Interplanetary Magnetic Flux Rope Observed by HAWC

Alejandro Lara[1],
Arun Babu, Tatiana Niembro
for the HAWC Collaboration

[1]Instituto de Geofísica, UNAM

alara@igeofisica.unam.mx

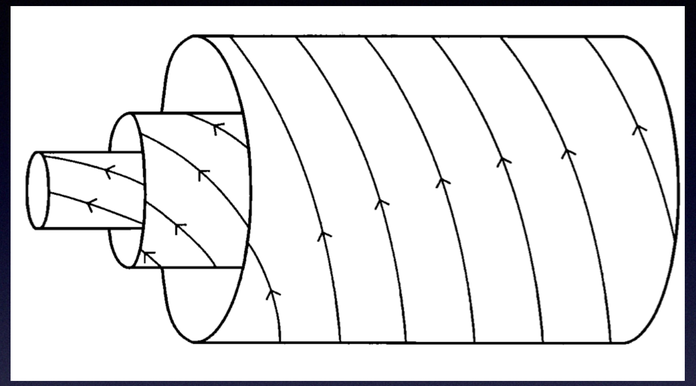
Outline

- Magnetic Flux Rope (MFR)
- MFR in the Interplanetary Medium
- The HAWC observatory and solar modulation
- The October 2016 event
- The MFR - GCR interaction model
- Conclusions

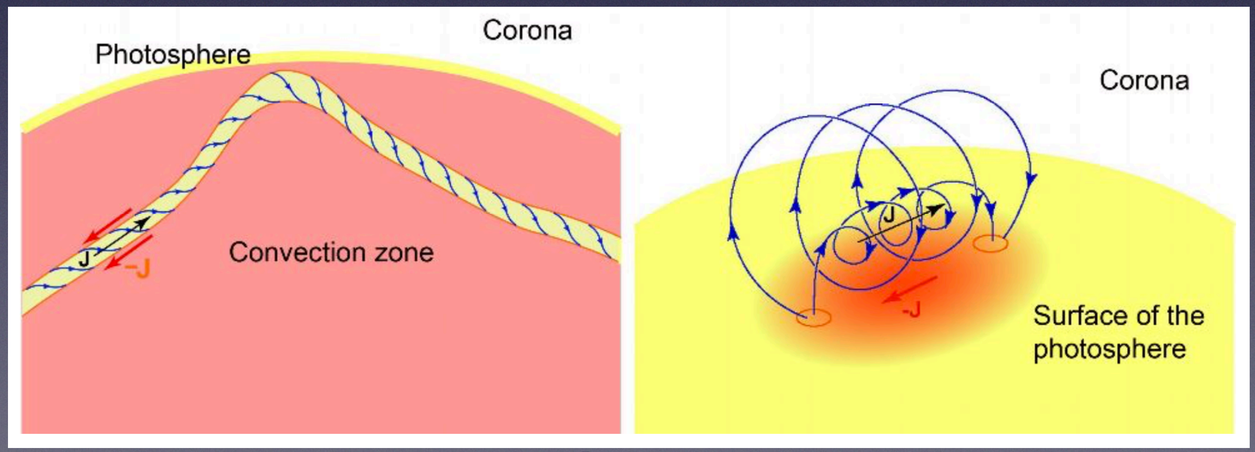
MFR - Magnetic Flux Ropes

- Magnetic flux ropes (MFR) are characterized by coherently twisted magnetic field lines, which are ubiquitous in magnetized plasmas.

- In the Sun MFR can emerge already formed from the interior or they can be formed in the atmosphere by photospheric movements, and are associated with magnetic polarity reversal lines.

