
EBL's role in answering the big questions on UHECRs

Leonel Morejon

Astroparticle Symposium - 2024

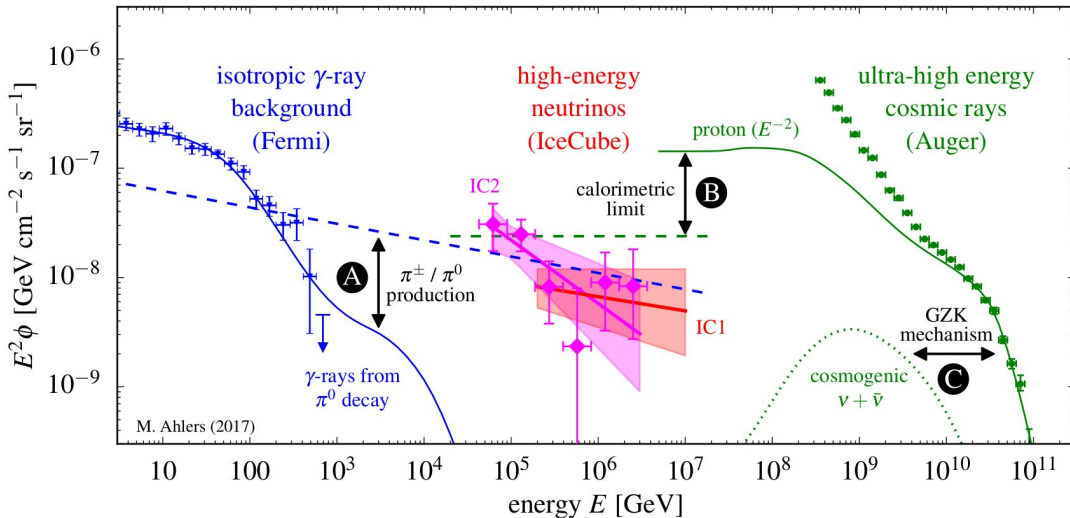
12-15.11.2024



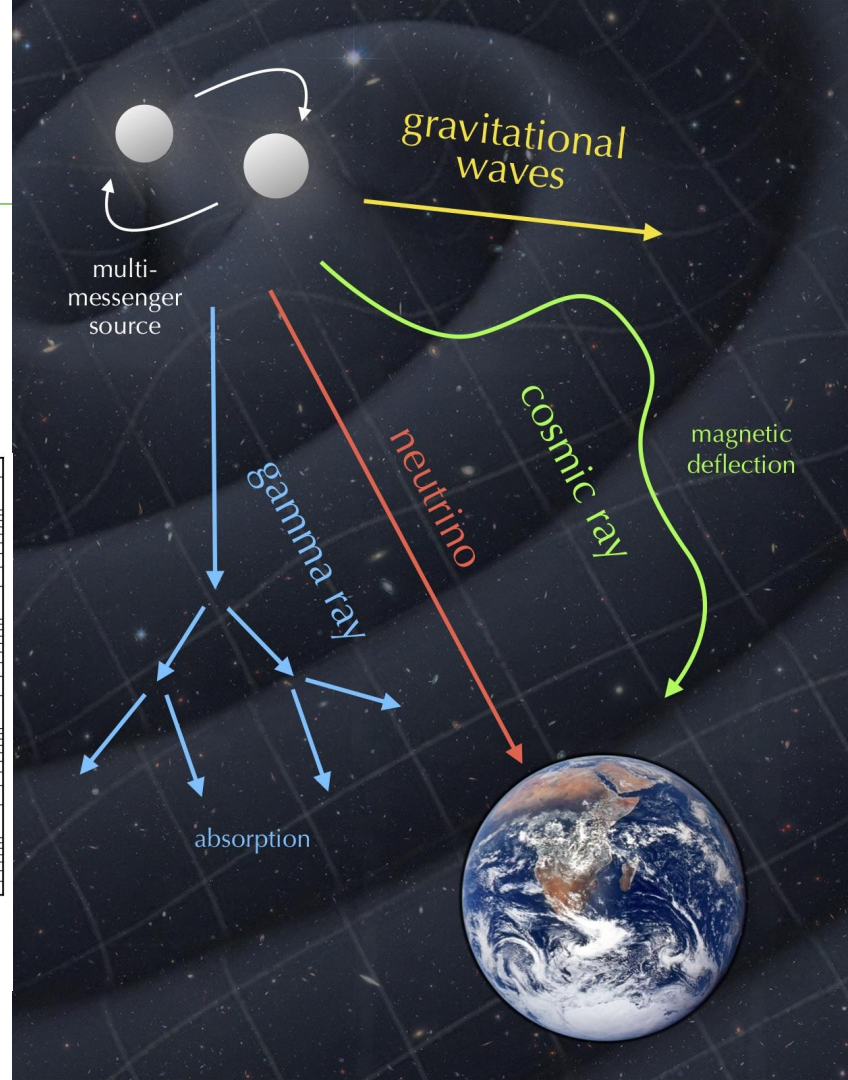
BERGISCHE
UNIVERSITÄT
WUPPERTAL

The big picture: multi-messengers

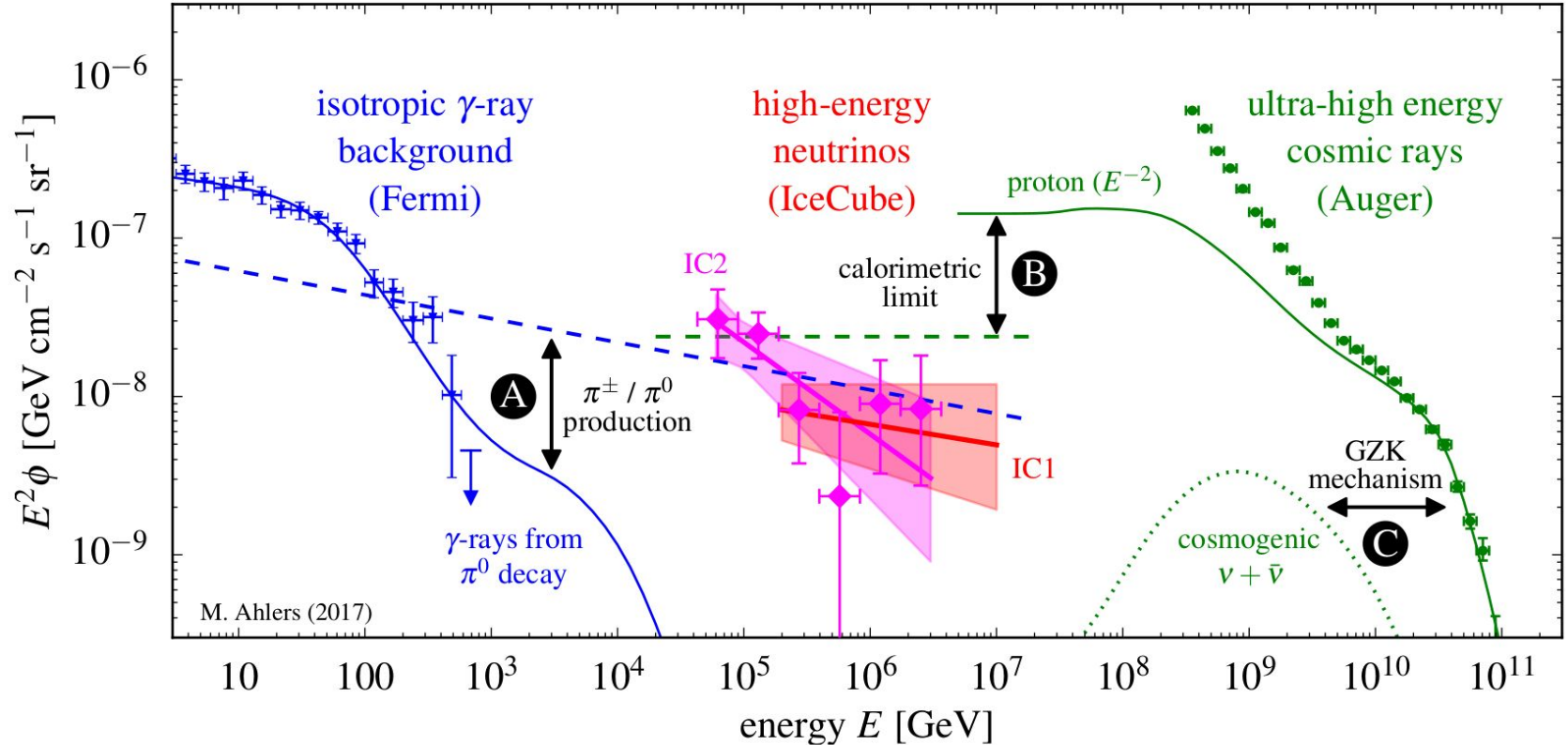
Cosmic rays' fingerprints are latent in all messengers: interactions are the key!



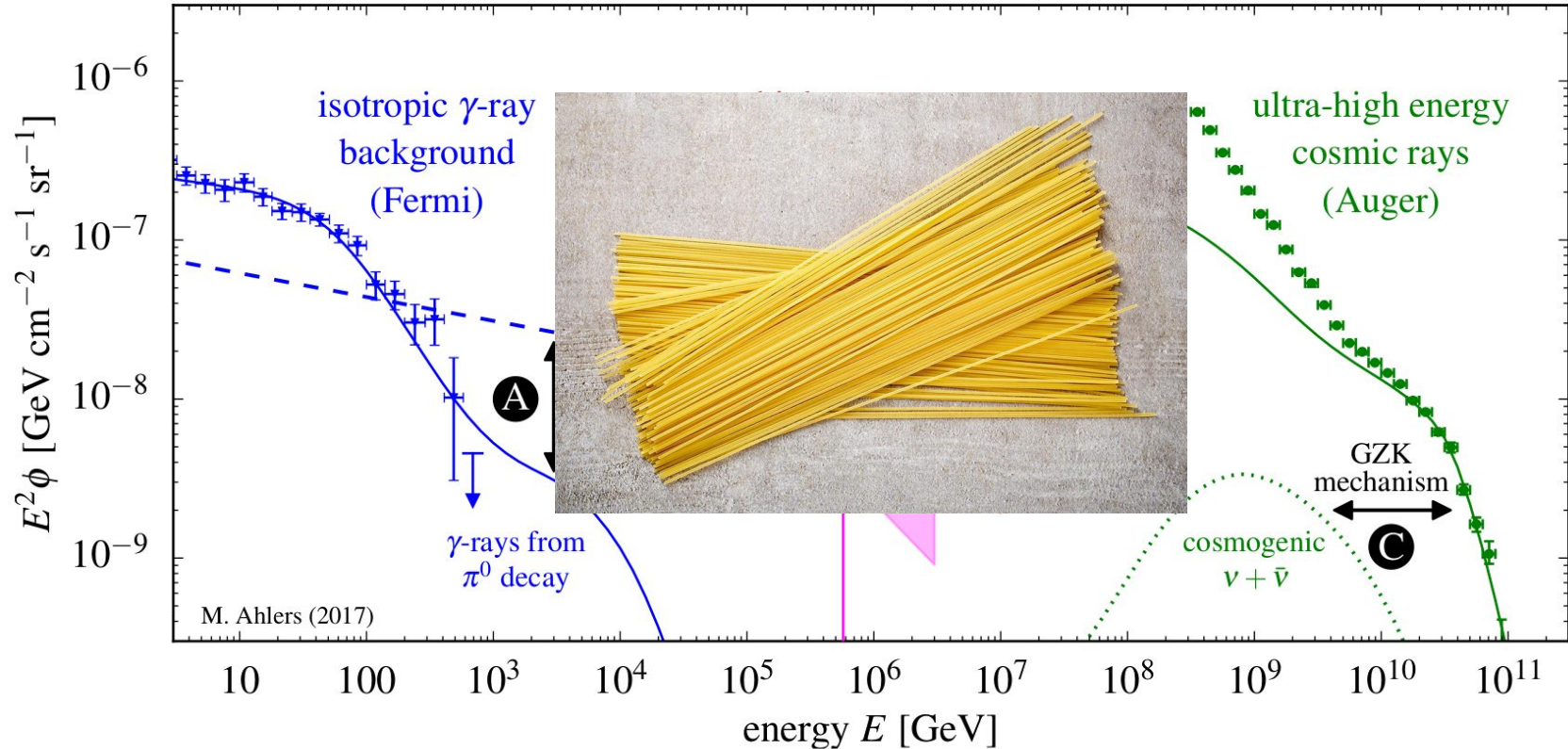
Source: Niels Bohr Institute's website



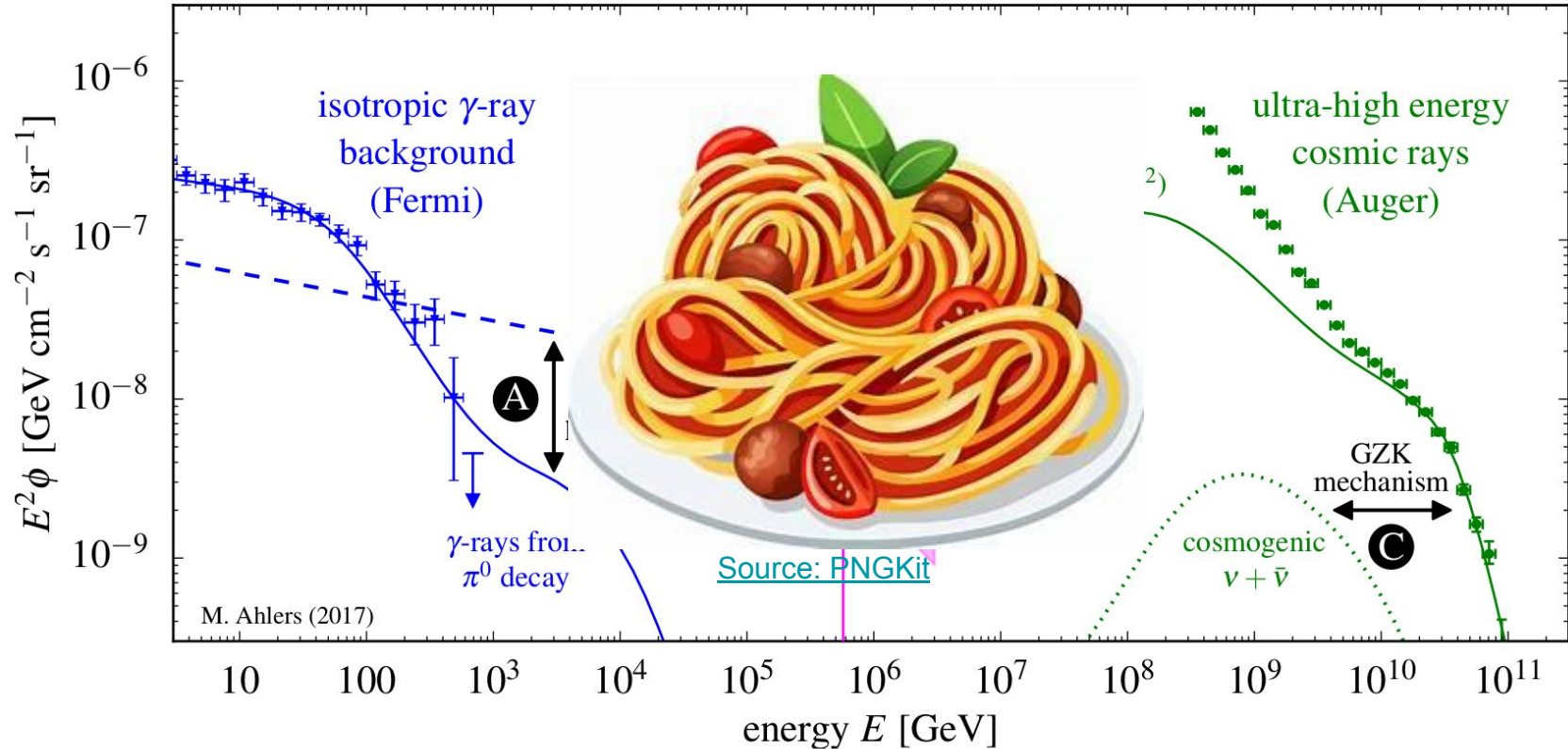
The “messy” picture: spaghetti correlations



