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High-energy gamma-ray and neutrino backgrounds from clusters of galaxies and radio constraints

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ABSTRACT

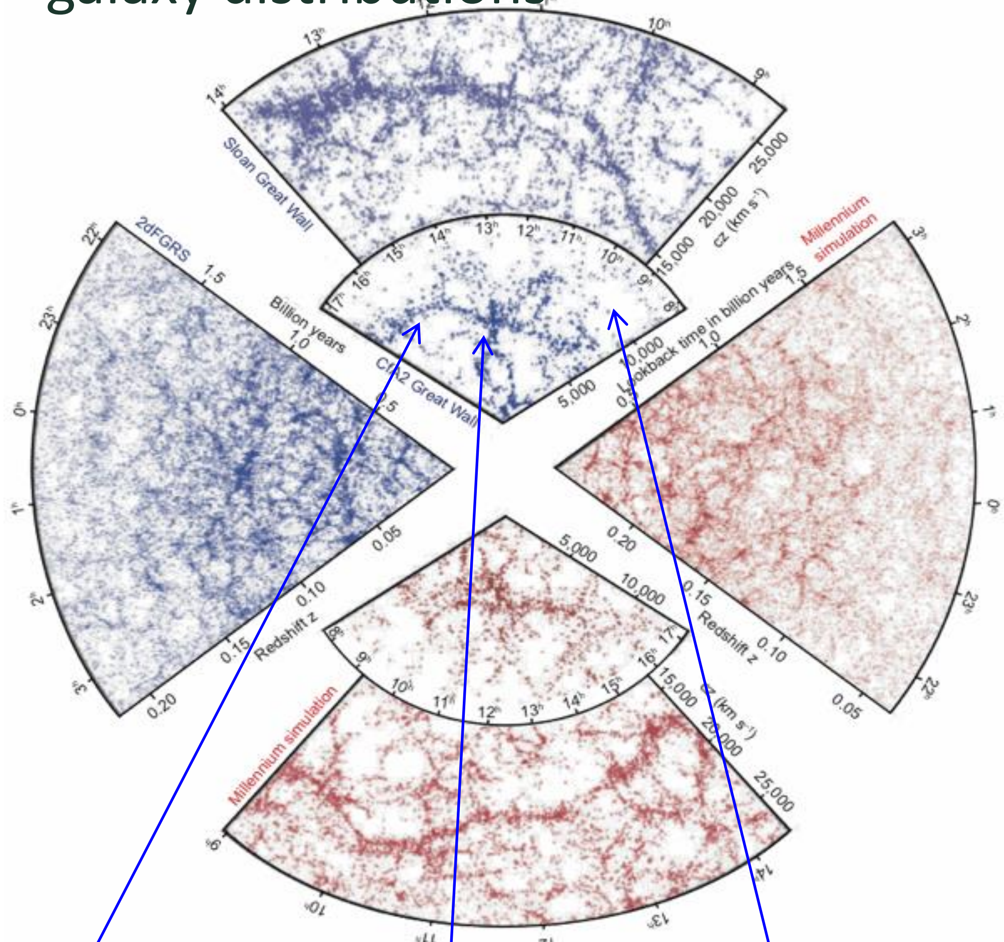
Cosmic-ray protons accumulate for cosmological times in clusters of galaxies because their typical radiative and diffusive escape times are longer than the Hubble time. Their hadronic interactions with protons of the intra-cluster medium generate secondary electrons, gamma rays, and neutrinos. In light of the high-energy neutrino events recently discovered by the IceCube neutrino observatory, for which galaxy clusters have been suggested as possible sources, and the forthcoming results from the *Fermi* gamma-ray survey, we here estimate the contribution from galaxy clusters to the diffuse gamma-ray and neutrino backgrounds. We modelled the cluster population by means of their mass function, using a phenomenological luminosity-mass relation applied to all clusters, as well as a detailed semi-analytical model. In the latter model, we divide clusters into cool-core/non-cool-core, and loud/quiet subsamples, as suggested by observations, and model the cosmic-ray proton population according to state-of-the-art hydrodynamic numerical simulations. Additionally, we consider observationally-motivated values for the cluster magnetic field. This is a crucial parameter since the observed radio counts of clusters need to be respected owing to synchrotron emission by secondary electrons. For a choice of parameters respecting current constraints from radio to gamma rays, and assuming a proton spectral index of –2, we find that hadronic interactions in clusters contribute less than 10% to the IceCube flux and much less to the total extragalactic gamma-ray background observed by *Fermi*. They account for less than 1% for spectral indices ≤–2. The high-energy neutrino flux observed by IceCube can be reproduced without violating radio constraints only if a very hard (and speculative) spectral index >–2 is adopted. However, this scenario is in tension with the high-energy IceCube data, which seems to suggest a spectral energy distribution of the neutrino flux that decreases with the particle energy. We prove that IceCube should be able to test our most optimistic scenarios for spectral indices ≥–2.2 by stacking a few nearby massive galaxy clusters. In the case of proton-photon interactions in clusters, we find that very likely protons do not reach sufficiently high energies to produce neutrinos in these environments. We argue that our results are optimistic because of our assumptions and that clusters of galaxies cannot make any relevant contribution to the extragalactic gamma-ray and neutrino backgrounds in any realistic scenario. Finally, we find that the cluster contribution to the angular fluctuations in the gamma-ray background is subdominant, less than 10% on sub-degree scales.

Key words. galaxies: clusters: general – gamma rays: diffuse background – gamma rays: galaxies: clusters – neutrinos

Dongsu Ryu (UNIST, Korea)

The large-scale structure of the universe
→ the cosmic web

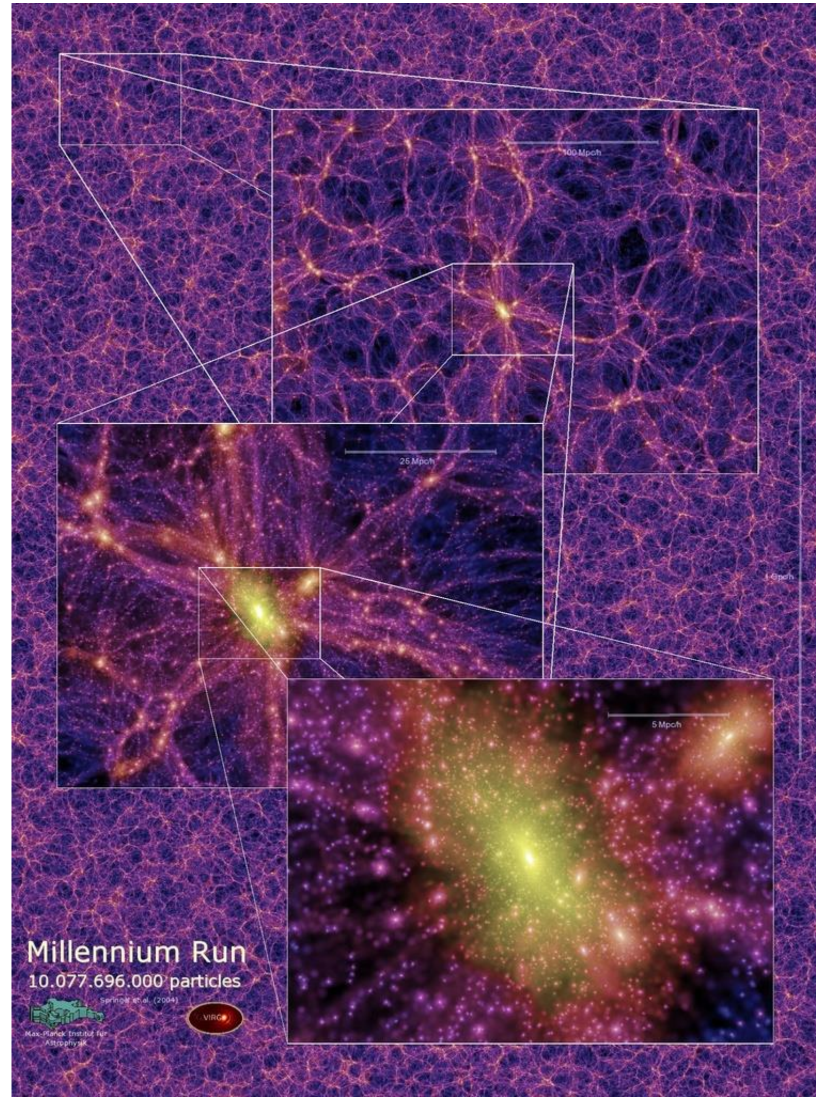
observed and simulated
galaxy distributions



