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# He isotopes spectra: a GALPROP-HelMod perspective

https://www.helmod.org

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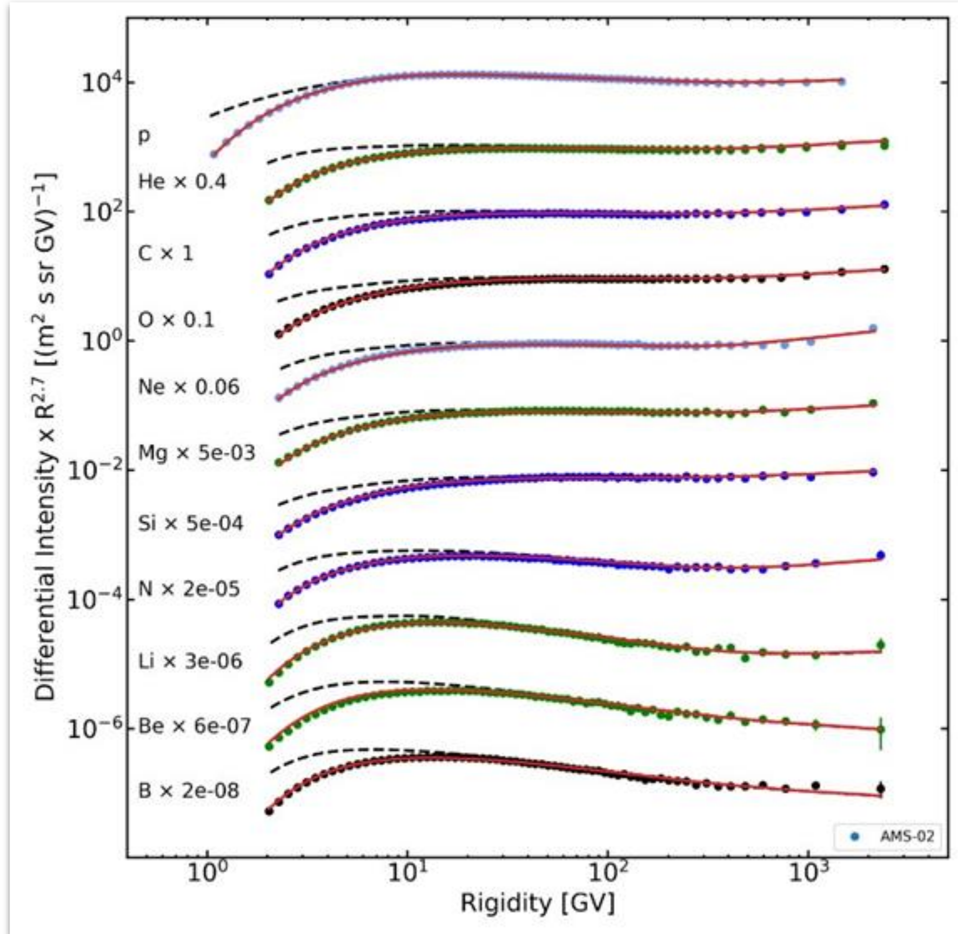
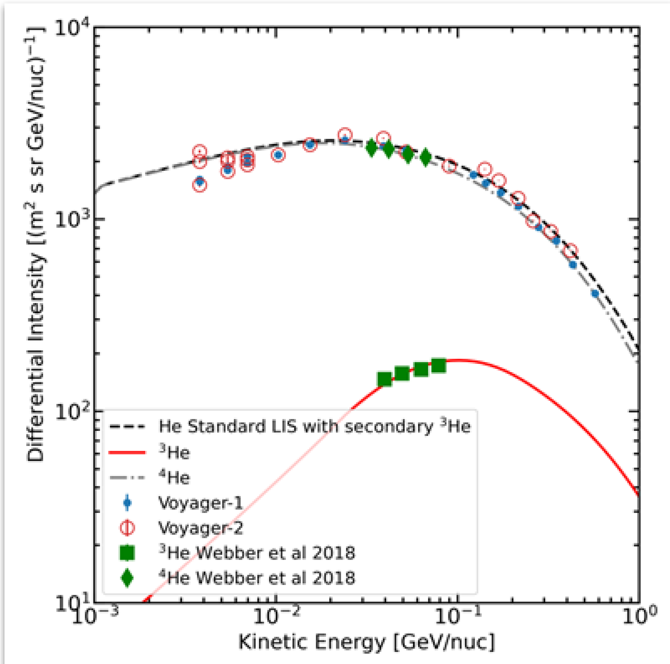
## Models for CR Transport

