Homogeneity of Interplanetary Space according to Charged Particle Observations

K. KECSKEMETY1, E.I. DAIBOG2, YU.I. LOGACHEV2

1KFKI Research Inst. for Particle and Nuclear Physics, Budapest, Hungary
2Skobeltsyn Inst. of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
kecske@rmki.kfki.hu

Abstract: 27-day variations of the fluxes of 0.25-10 MeV electrons, present in all the last four minima are studied on the basis of SOHO/COSTEP and IMP-8/CRNC data observed during the minimum of solar activity in 1996. Independent of the origin of particles, this means that during those periods some stable active structure existed on the Sun, providing quasi-stability of the interplanetary medium which manifested in the 27-day recurrence of electron fluxes.

Keywords: quiet time particles, energetic electrons, interplanetary medium state

1 Introduction

The propagation of energetic particles in the interplanetary medium is determined by the structure of the interplanetary magnetic field (IMF) along the way from the source to the point of observation. Thus these particles can also serve as probes to monitor the state of the medium.

During the decreasing phase of SEP events long-lasting exponential periods are frequently observed in the fluxes of charged particles suggesting that over that period the interplanetary medium preserved its integral properties which are responsible for the decrease rate of the particle flux. This means that the plasma should be in a quasi-homogeneous and quasi-stationary state at least within that sector of the interplanetary space where the observations took place. A decay lasting $\Delta T$ days corresponds to a sector $13.3 \frac{\Delta T}{\cos 113\deg}$ wide where a given relation between the fluctuation spectrum of the IMF and solar wind speed is preserved. The most frequent $\Delta T$ values of exponential decay lengths in serial SEP events are 3-5 days. In extreme cases they can last 13-15 days, that is, $\Delta \varphi > 180\deg$.

Such steady decreases with durations up to about 10 days have been observed (Fig. 1). These conclusions are drawn from the time profiles of energetic particle fluxes of SEP events. However, there is another measure of the invariability of the structure of the IMF, independent of solar flare activity. Solar activity minima offer particularly favorable conditions for such observations.

Figure 1. An exceptionally long period of exponential decay after a solar event (upper curve: electrons, lower curve: protons).

2 Electrons in solar activity minima

In these quiet periods, periodicities, related to the rotation of the Sun and discovered long ago in low-energy electron fluxes, should naturally be present. During high solar activity, however, such regions are „washed off” by powerful processes and can be observed very rarely, if ever.
The main purpose of this study is to prove the existence of long-lasting structures in the IMF (in agreement with active longitudes on the Sun). Usually, four different populations of energetic electrons are distinguished:

- galactic electrons,
- electrons accelerated in solar active processes,
- Jovian electrons, and
- electrons due to weak solar processes (absolutely quiet Sun is never observed), accelerated in different structures of the IMF (CIRs, interplanetary shocks).

As we consider quiet activity periods, any active solar processes (e.g. solar flares, CMEs) can be excluded as sources of electrons. The galactic electron flux is almost an order of magnitude smaller than observed during these periods and thus can be neglected. Jovian electrons have been investigated for many years [1-4]. Of particular interest are their long-term variations. [5,6] studied 0.25-10 MeV electron fluxes using SOHO/COSTEP data in the 1996 solar minimum.

According to conventional wisdom, in the absence of solar activity, the main source of electrons with such energies can be either galactic cosmic rays or the magnetosphere of Jupiter. Jovian electrons can freely reach the Earth when it is magnetically connected to Jupiter, an event having 13 month periodicity (the synodic period of Jupiter). These electrons, however, are still observed for about 5-6 months and are subject to 27-day variation due to solar rotation.

### Observations

We consider fluxes of electrons with similar energies during four consequent solar activity minima 1976-1977, 1986-1987, 1996-1997, and 2007-2008 according to IMP-8/CRNC (0.7-2 MeV) and SOHO/EPHIN (0.7-3 MeV) electron data for the time periods with noticeable flux enhancements, including 27-day variations.

