The ultra-high energy cosmic rays image of Virgo A

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Motivation: *How does look an UHECR image of a point source for light and heavy nuclei?*

Assumptions: UHECRs are charged particles, sources of cosmic rays above 50 EeV are nearby and strong radio sources

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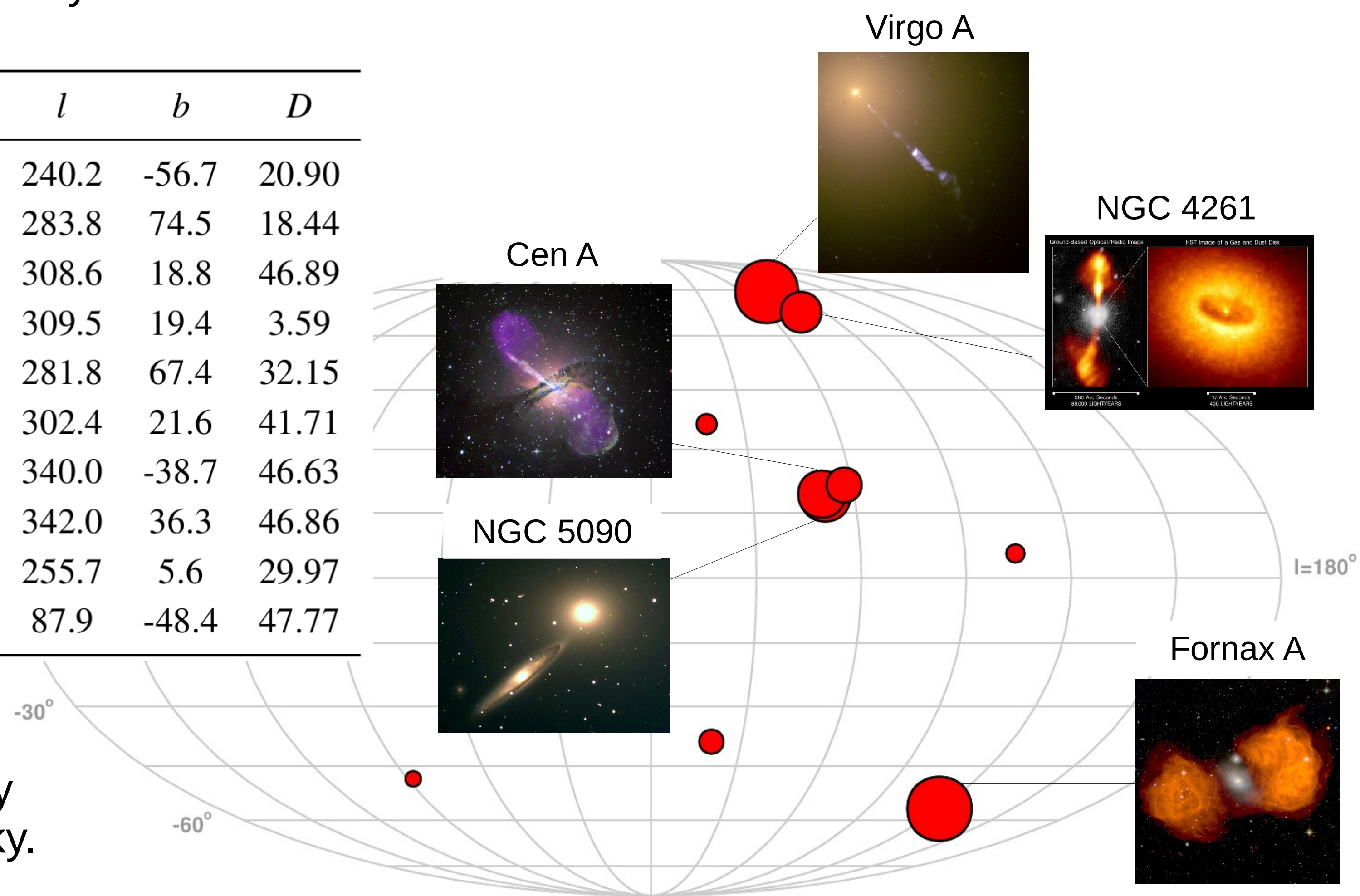
Source candidates

Radiogalaxies are suitable candidates for sources of UHECRs

10 brightest radiogalaxies in the local universe
- Catalogue by van Velzen et al., A&A 544 (2012) A18
- Distance less than 50 Mpc
- Synthetic luminosity at 1.1 GHz

