Living With a Star
Exploration Initiative Study

M.J. Golightly

and

M. Guhathakurta

Background

- Request from the Director, NASA Sun-Earth Connections Program to identify areas in which the Living With a Star (LWS) program can contribute to the successful implementation of this new "space exploration vision."
  - Develop a list of space physics/weather areas requiring further research or study in order to support the design and implementation of manned lunar and Mars missions
  - SEC this information to help identify how existing and future LWS missions and research can support these exploration goals

Expected Study Product

- Report to Director, NASA Sun-Earth Connections Program identifying
  - space physics/weather areas requiring further research or study in order to support the design and implementation of manned lunar and Mars missions
  - the areas addressed by currently designed LWS missions
  - the areas that are (potentially) addressed by future LWS missions
  - recommendations on ways to address outstanding areas/problems not currently addressed by the LWS program

Approach

- Establish a small team for short, focused study including experts in experts
  - Space radiation environment
  - Space radiation measurements
  - Space weather climate and transient modeling
  - Operational space weather forecasting
  - Astronaut radiation health and safety

Members

Name	Affiliation	Role
MEMBERS Michael Golightly	NASA Johnson Space Center	Chair, Manned Space Flight Support
Frank Cucinotta	NASA Johnson Space Center	Astronaut Radiation Safety
Thomas Gombozi	University of Michigan	Space Plasma Modeling
Paul Westmeyer	NASA Headquarters/Code SE	Exploration Systems
Robert Lin	University of California--Berkeley	High-energy Solar Physics
John Bieber	University of Delaware/Bartol Research Institute	Galactic Cosmic Rays
Steve Kahler	Air Force Research Laboratory	Solar Physics, Solar Energetic Particle Events
Joseph Kunches	NOAA Space Environment Center	Space Weather, Space Weather Forecasting
Janet Barth	NASA Goddard Space Flight Center	Radiation Environment Impacts to Spacecraft
Larry Townsend	University of Tennessee	Heavy-Ion Radiation Physics and Transport
Jim Garvin	NASA Headquarters /Code SE	Mars Exploration
Dick Mewaldt	California Institute of Technology	Galactic Cosmic Rays, Solar Energetic Particle Events
Neil Murphy	NASA Jet Propulsion Laboratory	Coronal Mass Ejections
Walter Schimmerling	NASA Headquarters /Code U	Space Radiation Health
John Wilson	NASA Langley Research Center	Heavy-Ion Radiation Physics and Transport /Mars Mission Radiation Exposure
Dona Fender	NASA Headquarters /Code T	Exploration Initiative
Glenn Mason	University of Maryland	Radiation Belts, Galactic Cosmic Rays
Jim Watzin	NASA Goddard Space Flight Center	Lunar and Mars Science/Lunar Robotics Program
EX-OFFICIO Lika Guhathakurta	NASA Headquarters /Code S	Headquarters Point-of-Contact
Chris St.Cyr	NASA Goddard Space Flight Center	Living With a Star Senior Project Scientist
Raymond Hinkle	NASA Headquarters /Code SS	Exploration System Engineer

Approach

- Conduct a brief workshop
  - 05-06 Apr 2004
  - Day 1: series of contributed talks
    - background
    - exploration missions issues
    - space environment--current definition and areas requiring further research
    - radiation protection and operations during exploration class missions

Approach

- Conduct a brief workshop
  - Day 2: breakout into small groups to discuss
    - areas requiring further research
    - infrastructure required to carry out research
    - areas currently covered by planned LWS program
    - gaps between research needs and planned programs

Identified Research Needs--SEPs

- Fully characterize measured SEP spectra, including uncertainties
  - Protons, He, HZE (spatially correlated)
  - Extend spectral measurements to high energies
    - > 100 MeV for protons
    - > 30 MeV/n for HZE
  - Temporal variations and evolution of isotropy
  - Ultra-heavy species energy spectra
    - Z > 26
    - Identify to energy range of the spectral “knee”
- Solar cycle dependence has to be considered
  - Solar cycle dependence needs to be understood at time scales finer that just “solar maximum” and “solar minimum”
- Develop a plausible but physically realistic worst-case event model
  - Statistical and/or deterministic approaches
  - Need to better characterize cumulative event fluences
- Measurements characterizing the azimuthal and radial SEP flux gradients
  - Requires multipoint measurements within 1 AU
- Continued CME and SEP synoptic observations
  - SOHO, SMEI
  - Space-based stereoscopic coronagraph observations are needed to better characterize the three-dimensional evolution and propagation of CMEs (e.g. STEREO)
  - Continue WIND EPACT instrument (provides spectral measurements of ultraheavy ions)
  - Cross-calibrate measurements throughout heliosphere
- Charged particle spectrometer development program for measuring high energy protons and helium ions and HZE particles
  - For use on crew transfer vehicles, on crew surface exploration vehicles, and heliospheric monitoring platforms
- Full exploitation of existing data archives
  - e.g., charged particle measurements from HELIOS and Voyager
- Shock models
  - When will they arrive
  - What particles/spectra are incorporated
  - What is the particle content, if any, of the associated CMEs
  - New heliospheric multipoint measurements to use in validating new 2D/3D CME/shock evolution models