filaments

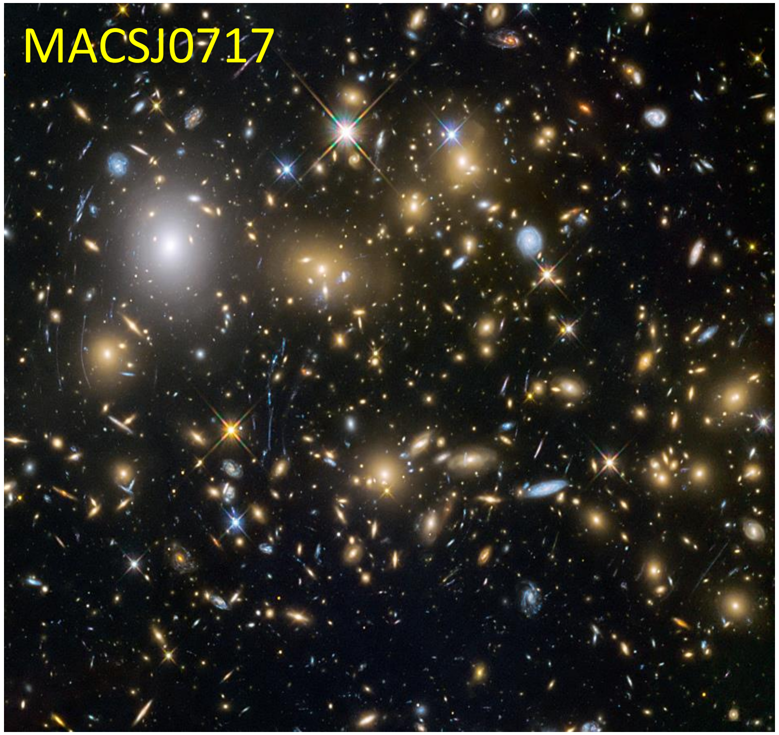
clusters
↓
where most matters reside

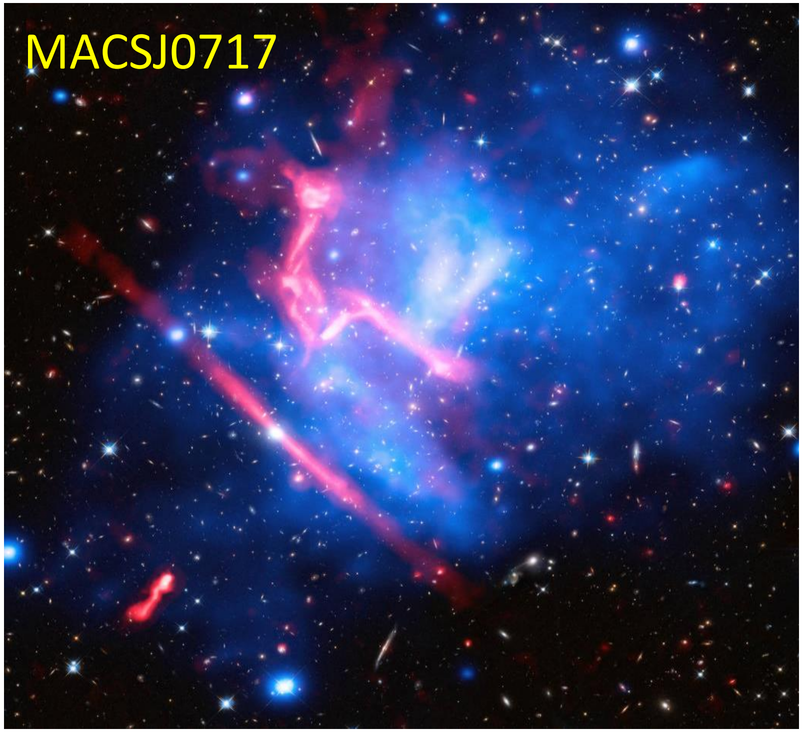
void regions



simulated matter distribution

Clusters of galaxies → aggregates of galaxies, which are the **largest known gravitationally bound objects** to have arisen thus far in the process of cosmic structure formation





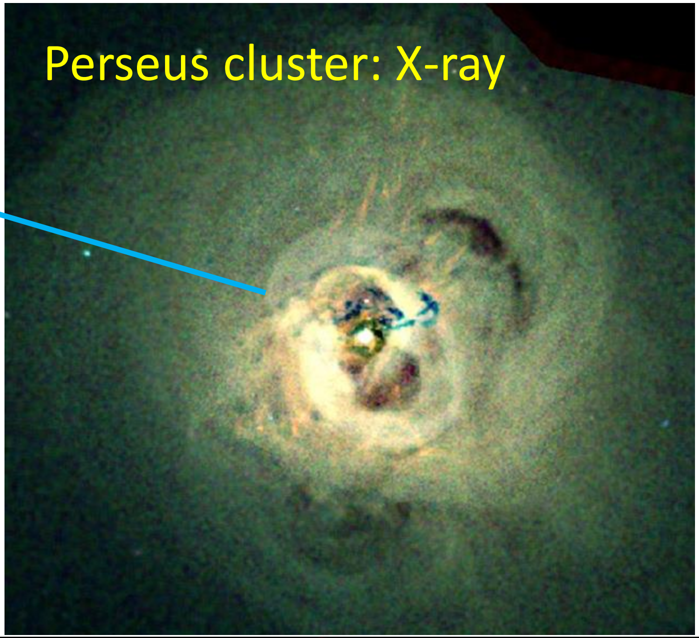
Hubble space telescope image
← mostly star light

