Pikabu

Combined fit of UHECRs with jetted AGN

HELMHOLTZ WEIZMANN RESEARCH SCHOOL MULTIMESSENGER ASTRONOMY

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Astroparticle School 2023
05.10.2023

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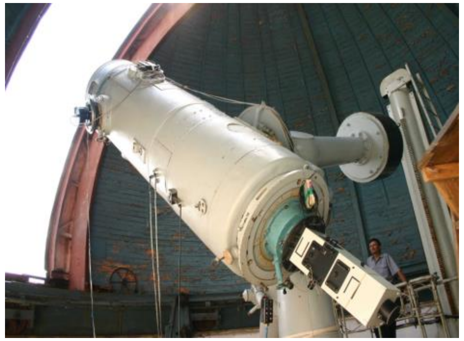
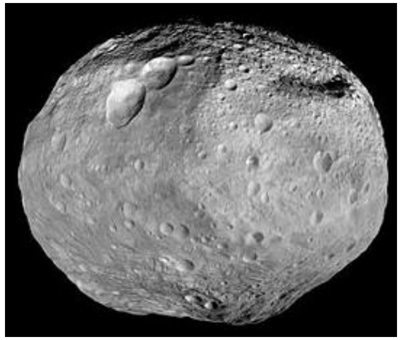
HELMHOLTZ

DESY.

Who am I?



