

Exploring Galactic Cosmic Ray Intensity: A HelMod Model Perspective

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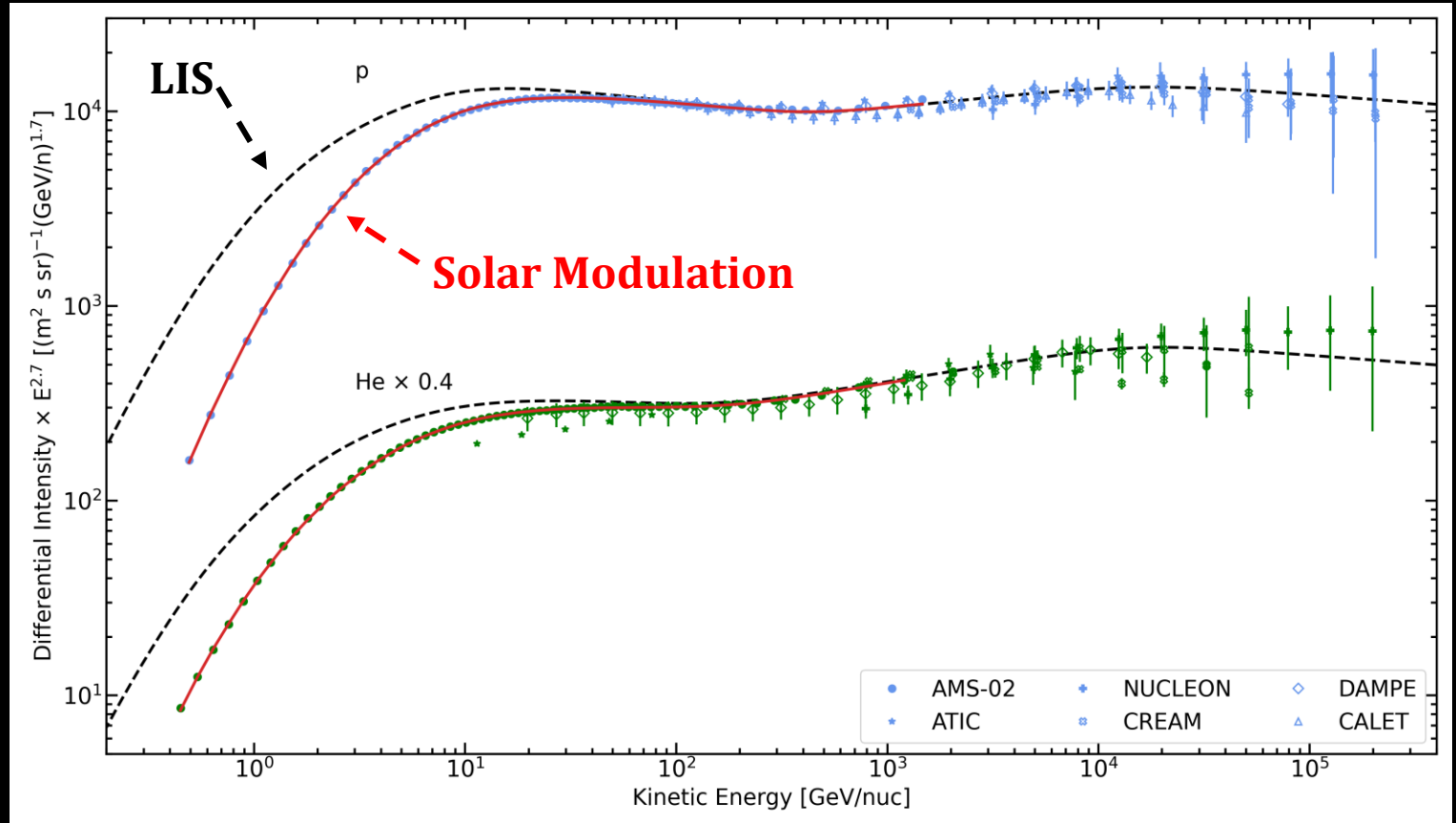
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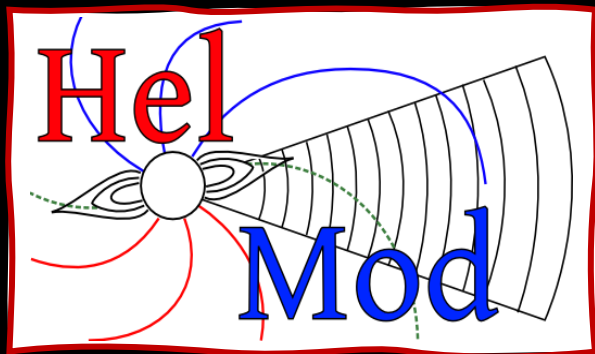
Solar Modulation

At low Energy,
**Galactic Cosmic Rays inside
the Heliosphere
are modulated** in intensity
related to **solar activity**.

