Cosmic rays in galaxy clusters and their non-thermal emission

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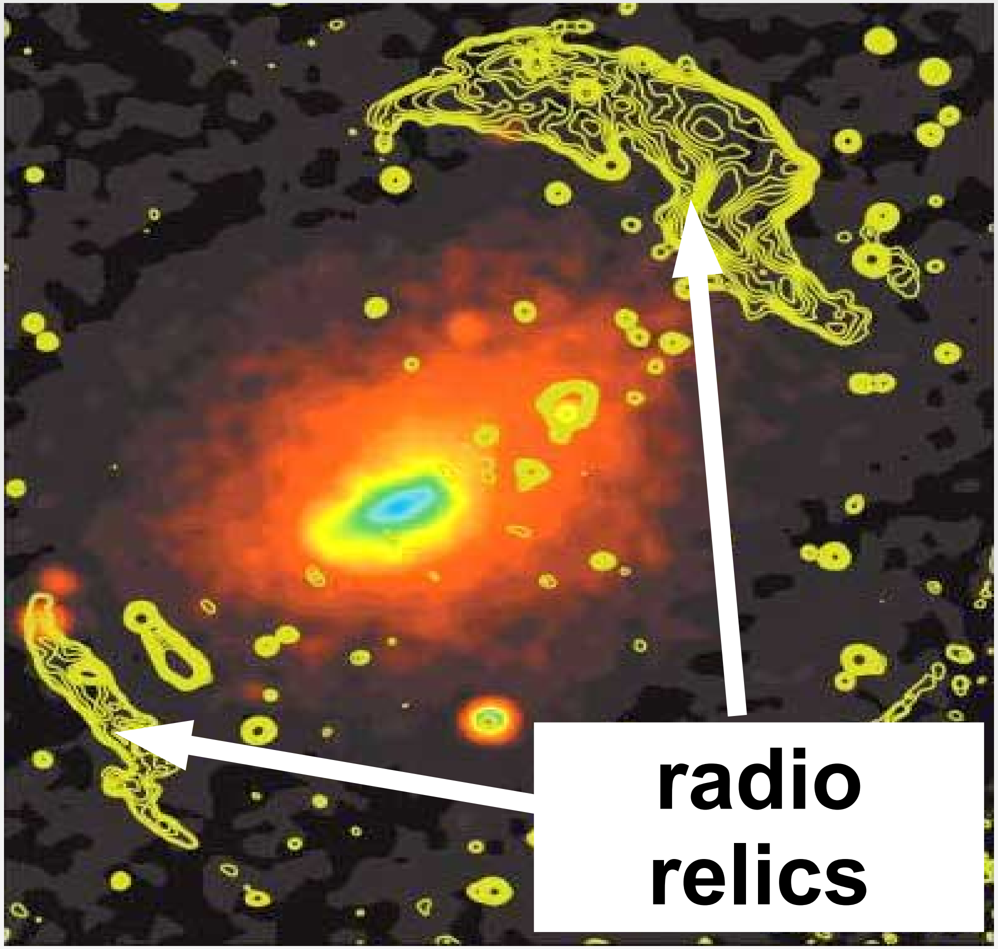
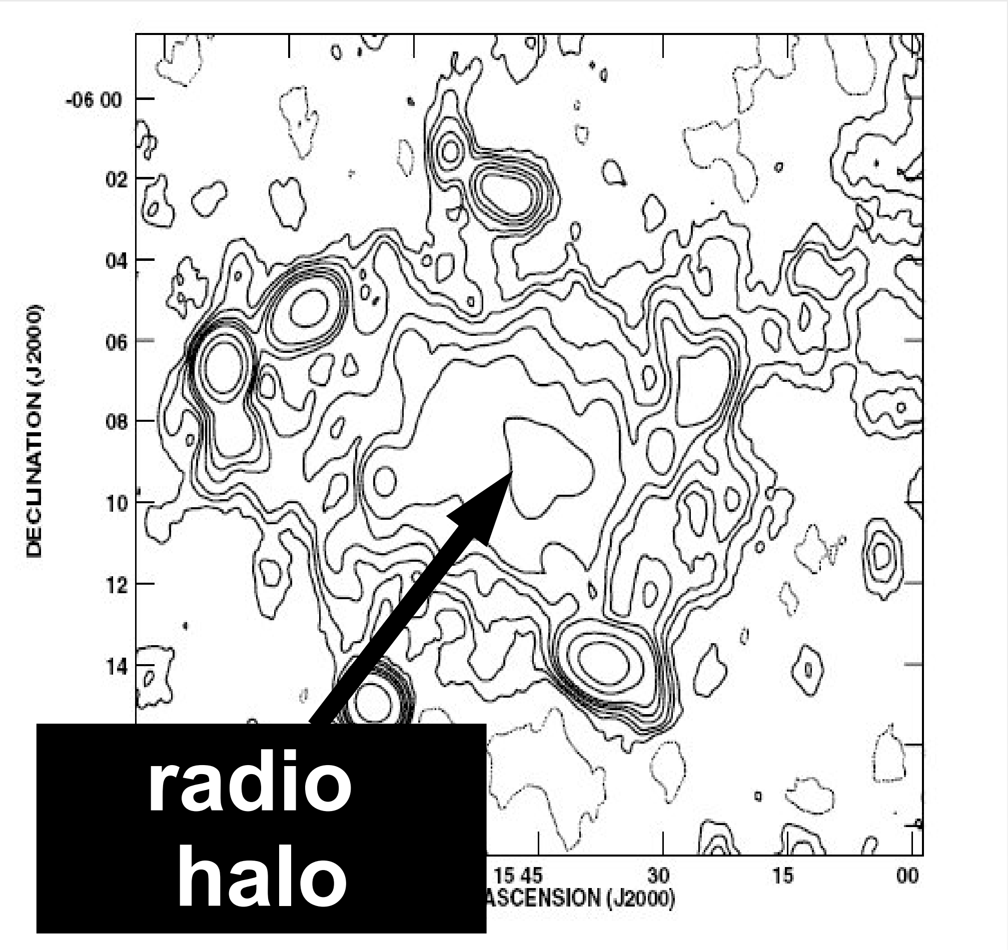
Copenhagen, NBI
Aug 14, 2014

Dark Cosmology Centre

Stockholm University

Signs of non-thermal activity in galaxy clusters





A 3667

Radio: *Johnston-Hollitt.;*
X-ray: *ROSAT/PSPC.*

A 2163

Radio: *Feretti at al, 2004*

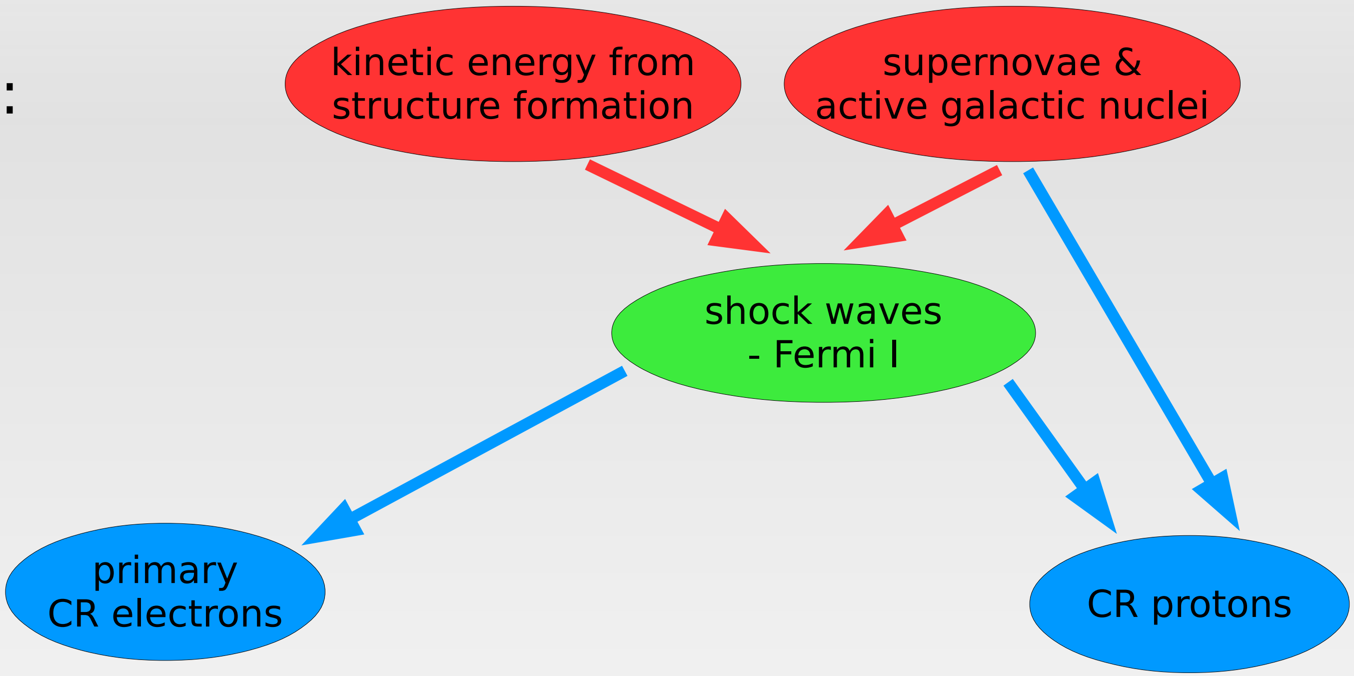
radio halo - Hadronic models

Relativistic populations and radiative processes in clusters:

Energy sources:

Plasma processes:

Relativistic particle pop.:



Observational diagnostics:

e.g. Ensslin+ 2011, Wiener+ 2013, Zandanel+ 2013, Zandanel and Ando 2014, Pfrommer+ 2004,2008, Pinzke and Pfrommer 2010, Pinzke+ 2012