Identified Research Needs--GCR

- GCR environment model for spacecraft/mission
  - Model energy spectra and composition
    - 10 MeV/n to 10 GeV/n
    - $1 \leq Z \leq 28$, $Z > 30$
  - Dynamic
    - Physics-based model of solar modulation
      - Can use data on solar variations, CMEs, GMIRs, current sheet tilt, and B-field for future predictions
    - Solar cycle variations over a complete solar cycle
    - Radial gradient
    - long-term temporal variations (beyond present decade)
      - developed from archival records of paleo Be-10 measurements
  - An error for any species at any energy and time of not more than 10%
  - Data assimilation
    - capability to predict GCR intensities 1-2 years into the future
  - End-to-end validation
    - Measure and model GCR and secondary neutron spectrum
      - In space (e.g., L1)
      - Above lunar surface
      - On Mars' surface
  - Best estimates of solar maximum and minimum conditions
  - Worst-case GCR spectrum
    - Maunder minimum
    - Interstellar spectrum

- Continued synoptic measurements
  - ACE: $Z > 2$
  - Ulysses, IMP-8, and or SAMPEX: protons, He
  - Voyager
  - Balloons: protons and He to high energy
  - Ground-based neutron monitors

Identified Research Needs— *In Situ* Measurements

- Radiation environment measurements at Mars orbit
  - SEP primary and secondary radiation
    - Protons
      - 10-1000 MeV
      - designed for accurate measurements at very high count rates
      - designed to operate for long periods (≥ 3 years)
      - measurements need to coincide with surface SEP measurements
- Radiation environment measurements on Mars surface
  - GCR and secondary charged-particles
    - Heavy ion charge and LET
      - Z = 3 to 28
      - LET = 100 – 30000 MeV•g/cm²
    - Proton and He energy spectrum
      - 10-500 MeV/n
    - 1-hour temporal resolution
  - Secondary neutrons from Mars atmosphere and surface albedo
    - Energy spectrum
    - Thermal neutron flux
    - Epithermal neutron flux
    - 1-100 MeV with 20% resolution in energy
    - distinguish forward from backward traveling neutrons
    - 1-hour temporal resolution
- Radiation environment measurements on Mars surface (cont).
  - Multiple measurements to characterize temporal and spatial variability
    - measure radiation environment changes over a solar cycle
    - measure radiation environment changes with locality (variation in surface composition and altitude)
  - SEP primary and secondary radiation
    - Protons
      - 10-1000 MeV
      - designed for accurate measurements at very high count rates
      - designed to operate for long periods (≥ 3 years)
    - Neutrons
      - 20-100 MeV (listed in Turner-Cucinotta presentation as “high energy”—does this characterize desired energy range?)
      - designed for accurate measurements at very high count rates
      - designed to operate for long periods (≥ 3 years)

Infrastructure Needs—*In Situ* Measurements

- Mars Surface
  - SEP + GCR/LET + neutron spectrometers
- Lunar Orbit
  - SEP + GCR spectrometers
- Lunar Surface
  - neutron spectrometer
- Earth Orbit
  - SEP + GCR spectrometers
- Inner Heliosphere
  - 2 STEREO/Sentinal/ Solwind spacecraft at 1AU
  - 1 STEREO/Sentinal/ Solwind spacecraft at L1
- Heliospheric State
  - Global view of heliospheric state desirable
  - Will understand requirements better following STEREO

LWS/ISTP Spacecraft—Recommendations

- Maintain
  - ACE
  - Ulysses
  - WIND
  - Voyager
- Rephase Sentinals
  - operating by next solar maximum
- Holes/Gaps
  - ACE follow-on

Additional Comments

- LWS TR&T program can be a very important contributor to meeting research needs for the Exploration Initiative
  - Continued study of spacecraft measurement archives