Evaluation of Galactic Cosmic Rays Models Using AMS2 Data

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WRMISS22 Workshop, Turin, Italy
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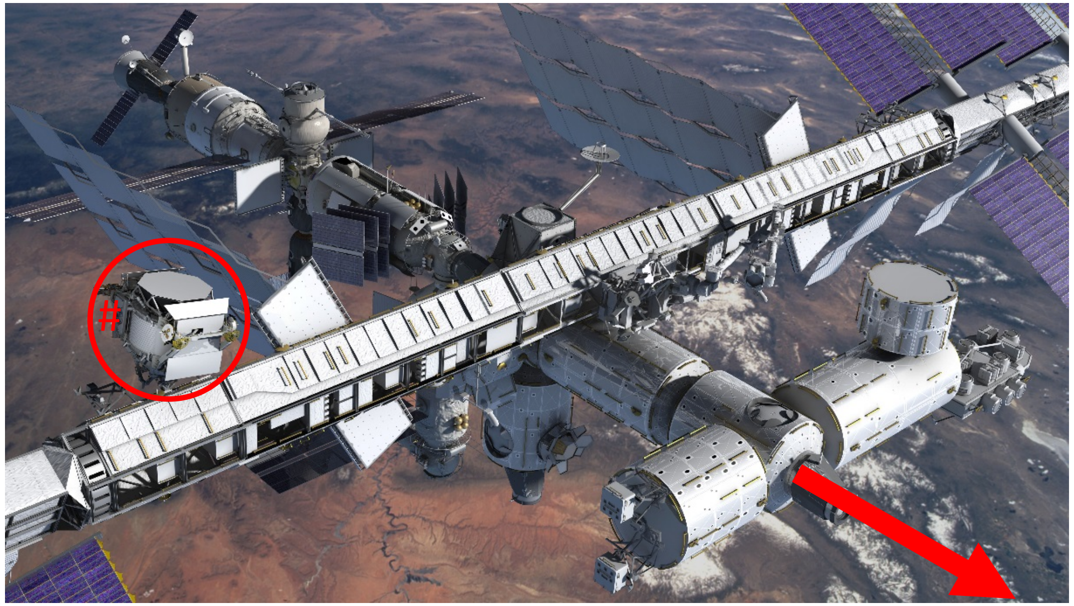
Motivation

Use **AMS2** cosmic rays (**GCR**) proton and helium data, to **highlight** differences among 3 existing GCR models at ≤ 3 GeV, and > 3 GeV ranges

AMS2 **(Alpha Magnetic Spectrometer 2)**
STS 134
May 19, 2011 – present
Data coverage: May 2011 - November 2013 (~922 days)
Perigee/Apogee: 341 - 353 km.
Inclination: 51.6°
Period: 91 min.
Proton E_K range: 0.43 - 1800 GeV (1.0 - 1800 GV)
Helium E_K range: 1.2 - 3000 GeV (1.9 - 3000 GV)
SAA data are excluded



#STS-134/ULF6-AMS, https://ams.nasa.gov, May, 2011

Existing GCR Models for Validation Work

Frequently used:

- %Badhwar-O'Neill (**BO - American**)
- *Matthia, German Aerospace center (**DLR - European**)
- #Nymmik, Moscow State University (**MSU - Russian**)

$\leq$ 3 GeV

> 3 GeV

Not frequently used:

- ^Galprop
- &Dragon2+Helioprop
- !HMF+NLGCE_F
- -Webber-McDonald
- …

%Badhwar G.D., O'Neill P.M. (1994), Long term modulation of galactic cosmic radiation and its model for space exploration, *Adv. in Space Res.*, v. 14, pp. 749-757

*Matthia, D., et al. (2013), A ready-to-use galactic cosmic ray model, *Adv. in Space Res.*, v. 51, pp. 329–338

#Nymmik, R., et al. (1994), An analytical model, describing dynamics of galactic cosmic ray heavy particles, *Adv. in Space Res.*, v. 14, pp. 759-763

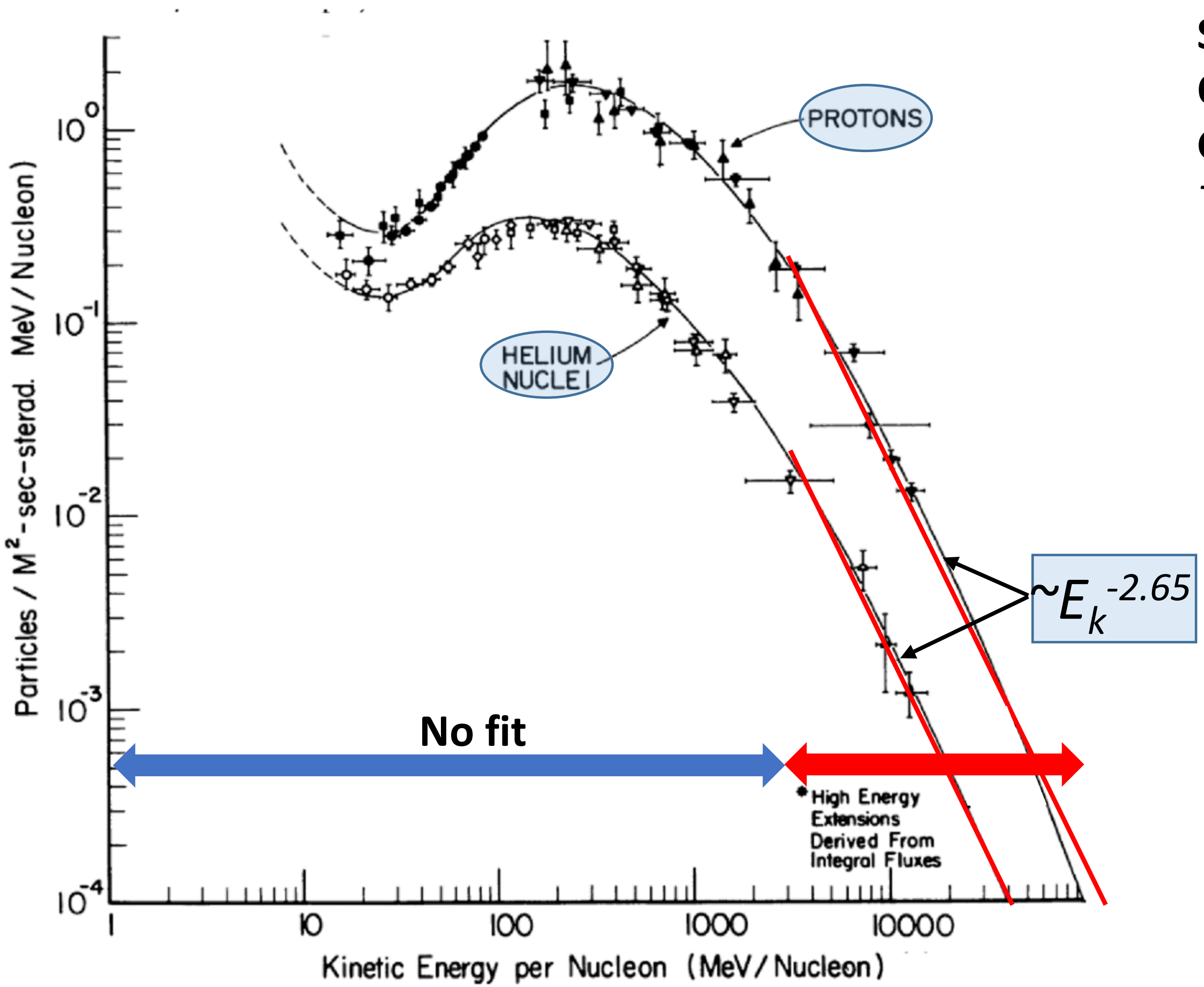
^Vladimirov A.E., et al. (2011), GALPROP WebRun: an internet-based service for calculating galactic cosmic ray propagation and associated photon emissions, arXiv.org >astro-ph.HE>arXiv:1008.3642v3

&Evoli C., et al. (2017), Cosmic-ray propagation with DRAGON2: I. numerical solver and astrophysical Ingredients, arXiv.org>[astro-ph.HE]>arXiv:1607.07886v2

!Qin G., Shen Z. (2017), Modulation of galactic cosmic rays in the inner heliosphere, comparing with PAMELA measurements, arXiv.org> physics > arXiv:1705.04847v2

-Webber W.R., McDonald F.B. (2013), Recent Voyager 1 data indicate that on 25 August 2012 at a distance of 121.7 AU from the Sun, sudden and unprecedented intensity changes were observed in anomalous and galactic cosmic rays, Geophys. Res. Lett., 40, 1665