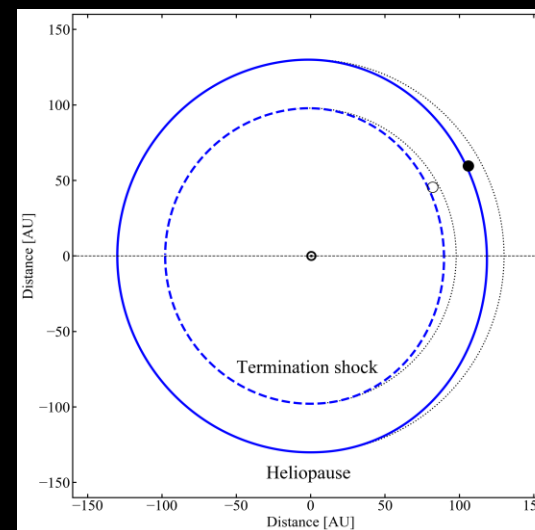
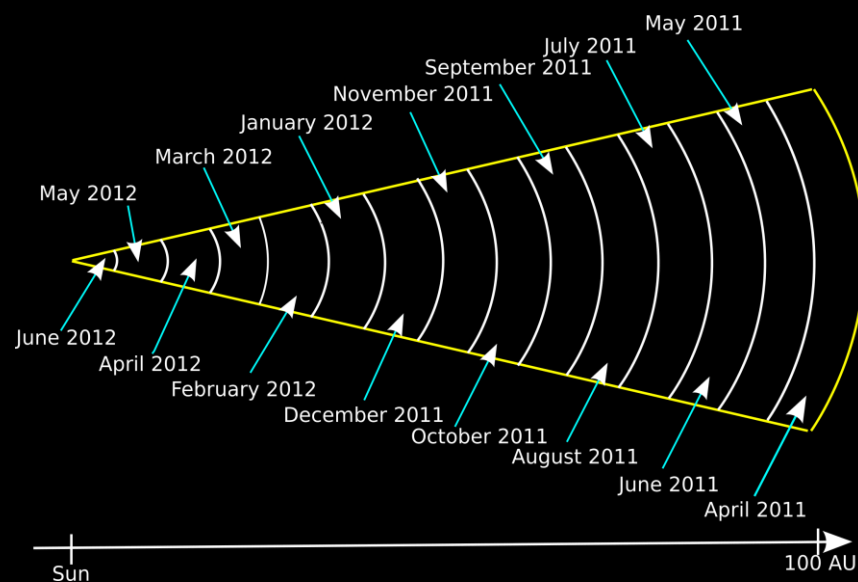
This process is well
described by the transport-
equation formulated by
Parker (1965)



The HelMod Perspective



The **HelMod Model** evaluate the solar modulation through the **heliosphere**. The Model is continuously updated, including, e.g., the shape of the outer heliosphere, and time variation of rigidity dependence of diffusion tensors...



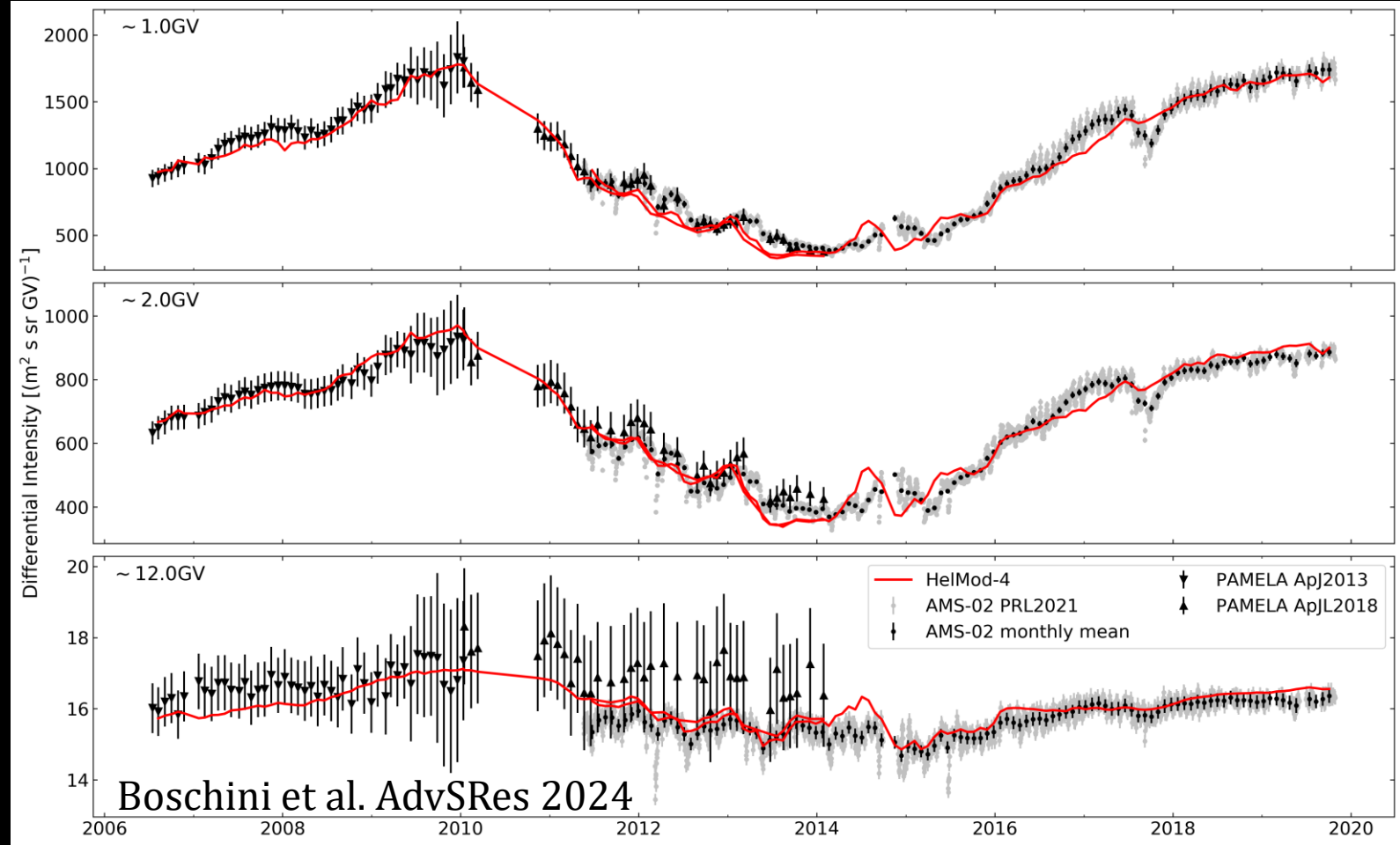
The model describes the interplanetary medium following the solar disturbances propagation time from the Sun.

