The PRObabilistic Solar Particle Event foRecasting (PROSPER) Model

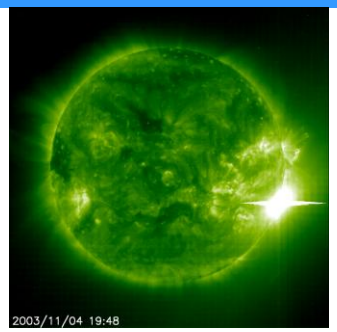
A. Papaioannou[1], R. Vainio[2], O. Raukunnen[2], A. Anastasiadis[1], A. Aran[3], M. Paassilta[2], S.A. Mallios[1], P. Jiggens[4]

[1]IAASARS, National Observatory of Athens, Penteli, Greece
[2]Department of Physics and Astronomy, University of Turku, 20014 Turku, Finland
[3]Dep. Física Quàntica i Astrofísica, Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona, Barcelona, Spain
[4]ESA Space Environments & Effects section (TEC-EES), ESA-ESTEC, Keplerlaan 1, 2201 AZ Noordwijk, Netherlands

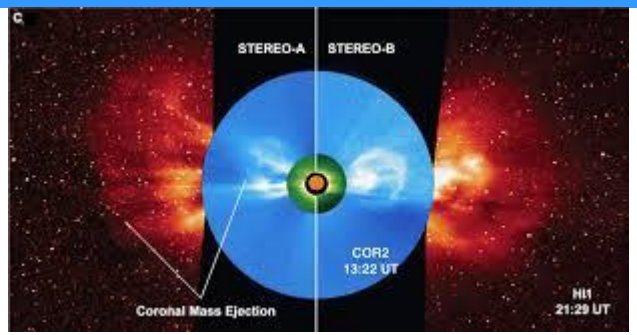
IAASARS · UNIVERSITY OF TURKU · UNIVERSITAT DE BARCELONA · esa

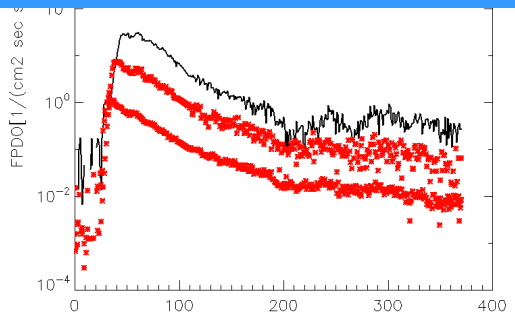
Background

Motivation

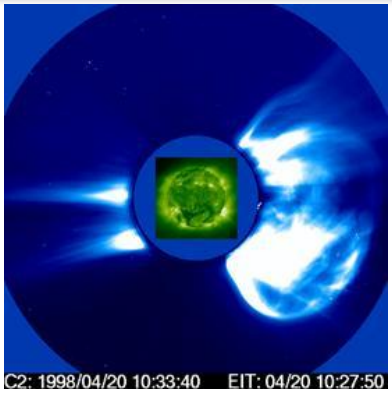


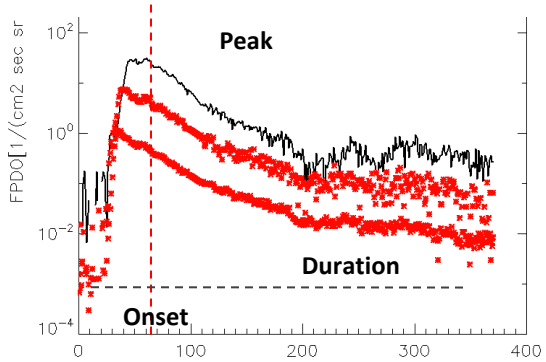
+





> Given **specific solar parameters** (**flare mag, cl, CME width, velocity**) identify the probability that an **SEP event** will **occur**



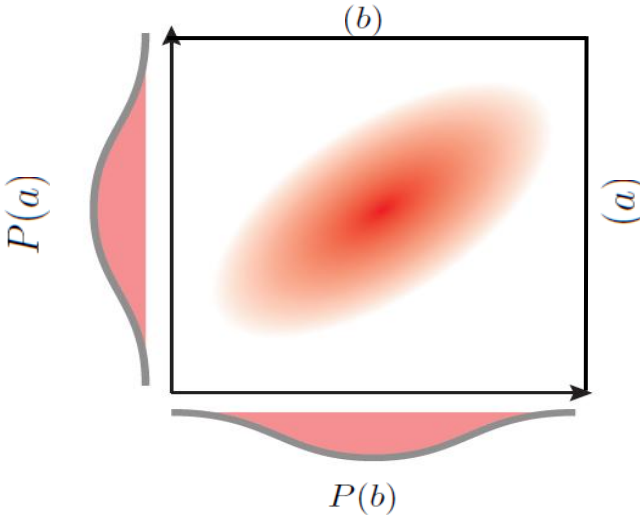


> Given **a subset of flares and CMEs** that **do produce SEP events**, how do the characteristics of the SEP event relate to those of the parent solar event?

Background

Bayes' theorem

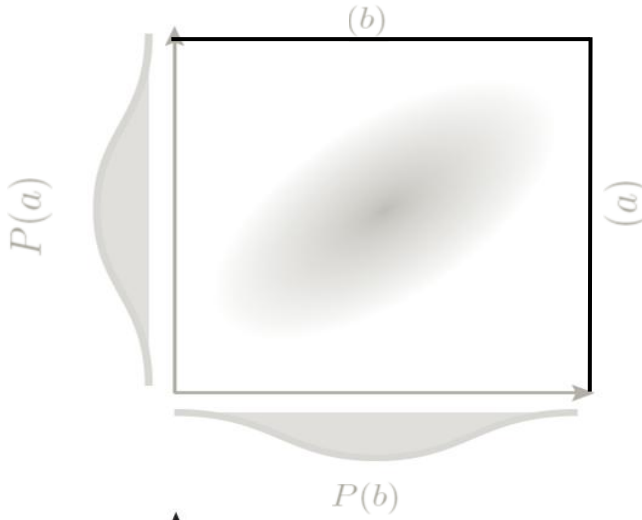
- $P(b)$ & $P(a)$ are the **probabilities** of observing **α** and **b** *independent of each other*



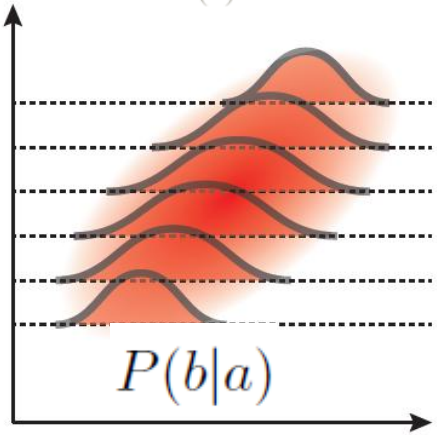
Background

Bayes' theorem

- $P(b)$ & $P(a)$ are the **probabilities** of observing **α** and **b** *independent of each other*



- $P(a|b)$ & $P(b|a)$ are the **conditional probabilities** which represent **the likelihood of event (e.g. b)** occurring given that **(e.g. α) is true**



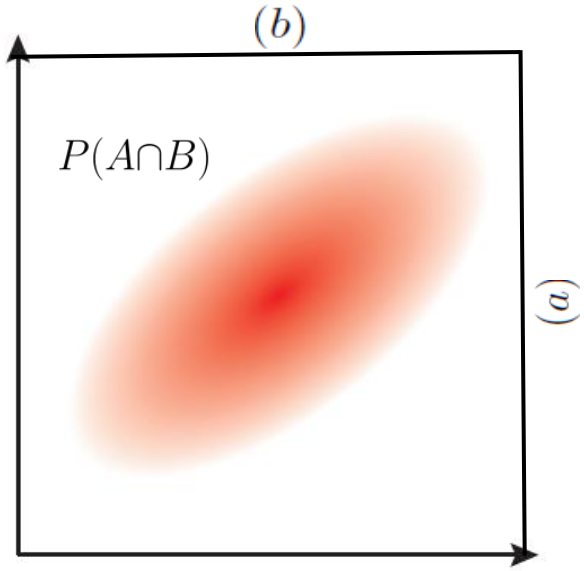
Background

Bayes' theorem

> $P(A \cap B)$ is the **joint probability** of observing **α** and **b** *together*

$$P(a|b)P(b) = P(A \cap B) = P(b|a)\ P(a)$$

$$P(b|a) = \frac{P(a|b)P(b)}{P(a)}$$



> **Bayes' theorem** allows one to calculate the **conditional probability** when the **joint probability** is *challenging to calculate*.

