

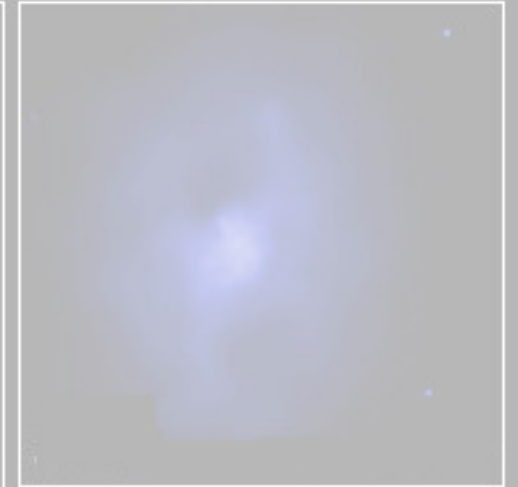
GALAXY CLUSTER, ACTIVE GALAXIES AND THE FEEDBACK PROBLEM

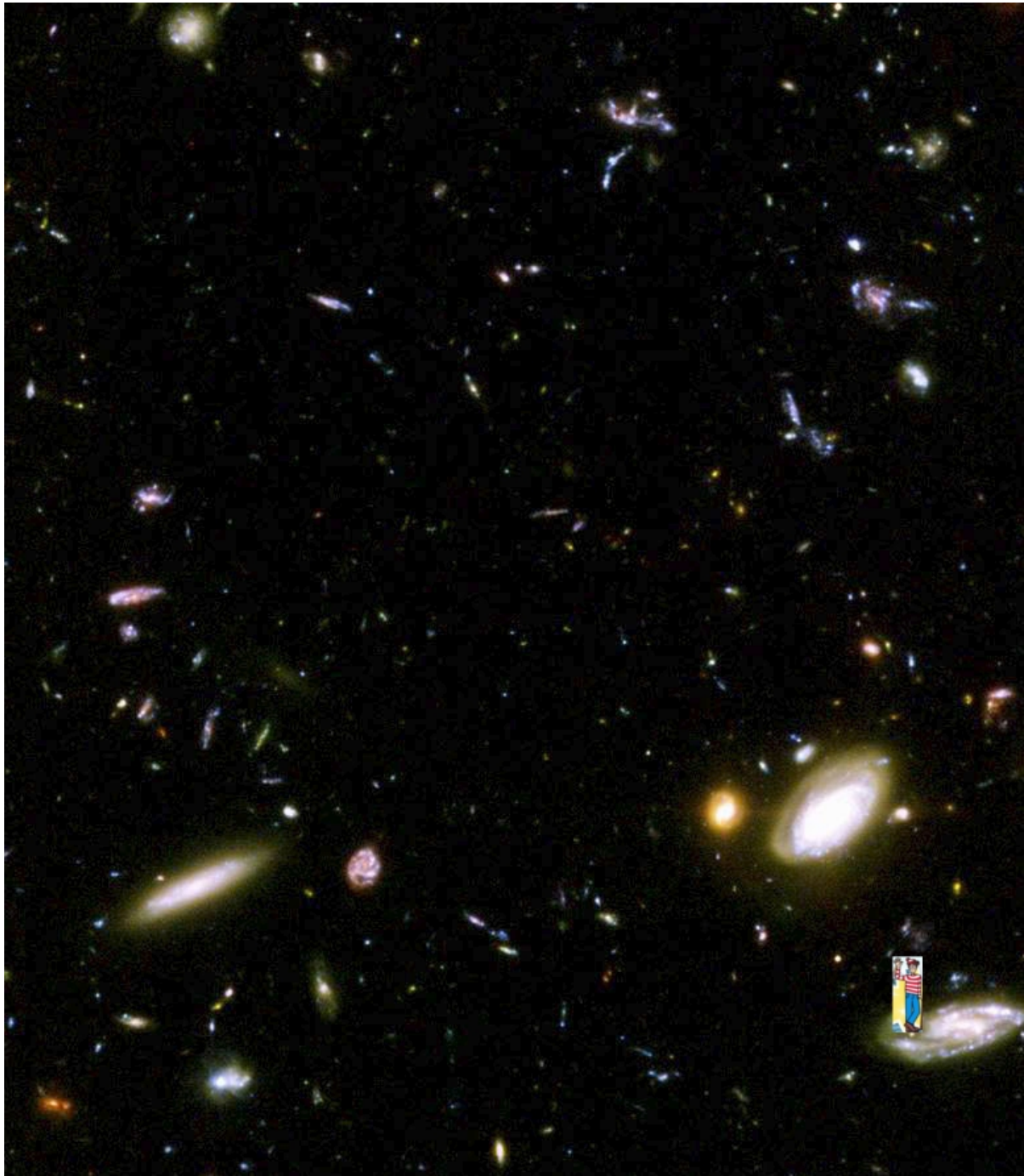
Martín Huarte Espinosa
<martinhe@pas.rochester.edu>
B & L 456

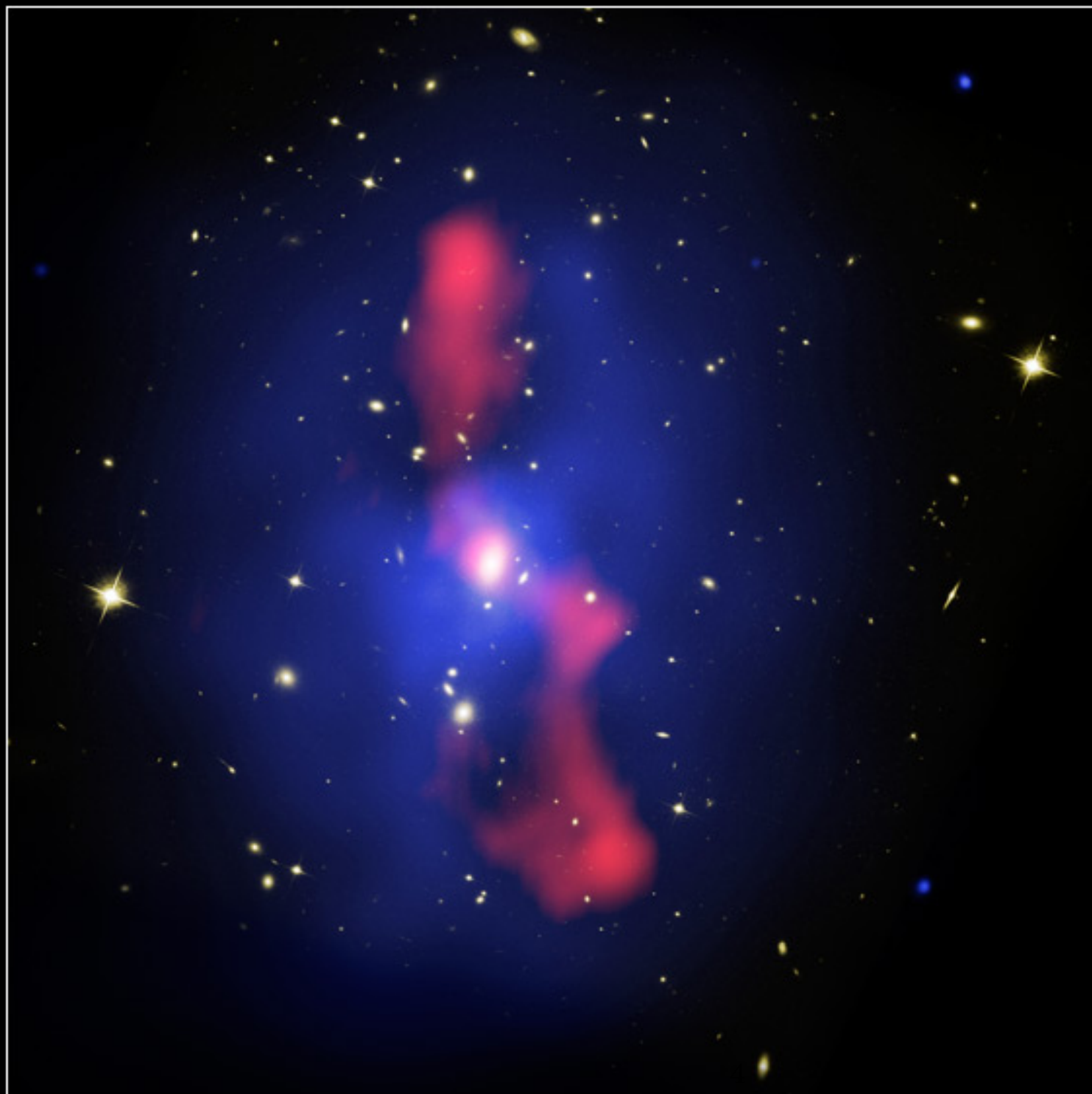
University of Rochester, Physics and Astronomy
AST242 guest lecture, 26 Apr 2010

Outline

- ★ Extragalactic sources... find Wally,
- ★ Galaxy cluster and the intra-cluster medium (ICM),
- ★ Cooling flows in the ICM,
- ★ Active Galactic Nuclei... as powerful as it gets,
- ★ Magnetic fields in the galaxy clusters (movie!.... get popcorn),
- ★ Feedback models,
- ★ Summary and discussion.







X-ray
Chandra X-Ray Observatory

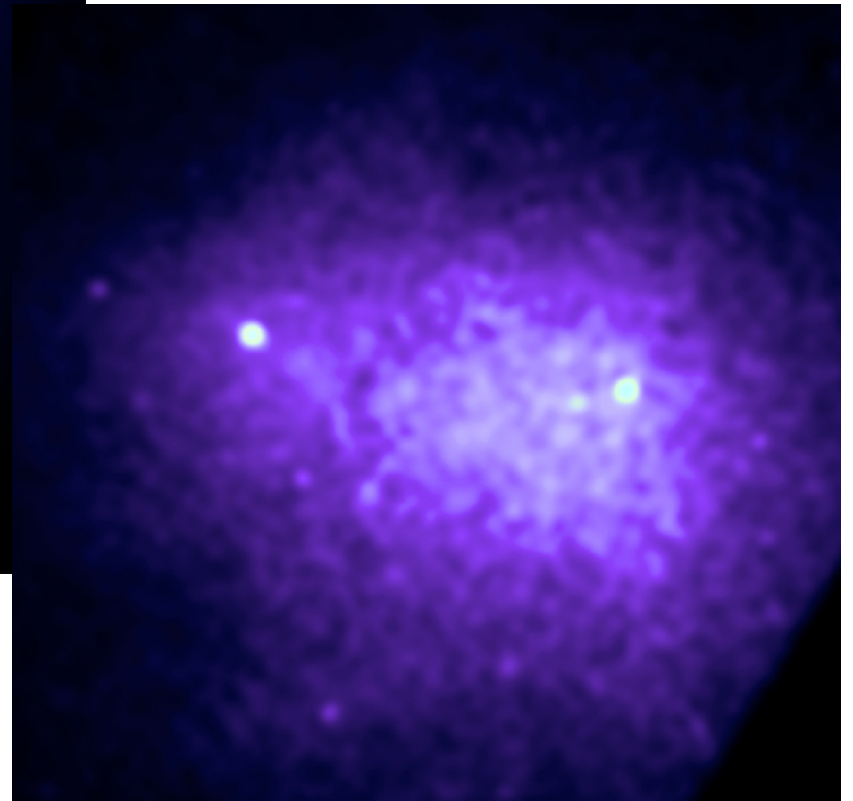
Visible
Hubble Space Telescope

Radio
Very Large Array

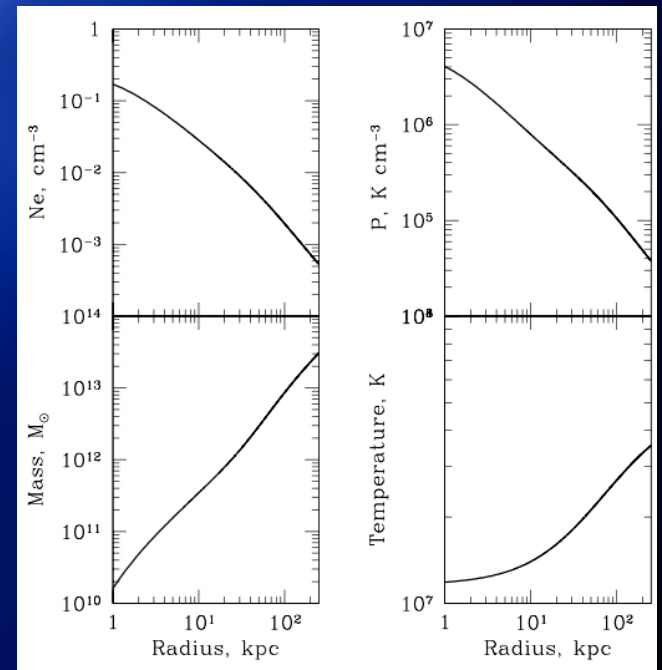


The ICM X-ray Bremsstrahlung

$T \sim 10^8 \text{ K}$
 $\rho \sim 10^{-2} \text{ cm}^{-3}$
 $\sim 2 \text{ Mpc long}$



