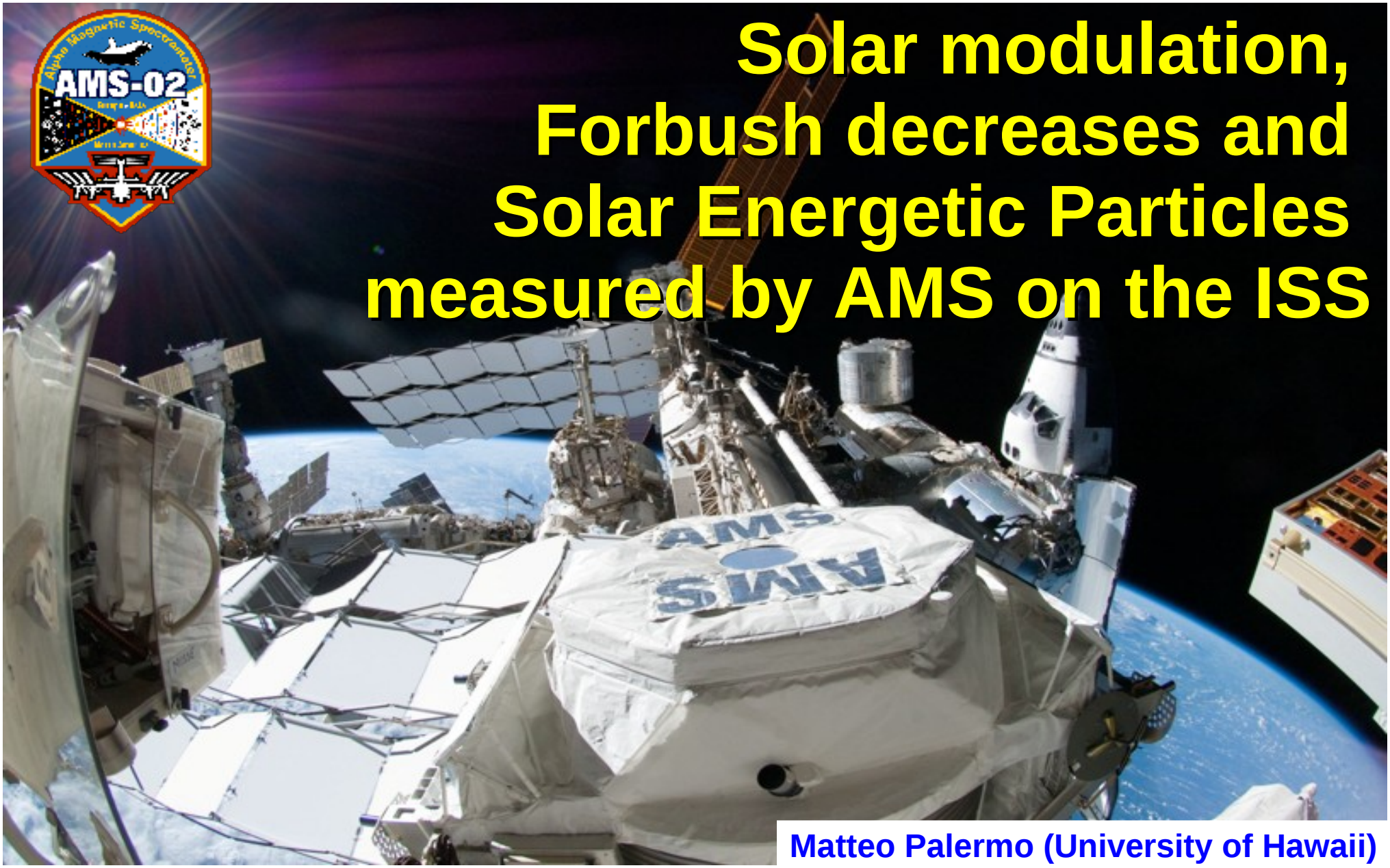


Solar modulation, Forbush decreases and Solar Energetic Particles measured by AMS on the ISS

Matteo Palermo (University of Hawaii)
on behalf of the AMS Collaboration

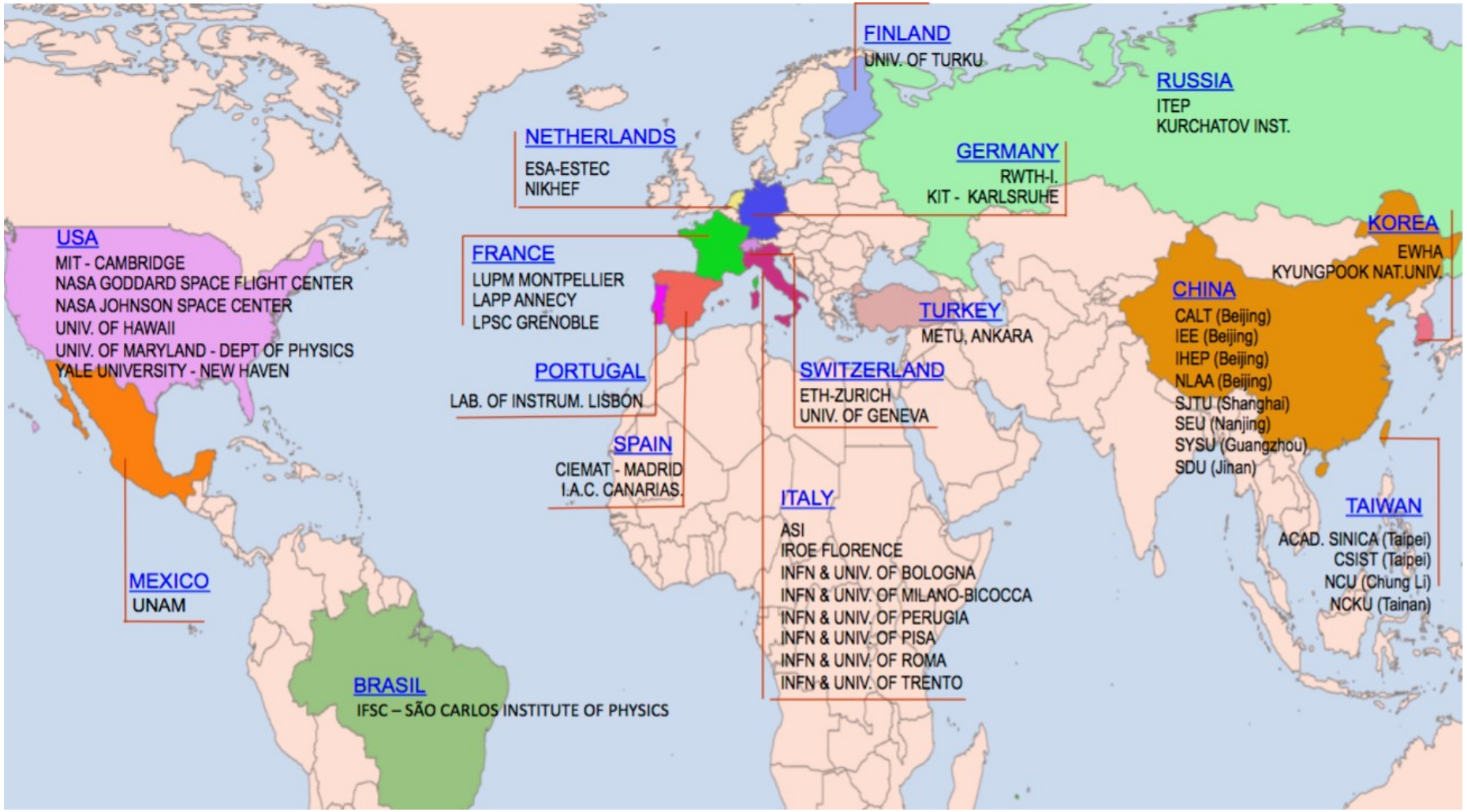
ThalesAlenia Space
A Thales / Finmeccanica Company

22nd WRMISS
5-7 September 2017
Torino, Italy

Physics and Astronomy Department
University of Hawaii at Manoa
Honolulu, Hawaii, US

AMS is an International Collaboration
15 Countries, 46 Institutes

AMS is sponsored by US DOE and NASA, and many agencies in the world.



The focus of this talk is the work performed at the University of Hawaii sponsored by NASA and NSF.

AMS on the iss

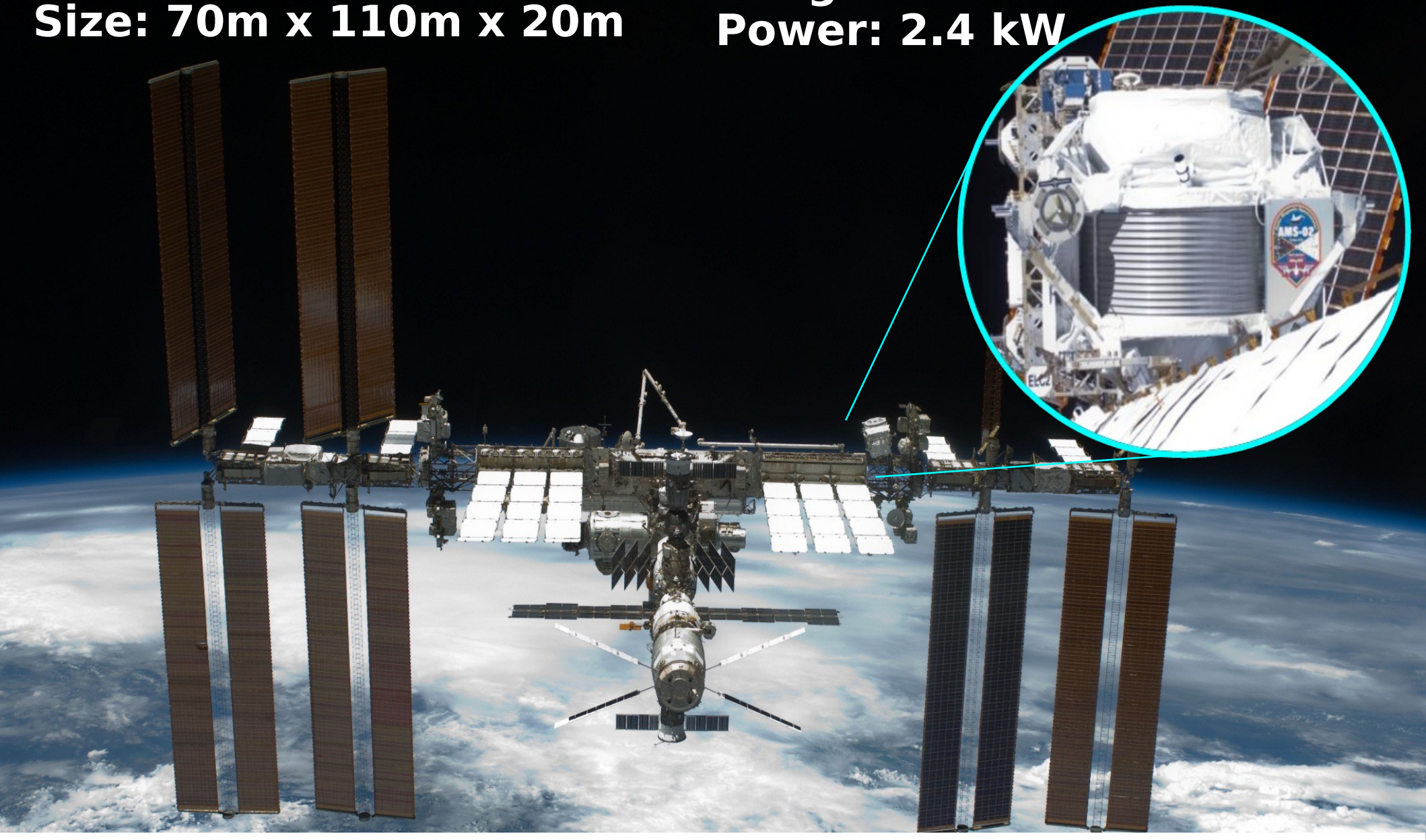
May 16, 2011: AMS Flight, Space Shuttle Endeavor

