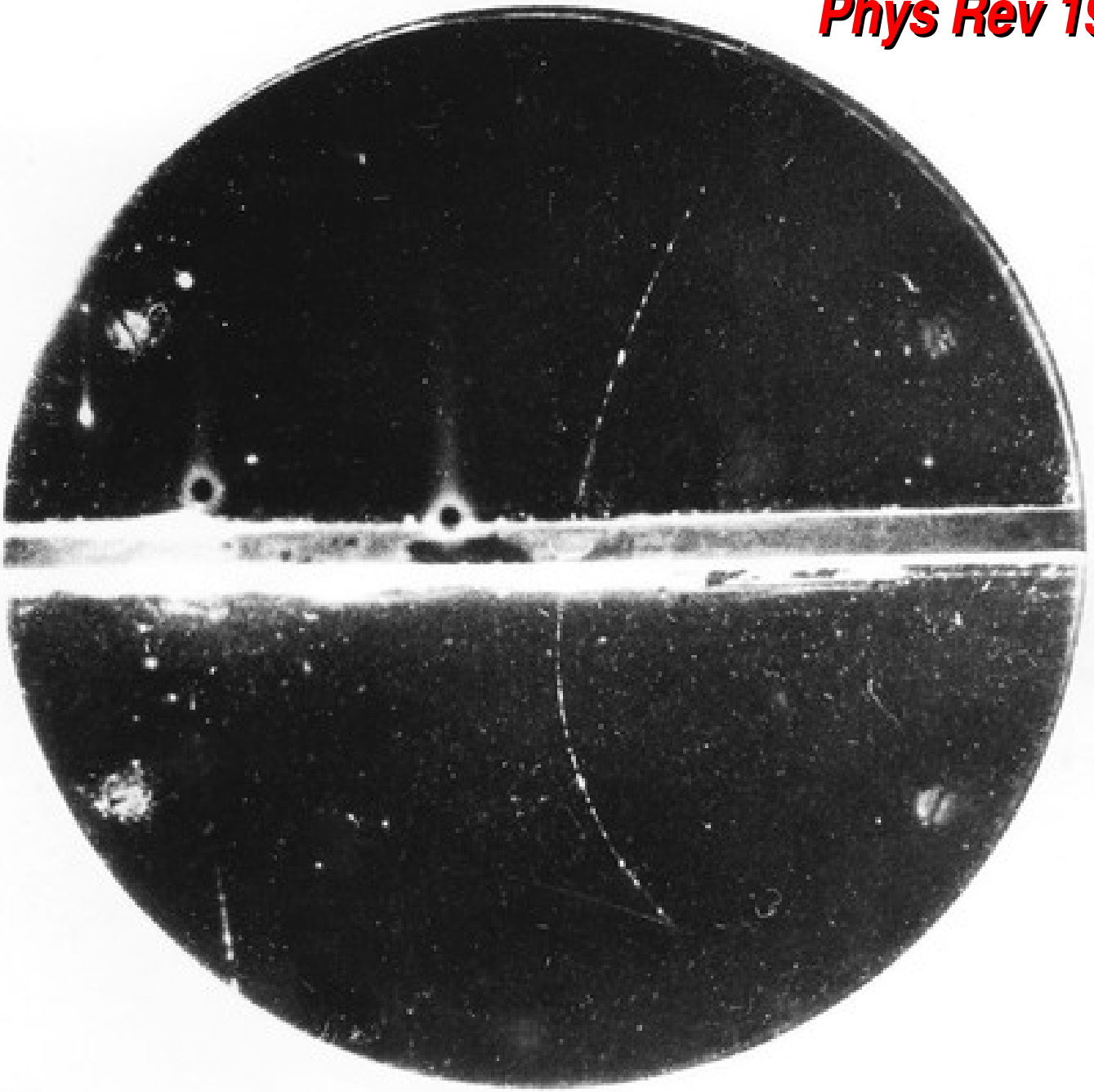
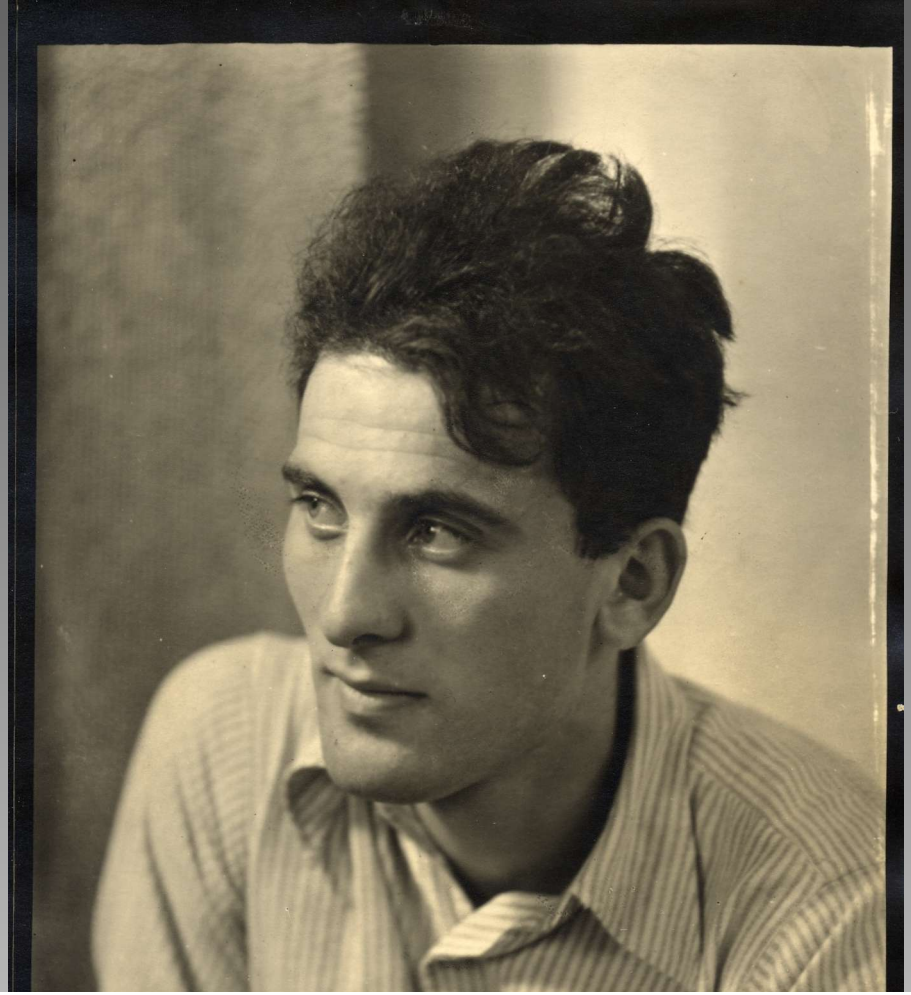
UHECRs: come correre il megaparsec in 1000 secondi

Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays

Phys Rev 1933

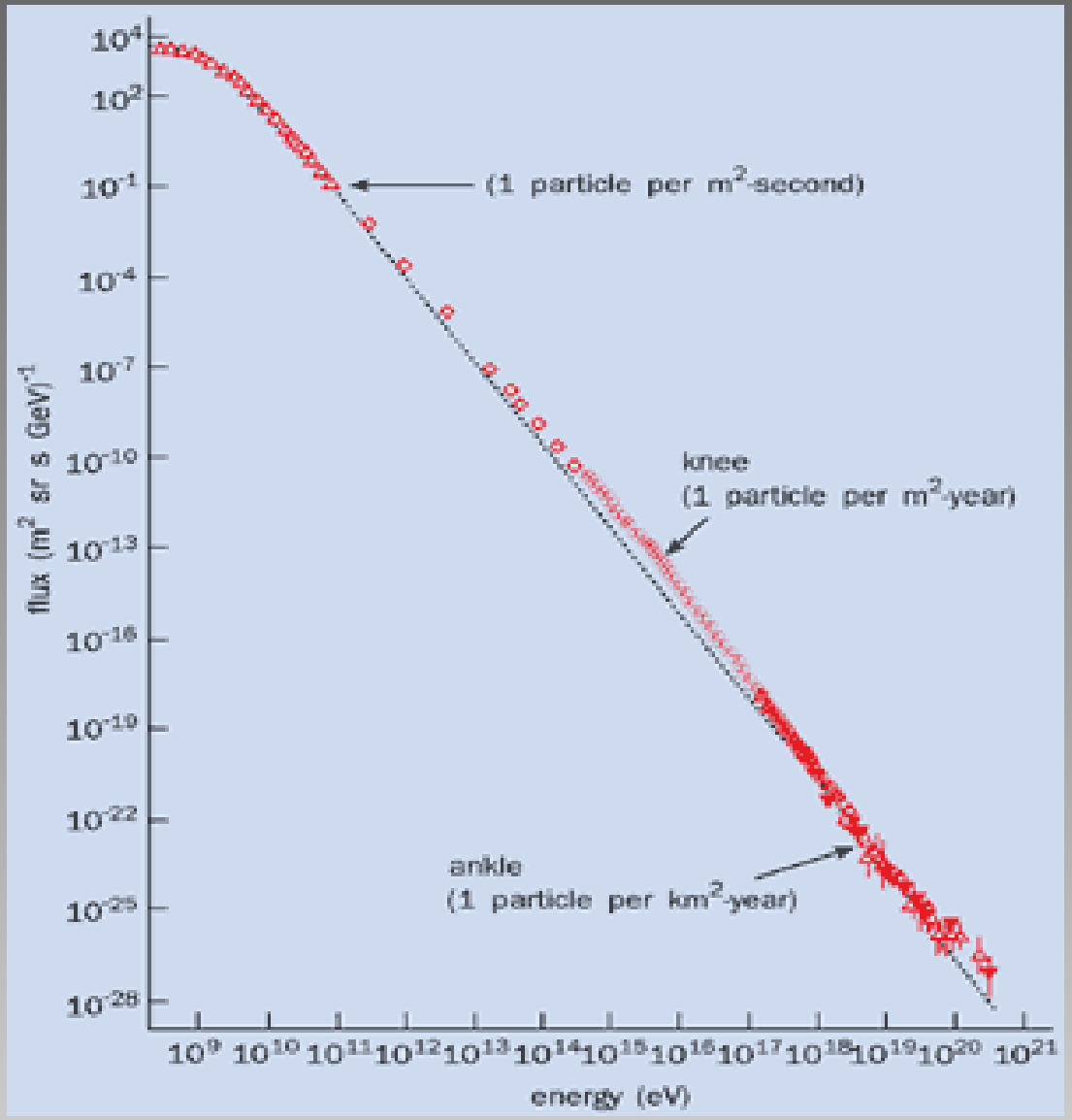


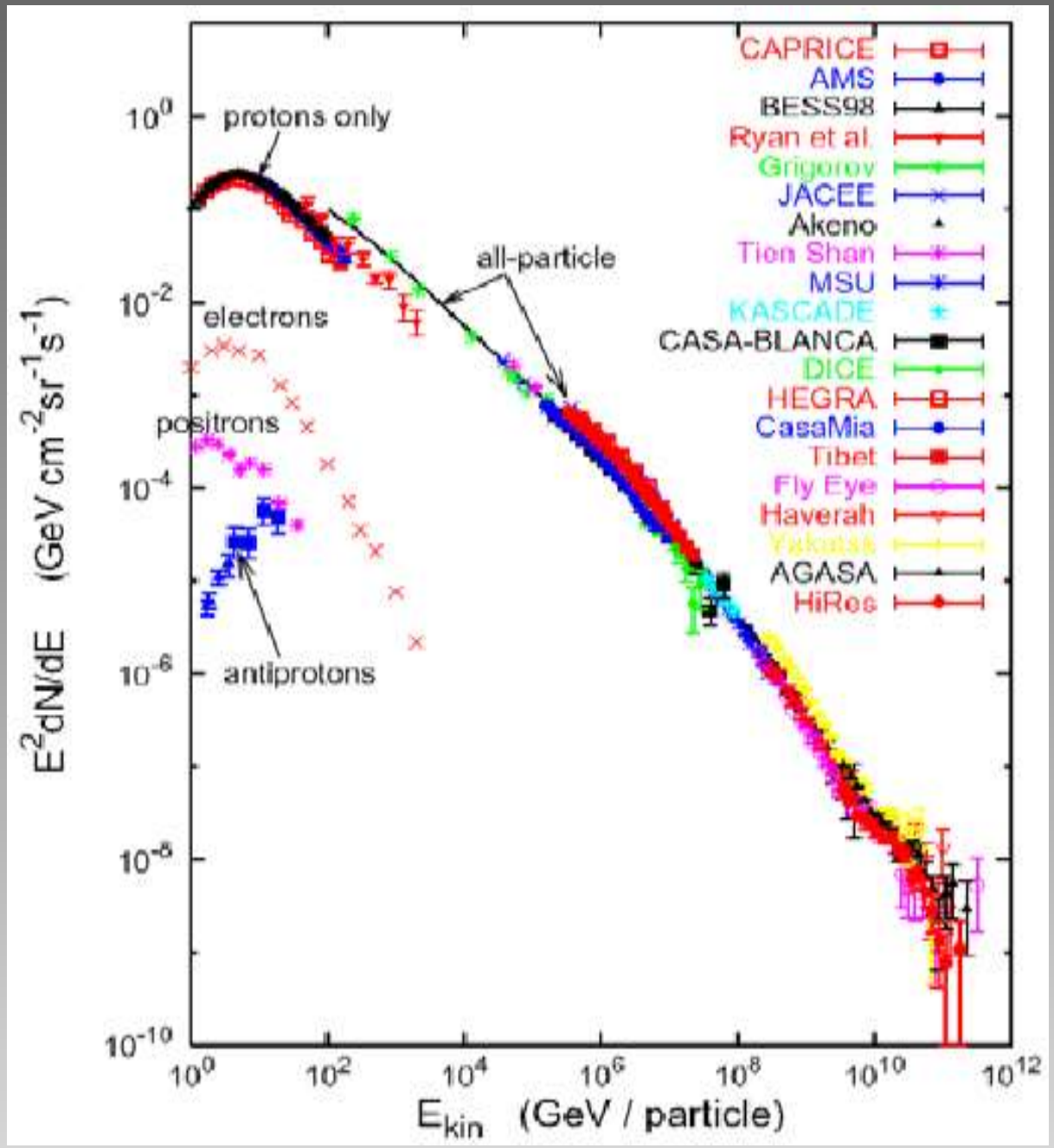


Pontecorvo, in a famous toast: "I drink not to Beppo, but to us all: may we collaborate with him, it is a practically sure way of winning a Nobel Prize".

