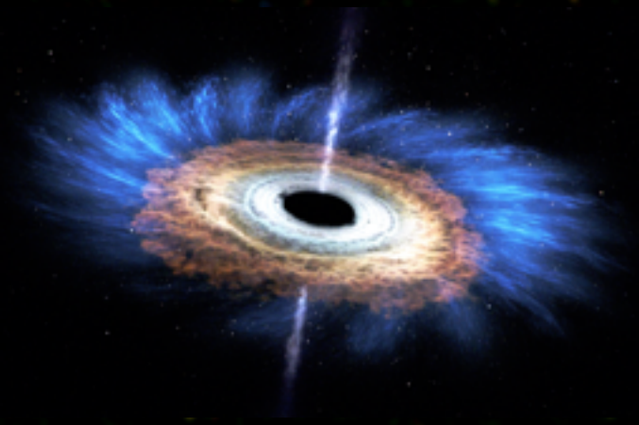
UHECR 2018

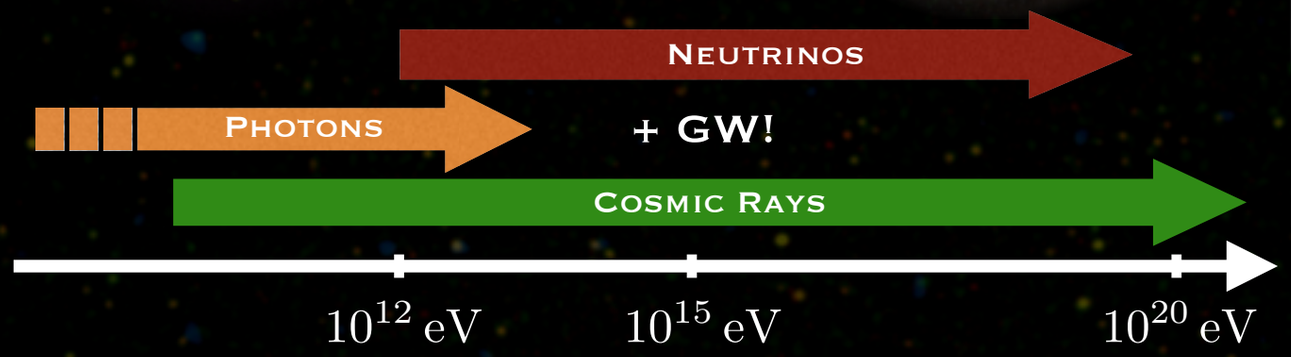
Ultra-high-energy cosmic rays and neutrinos from tidal disruptions by massive black holes

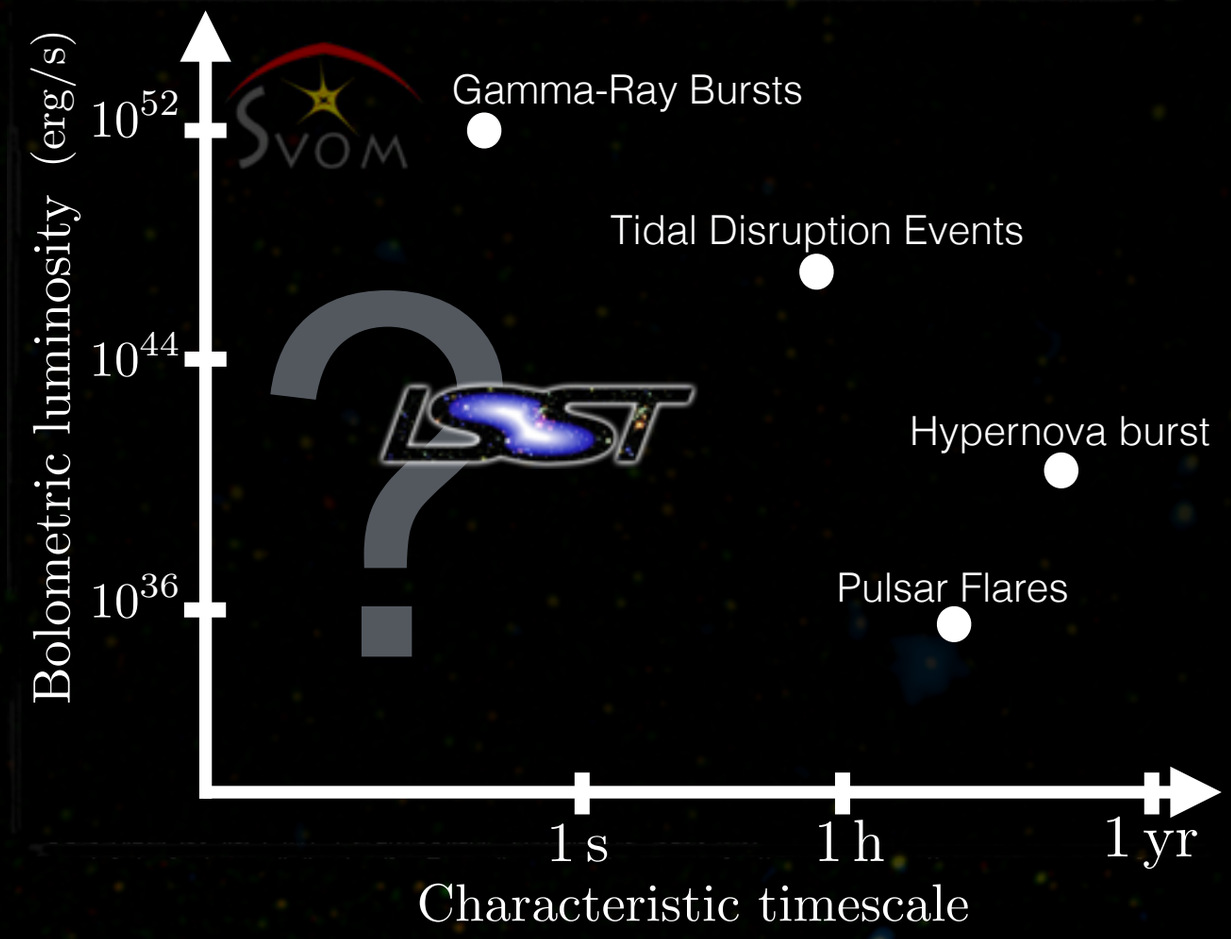
C. Guépin, K. Kotera, E. Barausse, K. Fang and K. Murase

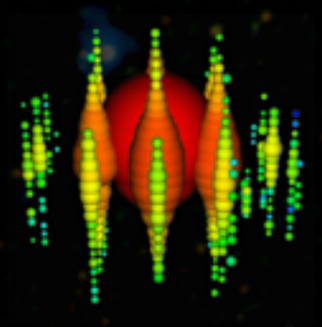


Claire Guépin
Institut d'Astrophysique de Paris

Multi-messenger transient astronomy





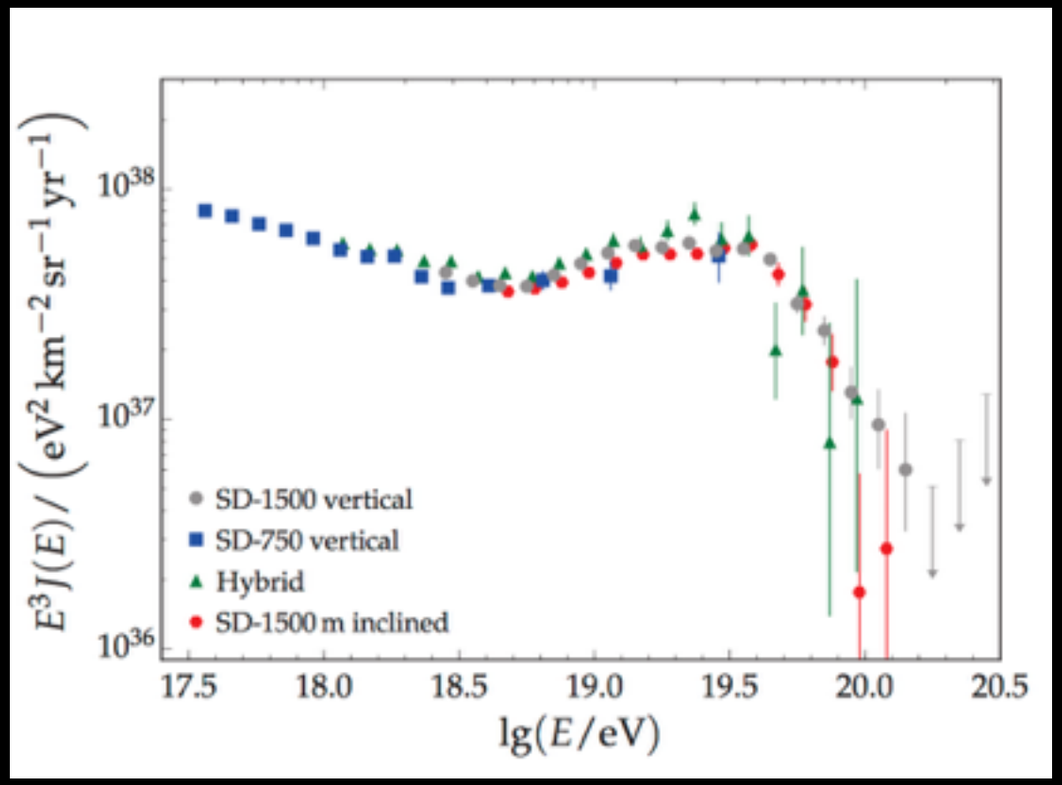


Sources for UHECRs and neutrinos?

