Neutrinos from Clusters of Galaxies and Radio Constraints

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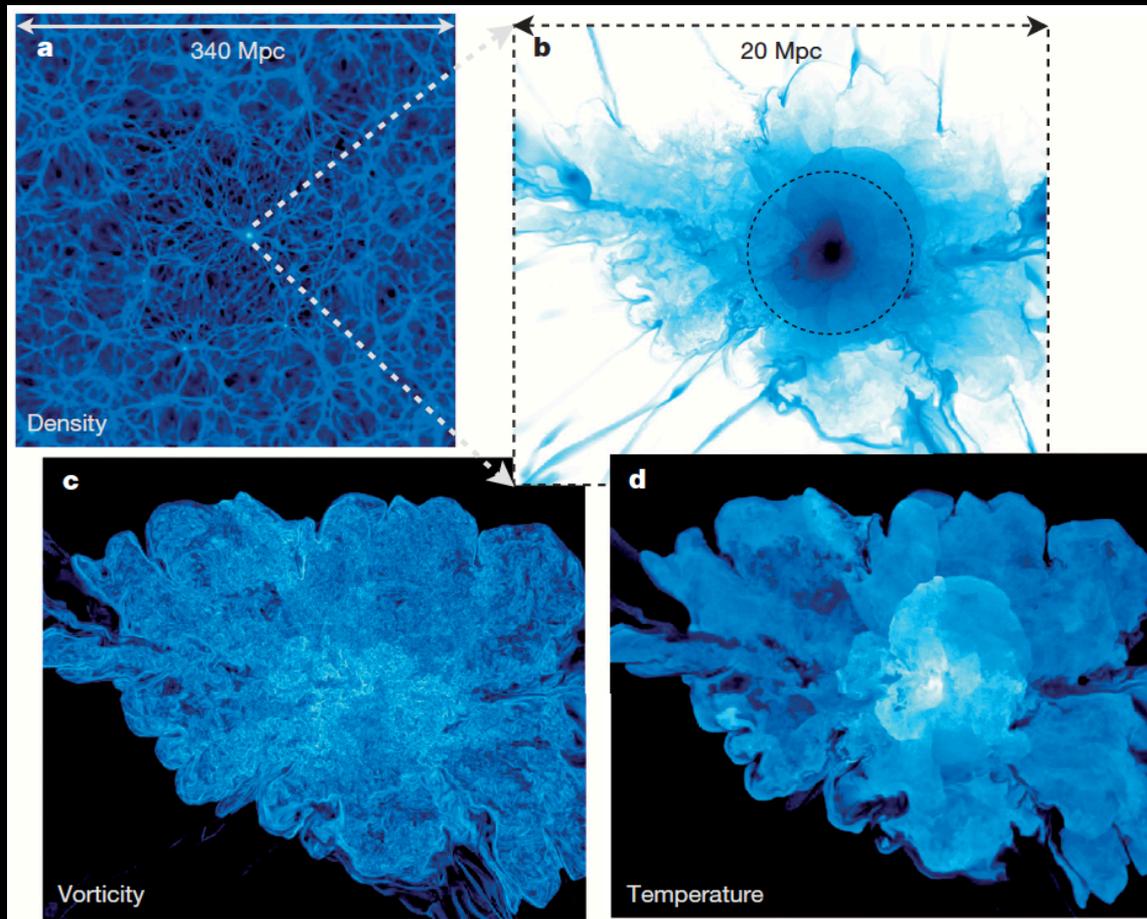f.zandanel@uva.nl