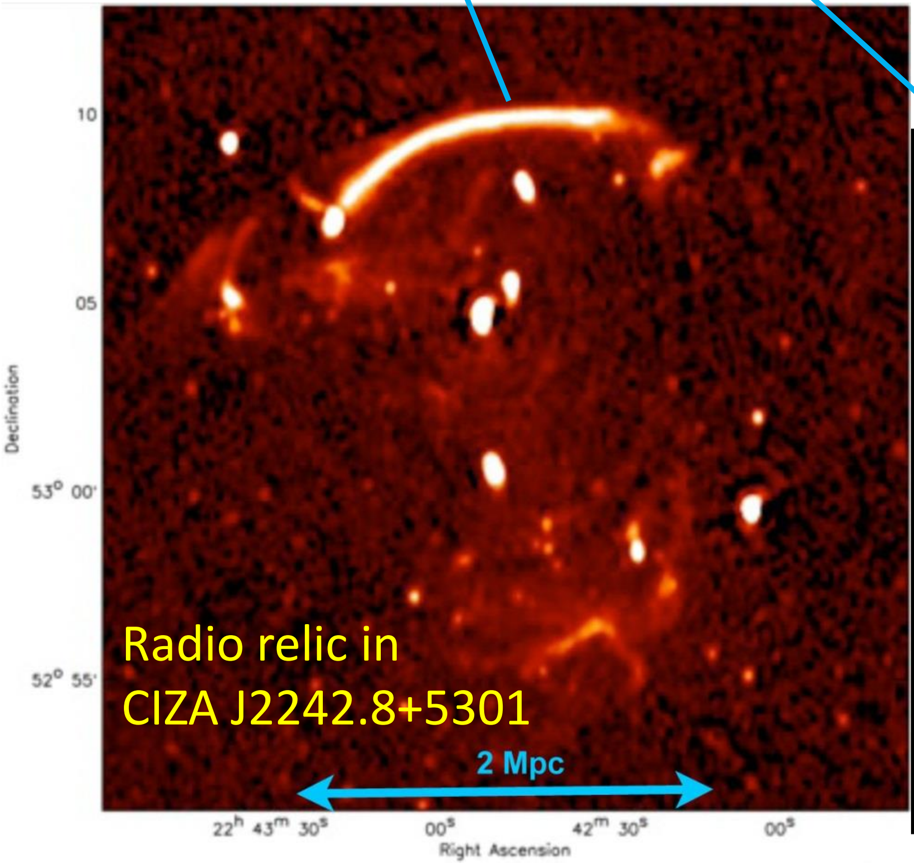
optical (Hubble, white)
X-ray (Chandra, blue) ← hot gas
radio (VLA, red) ← cosmic rays

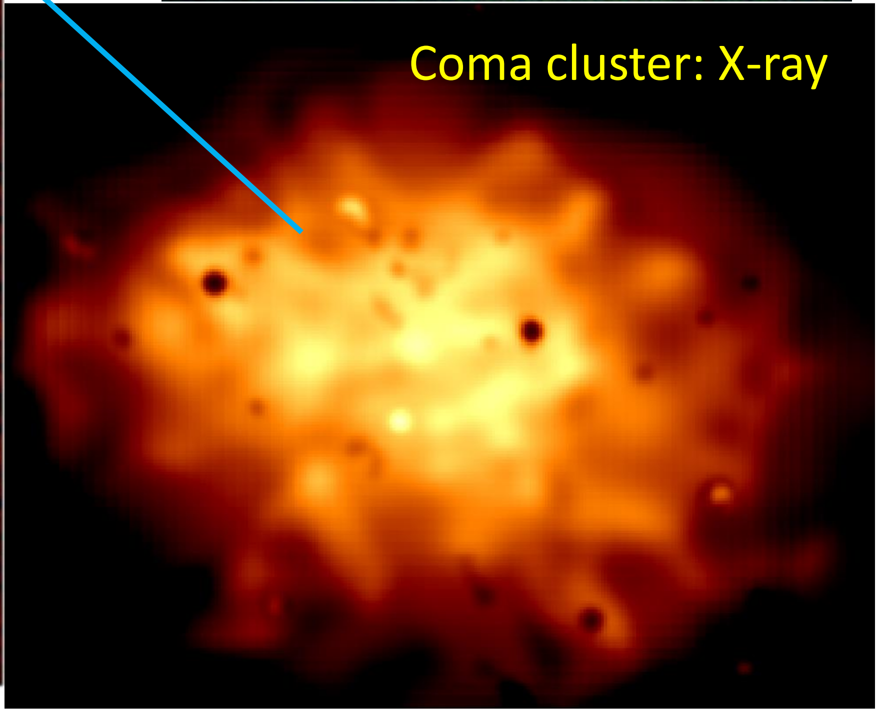
the intracluster medium (ICM) → the superheated **plasma with T ~ a few to several keV**, presented in clusters of galaxies

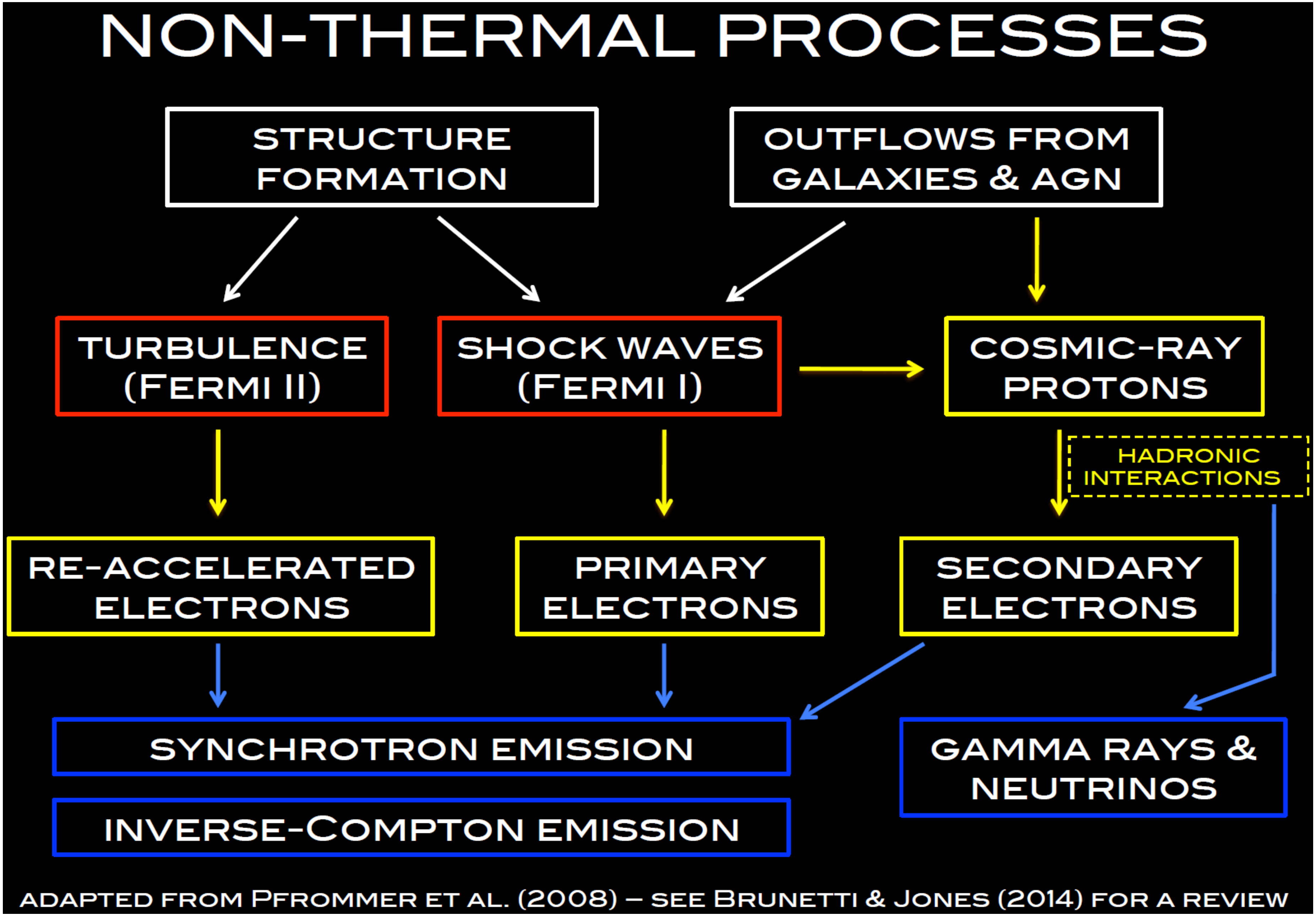
ICMs are dynamical:

