

PARTICLES AND ANTI PARTICLES IN THE HELIOSPHERE: RECENT MEASUREMENTS AND MODELING

VALERIA DI FELICE

ISTITUTO NAZIONALE DI FISICA NUCLEARE, ITALY
ITALIAN SPACE AGENCY SSDC

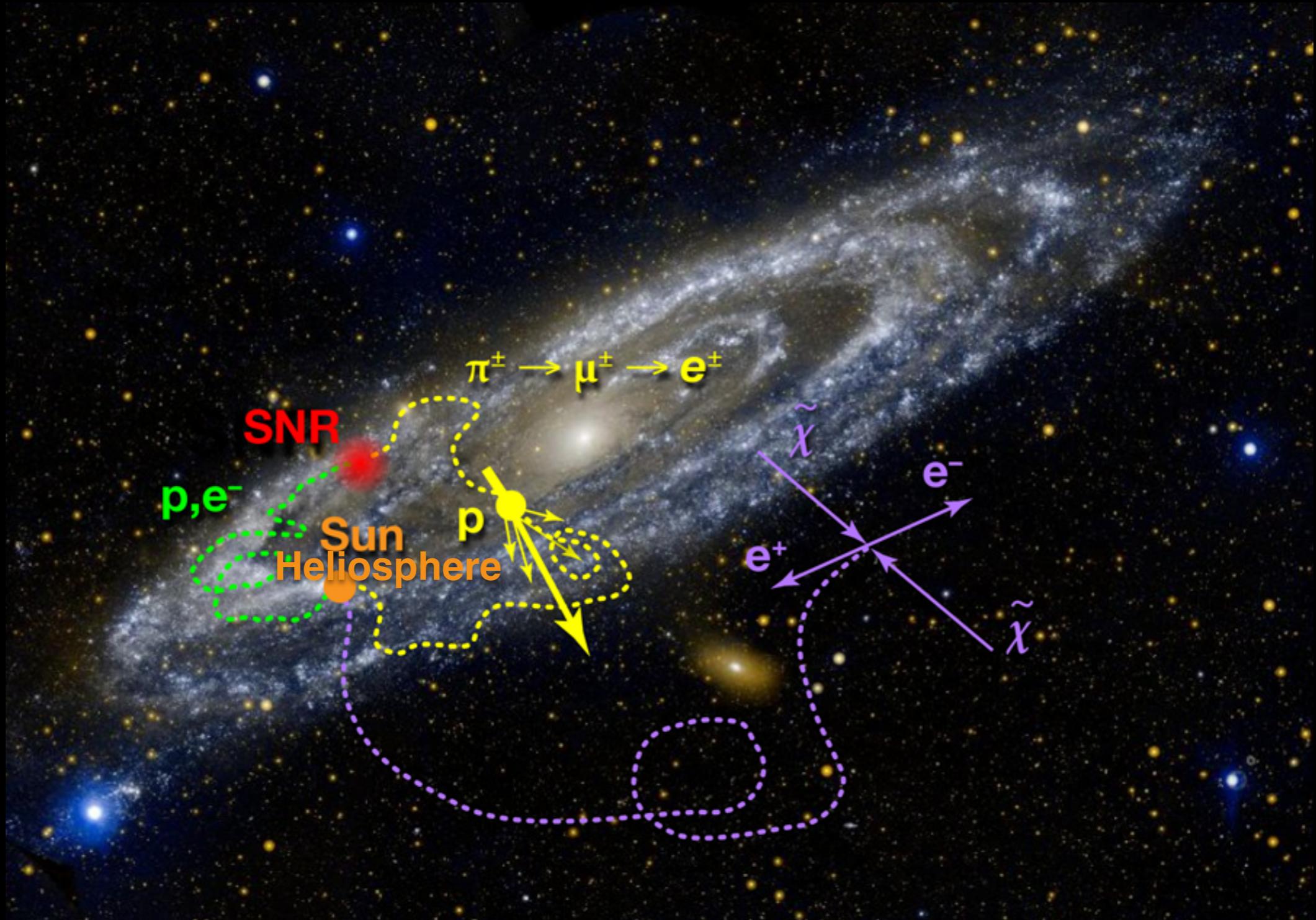
'LIGHT ANTINUCLEAR AS A PROBE FOR NEW PHYSICS'
LEIDEN - LORENTZ CENTER 16.10.2019

PARTICLES AND ANTI PARTICLES IN THE HELIOSPHERE: RECENT MEASUREMENTS AND MODELING



Image: SXP 1062 pulsar found within a supernova remnant in the Small Magellanic Cloud
Chandra X-ray Observatory and XMM Newton

A long journey for cosmic rays: from sources to detection at 1AU

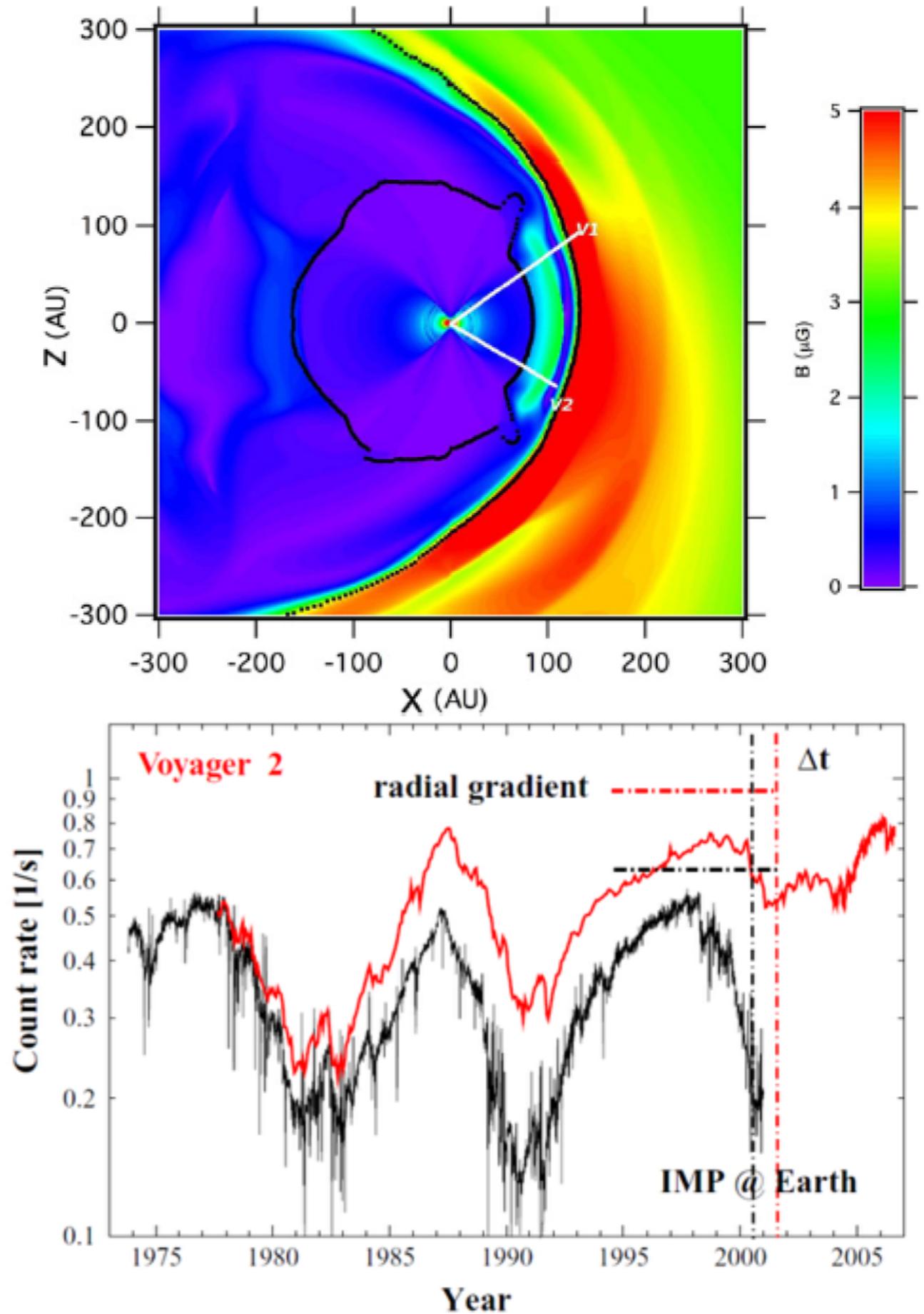


THE HELIOSPHERE AND ITS IMPACT ON CR_s



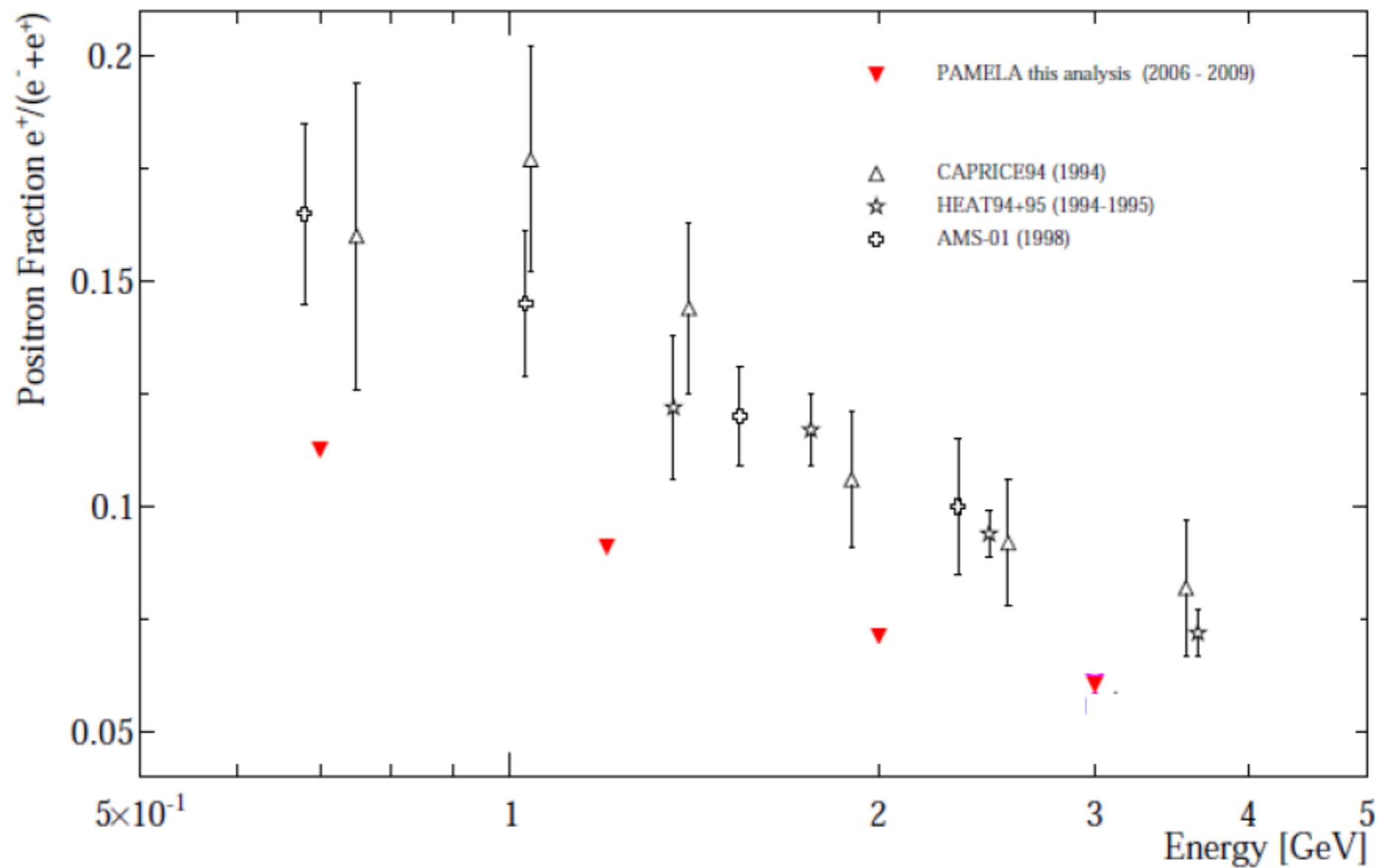
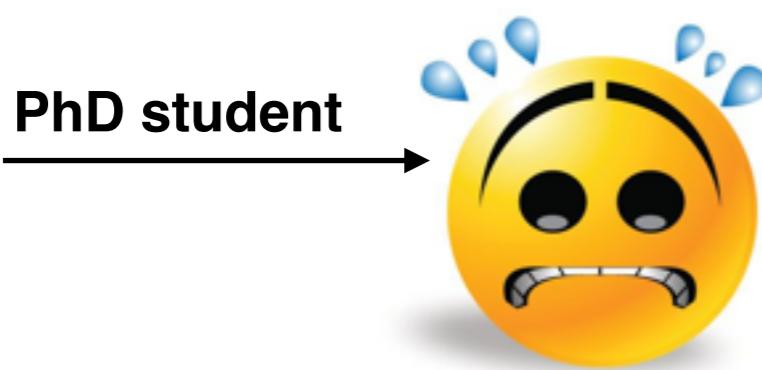
A. CUMMINGS

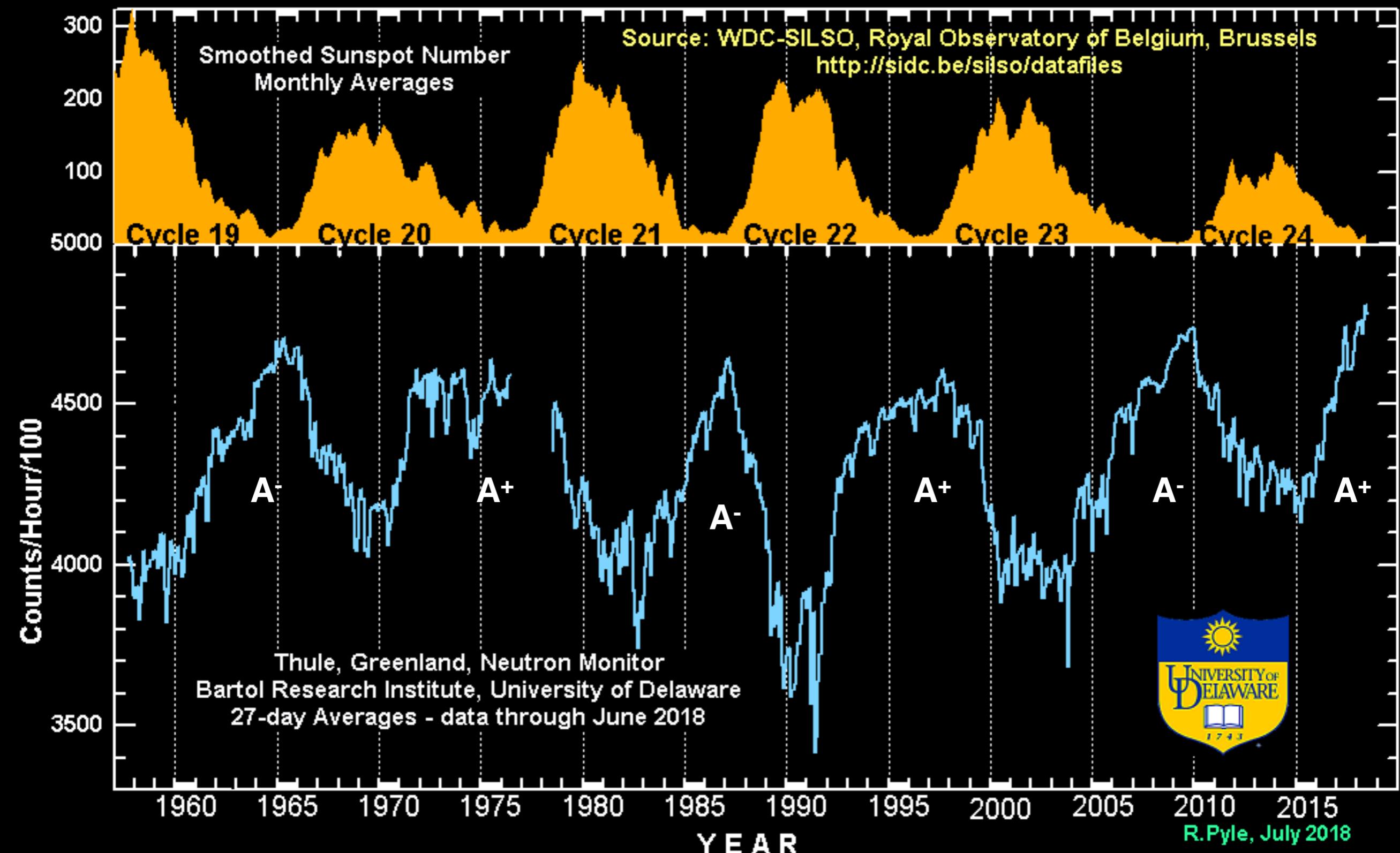
"YOU CAN MAKE AN HELIOSPHERE IN A KITCHEN SINK"