Historical GCR Fits to Data - I

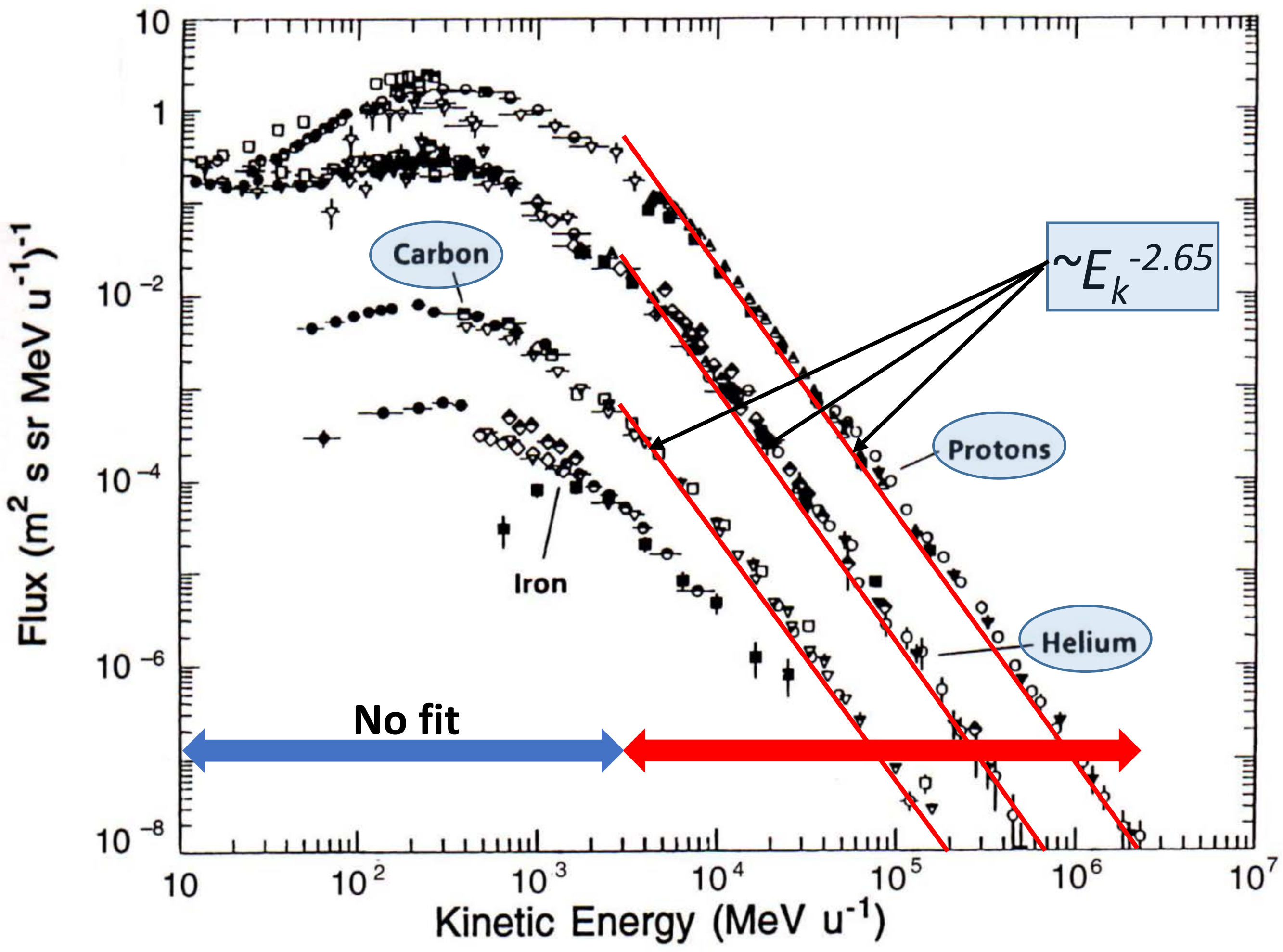


SOLAR MODULATION AND ENERGY DENSITY OF GALACTIC COSMIC RAYS

G. Gloeckler and J.R. Jokipii

The astrophysical journal, Vol. 148, April 1967

Historical GCR Fits to Data - II

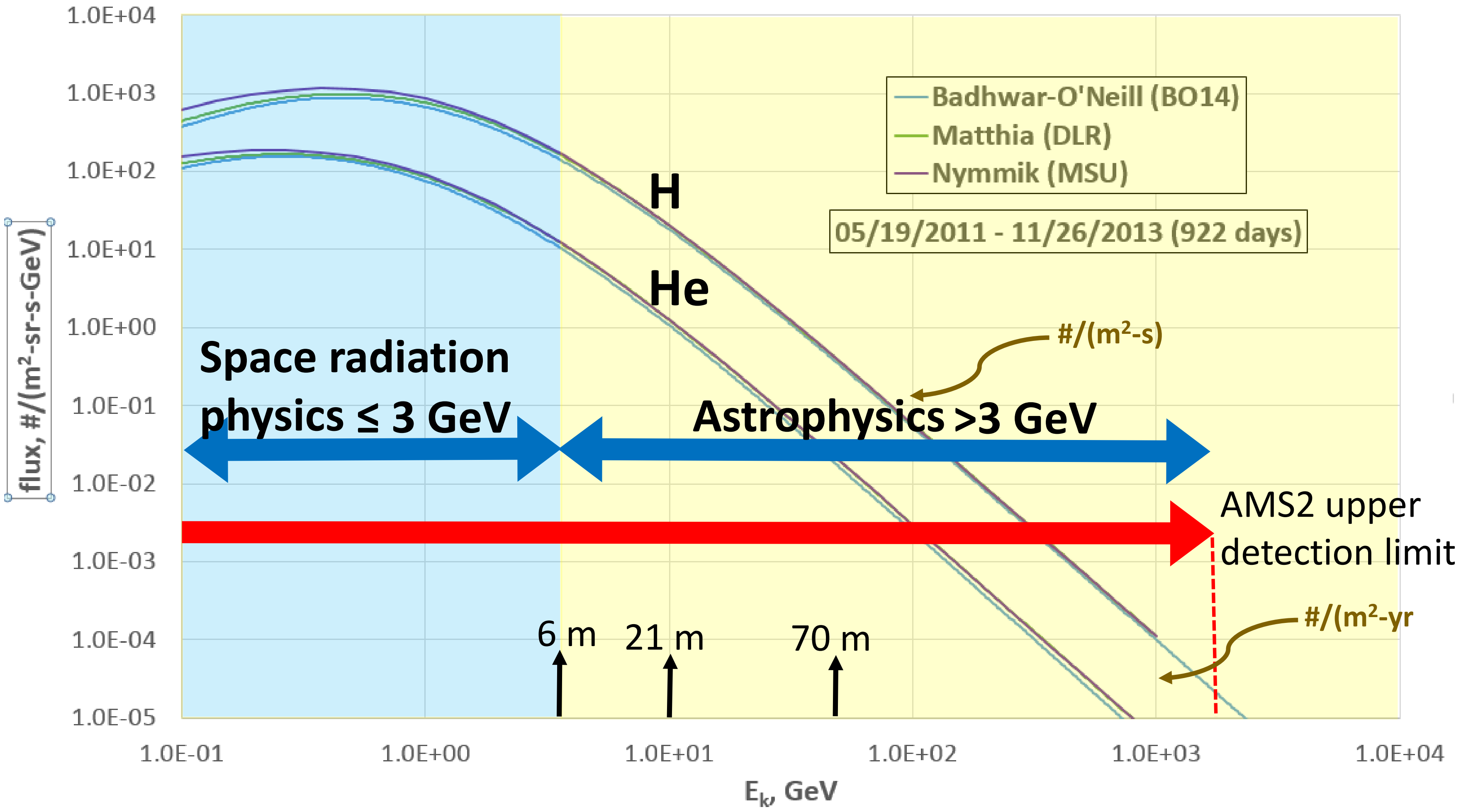


ELEMENTAL AND ISOTOPIC COMPOSITION OF THE GALACTIC COSMIC RAYS

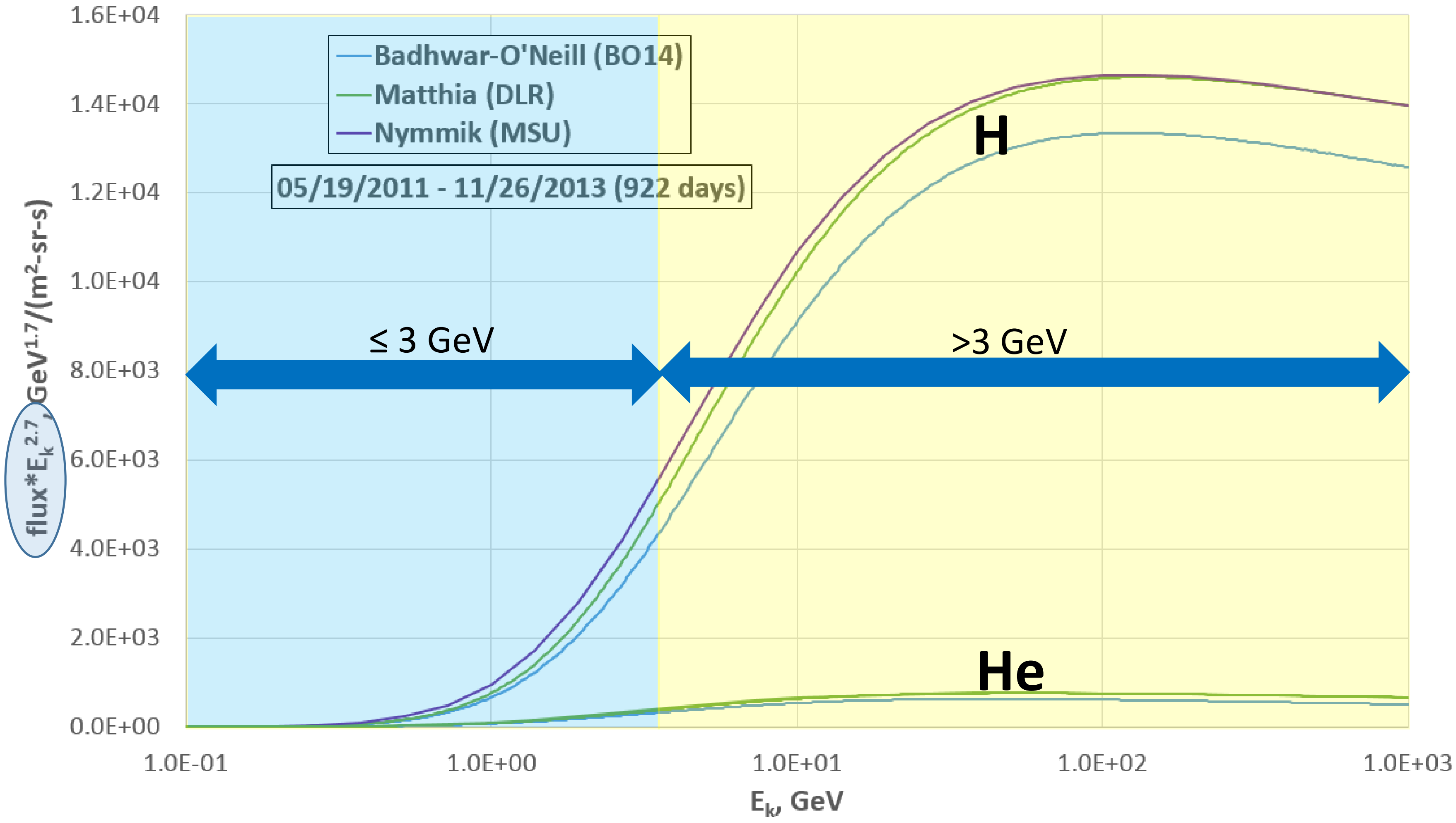
J. A. Simpson

Ann. Rev. Nucl. Part. Sci. 1983.33:323-81, 1983

BO/MSU/DLR GCR Proton and Helium Spectra



Scaled BO/MSU/DLR Proton and Helium Spectra



P.R.L. Paper on AMS2 Proton Data (May 2015)

PRL 114, 171103 (2015) PHYSICAL REVIEW LETTERS week ending 1 MAY 2015

Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station

(1 GV-1.8 TV) ➡ (0.43 GeV-1.8 TeV)

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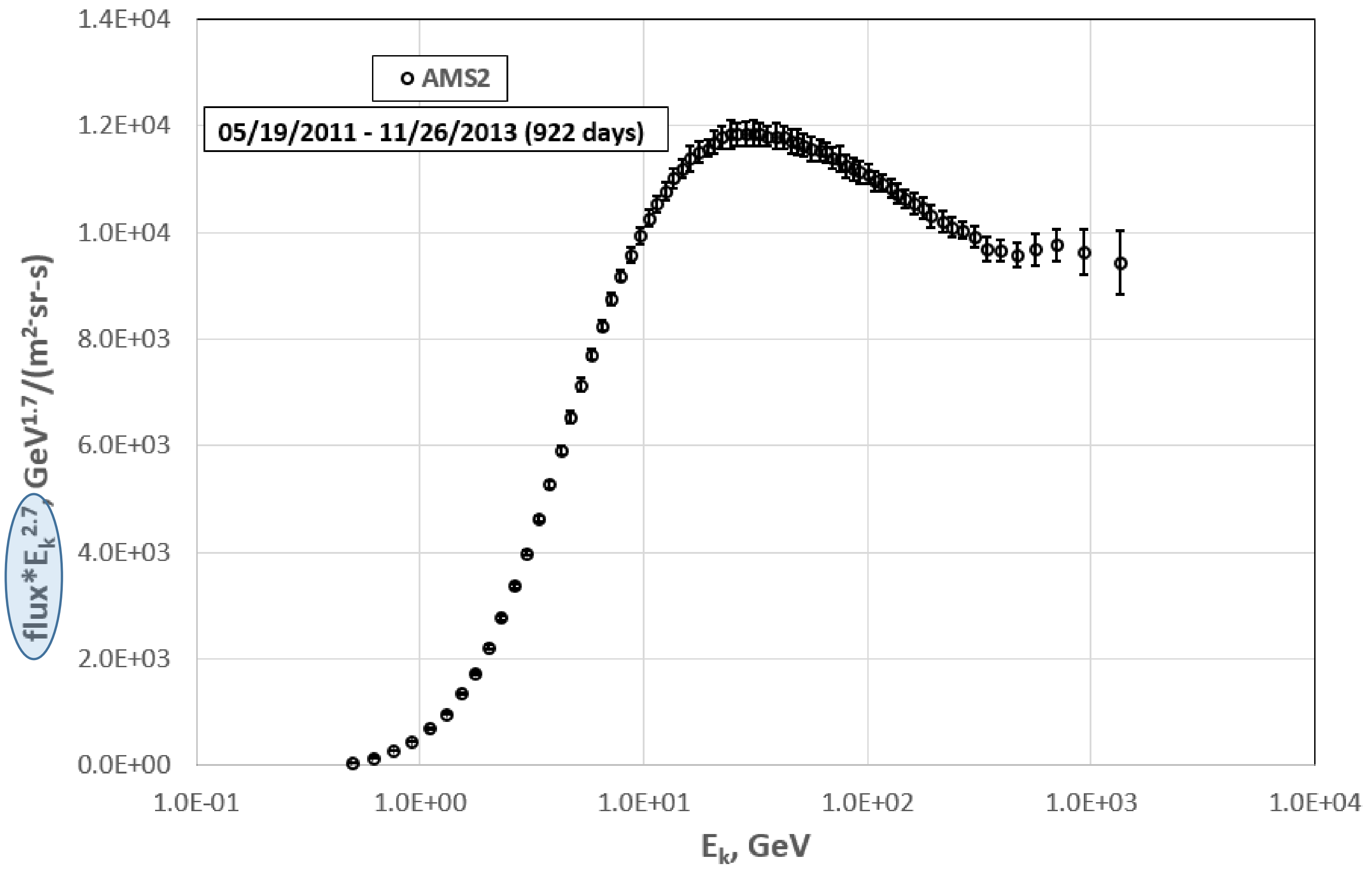
Aguilar, M., et al. (2015), Precision measurement of the proton flux in primary cosmic rays from rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station, *Phys. Rev. Letters, 114*

Scaled AMS2 Proton Data



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P.R.L. Paper on AMS2 Helium Data (November 2015)

PRL 115, 211101 (2015) PHYSICAL REVIEW LETTERS week ending 20 NOVEMBER 2015

Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station

(1.9 GV-3 TV) ➡ (1.2 GeV-3 TeV)

