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Relation between accretion rate and jet power in early-type galaxies

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Correlation between the accretion rate and jet power

A correlation between the mechanical power of **relativistic jets** $P_{\rm jet}$ and the approximate accretion power (**Bondi accretion**) $P_{\rm Bondi}$ of central supermassive black holes has been reported by Allen et al. 2006 [1] for 9 nearby massive early-type galaxies. A later work studying 14 nearby giant ellipticals by Russell et al. 2013 [3] found a relation with a much larger scatter.

To clarify the existence of this correlation, we performed an analysis of X-ray and radio observations for 20 early-type galaxies. Using radio contours of **VLA** observations (at 1–2 GHz), we estimated the extent of observed radio lobes and assuming rotational symmetry, we derived the total volume of corresponding cavities. To determine the pressure surrounding the cavities as well as the properties of the gas in the vicinity of the central supermassive black holes, we performed a spatially resolved spectral analysis of ***Chandra*** ACIS-S and ACIS-I observations.

In our paper [2], we have confirmed a correlation between the Bondi accretion power $P_{\rm Bondi}$ and mechanical jet power $P_{\rm jet}$. A tight correlation has however only been observed for a subsample of galaxies harbouring **thermally unstable atmospheres** indicated by the presence of Hα+[NII] emission. For this subsample, the relation is well described by a power-law model:

$$\log \frac{P_{\rm Bondi}}{10^{43}\,{\rm erg\,s^{-1}}} = (1.10 \pm 0.25) + (1.10 \pm 0.24) \log \frac{P_{\rm jet}}{10^{43}\,{\rm erg\,s^{-1}}}.$$

Galaxies with thermally stable atmospheres typically have an order of magnitude lower jet powers causing a larger scatter to the relation and leading to weaker correlation (Figure 1).

