Dark Matter and Cosmic Rays in Clusters of Galaxies

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Fermi Summer School – Lewes – May 31st, 2013

Clusters of Galaxies

Largest gravitationally bound systems in the Universe with mass of 10^{14} –10^{15} $M_\odot$ and radius of few Mpc

Actively evolving objects

Cosmic energy reservoirs

Expected to contain substantial populations of cosmic rays (CR)

About 80% of their mass is in form of dark matter (DM)

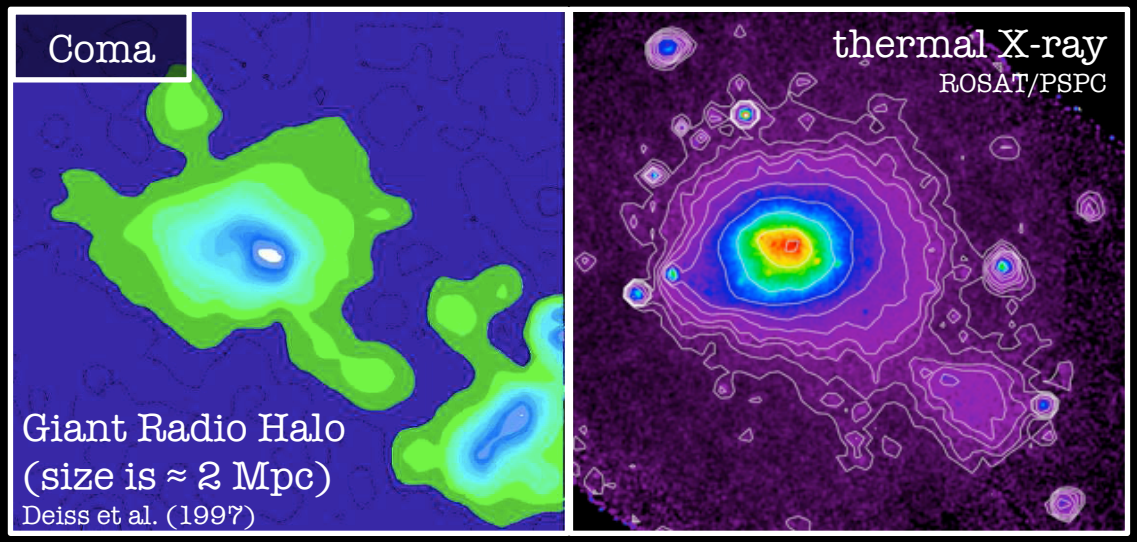
} can generate non-thermal emission from radio to gamma-ray frequencies

Non-thermal Diffuse Radio Emission

Radio Relics
- at the cluster periphery
- irregular morphology
- highly polarized
- seems to trace structure formation shocks

Radio (Mini-)Halos (RHs)
- at the cluster center
- regular morphology
- unpolarized
- similar to thermal X-ray emission

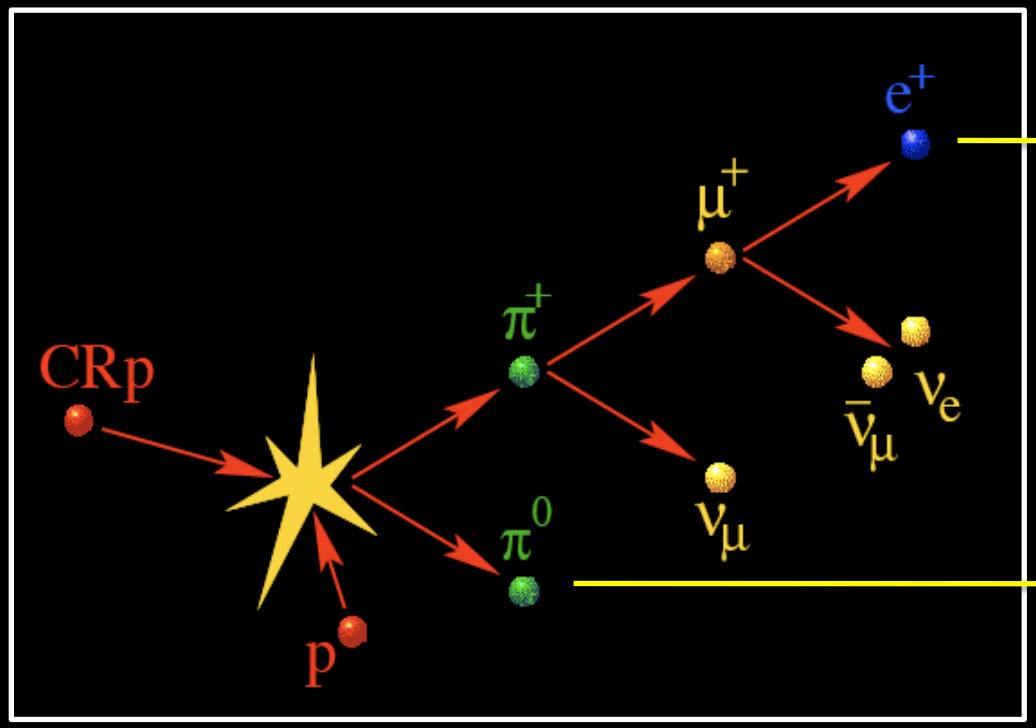
?



