A Physical Model for AGN Feedback: The role of BH Spin and Magnetic Field

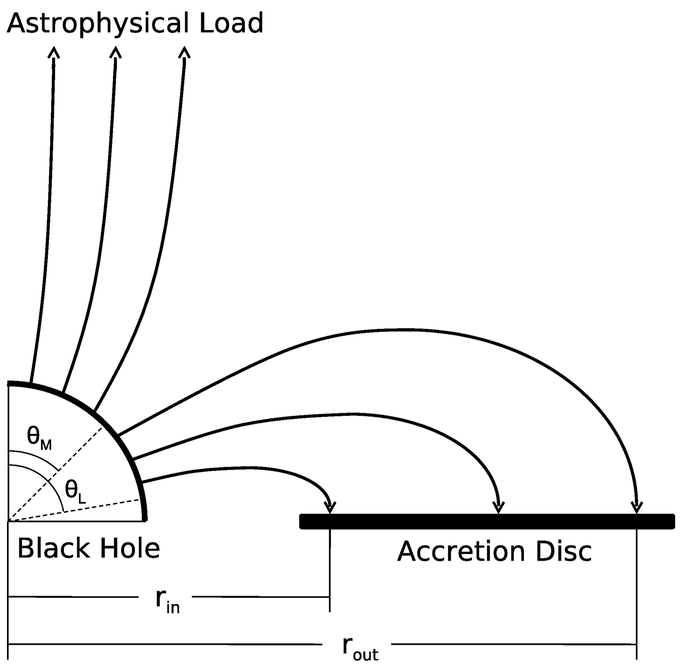
Felipe Garrido-Goicovic[1], Nelson Padilla[1] and Sofía Cora[2]
[1]Departamento de Astronomia y Astrofísica, P. Univerisdad Católica de Chile, Santiago, Chile
[2]Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, La Plata, Argentina

We study the effects of feedback from Active Galactic Nuclei on cosmological samples of galaxies using a semi-analytic model of galaxy formation (SAG) within a dark matter N-Body simulation. The SAG model allows us to follow the evolution of the black hole mass and spin. In the base model the process of mass accretion and AGN feedback have been included in a phenomenological way, which means that they scale to match certain observational data. We now explore a more physical description of the feedback process with a new model for the BH magnetosphere which invokes the Magnetic Coupling (MC) between the BH and its surrounding disc, and allows the existence of the Blandford-Znajek (BZ) effect, associated with jet production.

Penrose (1969) showed that a spinning BH has free energy that is available to be extracted. Using this idea we propose a new model for the luminosity of the accretion disc which includes the BH spin through Magnetic Coupling (MC) of the BH magnetosphere with the disc. With the existence of closed field lines, the rotating BH will exert a torque in the disc to transfer energy and angular momentum, so that the rotational energy of the BH provides an additional energy source for the radiation of the disc, together with the gravitational energy of the orbiting particles (Wang et al. 2003). And the existence of open magnetic field lines allows the presence of relativistic jets powered by the spinning BH, in what is called Blandbord-Znajek (BZ) effect (Blandford & Znajek 1977).

The Magnetic Field

We use the model of Wang, Xiao & Lei (2002)

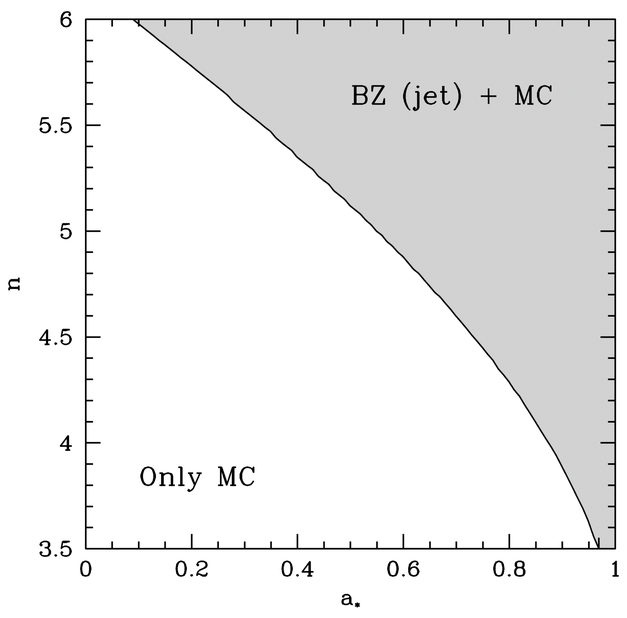


This model allows the coexistence of the jet (BZ effect) and magnetic coupling between BH and disc.

