Momentum Driven AGN Feedback In Galaxy Merger Simulations

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Introduction

• Observations suggest BH-Galaxy evolution link
• Feedback invoked as explanation
• Previous work uses largely similar models
  • Springel et al. 2005
  • Kazantzidis et al. 2005
  • Johansson et al. 2009
  • Booth & Schaye 2009
• Can simulation constrain AGN feedback physics?
Method

- Perform major mergers implementing new feedback model
  - Accretion via angular momentum transport
  - Feedback via radiation pressure
- Tree-SPH Gadget-3
  - Includes star formation model of Springel & Hernquist 2003
  - Added BH growth and feedback

DeBuhr, Quataert, Ma 2010, arXiv:1006.3312
Model: Accretion

\[ \dot{M} = 3\pi\alpha\Sigma \frac{c_s^2}{\Omega} \]

- Accretion via angular momentum transport
  - Bondi rate physically inappropriate
- Accretion radius \( R_{\text{acc}} \sim 188\text{pc} \)
  - Volume average of SPH particle properties
- \( \alpha \sim 0.05 \)
Model: Feedback

\[ \dot{\rho} = \frac{\tau}{c} \min \left( L_{edd}, \eta \dot{M} c^2 \right) \]

- Feedback via radiation pressure
- Applied inside \( R_{\text{acc}} \)
- Directed radially outward
- \( \tau \sim 10 \), IR optical depth
Simulations

• Fiducial Galaxy
  • \( M_{\text{gal}} = 5 \times 10^{10} \, M_\odot \), \( f_g = 0.1 \)
  • \( R_d = 3.5 \, \text{kpc} \), \( Z_0 = 0.71 \, \text{kpc} \)

• Orbit
  • Parabolic, prograde
  • \( r_i = 142 \, \text{kpc} \), \( r_{\text{peri}} = 14.2 \, \text{kpc} \)

• Model parameters
  • \( \alpha = 0.05 \), \( \tau = 10 \), \( R_{\text{acc}} = 188 \, \text{pc} \)

• Varied model and galaxies
Fiducial Simulation
Self-Regulation
Self-Regulation

• Balance gravity and feedback

\[ \tau \frac{L}{c} = \frac{GM M g}{R^2} \]

with

\[ \sigma^2 = \frac{GM}{2R} \]

\[ \dot{M}_{crit} = \frac{4f_g}{\tau \eta c G} \sigma^4 \]

• Independent of \( \alpha \)
Self-Regulation

- Feedback clears $R_{\text{acc}}$
- $\dot{M}$ approaches $\dot{M}_{\text{crit}}$
Other Results

- Robust SF and $M_{BH}$ with parameter variation
- Little gas blow-out
M-\(\sigma\) Relation

- \(\sigma_{\text{LOS}}\)
- Median of 1000 sight lines
- Scaled to \(\tau=25\)
- Flattening at low mass (tentative)
ISM Modeling

- SH03 $c_s$ too high
  - Reduce P by $\sim 10$
- After first passage
  - Lower $c_s$ gas fragments
  - Dense SF knots spiral into center
- Highlights importance of ISM modeling
  - See also Teyssier et al. 2010
Summary

- Robust integrated quantities
  - $M^*, M_{BH}$
- Model can match observed $M_{BH} - \sigma$
  - Requires high optical depth
  - Suggests additional feedback modes required

Next steps

- Use improved fueling model
- Improve radiation transport
- Connect with detailed simulations of central region