

"Badhwar-O'Neill 2011 Galactic Cosmic Ray Model Update and Future Improvements"

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ABSTRACT

The Badhwar-O'Neill Galactic Cosmic Ray (GCR) Model based on actual GCR measurements is used by deep space mission planners for the certification of micro-electronic systems and the analysis of radiation health risks to astronauts in space missions. The BO GCR Model provides GCR flux in deep space (outside the earth's magnetosphere) for any given time from 1645 to present. The energy spectrum from 50 MeV/n – 20 GeV/n is provided for ions from hydrogen to uranium.

This work describes the most recent version of the BO GCR model (BO'11). BO'11 determines the GCR flux at a given time applying an empirical time delay function to past sunspot activity. We describe the GCR measurement data used in the BO'11 update – modern data from BESS, PAMELA, CAPRICE, and ACE emphasized more than the older balloon data used for the previous BO model (BO'10). We look at the GCR flux for the last 24 solar minima and show how much greater the flux was for the cycle 24 minimum in 2010.

The BO'11 Model uses the traditional, steady-state Fokker-Planck differential equation to account for particle transport in the heliosphere due to diffusion, convection, and adiabatic deceleration. It assumes a radially symmetrical diffusion coefficient derived from magnetic disturbances caused by sunspots carried outward by a constant solar wind.

A more complex differential equation is now being tested to account for particle transport in the heliosphere in the next generation BO model. This new model is time-dependent (no longer a steady state model). In the new model, the dynamics and anti-symmetrical features of the actual heliosphere are accounted for so empirical time delay functions will no longer be required. The new model will be capable of simulating the more subtle features of modulation – such as the Sun's polarity and modulation dependence on gradient and curvature drift.

This improvement is expected to significantly improve the fidelity of the BO GCR model. Preliminary results of its performance will be presented.

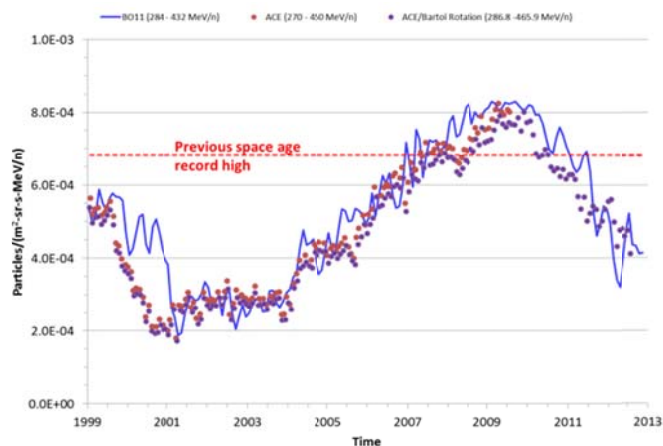


Fig. 1 GCR Ion Flux Comparison to BO11 model from 1999 to present (including the deepest Minimum of 2010). BO11 model calculation (solid line) shows very good agreement with Fe nuclei measurement.



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BO'11 GCR & Future

EV5-Electronic Design and Mnfr Branch

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GALACTIC COSMIC RAY (GCR) ENERGY SPECTRA

