High Energy Solar Energetic Particle Events

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ESWW14 on Thursday 30/11,

17:15 - 18:30, @ Permeke

Topical Discussion Meeting

Motivation

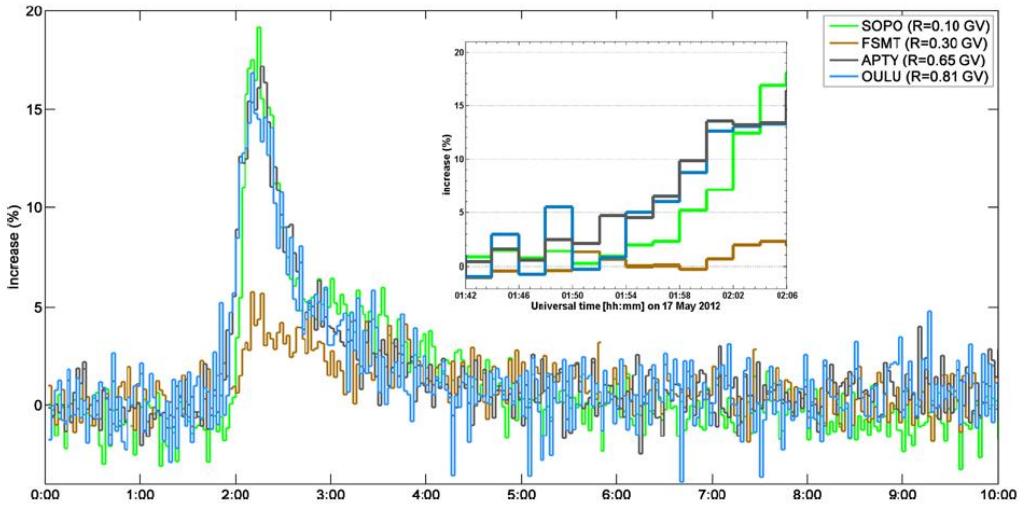
> **Where and how Solar Energetic Particles are generated?** There is no generally accepted opinion about the place of acceleration and the dominant mechanism of acceleration, so far…

> Many processes of multiple and/or prolonged acceleration, as well as propagation in the corona and interplanetary space influence the observed SEPs. Therefore, **it is difficult to distinguish signatures of acceleration mechanisms from particle observations, alone**.

> The early phase of SEP events is closer to the time of acceleration, and the role of interplanetary transport is minimal for the first arriving particles (*scatter-free propagation*). ***Relativistic solar protons (GLEs) are the most proper candidate to unfold the problem of particle acceleration***.

Ground Level Enhancements (GLEs)

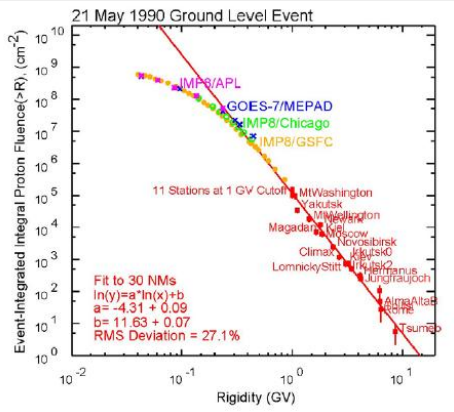
S. Forbush (1946)



Papaioannou et al, Solar Physics, 2014

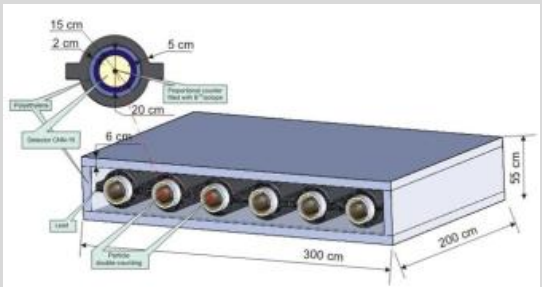
GLEs are *Rare* and *Extreme* SEPs

- ***Rare*** because **since 1956** there have been only **72 events** (***~1.2 events per year***)
- ***Extreme*** because they need to reach an energy of **E≥433 MeV** in order to be registered on the ground.



