AMS-02 isotopes: ^3He, ^4He and deuterons predictions

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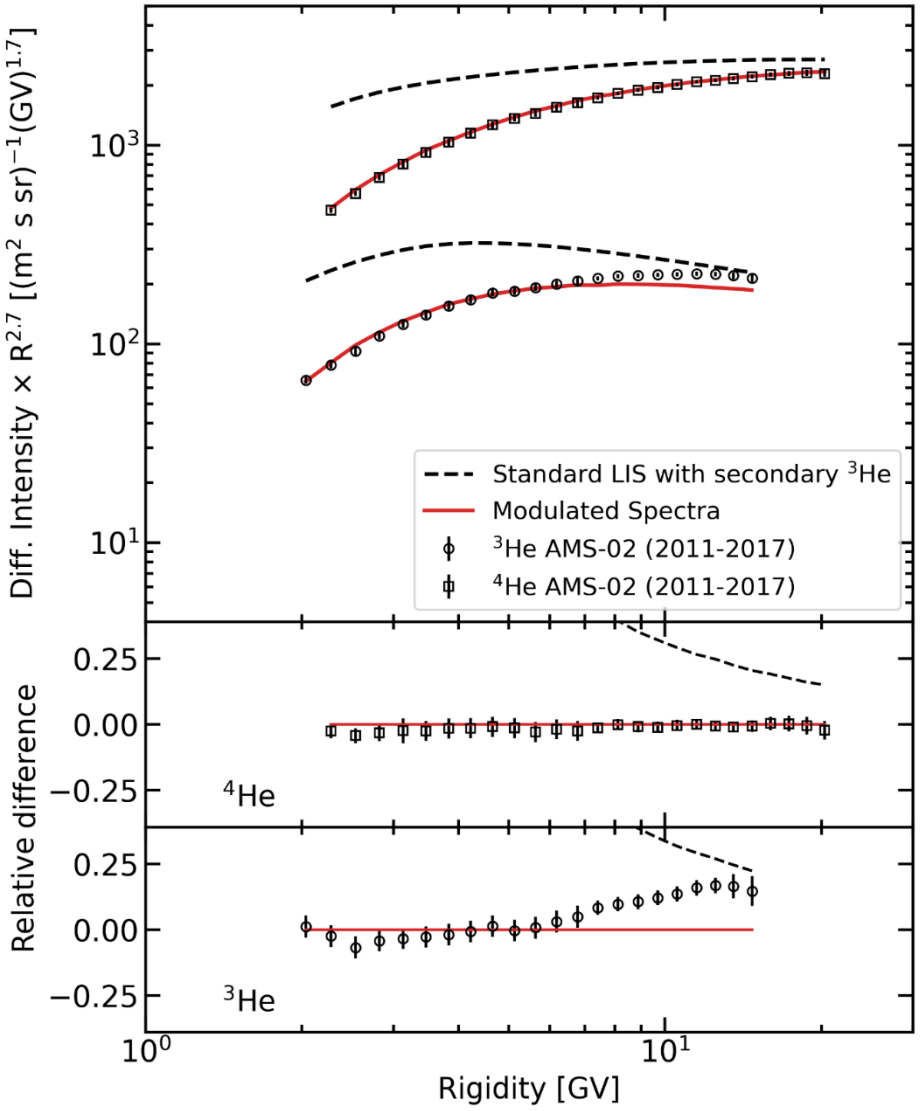
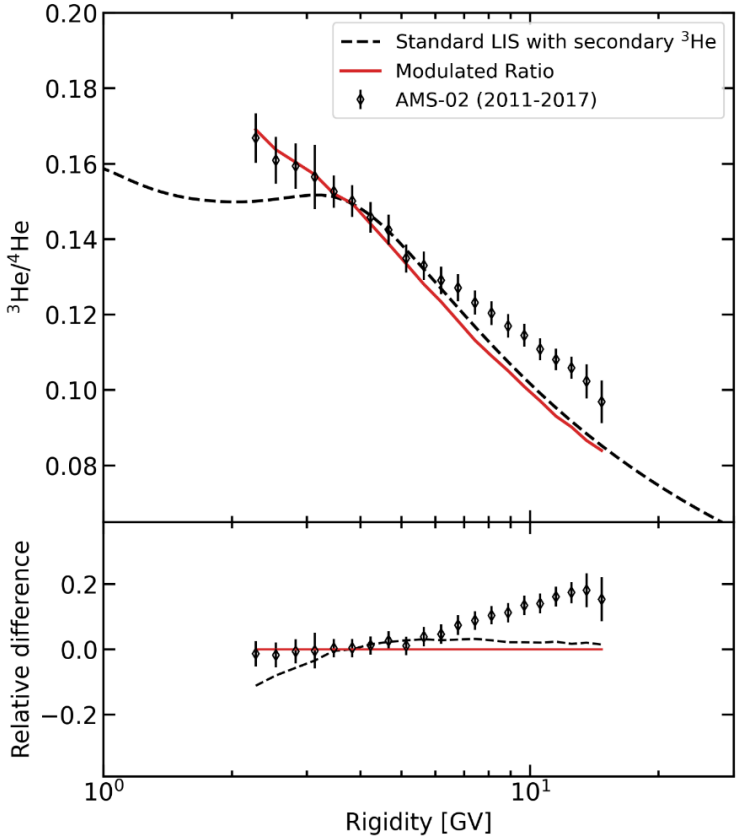
Explaining isotopic physics by means of GALPROP and HelMod

- AMS-02 published data can be fitted in the combined framework of GALPROP and HelMod (for Galactic and Heliosphere propagation, respectively) **with a single model**, capable of reproducing all primary and secondary spectra at the same time
- The 28 proposed LISs fit Voyager-1, ACE-CRIS, HEAO-3-C2, Pamela, AMS-02, CREAM, ATIC-2 and recent NUCLEON, CALET and DAMPE data, from 10 MeV/n up to 500 TeV/n, representing a **forecasting tool for the Collaboration.**
- This is the starting point to study **isotopes** and possibly **different propagation schemes** for light species.