NASA HEALTH PHYSICISTS
CREW RADIATION EXPOSURE

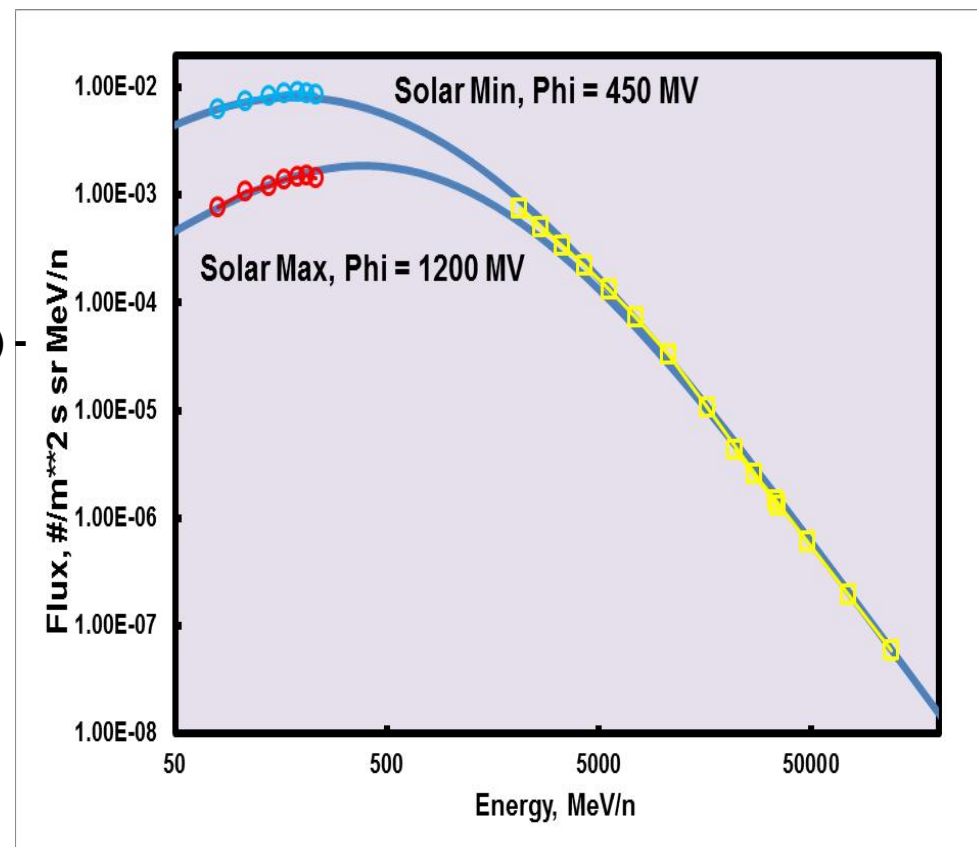
NASA ELECTRONIC'S ENGINEERS
MICROELECTRONIC COMPONENT
FAILURE

FLUX ENERGY SPECTRA
- PROTONS (Z=1) TO IRON IONS (Z=26)
- VS TIME (~5 SOLAR CYCLES)

LOW ENERGY
100's MeV/n
Solar Min - Higher Flux

HIGH ENERGY
Constant Flux > ~3 GeV/n

Oxygen GCR Energy Spectrum





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Protons & Helium - Balloon instruments and IMP Satellite



