ISSI Team Proposal: Radiation Interactions at Planetary Bodies

1. Abstract. Since the launch of the Lunar Reconnaissance Orbiter (LRO) in 2009, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) has directly measured the Lunar radiation environment [e.g., Spence et al., 2010; Schwadron et al., 2014] and mapped albedo protons (~100 MeV) coming from the Moon [Wilson et al., 2012]. Particle radiation has widespread effects on the lunar regolith ranging from chemical alteration of lunar volatiles [e.g., Schwadron et al. 2012; Jordan et al., 2013] to the formation of subsurface electric fields with the potential to cause dielectric breakdown that could modify the regolith in permanently shaded craters [Jordan et al., 2014, 2015]. LRO/CRaTER's direct measurements are transforming our understanding of the lunar radiation environment and its effects on the Moon.

Similarly, the Radiation Assessment Detector (RAD) [Zeitlin et al., 2013] has been measuring the energetic particle radiation environment on the surface of Mars since the landing of the Curiosity rover in August 2012 [Hassler et al., 2014]. The Martian surface is protected by the atmosphere above; though only about 1% as thick as Earth's, its depth is sufficient to stop solar wind ions and the large majority of Solar Energetic Particles. RAD, like CRaTER, measures radiation dose, dose equivalent (related to human health risks), and particle spectra to enable rigorous tests of environment and transport models.

Recent measurements of galactic cosmic radiation and solar energetic particle radiation at planetary bodies including the Moon, Mars and the potentially new measurements at other planetary objects (e.g., the moons of Mars) raise new fundamental questions about how radiation interacts at planetary bodies and what its long term impacts are.

We propose an ISSI team to advance the study of radiation interactions. The ISSI team enables development of a truly international and cross-disciplinary effort, and facilitates a unified approach to the problem involving international cooperation across different participating teams and those in formation.

We have identified two potential groups that would be helpful in making the effort to successful. The core team is a group of 9 individuals who will attend team meetings at ISSI in person and who will have significant responsibilities in bringing together various aspects of the research. The affiliated team is a much broader group of 17 members includes who have worked various aspects of the problem. The affiliated team will also play an important role in the effort. However, these team members may not attend all meetings in person. Rather, these team members would attend meetings via teleconference or video conference (skype or other software). The complete team including the core team and affiliated team will develop the body of research that comprises the effort. Authors and co-authors from across the complete team (core and affiliated members) will contribute research articles submitted to the SSR special issue devoted to the effort.

One of the main outcomes from the meeting will be development of a special journal issue devoted to the topic of radiation interactions. We will publish the special journal issue in either Space Science Reviews or Astrophysical Journal Supplement, depending on the interest of editors.

2. Scientific rationale, goals and timeliness. Since the launch of the Lunar Reconnaissance Orbiter (LRO) in 2009, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) has directly measured the Lunar radiation environment [e.g., Spence et al., 2010; Schwadron et al., 2014] and mapped albedo protons (~100 MeV) coming from the Moon [Wilson et al., 2012]. Particle radiation has widespread effects on the lunar regolith ranging from chemical alteration of lunar volatiles [e.g., Schwadron et al. 2012; Jordan et al., 2013] to the formation of subsurface electric fields with the potential to cause dielectric breakdown that could modify the regolith in permanently shaded craters [Jordan et al., 2014, 2015]. *LRO/CRaTER's direct measurements are transforming our understanding of the lunar radiation environment and its effects on the Moon.*

Similarly, the Radiation Assessment Detector (RAD) [Zeitlin et al., 2013] has been measuring the energetic particle radiation environment on the surface of Mars since the landing of the Curiosity rover in August 2012 [Hassler et al., 2014]. The Martian surface is protected by the atmosphere above; though only about 1% as thick as Earth's, its depth is sufficient to stop solar wind ions and the large majority of Solar Energetic Particles. RAD, like CRaTER, measures radiation dose, dose equivalent (related to human health risks), and particle spectra to enable rigorous tests of environment and transport models.

Recent measurements of galactic cosmic radiation and solar energetic particle radiation at planetary bodies including the Moon, Mars and the potentially new measurements at other planetary objects (e.g., the moons of Mars) raise new fundamental questions about how radiation interacts at planetary bodies and what its long term impacts are. Below we list recently studied topics that highlight the need and timeliness of the project.

2.1 New Radiation Environment Ushers In a New Era of Lunar Exploration. The solar wind is currently exhibiting extremely low densities and magnetic field strengths, representing states that have never been observed during the Space Age. The highly abnormal solar activity between cycles 23 and 24 has caused the longest solar minimum in over 80 years and continues into the unusually small solar maximum of cycle 24. As a result of the remarkably weak solar activity, we have also observed the highest fluxes of galactic cosmic rays in the Space Age, and relatively small solar energetic particle events [e.g., Schwadron et al., 2014]. The implication of these highly unusual solar conditions for human space exploration is that galactic cosmic ray (GCR) radiation remains a worsening factor that limits mission durations. While solar energetic particle (SEP) events in cycle 24 present some hazard, the accumulated doses for astronauts are well below current dose limits. Ironically, during a mission near solar maximum, astronauts would experience relatively low levels of GCR radiation due to heightened modulation and relatively low probabilities of large SEP events. Thus, *we are entering an era in which our understanding of evolving solar and galactic cosmic radiation uniquely enables the return of humans to the lunar surface.*

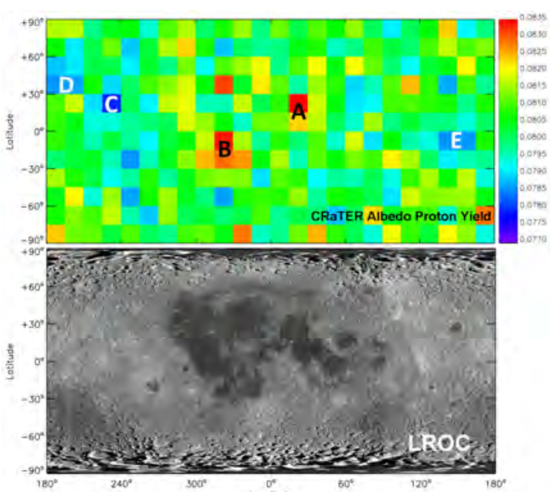


Figure 2. *Top: Lunar albedo proton yield map with anomalous yield regions "A" - "E". Regions A and B are centered near mare boundaries. Regions C, D and E are in the highlands. Bottom: Visible global composite image from the Lunar Reconnaissance Orbiter Camera (LROC)*

2.2 Albedo Proton Maps: Lunar albedo protons are produced by nuclear spallation, through GCR bombardment of the lunar regolith. Albedo protons provide a new method for mapping compositional variations across the Moon's surface (Figure 1). Recent work examines the angular (off-nadir) and spatial distribution of albedo protons, and their relationship to regolith composition and volatile content.

2.3 Lunar Surface Charging and Dielectric Breakdown. Lunar surface charging occurs due to the surface being exposed to space plasmas and solar photons [*e.g.* Halekas et al., 2002, 2005, 2007]. The dayside charges to +5-10 V due to photoemission, whereas the nightside charges negative due to the dominance of the electron thermal currents, except where significant secondary electron emission occurs. Deep dielectric charging [Jordan et al., 2014, 2015] of the regolith is largely due to energetic particles and GCRs depositing charge in the subsurface (to ~1 m for GCRs). The extremely low conductivity of the lunar regolith (particularly in cold regions) can result in the formation of large electric fields to dissipate the accumulated charge. Sufficiently large electric fields lead to electrostatic discharges [Jordan et al., 2015], and potentially, modification of regolith [Campins and Krider, 1989], particularly in permanently shaded craters where conductivities are extremely low [Figure 2, Jordan et al., 2014].