The periods studied are: 1976: DOY 3-303 (300 days running), 1977: DOY 80-347 (270 days), 1986: DOY 16-183, 1987: DOY 362 1986 r. – 300 (300 days), 1996: DOY 365 of 1995 – DOY 50 of 1996; 1997: DOY 17 – 72; 2007: DOY 285 – 2008, DOY 232 (310 days). That is, with the exception of the 1996-1997 minimum, the durations of these periods were of the order of 300 days, 1.5-2 times exceeding the generally accepted 5-6 months duration suggested by traditional interpretation of the Jovian origin of these electrons. A question arises about alternative origins. These may be either weak solar activity or acceleration directly in CIRs. We suppose this is valid at any rate for electron flux increases accompanied by synchronous enhancements of proton fluxes at MeV energies (DOY 330-365 of 1996, DOY 274-314, 2007, DOY 1-91, 2008).

Special attention is to be paid to the 2007-2008 minimum. The duration of the period with 27-day variations was 310 days. All intensity increases of electrons of above energies between DOY 327, 2007 and DOY 223, 2008 exhibited a 27-day periodicity (Fig. 2). At the same time,

![Figure 2. Flux variation of energetic electrons during a yearly period at the last solar minimum. Vertical arrows show the days of best magnetic connection to Jupiter for various solar wind speed values. Note that the average period of the variations is 26 days, not 27.](image-url)
neutron monitors also recorded large amplitude variations (Fig. 3).

Figure 3. A long interval of periodic neutron monitor and low-energy electron flux variations extending to 14 solar rotations. Whereas the first 4 enhancements in this series are synchronous, further variations anticorrelate. Average values of periods are 27.15 days (NM) and 26.15 days (electrons), respectively.

The optimum magnetic connection between the Earth and Jupiter at solar wind speed of ~450 km/s took place in the middle of this period (February 2008). Before and after this time the source of electrons is also Jupiter but with less efficiency depending on the conditions of perpendicular particle propagation near Jupiter (see Fig. 4).

All increases may be connected with long-living coronal holes (CH), observed throughout the whole period. As CHs are the source of high speed solar wind, they may be responsible for the formation of CIRs, which in turn may have accelerated the electrons under consideration.

Figure 4. Electron flux vs. $\Delta V = V_{\text{exp}} - V_{\text{Parker}}$ which characterizes the angular distance between the hypothetic Parker magnetic field line connecting the Earth with Jupiter and the magnetic field line corresponding to the observed solar wind velocity at the time of peak electron flux. The higher $|\Delta V|$ is, the less chance have the electrons to reach a magnetic field line passing near the Earth.

4 Conclusions

27-day variations of the fluxes of 0.25-10 MeV electrons, are studied on the basis of SOHO/EPHIN and IMP-8/CRNC data observed during the minimum of solar activity in 1996 year, present during every last four minima. The duration of corresponding periods were found up to 300 days long. The contribution of galactic electrons at these energies are almost an order of magnitude smaller than the observed flux. Independent of the origin of particles this means that during those sun rotations there was some stable active structure on the Sun, providing quasi-stability of the interplanetary medium (solar wind and magnetic field) manifesting in the 27-day recurrence of electron fluxes.

The analysis of the durations of the time periods during which these variations were observed, as well as of episodes of simultaneous electron and MeV proton flux increases allows to conclude that during solar activity minima the origin of electrons with energies of ~100 keV – few MeV is not exclusively Jupiter but the flux of accelerated electrons in different structures of IMF (CIRs, shocks, etc.) is not negligible. This confirms the existence of permanent IMF structures, rotating with the Sun, caused by long-living large scale structures on the Sun.

Acknowledgements

The Russian authors appreciate the support from RFBR grant 09-02-00718. The authors thank for using the data from the IMP-8/CRNC and the SOHO/COSTEP experiment.

References