The energetic and magnetic framework for intergalactic UHECR propagation: Some new results

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1.

First attempts to probe intergalactic fields in large scale filaments of galaxies

Magnetic energy reservoir from galactic black holes: A global calculation

Average galactic BH density($\gtrsim 10^6 M_\odot$)

$$< \rho_{BH} > \approx 2 \times 10^5 M_\odot / Mpc^3$$

Gravitational energy reservoir per BH (scaled to infall to R_S)

$$M_{BH} c^2 = 1.8 \times 10^{62} \frac{M_{BH}}{10^8 M_\odot} ergs$$

$$e_B = 1.36 \times 10^{-15} \left(\frac{\eta_B}{0.1} \right) \times \left(\frac{f_{RG}}{0.1} \right) \times \left(\frac{f_{FIL}^{-1}}{0.1} \right) \times \left(\frac{M_{BH}}{10^8 M_\odot} \right) \text{ erg cm}^{-3}$$

Gives $B_{IG}^{BH} = \sqrt{8\pi\varepsilon_B} = 1.8 \times 10^{-7}$ G Within galaxy filaments

Next: 2 examples of BH-fed systems

CR + B adds to i.g. magnetic energy from infall in LSS
Ryu, Kang, & Biermann ApJ **335**,19 (1998),
Ryu, Kang, Hallman, & Jones ApJ **593**, 599 (2003)

and

Energy density of quasar photon output (optical data based)

$\mathcal{E}_{QL} \approx 1.3 \times 10^{-15}$ erg cm^{-3} is remarkably similar
(Soltan, 1982, Richstone 2004, Choksi & Turner, *MNRAS*, **259**, 421, 1992.)

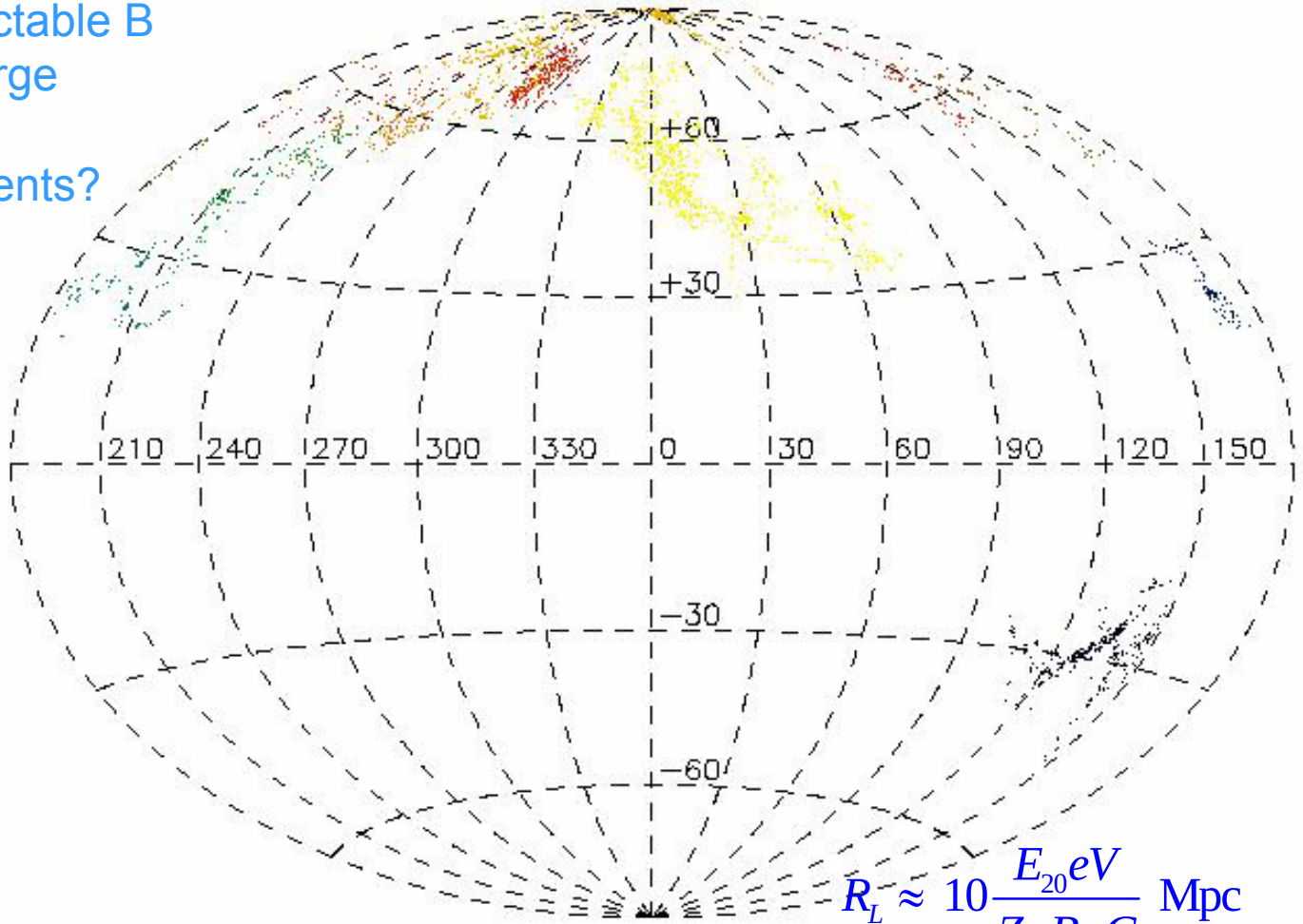
Conclusions:

Large galaxies appear to supply a non-trivial fraction of the distributed energy – in mag. field and CR's into LSS walls and filaments.