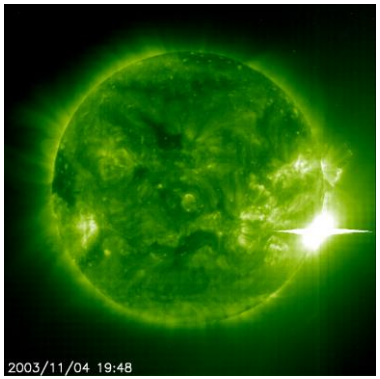
Tylka et al, Proc 29th ICRC, 2009

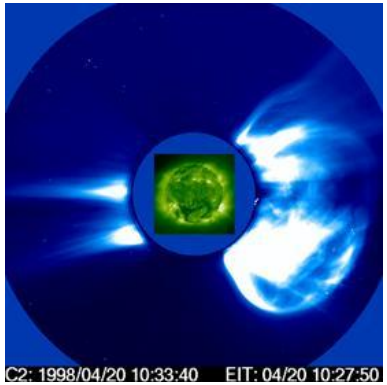
> **Detecting fast particle is challenging —**
> **One needs large instruments to register these rare events =>**
> **Neutron Monitors**



Solar Energetic Particle (SEP) events

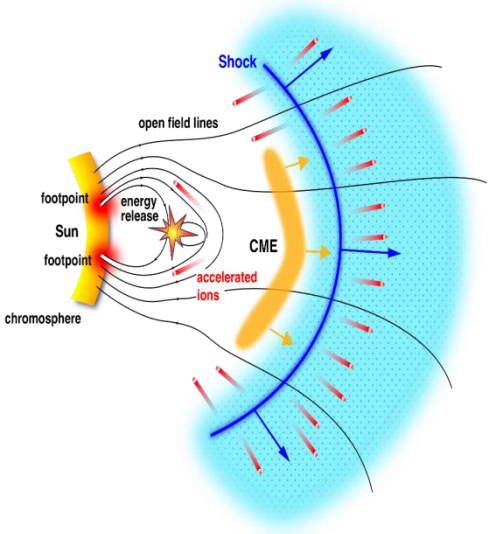
The origin of SEP/GLE events





-- **Solar flares** is an explosive release of energy (both electromagnetic and charged particles)

-- **Coronal Mass Ejections (CMEs)** are violent eruptions of solar mass. CMEs are efficient particle accelerators. When a CME is expelled into the interplanetary medium, it interacts with the slower solar wind and the corresponding shock wave accelerates particles.



