HelMod-4 for Predicting Galactic Cosmic Ray Intensities in the Space Radiation Environment

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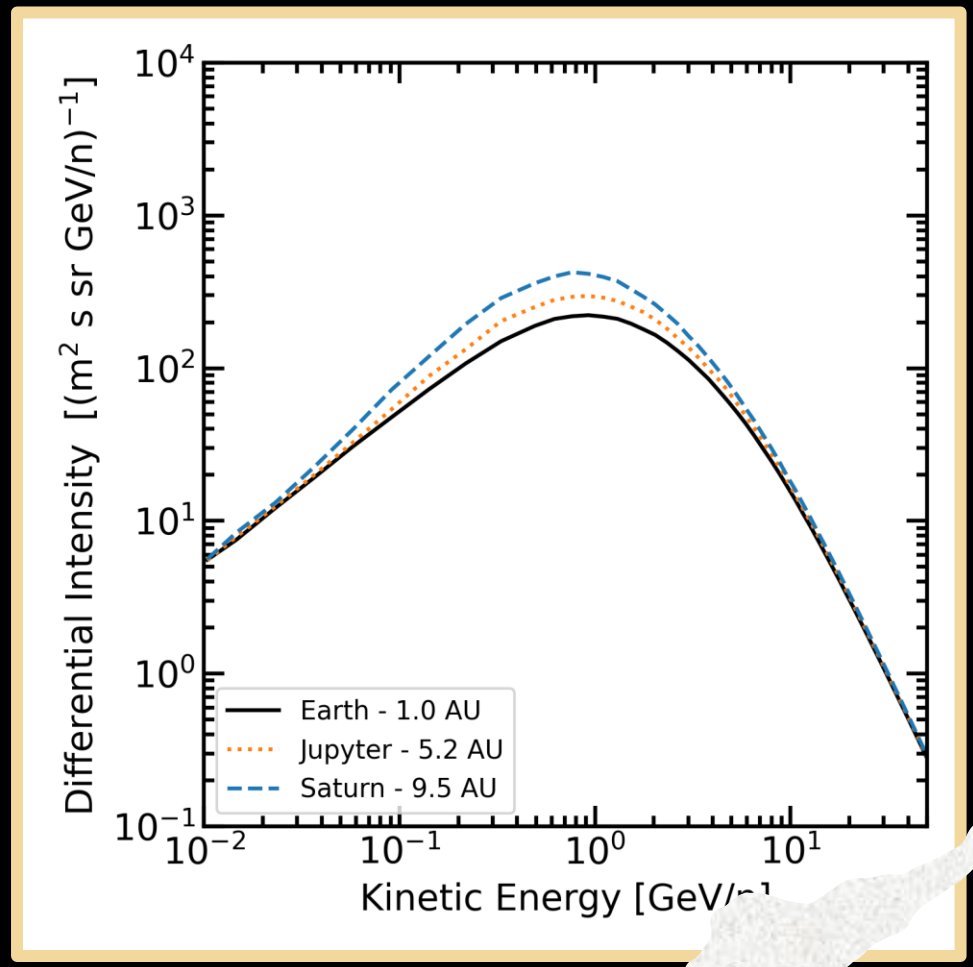
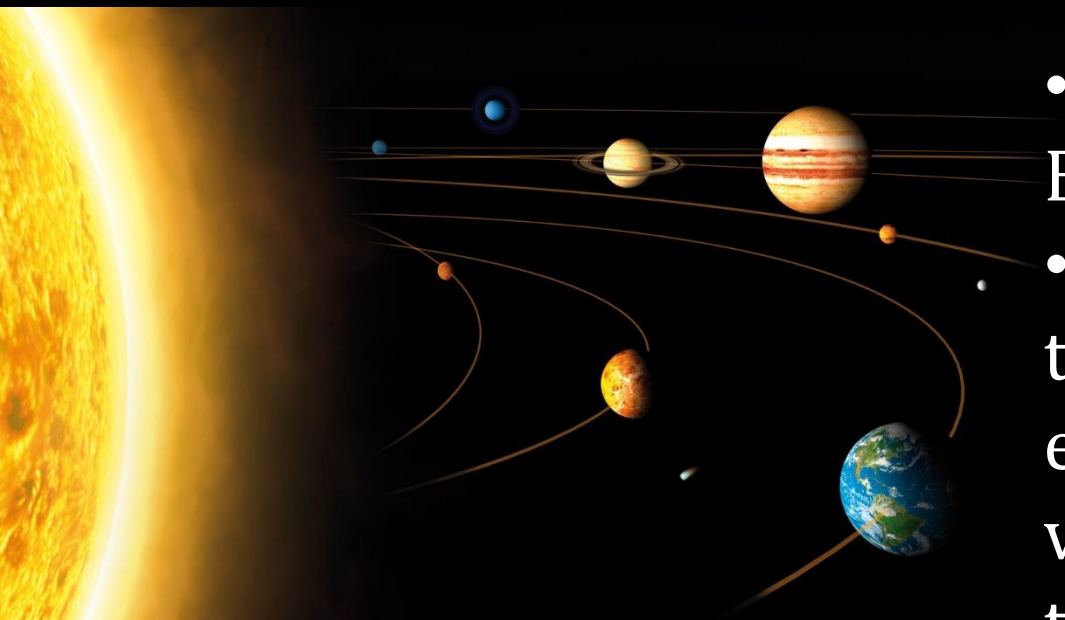


May 15-17,2023

SPACEMON23, ESA/ESTEC

High-energy ionized particles due to galactic cosmic rays (GCR) constitute a threat for interplanetary missions and exploration activities

The HelMod Monte Carlo Model



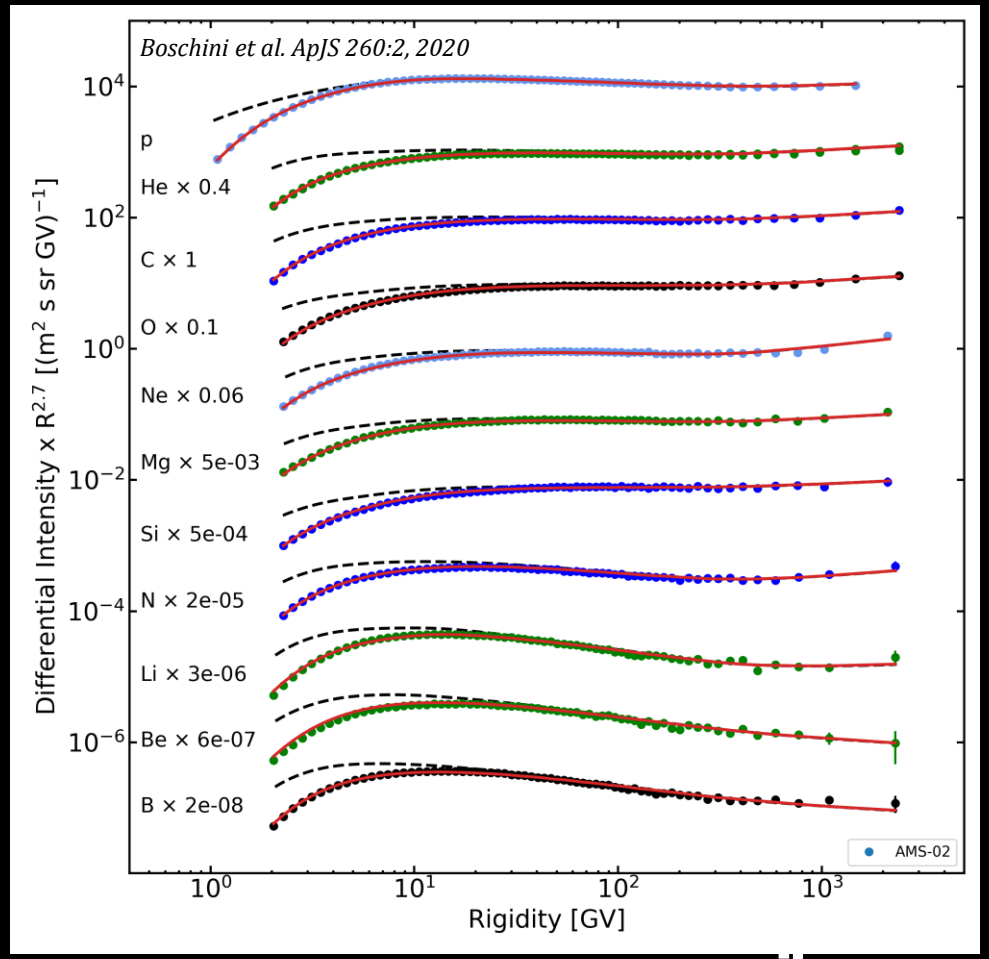
The HelMod Model use a MonteCarlo approach to evaluate the solar modulation through the Heliosphere.

