

# *Gamma rays from Galaxy Clusters*

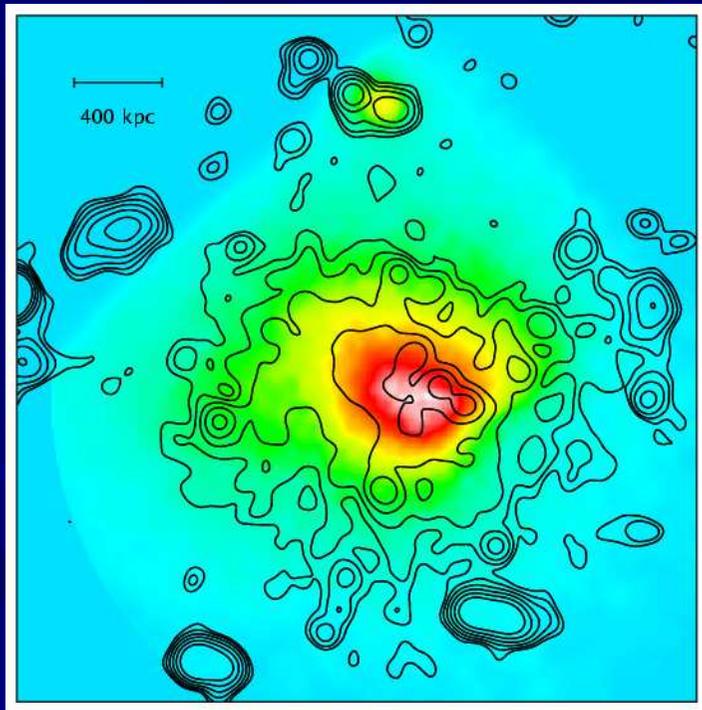
*Gianfranco Brunetti*

Institute of Radioastronomy –INAF, Bologna, ITALY

# *Gamma rays from Galaxy Clusters*

- ✦ *Fix our present understanding of PA in the IGM and give physical constraints ...*
- ✦ *Multifrequency modeling of non thermal emission from galaxy clusters*

# Our best friends to test current ideas of PA in galaxy clusters are Radio Halos



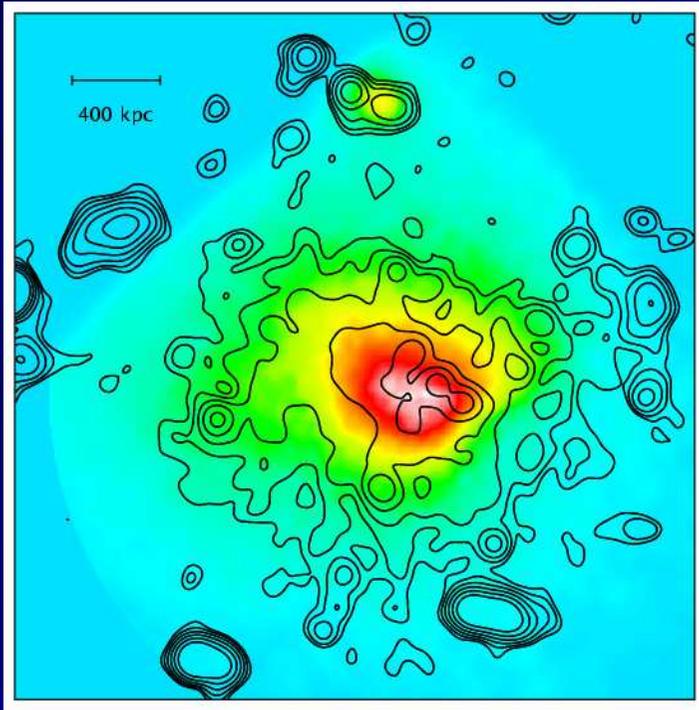
*Galaxy clusters are the largest gravitationally-bound objects in the present universe containing  $10^{15}$  solar Masses of DM, hot gas, galaxies ....but also NT components*

In situ acceleratio/injection of

**GeV electrons on Mpc scales**

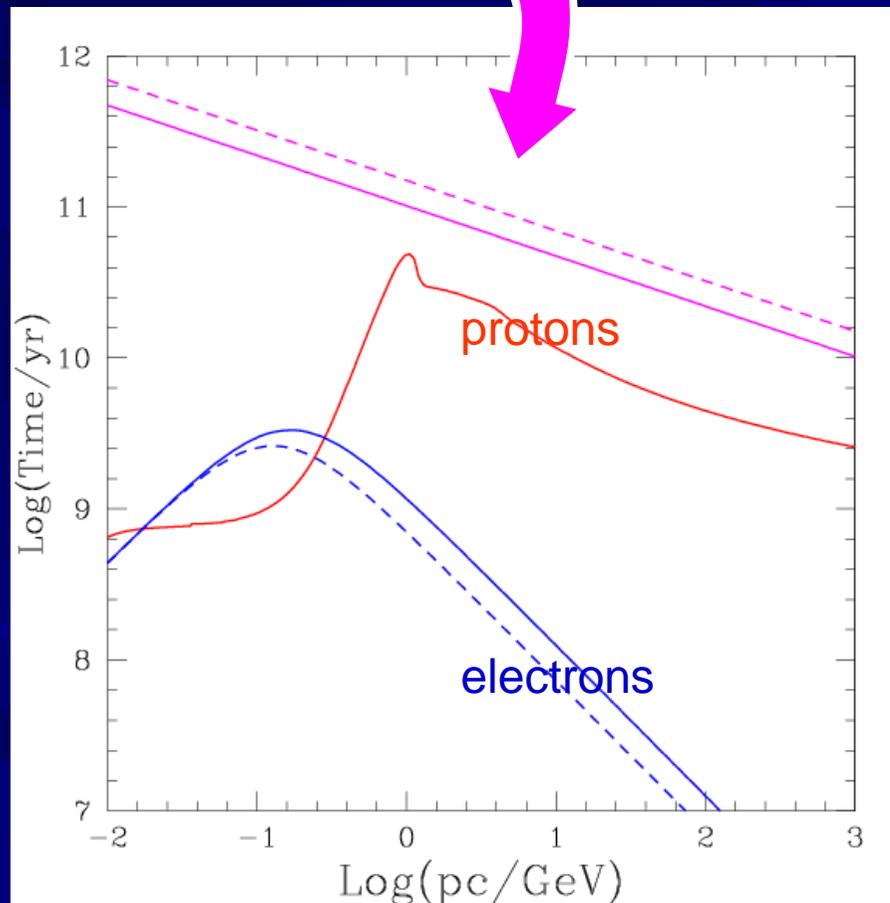
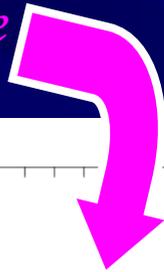
**$\mu$ G magnetic fields on Mpc scales**

*Secondary particles*, relativistic electrons continuously injected in the ICM by inelastic proton-proton collisions through productions and decay of charged pions (e.g., *Dennison 1980*, *Blasi & Colafrancesco 1999*, *Dolag & Ensslin 2000*, *Pfrommer+al.2008*)



# Motivation: Galaxy clusters are *reservoir* of CRp

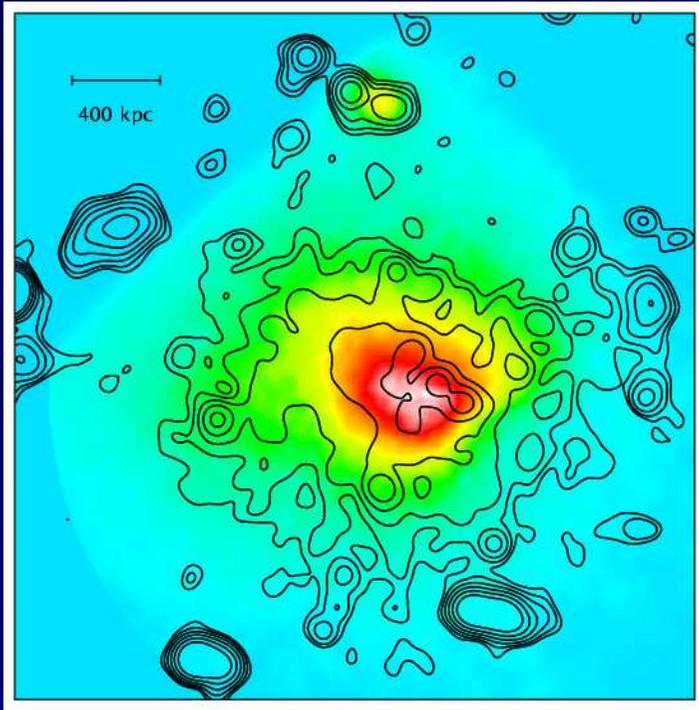
*Diffusion time*



- CR protons are long living particles and are confined (Voelk et al 1996; Berezhinsky, Blasi, Ptuskin 1997)
- CR electrons are short living particles and accumulated at  $\gamma \approx 100-300$  (e.g., Sarazin 1999)

Blasi, Gabici, Brunetti 2007

*Secondary particles*, relativistic electrons continuously injected in the ICM by inelastic proton-proton collisions through productions and decay of charged pions (e.g., *Dennison 1980*, *Blasi & Colafrancesco 1999*, *Dolag & Ensslin 2000*, *Pfrommer+al.2008*)



The **drawback** of *secondary models* is that diffuse radio emission should be common in galaxy clusters..... regardless of their “**present**” dynamical properties

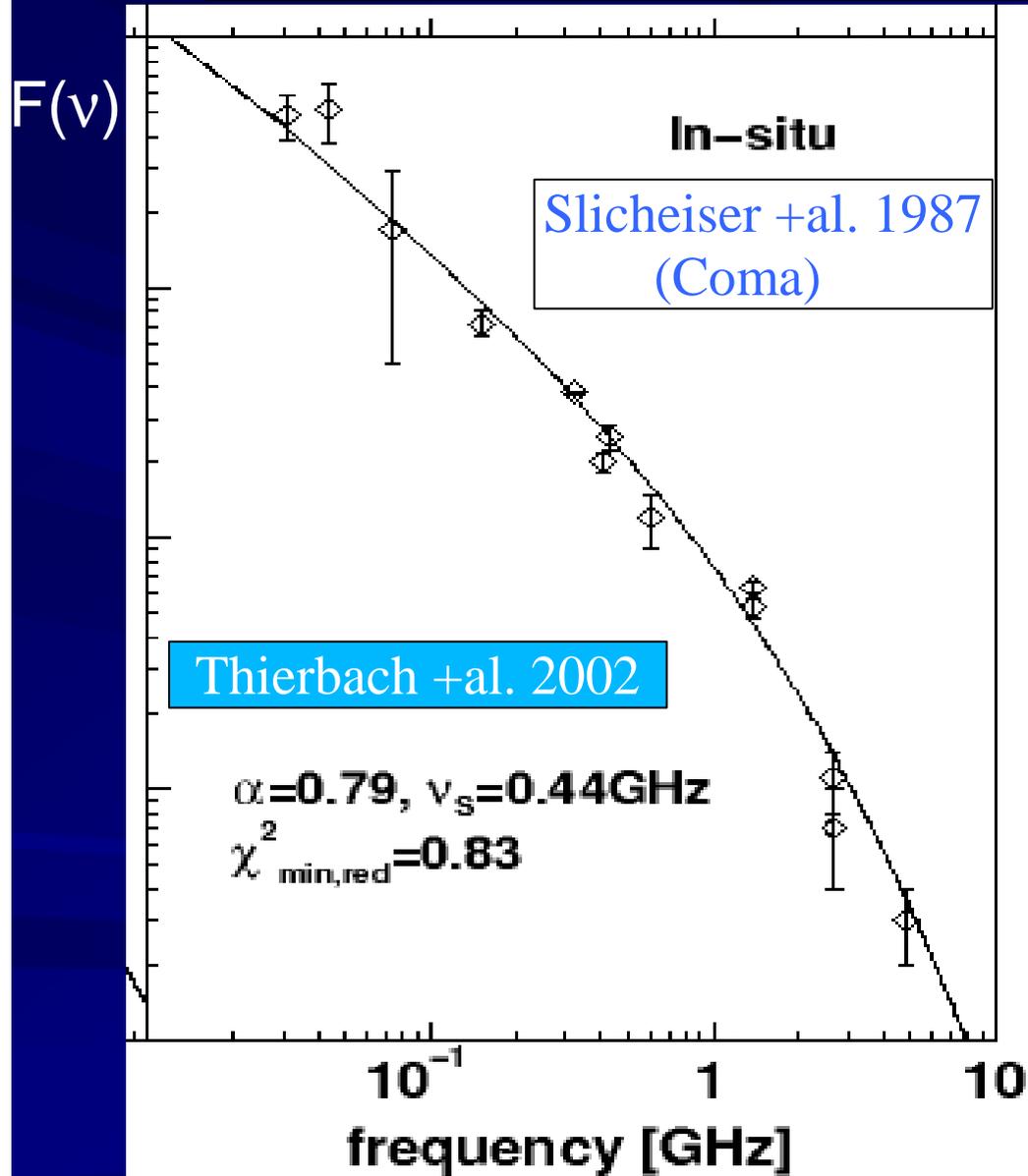
However **only 10-20%** of massive galaxy clusters have Radio Halos (*Giovannini+ al.1999*, *Cassano + al. 2008*)

