Istituto Nazionale di Fisica Nucleare

GRAN SASSO SCIENCE INSTITUTE

Starburst Galaxies as possible sources of UHECRs and neutrinos

Antonio Condorelli, Denise Boncioli, Enrico Peretti, Sergio Petrera

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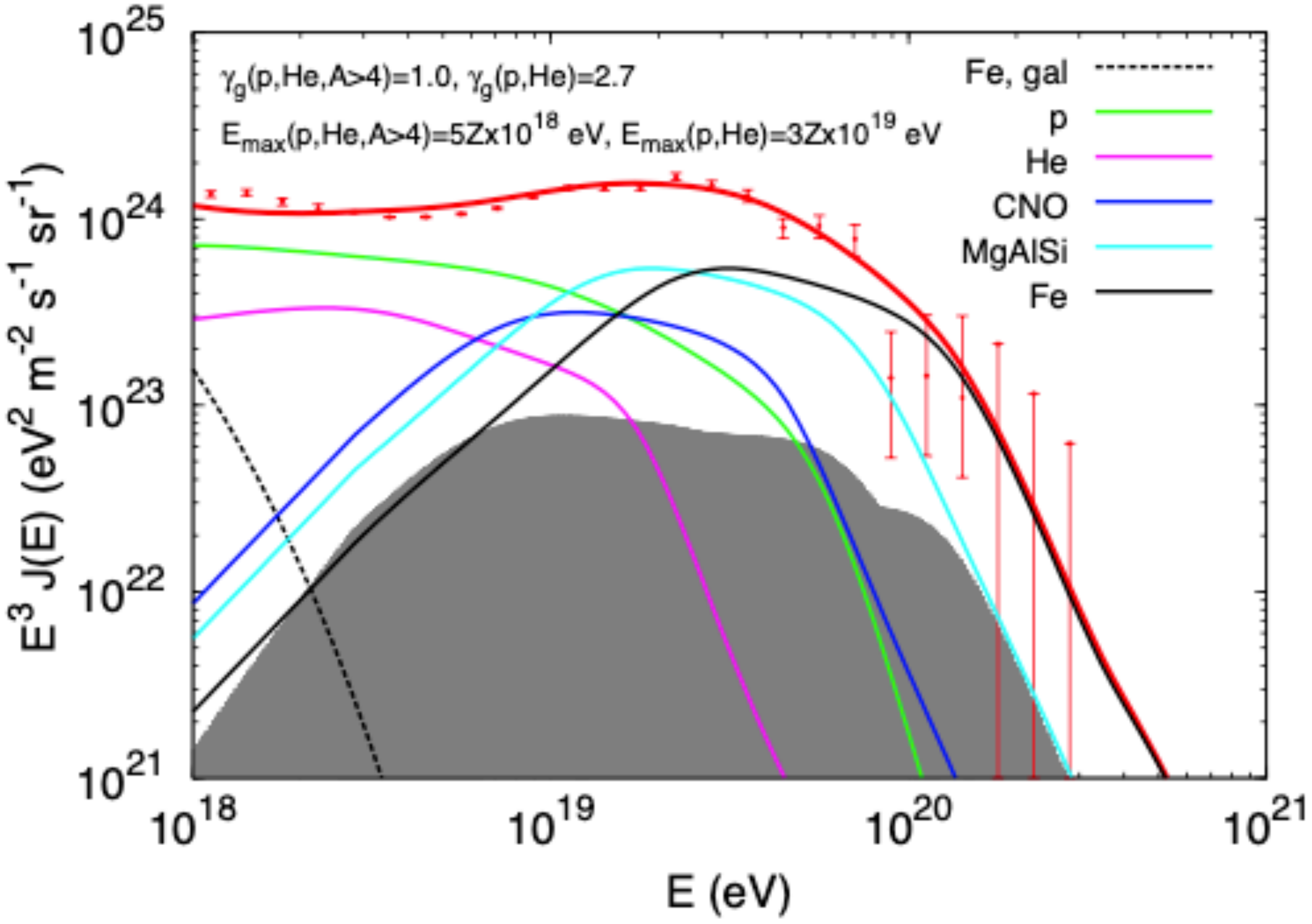
Interpretation of UHECR spectrum



The Ultra-High-Energy Cosmic Ray (UHECR) spectrum can be described as the interplay of two populations of sources:

- Hard spectral index at high energies;
- Soft spectral index at low energies.

Different classes of sources

Interactions at the source

R. Aloisio, V. Berezinsky and P. Blasi, JCAP 10 (2014), 020

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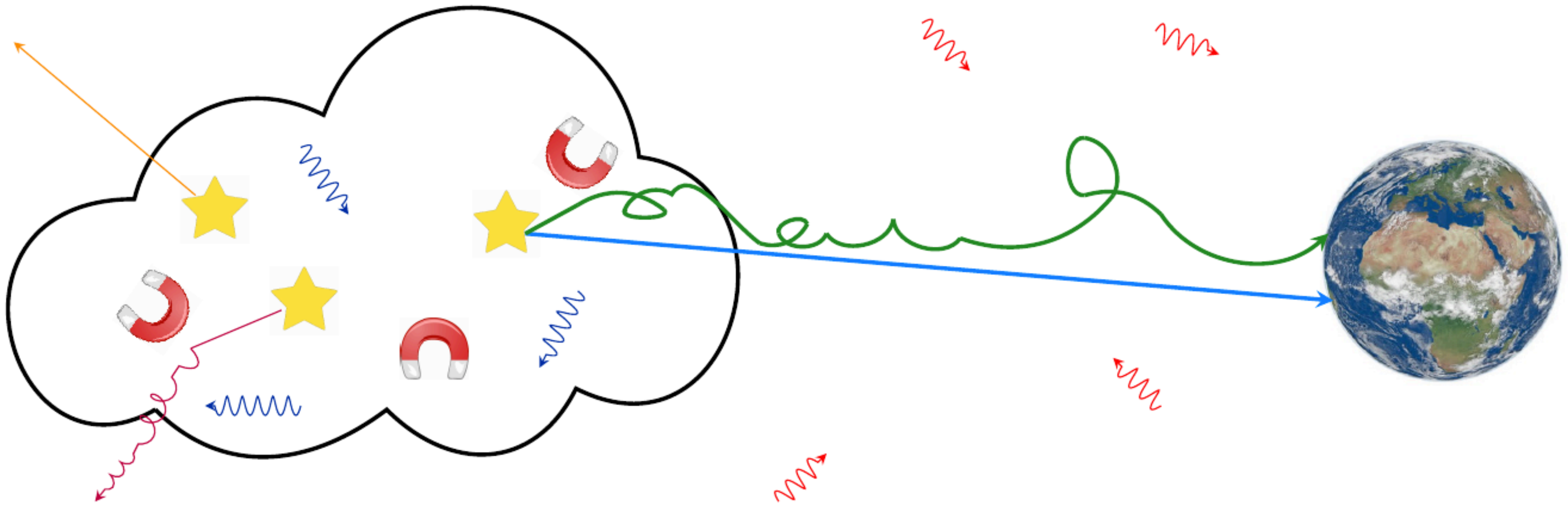
Source-propagation model