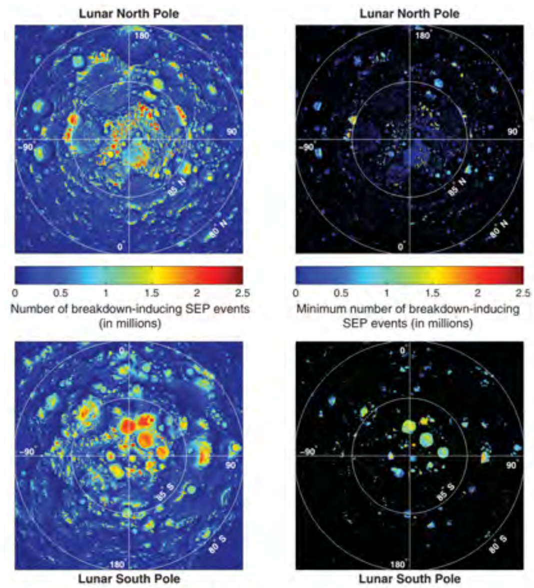


Figure 3. *Estimated number of breakdown-inducing SEP events in gardened regolith at poles: (Left) based on average temperature at 2 cm depth; and (Right) based on annual surface temperature (blackened regions on right have temperature >200K)*

Breakdown weathering can change the optical properties of the regolith. By reducing the mean grain size, breakdown weathering may cause low-porosity structures to form, thus explaining the reduced porosity (>70%) postulated for the lack of a flash detected by LCROSS when the Centaur stage impacted within a PSR (Schultz et al., 2010). Since it also causes melting and vapor deposition, it may account for the reduced far-ultraviolet plane albedo detected in PSRs by LRO/LAMP (Gladstone et al., 2012). Finally, the vitrification caused by breakdown weathering may also explain the increased normal albedo detected in the near infrared by LRO/LOLA (Lucey et al., 2014). All of these effects, however, are uncertain; therefore, we will need to assess how breakdown weathering may affect the regolith in PSRs and its optical properties.

2.4 Implications of Galactic Cosmic Rays and Solar Energetic Particles for Earth's atmosphere. Multiple sets of observations indicate that Earth's atmosphere and climate are influenced by GCRs and SEPs:

- The Sun is now emerging from a deep protracted solar minimum when Galactic Cosmic Rays (GCRs) achieved the highest levels observed in the space age [Mewaldt et al., 2010], and the power, pressure, flux and magnetic flux of solar wind were at the lowest levels [McComas et al., 2008; Schwadron et al., 2011; Connick et al., 2011]. Even observations of the global heliosphere show remarkably rapid changes [McComas et al., 2010] caused by dropping solar wind pressure [Schwadron et al., 2011]. The joint variations of microwave flux, total solar irradiance (TSI), and sunspot number do not follow the patterns expected for TSI variability [e.g., Lockwood, 2011]. It is possible that we are headed toward a grand minimum, two of which have been observed in the previous 500 years of sunspot counting. As GCR fluxes and the conditions of the Sun change, we are forced to ask fundamental questions about the effects on our atmosphere.

- Sediment cores and deep ice cores (e.g., the Greenland Ice Core record, GISP2) provide a longer-term record extending back hundreds of thousands of years. Here, the global response of Earth's atmosphere to orbital forcing, cometary impacts, and regional changes such as deglaciation are key to understanding Earth system response. Models simulating deglaciation events and the radiative forcing caused by Milankovich cycles attempt to explain the changes in climate deduced from isotopic records across the globe. Incorporation of isotopic composition [e.g., Park et al., 2008] in the WACCM model via the Model for Ozone And Related chemical Tracers (MOZART4) provides a new method to explore global responses to climate change inferred from isotopic records.
- One focus of the team will be development and publication of a growing global archive of cosmogenic radionuclide measurements along with state-of-the-art global climate model simulations to study solar activity, changes in the local interstellar medium, and global transport and deposition patterns during past climates. Our primary focus will be to identify solar variability in cosmogenic radionuclide archives, using the Whole Atmosphere Community Climate Model (WACCM) to study relationships between the production, transport, and eventual sequestration of cosmogenic radionuclides on solar timescales (e.g., individual solar events, ~11-year Schwab cycle, ~87-year Gleissberg cycle, ~210-year de Vries cycle, and ~2300-year Hallstatt cycle).

2.5 Implications of Galactic Cosmic Rays and Solar Energetic Particles for Mars. High-energy GCRs impinging on Earth interact or stop in the upper atmosphere. It has been suggested that the ionization from these particles may play a role in seeding clouds, though this remains a controversial theory that has not gained wide acceptance in the climate science community. As succinctly described by [Bazilevskaya, 2008], "Energetic cosmic rays initiate nuclear-electromagnetic cascades in the atmosphere, causing a maximum in secondary particle intensity at the altitude of 15–26 km depending on latitude and solar activity level, the so-called Pfotzer maximum." The column depth of atmosphere above the Pfotzer maximum is on the order of 60 g cm^{-2}. On Mars, the column depth of the entire atmosphere is only about 20 g cm^{-2}, meaning that the Pfotzer maximum on Mars exists a few tens of cm below the surface. (This is also the case on the Moon, qualitatively speaking.) We would therefore expect that GCR effects on Earth's atmosphere, if any, are not replicated on Mars. On the other hand, SEPs with energies up to about 150 MeV stop in the Martian atmosphere, so that solar events could conceivably exert an influence on atmospheric chemistry and/or charging on a sporadic basis. The presence of relatively high levels of radiation to a depth of many tens of cm in the Martian soil may have profound implications for the preservation of organics [Pavlov, 2012] and for the possibility of survival of dormant organisms [Dartnell, 2007], if any have ever been present.

2.6 Implications of Galactic Cosmic Rays and Solar Energetic Particles for other Planetary Bodies. There is a good example for the potential for generalization of radiation interaction processes in the three small, innermost satellites of Jupiter (Thebe, Amalthea, and Metis). These objects have nearly identical leading/trailing hemisphere albedo ratios (Simonelli et al., 2000). Each leading hemisphere has an albedo about 1.3 times brighter than the trailing. The reason for this is unclear, and the best suggestion is that somehow meteoroid impacts brighten the satellites' leading hemispheres (Simonelli et al., 2000). These three moons are exposed to very high fluxes energetic electrons in Jupiter's radiation belt (Fischer et al., 1996) and may therefore also experience breakdown weathering. For example, Voyager 1 likely experienced 42 internal electrostatic discharges due to deep dielectric charging by the jovian radiation belts (see the review of charging in the jovian radiation belt in Garrett et al., 2012). We plan to determine if breakdown weathering could continually darken the upper layer of the moons' regolith, while meteoroid impacts uncover the deeper, brighter material. If this model is validated, we will use it to constrain further how breakdown weathering can affect albedo, which will, in turn, improve our understanding of how breakdown weathering can affect lunar PSRs.

3. List of the expected output

- Study of space radiation weathering of icy moons/ring systems
- Study of space radiation weathering of atmosphere-less rocky bodies
- Study of multi-layer modeling of deep dielectric charging in the regolith of airless bodies
- Study linking recent changes in the space environment with historic and future space environments
- Study of particle radiation albedo including predictions at other bodies than Moon
- Inventory of radiation dose/dose rates and Linear Energy Transfer Spectra throughout the solar system
- Study of use of energetic particle reflection as probe of remnant magnetic anomalies at planetary surfaces (and at Io and other moons in terms of interaction with Jovian magnetic field)
- Study role of energetic particles to deep dielectric charging and physical weathering
- Study of energetic particle interactions with planetary atmospheres - shielding
- Study of energetic particle interactions with planetary atmosphere - drivers of chemistry and dynamics

Over the course of the team meetings, we will bring together contributions for a special issue of Space Science Reviews or possibly Astrophysical Journal Supplement, depending on the response of editors.