Secondary scenario

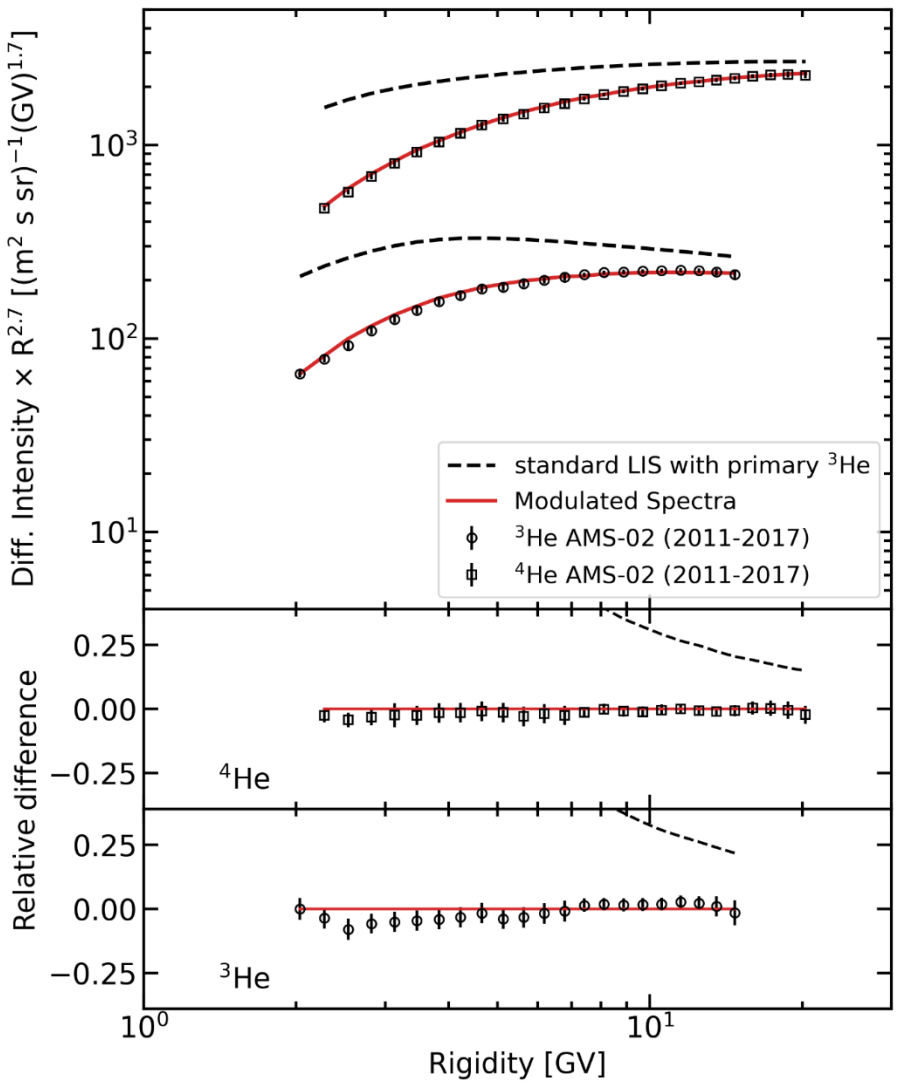


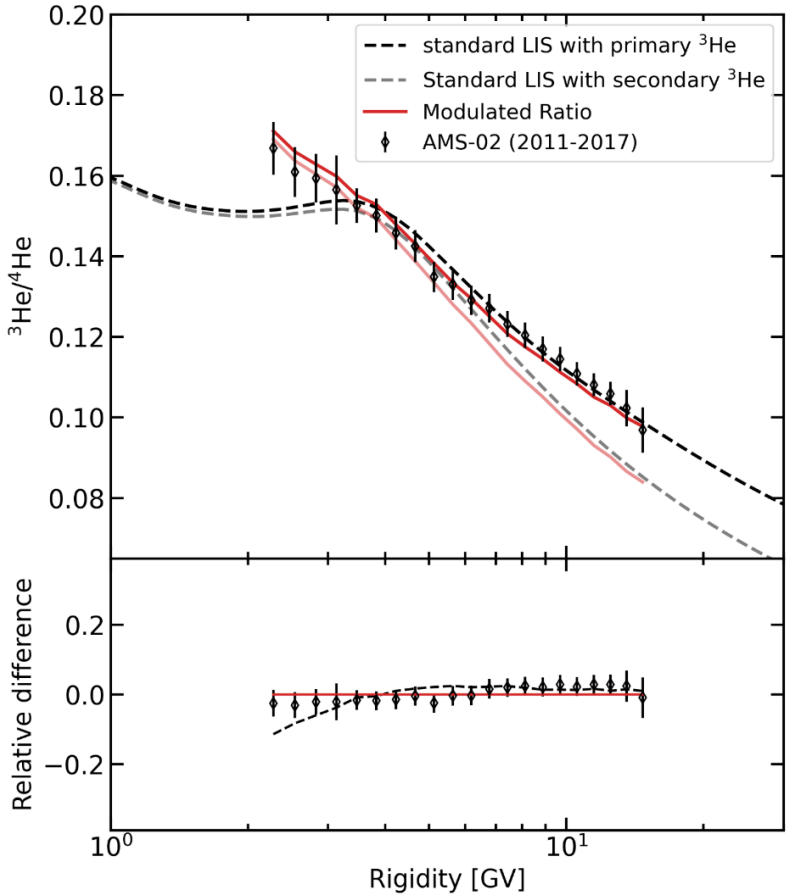


The ^{3}He **spectrum** obtained in a pure secondary production scenario shows an **underestimation w.r.t. AMS-02 data above 7 GV**, hard to be explained with nuclear uncertainties in the ^{3}He channel.

The ^{4}He spectrum agrees with AMS-02 data at the % level.

Primary component scenario



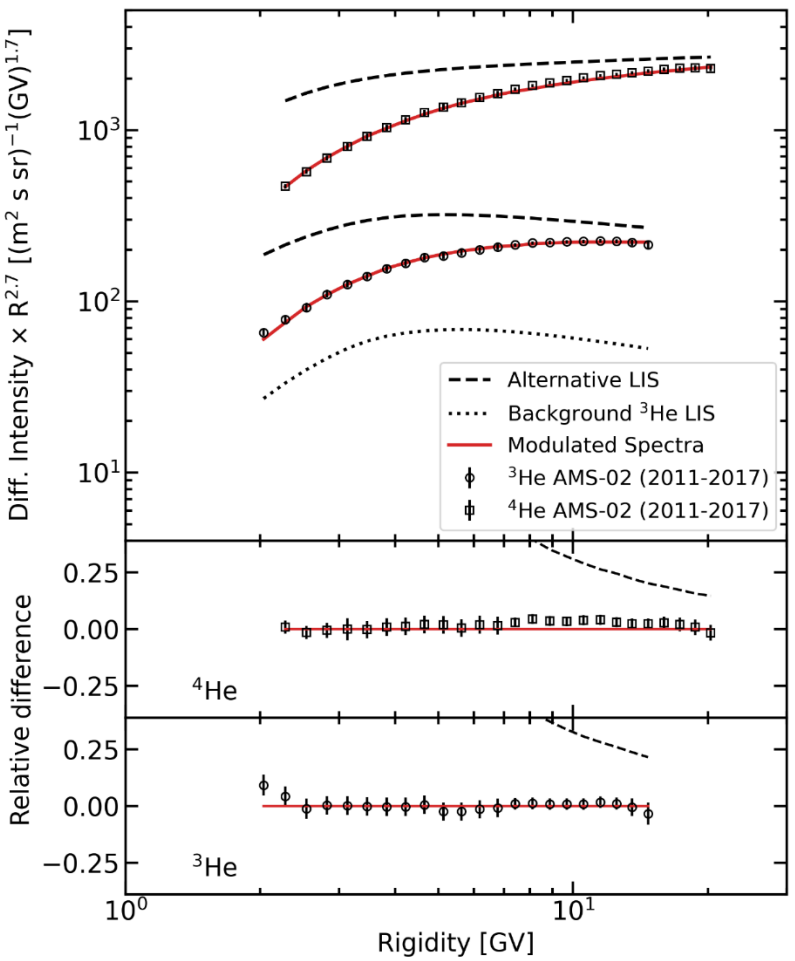


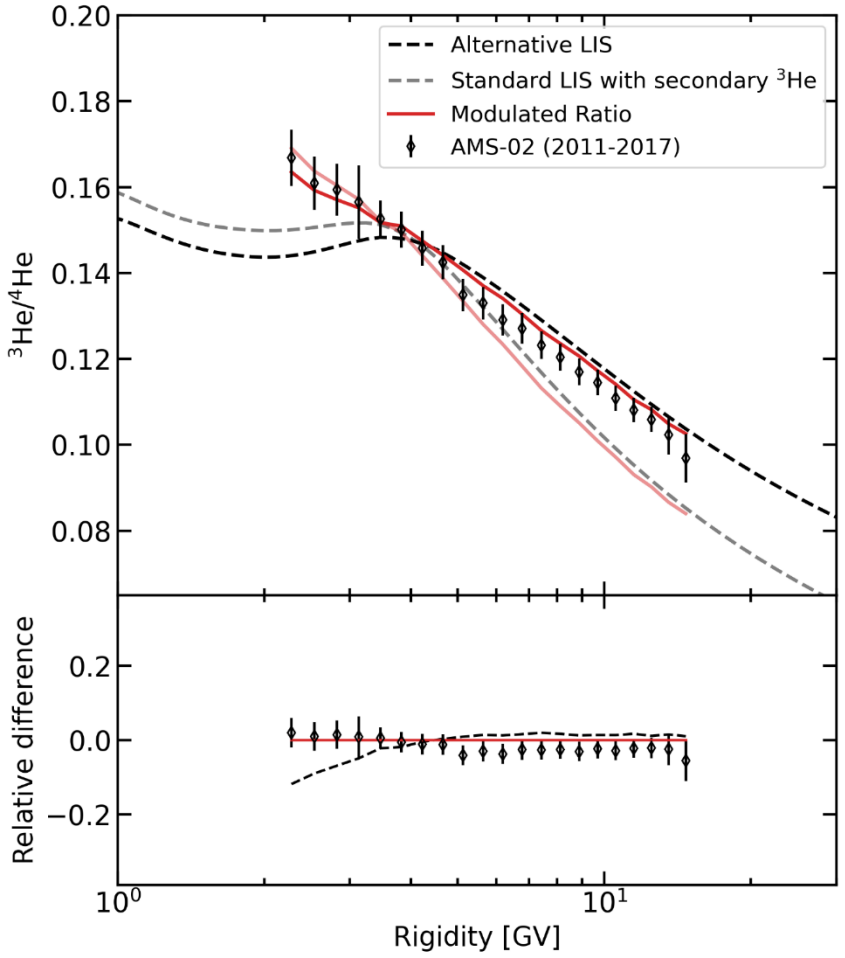
The hypothesis of possible enrichment of a CR source environment with ^3He isotope is plausible: the closest example is a **solar energetic particle event** (SEP).
Some of them are exhibiting resonant enhancements in the ratio $^3He/^4He$, that could even make ^3He dominant.