Cosmic Rays in Galaxy Clusters

E.g., cluster cosmological simulations of Pfrommer et al. (2008) and Pinzke & Pfrommer (2010) reproduce the observed synchrotron radio emission and predict gamma-ray emission

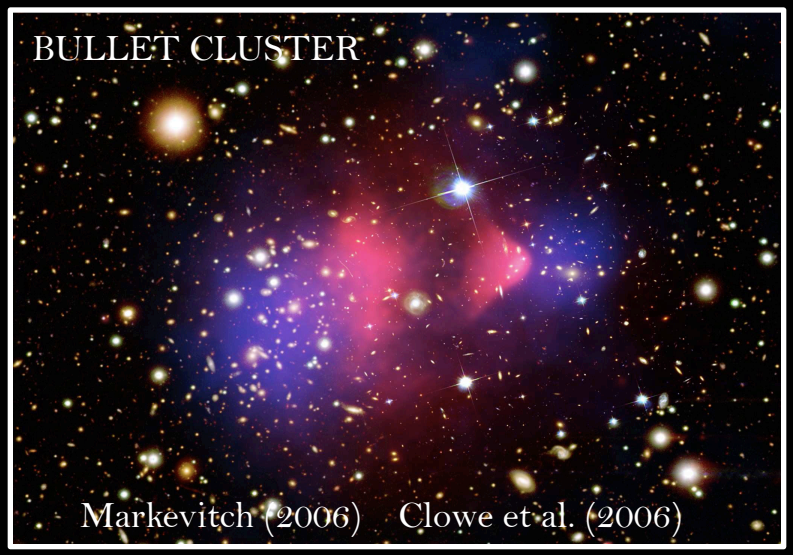
The dominant component results from CR hadronic interactions



secondary CR electrons produce synchrotron radio emission (observed in many clusters)

decay directly to gamma-rays (crucial to disentangle between different models)

Dark Matter Indirect Searches



WIMPs: Weakly Interacting Massive Particles

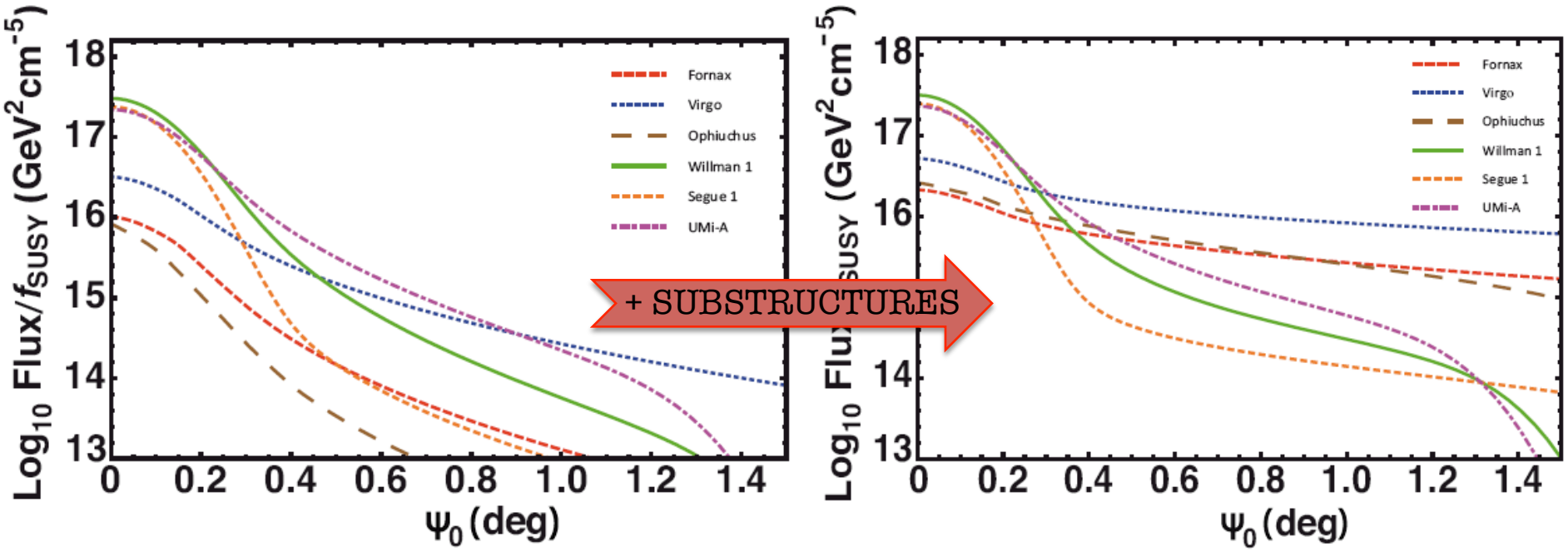
Direct products of DM annihilation or decay are model dependent. However, the decay and hadronisation of these products result (among others) in gamma-rays

