2016 CCMC Workshop Annapolis

# REleASE Update: Near-Realtime Forecasting of MeV Protons on the Basis of Sub- Relativistic Electrons

**J. Labrenz, B. Heber, P. Kühl**

Christian-Albrechts-Universität, Kiel, Germany

**C. Sarlanis**

ISNet Athens, Greece

**O. Malandraki**

National Observatory of Athens, Greece

**A. Posner**

NASA/HQ, SMD/Heliophysics, Washington, DC, USA

# Outline:

RElеASE Forecasting

Adaptation of RElеASE to ACE/EPAM Input

RElеASE and Mars Exploration

Conclusion / Future Work

Outline:

**REleASE Forecasting**

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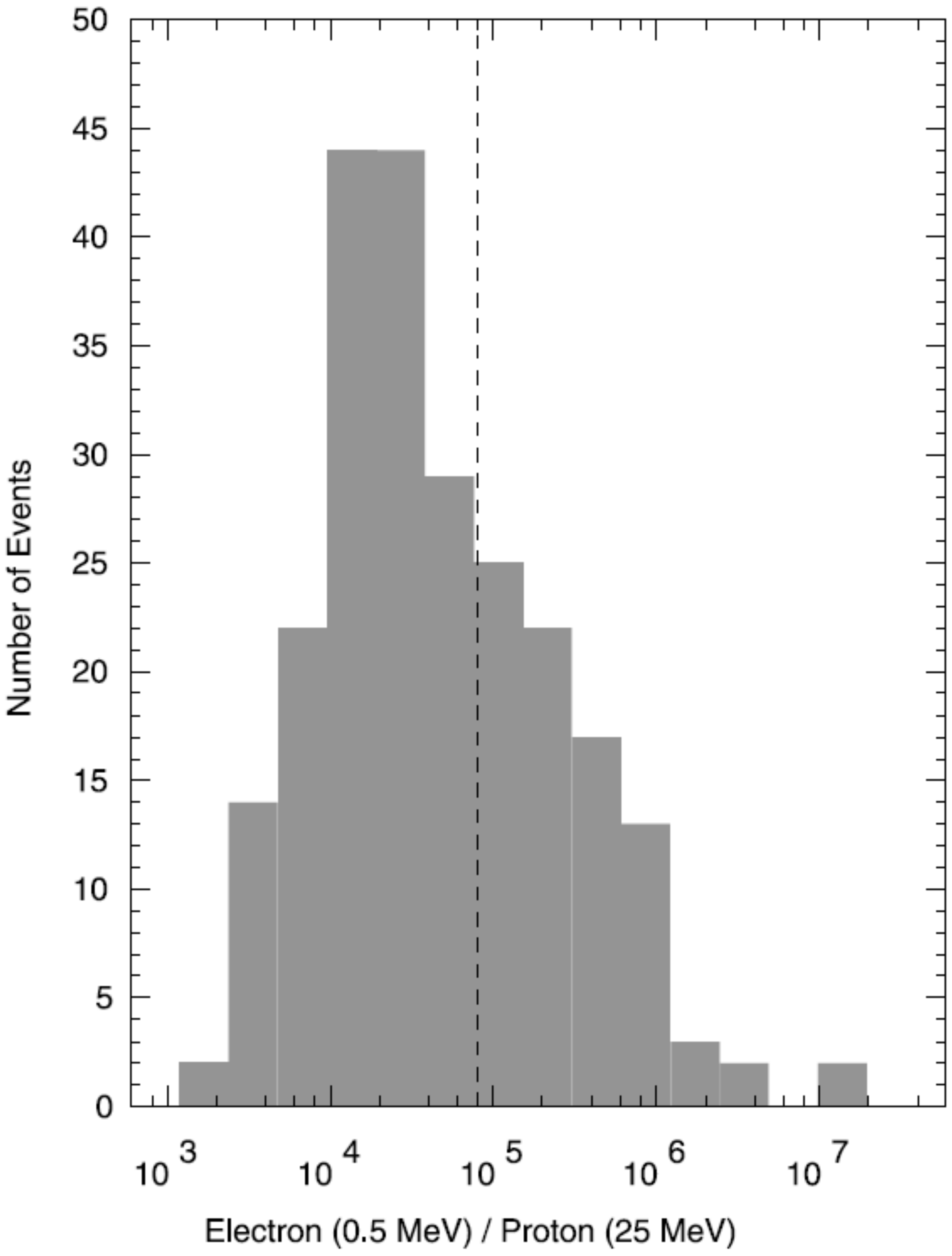
Cane, Richardson and von Rosenvinge (JGR, 2010):

- 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



REleASE

Relativistic Electron Alert System for Exploration

# Richardson et al., 2015

- Angular distributions for electrons and protons in SEP events

- STEREO A, B, SOHO Observations

- e and p have similar longitudinal spreads

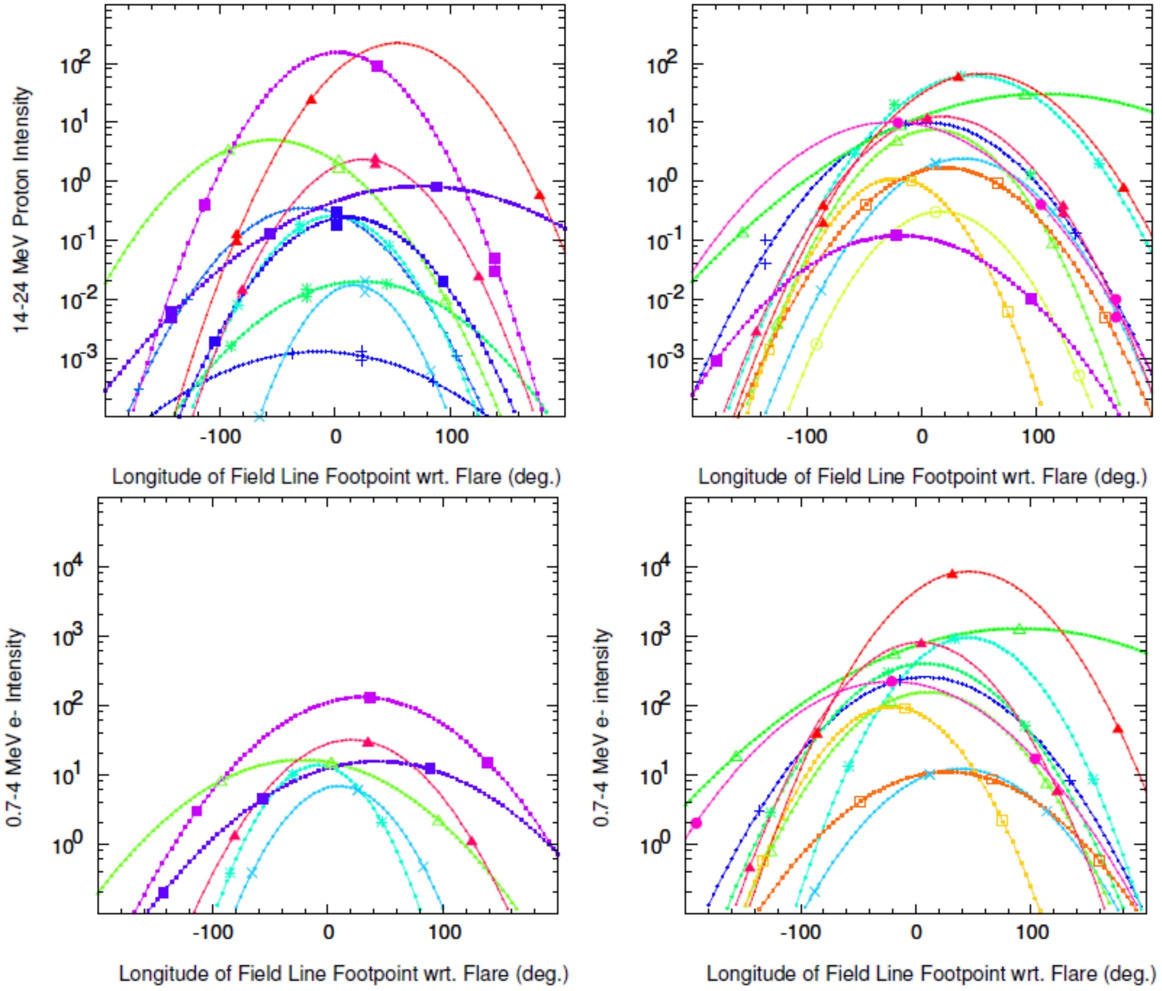
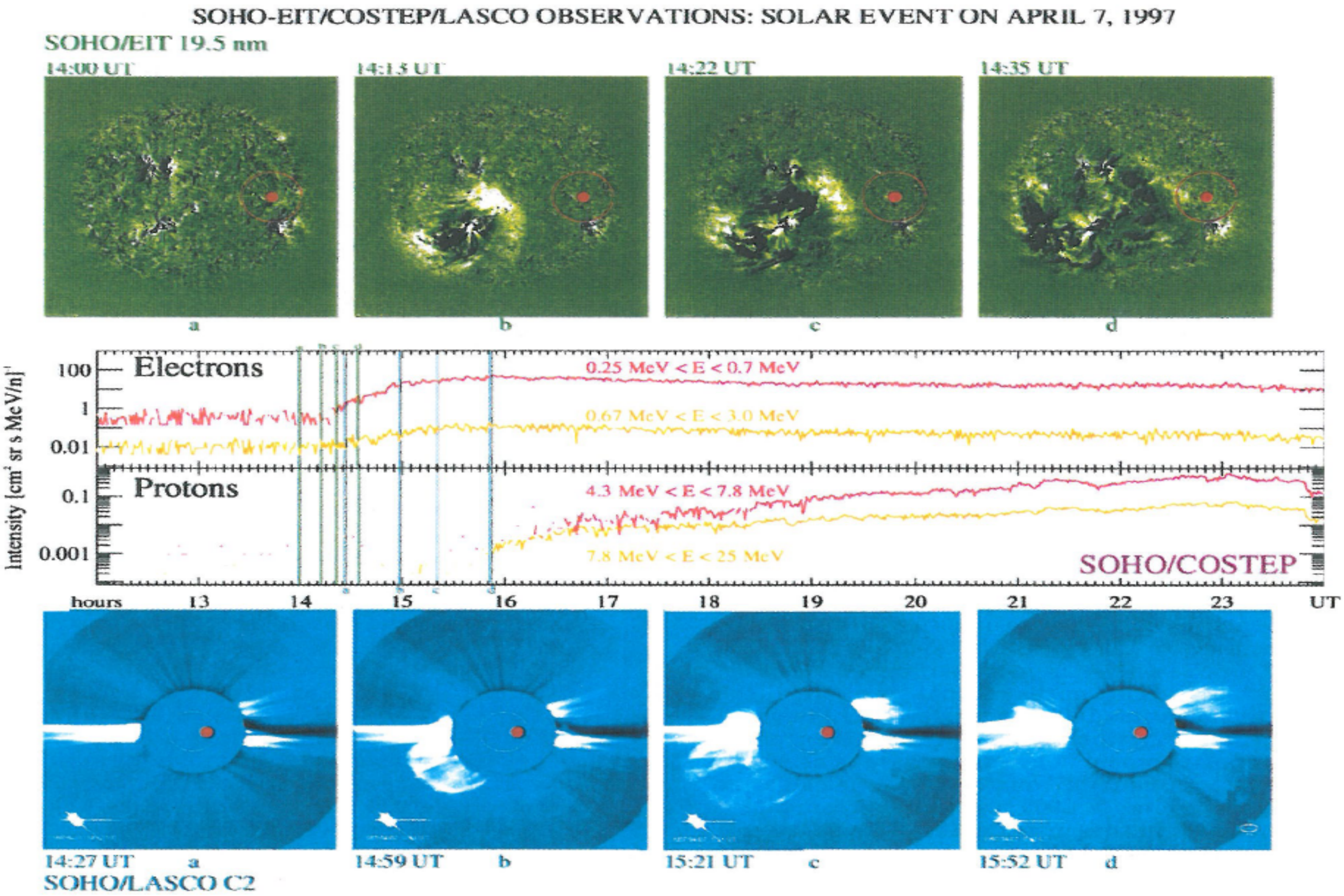


**Figure 23.** Top row: Gaussian fits to the peak 14–24 MeV proton intensity ((MeV s cm$^2$ sr)$^{-1}$) for three-spacecraft events in (left) December 2009–October 2011, and (right) November 2011–October 2012. In some cases, two estimates of the intensity at SOHO (from ERNE and EPHIN) are shown. A background of $10^{-4}$ (MeV s cm$^2$ sr)$^{-1}$ has been removed. Bottom row: Gaussian fits to the peak ∼ 0.3–4 MeV electron intensity ((MeV s cm$^2$ sr)$^{-1}$) for three-spacecraft events in (left) December 2009–October 2011, and (right) November 2011–October 2012. STEREO HET intensities have been multiplied by the factors discussed in Section 2.

