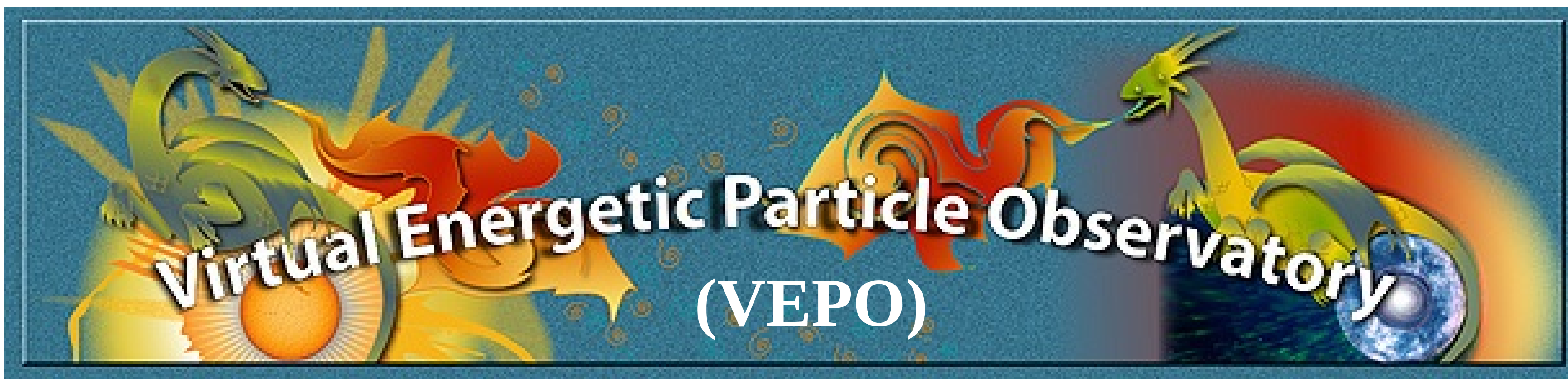
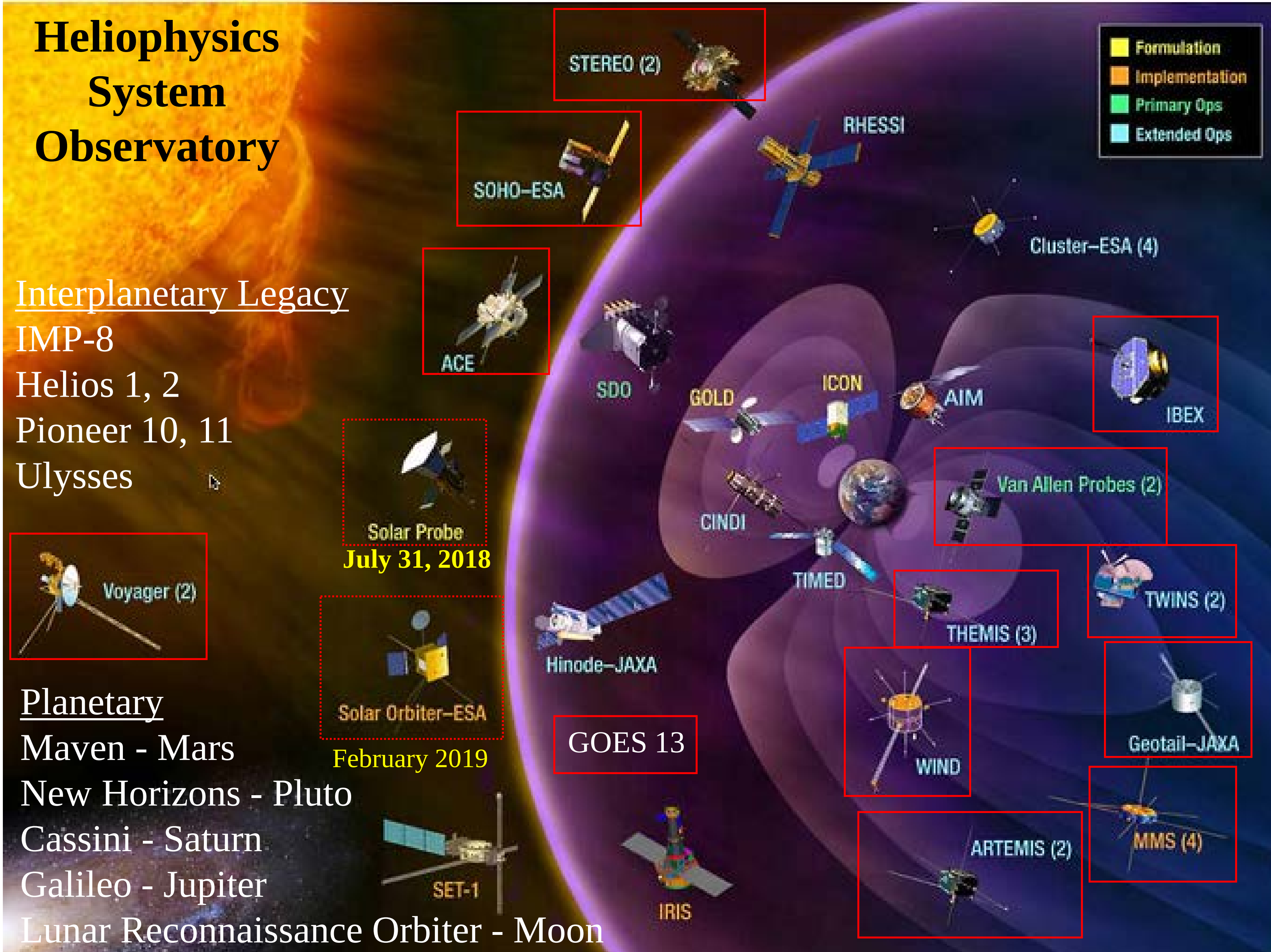
Interplanetary Energetic Particle Measurements with NASA's Heliophysics System Observatory

John F. Cooper
Chief Scientist, NASA Space Physics Data Facility
Principal Investigator, Virtual Energetic Particle Observatory
Heliophysics Science Division
NASA Goddard Space Flight Center



DREAM-2 is a Goddard-led science team of the NASA Solar System Exploration Research Virtual Institute (SSERVI)
PI: William Farrell, NASA GSFC


Heliophysics System Observatory
Interplanetary Legacy
IMP-8
Helios 1, 2
Pioneer 10, 11
Ulysses
Voyager (2)
Planetary
Maven - Mars
New Horizons - Pluto
Cassini - Saturn
Galileo - Jupiter
Lunar Reconnaissance Orbiter - Moon
STEREO (2)
SOHO–ESA
ACE
Solar Probe
July 31, 2018
Solar Orbiter–ESA
February 2019
SET-1
SDO
Hinode–JAXA
GOES 13
IRIS
RHESSI
Cluster–ESA (4)
GOLD
ICON
AIM
IBEX
CINDI
TIMED
Van Allen Probes (2)
THEMIS (3)
TWINS (2)
WIND
Geotail–JAXA
ARTEMIS (2)
MMS (4)
Formulation
Implementation
Primary Ops
Extended Ops

GODDARD SPACE FLIGHT CENTER
Space Physics Data Facility

Project Scientist: Robert E. McGuire NASA GSFC

Space Physics Data Facility

+ ABOUT | + DATA & ORBITS | + ModelWeb at CCMC | + SCIENCE ENABLED | + AND MORE

NASA's Space Physics Data Facility (SPDF)

The SPDF is a project of the Heliophysics Science Division (HSD) at NASA's Goddard Space Flight Center. SPDF consists of web-based services for survey and high resolution data and trajectories. The Facility supports data from most NASA Heliophysics missions to promote correlative and collaborative research across discipline and mission boundaries. Read More here.

News & Announcements

NOTICE: The MMS Level 2 data products are available via SPDF FTP/HTTP and all data sets are available in CDAWeb . The range of publicly available MMS data will continue to be updated weekly.

NOTICE: February 13, 2017 HTTPS: The SPDF web sites (CDAWeb, OMNIWeb, SSCWeb, etc.) will be automatically redirecting HTTP requests to use the HTTPS protocol. Please begin using the HTTPS protocol directly as soon as possible and contact us with any problems. FTP data access is not affected at this time. For further information, please read the SPDF HTTPS announcement.

New CDF Version 3.6.3.1 Released

Common Data Format (CDF) Version 3.6.3.1 is now available. This release contains a minor change to the earlier release of V3.6.3.0 and includes a new leap second added for 1/1/2017. Please read the change notes that describe the changes made in this release, as well as all previous releases. Updates for Perl, IDL, Matlab, and Java interfaces and the SKTeditor CDF editor are also available.

New CDF Version 3.6.3 Released

Common Data Format (CDF) Version 3.6.3 is now available. We strongly urge all CDF users to promptly

Access Data & Orbit Services

+ Heliophysics Data Portal (formerly VSPO)
+ Gateway to Services
+ CDAWeb
+ CDAWeb Inside IDL
+ OMNIWeb Plus (now including COHOWeb, ATMOWeb, FTP Browser, HelioWeb and CGM)
+ Direct FTP to Data
+ Direct HTTP(S) to Data
+ SSCWeb
+ 4D Orbit Viewer
+ GIFWalk data and orbit plots

Access Models

+ Community Coordinated Modeling Ctr. (CCMC)
+ ModelWeb at CCMC

Heliophysics Virtual Observatories

+ NASA's Heliophysics Data Environment
+ Heliophysics Data Portal (formerly VSPO)
+ SPASE Data Model and Dictionary
+ VEPO - Virtual Energetic Particle Observatory
+ VHO - Virtual Heliospheric Observatory

Special Services

+ CDF/netCDF/FITS/ /ASCII Format
HDF/XML Translations

SPDF Web Service APIs

+ CDAWeb
+ SSCWeb
+ Data Format Translations

Software

+ CDF (Common Data Format)
+ Space Physics use of CDF
+ Data Format Translations
+ CDF SKTEditor
+ MakeCDF
+ CDAWlib /CDFX (IDL)
+ ViSBARD (visualization)

Additional Databases

+ LunaSOX - Lunar Solar Origins Exploration
+ Magnetospheric State Database
+ Multi-satellite Bow Shock Database
+ Multi-satellite Magnetopause Crossing Database

Links

spdf.gsfc.nasa.gov

NASA Active Final Archive for non-imaging solar, geospace, and heliospheric data

Heliophysics Data Portal (VxO)

Value-Added Data Services

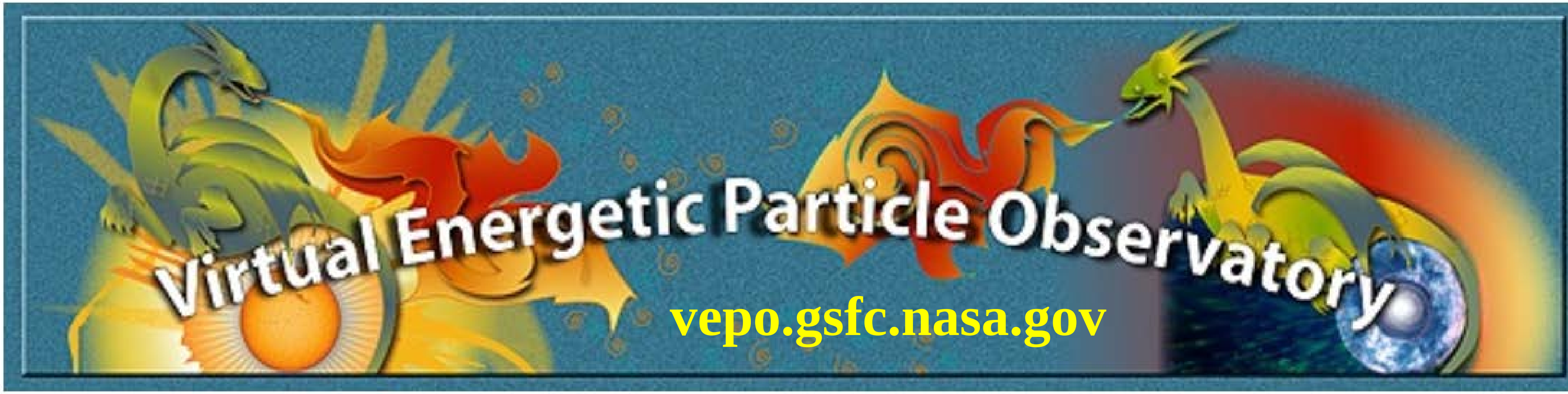
CDAWeb
OMNIWeb
HelioWeb
SSCWeb

Common Data Format (CDF) standards and tools

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

+ Goddard Home
+ NASA.gov
+ Heliophysics Science Div.
+ Heliospheric Physics Lab.

+ PROJECTS | + RESEARCH | + DATA SERVICES | + EDUCATION | + LINKS



+ Home

Virtual Energetic Particle Observatory

+ Introduction
+ Data Product Information
+ Organization
+ Data Sources
+ Multi-source Spectra

LATEST VEPO NEWS

Principal Investigator: John F. Cooper, NASA GSFC

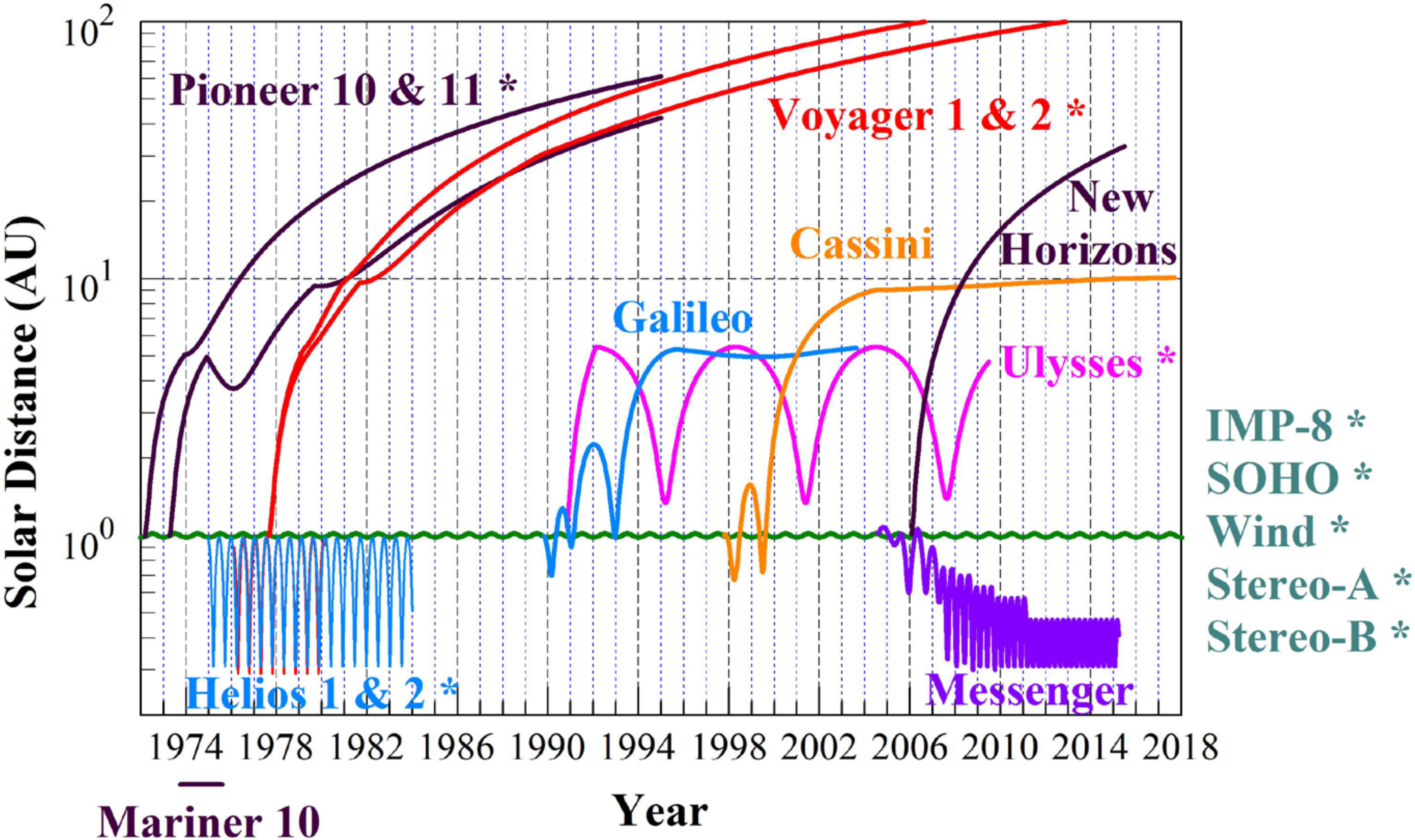
+ Relativistic Electrons Uncovered with NASA's Van Allen Probes
M. Johnson-Groh, NASA/GSFC, Mar. 15, 2017

