Constraining the origin of UHECRs and astrophysical neutrinos

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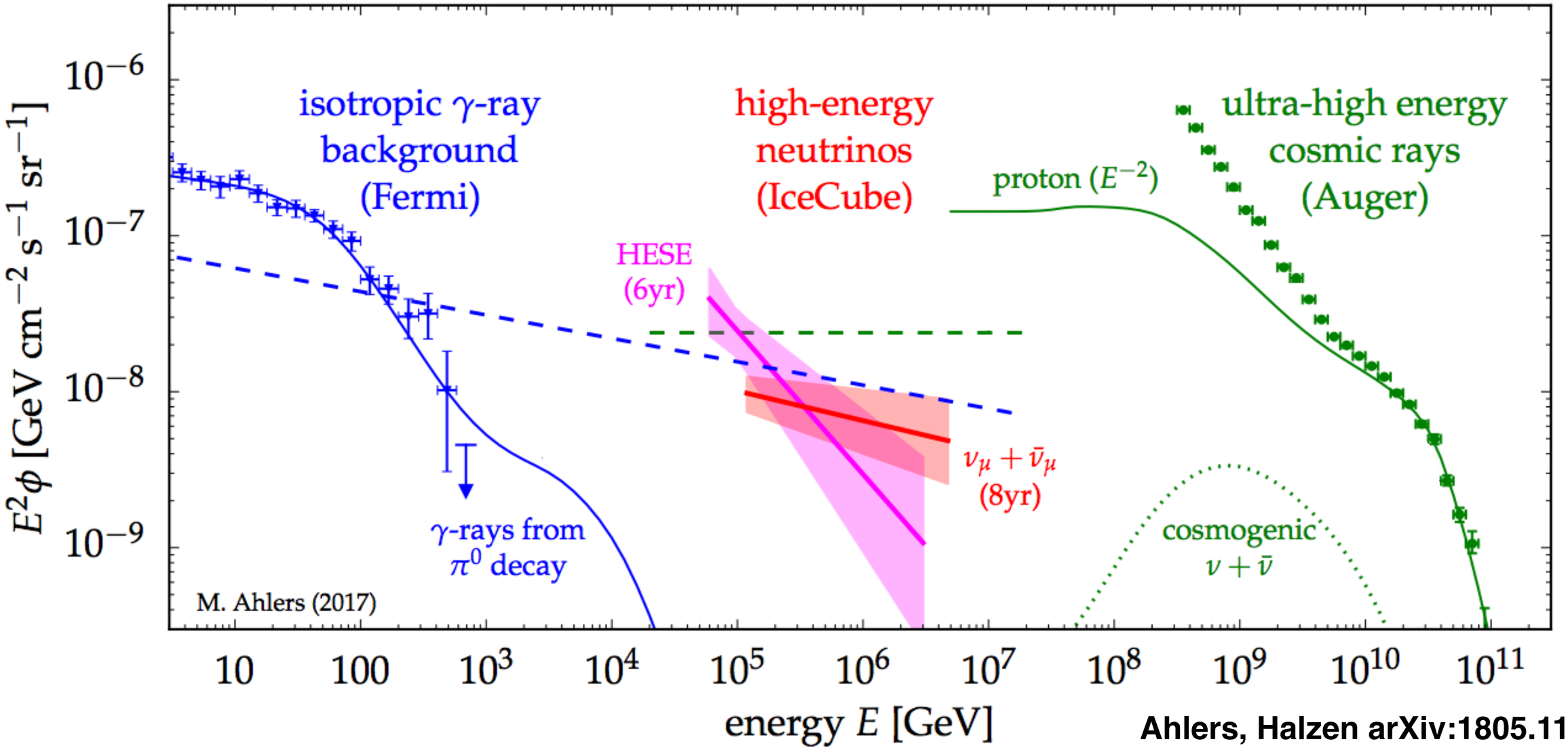
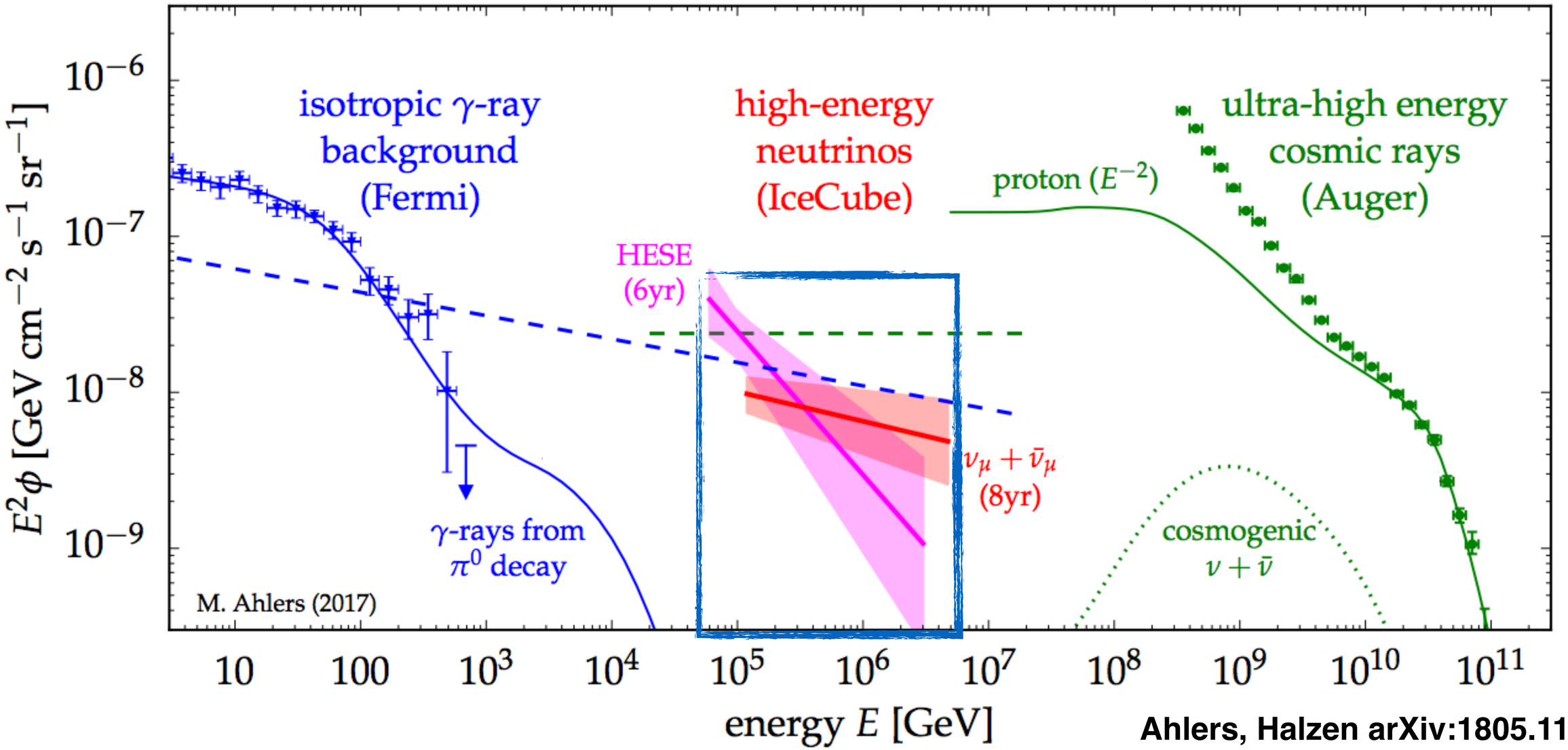


Ahlers, Halzen arXiv:1805.11112

Could astrophysical neutrinos have common origin with UHECRs?