1952 - present, 3 day float at 130,000 ft

Best low & hi energy quiet time P+ & He
- BESS, CAPRICE, IMAX



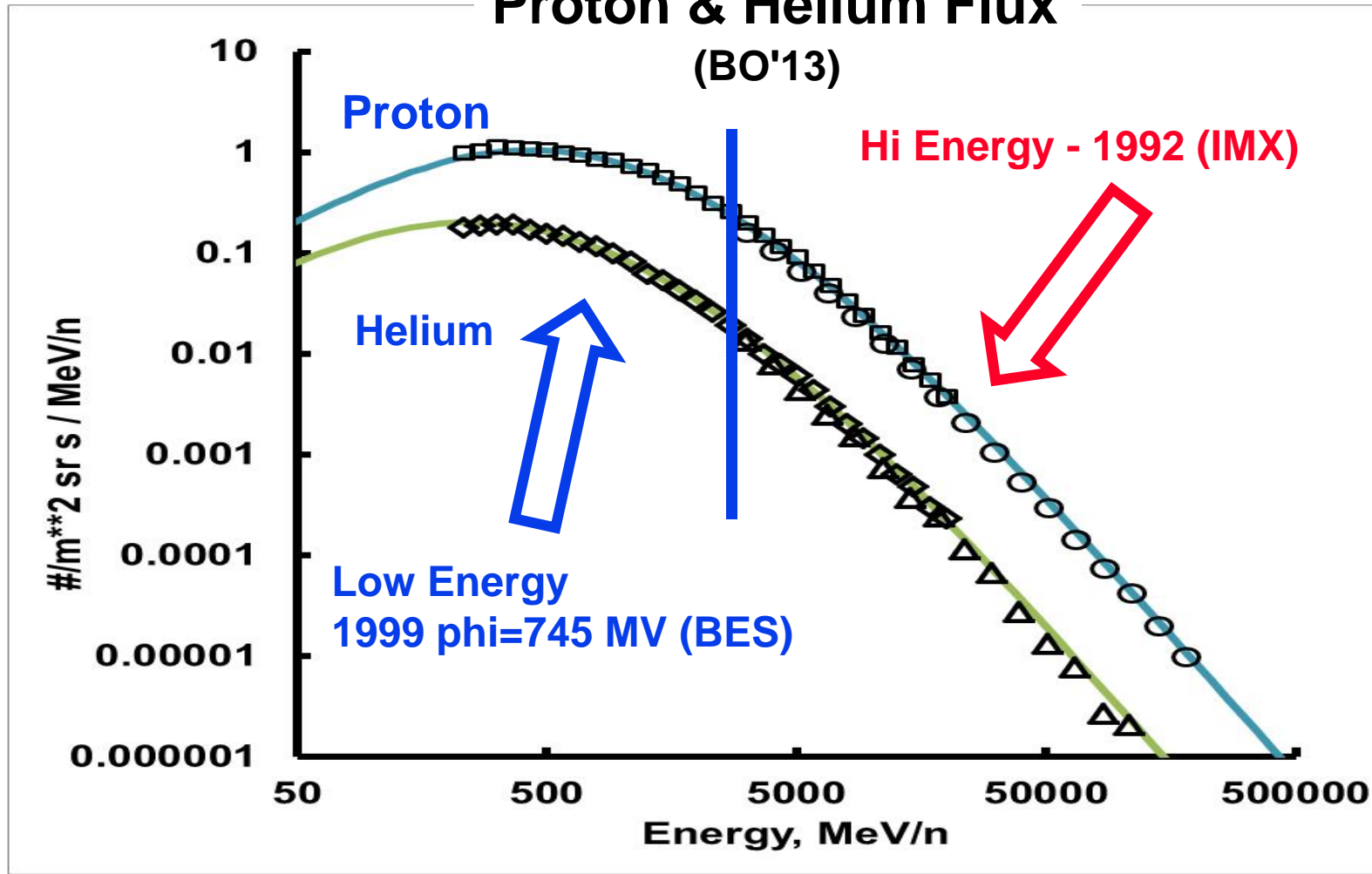
IMP-8

launched 1973 - died 2005
32 years = 3 solar cycles
orbit - half way to moon



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Proton & Helium Flux



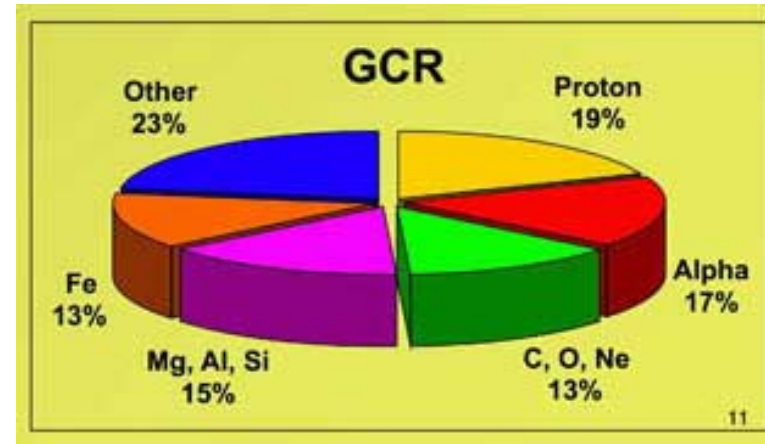
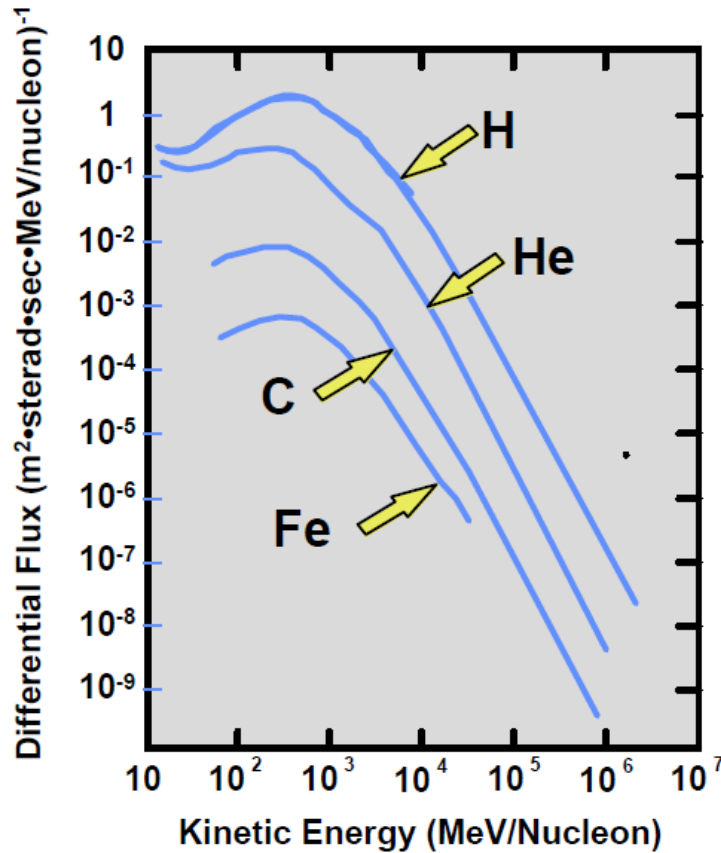


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Protons and Helium account for 99% of all GCR's* !

HOWEVER...

More than **60%** of the "dose" from heavier ions



*Space Radiation
behind 3 g/cm² of Aluminum
Dose Equivalent*

heavier ions are **even more** critical to **electronics**

**The Space Radiation Environment: An Introduction - Walter Schimmerling*



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Heavier ions - Li, Be, B, C, N, O, ... Fe come from NASA's ACE

ACE (Advanced Composition Explorer)

August 25, 1997 - present

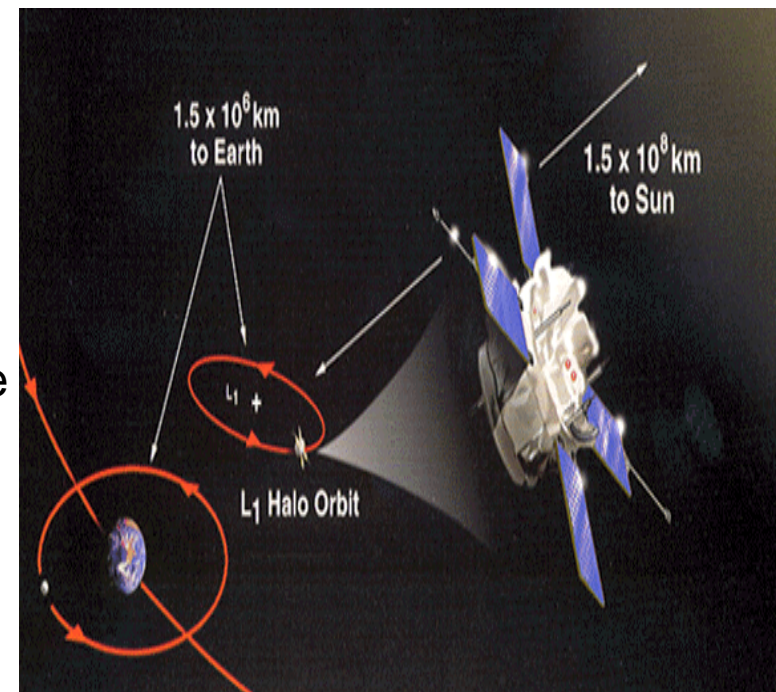
L1 libration point 1/10th distance to sun

Best measure of Low Energy quiet time

Sparse balloon & IMP ion data

Limited for C,N,O, ... Fe

NO DATA for rare ions: F, Mg, Al, P, ...



