Understanding and Problems

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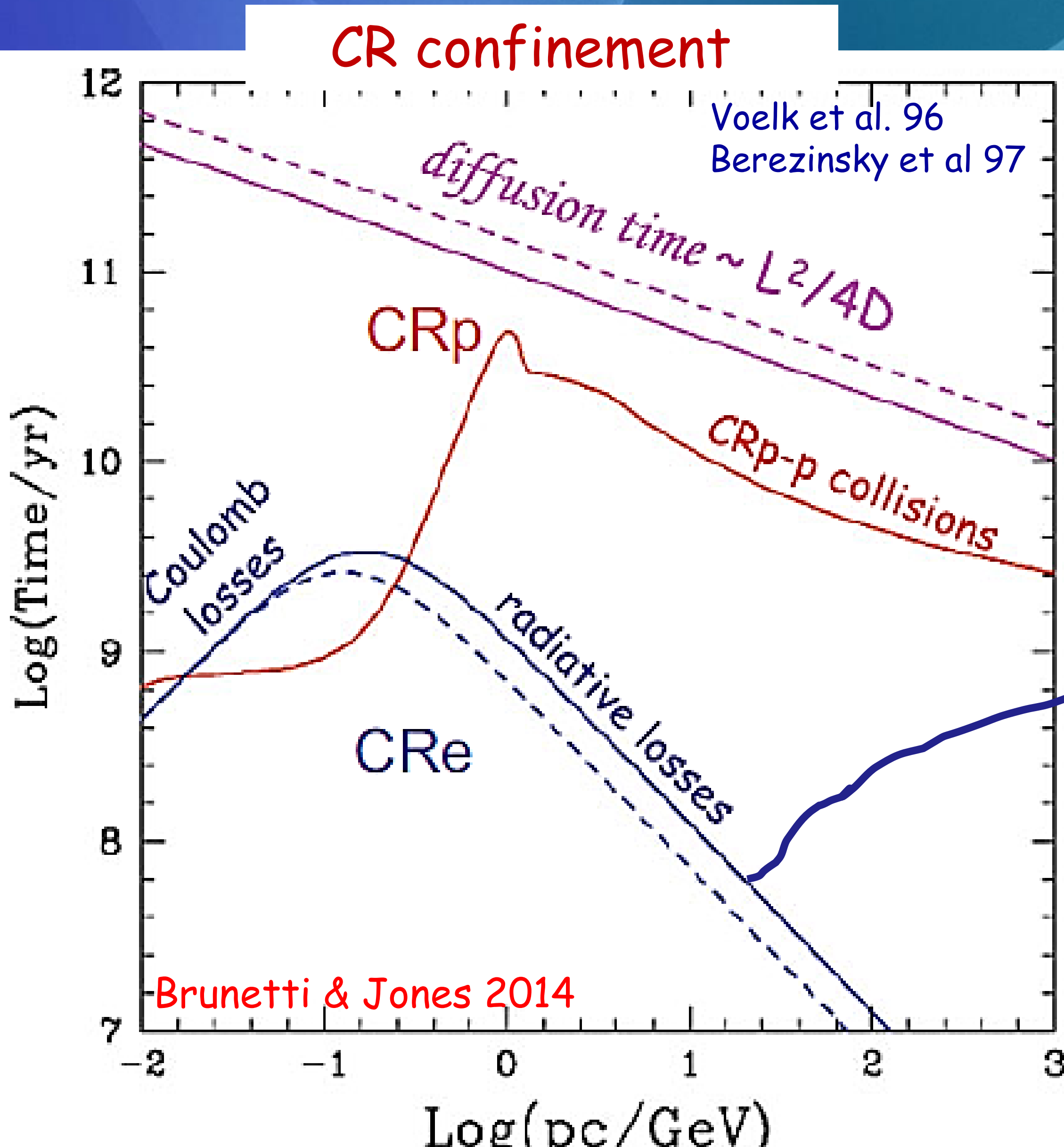
Alexander von Humboldt Stiftung / Foundation

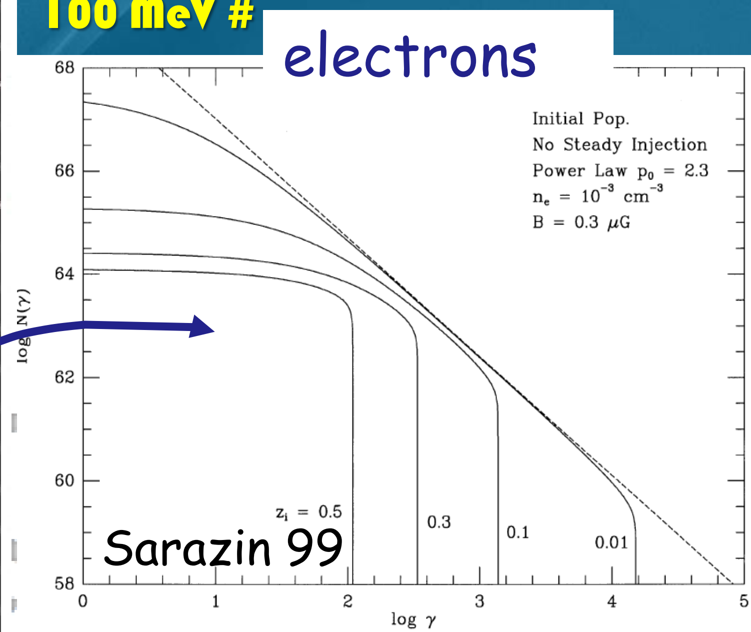
European Commission

CR-acceleration & dynamics



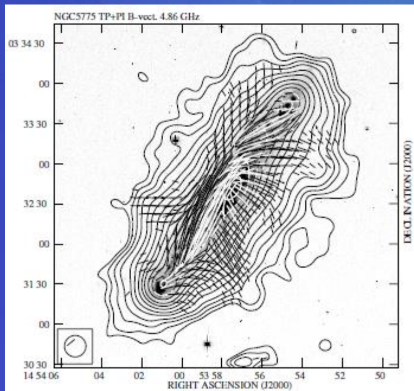
- ✓ CRp live for Hubble+ time and are confined and accumulated in the cluster volume
- ✓ CRe have short lifetime BUT

 # can be accumulated at energies 100 MeV #



 # electrons are not lost if mechanisms of in situ acceleration operate in the ICM #

CR-acceleration & dynamics

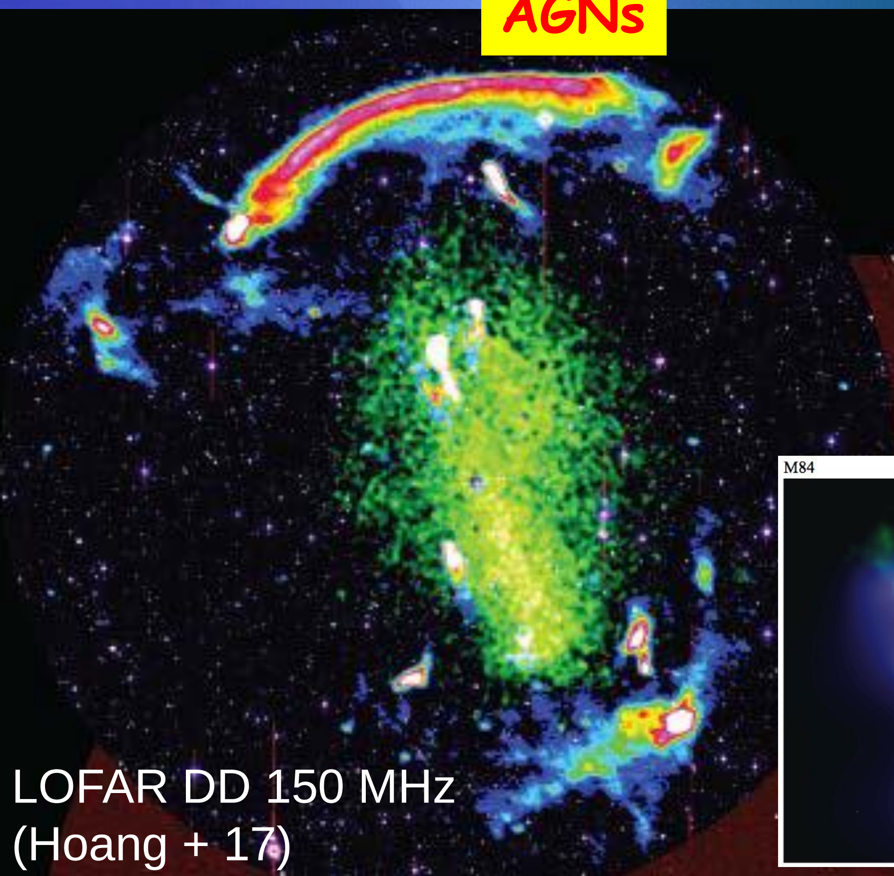


Galaxies (SN) [Voelk+ 96]

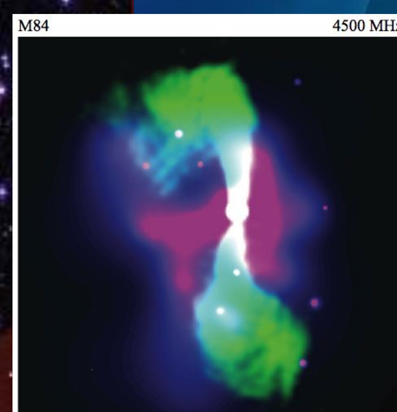
$$E_{CR}^{SN} = N_{SN}\eta_{CR}^{SN}E_{SN} \leq \frac{[Fe]_{\odot}X_{cl}M_{cl,gas}}{\delta M_{Fe}}E_{SN}\eta_{CR}^{SN}$$

Unavoidable pool of CRp accounting for 0.1% of thermal energy
GeV+ electrons diffuse on timescales ≈ energy losses

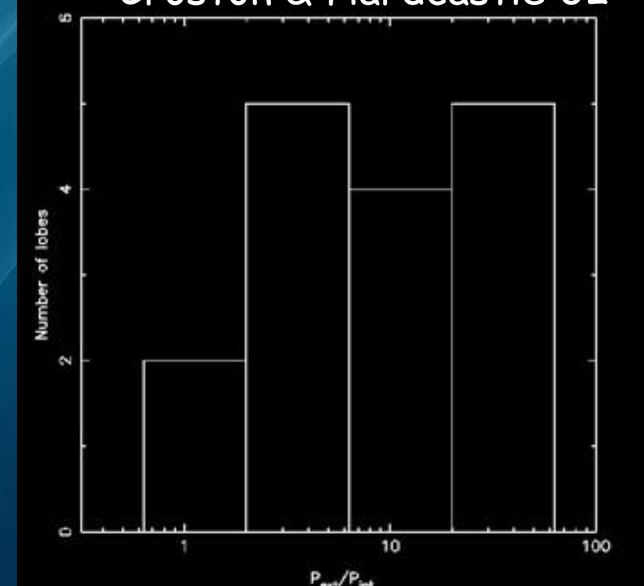
AGNs



LOFAR DD 150 MHz
(Hoang + 17)

