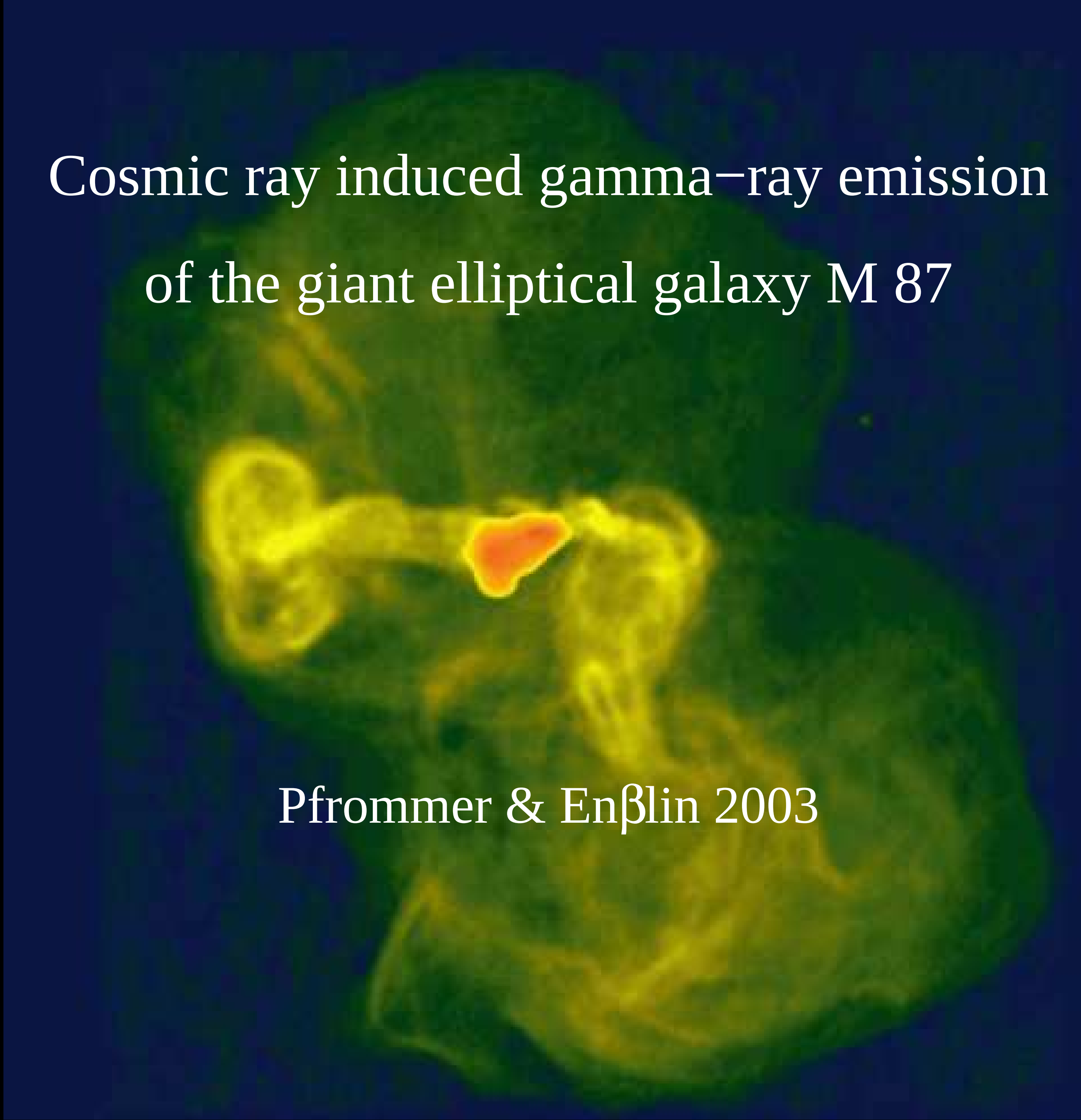
Cosmic ray induced gamma−ray emission of the giant elliptical galaxy M 87



Pfrommer & Enβlin 2003

Outline of the Talk

A) Introduction and Motivation

1.) Acceleration mechanism of CRp

2.) Hadronic CRp interactions in the ICM

B) CRp induced gamma−ray emission

1.) Gamma−ray emission of clusters of galaxies

2.) TeV gamma−ray emission of M 87

C) Conclusions

Main injection mechanisms of CRp into the ICM:

- CRp acceleration at structure formation and accretion shocks:

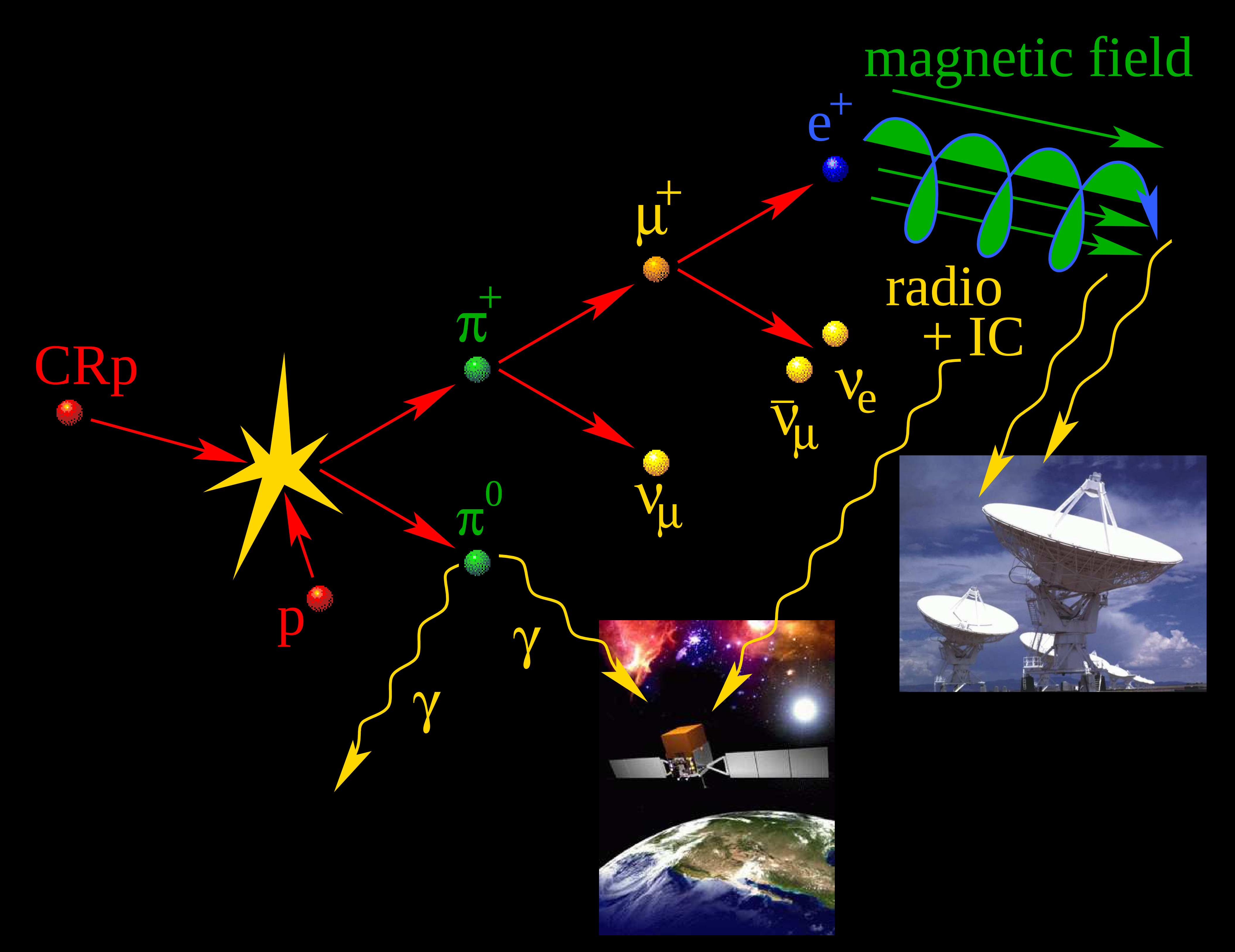
  Energy dissipation at the shock front → thermal energy
  Energy dissipation at the shock front → CRp acceleration

