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Interactive comment on "Multi-point galactic cosmic rays measurements between 1 and 4.5 AU over a full Solar cycle" *by* Thomas Honig et al.

Anonymous Referee #2

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SUMMARY

This manuscript is based on galactic cosmic ray measurements provided by the HEND instrument onboard Mars Odyssey and the SREM radiation monitors onboard Rosetta, and four different near-Earth s/c (INTEGRAL, Herschel, Planck and Proba-1). The period analyzed (2004-2016) covers more than one solar cycle and includes the Rosetta encounter with comet 67P/Churyumov-Gerasimenko. After removal of Solar energetic particle events, a cross-calibration of the counting rates provided by the different instruments is performed. SREM onboard near-Earth s/c are cross calibrated using INTEGRAL as reference measurement. Rosetta flybys of the Earth are used to cross-calibrate Rosetta/SREM and INTEGRAL/SREM. Finally, cross-calibration between Rosetta/SREM and Mars Odyssey/HEND is achieved using Rosetta data at he-

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Discussion paper

liocentric distances near 1.5 AU. As expected, cosmic ray fluxes at all locations anti-correlate with markers of the solar activity cycle (sunspot number and interplanetary magnetic field). Differences in the GCR rates measured near the Earth, at Mars and by Rosetta before hibernation are interpreted in terms of positive GCR radial gradients, with values consistent with previous studies. After hibernation, around the encounter of Rosetta and comet 67/P, an unexpected reduction of the counting rates at Rosetta compared to near-Earth measurements is reported. The authors briefly enumerate/discuss possible origins such as a negative GCR latitudinal gradient (unlikely, due to the small helio-latitudinal interval swept by the s/c), effects related to mission operations (mostly discarded by the authors) or attenuation by the plasma environment around the cometary coma.

Although the authors are rather inconclusive about the causes of the apparent decrease in the GCR flux around the comet encounter and leave this question open for future studies, the manuscript presents relevant new data. This study illustrates the scientific potential of the multiple SREM datasets, primarily intended for engineering purposes, providing cross-calibration factors valuable for future multi-point studies. GCR radial gradients constitute a relevant input for GCR modulation investigations.

I found this work interesting and adequate for publication in Annales Geophysicae once the following comments have been addressed in a revised version of the manuscript.

GENERAL COMMENTS

SREM TC2 channel is a single detector channel. Since no coincidence/veto logics are applied, this channel could include a significant contribution from secondary particles induced by cosmic ray interaction with the s/c. Authors should at least briefly discuss if this is the case, as well as the relative importance of possible sources of background. Since the study covers a long time interval and a relatively wide range of radial distances, spatial and/or temporal variations of the background can be a critical issue for the analysis of quiet-time fluxes (GCR) and could affect the reliability of cross-calibrations along the period under analysis.

SPECIFIC COMMENTS

Page 3, line 5. Although single detector channels such as TC2 are omnidirectional, it would be helpful for the later interpretation of the data to briefly describe the pointing of the Rosetta SREM aperture during the cruise phase and during the comet encounter.

P3 Table 1. The second column (logic) lists "D1" as logic for channels TC2 and S25. This seems inconsistent with e.g. page 2 line 26 and with Table 1 in Evans et al., 2008. Please check/correct since channel TC2 is the basis of the study presented in the manuscript. Instead of just providing a nominal "49 MeV to infinity" energy range, it would be valuable to discuss the rigidity or energy range roughly represented by TC2 counting rates (taking into account the typical shape of the modulated GCR spectrum above 49 MeV and probably the energy-dependent instrument response). This information would be quite useful when comparing the inferred radial gradient with previously published results (Page 12).

P4 Figure 1, bottom panel. Please define/clarify HEE, since this acronym normally stands for the Heliocentric Earth Ecliptic coordinate system and therefore latitudes would correspond to ecliptic latitudes and not to heliographic latitudes. Do the authors mean HEEQ (Heliocentric Earth Equatorial)? If not, replace "heliolatitude" by "ecliptic latitude". This difference is also relevant for the discussion in P14L10.

P5L19. The SREM channels and the exact procedure used to manually filter solar energetic particle events should be specified. Some events could be difficult to detect in TC2 (but still contribute) but become clearly visible at energies below 49 MeV.

P5L25. The reconfiguration of HEND should be explained with further detail. What is the ultimate reason for the count rate increase/offset?

P6L5-6. "We associate the 2.8% difference. . . . . .with differences in the sensitivity area of the two SREM detectors". Other factors such as noise levels, obstructions or different s/c mass distribution around the sensor head could contribute to this small difference between the nominally identical units onboard INTEGRAL and Rosetta (as well as Herschel, Planck and Proba-1).

P7L23. Is this equation correct? The preceding text mentions that Proba-1 counting rates are systematically lower than INTEGRAL counting rates, then why is INTEGRAL rate (and not Proba-1 rate) multiplied by a number >1 in order to obtain a "corrected" Proba-1 rate directly comparable with INTEGRAL? The same question applies to the rest of cross-calibration equations. Probably this is just a notation problem, but it should be checked.

P8L6. See comment P7L23 above and clarify how the calibration factors are applied to HEND data in order to make them directly comparable with Rosetta.

