AGN-controlled gas cooling in elliptical galaxies and galaxy clusters

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Abstract

The gaseous haloes of elliptical galaxies are strong X-ray emitters, yet the starformation rate in these systems is low. The energy losses from the gas must be replenished. Here we show that the observed radio-loud fraction of elliptical galaxies strongly suggests that the energy transported by relativistic jets driven by Bondi accretion onto the central black hole from a cooling flow can balance the radiative cooling. The same process may explain the reheating of gas in galaxy clusters, but, compared to field galaxies, at $M_{BH}\sim10^8$ $M_\odot$ a central cluster galaxy is ten times more likely to host an AGN.

Best et al. (2005) cross-correlated the 212,000 SDSS galaxies of Brinchmann et al. (2004) with the FIRST and NVSS radio surveys. 2712 galaxies are detected down to 5 mJy at 1.4 GHz. The normalisation of the resulting radio-loud fraction of elliptical galaxies, $P(L>L_{NVSS})$, strongly depends on the mass of the central black hole, but its shape as a function of L_{NVSS} does not.

Fig. 1: Radio-loud fraction, $P(L>L_{NVSS})$, of elliptical galaxies. The symbols show the binned and scaled observational data. The solid line is the best fit

$$P(L > L_{NVSS}) = f_0 M_{BH}^{1.6}\left[\left(\frac{L}{L_*}\right)^{1.79} + \left(\frac{L}{L_*}\right)^{0.37}\right]^{-1}$$

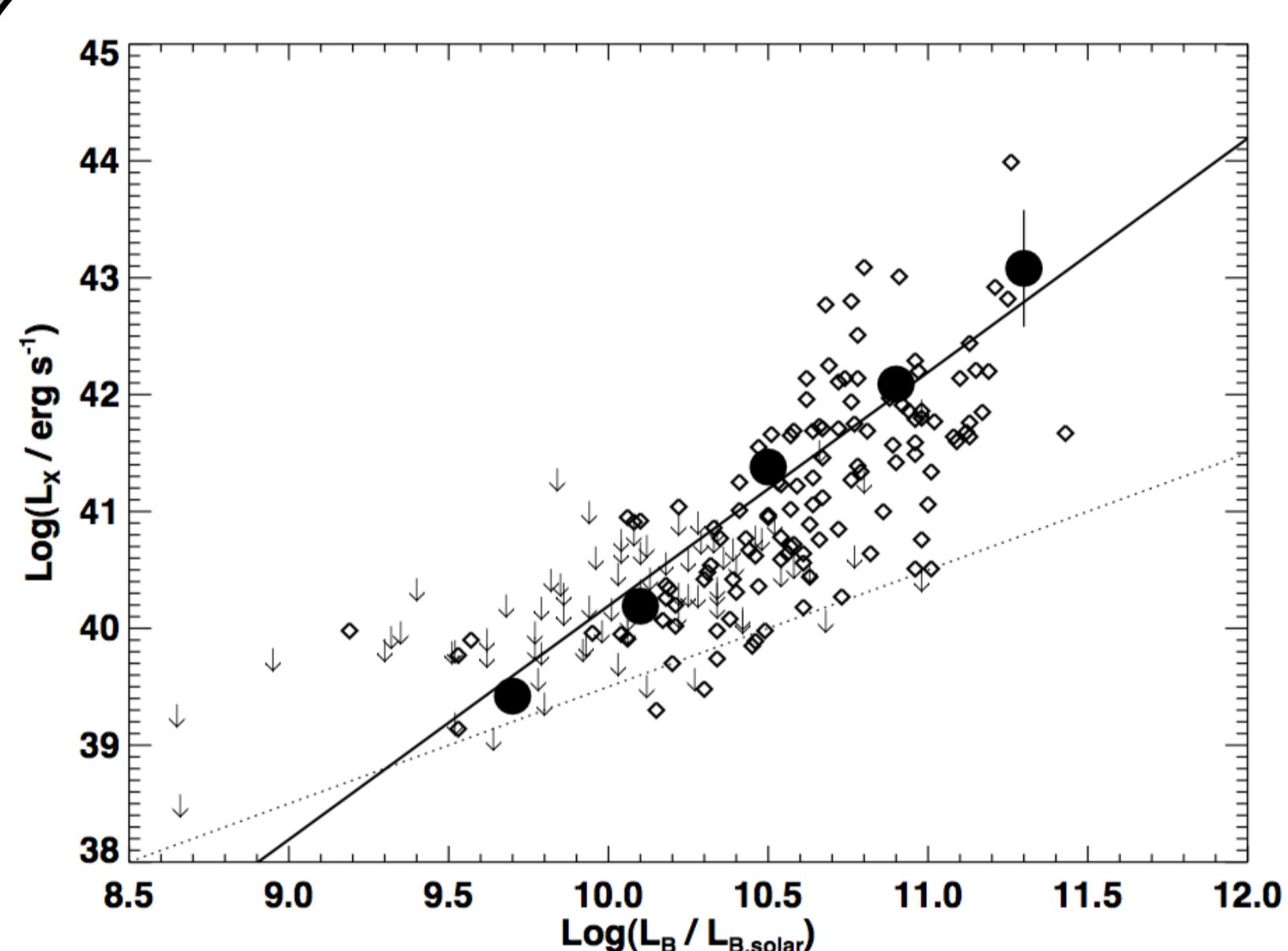with L_*=3.2x10^{24} W Hz^{-1} (Best et al., 2005).