LOW ENERGY POSITRON FRACTION

PAMELA DATA
2006-2009





GOALS

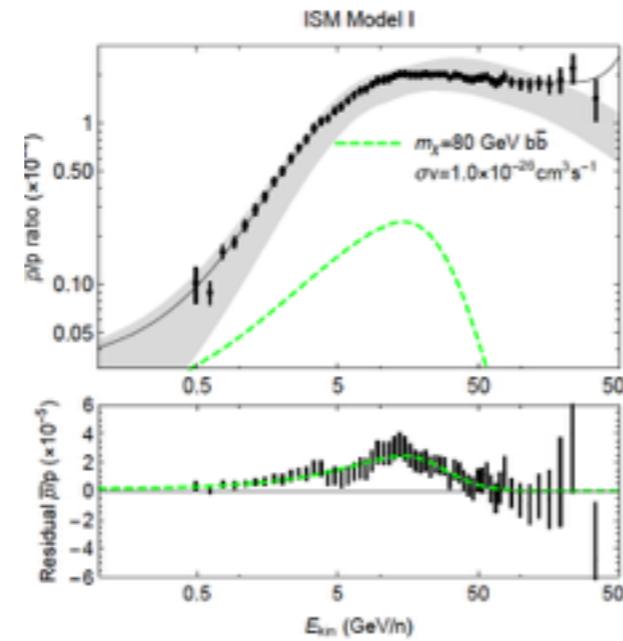
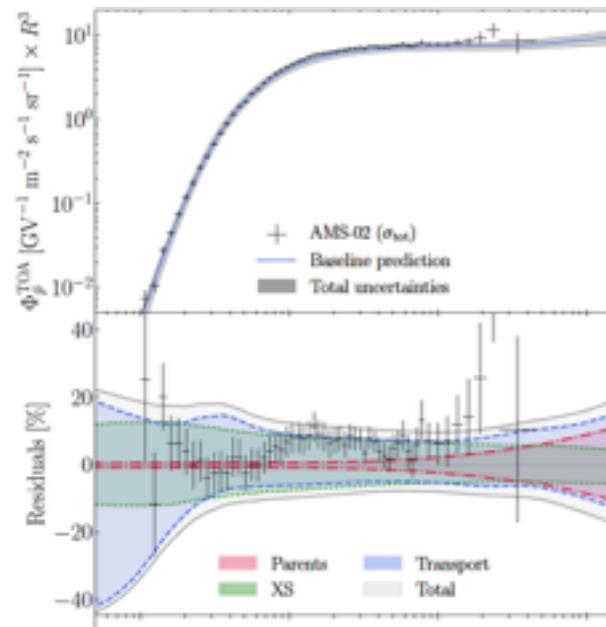
- HELIOSPHERIC PHYSICS
- CR PROPAGATION

SOLAR MODULATION EFFECT

- PARTICLE
- ENERGY
- SIGN OF CHARGE
- TIME

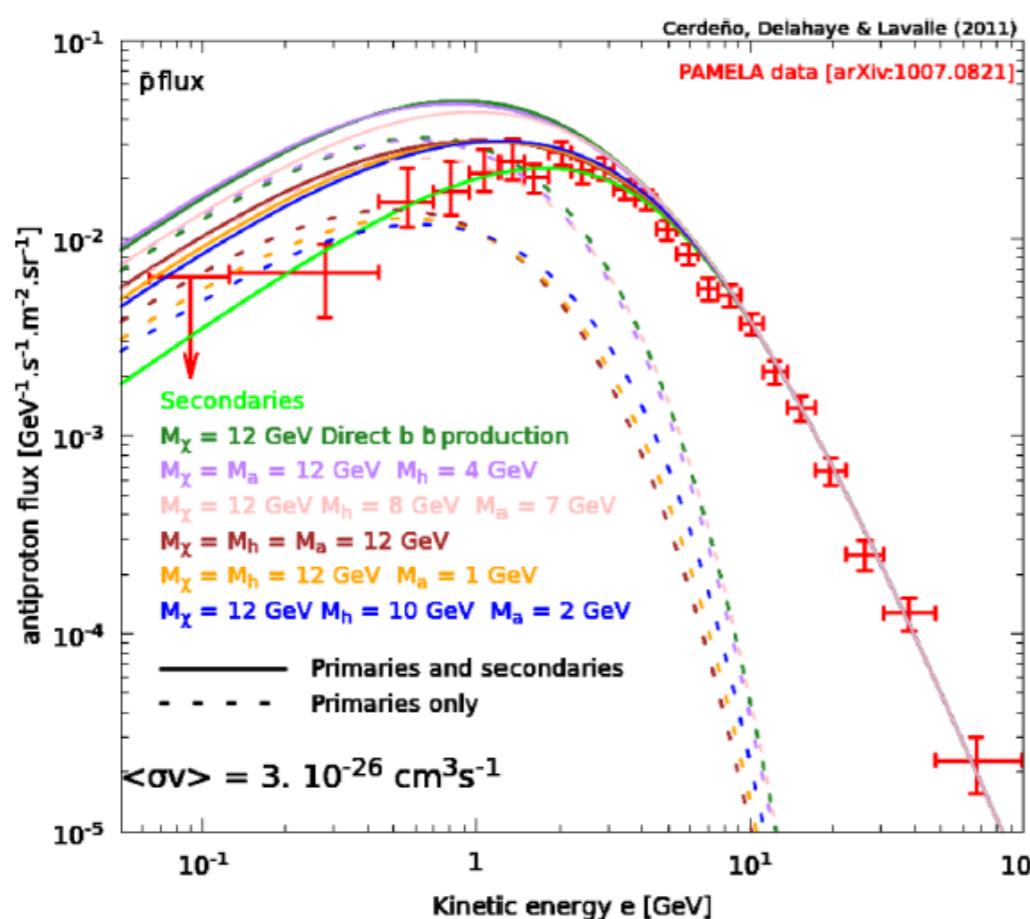
<http://neutronm.bartol.udel.edu/>

LOW ENERGY ANTIPROTONS

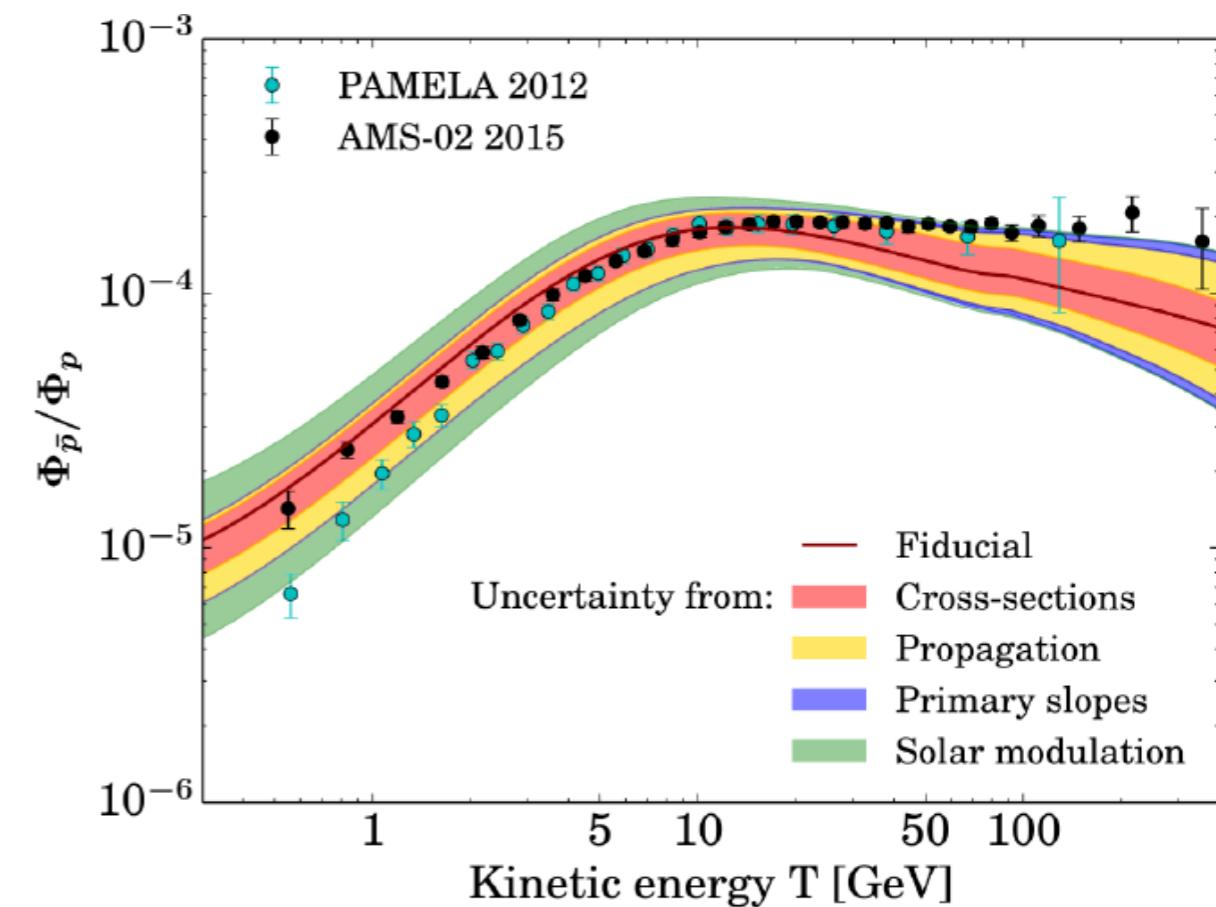


UNCERTAINTIES!
(THIS WORKSHOP F. DONATO, D. MAURIN)

Baudaud et al 1906.07119
Cholis, Linden, Hooper (2019; Phys. Rev. D 99, 103026)

