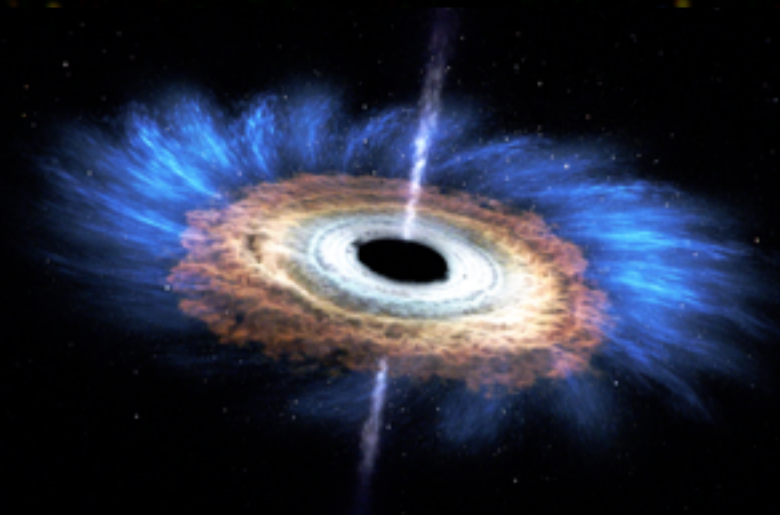
Ultra-high-energy cosmic rays and neutrinos from tidal disruptions by massive black holes

C. Guépin, K. Kotera, E. Barausse, K. Fang and K. Murase, arXiv:1711.11274



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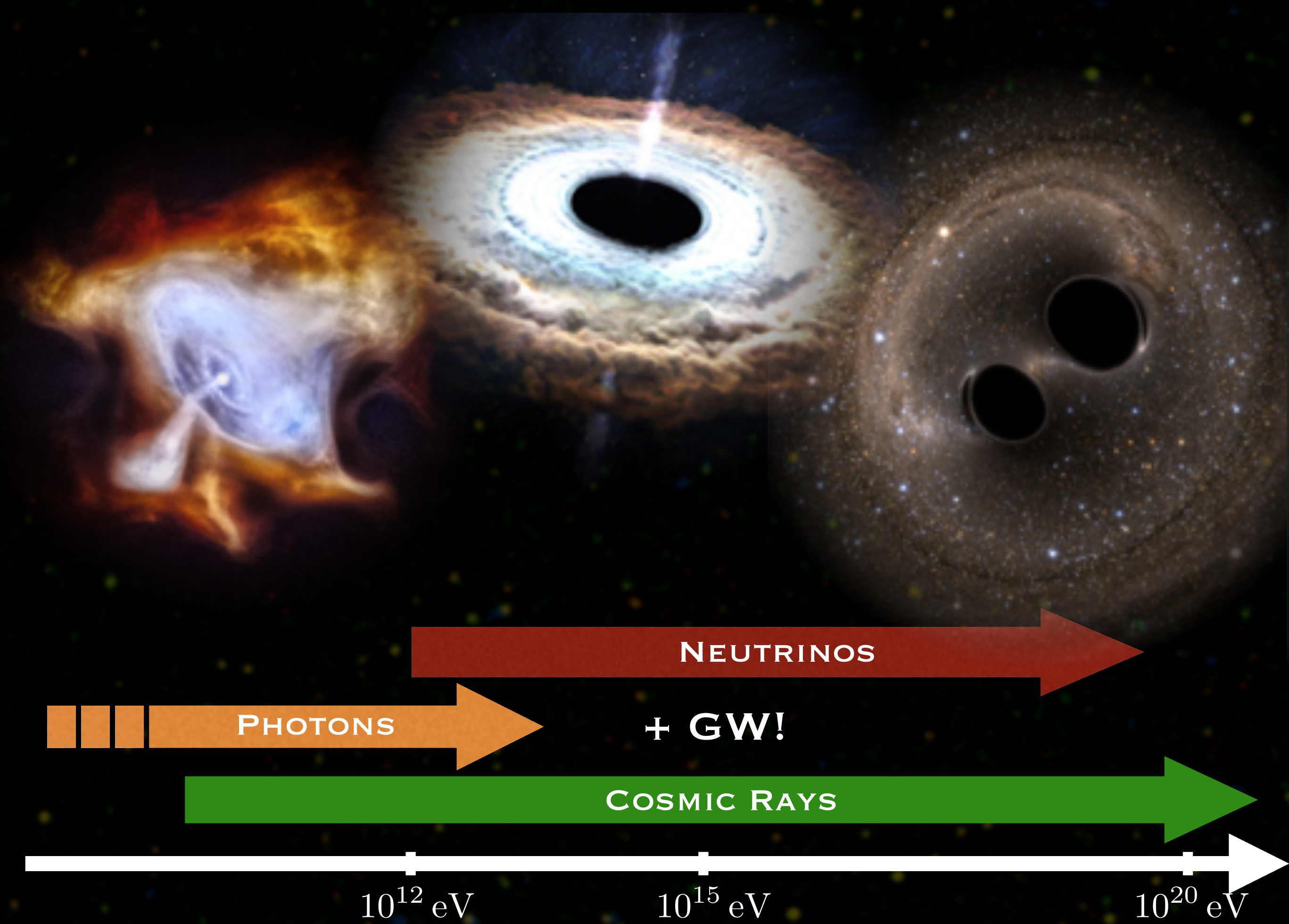
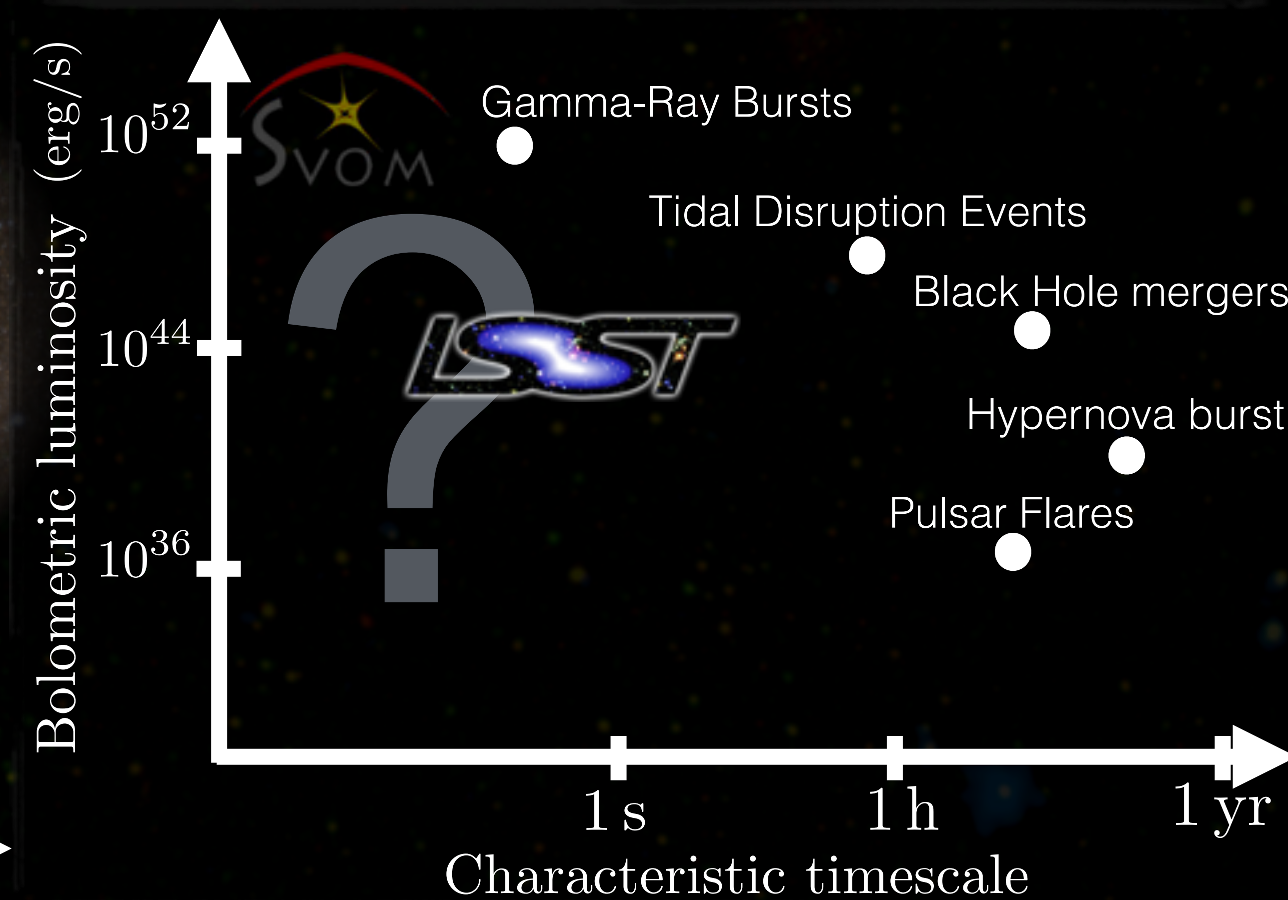
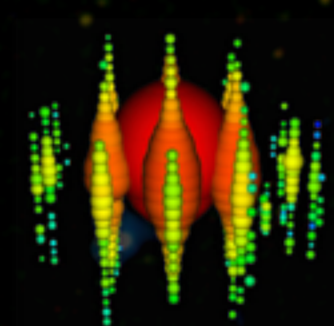
Multi-messenger transient astronomy