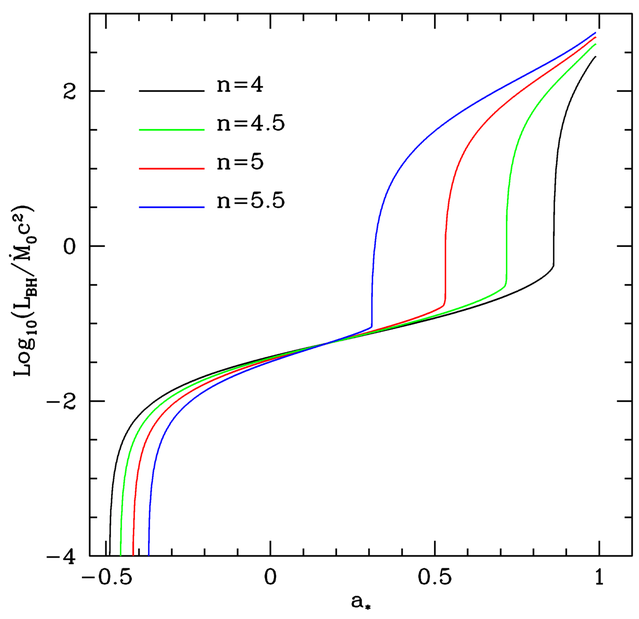
The magnetic field on the disc varies as a power law

$$B_z \propto \xi^{-n} \qquad \text{with} \qquad \xi = \frac{r}{r_{\rm ms}}$$

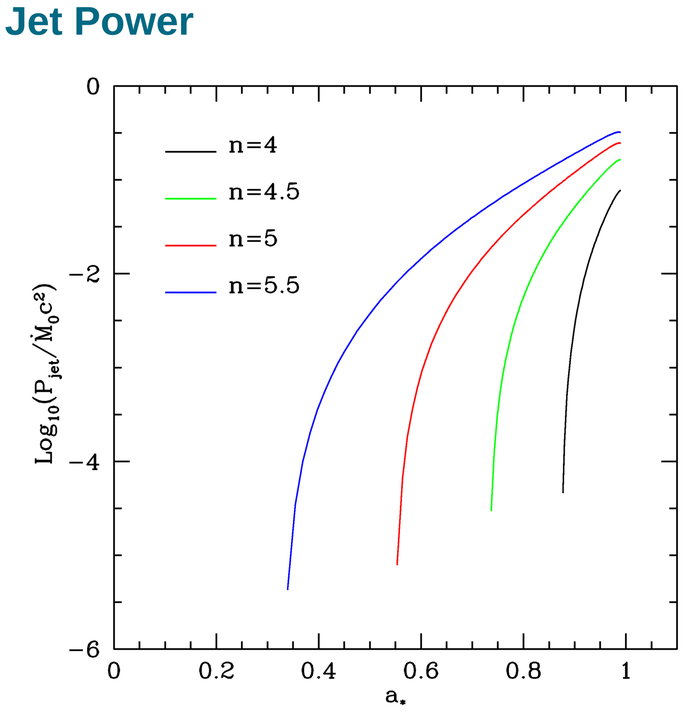
The presence of the jet depends on the combination of BH spin and power index:



Disc Luminosity



Jet Power



Feedback in the QSO mode

No stability conditions for the existence of a jet, thus only the luminosity of the disc (with MC) acts reducing the cooling from the hot halo:

$$\dot{M}'_{\rm cool} = \dot{M}_{\rm cool} - \eta_{\rm FB}(1 - f_{\rm CG})\frac{L_{\rm BH}}{c_s^2/2}$$

