Constraining cosmic-ray sources
with efficient propagation models

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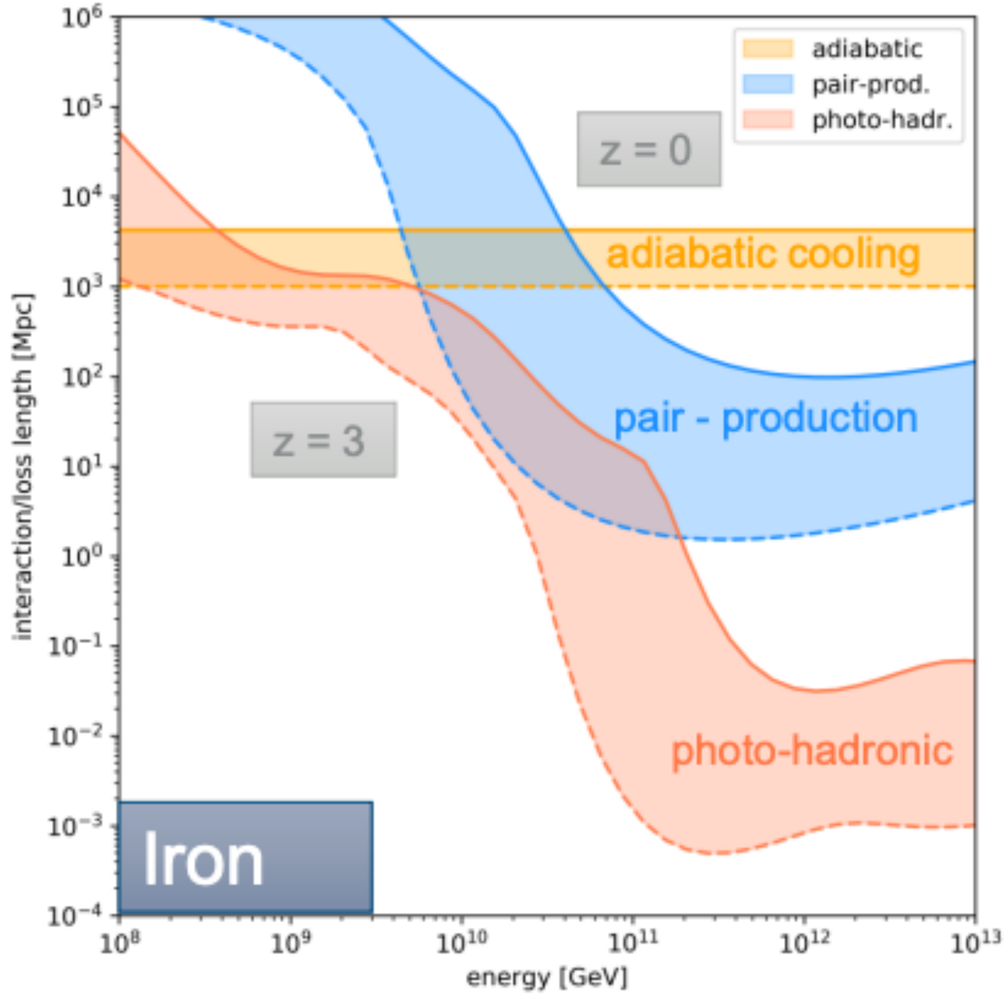
1. A novel framework: *PriNCe*
2. Combined source-propagation models
3. Two recent applications



$$\partial_t Y_i(E,z) = + \partial_E(HEY_i) - \partial_E\left(\frac{dE}{dt}Y_i\right) - \Gamma_i Y_i + \sum_j Q_{j\rightarrow i} + \mathcal{L}_i$$

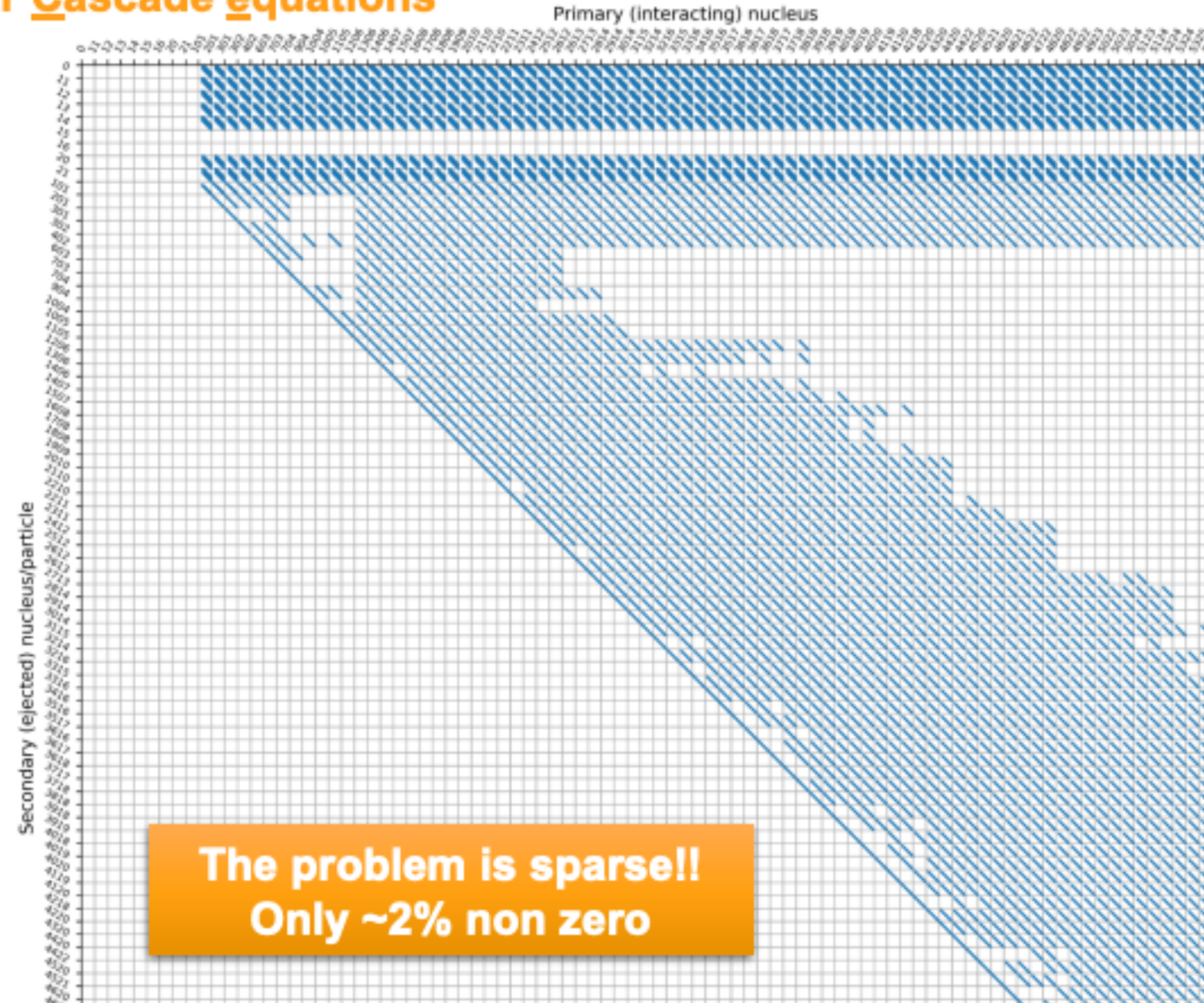
adiabatic cooling — pair - production — photo-hadronic — Injection

