Sunspot Cycle 24 Galactic Cosmic Ray Modulation

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Abstract: Galactic cosmic ray (GCR) modulation at earth orbit for the sunspot number (SSN) cycle 24 is studied, using data from the global network of detectors and the balloon measurements at high latitudes in Russia. The observed GCR modulation is modest compared to previous cycles. The tilt angle of heliospheric current sheet is close to its maximum value for a cycle. The solar polar field reversed in one hemisphere nearly a year ago but has not reversed yet in the other hemisphere. GCR modulation is close to its maximum value. A preliminary determination is made of the rigidity dependence of the observed modulation using data from some neutron monitors of the global network and the directional muon telescopes at Nagoya, Japan. It is a power law with an exponent -1.35, a bit steeper than reported earlier using balloon and neutron monitor data only.

Keywords: sunspots, galactic cosmic rays, 11-year modulation, rigidity-dependence

1 INTRODUCTION

Global network of neutron monitors (NMs), directional muon telescopes (at surface and underground sites), and detectors carried aloft on balloons have been monitoring the galactic cosmic ray (GCR) intensity for over seven decades [1] (and references therein). Several penetrating physical insights have been obtained into the nature of the physical processes operating in the heliosphere, driven by a variety of phenomena initiated by diverse modes of solar activity. The sustained effort has led to an appreciation of the pivotal role played by the interplanetary magnetic field (IMF) intensity (B) in modulating GCRs at earth orbit and in near heliosphere [2, 3, 4, 5, 6, 7].

The smooth SSN minimum was reached in December 2008 and the onset of cycle 24 ensued. It has risen slowly to its peak in May 2013, giving rise to 11y GCR modulation. We study the characteristics of the descending phase of GCR intensity using data from the global network of detectors and balloon measurements of GCR ions in Russia, the observed changes in the solar wind velocity V, B, and the tilt angle (TA) of the heliospheric current sheet (HCS).

2 OULU NM DATA

Figure 1 shows a plot of the monthly mean hourly Oulu NM (OU/NM) rates normalized to 100% in May 1965 and smooth SSNs for 1965-2013 January. The following points are noted.

- Five SSN cycles (19-24), two positive (A >0), two negative (A <0) and parts of 19 and 24, are covered. For A >0, the polar field in the northern hemisphere points out of the sun.
- The GCR intensity recovers to a higher level for A <0 epoch, but the recovery for cycle 23 (A <0 epoch) is to the highest level ever since NMs began operating in 1950s [1].
- The inverse correlation between the GCR intensity and the SSNs stands out [8]; in 2009, the solar activity reached a deep and prolonged minimum for cycle 23.

Ahluwalia [9] argues that the physical basis of this correlation arises from the fact that SSNs and B are very closely related (cc = 0.94).

- An arrow at the right hand top corner marks the sharp onset of modulation in January 2010. The decrease in GCR intensity after three years is modest compared to earlier cycles. Ahluwalia et al. [10] discuss the subtle features of 11y modulation for prior cycles. We describe the solar-terrestrial relations for cycle 24 GCR modulation.

3 SOLAR WIND DATA

The following features are noted from Figure 2; it shows a plot of solar wind parameters for October 1963 to January 2013 covering sunspot cycles 20 to the rising phase of cycle 24.

- Monthly means of V fluctuate about 450 km/s level (the horizontal dashed line).
- B values undergo solar (Schwabe) cycle variations. Also, they decrease systematically for cycle 23 to the lowest value ever (~3 nT) by the end of 2009.
- The monthly mean value of B increases sharply in Jan 2010, initiating the onset of GCR 11y modulation,
Figure 2: A plot of monthly means of solar wind parameters (B, V) for Oct. 1963- Jan. 2013 (cycles 20-24).

it then settles at a lower value (∼ 5nT) compared to prior cycles.

4 TILT ANGLE OF HCS

Figure 3 shows a plot of HCS tilt angle (average value along the line of sight) obtained from the Wilcox Solar Observatory, Stanford, CA website. The data are for each Carrington Rotation from May 1976 to January 2013 (cycles 21 to 24), m indicates SSN minimum. The following characteristics are noted.

