Galaxy Clusters with the Fermi LAT: Status and Implications for Cosmic Rays and Dark Matter Physics

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Summary: We present an overview of recent studies searching for γ-rays emanating from galaxy clusters and the consequences of their non-detection, primarily for understanding cosmic-ray (CR) physics in these environments.

Galaxy clusters are the most massive systems in the known universe. They host relativistic CR populations and are thought to be gravitationally bound by large amounts of Dark Matter (DM), which under the right conditions could yield to a detectable γ-ray flux.

Prior to the launch of the Fermi satellite, predictions were optimistic that Galaxy clusters would be established as γ-ray-bright objects by observations through its prime instrument, the Large Area Telescope (LAT). Yet, despite numerous efforts, even a single cluster detection is still pending.

Introduction

Clusters form by baryonic matter accreting onto the DM potential wells (DM observed directly through lensing)

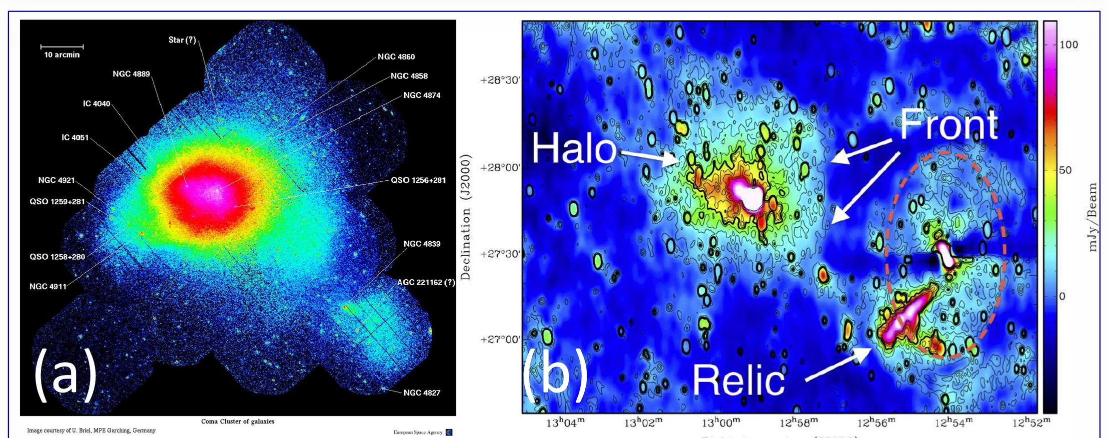


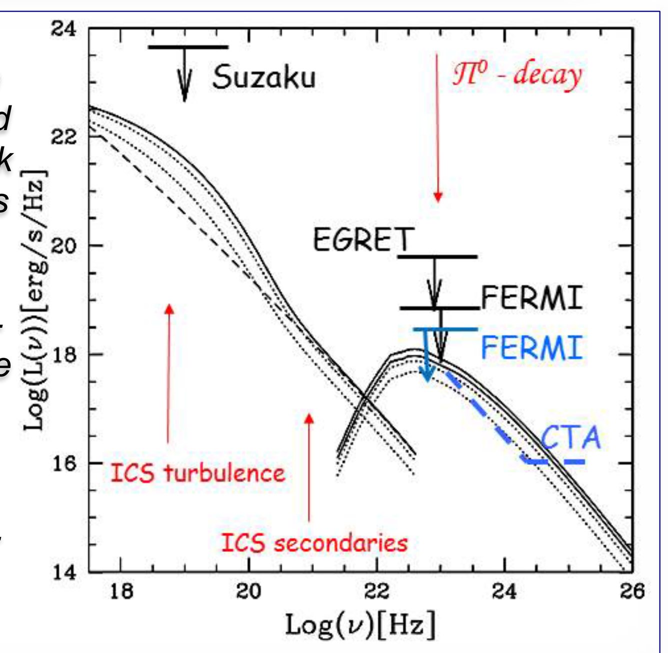
Figure 1: (a) XMM-Newton image of Coma cluster (0.3-2.0 keV). Image credit: U. Briel (MPE Garching) (b) Westerbork Synthesis Radio Telescope image of Coma at 352 MHz. Image credit: Brown & Rudnick (2010)

no signs of non-thermal X-rays in Coma, yet radio emission indicates relativistic electron populations (IC->γ, leptonic models)
CR protons (π^0->2γ, hadronic models)?