+ Alien Particles from Outer Space are Wreaking Low-grade Havoc on Personal Electronic Devices
D. Salisbury, Vanderbilt University, Feb. 17, 2017

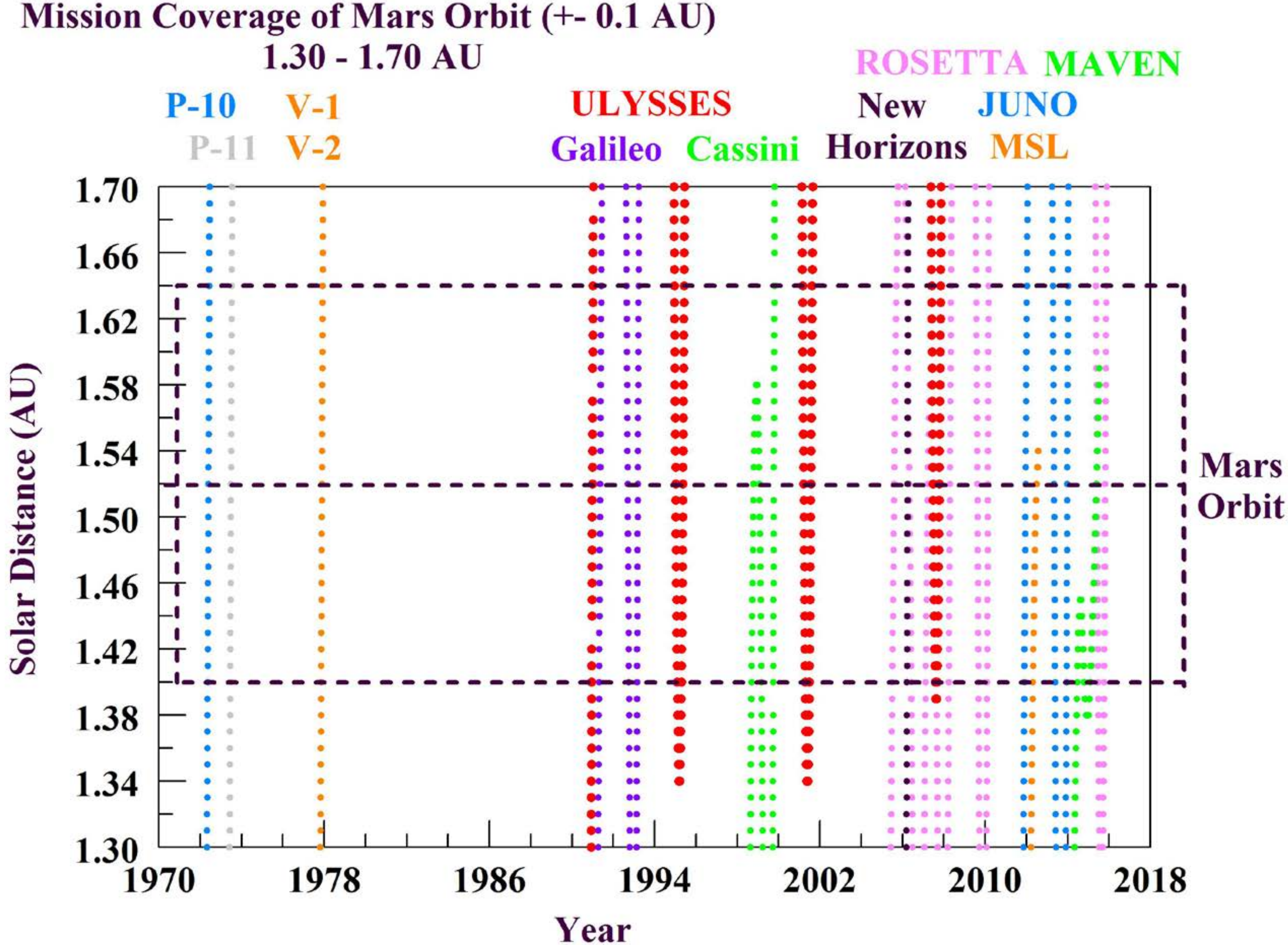
+ Extreme Space Weather-Induced Electricity Blackouts Could Cost U.S. more than $40 Billion Daily
American Geophysical Union, Jan. 18, 2017

Warning: Be careful what data you look for, you may find it !

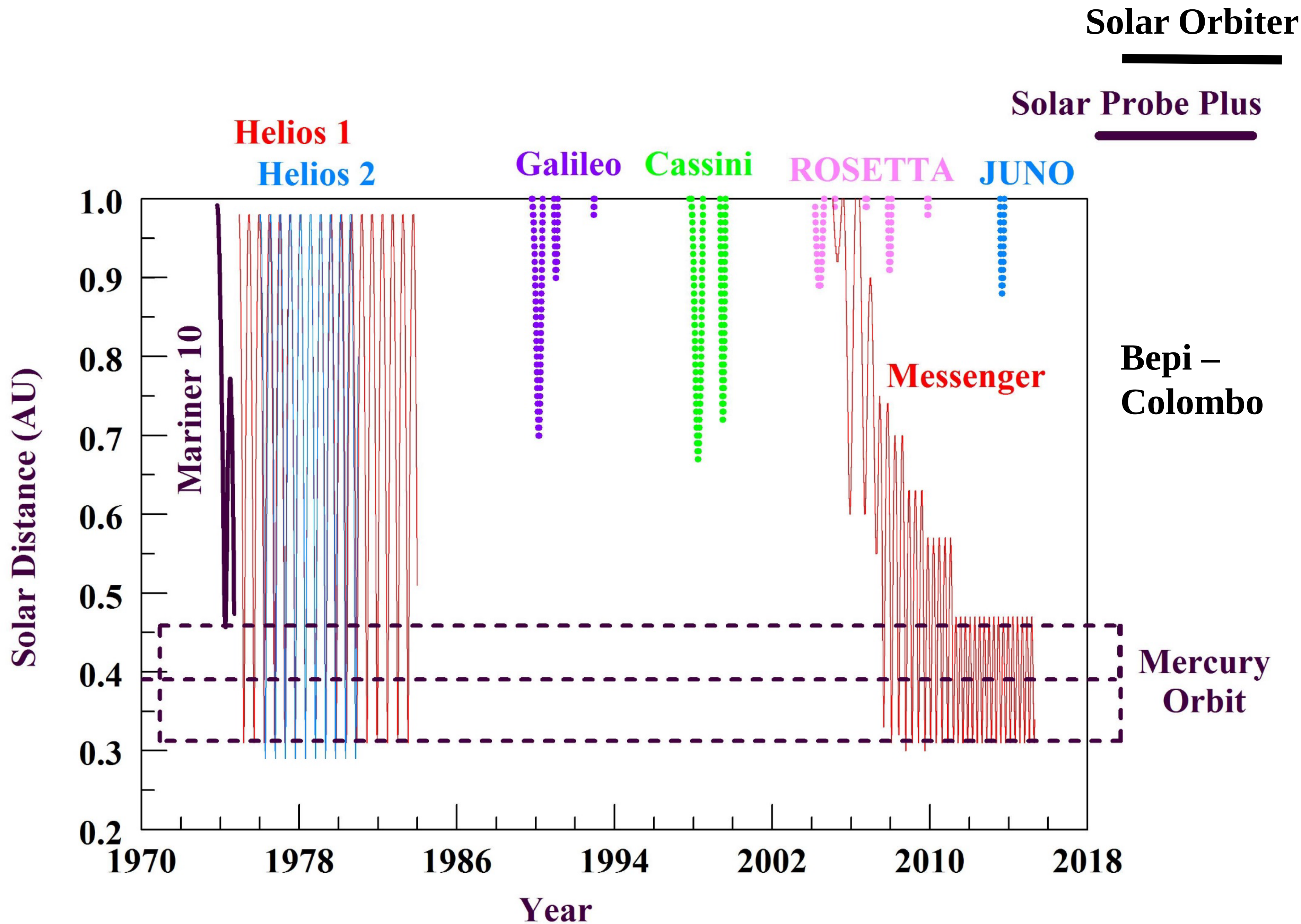
The multi-source spectral plots and tabular data allow investigation of large scale radial and longitudinal gradients in intensities from multiple spacecraft and instrument sources, e.g. between the orbits of Mercury, Venus, Earth, Mars, and beyond …

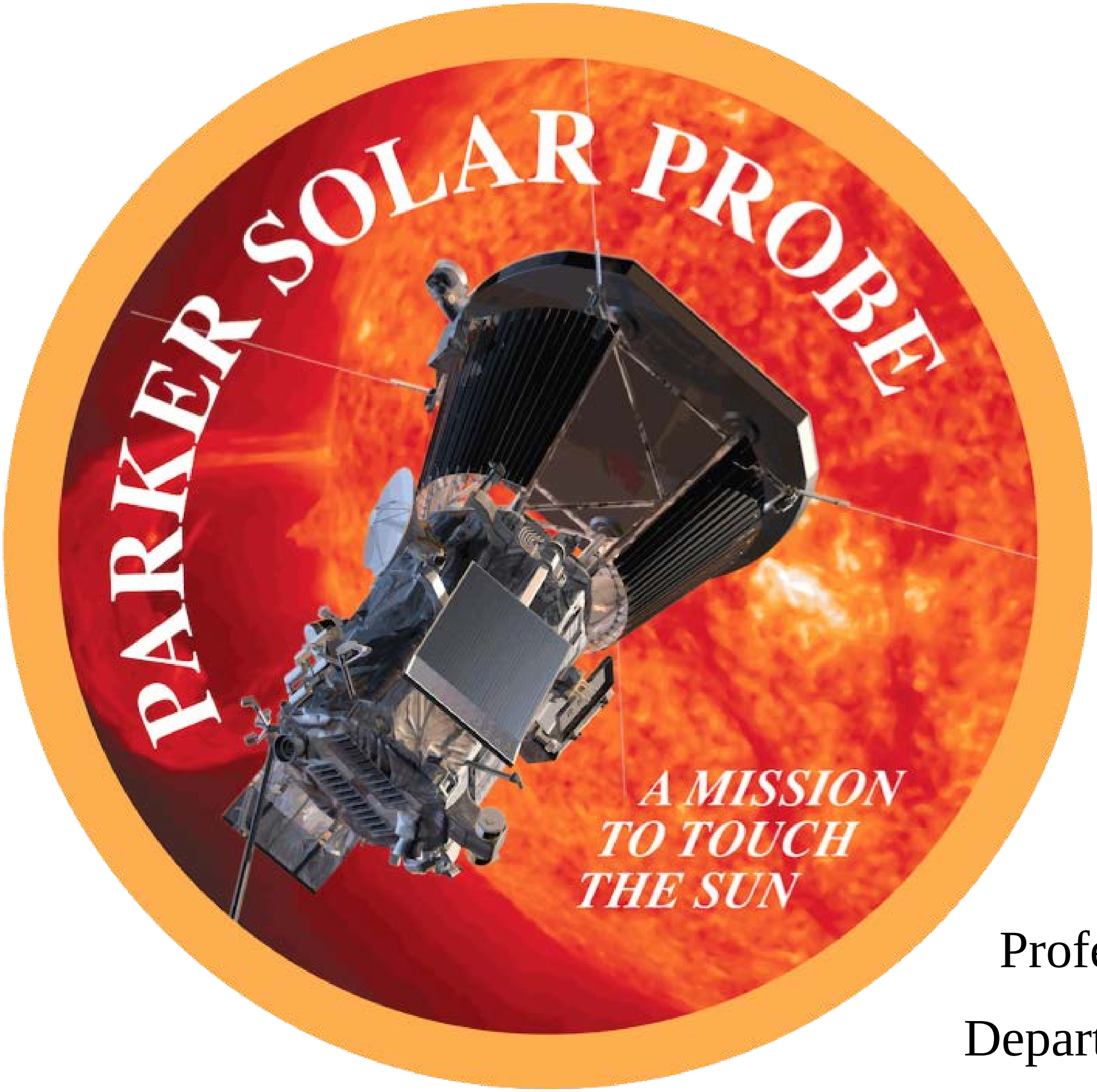


* Spectral Flux Data in VEPO



Mars Odyssey (MARIE) April 2001 to Present
Mars Express (ASPERA) June 2003 - Present


Solar Orbiter
Solar Probe Plus
Helios 1
Helios 2
Galileo
Cassini
ROSETTA
JUNO
Bepi – Colombo
Messenger
Mariner 10
Mercury Orbit
Solar Distance (AU)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1970
1978
1986
1994
2002
2010
2018
Year