Radio Halos are detected **only** in galaxy clusters with recent/ongoing merging activity (*Buote 2001*, *Venturi + al 2007,08*)

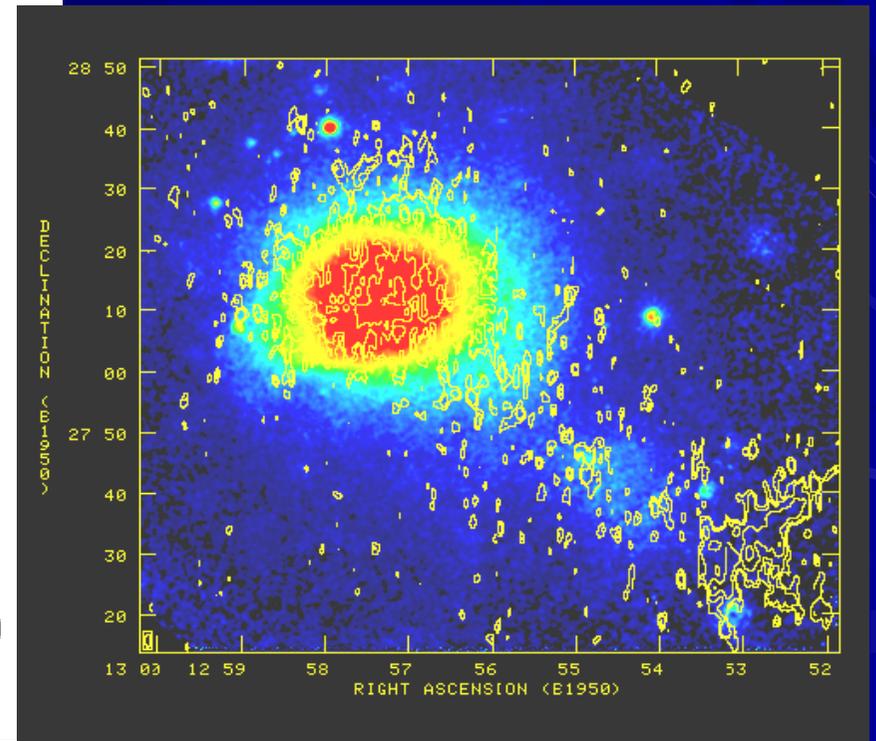
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*In situ re-acceleration* by MHD turbulence developed in the cluster volume during merger events  
(e.g., *Brunetti et al. 2001, 2004*; *Petrosian 2001*; *Ohno et al. 2002*; *Fujita et al. 2003*; *Brunetti & Blasi 2005*; *Brunetti & Lazarian 2007*; *Petrosian & Bykov 2008*)

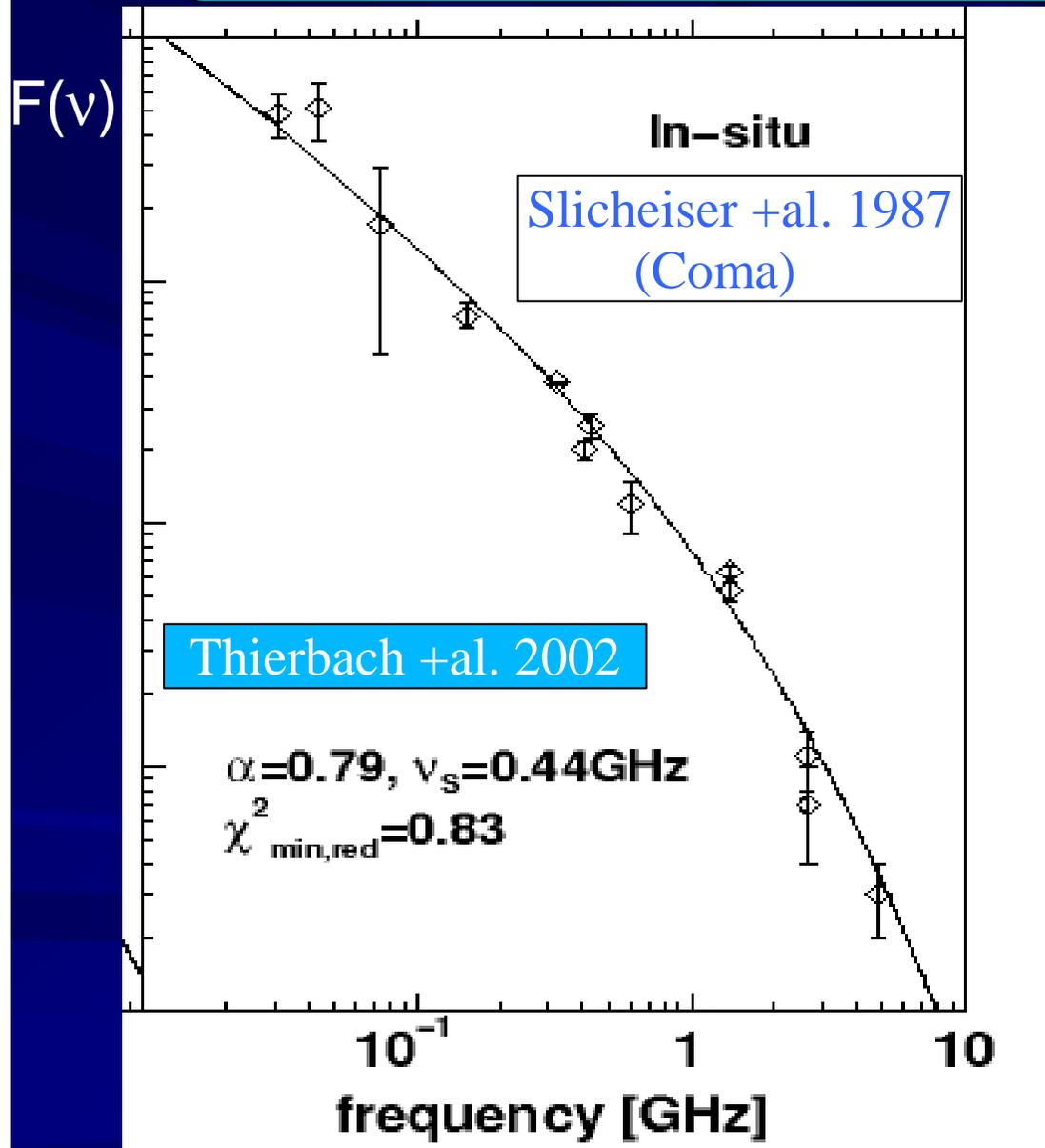
# Observations: Spectral Cut-Off



Evidence of break in the synchrotron spectrum

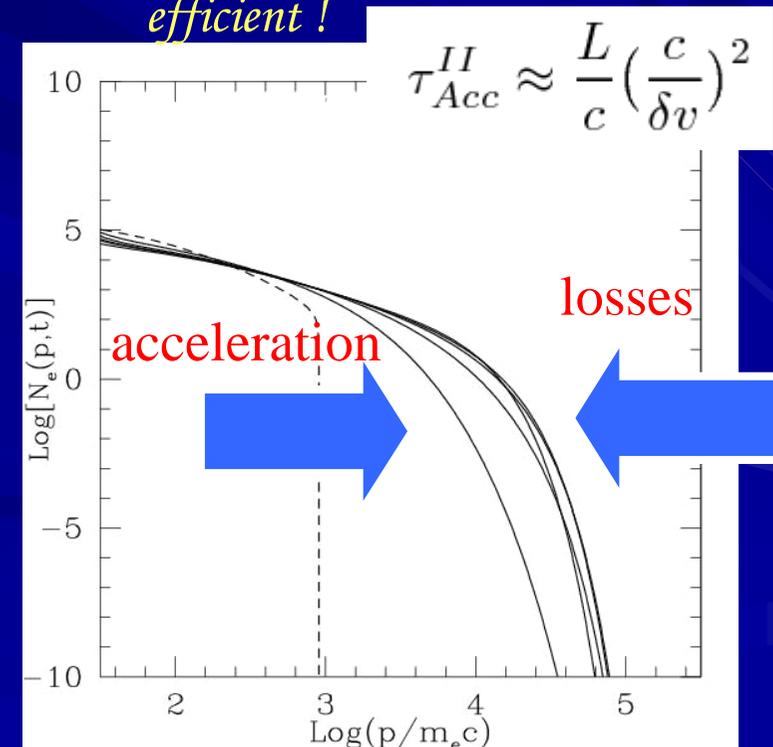


# Observations: Spectral Cut-Off



Evidence of break in the spectrum of the emitting electrons at energies of few GeV