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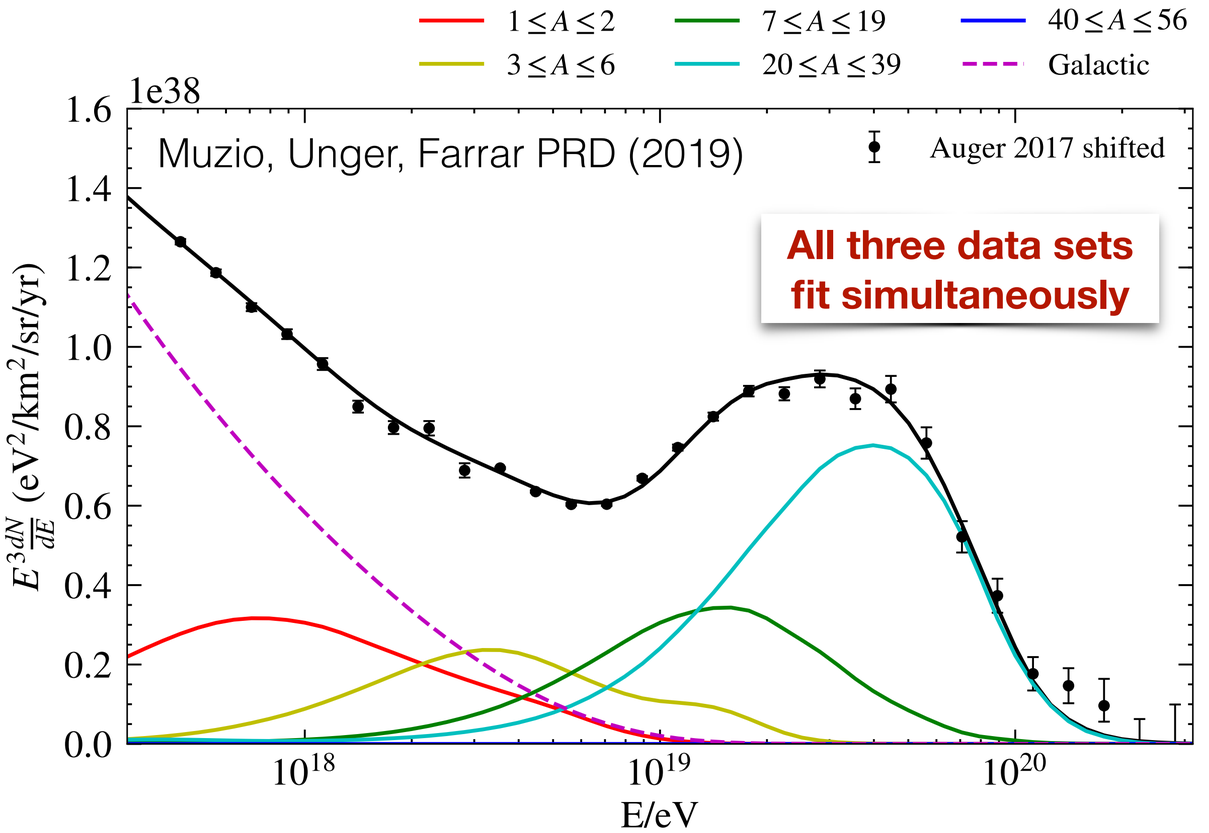
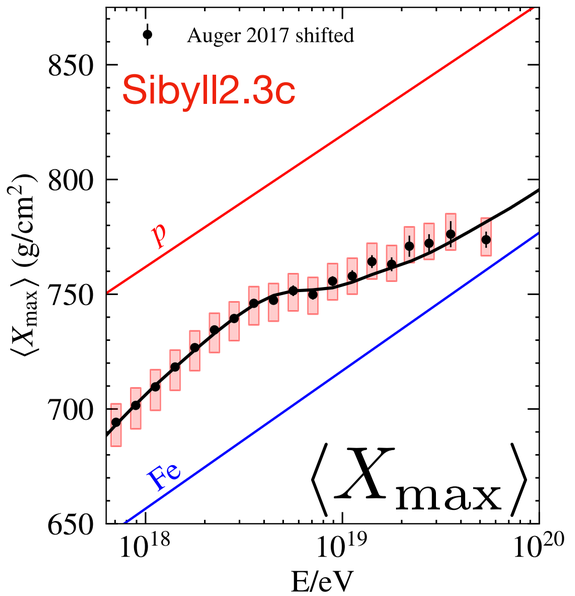
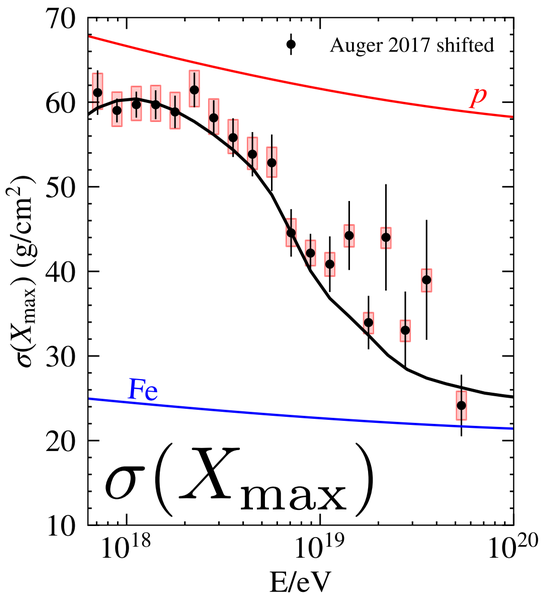
CR Source Model

- Unger-Farrar-Anchordoqui model (UFA, 2015 PRD):
  1. Inject CRs into source environment
  2. **CRs processed by *photon* interactions**
  3. CRs escape source environment
  4. CRs propagate to Earth
- Accounts for observed spectrum (>$10^{17.5}$ eV) & composition (>$10^{17.8}$ eV)

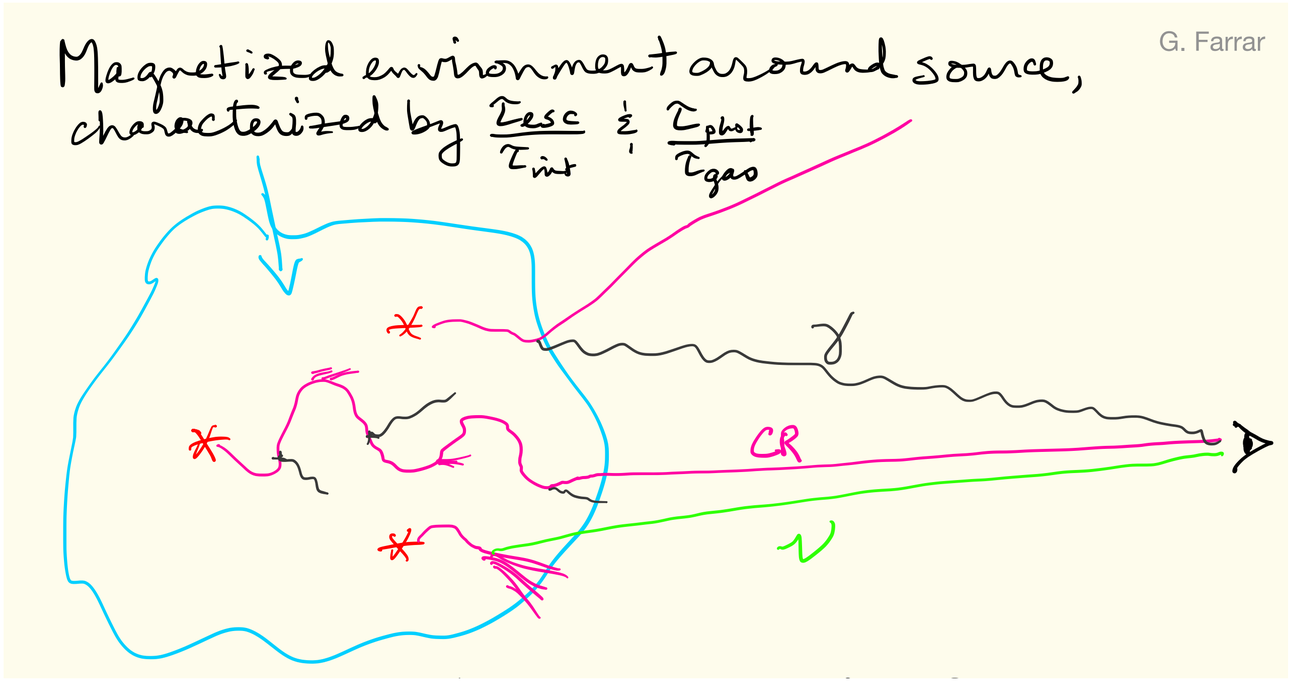






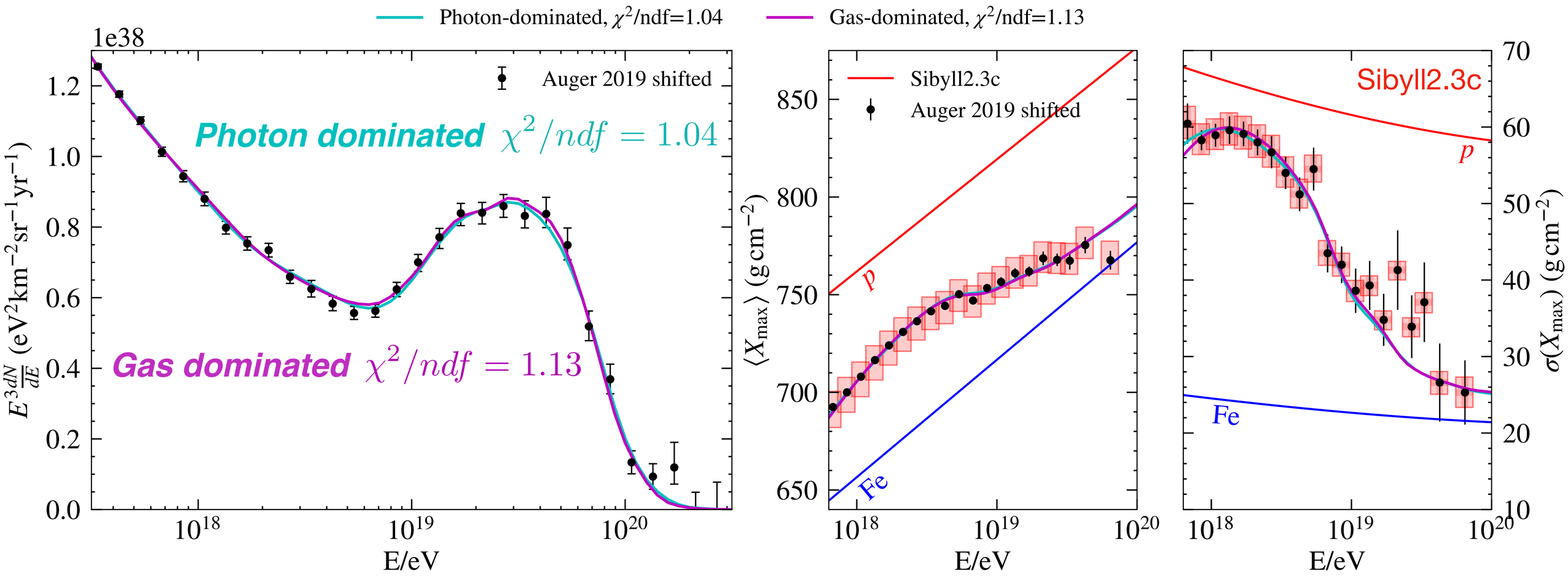
Elaborations to UFA

- **Addition of gas in source** environment (single zone) — hadronic interactions
  - Calculated interaction matrices with CRMC using Sibyll2.3c and EPOS-LHC
- **Realistic rigidity-dependent escape time**, allowing for transition between diffusive, Bohm, & quasi-ballistic propagation regimes and reflecting finite source size



- Model doesn't rely on specific astrophysical model
- Model parameters **(10 EeV Fe-56 as the reference)**
  - Average # interactions (10 EeV ^{56}Fe) $\langle N_{\rm int} \rangle$
  - Ratio of photon-to-gas interactions (10 EeV ^{56}Fe) $\frac{\langle N^{\gamma}_{\rm int} \rangle}{\langle N^{p}_{\rm int} \rangle}$
- Preferred astrophysical properties constrained by model parameters