The “messy” picture: spaghetti correlations



The “messy” picture: spaghetti correlations



The “messy” picture: spaghetti correlations

Background
photons



Interaction
types

Magnetic
fields

[Source: PNGKit](#)

Composition

“Cooking up” to understand the observed relations

Synthetic pasta with ingredients

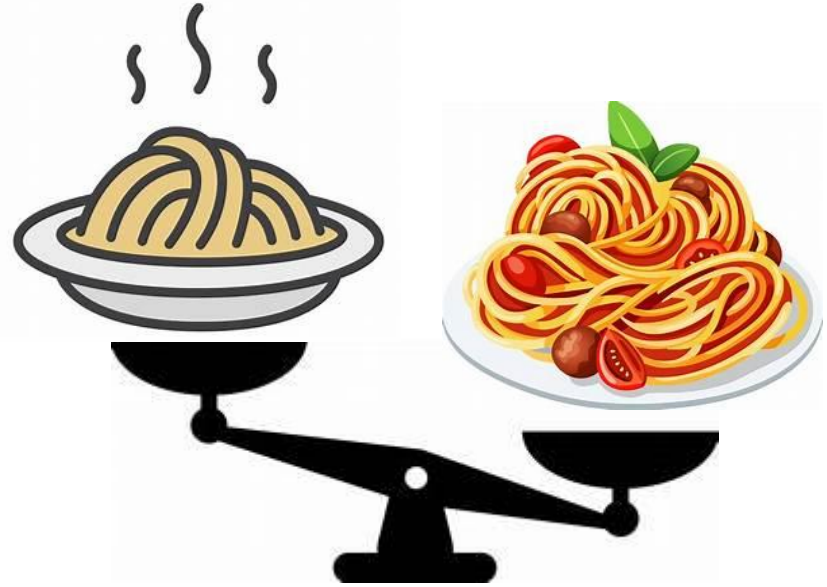
- Background photons
- Interaction types
- Composition
- Magnetic fields



“Cooking up” to understand the observed relations

Synthetic pasta with ingredients

- Background photons
- Interaction types
- Composition
- Magnetic fields



Too many cooks can spoil the **pasta**

UHECR Source



SHOCK WAVE

p

π^0

π^-

e

e

e

e

μ

e

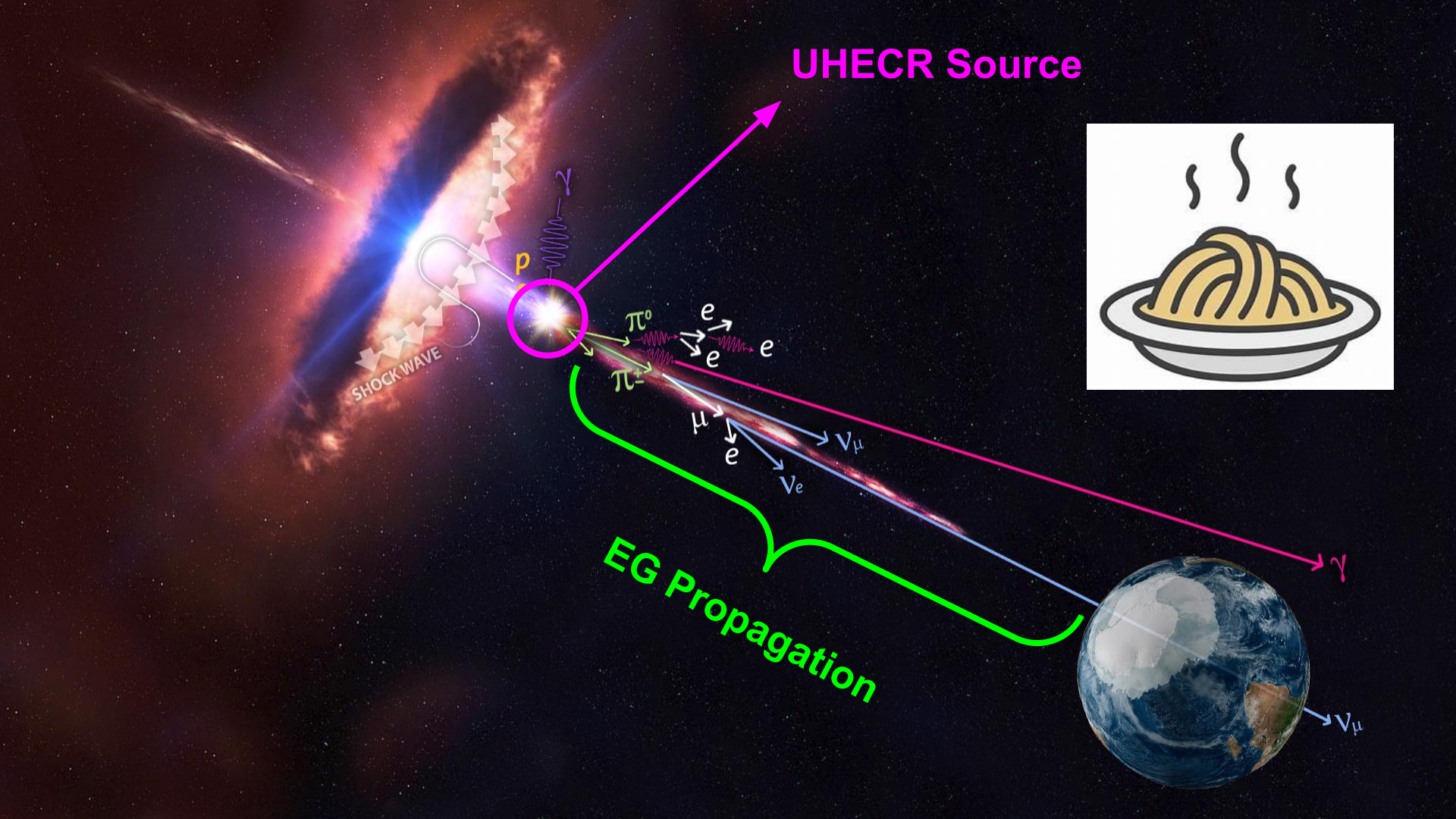
v_μ

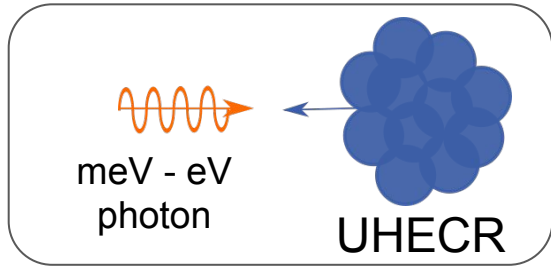
v_e

EG Propagation

γ

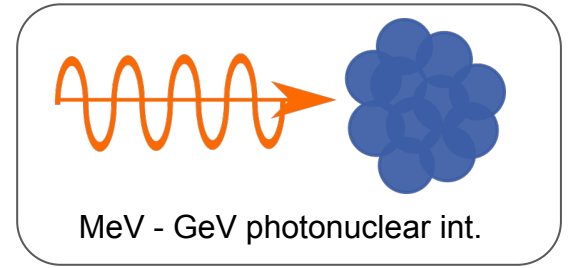
v_μ

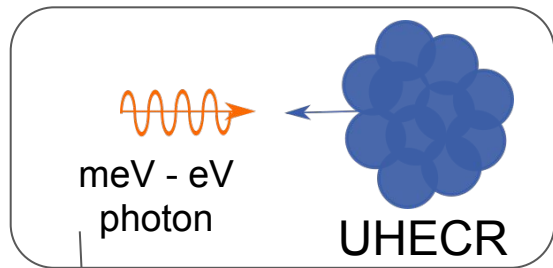




to center of mass
reference frame

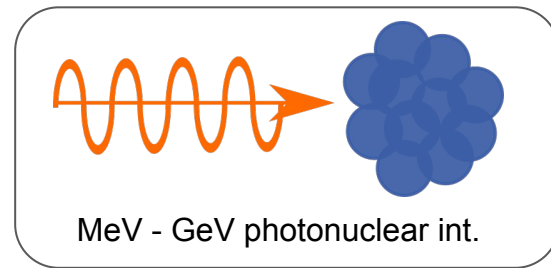
A dashed black arrow points from the left diagram to the right diagram, indicating a transition to the center of mass reference frame.



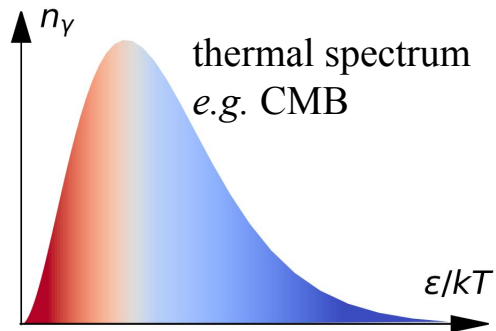


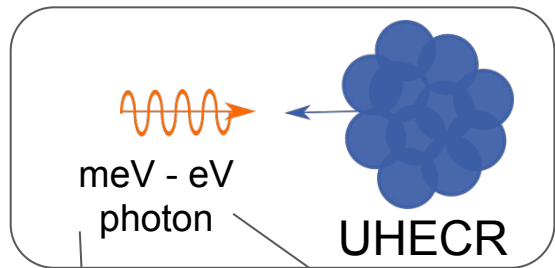
to center of mass
reference frame

A dashed arrow pointing to the right.



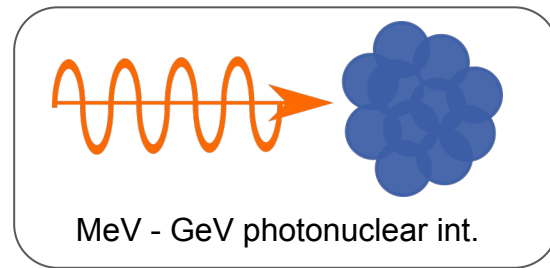
PROPAGATION





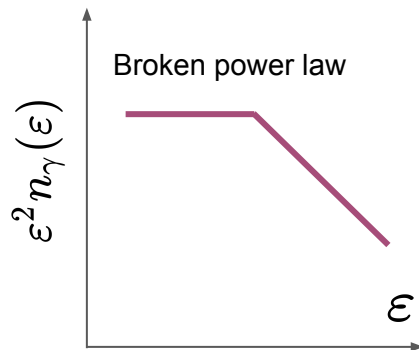
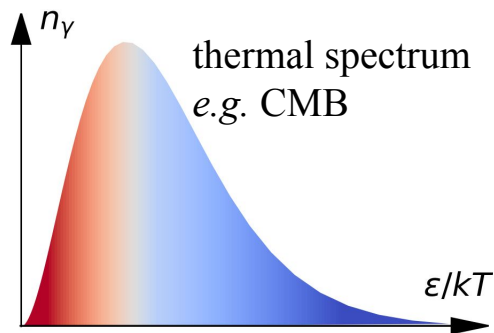
to center of mass
reference frame

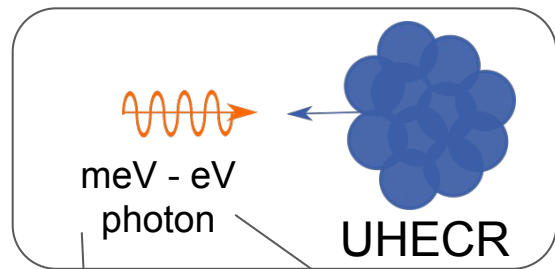
A dashed arrow pointing to the right.



PROPAGATION

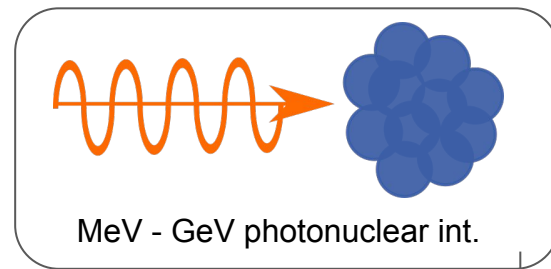
SOURCE





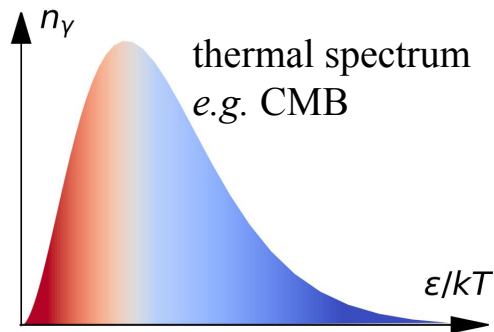
to center of mass reference frame

A dashed arrow points from the left diagram to the right diagram.

