Observational constraints on the importance of radio-mode feedback in massive galaxy formation

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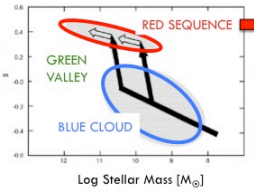
1 Massive galaxy formation & AGN feedback in cosmological models

Observations

Blue-to-red galaxy formation
Sanders & Mirabel 1996, Bell et al. 2004, Borch et al. 2006, Faber et al. 2007, Hopkins et al. 2007 & many others



Cosmological models

RADIO MODE

- Once a static hot (X-ray) halo forms around galaxy
- Modes BH growth
- Radio outflows heat surrounding gas → truncation of further stellar mass growth

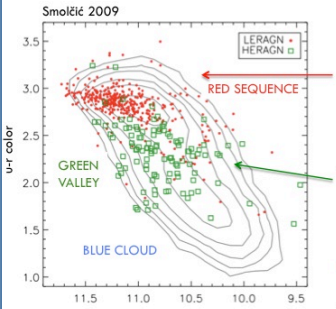
Allows good reproduction of observed galaxy properties but observational testing required!

Croton et al. 2006; Bower et al. 2006; Sijacki et al. 2006...

2 AGN in the radio regime: low-excitation (LE) vs. high excitation (HE)

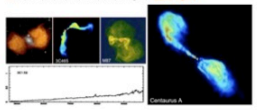
- Fundamental physical differences

	HERAGN	LERAGN	References
Radio luminosity	High ($L_{10cm} \geq 10^{25}$ W/Hz)	Lower ($L_{10cm} \leq 10^{25}$ W/Hz)	Kauffmann et al. 2008
Optical color	Green/Blue	Red	Baum et al. 1992; Baldi & Capetti 2008; Smolčić et al. 2008; Smolčić 2009
Stellar mass	Lower than LERAGN	Highest ($\geq 5\times10^{10} M_\odot$)	Kauffmann et al. 2008; Smolčić et al. 2008; Tasse et al. 2008; Smolčić 2009
Gas mass	Higher than LERAGN ($\sim10^9 M_\odot$)	Lower ($\leq 10^9 M_\odot$)	Smolčić & Riechers (in prep)
BH mass	Lower than LERAGN	Highest ($\sim10^9 M_\odot$)	Baum et al. 1992; Chiaberge et al. 2005; Kauffmann et al. 2008; Smolčić et al. 2008; Smolčić 2009
BH accretion mode	Radiatively efficient	Radiatively inefficient	Barthel 1989; Haas 2004; Evans et al. 2006; Hardcastle et al. 2006, 2007; Smolčić 2009
Evolution of space density ($z \leq 1.3$)	Strong	Modest	Smolčić et al. 2009

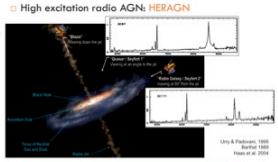


SDSS-NVSS ($z<0.1$) data (drawn from Kimball & Ivezic 2009 Unified radio catalog)

- Low excitation radio AGN: LERAGN



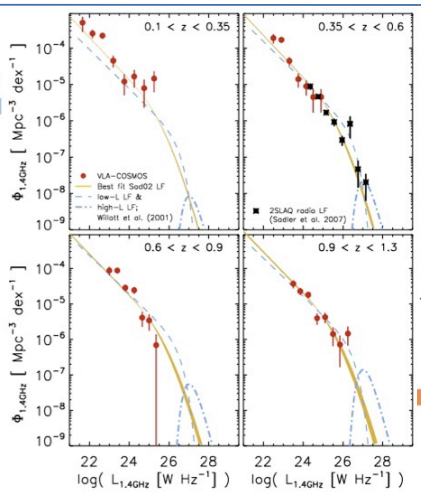
- High excitation radio AGN: HERAGN



Only LERAGN contribute to radio-mode feedback!