Propagation Code - PriNCe

Propagation including Nuclear Cascade equations

github.com/joheinze/PriNCe

- Written in pure Python using Numpy and Scipy
- Specifically makes use of sparse matrix structure
- **20s – 40s** for single spectrum (depending on number of system species)
- More efficient to study model uncertainties than Monte-Carlo (cross-section, photon fields etc.)

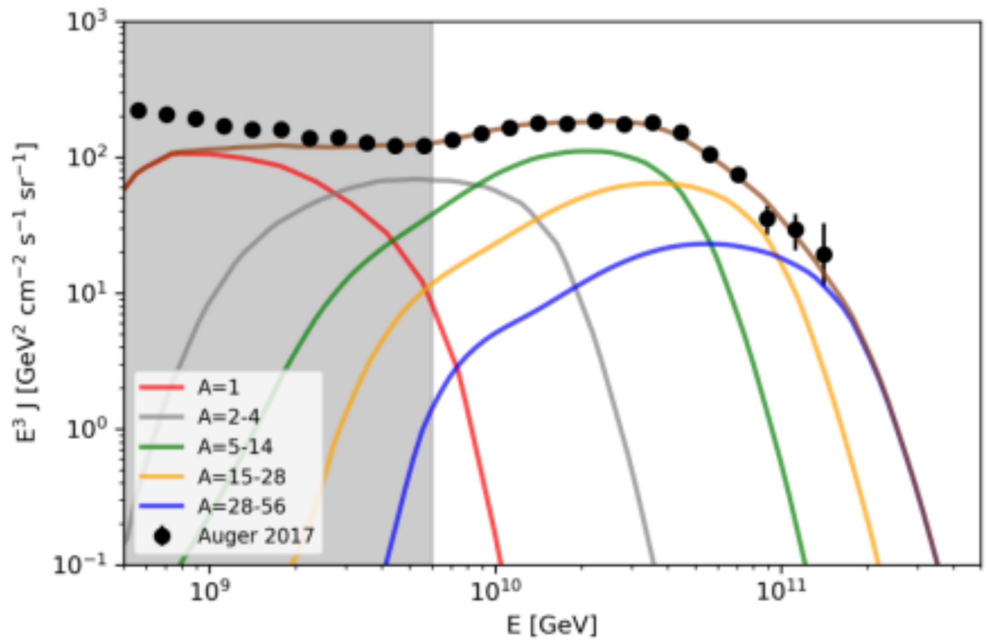


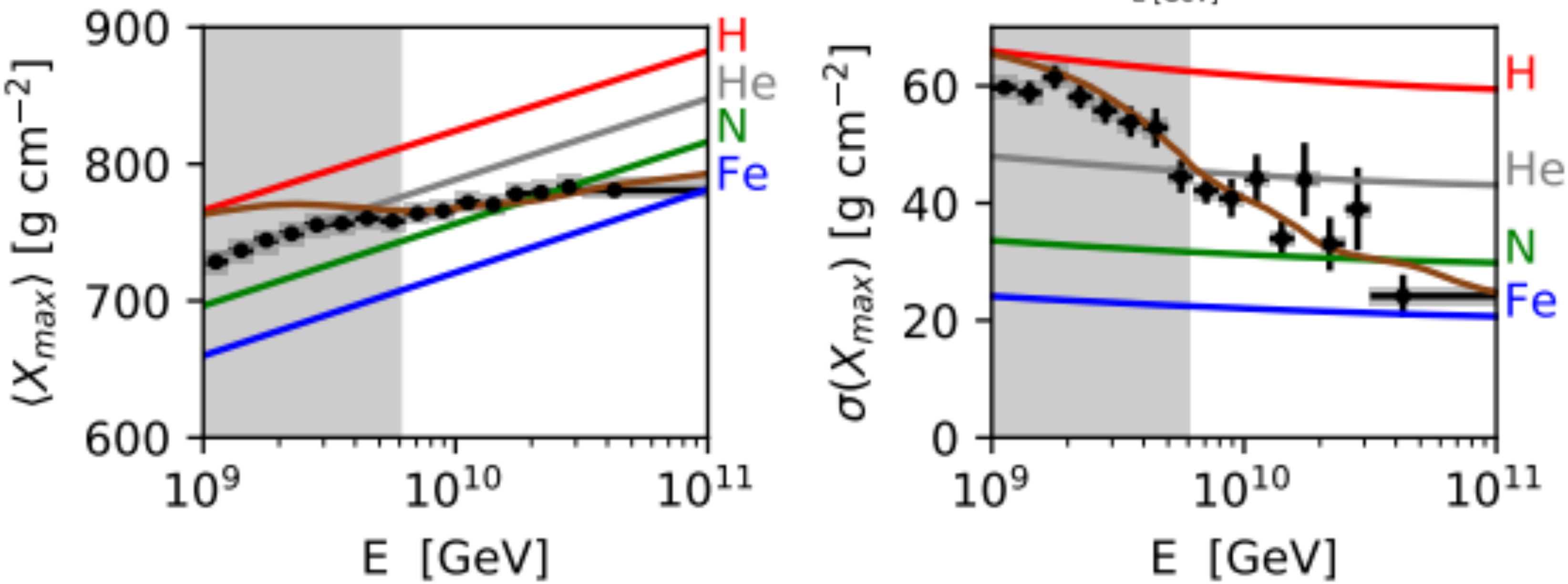
$$\partial_t Y_i(E,z) = +\,\partial_E(HEY_i) - \partial_E\left(\frac{dE}{dt}Y_i\right) - \Gamma_i Y_i + \sum_j Q_{j\to i} + \mathcal{L}_i$$