Name	α	δ	l	b	D
Fornax A	50.7	-37.2	240.2	-56.7	20.90
Virgo A	187.7	12.4	283.8	74.5	18.44
NGC 5090	200.3	-43.7	308.6	18.8	46.89
Cen A	201.4	-43.0	309.5	19.4	3.59
NGC 4261	184.8	5.8	281.8	67.4	32.15
NGC 4696	192.2	-41.3	302.4	21.6	41.71
IC 5063	313.0	-57.1	340.0	-38.7	46.63
NGC 5793	224.9	-16.7	342.0	36.3	46.86
NGC 2663	131.3	-33.8	255.7	5.6	29.97
NGC 7626	350.2	8.2	87.9	-48.4	47.77



They are not uniformly distributed over the sky.

Simulations

The CRT code was used for tracking particles in Galactic magnetic field (GMF), energy losses are not included

M.S. Sutherland, et al., APh 34 (2010) 198–204

We used forward-tracking, i.e. from outside the Galaxy towards the Earth

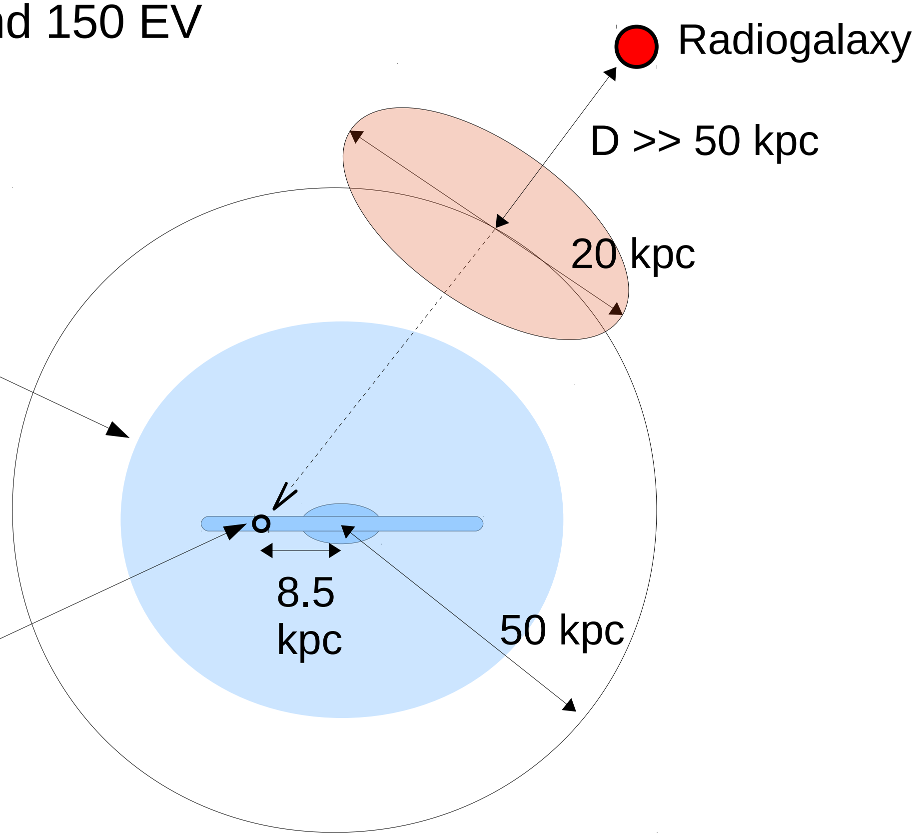
A parallel beam of randomly generated particles pointed towards the Earth was generated in a disk of 20 (or 10) kpc diameter at the Galacto-centric distance 50 kpc.

