Puzzles of the Cosmic Ray Anisotropy

Erlykin A.D., Machavariani S.K., Wolfendale A.W.

P.N.Lebedev Physical Institute, Moscow, Russia
Department of Physics. Durham University, Durham, UK
Basic characteristics of the anisotropy:

A – amplitude of the first harmonic

\( A \)

\( \Phi \) – phase: equatorial coordinate of the direction to the \( I_{\text{max}} \)
1964

Ginzburg V.L. and Syrovatskii S.I.
‘Origin of Cosmic Rays’

A < 1 %
1984

‘Astrophysics of Cosmic Rays’
by Berezinsky V.S., Bulanov S.V., Ginzburg V.L., Dogiel V.A., Ptuskin V.S.

\[ A < 0.1\% \text{ and rises with energy} \]
Present time
PUZZLE 1: inverse anisotropy

Inspite of that most cosmic ray sources (SNR, Pulsars etc) are in the Inner Galaxy cosmic rays come preferentially from the Outer Galaxy
Spiral arms of the Galaxy

Norma Arm
Scutum-Crux Arm
Sagittarius Arm
Orion Arm
Perseus Arm
Cygnus Arm

Sun
Experimental data used for the fit of the radial SNR distribution

Fits of the SNR radial distribution

In the study of the anisotropy it is better to use the distributions which reproduce local environment.
Propagation in the heterogenous medium

\[ \alpha = 0.75, \mu = 0.1 \text{ pc}^{-\alpha}, \lambda = 6 \text{ pc} \]
Possible explanation of the Puzzle 1:

Inverse anisotropy is a ‘local’ phenomenon, which is caused by the ‘reflection’ of CR from a nearby region of higher density interstellar medium.
Puzzle 2: irregular behaviour of A and Φ
At $E > 10 \text{TeV}$ $A$ starts to fall down, at $E \sim 200 \text{ TeV}$ has a minimum and after $E \sim 1000 \text{ TeV}$ it rises again. $\Phi$ changes to the opposite one at $E > 100 \text{ TeV}$.
Possible explanation: Galactic Halo (proposed by V.L. Ginzburg) and Single Source (proposed by EW)

termination shock

R = 100 kpc

Galactic Disk

Halo

Age = $10^{10}$ y
Possible role of isotropic Halo and Single Source in the Outer Galaxy
Present time
Questions:
* Do the Halo and the Single Source really exist?
* Is the CR energy spectrum harder in the Halo than in the Disk?
* To what extent are simplified assumptions, used in this scenario, reasonable?
PUZZLE 3:

• What is the Single Source?
Single Source Model of the Knee
One does NOT look in the sky for a direction of the maximum cosmic ray intensity, but that of the maximum difference in the characteristics of extensive air showers coming from the opposite directions.

*Sunrise or Sunset*
Search of the Single Source

Vela
Location of the Vela cluster in the Galaxy
Environment of the Solar System

(nearby 500 pc)
Morphology of the Vela Cluster

Vela Jr

pulsar B0833-45 & Vela X PWN
Minimum of the anisotropy amplitude in the PeV region can be caused by the contribution of the Single Source. The most likely candidate for the Single Source is the Vela Cluster
CONCLUSIONS

There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy.

W. Shakespeare, Hamlet