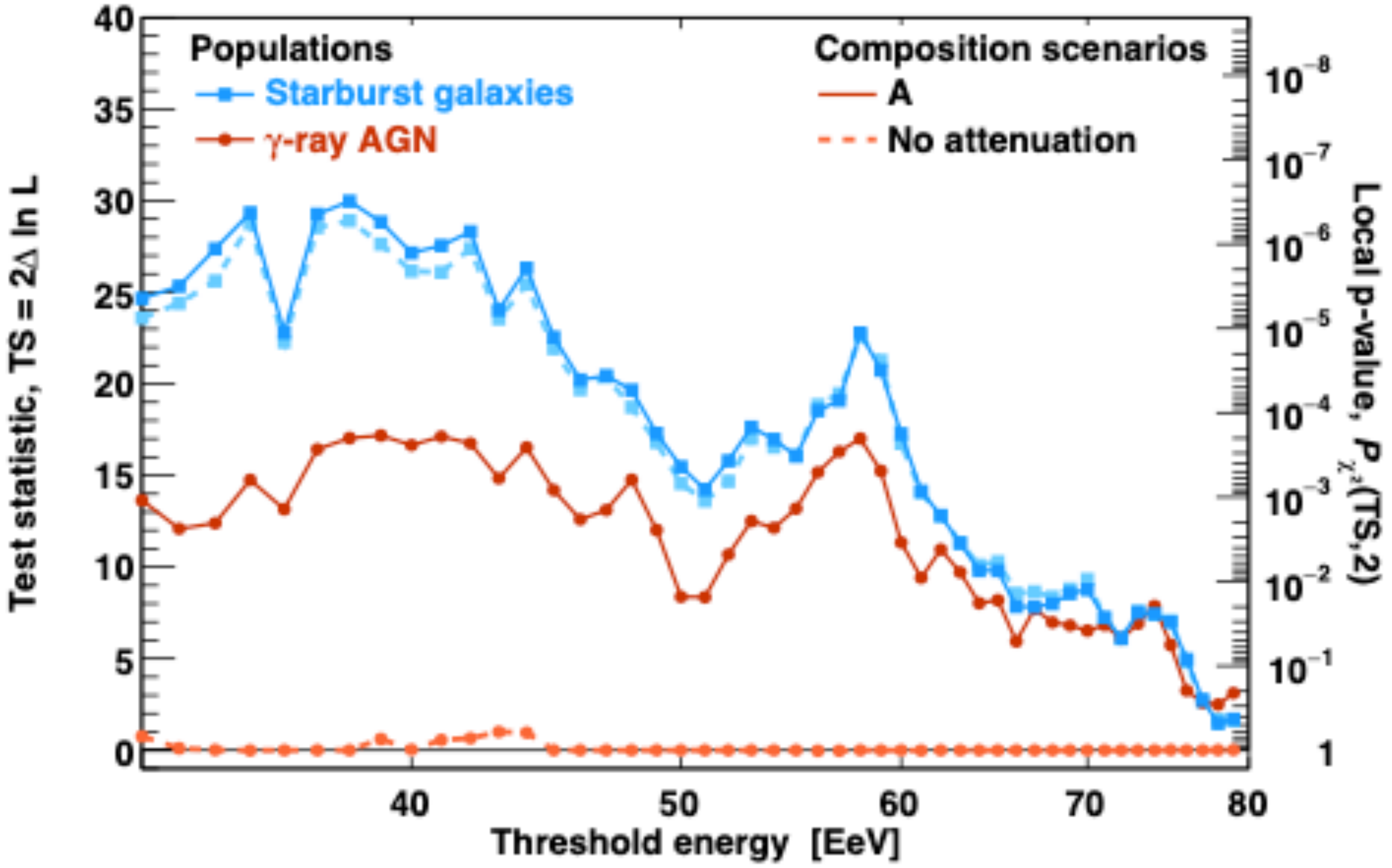
- Accelerated particles confined in the environment surrounding the source;
- Presence of photon and gas density;
- High energy particles–> escape with no interaction;
- Low energy particles –> Pile-up of nucleons at lower energies.



Phys. Rev. D 92, (2015) 123001
Phys. Rev. D 100, 103008 (2019)

Application to Starburst Galaxies

- Motivation: Acceleration & Correlation.
- Leaky box model: a particle can only interact or escape.
- Benchmark model: M82.

