Astrophysics from the Moon

ASI

13 technological studies

3 scientific studies

Observation of the Universe from the Moon
Observation of the Moon
Observation of the Earth from the Moon

Astrophysics from the Moon

ASI

Observation of the Universe from the Moon
(R. Mandolesi)

Astroparticle (P.I. R. Battiston)
Radioastronomy (P.I. G. Brunetti)
IR-Optical (P.I. R. Ragazzoni)
X-Gamma (P.I. P. Caraveo)

Astrophysics at VERY low radio frequencies: cluster scale emission

Gianfranco Brunetti

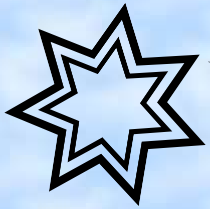
(IRA-INAF, Bologna, Italy)

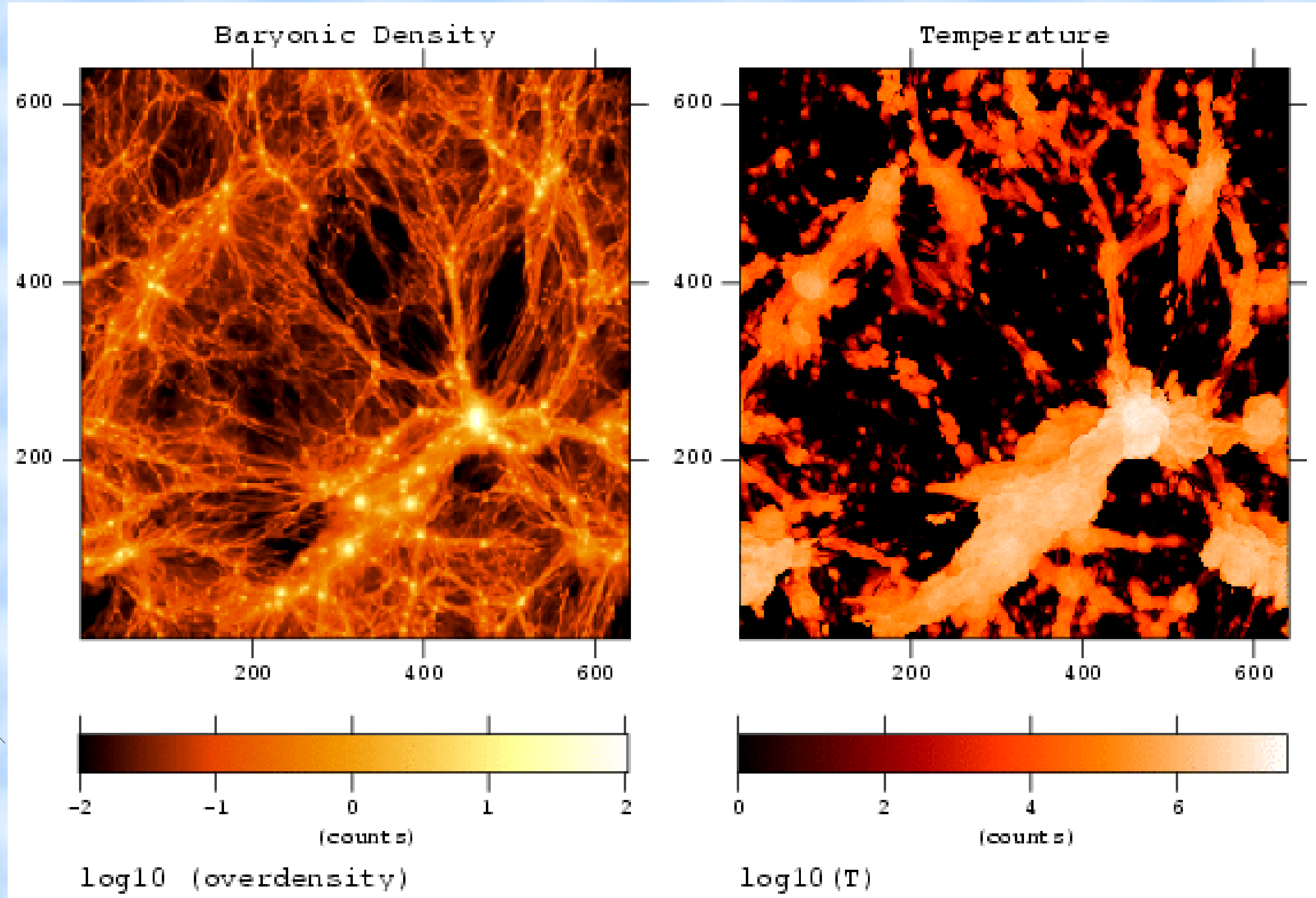
- Low Frequency: Real step forward in this issue ?
- Is the Moon Unique ?

Galaxy clusters and non-thermal radiation

$$M \approx 10^{15} M_o$$

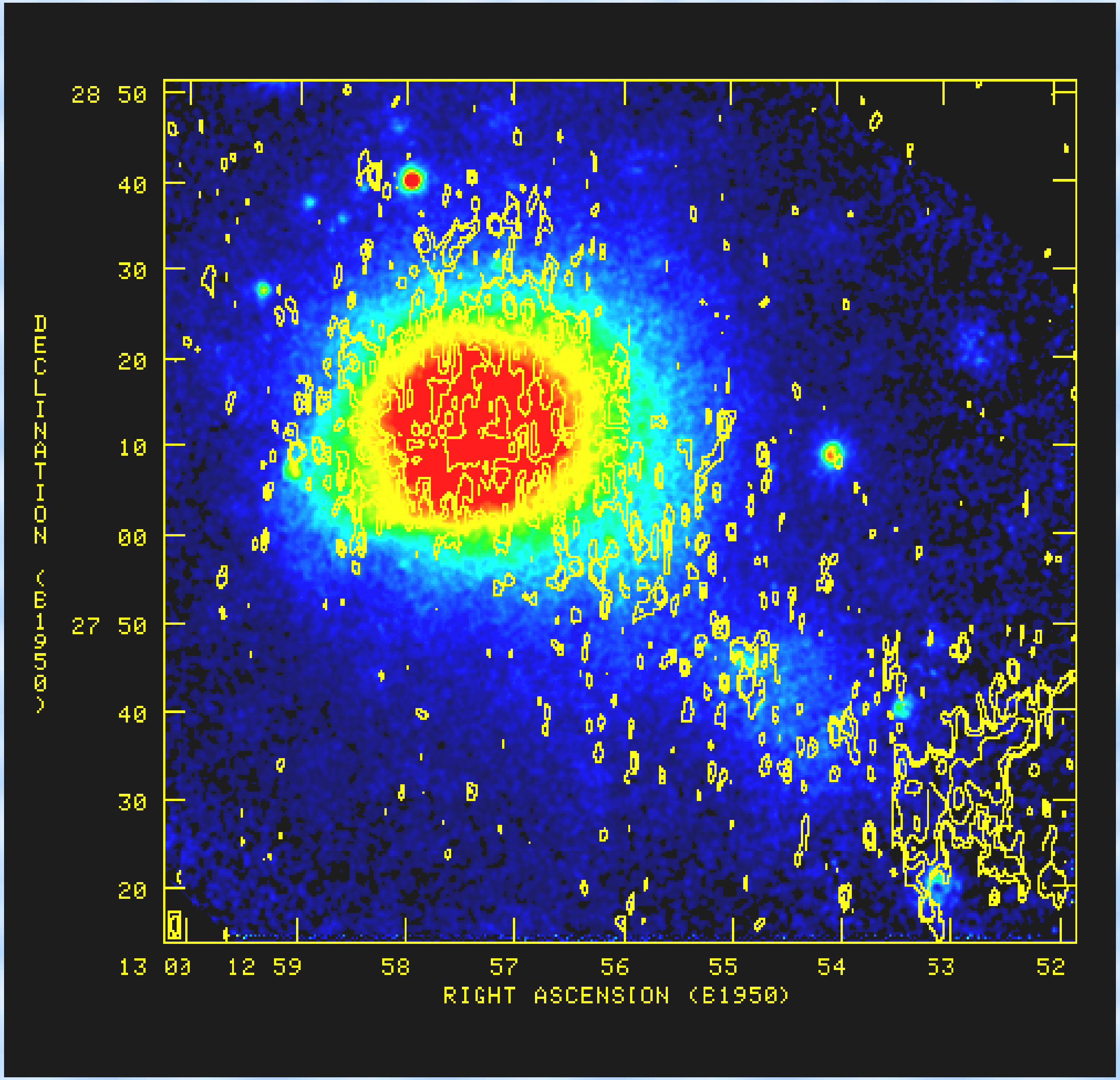
$$E_{th} \approx 10^{64} ergs$$





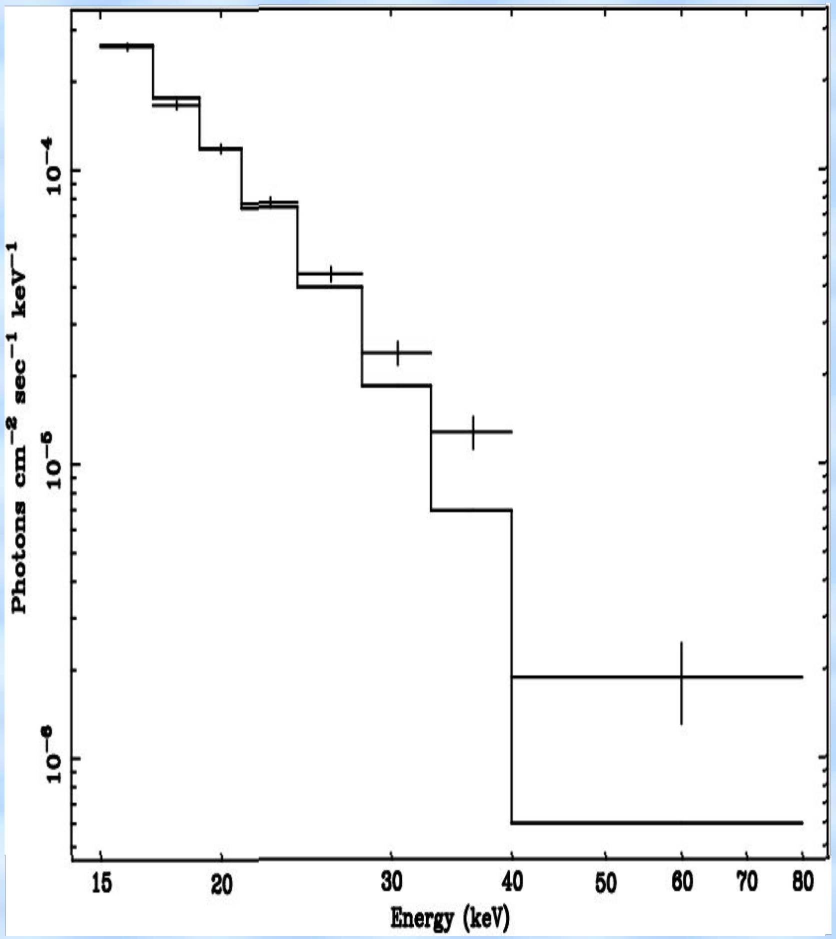
Diffuse (Mpc) radio emission

synchrotron radiation from GeV electrons



Hard X-ray Excess (HXR)

it may be due to IC emission from the same radio emitting electrons



Additional Ingredients in the ICM

B ~μG (RM, SYN, Theory)