Reames, Space Scie. Rev., 1999

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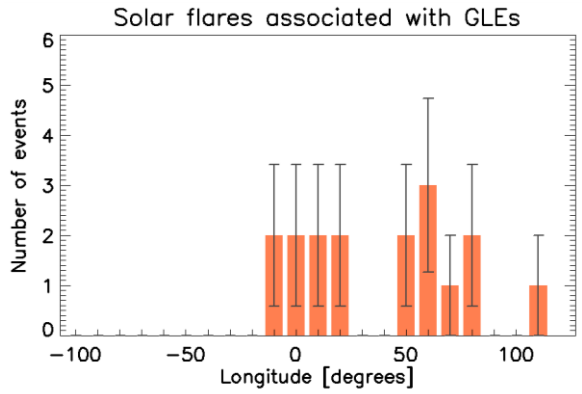
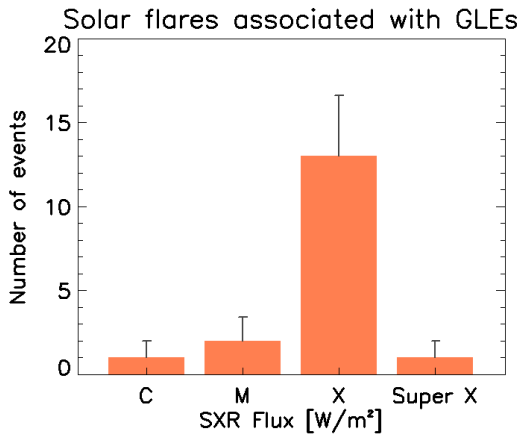
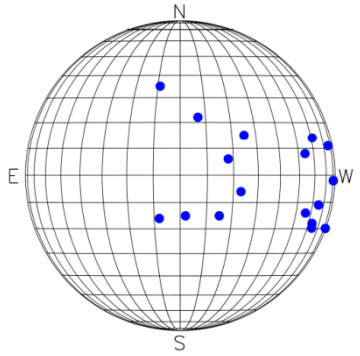
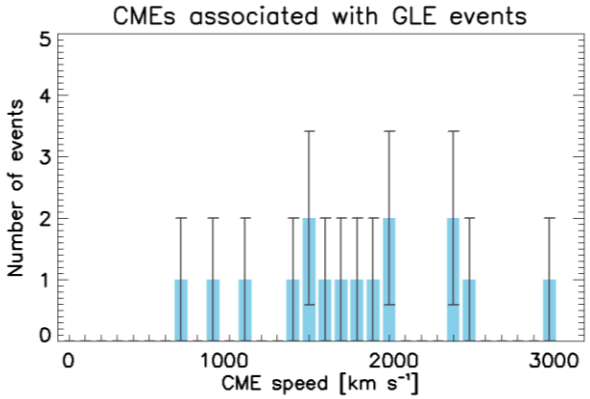
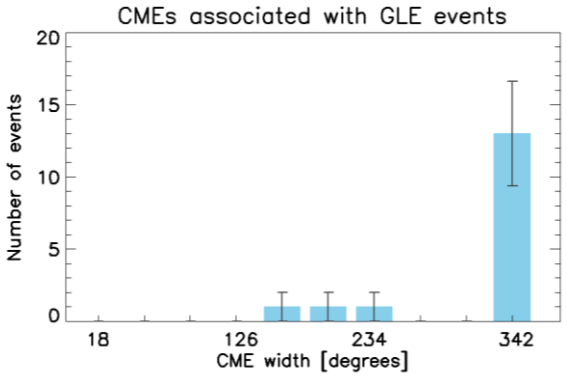