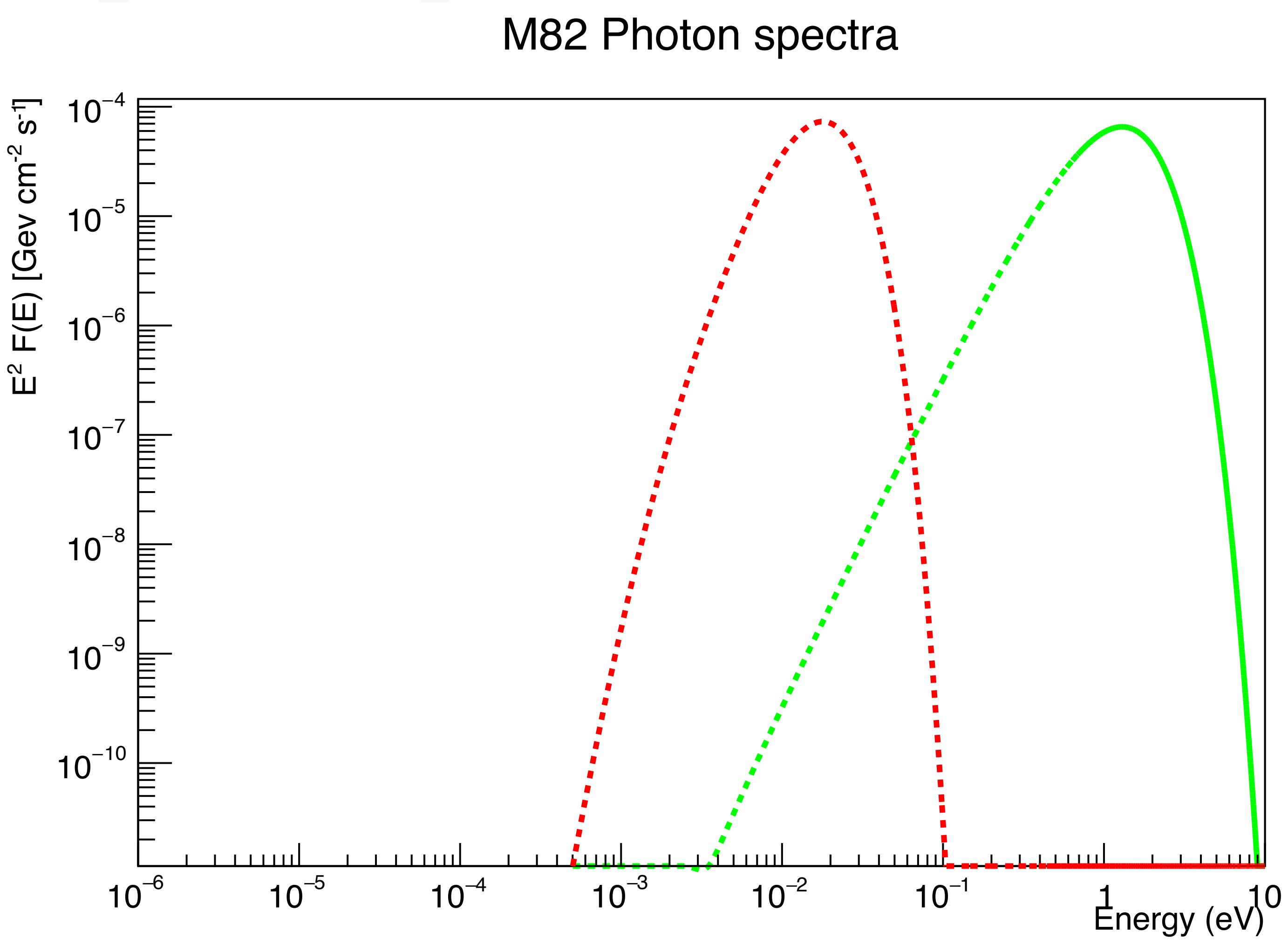


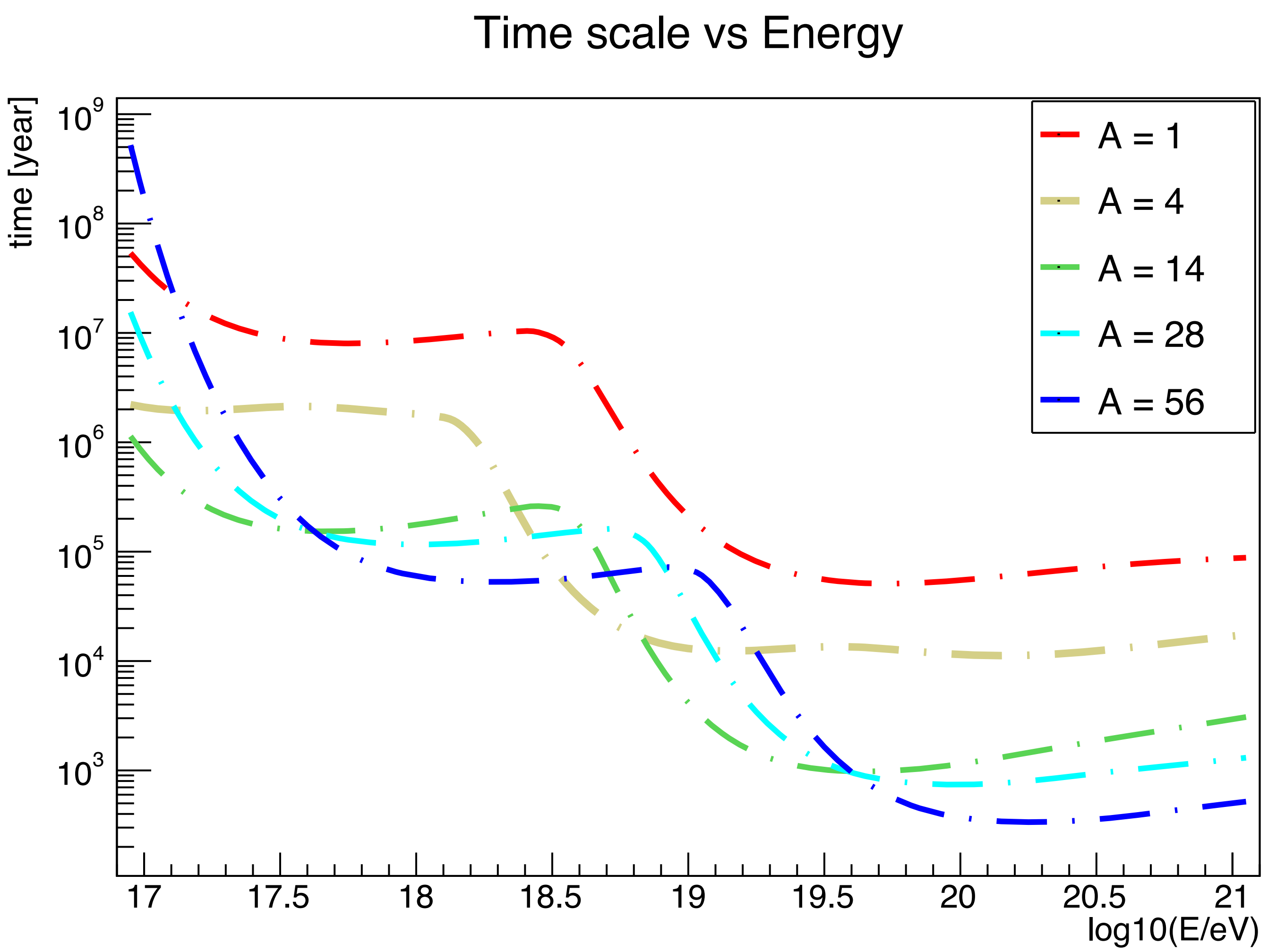
E. Peretti et al. Mon. Not. Roy. Astron. Soc. 487 (2019) no.1, 168-180

G. E. Romero, A. L. Müller and M. Roth, Astron. Astrophys. 616 (2018), A57

A. Aab et al. [Pierre Auger], Astrophys. J. Lett. 853 (2018) no.2, L29

Photo-interaction time





$$\frac{1}{\tau} = \frac{1}{2\Gamma^2} \int_{\epsilon'_{\rm min}}^{2\Gamma\epsilon} \int_{\epsilon=0}^{+\infty} \frac{n_\gamma(\epsilon)}{\epsilon^2} d\epsilon\, \sigma(\epsilon')\epsilon'\, d\epsilon'$$

Adapting SimProp (software for UHECRs propagation in extra-galactic space):

- ☐ Implementation of the photon field in the source;