Expect ≈ 0.1 μG fields in LSS galaxy filaments

An illustrative simple global calculation →

Detectable B in Large scale filaments?



$$R_L \approx 10 \frac{E_{20} eV}{Z \cdot B_{-7} G} \text{ Mpc}$$

1. SRM – CfA2 survey analysis

Create Voronoi diagrams (VD), from CfA redshift survey where z's enable 3-D galaxy mapping

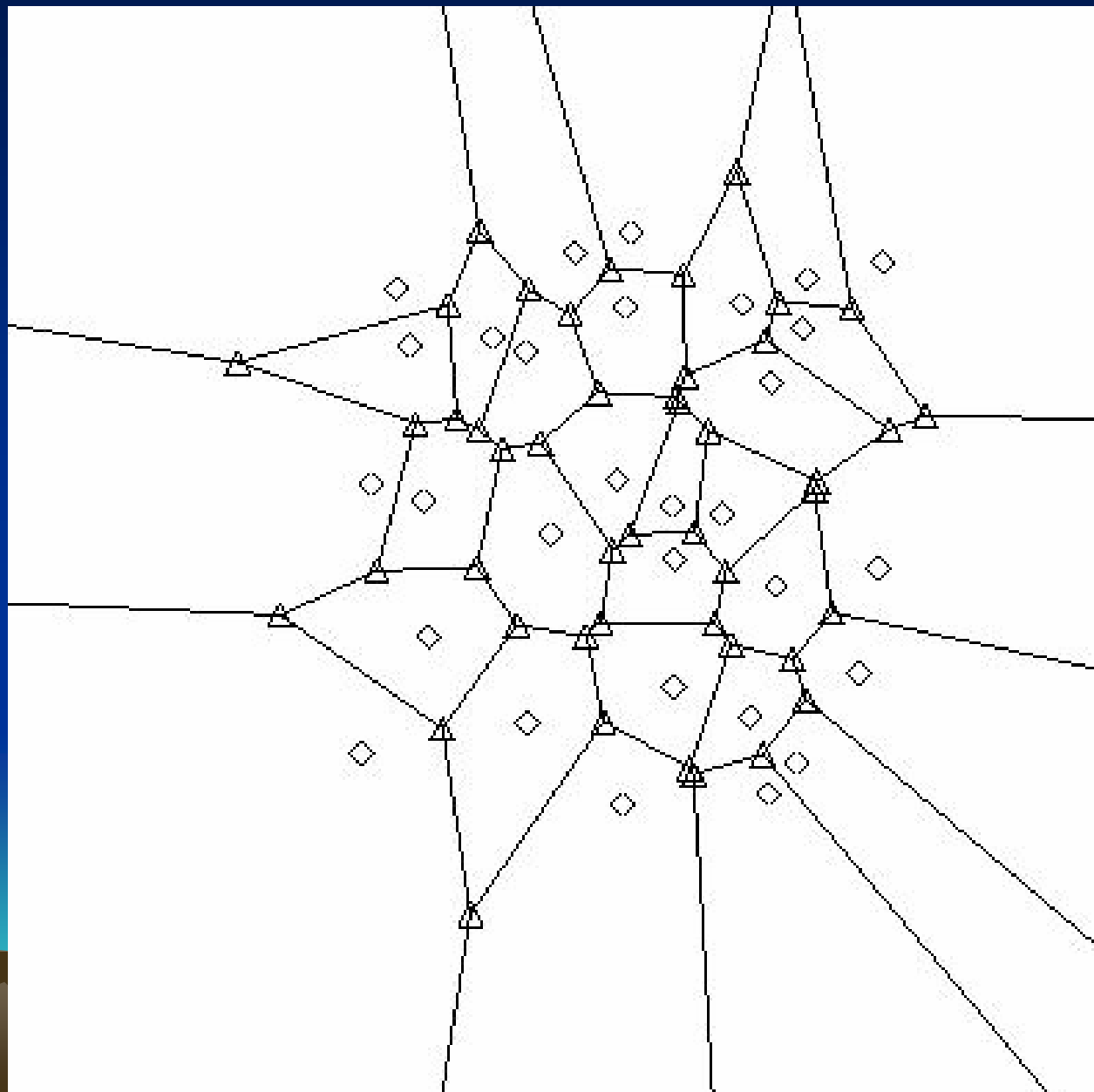
weighted path length:

$$wpl_j = \sum_i l_{ij}\,\delta_{ij}$$

i^{th} VD, j^{th} background RM probe direction

δ_i = overdensity of i^{th} galaxy

"QHULL" algorithm (C.B. Barber *et al*. 1996)
CfA redshift survey (J. Huchra *et al.* 1998)



2. SRM – 2MASS survey analysis

- Also used 2MASS survey. Only 2-D information, but for 1.3×10^6 galaxies $m_K < 14.5$
- Heirarchical Equal Area isoLatitude Pixelization (HEALPix) algorithm
- 3-level overdensity (N_g) ranges; lowest at 1σ above mean

$$\chi^2 = \sum_{i=1}^{N_s} \left(MRM_i - SRM_i \right)^2 / \sigma^2_{SRM}$$

Likelihood $L = e^{\frac{-\chi^2}{2}}$

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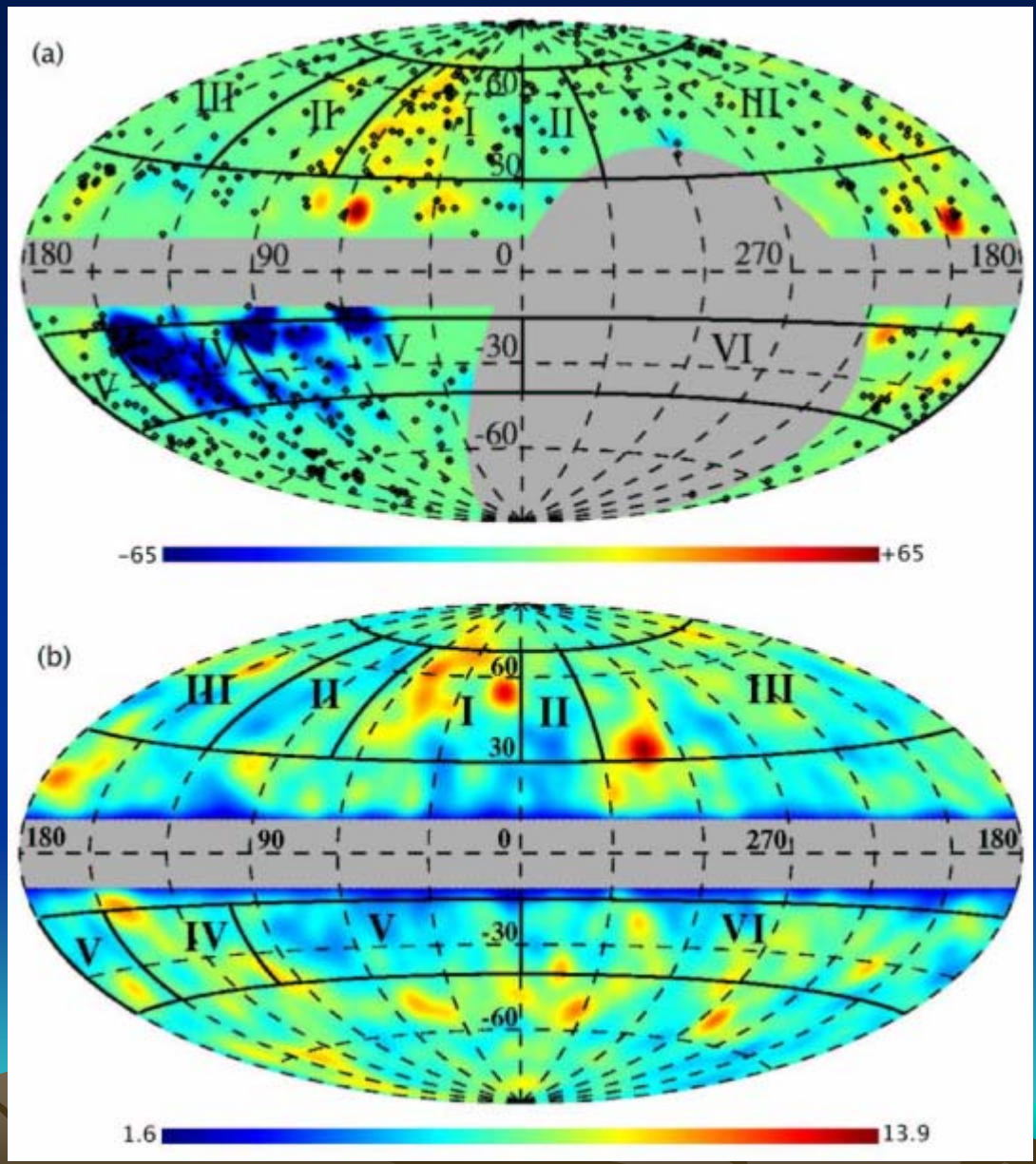
Xu, Kronberg, Habib, Dufton: ApJ 2006, 637, 19