The studied magnetic rigidity was between 1 and 150 EV and the spectral index was 1

A large-scale regular GMF model

A turbulent random component was also included (see later)

A detector is a disc of 0.1 kpc radius (oriented perpendicular to the particle velocity vector In each step) at the position of the sun



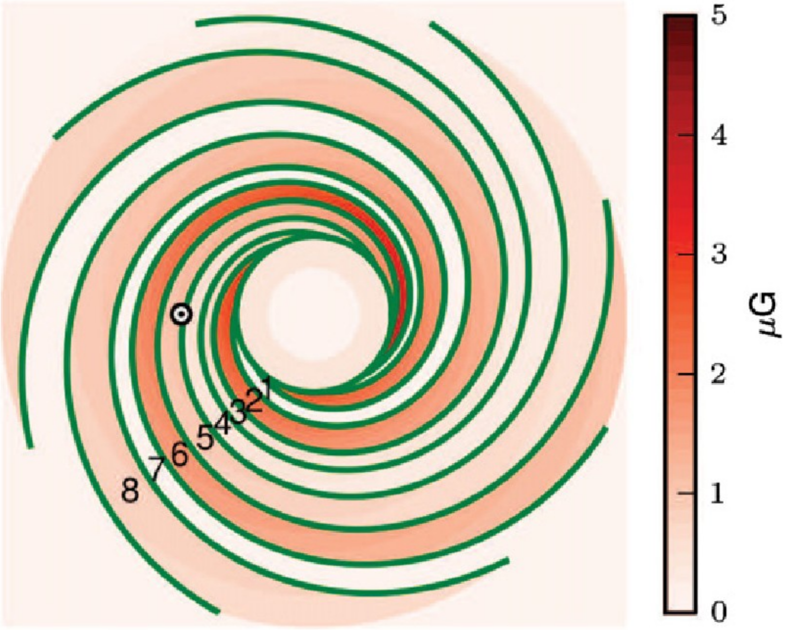
Regular GMF field

Down to what rigidity does the angular deflection follows 1/R behaviour?

The magnetic rigidity R = E / Z between 1 and 150 EV

The magnetic rigidity 10 EV corresponds to
10 EeV for protons, 60 EeV for carbon and 140 EeV for silicon nuclei

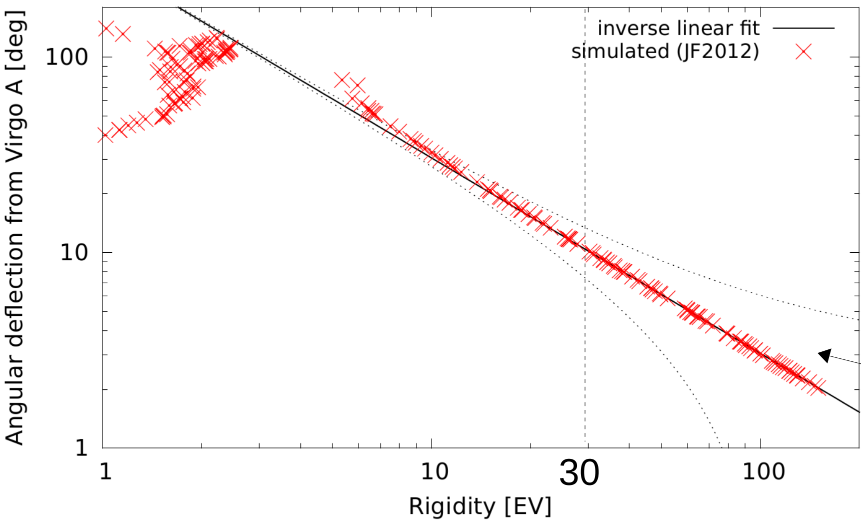
Only JF12 model in this talk
- Described in R. Janson & G. Farrar, ApJ 757 (2012) 14
- Contains a disk field component (azimuthal 3-5 kpc and eight log. spirals 5-20 kpc), a toroidal halo and an out-of-plane (X-field) component