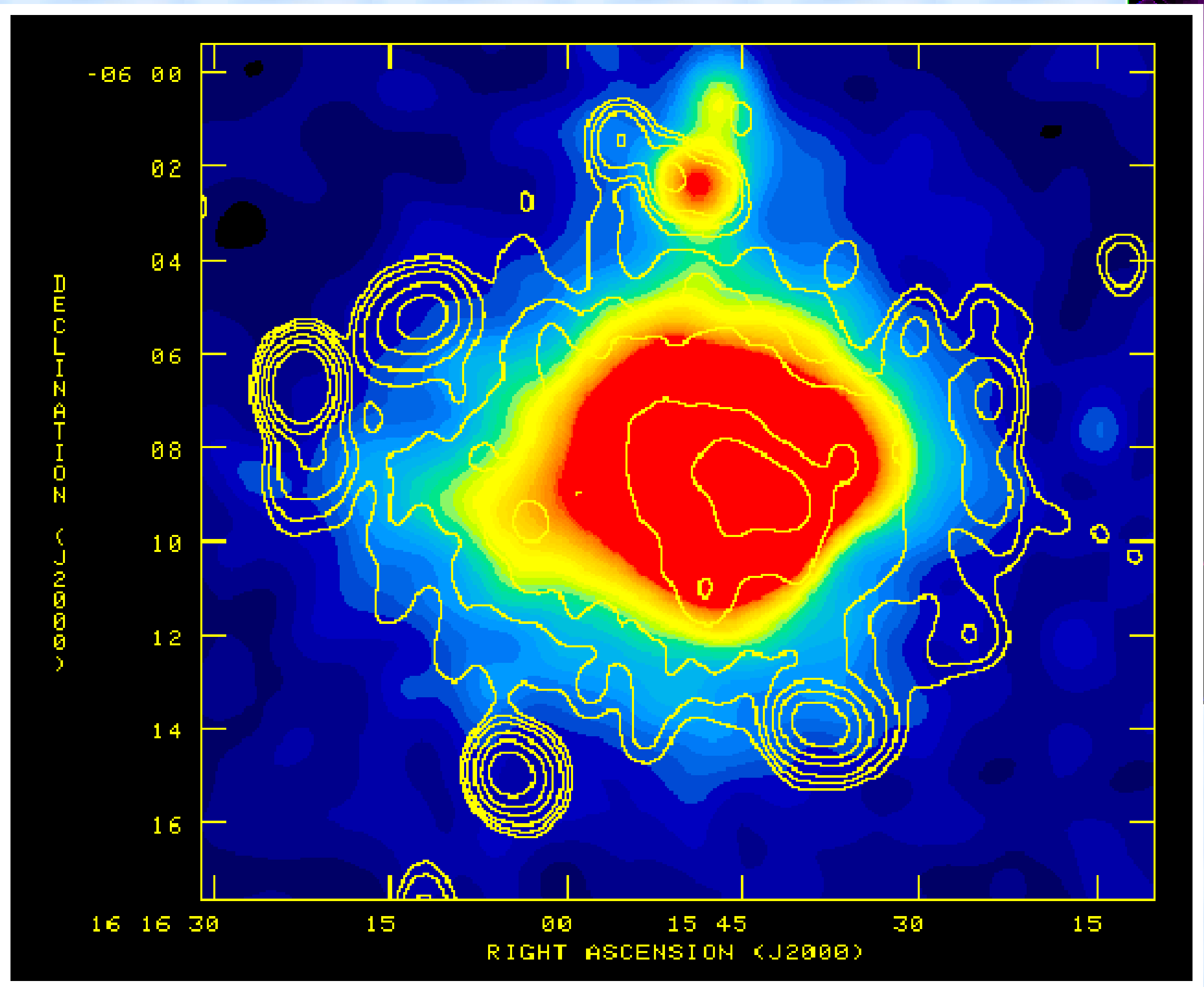
CR electrons & positrons (SYN, IC, Theory)

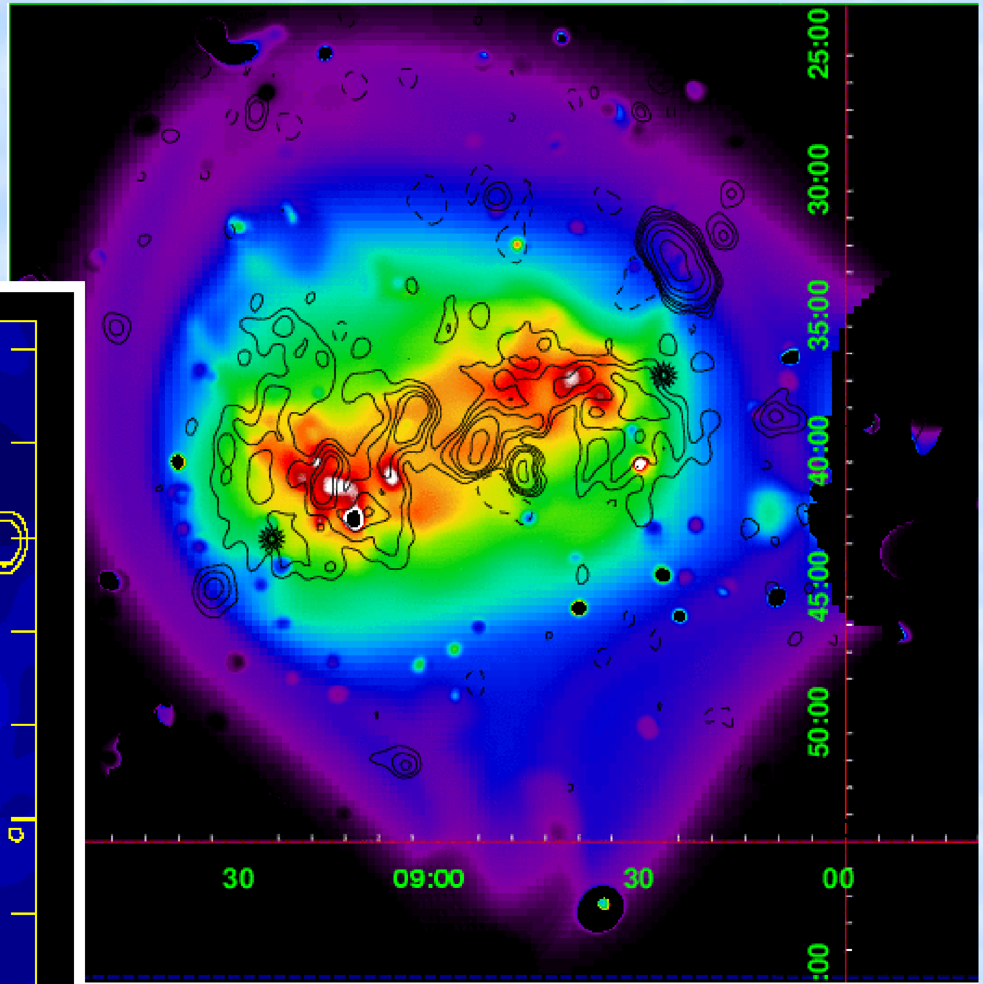
CR protons (observations?, Theory)

Radio observations (+observations in additional bands) allow to study the properties of these components in the LSS

The most spectacular example of non-thermal phenomena in LSS: Radio Halos

Abell 2163 (Feretti et al. 2001)



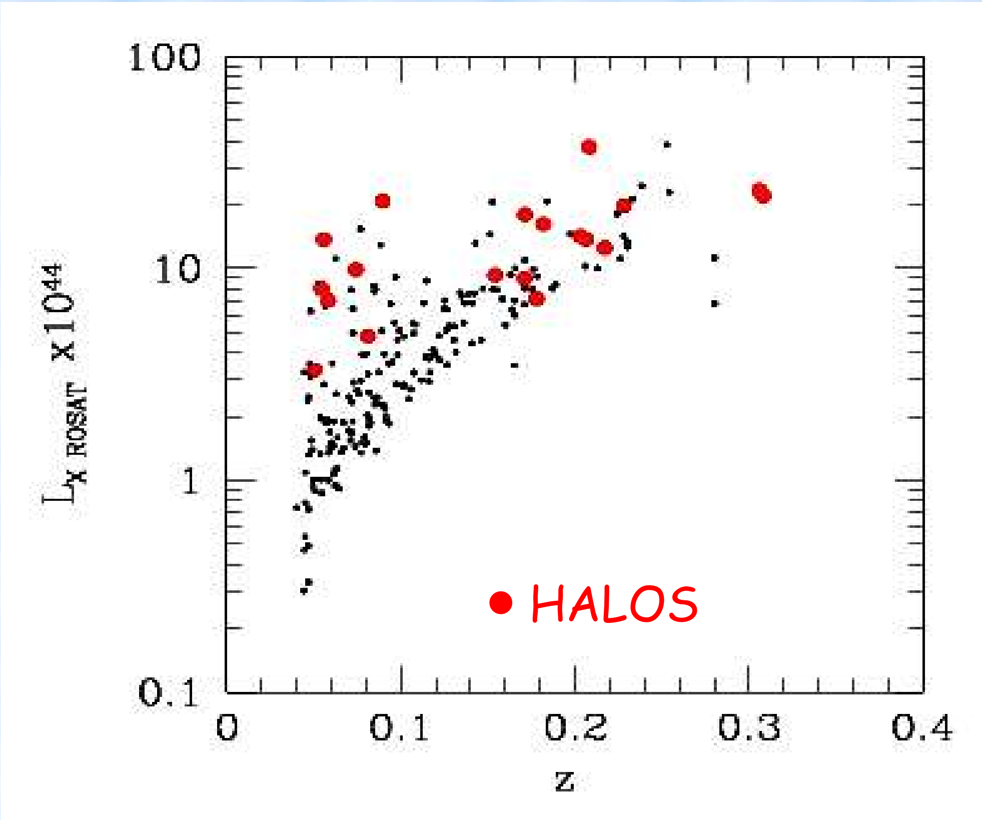


Abell 754 (Henry et al. 2004)

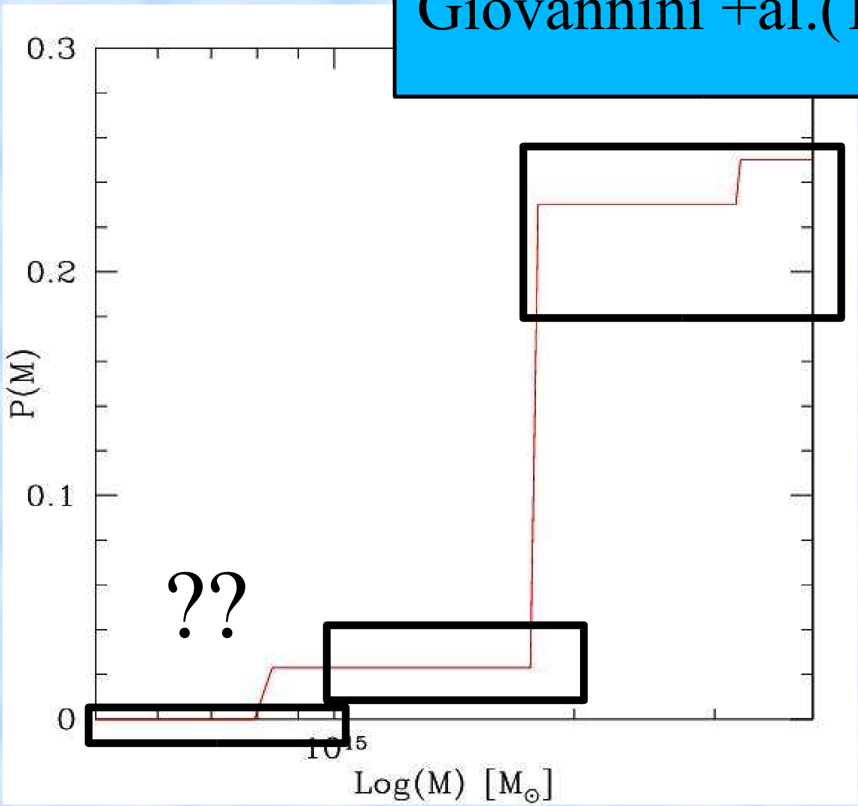
Occurrence of RH

RH are rare, only 5% of clusters (z=0.05-0.2) in the XBAC sample has a radio counterpart in the NVSS survey (Giovannini, Tordi, Feretti 1999)

