Black hole spin, accretion and feedback in hydrodynamical simulations

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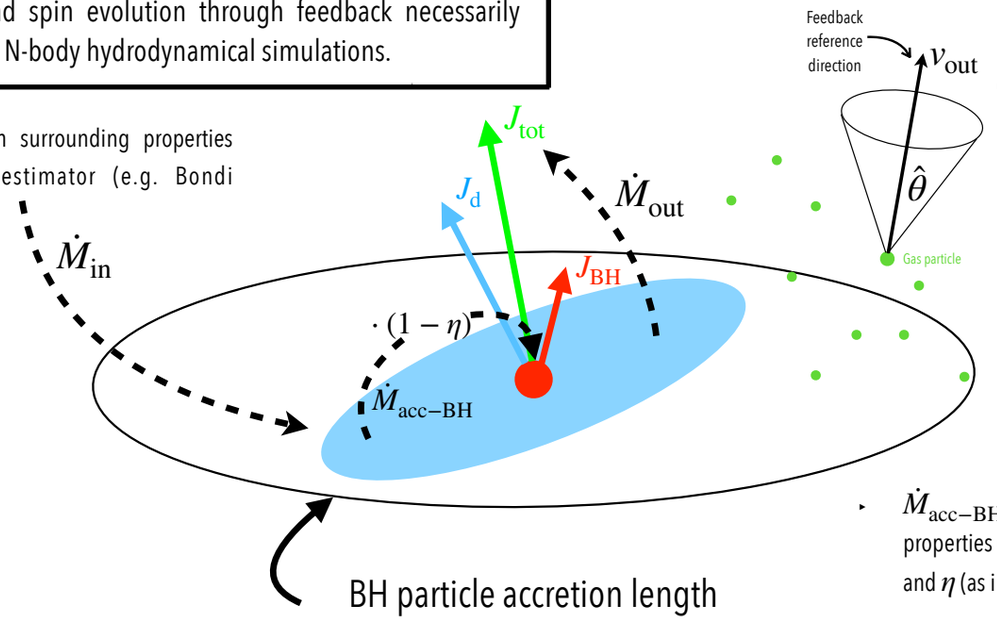
Motivation

- Feedback from supermassive black holes (SMBHs) can heavily affect their surroundings and can play a key role in galaxy evolution.
- Accretion and feedback processes involve a wide range of scales
  - ➡ **sub-resolution, effective models** for simulations due to resolution limits
- Central BH spin evolves due to gas accretion
  - ➡ modelling of **highly non-linear interaction** between gas reservoir and spin evolution through feedback necessarily requires full N-body hydrodynamical simulations.

A model for a sub-grid accretion disc and non-isotropic feedback (Sala+21, Cenci+21)

- Implemented in the hydrodynamical code GIZMO (*Hopkins 2015*)
- Sub-resolution accretion disc
  - accretes from the surroundings
  - is drained due to accretion onto the central BH and outflows
- Allows to **evolve the BH spin** due to gas accretion
- Feedback prescription that aims at reproducing **radiatively driven winds (outflows)**, built upon the model by *Anglés-Alcázar+17*



- $\dot{M}_{\rm in}$: evaluated from surrounding properties using a suitable estimator (e.g. Bondi parametrisation)

$$\dot{M}_{\rm out} = \frac{p_b \eta c}{v_{out}} \dot{M}_{\rm acc-BH}$$

where p_b is a free parameter and represents a momentum loading, η the radiative efficiency.

- $\dot{M}_{\rm acc-BH}$: depends on accretion disc and BH properties (masses and angular momenta), viscosity and η (as in *Fiacconi, Sijacki & Pringle 18*)

Feedback

- ❖ Momentum feedback by giving "kicks" to particles
  - ➡ v_{out} is added to the particle velocity magnitude in a direction randomly sampled within a cone of semi-aperture $\hat{\theta}$
- ❖ Particles stochastically selected in BH particle accretion length
  - ➡ accreted and outflow mass **consistent with computed mass rates**
- ❖ Allows the user to **choose the reference direction** and the cone aperture, if desired.