First results (Heinze et al 2019, ApJ 873)

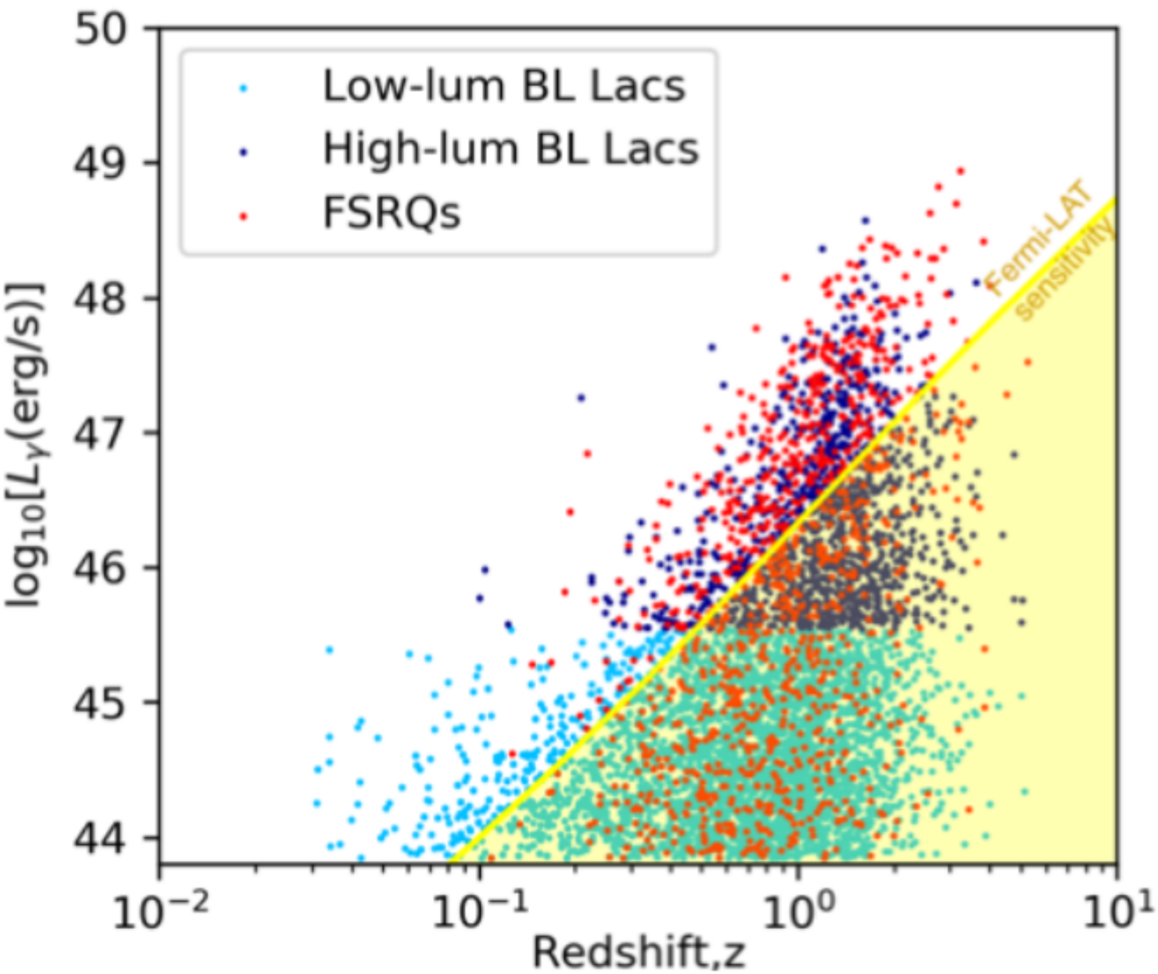
For combination Talys – Sibyll 2.3

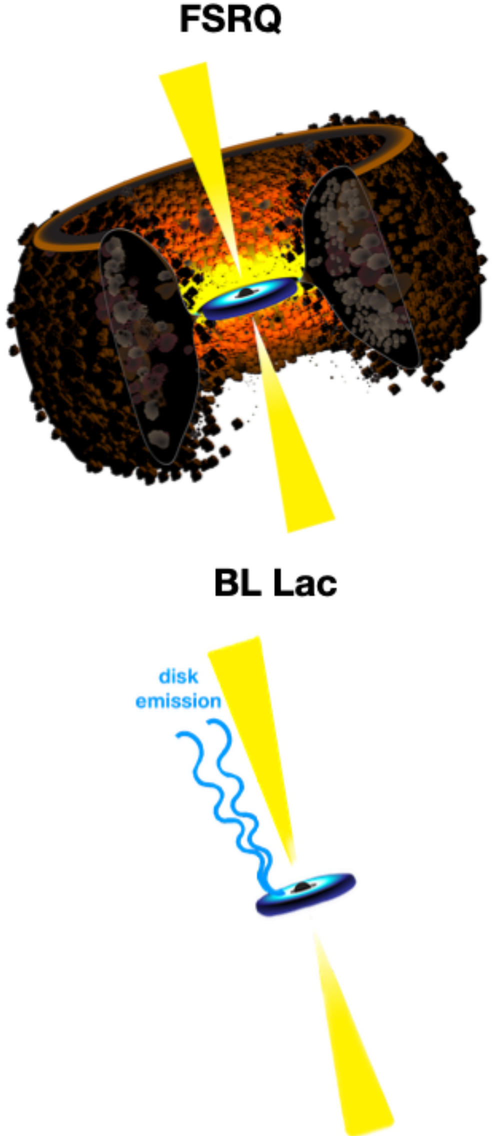
- Fit mainly sensitive to envelope of cutoffs
- Fit-range insensitive above z = 1!
- Composition below ankle proton dominated (by construction) …





Application 1: testing AGN as UHECR accelerators

