# Analyses of Space Weather Events Impact on Highly Elliptical Orbit

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## INTRODUCTION

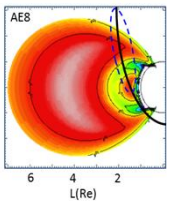


**Figure 1. AE8 model for electron belts in the magnetosphere. Dashed line is HEO orbit.**

The radiation environment on highly elliptical orbit is studied using data from HEO-3 mission, which are provided online by the Aerospace Corporation at http://virbo.org/HEO. Satellites in highly elliptical orbit pass through zones in the magnetosphere such as inner and outer electron belts and the slot region between them. HEO data could be used to study these zones. Here we analyse HEO-3 electron flux data to investigate the variability of the radiation environment in the slot region. The radiation environment of the slot region is considered to be a stable with low variability of radiation but recent studies (see *Zhao and Li, 2012*, and references within) demonstrate that the level of radiation in this area is also variable, especially after strong space weather events (SWE). We focus on the 1998-2008 to estimate an influence of SWE on radiation in the slot region

## HEO ORBIT. UNDISTURBED SLOT

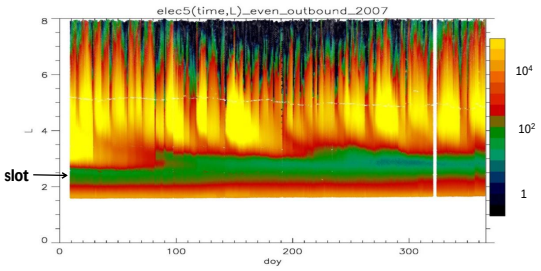


**Figure 2. Electron flux (time, L), E>1.5 MeV, 2007**

We examine the electron flux variability in 2007 for the even-outbound segment of the orbit for large altitude (Fig.2). This segment of the orbit starts at the inner electron belt, passes the slot and then the outer radiation belt (see Fig.1). Pair of 12h HEO orbits has one even-outbound segment per day. The slot between two electron belts corresponds to L-value around 2.5 and used to be considered as the area with small radiation value. 2007 had low solar activity and we can consider this value as a typical value for the slot region. In 2007 the electron flux in the slot region did not exceed 50 $cm^{-2}s^{-1}\,sr^{-1}$ (pfu) for E >1.5 MeV, with the mean around 25 pfu.

## STATISTICS OF ELECTRON FLUX IN THE SLOT

In 1998-2008 there were 25 'slot' events with enhancement of electron flux in the slot region. Figure 3 presents histograms for electron flux in the slot region during low solar activity, in 2006-2008. The distribution for the electron flux is close to normal with the mean which varies in the range 20-35 pfu. Histogram for 2003-2004, during declining phase of the solar cycle, has exponential distribution (Figure 4) which corresponds to days with enhanced electron flux. The distribution for small values (see inserts on Fig.4) still has the normal form like undisturbed distribution of electron fluxes in 2006-2008.

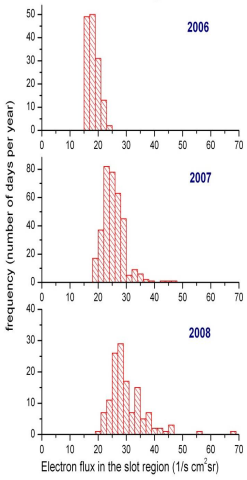


**Figure 3. Electron flux in the slot region. minimum solar activity**

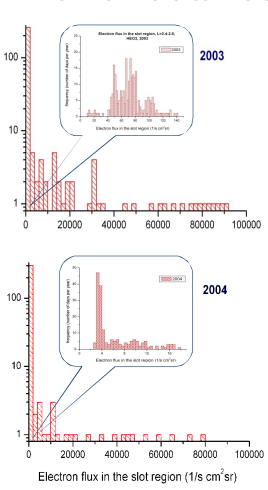


**Figure 4. Electron flux in the slot region, declining phase of solar cycle**

## ACKNOWLEDGEMENTS

We are grateful to Aerospace Corporation, NASA, to the group who made HEO data freely available and especially to Dr. Paul O'Brien.

## ELECTRON FLUX IN THE SLOT AFTER SPACE WEATHER EVENTS

Due to some space weather events the electron flux in the slot increases, and this increased value of radiation persists from several days to several months. Fig. 5 provides the dynamics of the slot region in September-November 2003. The right panel of Fig. 5 shows the electron flux during several days after the beginning of the storm on October 26th, 2003. The flux in the slot region (2<L<3) decreases during 1-14 November, 2003, while the electron flux at L>3 (the usual position of the electron belt) is gradually re-established.