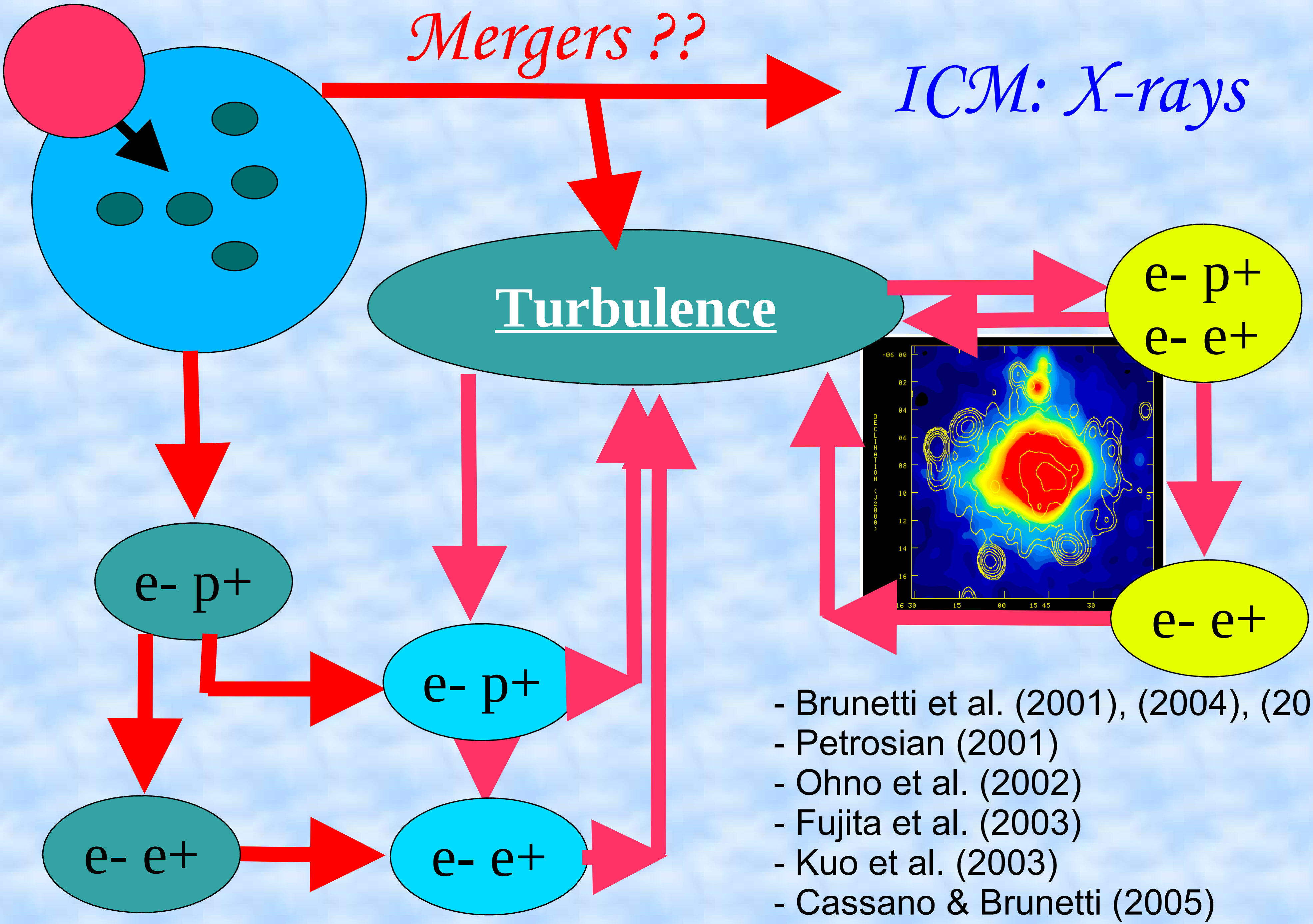
XBAC's sample
(Ebeling et al. 1996-2000)



Giovannini +al.(1999)



The Particle *RE-acceleration* model



- Brunetti et al. (2001), (2004), (2005)
- Petrosian (2001)
- Ohno et al. (2002)
- Fujita et al. (2003)
- Kuo et al. (2003)
- Cassano & Brunetti (2005)

Acceleration mechanisms

Shocks

Linear theory
(Ensslin+al.1998,01,03; Sarazin 1999; Blasi 1999; Waxman & Loeb 2000; Miniati+al.2001; Gabici & Blasi 2003; Berrington & Dermer 2003; Pfrommer+al.2006)

Non-linear theory (modified)
(Kang & Jones 2004; Blasi 2005;Gabici & Blasi 2005)

Turbulent modes (Fermi II)

Alfven Modes
(Schlickeiser et al.1987; Ohno et al.2002; Fujita et al.2003;Brunetti et al.2004,05)

Magnetosonic Modes
(Cassano & Brunetti 2005; Brunetti & Lazarian 2006)

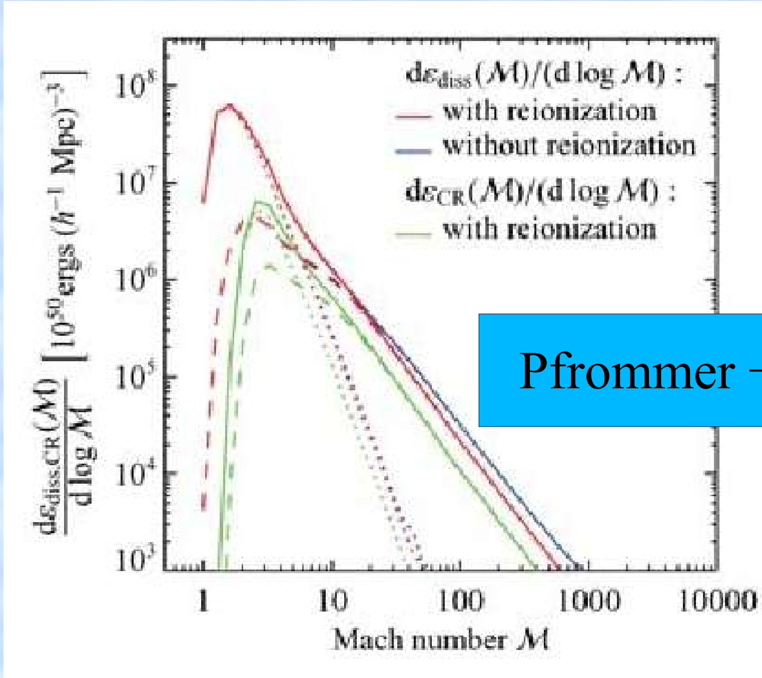
Modes generated by plasma instabilities....

Acceleration mechanisms

Shocks

Linear theory

Non-linear theory



Pfrommer +al. (2006)

Ryu +al. (2003)