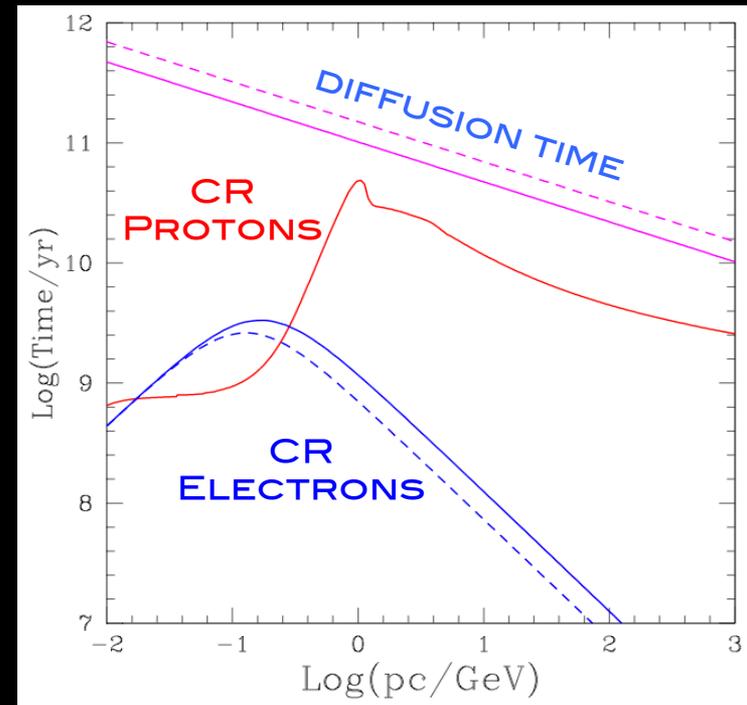ICRC 2015 – Den Haag – July 30, 2015

CLUSTERS OF GALAXIES

LARGEST GRAVITATIONALLY BOUND STRUCTURES IN THE UNIVERSE WITH $10^{14} - 10^{15}$ M$_\odot$ AND Mpc RADII

