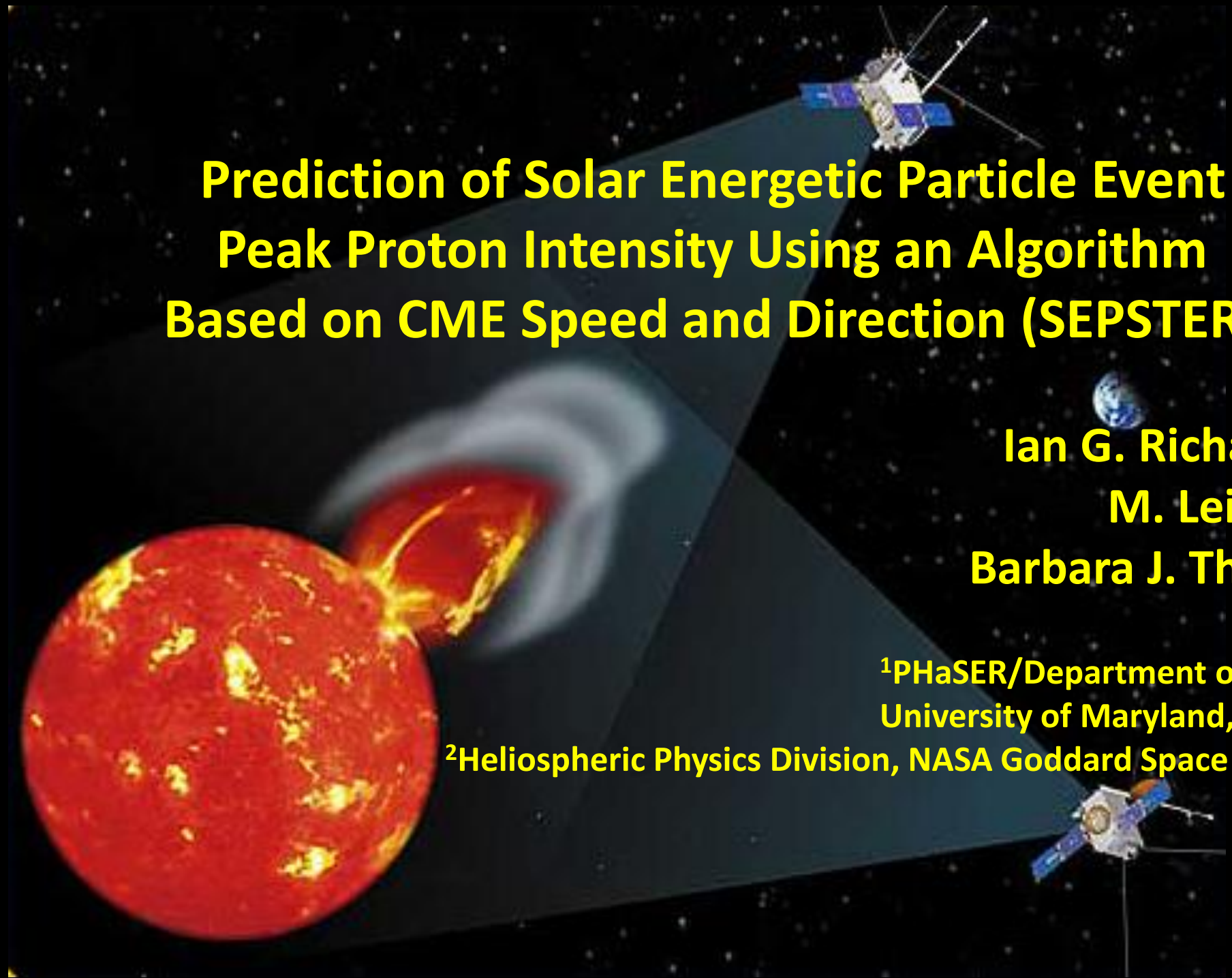

Prediction of Solar Energetic Particle Event Peak Proton Intensity Using an Algorithm Based on CME Speed and Direction (SEPSTER)

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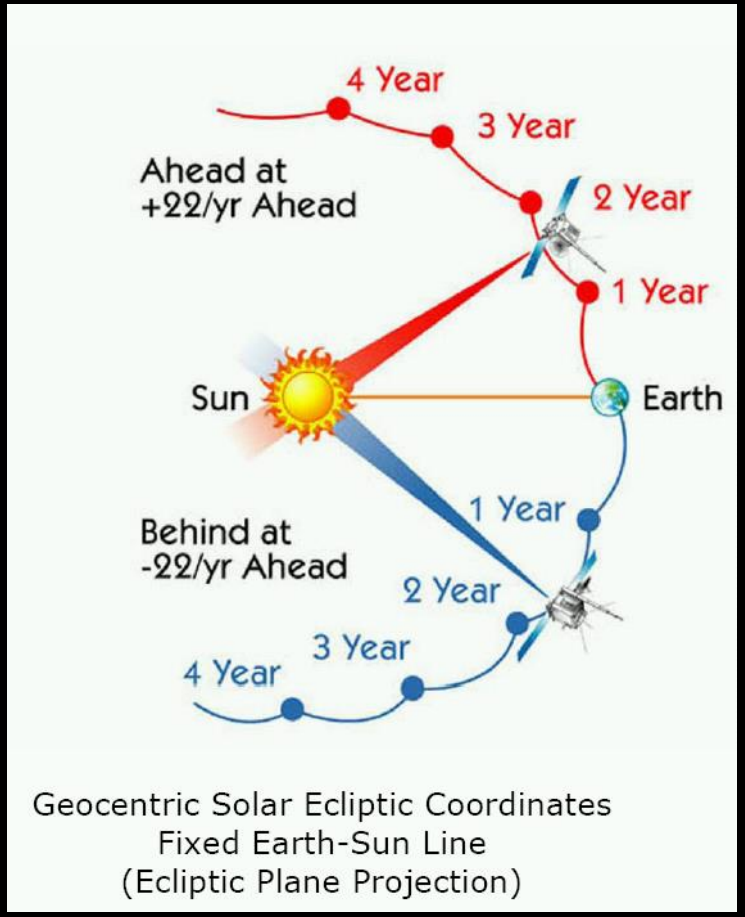
STEREO – Two Spacecraft in Heliocentric Orbits at ~1 AU, Launched October, 2006