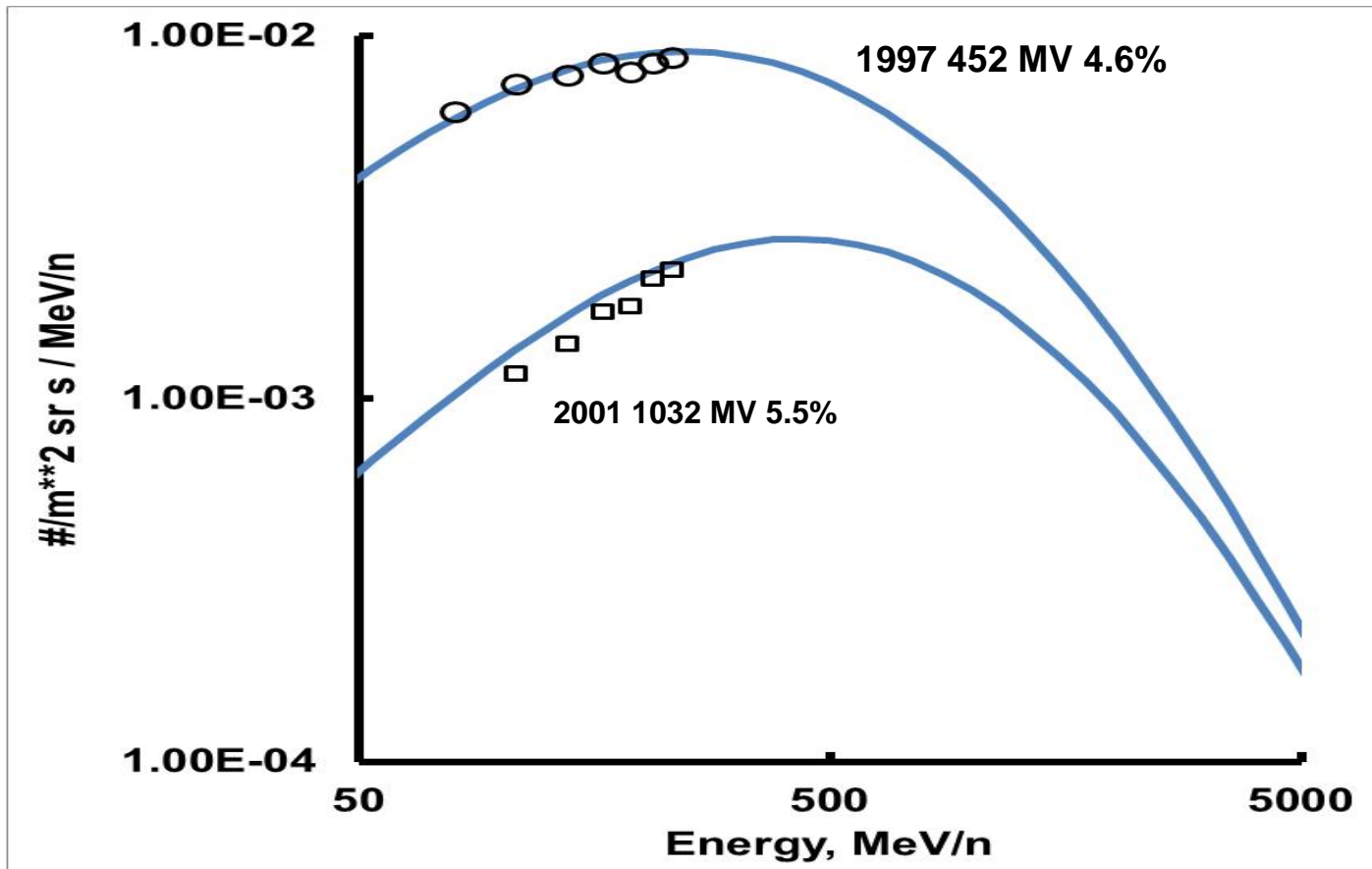
ACE has a large collecting power - its area is over 50 cm**2 - that's ~4" in diameter!

Even so, it still takes 10 days to collect enough Oxygen to get a good measurement



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ACE DATA - Oxygen Low Energy (BO'13)





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High Energy Heavy Ion Data

NASA Spacecraft

High Energy Astronomical
Observatory (HEAO)

