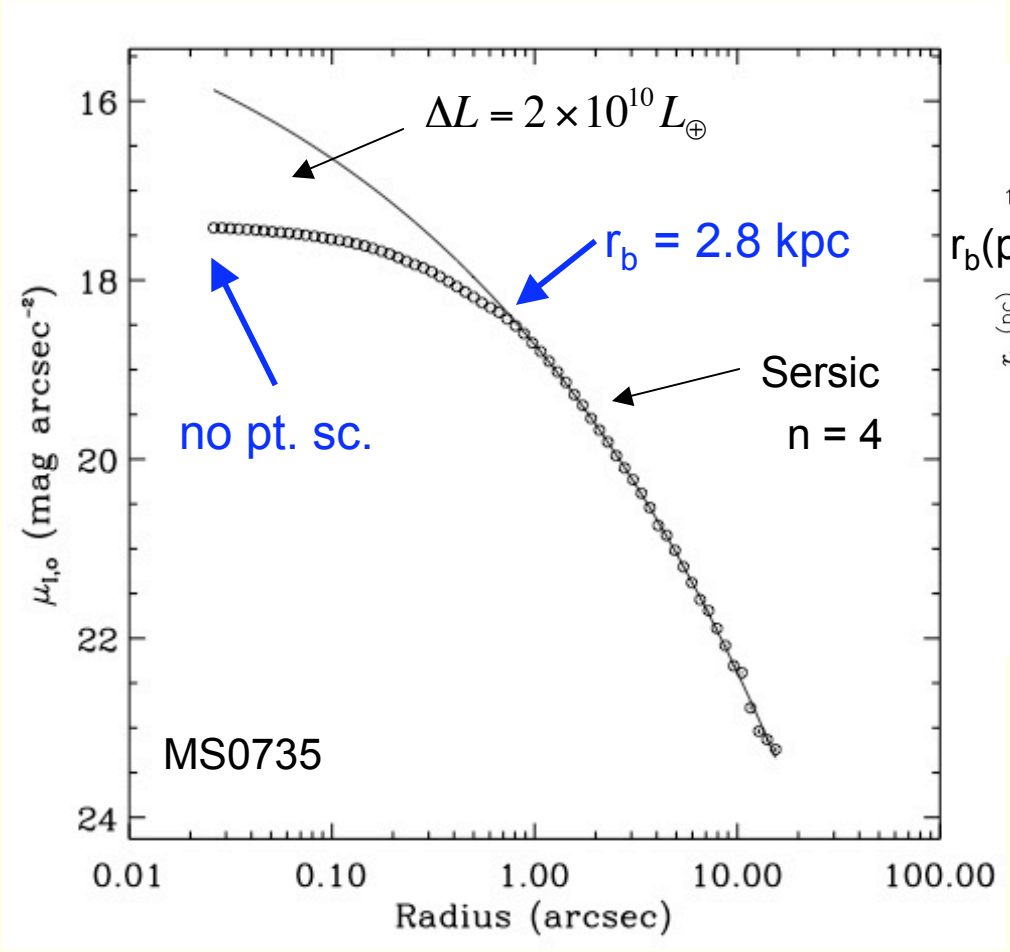
10 x less than MS0735

P_{cavity} = 1.4 x 10^{45} erg s^{-1}

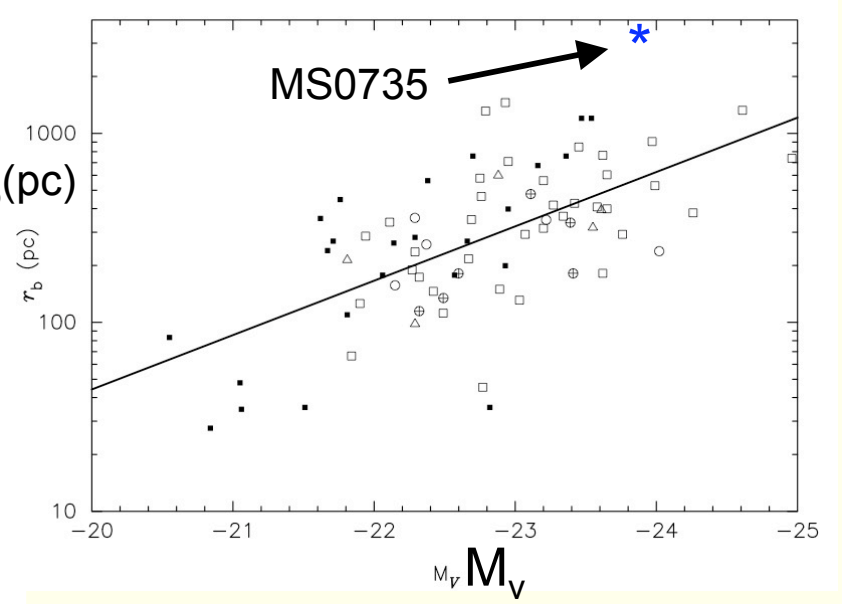
M_{gas} = 10^{11} M_o > 100 x more than MS0735