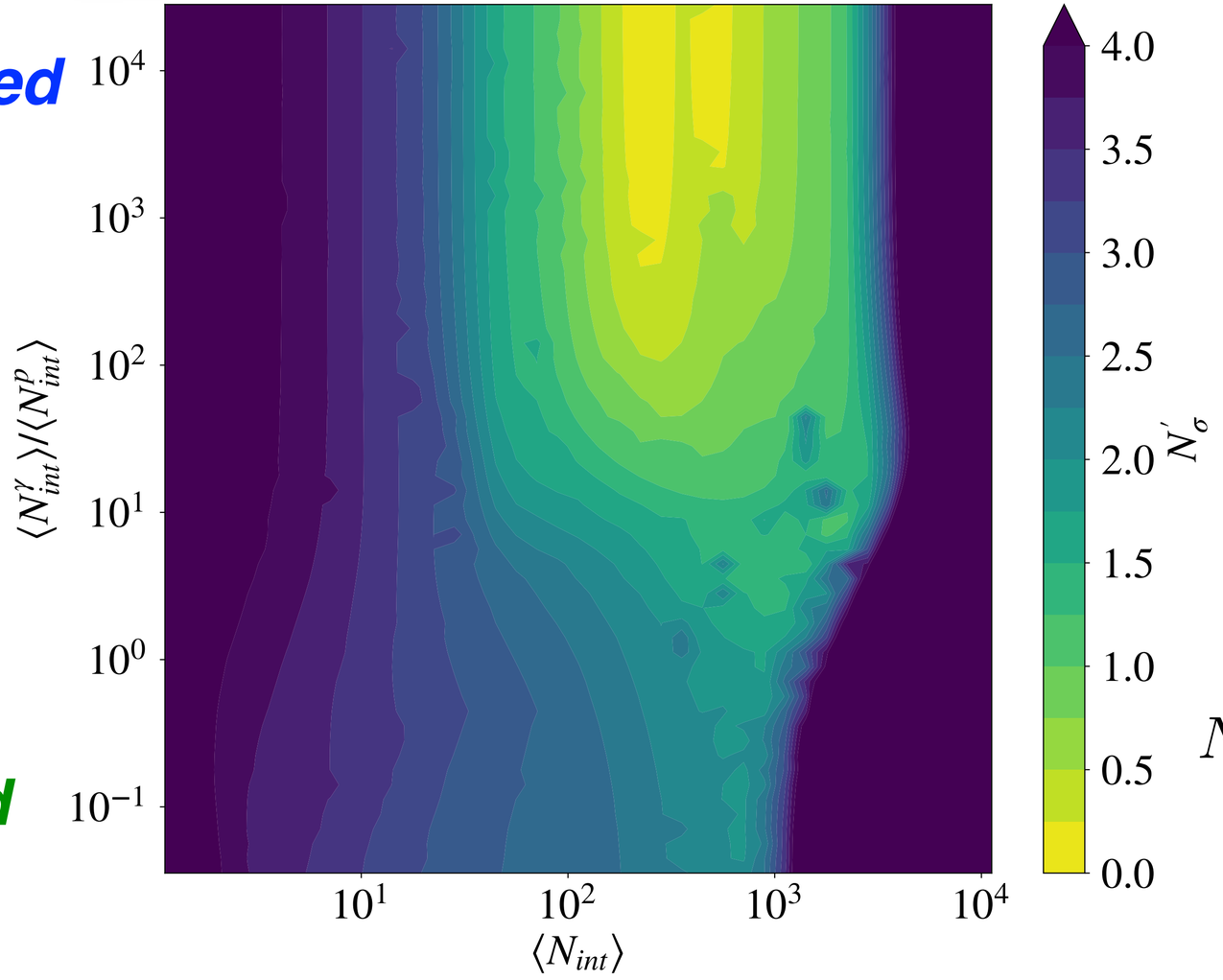
Both gas- and photon-dominated sources can give good fits to CR data



CRs: Slight preference for photon-dominated sources

Photon dominated

Gas dominated

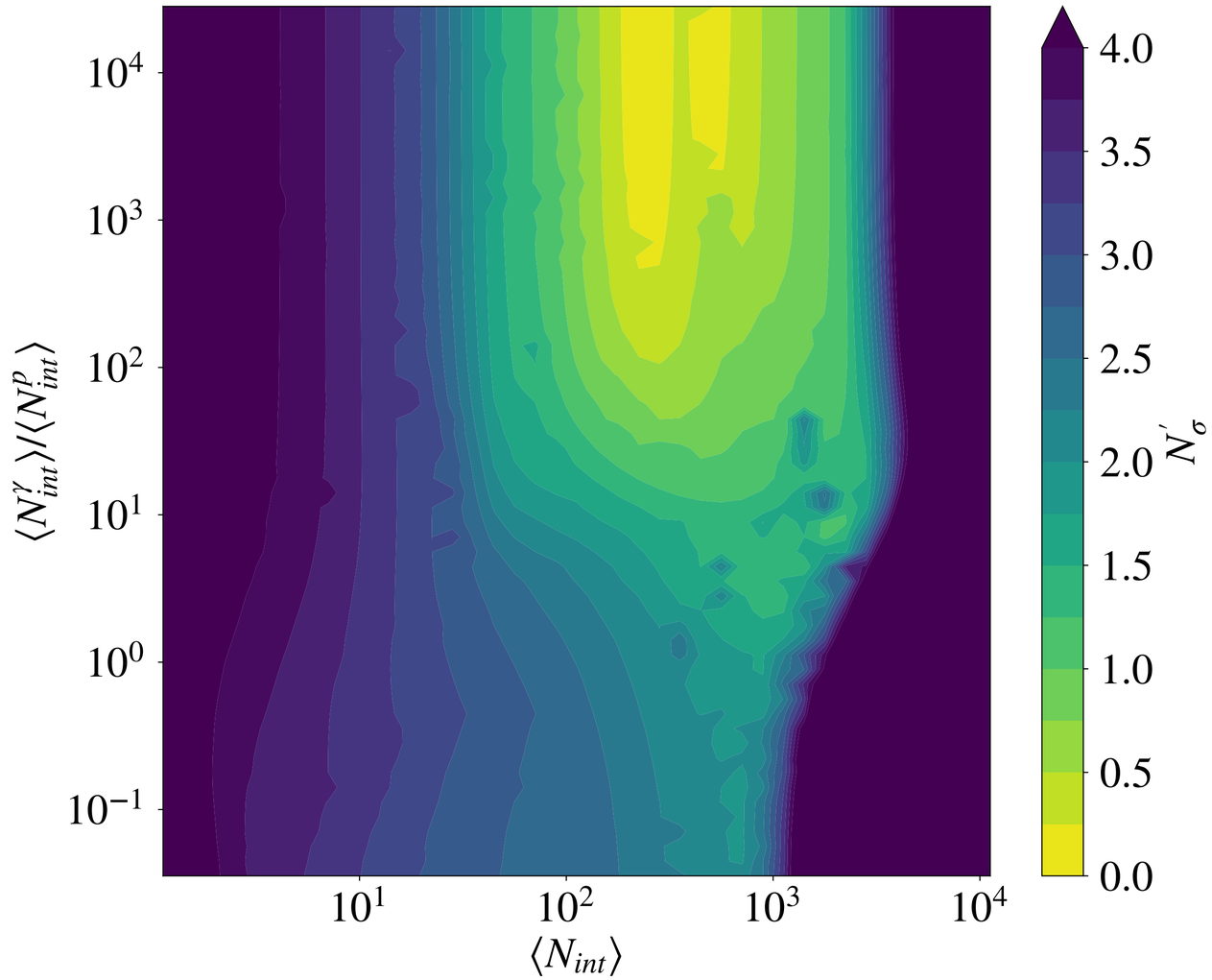


Photon-dominated sources less constrained

$$N'_{\sigma} = \sqrt{N_{dof} \frac{(\chi^2 - \chi^2_{\rm min})}{\chi^2_{\rm min}}}$$

Average number of interactions (10 EeV ^{56}Fe)

Multimessenger Constraints



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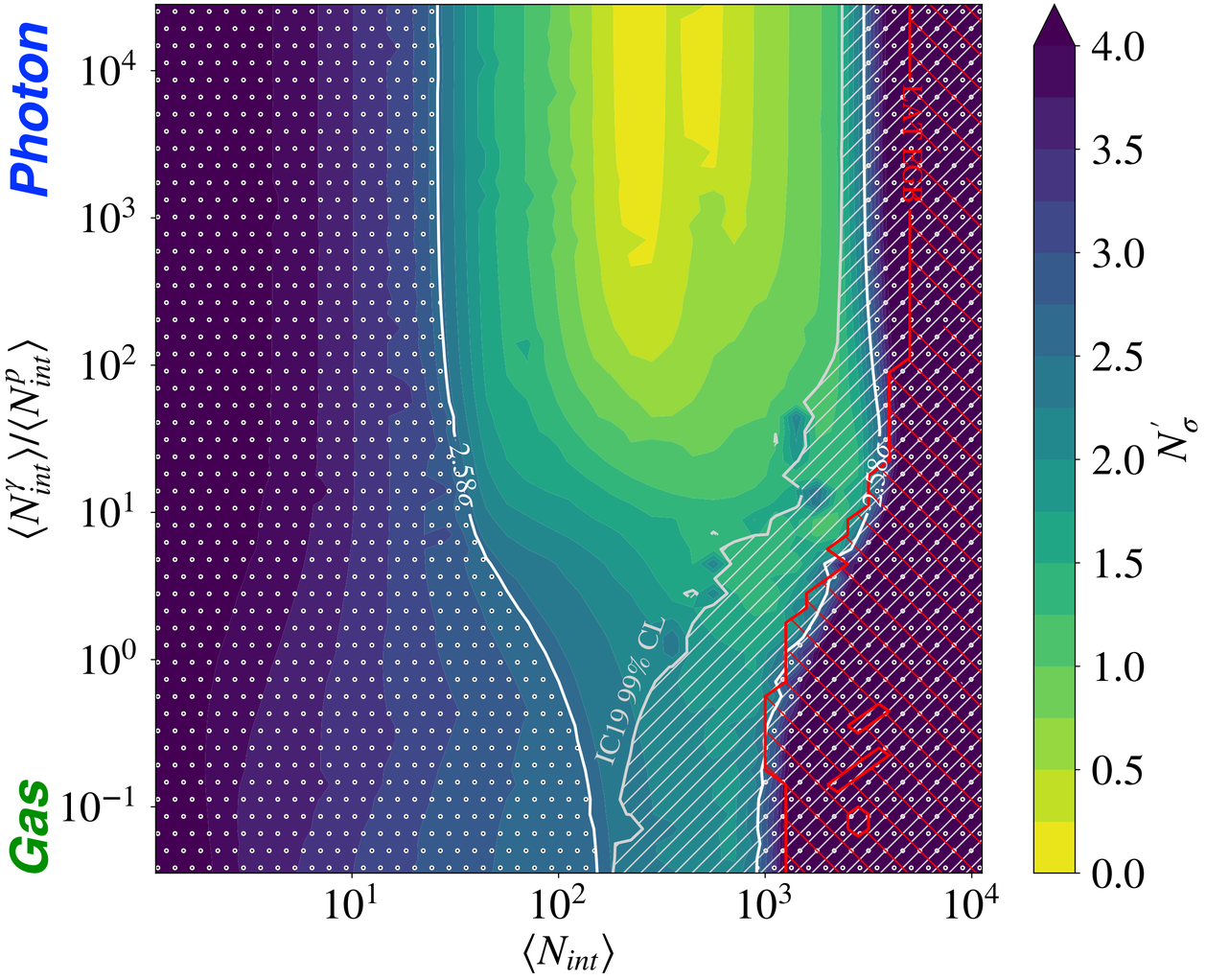

