Study of cosmic ray propagation using GALPROP

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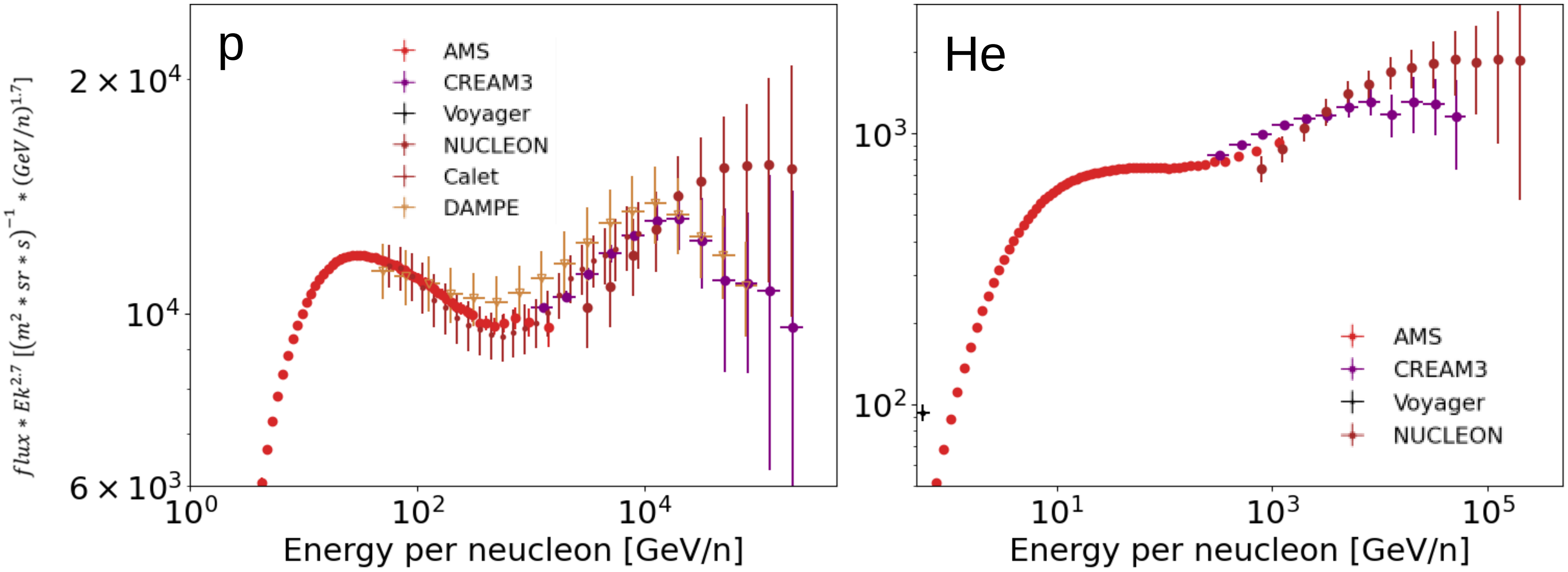
Introduction



GALPROP version:56.0.2870

Sources
including primary, spallation and decay contributions

Diffusion
Dxx: spatial diffusion coefficient

Fragmentation
τ_f: time

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi - \vec{V}\psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p}\frac{1}{p^2}\psi - \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