Cool core clusters



Nulsen & Böhringer 1995

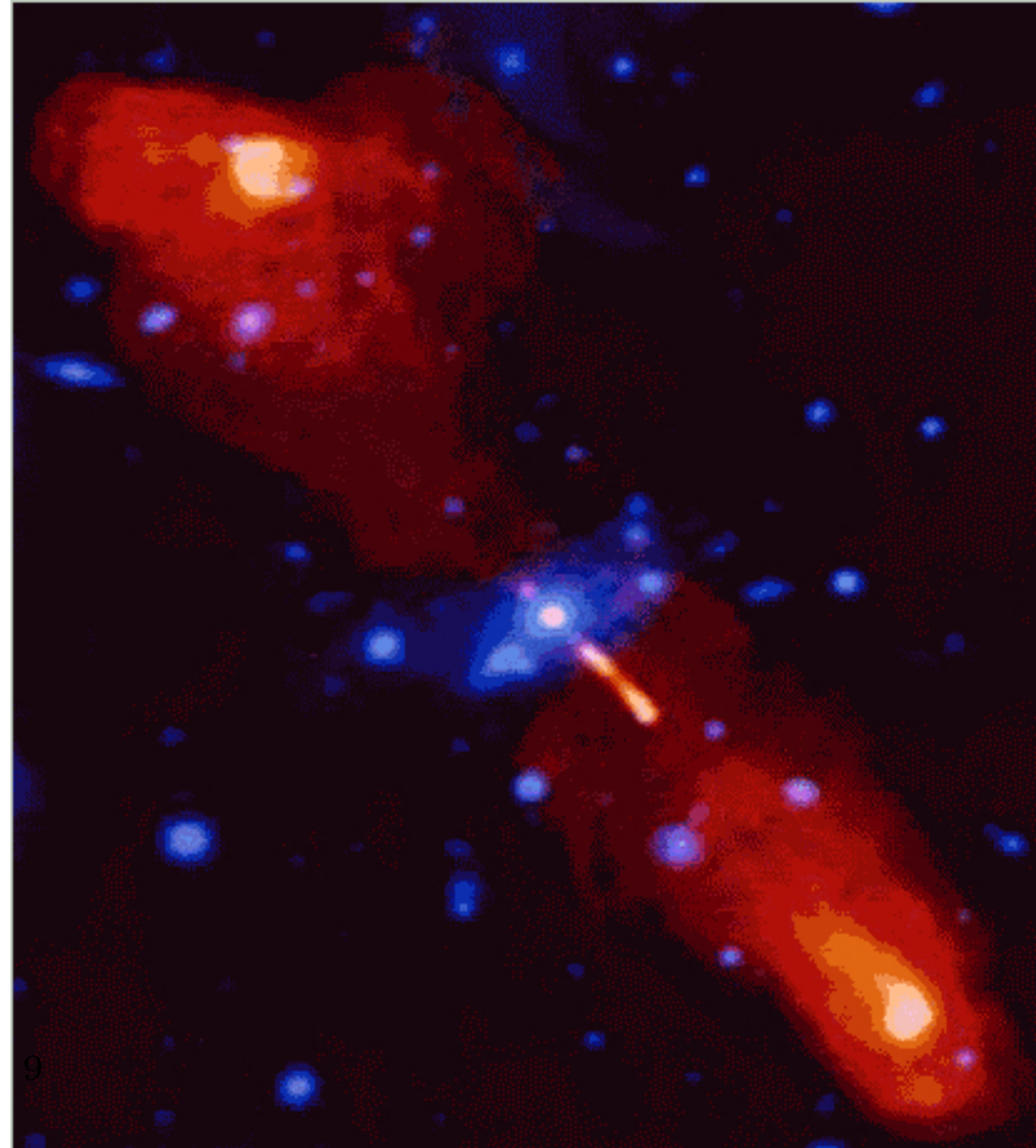
Cool core clusters



← Cooling flows

Radio galaxies and Quasars

3C 219



Carilli & Barthel 1996

5 GHz

Lobe

Hot Spot

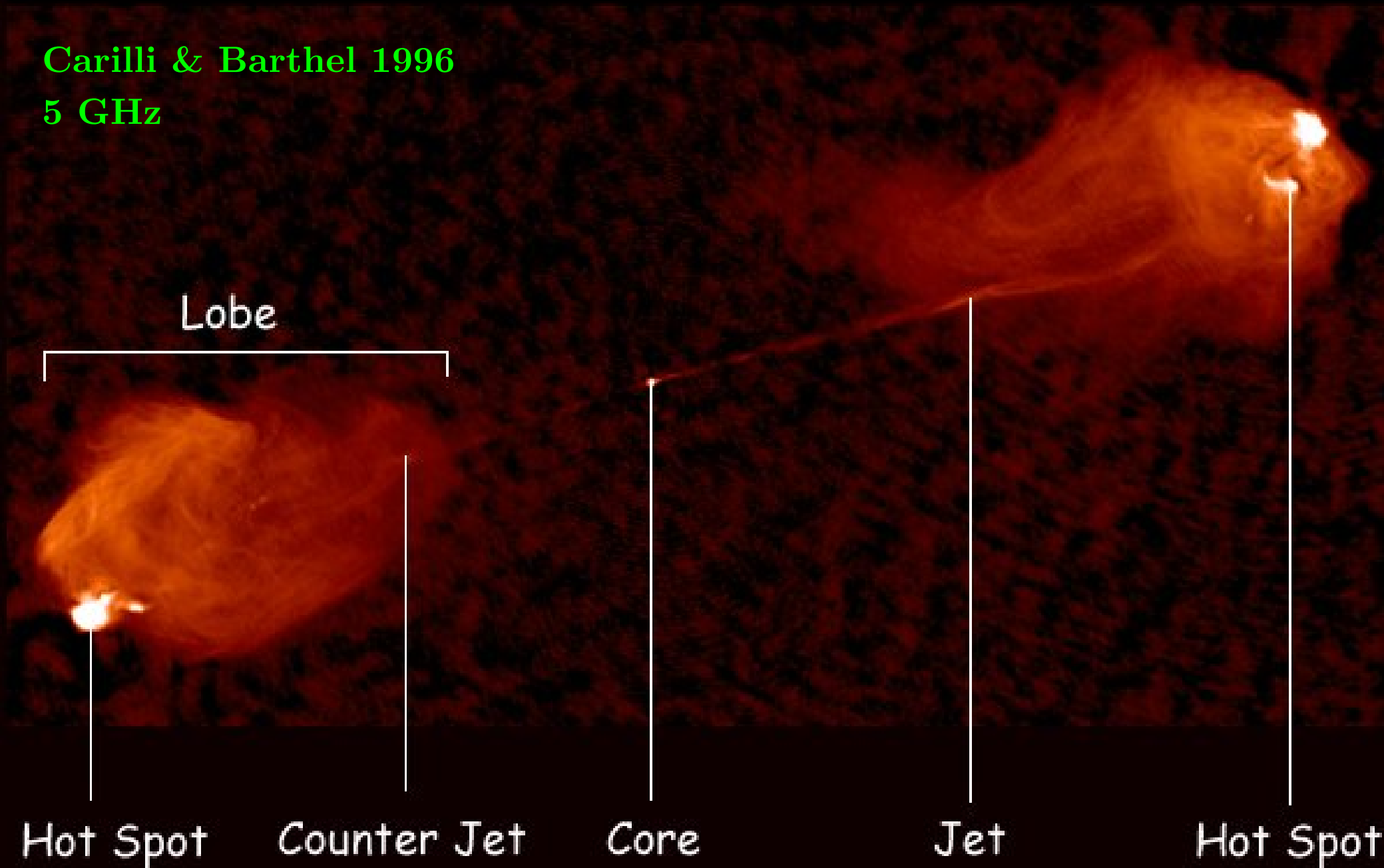
Counter Jet

Core

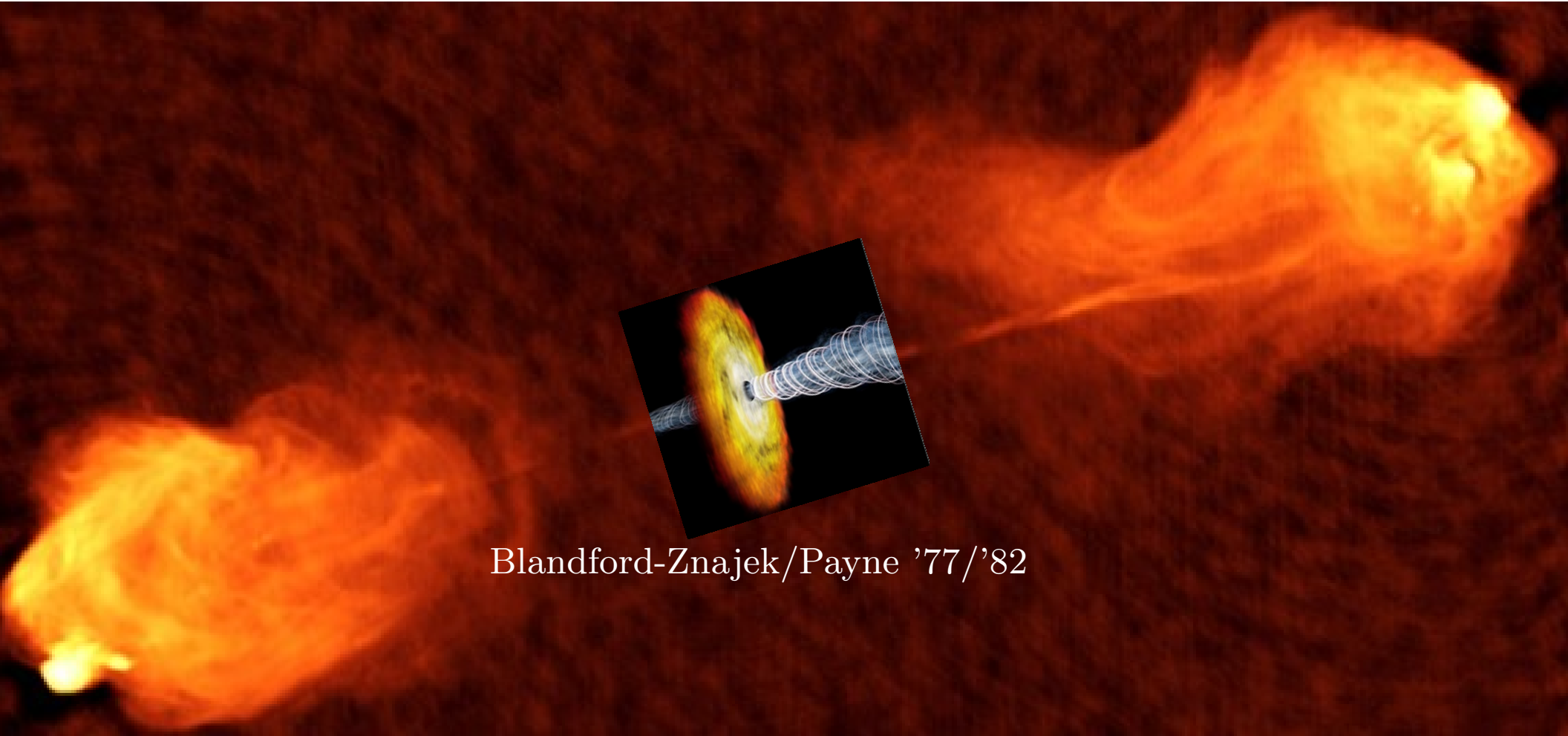
Jet

Hot Spot

Parts of a DRAGN (Cygnus A)