The HelMod Perspective

Model parameters are tuned along a complete 22-year solar cycle using CR proton data with the highest statistics and lowest systematics.

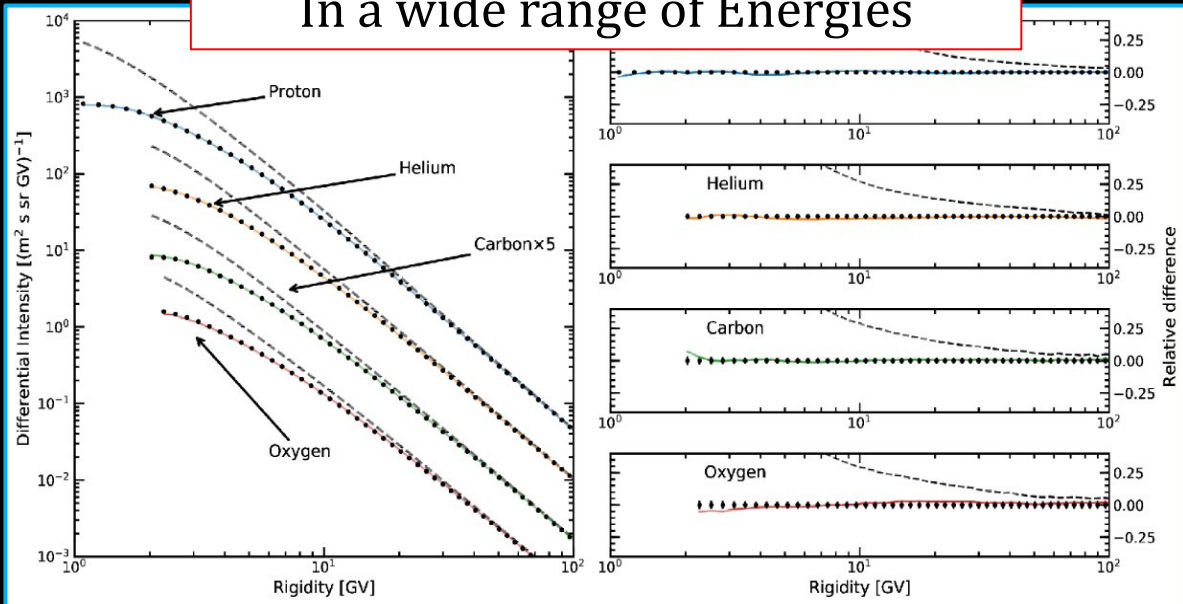
The same parametrization is then applied to all nuclei.

Latest updated, HelMod-4 (v5.1), was tuned including AMS-02 daily proton flux up to 2019

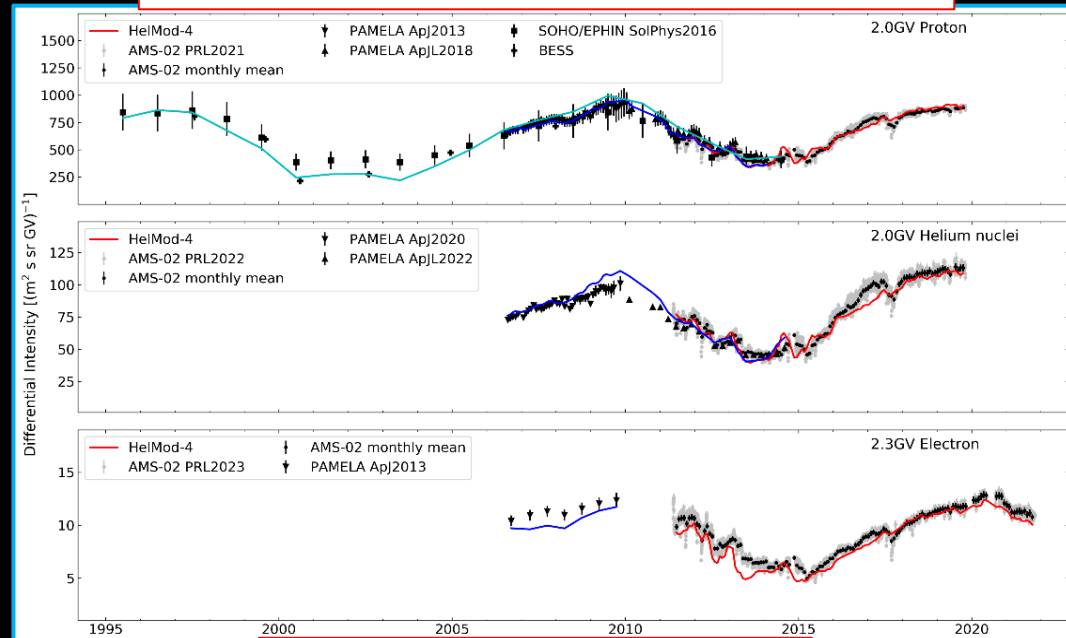


HelMod reproduces Ions:

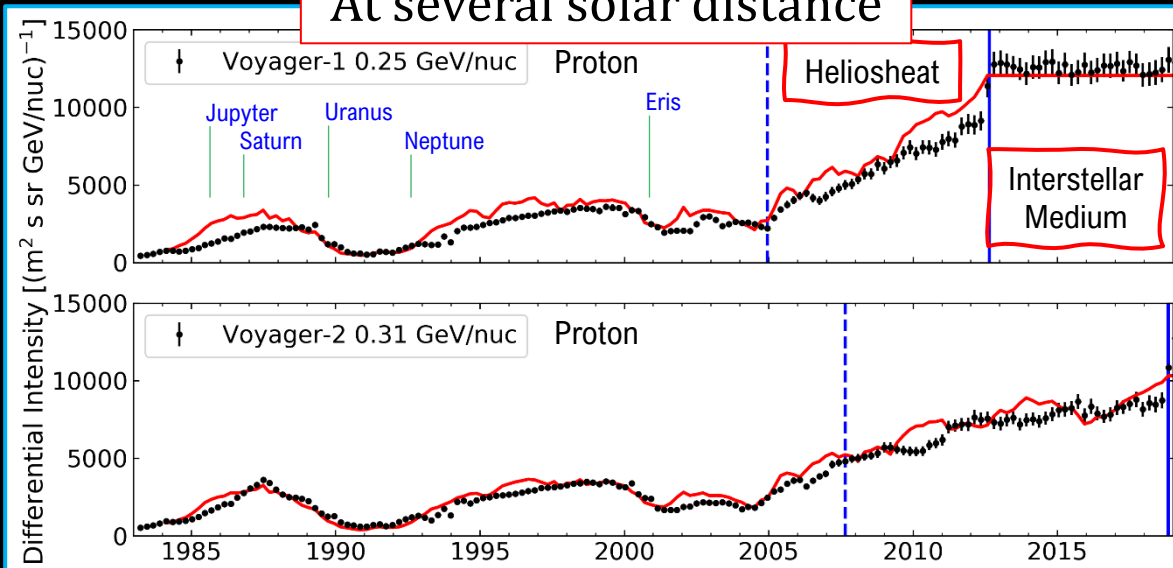
In a wide range of Energies



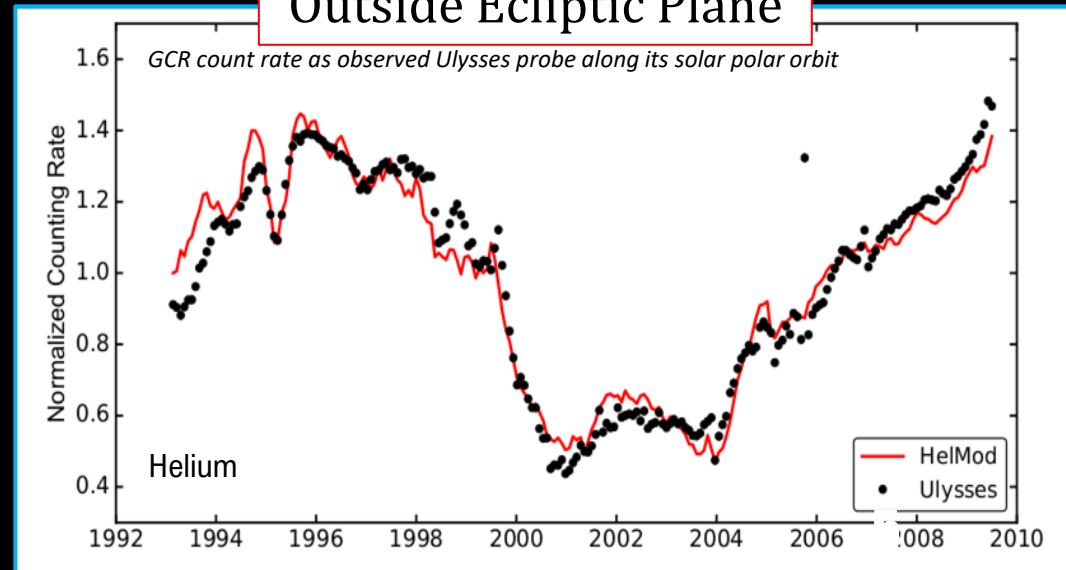
For different solar activities



At several solar distance



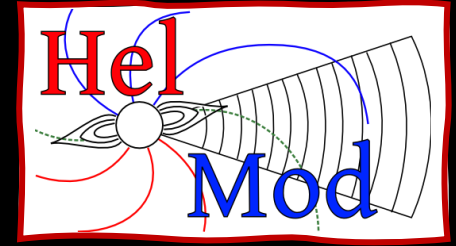
Outside Ecliptic Plane



GALPROP-HelMod joint effort

The local interstellar spectra (LIS) were estimated using an iterative procedure involving GALPROP, HelMod and latest GCR observations.