- HelMod is based on the Parker Propagation Equation
- HelMod use a description of the Heliosphere that is continuously keep updated, including, e.g., the shape of outer heliosphere, and time variation of rigidity dependence of diffusion tensors, …

HelMod: The Cosmic ray model for space radiation environment

HelMod is a Monte Carlo Code that evaluate modulated spectrum in the heliosphere for:

- *Protons*
- *Helium Nuclei*
- *Ions (Carbon, Oxygen,...,Nickel)*
- *Antiprotons*
- *Electrons*



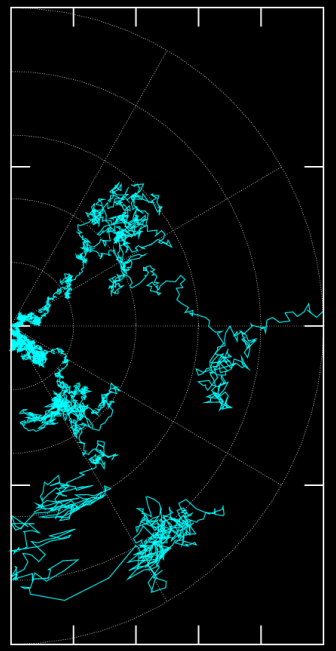
Boschini et al. ApJ 840:115, 2017
Boschini et al. ApJ 854:94, 2018
Boschini et al. ApJ 858:61, 2018
Boschini et al. ApJ 889:167, 2020
Boschini et al. ApJ 913:5, 2021
Boschini et al. ApJ 925:108, 2022

The GalProp-HelMod join effort:

The Local Interstellar Spectrum (LIS) were estimated using an iterative procedure involving GALPROP, HelMod and latest GCR observations.

A summary for Ions with Z<=28
Boschini et al. ApJS 260:2, 2020

HelMod: The Cosmic ray model for space radiation environment

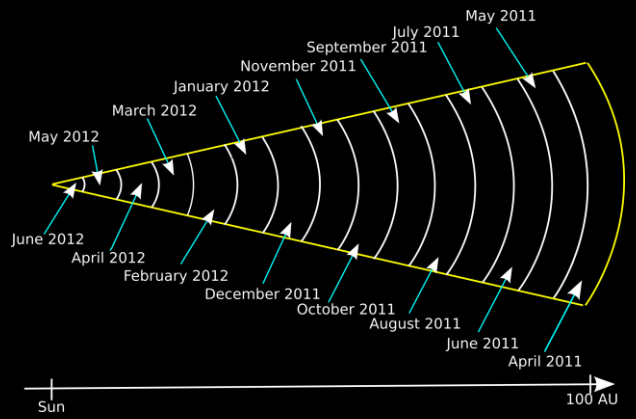


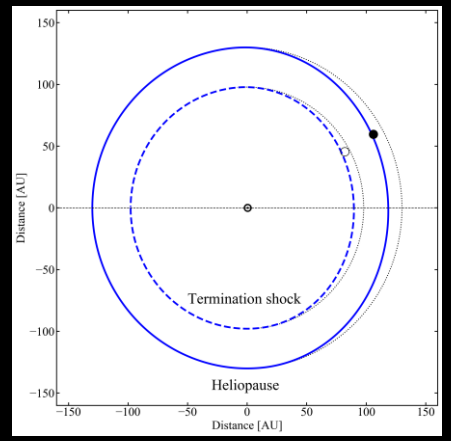
HelMod numerically solves the Cosmic Rays Propagation Equations With a Backward-in-time Monte Carlo Approach

The model describes the interplanetary medium following the solar disturbances propagation time from the Sun.

Model is tuned along a complete 22years solar cycle using CR Proton data with the highest statistics and lowest systematics.

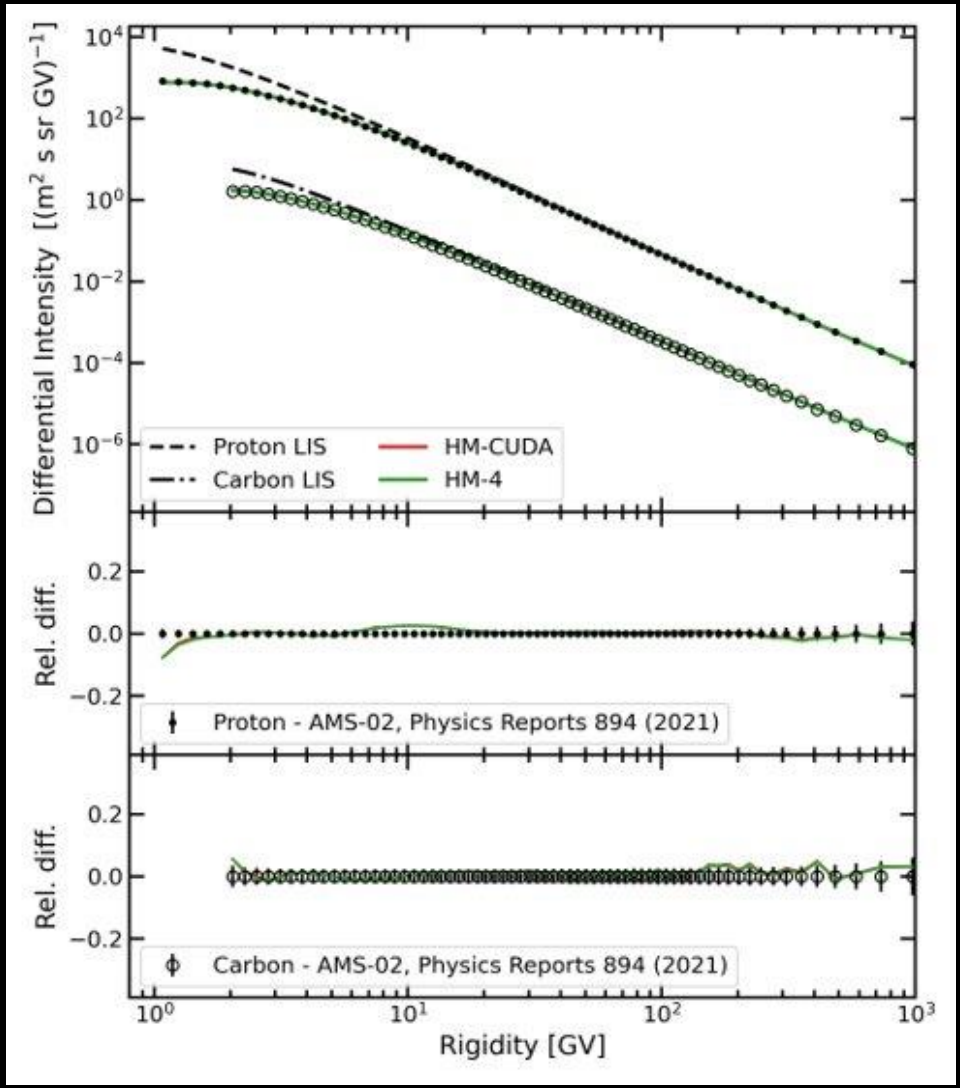
The same parametrization is then applied to all nuclei