Peculiar gamma-ray spectrum, a smoking gun for DM

DM Indirect Searches – Why Clusters?

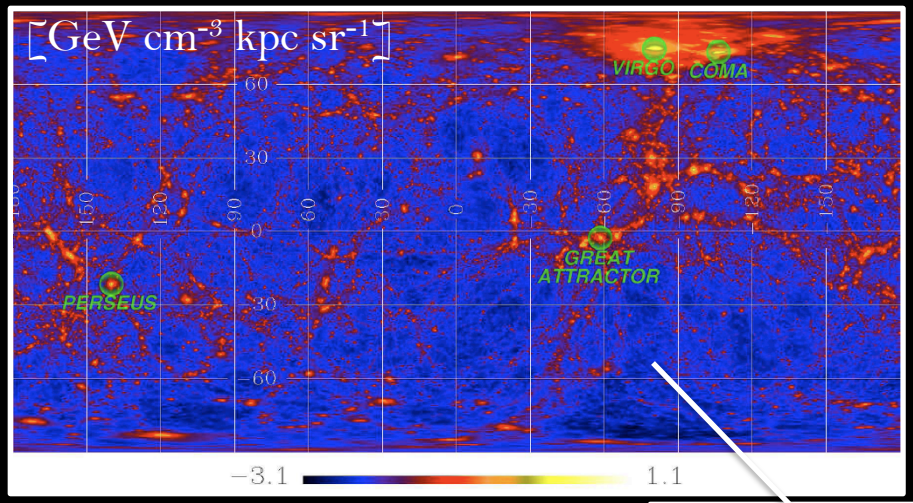
The Milky Way center and dwarf spheroidal satellite (dSph) galaxies are "classic" targets

Clusters → 80% of their mass is DM and we expect very high annihilation fluxes from them



Sanchez-Conde, Cannoni, FZ, Gomez & Prada (2011)
[see also Pinzke, Pfrommer & Bergström (2011)]

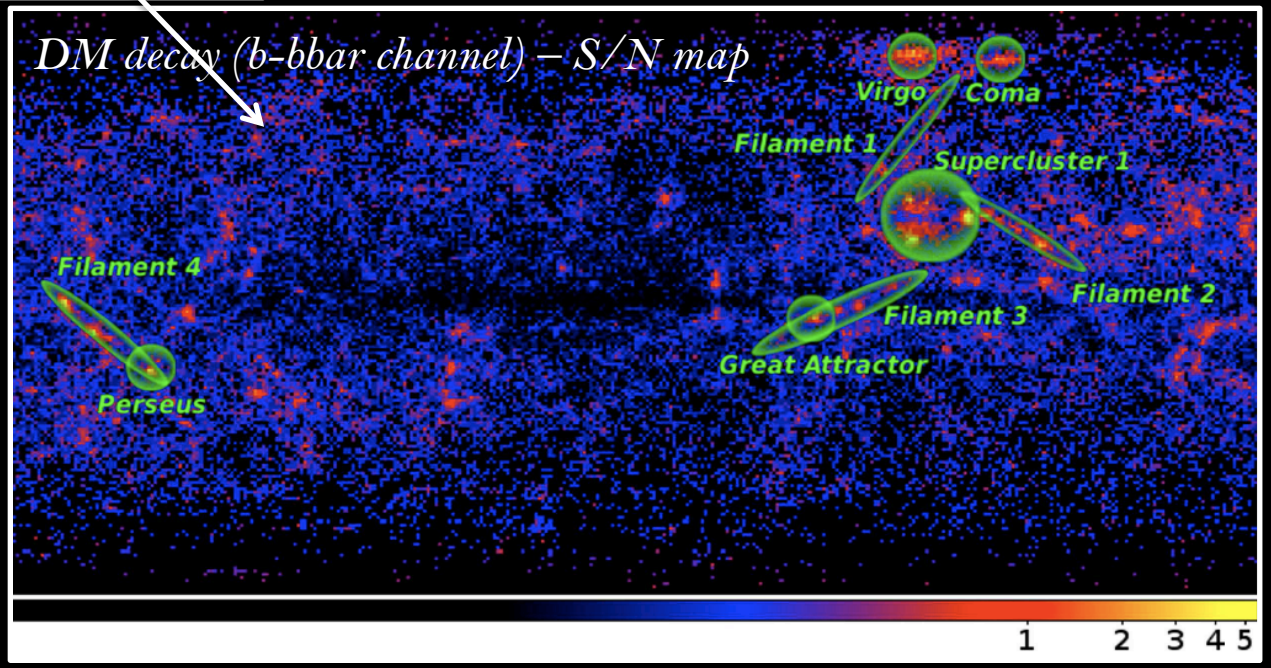
DM Indirect Searches – Why Clusters?