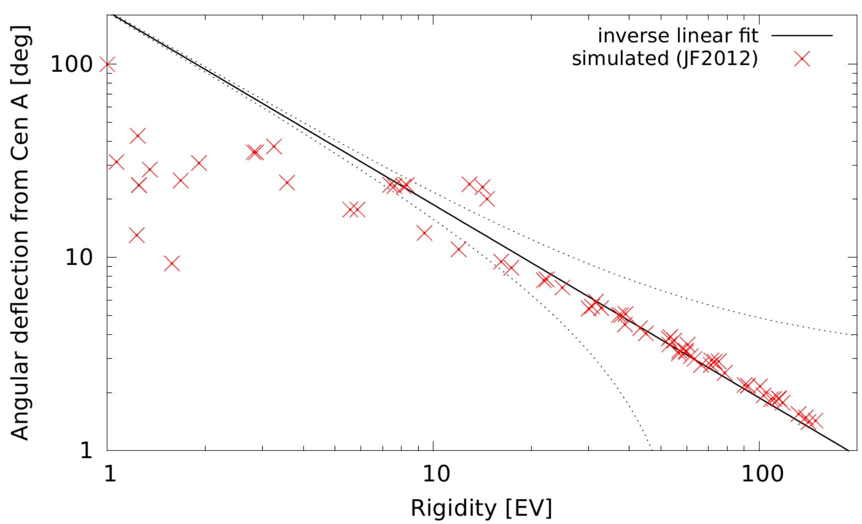


Angular deflection

In a uniform magnetic field the angular deflection is inversely proportional to the magnetic rigidity $\theta = K / R$

Results of our simulations above 30 EV were used to obtain the constant K.

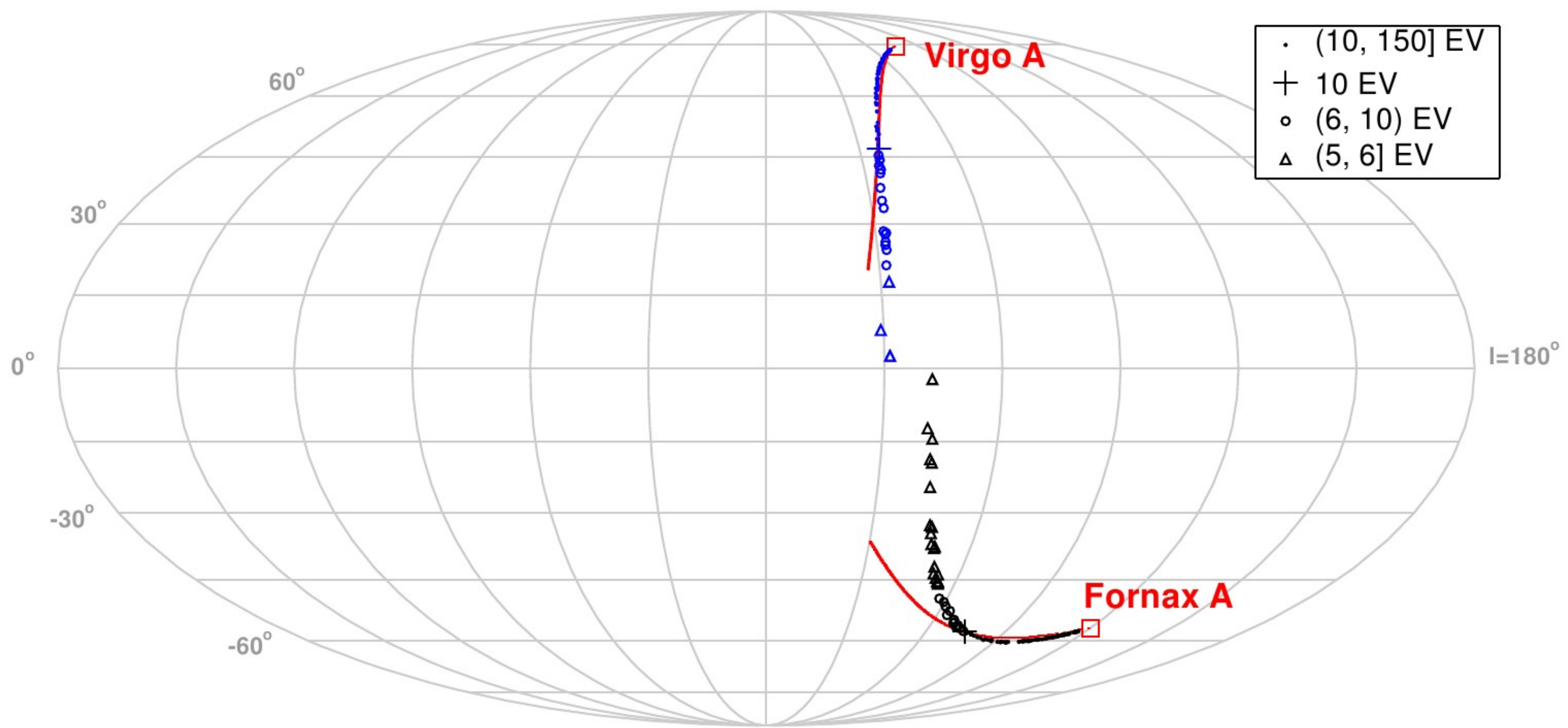




The magnetic rigidity, where arrivals deviate more than 3° from 1/R

Radiogalaxy	K (° EV)	R_{3° (EV)
Fornax A	242	4
Virgo A	306	7
NGC 5090	183	16
Cen A	191	15
NGC 4261	274	8
NGC 4696	149	12
IC 5063	330	10
NGC 5793	370	14
NGC 2663	192	10, 25
NGC 7626	413	10