The PROSPER model

Application of the Bayes' theorem

$$P(b|a) = \frac{P(a|b)P(b)}{P(a)}$$

$$P(SEP|event) = \frac{P(event|SEP)}{P(event)}P(SEP)$$

i. **Coronal Mass Ejections (CMEs)** $P(\mathrm{SEP} \mid V_{\mathrm{CME}} = V)$

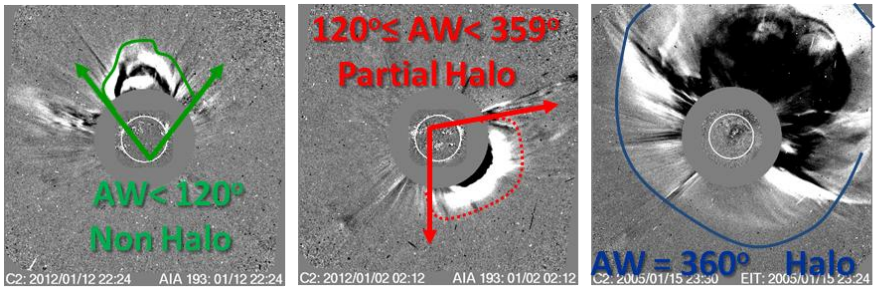
ii. **Solar Flares (SFs)** $P(SEP|Flare_{flux} = F)$

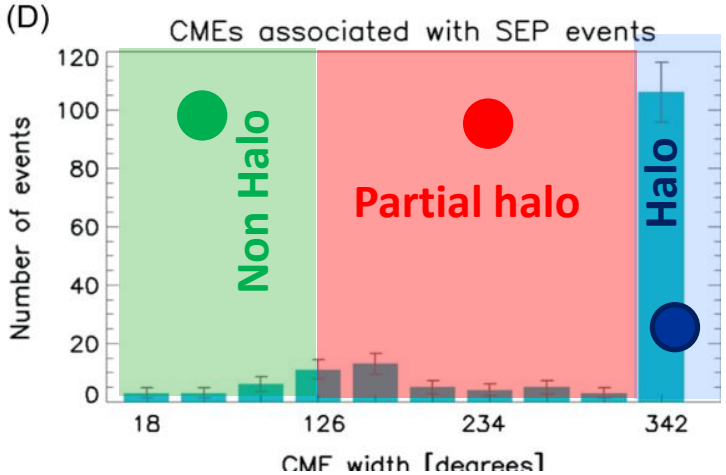
iii. **Solar Flares (SFs) & Coronal Mass Ejections (CMEs)** $P(SEP|V_{CME} = V, Flare_{flux} = F)$

The PROSPER model

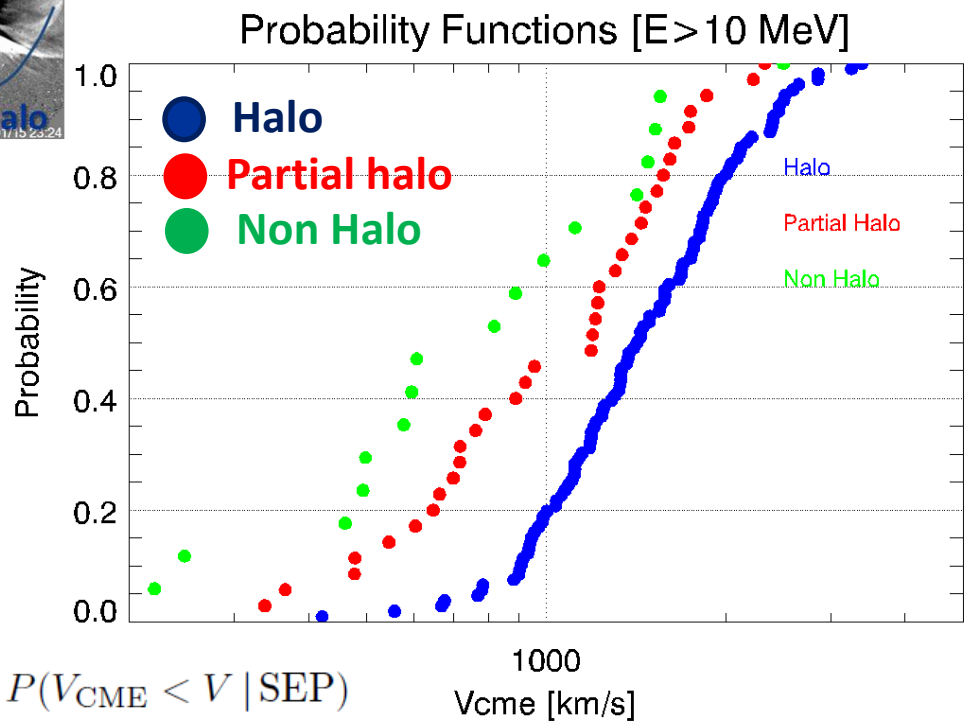
i. Coronal Mass Ejections (CMEs)

Papaioannou et al., JSWSC, 8, A37, 2018





> **Probabilistic approach**



$$P(V_{\mathrm{CME}} < V \,|\, \mathrm{SEP})$$

The PROSPER model

i. Coronal Mass Ejections (CMEs)

> **Bayes theorem**

$$P(\mathrm{SEP}\,|\,V_{\mathrm{CME}}=V)=\frac{P'(V_{\mathrm{CME}}<V\,|\,\mathrm{SEP})}{P'(V_{\mathrm{CME}}<V)}P(\mathrm{SEP})$$

$$P(\mathrm{SEP}\,|\,V_{\mathrm{CME}}=V)=P(b|a)=\frac{P(a|b)P(b)}{P(a)}=\frac{P'(V_{\mathrm{CME}}<V\,|\,\mathrm{SEP})}{P'(V_{\mathrm{CME}}<V)}P(\mathrm{SEP})$$

$P(V_{\mathrm{CME}}<V)$,

$P(V_{\mathrm{CME}}<V\,|\,\mathrm{SEP})$

$P(\mathrm{SEP})$

> From the **distributions of the available data**.

> A **factor** from the **database**

Papaioannou et al., JSWSC, 2019a – in preparation

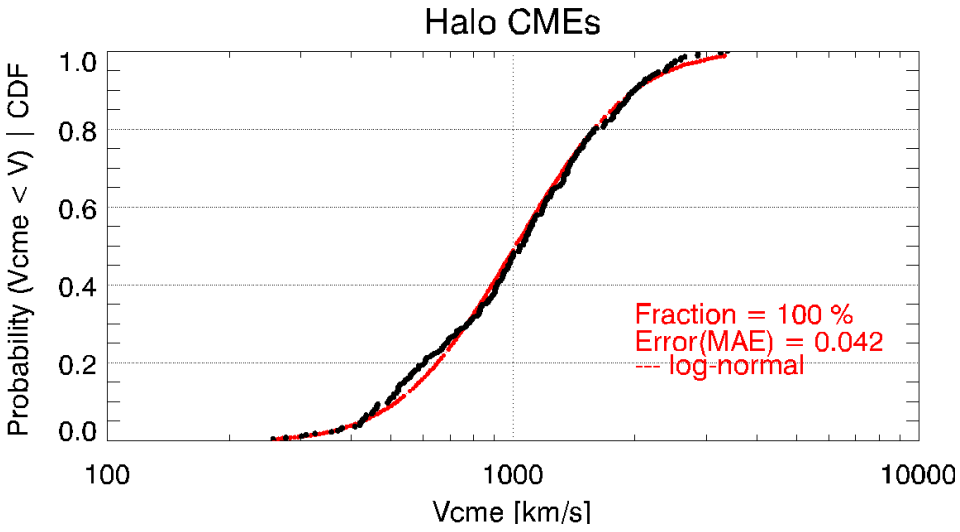
The PROSPER model

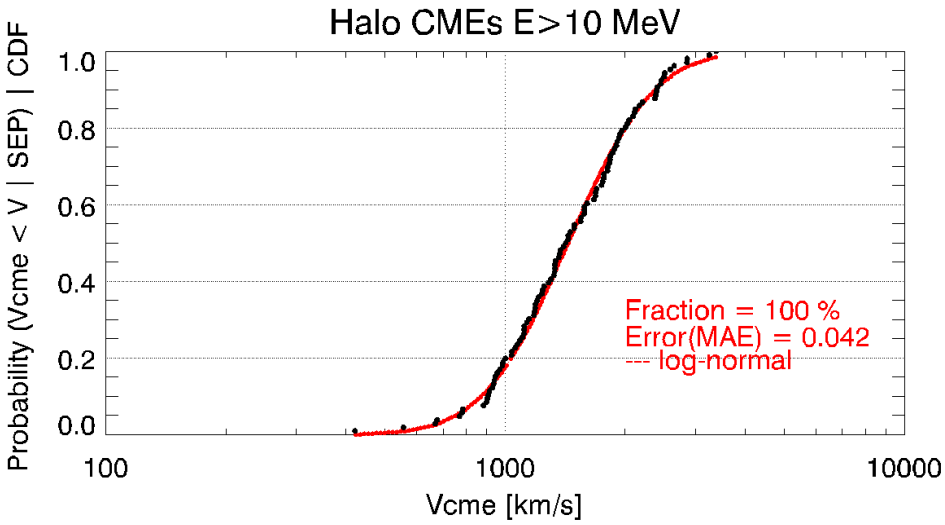
i. Coronal Mass Ejections (CMEs)