- TA reached a minimum value (∼ 10⁹) on 13 October 2009 and increased sharply afterwards, in contrast to prior cycles. The onset of modulation did not occur until 19 January 2010, with the ejection of a fast CME on 18 Jan 2010, leading to a phase lag of nearly 3 months.

- As of January 2013, TA is very close to its maximum value for a SSN cycle. So, one expects GCR modulation to be close to its maximum value also.

- The rate of decrease of TA for the odd cycles (21, 23) is flatter than for the even cycle 22. A similar effect is seen in the recovery of the earlier GCR 11y modulation cycles [11, 12]; the recovery for the odd cycles takes longer than for the even cycles, as can be seen for OU/NM in Figure 1. Even so, the decline of TA for cycle 23 is flatter than that for cycle 21, perhaps in keeping with the fact that the minimum activity for cycle 23 persisted over several months.

5 SOLAR POLAR FIELD

Figure 4 shows a plot of the Wilcox Solar Observatory (smoothed) measurements of the polar field strengths (µT) for January 1976 to April 2013, covering two complete sunspot cycles (22, 23) and parts of other two (21, 24); the amplitude of the polar field swing for cycle 23 is distinctly smaller than that for cycle 22 and that of cycle 24 is smaller still (∼ 50% smaller). Since polar fields supply most of the heliospheric magnetic flux during the solar minimum, one is not surprised by the lowest value of B in 2009 (plotted in Figure 2). The polar field reversed in the northern hemisphere in June 2012 and that in the southern hemisphere is decaying very slowly; it is close to but has not reversed yet. So, both solar hemispheres have the same magnetic polarity at this time.

6 COSMIC RAY DATA

Figure 5 shows a plot of the annual mean hourly rate (%) for some NMs of the global network and detectors on board the balloon flights at a polar location in Murmansk region, in Russia. The detectors are characterized by a median rigidity of response Rm; 50% counting rate of the NM lies below this GCR rigidity [13]. The plots show the annual mean hourly rates for NMs at Sanae (San, 11 GV), Apatity (AP, 16 GV), McMurdo (MM, Rm = 16 GV), Newark (NE, Rm = 17 GV), Rome (RO, Rm = 23 GV), Lomnicky Stit (LS, Rm = 11 GV), Mexico City (MX, Rm = 25 GV) and Tsumeb (Tsu, Rm = 28 GV); for detectors on balloons, Rm = 3 GV. The following points are noteworthy.

- The recovery for all detectors to residual modulation for cycle 23 continued until December 2009. It is the highest recovery level observed in the last half century of NM observations [1, 14]; Cosmic Ray Isotope Spectrometer on board the Advanced Composition Explorer in orbit around the inner Sun-Earth Lagrangian point, recorded intensities of major species from Carbon to Iron 20-26% higher in late 2009 than in 1997-1998 minimum [15].

- The onset of modulation (shown by an arrow in Figure 5) started in January 2010 [1]. The rigidity dependence (preliminary) of the observed 3-year decrease (%) is shown in Figure 6 based on data for NMs and the directional muon telescopes (MTs) at Nagoya, Japan. It is a power law in rigidity with an exponent -1.35, a bit steeper than previously reported value by Ahluwalia and Ygbuhay [16] based on NM and balloon data (not available yet for 2012) only. Even so, the rigidity dependence is similar to what was observed for four prior cycles (20-23) [10, 17].
Figure 5: Annual mean hourly rate (%) are plotted for some NMs and detectors on balloon flights at a polar location in Murmansk region, Russia, for 2007-2012.

As soon as the balloon data become available for 2012, we shall update Figure 5 and 6.

7 Summary and conclusions

We have studied 11y galactic cosmic ray modulation for sunspot cycle 24, using data from the global network of neutron monitors, directional muon telescopes at Nagoya, Japan, solar wind, and solar surface features. The amplitude of modulation is appreciably smaller compared to prior solar cycles but its rigidity dependence (preliminary) is similar to what was observed for earlier cycles.

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References

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