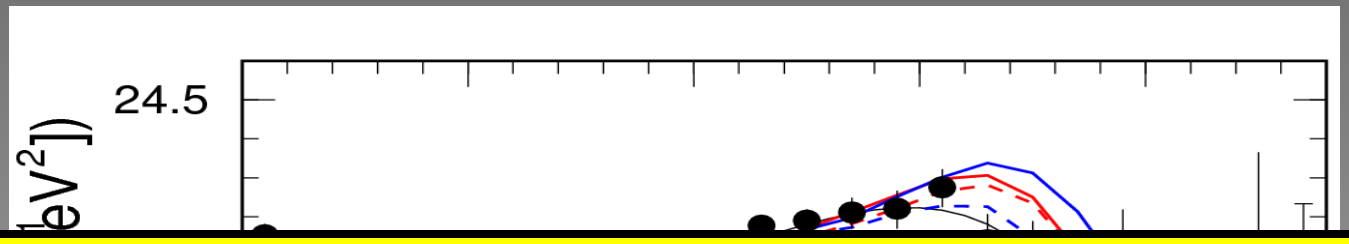
Carl Anderson (1905-1991) Nobel prize in 1936

Beppo Occhialini (1907-1993)


flux (m² sr s GeV)⁻¹
10⁴
10²
10⁻¹
10⁻⁴
10⁻⁷
10⁻¹⁰
10⁻¹³
10⁻¹⁶
10⁻¹⁹
10⁻²²
10⁻²⁵
10⁻²⁸
(1 particle per m²-second)
knee
(1 particle per m²-year)
ankle
(1 particle per km²-year)
10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷ 10¹⁸ 10¹⁹ 10²⁰ 10²¹
energy (eV)


protons only
all-particle
electrons
positrons
antiprotons
CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
E^2dN/dE (GeV cm^{-2}sr^{-1}s^{-1})
E_{kin} (GeV / particle)
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
10^{12}

UHE Cosmic rays



$E=mc^2$

$E=\gamma m_0 c^2$, if m_0 is a proton, then

$\gamma=10^{11}$ *22 times 9*

$\beta=0.99999999999999999995$

10^{20} eV = 10^{8} TeV = 10^{11} $m_p c^2$ = tennis ball at

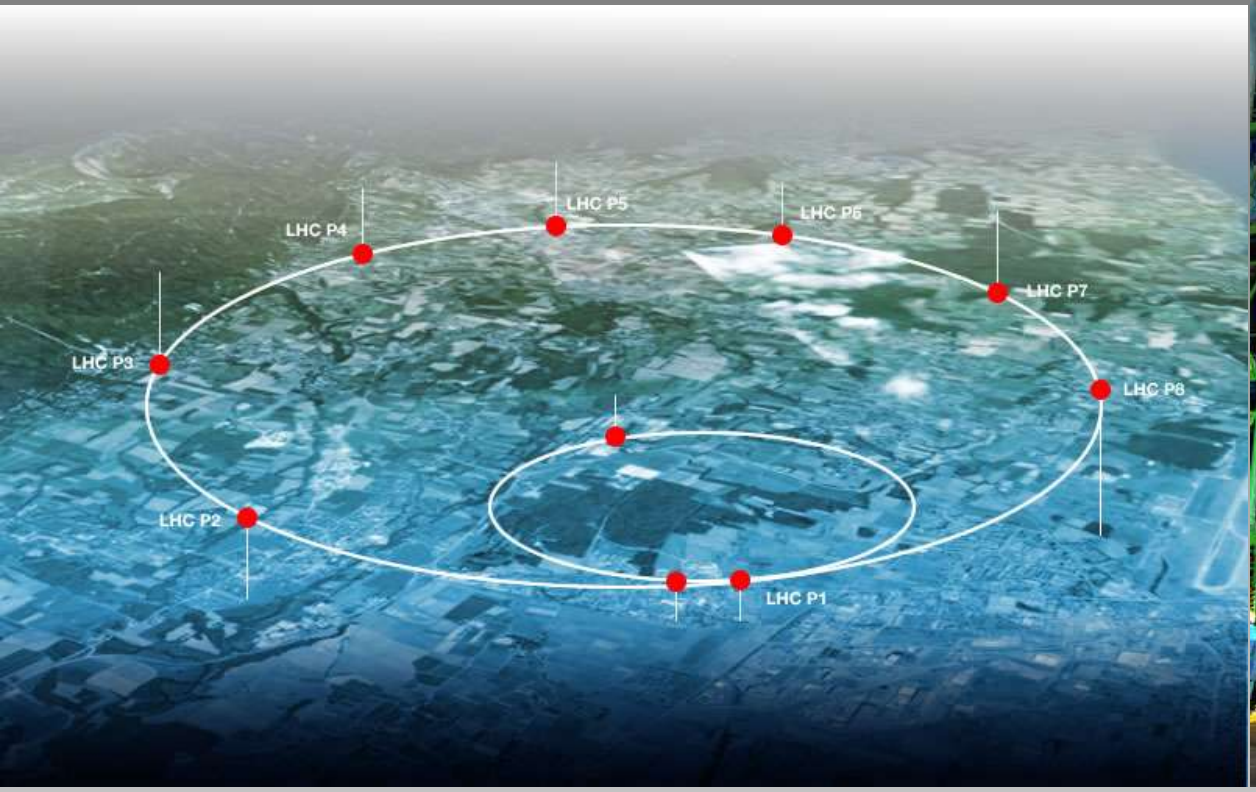
100 km/s

1 Megaparsec in 1000 seconds

Time for us, watching the moving particle, is $t = 3 \times 10^{24} / \beta c = 10^{14}$ sec

Time for the particle, watching us approaching, is $t' \sim t/\gamma = 10^{3}$ sec

Human accelerators

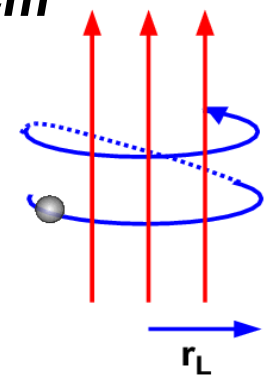


LHC → ~7 TeV protons → $\gamma = 7000$

Where do they come from?

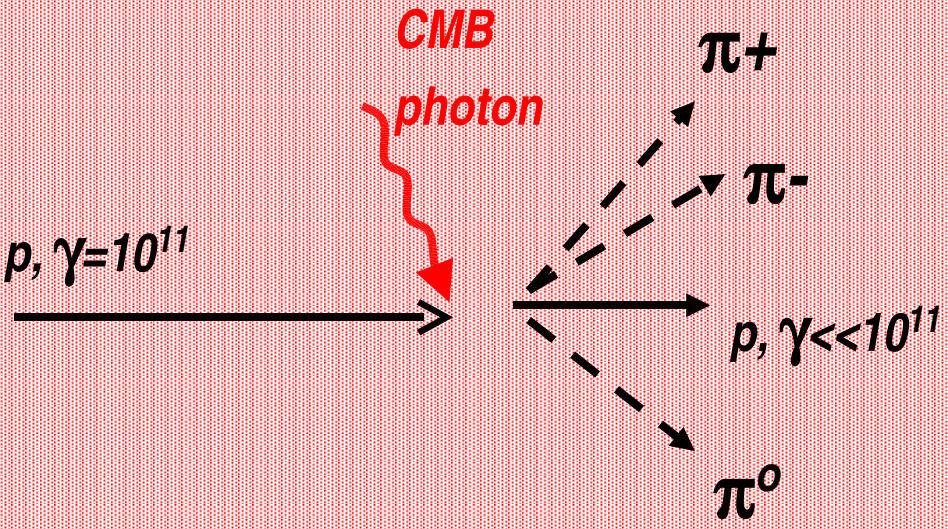
- Low energy: within our Galaxies. B-field mixes up all directions.
- High energy: B-field not enough to trap them, difficult to accelerate. Extra-galactic, but what sources? A mistery.

Larmor radius: $\frac{\gamma m_p c^2}{eB} = \frac{10^{12}\gamma}{B_{gal}}$ cm



GZK effect

Greisen 1996; Zatsepin & Kuz'min 1966



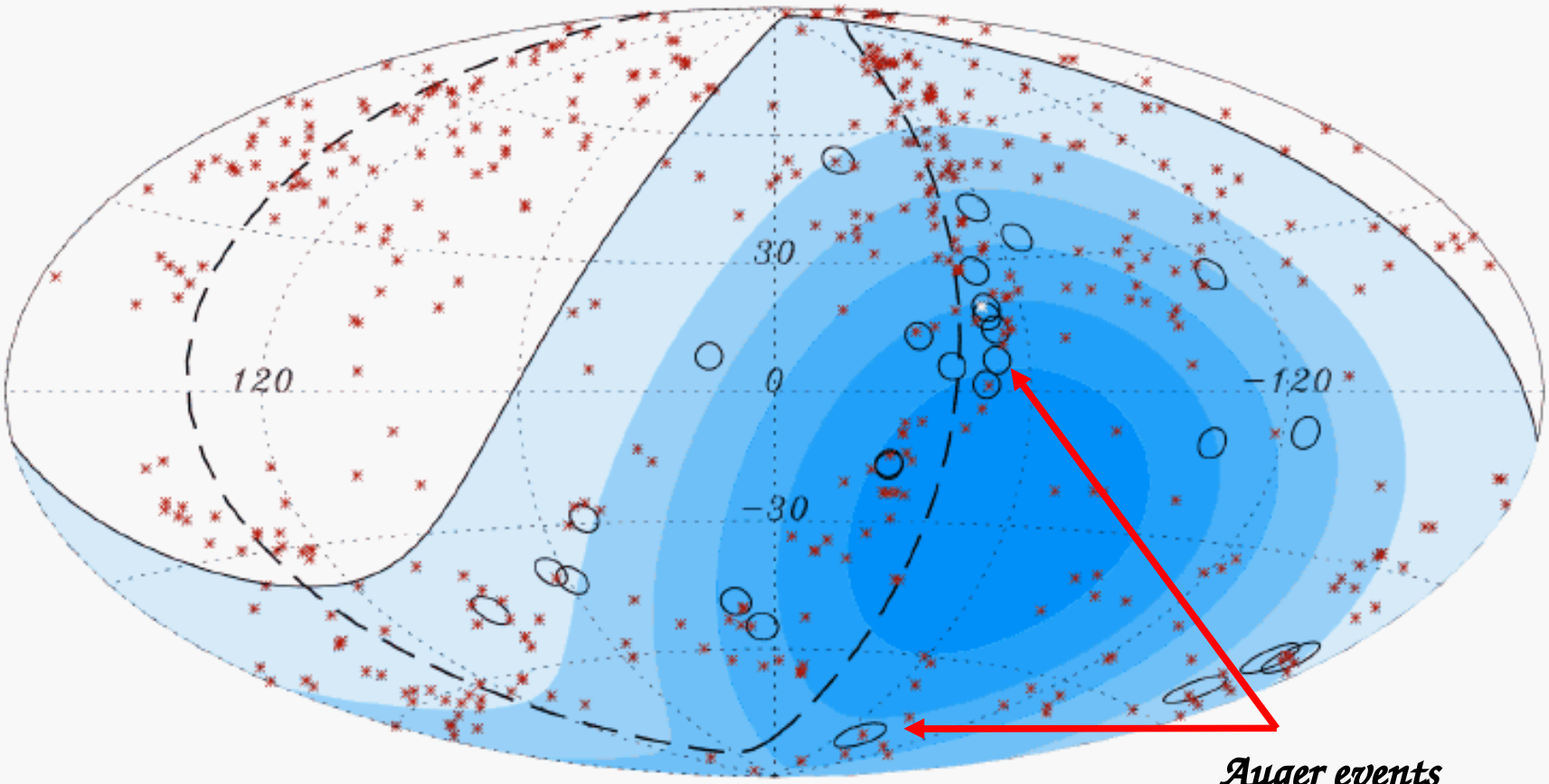
Important above 10^{19}ev. For 10^{20} ev, only those UHECRs born within 100 Mpc can reach us

75 c
20
ev
OBSERVATORIO
PIERRE
AUGER
MALARGÜE
MENDOZA
ARGENTINA
REPÚBLICA ARGENTINA
CORREO OFICIAL
2007

Auger - Loma Amarilla Fluorescence Telescope
Auger - Central Laser Facility 2
Auger - Central Laser Facility
Auger - Los Morados Fluorescence Telescope
Pierre Auger Observatory - Malargue Campus
Auger - Los Leones Fluorescence Telescope
Image © 2006 TerraMetrics
©2006 Google
17.1 mi
Pointer lat -35.234420° lon -69.282390° elev 4496 ft
Streaming 100%
Eye alt 61.11 mi