After fifty years of studies, the mechanism of this enhancement is not fully understood but, under favorable circumstance, ^3He 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 ^3He "excess" can be fitted adding a new tiny source term (additional primary ^3He) which is less than 1 ‰ of ^4He abundance at source

Alternative propagation scenario





Standard Scenario

Parameter	Units	Best Value
z_h	kpc	4.0
$D_0(R = 4\ \mathrm{GV})$	$\mathrm{cm}^2\ \mathrm{s}^{-1}$	4.3×10^{28}
δ^a		0.415
V_{Alf}	$\mathrm{km\ s}^{-1}$	30
dV_{conv}/dz	$\mathrm{km\ s}^{-1}\ \mathrm{kpc}^{-1}$	9.8

[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

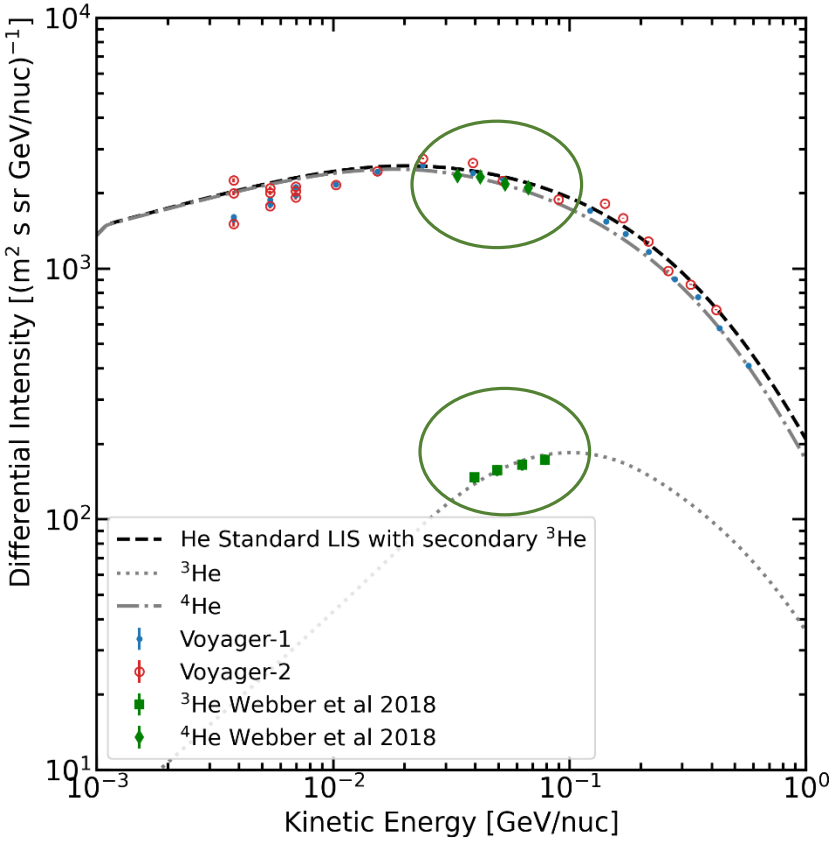
Alternative Scenario

z = 5.6 kpc,
D0 = 7.6 x 10^28 cm^2 s^-1,
delta = 0.19,
Va = 27 km s^-1,
dV0/dz = 2.0 km s^-1 kpc^-1

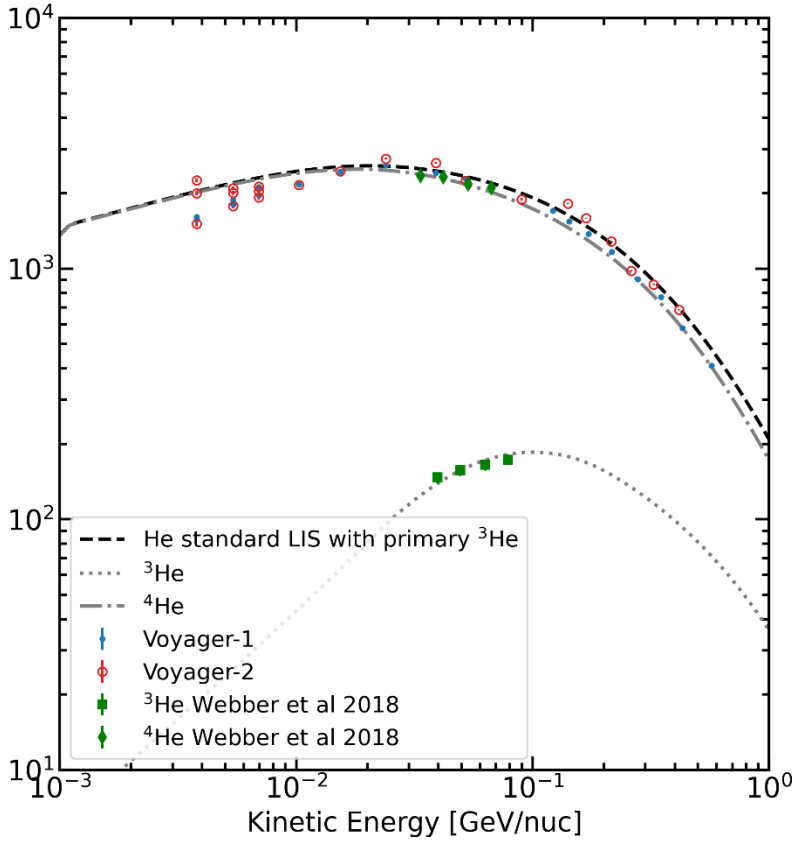
A new set of propagation parameters, trained on ^3He, ^4He and ^3He / ^4He using the mcmc approach, has been found to fit the ^3He discrepancy.
This could represent an alternative scenario for light isotopes propagation.

