Early Warning of Solar Energetic Particle Events with REleASE – SEP Scoreboard

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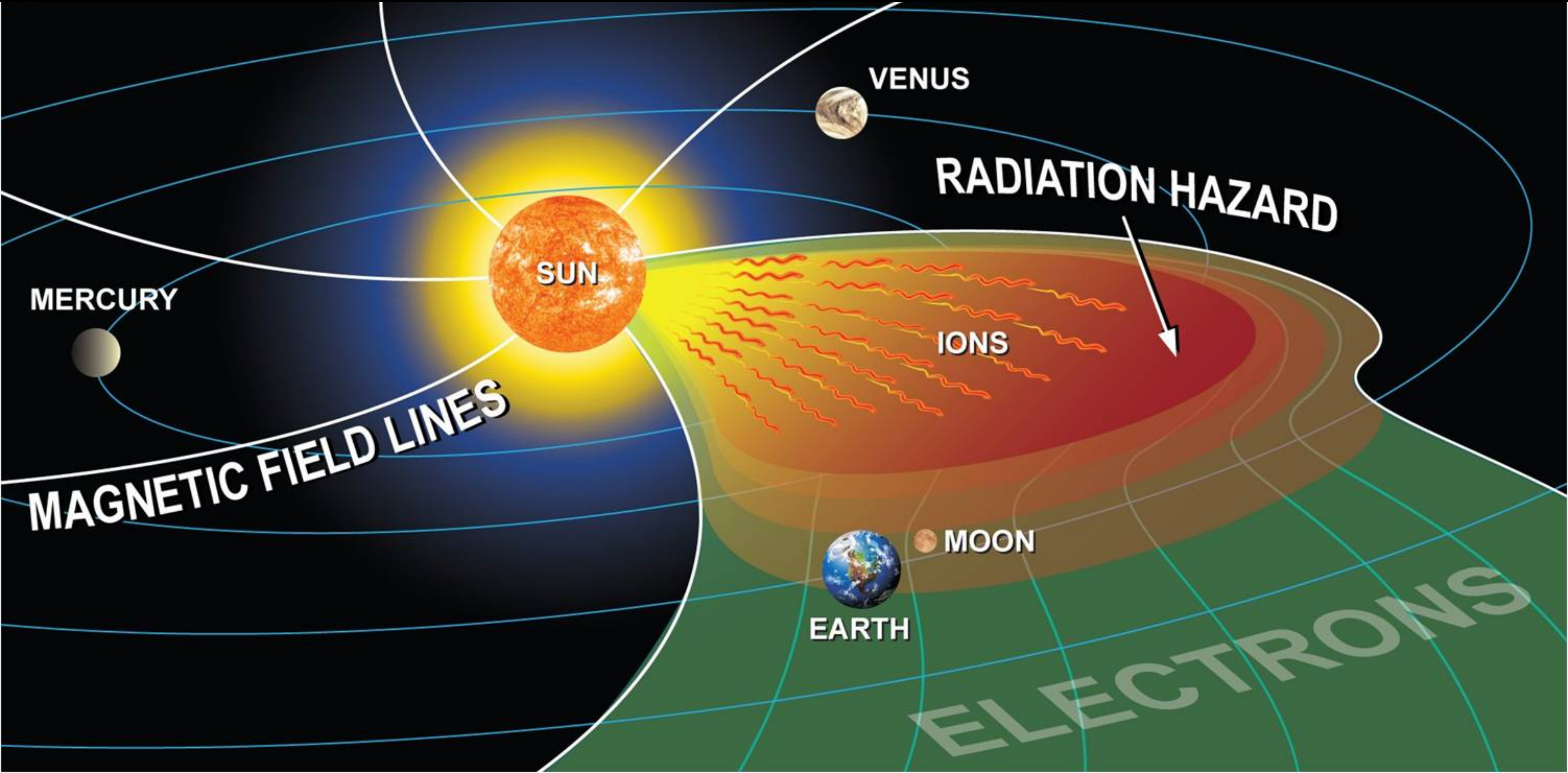
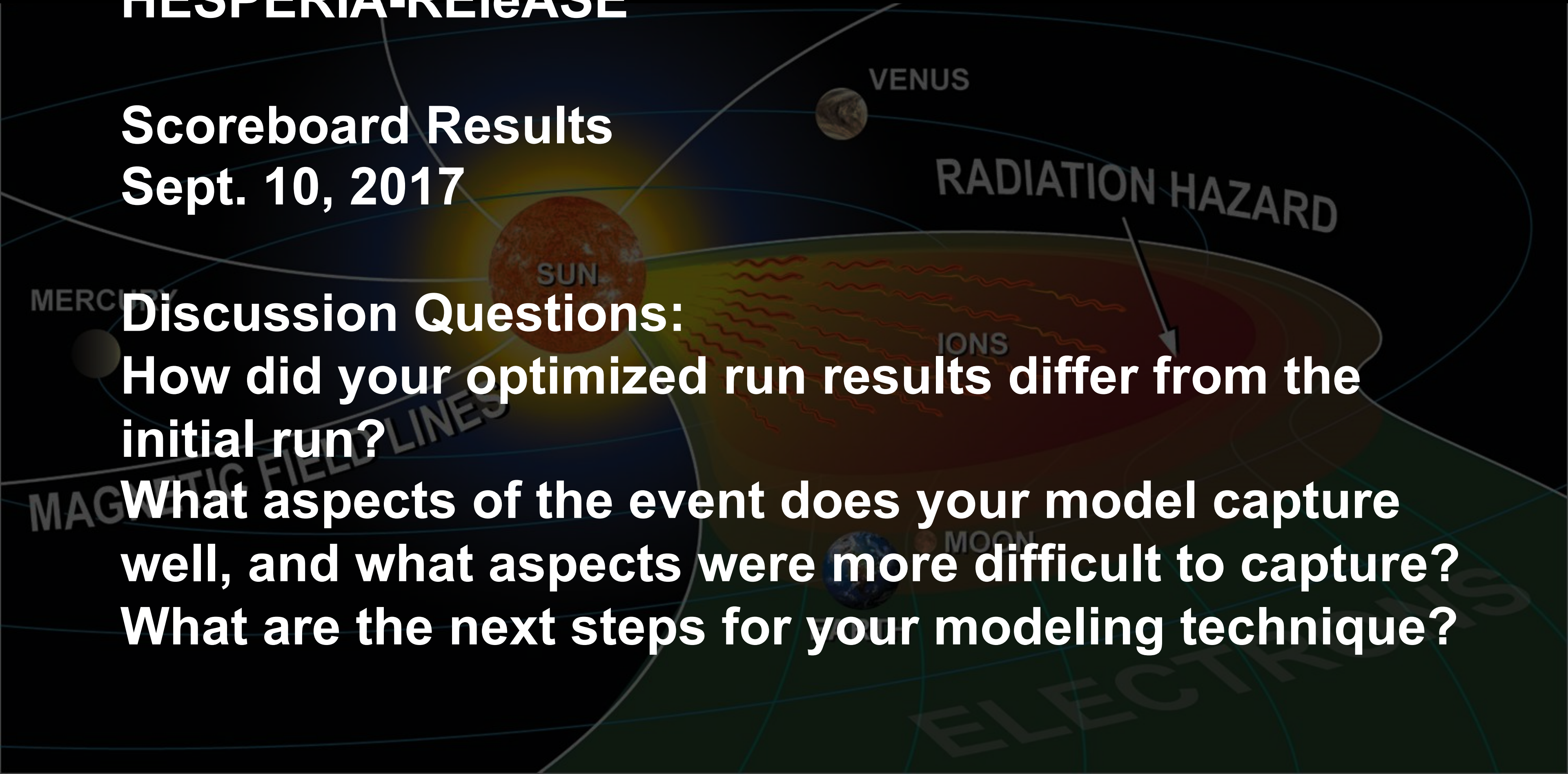
SHINE 2018

Cocoa Beach, FL, Aug. 3, 2018



Outline

Brief Description of and Context for the Relativistic Electron Alert System for Exploration (REleASE) and HESPERIA-REleASE



Scoreboard Results
Sept. 10, 2017

Discussion Questions:
How did your optimized run results differ from the initial run?
What aspects of the event does your model capture well, and what aspects were more difficult to capture?
What are the next steps for your modeling technique?

Fast Rise of Solar Energetic Particle Events

Acute Radiation Sickness Lower Threshold

Equivalent Dose Rate from SEP Protons Rises Rapidly

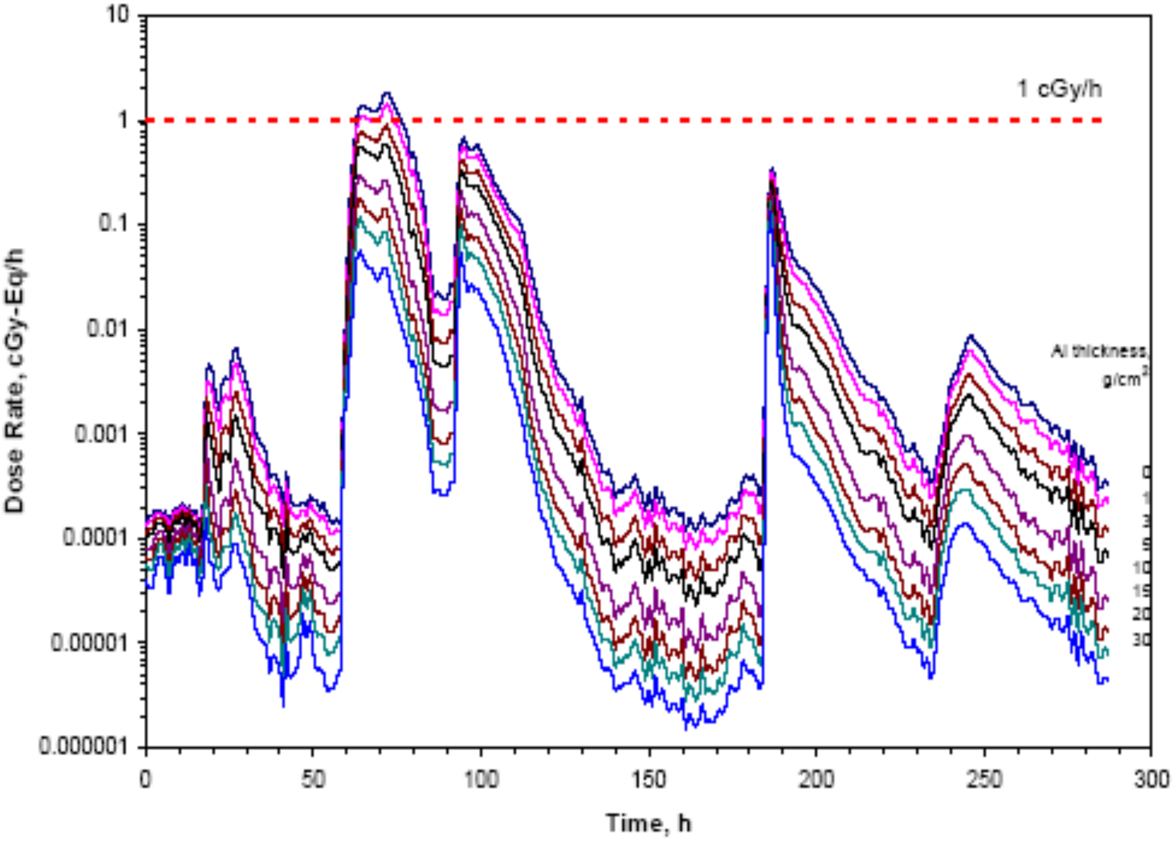


Figure 5. BFO dose rate behind various aluminum thicknesses during Oct 26-Nov 6, 2003 SPE.

Kim, Hu, and Cucinotta [*Proc. AIAA*, 2005]

Exploration:
Is SEP Forecasting Necessary and Feasible?

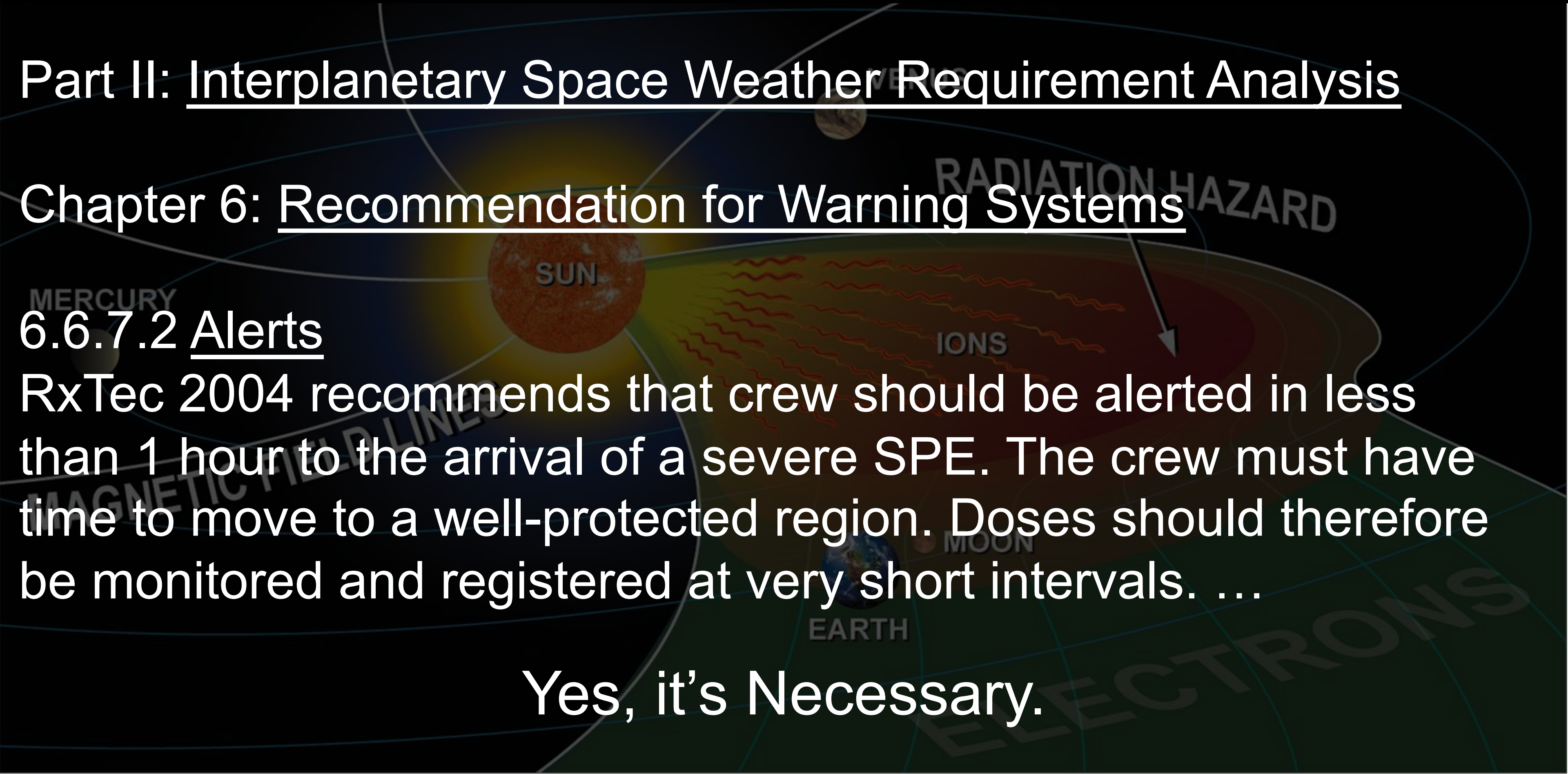
Radiation Exposure and Mission Strategies for Interplanetary Manned Missions (Foullon *et al*., 2004)

Part II: Interplanetary Space Weather Requirement Analysis

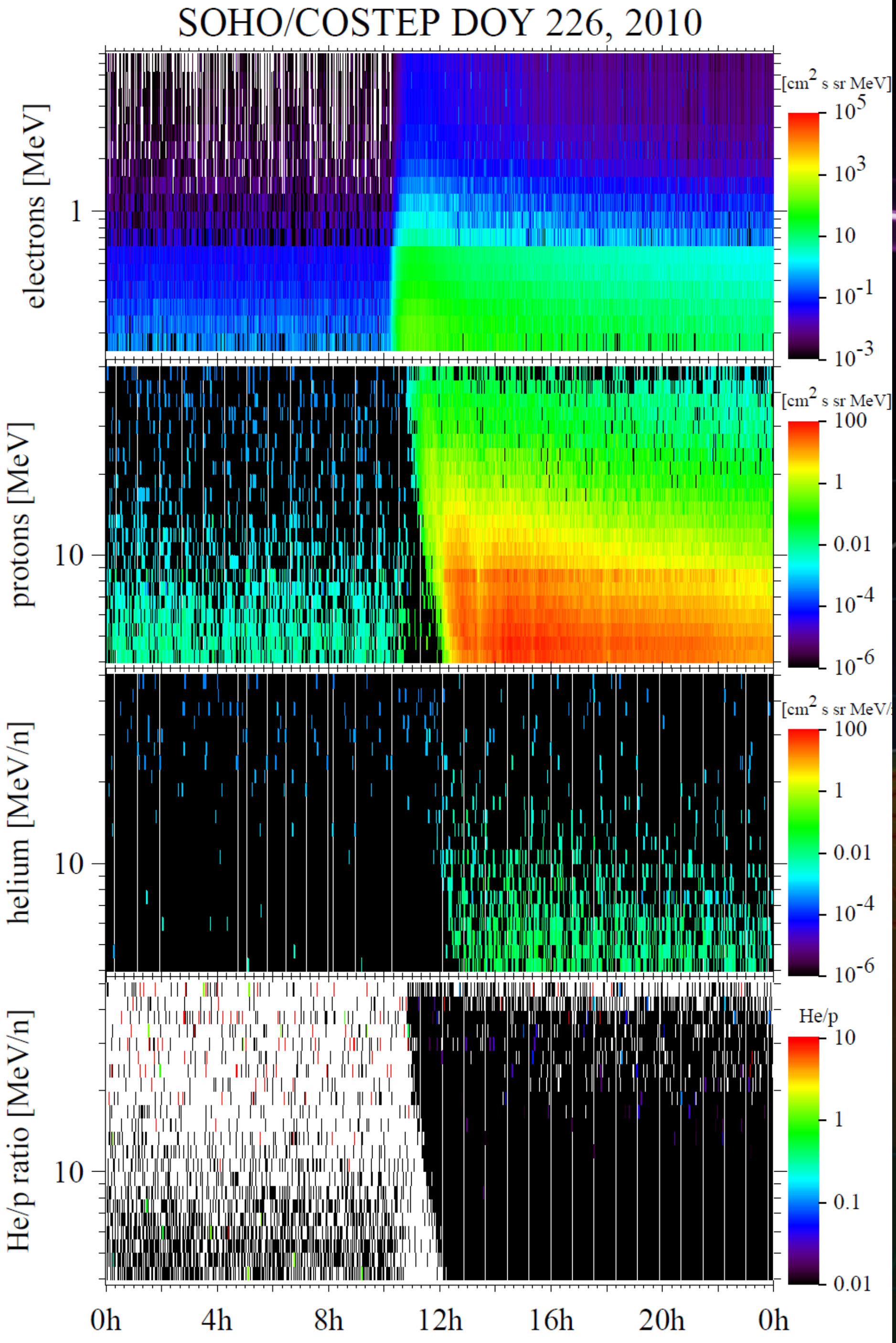
Chapter 6: Recommendation for Warning Systems