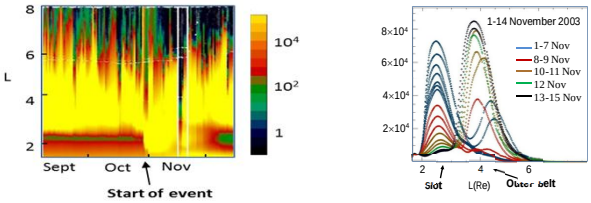


**Figure 5. Event October-November 2003. Electron flux, E>1.5 MeV**

Fig. 6 shows electron flux distribution for July/Aug 2000. The maximum of flux shifts to L≈ 2.5 after the storm on July 14th and moves back to L ≈ 3.5 during following two weeks (right plot on Fig. 6).

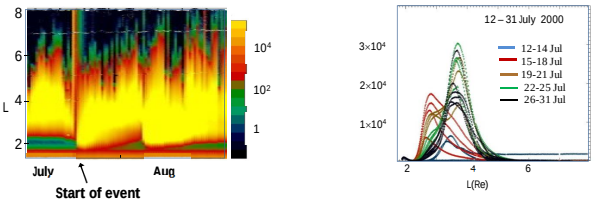


**Figure 6. Event July 2000. Electron flux, E>1.5 MeV**

## RELATIONS OF 'SLOT' EVENTS TO SPACE WEATHER PARAMETERS

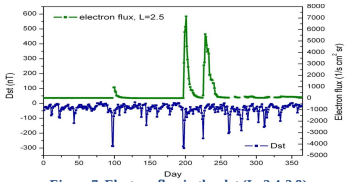


**Figure 7. Electron flux in the slot (L=2.4-2.8) and Dst index. 2000**

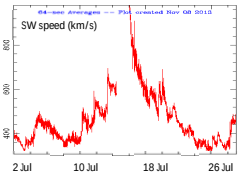


**Figure 8. Solar wind speed. July 2000**

Fig.7 for electron flux in the slot region and Dst index in 2000 demonstrates that the enhancements of electron flux is associated with peaks of minimum values of Dst index. It is also associated with parameters of solar wind. Peak of solar wind speed in July 2000 corresponds to SWE on 14th of July, 2000 (see Fig.8).

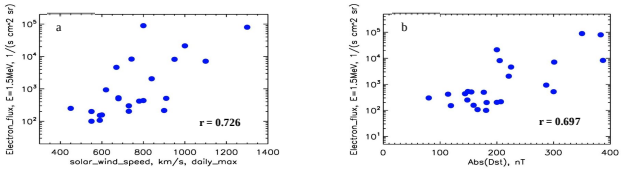


**Figure 9. Electron flux in the slot vs Dst index and solar wind speed**

25 events for 11 years when the slot region was filled by electrons were considered to study the relationship between maximum of electron flux in the slot region, Dst index and the peaks of solar wind speed for these events. Plots (Figure 9) demonstrate some association between the electron flux and Dst index with the correlation coefficient r = 0.697 (Fig.9a), and between electron flux and maximum of solar wind speed with r = 0.726 (Fig.9b). Figure 10 shows that for large SWE with $Dst_{min}$< -200nT and solar wind speed >650 km/s the electron flux in the slot is 100-1000 times larger than in quiet conditions.

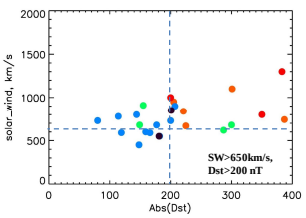


**Figure 10.** 25 events when the slot region was filled by electrons are presented by circles:

- for 100 < $e^-$ fluxes < 500 pfu
- for 500 < $e^-$ fluxes < 1000 pfu
- for 1000 < $e^-$ fluxes < 10000 pfu
- for $e^-$ fluxes > 10000 pfu
- absence of data for $e^-$ flux

Strong enhancement of $e^-$ fluxes (> 1000 pfu) corresponds to SW speed > 650 km/s and Dst < - 200 nT.

## CONCLUSIONS

- 25 "slot" events during 11 years, 1998-2008
- Duration of a 'slot' event: 3-100 days
- Conditions for strong 'slot' events: SW speed > 650 km/s, Dst < - 200 nT.

Electron flux in the slot region, E >1.5 MeV:

- SWE, max of $e^-$ flux: $10^2$ -$10^5$ pfu
- Quiet conditions, mean of $e^-$ flux: 20 - 60 pfu
- Correlation between e-flux and space weather parameters: r(e-flux, $Dst_{min}$) =0.726, r(e-flux, SWspeed)=0.629.

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