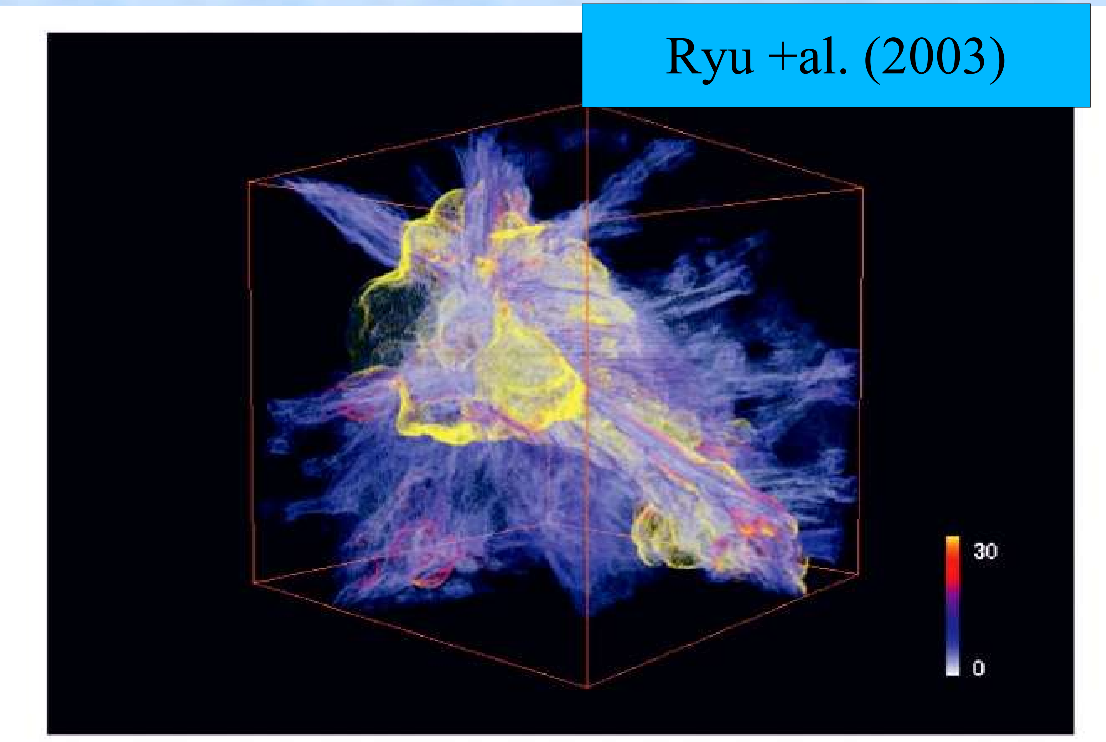
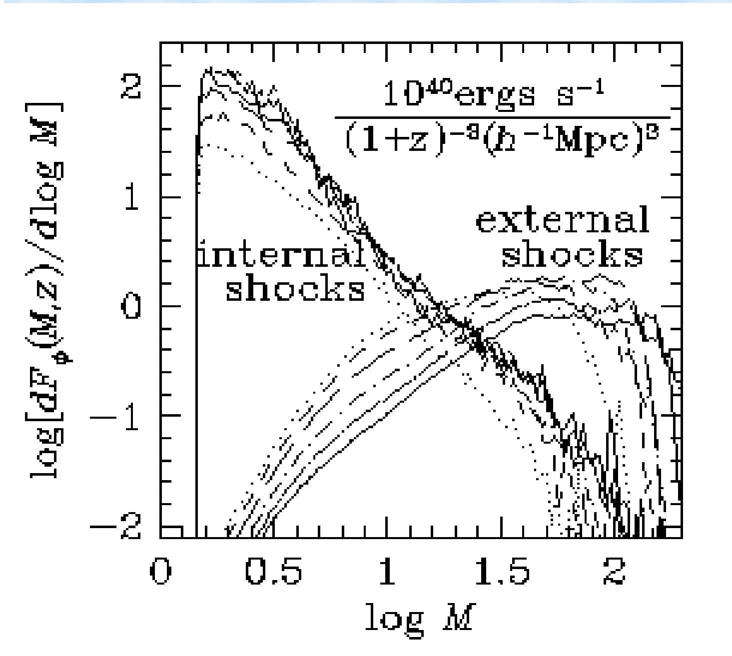
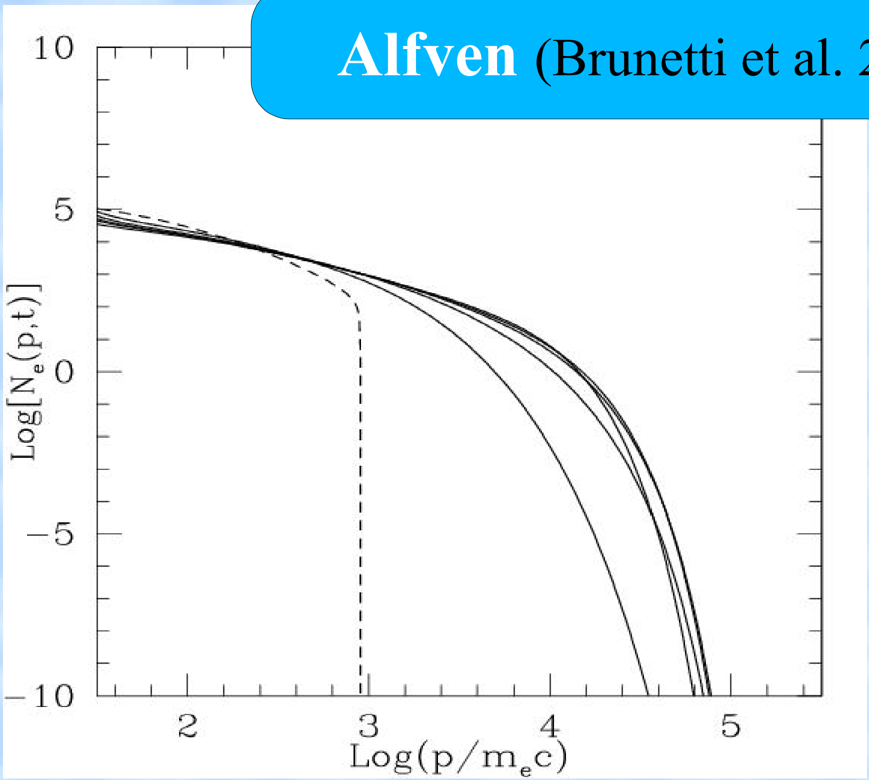
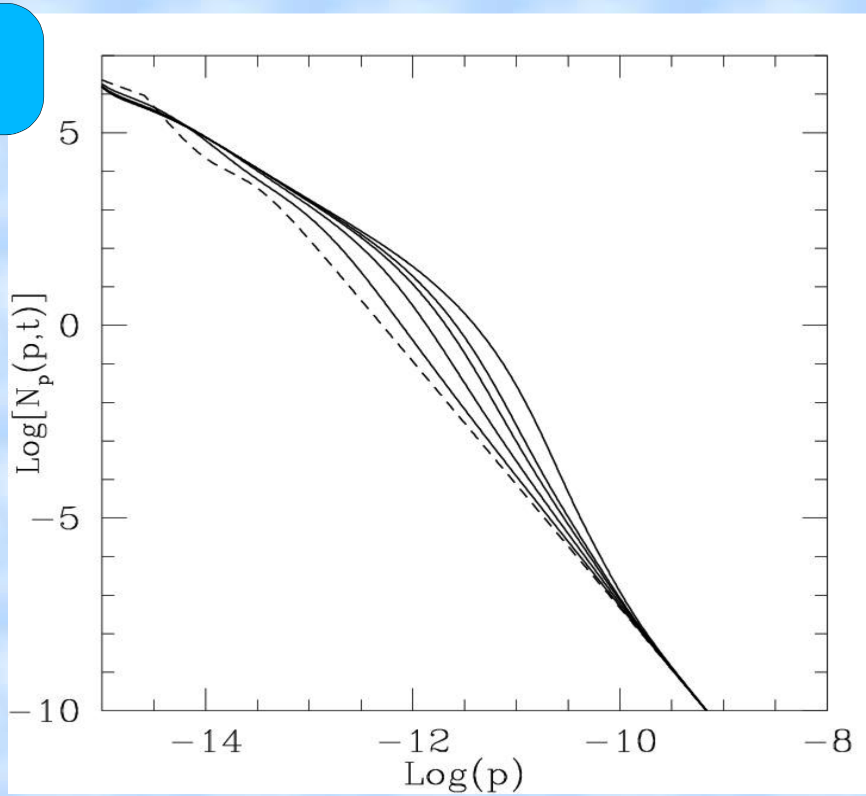


FIG. 4.—Three-dimensional shock surfaces in a volume of (25 h^{-1} Mpc)^3 around the same complex as in Fig. 3. The color bar shows the values of Mach numbers of shock surfaces.



Alfven (Brunetti et al. 2004)





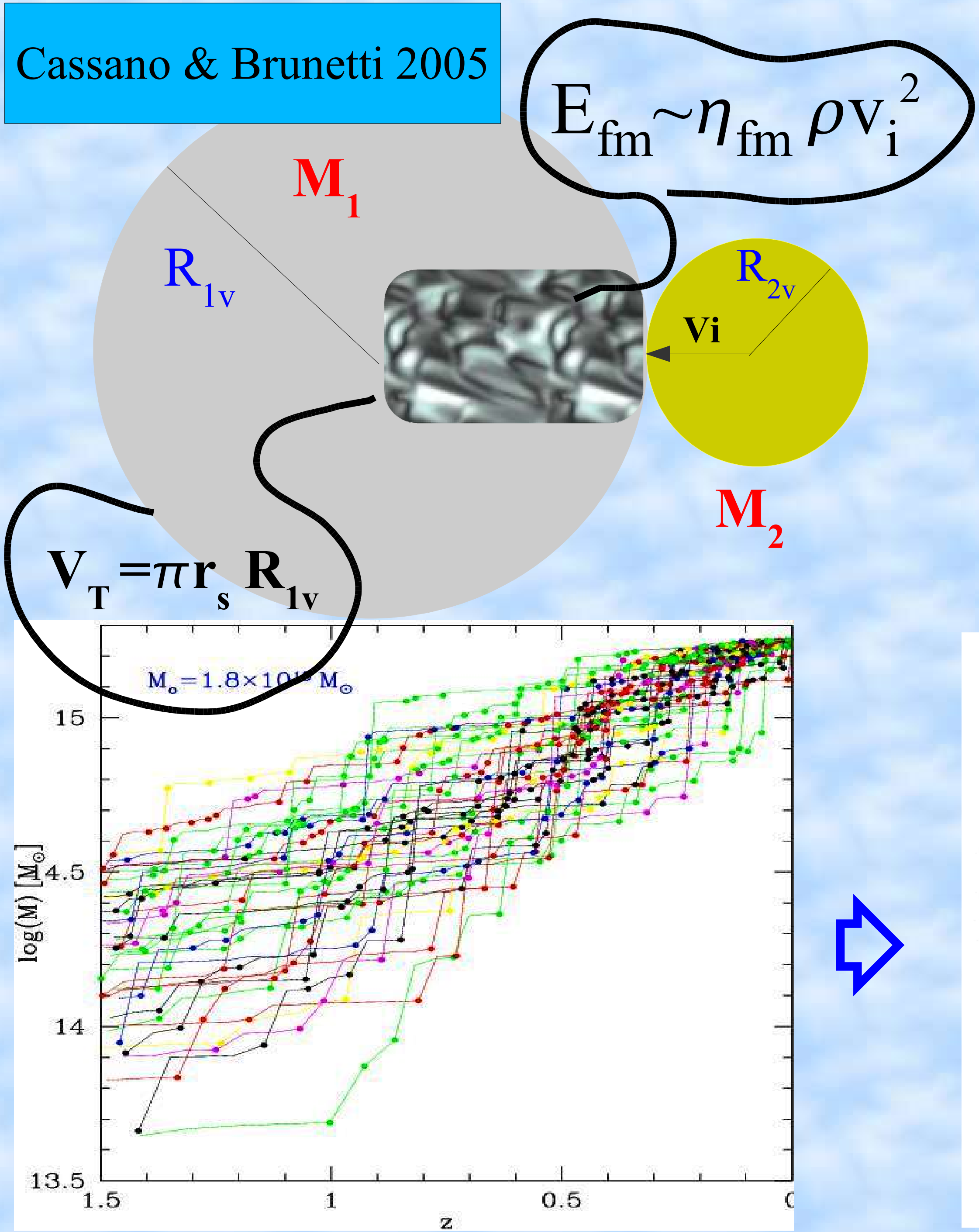
Turbulent modes (Fermi II)