McNamara + 06

Core “Scouring” by SMBH Mergers



MS0735: big break radius



cD galaxy sample Laine + 03

- no light cusp - no vestigial SF
- efficient & persistent feedback

Light deficit method of Merritt & co

$$\Delta M_s = \frac{M}{L}\times\Delta L \approx 6\times10^{10} M_{\otimes}$$

$$M_{\bullet} \sim \Delta M_s$$

Jumbo SMBH?

Accretion & Spin Paradigms

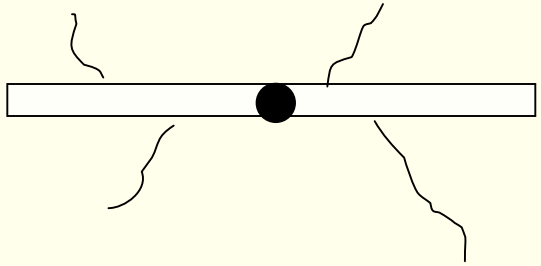
Accretion

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

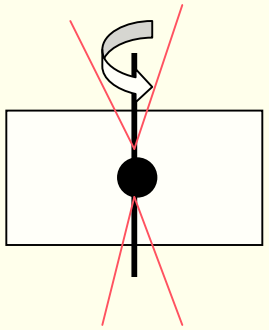


Spin

thick disk + fast spinning hole = powerful jet

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

Meier 99



Can we test this in clusters?

Possibly yes with cluster-scale outbursts that strain the limits of theory.

Power Output: spin/rotation or infall

➡ nearly independent constraints from jet energy & power measurements

	infall	spin
Total Energy	ΔM_{BH}	M_{BH}
Jet Power	$\dot{M}$	j^2, B_p^2

Meier 99, Nemmen + 07
Blandford & Znajek 77
Blandford & Payne 82

MS0735: $P_{jet} = 3.5 \times 10^{46} erg\, s^{-1}$ $E_{tot} = 1.2 \times 10^{62} erg$

Schwarzschild infall

$$\Delta M_{BH} \sim 6 \times 10^8 M_\otimes$$

$$\dot{M}_{BH} \approx 5.6 M_\otimes\, yr^{-1} \approx 1/3\, \dot{m}$$

MHD spin jet (Meier 99)

$$E_{rot} \approx 1.6 \times 10^{62} m_9 j^2 erg$$

so j~1 or $M_{SMBH} > 10^9 M_o$

$$P_{jet} = 1.1 \times 10^{46} \left[\frac{B_P}{10^4 G}\right]^2 m_9^2 j^2 \propto \left(\frac{\dot{m}}{0.01}\right)$$

remarkably efficient accretion ⟷ maximal spin or Jumbo SMBH

(Bondi ruled out) (Bondi possible)

Problems with the spin hypothesis

- What spins them up? SMBH mergers requires nearly equal mass or steady infall with constant $\vec{L}$ Wilson & Colbert 95 Voluntieri + 05

- How to regulate by feedback?

BUT

- ~10^{62} erg spin energy enough to quench cluster CF for ~ Hubble time. Function as *flywheel* periodically tapped via feedback loop?

- Dispense high power at low accretion rates (ie., Bondi)

- Must be important at some level. may be a factor in scatter in L_{cool} vs P_{cavity} & P_{jet} vs L_{rad} relations (Birzan + 04,08, Rafferty + 06, Dunn + 06)

- Hercules A shaping up similarly -- larger sample of big outbursts

real possibility that jumbo SMBHs exist!

thanks to Dan Evans