Miniati & Beresnyak (2015)
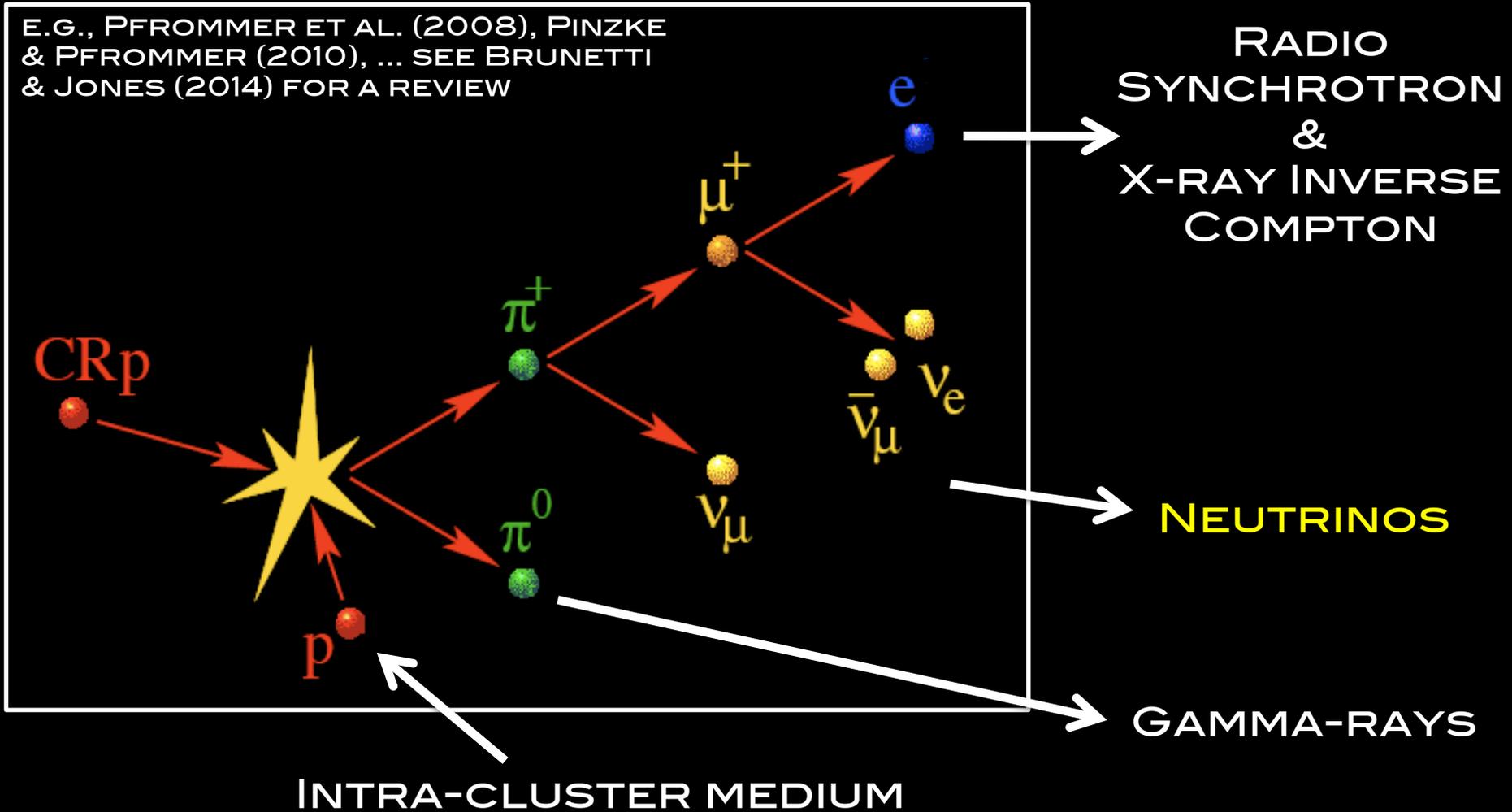
SHOCKS, TURBULENCE, AND GALAXY OUTFLOWS
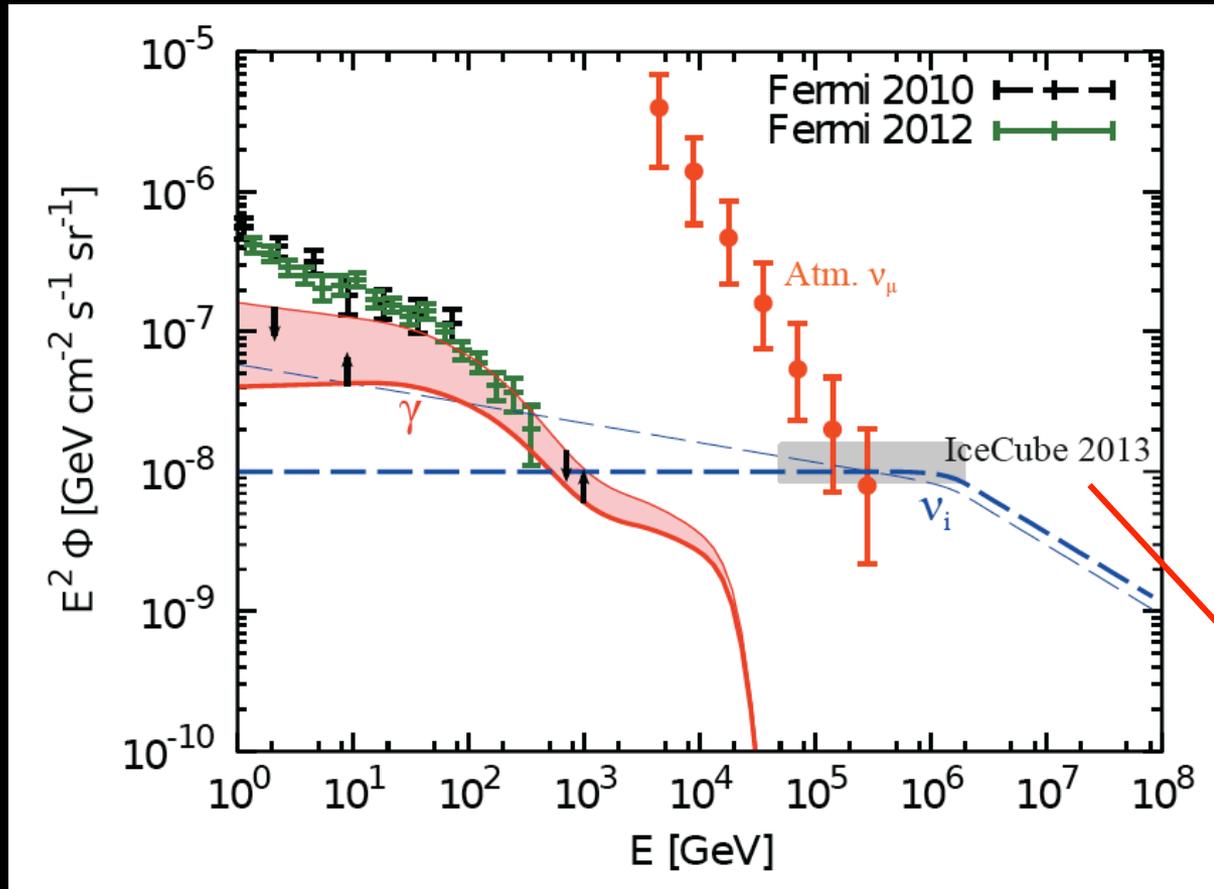
→ Cosmic Ray Protons

