UHECR spectrum and composition in two-population model

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Objectives

The mass composition of UHECRs ($E \gtrsim 0.1$ EeV) is not well known due to uncertainties in hadronic interaction models

- Mixed composition of light-to-heavy nuclei fits the UHECR spectrum & composition, but the $\langle X_{\rm max} \rangle$ fit can be improved further
- We add another light nuclei component (^{1}H) from a discrete source population extending up to the highest energies [1]
- We constrain the maximum allowed proton fraction at the highest-energy bin at 3.5σ statistical significance
- We also present the secondary neutrino flux in one- and two-population models, constraining the composition at highest energies

Methods

1. UHECRs induce extensive air shower (EAS) in the atmosphere, which is reconstructed to measure the maximum shower-depth profile ($X_{\rm max}$)
2. We use parametrizations by PAO to calculate $\langle X_{\rm max} \rangle$ and its dispersion $\sigma(X_{\rm max})$ from the first two moments of $\ln A$
3. Updated parameter values (S. Petrera and F. Salamida (2018), PAO) from CONEX simulations is used for post-LHC model SYBILL2.3c
4. We consider that all elements are injected by the sources following the spectrum given as

$$\frac{dN}{dE} = A_0 \sum_i K_i \left(\frac{E}{E_0}\right)^{-\alpha} \times \begin{cases} 1 & (E \leqslant ZR_{\rm cut}) \\ \exp\left(1 - \dfrac{E}{ZR_{\rm cut}}\right) & (E > ZR_{\rm cut}) \end{cases} \quad (1)$$

5. `Cls-I` injecting ^{1}H has a distinct $R_{\rm cut,1}$ and α_1 ($2.2 < \alpha_1 < 2.6$); the normalization is fixed by proton fraction in highest-energy bin ($f_{\rm H}$)
6. `Cls-II` injects He, N, Si, and Fe ($\sum_i K_i = 100\%$); contribution from both population is used to calculate best-fit

Results

1. A combined fit of spectrum and composition measured by PAO [2, 3] is performed above the ankle $E \gtrsim 5 \cdot 10^{18}$ eV
2. We calculate best-fit values of $\log_{10}(R_{\rm cut,1}/{\rm V})$, $\log_{10}(R_{\rm cut,2}/{\rm V})$, α_2, and composition K_i for each combination of $\{\alpha_1, f_{\rm H}\}$

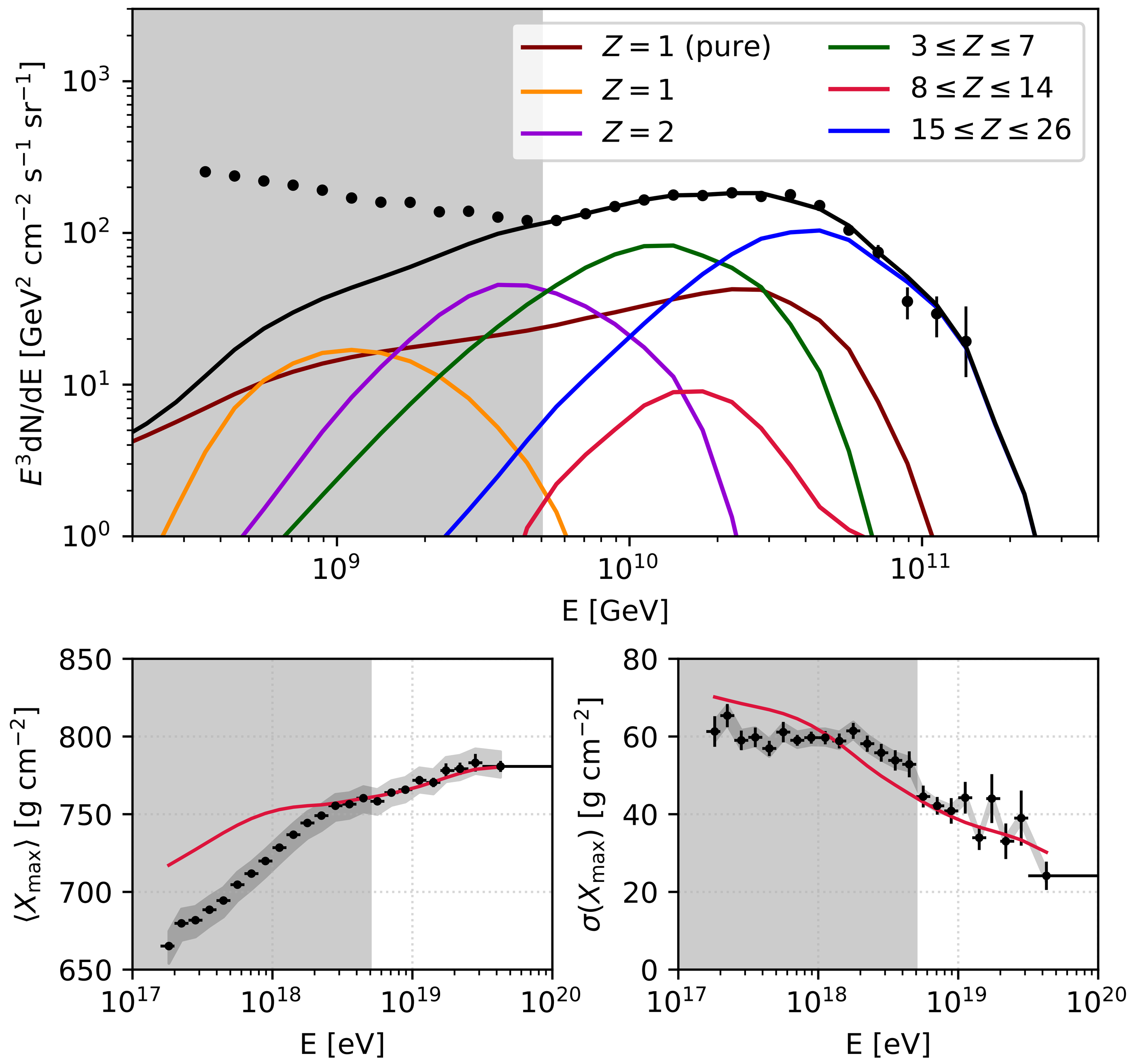

Figure 1: Best-fit spectrum+composition in two-population case ($\alpha_1 = 2.2$, $f_{\rm H} = 1.5\%$)