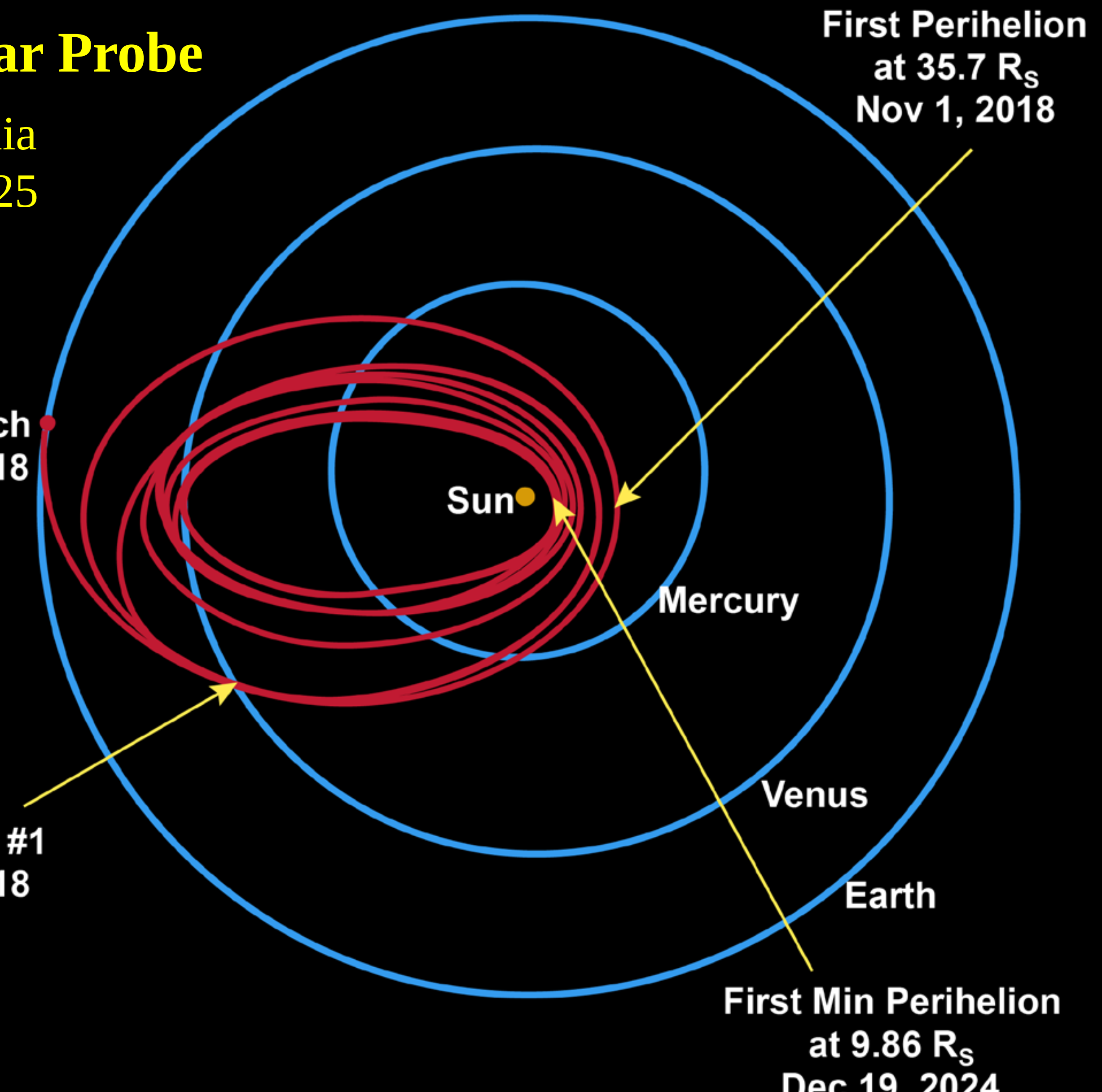


Professor Eugene (Gene) N. Parker

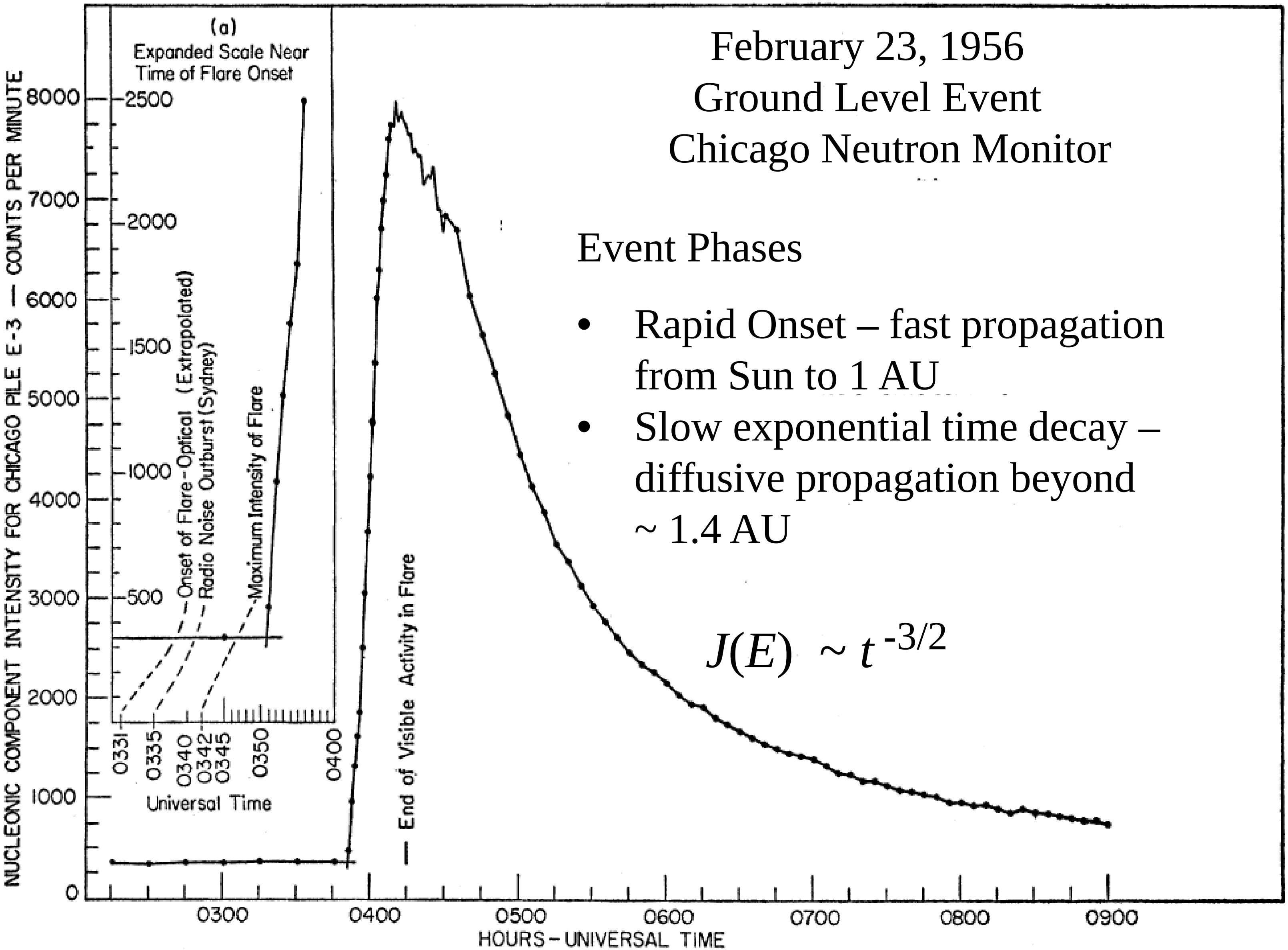
Department of Physics and Astronomy
Enrico Fermi institute
University of Chicago

Parker Solar Probe

24 Perihelia
2018 - 2025



Meyer, Parker, and Simpson (Phys. Rev., 1956)



February 23, 1956
Ground Level Event
Chicago Neutron Monitor

Event Phases

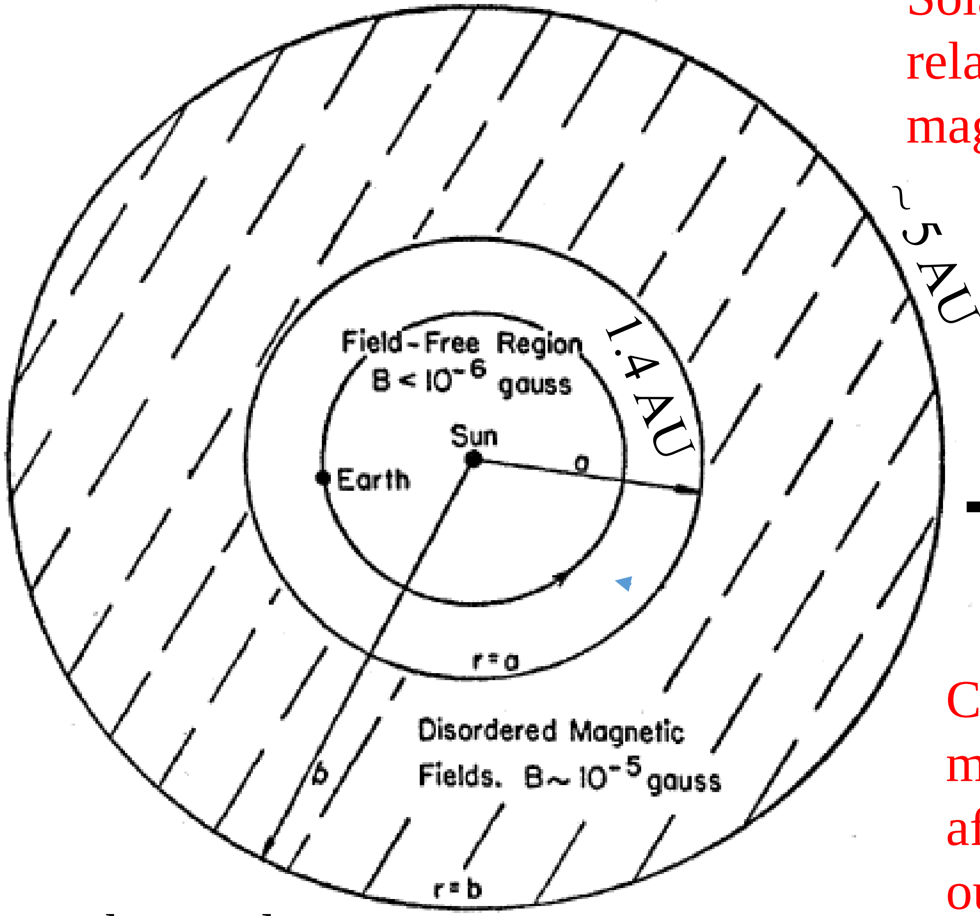
- Rapid Onset – fast propagation from Sun to 1 AU
- Slow exponential time decay – diffusive propagation beyond ~ 1.4 AU

$J(E) \sim t^{-3/2}$

FIG. 2. Nucleonic component intensity as a function of time for the Chicago neutron monitor E-3. One-minute intervals are shown between ~0350 and ~0423 U.T. (a) Onset of intensity increase on expanded scale. (b) Period of the cosmic ray increase during which balloon flight number 2 was undertaken (see also Fig. 5).

Mars orbits at 1.38 – 1.67 AU within inner zone of the Meyer et al. shell of turbulent interplanetary magnetic fields

Solar energetic particles propagate relatively freely along solar wind magnetic field lines from Sun to Mars



Voyager 1 left the heliosphere at 122 AU on Aug. 24, 2012

Cosmic ray particles are heavily modulated at Mars and Earth after inward diffusion from the outer heliosphere and local interstellar space.

Meyer, Parker, and Simpson (Phys. Rev., 1956)

FIG. 8. Cross section of the model for the inner solar system at the time of the solar flare of February 23, 1956. The inner volume $r=a$ represents a cavity "free" of magnetic fields (B (rms) $<10^{-6}$ gauss). The barrier of thickness $b-a$ represents the shell-like region through which the cosmic rays diffuse.

Carrington Solar Flare Event – Sept. 1, 1859

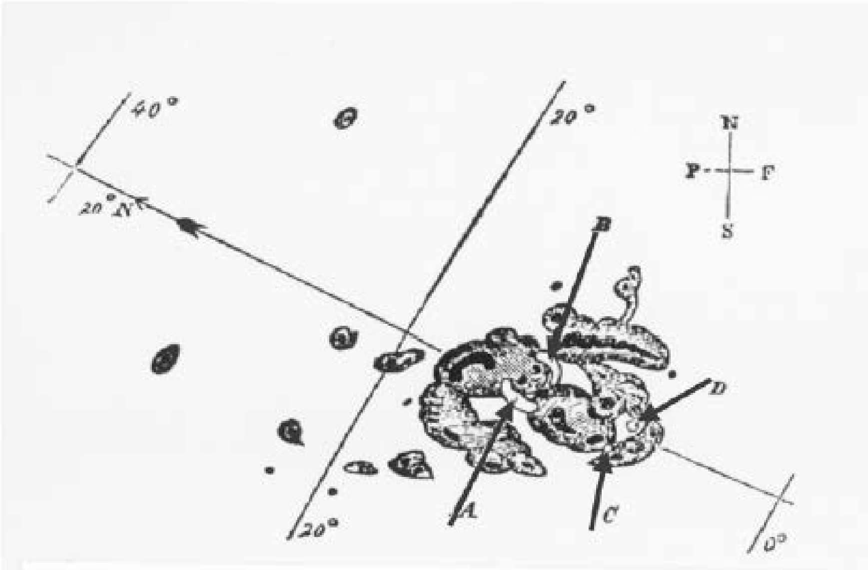
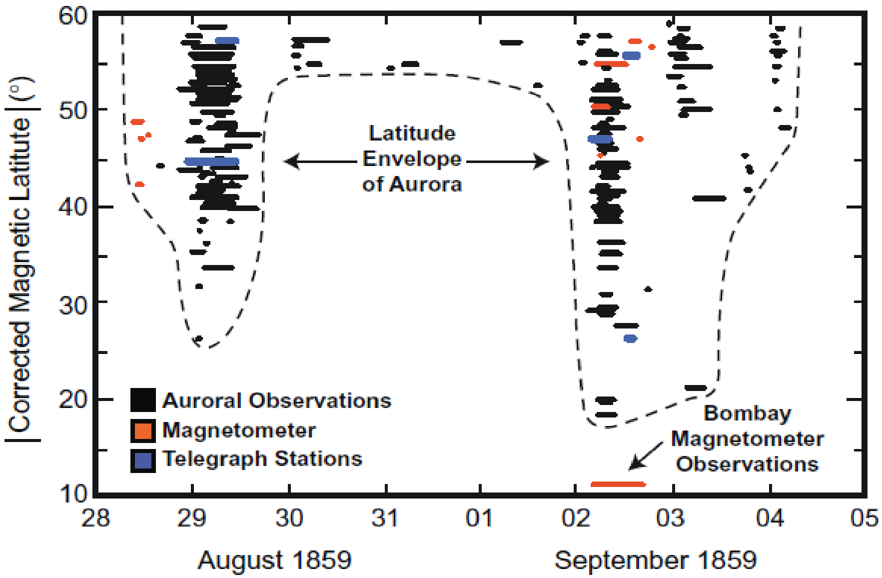
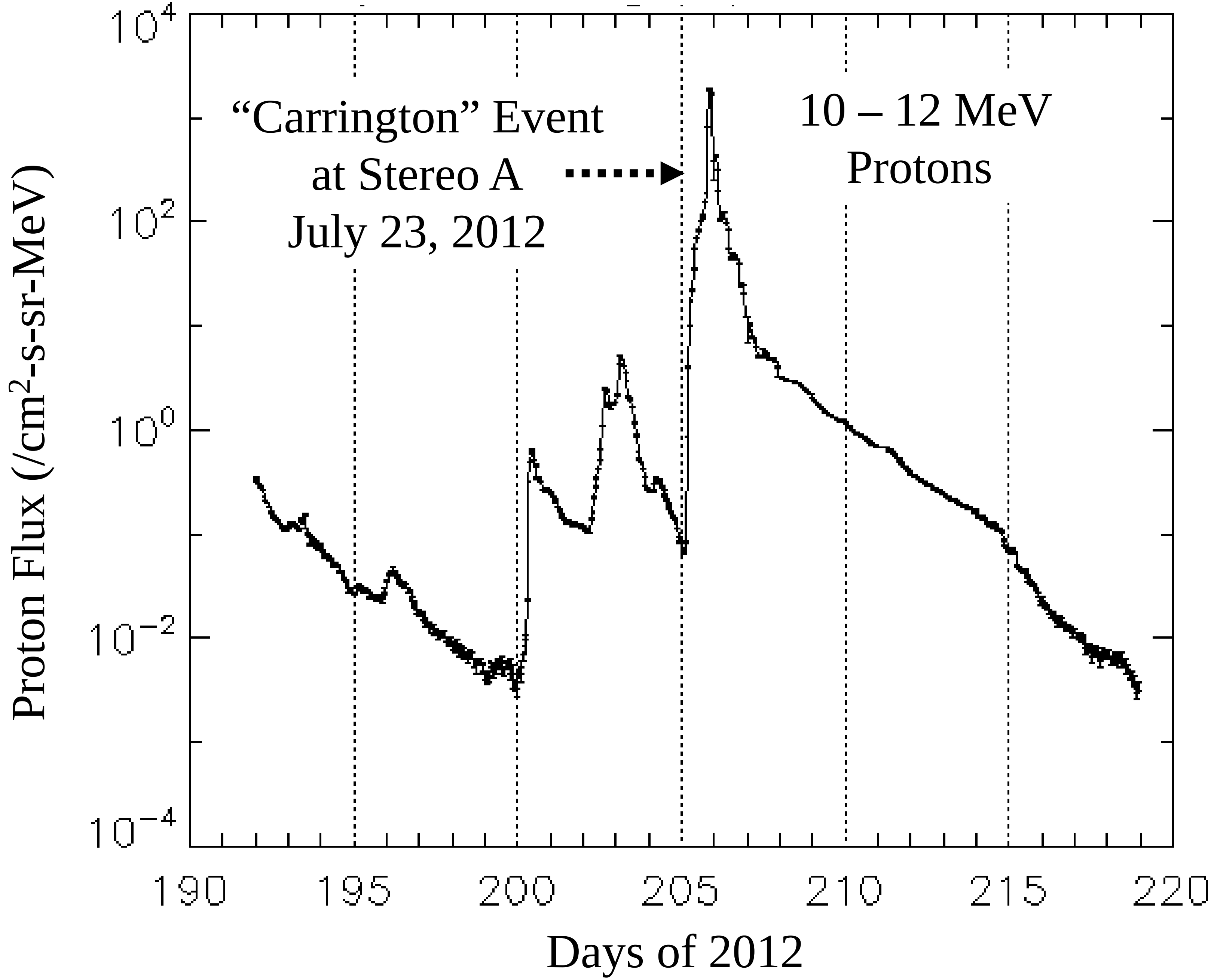


Fig. 3. Carrington's drawing of Sunspot Group 520 on 1 September 1859 (from Carrington, 1860). The initial locations of the white light

