PriNCe

Propagation including Nuclear Cascade equations

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Hands-on sessions
ACME

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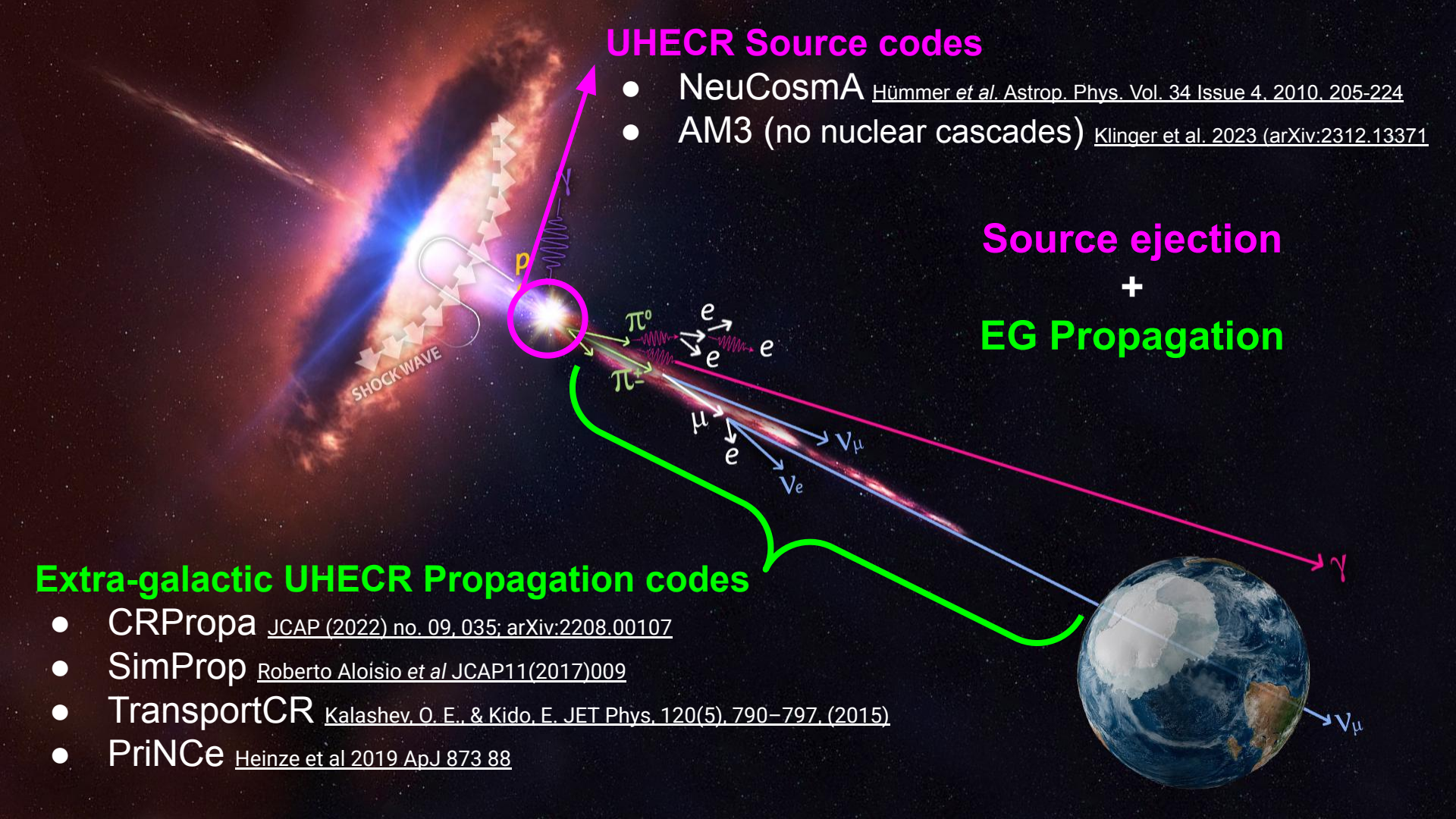
ACME
Astrophysics Centre for Multimessenger studies in Europe