ISS

Altitude: ~400 km
Orbit: 90 minutes
Size: 70m x 110m x 20m

AMS-02

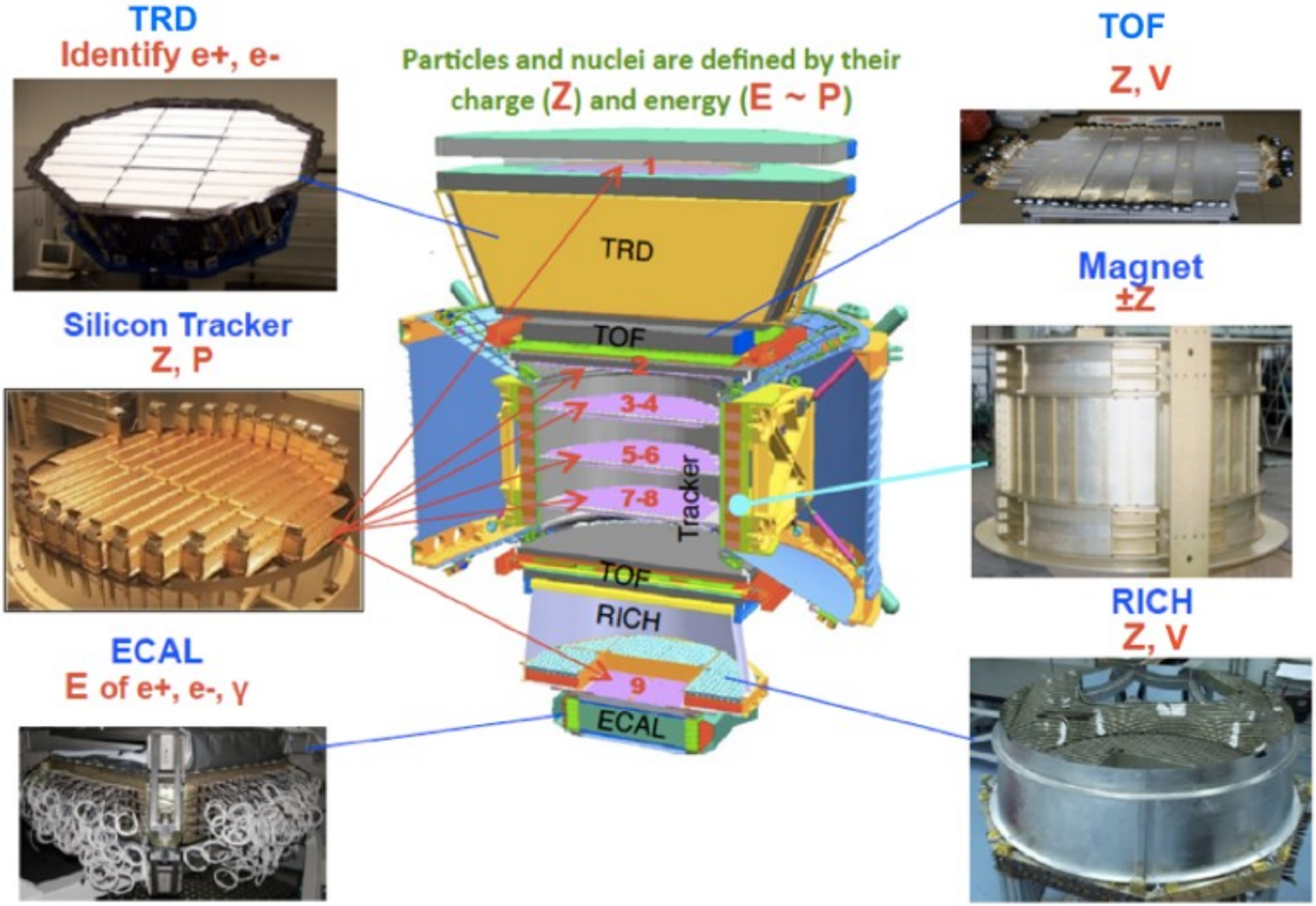
Size: 5m x 4m x 3m
Weight: 7 ton
Power: 2.4 kW



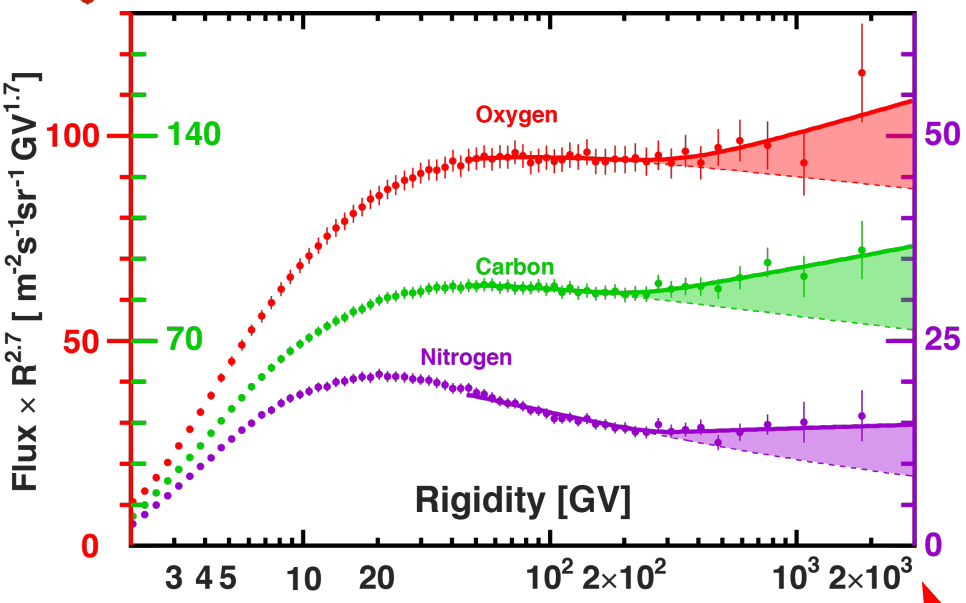
In 6 years of operation, AMS has measured over 100 billion events.
It will continuously take data for the entire duration of the ISS

Particle Identification with AMS

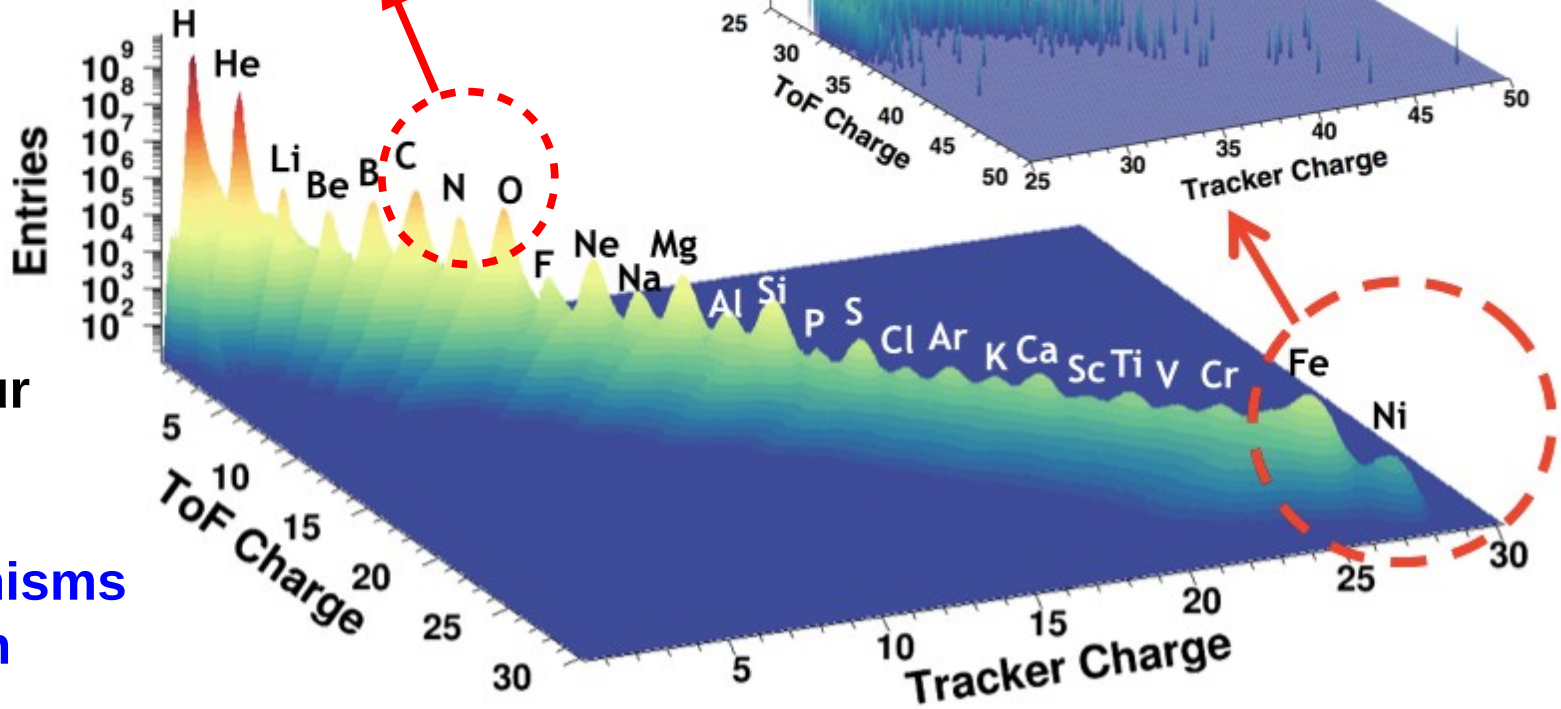
AMS is a general purpose detector which measures particles in the GV-TV rigidity range

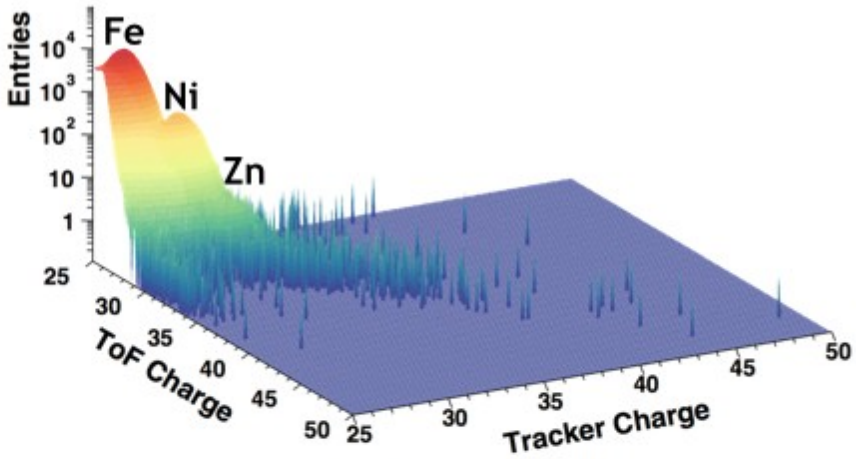


Scientific Goals: GCR Nuclei



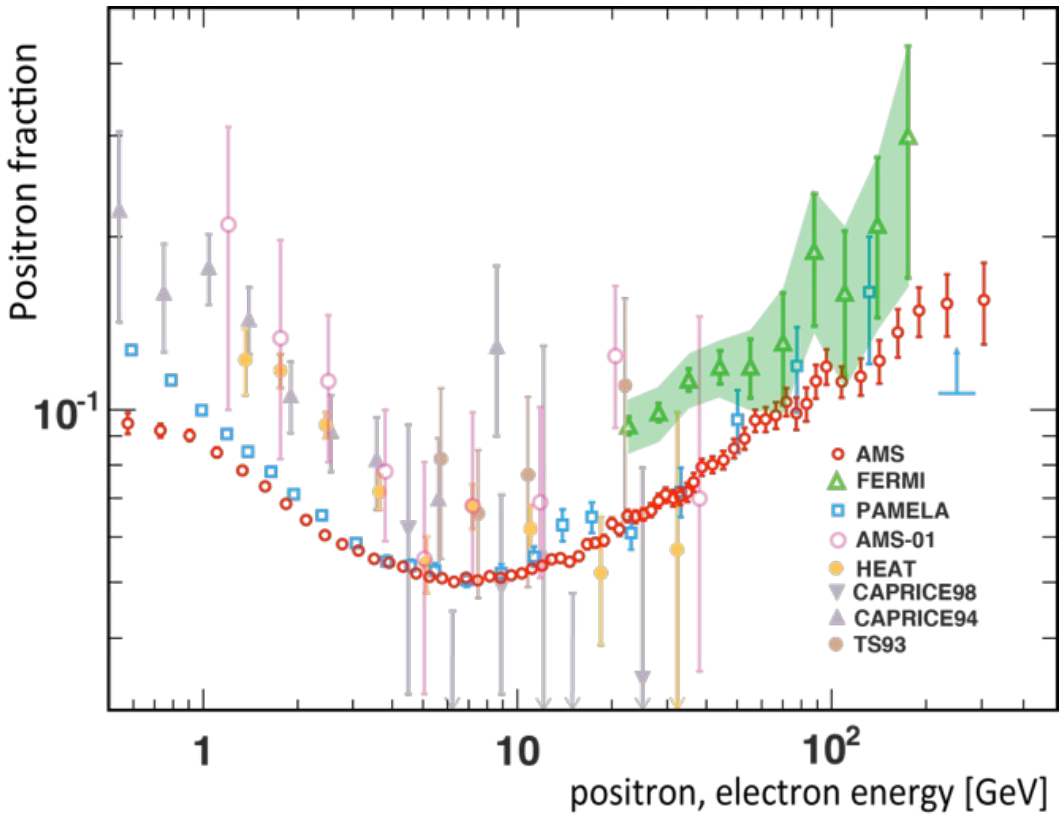
AMS measures all CR species with error at % level up to Fe and above





It will improve our knowledge of: CR sources, acceleration mechanisms and propagation

Scientific Goals: Dark Matter search



M. Aguilar
(AMS collaboration)
PRL110,141102 (2013)

Interesting features have been measured at high energies and more will come in the near future.

New Goal: Study of the time variation of the low energy part of the spectrum.