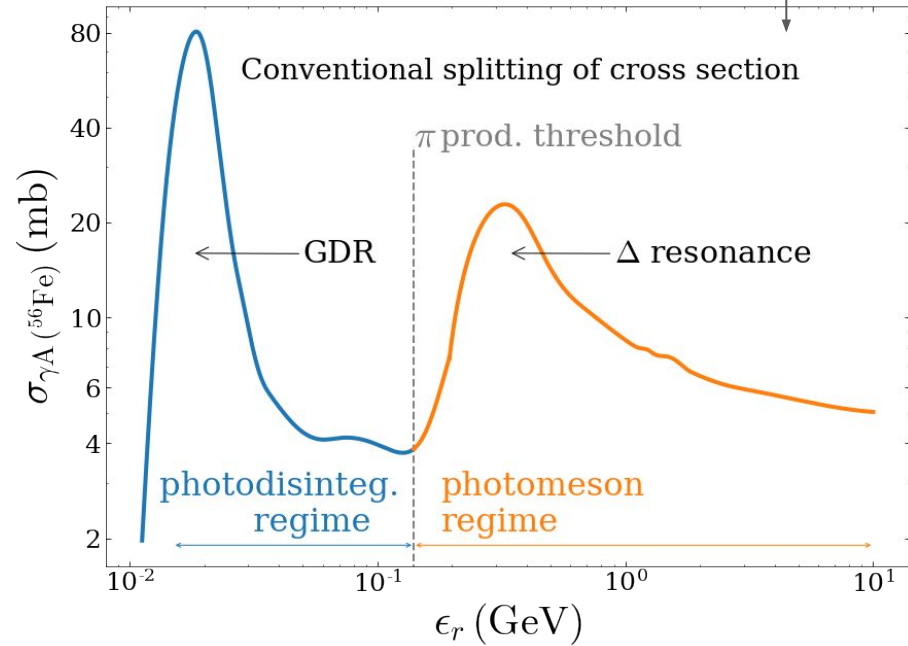
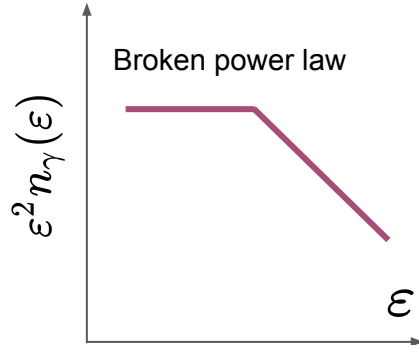


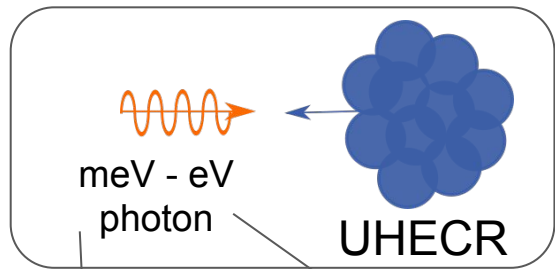
[L. Morejon et al JCAP11\(2019\)007](#)

PROPAGATION

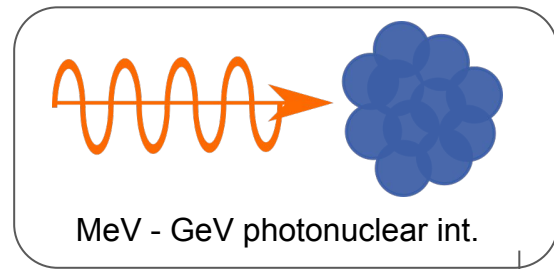


SOURCE



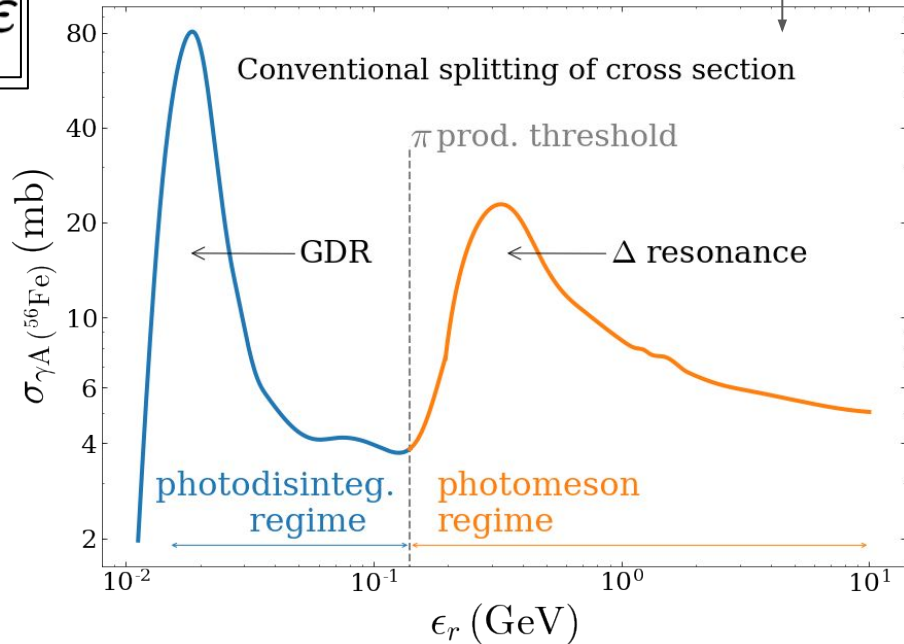


to center of mass reference frame



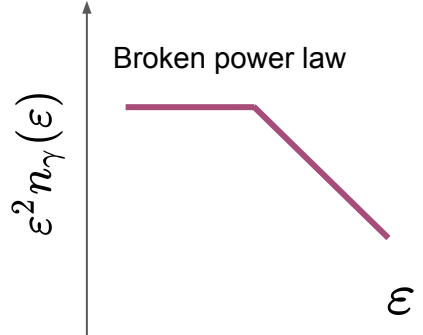
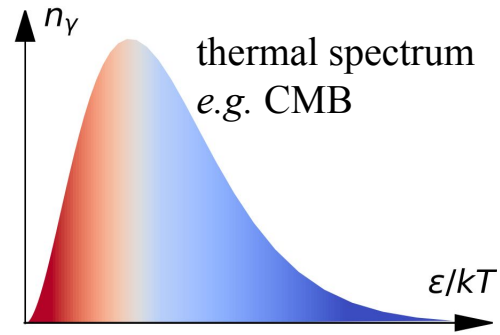
$$\lambda(\gamma) = \frac{1}{2\gamma^2} \int_0^\infty \frac{n(\epsilon)}{\epsilon^2} d\epsilon \int_0^{2\epsilon\gamma} \epsilon \sigma(\epsilon) d\epsilon$$

[L. Morejon et al JCAP11\(2019\)007](#)



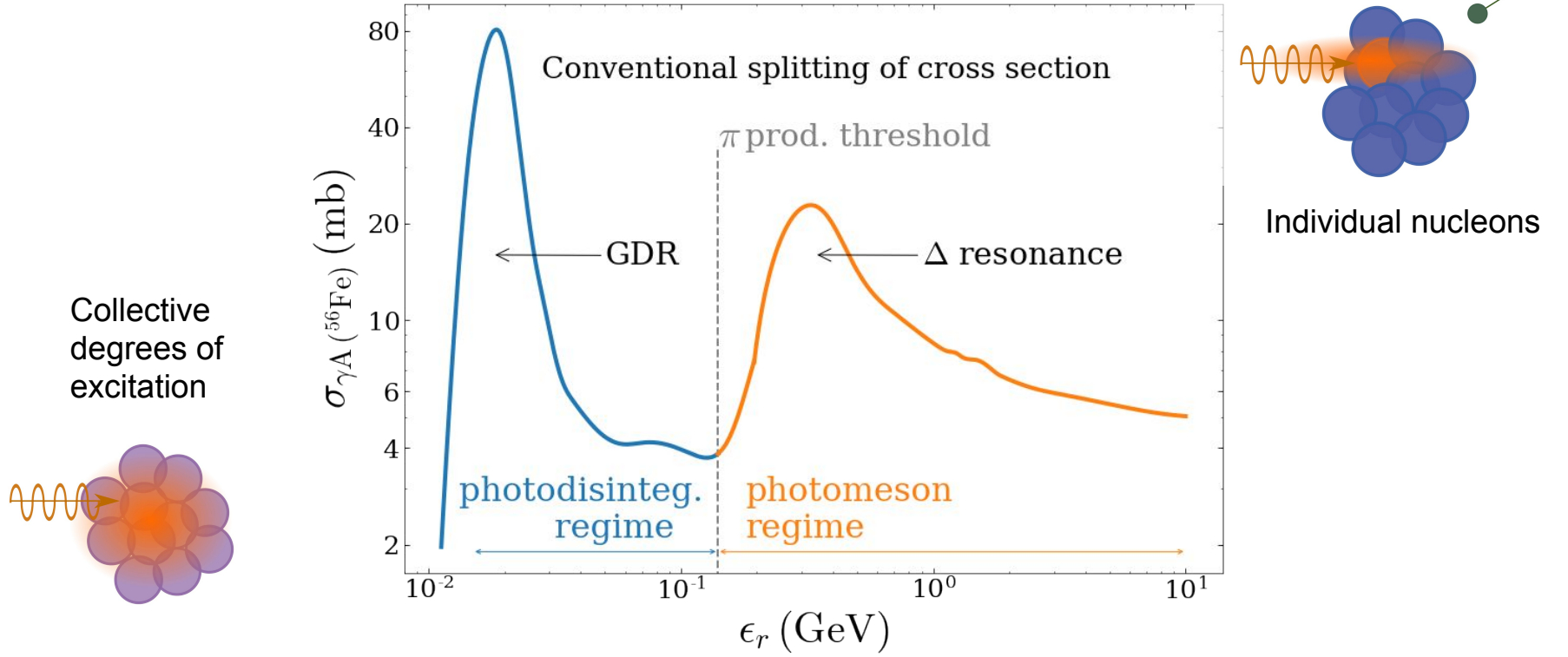
PROPAGATION

SOURCE



CR interactions

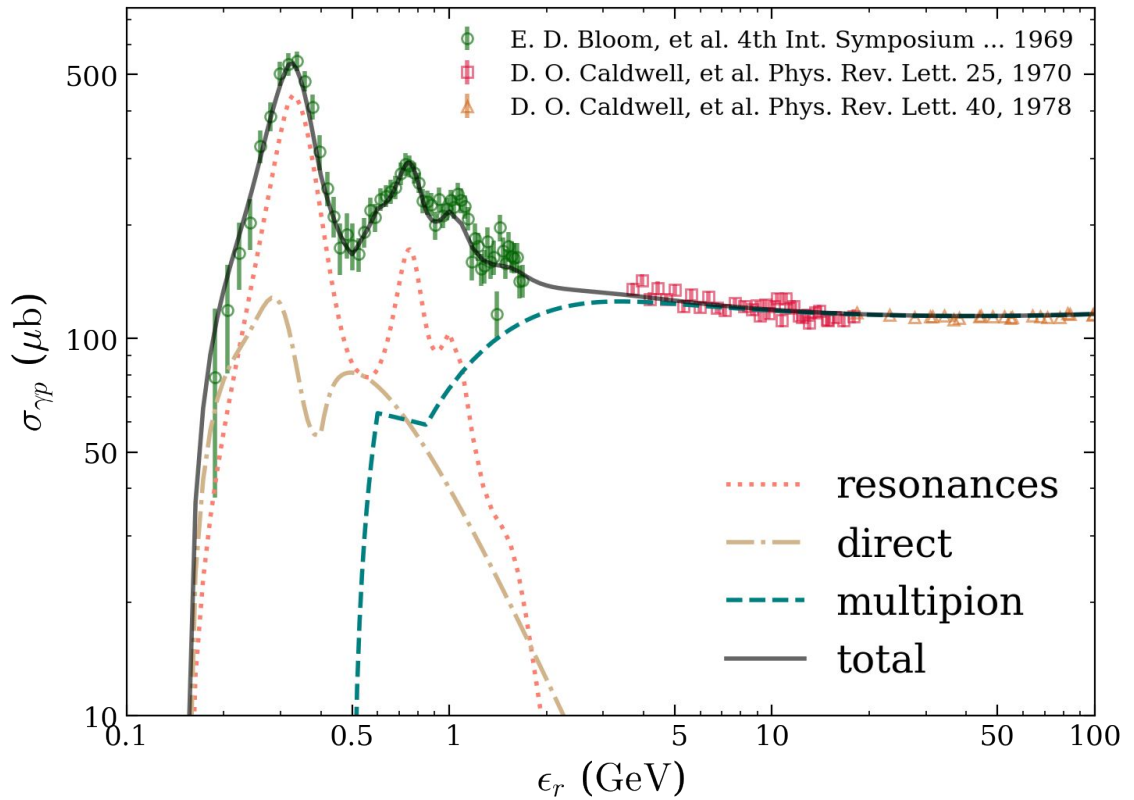
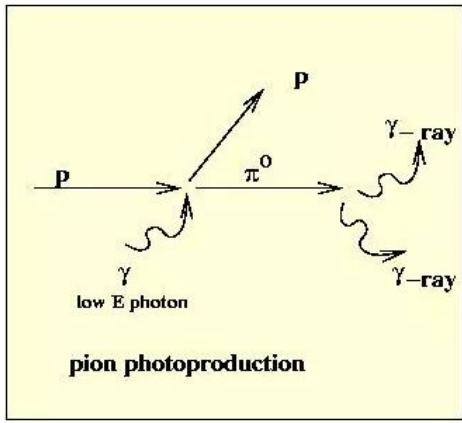
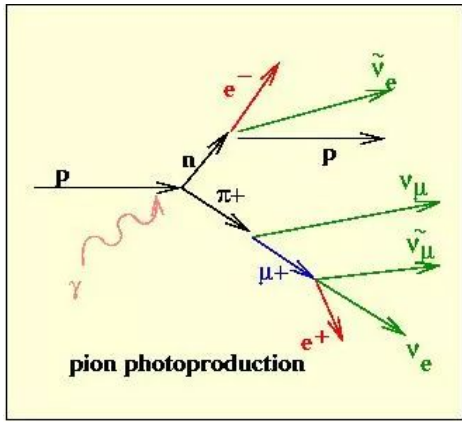
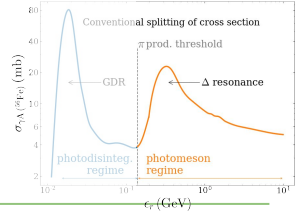
Photonuclear cross sections



Ref: [LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 \(2019\) 007](#)