SEPSTER - SEP prediction based on STEReo Observations



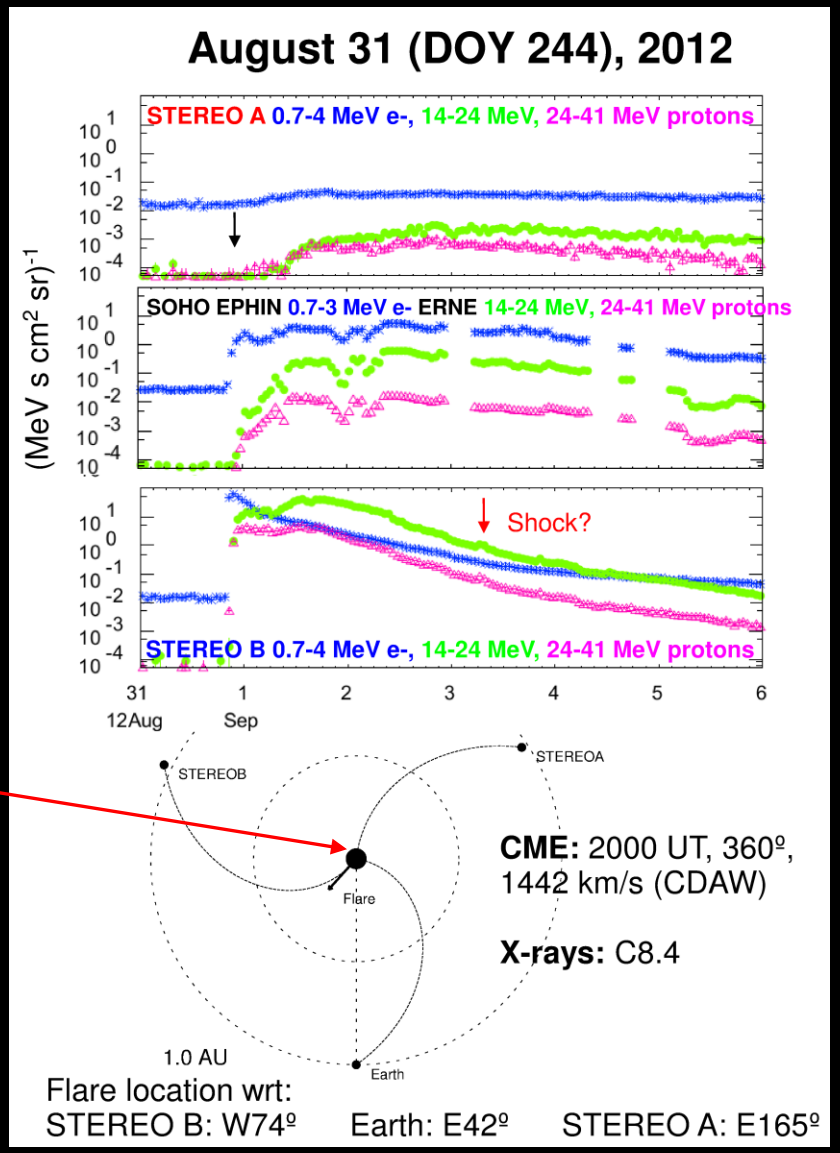
Measure SEPs using particle instruments on STEREO A and B together with similar instruments on near-Earth spacecraft (e.g., SOHO).

Example of a Solar Particle Event Detected at Both STEREO Spacecraft and at Earth ("3-Spacecraft Event")

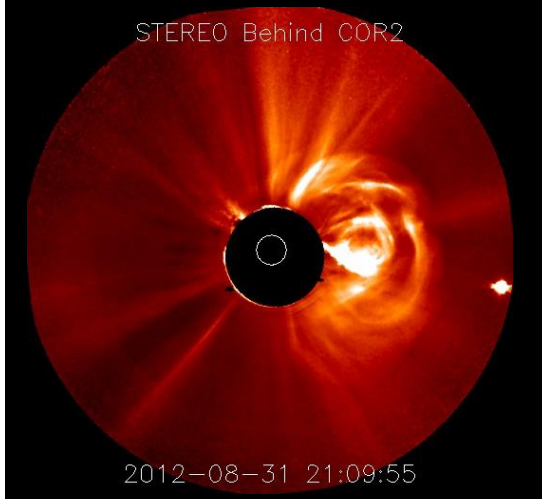
STEREO A

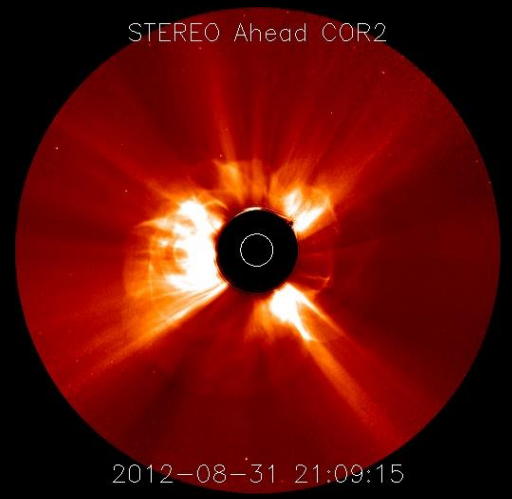
EARTH/SOHO

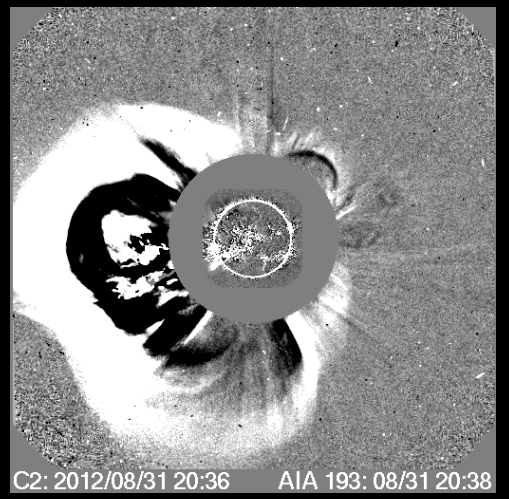
STEREO B



"Connection Angle": Angle between the spiral magnetic field footpoint at the Sun and the solar event

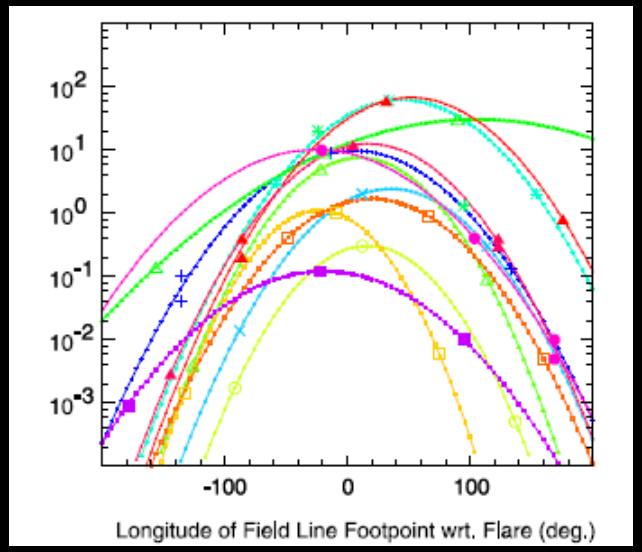






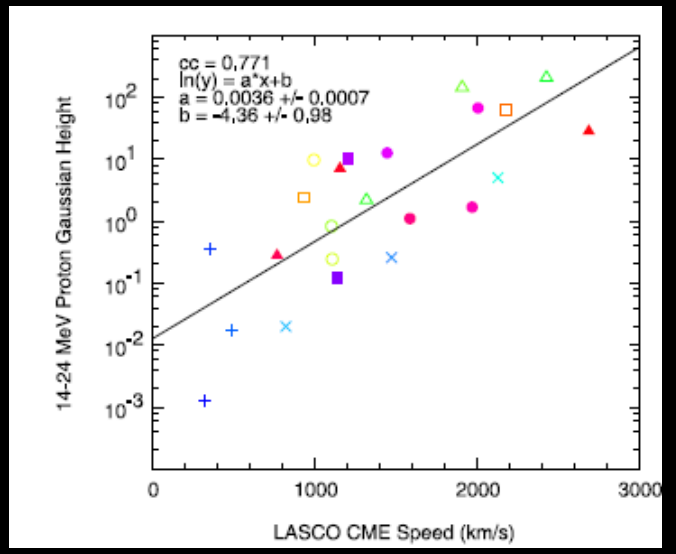
SEP Proton Intensity Formula (*Richardson et al., 2014*)

14-24 MeV Proton Intensity Gaussian fit vs. φ for 25 3 spacecraft (STEREOs + near Earth) events



=>

Gaussian peak intensity vs. LASCO CME speed



=>

$$I(\varphi)\ (\text{MeV s cm}^2\ \text{sr})^{-1} \approx 0.013\ \exp(0.0036V - \varphi^2/2\sigma^2)),\ \sigma = 43°,$$

where:

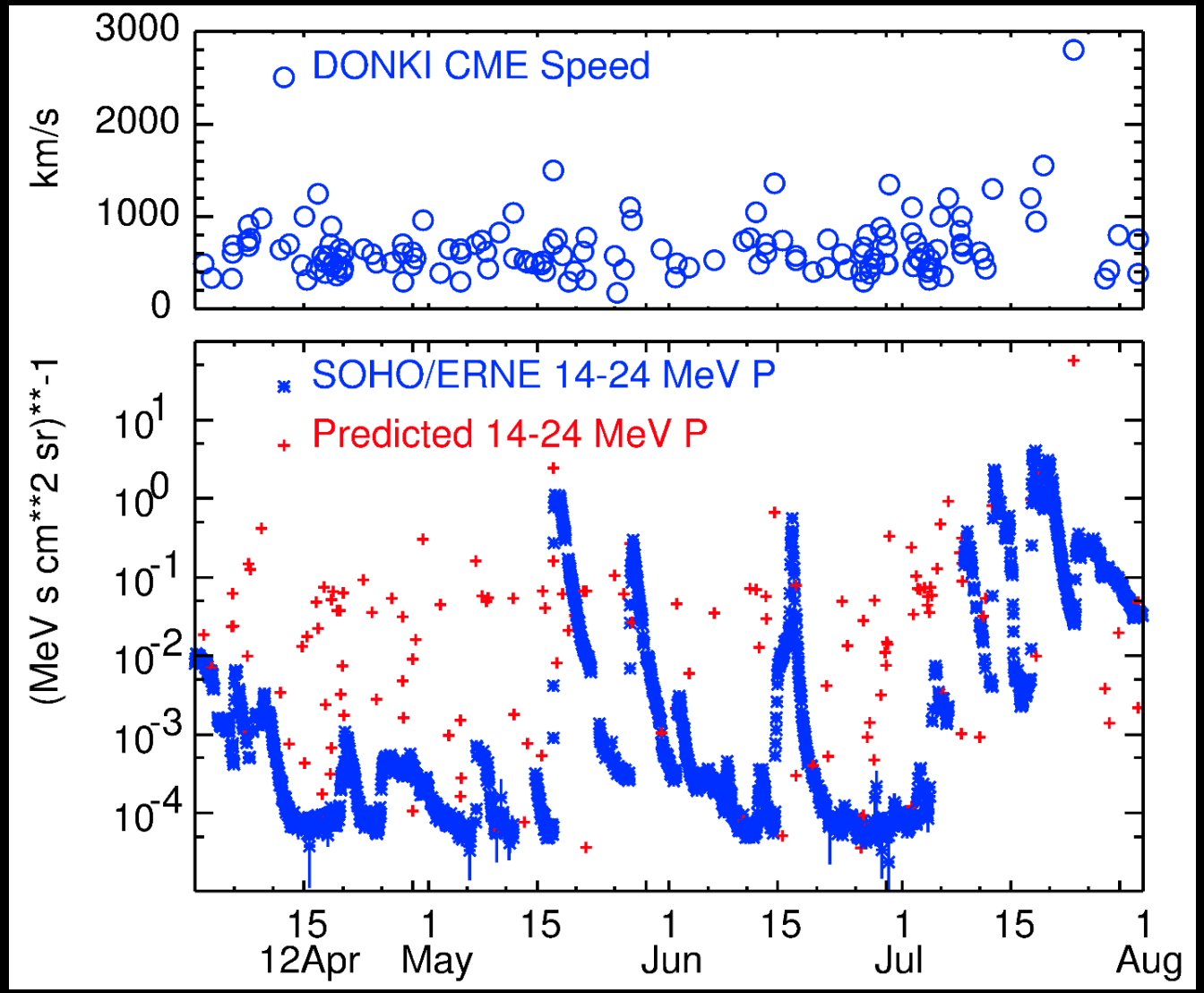
φ is the angle (longitude) between the solar event and the solar footpoint of the spiral magnetic field line passing the observing spacecraft, and

σ is the Gaussian width; 43° is the average value.

Richardson et al. (2018) used the *Richardson et al.* (2014) formula to predict the SEP intensity at Earth and both STEREO spacecraft for all 334 CMEs in the CCMC Space Weather "Database Of Notifications, Knowledge, Information" (DONKI) between October, 2011 and July 2012. (https://kauai.ccmc.gsfc.nasa.gov/DONKI/).

DONKI reports the CME speed, direction (both required for the SEP prediction formula) and width, inferred, where possible, from SOHO and STEREO coronagraph observations by the CCMC observers.

Observed and Predicted SEP intensities at Earth in April-July, 2012

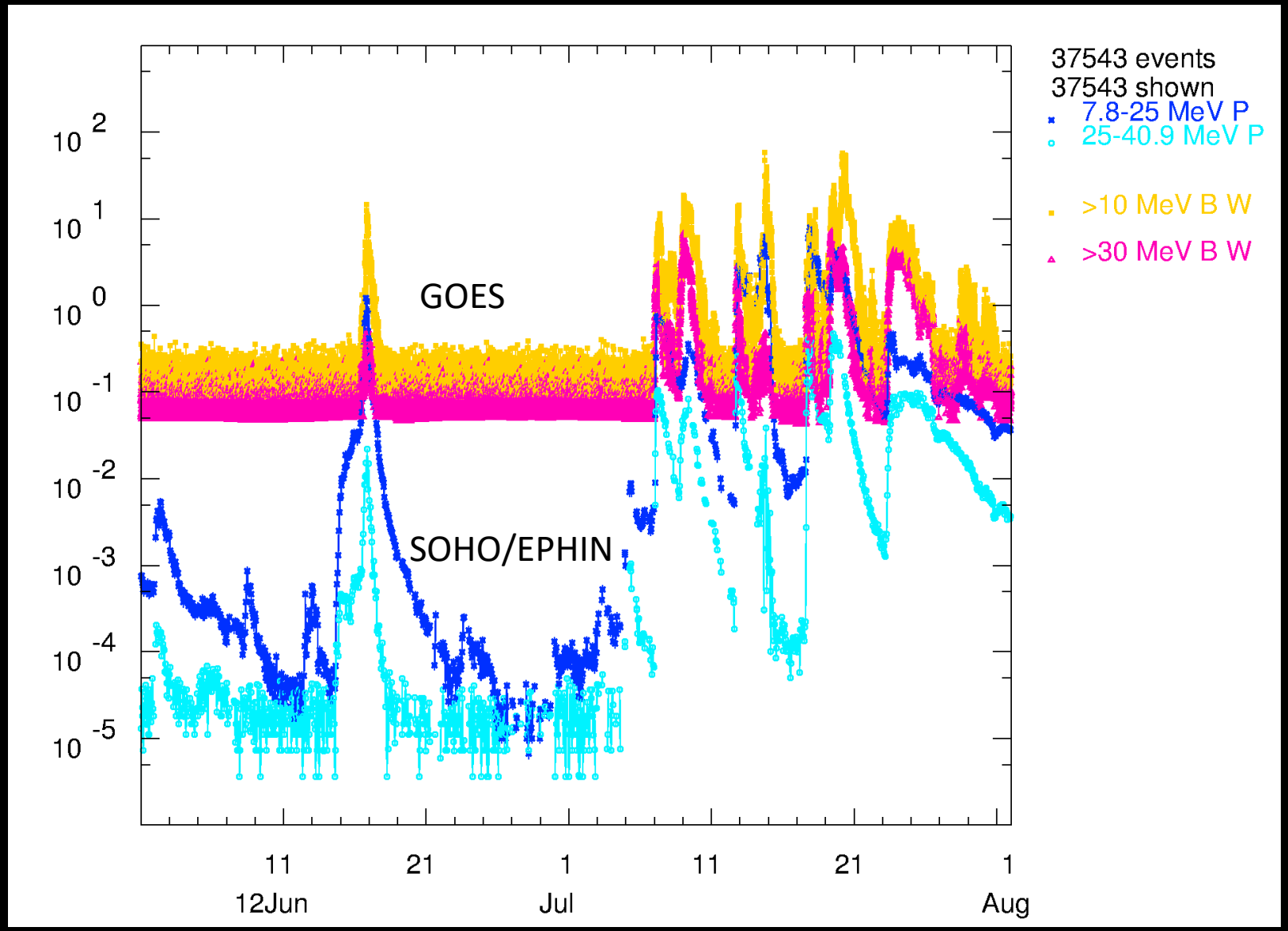


Problem: Most CMEs (~85%) are NOT accompanied by an SEP event.