Richardson et al., Sol. Phys., 2015



## Electron Onset Time at SOHO Rules Out EIT Wave as Acceleration Driver

Bothmer et al., Proc. ESLAB Symp., 1997

## Richardson et al., 2015

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

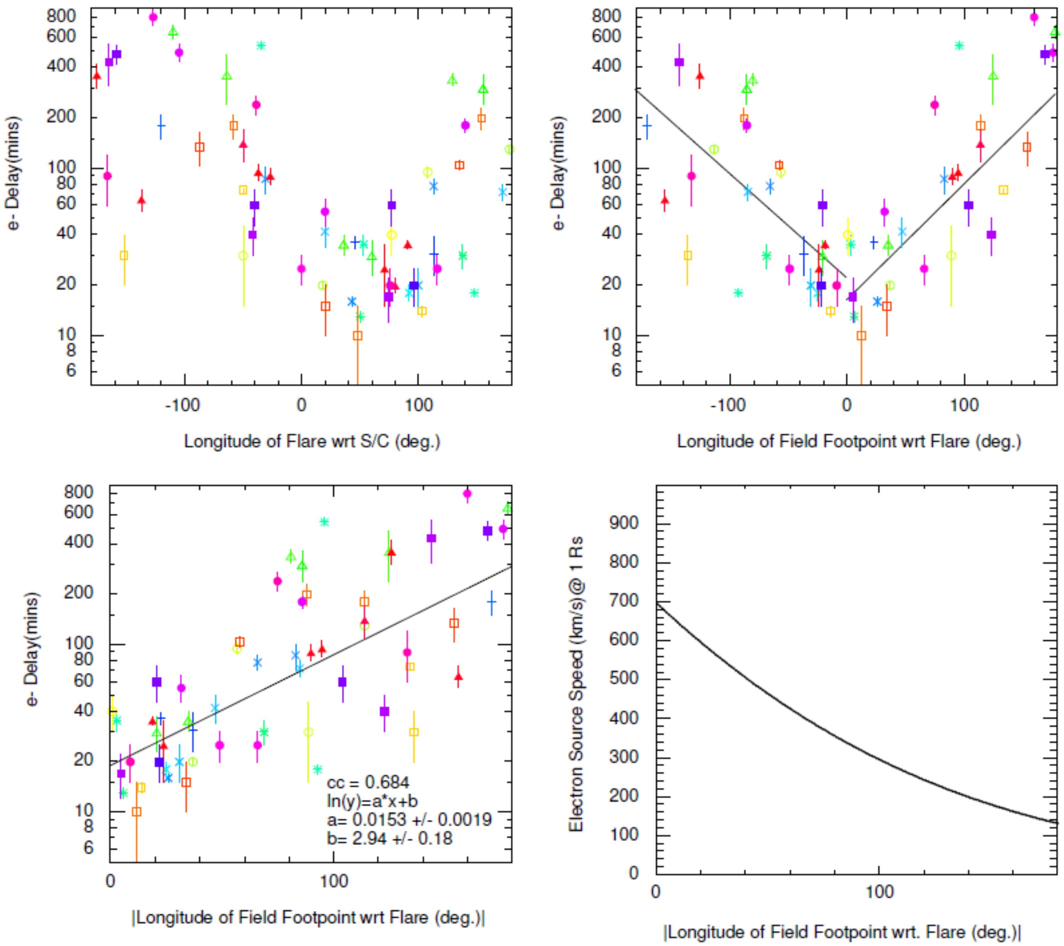


**Figure 15.** Summary of the ∼ 0.7–4 MeV electron onset delay versus solar event location with respect to the observing spacecraft (top left) and versus the angle between the footpoint of the field line passing the spacecraft and the solar event (connection angle; top right), for the three-spacecraft events in December 2009–December 2013. Symbols indicate different events. Delays are typically shortest for western hemisphere events when connection to the event is favorable. The fits to events with positive or negative connection angles suggest that delays are ∼symmetric to the east and west of the solar event. The bottom left panel shows the delay *vs.* the absolute connection angle. The delay at zero connection angle is ∼ 19 ± 3 minutes. The log-linear fit, if interpreted as increasing delays due to an electron “source” spreading in longitude at the surface of the Sun suggests propagation speeds in longitude shown in the bottom right that fall with distance from the event, from ∼ 700 km s$^{-1}$ near the event to ∼ 130 km s$^{-1}$ at 180$^o$ from the event.

Richardson et al., Sol. Phys., 2015

REleASE

Relativistic Electron Alert System for Exploration

# Richardson et al., 2015

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

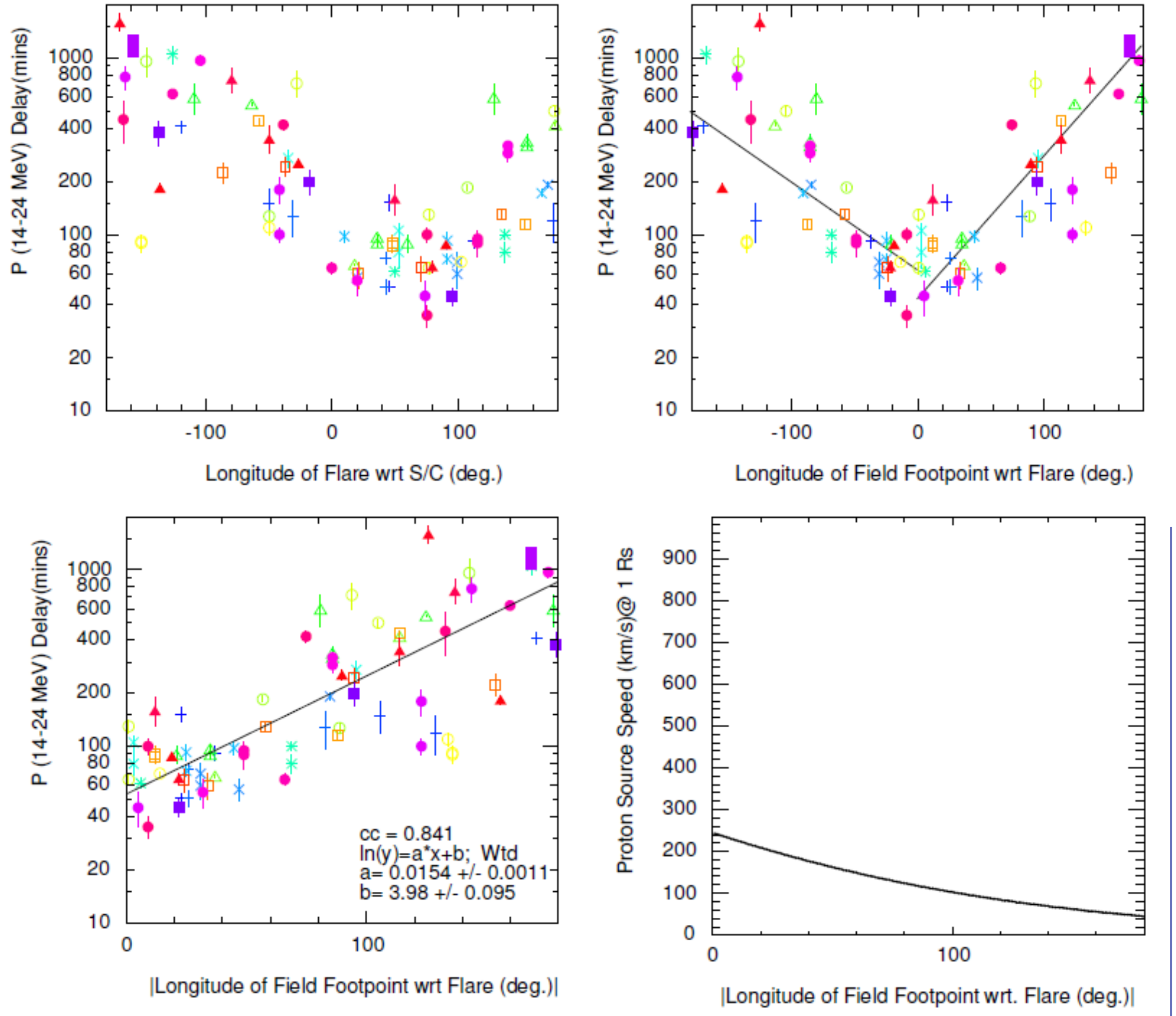
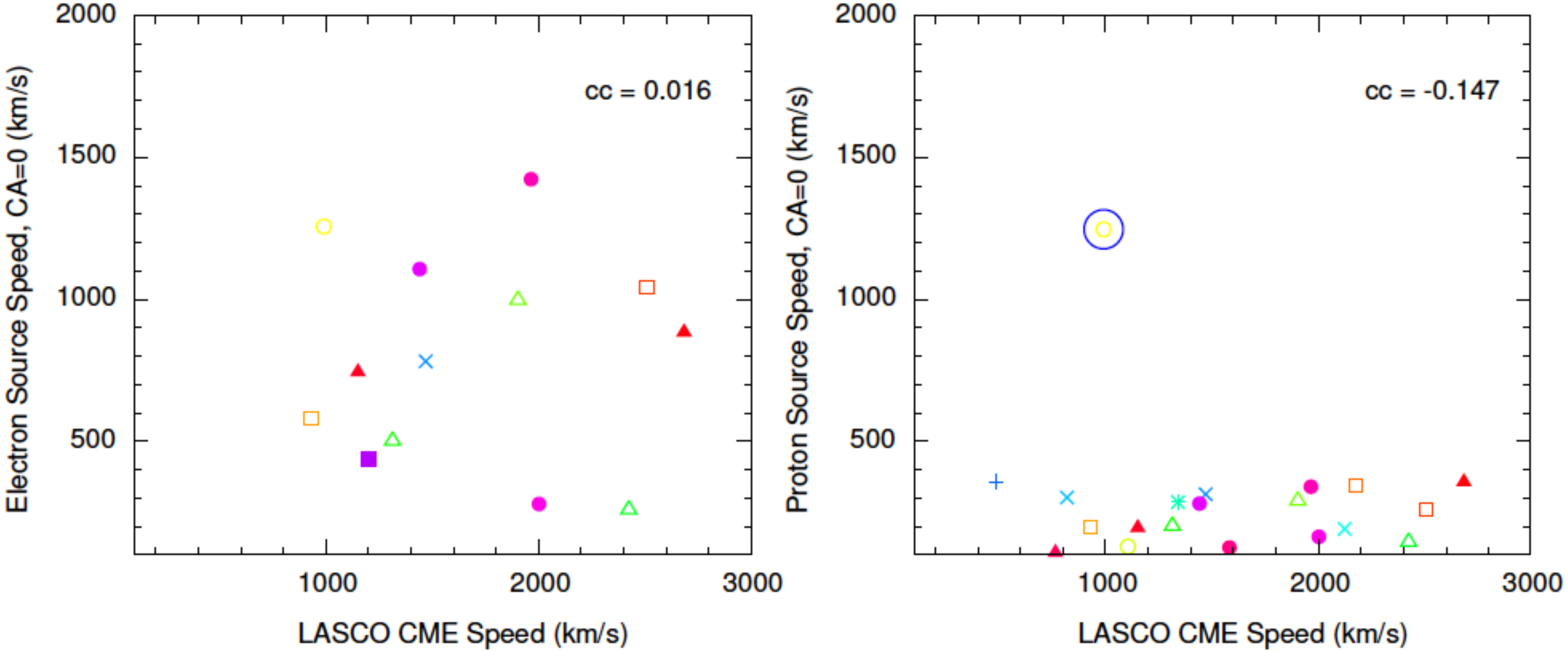


**Figure 16.** Summary plots of 14–24 MeV proton onset delays, in a similar format to Figure 15. Onset delays are again typically shortest for western hemisphere events when connection to the event is favorable. The fits to events with positive or negative connection angles (top left) suggest some east–west asymmetry in the proton onset delay. However, plotting the delays *vs.* $|CA|$ (lower left) indicates a typical delay at zero connection angle of ∼ 54 minutes. The slope of the log-linear fit is nearly identical to that for electrons. Thus, the ratio of the proton and electron onset delays is ∼constant at all connection angles. The source expansion speeds are slower than for electrons, ranging from ∼ 240 km $s^{-1}$ near the event to 45 km $s^{-1}$ at ∼ $180^o$ from the event.

Richardson et al., Sol. Phys., ApJ, 2015

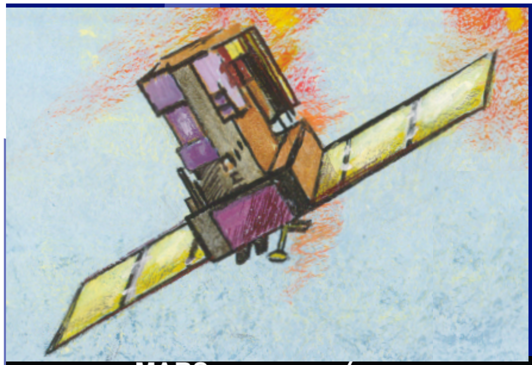


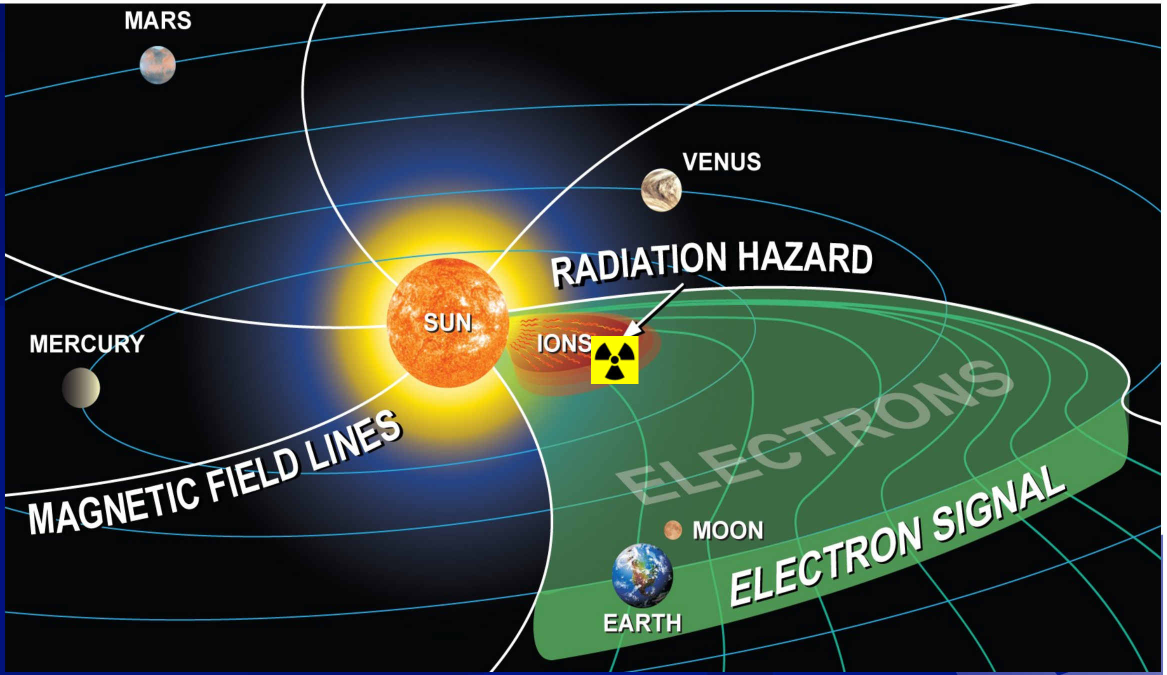
- No Correlation of Source Speeds with Observed CME Speeds