Observations

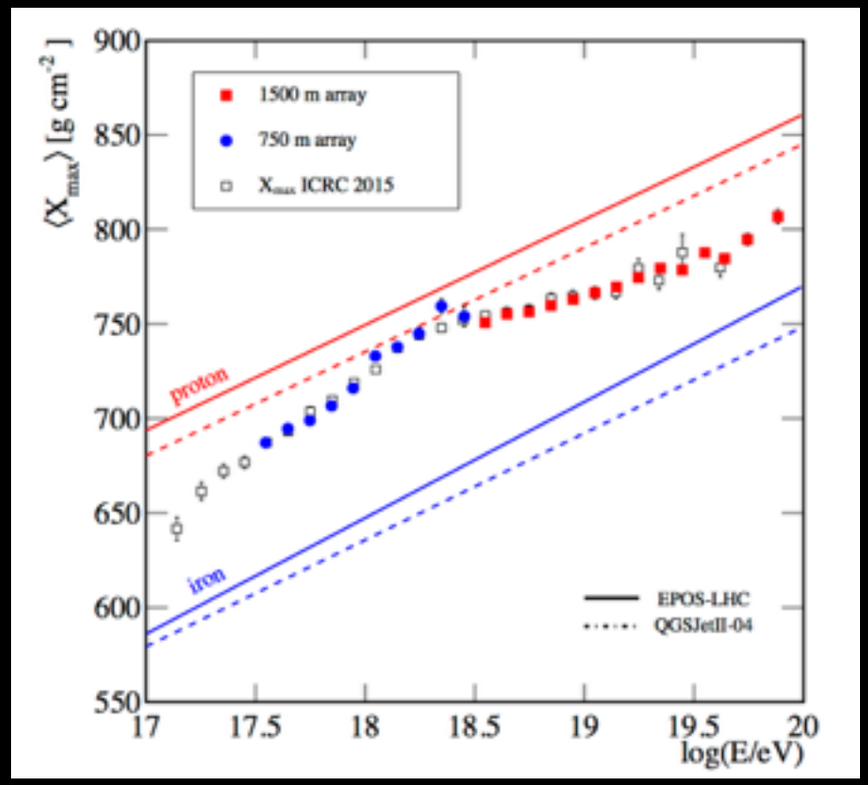
Ultra-High Energy Cosmic Rays and Neutrinos

UHECR spectrum



Pierre Auger Collaboration, ICRC2017

UHECR composition



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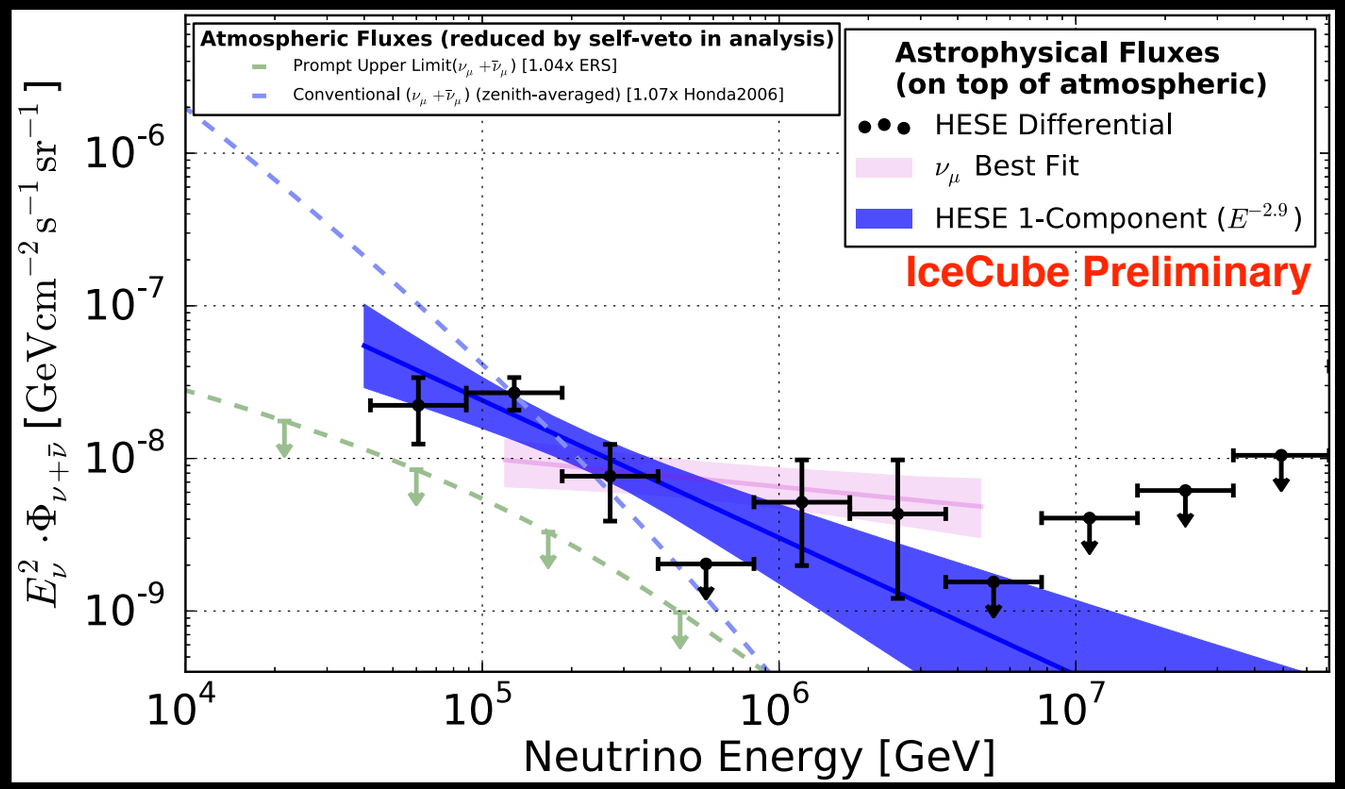
Astrophysical neutrino flux



