EFFECTS OF AGN WIND/RADIATION FEEDBACK ON GALAXY EVOLUTION

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“how does AGN feedback regulate the growth of black hole and its host galaxy?”
Traditional “Thermal” AGN feedback model

- Springel+05, Hopkins, Di Matteo +05, etc.
- SPH code GADGET
- Thermal Feedback with no specified mechanisms for transferring energy to gas particles
- cannot reproduce fast outflow we observe in AGN at high/low redshift

Springel+05
Theoretical Framework: Momentum Feedback

- Consider “outflowing mass rate”
  \[ \dot{M}_{acc} = \dot{M}_{inf} - \dot{M}_{outf}, \]

- Wind energy:
  \[ \dot{E}_w \equiv \epsilon_w \dot{M}_{acc} c^2 = \frac{1}{2} \dot{M}_{outf} v_w^2 \]

- Wind Momentum:
  \[ \dot{p} = \dot{M}_{outf} v_w \]

- The new dimensionless ratio:
  \[ \psi \equiv 2\epsilon_w c^2/v_w^2 = \dot{M}_{outf}/\dot{M}_{acc} \]
Theoretical Framework

\[ \psi \equiv 2 \epsilon_w c^2 / u_w^2 = \dot{M}_{\text{outf}} / \dot{M}_{\text{acc}} \]

\[ \dot{M}_{\text{acc}} = \dot{M}_{\text{inf}} \frac{1}{1 + \psi}, \]

\[ \dot{M}_{\text{outf}} = \dot{M}_{\text{inf}} \frac{\psi}{1 + \psi}, \]

\[ \dot{E}_w = \epsilon_w c^2 \dot{M}_{\text{inf}} \frac{1}{1 + \psi}, \]

\[ \dot{p} = \dot{M}_{\text{inf}} u_w \frac{\psi}{1 + \psi}. \]

\[ \epsilon_w = 5 \times 10^{-3} \]

\[ u_w = 10,000 \text{ km/s} \]

\[ \psi = 9 u_{w,10}^{-2} \]
Effect of “momentum” output

- Including momentum output from AGN drastically increases the effects of feedback

Ostriker, Choi, Ciotti+10
Mechanical AGN Feedback model

- Mechanical Feedback: BAL winds - mass/momentum outflow

- Radiative Feedback: Compton/Photoionization heating by hard X-ray (50-100 keV) component of AGN SEDs (Sazonov+05)

Choi+15
Gas temperature: without AGN vs. with AGN
Observed galaxy size growth

- Compact massive ellipticals at $z \sim 2$
- Strong size growth and stellar density decrease of massive galaxies since $z \sim 2$
- Mass increase by a factor of $\sim 2 / $ Size increase by a factor of $\sim 4$
- Maybe driven by dry minor merger
Observed stellar-mass surface densities

- core surface stellar-mass density evolution since $z \sim 3$
- Distinct linear relation in log $\Sigma_1$ vs. log $M$
- Constant slopes and scatter but their normalizations decline with time.

Barro+17
Evolution: size vs. stellar mass

- Steeper evolution in AGN models, after the star formation quenched.

- Overall, galaxy sizes are smaller in noAGN model in all redshift.

Choi+17 in prep
Effect of AGN on the stellar component

- **No AGN**
- **With AGN**

- **SFR**
  - **SF radial location**
    - in-situ
    - accreted
  - **SFR**

- **log $r/r_{vir}$**
  - **Age [Gyr]**
  - **normalized**

- **Mainly affects the Late and In-situ SF**: The ratio of in-situ formed to accreted stars is significantly reduced.

*Choi+16*
Effect of AGN on the stellar core

- decrease in surface core density from $z=1$ to $z=0$: via minor mergers, via adiabatic expansion (slow stellar mass loss associated with the stellar evolution), and via puffing-up (rapid mass loss by AGN winds)

Choi+17 in prep
Summary: Role of AGN feedback on size growth of massive galaxies

• Simulating red, dead, and extended massive galaxy: AGN feedback is not a primary channel for size growth but... prerequisite.

• It enhances the galaxy size growth via...

  1. (indirect but major) increasing the fraction of “accreted” stars - effect of dry merger increases

  2. (direct but minor) puffing-up by rapid mass loss via AGN-driven winds and adiabatic expansion by slow mass loss

• A quiescent buildup of extended stellar envelopes: Size growth accompanying SF quenching.
More size growth w/ AGN via...

1. grow mainly outside via accreted stars in the outskirts (building envelope): strong positive correlation between size and the fraction of accreted stelar mass

2. Central stellar density drop (center puffing up): reduced central stellar density from $z=2$ to $z=0$