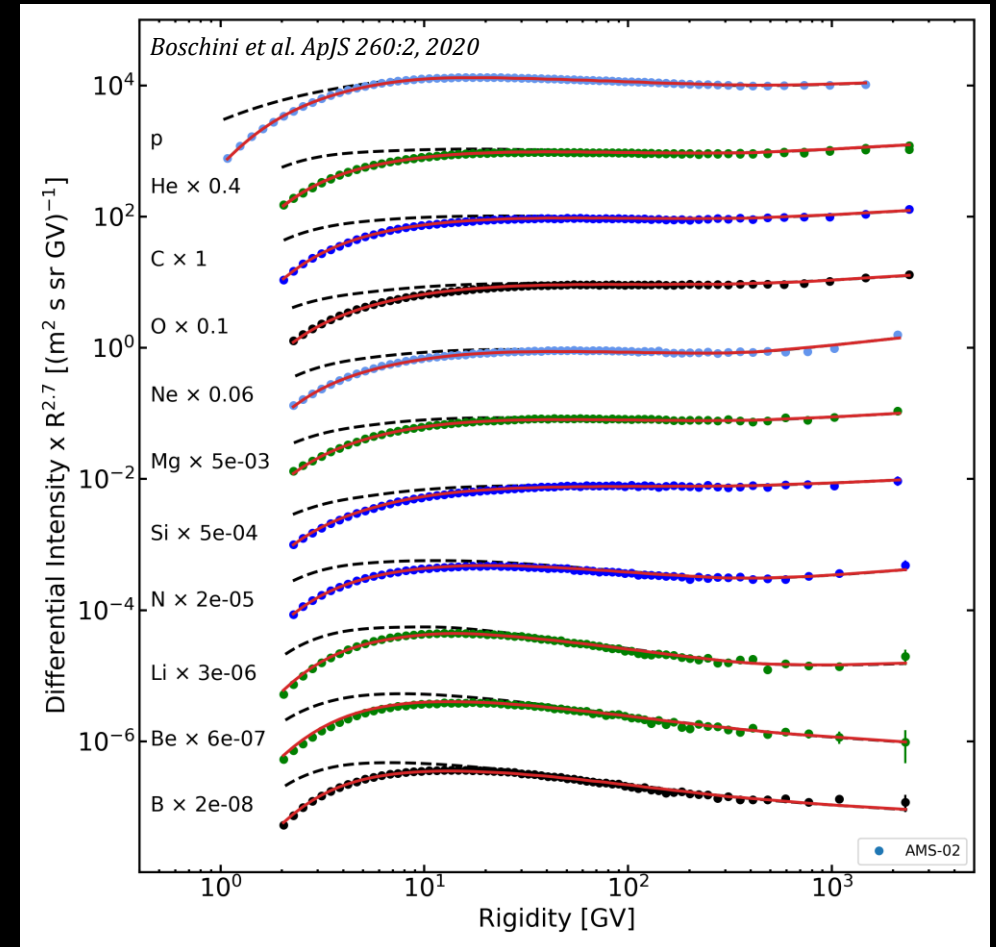
- *Protons*
- *Helium Nuclei*
- *Ions (Carbon, Oxygen,...,Nickel)*
- *Antiprotons*
- *Electrons*



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

Jul 13-21, 2024

A summary for Ions with $Z \leq 28$
Boschini et al. ApJS 260:2, 2020



GALPROP-HelMod Latest results

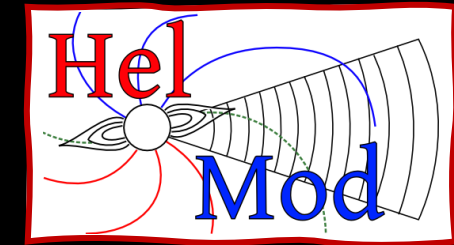
Spectra of He isotopes and the $3\text{He}/4\text{He}$ ratio

Boschini et al, submitted to ApJ



GALPROP v57.1

New improved parametrization for inelastic and production cross sections



HelMod-4 (v5.1)

Solar modulation fine tuning on latest AMS-02 time dependent measurements and Helium isotopes