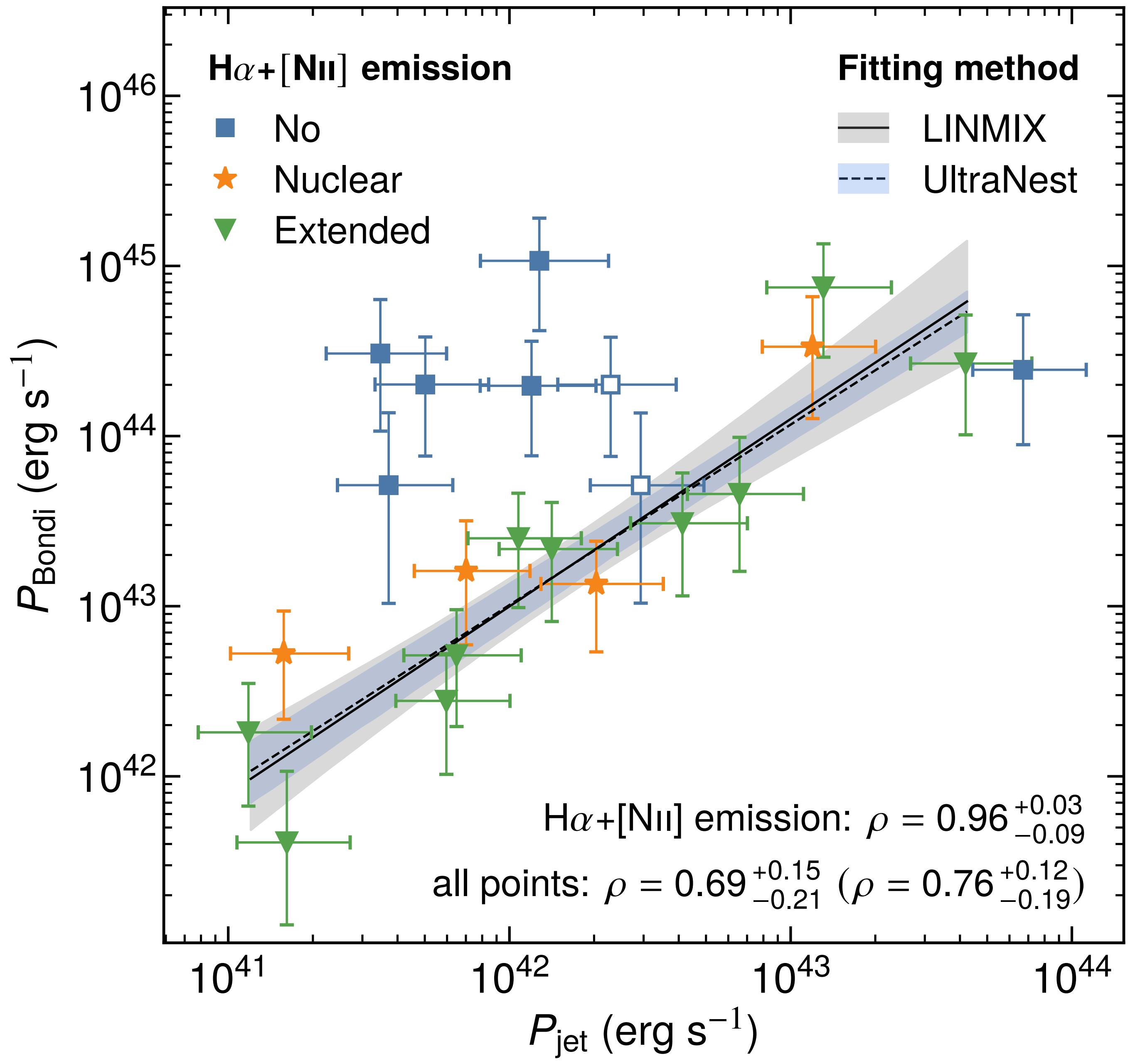

Figure 1. Correlation between Bondi accretion power $P_{\rm Bondi}$ and mechanical jet power $P_{\rm jet}$.

Correlation between jet power and black hole mass

By decomposing the Bondi formula and probing the dependency of the mechanical jet power $P_{\rm jet}$ on its individual components, we found that the source of the observed tight relation is a correlation between the mechanical jet power $P_{\rm jet}$ and **the mass of the supermassive black hole** $M_{\rm BH}$ (Figure 2). The Bondi accretion rate appears weakly dependent on the thermodynamic properties of the gas inside the Bondi radius ($K \propto -3/2$), but the central specific entropy appears to correlate with the mechanical jet power only mildly, although the data are rather uninformative.