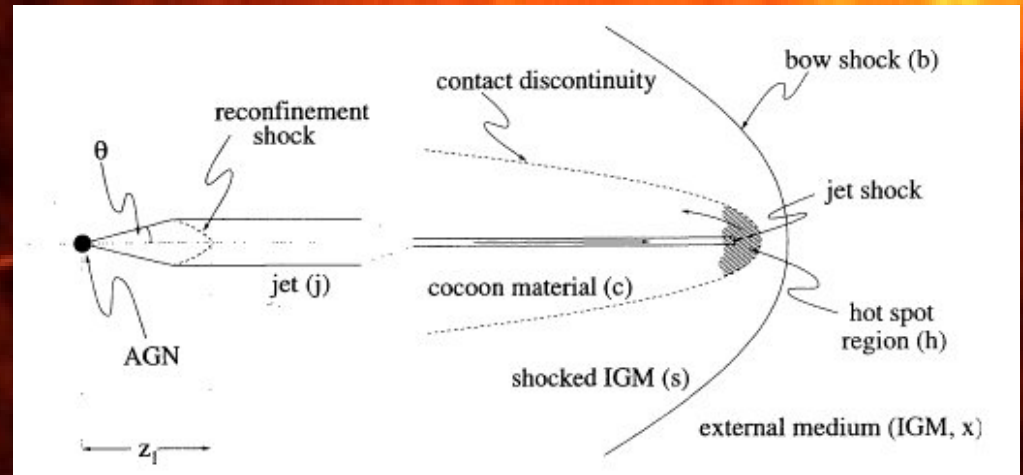
Formation and evolution



Blandford-Znajek/Payne '77/'82

Formation and evolution

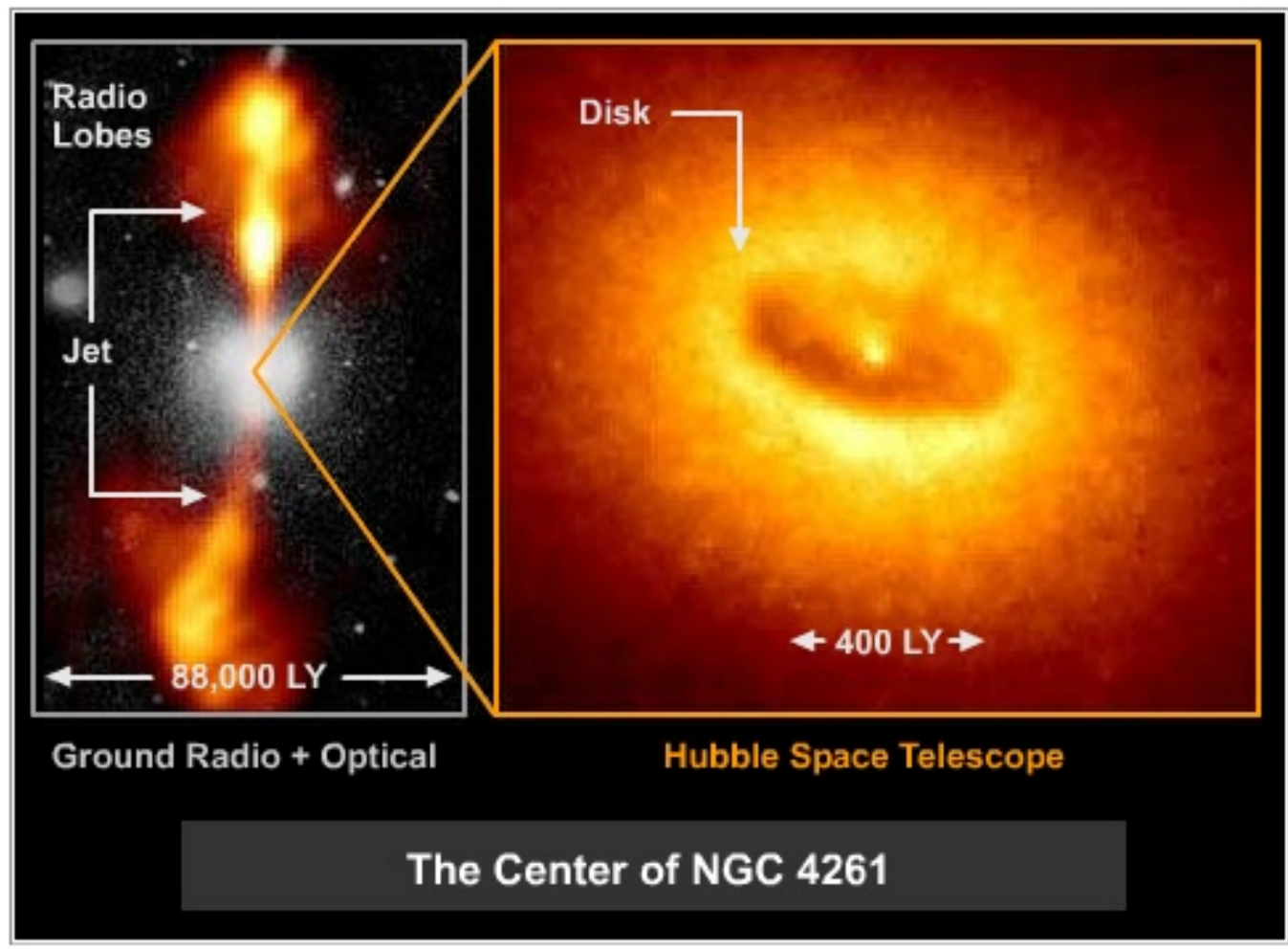
Sam Falle 1991

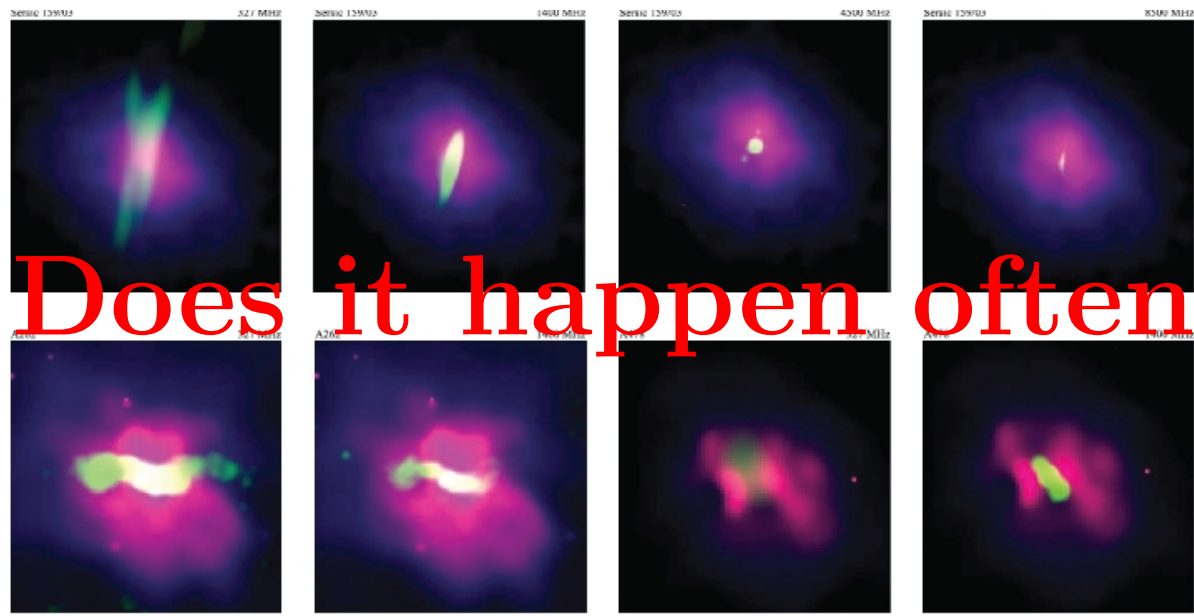


Self-similar model

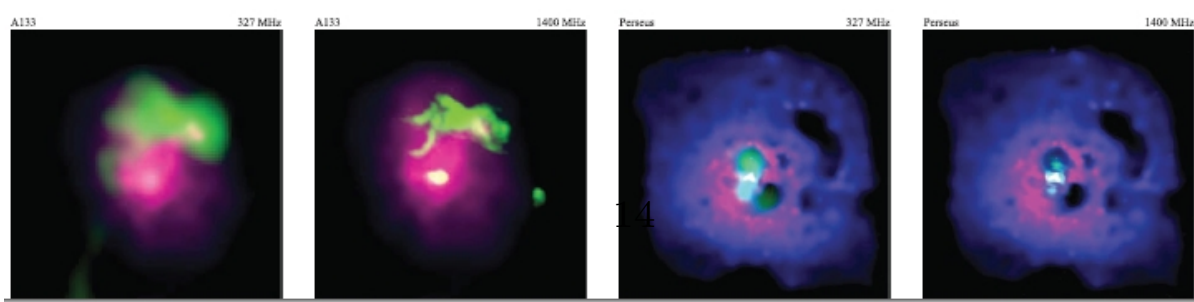
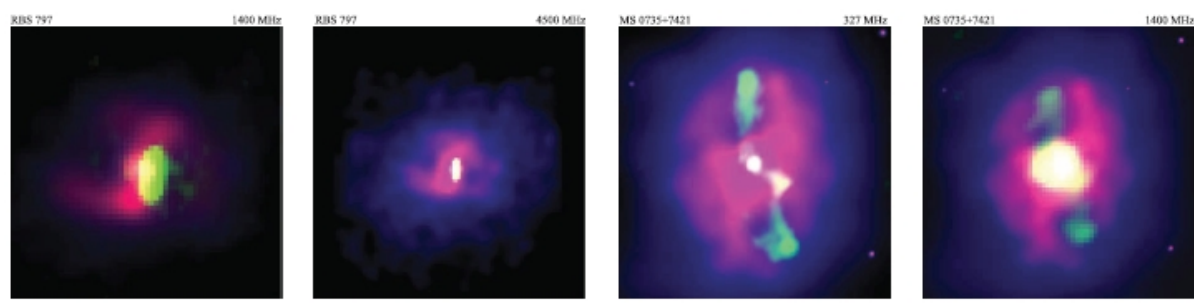
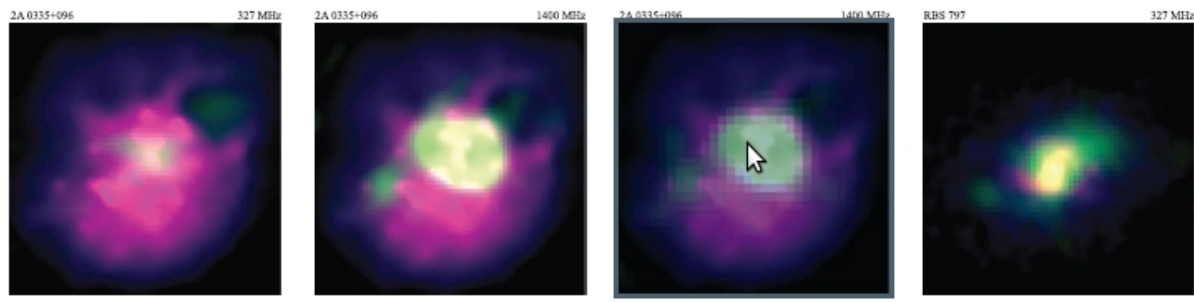
Kaiser & Alexander '97

The accretion disk





Does it happen often?