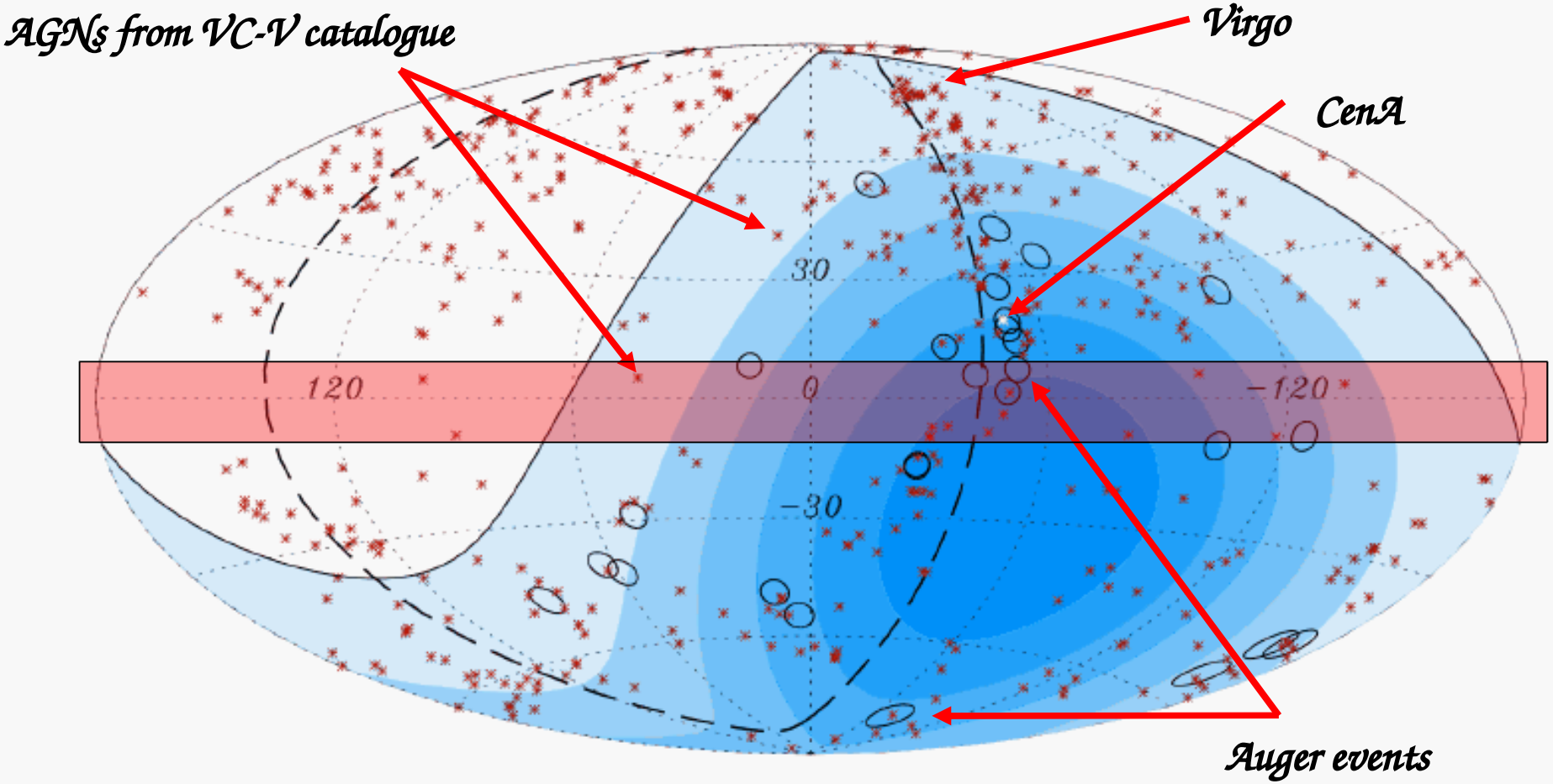
27 Auger Events >57 EeV

1 EeV=10^{18} eV



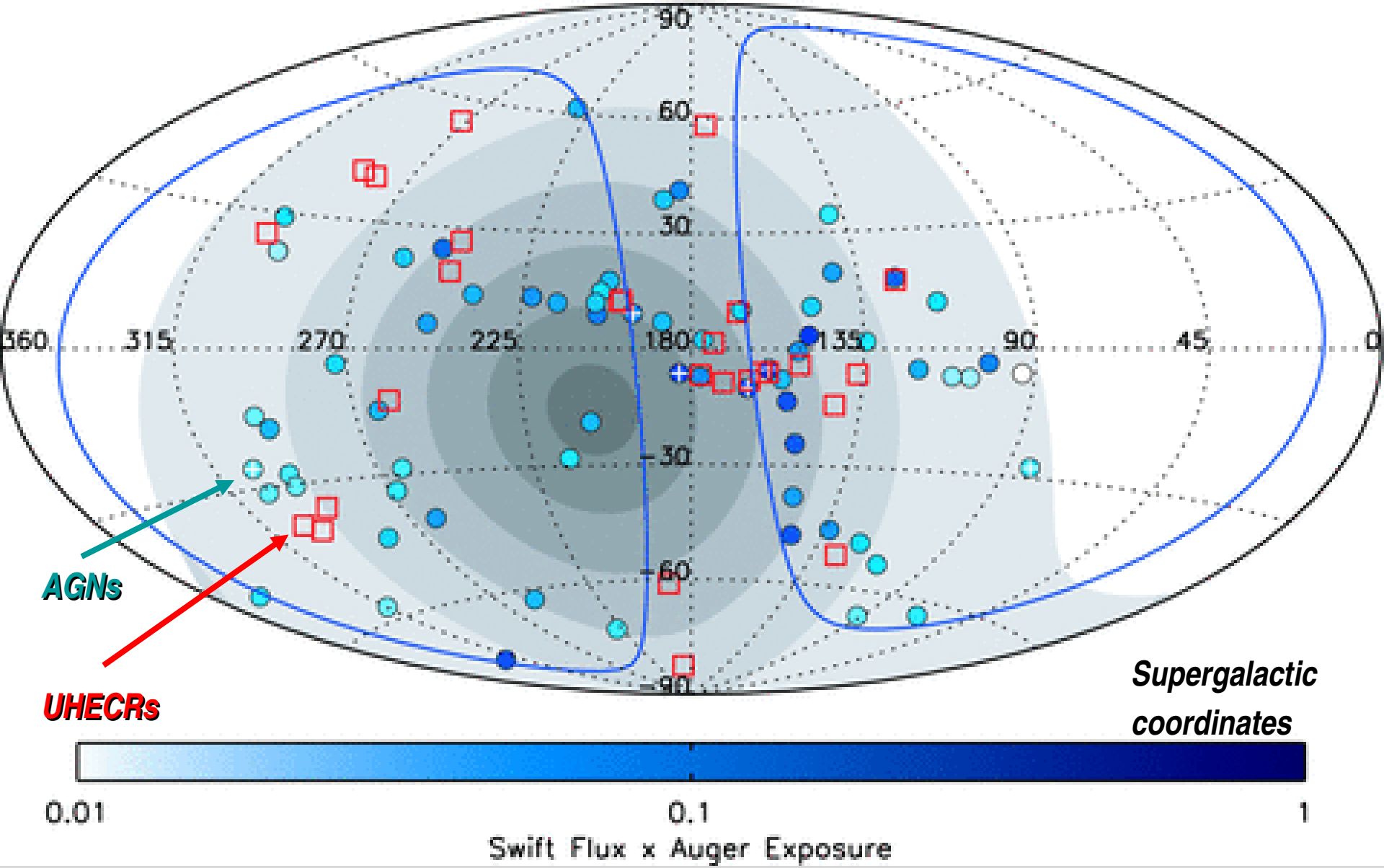
The Auger collaboration, 2007, Science

If the Galactic plane is excluded, 19 out of 21 events do correlate

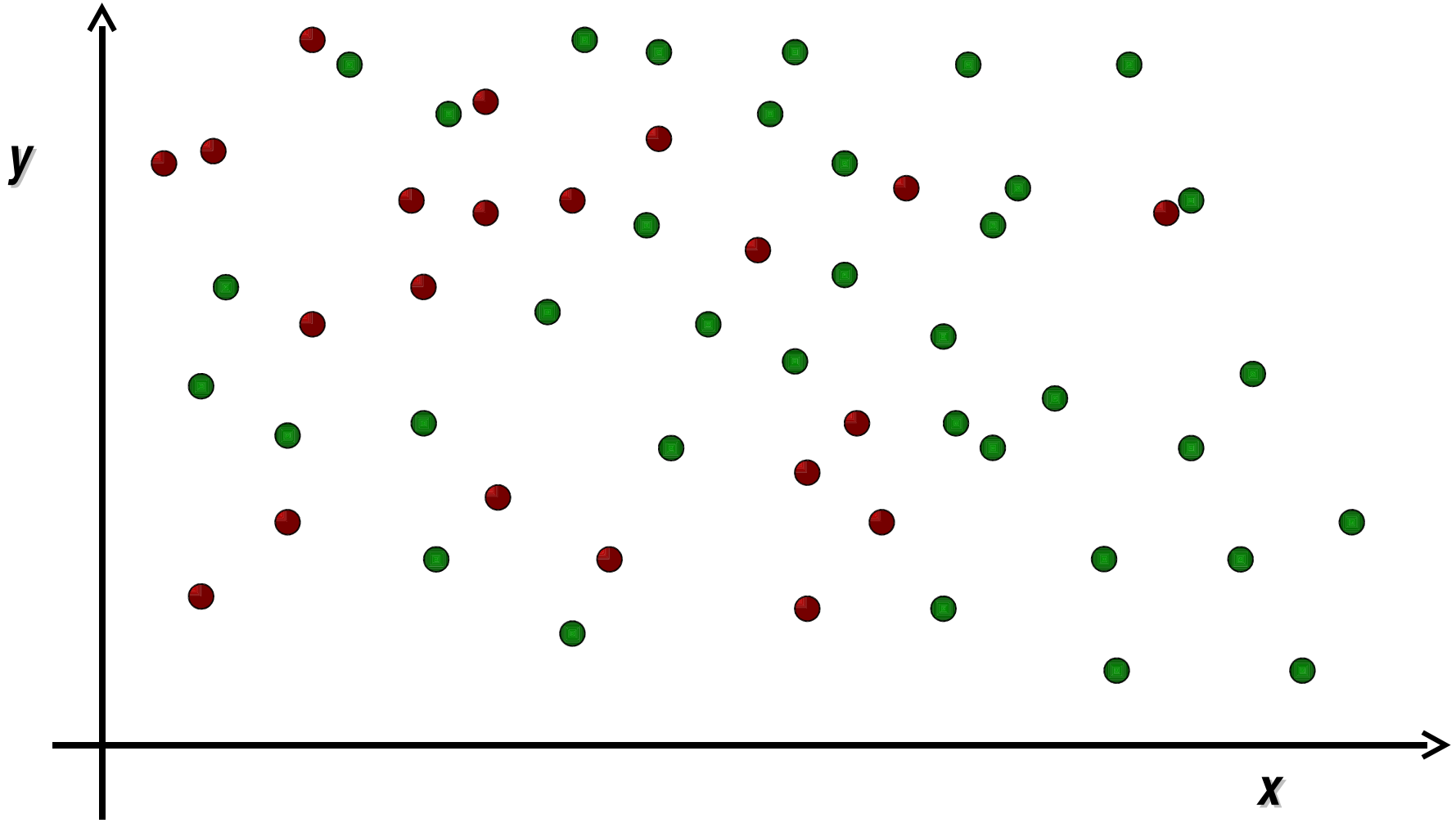


The Auger collaboration, 2007, Science

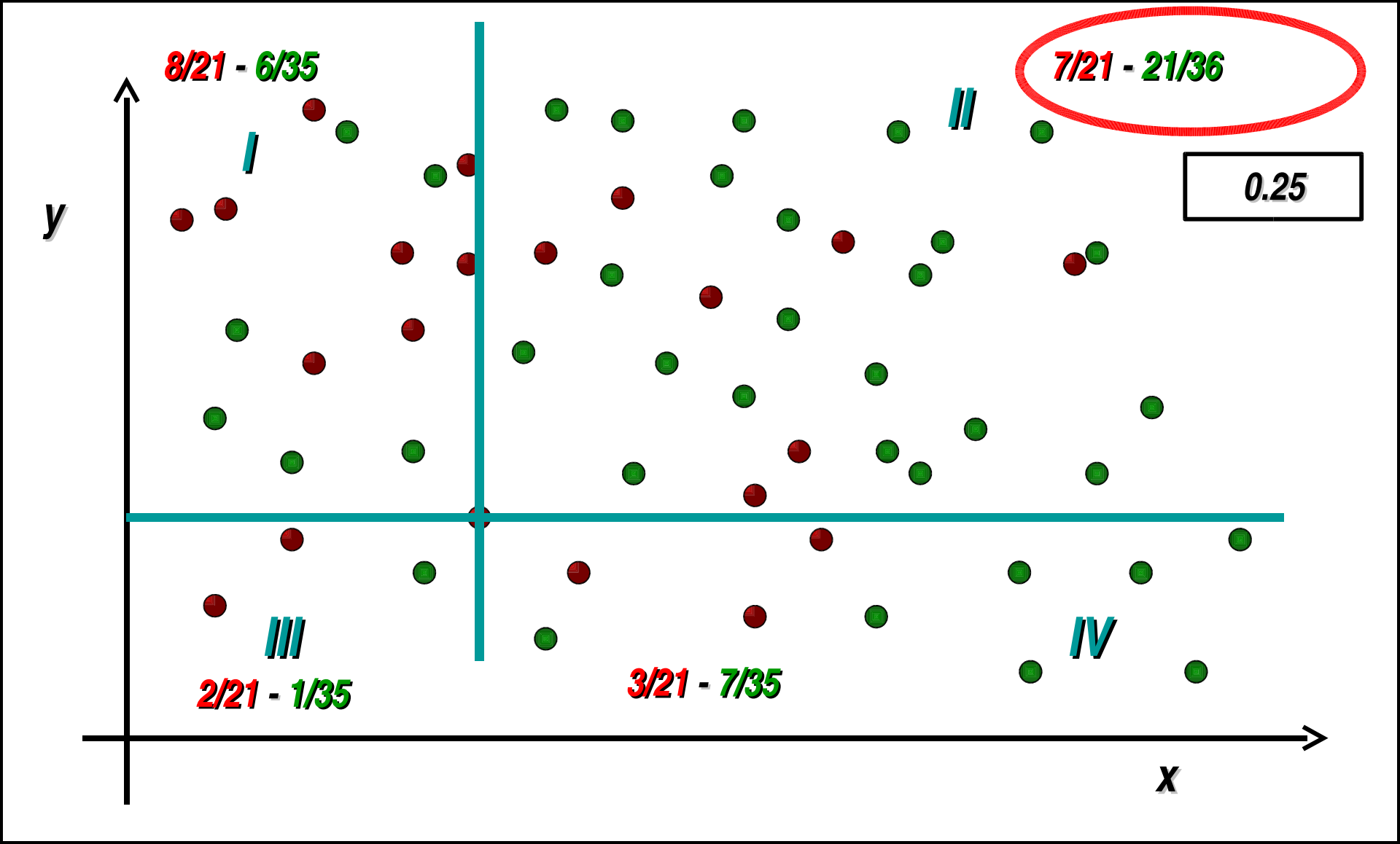
George, Fabian, Baumgartner, Mushotzky,Teueller 2008: Swift/BAT AGNs