Sub-grid accretion disc & spin

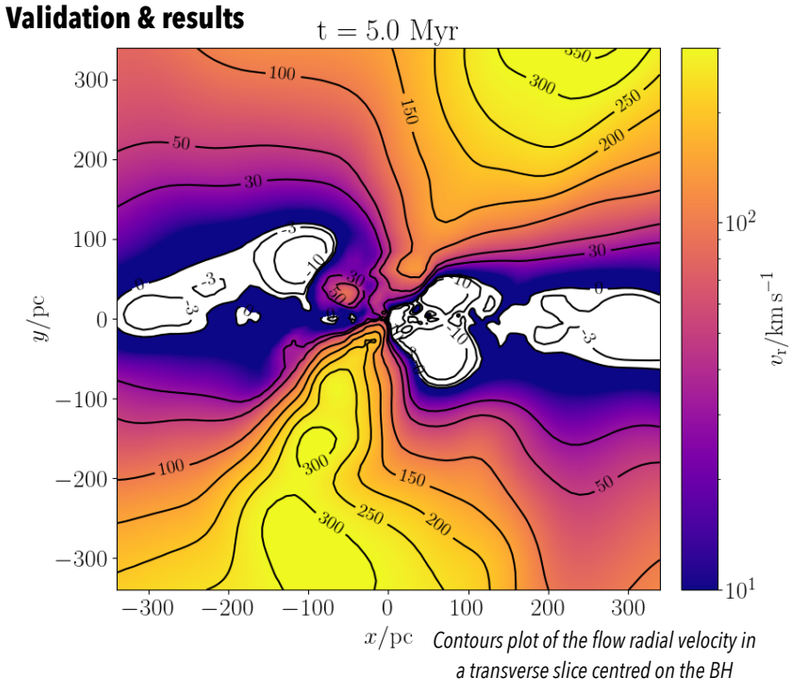
- ❖ Evolution of accretion disc & BH masses and angular momenta
- ❖ Modelling of the **accretion**, **precession** and **alignment** process (*King+05, Bardeen & Petterson 1975, Dotti et al. 2013*)

L. Sala, E. Cenci, P.R. Capelo, A. Lupi, M. Dotti, 2021, MNRAS, 500, 4788
https://ui.adsabs.harvard.edu/abs/2021MNRAS.500.4788S/

E. Cenci, L. Sala, A. Lupi, P.R. Capelo, M. Dotti, 2021, MNRAS, 500, 3719
https://ui.adsabs.harvard.edu/abs/2021MNRAS.500.4788S/

Self-consistent capture of the processes of feeding from resolved scales, the spin-disc coupling, and feedback loop

Validation & results

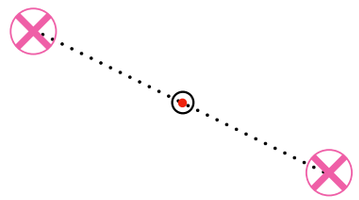


Contours plot of the flow radial velocity in a transverse slice centred on the BH

- Suite of idealized circumnuclear disc (CND) simulations
  - Stellar bulge, gaseous disc and central BH (*Lupi+15*)
- Different outflow cone axis directions, including a case **parallel to the BH spin**, which evolves with time.
- ➡ Resulting outflow maintains conical geometry
- ➡ The CND plays a dominant role in determining the final direction, which can be very different from the launching direction
- ➡ The more the cone axis is tilted towards the CND plane, the more the outflow is deviated and slows down

Future work

- Adapt the sub-grid accretion disc model to **more realistic systems**, as well as **larger scales** and lower resolutions (e.g. in a cosmological context).
- Design of a sub-grid model of feedback from SMBH that **injects energy displaced** with respect to the very central region through **jets**



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