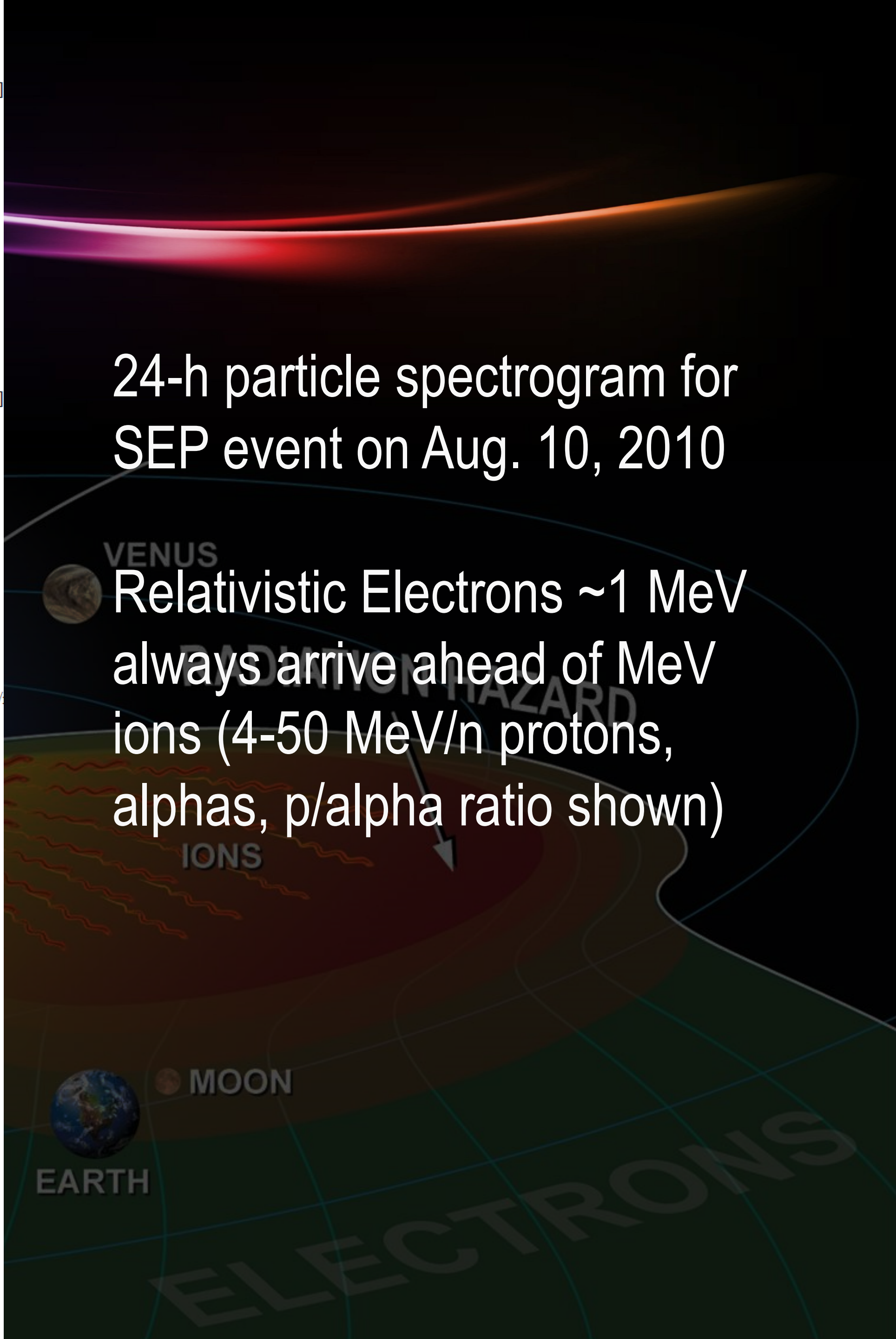
6.6.7.2 Alerts

RxTec 2004 recommends that crew should be alerted in less than 1 hour to the arrival of a severe SPE. The crew must have time to move to a well-protected region. Doses should therefore be monitored and registered at very short intervals. …



Yes, it’s Necessary.



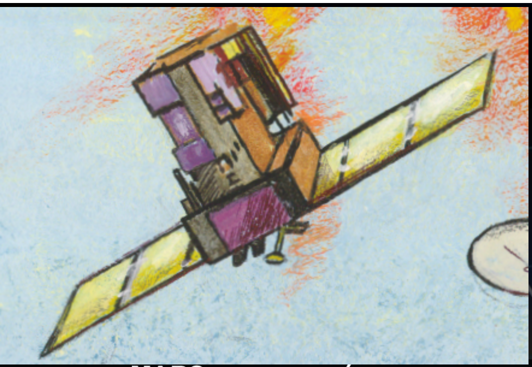


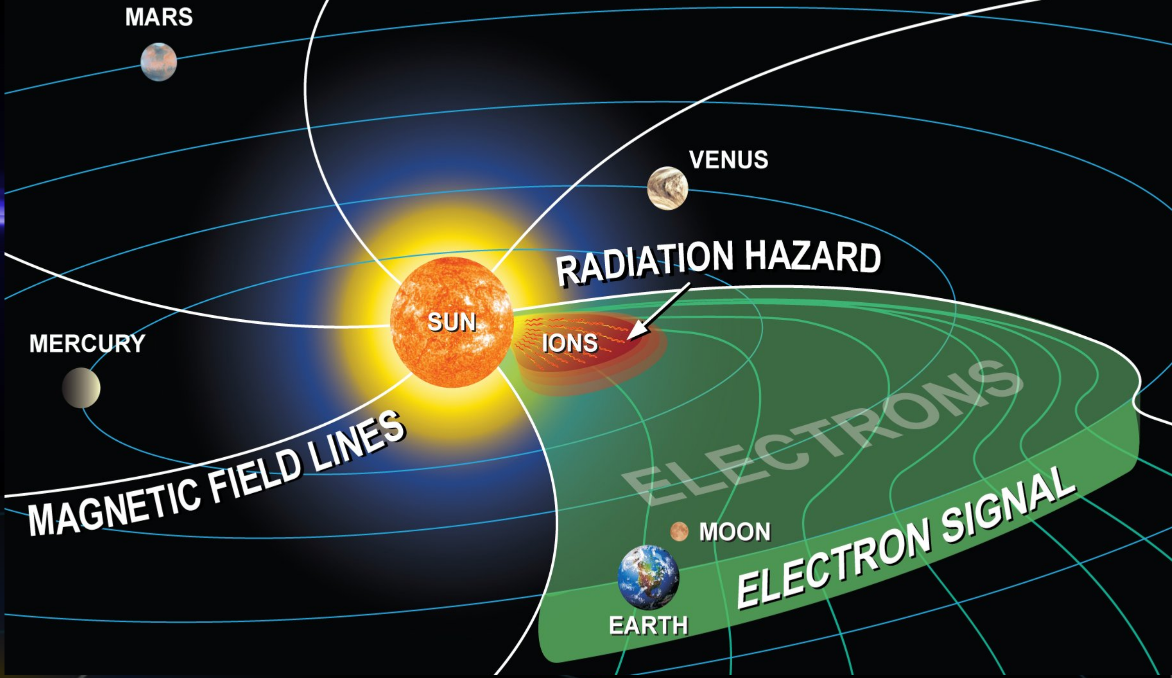
24-h particle spectrogram for SEP event on Aug. 10, 2010

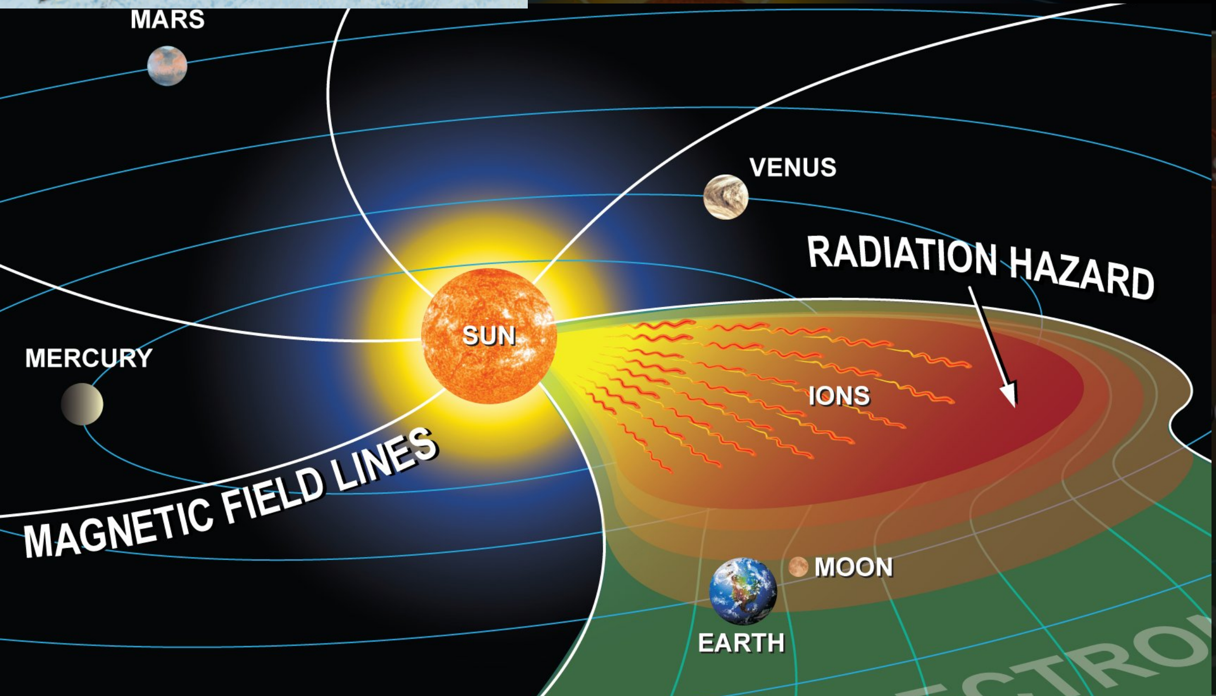
Relativistic Electrons ~1 MeV always arrive ahead of MeV ions (4-50 MeV/n protons, alphas, p/alpha ratio shown)

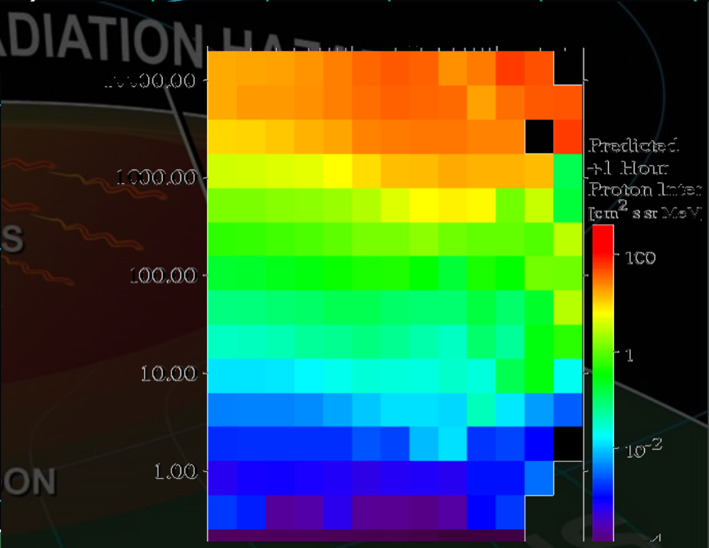
REleASE

Relativistic Electron Alert System for Exploration









Electron Rise Parameter

Empirical Forecasting Matrix Translates Solar Electron Data into +1h Proton Hazard Forecast

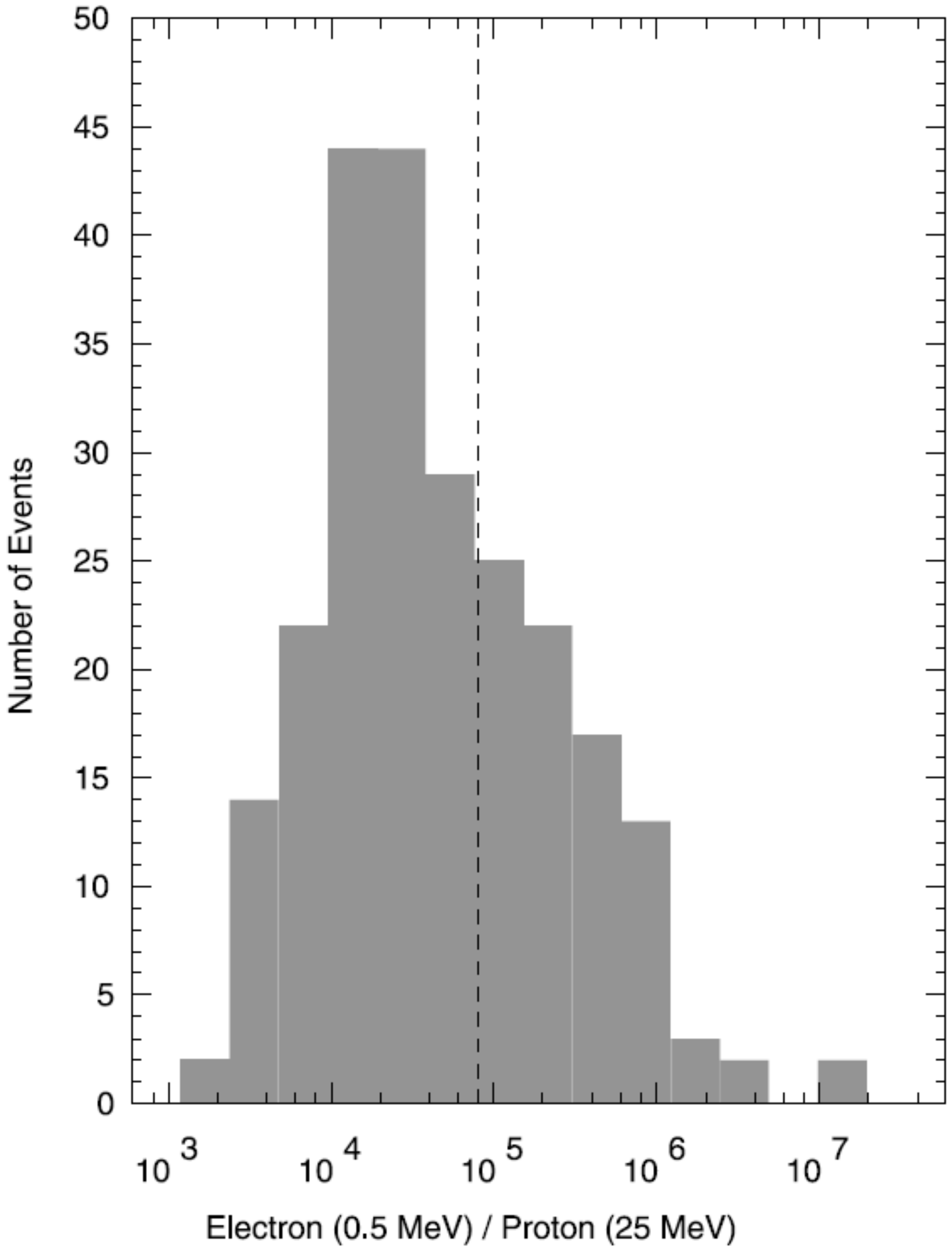
(Posner, *Space Weather*, 2007)

REleASE

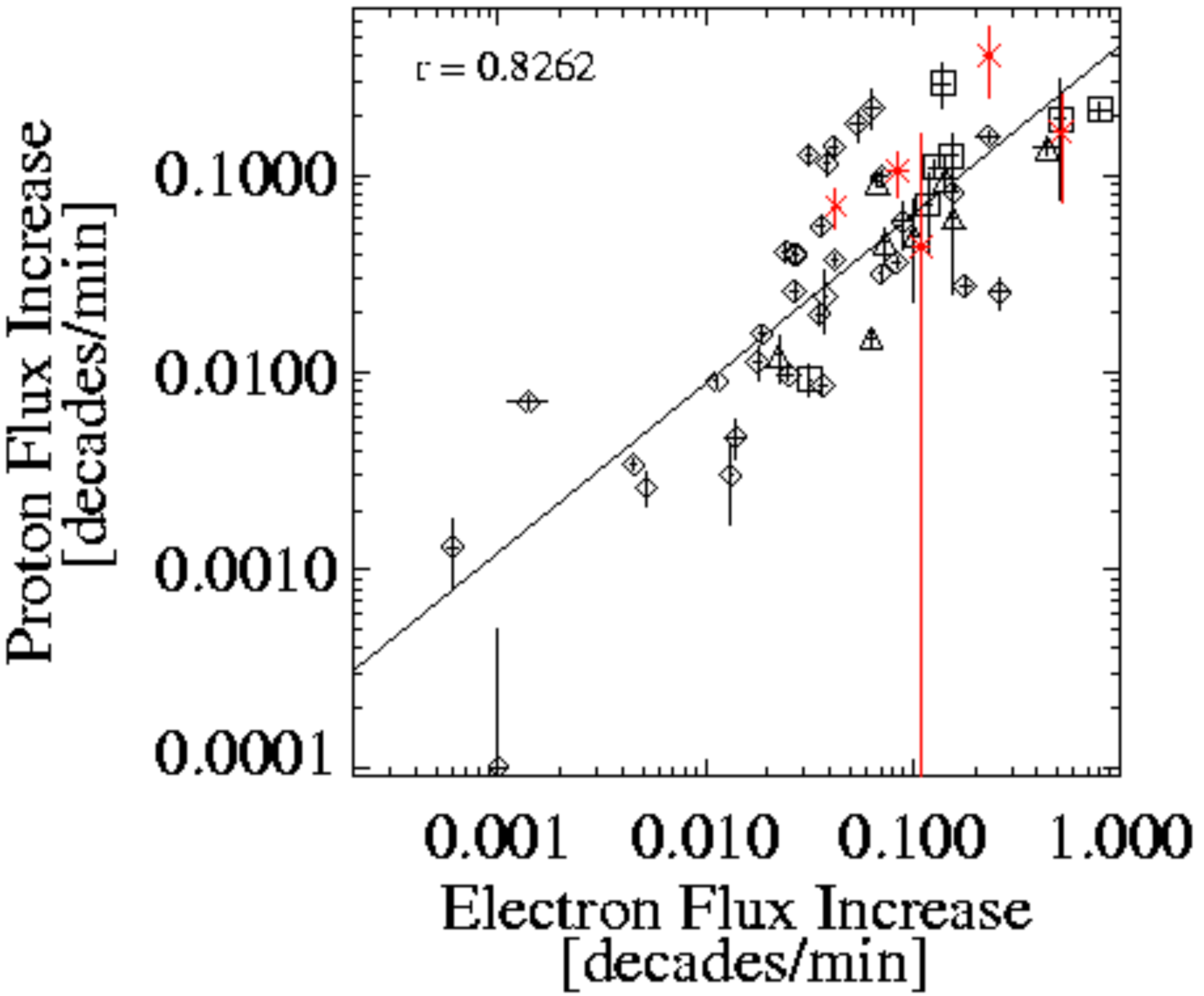
Relativistic Electron Alert System for Exploration

Cane, Richardson and von Rosenvinge (JGR, 2010):

- Electron-to-proton ratio of 1997-2006 SEPs
- Most SEPs within factor of 10 of a median e/p ratio
- Continuum of event properties that does not support the simplest “two class” picture of SEP events



Comparison of SEP Rise Times



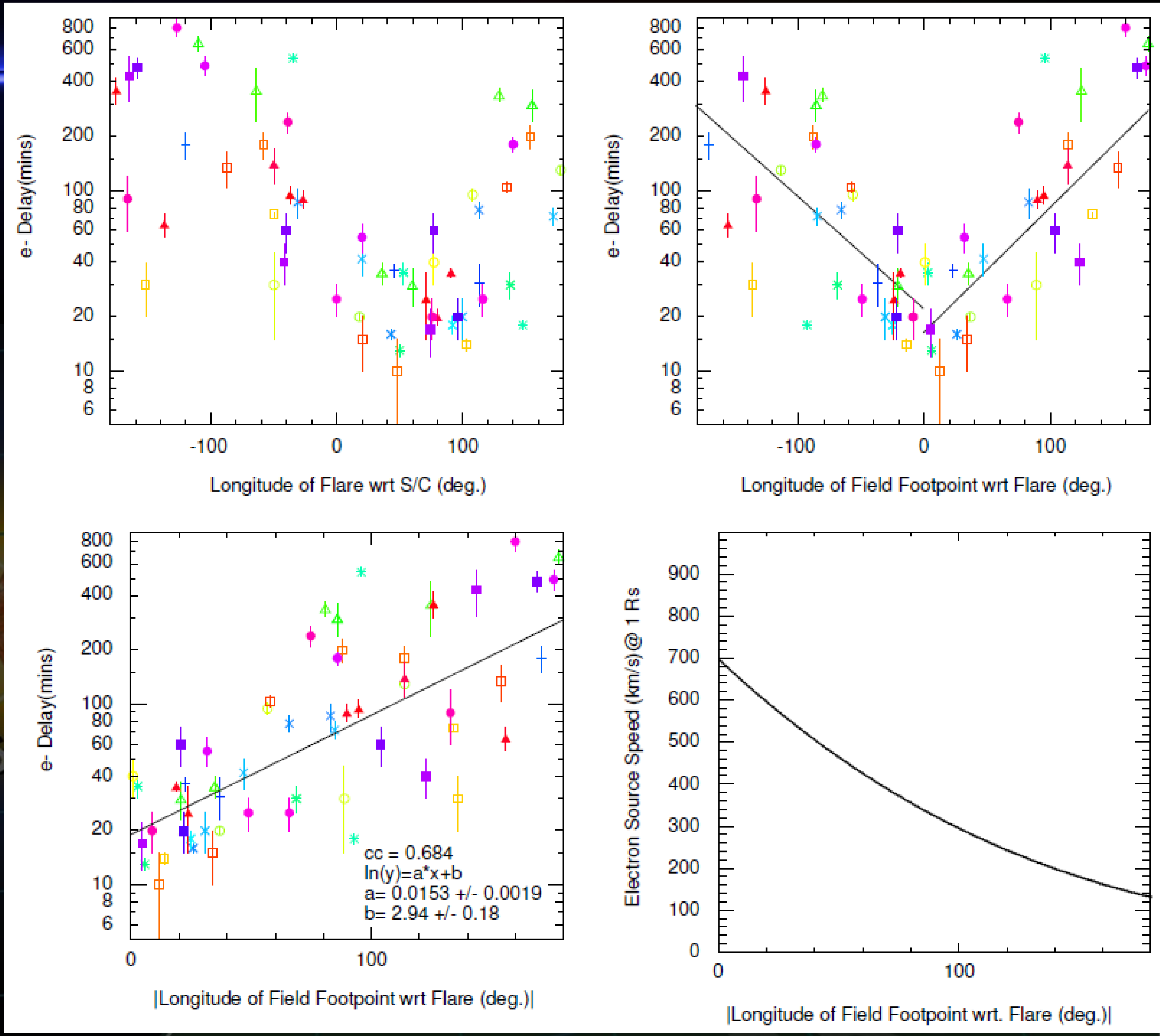
Diamonds: Regular Observing Mode
Triangles: Low Geometric Factor Mode
Squares: Extreme Fluxes, Not Used for Fit

Impulsive Events (red symbols) from List of Reames and Ng, *ApJ*, 2004

Exciter Speed Question

Richardson et al.