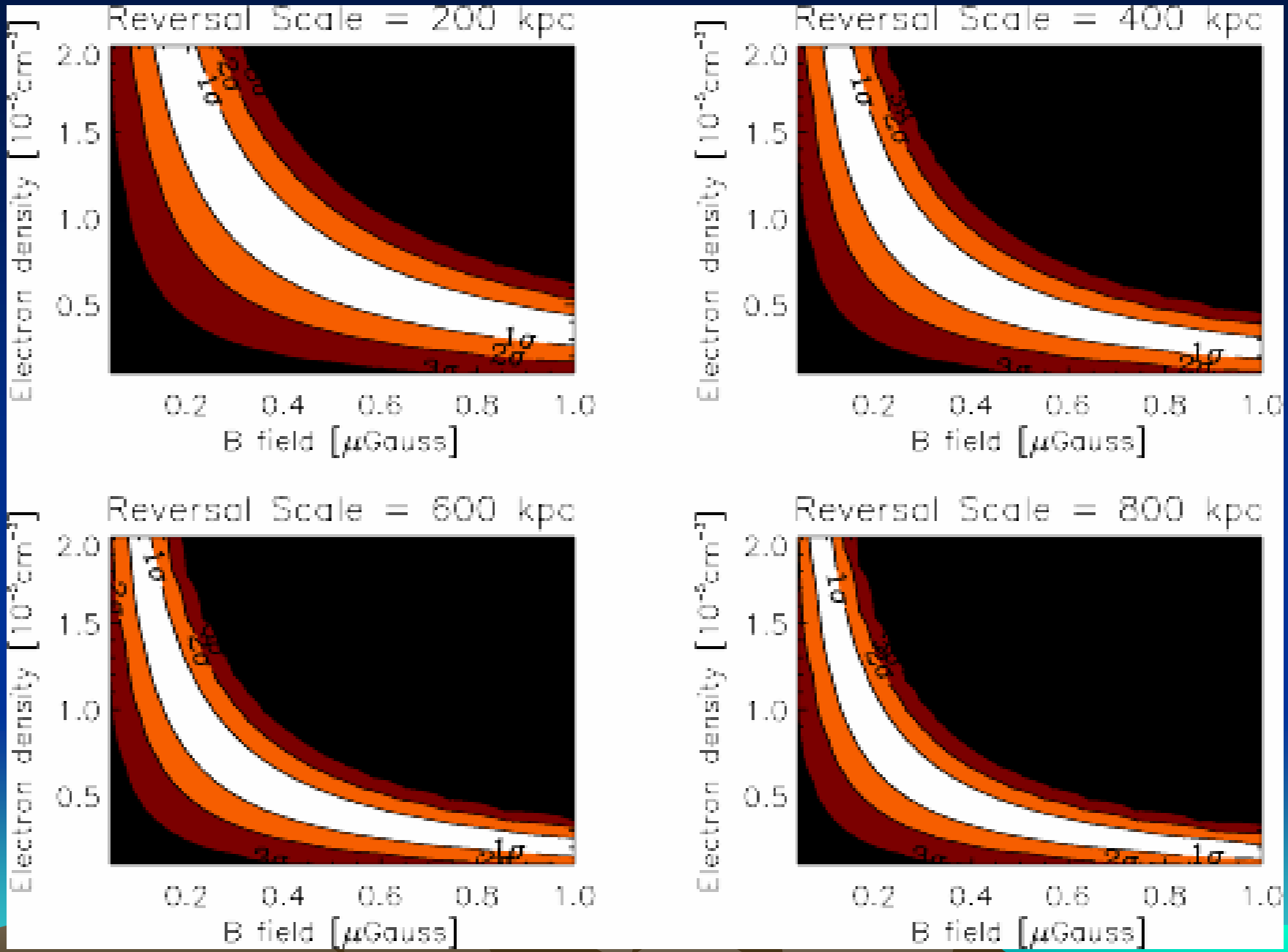


SMOOTHED RM

rad/m²

GALAXY COLUMN DENSITY (Method #2)

galaxies per pixel


Reversal Scale = 200 kpc
Reversal Scale = 400 kpc
Reversal Scale = 600 kpc
Reversal Scale = 800 kpc
Electron density [10^{-3}cm^{-3}]
B field [μGauss]
2.0
1.5
1.0
0.5
0.2
0.4
0.6
0.8
1.0
1σ
2σ
3σ

Summary of results

- Virgo supercluster: no meaningful result: $<N_G>$ (2MASS) and ***wpl*** (CfA2) too small. Also, galactic variations over its large angular extent.

- Hercules supercluster: Global association of enhanced RM's with the Hercules supercluster. But no detailed correlation with small scale galaxy concentration. Could be confused by Galactic features.

