ID #658 | T01: Astroparticle and Gravitational Waves

Mass composition modeling at sources of ultra-high energy cosmic rays

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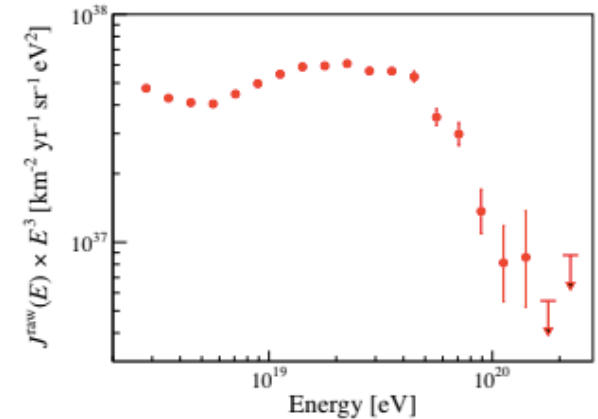Pontificia Universidad Católica del Perú

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Hypothesis:

astrophysical CR
sources accelerate
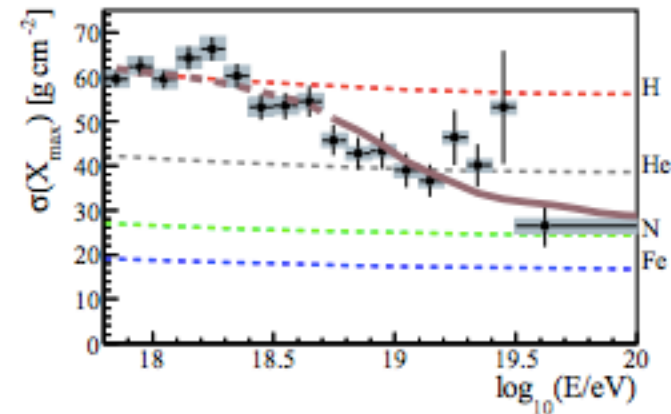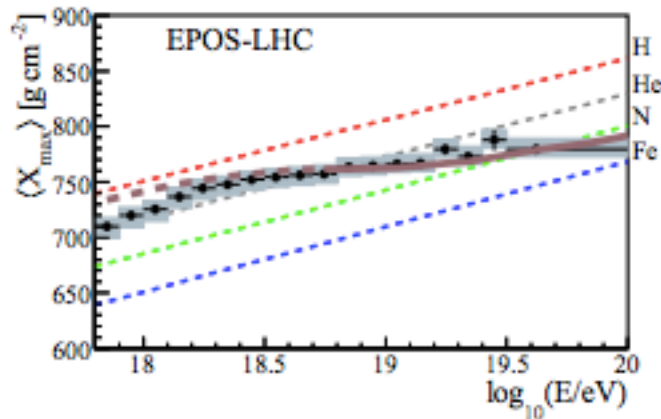different nuclei

Fit all-particle spectrum
above *ankle*

PAO: Phys. Rev. D 102, 062005 (2020)

PAO: arXiv:1612.07155

Evidence from PAO: X_{max} distribution (EPOS-LHC UHECR-air interactions)

Nuclear dependent broken exponential cut-off function: PAO: arXiv:1612.07155

$$\frac{dN_A}{dE} = \boxed{f_A} J_0 \left(\frac{E}{10^{18}\,eV}\right)^{\boxed{-\gamma}} \times f_{cut}(E, Z_A, R_{cut})$$

Cut-off function:

$$f_{cut}(E, Z_A, R_{cut}) = \begin{cases} 1 \ (E < Z_A R_{cut}) \\[2ex] \exp\left(1 - \dfrac{E}{Z_A \boxed{R_{cut}}}\right) (E > Z_A R_{cut}) \end{cases}$$

6 **Parameters** to fit (common to all sources):

- f_A: injected nucleus fraction

- R_{cut}: maximum rigidity

- γ: power law index

Input nuclei:

^{1}H, ^{4}He, ^{14}N, ^{28}Si, ^{56}Fe

Selection:

