The relation between accretion rate, black hole mass, and jet power in massive early-type galaxies

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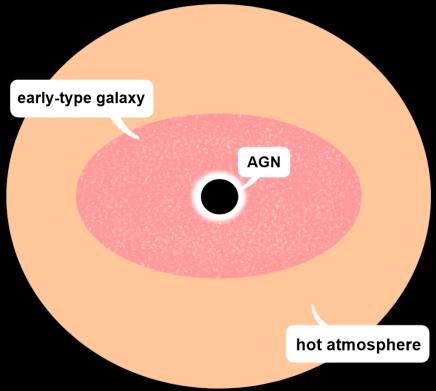
[3]Kavli Institute for Particle Astrophysics and Cosmology, Stanford University

CPB meeting 2022

June 2 2022

Hot atmospheres

- hot diffuse plasma
  - $n \approx 10^{-5} - 1\ \mathrm{cm}^{-3}$
  - $T \approx 10^{6} - 10^{8}\ \mathrm{K}$



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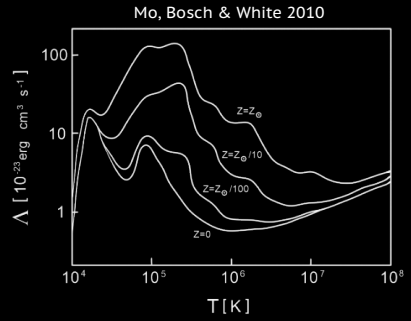

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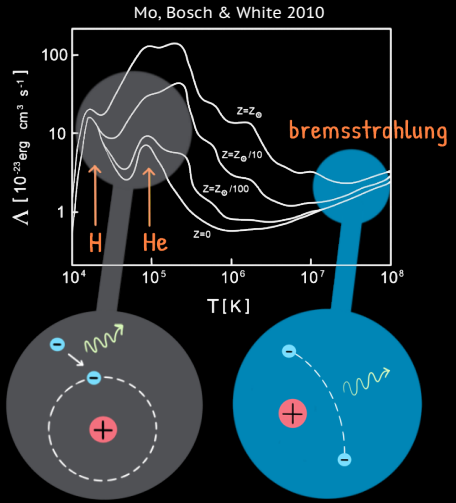

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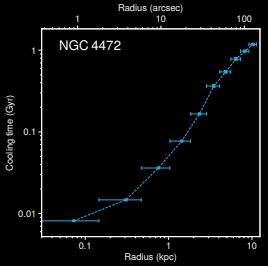

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- cools radiatively
- multiphase gas
  - X-ray emission (*blue*)
  - Hα filaments (*red*)

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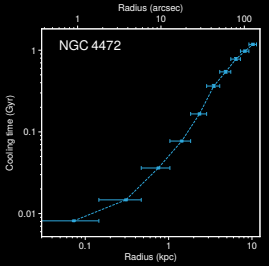

NGC5044, Credit: Werner et al. 2014

NGC1275, Credit: NASA, ESA

AGN feedback

- supermassive black hole
  - accretes ambient material
  - rest mass $\rightarrow$ energy

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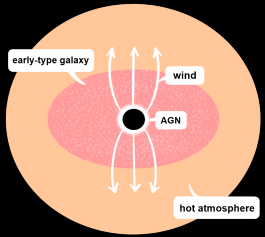

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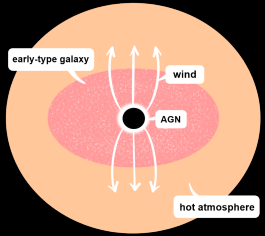
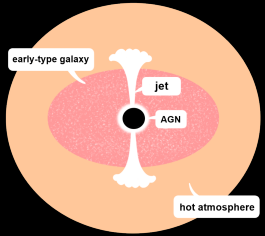
- EM radiation
  - radiative (wind) mode
- relativistic particles = jets
  - kinetic (radio-mechanical) mode
  - regulates accretion
  - prevents star formation





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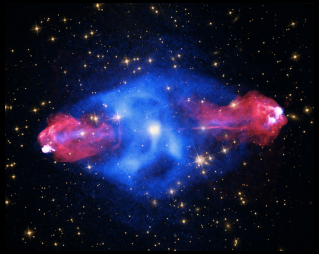
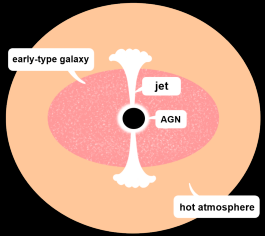