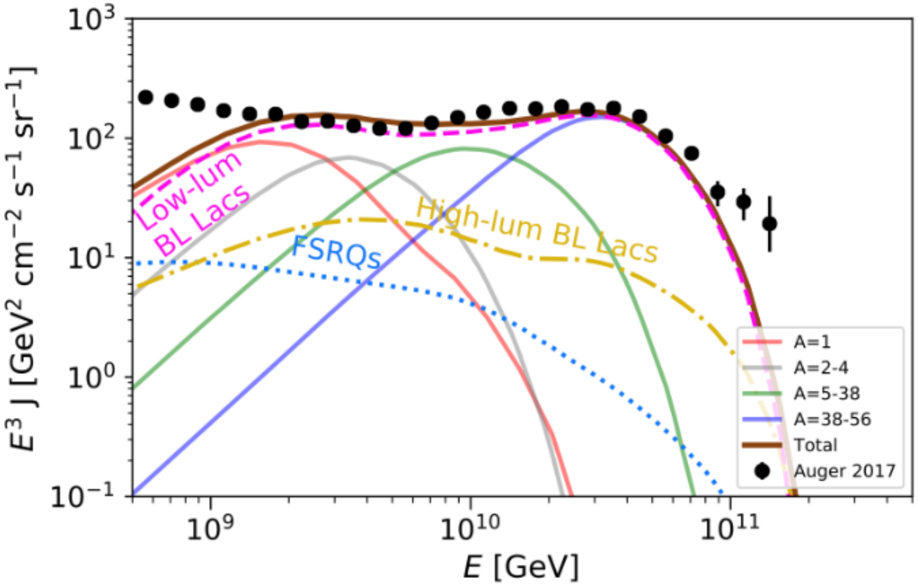




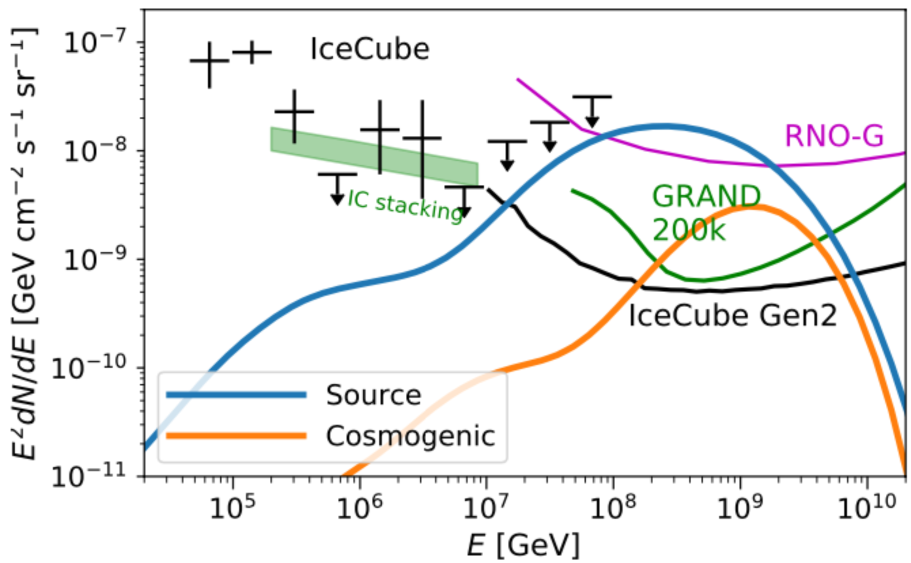
Rodrigues, Heinze, Palladino, van Vliet and Winter, PRL 126 (2021)

Application 1: testing AGN as UHECR accelerators

Spectrum



Neutrinos



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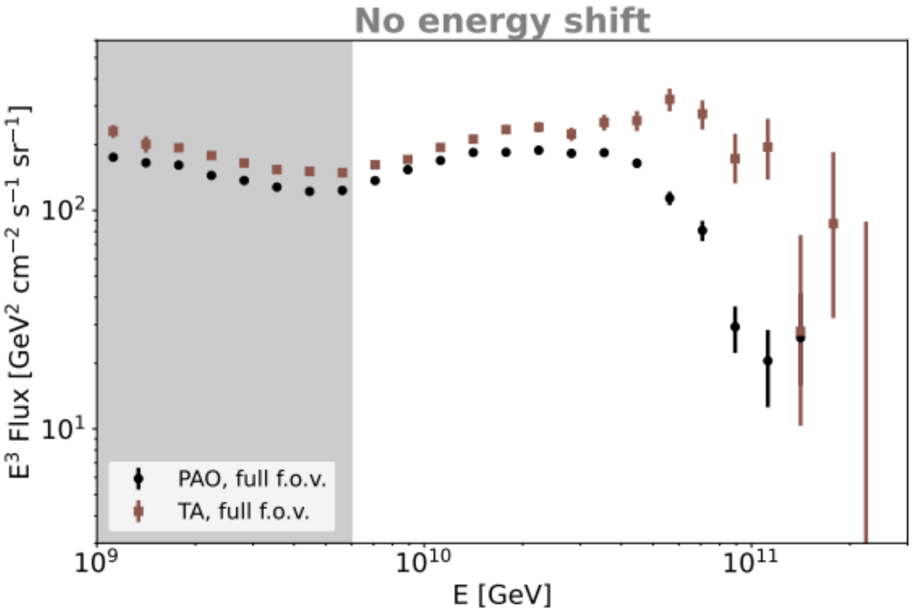
Application 2: testing astrophysics vs systematics