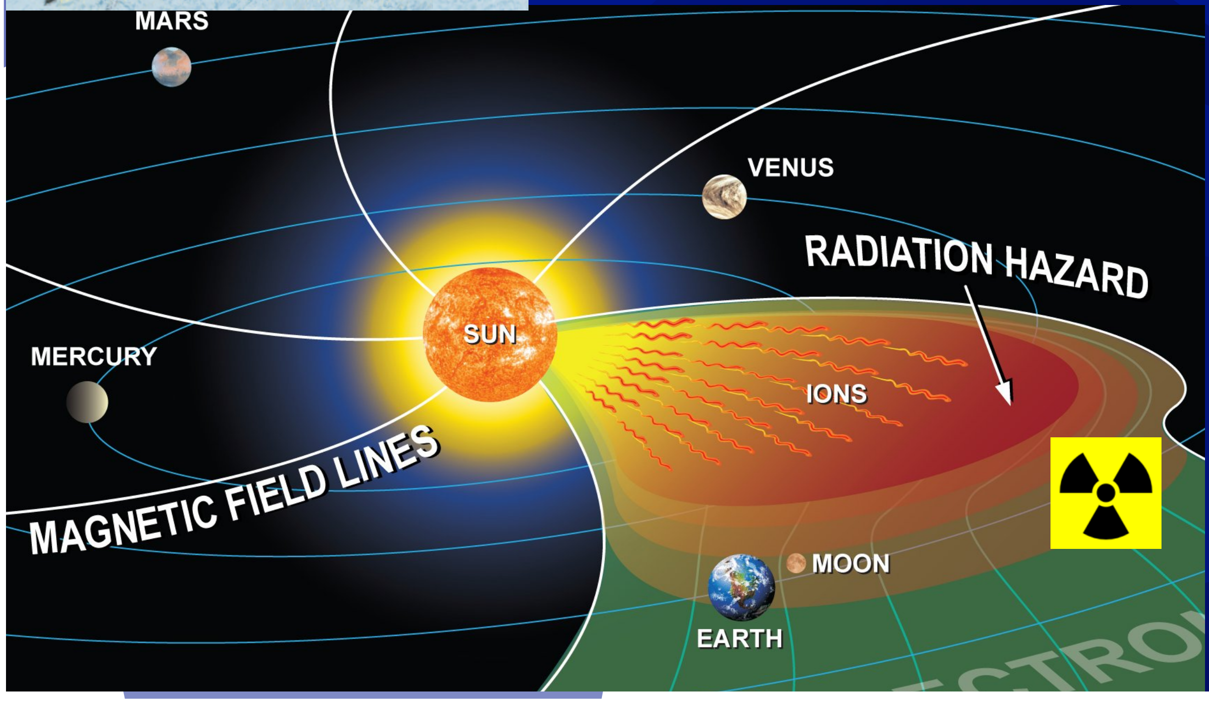
Richardson et al., Sol. Phys., ApJ, 2015

# REleASE

Relativistic Electron Alert System for Exploration







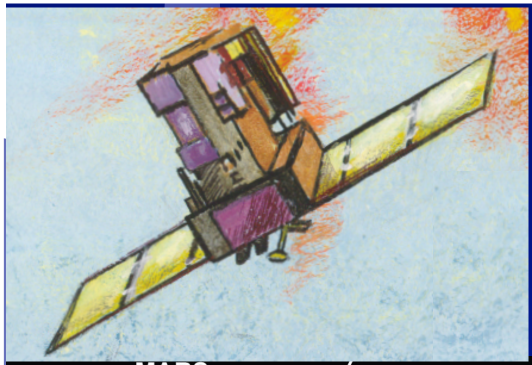
$D \sim 1.2$ AU

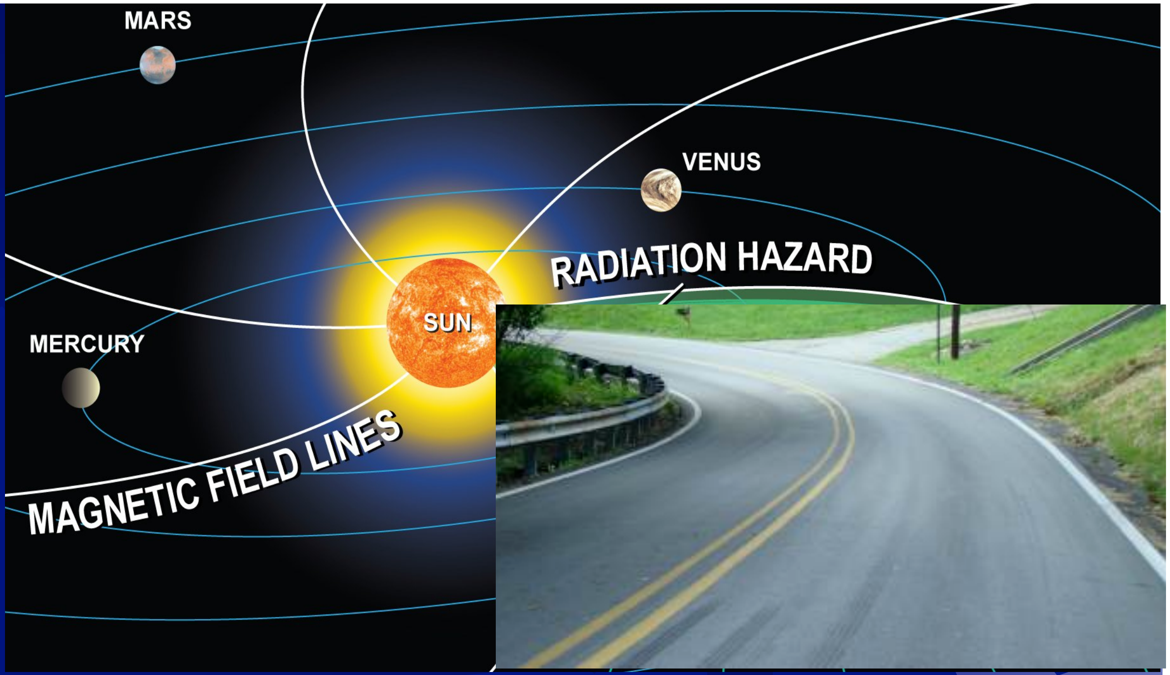
$v_{el}(1\ \mathrm{MeV}) = 0.95\ c$

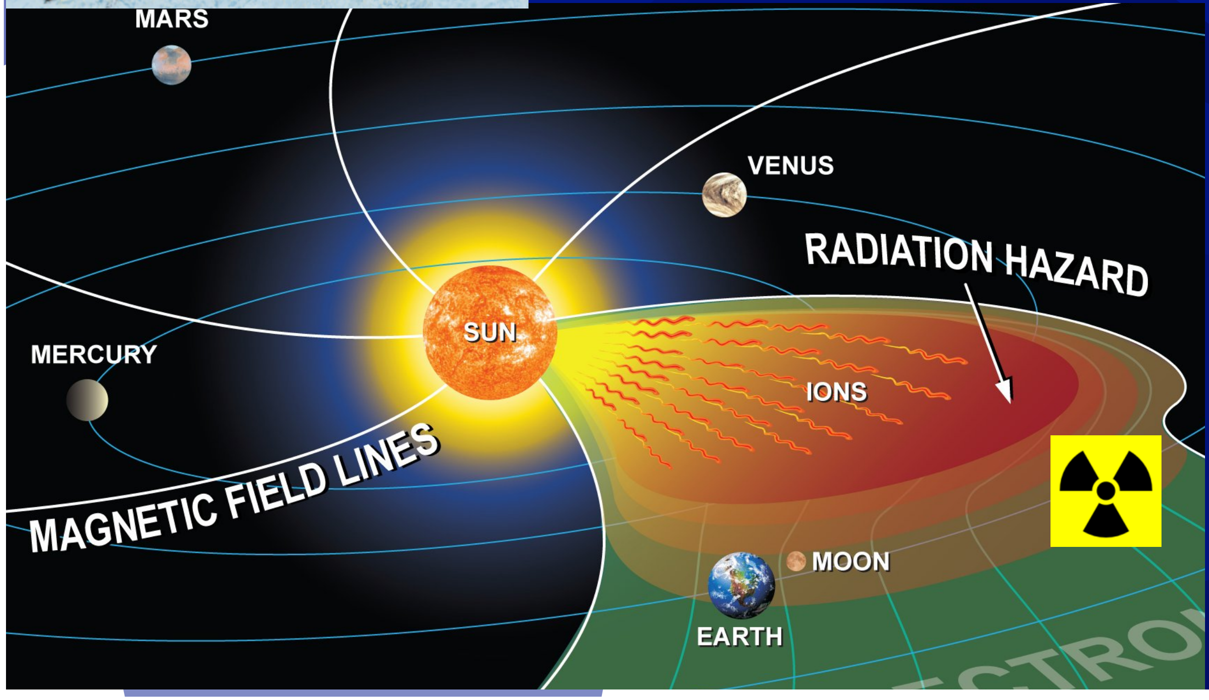
$T_{el}\ (1\ \mathrm{MeV}) = 10.5\ \mathrm{min}$

# REleASE

Relativistic Electron Alert System for Exploration







$D \sim 1.2$ AU

$v_{el}(1 \text{ MeV}) = 0.95\ c$

$v_p(30 \text{ MeV}) = 0.25\ c$

$T_{el}\ (1 \text{ MeV}) = 10.5 \text{ min}$

$T_p(30 \text{ MeV}) = 40 \text{ min}$

$\Delta T \sim 30 \text{ min}$

Relativistic electrons always arrive at 1 AU ahead of non-relativistic SPE ions allowing their forecasting.

Coming from one source with “identical” propagation conditions, significant correlations between electron and proton time-profiles exist.

Therefore, a matrix to forecast proton intensities was developed.