4. Added value of ISSI. The study of radiation impacts has expanded from individual measurements/teams (e.g., LRO/CRaTER, MSL/Rad, modeling and laboratory measurements) into a truly international and cross-disciplinary effort. ISSI facilitates a more unified approach involving international cooperation across different, quite disjoint teams and those currently being formed. It is very unlikely that such a cross-disciplinary effort would be possible without forming an international team via ISSI.

5. List of confirmed members with one page CVs incl. list of relevant publications. Two potential groups that would be helpful in making the effort to successful. The core team will attend team meetings at ISSI and will have significant responsibilities in bringing together various aspects of the research. The affiliated team members may not attend all meetings in person. Rather, these team members would attend meetings via teleconference or video conference. Authors and co-authors from across the complete team (core and affiliated members) will contribute research articles submitted to the SSR special issue devoted to the effort.

Core Team (Roles): **Nathan Schwadron** (Lead); **Harlan Spence** (Interactions at the moon and airless bodies throughout the solar system); **David Lawrence** (Interactions at the moon and bodies throughout the solar system); **Cary Zeitlin** (MSL/Rad Connection, modeling of particle radiation, interactions at Mars); **Bob Wimmer-Schweingruber** (MSL/Rad connection, grain interactions); **John Cooper** (Chemical alteration)**;** **Tim Stubbs** (Charging of the regolith); **Sonya Smith** (Atmospheric interactions); **Manuel Grande** (Planetary interactions)

Affiliated Team Members (role): Larry Townsend (Modeling of particle radiation, interactions at Mars); Ruedi von Steiger (Composition, Solar wind interacions); Carle Pieters (Composition of lunar regolith); Tom Prettyman (Composition and H abundance in regolith); Jay Melosh (Charging of regoliths); Bern Heber (Galactic Cosmic Rays); Arik Posner (Galactic Cosmic Rays and Solar Energetic Particles); Andrew Jordan (Charging and Dielectric Breakdown of the regolith); Jody Wilson (LRO/CRaTER observations and radiation albedo); Kathy Duderstadt (Radiation interactions with Earth's atmosphere); J. Bern Blake (Radiation interactions at bodies throughout the solar system); Ken McCracken (GCR radiation, the long-term record); Chuck Smith (Long-term record of magnetic fields in the solar system); Joe Mazur (GCR and SEP radiation interactions and implications); Mark Looper (Modeling of GCR radiation interactions); Reka Winslow (Radiation interactions at the moon and Mercury); Lou Lanzerotti (Radiation interactions at Earth and throughout solar system);; Cora Randall (Radiation interactions in Earth's upper atmosphere); Tony Case (LRO/CRaTER, GCRs, SEPs and LET spectra);Justin Kasper (LRO/CRaTER, GCRs, SEPs and LET spectra); Jamie Anderson (Radiation Environments throughout the Solar System, Europa, Mercury, the moon); Jan Koehler (Univ. Kiel, MSL/RAD connection); Jingnan Guo (Univ. Kiel, MSL/RAD connection); Daniel Matthiae (DLR Cologne, GCR modeling)

6. Schedule of the project (number and duration of meetings). Three week-long meetings at ISSI over the course of 1.5-2 years.

7. Facilities required. Conference room and nominal internet access.

8. Financial support requested from ISSI. We do not require support beyond what would expected for most ISSI teams and the standard use of facilities.

Supplemental Information

Addresses, telephone, fax, email of all participants

Nathan Schwadron, P: 603-862-3451, F: (603) 862-1915, n.schwadron@unh.edu
Harlan Spence, P: (603) 862-0322, F: (603) 862-1915, Harlan.Spence@unh.edu
David Lawrence, P: (240) 228-9615, F: (240) 228-8939, david.j.lawrence@jhuapl.edu
Cary Zeitlin, P: (510) 325-3836, F: (510)612-6142, zeitlin@boulder.swri.edu
Bob Wimmer-Schweingruber, P: +49 431 8803964, F: 49 (0)431 880-3968 wimmer@physik.uni-kiel.de
John Cooper, P: (301) 286-1193, F: 301-286-7194 , John.F.Cooper@nasa.gov
Tim Stubbs, P: (301) 286-1524, F: 301-286-7194 , timothy.j.stubbs.1@gsfc.nasa.gov
Sonya Smith, P: (603) 862-4380, F: (603) 862-1915, sonya.s@unh.edu
Manuel Grande, P: +44 (0) 1970 622624, F: (44)1970 622826, m.grande@aber.ac.uk

References

Bazilevskaya, G. A., et al., Cosmic Ray Induced Ion Production in the Atmosphere, *Space Sci. Rev.* (2008) 137: 149–173

Campins and Krider (1989) *Science*, *245*, 622

Connick, D. E., C. W. Smith, and N. A. Schwadron, Interplanetary Magnetic Flux Depletion During Protracted Solar Minima, *Astrophys. J.*, 727, 8-14, doi:10.1088/0004- 637X/727/1/8, 2011

Dartnell, L. R., et al. (2007), Modelling the surface and subsurface martian radiation environment: implications for astrobiology," *GRL* 34.2.

Fischer, H. M., E. Pehlke, G. Wibberenz, L. J. Lanzerotti, and J. D. Mihalov (1996), High-energy charged particles in the innermost jovian magnetosphere, *Science, 272*, 856-858

Garrett, H. B., I. Katz, I. Jun, W. Kim, A. C. Whittlesey, and R. W. Evans (2012), The jovian charging environment and its effects—A review, *IEEE Trans. Plasma Sci., 40,* no. 2, 144-154, doi: 10.1109/TPS.2011.2171369

Gladstone, G. R., et al. (2012), Far-ultraviolet reflectance properties of the Moon's permanently shadowed regions, *J. Geophys. Res. Planets, 117,* E00H04, doi:10.1029/2011JE003913.

Halekas et al. (2002) *GRL, 29,* 1435

Halekas et al. (2005) *GRL, 32,* L09102

Halekas et al. (2007) *GRL, 34,* L02111

Hassler, D. et al., Mars' Surface Radiation Environment Measured with the Mars Science Laboratory's Curiosity Rover, *Science*, 343, 1244797, 2014

Jordan et al. (2013) *JGR, 118,* 1257

Jordan, A. P., T. J. Stubbs, J. K. Wilson, N. A. Schwadron, H. E. Spence, and C. J. Joyce (2014), Deep dielectric charging of regolith within the Moon's permanently shadowed regions, *J. Geophys. Res. Planets*, *119,* 1806-1821, doi:10.1002/2014JE004648.

Jordan, A. P., T. J. Stubbs, J. K. Wilson, N. A. Schwadron, and H. E. Spence (2015), Dielectric breakdown weathering of the Moon's polar regolith, *J. Geophys. Res. Planet*, *120*, doi:10.1002/2014JE004710.

Lockwood, M, Was UV spectral solar irradiance lower during the recent low sunspot minimum? *J. Geophys. Res., 116,* D16103, 2011

Lucey, P. G., et al. (2014), The global albedo of the Moon at 1064 nm from LOLA, *J. Geophys. Res. Planets, 119,* 1665–1679, doi:10.1002/2013JE004592.