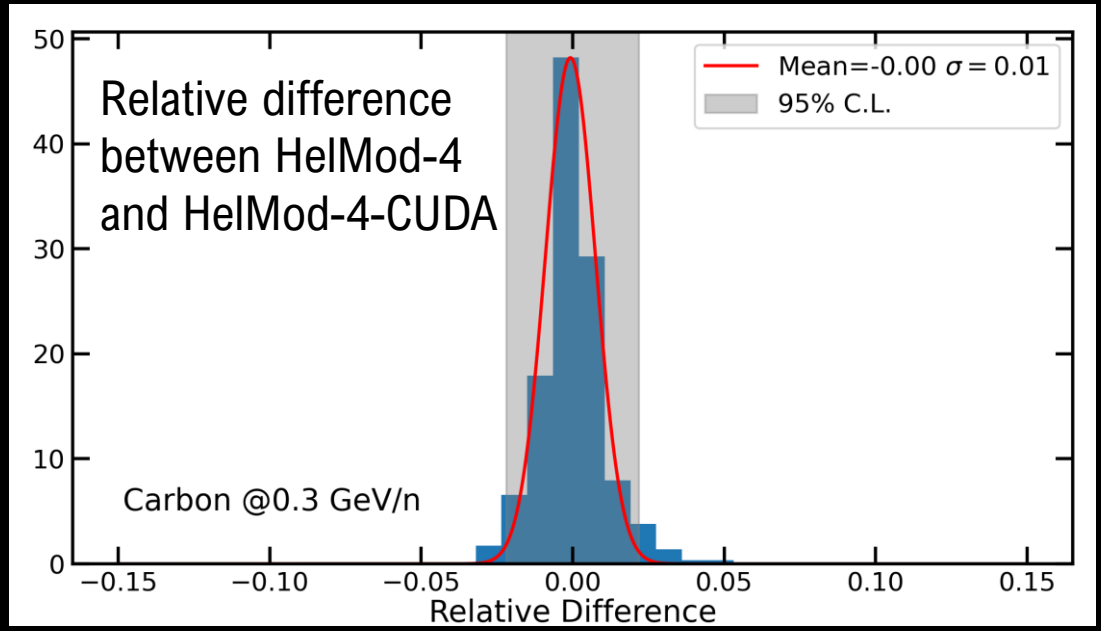


HELMOD-4-CUDA

The MonteCarlo Algorithm was re-designed to run on GPU-accellerated architecture



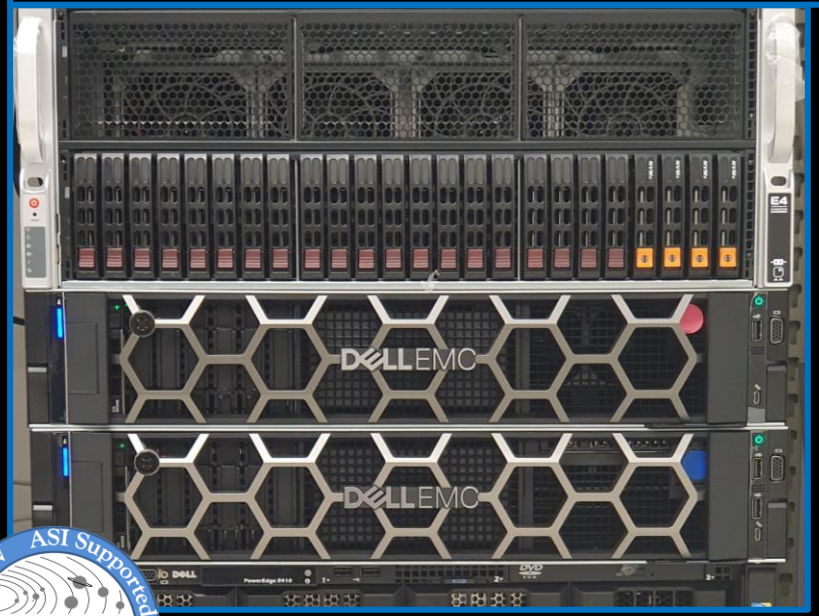
This allow to set-up an algorithm ~40x faster than previous code at same accuracy level.

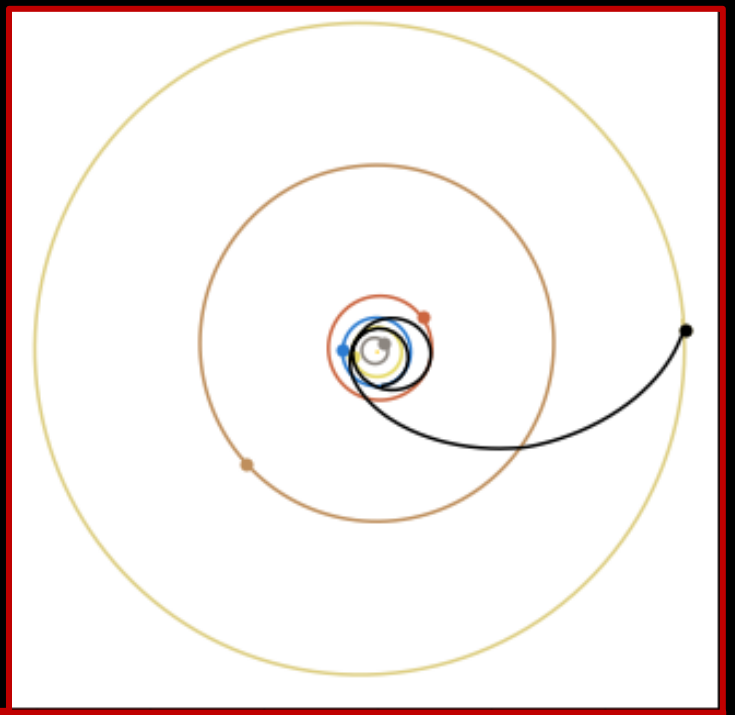


HELMOD-4-CUDA

The MonteCarlo Algorithm was re-designed to run on GPU-accellerated architecture

A dedicated datacenter with 9 NVIDIA-GPUs was deployed at University of Milano-Bicocca, additional GPU-cards will be available during this year

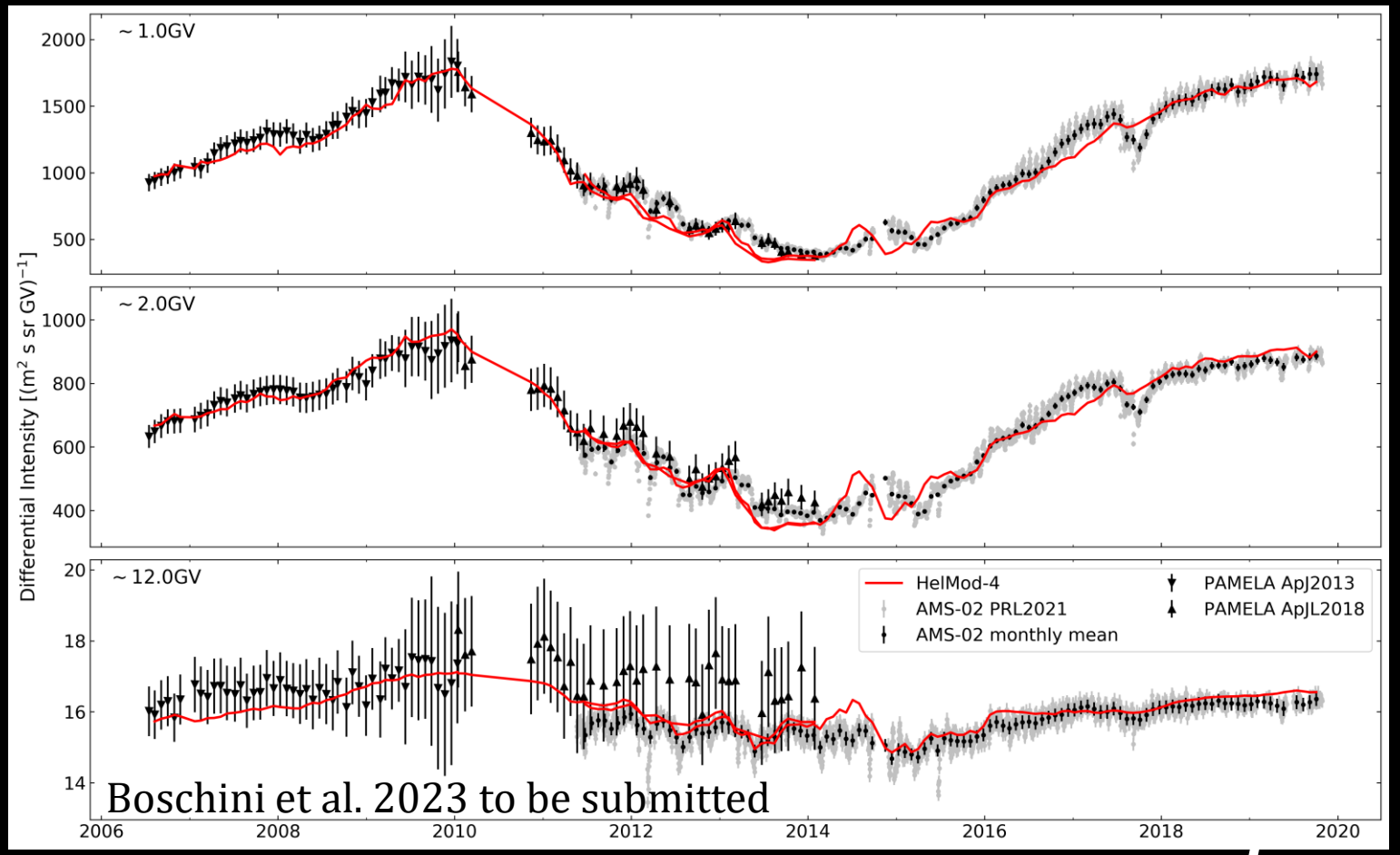




The emproved algorithm was designed to simulate the average radiation environment along an orbit within the same simulation realization.