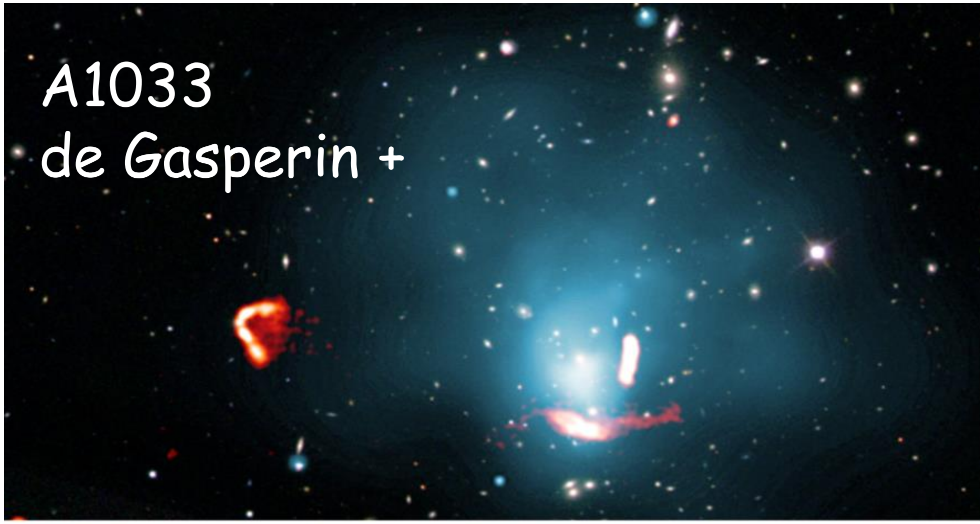


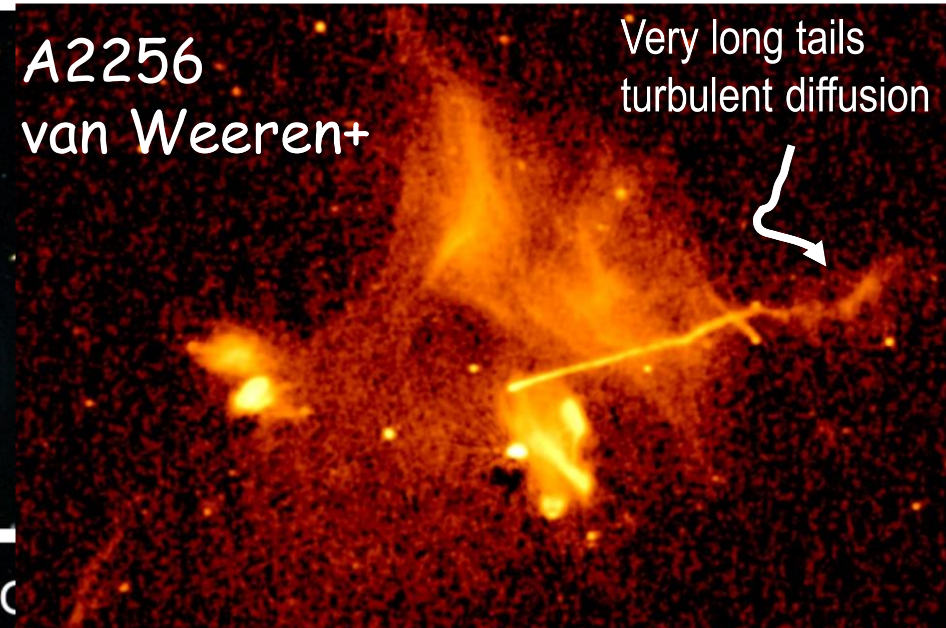
Croston & Hardcastle 02

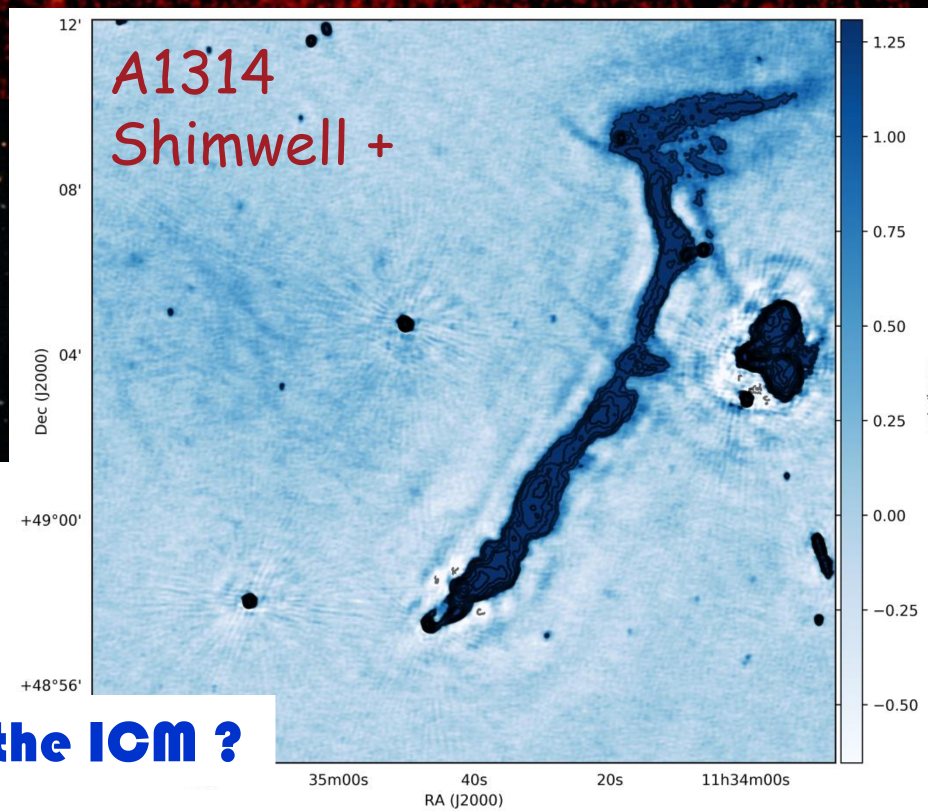


Internal energy in excess of rel electrons: thermal or CRp ?

 # Need to take into account #





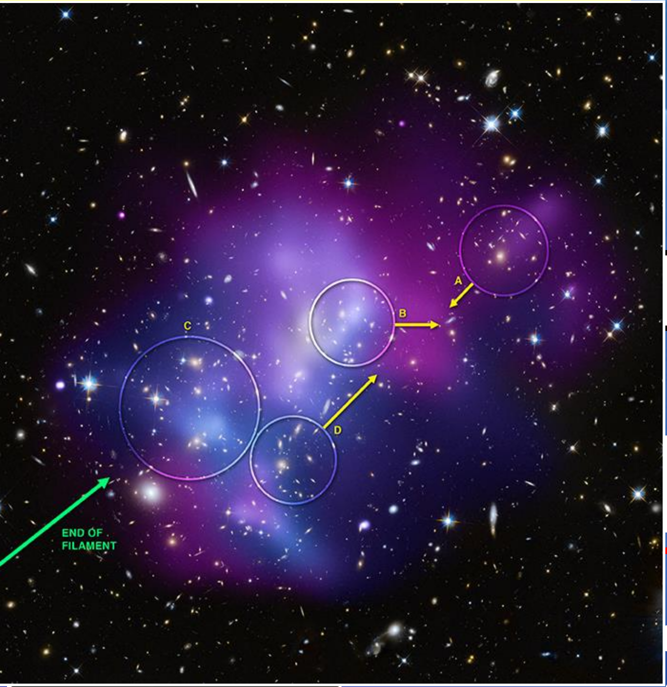


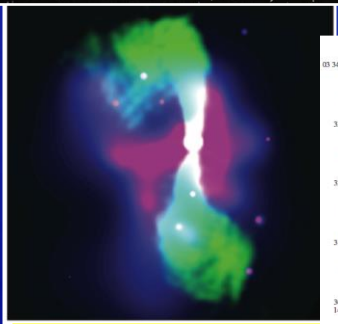
Is this common ?
- Weak shocks
- Plasma effect/magnetic pumping ?
- Reconnection ?

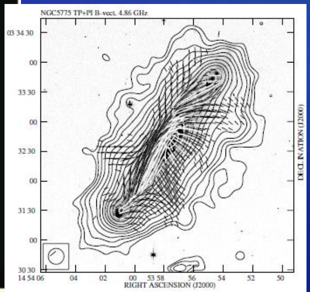
A new paradigm for CRe lifecycle in the ICM ?

THEORY

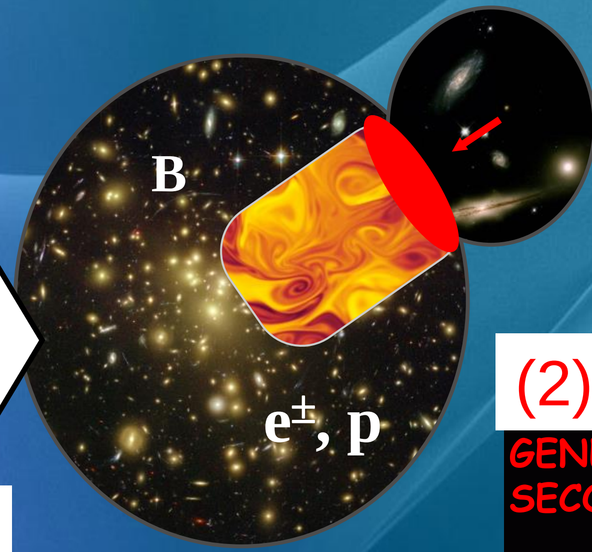
Mergers guide CRe acceleration/dynamics and/or amplify B

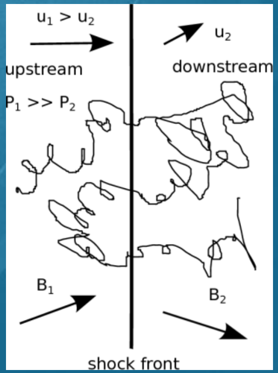






Astrophysical sources Galaxies (SN), AGN..



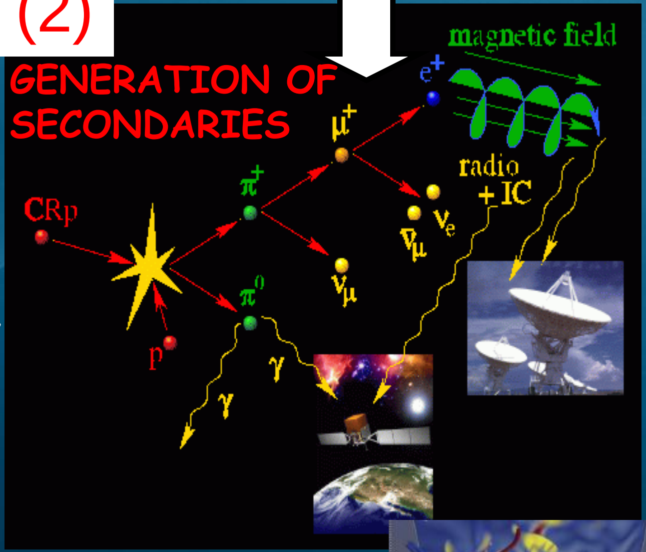


(1)

SHOCKS

accelerate CRe$^{\pm}$,CRp

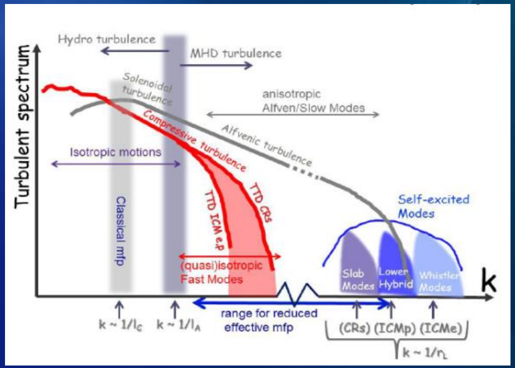
(2)



(3)

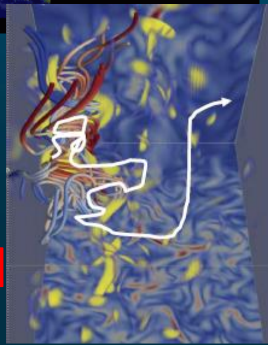
TURBULENCE

reaccelerates fossil CRe$^{\pm}$, CRp and secondaries CRe$^{\pm}$



(4)

MAGNETIC RECONNECTION



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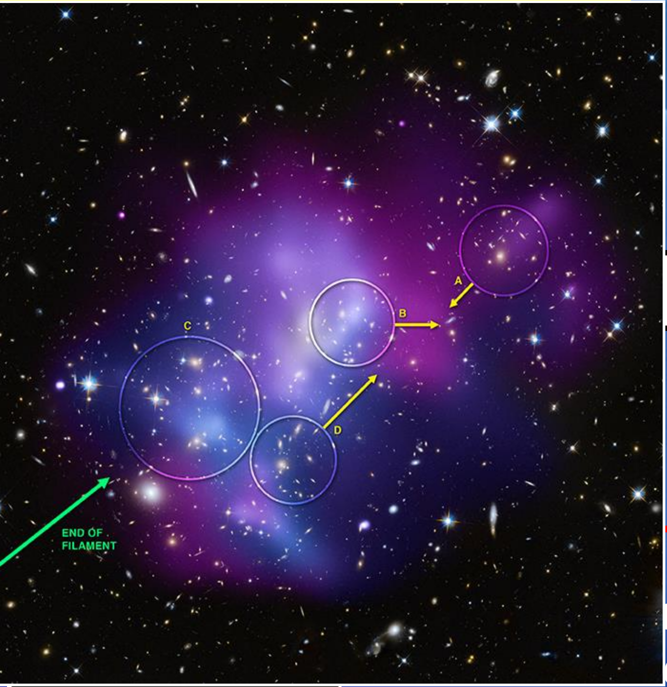

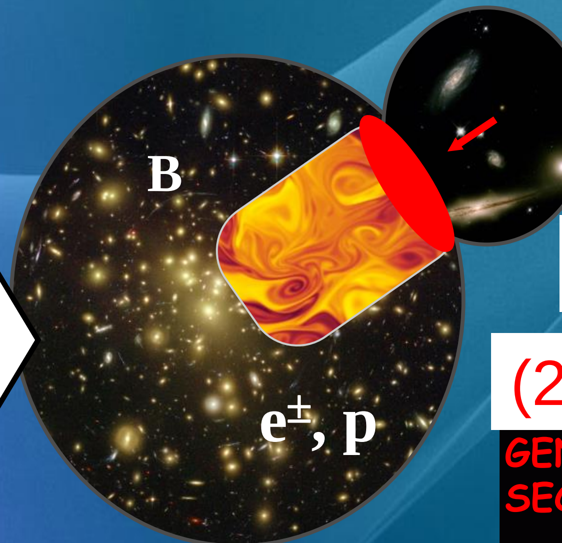

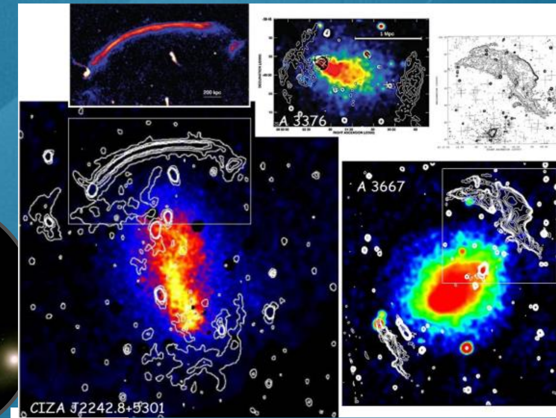

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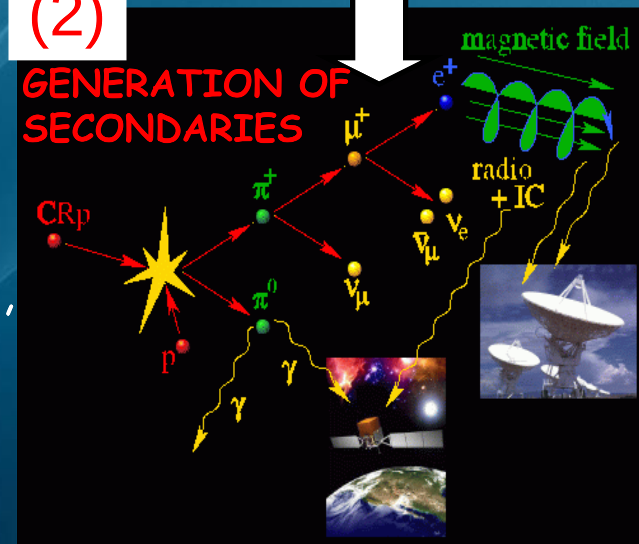
(2)