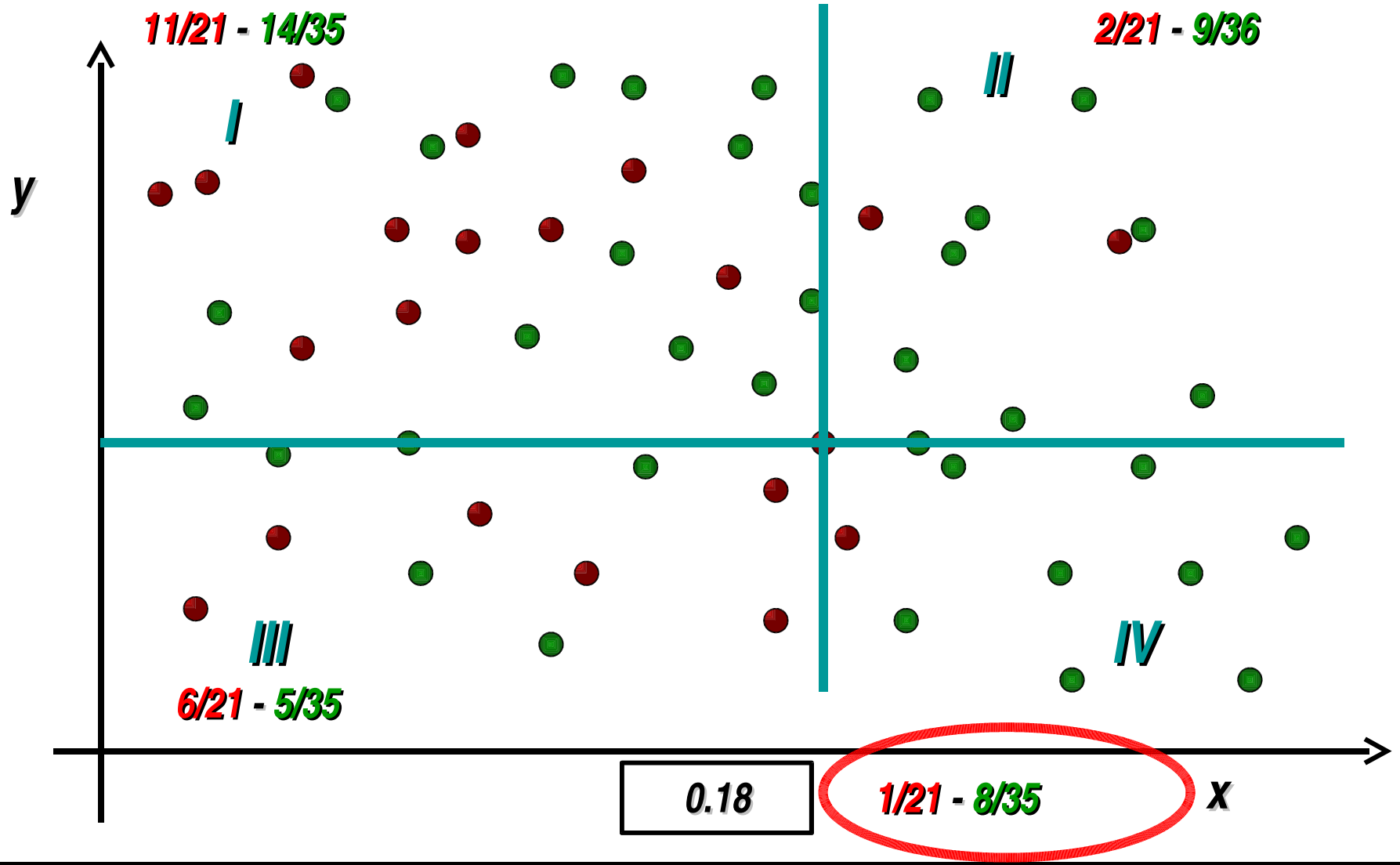
2D Kolmogorov Smirnov

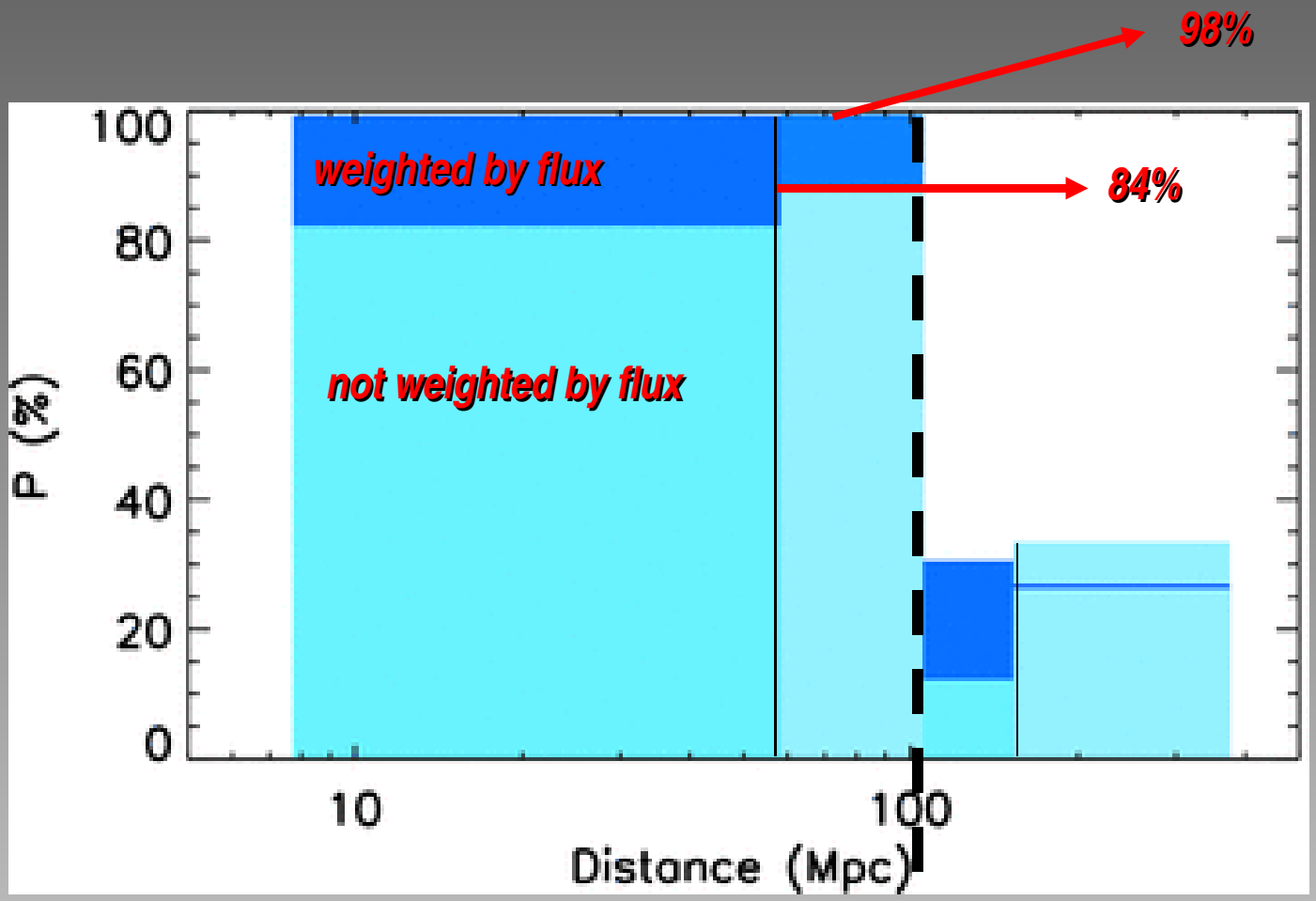


2D Kolmogorov Smirnov



2D Kolmogorov Smirnov





138 AGNs; 19 UHECRs with |b|<15°, δ <25°

57 AGNs within 100 Mpc

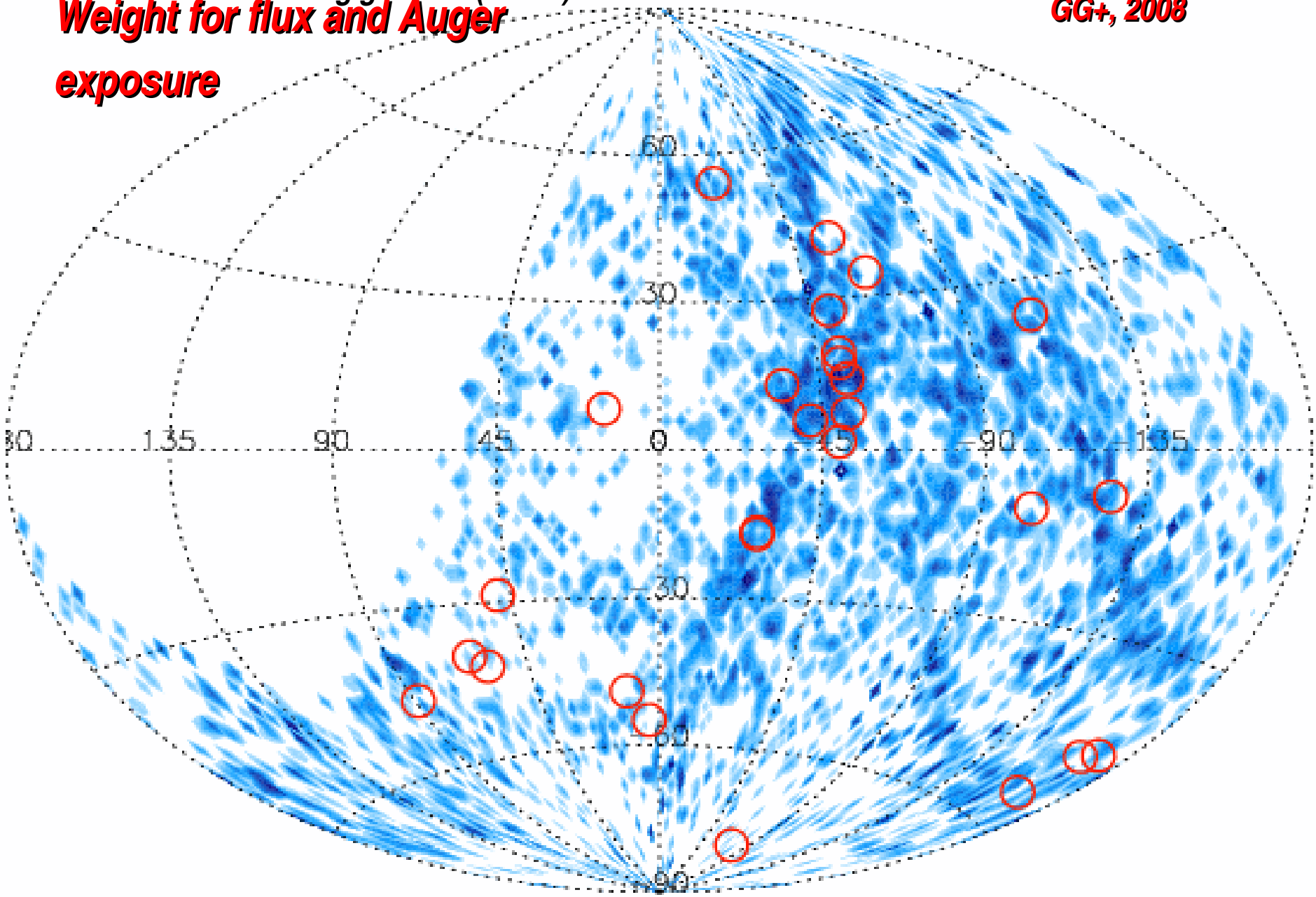
GZK effect

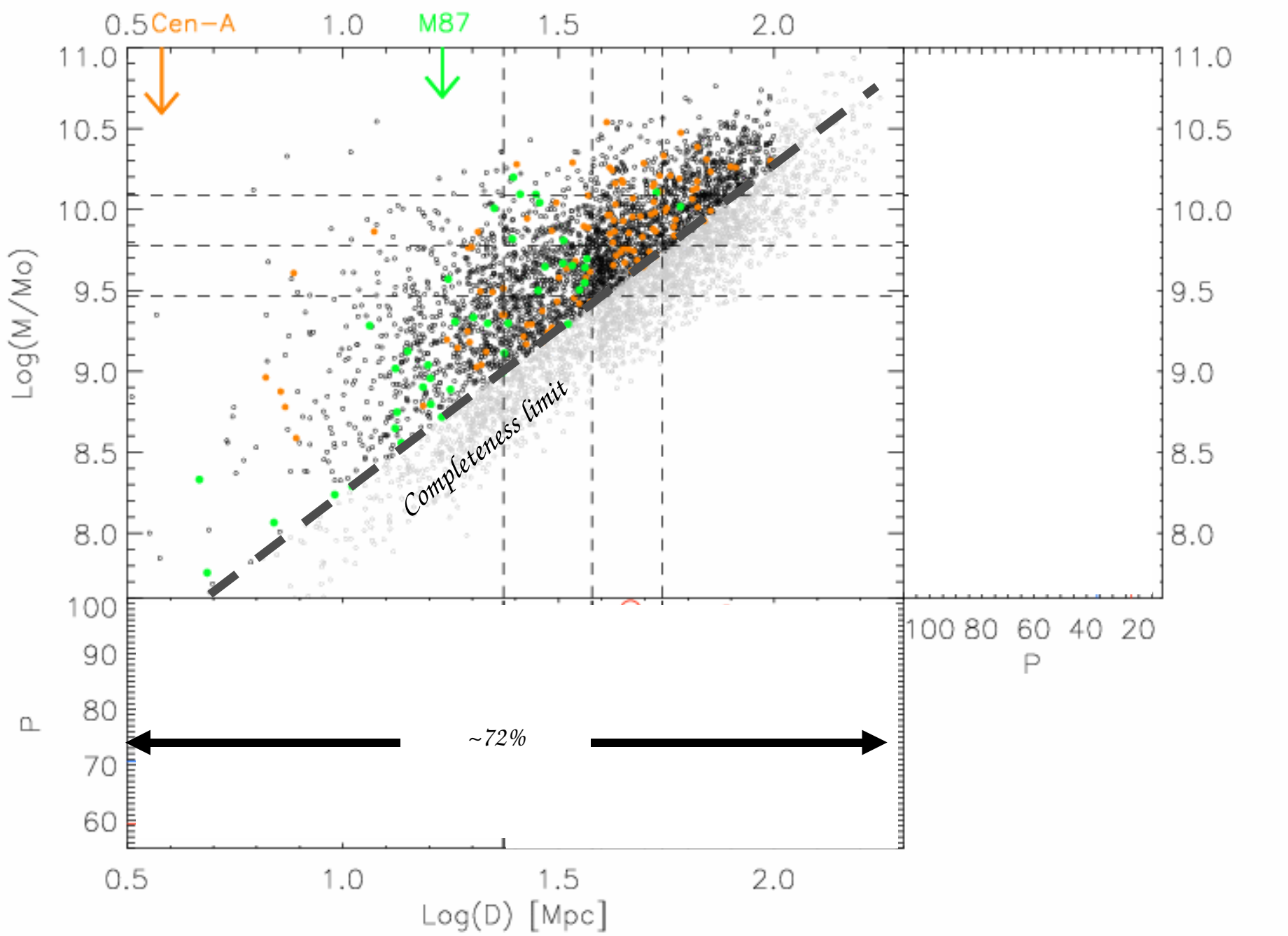
Radio quiet AGN???

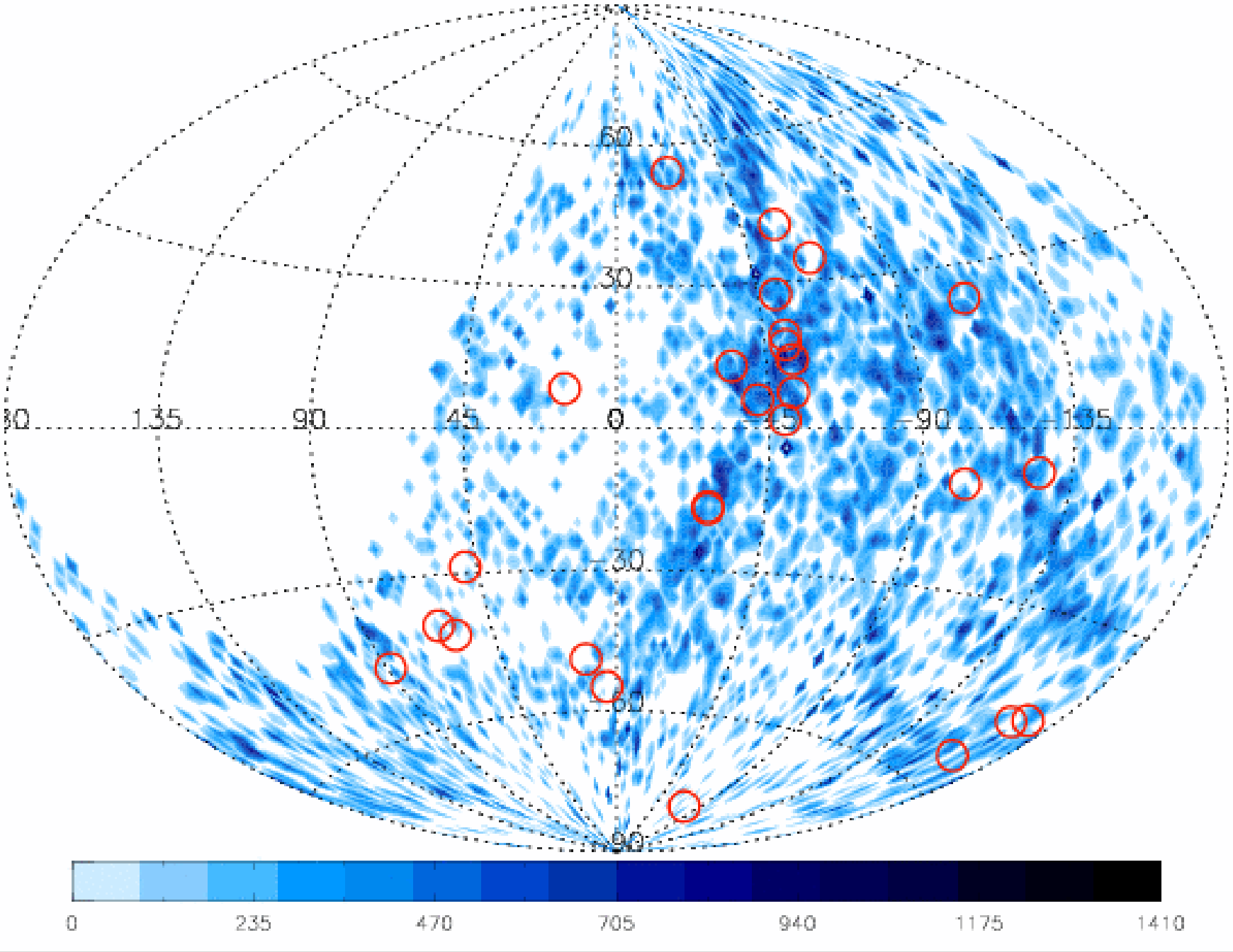
HIPASS: ~5000 HI emitting galaxies (21 cm)