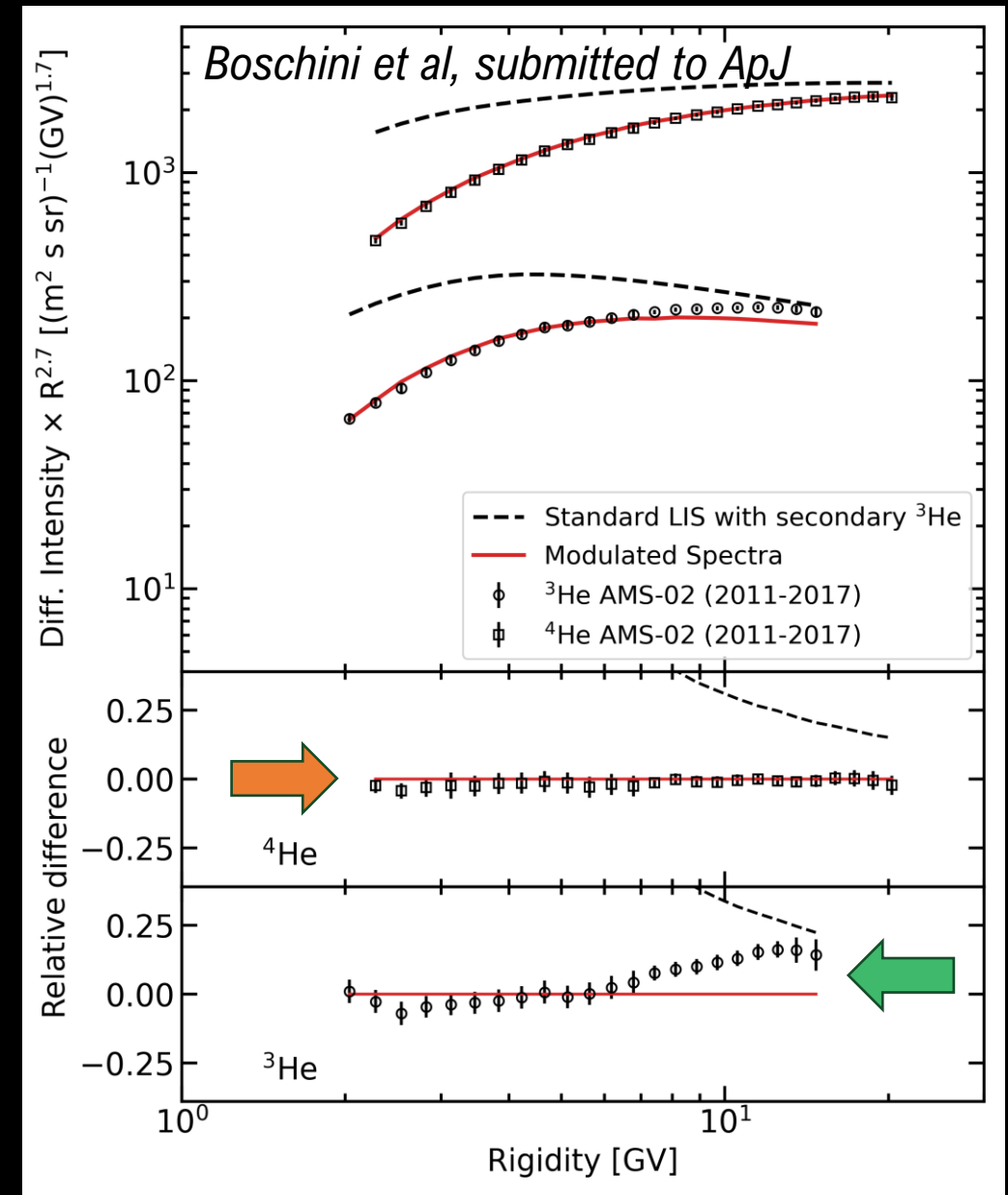
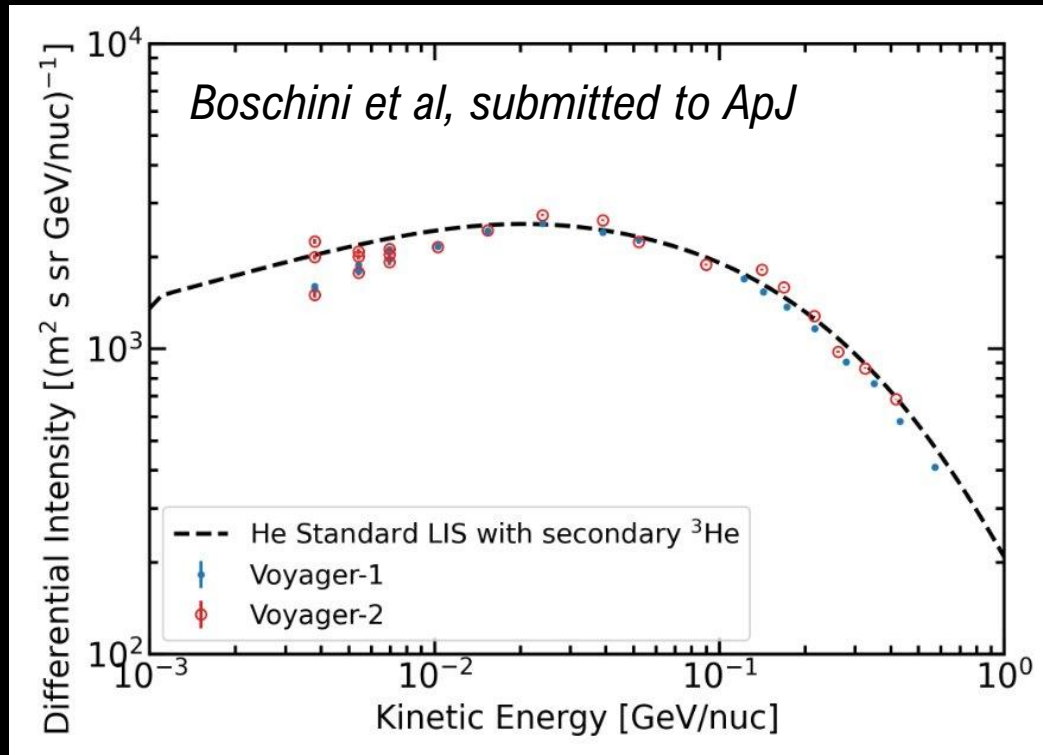
Parameter	Units	Standard	Model
z_h	kpc	4.0 ± 0.6	
$D_0(R = 4 \text{ GV})$	$10^{28} \text{ cm}^2 \text{ s}^{-1}$	4.3 ± 0.7	
δ	...	0.415 ± 0.025^a	
V_{Alf}	km s^{-1}	30 ± 3	
dV_{conv}/dz	$\text{km s}^{-1} \text{ kpc}^{-1}$	9.8 ± 0.8	
η	...	0.70	

We performed a MCMC scan over 5 main propagation parameters in GALPROP running in 2D mode.

the Galactic halo half-width z_h ,
the normalization of the diffusion coefficient D_0 at the reference rigidity $R = 4 \text{ GV}$
the index of its rigidity dependence δ ,
the Alfvén velocity V_{Alf} ,
the gradient of the convection velocity dV_{conv}/dz ($V_{\text{conv}} = 0$ in the plane, $z = 0$).

Total He and **He-4 spectra** are well reproduced.