Continously updated with state-of-art measurements

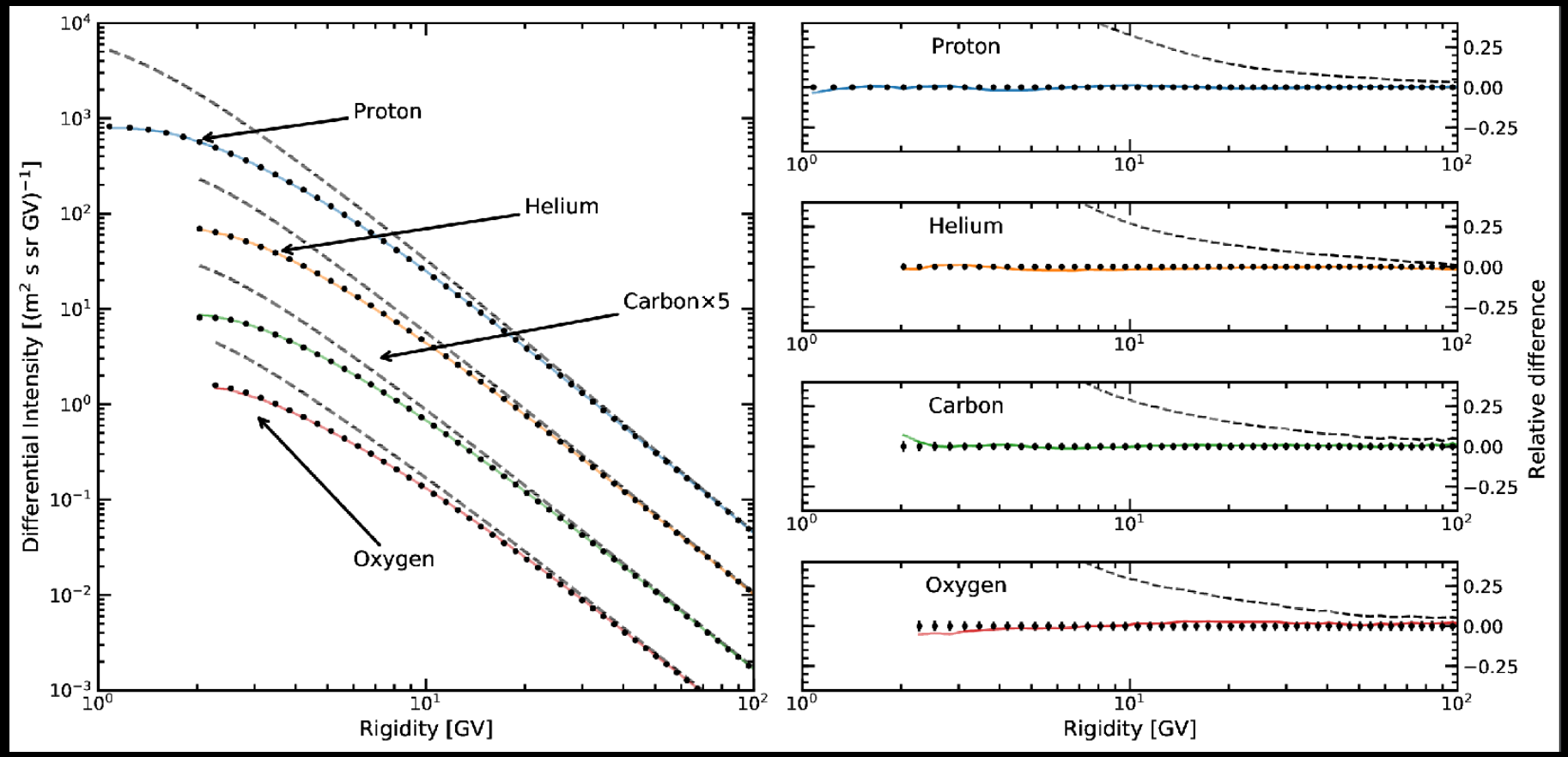
HelMod-4 parameters are continuously keep updated and HelMod-4 results are compared with data from state-of-art space detector (i.e. AMS-02)



Continously updated with state-of-art measurements

HelMod-4 parameters are continuously keep updated and HelMod-4 results are compared with data from state-of-art space detector (i.e. AMS-02)

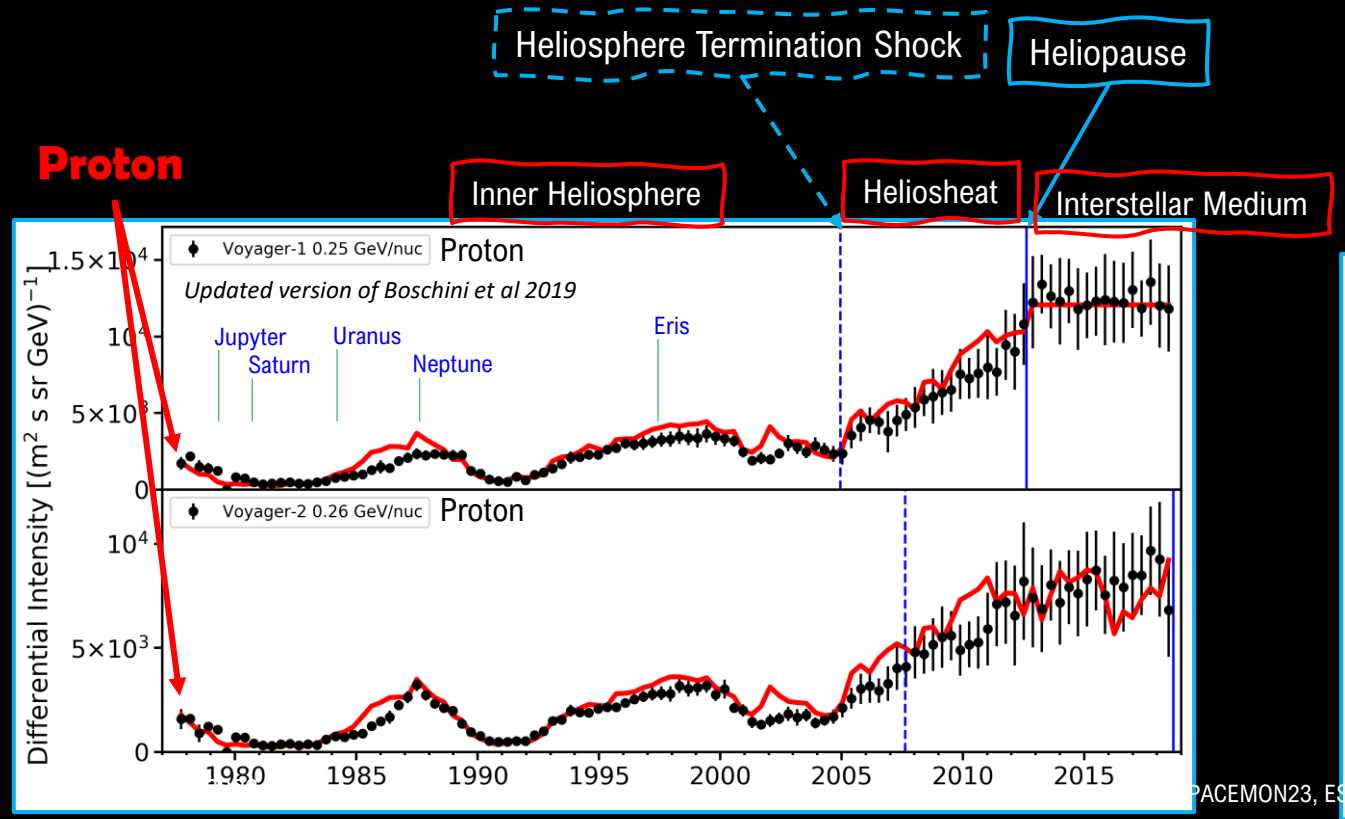
The fine tuning of the model allows to keep the general accuracy at same level of experimental uncertanties

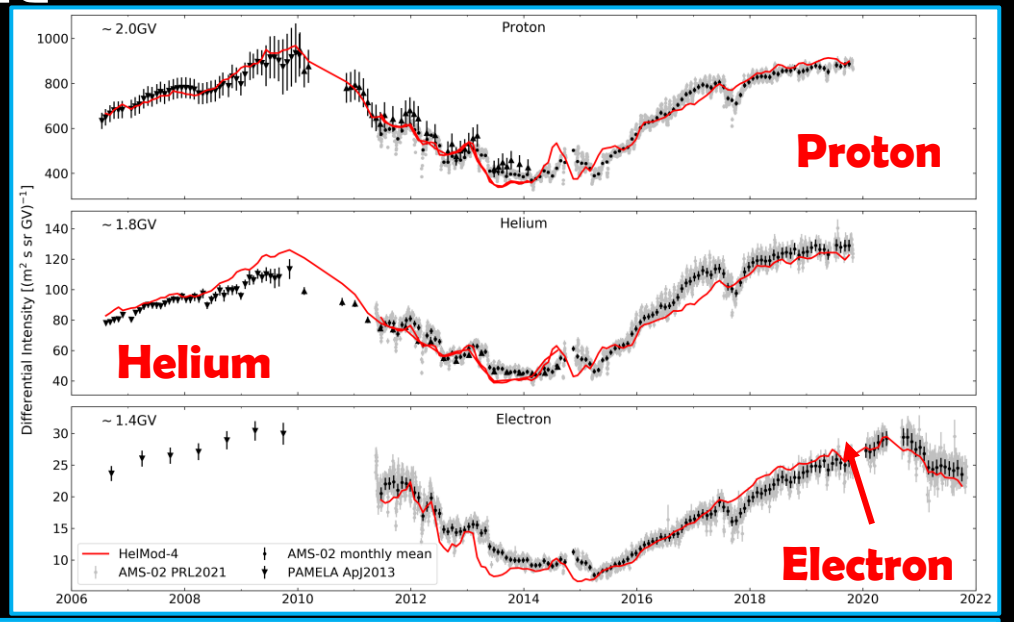


HelMod: The Cosmic ray model for space radiation environment

HelMod can reproduce ions:

- along the full 22 years solar cycle
- At several solar distance
- Outside the ecliptic plane