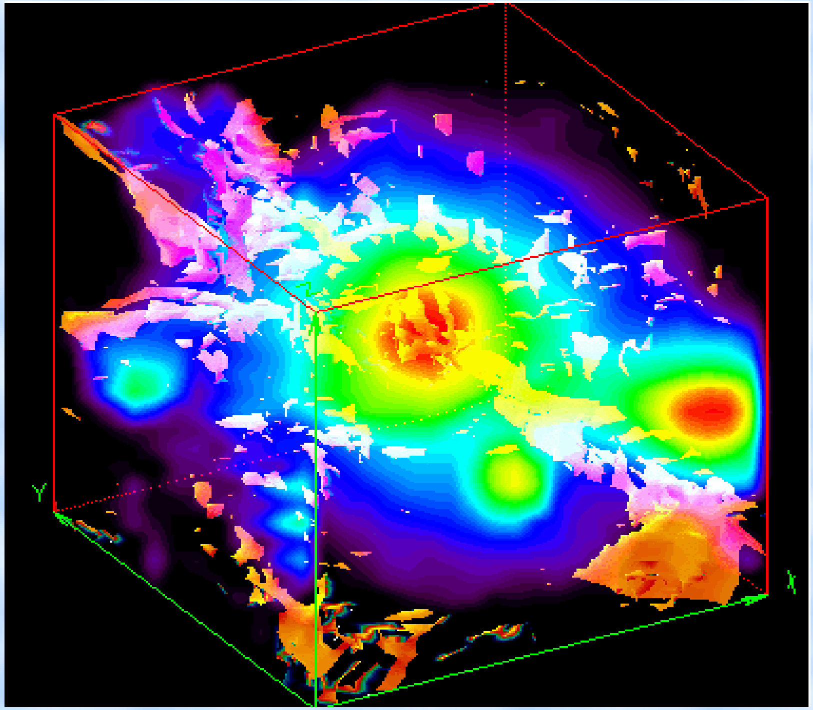
Alfven Modes

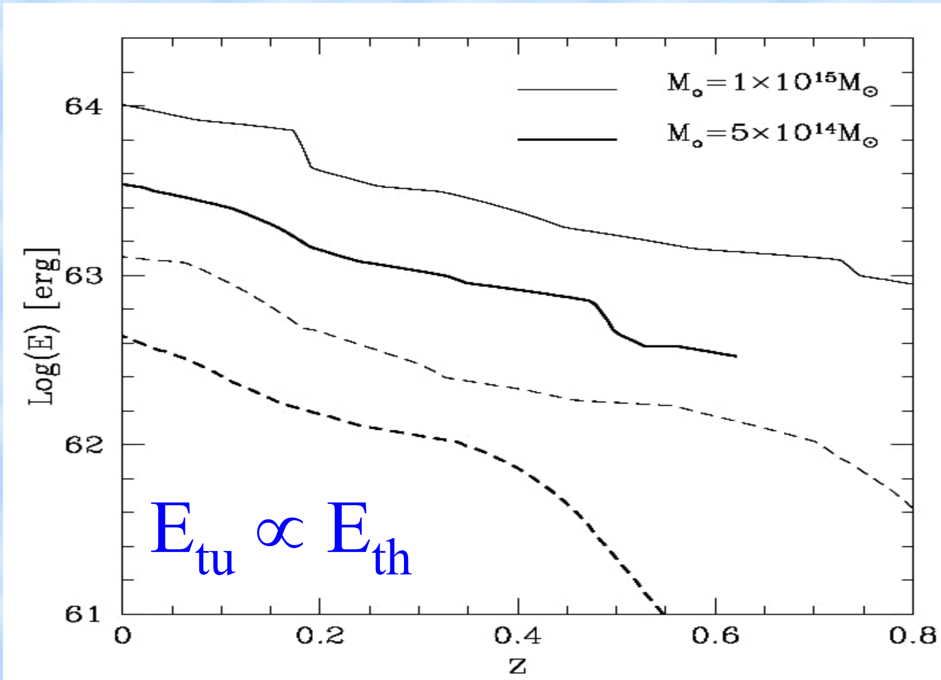
Magnetosonic Modes

Modes generated by plasma instabilities

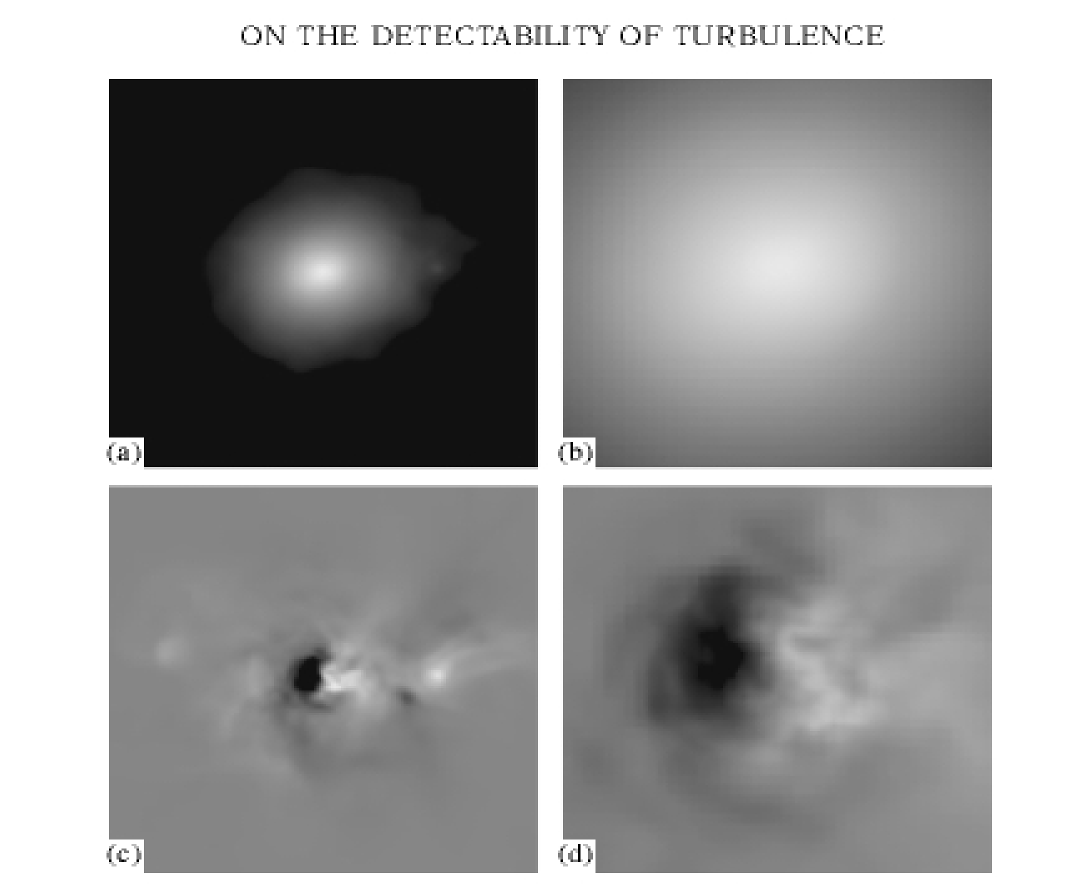
Additional ingredient: Turbulence





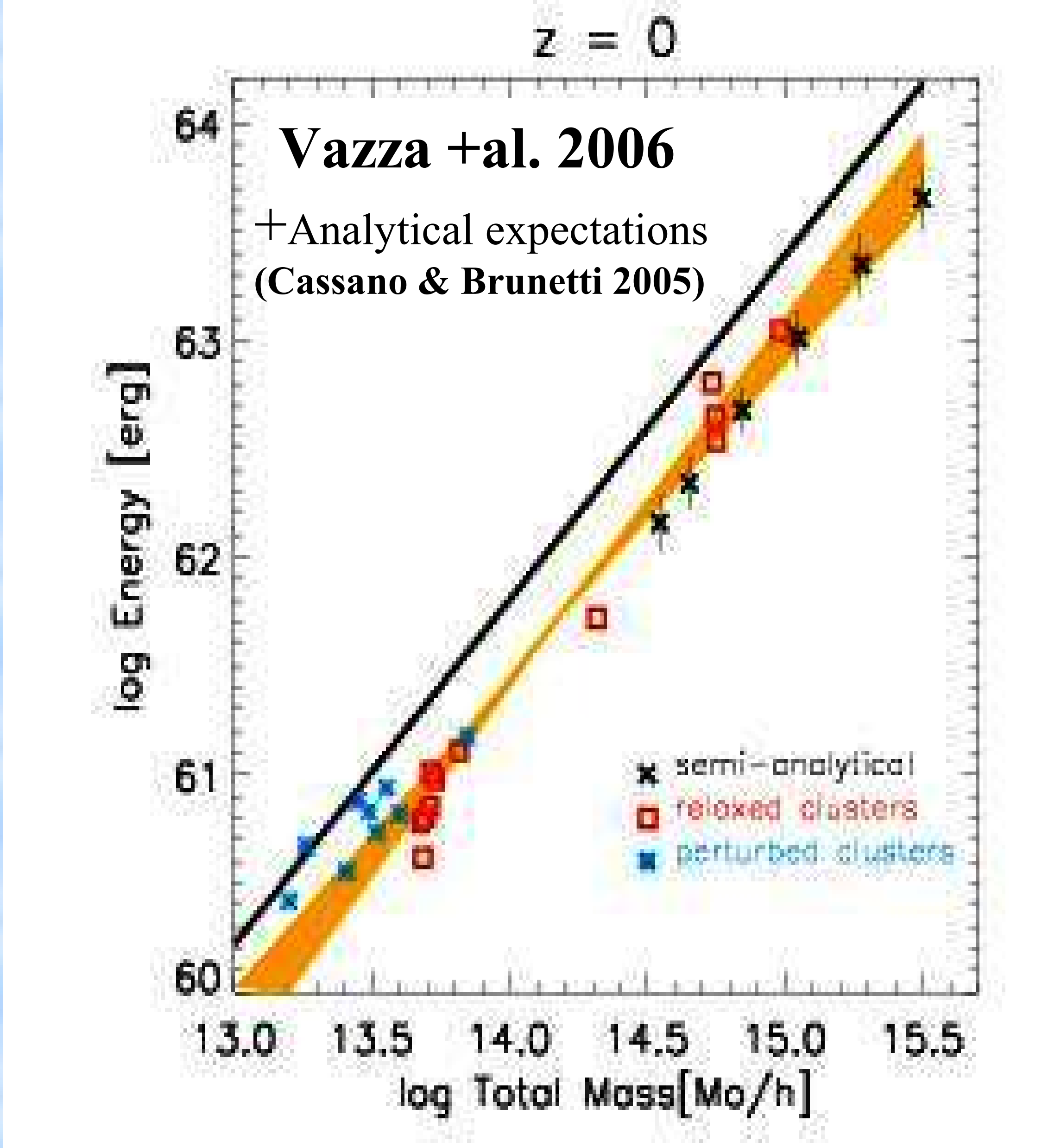


Mergers & Turbulence: simulations



Eulerian Simulations
(Sunyaev +al. 2003)

SZ: $\Delta T/T$



Magnetic Field in LSS

Cosmological injection and amplification:

Early Universe (phase transition, neutrino & photon decoupling,...)
(e.g., Grasso & Rubinstein 2001 for review)

Biermann Battery in cosmological shocks
(e.g., Kulsrud et al. 1997; Ryu et al. 1998)

B ~10^{-9}-10^{-12} G

Dwarf SB galaxies and AGN at z~4-6
(e.g., Kronberg et al. 1999)

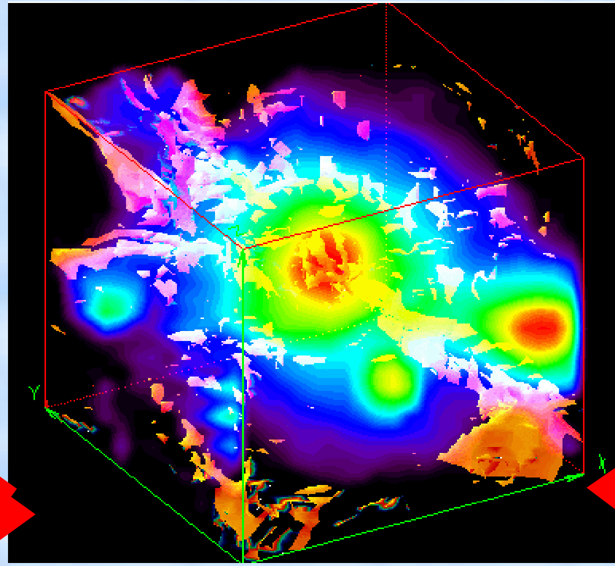
GW & AGN in Galaxy Clusters at z~1-3
(e.g., Voelk & Atoyan 2000; Furlanetto & Loeb 2001)