McComas, D. J., R. W. Ebert, H. A. Elliott, and B. E. Goldstein, B. E., J. T. Gosling, N. A. Schwadron, and R. M. Skoug, Weaker Solar Wind from the Polar Coronal Holes and the Whole Sun, Geophys. Res. Lett., 35, L18103-L18108, doi:10.1029/2008GL034896, 2008

Mewaldt, R. A., et al., Record-setting Cosmic-ray Intensities in 2009 and 2010, Astrophys. J., 723, L1-L6, doi:10.1088/2041-8205/723/1/L1, 2010

Park, K., Mak, J. E., and Emmons, L. K., Joint Application of Concentrations and Isotopic Signatures to Investigate the Global Atmospheric Carbon Monoxide Budget: Inverse Modeling Approach, AGU Fall Meeting Abstracts, 5, 2008

Pavlov, A. A., et al. (2012), Degradation of the organic molecules in the shallow subsurface of Mars due to irradiation by cosmic rays, Geophys. Res. Lett. 39, doi:10.1029/2012GL052166

Schultz, P. H., B. Hermalyn, A. Colaprete, K. Ennico, M. Shirley, and W. S. Marshall (2010), The LCROSS cratering experiment, *Science, 330*, 468–472, doi:10.1126/science.1187454.

Schwadron et al. (2014) *Space Weather*, *12,* 622

Schwadron, N. A., et al. (2011), Coronal Electron Temperature from the Solar Wind Scaling Law throughout the Space Age, ApJ, 739, 9, 2011

Schwadron et al. (2012) *JGR*, *117,* E00H13

Spence H. E.. et al. (2010) *Space Sci. Rev., 150(1-4),* 243-284.

Simonelli, D. P., L. Rossier, P. C. Thomas, J. Veverka, and J. A. Burns (2000), Leading/trailing albedo asymmetries of Thebe, Amalthea, and Metis, *Icarus, 147,* 353-365, doi: 10.1006/icar.2000

Wilson, J. K. et al. (2012) *JGR, 117*, E00H23

Zeitlin, C., et al., Measurements of Energetic Particle Radiation in Transit to Mars on the Mars Science Laboratory, *Science*, 340, 1080, 2013

Nathan A. Schwadron
Associate Professor
University of New Hampshire, Physics Department
Institute for the Study of Earth, Oceans and Space, Space Science Center
Morse Hall, Room 350, 8 College Road Durham, NH 03824
Phone: 603-862-3451
Email: n.schwadron@unh.edu

Project Role: **Lead for Radiation Interactions ISSI Team**

Education

- Ph.D., Physics, University of Michigan, Ann Arbor, 1997
  Thesis title: "Theoretical and Observational Studies of Ion Transport in the Heliosphere"
- B. A., Physics with honors, Oberlin College, 1990

Employment

2010-Sept-Present	Assoc. Prof., University of New Hampshire, Durham
2005-Aug, 2010	Assoc. Prof., Boston University
2005	Staff Scientist, Southwest Research Institute, San Antonio

Relevant Project Experience

- LRO/CRaTER PI since 2012.
- Research on particle acceleration and propagation in solar and heliospheric physics
- Studies interaction of radiation with materials and Tissue
- Helped innovate new dosimetry methods and PI of the DoSEN detector development, PI for NASA/NSF/LWS Strategic Capability Earth-Moon-Mars Radiation Environment Module (EMMREM)
- Co-lead of the NSF/FESD Sun-2-Ice project that studies particle acceleration and radiation interactions from the Sun through the Earth system
- NASA/NSF/LWS strategic capability lead of the recently selected Chromosphere-Solar-Wind and Energetic Particle Acceleration (C-SWEPA) Model
- PI of the radiation team for DREAM2, Dynamic Response of the Environments atAsteroids, the Moon, and moons of Mars

Awards, Achievements, and Professional Services

1994-96	National Aeronautics and Space Administration National Graduate Student Research Fellow
2005	Ulysses Achievement Award – 15 Years in Orbit
2008	NASA Group Achievement Award New Horizons Spacecraft Development Team
2010	Outstanding Alumni Award, Dept of Atmospheric Oceanic and Space Science, University of Michigan
2011	NASA Group Achievement Award to the IBEX Science Team
2011	NASA Group Achievement Award to the LRO Mission Operations Team
2011	NASA Group Achievement Award to the Lunar Reconnaissance Orbiter (LRO) Exploration
2012	Elected AAAS Fellow

Select Publications from 230 (h-index = 41)

Schwadron, N. A., L. A. Fisk, and G. Gloeckler, Statistical acceleration of interstellar pick-up ions in co-rotating interaction regions, *Geophys. Res. Lett., 23,* 2871, 1996.

Schwadron, N. A., J. Geiss, L. A. Fisk, G. Gloeckler, T. H. Zurbuchen, and R. von Steiger, Inner source distributions: theoretical interpretation, implications, and evidence for inner source protons, *J. Geophys. Res*., *105*, 7465, 2000.

Schwadron, N. A. and G. Gloeckler, Pickup Ions and Anomalous Cosmic Rays from Dust in the Heliosphere, *Space Science Reviews, 96,* doi 10.1007/s11214-007-9166-6, 2007.

Schwadron, N. A., M. Lee, and D. J. McComas, Diffusive Acceleration at the Blunt Termination Shock, *Astrophys. J.,* 675, num 2, 1584, March 10, 2008.

Schwadron, N. A., et al., Galactic Cosmic Ray Radiation Hazard in the Unusual Extended Solar Minimum between Solar Cycle 23 and 24, *Spaceweather Journal, 8*, doi:10.1029/2010SW000567, 2010.

Schwadron, N. A., Spence, H. E., and Came, R., Does the space environment affect the ecosphere?, EOS Transactions, 92, 297, 2011.

Schwadron, N. A., et al., Lunar Radiation Environment and Space Weathering from the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Journal of Geophysical Research (Planets), 117, 0, 2012

Schwadron, N. A., et al., Does the worsening radiation environment preclude future deep space missions, Space Weather, 12, 622, 2014

Harlan Ernest Spence

Education:	BA, Astronomy and Physics (with distinction), Boston University, 1983
	MS, Geophysics and Space Physics, Univ. Calif., Los Angeles, 1985
	PhD, Geophysics and Space Physics, Univ. Calif., Los Angeles, 1989
Appointments:	
2010 - present	Director, Institute for the Study of Earth, Oceans, and Space, UNH, Durham, NH
2010 - present	Prof. of Physics, University of New Hampshire, Durham, NH
2004 – 2009	Professor of Astronomy, Boston University, Boston, MA (Adjunct 2010-2014)
2002 – 2005	Chairman, Department of Astronomy, Boston University, Boston, MA
1999 – 2004	Associate Professor of Astronomy, Boston University, Boston, MA
1997 – 2004	Scientific Consultant, Physical Sciences, Inc.
1994 – 1999	Assistant Professor of Astronomy, Boston University, Boston, MA
1993 – 2006	Senior Member of the Technical Staff, The Aerospace Corporation
1989 – 1993	Member of the Technical Staff, The Aerospace Corporation

Recent Relevant Publications:

1. Spence, H. E**.**, et al., Cosmic Ray Telescope for the Effects of Radiation on the LRO Mission, *Space Sci. Rev., 150(1-4), 243-284,* 2010.
2. Spence, H. E., et al., Focusing on Size and Energy Dependence of Electron Microbursts From the Van Allen Radiation Belts, *Space Weather, doi:10.1029/2012SW000869*, 2012.
3. Reeves, G. D., H. E. Spence, M. G. Henderson, R. H. W. Friedel, H. O. Funsten, D. N. Baker, S. G. Kanekal, J. B. Blake, J. F. Fennell, S. G. Claudepierre, R. M. Thorne, D. L. Turner, C. A. Kletzing, W. S. Kurth, B. A. Larsen, J. T. Niehof, and S. K. Morley, Electron Acceleration in the Heart of the Van Allen Radiation Belts, *Science, DOI: 10.1126/science.1237743*, 2013.
4. Spence, H. E., et al., Science Goals and Overview of the Energetic Particle, Composition, and Thermal Plasma (ECT) Suite on NASA's Radiation Belt Storm Probes (RBSP) Mission, *Space Sci. Rev., DOI: 10.1007/s11214-013-0007-5*, 2013.
5. Spence, H. E., C. Joyce, M. D. Looper, N. A. Schwadron, S. S. Smith, L. W. Townsend, and J. K. Wilson, Relative contributions of Galactic Cosmic Rays and lunar proton "albedo" to dose and dose rates near the Moon, Space Weather, DOI: 10.1002/2013SW000995, 2013.
6. Joyce, C. J., N. A. Schwadron, J. K. Wilson, H. E. Spence, J. C. Kasper, M. Golightly, J. B. Blake, L. W. Townsend, A. W. Case, E. Semones, S. Smith, and C. J. Zeitlin, Radiation Modeling in the Earth and Mars Atmospheres Using LRO/CRaTER with the EMMREM Module, Space Weather, DOI: 10.1002/2013SW000997, 2014.
7. Spence, H. E., G. D. Reeves, and R. Kessel, An Overview of Early Radiation Belt Results From NASA's Van Allen Probes Mission, in "Waves, Particles and Storms in Geospace", Oxford University Press, accepted, 2014.

Scientific, Technical, and Management Performance on Relevant Prior Research Efforts:
Spence is PI or co-I on numerous NSF, NASA, DARPA, and DOD theory, analysis, hardware, and mission grants. He is author or co-author of over 200 refereed publications and 7 NAS reports, spanning space physics and geophysics topics. He was co-Investigator on two energetic particle instruments on the NASA Polar satellite and is co-Investigator on a suite of particle instruments on the upcoming Magnetospheric Multiscale (MMS) Mission. He was Principal Investigator on a cosmic ray sensor launched on NASA's Lunar Reconnaissance Orbiter (LRO) in June 2009, and is Principal Investigator of a comprehensive charged particle instrument suite that is providing key measurements for NASA's Van Allen Probes mission launched in late September 2012. Spence is also co-Principal Investigator of two NSF Cubesat missions (FIREBIRD I and II) aimed at exploring the physics of relativistic electrons which reach Earth's upper atmosphere from the radiation belts, and also on a multi-institution, interdisciplinary project supported by NSF's new Frontiers in Earth Systems Dynamics program.

David J. Lawrence
Principal Professional Staff
Johns Hopkins University Applied Physics Laboratory
11100 Johns Hopkins Drive, Laurel, MD

Phone: 240-228-9615
Email: David.J.Lawrence@jhuapl.edu

Project Role: **Interactions at the moon and bodies throughout the solar system**

Education

- Ph.D., Physics, Washington University, St. Louis, MO (1996)
- M.A., Physics, Washington University, St. Louis, MO (1992)
- B.S., Physics and Math (Summa Cum Laude), Texas Christian Univ., Ft. Worth, TX (1990)

Employment

2008 – Present: JHU/APL, Principal Professional Staff, SRE, Space Department.
2005 – 2008: Los Alamos National Laboratory (LANL), Section Leader of Gamma-Ray/Neutron Section of International, Space, and Response Group (ISR-1)
June 2006 – April 2007: LANL, Director of Center for Space Science and Exploration
Spring 2005: Visiting Scientist, Rutherford Appleton Laboratory, United Kingdom
1999 – 2008: Technical Staff Member, Group ISR-1, Los Alamos National Laboratory
1996 – 1999: Post-doctoral Research Associate, Los Alamos National Laboratory

Relevant Project Experience

- PI for NASA Maturation of Instruments for Solar System Exploration grant to develop a miniature gamma-ray spectrometer
- Participating Scientist for the NASA Dawn mission to the asteroid Vesta.
- Participating Scientist for the NASA MESSENGER Mission to Mercury.
- Principal Investigator for the SAVE Advanced Neutron Detector and the SABRS ZN Detector, which are DOE sponsored space-based treaty verification missions.
- PI for numerous NASA and internal science and instrument development grants.
- Design, development and implementation of spaceflight instrumentation.
- Analysis of data from spaceflight missions (Lunar Prospector, Mars Odyssey, Deep Space 1, SMART 1/D-CIXS).
- Particular scientific interests include studies of solar system and planetary elemental abundances along with magnetospheric and space physics.

Awards, Achievements, and Professional Services

NASA Group Achievement Award for Lunar Prospector, Deep Space 1, MESSENGER, Dawn, 1999, 2008, 2013.
JHU/APL Outstanding Publication Award, 2009, 2014.
Los Alamos National Laboratory Distinguished Performance Award, 1998, 2002, 2005.
NASA Graduate Student Researchers Fellowship, 1994-1996.
Washington University McDonnell Graduate Student Fellowship, 1990-1992.
Graduated Summa Cum Laude at Texas Christian University, 1990.
Phi Beta Kappa, Texas Christian University, 1990.

Select Publications from more than 120

David J. Lawrence, et al., Comprehensive survey of energetic electron events within Mercury's magnetosphere using data from the MESSENGER Neutron and Gamma-Ray Spectrometers, J. Geophys. Res. Space Physics, in press, 2015.
David J. Lawrence, et al., Bulk Hydrogen Abundances in the Lunar Highlands: Measurements from Orbital Neutron Data, Icarus, 10.1016/j.icarus.2015.01.005, in press, 2015.
David J. Lawrence et al., Detection of 0.5 – 8 MeV Neutrons Near Mercury: Evidence for a Solar Origin, Journal of Geophysical Research: Space Physics, 119, 5150 – 5171, 10.1002/ 2013JA019037, 2014.
David J. Lawrence et al. Evidence for Water Ice Near Mercury's North Pole from MESSENGER Neutron Spectrometer Measurements, Science, 339, 292, 10.1126/science.1229953, 2013.
David J. Lawrence, et al., Constraints on Vesta's Elemental Composition: Fast Neutron Measurements by Dawn's Gamma Ray and Neutron Detector, Meteoritics and Planetary Science, 10.1111/maps.12187, 2013.
David J. Lawrence, Water on the Moon, Nature Geoscience, News and Views, #4, 585 – 588, 10.1038/ngeo1251, 2011.

Cary J. Zeitlin
Principal Scientist
Southwest Research Institute
Earth, Oceans, and Space Department
8 College Road Durham, NH 03824
Phone: 510-325-3836
Email: cary.zeitlin@gmail.com

Project Role:

Education

- Ph.D., Physics, University of California, Davis, 1988, in experimental high-energy physics
- A. B., Physics with honors, University of California, Berkeley, 1981

Employment

2008-April-Present	Principal Scientist, Southwest Research Institute
1991-Nov to 2008-April	Staff Scientist, Lawrence Berkeley National Laboratory, Berkeley
1988-Nov to 1991-Nov	Postdoctoral Research Associate, University of Oregon, Eugene, at SLAC

Relevant Project Experience

- Over 30 years working with energetic particle detectors and analysis of data from experiments ranging in size from very large (SLD and TPC/Two-Gamma at SLAC) to very compact (MARIE, RAD for MSL, RAD for ISS), in high-energy physics, nuclear physics, and radiation biophysics.
- Principal Investigator, Martian Radiation Environment Experiment on Mars Odyssey (2002-2005).
- Seven years of experience in experimental high-energy physics (1984-1991).
- Radiation dosimetry with silicon detectors, ionization chambers, tissue-equivalent proportional counters.
- Neutron measurements with liquid and plastic scintillators, including boron-loaded plastic.