AMS: GCR and SEP studies

Collaboration between
NASA AES (Advanced Exploration Systems) group at JSC
and AMS research group at the University of Hawaii

- AMS measures CR fluxes with unprecedented accuracy

- **University of Hawaii** research group is focused on the **AMS energy range that supports NASA human space exploration missions (unavailable by other satellites)**

Improvement in the accuracy provides new insights in areas such as the study of CR and solar activity, and has **application to NASA space radiation health assessments and shielding design**

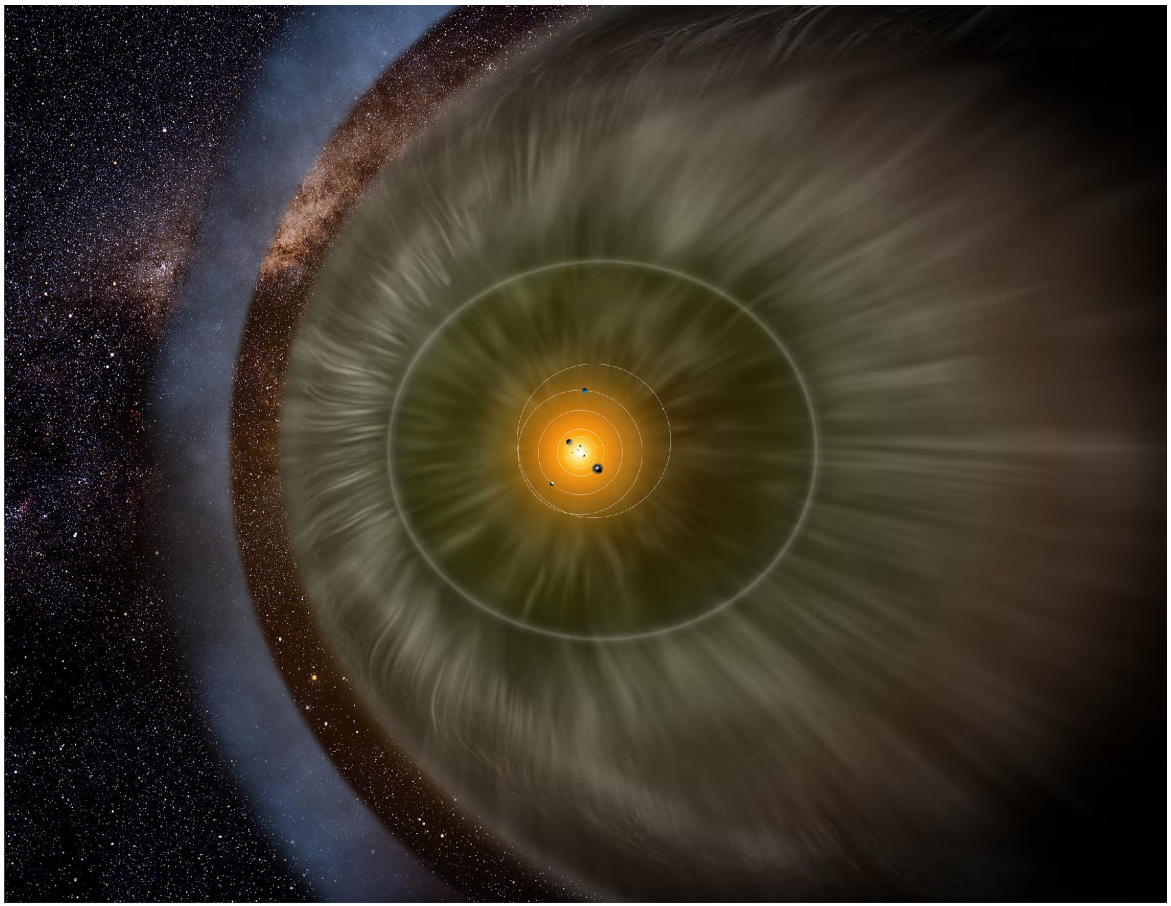
Main research studies:

- **GCR fluxes and their changes with solar activity**
- **Heliophysics: study of Solar Energetic Particles**

Solar Modulation: GCR in heliosphere

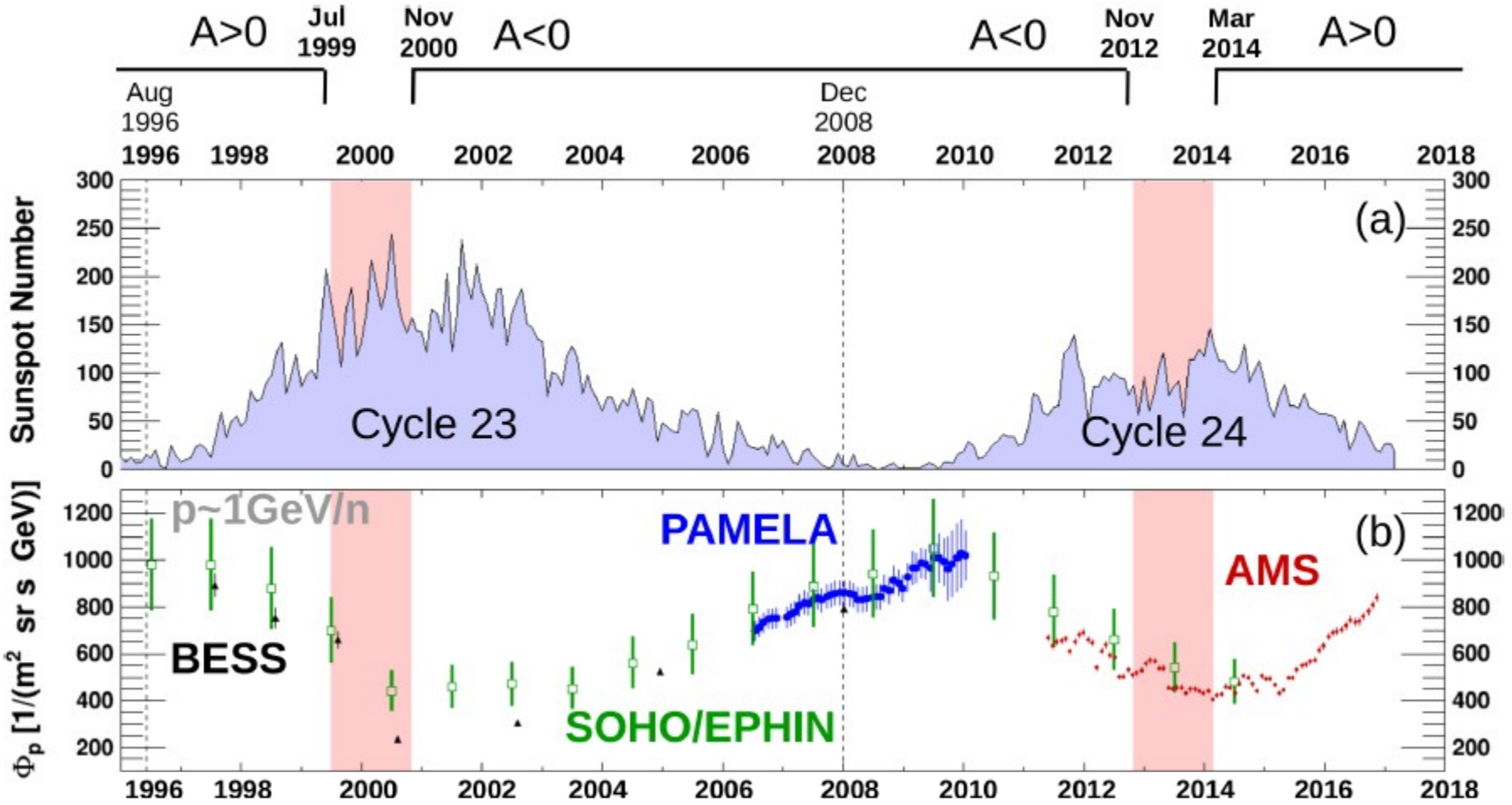
Precise measurements of the time-dependent GCRs spectra are important:

- **to understand the propagation of GCRs in the heliosphere.**
- **to test theories of particles diffusion (charge and mass) and drift (charge-sign).**
- **to study the effect on cosmic rays due to the reversal in the solar polarity.**
- **Space radiation monitoring**



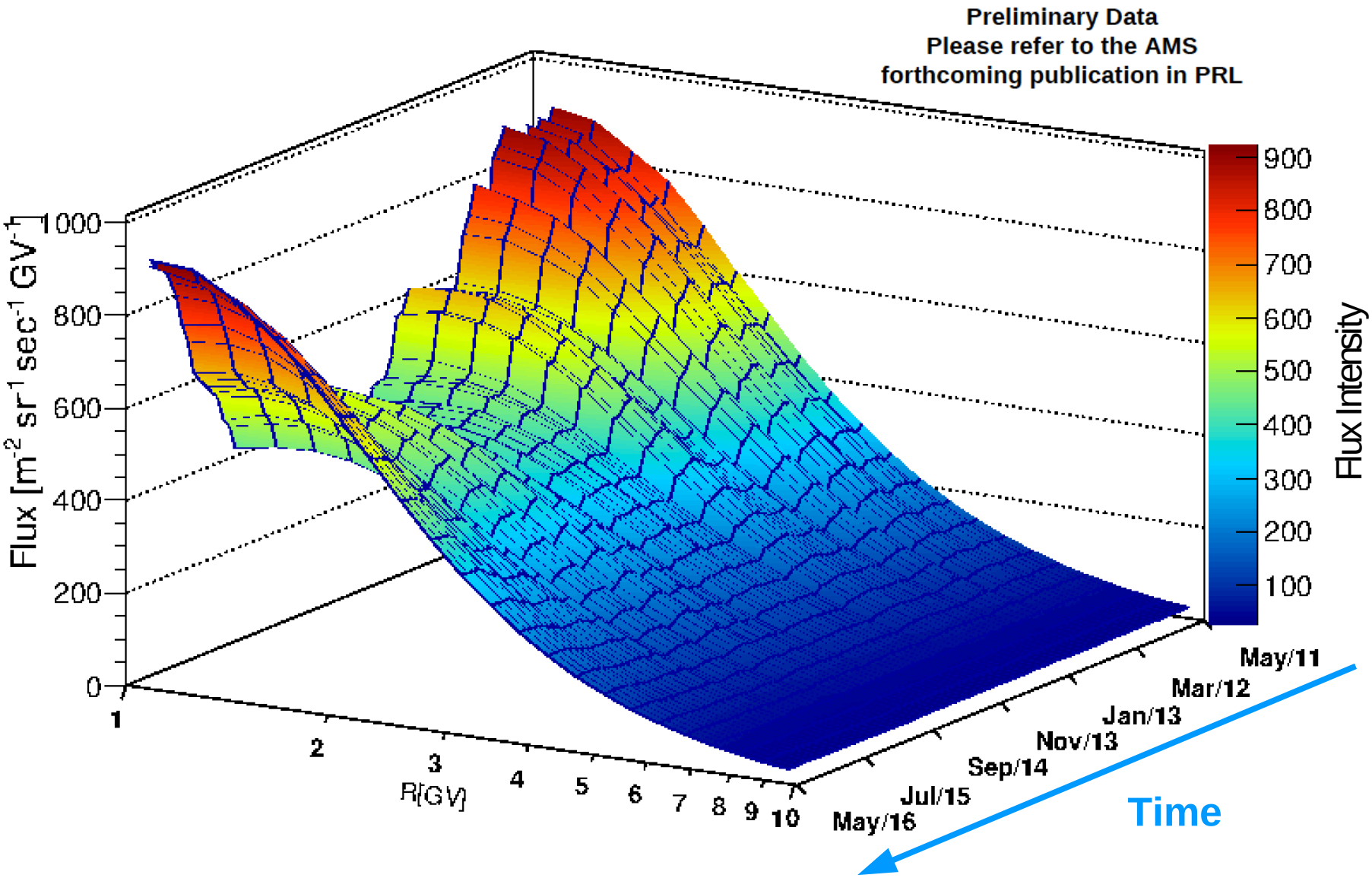
Solar activity measured by AMS

The Sun goes through an 11-year activity cycle shown by sunspots number. At each solar maximum the Sun flips its magnetic field polarity (A>0, A<0) showing a periodicity of 22 years.

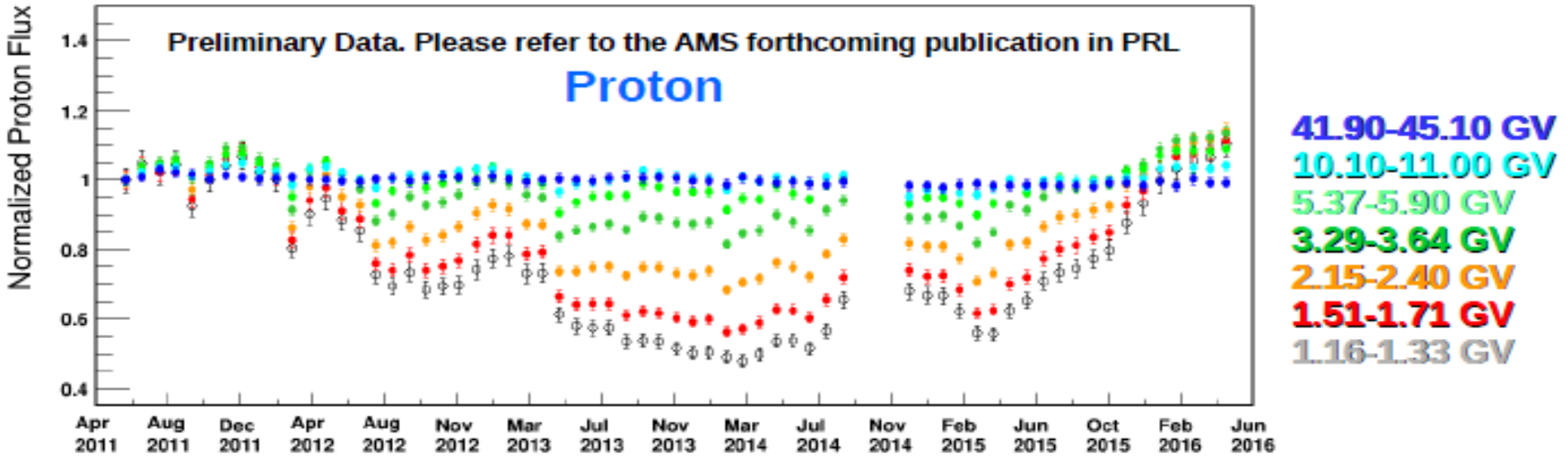


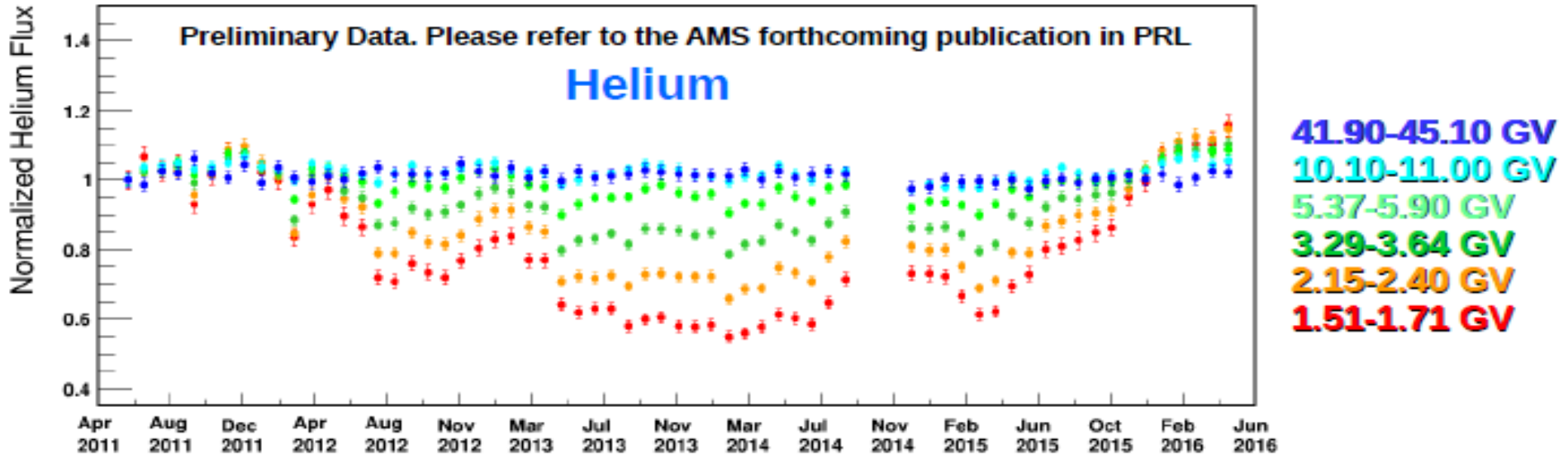
Daily sunspot number: http://www.sidc.be/silso/datafiles