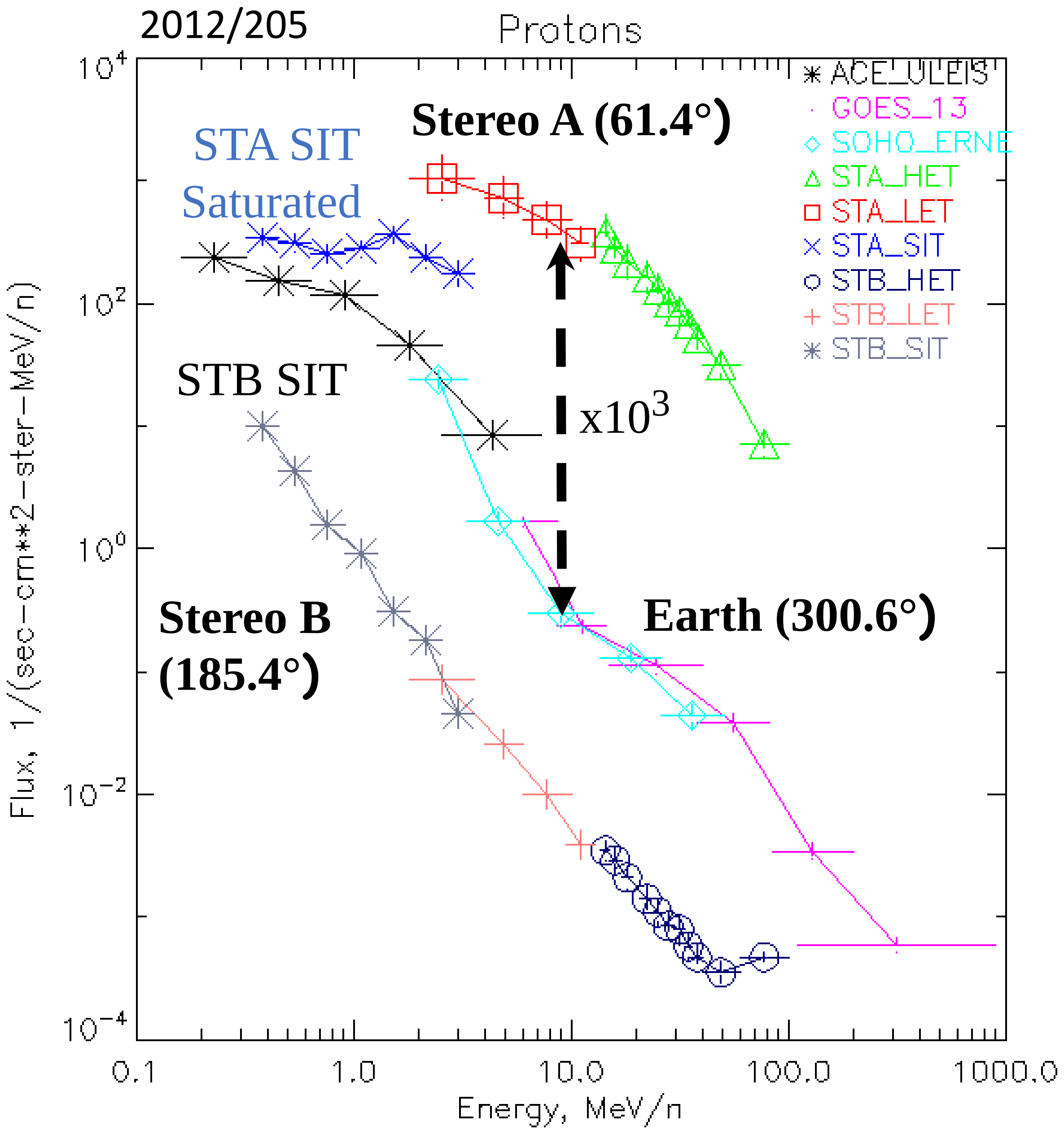


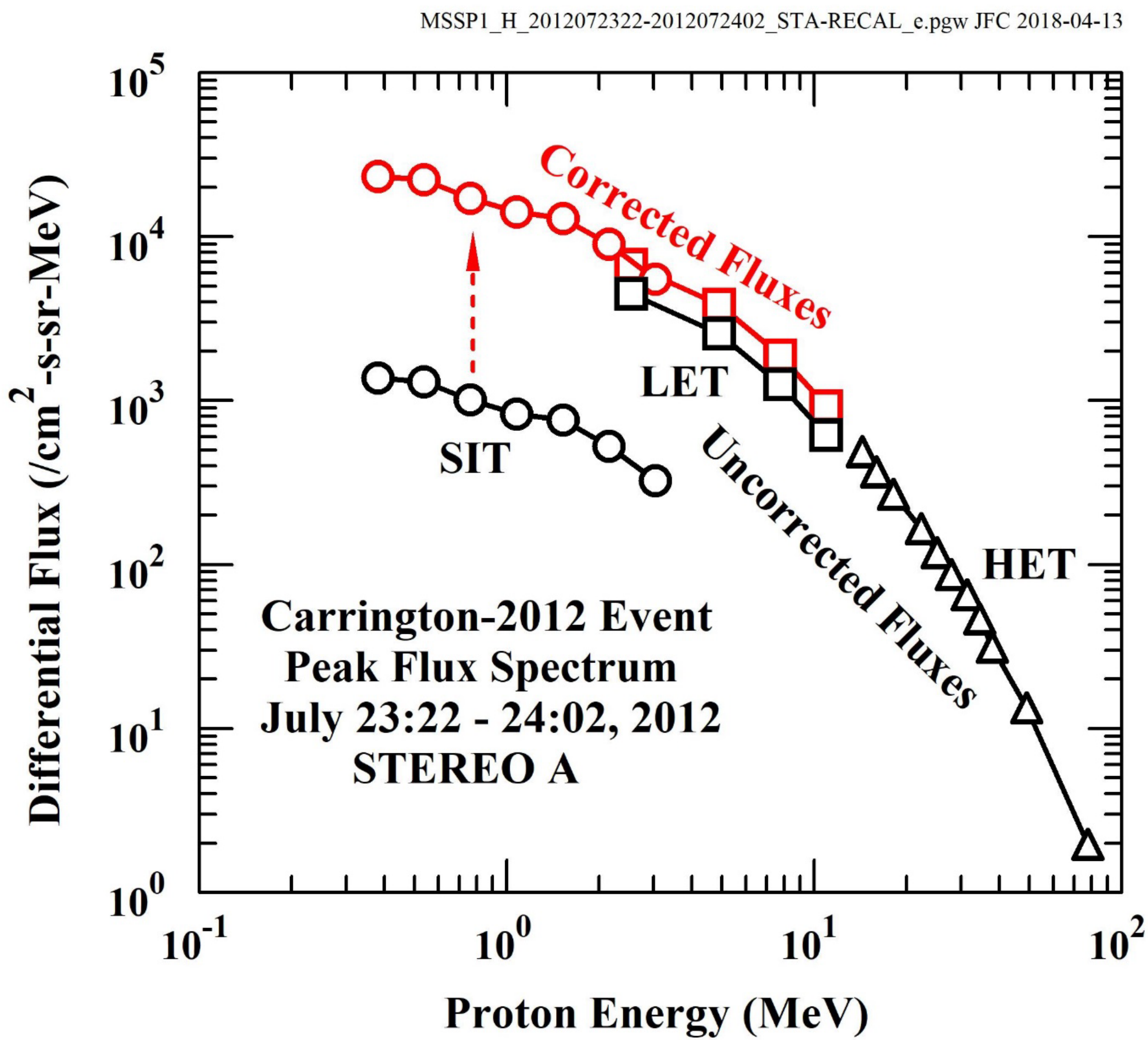
Airapetian et al. (Nature Geosci, 2016)
~ 1 Carrington Super-CME
Event per day @ 0.7 Gyr



“Carrington” Event
at Stereo A
July 23, 2012
10 – 12 MeV
Protons
Proton Flux (/cm^2-s-sr-MeV)
10^4
10^2
10^0
10^{-2}
10^{-4}
190
195
200
205
210
215
220
Days of 2012

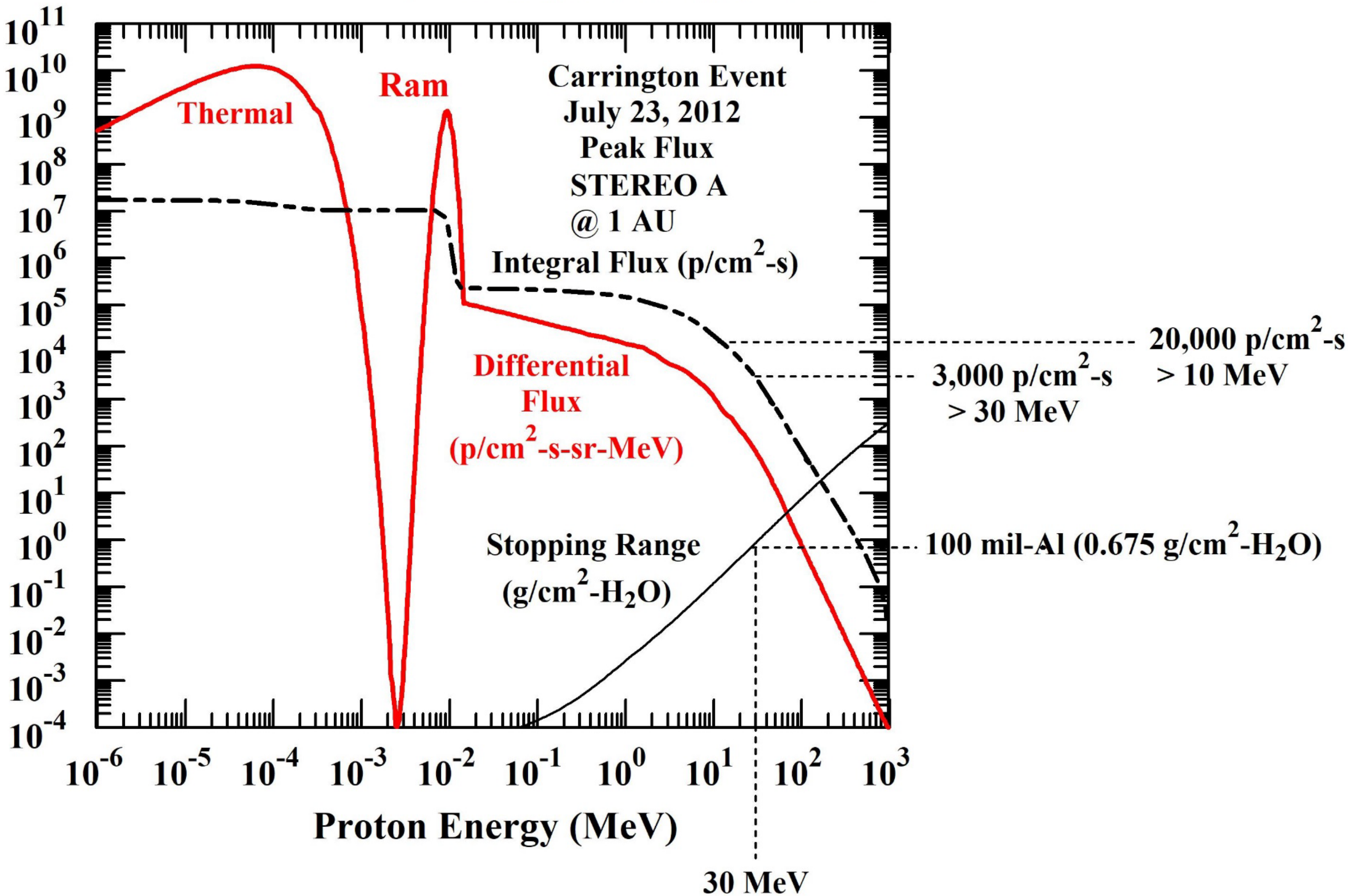
“1859 Carrington Event” at Stereo A (STA): July 23, 2012

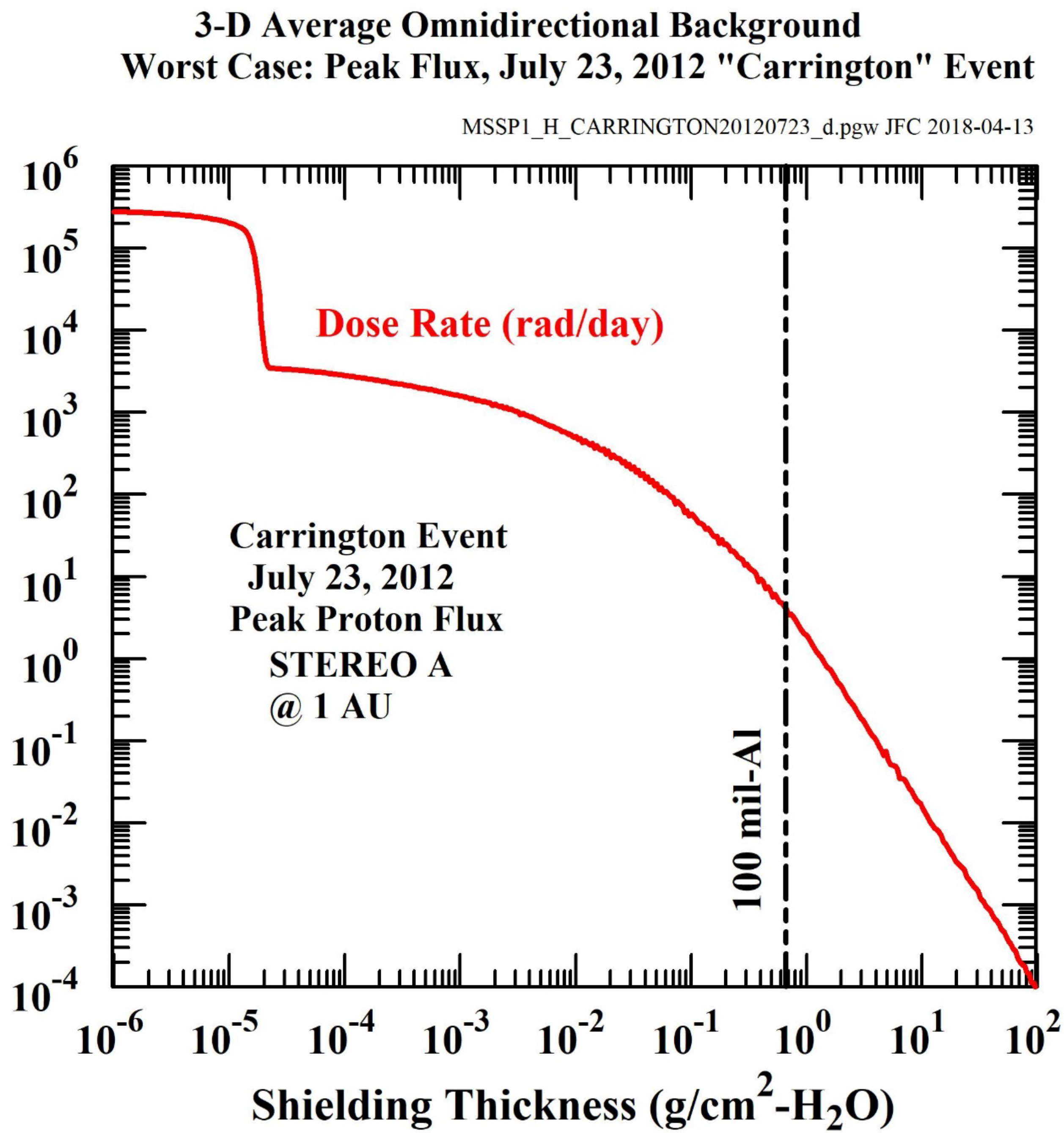



MSSP1_H_2012072322-2012072402_STA-RECAL_e.pgw JFC 2018-04-13
Differential Flux (/cm^2-s-sr-MeV)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^0
10^1
10^2
Proton Energy (MeV)
Corrected Fluxes
LET
SIT
Uncorrected Fluxes
HET
Carrington-2012 Event
Peak Flux Spectrum
July 23:22 - 24:02, 2012
STEREO A