Awards, Achievements, and Professional Services

March 2014	Elected to the National Council on Radiation Protection
October 2013	NASA Group Achievement Award presented to MSL-RAD Team.
July 2008	Named Co-Investigator on the RAD for MSL instrument.
June 2007	Organizer, NASA Space Radiation Summer School, Brookhaven National Lab
June 2005	NASA Group Achievement Award presented to MARIE Team.
May 2002	Named by NASA as Principal Investigator of the Martian Radiation Environment Experiment
February 2002	Outstanding Performance Award, LBNL Life Sciences Division
January 1996	Outstanding Performance Award, LBNL Life Sciences Division

Selected Publications

Zeitlin, C., et al., Measurements of Energetic Particle Radiation in Transit to Mars on the Mars Science Laboratory, Science 340, 1080 (2013).
Zeitlin, C., et al., Measurements of galactic cosmic ray shielding with the CRaTER instrument, Space Weather 11, 284-296 (2013).
Zeitlin, C., Physical Interactions of Charged Particles for Radiotherapy and Space Applications, Health Physics 103, 540–546 (2012).
Zeitlin, C., et al., Fragmentation of 14N, 16O, 20Ne, and 24Mg Nuclei at 290 to 1000 MeV/nucleon, Phys. Rev. C 83 (2011), 034909
Zeitlin, C., et al., Mars Odyssey Measurements of Galactic Cosmic Rays and Solar Particles in Mars Orbit, 2002 to 2008, Space Weather, 8, S00E06, doi:10.1029/2009SW000563 (2010).
Zeitlin, C., et al., Development and Evaluation of the Combined Ion and Neutron Spectrometer, Nucl. Instru. Meth. B, 267 (2009) 125-138.
Zeitlin, C., et al., Fragmentation Cross Sections of Medium-Energy ^{35}Cl, ^{40}Ar, and ^{48}Ti on Elemental Targets, Phys. Rev. C 77 (2008) 034605.
Zeitlin, C., et al., Shielding Experiments with High-Energy Heavy Ions for Spaceflight Applications, New J. Phys. 10 (2008) 075007.
Zeitlin, C., S. Guetersloh, L. Heilbronn, J. Miller, L. Sihver, C. La Tessa, D. Mancussi, Comparisons of Fragmentation Spectra Using 1 GeV/amu ^{56}Fe Data and the PHITS Model, Radiat. Meas. 43 (2008) 1242.
Zeitlin, C., et al., Fragmentation Cross Sections of 290 and 400 MeV/nuc ^{12}C Beams on Elemental Targets, Phys.Rev. C76, (2007) 014911.
Zeitlin, C., et al., Fragmentation Cross Sections of 28Si at Beam Energies from 290A to 1200A MeV, Nucl. Phys. A, 784 (2007) 341.
Zeitlin, C., et al., Radiation Tests of the Extravehicular Mobility Unit Spacesuit for the International Space Station Using Energetic Protons, Radiat. Meas., 41 (2006) 1158.
Zeitlin, C., S. B. Guetersloh, L. H. Heilbronn, J. Miller, Measurements of materials shielding properties with 1 GeV/nuc 56Fe, Nucl. Instru. Meth. B 252 (2006) 308.
Zeitlin, C., et al., Overview of the Martian Radiation Environment Experiment, Adv. Space Res., 33 (2004) 2204.
Zeitlin, C., A. Fukumura, L. Heilbronn, Y. Iwata, J. Miller, T. Murakami, Fragmentation cross sections of 600 MeV/nucleon 20Ne on elemental targets, Phys. Rev. C64 (2001) 024902.
Zeitlin, C., L. Heilbronn, J. Miller, Detailed characterization of the 1087 MeV/nucleon Iron-56 beam used for radiation biology at the Alternating Gradient Synchrotron, Radiat. Res. 149 (1998) 560.
Zeitlin, C., et al., Heavy fragment production cross sections from 1.05 GeV/nucleon ^{56}Fe in C, Al, Cu, Pb, and CH_2 targets, Phys. Rev. C56 (1997) 388.

TIMOTHY J. STUBBS

Research Space Scientist, Solar System Exploration Division
NASA Goddard Space Flight Center, Code 695, Greenbelt, Maryland, United States.

EDUCATION

- 1998 – 2002: Ph.D., Space Physics (CASE studentship), Imperial College, London, and Rutherford Appleton Laboratory, Oxfordshire, UK.
- 1994 – 1998: MSci., (Hons) Physics, Imperial College, London, UK.

EMPLOYMENT

- Research Space Scientist, NASA Goddard Space Flight Center, 2012 – present.
- Associate Research Scientist, University of Maryland, Baltimore County, 2012.
- Assistant Research Scientist, University of Maryland, Baltimore County 2005 –2012.
- Resident Research Associate, National Research Council, NASA/GSFC, 2002 – 2005.
- Research Assistant, Imperial College, London, 2002.

RESEARCH SPECIALIZATION

Current research focuses on how the space environment interacts with the regolith-covered surfaces of airless bodies in the Solar System, including such processes as surface/subsurface charging, the production and dynamics of exospheric dust, illumination conditions, and the stability and chemical modification of sequestered volatiles.

RELEVANT PROJECT EXPERIENCE

- Lunar Atmosphere and Dust Environment Explorer (LADEE) Guest Investigator (GI), 2013 – present
- Solar System Exploration Research Virtual Institute (SSERVI) DREAM2 Co-Investigator, 2014 – present
- NASA Lunar Science Institute (NLSI) DREAM Co-Investigator, 2009 – 2013
- LRO Cosmic Ray Telescope for the Effects of Radiation (CRaTER) Science Team, 2008 – present
- Lunar Reconnaissance Orbiter (LRO) Participating Scientist, 2008 – 2012

AWARDS

- NASA Exceptional Achievement for Science: The LRO Science Mission Team, 2013.
- NASA Group Achievement Award: Lunar Reconnaissance Orbiter (LRO) Team, 2010.
- Early Career Fellowship (ROSES-2008), NASA Planetary Science Division, 2009.
- Outstanding Student Paper Award, American Geophyscial Union, 2000.

SELECTED PUBLICATIONS

Jordan, A. P., T. J. Stubbs, J. K. Wilson, N. A. Schwadron, and H. E. Spence (2015), Dielectric breakdown weathering of the Moon's polar regolith, *J. Geophys. Res. Planets*, 120, 210–225. doi: 10.1002/2014JE004710.

Jordan, A. P., T. J. Stubbs, J. K. Wilson, N. A. Schwadron, H. E. Spence, and C. J. Joyce (2014), Deep dielectric charging of regolith within the Moon's permanently shadowed regions, *J. Geophys. Res. Planets*, 119, doi:10.1002/2014JE004648.

Stubbs, T. J., et al. (2014), Dependence of lunar surface charging on ambient solar wind plasma conditions and solar irradiation, *Planet. Space Sci.*, 90, 10–27.

Zimmerman, M. I., W. M. Farrell, and T. J. Stubbs (2013), Recursive plasma wake formation on the Moon and its effect on polar volatiles, Icarus, 226, 1, 992–998.

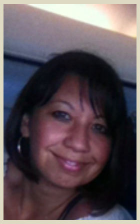
Jordan, A. P., T. J. Stubbs, C. J. Joyce, N. A. Schwadron, H. E. Spence, and J. K. Wilson (2013), The formation of molecular hydrogen from water ice in the lunar regolith by energetic charged particles, J. Geophys. Res. Planets, 118, doi:10.1002/jgre.20095.