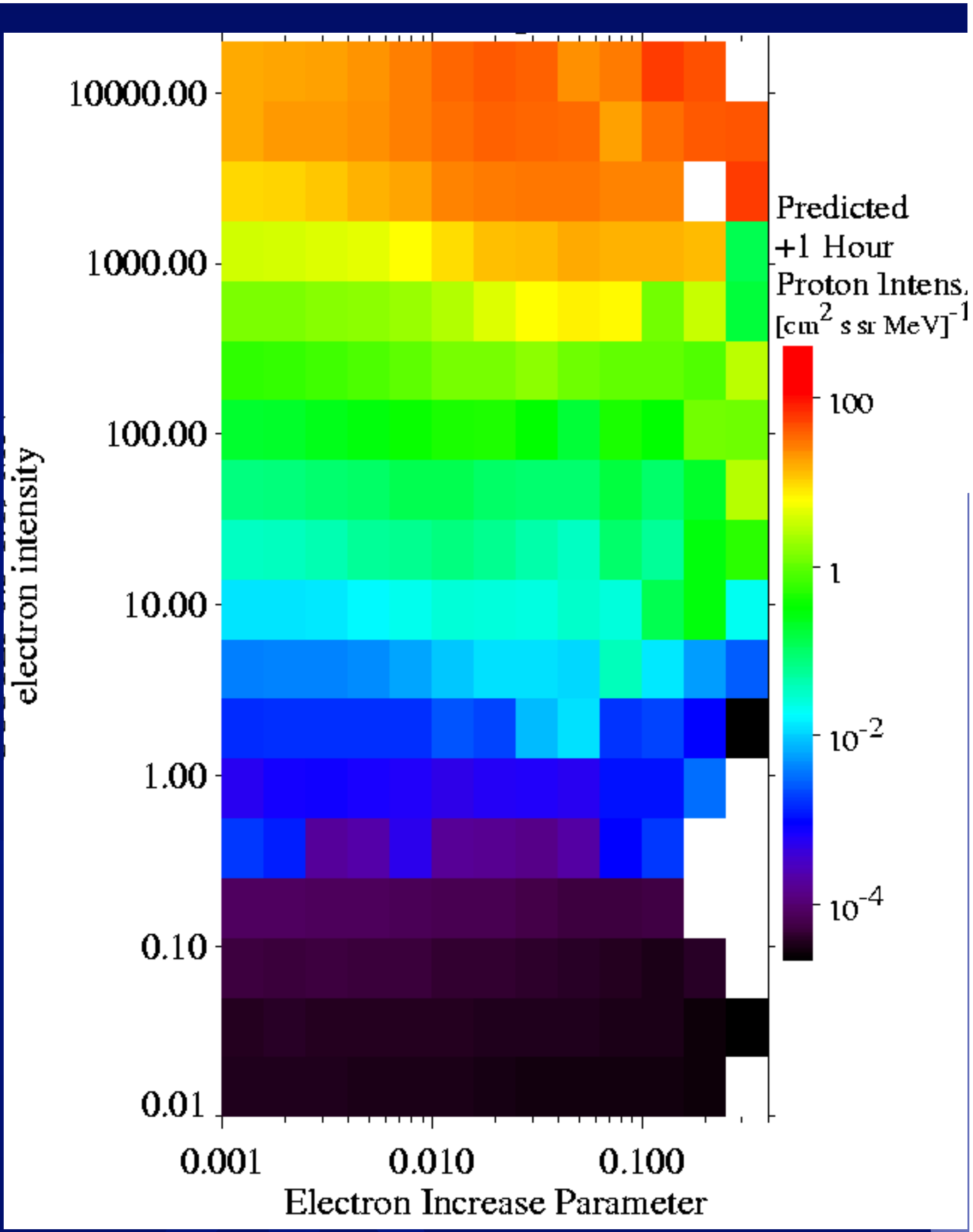
Posner, *Space Weather J.*, 2007

# The Forecasting Matrix

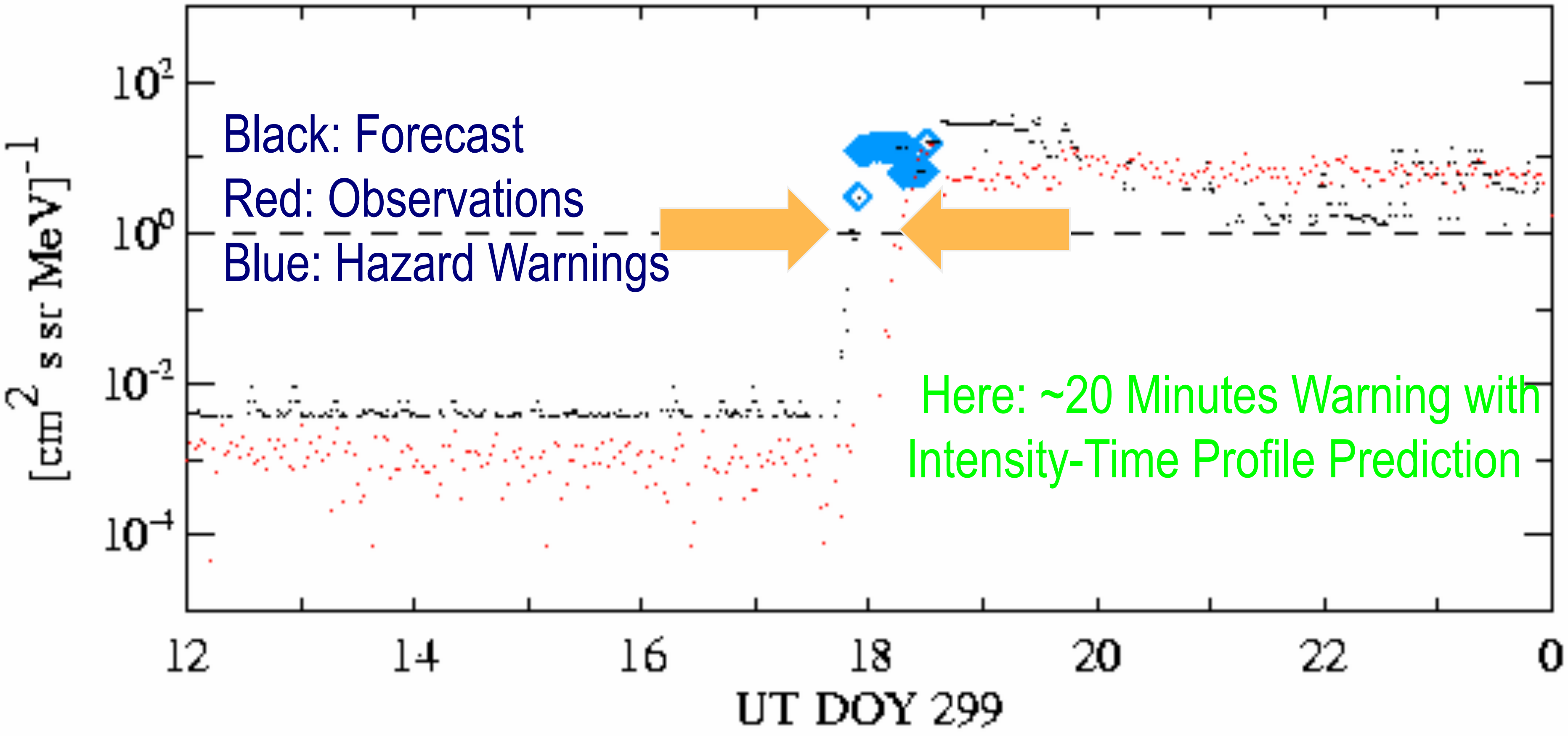
A matrix is the foundation of this forecasting technique. It combines continuous minute-by-minute observations through the main phase of solar cycle 23 (“learning phase”, 1998-2002). The matrix spans across electron intensities and rise times and any time the electron intensity increases, a value is added at the locus given by the two parameters. The value that is filled in is the proton intensity observed one hour later.

At any one time, a forecast simply pulls the average matrix proton value for the given electron locus and turns it into a near-term proton intensity prediction.

From Posner, *Space Weather J.*, 2007



# Proton Event Prediction DOY 299, 2003



Black: Forecast
Red: Observations
Blue: Hazard Warnings

Here: ~20 Minutes Warning with Intensity-Time Profile Prediction

The Oct. 26, 2003 event in detail. The forecast intensity is provided in black, the observations in red. A 20-minute warning allows astronauts on EVAs or inside spacecraft to seek shelter early.

Posner, *Space Weather, 2007*

> “We note that Posner (2007) proposed using observations of near-relativistic electron onsets to give ~1 hour or more warning of the arrival of more hazardous protons and heavy ions with energies 10s of MeV. The results presented here provide further justification for this technique.”

Richardson et al., Sol. Phys., 2015

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Conclusion / Future Work

*National Observatory of Athens*
*(NOA)*

IAASARS

INSTITUTE FOR ASTRONOMY, ASTROPHYSICS,
SPACE APPLICATIONS & REMOTE SENSING
*(formerly INSTITUTE OF ASTRONOMY & ASTROPHYSICS)*
National Observatory of Athens

HESPERIA

# PROTEC-1-2014 'Space Weather'
# High Energy Solar Particle Events Forecasting and Analysis

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

✓ **Solar energetic particles (SEPs)** are of prime astrophysical interest, but are also a space weather hazard motivating the development of predictive capabilities.

✓The project is coordinated by the National Observatory of Athens in Greece **(Project Coordinator: Dr. Olga Malandraki**) .

✓It will combine data and knowledge from **9 European partners** and several collaborating parties from US and Russia.

✓ Team Members: Olga Malandraki, Ludwig Klein, Rami Vainio, Neus Agueda, Marlon Nunez, Bernd Heber, Rolf Buetikofer, Christos Salarnis, and Norma B. Crosby

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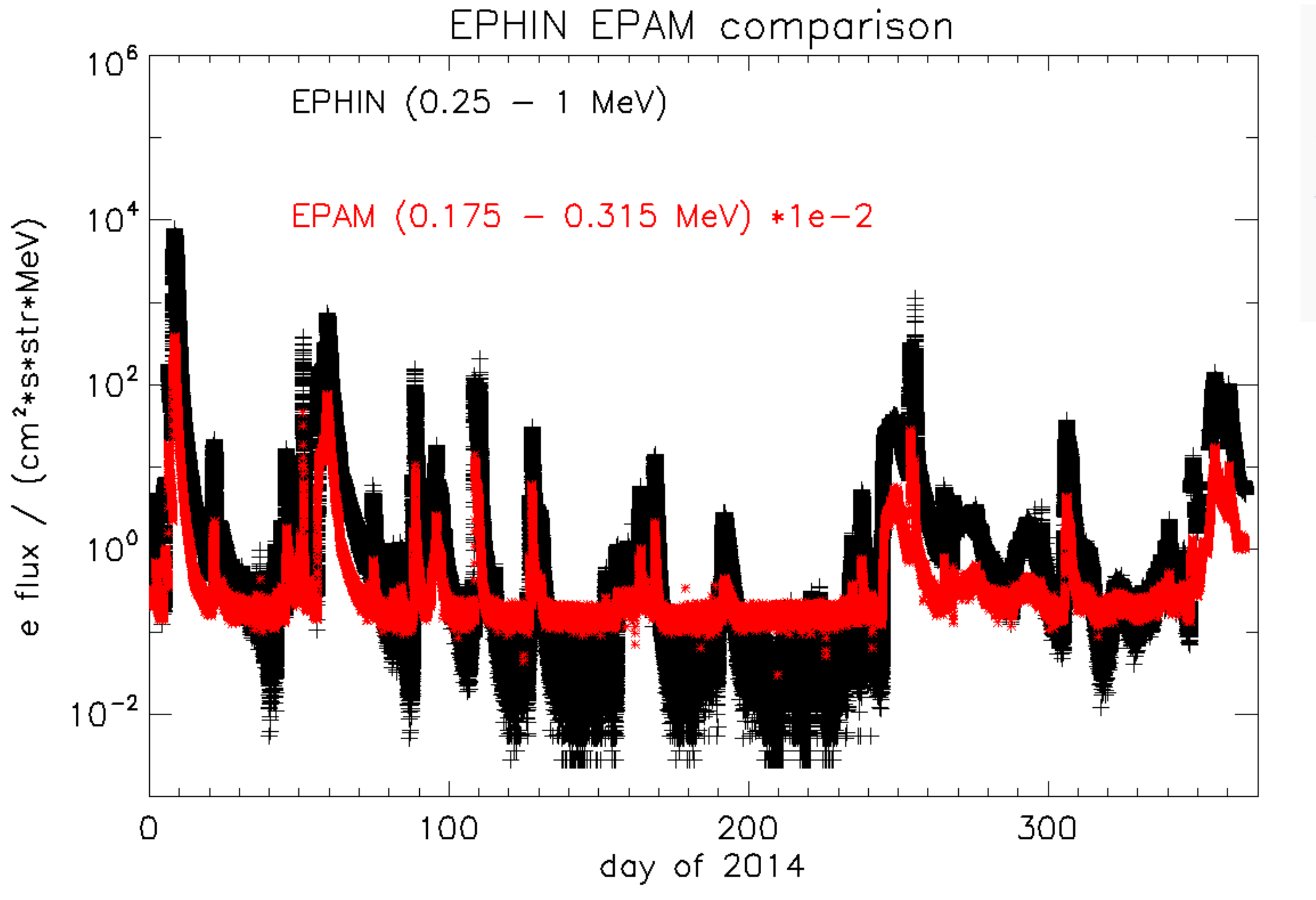
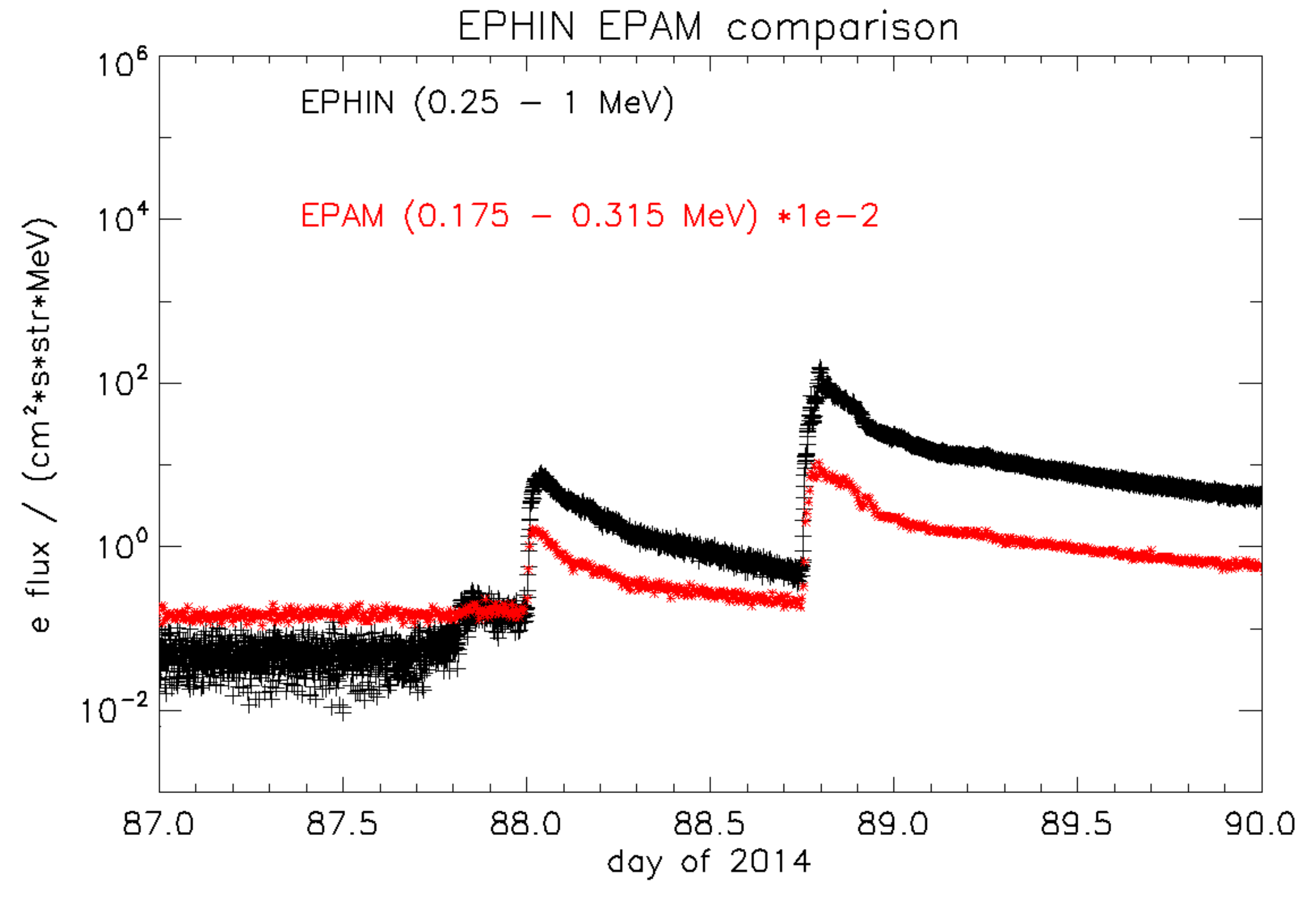
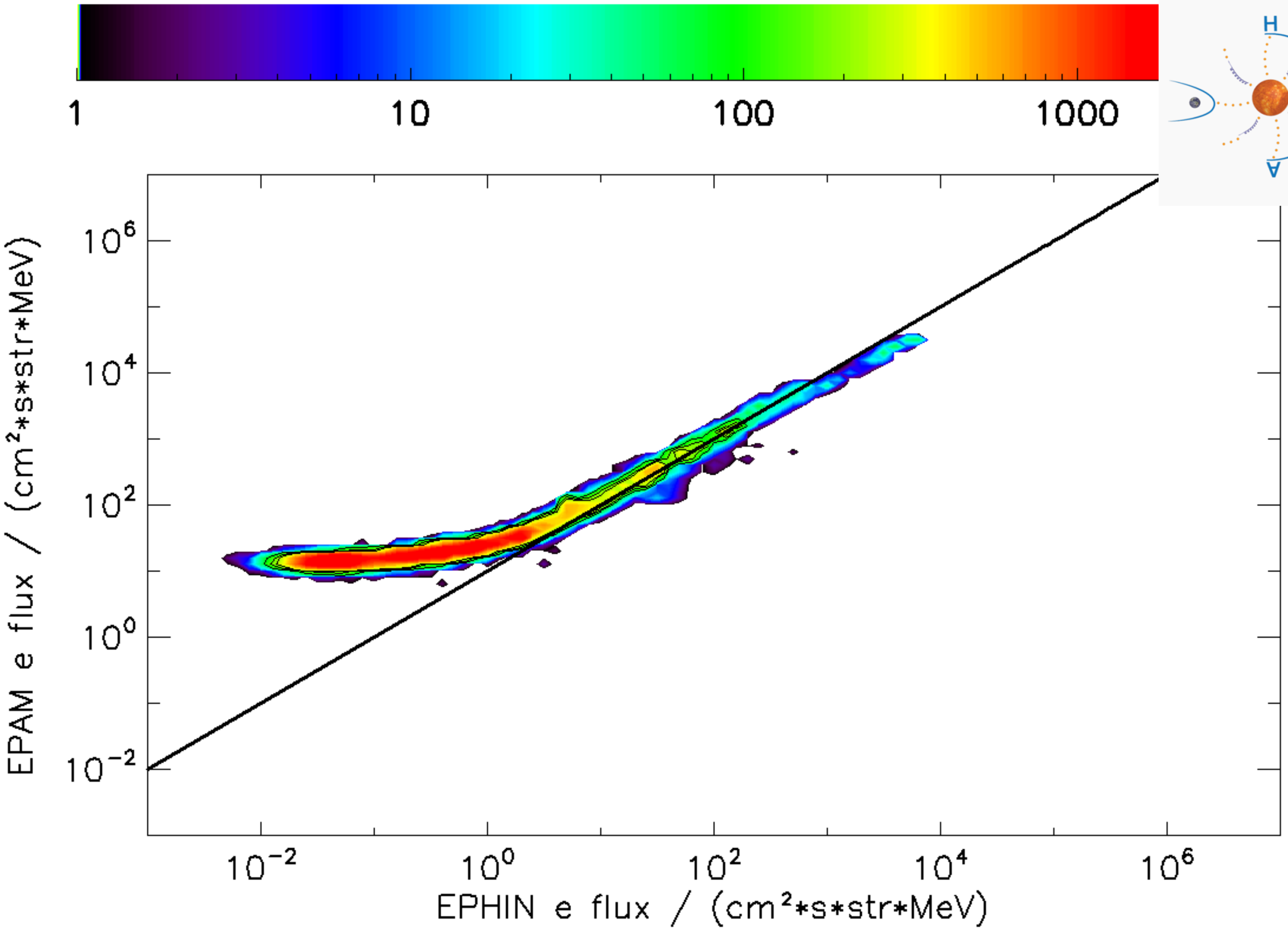
ISNet
Intelligent Systems Networks