*Acceleration mechanism is not efficient!*



# Evidence for turbulent acceleration

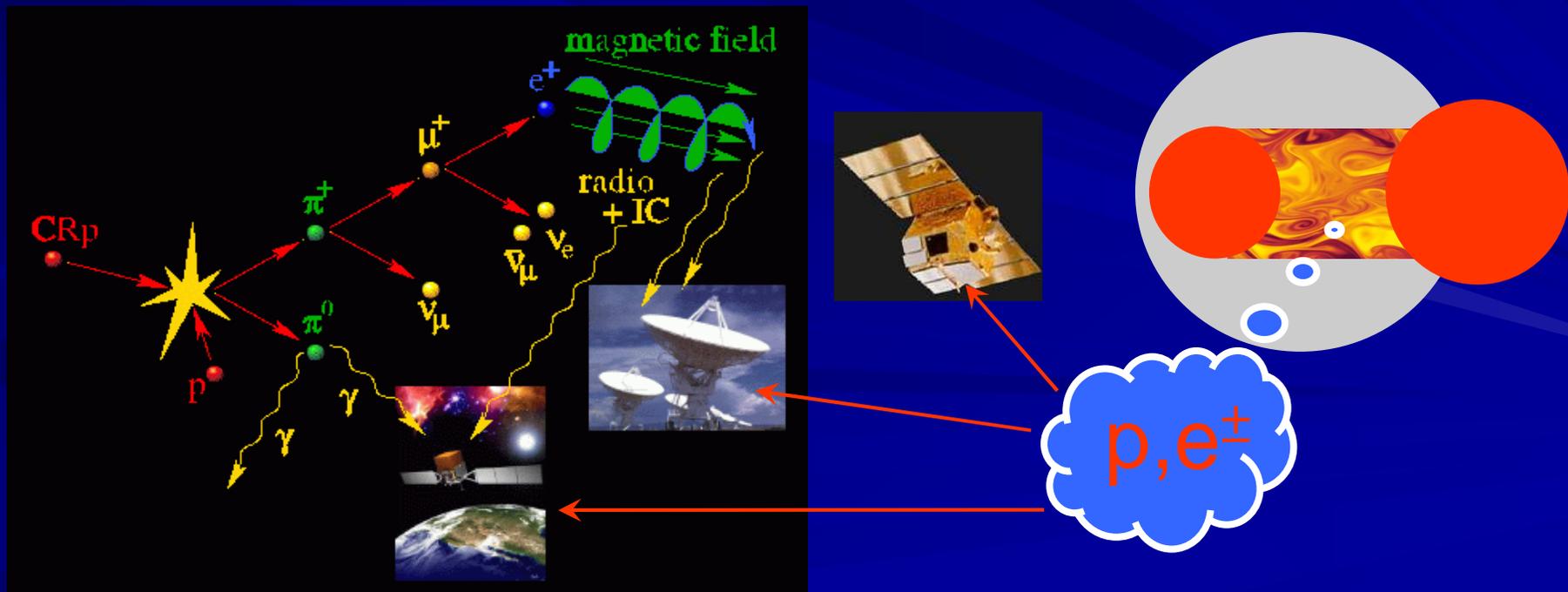
# Aim of the work

Use **Protons** and **Turbulence** to reproduce at the same time the most important constraints from radio observations and to calculate expectations at High energy

Protons are long living and confined

Turbulence seems to play a role

Re-acceleration (turbulence) + secondaries



# Alfvenic: results

(physics in : Brunetti +al. 2004 , Brunetti & Blasi 2005)

$n_{\text{th}}, T, B_0, N_p(p,0)$

$I(k)$

# Alfvenic: results

$n_{th}, T, B_0, N_p(p,0)$

$I(k)$



$p + p \rightarrow \pi^0 + \pi^+ + \pi^- + \text{anything}$

$\pi^0 \rightarrow \gamma\gamma$

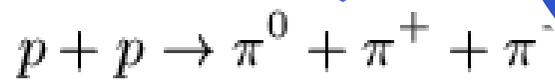
$\pi^\pm \rightarrow \mu + \nu_\mu \quad \mu^\pm \rightarrow e^\pm \nu_\mu \nu_e.$

# Alfvenic: results

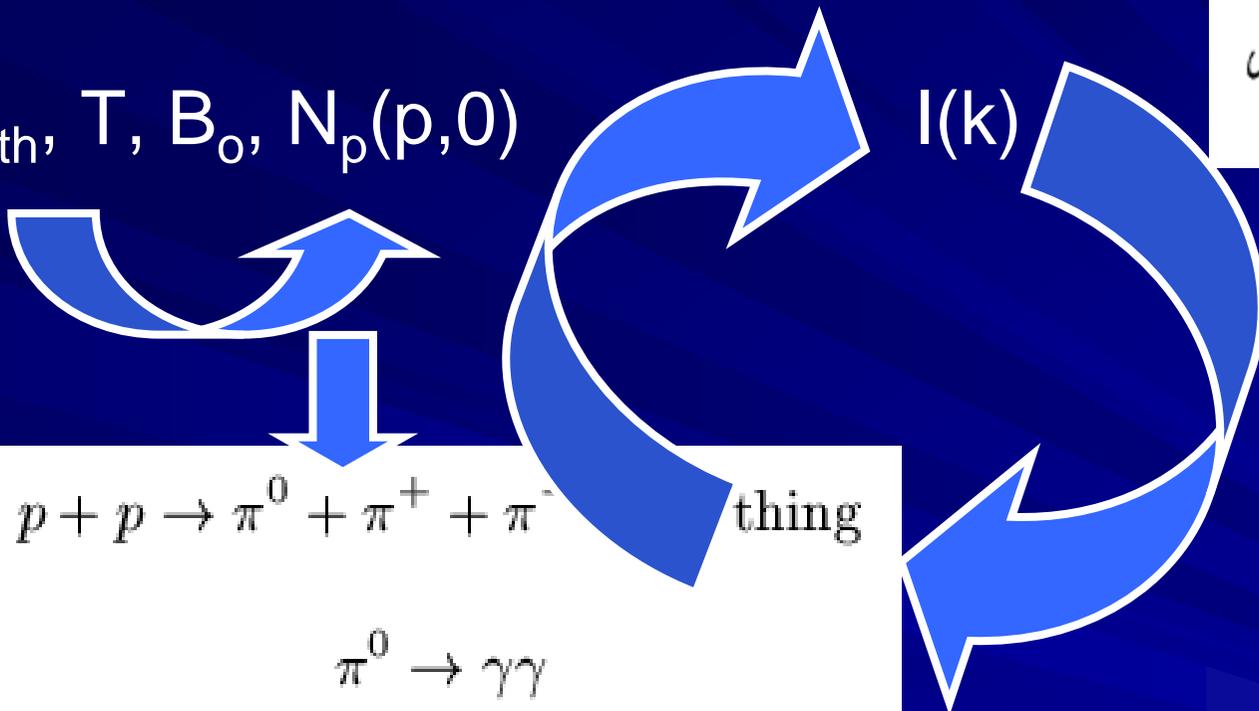
$n_{th}, T, B_o, N_p(p,0)$

$I(k)$

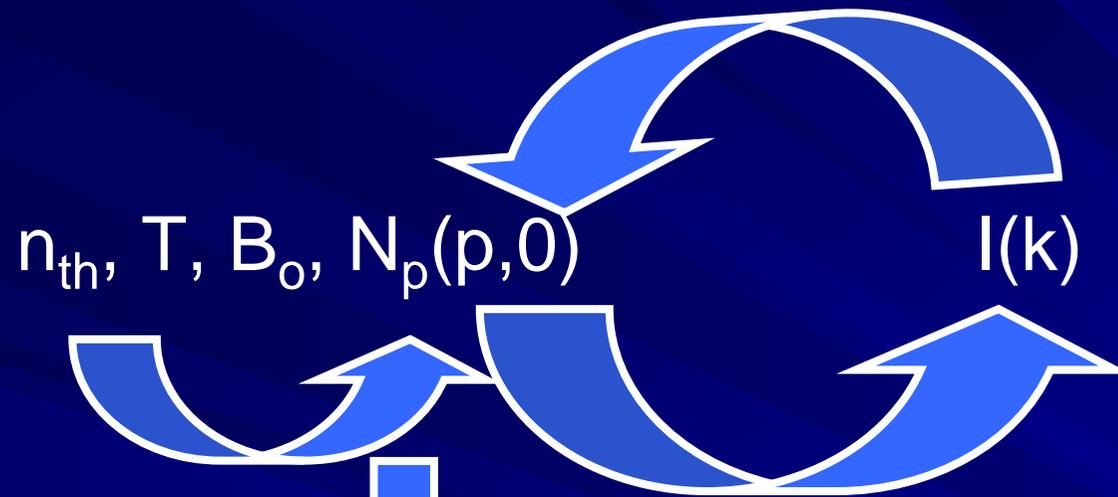
$$\omega - k_{\parallel} v_{\parallel} - n \frac{\Omega_o}{\gamma} = 0$$



thing



# Alfvenic: results



$$\omega - k_{\parallel} v_{\parallel} - n \frac{\Omega_o}{\gamma} = 0$$

$$p + p \rightarrow \pi^0 + \pi^+ + \pi^- + \text{anything}$$

$$\pi^0 \rightarrow \gamma\gamma$$

$$\pi^{\pm} \rightarrow \mu + \nu_{\mu} \quad \mu^{\pm} \rightarrow e^{\pm} \nu_{\mu} \nu_e.$$

# Alfvenic: results

$n_{th}, T, B_o, N_p(p,0)$

$I(k)$

$$\omega - k_{\parallel} v_{\parallel} - n \frac{\Omega_o}{\gamma} = 0$$

$p + p \rightarrow \pi^0 + \pi^+ + \pi^-$  thing

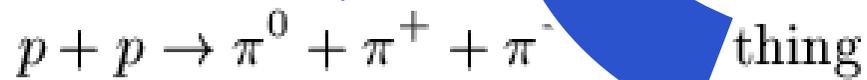
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$n_{th}, T, B_0, N_p(p,0)$