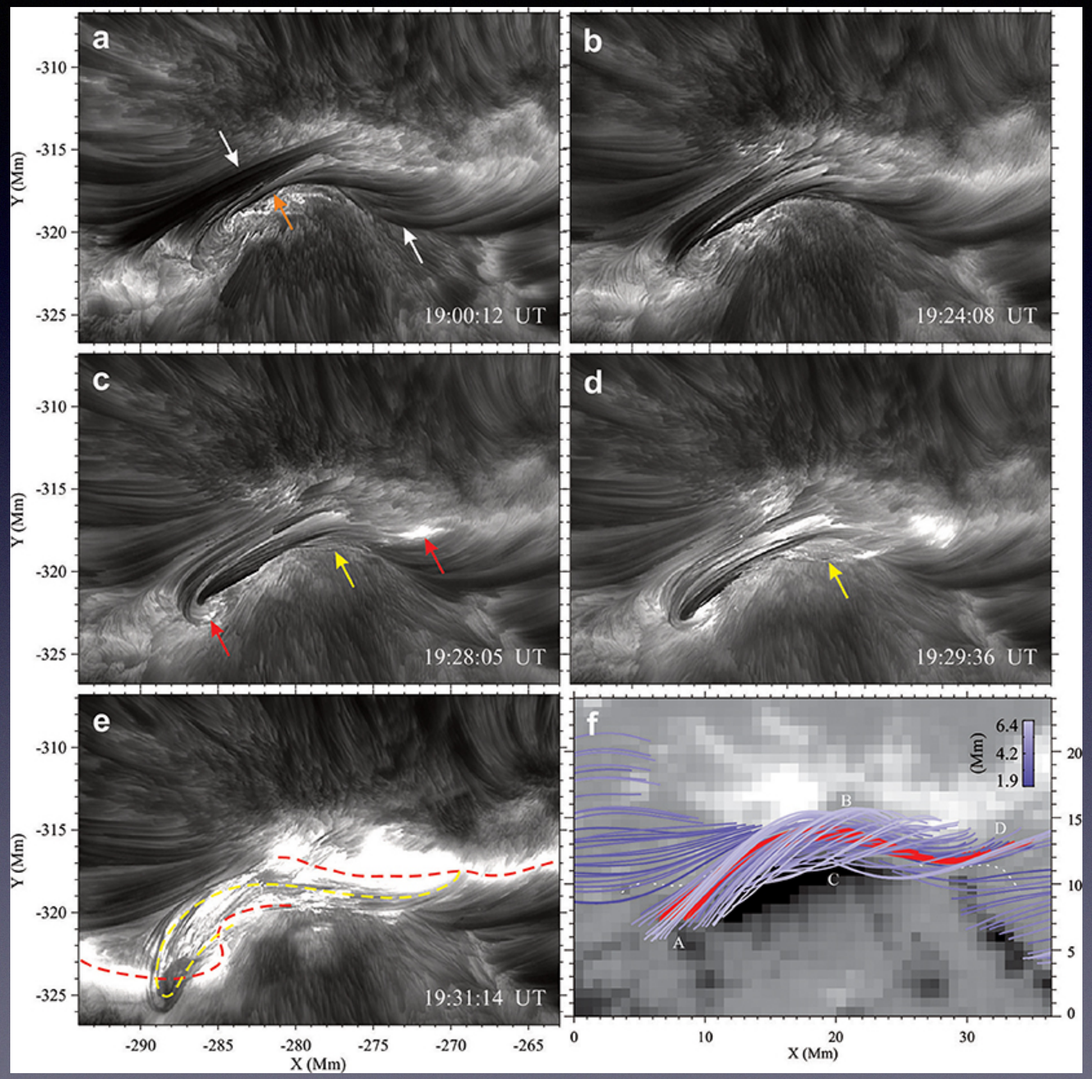


Russell, Priest and Lee, 1989

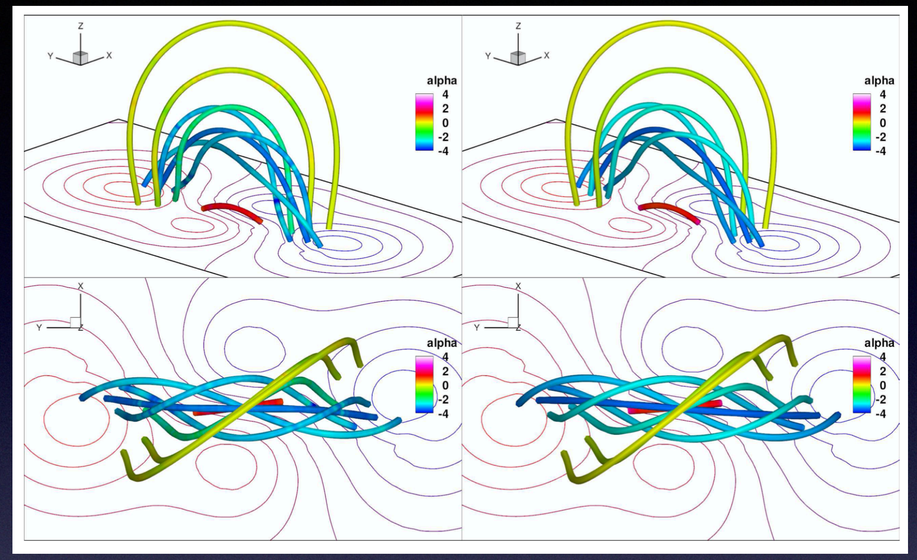


Filippov, Martsenyuk, Srivastava and Uddin 2015

MFR at the low atmospheric levels

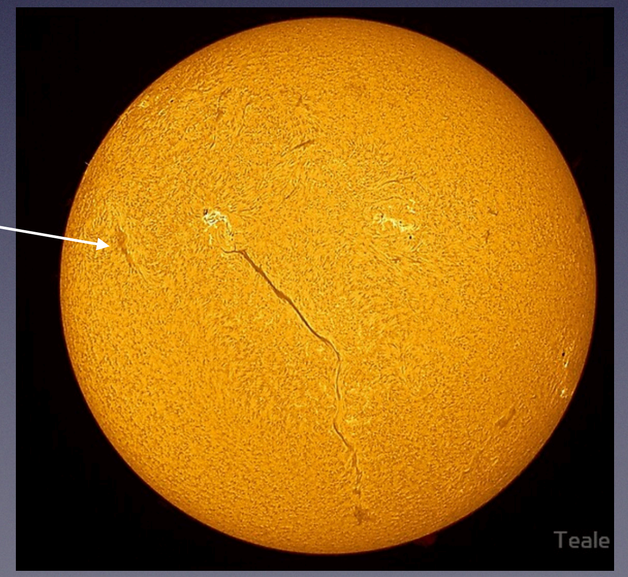


Wnag and Liu, 2019

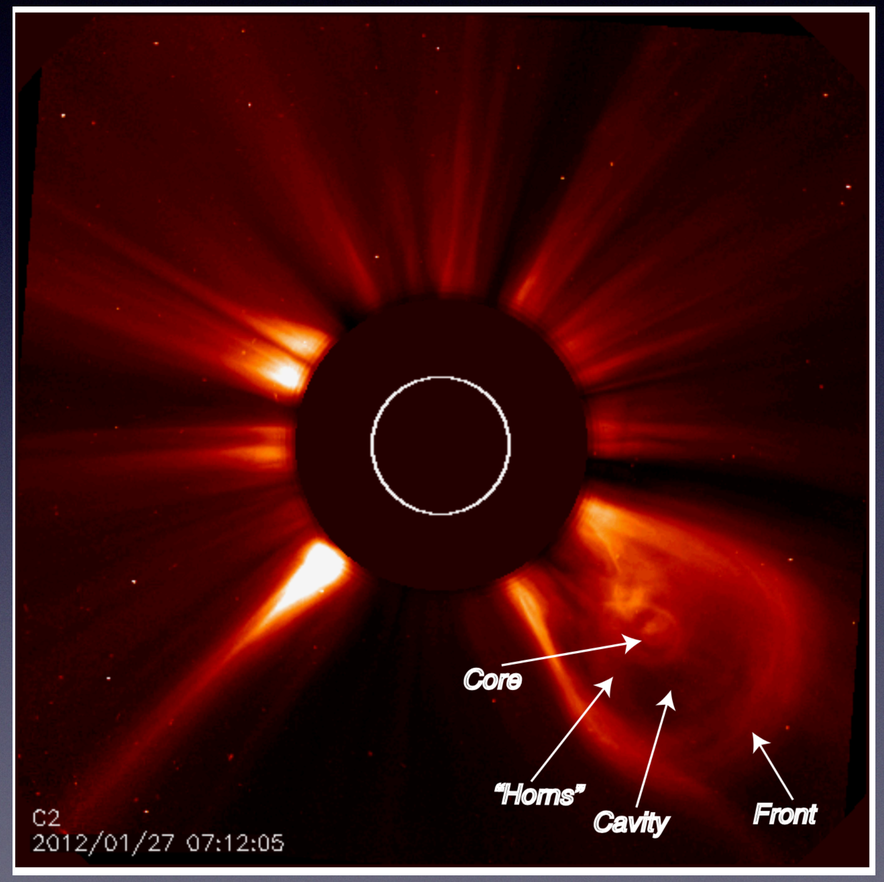


Jiang and Feng, 2016

