Impact of AMS-02 Measurements on Reducing GCR Model Uncertainties

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Solar Energetic Particles, Solar Modulation and Space Radiation:
New Opportunities in the AMS-02 ERA
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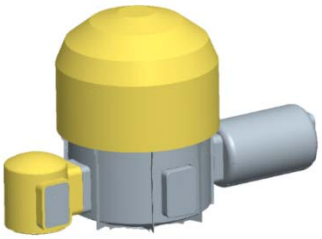
Outline

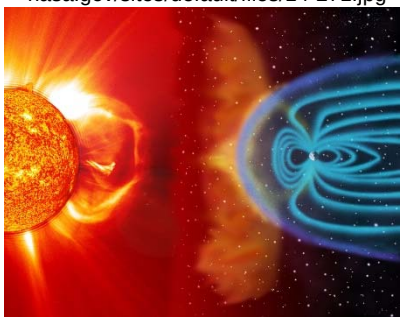
- Radiation exposure analysis overview
- Initial sensitivity and uncertainty quantification results
- Galactic cosmic ray (GCR) models
- Impact of AMS-02 measurements on reducing uncertainties

Exposure Analysis Overview

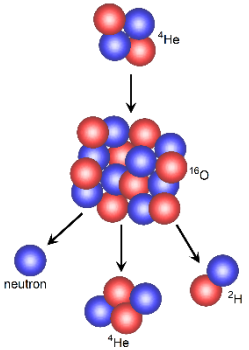


Shielding models

nasa.gov/sites/default/files/14-271.jpg

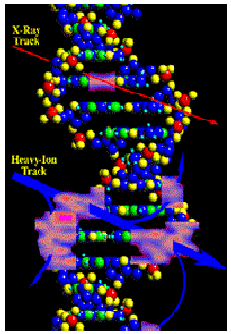


Environment models



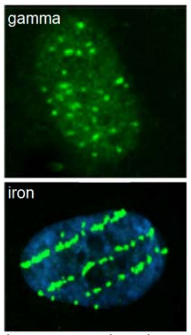
Physics models

Radiation transport models



nasa.gov/centers/johnson/slsd/about/divisions/hacd/hrp/about-space-radiation.html

Exposure & Biological response



humanresearchroadmap.nasa.gov/evidence/reports/Carcinogenesis.pdf

Impact of GCR Model Uncertainty

- GCR protons account for >50% of the total exposure behind shielding[(1)]
- GCR alphas are the next largest contributor
- Ions with Z > 2 and energy below 500 MeV/n (ACE) account for less than 5% of the exposure

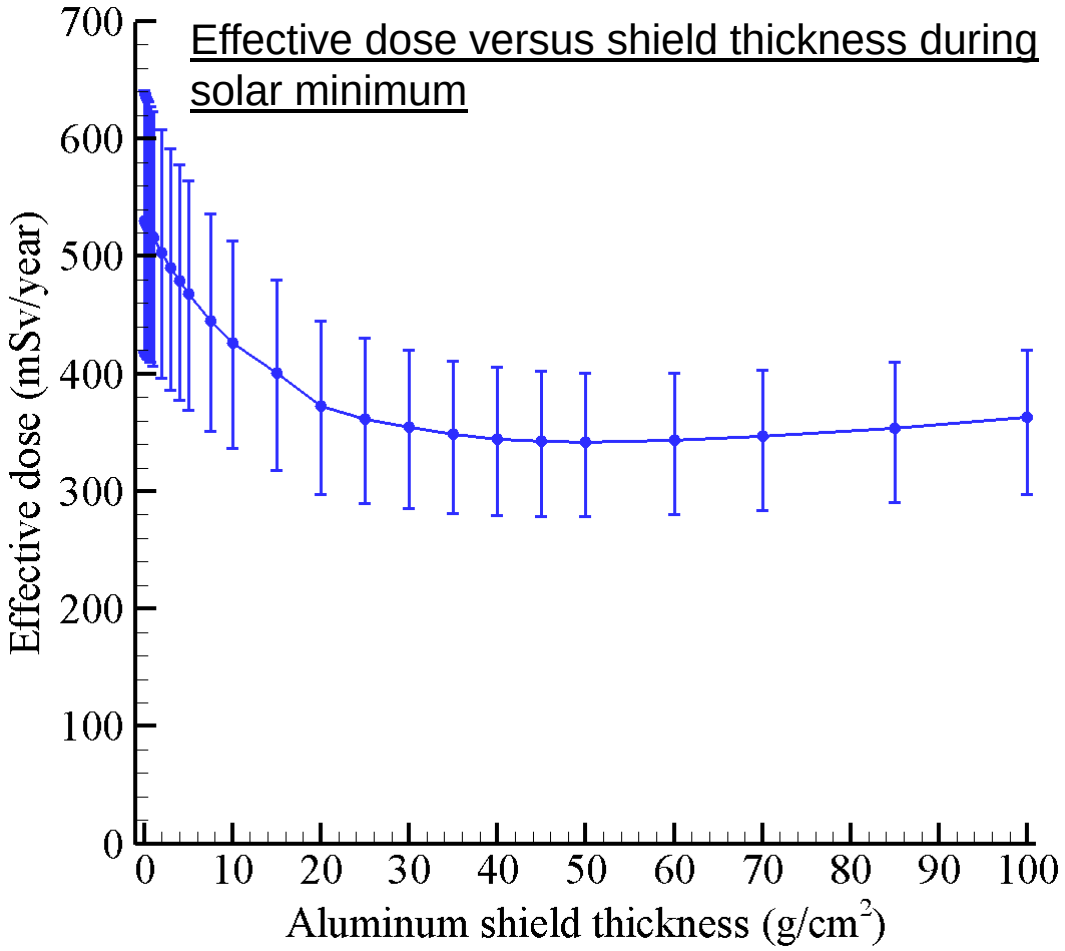
Relative contribution (%) of each boundary ion/energy group to effective dose behind 20 g/cm^2 aluminum during solar minimum[(1)].

