STRUCTURES AROUND GALAXIES IN CLUSTERS: BOW-SHOCKS WAKES AND STRIPPED TAILS

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Talk Overview

1. Extended structures around galaxies in clusters: examples
2. Physical origin of morphological features
3. Importance of studying such structures
4. Numerical simulations of elliptical galaxies moving through the ICM

Structures around Galaxies in Clusters

Elliptical Galaxies: X-ray structures

- M86: X-ray plume (Rangarajan et al. 1995)
- NGC 5044: linear X-ray structure behind a galaxy in a group (David et al. 1994)
- NGC 4472: distorted X-ray morphology - possible evidence for a bow-shock structure (Irwin & Sarazin 1996)
- 4C 34.16: two radio-tails bent into a wide C-shape with an X-ray enhancement between the tails (Sakelliou et al. 1996)
- NGC 1404: X-ray tail pointing away from Fornax cluster centre (Jones et al. 1997)
- NGC 4839: elongated X-ray structure pointing away from Coma cluster centre (Dow & White 1995)

Spiral Galaxies: Optical/radio structures

NGC 2276 (Gruendl et al. 1993)
NGC 4388 (Veilleux et al. 1999)
NGC 4485 (Clemens et al. 2000)
NGC 4522 (Kenney & Koopmann 1999)
NGC 7421 (Ryder et al. 1997)

Types of Morphological Features

Bondi-Hoyle Wake

Gravitational focussing of the ICM by the galaxy will result in an over-dense region behind the galaxy - analogous to Bondi-Hoyle accretion (Sakelliou 2000). Bondi-Hoyle wakes will be most prominent in massive, subsonic galaxies.

Bow-shock

Transonic or supersonic galaxy motion through the ICM will result in the formation of a leading bow-shock, compressing and heating the ICM.

In the simulations more than one shock can be formed due to complex flow patterns around the galaxy.

Ram-pressure Stripped Tails

The ISM of the galaxy will be stripped by the incipient ICM and be replenished by stellar mass-loss. The details of the stripping process results in complex structures being torn off the galaxy.

The rate of stripping increases as the galaxy velocity increases. The relationship for the "observability" of the stripped tail is more complex. The more efficient the stripping the less visible the tail will be.

Galaxy Outflows

Starburst type outflows could also give rise to extended X-ray emission (cf. M82).

Why these structures are important

Spiral galaxies:

Formation of S0's
Morphological differences with redshift
Termination of star-formation
HI/Hα morphological features in nearby spirals

Recent 3D simulations by Quilis et al. (2000) show very rapid ICM ram-pressure stripping of the spiral disk ($t_{strip} < 100$Myr $\ll$ orbital timescale).

Elliptical galaxies:

Means of studying galaxy cluster kinematics (Merrifield 1998)
X-ray morphological features
Effect on star-formation
'pollution' of ICM

New deep/high resolution data from *Chandra* and *XMM* will reveal a lot more such structures - we need the tools to interpret them.

Numerical Simulations of Elliptical Galaxies

Balsara et al. (1994): 2D simulations for spherical galaxy - chaotic ram-pressure stripping, pumping mode instability in stripped tail with inflow into the back of the galaxy.

Stevens et al. (1999): 2D simulations - wide range of cluster parameters - theoretical images of morphological features.

Two main modes of behaviour:

Efficient-Stripping mode: Galaxy completely stripped, no observable ram-stripped tail

Mass-Retention mode: galaxy not completely stripped, stripping occurs at edges - complex instabilities and an overdense, clumpy tail.

New Simulations

- Elliptical potential (prolate and oblate)
- Self-consistent mass-replenishment from an ageing stellar population
- Generate realistic synthetic X-ray maps to investigate effects of cluster/galaxy parameters

Numerical Results

Simulations: Parameters

Elliptical galaxy age at start of simulation = 5Gyr

Mass of galaxy $M_{Gal} = 1.2 \times 10^{12}\, M_{\odot}$

Galaxy types: E0, E2, E4, E6 (oblate and prolate)