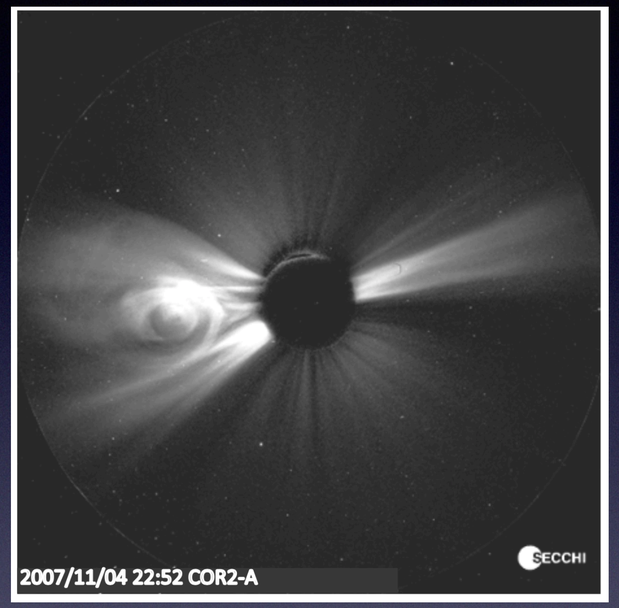
MFR are seen as Filaments or protuberances which may destabilize and erupt



MFR and CMEs

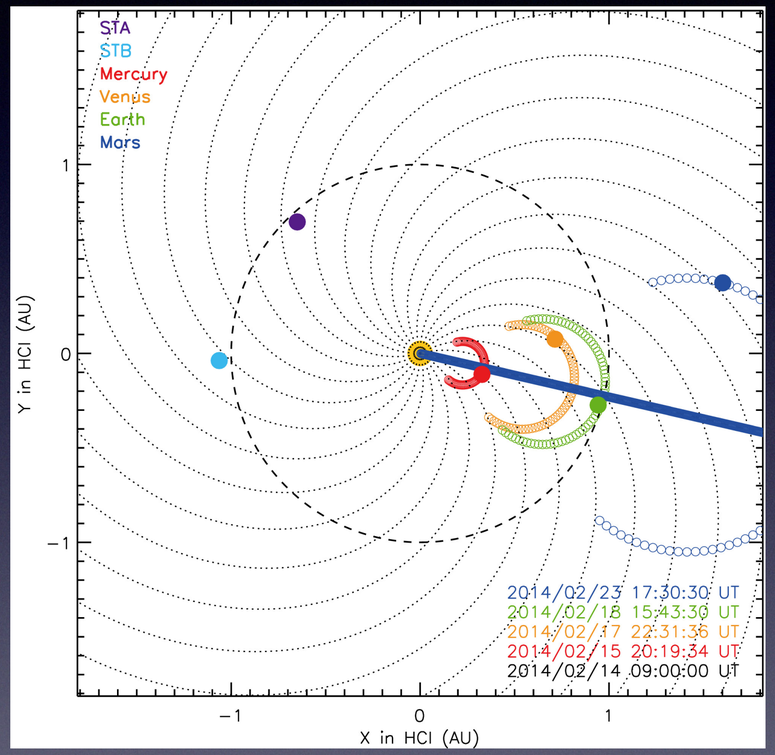


Vourlidas et al, 2012

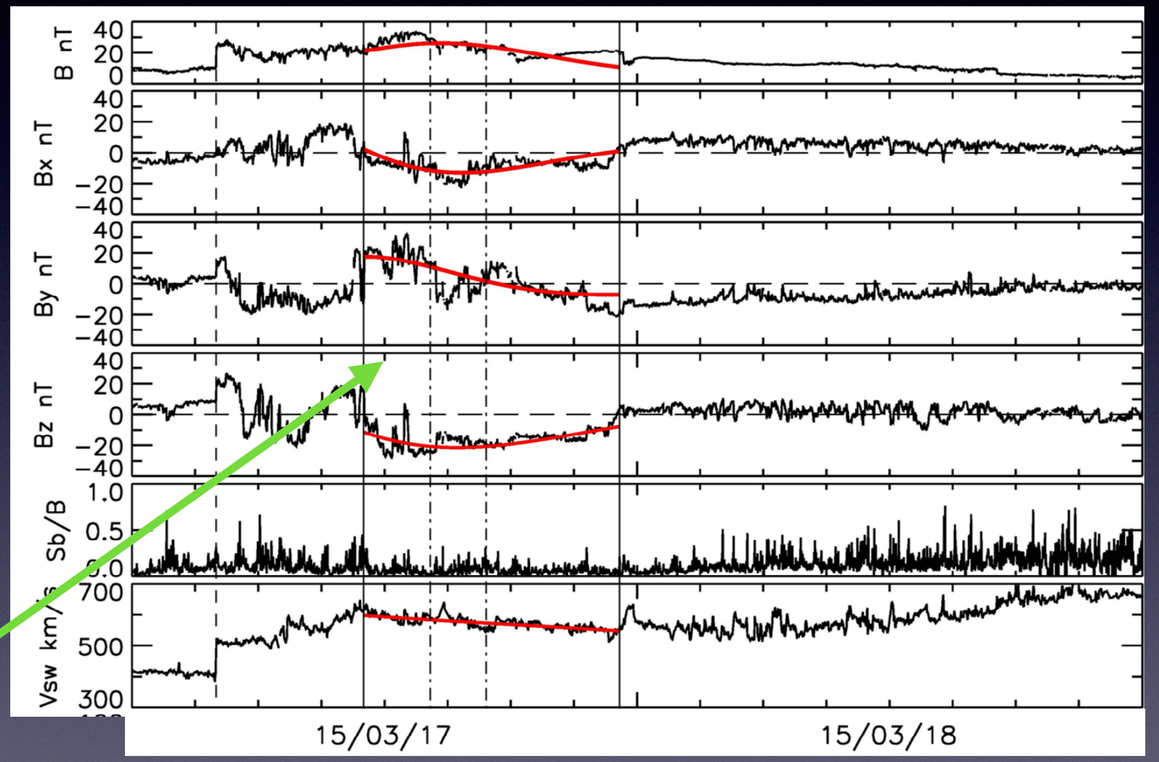


The MFR are expelled from the Sun through Coronal Mass Ejections (CMEs)