CR interactions

Photomeson interactions: nucleons

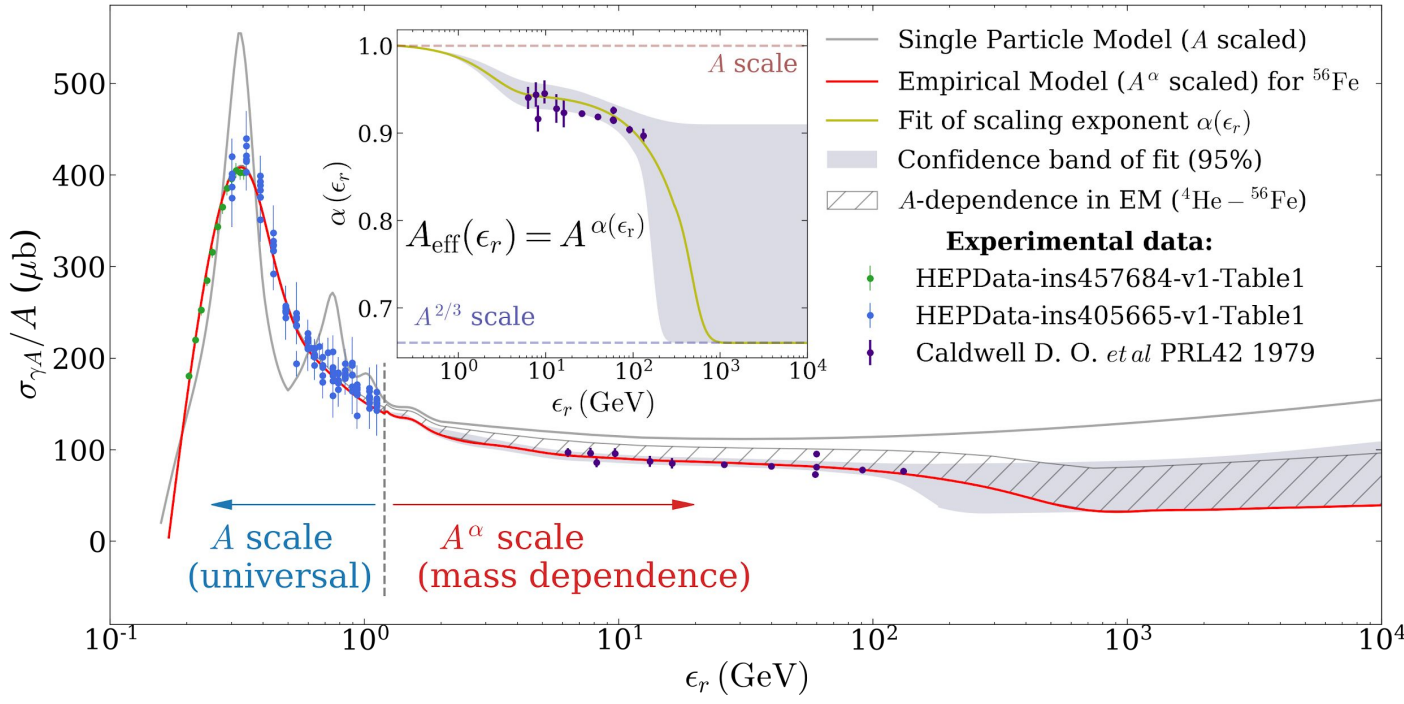
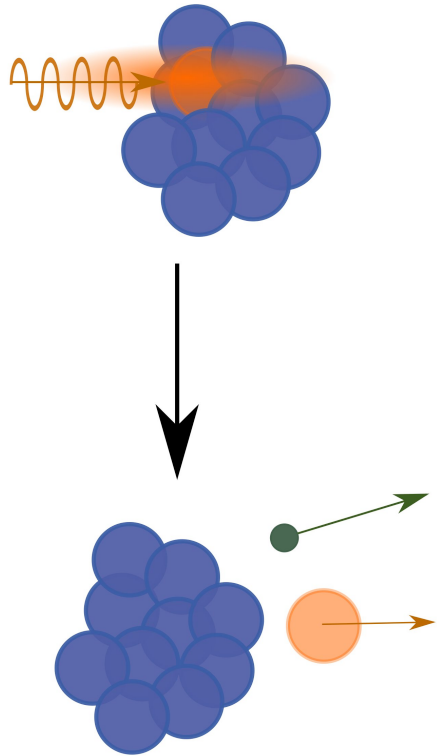
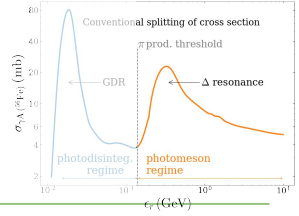


Source: SOPHIA website

Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 (2019) 007

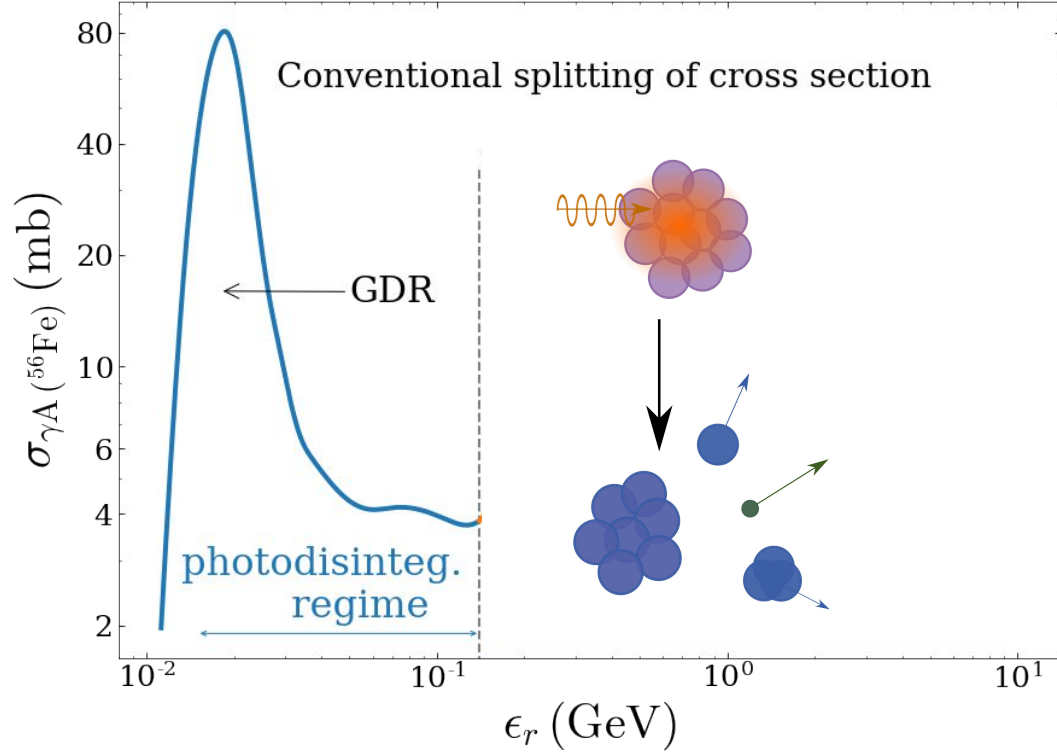
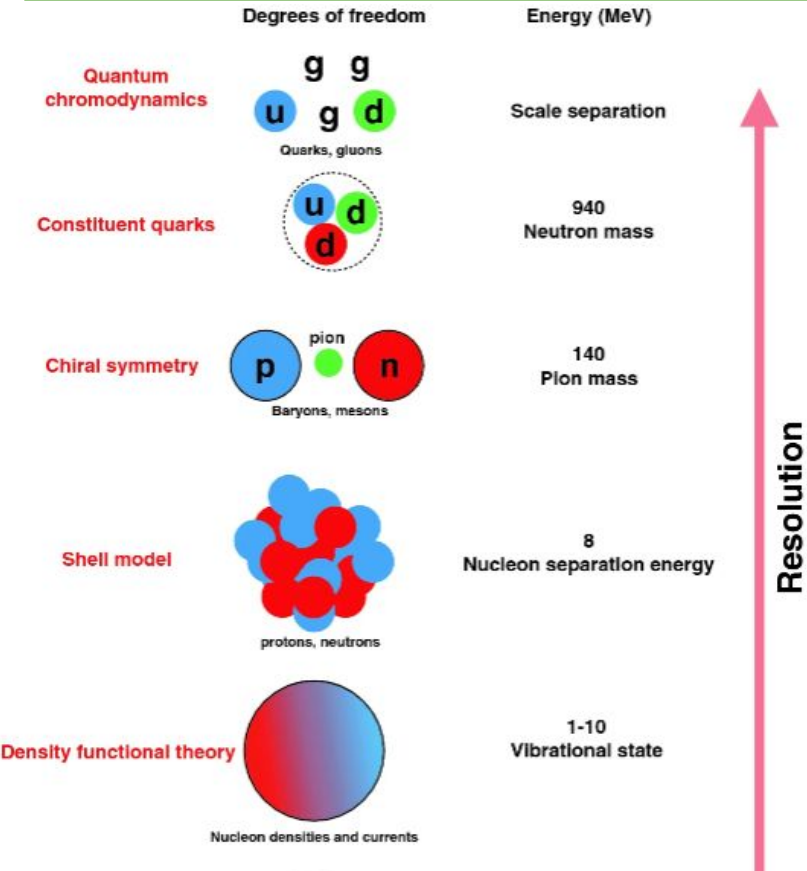
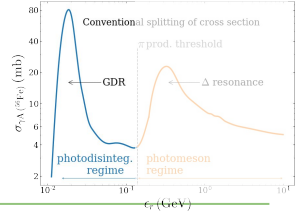
CR interactions

Photomeson interactions: nuclei



CR interactions

Photodisintegration interactions

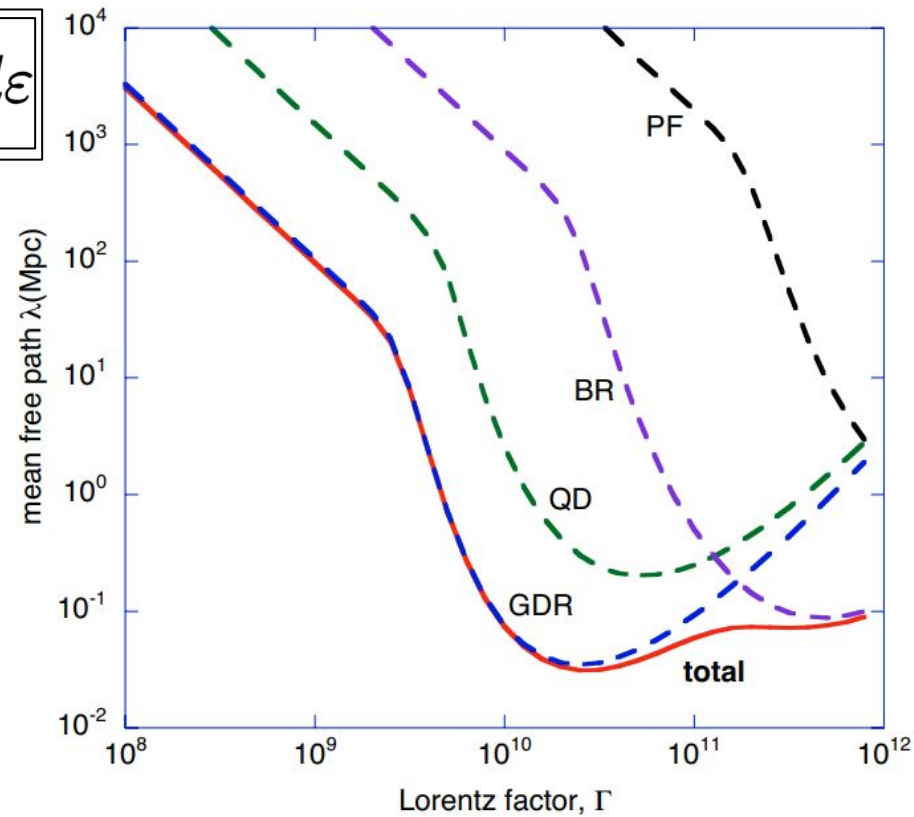
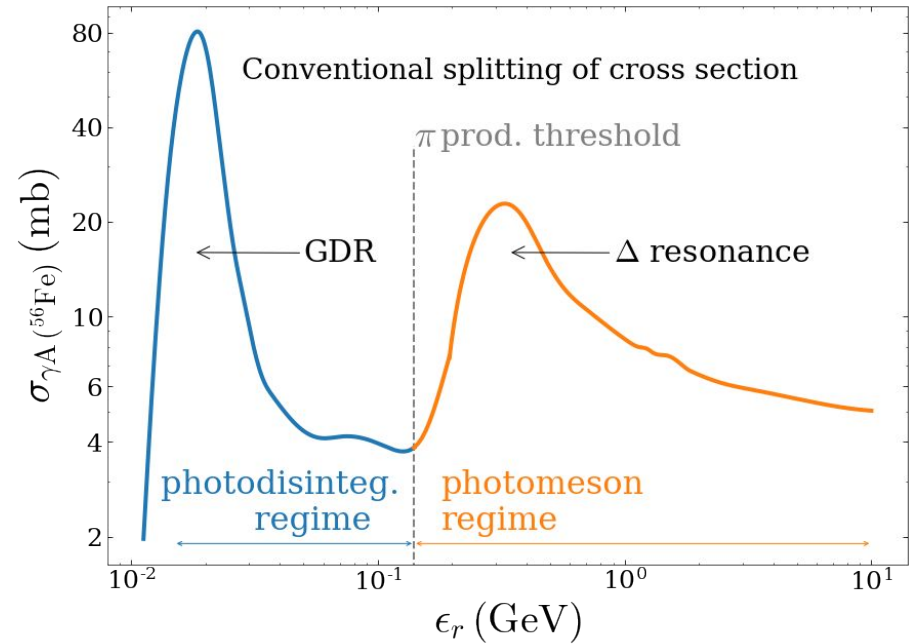


Ref: [LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 \(2019\) 007](#)

CR interactions

Mean propagation lengths

$$\lambda^{-1}(\gamma) = \frac{1}{2\gamma^2} \int_0^\infty \frac{n(\epsilon)}{\epsilon^2} d\epsilon \int_0^{2\epsilon\gamma} \epsilon \sigma(\epsilon) d\epsilon$$