3-D Average Directional Proton Flux Spectrum
Worst Case: Peak Flux, July 23, 2012 "Carrington" Event

MSSP1_H_CARRINGTON20120723_b.pgw JFC 2018-04-13

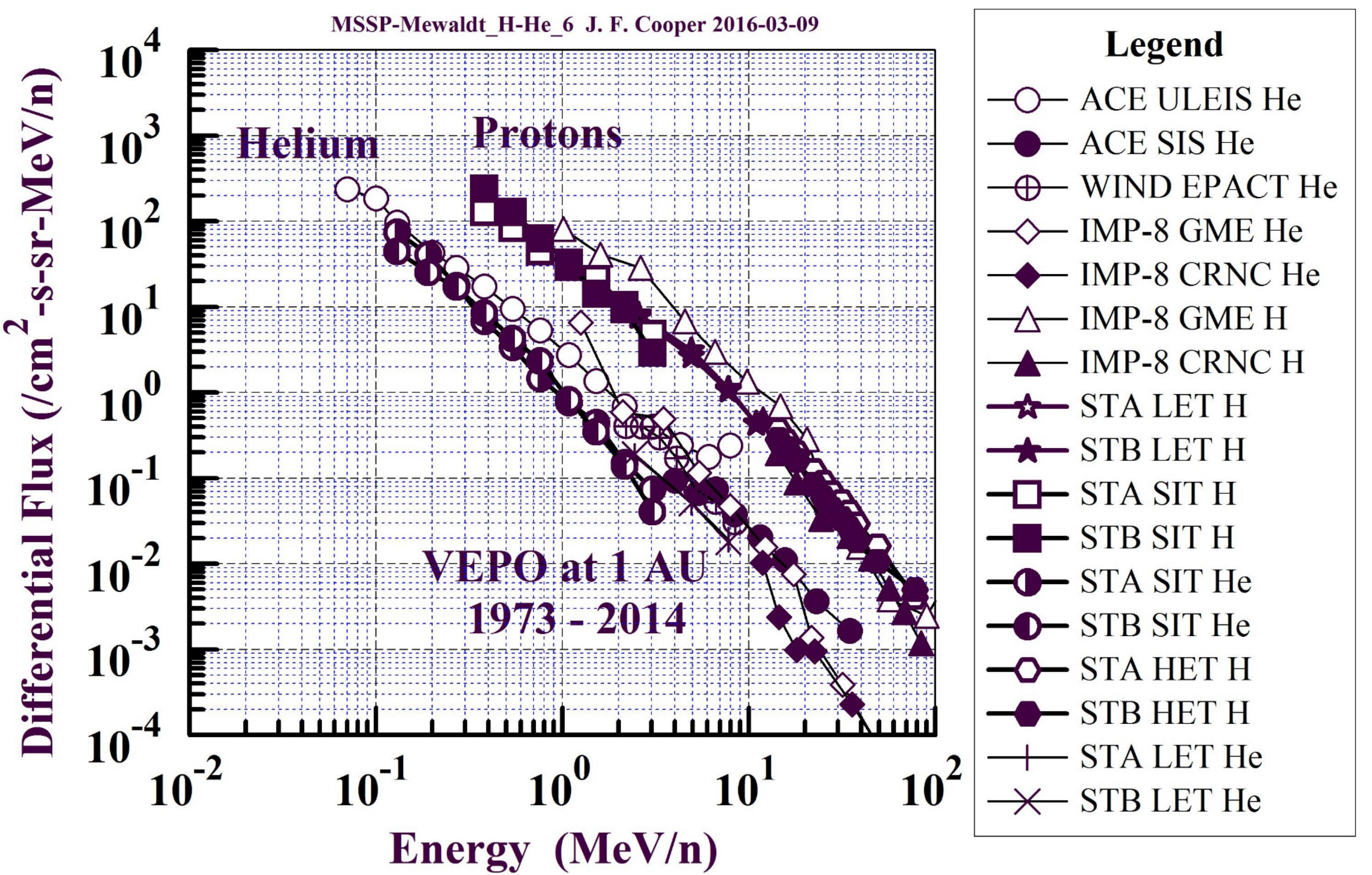


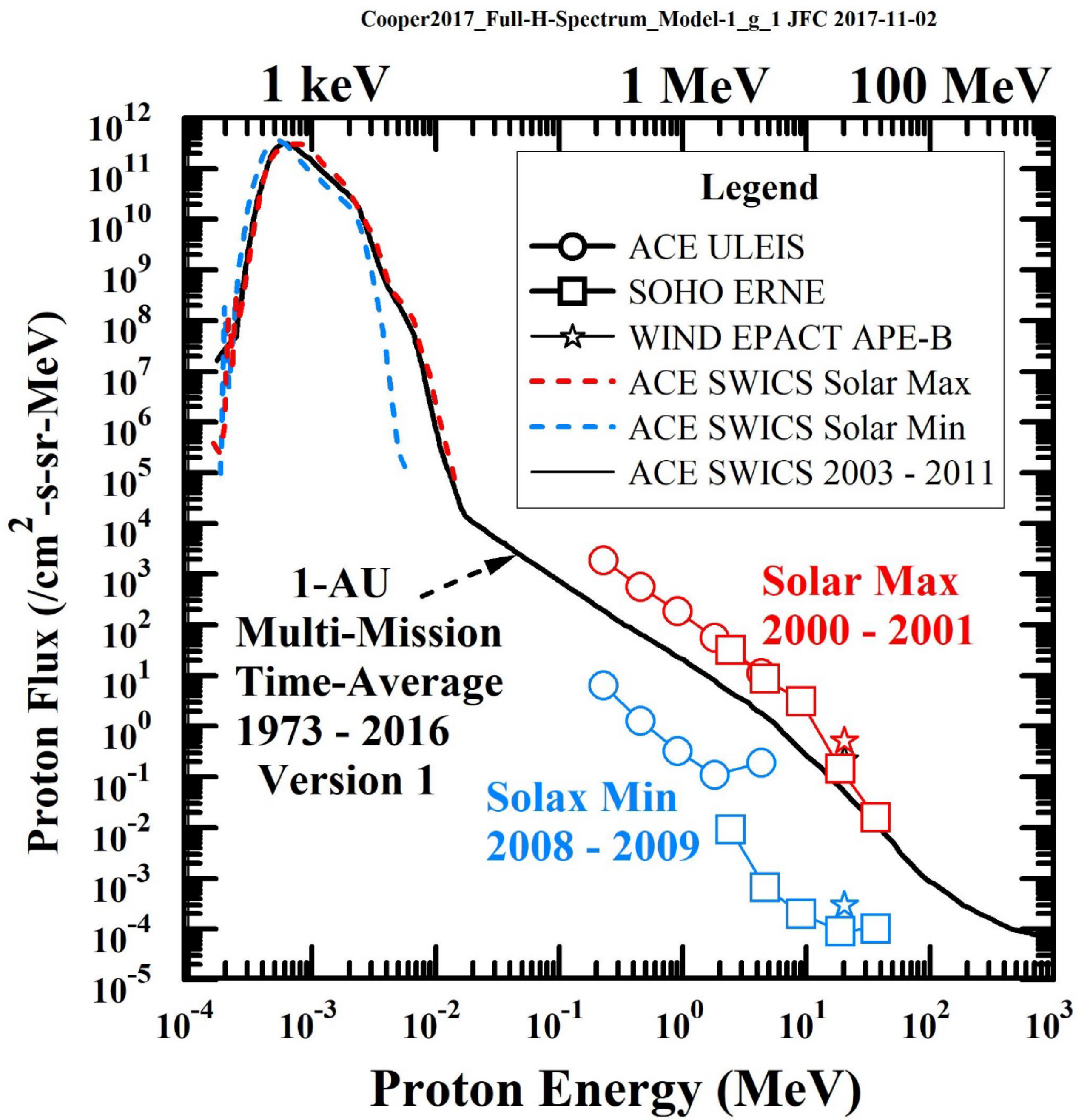


3-D Average Omnidirectional Background
Worst Case: Peak Flux, July 23, 2012 "Carrington" Event
MSSP1_H_CARRINGTON20120723_d.pgw JFC 2018-04-13
Dose Rate (rad/day)
Carrington Event
July 23, 2012
Peak Proton Flux
STEREO A
@ 1 AU
100 mil-Al
Shielding Thickness (g/cm2-H2O)

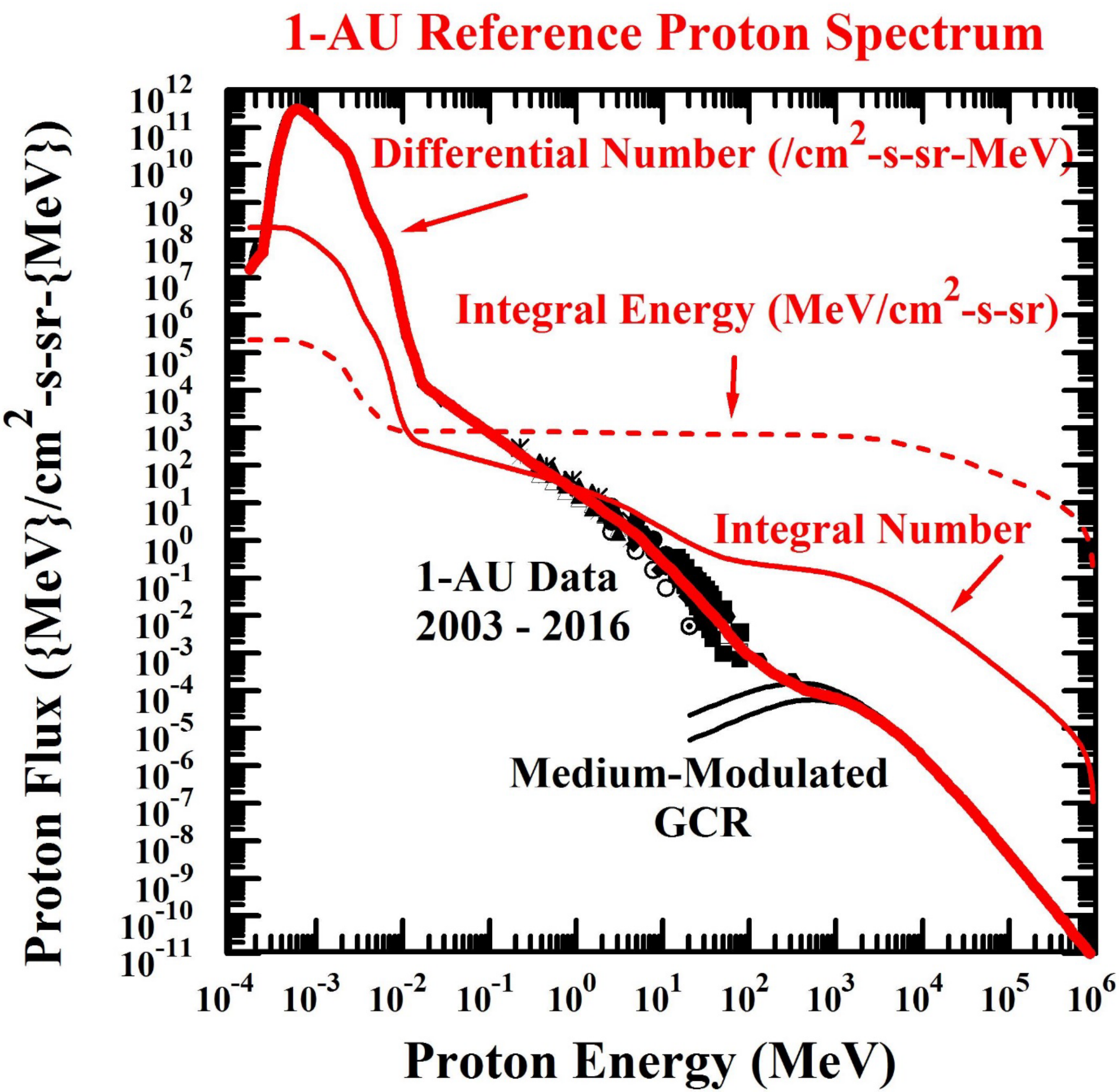
What are the time-averaged proton and helium ion flux spectra at 1 AU?

Composite Proton and Helium Spectra at 1 AU from VEPO MSSP-1 Data



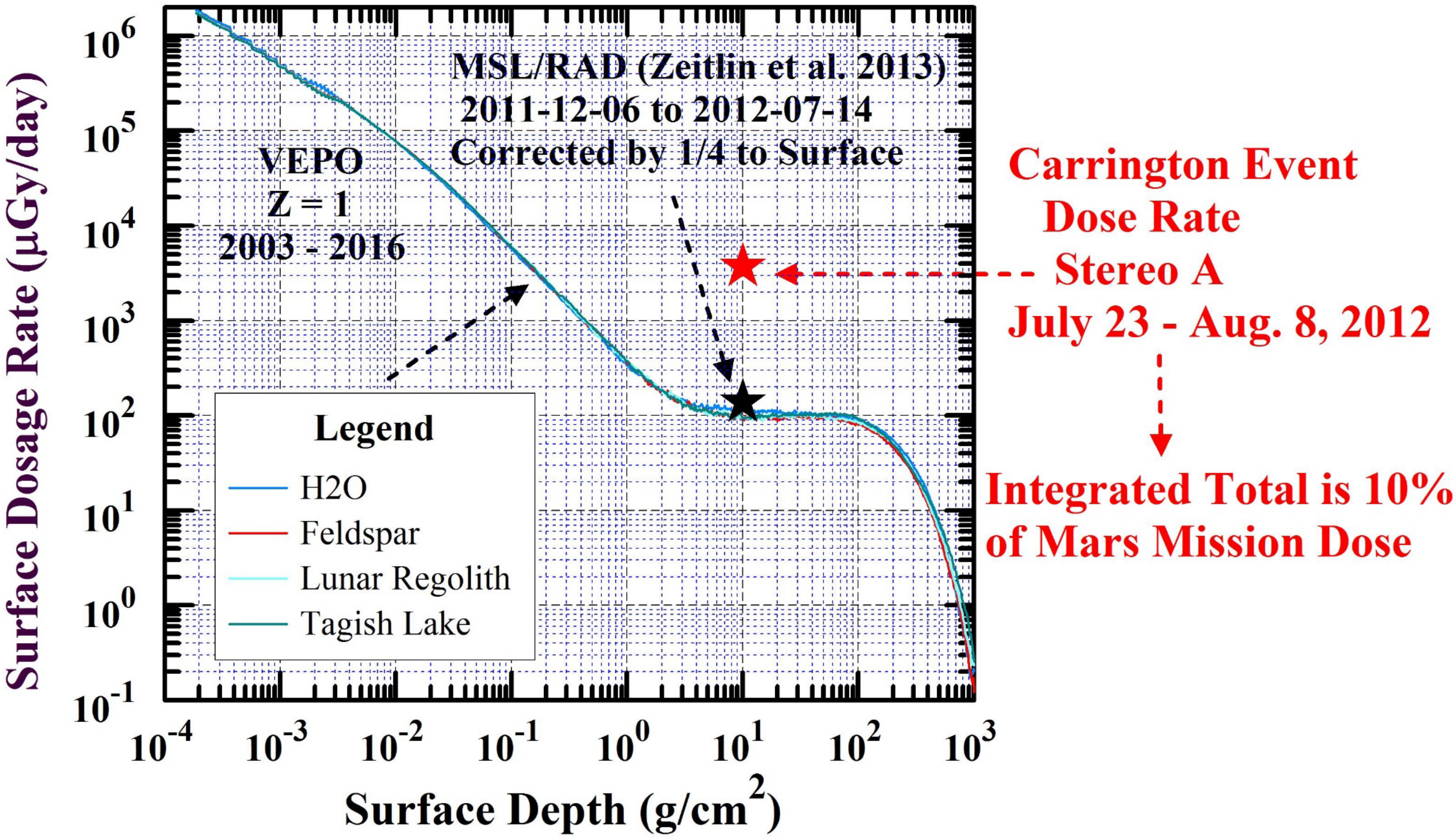


High Energy
Vos and Potgieter
(ApJ, 2015)