Bondi power to jet power correlation

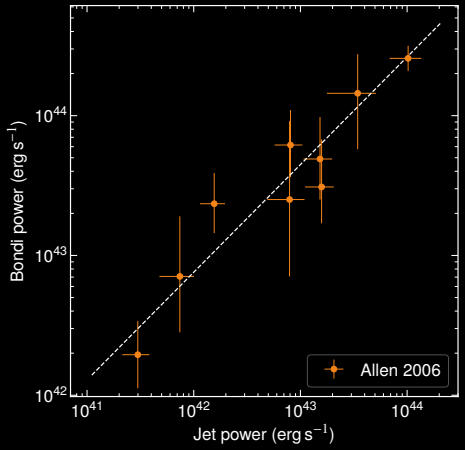
Bondi accretion power

$$\dot{m}_{\mathrm{Bondi}} = 4\pi\lambda\rho(GM_\bullet)^2 c_s^{-3}$$

$$P_{\mathrm{Bondi}} = \eta \dot{m}_{\mathrm{Bondi}} c^2$$

Jet power

$$P_{\mathbf{jet}} = \frac{4pV}{t_{\mathbf{age}}} \qquad t_{\mathbf{age}} = \frac{R}{c_s}$$



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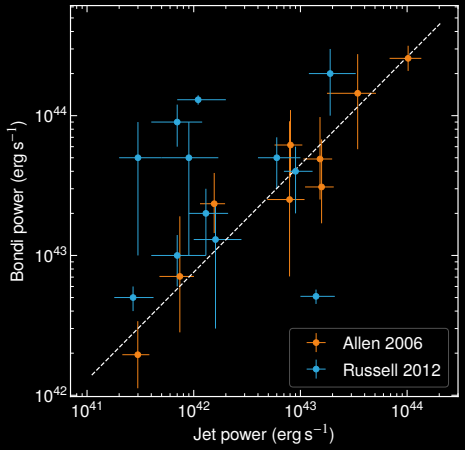

Spectral analysis

- 20 early-type galaxies
  - Bondi radius $r_{\mathrm{Bondi}} = \frac{2GM_\bullet}{c_s^2}$
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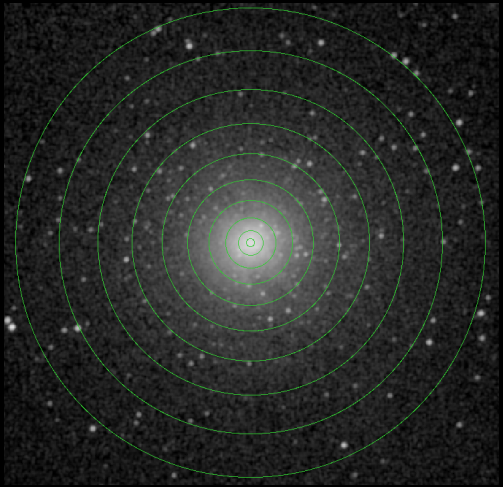

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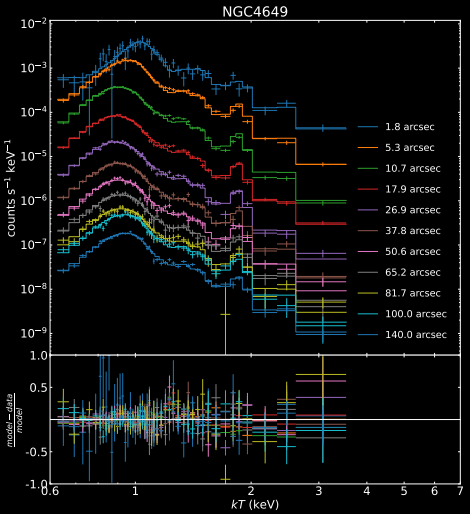
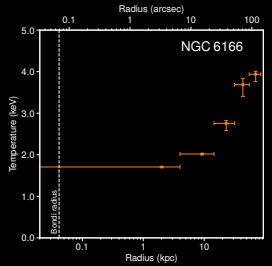
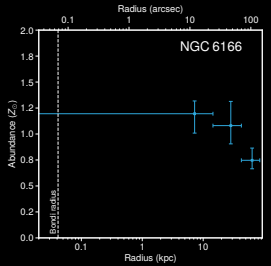
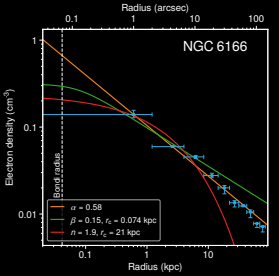
  - radio lobes (VLA) + X-ray cavities
- deprojected spectra
- spectral models (Xspec)
  - `apec` – kT, n_e, Z
  - `powerlaw` – $\Gamma \approx 1.9$
  - `bremss` – $kT \approx 7.3$ keV