- Onset delays for electrons in SEP events
- STEREO A, B, SOHO Observations
- Determines “Electron Source Speed”: 700 -> 130 km/s (0°-180° from Source)

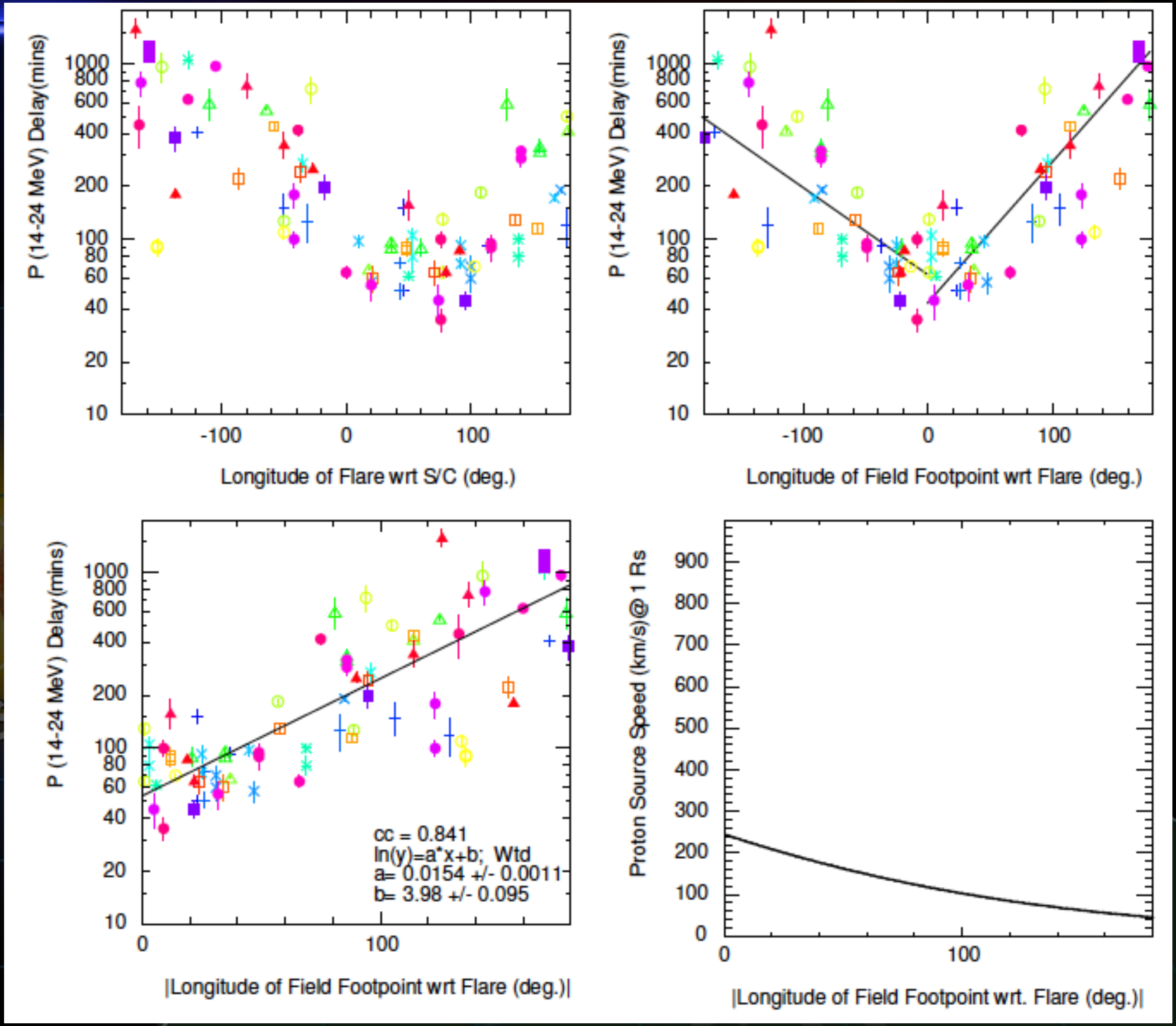


Richardson et al., Sol. Phys., 2014

Exciter Speeds?

Richardson et al.

- Onset delays for protons in SEP events
- STEREO A, B, SOHO Observations
- Determines “Proton Source Speed”: 240 -> 45 km/s (0°-180° from Source)



Richardson et al., Sol. Phys., 2014

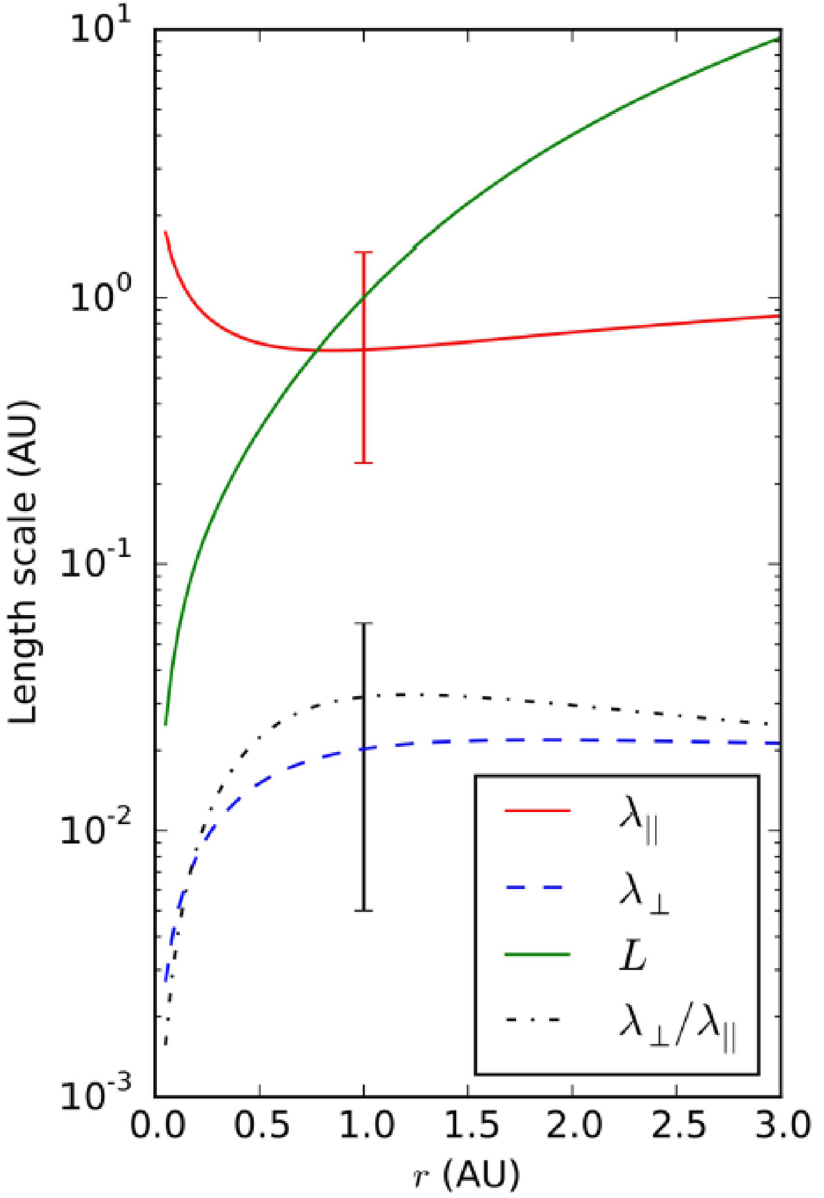


Figure 3. Parallel (solid red line) and perpendicular (dashed blue line) MFP as a function of radial distance. Also shown is the focusing length (solid green line) and the ratio η (dot-dashed black line; note that this quantity does not have any units). The vertical red and black error intervals show estimates for $\lambda_{||}$ and η, respectively. For the calculation of $\lambda_{\perp}$, we used $a = 1/10$.

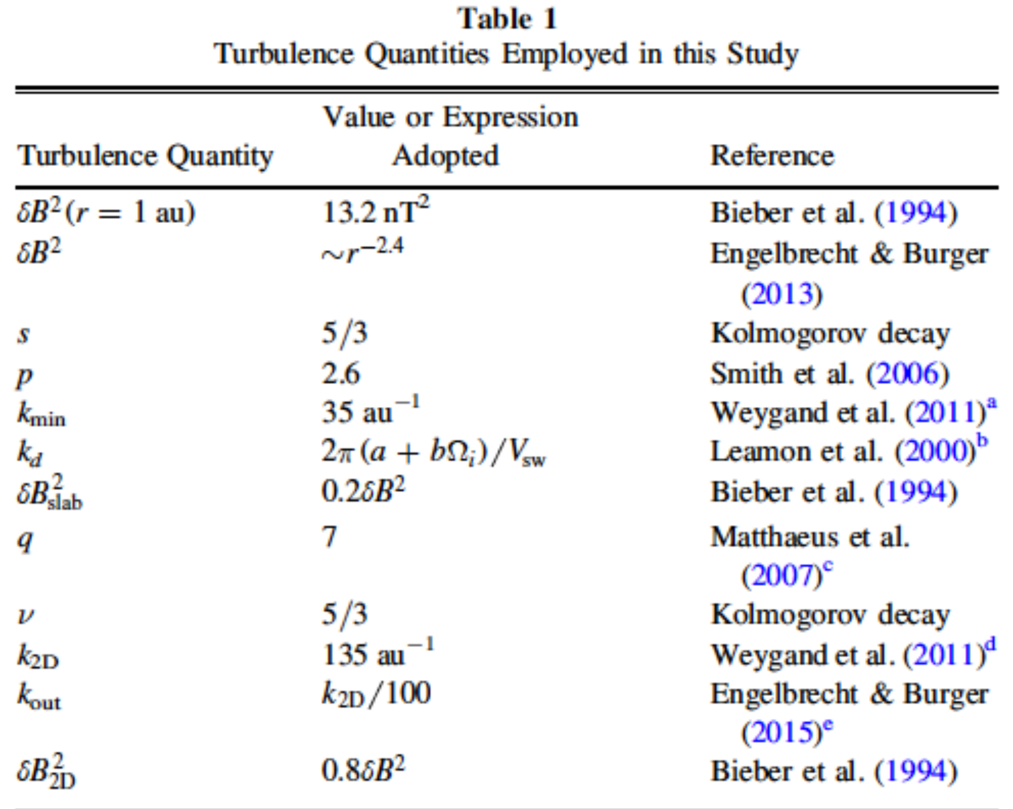
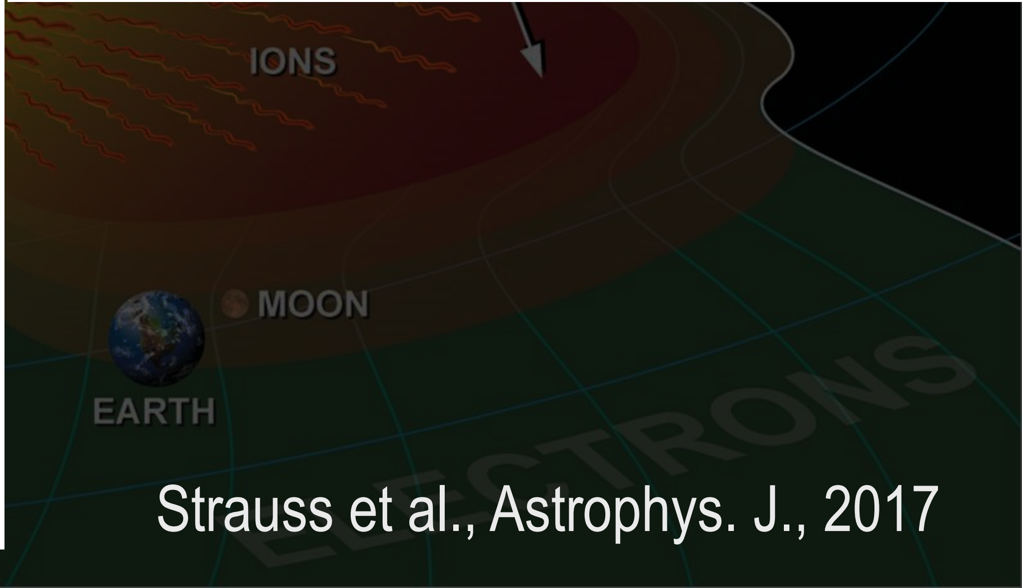


Table 1
Turbulence Quantities Employed in this Study

Turbulence Quantity	Value or Expression Adopted	Reference
$\delta B^2(r = 1\ \mathrm{au})$	$13.2\ \mathrm{nT}^2$	Bieber et al. (1994)
δB^2	$\sim r^{-2.4}$	Engelbrecht & Burger (2013)
s	$5/3$	Kolmogorov decay
p	2.6	Smith et al. (2006)
k_{min}	$35\ \mathrm{au}^{-1}$	Weygand et al. (2011)[a]
k_d	$2\pi(a + b\Omega_i)/V_{\mathrm{sw}}$	Leamon et al. (2000)[b]
$\delta B^2_{\mathrm{slab}}$	$0.2\delta B^2$	Bieber et al. (1994)
q	7	Matthaeus et al. (2007)[c]
ν	$5/3$	Kolmogorov decay
k_{2D}	$135\ \mathrm{au}^{-1}$	Weygand et al. (2011)[d]
k_{out}	$k_{\mathrm{2D}}/100$	Engelbrecht & Burger (2015)[e]
δB^2_{2D}	$0.8\delta B^2$	Bieber et al. (1994)



Strauss et al., Astrophys. J., 2017

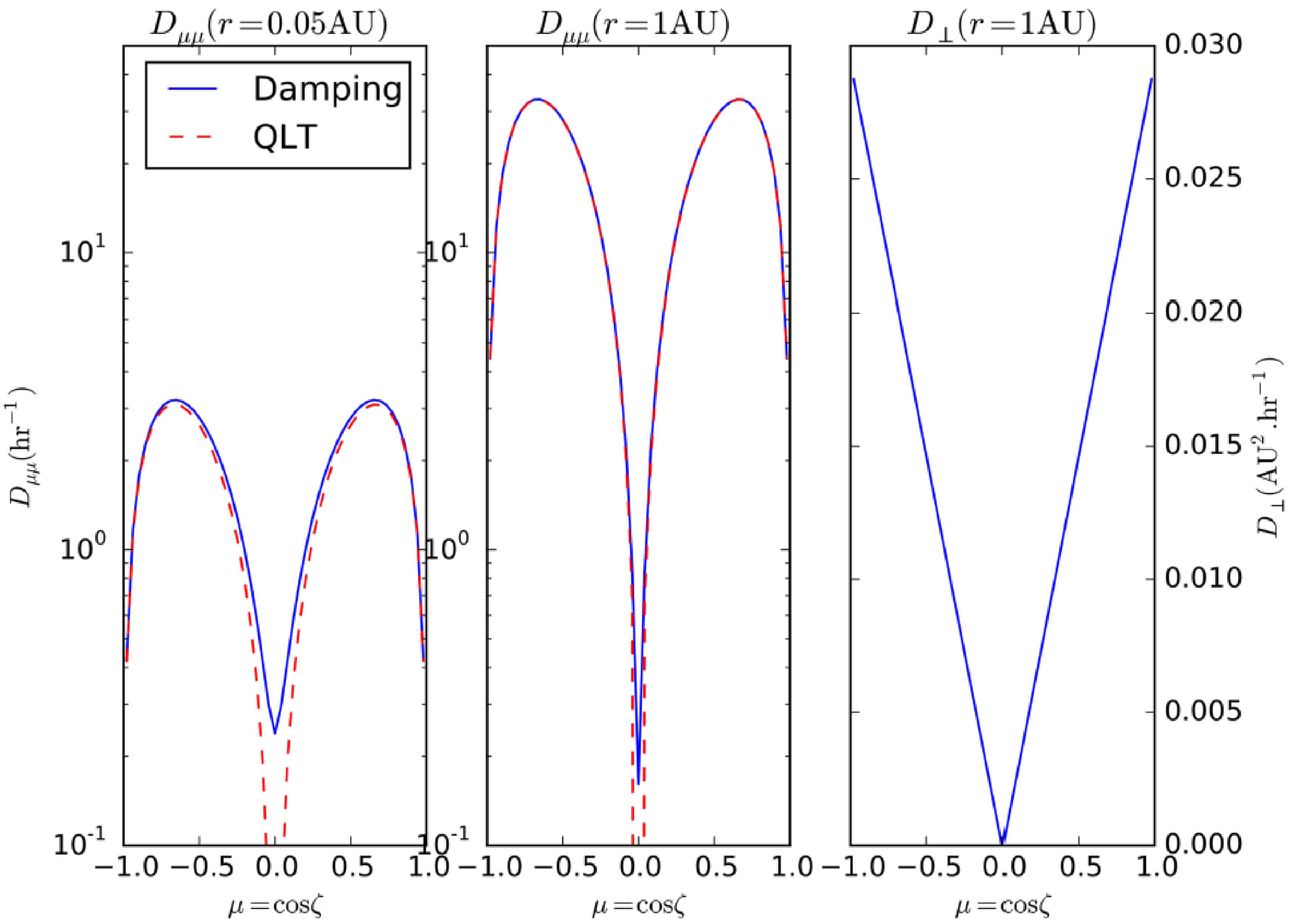


Figure 2. Calculated $D_{\mu\mu}$ at 0.05 au (left panel) and 1 au (Earth; middle panel) and $D_{\perp}$ at 1 au (Earth; right panel) as a function of μ. For $D_{\mu\mu}$, two scenarios are shown at each radial position, namely, using the damping function (solid blue lines) and using standard QLT (dashed red lines).

Strauss et al., Astrophys. J., 2017

Exciter Speeds?