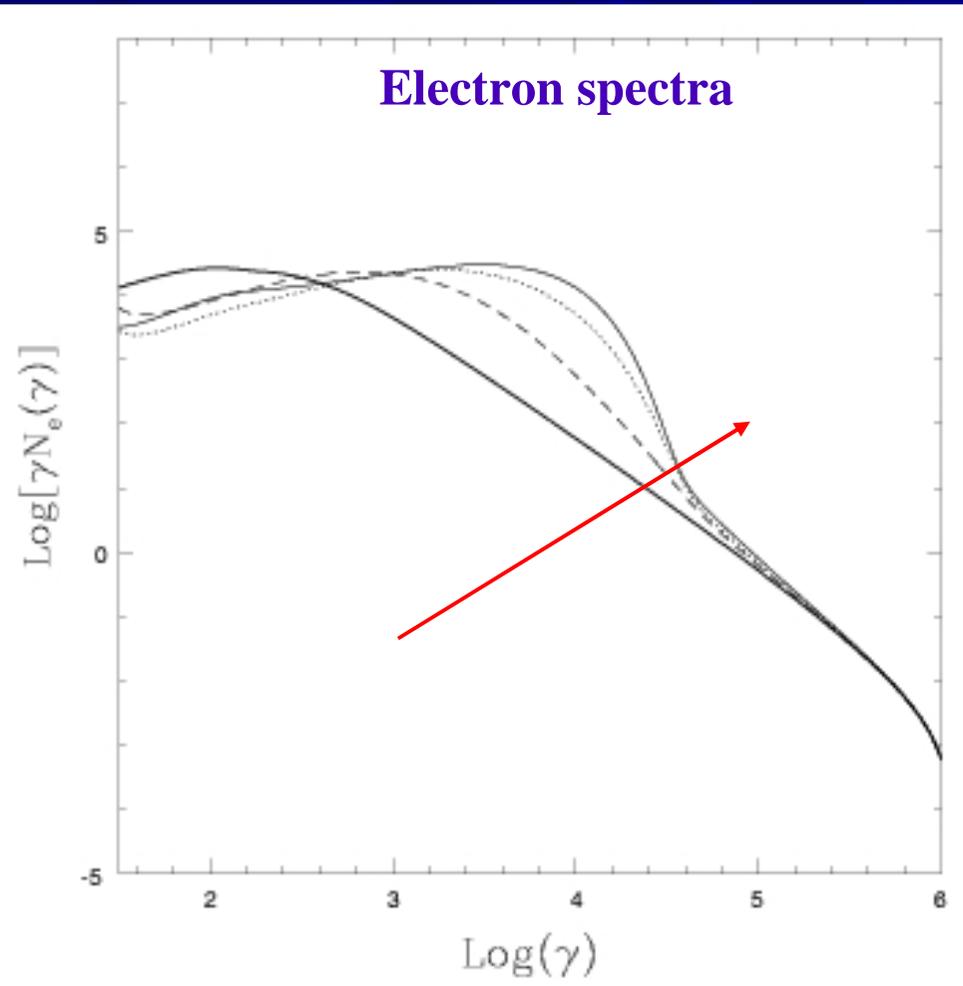
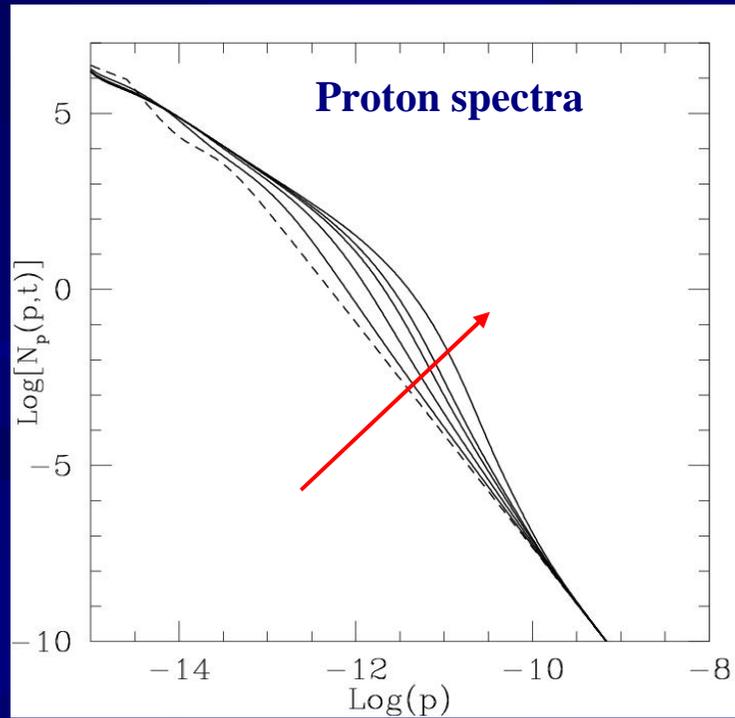
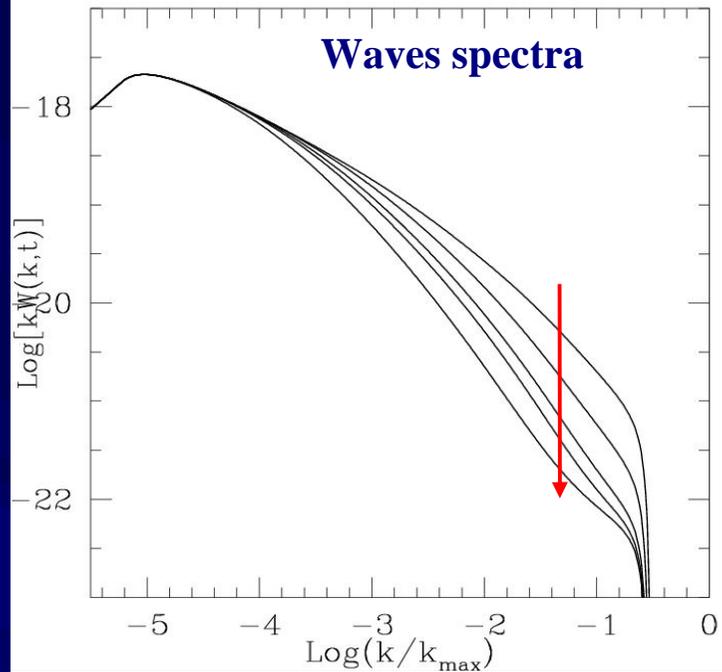
$I(k)$



$N_p(p,t), N_{e^\pm}(p,t), W(k,t), Q_{e^\pm}(p,t), Q_\pi(p,t)$

# Full Alfven-Wave--Particle Coupling

(Brunetti +al. 2004; Brunetti & Blasi 2005)

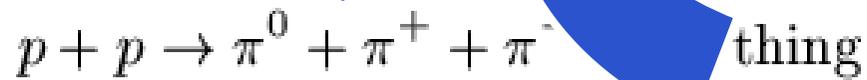


Waves + Protons + Secondaries

# Alfvenic: results

$n_{th}, T, B_0, N_p(p,0)$

$I(k)$



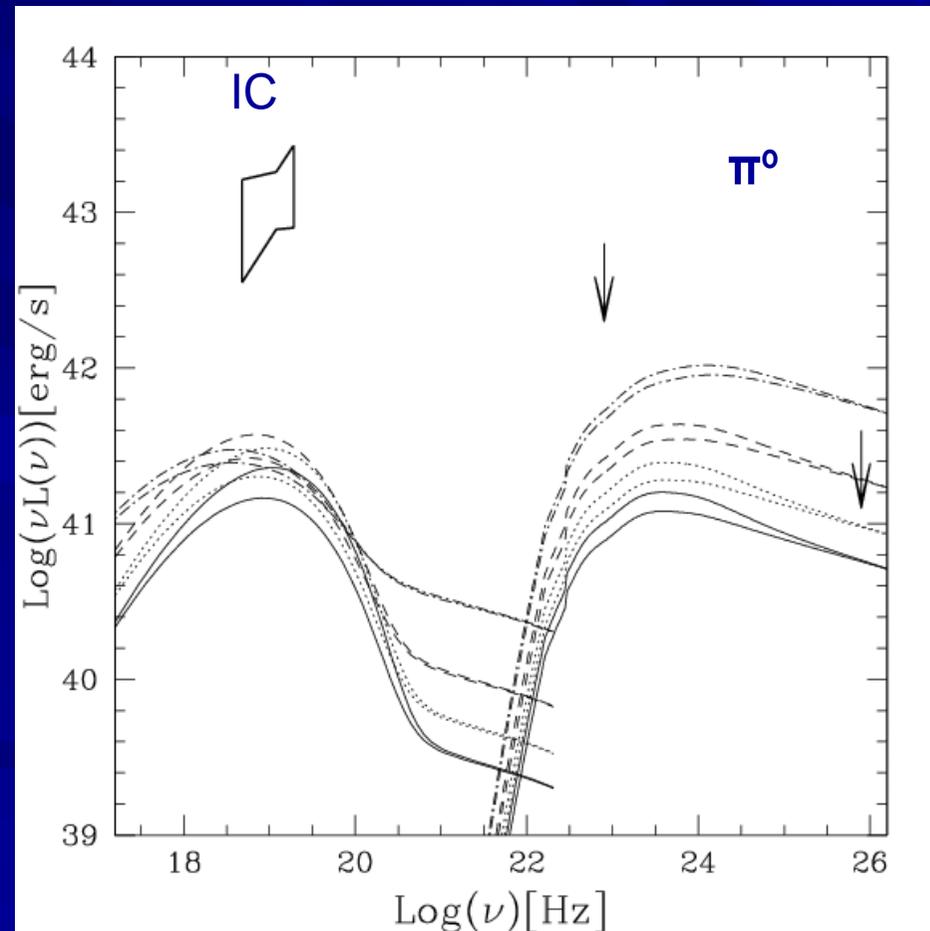
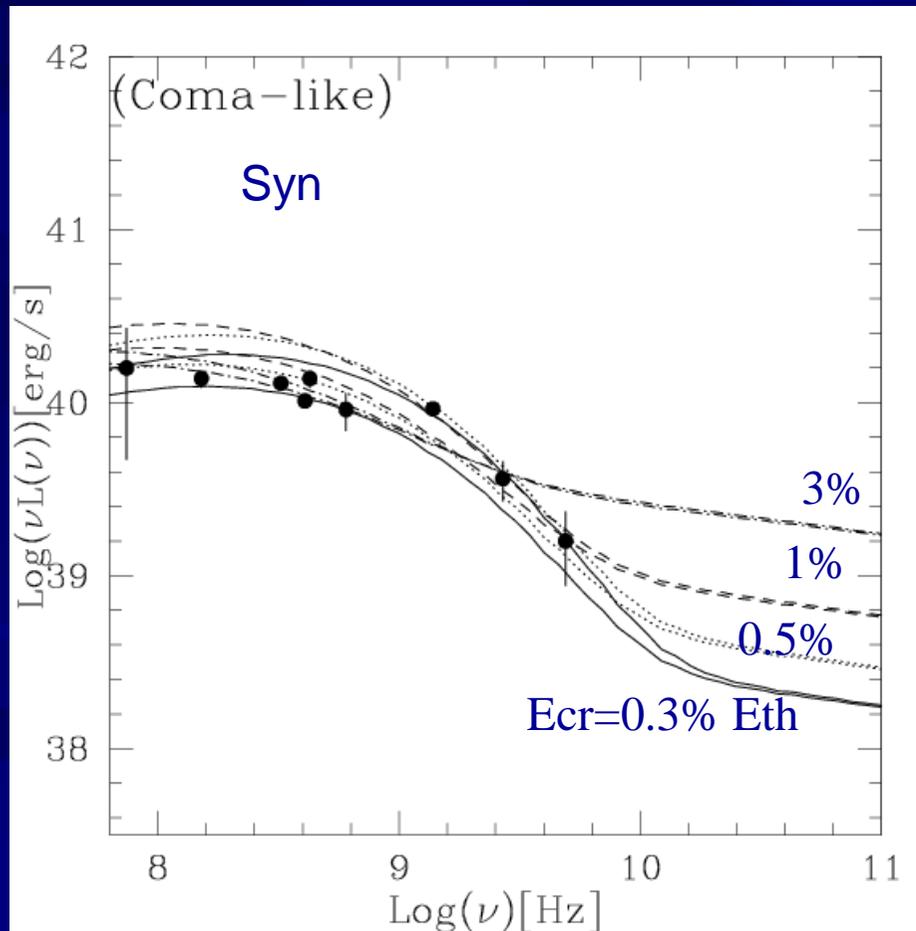
SYN  
IC  
Gamma