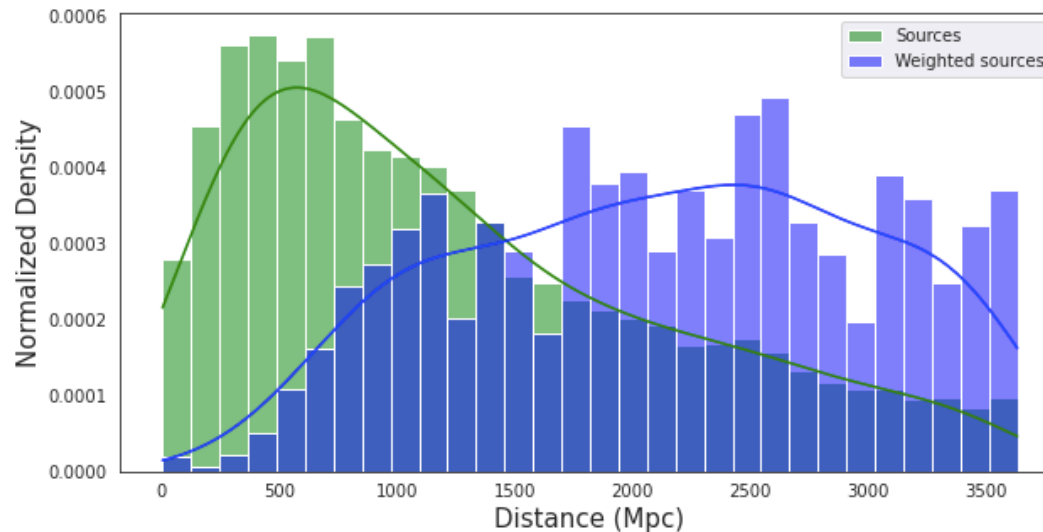Véron-Cetty, Véron(VCV) AGN catalogue 13th Ed (2010)
-redshift: **z < 0.6**

      -> conversion to Mpc: astropy.coordinates.Distance(Planck18)

Total selected sources: 29.5k

- Grouped by same distance (~442)
- Weighted by total flux by distance (F_{20cm} Jy)

Simulation characteristics:

- 1D (next step 3D with magnetic fields)
- E_{min} = 1 EeV
- SourceList, SourceMultipleParticleTypes

Event generation method:

For values taken from a PDF of distances weighted with radio flux:
-Randomly generate 10k energies from a broken exponential cut-off distribution and apply a nucleus fraction (f_A) weight to each nuclei.

Using this larger distance-energy distribution:
Simulate 750k events for each set of parameters: best fit search.

Interactions during propagation:

- PhotoPionProduction (CMB, IRB)
- ElectronPairProduction (CMB, IRB)
- PhotoDisintegration (CMB, IRB)
- NuclearDecay