E. Peretti et al. Mon. Not. Roy. Astron. Soc. 487 (2019) no.1, 168-180

R. Aloisio et al. JCAP11(2017)009

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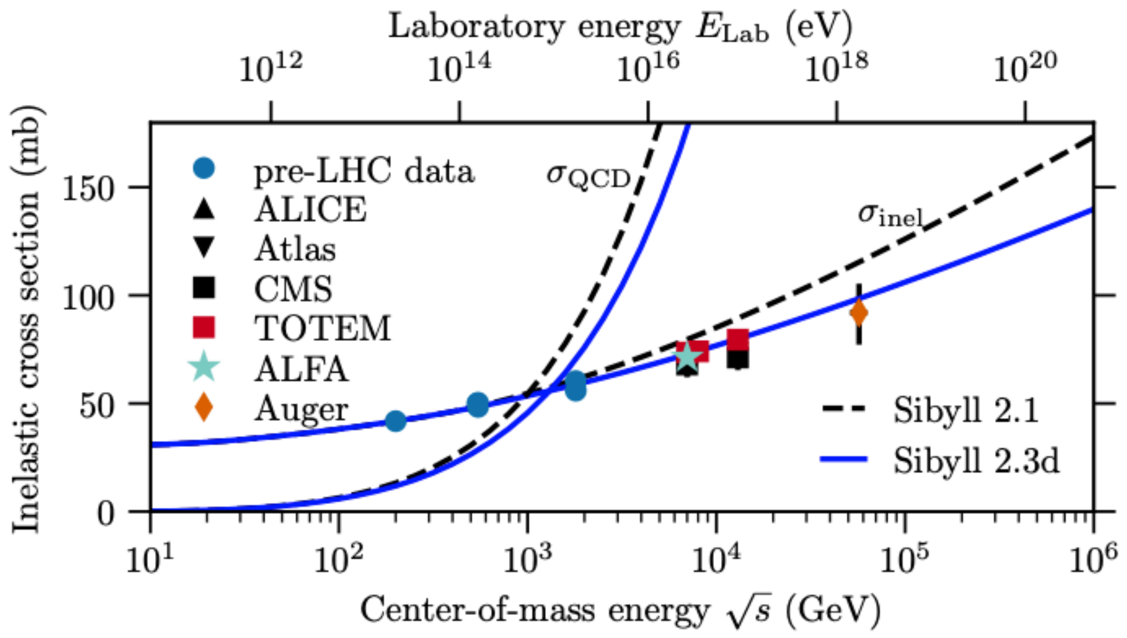
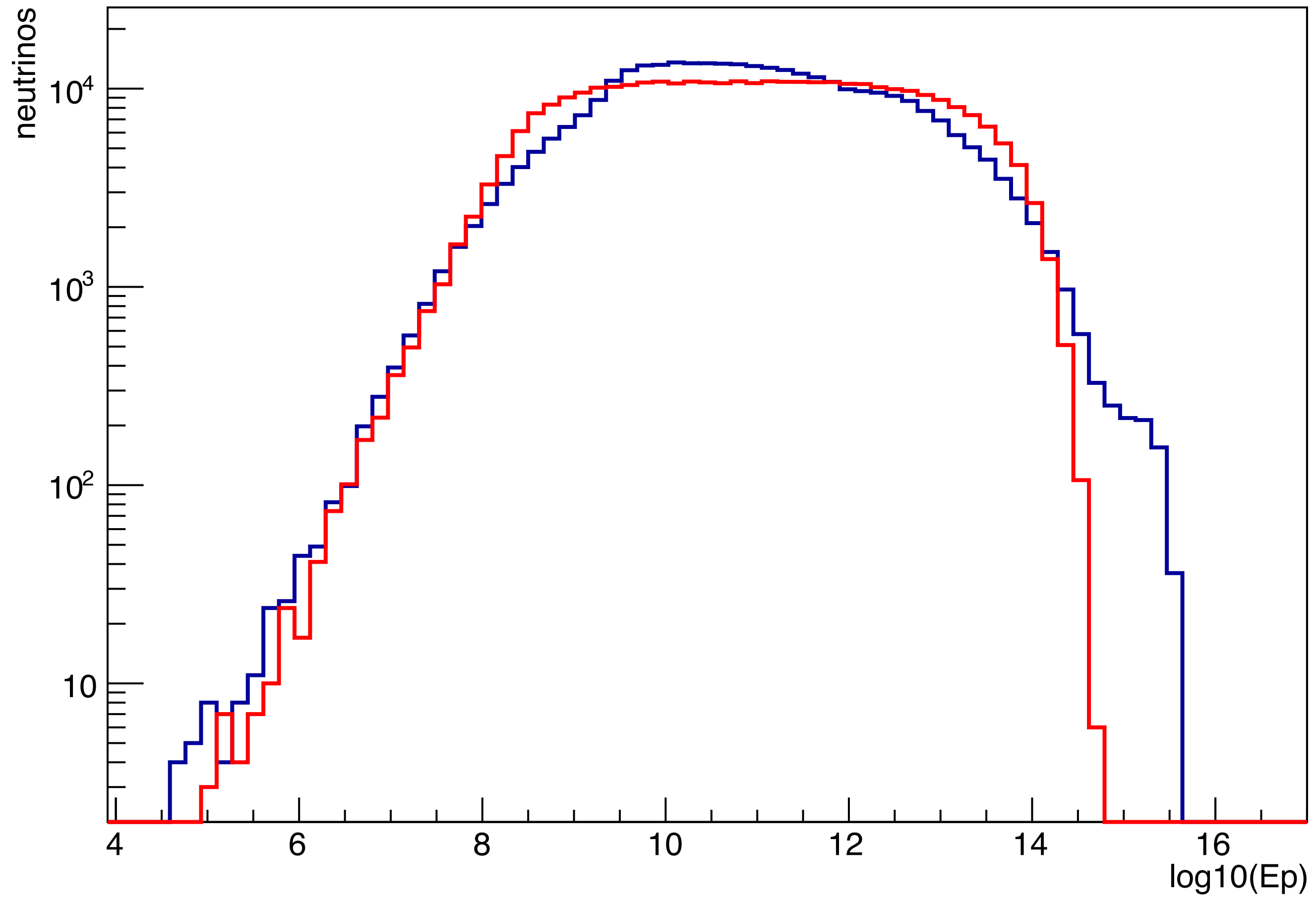
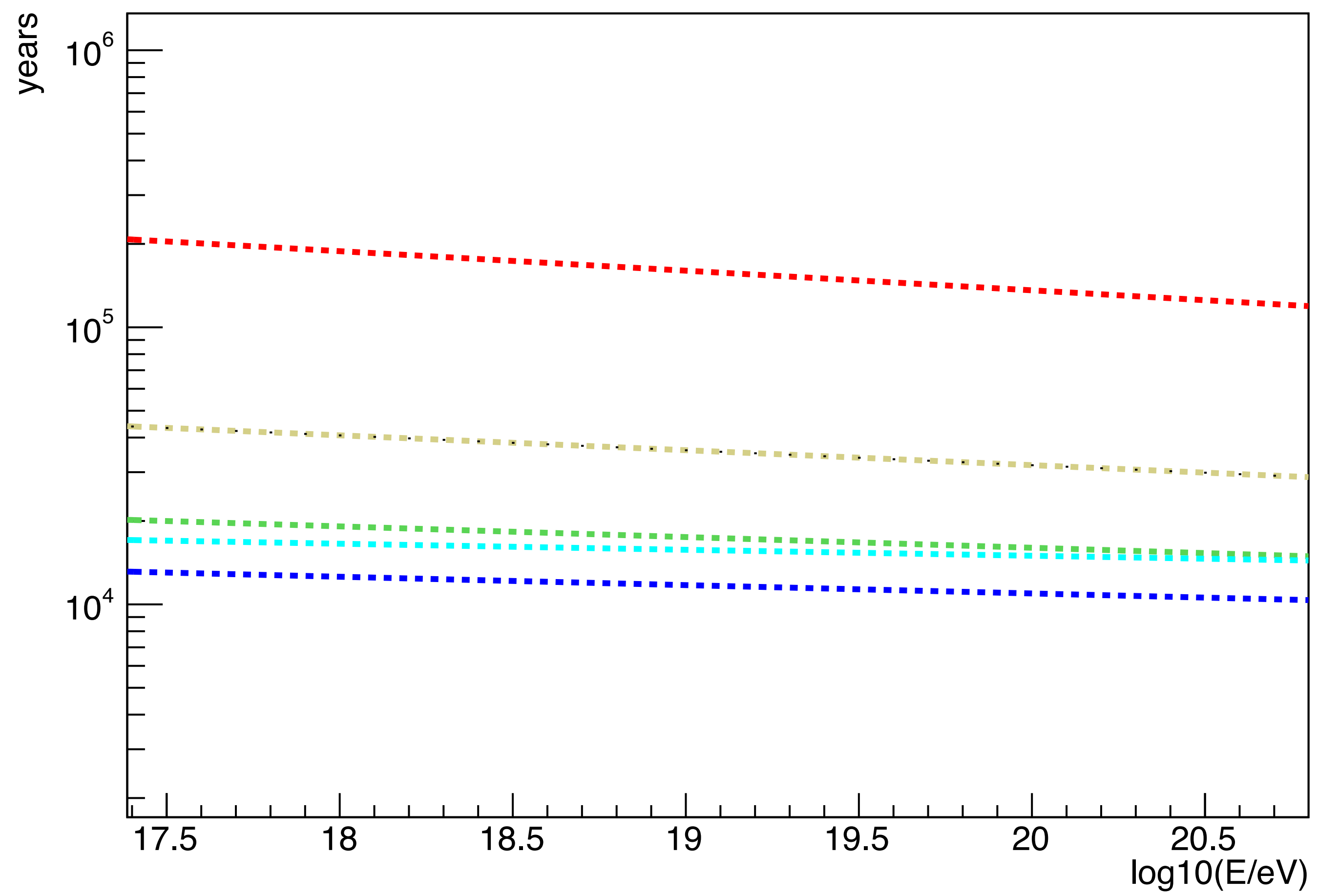
Spallation time