M. Aguilar,[26] D. Aisa,[32,33] B. Alpat,[32] A. Alvino,[32] G. Ambrosi,[32] K. Andeen,[22] L. Arruda,[24] N. Attig,[21] P. Azzarello,[16] A. Bachlechner,[1] F. Barao,[24] A. Barrau,[17] L. Barrin,[15] A. Bartoloni,[38] L. Basara,[36] M. Battarbee,[47] R. Battiston,[36,37,a] J. Bazo,[32,b] U. Becker,[9] M. Behlmann,[9] B. Beischer,[1] J. Berdugo,[26] B. Bertucci,[32,33] V. Bindi,[19] S. Bizzaglia,[32] M. Bizzarri,[32,33] G. Boella,[28,29] W. de Boer,[22] K. Bollweg,[20] V. Bonnivard,[17] B. Borgia,[38,39] S. Borsini,[32] M. J. Boschini,[28] M. Bourquin,[16] J. Burger,[9] F. Cadoux,[16] X. D. Cai,[9] M. Capell,[9] S. Caroff,[3] J. Casaus,[26] G. Castellini,[14] I. Cernuda,[26] D. Cerreta,[32,33] F. Cervelli,[34] M. J. Chae,[41] Y. H. Chang,[10] A. I. Chen,[9] G. M. Chen,[6] H. Chen,[9] H. S. Chen,[6] L. Cheng,[42] H. Y. Chou,[10] E. Choumilov,[9] V. Choutko,[9] C. H. Chung,[1] C. Clark,[20] R. Clavero,[23] G. Coignet,[3] C. Consolandi,[19] A. Contin,[7,8] C. Corti,[19] E. Cortina Gil,[16,c] B. Coste,[36,15] W. Creus,[10] M. Crispoltoni,[32,33] Z. Cui,[42] Y. M. Dai,[5] C. Delgado,[26] S. Della Torre,[28] M. B. Demirköz,[2] L. Derome,[17] S. Di Falco,[34] L. Di Masso,[32,33] F. Dimiccoli,[36,37] C. Díaz,[26] P. von Doetinchem,[19] F. Donnini,[32,33] M. Duranti,[32,33] D. D'Urso,[32,d] A. Egorov,[9] A. Eline,[9] F. J. Eppling,[9,*] T. Eronen,[47] Y. Y. Fan,[46,e] L. Farnesini,[32] J. Feng,[3,46,f] E. Fiandrini,[32,33] A. Fiasson,[3] E. Finch,[31] P. Fisher,[9] V. Formato,[32,15] Y. Galaktionov,[9] G. Gallucci,[34] B. García,[26] R. García-López,[23] C. Gargiulo,[15] H. Gast,[1] I. Gebauer,[22] M. Gervasi,[28,29] A. Ghelfi,[17] F. Giovacchini,[26] P. Goglov,[9] J. Gong,[30] C. Goy,[3] V. Grabski,[27] D. Grandi,[28] M. Graziani,[32,33] C. Guandalini,[7] I. Guerri,[34,35] K. H. Guo,[18] D. Haas,[16,g] M. Habiby,[16] S. Haino,[46] K. C. Han,[25] Z. H. He,[18] M. Heil,[9] J. Hoffman,[10,19] T. H. Hsieh,[9] Z. C. Huang,[18] C. Huh,[13] M. Incagli,[34] M. Ionica,[32] W. Y. Jang,[13] H. Jinchi,[25] K. Kanishev,[36,37,15] G. N. Kim,[13] K. S. Kim,[13] Th. Kirn,[1] M. A. Korkmaz,[2] R. Kossakowski,[3] O. Kounina,[9] A. Kounine,[9] V. Koutsenko,[9] M. S. Krafczyk,[9] G. La Vacca,[28] E. Laudi,[32,33,h] G. Laurenti,[7] I. Lazzizzera,[36,37] A. Lebedev,[9] H. T. Lee,[45] S. C. Lee,[46] C. Leluc,[16] H. L. Li,[46,i] J. Q. Li,[9,j] J. Q. Li,[30] Q. Li,[30] Q. Li,[9,j] T. X. Li,[18] W. Li,[4] Y. Li,[16,f] Z. H. Li,[6] Z. Y. Li,[46,f] S. Lim,[13] C. H. Lin,[46] P. Lipari,[38] T. Lippert,[21] D. Liu,[46] H. Liu,[30] Hu Liu,[26,k] M. Lolli,[7] T. Lomtadze,[34] M. J. Lu,[36,*,l] S. Q. Lu,[46,f] Y. S. Lu,[6] K. Luebelsmeyer,[1] F. Luo,[42] J. Z. Luo,[30] S. S. Lv,[18] R. Majka,[31] C. Mañá,[26] J. Marín,[26] T. Martin,[20] G. Martínez,[26] N. Masi,[7] D. Maurin,[17] A. Menchaca-Rocha,[27] Q. Meng,[30] D. C. Mo,[18] L. Morescalchi,[34,m] P. Mott,[20] M. Müller,[1] T. Nelson,[19] J. Q. Ni,[18] N. Nikonov,[22] F. Nozzoli,[32,d] P. Nunes,[24] A. Obermeier,[1] A. Oliva,[26] M. Orcinha,[24] F. Palmonari,[7,8] C. Palomares,[26] M. Paniccia,[16] A. Papi,[32] M. Pauluzzi,[32,33] E. Pedreschi,[34] S. Pensotti,[28,29] R. Pereira,[19] N. Picot-Clemente,[12] F. Pilo,[34] A. Piluso,[32,33] C. Pizzolotto,[32,d] V. Plyaskin,[9] M. Pohl,[16] V. Poireau,[3] A. Putze,[3,n] L. Quadrani,[7,8] X. M. Qi,[18] X. Qin,[32,i] Z. Y. Qu,[46,o] T. Räihä,[1] P. G. Rancoita,[28] D. Rapin,[16] J. S. Ricol,[17] I. Rodríguez,[26] S. Rosier-Lees,[3] A. Rozhkov,[9] D. Rozza,[28] R. Sagdeev,[11] J. Sandweiss,[31] P. Saouter,[16] S. Schael,[1] S. M. Schmidt,[21] A. Schulz von Dratzig,[1] G. Schwering,[1] G. Scolieri,[32] E. S. Seo,[12] B. S. Shan,[4] Y. H. Shan,[4] J. Y. Shi,[30] X. Y. Shi,[9,p] Y. M. Shi,[43] T. Siedenburg,[1] D. Son,[13] J. W. Song,[42] F. Spada,[38] F. Spinella,[34] W. Sun,[9] W. H. Sun,[9,q] M. Tacconi,[28,15] C. P. Tang,[18] X. W. Tang,[6] Z. C. Tang,[6] L. Tao,[3] D. Tescaro,[23] Samuel C. C. Ting,[9] S. M. Ting,[9] N. Tomassetti,[17] J. Torsti,[47] C. Türkoğlu,[2] T. Urban,[20] V. Vagelli,[22,32] E. Valente,[38,39] C. Vannini,[34] E. Valtonen,[47] S. Vaurynovich,[9] M. Vecchi,[40] M. Velasco,[26] J. P. Vialle,[3] V. Vitale,[32,d] S. Vitillo,[16] L. Q. Wang,[42] N. H. Wang,[42] Q. L. Wang,[5] R. S. Wang,[43] X. Wang,[9] Z. X. Wang,[18] Z. L. Weng,[9] K. Whitman,[19] J. Wienkenhöver,[1] M. Willenbrock,[9] H. Wu,[30] X. Wu,[16] X. Xia,[26,i] M. Xie,[9,j] S. Xie,[43] R. Q. Xiong,[30] N. S. Xu,[18] W. Xu,[9] Q. Yan,[9] J. Yang,[41] M. Yang,[6] Y. Yang,[44] Q. H. Ye,[43] H. Yi,[30] Y. J. Yu,[5] Z. Q. Yu,[6] S. Zeissler,[22] C. Zhang,[6] J. H. Zhang,[30] M. T. Zhang,[18] S. D. Zhang,[9,j] S. W. Zhang,[6] X. B. Zhang,[18] Z. Zhang,[18] Z. M. Zheng,[4] H. L. Zhuang,[6] V. Zhukov,[1] A. Zichichi,[7,8] N. Zimmermann,[1] and P. Zuccon[9]

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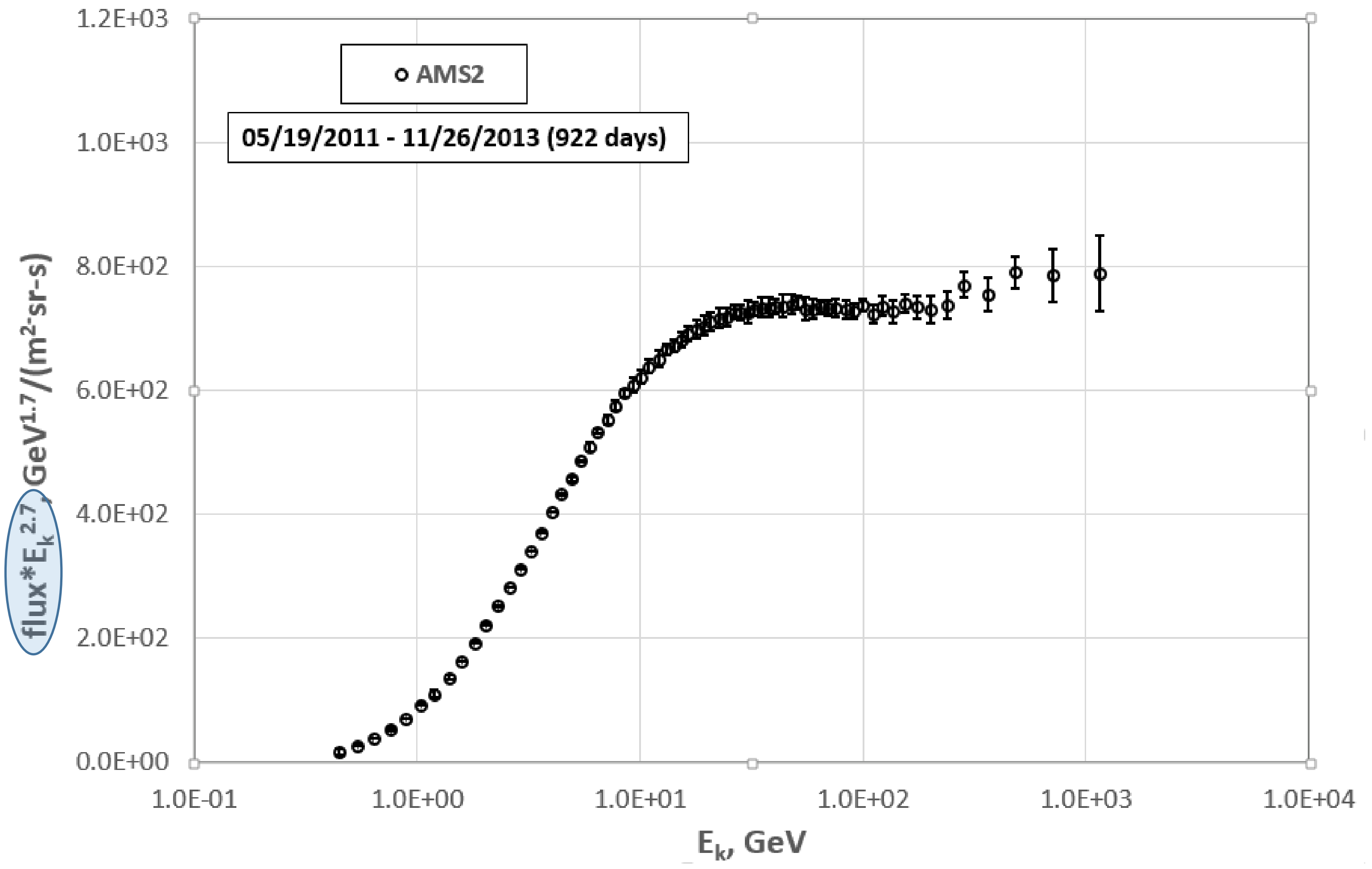