The magnetic fields in galaxy clusters



H α filaments in NGC 1275

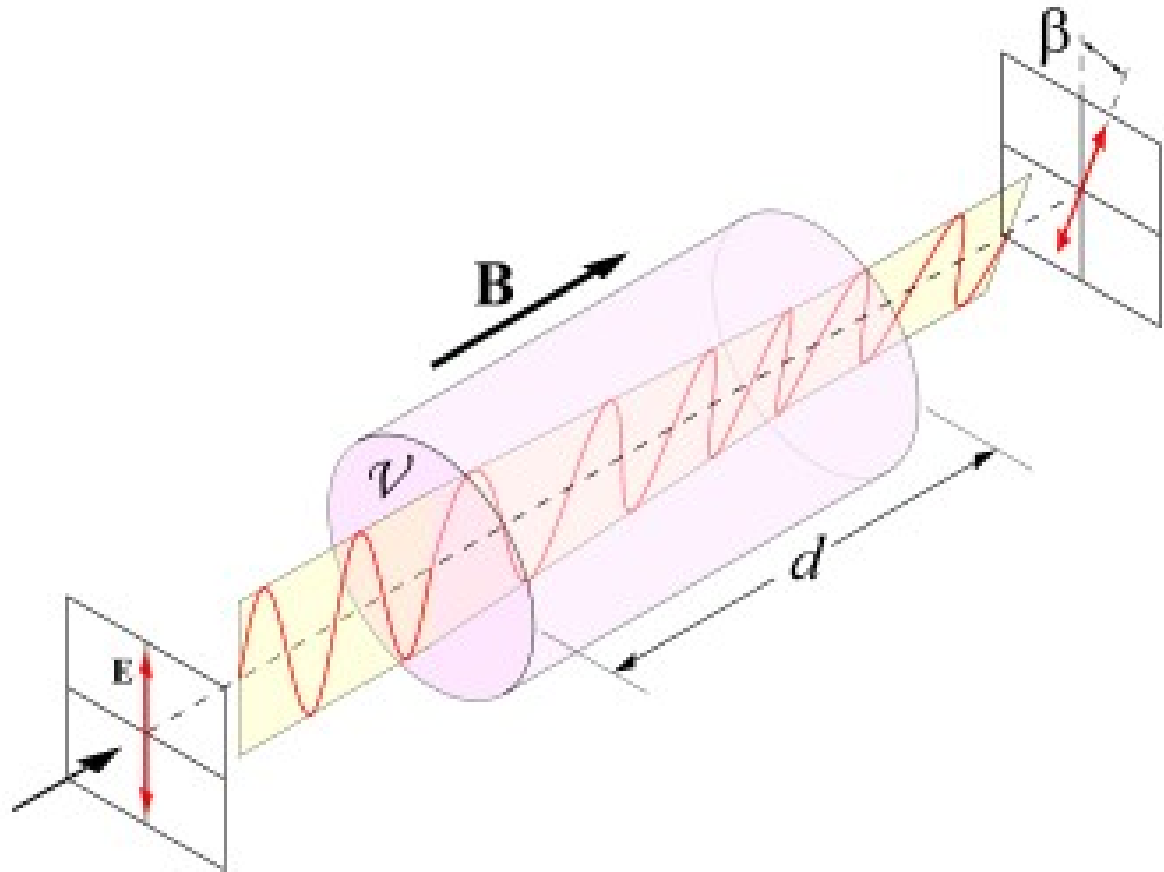
Fabian et al. '08

MOVIE TIME!

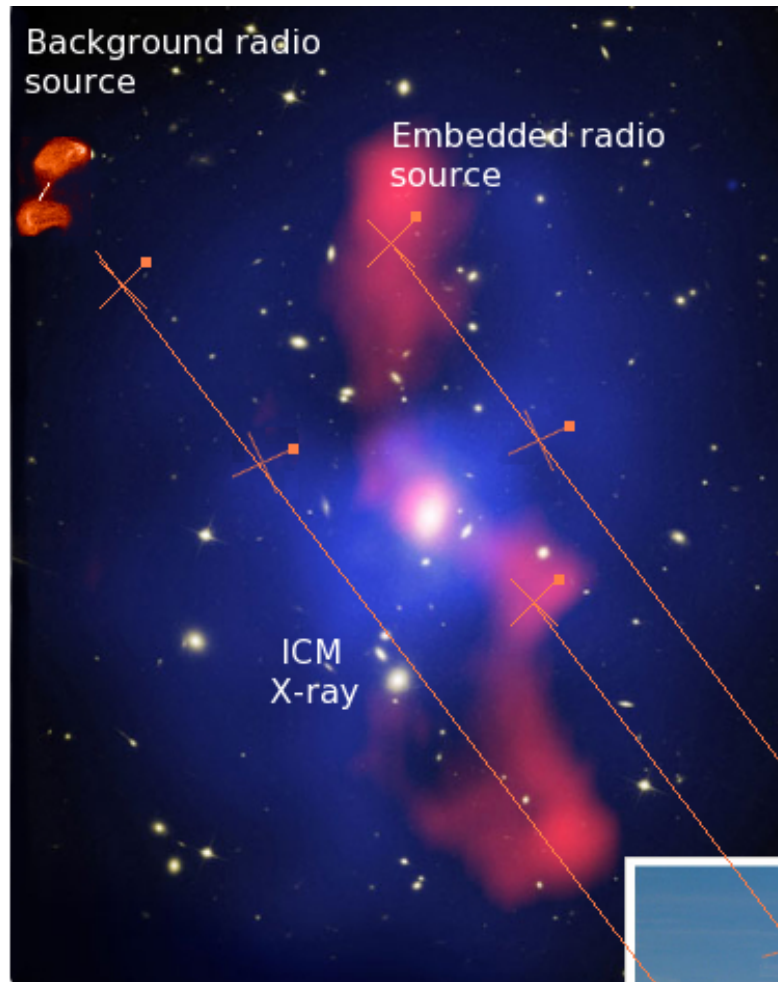
(<http://hubblesite.org/newscenter/archive/releases/2008/28/video/b/>)

Faraday rotation

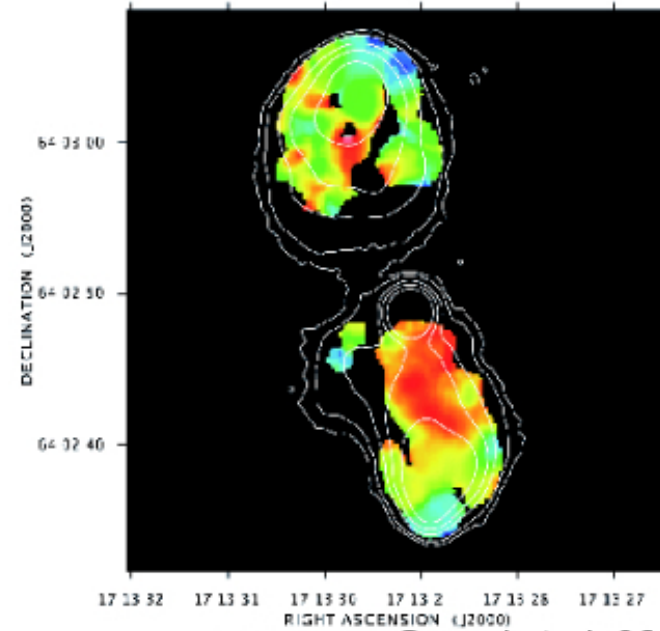
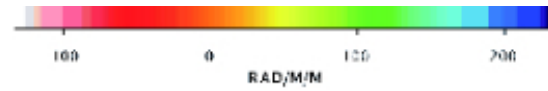
$$\beta = \text{RM} \lambda^2$$
$$\text{RM} \approx 0.81 \int_0^d n_e B ds$$