Combined Cluster searches: Cosmic-Rays Induced γ-rays & Implications of Non-detection

no cluster detection in γ-rays: single (radio?) galaxies to be blamed for observed mild excess

Figure 2: *the high-energy emission of the Coma cluster compared with current limits. Black lines denote predictions from turbulent reacceleration models. In all predictions the B-field is fixed to the value and radial profile that are favored by current Faraday rotation measurement analysis. figure & caption credit [2]*



Secondary models in trouble?: Fermi LAT limits a factor two above theoretically predictions which do not conflict with radio observations

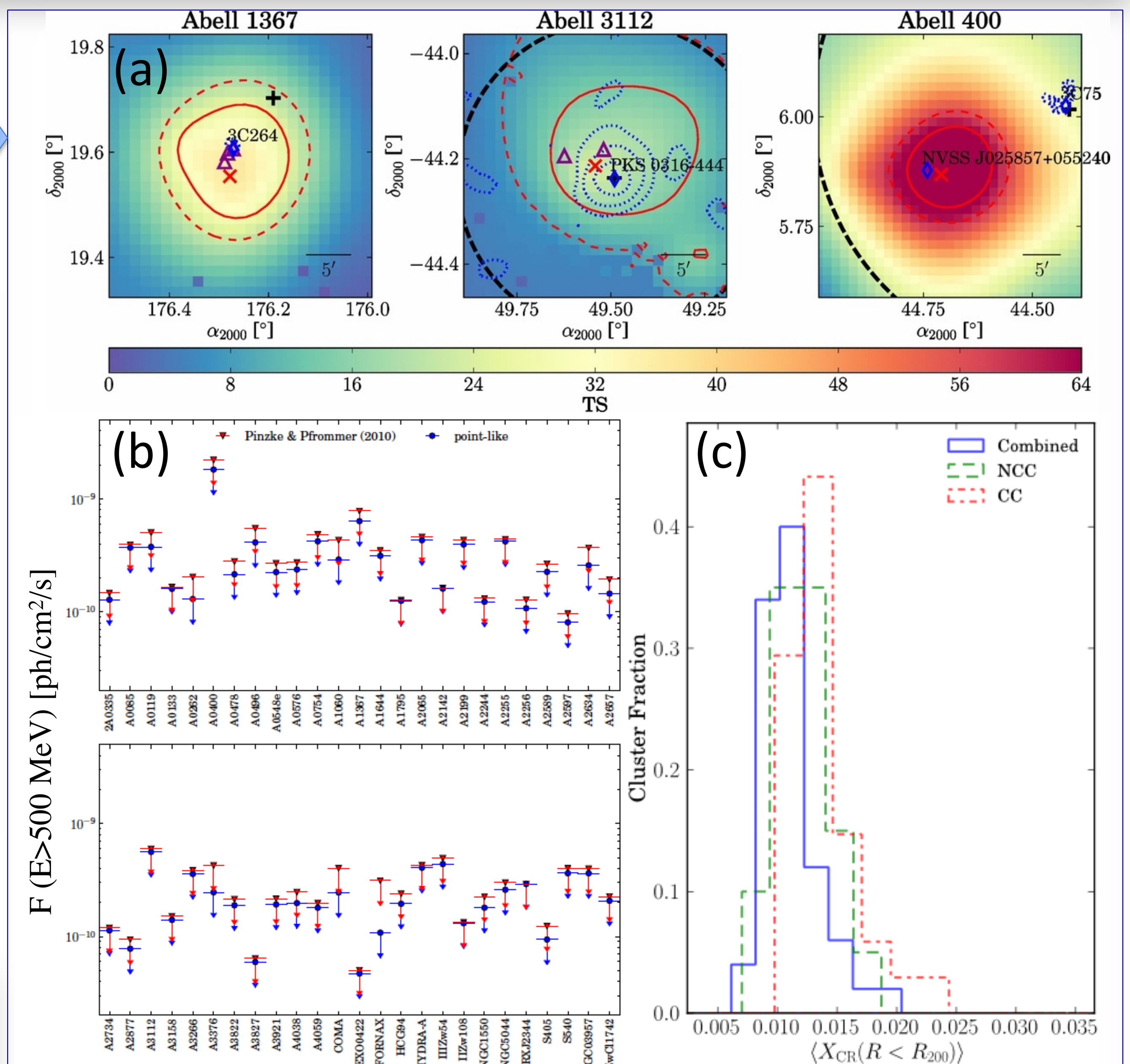


Figure 3: *(a) TS-maps for clusters with TS>9. The solid (dashed) red contours indicate the 68% (95%) γ-ray contours (red cross is best fit). Blue diamonds indicate NED positions of radio galaxies with their associated contours in dashed-blue lines. Finally, purple triangles indicate Chandra X-ray point sources (b) Individual 95% limits on hadronically-induced γ-ray flux (c) CR-to-thermal pressure ratio for three samples: full stack, cool-core (CC) and non-cool core (NCC). [1]*