Deligny+ ICRC2019
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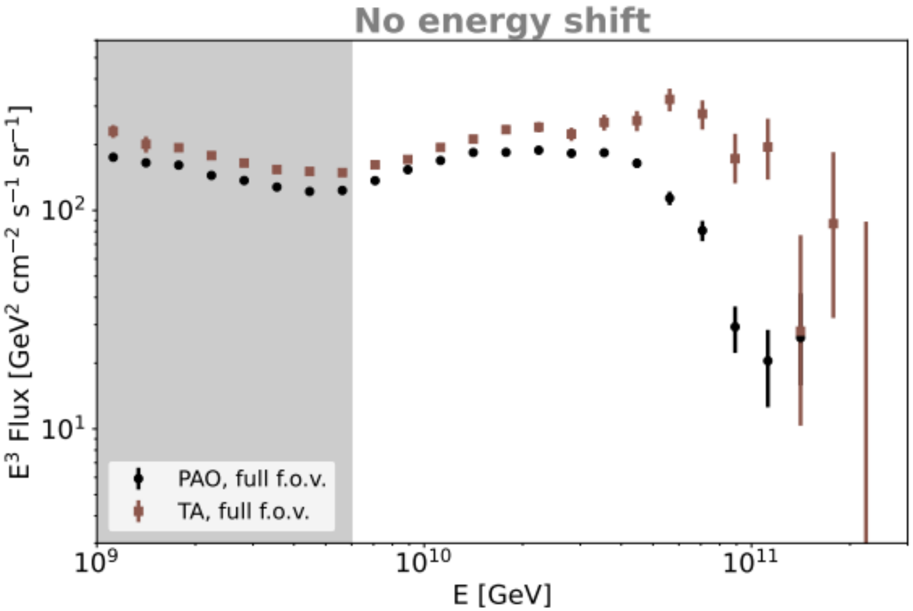

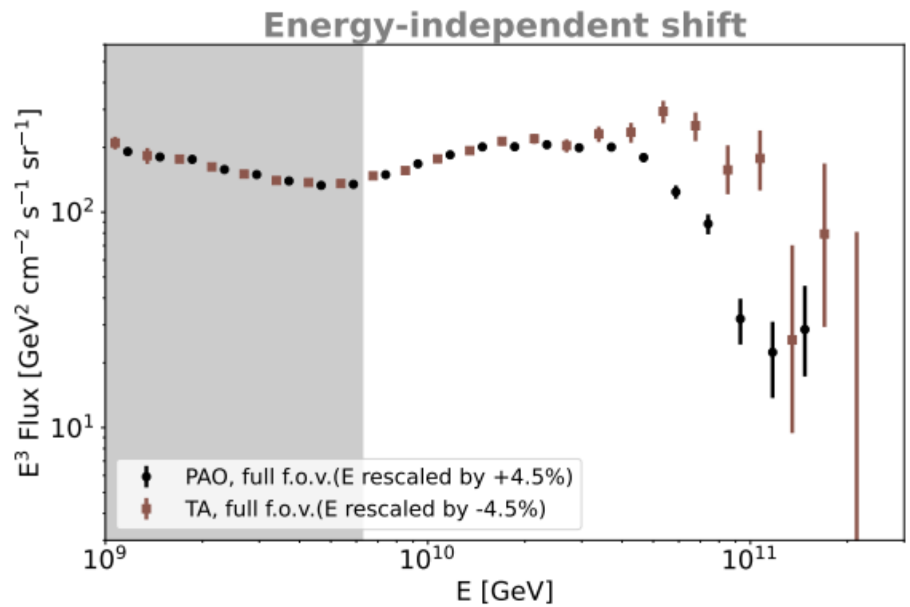

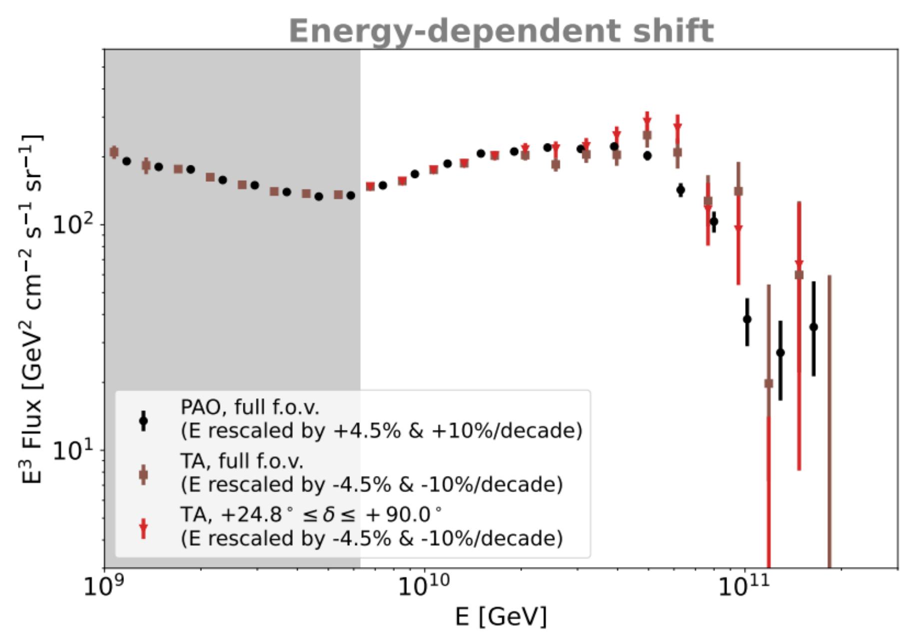

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Application 2: testing astrophysics vs systematics