Weight for flux and Auger exposure

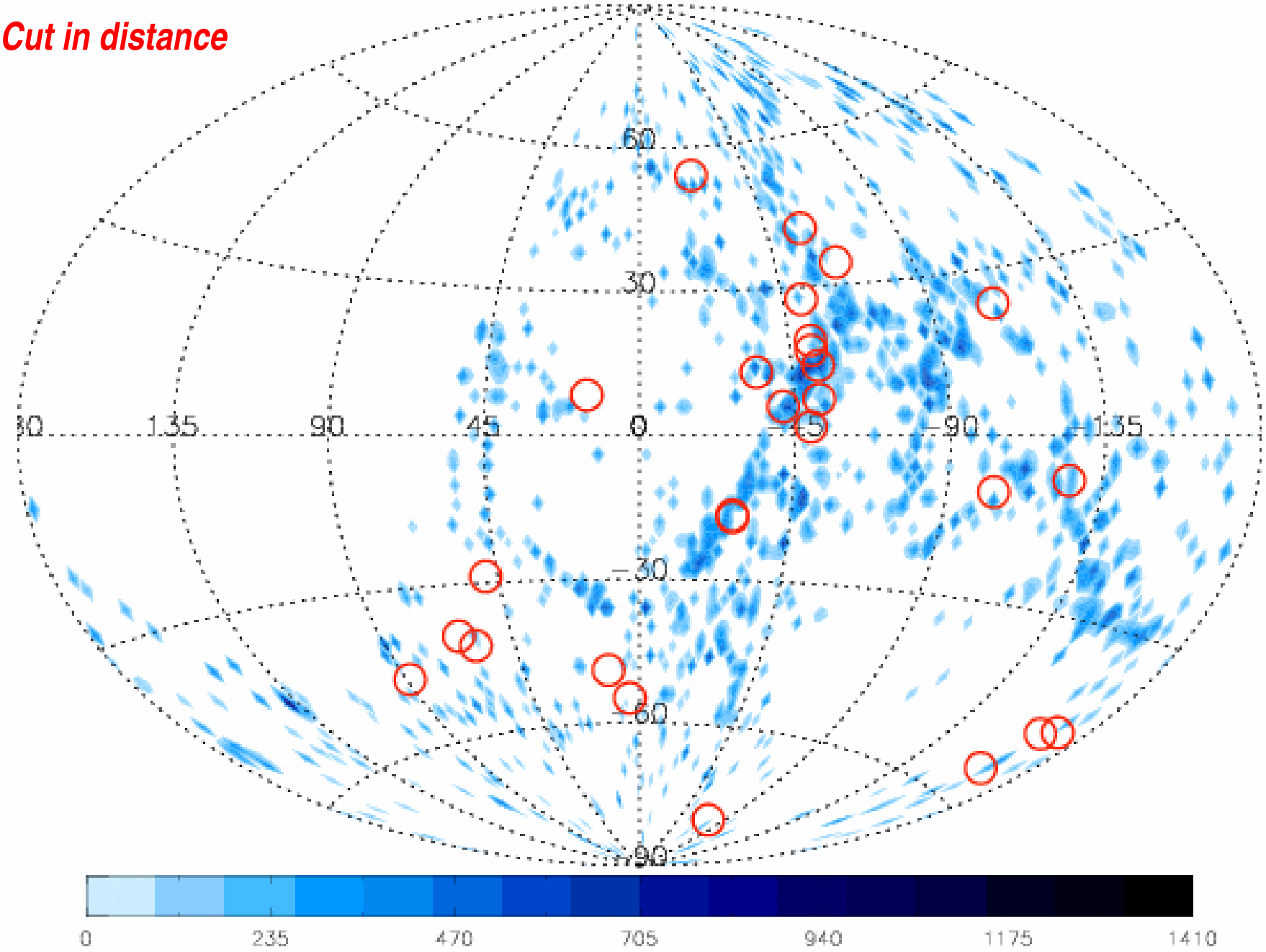
GG+, 2008

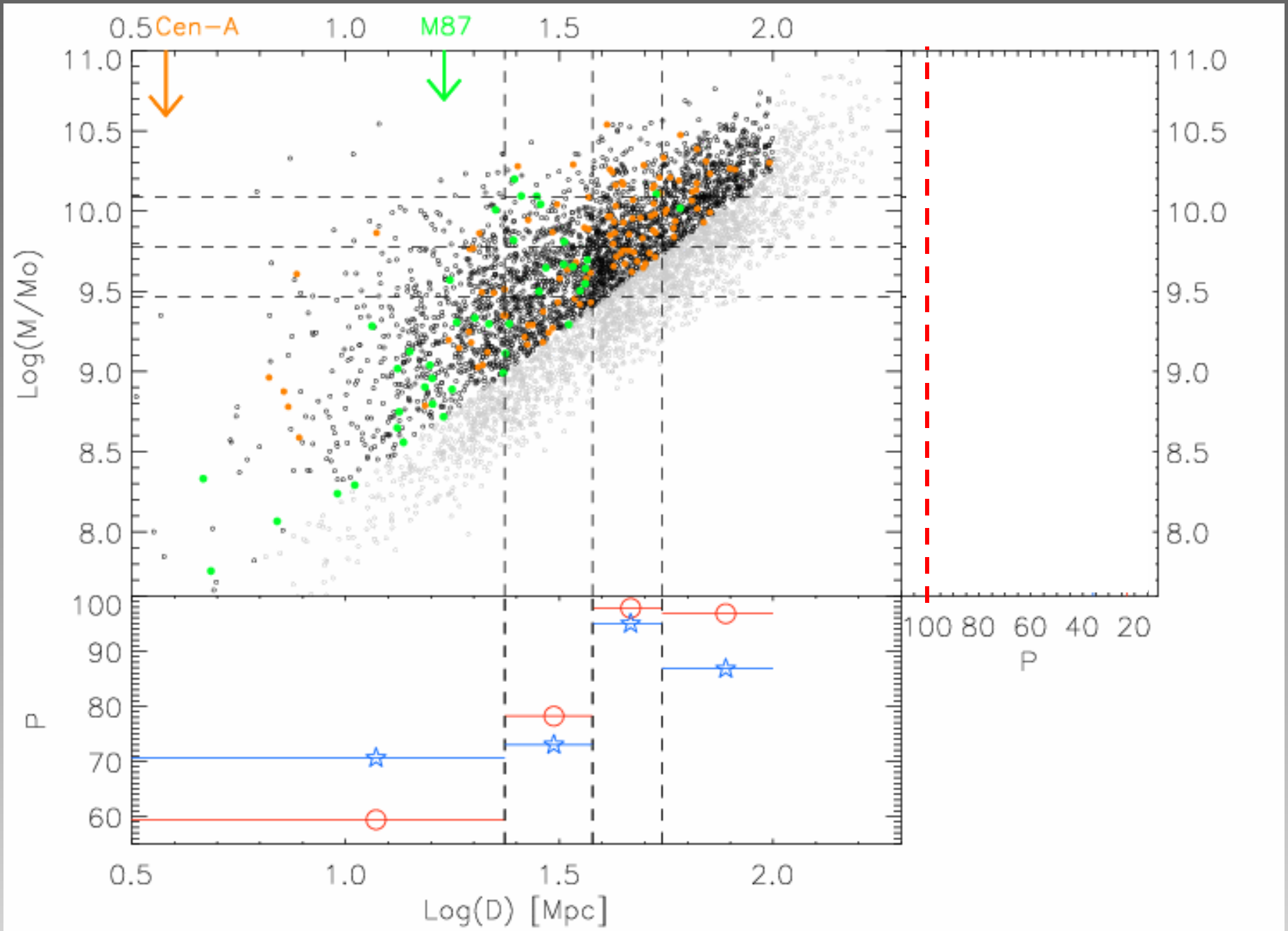


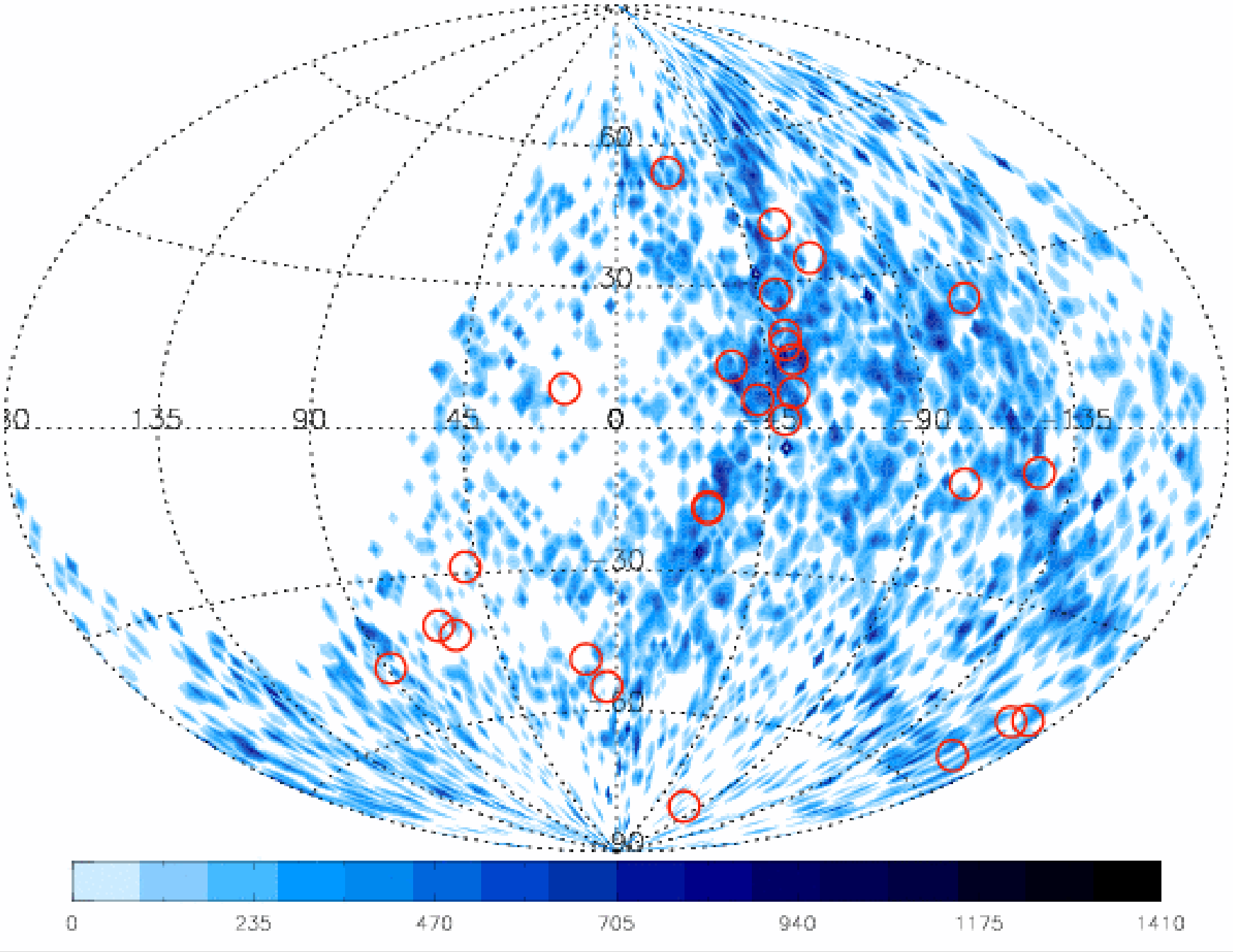

0.5
Cen−A
1.0
M87
1.5
2.0
11.0
10.5
10.0
9.5
9.0
8.5
8.0
Log(M/Mo)
Completeness limit
100
90
80
70
60
P
~72%
100 80 60 40 20
P
0.5
1.0
1.5
2.0
Log(D) [Mpc]


60
30
-30
-60
-90
-135
-90
-45
0
45
90
135
0
235
470
705
940
1175
1410

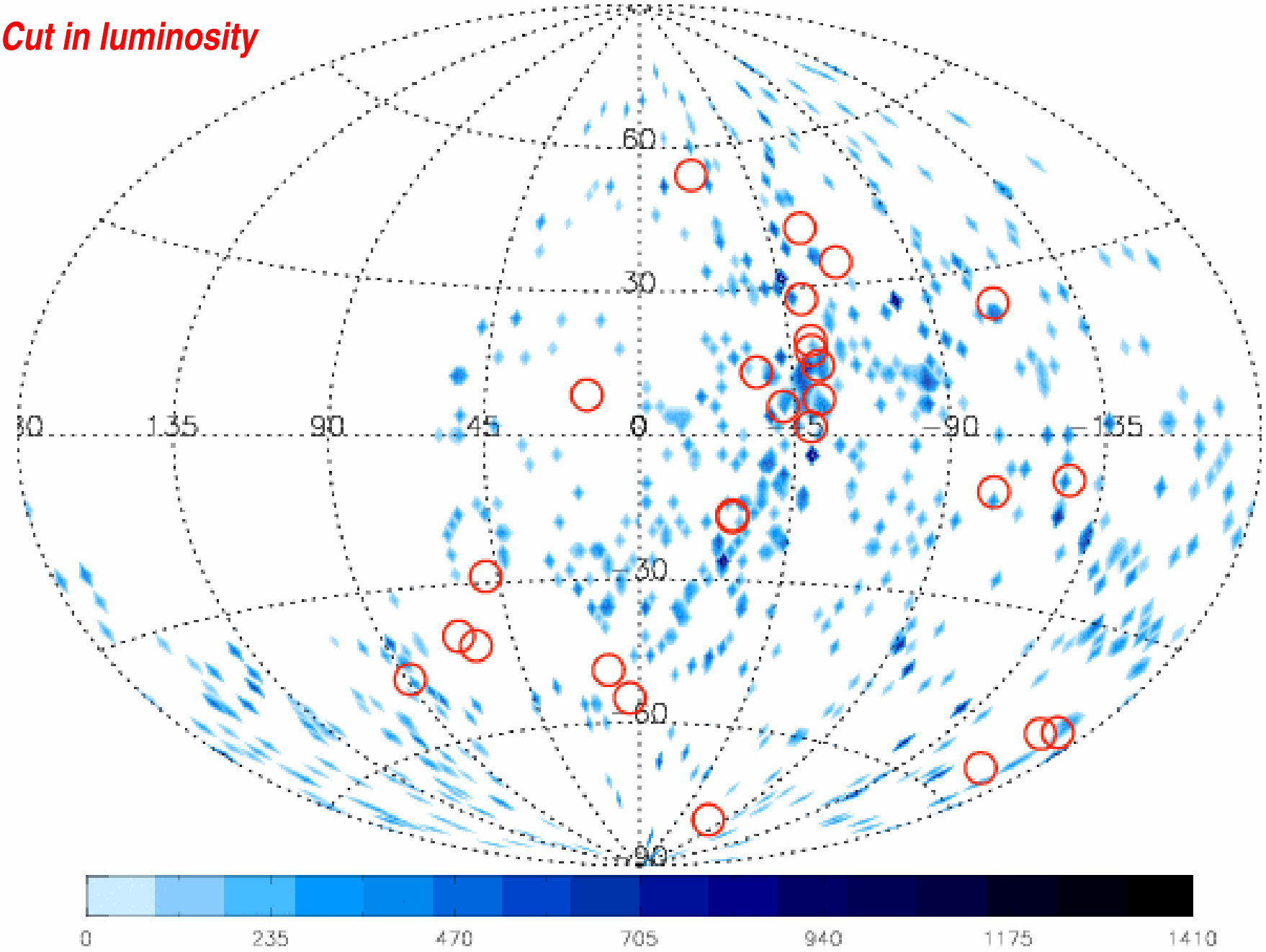
Cut in distance

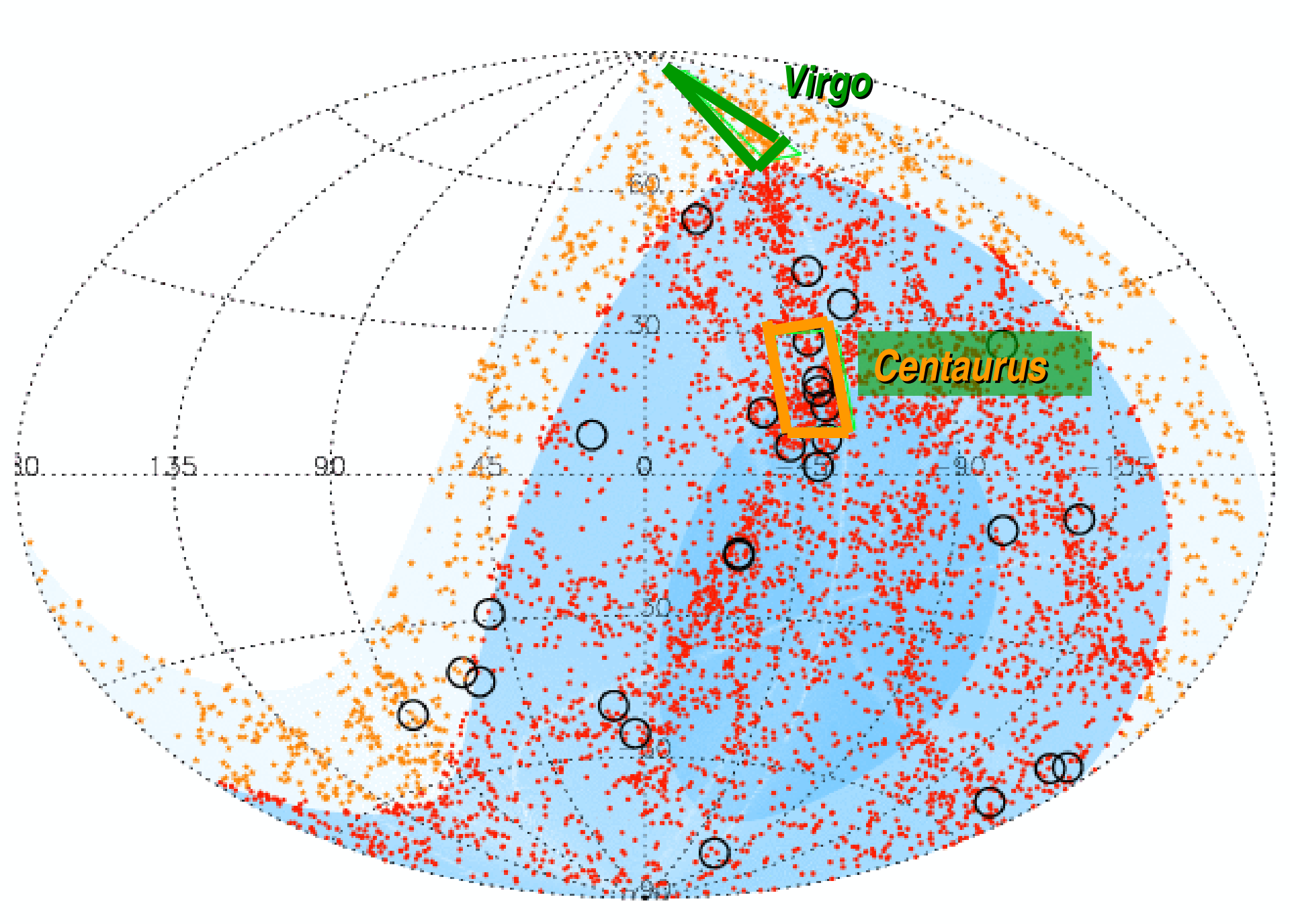


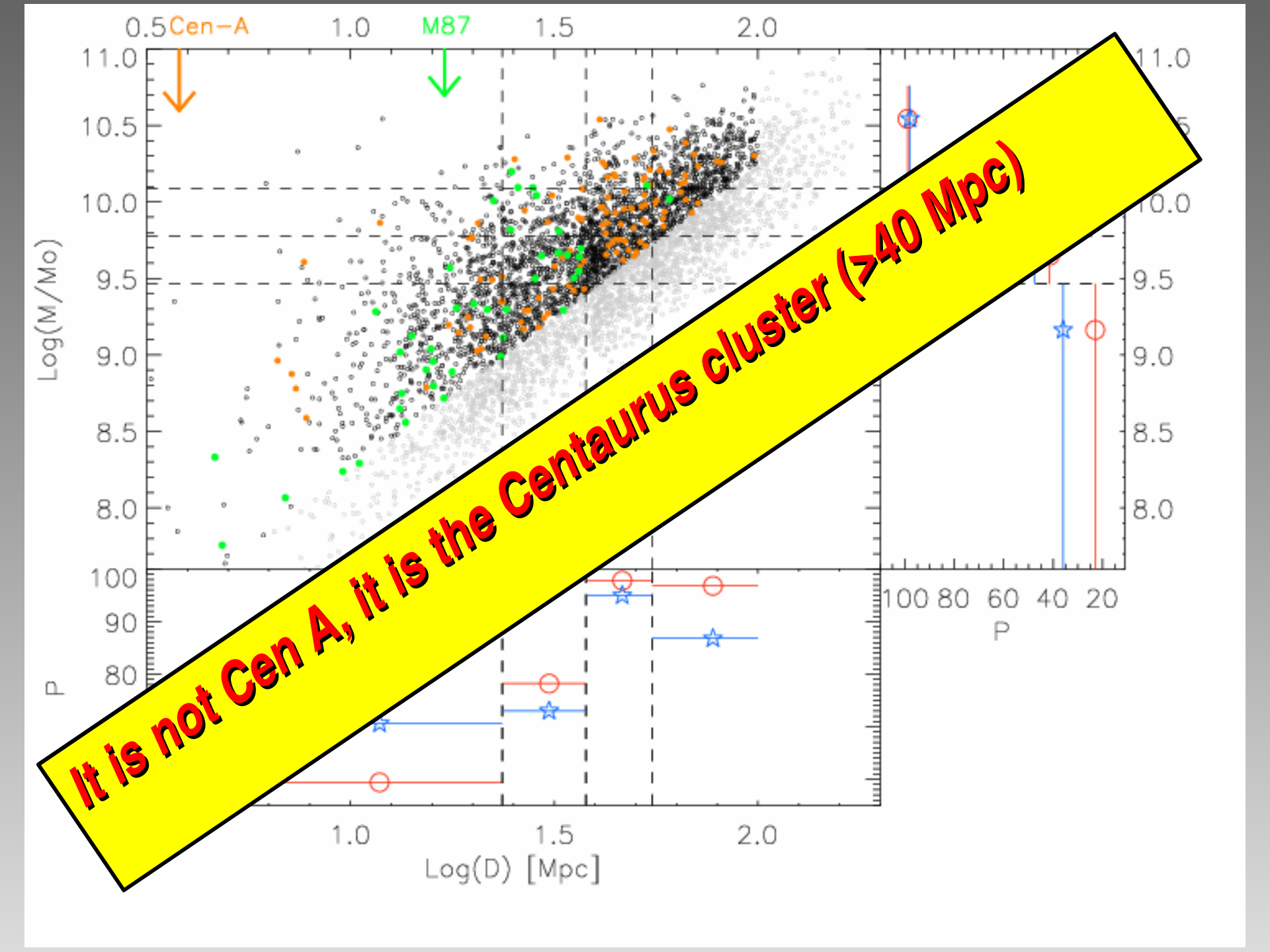

0.5
Cen−A
1.0
M87
1.5
2.0
11.0
10.5
10.0
9.5
9.0
8.5
8.0
Log(M/Mo)
100
90
80
70
60
P
0.5
1.0
1.5
2.0
Log(D) [Mpc]
100 80 60 40 20
P