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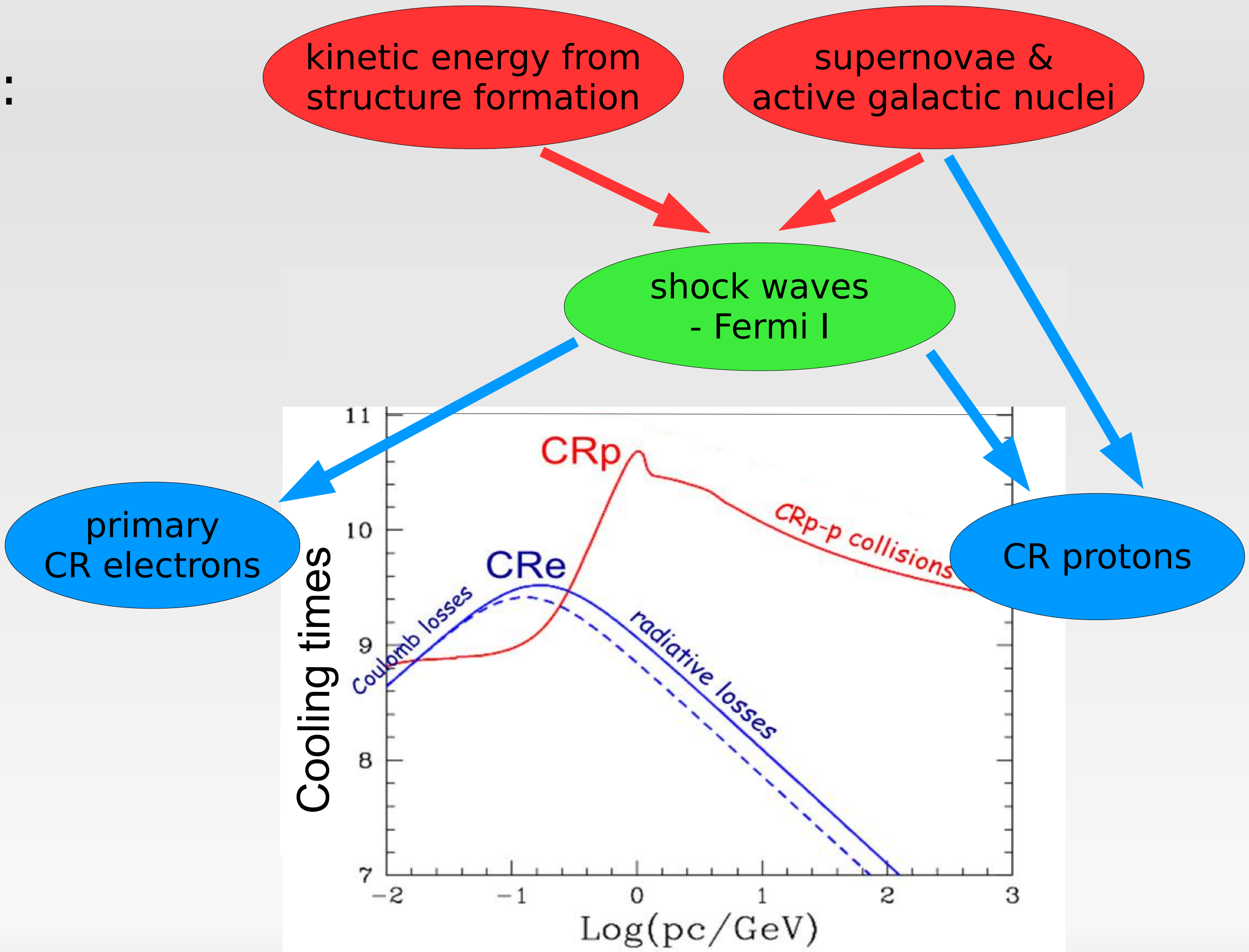

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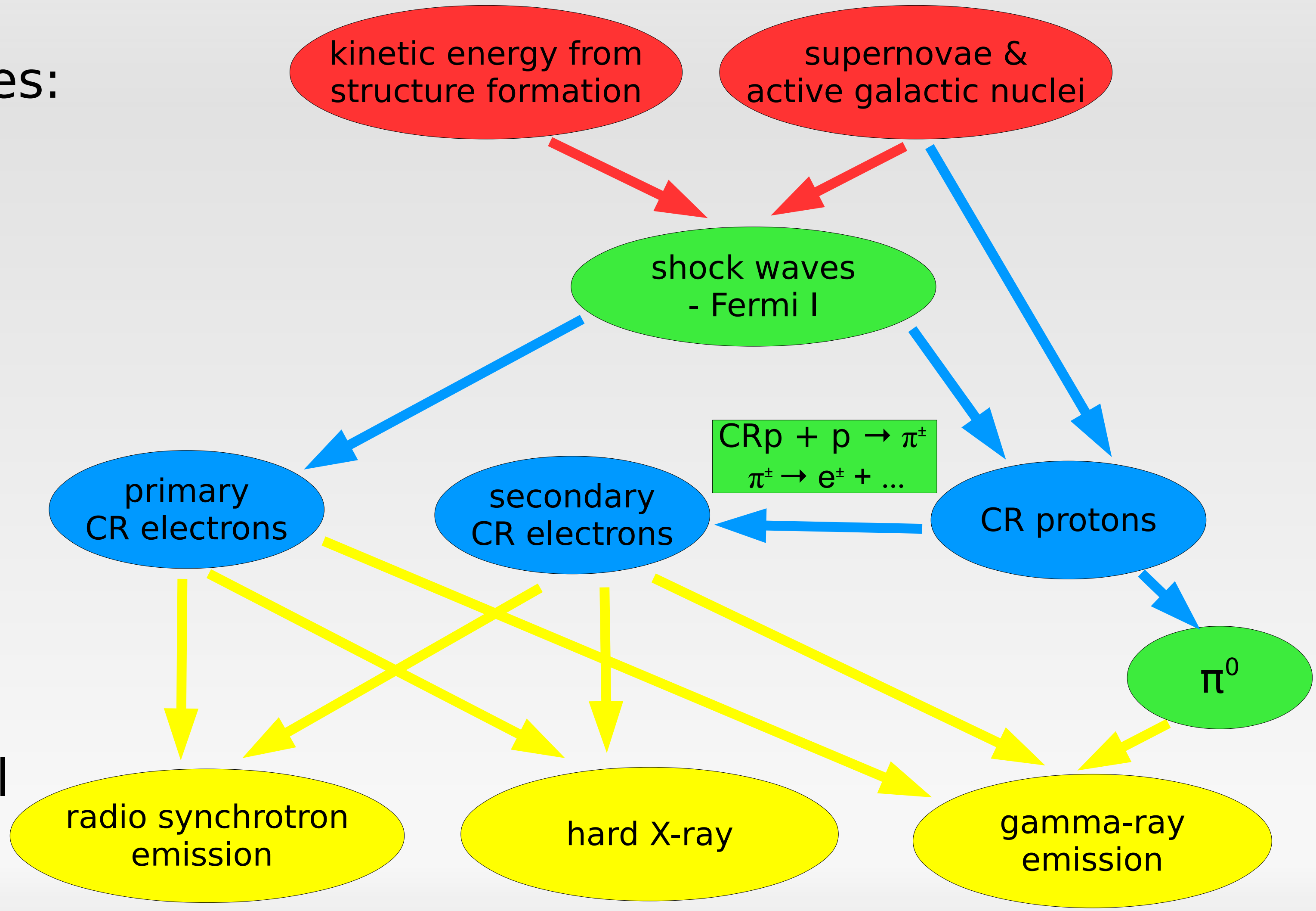


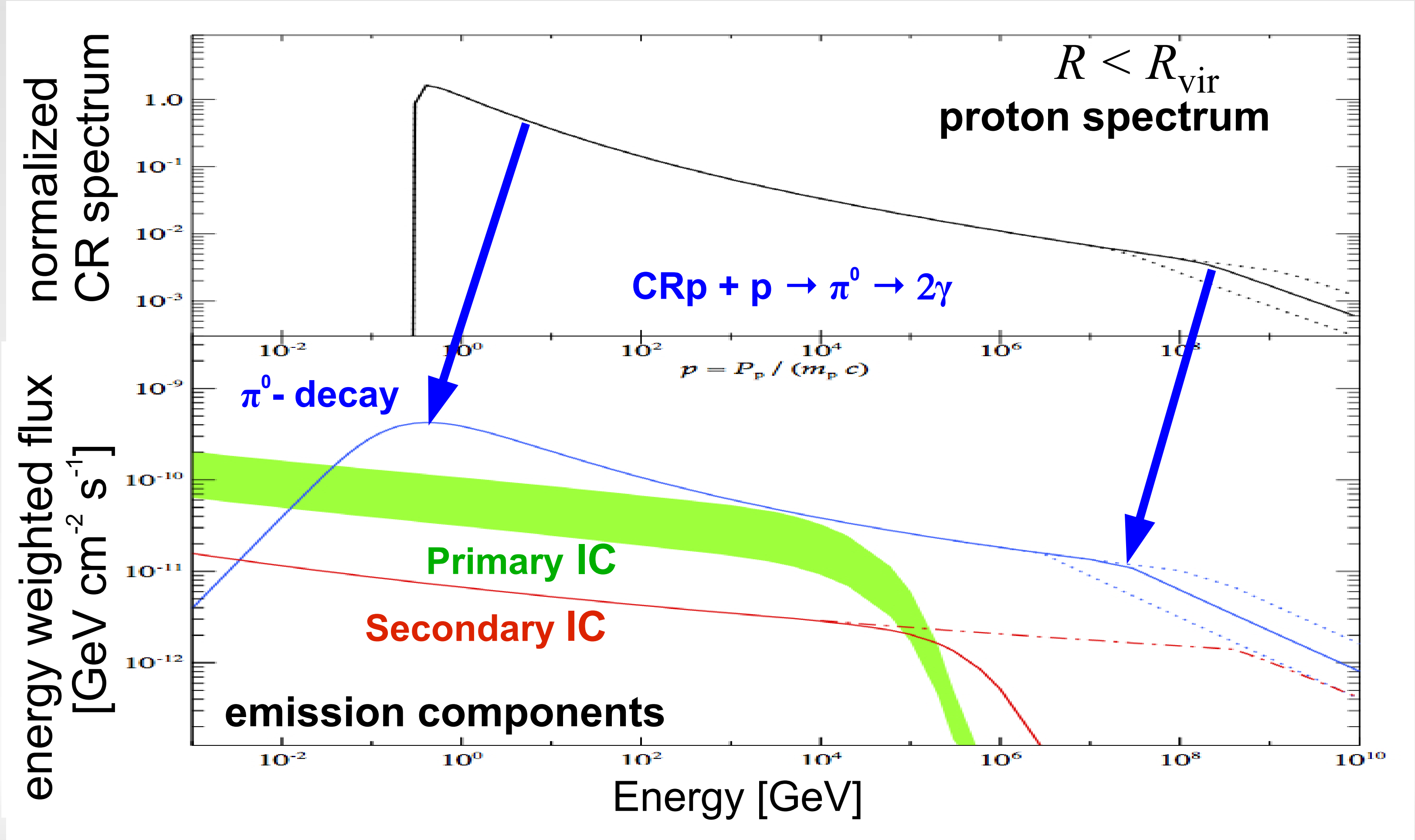
e.g. Ensslin+ 2011, Wiener+ 2013, Zandanel+ 2013, Zandanel and Ando 2014, Pfrommer+ 2004,2008, Pinzke and Pfrommer 2010, Pinzke+ 2012