$$\boldsymbol{\lambda}_{\rm cosmo} = (\gamma_{\rm cosmo}, R^{\rm max}_{\rm cosmo}, m_{\rm cosmo}, \mathcal{L}^{\rm CR}_{\rm cosmo}, \boldsymbol{f}^{\rm cosmo}_{\rm A}),$$

$$\boldsymbol{\lambda}_{\rm local} = (\gamma_{\rm local}, R^{\rm max}_{\rm local}, D_{\rm local}, L^{\rm CR}_{\rm local}, A_{\rm local}).$$

$$\chi^2_{\rm PAO} = \chi^2_{\rm PAO}(\boldsymbol{\lambda}_{\rm cosmo}, \delta^{\rm PAO}_{E}, \delta^{\rm PAO}_{\langle X_{\rm max}\rangle}, \delta^{\rm PAO}_{\sigma(X_{\rm max})}).$$

$$\chi^2_{\rm TA} = \chi^2_{\rm TA}(\boldsymbol{\lambda}_{\rm cosmo}, \boldsymbol{\lambda}_{\rm local}, \delta^{\rm TA}_{E}, \delta^{\rm TA}_{\langle X_{\rm max}\rangle}, \delta^{\rm TA}_{\sigma(X_{\rm max})}),$$

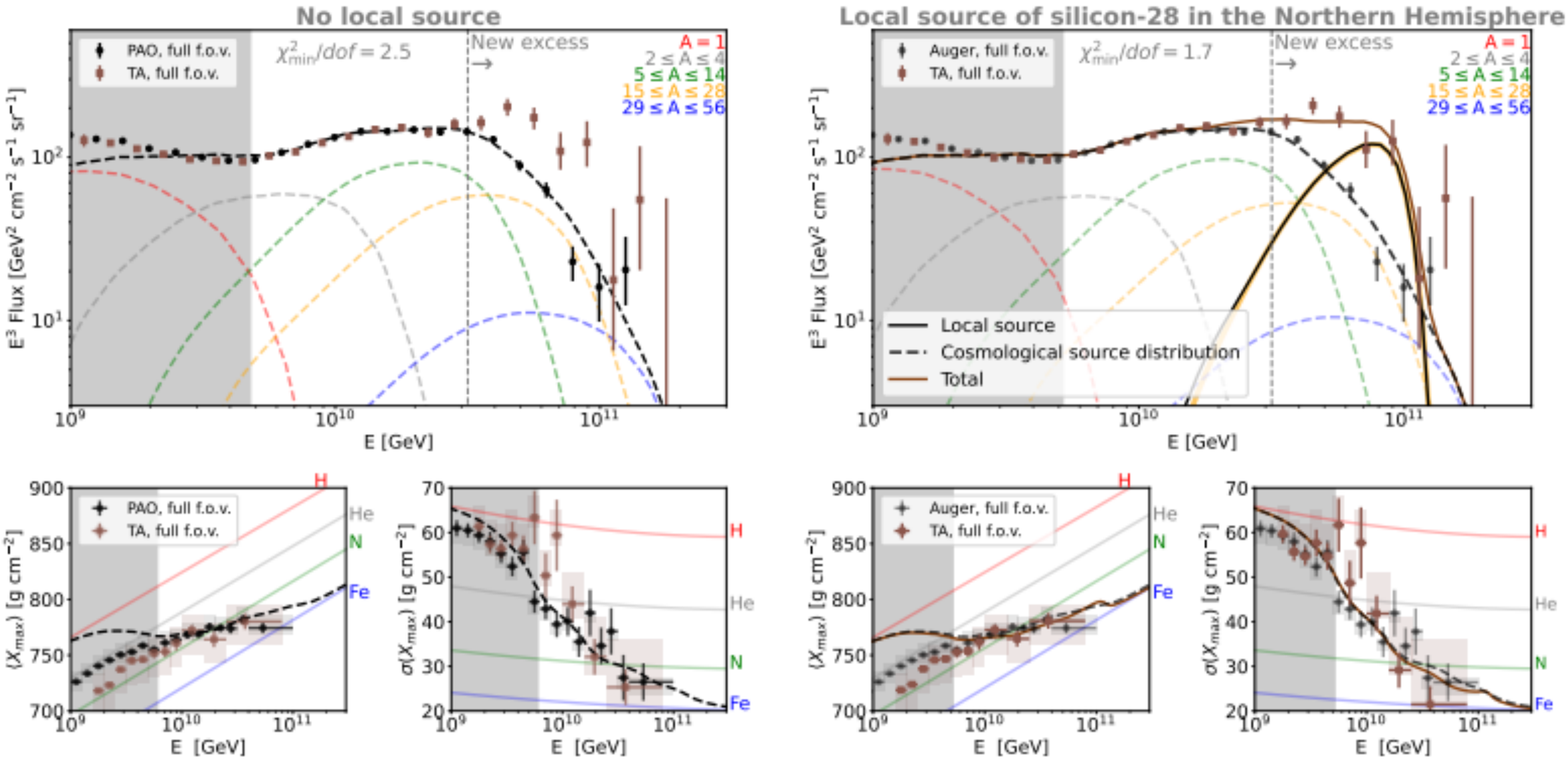
astrophysics

systematics

PAVLO PLOTKO,[1] ARJEN VAN VLIET,[1,2] XAVIER RODRIGUES,[1,3] AND WALTER WINTER[1]

arXiv:2208.12274

Application 2: testing astrophysics vs systematics



Assuming a simple scenario of energy-independent systematic shift between PAO and TA, a local UHECR source in the northern sky significantly improves a joint combined fit

Pavlo Plotko [1], Arjen van Vliet [1, 2] Xavier Rodrigues [1, 3] and Walter Winter [1]