	Boundary energy interval (GeV/n)					
	< 0.25	[0.25, 0.5]	[0.5, 1.5]	[1.5, 4]	> 4	Total
Z = 1	1.2	5.4	18.2	18.4	14.8	58.1
Z = 2	1.2	2.2	4.1	2.9	1.7	12.2
Z = 3-10	< 0.1	3.3	3.8	1.3	0.8	9.1
Z = 11-20	< 0.1	0.2	6.6	2.0	1.1	10.0
Z = 21-28	< 0.1	< 0.1	4.7	3.8	2.1	10.6
Totals	2.5	11.1	37.4	28.4	20.5	100.0

(1) Slaba, T.C., Blattnig, S.R., *Space Weather* **12**: 217-224, 2014.

Impact of GCR Model Uncertainty

- GCR model uncertainty induces roughly ±20% error on effective dose[2]
  - Results below for Badhwar-O'Neill (BON) 2014 GCR model[3]



- Error bars represent uncertainty associated with GCR model only
- For nominal vehicle shielding (>10 g/cm^2), relative errors are roughly ±20%

(2) Slaba, T.C., Xu, X., Blattnig, S.R., Norman, R.B., *Space Weather* **12**: 233-245, 2014.

(3) O'Neill, P.M., Golge, S., Slaba, T.C., NASA TP 2015-218569, 2015.