Local Interstellar Spectra

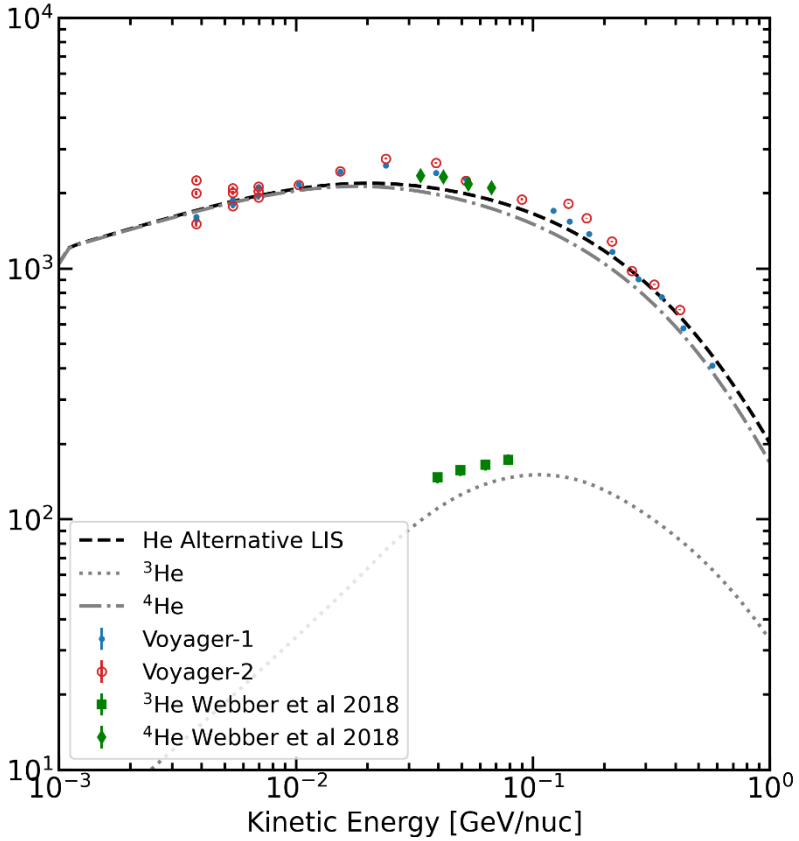
Secondary



Primary



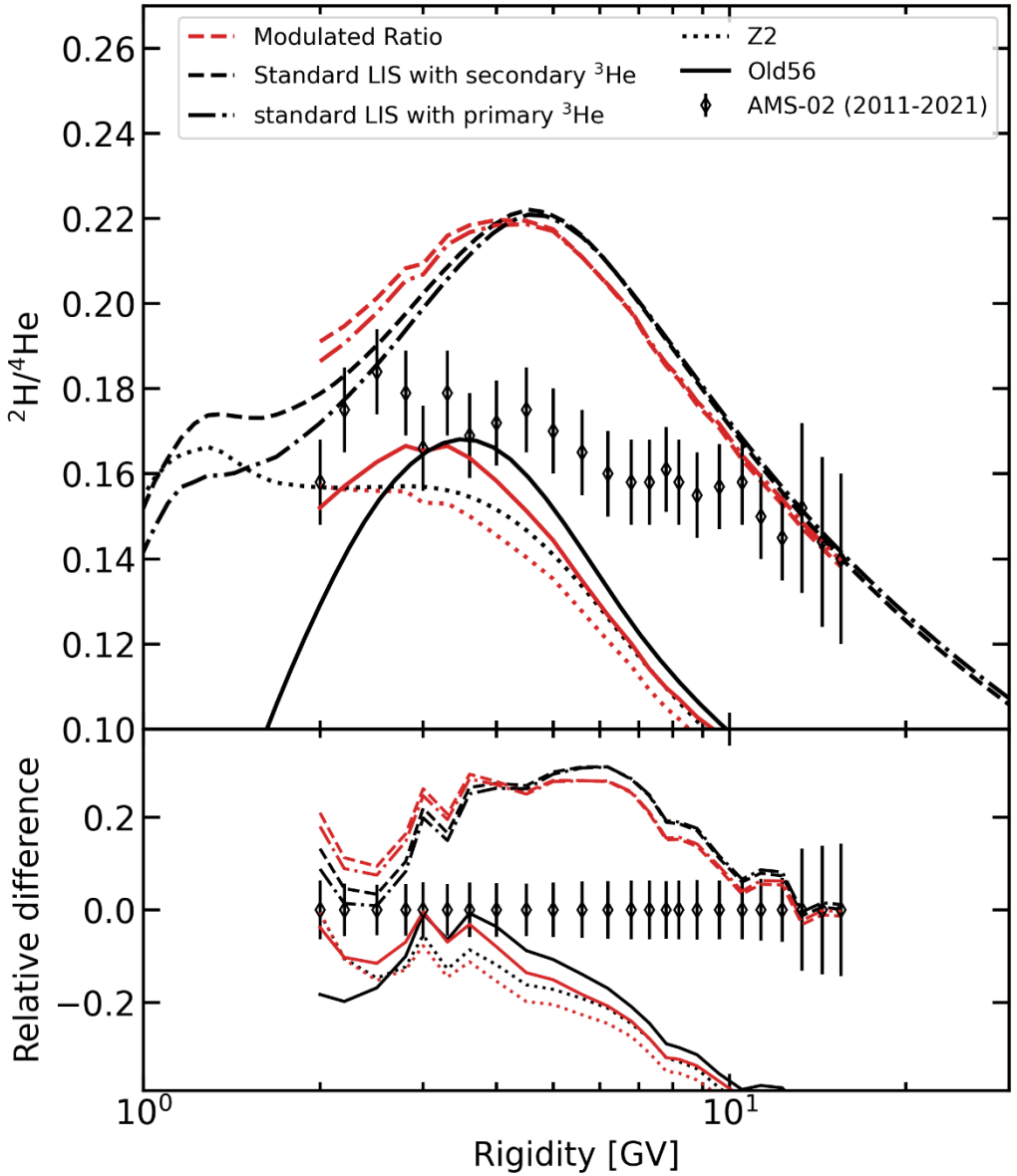
Alternative



Voyager-1 data are well fitted by standard scenarios LIS, with and without primaries: secondary produced ^3He is correctly predicted by new GP57

