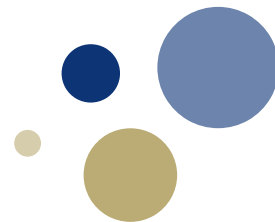


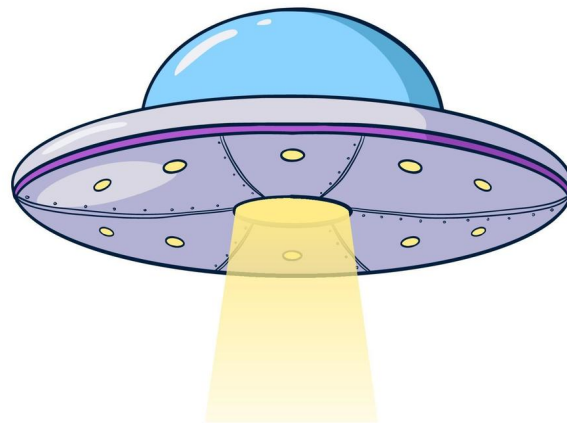


NTNU

Norwegian University of
Science and Technology

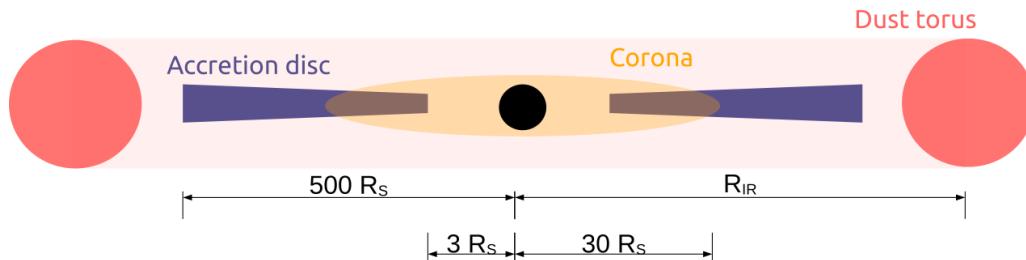
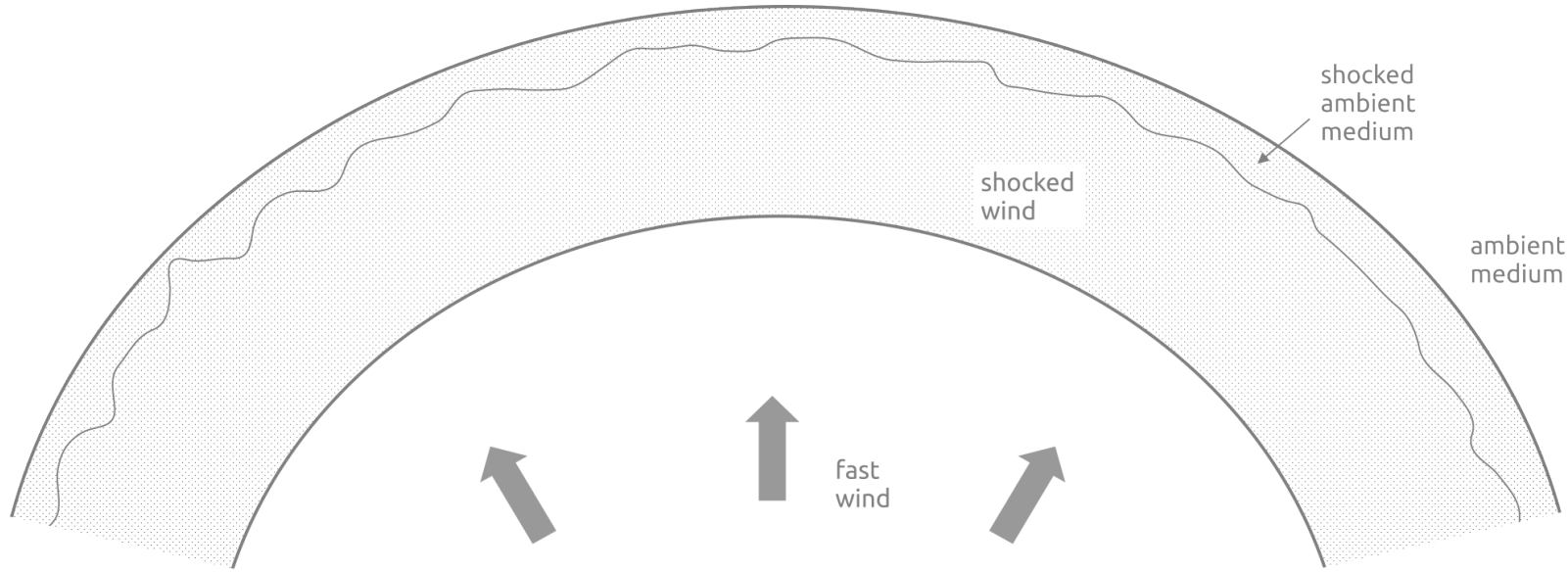