Badhwar-O'Neill Model Description

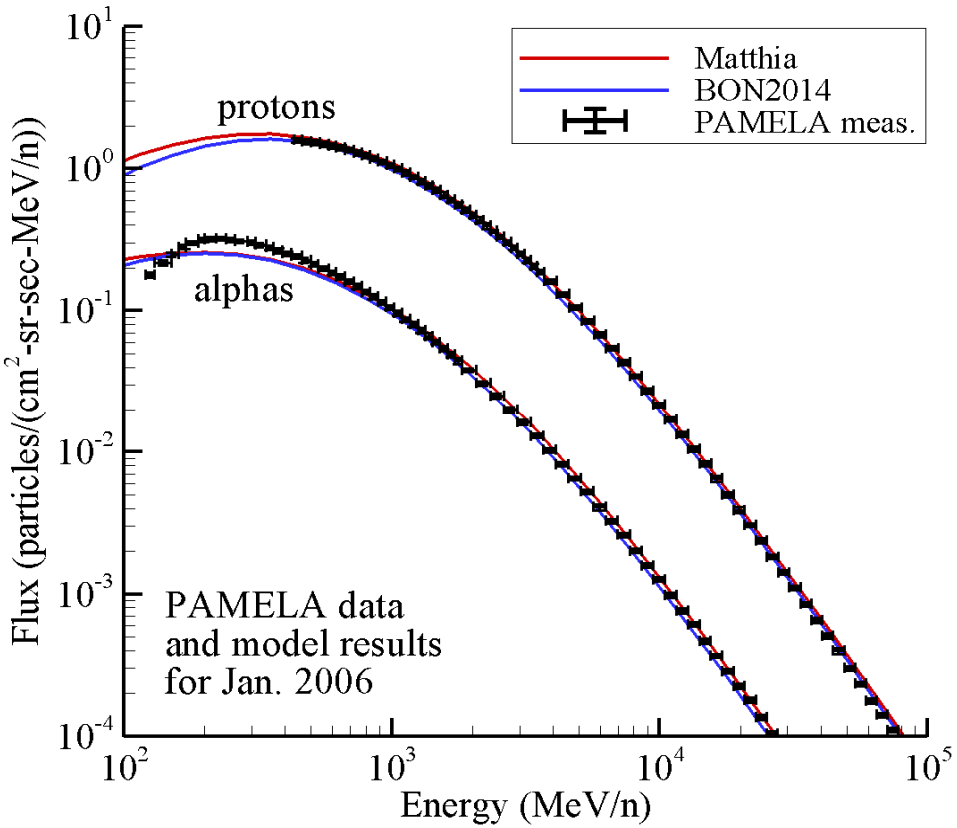
- The Badhwar O'Neill (BON) galactic cosmic ray model is used at NASA as input into radiation transport codes for
  - vehicle design, mission analysis, astronaut risk analysis
  - other models used as well (discussed in later slides)

- BON model revisions are based on the same fundamental framework
  - Model equations are solved to describe particle transport through solar system
  - Solar activity is described by a single parameter related to observed sunspot numbers

International Models and Comparisons

- GCR models tend to agree reasonably well at highest energies[2]
  - Effects of solar modulation are less pronounced
  - Significant contributor to exposure behind shielding

GCR proton & alpha flux compared to measurements



- Matthia et al. (DLR) recently developed a simplified form of Nymmik's model[6]
  - Shown to be reasonably accurate[2,6]
- Nymmik (MSU) has developed a semi-empirical model[4,5] (not shown)
  - Used by Russian Space Agency & others (DLR, ESA)
  - Official update has not been provided recently

(2) Slaba, T.C., Xu, X., Blattnig, S.R., Norman, R.B., *Space Weather* **12**: 233-245, 2014.

(4) Nymmik, R.A., Panasyuk, M.I., Suslov, A.A., *Adv. Space Res.* **17**: (2)19-(2)30, 1996.