Fornax A and Virgo A (5 – 150 EV)

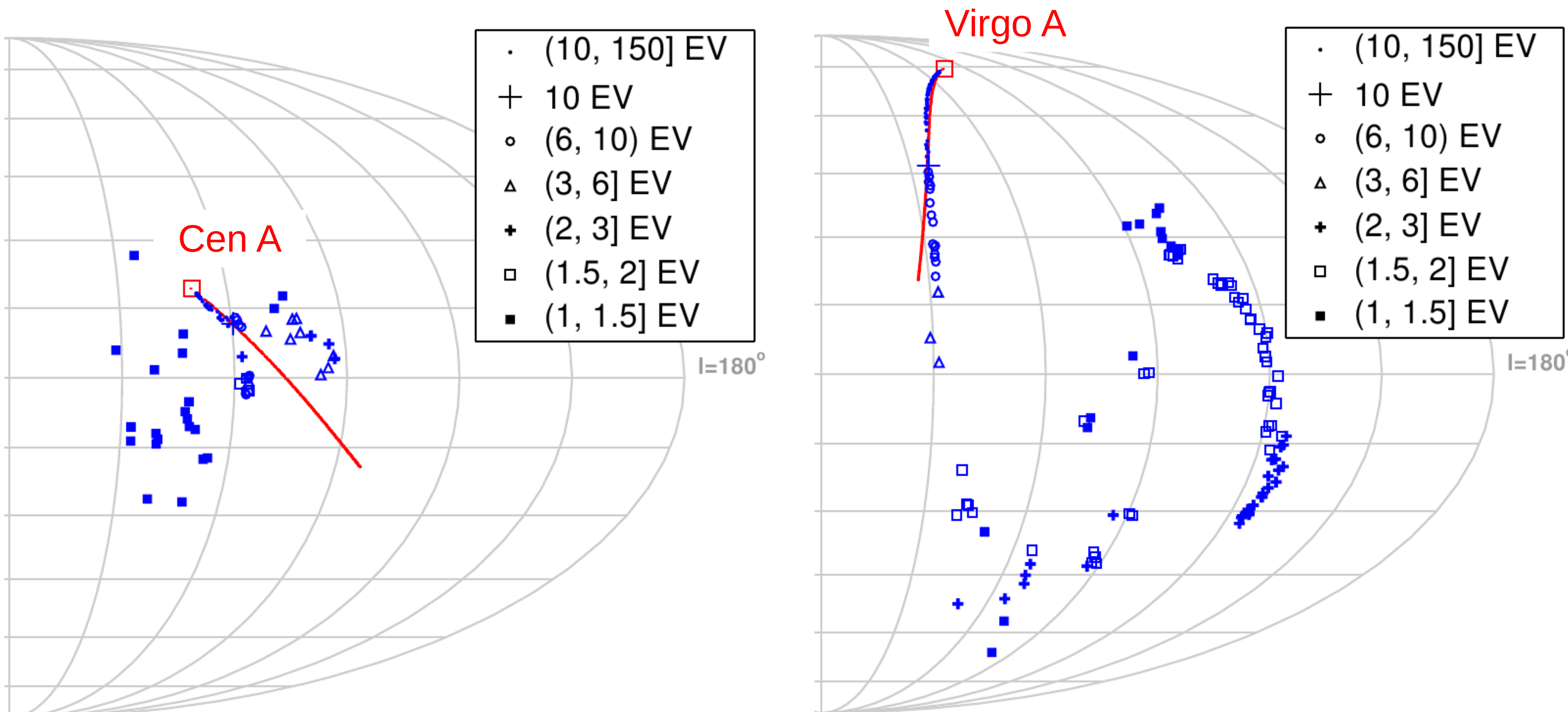


Red line shows an arc 60° long defined by a source and 10 EV event.

Even if arrival directions of particles from Fornax A follow 1/R behaviour they are not along an arc.

Virgo A is the best candidate for our further study.