Blasi, Gabici & Brunetti (2007)

HADRONIC PROTON-PROTON INTERACTIONS

E.G., PFROMMER ET AL. (2008), PINZKE & PFROMMER (2010), ... SEE BRUNETTI & JONES (2014) FOR A REVIEW

CRp

p

π^+

π^0

μ^+

e^-

$\bar{\nu}_\mu$

ν_e

ν_μ

RADIO SYNCHROTRON & X-RAY INVERSE COMPTON

NEUTRINOS

GAMMA-RAYS

INTRA-CLUSTER MEDIUM

NEUTRINOS FROM CLUSTERS

CAN THE SUMMED OUTPUT OF ALL GALAXY CLUSTERS IN THE UNIVERSE EXPLAIN THE ICECUBE NEUTRINOS?

AARTSEN ET AL. (2014)
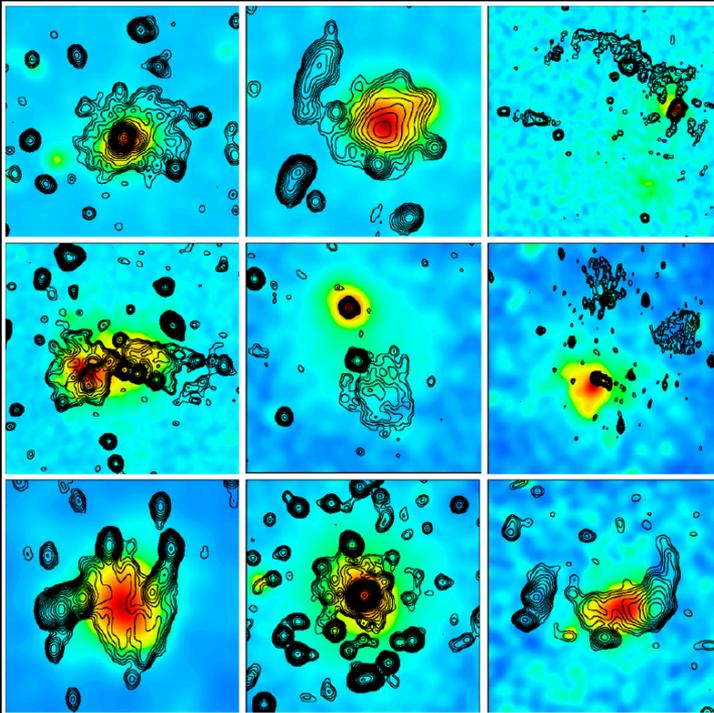
MURASE, AHLERS & LACKI (2013)

E.G., BEREZINSKY ET AL. (1997), MURASE ET AL. (2008), KOTERA ET AL. (2009), MURASE & BEACOM (2013), MURASE ET AL. (2013), ...

CONSTRAINTS

- **NON-DETECTIONS OF CLUSTERS IN GAMMA RAYS**

REFERENCE: UPPER LIMITS ON
PERSEUS (MAGIC COLL. 2012) AND COMA (ZANDANEL & ANDO 2014)

- **OBSERVED DIFFUSE RADIO EMISSION IN CLUSTERS**

FERETTI ET AL. (2012)

CONSERVATIVE CONSTRAINT:

NOT OVERSHOOT OBSERVED CLUSTER RADIO COUNTS!

REFERENCE: NVSS SURVEY
(GIOVANNINI ET AL. 1999)

WHY CONSERVATIVE?

WE DO KNOW THAT MOST EMISSION IS LIKELY NOT FROM SECONDARIES

(BRUNETTI ET AL. 2012, ZANDANEL ET AL. 2014)

SIMPLE APPROACH

CALCULATE TOTAL GAMMA-RAY AND NEUTRINO FLUXES FOR ALL CLUSTERS IN THE UNIVERSE USING THEIR MASS FUNCTION

WE ADOPT A GAMMA-RAY LUMINOSITY – MASS RELATION RESPECTING CONSTRAINTS FROM RADIO TO GAMMA-RAYS

GAMMA LUMINOSITY:

$$L_\gamma = A_\gamma \int \rho_{CR}\, \rho_{ICM}\ dV$$

⟷

RADIO LUMINOSITY:

$$L_f = A_f \int \rho_{CR}\, \rho_{ICM} \frac{\epsilon_B}{\epsilon_B + \epsilon_{CMB}} \left(\frac{\epsilon_B}{\epsilon_{B_c}}\right)^{\frac{\alpha_p - 2}{4}} dV$$

IGNORING MAGNETIC FIELD SPATIAL STRUCTURE

⟶

$$\frac{L_\gamma}{L_f} = \frac{A_\gamma}{A_f} \frac{\epsilon_B + \epsilon_{CMB}}{\epsilon_B} \left(\frac{\epsilon_{B_c}}{\epsilon_B}\right)^{\frac{\alpha_p - 2}{4}}$$