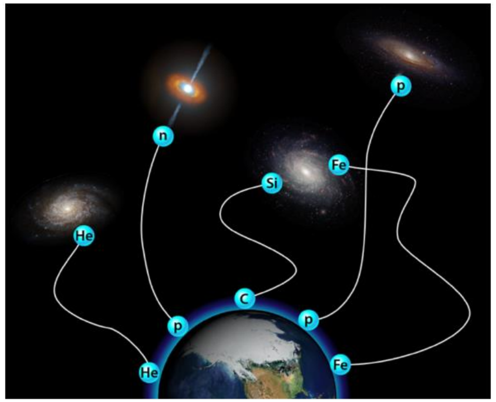


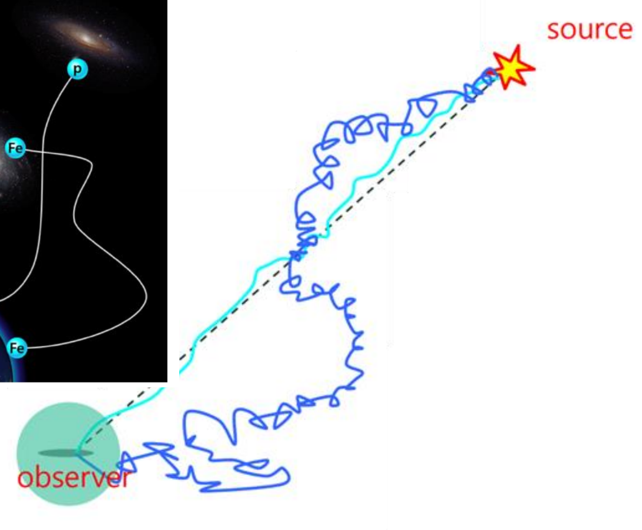
2012

INTERNATIONAL COSMIC DAY

Astronomy Tournament
Astrophysics Olympiad
Astrophysics Conference

DESY-Ukraine Winter School



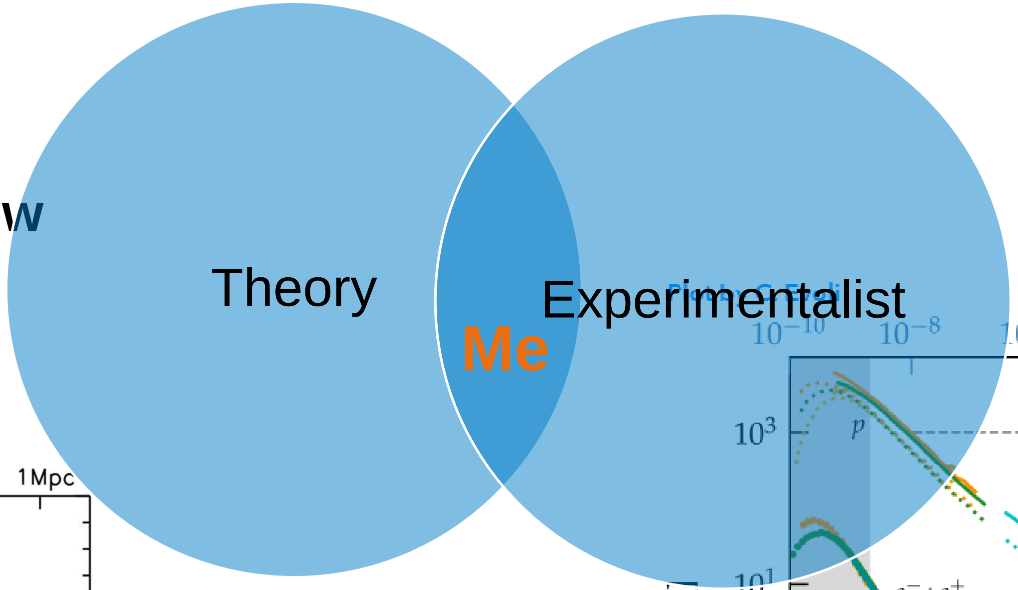


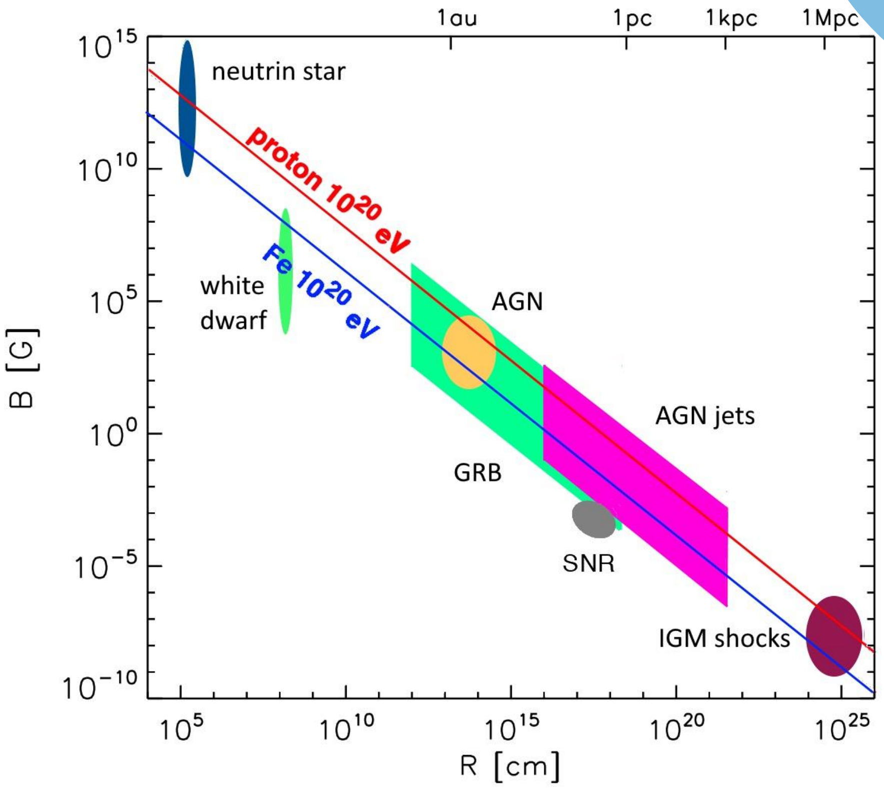
(1) From Denise Boncioli, 2022 Varenna

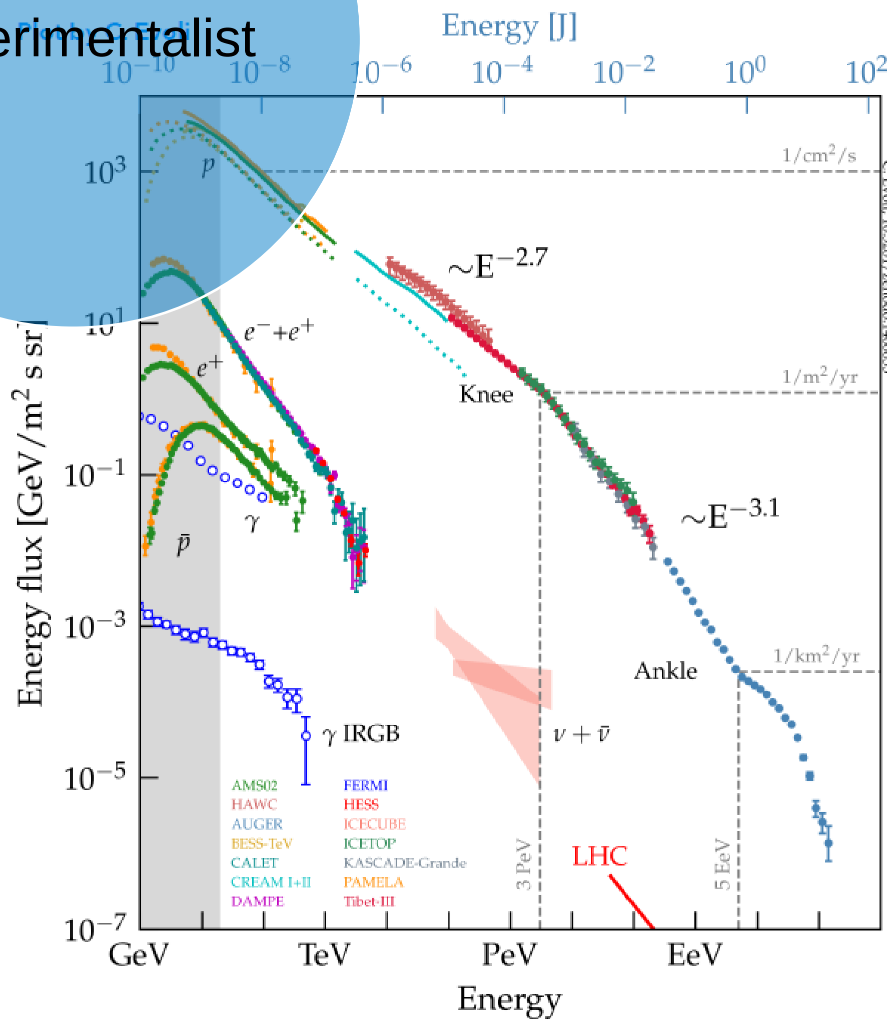
Motivation

I will focus more on **Why** and **How**

Thanks to Oleg Kalekin







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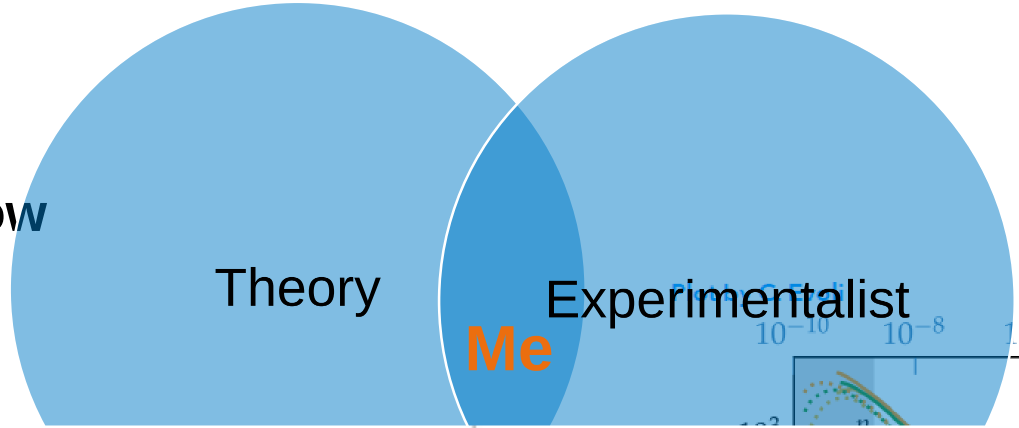
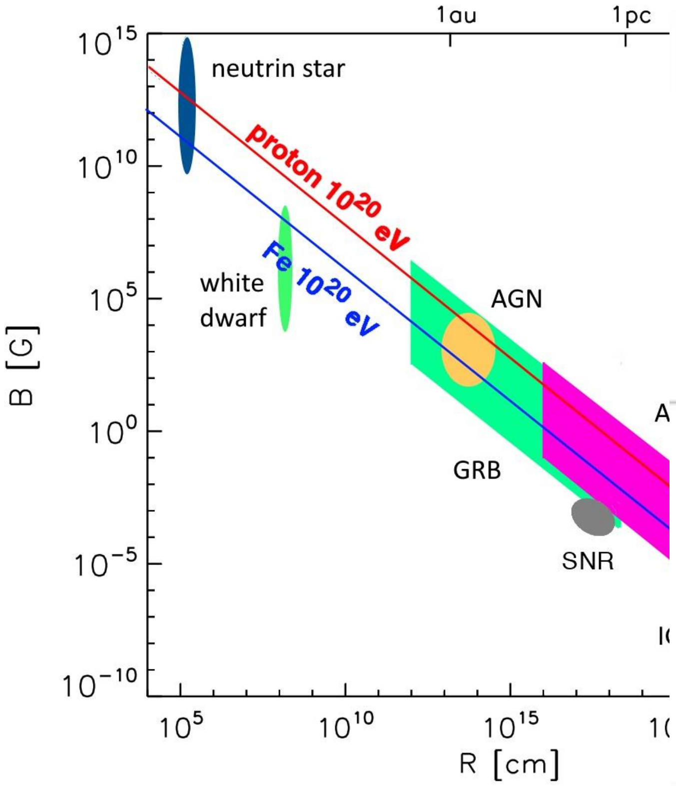
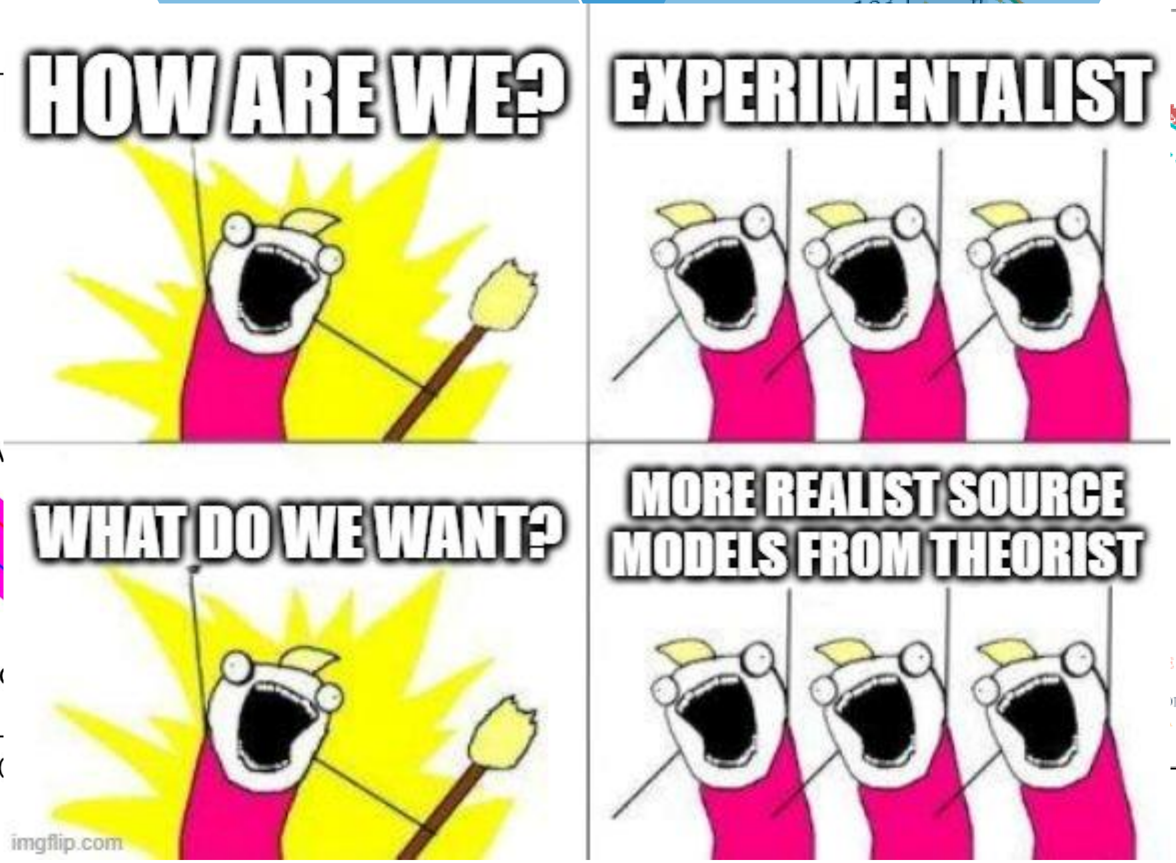
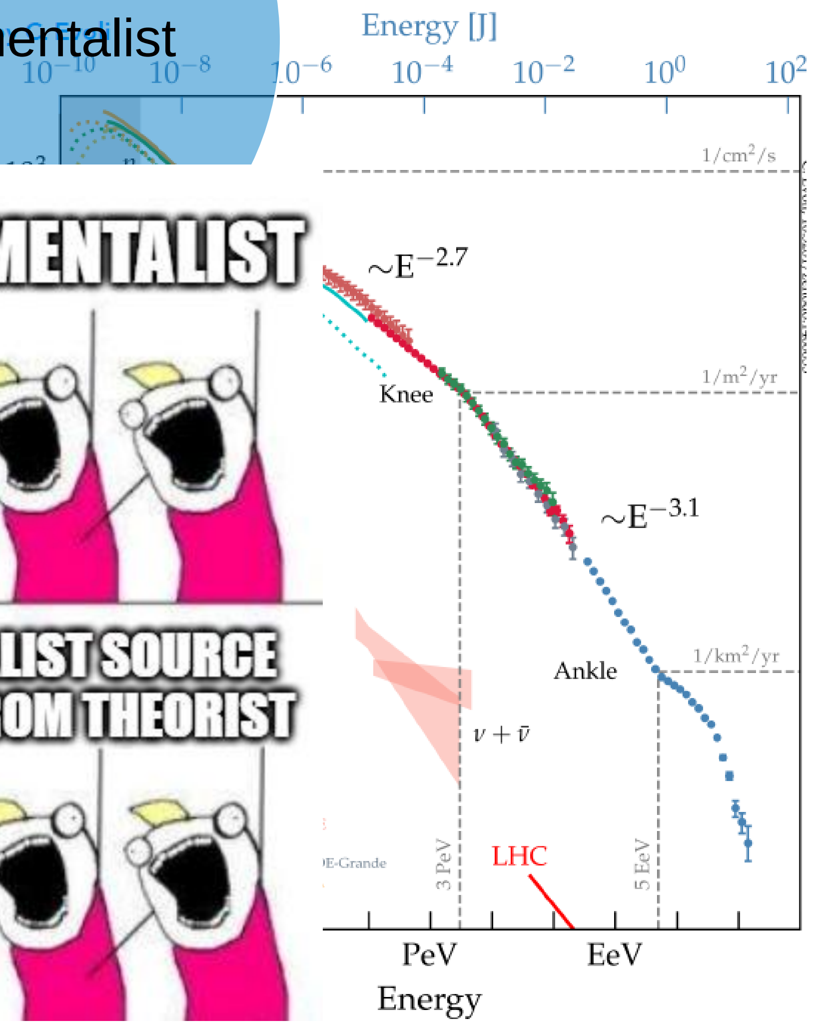


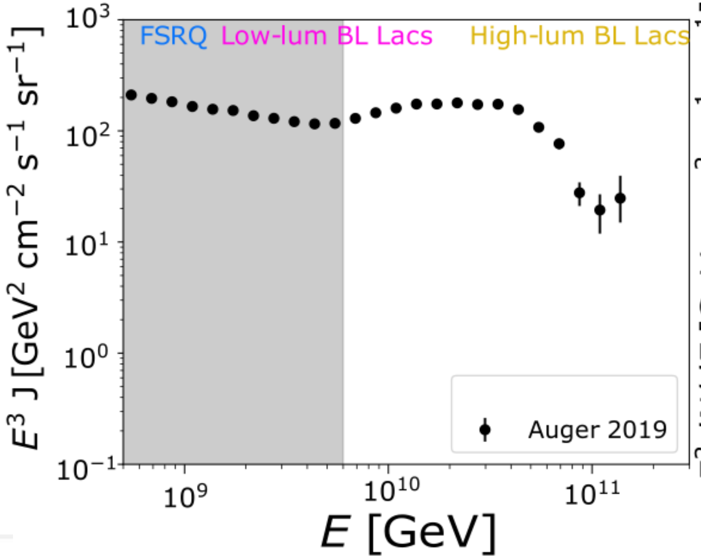


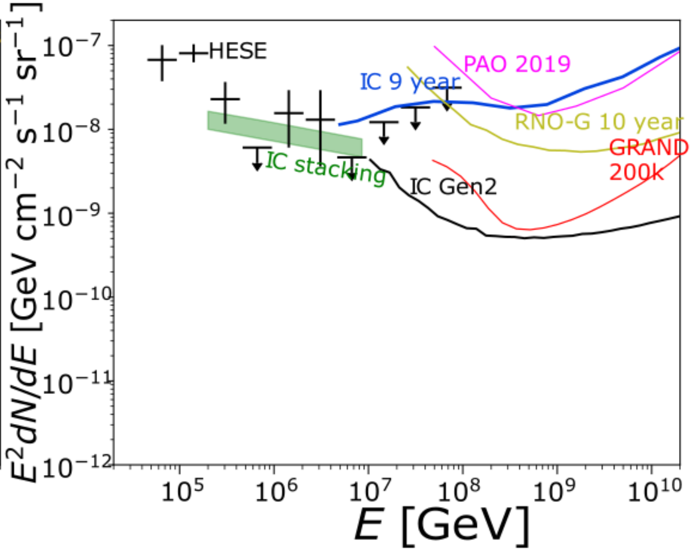


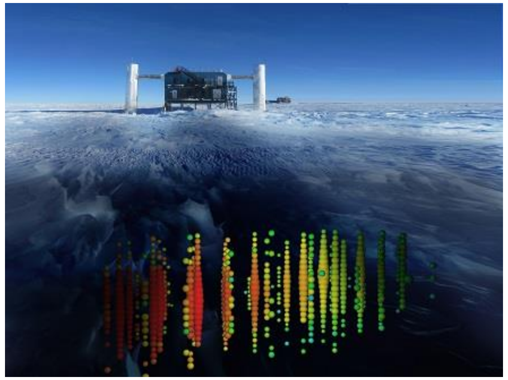


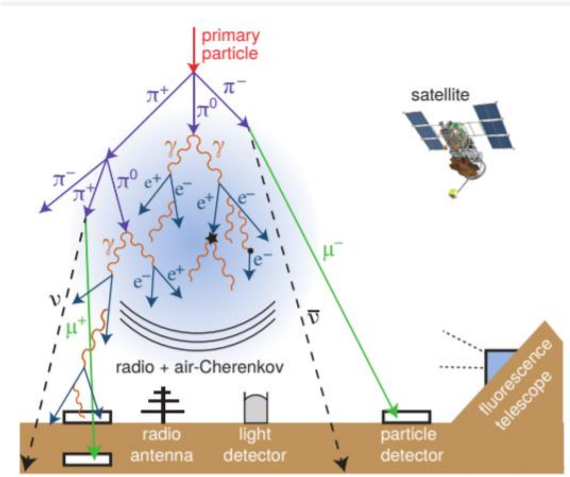
Motivations

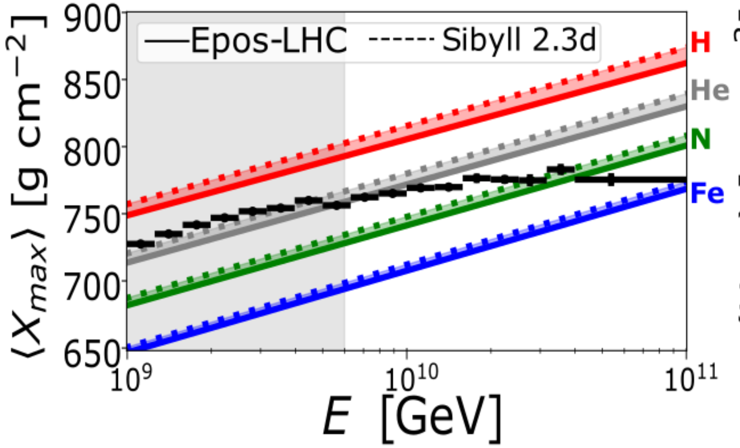
UHECR and Neutrino data

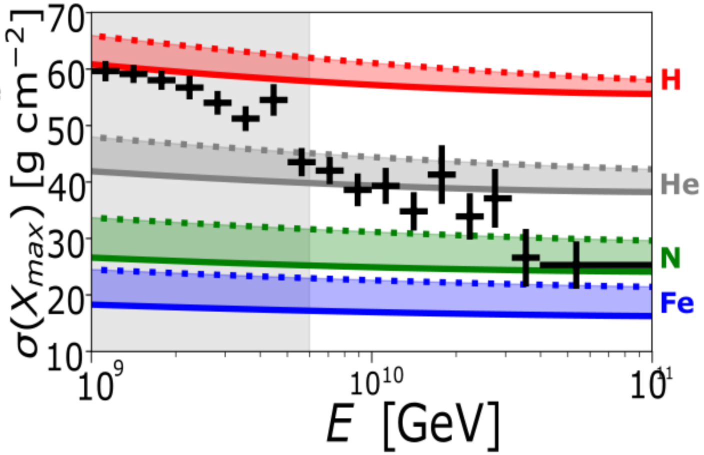








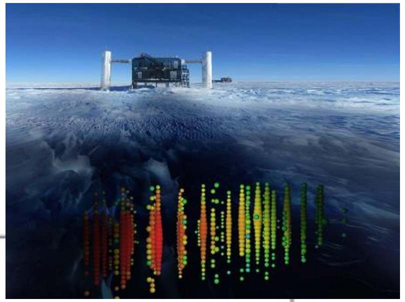


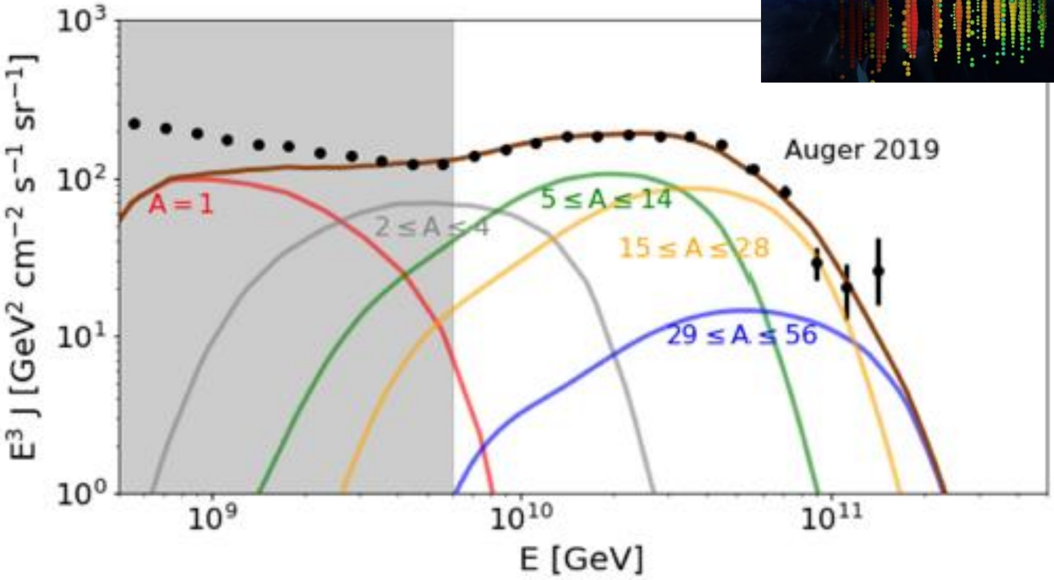


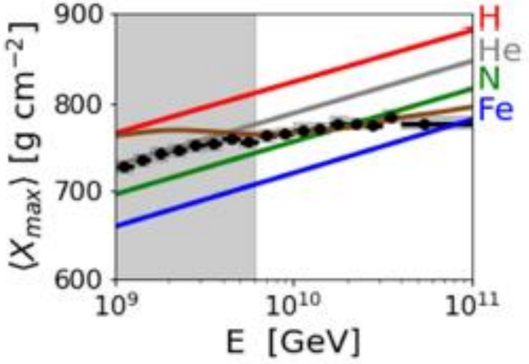
We use EPOS-LHC and SIBYLL2.3d air-shower models