IceCube collaboration, ICRC2017

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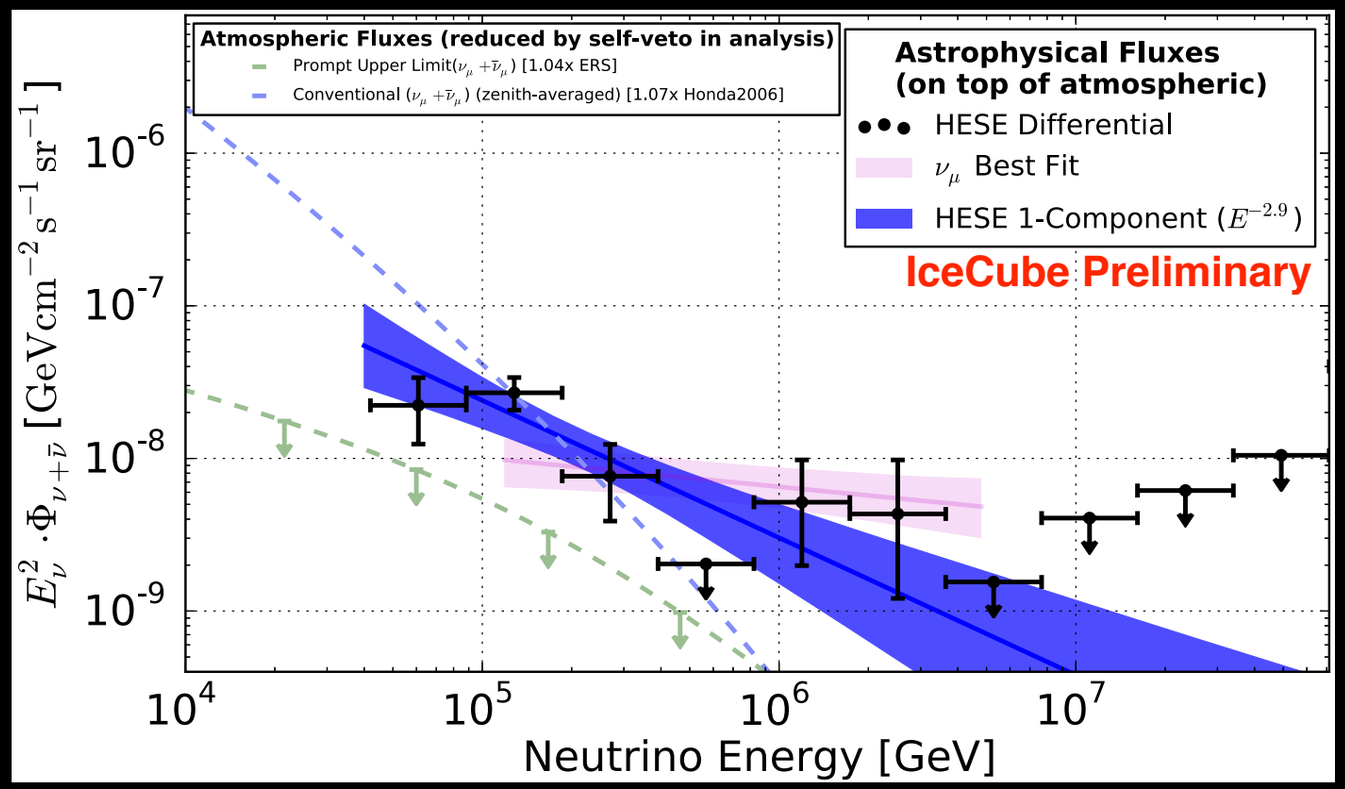


IceCube collaboration, ICRC2017

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, 2018, A&A, 616, A179

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

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

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

Impact of interactions within the jet?

Especially for nuclei, numerical treatment required:

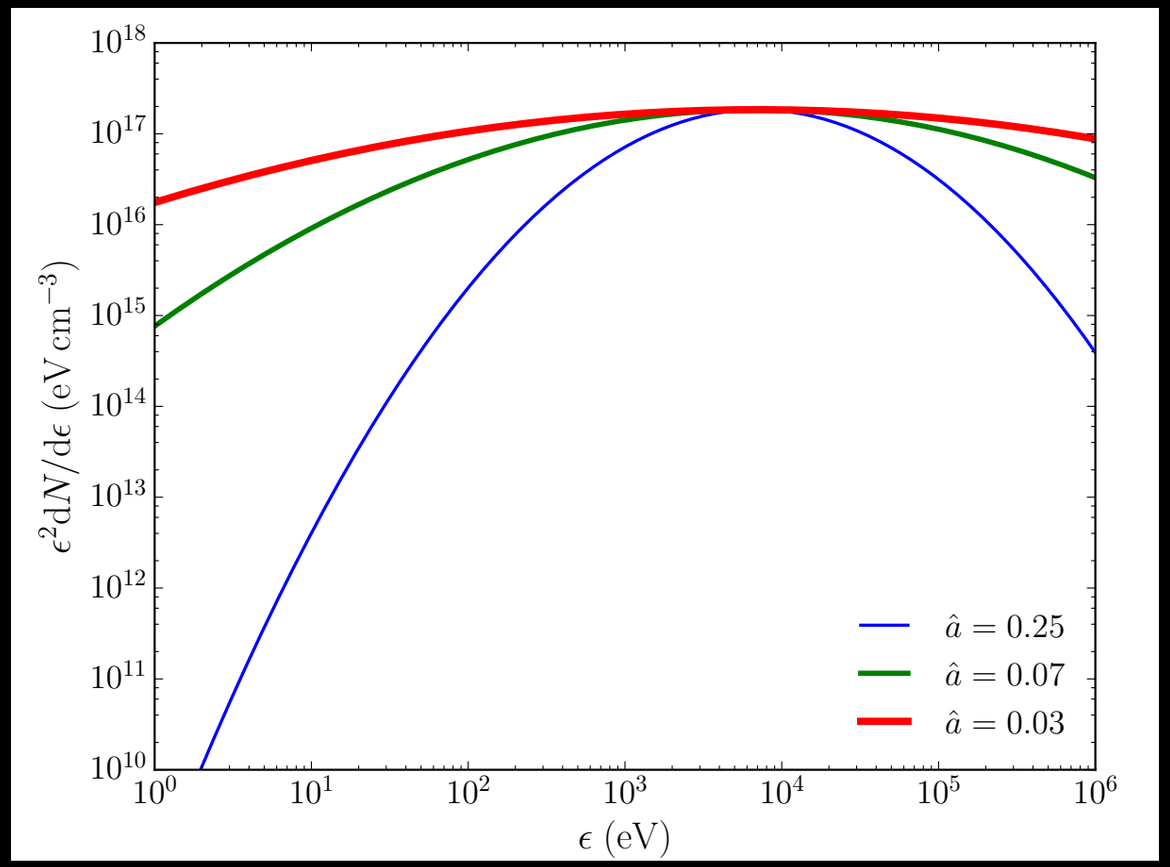
- various interaction and energy-loss processes
- production of secondary particles

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

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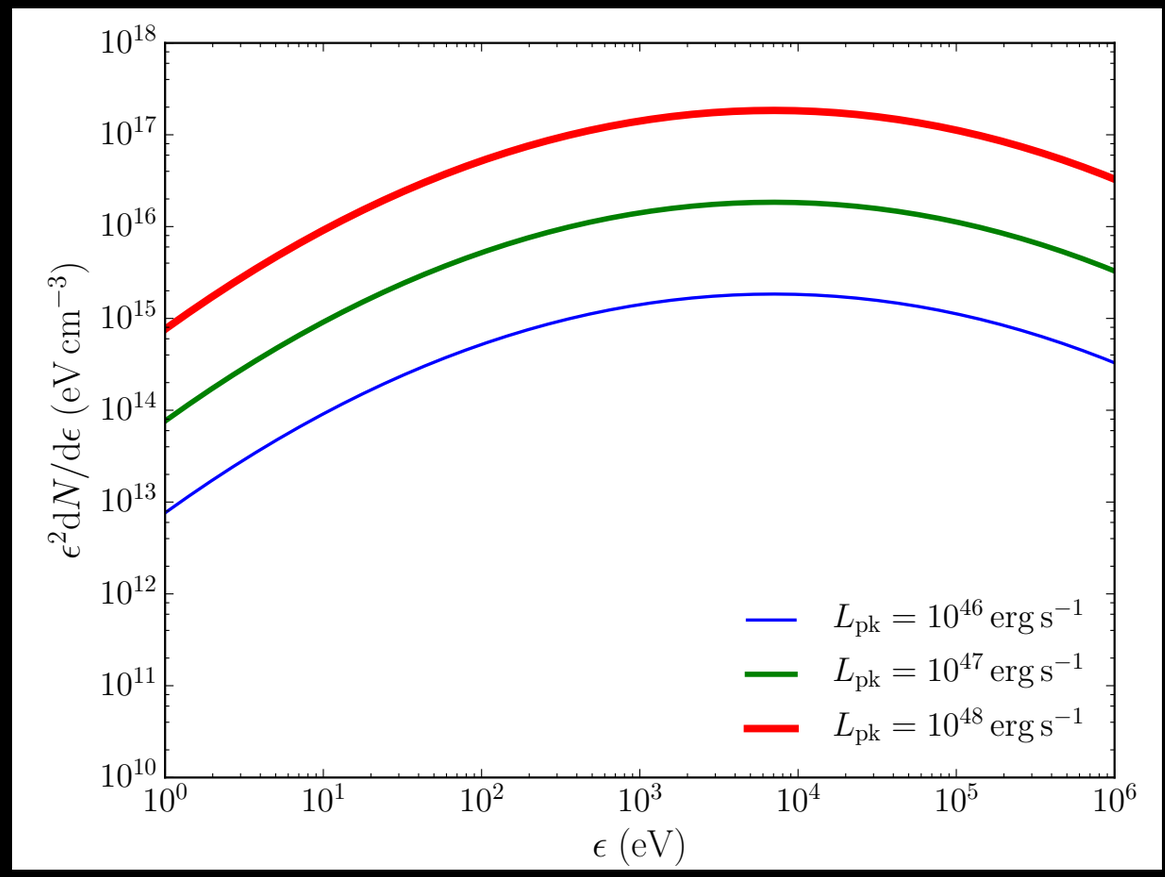