- Supernova driven galactic winds advect and inject CRp into the ICM

- CRp diffusion away from an AGN/radio galaxy into the ICM

How can we observe CRp in clusters of galaxies?

→ How many CRp are there?

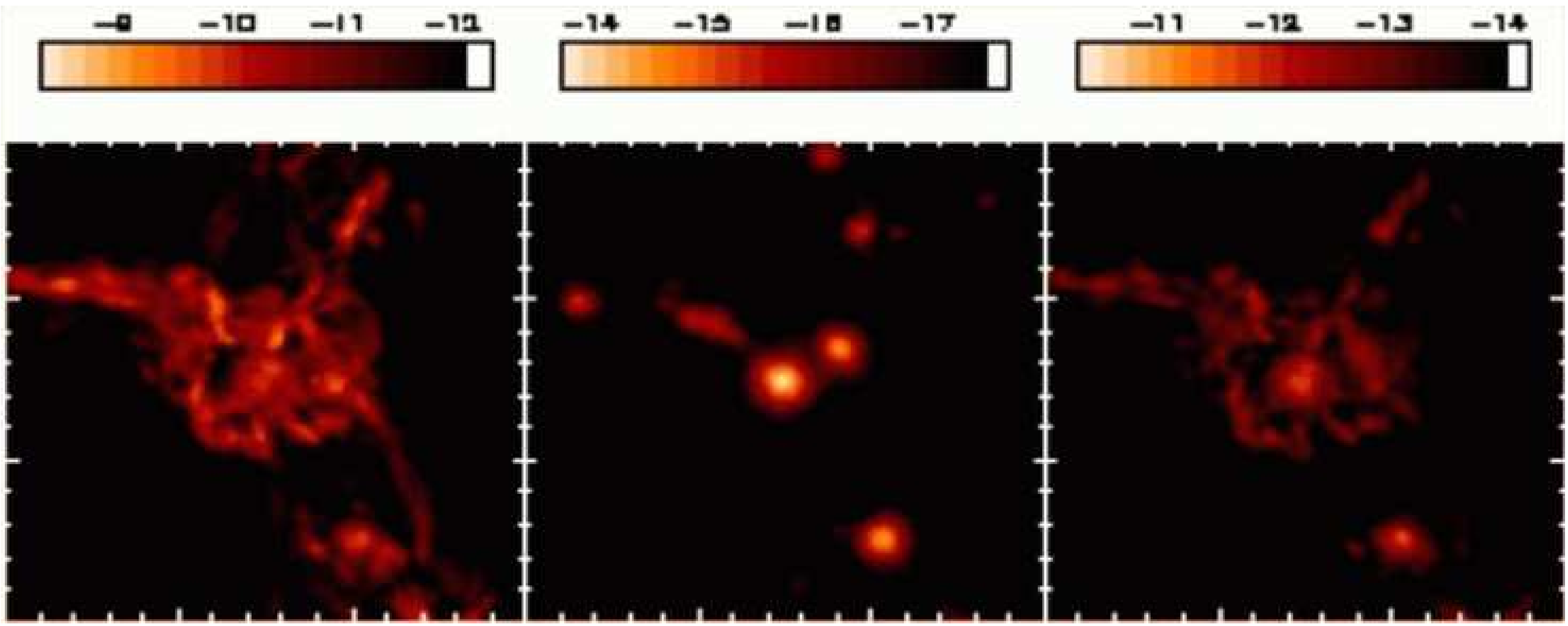

magnetic field
e+
μ+
π+
π0
CRp
p
radio
+ IC
ν̄μ
νe
νμ
γ
γ

Simulation of CR emission processes in galaxy clusters

Hard X−ray: F(> 100 keV)

Thermal X−ray:

γ−ray: F(> 100 MeV)



Miniati 2003, MNRAS

Gamma ray source function

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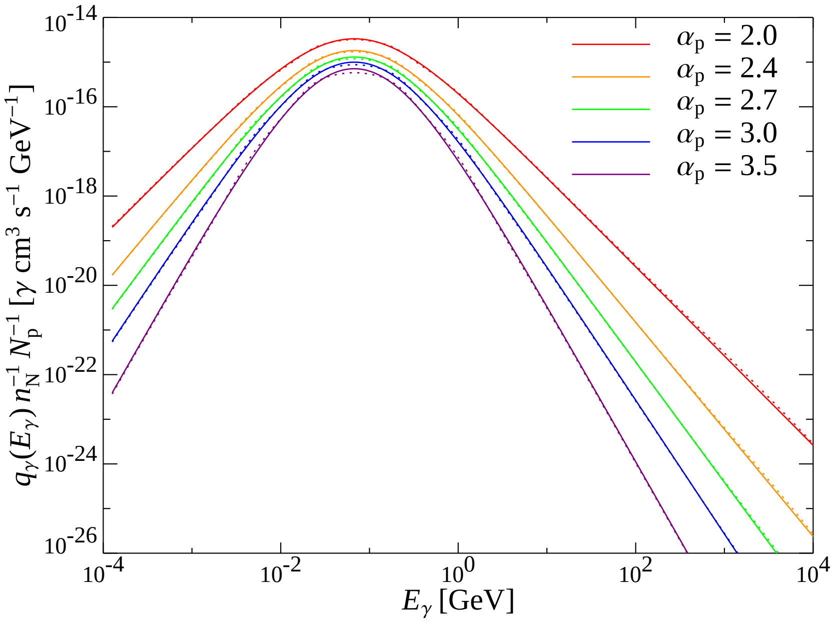
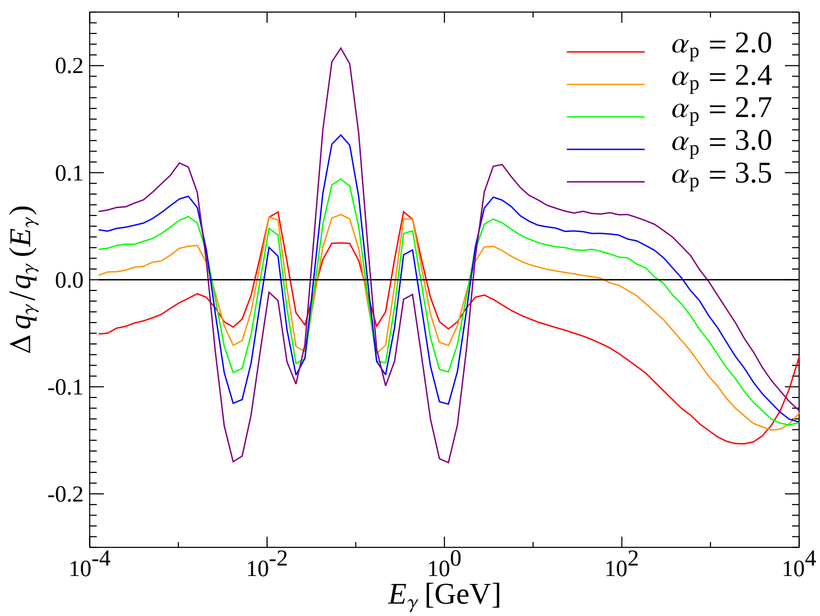