Hadronic models – CRs and gamma

Acceleration mechanism: diffusive shock acceleration

Simulation based CR proton model with adiabatic transport

Ensslin et al. 2006, Pfrommer et al. 2008, Pinzke et al. 2010, 2012



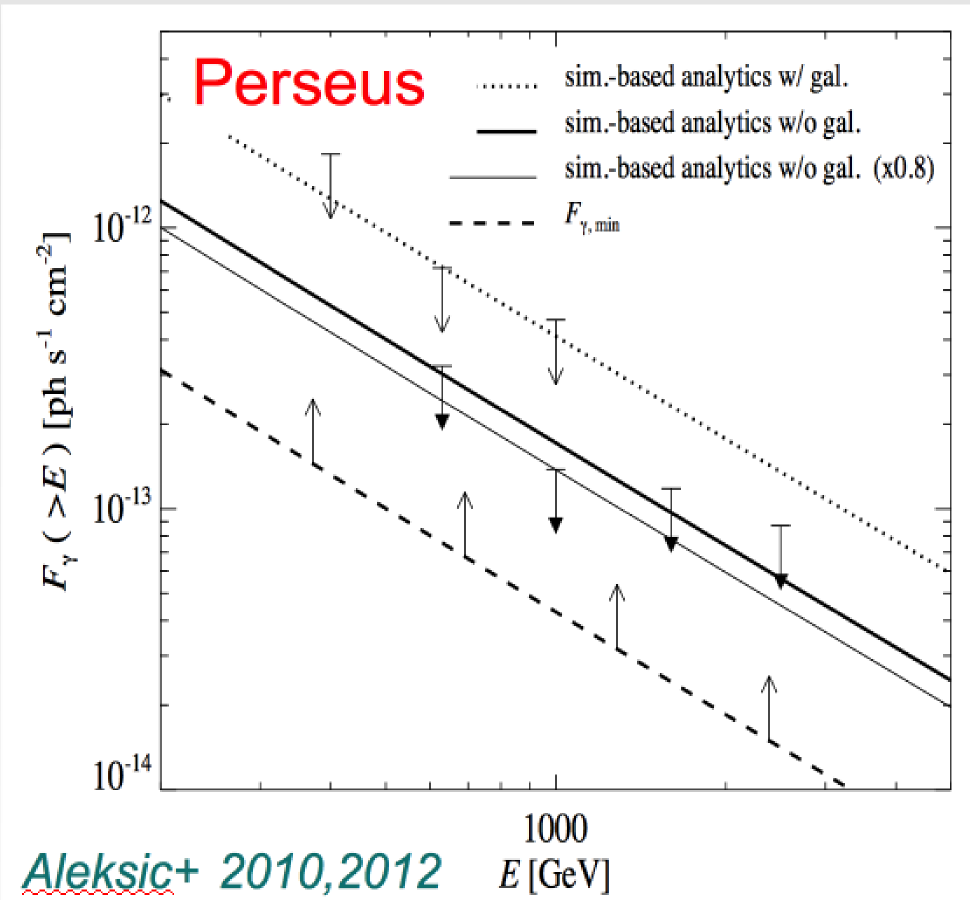
Pinzke and Pfrommer 2010

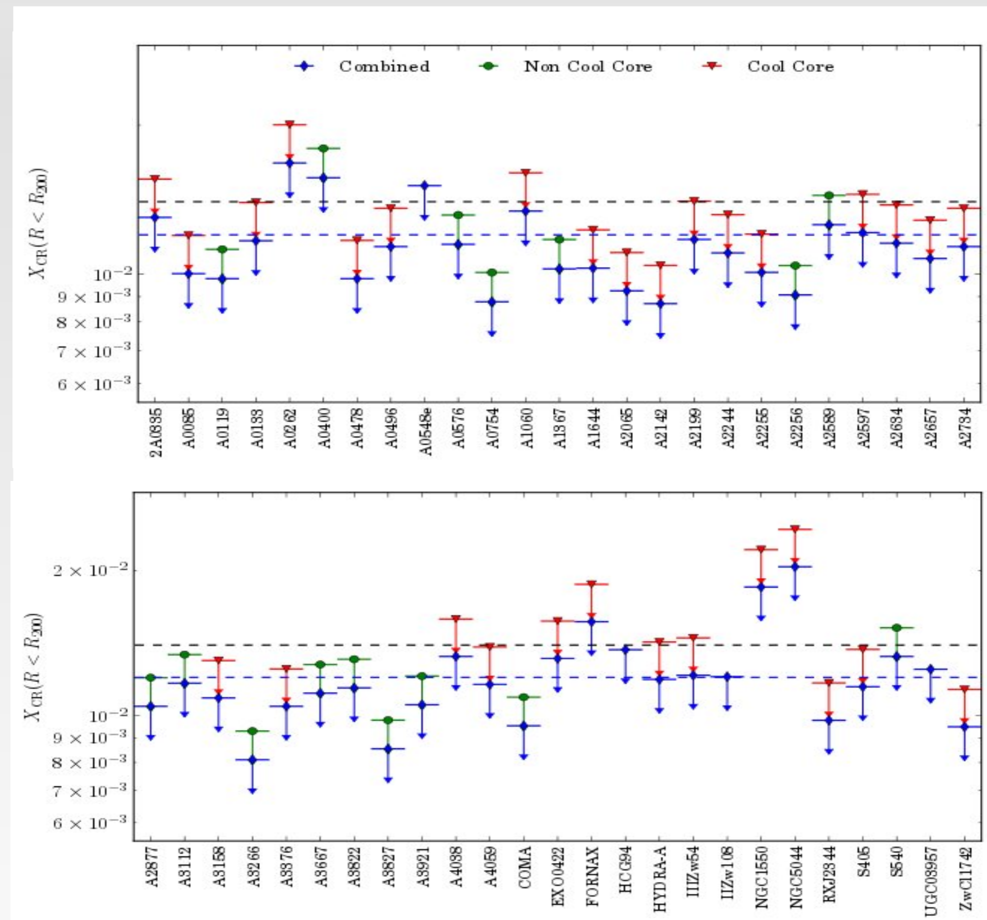
Gamma-ray emission dominated by decaying π^0:s

Hadronic models – gamma rays

Magic *Observation time*: 85 h
deepest observation of a cluster ever

Fermi-LAT 4 year data
Combined likelihood analysis

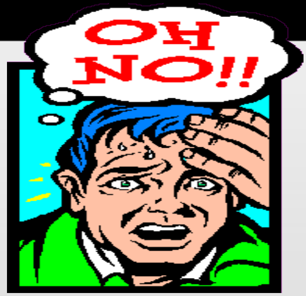




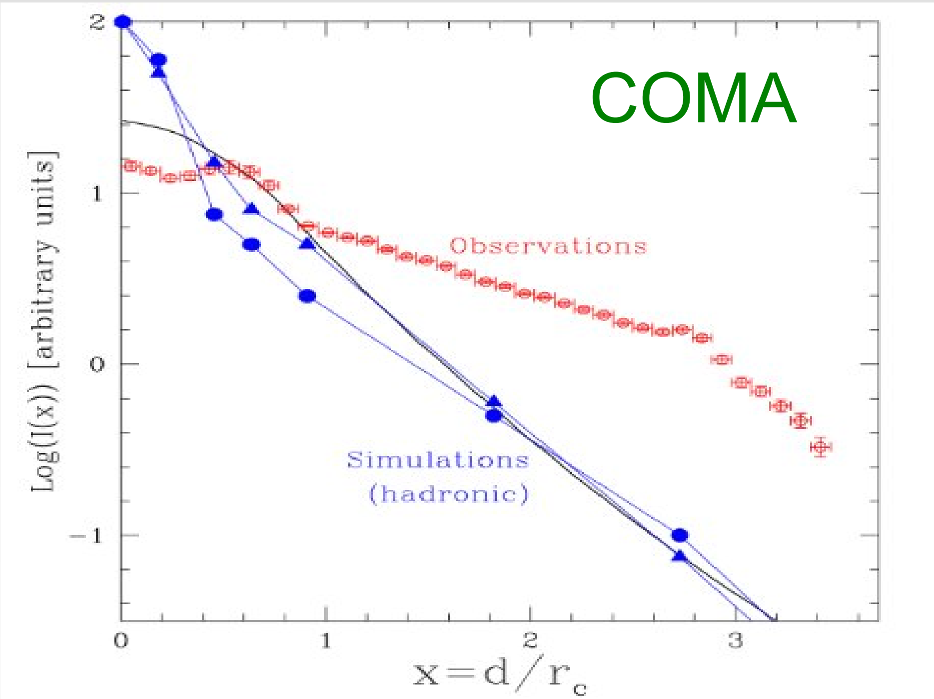
Zimmer et al. (Fermi-LAT) 2013

➔ P_{CR}/P_{th} and E_{CR}/E_{th} < few percent
➔ Fermi-LAT upper limit constrain hadronic models (acc. Eff. < 25%)

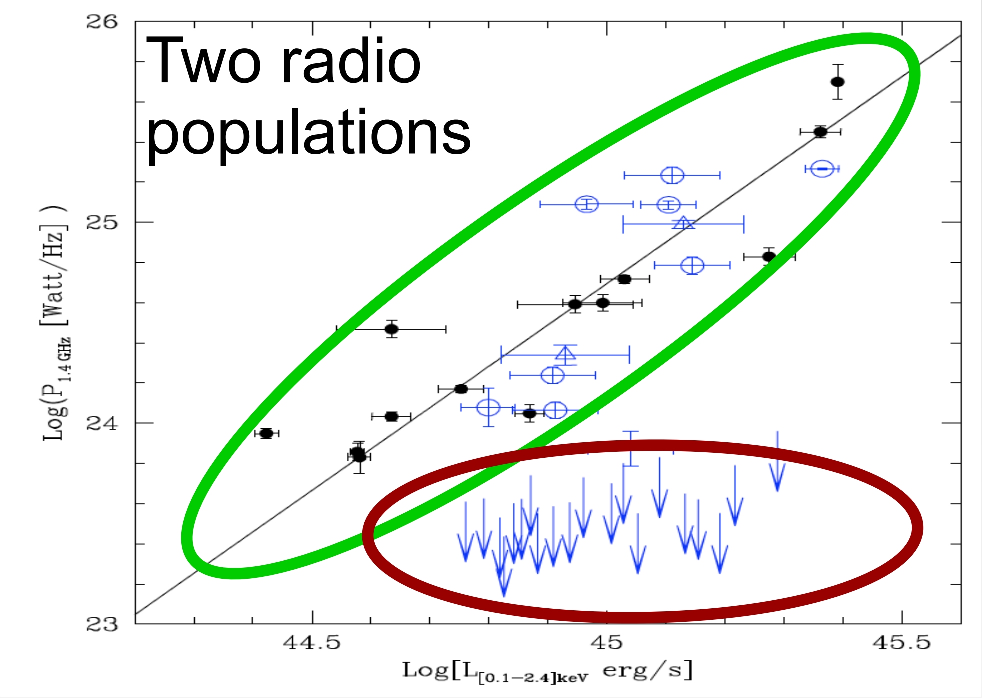
Hadronic models – missing pieces



However, simple CR model in tension with some observations of giant radio halos



Brunetti et al. 2013



Brunetti et al. 2009

Hadronic model can **not** explain radio observations of COMA cluster

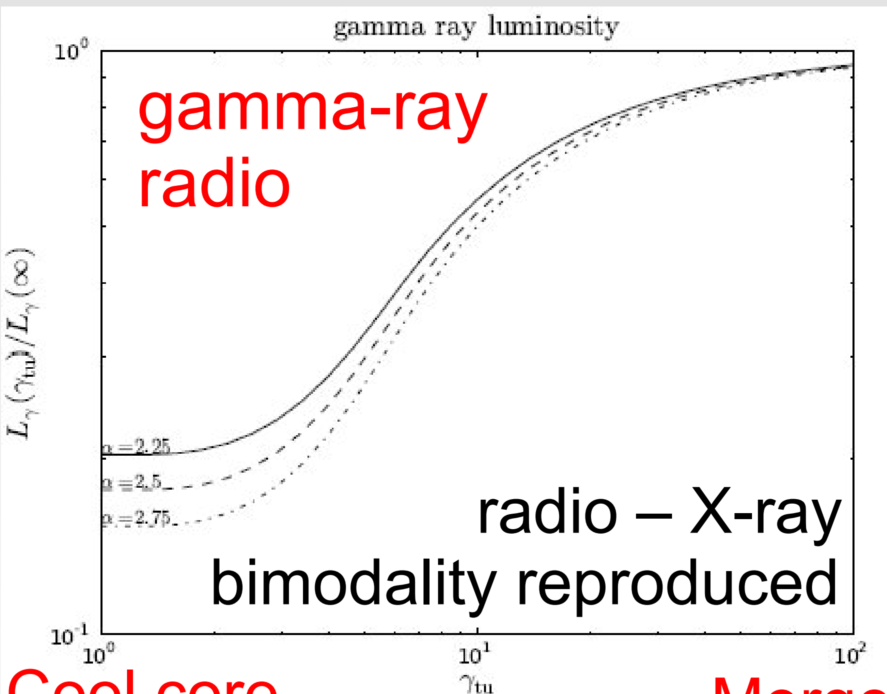
Long cooling time of CR protons → Hadronic model predicts only **one population** of radio halos