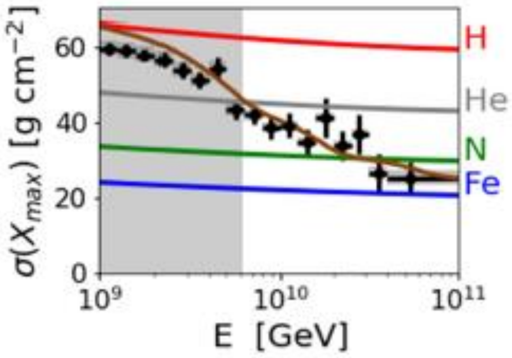
Motivation

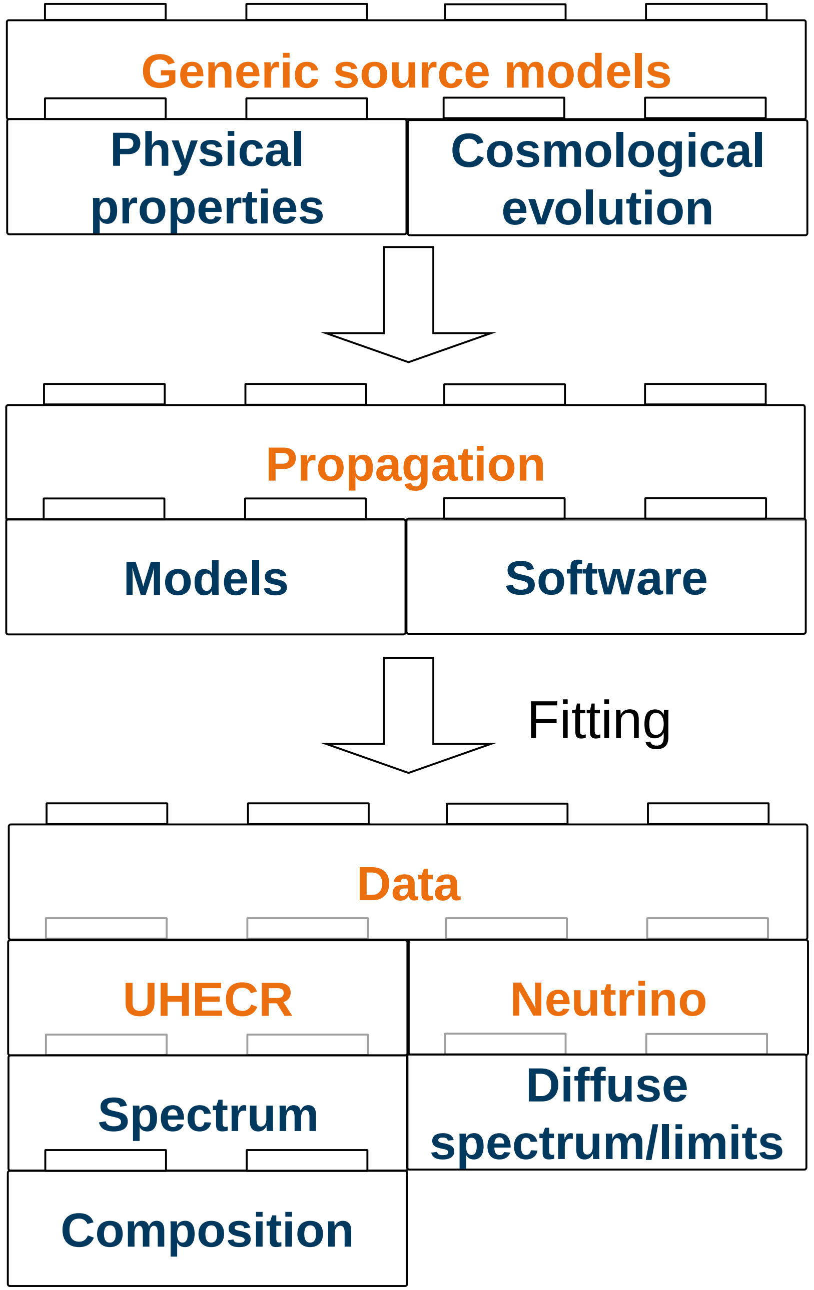
Standard combined fit











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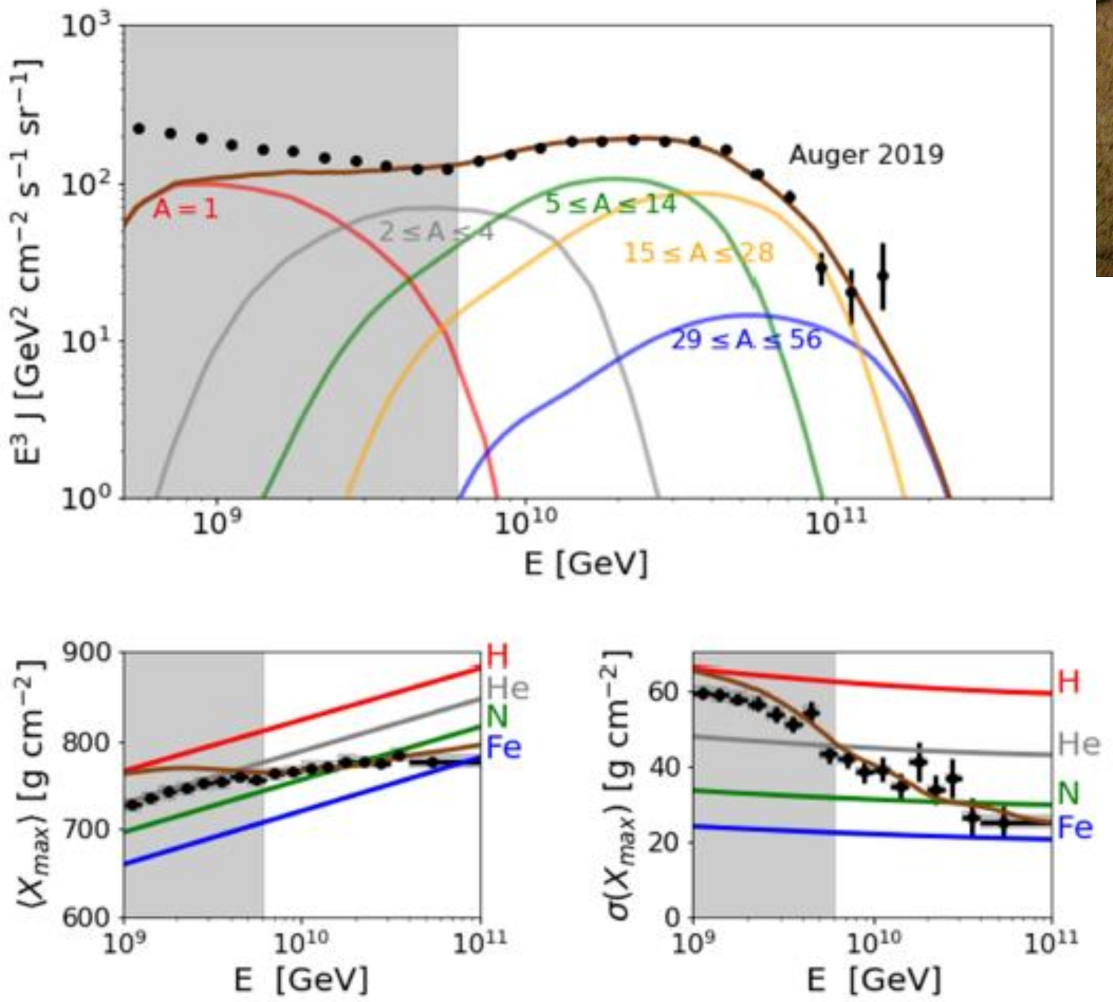
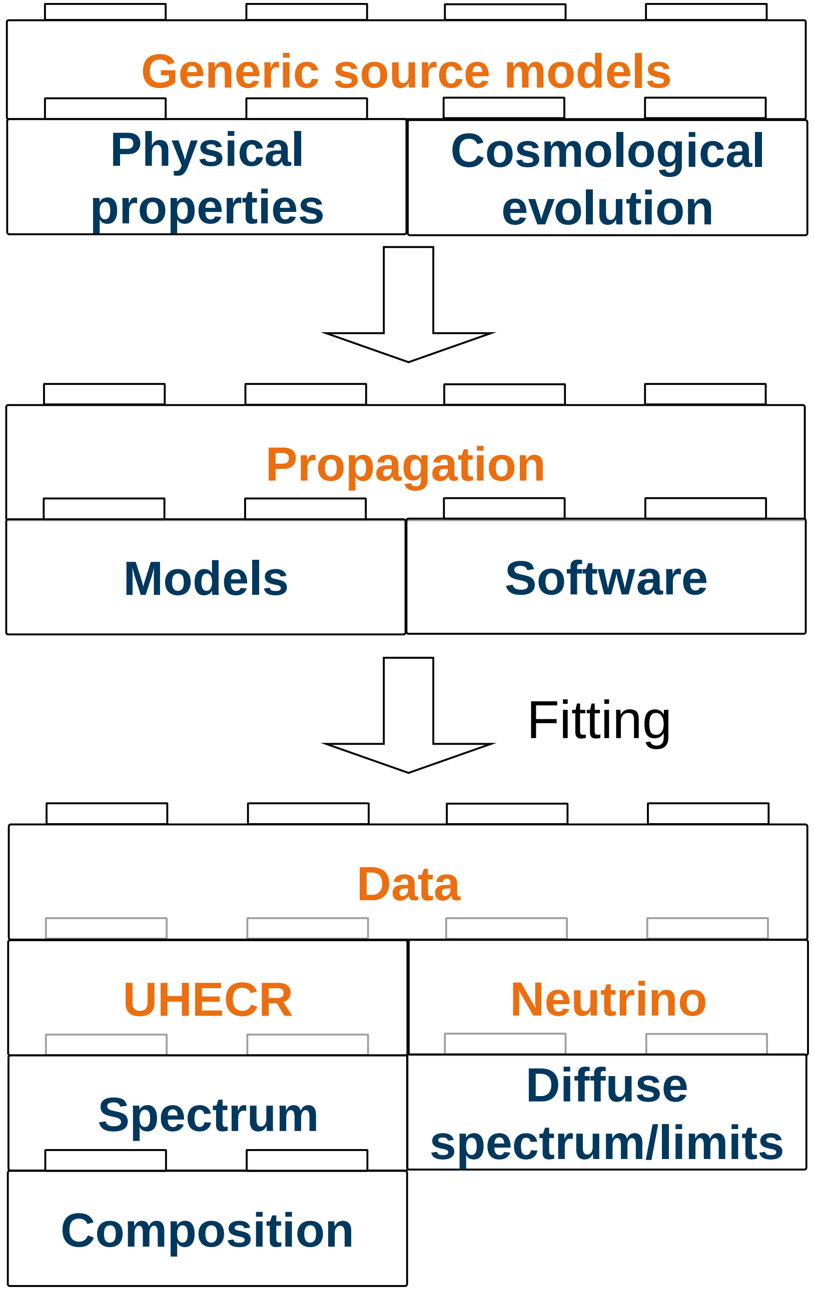


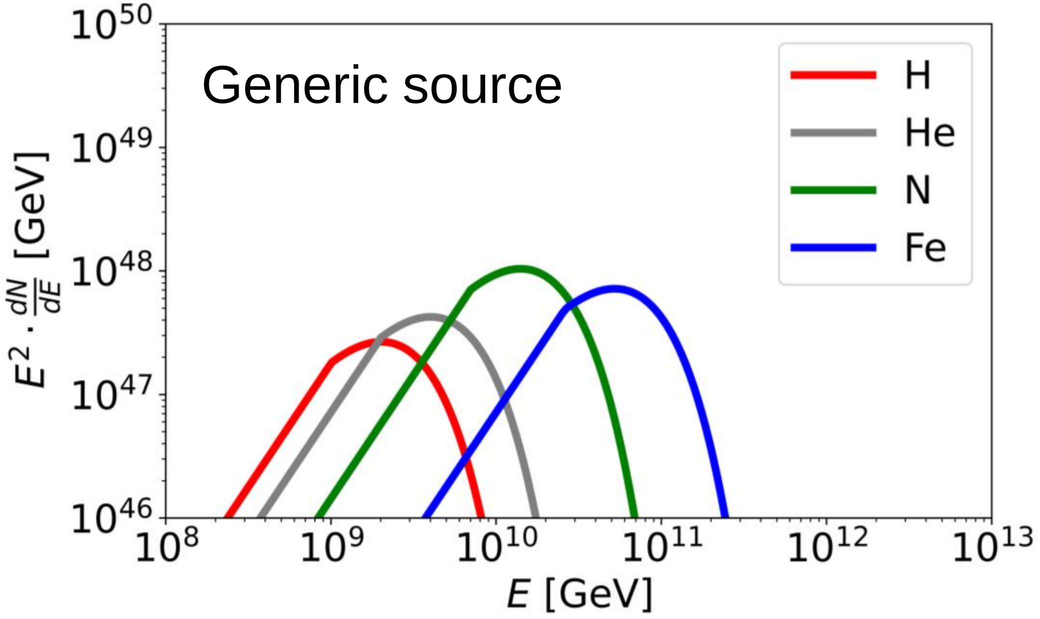


Motivation

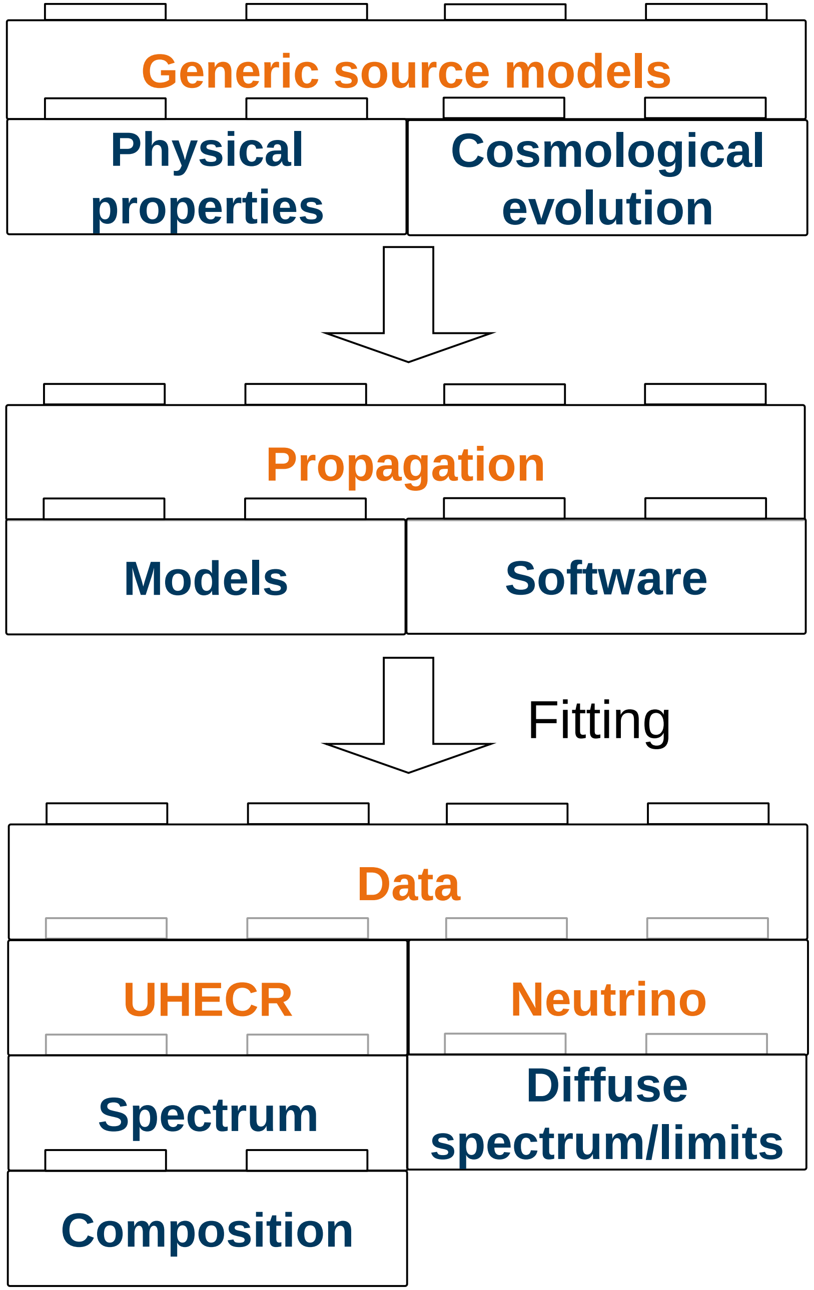
Type of courses

Simple Power-law with rigidity-dependent cut-off:

$$J_{source} \sim E^{-\gamma} f_{\mathrm{cut}}(E)\ ,\ E_{\max} \sim Z$$



Allard et al **2007** Unger et al **2015**, Aab et al. **2015**, Fang & Murase **2018**, Muzio et al **2019**, Batista et al **2019**, Heinze et al **2020**, Bergman et al. **2021**, Halim et al. **2023**, Plotko et al **2023**



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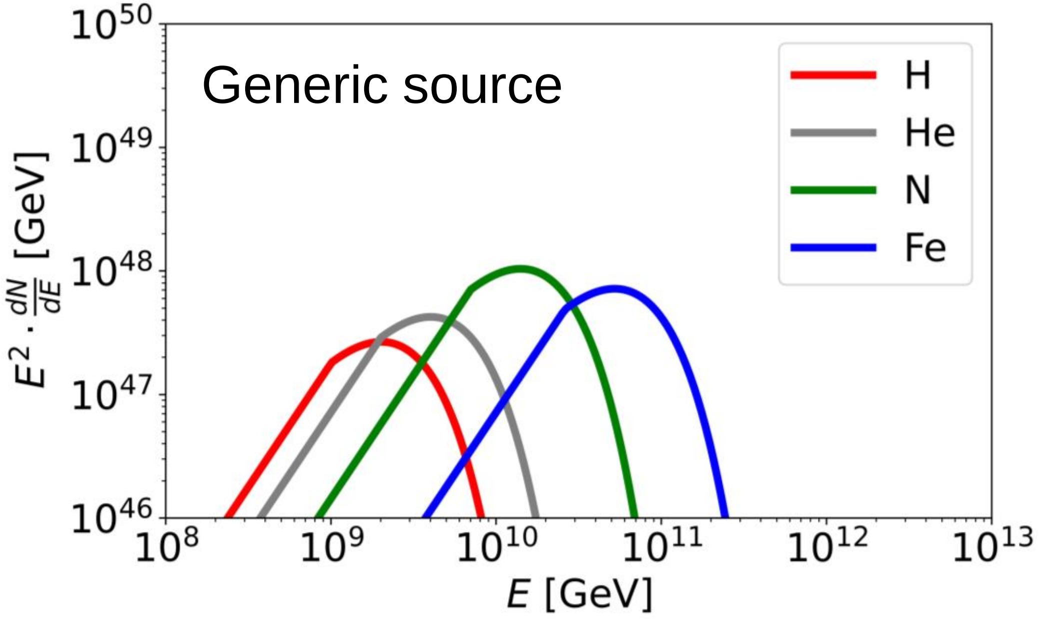
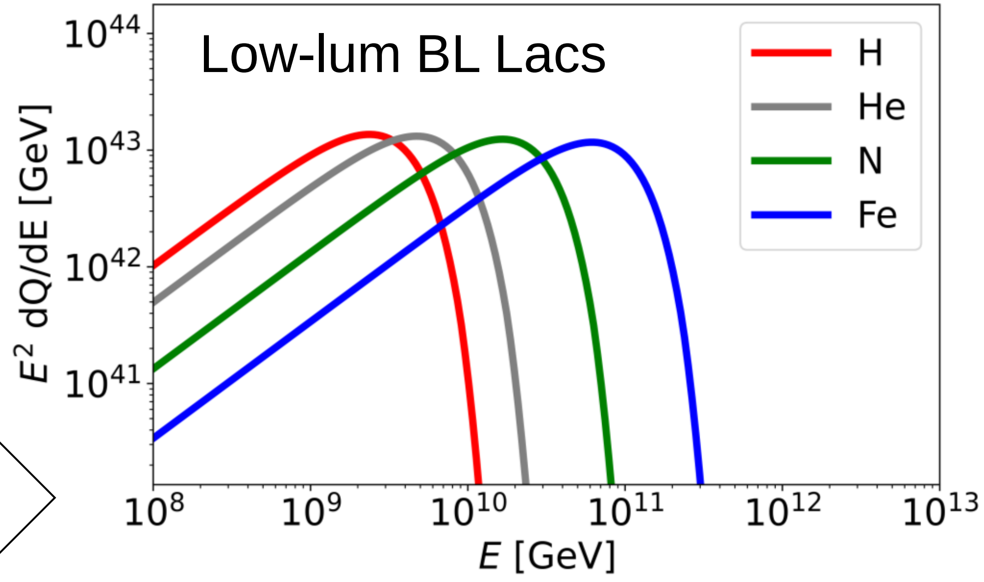
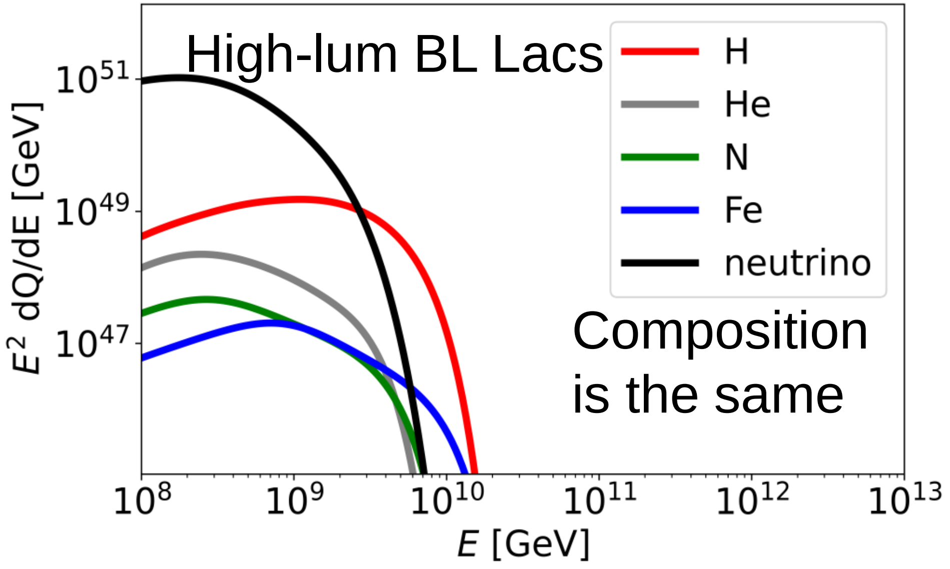


$$J_{source} \sim E^{-\gamma} f_{\text{cut}}(E)$$

$$E_{\text{max}} \sim Z$$

Simulated spectrums of jetted AGN:



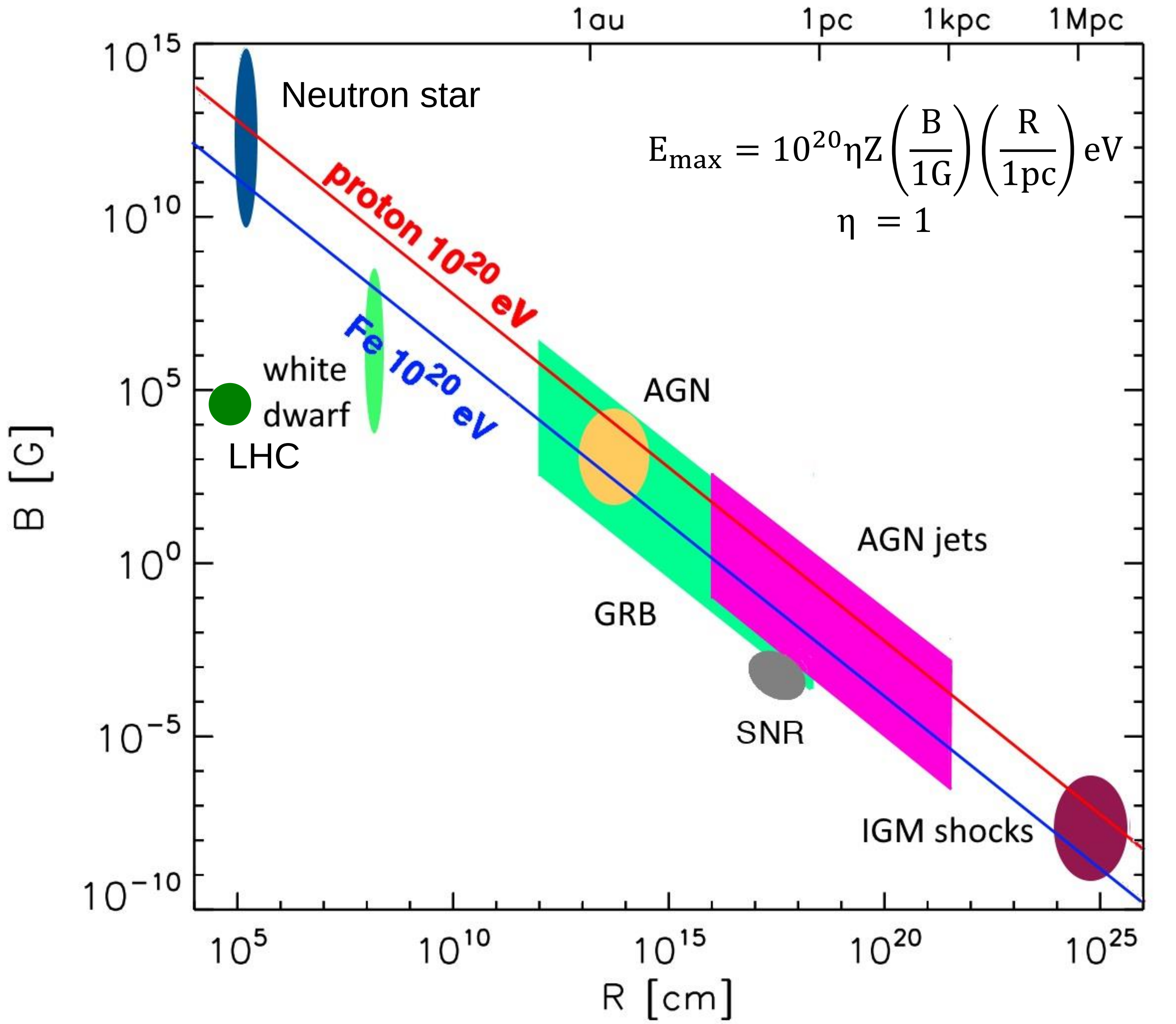


The Hillas criterium

AGNs are the most luminous objects in the universe

Association with neutrino event from IceCube (TXS 0506+056)