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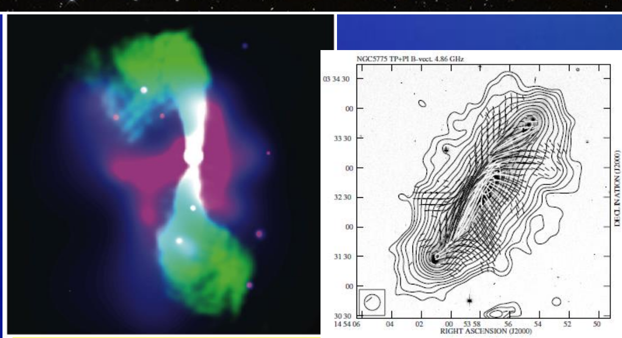

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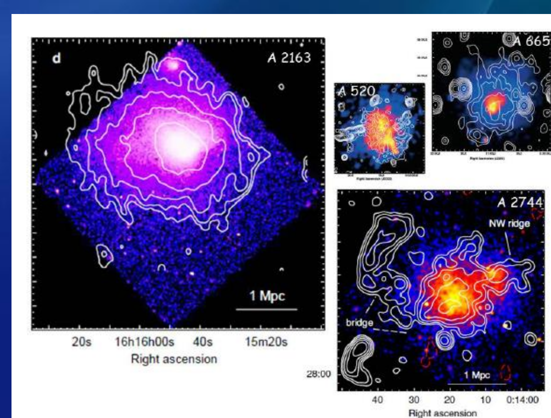

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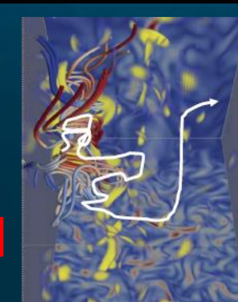

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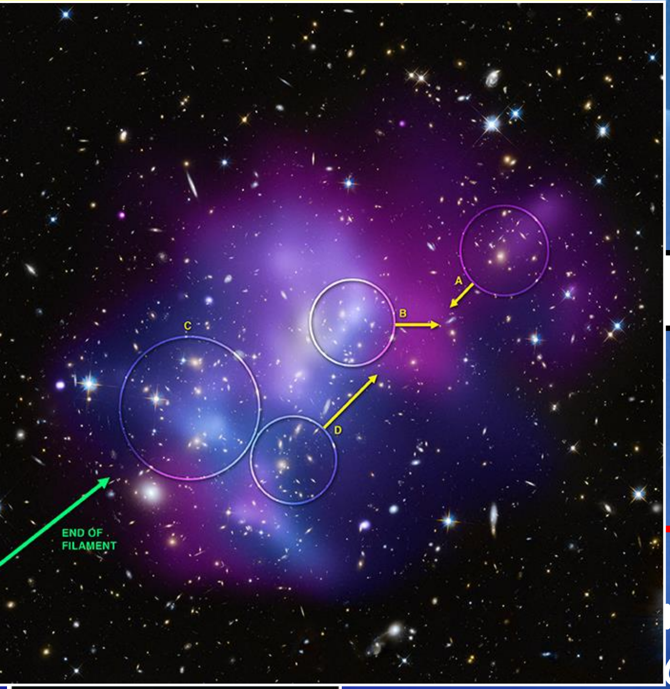

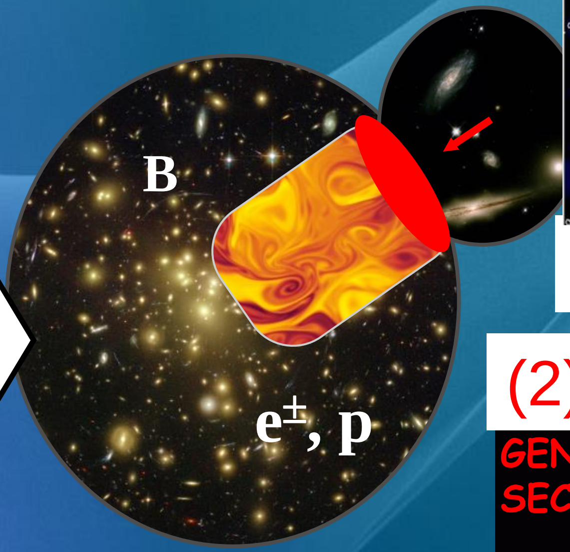

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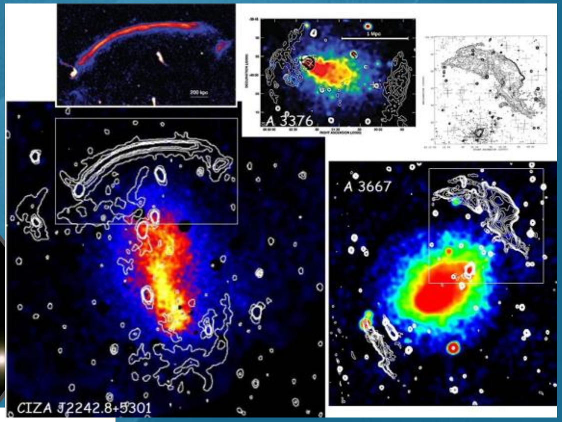

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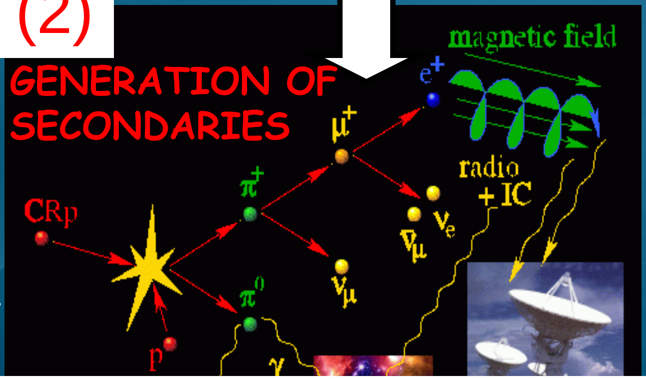
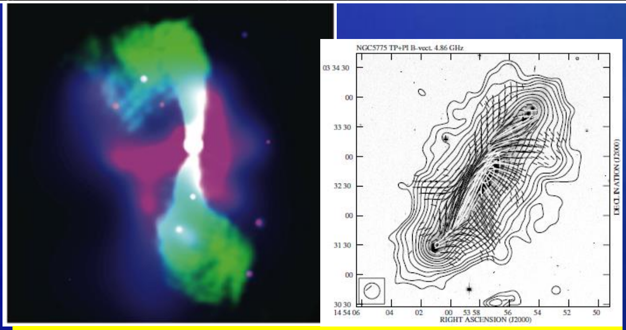
GENERATION OF SECONDARIES





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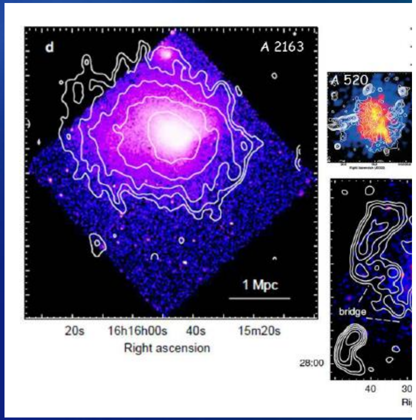


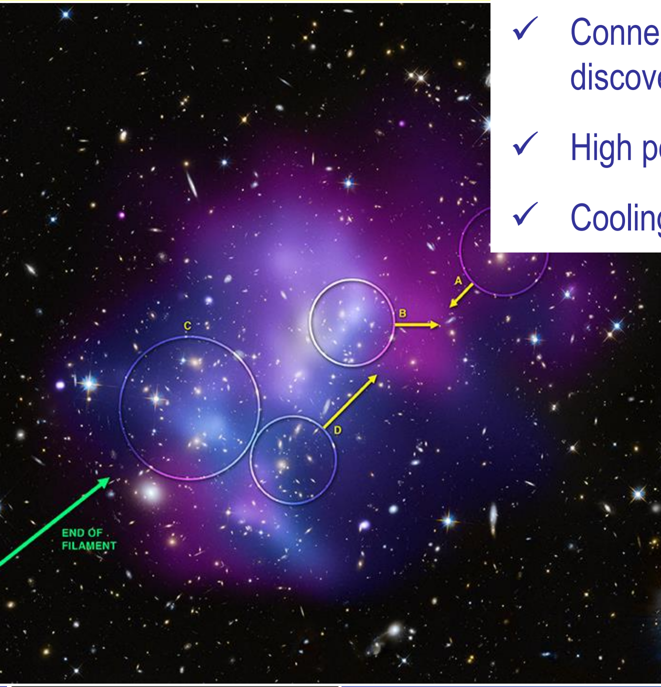
GENERAL AGREEMENT ON :
a fraction of the merger-turbulent energy flux is channelled into CRe

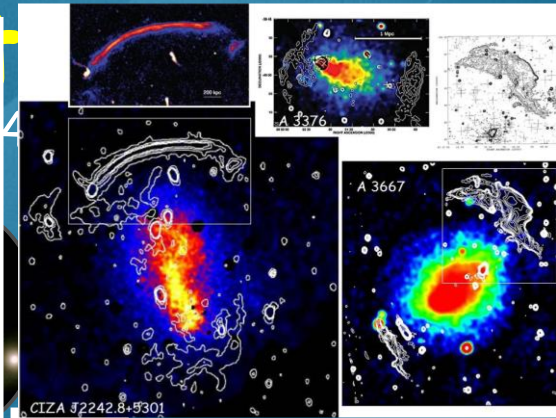
- ✓ No gamma-rays from clusters (faint gamma-rays in case of reacceleration of secondaries)
- ✓ Statistical connection with mergers ''bimodal behaviour'' : mergers +Syn powerful and giant
- ✓ Existence of a large population of USS RHs

Mergers guide CRe acceleration/dynar and/or amplify B

GENERAL AGREEMENT ON :
a fraction of the energy flux at cosmological shocks is channelled into CRe

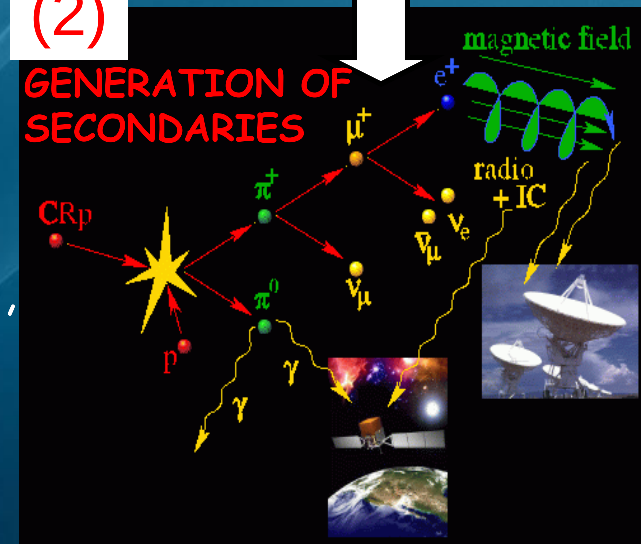
- ✓ Connection with shocks [shocks have been discovered first by radioastronomers !]
- ✓ High polarization level
- ✓ Cooling (steepening) in the downstream





(1) SHOCKS accelerate $CRe^{\pm}$,CRp

(2) GENERATION OF SECONDARIES



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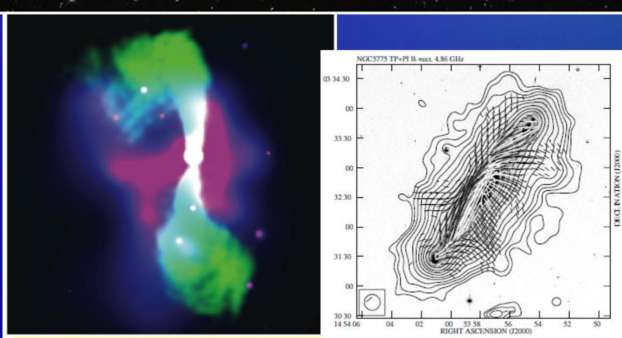

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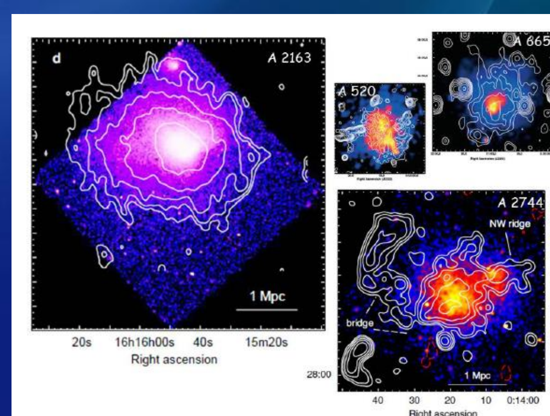

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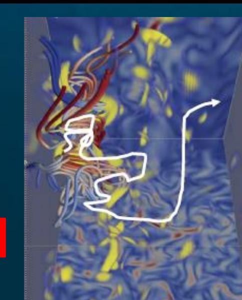


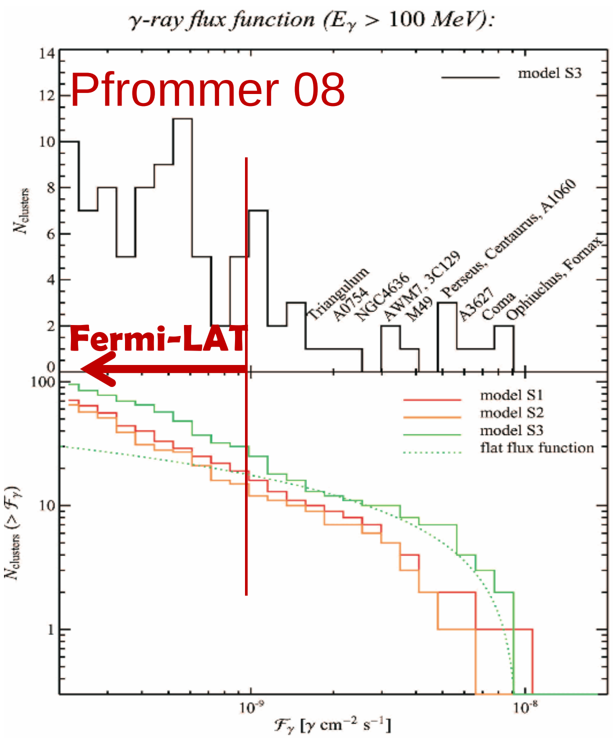
Problems … expectations

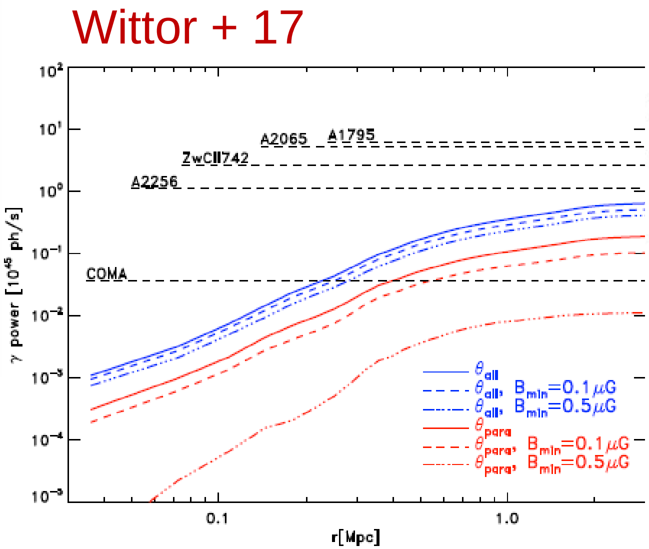
- Gamma rays from clusters
- Turbulent reacceleration and expectations
- Complexity of RS and new obs approaches
- A connection between MHs and GRHs ?