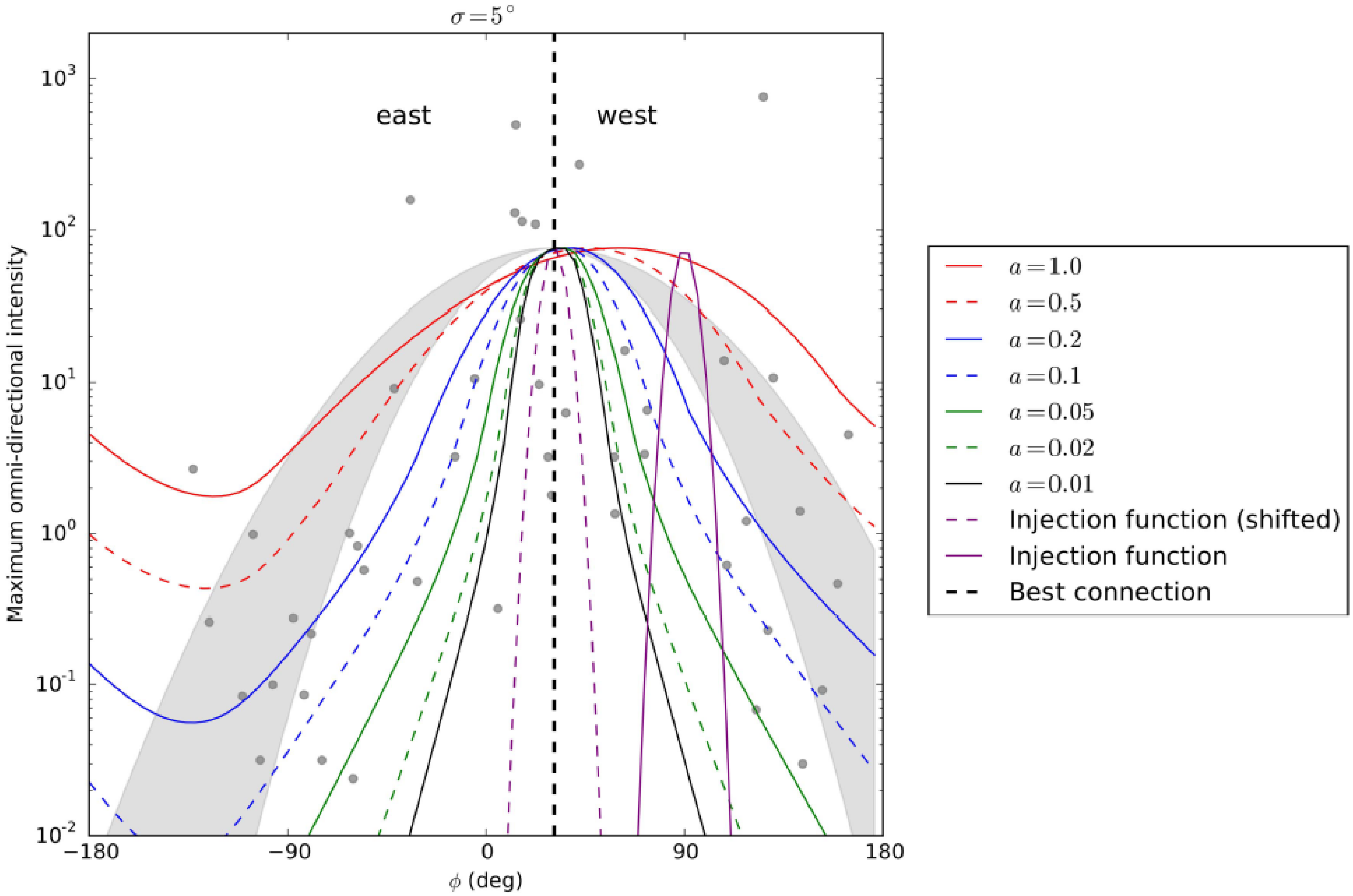


Figure 4. Modeled maximum omnidirectional intensity as a function of longitude for different levels of perpendicular diffusion (indicated by a). The solid purple line shows the injection function, with $\sigma = 5^\circ$, specified at the inner boundary, while the dashed purple line shows this distribution shifted to the position of best magnetic connection at Earth ($\phi \approx 30^\circ$, indicated by the vertical dashed line). The gray symbols and band are observed electron peak intensities in the range of 55–105 keV and the range of corresponding Gaussian fits of these multiple-spacecraft events taken from Dresing et al. (2014).

Strauss et al., Astrophys. J., 2017

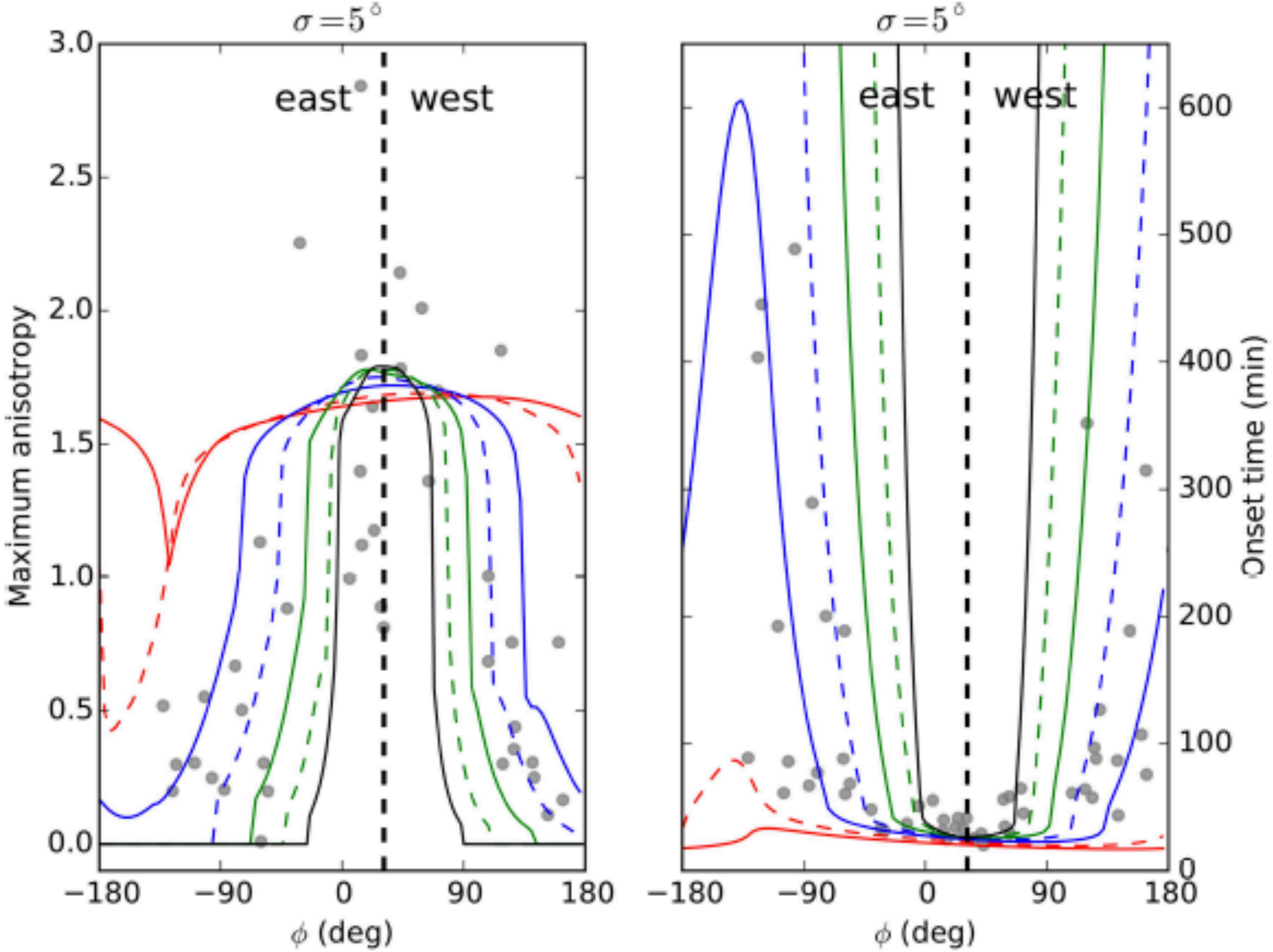


Figure 5. Computed maximum anisotropy (left panel) and onset time (right panel) for different levels of perpendicular diffusion (see again the legend of Figure 4, where the lines correspond to different values of a). The observations from Dresing et al. (2014) are shown as gray symbols.

Strauss et al., Astrophys. J., 2017

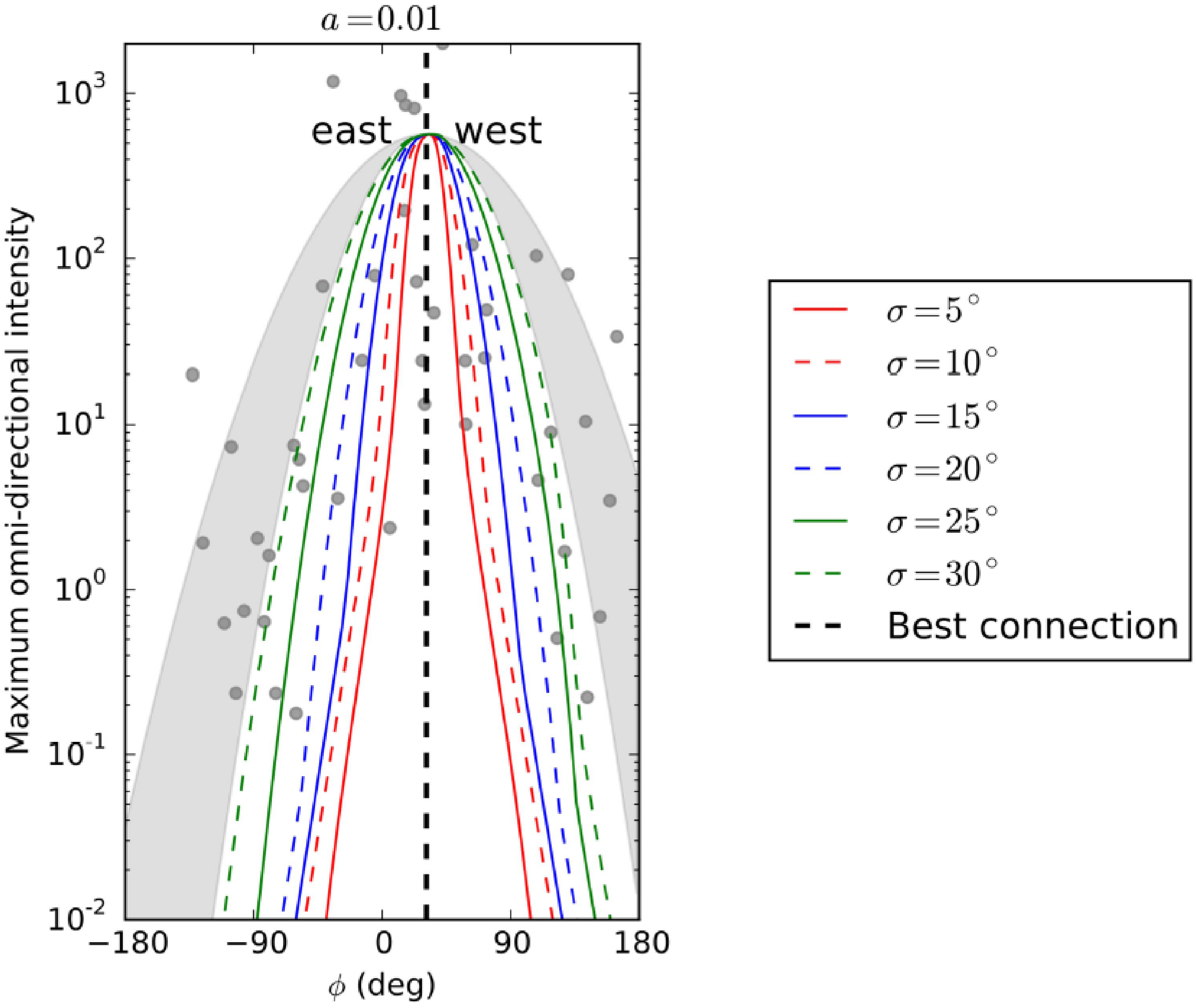


Figure 7. Similar to Figure 4, but now for $a = 0.01$ held fixed and varying the injection broadness σ.

Strauss et al., Astrophys. J., 2017

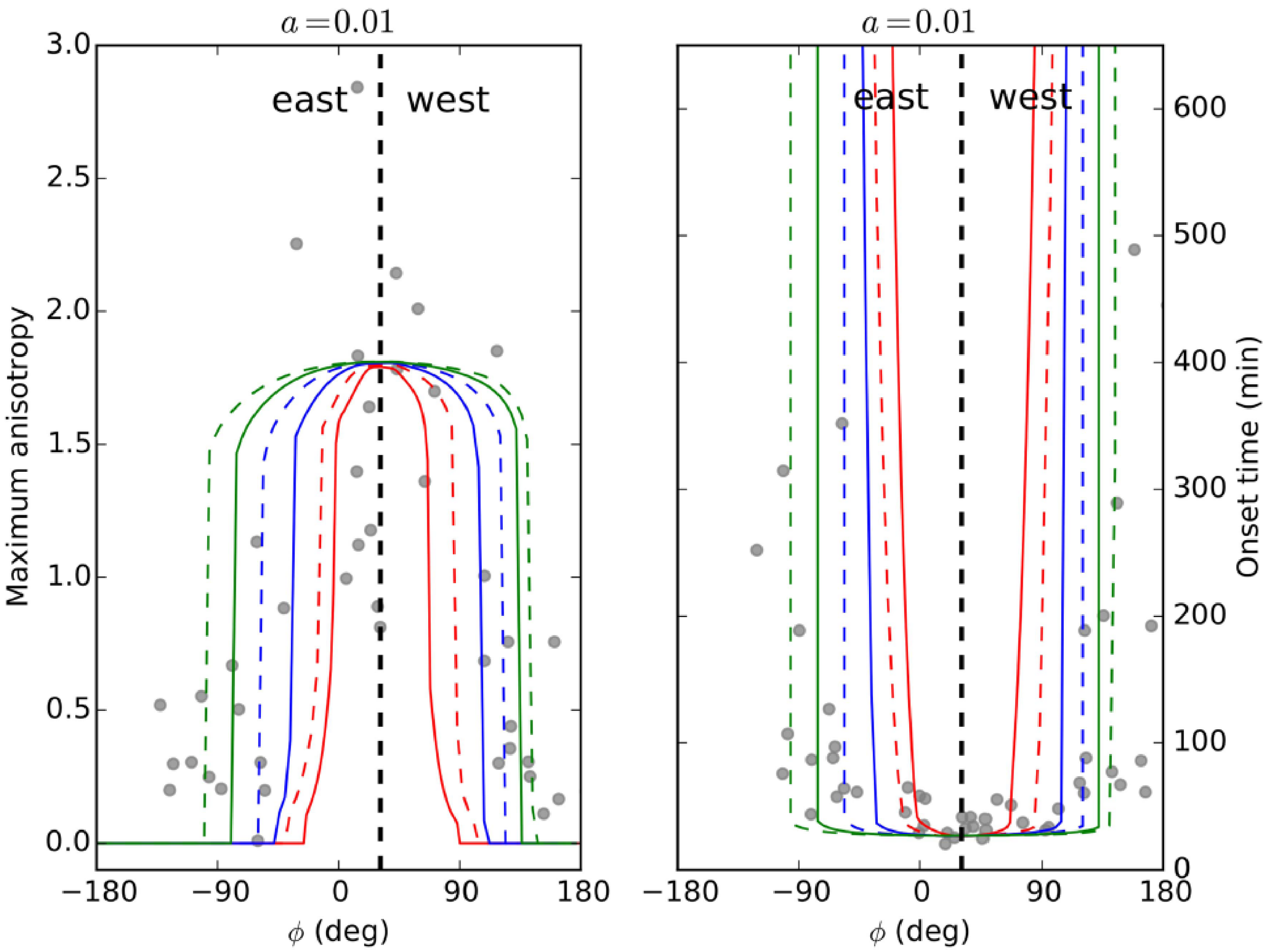
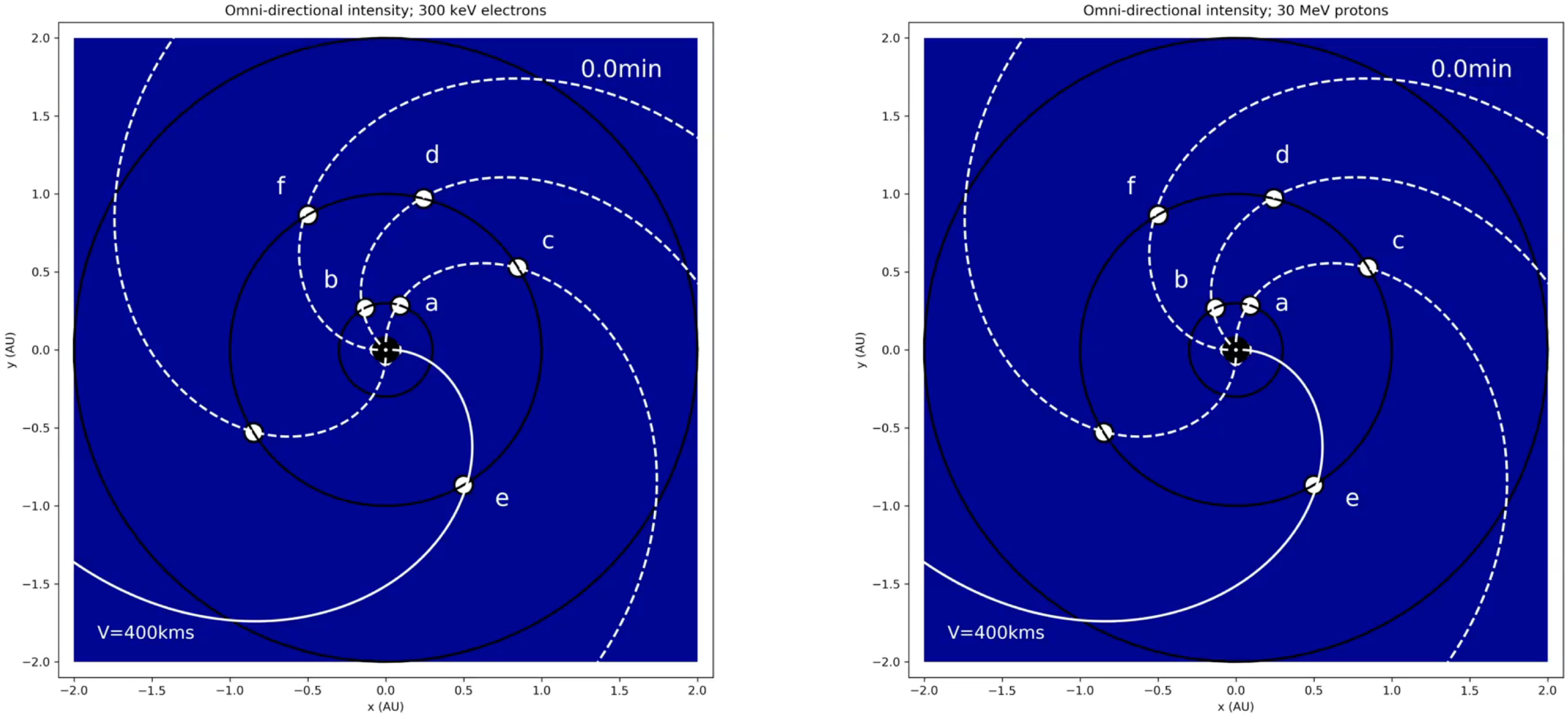


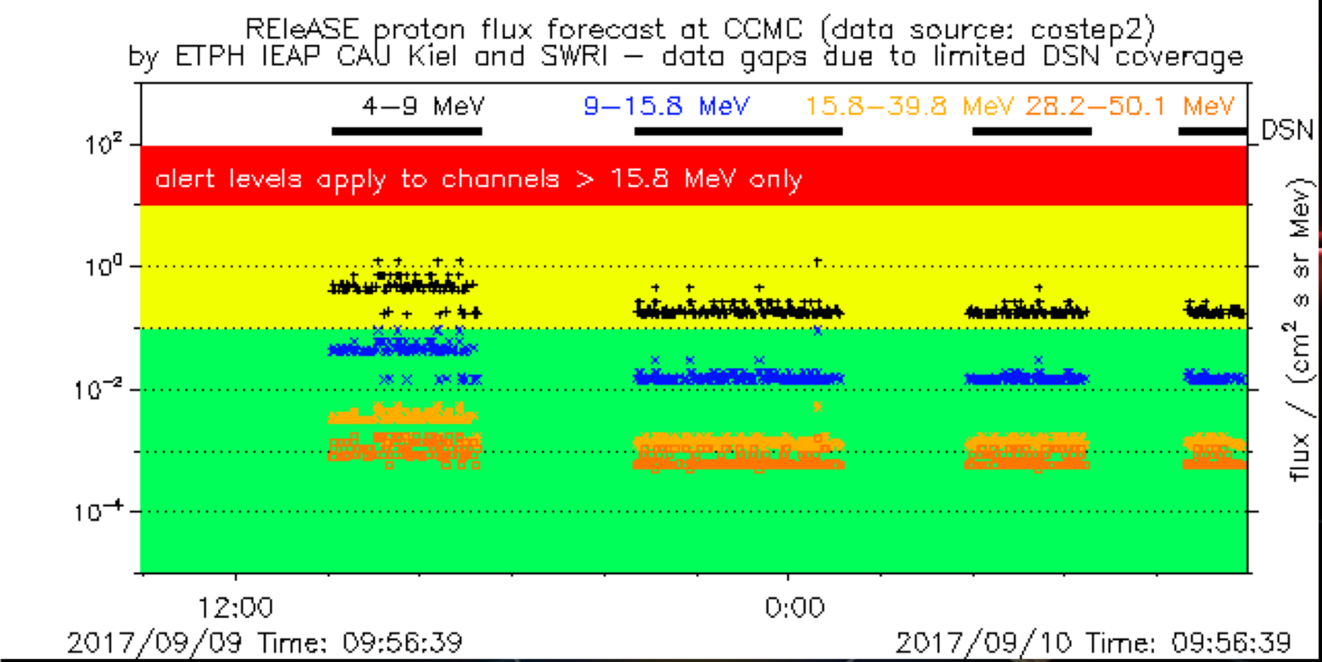
Figure 8. Similar to Figure 5, but now for $a = 0.01$ held fixed and varying the injection broadness σ.