Hadronic models – Streaming CRs

Acceleration mechanism: diffusive shock acceleration

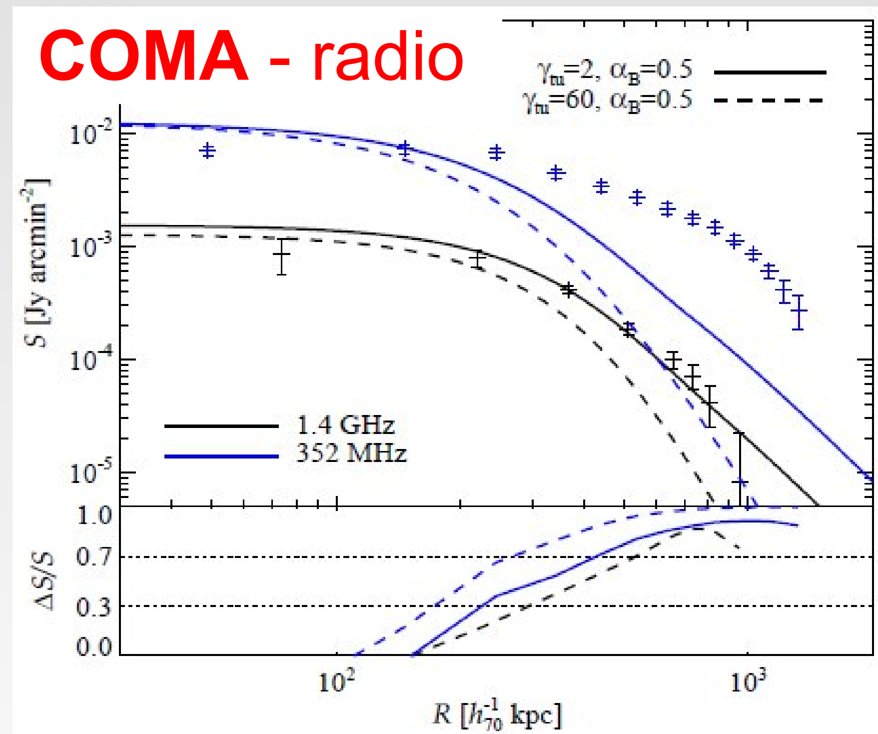
Simulation based CR proton model with adiabatic transport
+ streaming and diffusion
Ensslin et al. 2011, Zandanel et al. 2013, 2014, Wiener et al. 2013

$$\frac{\tau_{st}}{\tau_{tu}} \equiv \gamma_{tu}$$



Cool core

Merger



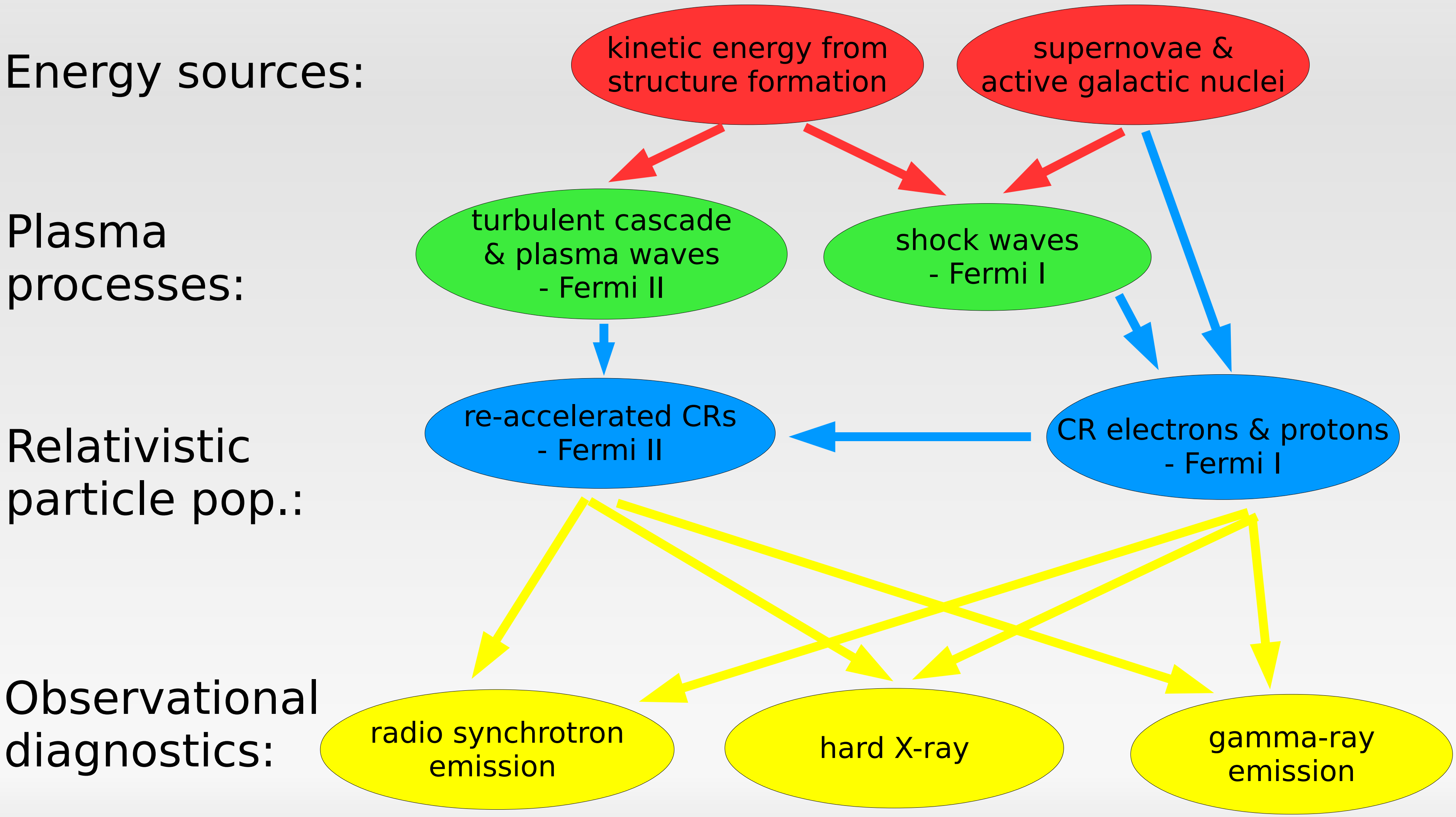
Gamma-ray emission suppressed by ~ 10 in low turbulent clusters

Can reproduce the radio profile in most clusters (COMA a problem)

Need additional component in cluster outskirts: primary CRes?

Giant radio halo - reacceleration model

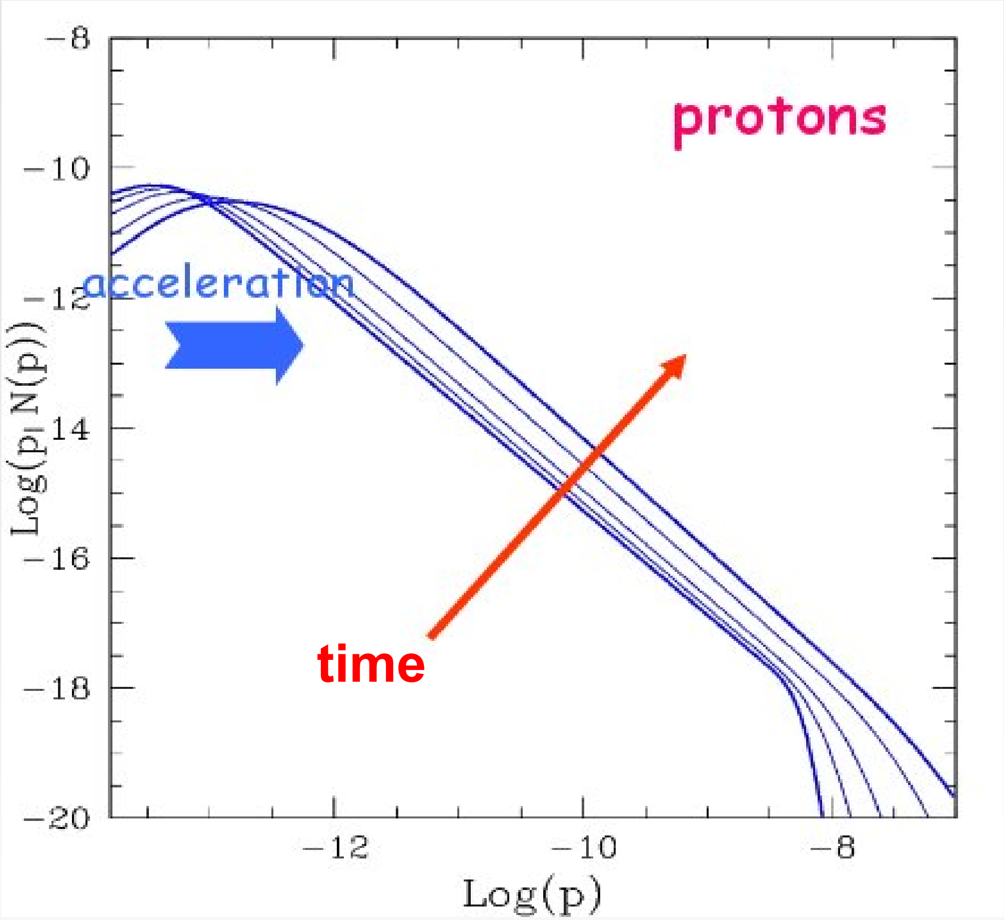
Relativistic populations and radiative processes in clusters:

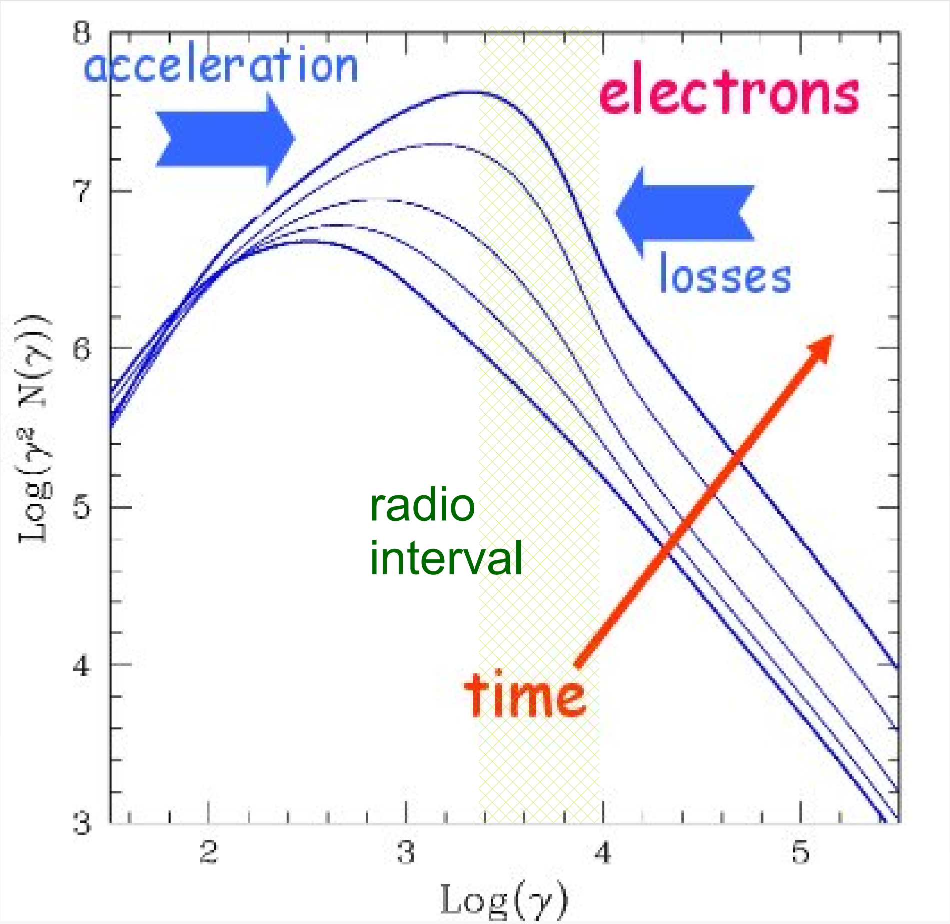


e.g. Brunetti+ 2001,2004,2012, Brunetti and Lazarian 2007, 2011, Petrosian 2001, Cassano and Brunetti 2005