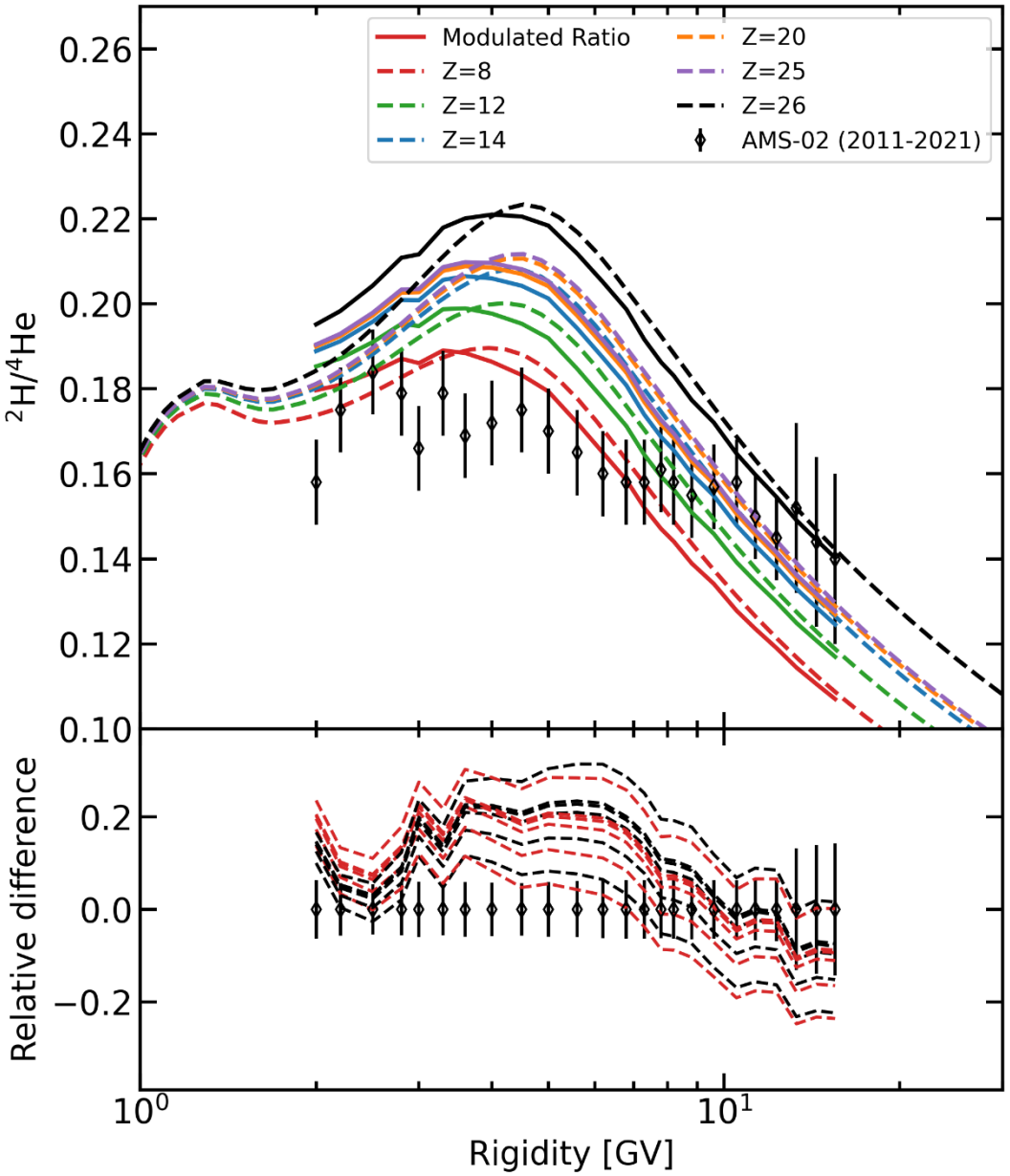
Deuteron predictions

$d/\ ^4He$ ratio



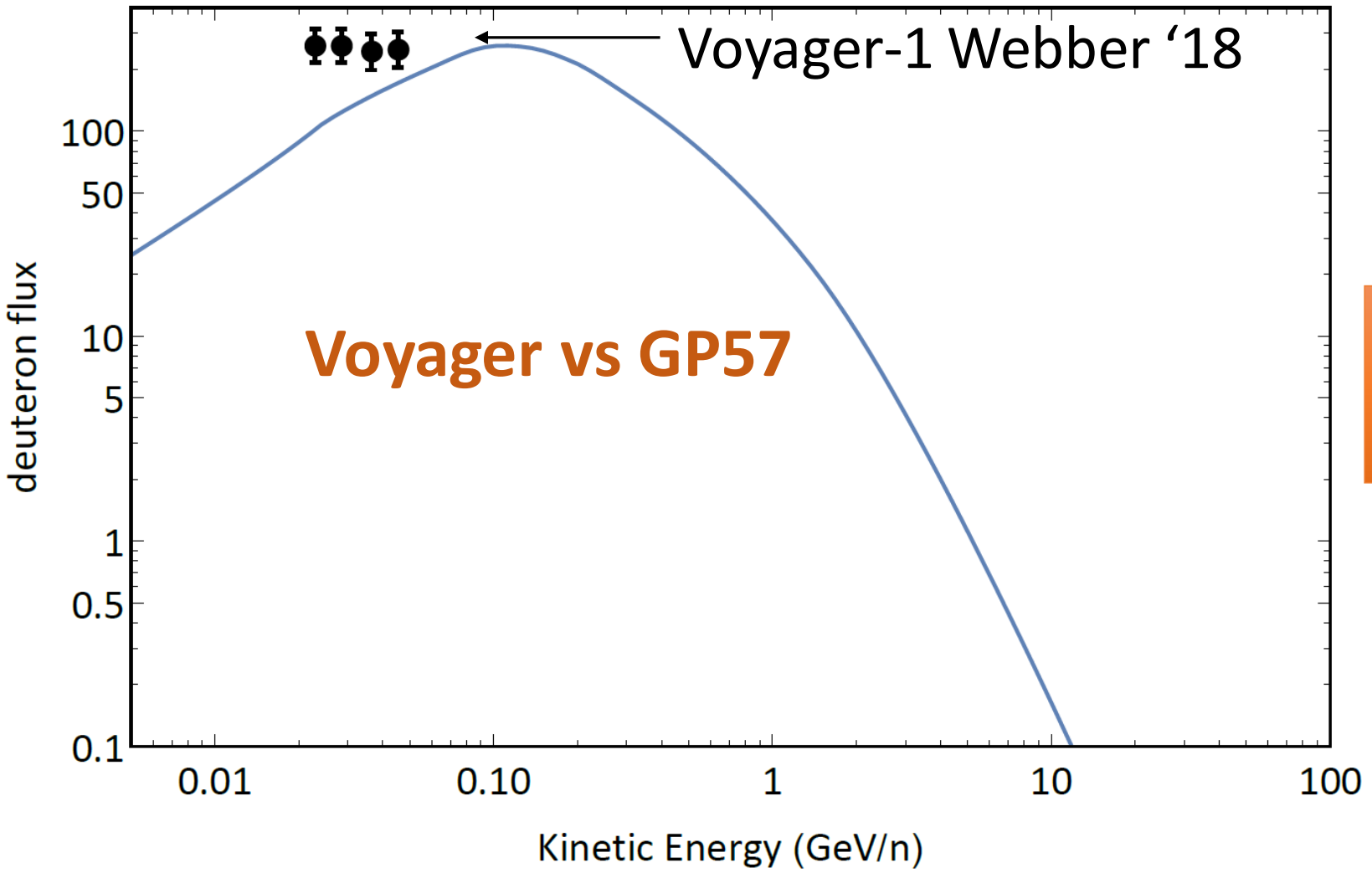
- In GP56/early GP57 there were no Z>2 d production channels
- The difference between the ^3He primary-secondary scenarios and the choice of the nuclear cross section parametrization are not relevant in the AMS-02 data range
- HelMod modulation produces only a slight shift towards the left
- Alternative propagation scenarios are going to be tested in order to see if they can fit deuterons and ^3He at the same time

Incremental cross section channels



- For $Z \leq 8$ the peak is good
- Silicon does not affect deuteron production and the **prediction is comparable with AMS-02 up to $Z \leq 12$**
- Sulfur and Calcium appreciably affect *d*
- $21 \leq Z \leq 25$ are not relevant whereas **Fe produces the final jump** which reaches 0.23 value
- From literature, the only available data are:
  CNO+p->d 6 points: Ramaty & Lingenfelter(1969) & Olson et al ('83)

Voyager-1 Deuterons

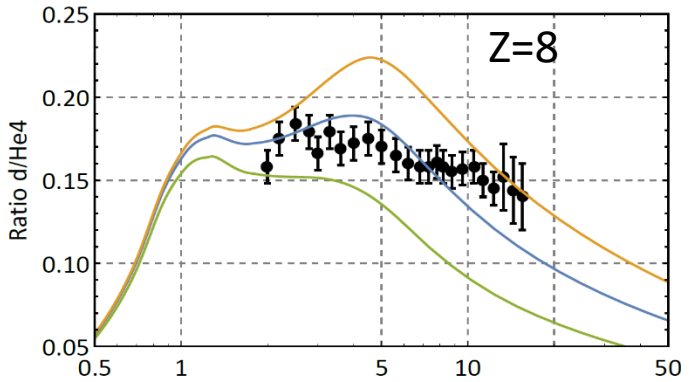


No GP model can reproduce arXiv Voyager-1 Webber ’18 data

Conclusions

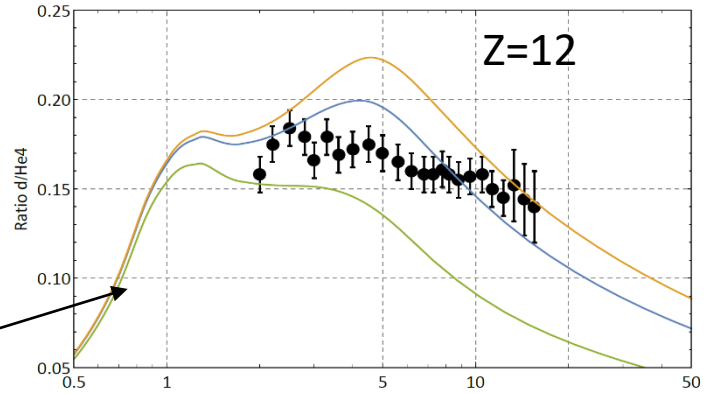
- The analysis of receent heavy nuclei by AMS-02 within the GALPROP–HELMOD framework, together with Voyager-1 and ACE-CRIS data, provided updated local interstellar spectra up to Z=28: the following step is to characterize isotopes contributions.
- AMS-02 high precision data put models to a severe test, highlighting fine features in nuclei spectra and isotopes.
- The helium isotopes and their ratio have been calculated using the GALPROP-HelMod environment and compared with AMS-02 : primary ^{4}He is perfectly described, as expected, whereas ^{3}He flux shows an underestimation for R > 7 GV, which points towards a non-nuclear explanation.
- Two solutions are proposed: a new primary ^{3}He component or a different propagation model for helium isotopes with respect to heavy nuclei.
- The comparison with GP deuterons production is ongoing, the case is not clear: before the inclusion of Z>2 channels, GP underestimates AMS-02, after it overestimates.
- Deuterons cross section data and analytic models for high Z production are poor and the parametrization are very qualitative.