- large-scale flow motion
- turbulence
- shocks
- magnetic fields
- **cosmic-rays**



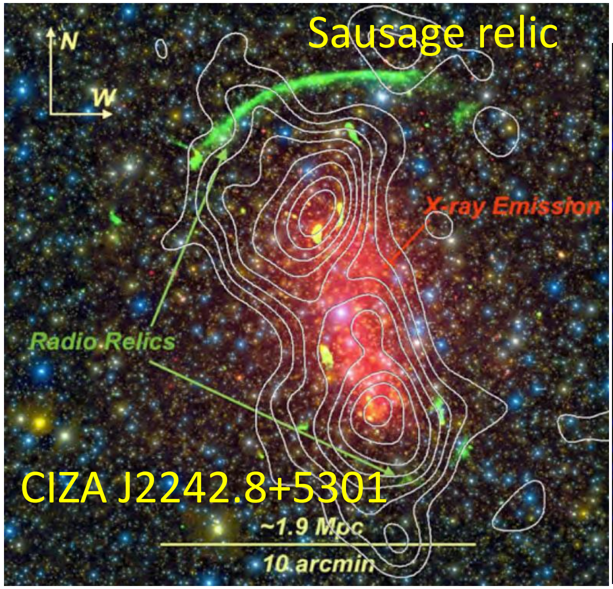


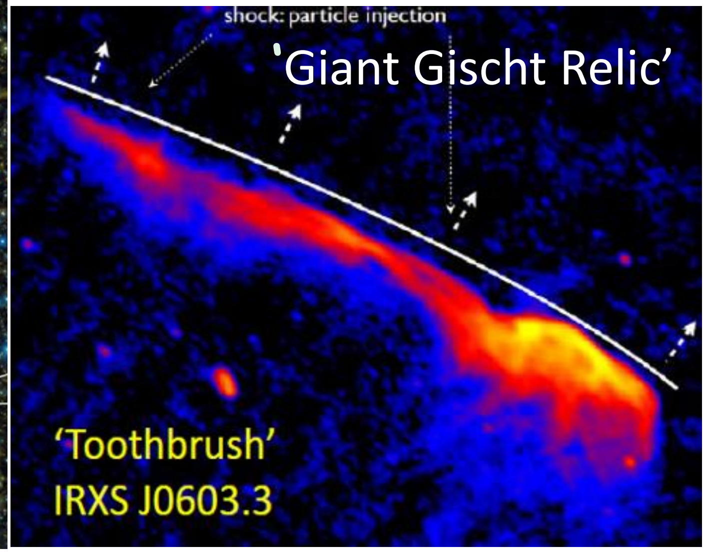




From Zandanel

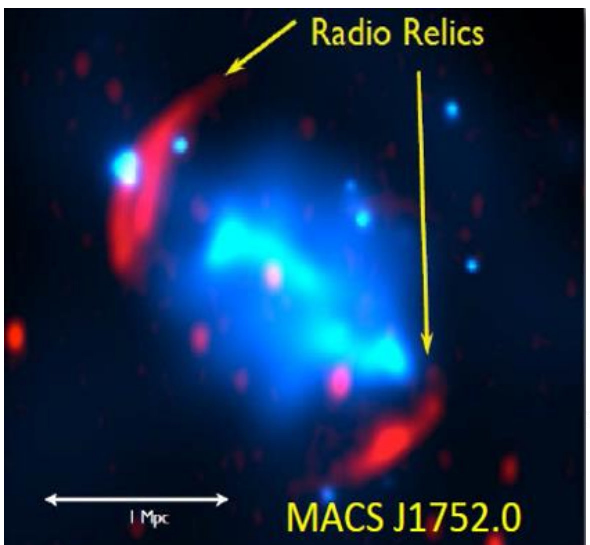
Evidence of “**CR electrons**” in clusters: radio relics

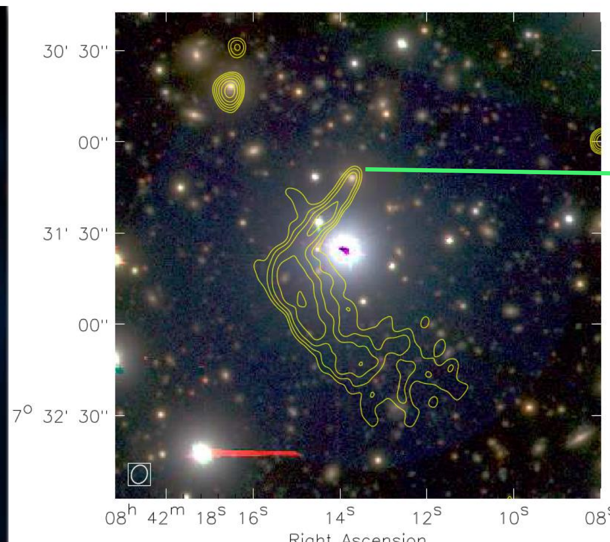




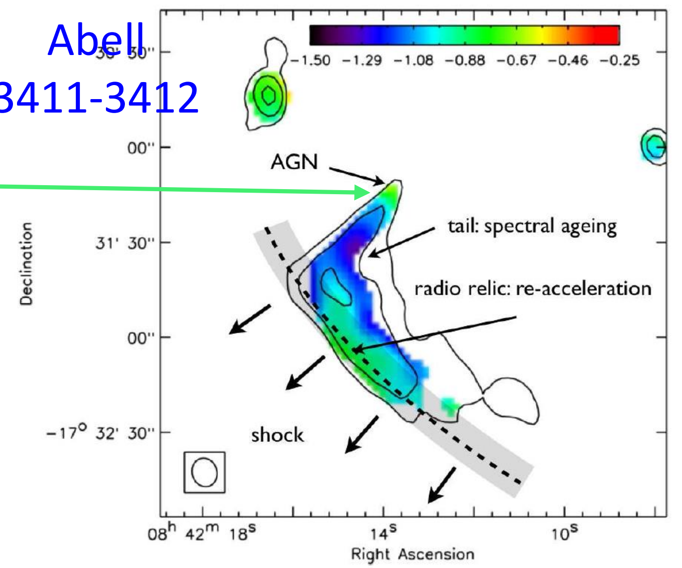
“**radio relics**” (L ~ up to 10^7 light-years): synchrotron emission due to CR electrons accelerated at “**shocks**”