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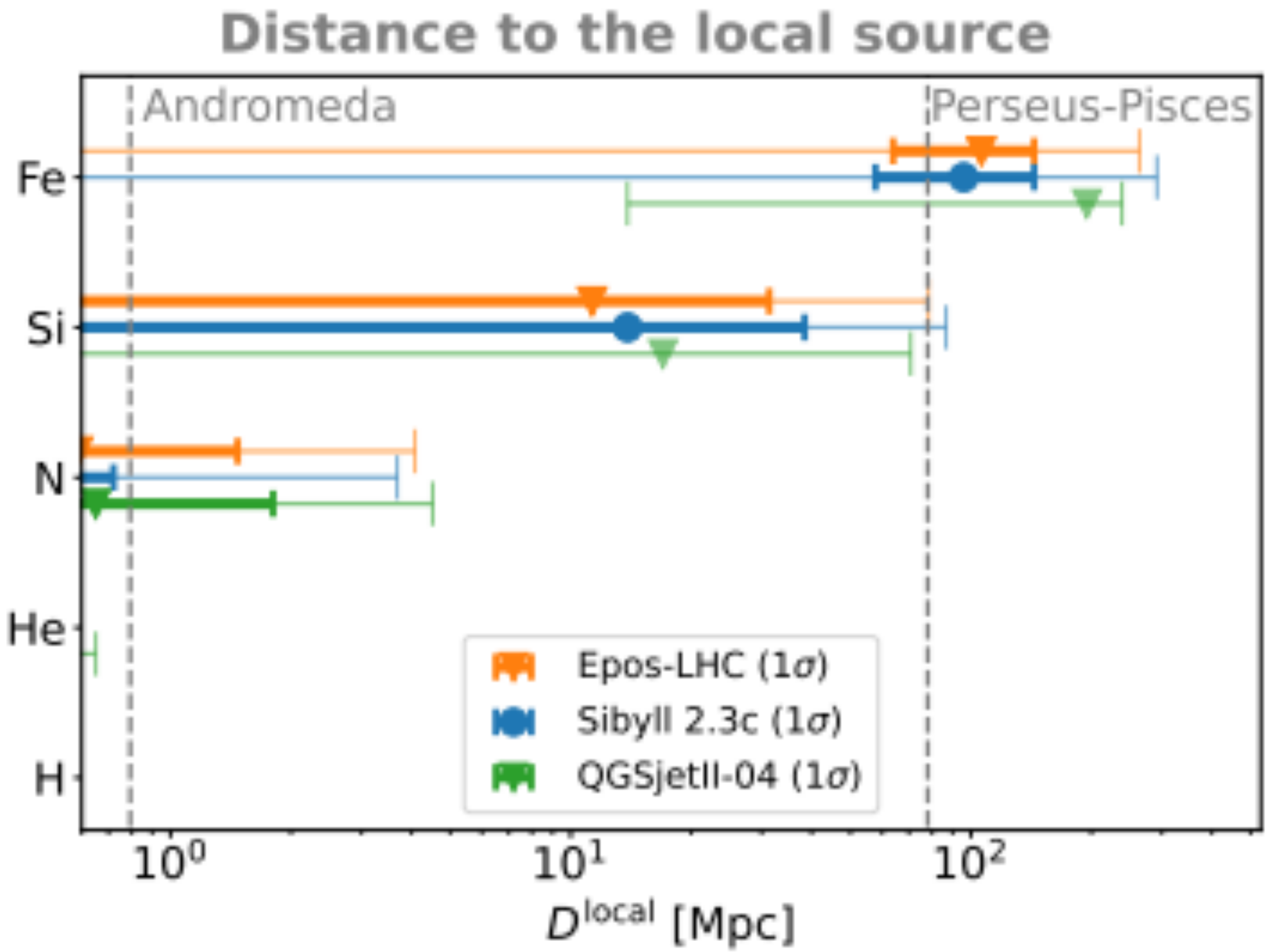

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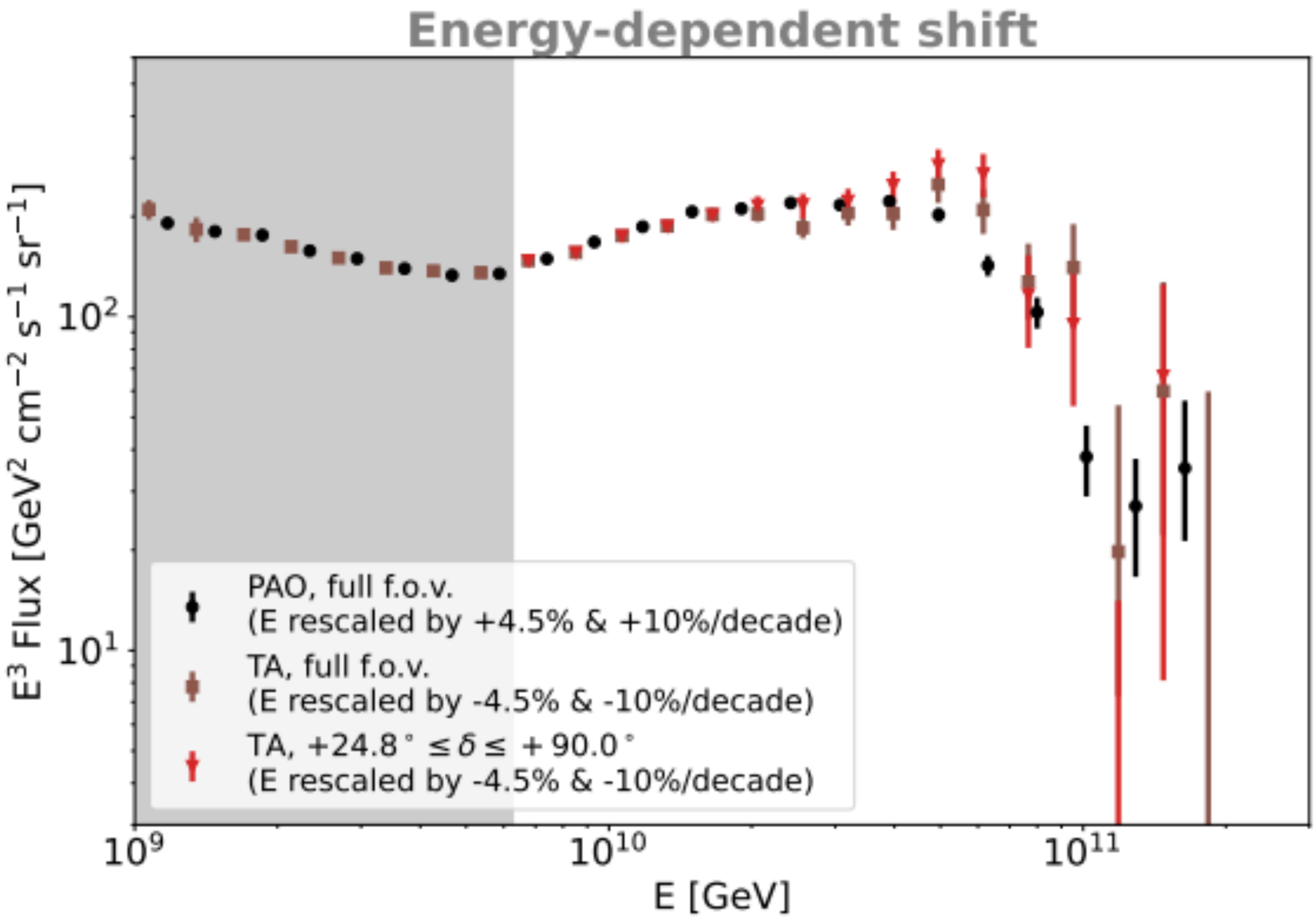