CR density per unit

Diffusive reacceleration

Energy loss
$\dot{p}$: Momentum

Decay
τ_r: time

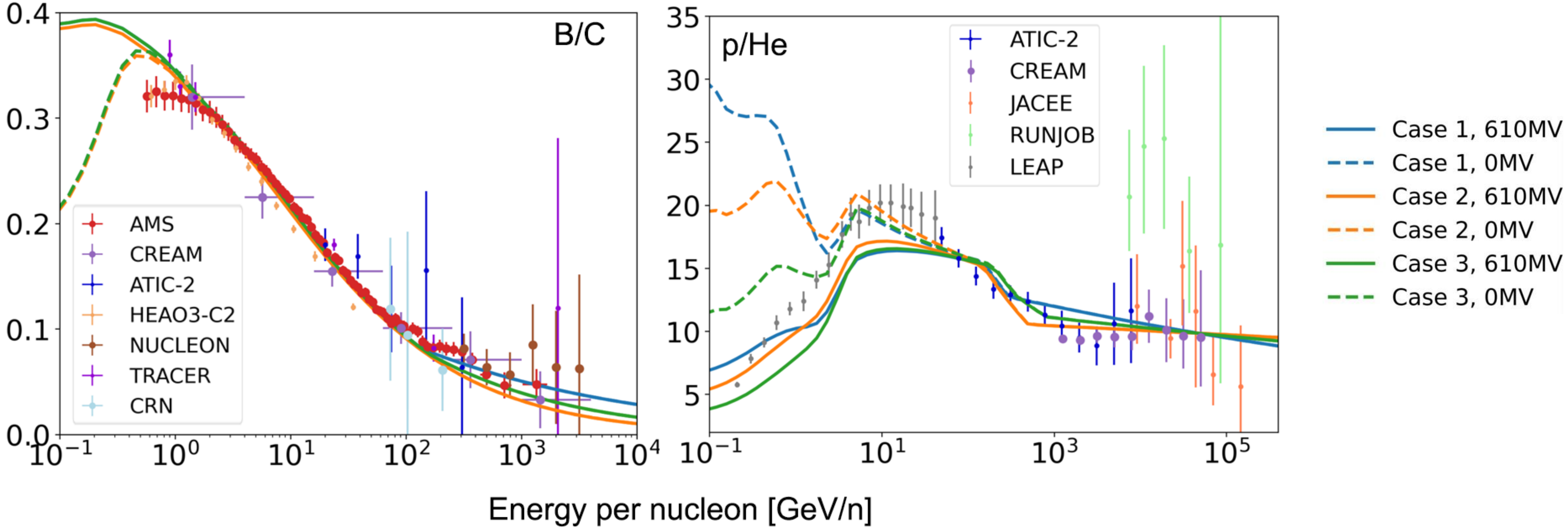
Model

Item		Case 1	Case 2	Case 3
Diffusion coefficient: $D \propto \beta D_{0xx} R^{-D_g}$	D_{0xx} ($10^{29} cm^2 s^{-1}$)	3.0	2.5	3.25
	D_{g1} [1]	0.514	0.51	0.514
	R (GV)	300	-	200
	D_{g2} [2]	0.27	-	0.40
Proton source injection: $\Phi \propto R^{-\gamma}$	γ_1 [3]	1.84	1.84	1.84
	R_1 (GV)	5.78	5.78	5.78
	γ_2 [4]	2.350	2.350	2.330
	R_2 (GV)	-	500	800
	γ_3 [5]	-	2.035	2.18
Helium source injection: $\Phi \propto R^{-\gamma}$	γ_1	1.344	1.644	1.644
	R_1 (GV)	5.78	5.78	5.78
	γ_2	2.3	2.274	2.274
	R_2 (GV)	-	300	400
	γ_3	-	2.039	2.099

Item		Case 1	Case 2	Case 3
Heavy nuclei with Z>2 source injection: $\Phi \propto R^{-\gamma}$	γ_1	1.864	1.864	1.864
	R_1 (GV)	5.78	5.78	5.78
	γ_2	2.364	2.364	2.364
	R_2 (GV)	-	300	250
	γ_3	-	2.06	2.18
Electron source injection: $\Phi \propto R^{-\gamma}$	γ_1	1.63	1.63	1.63
	R_1 (GV)	5.78	5.78	5.78
	γ_2	2.725	2.725	2.725
	R_2 (GV)	-	1000	1000
	γ_3	-	2.520	2.620