$N_p(p,t), N_{e^\pm}(p,t), W(k,t), Q_{e^\pm}(p,t), Q_\pi(p,t)$

# Alfvenic: results

Brunetti, et al. in prep

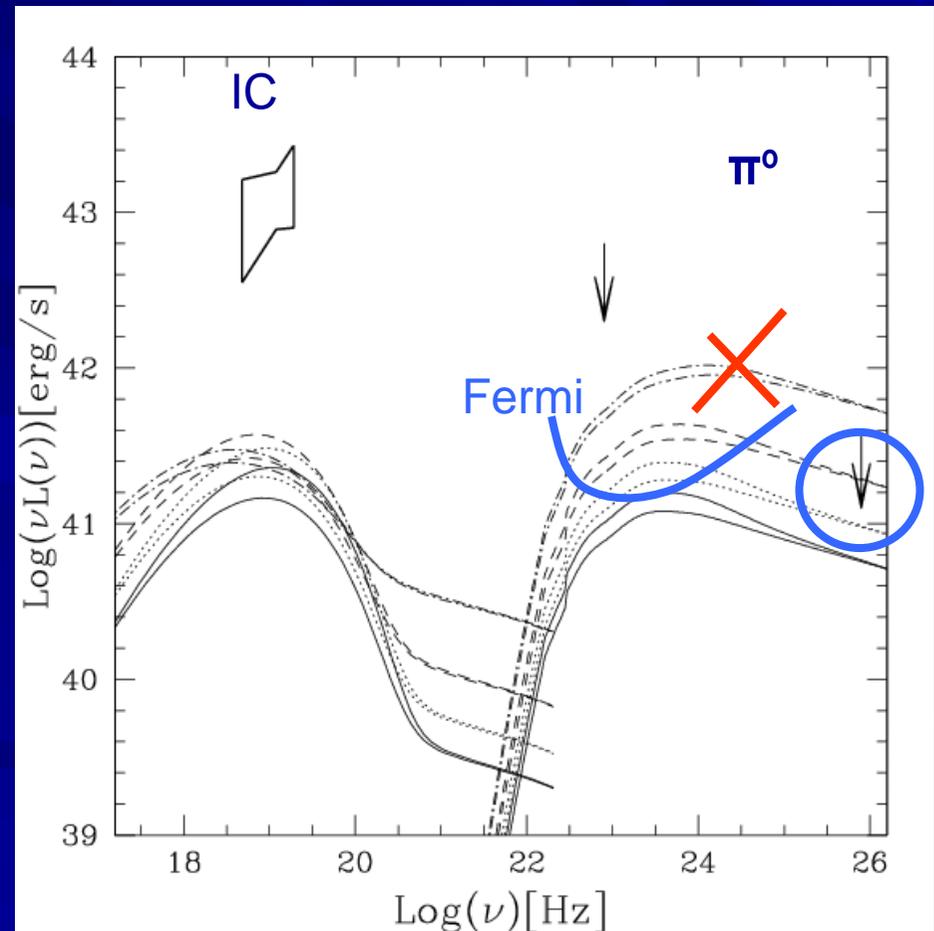
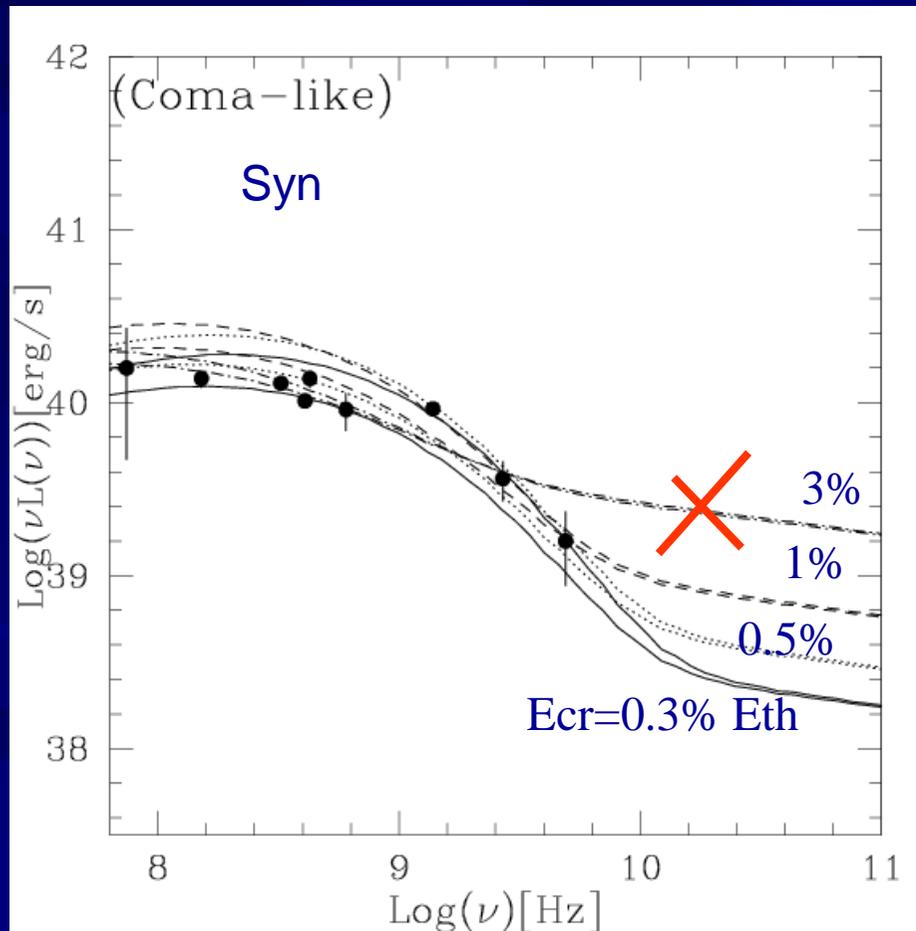
Toy Model:  $\beta$ -profile,  $B_0 \approx A n_{th}$ ,  $B_0(0)=2\mu\text{G}$ ,  $W_{CR} \approx f W_{th}$ ,  $P_A \approx Q n_{th}^{5/6}$

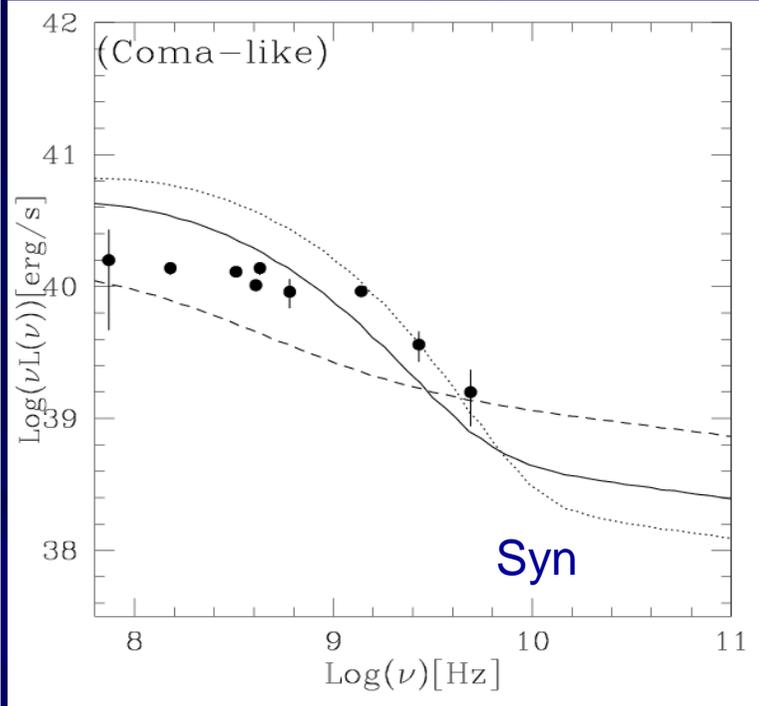


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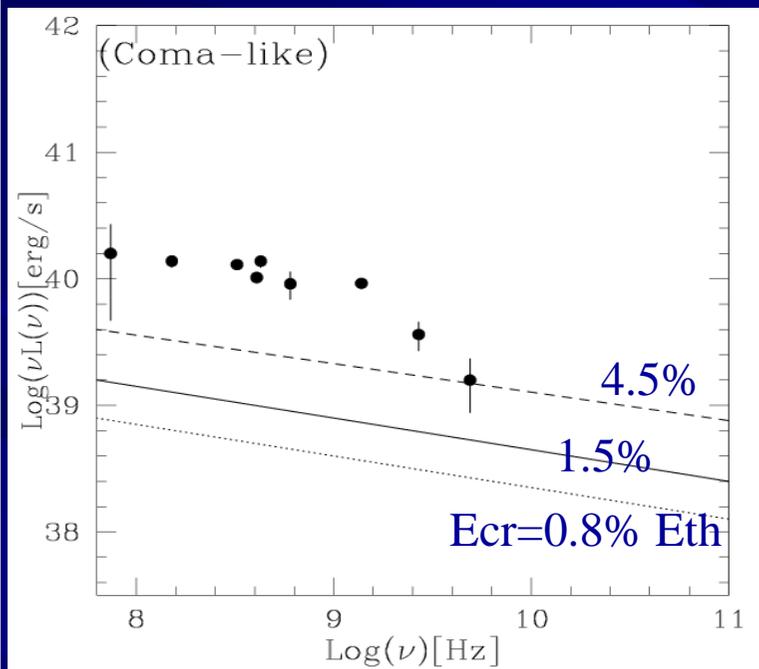
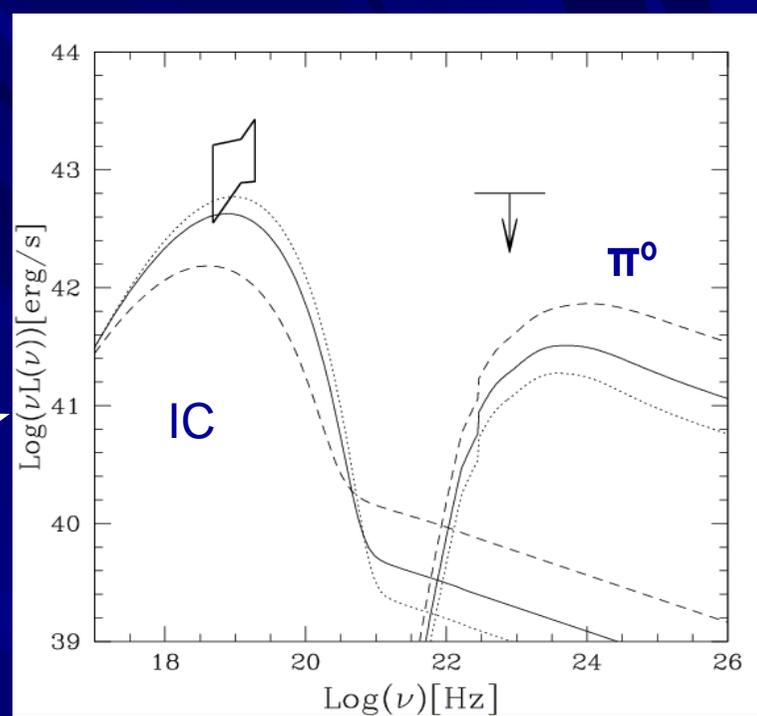
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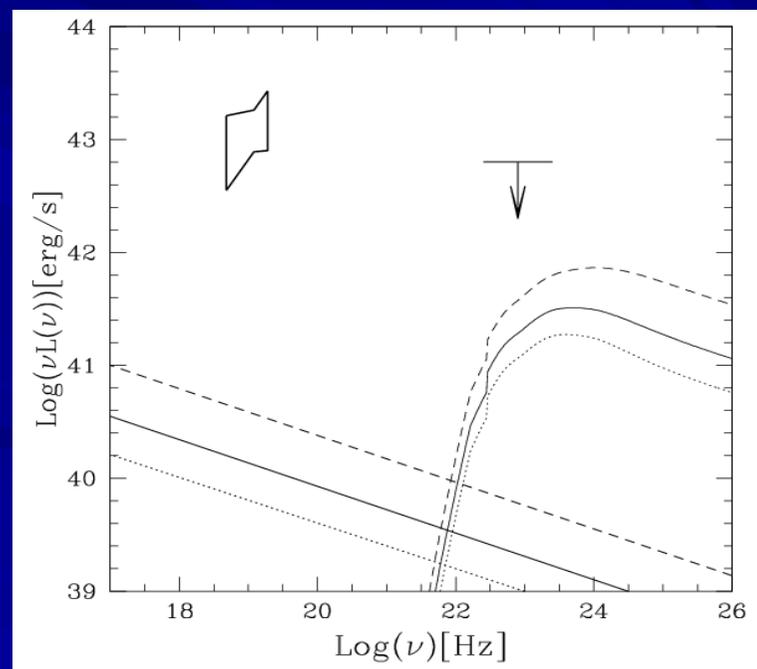