1. The pure-proton component favors higher values of cutoff rigidity than `Cls-II` and steeper injection spectral index
2. The shaded region corresponds to the allowed range of neutrino flux from `Cls-I` and `Cls-II` for $f_{\rm H} = 1.0 - 20.0\%$
3. With increase in exposure time, GRAND should constrain our two-population model parameters if $f_H \gtrsim 10\%$

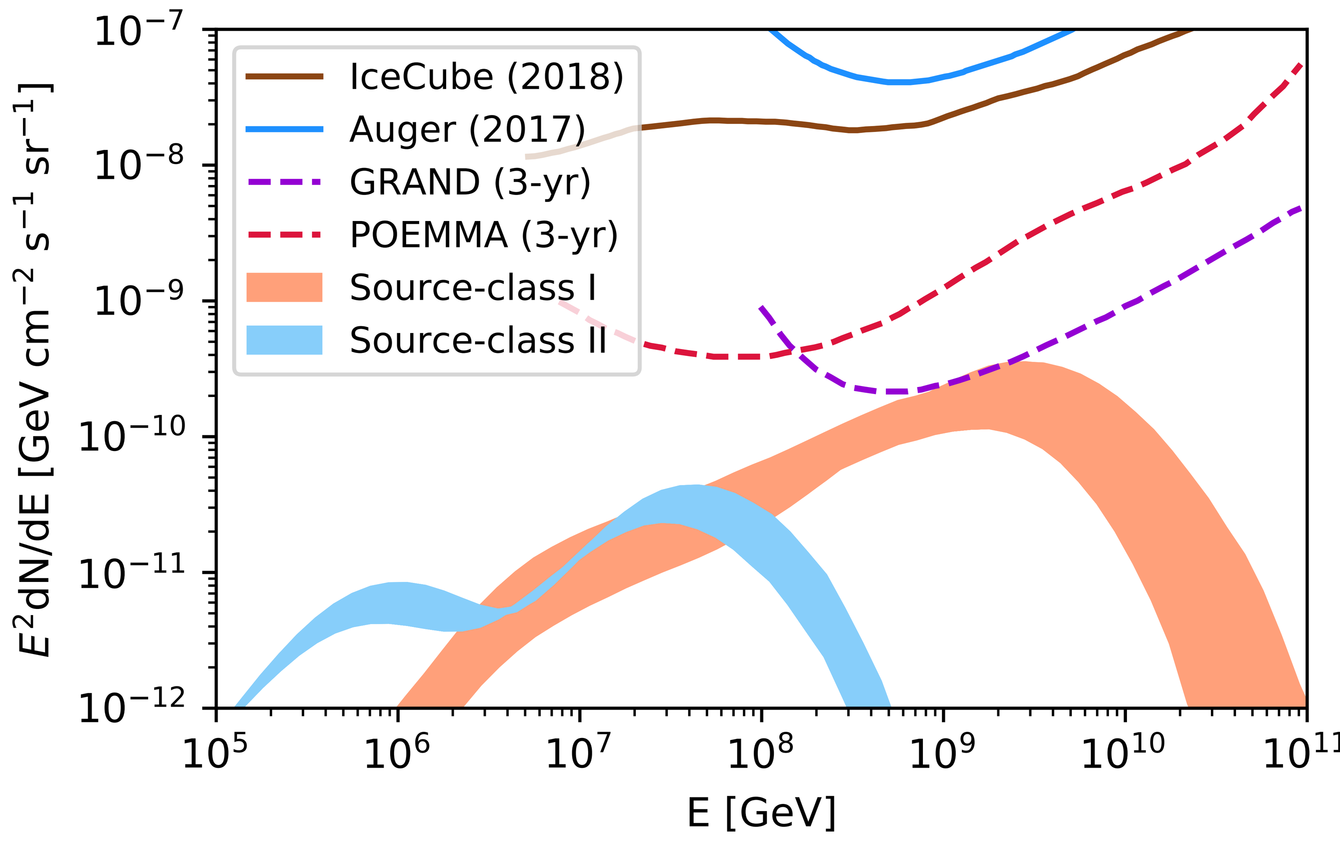

Figure 2: Cosmogenic neutrino flux from `Cls-I` and `Cls-II` in two-population model

Conclusions

1. We estimate the maximum allowed proton fraction at 3.5σ confidence level (C.L.) in the highest-energy bin. For $\alpha_1 = 2.2$, 2.4, and 2.6 this corresponds to $\approx 12.5\%$, 15%, and 17.5% respectively
2. Here, both H and Fe contributes at the cutoff region. Thus, pion production is responsible for cutoff in H ($\log_{10}(R_{\rm cut,1}/{\rm V}) = 19.5$)and maxm rigidity at the source for `Cls-II` ($\log_{10}(R_{\rm cut,2}/{\rm V}) = 18.3$)
3. Including $(1+z)^m$ redshift evolution indicates luminous AGNs or GRBs as candidates for `Cls-I` ($m_1 = +3$) and tidal disruption events (TDEs) as the candidates for `Cls-II` ($m_2 = -6$)

References

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