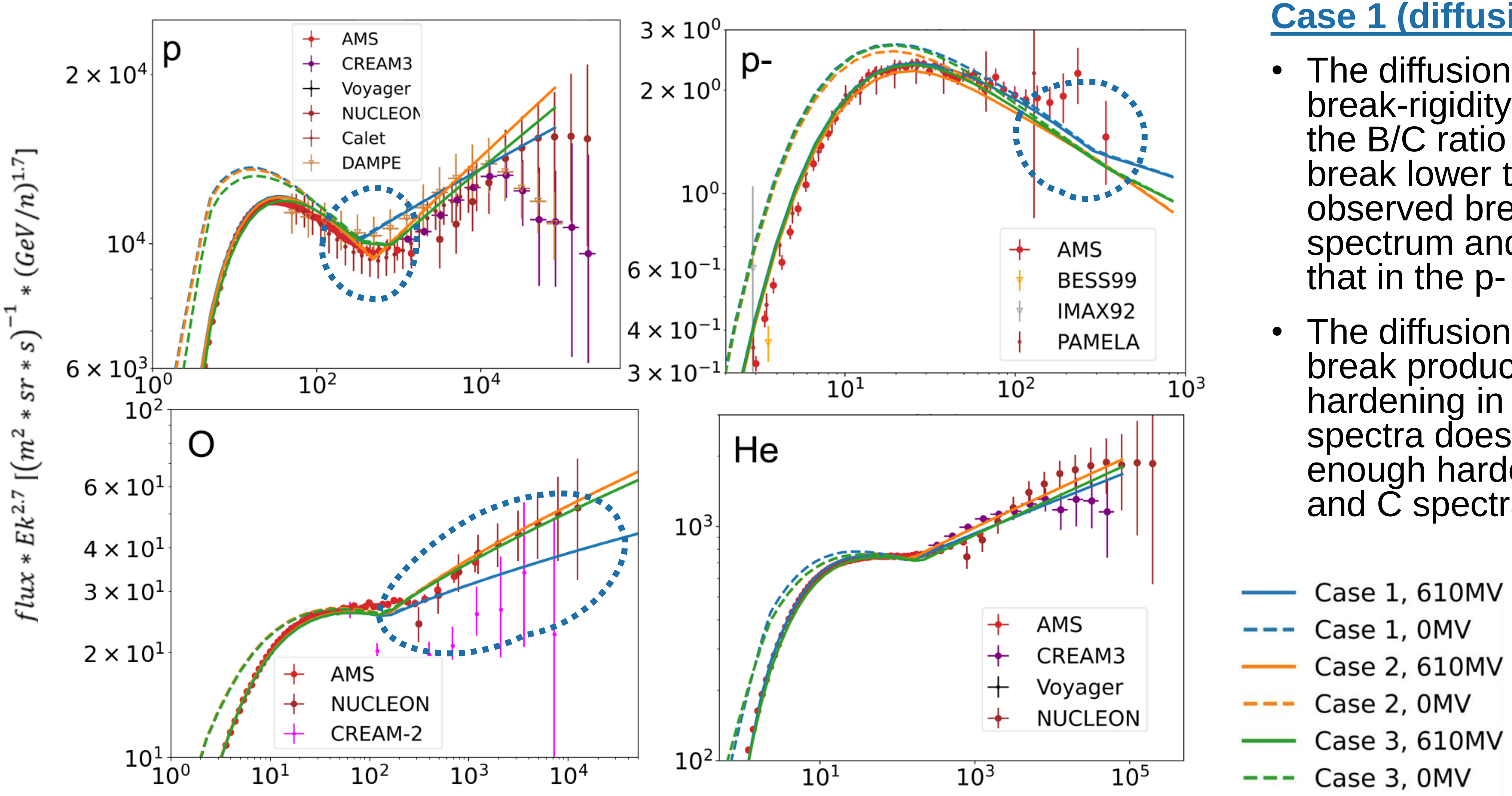
[1] the diffusion coefficient index D_g below the rigidity break R; [2] D_g above the rigidity break; [3] the injection index γ below the first rigidity break R_1; [4] γ above R_1 and below R_2; [5] γ above R_2.