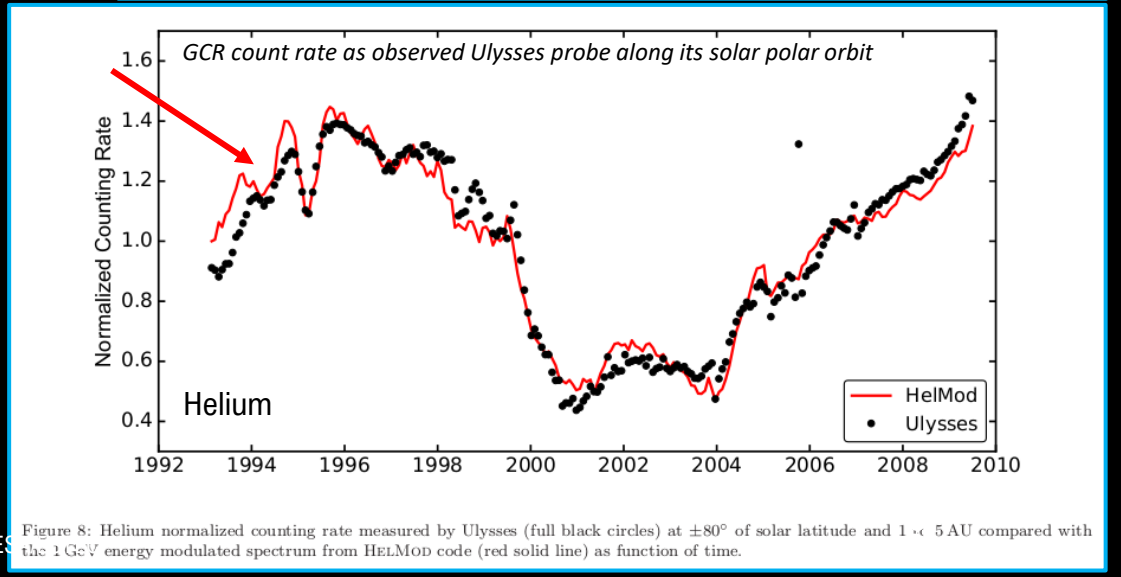
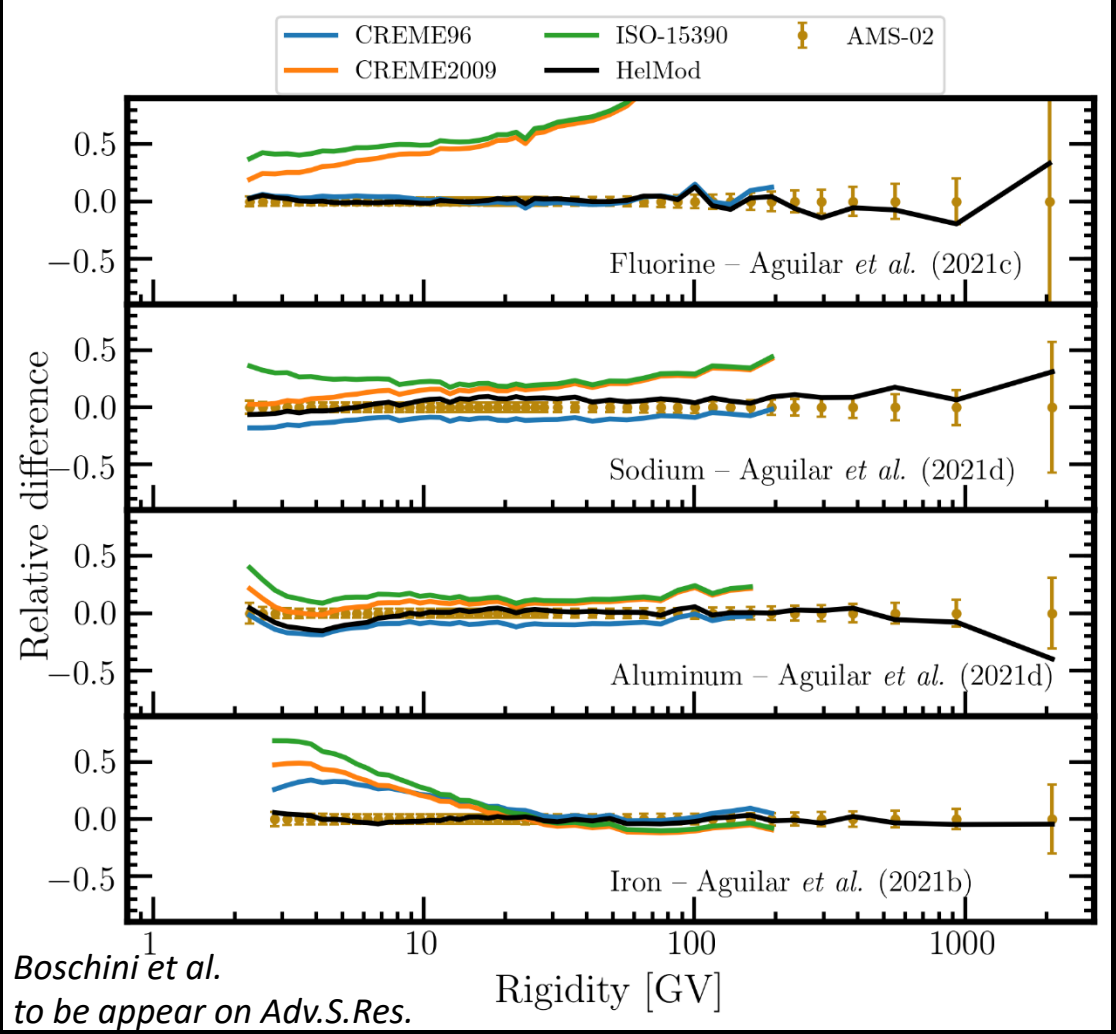


Figure 8: Helium normalized counting rate measured by Ulysses (full black circles) at ±80° of solar latitude and 1 ÷ 5 AU compared with the 1 GeV energy modulated spectrum from HELMOD code (red solid line) as function of time.

Comparison with other models



Boschini et al.
to be appear on Adv.S.Res.

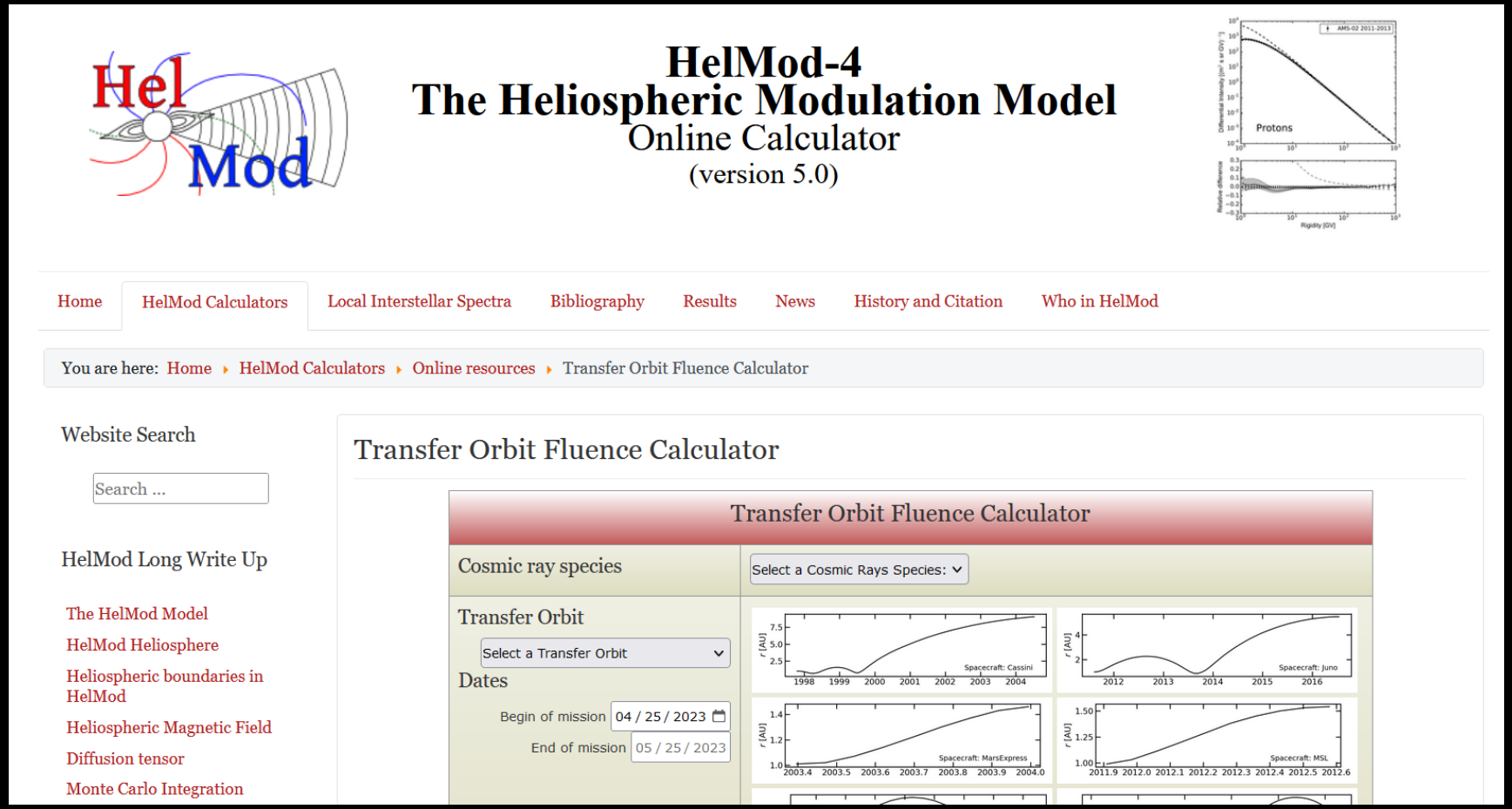
HelMod was found to achieve a good agreement over the full set of experimental data with, typically, $\Delta\Phi$ **within ±2.5% and RMS within 5%.**
Usually larger or, in a few cases, much larger values for $\Delta\Phi$ and ηRMS were found for the other models.