We estimated Local Interstellar Spectra (LIS) using an iterative procedure involving GALPROP, HelMod and latest GCR observations. GALPROP code that describes propagation of Galactic CRs and production of the associated diffuse emissions The GALPROP code uses information from astronomy, particle, and nuclear physics to predict CRs, γ-rays, synchrotron emission, and its polarization in a self-consistent manner. The key concept underlying the GALPROP code is that various kinds of data, e.g., direct CR measurements, p̄, e±, γ-rays, synchrotron radiation, and so forth, are all related to the same Galaxy and hence have to be modeled self-consistently. The goal for the GALPROP-based models is to be as realistic as possible and to make use of available information with a minimum of simplifying assumptions. Before reaching Earth orbit, CR particles pass through the interplanetary medium, called the heliosphere. Though many processes are similar to the Galactic propagation, the heliosphere has its own specifics. Solar activity changes on weekly and monthly scales, and the solar wind and magnetic field vary with time and position in space, and therefore they require a dedicated modeling to understand all factors involved. In this work, the particle transport within the heliosphere is treated by means of the HELMOD model. The HELMOD model, now version (HELMOD-4), numerically solves the Parker (1965) transport equation using a Monte Carlo approach involving stochastic differential equations.



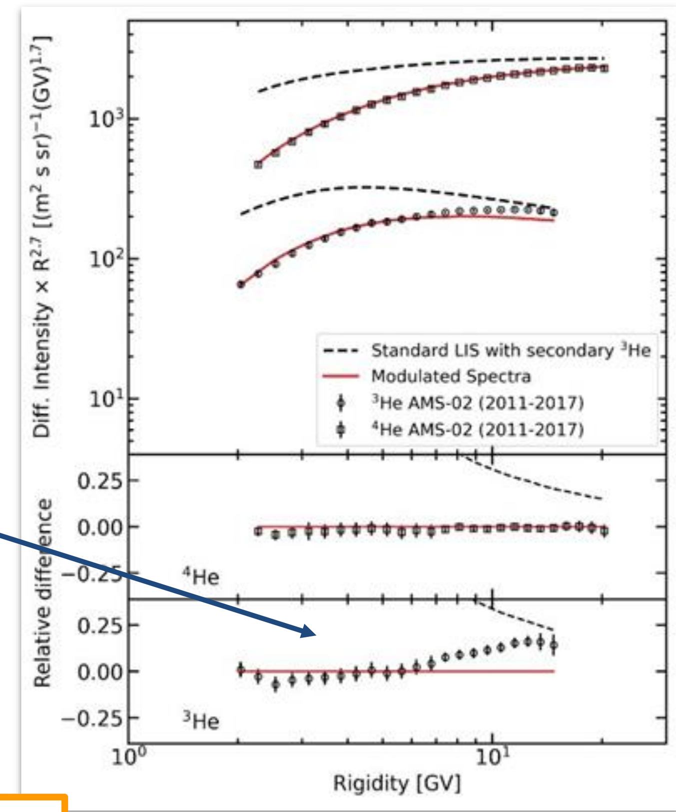

## Calculation for He-3 & He-4 LIS spectra

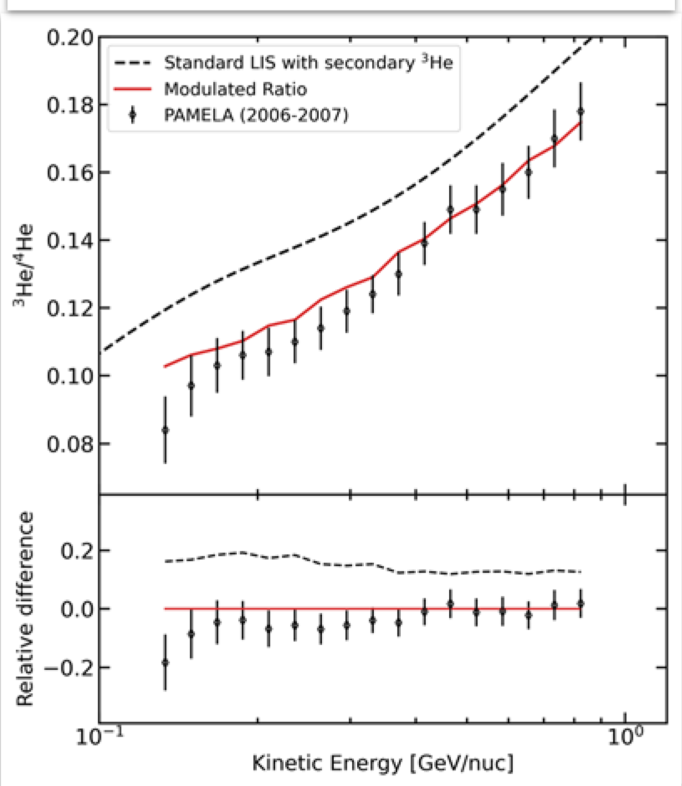


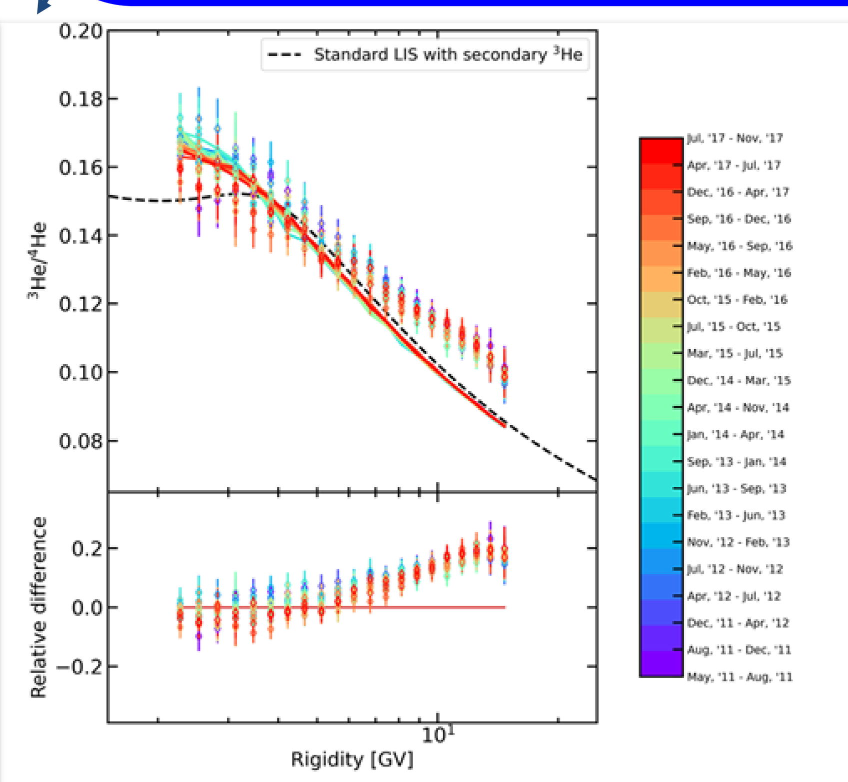

The Model confirms its prediction capability for all AMS-02 species with a single set of parameters. We evaluated the He isotopes spectrum obtained in a pure secondary production scenario.

We found that modulated He-3 spectra under-estimate AMS-02 data above 7GV, while the He-4 spectrum agrees with AMS-02 data at the % level.