Zimmerman, M. I., W. M. Farrell, T. J. Stubbs, et al. (2011), Solar wind access to lunar polar craters: Feedback between surface charging and plasma expansion, *Geophys. Res. Lett.*, 38, L19202, doi:10.1029/2011GL048880.

Spence, H. E., et al. (2010), CRaTER: The Cosmic Ray Telescope for the Effects of Radiation Experiment on the Lunar Reconnaissance Orbiter mission, *Space Sci. Rev.*, 150, 1–4, 243–284, doi:10.1007/s11214-009-9584-8.

Halekas, J. S., G. T. Delory, R. P. Lin, T. J. Stubbs, and W. M. Farrell (2009), Lunar surface charging during solar energetic particle events: Measurement and prediction, *J. Geophys. Res.*, 114, A05110, doi:10.1029/2009JA014113.

Halekas, J. S., et al. (2007), Extreme lunar surface charging during space weather events, *Geophys. Res. Lett.*, 34, L02111, doi:10.1029/2006GL028517.



Sonya Smith

Project Manager
University of New Hampshire, Physics Department
Institute for the Study of Earth, Oceans and Space, Space Science Center
Morse Hall, Room 352, 8 College Road Durham, NH 03824
Phone: 603-862-1372
Email: sonya.s@unh.edu

Project Role: **Project Manager for Radiation Interactions ISSI Team**

Education

- B. S, M.B.A Almeda University, 2009

Employment

2010-April-Present	Project Manager, University of New Hampshire, Durham
2005-April, 2010	Assistant Director Space Physics, Boston University, Boston
2000-Jan-Aug 2003	Associate Director, Grant and Contract Accounting, Boston University, Boston
1990-Sept-Jan2000	Grant Specialist, Office of Naval Research, Boston

Relevant Project Experience

- LRO/CRaTER Project Manager/Calibration since 2009.
- RBSP ECT Project Manager since 2009
- MMS EPD Project Manager/Calibration of FEEPs instrument
- DoSEN Projectect Manager
- Project Manager on NSF/FESD Sun-2-Ice project that studies particle acceleration and radiation interactions from the Sun through the Earth system

Awards, Achievements, and Professional Services

2010	NASA Group Achievement Award to the LRO Mission Operations Team
2011	NASA Group Achievement Award to the LRO Mission Operations Team
2011	NASA Group Achievement Award to the Lunar Reconnaissance Orbiter (LRO) Exploration
2012	RBSP Education and Public Outreach Award
2013	NASA Group Achievement Award to the LRO Science Mission Team
2013	NASA Group Achievement Award to the Van Allen Probes Project Team

Select Publications

Schwadron, N. A., et al., Galactic Cosmic Ray Radiation Hazard in the Unusual Extended Solar Minimum between Solar Cycle 23 and 24, *Spaceweather Journal, 8*, doi:10.1029/2010SW000567, 2010.

Schwadron, N. A., et al., Lunar Radiation Environment and Space Weathering from the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Journal of Geophysical Research (Planets), 117, 0, 2012

Schwadron, N. A., et al., Does the worsening radiation environment preclude future deep space missions, Space Weather, 12, 622, 2014

Name: ***Manuel Grande, Ph.D.***
Position: ***Head of Solar System Physics***
Organization: IMAPS Aberystwyth University, Penglais, STY23 3B Aberystwyth, UK
Nationality: UK
Phone: (44)1970 622624, **Fax:** (44)1970 622826, **Mobile:** (44) 7881 858945 **E-mail**: m.grande@aber.ac.uk

Biography:
PROFESSOR MANUEL GRANDE is Head of Solar System Physics, having just finished his term as Director of the Institute of Mathematics and Physics, Aberystwyth University, UK, and a visiting professor at the Open University, UK. As well as PI for the X-ray spectrometers C1XS on Chandrayaan-1 and D-CIXS on SMART-1, he is Co-PI on BepiColombo SIXS and Cluster/Rapid, and has Co-I roles in JUICE, Bepicolombo(4 instruments), Cassini/CAPS and Cassini/CDA, Cluster/Peace, POLAR Cammice and Ceppad, IMAGE MENA, Venus Express ASPERA4, Mars Express ASPERA3, IMEX, and the Japanese SELENE Lunar Mission, and a number of ongoing proposals for upcoming space plasma and planetary missions.

He is currently Chair of the Institute of Physics of Wales, and Europlanet Coordinator for Scientific Dissemination. He has been President of the European Geoscience Union for Planetary Science and has served on the council of the Royal Astronomical Society, the Executive Committee of the French national Centre for Plasma Physics Data (CDPP). He has served on a number of ESA and NASA committees, and the council of the Royal Astronomical Society. He has some 140 refereed publications over a wide range of topics, having received his PhD (on cosmic ray detection) from Bristol University in 1983. He is UK representative on COSPAR, and Vice Chair of the COSPAR panel on Space Weather. His main scientific interests are energetic particles in planetary magnetospheres, including the Earth, and planetary surfaces.

1982-83 Bristol Post Doc Electron Microscopy
1983-1986 Senior Research Associate Rutherford Appleton Lab (RAL)
1986 -1997 Senior Scientific officer, RAL
1995-2000 Principal Research Fellow Warwick University
1997-2004 Principal Scientific Officer (Grade 7) RAL
2000 Honorary Professor Warwick University
2005-2006 Individual Merit (Band 2) CCLRC fellow (RAL)
2005 Visiting Professor Open University
2006 -2010 Established Professor of Solar System Physics, Aberystwyth University
2010-2012 Director of Institute of Maths and Physics, Aberystwyth University
2012- Present Head of Solar System Physics, Director of International and External Affairs, Aberystwyth Univ

M Grande Selected Refereed Publications

1. Forster, D. R.; Denton, M. H.; **Grande, M**.; Perry, C. H., Inner magnetospheric heavy ion composition during high-speed stream-driven storms Journal of Geophysical Research: Space Physics, Volume 118, Issue 7, pp. 4066-4079, **2013**
2. **Grande, M**., and T. M. Knight (2013), The Future of Spacecraft Radiation Design: A Workshop at Aberystwyth University, UK, 28–30 November 2012, Space Weather, 11, doi:10.1002/swe.20102. **2013**
3. I. C. Whittaker , G. D. Dorrian, A. Breen, **M. Grande**, S. Barabash In-Situ observations of a co-rotating interaction region at Venus identified by IPS and STEREO – accepted subject to minor change Solar Physics **2010**
4. Walker, TE; Smith, DR; Howe, CJ; Kellett, BJ; Sreekumar, P; **Grande, M**, The effects of radiation damage on the spectral resolution of the Chandrayaan-1 X-ray Spectrometer, SPIE Vol 7742 No 774215 **2010**
5. **Grande, M.,** Maddison, B.J., Howe, C.J., Kellett, B.J., Swinyard, B., Sreekumar, P., Huovelin, J., Crawford, I.A., Duston, C.L., Smith, D., Cook, A., Wilding, M., Shrivastava, A., Narendranath, S., Joy, K.H., Gasnaut, O., Maurice, S., Holland, A., Rothery, D.A., Anand, M., Russell, S.S., Goswami, N., Bhandari, N., Lawrence, D., Fernandes, V.A., Wieczorek, M., Okada, T., Koschney, D., Foing, B., Pieters, C., 2009. The C1XS X-Ray Spectrometer on Chandrayaan-1, Planet. Space Sci. Volume: 57.7 Pages: 717-724 **2009**.
6. Worms JC, Lammer H, Barucci A, Beebe R, Bibring JP, Blanc M, Bonnet R, Brucato JR, Chassefiere E , Coradini A , Crawford I, Ehrenfreund P, Falcke H .Gerzer R), Grady M , **M. Grande,** Haerendel G, Horneck G, Koch B, Lobanov A, Lopez-Moreno JJ, Marco R, Norsk P, Rothery D, Swings JP, Tropea C, Ulamec S, Westall F, Zarnecki J, ESSC-ESF Position Paper Science-Driven Scenario for Space Exploration: Report from the Europe Space Sciences Committee (ESSC). Astrobiology, Volume 9, Issue 1,: 23-41: **2009**
7. Okada, T., **M. Grande**, J. Oberst and N. Namiki. "Lunar science with the SELENE "Kaguya" mission - Prelaunch studies - Preface." Earth Planets and Space **60**(4): 241-241.**2008**