P10 Figure 4. What is the reason for the peaks observed in HEND rates shortly after the vertical red dashed line? The difference between the near-Mars HEND and near-Earth SREM rates seem larger at the end of the plot (2015-16) than at the beginning (2003), while solar activity levels are comparable (although with opposite solar polarity). This, together with the comment on P5L25 raises some doubts about the stability of cross-calibration. Some discussion of these differences could be introduced e.g. in P11L7-8. Visibility of the different lines in the first panel could be improved.

P12L13-14. When citing agreement with Vos and Potgieter, 2016 and Gieseler and Heber, 2016, please mention the rigidity/energy ranges studied by these authors. The radial gradients presented here are based on counting rates accumulated over a broad energy range, which makes difficult to define a reference energy for comparison (see comment about Table 1 above).

P12L16-17 and P14 Figure 6. "After that period, the count rate variation is in very good agreement with the expectation of a positive(?) radial gradient. . .". This sentence sounds quite confusing since the Rosetta rates remain below the INTEGRAL rates till late 2016 (Figures 4 and 5 and discussion in following pages). In order to make easier the interpretation of Figure 6, I strongly suggest including panels showing the heliocentric distance of Rosetta and the distance between Rosetta and Comet 64P. In order to keep consistency with Figure 4, I also suggest plotting INTEGRAL SREM rates in green color.

P14L13. “The decreasing ratio begins when Rosetta reaches around 20,000 km from the cometary nucleus”. See comment above about including distance between Rosetta and the comet in Figure 6.

P14 and P15. Please briefly mention that the counting rates at Mars/HEND always stay higher than those registered near the Earth (Figure 4), even during the period shown in Figure 6. This is consistent with a permanent positive GCR radial gradient and supports that the reduction in the GCR rates at Rosetta compared to Earth is related to the comet approach.

P15L16-17. In order to substantiate this suggestion, the authors should consider including and discussing the local plasma and magnetic field observations by Rosetta during the period shown in Figure 6.

MINOR AND TYPOGRAPHIC COMMENTS

Affiliations: Please replace “Universitycity” by “University”.

Page 1, Line 21. “Major sources of this radiation are the Van Allen radiation belts,. . .”. The preceding sentences put the focus on missions outside the Earth’s magnetosphere, therefore this reference to radiation belts seems out of place.

P2L4. “cover a range of heliocentric distances up to 3.5 AU”. Since Rosetta reached 4.5 AU, the term “heliocentric distance” sounds confusing here. Do the authors refer to the difference between the radial distances of two s/c, rather than to the Sun-s/c distance?

P2L9. “with two of them still operating. . .”. Please specify which ones.

P2L10. I suggest replacing “high energetic charged particles” by “high-energy charged particles” here and elsewhere in the manuscript.

P3 Table 1. I suggest avoiding the redundant “MeV” labelling in the first and second line of the header, e.g. keeping it only in the first line.

P3L21. “This sensor is the best one for space weather. . .”. Please reformulate this sentence in a more specific way.

P4L11. Replace “Figure 1 shows. . ..” by “Top panel of Figure 1 shows. . .”.

P5L5. Please, replace “and HEND’s orbits. . .” by “and Mars Odyssey’s orbits. . .”.

P5L15. What is the energy and/or intensity threshold of the Solar Proton Event list used here?

P6L3. I suggest replacing “the fit curve” by “the linear fit”.

P7L20. Since the energy threshold of SREM TC2 is relatively low (49 MeV), magnetospheric shielding of the lower energy part of the GCR spectrum could also play a role here.

P7L39. I suggest replacing “The neutron monitor HEND” by “The HEND neutron detector” or just “HEND- Mars Odyssey”.

P8L8. Indeed, the possible effect of Mars shadow would be implicitly included in the empirical cross-calibration procedure.

P8 Table 2. Please add the units of b coefficient in the first row and include a and b uncertainties in the table.

P10 Figure 4 caption, P11L10 and P11L27. Replace “sun spot” by “sunspot”.

P11L5 and P15L25 “solar rotation (27 days)” While this is OK for the purpose of smoothing longitudinal and transient variations at all locations, 27 days is just the Carrington (synodic and at intermediate latitude) solar rotation period. Therefore, I suggest removing “one solar rotation” and leaving just “27 days”.

P11L9 “different heliographic locations”. Do the authors mean “heliospheric locations”?

P11L12 “one of its orbits”.

P11L20 “long-term”.

P11L27 “anticorrelation. . .was calculated”. I suggest replacing either by “anticorrelation. . .was analyzed” or by “correlation coefficient. . ..was calculated”.

P12L14 and P13L10 the term “comet phase” should be clarified/defined.

P13L12. Replace “dark” by “black”.

P14L16 “hundreds of kg of propellant. . .etc.”. Could this mass loss significantly change the mass environment around the SREM detector and reduce the rate of secondaries contributing to TC2? For completeness, the authors could also mention the separation date of the Philae module and its (small) mass.

P15L22 “they are highly. . .”.

P15L29 “sunspot”.

P15L29. Please replace “annex” by “Annex 1”.

P15L30 Please replace “geographically” by “spatially”.

P15L31 “demonstrated”.

P16L3. The period corresponding to this radial gradient should be mentioned here.

P16L4 “this information provides”.

P18L27 Replace “cosmis” by “cosmic”.

P19L24 Replace “intergral” by “INTEGRAL”.

P22 Figure Annex 2. A panel showing the azimuthal separation between Rosetta and the Earth could be added to illustrate the origin of the time delays in the observed co-rotating structures.

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