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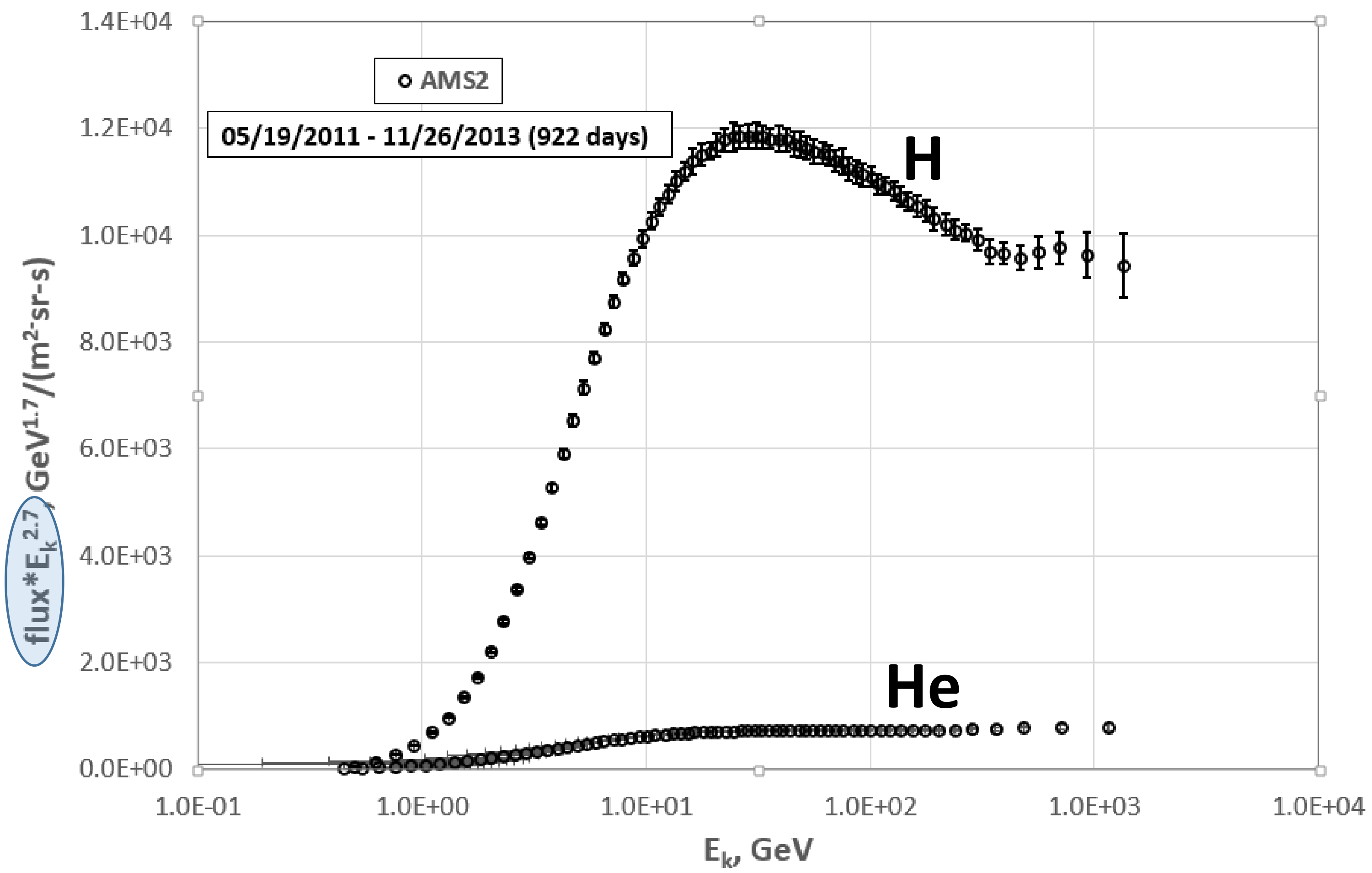

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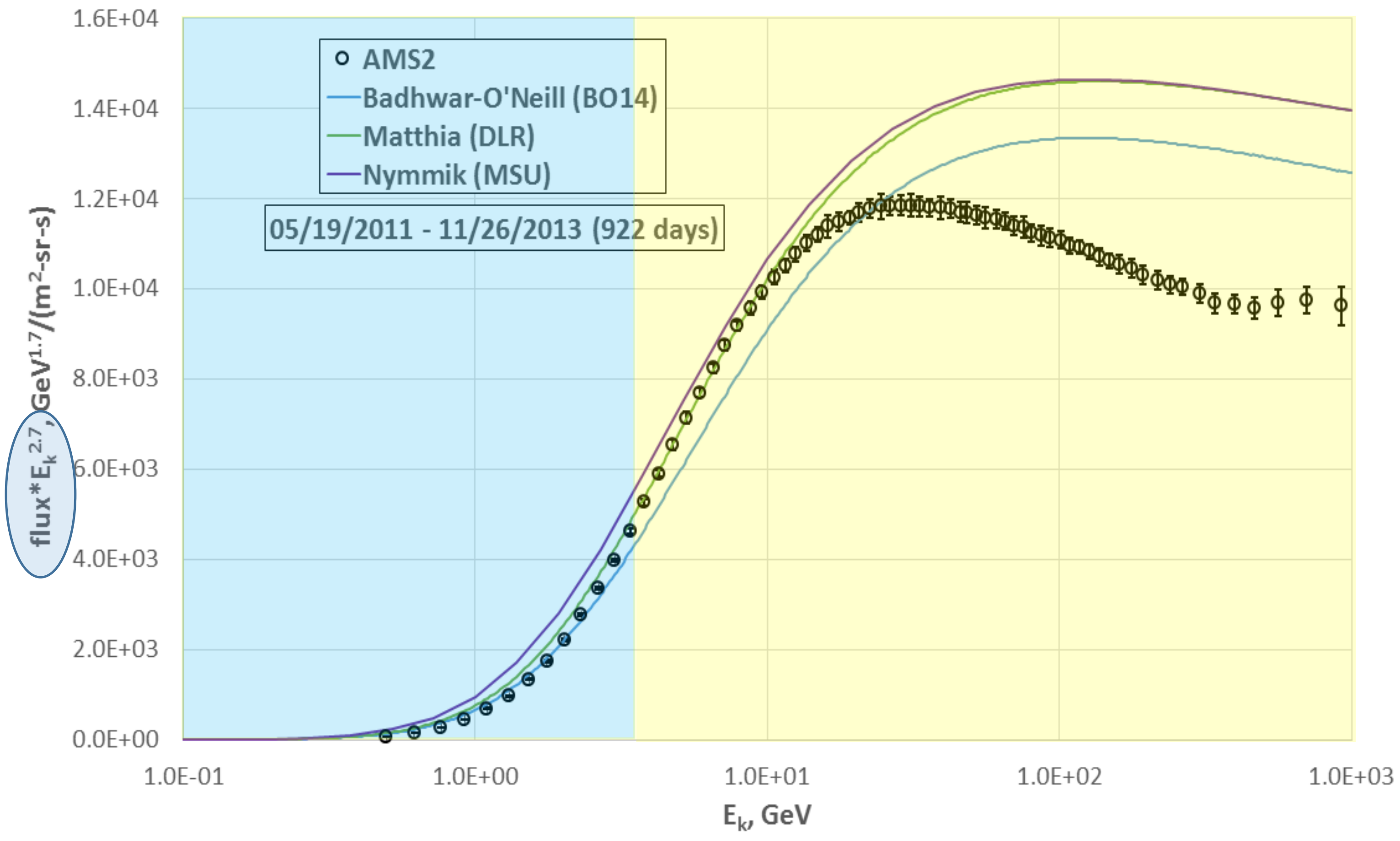
Scaled AMS2 Proton Data vs. GCR Models



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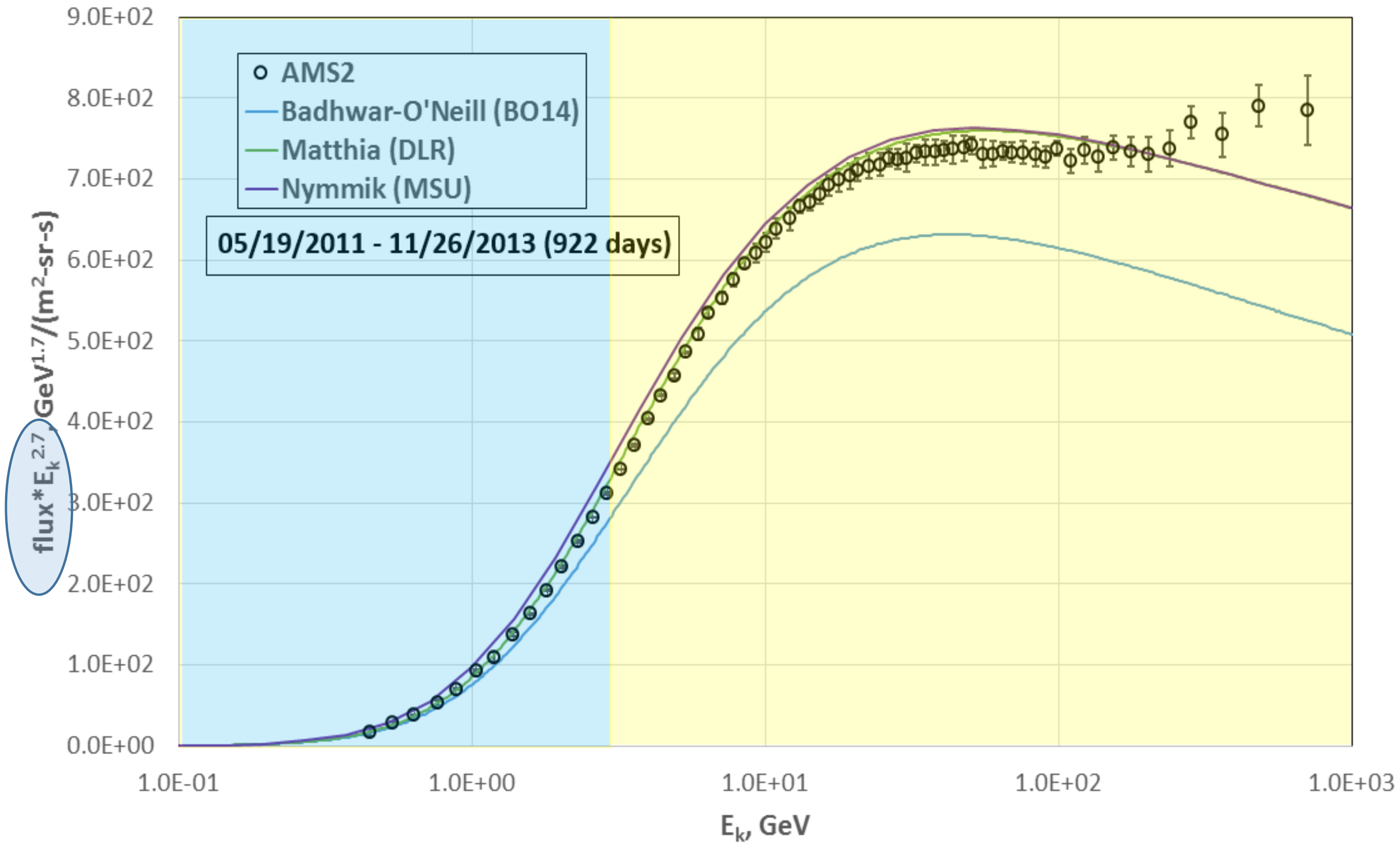

