HAWC and Solar Energetic Transient Events

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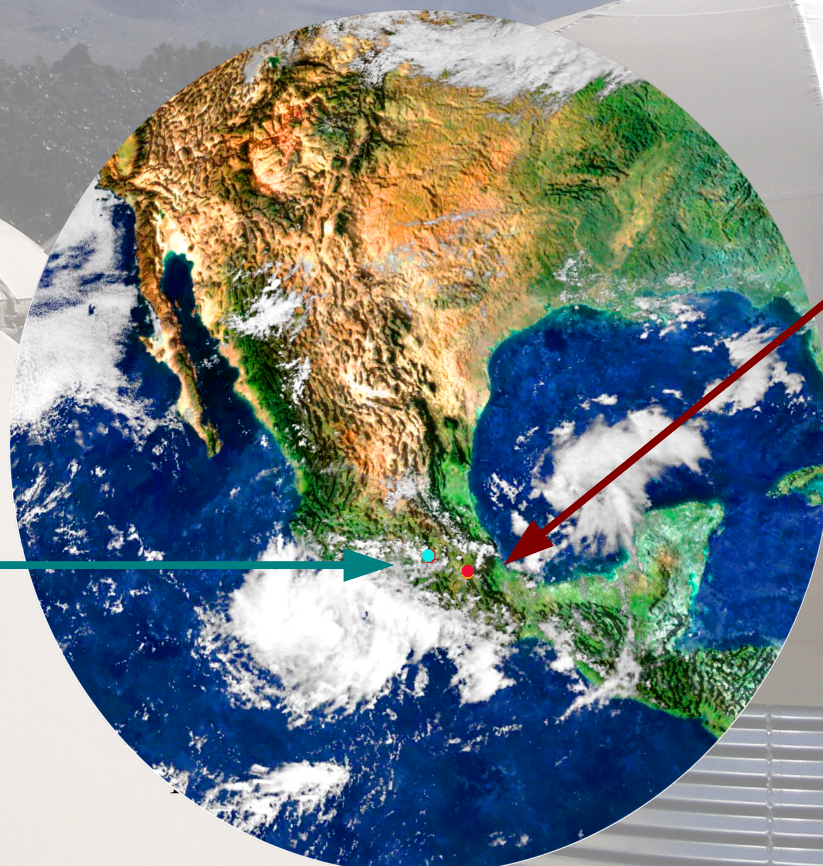
ABSTRACT

The High Altitude Water Cherenkov (HAWC) observatory is being constructed at the volcano Sierra Negra (4100 m a.s.l.) in Mexico. HAWC's primary purpose is the study of both: galactic and extra-galactic sources of high energy gamma rays. HAWC will consist of 300 large water Cherenkov detectors (WCD), instrumented with 1200 photo-multipliers. The Data taking has already started while construction continues, with the completion projected for late 2014. The HAWC counting rate will be sensitive to cosmic rays with energies above the geomagnetic cutoff of the site (Ґ 8 GV). In particular, HAWC will detect solar energetic particles known as Ground Level Enhancements (GLEs), and the effects of Coronal Mass Ejections on the galactic cosmic ray flux, known as Forbush Decreases. In this paper, we present a description of the instrument and its response to interplanetary coronal mass ejections, and other solar wind large scale structures, observed during the August-December 2013 period.

The High Altitude Cherenkov Array (HAWC)

HAWC is a second generation water Cherenkov array which is being constructed at "Sierra Negra" in the state of Puebla, México.

When finished HAWC will be an array of 300 "water Cherenkov Detectors" (WCDs).



Institutions in the United States

Colorado State University
George Mason University
Georgia Institute of Technology
Harvey Mudd College
Los Alamos National Laboratory
Michigan State University
Michigan Technological University
NASA/Goddard Space Flight Center
Ohio State University at Lima
Pennsylvania State University
University of California, Irvine
University of California, Santa Cruz
University of Maryland
University of New Hampshire
University of New Mexico
University of Utah
University of Wisconsin-Madison

Institutions in Mexico

Benemérita Universidad Autónoma de Puebla (BUAP)
Centro de Investigación y de Estudios Avanzados (CINVESTAV)
Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)
Universidad Autónoma de Chiapas (UAC)
Universidad de Guadalajara (UdG)
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- Instituto de Astronomía (IA-UNAM)
- Instituto de Física (IF-UNAM)
- Instituto de Ciencias Nucleares (ICN-UNAM)
- Instituto de Geofísica (IGeof-UNAM)

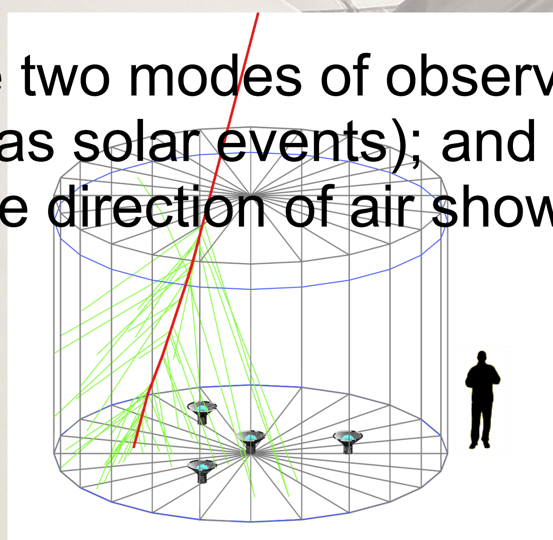
Water Cherenkov Detectors (WCDs)

The WCD consist of a cylinder of ~7m of diameter and ~5m of height filled with pure water and instrumented with four photomultipliers (PMTs).

Cherenkov emission is produced when secondary particles created, in the low atmosphere, enter into the WCD and travels with relativistic speed trough the water.

This light is detected by the PMTs and the signal of each individual PMT is collected in the central electronic room.

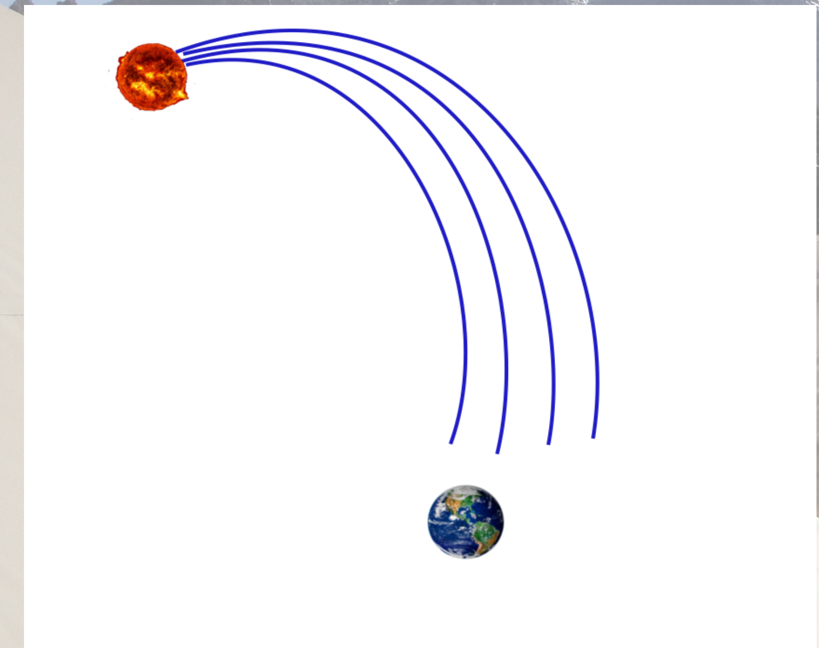
We have two modes of observation: scalers: well suited for low energy studies (as solar events); and and main or TDC mode which is able to detect the direction of air showers produced by high energy particles.



We have constructed 300 WCD

The final array was operational at the beginning of 2015

HAWC will detect solar energetic transient events

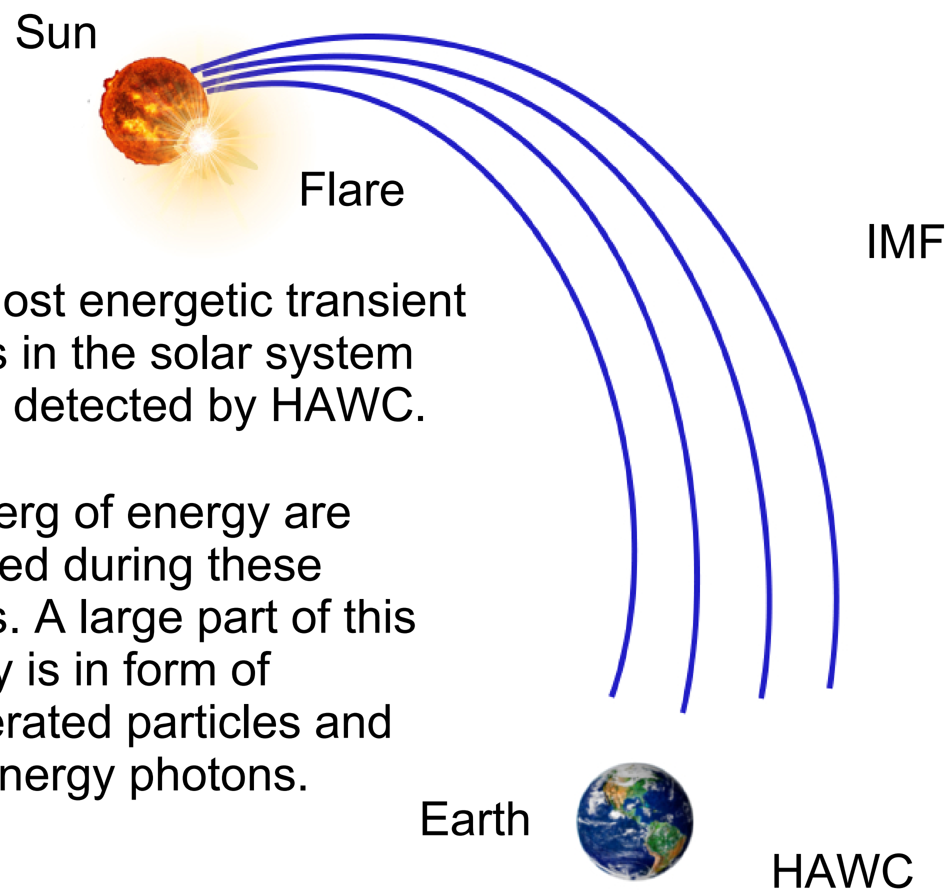


The main objective of HAWC is the detection of high energy gamma rays.

Nevertheless, HAWC will detect particles of relatively low energy by using both the scaler system and the solar mode (triggered by low energy events).