UHECR from UFOs



Domenik Ehlert | 09.12.2024 | Paris

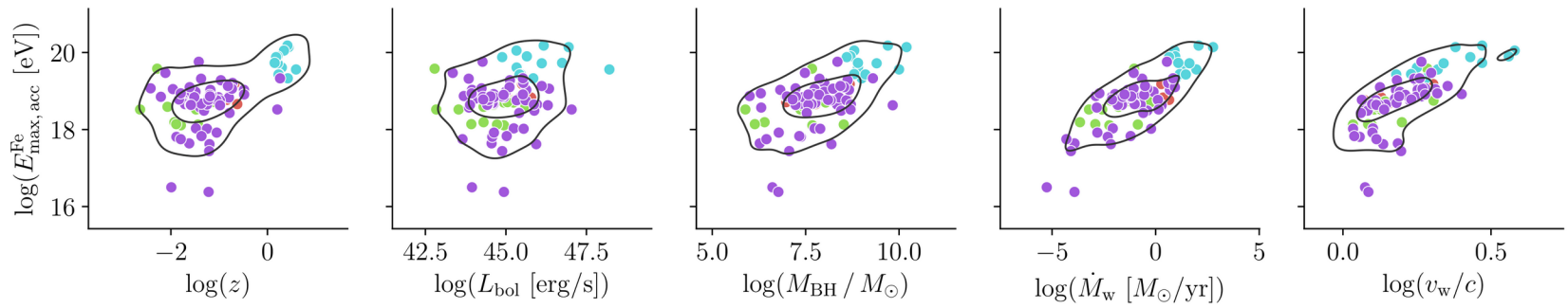
UFO = “Ultra-Fast Outflow” (from AGN)



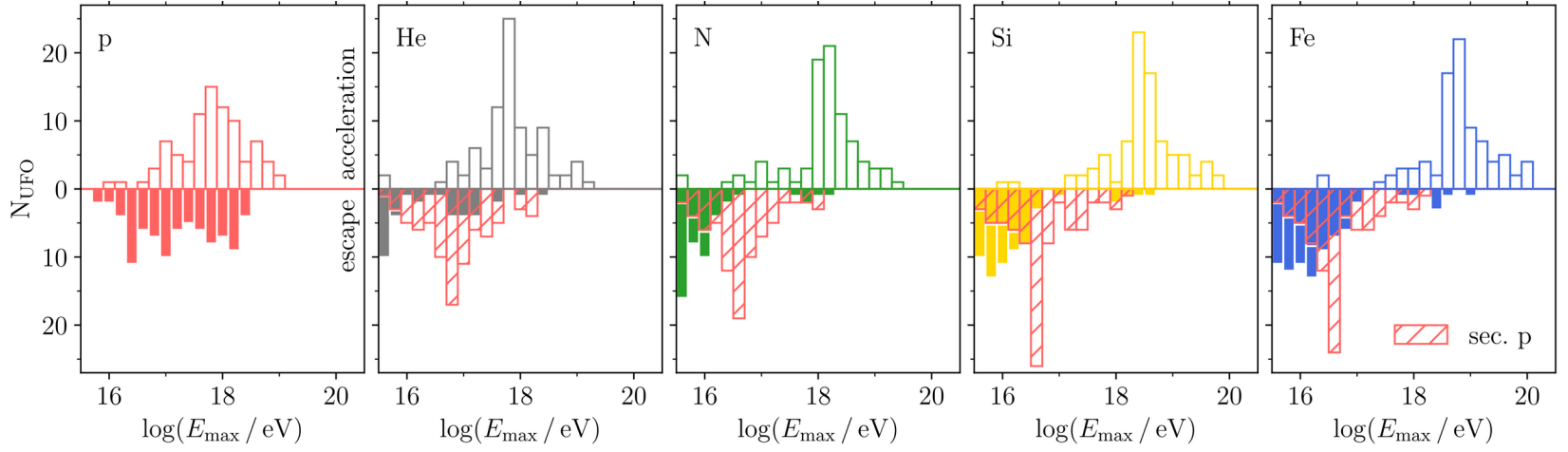
- wind bubble
- in 50% of AGN
- 0.5c; wide angle
- study 87 UFOs