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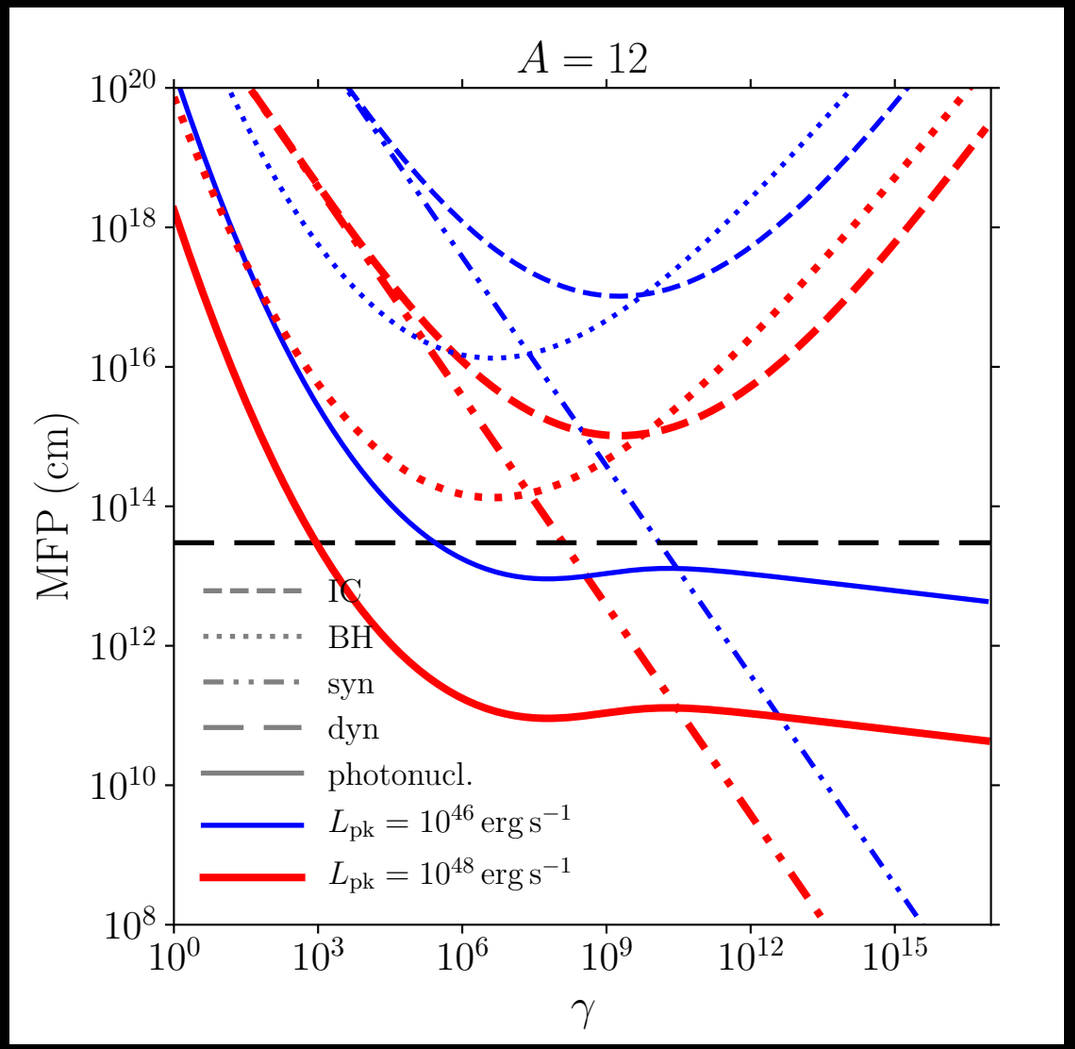
↓

Mean free paths for various interaction processes



- No deflection, $t_{\rm dyn}$ prevail over $t_{\rm diff}$ at these energies
  ⟶ 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

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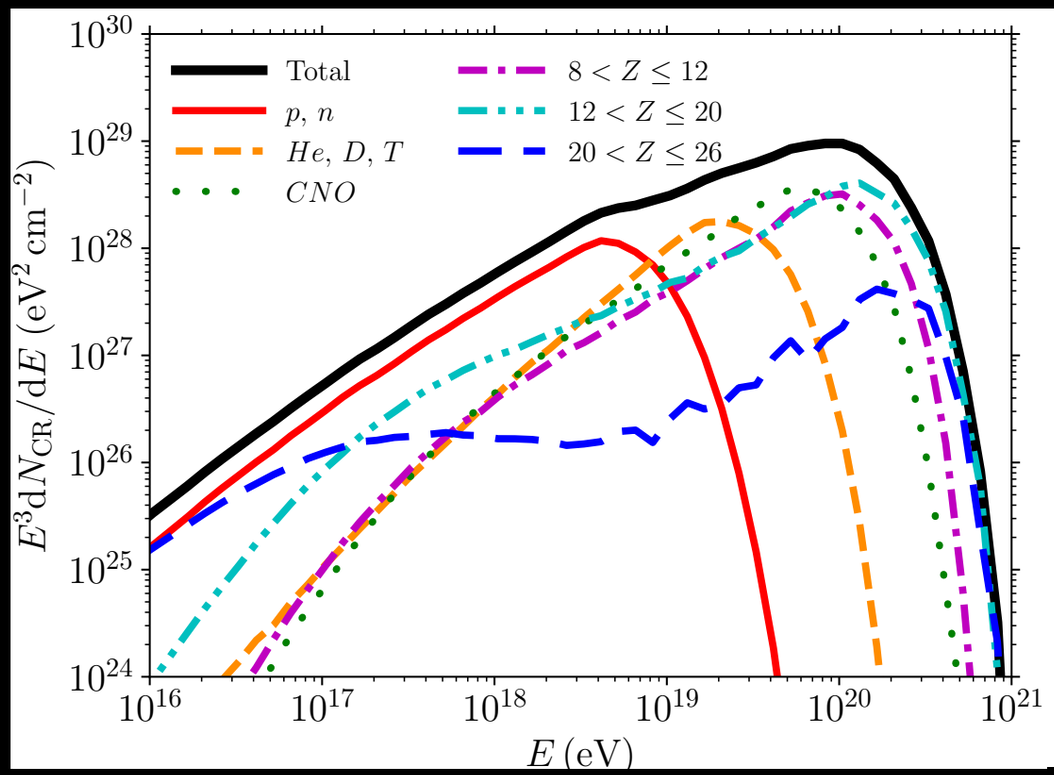
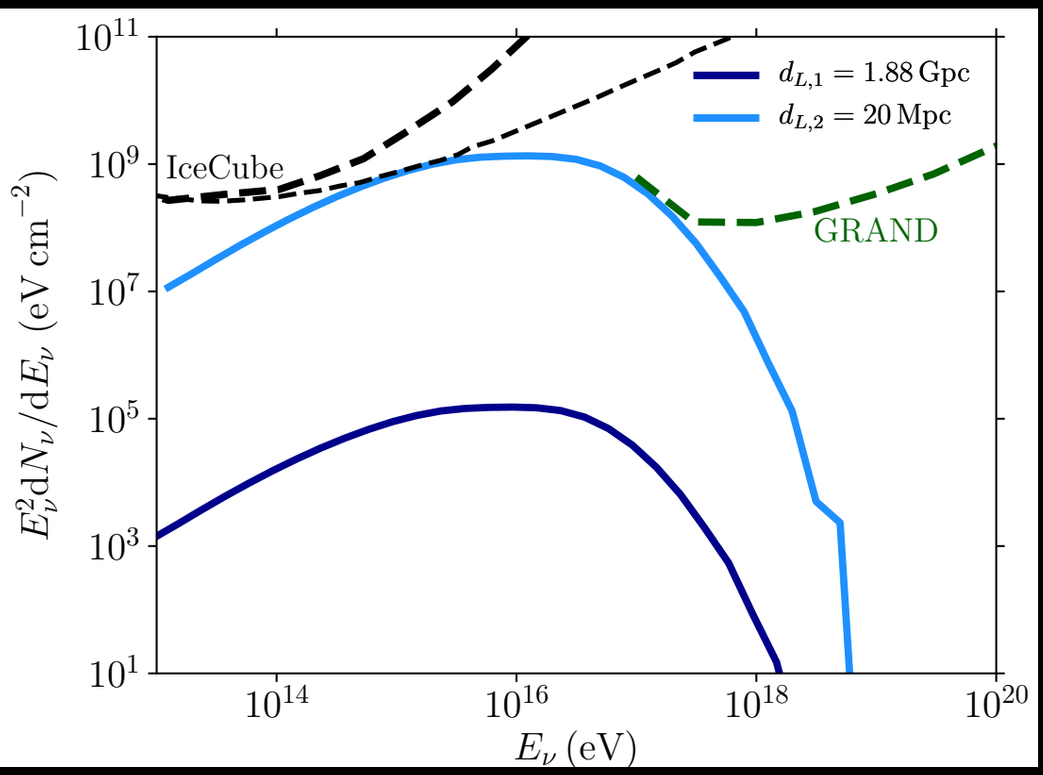
Mean free paths for various interaction processes