AMS Monthly Proton Flux five years of data



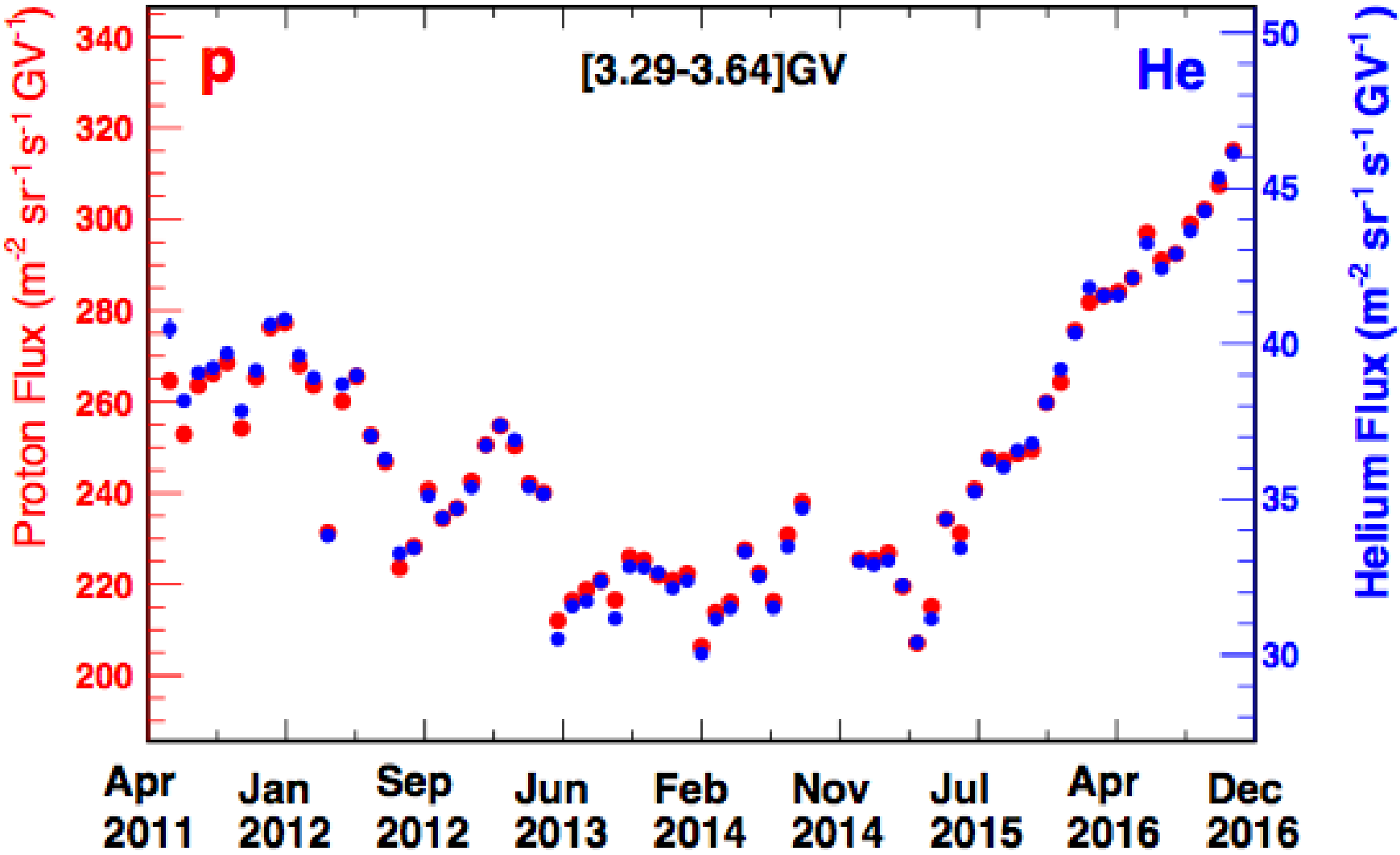
Proton & He Monthly Fluxes





At low rigidities, not only long-term solar modulation but also short-term solar activity

Proton & He Monthly Fluxes



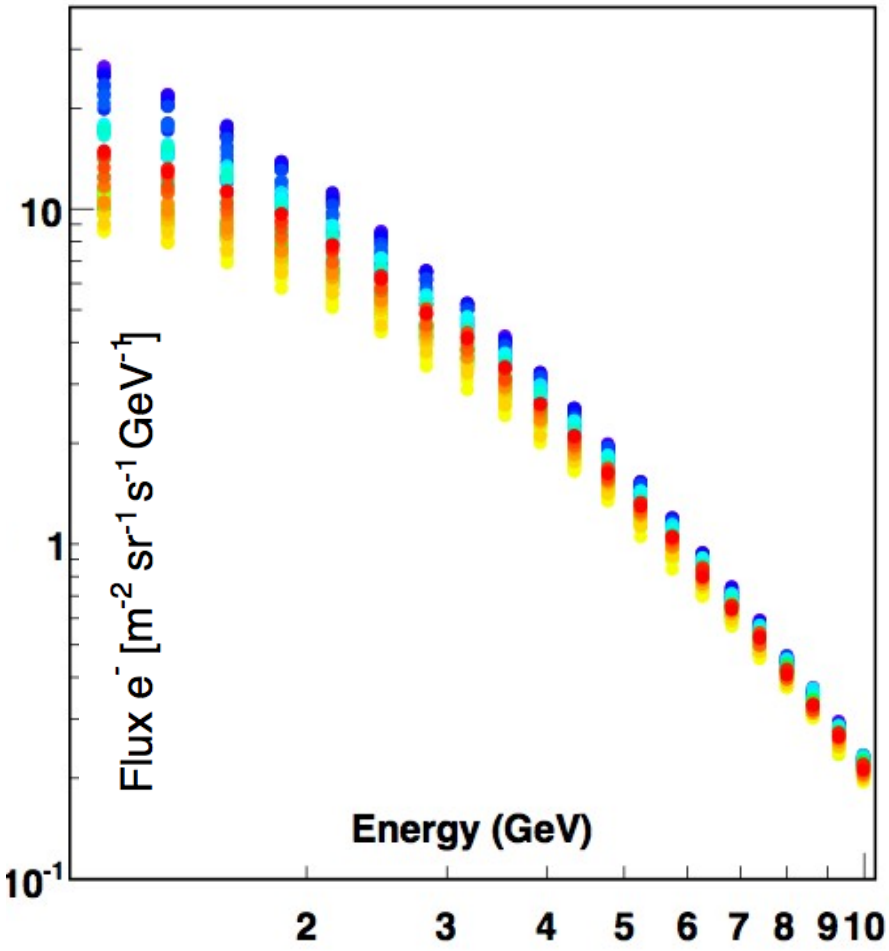
AMS will study how solar modulation affects all different cosmic ray species.

Electron & Positron Monthly Fluxes

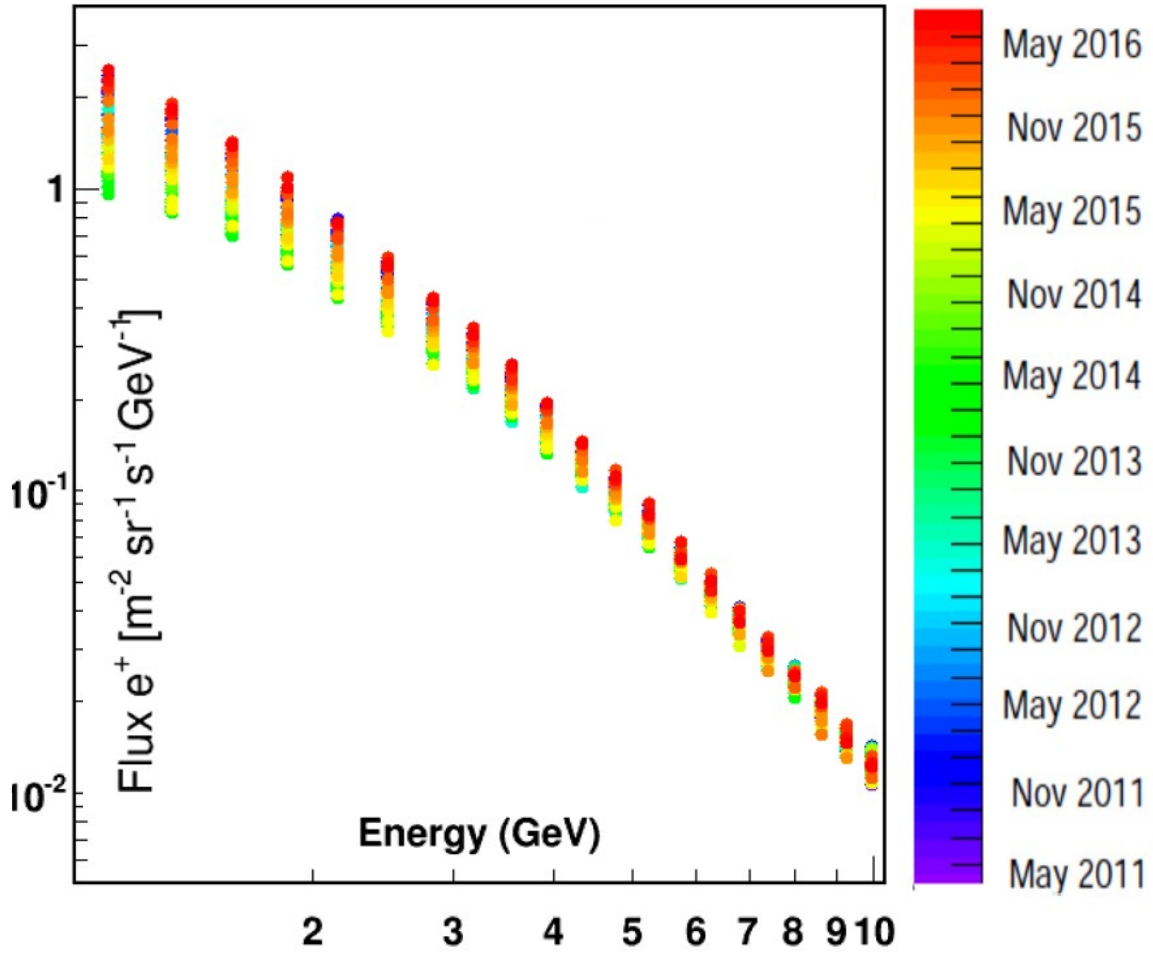
Each color represents a 27 days integration flux.