Ratios



B/C
AMS
CREAM
ATIC-2
HEAO3-C2
NUCLEON
TRACER
CRN
p/He
ATIC-2
CREAM
JACEE
RUNJOB
LEAP
Case 1, 610MV
Case 1, 0MV
Case 2, 610MV
Case 2, 0MV
Case 3, 610MV
Case 3, 0MV
Energy per nucleon [GeV/n]

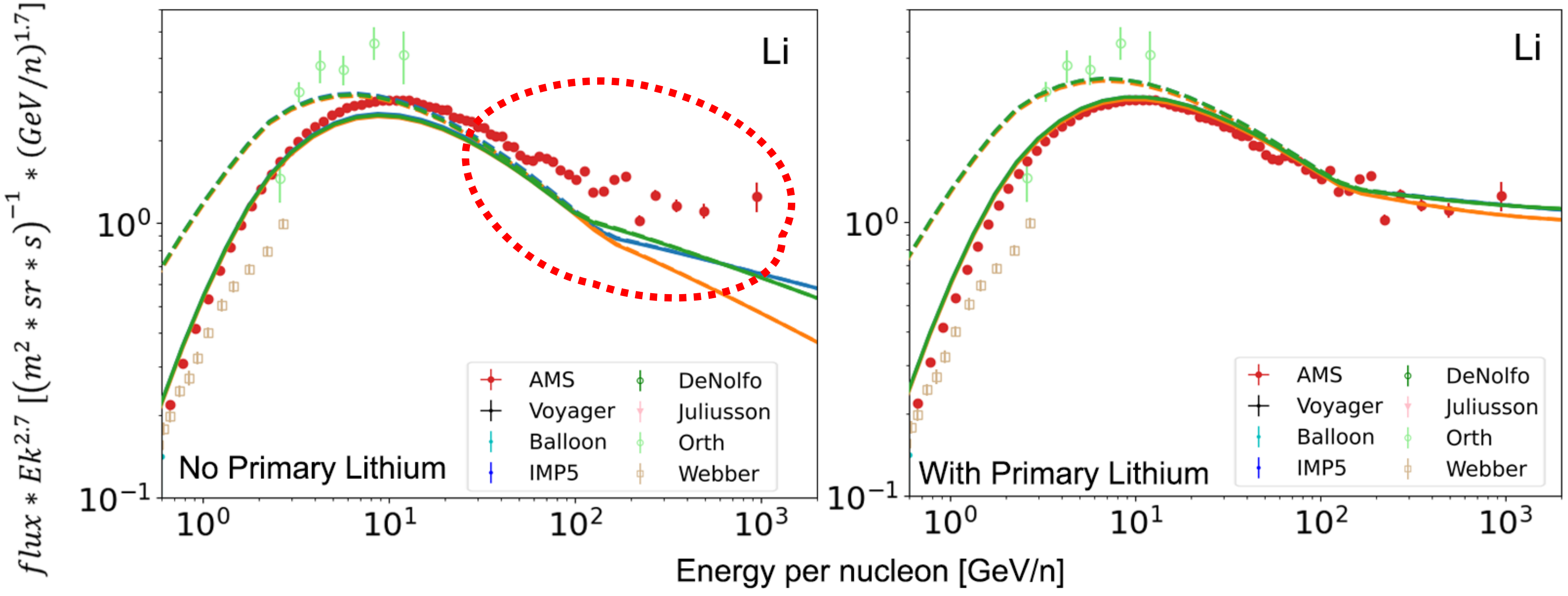
Calculated spectra: p, p-, O, and He



Case 1 (diffusion break):

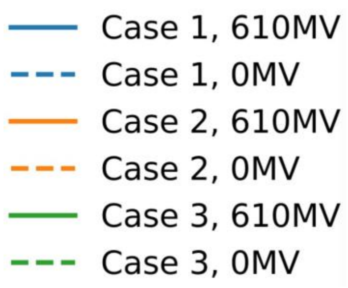
- The diffusion-coefficient break-rigidity calculated for the B/C ratio fit results in a break lower than the observed break in the p spectrum and higher than that in the p- spectrum.
- The diffusion coefficient break producing enough hardening in the p and He spectra does not produce enough hardening in the O and C spectra.