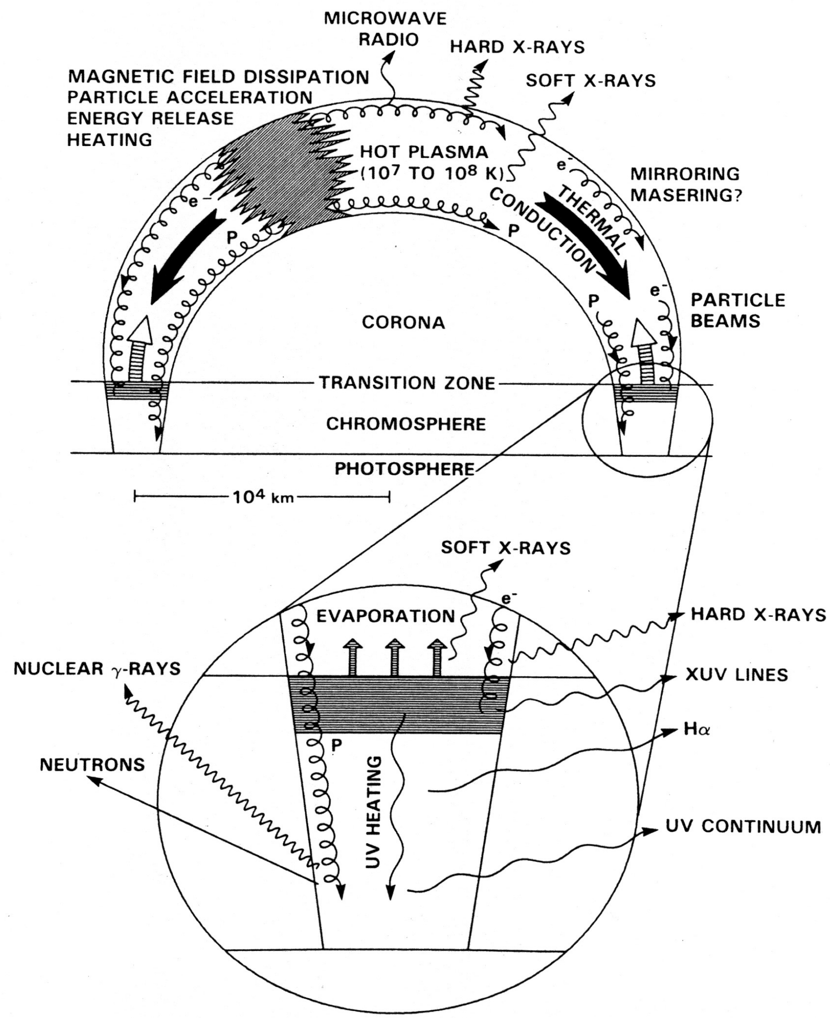
Therefore HAWC is able to observe solar transient events.

Solar Flares

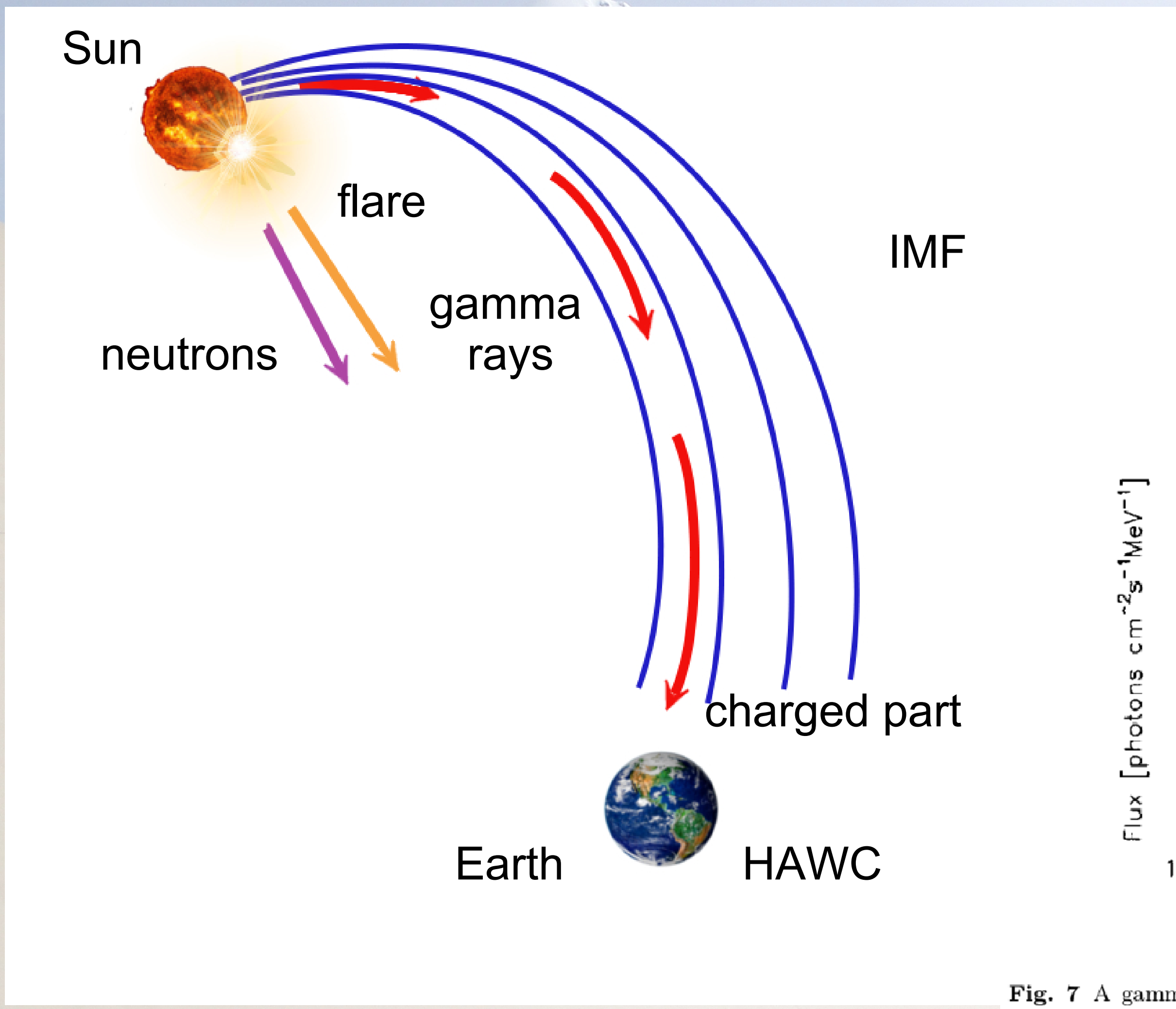


The most energetic transient events in the solar system will be detected by HAWC.

~10^{32} erg of energy are liberated during these events. A large part of this energy is in form of accelerated particles and high energy photons.



Solar Flares



HAWC is able to detect:

Solar gamma rays

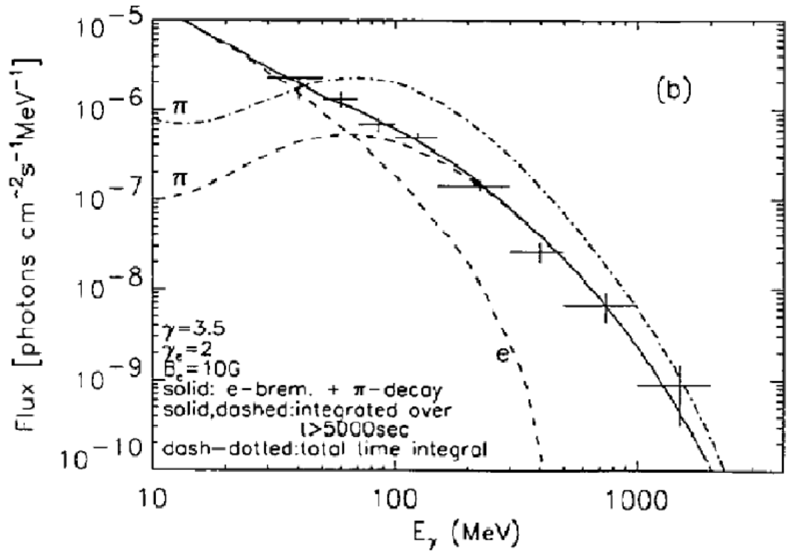
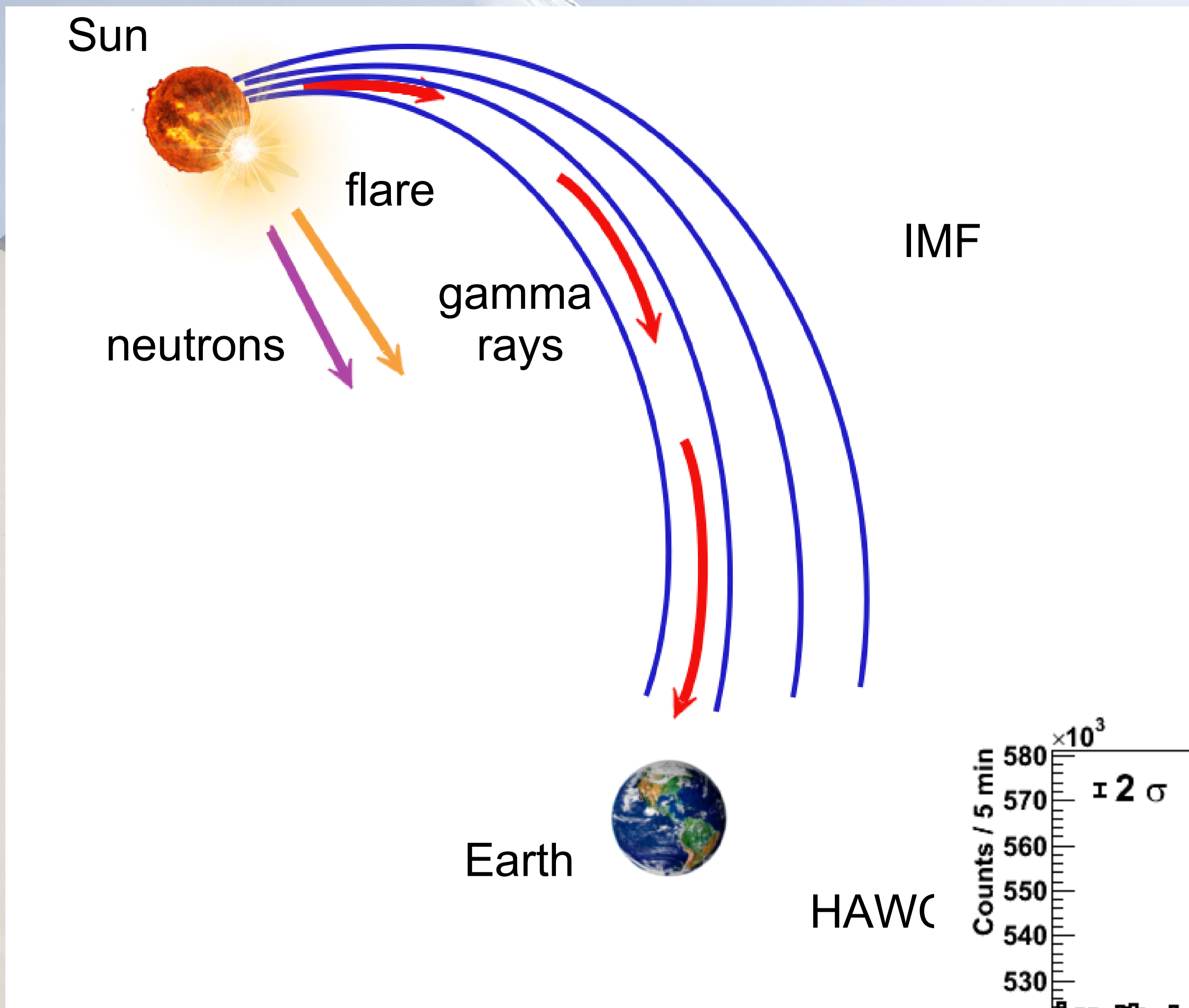