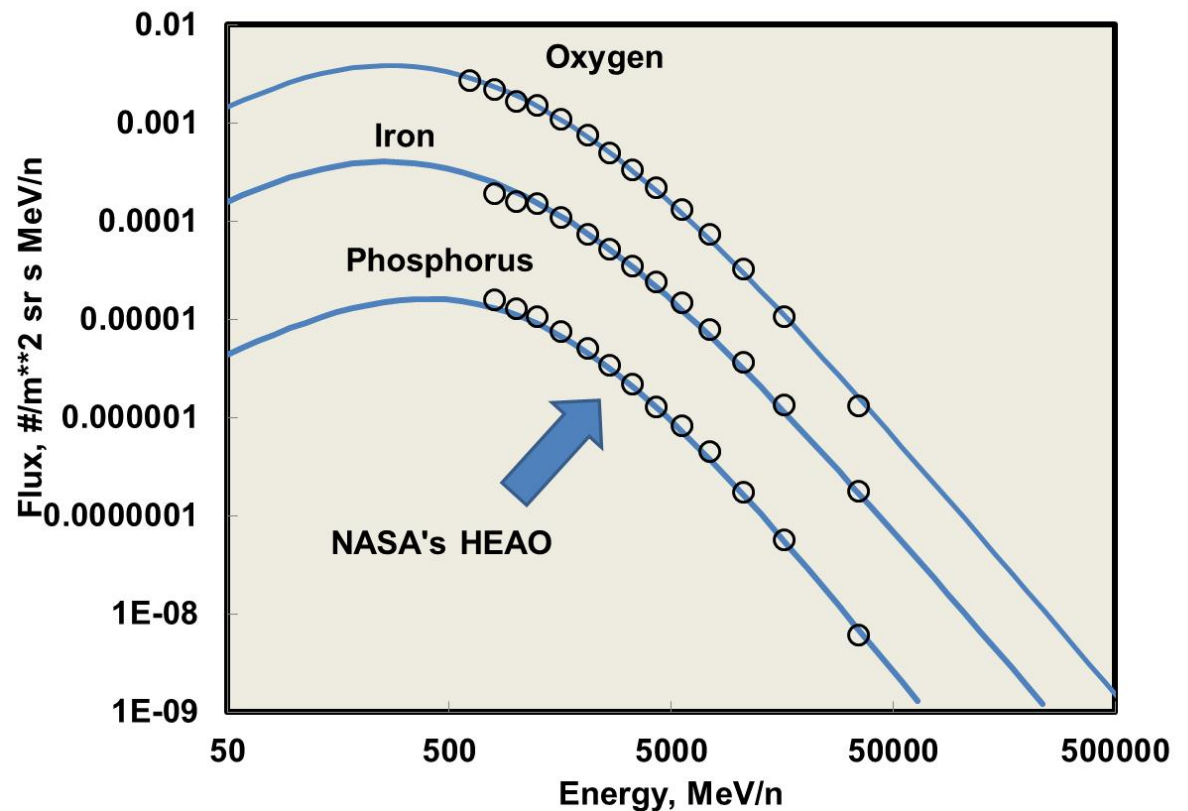
44 deg/500 km

1980 - 8 Months

Large - 700 cm^{**2} sr

Be (z=4) to Fe(z=26)