This features appears also in He-3/He-4 ratio systematically even in the time variation analysis. At low energy modulated ratio agrees well with data.



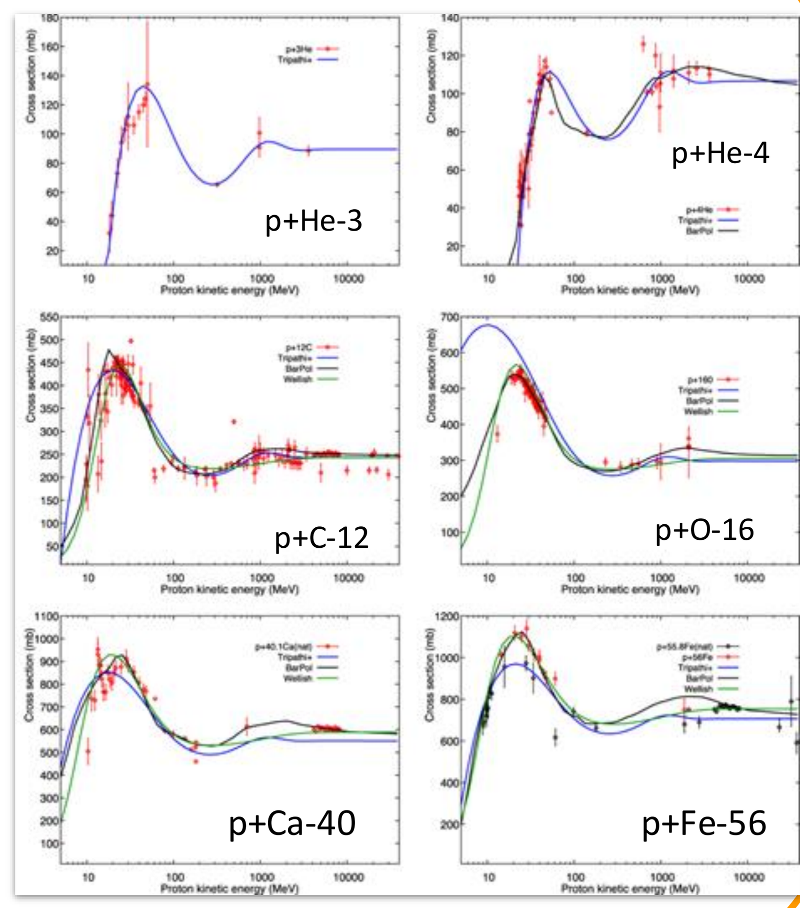




## Hypothesis1 : nuclear cross section accuracy

A fundamental property of the production and fragmentation cross sections is their energy independence above ~1÷2 GeV/n. One can see the examples of the total fragmentation cross sections of different isotopes:

The excess in the $^3$He spectrum and the $^3$He/$^4$He ratio is observed above 7 GV, which corresponds to 3.8 GeV/n for $^3$He and 2.7 GeV/n for $^4$He and for other most abundant heavier projectiles (A/Z≈2), such as $^{12}$C,$^{16}$O, etc…

Therefore, the energy-independent (rigidity-independent) cross sections cannot be the reason of the observed rigidity-dependent $^3$He excess: **this rules out the hypothesis of the accuracy of the cross sections**.