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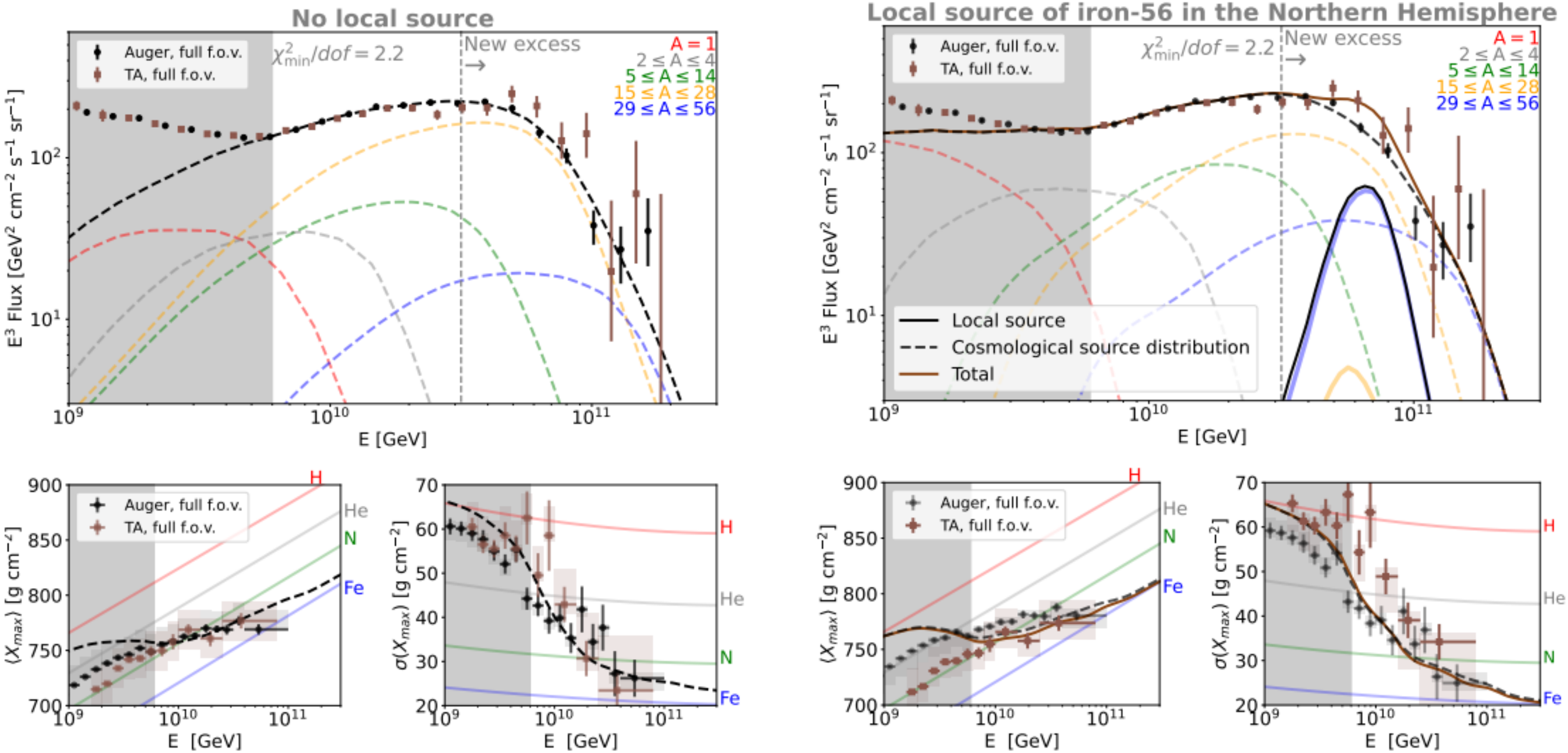

Even in the case where all the differences in the common declination band are explained by systematics, there is still room for a local source in the Northern Hemisphere.
(neither scenario is currently favoured compared to the other for the full-sky data set)

PAVLO PLOTKO [1], ARJEN VAN VLIET [1,2] XAVIER RODRIGUES [1,3] AND WALTER WINTER [1]

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