He-3 spectrum exhibits a significant excess above 7 GV

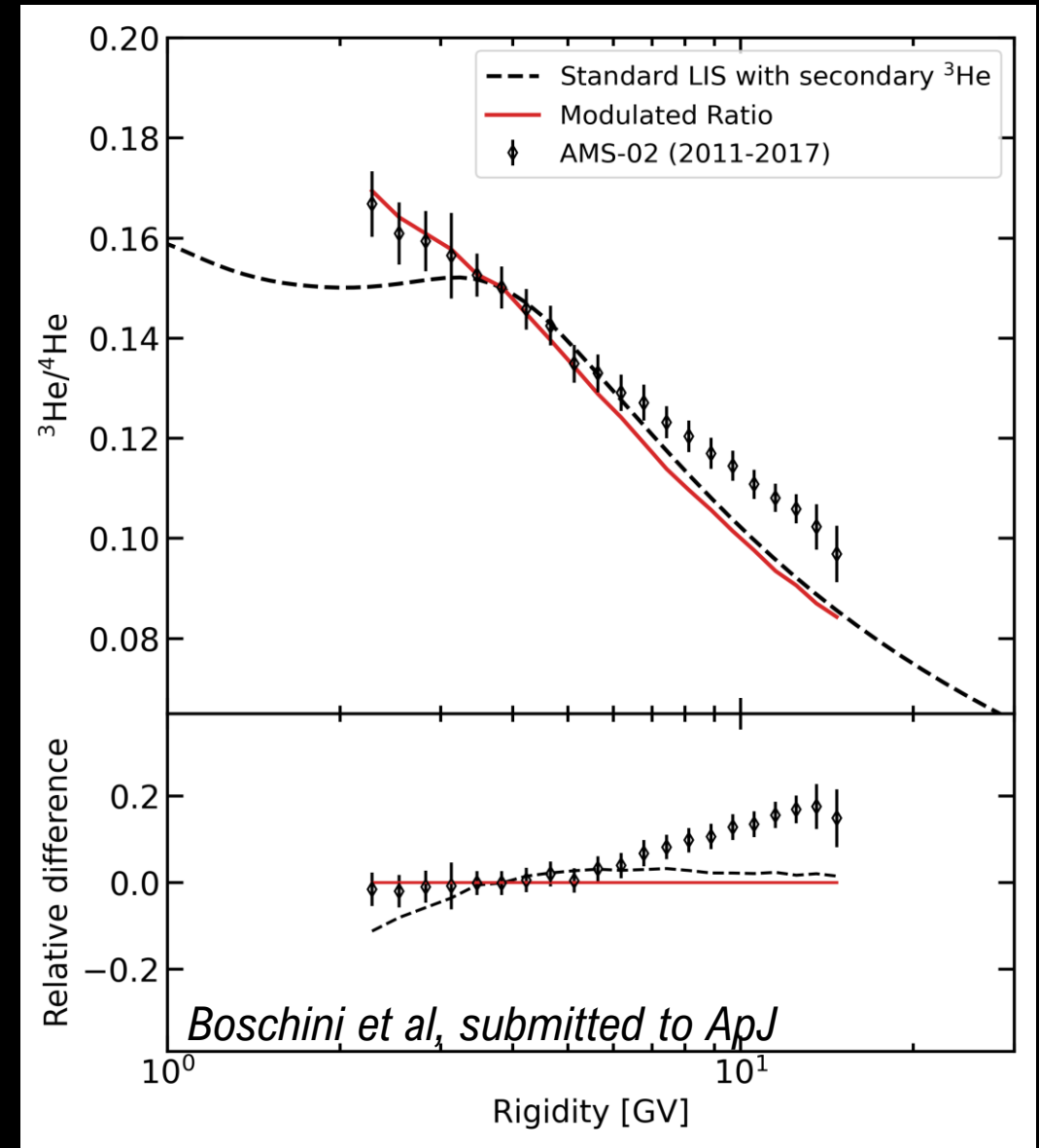


He spectra contains:

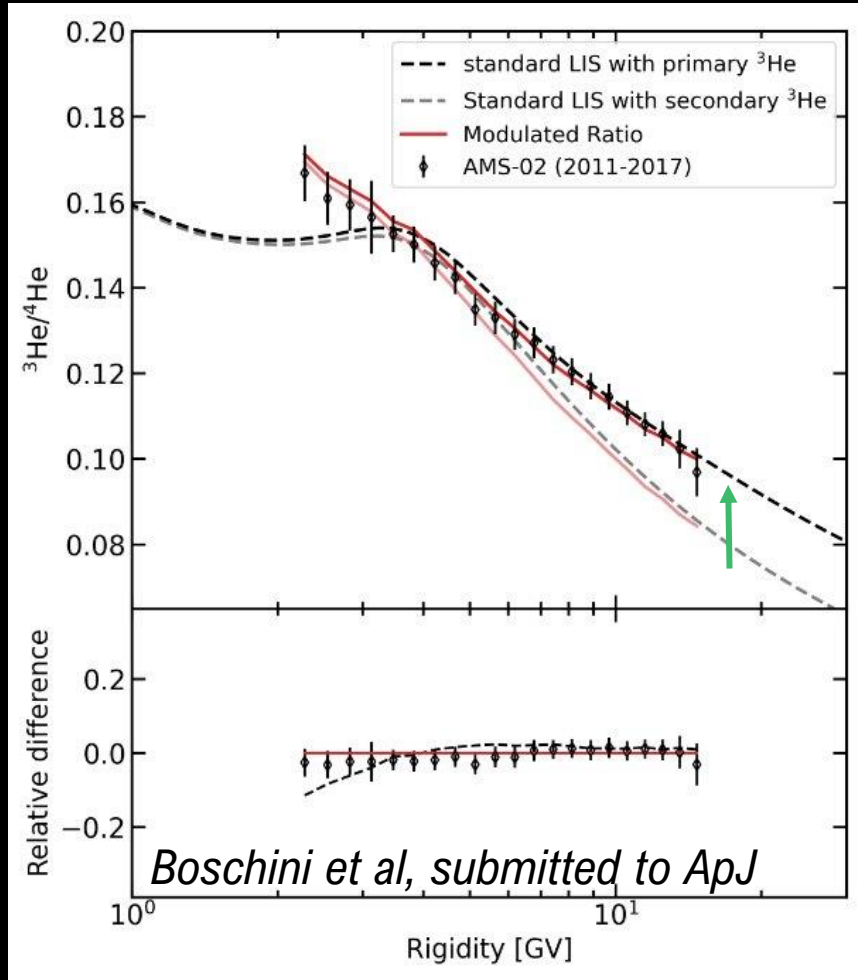
- Primary He-4 standard injection spectra
- Full secondary He-3 produced in fragmentations of $Z \geq 2$ nuclei
- *Something else to be investigated*