→ E_{CRe} / E_{shock} **~ a few to 10 %** at shocks

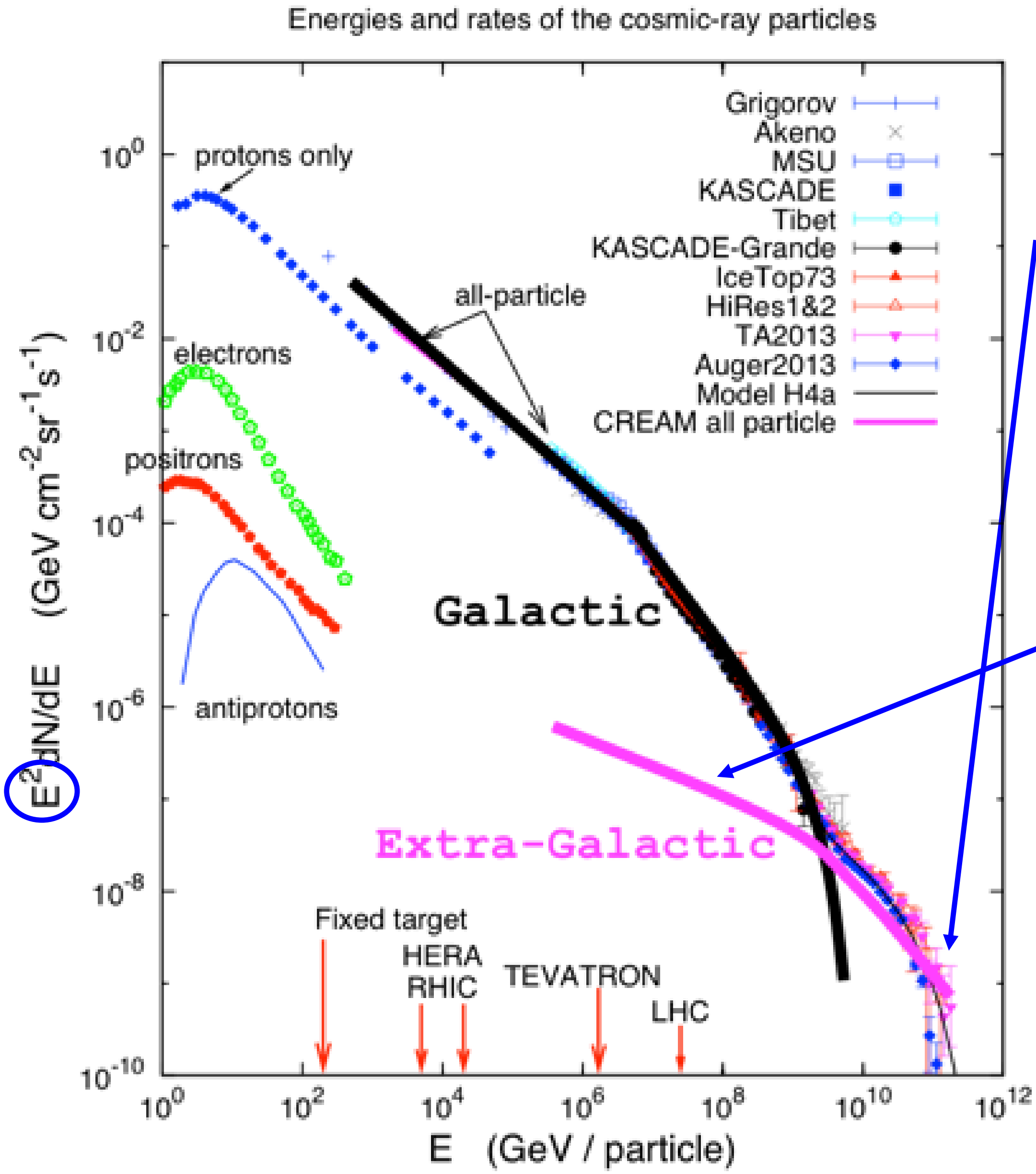




Abell 3411-3412



Extra-galactic cosmic rays (CRs)



ultra-high energy cosmic rays (UHECRs) with E > ~ 5×10^{19} eV,

mostly hadrons (P, CNO, Fe, …)

"**sources**" ?

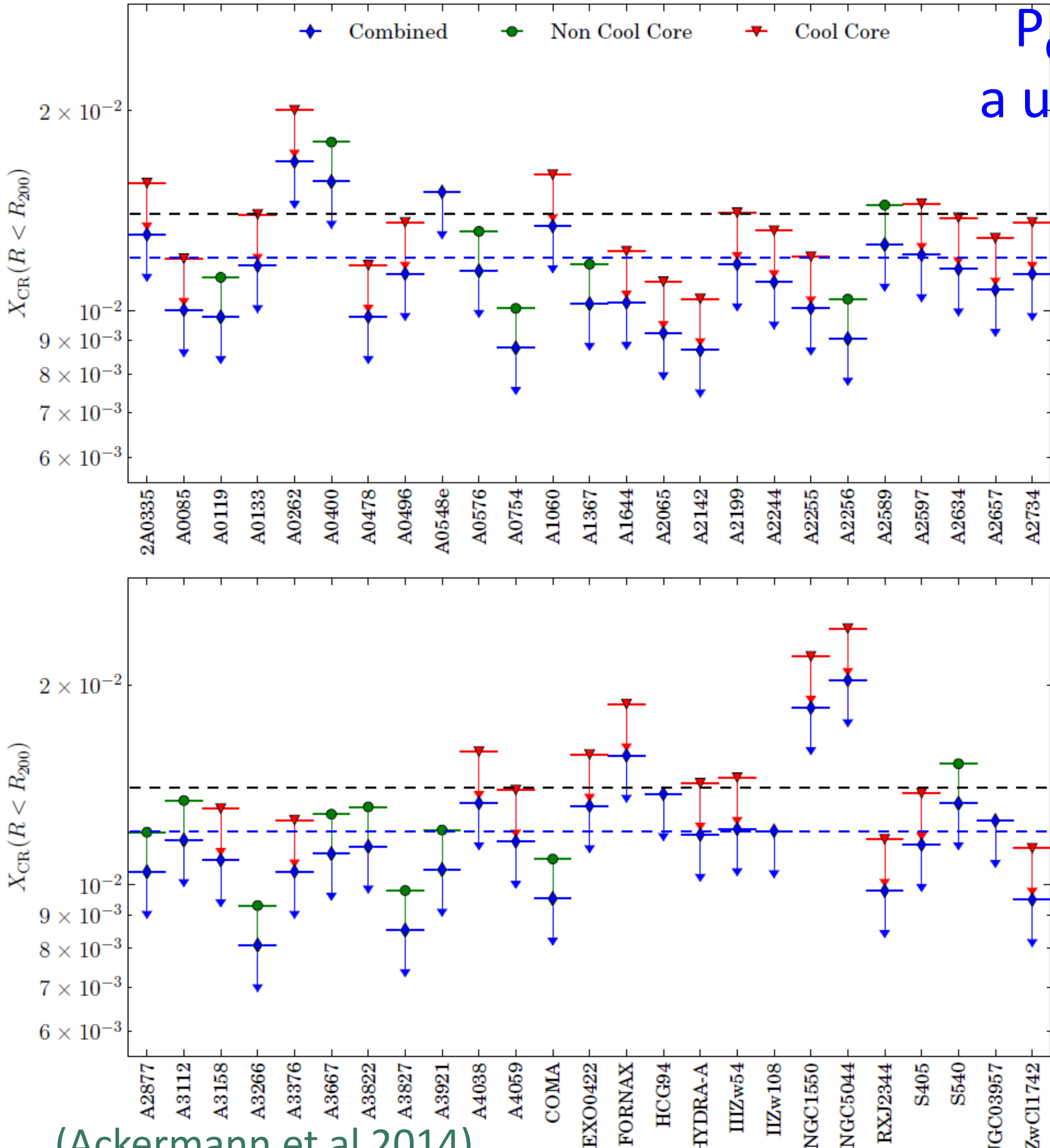
extragalactic CRs in lower energies:

do they exist? how much?

where are they? mostly in clusters of galaxies?

what are they?