- CRp population:

$$f_{\mathrm{p}}(\mathbf{r}, p_{\mathrm{p}}) = \frac{\tilde{n}_{\mathrm{CRp}}(\mathbf{r})\, c}{\mathrm{GeV}} \left(\frac{p_{\mathrm{p}}\, c}{\mathrm{GeV}}\right)^{-\alpha_{\mathrm{p}}}$$

- Pion decay induced differential gamma−ray source function:

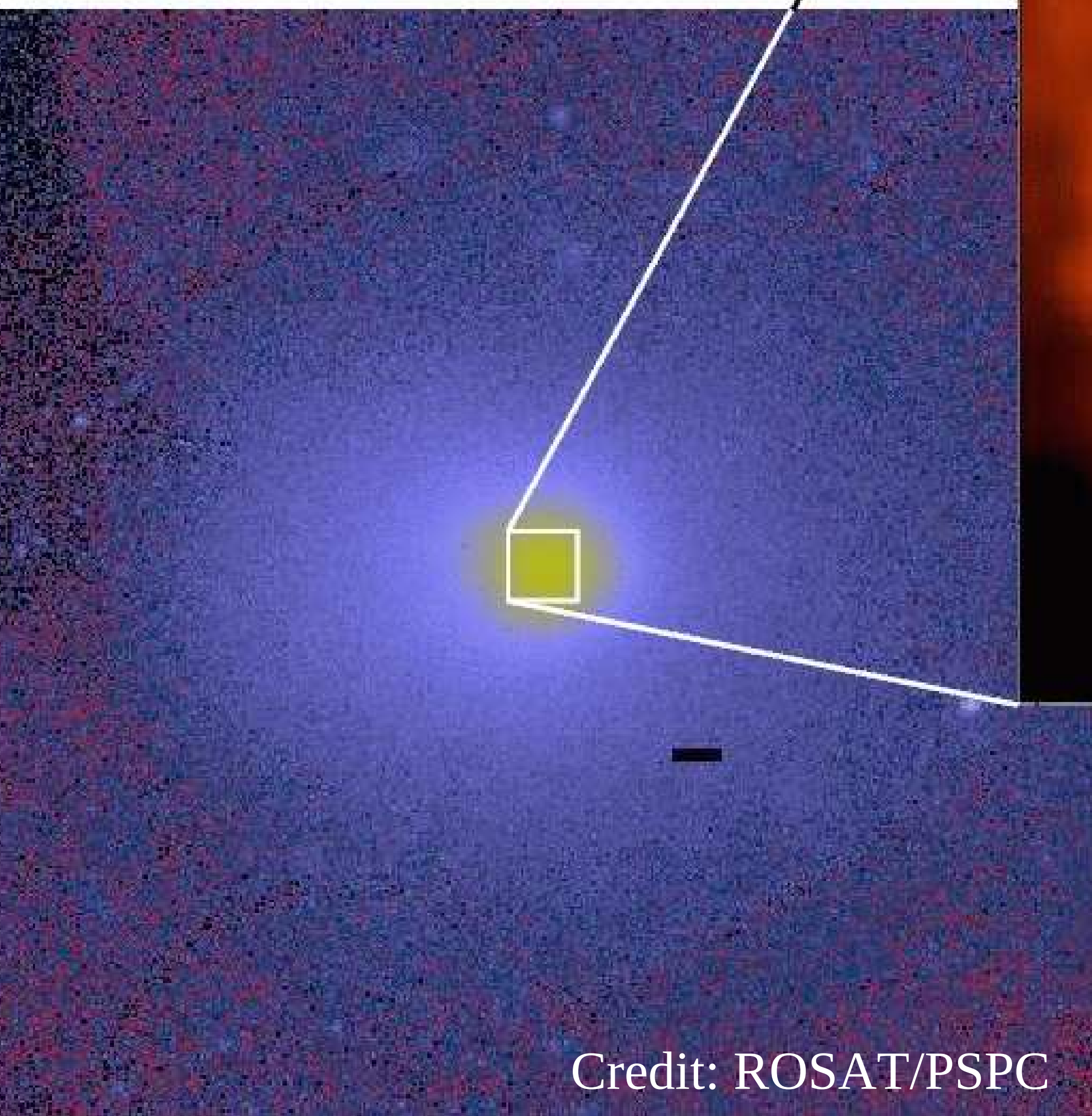
$$q_\gamma(\mathbf{r}, E_\gamma) \simeq \sigma_{\mathrm{pp}}\, c\, n_{\mathrm{N}}(\mathbf{r})\, 2^{2-\alpha_\gamma} \frac{\tilde{n}_{\mathrm{CRp}}(\mathbf{r})}{\mathrm{GeV}} \times$$