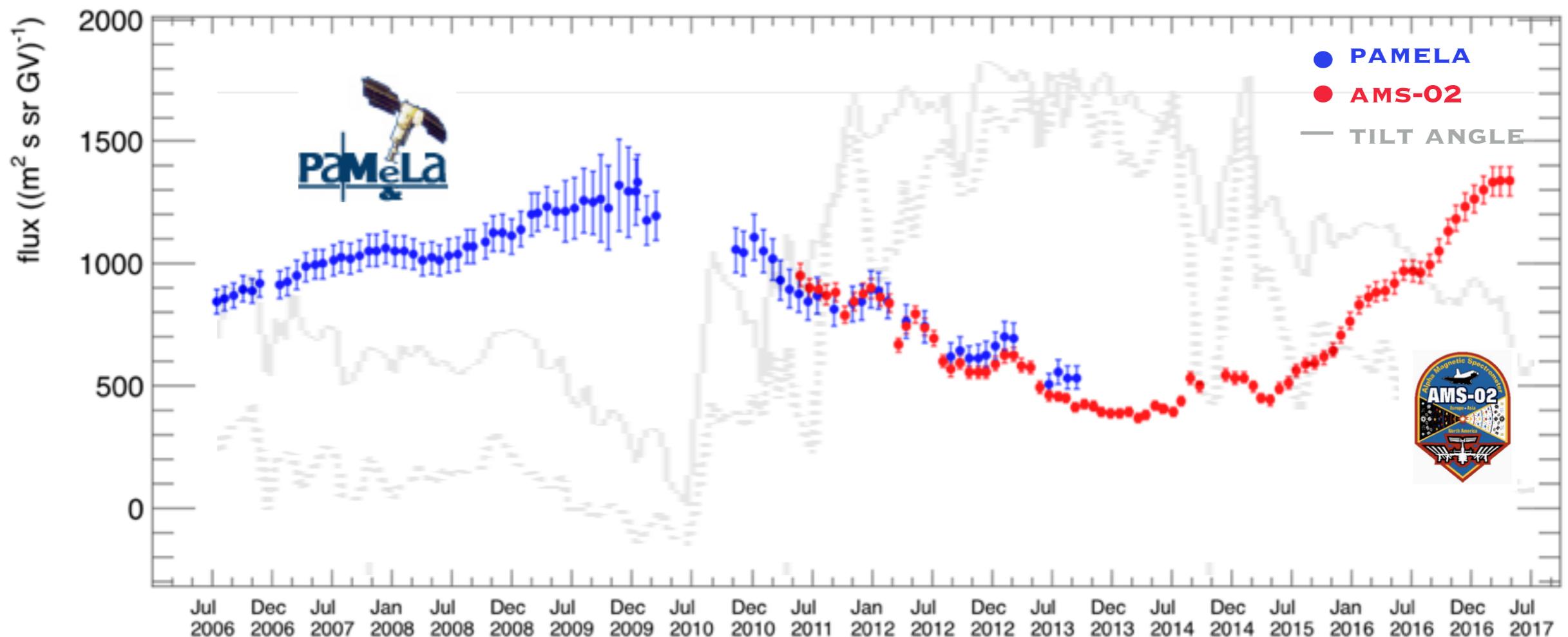


D. G. Cerdeno, T. Delahaye, J. Lavalle, Nucl. Phys. B 854 (2012) 738

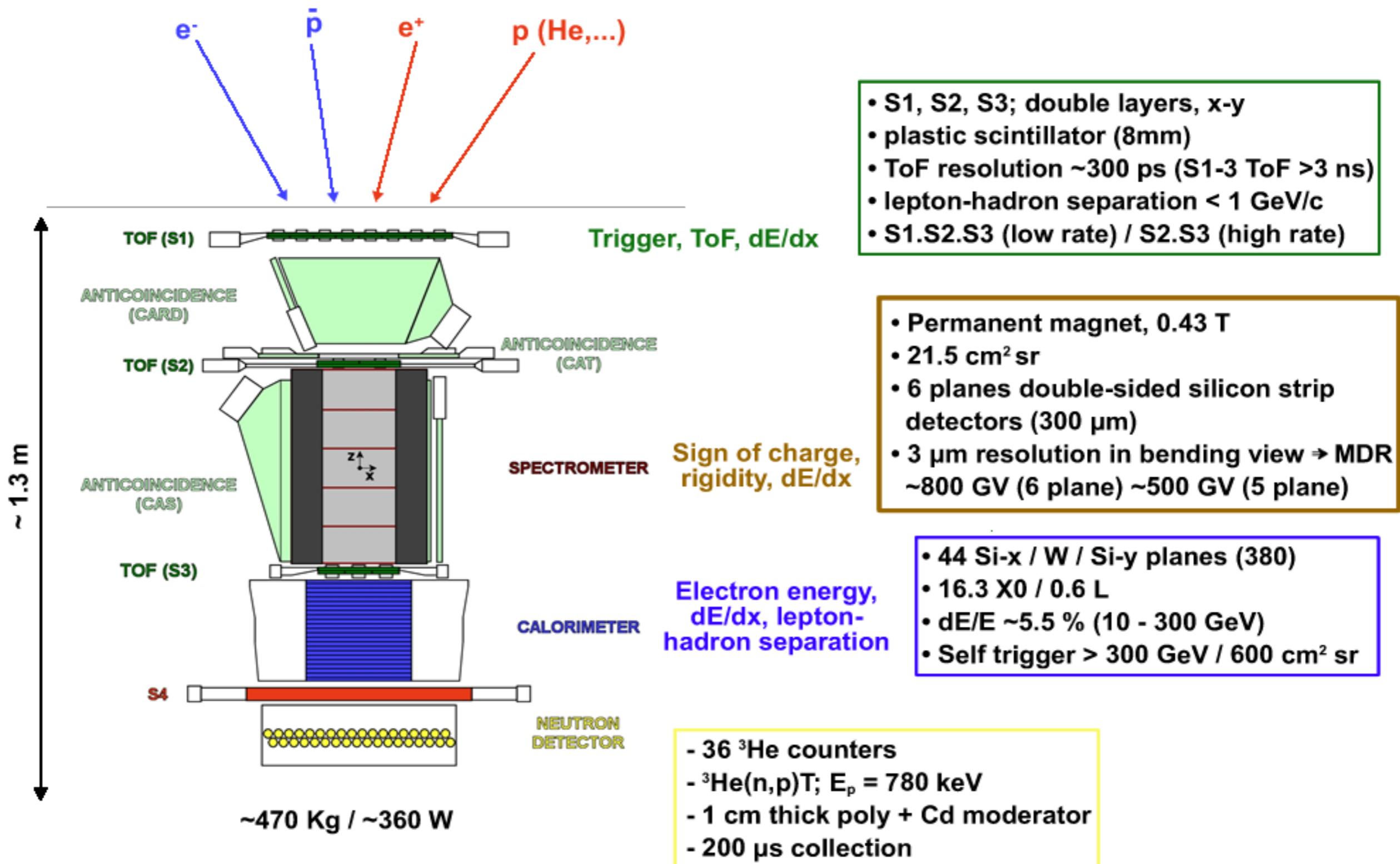


G. Giesen et al., JCAP 1509 (2015) 023, arXiv:1504:04276

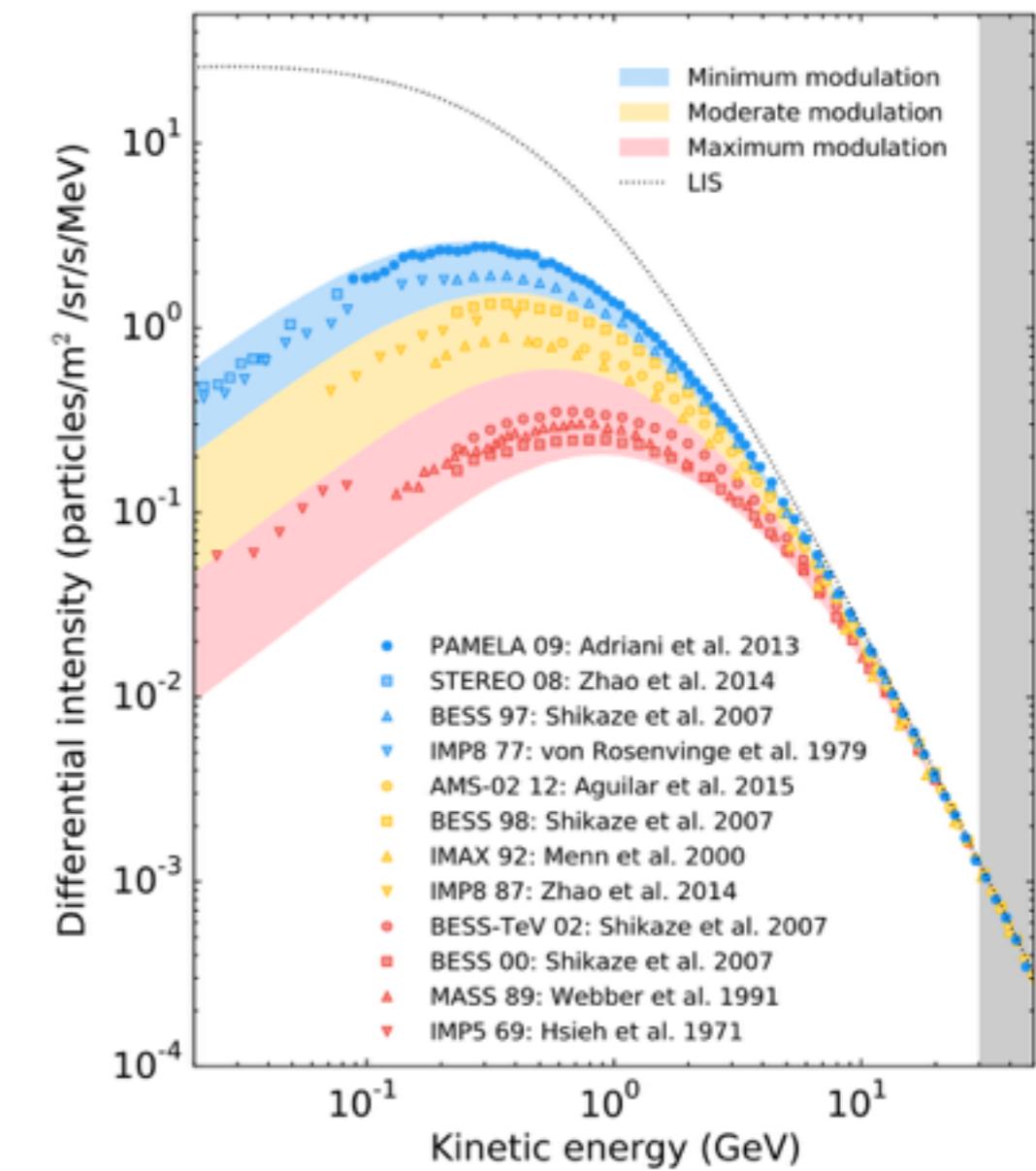
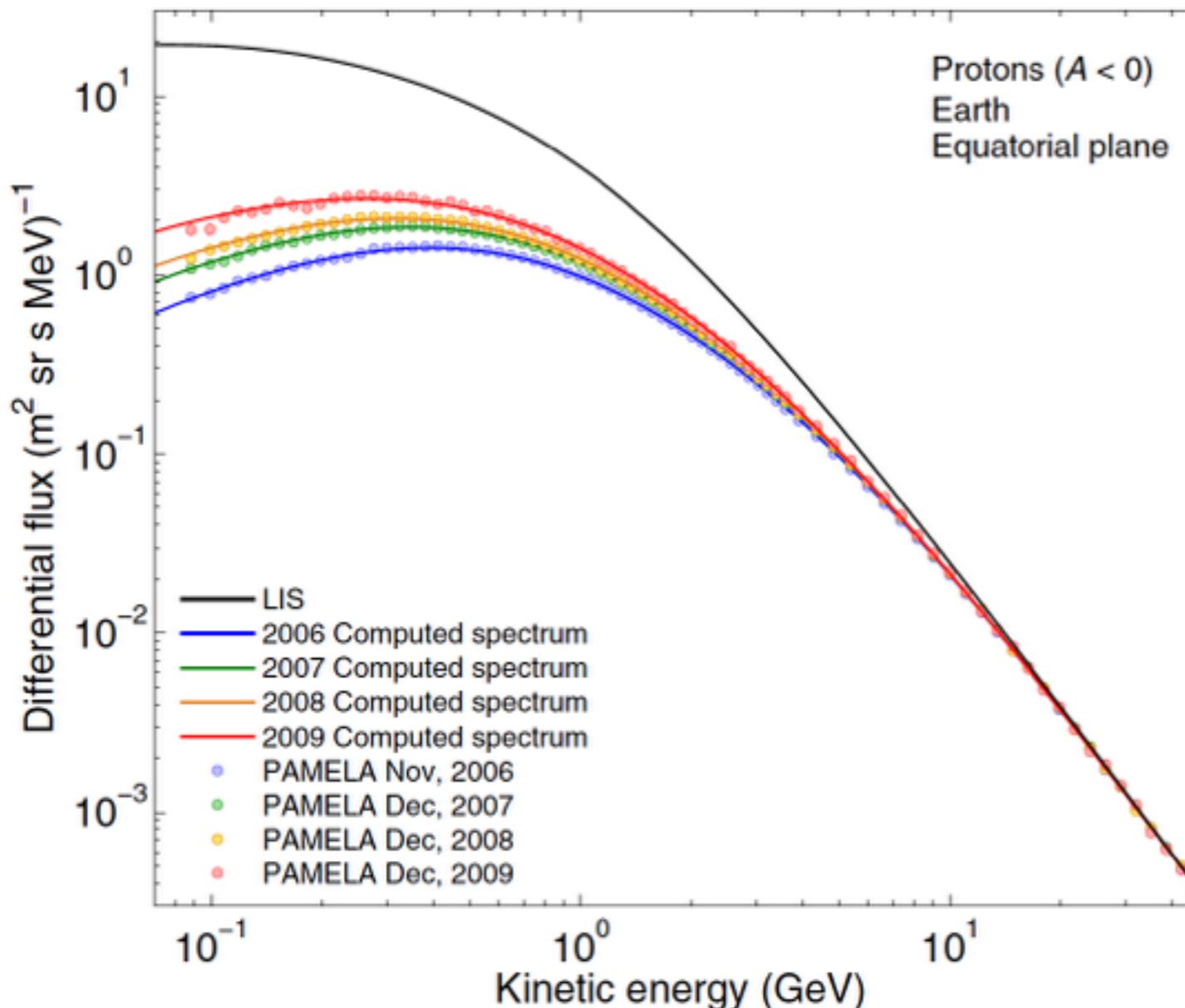
(RELATIVELY) RECENT MEASUREMENTS



THE PAMELA SPECTROMETER



MEASUREMENTS AT SOLAR MINIMUM - PROTONS



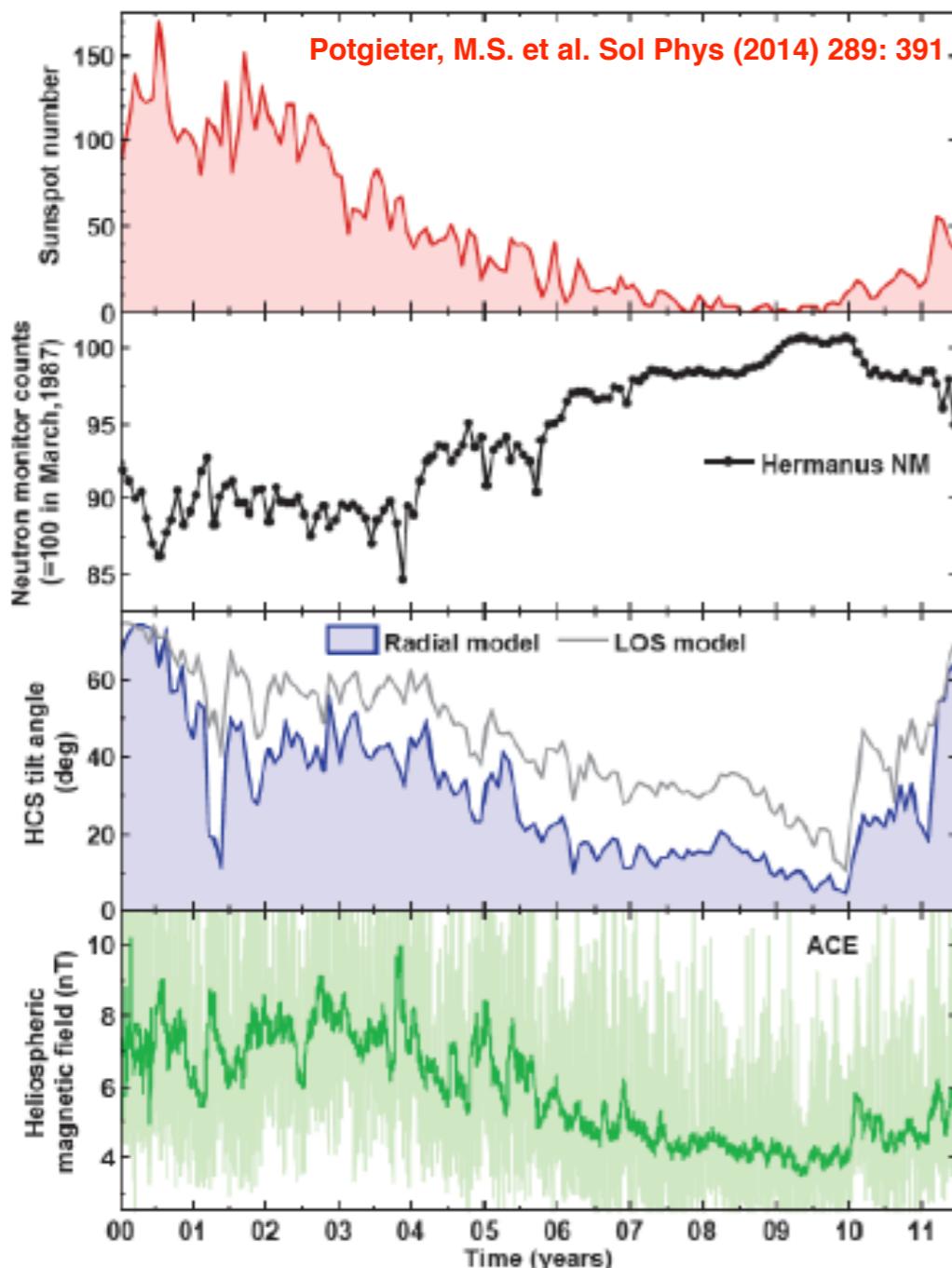
Adriani et al., ApJ 765, 2 (2013)
Potgieter, M.S. et al. Sol Phys (2014) 289: 391

Vos & Potgieter, ApJ 815, 119 (2015)
Strauss R.D., Potgieter M.S., Solar Physics, 289, 8 (2014)

HELIOSPHERIC TRANSPORT MODELING

$$\frac{\partial f}{\partial t} = \underbrace{-\mathbf{V} \cdot \nabla f}_a + \underbrace{\nabla \cdot (\mathbf{K}_s \cdot \nabla f)}_b - \underbrace{\langle \mathbf{v}_D \rangle \cdot \nabla f}_c + \underbrace{\frac{1}{3}(\nabla \cdot \mathbf{V}) \frac{\partial f}{\partial \ln p}}_e + \underbrace{Q(x, p, t)}_f$$

(a) $f(x, p, t)$, omnidirectional function distribution of CRs; (b) convection with solar wind \mathbf{V} ; (c) diffusion by magnetic field irregularities; (d) drift, curvature and gradient in magnetic field; (e) adiabatic energy losses; (f) local sources (Jovian electrons);



SOLAR MODULATION MECHANISMS

- CONVECTION WITH SOLAR WIND
- DIFFUSION BY MAGNETIC FILED IRREGULARITIES
- DRIFT (CURVATURE, GRADIENTS IN MAGNETIC FIELD AND HCS)
- ADIABATIC ENERGY LOSSES

MODEL INPUT PARAMETERS:

- GEOMETRY AND PHYSICAL BOUNDARIES OF THE HELIOSPHERE
- SOLAR ACTIVITY PARAMETERS (TIME-VARYING)
- INPUT LOCAL INTERSTELLAR SPECTRUM (LIS)