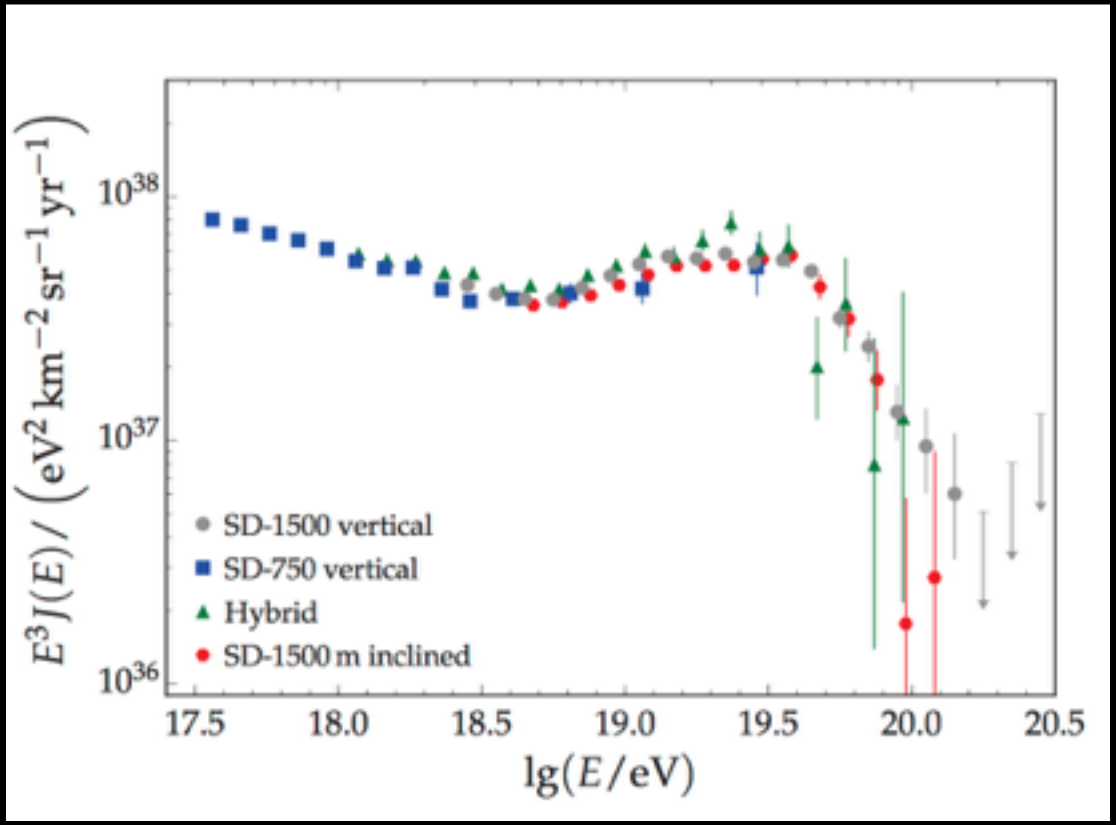




Observations

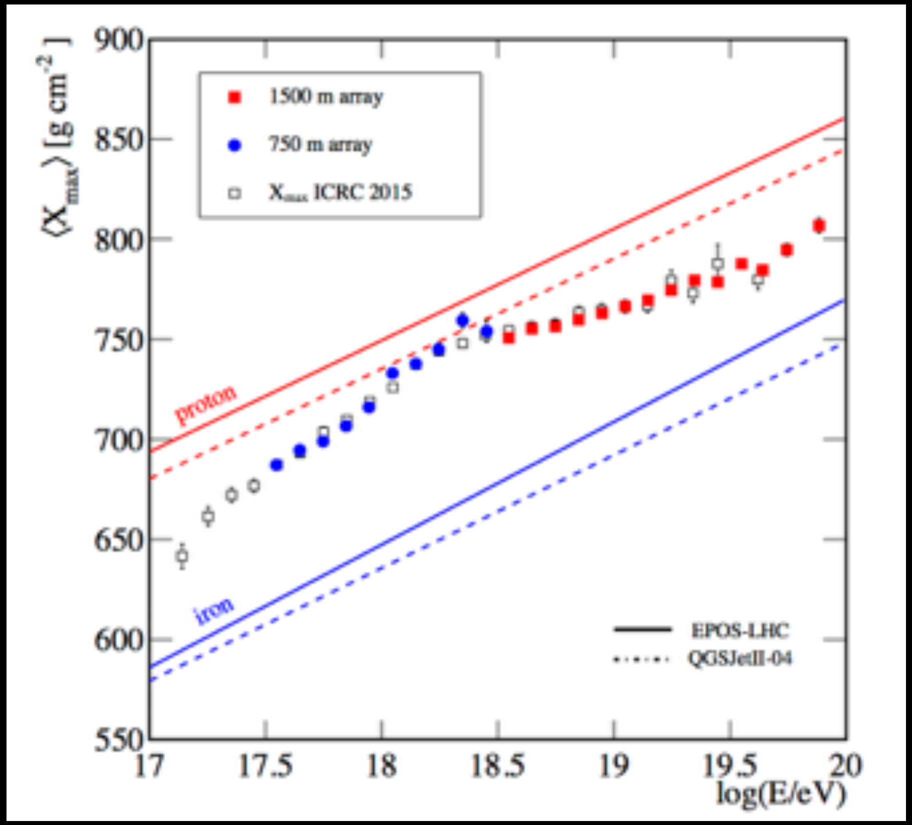
Ultra-High Energy Cosmic Rays and Neutrinos