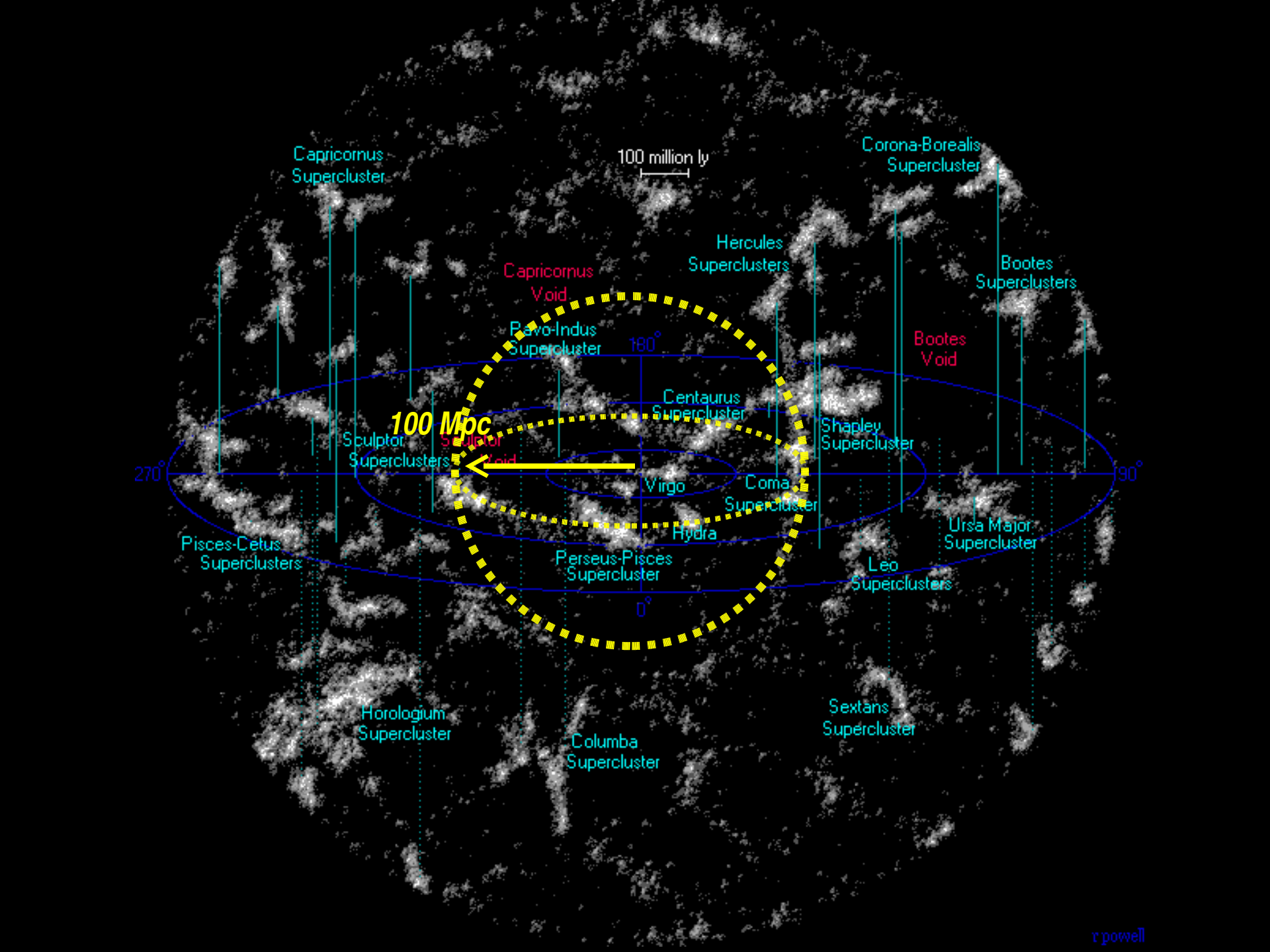

60
30
-30
-60
-90
-135
-90
-45
0
45
90
135
0
235
470
705
940
1175
1410

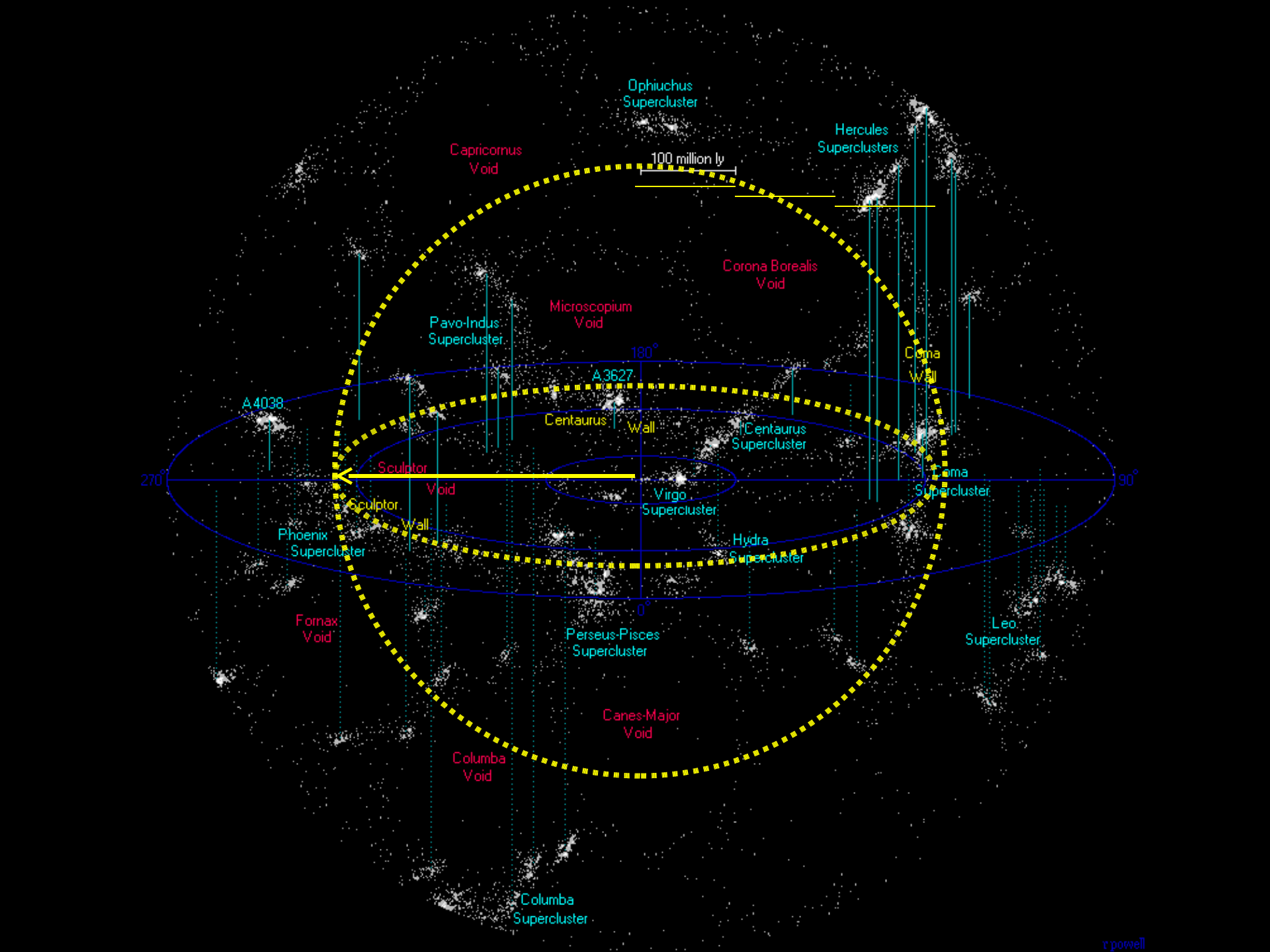
Cut in luminosity




Virgo
Centaurus
60
30
0
-30
-60
-90
135
90
45
0
-45
-90
-135


0.5
Cen−A
1.0
M87
1.5
2.0
11.0
10.5
10.0
9.5
9.0
8.5
8.0
Log(M/Mo)
100
90
80
P
1.0
1.5
2.0
Log(D) [Mpc]
100 80 60 40 20
P
It is not Cen A, it is the Centaurus cluster (>40 Mpc)


100 million ly
Capricornus Supercluster
Corona-Borealis Supercluster
Hercules Superclusters
Bootes Superclusters
Capricornus Void
Pavo-Indus Supercluster
180°
Bootes Void
Centaurus Supercluster
100 Mpc
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Columba Supercluster
Sextans Supercluster
r powell


Ophiuchus
Supercluster
Hercules
Superclusters
Capricornus
Void
100 million ly
Corona Borealis
Void
Microscopium
Void
Pavo-Indus
Supercluster
180°
A3627
Coma
Wall
A4038
Centaurus
Wall
Centaurus
Supercluster
270°
Sculptor
Void
Coma
Supercluster
90°
Virgo
Supercluster
Sculptor
Wall
Phoenix
Supercluster
Hydra
Supercluster
0°
Fornax
Void
Perseus-Pisces
Supercluster
Leo
Supercluster
Canes-Major
Void
Columba
Void
Columba
Supercluster
r powell

Progenitors

$F_{Auger} \sim 10^{-11}$ erg cm^2 s^{-1} Flux for E>57 EeV

- Easy for AGNs (but they are radio-quiet… no γ)

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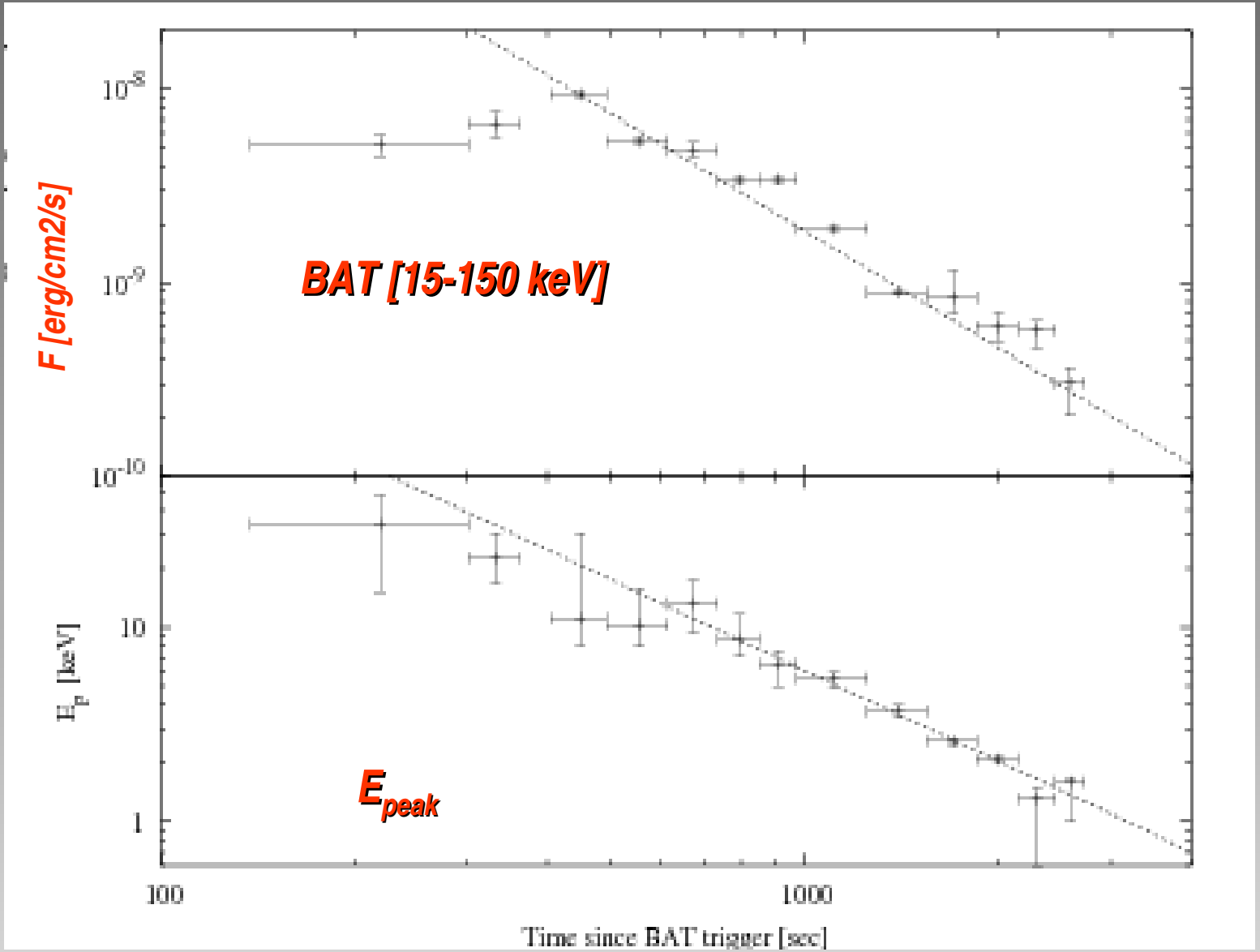
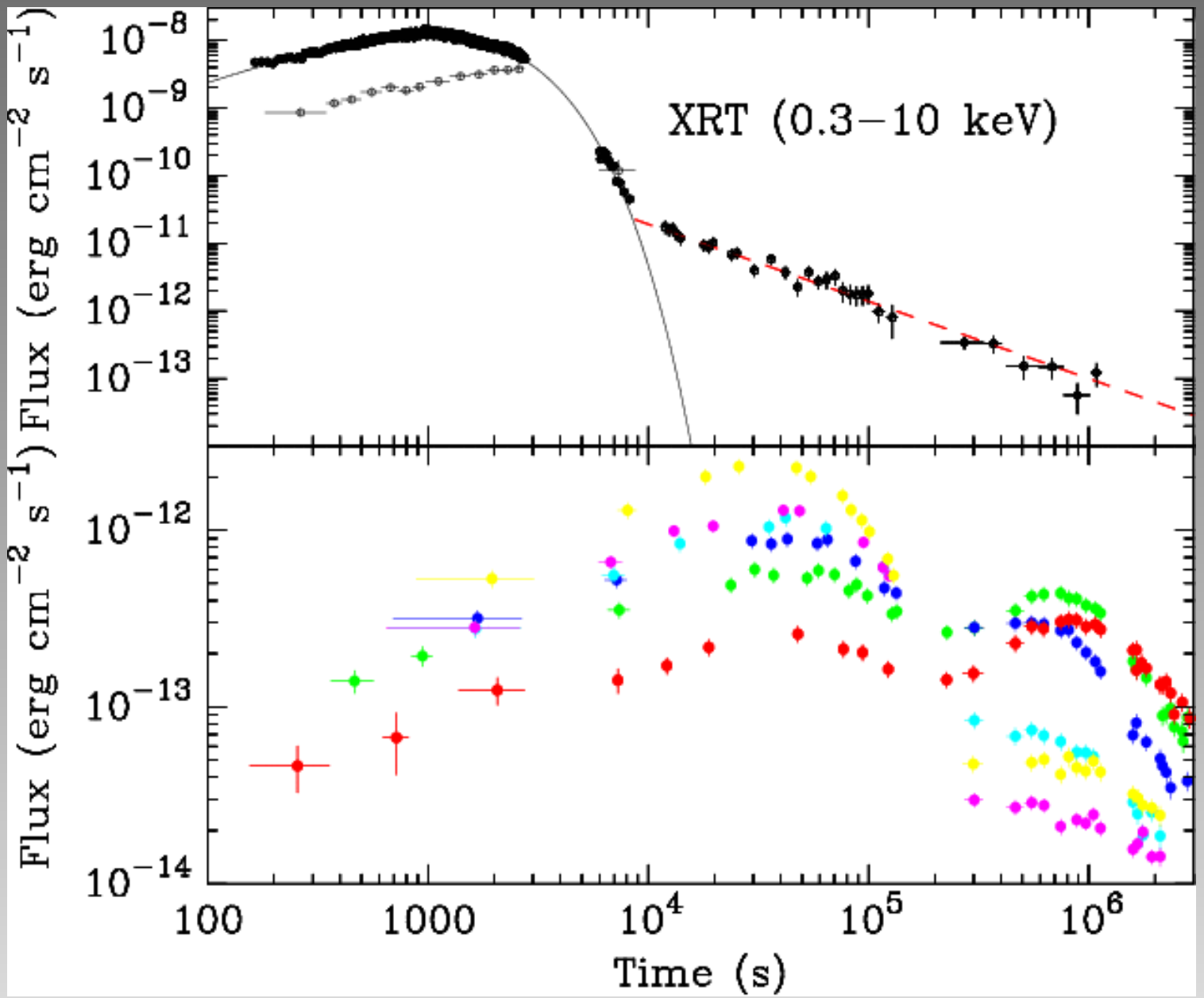
- Giant Flares of Magnetars (flux not enough)
- Newly born, fastly spinning Magnetars (!!!, but went unobserved by BATSE)

GRB 060218 ???