Introducing Lithium Source Injection

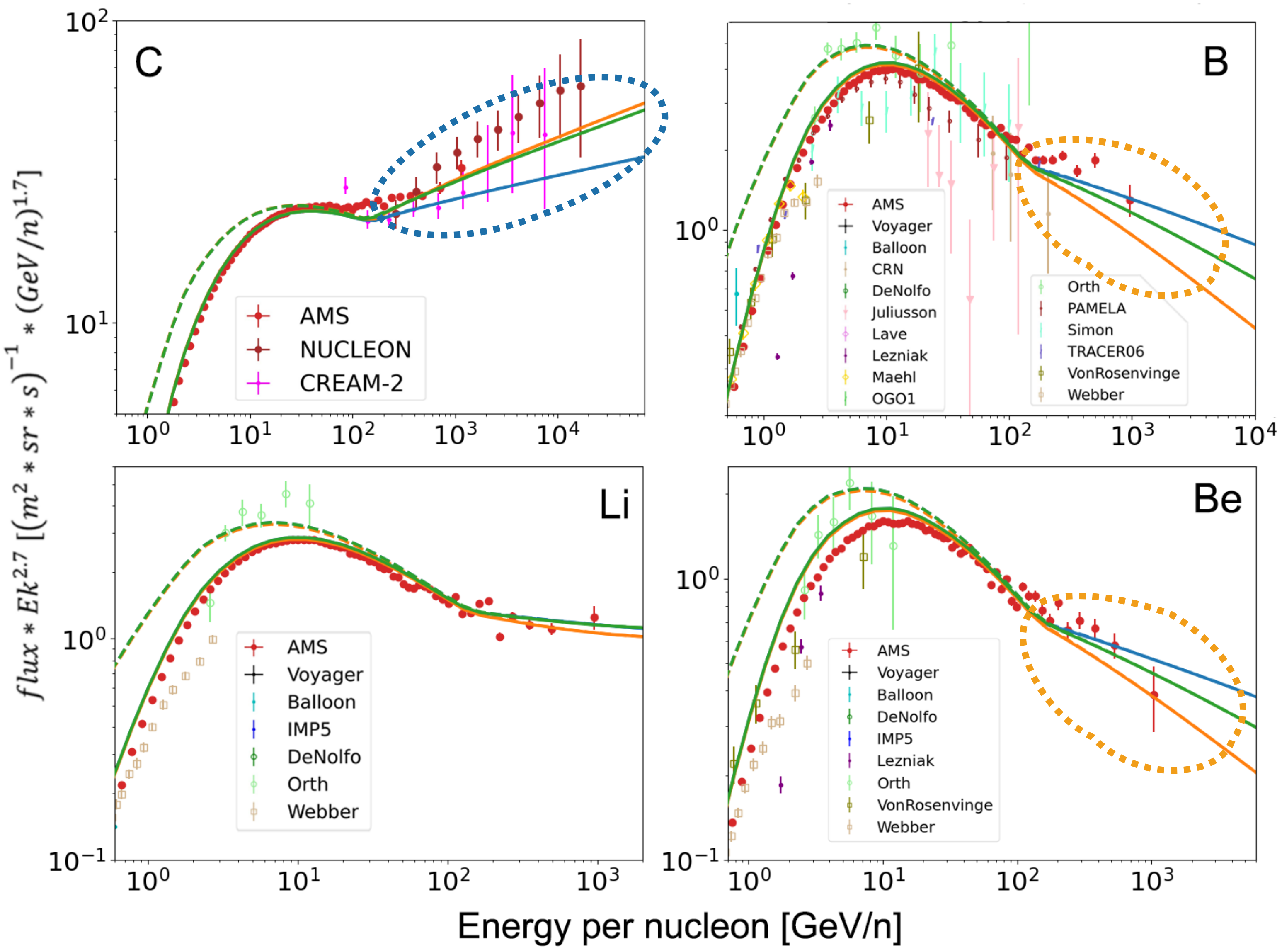


Nuclei	Source abundance
^{1}H	1.06*10^{6}
^{4}He	95525.52
^{12}C	3154.92
^{12}O	4106.8
^{20}Ne	477.36
^{24}Mg	622.64
^{28}Si	726.52
^{54}Fe	36.08
^{7}Li	**65.00**

- Inconsistency between calculated Li spectrum with data can be fixed by adding primary Lithium [M. J. Boschini, et al. *Astrophys. J.* 2 (2020): 167]