ASSUMING B ≫ B$_{CMB}$

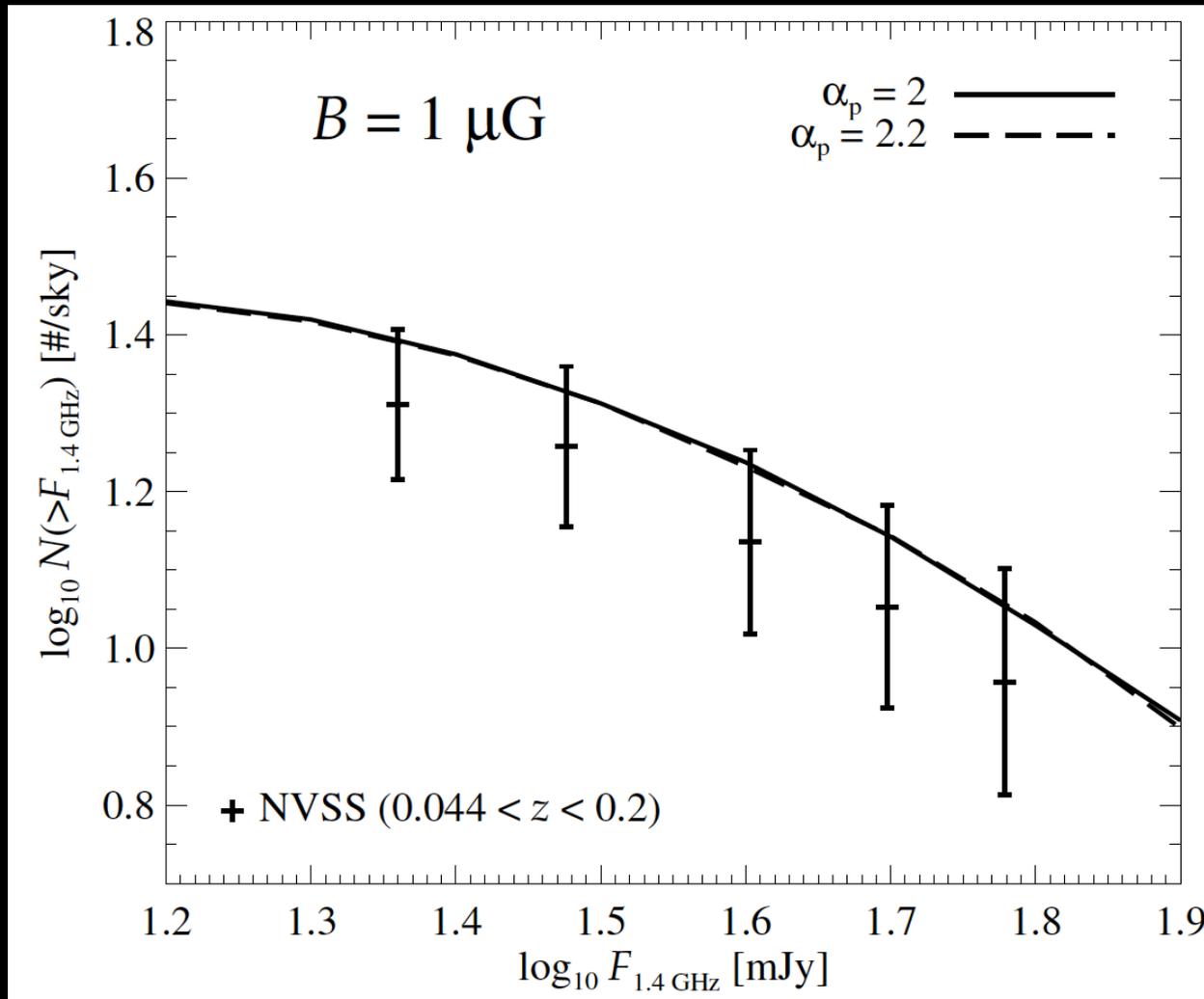$$\frac{L_\gamma}{L_f} \approx \frac{A_\gamma}{A_f}$$
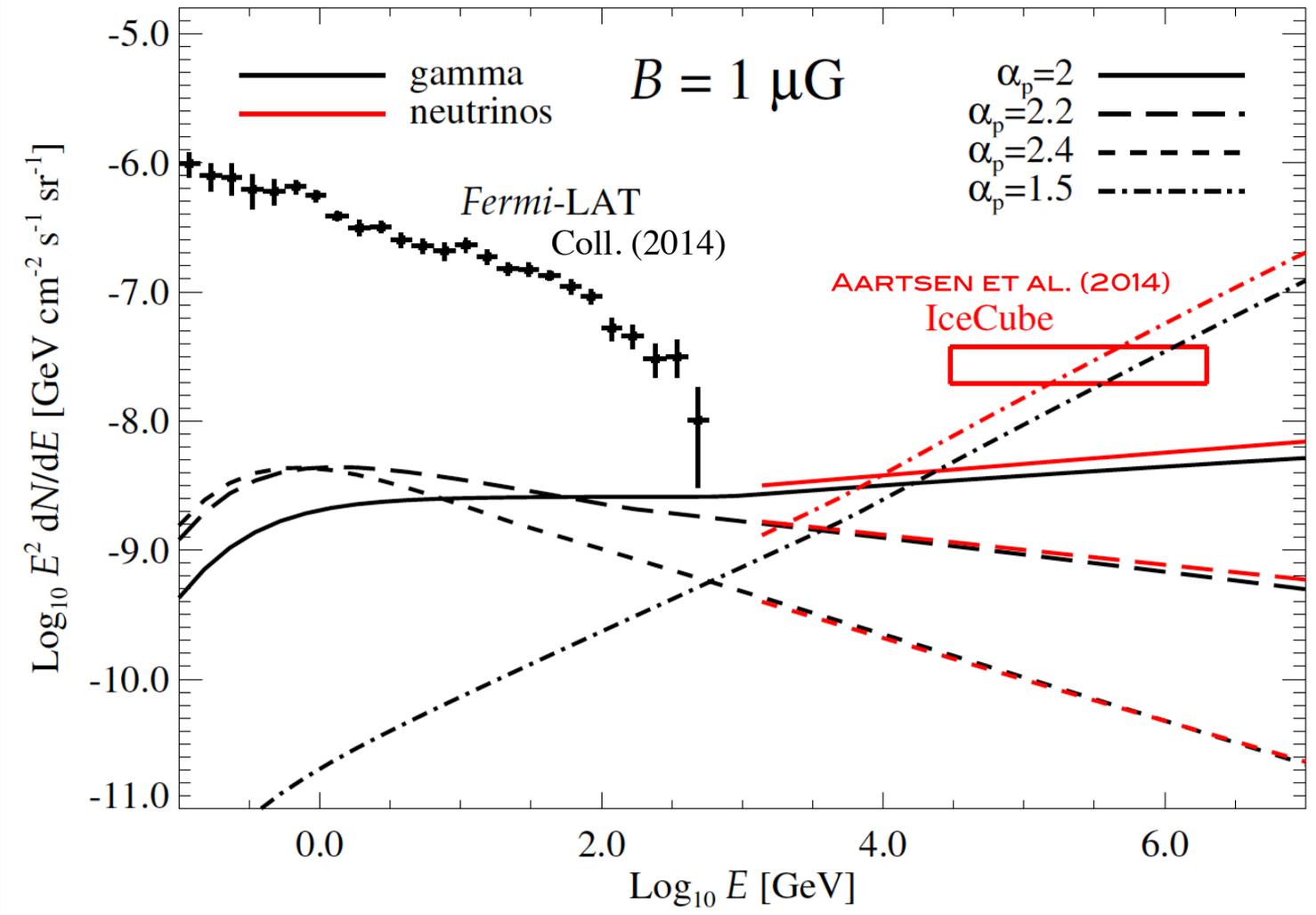