BIG ASSUMPTION: all observed UHECRs are produced by jetted AGN



Adapted from Roberto Aloisio 2017

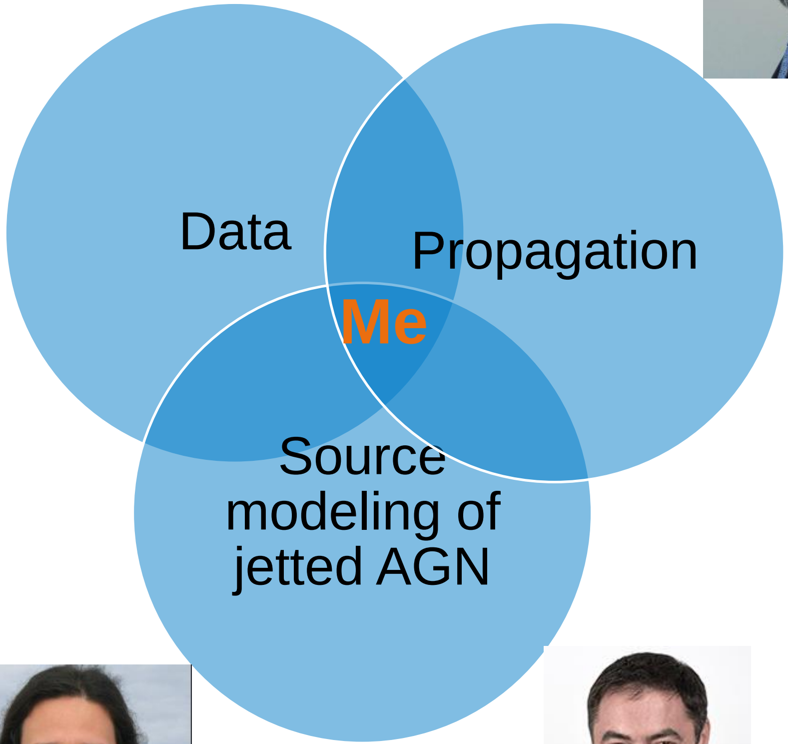
Motivation

1. Switch from generic sources to simulated spectrums from jetted AGN for fitting

2. Provide constraints on the models using UHECR and neutrino data *

3. Predict EeV cosmogenic and source neutrino flux for the future neutrino observations

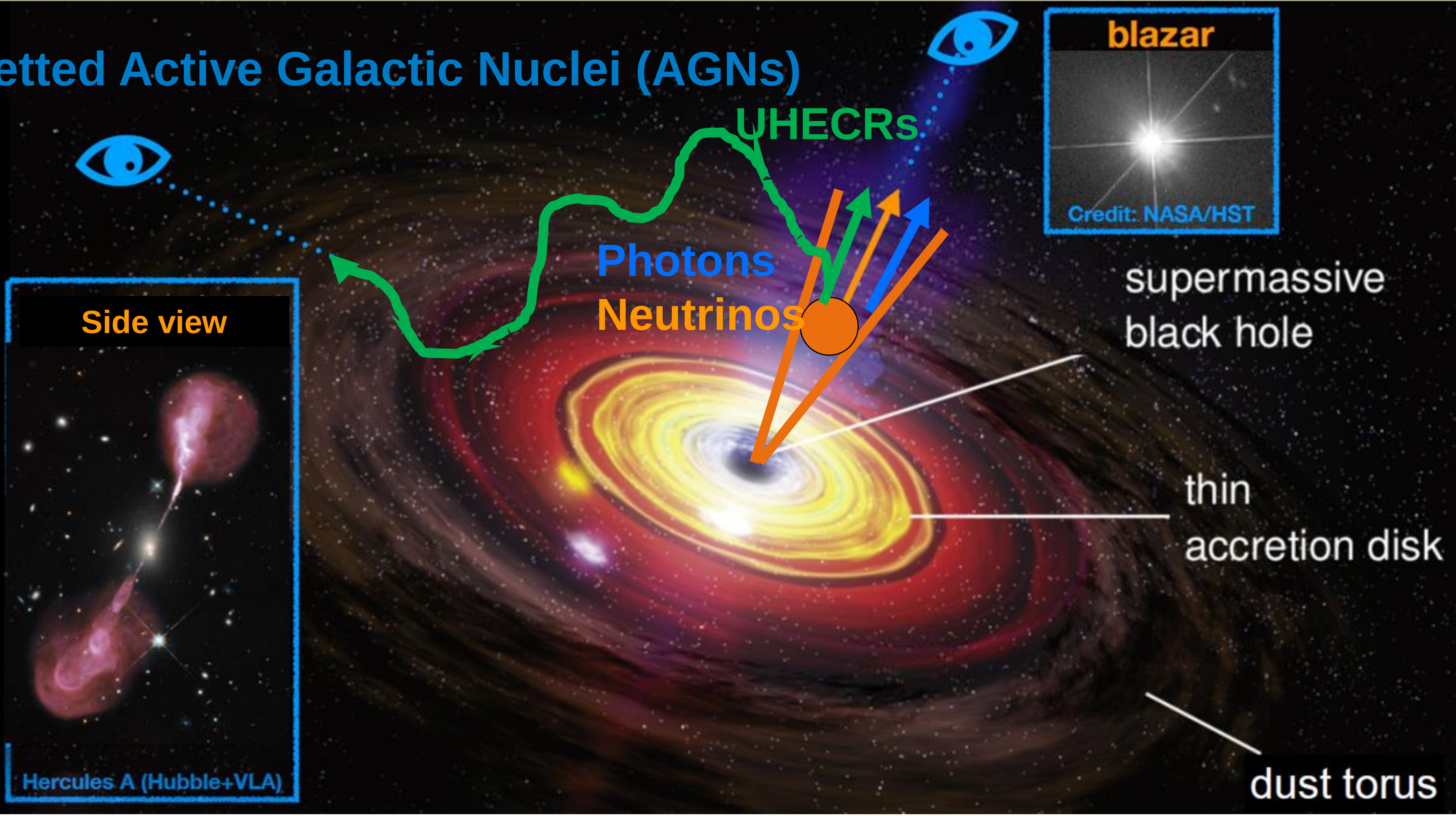
Arjen van Vliet



Xavier Rodrigues

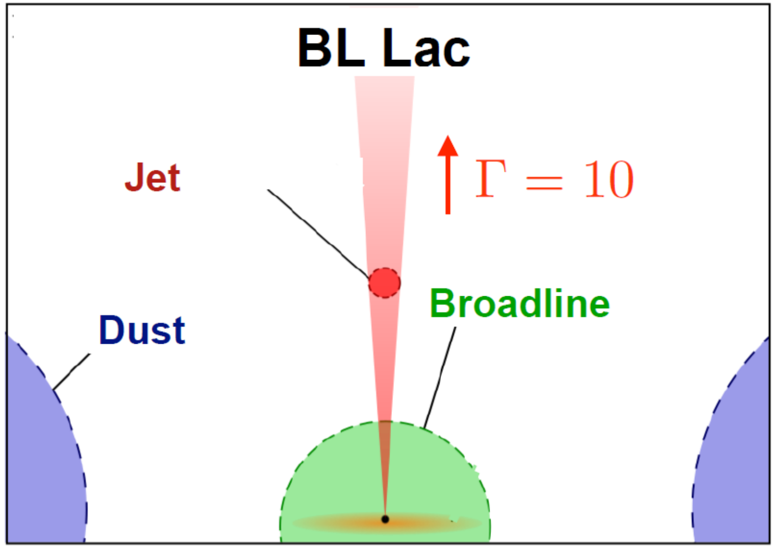
Walter Winter

Jetted Active Galactic Nuclei (AGNs)



Source models

BL Lacs



No evidence of external fields

⇩

One-zone model

Model ingredient list:

Spherical radiation zone with blob size (R)

Injected CR spectrum is power-low with 2 and Maximum energy:

$$E_{max} = 10^{20} \eta Z \left(\frac{B}{1G}\right)\left(\frac{R}{1pc}\right) eV$$

acceleration efficiency (*η)*

Magnetic field scaling as power law of L_γ

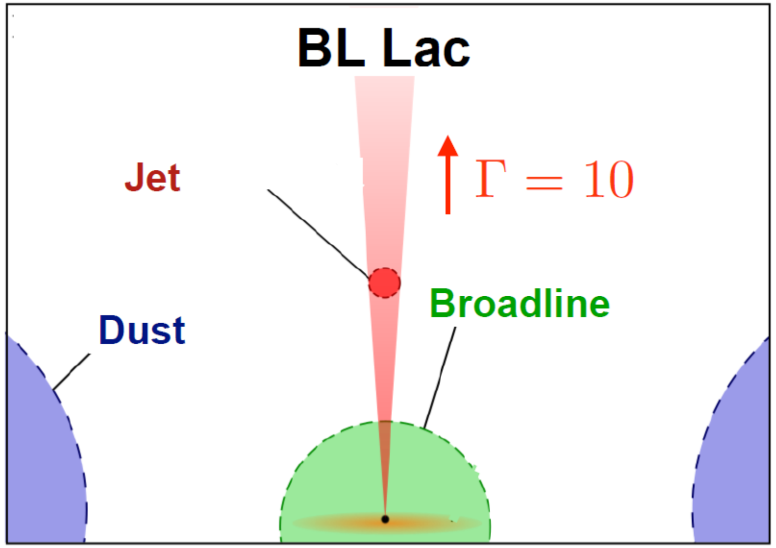
How much energy goes to CR compared to gamma (baryonic loading):

$$\xi_{CR} = \frac{L_{CR}}{L_e} \sim \frac{L_{CR}}{L_\gamma}$$

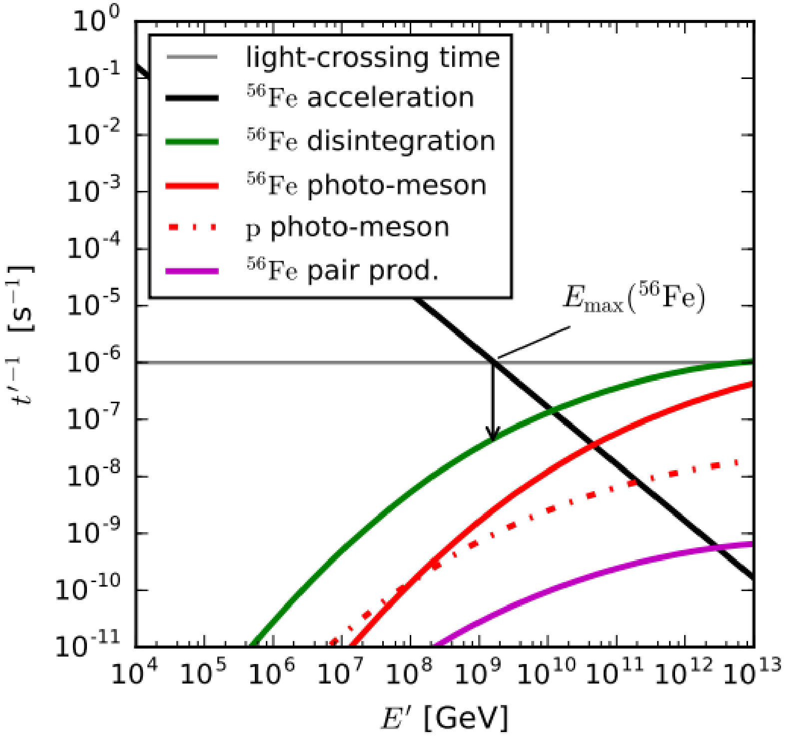
Rodrigues X. et al 2018

Source models

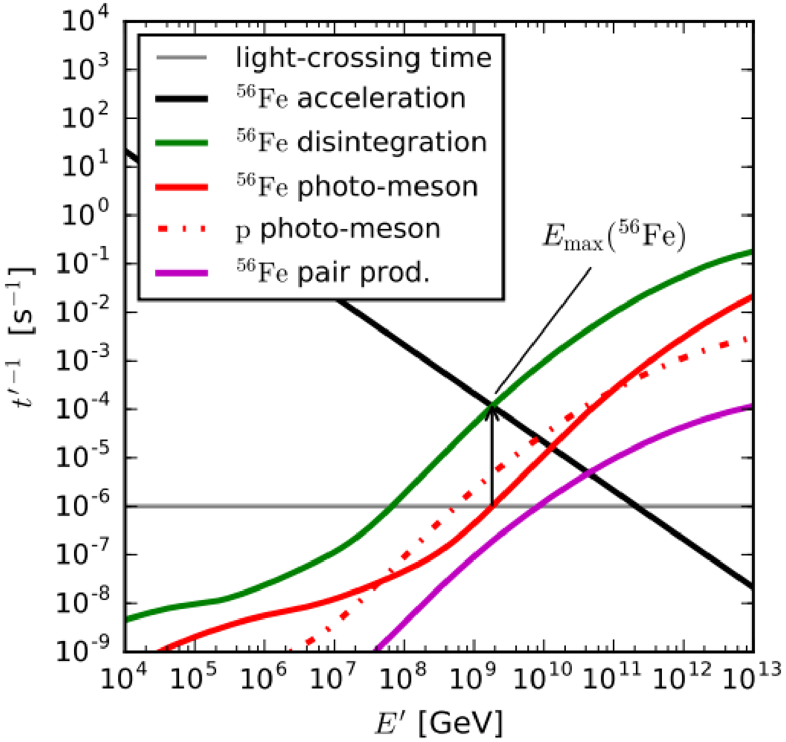
BL Lacs



$L_\gamma = 10^{44.6}\ erg/s$



$L_\gamma = 10^{48.8}\ erg/s$



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Rodrigues X. et al 2018

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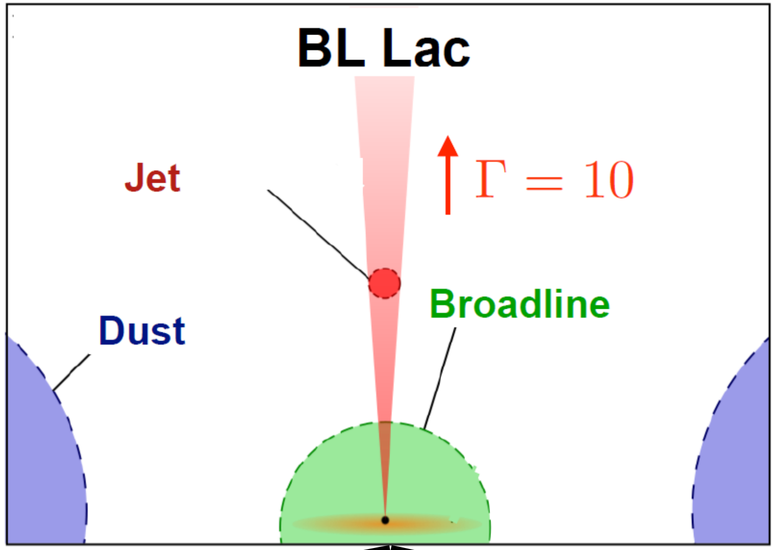