> **Fit(s) | Halo CMEs**

$$P(V_{\mathrm{CME}} < V),$$

$$P(V_{\mathrm{CME}} < V \,|\, \mathrm{SEP})$$



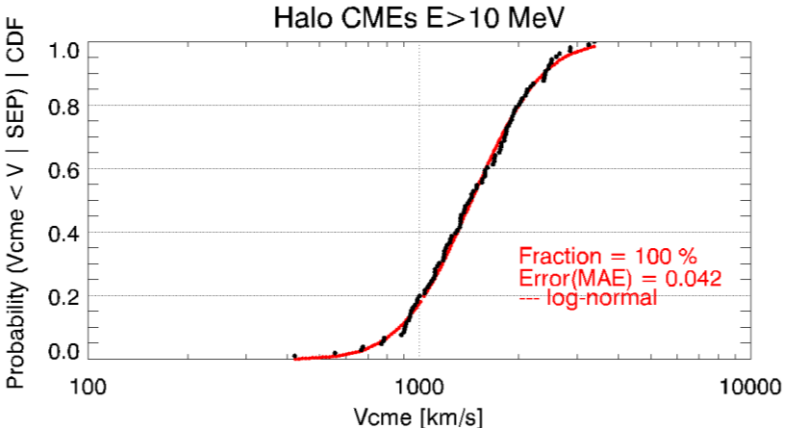


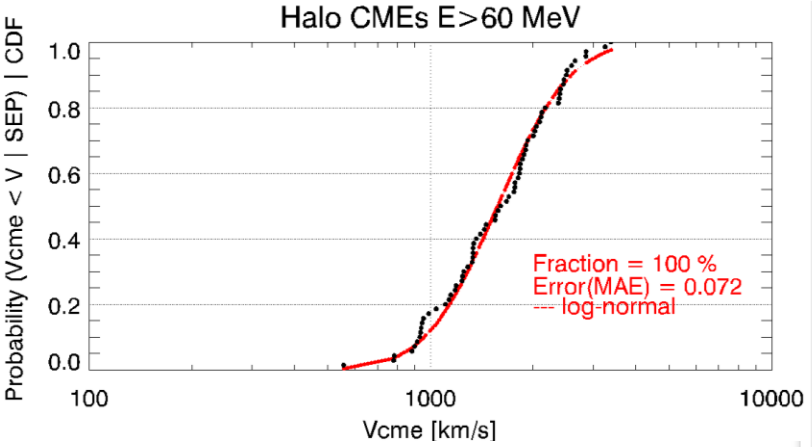
Papaioannou et al., JSWSC, 2019a – in preparation

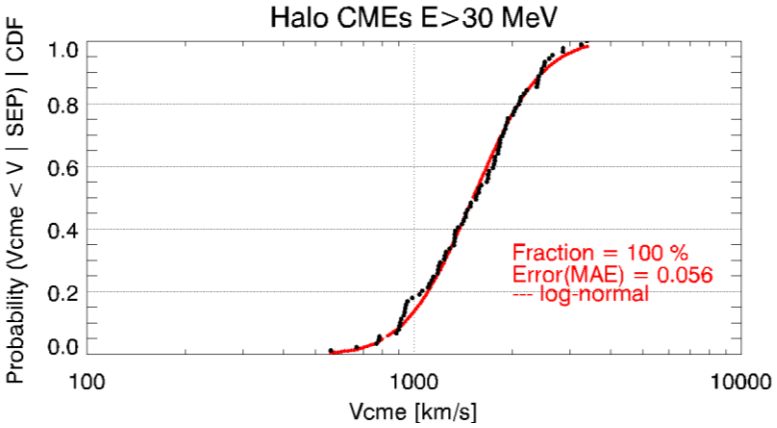
The PROSPER model

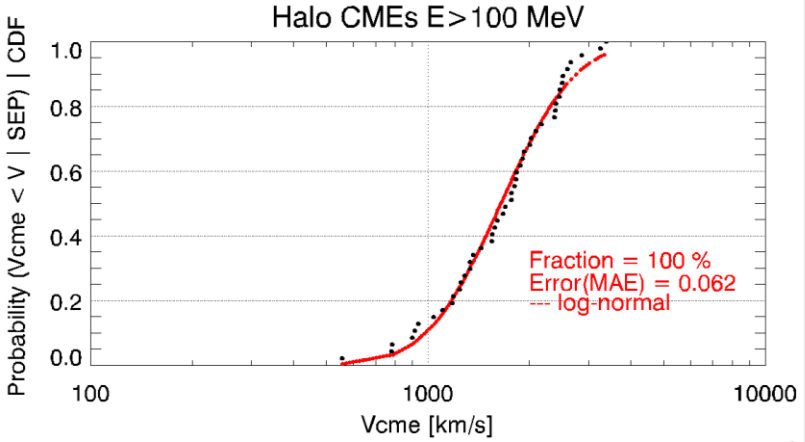
i. Coronal Mass Ejections (CMEs)

Papaioannou et al., JSWSC, 2019a – in preparation







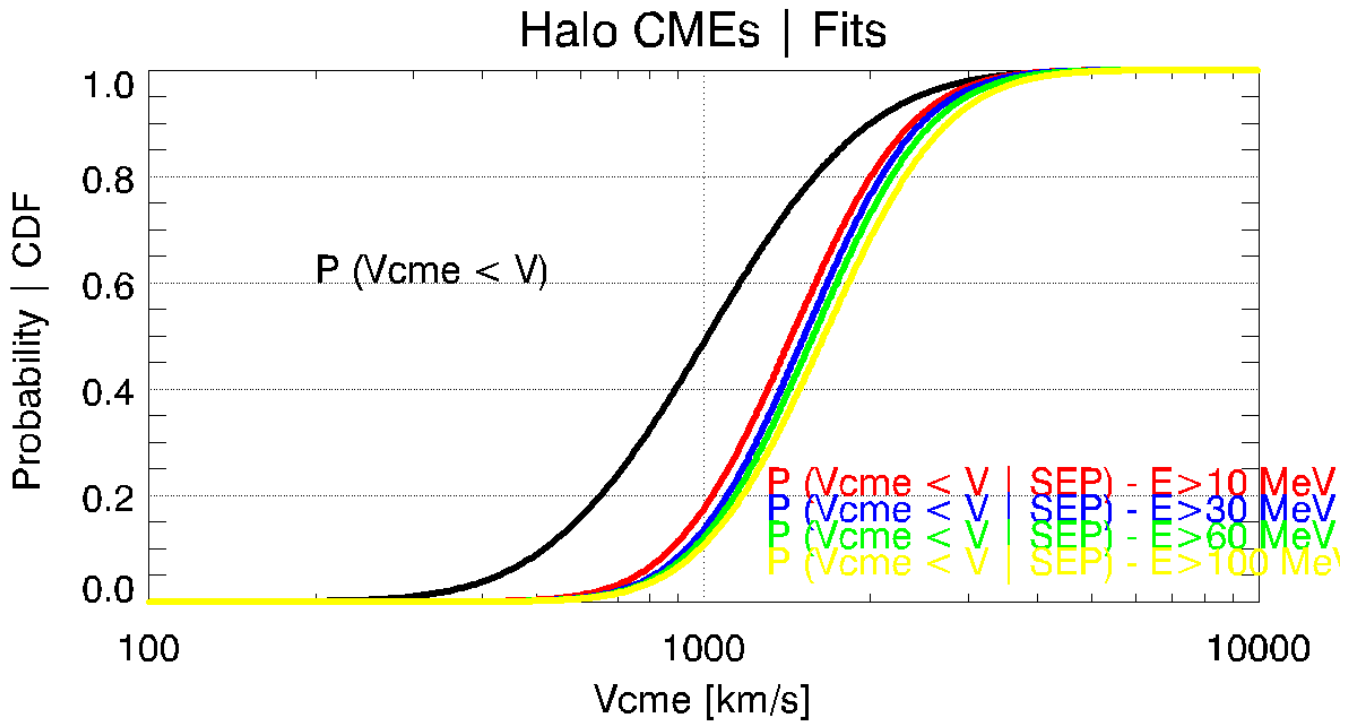


V Fits @ all energies

The PROSPER model

i. Coronal Mass Ejections (CMEs)