Maximum Energy of the Cosmic Rays

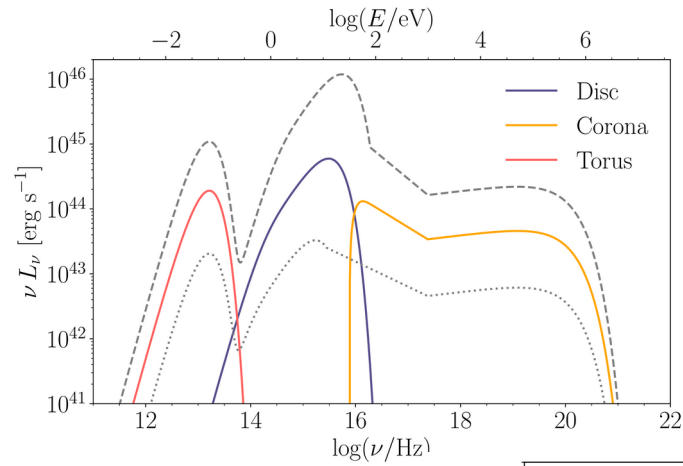
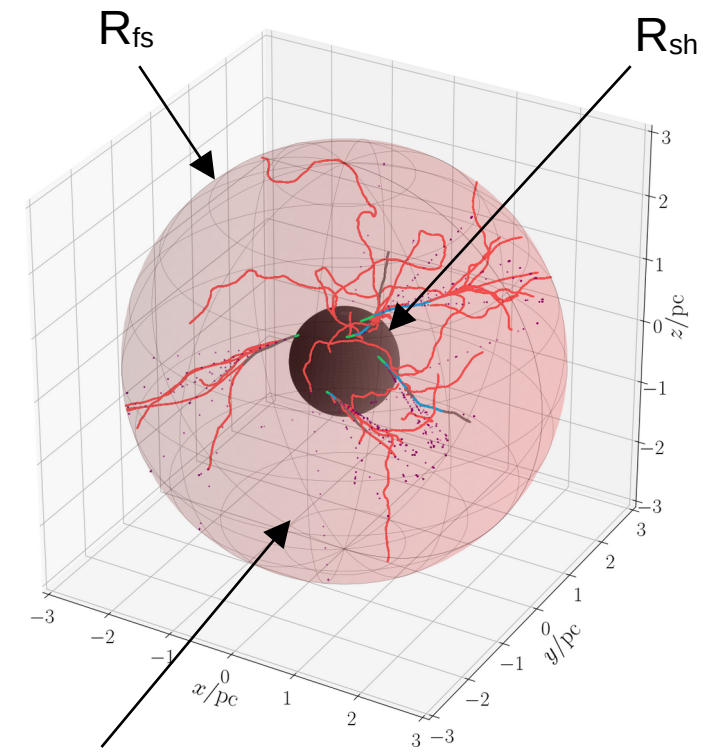
DE, F. Oikonomou, E. Peretti;
MNRAS (soon); arxiv:2411.05667