Cen A and Virgo A (1 – 150 EV)



Turbulent magnetic field

The small-scale random magnetic fields included to the large-scale regular GMF to obtain more realistic description of arrival directions.

CRT: boxes containing a grid of field magnitudes that follow a Kolmogorov spectrum. (For more details see A. Keivani et al., APh 61 (2014) 47.)

Four different realisations and each realisation is described by eight parameters:

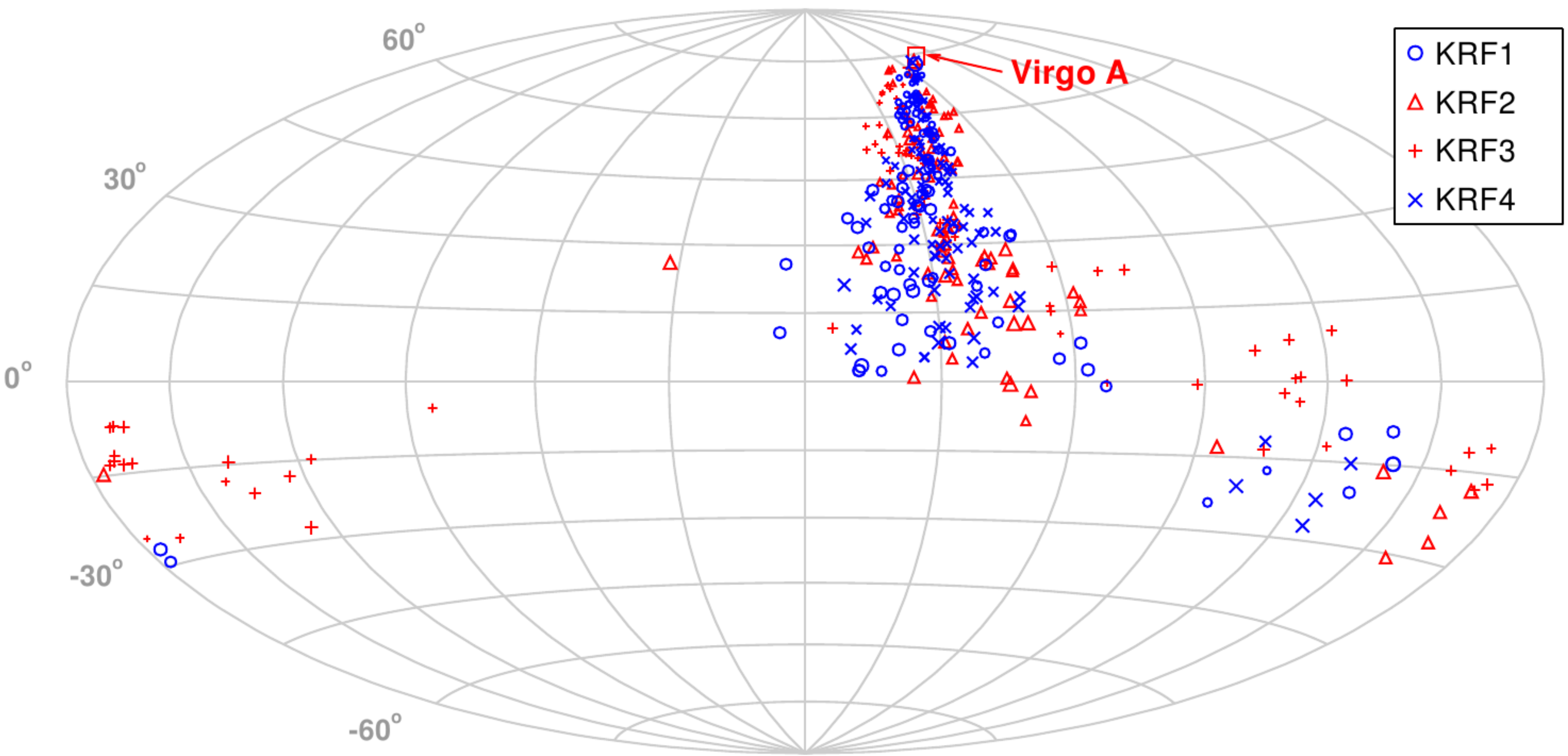
- number of divisions within a box in each space coordinate axis (NX, NY, NZ)
- length of each side of a KRF box (LX, LY, LZ)
- the minimum and maximum wavelengths (LMI and LMX)

Realisation	NX, NY, NZ	LX, LY, LZ (kpc)	LMI, LMX (pc)
KRF1	256, 256, 256	5.12, 5.12, 5.12	5, 100
KRF2	256, 256, 256	5.12, 5.12, 5.12	5, 100
KRF3	256, 256, 256	5.12, 5.12, 5.12	5, 512
KRF4	256, 256, 256	2.56, 2.56, 2.56	5, 100

The magnetic field was scaled by the JF12 r.m.s. random field strength.