BERGISCHE UNIVERSITÄT WUPPERTAL

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

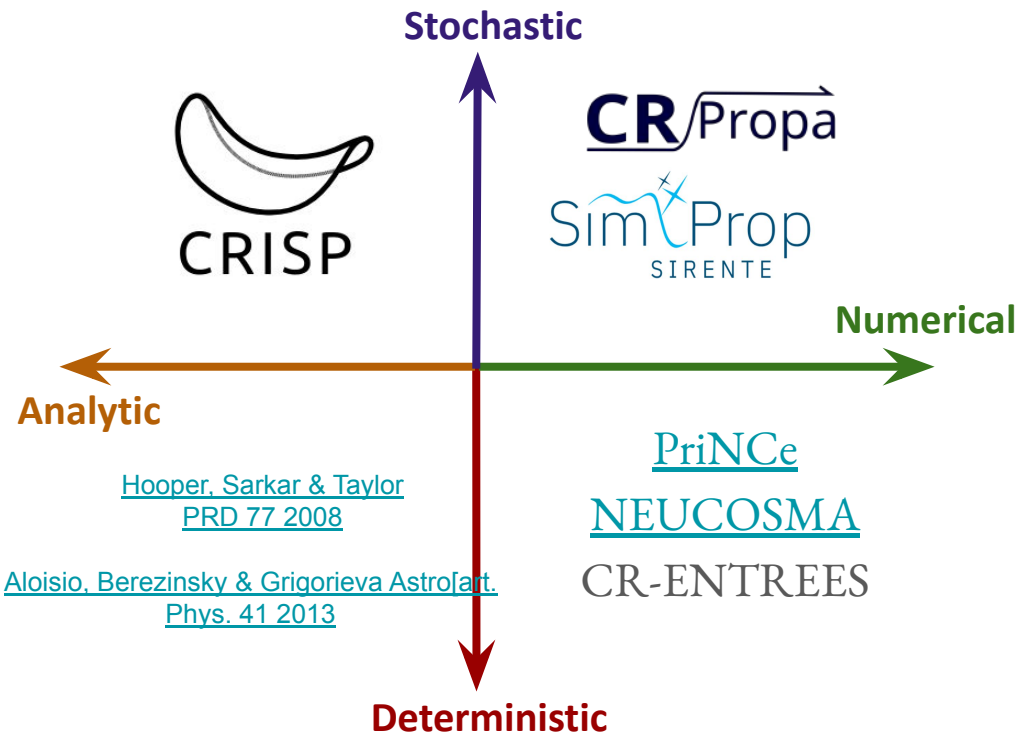
Source ejection
+
EG Propagation



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

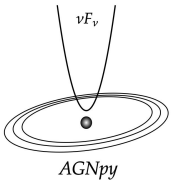
PriNCe: compared to other frameworks



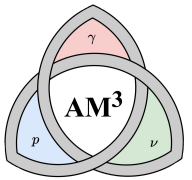
CRISP could be coupled to…

SOPRANO

OneHaLe



JetSeT
Jets SED modeler and fitting Tool



PriNCe: access and documentation

Main sources for PriNCe

- Documentation: prince.readthedocs.io/en/latest/
- Original Repository: github.com/joheinze/PriNCe
- Examples: github.com/joheinze/PriNCe-examples
- PhD thesis, Jonas Heinze

Resources for today's session on PriNCe

- Repository for today's session: github.com/mohller/PriNCe
- Examples: github.com/joheinze/PriNCe-examples

Nuclear Cascade Equations

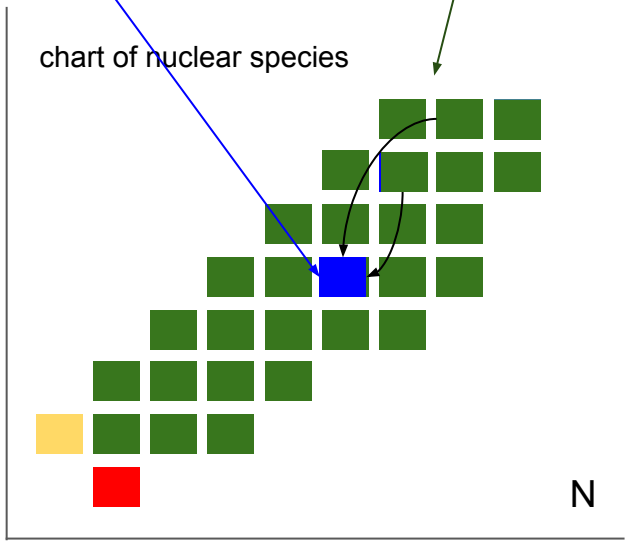
$$\frac{\partial}{\partial t} N_i(E,t) = \frac{\partial}{\partial E}\left(b(E) N_i(E,t)\right) + Q_i^{\text{ext}}(E,t) - \Gamma_i N_i(E) + \sum_j Q_{j\to i}(N_j(E,t))$$