F. Riehn et al, Phys. Rev. D 102, 063002 (2020),

Adapting SimProp (software for UHECRs propagation in extra-galactic space):

- ❑ Implementation of the photon field in the source;
- ❑ Implementation of the spallation process;

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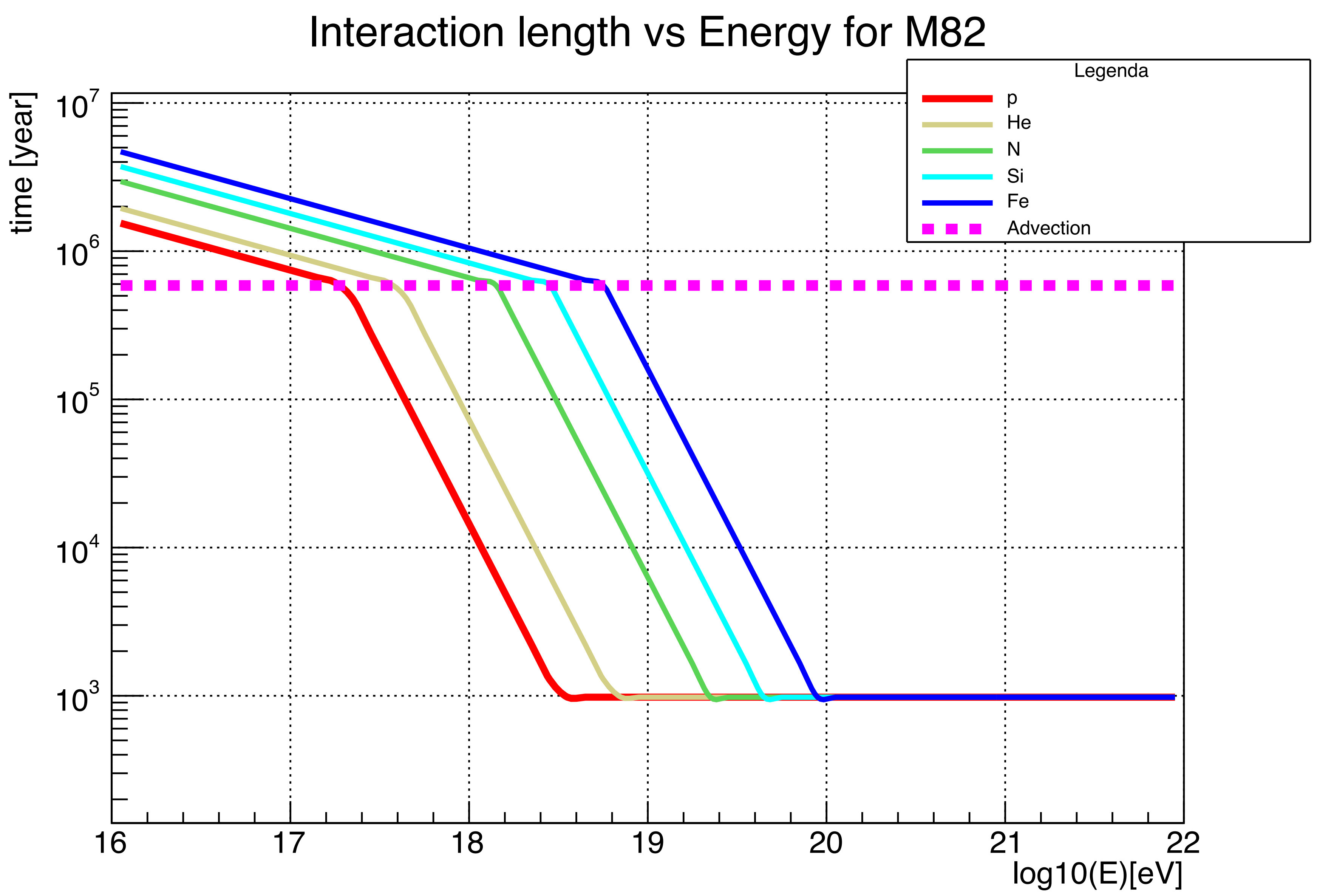
Escape time

Diffusion

$$\tau_D = \frac{R^2}{D}$$

Depends on the magnetic field B , on the coherence lenght l_c and on the strength of the turbulence $\frac{\delta B}{B}$



Advection

$$\tau_{adv} = \frac{R}{v_w}$$

P. Subedi *et al* 2017 *ApJ* **837** 140

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Comparison to the experimental data

- A single nuclear specie (A = 28) is propagated inside the source. Sources are considered identical and uniformly distributed.
- The escaping fluxes are propagated through the Universe.
- The fluxes arriving in atmosphere are compared to the experimental data.
- The chosen prototype is not able to describe the data at Earth;
- Within the parameter space, a set of parameters at the source that can describe energy spectrum and composition at Earth was found.