Uncertainties in heliospheric propagation

Geometry and physical boundaries of the Heliosphere

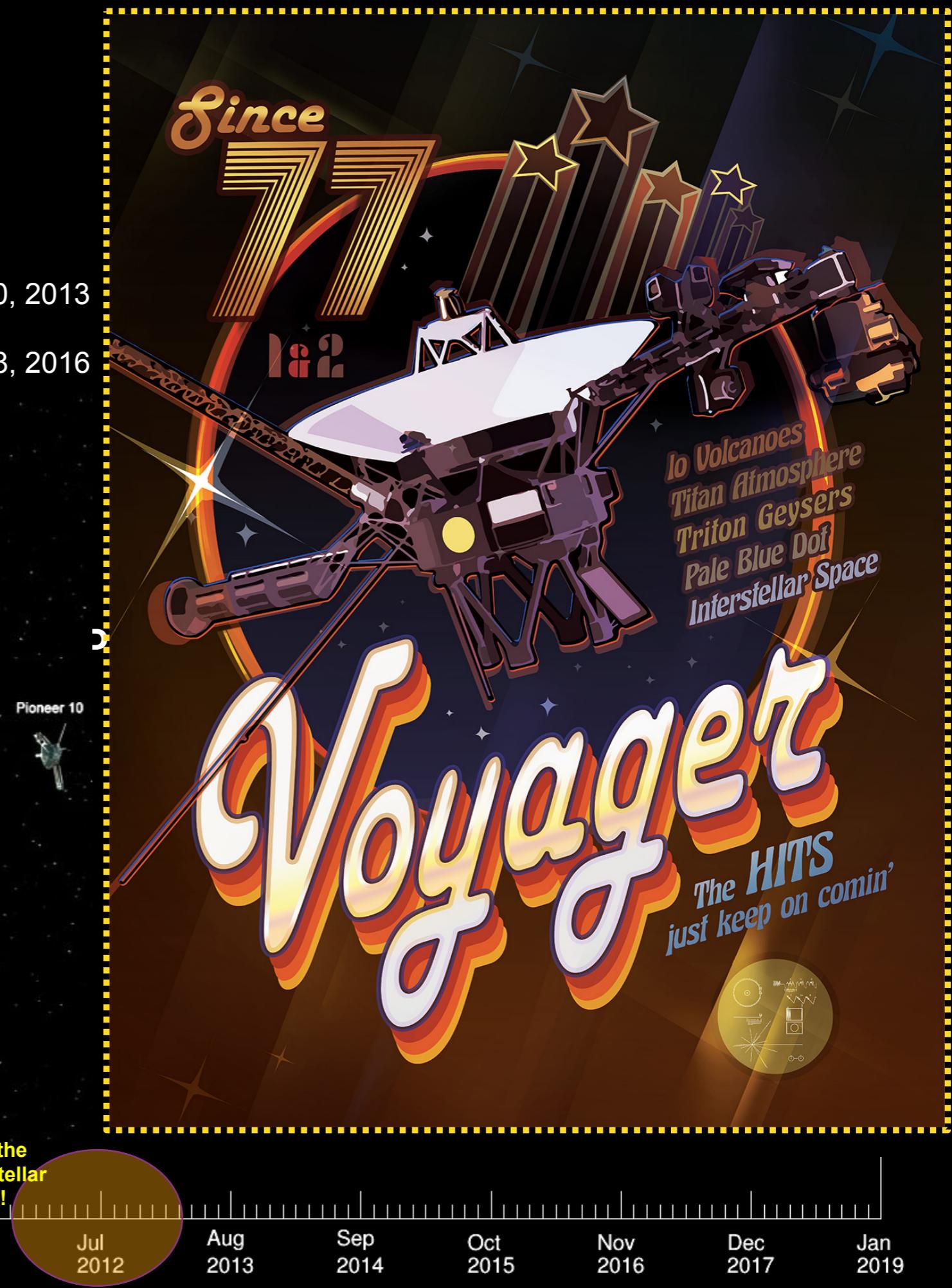
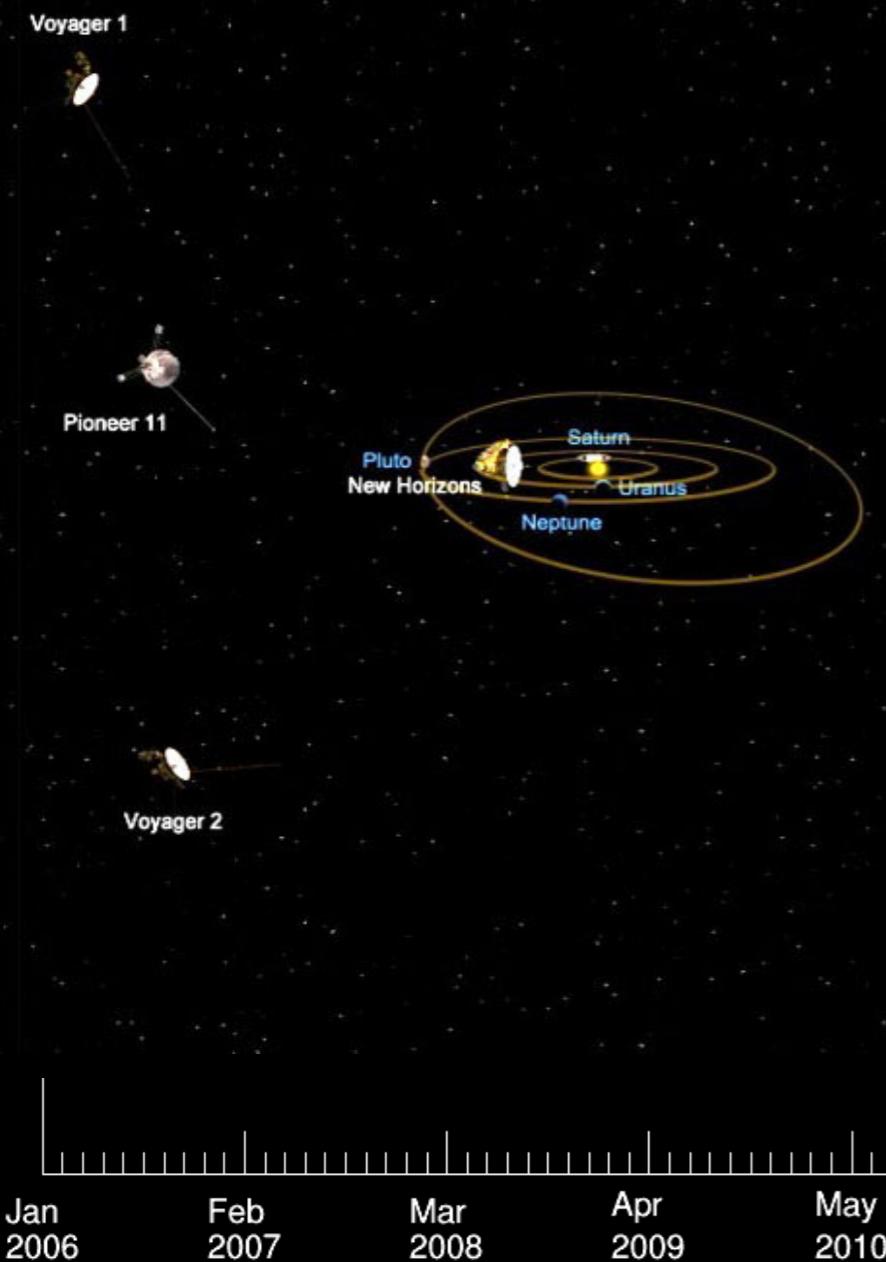
Solar activity parameters (time-varying)

Input Local Interstellar Spectrum (LIS)

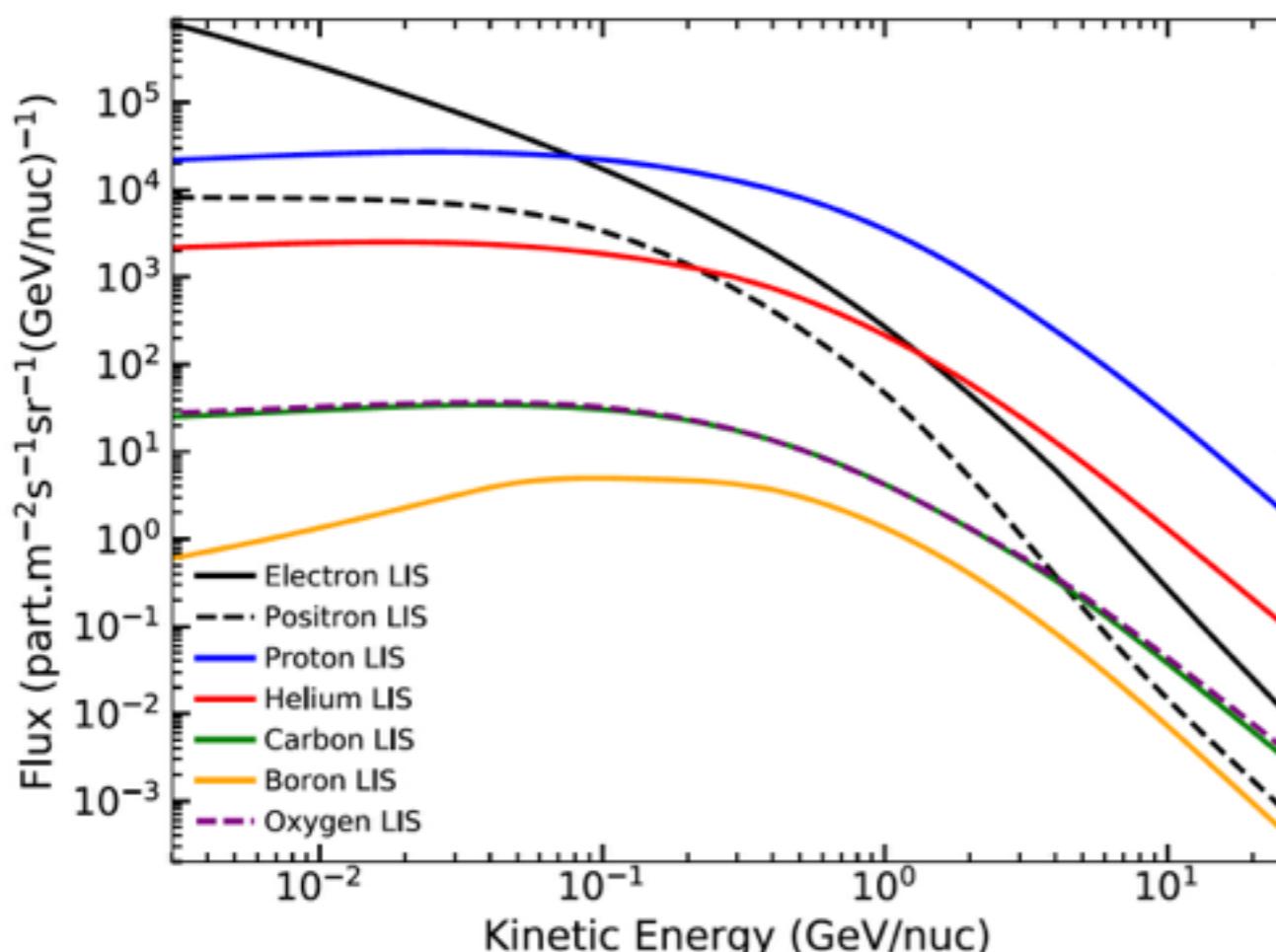
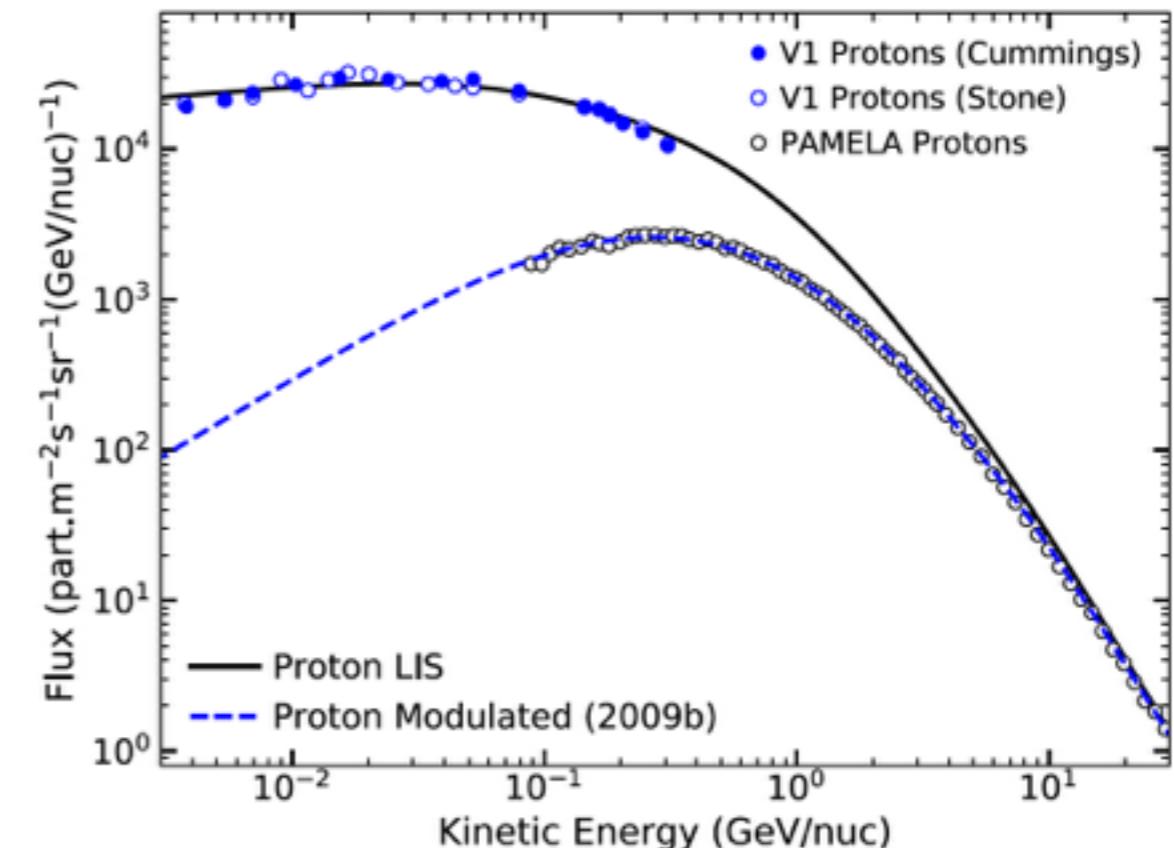
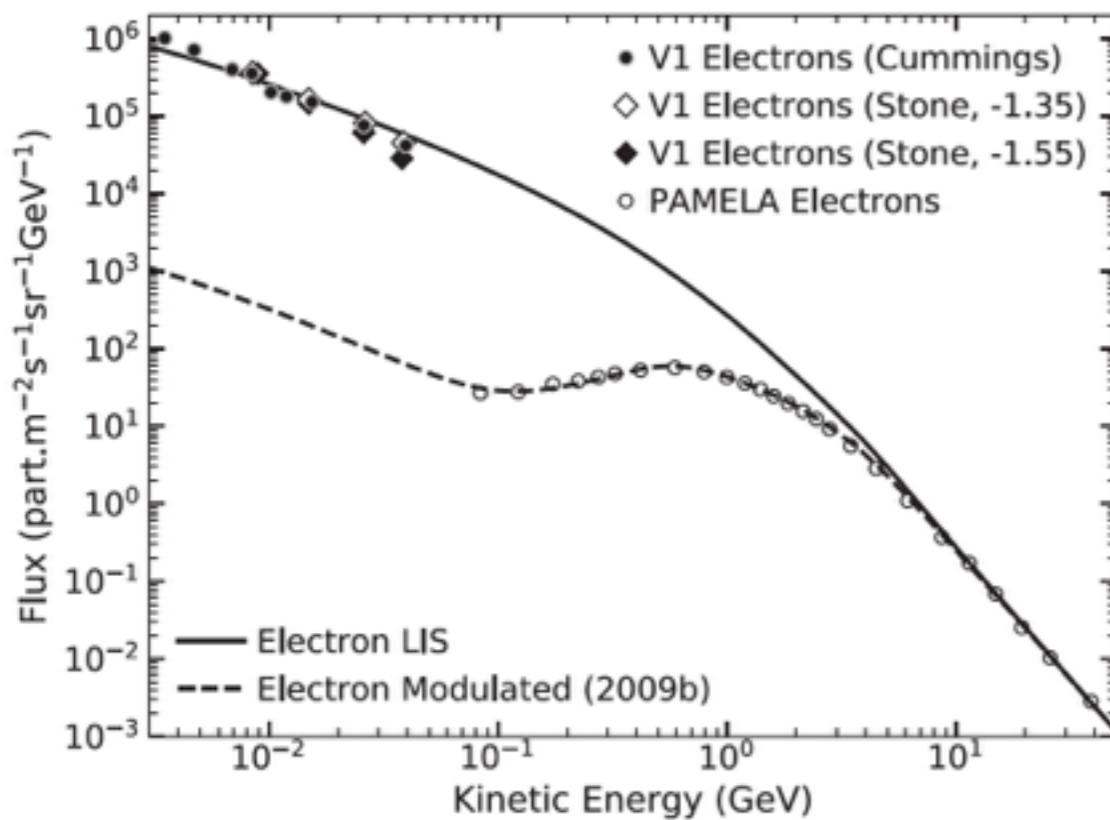
Webber W. R. and F. B. McDonald, Geoph. Res. Lett., 40, 2013

Stone E. C. et al., Science, 341 (6142), 2013

Cummings A. C. et al., The Astrophysical Journal, 831:18, 2016



NEW VERY LOCAL INTERSTELLAR SPECTRA (LIS)