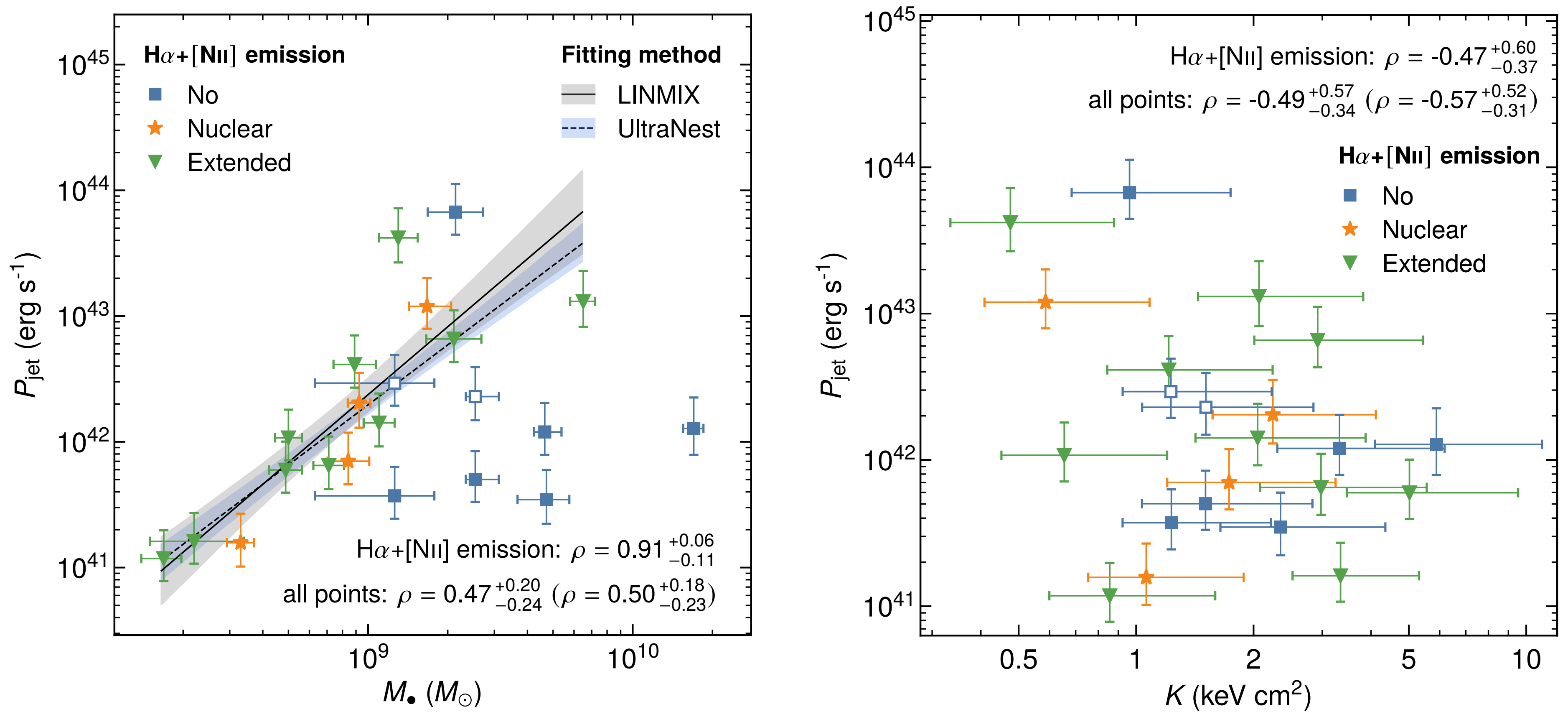

Figure 2. Mechanical jet power $P_{\rm jet}$ versus SMBH mass $M_{\rm BH}$ (left) and central specific entropy K (right).

Feeding from thermally unstable atmospheres

The thermal stability of atmospheres was, besides the presence of Hα+[NII] emission, also probed using the minimum value of the cooling time to free-fall time ratio. Figure 3 shows that, for galaxies with min($t_{\rm cool}/t_{\rm ff}$) lower than or close to the **precipitation limit**, the jet-to-Bondi power efficiency is approximately constant (≈ 10 per cent), while for larger min($t_{\rm cool}/t_{\rm ff}$) ratios the efficiency appears to decrease.

The fact that we only see a strong correlation for thermally unstable atmospheres with lower min($t_{\rm cool}/t_{\rm ff}$) suggests that the black holes producing the jets and lobes are fed by thermally unstable gas from the galactic atmospheres. It appears that once the atmosphere becomes thermally unstable, the cooling gas feeds the black holes in the centres of all galaxies at a similar jet-to-Bondi power ratio, possibly indicating a key universal property of black hole accretion in early-type galaxies.