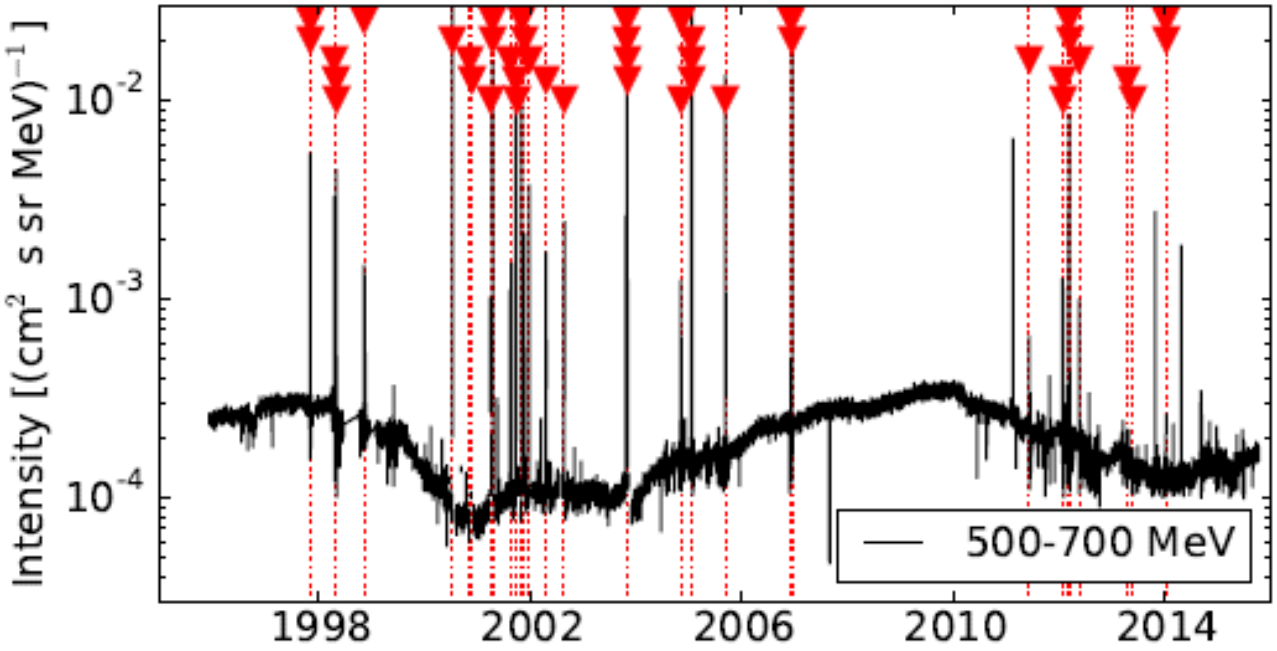






> Fast CMEs and powerful SFs occur (almost always) together in GLEs. This makes it difficult to directly identify the actual parent solar source of the GLE.

High Energy Solar Energetic Particle events



> **42 SEP events @ E>500 MeV** presented by ***Kuehl et al.*, 2017**
> **16/42** [*38%*] ***are*** **GLEs**
> **26/42** [62%] ***<u>are NOT</u>*** **GLEs**

Kuehl et al, Solar Physics, 2017

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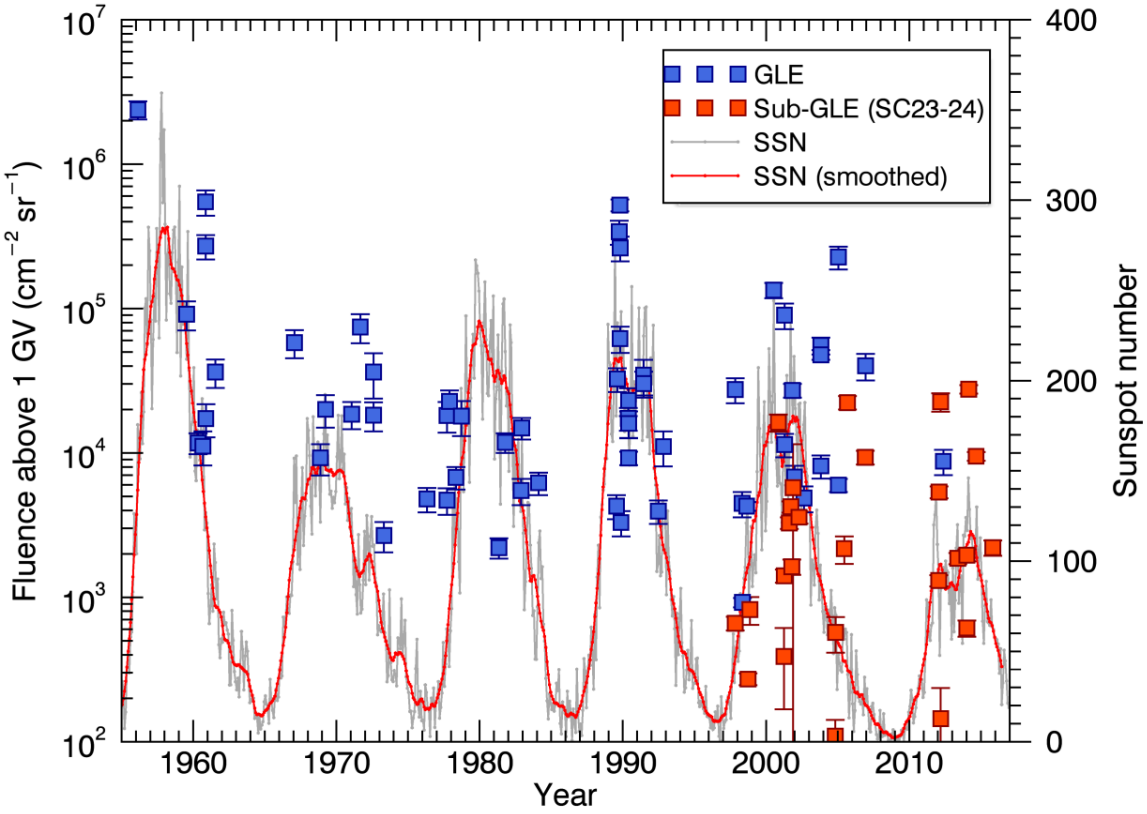
High Energy Solar Energetic Particle events



Vainio et al, Astron. Astrophys., 2017

> A similar list was presented *independently* by **Vainio *et al.*, 2017**

> **35/42** SEP events are common in both lists.