“CR protons (ions)” in clusters



(Ackermann et al 2014)

gamma-ray

$P_{CR} + P_{ICM,thermal} \to X + \pi^o \to 2\gamma$

a unique signature of CR protons

no detection of gamma-ray from clusters!

- upper limits of CR proton contents in clusters se by **Fermi LAT observation**:

$P_{CR} / P_{thermal} <\sim 1\ \%$

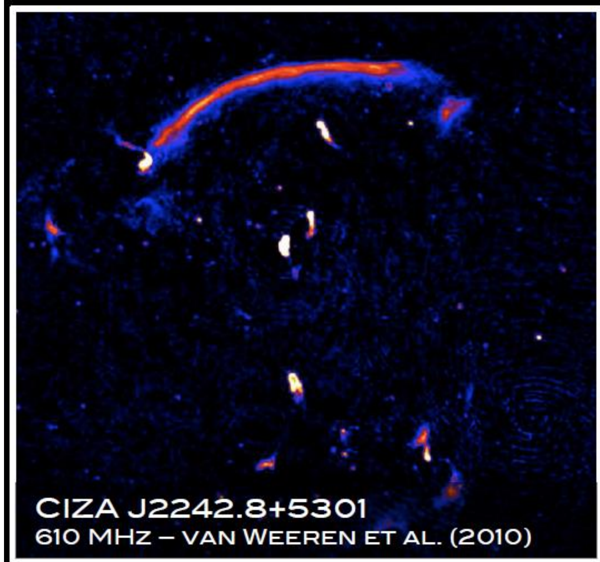
- the fraction of shock energy converted to heat ~ 10 %

- then, the fraction of shock energy converted to CR protons, **CR acceleration efficiency <~ 0.1 %**

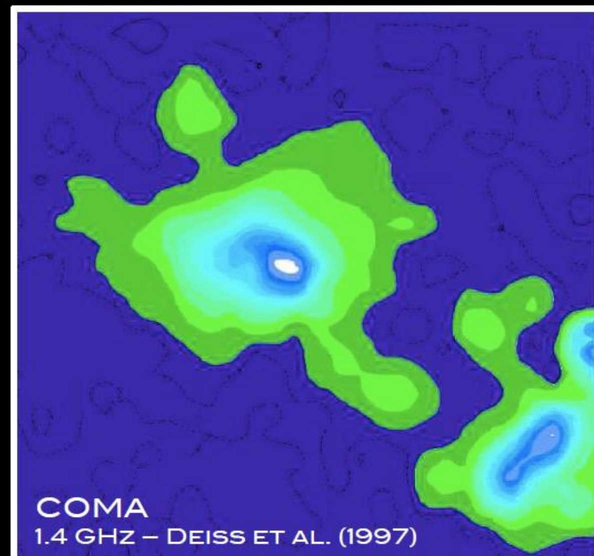
plentiful CR electrons, but little CR protons (ions) in clusters!

SYNCHROTRON RADIO EMISSION

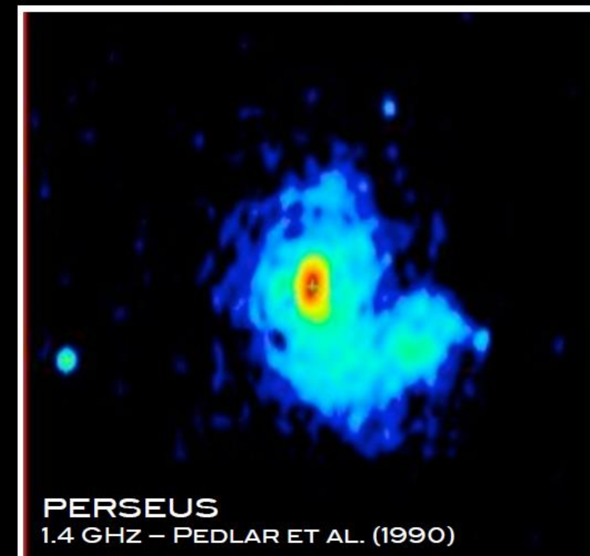
RELICS



GIANT HALOS



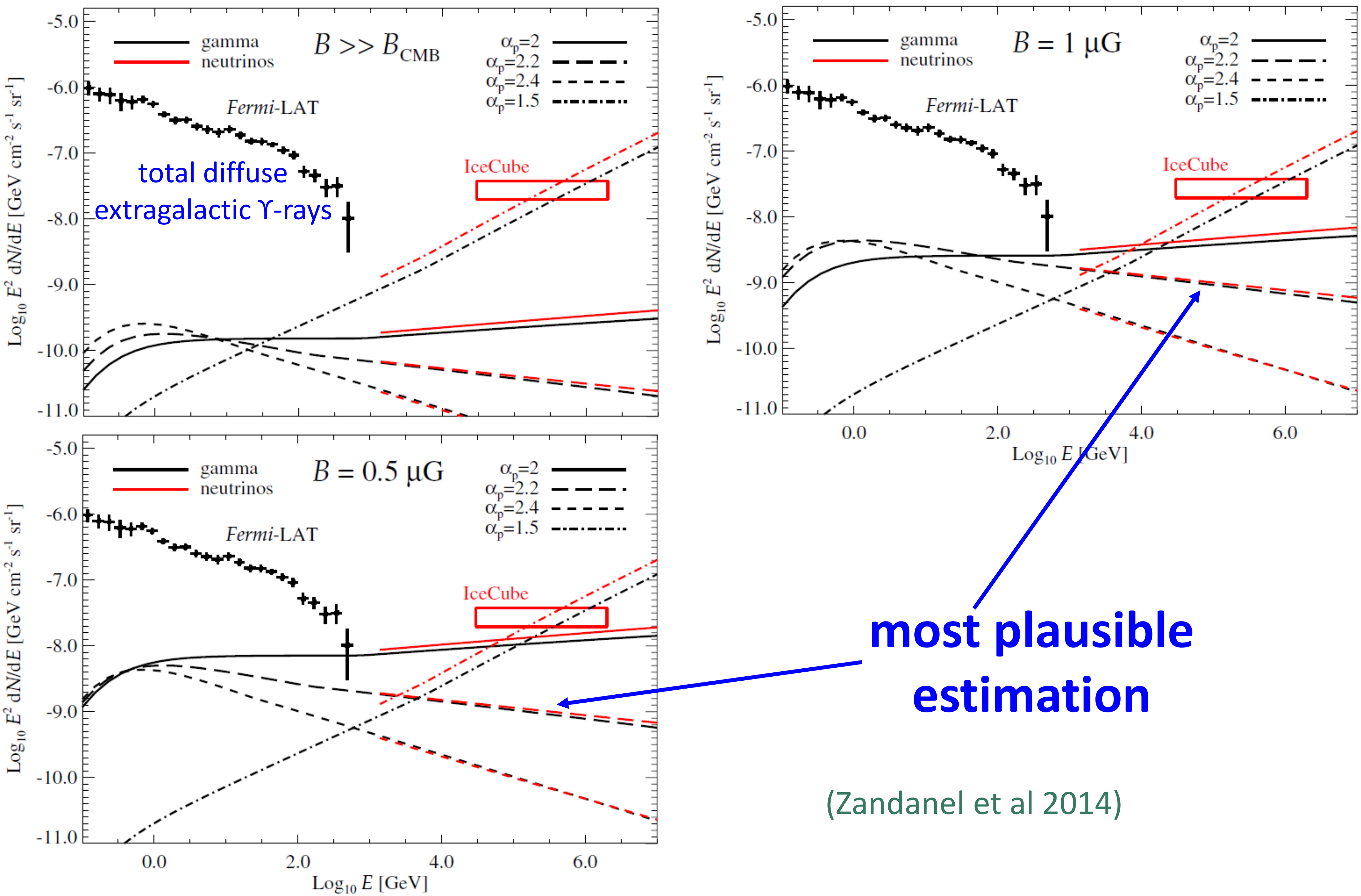
MINI HALOS



- Origin of radio-emitting electrons and magnetic fields?
- Contribution of cosmic-ray protons?
- Impact on cluster environment (P_{CR}/P_{TH})?