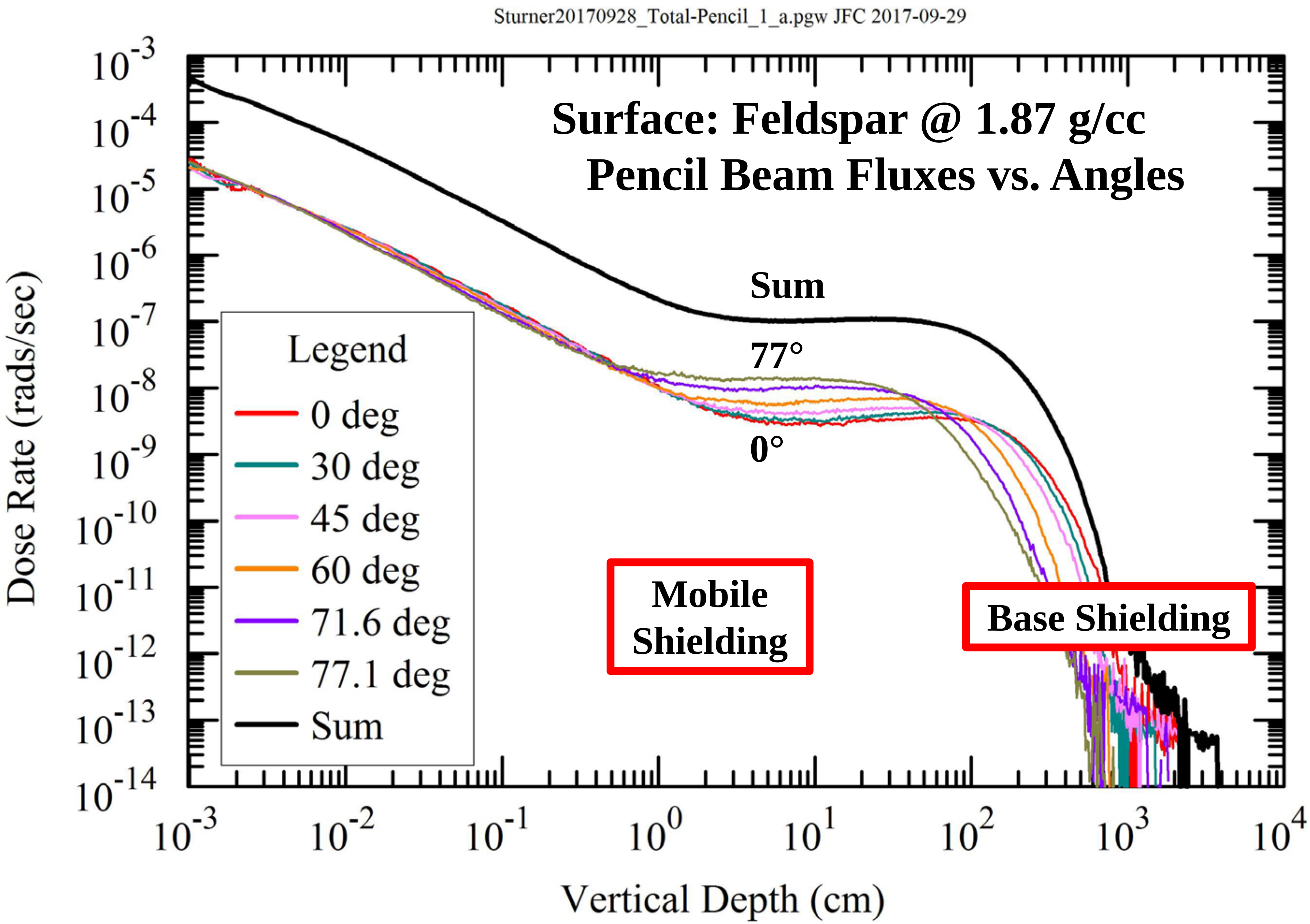


Cooper2017_Full-H-Spectrum_Model-1_d JFC 2017-08-12

Phobos Surface Radiation Model
Version 1 (Protons > 10 keV)

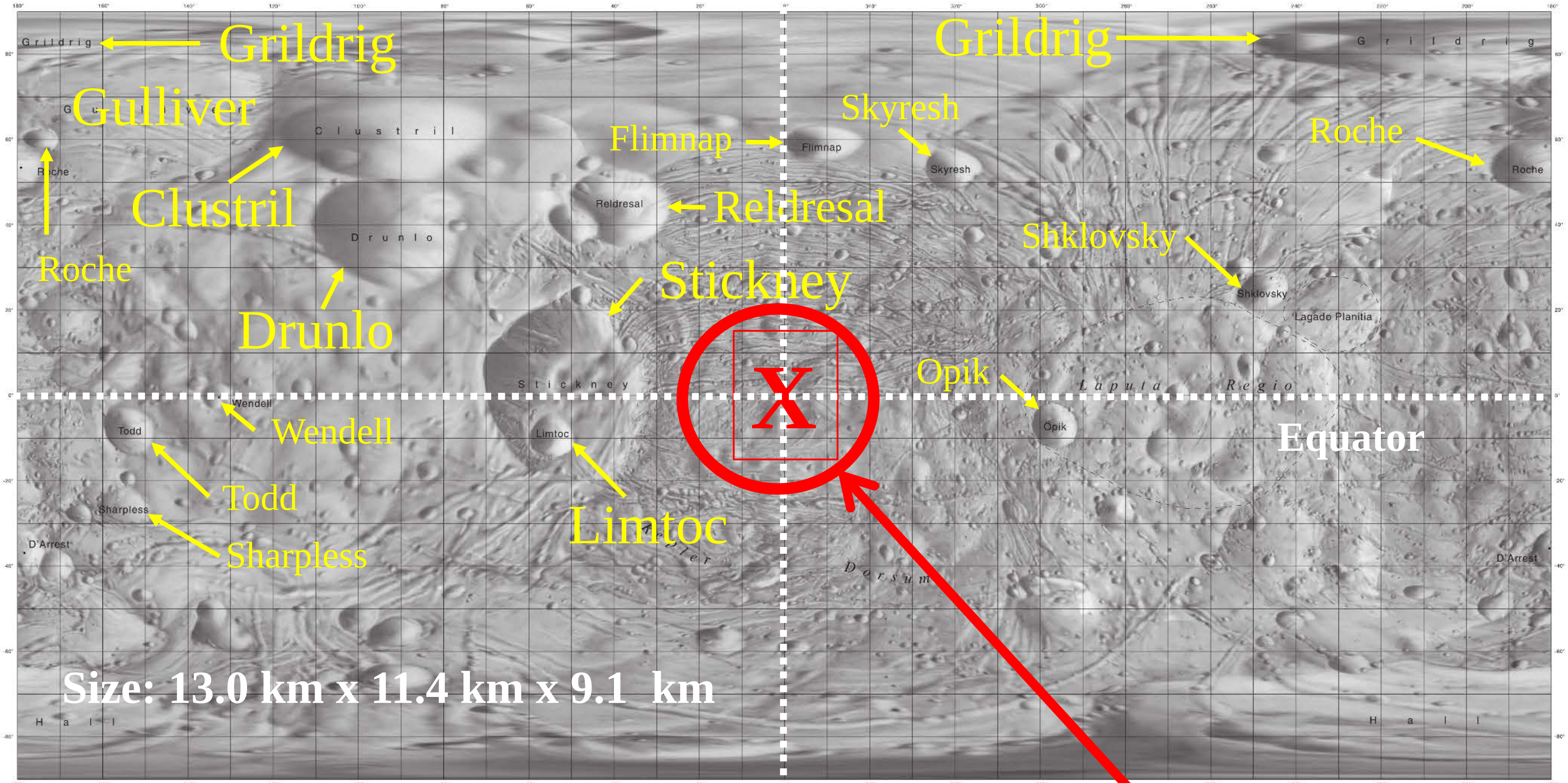


Sturner20170803_compare_all_H2O_Z-DOSRATE_b.pgw JFC 2017-08-13



Sturner20170928_Total-Pencil_1_a.pgw JFC 2017-09-29
Surface: Feldspar @ 1.87 g/cc
Pencil Beam Fluxes vs. Angles
Sum
77°
0°
Legend
0 deg
30 deg
45 deg
60 deg
71.6 deg
77.1 deg
Sum
Mobile Shielding
Base Shielding
Dose Rate (rads/sec)
Vertical Depth (cm)

The Most Valuable Real Estate on Phobos: sub-Mars point (X)



Credits:
Shaded relief - USGS
Control - Peter Thomas
Rectification - Phil Stooke

PHOBOS

Gravity g = 0.0057 m/s^2

Escape Velocity = 11.39 m/s
(25.3 mph)

Orbit = 2.76 R_M

West

East

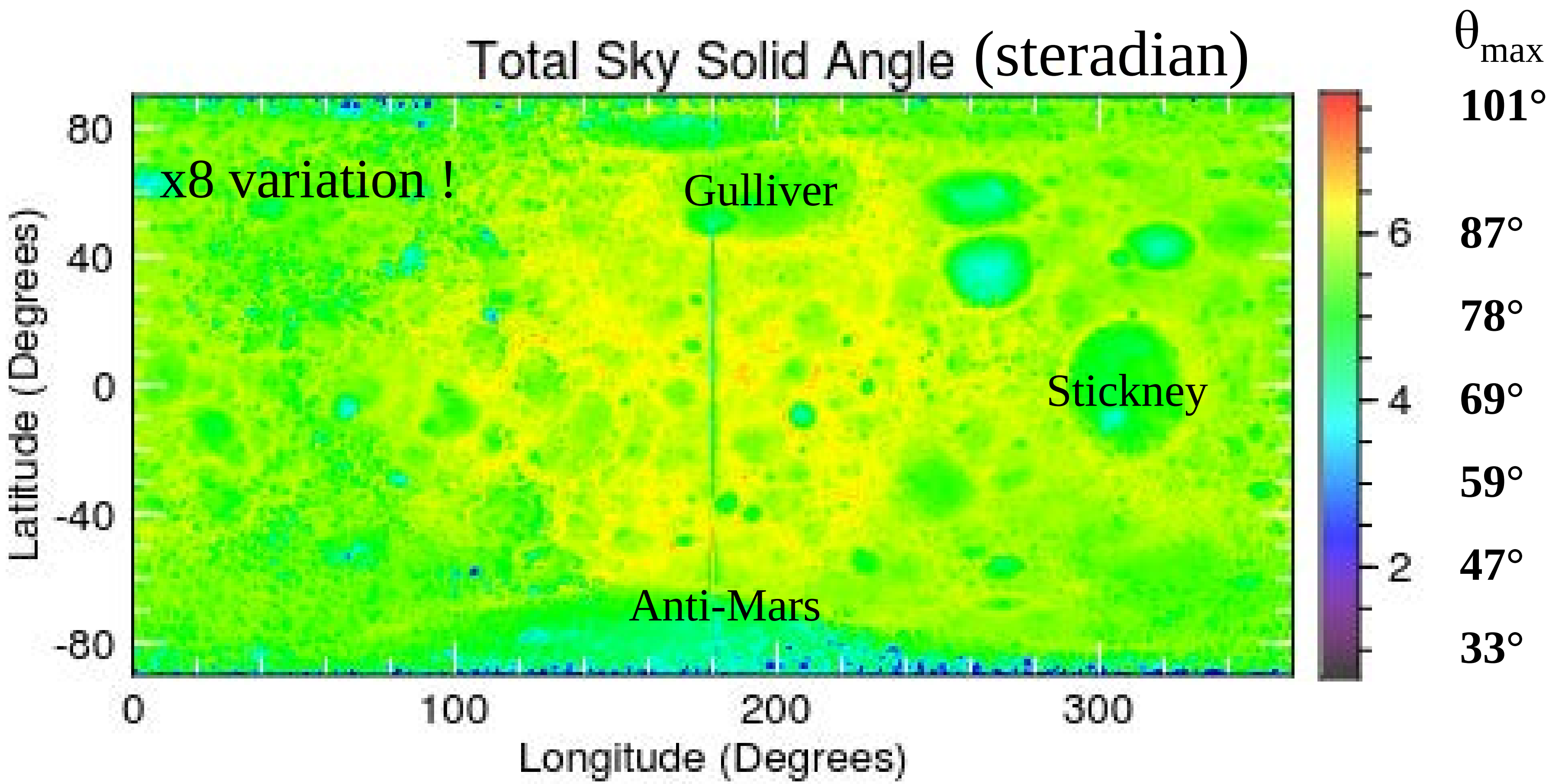
25° W
Stickney

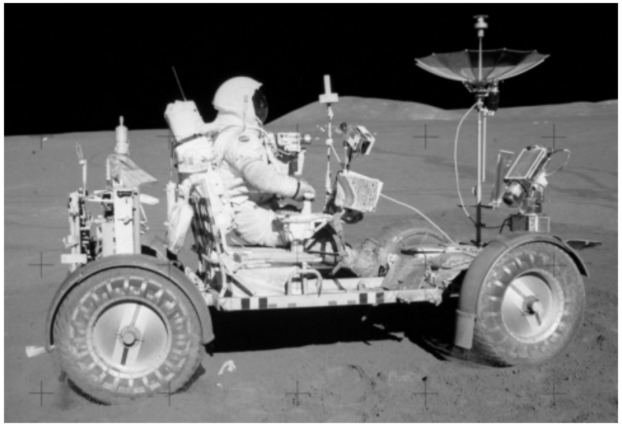
Sub-Mars
Longitude

Apparent diameter of Mars
is 42.5° from Phobos
sub-Mars surface point (X)
→ 6.8 % of visible sky