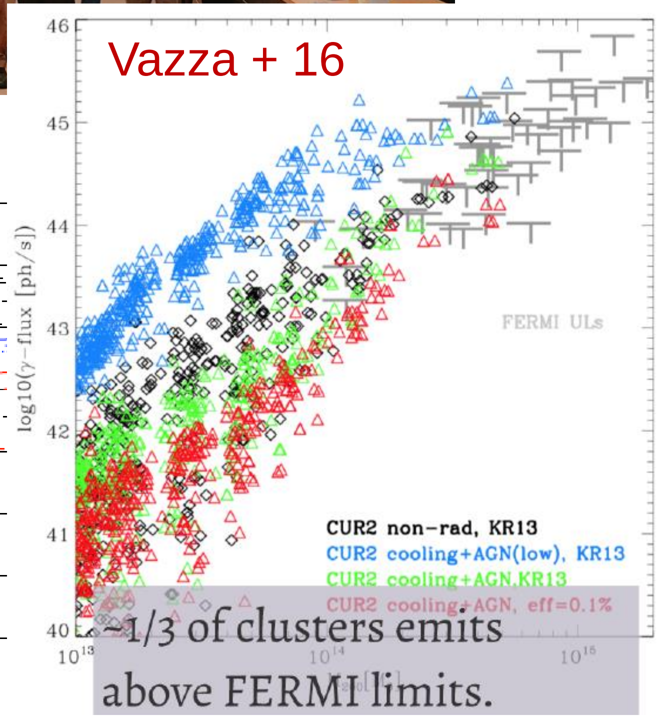
Real Problems …

NO GAMMA-RAYS FROM CLUSTERS

- ACCELERATION PHYSICS ?
- DIFFUSION/TRANSPORT ?
- SPECTRUM ?







Simulations do not include reacceleration, AGNs, GW !

Real Problems …

NO GAMMA-RAYS FROM CLUSTERS

- **ACCELERATION PHYSICS ?**
- DIFFUSION/TRANSPORT ?
- SPECTRUM ?

B inclination controls the shock structure

- quasi_II shocks : ions eff10-20%, Kep~0.001
- quasi_p shocks: eff CR reacc, electrons ?

The Subcritical/Supercritical Shock Domains

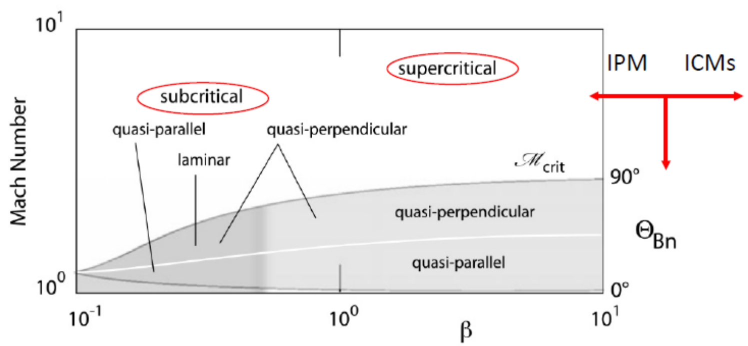


Figure 4.2: The range of supercritical and subcritical shocks in the ($\mathcal{M}_{ms}, \beta$)-plane. The critical Mach number range is shown in shading varying between perpendicular and parallel shocks. The *white line* is the demarcation line between quasi-perpendicular and quasi-parallel shocks. The *lower dark* line belongs to strictly parallel shocks. At low β the parameter range of laminar shocks is shown in fuzzy shading. The transition to higher beta is blurred as it is not sharply defined. For a given shock normal angle Θ_{Bn} the *region below the curve* is subcritical. Quasi-parallel shocks can be subcritical only below the *white line*, depending on their shock normal angle.

Balogh & Treumann 2013

Ion reflection happens in supercritical shocks
Most of the merger shocks may be in the transition between sub/supercritical Mach

Real Problems …

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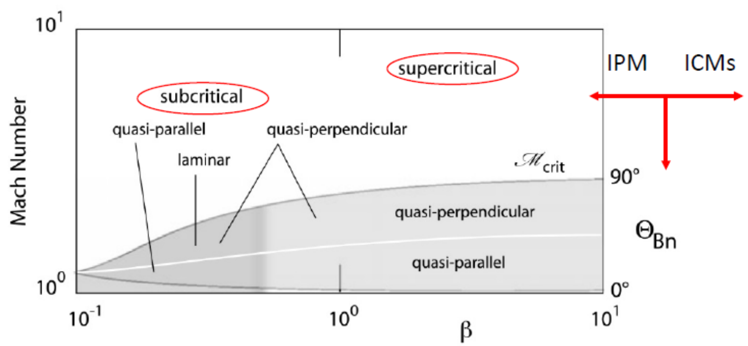

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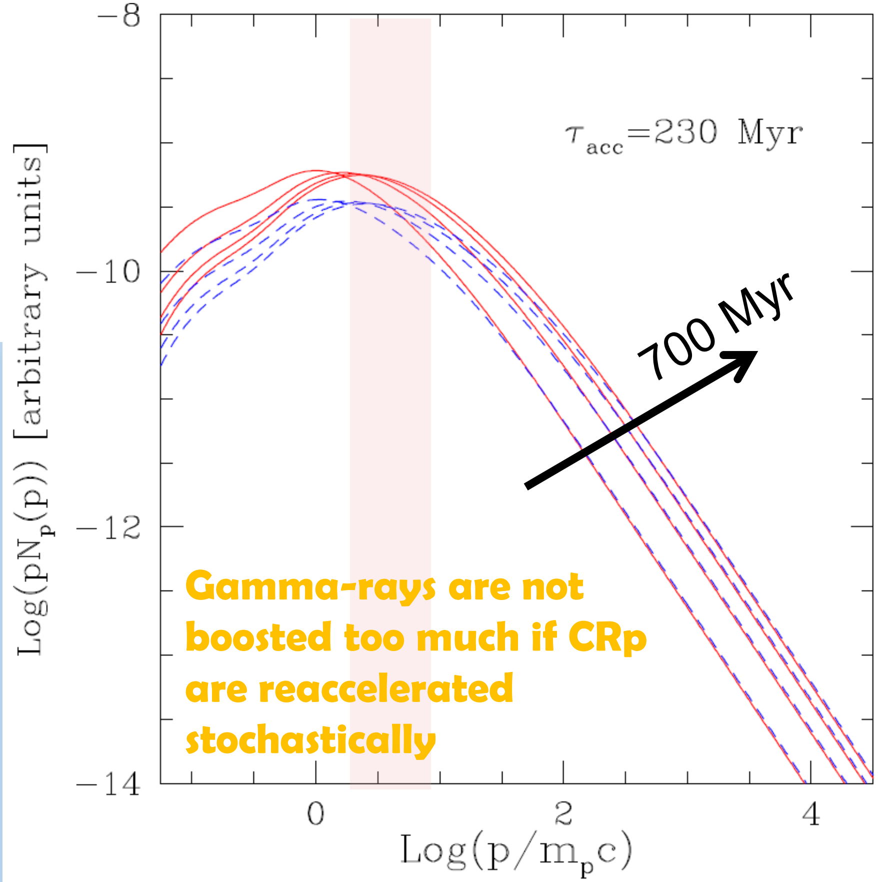
Fermi-LAT



Reacceleration preserves the number of particles.
 # need to understand the impact on gamma-rays #

Real Problems …

NO GAMMA-RAYS FROM CLUSTERS

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- **DIFFUSION/TRANSPORT ?**
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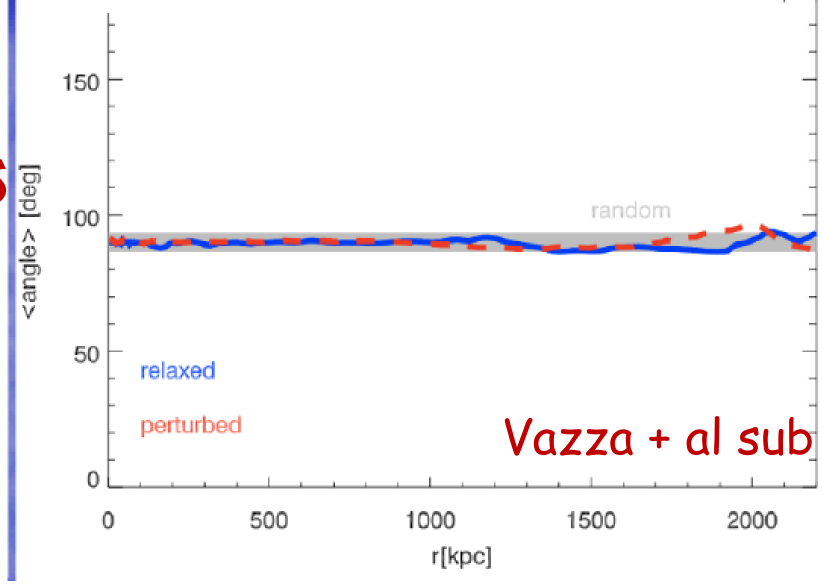
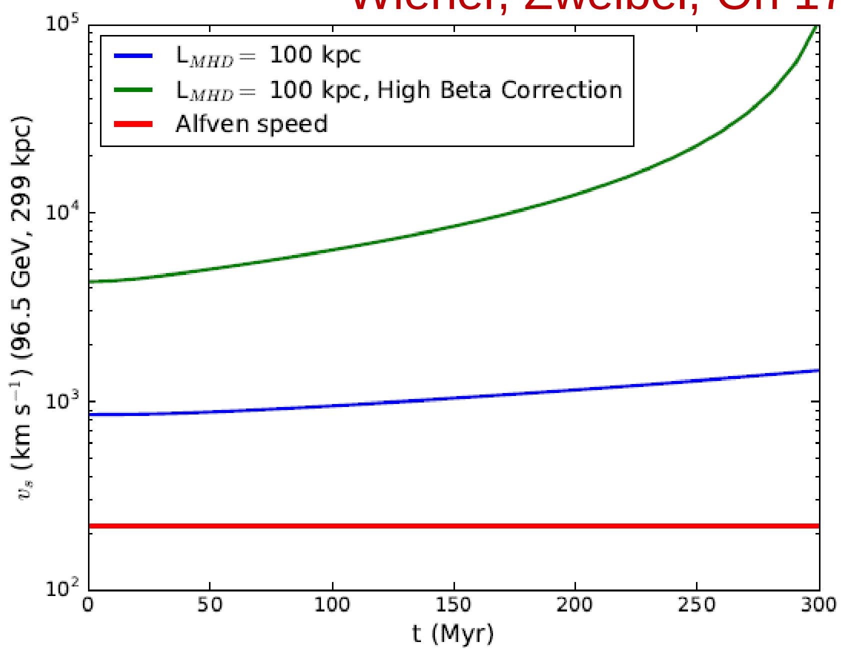
Magnetic field is "tangled" in GC



Extreme solution: streaming along field lines (Wiener + 13,17, Lazarian 17)

Wiener, Zweibel, Oh 17



D ~ 1/3 Vdrift l_A

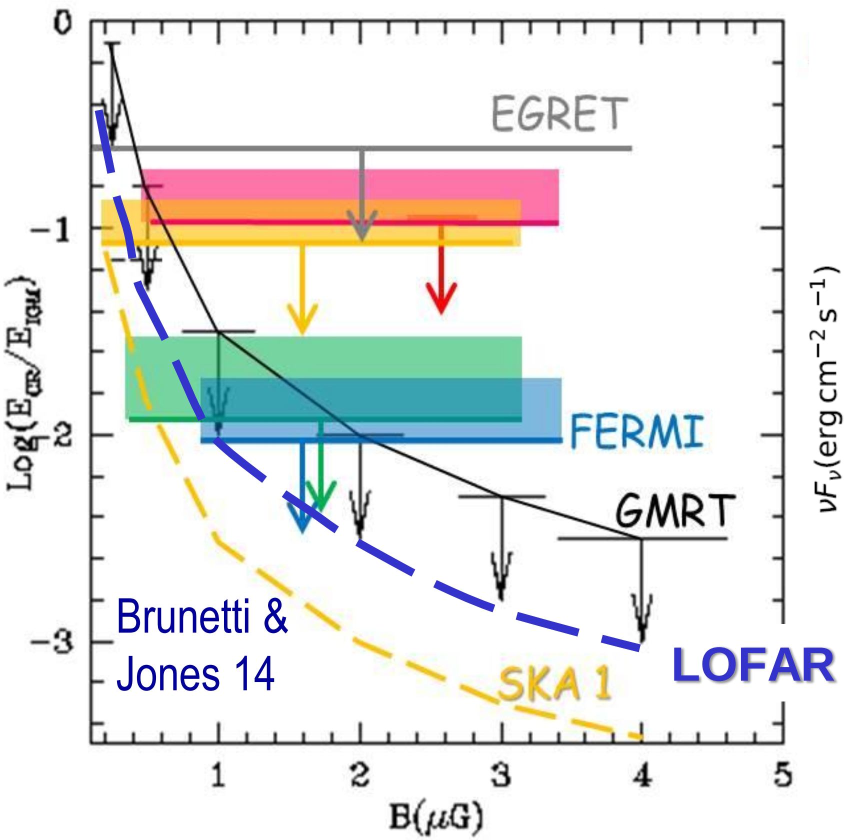
$$l_A = L_0 M_A^{-3} = \frac{(6/5)^3 L_0}{(\sqrt{\beta_{pl}} M_0)^3}$$