RM maps



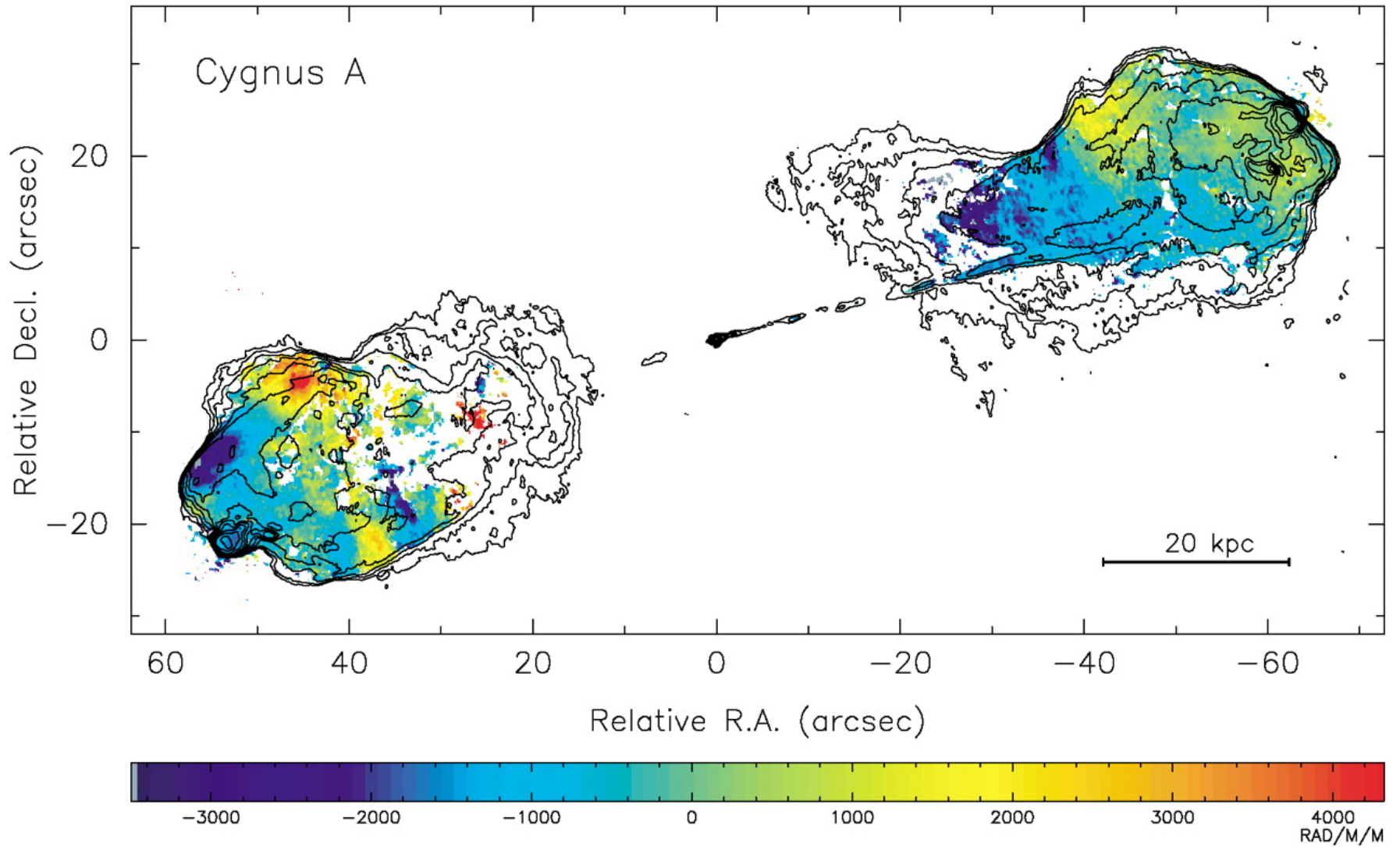
MS 0735.6+7421 NASA composition



Govoni et al. 06
J1713.5+6402
Abell 2255

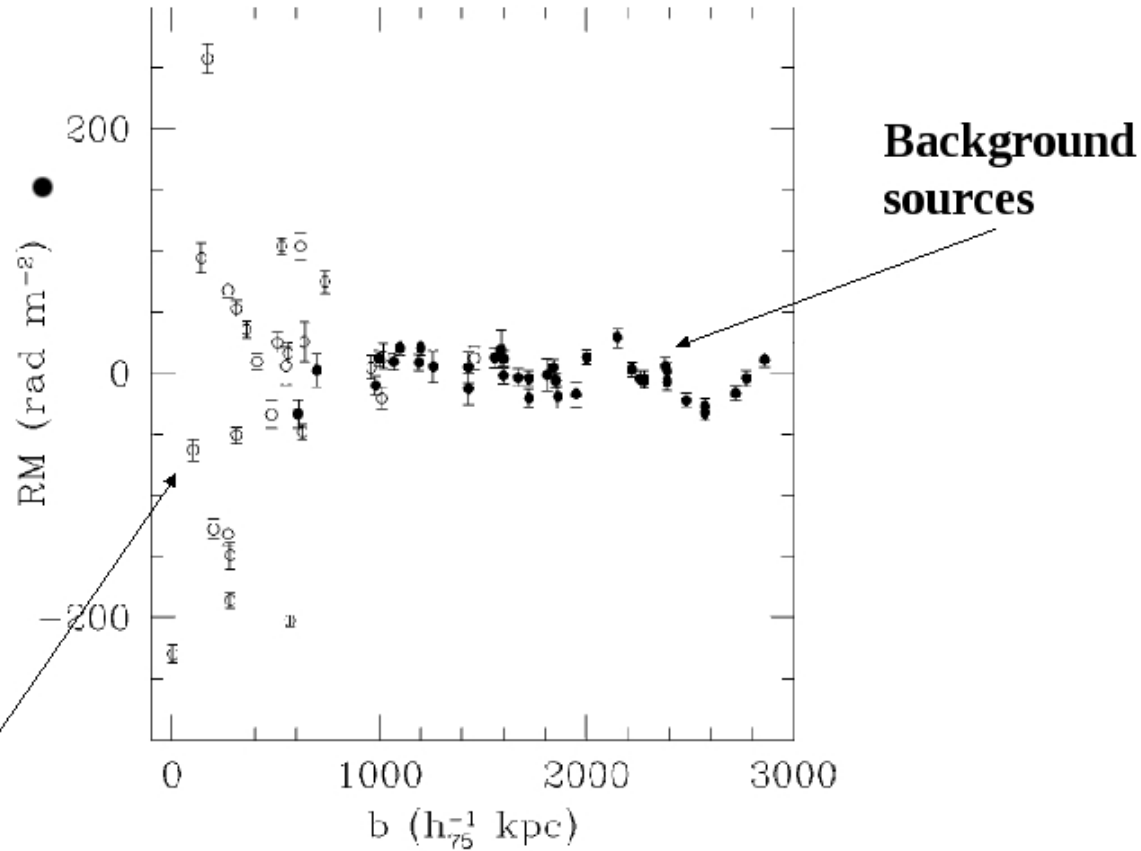


Good 'ol Cygnus A



RM against background radio sources

$B \sim 1\text{--}10 \mu\text{G}$ and coherence lengths of $\sim 5\text{--}10 \text{ kpc}$

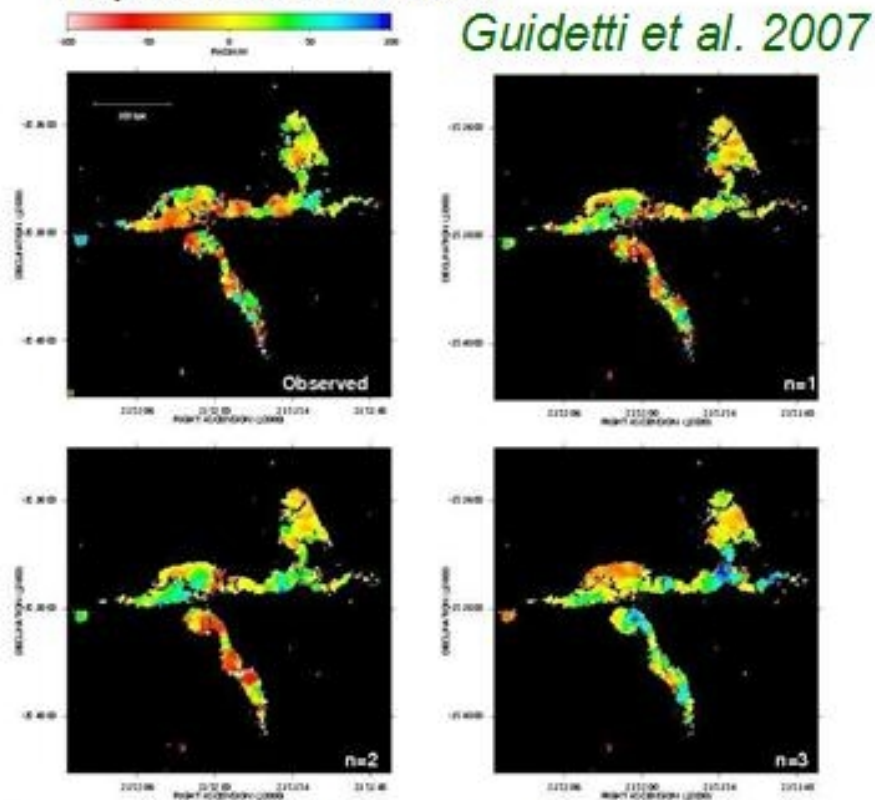


**Results from 16
Abell clusters**

Clarke et al. 2001

RM against embedded radio sources

- A23825 contains 2 extended radio galaxies
- Kolmogorov $n=11/3$ spectral index reproduces the data

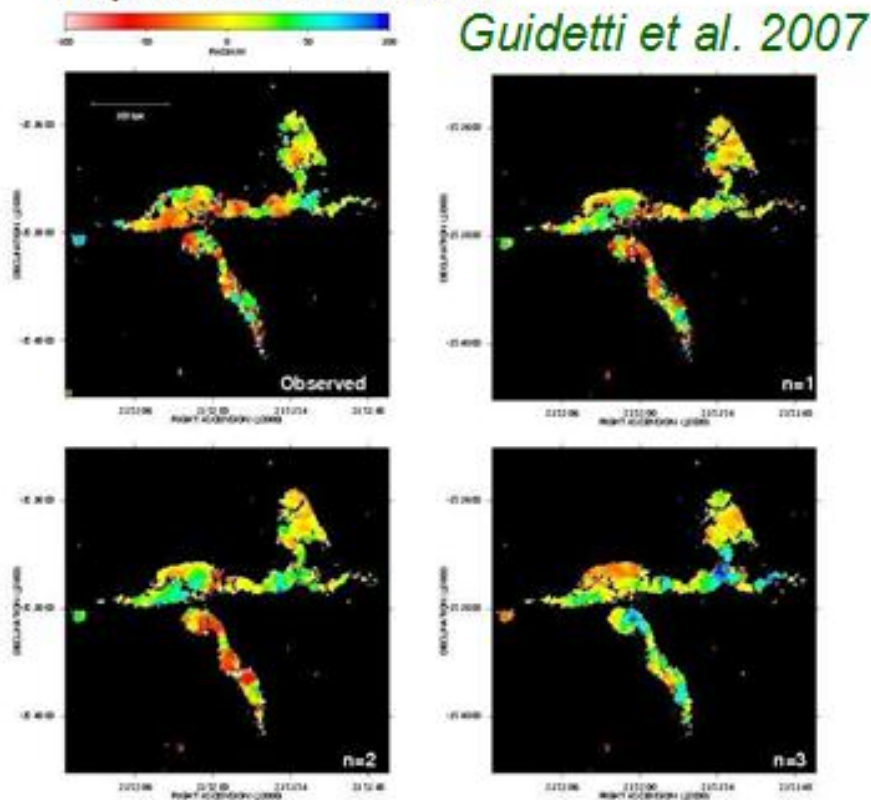


Laing Garrington effect (the further radio lobe is more depolarised)

Power-spectrum of magnetic fields

RM against embedded radio sources

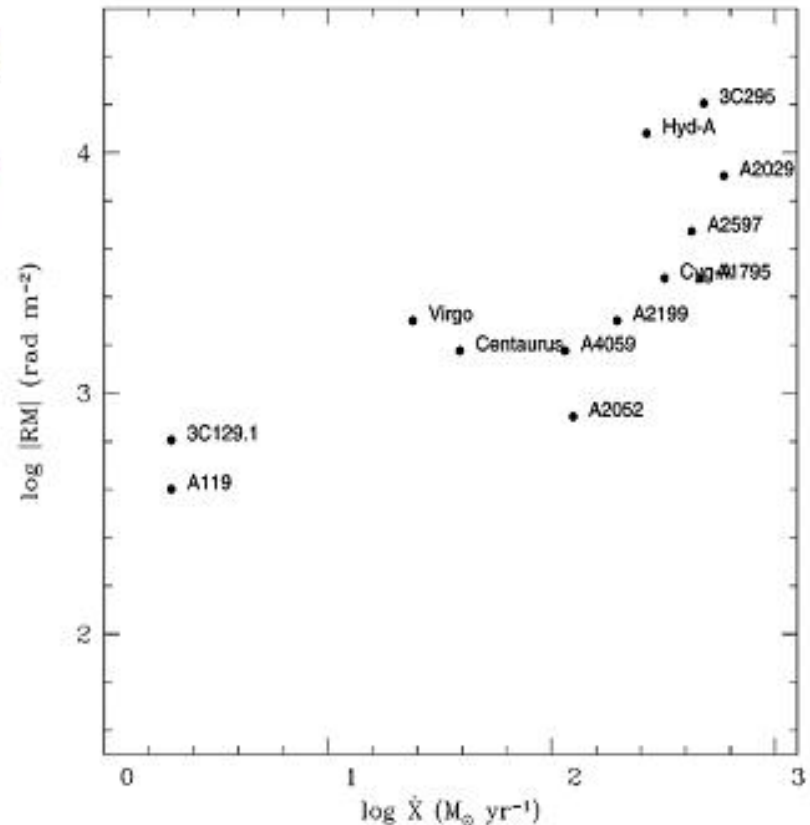
- A23825 contains 2 extended radio galaxies
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Power-spectrum of magnetic fields