Reacceleration models - CRs

Acceleration mechanism: Compressible MHD turbulence



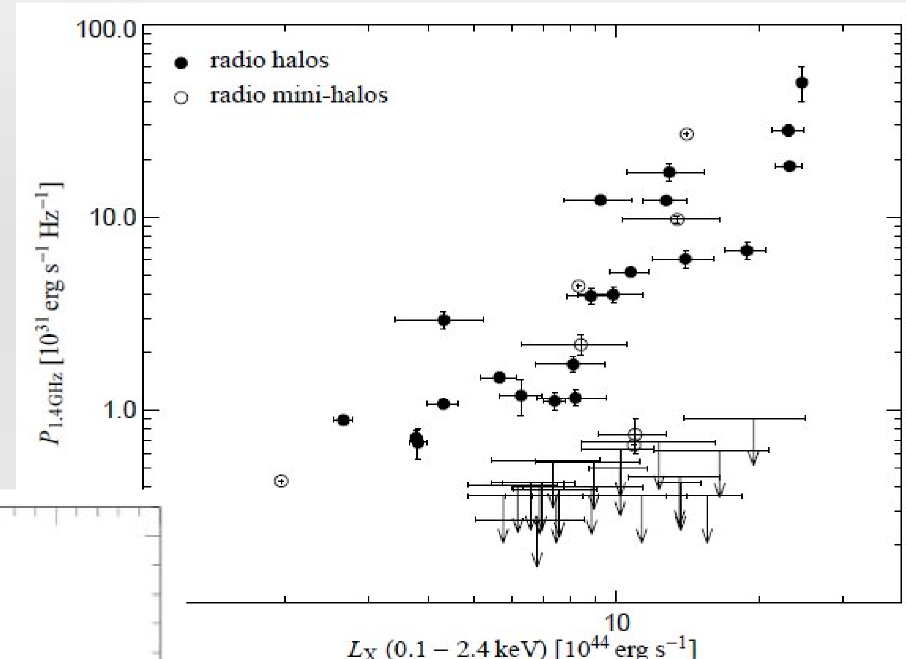


Brunetti and Lazarian 2007, 2011, Brunetti et al. 2012

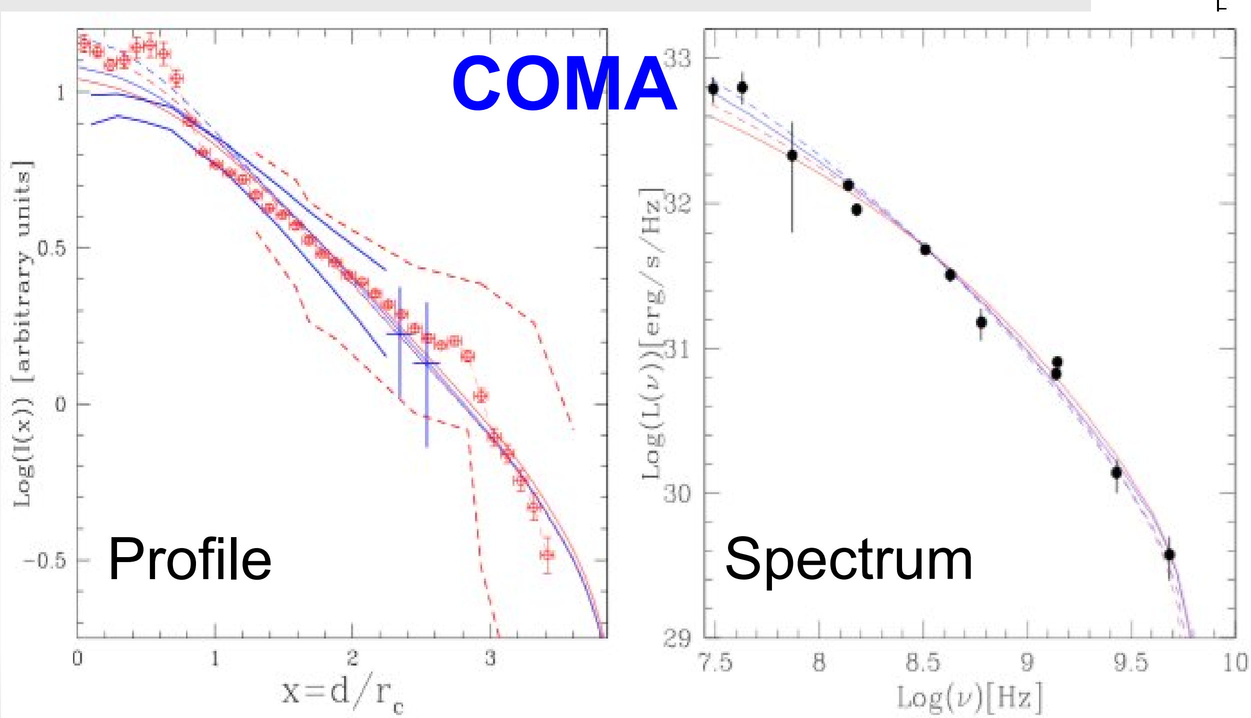
Reacceleration models - radio

Characteristics

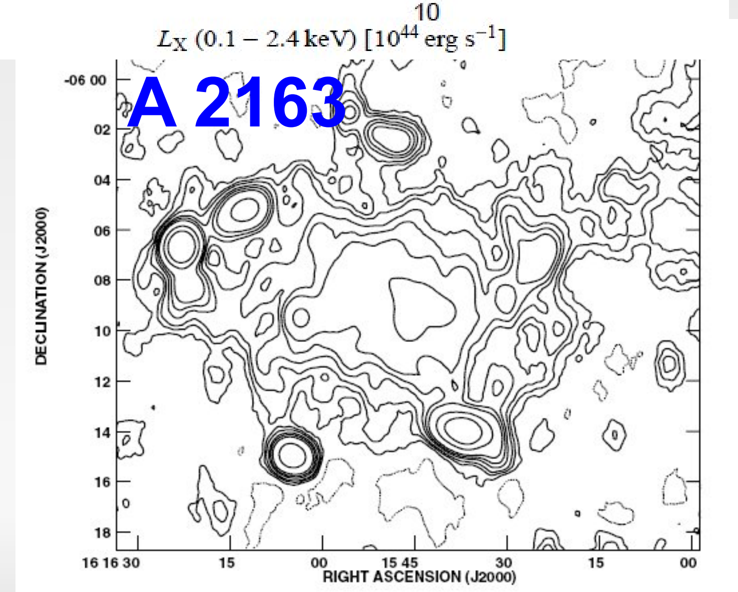
- Bimodality in radio – X-ray luminosity
- Curved radio spectrum
- Flat brightness profile
- Turbulence => complex morphology



Ensslin et al. 2011



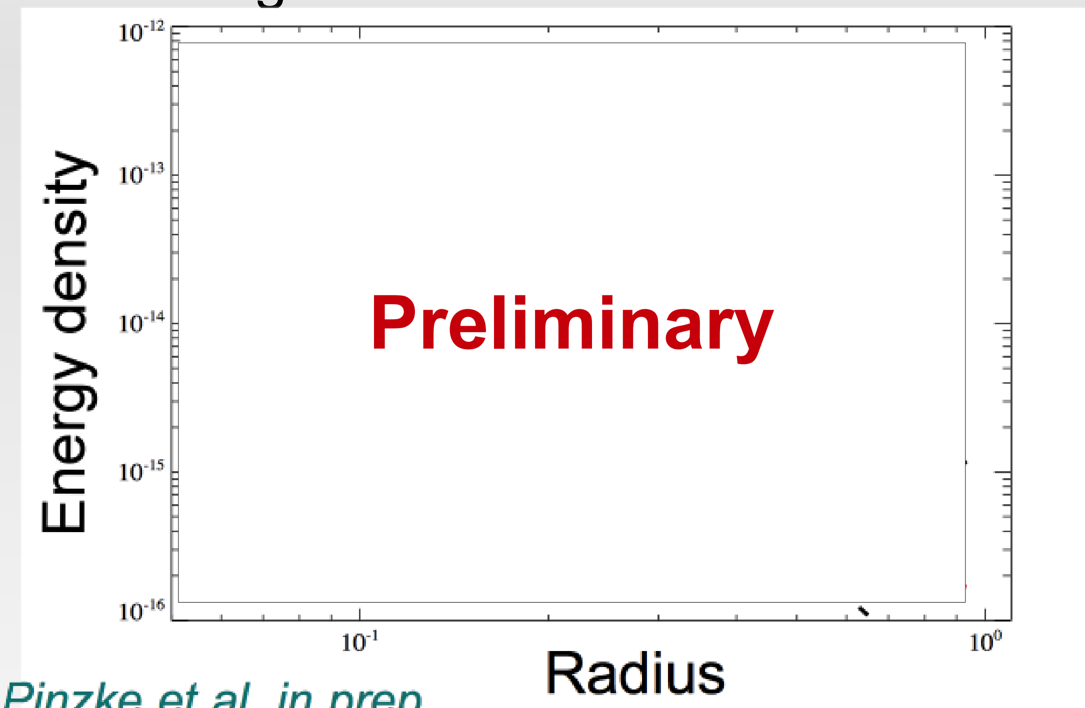
Brunetti and Lazarian 07,11, Brunetti et al. 2012



Feretti at al, 2004

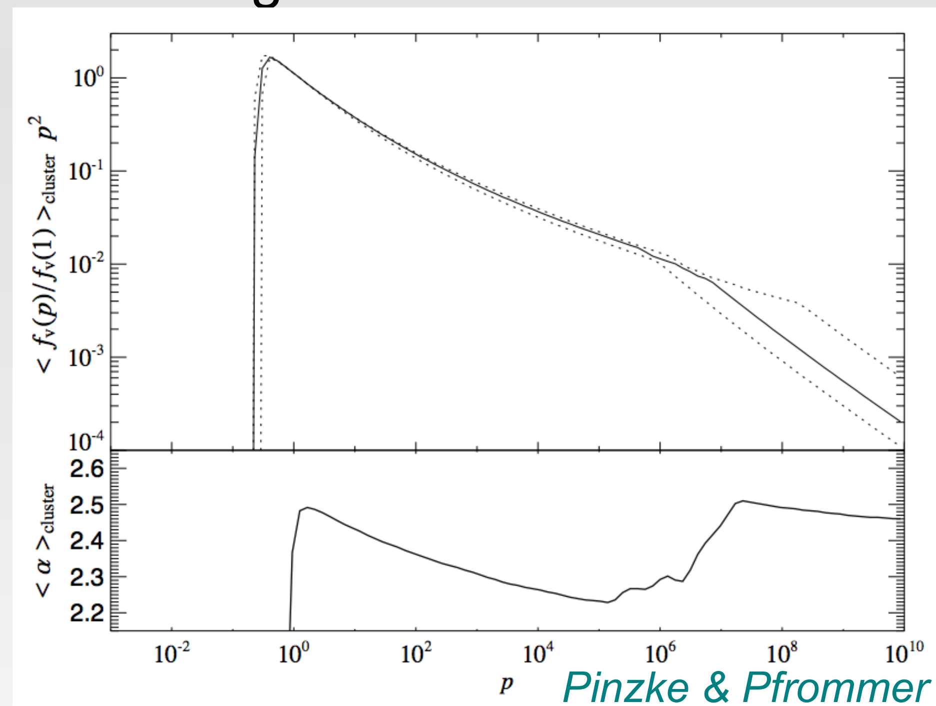
Reacceleration models - uncertainties

- flat CR profile (out to ~0.4 R_{200})
  - strong tension with simulations



Pinzke et al. in prep.