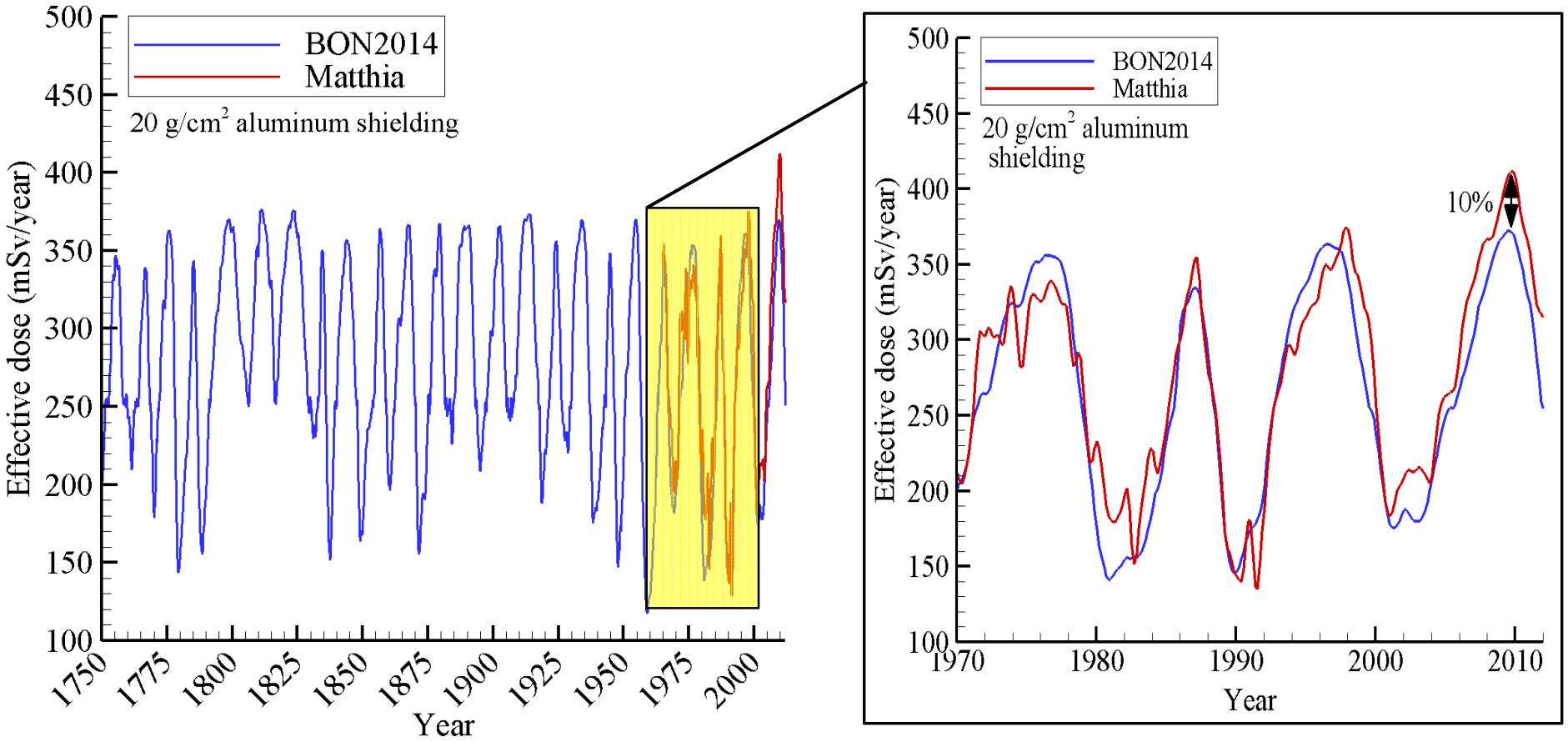
(5) International Standards Organization (ISO) 15390, 2004.

(6) Matthia, D., Berger, T., Mrigakshi, A.I., Reitz, G., *Adv. Space Res.* **51**: 329-338, 2013.

International Models and Comparisons

- Exposures behind shielding are in good agreement if updated GCR models are used
  - BON2014 and Matthia are within 10% of each other, on average, over past 40 years

Effective dose versus time behind 20 g/cm^2 aluminum shielding



GCR Model Development

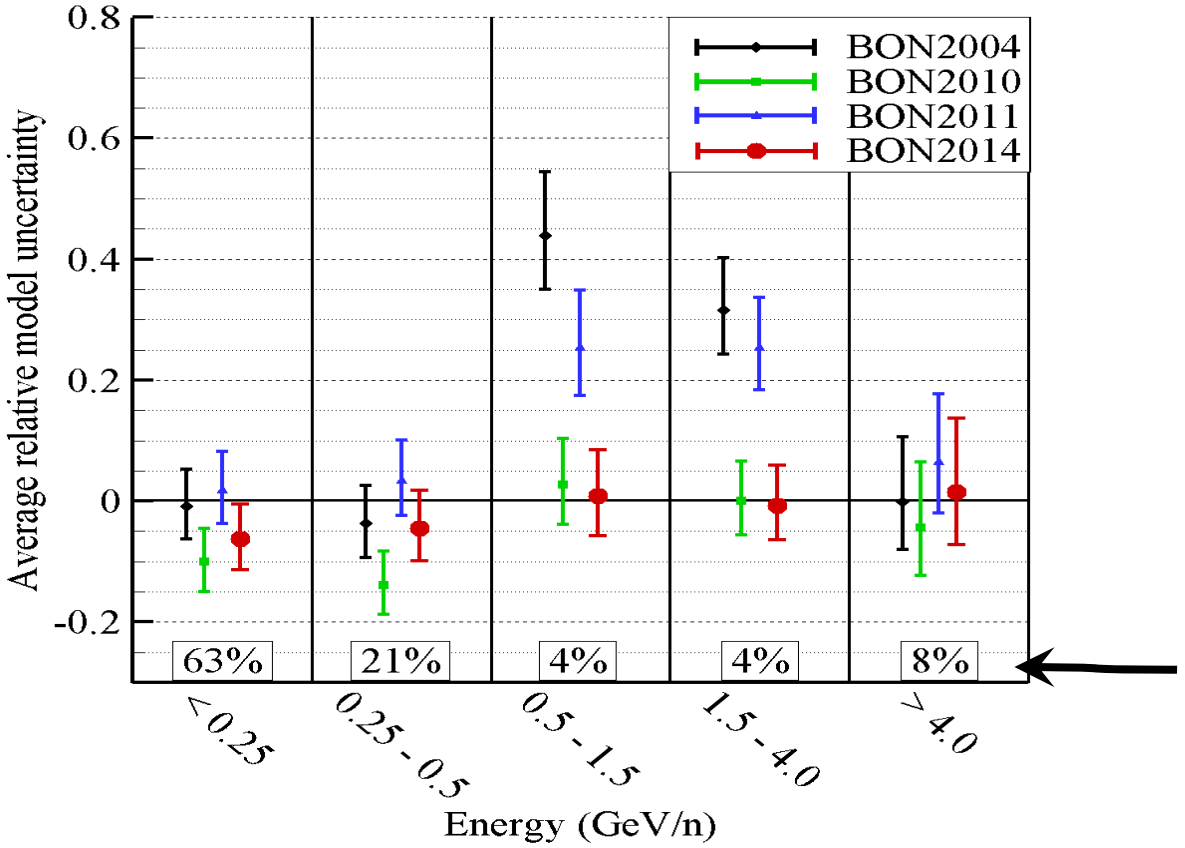
- GCR models are developed and validated using available measurements
  - Short duration, high energy, balloon and satellite measurements
  - Low energy, continuous measurements from ACE/CRIS (most of the available measurements)
  - Current gap in measurement database for continuous, high energy measurements