Cuesta, Jeltema, FZ et al.
APJ 726, 1, L6, 2011

5-years *Fermi* observation simulations of the DM annihilation and decay all-skymaps from N-body (constrained) cosmological simulations

DM ANNIHILATION AND DECAY TEMPLATE MAPS AVAILABE ON-LINE as FITS



The MAGIC Telescopes

Major Atmospheric Gamma Imaging Cherenkov

- Cameras FoV: 3.5 deg
- Energy Threshold: 50 GeV
- Angular Resolution: 0.1 deg @ 300 GeV
- Energy Resolution: 15% @ 1 TeV
- Sensitivity: 0.7% Crab Nebula (>600 GeV, 5 σ in 50 h)

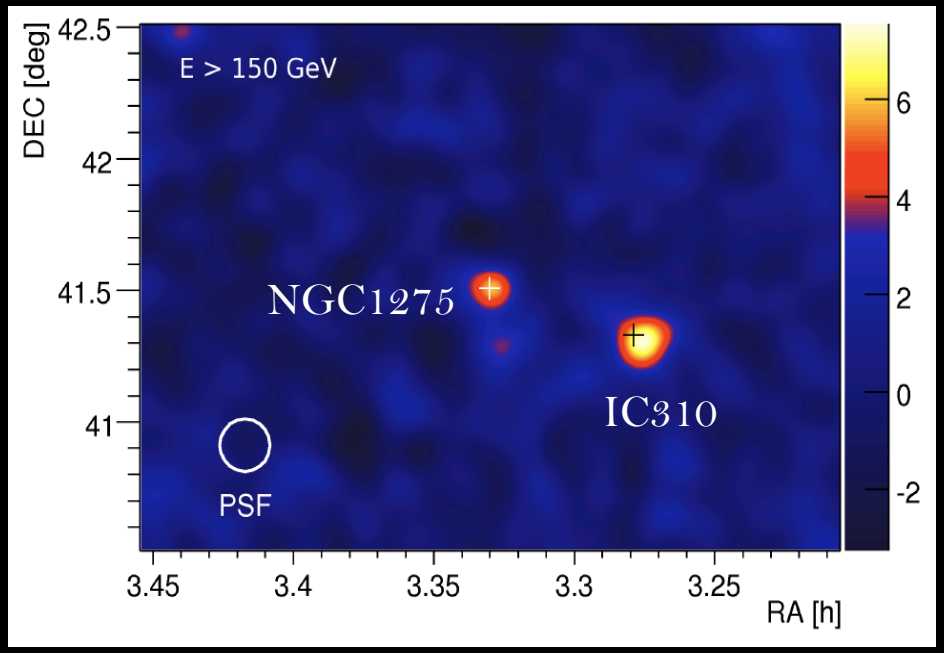
MAGIC Stereo Observation of Perseus

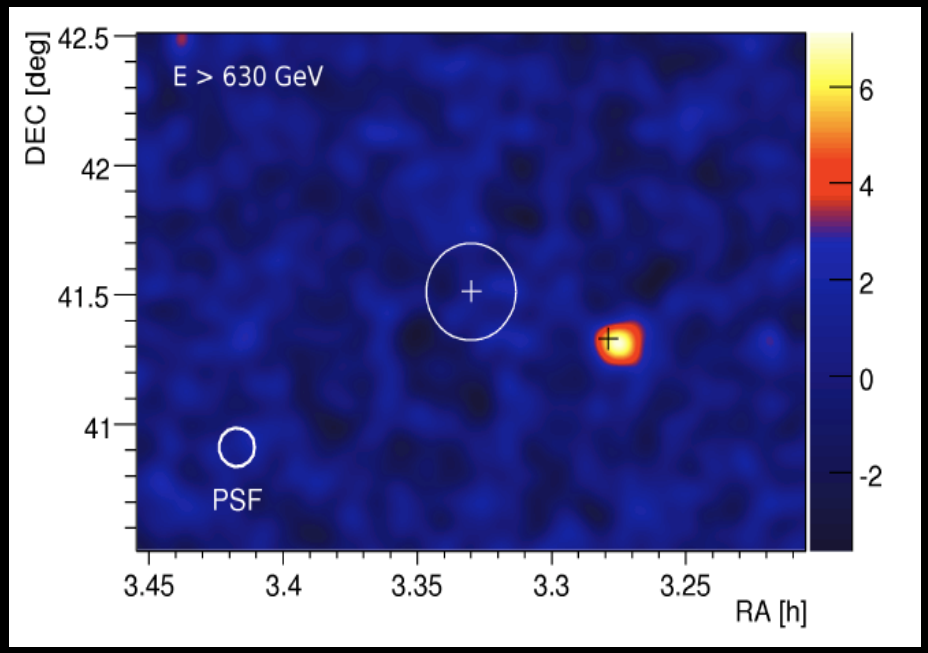
"Constraining Cosmic Rays and Magnetic Fields in the Perseus Galaxy Cluster with TeV observations by the MAGIC telescopes"

Aleksić et al. (FZ, Pfrommer, Colin, Pinzke & Lombardi as corr. authors)
A&A 541, A99, 2012