> **CDFs per energy**

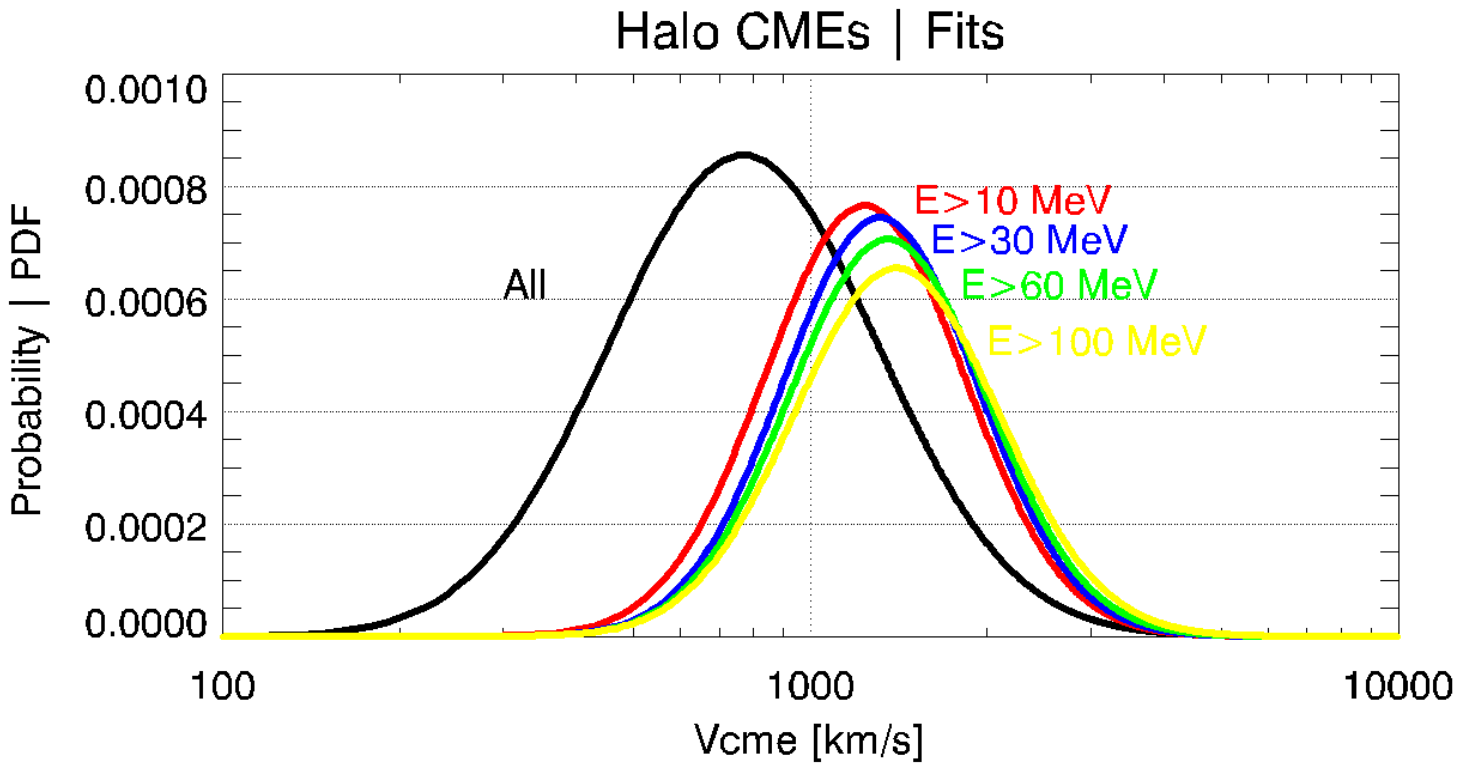


Papaioannou et al., JSWSC, 2019a – in preparation

The PROSPER model

i. Coronal Mass Ejections (CMEs)

> **PDFs per energy**

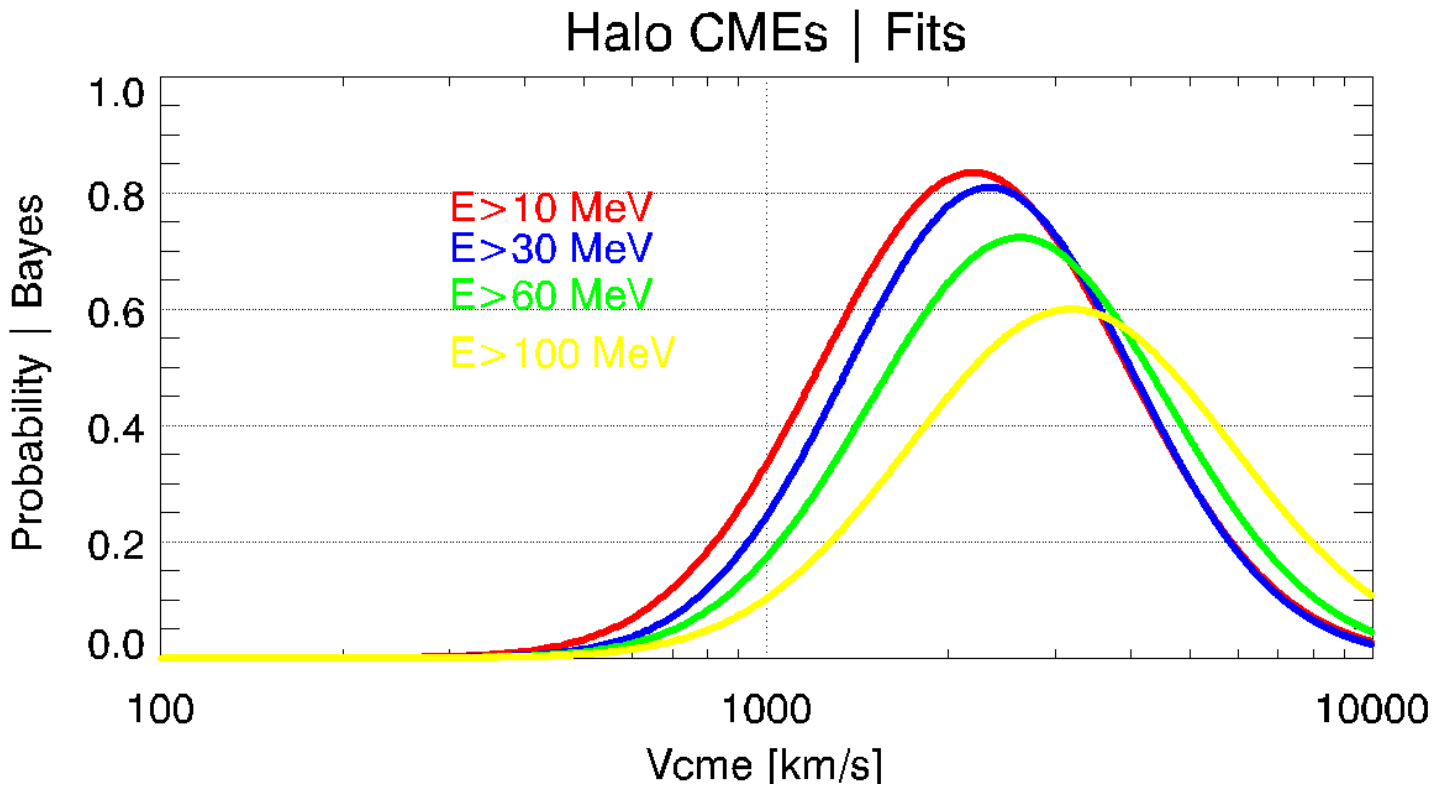


Papaioannou et al., JSWSC, 2019a – in preparation

The PROSPER model

i. Coronal Mass Ejections (CMEs)

> **Bayes per energy**



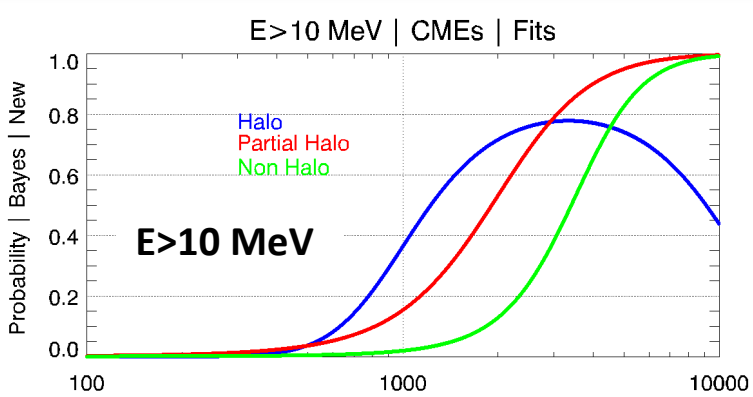
Papaioannou et al., JSWSC, 2019a – in preparation

