AGN feeding and feedback: beyond sub-grid physics

Andrea Negri

In collaboration with Marta Volonteri

Hot spots in the XMM sky: Cosmology from X-ray to Radio
Friday 17 June 2016
~last decade: hydro cosmological simulations

dark matter + stars + gas

Evolution of the large scale structure

Illustris simulation

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Huge dynamical range! Currently impossible to simulate.

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Simulations are forced to adopt lower resolution

- ~ 6 kpc for MassiveBlack at $z=0$ (Di Matteo+2012)
- ~ 1 kpc for Horizon-AGN (Dubois+2012)
- > 750 pc Illustris (10 pc hydro, Vogelsberger+14)
- 350 pc EAGLE simulation, $z=0$ (Schaye+14)

need to resort to subgrid models for BH accretion
Subgrid models for BH accretion
Subgrid models for BH accretion

Various models are present in literature, most of them based on Bondi accretion

\[ \dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3} \]

formal solution of:
• spherically symmetric accretion problem
• adiabatic, no feedback, no rotation
Subgrid models for BH accretion

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In simulations we have:
- non spherical accretion
- multiphase gas
- rotation

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How accretion is implemented

\[ \dot{M}_{BH} = \alpha \frac{4 \pi G^2 M_{BH}^2 \rho}{c_s^3} \]

\( \rho \) and \( c_s \) are calculated using information on the surrounding gas, plenty of ways (every code/author)

- Volume weighted (GADGET, Booth+09, Vogelsberger+13)
- Mass weighted (Dubois+12)
- ISM subgrid model (hot/cold phase, Pelupessy+07)
- Global mass w. averages from all the cells (Choi+2012)
- Direct accretion of hot and cold gas when hydro is more resolved than gravity (Steinborn+15)

Sometimes it is not even mentioned!
How accretion is implemented

\[ \dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{c_s^3} \]

\(\alpha (~100-300)\) is a **boost factor**, depends on resolution and sub-grid models of ISM

- Constant (Springle+05, Dubois+12, Curtis+15)
- Depends on ISM density (Booth+09, Steinborn+15)
- Depends on feedback (Vogelsberger+13)
- Sometimes not used (Pelupessy+07, Choi+12)
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**Philosophy behind \( \alpha \):**
- Low resolution: ISM cold phase not resolved
  - Bondi radius not resolved
  - \( \rho \) underestimated
  - \( c_s \) overestimated

BH accretion rate \textbf{underestimated}
Past attempts to compare few schemes with simulation employing Bondi accretion (again?!)

see Wurster+13, Elahi+16
A simple idea

Comparison with

Sims with same setup but with Bondi accretion:
• Different schemes of weighting
  • Different resolution
A simple idea

Simulations of an isolated galaxy:

- High resolution \( \sim 0.1 \text{ pc} \) (cold and hot phase)
- Well resolved Bondi radius for all the T
- No parametrized accretion

Comparison with

Sims with same setup but with Bondi accretion:
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Simulations in a nutshell

Code: ZEUSMP (modified in Novak et al. 2011)

- 2D axisymmetric
- $M_{\text{BH}} = 3 \times 10^7 M_\odot$
- $R_{\text{bondi}} = 0.1 \text{ pc at } T=10^8 \text{ K}$
- $r$ from 0.1 pc to 250 kpc

- **Mechanical Feedback** from broad absorption line (BAL) winds
- **Radiative** feedback
- Compton heating/cooling
- Radiative cooling
Simulations in a nutshell

Code: ZEUSMP (modified in Novak et al. 2011)

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**Fiducial model:**

**BH accretion is flux on the innermost radial grid**

- Mechanical Feedback from broad absorption line (BAL) winds
- Radiative feedback
- Compton heating/cooling
- Radiative cooling

$T = 10^8$ K

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cooling – accretion – feedback – hot bubble cycle
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CHAOTIC ACCRETION

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Feedback self-limits accretion to sub-Eddington values

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What happens with Bondi?

1) We keep the same grid
2) Define accretion radius $r_{\text{acc}}$
3) Calculate $\rho$ and $c_s$ as mass weighted inside $r_{\text{acc}}$
4) no boost factor
Bondi high resolution
mass weighted

Explored $r_{\text{acc}} = 3, 30, 300 \text{ pc}$
Bondi high resolution mass weighted

Explored $r_{acc} = 3, 30, 300$ pc
Bondi high resolution mass weighted

Explored $r_{\text{acc}} = 3, 30, 300$ pc

Trend: the larger $r_{\text{acc}}$ the larger $\Delta M_{\text{BH}}$!
Bondi high resolution mass weighted
Explored $r_{\text{acc}} = 3, 30, 300$ pc

Trend: the larger $r_{\text{acc}}$ the larger $\Delta M_{\text{BH}}$!

I was expecting the opposite! Why?

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Sims with large $r_{\text{acc}}$ there is a **stronger feedback** but a **larger gas** mass to heat/sweep away to stop the accretion.
Sims with large $r_{\text{acc}}$ there is a stronger feedback but a larger gas mass to heat/sweep away to stop the accretion.
Bondi high resolution

Sims with large $r_{\text{acc}}$ there is a stronger feedback but a larger gas mass to heat/sweep away to stop the accretion.

At small $r_{\text{acc}}$ the AGN feedback is more effective in stopping the accretion.
Opposite situation!
In this case the accretion is dominated by **hot mode**.
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In this case the accretion is dominated by **hot mode**.
Bondi low resolution mass weighted
NO AGN

The central resolution is 3, 30 and 300 pc

The expected trend is recovered in absence of AGN feedback
Bondi low resolution mass weighted full feedback

The central resolution is 3, 30 and 300 pc

Same trend as in the high resolution runs
Bondi low resolution mass weighted full feedback

The central resolution is 3, 30 and 300 pc

Same trend as in the high resolution runs
Again, at low resolution the AGN feedback is less efficient.
Take home points

• Force people to write EVERYTHING on papers

• The adopted method used to calculate the Bondi accretion rate is relevant

• The common assumption of low resolution = low accretion is not verified in presence of feedback

• Efficiency of (mechanical) feedback in stopping accretion is low at low resolution
THANKS!
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