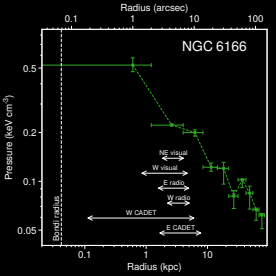


Thermodynamic profiles









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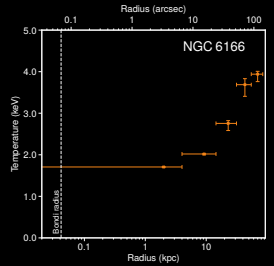
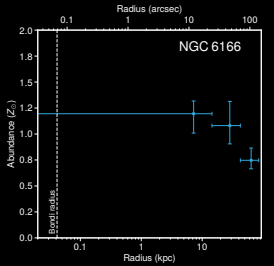
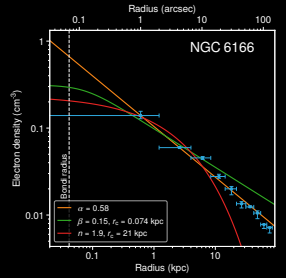
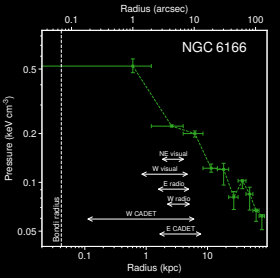


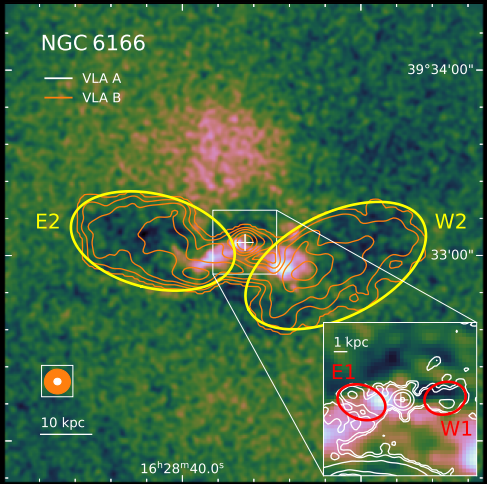






Cavity size estimation

- Radio contours
  - Very Large Array (VLA)



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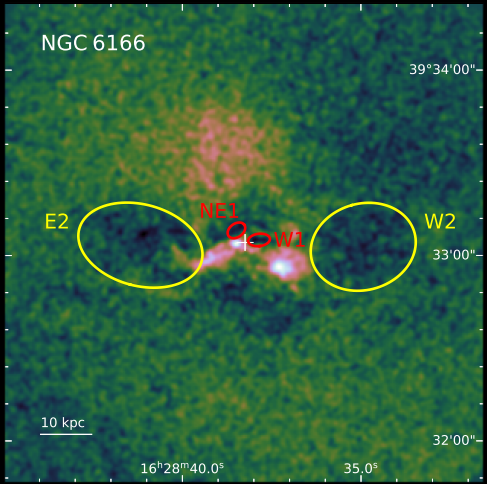

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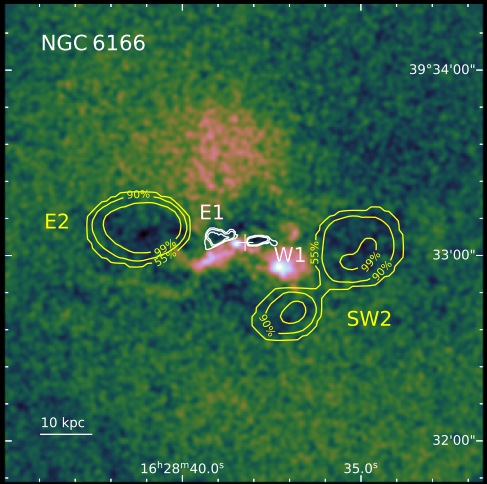
- Neural network (CADET)
  - raw X-ray images