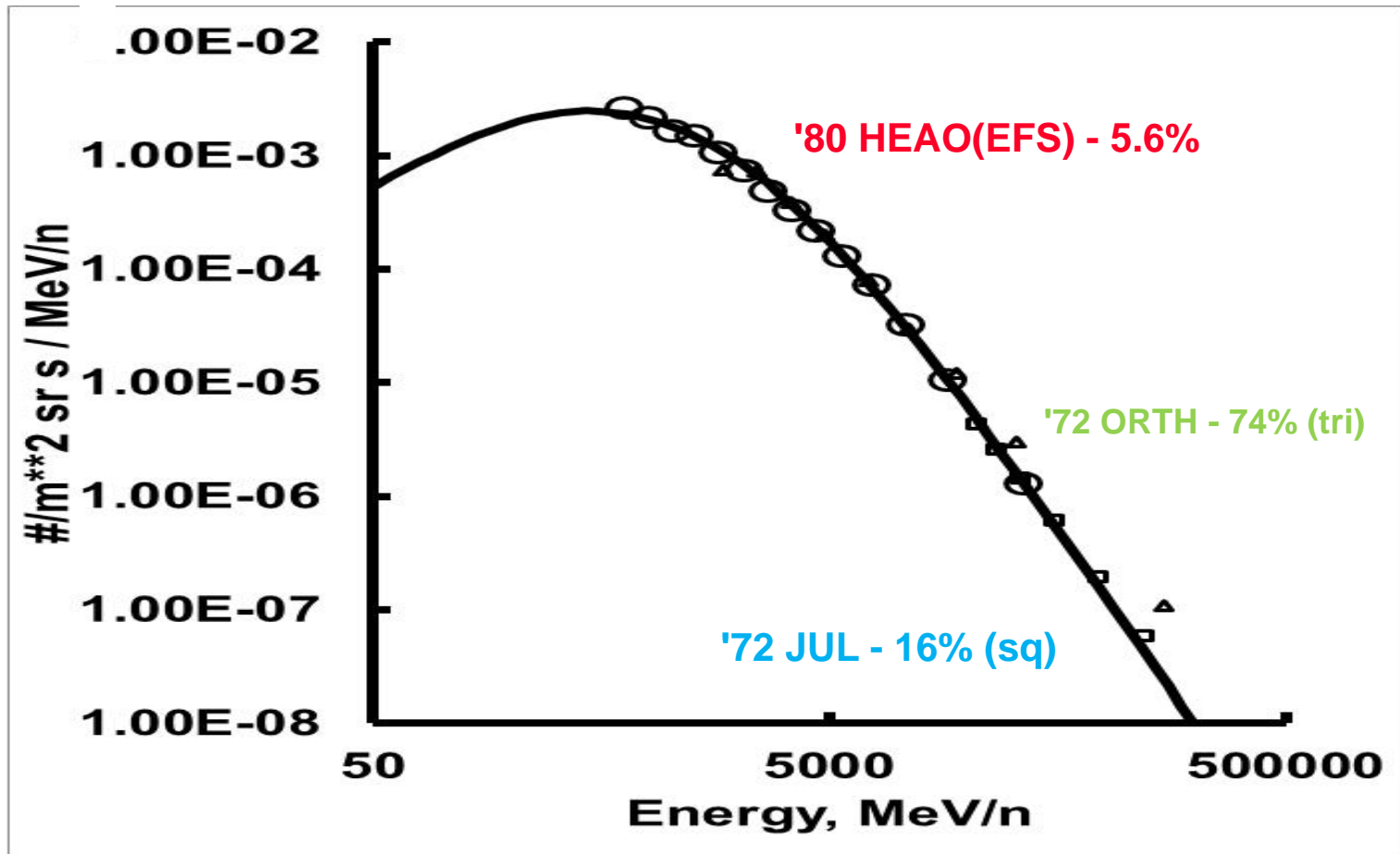
Easy to fit, exponential form





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Balloon Data too, Oxygen Hi Energy (BO'13)





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MODEL SENSITIVE TO SOLAR MODULATION (PHI)

MODULATION ~ # OF SUNSPOTS AT
TIME DATA WAS TAKEN

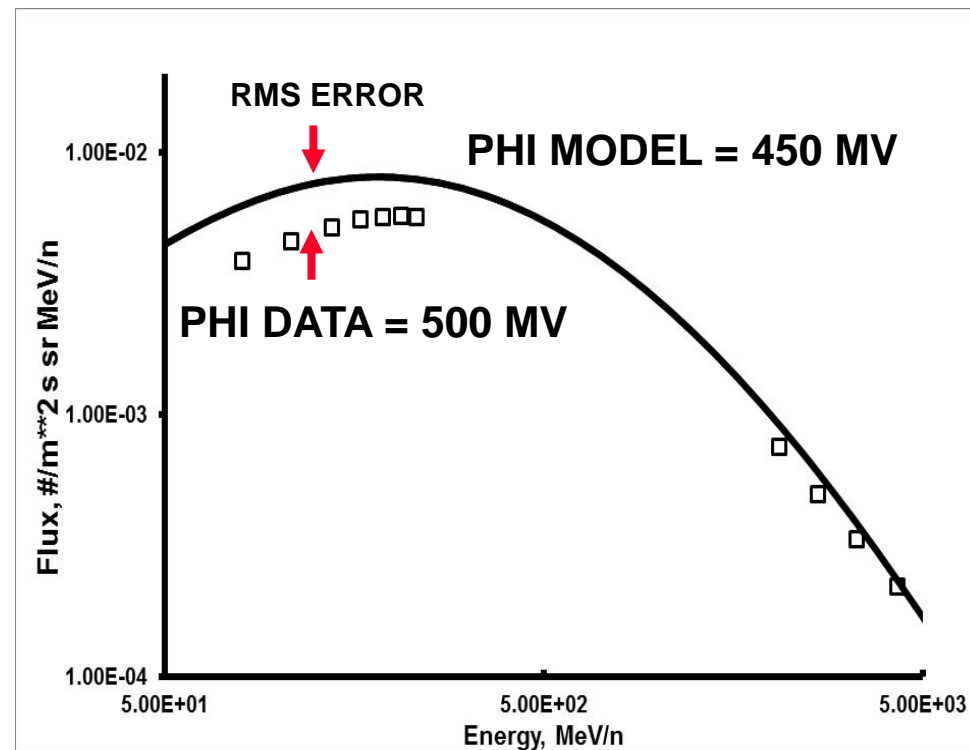
MODEL - SUNSPOTS AT TIME OF
DATA

DATA - ACTUAL MODULATION AT
TIME & PLACE OF DATA

- FLUX IS SHIFTED UP OR DOWN

- COULD ALSO BE DUE TO
SYSTEMATIC INSTRUMENT
ERROR

THE ERROR CAN BE SIGNIFICANT!