UHECR spectrum



Pierre Auger Collaboration, ICRC2017

UHECR composition

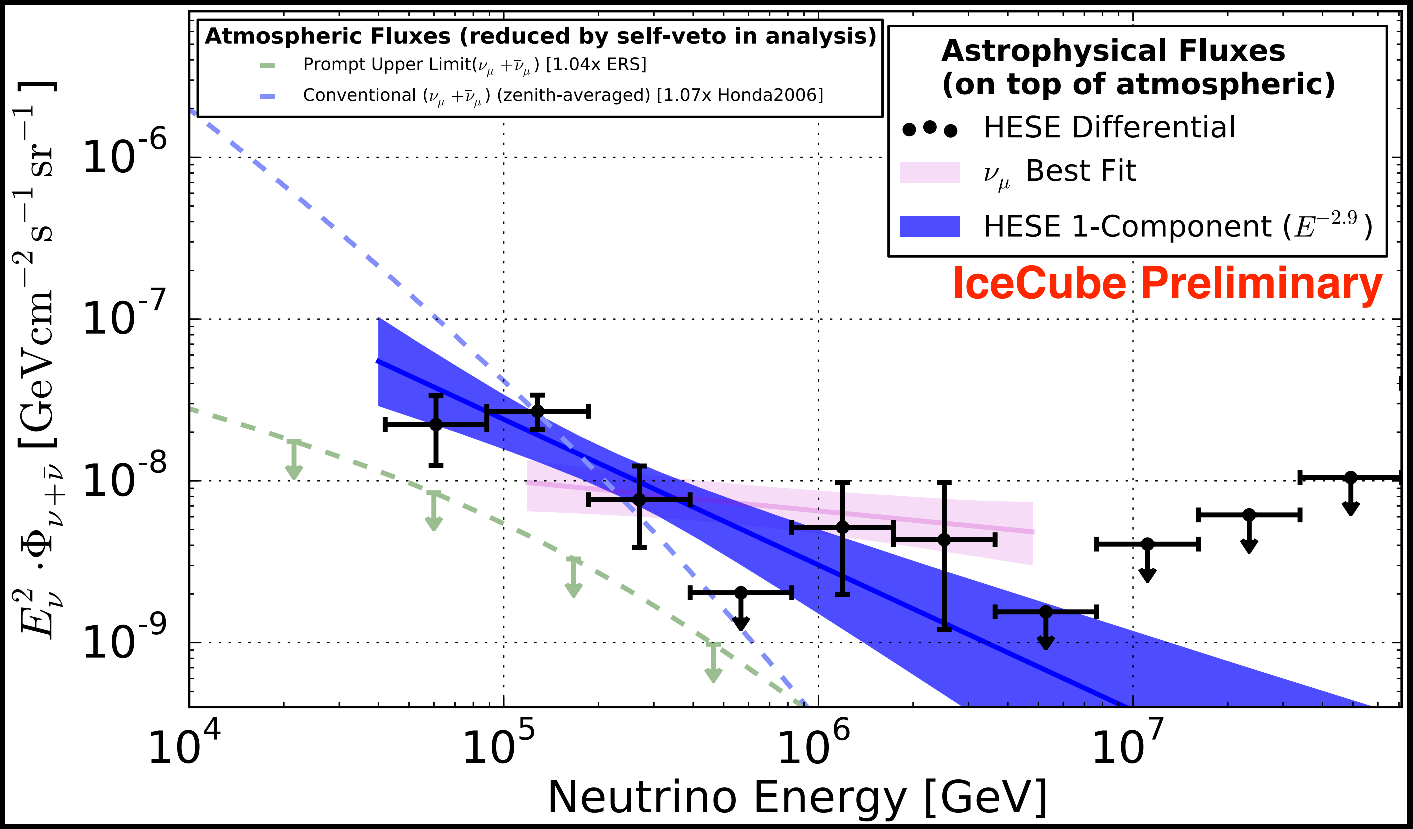


Pierre Auger Collaboration, ICRC2017

Observations

Ultra-High Energy Cosmic Rays and Neutrinos

Astrophysical neutrino flux



IceCube collaboration, ICRC2017

Observations

Ultra-High Energy Cosmic Rays and Neutrinos

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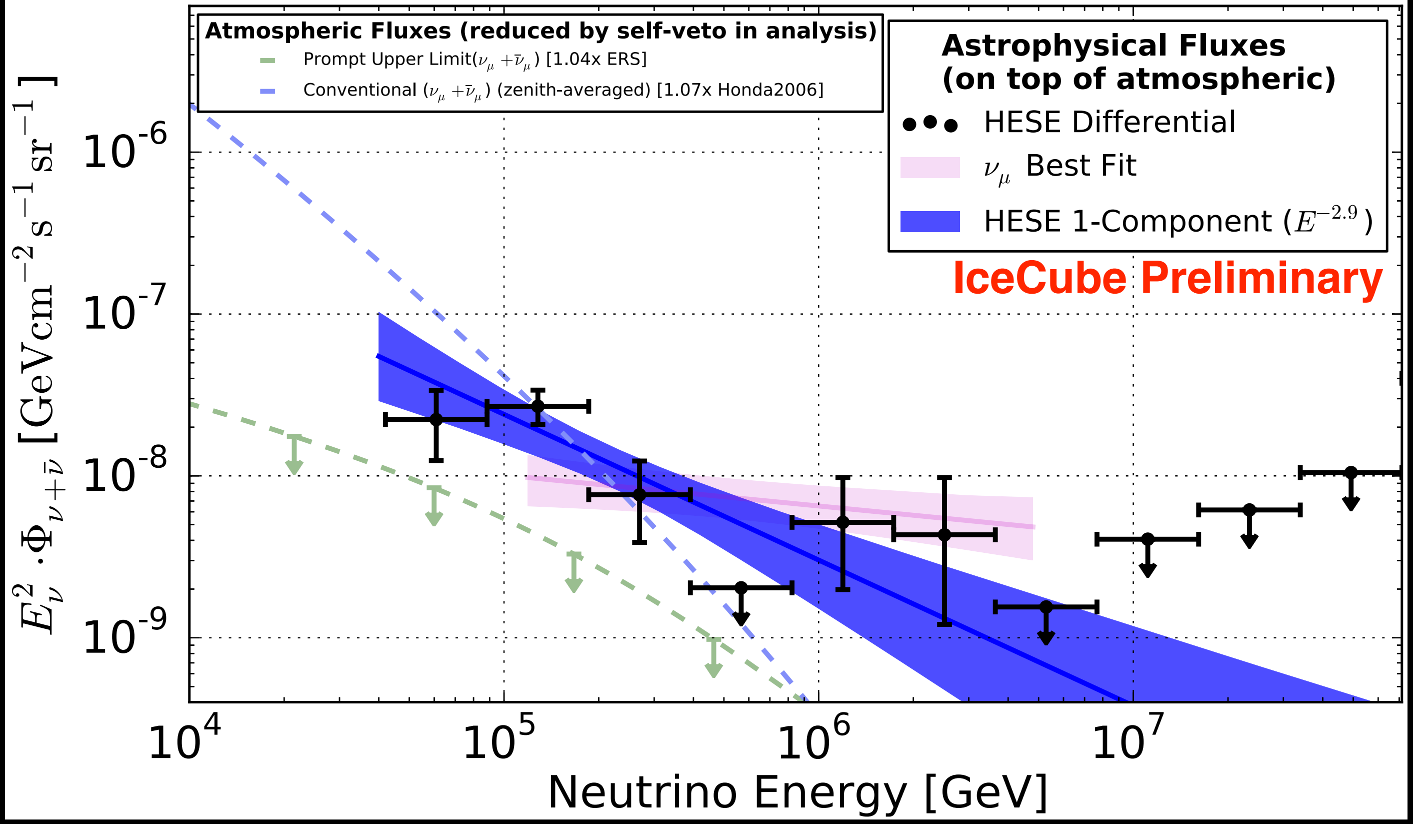


IceCube collaboration, ICRC2017

Sources?