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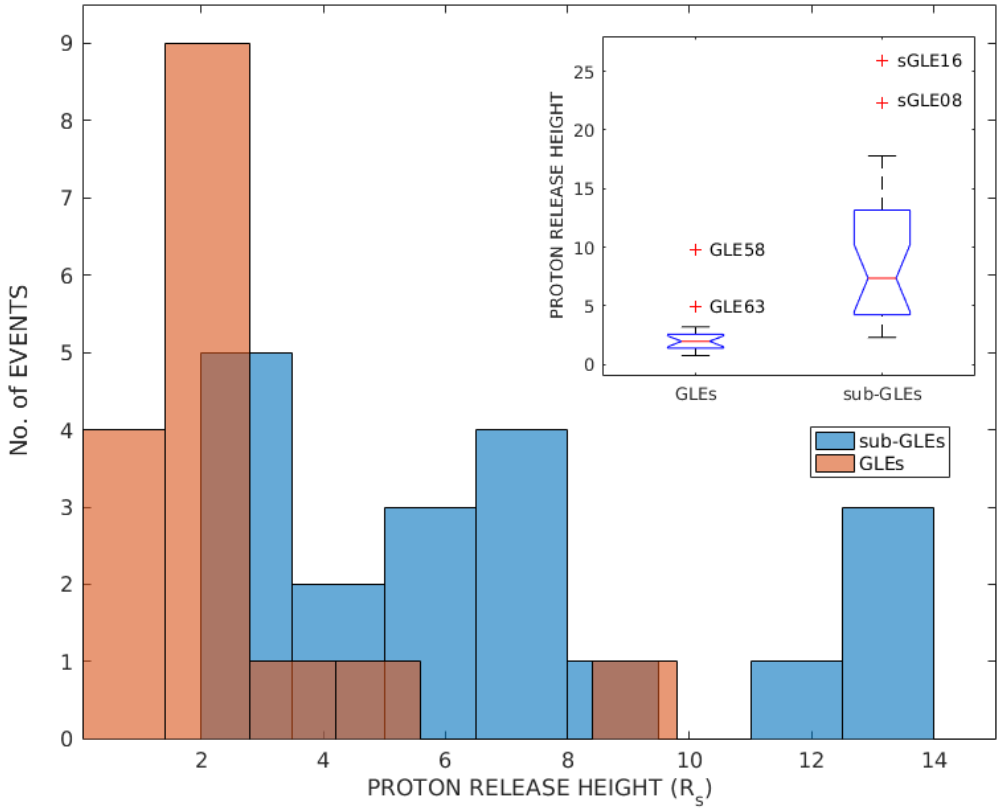
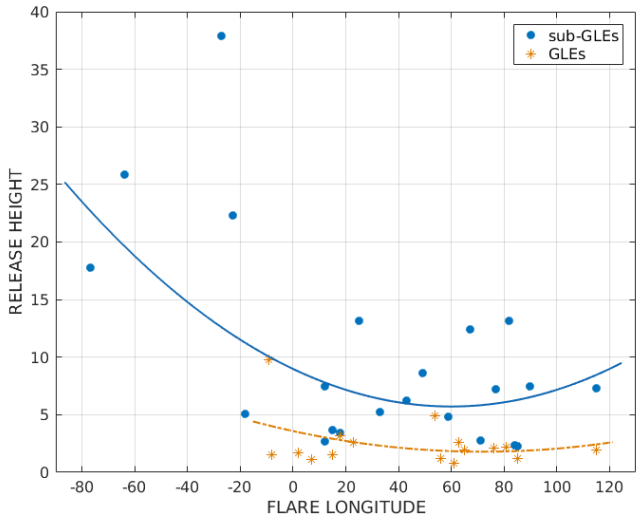
High Energy Solar Energetic Particle events



> **Particles** in **GLEs** are released ***low in the corona*** of the Sun (~ 1.8 Rs) **whereas particles in non-GLEs** are released significantly ***higher in the corona*** (~6 Rs)



Papaioannou et al, Astron. Astrophys., 2017a [in preparation]