Toma et al. 2006

GRB 060218 ???

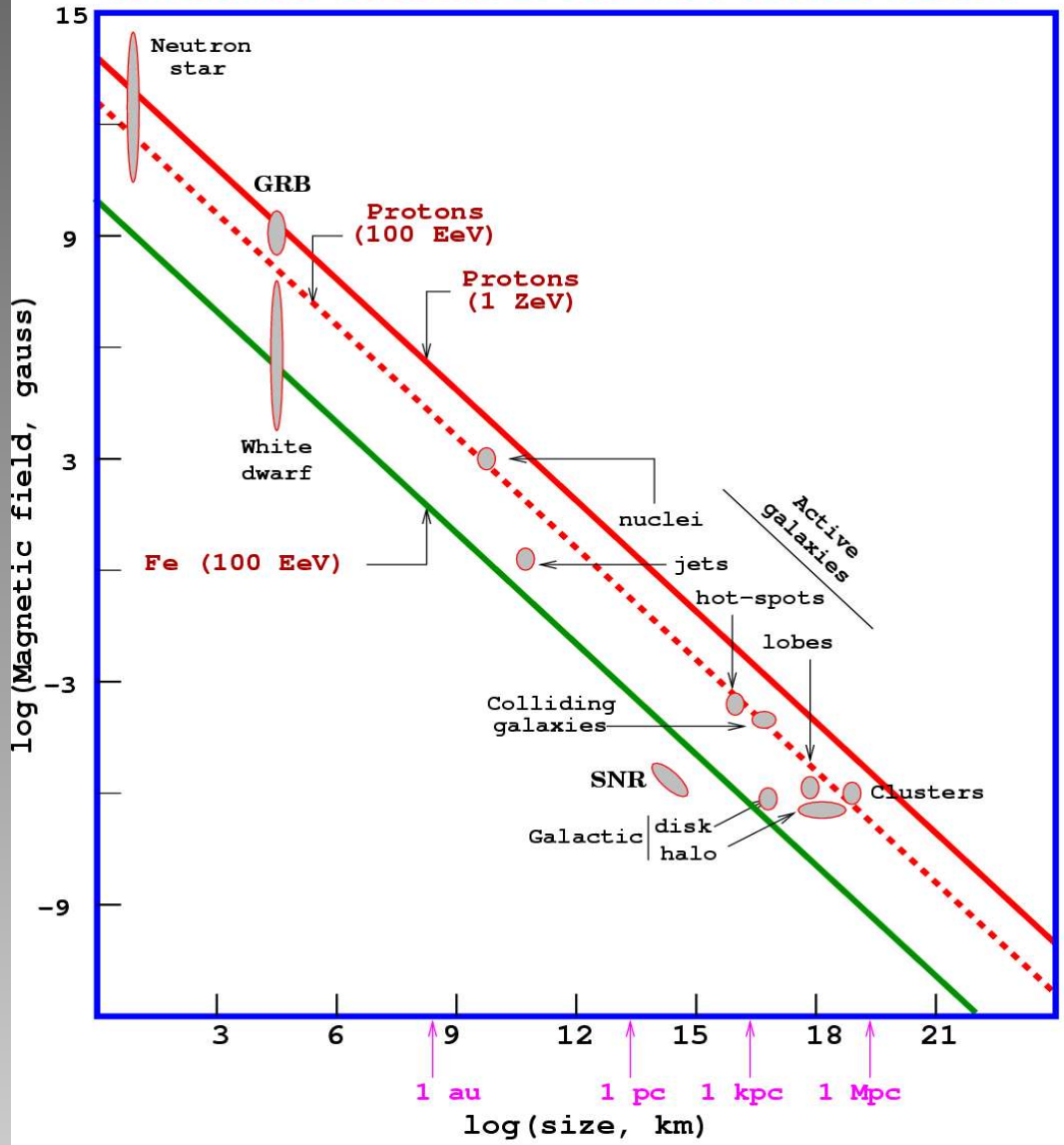


Campana et al. 2006

GRB 060218 ???

- Very long, soft, underluminous, nearby (145 Mpc)
- It could not have triggered BATSE
- Proposed to be a newborn magnetar (Soderberg+ 2007; Toma+ 2007)
- Right rate

Hillas-plot
(candidate sites for E=100 EeV and E=1 ZeV)



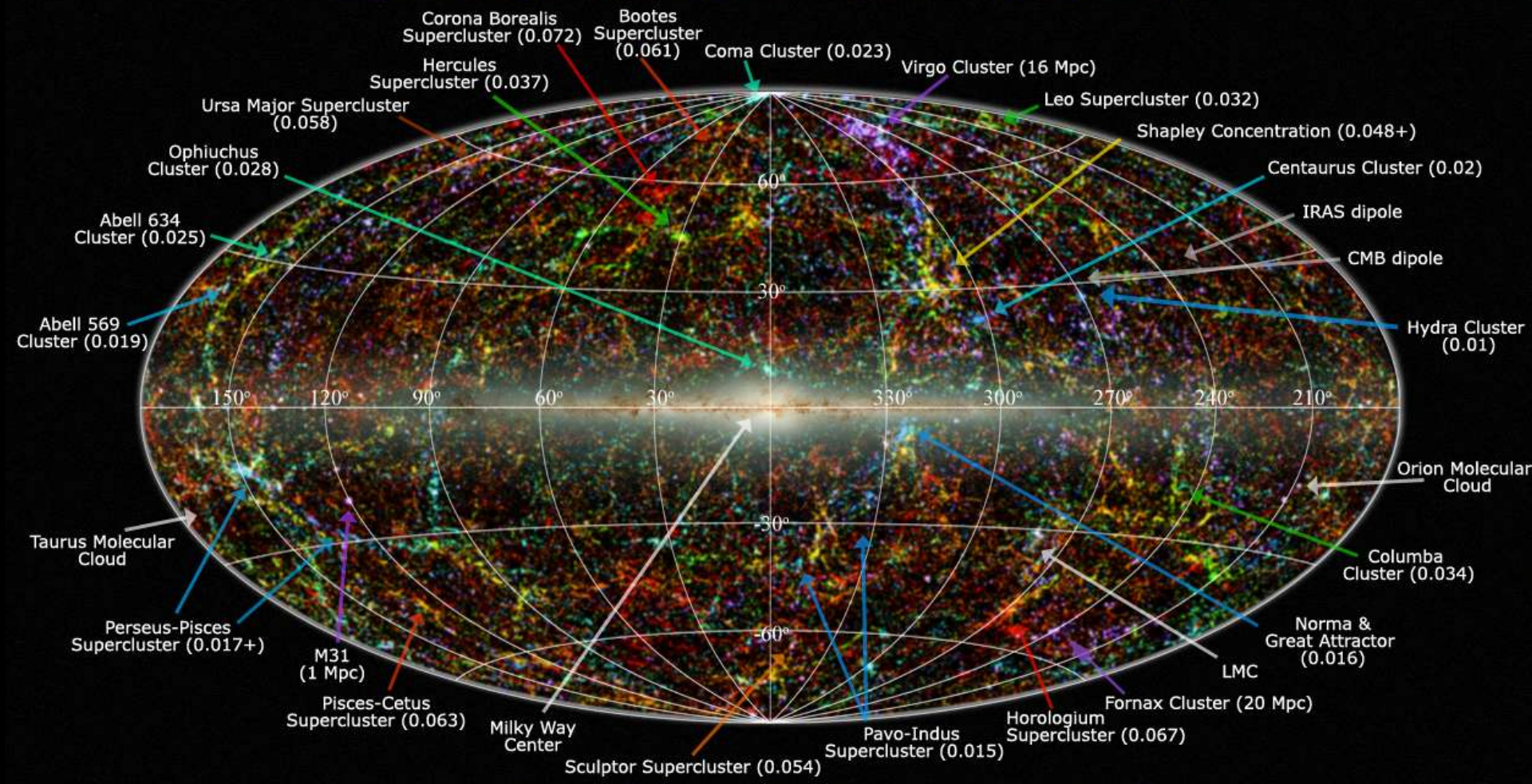
$E_{max} \sim ZBL$ (Fermi)

$E_{max} \sim ZBL\,\Gamma$ (Ultra-relativistic shocks-GRB)

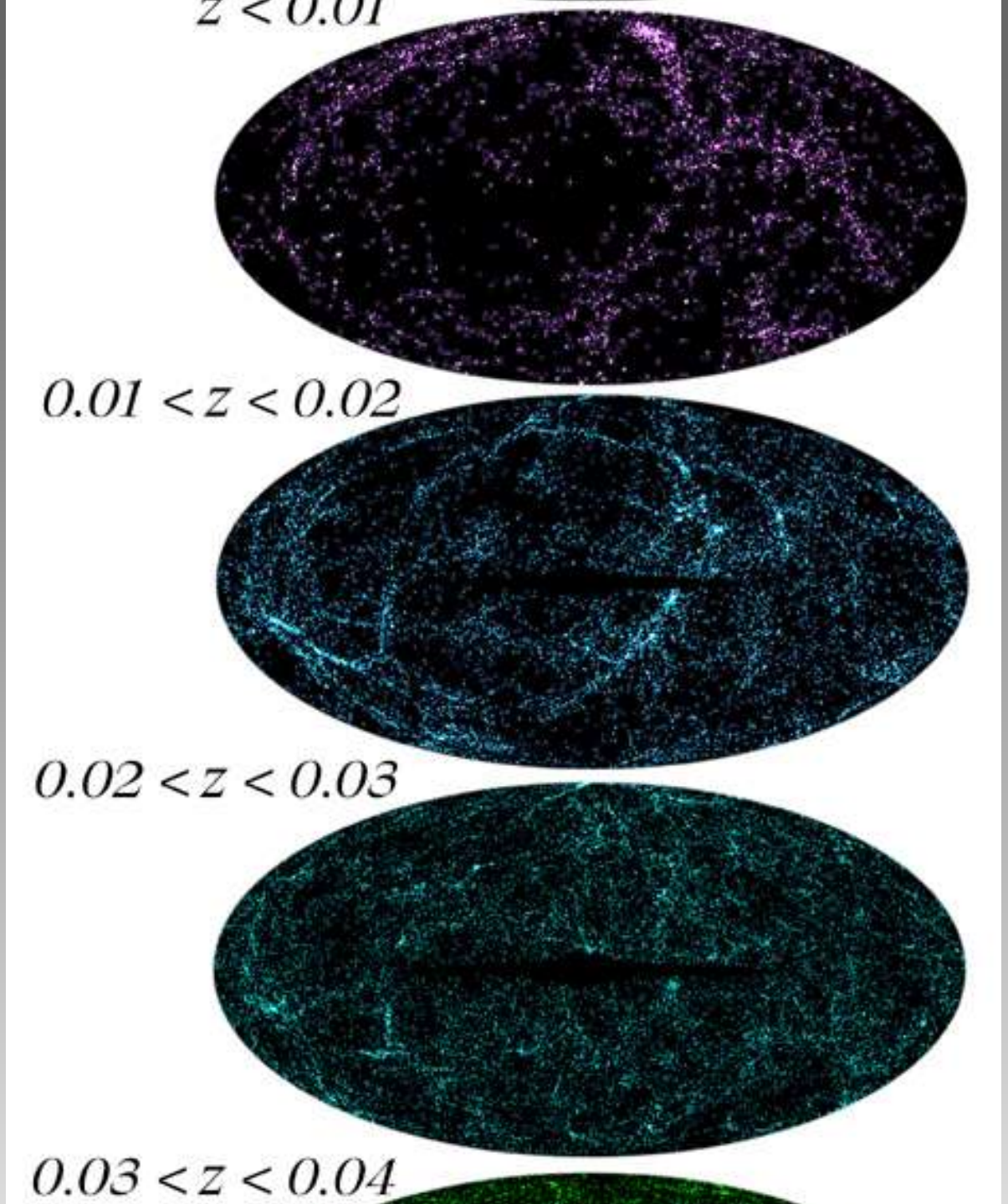
Conclusions

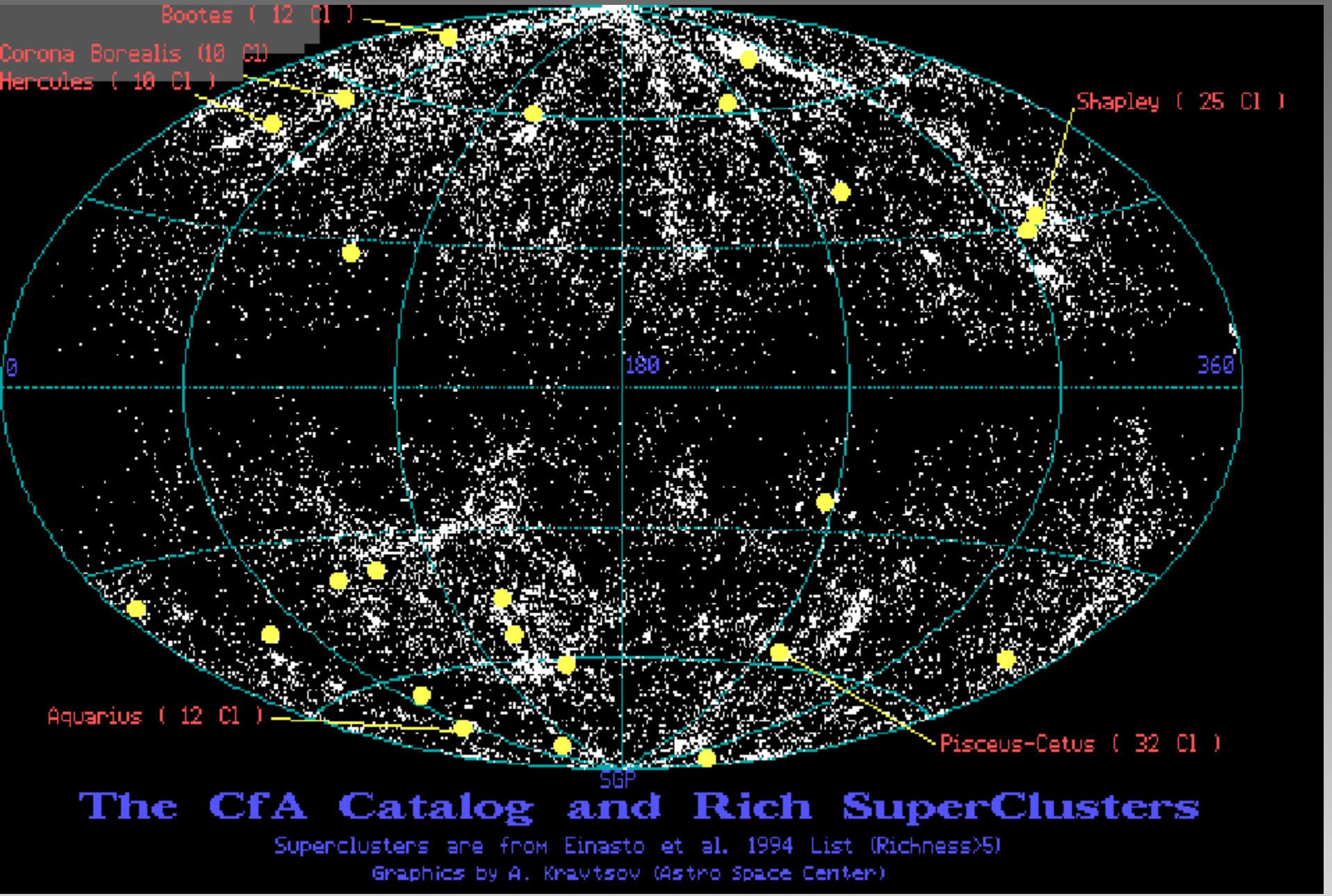
- UHECRs correlate with spirals
- → newly born magnetars?
- $E_{CR} \sim 10^{50}$ erg. Rate: 1 every 10^4 years per galaxy
- New class of GRBs (2 per yr all sky): similar to GRB 060218: soft, very long, underluminous+SN