3 Radio AGN luminosity function

- Good agreement with local LF (Sadler et al. 2002) & LF @ z~0.5 (Sadler et al. 2007)
- Modest evolution (consistent with with Clewley & Jarvis 2004, Sadler et al. 2007, Donoso et al. 2008):
  - $\alpha_0 = 0$ & $\alpha_1 = 0.8 \pm 0.1$
  - $\alpha_0 = 1.1 \pm 0.1$ & $\alpha_1 = 0$
- High-power radio AGN LF (Willott et al. 2001; 3CRR, 6CE, 7CRS), stronger evolution than low-power radio AGN

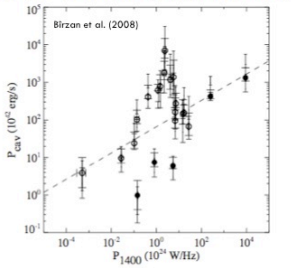


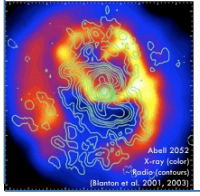
Smolčić et al. (2009)

4 20cm power → mechanical power output

- Scaling relation based on radio galaxies in galaxy clusters (Birzan et al. 2004, 2008): radio emission inflates buoyantly rising bubbles in X-ray plasma (i.e. cavities)
- 0.85 dex scatter when 20cm radio power used

$$\log P_{cav} = (0.35 \pm 0.07) \log P_{1400} + (1.85 \pm 0.10)$$



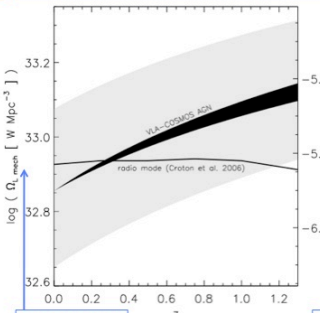


$$P_{cav} = \frac{E_{cav.}}{t_{cav}} = \frac{E_{int} + PdV}{R/c_s} = \{rel.plasma\} = \frac{4PV}{R/c_s}$$

Dunn & Fabian 2004
Birzan et al. 2004
Allen et al. 2006
Rafferty et al. 2006

5 Radio-AGN feedback models vs. observations

~600 radio AGN ($L_{1.4GHz} \leq 10^{25}$ W/Hz; $z \leq 1.3$) drawn from the VLA-COSMOS survey (Smolčić 2007, PhD Thesis; Schinnerer, et al. et al. 2007; Smolčić et al. 2008)



Volume averaged mechanical heating rate ← $\Omega_{L\,mech} = 0.1 \dot{m} c^2$ → Comoving BH accretion rate density

Good agreement between cosmological model and observations is very encouraging for the idea of 'radio mode' feedback in the context of massive galaxy formation

Smolčić et al. (2009)

References: Allen et al. 2006, MNRAS, 372, 21 • Baldi & Capetti 2008, A&A, 489, 989 • Barthel 1989, ApJ, 336, 606 • Baum et al. 1992, ApJ, 336, 702 • Bell et al. 2004, ApJ, 608, 752 • Birzan et al. 2004, ApJ, 607, 800 • Birzan et al. 2008, ApJ, 686, 859 • Borch et al. 2006, A&A, 453, 869 • Bower et al. 2006, MNRAS, 370, 645 • Chiaberge et al. 2005, ApJ, 625, 716 • Clewley & Jarwis 2004, MNRAS, 352, 909 • Croton et al. 2006, MNRAS, 365, 11 • Donoso et al. 2009, MNRAS, 392, 617 • Dunn & Fabian 2004, MNRAS, 355, 862 • Evans et al. 2006, ApJ, 642, 96 • Faber et al. 2007, ApJ, 665, 265 • Haas 2004, A&A, 424, 531 • Hardcastle et al 2006, MNRAS, 370, 1893 • Hardcastle et al 2007, MNRAS, 376, 1849 • Hopkins et al. 2007, ApJ, 659, 976 • Kauffmann et al. 2008, MNRAS, 384, 953 • Rafferty et al. 2006, ApJ, 652, 216 • Sadler et al. 2002, MNRAS, 329, 227 • Sadler et al. 2007, MNRAS, 381, 211 • Sanders & Mirabel 1996, ARA&A, 34, 749 • Schinnerer et al. 2007, ApJS, 172, 46 • Sijacki et al. 2006, MNRAS, 366, 397 • Smolcic 2007; PhD Thesis • Smolcic et al. 2008, ApJS, 177, 14 • Smolcic et al. 2009, ApJ, 696, 24 • Smolcic 2009, ApJL, 699, 43 • Tasse et al. 2008, A&A, 490, 893 • Willott et al. 2001, MNRAS, 322, 536