SOLAR-PROTON FLUXES DURING THE CURRENT SOLAR CYCLE AND THEIR SPACE EFFECTS.

R. C. Reedy[1], T. H. Prettyman[1], and N. Yamashita[1],
[1]Planetary Science Institute, Suite 106, 1700 E Fort Lowell, Tucson, AZ 85719. <reedy@psi.edu>.

Summary: The fluxes of solar protons during the current solar cycle (2009-2012) in the inner solar system are presented and compared with measurements by the GRaND instrument on Dawn.

Introduction: Solar energetic particles (SEPs) are occasionally present in the solar system [1]. SEPs occur in what are called solar particle events (SPEs). SEPs often have high enough energies (>10 MeV) and can have intense-enough fluxes to seriously affect objects and material in space. These effects and nuclides produced in matter occur within ~1 cm depth, as seen for radionuclides in lunar samples [2].

Fluxes of solar energetic particles: The fluxes of SEPs were very low during the recent minimum in solar activity, which was the lowest in late 2008. The last large SPE before then was in Dec. 2006. In 2010, solar activity started to increase for the current maximum in solar activity, solar cycle 24.

The distribution of SEPs in the inner solar system varies, with some SPEs being more directional than others. Thus, a network of spacecraft are used to study them. SEPs are measured by several spacecraft in Earth orbit, the Geostationary Operational Environmental Satellites (GOES) of NOAA and the Advanced Composition Explorer (ACE) of NASA's Explorer program. Two other satellites, NASA's Solar Terrestrial Relations Observatory (STEREO) spacecraft, are in orbits near 1 AU about 130 degrees ahead (STEREO-A) and behind (STEREO-B) the Earth.

All of these spacecraft measure SEPs in a variety of energy ranges, including the energies of interest to the work here, solar protons of 10 MeV and higher. GOES initially reports SEPs of >10 and >100 MeV, ACE has level 1 data (raw data) for >10 and >30 MeV protons, and STEREO has results for >14 and >30 MeV. Although only level 1 and with a very large background, ACE data for large SPEs agree fairly well with GOES. (ACE's high background is especially well seen in Fig. 1 for a period with almost no solar activity.)

The particle fluxes for 2009-2012, the first part of the current solar cycle, for these 4 sets of spacecraft are shown in Figs. 1-3. The energies used vary but show the basic trends in SEPs for the current solar cycle.

The recent fluxes of solar energetic particles: Figs. 1-3 give most of the measurements for energetic SEPs for the current solar cycle, which started late in 2008. No SEPs occurred in 2007-2009 and only a few fairly-weak SPEs occurred in 2010 (Fig. 1). Such low fluxes of SEPS are typical for the first ~2 years after solar minimum.

Fig. 1 results, especially for ACE, show the background due to galactic cosmic rays (GCRs) peaking in and near the end of 2009. The decrease of GCRs in 2010 is due to the increased levels of solar activity keeping GCRs from the inner solar system. Low levels of SEPs is consistent for low levels for solar activity.

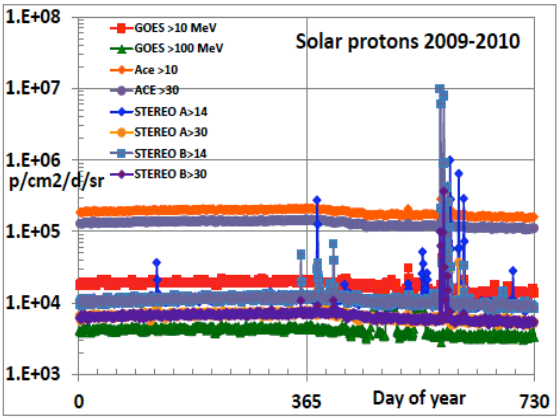

Fig. 1. Fluxes of solar energetic particles above several energies in 2009 and 2010, a period of relatively-weak solar activity. Results for 4 spacecraft are shown.

Since the start of 2011, there have been fairly high fluxes of SEPs (Figs. 2-3). As for earlier solar cycles, large SPEs can occur for many years (~7 years). The peak in solar activity is expected in about 2013.

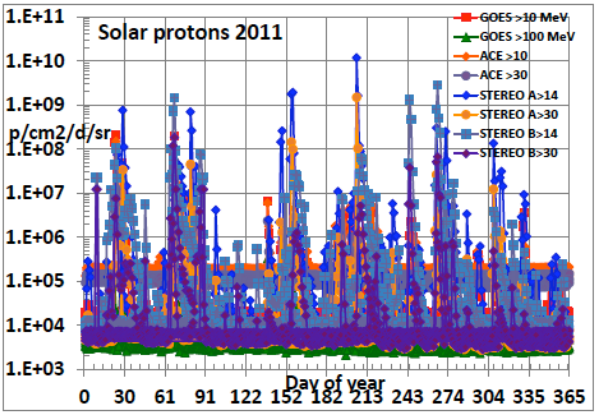

Fig. 2. Fluxes of solar energetic particles above several energies in 2011. The Sun finally was active in the current solar cycle (number 24). Results for 4 spacecraft are shown.