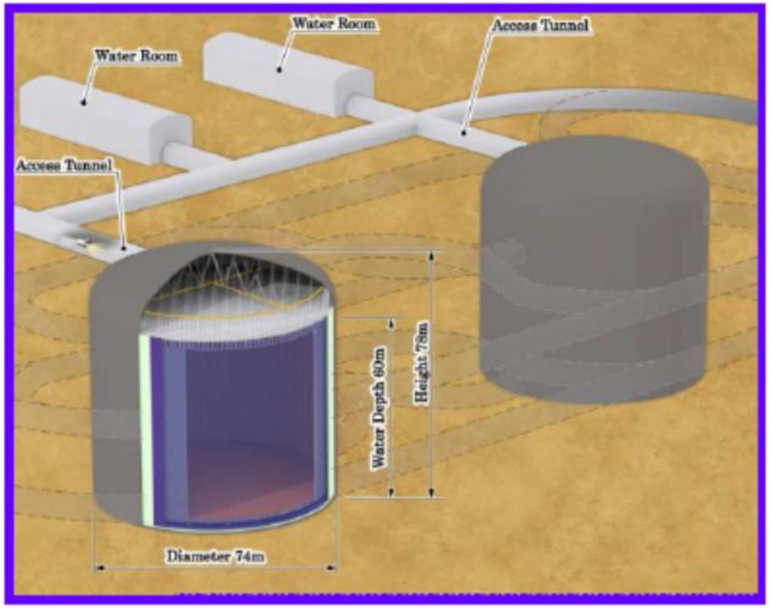
From Zandanel

Estimated Neutrinos from Clusters of Galaxies with Constraints from Radio and ϒ-ray Observations



Hyper-Kamiokande (Hyper-K)