*IRB=Gilmore12

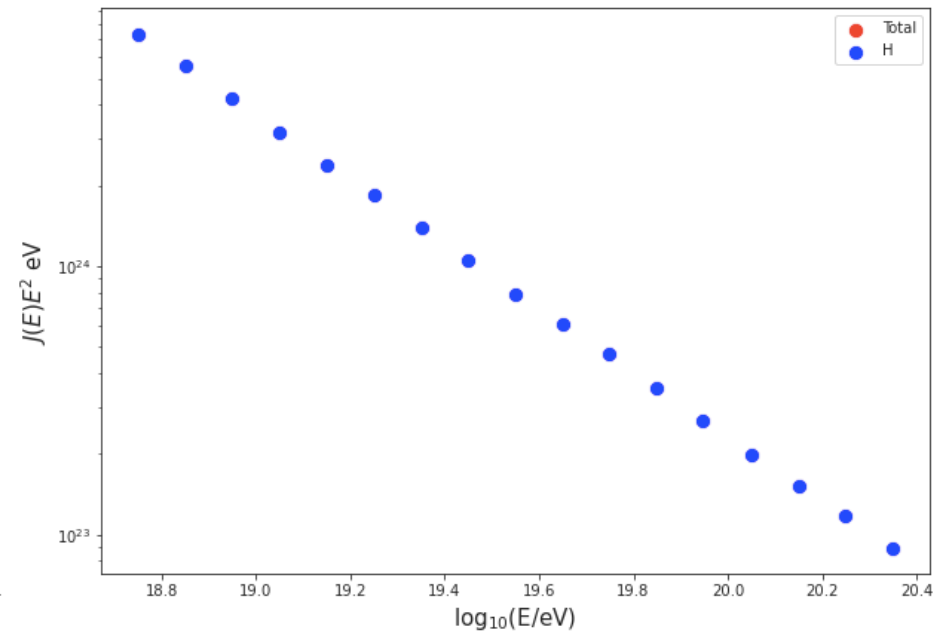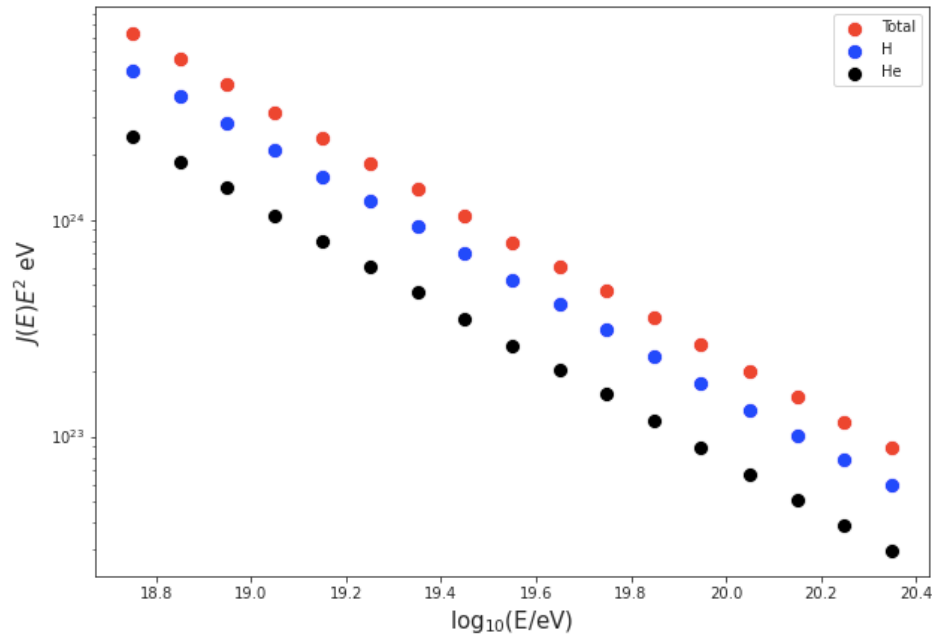For curve shape distribution comparison (normalized with N_{tot} at Earth) and few events in some bins:

$$\chi^2 = \sum_{E-bin} \frac{\left(\dfrac{N_i^{PAO}}{N_{tot}^{PAO}} - \dfrac{N_i^{sim}}{N_{tot}^{sim}} \right)^2}{\dfrac{N_i^{PAO}}{N_{tot}^{PAO^2}} - \dfrac{N_i^{sim}}{N_{tot}^{sim^2}}}$$

PAO: energy bins
$E > 10^{18.7}$ eV

Look for minimum for set of 6 parameters (720 combinations):

- f_A: [0,1] step=1/3 (5 points x 4 independent variables)