- Perseus-Pisces supercluster: SRM enhancement shows positive correlation with 2MASS N_G .Also with *wpl* in CfA2 data (VD analysis). 2σ result. Implies $B_{IGM} \sim 0.3\ (L_{500kpc})^{-0.5}$ microgauss IGM field.

- Can't exclude some possibility of (perverse) mimicking of SRM by galactic foreground effects

2.

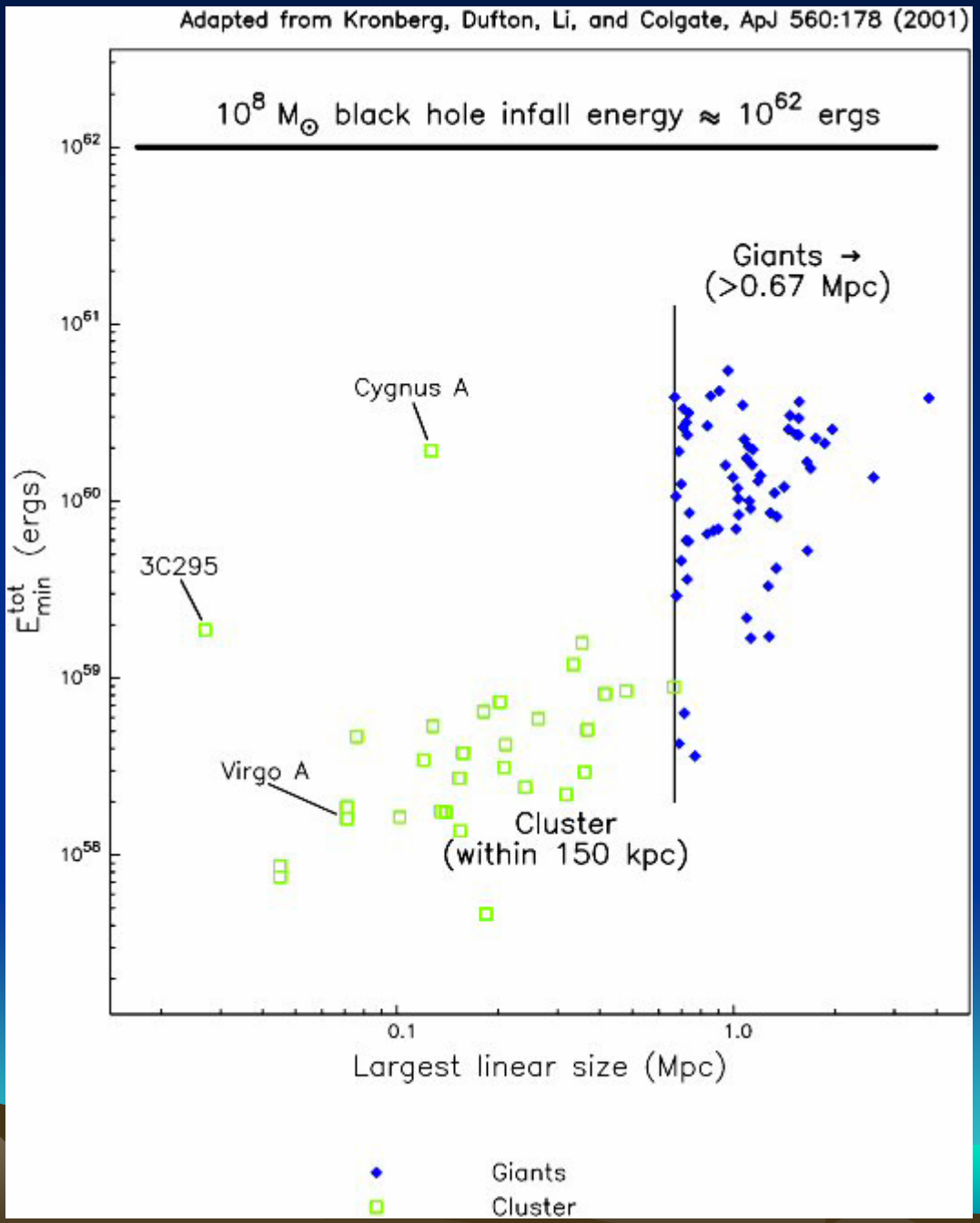
Giant radio galaxies (GRG) are

prime calorimeters of BH energy release (B + CR's)

into extragalactic space.

And possibly UHECR acceleration sites?

(*Kronberg, Dufton, Li & Colgate ApJ 2001*)


Adapted from Kronberg, Dufton, Li, and Colgate, ApJ 560:178 (2001)
10^8 $M_\odot$ black hole infall energy ≈ 10^{62} ergs
Giants →
(>0.67 Mpc)
Cygnus A
3C295
Virgo A
Cluster
(within 150 kpc)
E^{tot}_{min} (ergs)
10^{62}
10^{61}
10^{60}
10^{59}
10^{58}
0.1
1.0
Largest linear size (Mpc)
Giants
Cluster

BH (magnetic + CR) energy output ($\gtrsim 10^{60}$ ergs) is "captured" within a few Mpc,

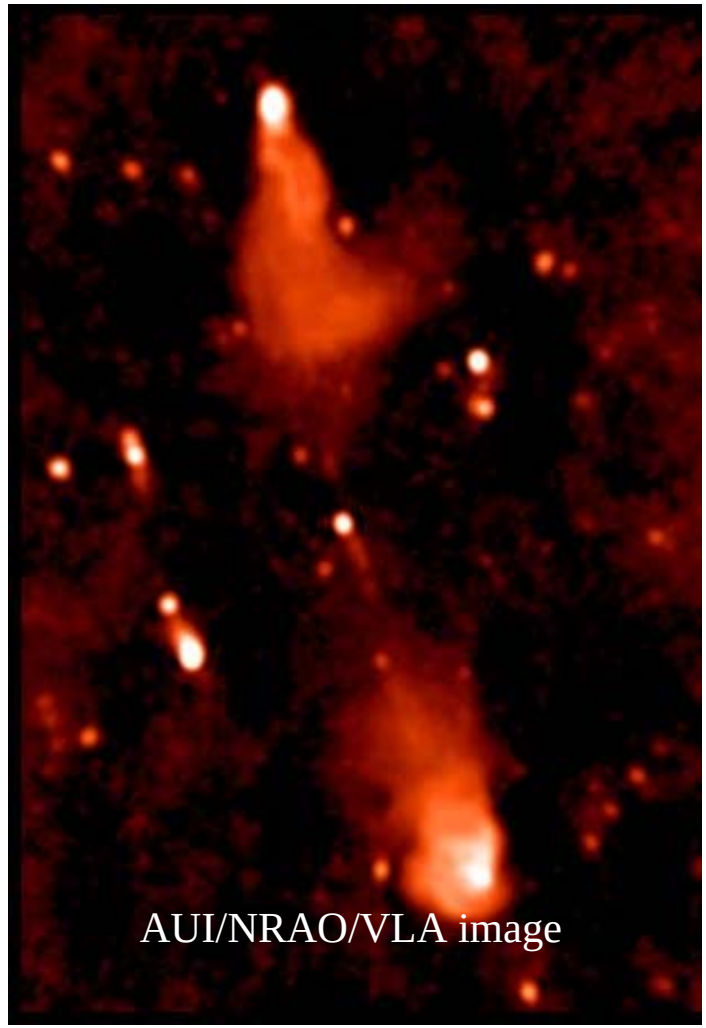
η (photons), $\approx$ 20% (mostly not captured) appears comparable to η (CR + B),