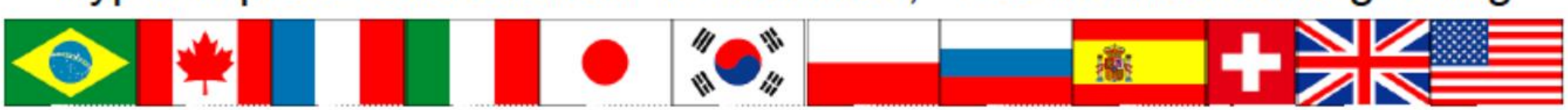
Inauguration: Jan. 2015



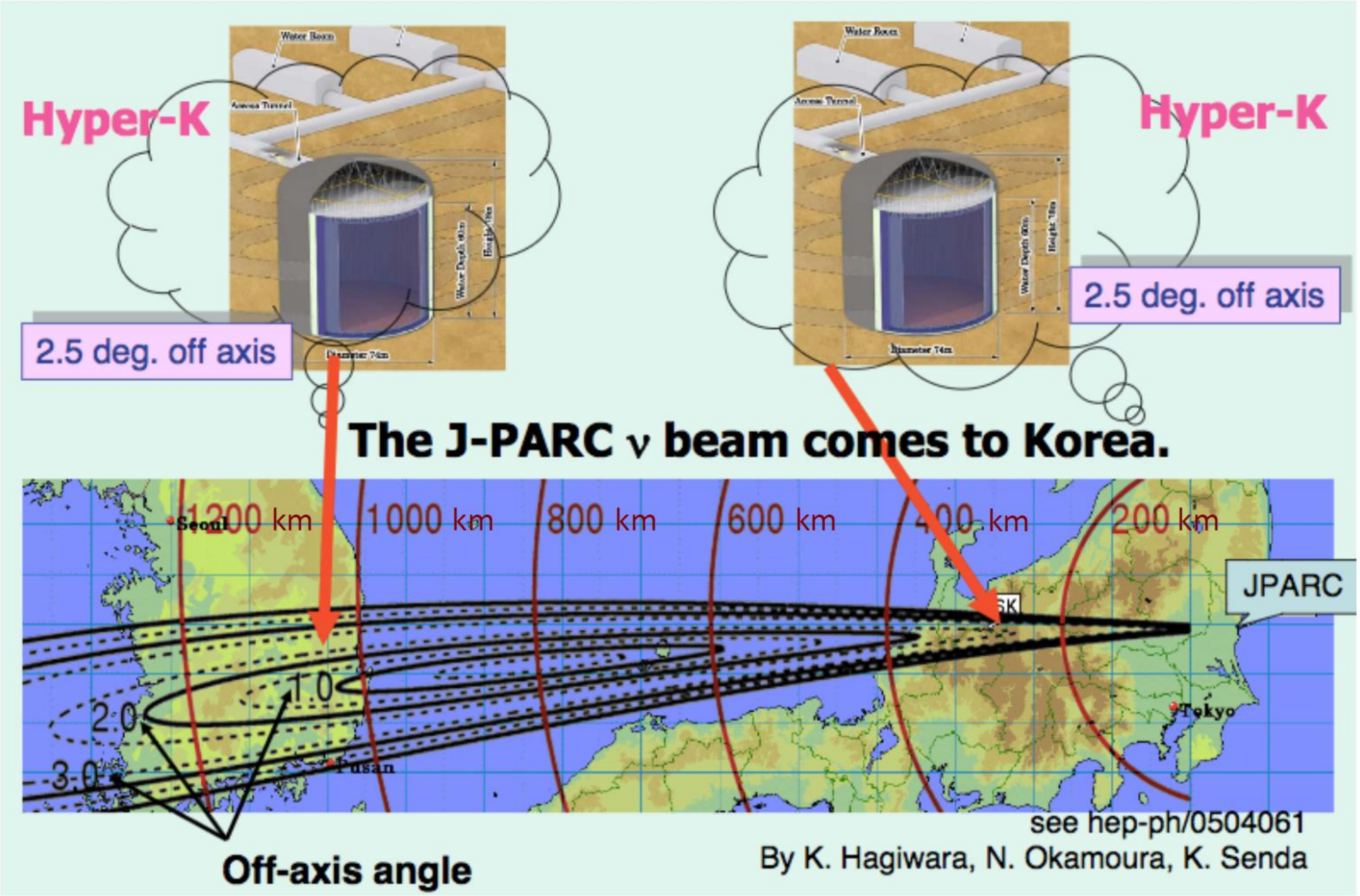
Hyper-K

J-PARC

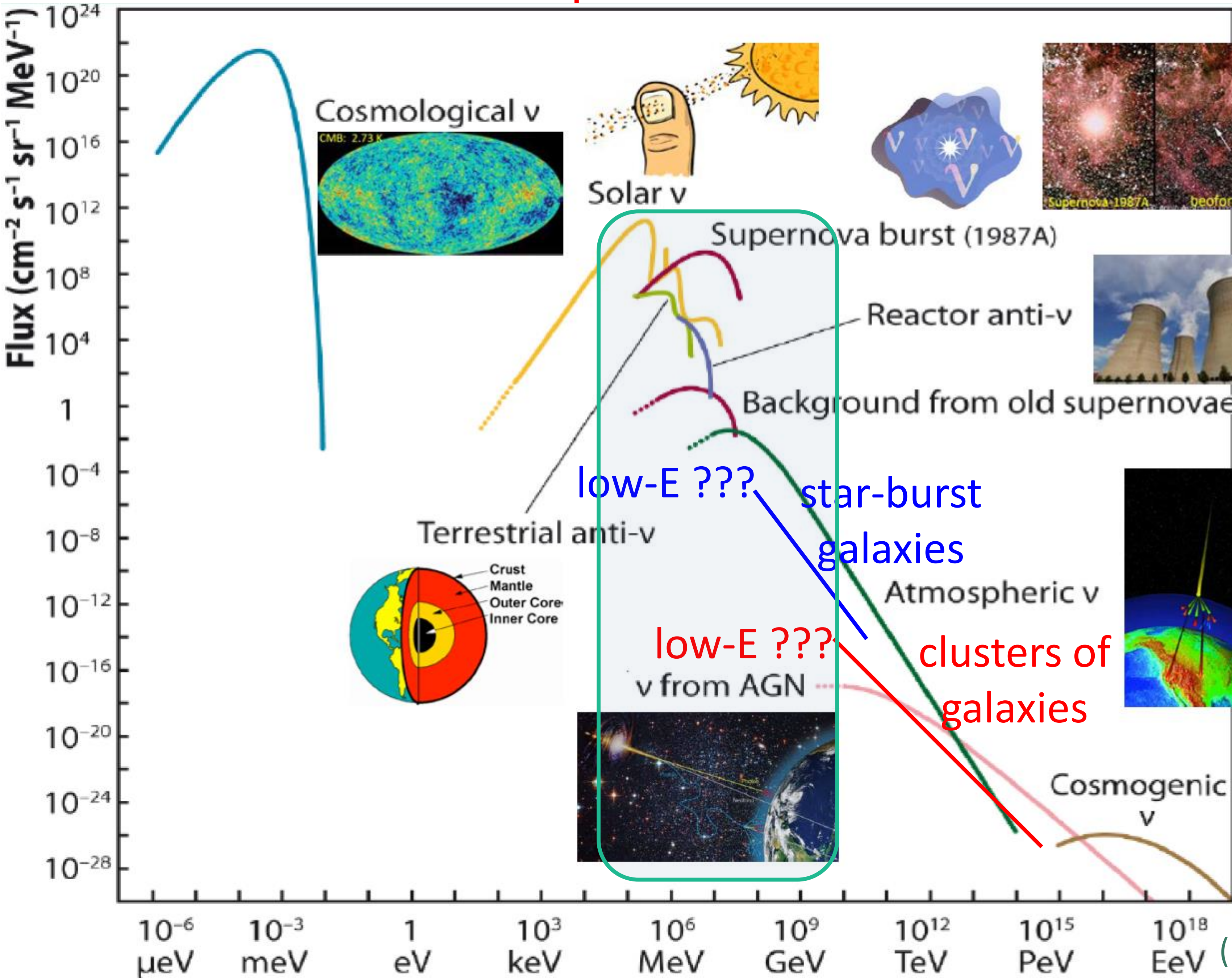
Hyper-K proto-collaboration: 12 countries, ~250 members and growing



2nd Hyper-K Detector in Korea



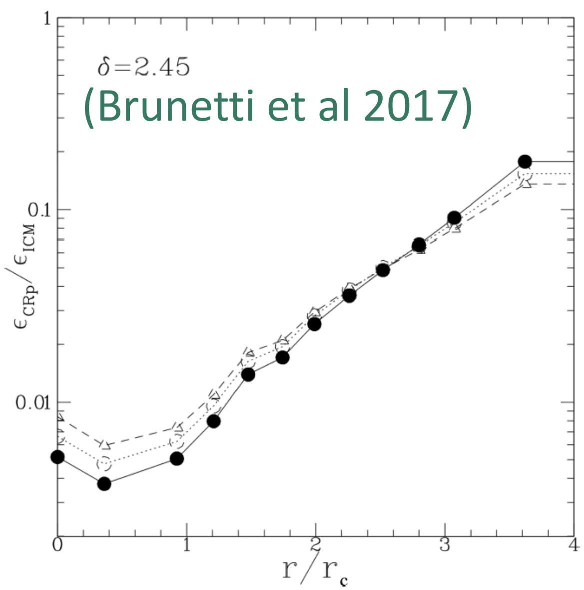
Neutrinos Expected to be Observed



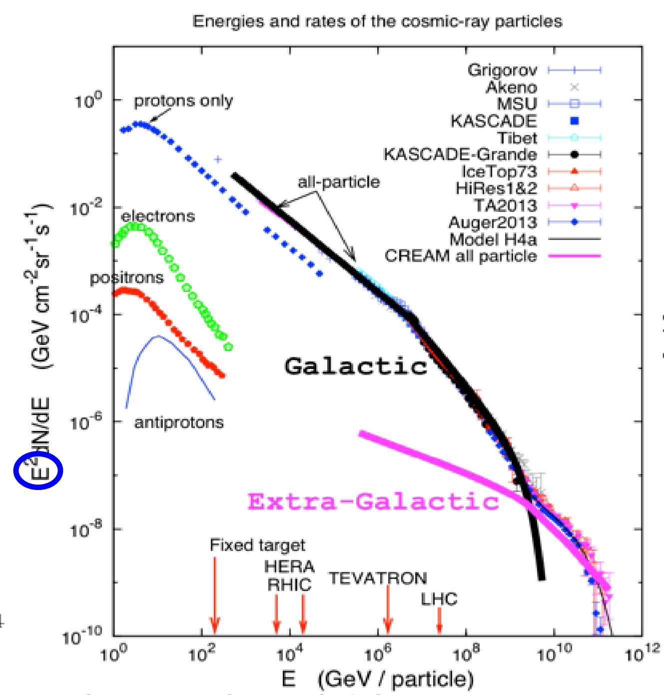
(김수봉 ?)

To estimate MeV - GeV neutrinos from clusters of galaxies

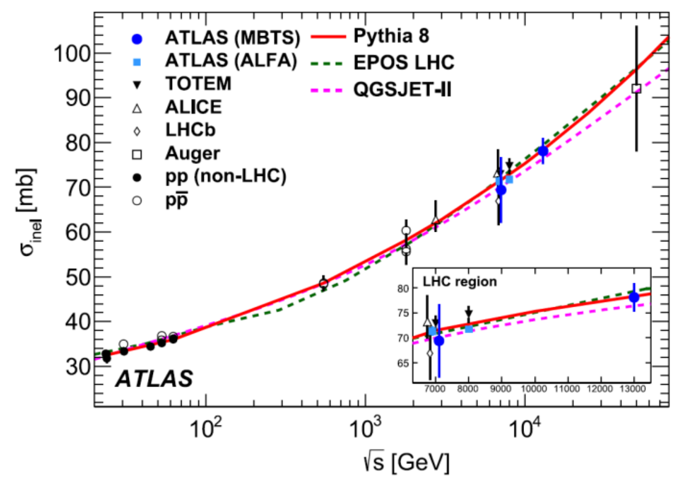
- possible detection through “anisotropy” observation
- spatial distribution of CR protons in clusters of galaxies
- energy spectrum of CR protons in clusters of galaxies
- cross section of inelastic proton-proton collisions
- etc



less CRp’s in core, and more in outskirts



slope should be steeper than 2, but the low-energy part is not clear



cross-section at low energies?

Thank you !