Low-lum

$L_\gamma < 10^{45.5}\ {}^{\text{erg}}/_{s}$

No interactions

Good CR sources

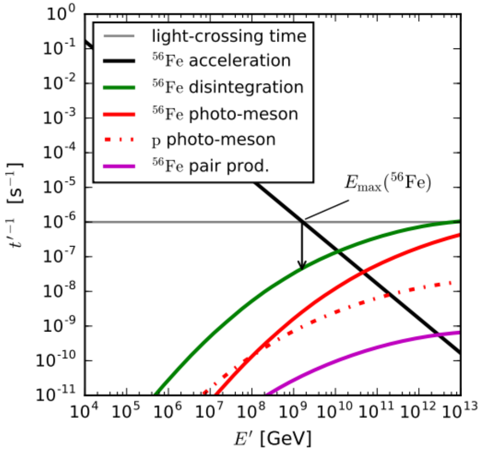
High-lum

$L_\gamma > 10^{45.5}\ {}^{\text{erg}}/_{s}$

a lot of interactions

Good Nu sources

$L_\gamma = 10^{44.6}\ {}^{\text{erg}}/_{s}$



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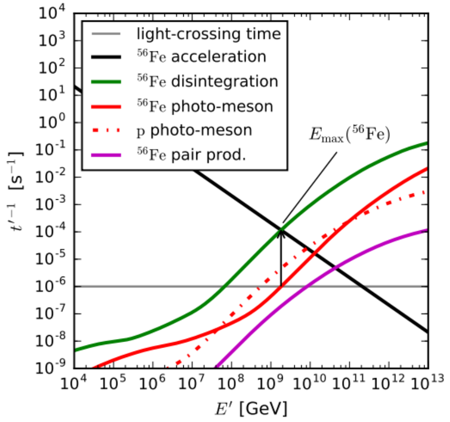
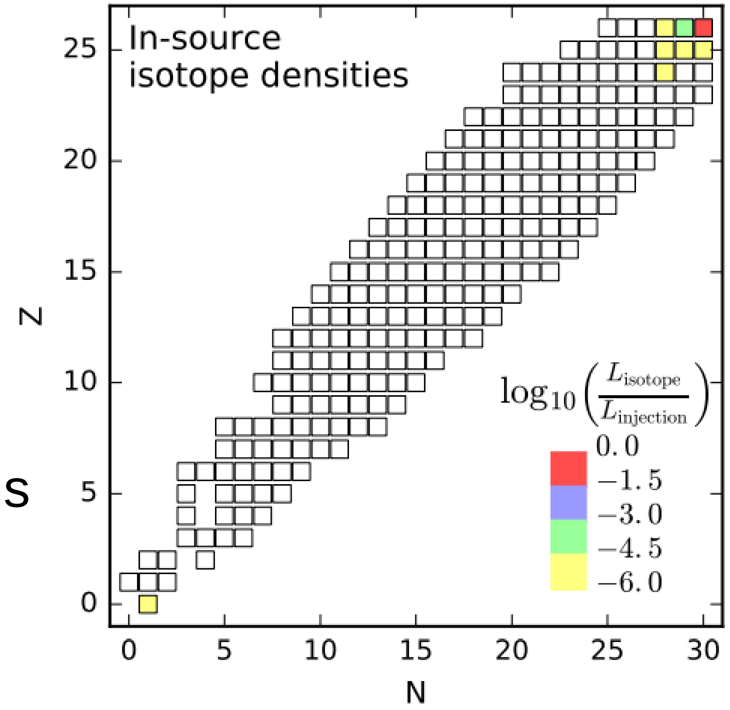
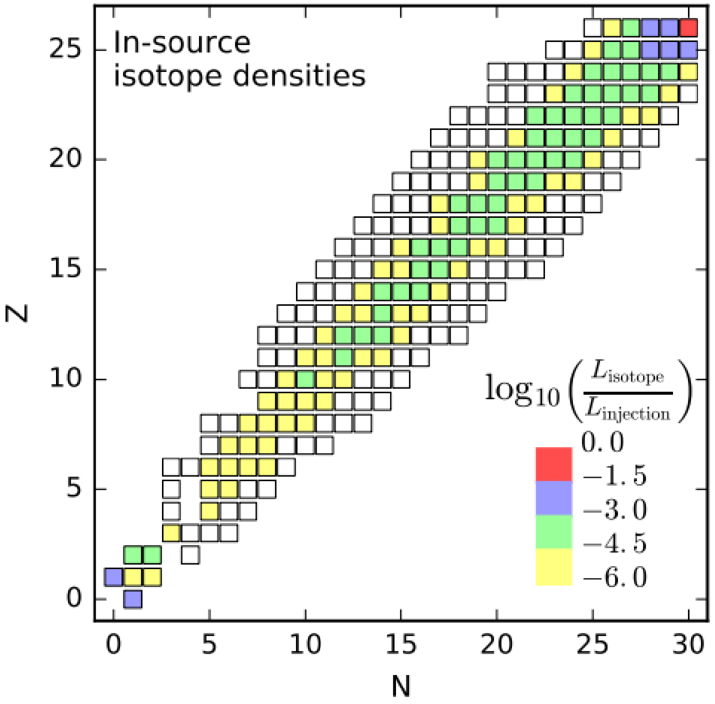


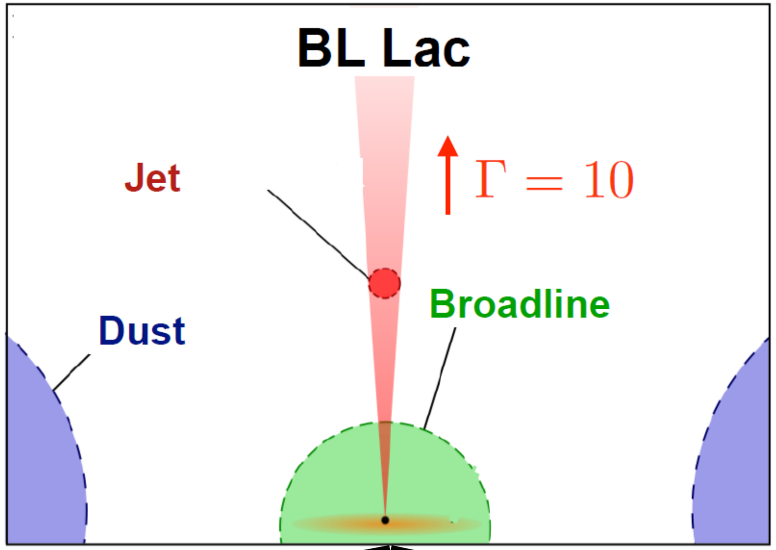
We have to keep the up to 83 spectrum for propagation part





Source models

BL Lacs



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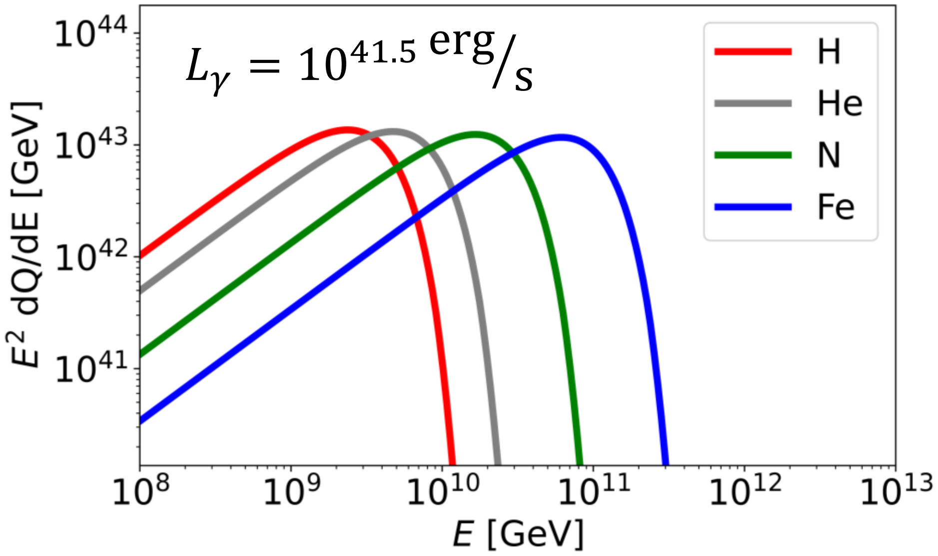
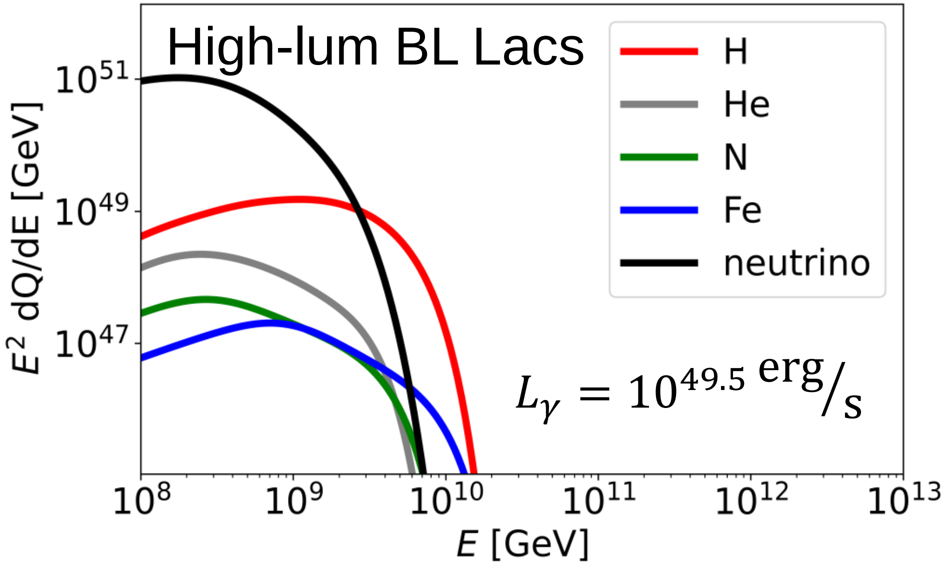




$R = 0.03pc$

$\eta = 0.5$

Bar. loading =100

H: 25%

He: 25%

N: 25%

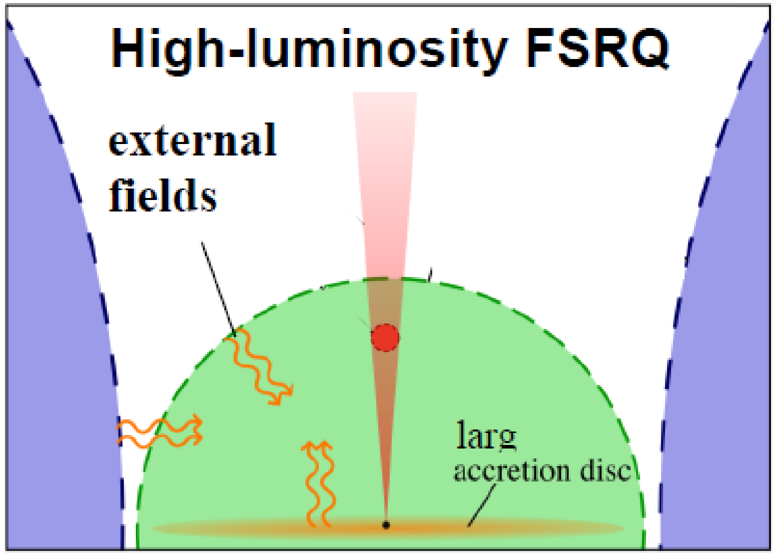
Fe: 25%

Rodrigues X. et al 2018

Rodrigues X. et al 2018

Source model

Flat-Spectrum Radio Quasars (FSRQ)



Large broadline region and dust torus

⇩

External contributions of target photon field for CR interactions

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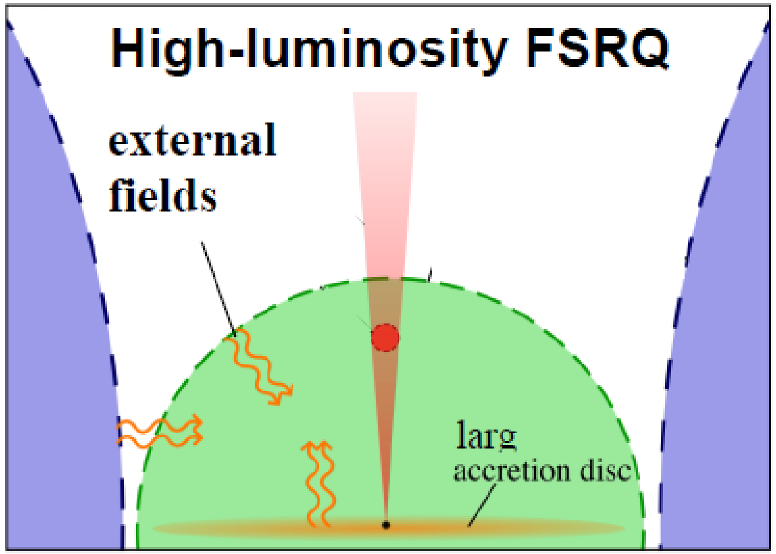

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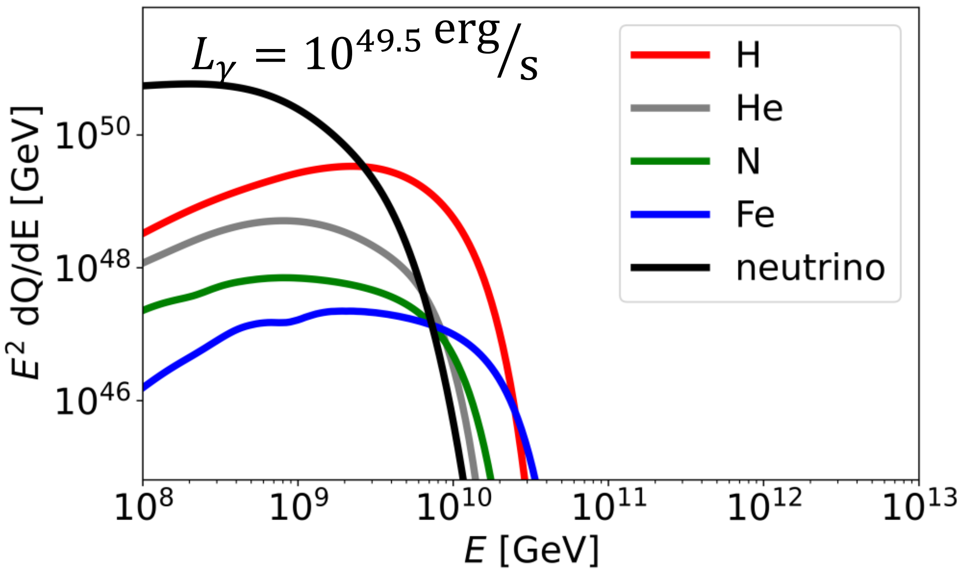
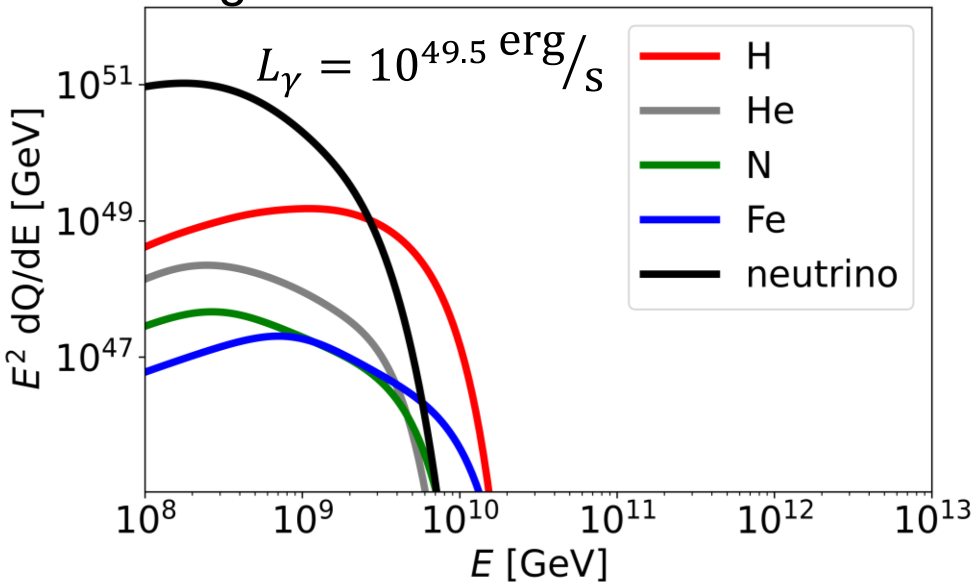