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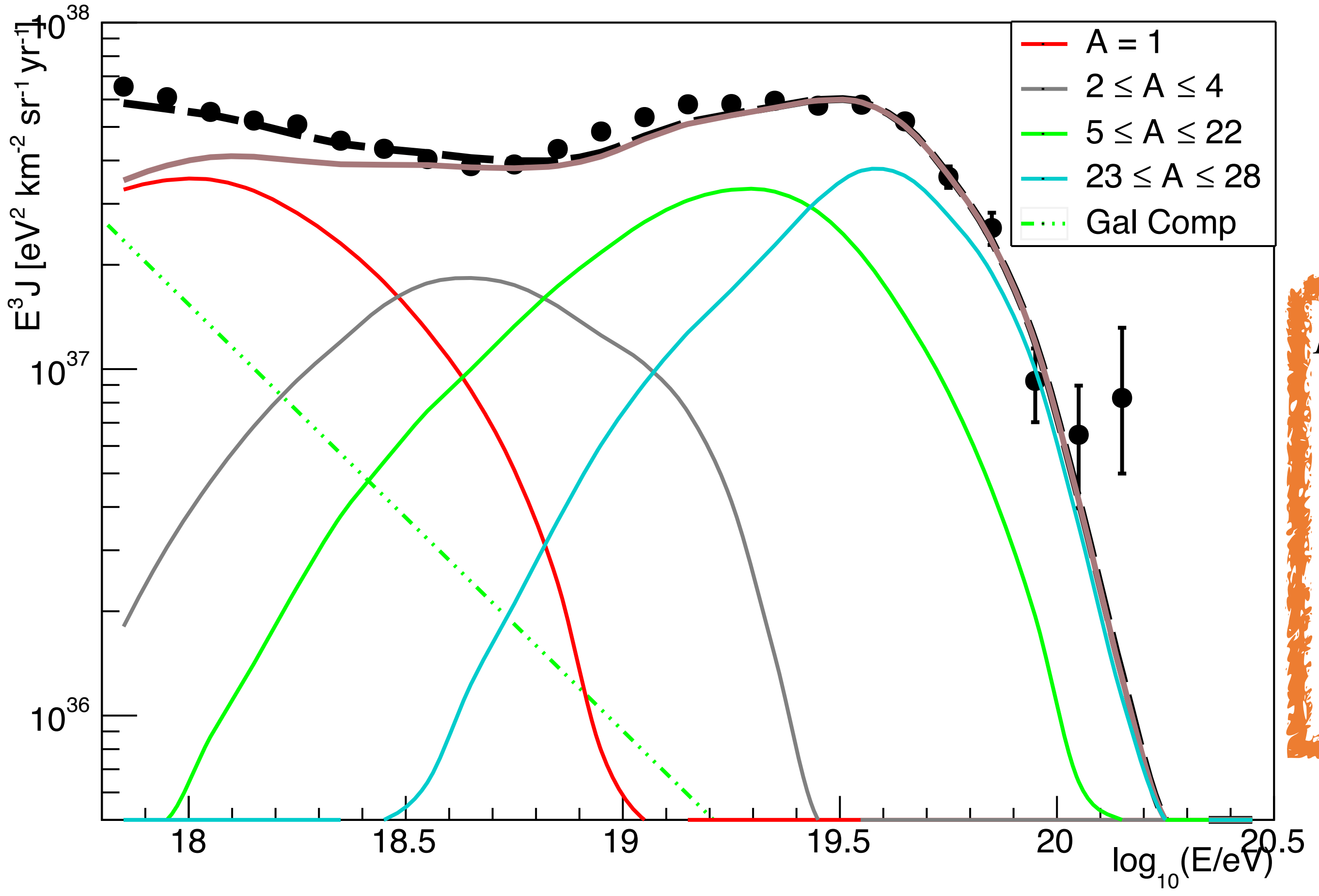