Preliminary Data
Please refer to the AMS forthcoming publication in PRL

Electrons

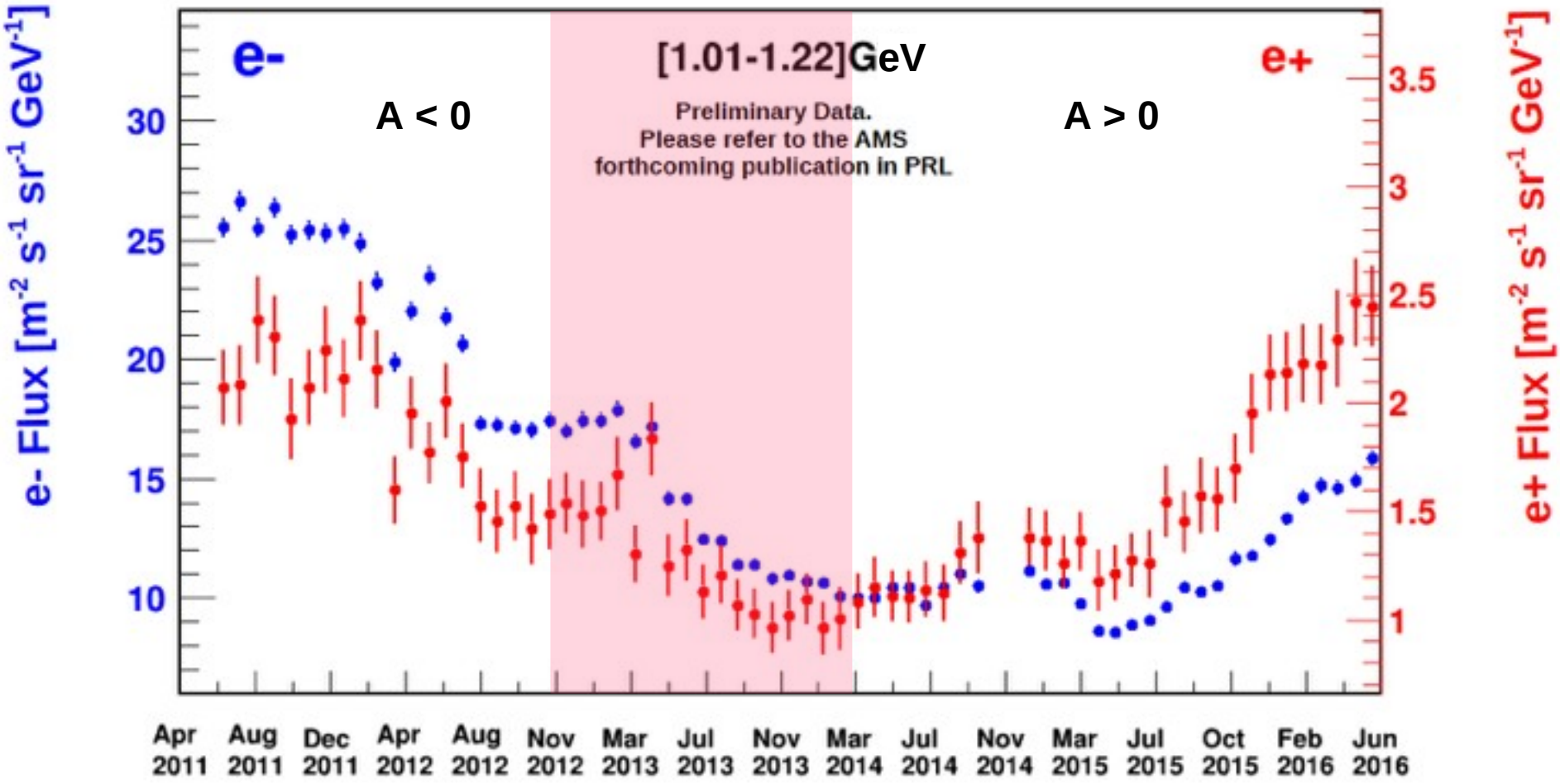


Positrons



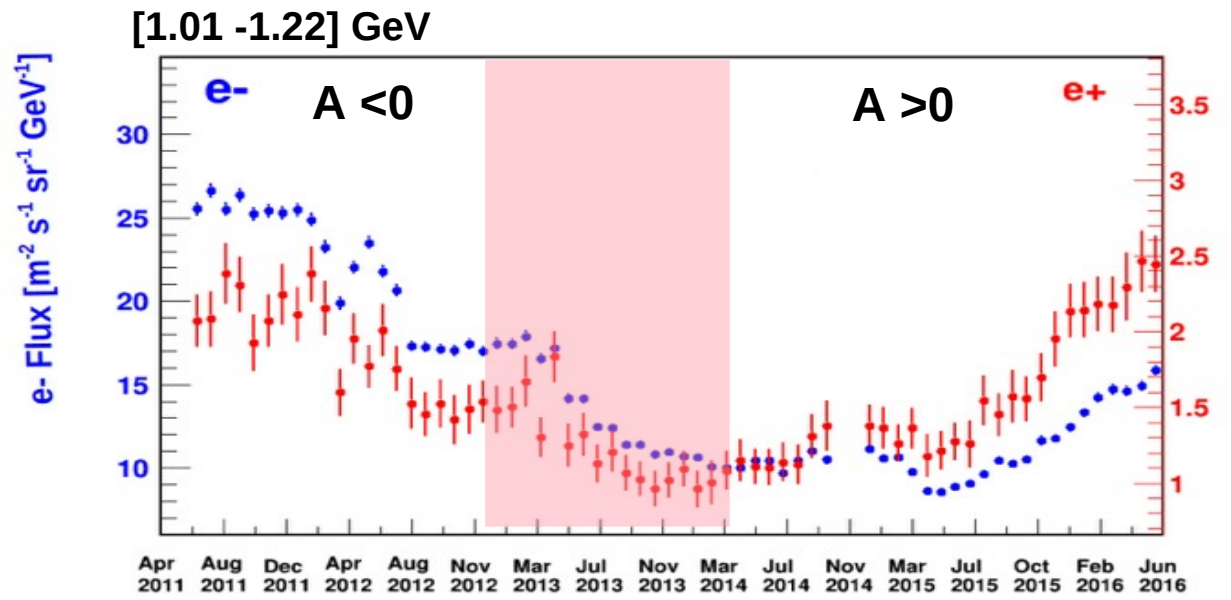
Electron & Positron Fluxes Time Profile

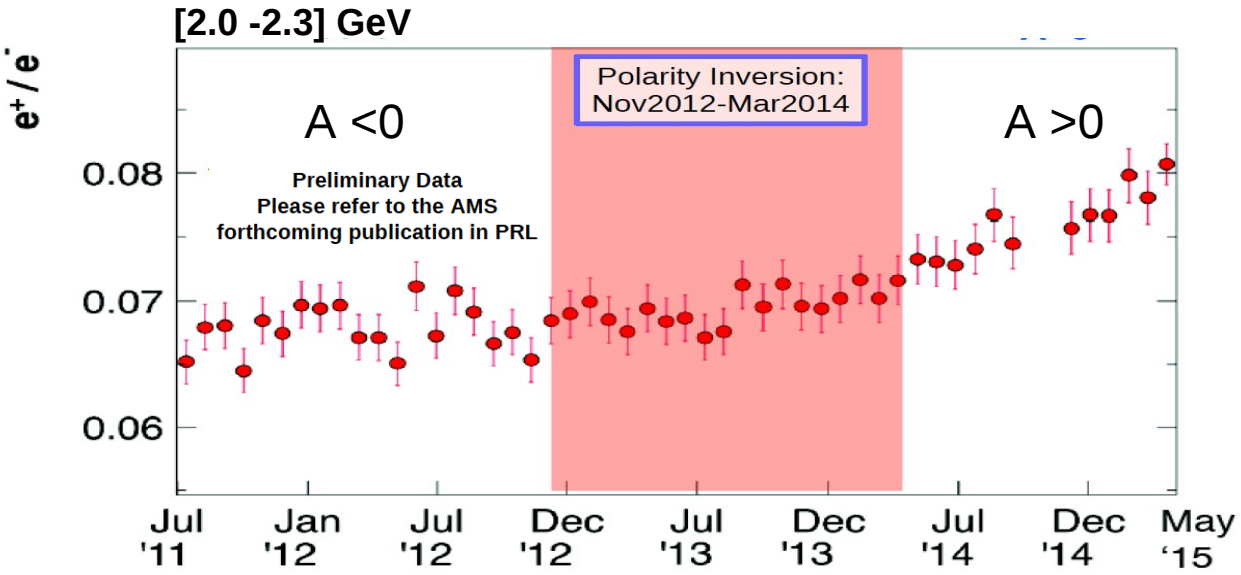
Polarity Inversion:
Nov. 2012 – Mar. 2014



Polarity inversion period from: X. Sun et al., Astroph. J., 798, 114 (2015)

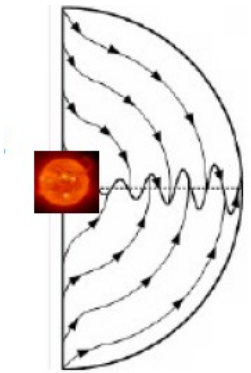
Change of Solar Polarity & Particles Drift



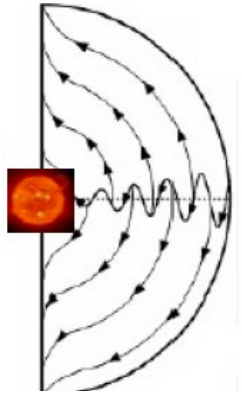


Polarity inversion period from: X. Sun et al., Astroph. J., 798, 114 (2015)

Electrons A<0



Electrons A>0



AMS e+/e- ratio clearly shows the charge-sign dependence of solar modulation.

Repeat the study with pbar/p.

AMS will measure the drift of positive vs negative particles during a solar minimum with positive polarity A>0.

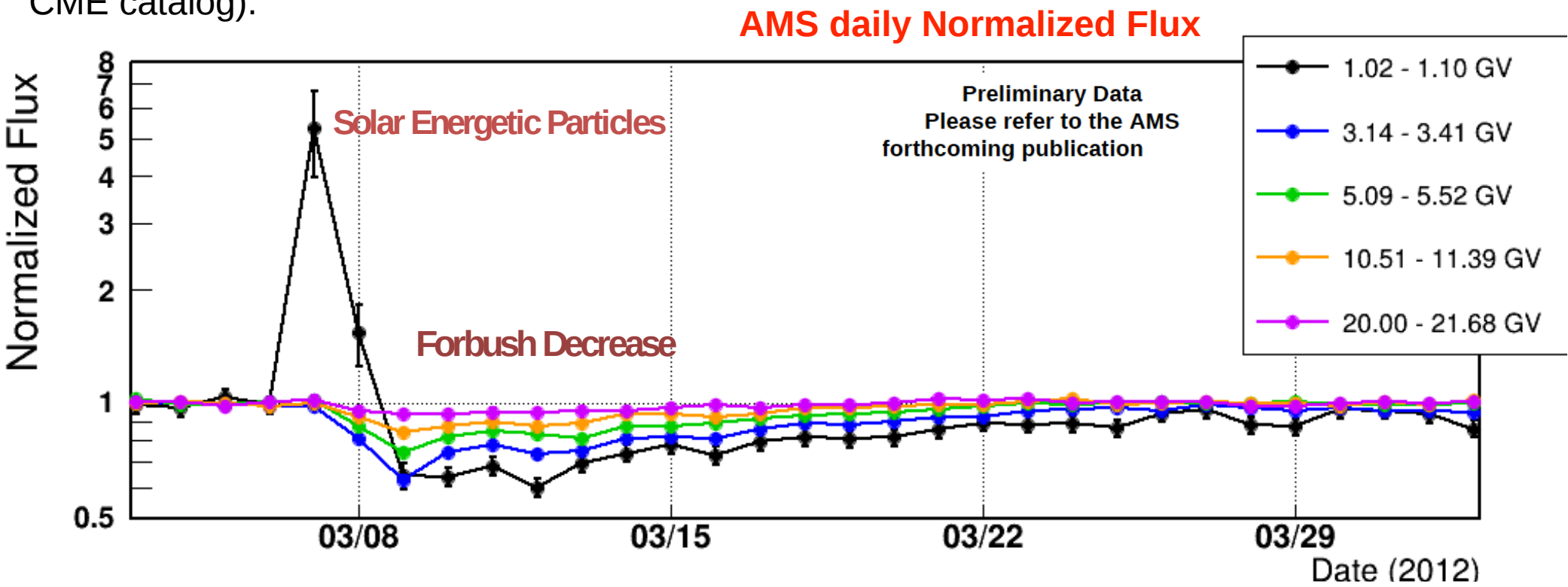
Short-Term Solar Activity

Solar events measured by AMS

March 7, 2012

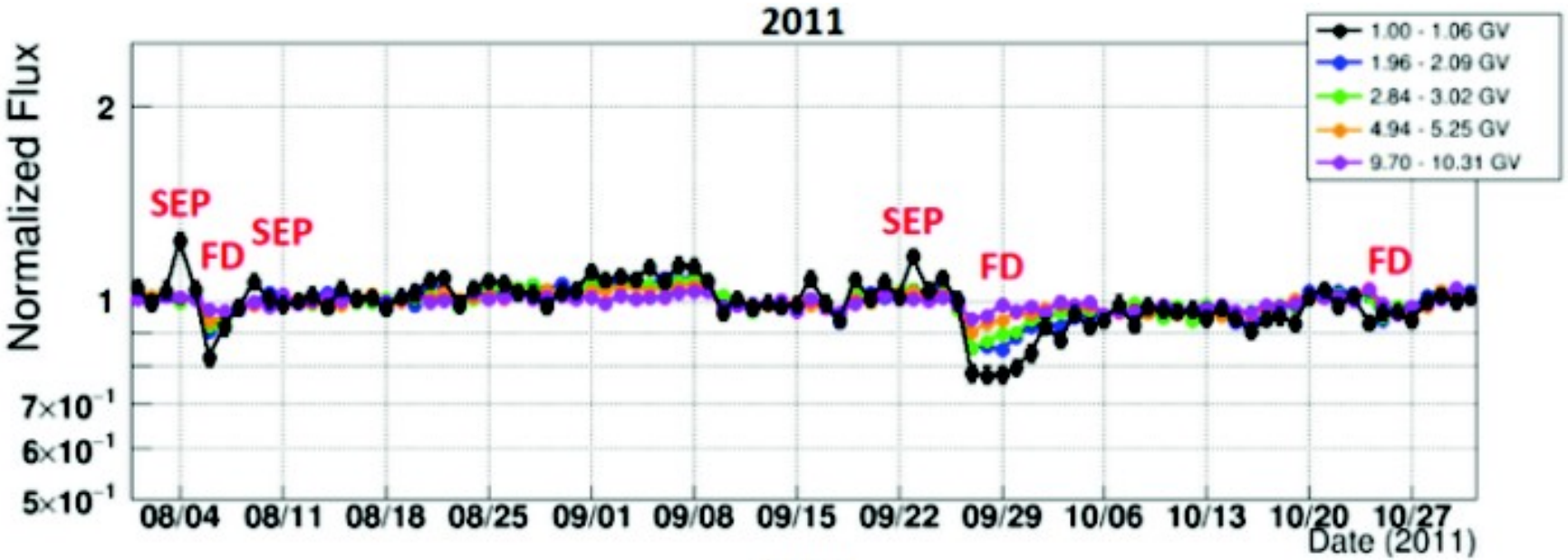
Two Solar Flares of class X5.4 and X1.3 (XRT Flare catalog).