High-lum BL Lacs



$R = 0.03pc$

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Bar. loading =100

H: 25%

He: 25%

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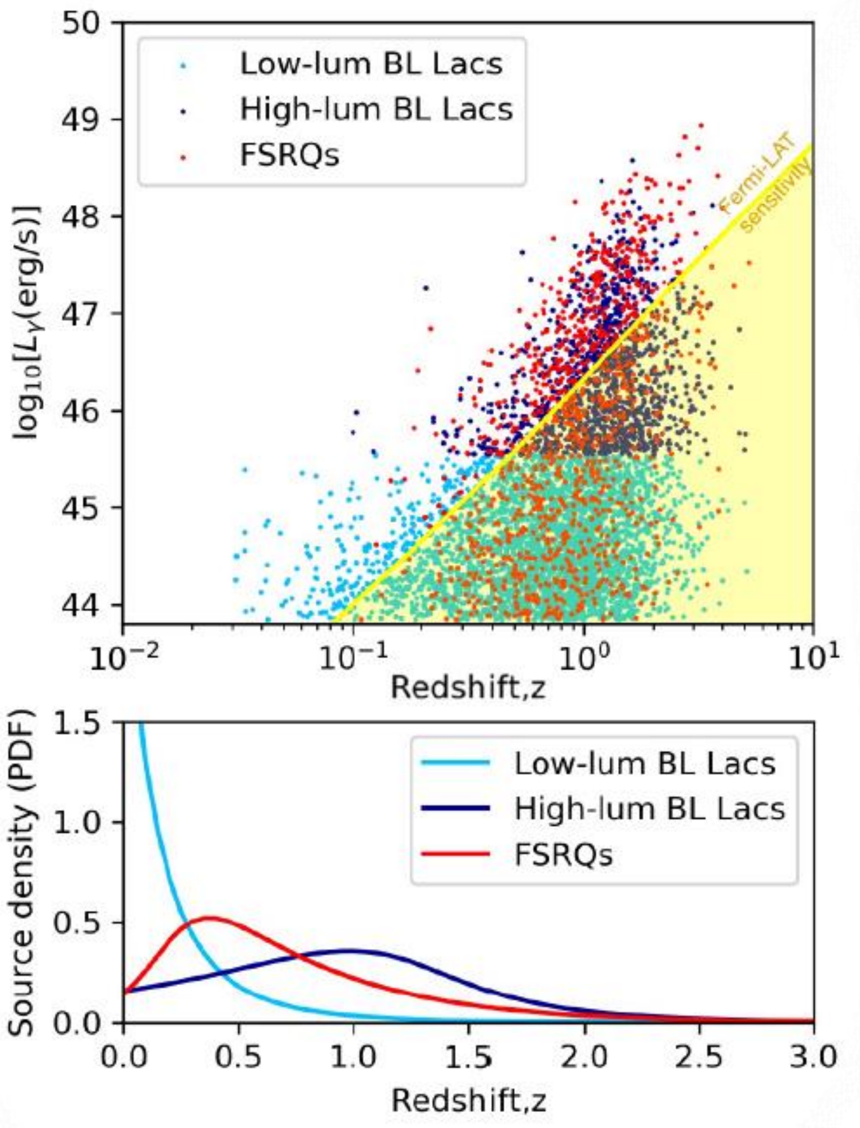
Fe: 25%

Neutrinos and UHECRs from blazar AGN

Population model



~1500 resolved blazars (above the Fermi flux threshold)

50% of FSRQs resolved by *Fermi*

only 15% of BL Lacs resolved by *Fermi*

Model ingredient list:

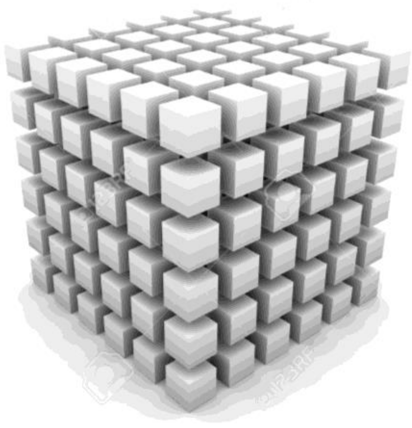
- Fermi catalog(3LAC)
- Observed diffuse γ-ray background
- Distributions of FSRQs and BL Lacs (Ajello)

Integrate over L_γ

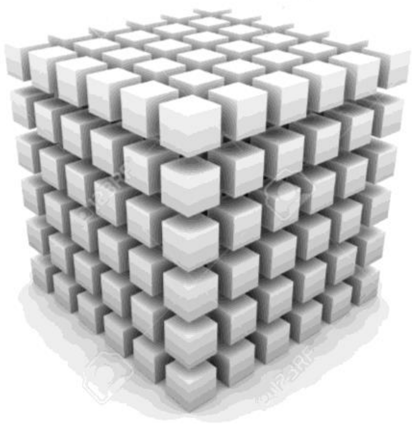
Setup

Parameter scans

- Jetted AGN
  - Low-lum BL Lacs
    - Blob size
    - Acc efficiency
    - Lum gamma
  - High-lum BL Lacs
    - Blob size
    - Acc efficiency
    - Lum gamma
  - FSRQ
    - Blob size
    - Acc efficiency
    - Lum gamma



- H
- He
- N
- Fe



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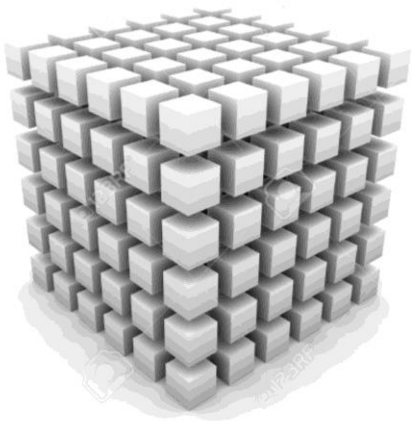


- H
- He
- N
- Fe

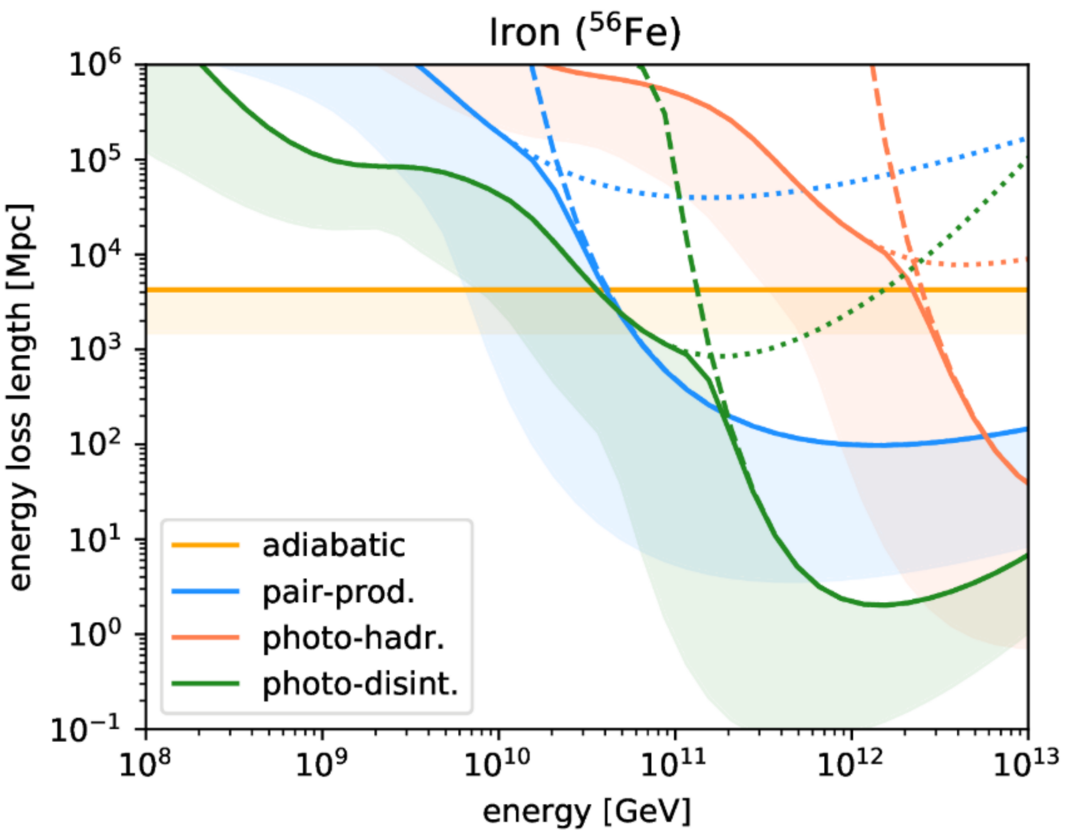
4096 simulated model files from source modeling

Fe: up to 83 different escaped spectrums

Propagation

Transport equation

- About 50 coupled differential equations
- Non-linear in time and energy



Energy loss, CMB (dashed) and EBL (dotted)

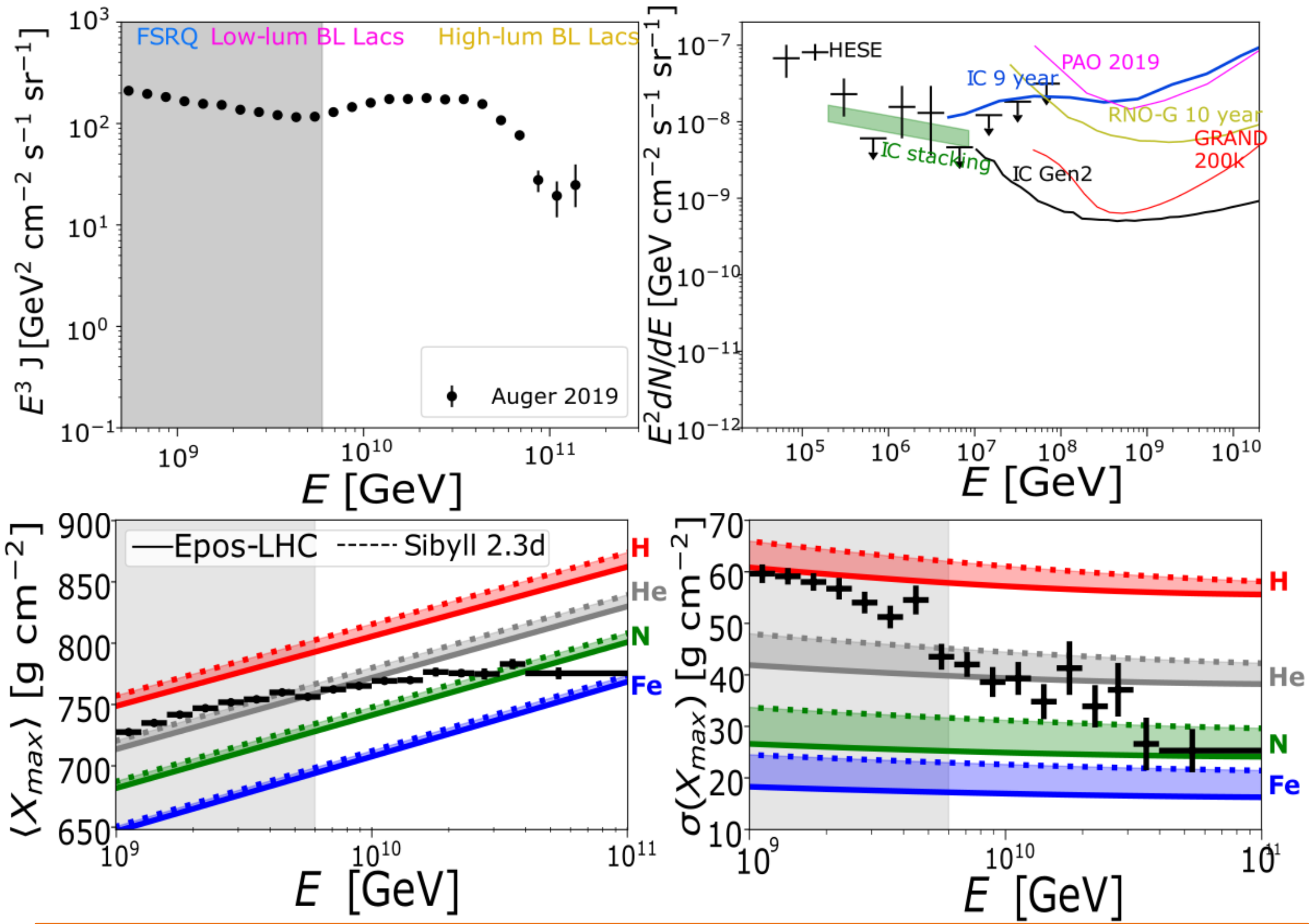
$$\partial_t Y_i(E,z) = +\partial_E(HEY_i) - \partial_E\left(\frac{dE}{dt}Y_i\right) - \Gamma_i Y_i + \sum_j Q_{j\to i} + \mathcal{L}_i$$

adiabatic cooling | pair - production | photo-hadronic, Photo-disintegration | Injection

Jonas Heinze at TeVPA 2018;

Setup

UHECR and neutrino data



We use EPOS-LHC and SIBYLL2.3d air-shower models

χ^2 used to estimate goodness of fit and find best parameters:

$$\chi^2 = \chi^2_{spectrum} + \\ + \chi^2_{\langle X_{max} \rangle} + \chi^2_{\sigma(X_{max})} \\ + \chi^2_{nu} + \left(\frac{\delta_E}{\sigma_E}\right)^2$$

Spoiler: $\chi^2_{nu} = 0$

Akaike information criterion (AICc) used to compare different models:

$$AICc = \chi^2 + 2k + \frac{2k^2 + 2k}{N - k - 1}$$

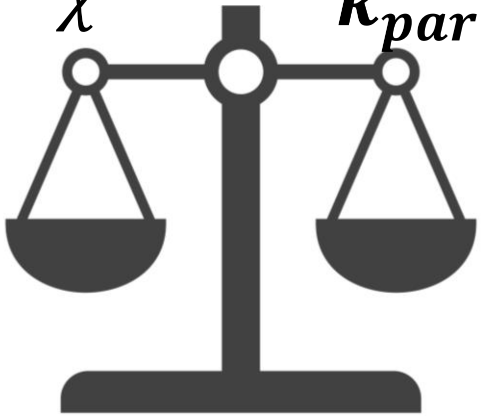
N – number of data points (37)
k – number of free parameters (7-19)