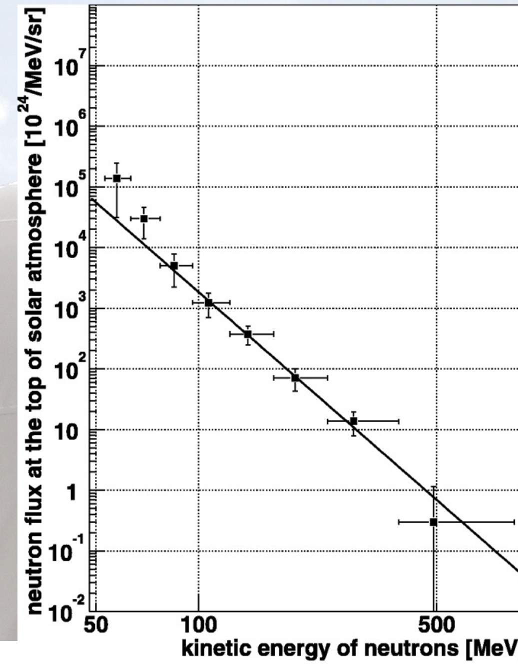
Fig. 7 A gamma-ray spectrum observed with *EGRET/CGRO* during the GLE event #51 on 1991 Jun 11, 02:04 UT flare, accumulated during 03:26 06:00 UT (Kanbach et al. 1993). The spectrum is fitted with a combination of primary electron bremsstrahlung and pion-decay radiation. Note that pion decay is dominant at energies > 40 MeV (Mandzhavidze & Ramaty 1992).

Solar Flares



HAWC will detect:

Solar neutrons



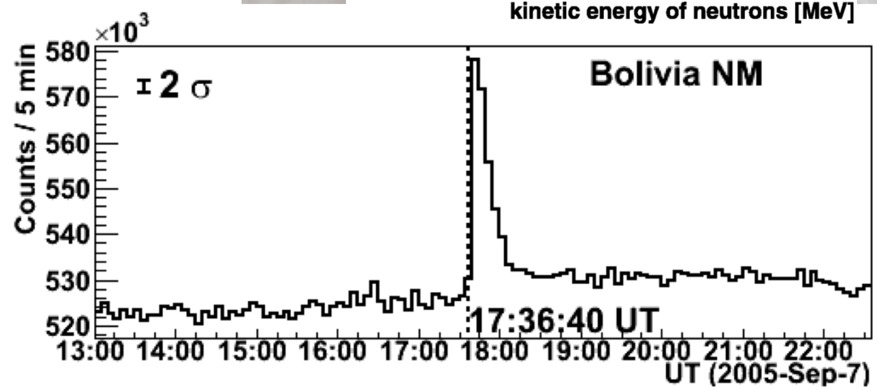
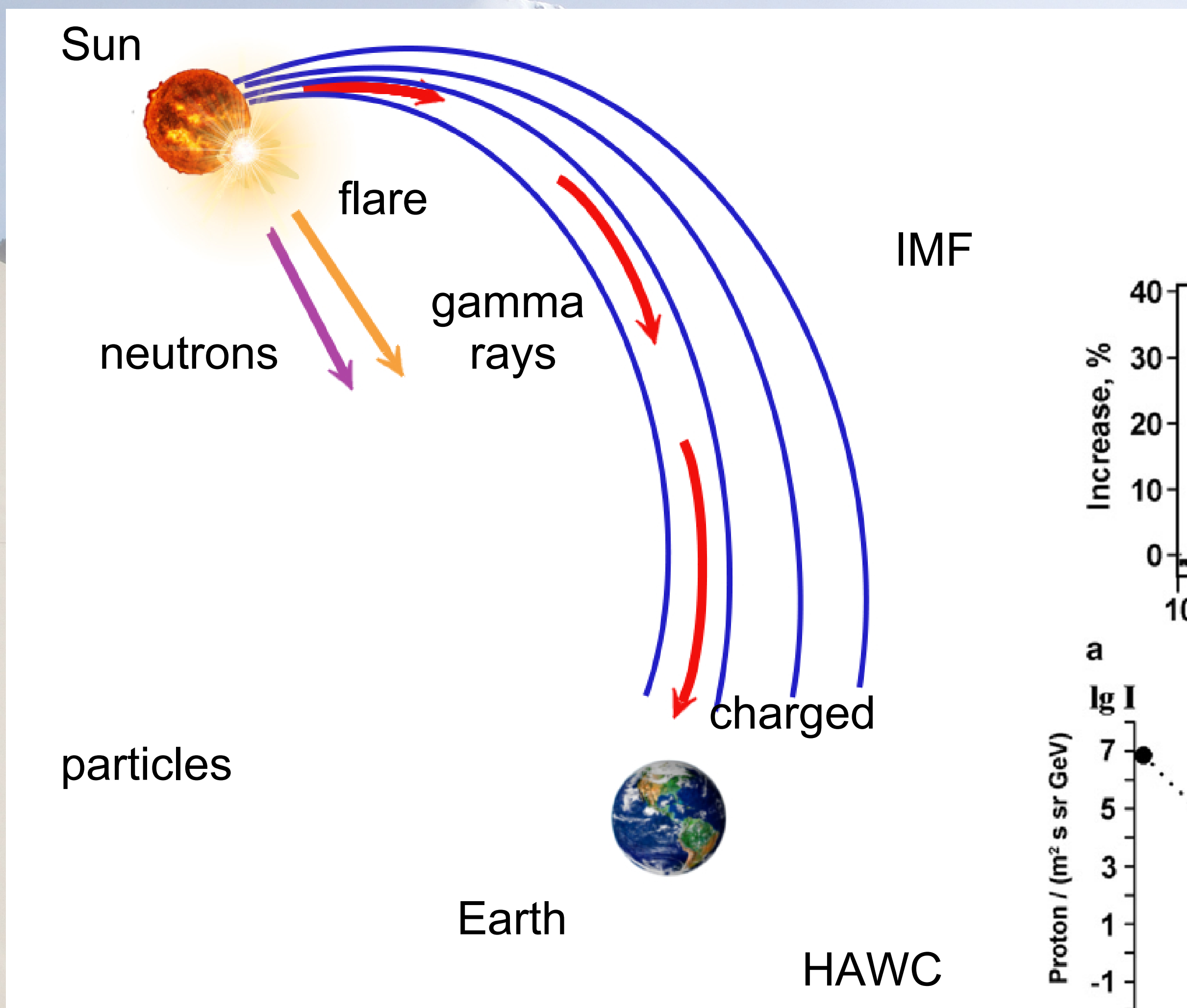


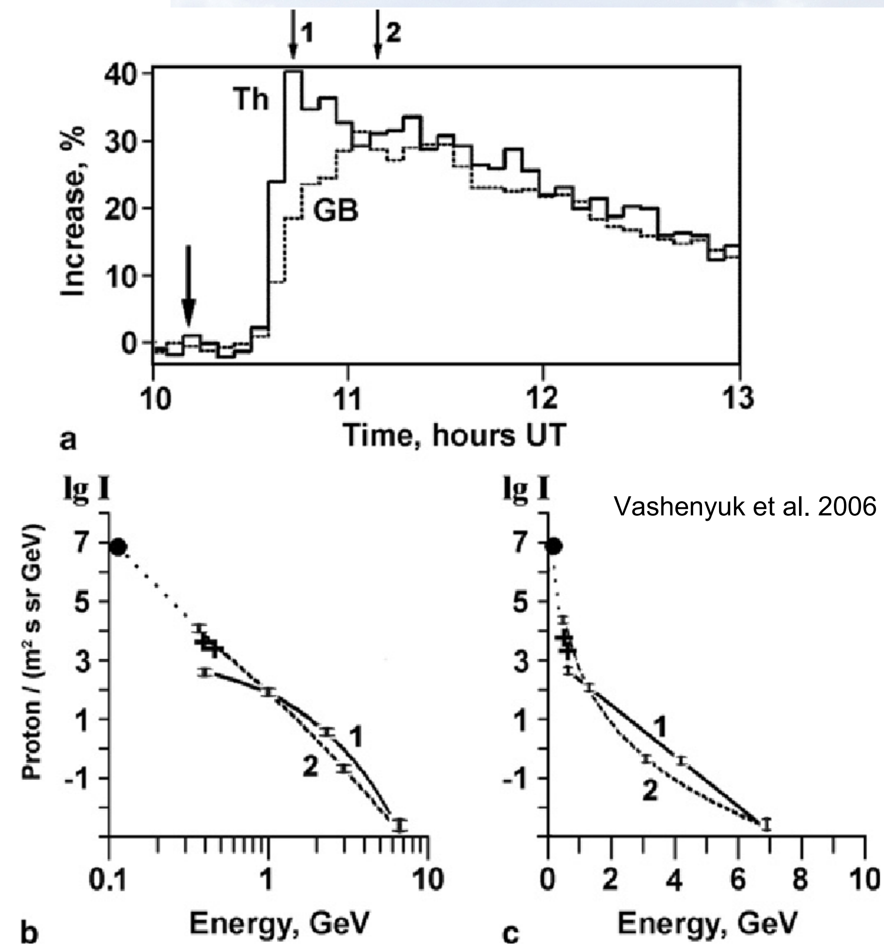
Figure 3: *The 5 minute counting rate observed by the Bolivia neutron monitor.* Watanabe et al. 2009