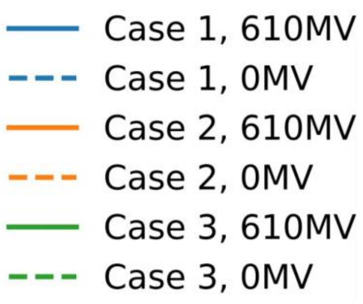


Calculated spectra: C, B, Li, and Be

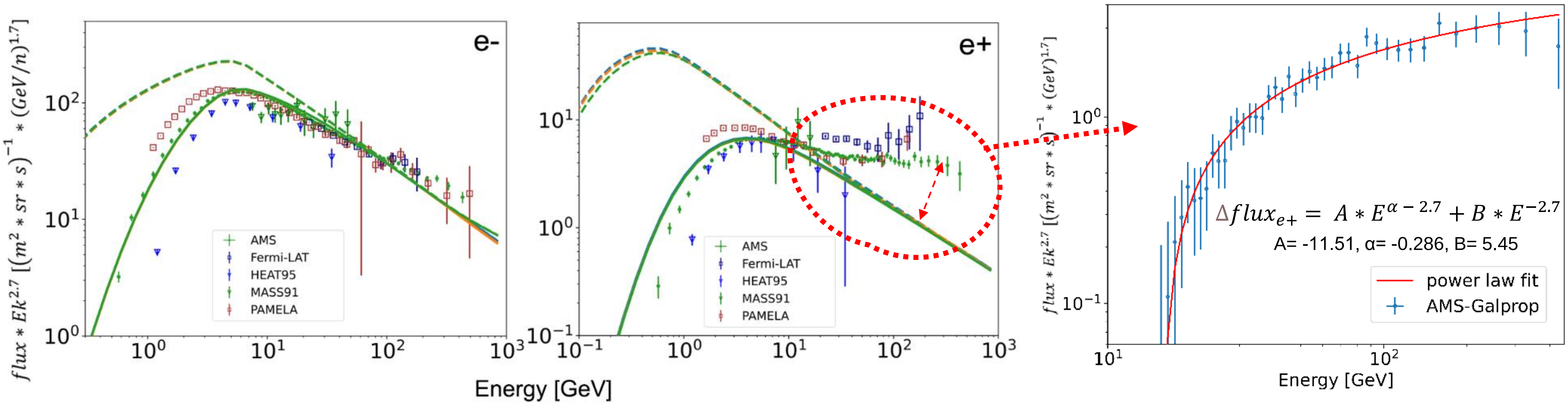


Case 2 (source break):

- The source-spectra break that fits the C and O spectral hardening does not produce enough hardening in the B and Be spectra.