Configuration was the same for all particles simulated in a given realisation.

Arrivals in regular + turbulent field



Four realisations of KRF fields + JF12

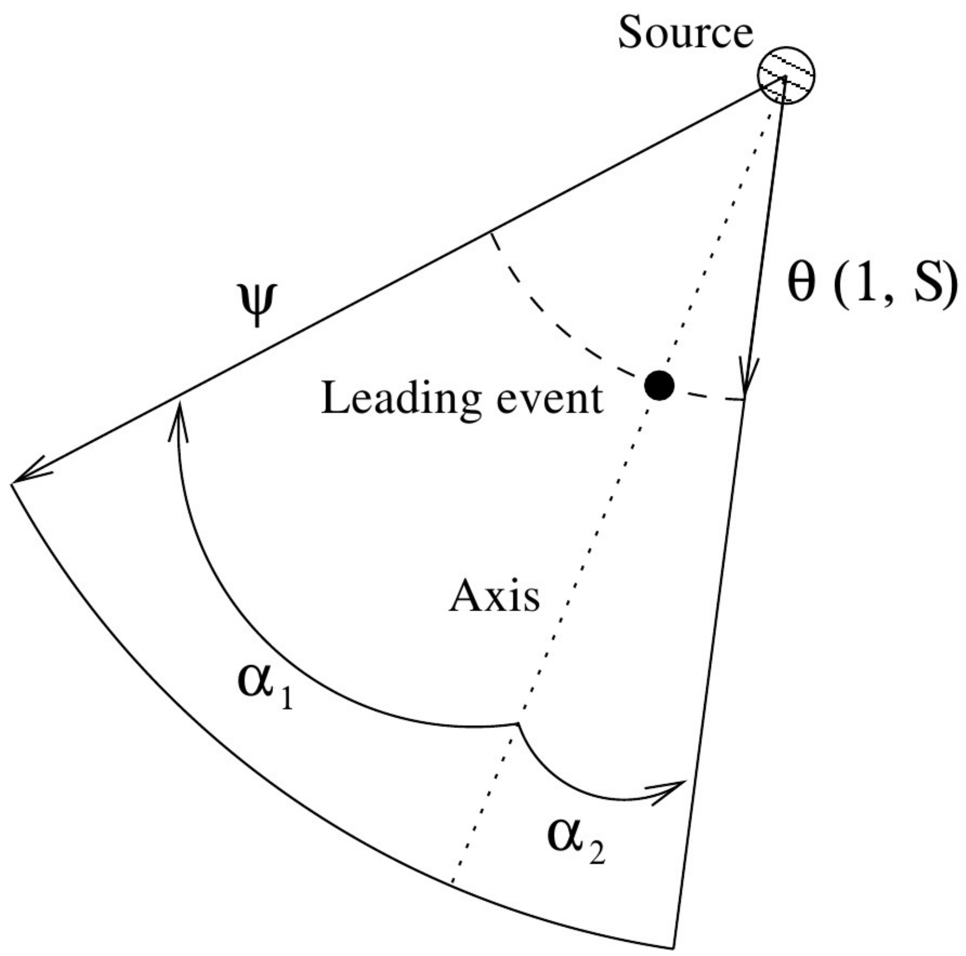
The magnetic rigidity was 5-150 EV and the spectral index 3.

The lower limit of the rigidity was set at 5 EV to avoid trajectories crossing the Gal. plane.

Simulations were stopped when at least 90 hits were reached.

