Simulations of large-scale structure with “AGN” feedback

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Motivation

• Use galaxy clusters as cosmological tool (SZ PS)
• ACT, SPT & Planck (Chandra, XMM, RCs…)

\[ C_l = g_v^2 \int_0^{z_{\text{max}}} dz \frac{dV}{dz} \int dM \frac{dn(M, z)}{dM} |\tilde{y}_l(M, z)|^2 \]

• Analytically (e.g KS...B10 in prep: fast CosmoMC plugin)
• SZ sky maps (e.g. Da Silva et al. 00, Springel et al., B02…)
• “Gastrophysics” correct
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- Use galaxy clusters as cosmological tool (**SZ PS**)
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\[ C_l = g_\nu^2 \int_0^{z_{\text{max}}} dz \frac{dV}{dz} \int dV \]

![Image of galaxy cluster sky map with color scale]
ICM Modeling

X-ray observations

- Match both aperture quantities / profiles / $f_{\text{gas}}$
- Match both aperture quantities / PS / profiles
- $f_{\text{star}}$ from optical observations

• Problems

Analytically: HSE, non-thermal....

Simulations: Sub-grid physics, Over-cooling!
ICM Modeling

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- Match both aperture quantities / profiles / $f_{\text{gas}}$
- Sunyaev–Zel’dovich Observations
- Match both aperture quantities / profiles / PS
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  - Analytically: HSE, non-thermal pressure support..
  - Simulations: Overcooling

Pfrommer et al. 07
ICM Modeling

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  - Simulations: Over-cooling

Over production stars / thermal properties
Our ICM Modeling

X-ray observations
✓ Match both aperture quantities / profiles / $f_{\text{gas}}$
Sunyaev – Zel’dovich observations
✓ Match both aperture quantities / PS / profiles
✓ $f_{\text{star}}$ from optical observations

We introduce a form of ”AGN” feedback
→ Does well to match current observations
Previous work on AGN feedback

- Magorrian relation
  \[ M_{BH} \propto \sigma^4, \dot{M}_{BH} \propto \dot{M}_{EDD} \]
  Thacker, Sijacki, Bhattacharya, Chatterjee....
  - Run on smaller scales (Quasars/galaxies)

- Estimate Bondi-Hoyle accretion (BH particles)
  Springel, Sijacki, Shaye
  - Require high resolution
  \[
  \dot{M}_{BH} = \frac{\alpha 4\pi G^2 M_{BH}^2 \rho}{(c_s^2 + v^2)^{3/2}}
  \]
AGN Model

- Sub grid (~$10^9$ [OM]) (Thompson et al. 05)

\[ \dot{M}_* \propto \dot{M}_{BH} \]

\[ E_{inj} = \varepsilon_r \dot{M}_* c^2 \Delta t \]

- Spherically injecting $E_{inj} \rightarrow R_{AGN}$
- Parameters: $\Delta t$, $\varepsilon_r$ & $R_{AGN}$
- $\varepsilon_r$ includes many #s

Match previous AGN models
Simulations (many of them)

- TreePM-SPH Gadget-2+
- Single cluster ‘g676’ (Zoom simulation)
- Cosmological box simulations (256³ & 512³)

Models:
- “adiabatic”
- cooling + SF
- AGN feedback

Thank you SciNET (30 k cores) & Sunnyvale
Model comparison/calibration

\[ f_{\text{star}} (< r) = \frac{M_{\text{star}} (< r)}{M_{\text{TOT}} (< r)} \]
Observational comparisons

Bonus:
We match Recent X-ray results
• Stacked pressure profiles
Observational comparisons

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Power spectra comparisons

Average PS from our simulations
- Rotate & Translate redshift slices
Power spectra comparisons

Average PS from our simulations - Rotate & Translate redshift slices
Cosmological constraints

- Included kSZ spectra
- Templates CosmoMC
- Constraints on $A_{SZ}$ & $\sigma_8$
- Using SPT within WMAP7 values for $\sigma_8$
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Conclusions

"AGN" feedback does well
✓ X-ray observations
✓ Sunyaev – Zel’dovich observations
✓ $f_{\text{star}}$ from optical observations
✓ Consistent with WMAP7 $\sigma_8$

Much more to be done!