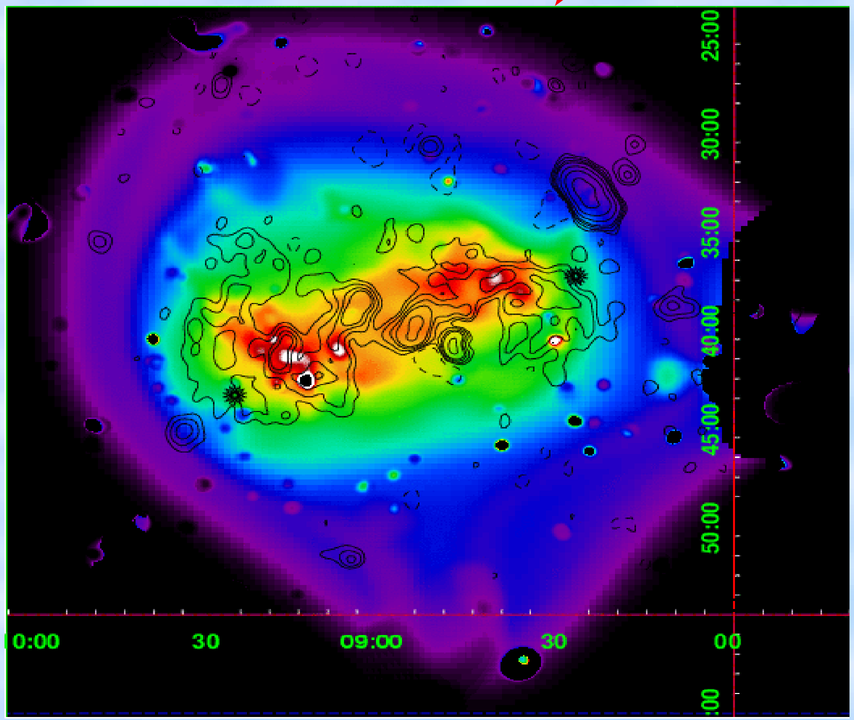
B ~10^{-8}-10^{-7} G

Magnetic field amplification by compression & shear-flows driven by accretion/mergers
(e.g., Dolag et al. 2002-2006; Bruggen et al. 2005; Subramanian et al. 2006)

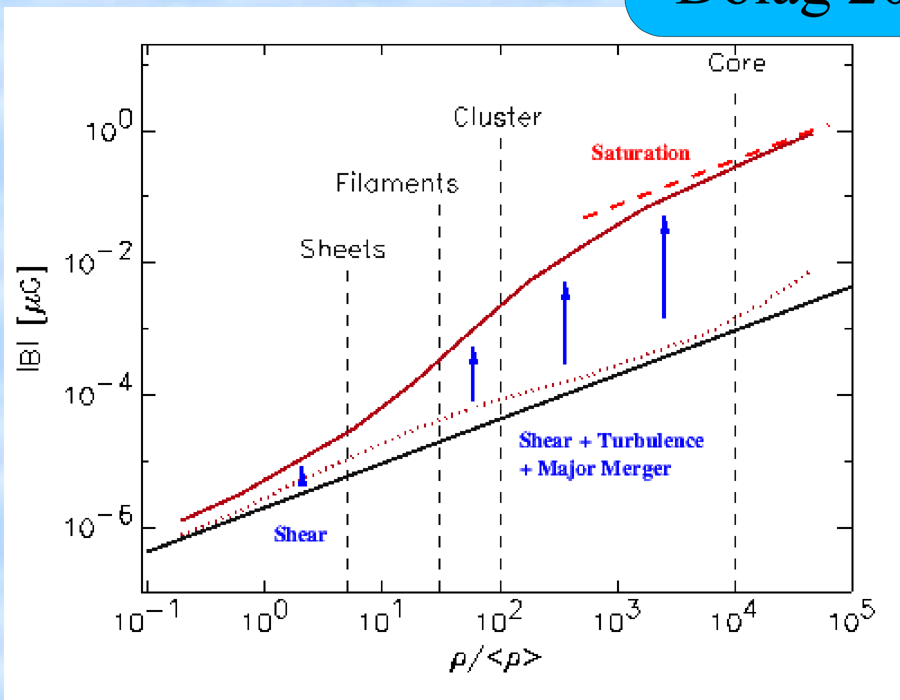
time

Mergers and non-thermal in LSS

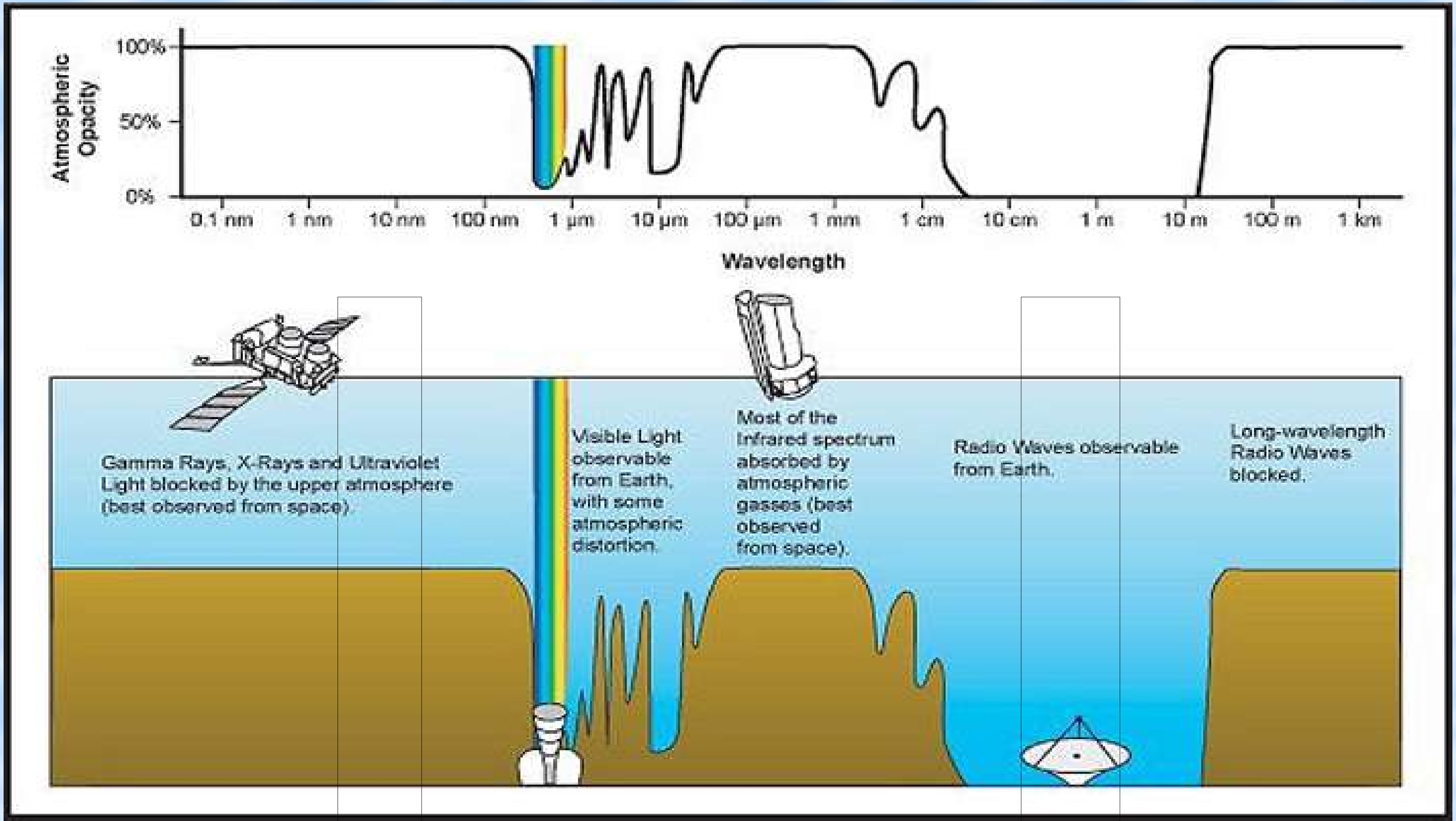




Dolag 2006



VERY low radio frequency : a new window



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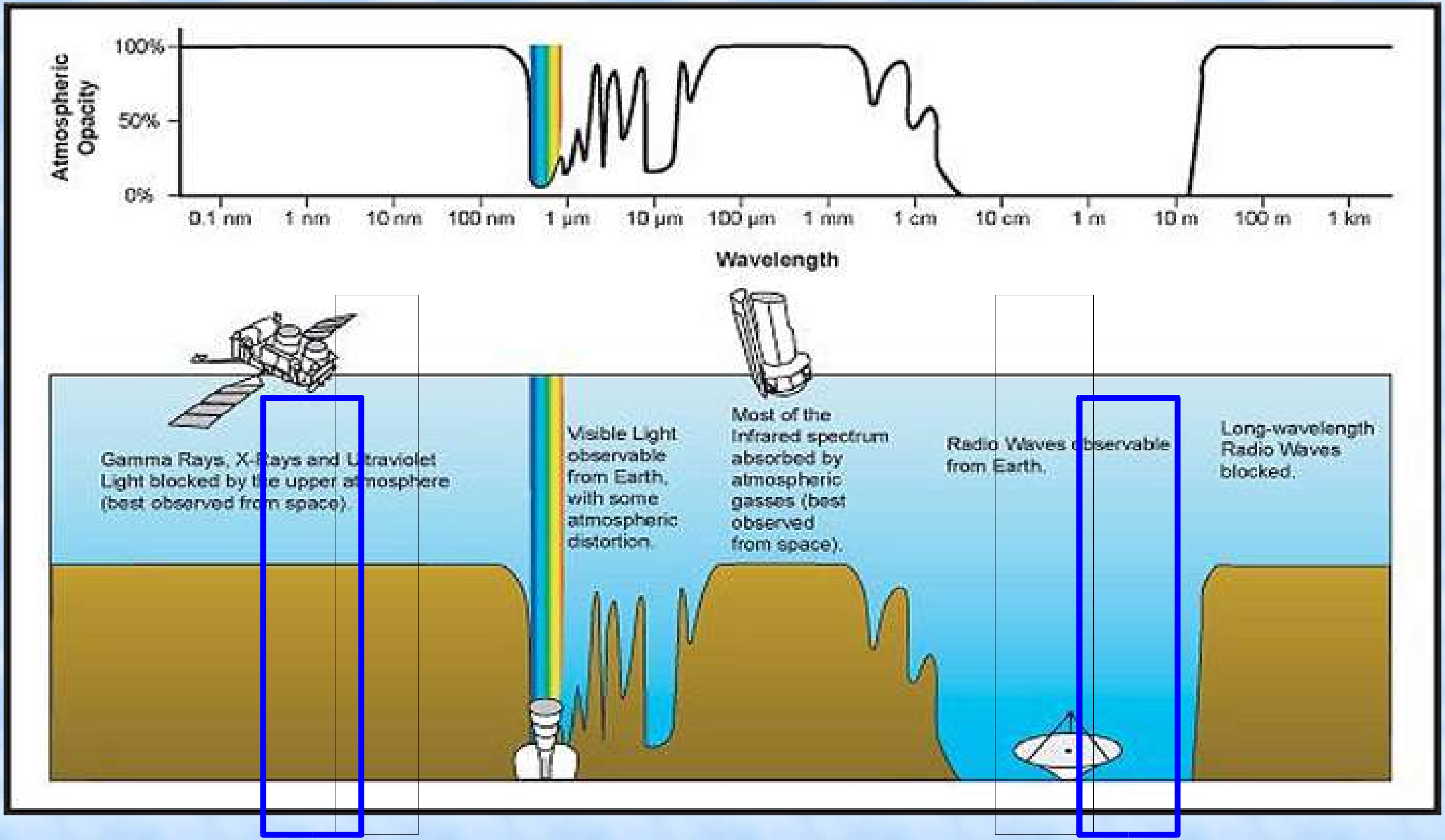