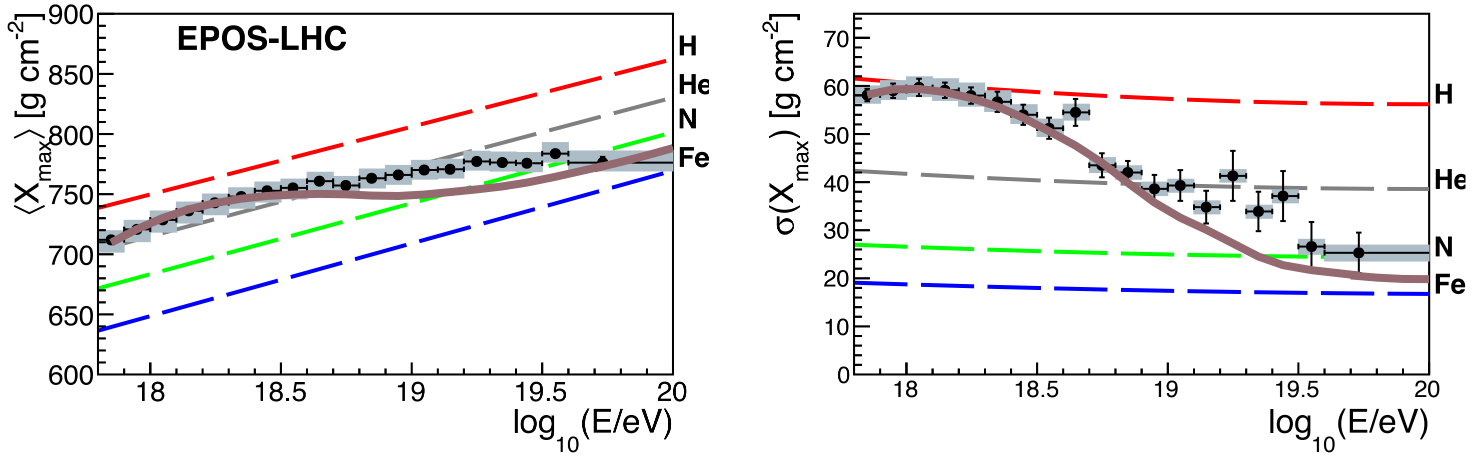
$L_{IR} = 3.46 \cdot 10^{45}$erg/s

$R = 225$ pc

$n_{\rm ISM} = 1875\ \rm cm^{-3}$

$\gamma^* = 1$

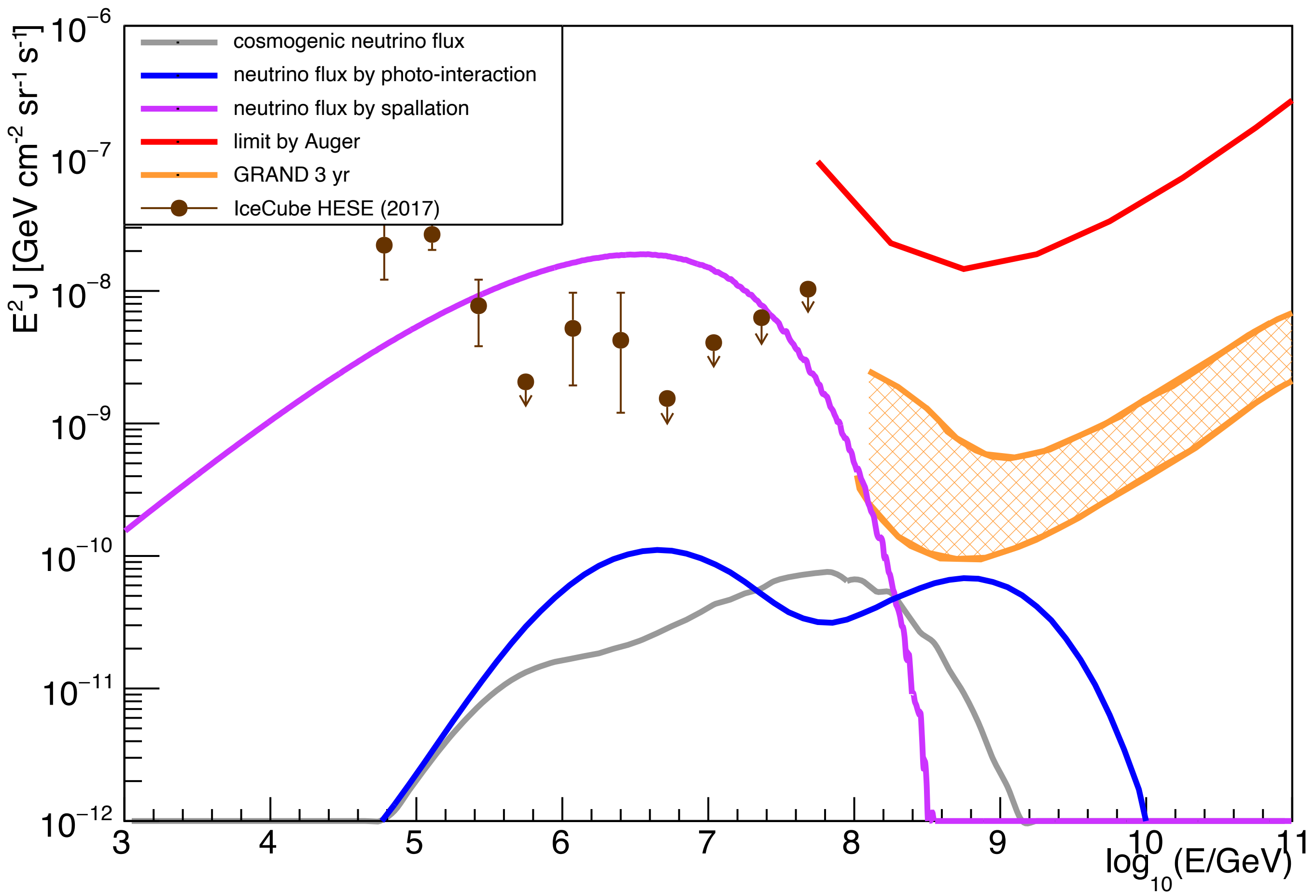
$\log_{10}(R^*_{\rm cut}/V) = 18.5$



* assuming an injection shape $\frac{dN}{dE} \propto E^{-\gamma} \cdot f(E, Z \cdot R_{\rm cut})$

Associated neutrino fluxes

best case



- In this configuration cosmogenic neutrinos are comparable to photo-interaction neutrinos produced in the source.

- Once taken into account also the hadronic interactions, the expected neutrino flux is larger and can be used to constrain plausible scenarios that describe the UHECR data.