Hence, there are many cases when a predicted event is not observed.

Richardson et al., 2018

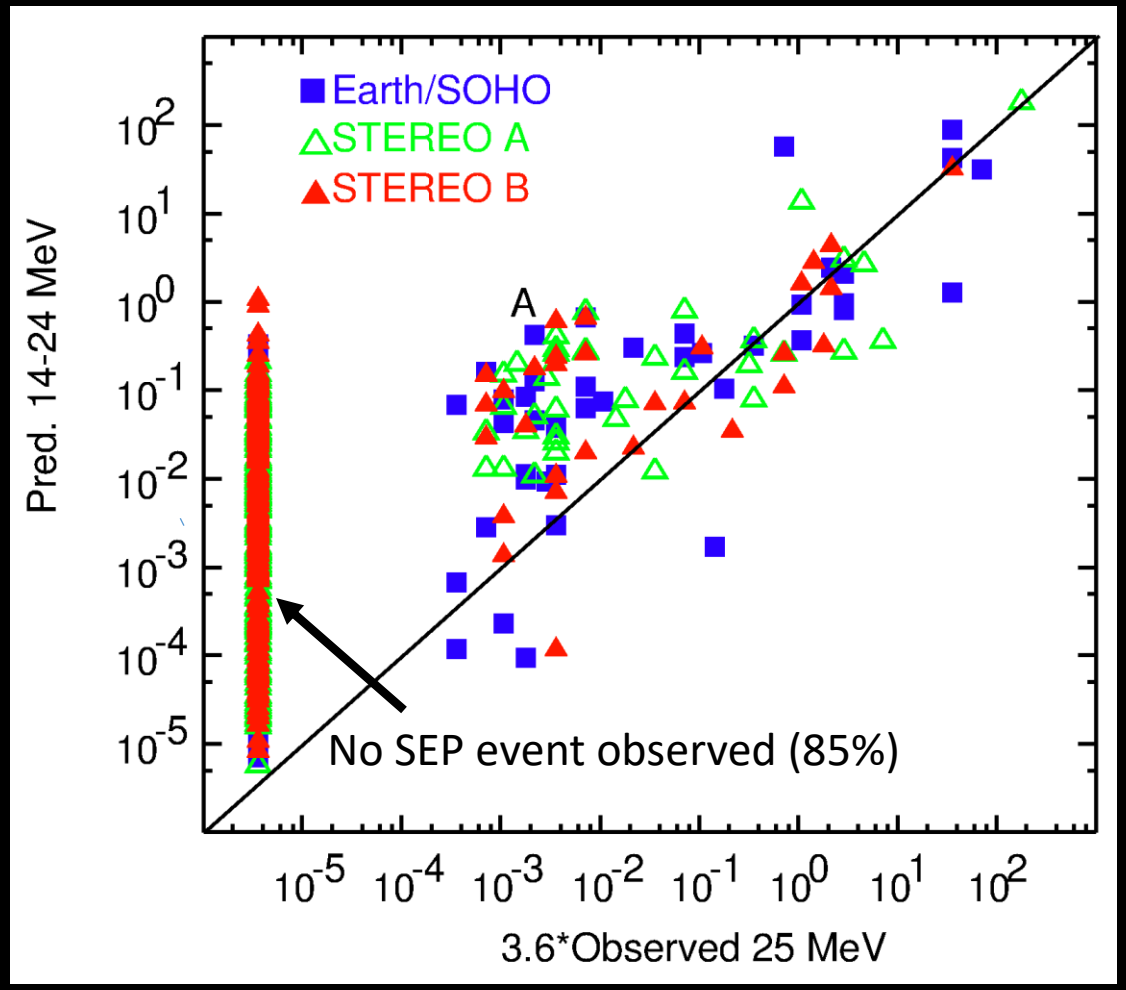
N.B. GOES only sees the “tip of the SEP iceberg”!



Comparison of GOES and SOHO/EPHIN shows the high background in GOES.

Many more features, including small SEP events, are visible in the EPHIN data

Predicted vs. Observed SEP intensity at Earth and the STEREO Spacecraft

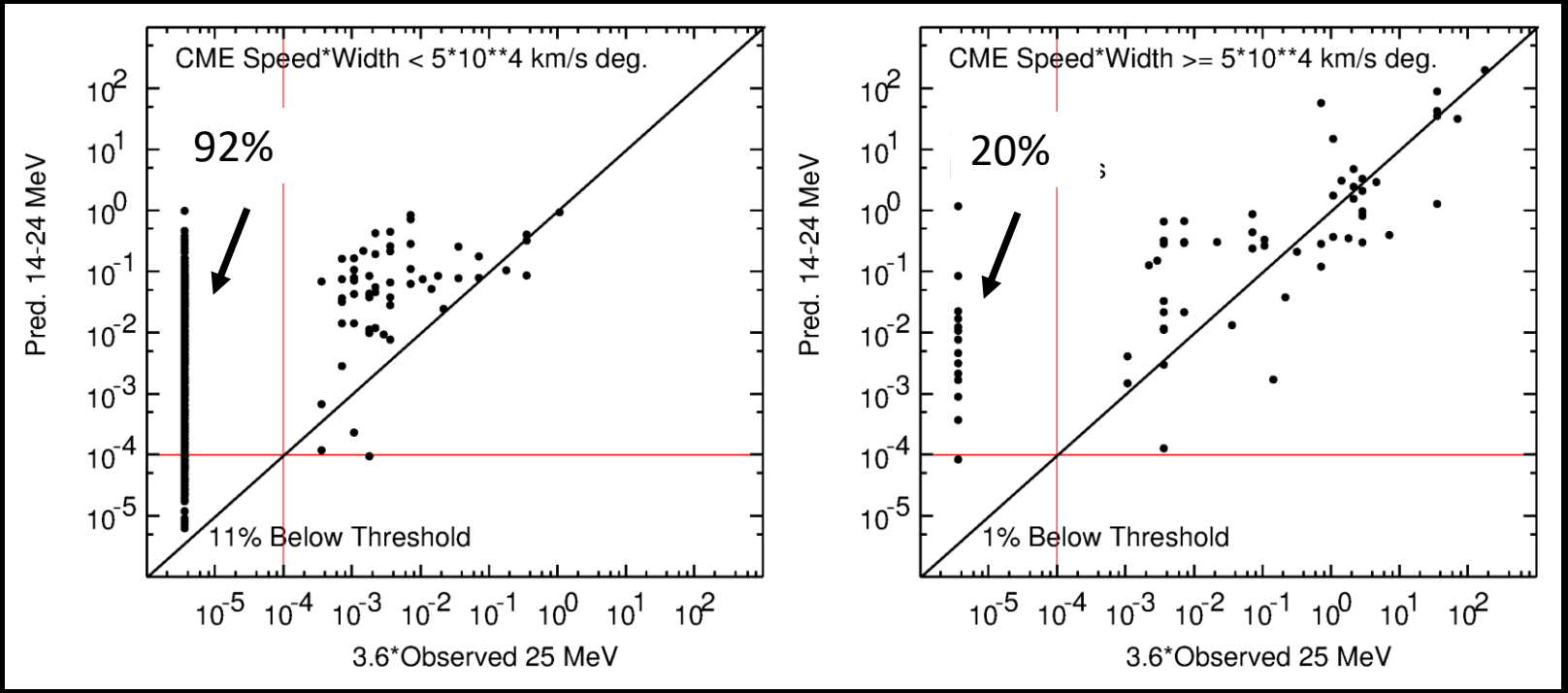


No SEP event was observed for 85% of cases; the predicted intensities are placed at an arbitrary "observed intensity" of 3.6×10^{-6} to include them in the figure.