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

UHECR and neutrino spectra for one source





Example: pure iron injection

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

Tidal disruptions by massive black holes

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Mean free paths for various interaction processes

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UHECR and neutrino spectra for one source

↓ **Population model + intergalactic propagation**

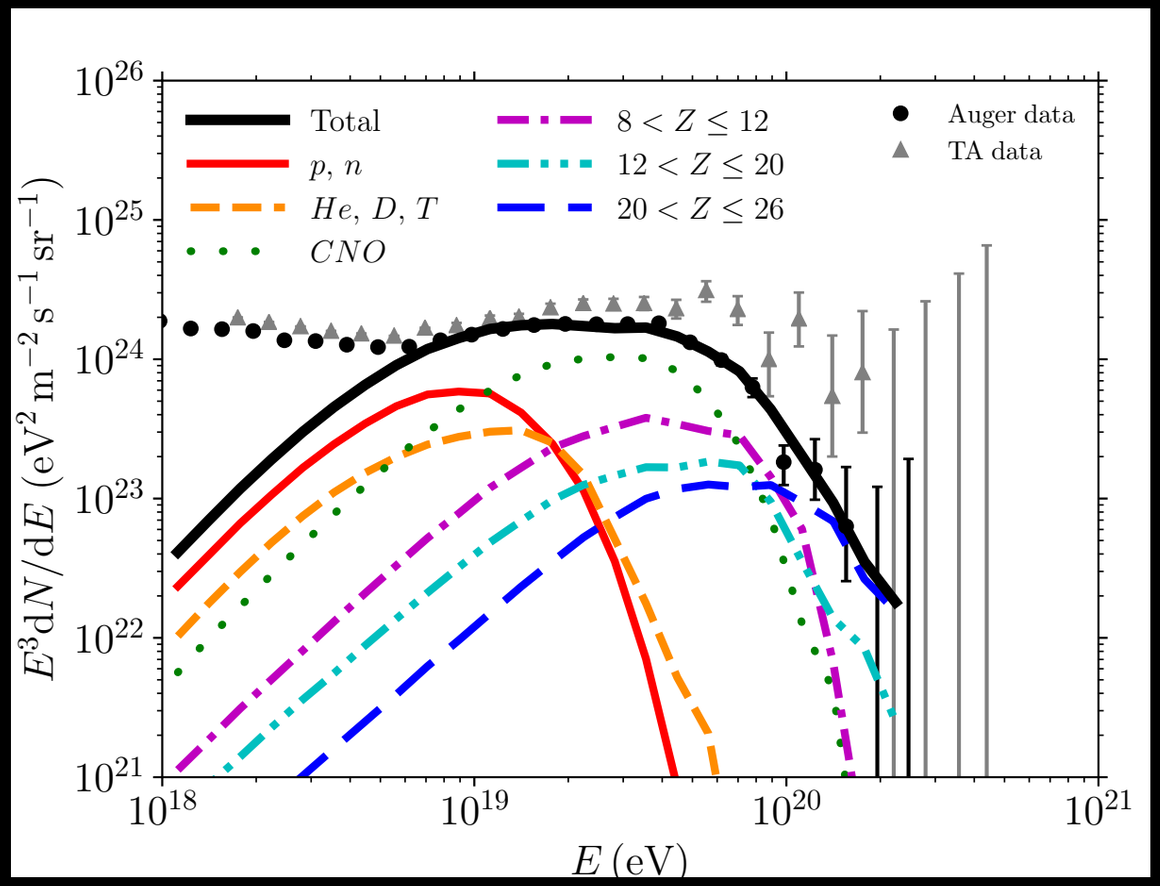
Diffuse UHECR and neutrino spectra

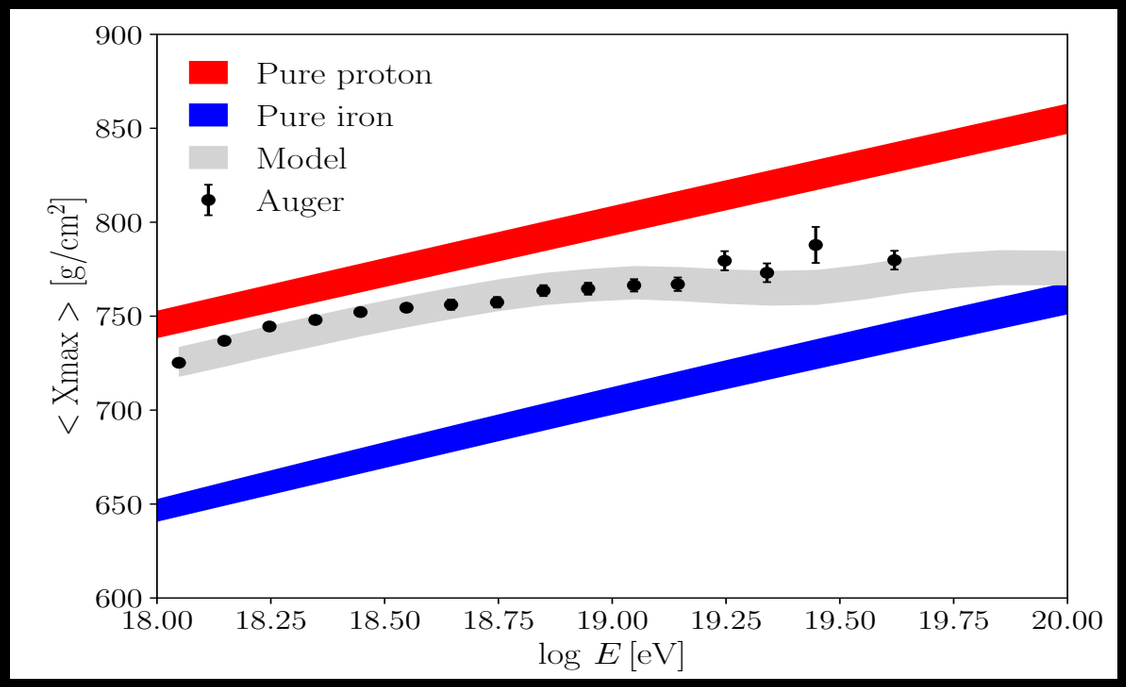
- Only TDEs powering jets, **comoving event rate density** from simulations.
  - Dependences: redshift z and black hole mass $M_{\rm bh}$
  - Modeling jet luminosity (following Krolik & Piran, 2012) $L_{\rm jet} \propto M_{\rm bh}^{-1/2}$

