Sun Shadow in the Solar Activity Cycle 23 Observed with the Tibet Air Shower Array

The Tibet ASγ Collaboration
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Abstract

Recent solar observations show that the Sun in the Cycle 23 is still in a high state, although the maximum activity term has passed. Since 1991, the Tibet air-shower array has been successfully operating to observe the shadowing of cosmic rays by the Sun and Moon. In this paper, we discuss about the relation between the solar activity and the variation of the Sun's shadow.

1. Introduction

The Tibet air-shower for the first time observed the displacement of Sun's shadow in the 10-TeV cosmic ray flux using 1991-1992 observation dataset with two-dimensional analysis[1]. As well known, the configuration of solar and interplanetary magnetic fields considerably changes with solar activity. We have reported that the Sun's shadow was affected by the changing solar and interplanetary magnetic fields[1,2]. Around the year of 2001, the solar activity was in a highest state of the major solar variation cycle23. We report the current result of the Sun's shadow in a high state of solar activity in comparison with the previous observation.

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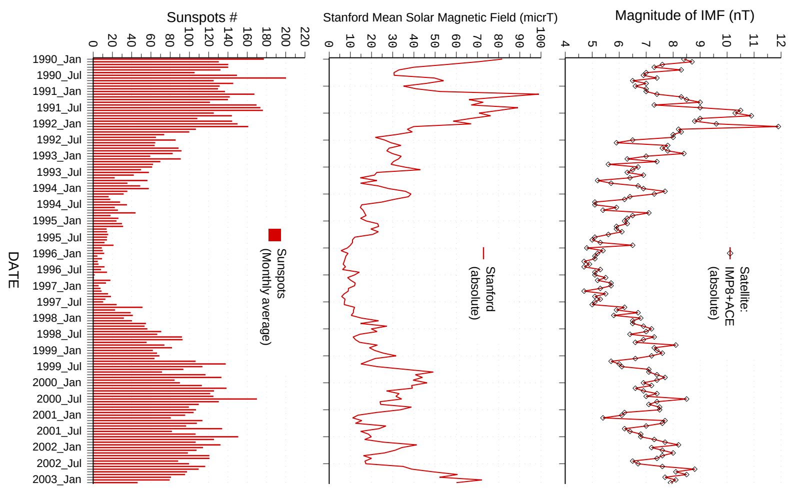

Fig. 1. Magnitude of IMF at Earth's orbit by the IMP-8 and ACE satellites [4] (right), SMSMF at the source surface [3] (center) and sunspot numbers (left) [3].

2. Solar Activity

The Sun's shadow by 10 TeV cosmic rays is strongly affected by the solar and interplanetary magnetic fields (IMF). The strength of solar magnetic field at the source surface is observed by the Stanford group as the Stanford mean solar magnetic field(SMSMF)[3]. It is well understood that the IMF is formed as a result of the transport of the photospheric magnetic field by the solar wind flowing continuously from the Sun. The strength and direction of IMF at the Earth orbit are continuously observed by IMP-8 and ACE satellites[4]. Figure 1. shows monthly variations of the strength of IMF at Earth's orbit(right), SMSMF(center) and sunspot numbers(left)[3], showing the changes of the SMSMF and IMF with the solar activity. This figure suggests that the ratio of variation of SMSMF from quiet to active phase is about two times larger than that of IMF.

3. Observation

The effective area of the Tibet array has been gradually enlarged by adding the detectors and then the Tibet-III array, consisting of 533 detectors which are placed on a lattice of 7.5 m with the area of 22000 m^2, was constructed late in 1999. This array can observe air shower events in the energy region of a few TeV and the number of events recorded with this new array becomes about 35 times that of Tibet-I array.

Hence, we can observe enough events to study a yearly variation of the position of Sun's or Moon's shadow in cosmic-ray flux. The observation periods and characteristics of the Tibet array are listed in Table 1. Note that the Tibet-II array has about 4.5 times larger effective area than the Tibet-I.

	Year	# FT	Ev. Rate(Hz)	E(TeV)	B.G. Ev. Den.(SUN)
Tibet II	1996	185	200	10	2.3×10^4
	1997	185	200	10	3.3×10^4
	1998	185	200	10	1.8×10^4
	1999	185	200	10	3.0×10^4
Tibet III	2000	497	680	3 (10)	3.8×10^4 (1.7×10^4)
	2001	497	680	3 (10)	7.7×10^4 (2.4×10^4)
	2002	497	750	3 (10)	6.9×10^4 (2.0×10^4)

Table 1. Observation period, number of detectors, event rate, mode energy and background event density (per square degrees)of the Sun's shadow. (Values in brackets: equi-Tibet-II analysis)

4. Yearly Variation of the Sun's Shadow

Figure 2. shows a yearly variation of two dimensional Sun's shadow during the period from 1996 through 2003. The contour lines in each map start from 0 σ level with 1σ step.