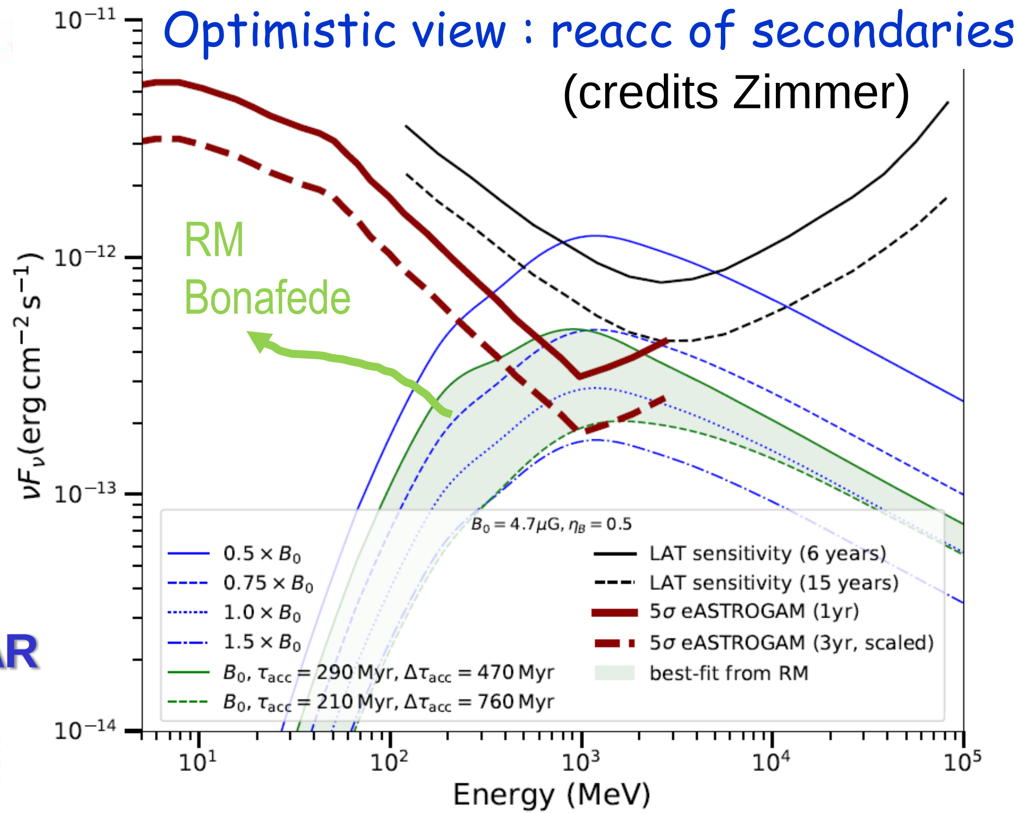
⇩

D < 10^{29} cm^2 /s

$$\tau_{diff} \approx \frac{1}{4}\frac{L^2}{D}$$ > Hubble

Future obs constraints on CRp ?





 # smaller B makes detection easier #

 # deep LOFAR observations of ‘radio quiet’ and nearby clusters allow extremely deep constraints #

cta
cherenkov telescope array

KSP on Perseus
Factor 6 better than MAGIC

Critical issues … and minor issues

PHYSICS OF TURBULENT ACCELERATION

- IS THERE ENOUGH ROOM TO GENERATE RHs ?
- WHAT DO WE PREDICT FOR THE RH/MERGER BIMODALITY ?
- DO WE UNDERSTAND TURBULENT ACC IN THE ICM ?

Energy flux x fraction of energy into CRe "vs" nonthermal radiation

$$\frac{P_\nu}{W/Hz} \approx 3 \times 10^{25} \eta_{-4} n_{-3} \phi_H (kT_8)^{3/2} \left(\frac{M_t}{0.2}\right)^3 \left(\frac{L_H/L_t}{10}\right) \left(\frac{L_H}{Mpc}\right)^2 \left(\frac{B^2}{B^2+B^2_{cmb}}\right)_H$$

Kolmogorov

 # Problems for sub-μG #

$$\rho_{ICM} V_A^3 l_A^{-1} \eta_{CR} \sim \int d^3p E \frac{\partial f_i}{\partial t} = \int d^3k W(\vec{k}) \Gamma(\vec{k})$$

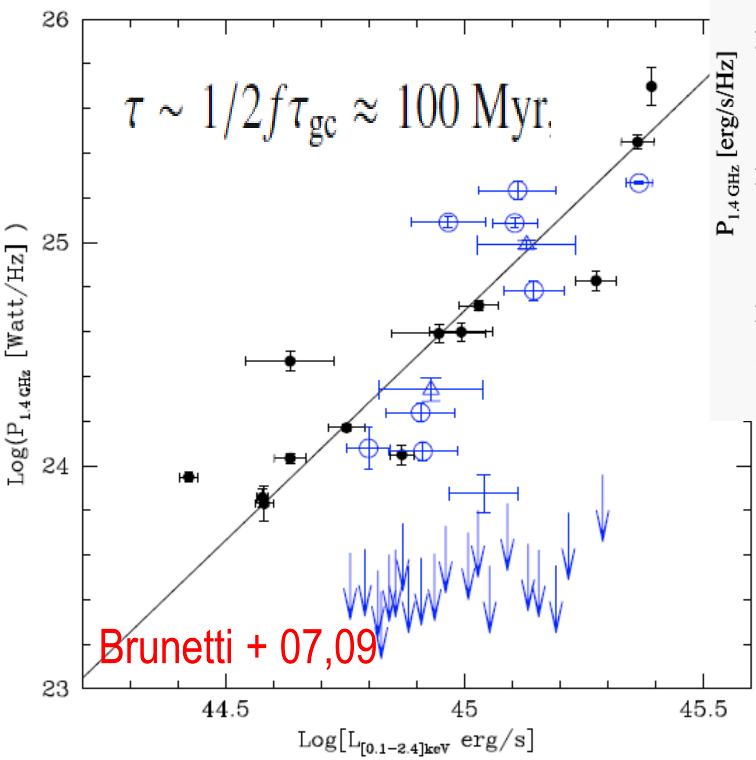
Gray region between MHD and plasma

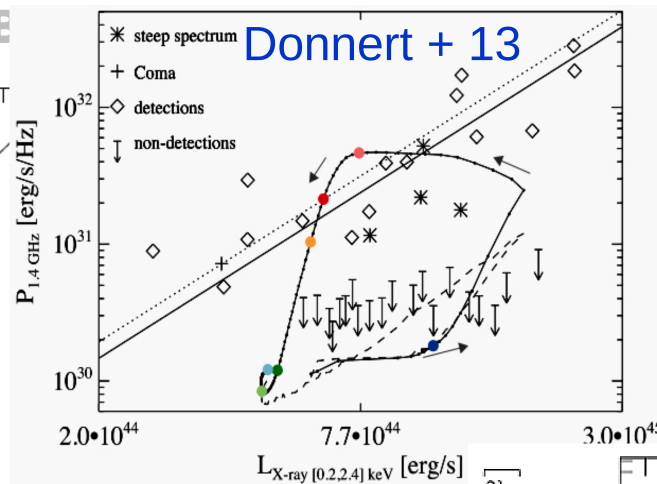
Plasma physics

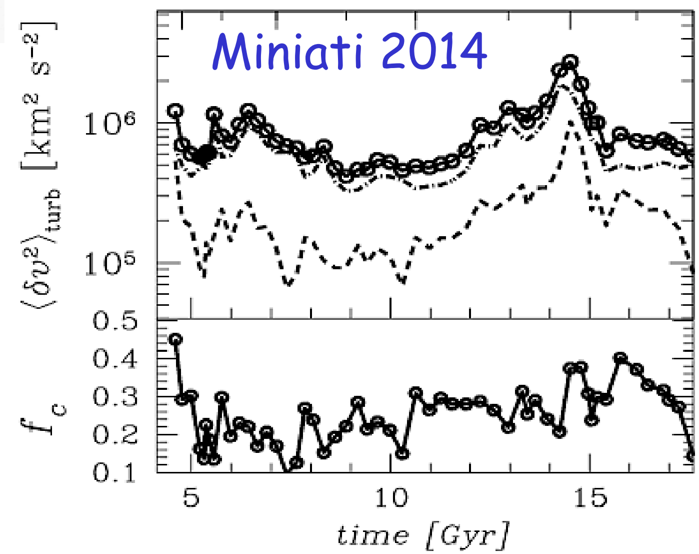
Critical issues … and minor issues

PHYSICS OF TURBULENT ACCELERATION

- CAN WE GENERATE RHs ?
- **WHAT DO WE PREDICT FOR THE RH/MERGER BIMODALITY ?**
- DO WE UNDERSTAND TURB







Transition phase surprisingly short

Critical issues … and minor issues

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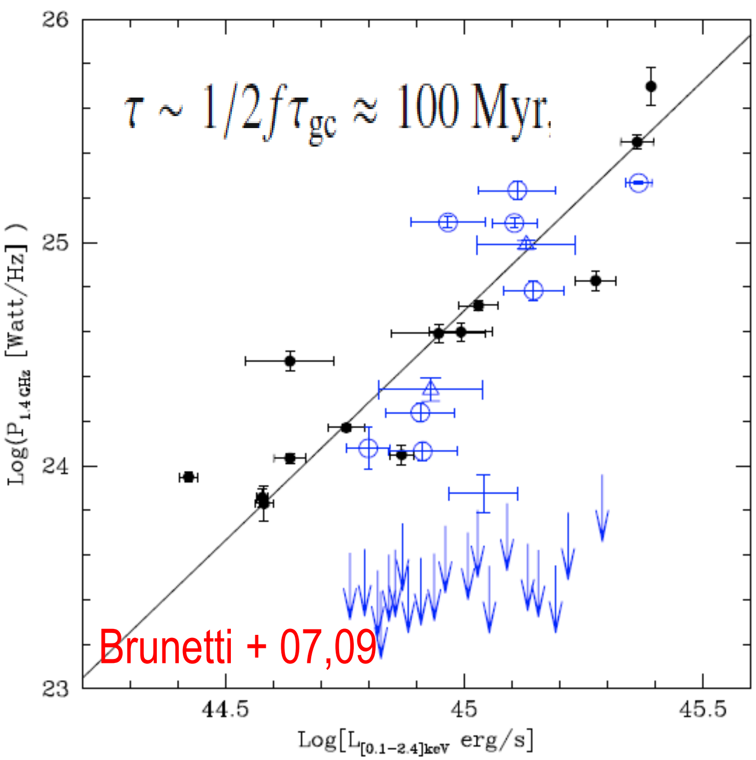
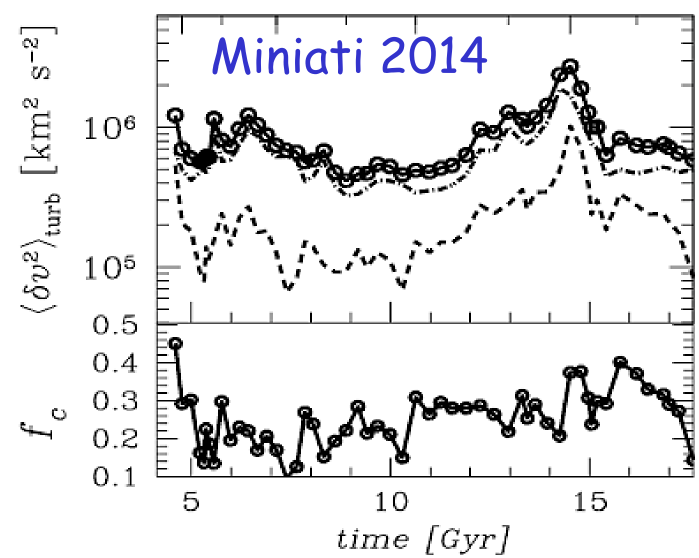


Also, Fig. 5 suggests that under these conditions the suppression of synchrotron emission that follows the dissipation of MHD turbulence is more efficient at higher frequencies and thus cluster *bi-modality* is expected to be less pronounced in considering the synchrotron emission of galaxy clusters at lower frequencies. This is a clear expectation of the scenario that can be tested with future observations of samples of galaxy clusters at 100–200 MHz that may be carried out with LOFAR in a couple of years.