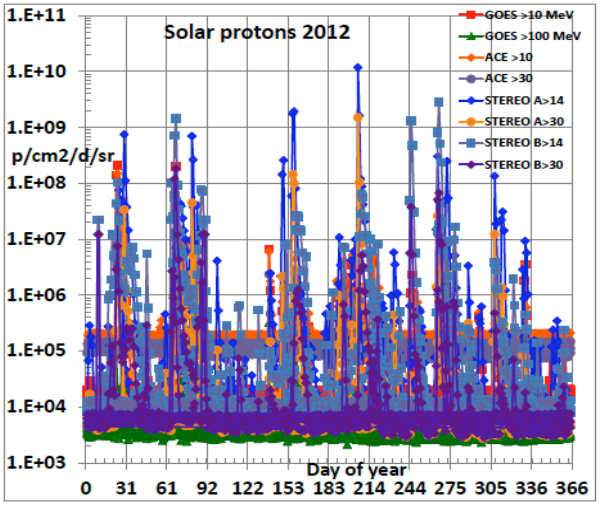

Fig. 3. Fluxes of solar energetic particles above several energies in 2012. The Sun continued to be active, as its current activity cycle was approaching its maximum. Results for 4 spacecraft are shown.

The fluxes of the high-energy solar protons at about 1 AU in the solar system around LAMO are shown in Fig. 4. Vesta orbits 2.15-2.57 AU from the Sun, and the SEP fluxes there are expected to be lower there than at 1 AU. However, the basic trends should be similar.

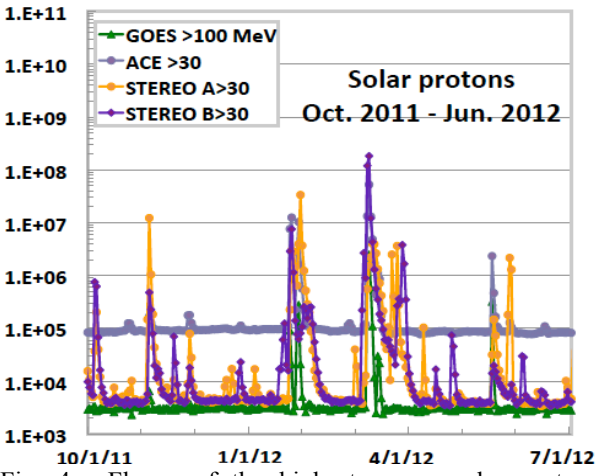

Fig. 4. Fluxes of the highest-energy solar protons around and during the closest approach to Vesta (12/11 to 4/12)

The GRaND instrument on Dawn. The gamma-ray and neutron detector (GRaND) measures gamma rays and neutrons for a range of energies [3,4]. GRaND got it prime data when Dawn was in its lowest orbit at Vesta, the low altitude mapping orbit (LAMO) that started on 8 Dec. 2011 and ended on 1 May 2012. Measurements in higher orbits are used to help determine backgrounds and other corrections to the data.

The largest SPEs during the LAMO time period in Fig. 4 peaked on 1/28/12, 3/8/12, and 3/24/12. The last peak was not observed by either ACE or GOES near the Earth. The orbit of Vesta (and the Dawn spacecraft) during LAMO was trailing behind the Earth, and STEREO-B was the spacecraft closest to the Sun-Vesta line.

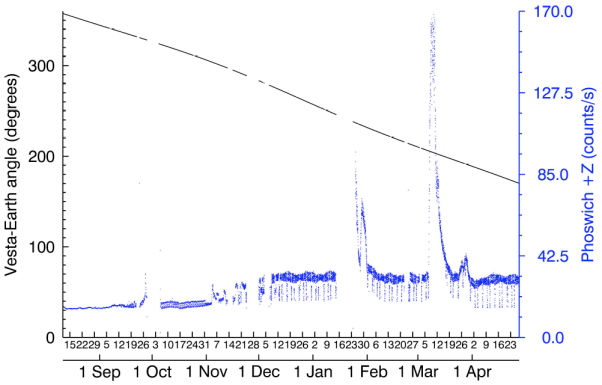

Fig. 5. The counts/s of the GRaND +Z phoswich (blue curve) and the Vesta-Earth angle (black) for late 2011 and early 2012.

The counting rate in the +Z phoswich of GRaND [3] is shown in Fig. 5. The large GRaND peaks in late January and early March correspond to large SEP peaks in Fig. 4. The weak peak near the end of March corresponds to a fairly-large SEP peak, probably weaker because the solar-proton fluxes were not the same at Dawn and at the Earth or the 2 STEREO spacecraft.

Discussion: The solar-proton fluxes at 1 AU in the inner solar system as reported by GOES, ACE, and STEREO spacecraft were presented for the first 4 years of the current solar cycle (2009-2012). Solar activity was quiet until late 2010. Since then, there have been many solar particle events. Peaks in the counting rate of GRaND instruments correspond to peaks in solar-proton fluxes, although the correspondence is poor for an event when Dawn was not in line with any of the above spacecraft. These solar proton fluxes will help in interpreting the GRaND data.

Acknowledgments: NASA supported this work through the Dawn program (THP and NY) and the Dawn at Vesta Participating Scientist program (RCR). Some SEP work, especially earlier, by RCR was supported by NASA's Cosmochemistry program.

References: [1] Reedy R. C. (2012) *LPS 43*, #1285. [2] Nishiizumi N. et al. (2009), *Geochim. Cosmochim. Acta, 112*, E03S04. [3] Prettyman T.H. et al. (2011) *Space Sci. Rev.*, 163, 371. [4] Prettyman T.H. et al. (2012b) *Science*, *338*, 242.