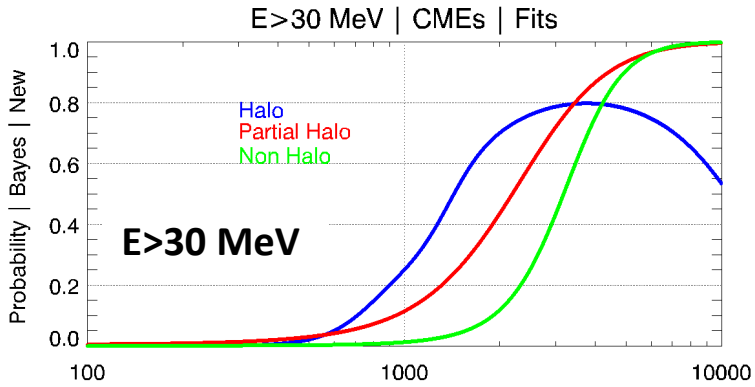
The PROSPER model

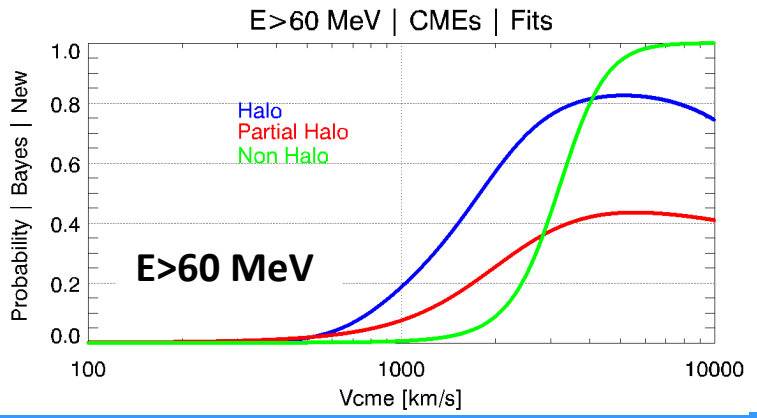
i. Coronal Mass Ejections (CMEs)

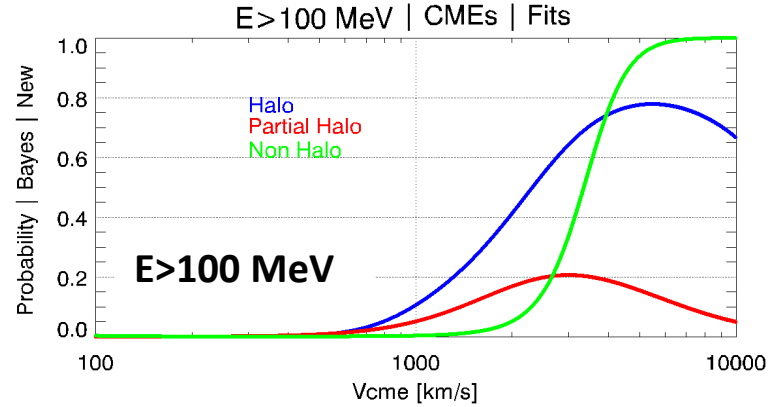
Papaioannou et al., JSWSC, 2019a – in preparation

> **Probabilities of SEP Occurrence per energy**







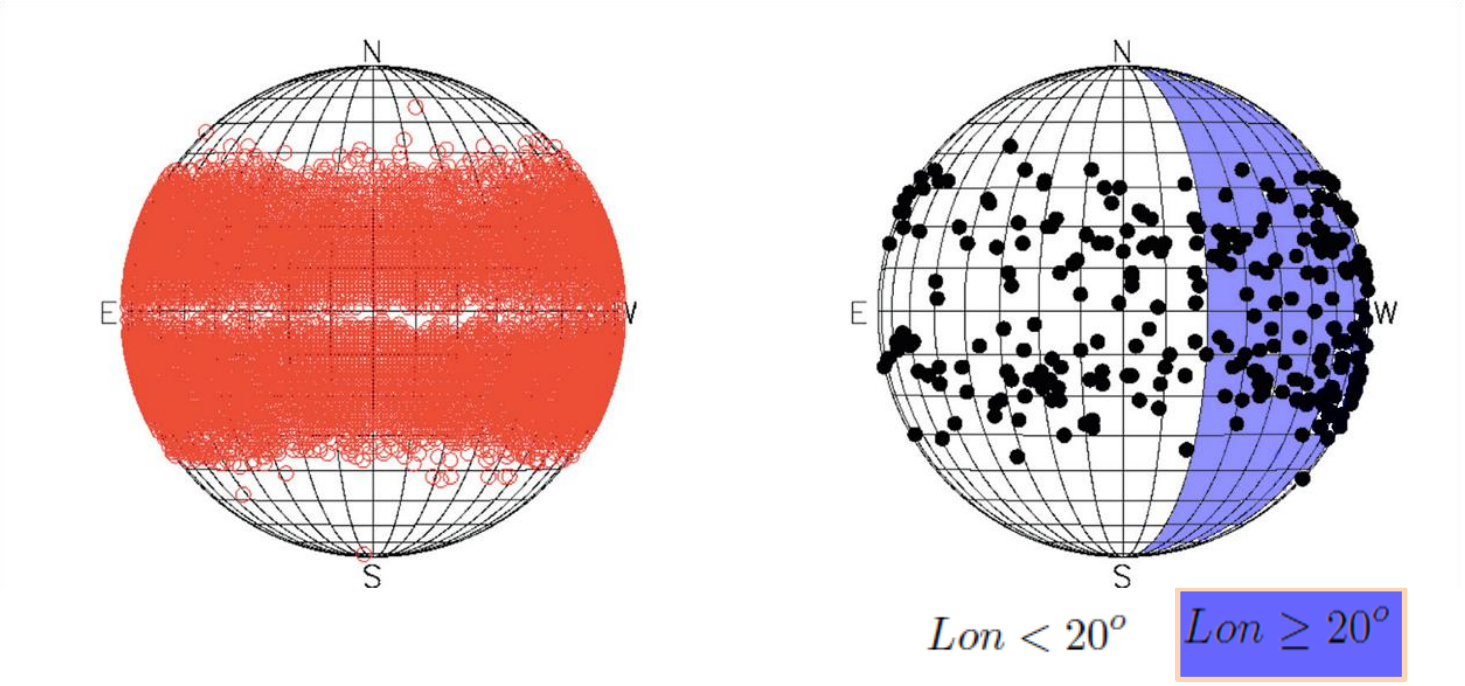


The PROSPER model

ii. Solar Flares (SFs)