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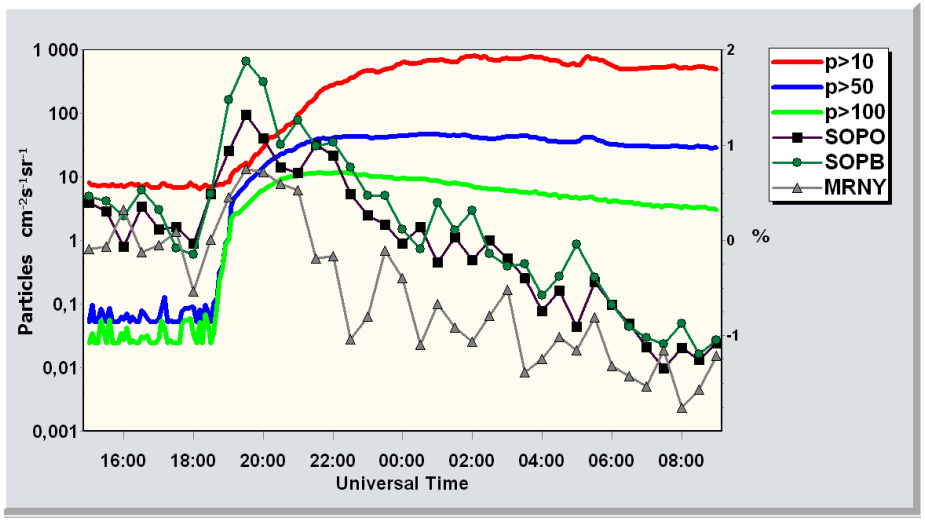
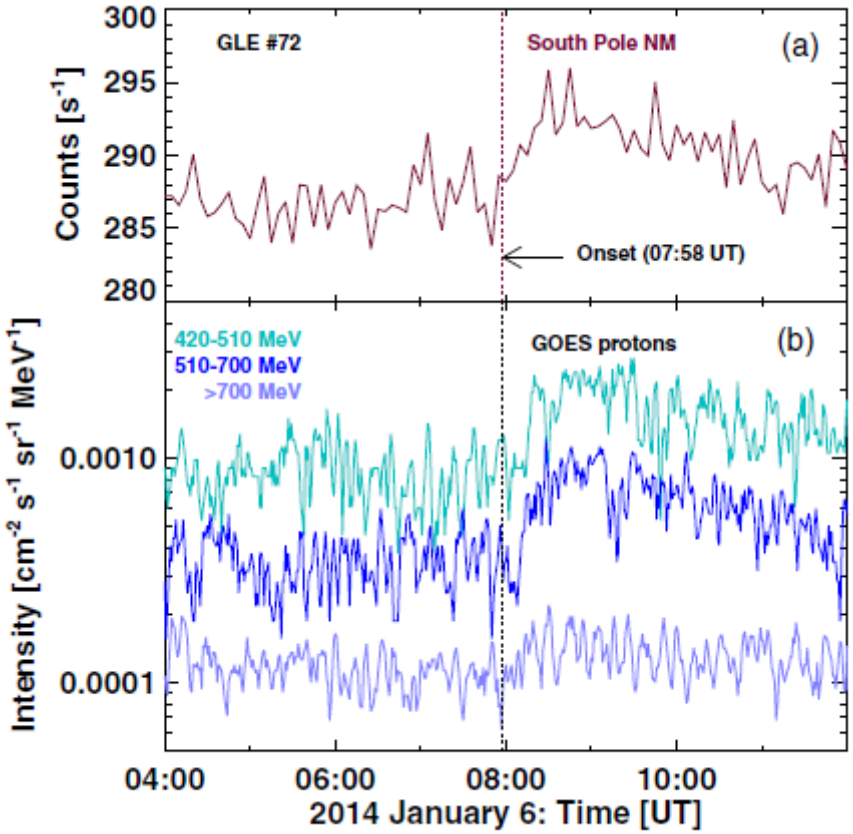