HelMod looks to exhibit an overall better agreement with AMS–02 data concerning the other solar modulation models here discussed

www.helmod.org

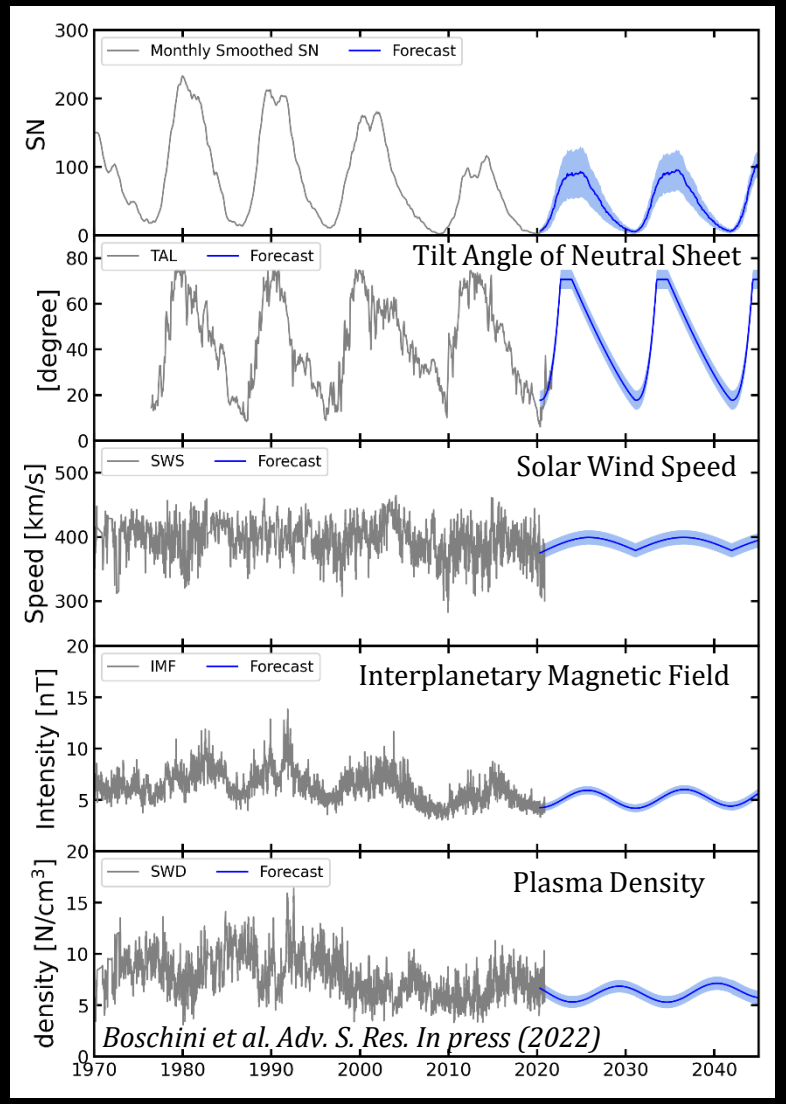
HelMod-4 is available as web service

- Flux Calculator at Earth Orbit
- Transfer Orbit Fluence Calculator



The available spectra covers a time range from ‘80s to 2040s

Forecast



The modulated GCR intensity is directly predicted employing the heliospheric parameters such as sunspot numbers, solar wind speed & density,…

The historical value of previous cycle allow to make a prediction for future cycles

The procedure is used to forecast:

- Sunspot numbers
- Tilt Angle of Neutral Sheet
- IMF
- Solar Wind Speed
- Plasma Density

The procedure can optimize the forecast up to 3-5 years using the measured parameters of last 3 years

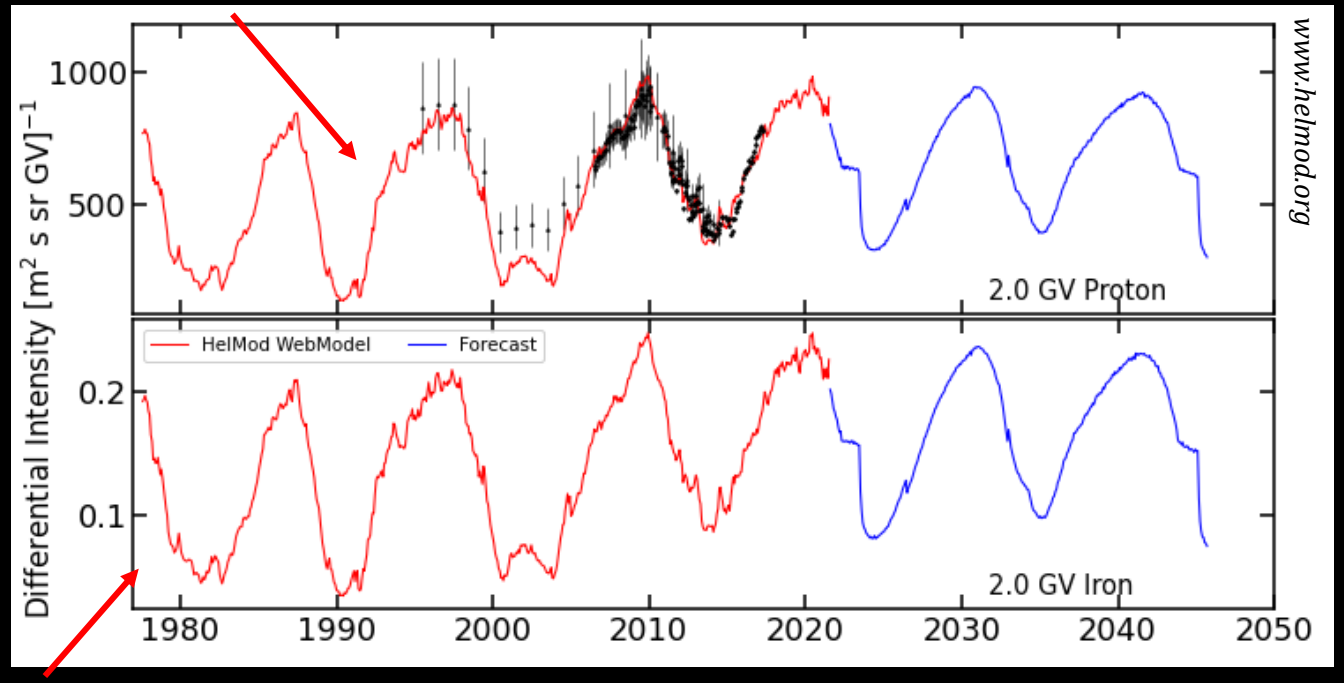
Forecast

The accuracy is estimated applying the procedure in past years in order to compare them with the HelMod simulations reproducing missions' data. In these case any discrepancies between the two are due to the forecasting method itself.

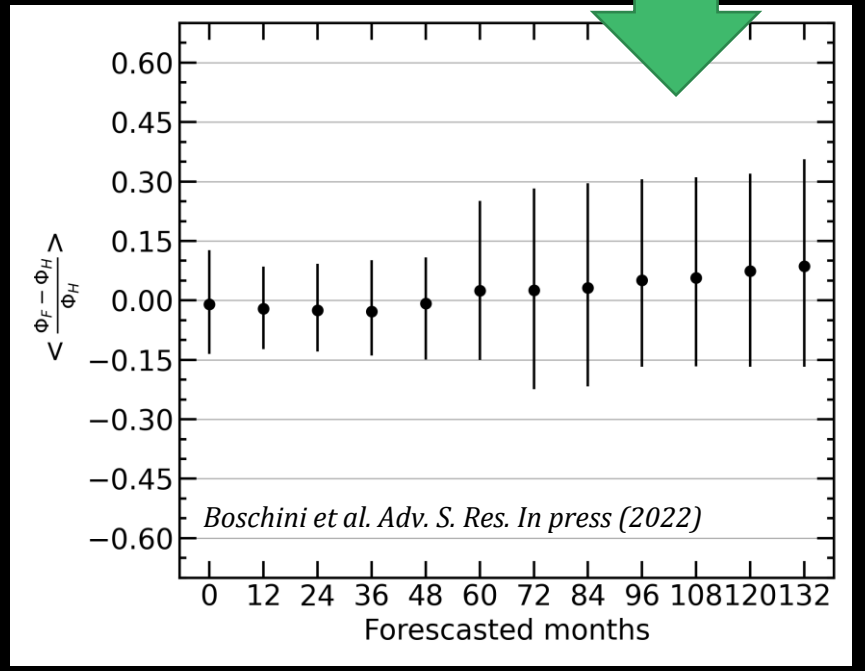
The forecasting procedure can reproduce HelMod fluences with an accuracy:

- **below 5% (±10% at 68% C.L.) for short time predictions (up to 4 years)**
- **below 15% (±(20–25)% at 68% C.L.) for long time predictions (up to 9 years).**