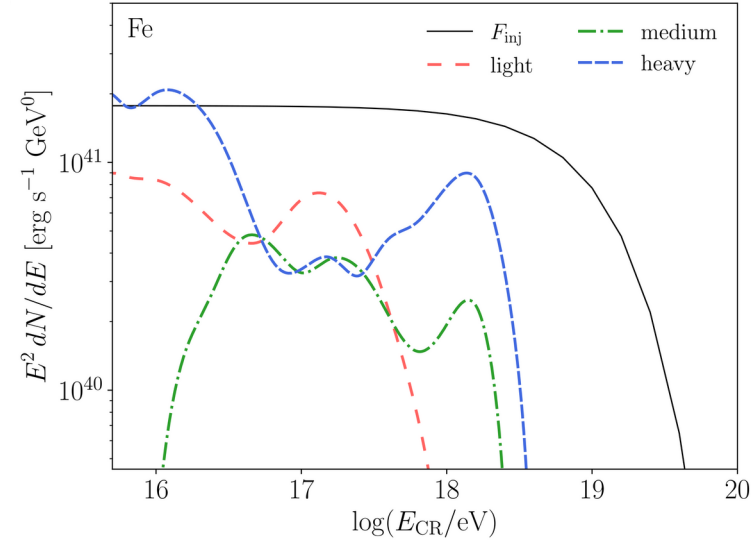
● S23 ● T10 ● C21 ● XWING



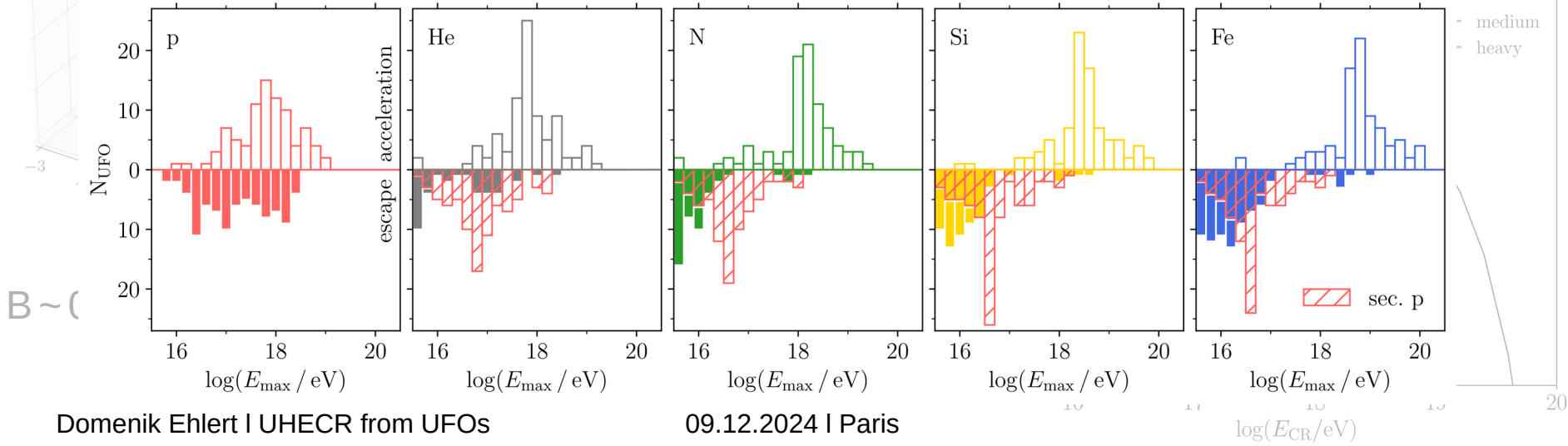
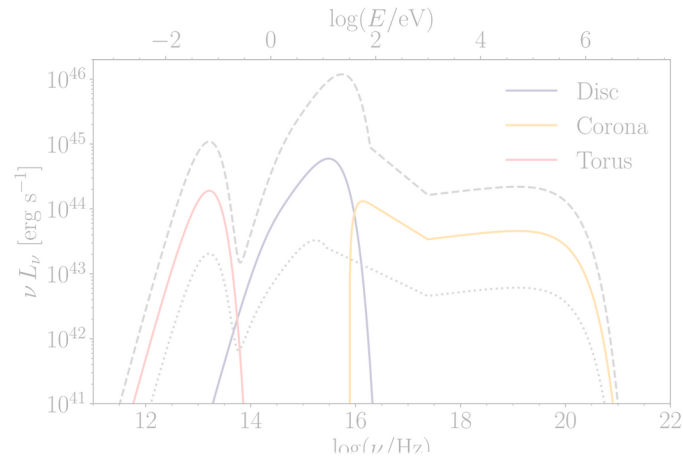
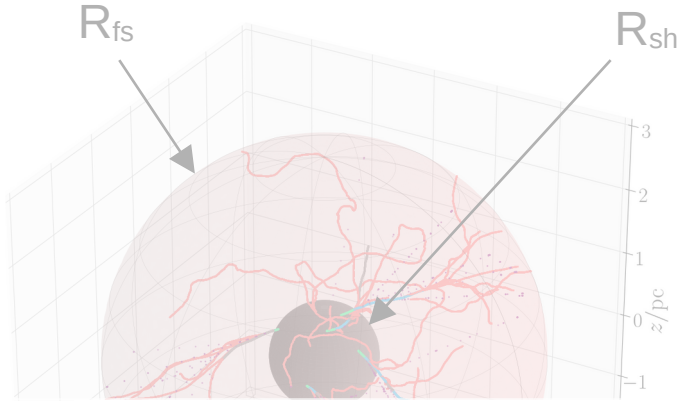
Maximum Energy of the Cosmic Rays