Solar Flares

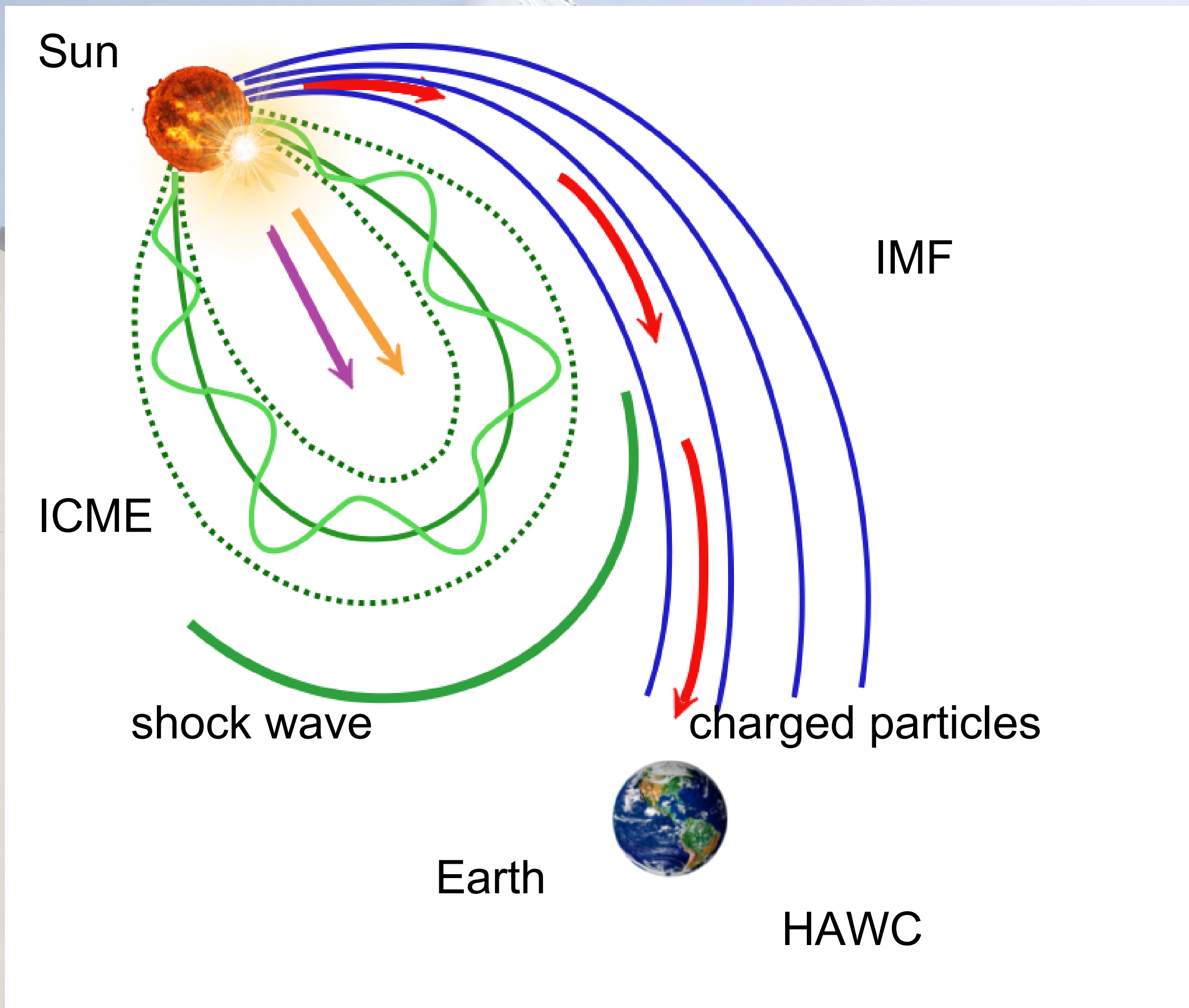
HAWC is able to detect:

Solar flare charged particles





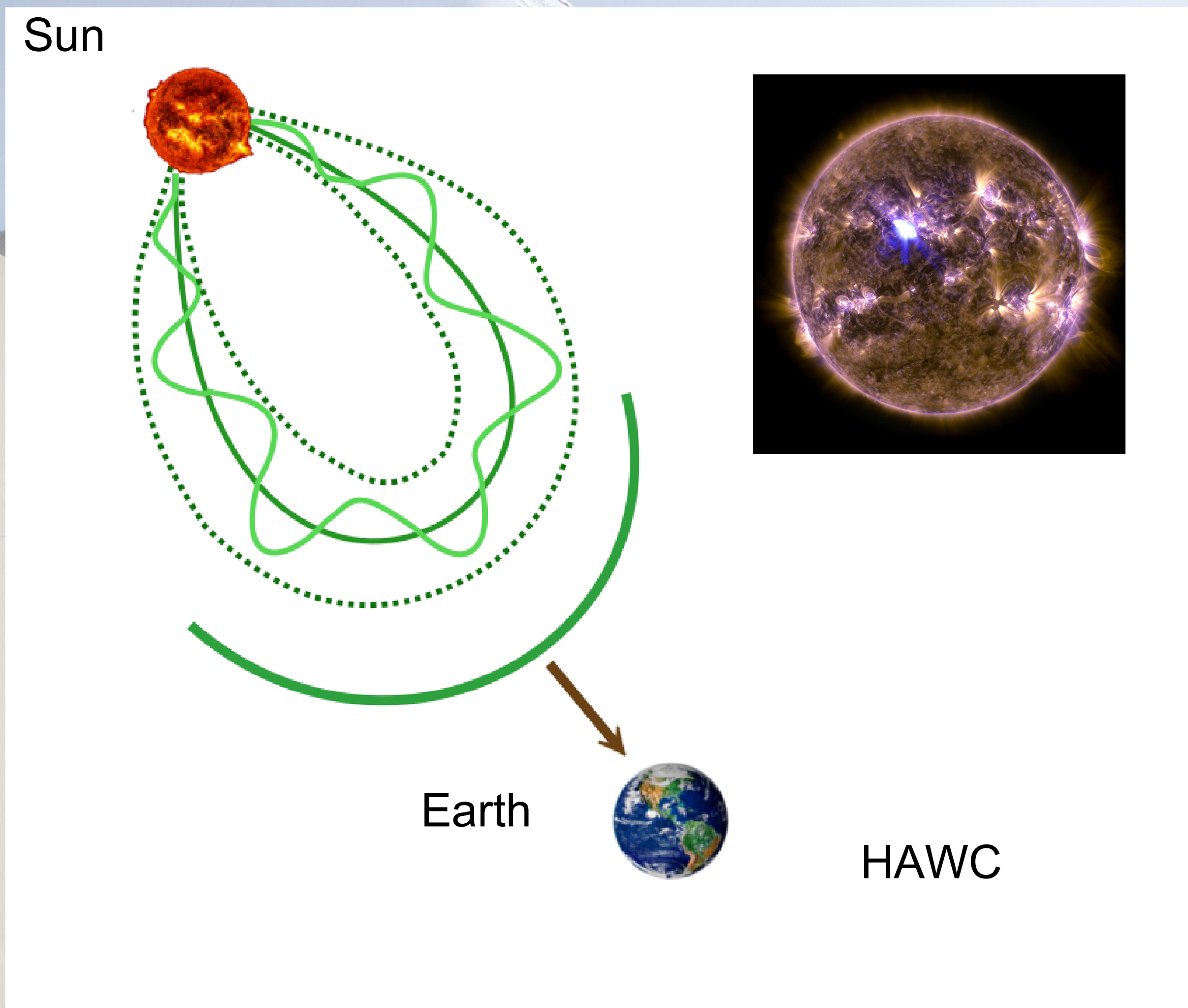
Solar Flares and Interplanetary Coronal Mass Ejections



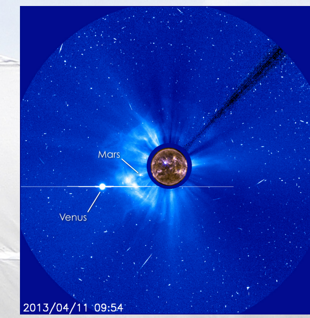
HAWC will detect also the effects of the Interplanetary Coronal Mass Ejections (ICMEs) on the galactic cosmic ray (GCR) flux:

Forbush decreases and other solar modulation on the GCR flux.

April 14, 2013 Forbush Decrease

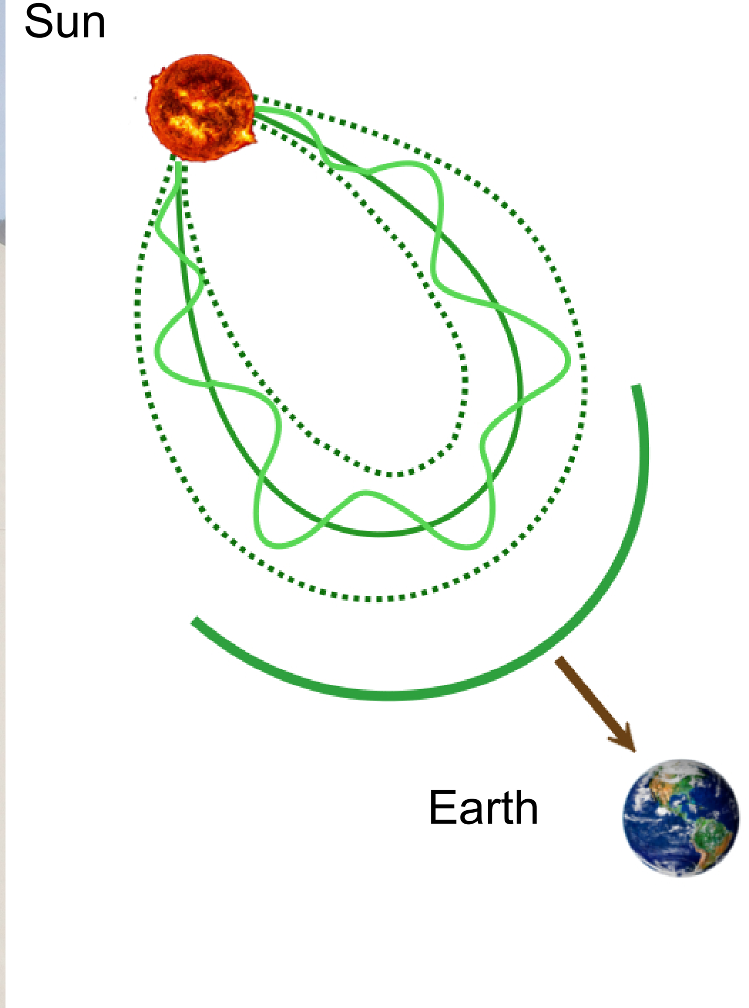


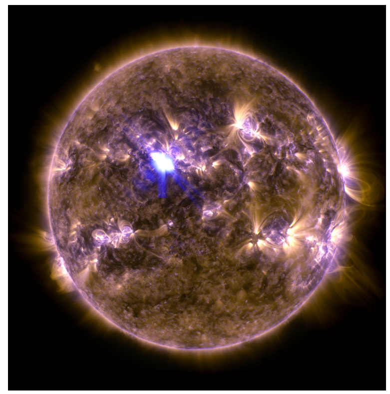
On April 14, 2013 HAWC (working with 30 WCDs,) observed a decrease on the GCR flux due to an ICME.