Setup

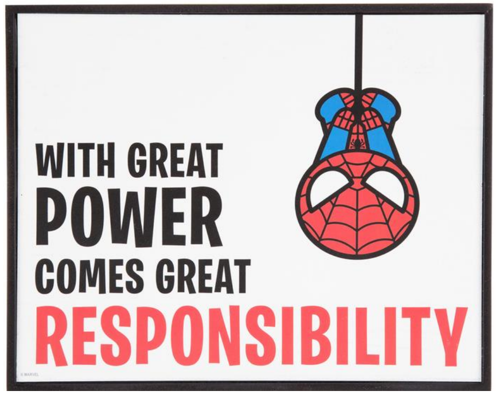
- Jetted AGN
  - Low-lum BL Lacs
    - Blob size
    - Acc efficiency
    - Composition

15 models
x 2 air-shower model
500 CPU days

χ^2 k_{par}



Akaike information criterion



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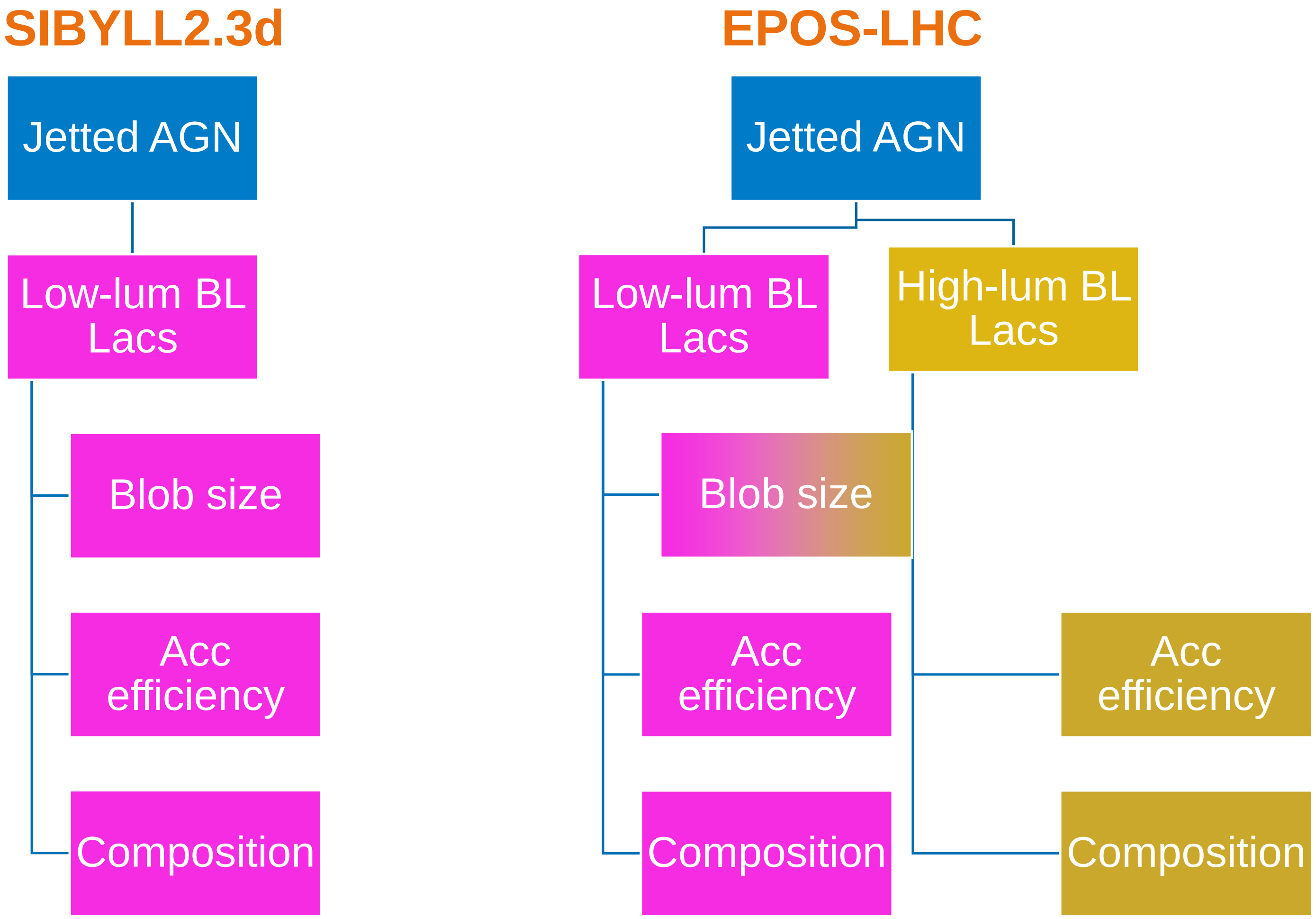
    - Composition
  - High-lum BL Lacs
    - Blob size
    - Acc efficiency
    - Composition
  - FSRQ
    - Blob size
    - Acc efficiency
    - Composition

Plotko P. et al. in preparation

Results



$$\chi^2/_{d.o.f.} \approx {}^{89.2}/_{30}$$

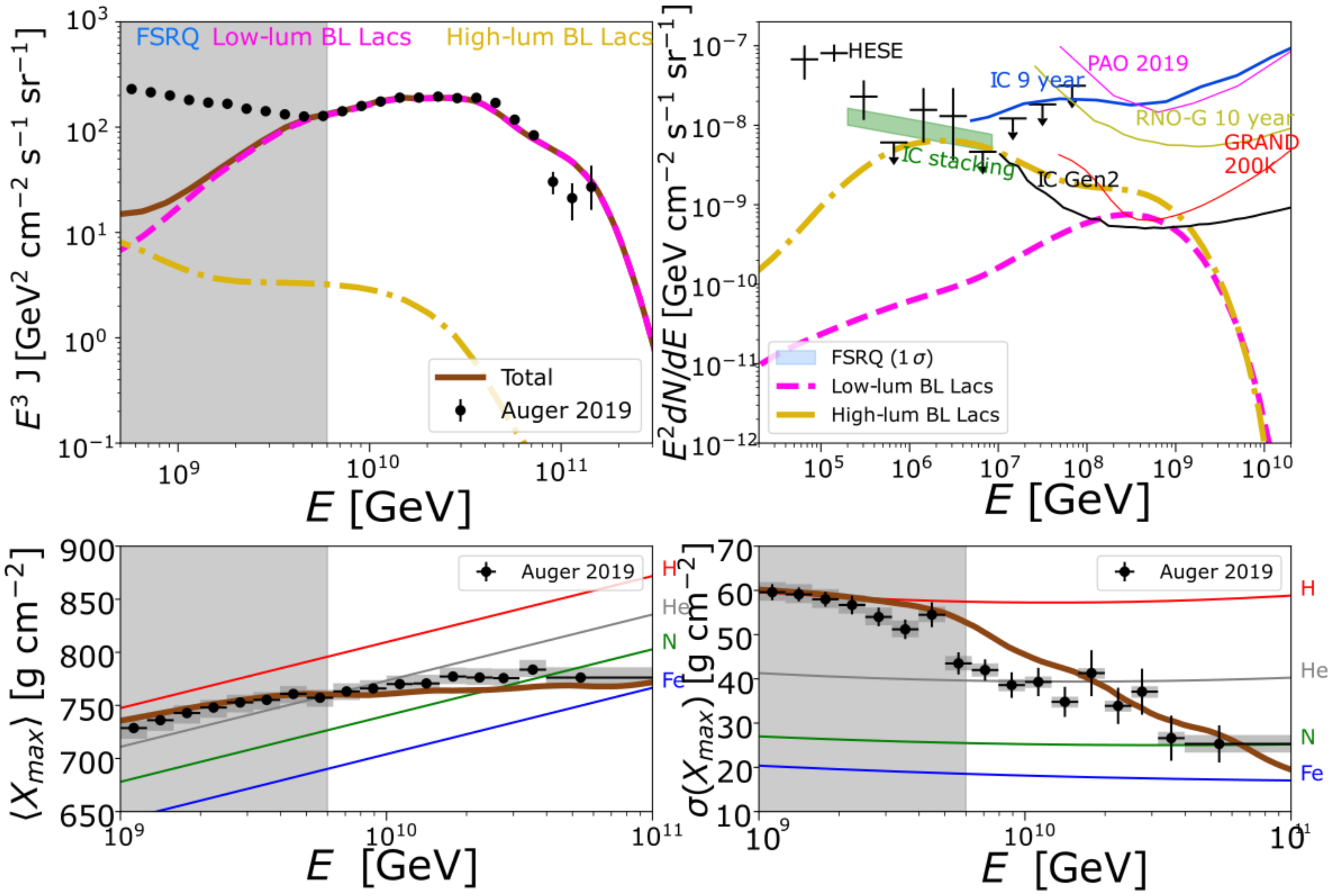
$$\chi^2/_{d.o.f.} \approx {}^{91.5}/_{25}$$

1. Results strongly depend on the air shower model.
2. Low-lum BL Lacs are the main source of UHECR (local sources)
3. FSRQs are excluded for both scenarios
4. The fits are not sensitive to some elements

Plotko P. et al. in preparation

Results

SIBYLL2.3d: best fit



1. Low-lum BL Lacs can explain UHECR data
2. Diffuse neutrinos from High-lum BL Lacs

Baryonic loading 32

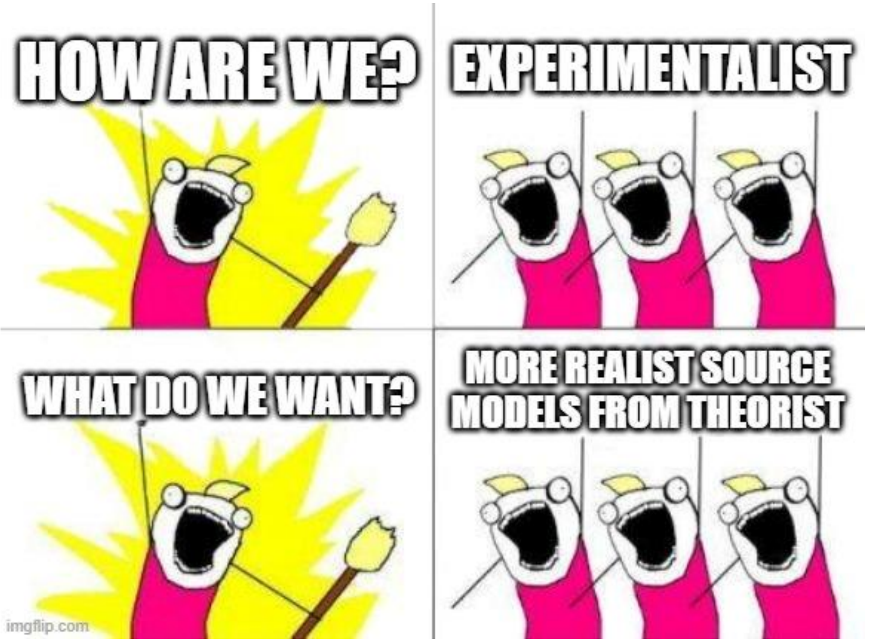
H: 7 %

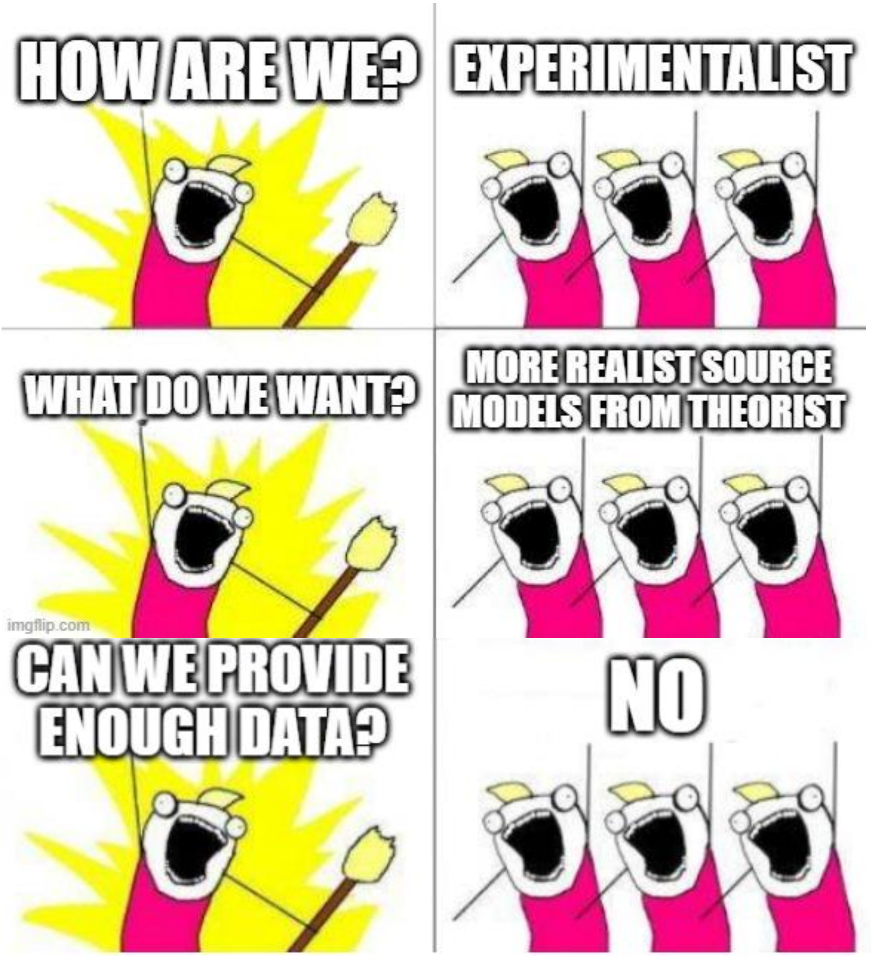
He: not sensitive

N: 83%

Fe: 10%

Take-home messages





Take-home messages

Jetted AGN can explain the UHECR data

Results strongly depend on air shower model

EPOS-LHC:

1. UHECR from Low- and High-lum BL Lacs
2. High neutrino flux

SIBYLL 2.3d:

1. UHECRs from Low-lum BL Lacs
2. Low neutrino flux

FSRQs are free source of neutrinos

I am looking for sponsors/support for Ukrainian Astronomy and Astrophysics projects

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