- R_{cut}: [10^{18}, 10^{21}] step=$10^{0.6}$ (6 points)
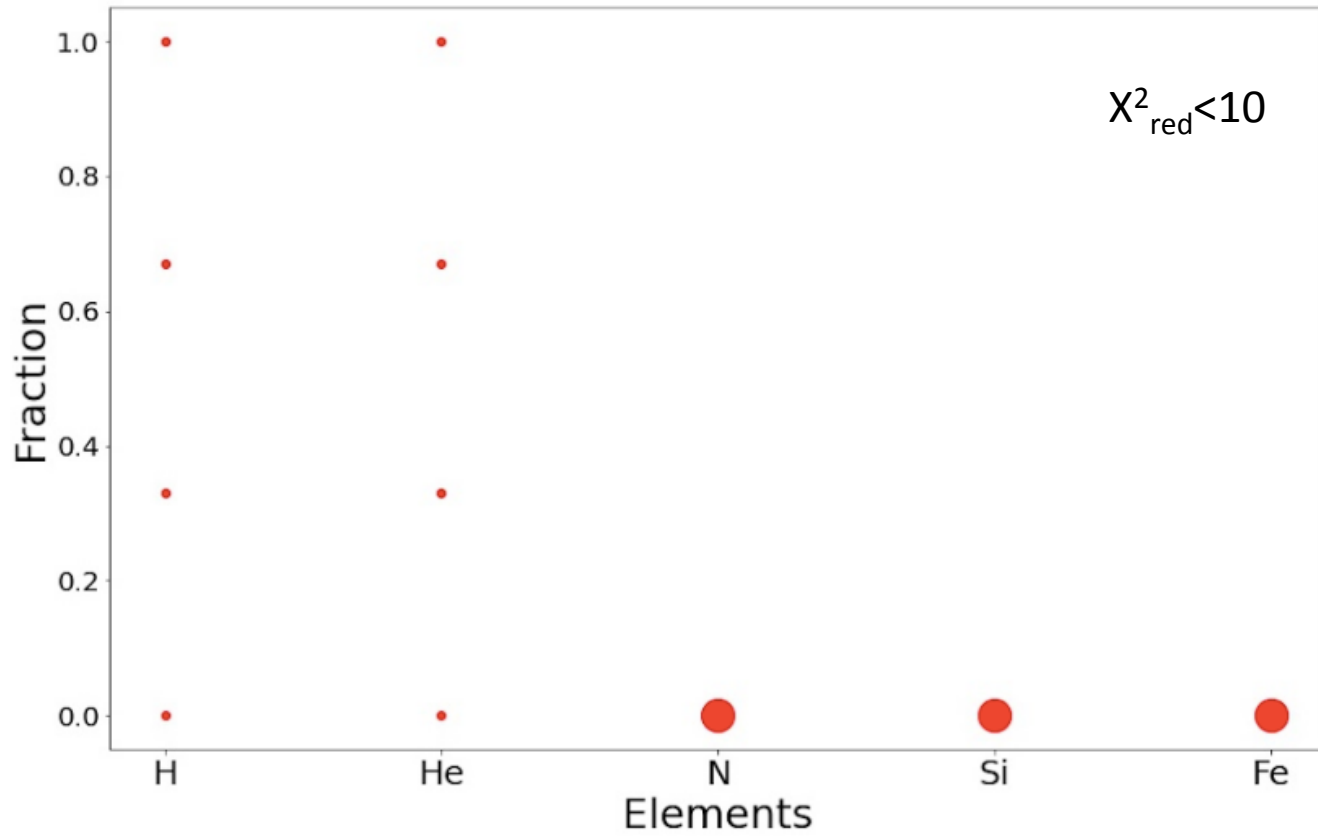
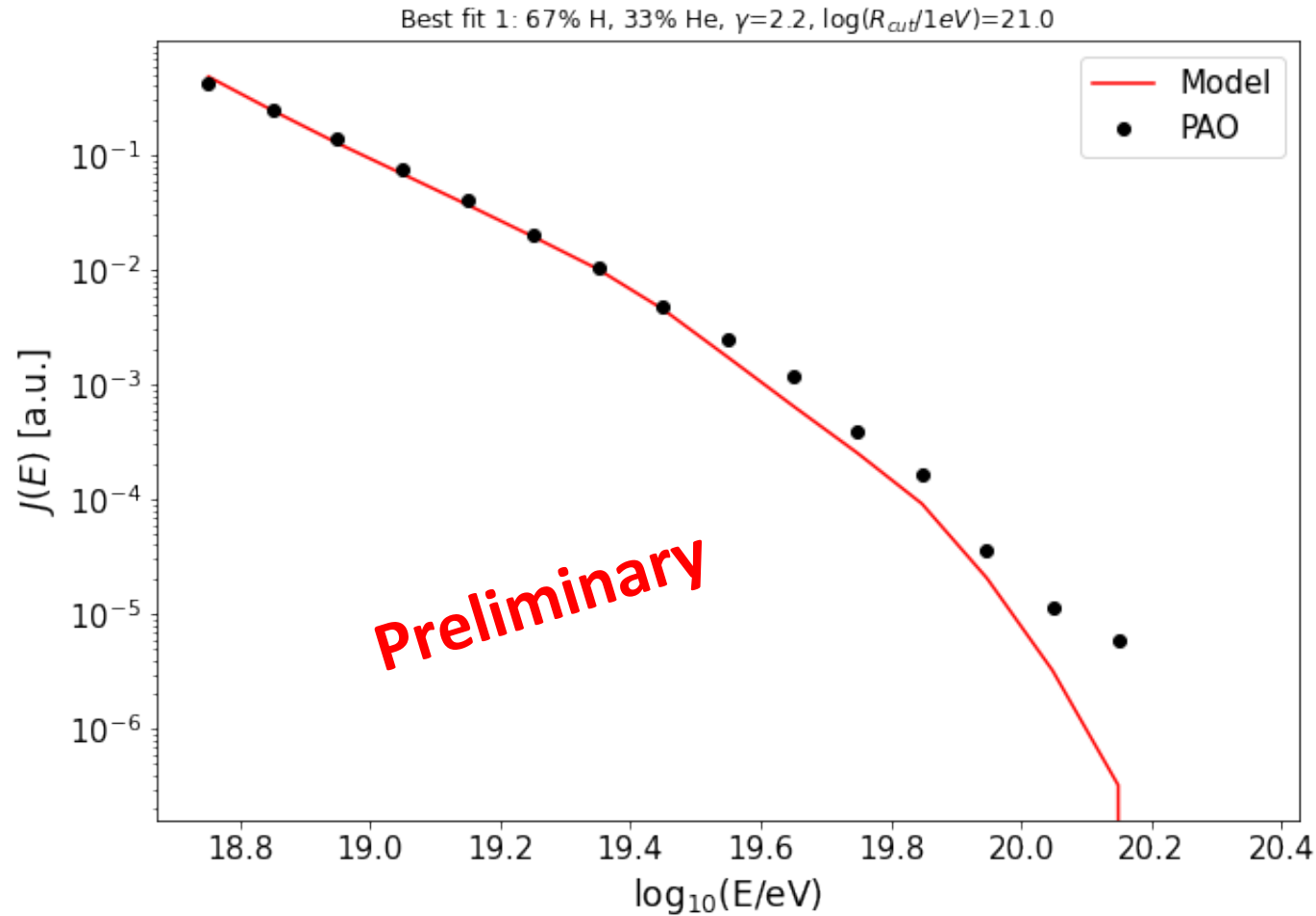- γ: [1, 3] step=0.4 (6 points)