April 14, 2013 Forbush Decrease

On April 11, 2013 a M6.5 flare was observed close to the central meridian of the solar disk.





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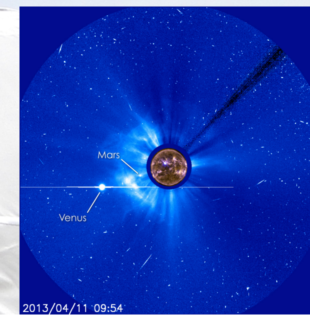
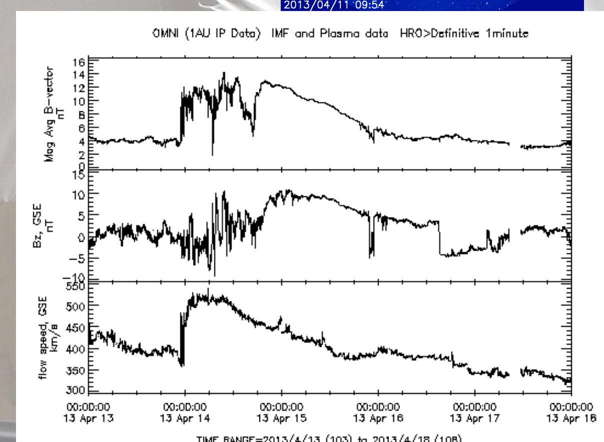
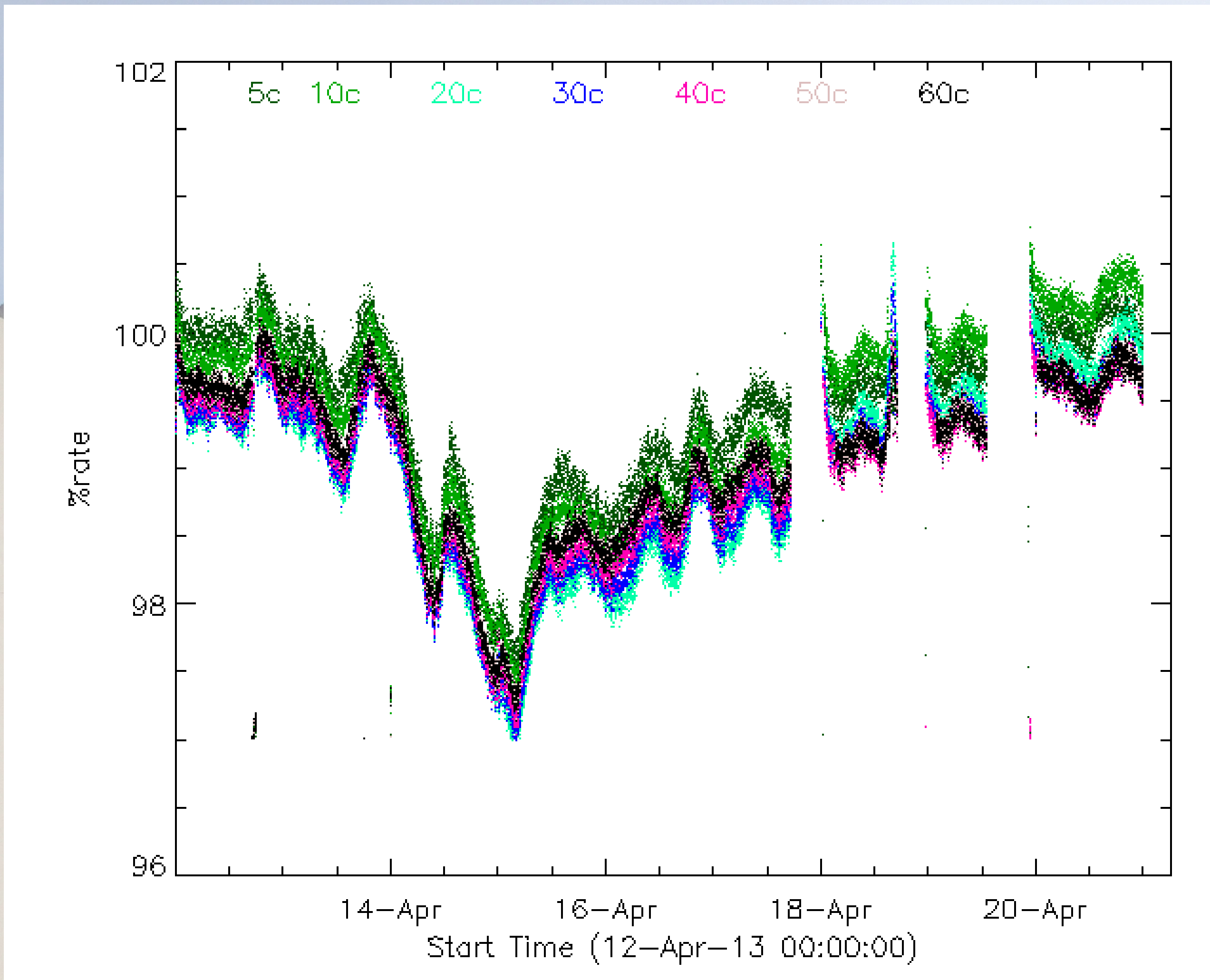
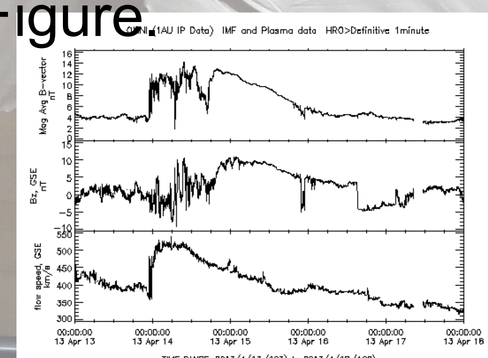




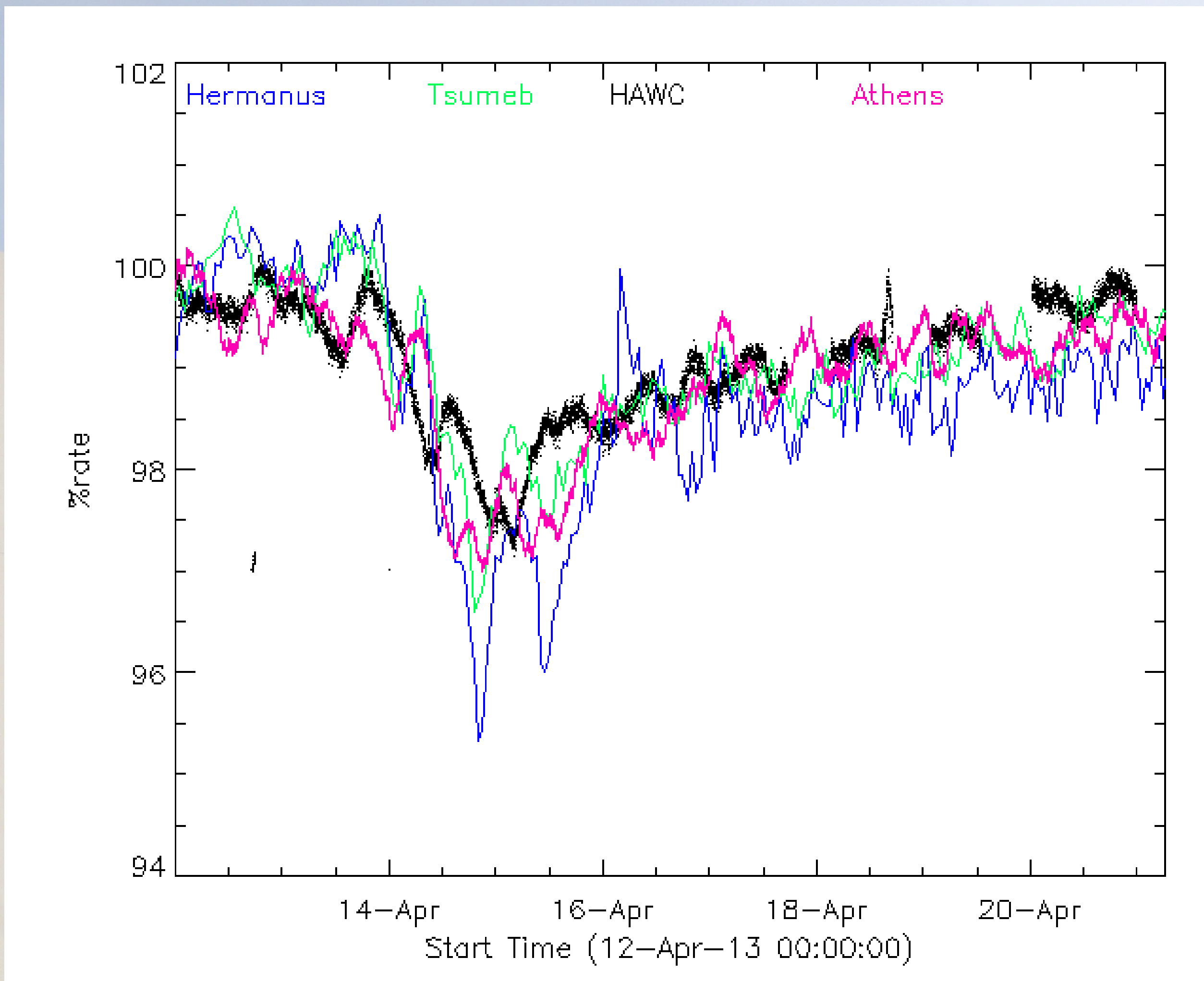
April 14, 2013 Forbush Decrease



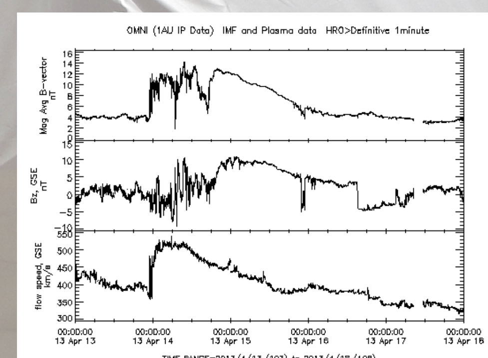
After barometric corrections, we constructed seven multiplicity sets, containing 5, 10, 20, 30, 40, 50 60 PMTs (or channels) shown in different colors in this Figure.



April 14, 2013 Forbush Decrease



Even though, we were in a early stage of construction, the performance of HAWC30 was very good as seen by the comparison of the FD observed by HAWC30 and three neutron monitors.