Triangular area

We propose to describe the image of Virgo A with a triangular area

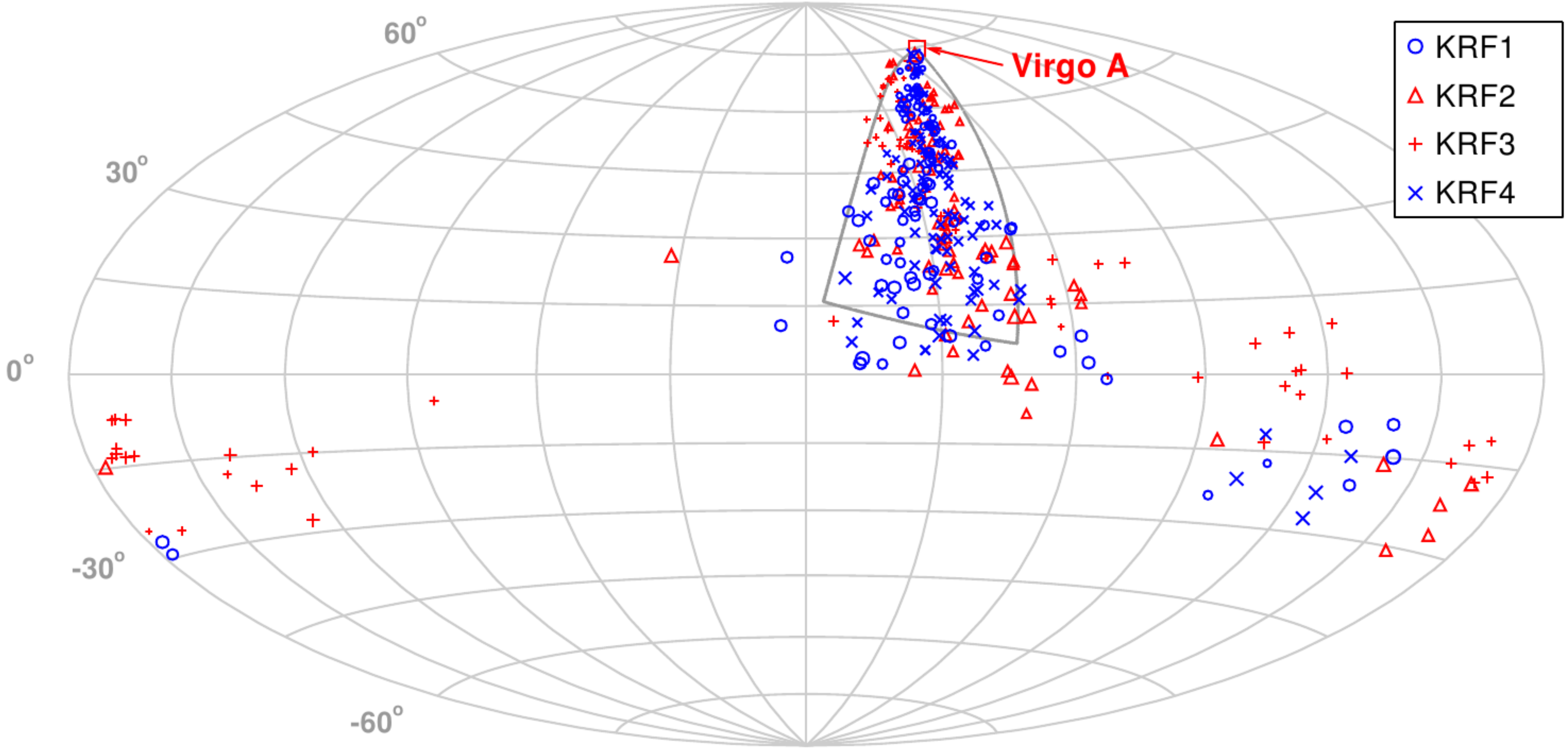


Similar idea has been suggested by G. Giacinti & D. Semikoz in PRD 83 (2011) 083002

Triangular area for Virgo A

The same triangular area for all four realisations:

- the leading event is 10 EV event from the simulation w/ only the JF12 model
- $\psi = 70°$ and both $\alpha_1 = \alpha_2 = 25°$



The majority of events above 6 EV in our four realisations lies inside the triangular area.

Conclusions

Simulations of arrival directions from various UHECR source candidates have been performed.

Events from Virgo A propagated through the large-scale GMF arrives along an arc over large fraction of the sky and wide range of the rigidity.

The angular deflection may be described with the relation $\theta = 306$ (° EV) / R (EV)

Arrivals are significantly smeared by the turbulent magnetic field component.

By including both GMF components we get the UHECR image of Virgo A of rather a triangular than circular shape.

Information about mass composition of individual events is of the utmost importance.