WE STUDY THE CASES WITH:
B ≫ B$_{CMB}$, B = 1 μG AND B = 0.5 μG
α_P = 1.5, 2, 2.2 AND 2.4
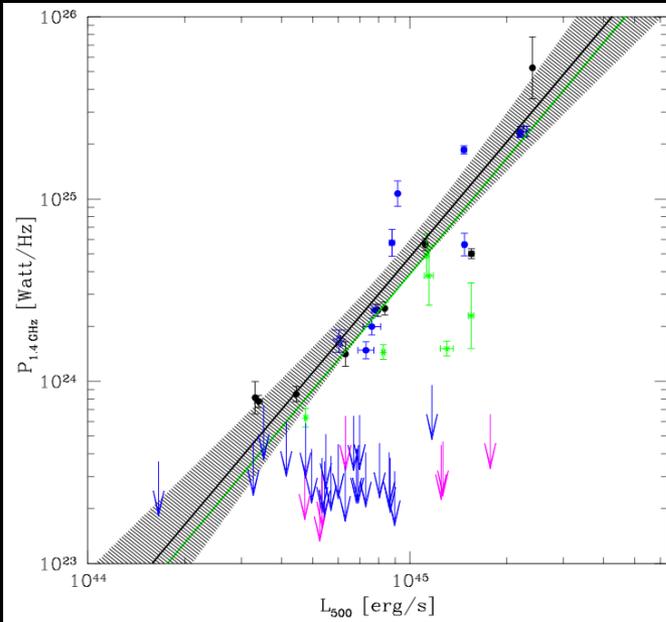
RADIO COUNTS