Another interesting question is about the FD precursors

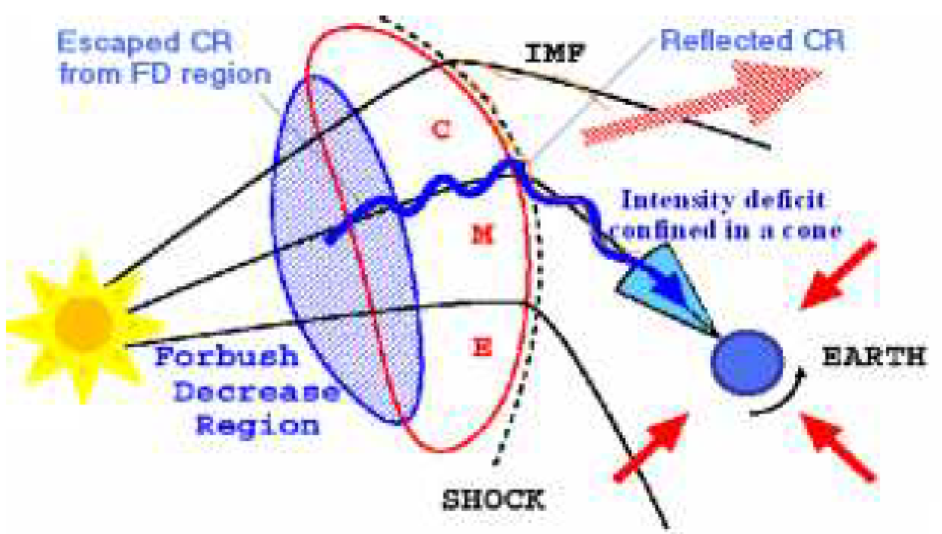
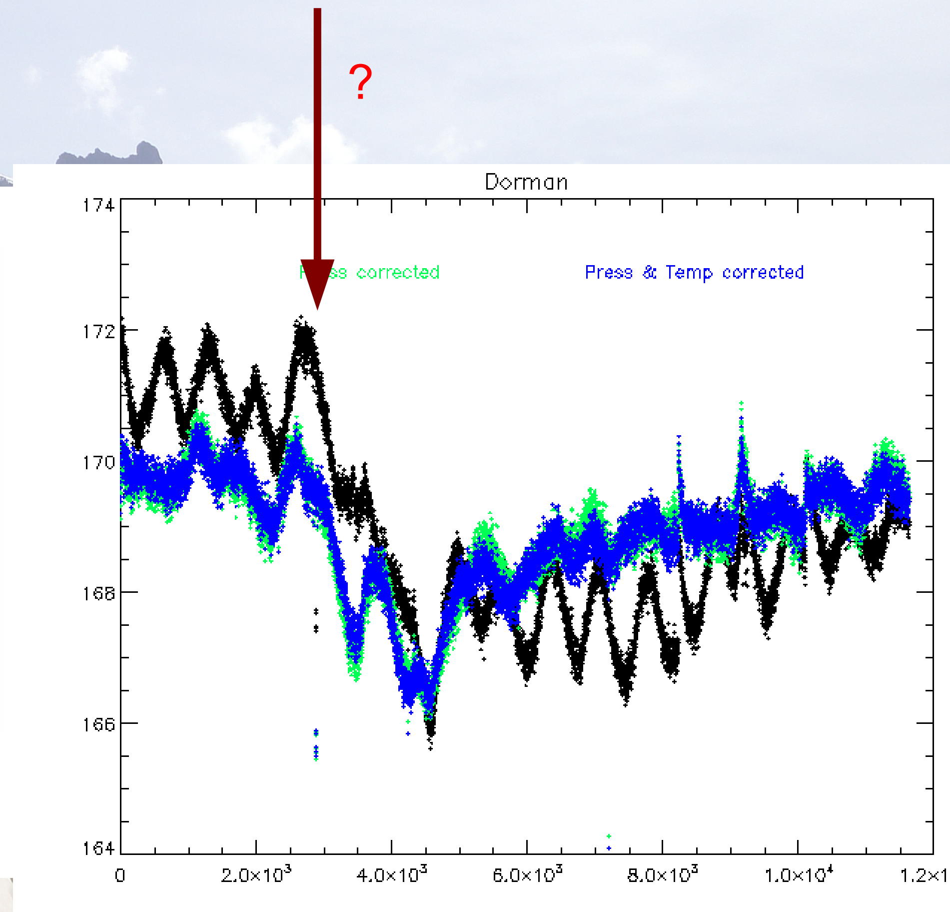
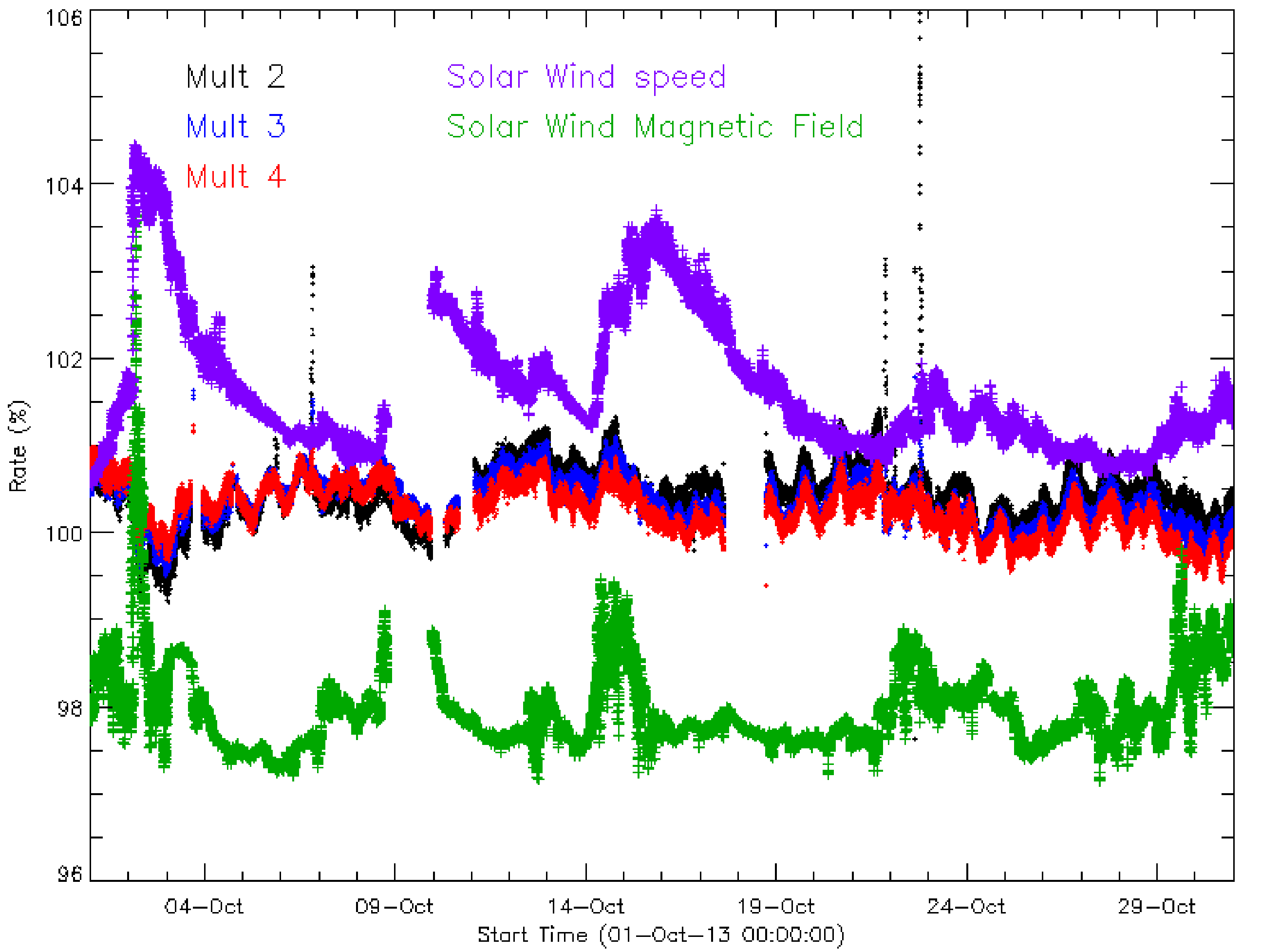


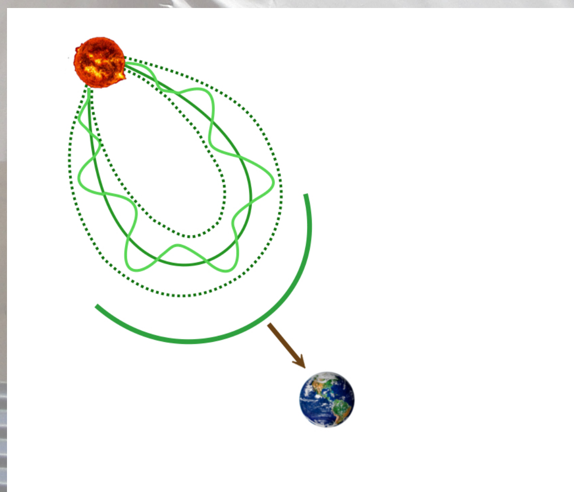
Fig. 1: Loss-cone effect.



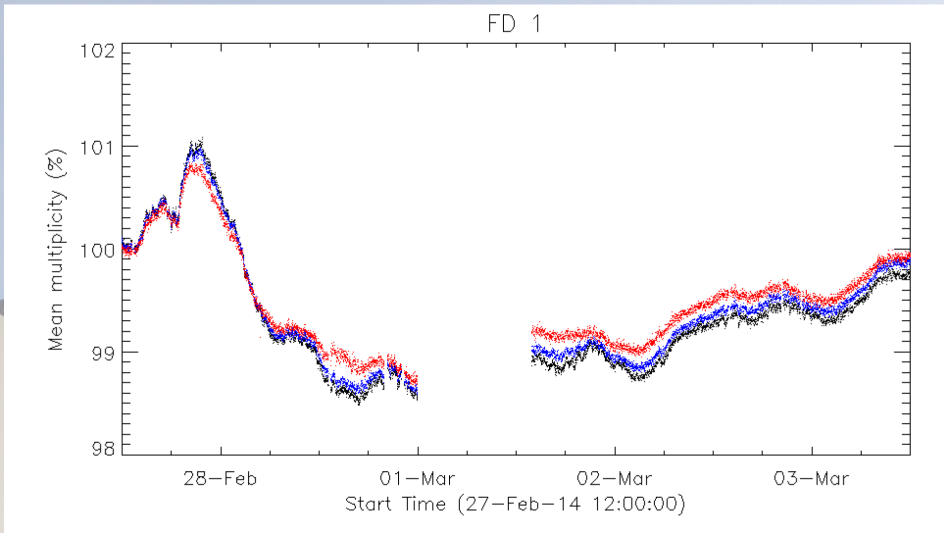
TDC Scaler rate during October 2014 and Solar Wind Data