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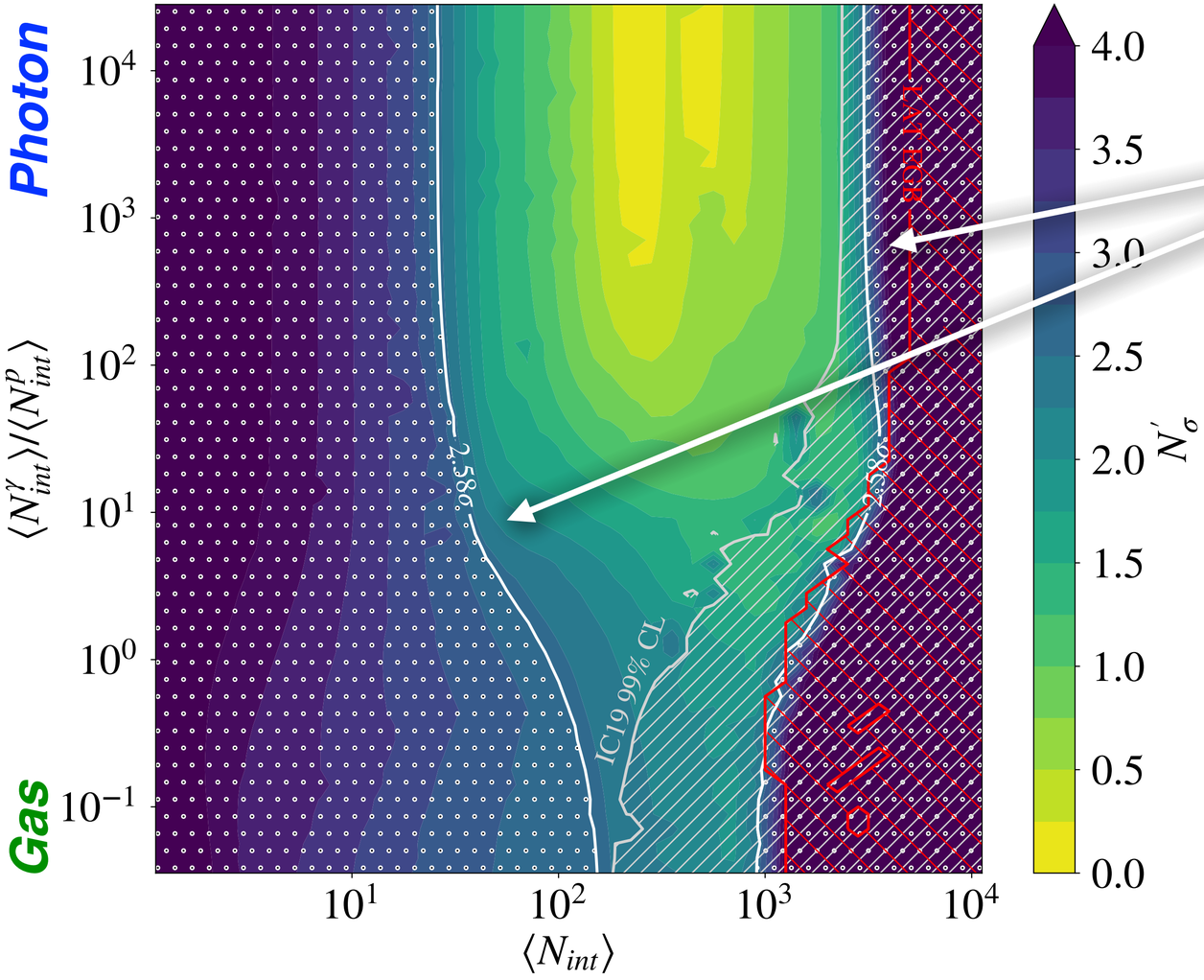
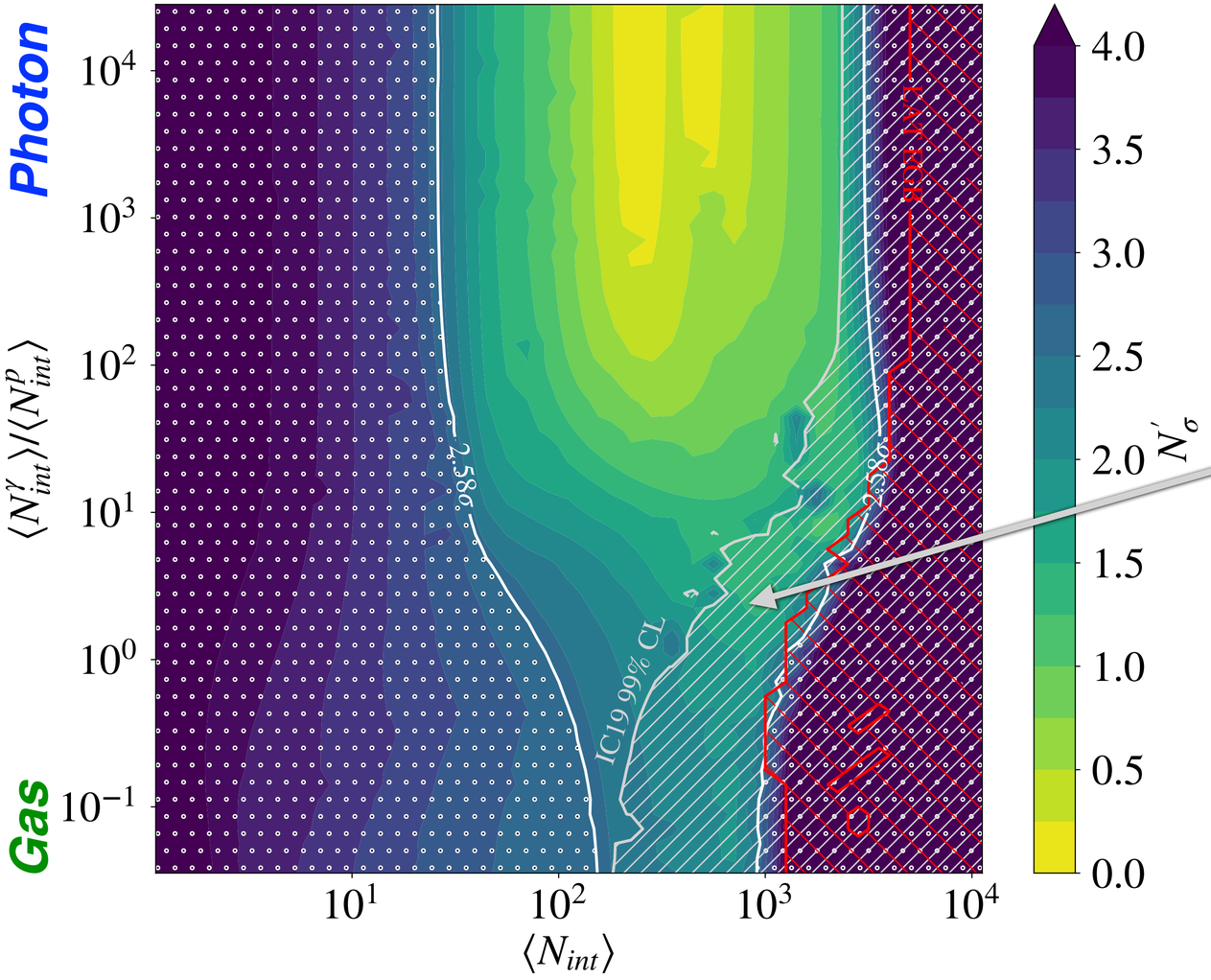