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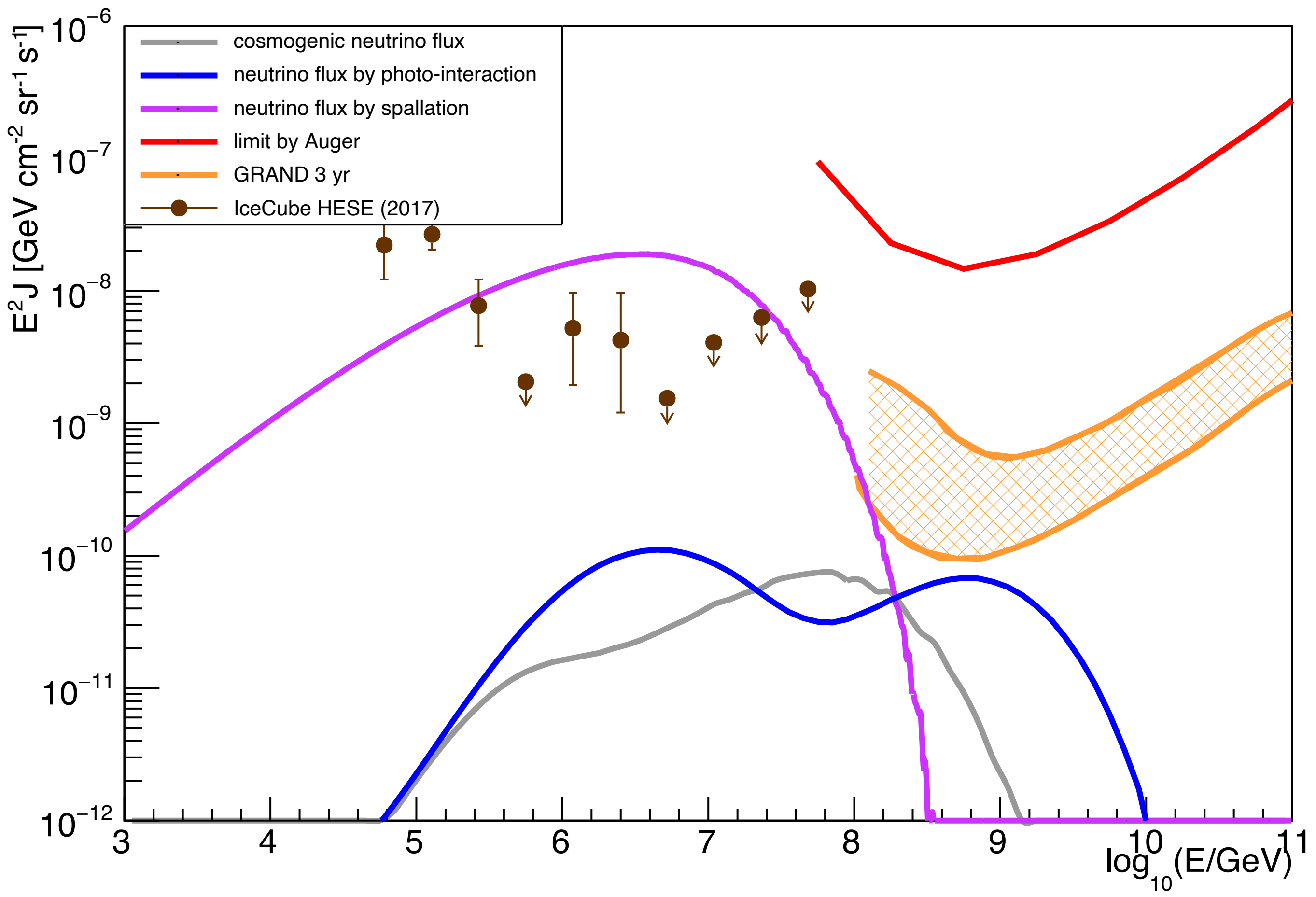
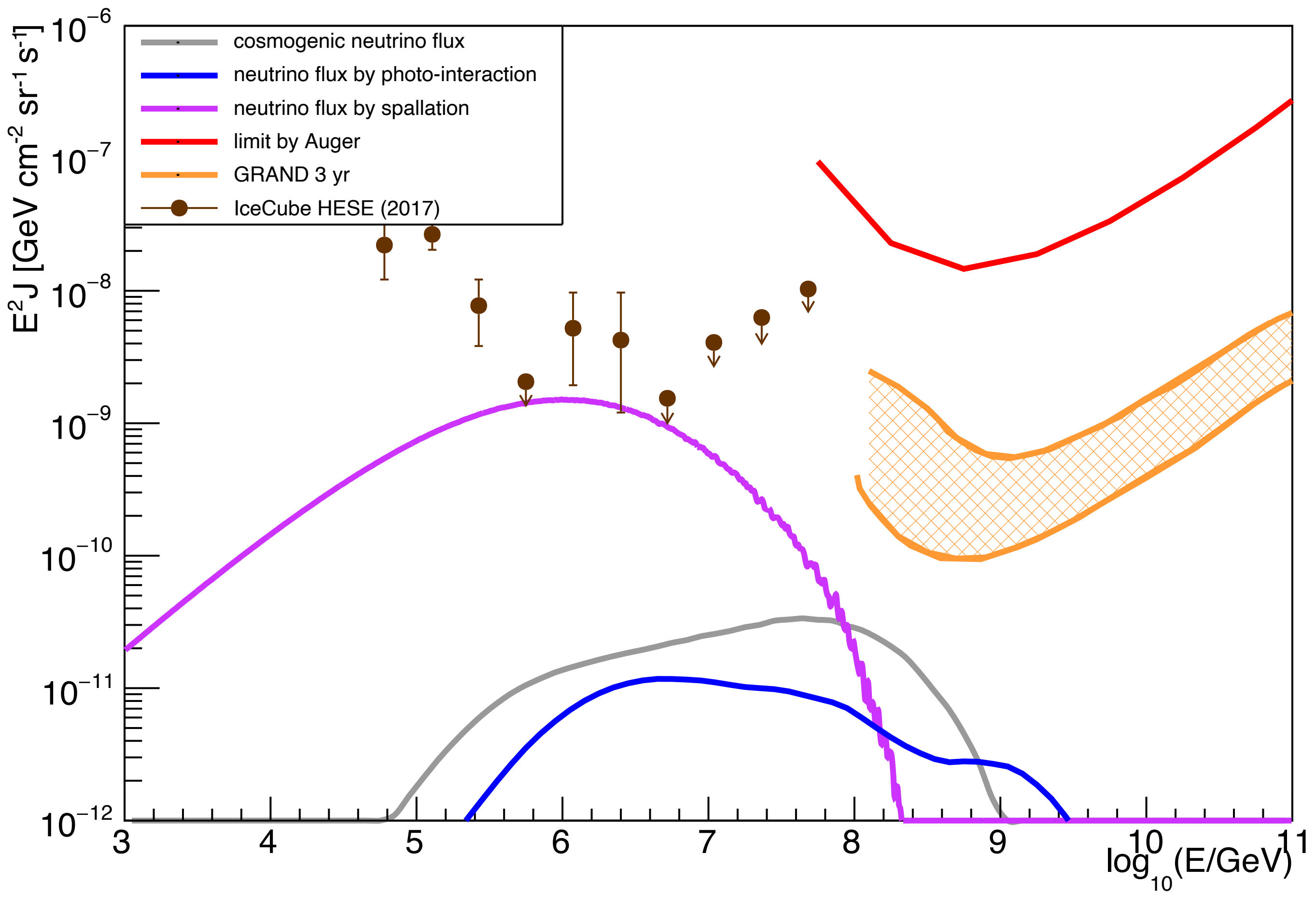
Associated neutrino fluxes

best case



M82



- Decreasing the luminosity, the neutrino fluxes from source decrease ;
- A detailed study of the parameter space is foreseen.

Cross-check on the number of sources

$$n_{\rm SBG} = \frac{\varepsilon_{\rm CR}}{\alpha \cdot L_{\rm IR}} = 1.8 \cdot 10^{-6} \left[\frac{\alpha}{0.1}\right]^{-1} \,{\rm Mpc}^{-3}$$

From the comparison to the data

Using the luminosity functions

$$n_{\rm SBG} \simeq 3 \cdot 10^{-5} \,{\rm Mpc}^{-3}$$

C. Gruppioni et al. , Mon. Not. Roy. Astron. Soc. 432 (2013), 23

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SUMMARY

- ☑ Source-propagation model in a Starburst Galaxy : M82;
- ☑ Computing interaction and escape times;
- ☑ Exploring the parameter space in order to describe both the energy spectrum and composition;
- ☑ Cosmogenic and source neutrino fluxes for each configuration; Increasing the constrain capability of this model.
- ☑ Cross-check using luminosity functions.

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THANKS FOR YOUR ATTENTION!

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https://www.gssi.it/people/students/students-physics/item/2054-condorelli-antonio

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Starburst Galaxies as possible sources of UHECRs and neutrinos

- Study of the UHECRs interactions in the environment surrounding the sources, applied to Starburst Galaxies (SBG).
- Connection between the features of the UHECR spectrum and composition at Earth to the SBG parameters.
- Using a SBG prototype, a diffuse flux from sources uniformly distributed is propagated and then compared to the measurements at Earth.
- Outcomes in cosmic ray and neutrino fluxes can constrain the parameter space.