Proton



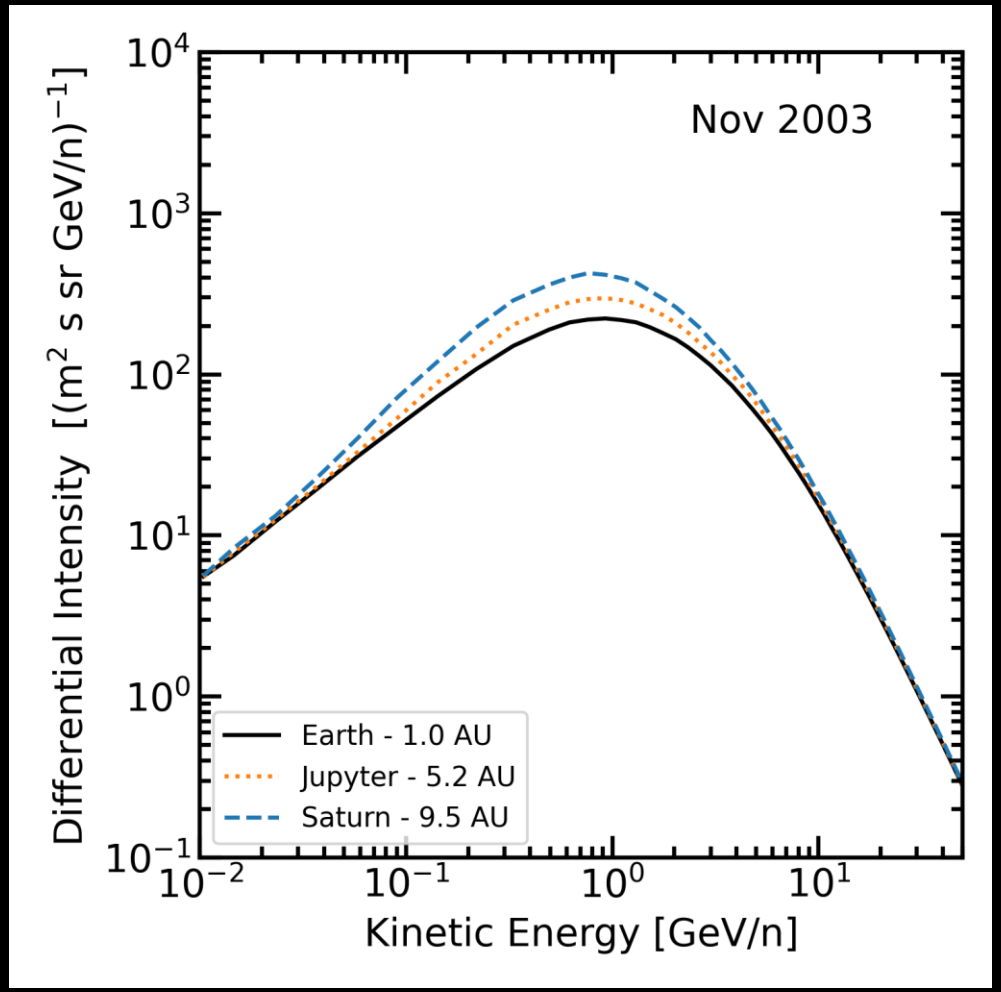
Iron Differential intensity at 2 GV (red is HelMod, Blue is forecasted HelMod)



Average Relative difference fluence evaluated with Helmod and with forecast procedure

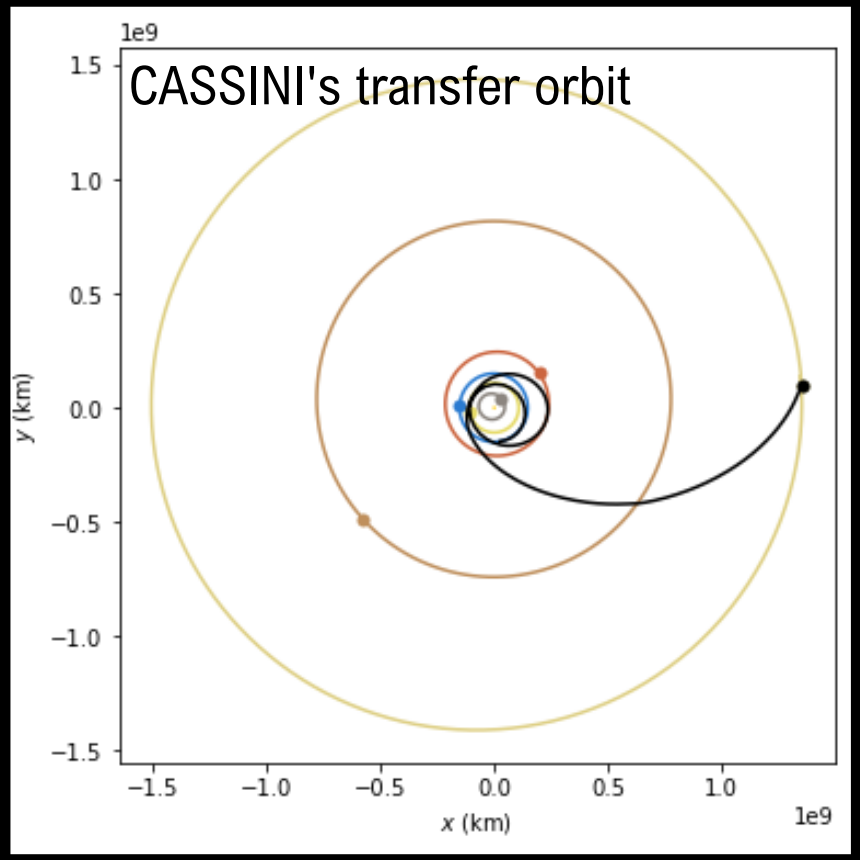
Transfer orbit fluence calculator

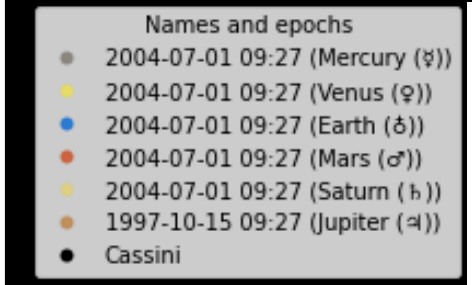
GCR spectra increase with increasing the solar distance.



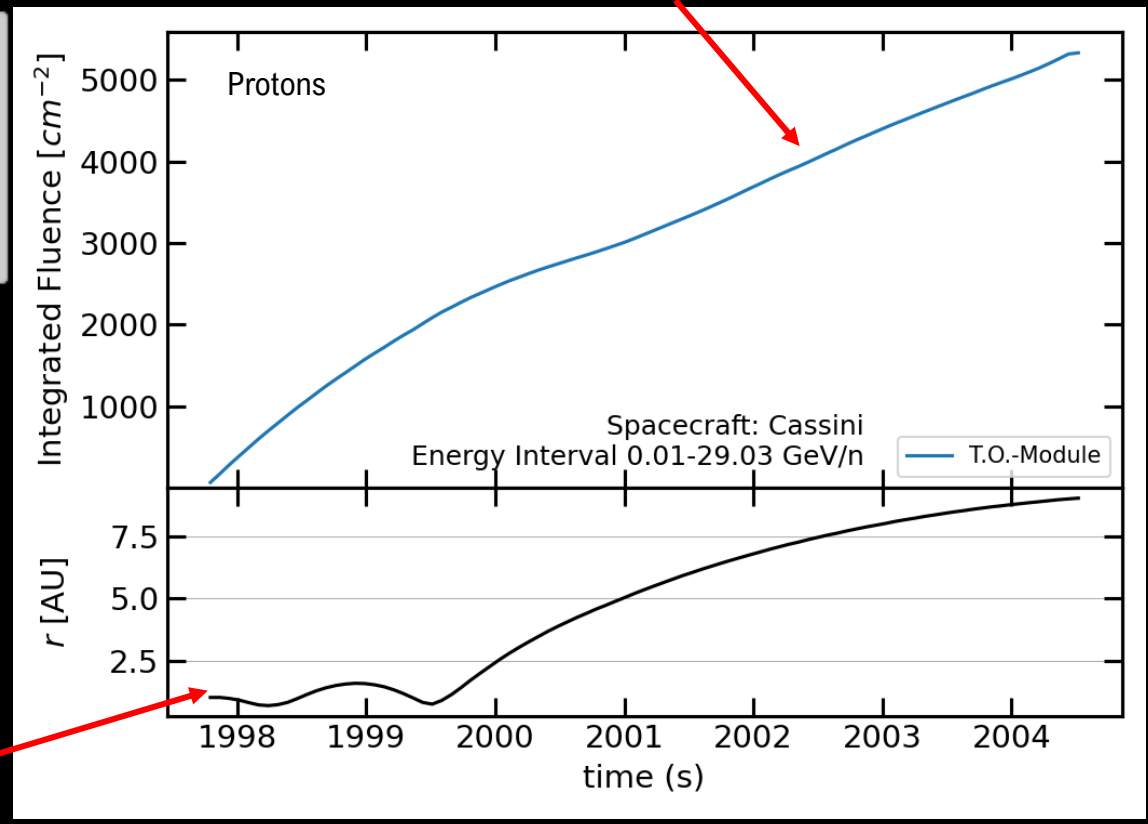
Transfer orbit fluence calculator

HelMod can evaluate the GCR fluence at any orbital position in the inner heliosphere