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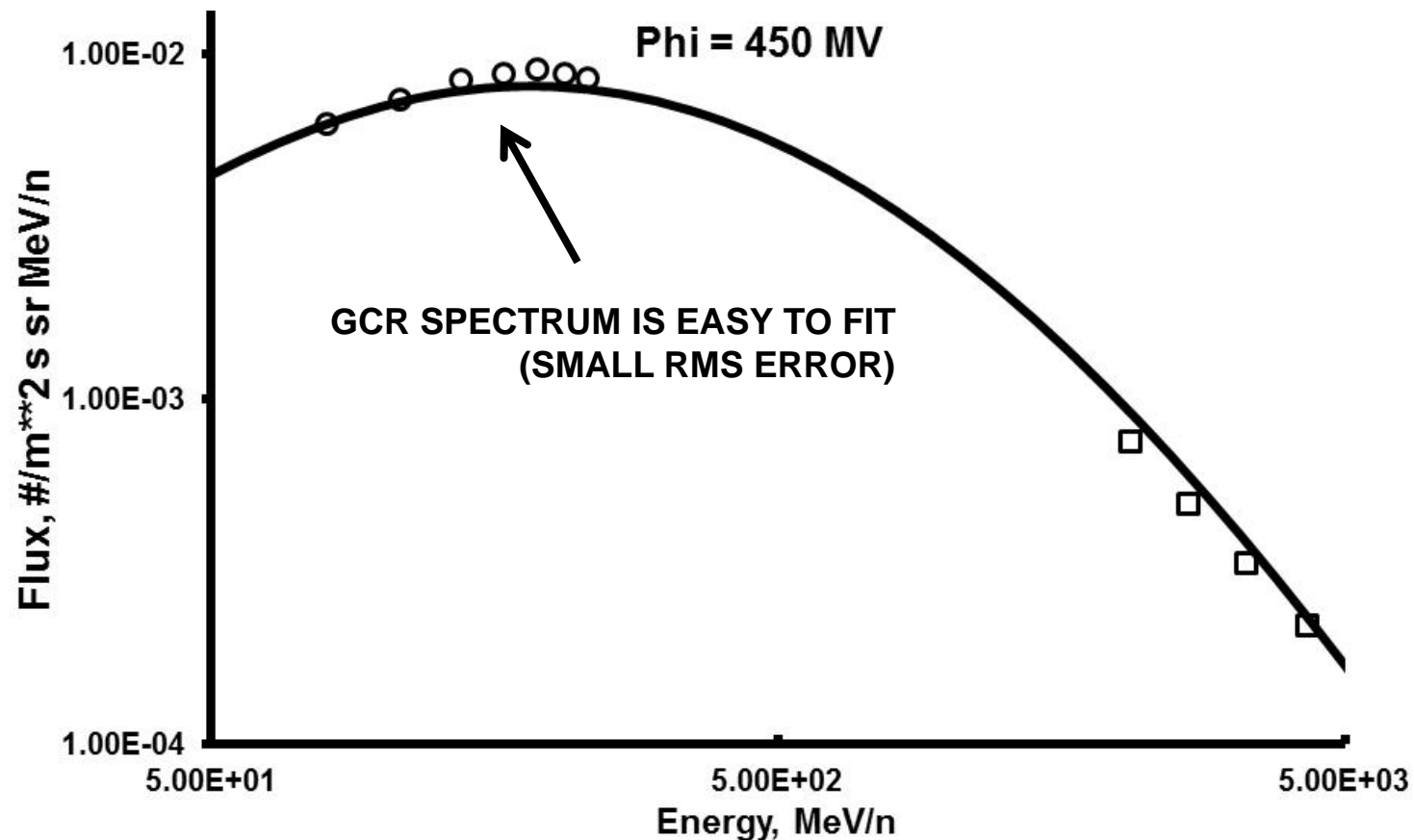
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LOW ENERGY - Solar Modulation (PHI)

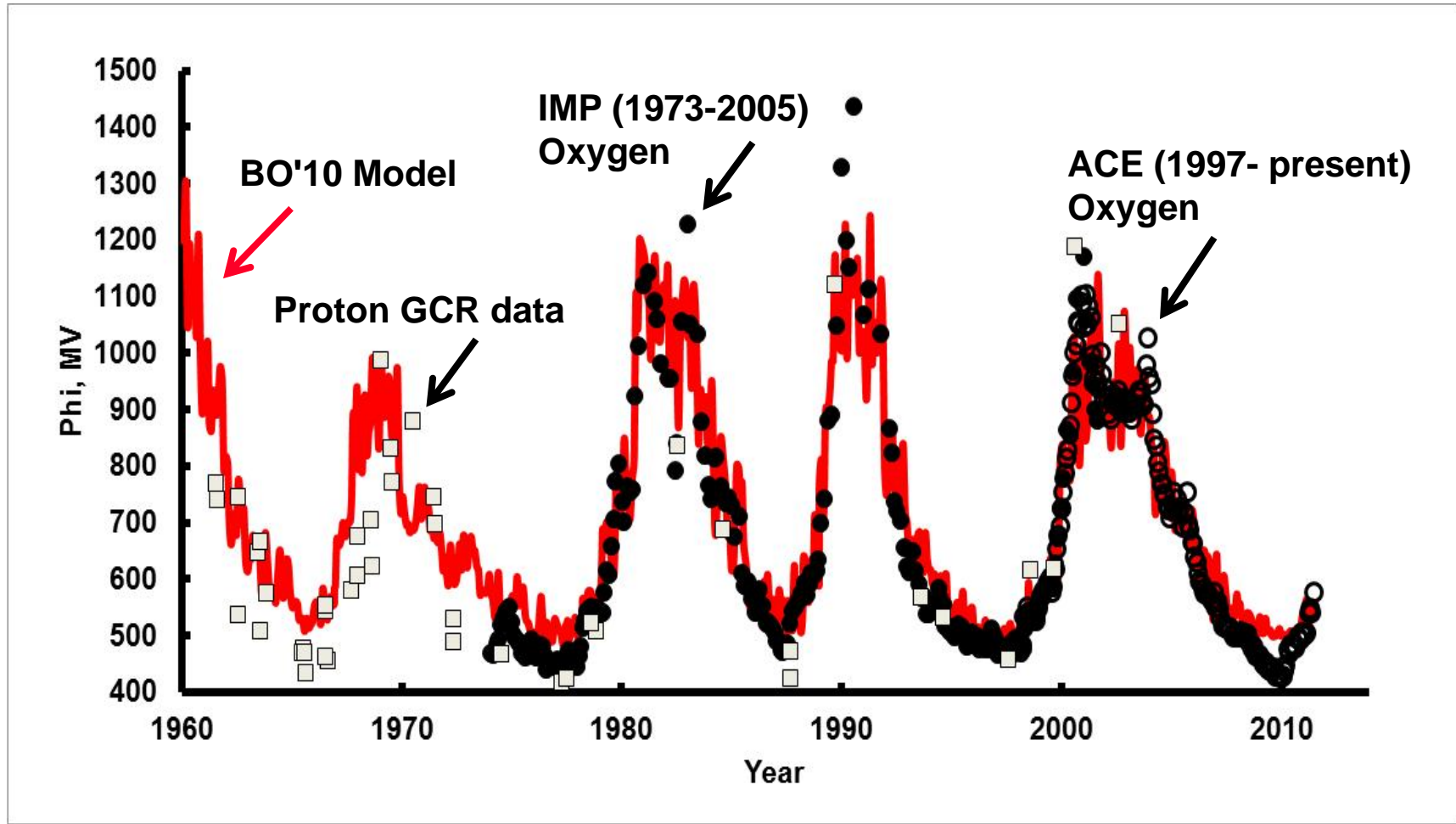
WHEN MODEL & DATA HAVE SAME SOLAR MODULATION (PHI): GOOD FIT (RMS ERROR~2%)