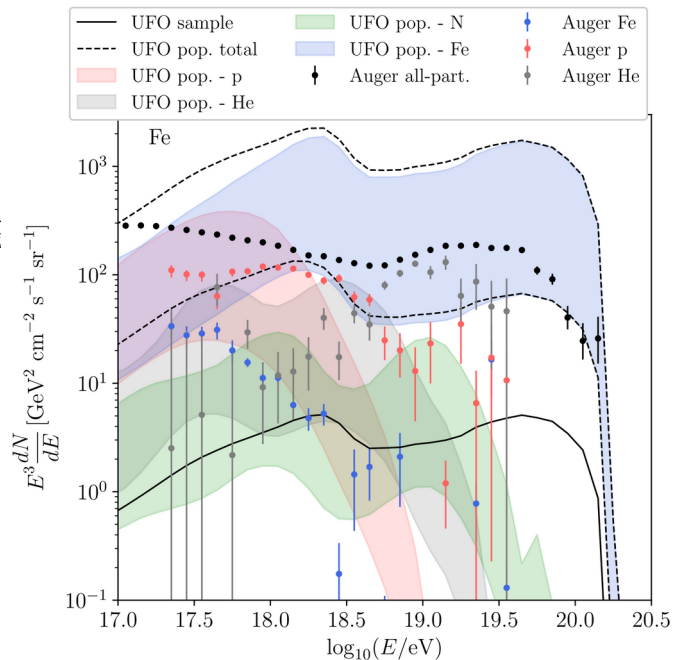
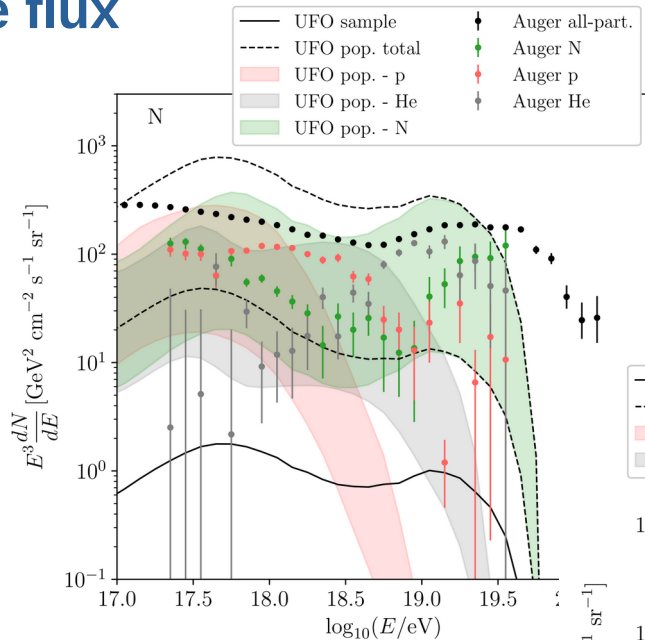
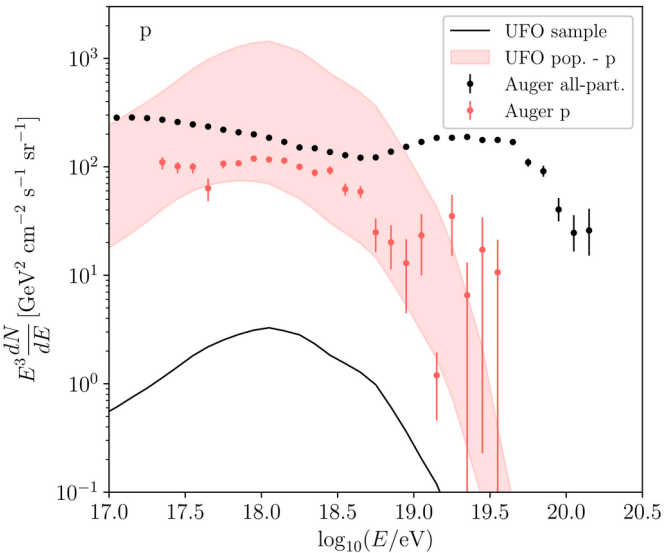
- 1) Strong magnetic field (mG ~ G)
 - 2) Dense external photon fields
- > Disintegration of CR nuclei