$N_\sigma > 2.58$ **UHECR Constraint**

Multimessenger Constraints



$N_{\sigma} > 2.58$ **UHECR Constraint**

$N_{\nu}^{\mathrm{EHE}} > 4.74$ **EHE ν Constraint**

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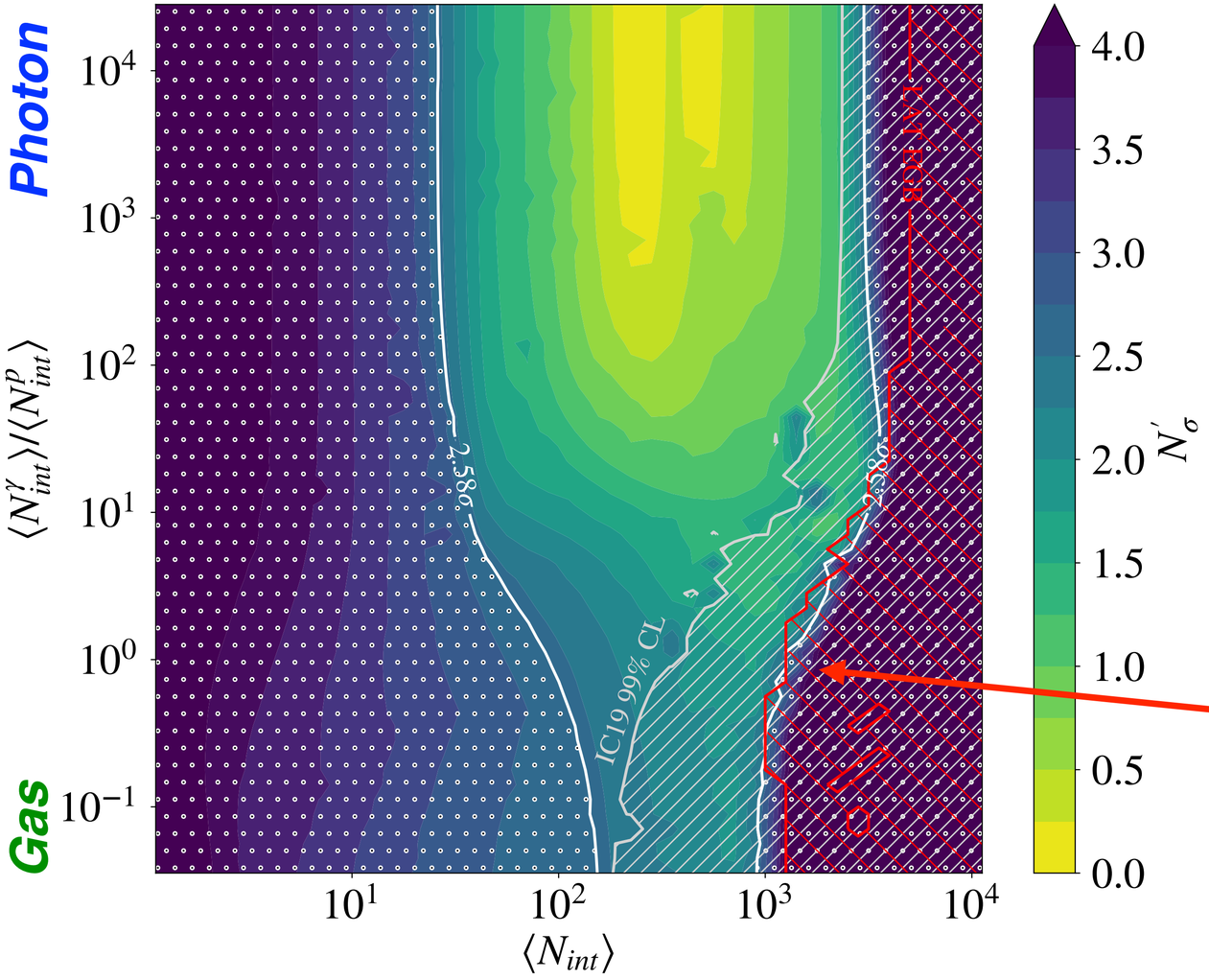

$N_\sigma > 2.58$ **UHECR Constraint**

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γ-ray flux > EGB + 1σ
(always weaker than ν-bound)

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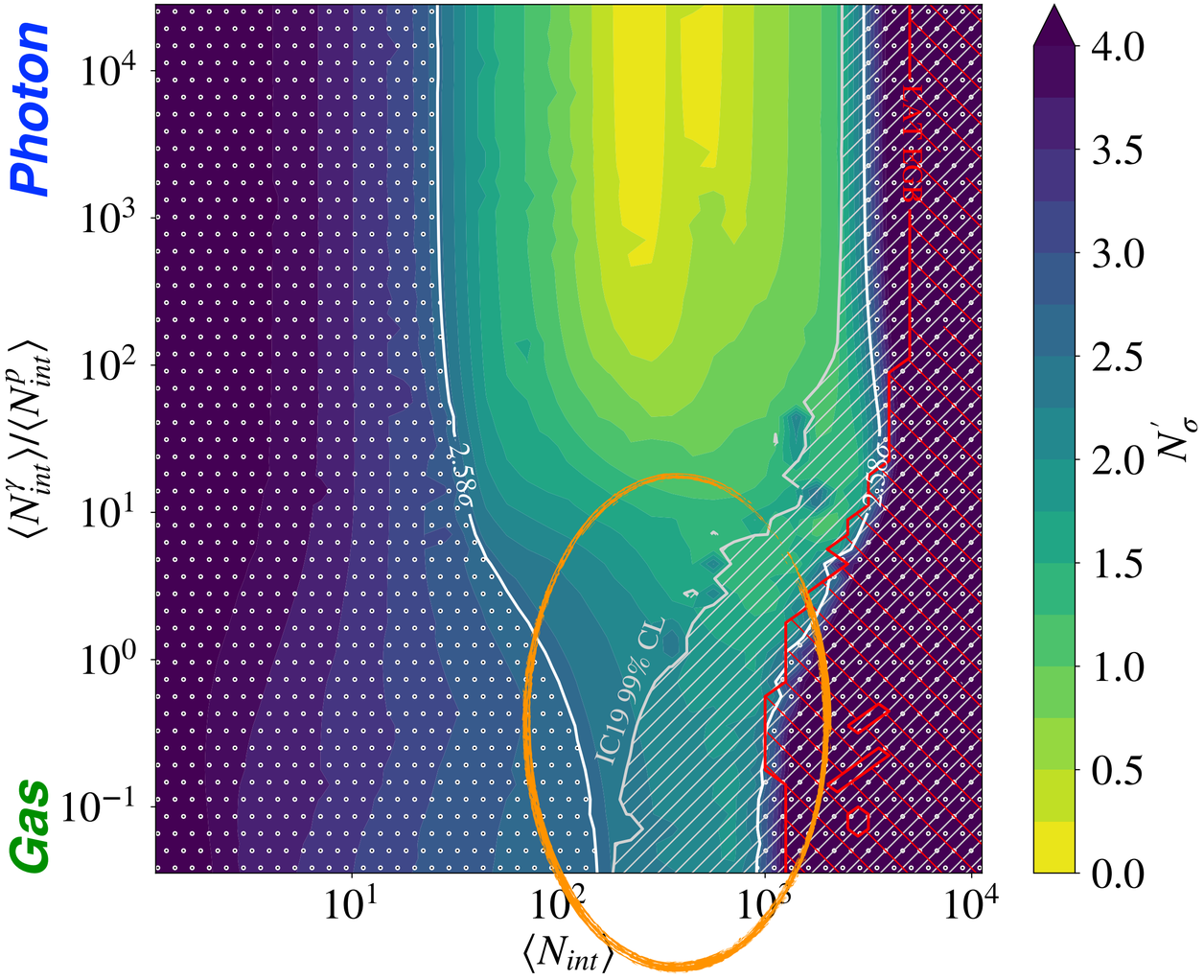
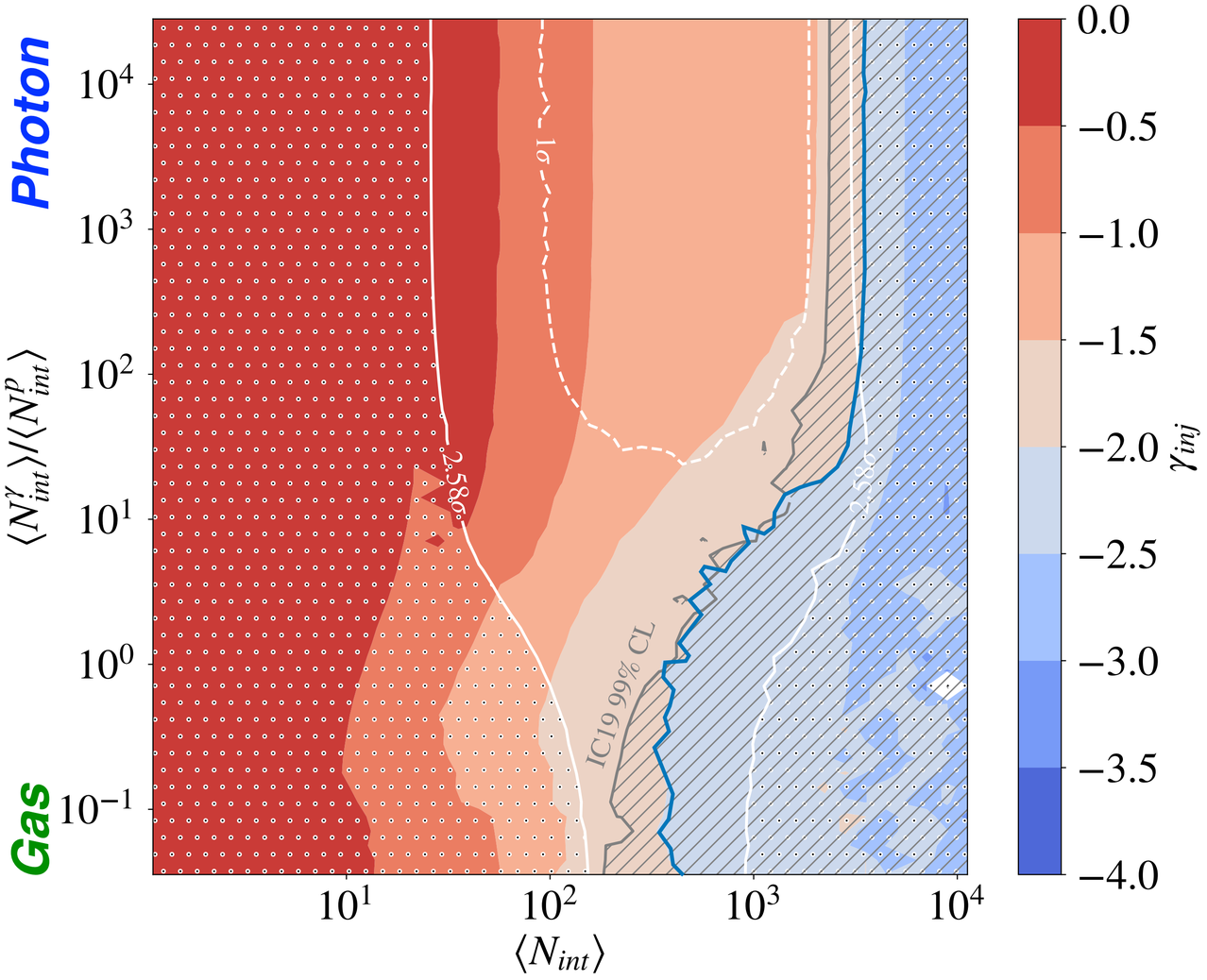


$N_\sigma > 2.58$ **UHECR Constraint**

Gas-dominated sources in tension with EHE neutrino constraints

γ-ray flux > EGB + 1σ
(always weaker than ν-bound)