Then, the MFR are transported through the Interplanetary medium by ICMEs and form “magnetic clouds”



At the Earth the MFR have dimensions comparable with 0.5 AU



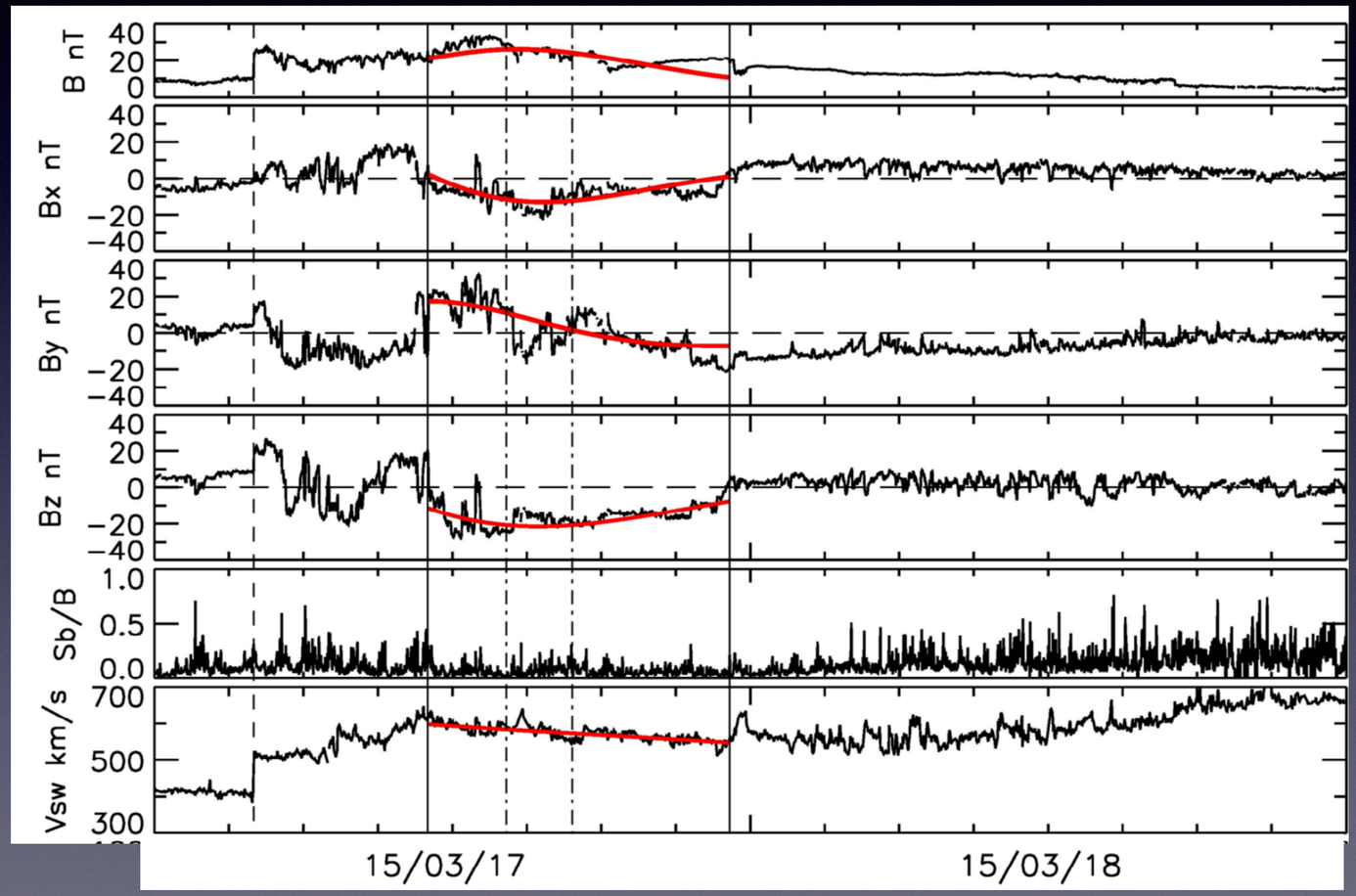
Wang et al. 2018

Marubashi et al. 2016

MFR are characterized by a rotation of magnetic field

MFR in the Interplanetary medium near Earth

- Velocity 400 to 1000 km/s
- Magnetic field 10 to 50 nT
- Density <10 part/cm^3
- Temperature10^5 K
- Collision-less
- Dimensions ~ 0.5 UA
- Magnetic field rotation



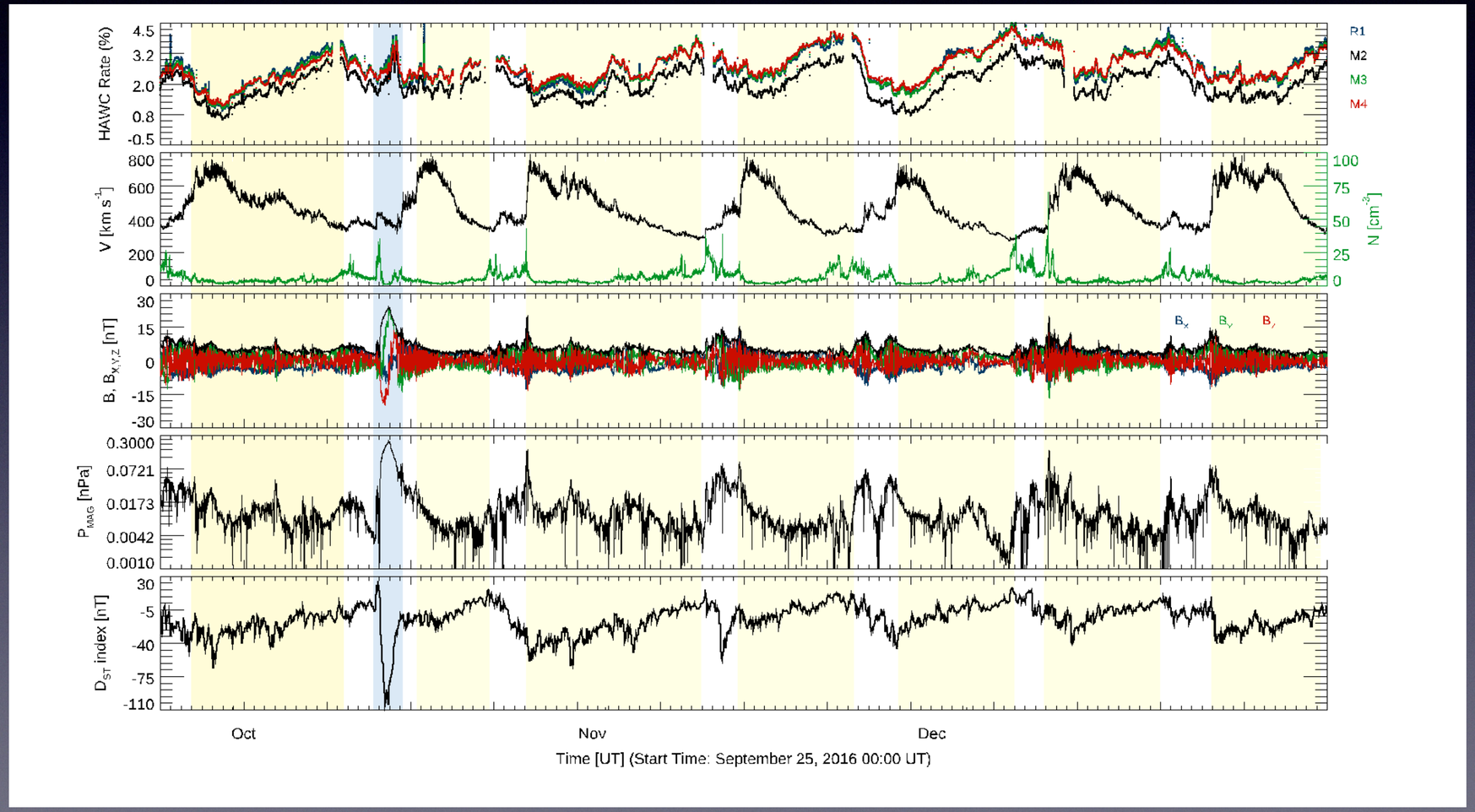
Marubashi et al. 2016

HAWC

- Detector of High eneergy cosmic rays
- 300 Water Cheremkov Detectors
- 1 200 photo multipliers (PMTs)
- Main detector area 22 000 m^2
- Altitud 4100 m asl
-