Gamma-ray bursts, Active Galactic Nuclei, pulsars…

Tidal disruptions by massive black holes

→ promising candidate sources of ultrahigh energy messengers

C. Guépin, K. Kotera, E. Barausse, K. Fang and K. Murase, arXiv:1711.11274

- Propagation and interaction of UHECRs in various radiative backgrounds
- Applied to TDEs powering jets

Observed non-thermal emission
$\longrightarrow$ **properties** of radiation region/jet
(e.g. Swift J1644+57)

- time variability of the emission $t_{\rm var} = 10^2\,{\rm s}$
- equipartition $U_B = U_{\rm rad}$ $\longrightarrow$ mean magnetic field
- bulk Lorentz factor $\Gamma \sim 10$

Impact of interactions within the jet?

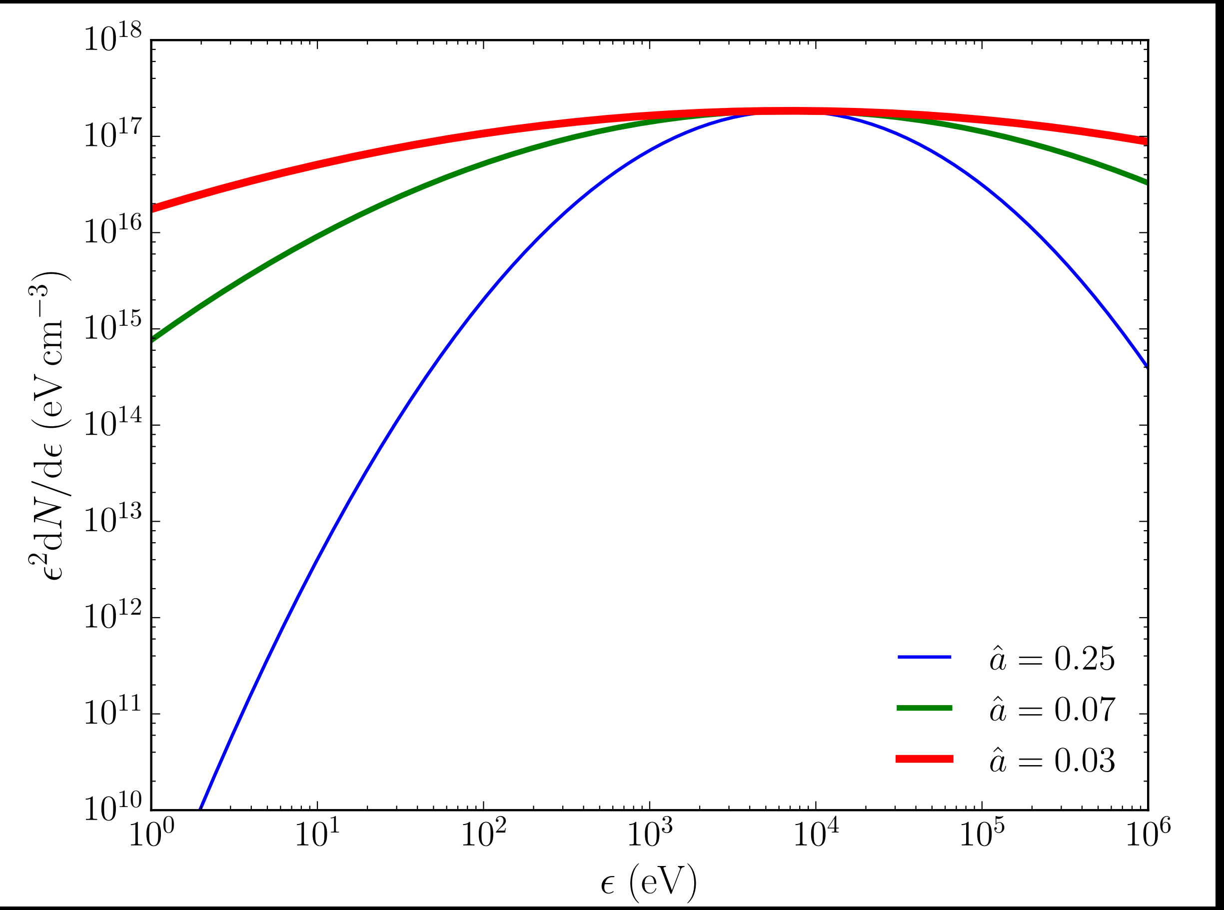
Especially for nuclei, numerical treatment required:
- various interaction and energy-loss processes
- production of secondary particles

Tidal disruptions by massive black holes

Photon density in the jet (observable)

$$\epsilon'^2 n'_{\epsilon'} = \frac{L_{\rm pk}}{4\pi\Gamma^2 R^2 c} (\epsilon'/\epsilon'_{\rm pk})^{-\hat{a}\log(\epsilon'/\epsilon'_{\rm pk})}$$

- Non-thermal emission ⟶ accelerated particles radiation. **Jet emission dominates**, not accretion disk emission (thermal).
- Observed spectrum (absorption-corrected) as **target for UHECR interactions inside the jet**.
- Galactic absorption! Ex: Swift J1644+57. Corrections ⟶ uncertainties.



In the following, fixed width, variable peak luminosity: high state, medium state

Tidal disruptions by massive black holes

Photon density in the jet (observable)