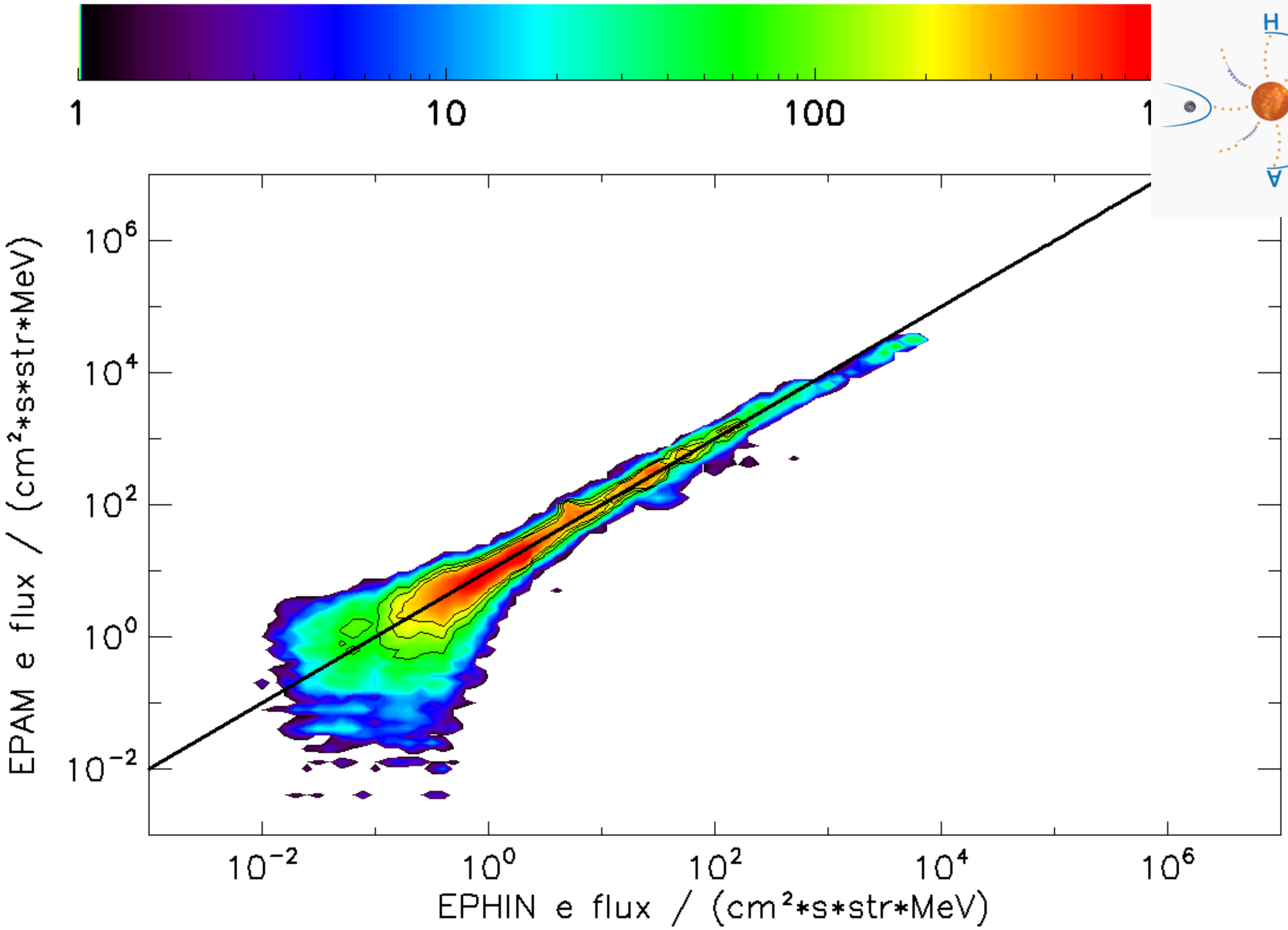
- – SOHO/COSTEP-EPHIN Realtime Data has Limited Temporal Coverage (~4 hrs/day)
- – ACE/EPAM Realtime Data has Nearly Full Time Coverage
- – But Lower Time Resolution (5 min EPAM vs. 1 min EPHIN) and Different Energy Range (0.175-0.315 MeV EPAM vs. 0.25-1.0 MeV EPHIN).
- – ACE/EPAM Data Can't be Used Directly with Existing REleASE Forecast Matrices



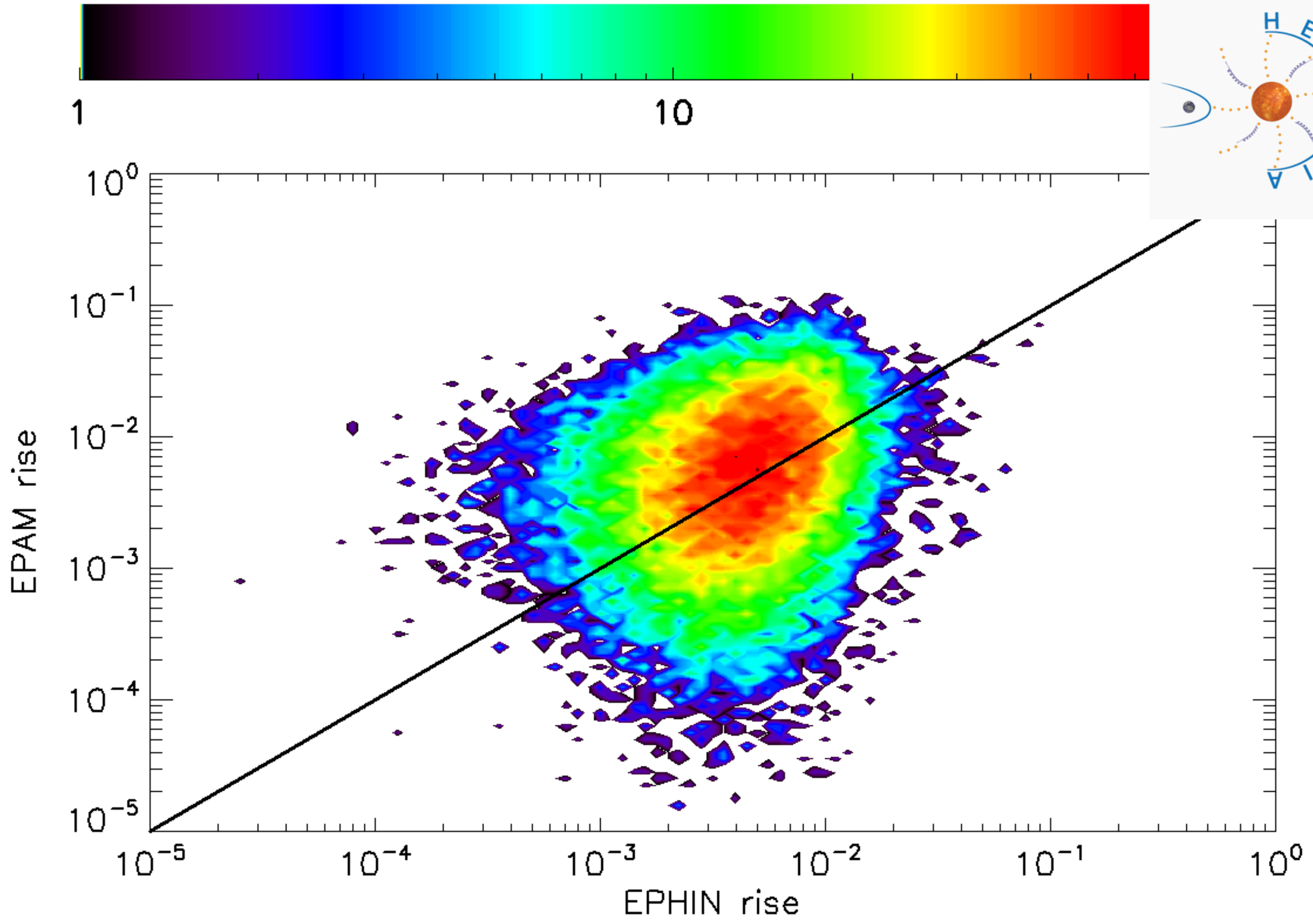
**First parameter: Electron Intensities**
- **ACE/EPAM has higher background**
- **EPAM bg vs EPHIN bg: ~ x10**
- **Task: Find correlation**



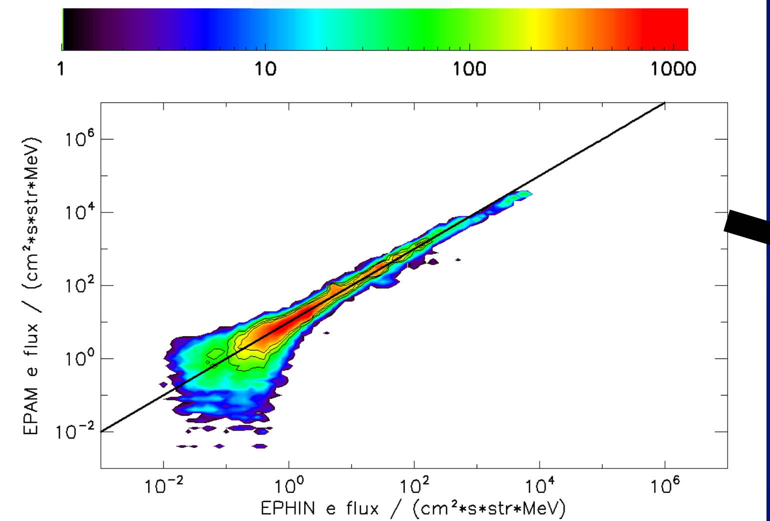
# EPAM vs EPHIN Electron Flux: High Background at ~10/cm$^2$ s sr MeV