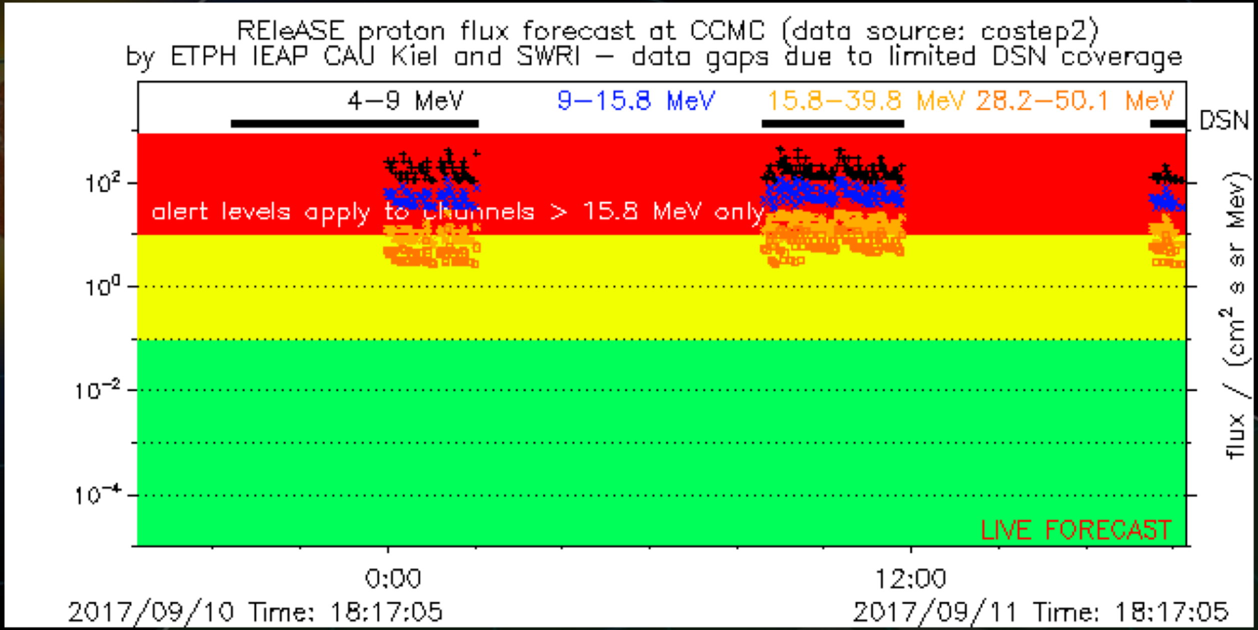
Strauss et al., Astrophys. J., 2017

Exciter Speeds?



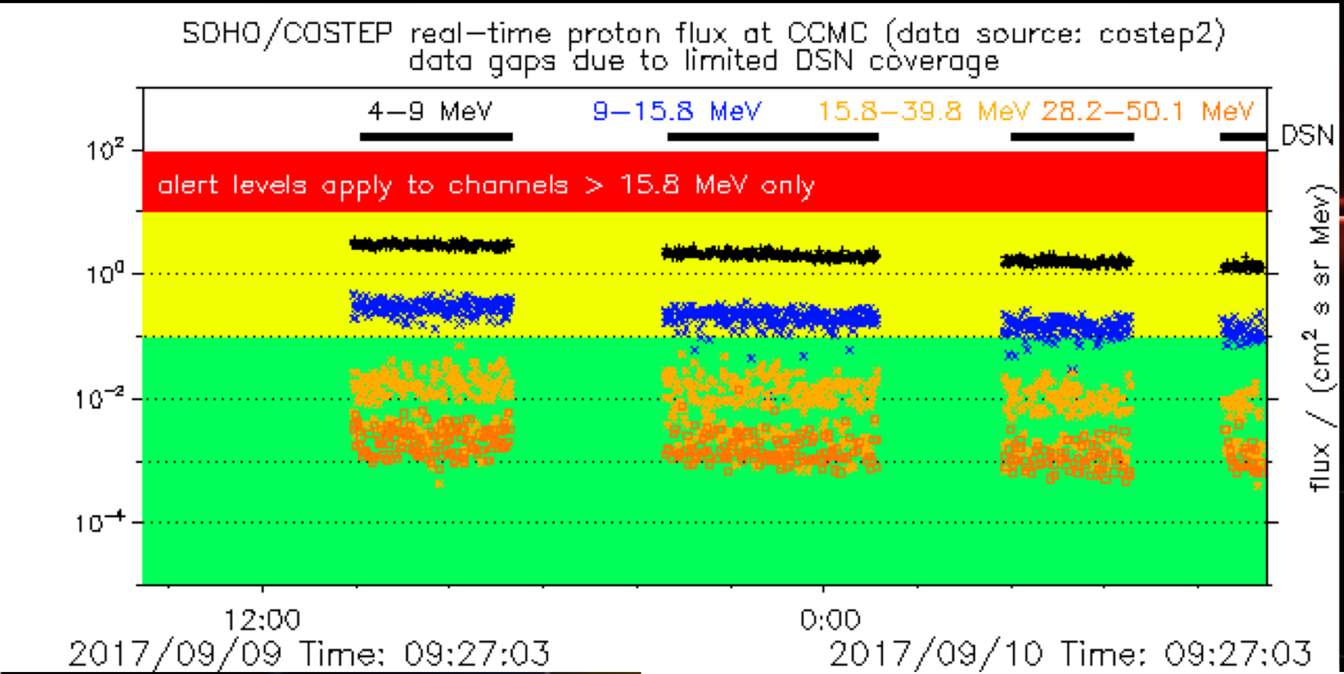
Strauss et al., Astrohys. J., 2017

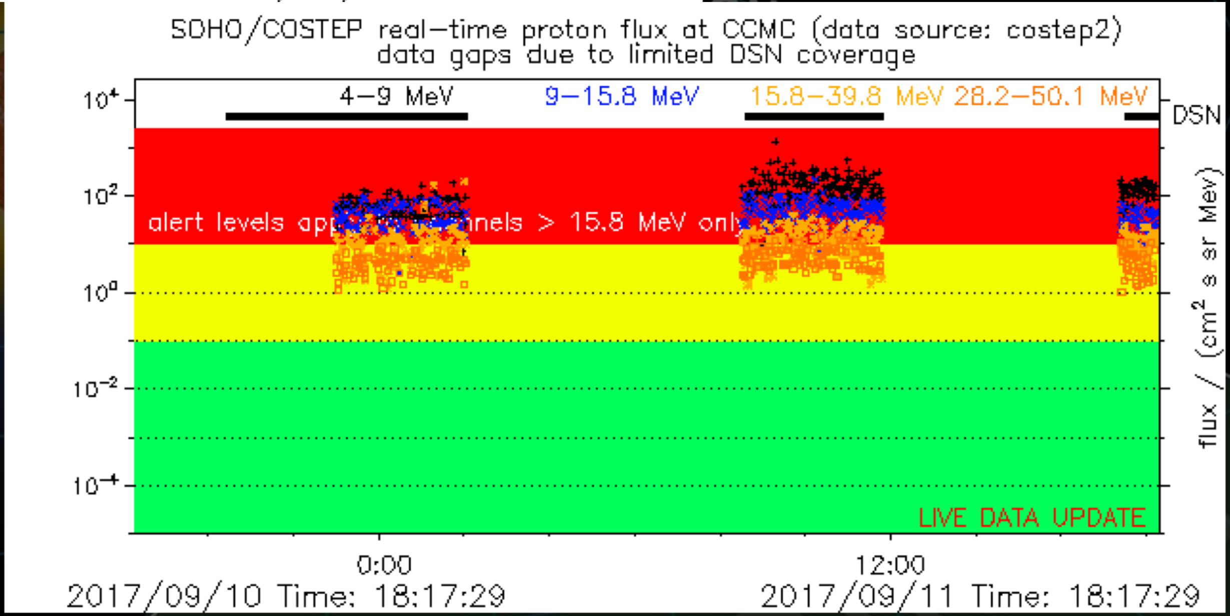




RElеASE @ CCMC iSWA

RElеASE @ CCMC iSWA





RElеASE @ CCMC iSWA

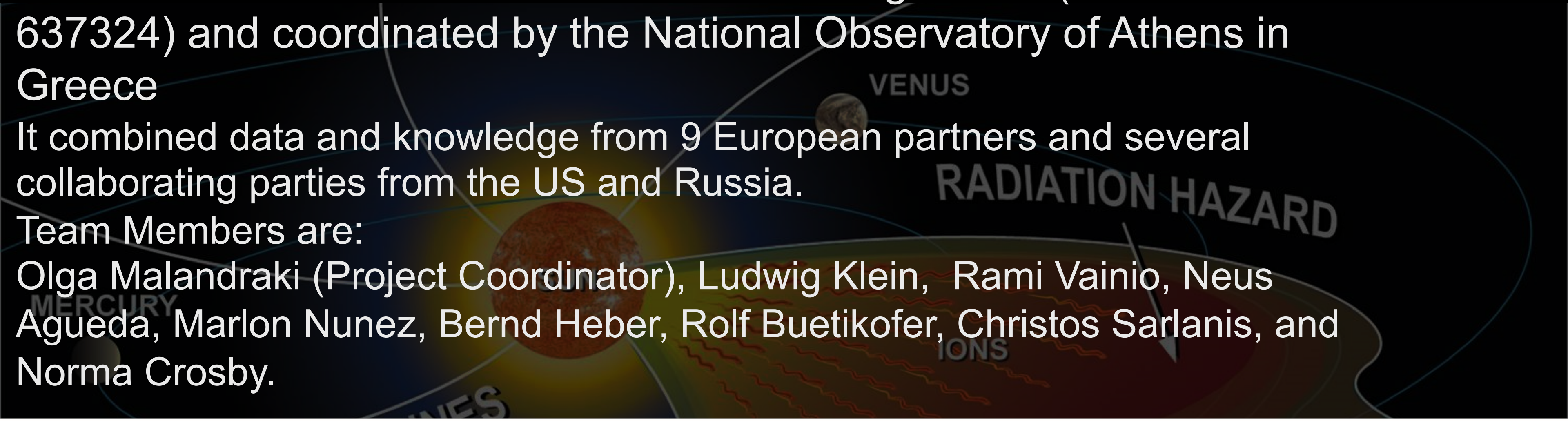
HESPERIA-REleASE:
High-Energy Solar Particle Events Forecasting and Analysis

The HESPERIA project was funded through the European Union's HORIZON 2020 research and Innovation Programme (Contract No 637324) and coordinated by the National Observatory of Athens in Greece

It combined data and knowledge from 9 European partners and several collaborating parties from the US and Russia.

Team Members are:

Olga Malandraki (Project Coordinator), Ludwig Klein, Rami Vainio, Neus Agueda, Marlon Nunez, Bernd Heber, Rolf Buetikofer, Christos Sarlanis, and Norma Crosby.

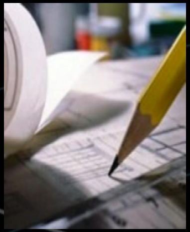


HESPERIA-REleASE as Part of the HESPERIA Project

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

HESPERIA

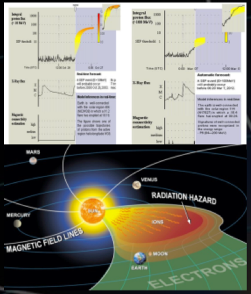
WP1



Leader **NOA**

MANAGEMENT

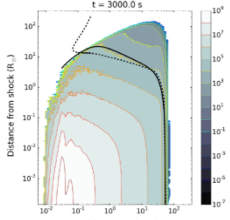
WP2



Leader **UMA**

FORECASTING OF SOLAR RADIATION STORMS

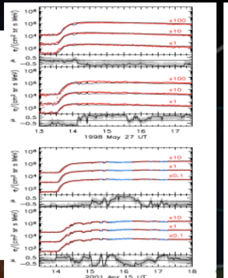
WP3



Leader **UTU**

MODELING OF SHOCK-ACCELERATED EVENTS

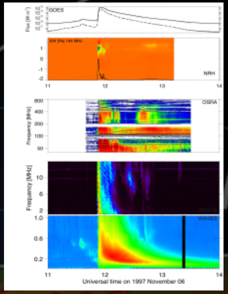
WP4



Leader **UB**

INVERSION METHODS

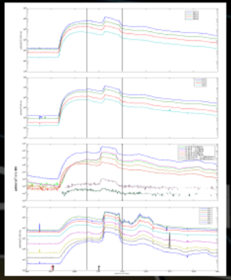
WP5



Leader **OBSPM**

SCIENTIFIC DATA ANALYSIS: GAMMA-RAYS, RADIO SEPS

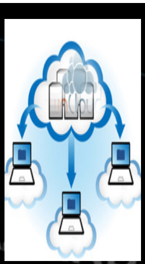
WP6



Leader **NOA**

SEP RADIATION IMPACT

WP7



Leader **ISNet**

SERVER DEVELOPMENT

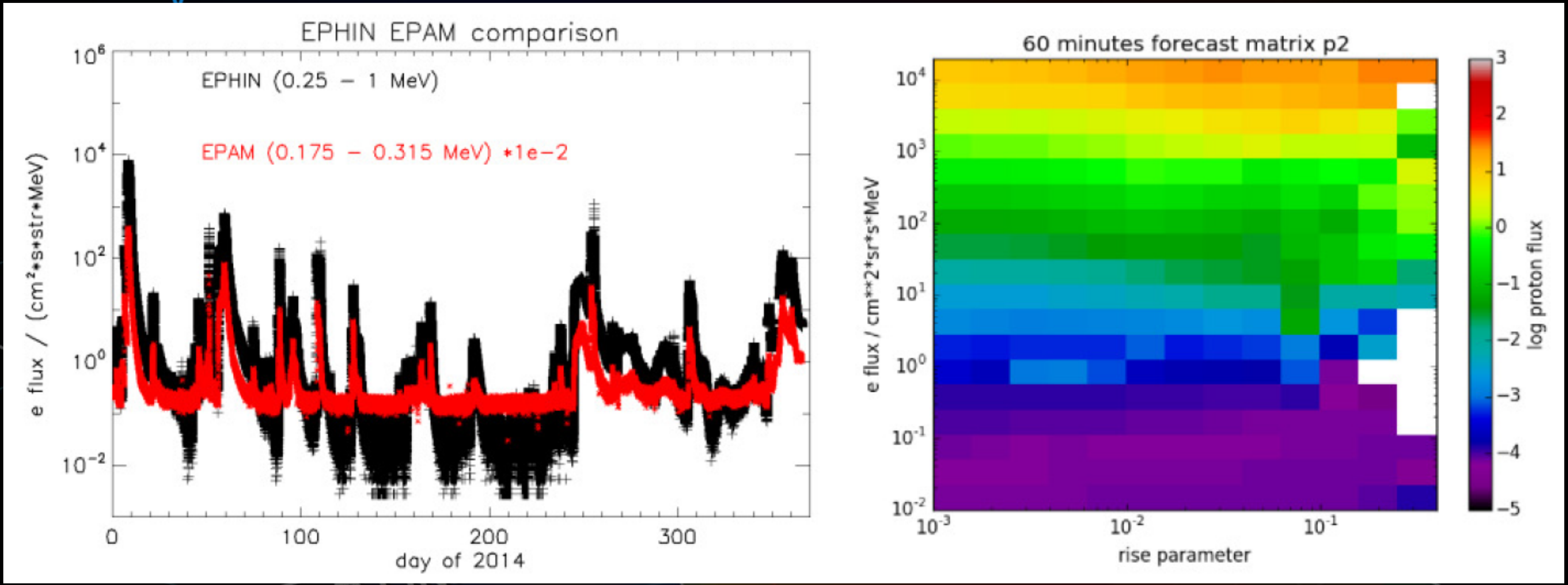
WP8

Leader **NOA**

DISSEMINATION AND EXTERNAL COORDINATION

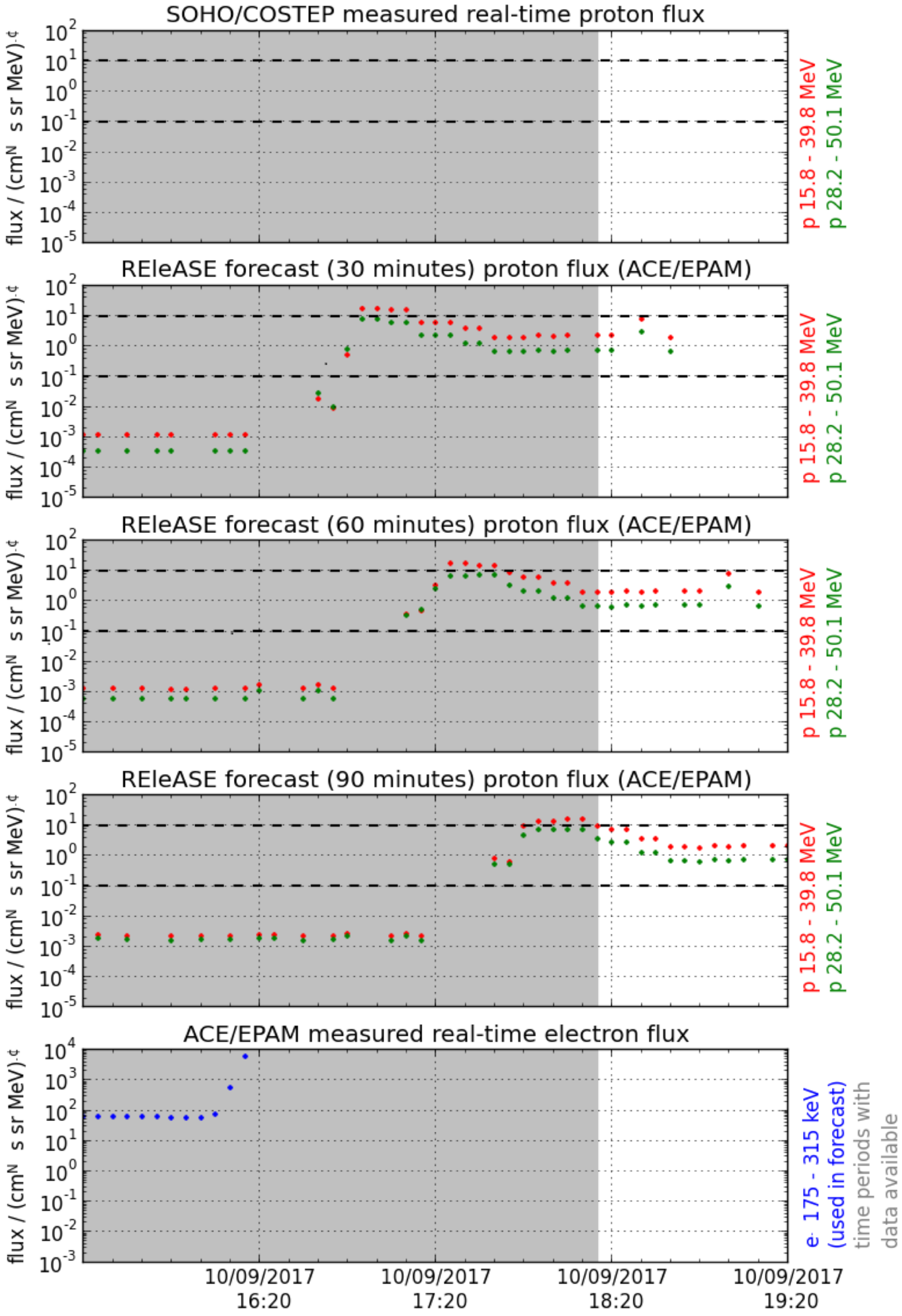
The HESPERIA 'High Energy Solar Particle Events Forecasting and Analysis' project produced two novel forecasting tools based upon proven concepts: HESPERIA UMASEP-500 and HESPERIA REleASE (WP2).