Belov et al., J. Phys.: Conf. Ser, 2015



Takur et al., Astrophys. J. 2014

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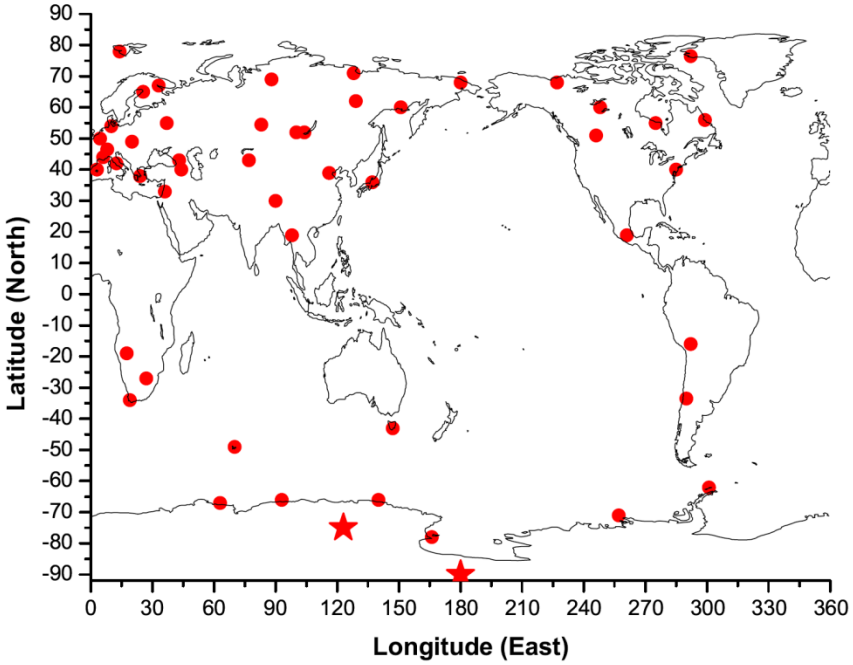

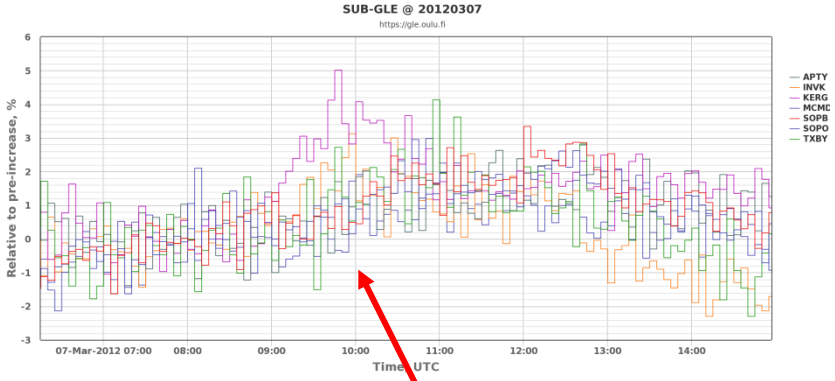

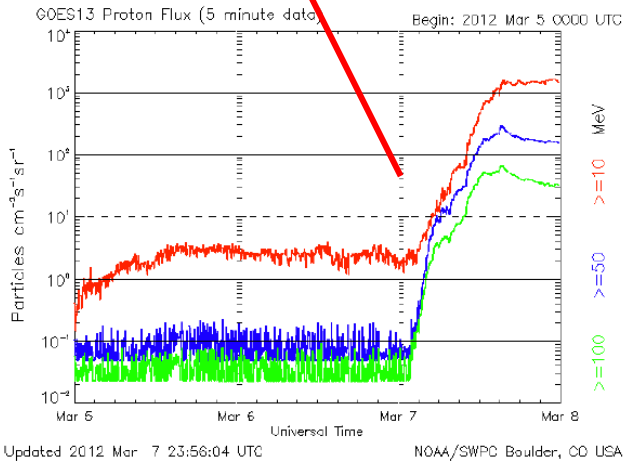

> Birth of the term "sub-GLEs"