And reheating the cold gas:

$$(\Delta M_{\rm reheated})_{\rm QSO} = \eta_{\rm BH} f_{\rm CG} \frac{L_{\rm BH}}{c_s^2/2}\Delta T$$

Feedback in the Radio mode

We allow the existence of a jet, if possible according BH spin, together with the disc luminosity. The total energy coming from the BH reduces the cooling:

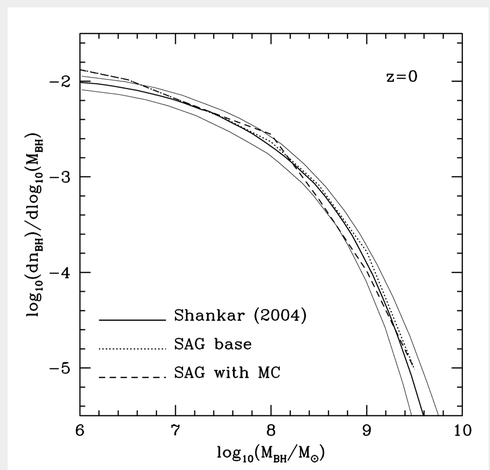
$$\dot{M}'_{\rm cool} = \dot{M}_{\rm cool} - \eta_{\rm FB}\frac{P_{\rm jet} + (1 - f_{\rm CG})L_{\rm BH}}{c_s^2/2}$$

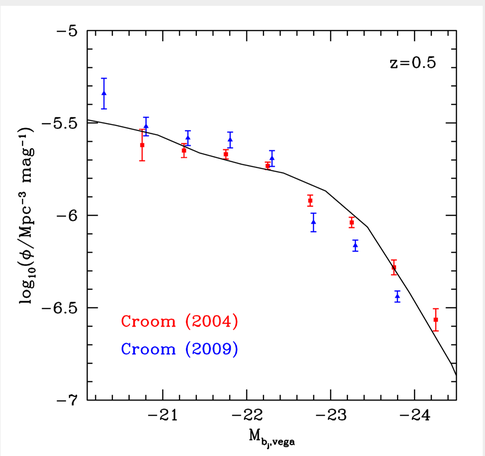
While only the disc is capable of reheating the cold gas:

$$(\Delta M_{\rm reheated})_{\rm AGN} = \eta_{\rm BH} f_{\rm CG} \frac{L_{\rm BH}}{c_s^2/2}\Delta T$$

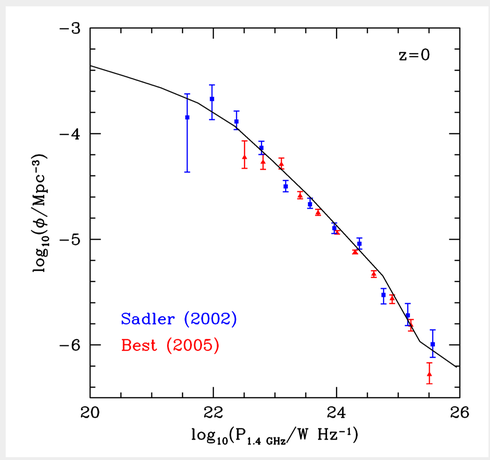
Galaxy Luminosity Functions in 2 bands, used to calibrate both models

Local BH Mass Function predicted with both SAG models





Quasar Luminosity Function at intermediate redshift predicted with SAG + MC model



Local Radio Luminosity Function predicted with SAG + MC model

Conclusions

- Our model of Magnetic Coupling between the BH and its accretion disc allows the rotational energy of the BH as an additional power source for the AGN.
- The disc luminosity and the jet power depend strongly with the spin of the BH.
- During the episodes of BH mass growth, the energy coming from it acts reducing the cooling of gas from the hot halo and reheating the cold gas.
- The predictions for the Luminosity Functions and population of BHs are in very good agreement with observations.
- Because of these results, we contend that our model presents a more physical way of describing the AGN feedback process.

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