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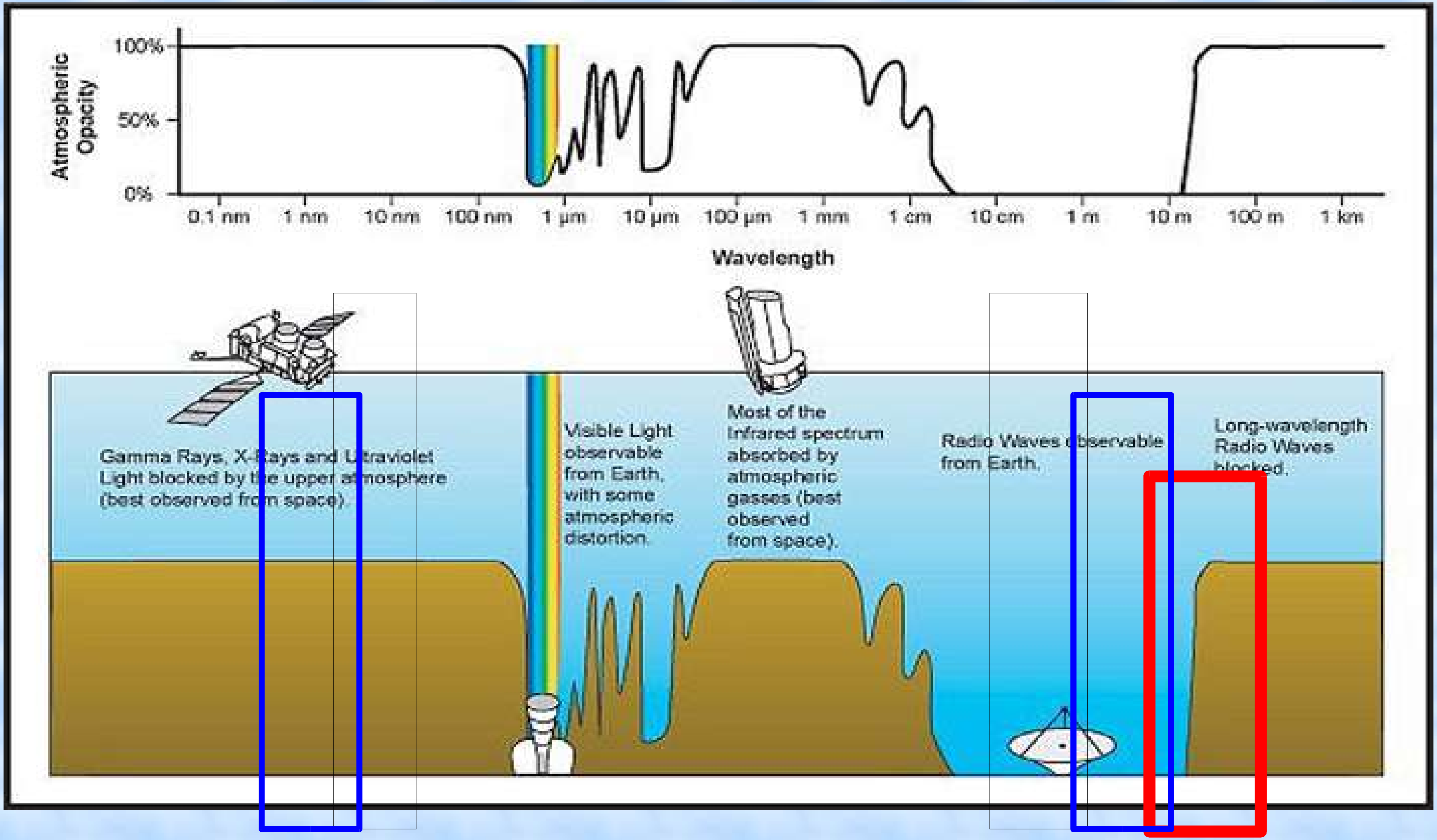

Why low frequency ??

- Catching the bulk of the non-thermal emission from LSS
- Testing the particle reacceleration model
- Understanding the amplification of magnetic fields
- Low freq. Synchrotron from LSS should be common

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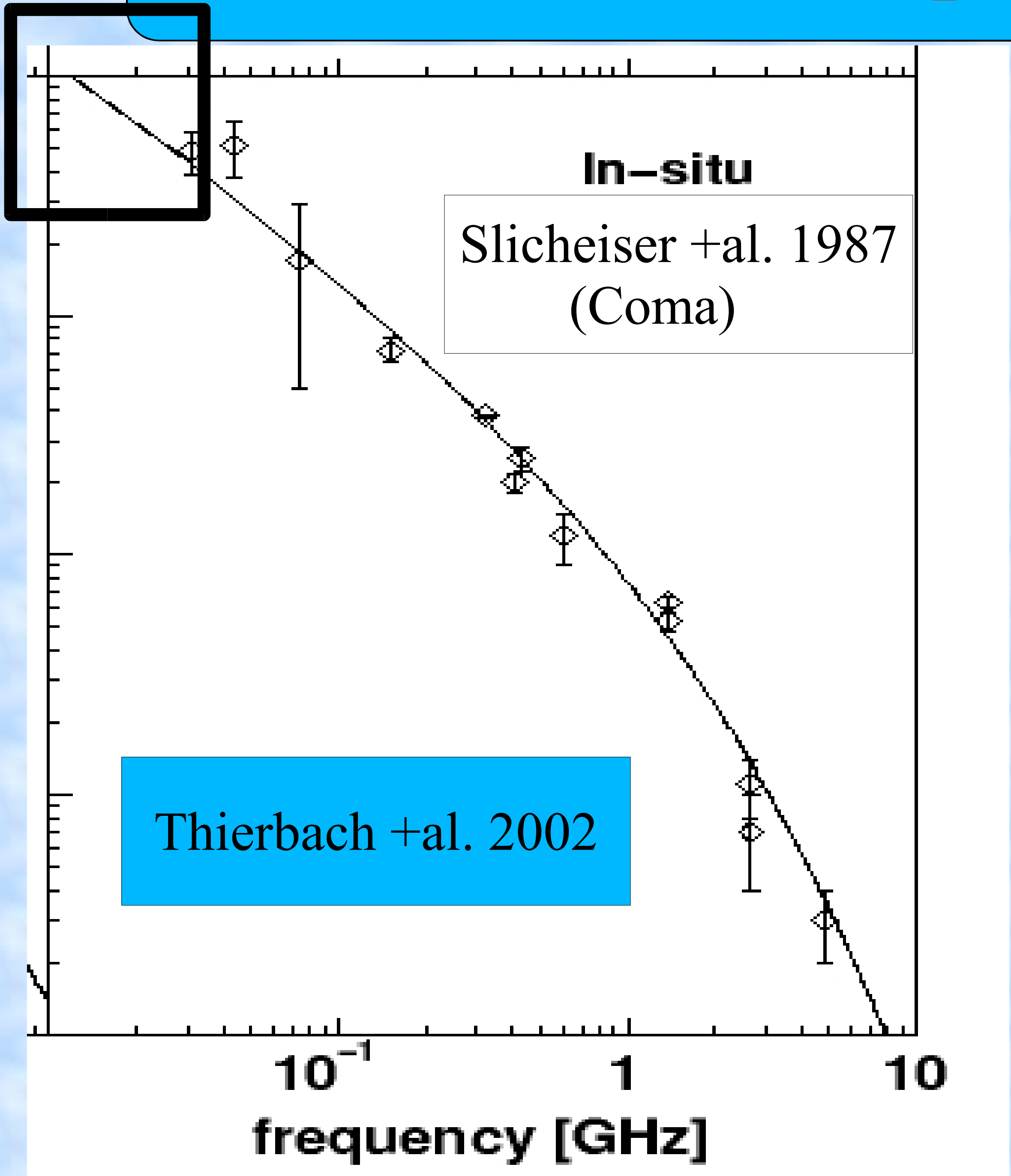
Observations: Spectral Cut-Off



The radio spectrum of the LSS synchrotron radiation is very steep ($\alpha \approx 1.2$; e.g. Feretti 2005) : the monochromatic flux increases by a factor of 200 from 1 Ghz to 10 Mhz

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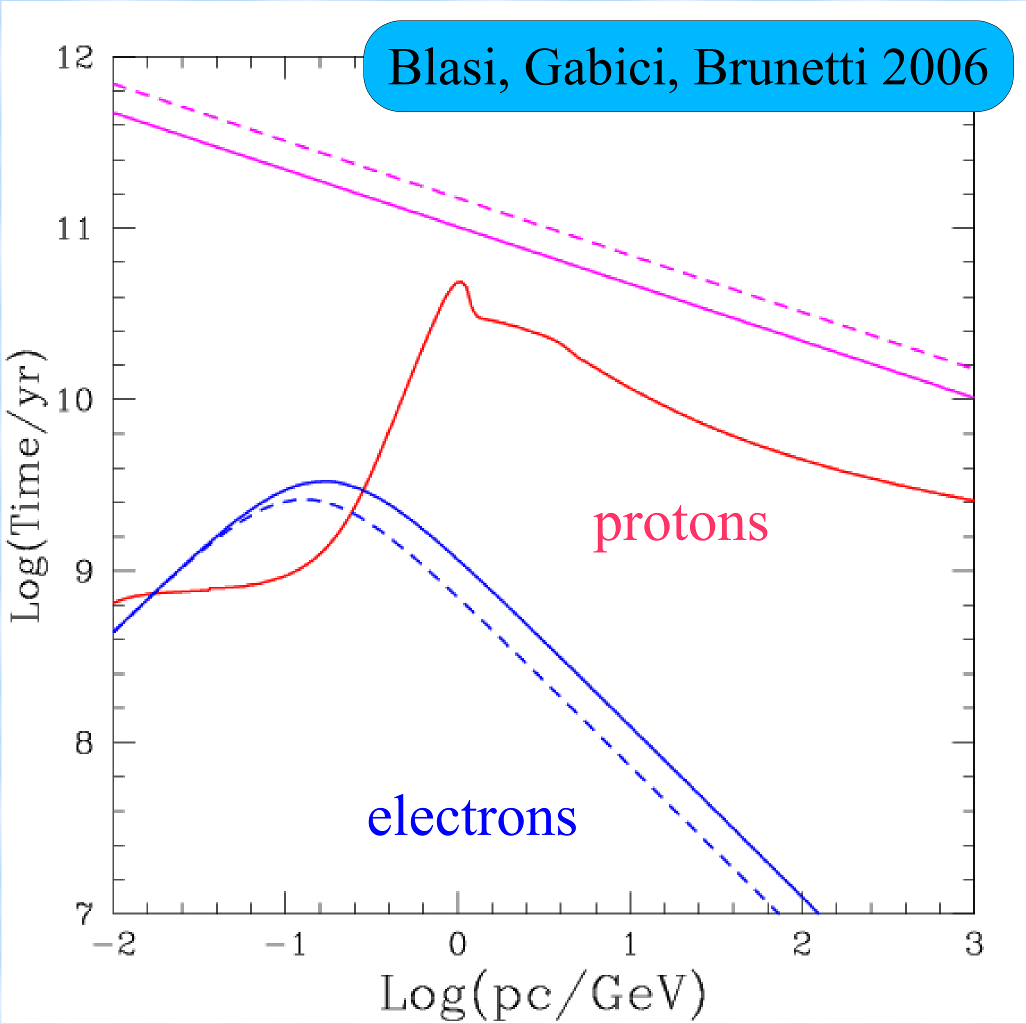
Low Frequency SYN emission should be common in the Universe

$$\gamma \propto (\nu/B)^{1/2}$$



$$\gamma \approx 10^4 \quad \nu \approx 1\text{GHz}$$

⇩

$$\gamma \approx 10^3 \quad \nu \approx 10\text{MHz}$$

LSS synchroton emission at very low frequencies should be much common than at higher frequencies: LSS may be efficiently imaged by low frequency radio observations

Why low frequency ??