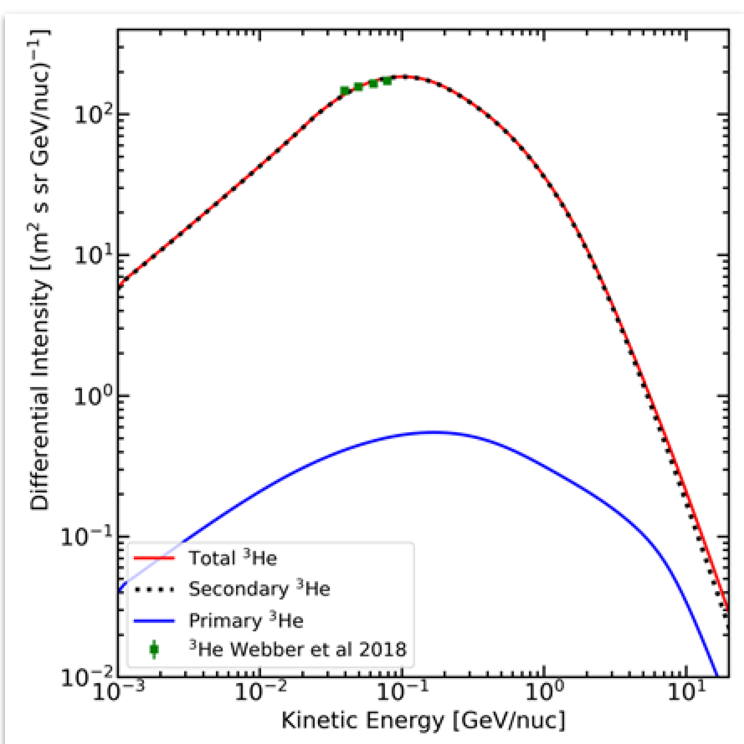

*Porter et al 2022 ApJS 262 30*

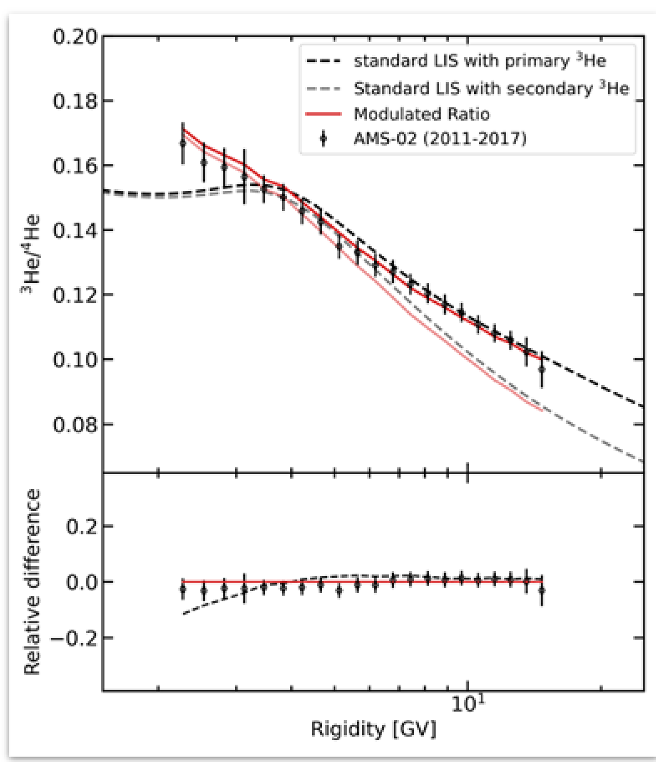
## Hypothesis 2: Primary hard spectrum component

The hypothesis of possible enrichment of a CR source environment with $^3$He isotope is plausible: the closest example is a solar energetic particle event (SEP).

Some of them are exhibiting resonant enhancements in the ratio $^3$He/$^3$He, that could even make $^3$He dominant.

After fifty years of studies, the mechanism of this enhancement is not fully understood but, under favorable circumstance, $^3$He-rich material could be injected into the ISM, where it can be picked by a propagating shock, or injected directly into the shock at the CR accelerator.




**The $^3$He "excess" can be fitted adding a new tiny source term (additional primary $^3$He ) which is few ‰ of $^4$He abundance at source**

## Hypothesis 3: Alternative propagation: inhomogeneous diffusion

We performed a calculation of secondary $^3He$ (the "background") produced by fragmentation of nuclei Z > 2 with standard model propagation and source abundance of $He$ set to 0.