Total of 85 hours of data from Oct 2009 to Feb 2011

Deepest cluster observation at very high energy

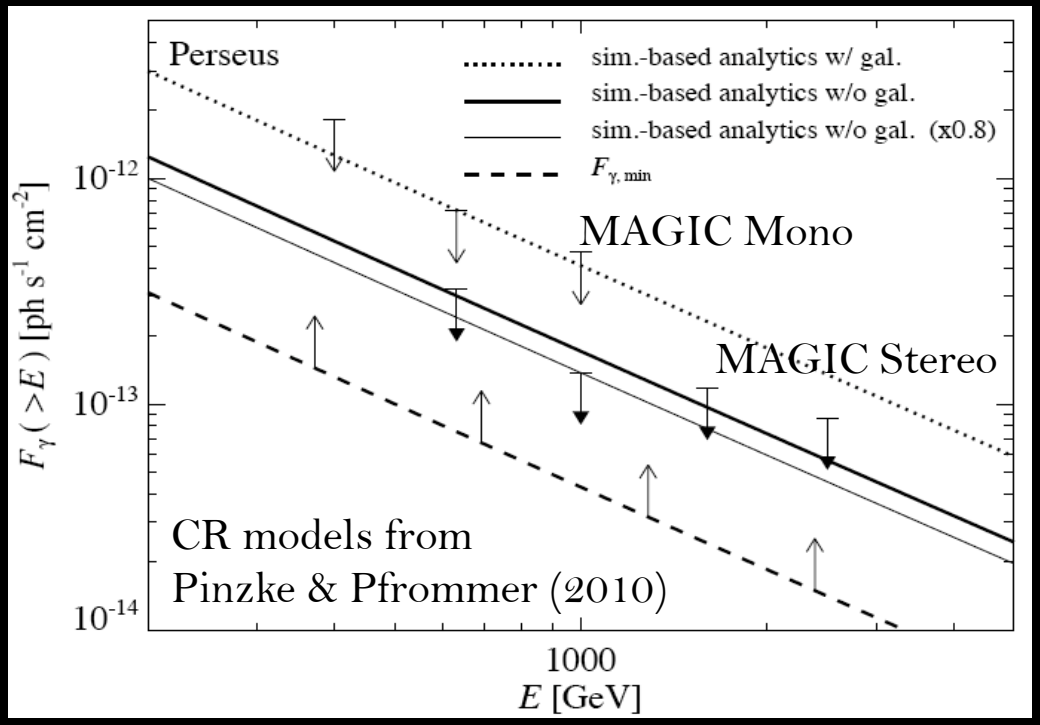


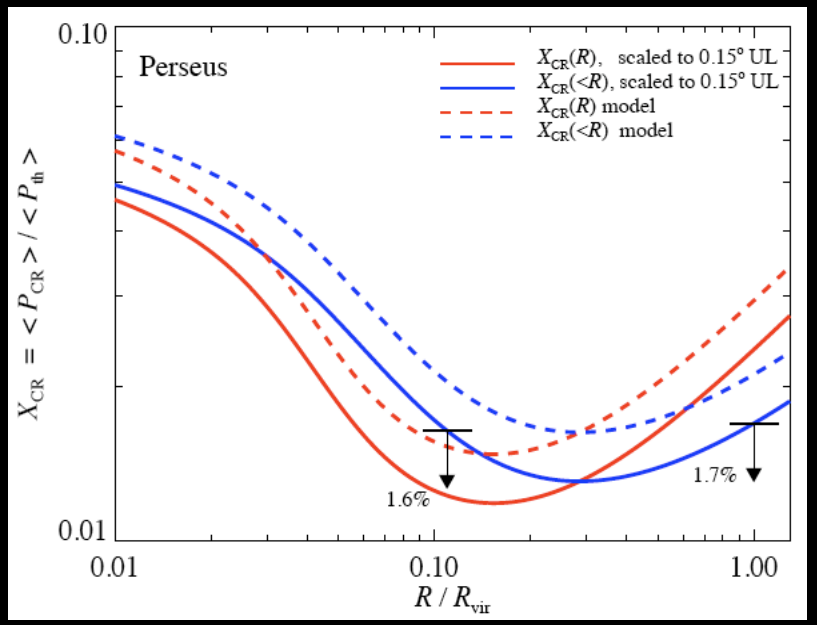


MAGIC Stereo Observation of Perseus

Simulation predictions are constrained for the first time