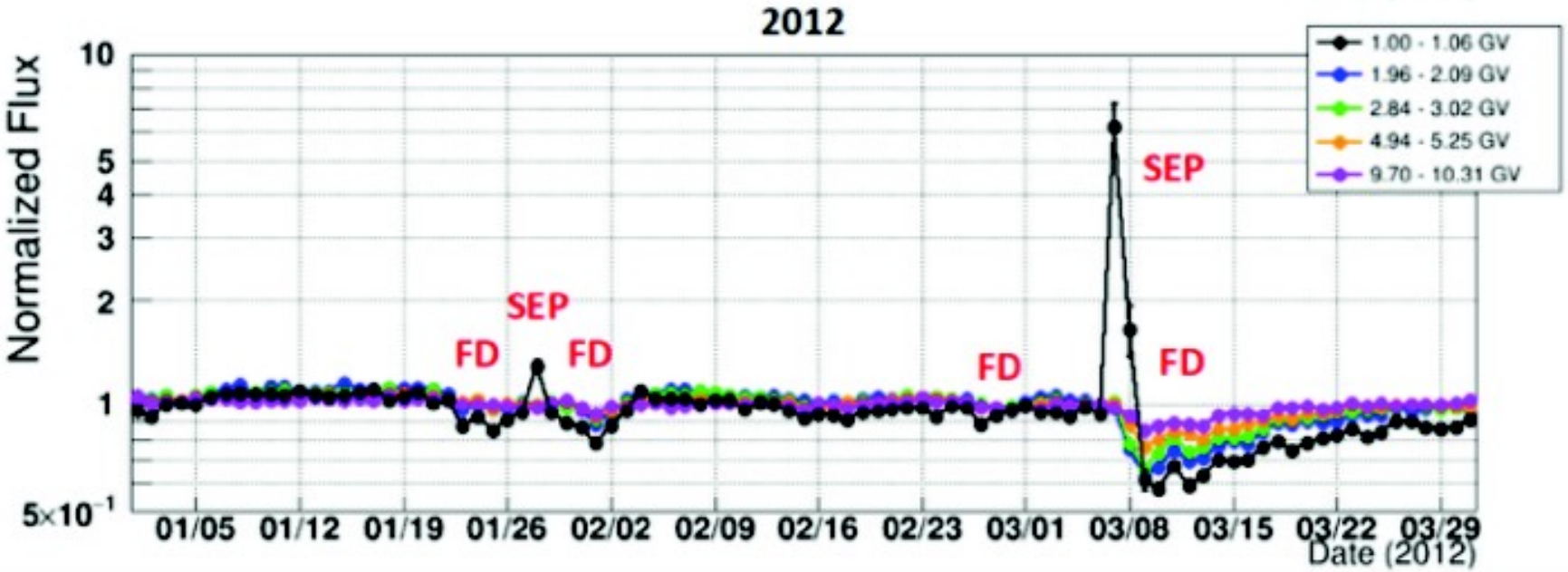
Two Coronal Mass Ejections with linear speeds of 2684 km/s and 1825 km/s (SOHO LASCO CME catalog).



- **Temporary decreases in the CR flux, followed by gradual recovery**
- **Often associated to passing of Interplanetary Coronal Mass Ejections and or Corotating Interacting Regions**

Normalized Daily Proton Flux

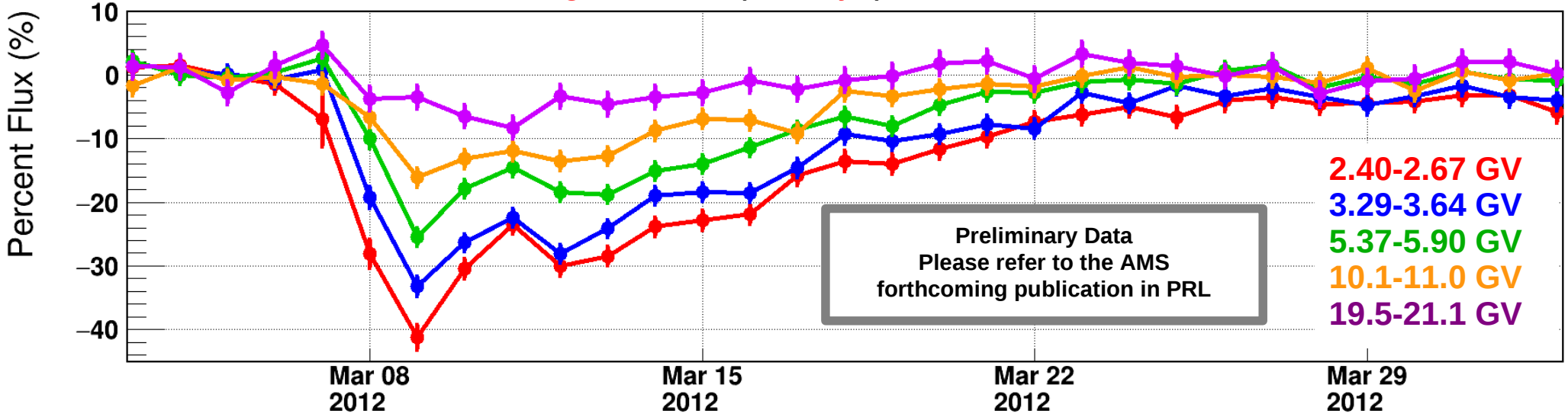




Forbush Decreases Characteristics

- **Start date:** date when decrease is first observed
- **Date of minimum:** date when majority of rigidity reach a minimum value
- **Recovery date:** date when normalized flux is within 2 SD of day-to-day variability
- **Duration:** number of days a decrease is observed
- **Maximum rigidity:** highest rigidity that shows a decrease
- **Maximum decrease at 2 GV:** percent decrease of the flux in the rigidity bin around 2 GV on the date of minimum.

March 8 2012: FD with long duration (20 days) and maximum decrease at 2 GV of 40%



FD Event List

List of FDs between May 2011 and May 2016 studied by AMS with estimated start date and duration.

Number	Start Date	Duration Days
1	2011/06/24	5
2	2011/08/06	4
3	2011/09/26	23
4	2011/10/25	3
5	2012/01/22	13
6	2012/02/27	4
7	2012/03/08	20
8	2012/04/06	4
9	2012/06/17	5
10	2012/07/15	9
11	2012/09/04	4
12	2012/11/24	5
13	2013/03/17	16
14	2013/04/15	3
15	2013/06/23	9
16	2013/11/08	13
17	2013/12/15	4

Number	Start Date	Duration Days
18	2014/02/15	5
19	2014/02/20	6
20	2014/02/26	14
21	2014/06/08	4
22	2014/06/18	20
23	2014/09/12	12
24	2014/12/01	17
25	2014/12/21	22
26	2015/03/16	10
27	2015/05/06	8
28	2015/06/22	14
29	2015/08/15	3
30	2015/08/26	3
31	2015/11/07	3
32	2015/12/20	4
33	2015/12/31	8

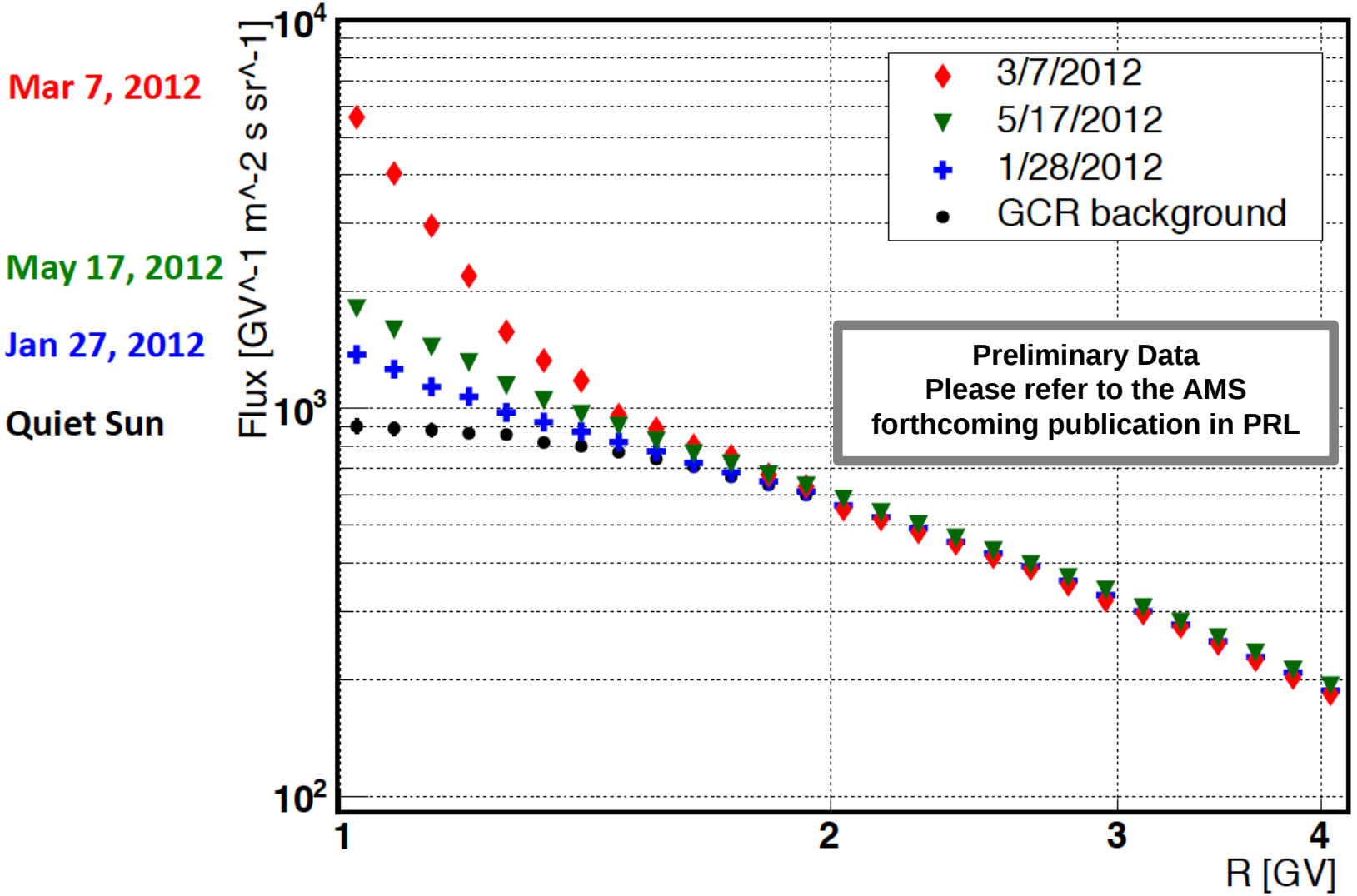
FD Characteristics for selected events

Longest duration: 23 days
Highest rigidity affected: 28.8 – 31.1 GV
Largest amplitude: 41.5% at ~2 GV

Preliminary Data
Please refer to the AMS forthcoming publication in PRL

AMS-02 FD	Start Date	Date of Minimum	Duration (Days)	Max Rigidity (GV)	Amplitude 1.92 - 2.15 GV (%)
1	2011/06/23	2011/06/24	6	19.5 - 21.1	8.5 ± 2.2
2	2011/08/06	2011/08/06	4	14.1 - 15.3	16.6 ± 2.0
3	2011/09/26	2011/09/27	23	15.3 - 16.6	20.6 ± 1.9
4	2011/10/25	2011/10/25	3	16.6 - 18.0	9.9 ± 2.1
5	2012/01/22	2012/02/01	13	28.8 - 31.1	21.3 ± 1.9
6	2012/02/27	2012/02/27	4	14.1 - 15.3	8.8 ± 2.2
7	2012/03/08	2012/03/09	20	28.8 - 31.1	41.5 ± 2.8
8	2012/04/06	2012/04/06	4	8.48 - 9.26	7.9 ± 2.2
9	2012/06/17	2012/06/18	5	18.0 - 19.5	10.3 ± 2.4
10	2012/07/15	2012/07/16	9	14.1 - 15.3	20.1 ± 2.0
11	2012/09/04	2012/09/05	4	22.8 - 24.7	14.7 ± 2.1
12	2012/11/24	2012/11/25	5	14.1 - 15.3	8.2 ± 2.2
13	2013/03/17	2013/03/19	16	21.1 - 22.8	17.9 ± 2.0
14	2013/04/15	2013/04/15	3	13.0 - 14.1	10.5 ± 2.2
15	2013/06/23	2013/06/28	9	12.0 - 13.0	12.1 ± 2.2
16	2013/12/15	2013/12/15	4	7.09 - 7.76	6 ± 1.8

