Cosmic Ray Anisotropy and Magnetic Reconnection in the Heliospheric-Tail

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ABSTRACT: Cosmic ray detected on Earth have been observed to have an energy-dependent anisotropy in arrival direction of the order of $10^6$ – $10^8$. The origin of such anisotropy is not known but it is believed to provide a probe into the properties of the local interstellar magnetic field at distance scales proportional to the cosmic ray’s gyro-radius. At sub-TeV energies (i.e. below $10^4$ eV), the cosmic proton’s gyro-radius is of the order of the heliospheric size ($\approx 100$ AU). In addition, this energy range of cosmic rays arrival direction is observed toward the region of the heliospheric-tail (tail-in anisotropy), and it appears to be modulated in time. Depending on the location of Earth relative to推介会s, there might be a significant effect on the energy of a few TeV, which may be due to the large scale structure of the interstellar magnetic field. The coincidence of this excess with the direction of the heliospheric-tail and its limited angular size ($\approx 10^4$) might suggest this to be the high energy residual of the tail-in anisotropy observed at lower energy. We discuss the possibility that magnetic reconnection in the heliospheric-tail might be the origin of such an observation.

COSMIC RAY ANISOTROPY

The first comprehensive observation of a large angular scale anisotropy in the sub-TeV cosmic rays arrival direction was reported by Nagashima et al. [NP09].

The anisotropies feature persist in the multi-TeV region, where small angular scale characteristics seem to overlap to the smooth broad modulation of the cosmic rays arrival distribution.

The Tibet ASy array [A06] measured the cosmic rays arrival direction distribution at different median energies in the multi-TeV region. While the loss-cone deficit structure does not seem to change with energy, the tail-in excess seems to get thinner and to show smaller angular scale structures at higher energy.

The MILAGRO coll. [A08], with techniques used in γ-ray detection, filtered out all anisotropy features wider than $30^\circ$ and revealed two localized regions of multi-TeV (i.e. $1-10$ TeV) cosmic rays.

The most significant region A ($12^\circ$) coincides with the direction of the heliospheric-tail (the black dot in figure).

ANGULAR SCALE OF COSMIC RAY ANISOTROPY

A localized excess of multi-TeV cosmic rays is more likely produced by a perturbation in their directional propagation that occur nearby, with respect to their gyro-radius. Multi-TeV cosmic rays have relatively small gyro-radius. They are strongly bent by the magnetic field and experience energy hardening propagating processes.

Sub-TeV cosmic rays hardly have small angular scale structures even if nearby effects are responsible of their origin. Scattering in magnetic field is more significant at low energy.

It is likely that the broad sub-TeV tail-in excess and the multi-TeV localized region are manifestations of the same local phenomenology at different energies.

We propose that the broad sub-TeV tail-in excess and the localized multi-TeV excess are caused by acceleration from magnetic reconnection in the heliospheric-tail.

MAGNETIC RECONNECTION IN THE HELIOSPERIC-TAIL

The 11-year solar dynamo cycle generates magnetic field of opposite polarities. As the magnetic field is carried away by the ~ 450 km/sec solar wind, the reversed field regions are accumulated in the magneto-tail region. This is where we reconnection is expected to occur. Turbulence is also expected to exist, which affects reconnection speed, i.e. the speed at which in-flowing magnetic field is annihilated by ohmic dissipation.

In the Sweet-Parker model of reconnection [SS8, PS7], the outflow is limited within the width of transition zone A, which is determined by ohmic diffusivity.

In the Lazarian-Vishniac [LV99] model of reconnection of weakly stochastic magnetic field, the outflow is limited by the diffusion of magnetic field lines, which depends on turbulence.

Reconnection rate is consequently increased by the turbulence effect of many magnetic field lines. In particular reconnection speed is close to the turbulent velocity in the fluid.

More detailed calculations should provide a more accurate estimation of the magnetic field intensity and size scale. In fact, we can predict that, unless some process of field amplification occurs in the turbulent heliospheric-tail, the acceleration of the cosmic rays of energies much larger than 10 TeV is unlikely possible with magnetic reconnection. This is about the energy where the MILAGRO collaboration observes an apparent cut-off of the the cosmic rays from the localized regions [A08].

REFERENCES


DISCUSSION AND SUMMARY

We attempt to explain the cosmic ray excess in the range from 50 GeV to 1-10 TeV as arising from magnetic reconnection in the heliospheric-tail. The direction of the multi-TeV localized excess of cosmic rays seems correlated to the sites of acceleration via reconnection. The lower energy particles, on the other hand, can be accelerated over extended regions of the heliospheric-tail and they are also expected to experience more scattering prior to reaching the observer at the Earth. This would give rise to a broad excess of cosmic rays toward the heliospheric-tail [L10].

The high energy cut-off observed corresponds roughly to what is expected from the reconnection-driven acceleration. It is virtually impossible to explain the acceleration of higher energy particles with this mechanism, unless appealing to some hypothetical magnetic field acceleration processes.

This study has still exploratory character, as the quantitative description of mechanisms of cosmic ray acceleration in the reconnection regions are still at its infancy. Even though the models of acceleration in the reconnection regions require more study, we think that the proposed scenario has more realistic grounds than the astrophysical interpretations (see e.g. [S08] and [D08]).