2147+816 giant radio galaxy

Analysis of ≈ 70 GRG images
Kronberg, Dufon, Li, Colgate
ApJ 2001

z=0.146

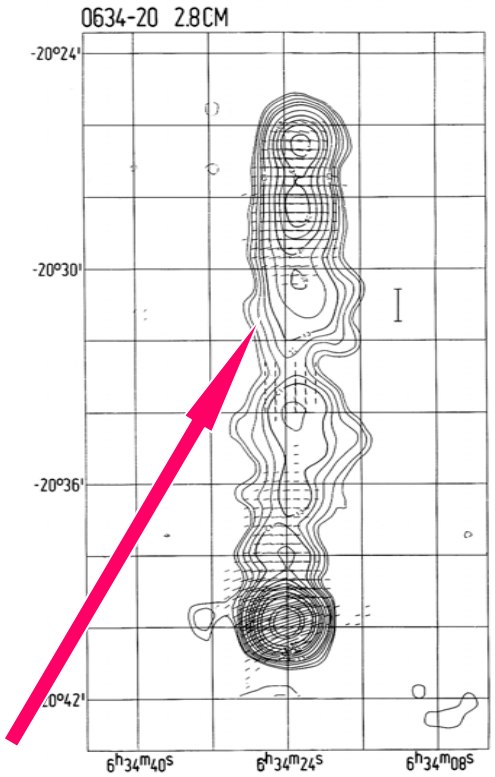
2.6 Mpc



8 FRII-like GRG's, w. detailed, multi-λ obs. & analysis
Kronberg, Colgate, Li, Dufton ApJL 2004
Willis & Strom, 1978,80
Kronberg, Wielebinski & Graham.1986
Schoenmakers et al. 1998
Subrahmanian et al.1996
Feretti et al 1999

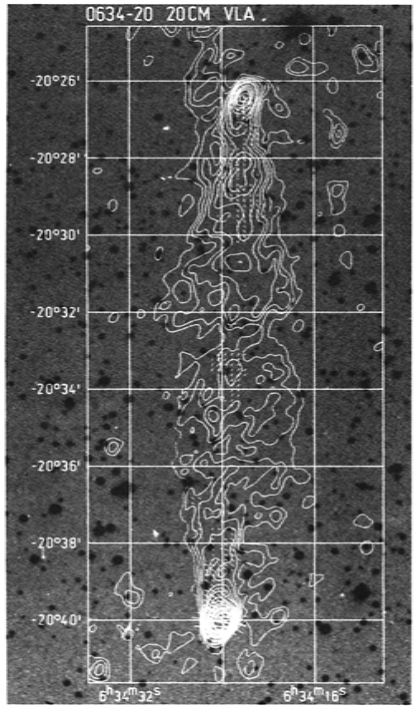
Indications for distributed acceleration of CR's within Mpc-sized (intergalactic) radio lobe volumes *Kronberg, Colgate, Li & Dufton ApJ 2004*
a "template" for widespread IGM CR acceleration??

10 GHz



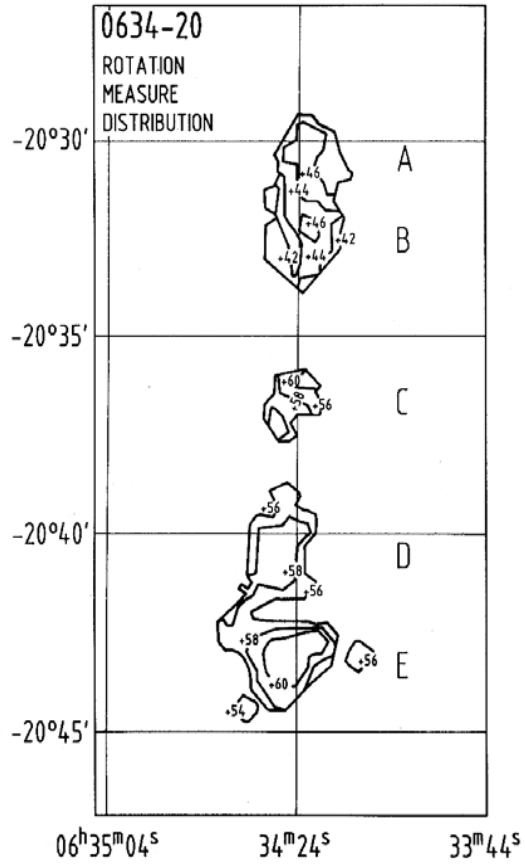
Effelsberg 100m. Telescope 10.6 GHz

1.4 GHz



VLA 1.4GHz

Faraday RM(radians/m²)



Freshly accelerated, starved of thermal Plasma?

Kronberg, Wielebinski & Graham
***A&A* 169**, 63, 1986

$$E \approx 10^{19} \left(\frac{B}{3\mu G}\right)\left(\frac{L}{1\,\mathrm{Mpc}}\right)\ \mathrm{eV}$$

Could UHECR's be energized outside of galaxy systems – no galaxy-localized sources?

BH energy feedback into the IGM a uniquely large energy factor

Faint intergalactic synchrotron emission a new tracer of large scale structure?