Incremental cross section channels

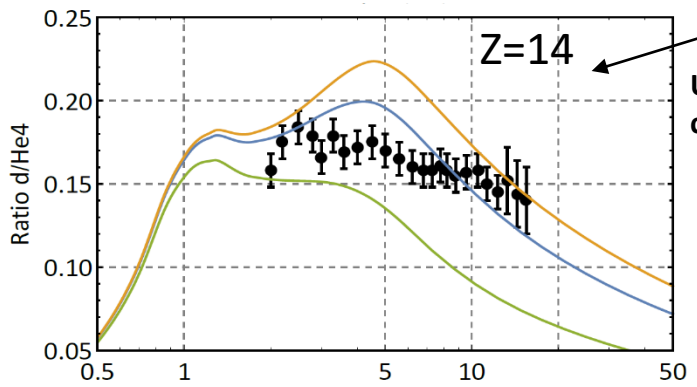


At Z<=8 D peak is good

Z<=8
GP57 opt4−12
Z<=2

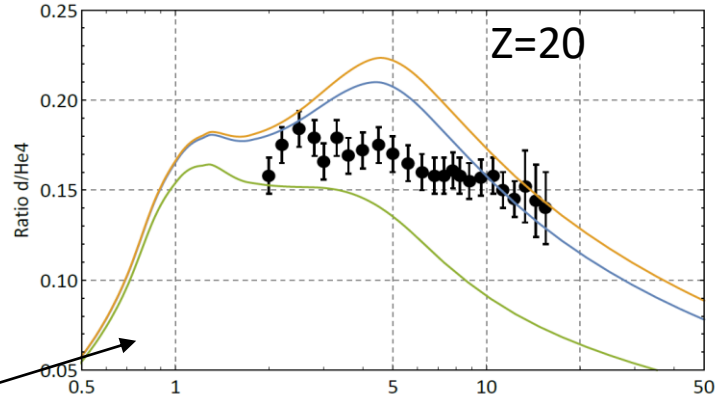


Si does not affect



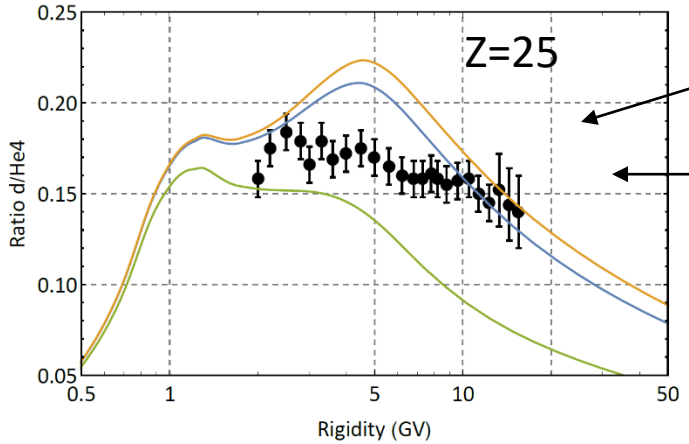
Up to Z=14 D production is comparable with AMS02