Electron and Positron spectra



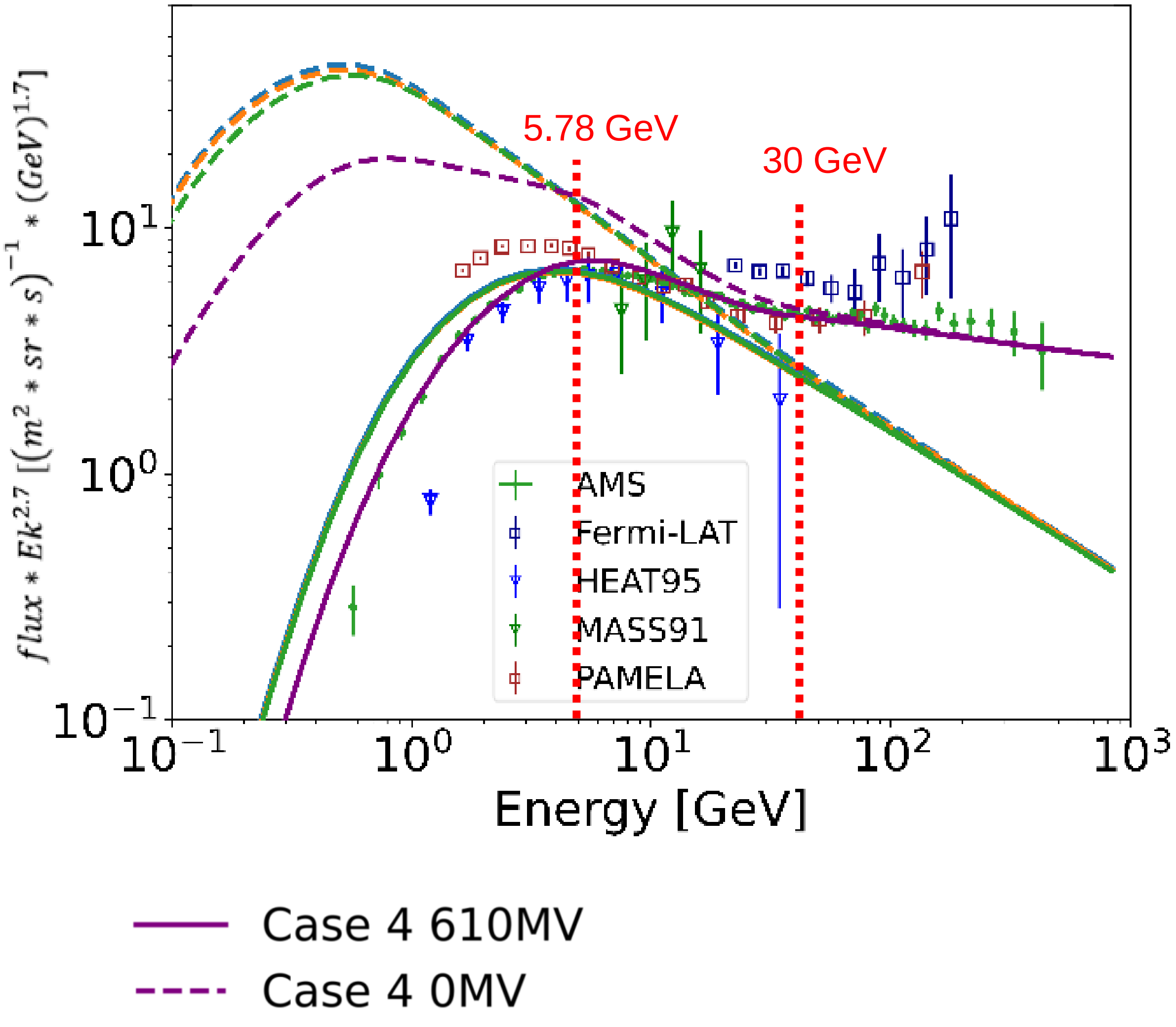
- All 3 cases show identical and acceptable agreement with electron data
- The disagreement with data in positron is much more significant

Introducing positron source injection

- Another Galprop run named Case 4 (purple curves) based on Case 3
- Source injection given by:

$$\boldsymbol{\Phi} \propto \boldsymbol{R}^{-\gamma} \begin{cases} \gamma = 1.83, for\ R \leq 5.78\ GV \\ \gamma = 2.5, for\ 5.78\ GV \leq R < 30\ GV \\ \gamma = 2.05, for\ R > 30\ GV \end{cases}$$

- Positron source with hardening starting at 30 GV produces e+ spectrum in agreement with data



Conclusion

- We studied three cases introducing a diffusion coefficient break, source injection breaks, and a combination of both.
  - Case 1 (diffusion break): The break-rigidity for the B/C ratio fit results in a break lower than the observed break in the p spectrum and higher than that in the p- spectrum. The break producing enough hardening in p and He does not produce enough hardening in O and C.
  - Case 2 (source break): The break that fits the C and O spectral hardening does not produce enough hardening in the B and Be spectra.
  - Case 3 (Mixed): has correct break rigidities in different elements, fits the hardenings in p, He, C and O spectra, while producing enough hardenings in B and Be spectra simultaneously.
- The spectral hardening supports the existence of a primary Lithium source with an abundance of 65 (relative to the proton source abundance $1.06*10^6$).
- The hardening in positron cannot be explained with all 3 cases we studied but can be fitted by introducing a primary positron under the same diffusion coefficient settings in case 3. This positron source has a rigidity break at 30 GV at which the injection index changes from 2.5 to 2.05.