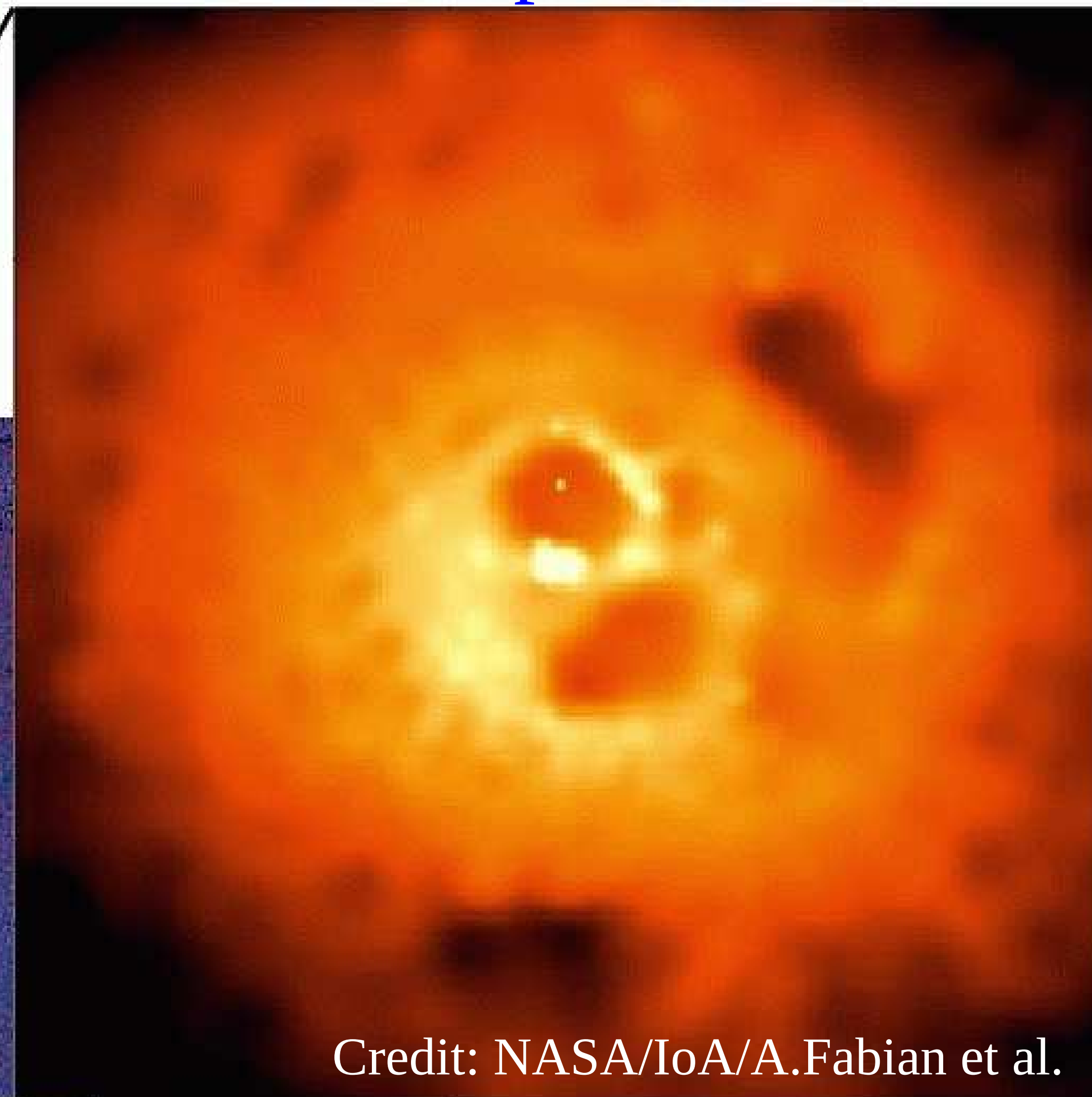
$$\frac{4}{3\,\alpha_\gamma} \left(\frac{m_{\pi^0}\, c^2}{\mathrm{GeV}}\right)^{-\alpha_\gamma} \left[\left(\frac{2\,E_\gamma}{m_{\pi^0}\, c^2}\right)^{\delta_\gamma} + \left(\frac{2\,E_\gamma}{m_{\pi^0}\, c^2}\right)^{-\delta_\gamma}\right]^{-\alpha_\gamma/\delta_\gamma}$$

- Relative deviation of our analytic approach to simulated gamma−ray spectra.

Cooling flow clusters are efficient CRp detectors!

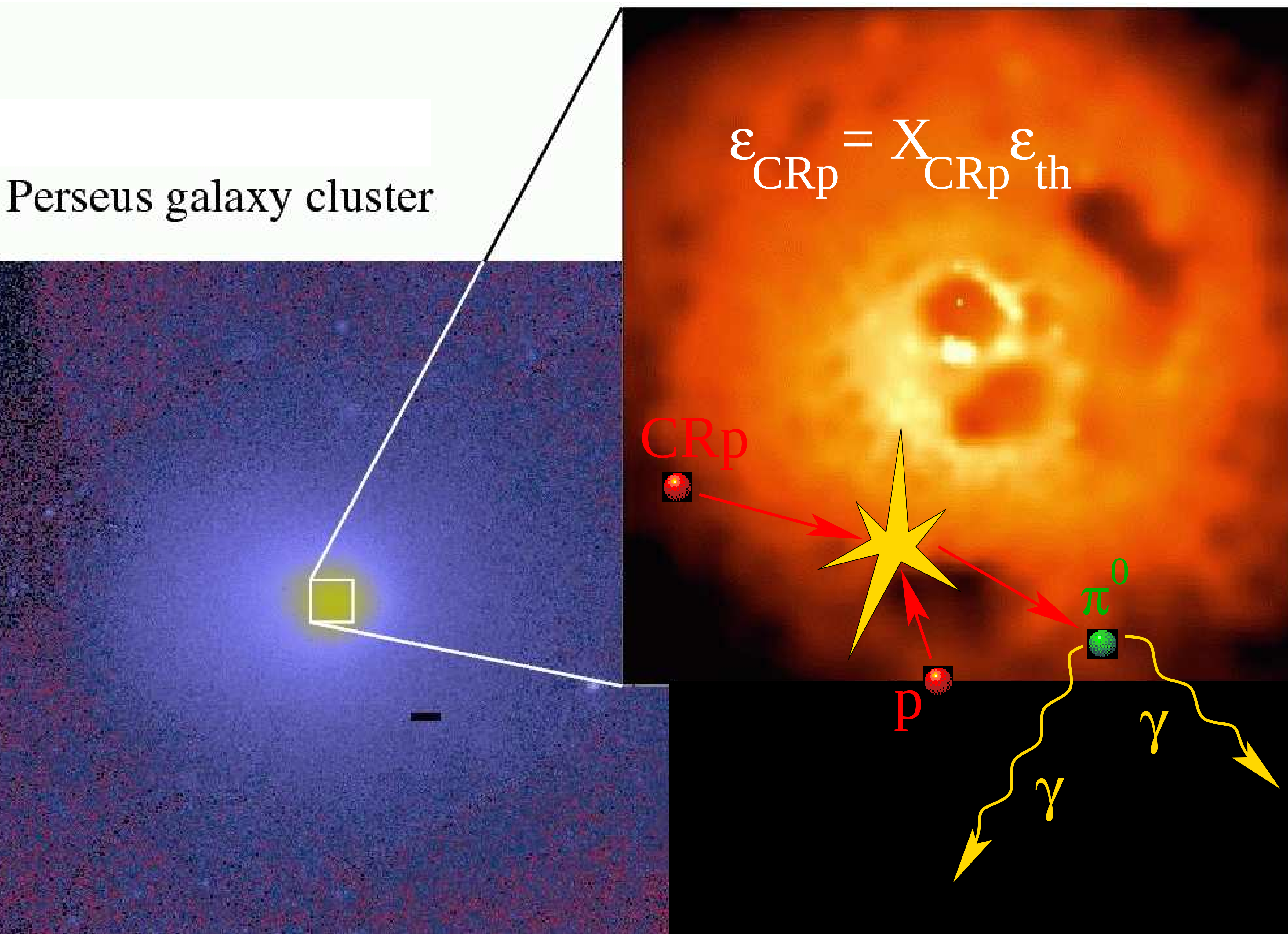
ROSAT observation:
Perseus galaxy cluster