Z<=14
GP57 opt4−12
Z<=2



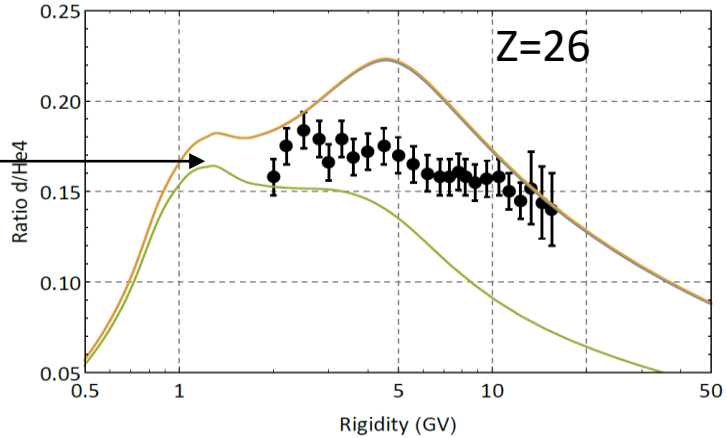
S and Ca appreciably affect

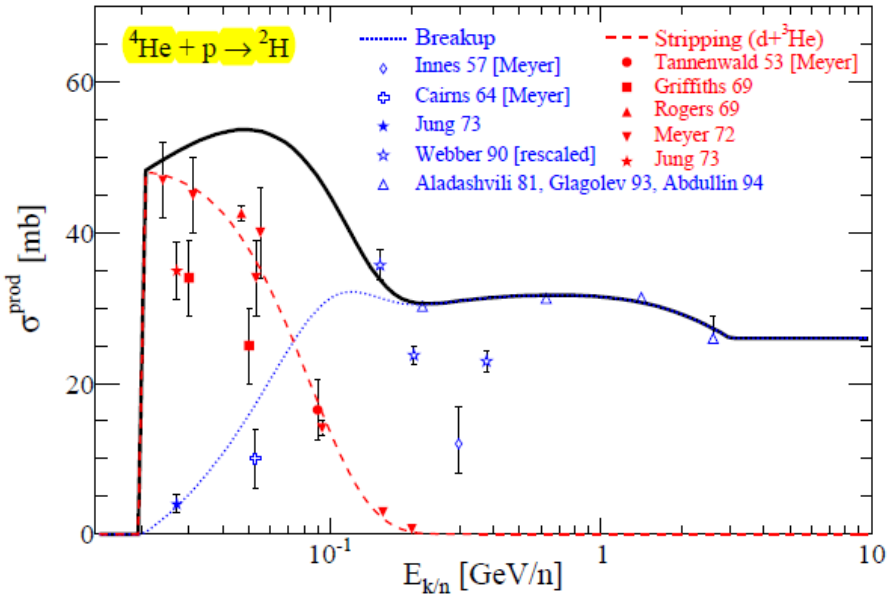
Z 21-25 do not affect

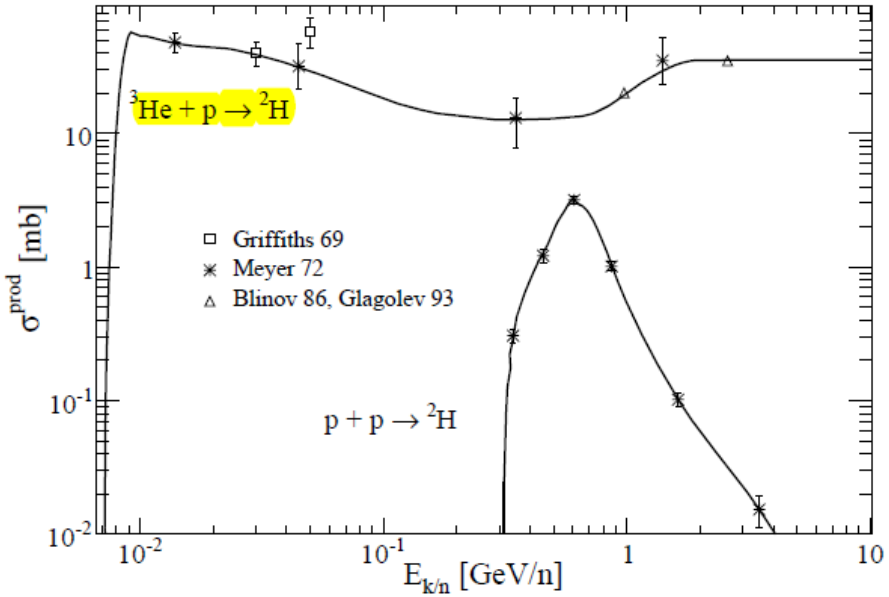


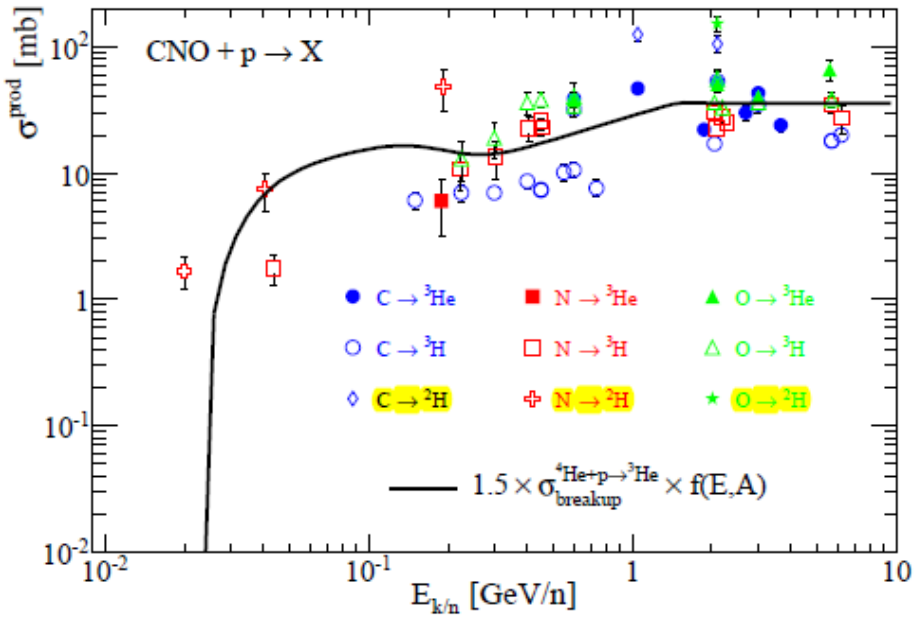
Fe produces the jump from 0.21 to 0.23

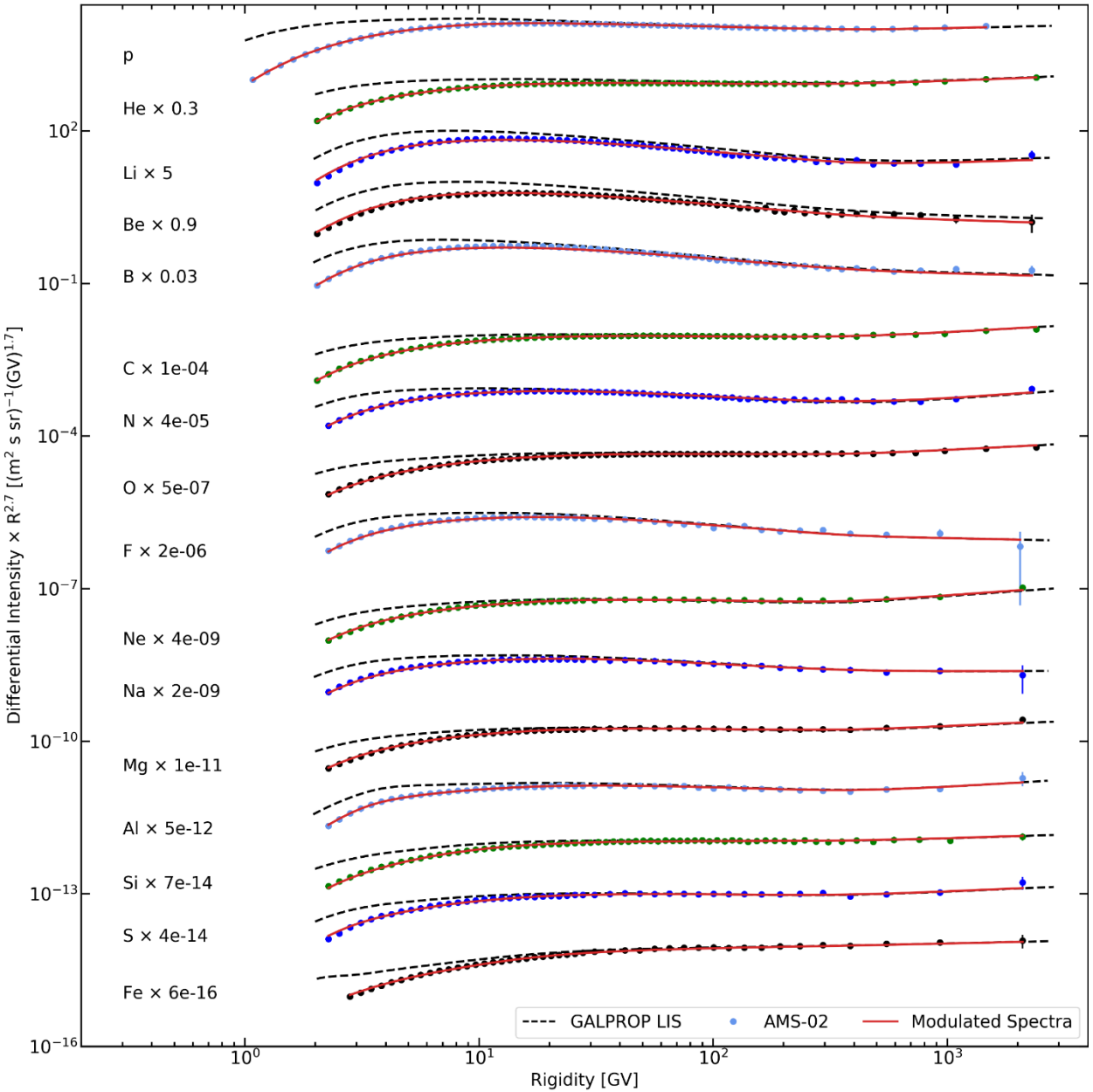
Z<=25
GP57 opt4−12
Z<=2




$^4He + p \rightarrow {}^2H$
Breakup
Innes 57 [Meyer]
Cairns 64 [Meyer]
Jung 73
Webber 90 [rescaled]
Aladashvili 81, Glagolev 93, Abdullin 94
Stripping (d+^{3}He)
Tannenwald 53 [Meyer]
Griffiths 69
Rogers 69
Meyer 72
Jung 73
σ^{prod} [mb]
$E_{k/n}$ [GeV/n]