HAWC
As a space weather detector

The TDC-scaler system
Captures the low energy GCR rate with high time cadence in four multiplicities, with 1200 PMTs



HAWC

SW-V

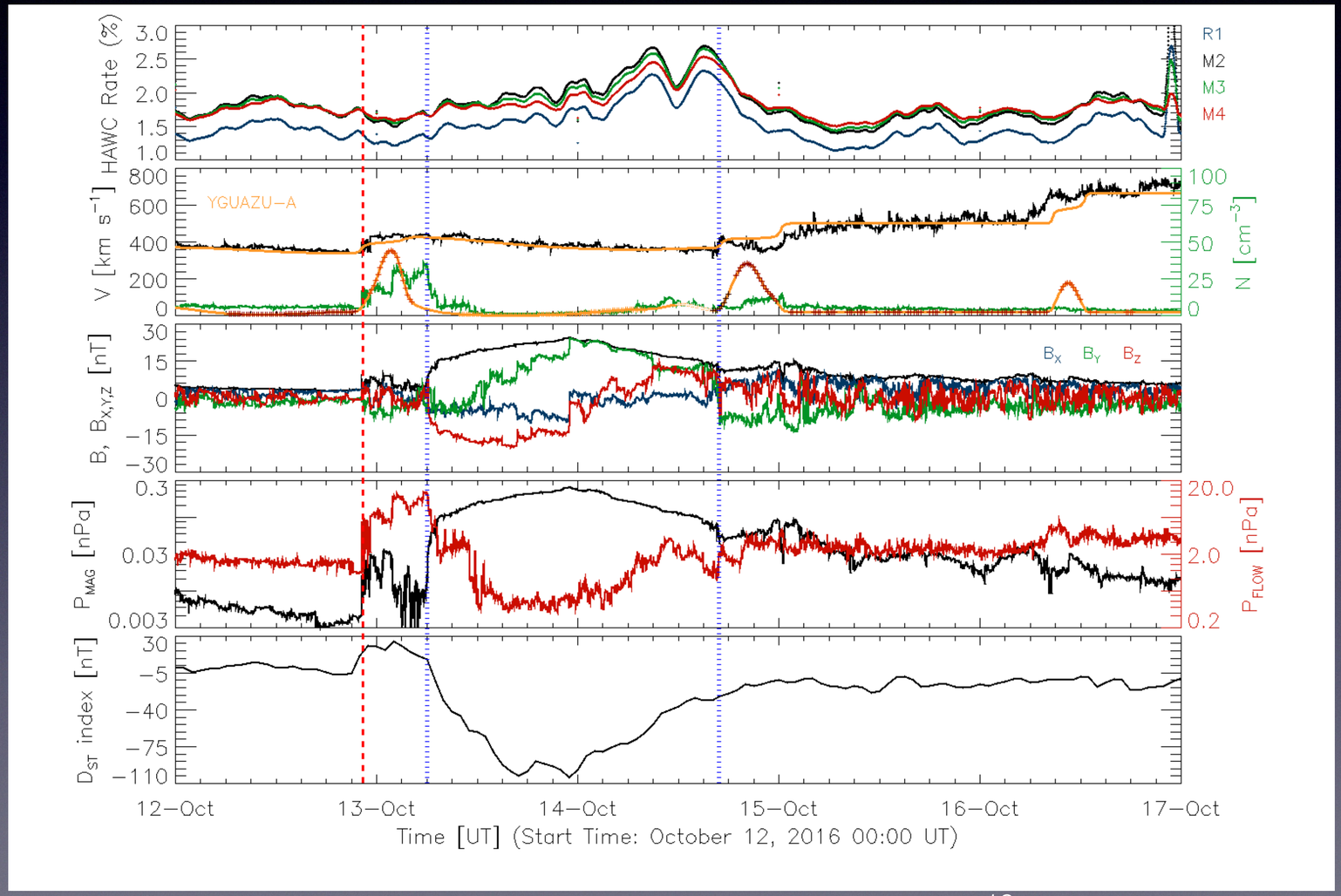
SW-B

SW-P

DST

Akiyama et al 2020

The October 2016 event
HAWC TDC-scaler Rate increase



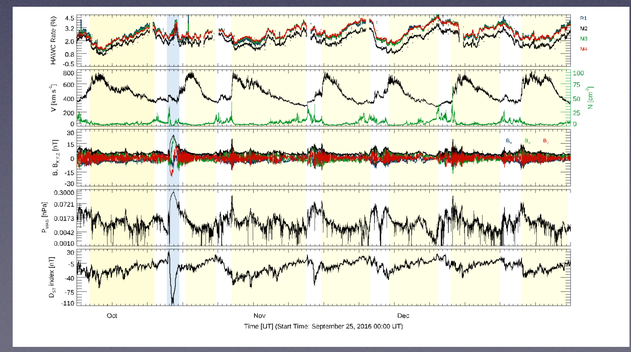
GCR rate

SW velocity and density

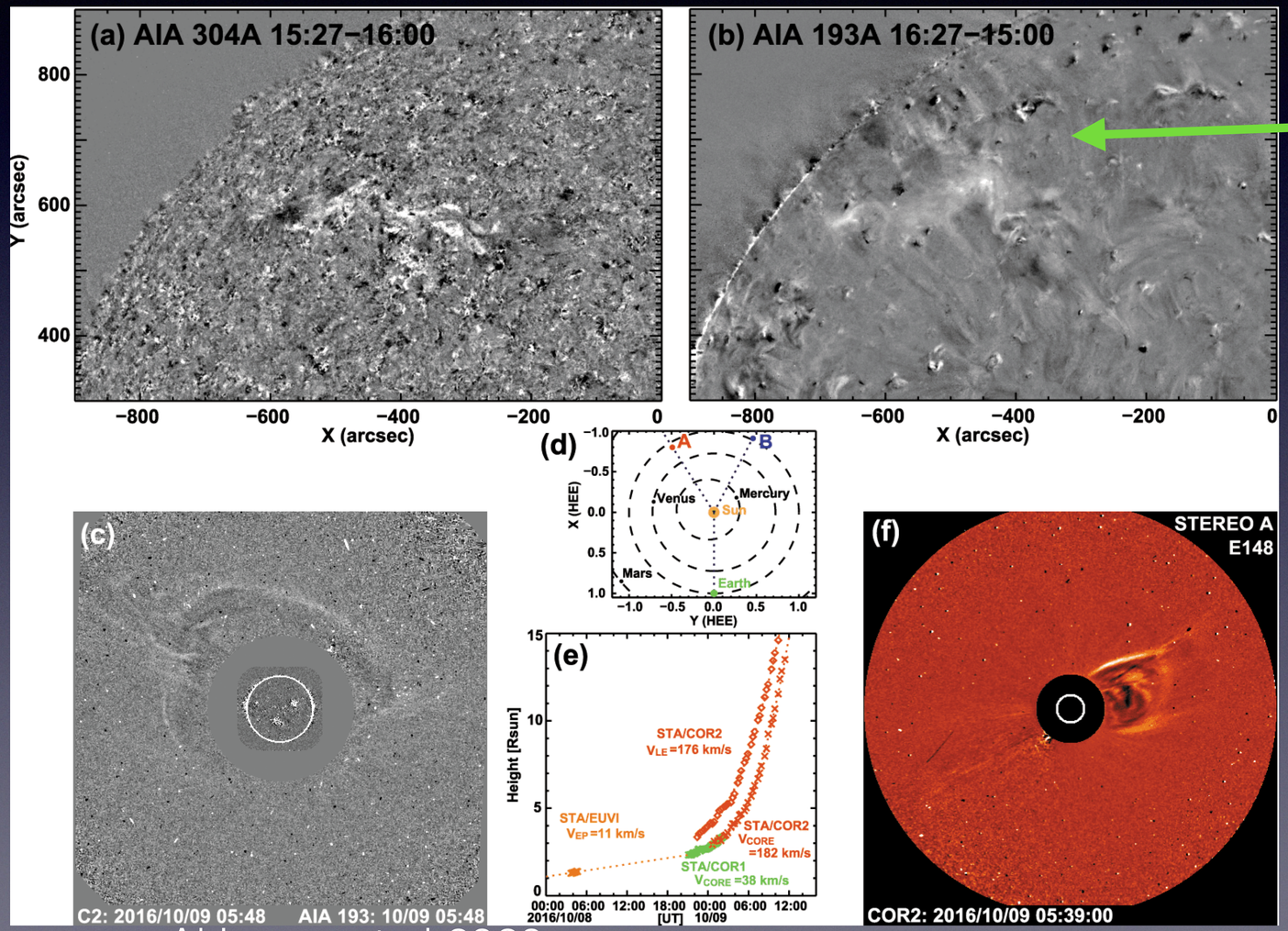
SW Magnetic Field

SW Press

DST



The October 2016 event solar origin



October 8
A filament activation

October 9
A slow V< 200 km/s CME was observed as halo CME by Lasco and limb CME by Stereo A