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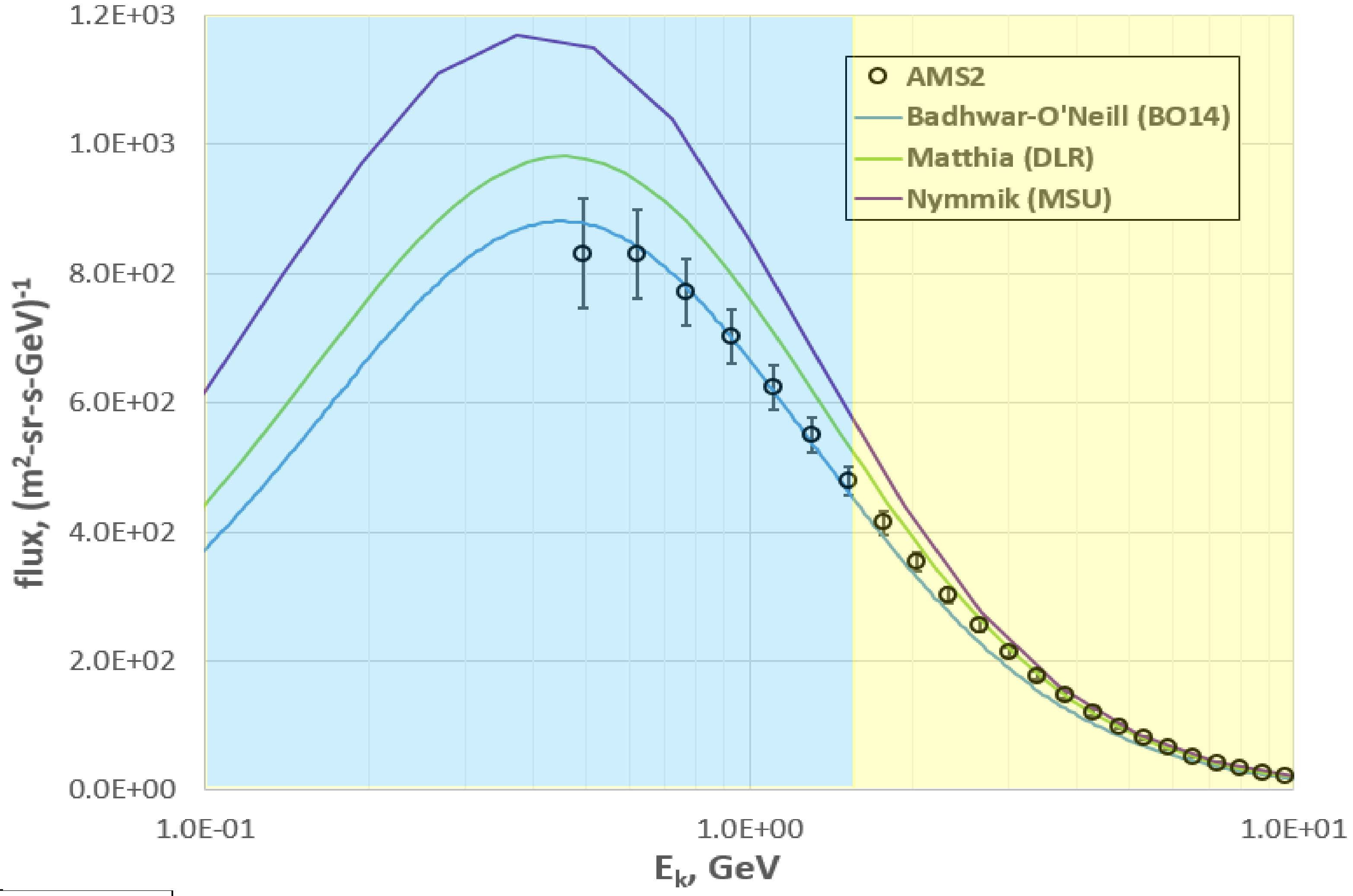
AMS2 Lower Energy Proton Data vs. GCR Models



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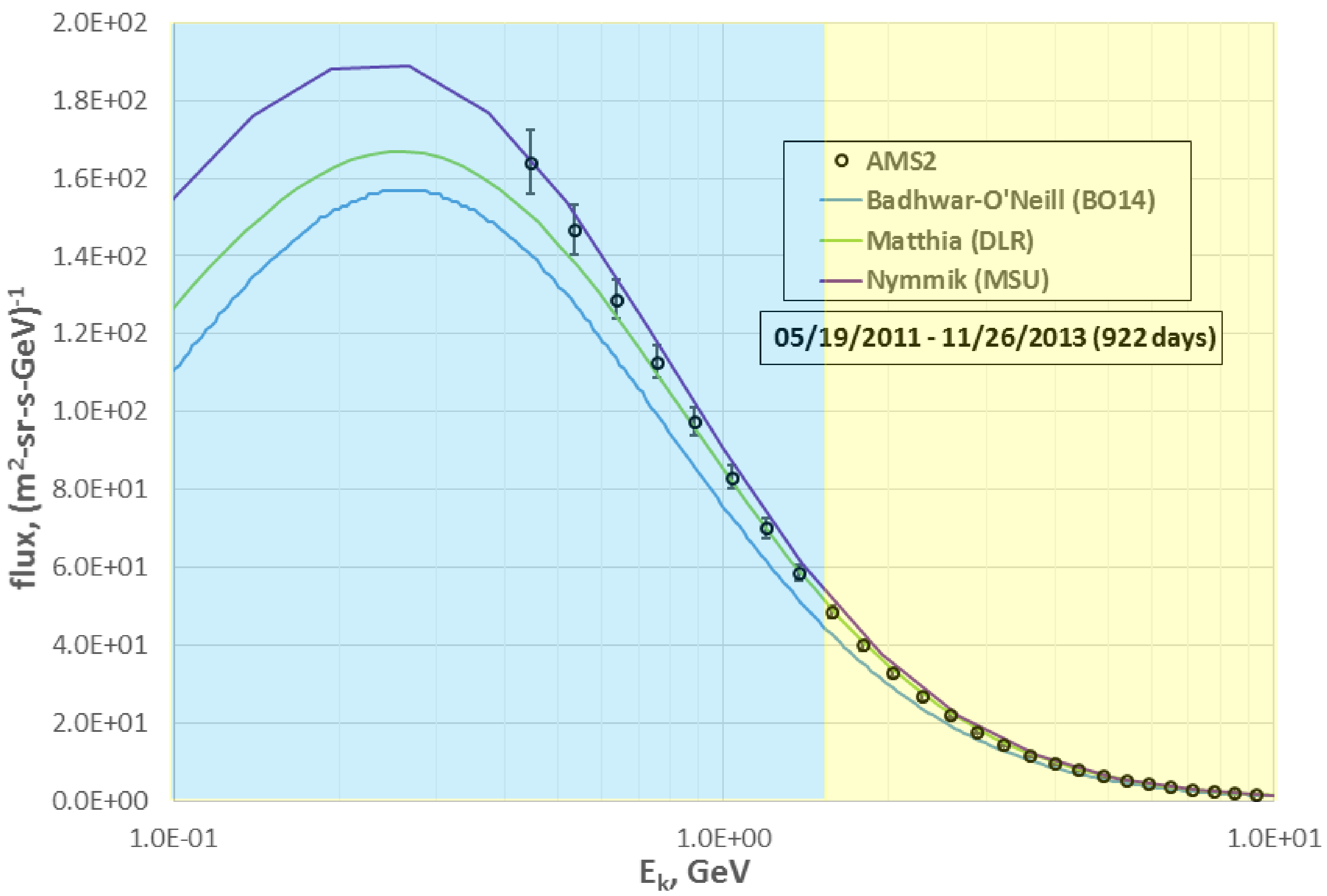
AMS2 Lower Energy Helium Data vs. GCR Models