HESPERIA-REleASE: New Developments



REleASE forecasting depends on measured electron intensities and their level of increase. A comparison of electron intensity time series between SOHO/EPHIN (black) and ACE/EPAM (red) shows good correlation above the EPAM background.

If there is an increase in EPHIN electron intensity there is also one in EPAM.



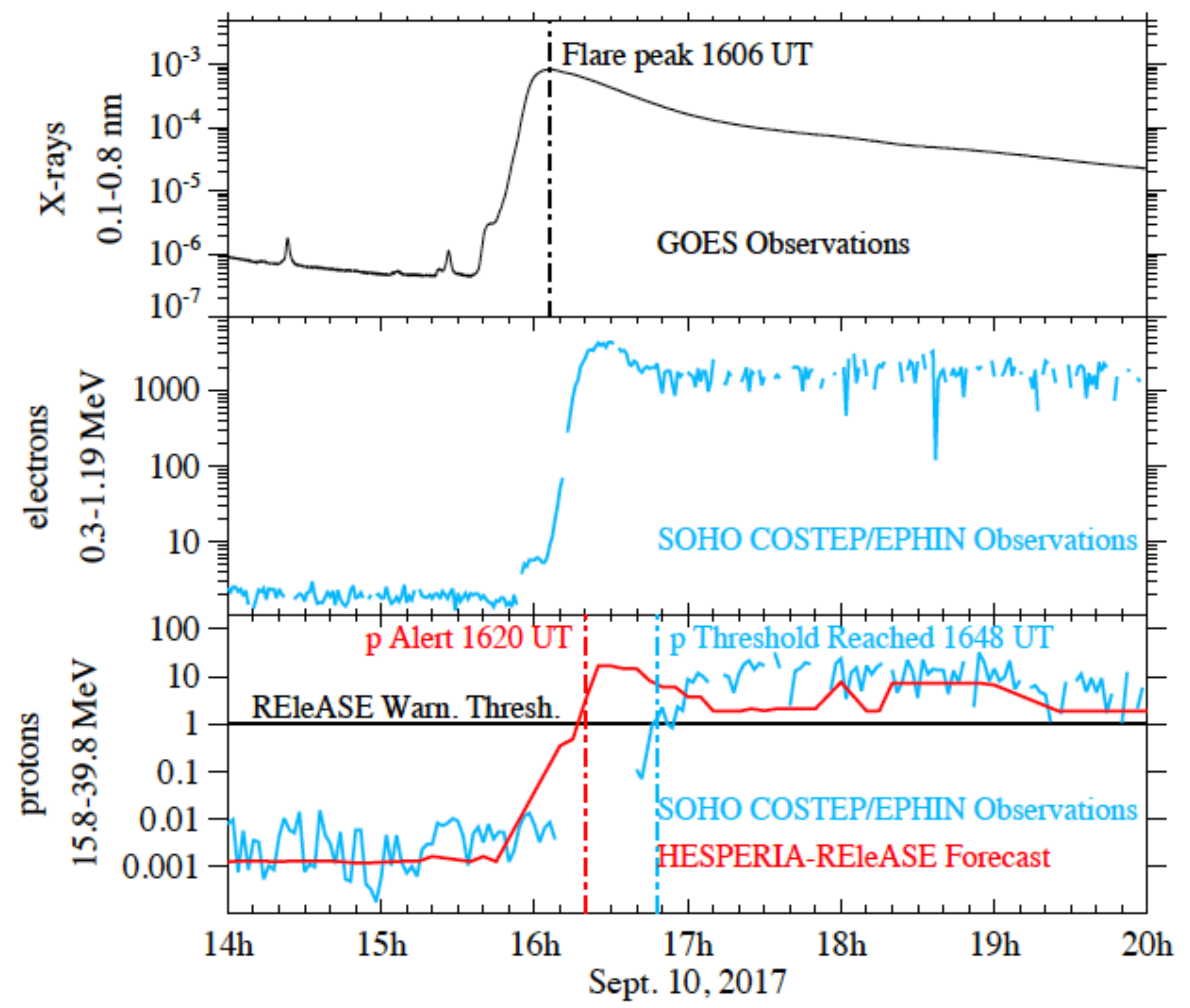
SOHO/COSTEP measured real-time proton flux

REleASE forecast (30 minutes) proton flux (ACE/EPAM)

REleASE forecast (60 minutes) proton flux (ACE/EPAM)

REleASE forecast (90 minutes) proton flux (ACE/EPAM)

ACE/EPAM measured real-time electron flux

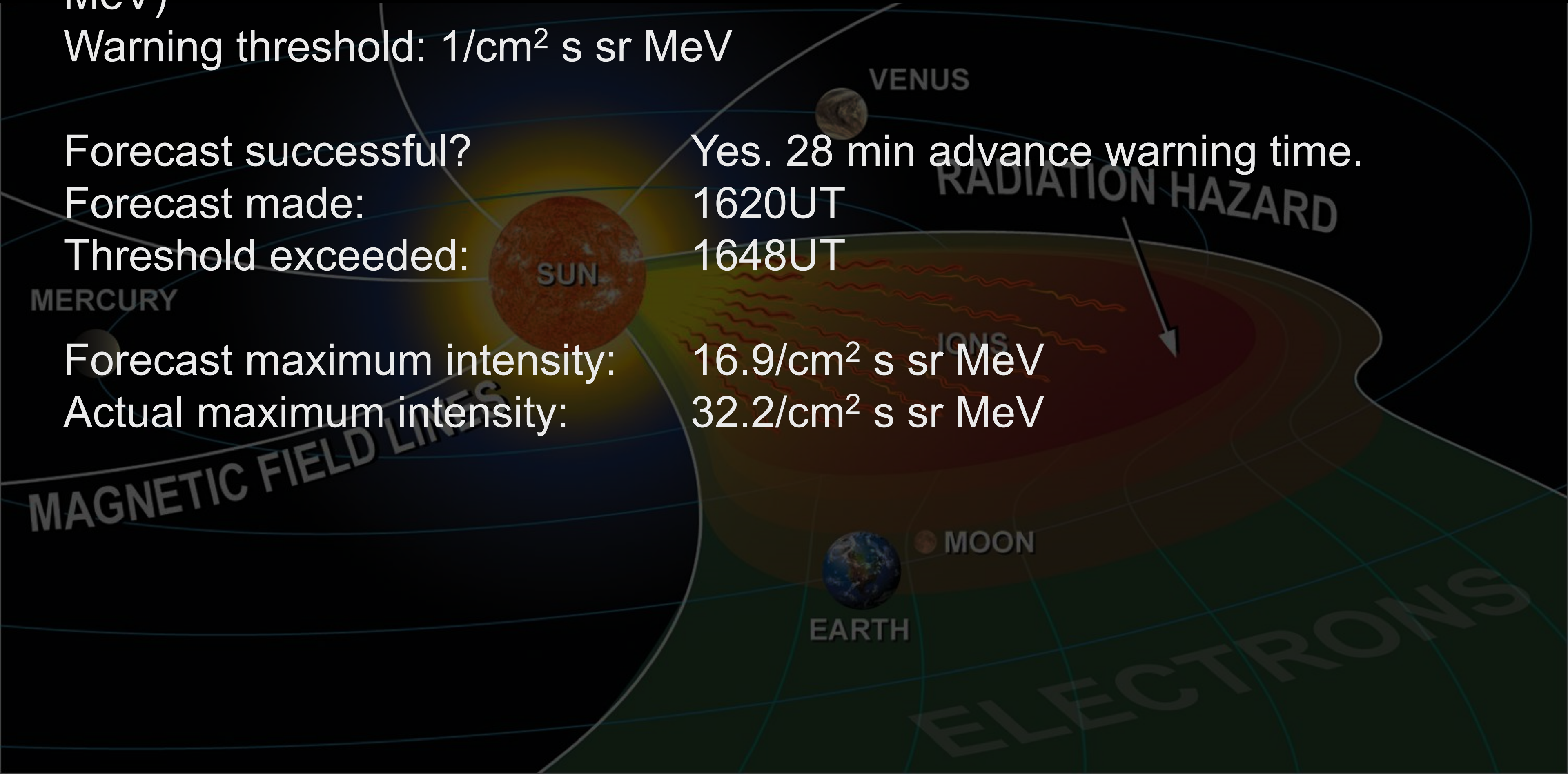

X-rays
0.1-0.8 nm
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Flare peak 1606 UT
GOES Observations
electrons
0.3-1.19 MeV
1000
100
10
SOHO COSTEP/EPHIN Observations
protons
15.8-39.8 MeV
100
10
1
0.1
0.01
0.001
p Alert 1620 UT
p Threshold Reached 1648 UT
REleASE Warn. Thresh.
SOHO COSTEP/EPHIN Observations
HESPERIA-REleASE Forecast
14h
15h
16h
17h
18h
19h
20h
Sept. 10, 2017

HESPERIA-REleASE SEP Scoreboard Data for 9/10/2017 Campaign Event

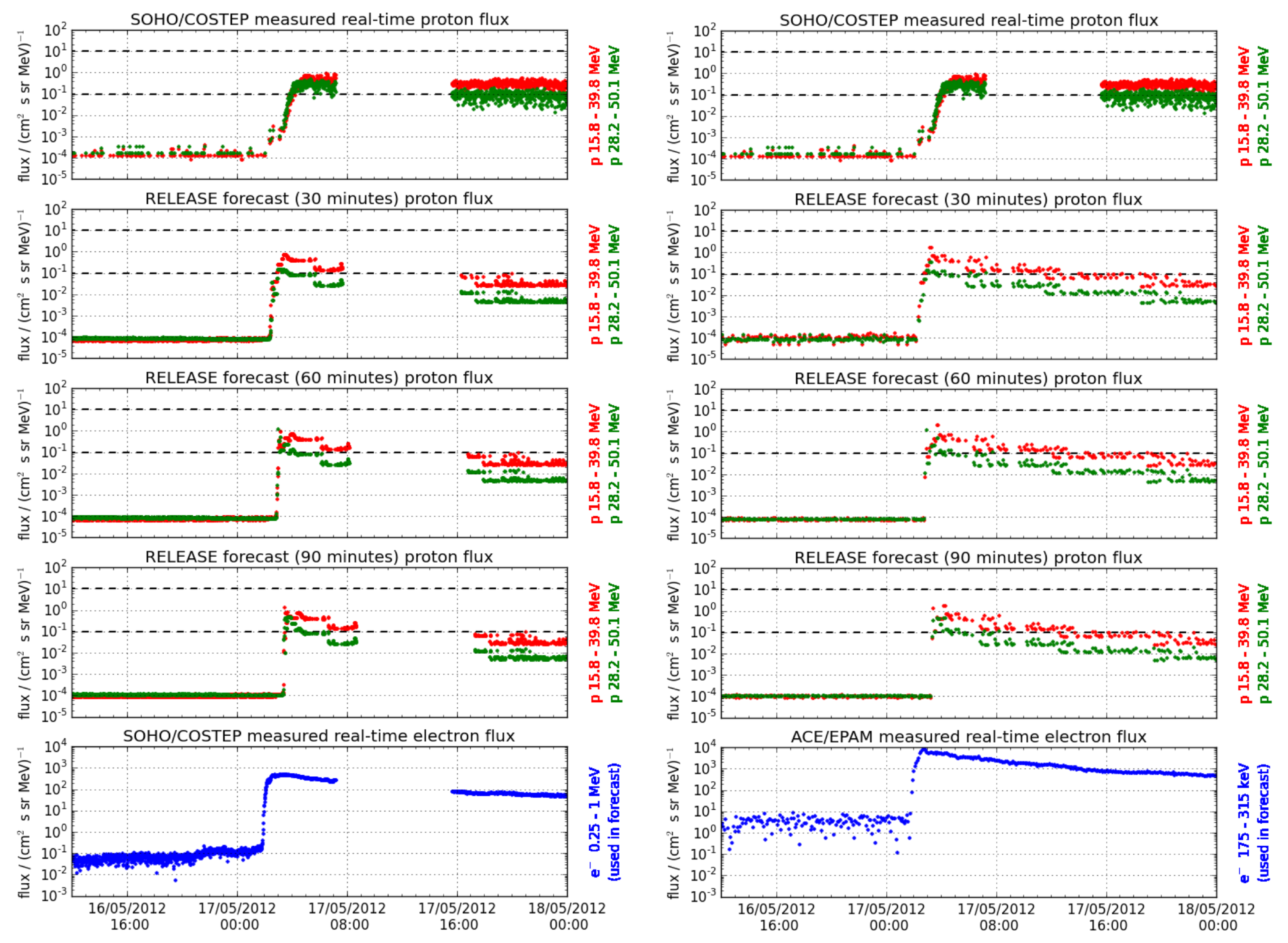
16-40 MeV proton forecast based on ACE/EPAM electrons (0.175-0.315 MeV)
Warning threshold: 1/cm^2 s sr MeV

Forecast successful? Yes. 28 min advance warning time.
Forecast made: 1620UT
Threshold exceeded: 1648UT

Forecast maximum intensity: 16.9/cm^2 s sr MeV
Actual maximum intensity: 32.2/cm^2 s sr MeV



Real-time SEP predictions are public available via the HESPERIA project website:
https://www.hesperia.astro.noa.gr/index.php/results/real-time-prediction-tools/release



The HESPERIA REleASE system can generate alerts which are distributed to registered users:
https://www.hesperia.astro.noa.gr/webform/ReleaseAlert/contact.php

Discussion

How did your optimized run results differ from the initial run?

There is only one live run, available at the HESPERIA project web site.

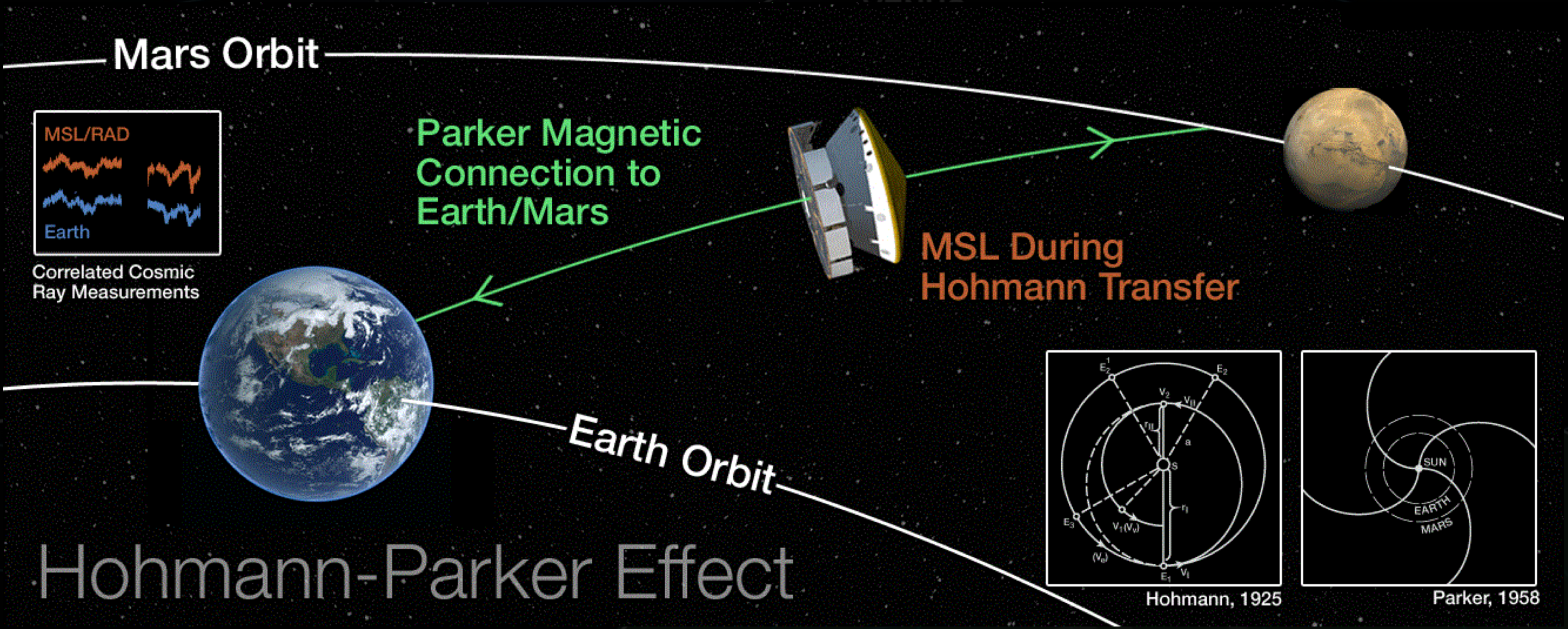
What aspects of the event does your model capture well, and what aspects were more difficult to capture?

- REleASE provides advance warning of crossing the intensity threshold of 1/cm^2 s sr MeV for 16-40 MeV protons, and providing a maximum expected SEP proton intensity.
- Current detectors not ideal for extreme events.

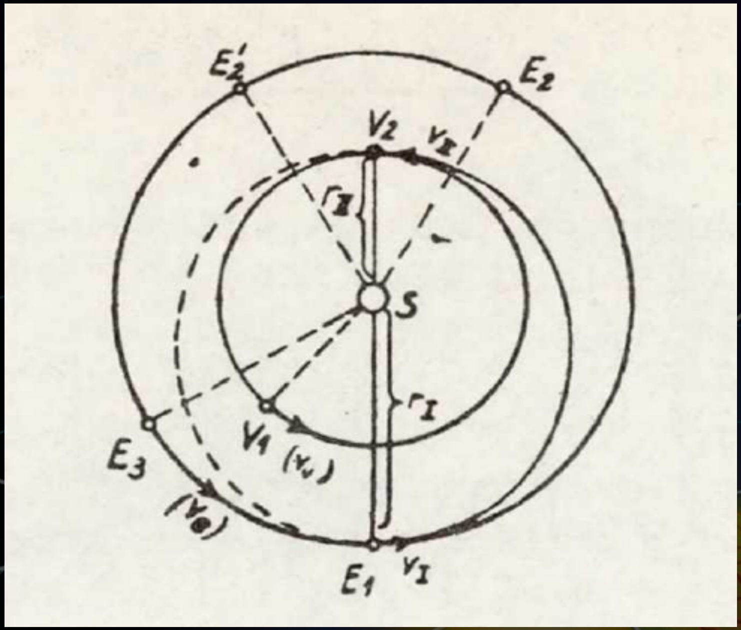
What are the next steps for your modeling technique?

Implementation for exploration of moon and Mars (HP effect).