Papaioannou et al., JSWSC, 2019b – in preparation

> **Probabilities of SEP Occurrence per energy**

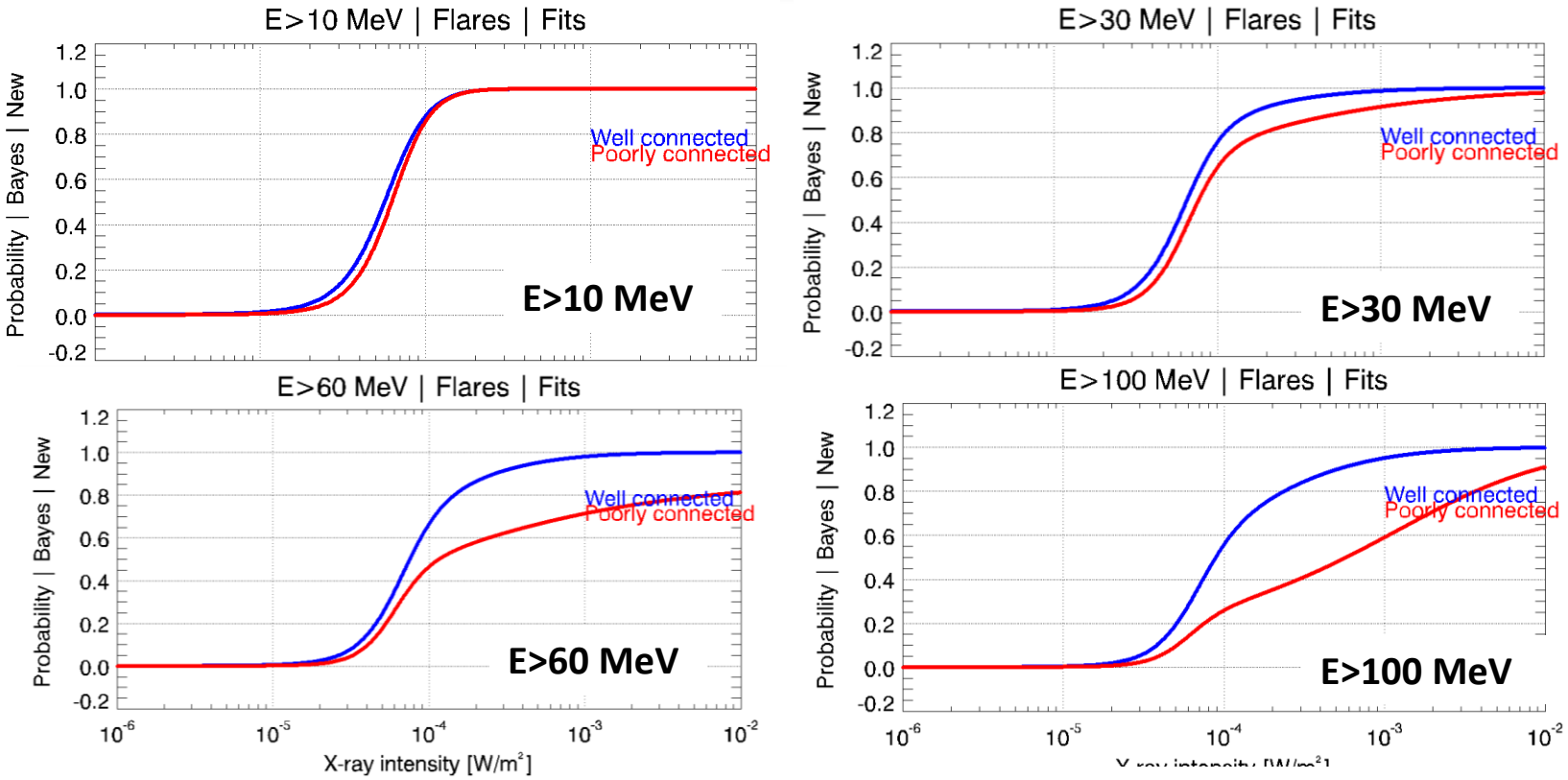


The PROSPER model

ii. Solar Flares (SFs)

Papaioannou et al., JSWSC, 2019b – in preparation

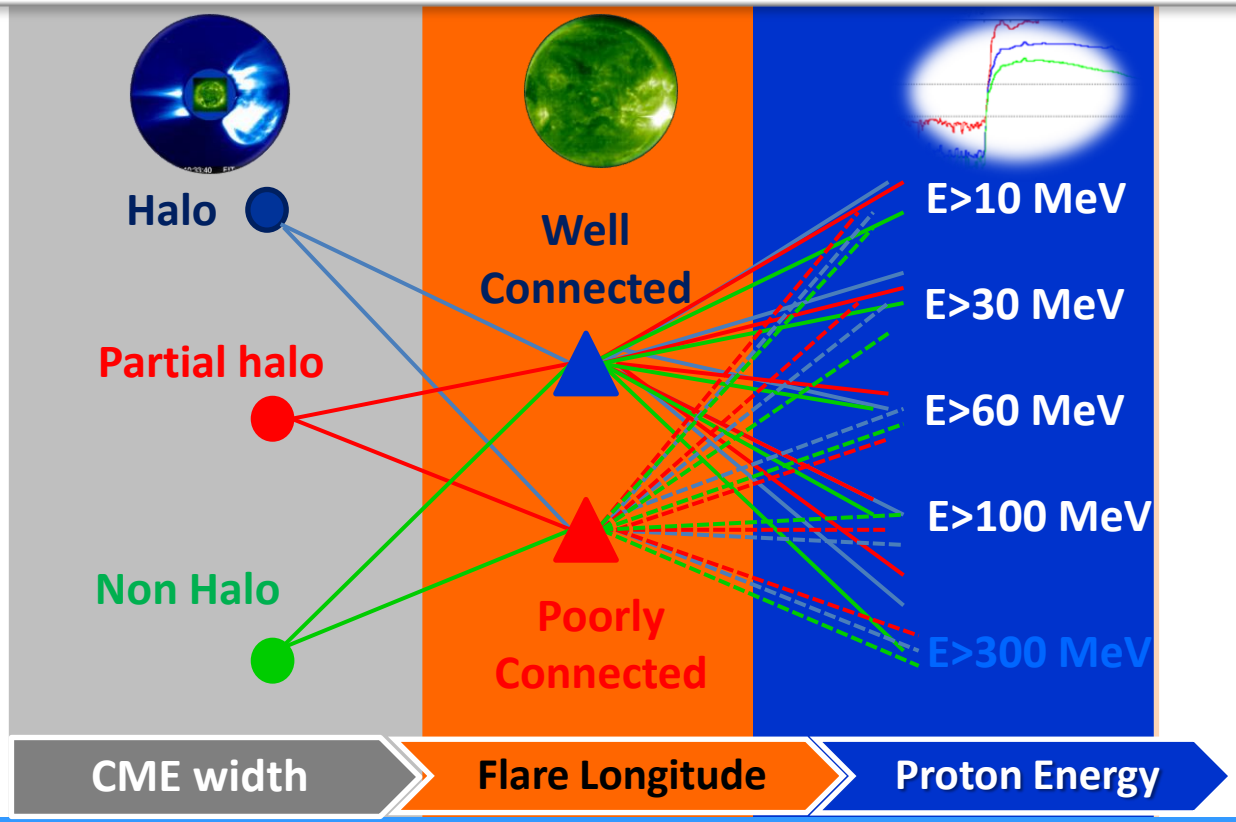
> **Probabilities of SEP Occurrence per energy**



The PROSPER model

iii. Solar Flares (SFs) & Coronal Mass Ejections (CMEs)

> Combining all of the aforementioned selections into different groups



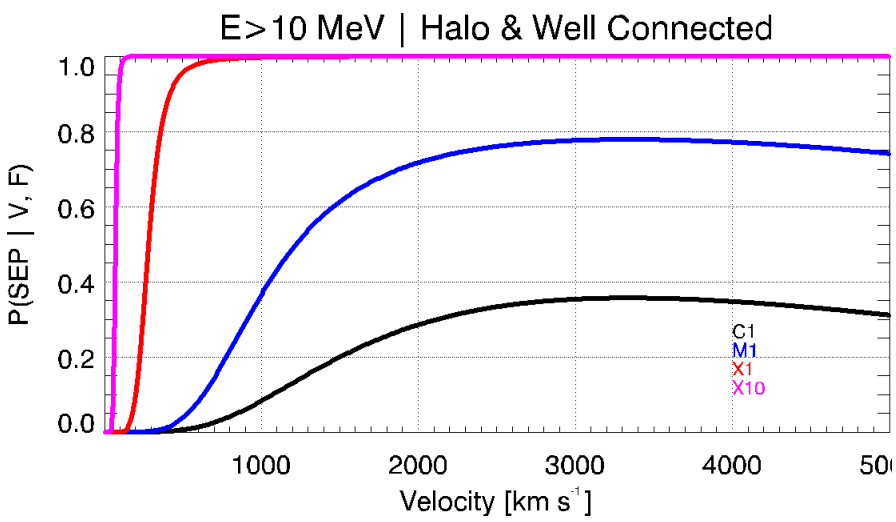
Papaioannou et al., JSWSC, 2019c – in preparation

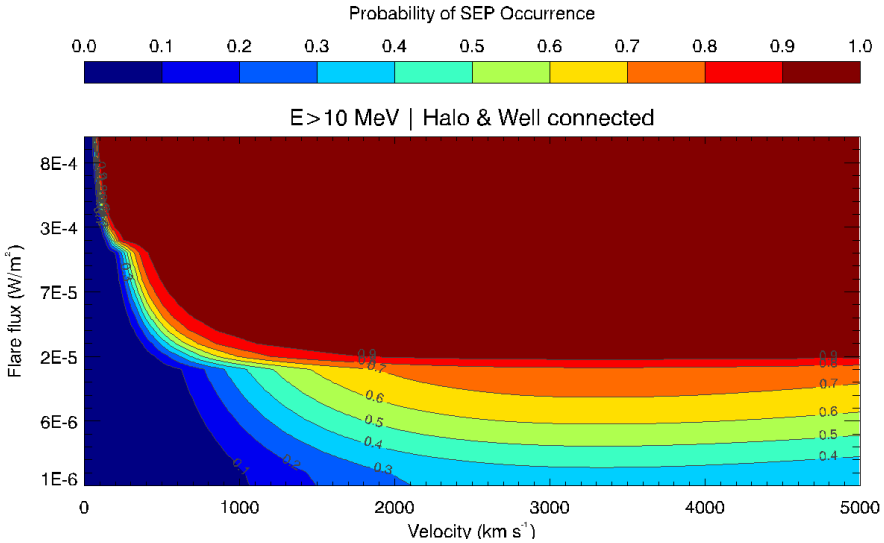
The PROSPER model

iii. Solar Flares (SFs) & Coronal Mass Ejections (CMEs)