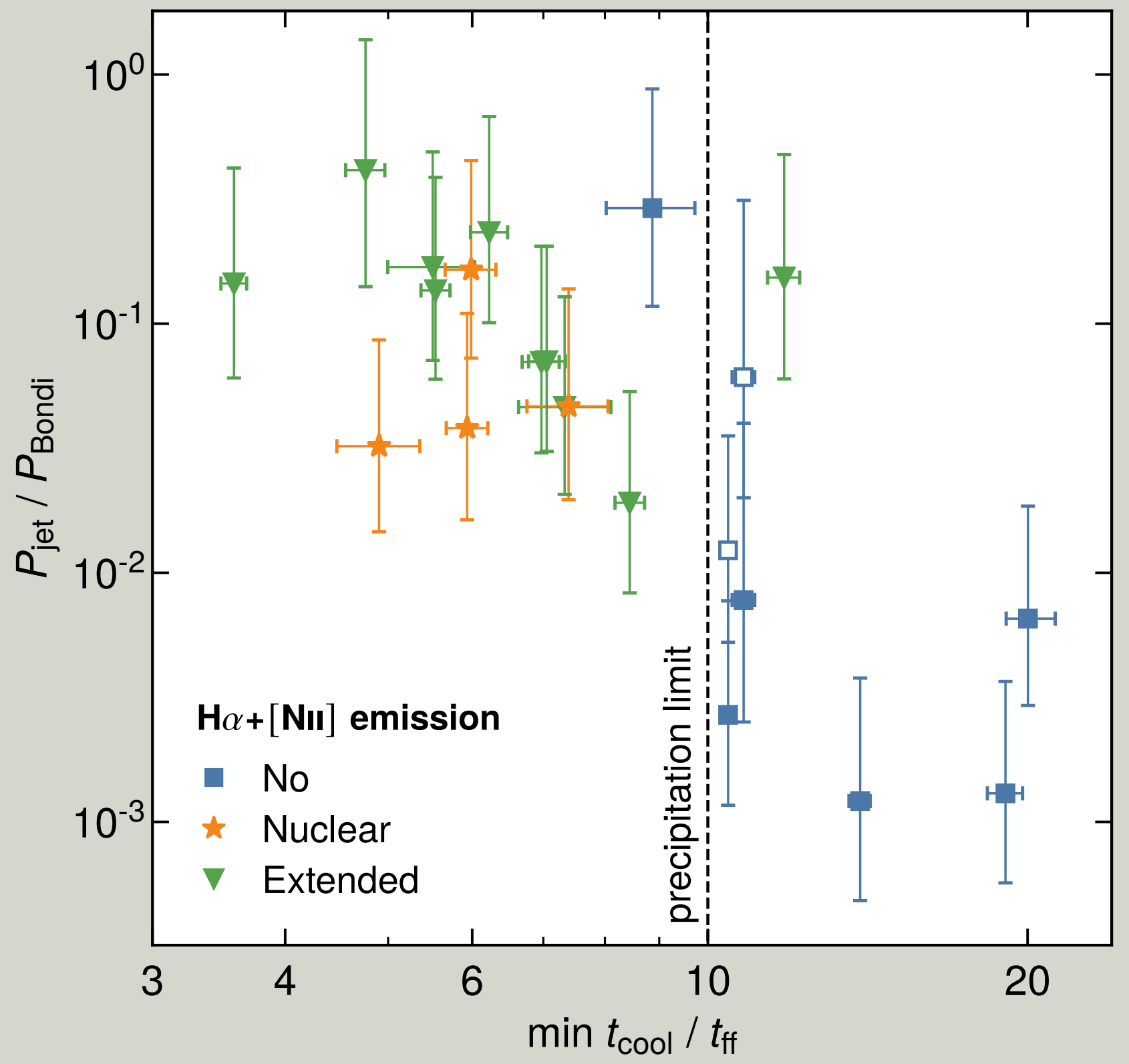

Figure 3. The efficiency of jet-to-Bondi power as a function of the minimum of the cooling time to free-fall time ratio.

Conclusions

We have confirmed the presence of a correlation between Bondi accretion power and mechanical jet power in early-type galaxies previously reported by Allen et al. 2006 [1]. We show that a particularly strong correlation holds for galaxies with thermally unstable atmospheres, as indicated by the presence of cool gas traced by Hα+[NII] emission and with min($t_{\rm cool}$ / $t_{\rm ff}$) $\lesssim 10$, while for the whole sample of galaxies the correlation is weaker.

Interestingly, according to the power-law fit for the Hα+[NII] subsample, the Bondi power scales with jet power as $\propto P_{\rm jet}{}^{1.10\pm0.25}$ with correlation coefficient of $\rho = 0.96^{+0.03}_{-0.09}$. We note that the exponent is remarkably close to unity, which yields a **constant jet-to-Bondi power efficiency** (11^{+6}_{-3} per cent).

Importantly, we find a strong correlation between the mechanical jet power ($P_{\rm jet}$) and the mass of the central supermassive black hole ($M_\bullet$) and, although poorly constrained, a hint of an anti-correlation with the specific entropy (K) of the ambient gas inside the Bondi radius. The mechanical jet power for the galaxies with Hα+[NII] emission scales with the supermassive black holes mass as

$$\log \frac{P_{\rm jet}}{10^{43}\,{\rm erg\,s^{-1}}} = (-0.62 \pm 0.14) + (1.79 \pm 0.36) \log \frac{M_\bullet}{10^{9}\,M_\odot},$$

with a correlation coefficient of $\rho = 0.91^{+0.06}_{-0.11}$, while for the full sample the correlation is weaker.

The results indicate that at least for thermally unstable systems, the jet power is set primarily by the supermassive black hole mass. Since the central black hole mass of X-ray luminous early-type galaxies correlates with the total mass of the host halo, more massive systems undergoing thermally unstable cooling will naturally have larger jet powers.

References

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MNRAS doi:10.1093 (arXiv/2203.15809)

3rd Athena Scientific Conference 2022, Barcelona — CosmoCaixa

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