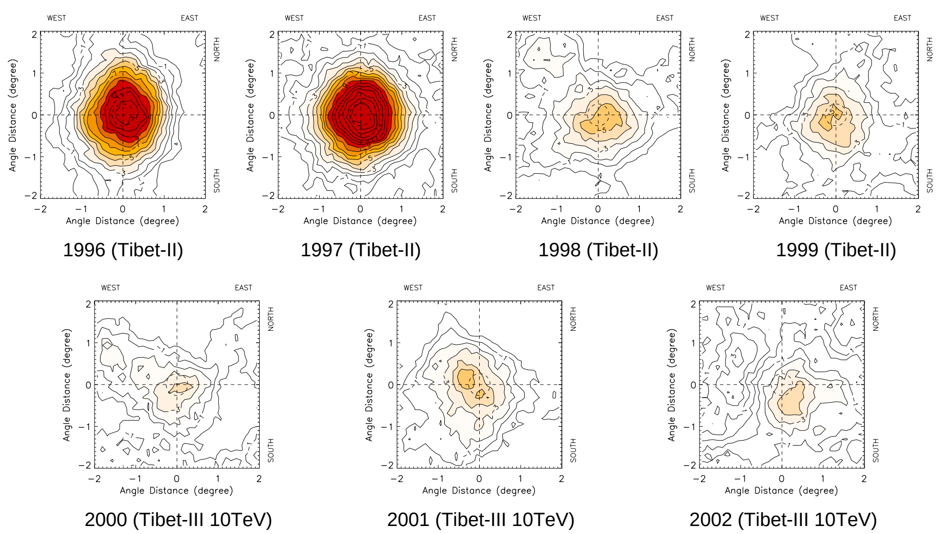

Fig. 2. Yearly variation of the Sun's shadow at 10 TeV region observed with the Tibet array in 1996 - 2002.

For the analysis of the Tibet-III data, we used the sub-data set taken from the 221 sets of detectors which are placed on a lattice of 15 m spacing with the same detector arrangement as the Tibet-II. Therefore, all event density maps of the Sun's shadow have the same mode energy of 10TeV. Background event density (per square degrees) in each map is listed in Table 1.. An obvious difference is seen between quiet phase (1996, 1997) and others. Although there exists no clear difference between increasing phase (1998, 1999) and maximum phase (2000, 2001, 2002), the significances of the deficits around the maximum phase are relatively lower. It is also noted that a slight shift of the deficit center to the south-eastward

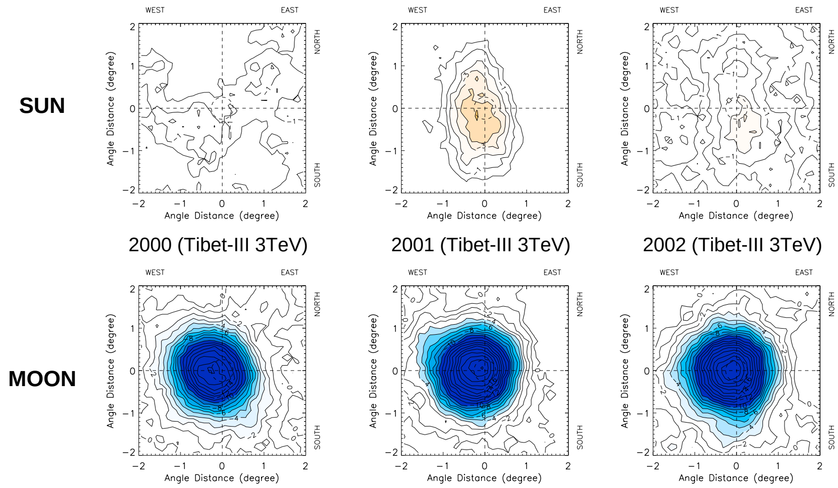

Fig. 3. Yearly variation of the Sun's (top) and Moon's (bottom) shadows at 3 TeV region observed with the Tibet-III in 2000 - 2002.

may be seen for the shadow in 2002.

Figure 3. shows yearly variations of the Sun's and Moon's shadows in 3 TeV region at around maximum phase (2000, 2001, 2002) in the solar cycle 23 observed with the Tibet-III array. Each background event density of the Sun's shadow (per square degrees) is listed in Table 1.. In this figure, the Sun' shadow is slightly seen only in the 2001 dataset. It is interesting to learn from Figure 1. that the present solar activity has double peaks at 2000 and 2002 and the year of 2001 corresponds to the interval of two peaks. Thus, the Tibet-III array has a good sensitivity for monitoring the variation of solar magnetic field. Further observation of the Sun' shadow in the present decreasing phase as well as the next quiet phase is interesting for understanding the structure of magnetic field near the Sun.

Acknowledgements

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