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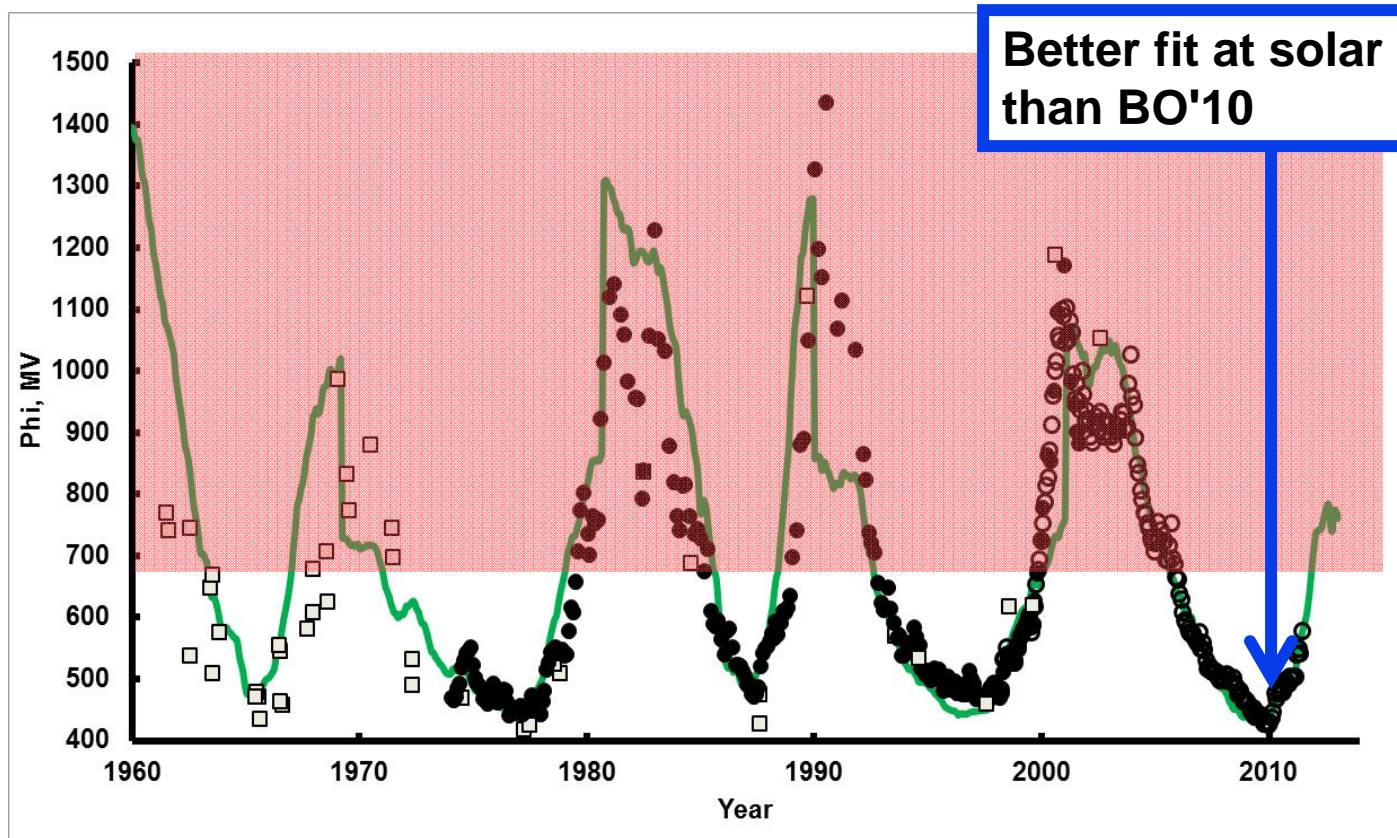
BO'10 PHI (MODEL) & PHI (DATA)





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BO'11 Emphasized Solar Minimum - but, way off around Solar Maximum





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BO'13 Corrects Fit at Max with better Min fit