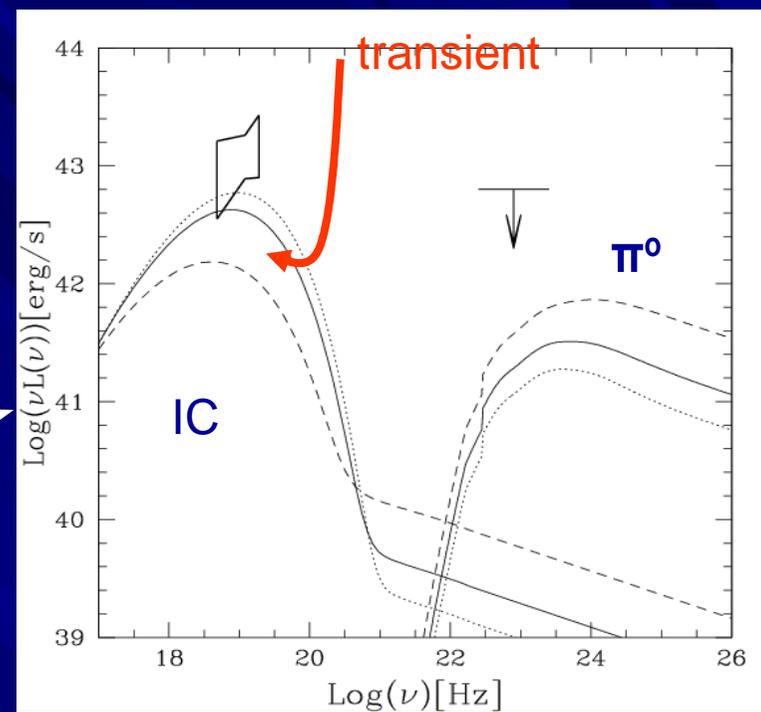
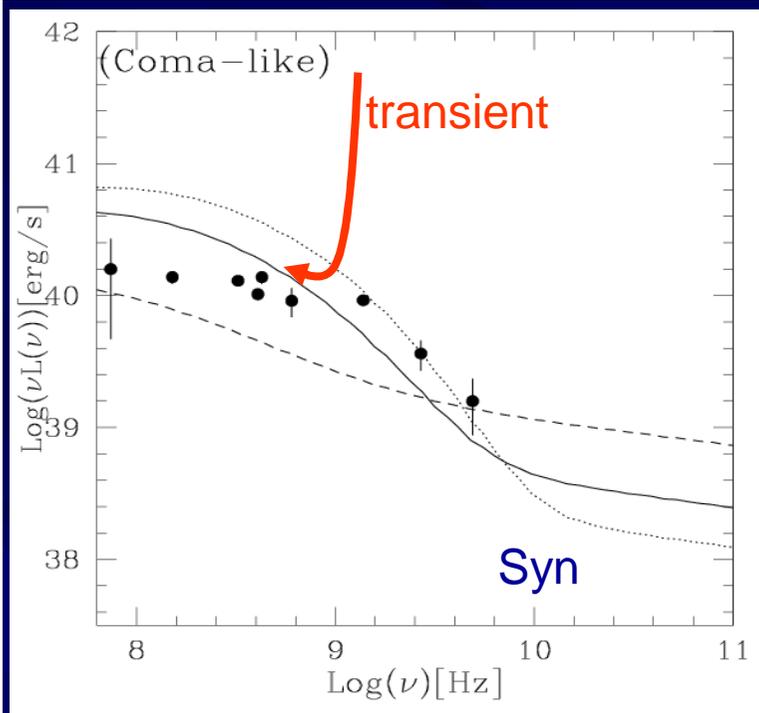


Merging clusters

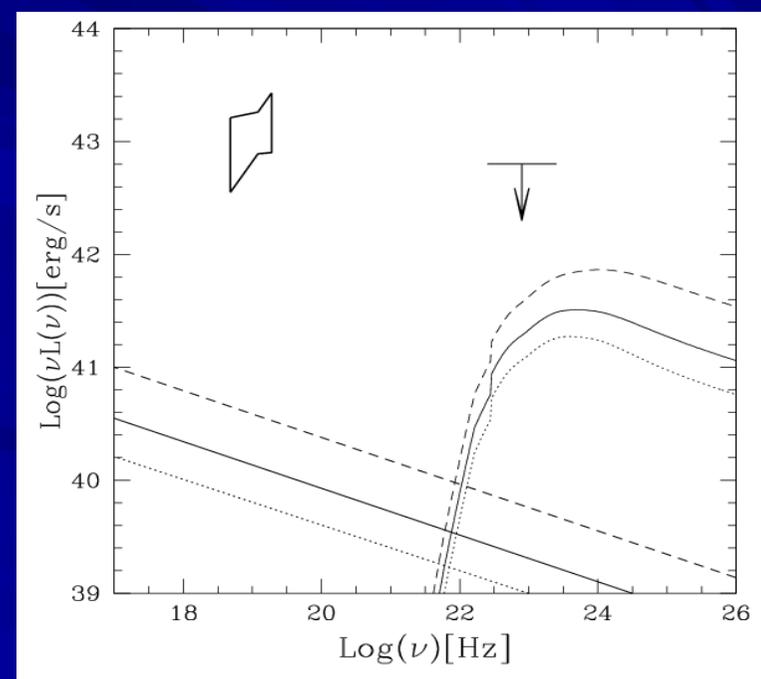
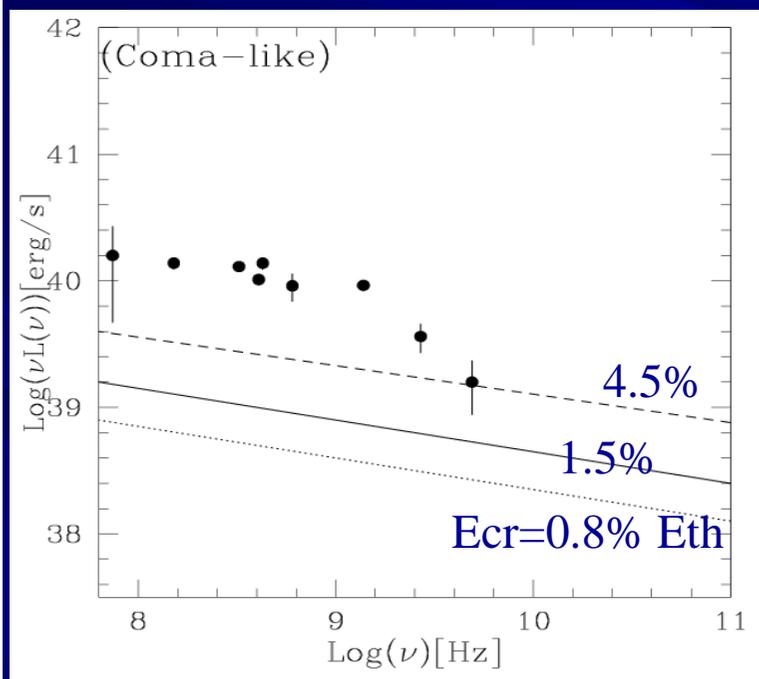


all clusters

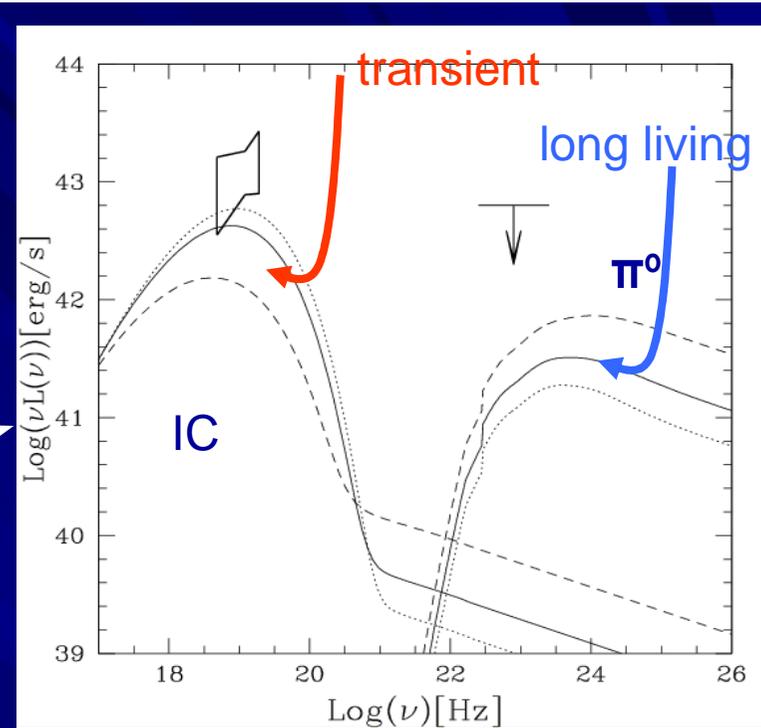
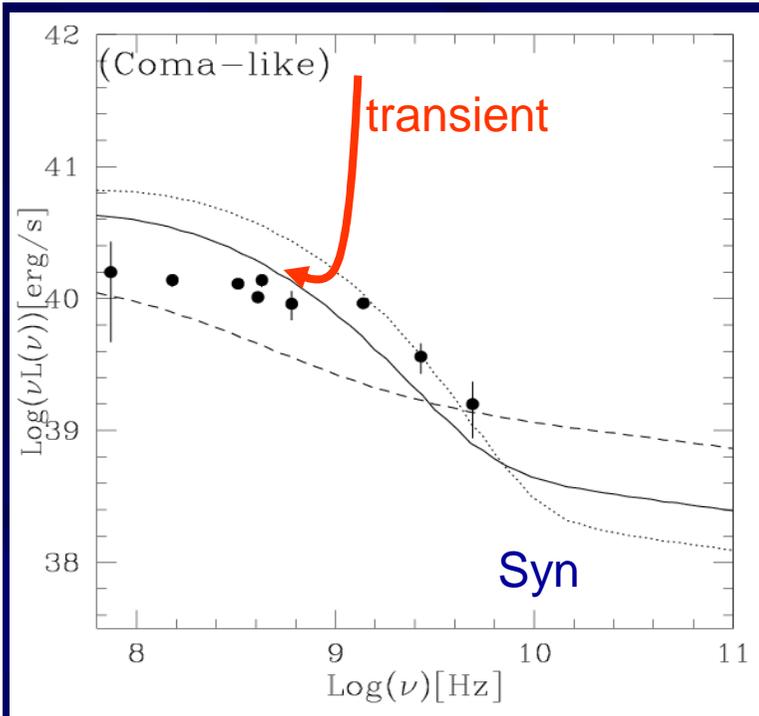