Hypothesis 1: primary ^3He component with a harder injection spectrum

Hypothesis 2: a non-uniform propagation probed on different spatial scales by (light) He isotopes and heavier species



Hypothesis 1: primary ^3He component with a harder injection spectrum



This hard spectrum component Could come from either:

- accelerated in a source enriched with ^3He isotope relative to an “average” Galactic CR source

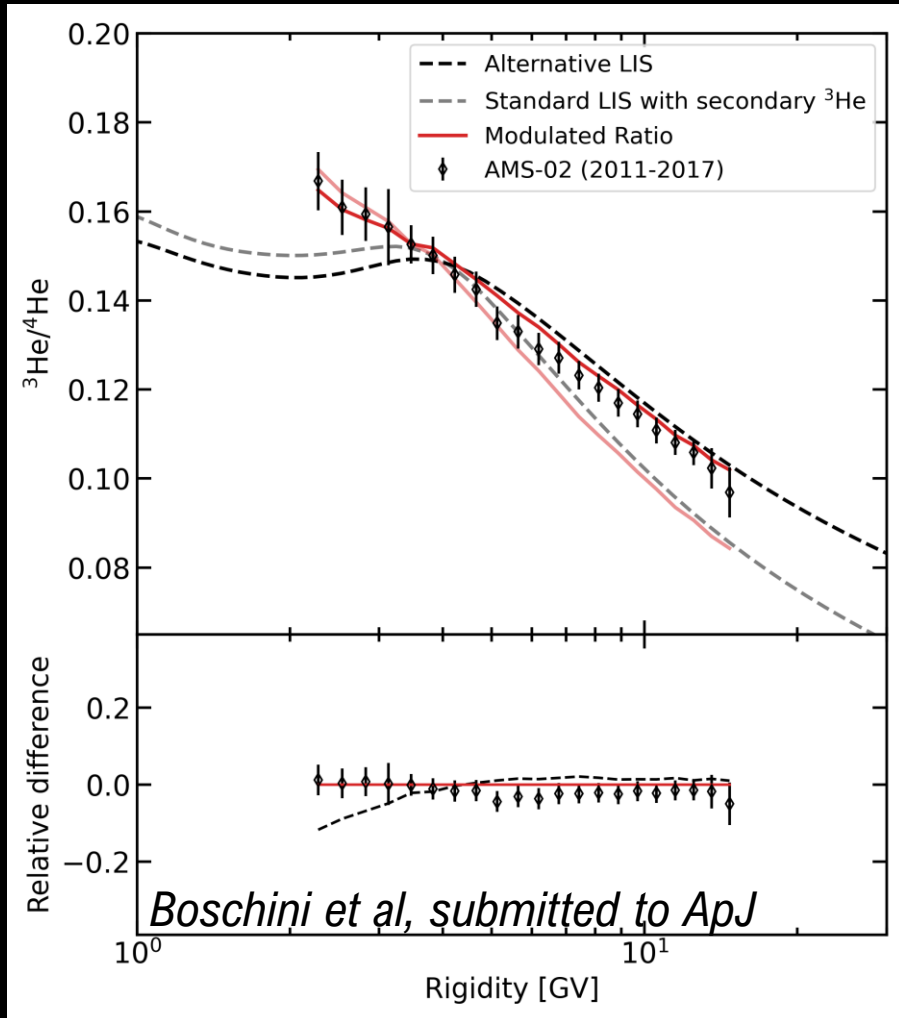
Similar effect may be observed during solar energetic particle events -> this could be a plausible mechanism.

- is produced locally in $Z \geq 2$ ions fragmentation in the source or in the ISM near the source

In this scenario, one should also observe an excess in Be and B since their cross-section production from C, N, and O, is much larger than He-3 production from He-4 fragmentation.

Details and discussions can be found in the submitted ApJ paper

Hypothesis 2: a non-uniform propagation probed on different spatial scales by (light) He isotopes and heavier species



Based on the assumption that the properties of Interstellar medium are not uniform throughout the galaxy

In this scenario, a similar effect should be observed in Secondary/primary ratios between nuclei with significantly different inelastic cross-sections

Details and discussions can be found in the submitted ApJ paper

Conclusions

- We presented the **HelMod Model** for the propagation of Cosmic rays through the heliosphere.
- **HelMod is available on-line** at www.helmod.org and through the SR-NIEL framework (www.sr-niel.org)
- Within the GALPROP-HelMod Join effort we present **the He-isotopes LIS**
- **We found an excess of He-3 at high energy** that may be due to a primary harder spectrum or non-uniform propagation in the galaxy