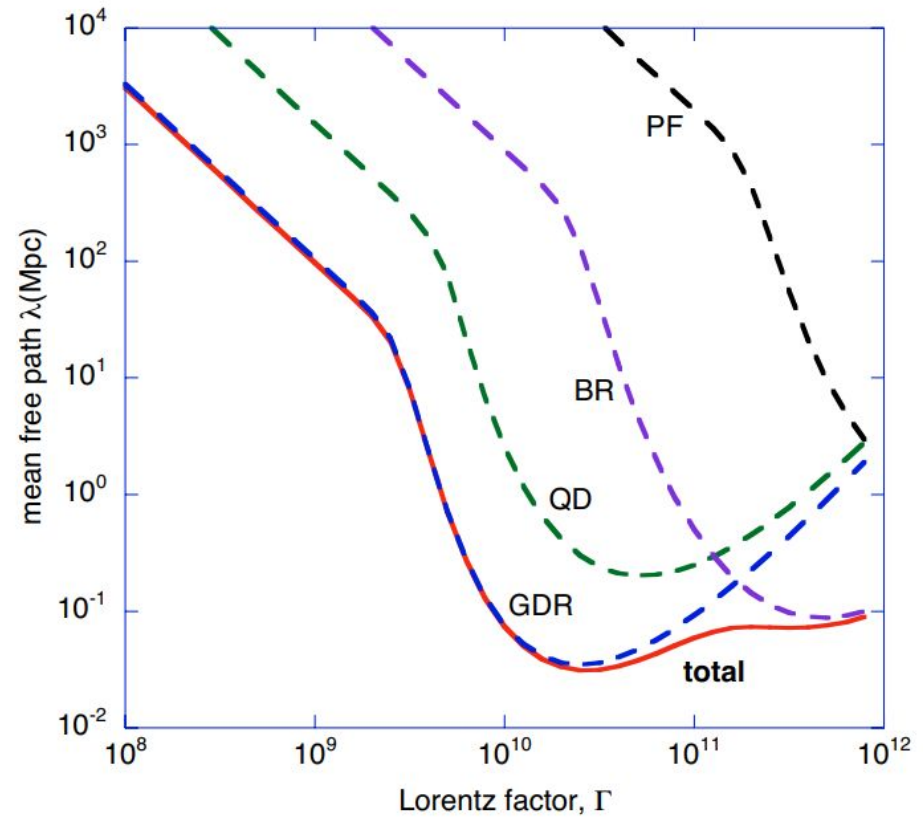
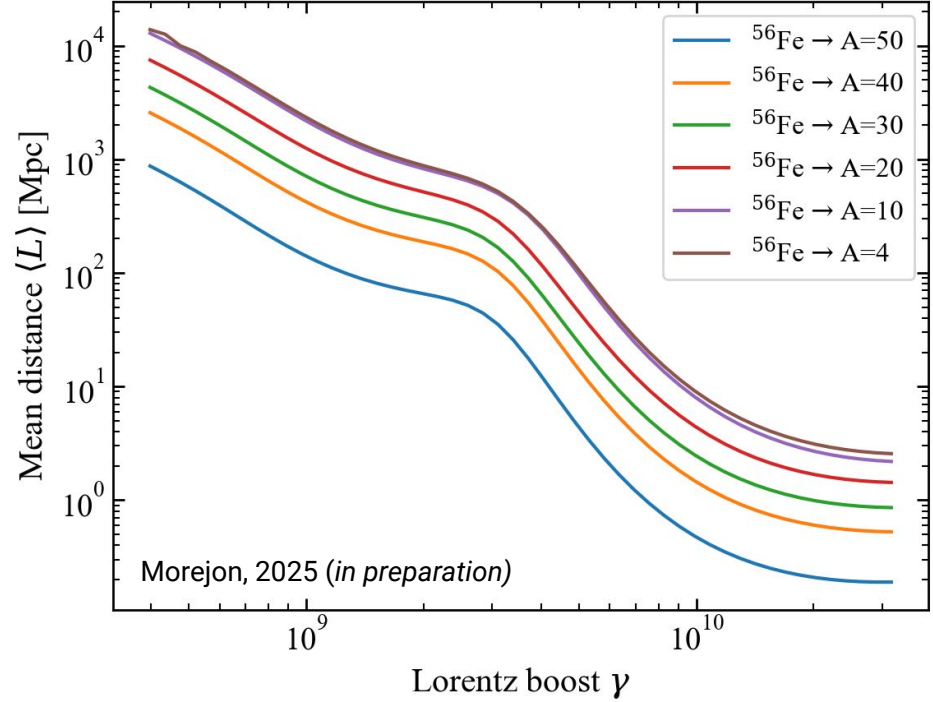


Ref: [LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 \(2019\) 007](#)

Ref: [Allard, Parizot, Olinto, Khan, Goriely, A&A 443, L29–L32 \(2005\)](#)

CR interactions

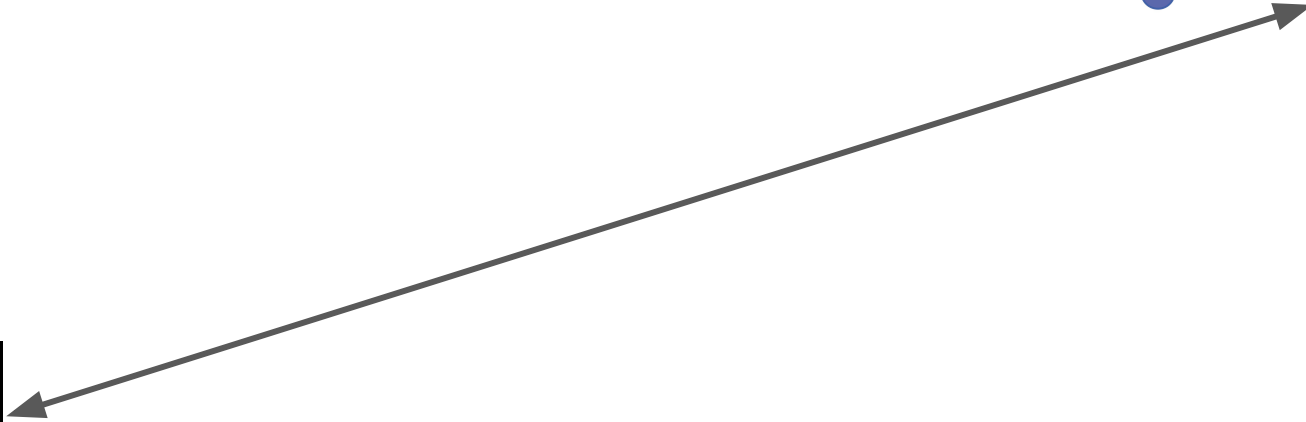
Photodisintegration interactions



Ref: Allard, Parizot, Olinto, Khan, Goriely, A&A 443, L29–L32 (2005)

Stochastic interactions

Nuclear interactions over cosmic distances



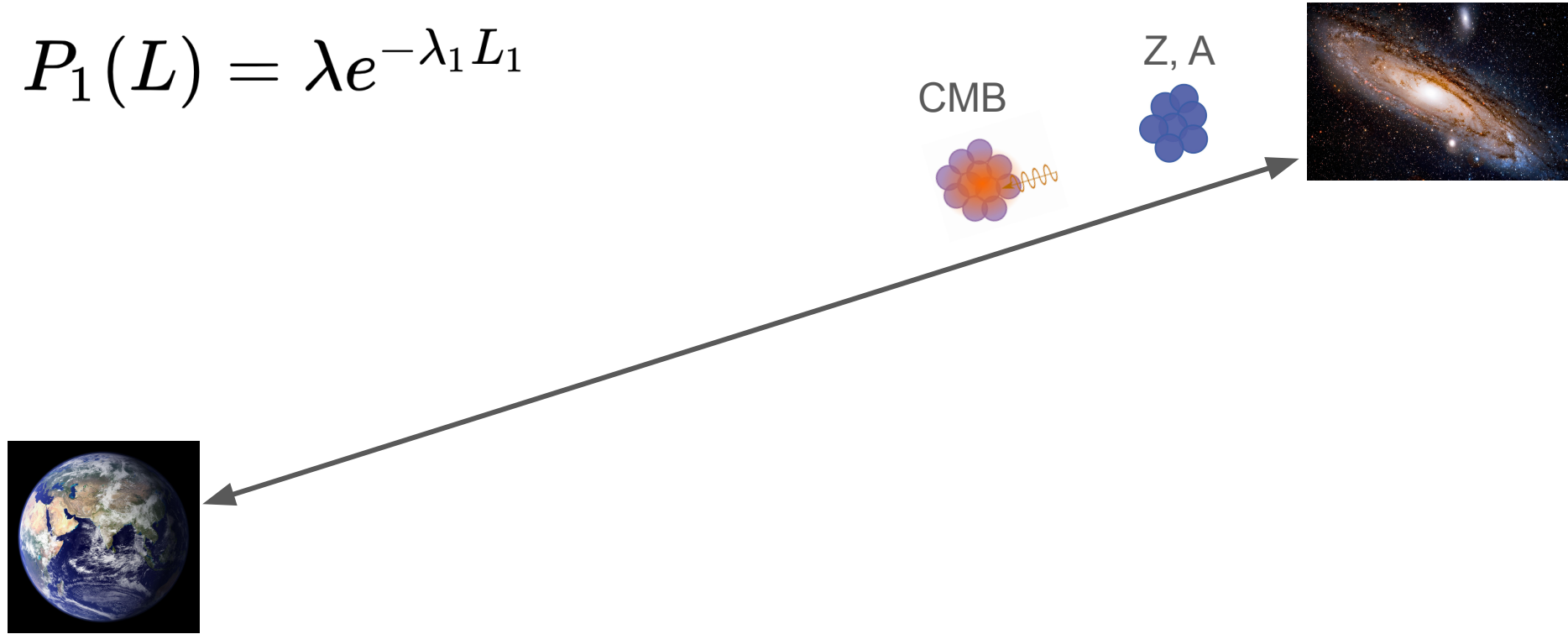
Z, A



Probabilistic description

Nuclear interactions over cosmic distances

$$P_1(L) = \lambda e^{-\lambda_1 L_1}$$

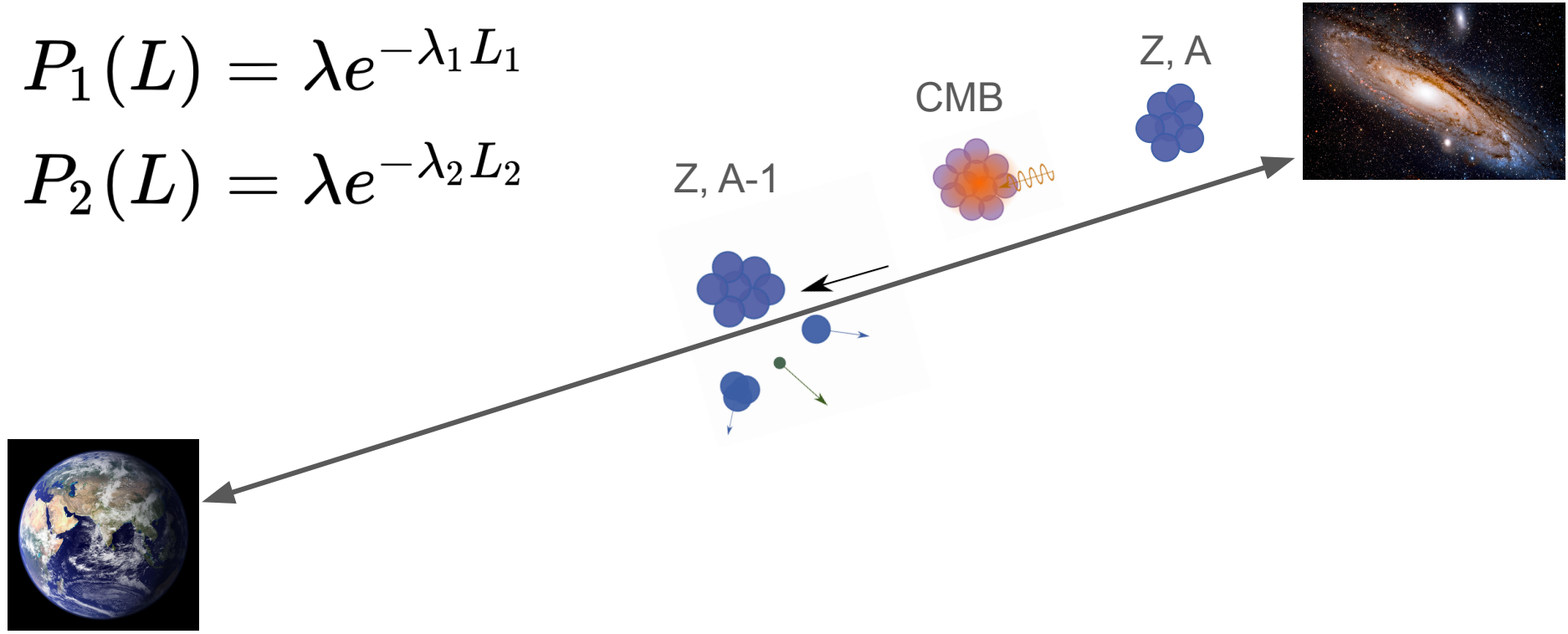


Probabilistic description

Nuclear interactions over cosmic distances

$$P_1(L) = \lambda e^{-\lambda_1 L_1}$$

$$P_2(L) = \lambda e^{-\lambda_2 L_2}$$

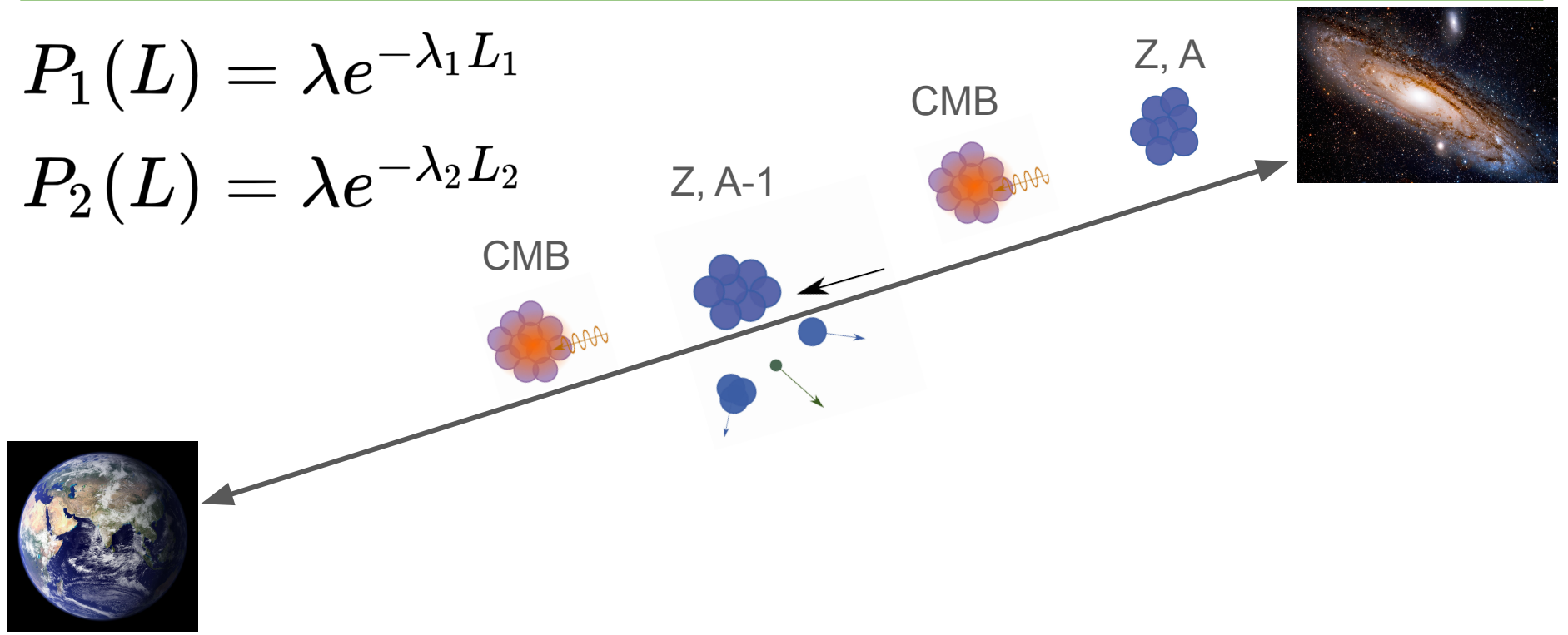


Probabilistic description

Nuclear interactions over cosmic distances

$$P_1(L) = \lambda e^{-\lambda_1 L_1}$$

$$P_2(L) = \lambda e^{-\lambda_2 L_2}$$



Probabilistic description

Nuclear interactions over cosmic distances

$$P_1(L) = \lambda e^{-\lambda_1 L_1}$$

$$P_2(L) = \lambda e^{-\lambda_2 L_2}$$

...