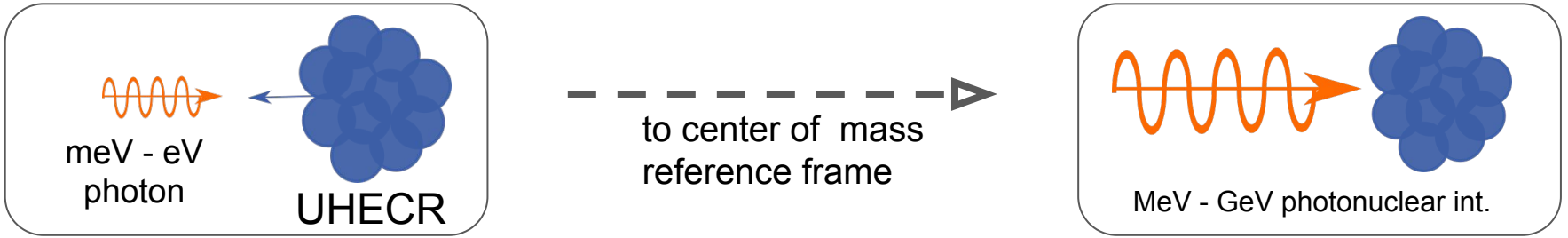
System of first order PDEs.
Particle densities for different species.

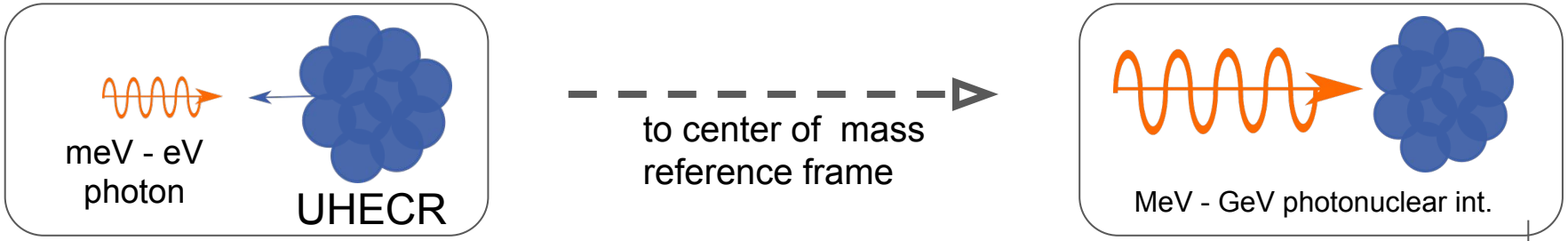
Energy losses causing redistribution

Injection (accelerated particles)

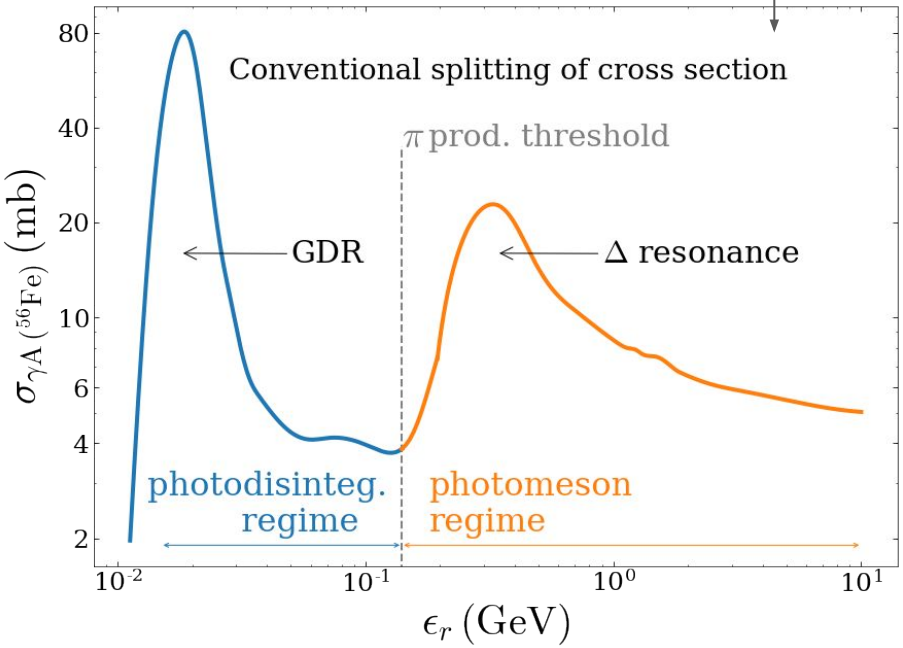
- SODE describes time evolution
- CR injection constant in time
- Integration over source time-scale
- Production of all particle species (including nuclei, mesons and neutrinos)