Maximum Energy of the Cosmic Rays



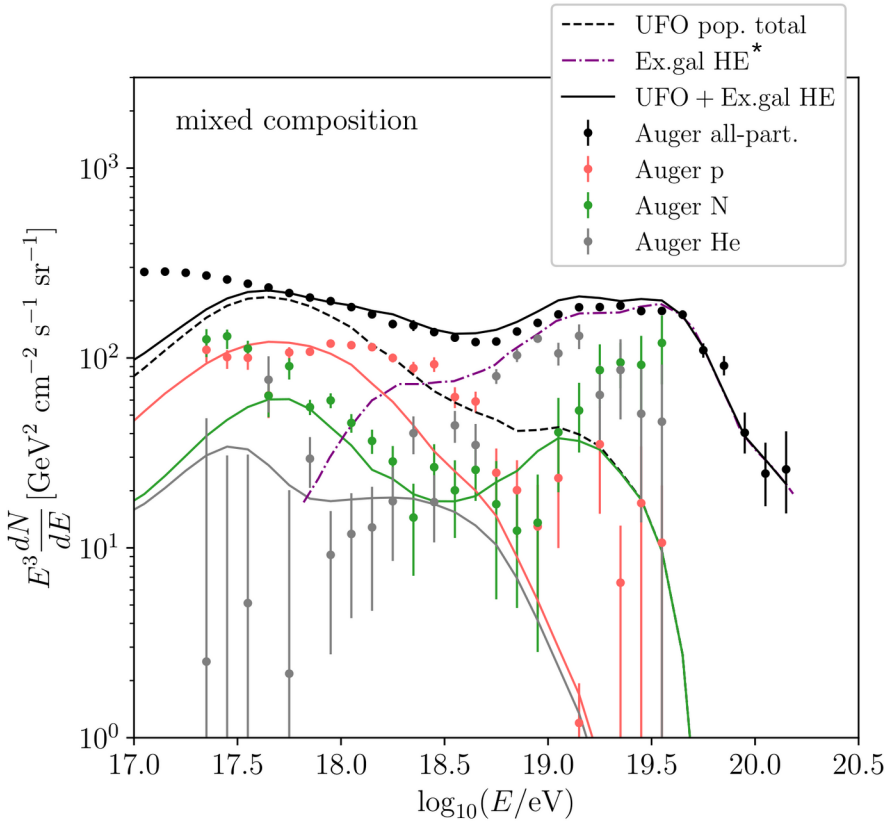
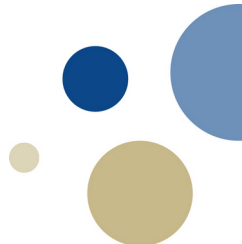
Contribution to the diffuse flux



Extrapolate to total UFO population (~50% of AGN)