Chandra observation:
central region of Perseus

Cooling flow cluster model of CRp detection:



Gamma ray flux of Perseus galaxy cluster:

Inverse Compton emission of secondary CRe (B = 0),

pion decay induced gamma ray emission

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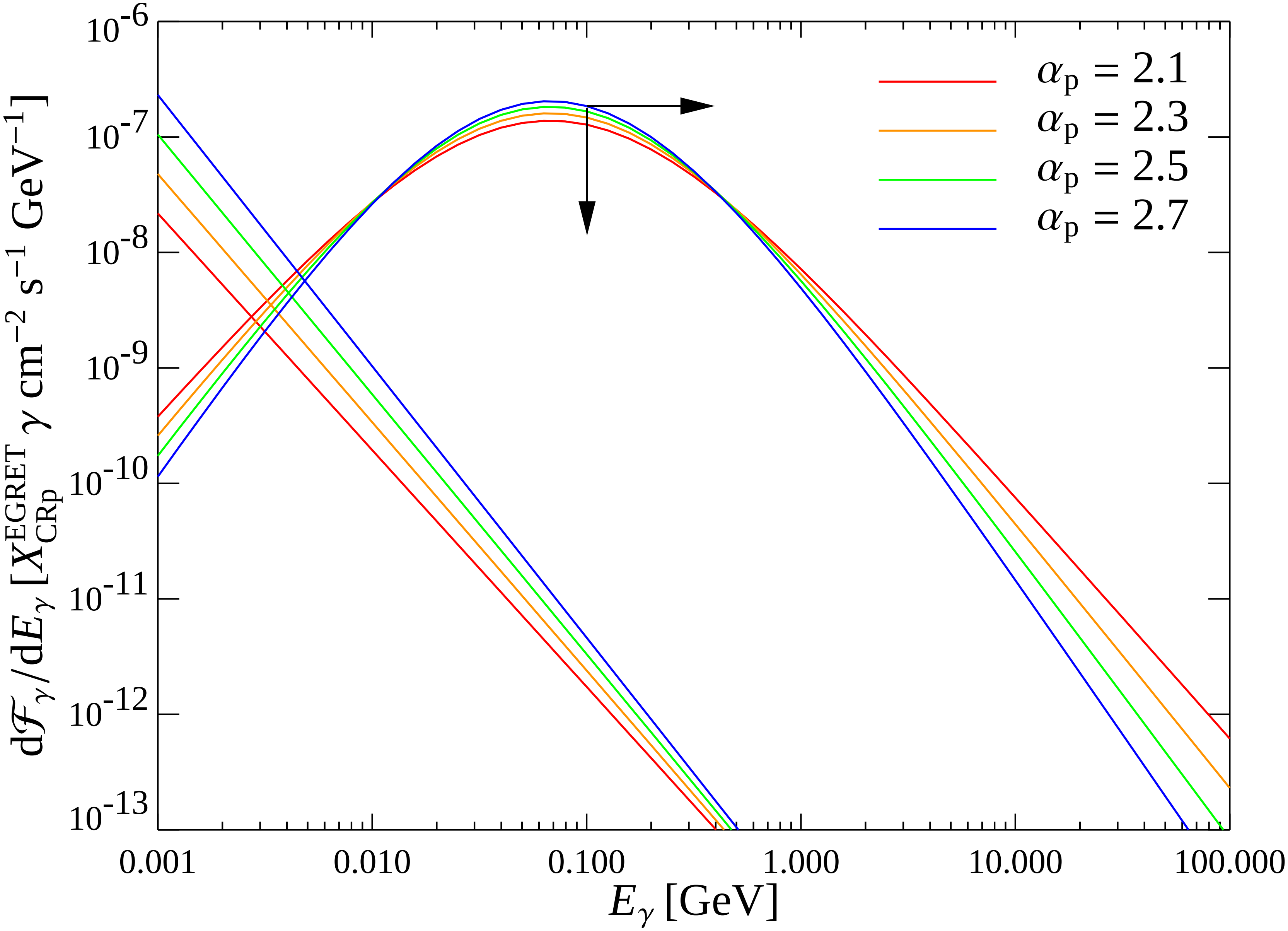
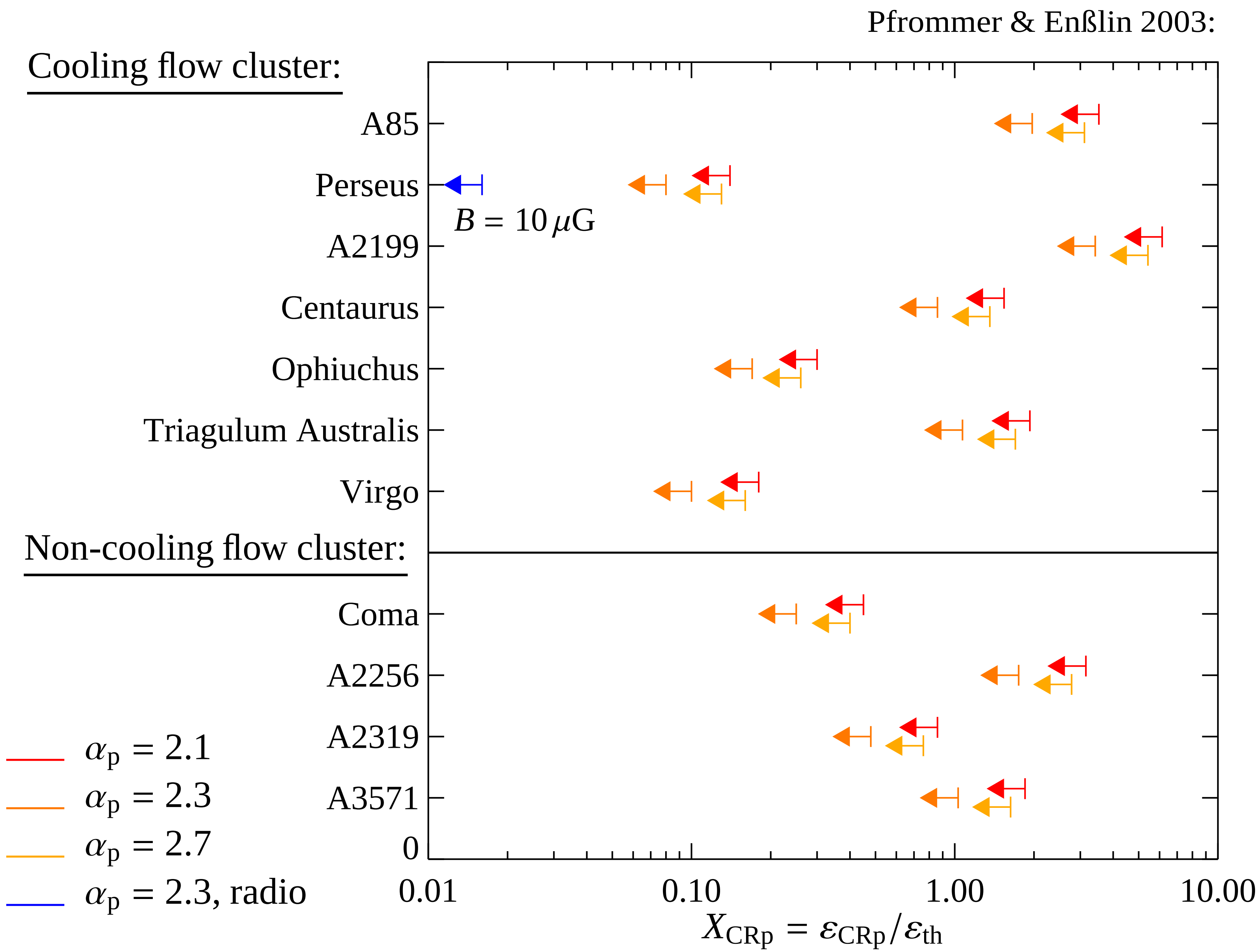