Fig. 2: Comparison of mechanical energy supplied to gas by radio source (solid line) compared to X-ray observations (symbols; from O'Sullivan et al. 2001). The dotted line shows the estimated contribution from X-ray binaries. The filled dots are the median of the binned data points.

Radio emission probably implies outflows in the form of jets. We convert radio luminosity to mechanical power,

$$L_{mech} \propto L_{1.4\,GHz}^{0.4}$$

(Bîrzan et al. 2004) and derive the energy injection into the gaseous halo as a function of mass of the central black hole. This balances radiative cooling (Best et al., 2006; see Fig. 2).
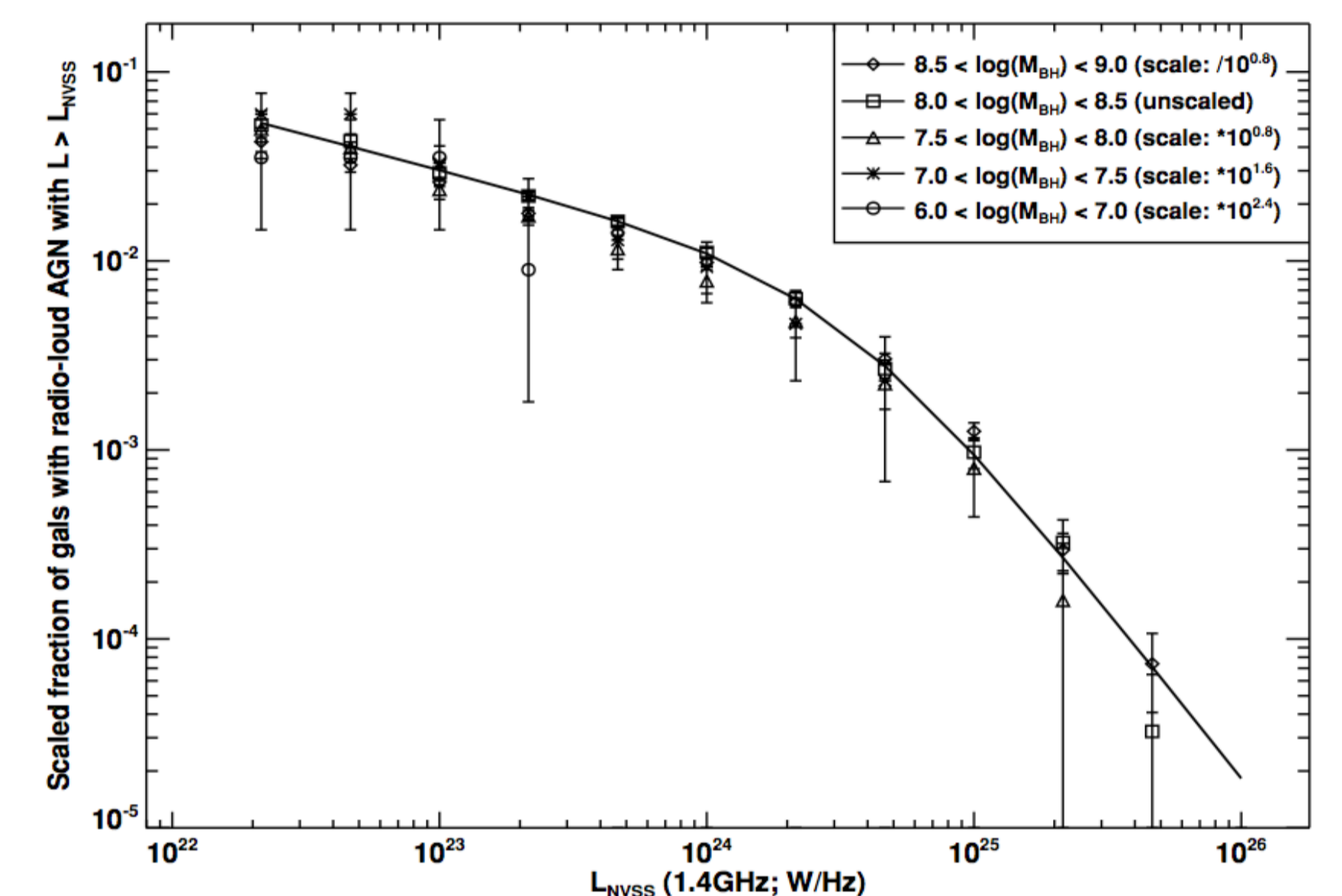
How does the AGN couple to the cooling gas? We investigate various accretion modes onto the central black hole: Eddington-limited accretion (depends only on black hole mass), cooling flow (depends only on properties of gas halo) and Bondi accretion from a cooling flow (depends on both). Only the latter provides adequate heating of the gas (see Fig. 3). Both, the black hole mass and the gas halo determine the energy feedback (Pope et al., 2006)
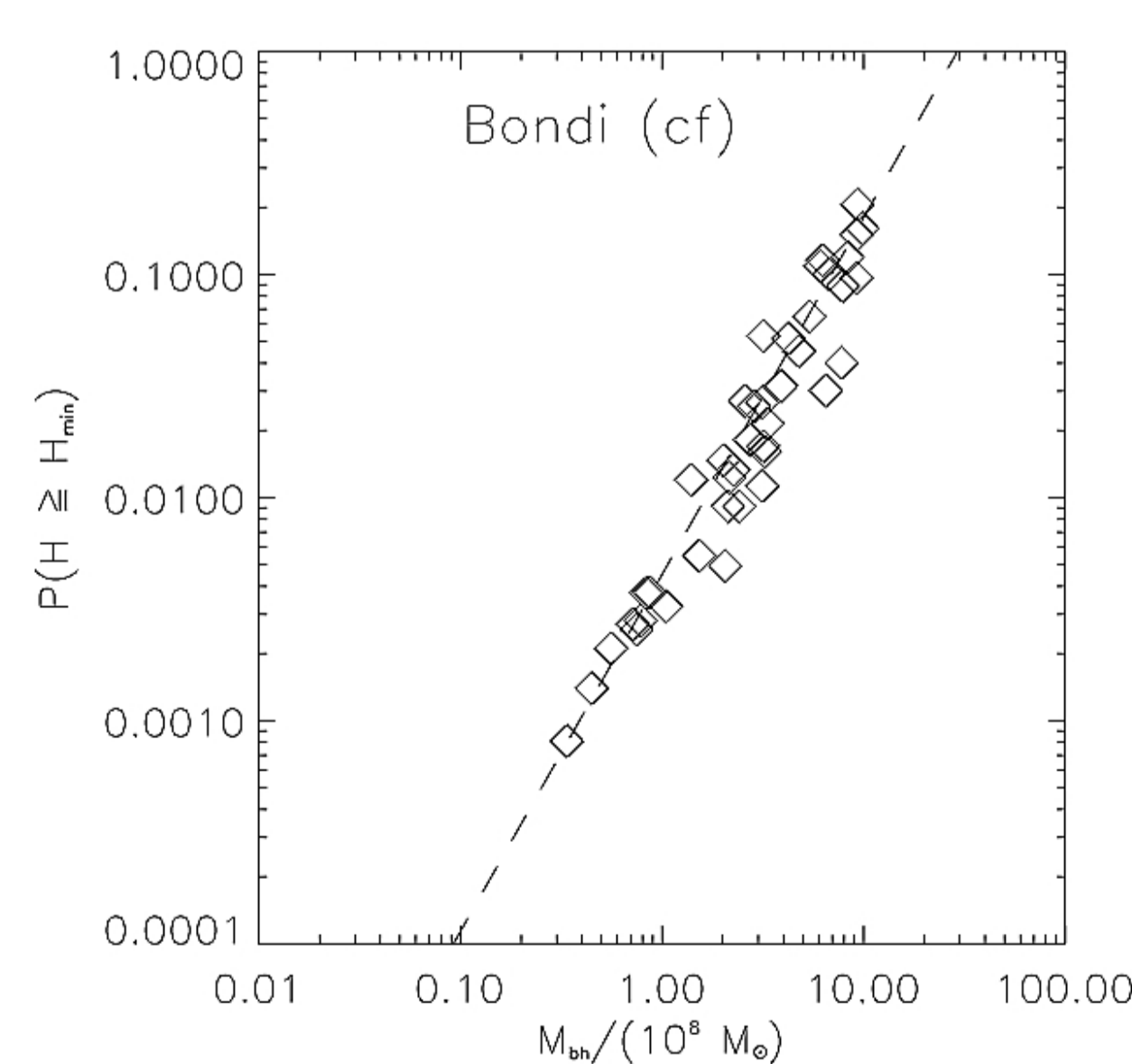