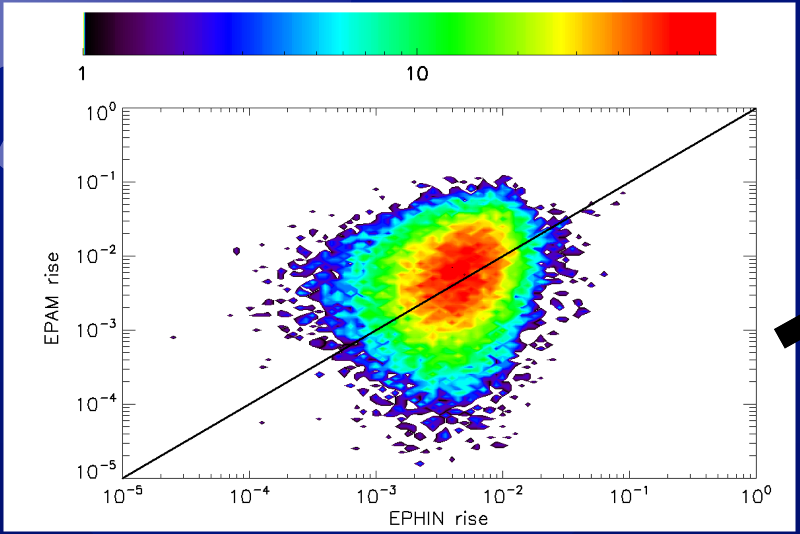


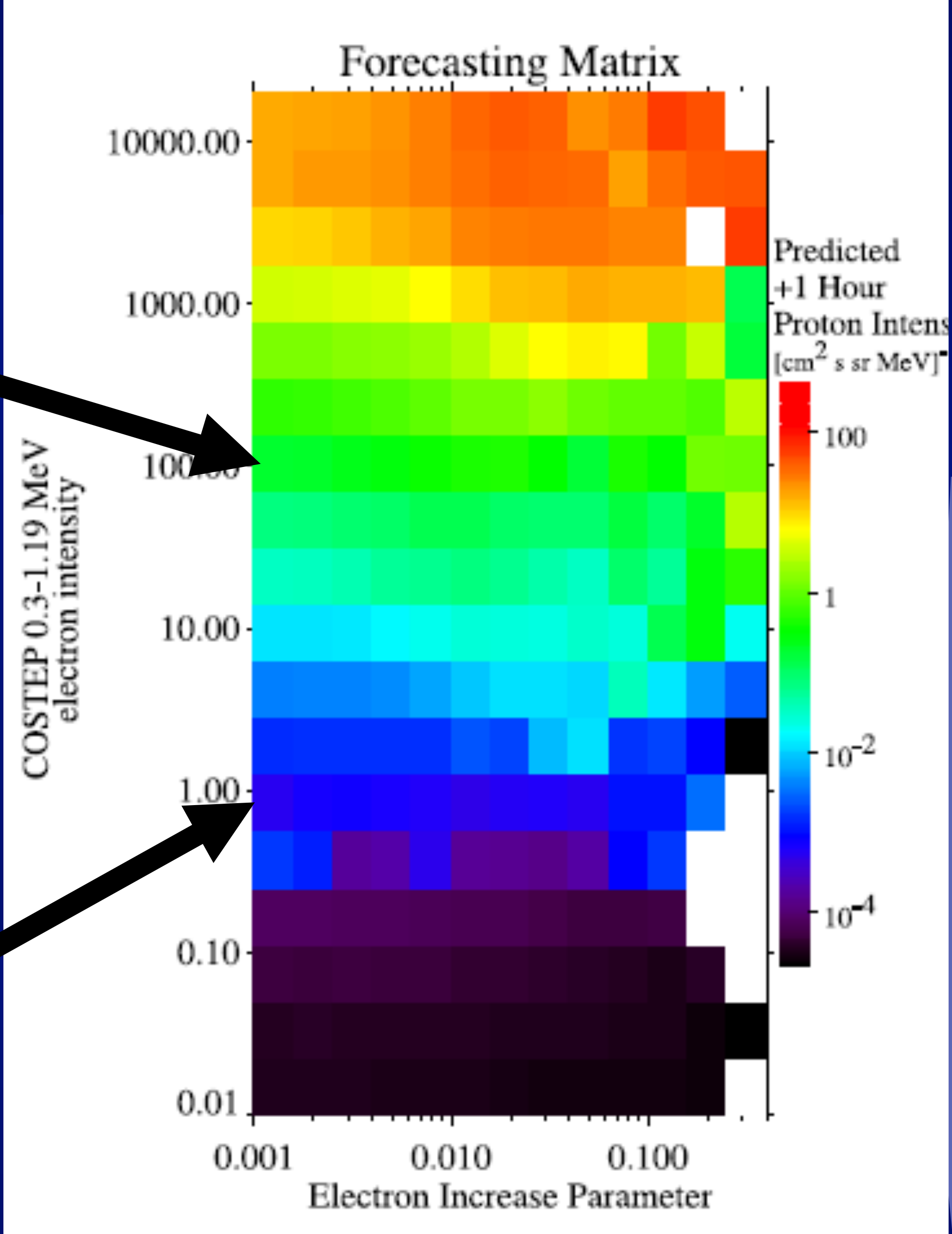
# EPAM vs EPHIN Electron Flux After EPAM Background Subtraction



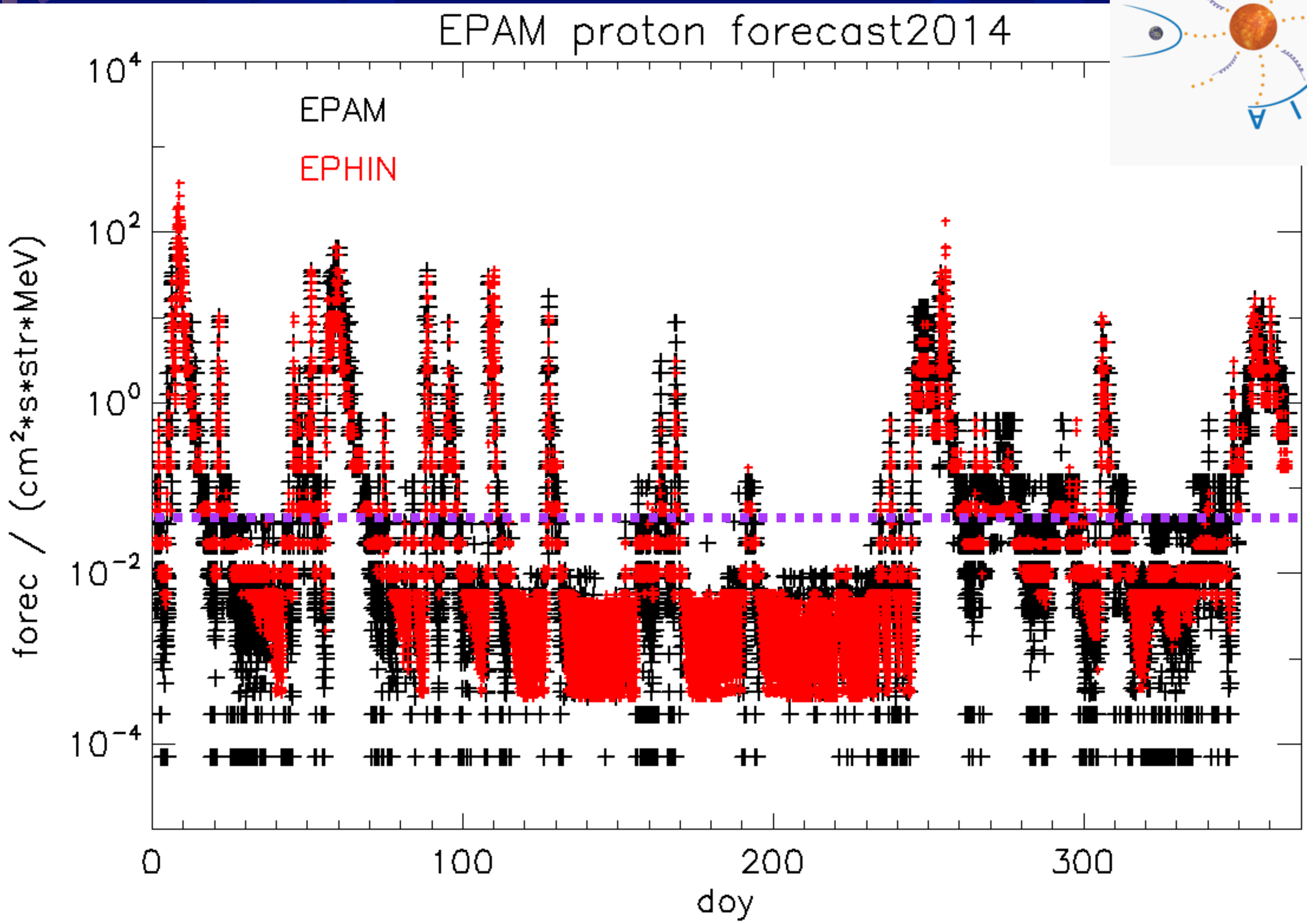
# EPAM vs EPHIN Electron Increase Parameter







## Input Parameters


EPAM proton forecast2014
EPAM
EPHIN
forec / (cm²*s*str*MeV)
10⁴
10²
10⁰
10⁻²
10⁻⁴
0
100
200
300
doy

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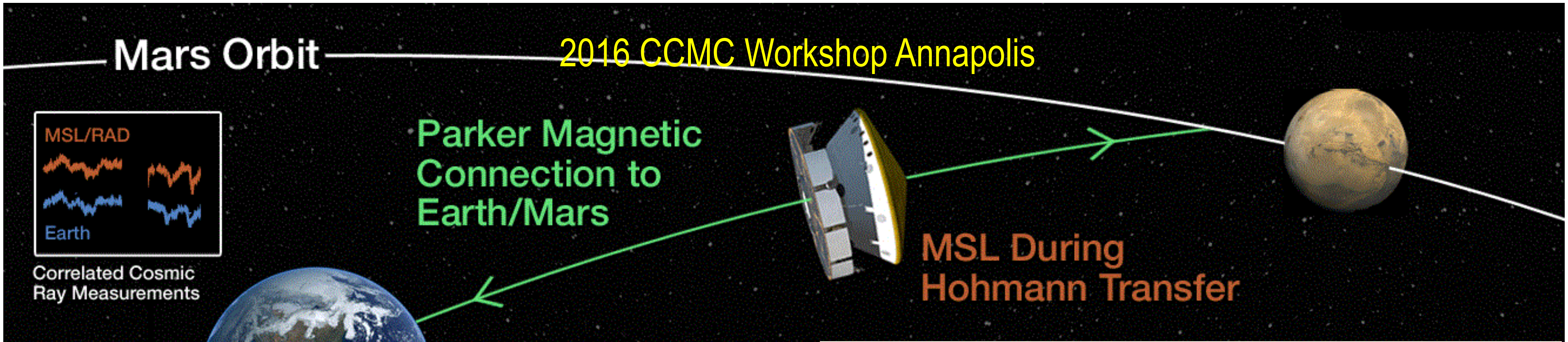
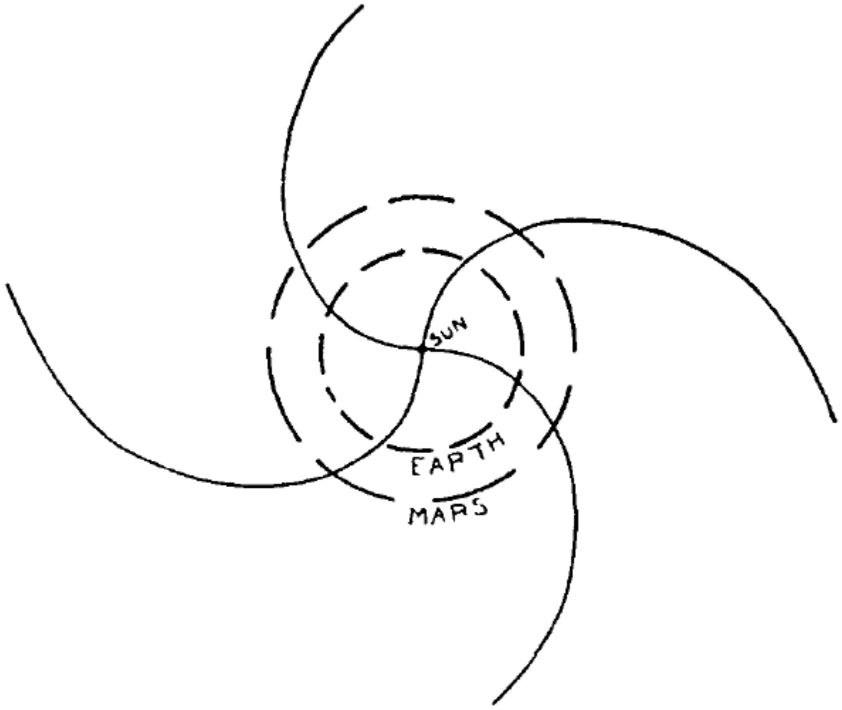
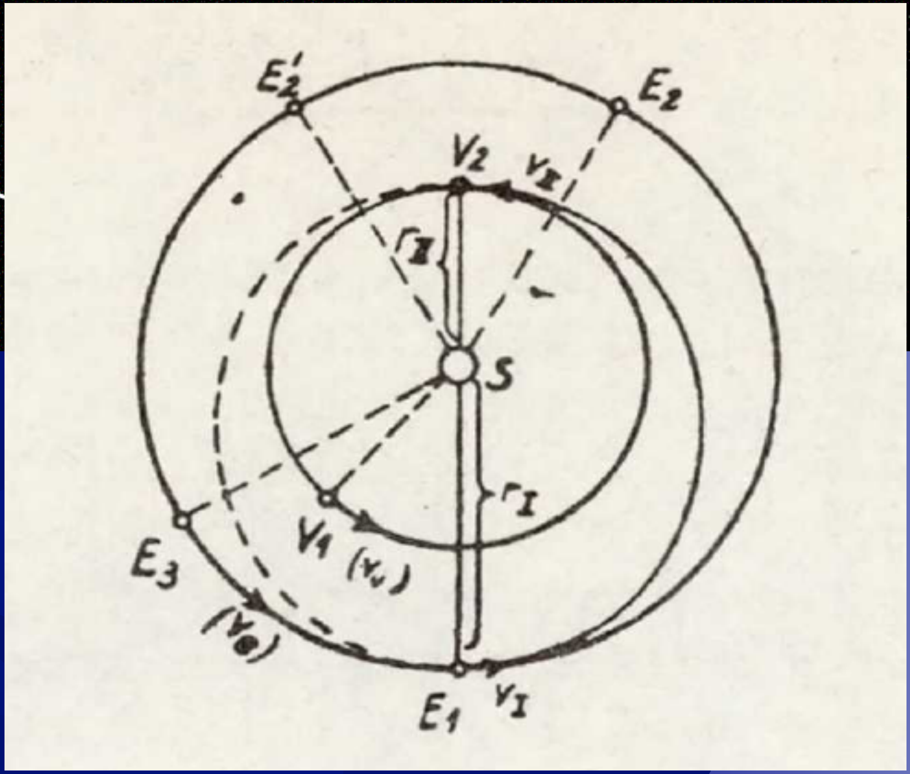
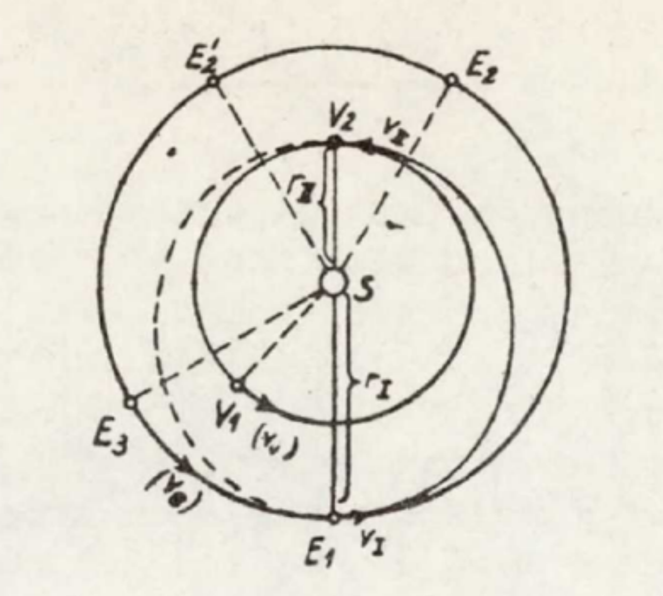