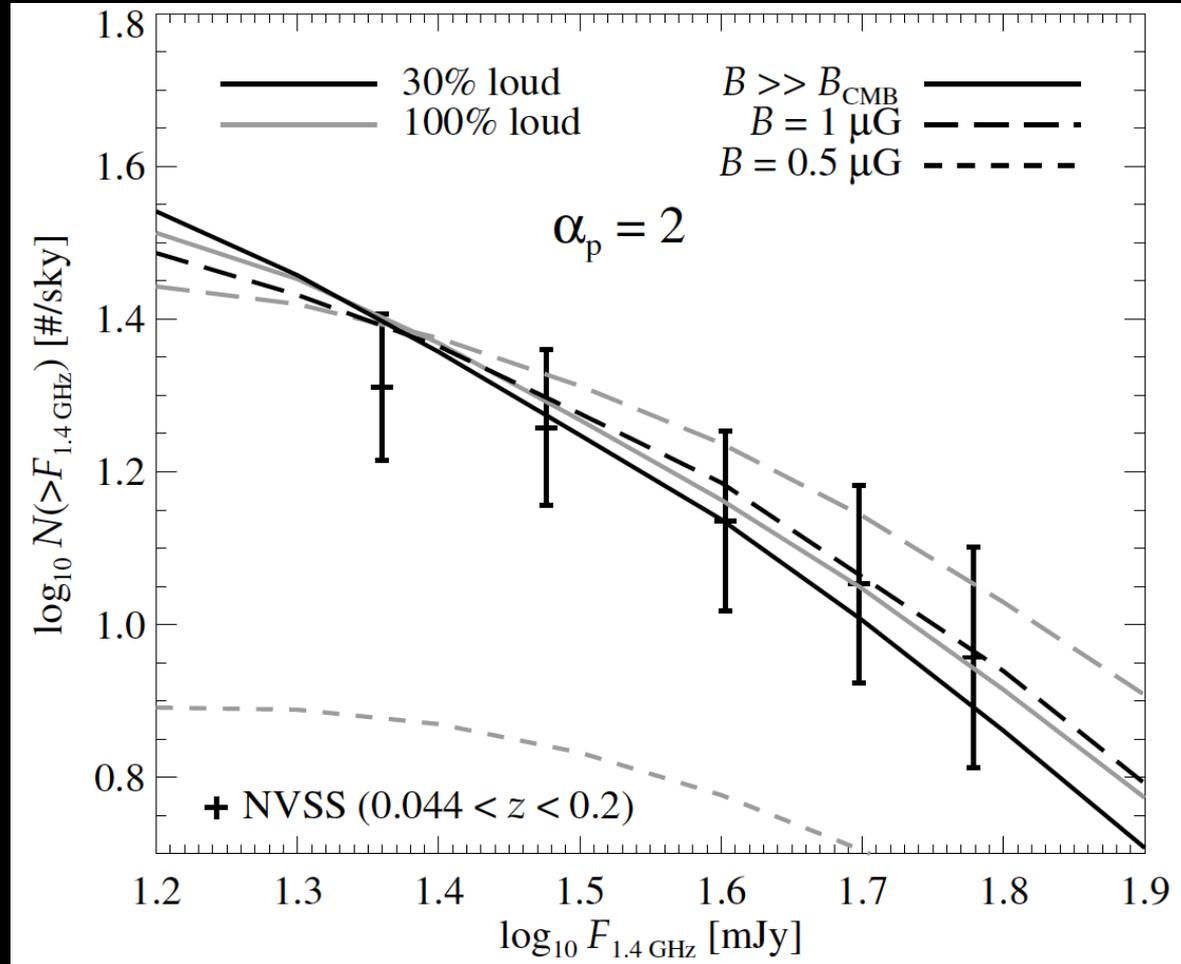Zandanel, Tamborra, Gabici & Ando (2015)