- fixed CR spectral index (~2.6)
  - strong tension with simulations

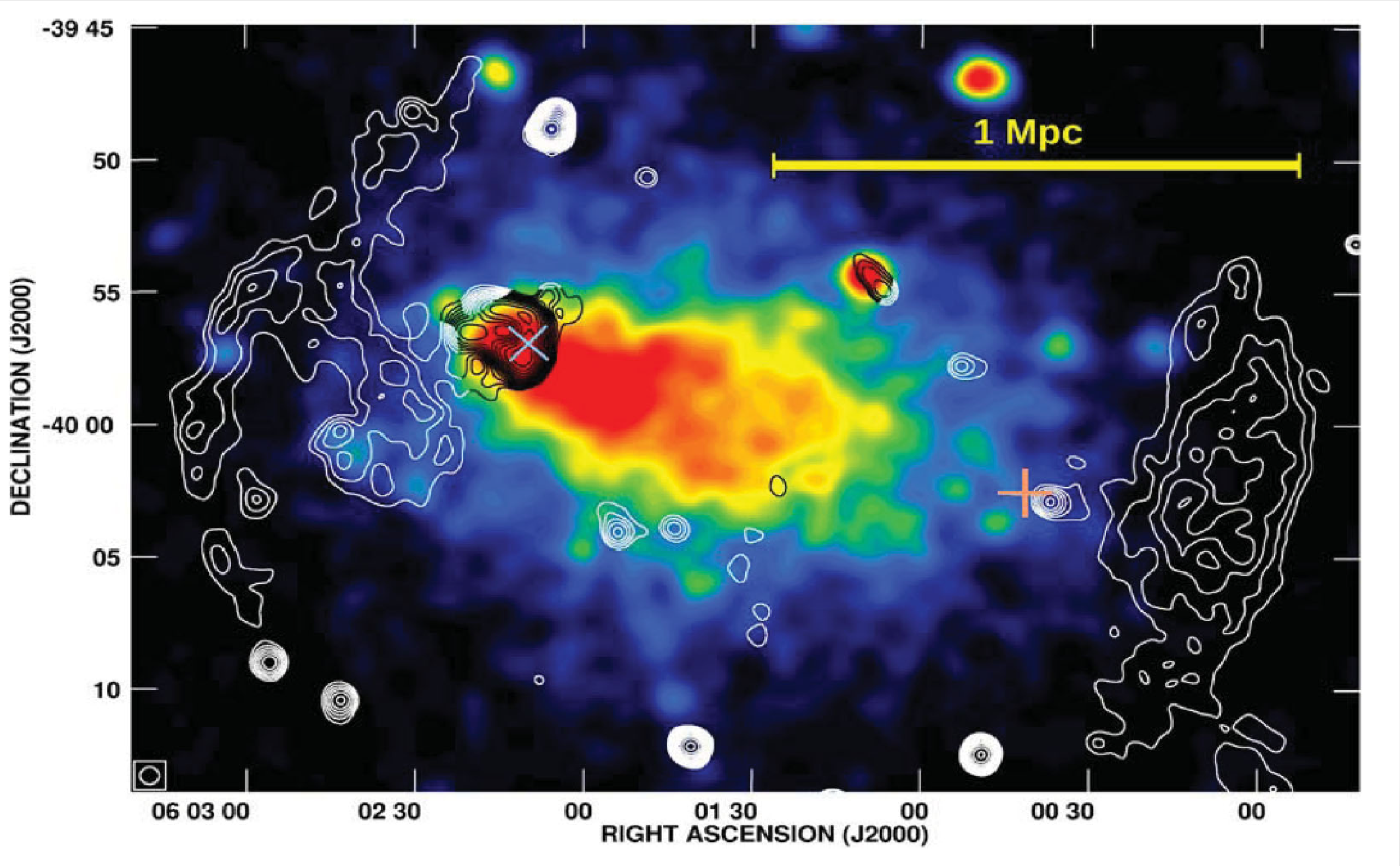


Pinzke & Pfrommer 2010

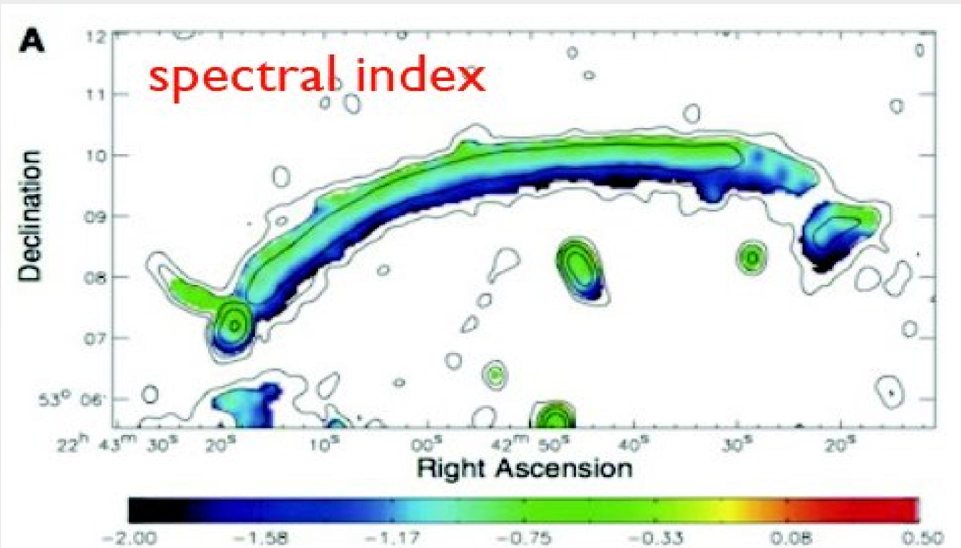
- efficiency acceleration mechanism
- injection rate of turbulence constant over halo region

Realistic cluster simulations with relevant physics need to fully establish reacceleration models!