Akiyama et al 2020

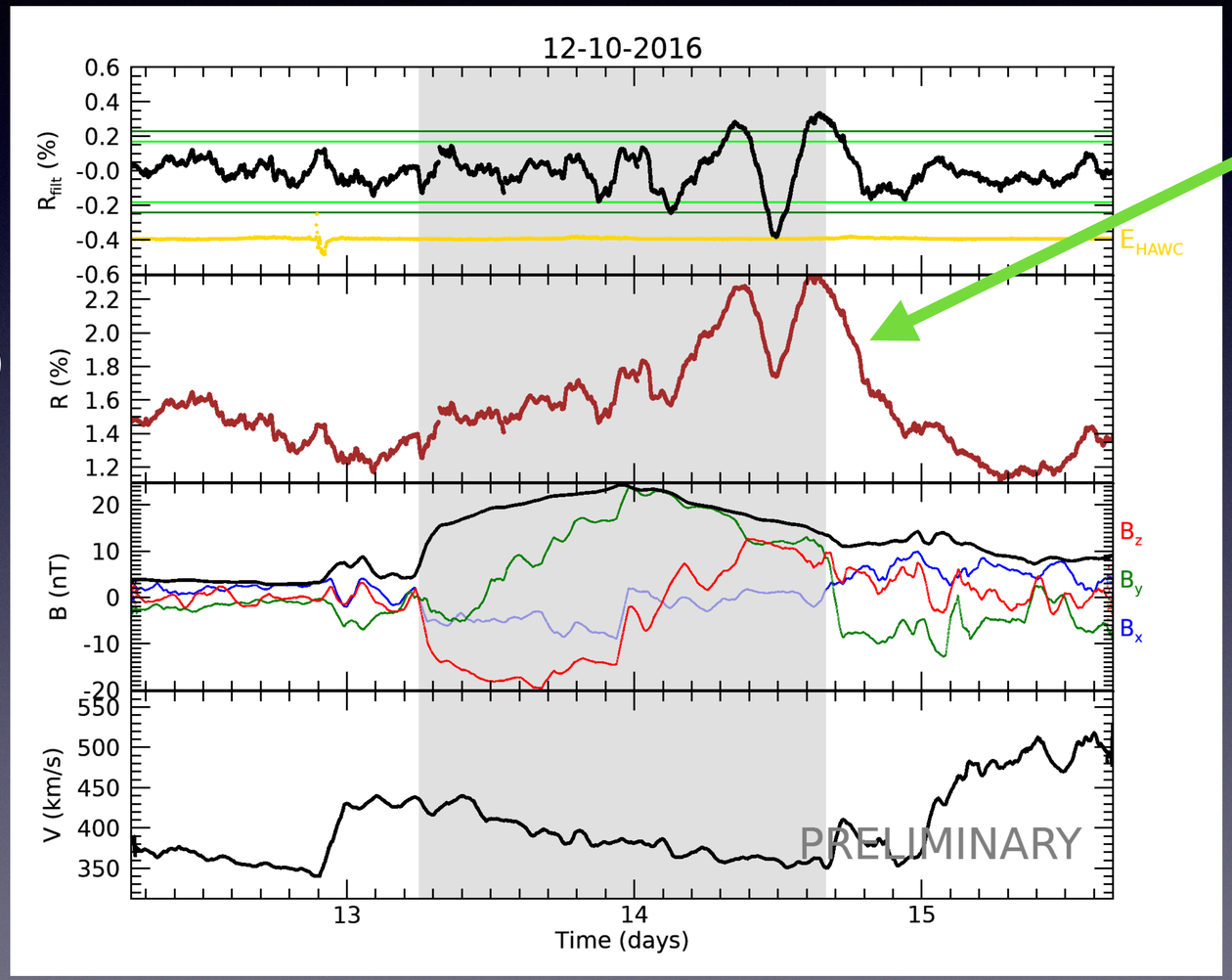
The October 2016
At ground level - GCR increase

Filtered rate (HAWC)

Original rate (HAWC)

Magnetic field (SW)

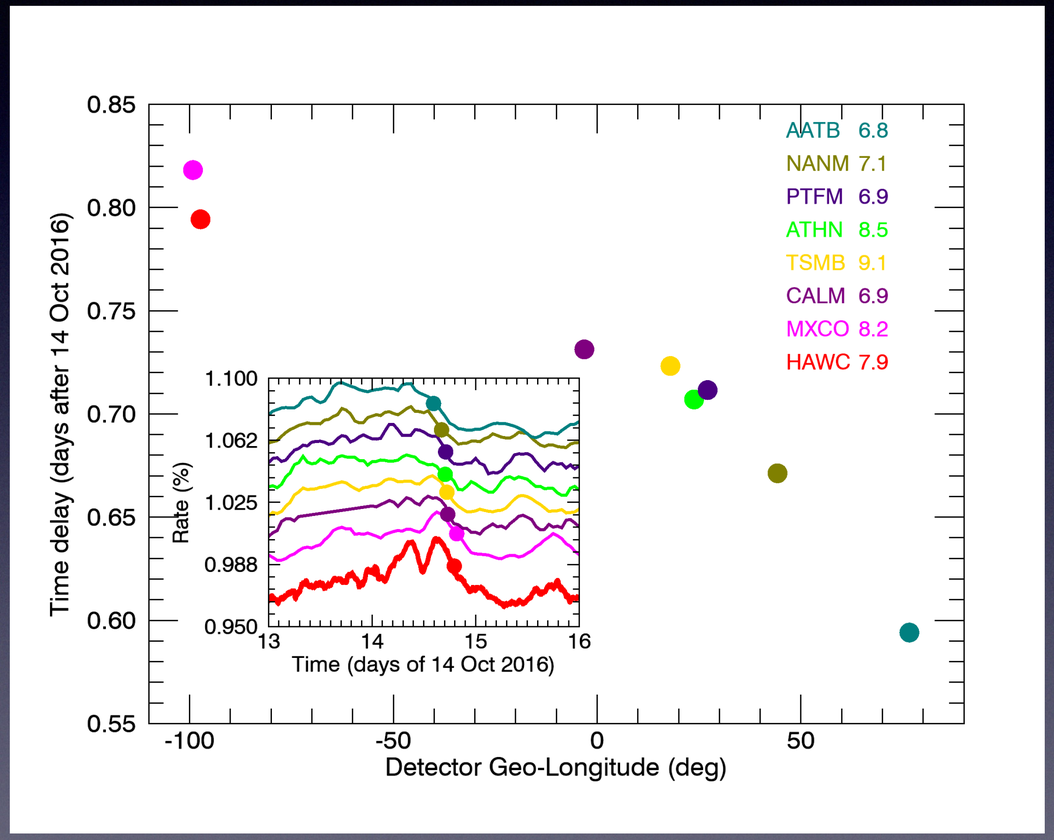
Velocity (SW)

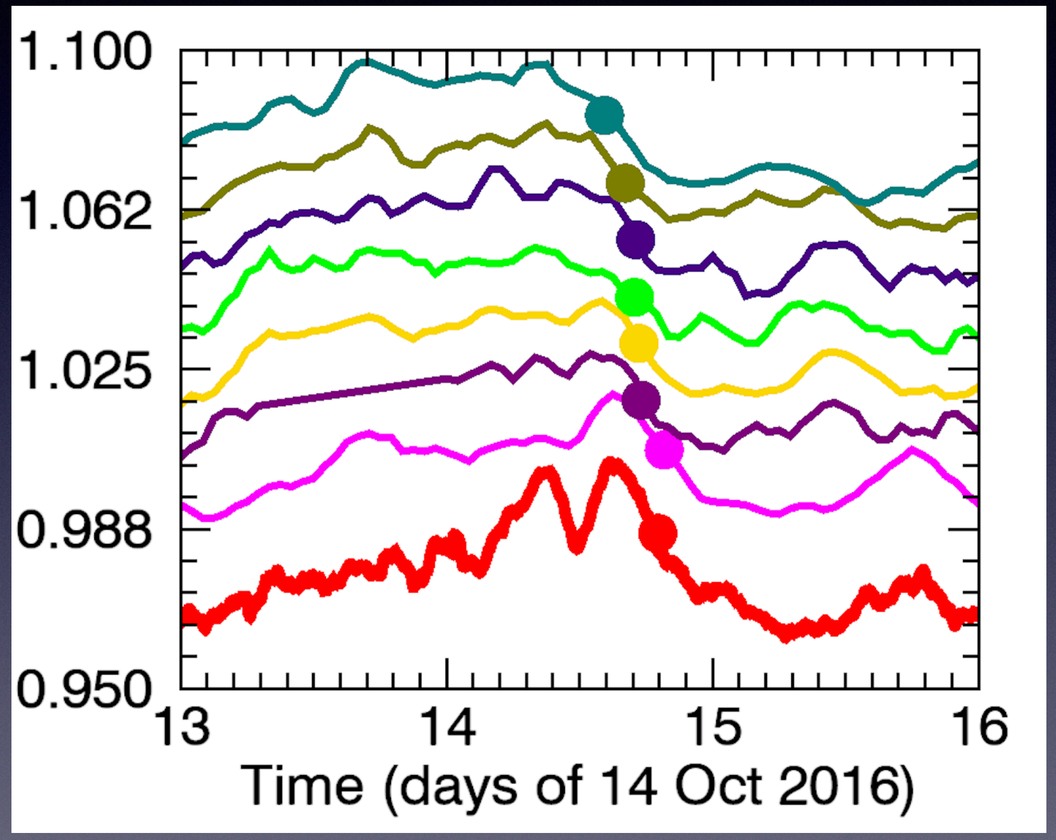


The TDC-scaler system of HAWC detected a GCR increase related to the MFR passage

To quantify the importance of this event, we use a high pass filter, with a cutoff frequency of 1 day and found a significance higher than 5 sigma (see the proceedings for details).