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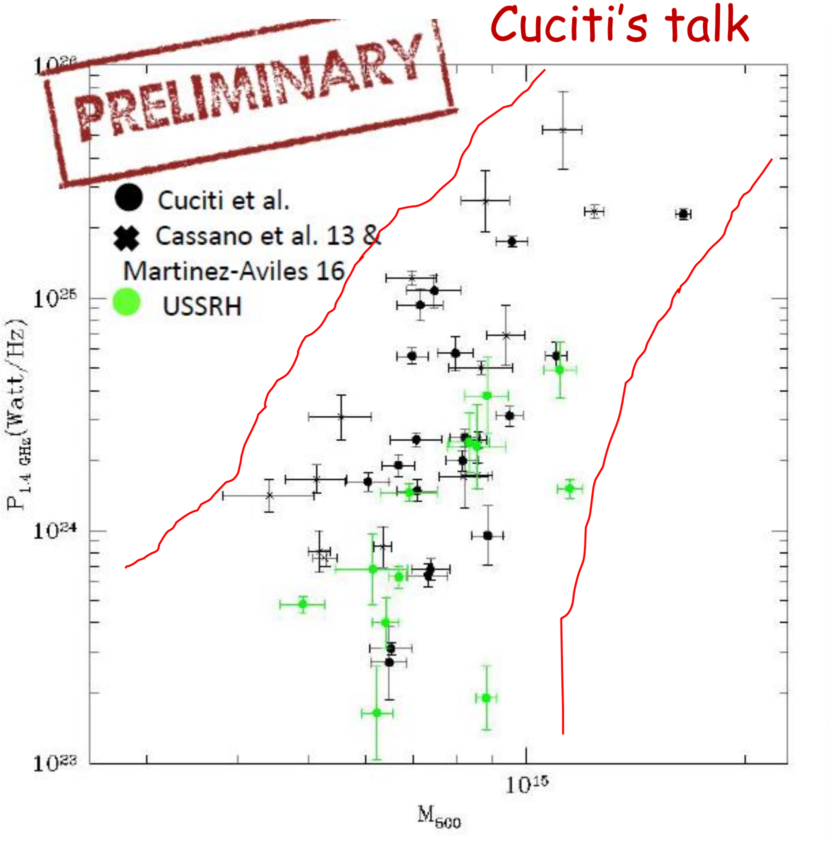
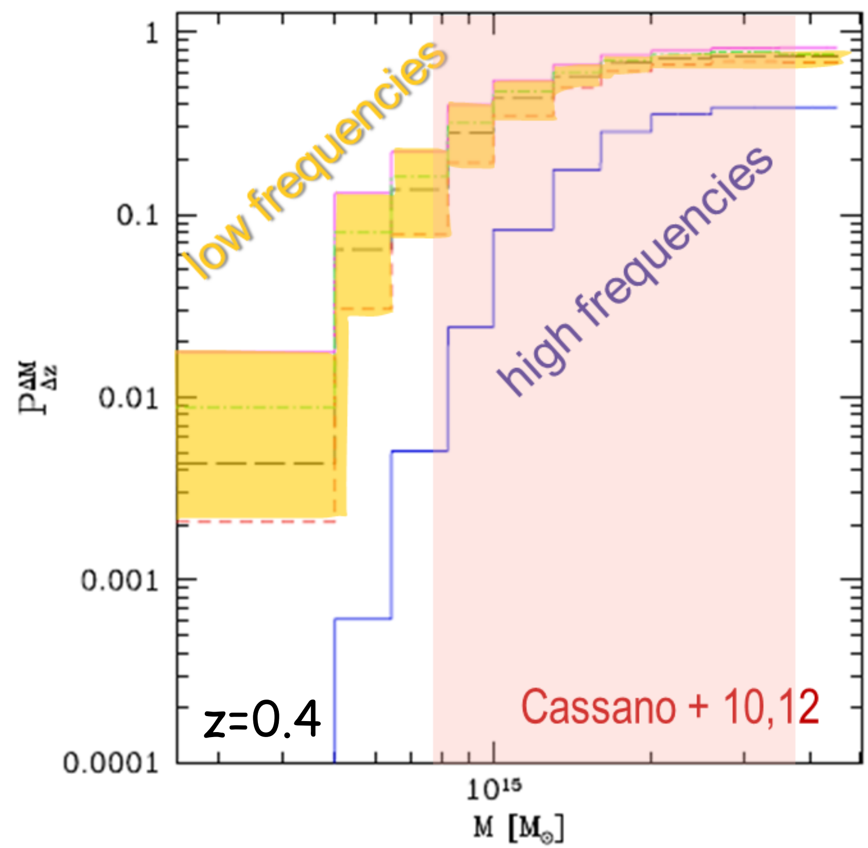
Cuciti's talk





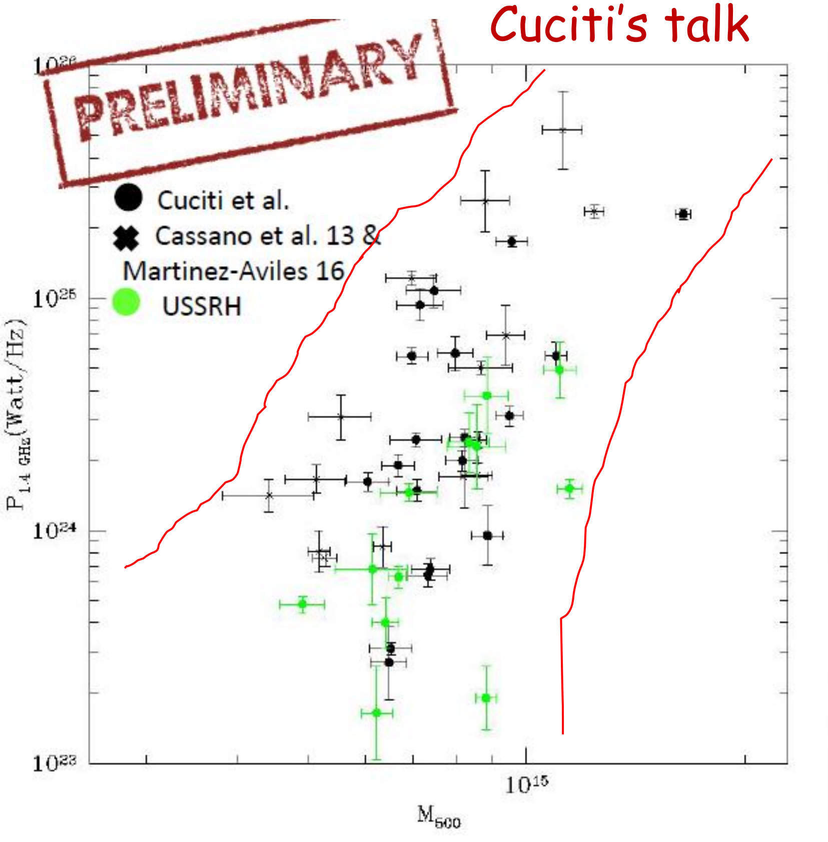
Critical issues … and minor issues

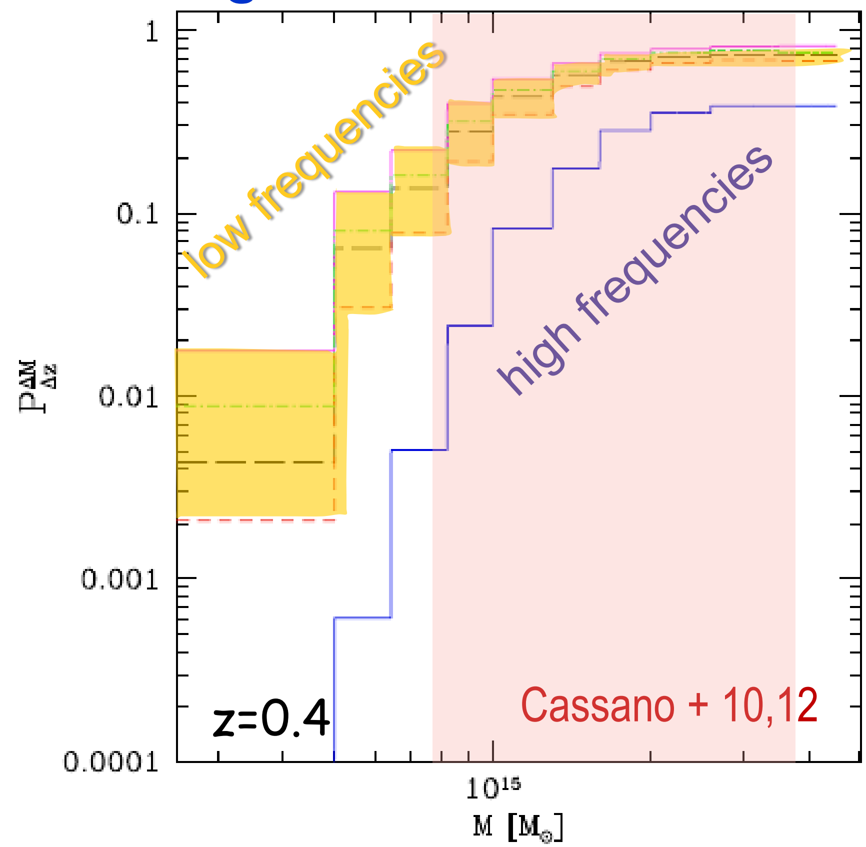
PHYSICS OF TURBULENT ACCELERATION

- CAN WE GENERATE RHs ?
- **WHAT DO WE REALLY EXPECT FOR THE RH/MERGER BIMODALITY ?**
- DO WE UNDERSTAND TURBULENT ACC IN THE ICM ?

Mix of populations: larger/smaller,flatter/steeper
Mix of evolutionary stages
Different magnetic fields/seeds

Cuciti's talk





Critical issues … and minor issues

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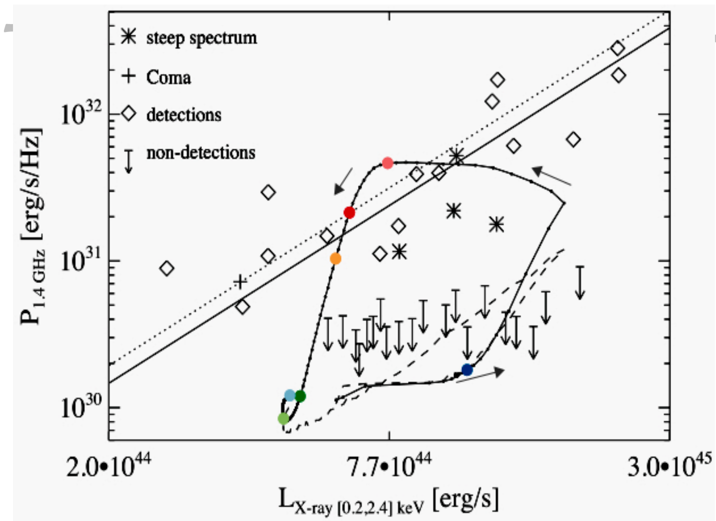
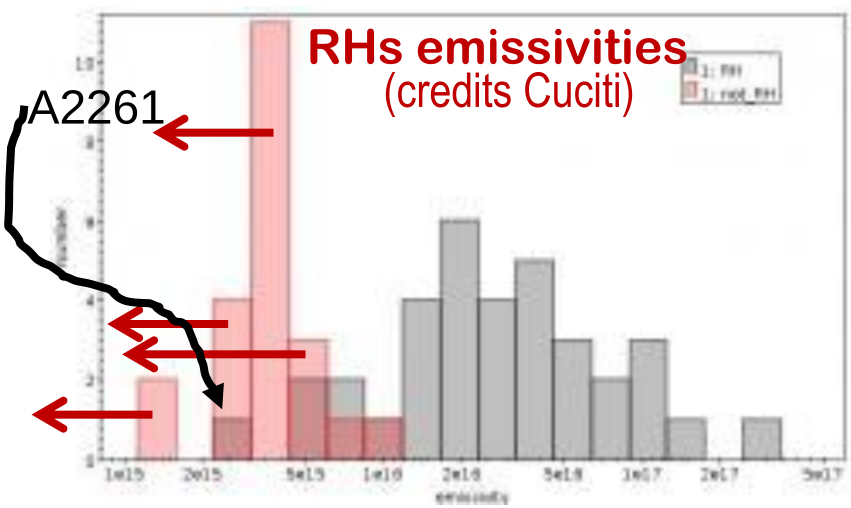


Mix of populations: larger/smaller,flatter/steeper

Mix of evolutionary stages

Different magnetic fields/seeds

Also, Fig. 5 suggests that under these conditions the suppression of synchrotron emission that follows the dissipation of MHD turbulence is more efficient at higher frequencies and thus cluster *bi-modality* is expected to be less pronounced in considering the synchrotron emission of galaxy clusters at lower frequencies. This is a clear expectation of the scenario that can be tested with future observations of samples of galaxy clusters at 100–200 MHz that may be carried out with LOFAR in a couple of years.



 # low frequencies #

 # higher z ? #

 # smaller masses ? #

 # work on theoretical side#

Real Problems … and minor issues

PHYSICS OF TURBULENT ACCELERATION

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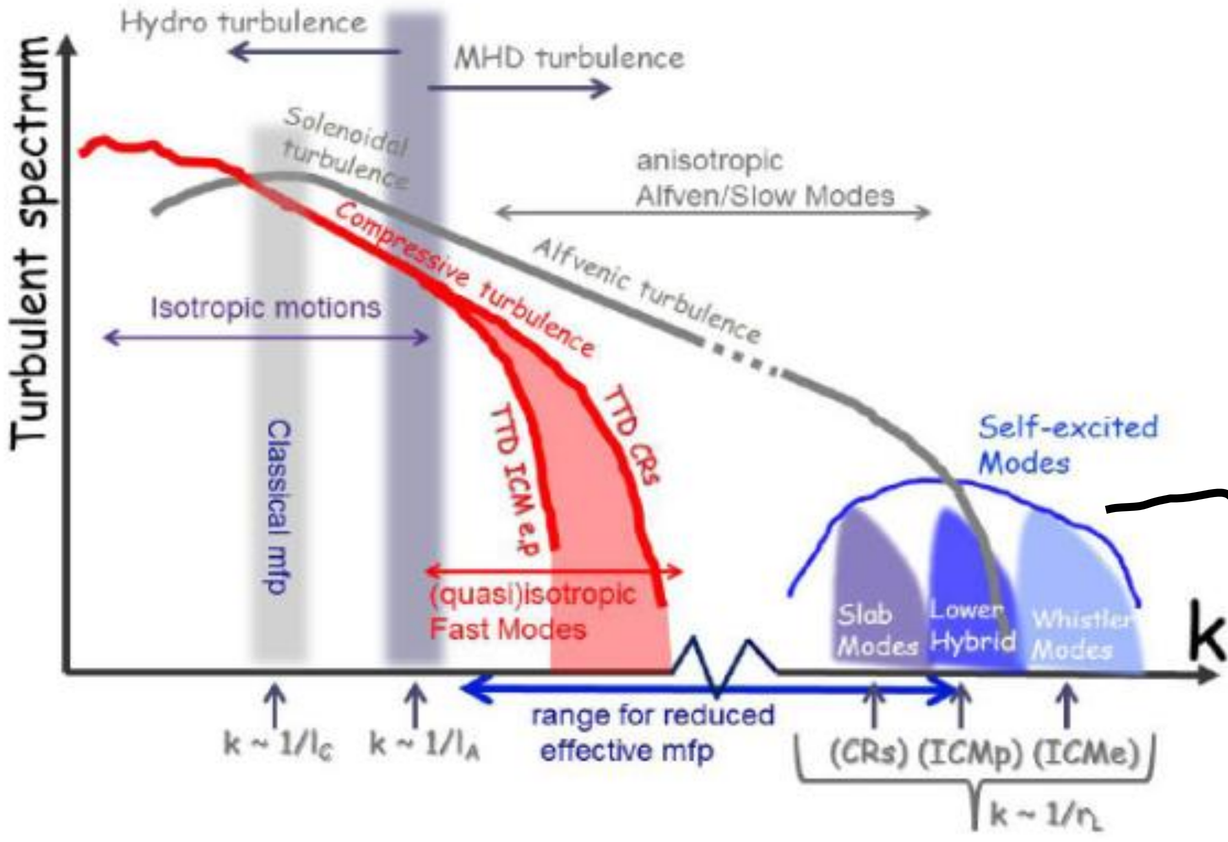
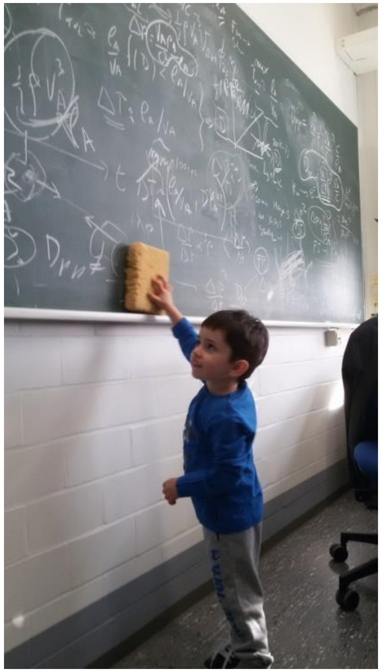