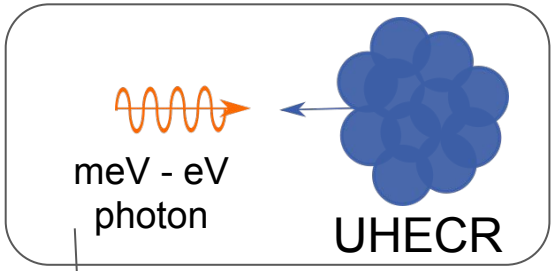



meV - eV
photon
UHECR
to center of mass
reference frame
MeV - GeV photonuclear int.

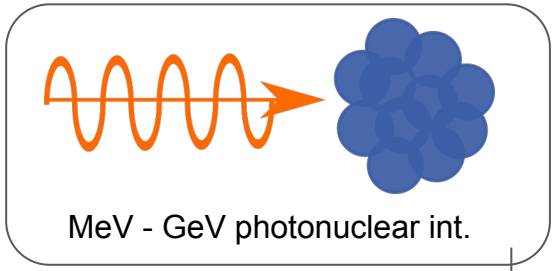


L. Morejon et al JCAP11(2019)007

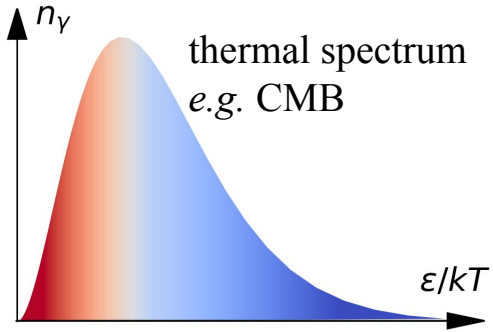




to center of mass reference frame



PROPAGATION



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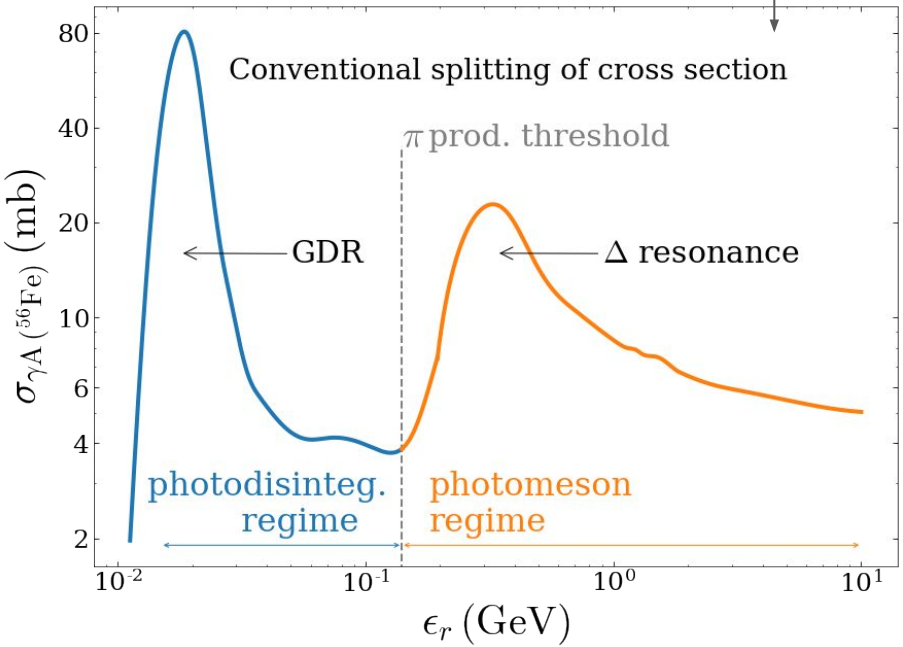