Radiation shielding by topography on airless bodies: Phobos case study

Tim Stubbs, Yongli Wang and Dave Glenar
NASA/GSFC and UMBC





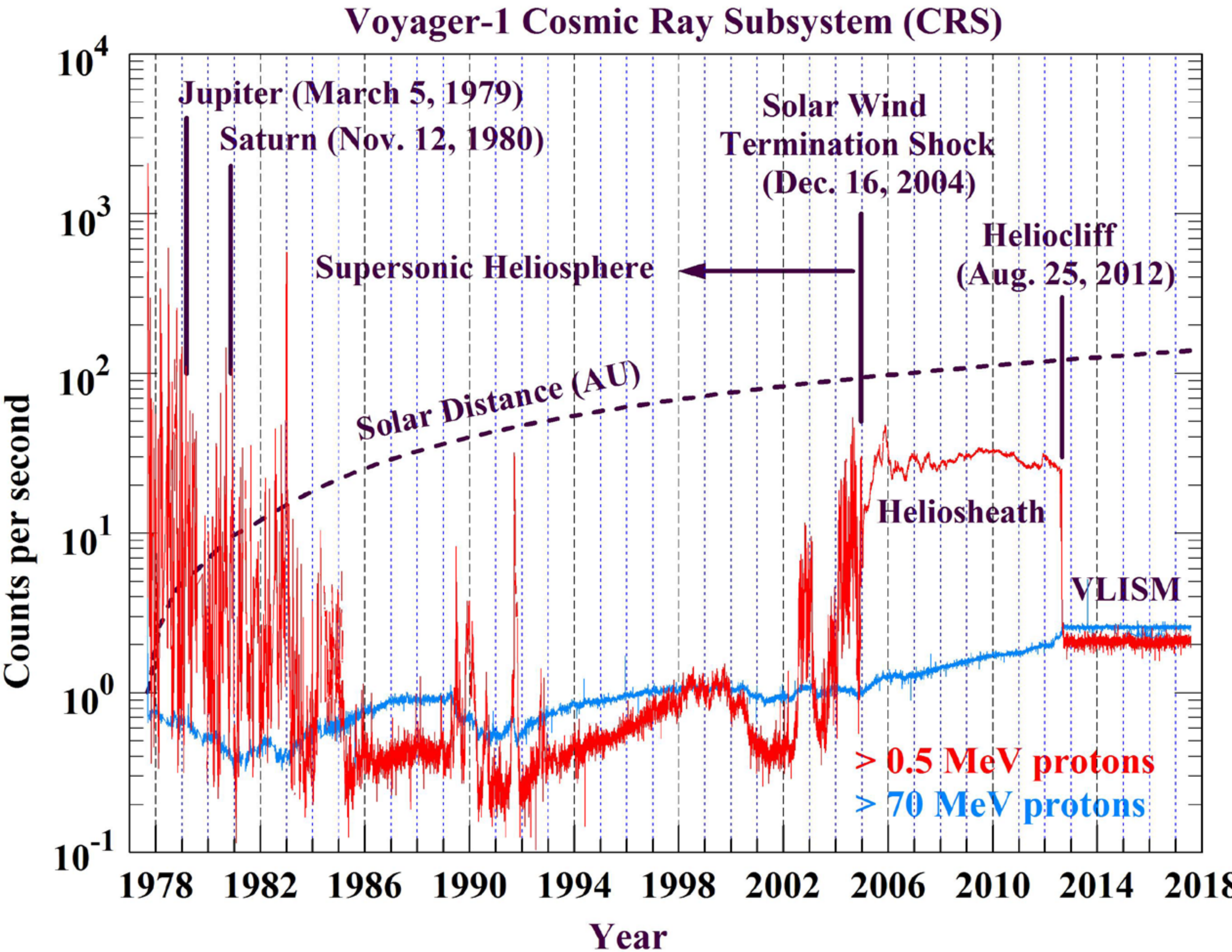
Least Shielding
$1 – 10$ g/cm^2

More Shielding
10^2 g/cm^2

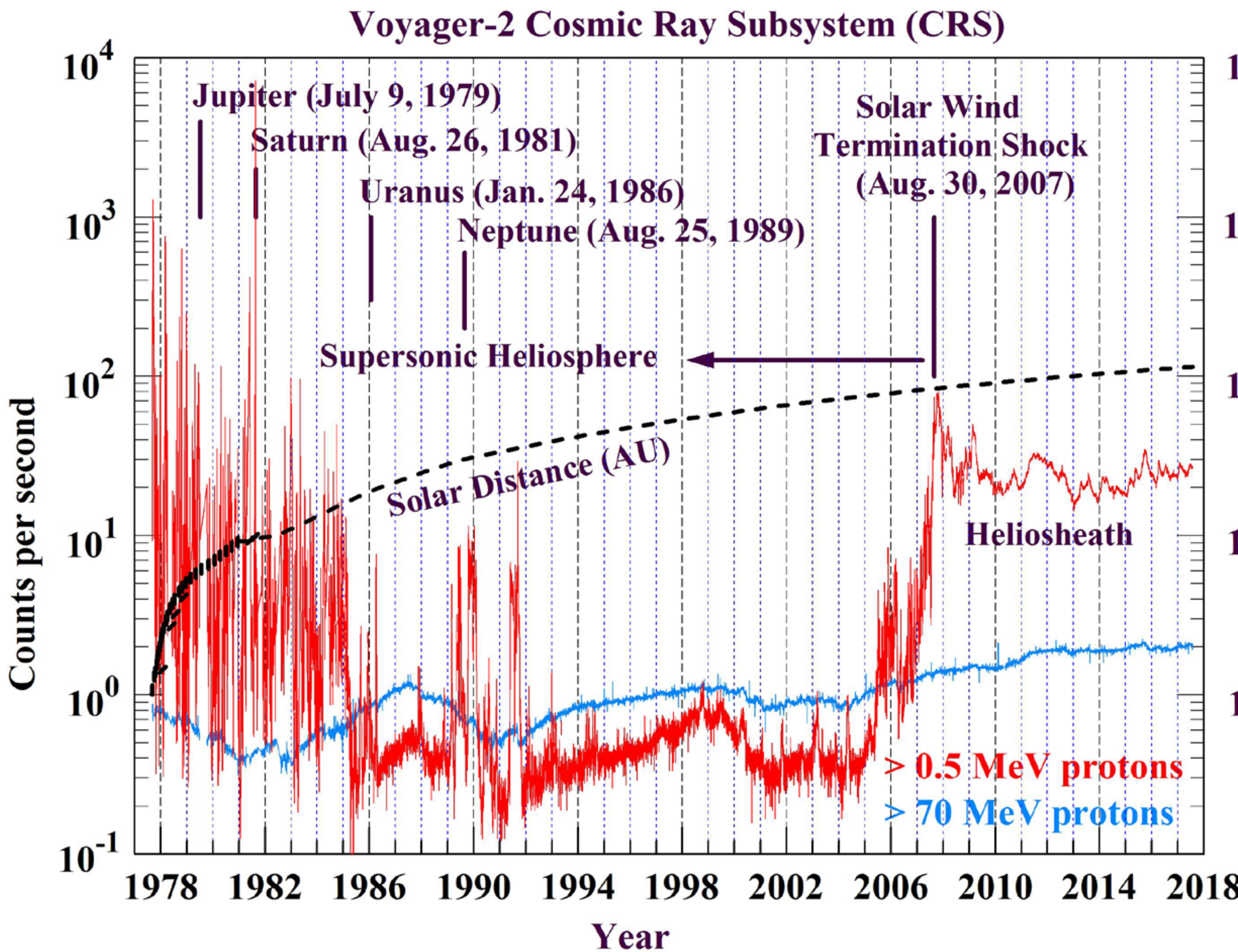
Most Shielding
$\geq 10^3$ g/cm^2

Human Explorations on the Moon

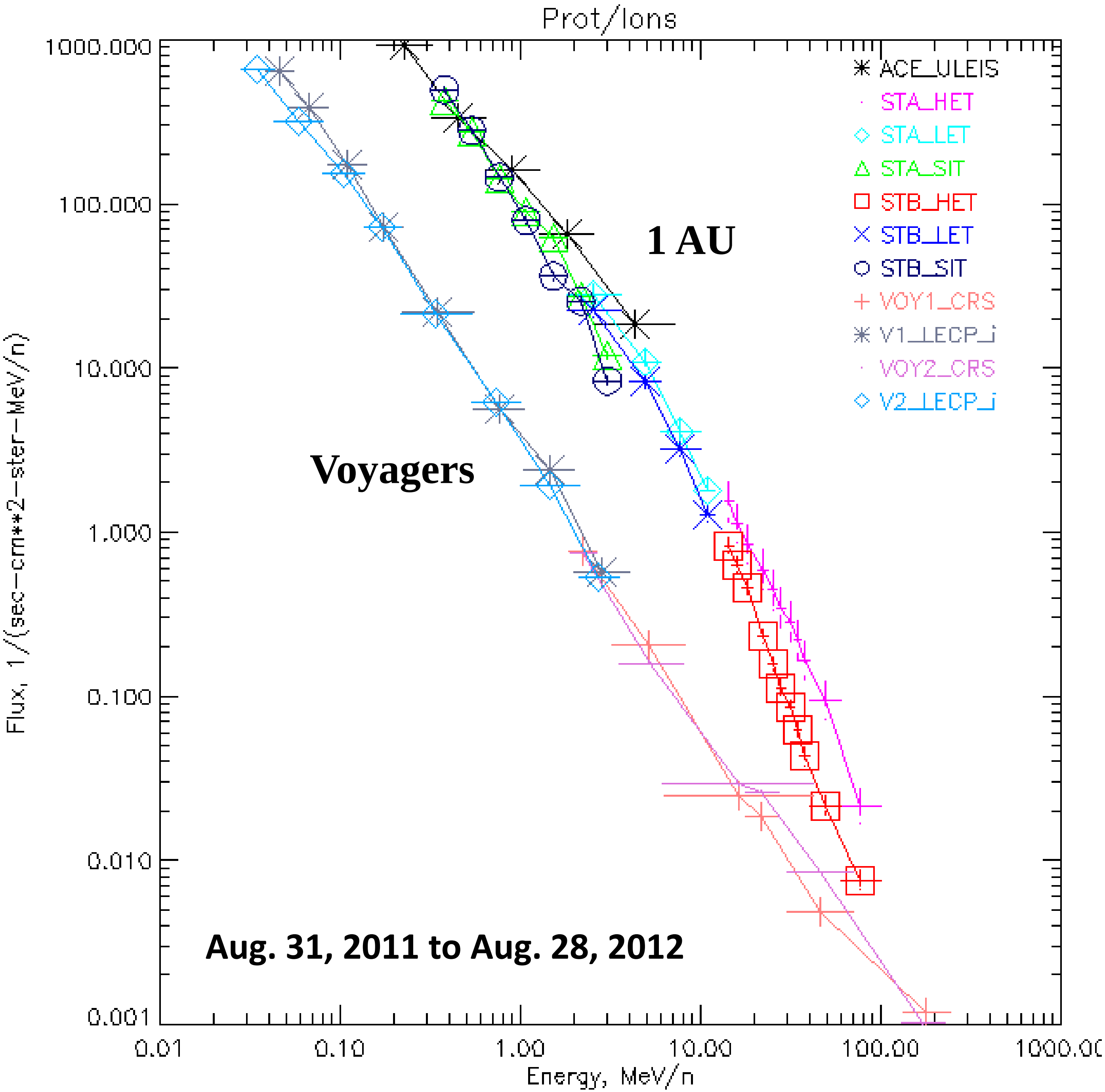
NASA



Voyager-1 Cosmic Ray Subsystem (CRS)
Jupiter (March 5, 1979)
Saturn (Nov. 12, 1980)
Solar Wind
Termination Shock
(Dec. 16, 2004)
Supersonic Heliosphere
Heliocliff
(Aug. 25, 2012)
Solar Distance (AU)
Heliosheath
VLISM
> 0.5 MeV protons
> 70 MeV protons
Counts per second
Solar Distance (AU)
Year
10^4
10^3
10^2
10^1
10^0
10^{-1}
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
2018

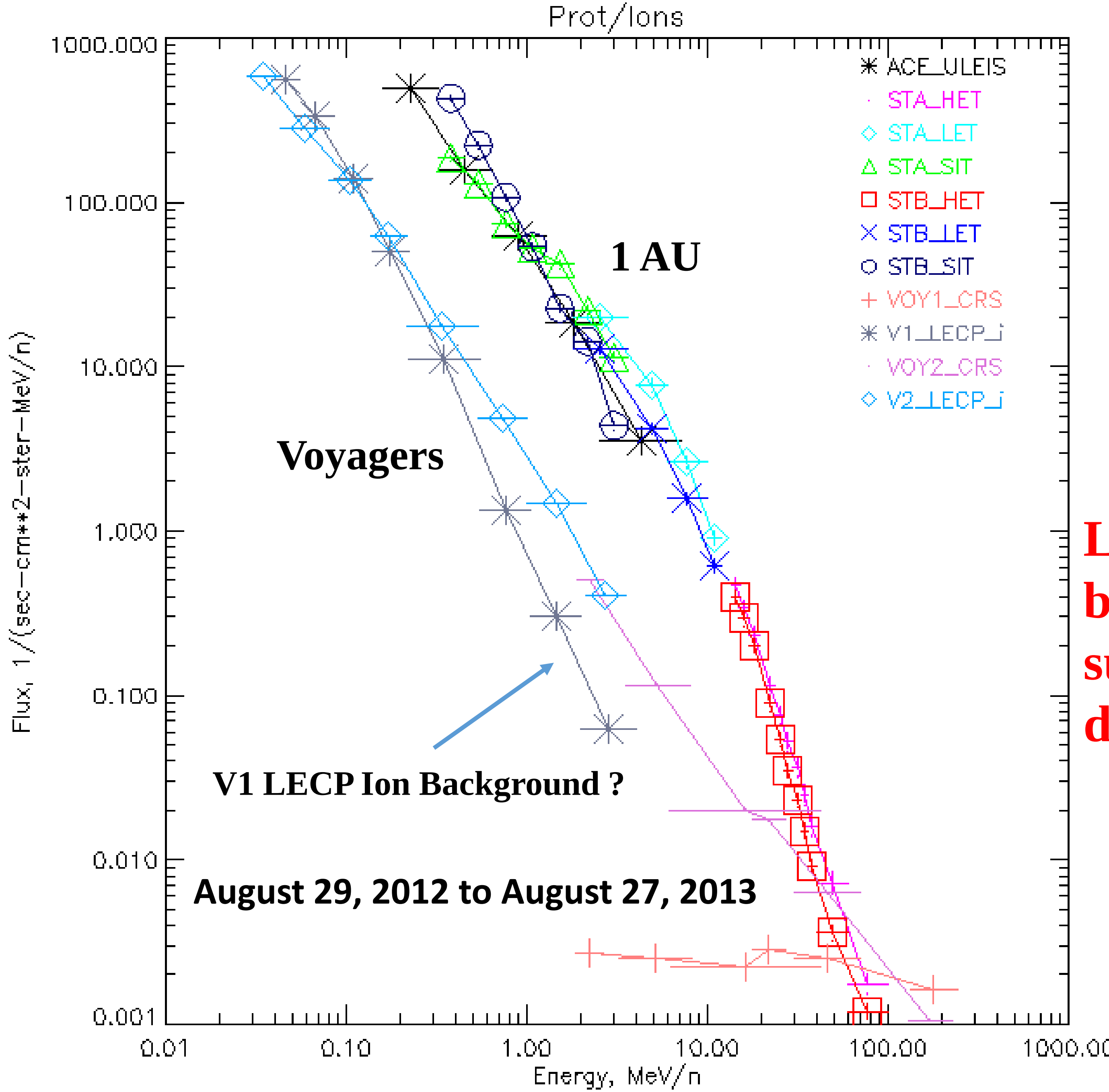


Voyager-2 Cosmic Ray Subsystem (CRS)
Jupiter (July 9, 1979)
Saturn (Aug. 26, 1981)
Uranus (Jan. 24, 1986)
Neptune (Aug. 25, 1989)
Solar Wind
Termination Shock
(Aug. 30, 2007)
Supersonic Heliosphere
Solar Distance (AU)
Heliosheath
> 0.5 MeV protons
> 70 MeV protons
Counts per second
Solar Distance (AU)
Year
10^4
10^3
10^2
10^1
10^0
10^{-1}
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
2018