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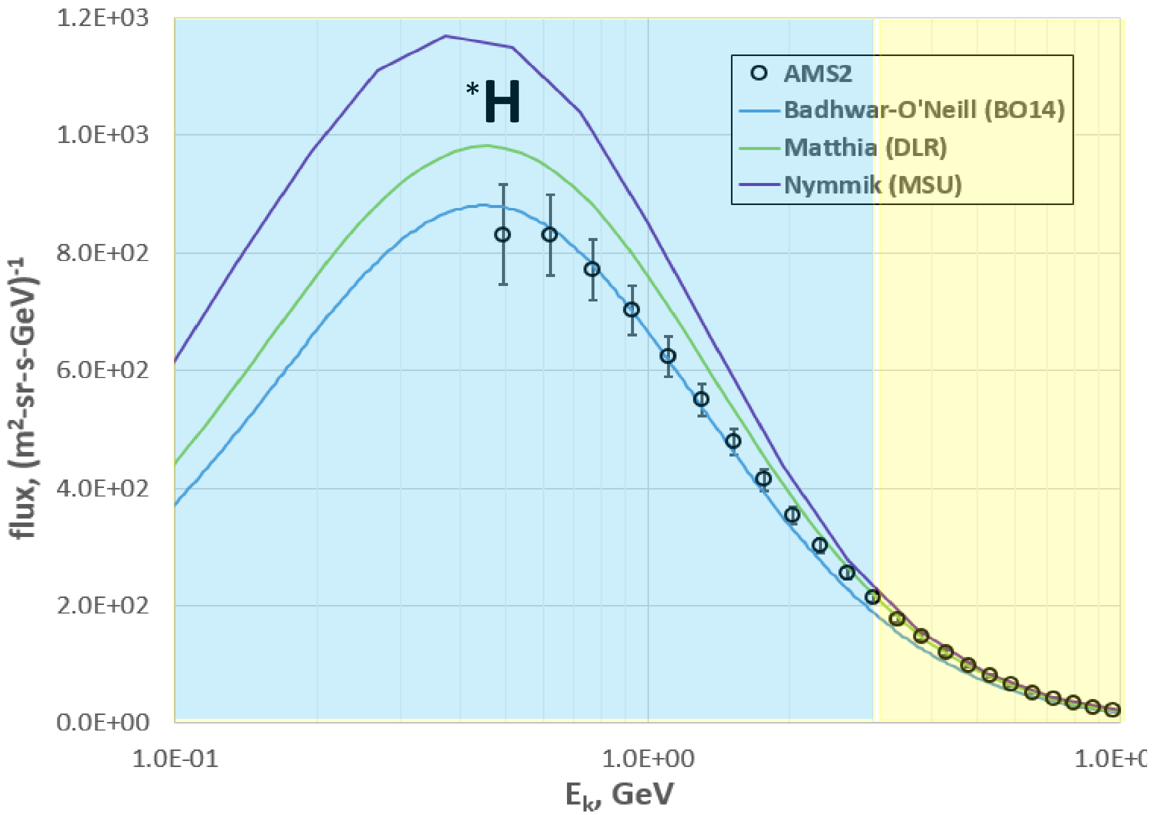
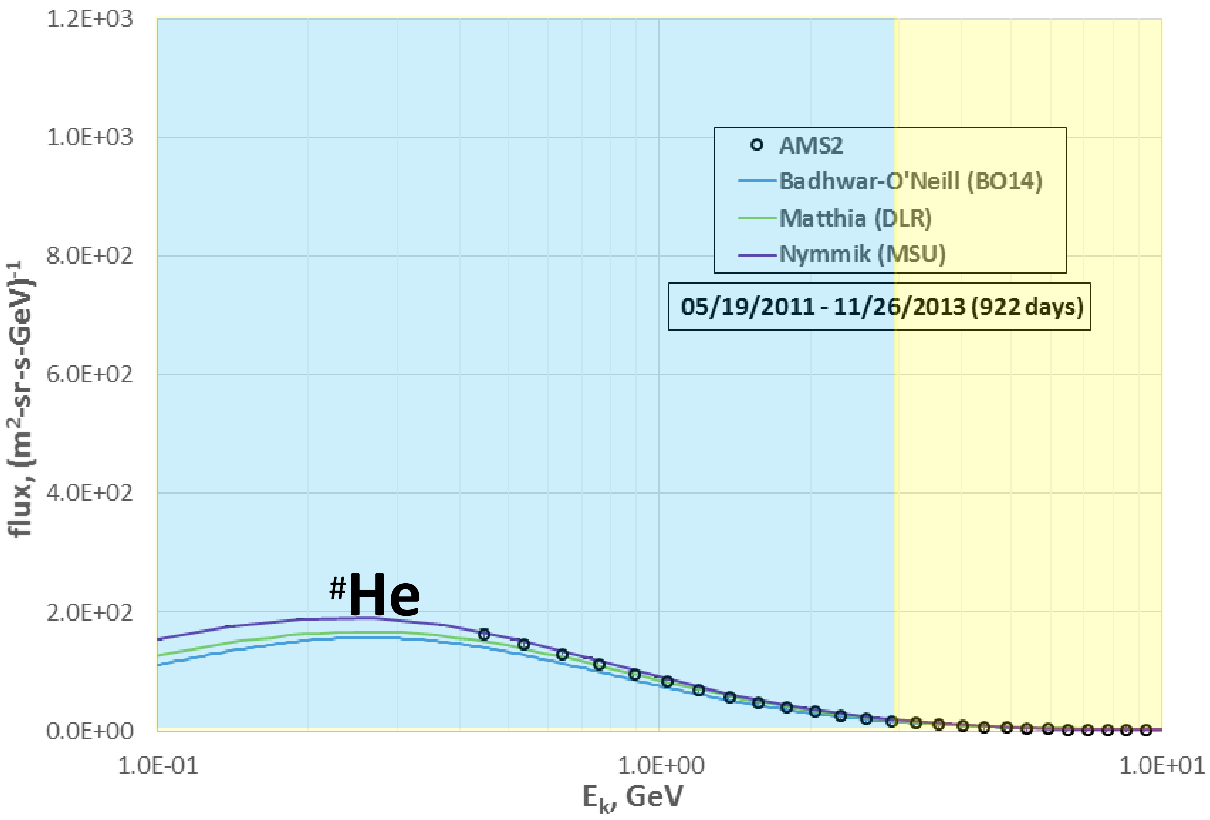
AMS2 Lower Energy Proton and Helium Data vs. GCR Models

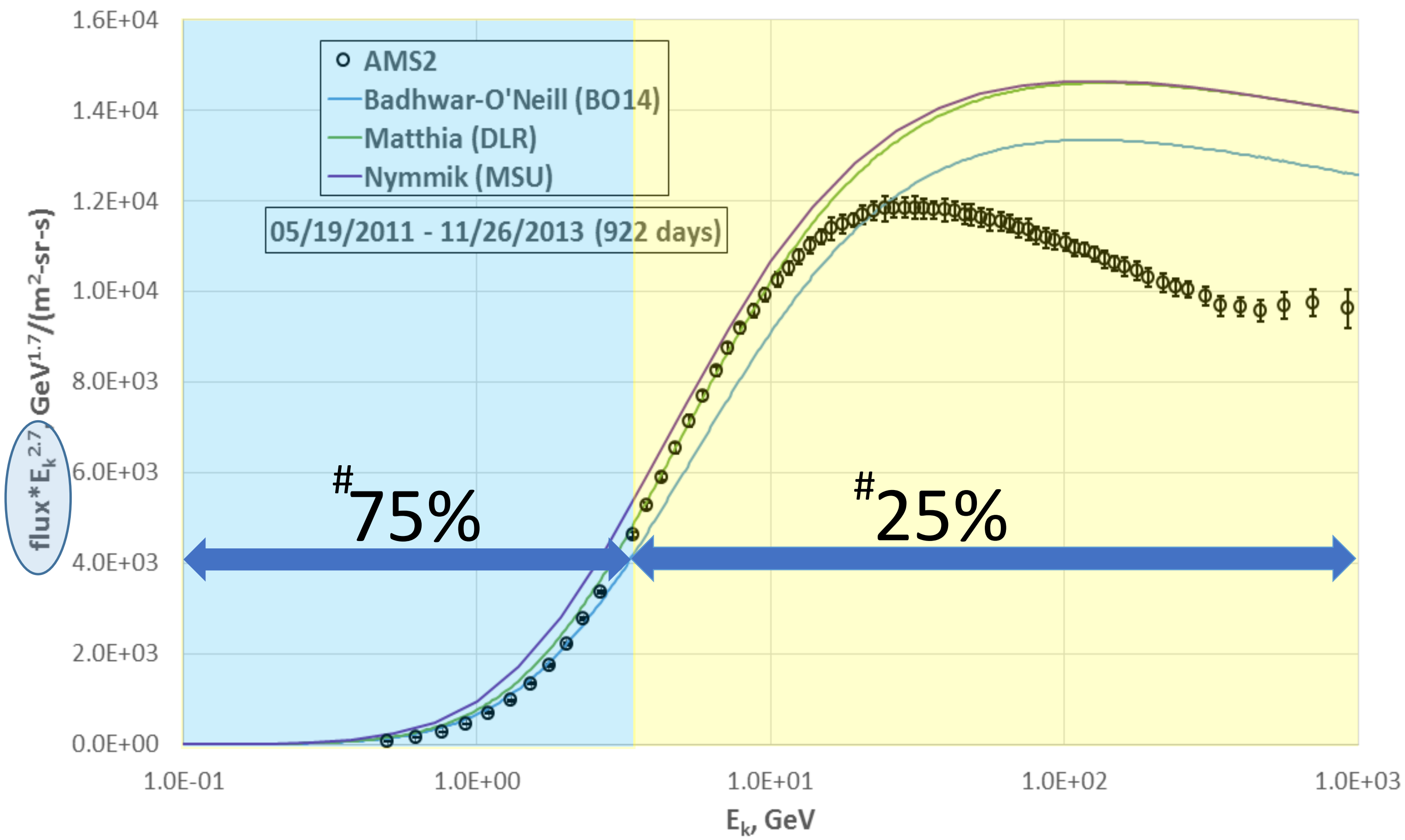




*Aguilar, M., et al. (2015), Precision measurement of the proton flux in primary cosmic rays from rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station, *Phys. Rev. Letters*, *114*

#Aguilar, M., et al. (2015), Precision measurement of the helium flux in primary cosmic rays of rigidity 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station, *Phys. Rev. Letters*, *115*