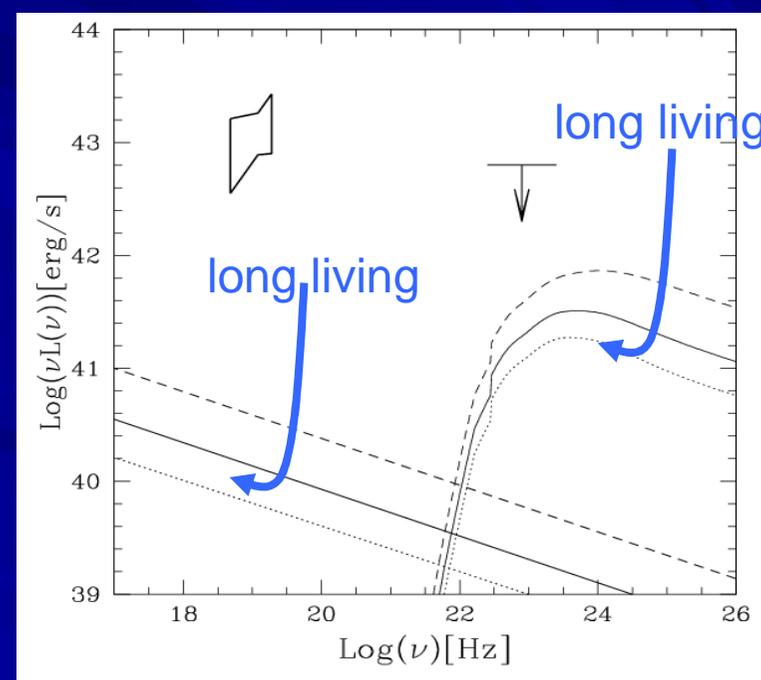
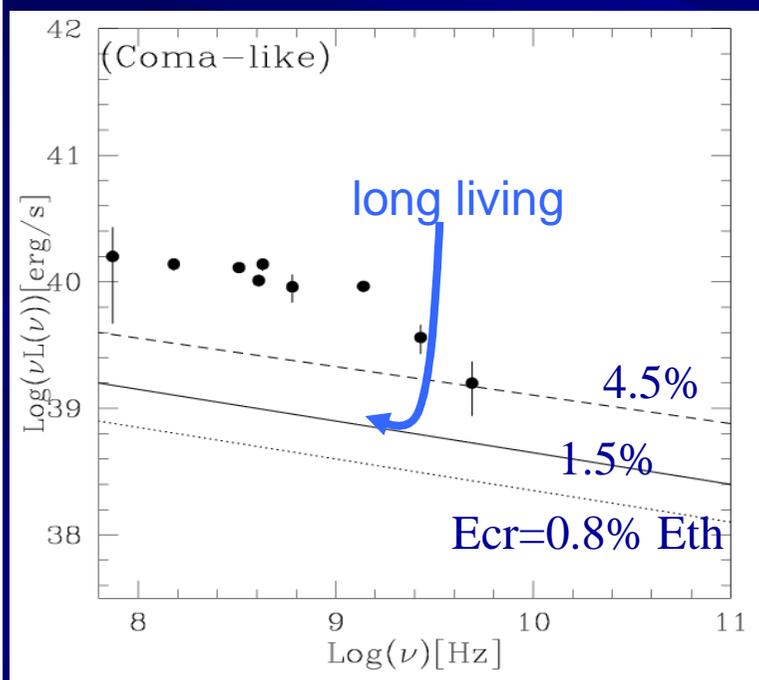
Merging clusters



all clusters



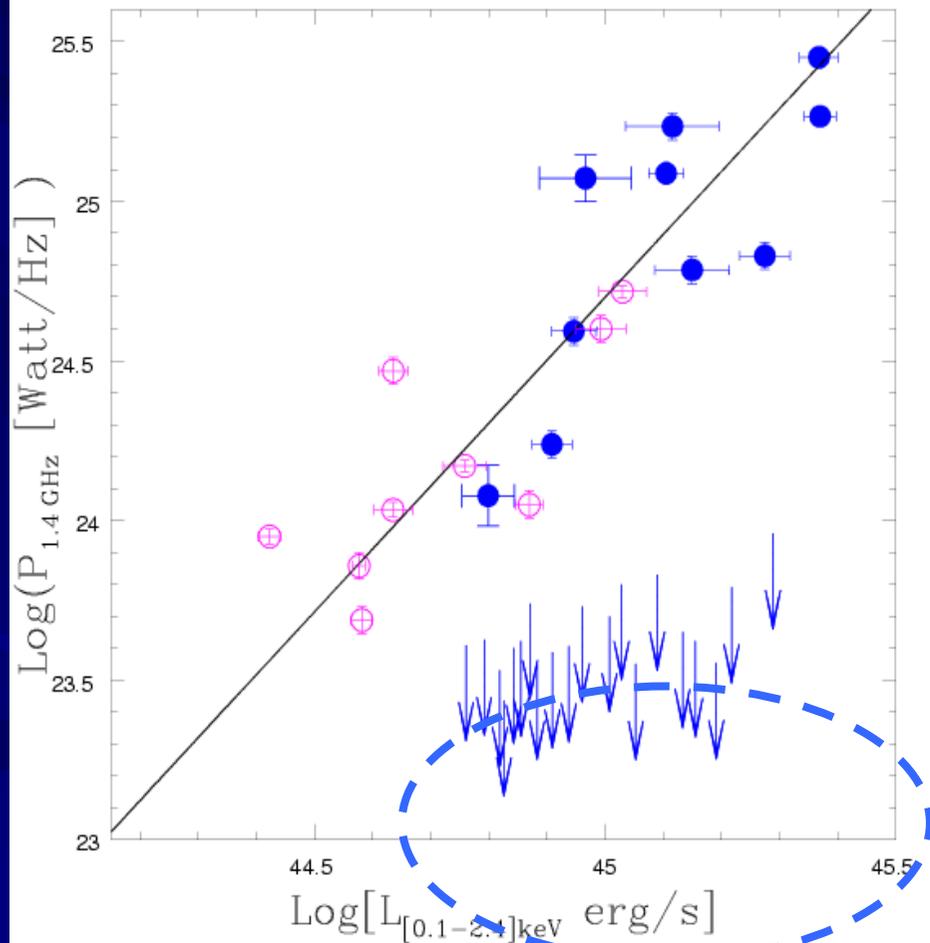
Merging clusters



all clusters

# Bi-modality in Galaxy Clusters

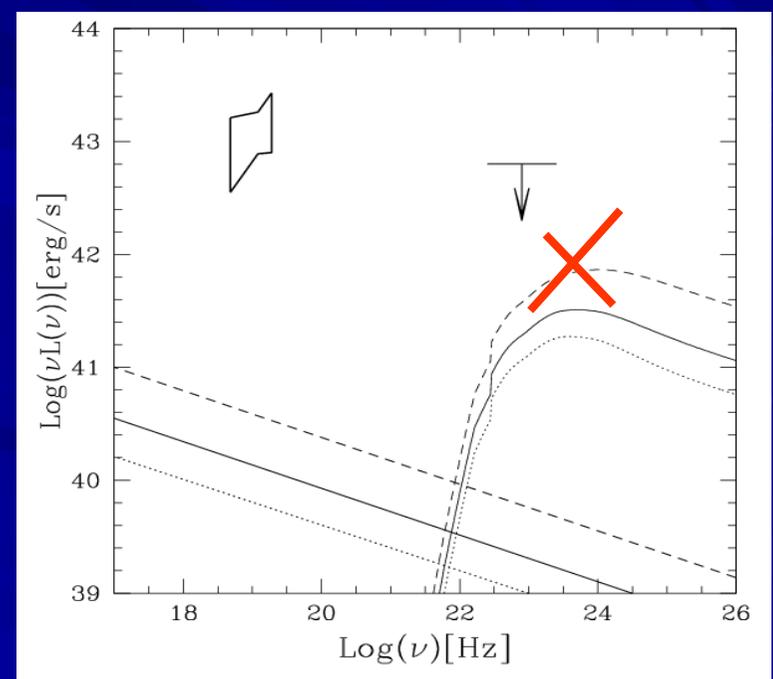
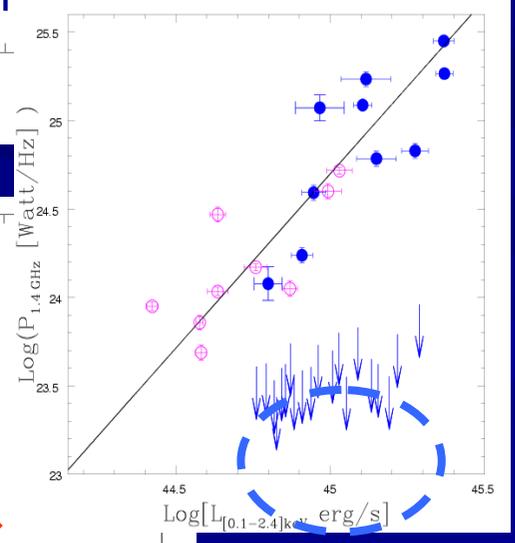
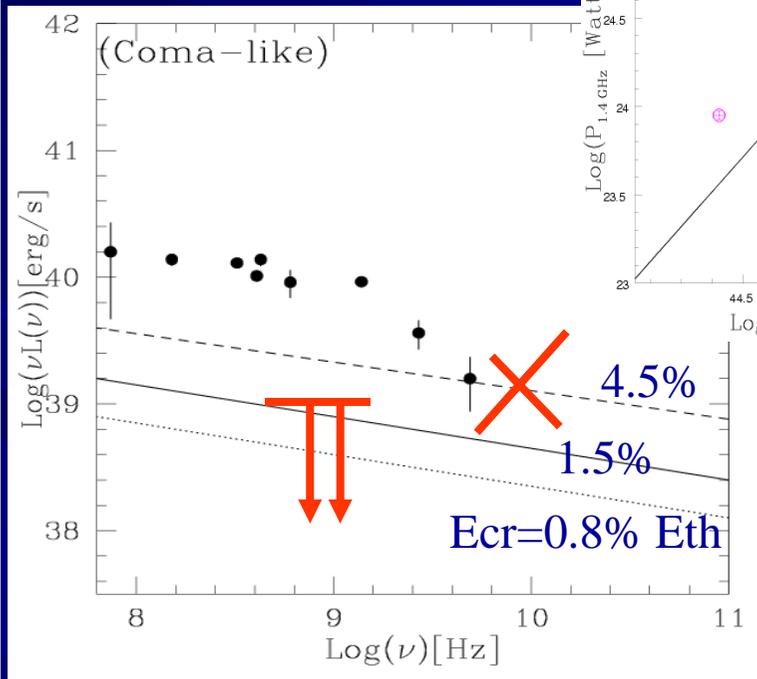
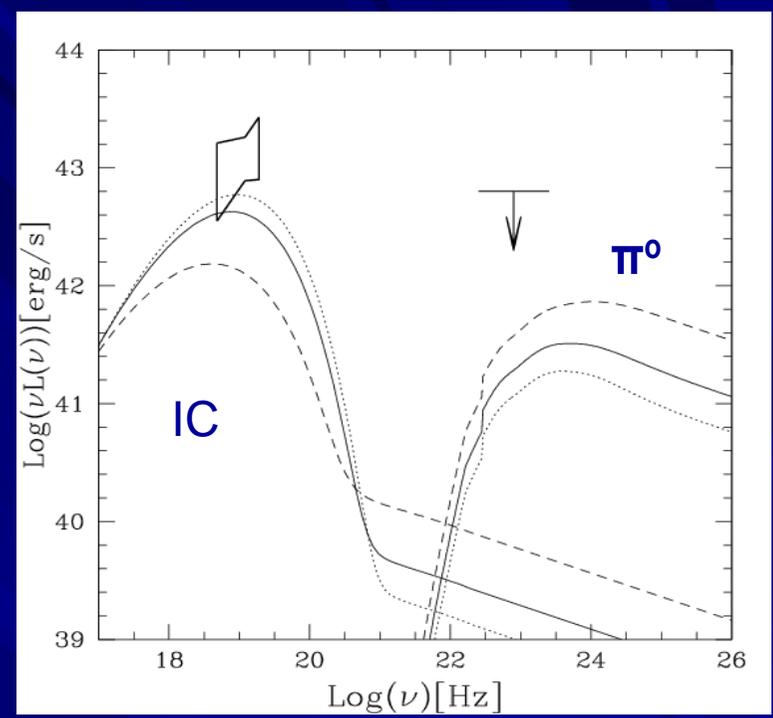
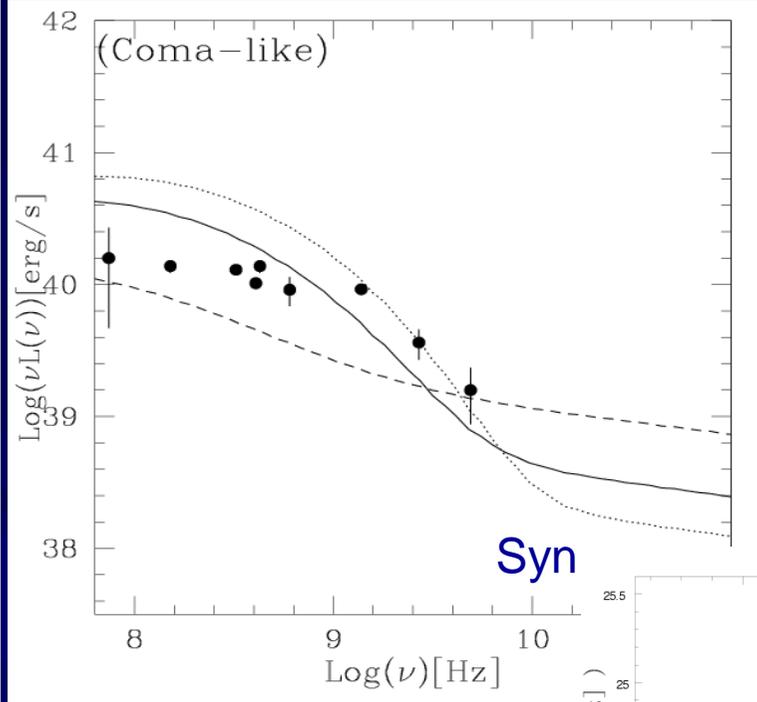
Brunetti +al. 2007