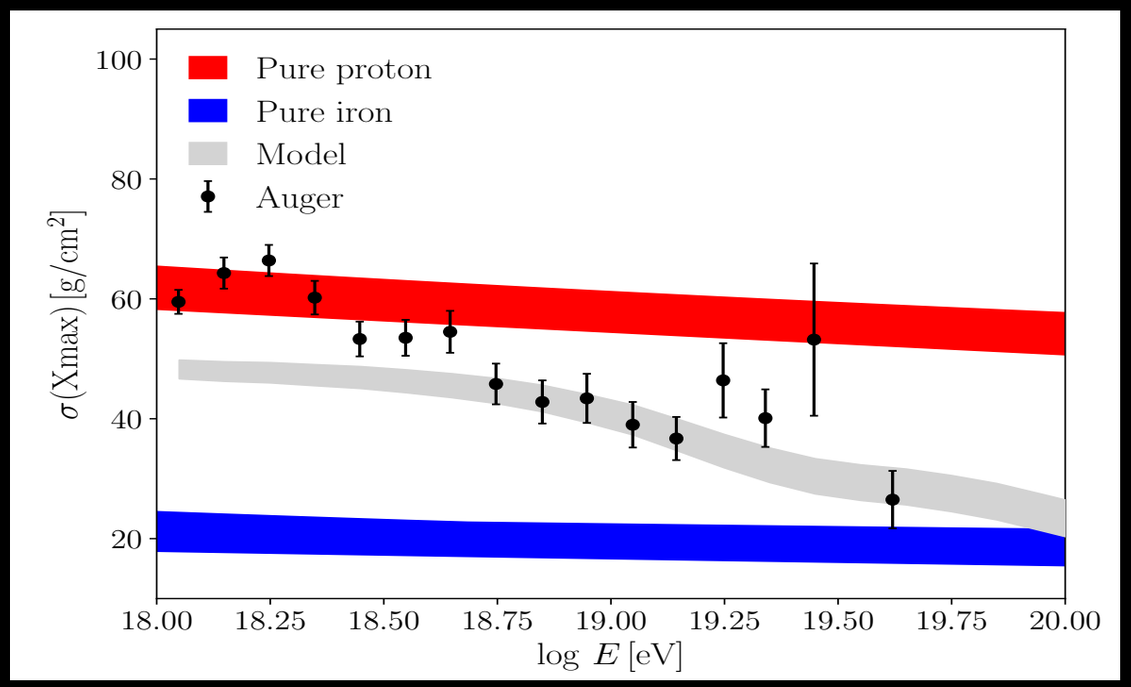
$$\Phi_{\rm CR}(E_{\rm CR}) = \frac{c}{4\pi H_0}\int_{z_{\rm min}}^{z_{\rm max}}\int_{L_{\rm min}}^{L_{\rm max}} {\rm d}z\,{\rm d}L\,\frac{f_{\rm s}\,\xi_{\rm CR}\,\dot{N}_{\rm TDE}\,{\rm d}n_{\rm bh}(z,L)/{\rm d}L}{\sqrt{\Omega_{\rm M}(1+z)^3+\Omega_\Lambda}} \times F^c_{\rm CR,s,p}(E^c_{\rm CR},z,L)t^c_{\rm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

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 Gpc^{-3} yr^{-1}

Tidal disruptions by massive black holes

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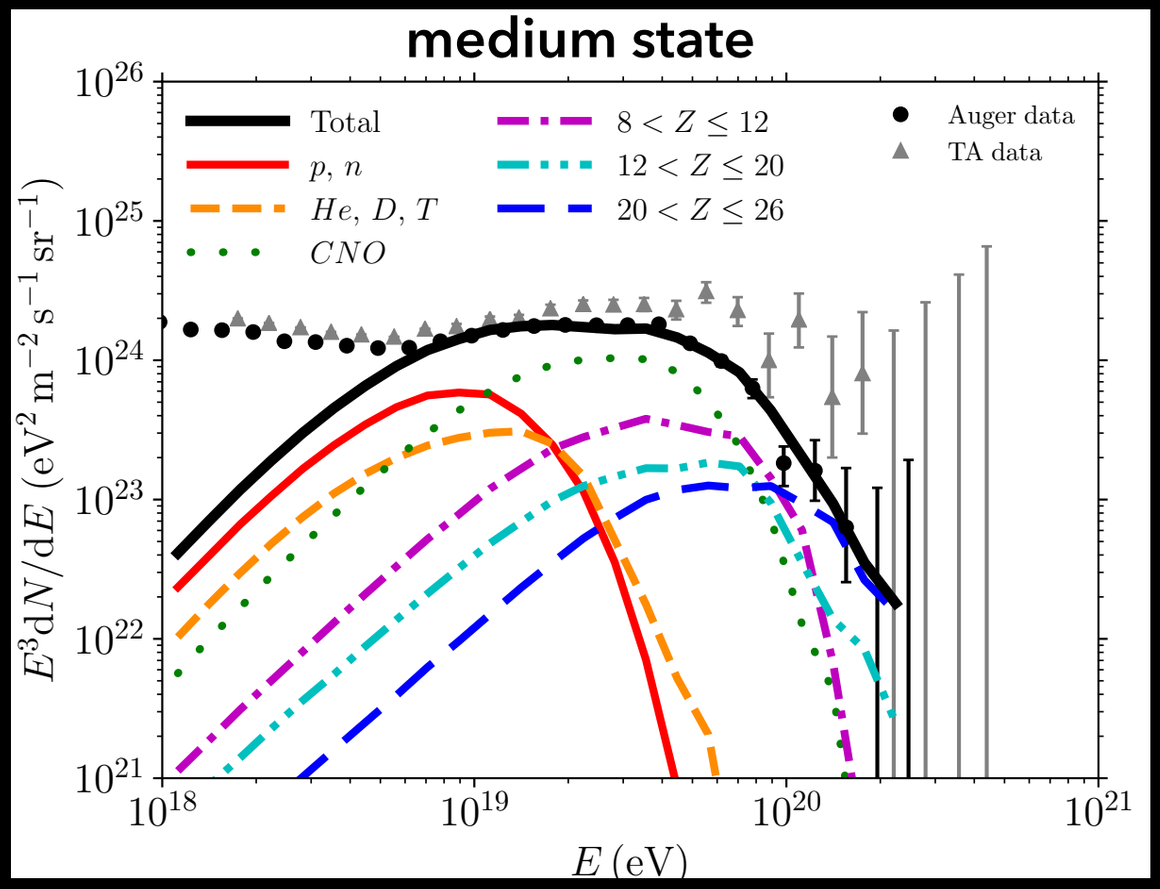