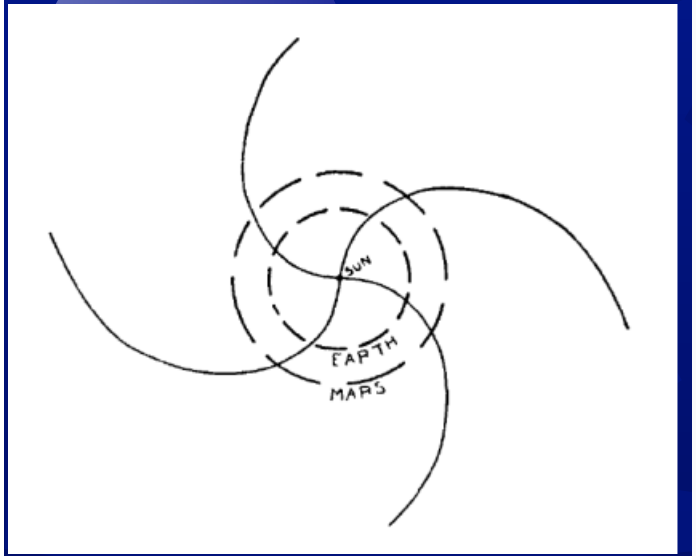


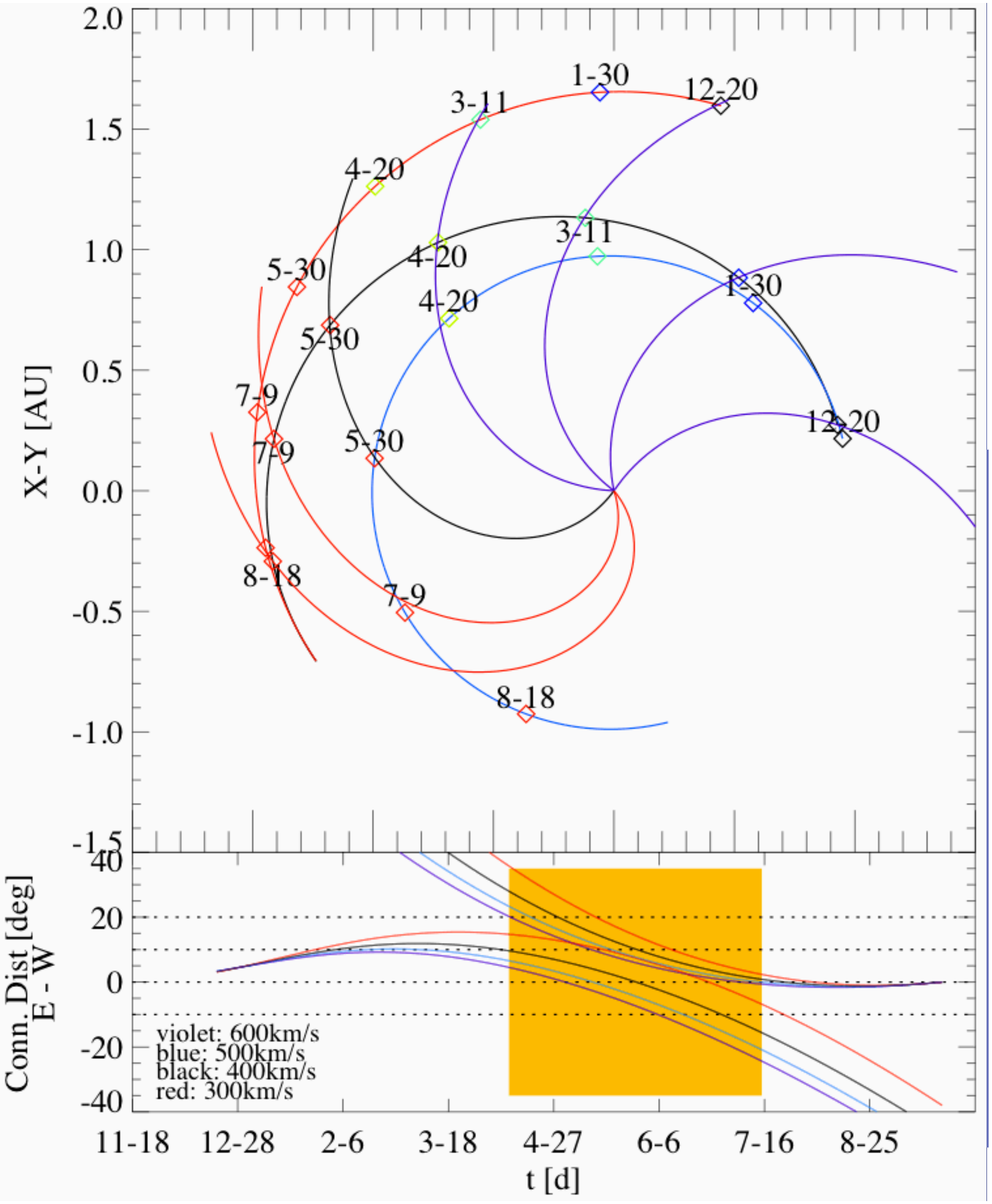
**Hohmann, 1925**

**Parker, 1958**

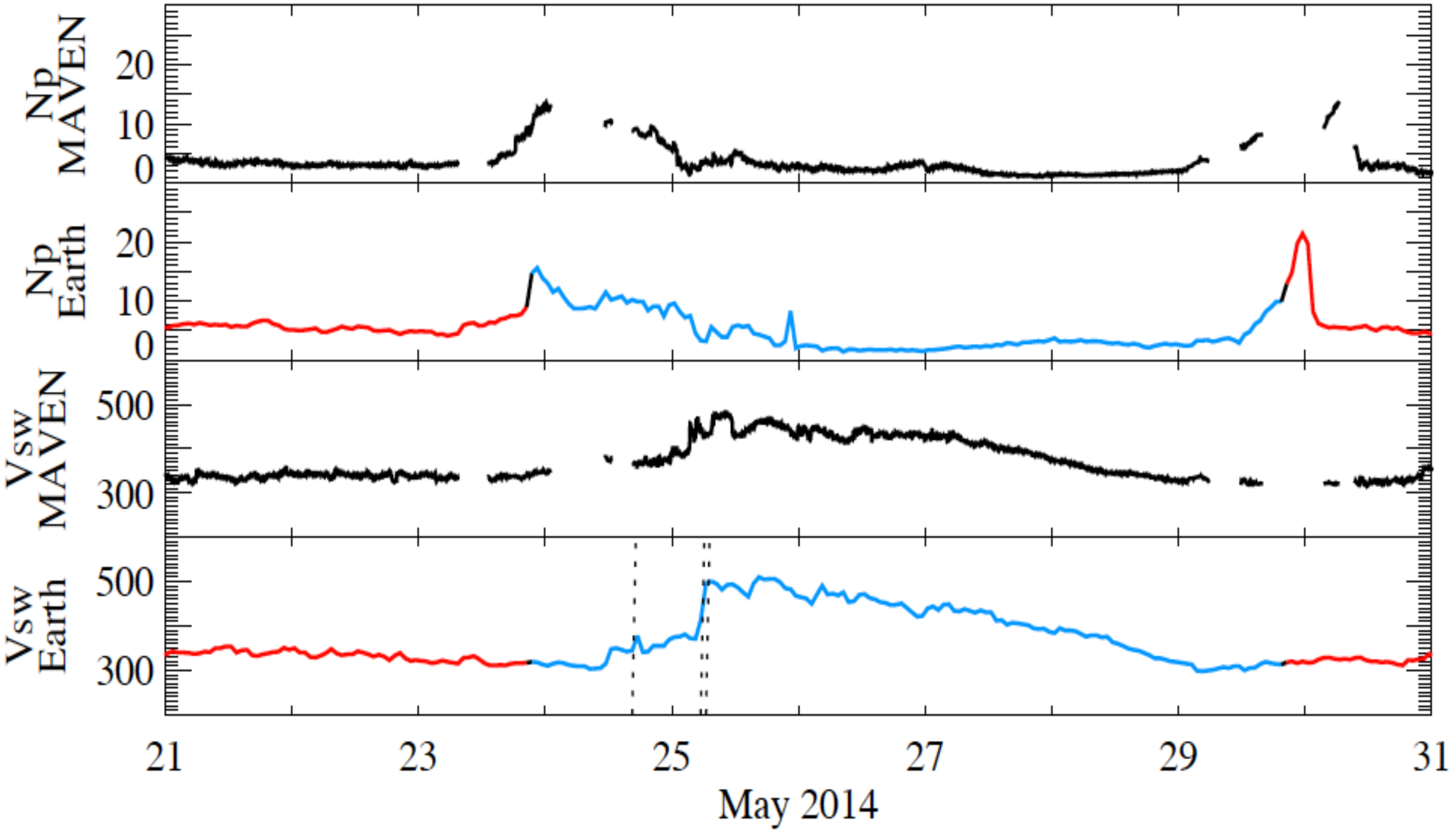


# Transfer from Earth to Mars: MAVEN

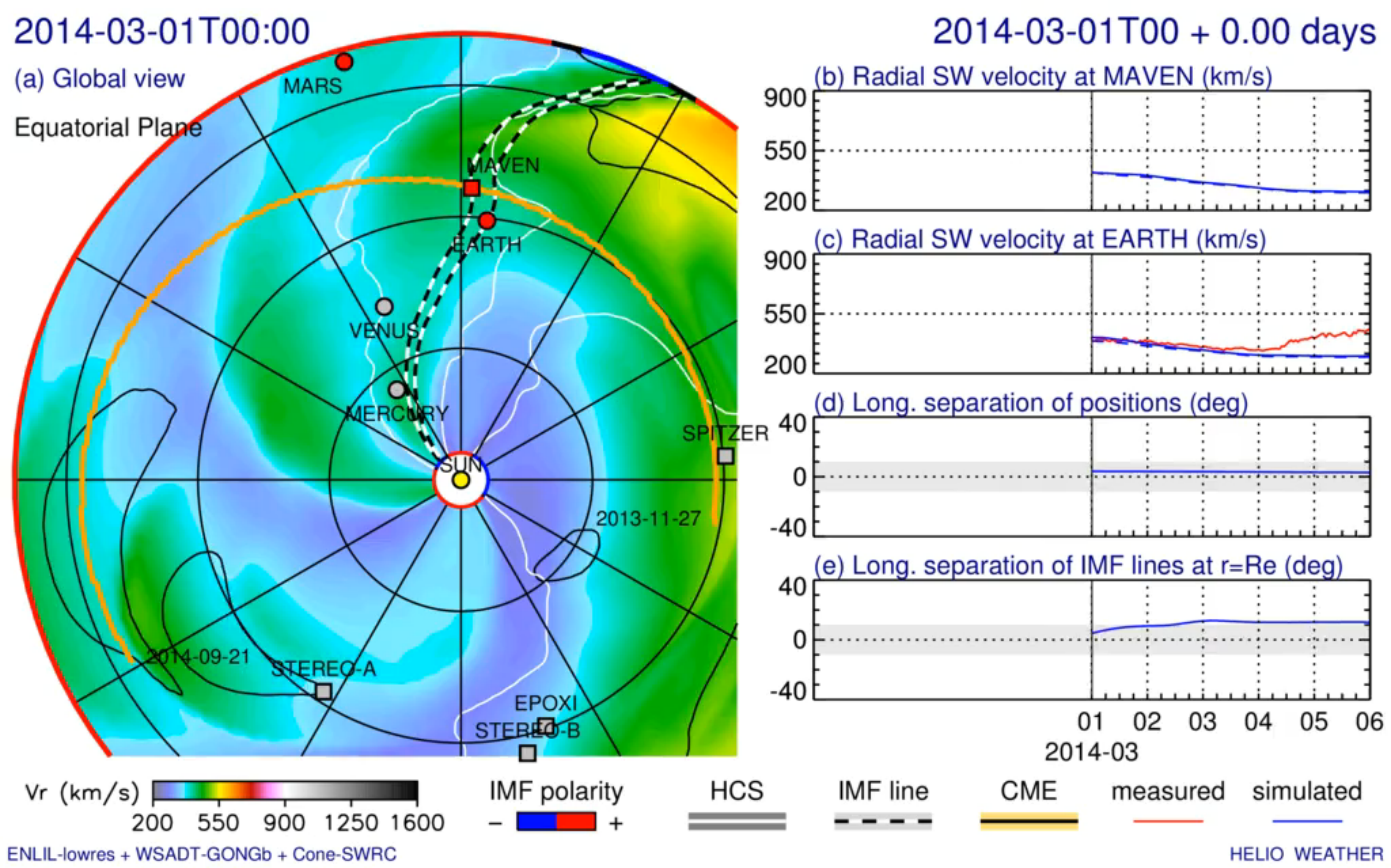




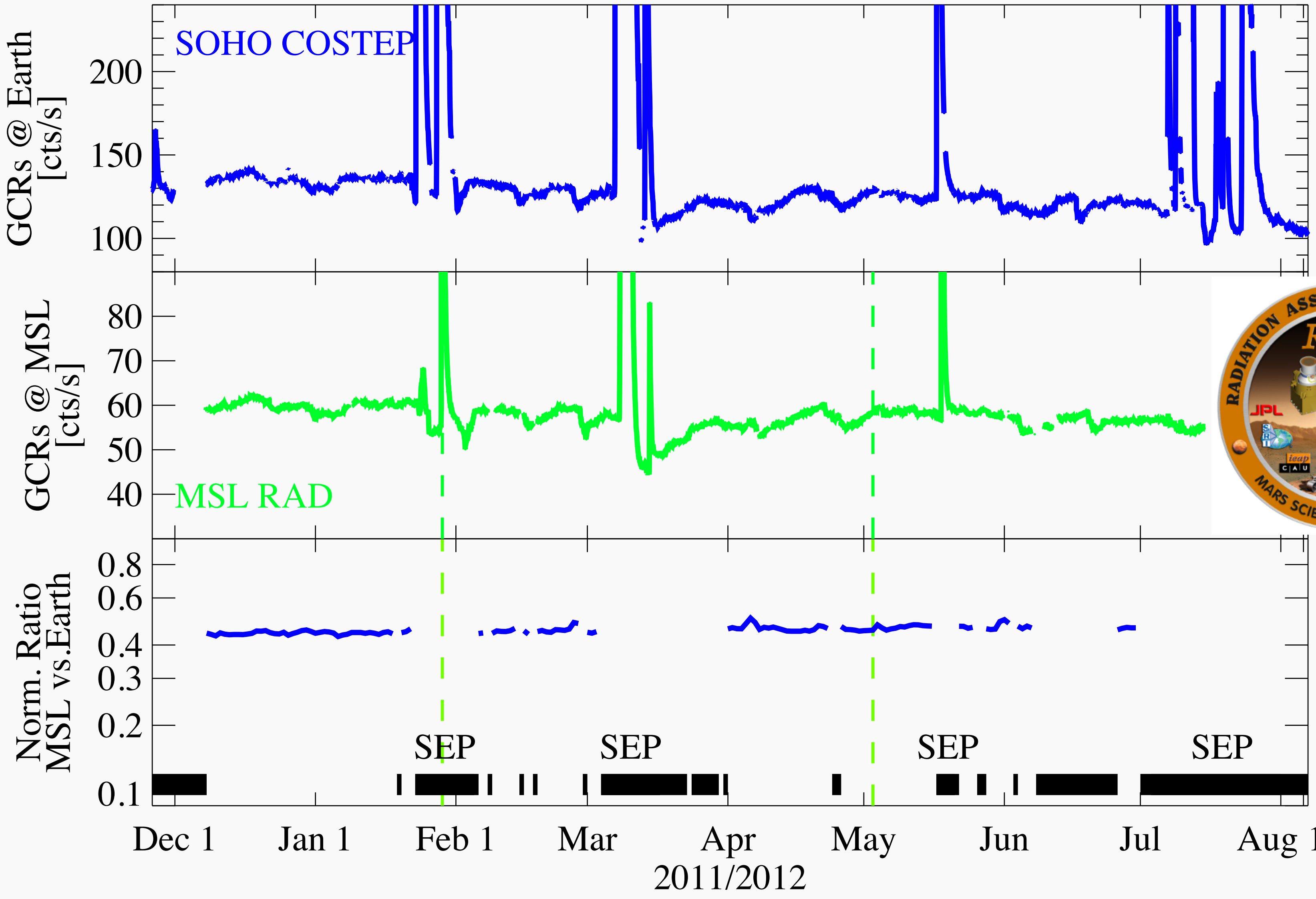
Labrenz, Heber, Kühl, Sarlanis, Malandraki & Posner



# Solar Wind at MAVEN and Earth Under HP-Effect Conditions



# MAVEN Cruise Phase



## Hohmann-Parker Effect Conditions

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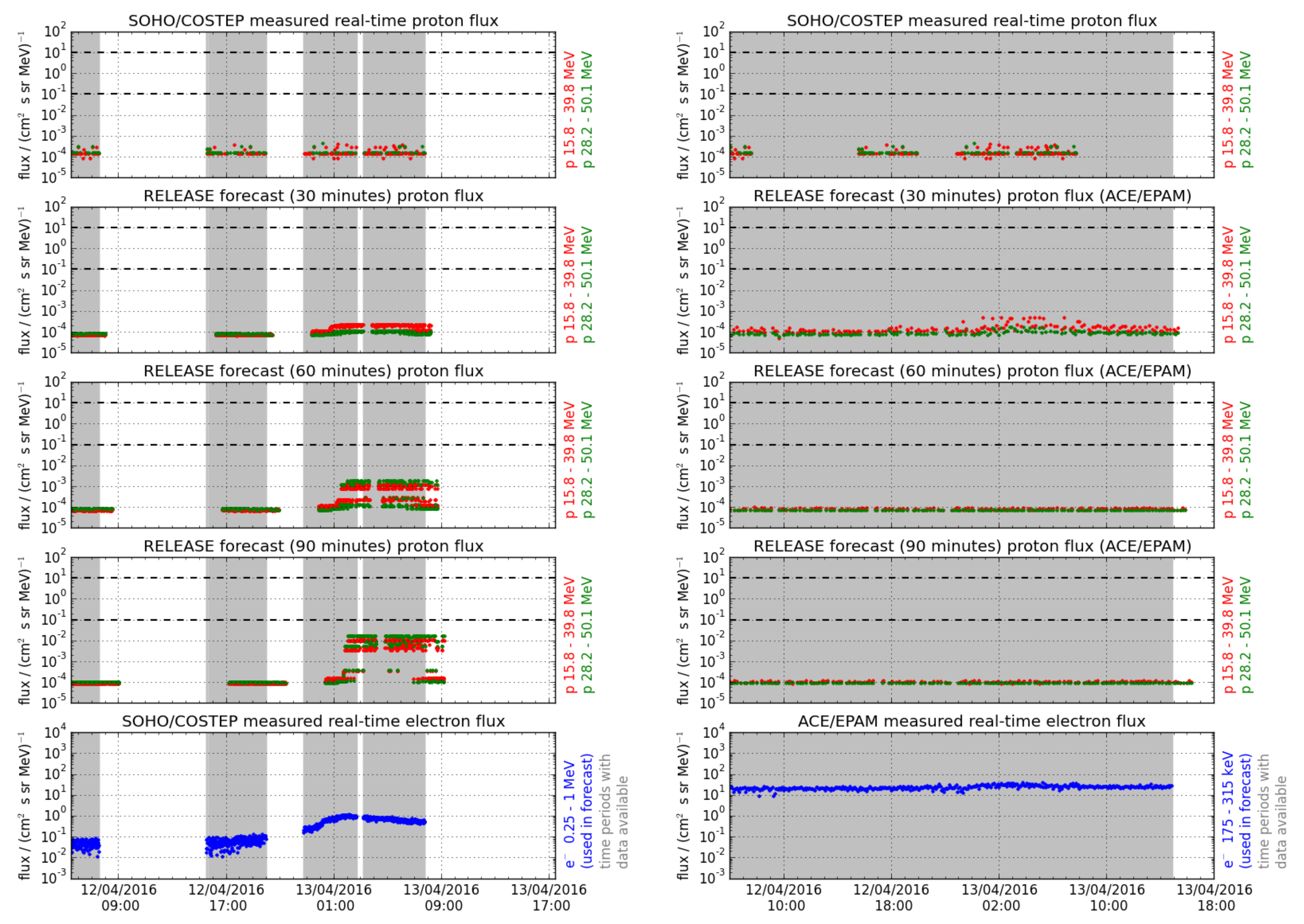

- **EPAM can be used as input for REleASE-Type forecasting**
- **If the ACE/EPAM realtime downlink continues as is, with good time coverage, a much improved capability of Solar Proton Event forecasting could be obtained**