The October 2016 event
At ground level - Neutron Monitor Network observations





Mexico City

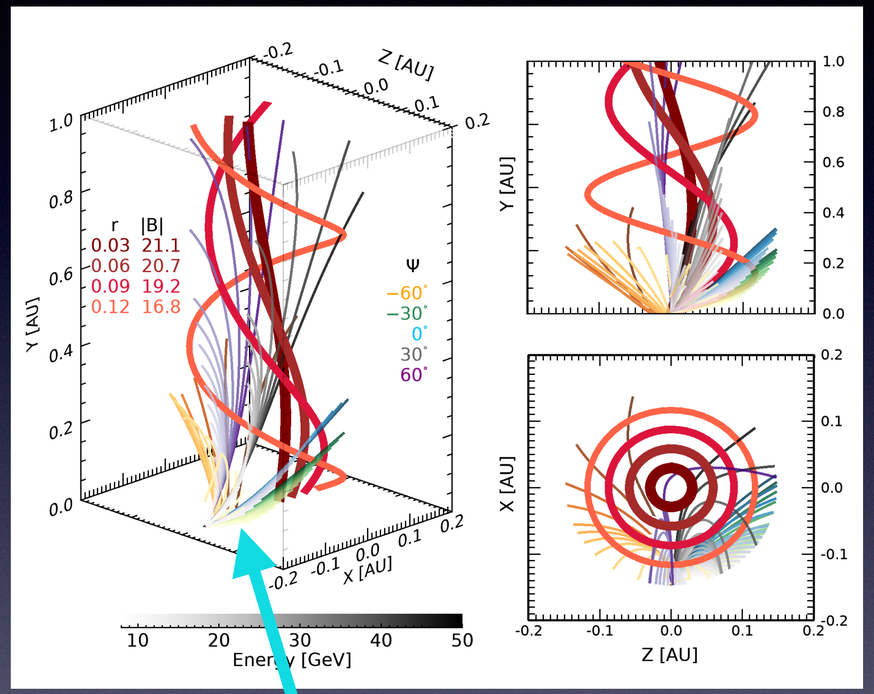
HAWC/40

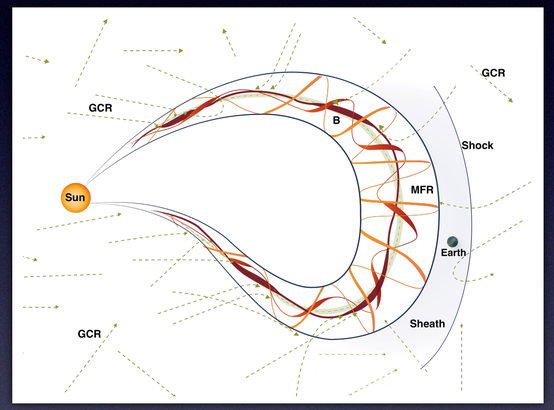
Akiyama et al 2020

The Longitude of the observatory is important for the detection

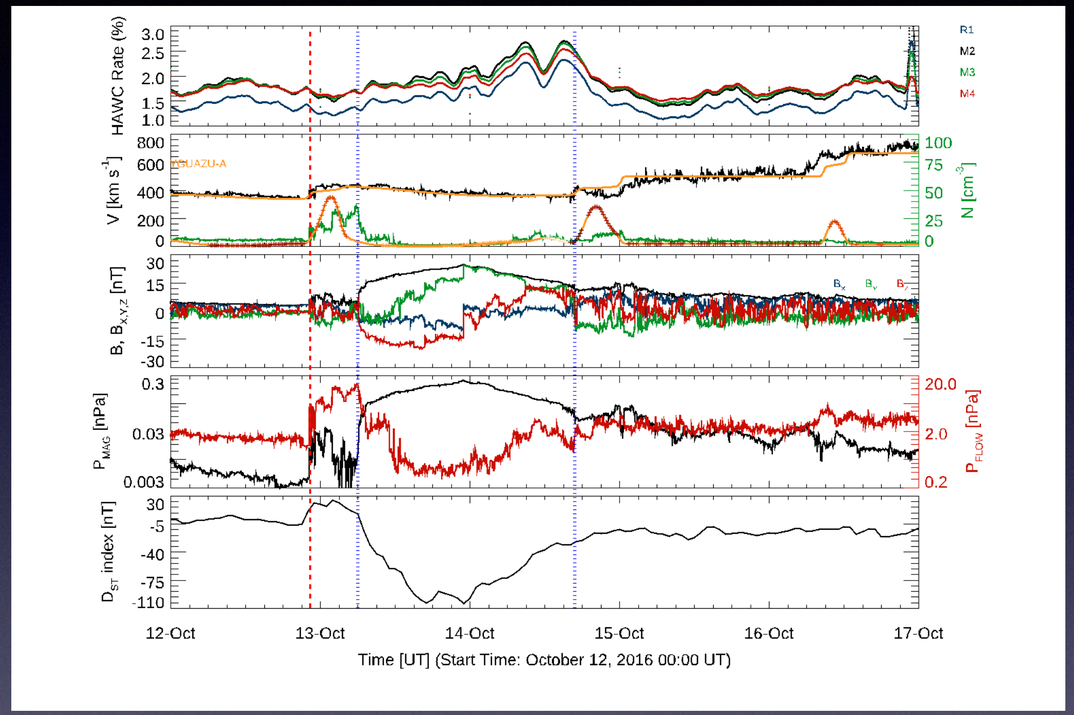
The Model
MFR - GCR interaction

Fitted MFR





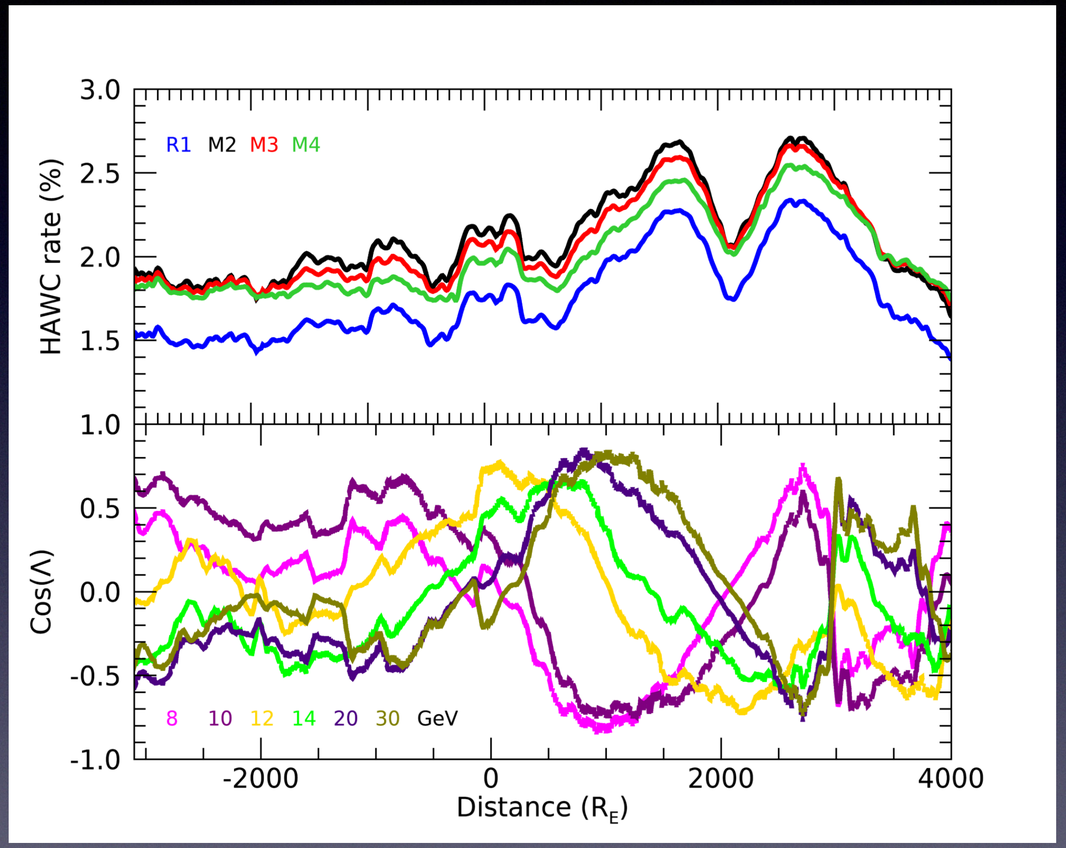
Akiyama et al 2020



Computed trayectorias of the GCR inside the fitted MFR

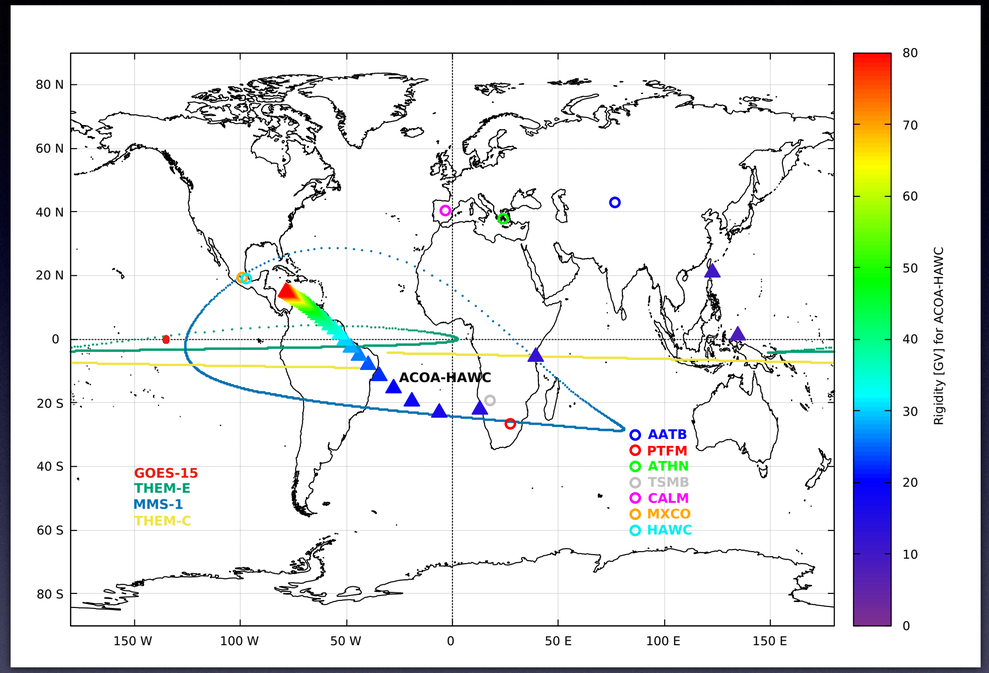
Depending on the energy, the GCR are guided by the helical magnetic field and forced to follow the direction of the MFR axis, creating in this way, the observed anisotropy.

The October 2016 event
MFR axis and cone of acceptance alignment

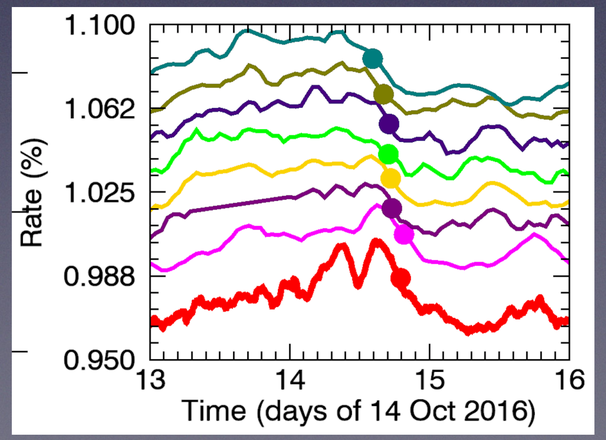


Akiyama et al 2020

Cosine of the angle between the MFR axis and the Asymptotic cone of acceptance of HAWC, for different energies

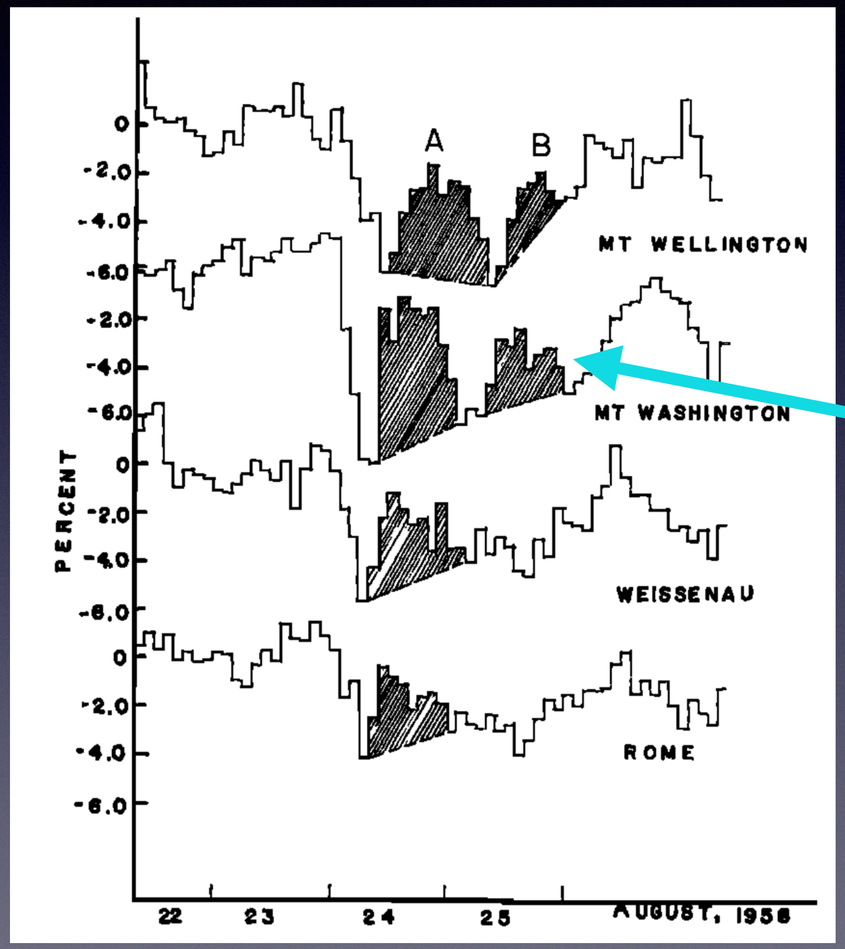


Asymptotic cone of acceptance of HAWC

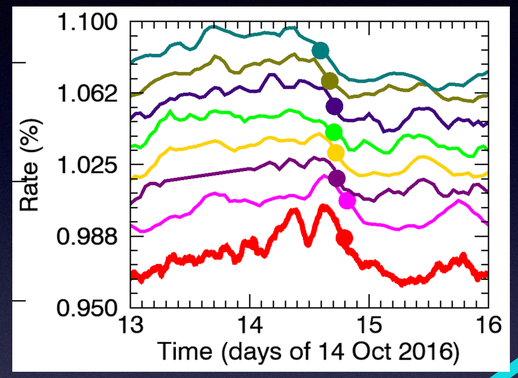


The Longitude of the observatory is important!

Similar increments of the GCR rate have been observed since long time ago.