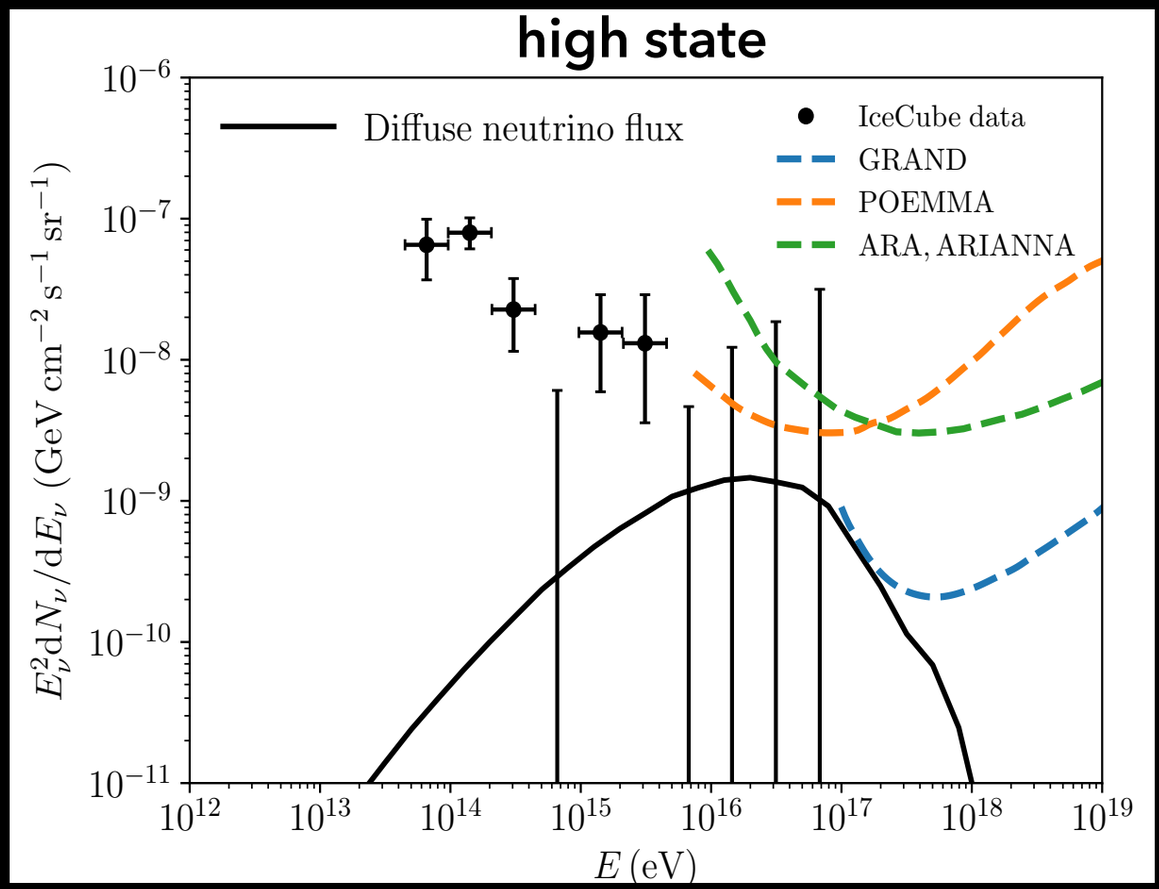

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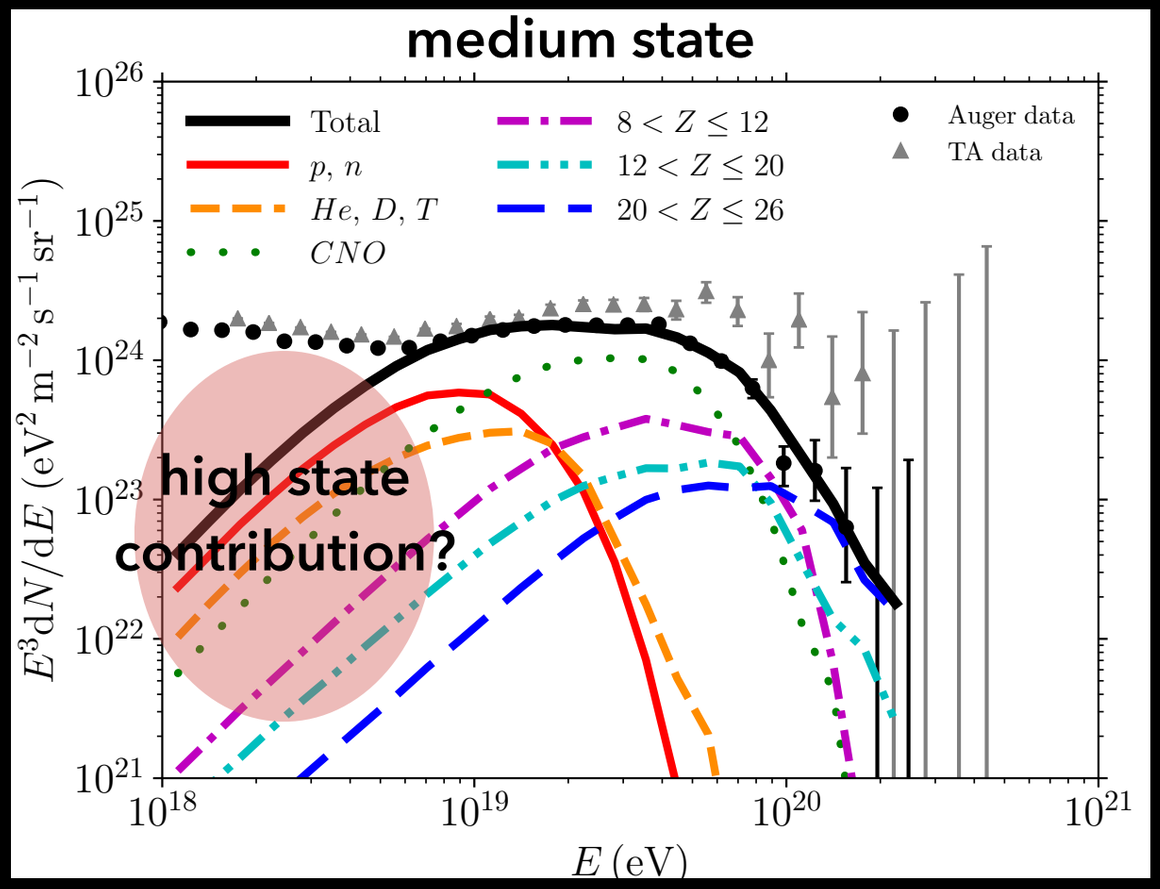
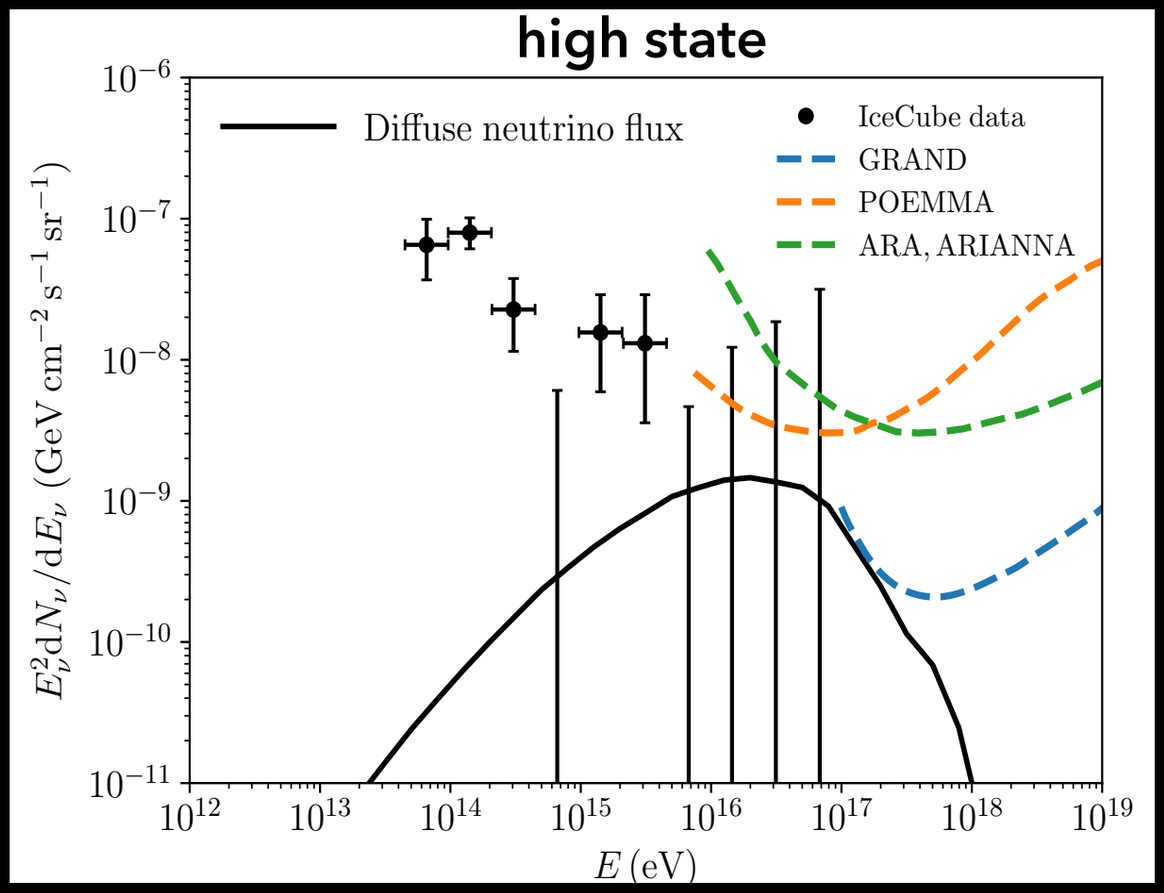
Lighter composition requires:

- harder injection spectral index
- higher acceleration efficiency

Tidal disruptions by massive black holes

Diffuse UHECR and neutrino spectra + composition





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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,
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- predicted neutrino spectrum only marginally detectable with GRAND.