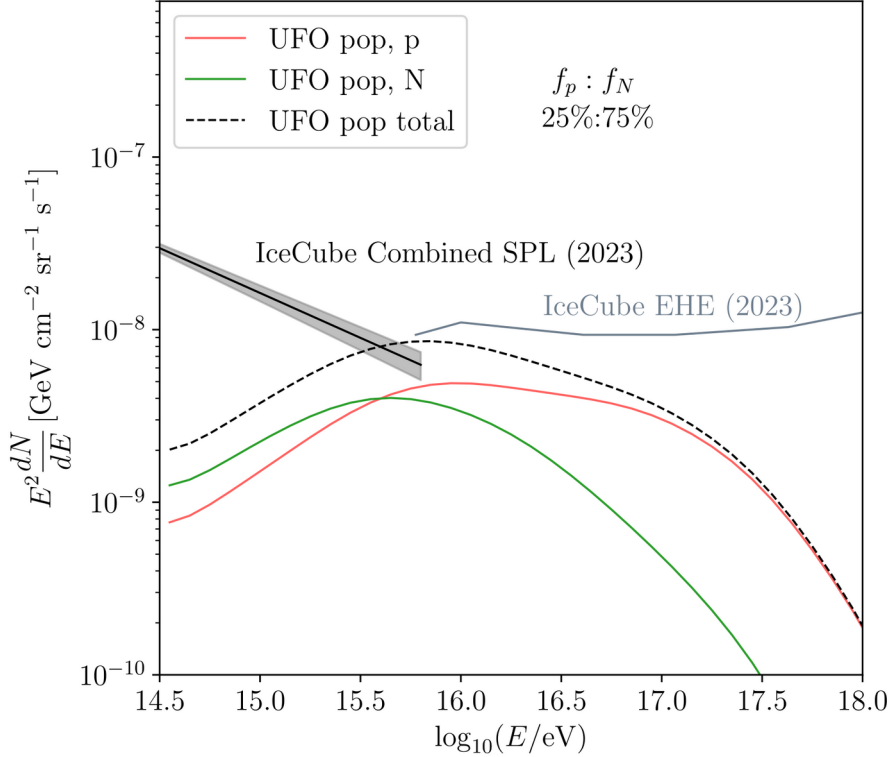
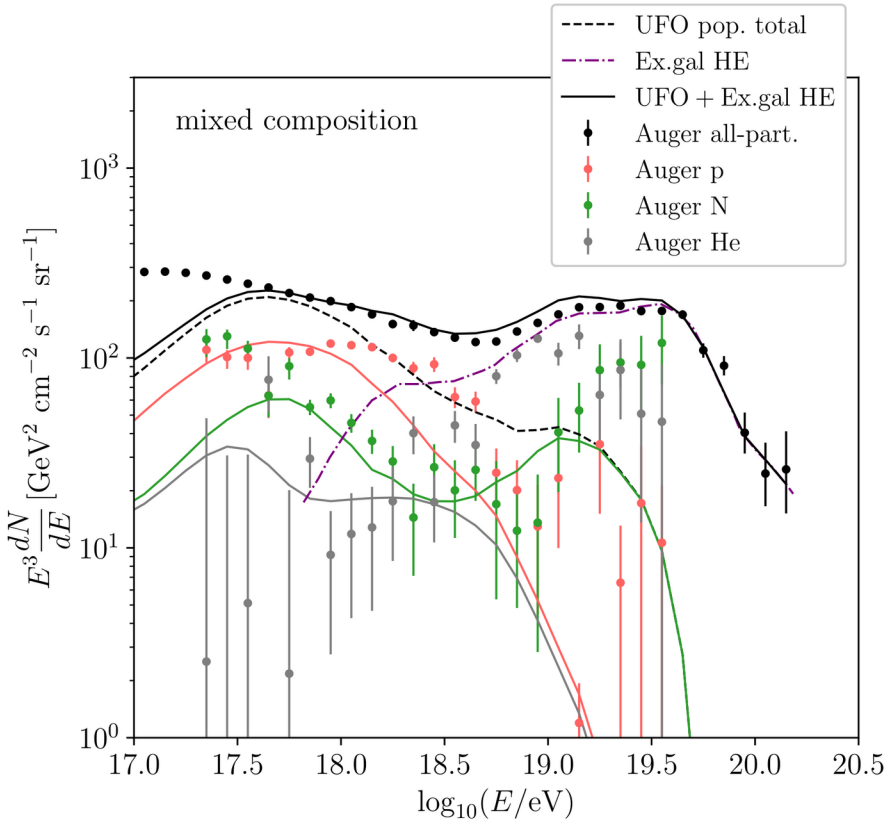


Contribution to the diffuse flux



* Pierre Auger Collab.
JCAP 05 (2023) 024

Contribution to the diffuse flux



Conclusions:

- 1) promising source of sub-ankle flux
- 2) potentially also significant contribution above the ankle

see arXiv:[2411.05667](https://arxiv.org/abs/2411.05667), MNRAS (soon)

Ultra-high-energy cosmic rays from ultra-fast outflows of active galactic nuclei

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²Université Paris Cité, CNRS, Astroparticule et Cosmologie, 10 Rue Alice Domon et Léonie Duquet, 75013 Paris, France

Ultra-high-energy cosmic rays from ultra-fast outflows of active galactic nuclei



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[2] Université Paris Cité, CNRS, Astroparticule et Cosmologie, Paris, France

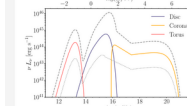
Abstract

Introduction: Ultra-fast outflows (UFOs) are potential sources of ultra-high-energy cosmic rays (UHECRs). These large-scale, mildly-relativistic outflows are a common feature of AGN. We have studied the maximum energy and escaping flux of cosmic rays with 3D CRPropa simulations for 87 observed UFOs.