Carilli & Taylor 2002



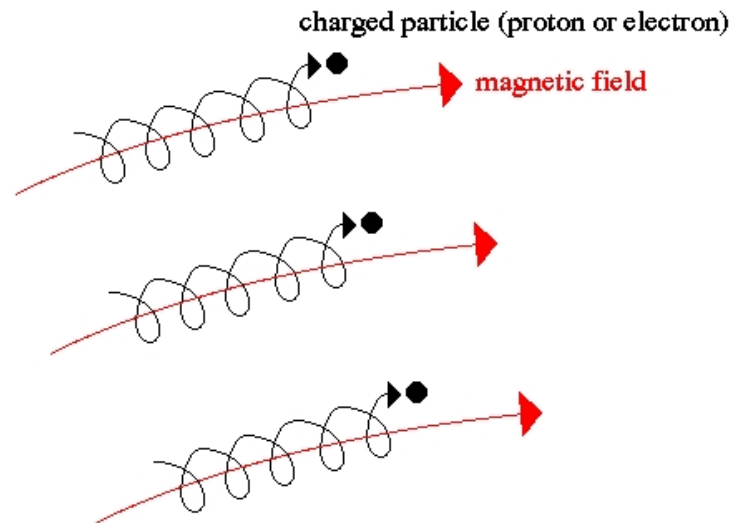
RM increases in strong cooling flow clusters (denser in the core)

How important are the magnetic fields?

$$\beta \equiv \frac{P}{\vec{B}^2/2}$$

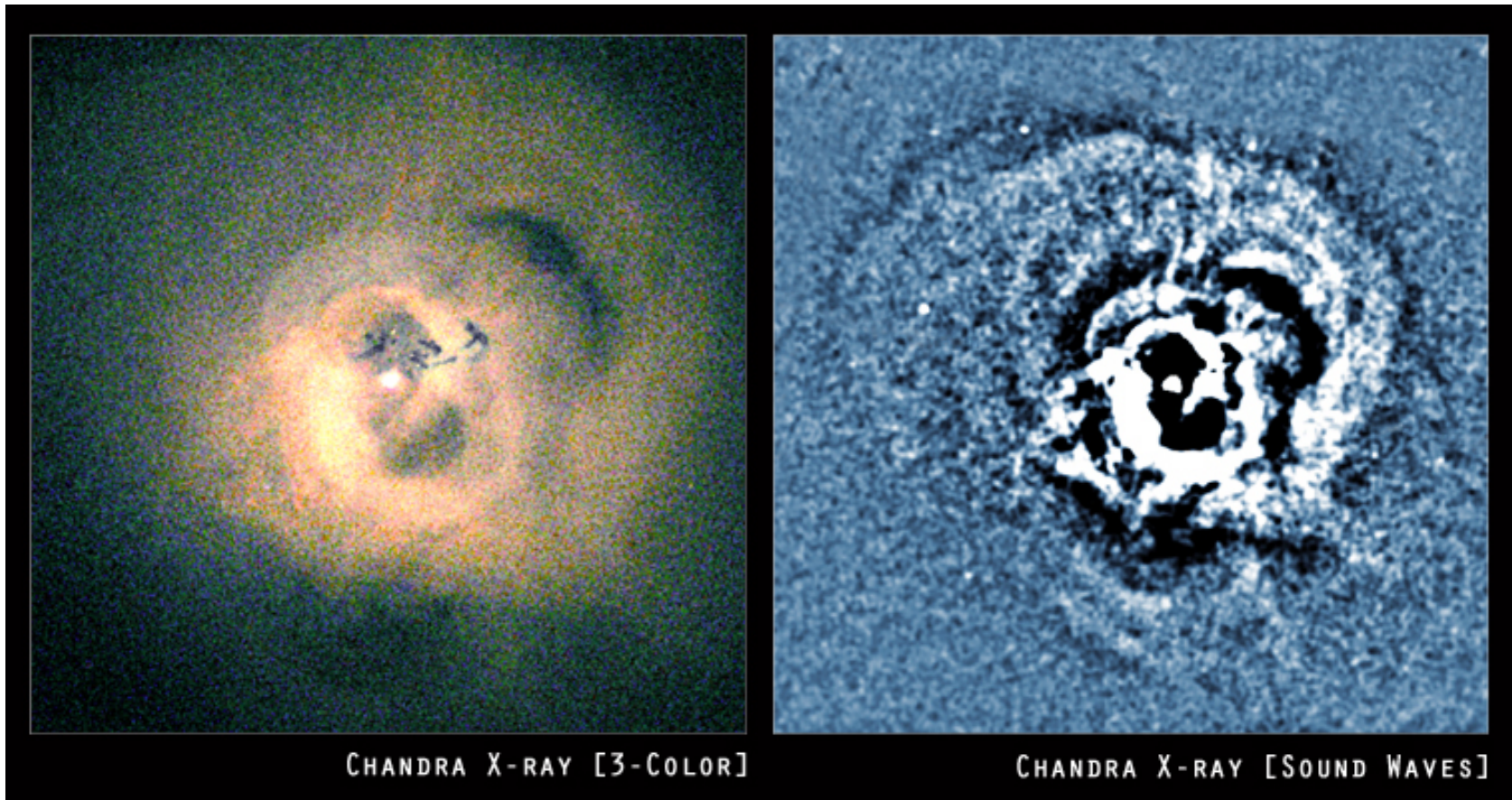
Anisotropic heat conduction: $\mathbf{Q} = -\chi \hat{\mathbf{b}}(\hat{\mathbf{b}} \cdot \nabla T)$

They can lead to instabilities.



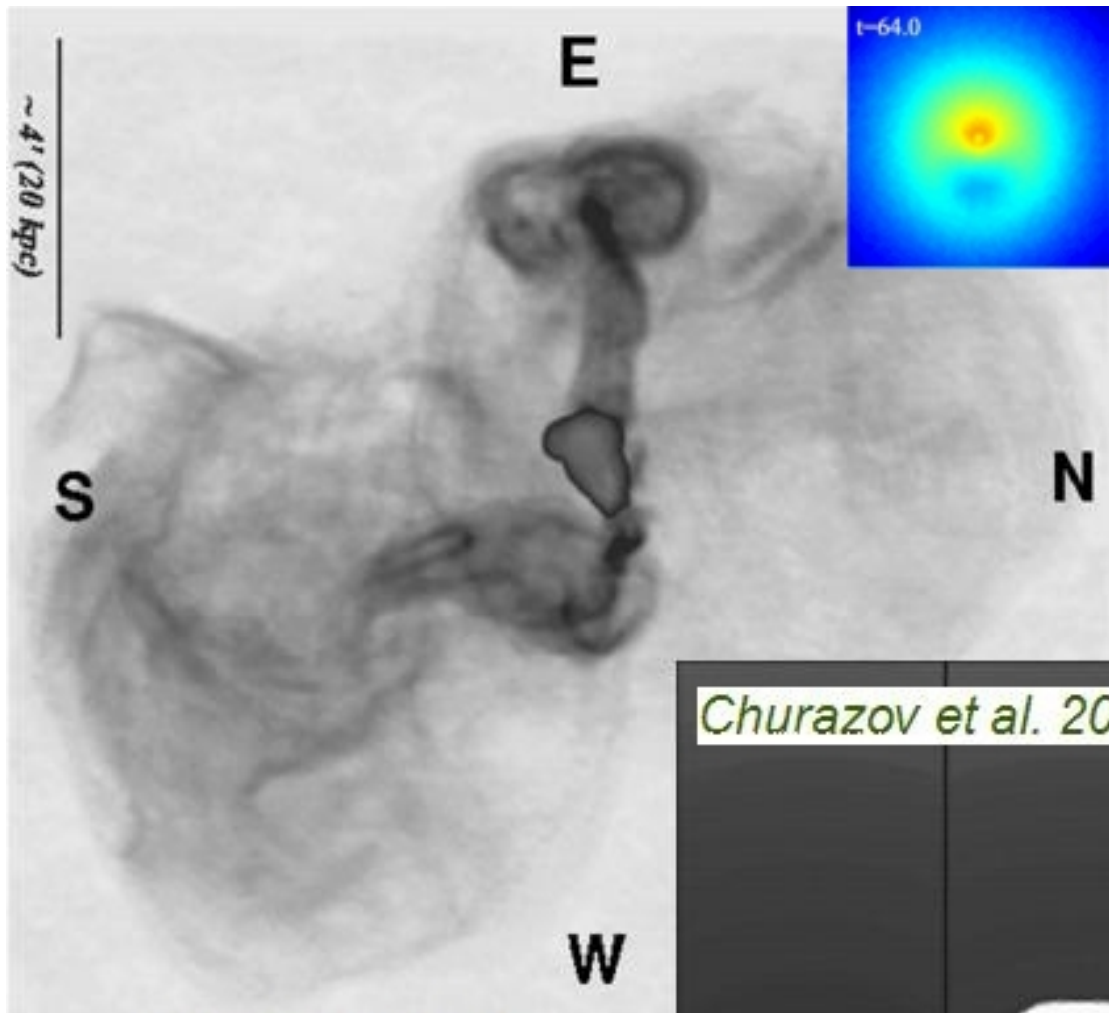
Paper... don't be scared (<http://adsabs.harvard.edu/abs/2009ApJ...704..211B>)