Perspectives

- include gamma-ray production
- uncertainties?
  - bulk Lorentz factor
  - interactions cross sections, production of secondaries
  - propagation…

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Thank you for your attention!

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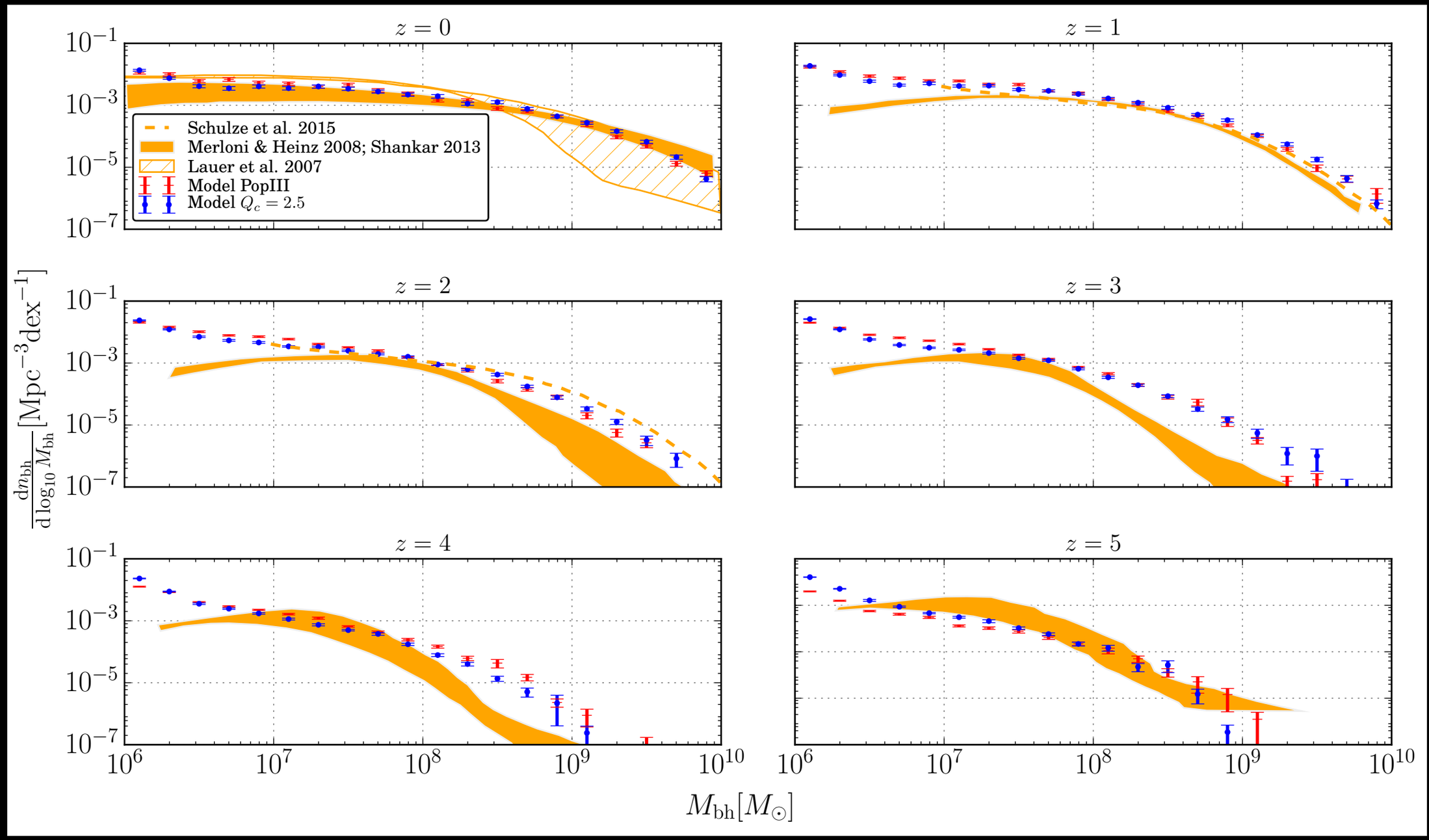
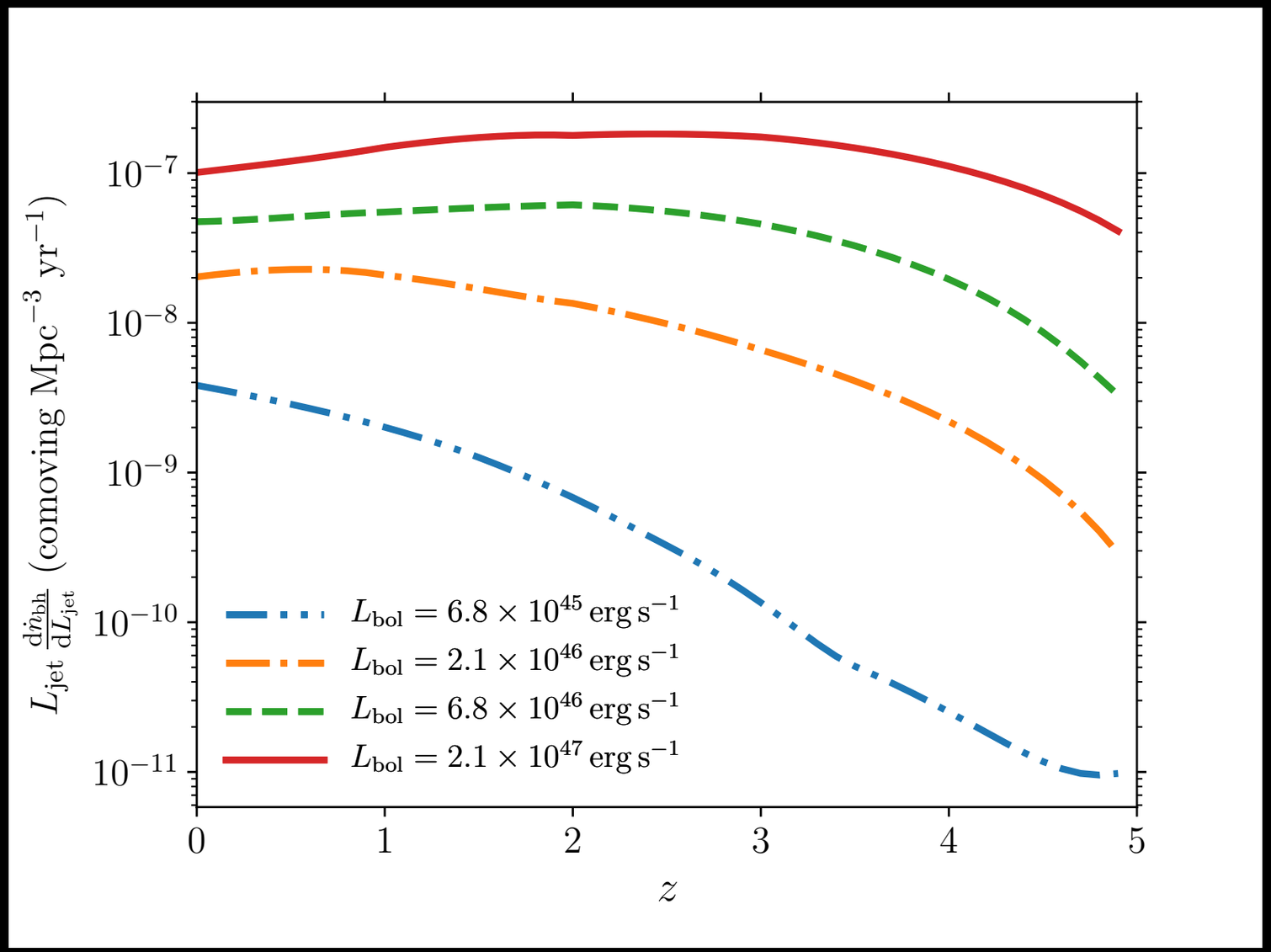


Mass function of black holes as a function of redshift

Semi-analytic galaxy formation model, Barausse (2012)

Tidal disruptions by massive black holes



Comoving TDE luminosity density (medium state) as a function of redshift

for TDE rate per galaxy 10^{-5} yr^{-1}

$$L_{\rm jet} \propto M_{\rm bh}^{-1/2}$$