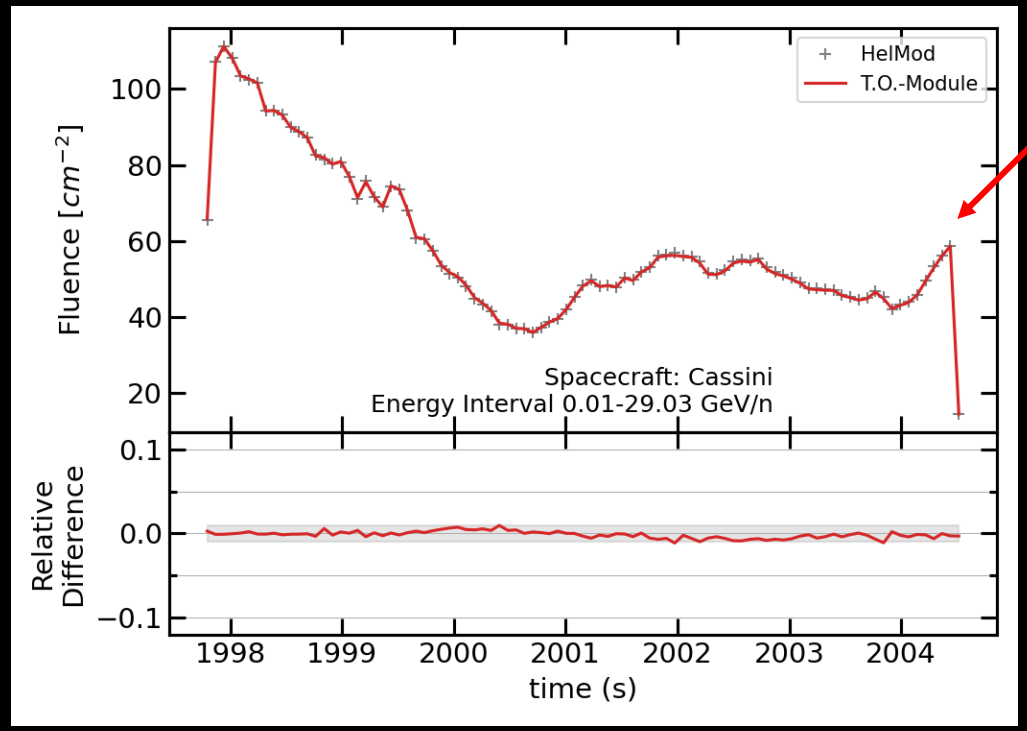
Proton



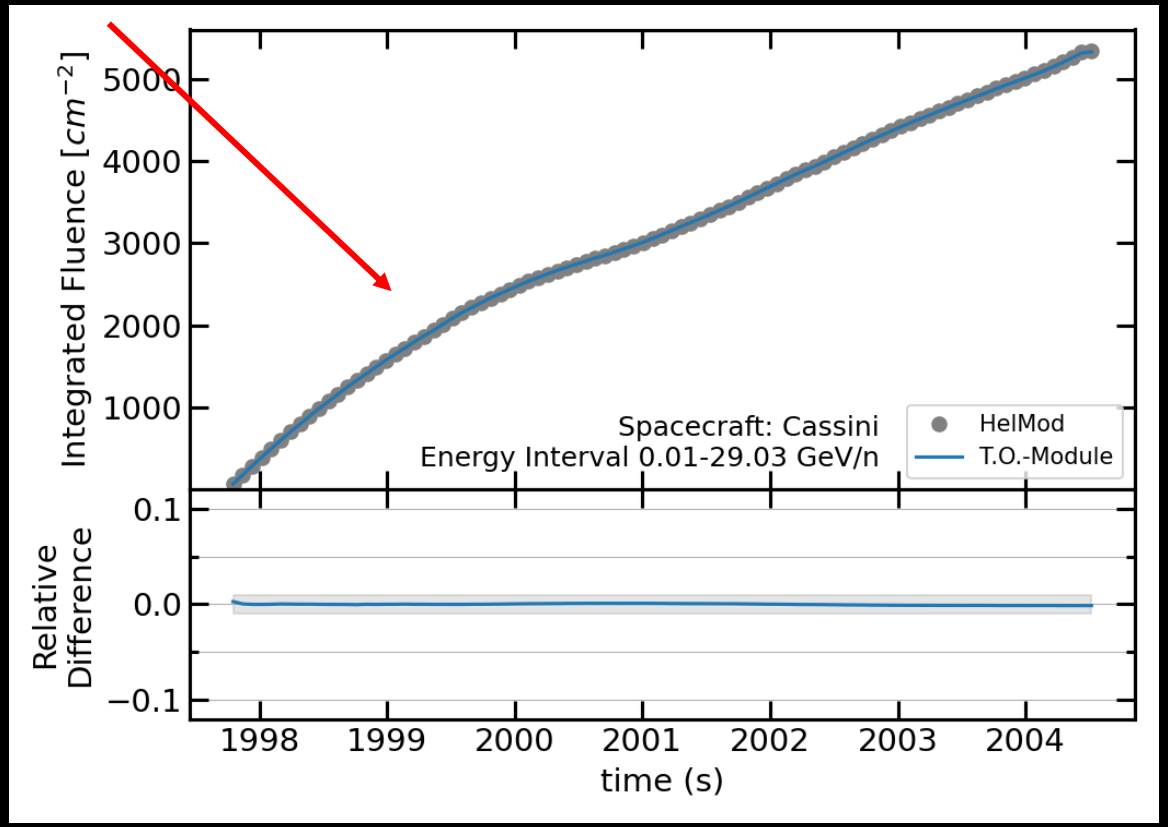
Radial distance of Transfer Orbit

Transfer orbit fluence calculator

A proper fast calculator will be available on HelMod.org to provide an immediate estimation of GCR fluence on transfer orbits provided by the user



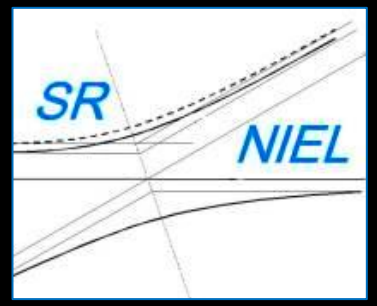
Proton



The accuracy of the calculator compared the full simulation is at few percent level

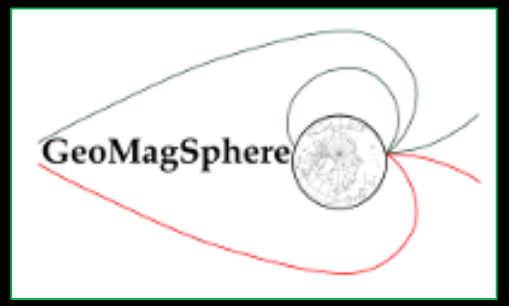
Within ASIF

it is available an integrated framework dedicated the space radiation environment



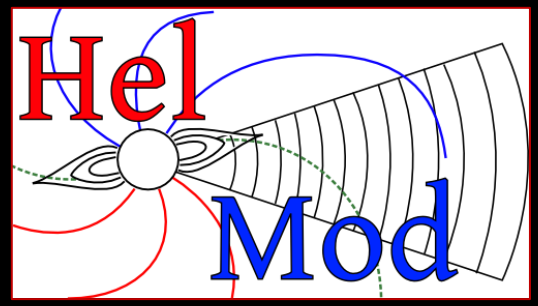
Nuclear and electronic stopping powers: TID and TNID doses, and SEE estimates

www.sr-niel.org



Geomagnetic processes and particle transport

www.geomagsphere.org



Galactic Cosmic Rays heliospheric transport

www.helmod.org

Key people involved in developing and operating the tools are:
P.G. Rancoita, M. Gervasi, M. Tacconi, S. Della Torre, D. Grandi, G. La Vacca, M.J. Boschini

All services are available as stand-alone with a dedicated website presenting how calculators works and examples, trough ASIF framework we will provide unique integrated interfaces to allow for simplified and intuitive calculators.

ASIF framework

The ASIF framework allows one

- to evaluate the contribution of galactic cosmic ions to space radiation environment.

- to assess qualifications of devices related to SEE, TID and TNID for space missions using test beams data.

The ASIF framework support the broader activities of ASIF project, that include the use of irradiation facilities for characterization and test activities through the ASIF gateway www.asif.asi.it and www.asifgateway.asi.it

The ASIF, ASIFgateway, Sr-niel, HelMod and Geomagphere websites are hosted in ASIF support Center located at the University of Milano-Bicocca, following the ASI-University implementation agreement for ASIF.

Thanks for your attention

Conclusions

For missions in space radiation environment, the long-term modulation is relevant for accounting some type of radiation effects (for instance SEE). Thus, a realistic model is required for planning missions

- We presented the HelMod Model for the propagation of Cosmic rays through the heliosphere.
- The model reproduce the overall time variation between Low and High activity periods as well the observed spatial variation.
- The averaged fluxes of AMS-02 Cosmic rays ions seem to be better reproduced by HelMod with respect to CREAM96, CREAM2009, ISO-15390 and ISO-DLR.
- The model is provided with a forecast tools that allow to predict the GCR fluence for future deep space missions
- HelMod is available on-line at *www.helmod.org and through the SR-NIEL framework (www.sr-niel.org)*
- In sr-niel HelMod spectral fluences can be combined with SEE cross-section to predict the expected number of SEE - due to GCRs - in future (deep) space missions
- At present a new feature is available for space missions, e.g., the transfer orbit fluence calculator