Feedback models

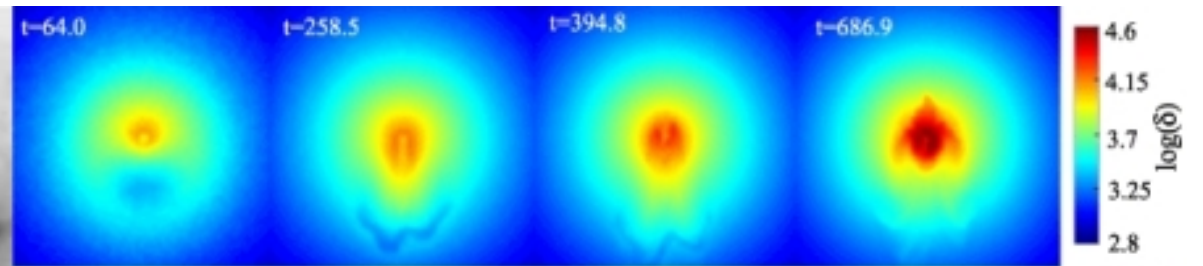


Fabian et al. 2003

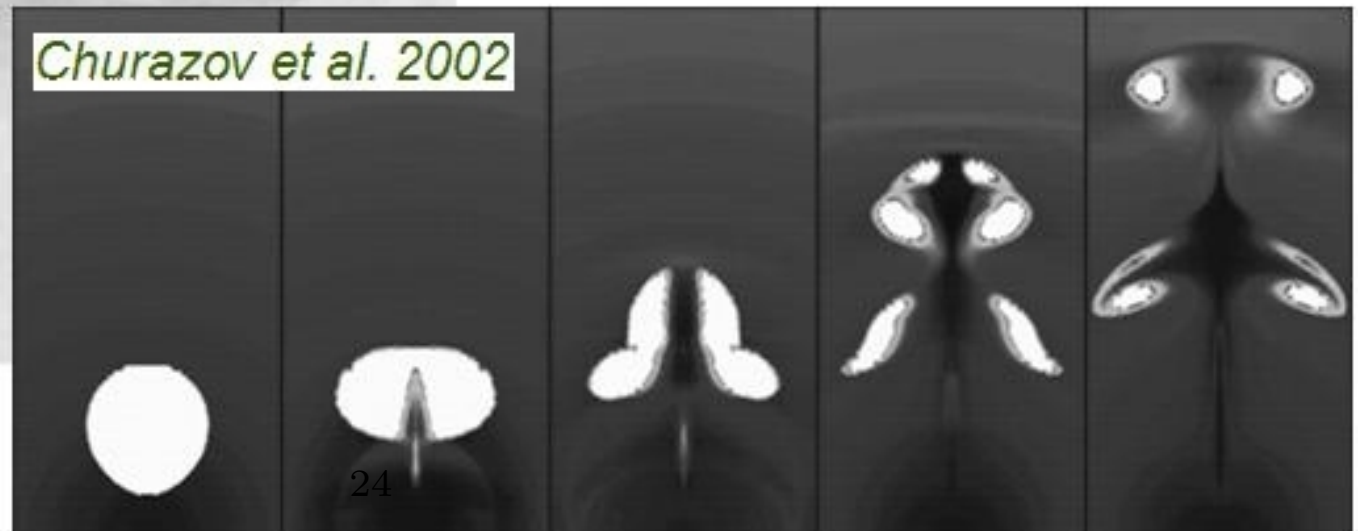
Relic (fossil) buoyant bubbles



M87 at 327 MHz

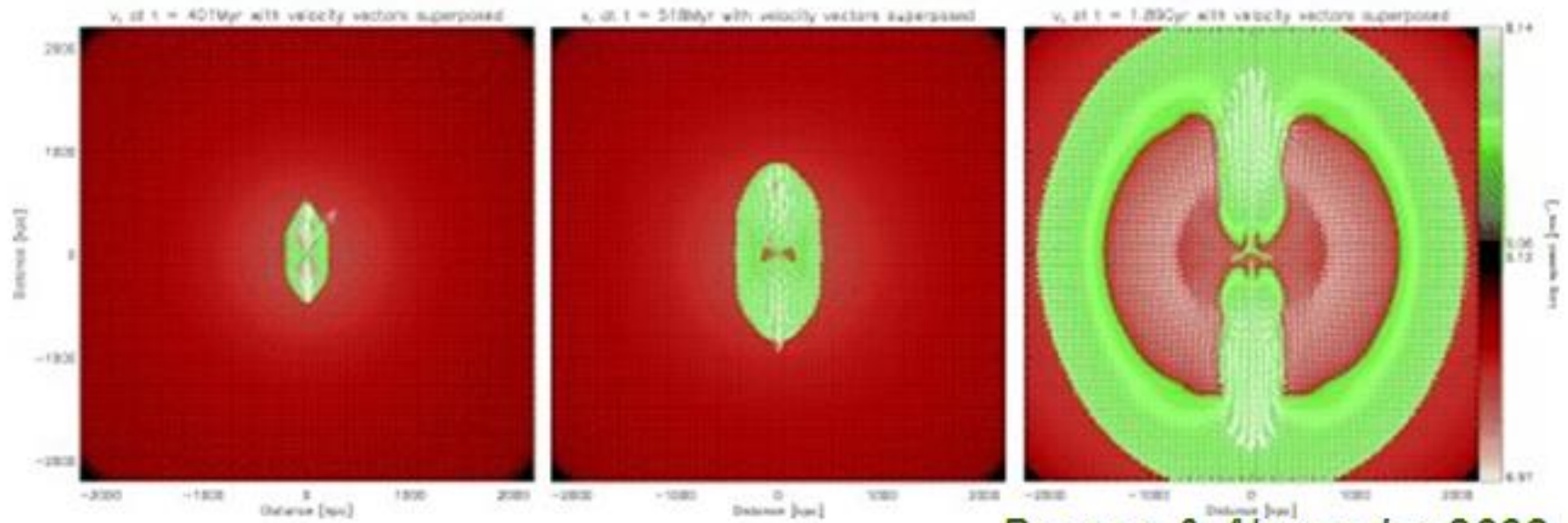


Quilis et al. 2001



Churazov et al. 2002

Large scale convective flows



Basson & Alexander 2003

Modeling the AGN feedback on the cluster magnetic fields

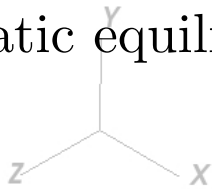
We use the random magnetic cubes to do 3DMHD simulations with FLASH3.1.

The grid:

- ★ A cubic domain, Cartesian geometry $|x| \leq L, |y| \leq L, |z| \leq L$,
- ★ A fixed grid with 200^3 cells, getting a maximum resolution of 5×10^{-3} .

The initial conditions (the ICM):

- ★ An ideal gas equation of state with $\gamma = 5/3$,
- ★ Constant initial temperature,
- ★ A King-like density profile ($\beta=2/3$): $\rho_{ICM}(r) = \frac{\rho_0}{1+(r/r_c)^2}$ and
- ★ Hydrostatic equilibrium between dark matter & ICM pressure.



Pseudocolor

Var: dens

0.9884

0.3776

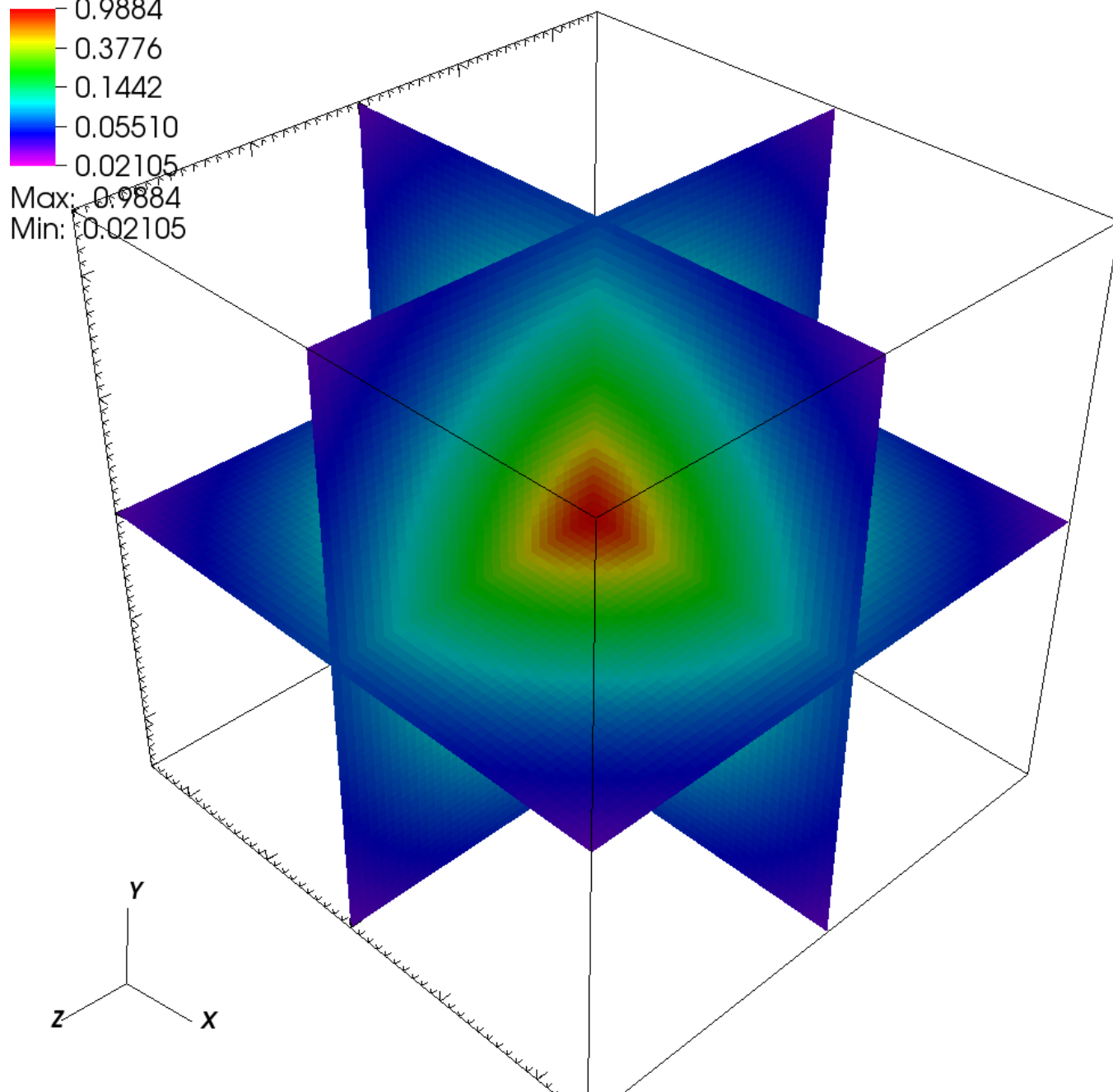
0.1442

0.05510

0.02105

Max: 0.9884

Min: 0.02105



Y
Z X

Pseudocolor

Var: B

0.4738

0.09994

0.02108

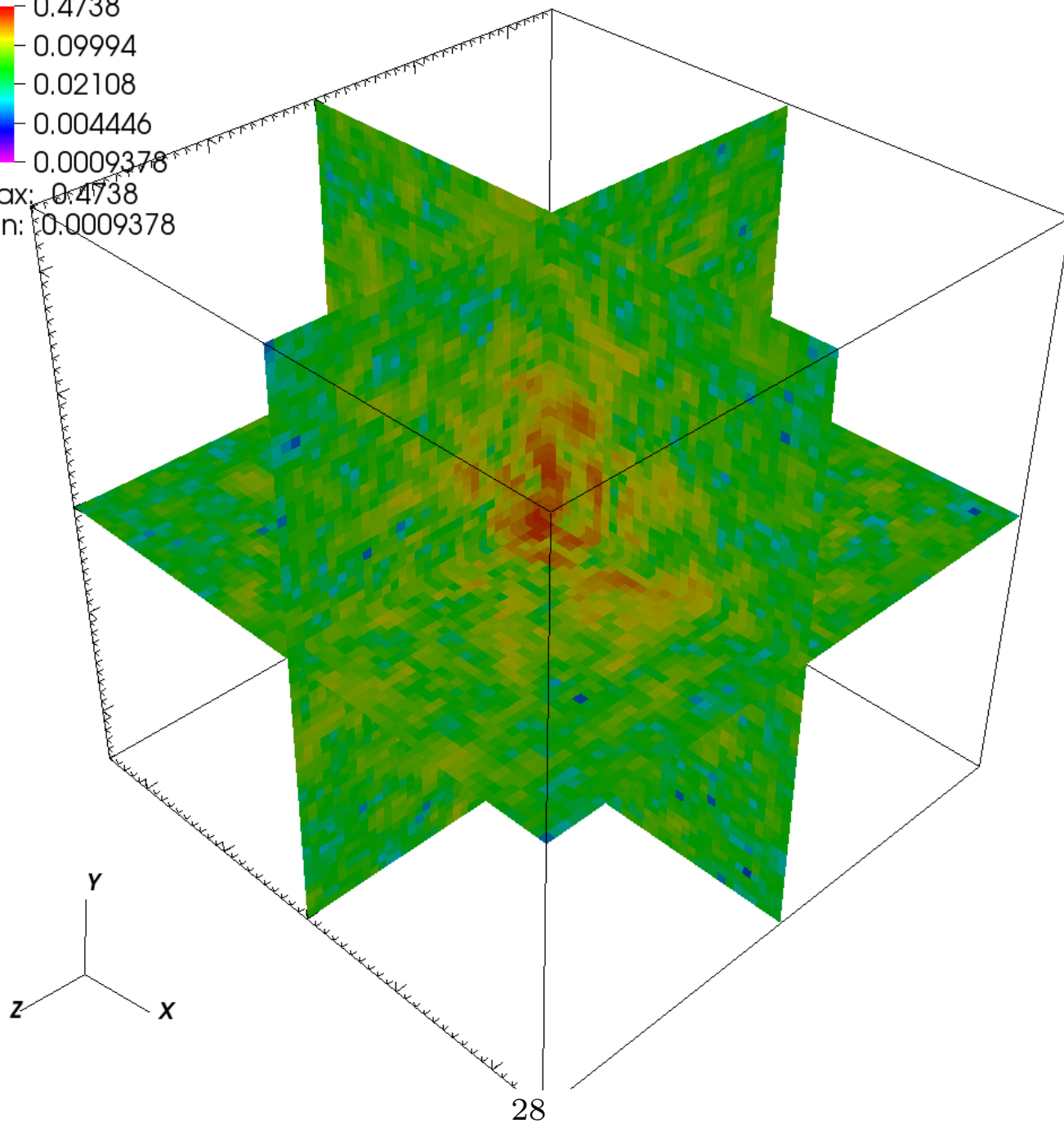
0.004446

0.0009378

Max: 0.4738

Min: 0.0009378

Power spectrum index = -3



The Jets

We add source terms to the mass and energy equations:

$$\rho_{\text{cent}}^{n+1} = \rho_{\text{cent}}^n + \rho_j$$

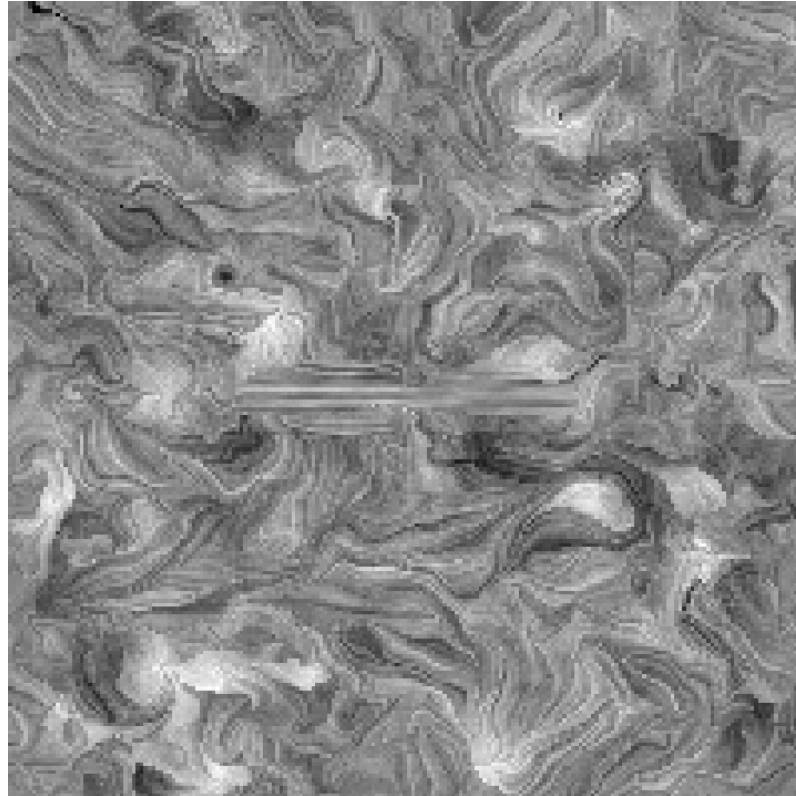
$$V_{\text{Xcent}}^{n+1} = V_{\text{Xcent}}^n + V_{\text{Xj}}$$

The jets have the following properties:

- ★ Low density: ($\rho_{ICM}/\rho_{jet} = 10^{-3}$),
- ★ Pressure equilibrium with the central ICM,
- ★ A velocity of $\approx 0.4c$, ≈ 60 Mach,
- ★ Collimated and,
- ★ A power $\approx 5 \times 10^{45}$ erg/s for 10 Myrs.

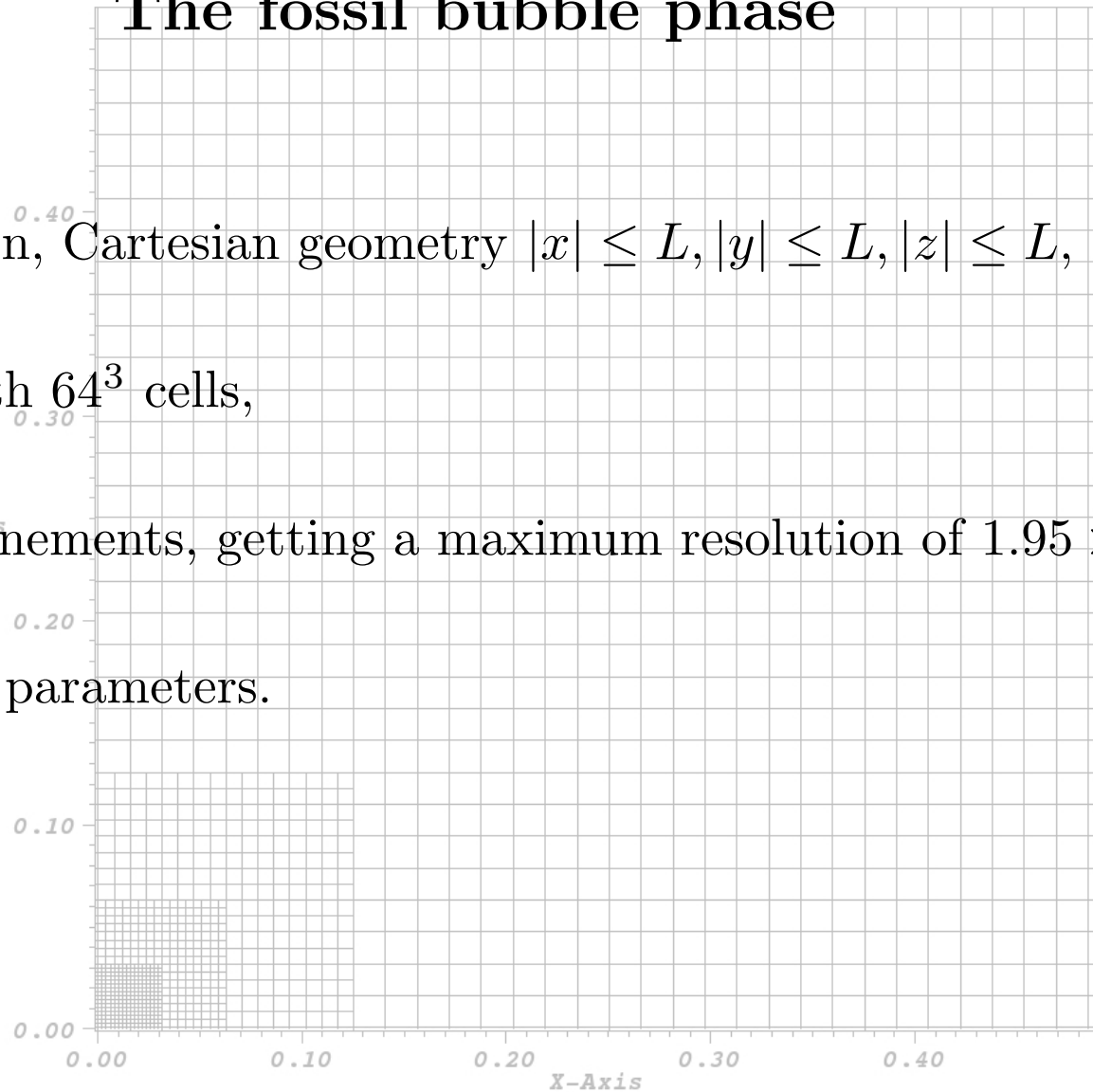
MOVIE!

The topology of the magnetic fields lines at 16.2 Myr:



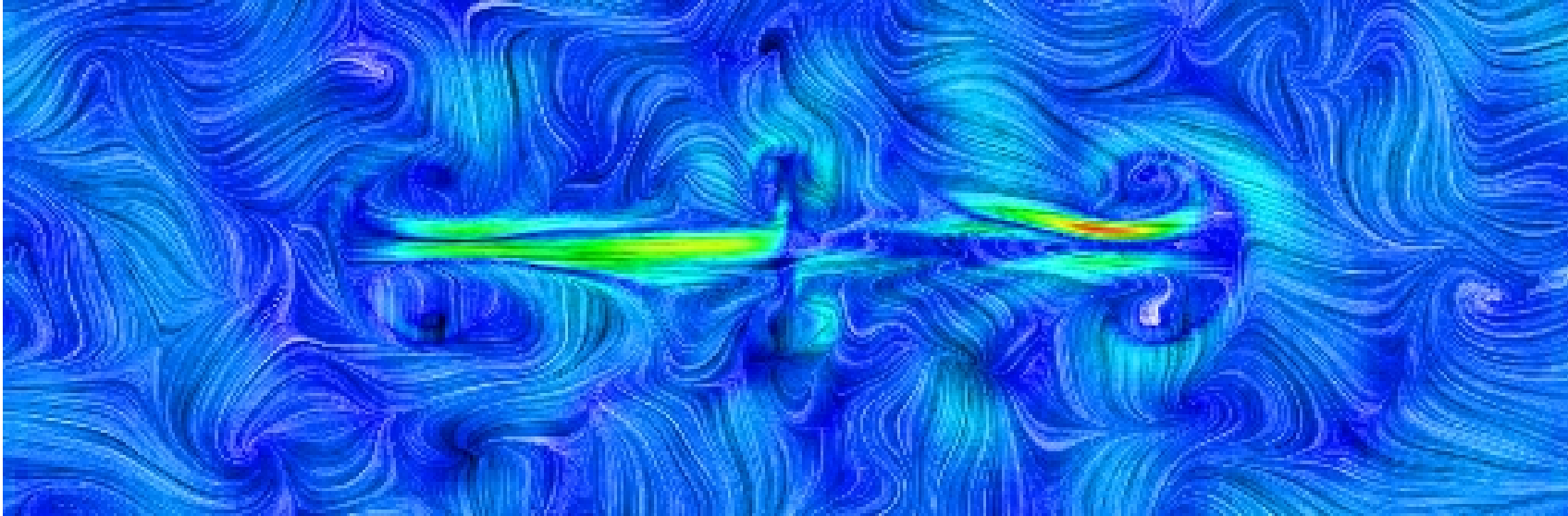
The fossil bubble phase

- ★ A cubic domain, Cartesian geometry $|x| \leq L, |y| \leq L, |z| \leq L,$
- ★ Initial grid with 64^3 cells,
- ★ 3 adaptive refinements, getting a maximum resolution of 1.95×10^{-3} and
- ★ The same jets parameters.



MOVIE!

The topology of the magnetic fields lines:



Summary and discussion

- ★ The ICM is a huge plasma physics lab. Many questions are still open.
- ★ The ICM cooling problem has not been solved. AGN jets are the obvious heating mechanism.
- ★ Anisotropic heat conduction instabilities are likely to develop in the ICM.
- ★ AGN jets play an important role in the ICM energetics and, viceversa.

Find this talk @ <http://www.pas.rochester.edu/~martinhe/>.

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