Maybe not; rather B^2 and CR energy:

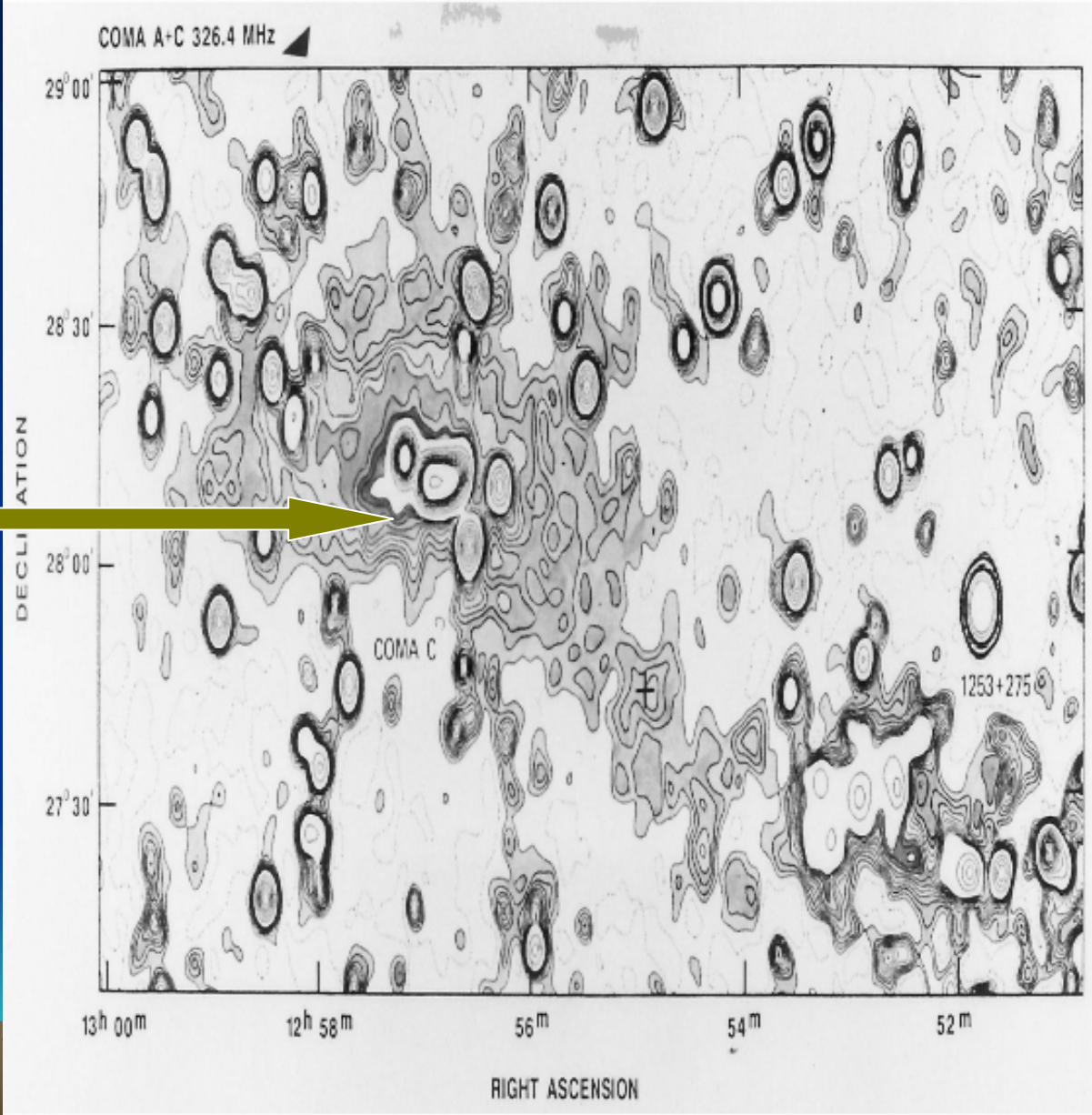
(discussed next)

3.

New probes for for distributed, intergalactic (CR + B) energy on supra-cluster scales

Kronberg, Kothes, Salter, Perillat, ApJ April 2007

Adapted from: Kim, Kronberg, Giovannini and Venturi, NATURE, 1989



Coma Cluster

HPBW
1’ EW x 2’ NS

WSRT

326 MHz

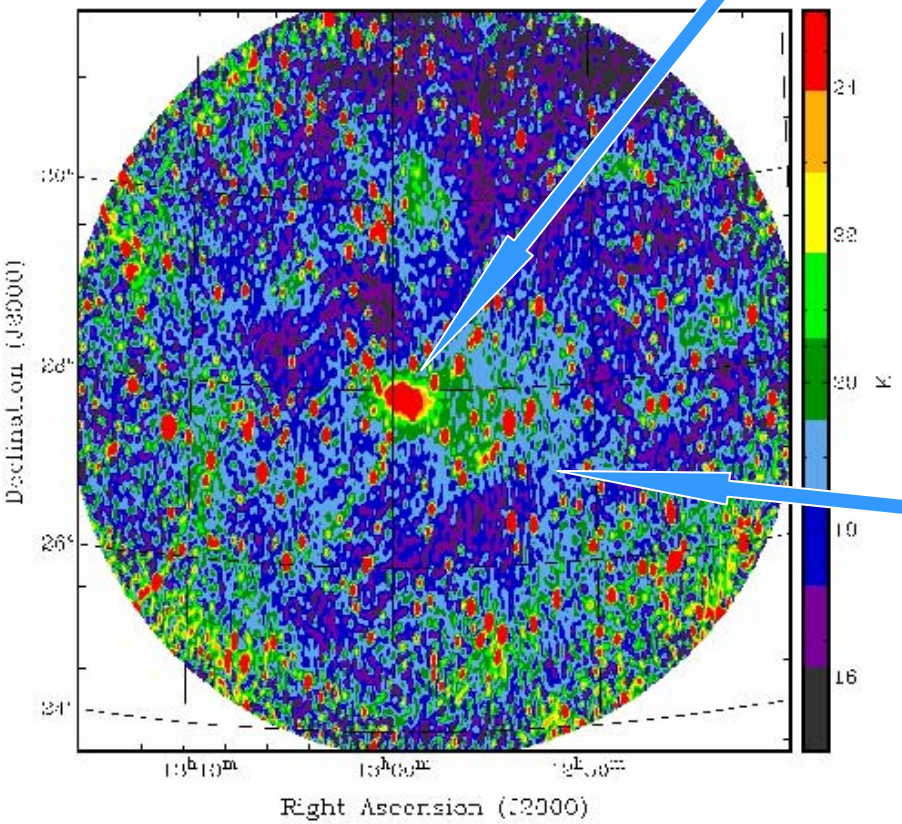

Arecibo 305m Telescope, PR

Dominion Radio Astrophysical Observatory
Penticton BC, Canada

In 12 days, 1 full image within 9° circle at 408 MHz

8° dia. Field containing combined Arecibo + DRAO data, at a resolution of 2.5’ x 6.5’ 0.4 GHz