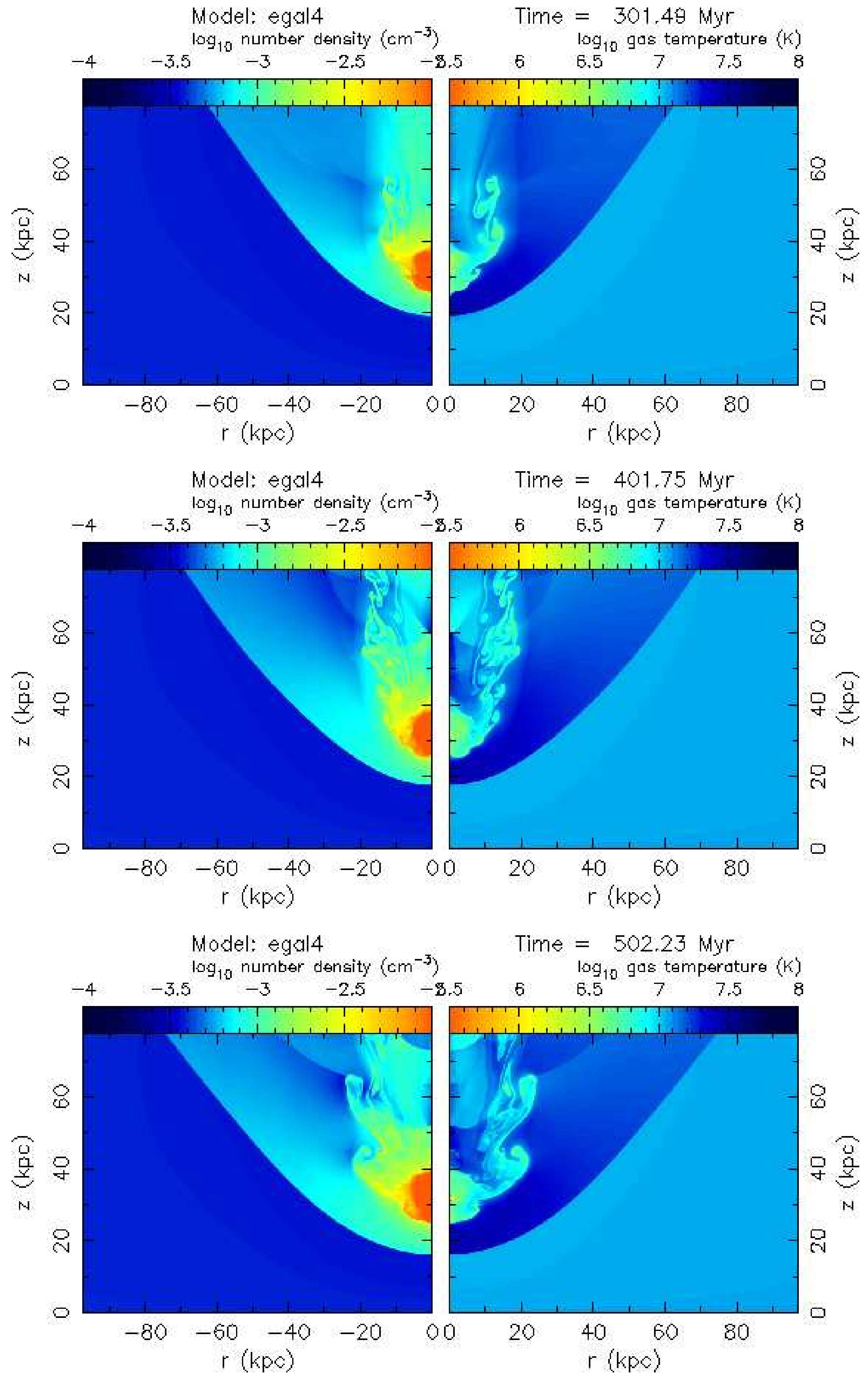
$V_{gal} = 960\,\mathrm{km\ s^{-1}}$; Mach no. $\mathcal{M} \sim 1.9$.