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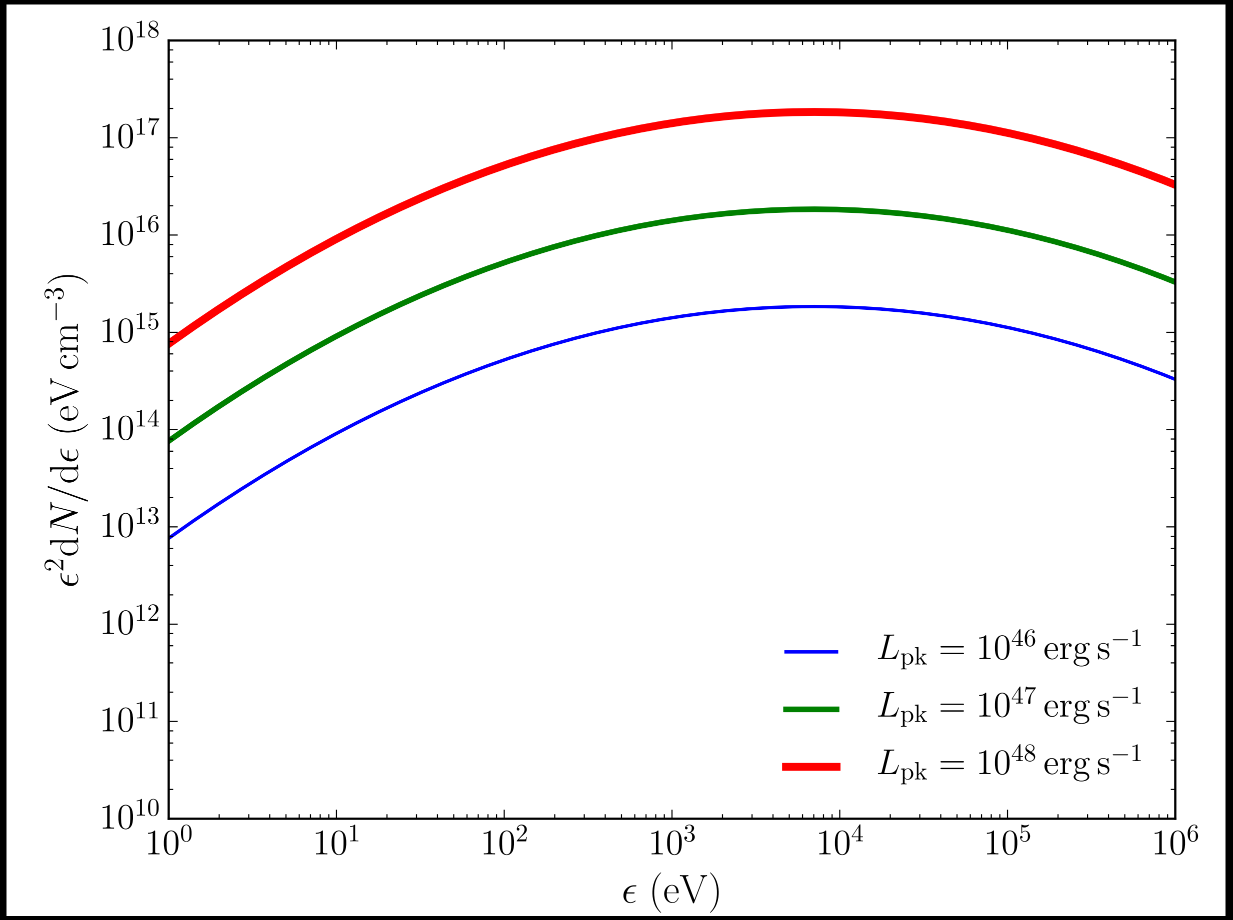

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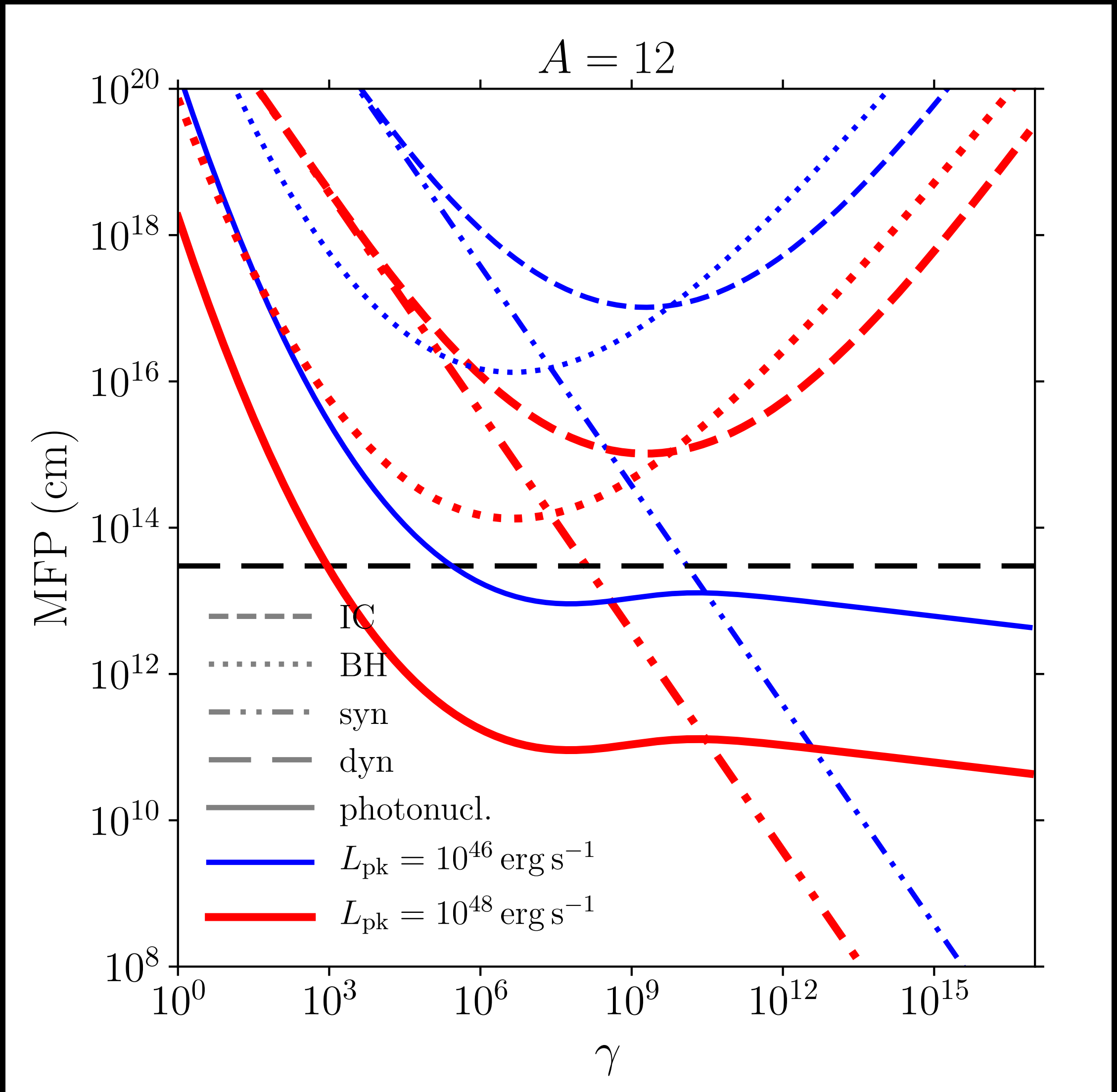
↓

Mean free paths for various interaction processes



- No deflection, $t_{\rm dyn}$ prevail over $t_{\rm diff}$ at these energies $\longrightarrow$ escape of particles directly related to $t_{\rm dyn}$
- Interaction/energy-loss timescales (discrete or continuous processes):

$$t^{-1}_{N\gamma}(\gamma_N) = \frac{c}{2\gamma_N^2} \int_{\epsilon'_{\rm th}}^{\infty} {\rm d}\epsilon' \frac{n'_\epsilon(\epsilon')}{\epsilon'^2} \int_0^{2\gamma_N \epsilon'} {\rm d}E E \sigma_{N\gamma}(E)$$

Tidal disruptions by massive black holes

Photon density in the jet (observable)