Results: Nuclei can be accelerated up to 100 EeV in some UFOs but the escaping flux is strongly suppressed by photo-disintegration via the AGN photon fields. An intermittent escape during low-emission states of the AGN may be possible. Protons typically escape with only mild attenuation. We show that UFOs can explain the observed UHECR flux in the transition region below the ankle and potentially contribute to the flux of cosmic-ray nuclei up to the highest energies.

Acceleration and Escape of UHECRs

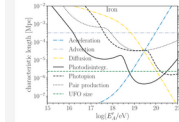
External Photon Fields in the AGN



Relevant Photon Fields:

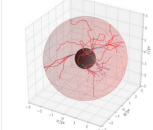
- Blackbody IR dust torus, T=200K
 - Multi-colour blackbody accretion disc
 - broken-powerlaw X-ray corona
- Normalised via obs. lumi. scaling factors.

Semi-analytical Acceleration



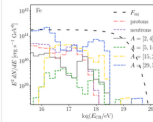
Estimate maximum energy by comparison of characteristic timescales. We assume photon density and mag. field corresponding to R_{in} .

3D Simulation of the Escape



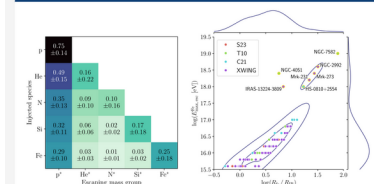
Example for injection of five nitrogen nuclei with >500 EeV. Cosmic rays are confined by the C(10:1) mag. field in the outflow. Particles escape at forward shock.

Numerical Escape Spectra



Model propagation in UFO with CRPropa: include photo-disintegration, photopion production & e^+e^- pair production.

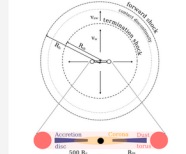
Disintegration of Nuclei in the UFO



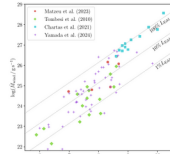
Left: Average fraction of the injected luminosity above 30 PeV contained in each escaping mass group for a given species of primary cosmic rays. Right: Correlation of the maximum energy after escape of iron nuclei with the distance between forward shock and dust torus.

Ultra-Fast Outflows

Physics of UFOs

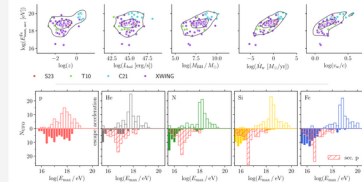


Observed UFOs



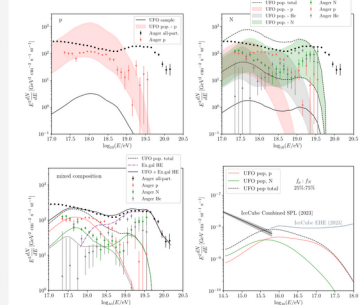
- Wind driven by radiation or MHD
- Termination shock and forward shock [1]
- Term. shock can persist for > 1000 yrs; acceleration of protons up to few EeV? [2]
- Use 87 observed UFOs (5 from [4], 12 from [4], 7 from [5], 53 from [6])
- Up to 50%+ speed of light; $\Gamma \sim 10 \sim 10^5$
- Relative abundance: 50% of AGN; $\sim 10^{10}$ known UFOs

Maximum Energies for the UFO sample



Distribution of maximum energies over the UFO sample for different primary cosmic rays.

Contribution to the diffuse UHECR and neutrino flux



Flux at Earth for injection of protons, nitrogen, and p+n = 25%/75% and the assoc. neutrinos.



[1] C.A. Faucher-Giguère et al. MNRAS 425 (Sept. 2012), 2215
[2] E. Peretti et al. MNRAS 461 (Sept. 2016), 3020
[3] F. Sanchez et al. Astron. Astrophys. 521, A27 (Oct. 2010)
[4] G. Chabrier et al. Astrophys. J. 190A, 64 (Dec. 2002), 34
[5] G. A. Mattoni et al. Astron. Astrophys. 656, A82 (Jan. 2011)
[6] S. Inoue et al. Astrophys. J. Suppl. 204, 16 (Jan. 2013), 16