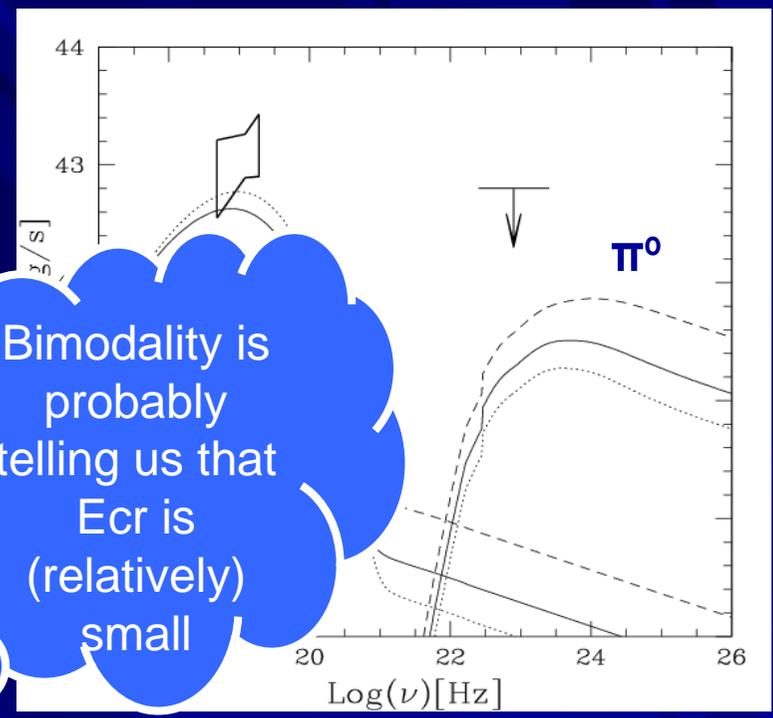
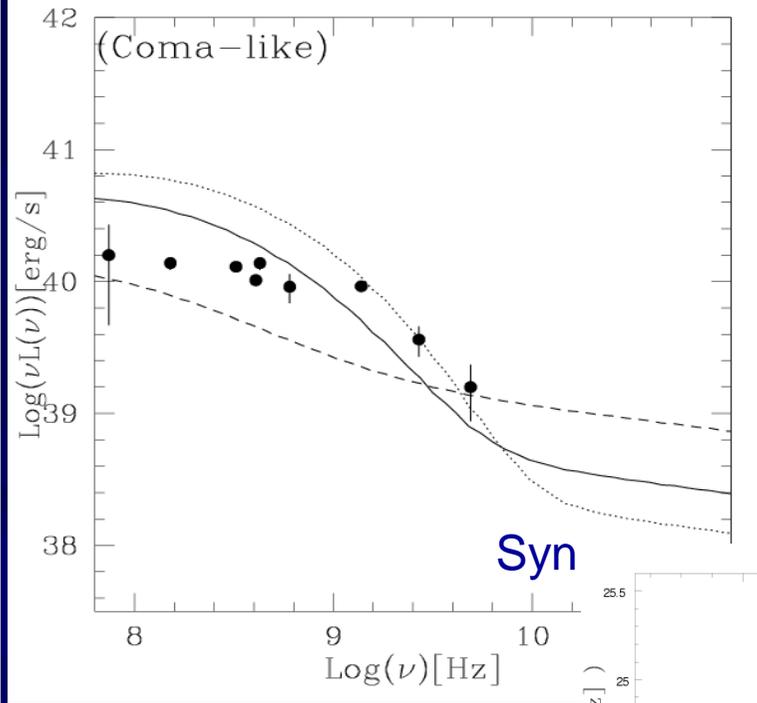


Blue = clusters at  $z=0.2-0.4$   
(GMRT+literature)

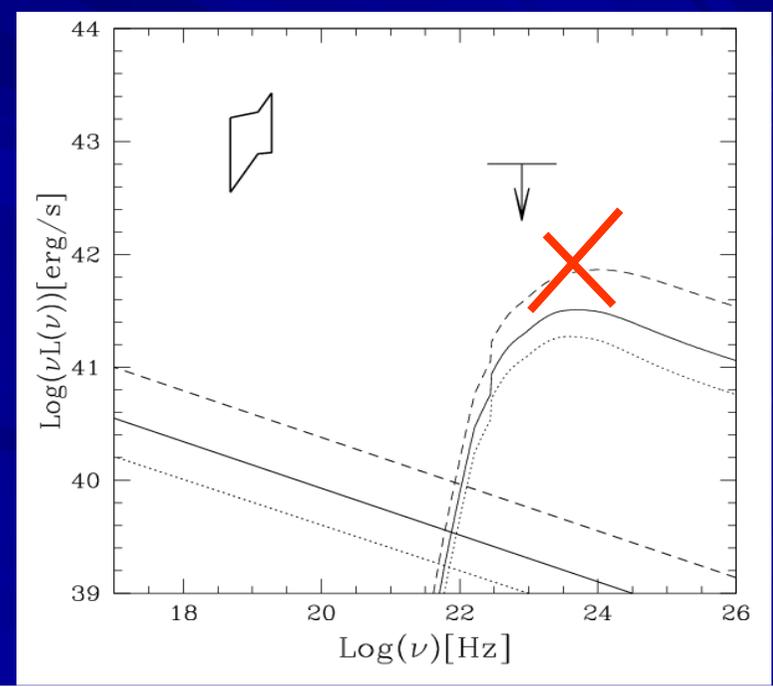
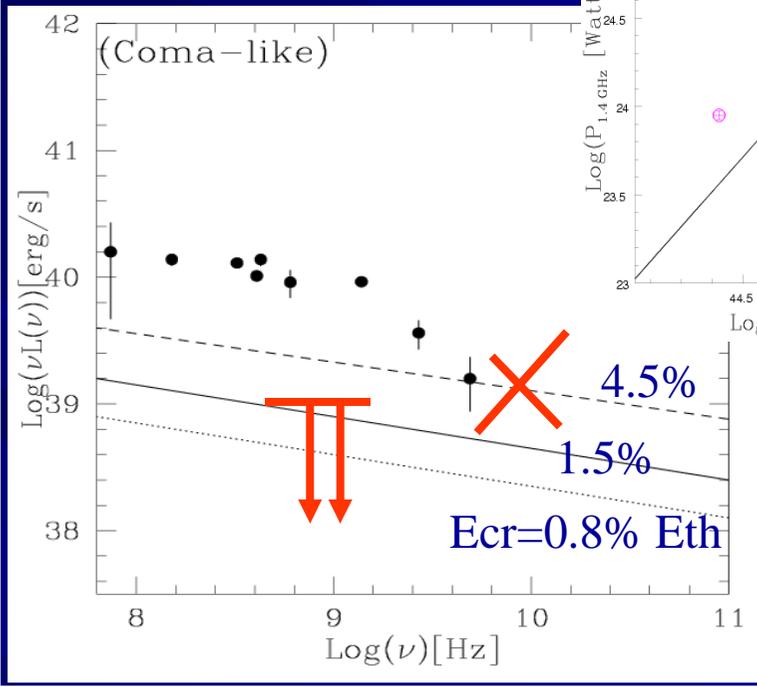
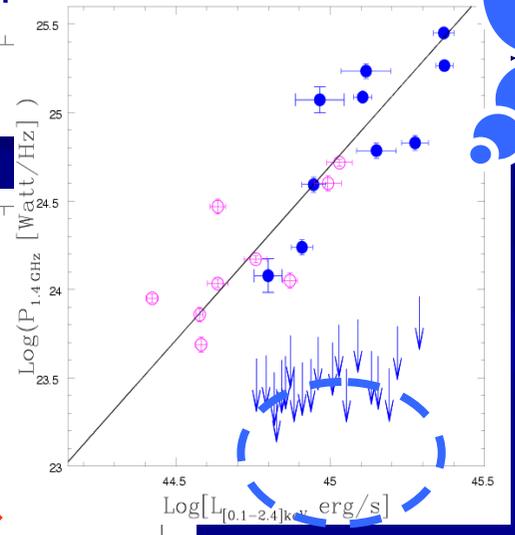
Magenta = Radio Halos in  
clusters at  $z=0-0.2$

*Evidence that GeV electrons are  
generated/accelerated by "on-off"  
mechanisms (transient.. episodes).*





Bimodality is probably telling us that Ecr is (relatively) small



# Conclusions

Present data suggest that turbulence plays a role in the acceleration of particles in galaxy clusters and must be taken into account in self-consistent modellings

The non-thermal emission from galaxy clusters is a mixture of a transient (turbulnce) and long-living (protons) component

FERMI may detect gamma rays (pi-o decay) from clusters in the case of  $B \approx \mu\text{G}$  (or lower), higher energy experiments may also play an important role