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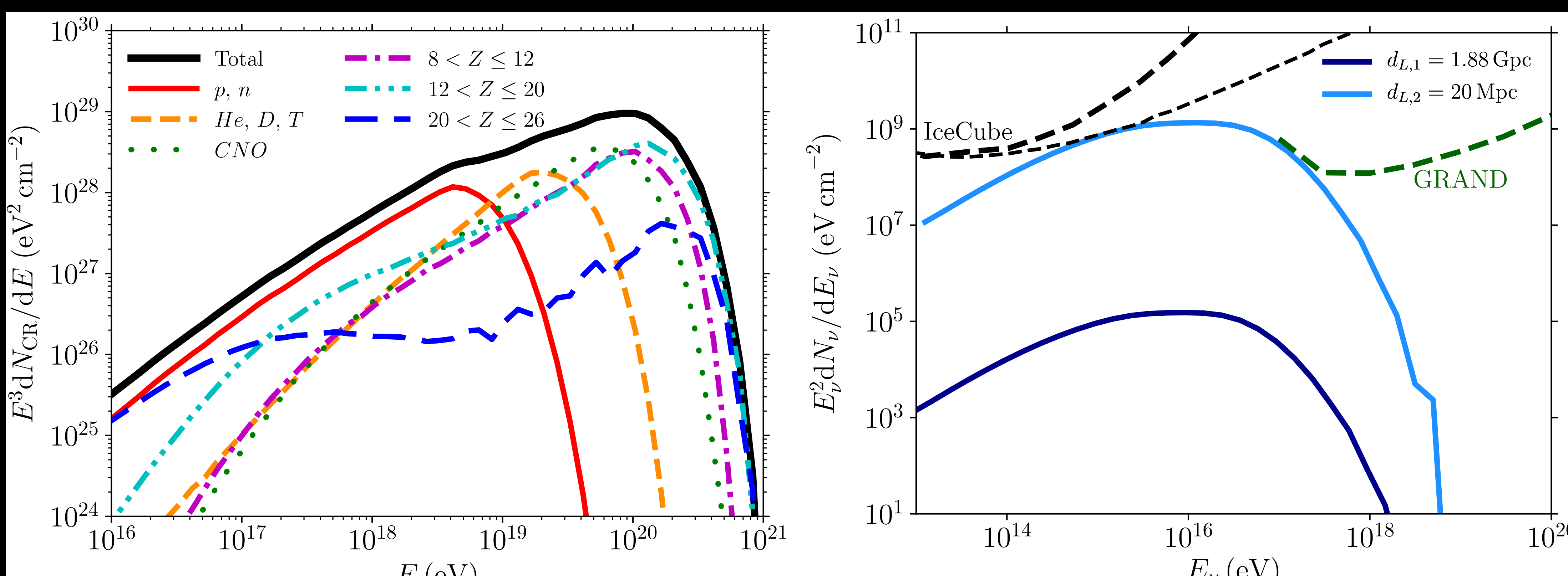
Mean free paths for various interaction processes

↓ **Propagation and interaction of nuclei in the jet**

UHECR and neutrino spectra for one source



Example: pure iron injection

CRs: medium state $L_{\rm pk} = 10^{46}$ erg s^{-1}, neutrinos: high state $L_{\rm pk} = 10^{47.5}$ erg s^{-1}

Tidal disruptions by massive black holes

Photon density in the jet (observable)

$$\epsilon'^2 n'_{\epsilon'} = \frac{L_{\rm pk}}{4\pi\Gamma^2 R^2 c} (\epsilon'/\epsilon'_{\rm pk})^{-\hat{a}\log(\epsilon'/\epsilon'_{\rm pk})}$$