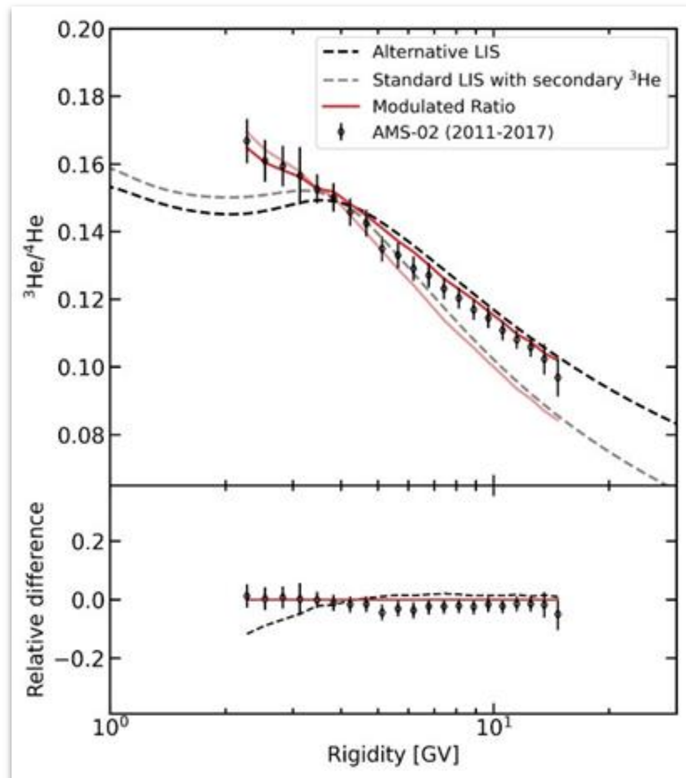
Second, we performed an MCMC scan to derive the alternative propagation parameters with fixed halo size z=4 kpc, free source abundance of $^4He$ and abundances of nuclei Z > 2 set to 0.

The final spectrum of $^3He$ was calculated as a sum of the first background plus secondary $^3He$ produced in fragmentation of $^4He$ with alternative propagation

**Table 1.** Best-fit propagation parameters for *I*- and *P*-scenarios

| Parameter | Units | Model: Standard | Model: Alternative |
|---|---|---|---|
| $z_h$ | kpc | $4.0 \pm 0.6$ | 4.0 (fixed) |
| $D_0(R = 4\,\mathrm{GV})$ | $10^{28}$ cm$^2$ s$^{-1}$ | $4.3 \pm 0.7$ | $5.9 \pm 1.0$ |
| $\delta$ | … | $0.415 \pm 0.025^a$ | $0.19 \pm 0.06$ |
| $V_{\mathrm{Alf}}$ | km s$^{-1}$ | $30 \pm 3$ | $27.3 \pm 5$ |
| $dV_{\mathrm{conv}}/dz$ | km s$^{-1}$ kpc$^{-1}$ | $9.8 \pm 0.8$ | $2 \pm 2$ |
| $\eta$ | … | 0.70 | 1.2 |

$^a$The *P*-scenario assumes a break in the diffusion coefficient with index $\delta_1 = \delta$ below the break and index $\delta_2 = 0.15 \pm 0.03$ above the break at $R = 370 \pm 25$ GV (for details see Boschini et al. 2020b).




**A new set of propagation parameters, trained on $^3$He, $^4$He and $^3$He/$^4$He using the MCMC approach, has been found to fit the $^3$He discrepancy. This could represent an alternative scenario for light isotopes propagation.**

Acknowledgements: This work is currently supported by ASIF implementation agreements 2017-15-HD.0 ASI-INFN, 2017-22-HD.0 ASI-ENEA, 2021-36-HH.0 ASI-Milano-Bicocca University, 2021-39-HH.0 ASI-ENEA and 2024-21-HH ASI-INFN.
This work is also supported by ASI contract ASI-INFN 2019-19-HH.0 and ESA (European Space Agency) contract 4000116146/16/NL/HK.
Igor V. Moskalenko and Troy A. Porter acknowledge support from NASA Grants No. 80NSSC23K0169, 80NSSC22K0718, 80NSSC22K0477. This research has made use of the SSDC CR database and LPSC Database of Charged CRs.