CR acceleration efficiency is < 50%
OR
significant CR propagation



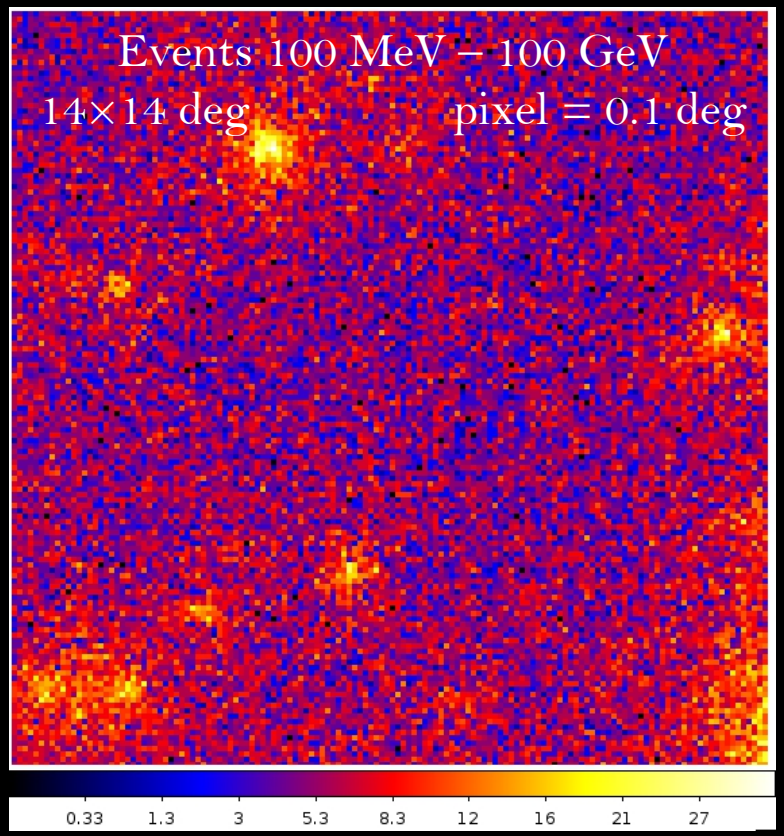


α_B	Minimum magnetic field, $B_{0,\mathrm{min}}$ [μG]: Γ			
	-2.1	-2.2	-2.3	-2.5
0.3	5.86	4.09	3.15	2.06
0.5	8.62	6.02	4.63	3.05
0.7	13.1	9.16	7.08	4.68