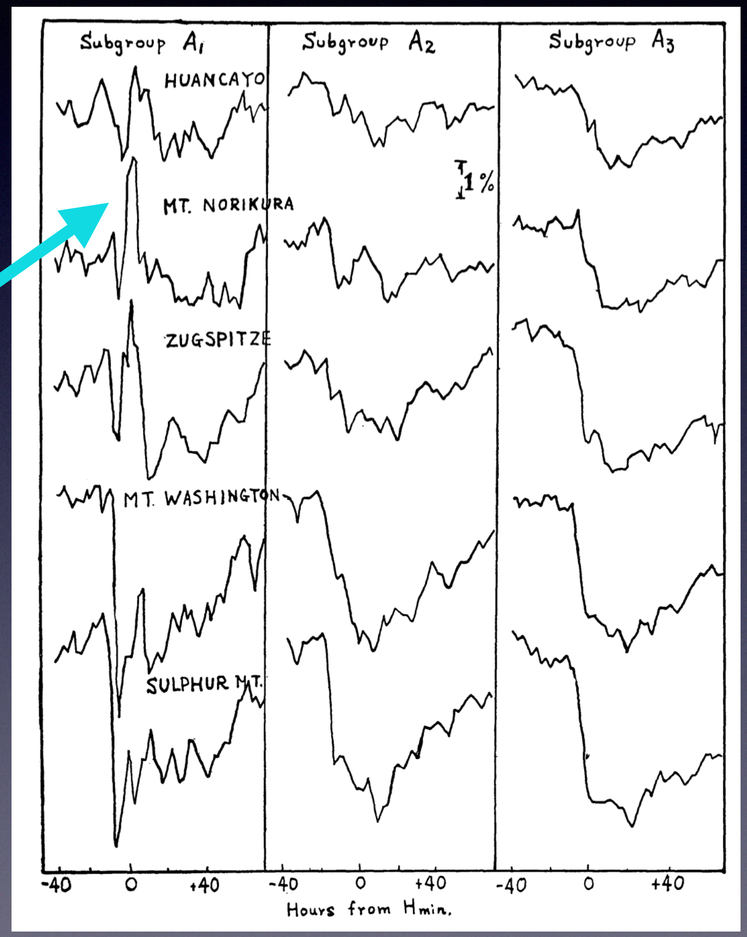


Lockwood and Razdan 1963



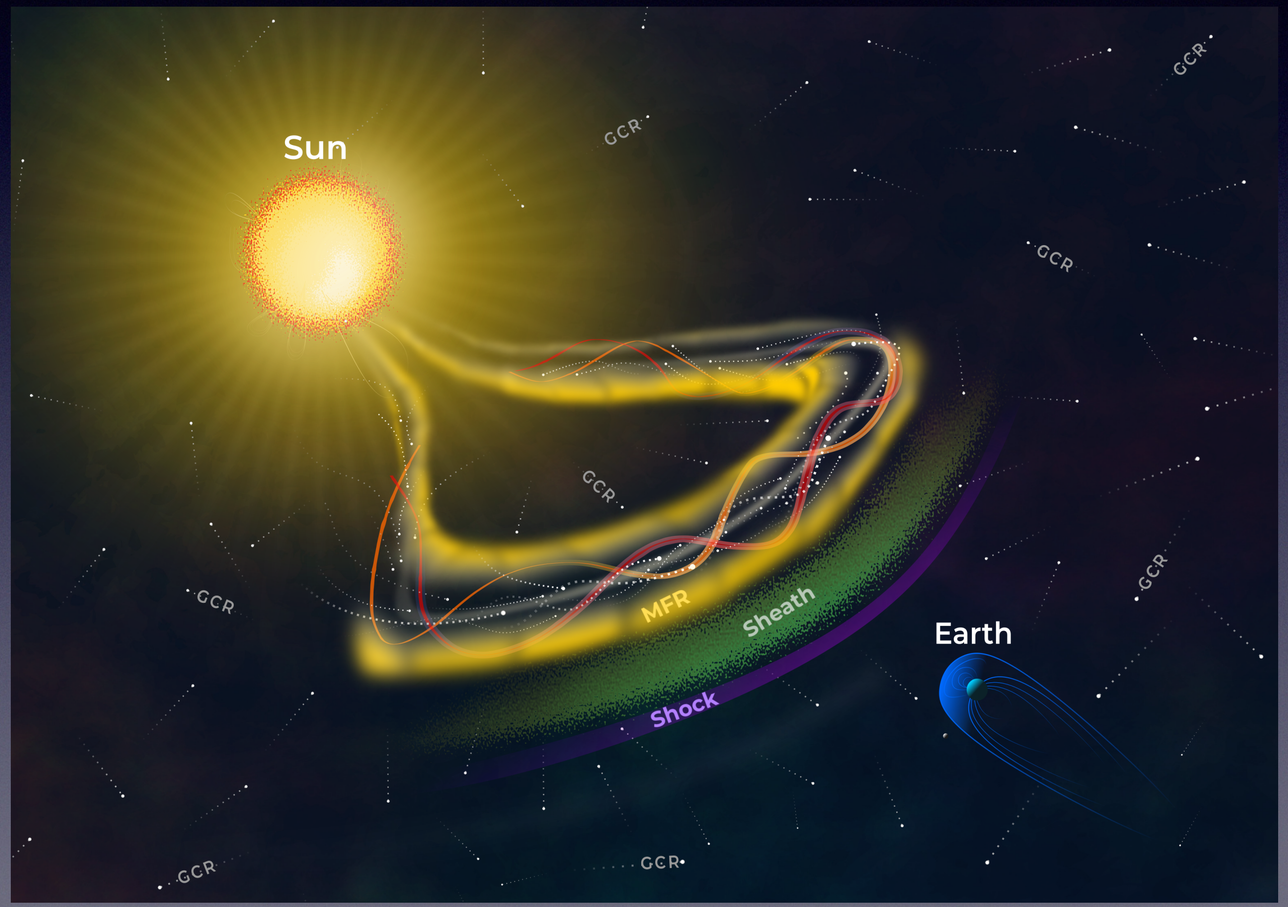
Anisotropic GCR flux increases observed by neutron monitors

Until now, this phenomenon had not been explained. However, our model explains it satisfactorily.



Kondo 1962

The model
The full image

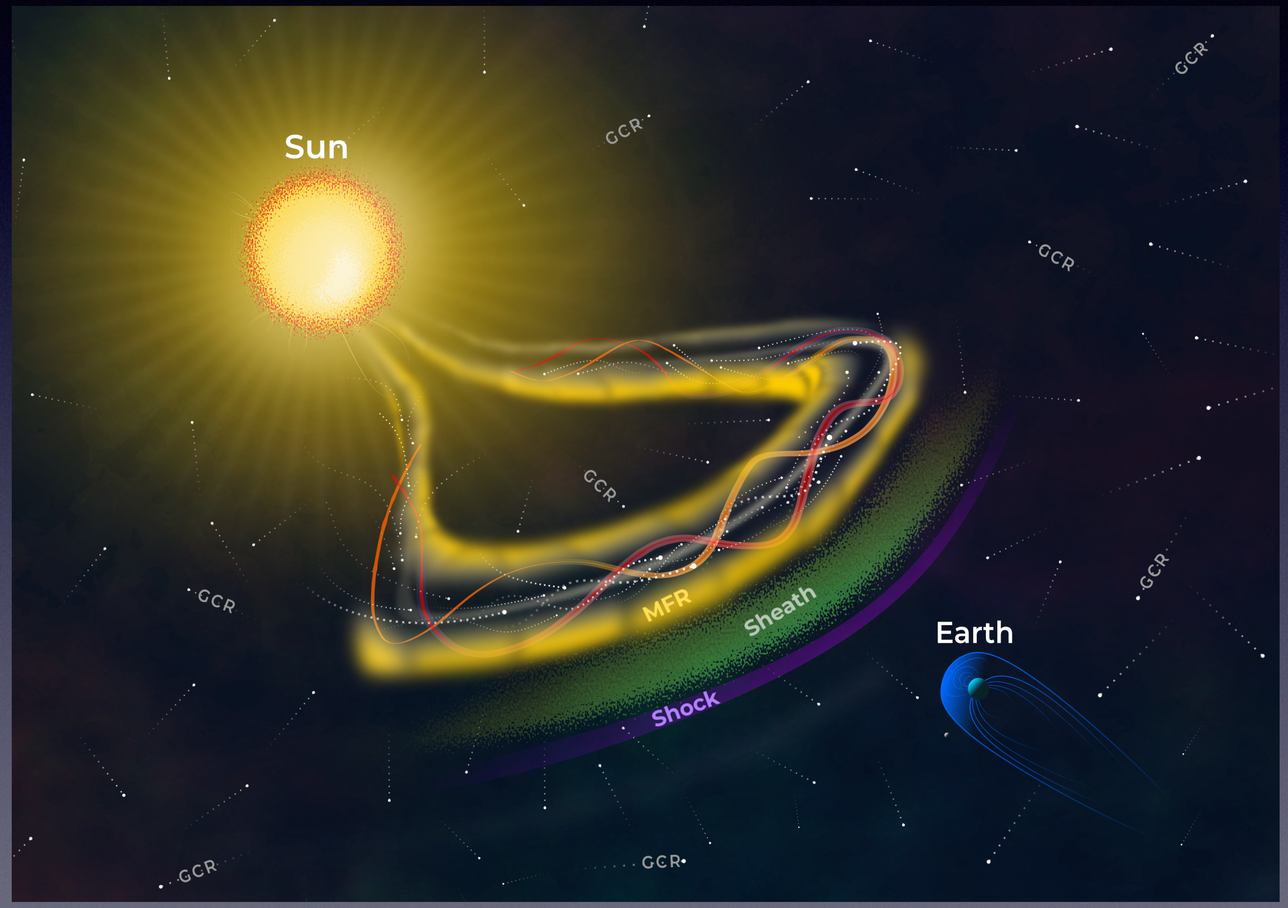


The GCR are guided by the MFR field and forced to follow the direction of its axis, creating in this way, an anisotropy.

Any CR detector with enough sensitivity situated inside the MFR will detect the anisotropic flux!

Conclusions

- HAWC represents an excellent tool to study the solar modulation on the galactic cosmic rays
- In particular, HAWC has detected the anisotropic flux of GCR caused by the magnetic flux rope
- The helical topology of the magnetic field of interplanetary coronal mass ejections creates a GCR anisotropy
- This anisotropy is detected depending on the geometry between the observatory and the MFR axis
- See Akiyama et al 2020 (APJ) for the detailed analysis



Thanks!