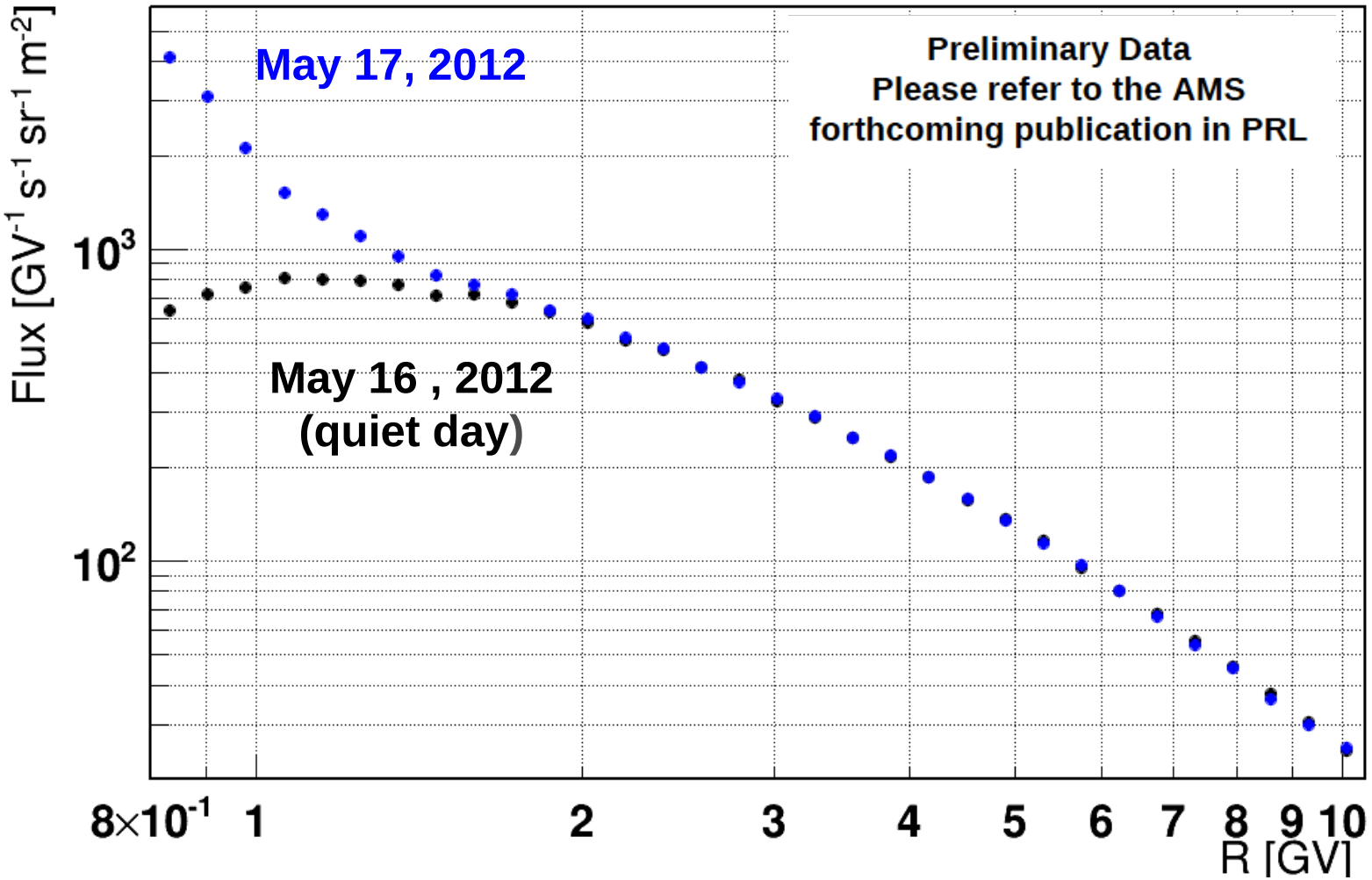
SEP: excess above the GCR background



AMS daily proton flux

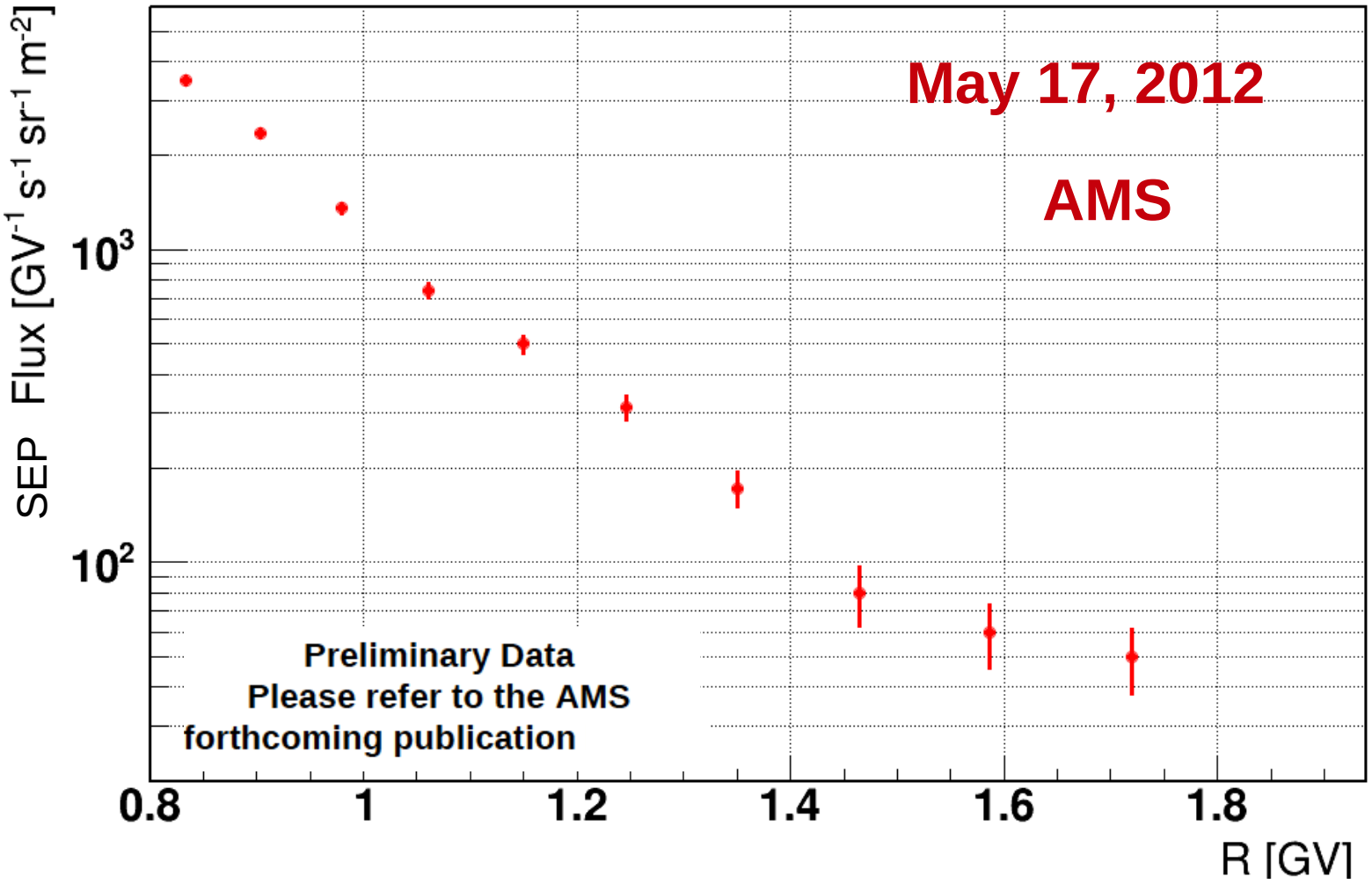
AMS Daily Proton Flux

May 17, 2012 - Ground Level Enhancement (GLE)
Solar Flare of class M5.1 (XRT Flare catalog).
Coronal Mass Ejection with linear speeds of 1582 km/s (SOHO LASCO CME catalog).

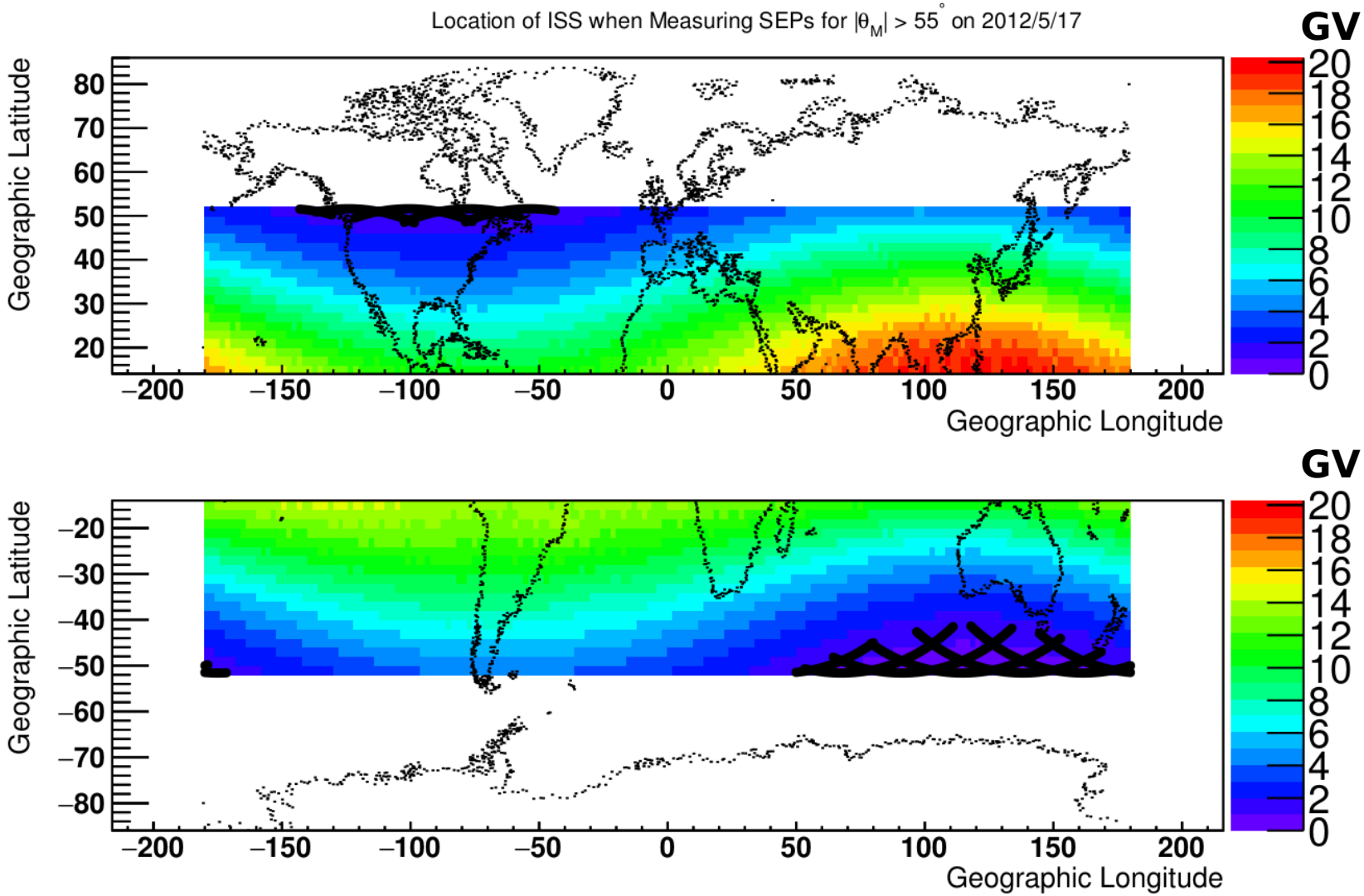


Solar Energetic Particle Flux

SEP flux obtained subtracting the galactic cosmic ray background



IGRF Geomagnetic Cutoff in the AMS field of view

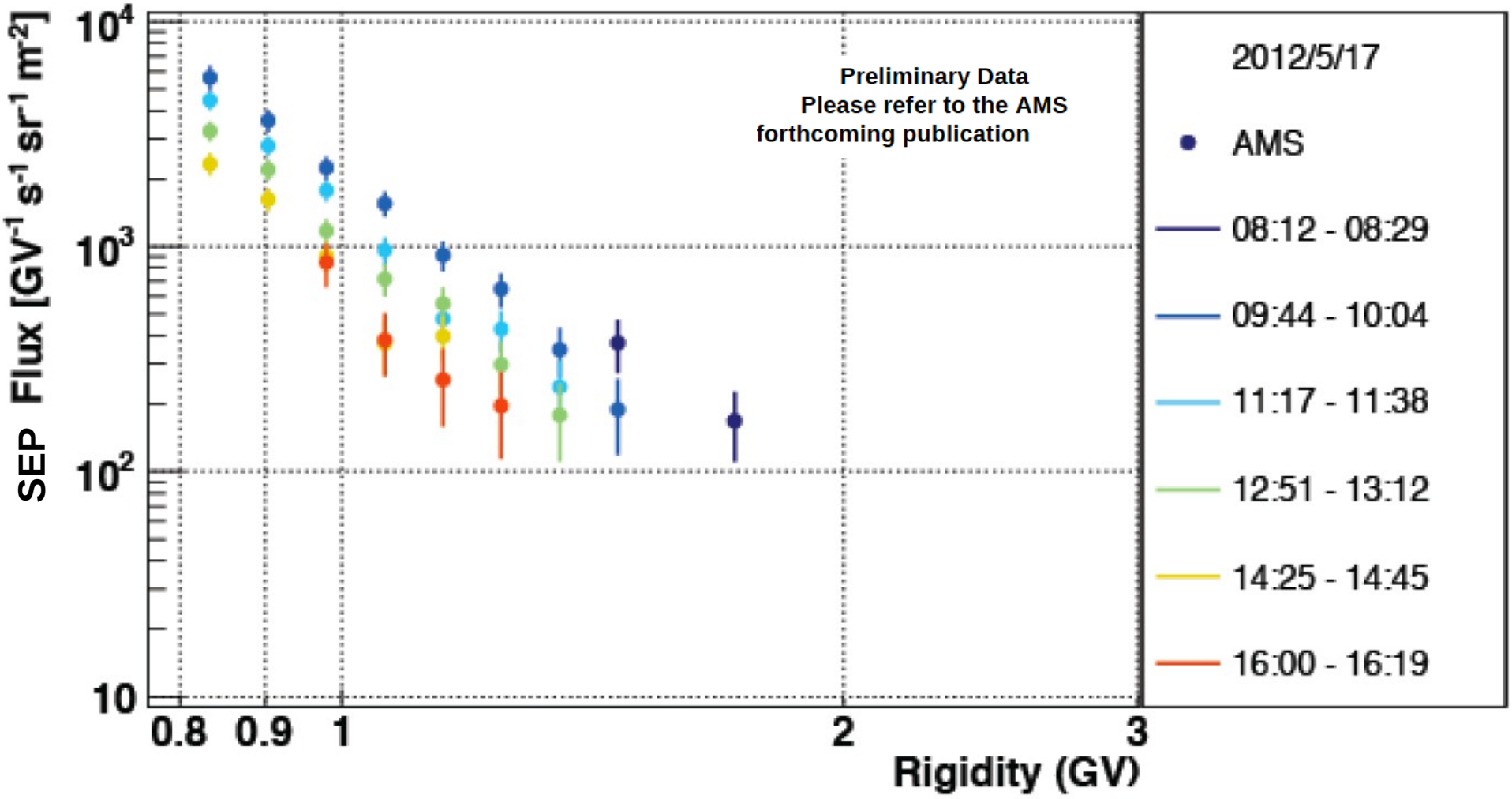


SEPs can be observed in the part of the orbit close to geomagnetic poles (~27% for orbiting period)