Spectral Index of UHECR Accelerator



$$J \sim E^{\gamma_{\rm inj}}$$

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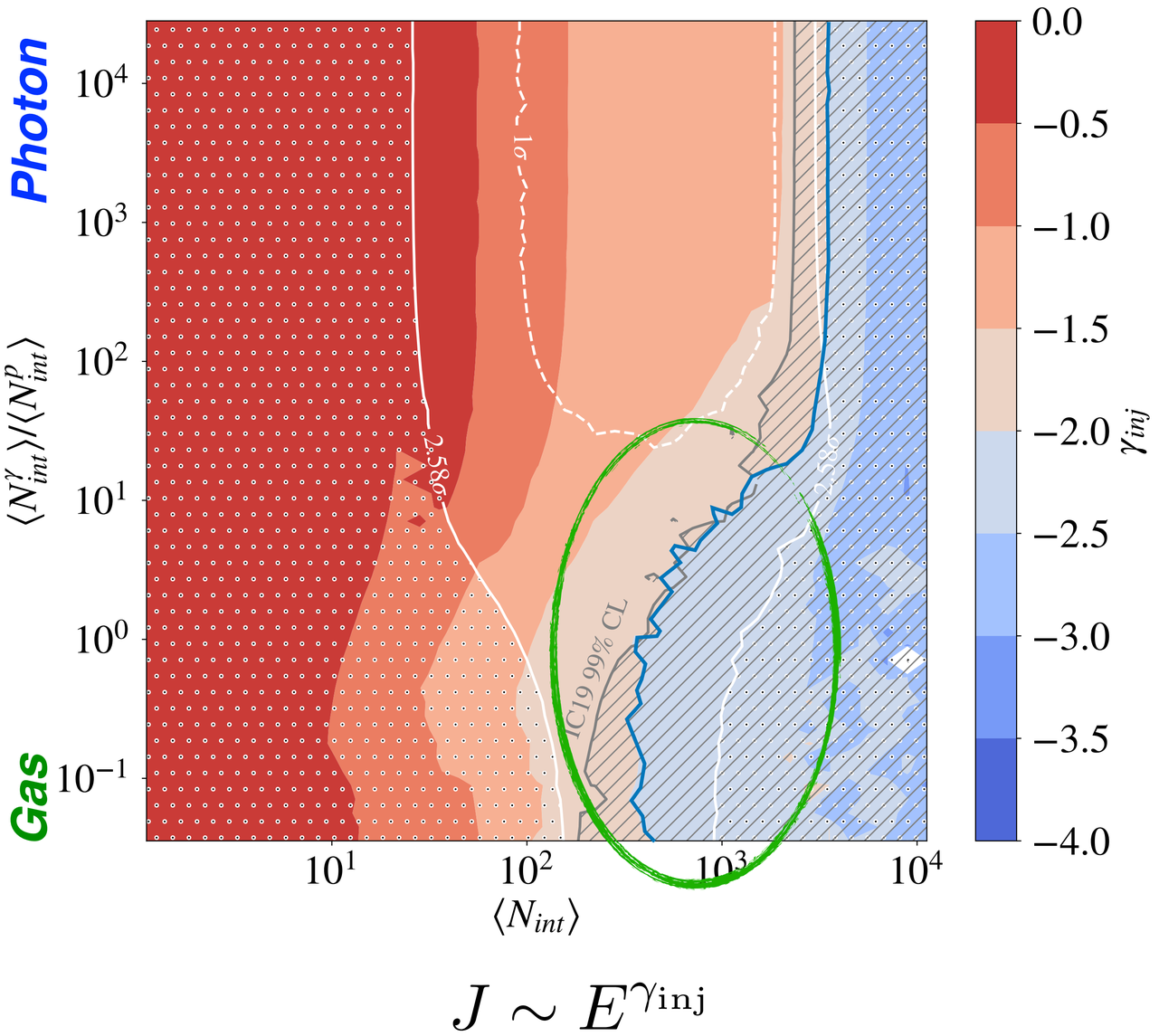

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Spectral indices ~E^{-2} compatible with UHECRS in tension with EHE neutrinos

Accurate measurement of neutrino flux in ~10 PeV energy range could exclude E^{-2}

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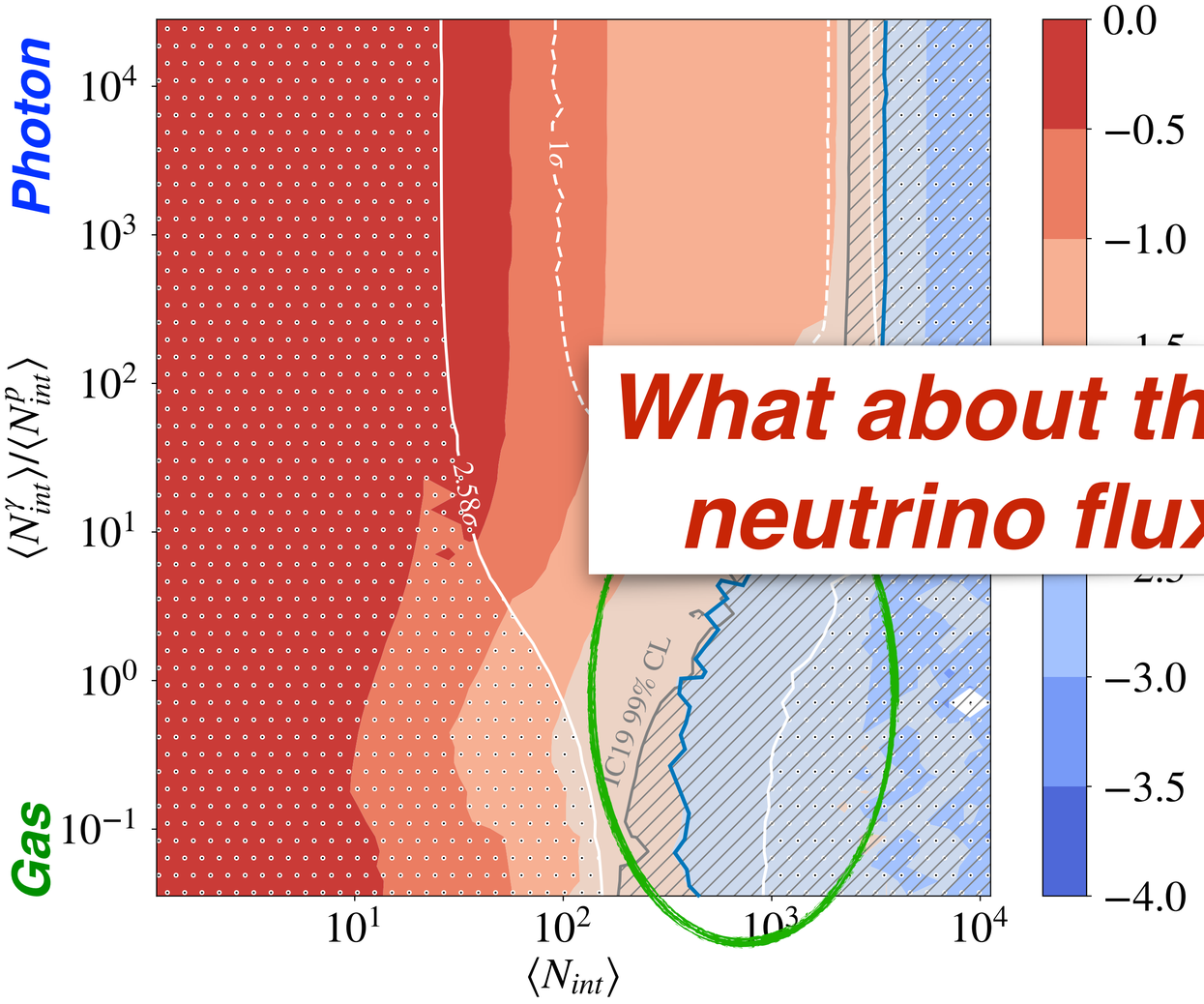

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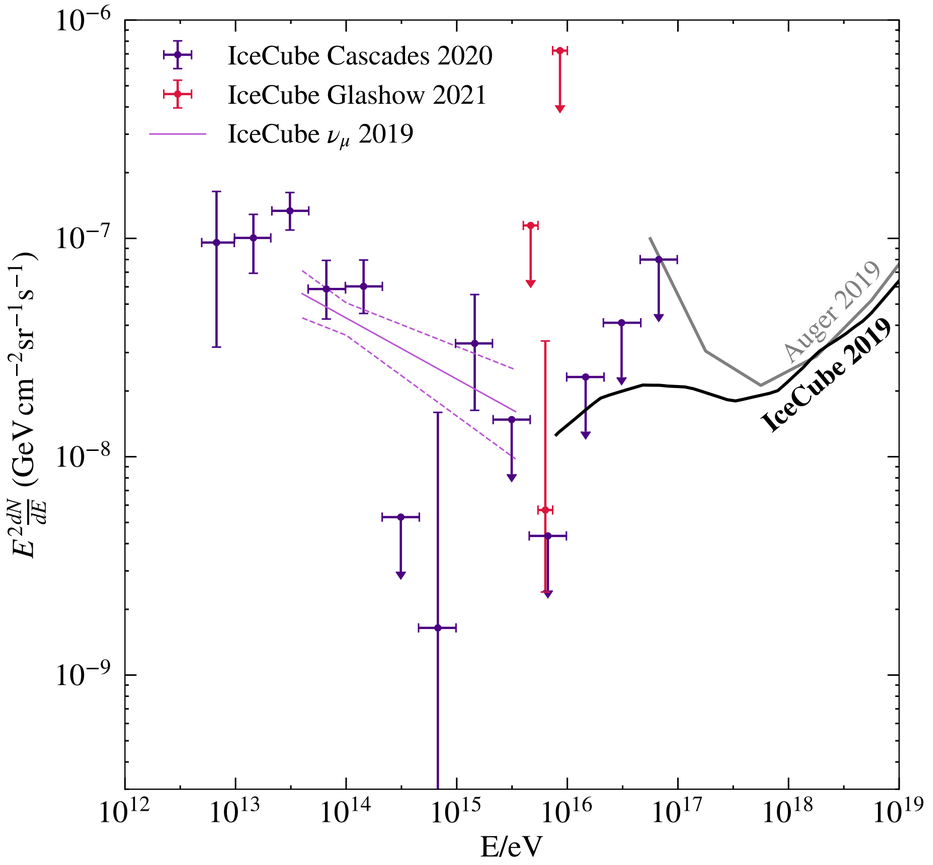
Spectral indices ~E^{-2} compatible with UHECRS in tension with EHE inos

What about the astrophysical neutrino flux description?

