Solar Modulation of galactic cosmic ray

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Abstract: In studying solar modulation of galactic cosmic rays, a modulation parameter ϕ is often used, whose value vary by a factor of more than 2 from the solar maximum to the solar minimum, reflecting the effects of different levels of solar activities on the modulation. Simple and elegant, this approach however, based on the assumption that the current of GCRs is small and can be taken to be zero, leading to a steady state solution of the transport equation. Recently, Wiedenbeck et al, using data from CRIS/ACE and neutron monitor, found that, for the declining phase of the solar cycle 23, the neutron monitor counting has been at a level of 4 percents higher than during the period when ϕ had comparable values during the rising phase of solar cycle 23. In this paper, we address this differences of neutron monitor counting rates (or alternatively, the difference of ϕ themselves) between the rising phase and declining phase of solar cycle. We show that the modulation of low energy GCRs is more sensitive to the phase of the solar cycle than high energy GCRs. By solving the transport equation using a new approach, we identify the influence of the solar cycle phase on the transport of galactic cosmic ray. We compare our simulation with ACE/CRIS observations.

Introduction

The magnetic field carried out by solar wind strongly modulates the spectrum of GCR in the inner heliosphere. Since the solar activity is periodic, one thus expect the modulation will be a function of time. Using Cosmic-Ray Isotope Spectrometer (CRIS) on the Advanced Composition Explorer (ACE) spacecraft, GCR measurements of various elements (from Li through Zn) in the energy range ~ 50 to ~ 500 MeV/nuc (close to the peak of the energy spectrum) are obtained for the solar cycle 23 [5].

In investigating the modulation effect, [5] adopted a simple force-free model [2]. In this model, the process of diffusion, convection, drift and adiabatic energy loss of cosmic rays are integrated into a single modulation parameter ϕ (MV), which describes the energy loss of a GCR particle coming in from the solar wind boudary. This simple model assumes a quasi-state soluation of the transport equation [4]

$$\frac{\partial f}{\partial t} + V_{sw} \cdot \nabla f - \nabla \cdot (\kappa \cdot f) - \frac{1}{3} \nabla \cdot V_{sw} \frac{\partial f}{\partial lnp} = 0. \tag{1}$$

By requiring the current [1]

$$S = CVU_p - \kappa \cdot (\partial U_p / \partial x) \tag{2}$$

equuals to zero (where $C = -\frac{\partial lnf}{\partial lnp}$ is the Compton-Getting factor), one obtains the force field soulation,

$$\int_p^{p*} \frac{\kappa_2 \beta}{p'} dp' = \int_r^R \frac{V_{sw}}{3\kappa_1} = \phi(r) \tag{3}$$

where $\kappa(r, p) = kappa_1(r) \kappa_2(P) \beta$ is assumed.

Physically, $Ze\phi$ can be regarded as a loss in potential energy when a particle moves in potential from R to r. [5] have used data from CRIS/ACE and neutron monitor for the solar cycle 23 and found that, for the declining phase of the solar cycle 23, the neutron monitor counting has been at a level of 4 percents higher than during the period when ϕ had comparable values during the rising phase of solar cycle 23. This is the so called hesterisis effect. Clearly, the rising and declining phase are experiencing different solar activity histories, one is going into solar maximum and the other is going into the solar minimum. Because of the presence of solar cycle, we expect the modulation will show a time dependent effect. In this paper, we consider how one can describes the time variation of ϕ using a simple Monte-Carlo simulation.

Quasi-particle approach

We consider here the simplest geometry case i.e. spherical symmetric and we ignore $\kappa_{\theta,\theta}$ and $\kappa_{\theta,r}$ (thus drift). We then translate the diffusion equation to a suitable form, which allows us to perform a single quasi-particle Monte-Carlo simulation. We then follow the motion of this quasi-particle and obtain f at a later time and location (1 AU) by summing over all individual quasi-particles. Using this approach, a time-varying solar activity is modeled by a change of κ. In this work, we assume κ varies as a cosine function in time [3].

$$\kappa = (\kappa_{>} + \kappa_{<})/2. + (\kappa_{>} - \kappa_{<})/2.cos(t/T) \quad (4)$$

where T is the solar activity period.

Conclusion

We have investigated the time variation of the GCR modulation using a simple Monte-Carlo simulation. By introducing a "quasi-particle" which describes how f, the phase space distribution function, moves in the phase space of (r, p), we can follow the gradual changes of GCR modulations as a function of t and r. We believe the hesterisis effect can be well accounted by the solar cycle.

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