Large Scale Structure in the Local Universe



Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004); familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

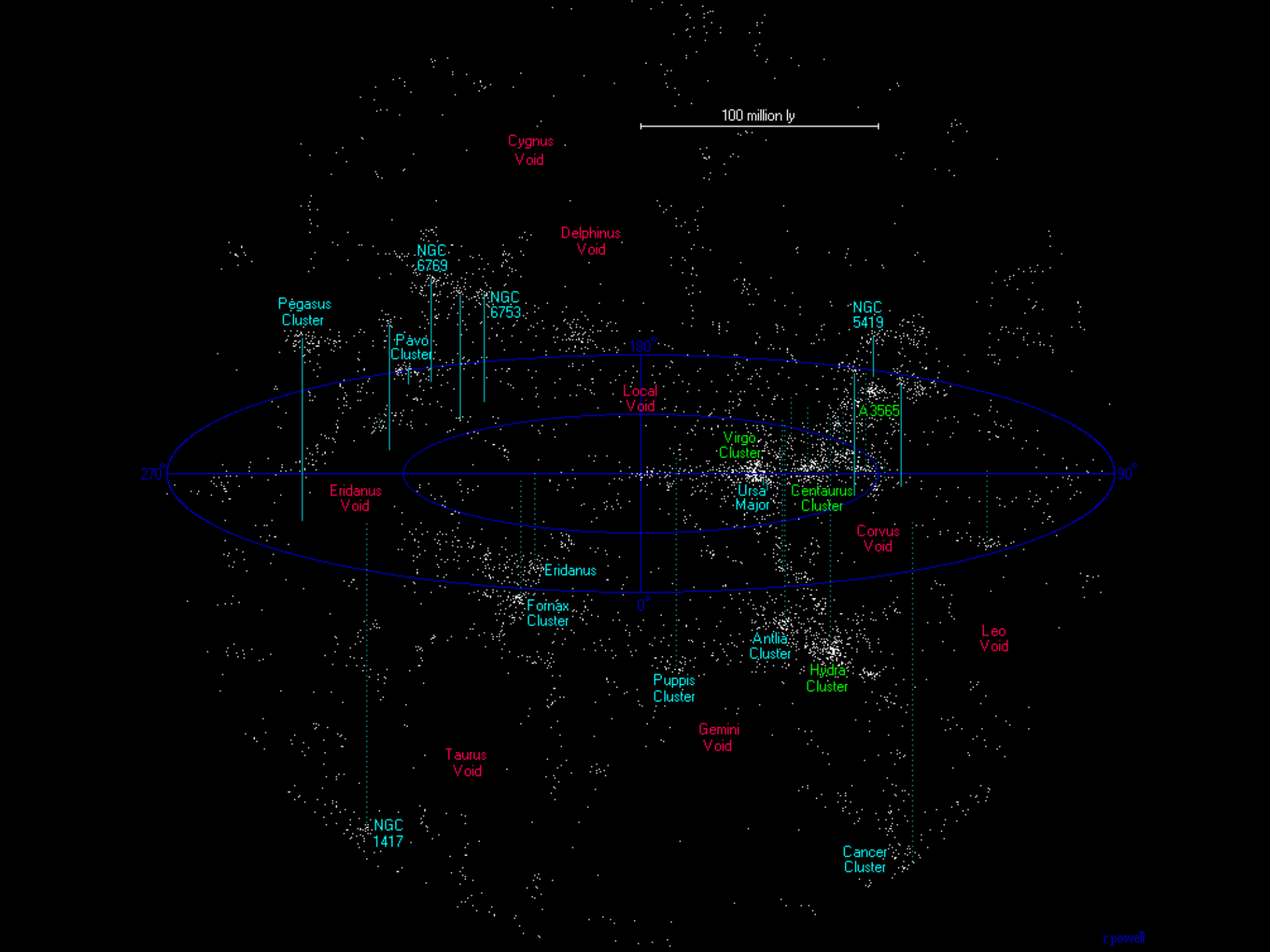

z < 0.01
0.01 < z < 0.02
0.02 < z < 0.03
0.03 < z < 0.04

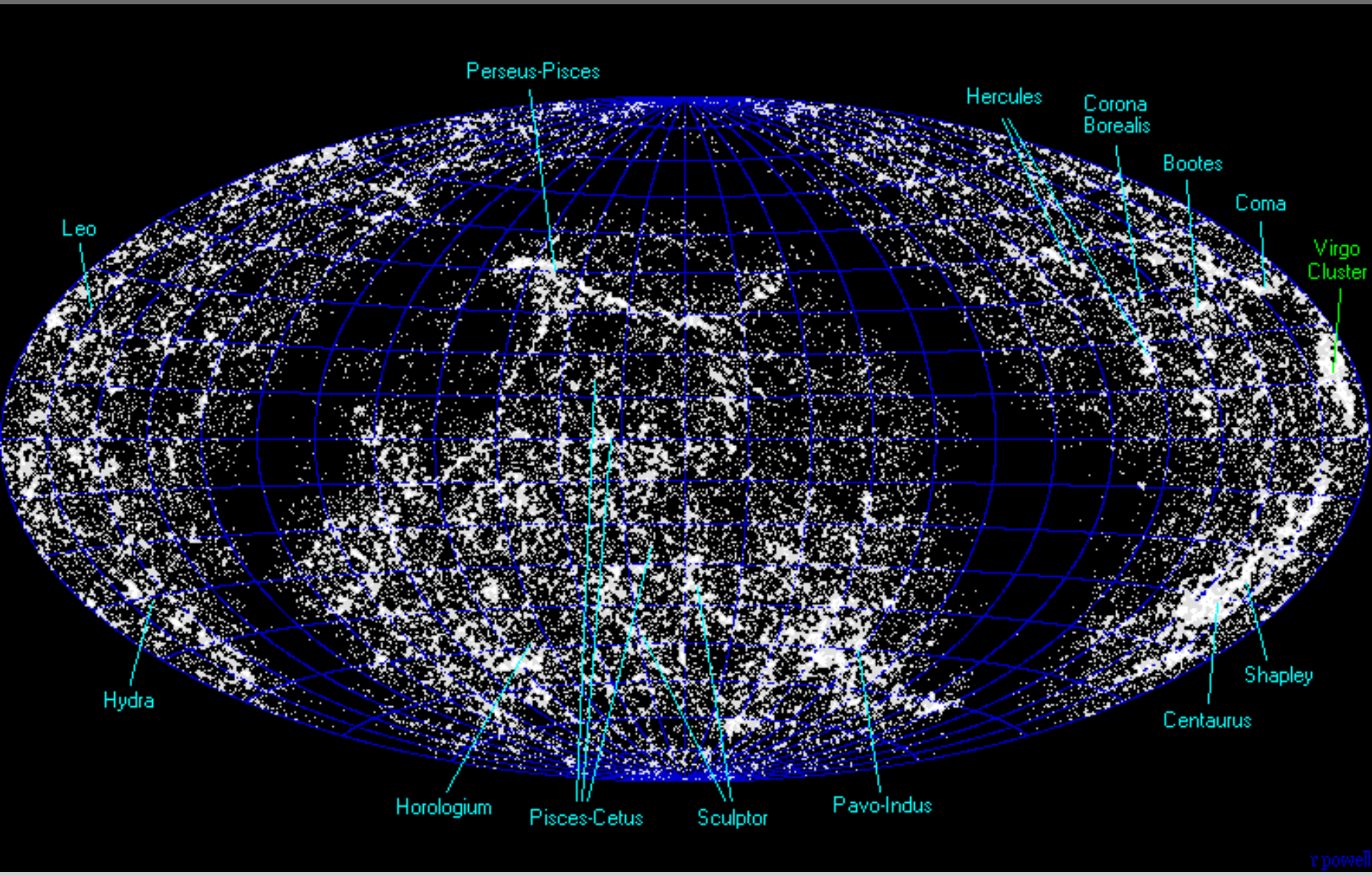


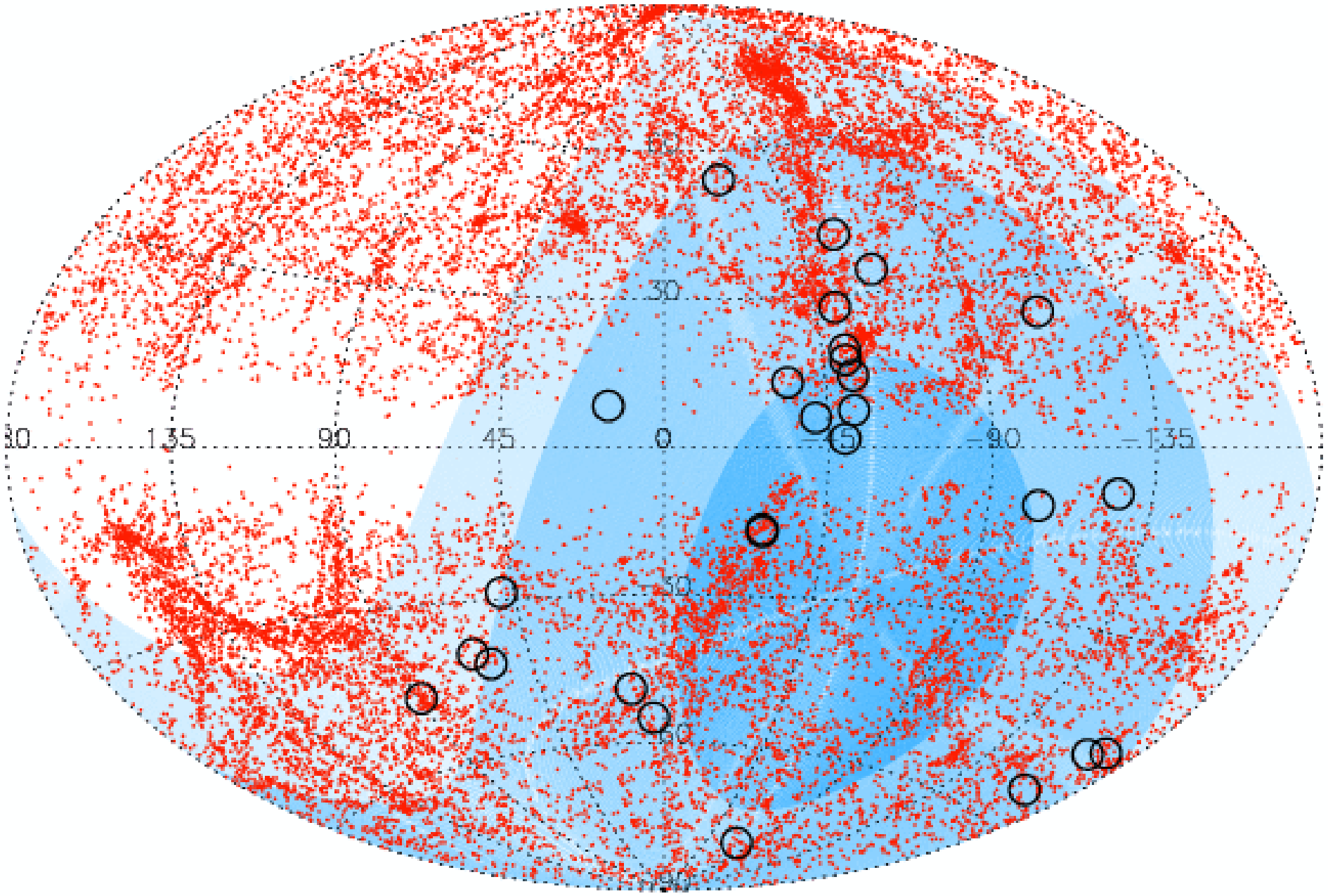
The CfA Catalog and Rich SuperClusters

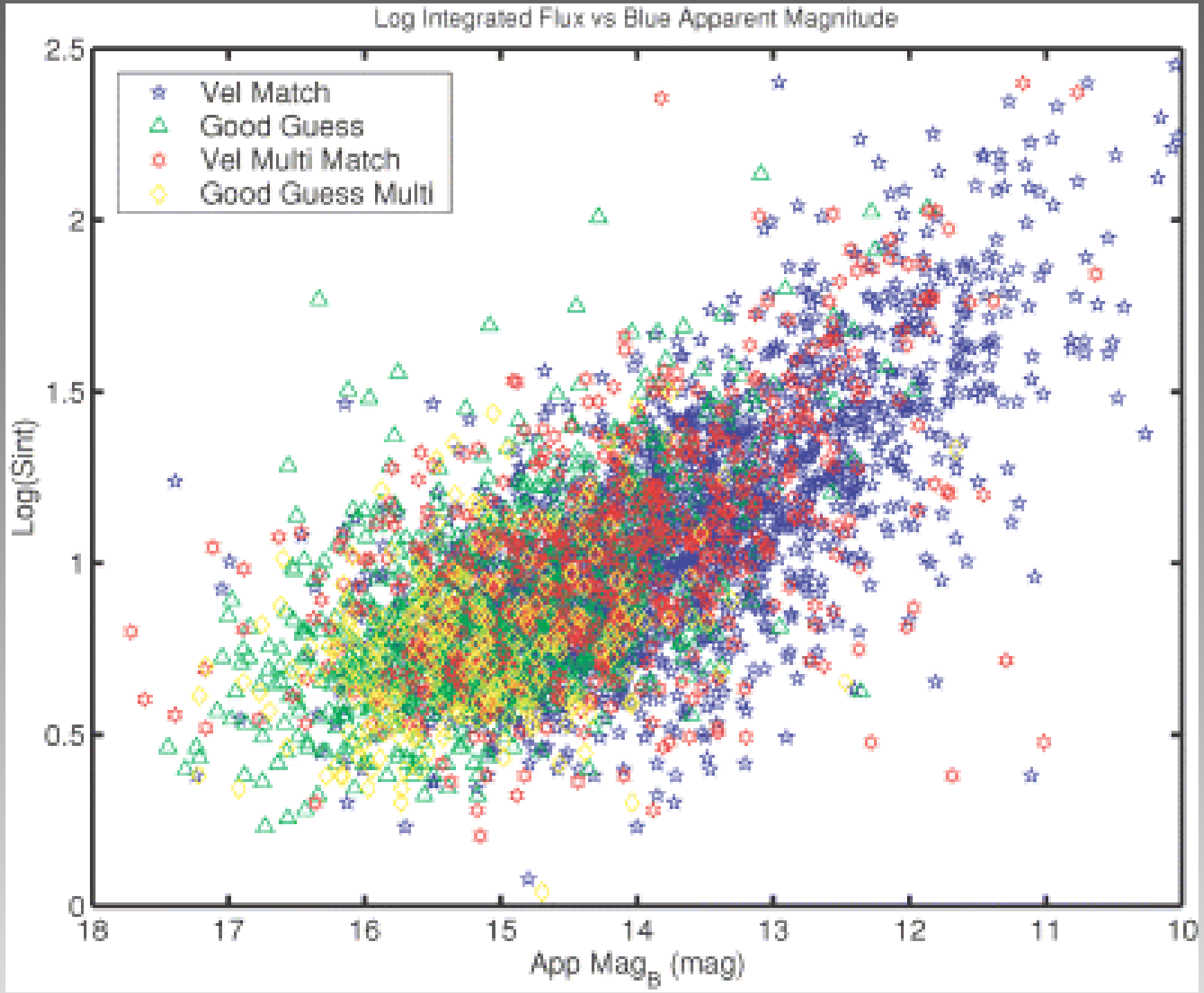
Superclusters are from Einasto et al. 1994 List (Richness>5)

Graphics by A. Kravtsov (Astro Space Center)


100 million ly
Cygnus Void
Delphinus Void
NGC 6769
NGC 6753
Pegasus Cluster
Pavo Cluster
NGC 5419
180°
Local Void
A3565
Virgo Cluster
270°
90°
Eridanus Void
Ursa Major
Centaurus Cluster
Corvus Void
Eridanus
Fornax Cluster
0°
Antlia Cluster
Leo Void
Hydra Cluster
Puppis Cluster
Gemini Void
Taurus Void
NGC 1417
Cancer Cluster
rpowell


Perseus-Pisces
Hercules
Corona Borealis
Bootes
Coma
Leo
Virgo Cluster
Hydra
Shapley
Centaurus
Horologium
Pisces-Cetus
Sculptor
Pavo-Indus
rpowell


30
135
90
45
0
−45
−90
−135
30
0
−30
−90


Log Integrated Flux vs Blue Apparent Magnitude
Vel Match
Good Guess
Vel Multi Match
Good Guess Multi
Log(Sint)
App Mag$_B$ (mag)
2.5
2
1.5
1
0.5
0
18
17
16
15
14
13
12
11
10