$kT_{cluster} = 1$ keV

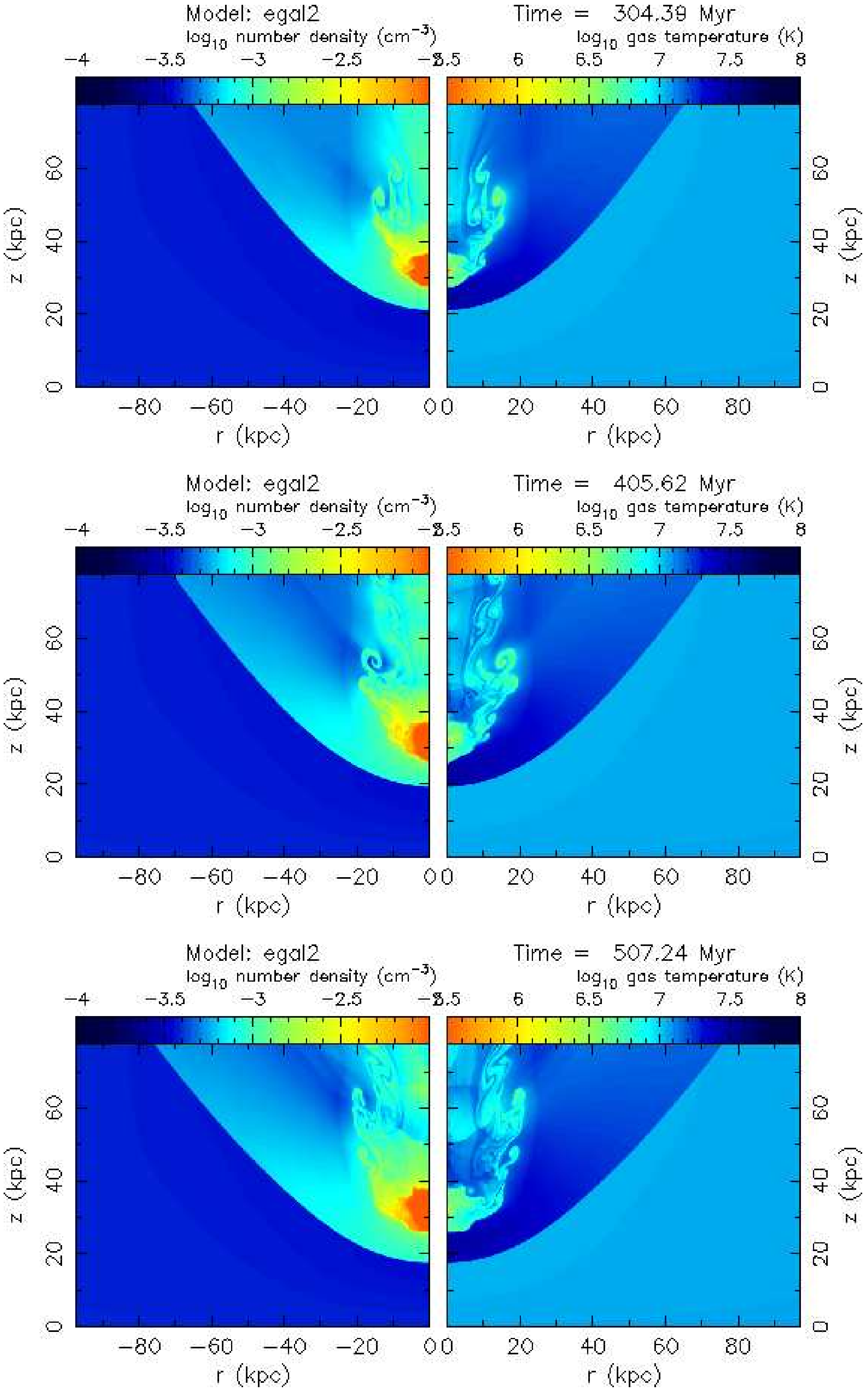
$n_{cl} = 3.8 \times 10^{-4}\ \mathrm{cm^{-3}}$