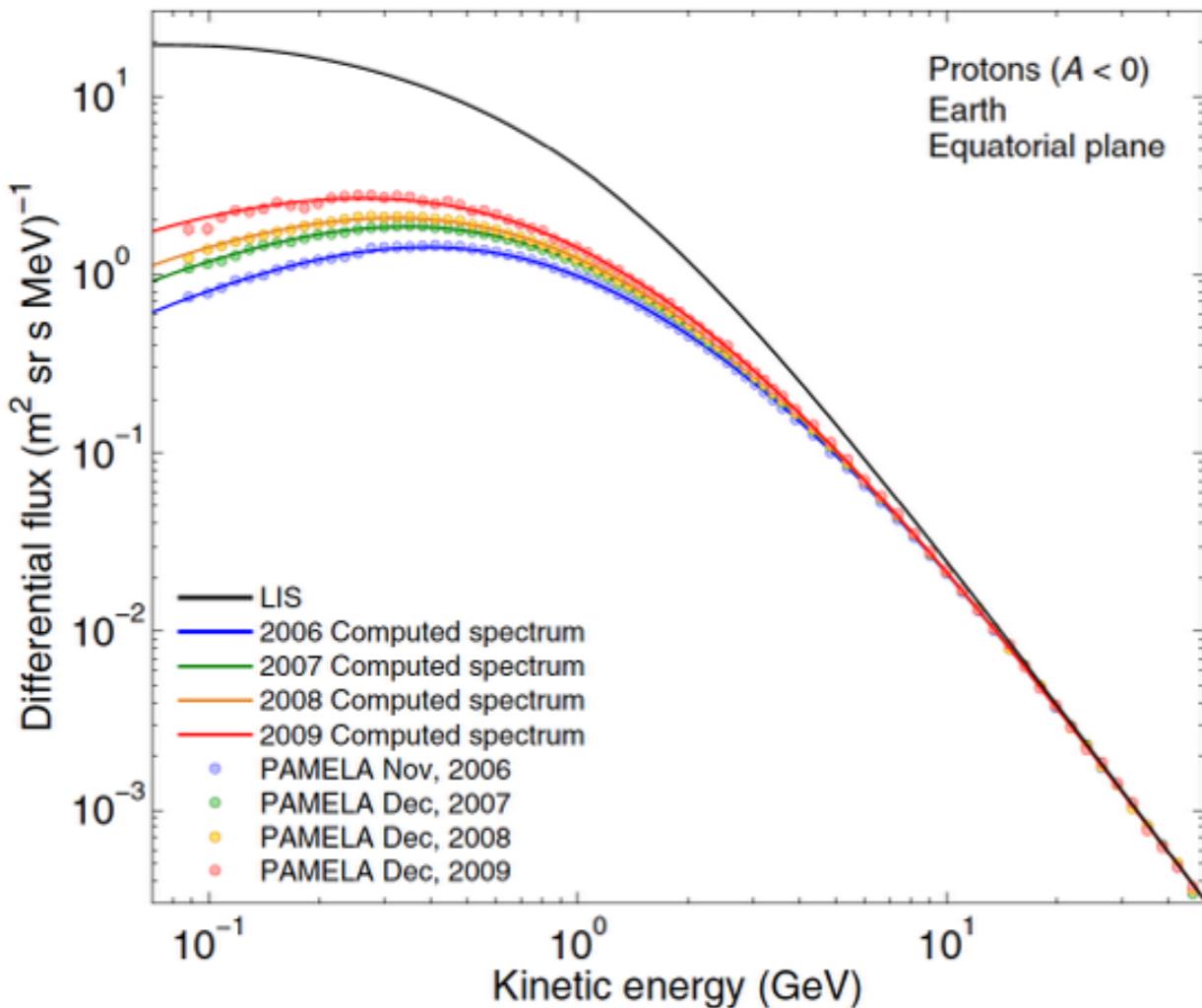
[Bisschoff, Potgieter, & Aslam, ApJ 878:59 \(2019\)](#)

New Very Local Interstellar Spectra for:
e-, e+, H, He, B, C, O

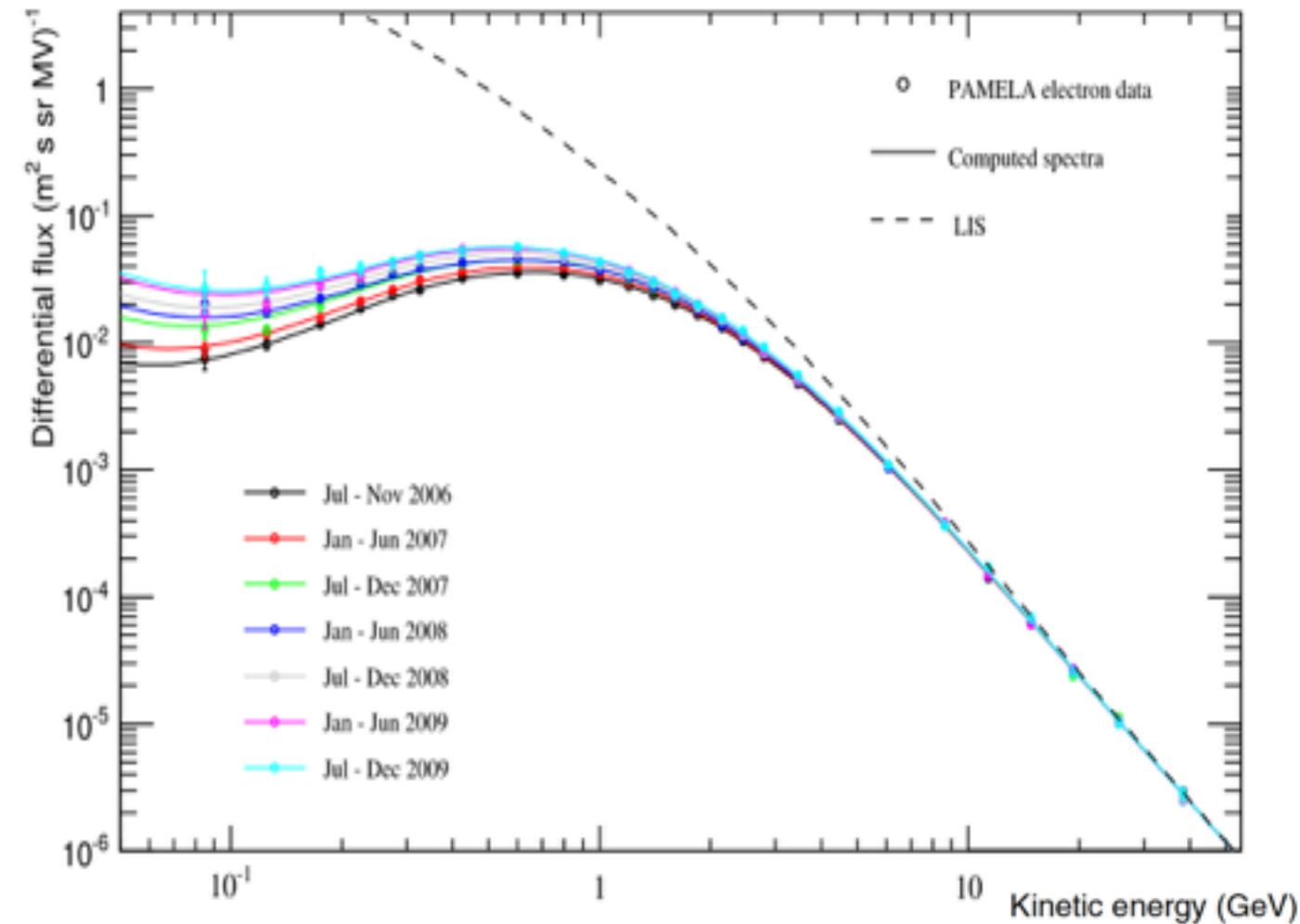
LIS calculated for several species, simultaneously, with an iterative method

3 MeV/n - 100 GeV/n

MEASUREMENTS AT SOLAR MINIMUM PROTONS AND ELECTRONS



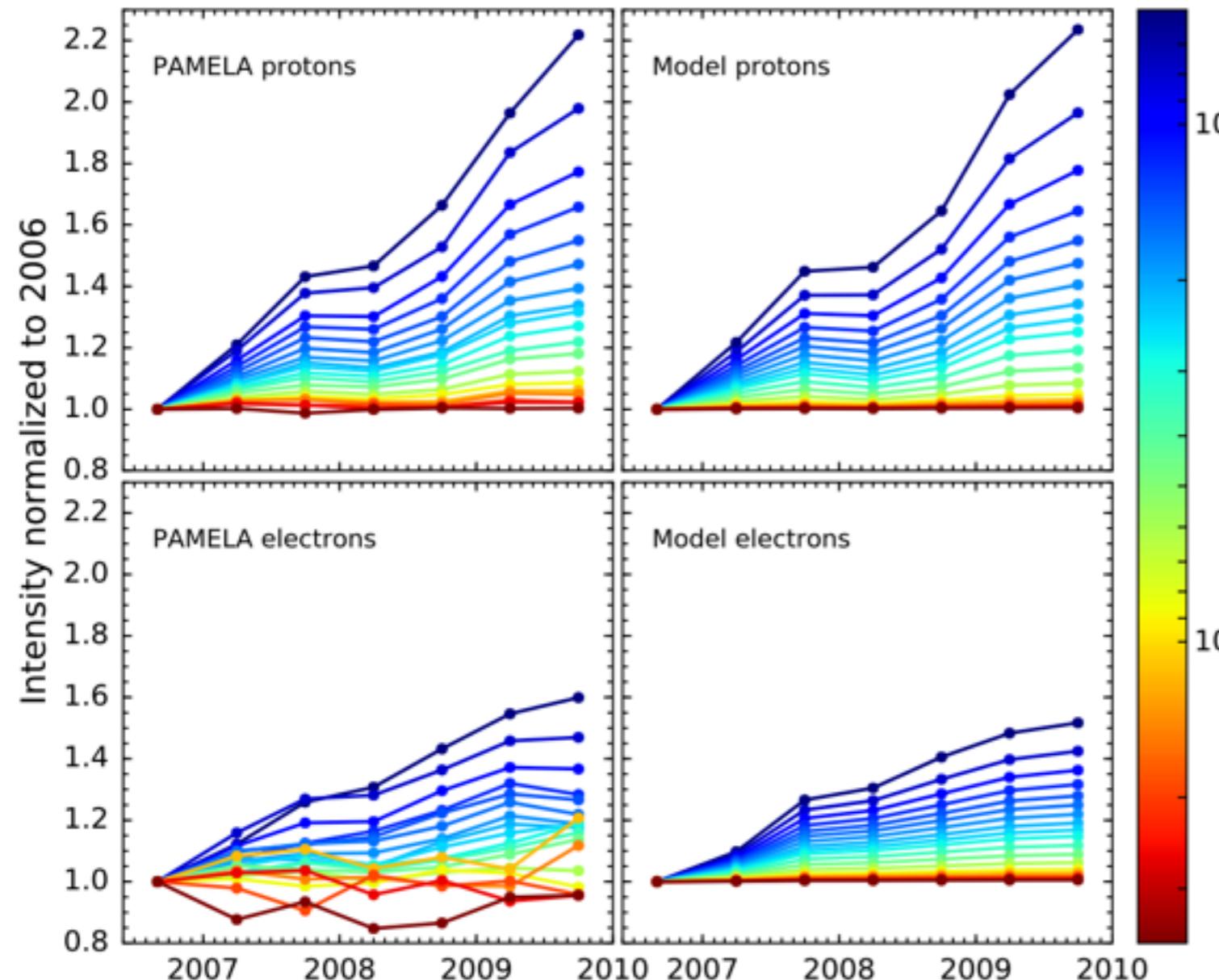
Adriani et al., ApJ 765, 2 (2013)
Potgieter, M.S. et al. Sol Phys (2014) 289: 391



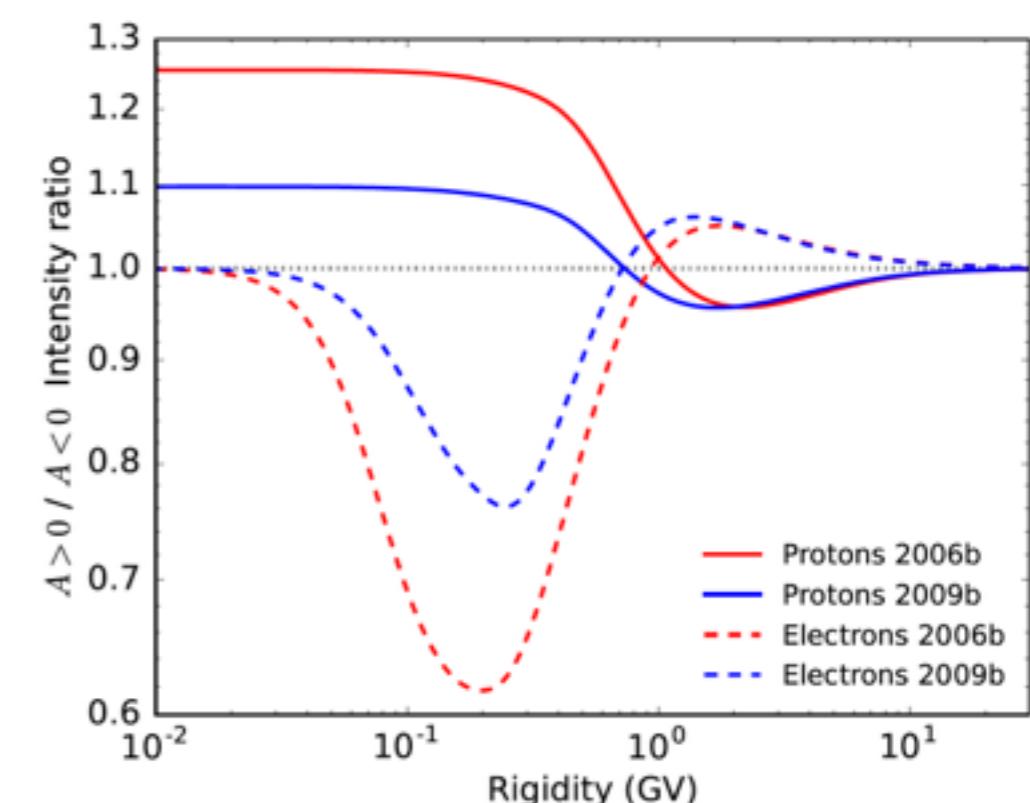
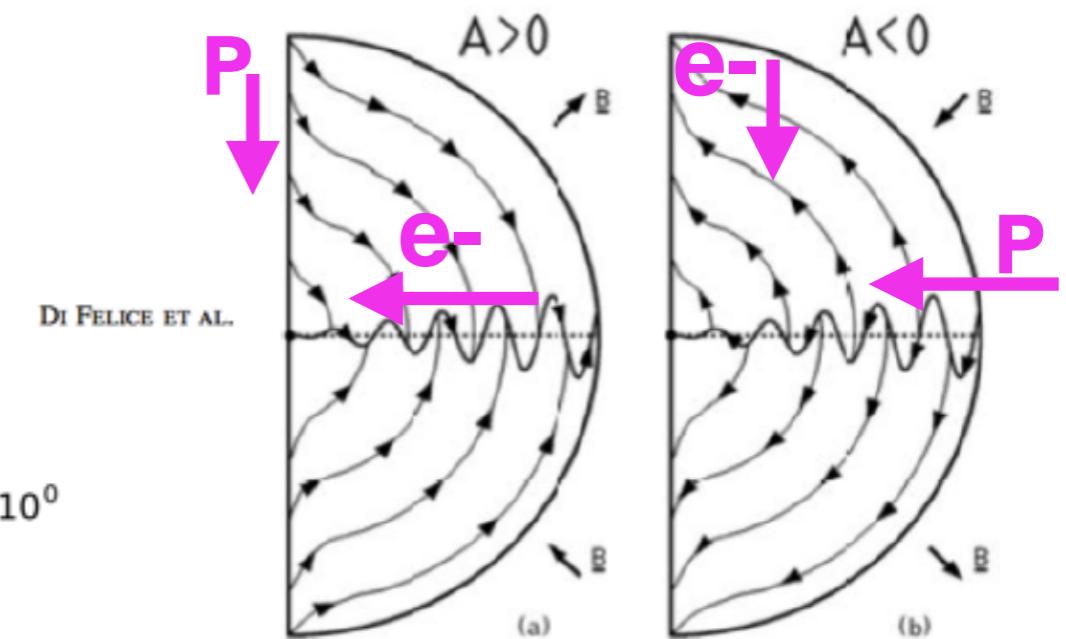
Adriani, et al., ApJ 810, 142 (2015)
Potgieter et al., ApJ 810, 141 (2015)