> **Probabilities of SEP Occurrence (Halo CMEs + Well Connected flares)**

Papaioannou et al., JSWSC, 2019c – in preparation

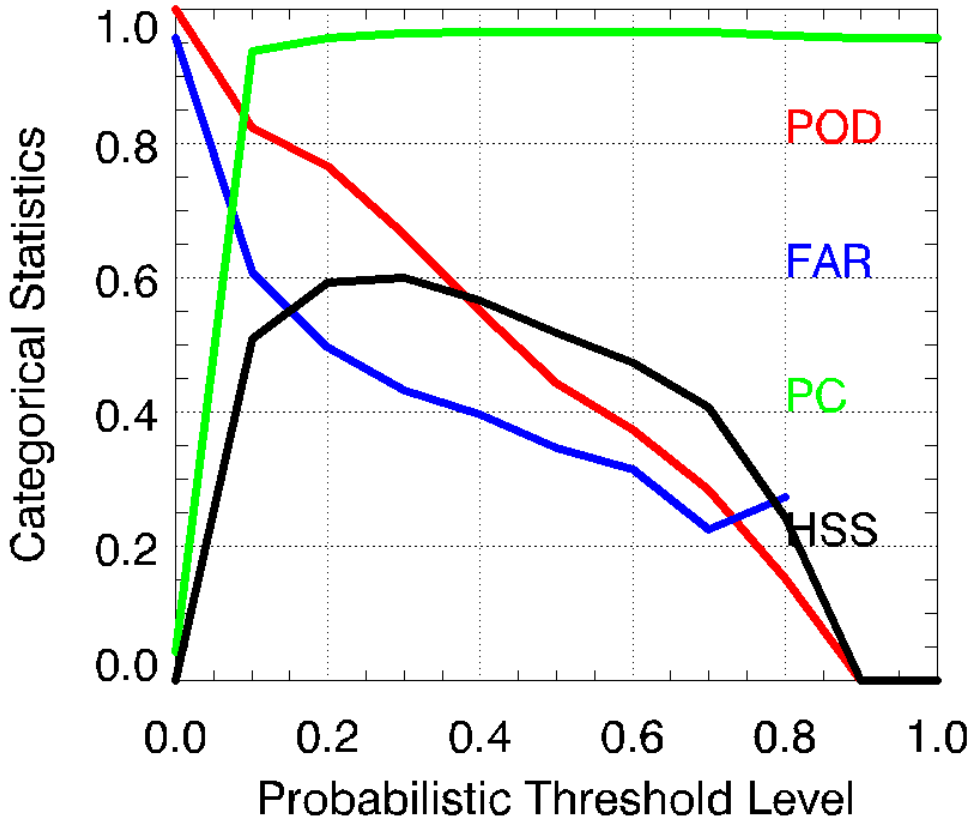




$$P(SEP|V_{CME} = V, Flare_{flux} = F)$$

The PROSPER model

Validation [**Preliminary**]



> Using a **totally independent test sample** (i.e. all CMEs from 2014 – 2017)

> Build a *contingency table* and *relevant scores* for the **PROSPER CME module**

> POD: 0.71

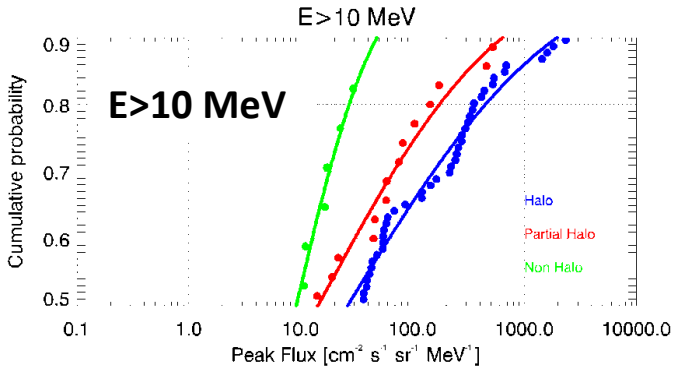
> FAR: 0.42

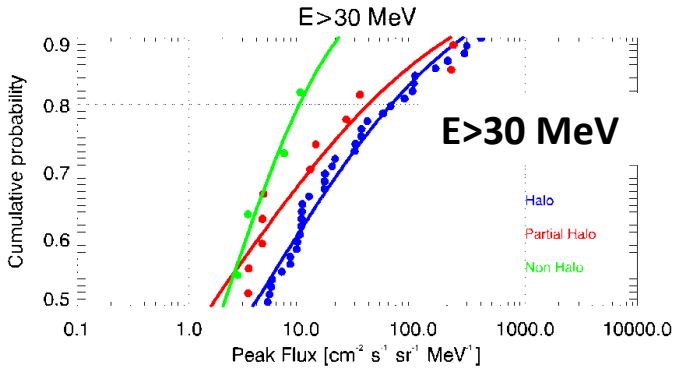
The PROSPER model

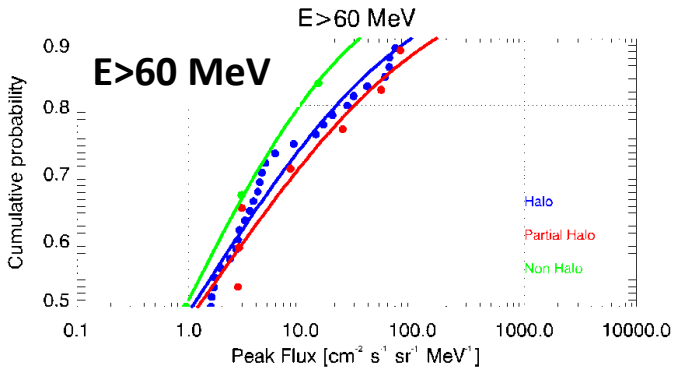
Expected Peak Flux @ Different Confidence Levels

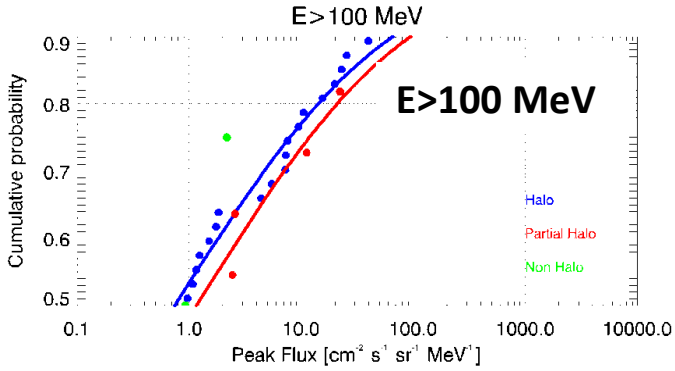
i. Coronal Mass Ejections (CMEs)