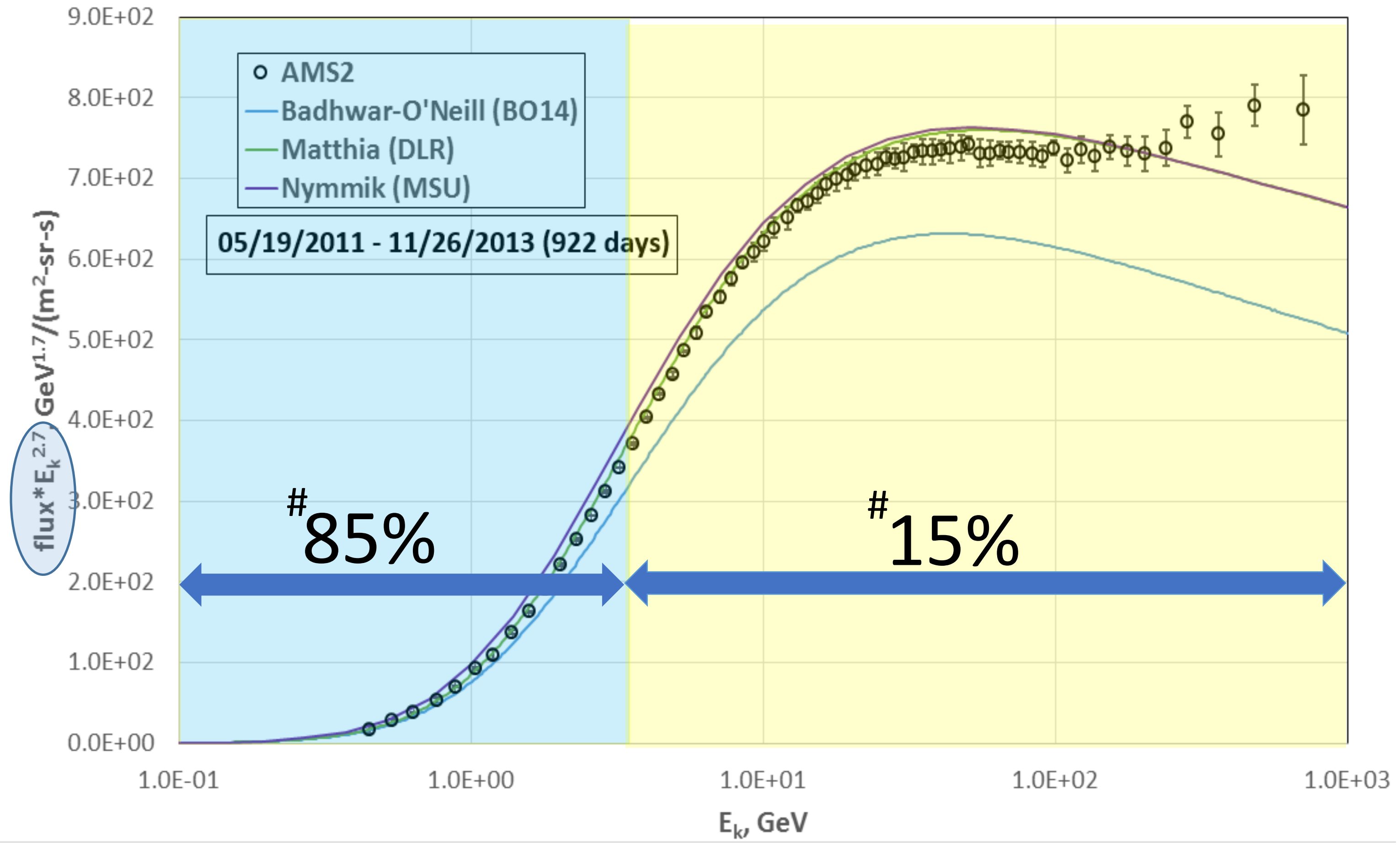
Significance of Proton Exposure (E) in Each Energy Region



Aguilar, M., et al. (2015), Precision measurement of the proton flux in primary cosmic rays from rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station, *Phys. Rev. Letters*, *114*

#Slaba, T. C., Blattnig, S. R. (2014), GCR environmental models I: Sensitivity analysis for GCR environments, AGU pubs., *Space Weather*, *12*, 217-224

Significance of Helium Exposure (E) in Each Energy Region



Aguilar, M., et al. (2015), Precision measurement of the proton flux in primary cosmic rays from rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station, *Phys. Rev. Letters*, *115*

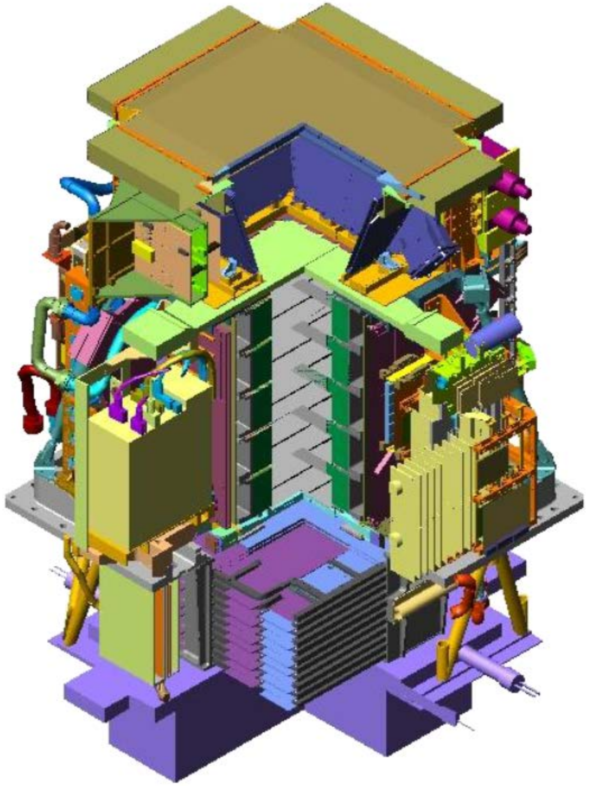
#Slaba, T. C., Blattnig, S. R. (2014), GCR environmental models I: Sensitivity analysis for GCR environments, AGU pubs., *Space Weather*, *12*, 217-224

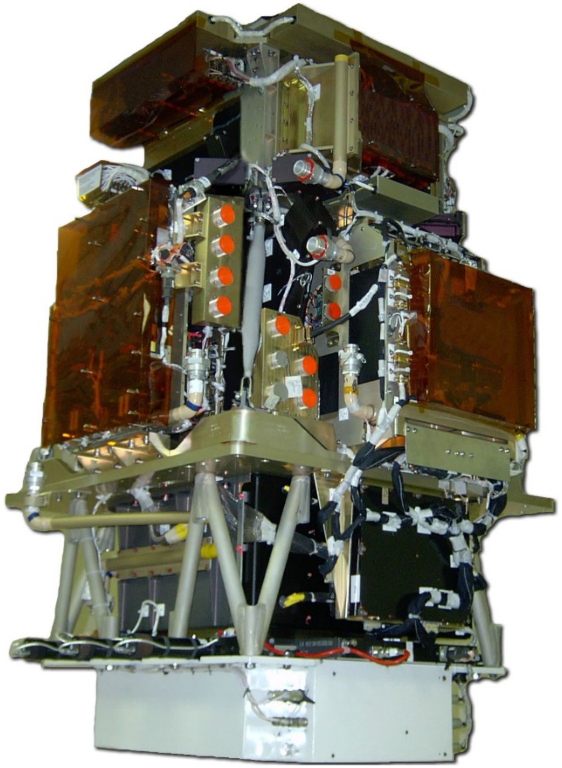
Summary and Conclusion

- Compared 3 GCR models prediction with AMS2 proton and helium data
- Showed that for AMS2 proton data, **BO** model is closest to the data in the region of greatest importance to astronaut exposure ($\leq$ 3GeV)
- Showed that for AMS2 helium data **DLR** model is closest to the data in the region of greatest importance for astronaut exposure ($\leq$ 3GeV)

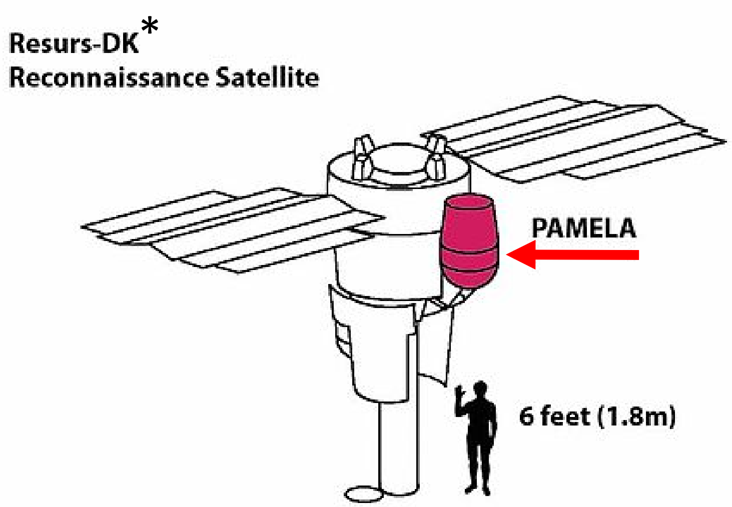
PAMELA Specifications

Wizard collaborators:
Italy, Germany, Sweden, Russia





PAMELA **(Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics)**
Host Satellite, Resurs DK1 (Soyuz-FG)
June 15, 2006 - February 7, 2016
Data coverage: 2006 - 2010
Perigee/Apogee: 360 - 604 km. (~600 km. circular since 2010)
Inclination: 70°
Period : 94 min.
Proton E_K range: 0.1 - 1000 GeV (0.6 - 1000 GV)
SEP/SAA data are excluded



*Adriani, O., et al. (2011), PAMELA measurements of cosmic-ray proton and helium spectra, *Science*, *332*, p: 69-72, Apr. 2011