DRIFT EFFECT

THE ASTROPHYSICAL JOURNAL, 834:89 (9pp), 2017 January 1



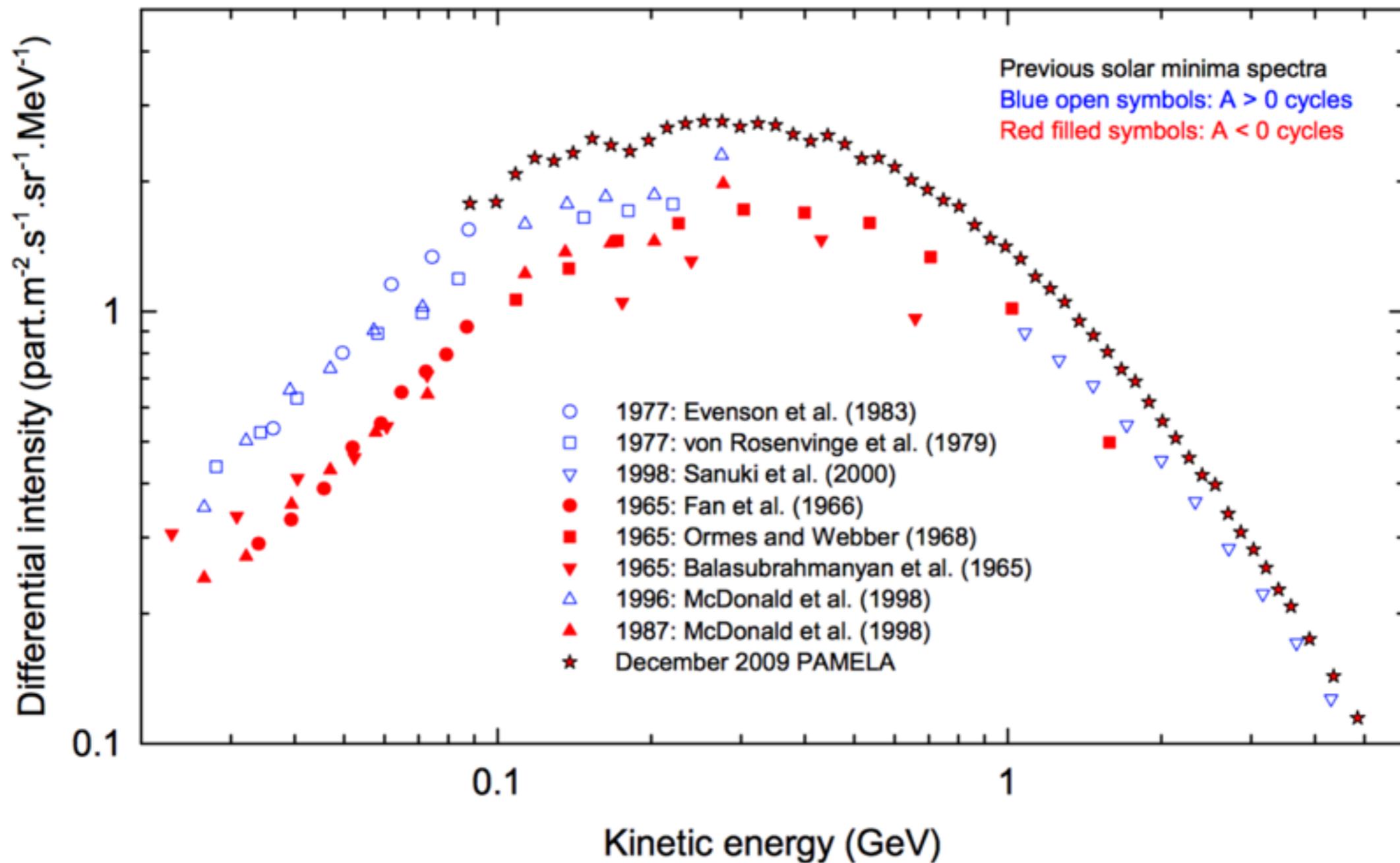
[Di Felice et al., ApJ 834, 89 \(2017\)](#)



[Potgieter & Vos, A&A 601, A23 \(2017\)](#)

RECORD HIGH PROTON FLUX ...

Strauss R.D., Potgieter M.S., Solar Physics, 289, 8 (2014)



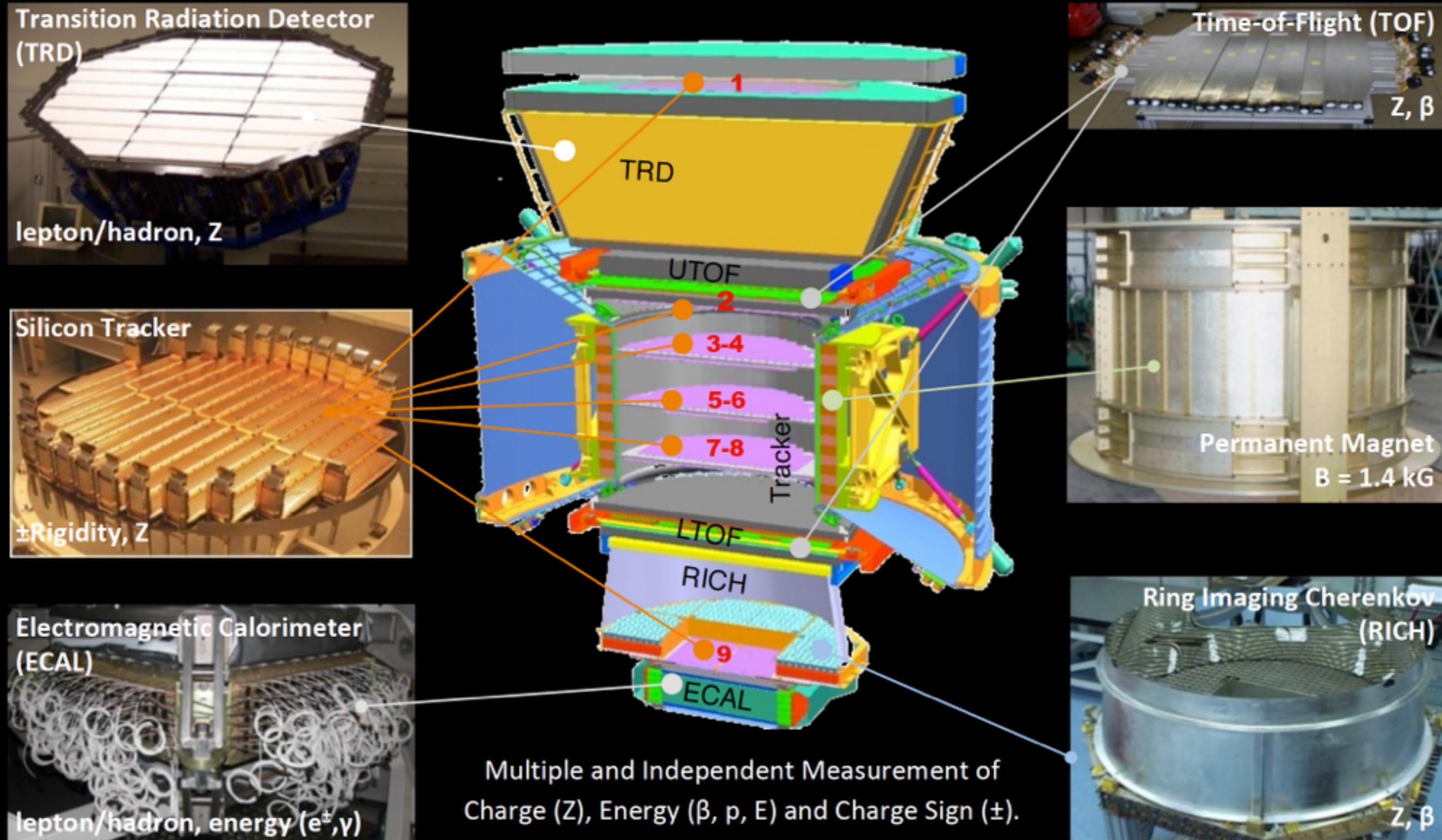
..... TILL NOW



AMS
WAS INSTALLED
ON THE ISS
MAY THE 19TH 2011
IT WILL CONTINUE
THROUGH THE LIFETIME OF
ISS (2024)