Zandanel, Tamborra, Gabici & Ando (2015)

RADIO LOUD/QUIET CLUSTERS

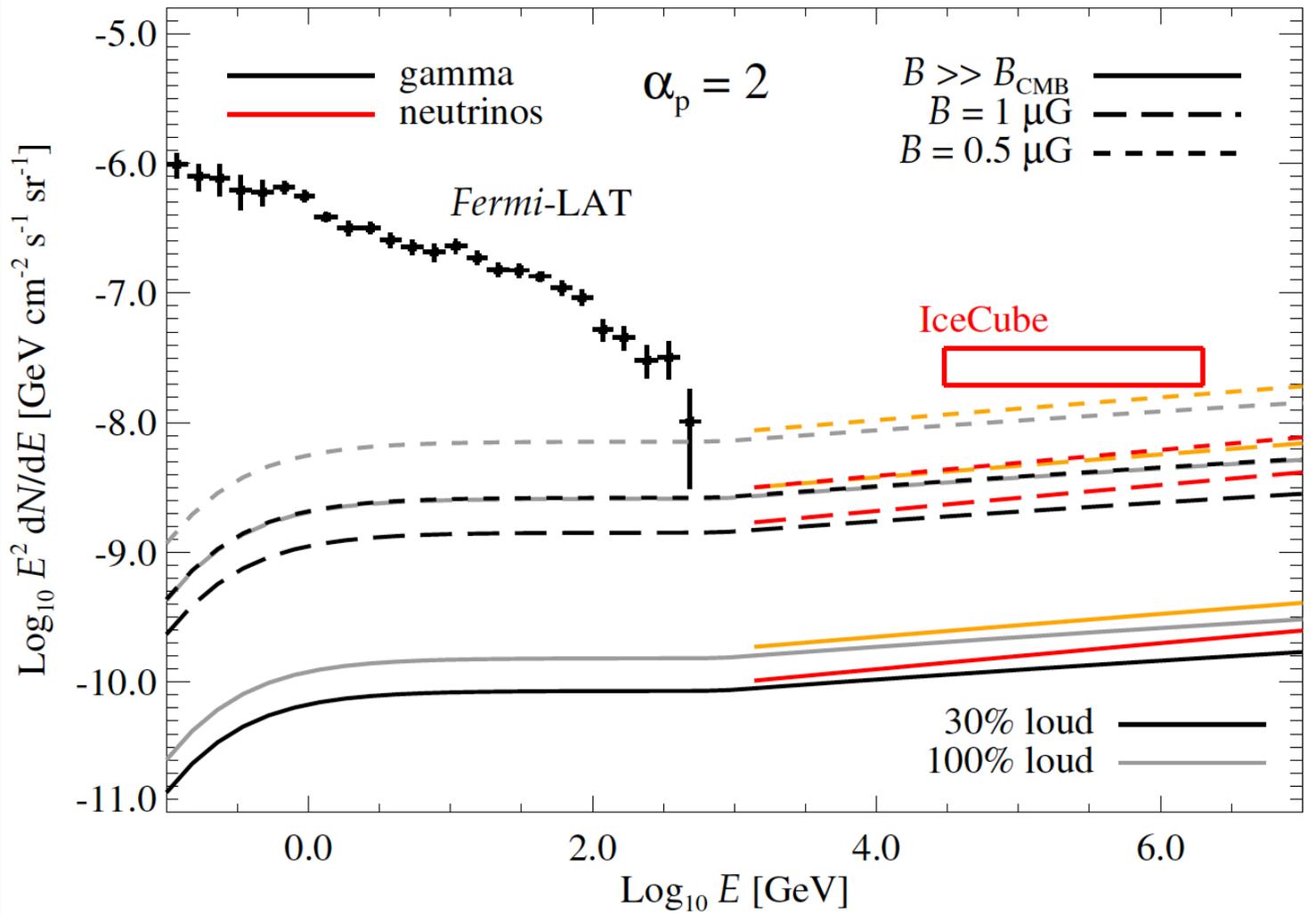**Not all host radio emission**

e.g., Cassano et al. (2013)

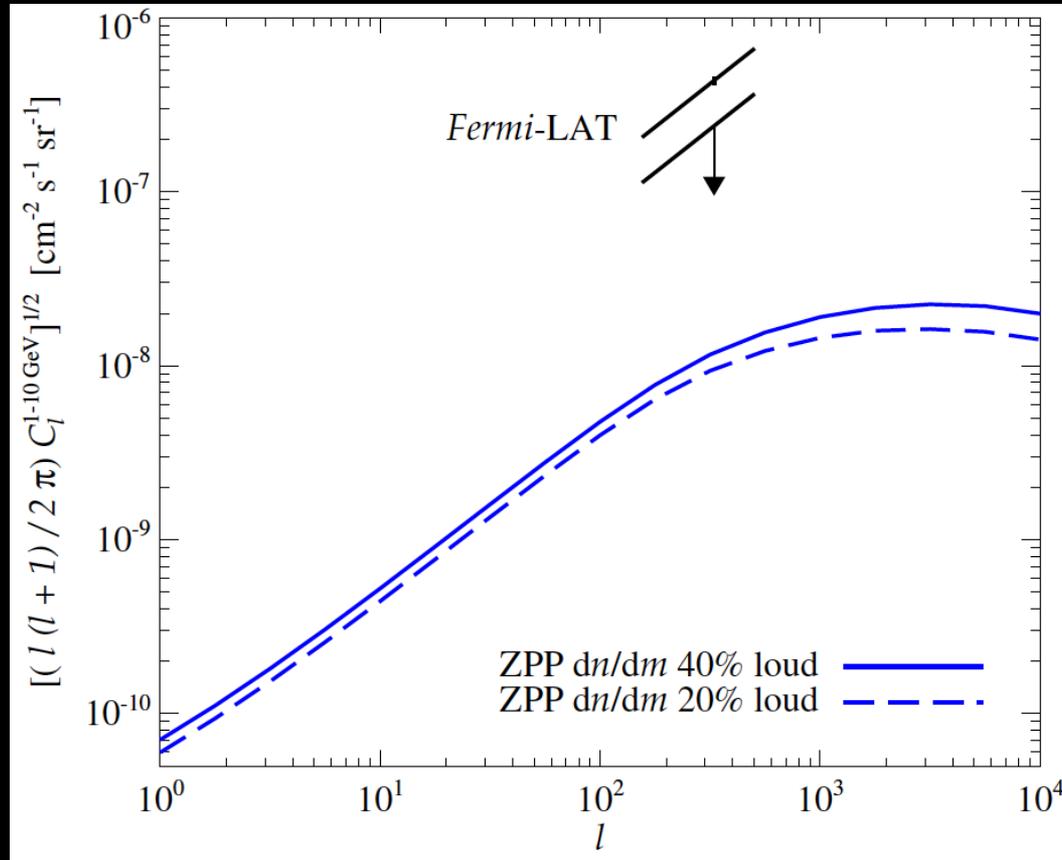Zandanel, Tamborra, Gabici & Ando (2015)

TOTAL GAMMAS AND NEUTRINOS

Zandanel, Tamborra, Gabici & Ando (2015)

ANISOTROPY POWER SPECTRUM

Full spatial modeling of CRs, Gas and Magnetic Field
(following Zandanel, Pfrommer & Prada 2014) → WE CAN ESTIMATE THE
POWER SPECTRUM OF GAMMA-RAY ANISOTROPIES

Zandanel, Tamborra, Gabici & Ando (2015)

SUMMARY & CONCLUSIONS

- We consider radio constraints for the first time

  - clusters ≤ 10% of IceCube flux for $\alpha_P = 2$

    - Much less for $\alpha_P > 2$, but can explain data for speculative values of $\alpha_P < 2$

- Contribution to diffuse gamma-ray background always negligible + anisotropies

  - IceCube can test most optimistic scenarios stacking nearby sources

Our conclusions are valid for all sources injecting CRs into the intra-cluster medium!