Name	Flight	Time	Ions (Z)	Energy (GeV/n)	Data pts.
ACE/CRIS	Satellite	1998-present	5-28	0.05 – 0.5	8288
AMS	STS-91	1998	1, 2	0.1 – 200	58
ATIC-2	Balloon	2002	1, 2, 6, 8, 10,…,14, 26	4.6 – 10^3	55
BESS	Balloon	1997-2000, 2002	1, 2	0.2 – 22	300
CAPRICE	Balloon	1994, 1998	1, 2	0.15 – 350	93
CREAM-II	Balloon	2005	6-8, 10, 12, 14, 26	18 – 10^3	42
HEAO-3	Satellite	1979	4-28	0.62 – 35	331
IMAX	Balloon	1992	1, 2	0.18 – 208	56
IMP-8	Satellite	1974	6, 8, 10, 12, 14	0.05 – 1	53
LEAP	Balloon	1987	1, 2	0.18 – 80	41
MASS	Balloon	1991	1, 2	1.6 – 100	41
PAMELA	Satellite	2006-2009	1, 2	0.08 – 10^3	472
TRACER	Balloon	2003	8, 10, 12,…,20, 26	0.8 – 10^3	55
Lezniak	Balloon	1974	4-14, 16, 20, 26	0.35 – 52	131
Minagawa	Balloon	1975	26, 28	1.3 – 10	16
Muller	STS-51	1985	6, 8, 10, 12, 14	50 – 10^3	16
Simon	Balloon	1976	5-8	2.5 – 10^3	46

82% of available data

Galactic Cosmic Ray Model Development

- Recent work has significantly reduced model uncertainties[3]
  - More rigorous approach to model calibration and validation – resulted in BON2014
  - Determined measurements (energies) most important for exposure quantities behind shielding
  - Model parameters calibrated using optimization methods with an emphasis on higher energies
  - Comprehensive validation metrics applied to quantify model uncertainty
  - Process can include new measurements and is repeatable



Fraction of available measurements in each energy bin

(3) O'Neill, P.M., Golge, S., Slaba, T.C., NASA TP 2015-218569, 2015.