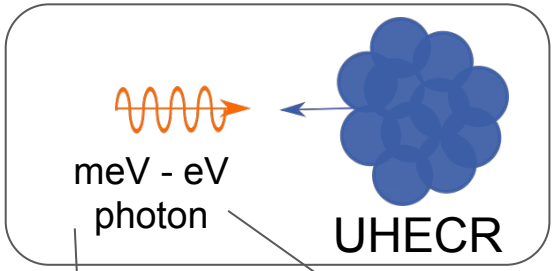

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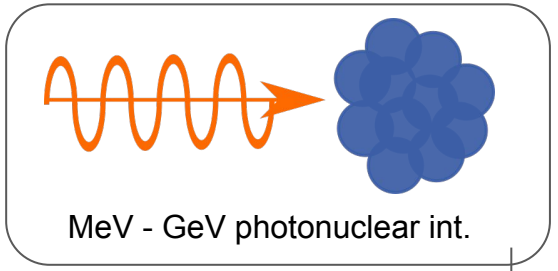

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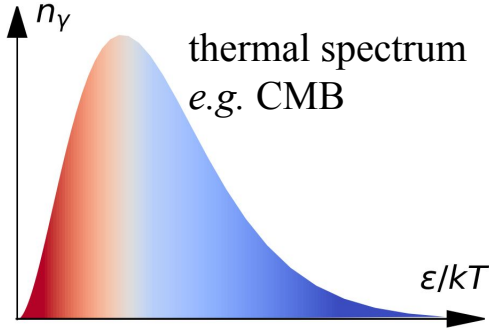
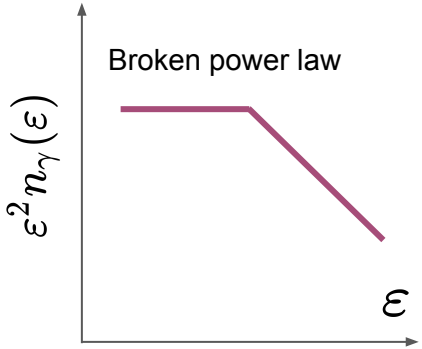
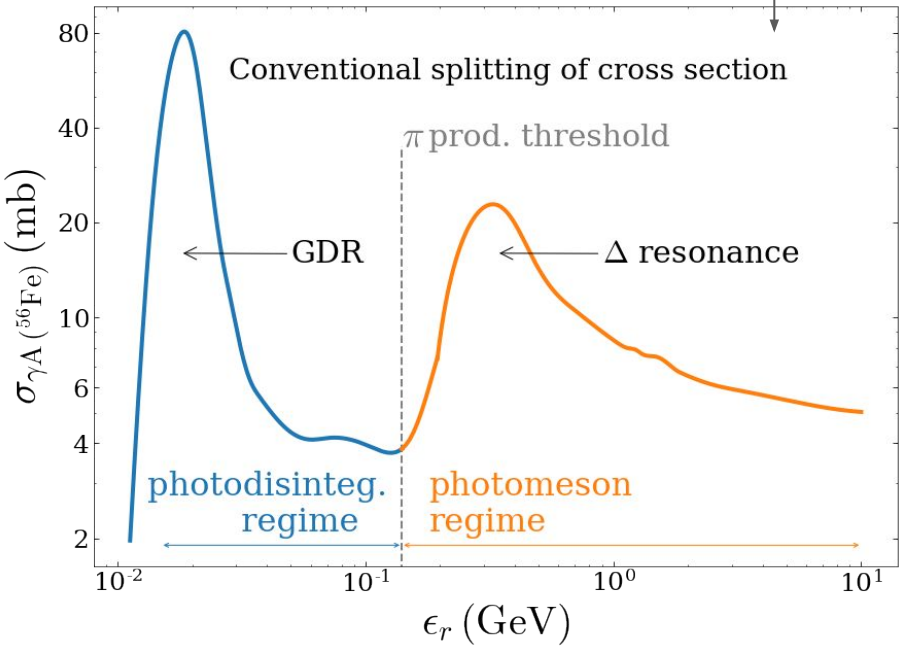
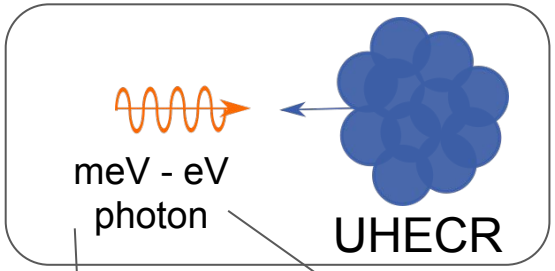