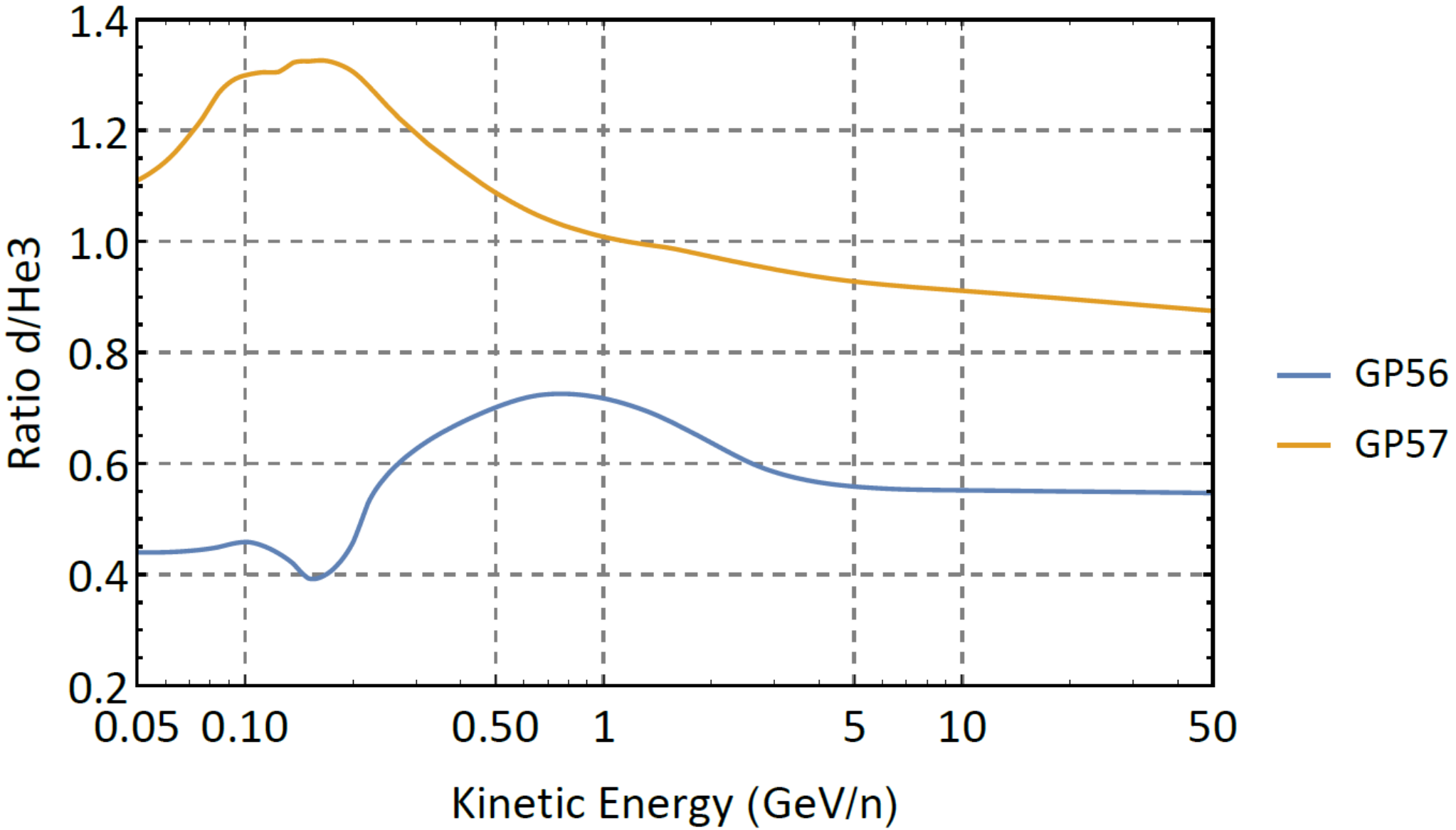

$^3He + p \rightarrow {}^2H$
Griffiths 69
Meyer 72
Blinov 86, Glagolev 93
$p + p \rightarrow {}^2H$
σ^{prod} [mb]
$E_{k/n}$ [GeV/n]


CNO + p → X
C → ^{3}He
N → ^{3}He
O → ^{3}He
C → ^{3}H
N → ^{3}H
O → ^{3}H
C → ^{2}H
N → ^{2}H
O → ^{2}H
$1.5 \times \sigma^{^4He+p\rightarrow{}^3He}_{breakup} \times f(E,A)$
σ^{prod} [mb]
$E_{k/n}$ [GeV/n]

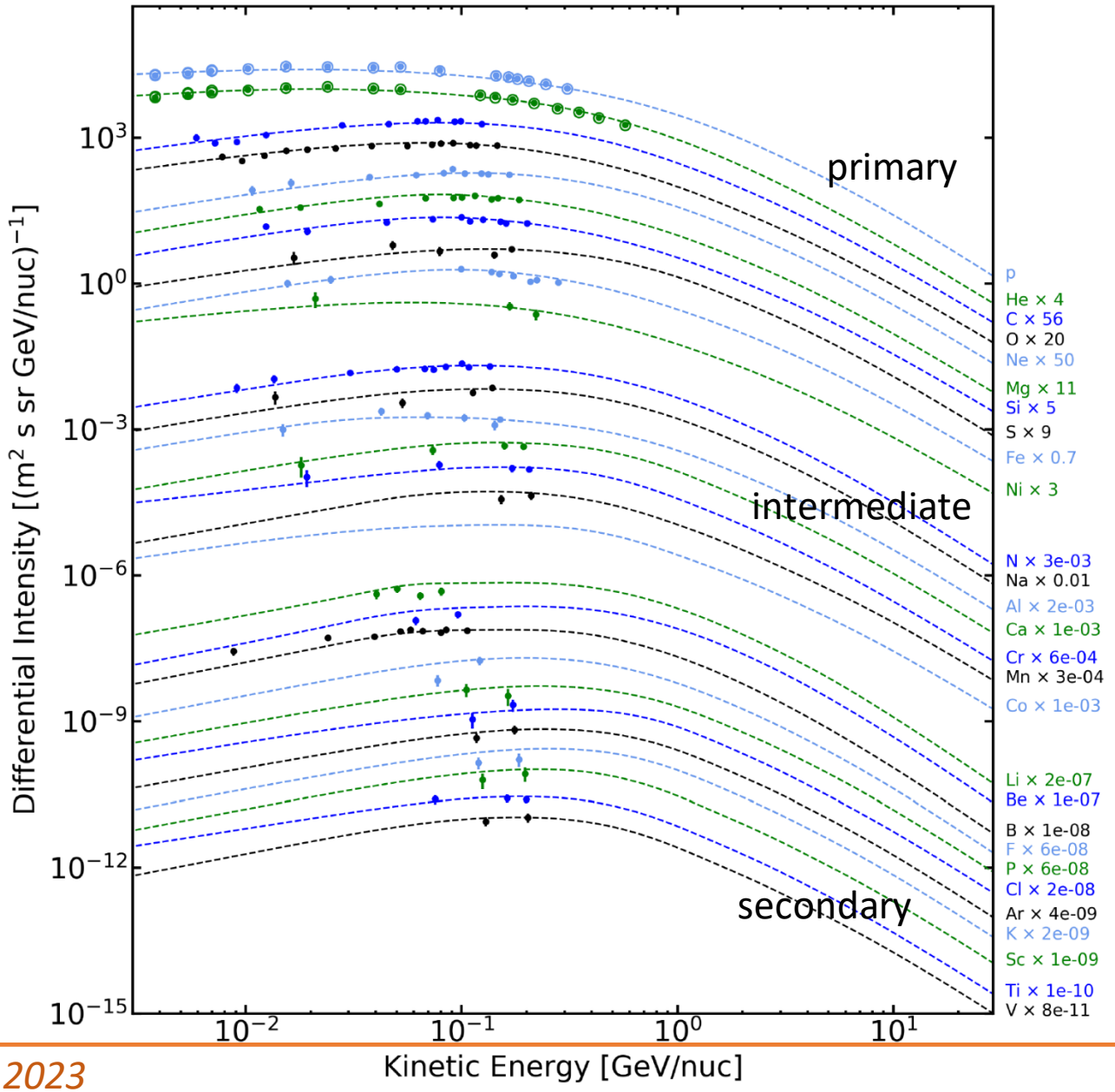


The Model confirmed its prediction capability for all AMS-02 species with a single set of parameters

$d/\ ^3He$ ratio


1.4
1.2
1.0
0.8
0.6
0.4
0.2
Ratio d/He3
0.05
0.10
0.50
1
5
10
50
Kinetic Energy (GeV/n)
GP56
GP57

Interstellar spectra measured by Voyager-1



All Z ≤ 28 are well reproduced