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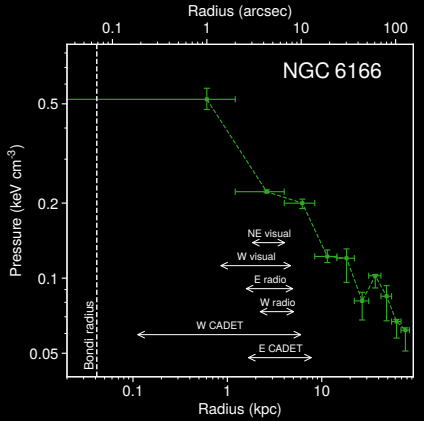
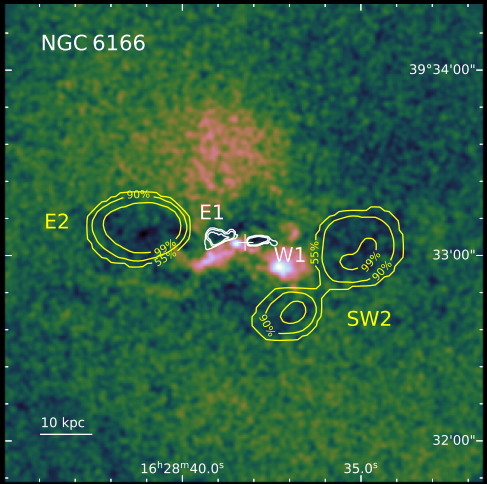
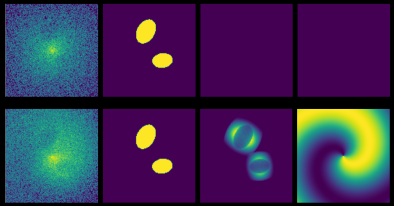




CAvity DEtection Tool (CADET)

- artificial training data
  - 300k images (50% cavities)
  - beta model + ellipsoidal cavities
- CNN + DBSCAN
  - Fort 2017 & Secká 2018



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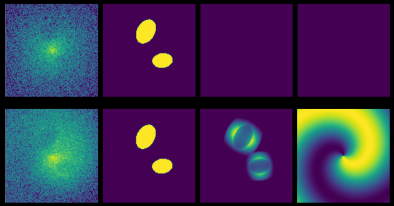
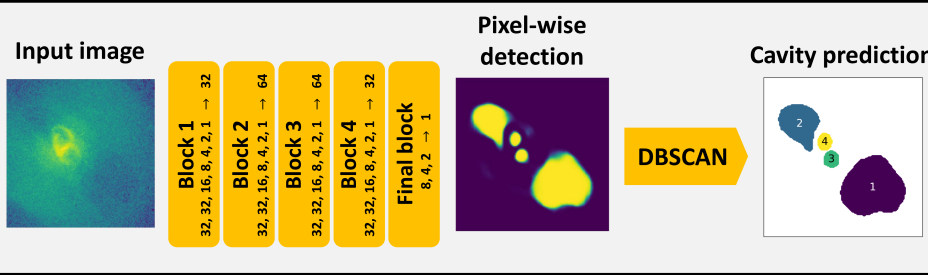
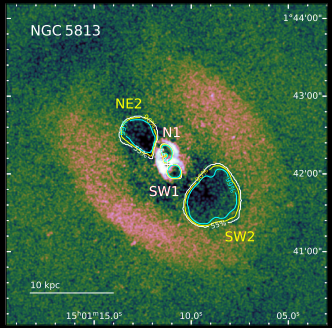
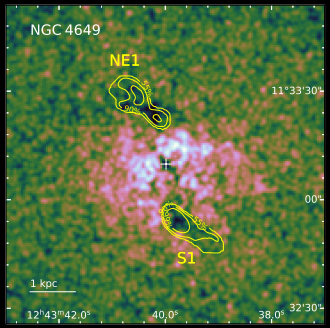
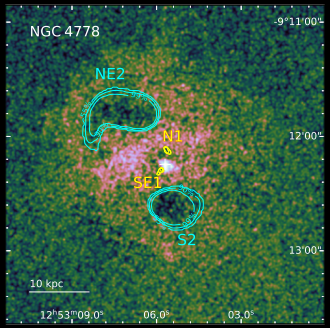