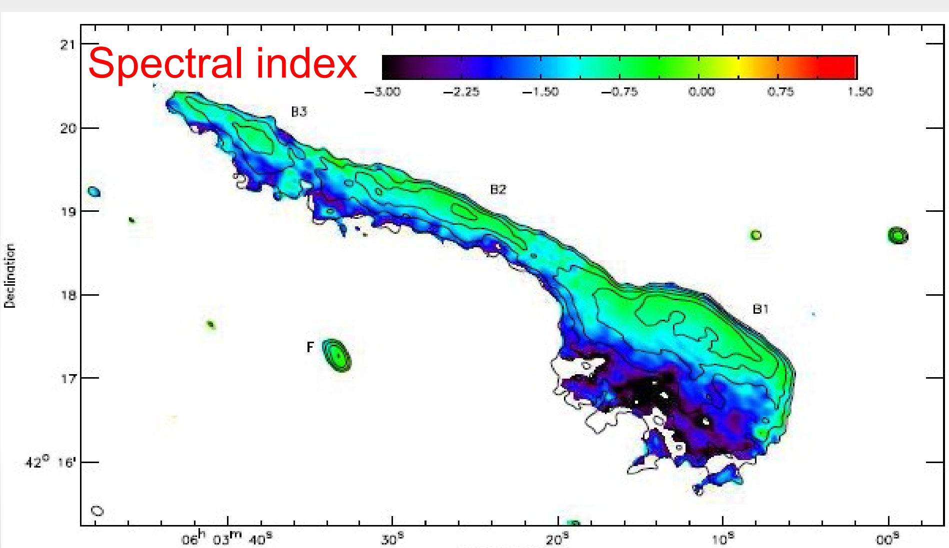
Radio Relics



Radio Relics in a nut-shell

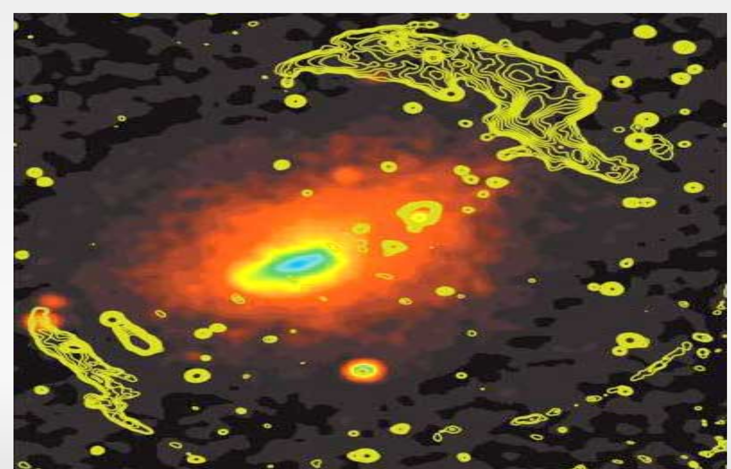


Van Weeren et al., 2010

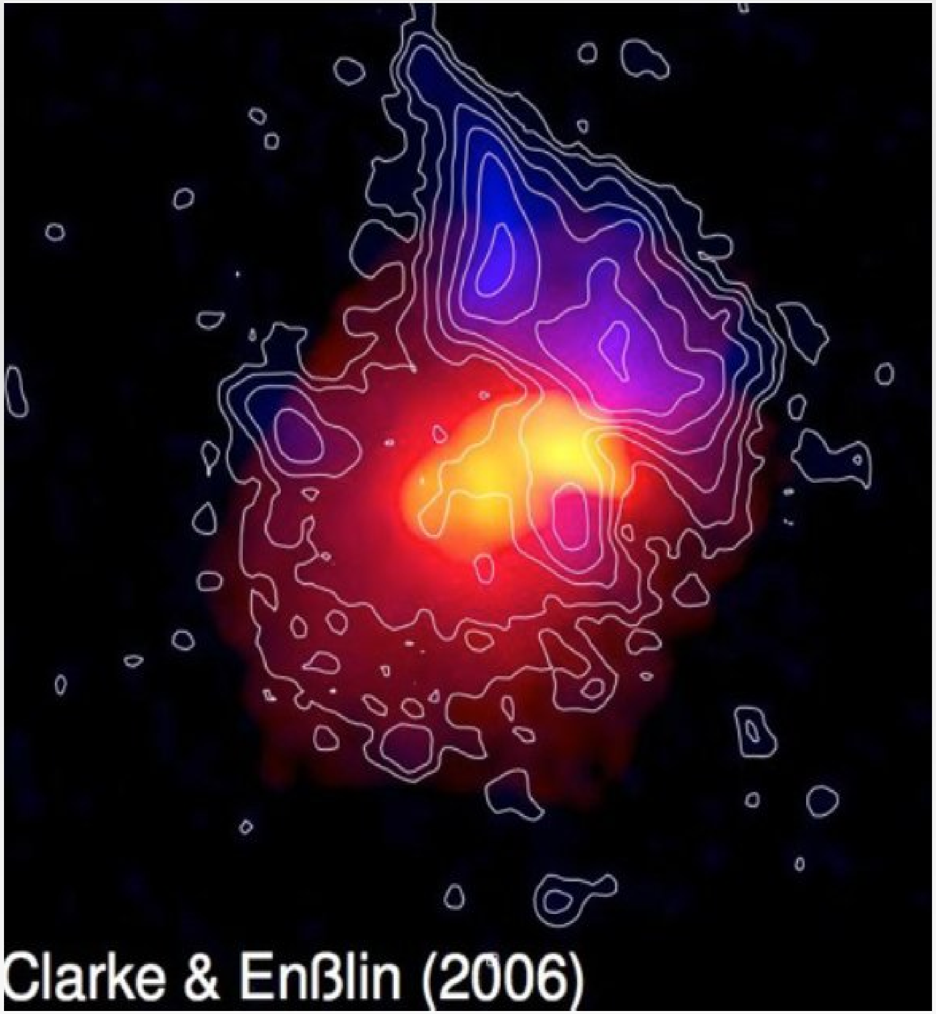


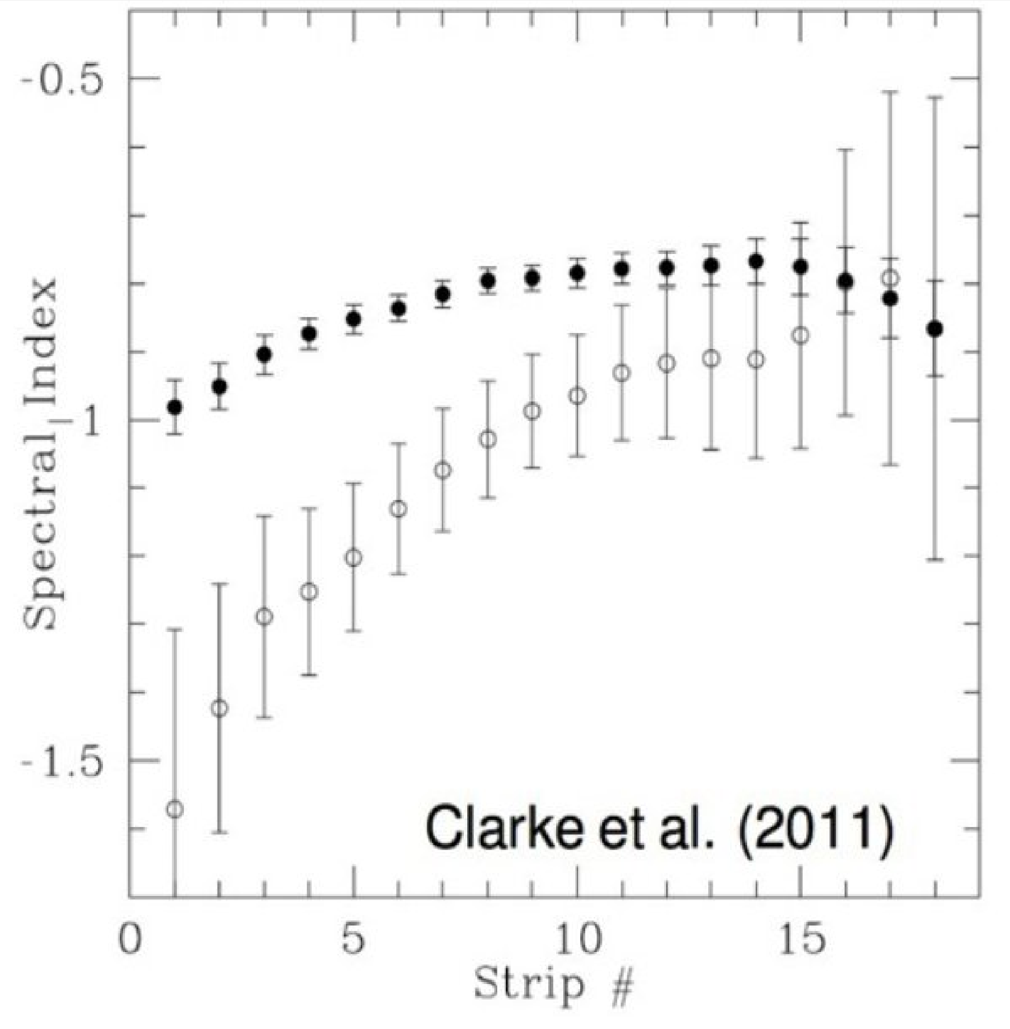
Van Weeren et al., 2012

- Trace shocks in cluster outskirts
- Spectral index: shock Mach number
- Spectral ageing: B-field strength



A radio relic poster child: A2256

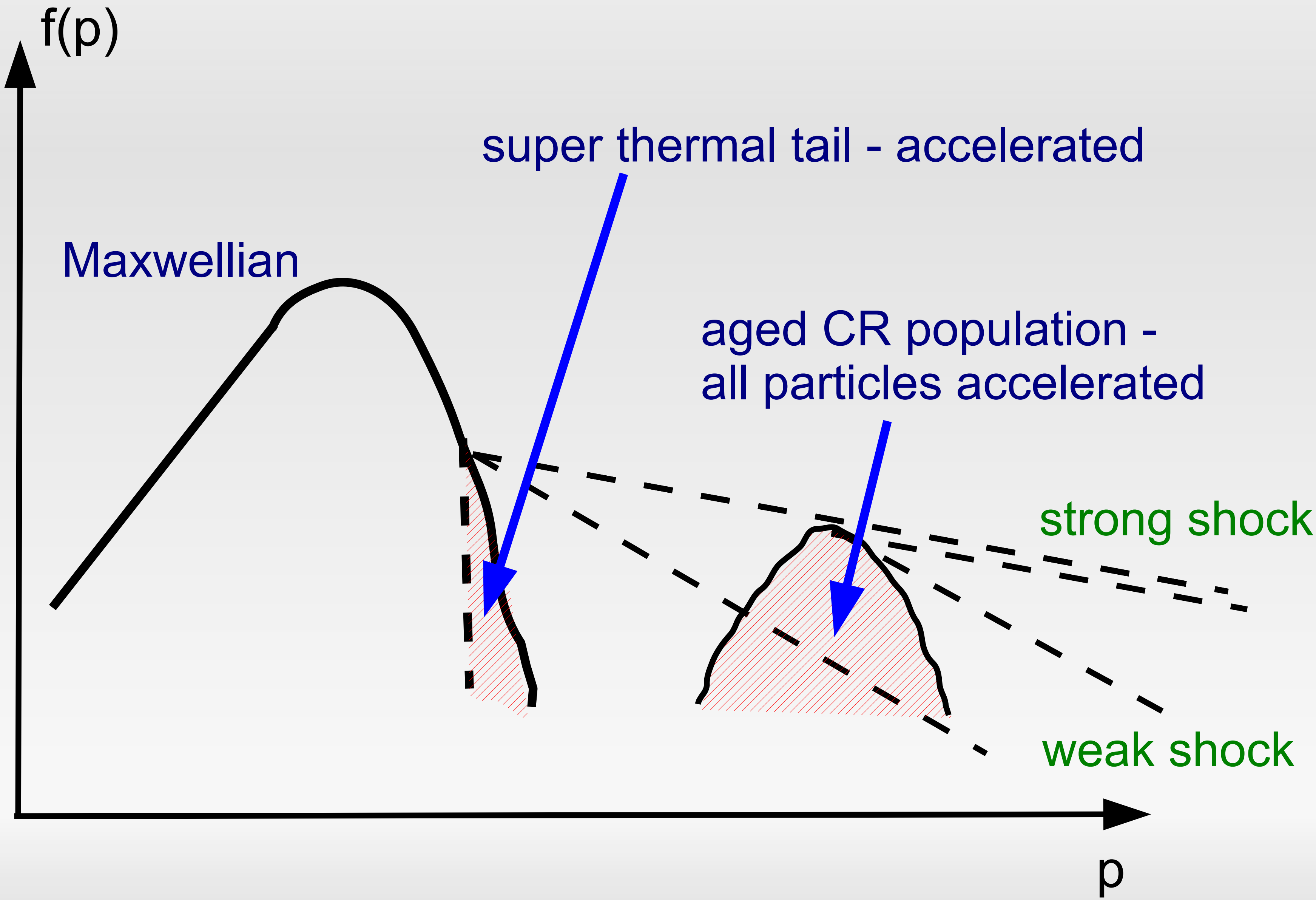




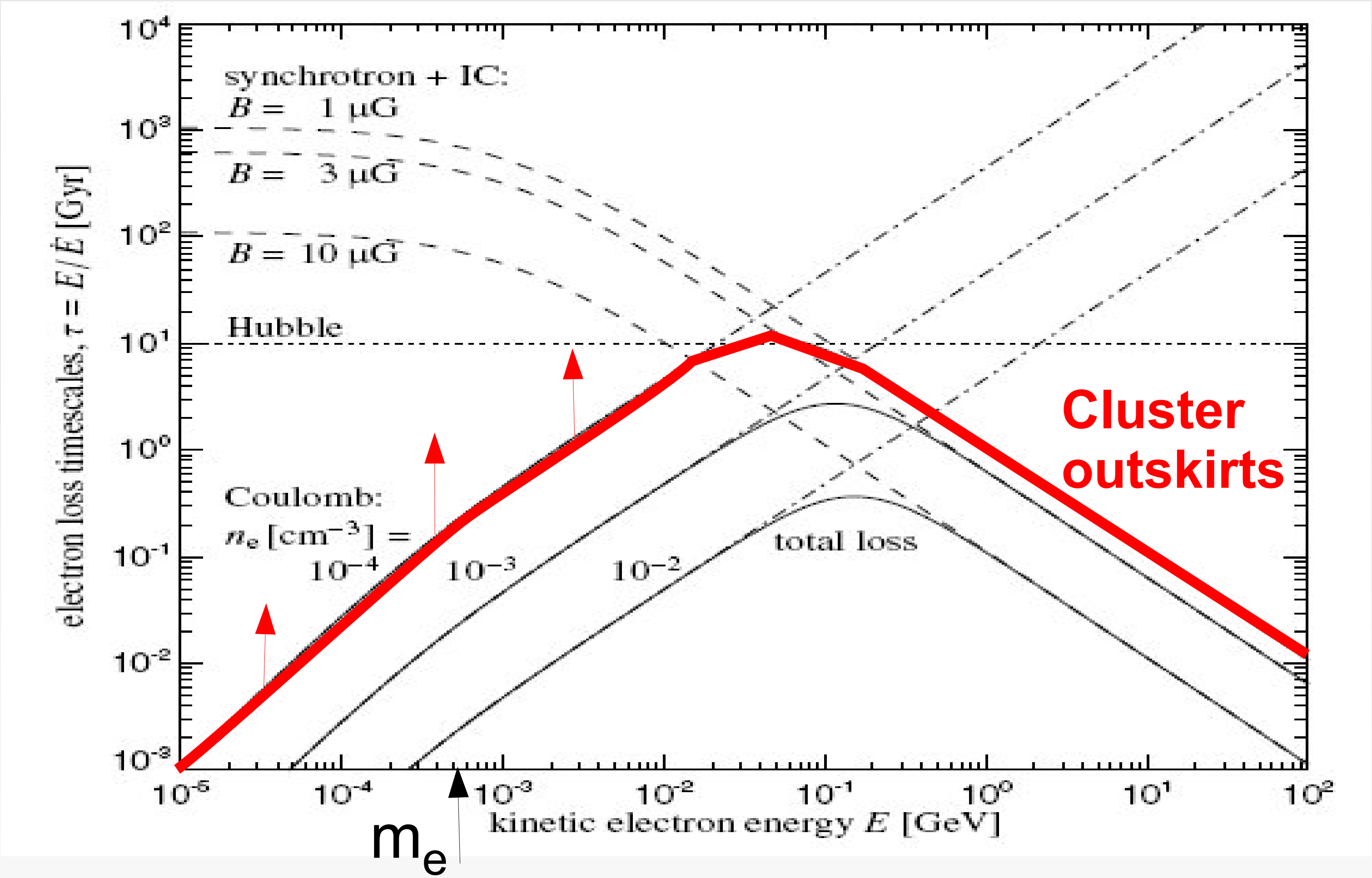
$\alpha_\nu = 0.85 \rightarrow$ Mach = 2.6

How is this possible???