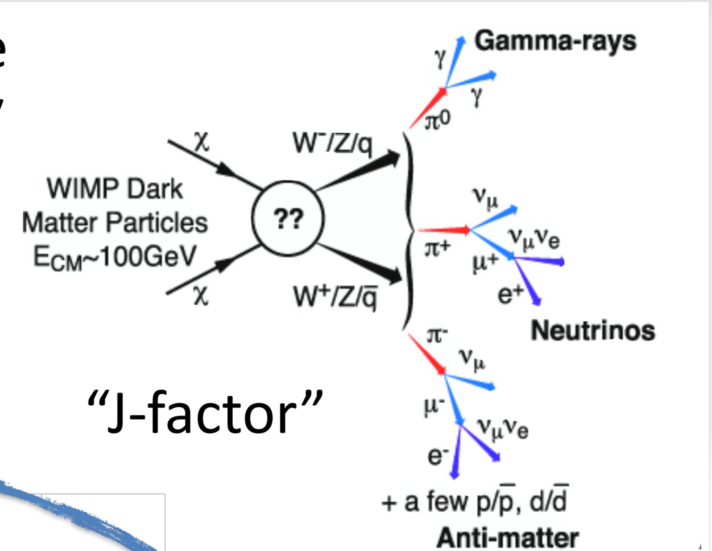
Combined Cluster searches: Dark Matter

Potential γ-ray signature due to self-annihilation/ -decay of DM [3]

$$\Phi_{DM} = \frac{1}{4\pi}\frac{\langle\sigma_{ann} v\rangle}{2 m^2_{WIMP}} \sum_f \frac{dN^f_\gamma}{dE_\gamma} B_f$$

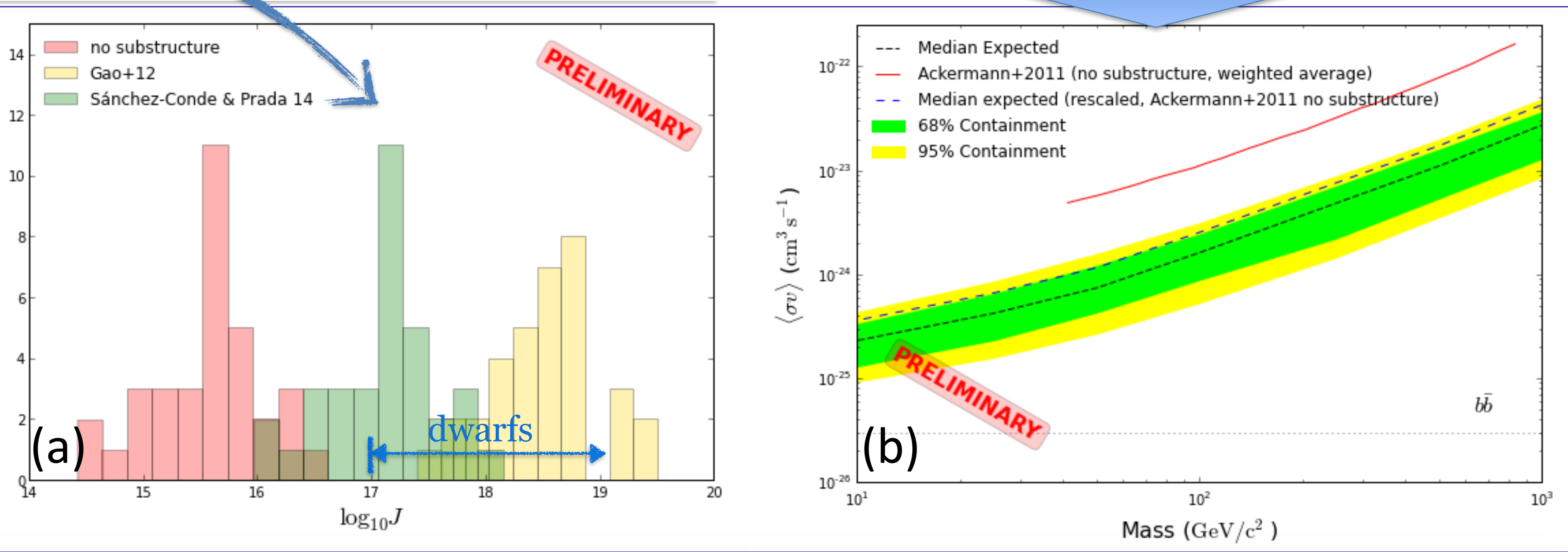
$$\times \int_{l.o.s.} dl(\psi)\rho^2(l(\psi))$$

