Numerical Studies if Jet Driven Feedback in Clusters

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Outline

- Jets in dynamic clusters
- Results
  - Multiple bubbles
  - AGN sphere of influence
  - Iron line studies with IXO
  - Turbulence signatures of jet activity
- XIM
Non-spherical clusters

- Initial conditions in jet simulations matter: spherically symmetric vs. dynamic clusters

- Clusters are anisotropic & dynamic

Springel et al. 2002
The dentist drill effect

- Scheuer 1974:
  - Lobe morphology requires jet wiggle (see also Begelman & Cioffi, 89)
  - Dynamical instabilities, e.g. 3C273
  - Hot spot - jet misalignment

- Modeled as:
  - Random walk of jets axis
  - Opening angle 20°
  - fast compared to dynamical time

Heinz, Brüggen, Young, & Levesque 2006
The VLA view of Cygnus A
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- Simulated VLA movie of “Digital Cygnus A”:
  - Simulated in a realistic galaxy cluster (from cosmo. sim.)
  - $10^{46}$ ergs s$^{-1}$
  - 160 Myrs in 500 CPU days
  - Resolution: 170 pc

Heinz, Brüggen, Young, & Levesque 2006
Multiple cavities ≠ intermittency

- Dynamics in cluster core:
  - “Target” material mixed into jet path
  - New cavities generated after ~ free fall time
  - Cannot use multiple cavities to infer duty cycle!
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Cluster weather: AGN sphere of influence

- Interaction with cluster weather
  - AGN impact limited to “sphere of influence”
  - Radius $R \sim P^{1/3}$
  - AGN excavates deeper, rather than further
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“Sphere of influence”: Time after onset

- Excavated zone reaches asymptotic terminal size
“Sphere of influence”:
Jet duration

- 1e45 ergs/s, on for
  - 30 Myrs
  - 50 Myrs
  - Continuously
- Excavated zone stationary, just deeper
“Sphere of influence”: Jet power

- **Comparison:**
  - $1 \times 10^{44}$ ergs/s for 30 Myrs
  - $1 \times 10^{45}$ ergs/s for 30 Myrs
  - $1 \times 10^{46}$ ergs/s for 30 Myrs

- **Excavated radius:**
  - $R \sim P^{1/3}$
Chandra legacy

- Imaging
  - Cavities
  - Sound waves
  - Shocks

- What are we missing?
  - Photons
  - Spectral resolution
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IXO - the International X-ray Observatory

- An X-ray integral field spectrograph with
  - 5” angular resolution
  - ~ 5’ field of view
  - spectral resolution of 2500 @ 6.4 keV
  - ~ 50 x area of ACIS

- Cavity kinematics
  - Ages (no more $t_{\text{sonic}}$, $t_{\text{buoyant}}$, $t_{\text{whatever}}$)
  - Unambiguous cavity and jet powers
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1. Take a 3D simulation of thermal gas

2. Simulate the spectrum emitted by the gas

3. "Observe" it with an X-ray telescope
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XIM: A virtual X-ray observatory for numerical simulations

1. 3D Input: $n_e n_H$, T, velocity, metallicity, filling factor
2. Thermal emission (APEC + thermal broadening)
3. Line-of-sight integration along arbitrary vector
4. Telescope PSF convolution (IXO & Chandra)
5. Convolution with instrument response
6. Add blank sky & instrument background
7. Add Poisson noise
8. Optional: Interface with MARX (Chandra only)
9. Output FITS events file, pha file

Download: http://www.astro.wisc.edu/~heinzs/XIM

Heinz & Brüggen 2009, submitted
The IXO view of Cygnus A

- Taylored jet simulation
- Reproduces Chandra observation
- Fe XXV and XXVI Kα line
- Line structure reflects expansion of cavity.
- Measure expansion velocity directly
- Measure power directly

F II R

Fe XXV Fe XXVI

Friday, August 13, 2010
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The IXO view of Hydra A

Wise et al. 07

Wise et al. 07
Jet-induced turbulence

- Cluster background turbulence:
  - inner: $v_{1\sigma} \sim 200$ km/s
  - outer: $v_{1\sigma} \sim 300$ km/s
- Jets generate strong turbulence
- Detectable with ASTRO-H, IXO
Summary

- Multiple cavities ≠ intermittency
- Sphere of influence of Jet on cluster limited by dynamics, with $R \sim P^{1/3}$
- IXO cavity spectra will show clear kinematic signatures which will allow us to measure ages directly
- Download XIM at http://www.astro.wisc.edu/~heinzs/XIM to generate virtual IXO & Chandra observations from numerical simulations