↓

Mean free paths for various interaction processes

↓ **Propagation and interaction of nuclei in the jet**

UHECR and neutrino spectra for one source

↓ **Population model + intergalactic propagation**

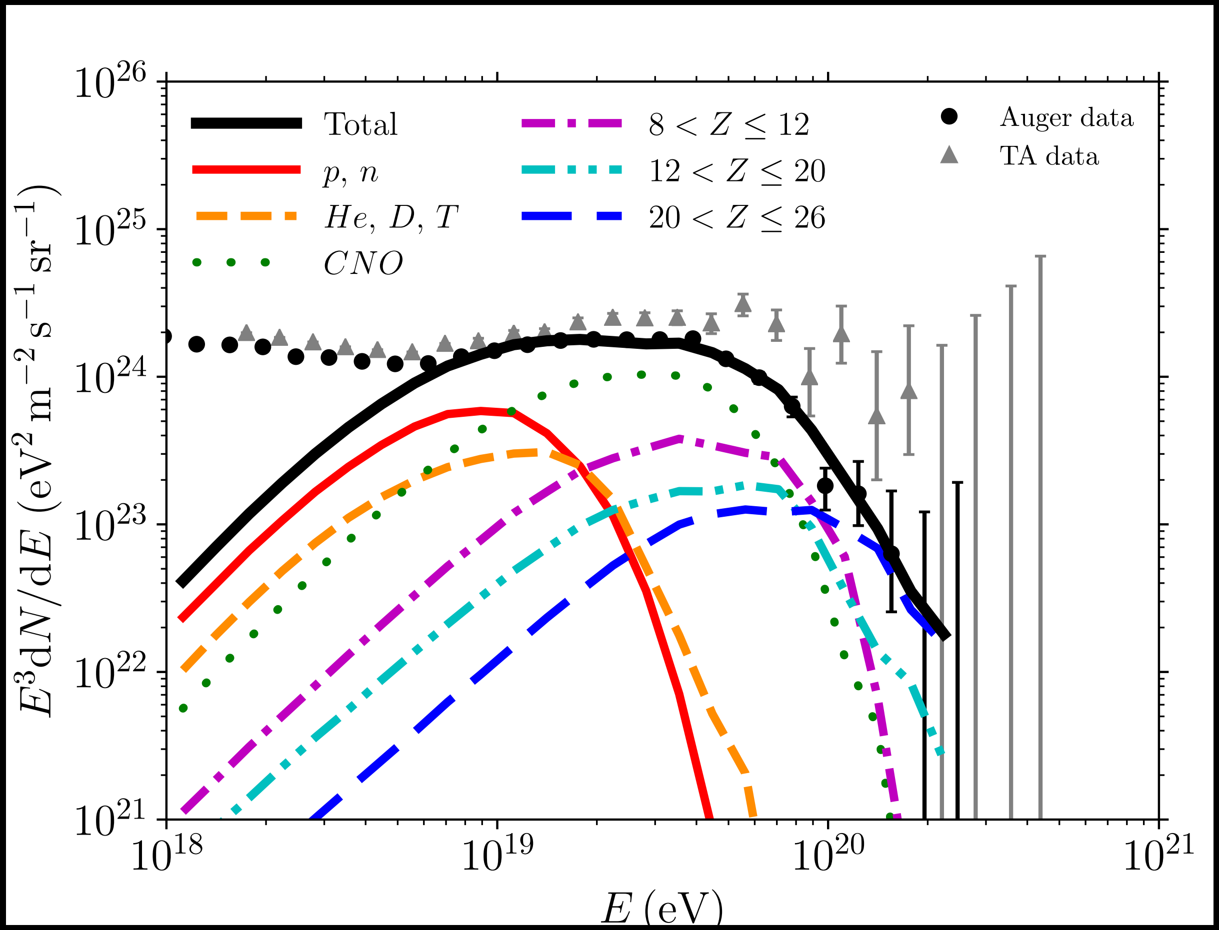
Diffuse UHECR and neutrino spectra

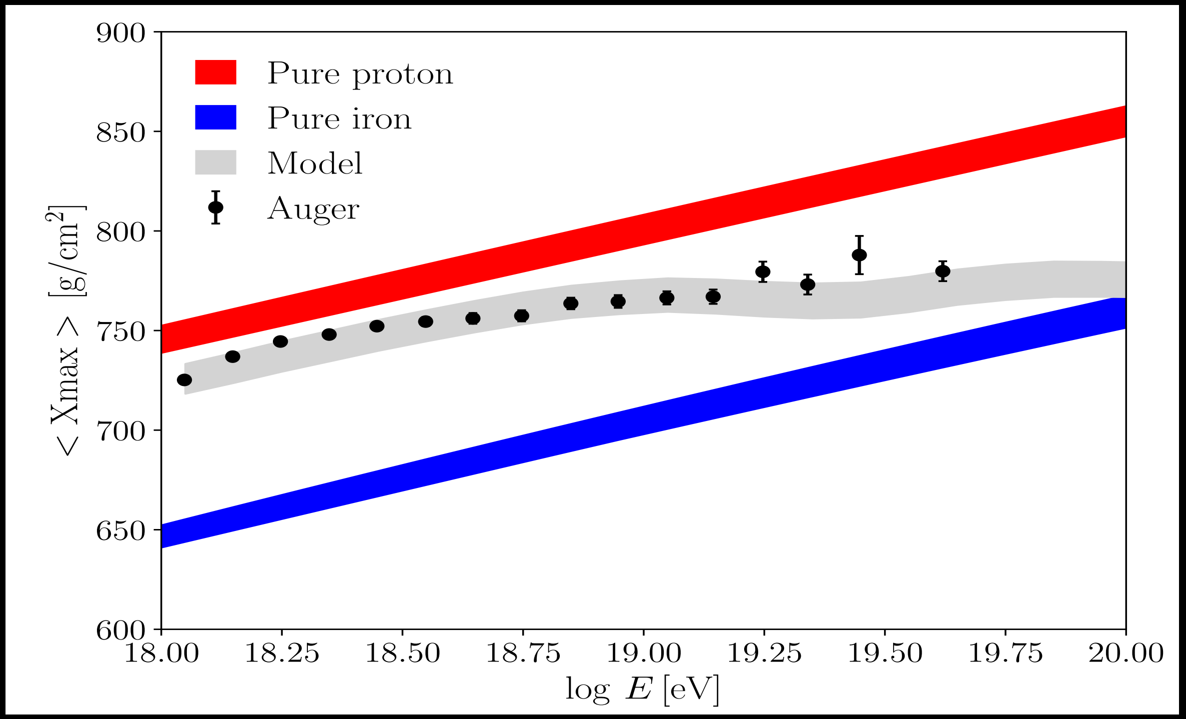
- Only TDEs powering jets, comoving event rate density derived from simulations.
  - Dependences: redshift z and black hole mass $M_{\rm bh}$
  - Modeling jet luminosity (following Krolik & Piran, 2012) $L_{\rm jet} \propto M_{\rm bh}^{-1/2}$

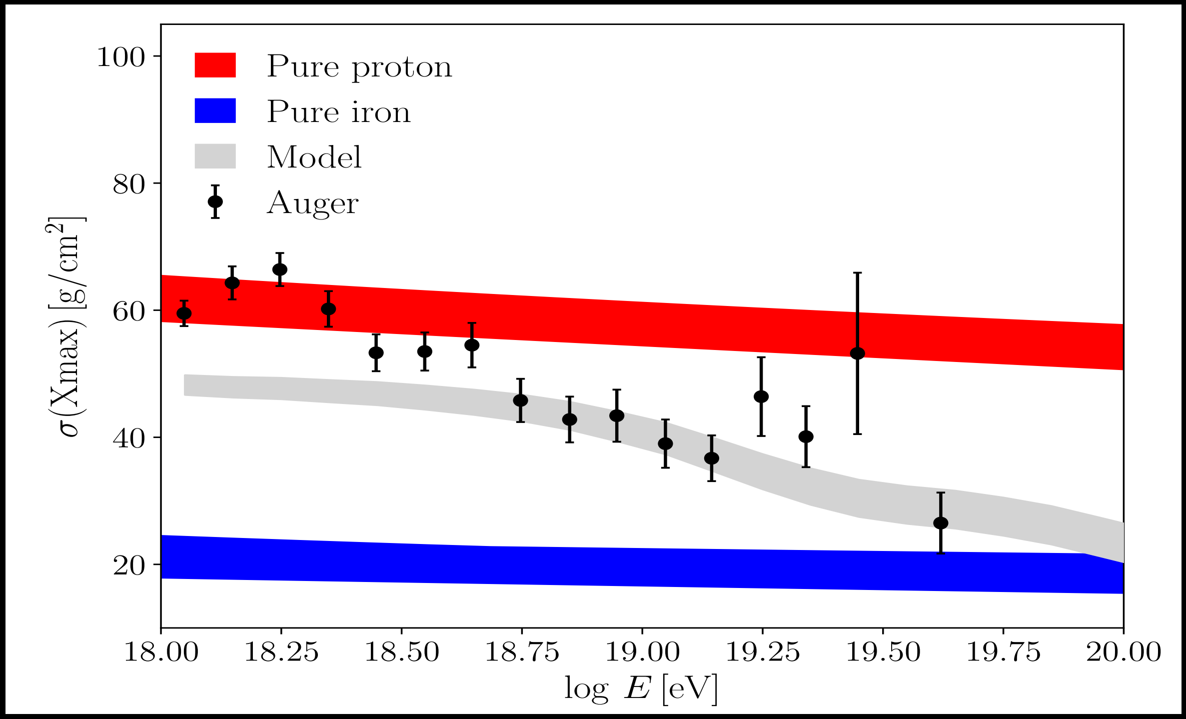
$$\Phi_{\rm CR}(E_{\rm CR}) = \frac{c}{4\pi H_0} \int_{z_{\rm min}}^{z_{\rm max}} \int_{L_{\rm min}}^{L_{\rm max}} {\rm d}z\, {\rm d}L\, \frac{f_{\rm s}\, \xi_{\rm CR}\, \dot{N}_{\rm TDE}\, {\rm d}n_{\rm bh}(z,L)/{\rm d}L}{\sqrt{\Omega_{\rm M}(1+z)^3 + \Omega_\Lambda}} \times F^c_{\rm CR,s,p}(E^c_{\rm CR}, z, L)\, t^c_{\rm dur}$$