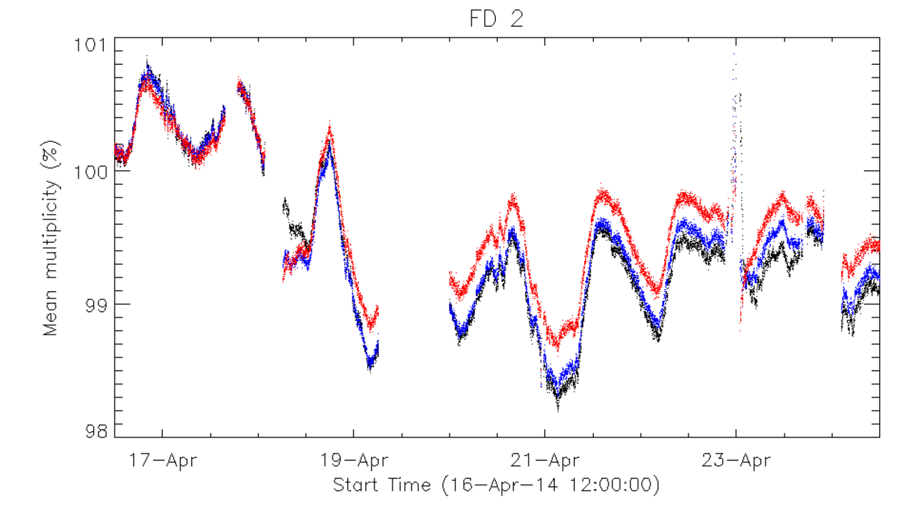


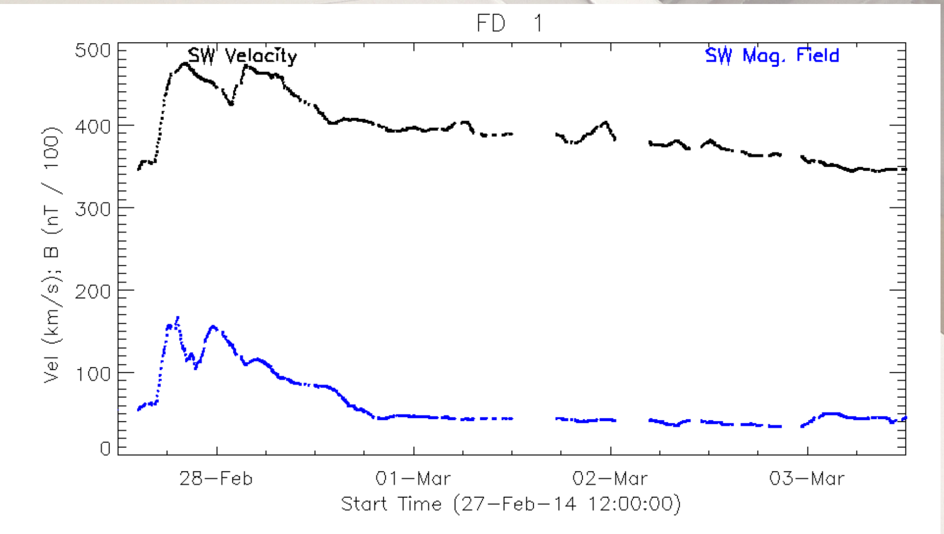
It is clear the HAWC is highly sensitive to the magnetic structures (and velocity) of the solar wind.