Simulations grid size: 480 × 600 cells, cell size 0.16kpc

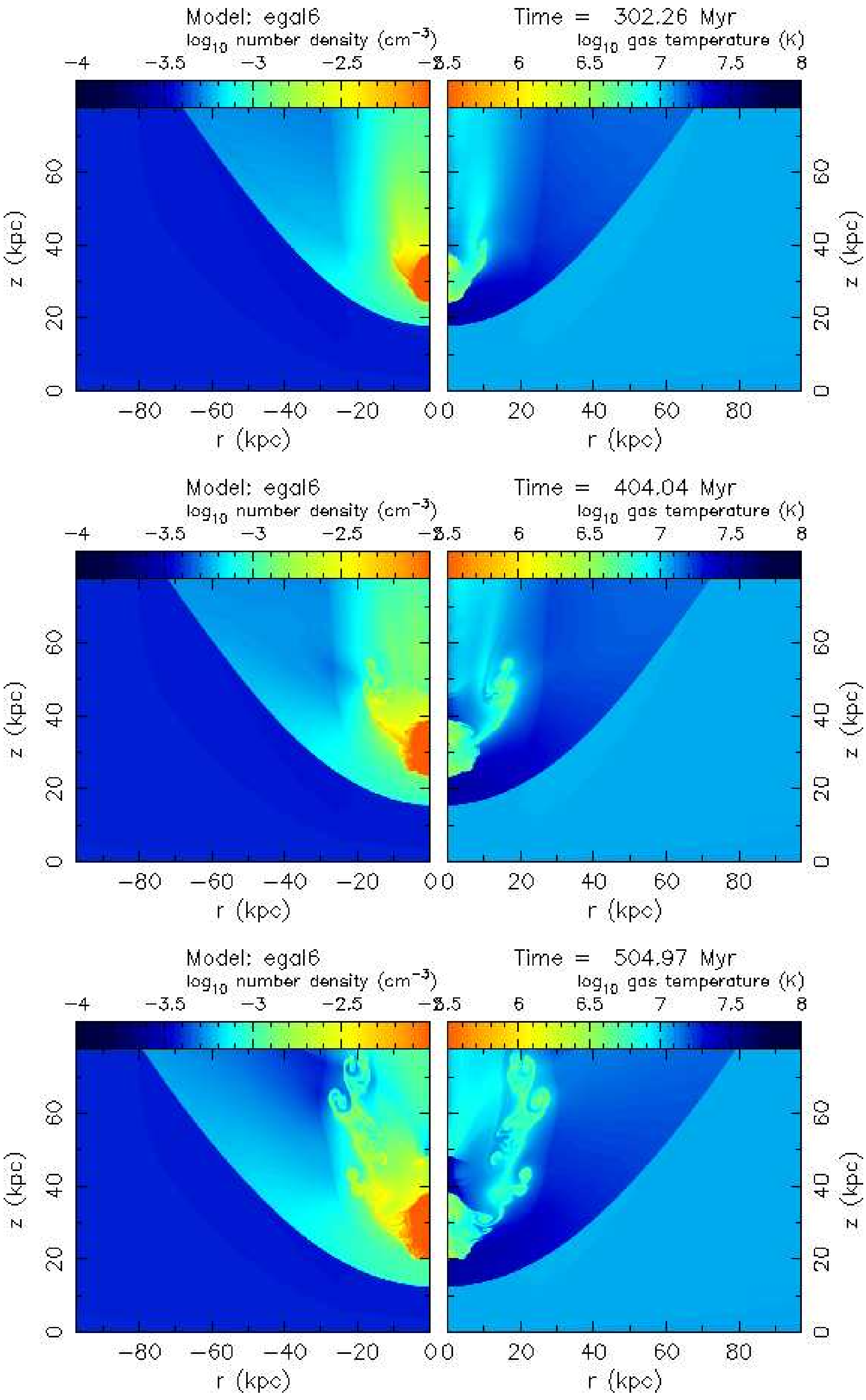
SPHERICAL GALAXY



OBLATE ELLIPTICAL GALAXY: Type E4



PROLATE ELLIPTICAL GALAXY: Type E4



Summary and Conclusions

- Simulations predict the presence of clumpy X-ray tails behind some elliptical galaxies in clusters, at observable levels.
- Ram-pressure stripped tails more likely to be seen in cooler clusters or in the periphery of richer clusters
- Galaxies with younger populations are more likely to show brighter tails
- Bondi-Hoyle wakes and bow-shocks tend to be less prominent in the simulated images than the ram-pressure stripped tails
- No very apparent differences in tail morphology between prolate and oblate elliptical galaxies
- New *Chandra* and *XMM* will provide a much clearer picture of the phenomena