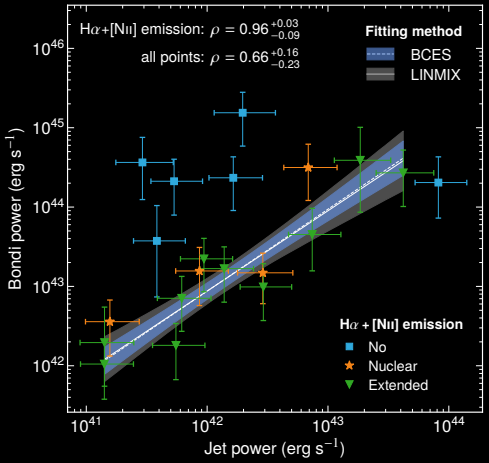
CAvity DEtection Tool (CADET) - results







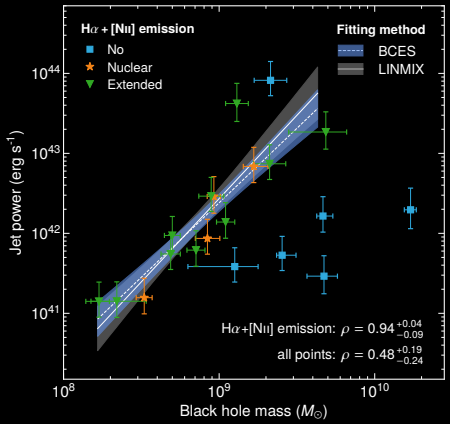
Apparent Bondi to jet power correlation



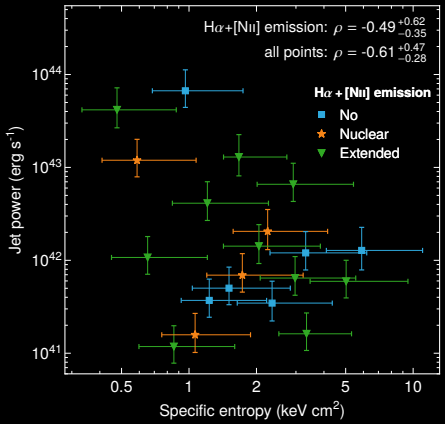
Apparent Bondi to jet power correlation

$$P_{\rm Bondi} \propto M_\bullet^2\, K^{-3/2}$$

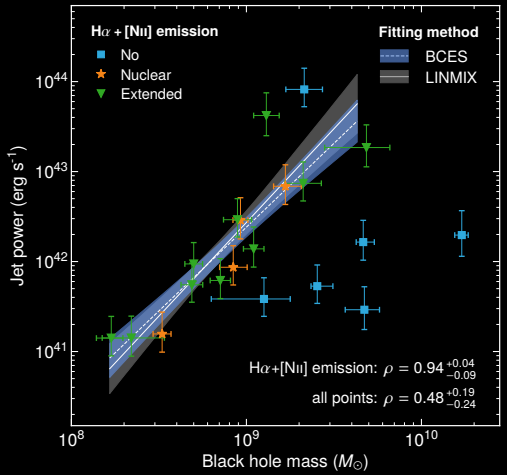
$$P_{\rm jet} \propto M_\bullet^{2.08\pm0.42}$$