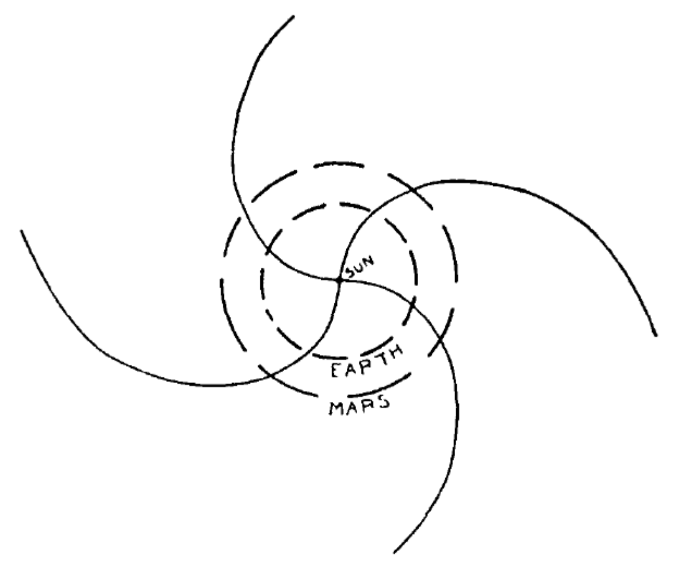
SEP Forecasting: New Applications



Mars Exploration:
Is SEP Forecasting Feasible?

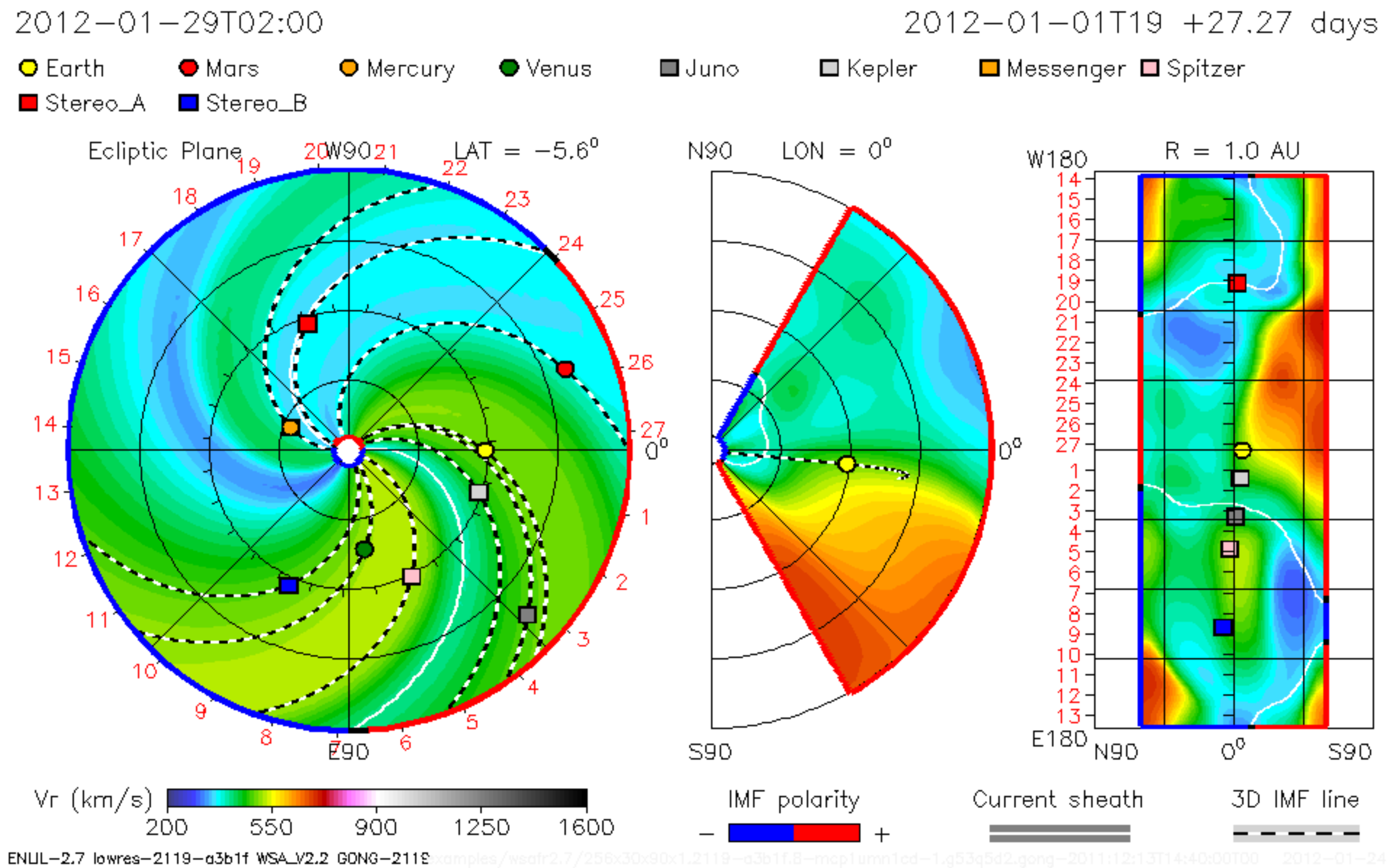


Hohmann, 1925



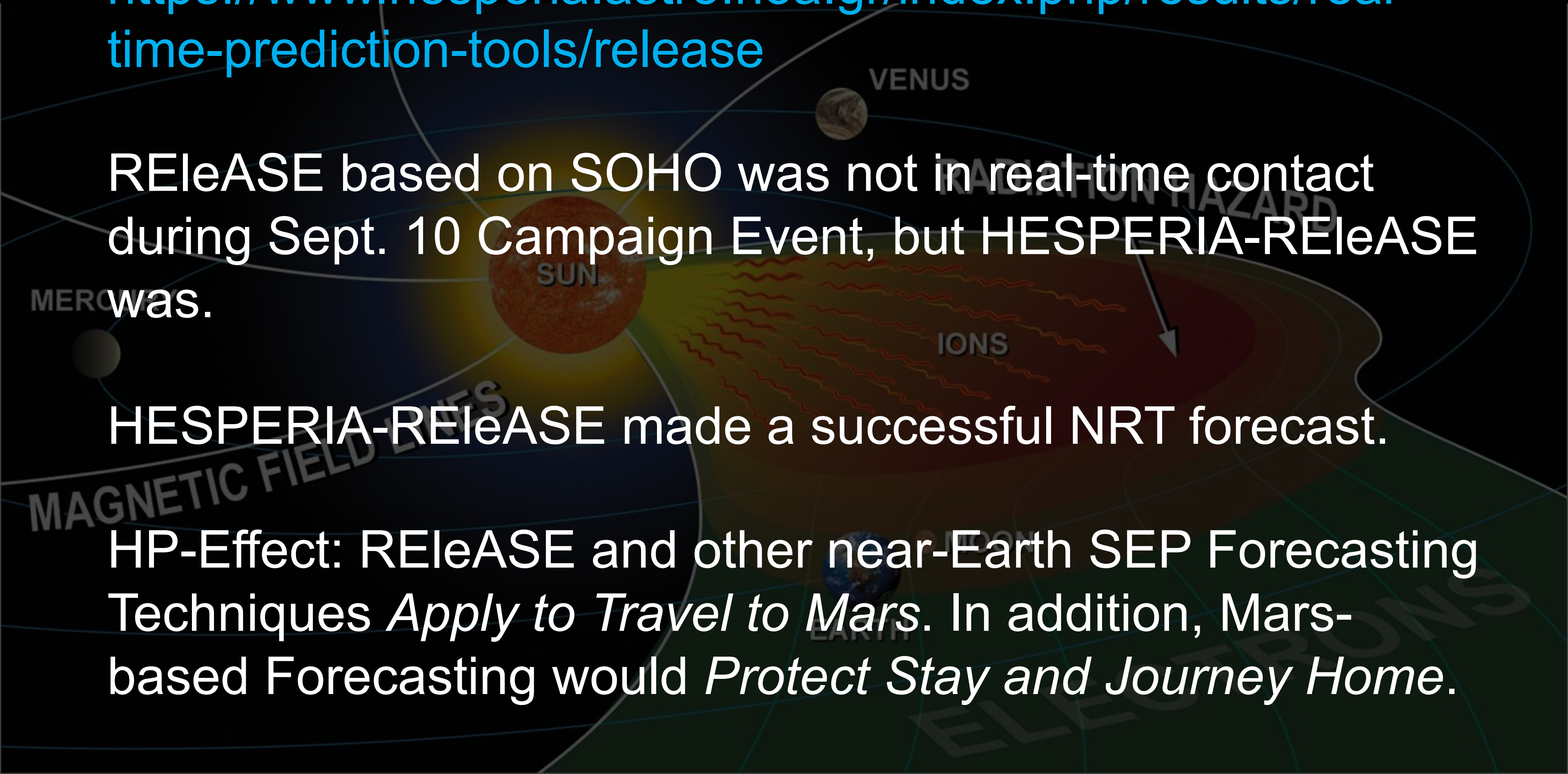
Parker, 1958

ENLIL Simulation: MSL Transfer to Mars



January – May 2012

Summary



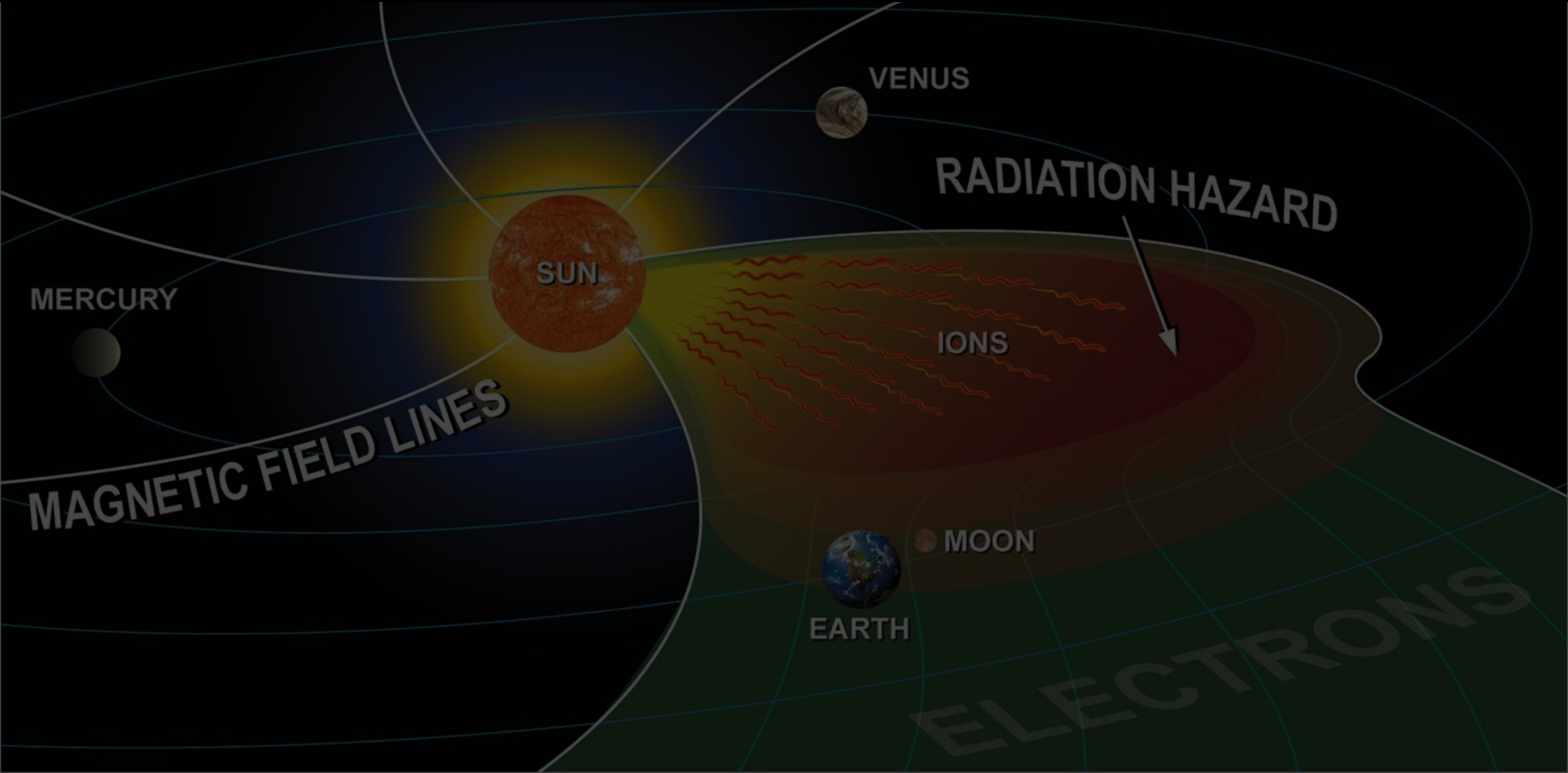
The HESPERIA-REleASE System *Has Been Implemented with ACE/EPAM Observations* at https://www.hesperia.astro.noa.gr/index.php/results/real-time-prediction-tools/release

REleASE based on SOHO was not in real-time contact during Sept. 10 Campaign Event, but HESPERIA-REleASE was.

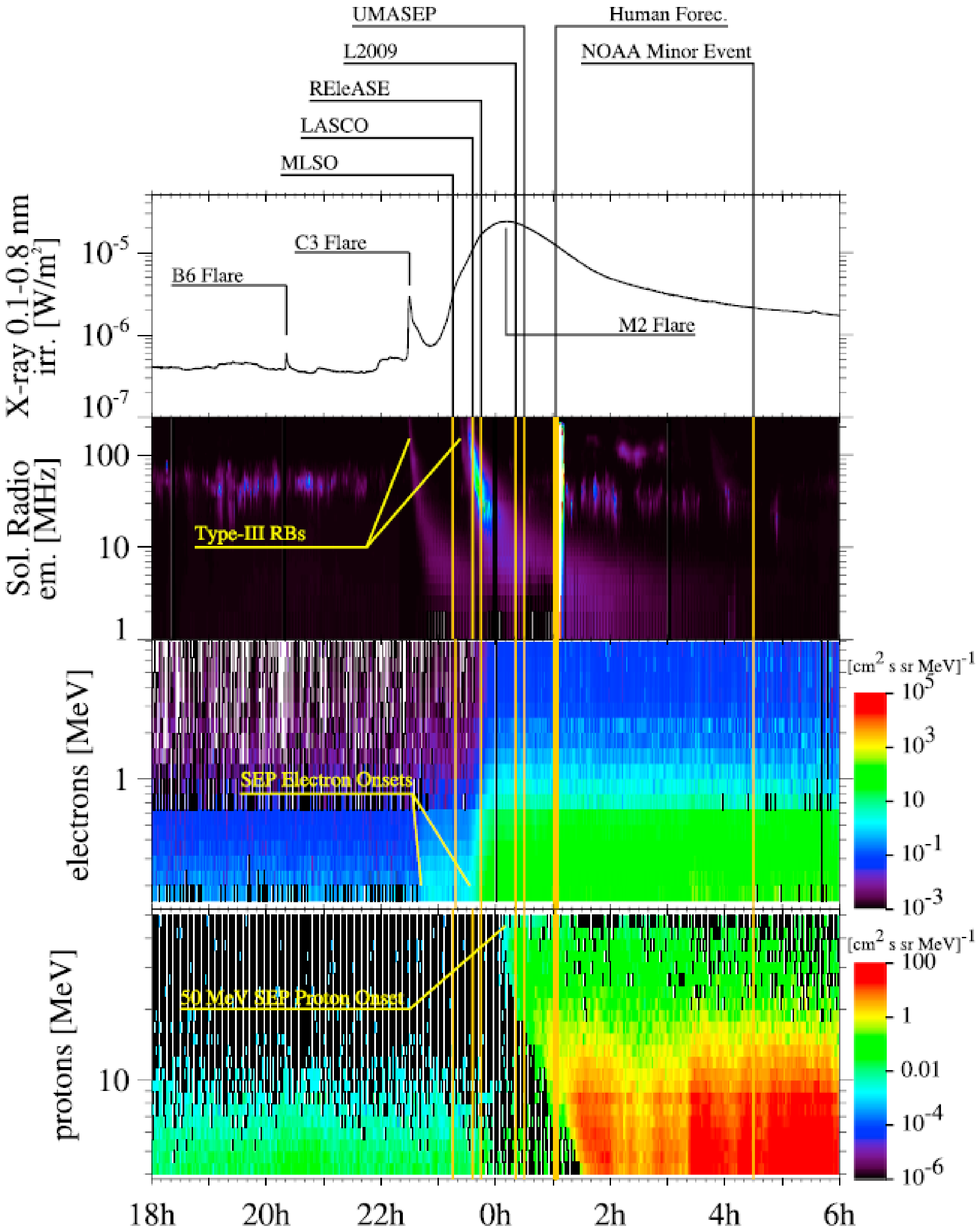
HESPERIA-REleASE made a successful NRT forecast.

HP-Effect: REleASE and other near-Earth SEP Forecasting Techniques *Apply to Travel to Mars*. In addition, Mars-based Forecasting would *Protect Stay and Journey Home*.

Backup Slides



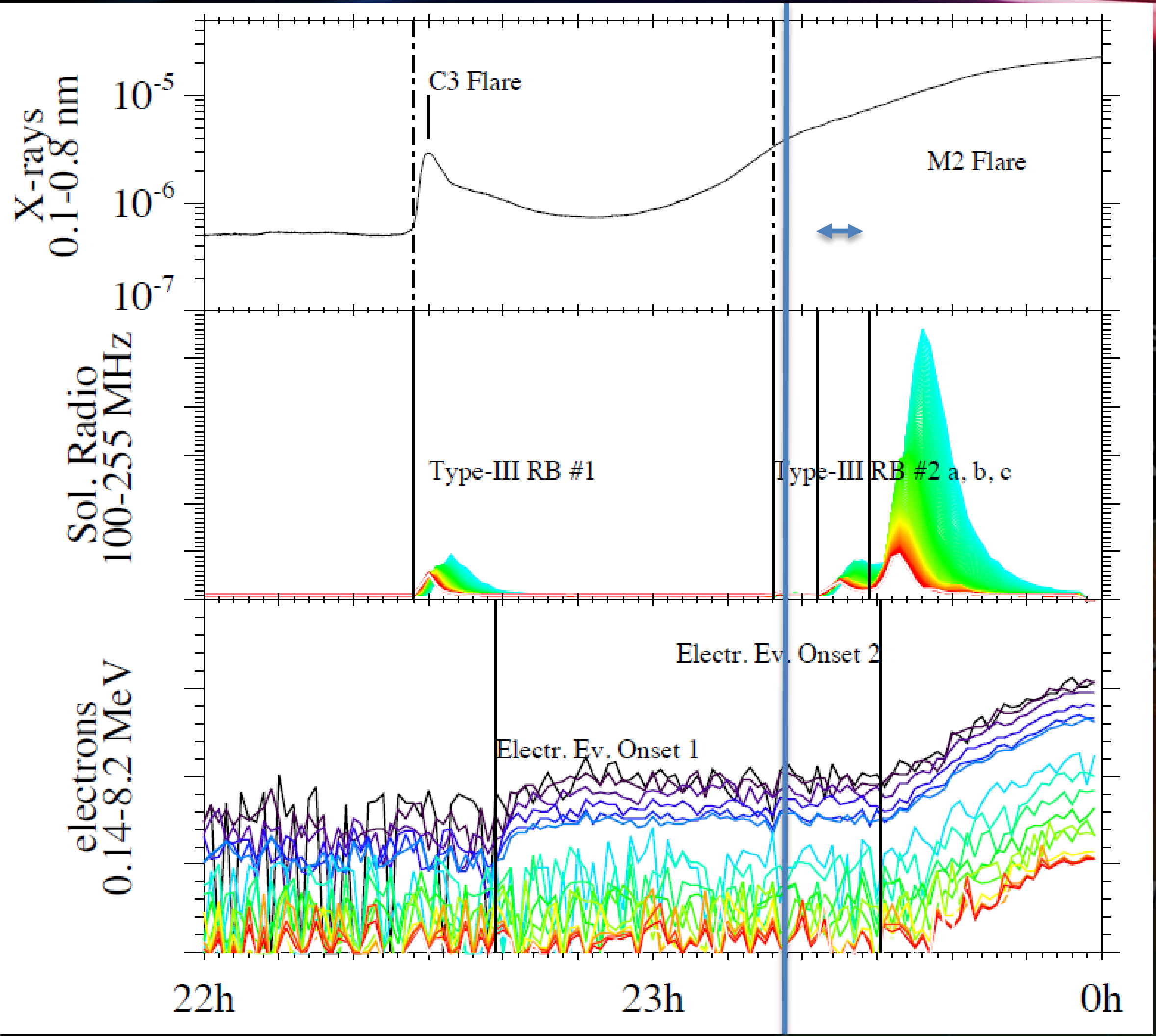
Warning Time Spread



MLSO K-Cor Fast CME: 23:17UT
LASCO Fast CME: 2336UT
REleASE p Forec: 23:45UT
Laurenza p Forec: 00:21UT
UMASEP p Forec: 00:44UT
NOAA p Forec: 01:03UT
NOAA minor event: 0430UT