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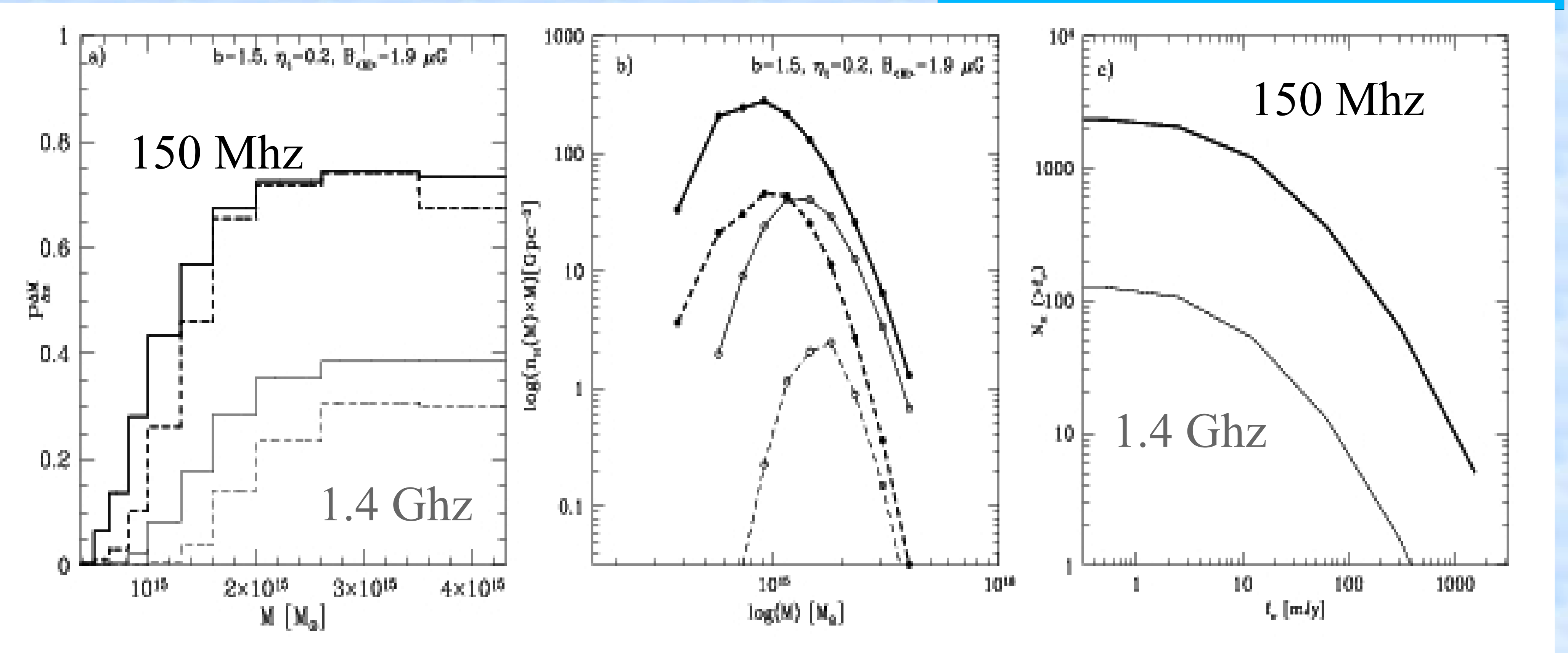
Model calculations at lower frequencies

Cassano, Brunetti, Setti 2006



The number of RH for a given Flux is expected to <u>increase with decreasing</u> observing <u>frequency</u>

Why low frequency ??

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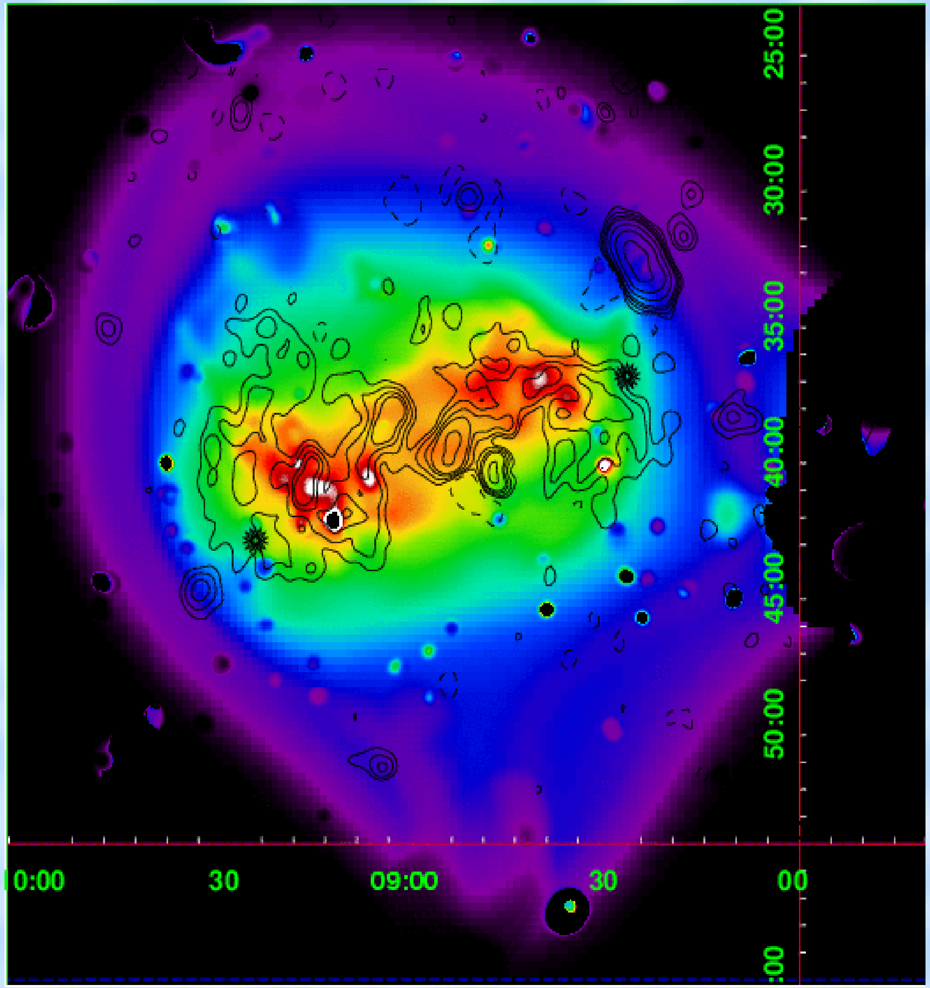
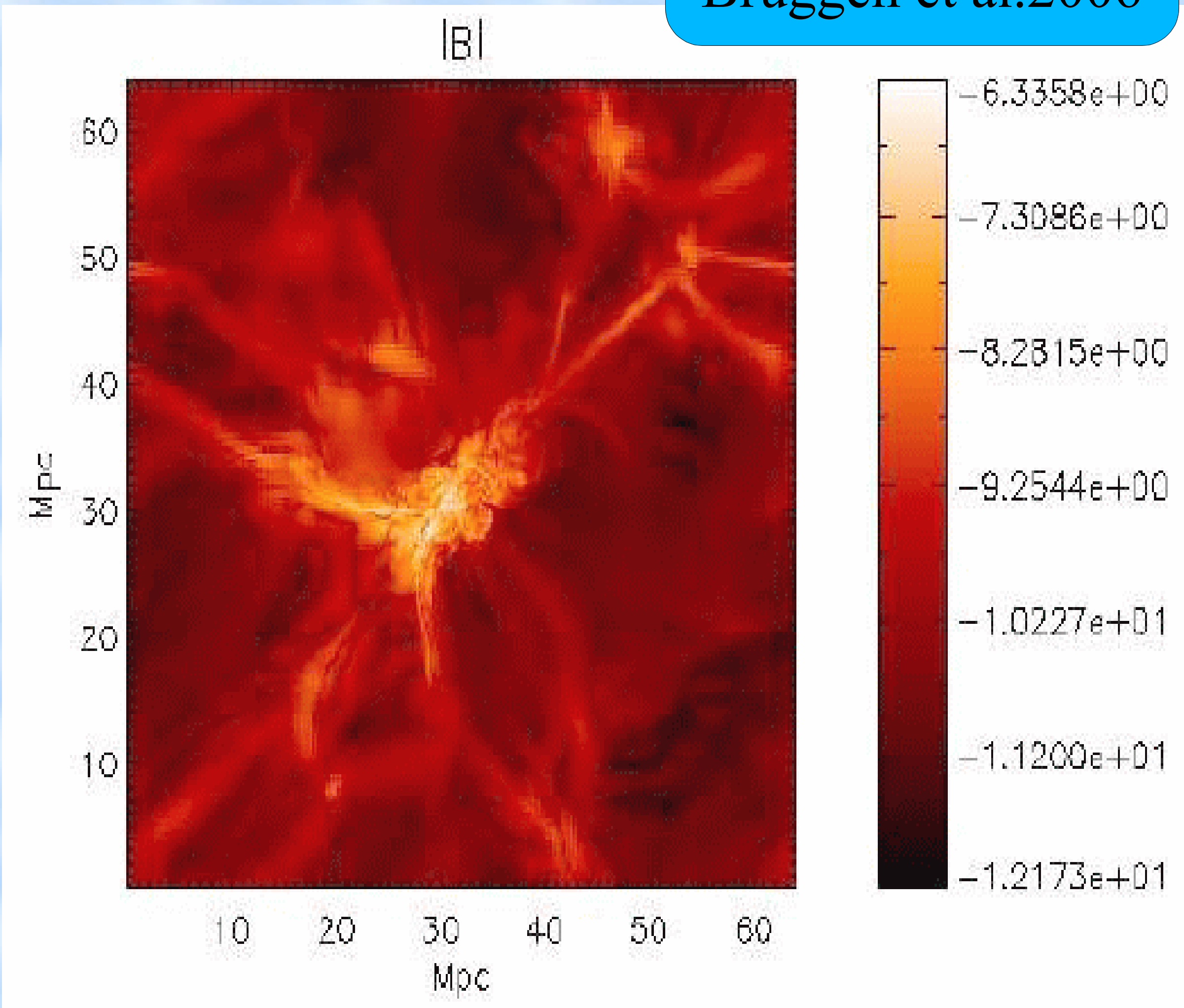
Magnetic Fields & CR in LSS



Bruggen et al.2006



$$\gamma \propto (\nu/B)^{1/2}$$

Basic "telescope" requirements :

Large effective Area $\approx$ 5.000-100.000 m^2

Frequency band $\approx$ 1-50 MHz

Confusion limits ! $\Theta \approx$ 10-100 arcsec

$$\Theta \approx \lambda/D$$

Dipole Array with max baseline $\approx$ 30-300 km

Conclusions

Observations at low frequency allow to go beyond the tip of the iceberg of the non-thermal phenomena in LSS:

Moon the unique possibility

turbulence + magnetic fields:
physics of the ICM (viscosity, transport processes, heating)

cluster mergers + nonthermal connection:
follow the process of dissipation of the bulk of the kinetic energy in the Universe

observation of low density regions in the Universe (e.g. filaments)

process of particle acceleration in LSS