Important for scattering, mfp and dissipation of energy/generation of entropy in the ICM

TTD acceleration

(Miller et al 96, Schlickeiser & Miller 98
ICM: Brunetti & Lazarian 07, 11)

Transit Time Damping (TTD)

$\omega - k_{//} v_{//} = 0$

Interaction between magnetic momentum of particles and parallel gradient of B

Dissipation scale

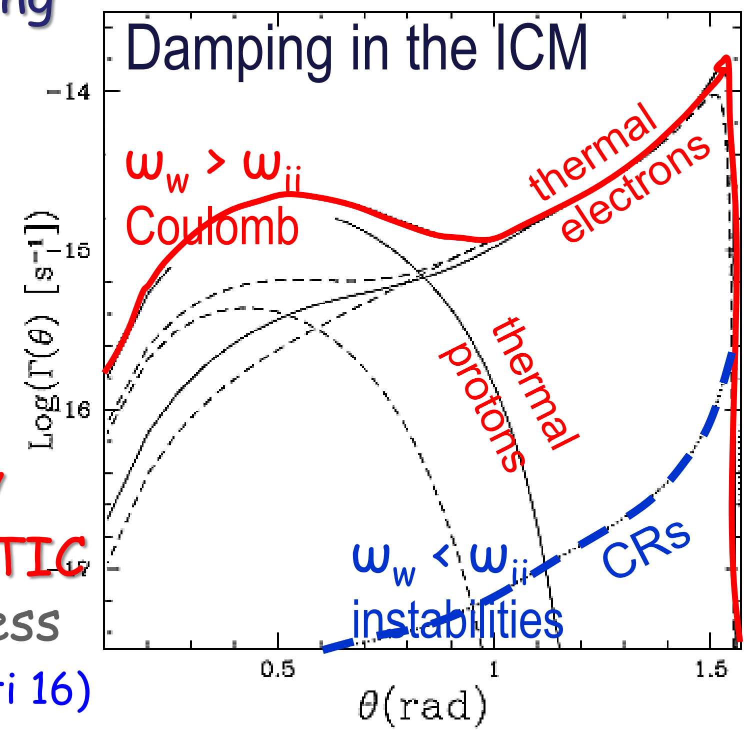
$$\tau_{acc} \approx \frac{p^2}{D_{pp}}$$

k_{cut}

$$D_{\rm pp}(p) = \frac{\pi^2}{2c} p^2 \frac{1}{B_o^2} \int_0^{\pi/2} d\theta\, V_{\rm ph}^2 \frac{\sin^3(\theta)}{|\cos(\theta)|} \mathcal{H}\left(1 - \frac{V_{\rm ph}/c}{\cos\theta}\right) \left[1 - \left(\frac{V_{\rm ph}/c}{\cos\theta}\right)^2\right]^2 \int^{k_{cut}} dk\, \mathcal{W}_{\rm B}(k) k$$

Cut-off is generated at scales where damping is faster than cascading.

$$k_{\rm cut,K} \simeq \frac{81}{4} \left(\frac{\delta V^2}{c_s}\right)^2 \frac{k_0}{\left(\sum_\alpha \langle \Gamma_\alpha \rangle k^{-1}\right)^2}$$



Acceleration depends on COLLISIONALITY and on the SPECTRUM of ELECTROMAGNETIC fluctuations in the ICM… kinetic spectrum less relevant ! (Brunetti & Lazarian 11, Miniati 15, Brunetti 16)

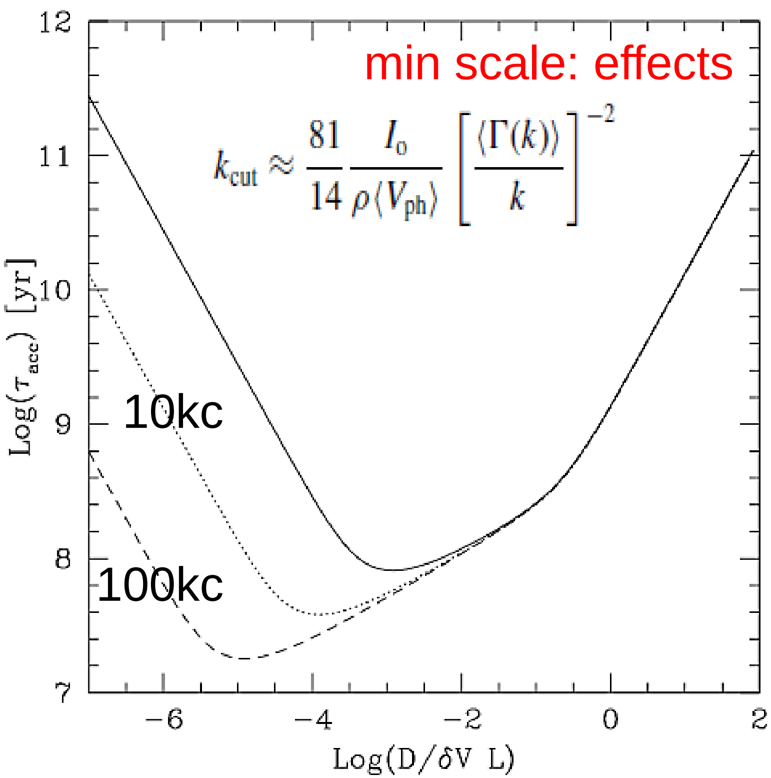
Nonresonant acceleration

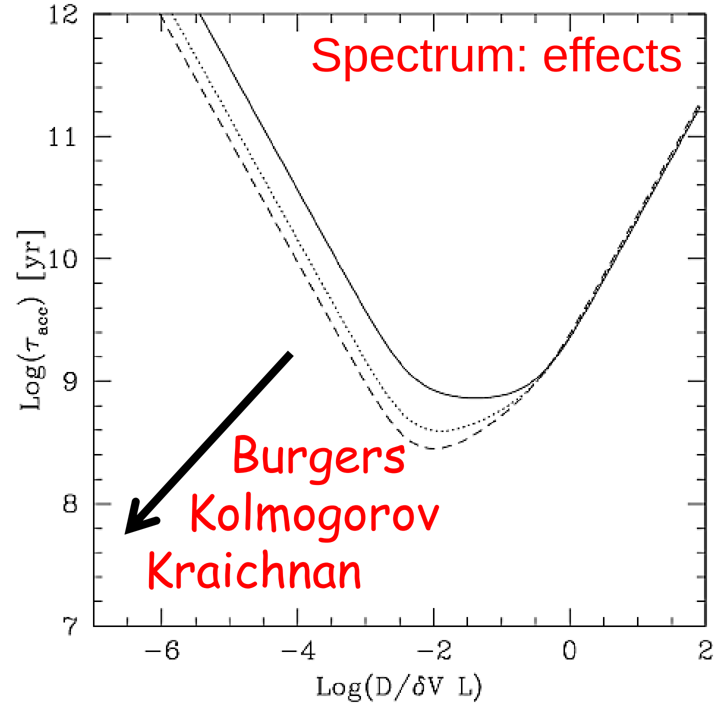
(Ptuskin 88, ..Brunetti & Lazarian 07)

$$D_{\rm pp} = \frac{2}{9} p^2 D \int_k \frac{{\rm d}y\, y^2 \mathcal{V}(y)}{c_s^2 + y^2 D^2}$$

and

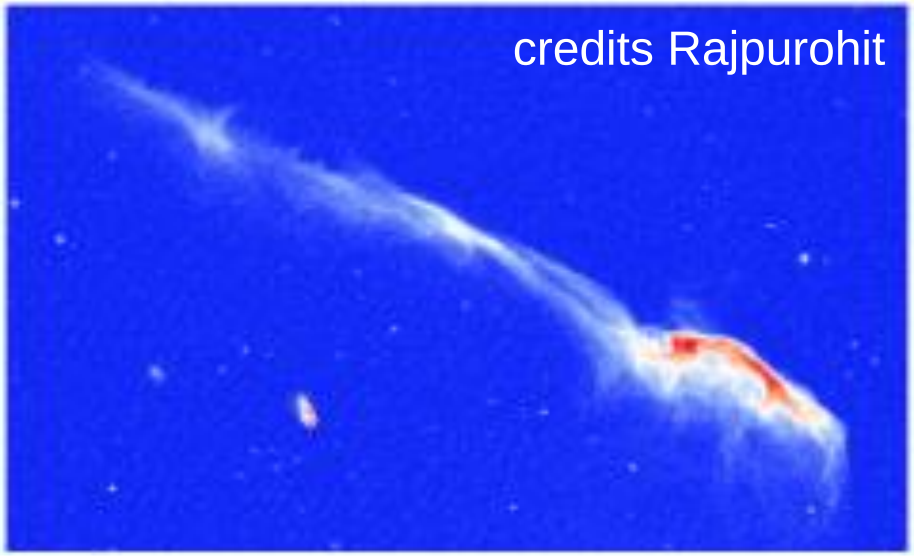
$$D_* = D \left[1 + \frac{4}{3} \int_k \frac{{\rm d}y\, \mathcal{V}(y)}{c_s^2 + y^2 D^2} \right]$$