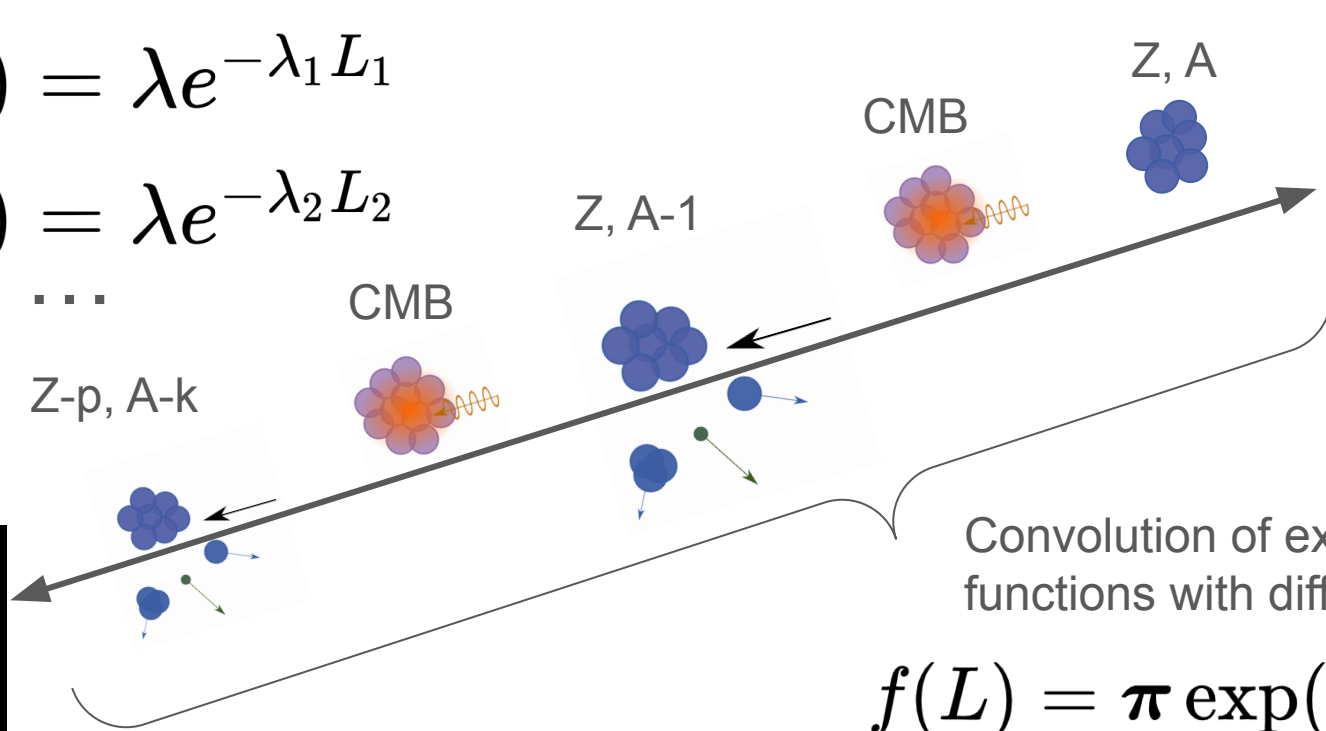
Z-p, A-k

CMB

Z, A-1

CMB

Z, A



Convolution of exponential functions with different rates!

$$f(L) = \pi \exp(\Lambda L) \Lambda e$$

Probabilistic description

Nuclear interactions over cosmic distances

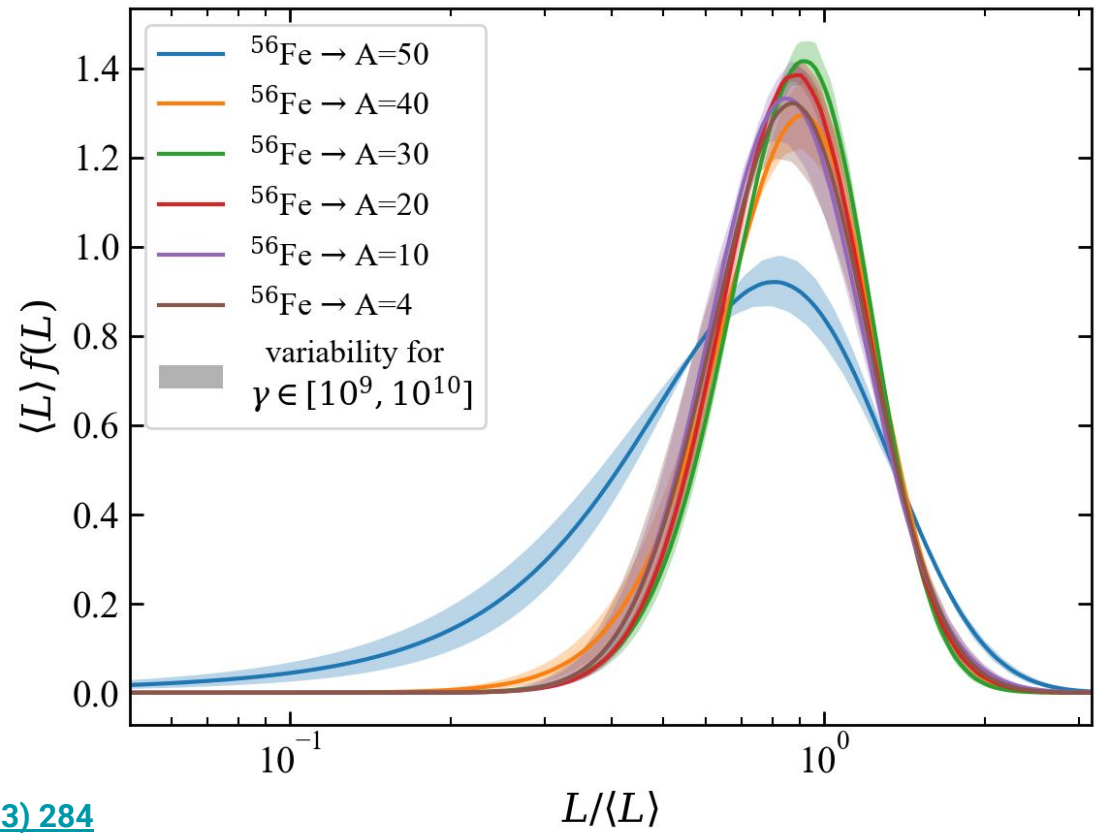
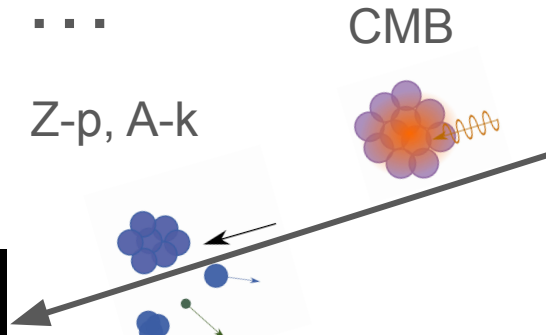
$$P_1(L) = \lambda e^{-\lambda_1 L_1}$$

$$P_2(L) = \lambda e^{-\lambda_2 L_2}$$

...

Z-p, A-k

CMB

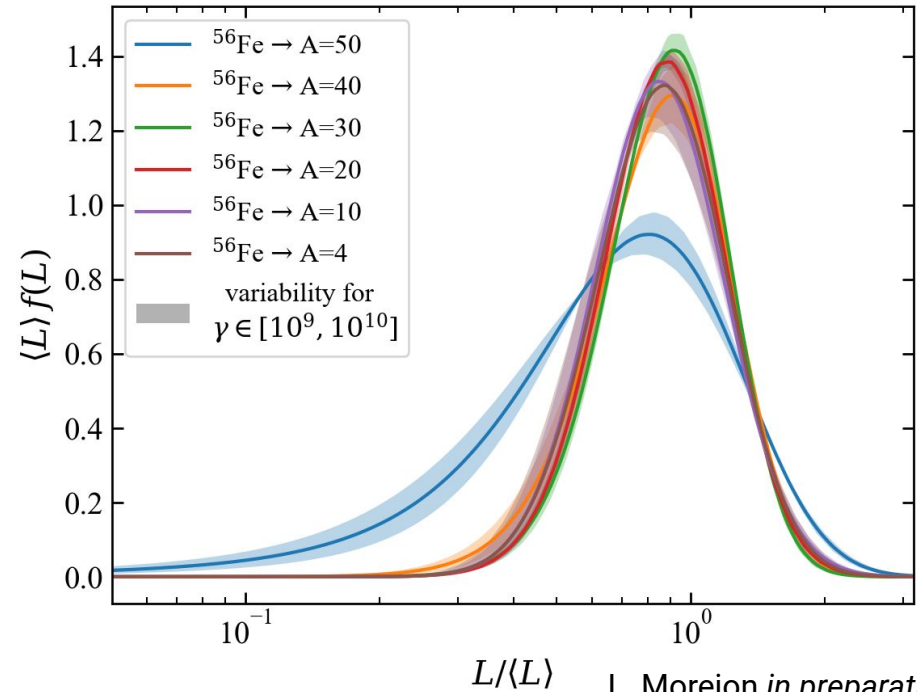
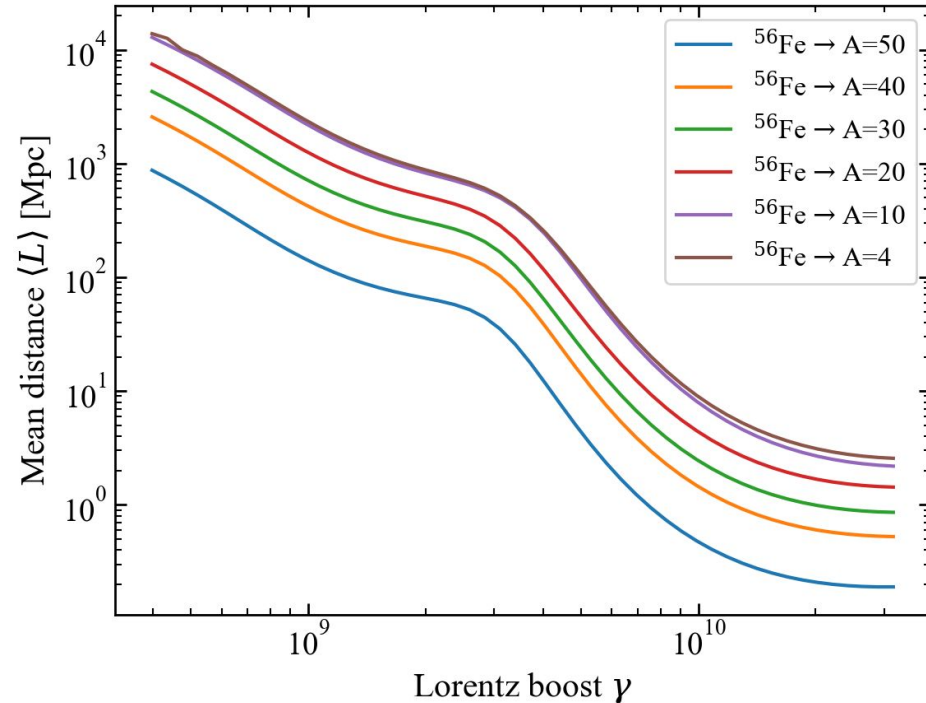


$$f(L) = \pi \exp(\Lambda L) \Lambda e$$

[L. Morejon PoS ICRC2023 \(2023\) 284](#)