Mishev et al, J. Space Weather Space Clim, 2017

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Program

1. **Introduction** | A. Papaioannou
2. **Modeling of Proton acceleration in application to a GLE** | A. Afanasiev, *R. Vainio*, A. P. Rouillard, M. Battarbee, A. Aran and P. Zucca
3. **Flare, CME and the acceleration of relativistic protons at the Sun** | K.-L.. Klein
4. **Solar Energetic Particle Events with Protons Above 500 MeV Between 1995 and 2015 Measured with SOHO/EPHIN** | P. Kühl, N. Dresing, *B. Heber*, and A.B. Klassen
5. **Sub-GLE and GLE events: in the light of the global NM network** | *A. Mishev*, I. Usoskin, S. Poluianov
6. **General Discussion**

Modelling of proton acceleration in application to a GLE

Alexandr Afanasiev, Rami Vainio, Alexis P. Rouillard, Markus Battarbee, Angels Aran, Pietro Zucca

Flare, CMEs, and the acceleration of relativistic protons at the Sun

Karl-Ludwig Klein

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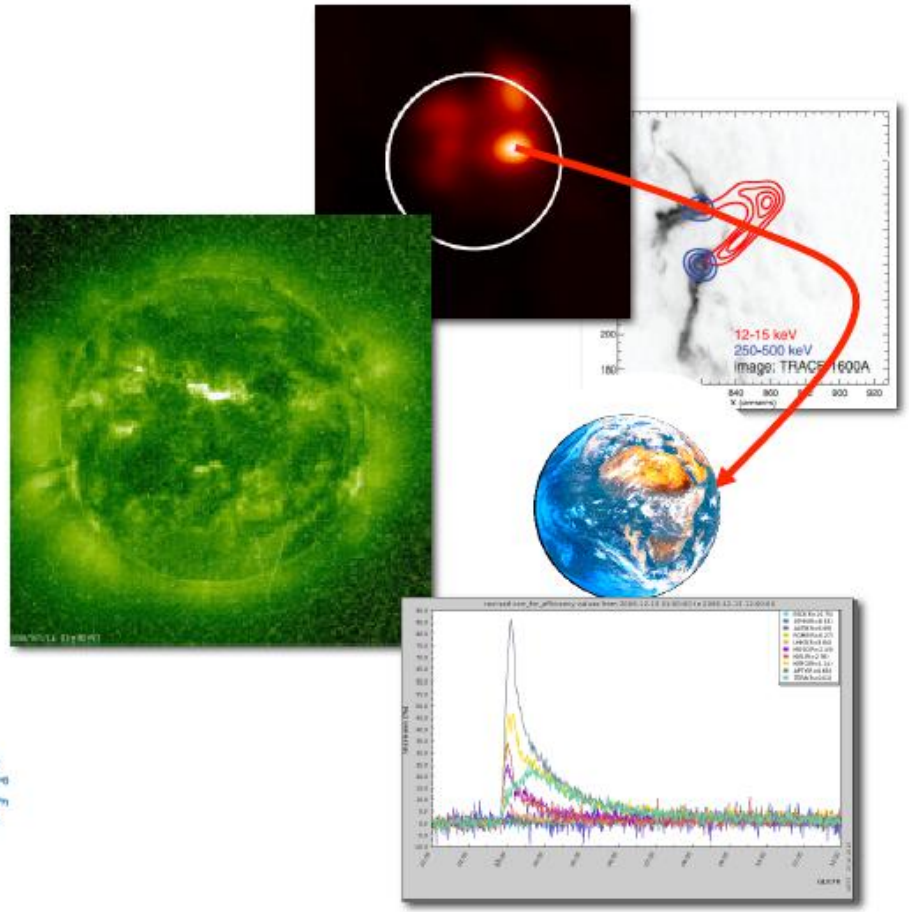

P. Zucca, N. Agueda, R. Bütikofer,
S. Masson, G. Trottet, N. Vilmer,
C. Hamadache, J. Kiener,
V. Tatischeff, G. Share

CNRS, Univ. P&M Curie, Paris Diderot, PSL Research University

SEP Events with Protons > 500 MeV from 1995 to 2015 SOHO/EPHIN results

P. Kühl, N. Dresing, B. Heber and A. Klassen

Christian-Albrechts-Universität zu Kiel

HESPERIA workshop 27.02-2.03.2017

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Sub-GLE and GLE events: in the light of the global NM network

A. Mishev, I.Usoskin, S. Poluianov