VEPO MSSP-2

Protons Ions



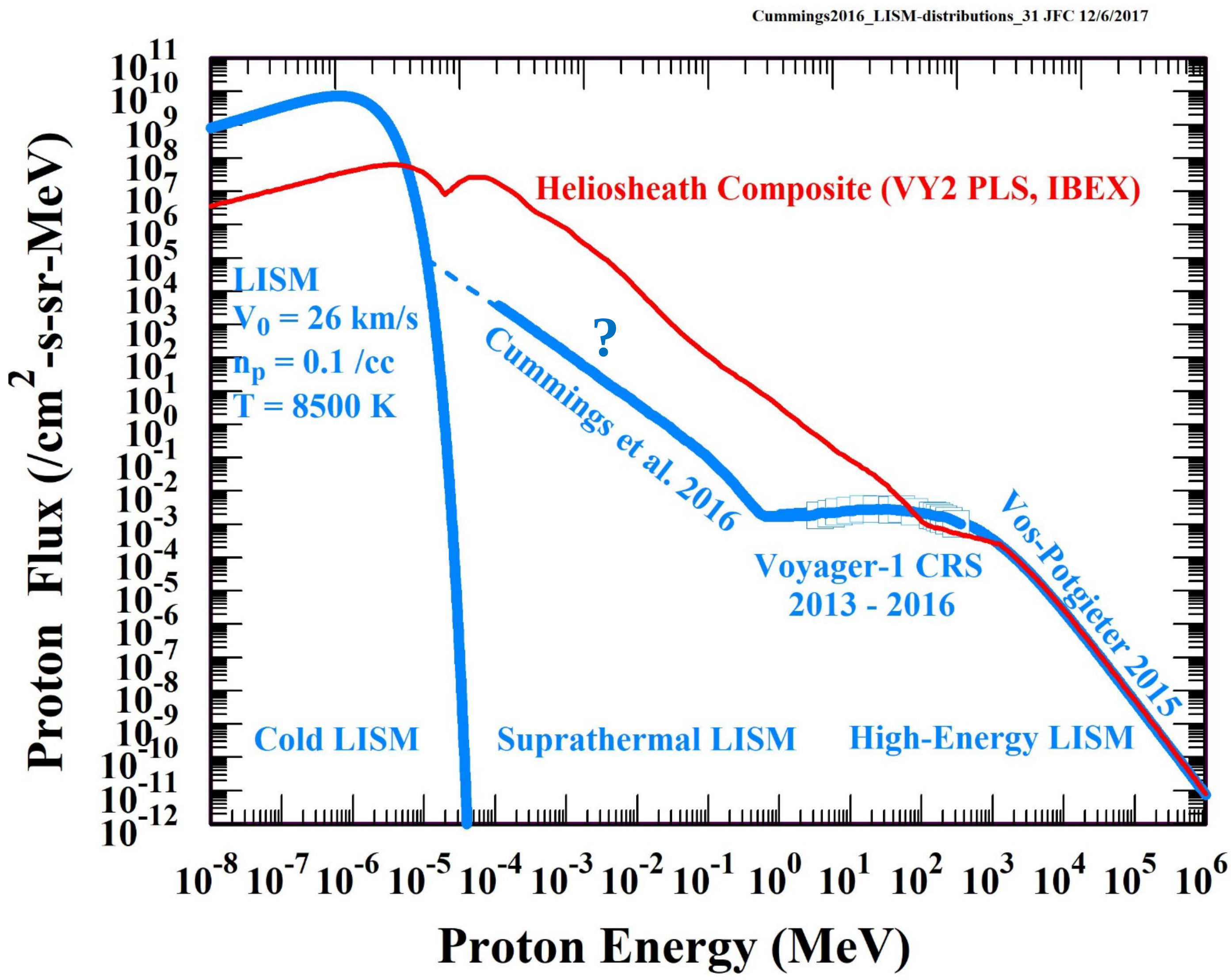
VEPO MSSP-2

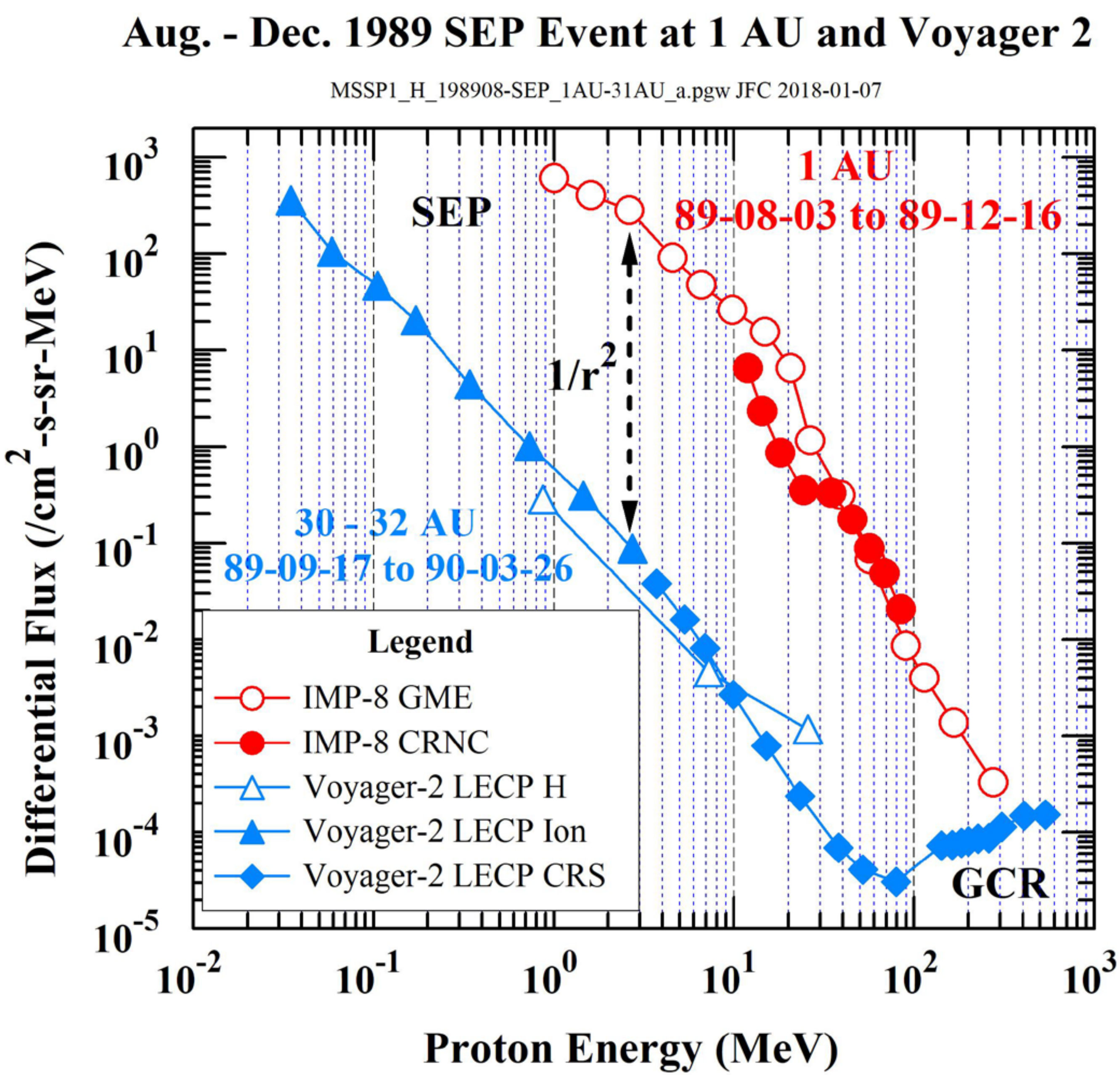
Protons Ions

LECP background-subtracted data ?

Comparison of Local Interstellar and Inner Heliosheath Model Flux Spectra

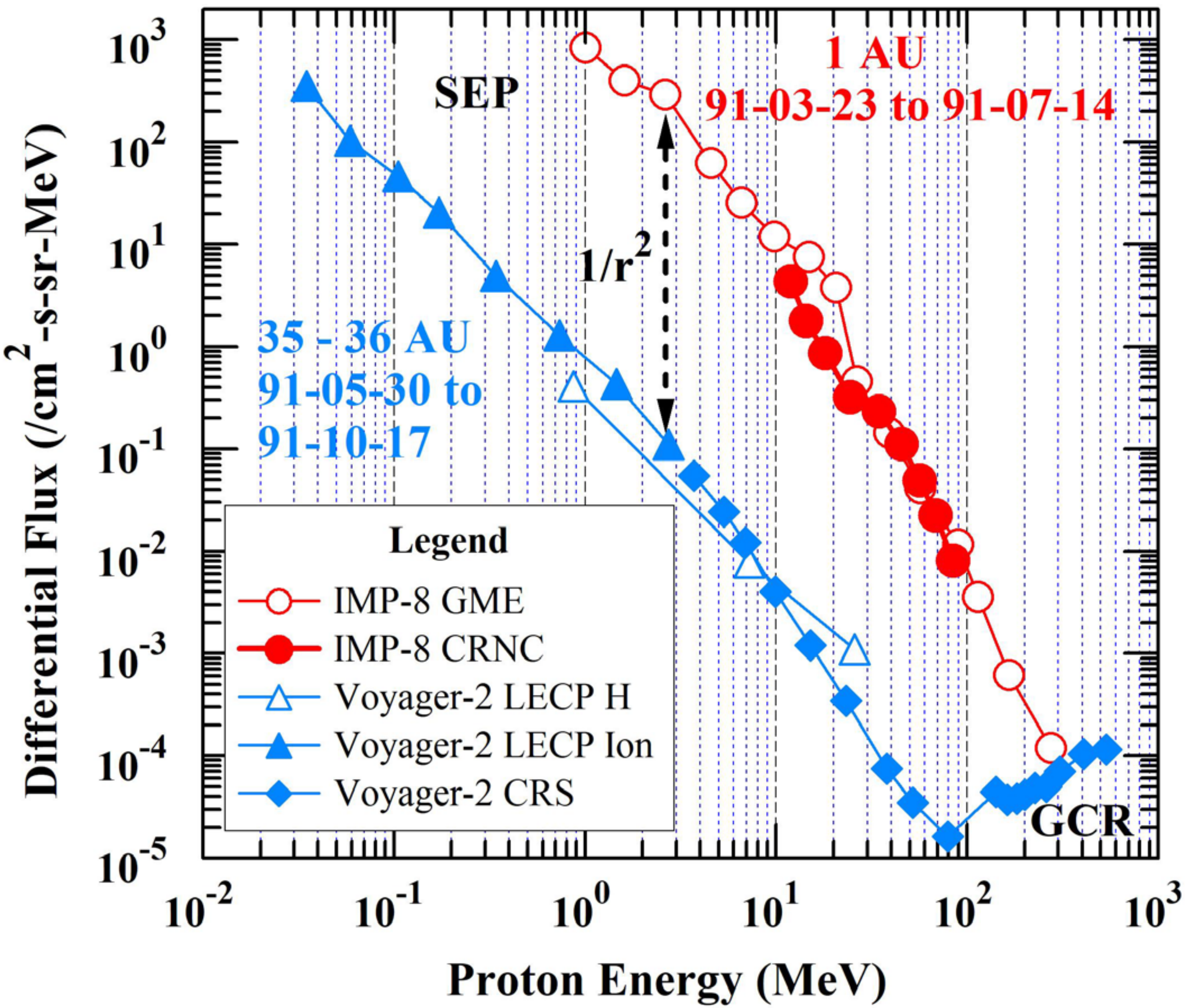
No direct LISM suprathermal particle measurements below 1 MeV, so we use Cummings et al. (2016) limit for suprathermal 0.01 keV – 1 MeV spectrum from molecular cloud ionization. We consider this to be lower limit, as per following slides.




Aug. - Dec. 1989 SEP Event at 1 AU and Voyager 2
MSSP1_H_198908-SEP_1AU-31AU_a.pgw JFC 2018-01-07
Differential Flux (/cm^2-s-sr-MeV)
Proton Energy (MeV)
SEP
1/r^2
1 AU
89-08-03 to 89-12-16
30 - 32 AU
89-09-17 to 90-03-26
GCR
Legend
IMP-8 GME
IMP-8 CRNC
Voyager-2 LECP H
Voyager-2 LECP Ion
Voyager-2 LECP CRS

March - July 1991 SEP Event at 1 AU and Voyager 2

MSSP1_H_199103-SEP_1AU-35AU_a.pgw JFC 2018-01-06



SPDF in the Heliophysics Science Data Management Policy

- One of two (active) Final Archives
  - Find, ingest, preserve long-term and ensure ongoing (online) useful access to non-solar NASA heliophysics science data
- Support critical infrastructure in the Heliophysics Data Environment
  - Heliophysics-wide dataset inventory (Heliophysics Data Portal / HDP)
  - CDF (Common Data Format) and metadata standards
  - APIs (Application Programming Interfaces, e.g. webservices) to SPDF system capabilities and data
- Center of Excellence for unique science-enabling services
  - CDAWeb
  - SSCWeb and 4D Orbit Viewer
  - OMNIweb

Spacecraft or Instrument	Time Average	Ion	Time Duration	Energy Range (MeV/n)
Advanced Composition Explorer (ACE)			1997-08-25 – Present	
Electron, Proton, and Alpha Monitor (EPAM)	1 day	He	1997-08-30 – 2015-05-30	0.4 – 3.9
Solar Energetic Particle Ionic Charge Analyzer (SEPICA)	1 hour	H, He	1997-10-07 – 2005-02-05	0.40 – 6.0
Solar Isotope Spectrometer (SIS)	1 hour	He	1997-08-29 – 2018-01-07	3.4 – 41.2
Ultra-Low-Energy Isotope Spectrometer (ULEIS)	1 hour	H, He	1998-02-19 – 2018-01-07	0.06 – 8.7
Helios 1			1974-12-10 – 1986-02-10	
Cosmic Ray Particle Instrument (E6)	1 hour	H, He	1974-12-11 – 1983-12-31	4.0 - 51.0
Cosmic Ray Instrument (E7)	30 min	H, He	1974-12-16 – 1982-12-31	3.4 - 206.5
Helios 2			1976-01-15 – 1980-03-03	
Cosmic Ray Particle Instrument (E6)	1 hour	H, He	1976-01-16 – 1980-03-08	4.0 - 51.0
Cosmic Ray Instrument (E7)	30 min	H, He	1976-01-19 – 1979-12-23	3.4 - 204.5
Interplanetary Monitoring Platform 8 (IMP-8)			1973-10-26 – 2006-10-07	
Charged Particle Measurements Experiment (CPME)*				
Cosmic Ray Nuclear Composition (CRNC) Experiment	1 hour	H,He	1973-10-30 – 2001-10-26	10.9 - 95.0
Goddard Medium Energy (GME) Experiment	30 min	H,He	1973-10-30 - 2001-10-26	0.9 - 237.0
WIND			1994-11-01 - Present	
Energetic Particle Acceleration, Composition and Transport (EPACT) - LEMT	1 hour	He	1994-11-03 - 2017-12-31	2.0 - 7.4
EPACT - STEP	1 hour	He	1995-01-01 - 2017-12-17	0.04 - 2.5

Spacecraft or Instrument	Time Average	Ion	Time Duration	Energy Range (MeV/n)
Pioneer 10			1972-03-03 – 2003-01-23	
Charged Particle Instrument (CPI)	15 min	H, He	1972-03-03 – 1992-08-27	3 - 67
Cosmic Ray Telescope (CRT) Experiment	6 hour	H, He	1972-03-06 – 1994-12-31	3.4 - 413.0
Pioneer 11			1973-04-06 – 1995-09-30	
Charged Particle Instrument (CPI)	15 min	H, He		3 - 67
Cosmic Ray Telescope (CRT) Experiment	6 hour	H, He	1973-04-06 – 1994-12-31	3.4 - 413.0
Solar Heliospheric Observatory (SOHO)			1995-12-02 – Present	
Energetic and Relativistic Nuclei and Electron (ERNE) Experiment	1 hour	H, He	1996-05-07 – 2017-12-25	1.3 - 130.0
Solar Terrestrial Relations Observatory A (STEREO A)			2006-10-26 – Present	
IMPACT/SEP High Energy Telescope (HET)	1 hour	H	2006-12-01 - 2018-01-14	13.6 - 100.
IMPACT/SEP Low-Energy Telescope (LET)	1 hour	H, He	2007-03-29 - 2017-11-30	1.8 - 15.0
IMPACT/SEP Suprathermal Ion Telescope (SIT)	1 hour	H, He	2007-01-01 - 2017-09-14	0.1 - 10.2
Solar Terrestrial Relations Observatory B (STEREO B)				
IMPACT/SEP High Energy Telescope (HET)	1 hour	H	2006-12-01 - 2014-09-27	13.6 - 100.
IMPACT/SEP Low-Energy Telescope (LET)	1 hour	H, He	2007-03-29 - 2014-09-27	1.8 - 15.0
IMPACT/SEP Suprathermal Ion Telescope (SIT)	1 hour	H, He	2007-01-27 - 2014-09-29	0.1 - 10.2
Ulysses				
Cosmic Ray and Solar Particle Investigation (COSPIN)	1 day	H, He	1990-10-23 - 2009-06-30	2.0 - 95.0
Heliosphere Instrument for Spectra, Composition and Anisotropy at Low Energies (HISCALE)	1 day	He	1990-11-14 - 2009-06-09	0.3 - 3.9

Radiation Effects in the Solar System

- Space weathering of surfaces and atmospheres

  Solar coronal plasma implantation → solar wind ^3He on the Moon (ISRU)

  Surface erosion by ion sputtering → moon exospheric production

  Radiolytic change of molecular chemistry: H_2O → OH, O_2 → biology ?

  Deep dielectric charging by energetic particles → discharge effects ?

  Secondary neutrons → detect hydrogeneous composition (e.g. H_2O, CH_4)

  Radioisotopes → surface and subsurface dating, heating of subsurface

- Hazards to robotic spacecraft and human explorers

  August 7, 1972 solar flare event:

  Between Apollo 16 (April 16 – 27) & Apollo 17 (Dec. 7 – 19)

  The next centennial "Carrington" event: *12% chance in next 10 years !*

  Mars mission round trip dose = 0.66 Sievert (66 rems) + large SEP dose?

  Spacecraft and surface charging hazards at $\Phi \leq 10$ kV ?

Goal: Determine the characteristic flux spectra of protons, alphas and heavier ions measured on various time scales of days, months, years, solar cycles and epochs (e.g., Maunder Minimum to Modern Maximum), and, if possible, even over the age of affected solar system planets, moons, and rings.