SOURCE







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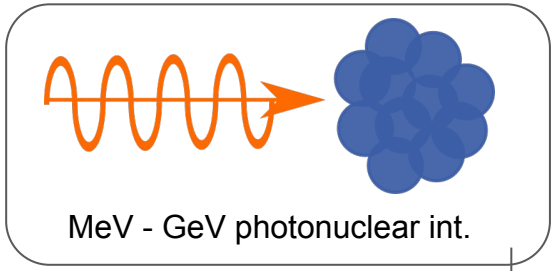
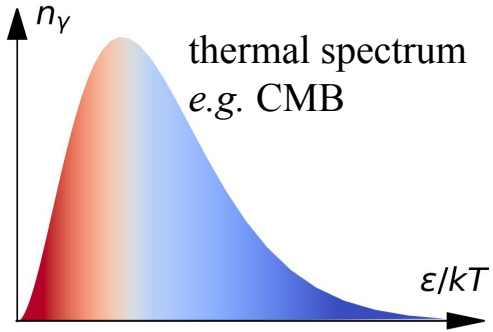
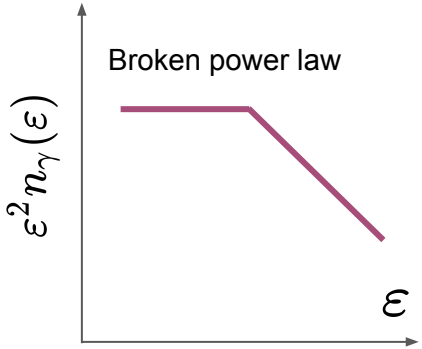


$$\lambda(\gamma) = \frac{1}{2\gamma^2}\int_0^\infty \frac{n(\epsilon)}{\epsilon^2} d\epsilon \int_0^{2\epsilon\gamma} \varepsilon\sigma(\varepsilon) d\varepsilon$$

PROPAGATION

SOURCE





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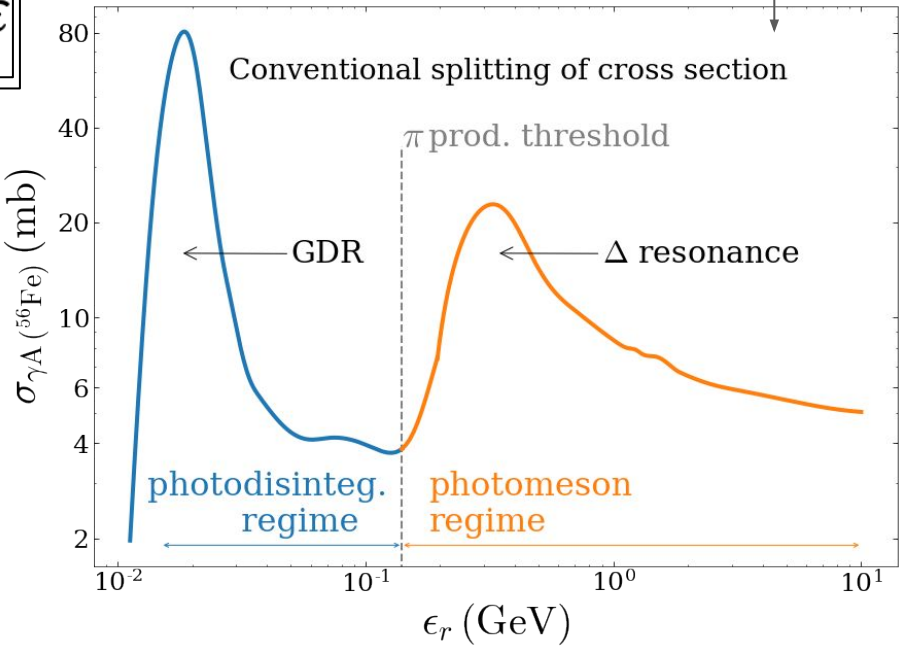

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Feedback

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For questions, support and issues in the code you can open an issue on the github repository.

Additionally you can open a ticket in the ACME support website:

https://support.acme-astro.eu/