Tidal disruptions by massive black holes

Diffuse UHECR and neutrino spectra + composition







composition: **70% Si et 30% Fe**

injection spectral index: 1.5

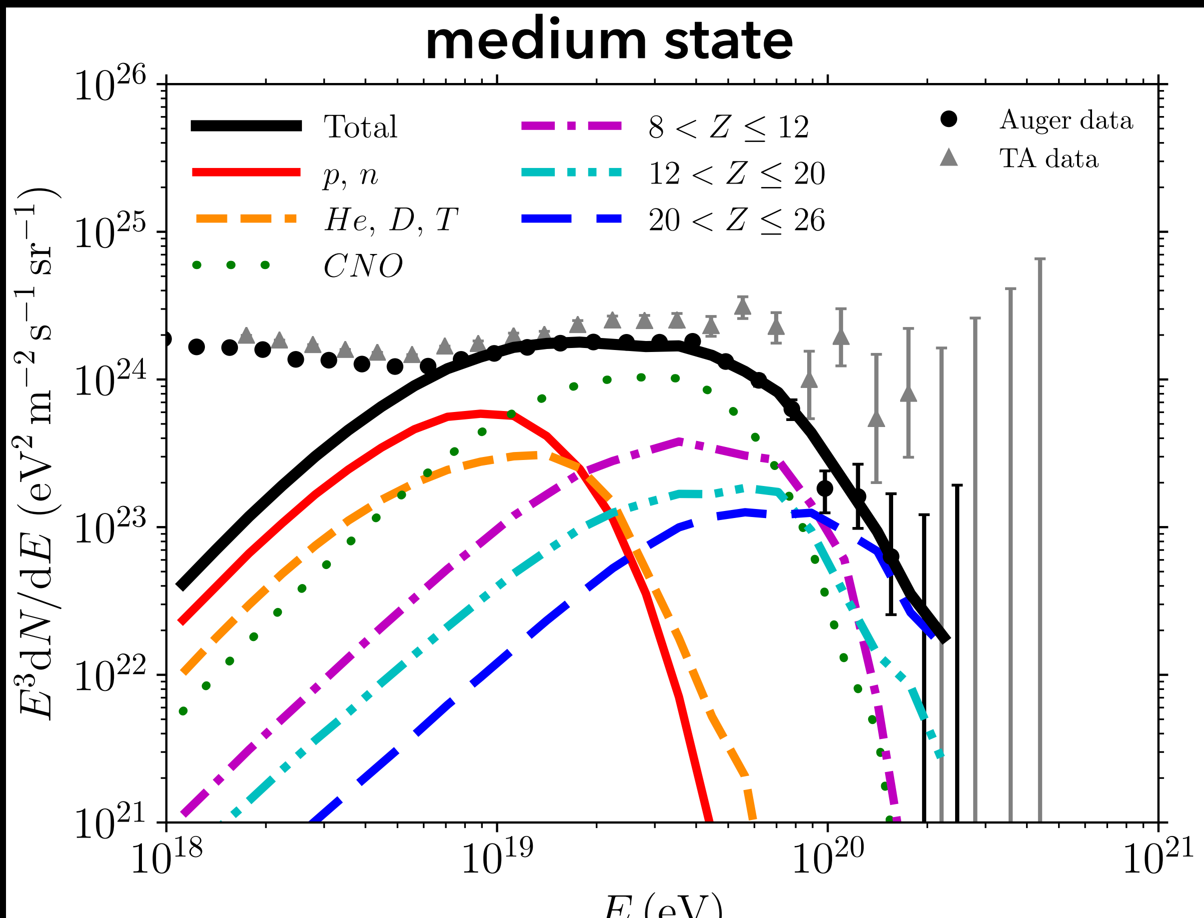
acceleration efficiency: 0.1

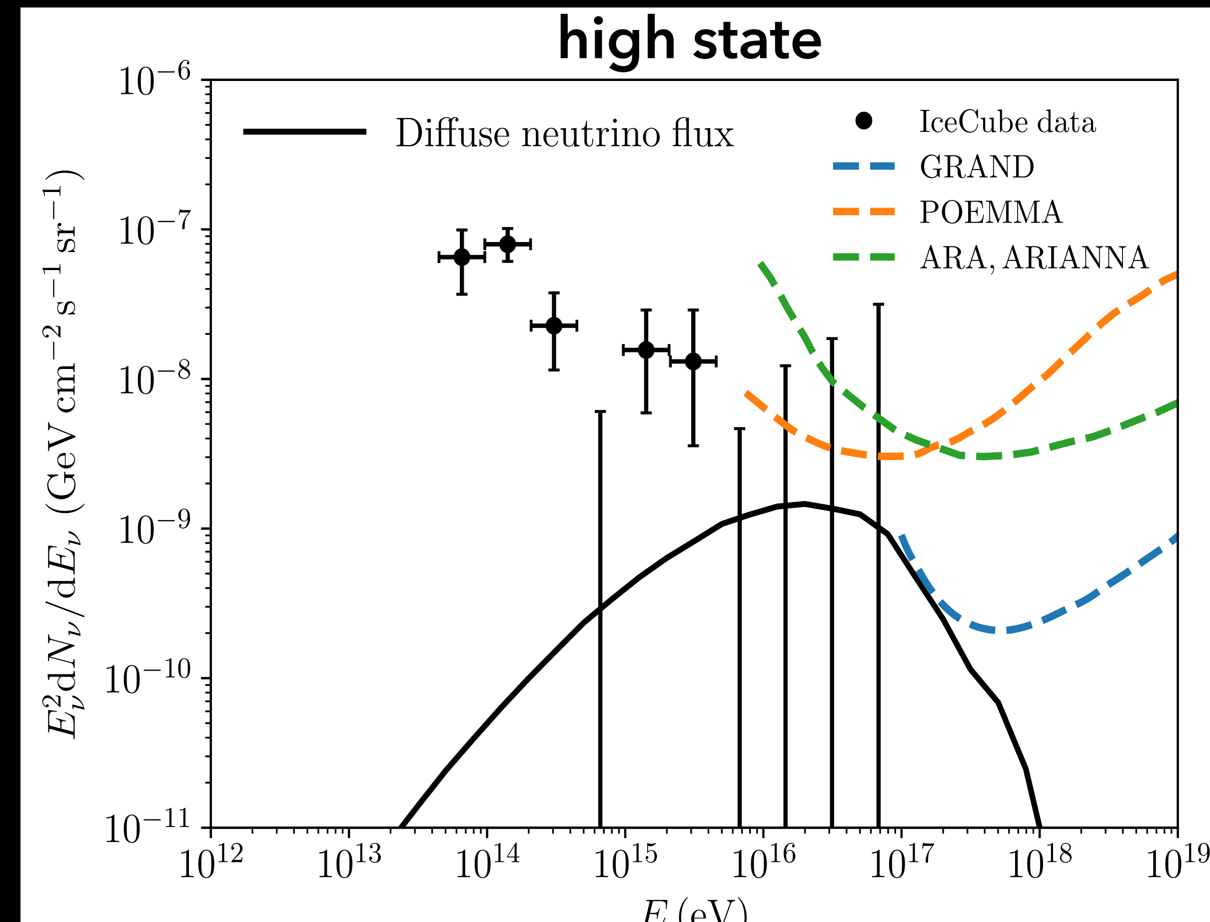
fraction of the event local rate: 1%

- maximum local event rate density: 155 $\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$

Tidal disruptions by massive black holes

Diffuse UHECR and neutrino spectra + composition





composition: **70% Si et 30% Fe**

injection spectral index: 1.5

acceleration efficiency: 0.1

Lighter composition requires:

- harder injection spectral index
- higher acceleration efficiency

fraction of the event local rate: 1%

- maximum local event rate density: 155 $\mathrm{Gpc^{-3}\,yr^{-1}}$

Conclusion

UHECRs and neutrinos from jetted tidal disruption events

- numerical tool, propagation and interaction of UHECR in any type of radiative background
- applied to tidal disruptions by massive black holes powering jets
- parameters chosen to reproduce the Auger UHECR spectrum and composition:
  - composition and spectral index of injection,
  - acceleration efficiency,
  - fraction of the event local rate,
- predicted neutrino spectrum only marginally detectable with GRAND.

Perspectives

- include gamma-ray production
- reduce uncertainties related to interactions cross sections, production of secondaries and propagation,
- apply to other categories of sources

Thank you for your attention!