Accurate measurement of neutrino flux in ~10 PeV energy range could exclude E^{-2}

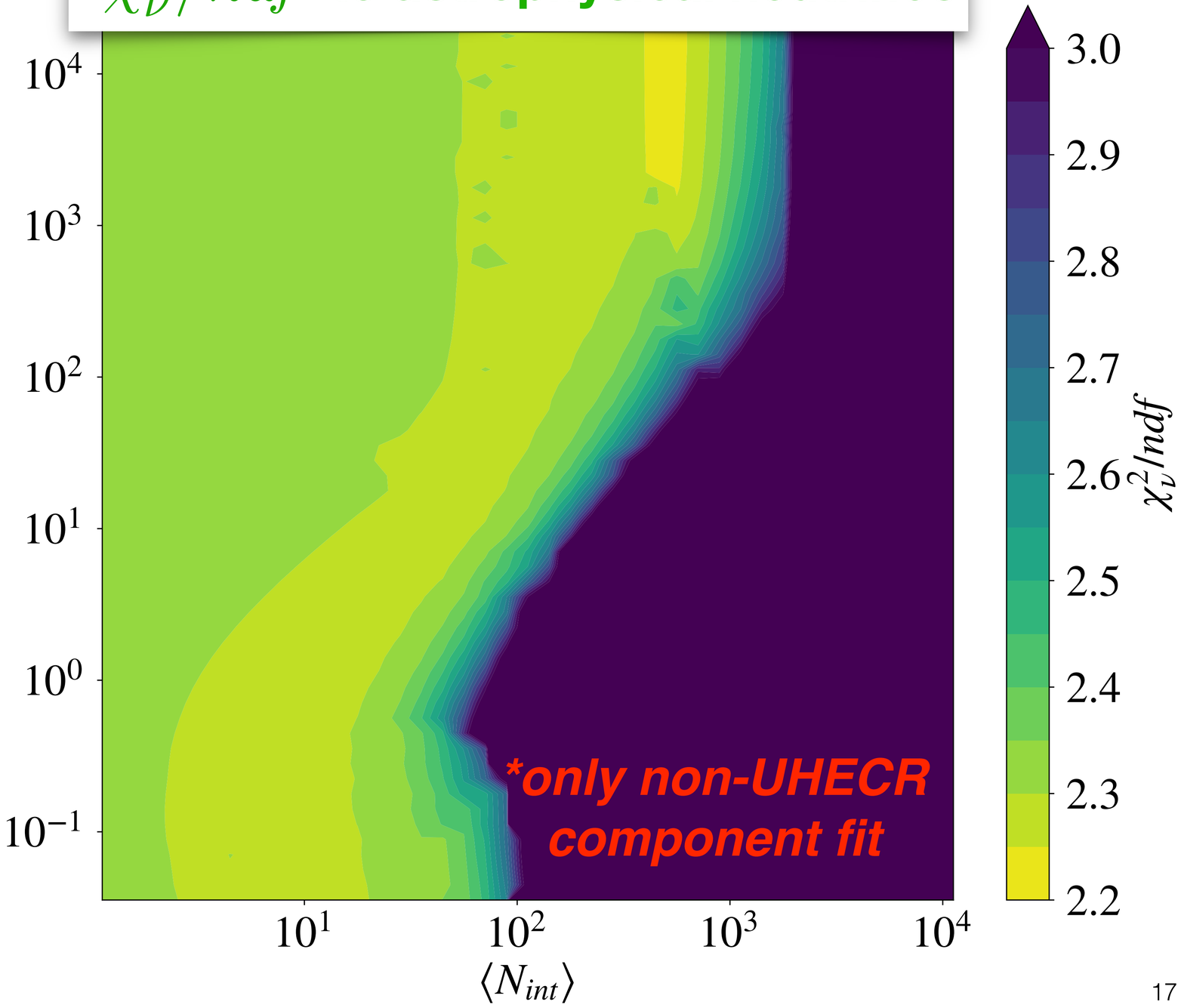


High-energy component from UHECRs

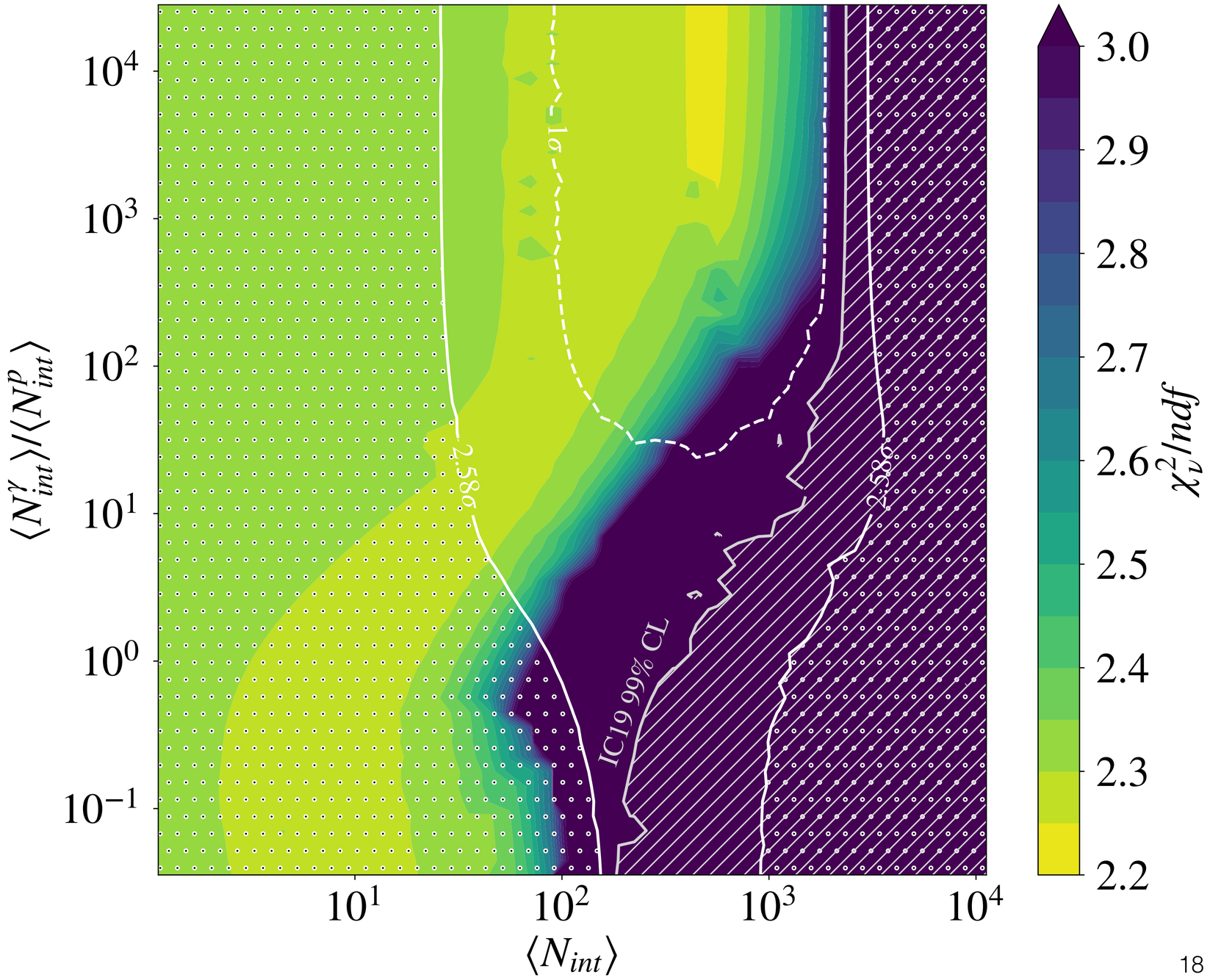
Fit for low-energy component not from UHECRs