Diffusive shock acceleration – reacceleration through Fermi I

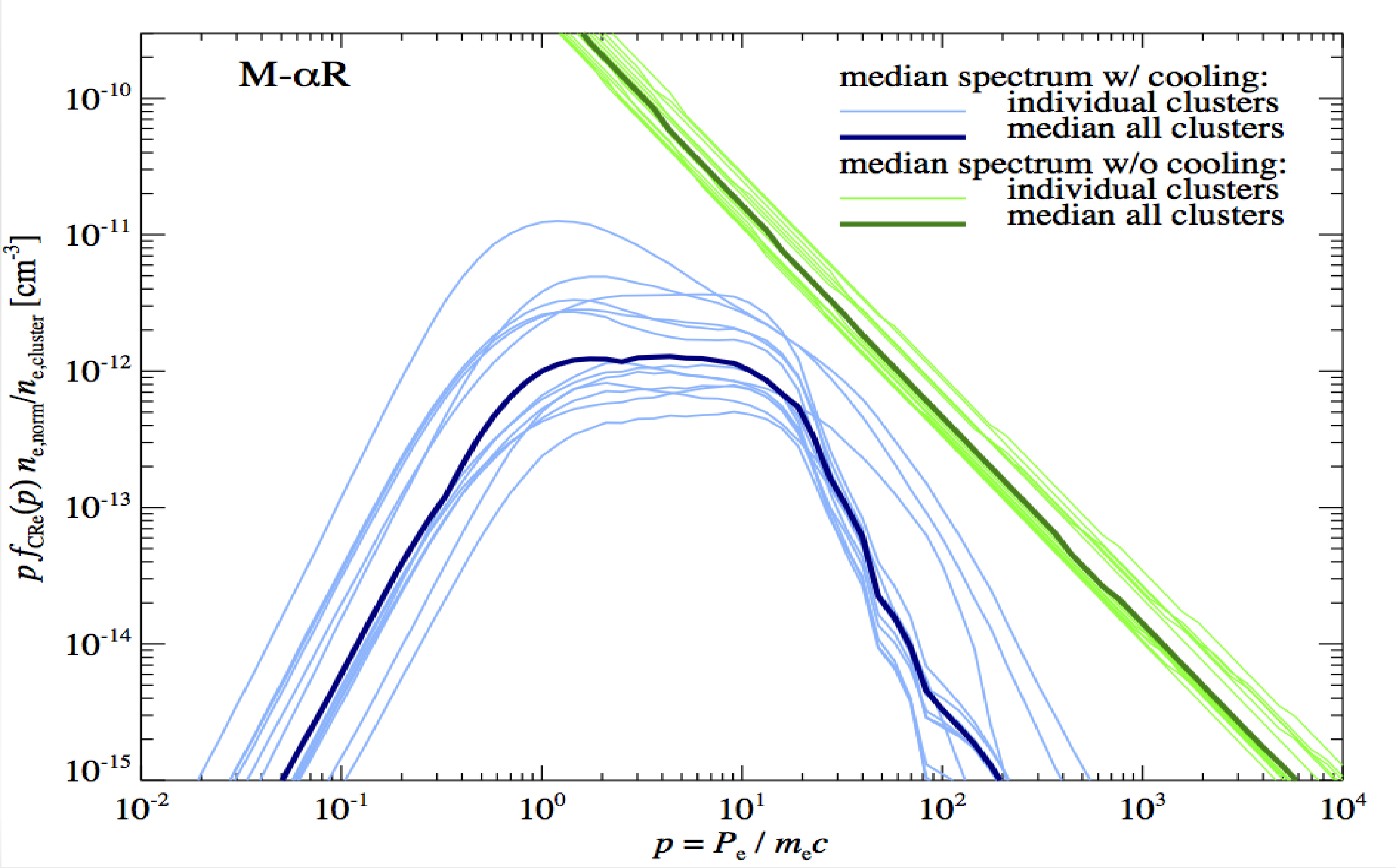


Cooling time of CR electrons

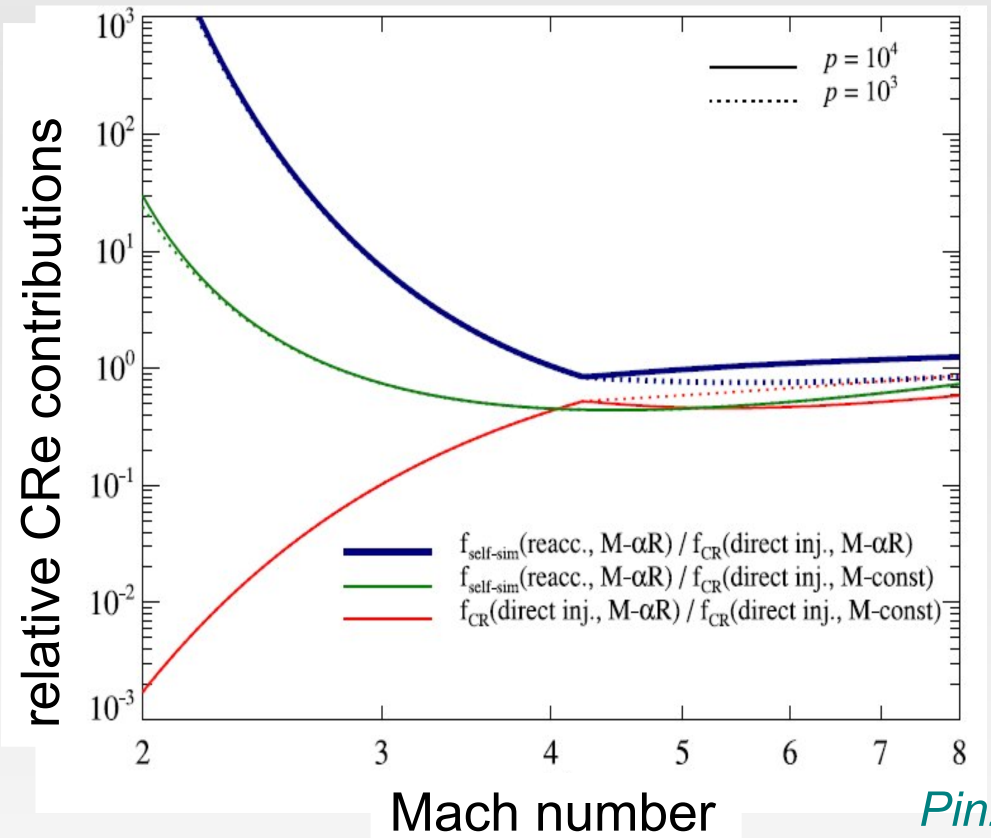


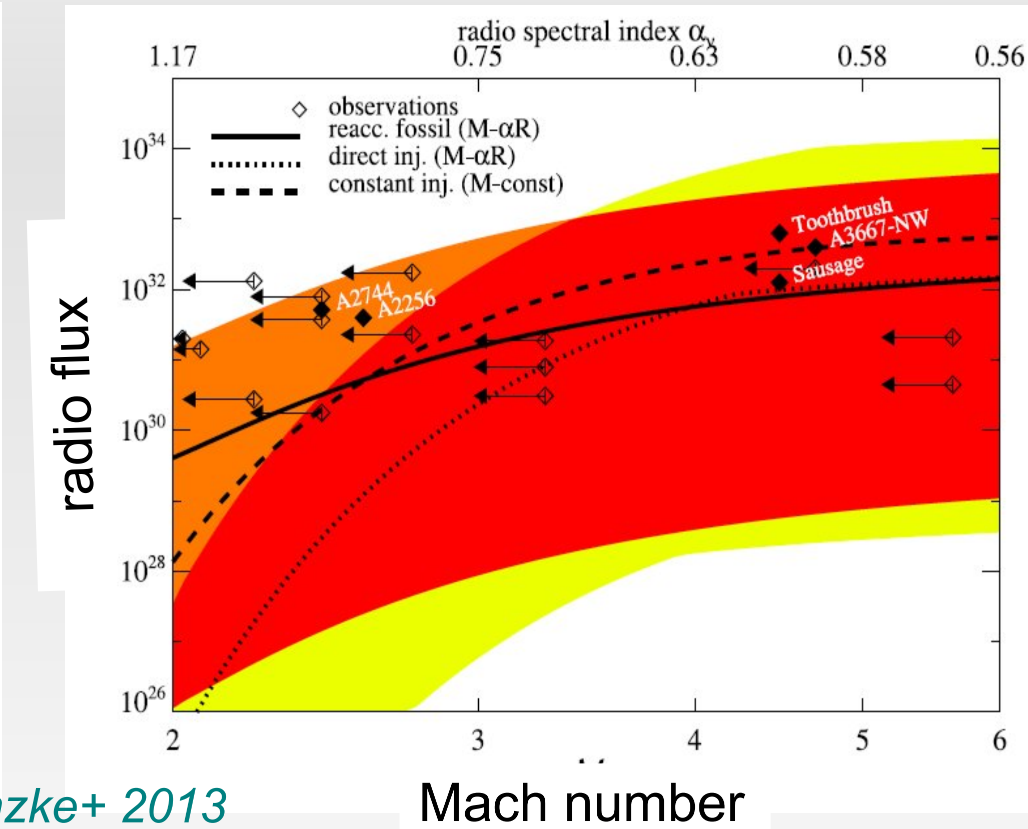
CR electrons accumulate in energy range $\gamma_e \sim 10 - 1000$

Fossil CR electron population



Re-acceleration in radio relics





Pinzke+ 2013

Fossil contribution comparable to direct injection at high M

Dominates at low M !

Take home message

Giant radio halos

- *Classical hadronic models* ruled out by observations, however streaming and diffusion might help solve the problem
- *Reacceleration scenario* preferred, however strong assumptions on initial CR distribution that do not agree with simulations

Radio relics

- *DSA reaccelerated* fossil CR electron in cluster outskirts can explain radio emission from low Mach number shocks