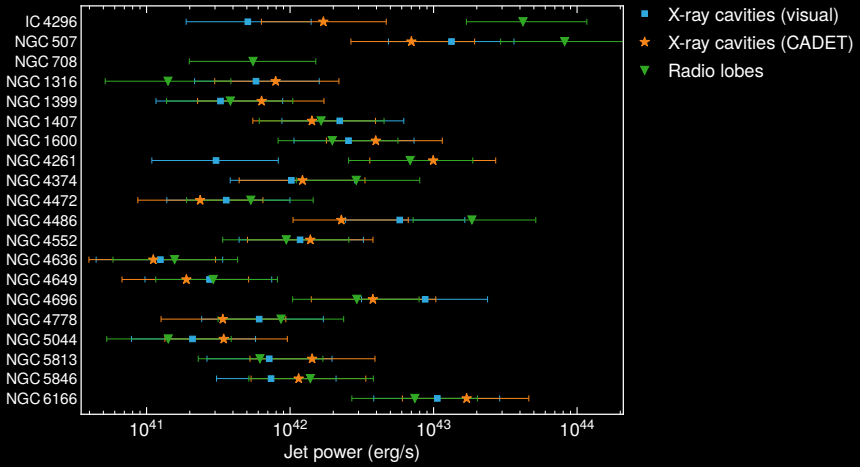
$$P_{\rm jet} \neq f(K)$$



Feeding from thermally unstable atmospheres



Discrepancy between radio lobes & cavities



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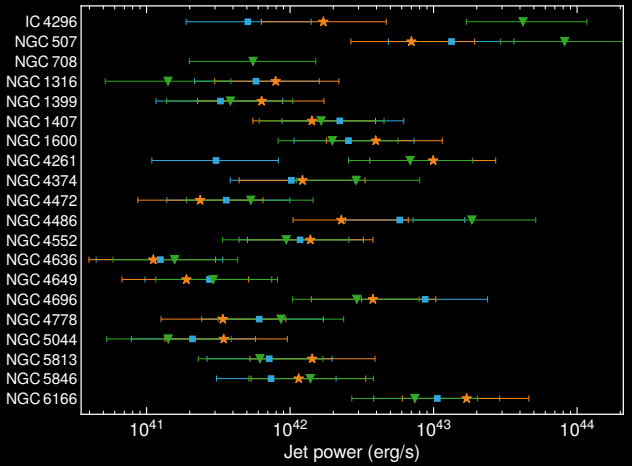
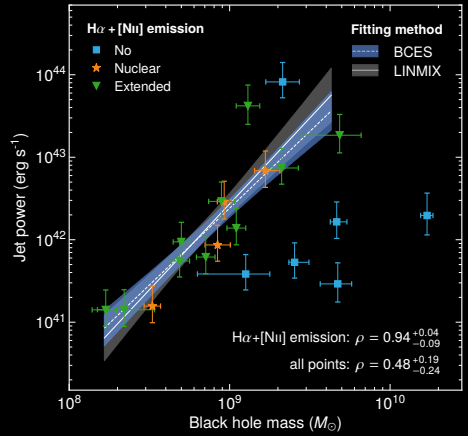


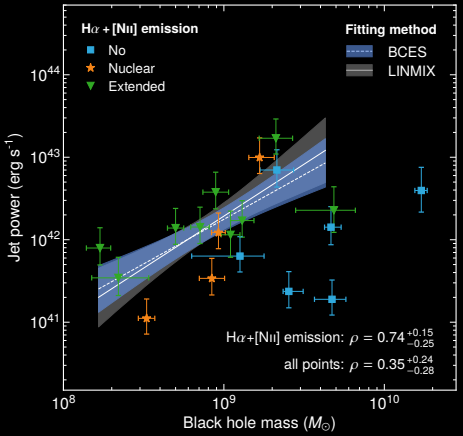
radio lobes have on average 1.5 times higher P_{jet}

Discrepancy between radio lobes & cavities

Radio lobes



X-ray cavities (CADET)



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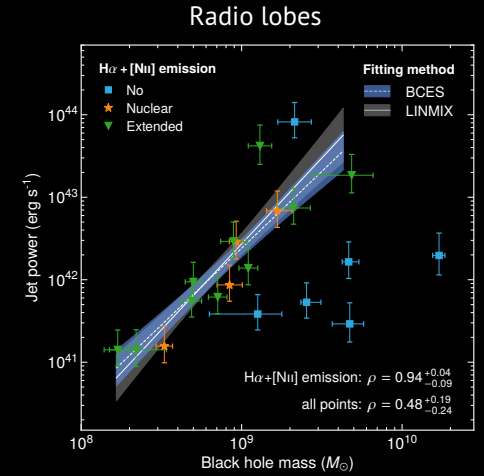

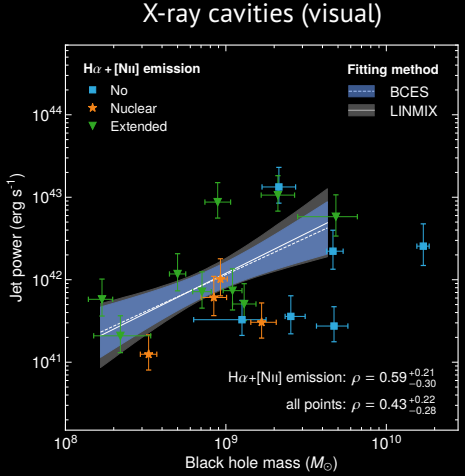

Conclusion

- Bondi-to-jet power correlation
  - caused by underlying $P_{\mathrm{jet}} - M_{\bullet}$ correlation
- SMBHs are fed from thermally unstable atmospheres
  - thermal state provides on/off switch
  - for unstable P_{jet} scales with $M_{\bullet}$
- discrepancy between lobes and cavities
- CNN for finding X-ray cavities (CADET)