John F. Cooper Goddard Space Flight Center Principal Investigator

PRESENT POSITION (FROM JAN. 24, 2005)

Chief Scientist, Space Physics Data Facility, Heliospheric Physics Laboratory, Code 672, NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771

EDUCATION

B.S., Physics, Georgia Institute of Technology, Atlanta, Georgia, 1972
M.S., Physics, University of Chicago, Chicago, Illinois, 1977
Ph.D., Physics, University of Chicago, Chicago, Illinois, 1983

PREVIOUS EXPERIENCE

1990 to 2005	Senior Research Scientist, Raytheon ITSS, SSDOO Project, NASA Goddard Space Flight Center
1988 to 1990	Senior Research Fellow, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana
1985 to 1988	Postdoctoral Research Fellow, Space Radiation Laboratory, California Institute of Technology, Pasadena, California
1983 to 1985	Postdoctoral Research Fellow, Max Planck Institute for Extraterrestrial Physics, Munich, Germany

RESEARCH INTERESTS

Dr. Cooper is responsible as Chief Scientist within the Space Physics Data Facility at NASA's Goddard Space Flight Center for science and data archiving interactions with operational geospace and heliospheric missions, while also having strong research interests in convergent science themes related to space physics for NASA's Heliophsyics and Planetary Science. He also leads the NASA Heliophysics Virtual Energetic Particle Observatory (VEPO). His research interests focus on space environment interactions icy bodies of the outer solar system including Kuiper Belt Objects and moons & rings of Saturn and Jupiter.

He is a member of the NASA Goddard science team, DREAM2 – Dynamic Response of Environments at Asteroids, the Moon, and Moons of Mars, for the Solar System Exploration Research Virtual Institute. He has been Principal Investigator on many NASA data and modeling research projects relating to Galileo Orbiter energetic particle data, moon-magnetosphere interactions for the Galilean moons in the Jupiter system, cosmic ray flux modeling and icy body interactions for the outer heliosphere, and solar wind interactions with the Moon.

Selected Publications

Lipatov, A. S., J. F. Cooper, E. C. Sittler Jr., R. E Hartle, The light (H+, H2+, He+) and heavy (Na+) pickup ion dynamics in the lunar plasma environment: 3D hybrid kinetic modeling, Adv. Sp. Res., 52, 1929–1938, 2013.

Cooper, J. F., and 17 co-authors, Space Weathering Investigations Enabled by NASA's Virtual Heliophysical Observatories, in Space Weather – the Space Radiation Environment, AIP Conf. Proc. 1500, 204 – 209, doi: 10.1063/1.4768767, 2012.

Lipatov, A.S., J. F. Cooper, et al., Effects of Na+ and He+ pickup ions on the lunar-like plasma environment: 3D hybrid modeling, Adv. Sp. Res., 50, 1583–1591, 2012.

Schwadron, N. A., T. Baker, B. Blake, A. W. Case, J. F. Cooper, M. Golightly, C. Joyce, J. Kasper, K. Kozarev, J. Mislinski, J. Mazur, A. Posner, O. Rother, S. Smith, H. E. Spence, L. W. Townsend, J. Wilson, and C. Zeitlin, The Lunar Radiation Environment from the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), J. Geophys. Res. - Planets, 117, E00H13, doi:10.1029/ 2011JE003978, 2012.

Cooper, J. F., E. R. Christian, J. D. Richardson, and C. Wang, Proton irradiation of Centaur, Kuiper Belt, and Oort Cloud Objects at Plasma to Cosmic Ray Energy**,** *Earth, Moon, and Planets*, 92(1-4), 261-277, 2003.

CV Robert F. Wimmer-Schweingruber

Date of birth: August 15, 1963,
Nationality: Swiss-Canadian dual citizen
Address: Institute for Experimental and Applied Physics (IEAP),
CAU University of Kiel, 24098 Kiel, Germany
Phone: (+) 49 (0)431 880-3964, Fax: (+) 49 (0)431 880-3968,
Email: `wimmer@physik.uni-kiel.de`
Home address: Bernstorffweg 22, D-24229 Strande, Germany
Matura (university entrance exam): 1982 in Köniz, Switzerland
Studies: Physics (major), Mathematics (minor), Astronomy (minor) at the University of Bern, Switzerland
Diploma: in theoretical physics, 1991, Prof. Dr. H. Leutwyler, Thesis title: "Dynamics of the Scalar Field in the Slow Roll Over Phase of the Inflationary Universe"
PhD: in experimental physics, 1994, Prof. Dr. H. Balsiger & Prof. Dr. J. Geiss, Thesis title: "Oxygen, Helium, and Hydrogen in the Solar Wind: SWICS/Ulysses Results"
Habilitation (venia legendi) in experimental physics: 2001, Thesis title: "Lunar Soils: A Long-Term Archive for the Galactic Environment of the Solar System?"

Scientific activity after PhD:
1995 - 1996: Post-Doc, University of Maryland, College Park, MD, USA
1996 - 2001: Research Fellow, University of Bern, Switzerland, teaching at university level ("Lehrauftrag")
2001 - 2002: Senior Scientist (Oberassistent), University of Bern, Switzerland, teaching at university level ("Lehrauftrag")
since 2002: Full, tenured professor (C4) at the IEAP, University of Kiel, Germany
2004 - 2006, 2010 - 2012: 2-year terms as executive director IEAP
2008 - 2010: 2-year term as Chair of the Physics Section

Instrument-Team memberships:
PI: SOHO/CELIAS
Co-PI: Solar Orbiter EPD (SOLO/EPD)
Lead-CoI: STEREO/PLASTIC, Mars Science Laboratory/RAD, Exomars/IRAS, SOLO/EPD EPT, HET, STEP, and SIS
CoI: Ulysses/SWICS, Wind/MASS, ACE/SWICS & SWIMS, SOLO/MAG, /RPW, /SWA

Services and Awards:
1992: NASA Group Achievement Award Ulysses Jupiter Flyby
1998: NASA Group Achievement Award Advanced Composition Explorer
2002 - 2006: Co-Chair ESA Solar Orbiter Payload Working Group
2003 - 2007: member ESA Solar Orbiter Science Definition Team
2004 - 2006: 3-year term as member ESA Solar Science System Working Group
2004 - 2007: member NASA Solar Sentinels Science Definition Team
2005/2007: member/chair ESA RSSD Advisory/Evaluation Committee
2006: Recipient of the Greinacher prize
2007: member ESA/NASA HELEX Joint Science and Technology Definition Team
2008 - 2009: member ESA Cross Scale Science Study Team (SST)
2013: NASA Group Achievement Award Mars Science Laboratory
convenor/chair of special sessions of the American Geophysical Union, etc.
chair/member SOC of several international conferences/workshops
Referee for Adv. Space Sci., A&A, ApJ, JGR, GRL, Science, Space Sci. Rev., etc.

NASA's ADS database currently shows 324 publications under my name.