Impact of AMS-02 Data

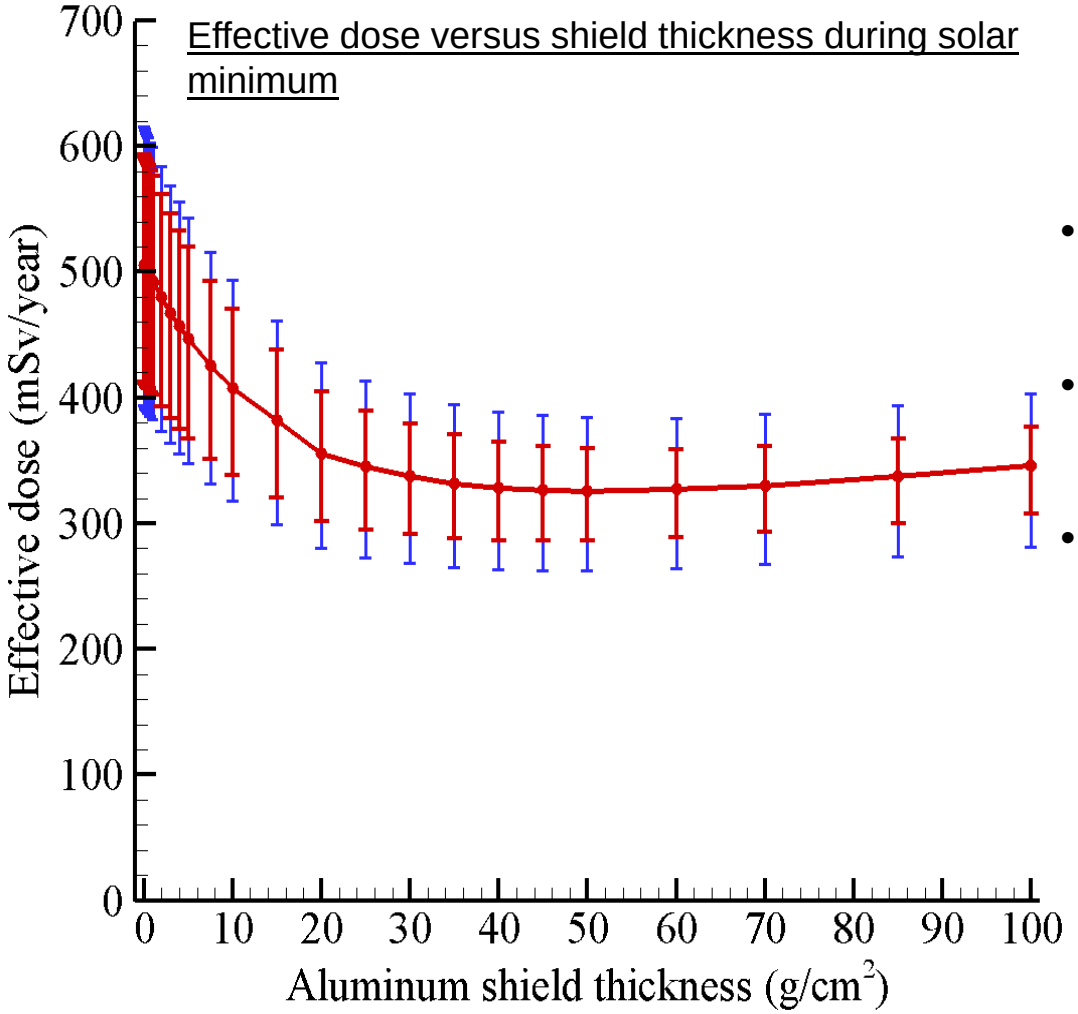
- Widely used GCR models are mainly semi-empirical
  - Data is needed to refine free parameters in models

- AMS-02 data will serve two important functions
  - Provide substantial data for independent validation (i.e. data not used to tune model)
  - Fill important data gaps to enable improved parameter calibration

- Current schedule for using AMS-02 for GCR measurements is mainly driven by impact on exposure
  - Monthly GCR proton measurements for energies greater than 500 MeV
  - Next step is to analyze GCR alphas
  - Specific heavy ions will be emphasized later