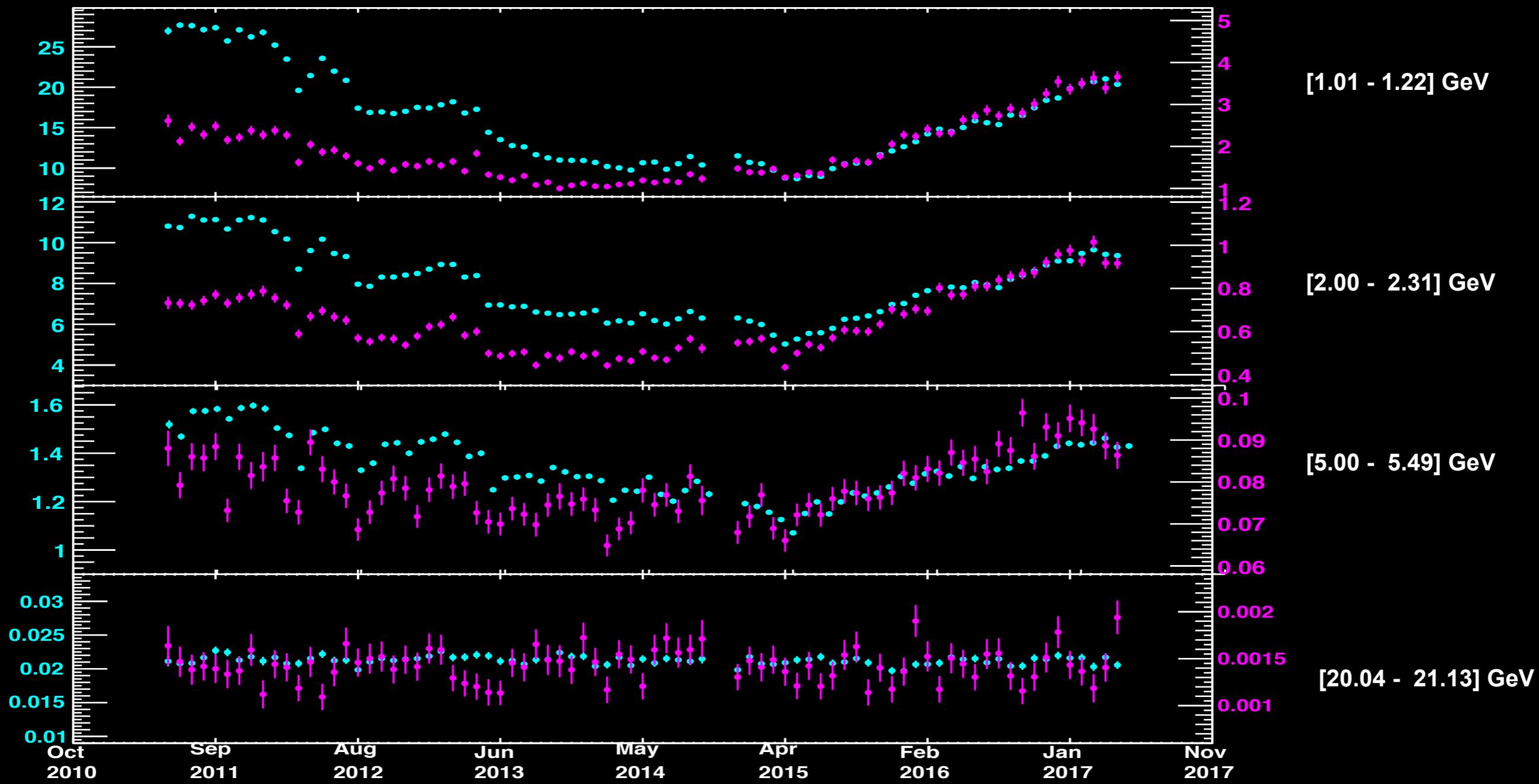
OVER
140 BILLION
CHARGED
COSMIC RAYS
HAVE
BEEN MEASURED

THE AMS-02 SPECTROMETER

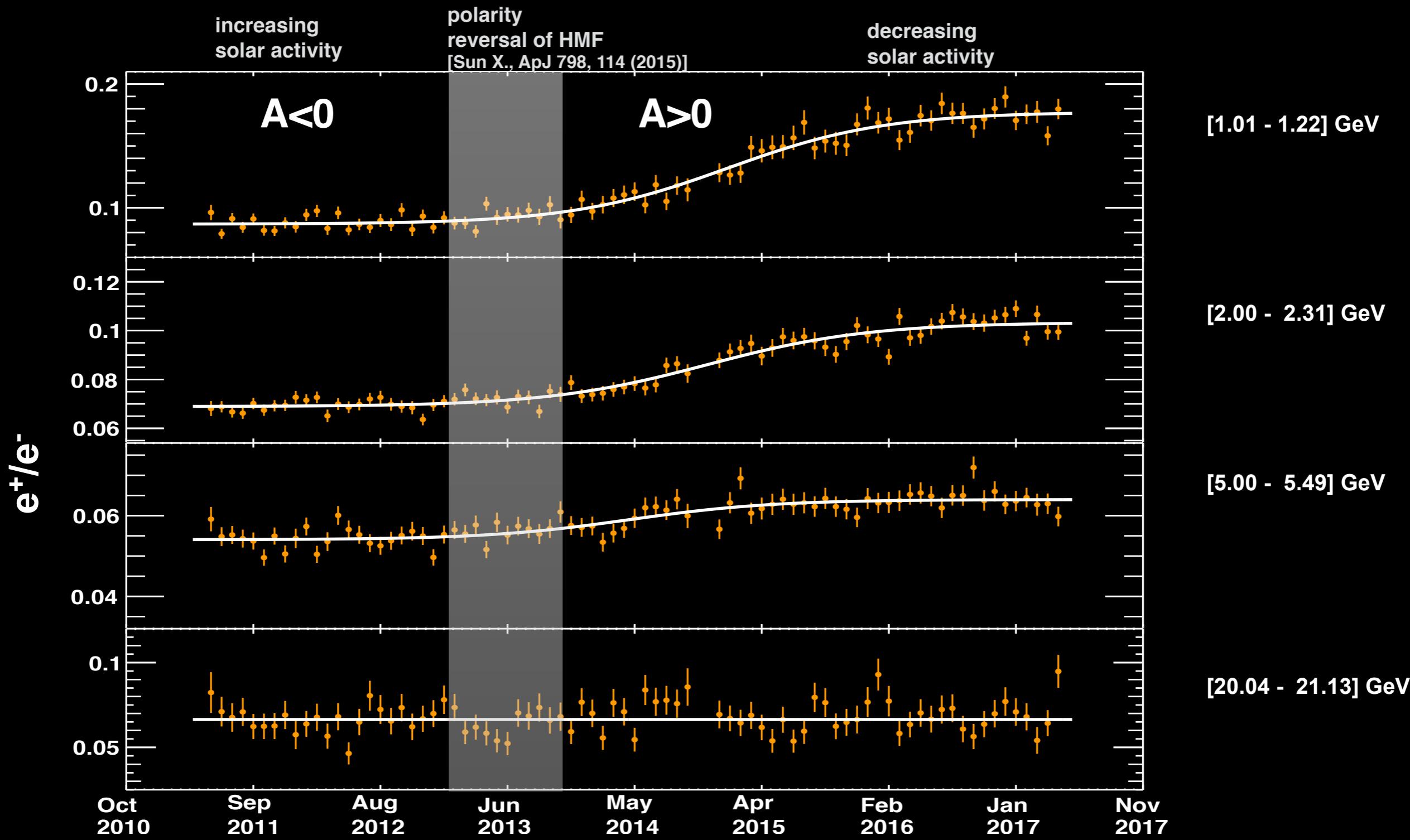


ELECTRONS AND POSITRONS

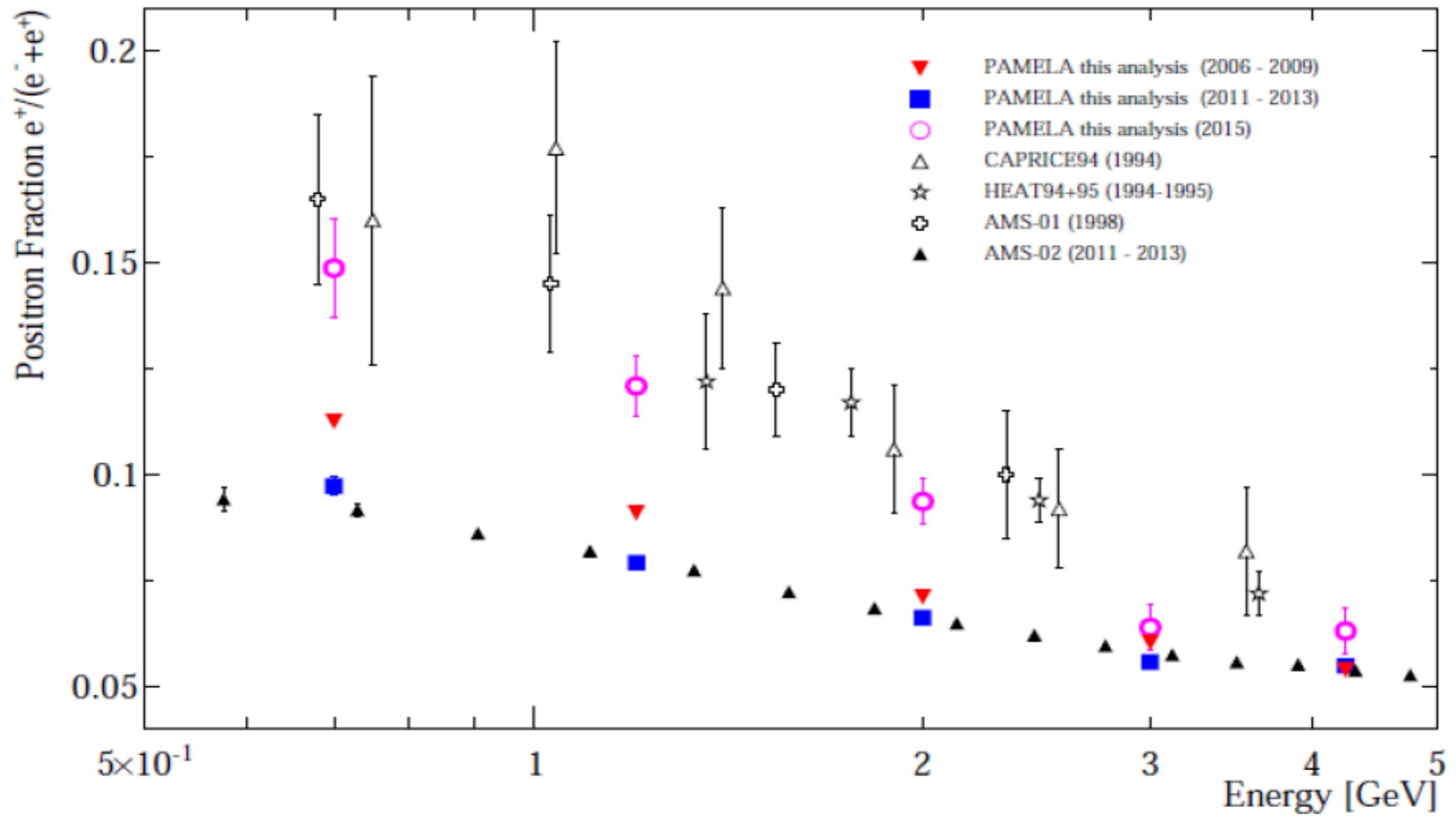
AMS MEASUREMENTS



POSITRON TO ELECTRON RATIO AMS MEASUREMENTS



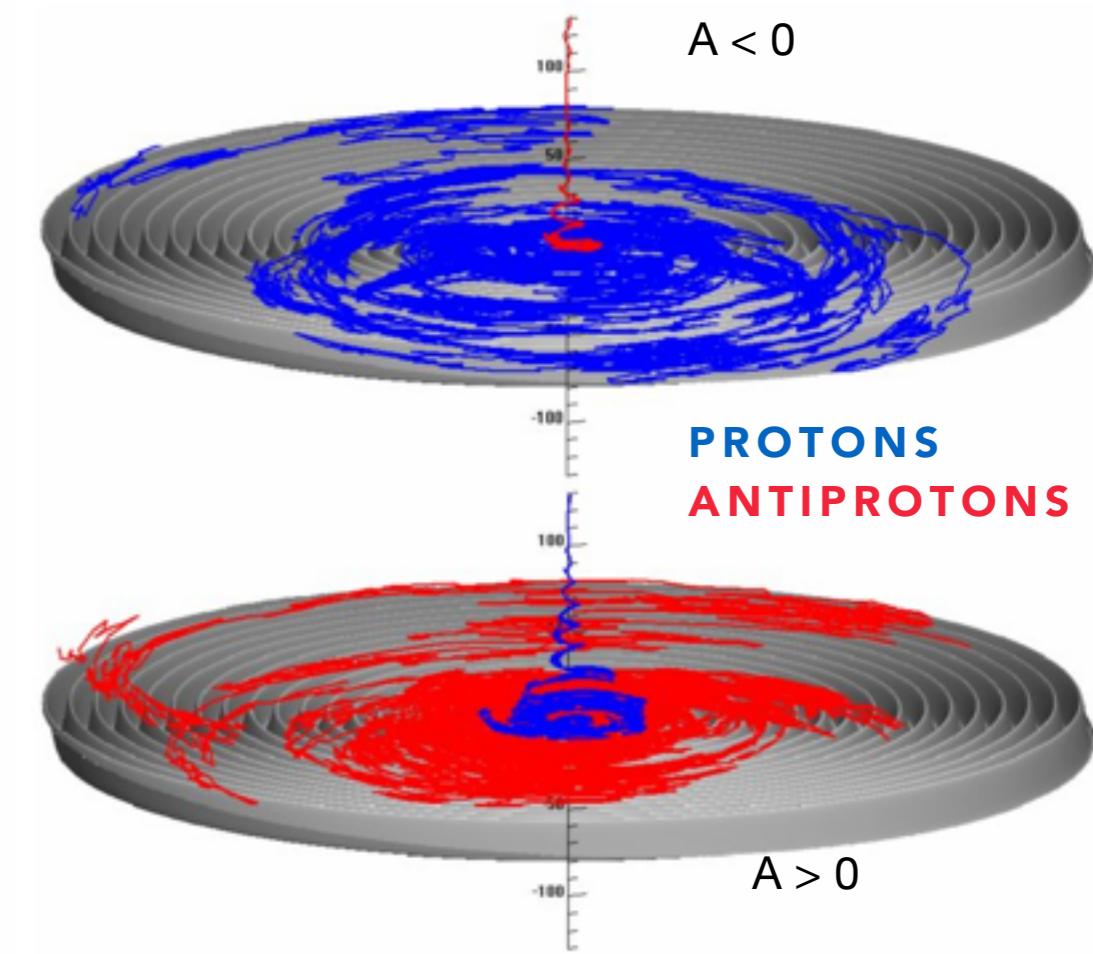
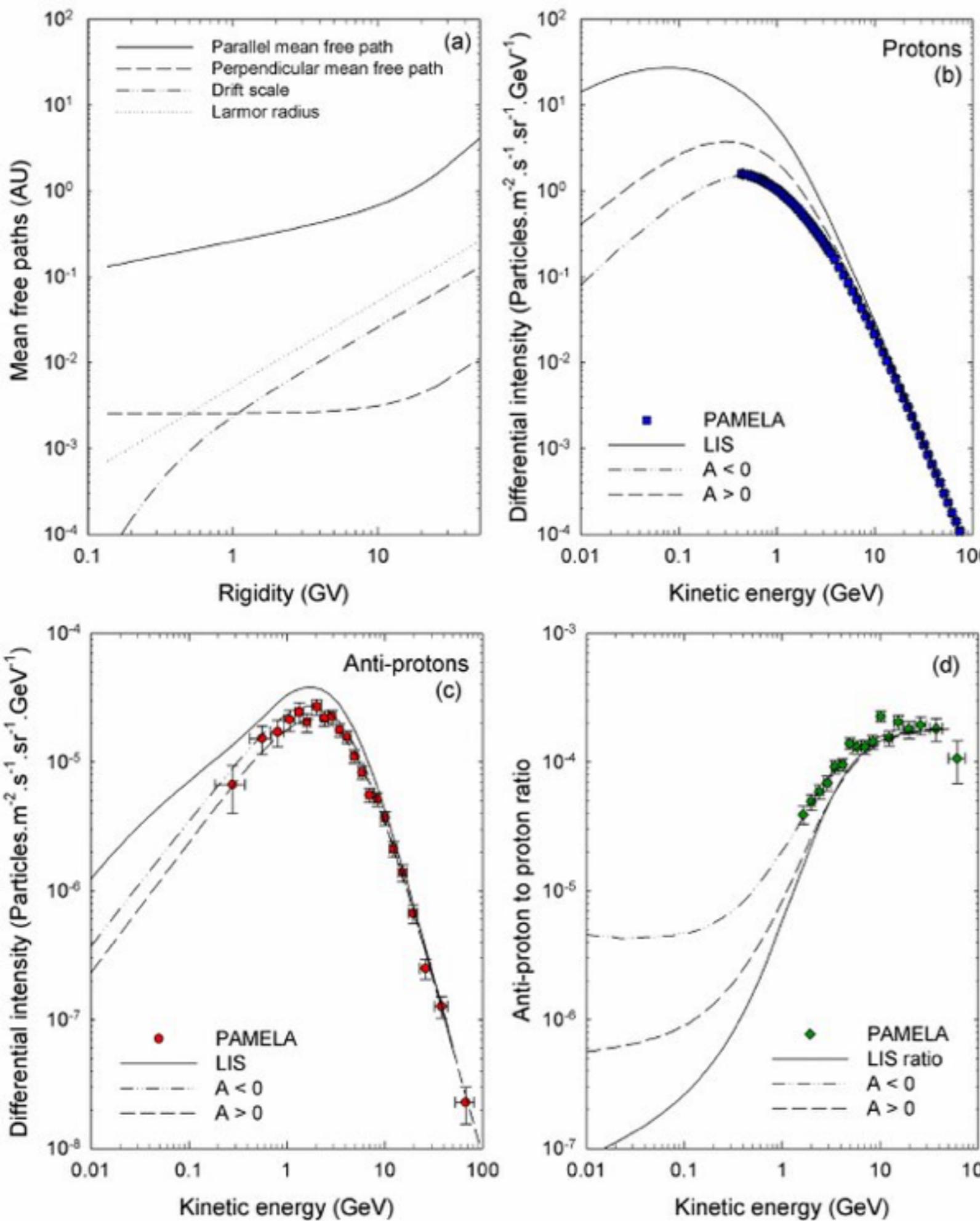
LOW ENERGY POSITRON FRACTION



O. Adriani et al., Phys. Rev. Lett. 116, (2016), 241105

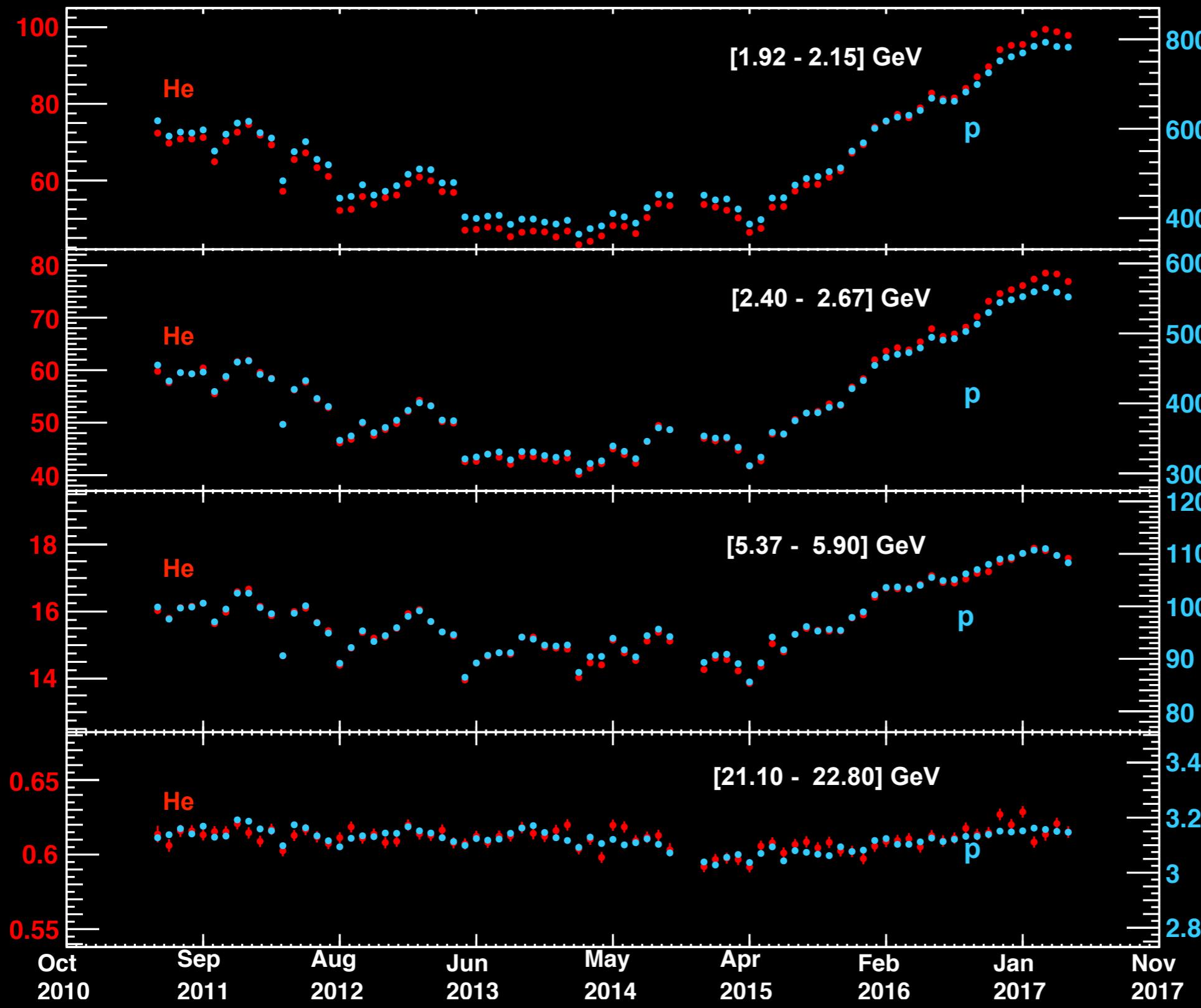
ANTIPROTONS

STOCHASTICAL MODELING APPROACH



Strauss et al. 2012
see also Della Torre et al. 2016

PROTONS AND HELIUM TEMPORAL EVOLUTION AMS MEASUREMENTS

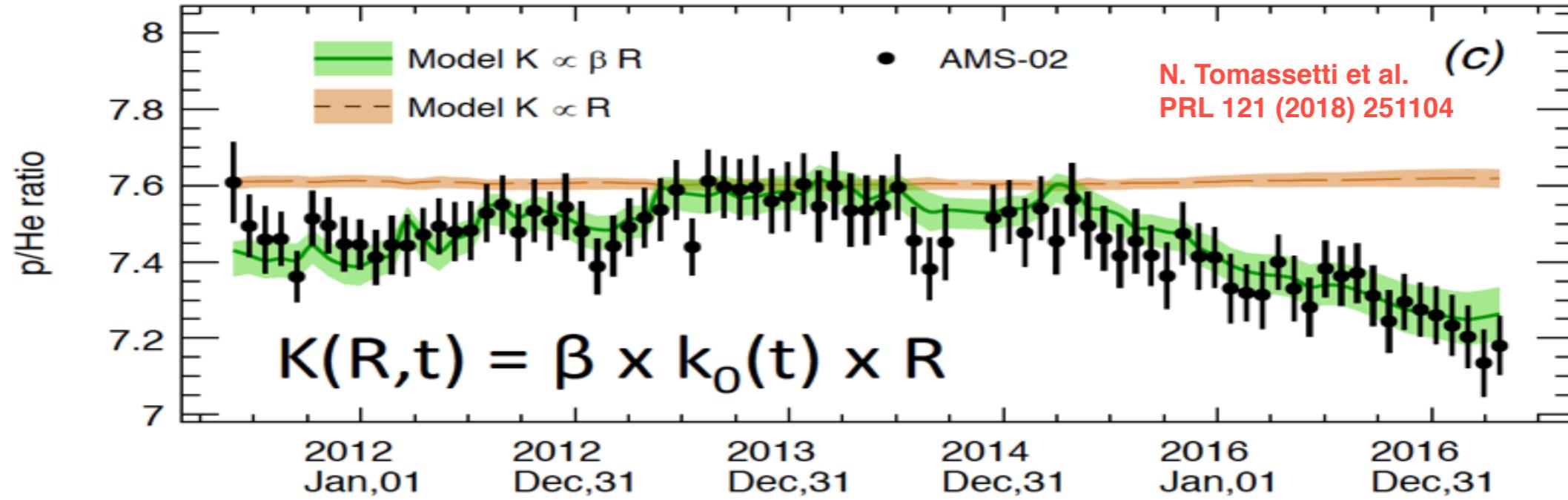


PROTONS TO HELIUM RATIO AMS MEASUREMENTS



PROTONS TO HELIUM RATIO INTERPRETATION

- Universality of the mean free path
- Velocity dependent diffusion (K)



THE ASTROPHYSICAL JOURNAL, 871:253 (15pp), 2019 February 1
Corti et al.