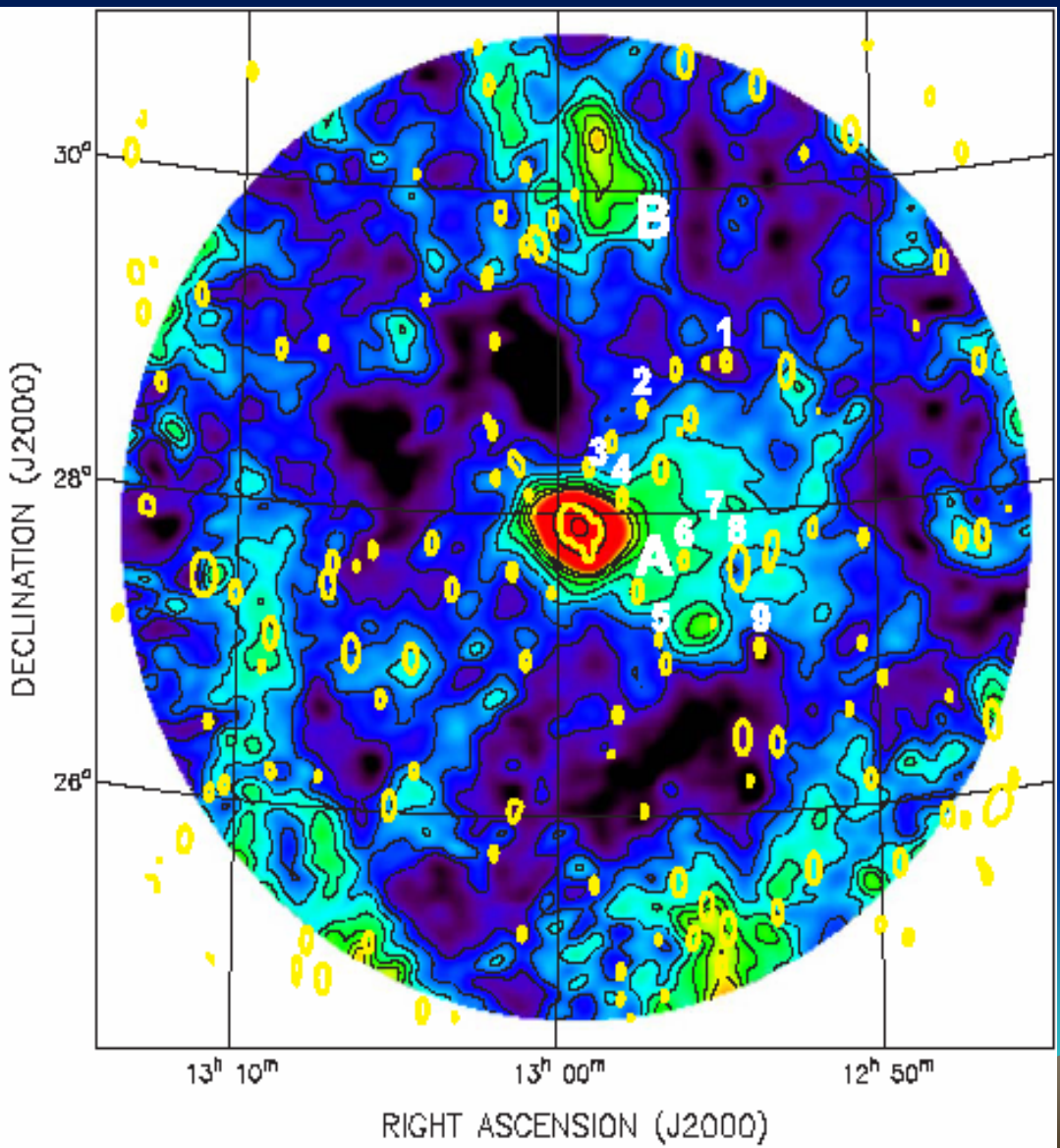
Coma cluster radio halo



2.7K CMB background and galactic foregrounds (≈ 18K) are included

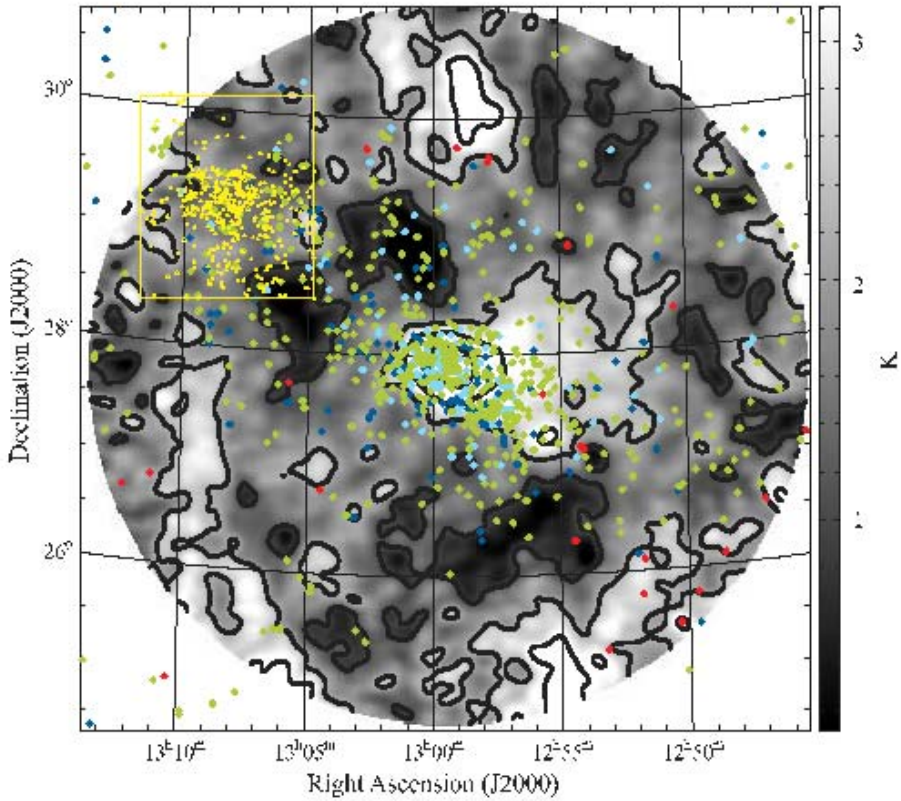
NGP

COMBINED Arecibo-DRAO image, smoothed to *10' resolution (Arecibo)*



- *Discrete sources removed,*
- *CMB + smooth Milky Way foreground removed*
- *Strongest discrete sources re-overlaid (yellow ellipses)*
- *Black contours at 1.4, 1.9, 2.4, 2.9, 3.4, 3.9, 4.4, 10, 40K*
- *1.4K ≈ 5.6 σ*

Contours at 1.0 (≈ 4σ), 2.25, 3.5, 10 K,
10’ x 10’ radio (Arecibo) beamwidth



A 16 – 22K linear T_B plane has been subtracted out (= CMB + smooth gal. foreground)

0°K defined as the average mean T_B of 3 approx. equally **cold zones** – see image.