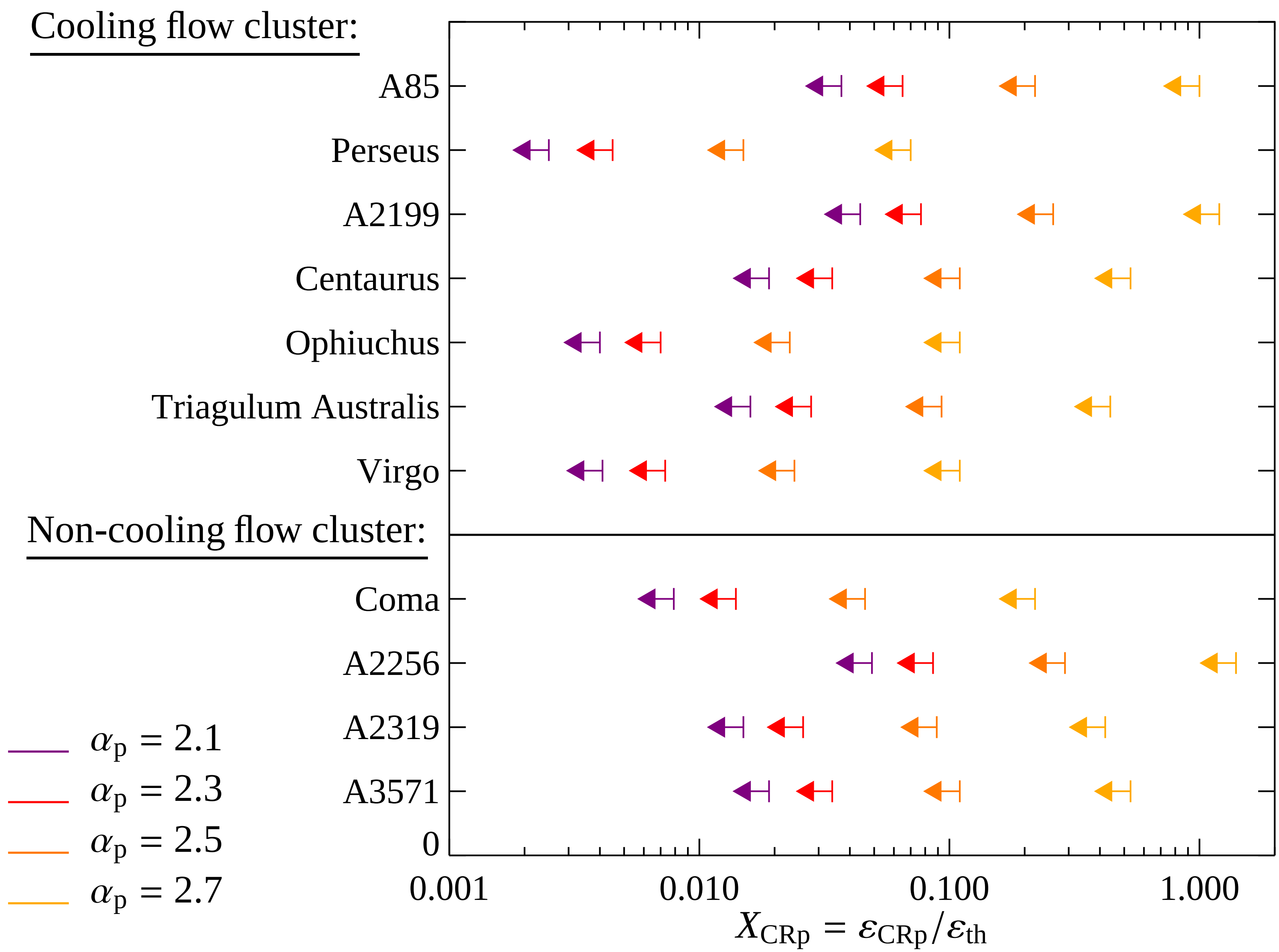
Upper limits on X_CRp using EGRET limits:



Expected limits on X_CRp using Cerenkov telescopes:

Sensitivity: $\mathcal{F}_{\gamma,\mathrm{exp}}(E > E_{\mathrm{thr}}) = 10^{-12}\,\gamma\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,(E_{\mathrm{thr}}/100\,\mathrm{GeV})^{1-\alpha_\gamma}$

Pfrommer & Enßlin 2003:



HEGRA − M87: TeV position

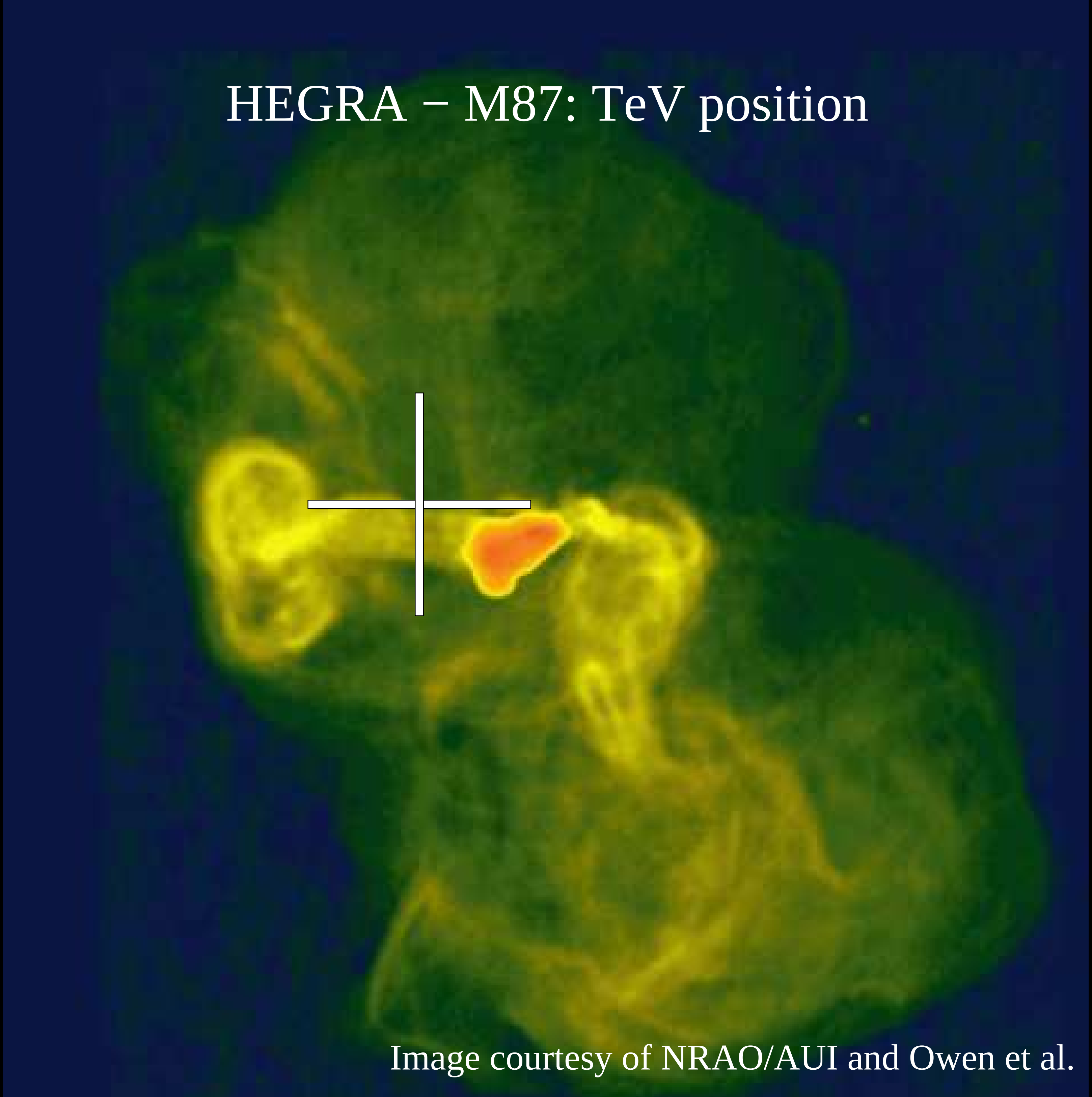


Image courtesy of NRAO/AUI and Owen et al.

What is the origin of the M 87 gamma−ray emission?

- Processed radiation of the relativistic outflow (jet):

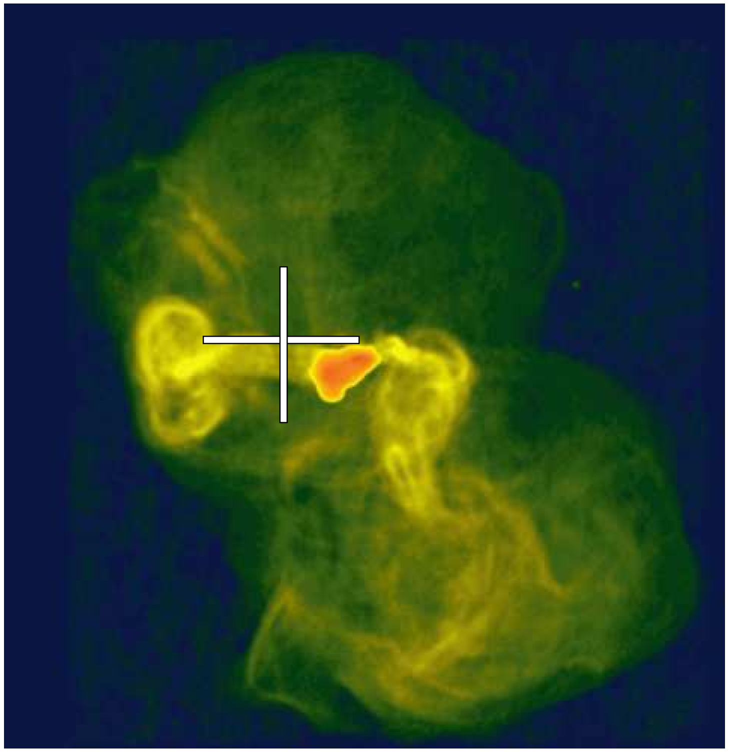
  e.g. IC upscattering of CMB photons by CRe (jet), SSC scenario

- Dark matter annihilation or decay processes

- Hadronically originating gamma−rays:

  Assuming CRp power−law distribution and a model for the CRp spatial distrib.