Analysis of *Fermi*-LAT data of the Coma Cluster

FZ & Ando 2013, *in preparation*

Analysis of 56 months of *Fermi*-LAT data on the Coma Cluster



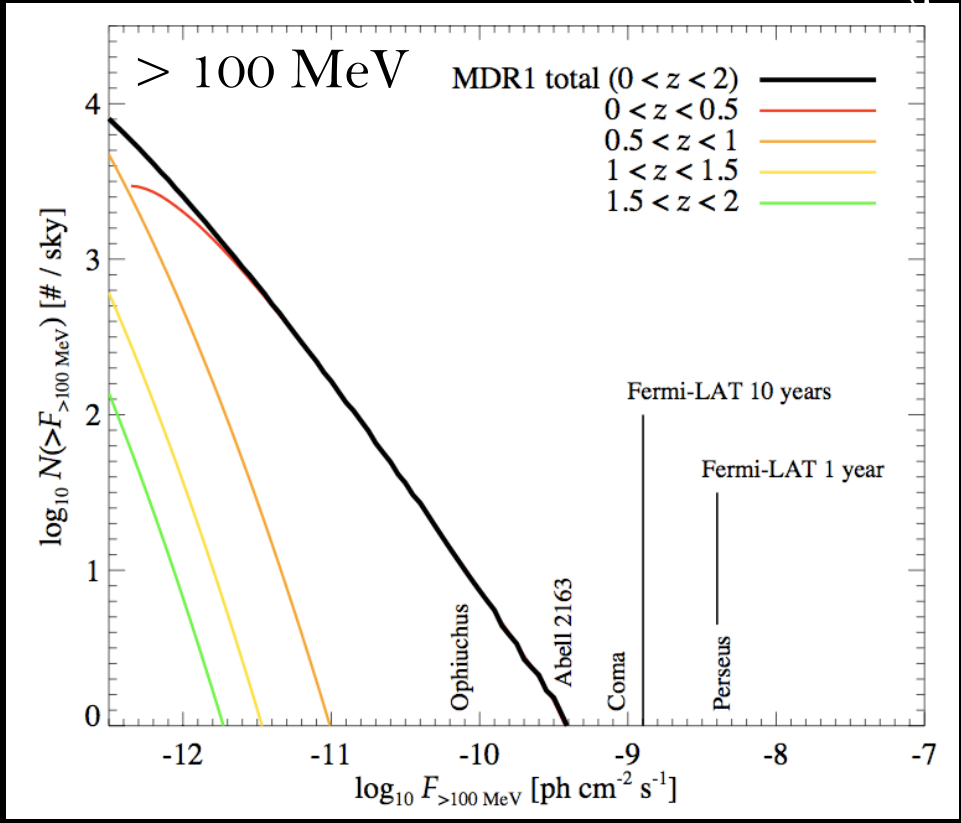
We test different diffuse CR models:

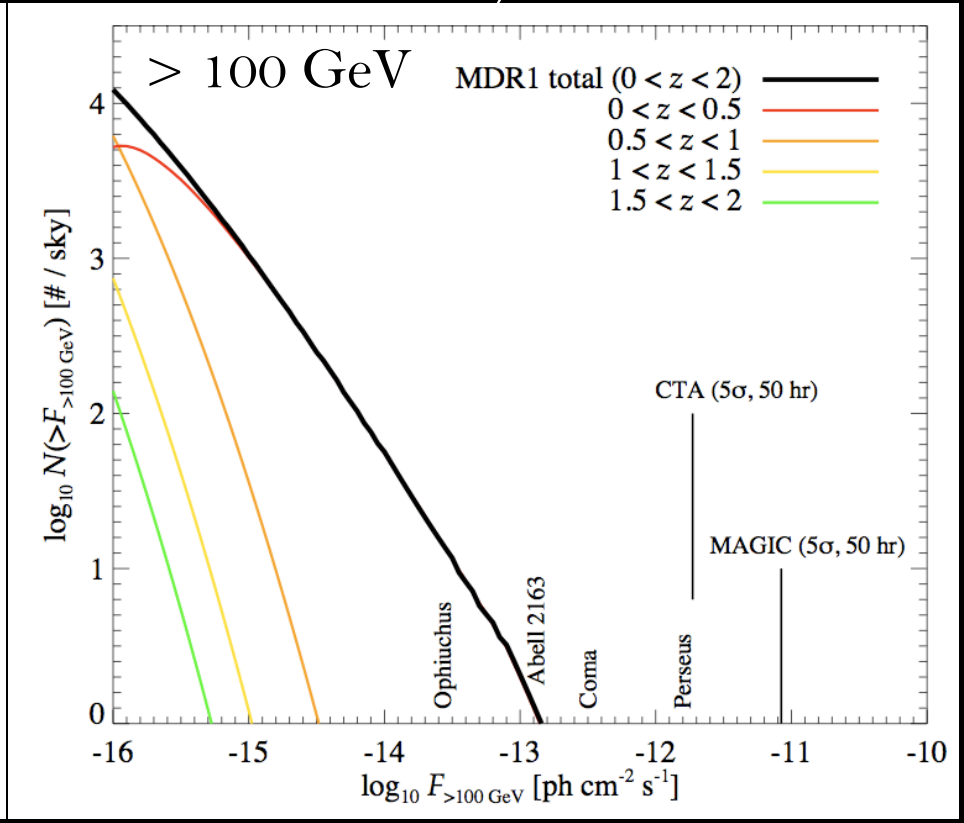
- Pinkze & Pfrommer (2010)
- FZ, Pfrommer & Prada (2012)
- Ring-like Model (Keshet et al. 2012)
- …