The extended CfA survey (Huchra et al.) contains 2 superimposed clusters at ≈ 38,000 km/s & 70,000 km/s, respectively. (yellow box)

Yellow points:
30,000 < *v* < **100,000** km/s

In contrast to Coma, there is **no** radio glow - galaxy overdensity correspondence.

Tentative conclusions:

- Radio glow not a 1:1 tracer of stellar baryonic mass
- Rather, biased to CR + magnetic *energy density*

Summary (I)

- Conclude from above: Diffuse synchrotron, and (*predict)* I.C. X, and *γ*-ray emission, is NOT a faithful global tracer of baryonic LSS.

- Rather, diffuse cm radio traces zones of enhanced intergalactic CR and magnetic energy density

Summary (II)

- Many similar features (and distributed i.g. energy) on Mpc scales are yet to be discovered (e.g. features like “A” & “B”)
- First discovery of low-foreground “peep-holes” for future high- l CMB fluctuation analyses.
- Emphasizes future possibilities of large reflector + synthesis telescope combinations

Summary (III)

1. B ~ 10^{-7} G in IGM reasonable to expect, and may have (just) been detected. Significant curvature of UHECR propagation paths are likely.

2. Long, kpc – Mpc EG jets candidates for making UHECR's

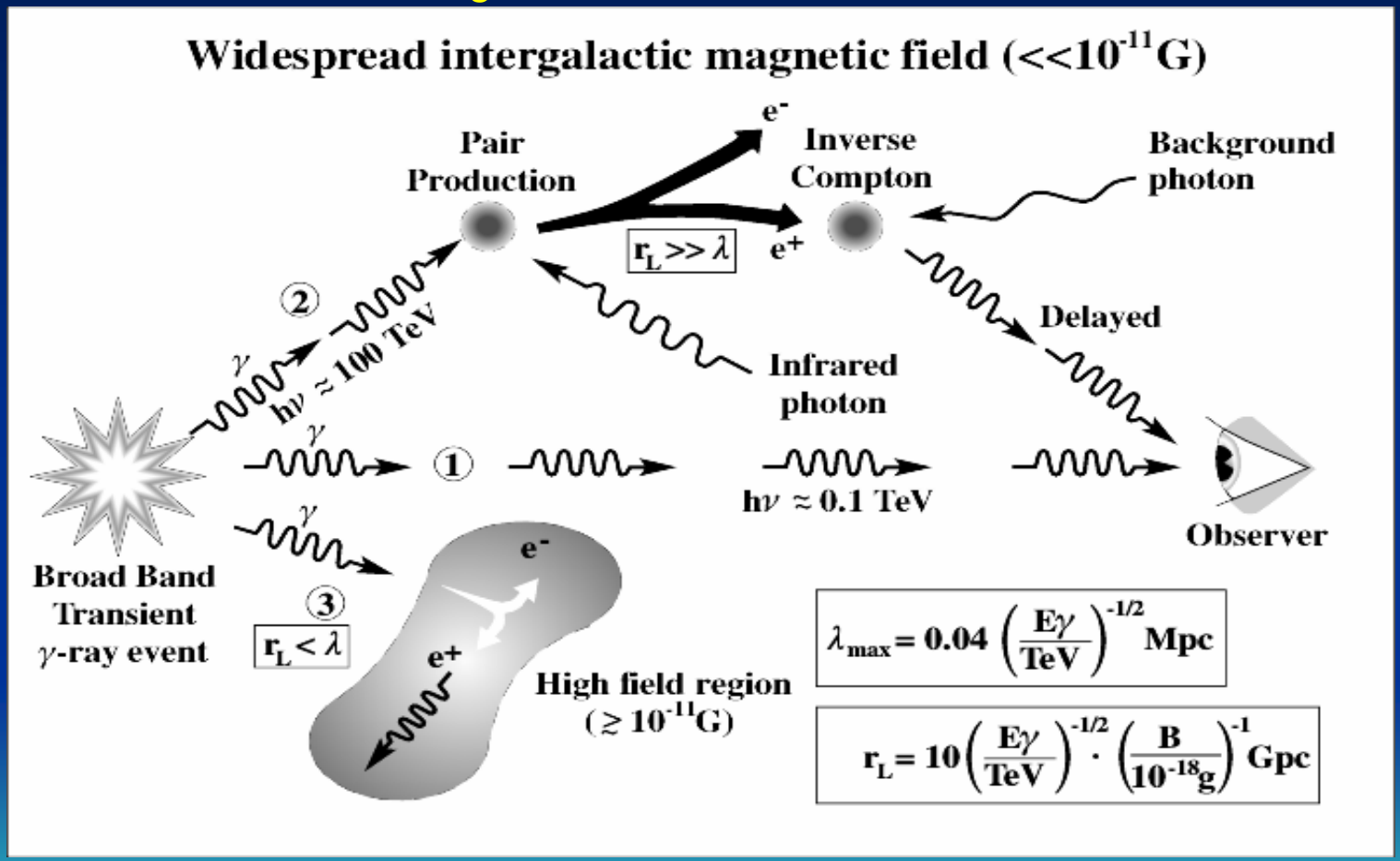
3. If so, UHECR acc'n sites are distributed, although energized from a (localized) central BH.

4. Large, Mpc diffuse, "CR + B"- energized regions may be be more common in the local universe.

5. Baryonic and dark ,matter distribution seem quite different from that of CR and magnetic energy in the Universe

A γ-ray burst as an IGM *B*-probe

*R. Plaga, NATURE **374**, 430, 1995*



*(Illustration: Kronberg, NATURE, **374**, 404, 1995)*