"J-factor"



Sensitivity to previously published results factor ~2 better (less than pure statistical improvement) but: advanced (more realistic) modeling of DM spatial distribution (conservative and optimistic boost scenarios considered) [5]

Figure 4: *(a) J-factor distribution for different models of DM substructure modeling (dwarf range added for comparison purposes [4]) (b) Expected sensitivity for WIMP annihilation into bb with 5 year LAT dataset (500 MeV - 500 GeV, 34 clusters) based on full MC simulation of γ-ray sky.*



Single target searches: Extended Emission from Virgo?

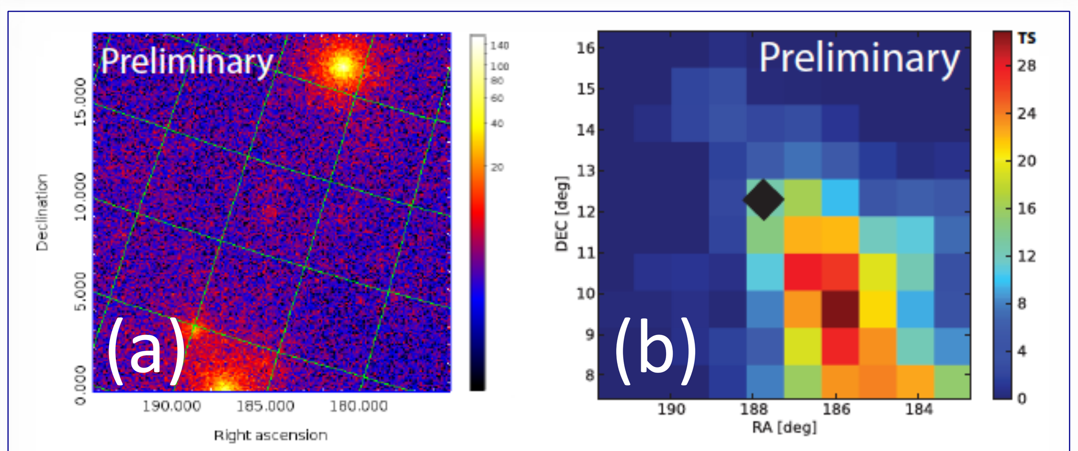


Figure 5: *Virgo ROI (20°x20°) (a) counts map between 100 MeV - 100 GeV, 2 years (b) TS map searching for extended excess emission. The large gradient seen in (b) indicates the presence of a very extended (~ several degrees) but weak source.*

Closest most massive nearby merging system (R_{vir}~7°); foreground emission dominated by components of interstellar diffuse emission

Extended excess is present but a) significantly offset from cluster and b) significance depends heavily on interstellar emission model [6]

Conclusions

- Comprehensive suite of analyses but no detection of γ-rays from clusters (yet!) -> all-sky coverage provides unique opportunities for sample studies;
- Large field-of-view allows studying very large structures (such as Virgo), but care must be taken of diffuse foreground emission modeling.
- DM constraints from clusters are generally weaker than from 'cleaner' targets such as dwarf spheroidal galaxies, but detection prospects are better.

References

[1] Ackermann et al. *ApJ* **787** (2014) 18 [arxiv:1308:5654]
[2] Brunetti & Jones *Int. J. Mod. Phys. D* **23** (2014) [arxiv:1401.7519]
[3] Baltz et al. *JCAP* **07** (2008) 013 [arxiv:0806.2911]
[4] Ackermann et al. *PRD* **89** (2014) 042001 [arxiv:1310.0828]
[5] Ackermann et al. (in preparation)
[6] Ackermann et al. (in preparation)