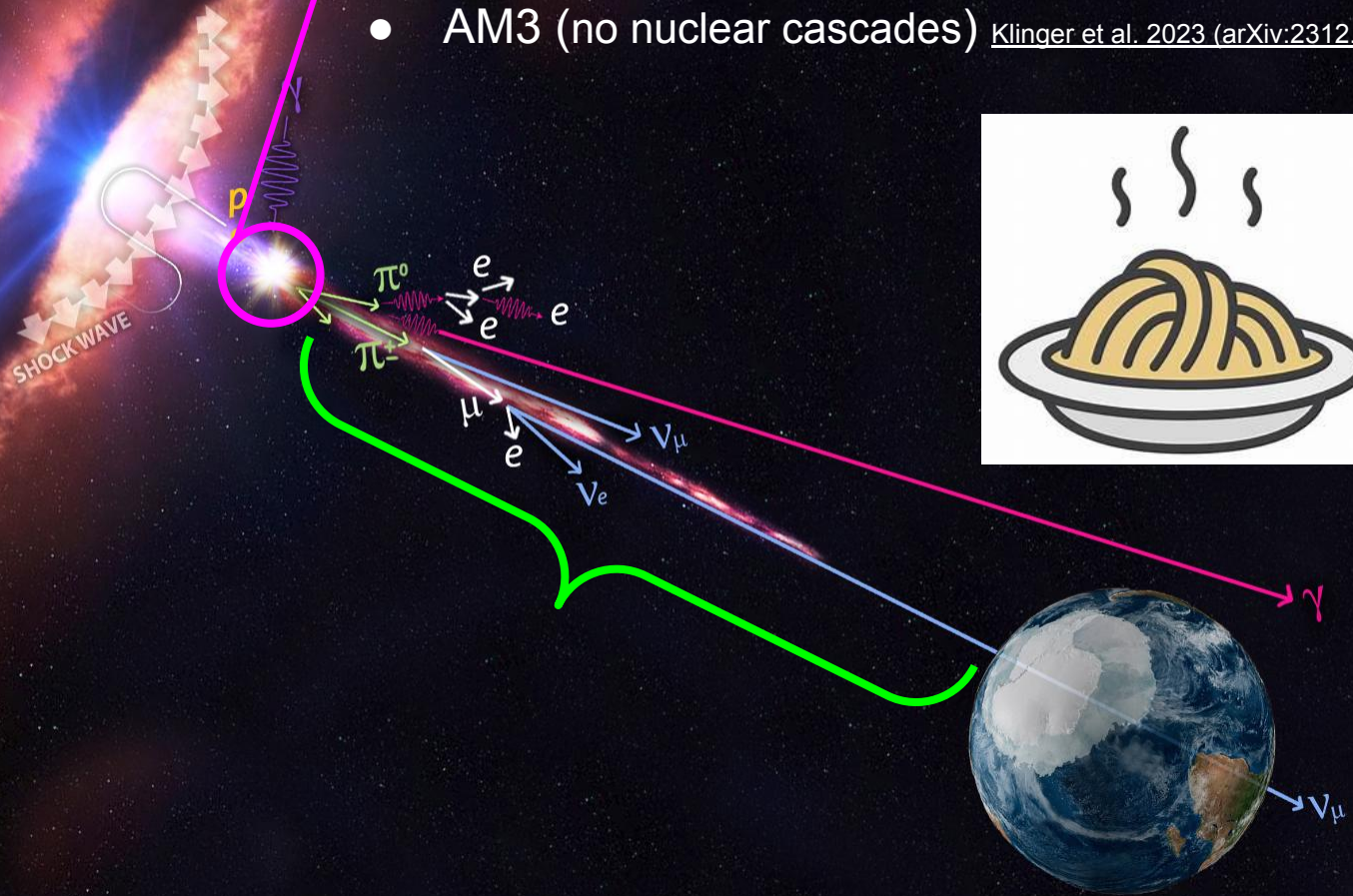
Extragalactic propagation distributions

Rates ranging several orders of magnitude ... but very similar distribution shapes



UHECR Source codes

- NeuCosmA [Hümmer et al. Astrop. Phys. Vol. 34 Issue 4, 2010, 205-224](#)
- AM3 (no nuclear cascades) [Klinger et al. 2023 \(arXiv:2312.13371\)](#)



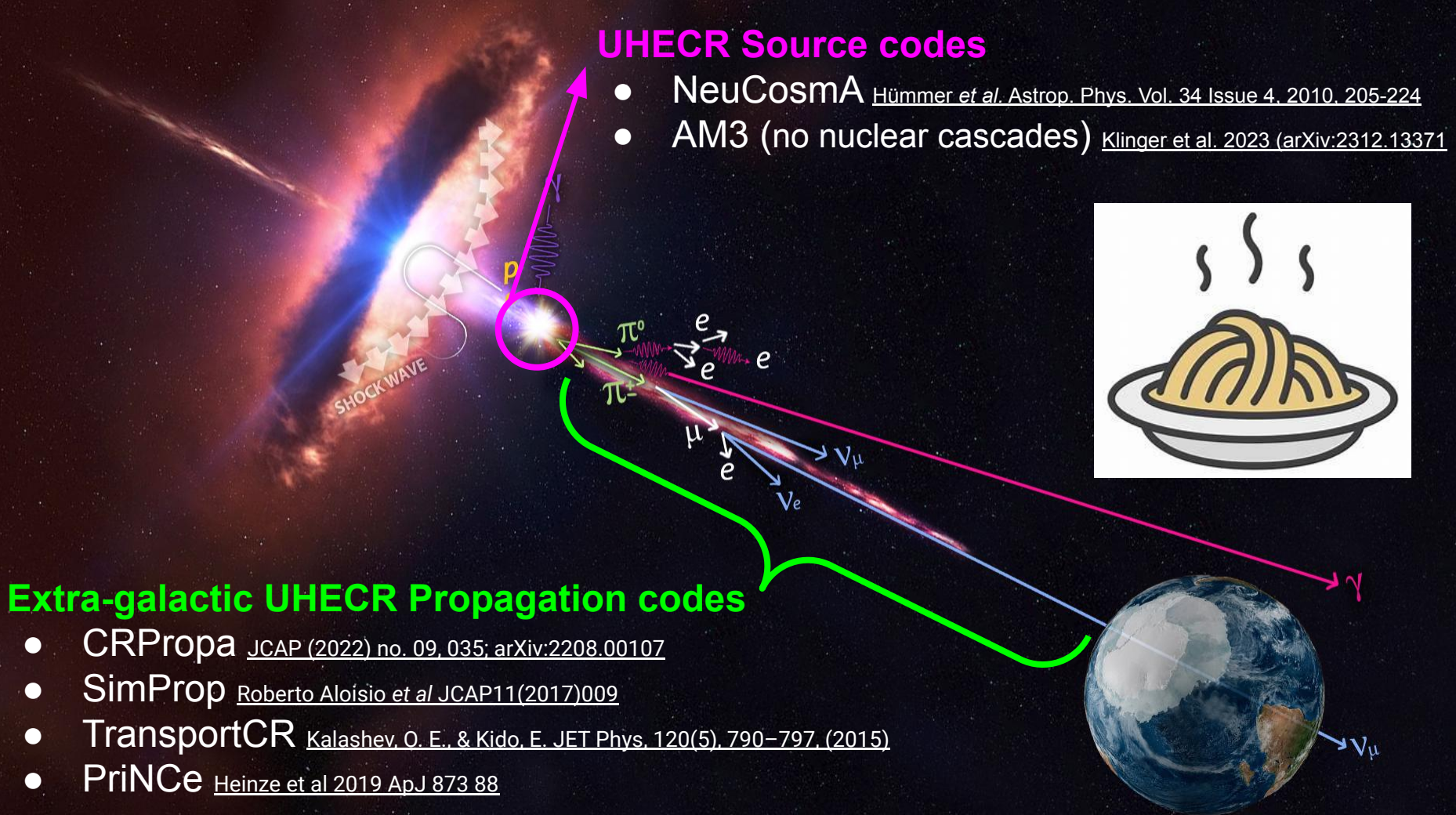
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Extra-galactic UHECR Propagation codes

- CRPropa [JCAP \(2022\) no. 09, 035; arXiv:2208.00107](#)
- SimProp [Roberto Aloisio et al JCAP11\(2017\)009](#)
- TransportCR [Kalashev, O. E., & Kido, E. JET Phys, 120\(5\), 790–797, \(2015\)](#)
- PriNCe [Heinze et al 2019 ApJ 873 88](#)



UHECR Source codes

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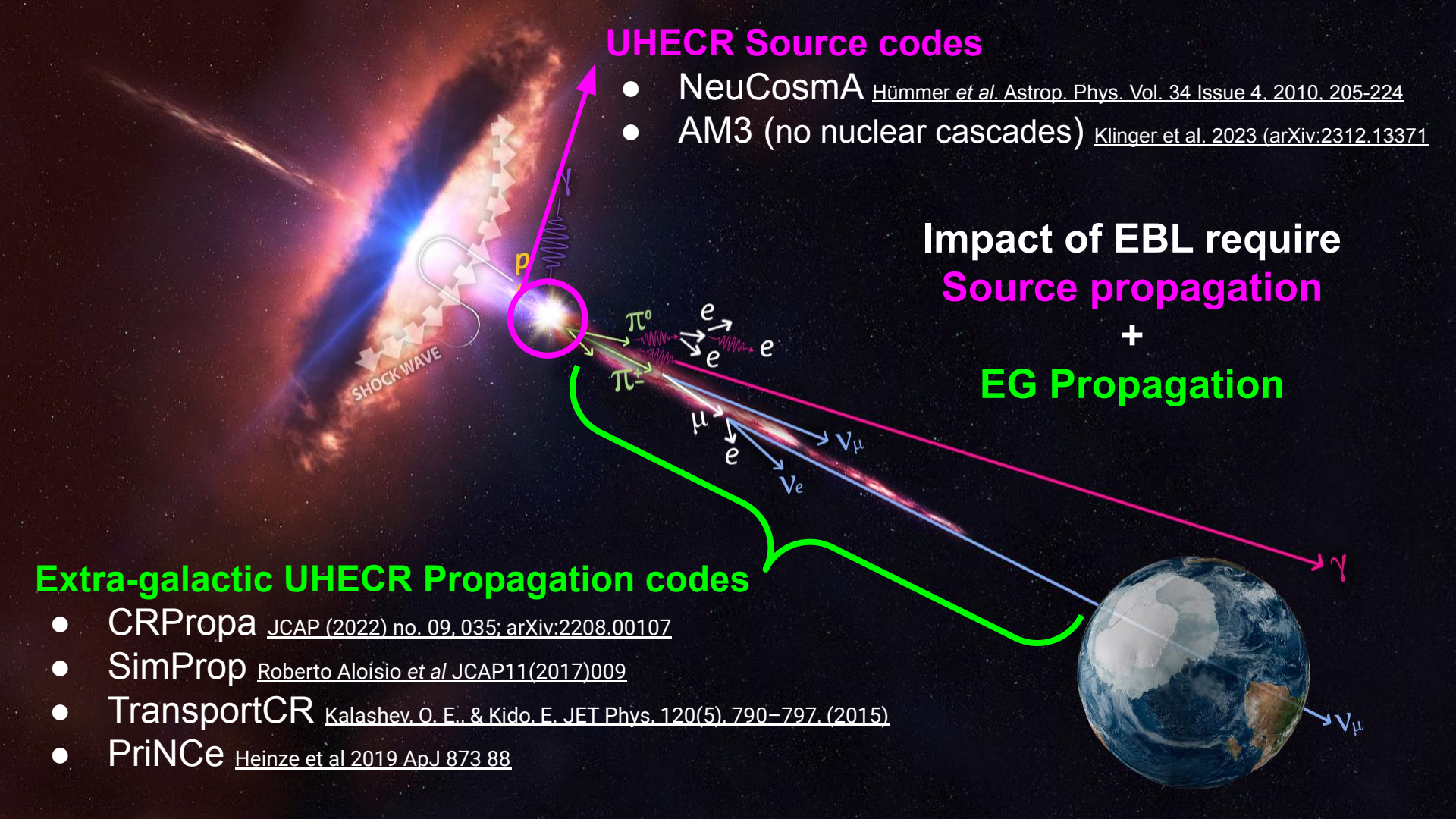
Impact of EBL require
Source propagation

+

EG Propagation

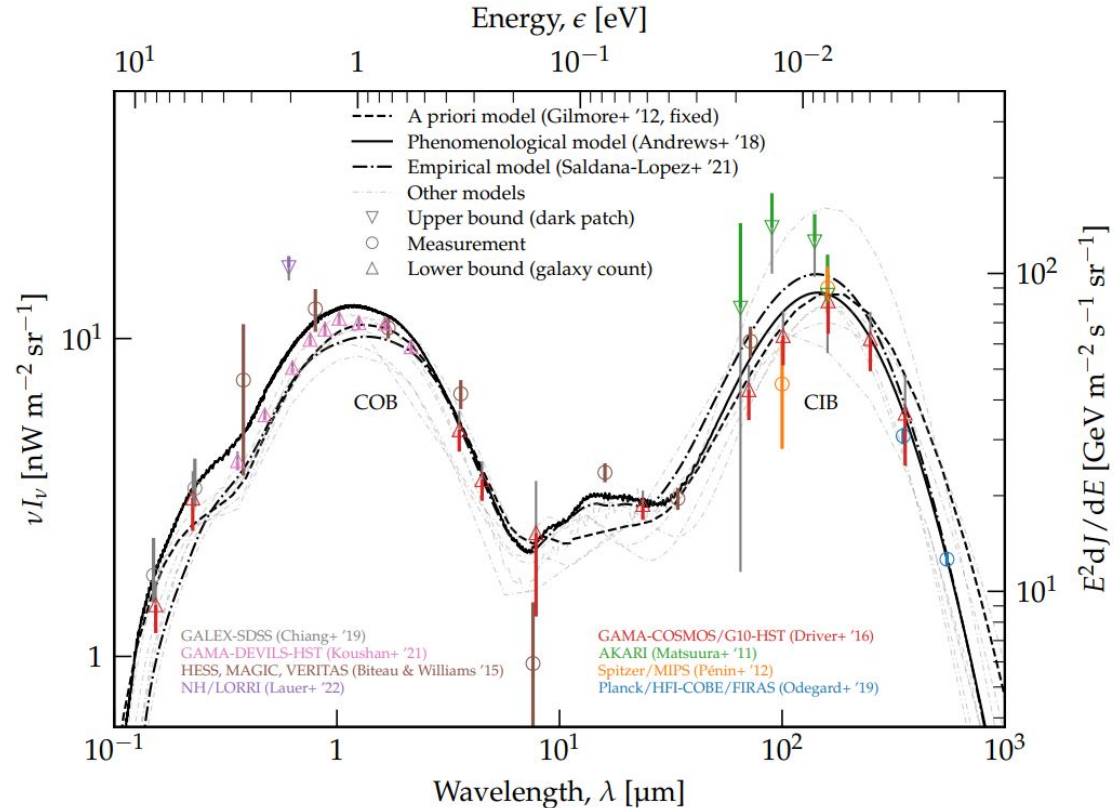
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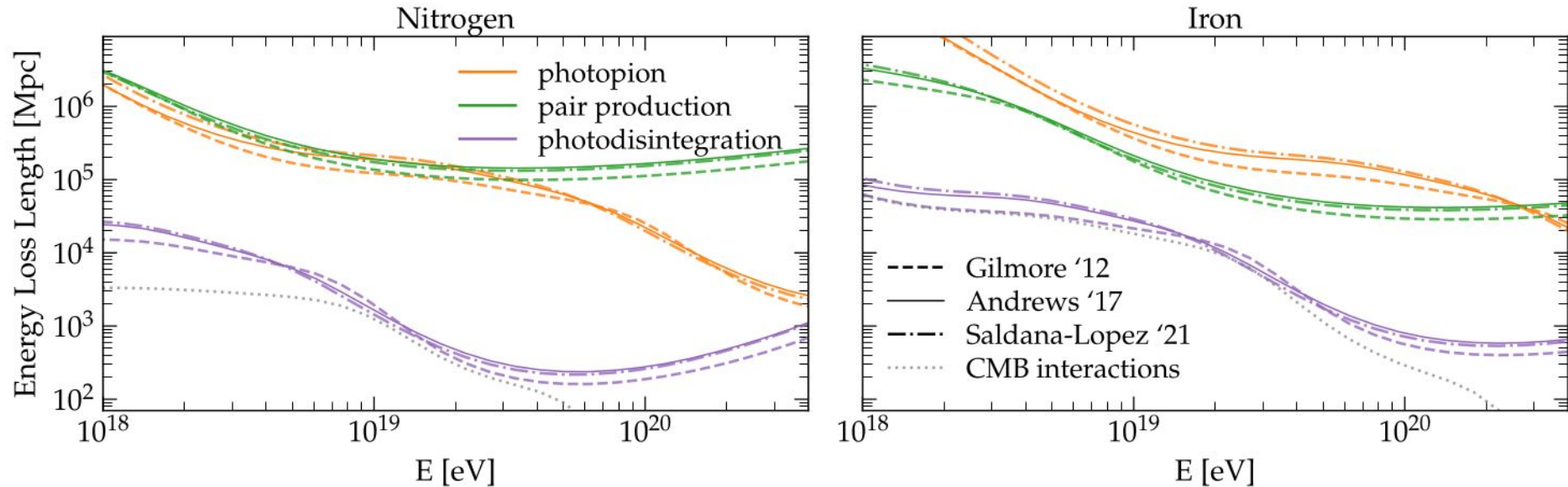
EBL effects on the production probability

Differences in the disintegration of N with the loss of 2 nucleons for a range of distance and two energies: purple is CMB dominated, cyan is EBL dominated.