Otherwise, there is a reasonable correlation between the observed and predicted SEP intensities – the diagonal line is the line of equality.

Richardson et al., 2018

Predicted vs. Observed ~14-25 MeV Proton Intensity Filtered by CME Speed x Width (1000 km/s x 50 deg.)

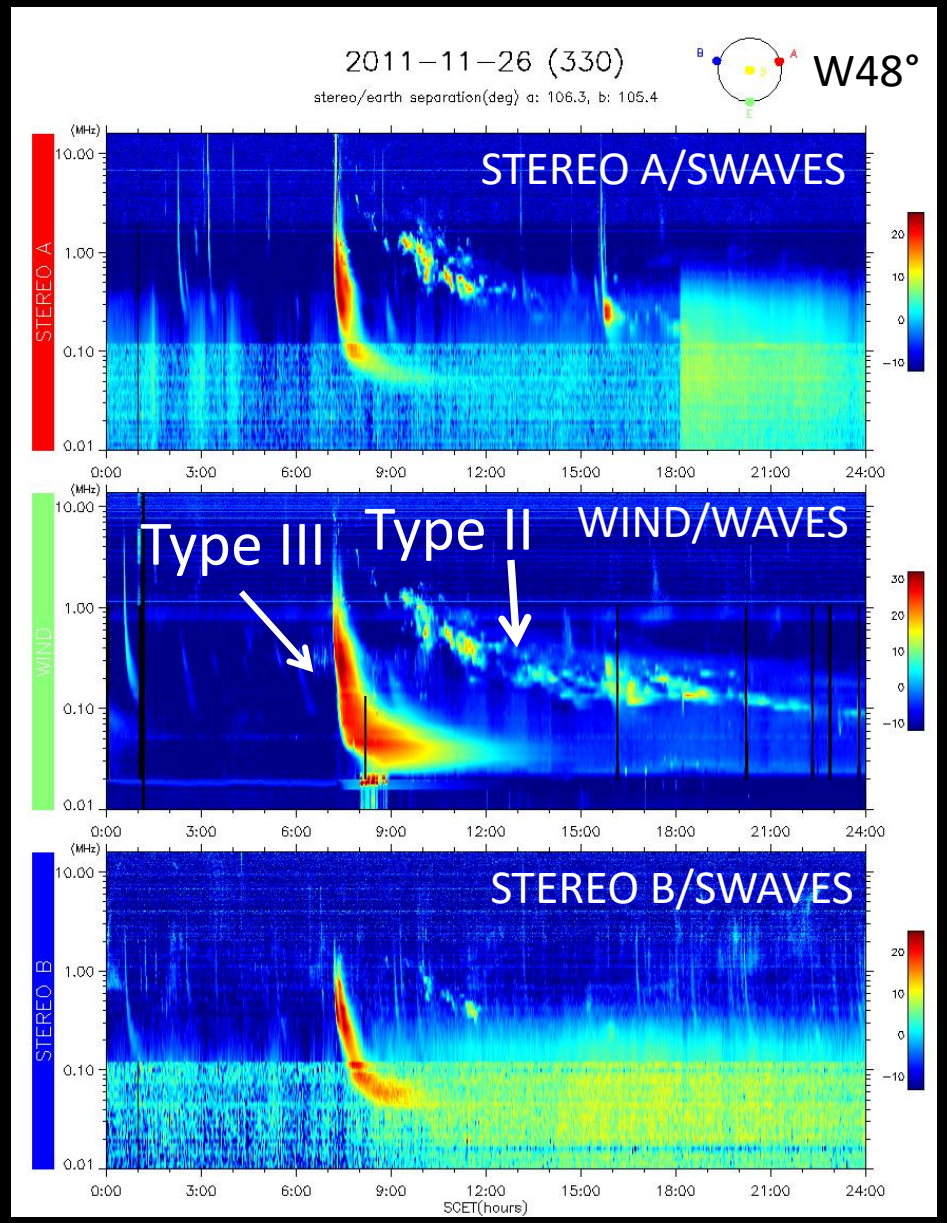


False predictions are:

< 50000 km/s. deg 92%

> 50000 km/s. deg 20%

Richardson et al., 2018

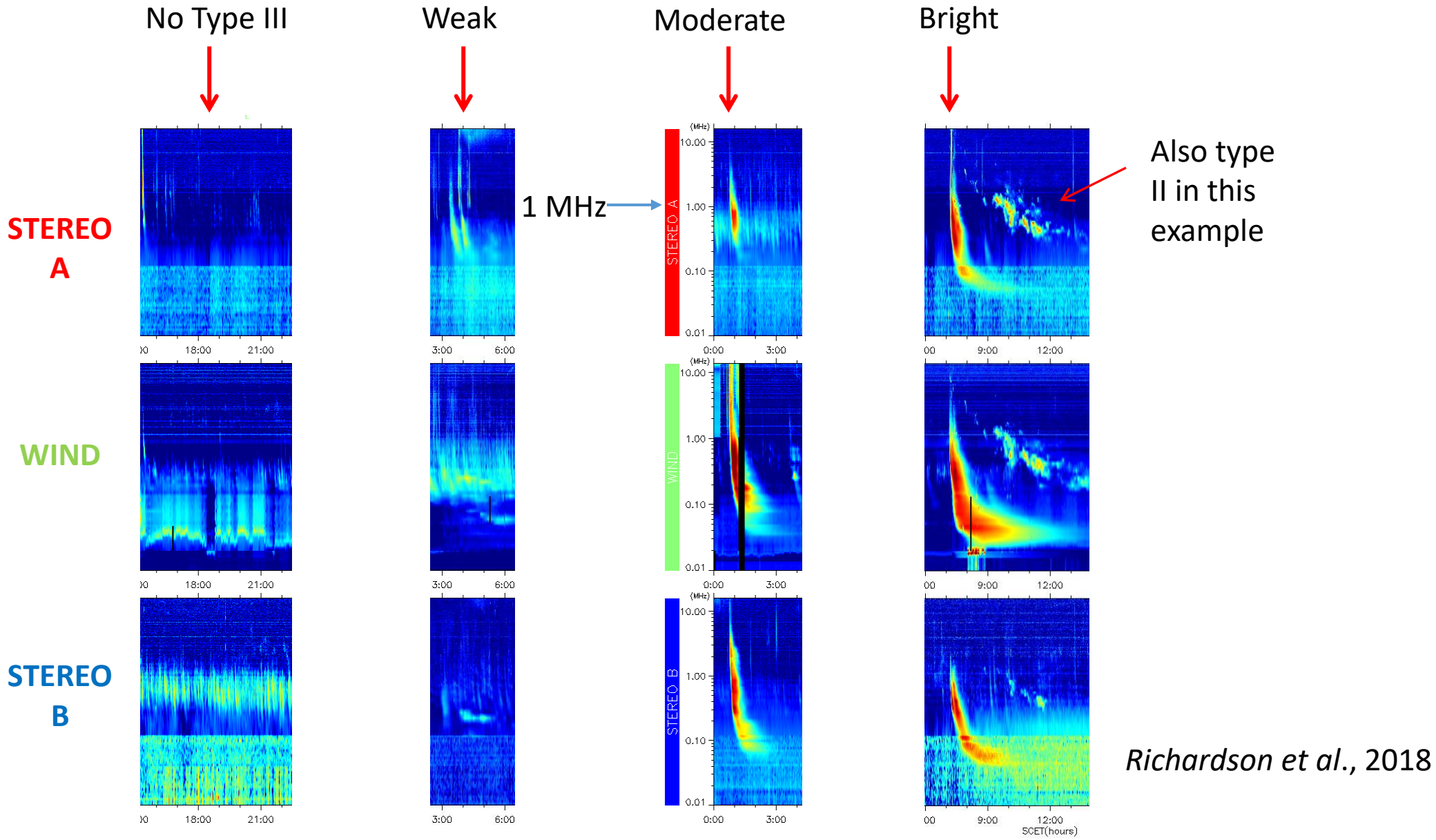


https://swaves.gsfc.nasa.gov/cgi-bin/wimp.py

Can we use radio observations to identify those CMEs that are more likely to have SEP events?

- Examine solar radio emissions observed by the WIND/WAVES and STEREO SWAVES instruments.
- **Type II (slow drift):** Evidence for particle acceleration at CME-driven shocks;
- **Type III (fast drift):** Evidence for release of fast electrons.
- Three S/C provide a global view of the radio emissions.

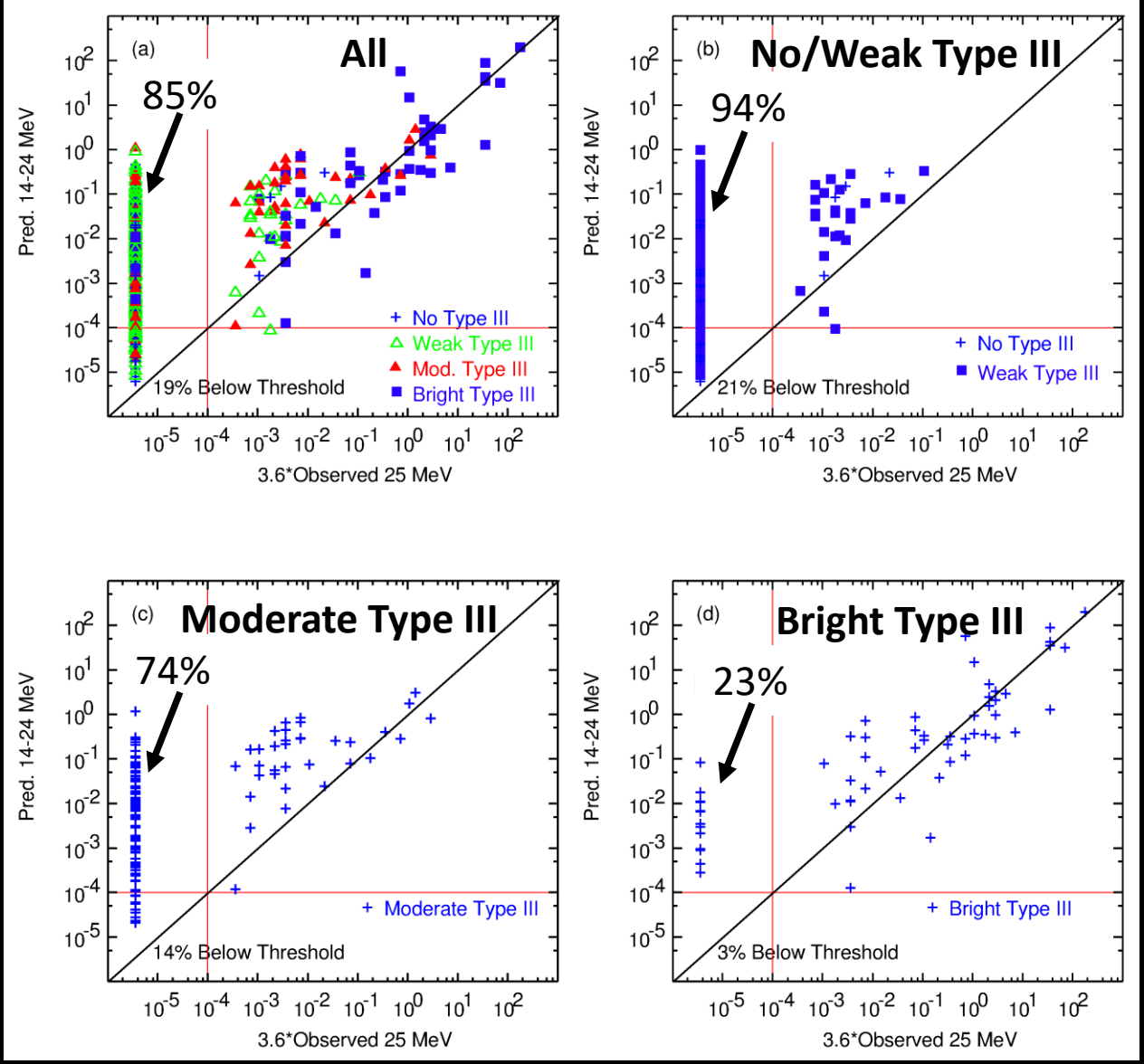
Examples of Type III Classes (STEREO SWAVES/WIND WAVES)