Fig. 3: Prediction of the radio-loud fraction for ellipticals based on Bondi accretion from a cooling flow onto the central black hole (dashed line; Pope et al., 2006). Diamonds show data from Fukazawa et al. (2006) and McElroy (1994).
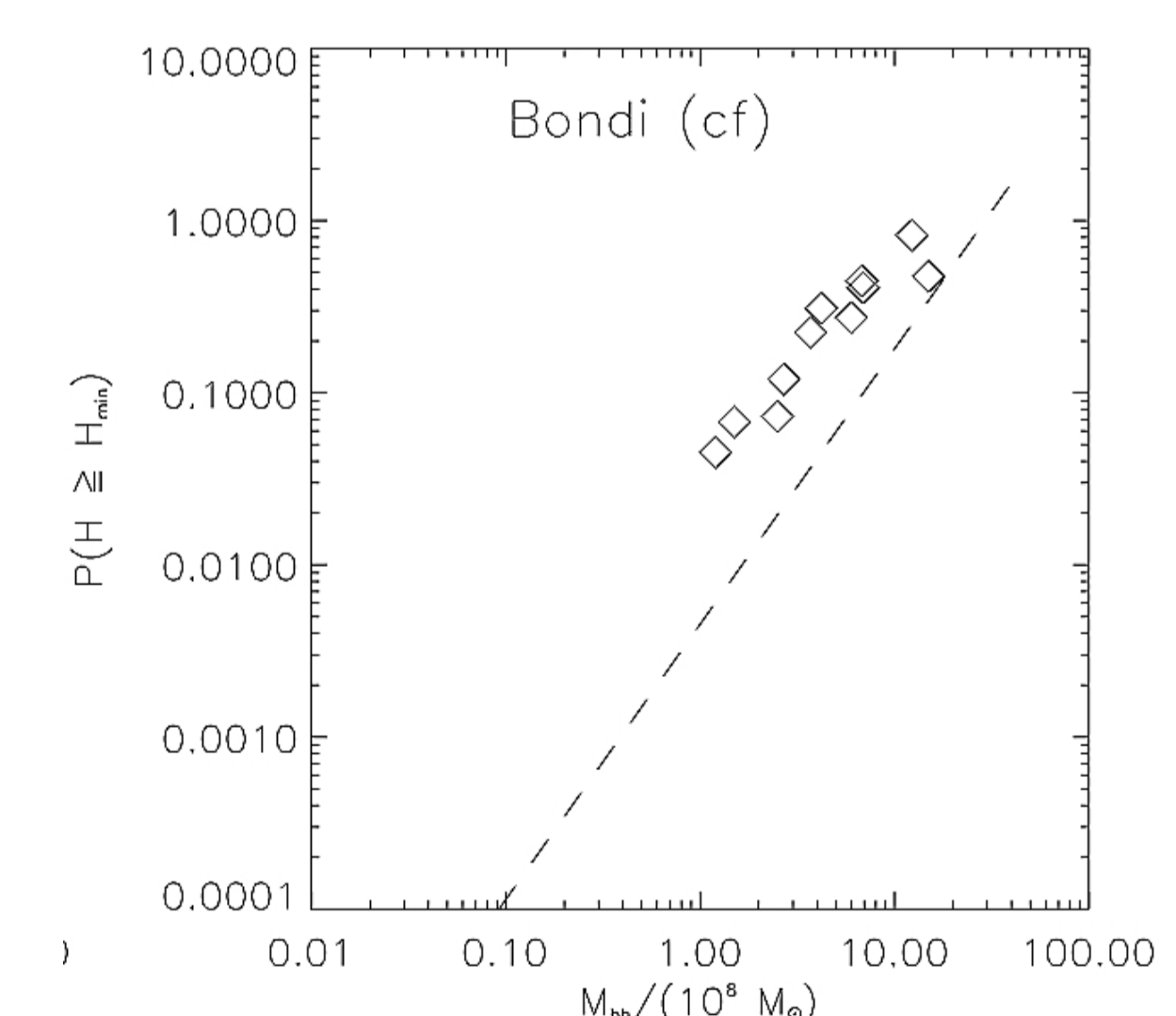

Fig. 4: Same as Fig. 3, but for Brightest Cluster Galaxies (BCG). Bondi accretion from a cooling flow in the cluster atmosphere can balance radiative cooling. Note that the required slope of $P(L>L_{NVSS})$ as a function of M_{BH} is flatter. Also, at $M_{BH}\sim10^8$ $M_\odot$ the normalisation needs to be an order of magnitude higher (Pope et al., 2006). Data from Kaastra et al. (2004), Donahue et al. (2006) and Fujita & Reiprich (2004).