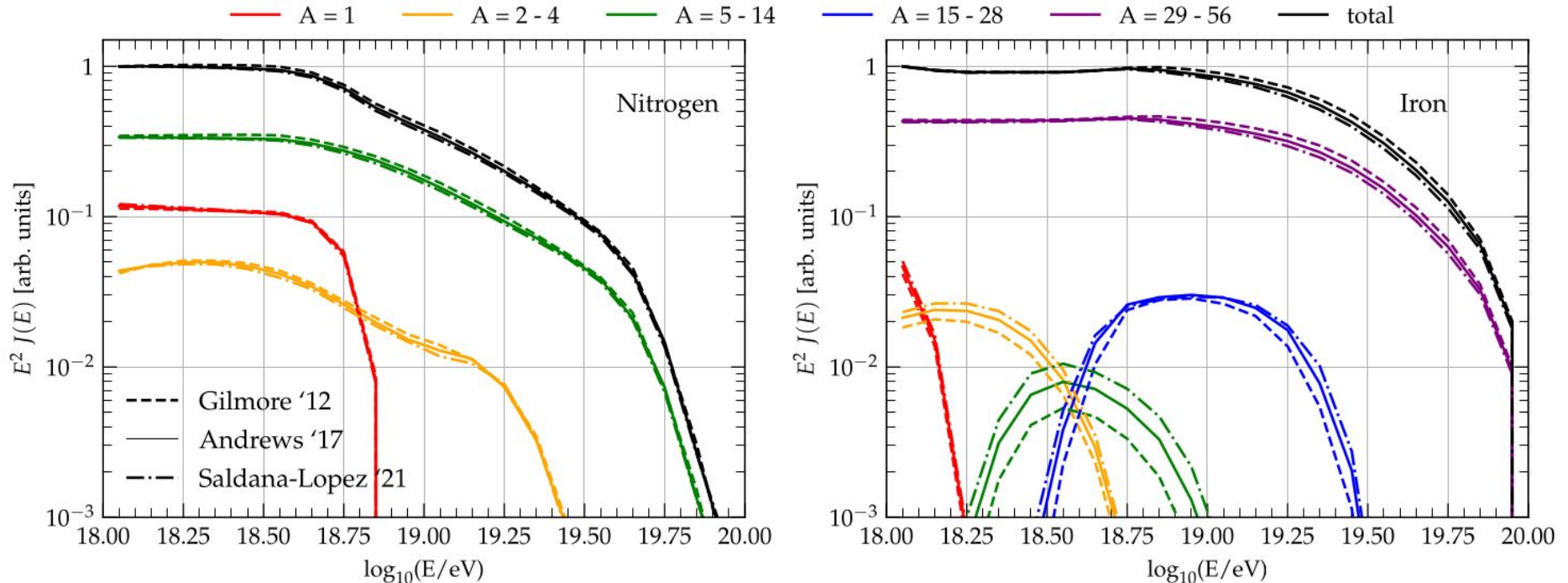
EBL effects on the production probability

Small changes in the energy loss lengths, dominated by interactions with the CMB
However, somewhat dependent on the on the nuclear species.



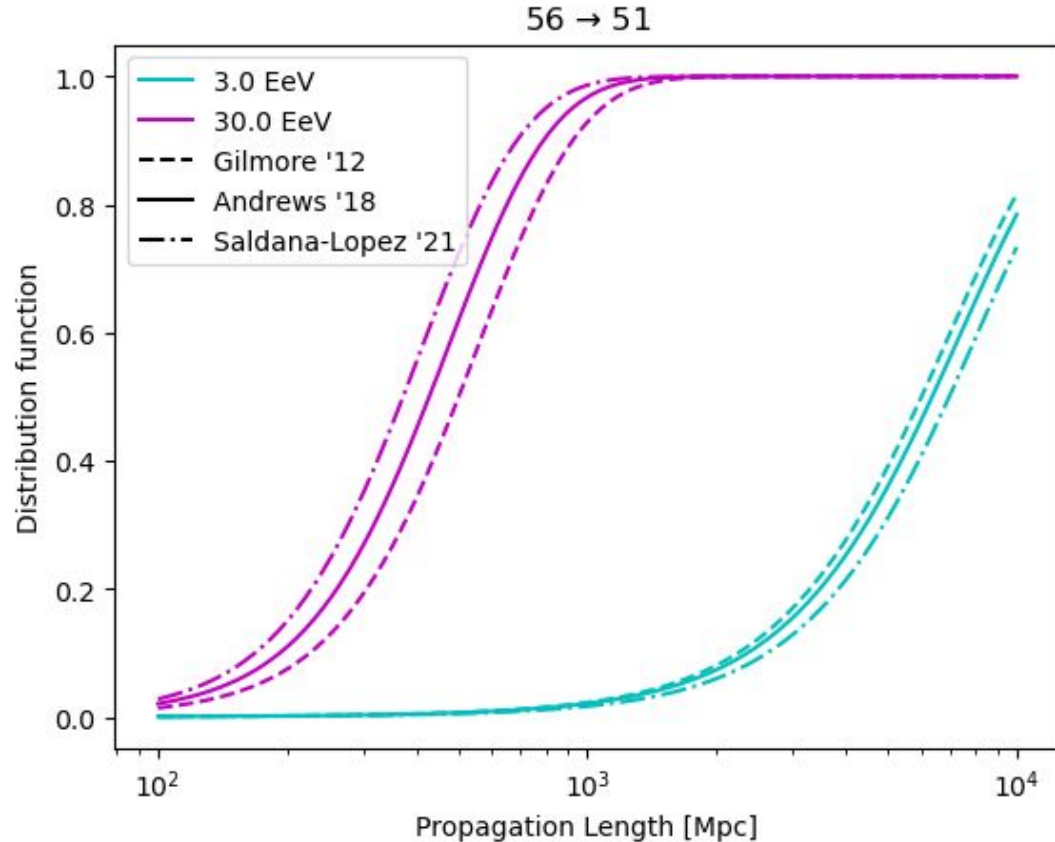
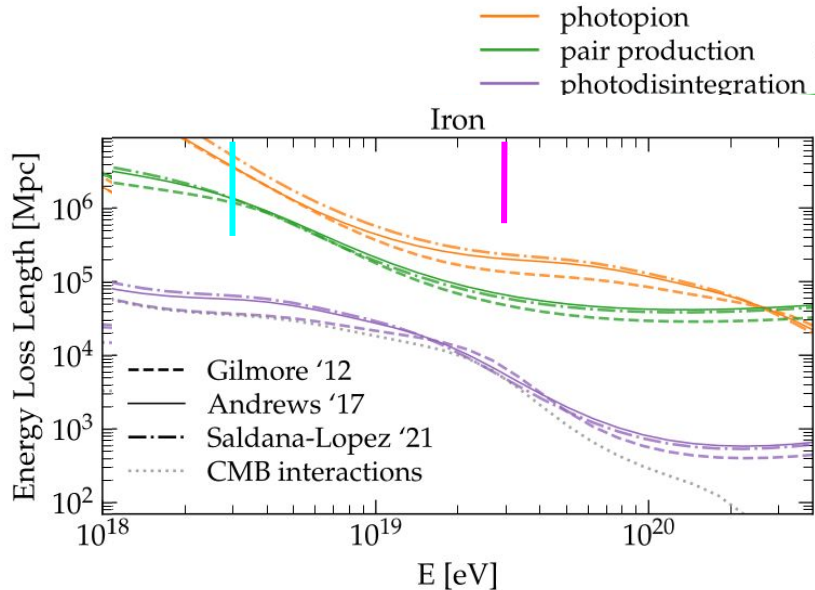
Effects on the UHECR spectrum (flat distribution)

Nuclear spectra reflect the small differences, secondaries slightly more affected because of statistics.



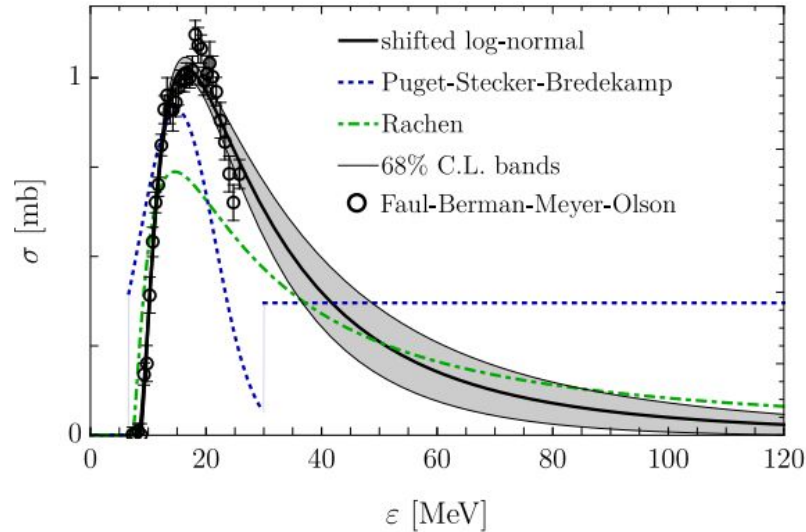
Effects on the probability of secondaries production

Differences in the disintegration of iron with the loss of 5 nucleons for a range of distance and two different energies



EBL models are only one side of the coin

$$\lambda^{-1}(\gamma) = \frac{1}{2\gamma^2} \int_0^\infty \frac{n(\epsilon)}{\epsilon^2} d\epsilon \int_0^{2\epsilon\gamma} \epsilon \sigma(\epsilon) d\epsilon$$



EBL models are only one side of the coin

$$\lambda^{-1}(\gamma) = \frac{1}{2\gamma^2} \int_0^\infty \frac{n(\epsilon)}{\epsilon^2} d\epsilon \int_0^{2\epsilon\gamma} \epsilon \sigma(\epsilon) d\epsilon$$

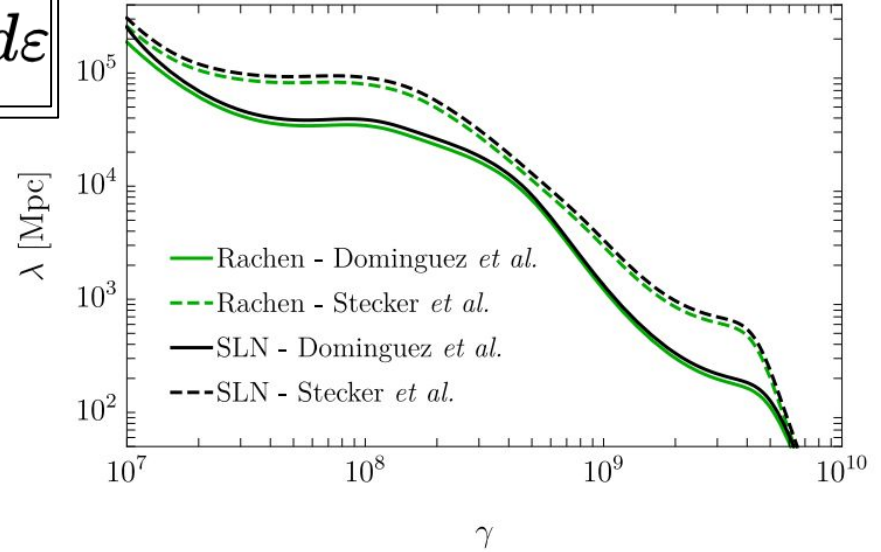
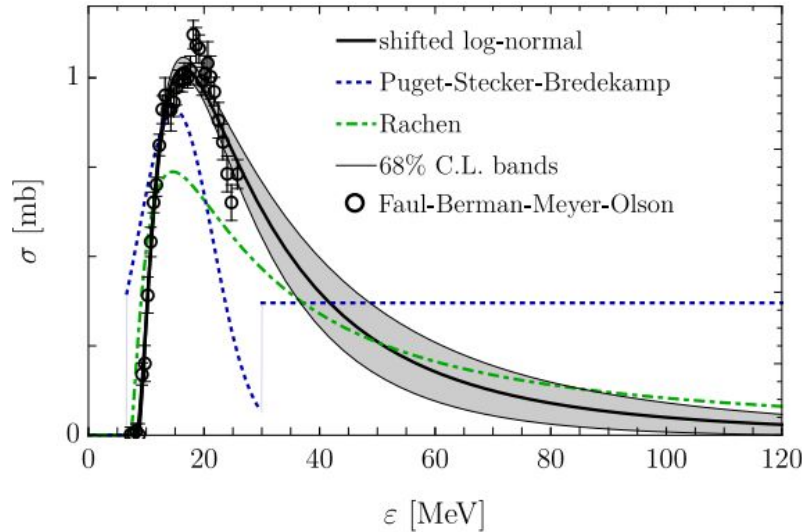
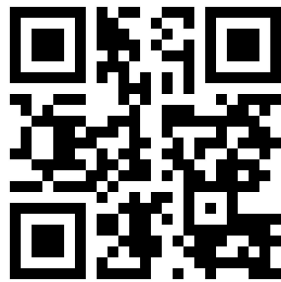


FIG. 6: Photodisintegration mean-free-path of ${}^4\text{He}$ on the IR photon background as estimated in [47] and the lower limit derived in [49]. In the comparison we have used the photodisintegration derived in this work and those obtained earlier by Rachen [14].



MICRO website



MICRO@github



CRISP

Cosmic Ray Stochastic Interactions for Propagation [↗](#)

On Github soon!

Thanks!



[L. Morejon PoS ICRC2023 \(2023\) 284](#)