AMS Multi-orbit Observations Time evolution

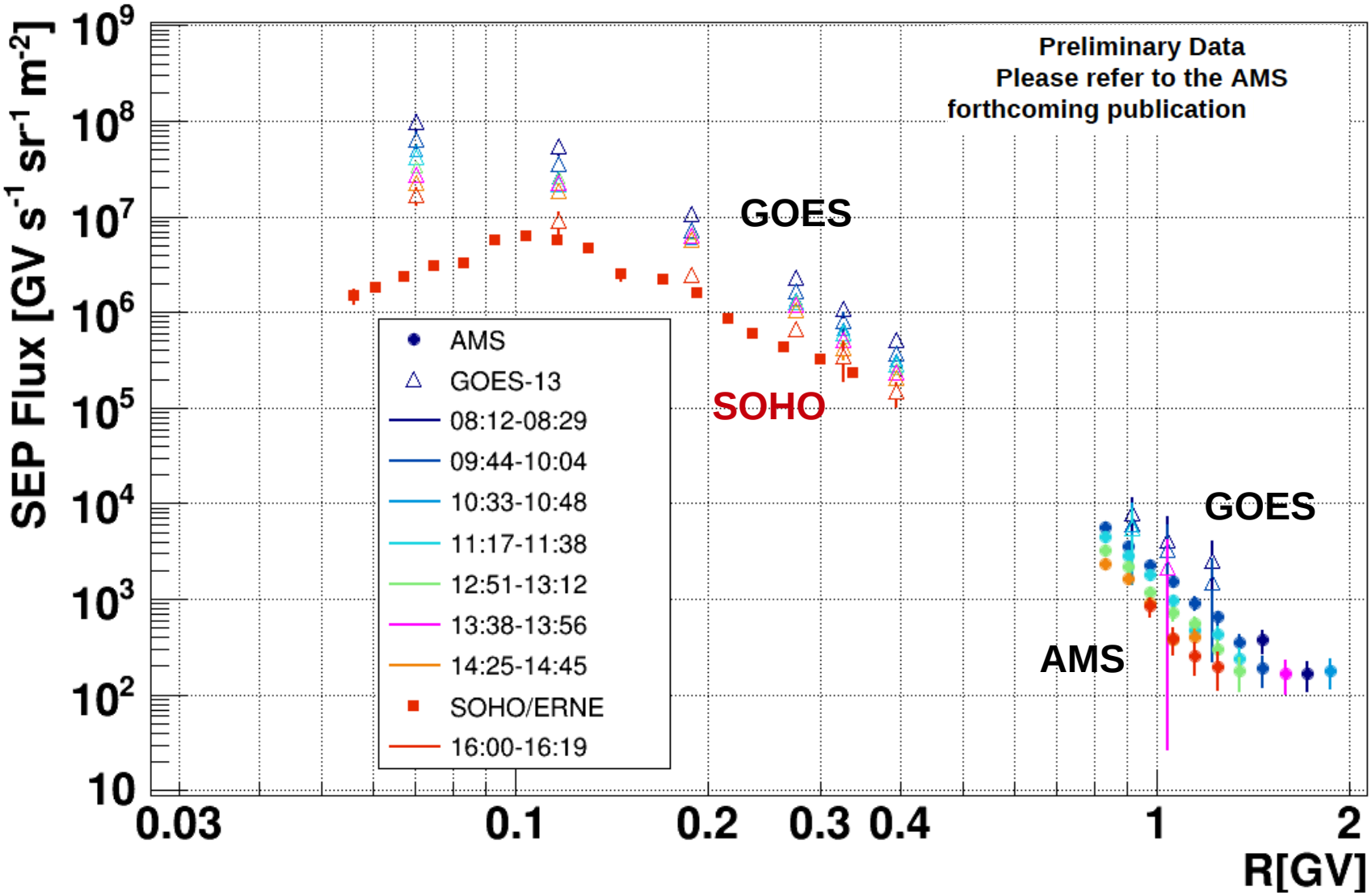
Average integration time about 10 minutes

May 17, 2012



AMS data provide information at high rigidity with fine resolution.

SEP flux May 17, 2012: Multi-instrument observation



AMS data, combined with other instruments at lower energy, will provide a baseline for the modeling of SEP production.

SEP events Observed by AMS

Preliminary Data
Please refer to the AMS forthcoming publication

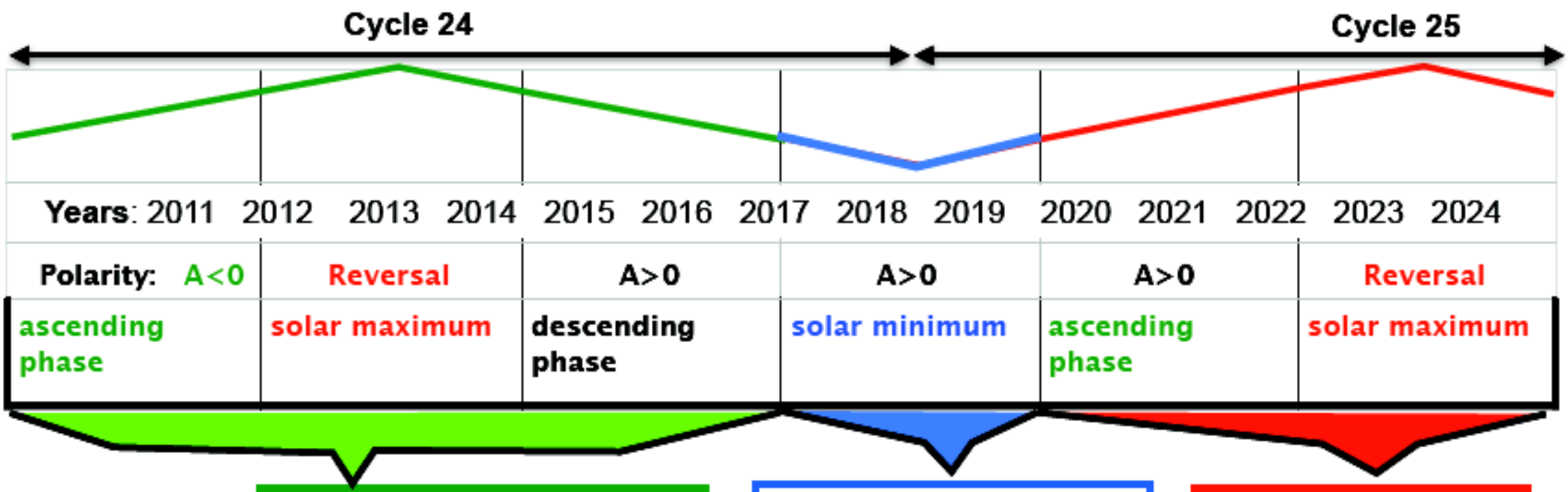
AMS observed 27 high energy SEP events at ~ 1 GV from May 2011 to May 2016.

AMS SEP events are typically associated with M and X class flares and fast CMEs.

Ground Level Enhancement (GLE)

AMS Event		Event Date	Flare Class	CME Vel. (km/s)	
1		**2011/06/07**	**M2.5**	**1255**	
2	FD	**2011/08/04**	**M9.3**	**1315**	
3		**2011/08/09**	**X6.9**	**1610**	
4		2011/09/06	X2.1	575	
5		2011/09/22	X1.4	1905	
6	FD	**2012/01/23**	**M8.7**	**2175**	
7	FD	**2012/01/27**	**X1.7**	**2508**	
8	FD	**2012/03/07**	**X5.4, X1.3**	**2684, 1825**	
9	FD	**2012/03/13**	**M7.9**	**1884**	
10		**2012/05/17**	**M5.1**	**1582**	GLE
11		2012 /07/06	X1.1	1854	
12		2012/07/08	M6.9	1495	
13	FD	**2012/07/19**	**M7.7**	**1631**	
14	FD	**2012/07/23**	**backside**	**2003**	
15		**2013/04/11**	**M6.5**	**861**	
16	FD	**2013/05/22**	**M5.0**	**1466**	
17	filament	2013/09/29	C1.2*	1179	
18		2013/10/28	M5.1, M2.8, M4.4	1201, 1073, 812	
19	FD	2013/11/02	backside	828	
20		2013/12/28	backside	1118	
21	FD	2014/01/06	backside	1118	
22	FD	2014/01/07	X1.2	1830	
23	FD	2014/02/25	X4.9	2147	
24	FD	2014/04/18	M7.3	1203	
25		2014/09/01	backside	1404	
26	FD	2014/09/10	X1.6	1267	
27		2015/10/29	backside	530**	

AMS data taking till 2024 - Agenda



DRIFT :
e-, e+ , p, pbar

Comparing data collected before, during and after the solar maximum AMS can study in details the effects due to the solar polarity reversal.

AMS will measure the drift of positive vs negative particles during the solar minimum with positive polarity A>0.

AMS will compare solar maximum of cycles 25 (A>0) and 24 (A<0) and the solar polarity reversal.

DIFFUSION :
All species of GCR

AMS is measuring the modulation of different nuclei during a solar cycle.

FD and SEP :

Measured 27 SEPs and identified so far 33 FDs.

Not expected major events during minimum

Lots of new SEPs and FDs.

Summary & Conclusions

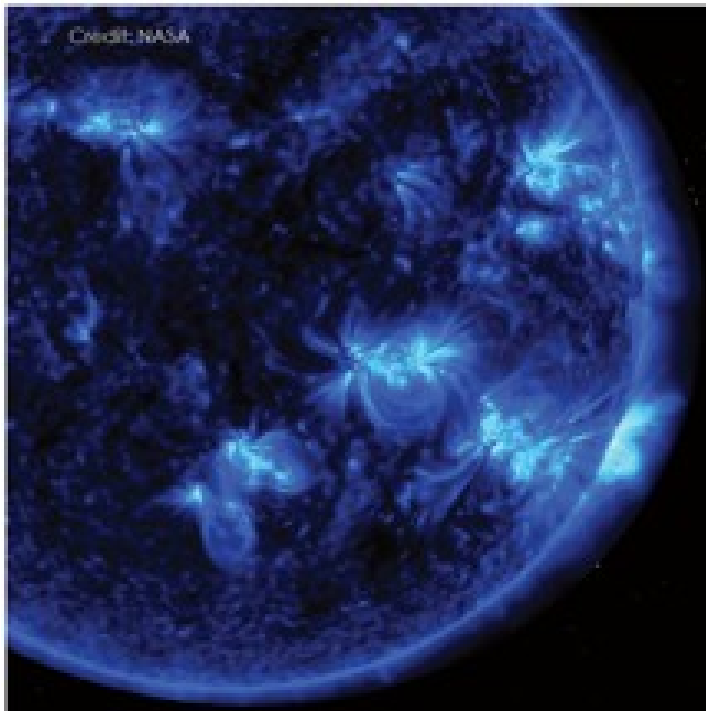
A new era in galactic cosmic rays understanding has started, not only at high energy, but also **at low energy in the region affected by the solar modulation** thanks to the precise and continuous observations from space by PAMELA in solar cycle 23 and now AMS-02 in solar cycle 24 and 25.

New and precise measurements are increasing our knowledge of important effects such as **diffusion and drift in the heliosphere**, allowing the detailed study of propagation.

These measurements will serve as a **high-precision baseline** for continued studies of GCR solar modulation, SEPs, space radiation hazards, magnetospheric effects, trapped particles and in many other fields.

Near future forthcoming AMS publications on solar modulation: time evolution of proton and helium fluxes, electron and positron fluxes, and antiproton/proton ratio.

Workshop in DC, May 2018



SOLAR ENERGETIC PARTICLES SOLAR MODULATION AND SPACE RADIATION

NEW OPPORTUNITIES IN THE AMS-02 ERA #3

MAY 21 - 23, 2018
WASHINGTON DC

ORGANIZER
VERONICA BINDI
UNIVERSITY OF HAWAI'I AT MĀNOA

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