→ NO DETECTION so far (TS ≤ 3)

CR-induced Gamma Emission in Clusters

PRELIMINARY (point-like sensitivities)



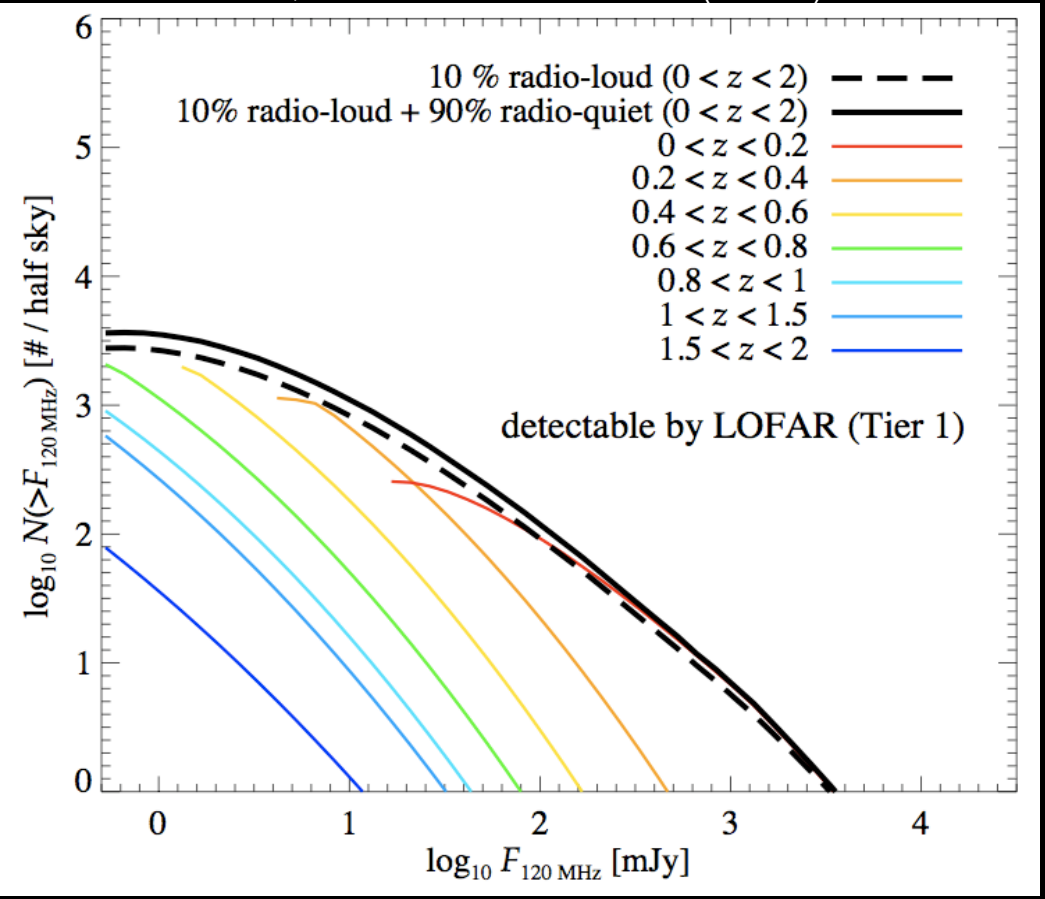


(from the mock cluster catalog of FZ, Pfrommer & Prada 2012)

CTA and *Fermi* (10 years) could be able to detect CR-induced gamma-ray emission from a handful of clusters at most

120 MHz Radio Emission in Clusters

FZ, Pfrommer & Prada (2012)



LOFAR Tier 1 at 120 MHz should detect about 3500 RHs above 0.5 mJy, under this model assumptions

Future Prospects

Detection of cluster gamma-ray emission would be a major scientific discovery

A tremendous breakthrough in the understanding of the physics of particle acceleration and structure formation

<u>Open up a new window to study</u>:

- non-thermal processes in clusters
- high-energy physics in the largest and latest structures
- DM, CR, ICM, and cluster magnetic field
- formation and evolution of clusters and of the Universe itself…

Thanks!