Impact of AMS-02 Data

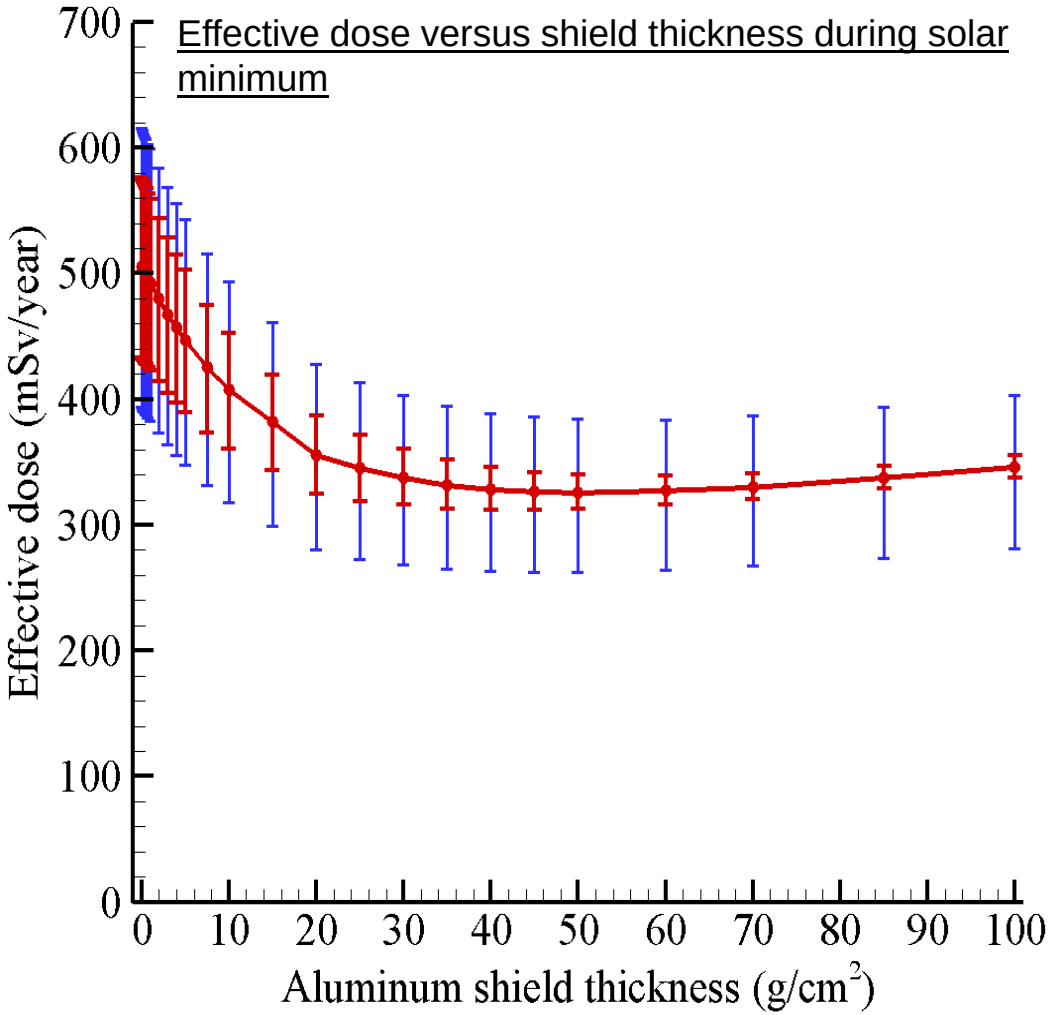
- If GCR proton and alpha uncertainty is cut in half
  - Uncertainty estimate drops from roughly ±20% to ±15%



- Error bars represent uncertainty associated with GCR model only
- Blue error bars represent current model uncertainties
- Red error bars represent assumed modified uncertainties with AMS-02 measurements

Impact of AMS-02 Data

- If GCR proton and alpha uncertainty is entirely removed
  - Uncertainty estimate drops from roughly ±20% to ±5%



- Error bars represent uncertainty associated with GCR model only
- Blue error bars represent current model uncertainties
- Red error bars represent assumed modified uncertainties with AMS-02 measurements

Summary

- Widely used GCR models rely on available measurements
  - Measurements used directly for development and validation
  - Updated models are in reasonable agreement
  - GCR models induce roughly ±20% uncertainty on effective dose behind shielding
- AMS-02 will fill an important gap in the measurement database
  - Significant need for high energy, time-resolved proton and alpha measurements
  - Current measurement database is dominated by ACE/CRIS
  - ACE/CRIS measurement domain induces less than 5% of exposure behind shielding
- Proton and alpha measurements from AMS-02 will reduce model uncertainties
  - Possibility exists to have a significant impact on reducing overall exposure uncertainties

References

(1) Slaba, T.C., Blattnig, S.R., *Space Weather* **12**: 217-224, 2014.

(2) Slaba, T.C., Xu, X., Blattnig, S.R., Norman, R.B., *Space Weather* **12**: 233-245, 2014.

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