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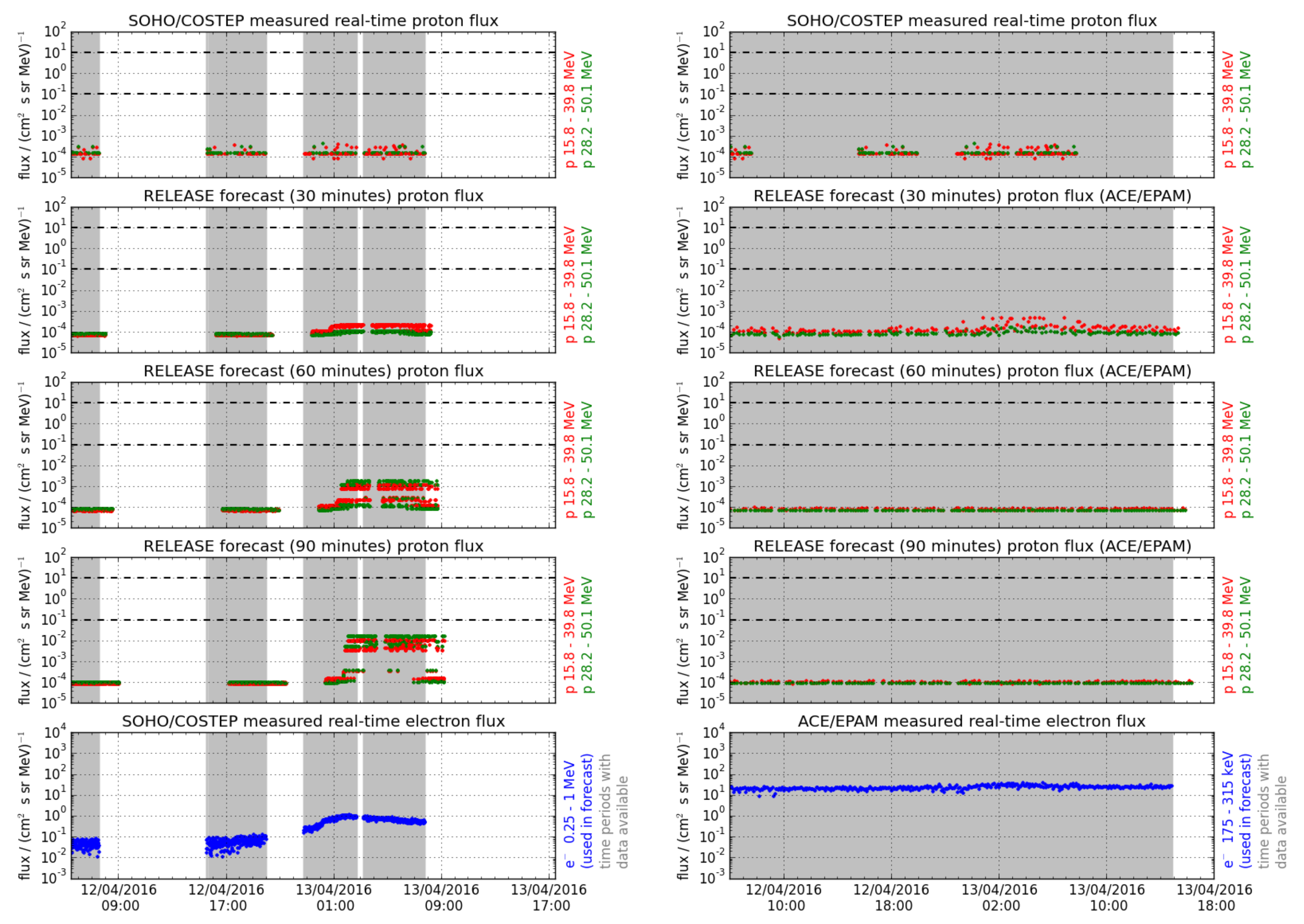

- **Available now at the HESPERIA web site:**

**http://www.hesperia-space.eu/index.php/real-time-prediction-tools/release**

# Future EPAM/REleASE Work:

– Determine: Probability of Detection

– Determine: False Alarm Rate

– Accuracy of Predicted Proton Flux

– Implement Online and Document Criteria for Future Instrumentation

– Test Forecasting Capability for Earth-Mars Transfers with MAVEN SEP Data

**Acknowledgements:**

**The HESPERIA Project Members J. Labrenz, P. Kühl, B. Heber, C. Salarnis and O. Malandraki have Received Funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement #637324**