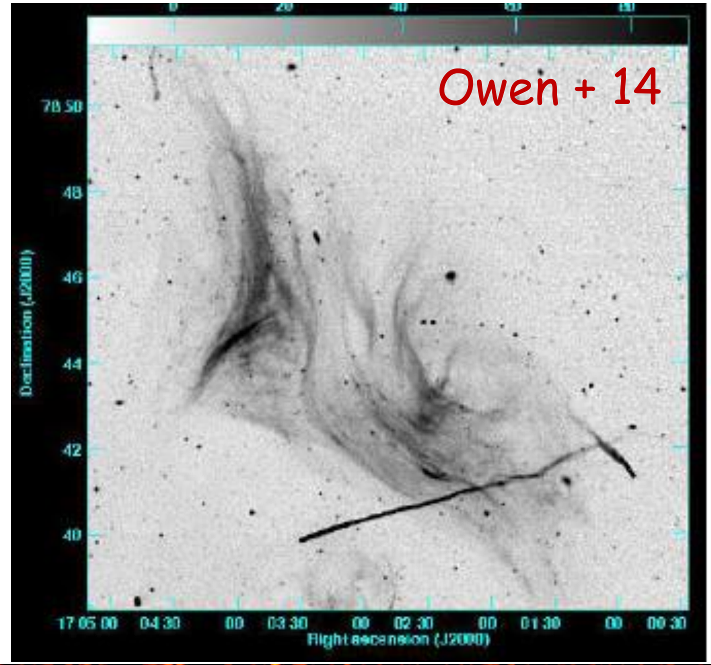


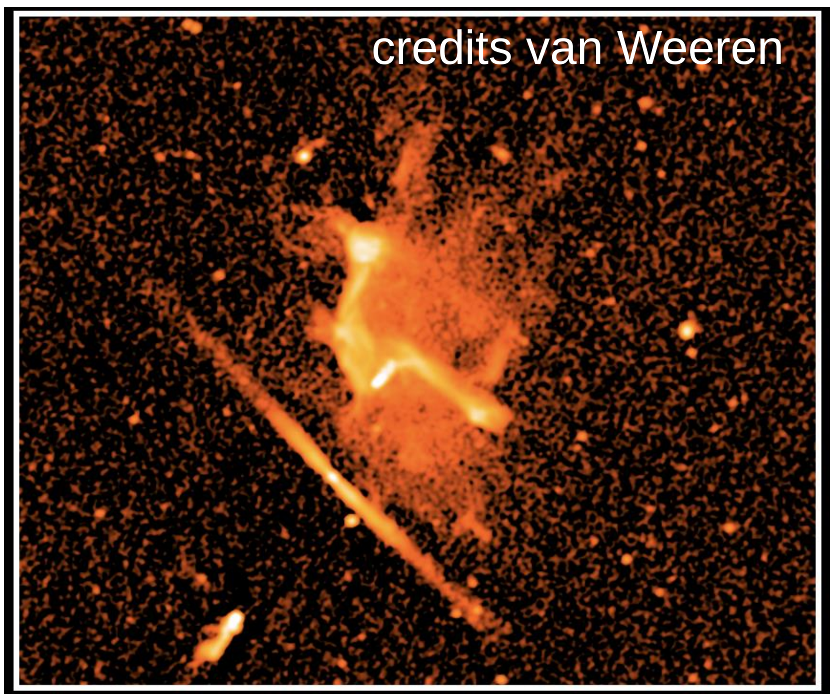


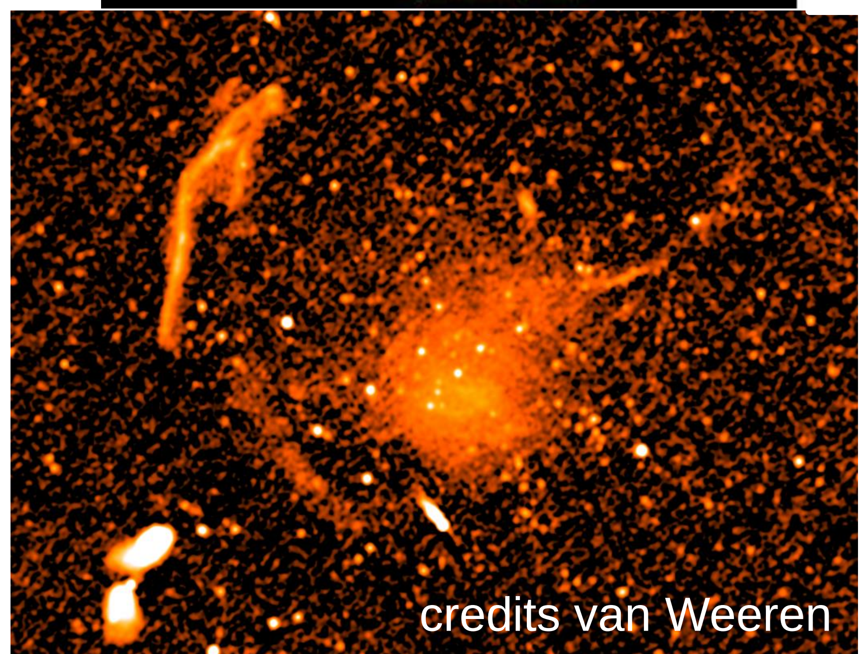
- **Turbulent energy**
- **Turbulent scales**
- **CRs diffusion (self-generated, & background turbulence)**
- **Plasma collision frequency (effective mfp)**

Details … however details can kill us !



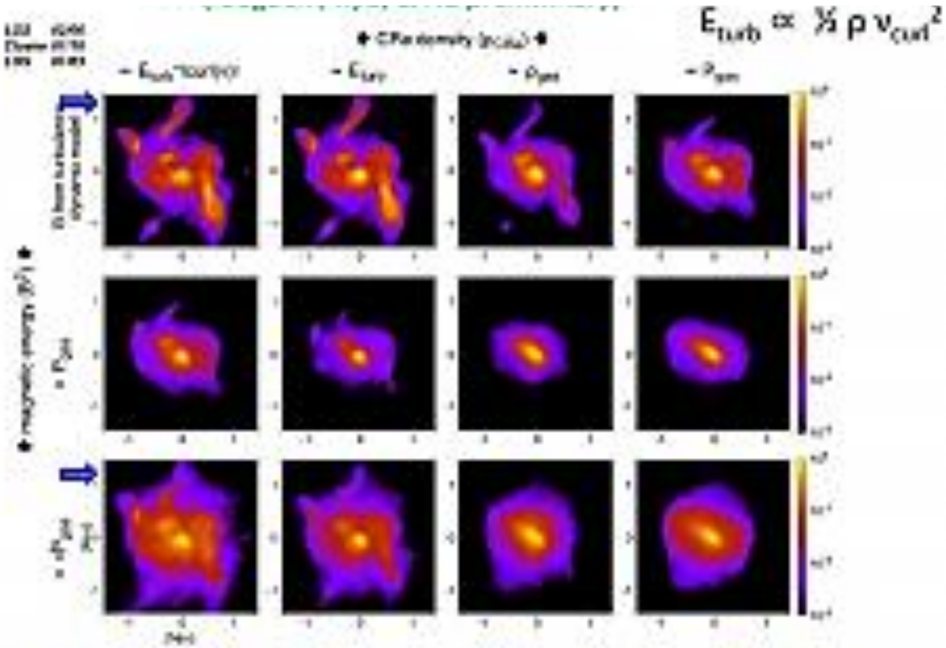




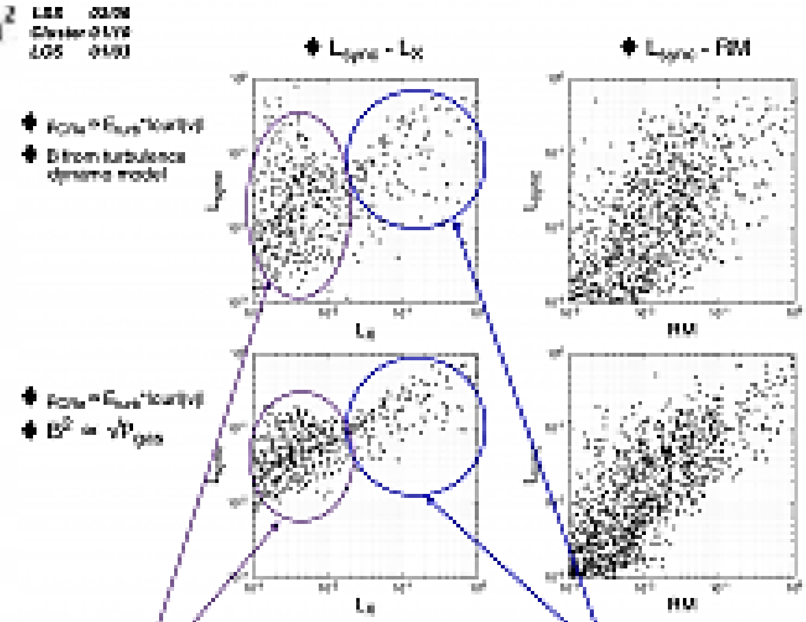


The proje
with unifo

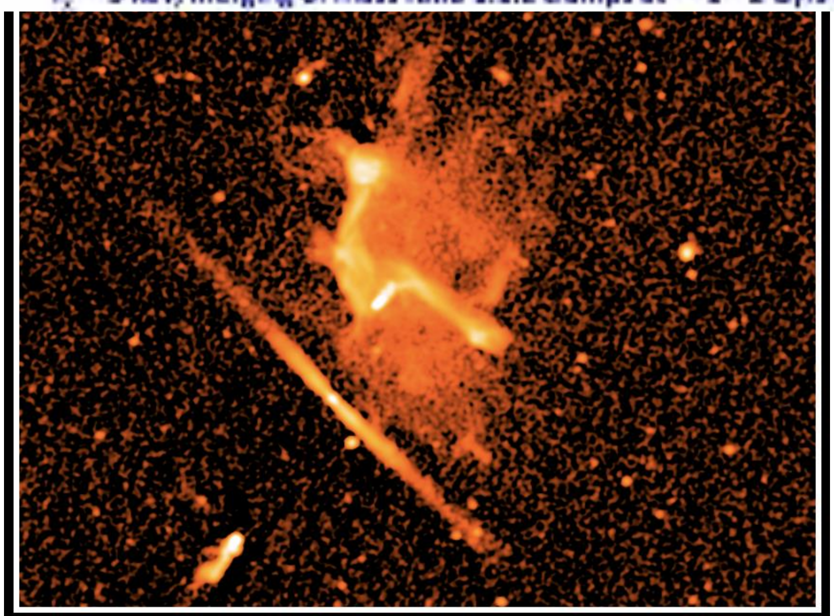
Details … however details can kill us !

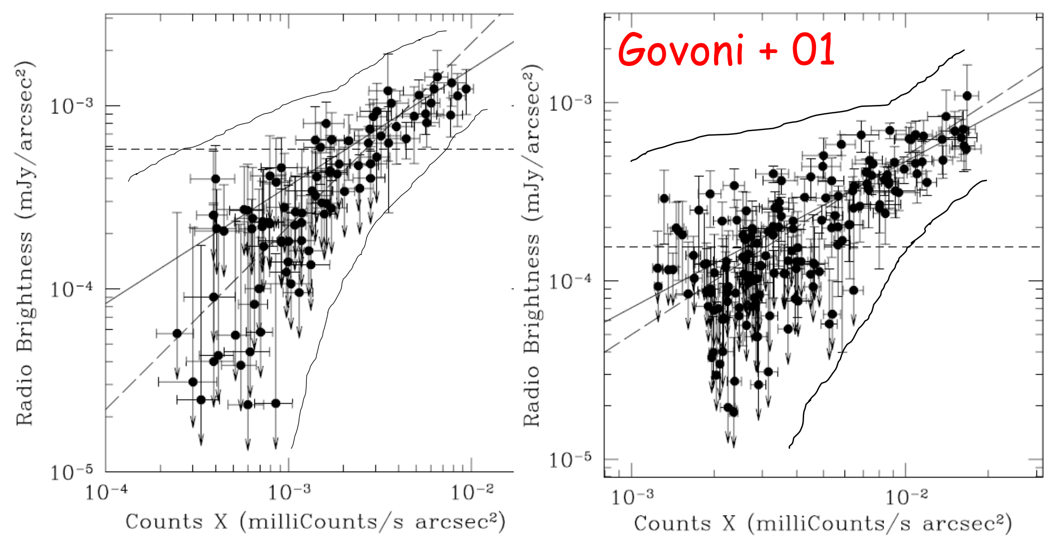


T_x ~ 5 keV, merging of mass ratio 1:1.2 clumps at ~ 1 - 2 Gyrs ago



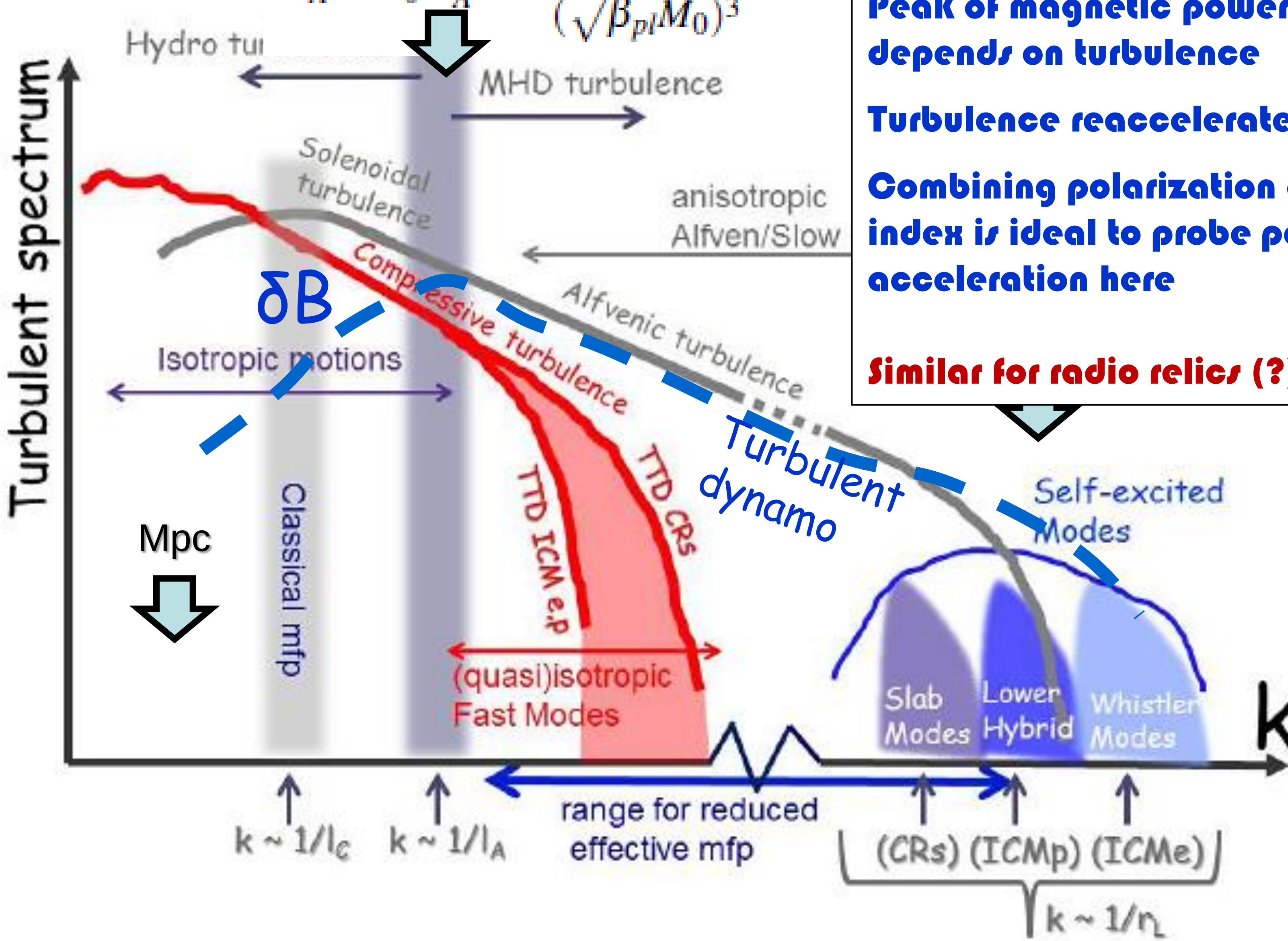
(credits D.Ryu)





A POSSIBLE OBSERVATIONAL STEP ??

$$l_A = L_0 M_A^{-3} = \frac{(6/5)^3 L_0}{(\sqrt{\beta_{pl}} M_0)^3}$$



Peak of magnetic power spectrum depends on turbulence

Turbulence reaccelerates particles

Combining polarization and spectral index is ideal to probe particle acceleration here

Similar for radio relics (?)

MHs .. GRHs

- Particle mixing/transport by sloshing ?
- Reacceleration ? Hadronic collisions ?
- Is there a population in between MHs and GRHs ?
- Do MHs evolve into GRHs in merging systems ?