$$P(X_i < X | SEP = 1)$$





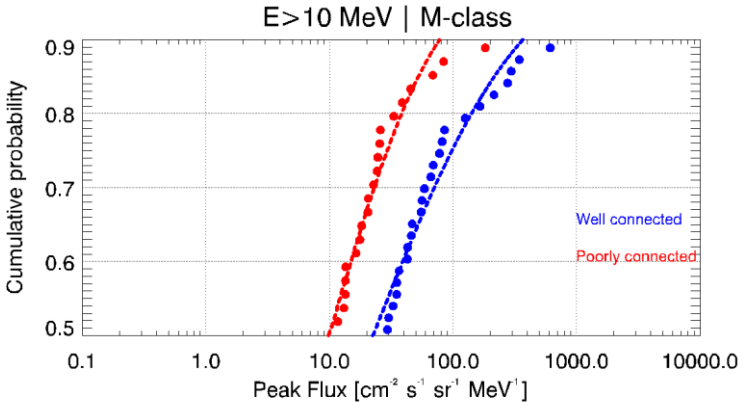


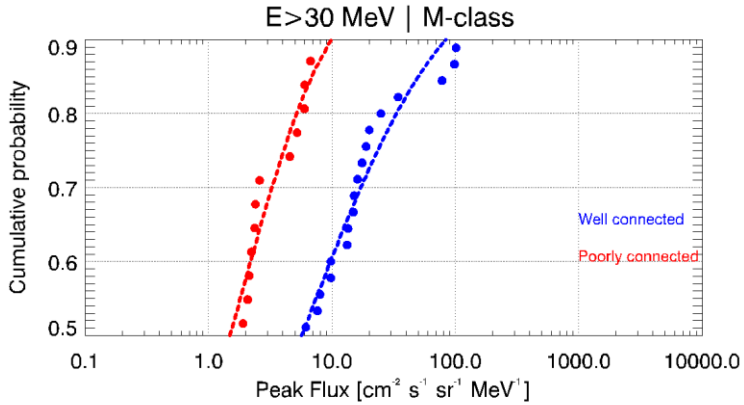


The PROSPER model

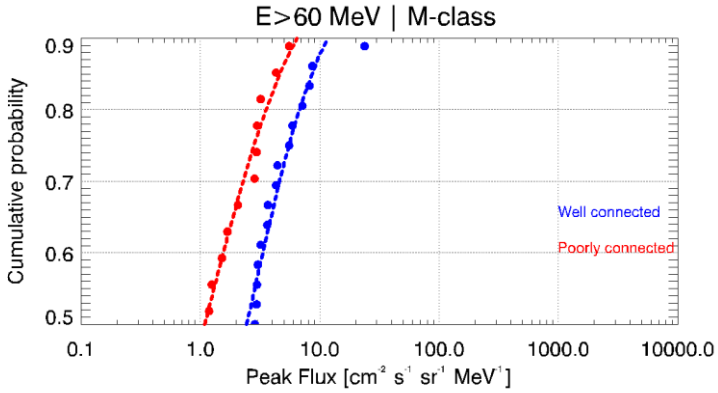
Expected Peak Flux @ Different Confidence Levels

ii. Solar Flares (SFs)





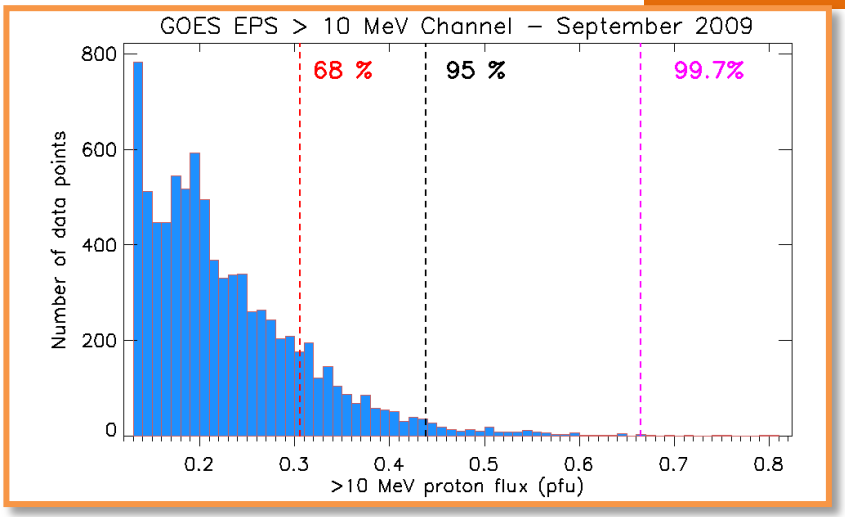
$$P(X_i < X | SEP = 1)$$



The PROSPER model

Expected Peak Flux Correction based on *P(SEP)*

$$PeakFlux = P(X_i < X|SEP = 1) * P(SEP|event) + backgroundflux * [1 - P(SEP|event)]$$

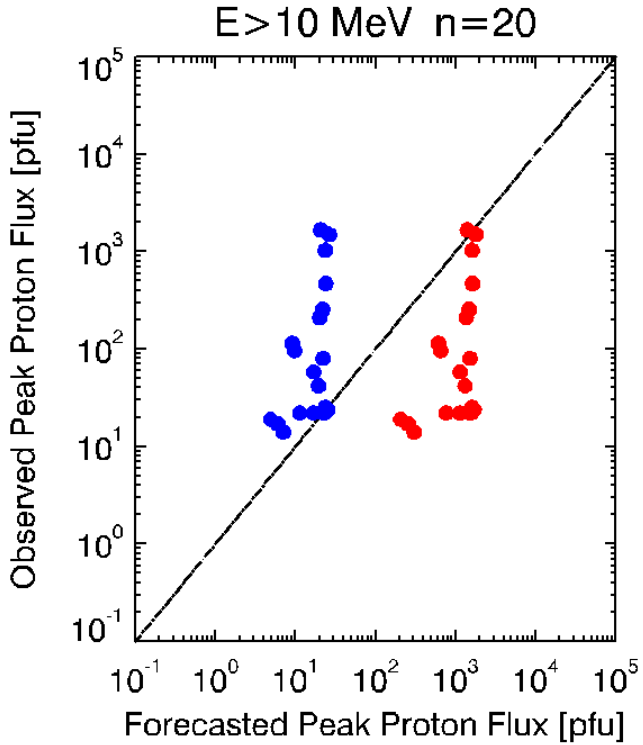


> If P(SEP | event) ~1 then $PeakFlux = P(X_i < X|SEP = 1) * P(SEP|event)$

> If P(SEP | event) ~0 then $PeakFlux = backgroundflux * [1 - P(SEP|event)]$

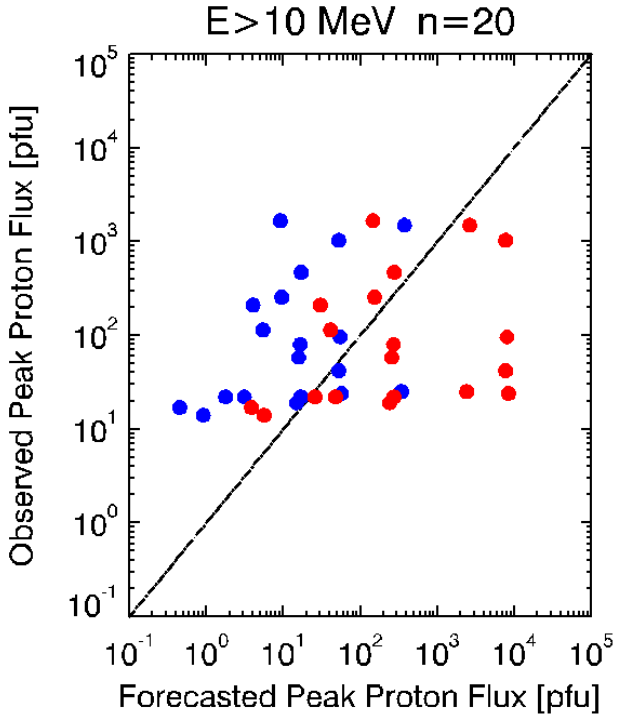
The PROSPER model

Validation [**Preliminary**]



CL1=50%

CL2=90%



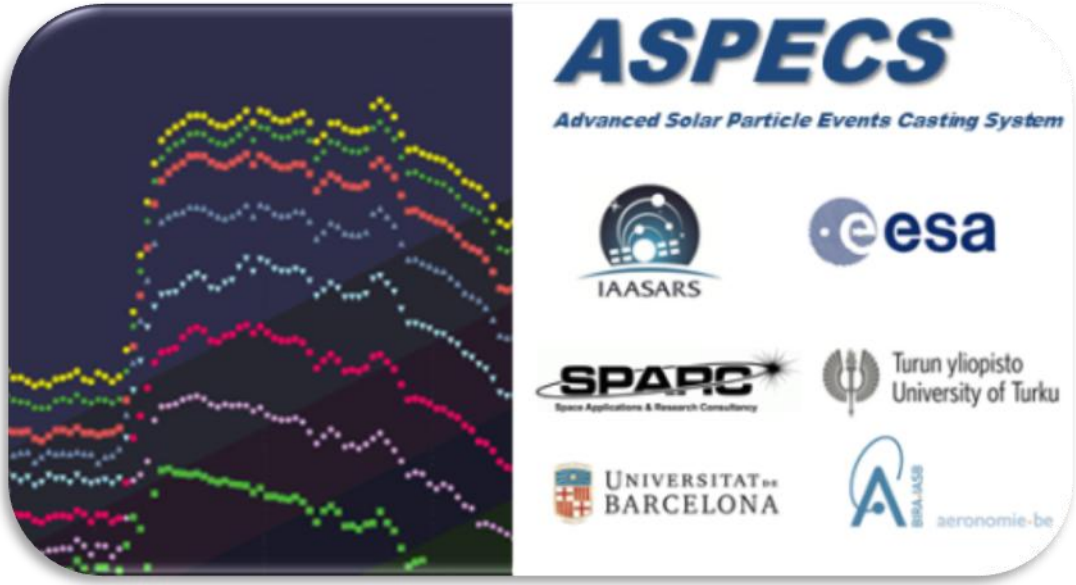
i. **Coronal Mass Ejections (CMEs)**

ii. **Solar Flares (SFs)**

The PROSPER model

Intergraded into the ASPECS Tool

ASPECS – Advanced Solar Particle Events Casting System



> http://phobos-srv.space.noa.gr/