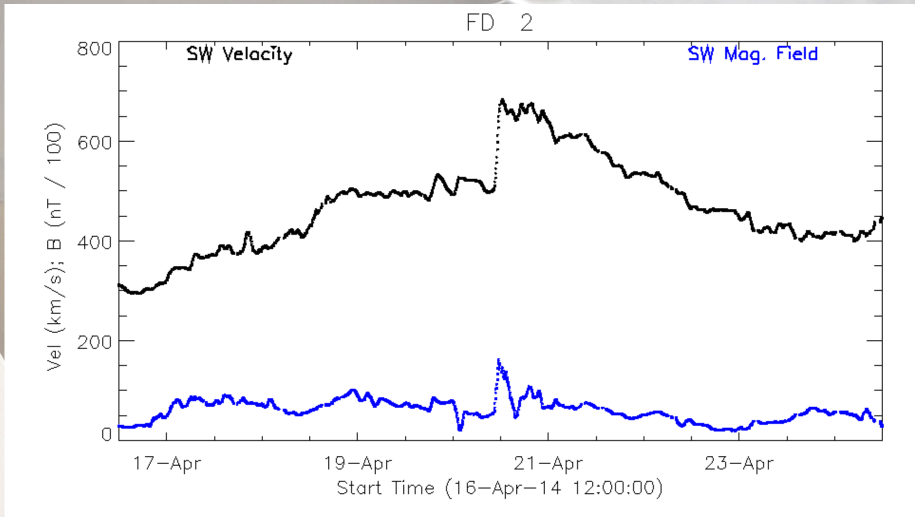


Feb 2014 & Apr 2014

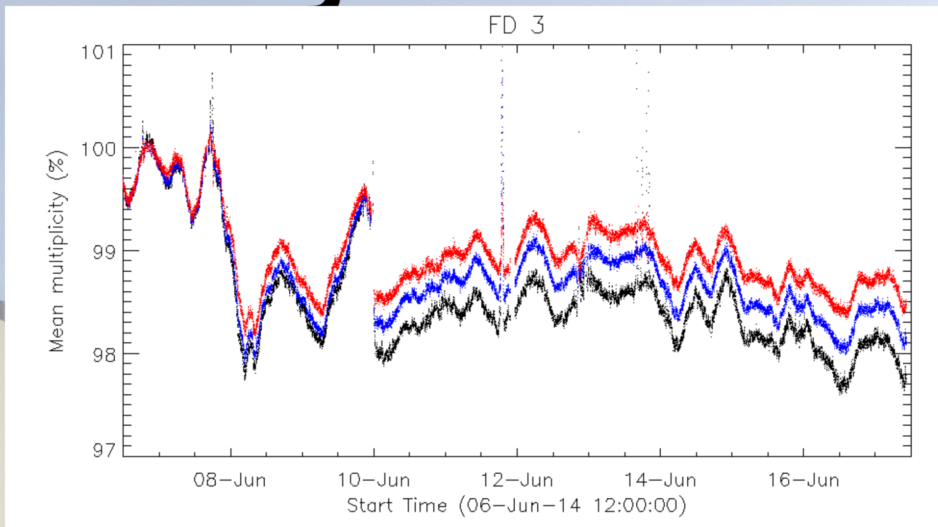


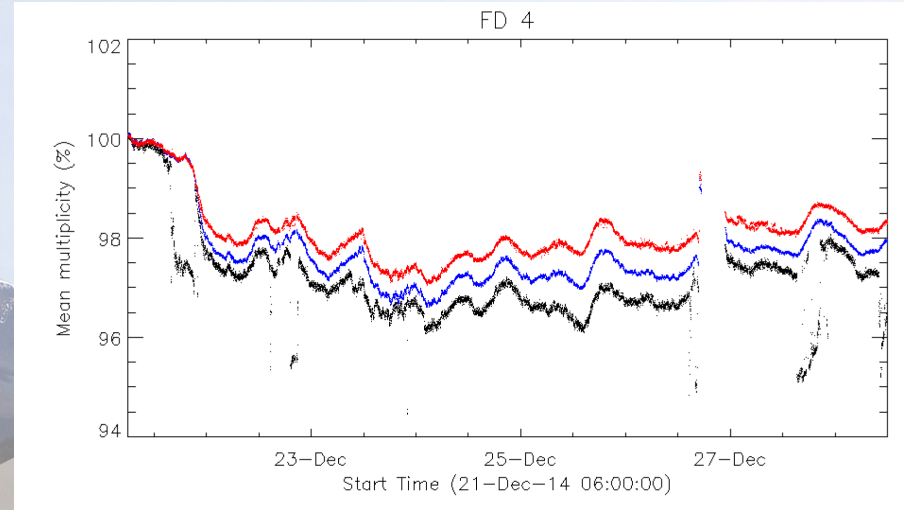


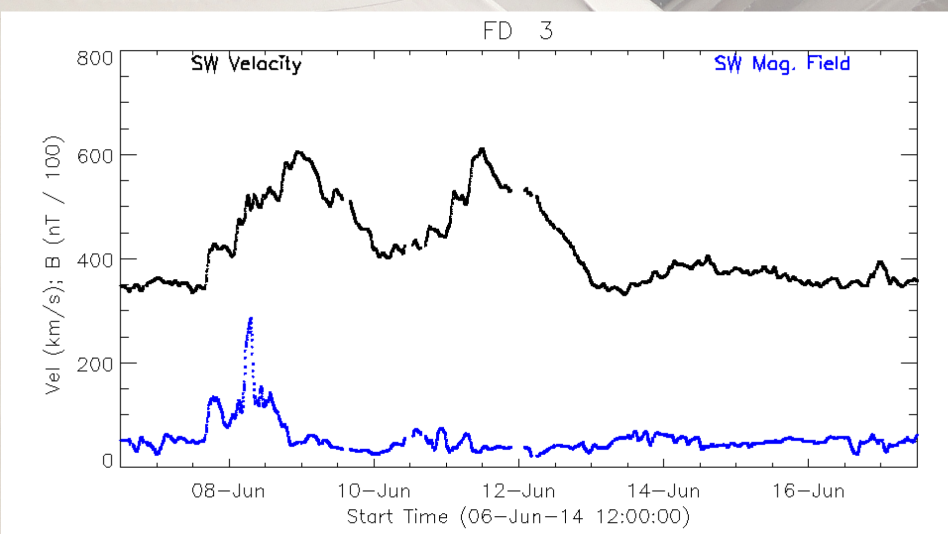


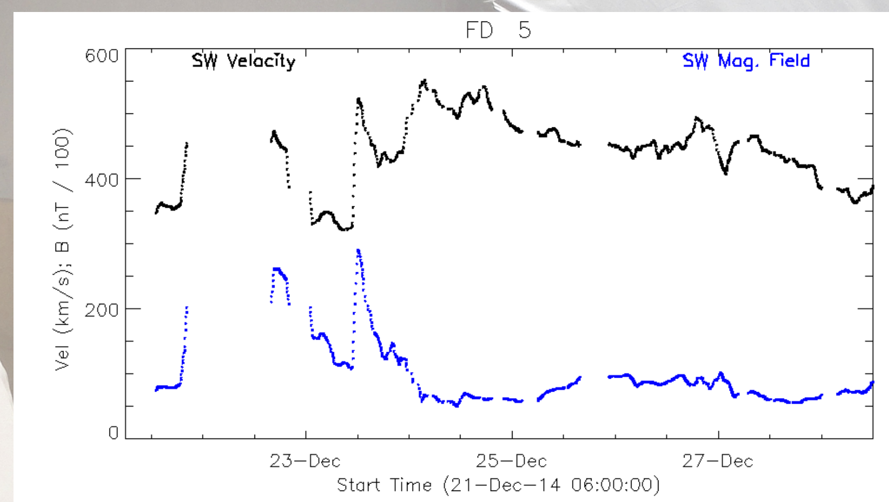


Jun 2014 & Dec 2014

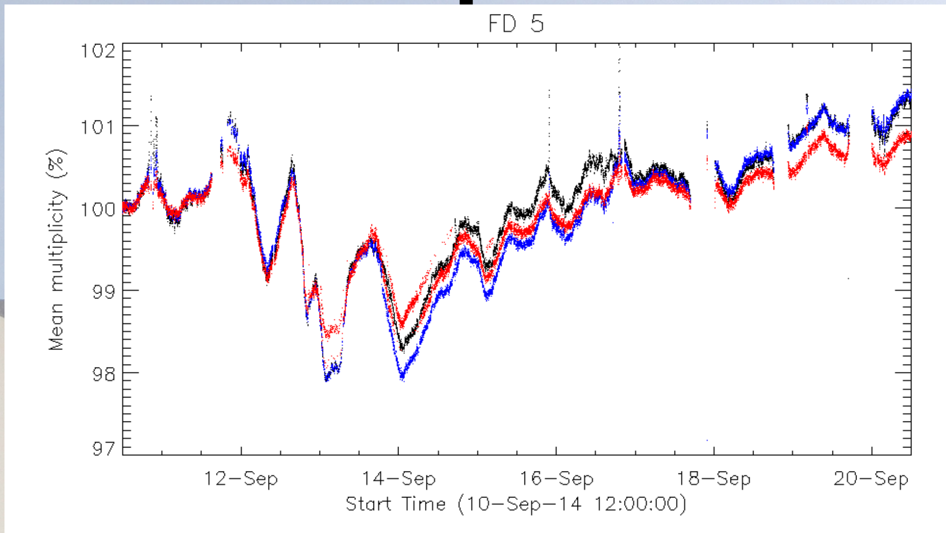


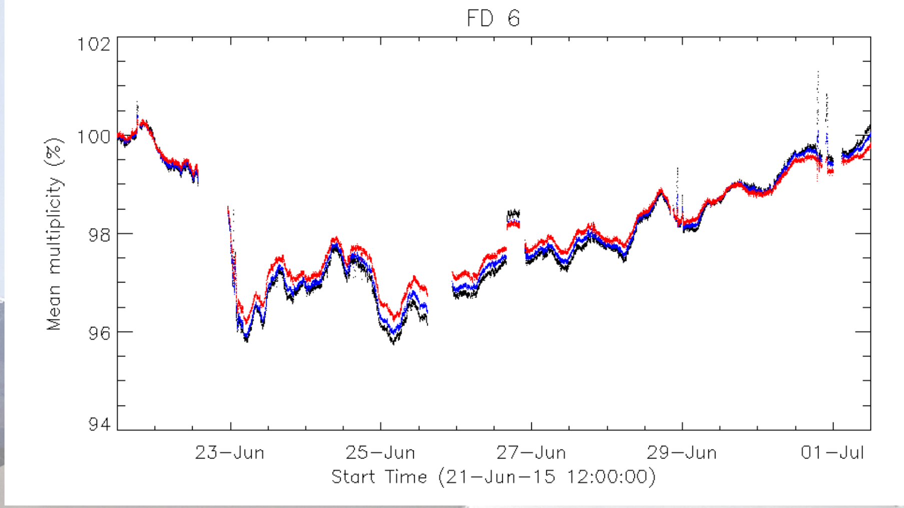


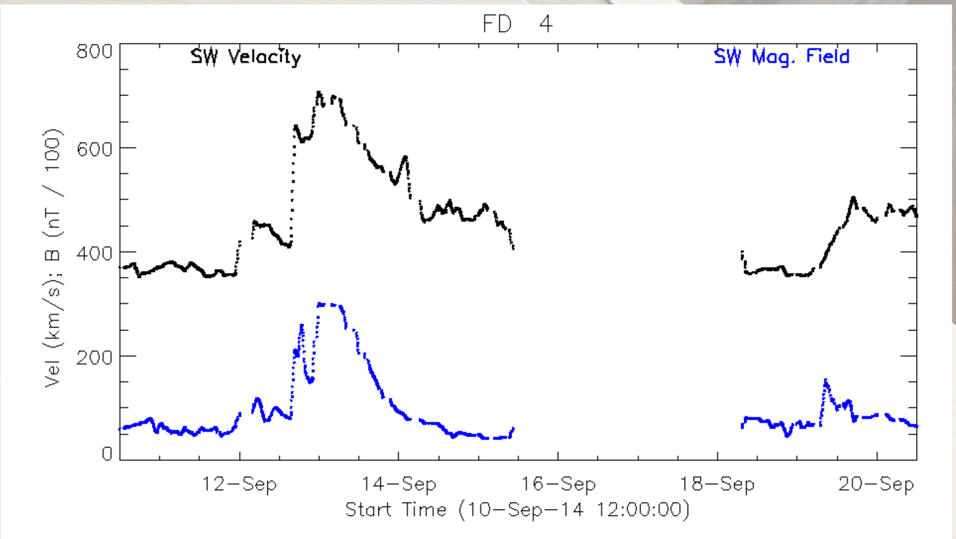


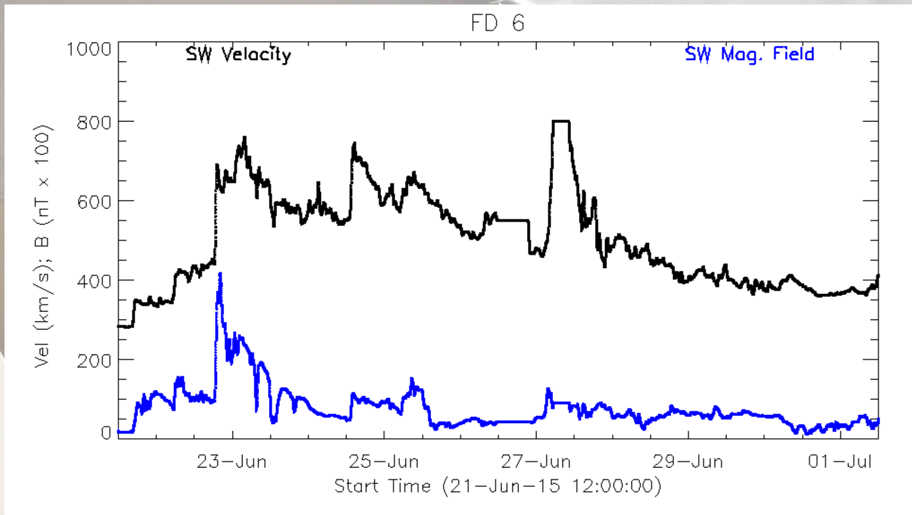


Sep 2014 & Jun 2015







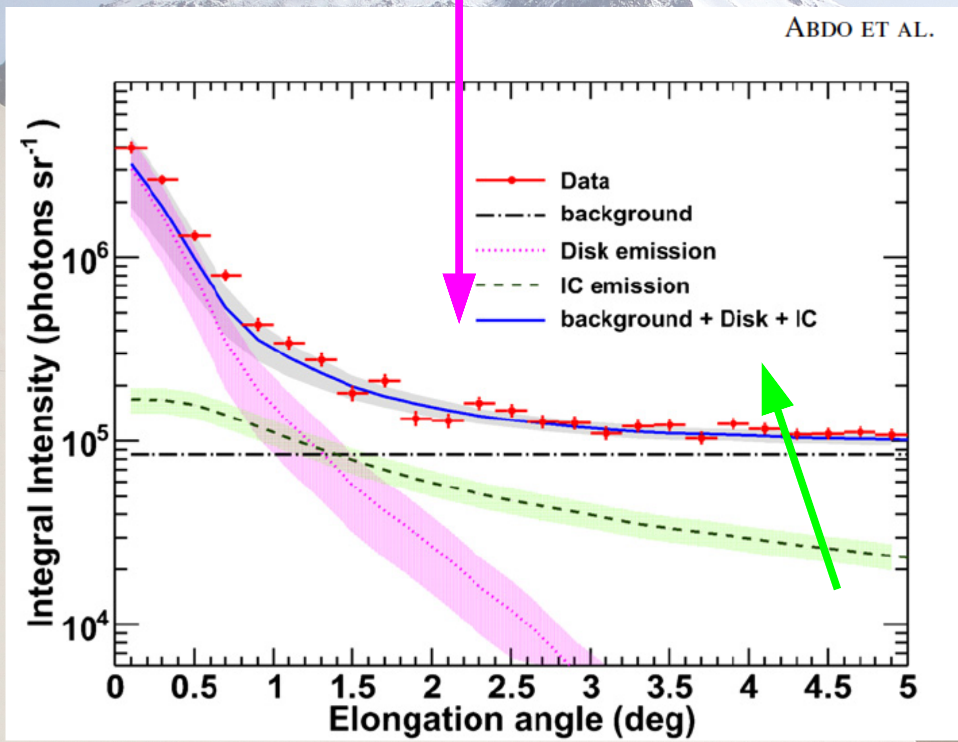


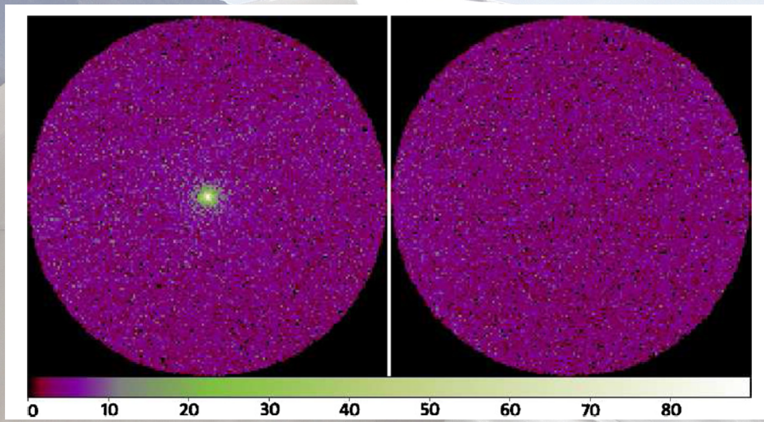
Sun gamma ray emission

Pulse para añadir texto

2011

Disk emission due to GCR showers in the solar atmosphere





Inverse Compton emission due to the GCR electrons and solar photons

Summary

- HAWC will be an excellent tool to explore the high energy limit of solar energetic particles.
- A single array will give us information about:

  Charged particles accelerated during the flare and the CME driven shock

  Neutrons and gamma rays generated by the flare and unaffected by magnetic fields.
- HAWC will allow us to study, with great detail, Forbush decreases and therefore understand better the large scale ICME magnetic field.