Richardson et al., 2018

https://swaves.gsfc.nasa.gov/cgi-bin/wimp.py

Predicted vs. Observed ~14-25 MeV Proton Intensity Filtered by Type III



False predictions are

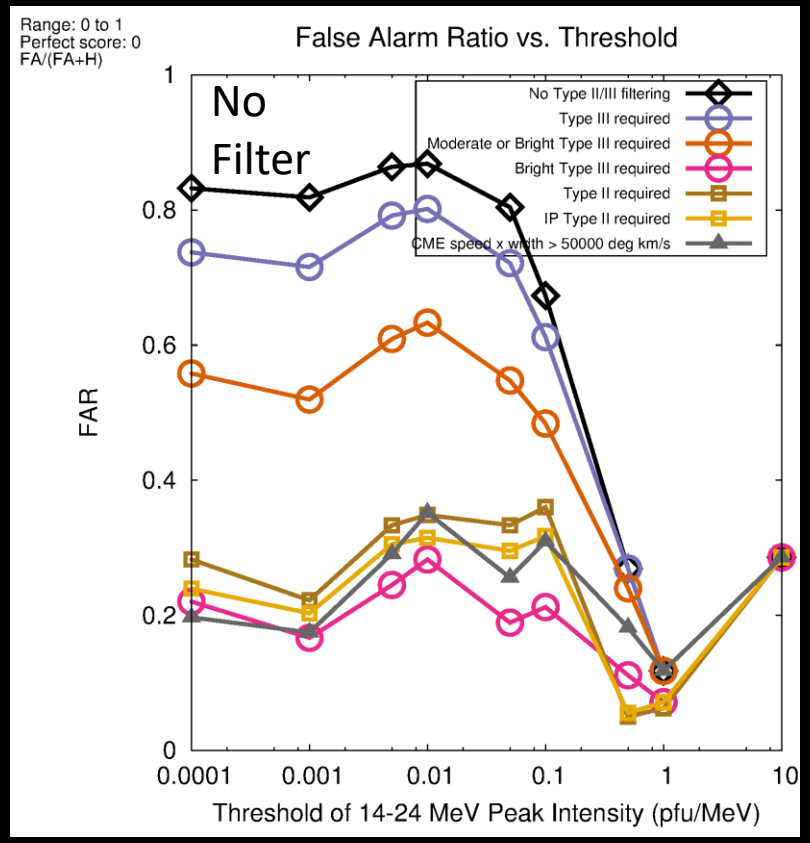
94% for no or weak type III emission

74% for moderate type III emissions

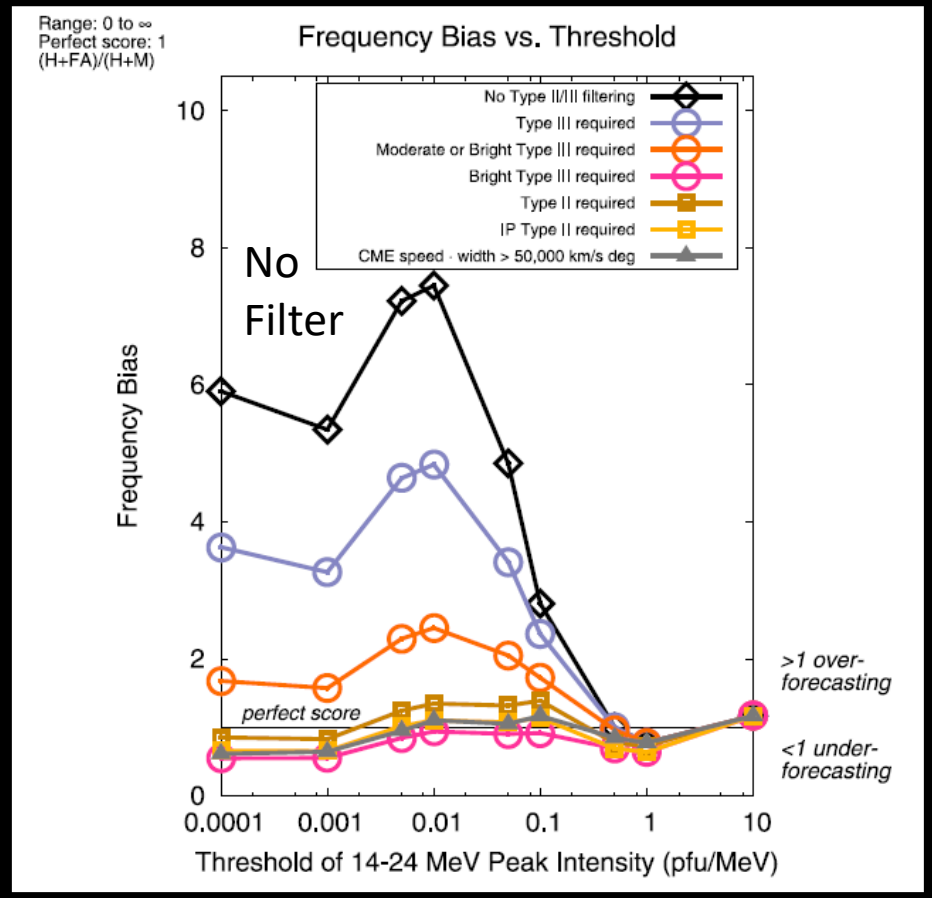
23% if bright, extended type III emissions accompany a CME (d).

Richardson et al., 2018

Examples of Skill Scores

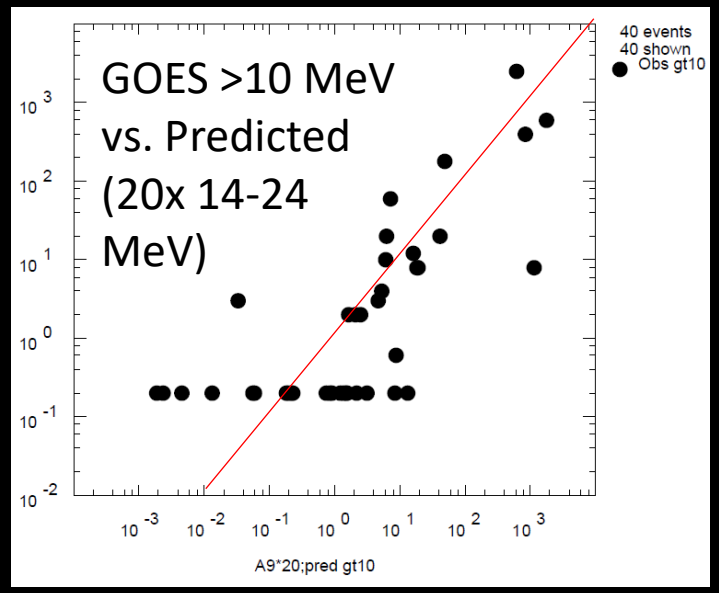


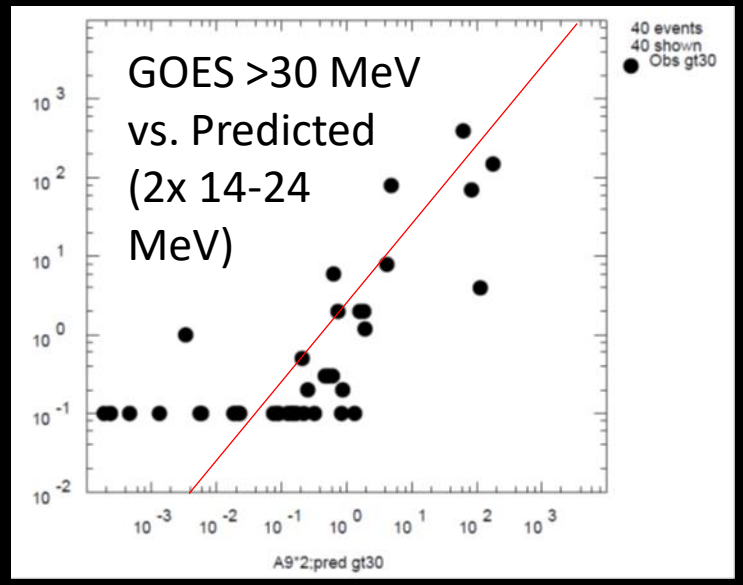
<= The false alarm ratio False Alarms/(False Alarms + Hits) vs. threshold intensity. This represents the fraction of predicted SEP events that were false alarms, and 0 is a perfect score.