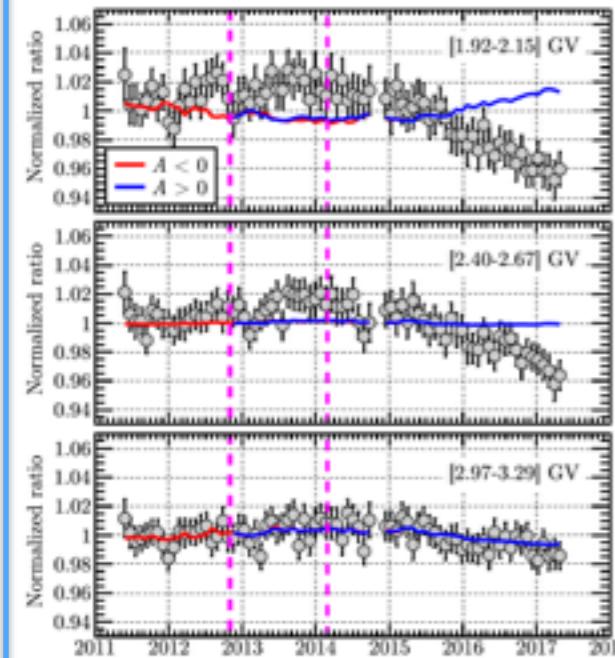


Figure 7. Effect of the difference in LIS shape on the time variation of p/He . The normalized modeled p/He (red and blue lines; left) and p/He (red and blue lines; right) compared to the observed p/He (gray circles) are shown as a function of time for three selected rigidity bins. The vertical dashed magenta lines delimit the period of the solar magnetic field polarity reversal.

B) the dependence of the diffusion tensor on the particle mass-to-charge ratio, A/Z tested

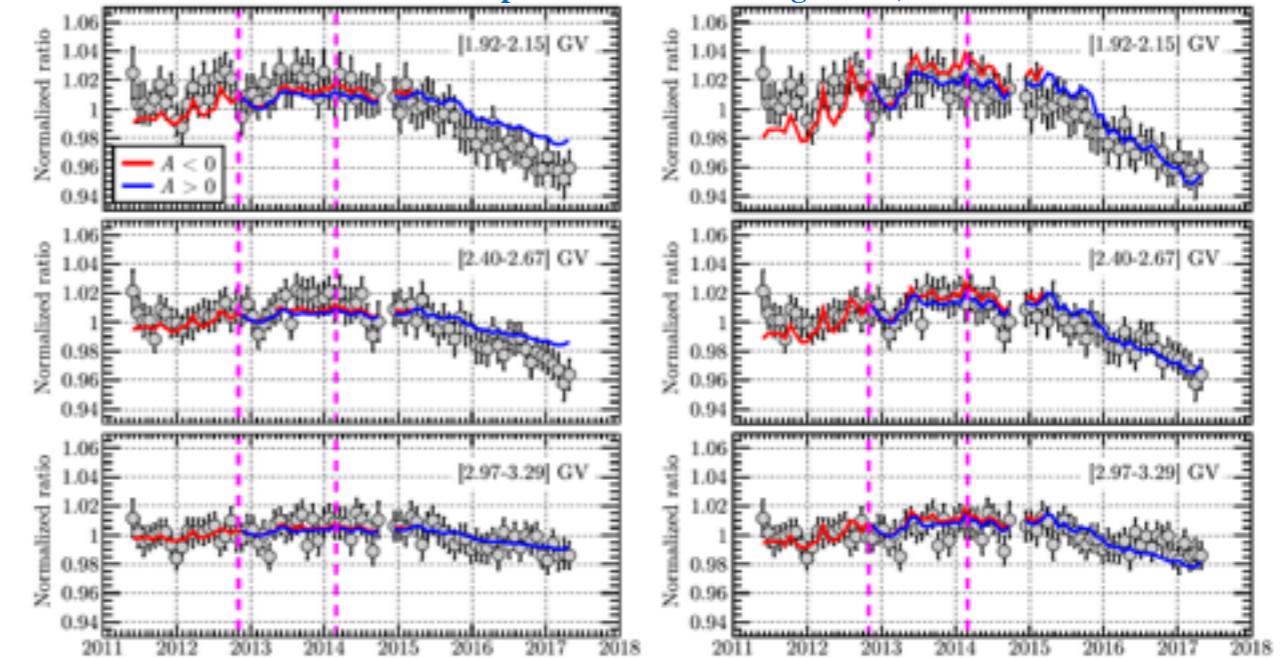
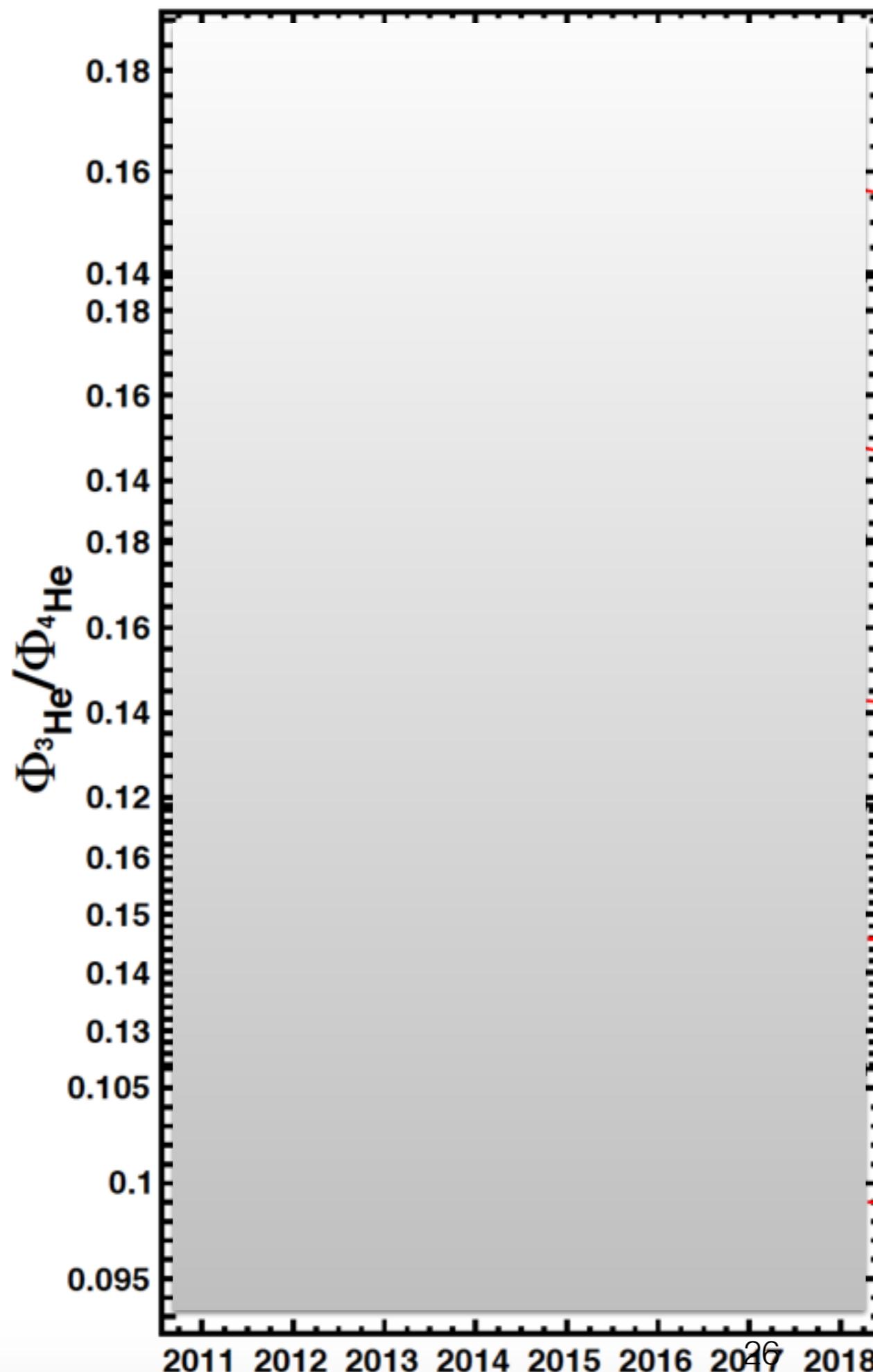


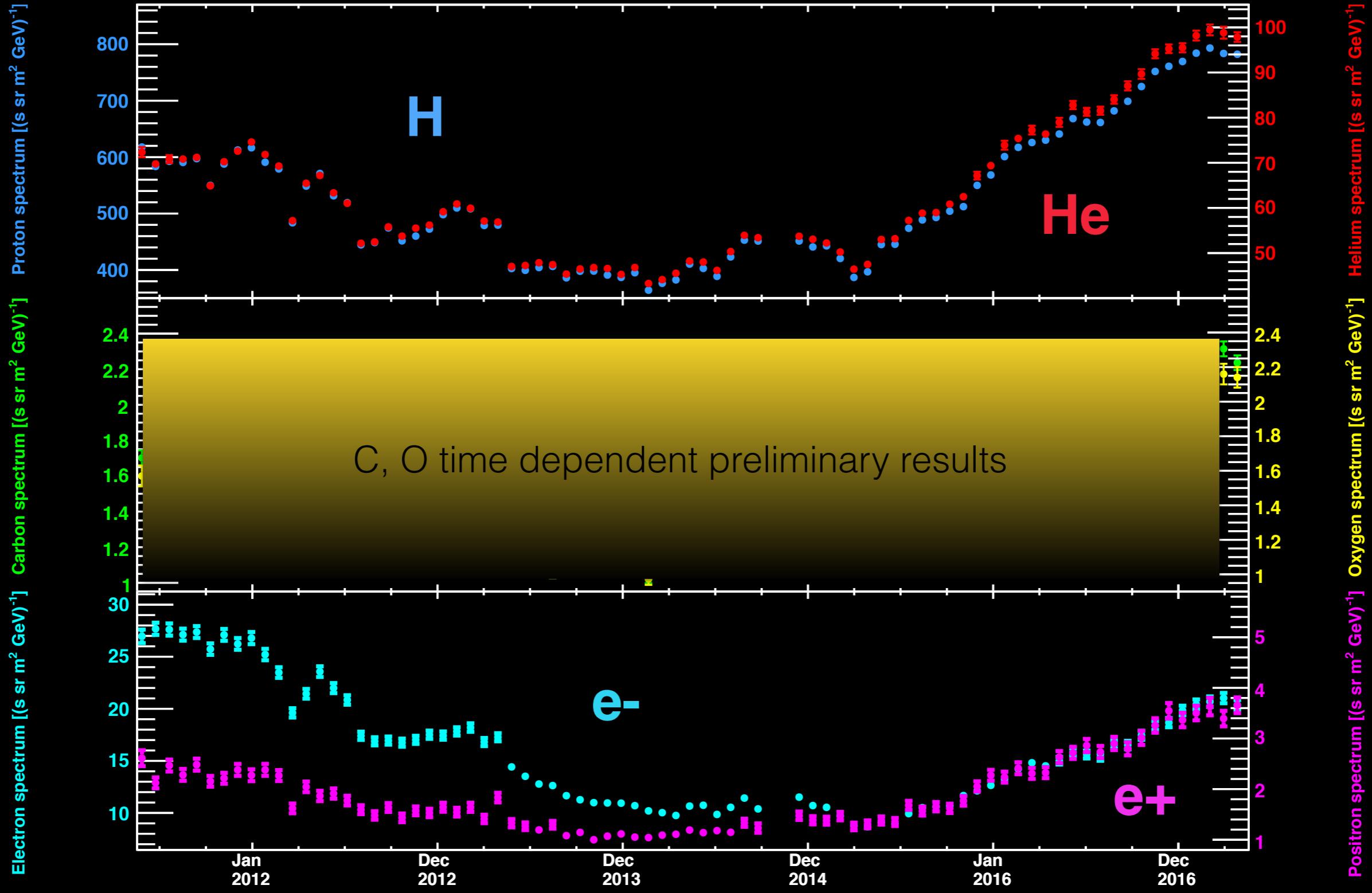
Figure 8. Effect of the A/Z dependence of the diffusion tensor on the time variation of p/He . The normalized modeled p/He (red and blue lines; left) and p/He (red and blue lines; right) compared to the observed p/He (gray circles) are shown as a function of time for three selected rigidity bins. The vertical dashed magenta lines delimit the period of the solar magnetic field polarity reversal.



**HE ISOTOPES PRL PAPER
ACCEPTED FOR PUBLICATION**

MORE TIME DEPENDENT MEASUREMENTS FROM AMS DATA

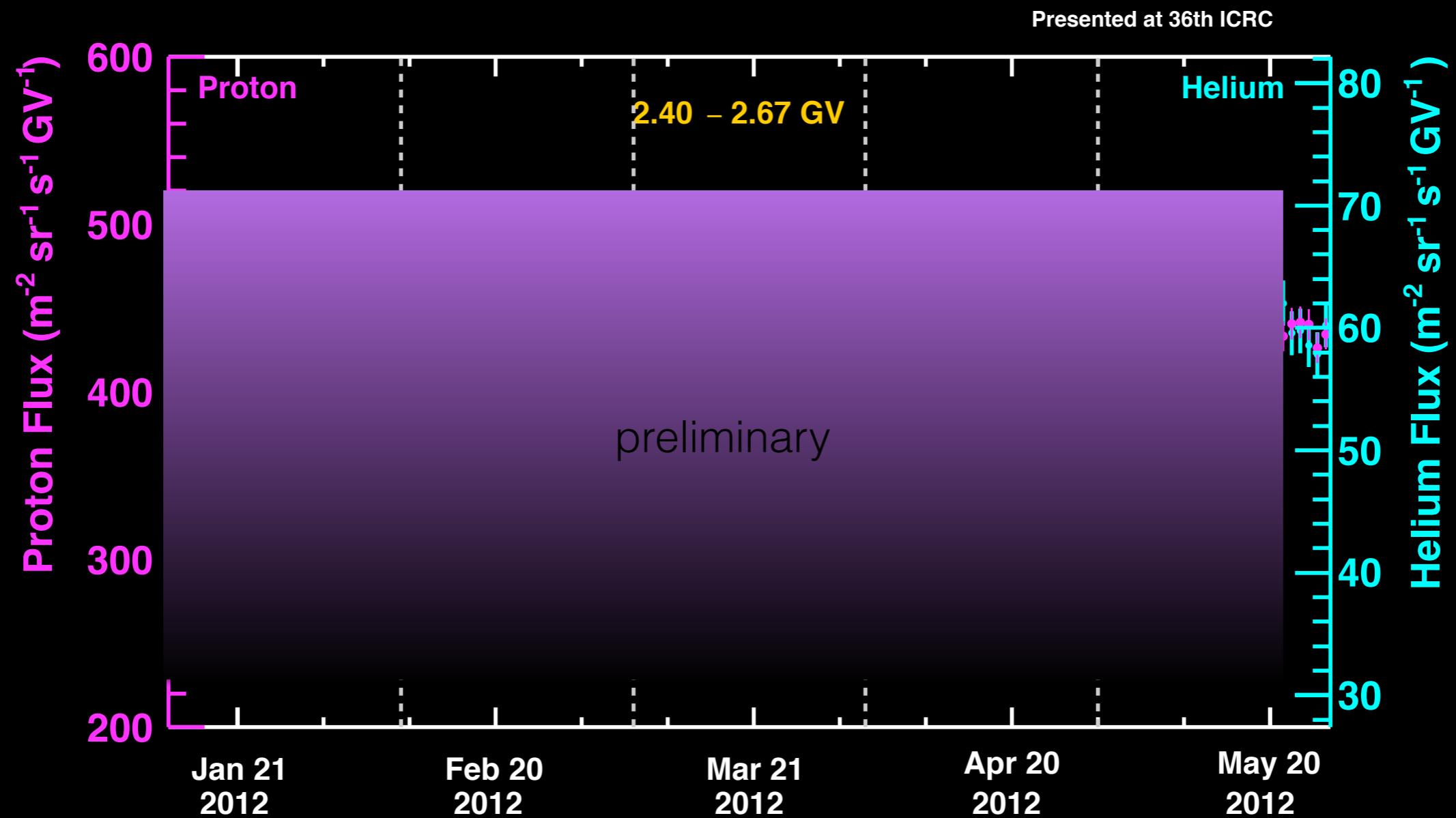
Presented at 36th ICRC



C, O PRELIMINARY DATA

FORTHCOMING PUBLICATION ON HE ISOTOPES

DAILY VARIATION OF FLUXES: H AND HE



CONCLUSIONS

- WE CAN FINALLY STUDY THE DETAILS OF THE SOLAR MODULATION OF GCRS
- NEW MEASUREMENTS AND COMPREHENSIVE MODELLING GIVE US SIGNIFICANT INSIGHTS
- PARTICULARLY DRIFT EFFECTS AND CHARGE SIGN DEPENDENCE
- IMPROVED AND IMPROVING PREDICTION AND FORECASTING CAPABILITIES
- MORE DATA TO COME....