Best fits: γ = 2.2

Best fits fractions

$X^2_{red} < 10$

Best fit 1: 67% H, 33% He, $\gamma=2.2$, $\log(R_{cut}/1eV)=21.0$

Best Parameters

γ	R$_{cut}$	H	He	N	Si	Fe	χ^2
2.2	21	0.67	0.33	0	0	0	28.37
2.2	20.4	1	0	0	0	0	38.43
1.8	20.4	0.33	0.67	0	0	0	44.79
1.8	19.8	1	0	0	0	0	46.92
1.8	21	0.33	0.67	0	0	0	49.5
1.8	20.4	0	1	0	0	0	52.6
1.8	19.8	0.67	0.33	0	0	0	53.7
1.8	21	0	1	0	0	0	53.74
1.8	20.4	0.67	0.33	0	0	0	75.01
2.2	21	1	0	0	0	0	75.25

- CR-Propa simulations of astrophysical sources with precise 1D distance distributions (radio weighted AGNs)

- Broken exponential cutoff fit with 6 parameters common to all sources.

- Favoured mass composition at source that fits PAO data (E>$10^{18.7}$ eV):

  ➢ **Heavier nuclei disfavoured**: Si ≈ Fe ≈ 0
  ➢ Lighter nuclei: **H and He greatest contributions**, small N composition

  ➢ Power law index ≈ 1.9 ± 0.2
  ➢ Log(Rigidity cutoff/eV) ≈ 20.1 ± 0.4

❑ **Plans**:

  - 3D simulations with galactic and extragalactic magnetic fields.
  - Use radio bright AGN catalogue with neutrino correlations.