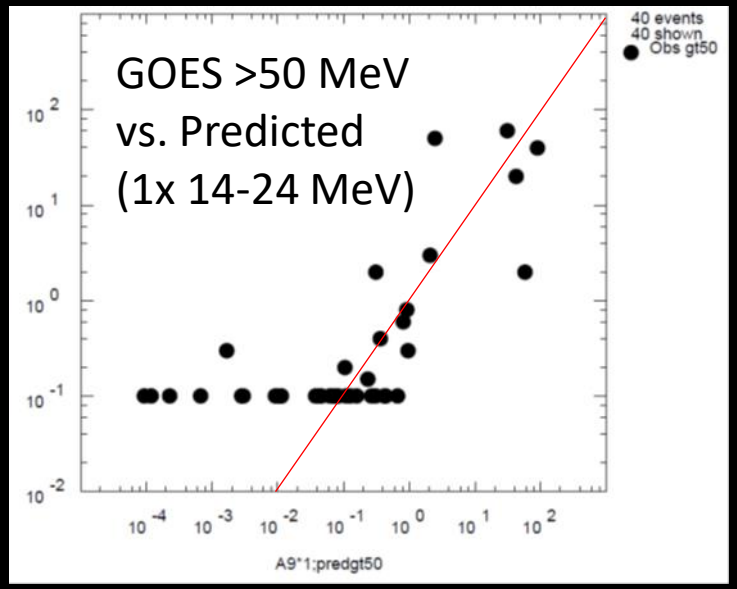


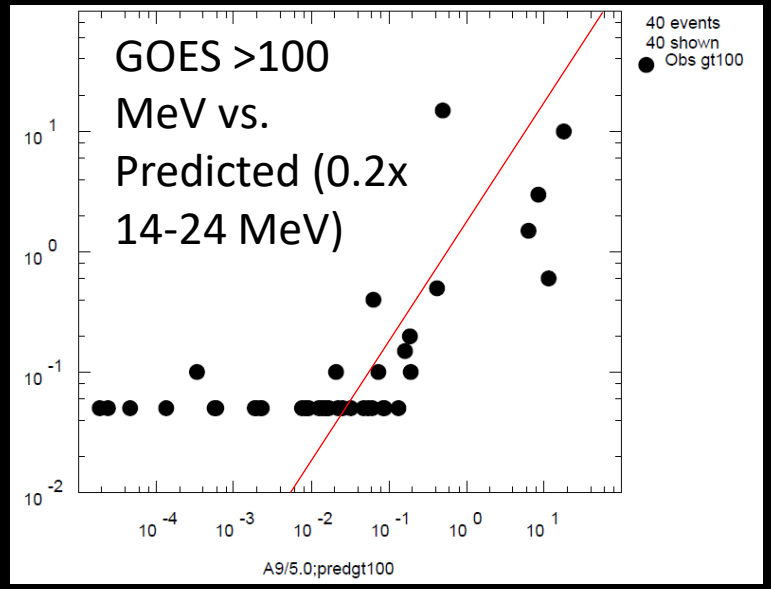
Frequency bias (Hits+False Alarms)/(Hits+Misses) => The ratio of predicted SEP events to observed SEP events. Perfect score is 1 (no false alarms and no misses)

Richardson et al., 2018









SEPSTER Predictions for various peak GOES proton integral fluxes for 40 events based on ratios of the predicted 14-24 MeV proton intensity.

- Running “in real time” at CCMC.
- Checks the CCMC DONKI CME catalog every minute.
- Predicts the 14-24 MeV proton intensity and hence GOES fluxes.
- “All clear” if speed x width < 50000 and >10 MeV proton flux < 10 pfu.

SEP Scoreboard

-1 week | -1 day | -1 hour | 2017-09-11 18:12 | +1 hour | +1 day | +1 week
Today | Refresh Plots

Proton Intensity Forecasts:

2017-09-18:12 UT

	> 10 MeV	> 100 MeV
GOES	864.0	13.2
SEPMOD	24620.0	561.0
SEPSTER	No Data	No Data
SEPSTER2D	2066.0	22.24
STAT	No Data	No Data
UMASEP	2321.1 ± 533.9	Not Clear

pfu: 10 | 10 | 10 | 10 | 10 | 10 | 10 | no
pfu: 300 | 200 | 100 | 50 | 10 | 1 | 10^{-1} | 10^{-2} | 10^{-3} | not clear | clear | no data

Proton All Clear Forecasts:

2017-09-11 18:12 UT

GOES	Not Clear	Not Clear	N/A
SEPMOD	Not Clear	Not Clear	N/A
SEPSTER	No Data	No Data	N/A

selected date/time: 2017-09-11 18:12 UT

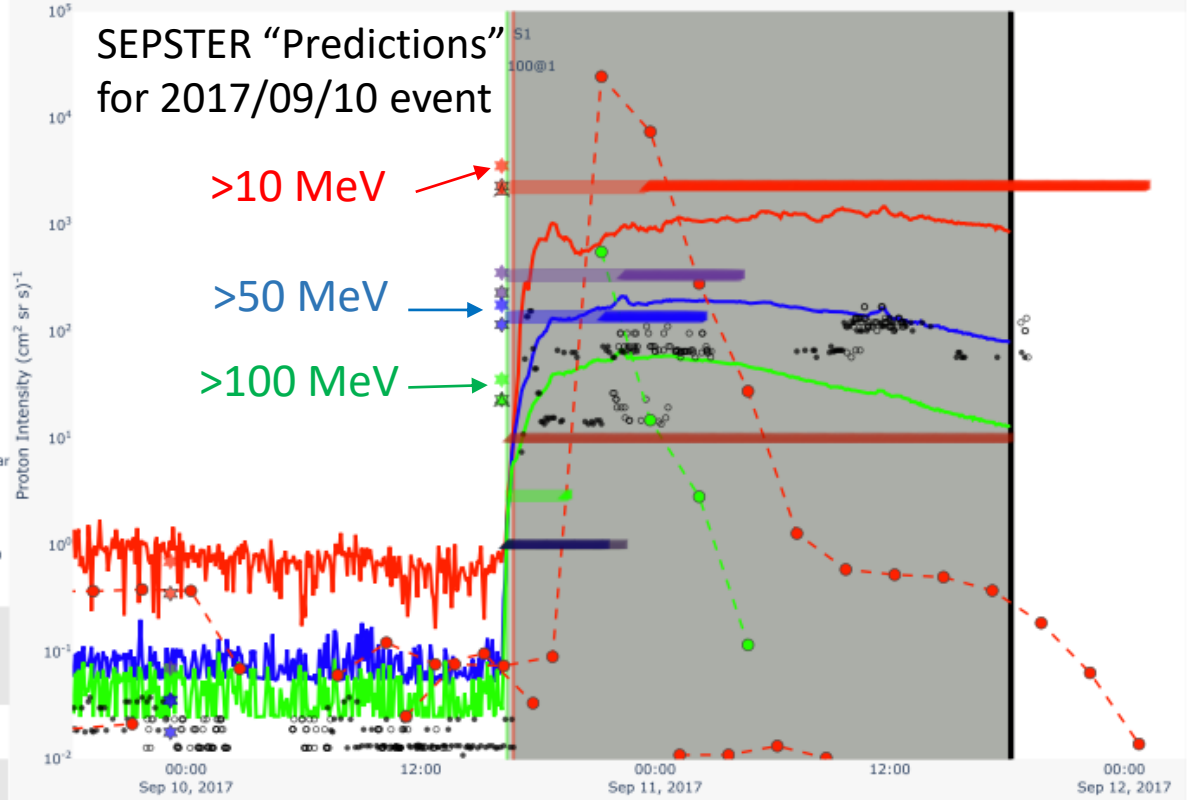
SWPC Alerts

SEPSTER "Predictions" for 2017/09/10 event

>10 MeV

>50 MeV

>100 MeV



GOES: > 10 MeV | GOES: > 30 MeV | GOES: > 50 MeV | GOES: > 100 MeV | HESPERIA REleASE ACE 60-min: 15.8 - 39.8 MeV | HESPERIA REleASE ACE 60-min: 28.2 - 50.1 MeV
HESPERIA REleASE SOHO 60-min: 28.2 - 50.1 MeV | SEPMOD-SWPC params: > 10.0 MeV | SEPMOD-SWPC params: > 100.0 MeV | SEPMOD (latest): > 10.0 MeV | SEPMOD (older): > 10.0 MeV
SEPSTER (Parker Spiral): > 10.0 MeV | SEPSTER (Parker Spiral): 14.0 - 24.0 MeV | SEPSTER (Parker Spiral): > 30.0 MeV | SEPSTER (Parker Spiral): > 50.0 MeV | SEPSTER (Parker Spiral): > 100.0 MeV

Summary

SEPSTER is a simple (one equation!) empirical model to predict SEP event peak intensity from coronagraph CME observations.

Running in “real time” at M2M using DONKI CME observations. Unfortunately, there are delays in receiving and interpretating observations for DONKI before a prediction may be made.

Many false predictions for small-medium sized events but may be reduced by various filtering methods that may be added to SEPSTER in the future.

More details are in *Richardson et al*. (2018), Space Weather, 16, 1862–1881. https://doi.org/10.1029/2018SW002032