St.Cyr, Burkepile & Posner, SWJ, 2017

K-Cor Enables SEP Warning Before Evidence of Particle Escape at the Sun



MLSO K-Cor Fast CME: 23:17UT

Particle Release: 23:22-29UT

LASCO Fast CME: 2336UT

REleASE p Forec: 23:45UT

Laurenza p Forec: 00:21UT

UMASEP p Forec: 00:44UT

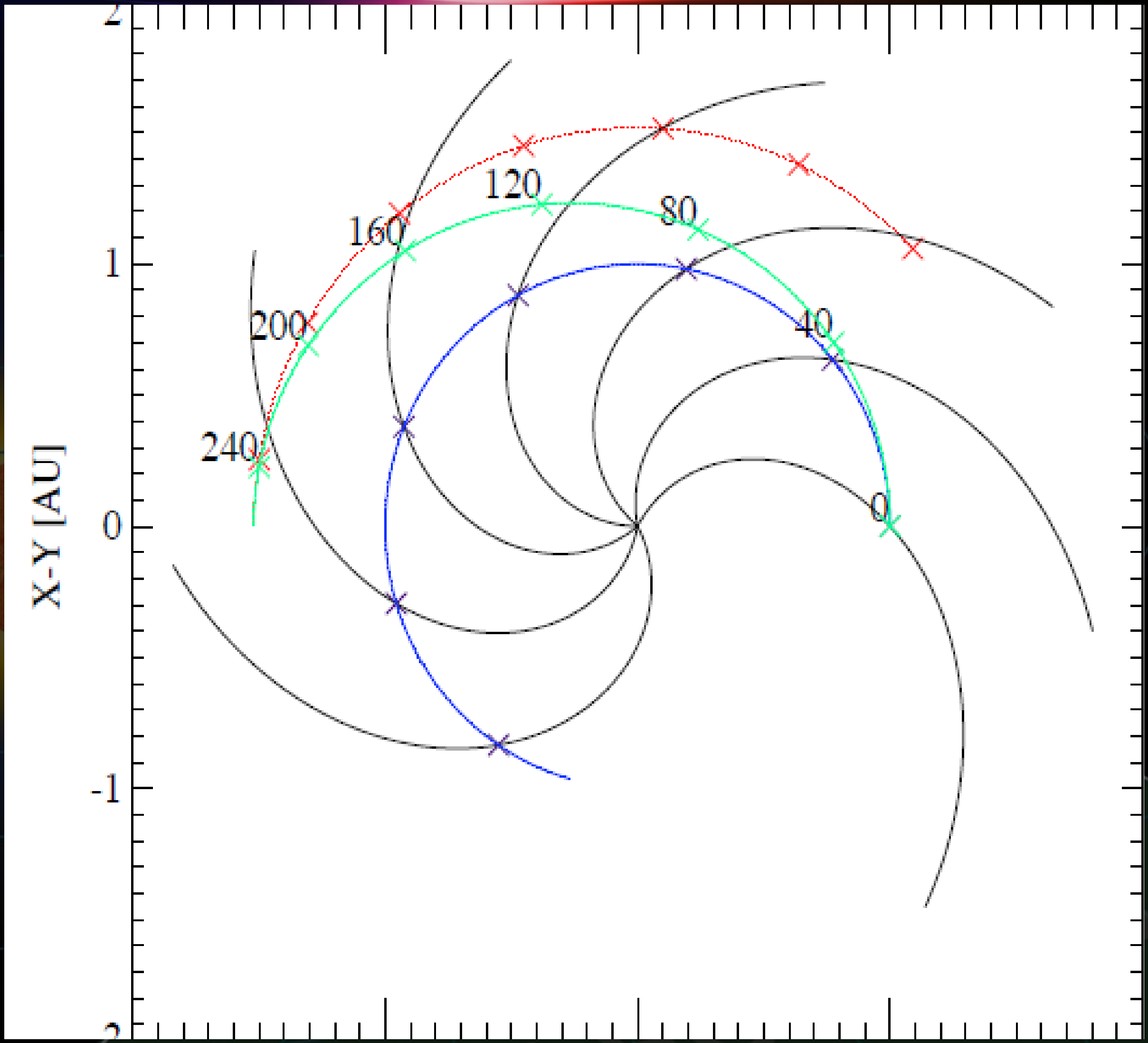
NOAA p Forec: 01:03UT

NOAA minor event: 0430UT

Mars Exploration: Is SEP Forecasting Feasible?

Journey to Mars:

Relative Locations of Earth (blue), Astronauts (green) and Mars (red) in 40-day Intervals

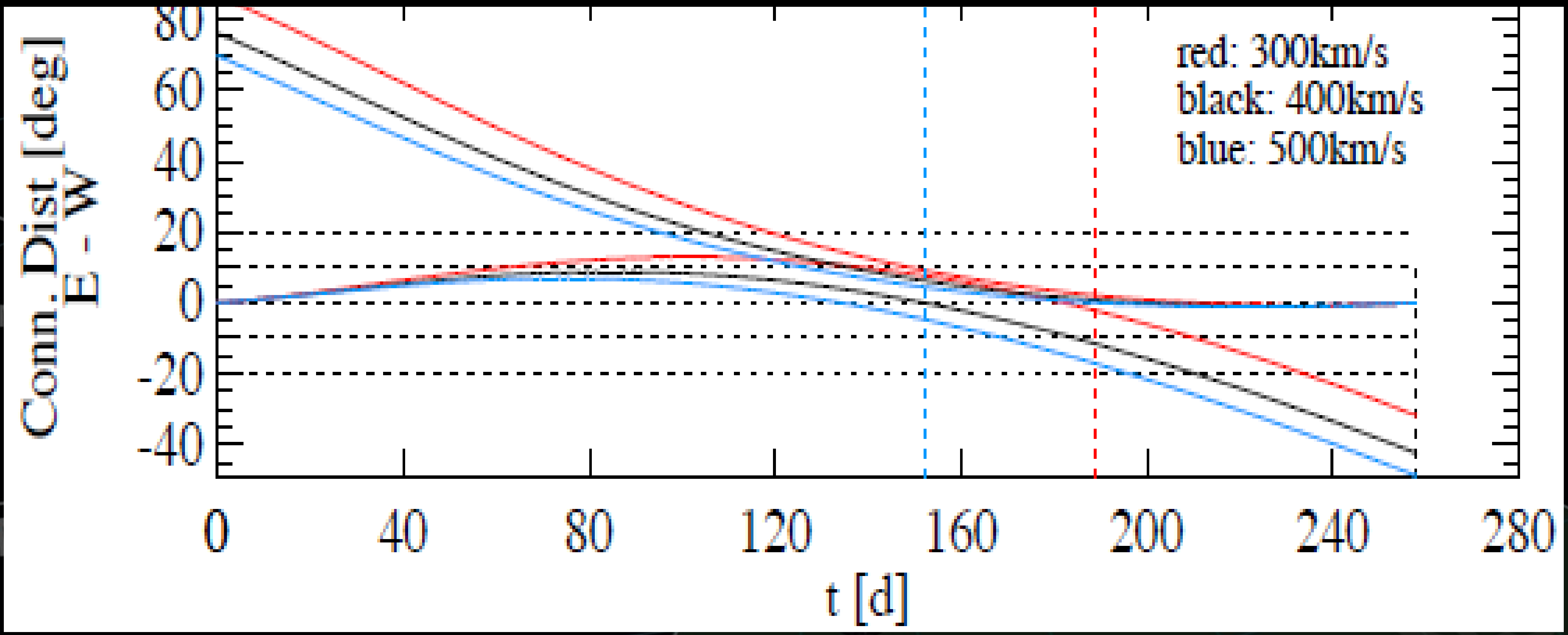


Posner et al., PSS, 2012

Mars Exploration:
Is SEP Forecasting Feasible?

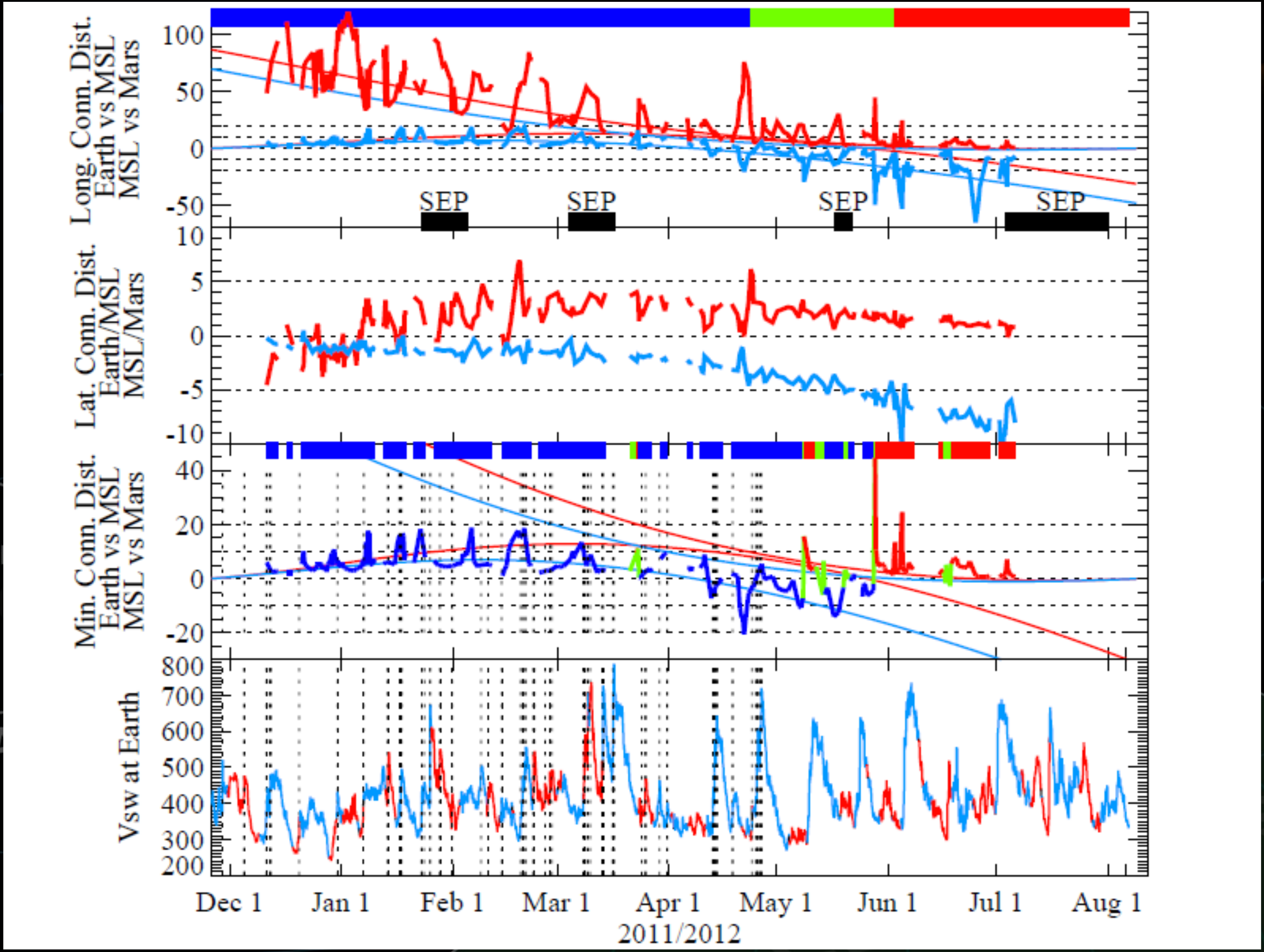
Journey to Mars:
The Equivalent Magnetic Connection Distances
(for Three Solar Wind Speeds)

Posner et al., PSS, 2012



Yes: Earth-L1 REleASE System Supports SEP Forecast on Journey to Mars

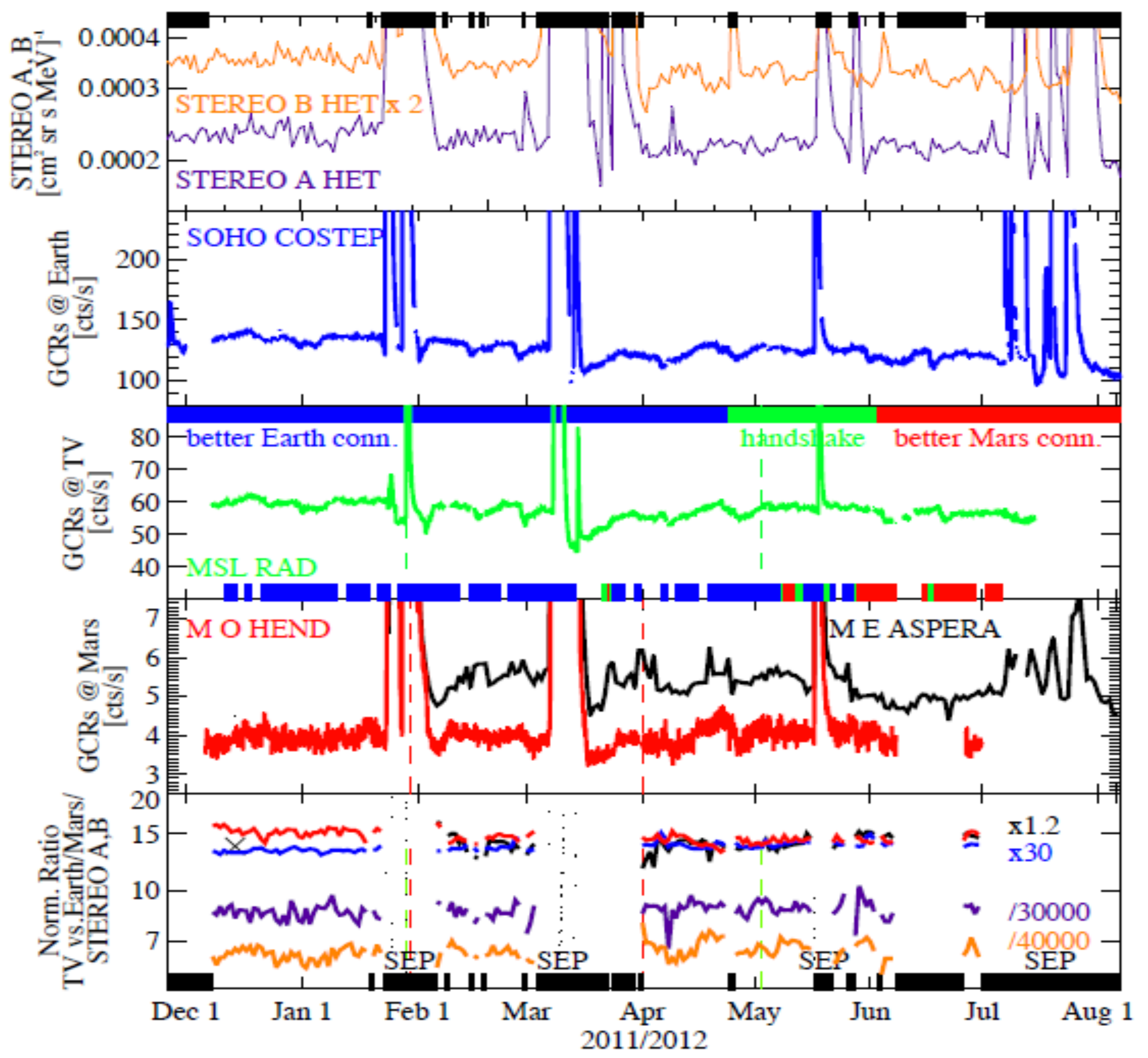
Comparison Theory vs Data-Driven Model



Earth
(SOHO)

Mars
(MSL)

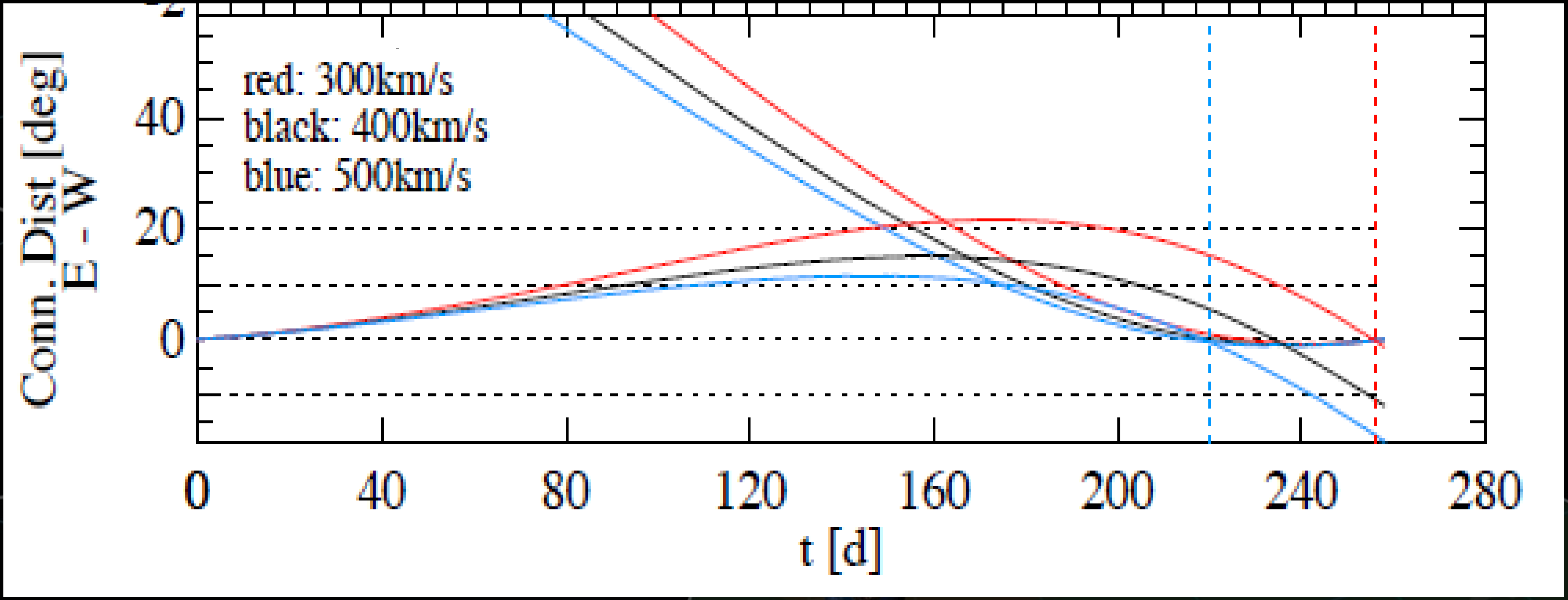
Earth/
Mars GCR
Ratio (blue)



Mars Exploration:
Is SEP Forecasting Feasible?

Journey from Mars to Earth:
The Equivalent Magnetic Connection Distances
(for Three Solar Wind Speeds)

Posner et al., PSS, 2012



Mars-L1 REleASE System Would Support SEP Forecast on Journey Home!
And (of course) Staying at Mars.

Earth/Mars and Other Planetary Transfers

Transfer	Solar Wind at 300 km/s [deg]	Solar Wind at 400 km/s [deg]	Solar Wind at 500 km/s [deg]	Semimajor Axes Ratio (outer vs inner planet)
Mercury Venus	10	9	9	1.85
Venus Mercury	13	10	9	1.85
Venus Earth	7	5	5	1.39
Earth Venus	10	7	6	1.39
Earth Mars	13	9	8	1.52
Mars Earth	22	15	12	1.52