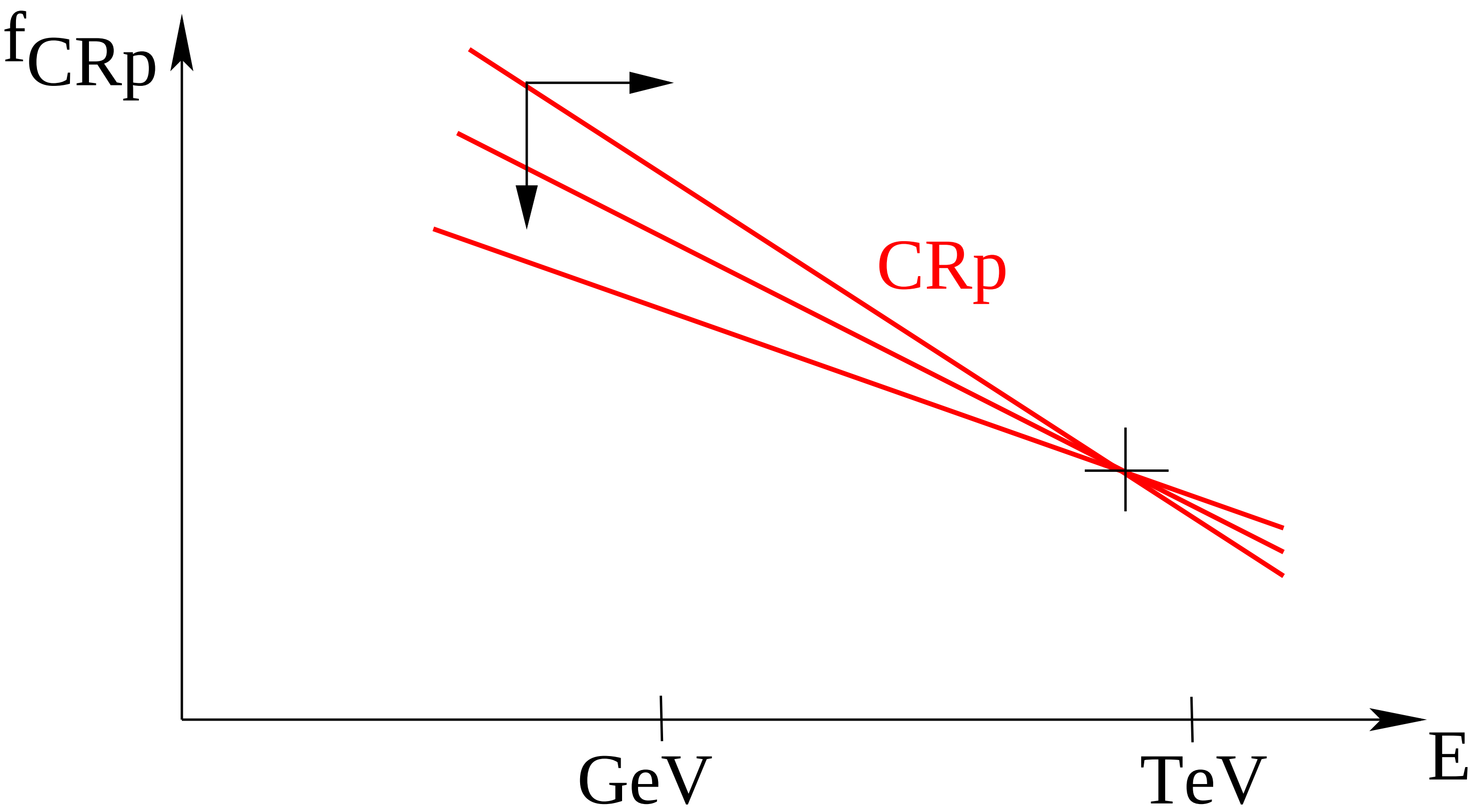
  ⟶ measurement of the CRp population in ICM/ISM of M 87!



Constraints on the CRp spectral index

- Combining EGRET upper limits (E > 100 MeV, Reimer et al. 2003) and HEGRA TeV γ −ray flux (E > 730 GeV, Aharonian et al. 2003)

  → CRp spectral index: $\alpha < 2.275$



Gamma ray flux profile of M 87 (Virgo):

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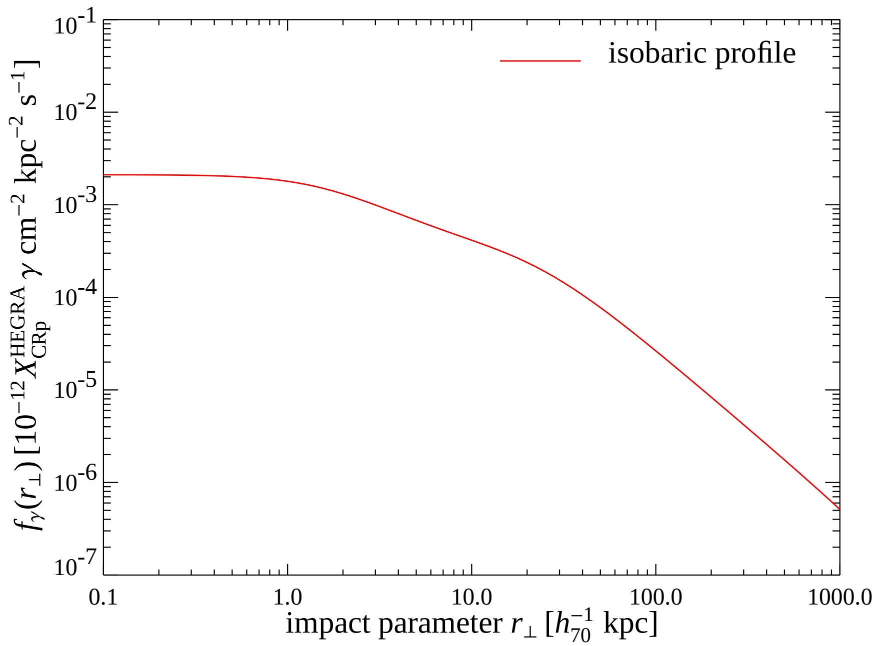

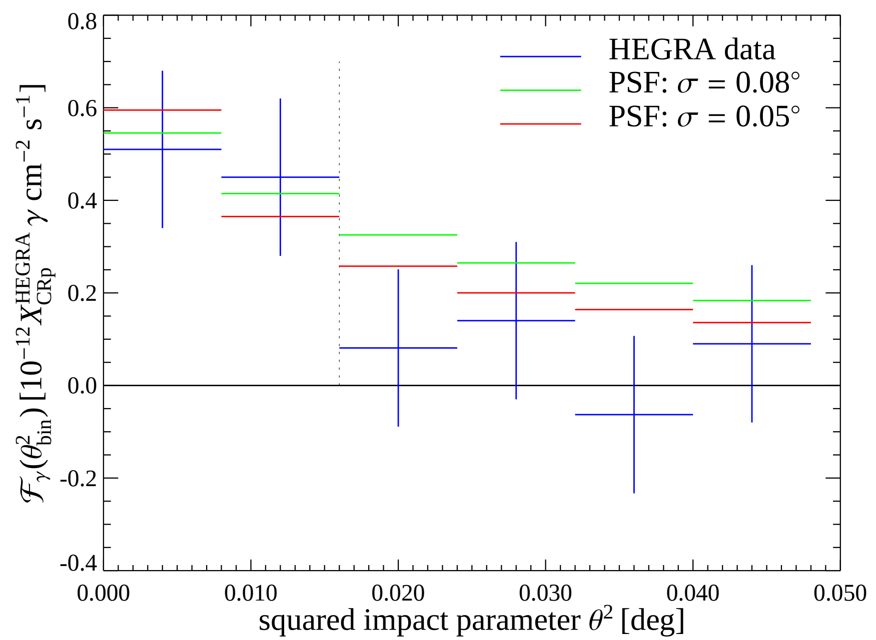

Top:

- modeled gamma−ray surface flux profile
- normalized to the HEGRA flux (>730 GeV) within the two innermost datapoints

Bottom:

- comparison of detected to simulated gamma−ray flux profiles which are convolved with two different widths of the PSF

Conclusions

Cosmic ray protons:

$$X_{\mathrm{CRp}}(r) = \frac{\varepsilon_{\mathrm{CRp}}}{\varepsilon_{\mathrm{th}}}(r)$$

- Cooling flow clusters are efficient CRp detectors
- Limits from γ−rays (EGRET): $X_{\mathrm{CRp}} < 20\%$
- M 87 gamma−ray emission is consistent with hadronic scenario!

Simulation of CR emission processes

Secondary emission: Primary emission:

F(>100 keV)

F(>100 MeV)