$$\phi_\nu \sim \phi_0 E^\gamma e^{-E/E_{\rm cut}}$$

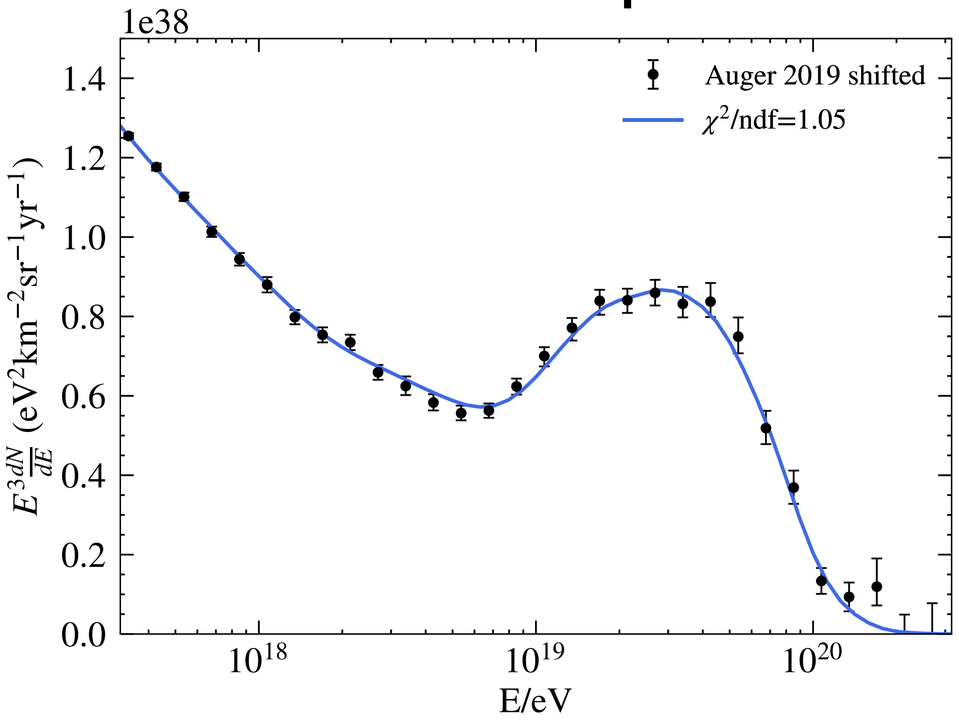
χ^2_ν/ndf to astrophysical neutrinos

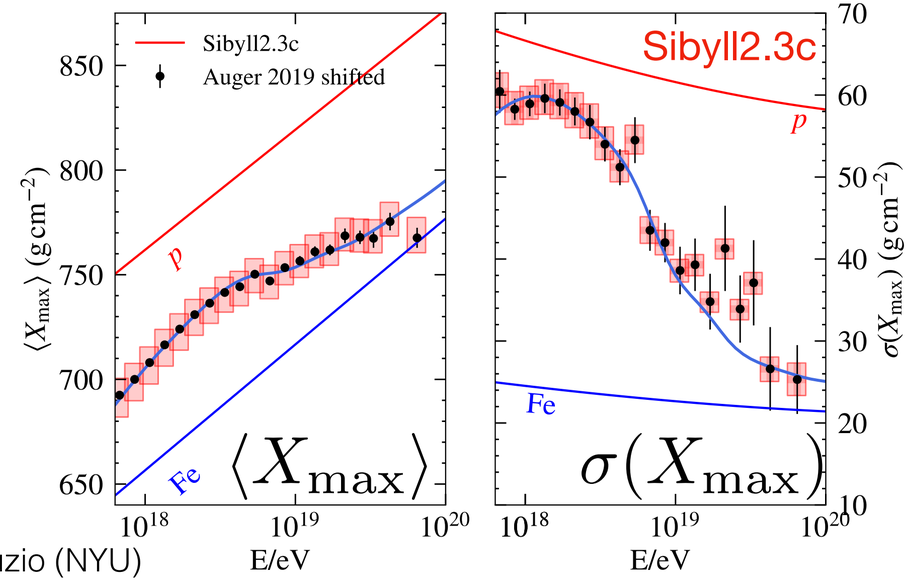


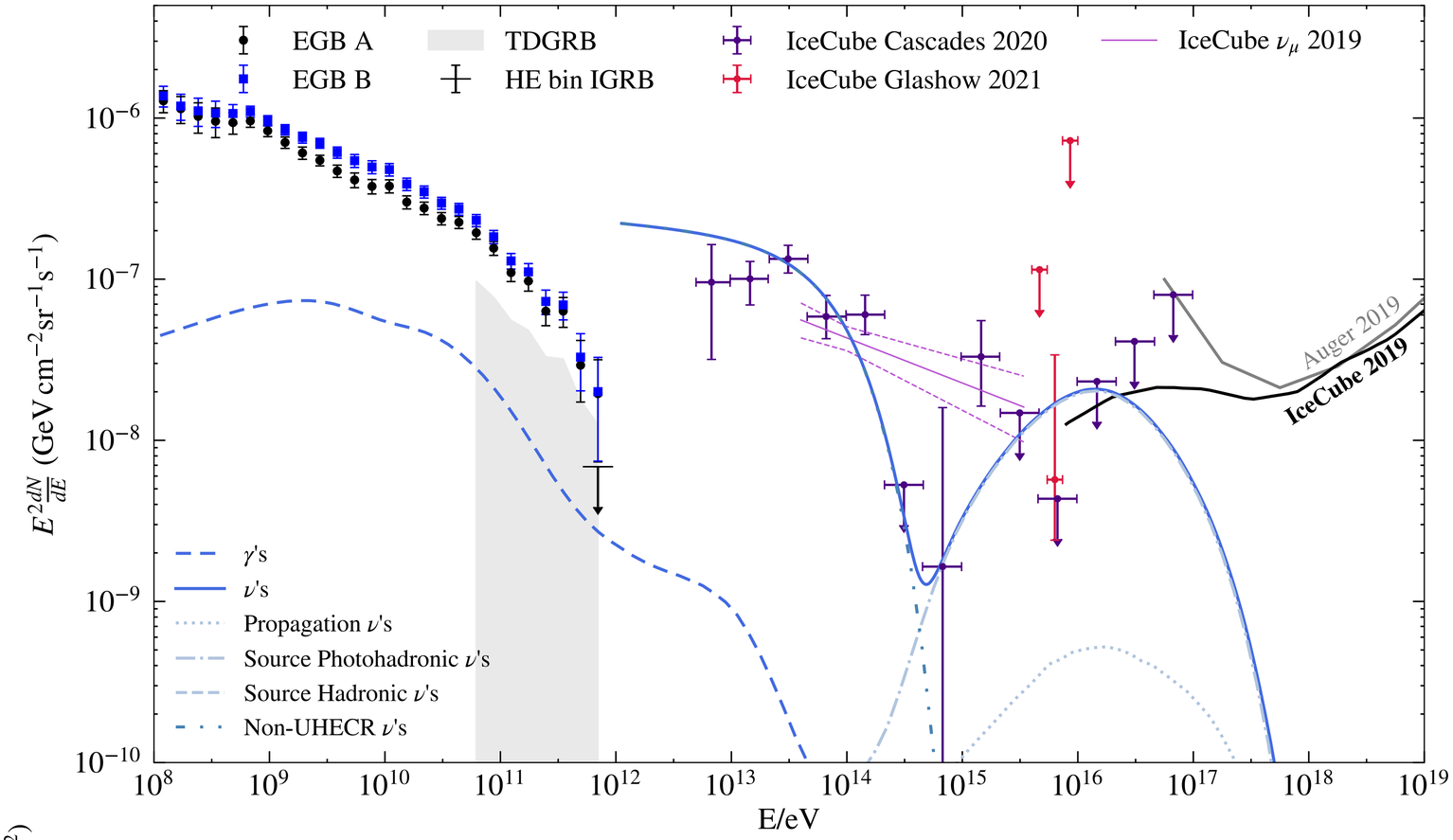
Best description of astrophysical neutrino flux corresponds to best-fit UHECR region!



Best Description of Astrophysical Neutrino Flux







Inferred Source Parameters:

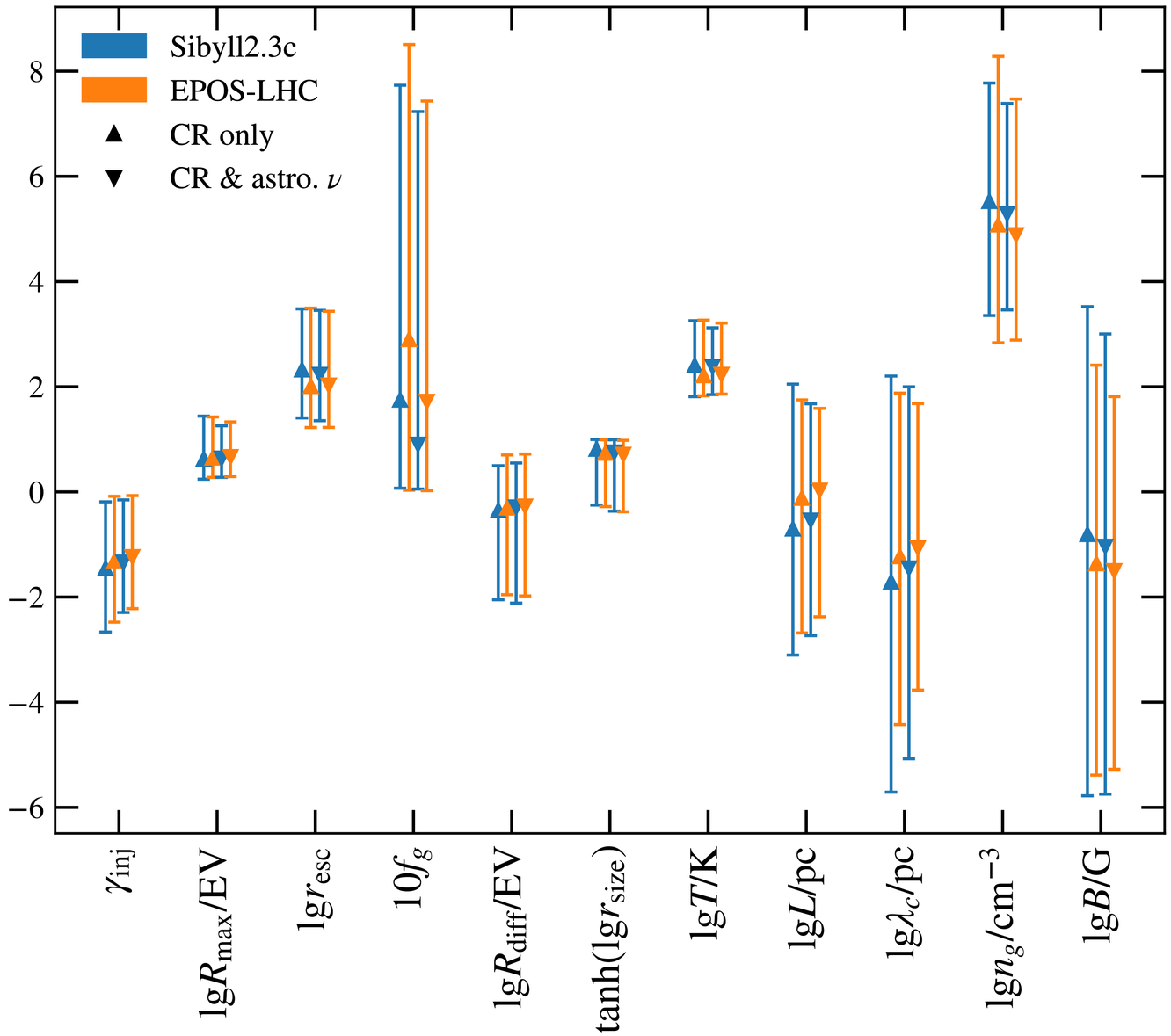
$$\langle N_{\rm int}\rangle = 447 \qquad T_{\rm BB} = 8987\ {\rm K} \qquad R_{\rm diff} = 10^{17.8}\ {\rm V}$$

$$\frac{\langle N^{\gamma}_{\rm int}\rangle}{\langle N^{p}_{\rm int}\rangle} = 22387 \qquad \gamma_{\rm inj} = -1.16 \qquad L/\lambda_c = 9.5$$

Narrowing in on Possible Sources

Performed MCMC to find spread of parameter values compatible with data and constraints

Posterior distribution modes and 16th/84th percentiles indicated

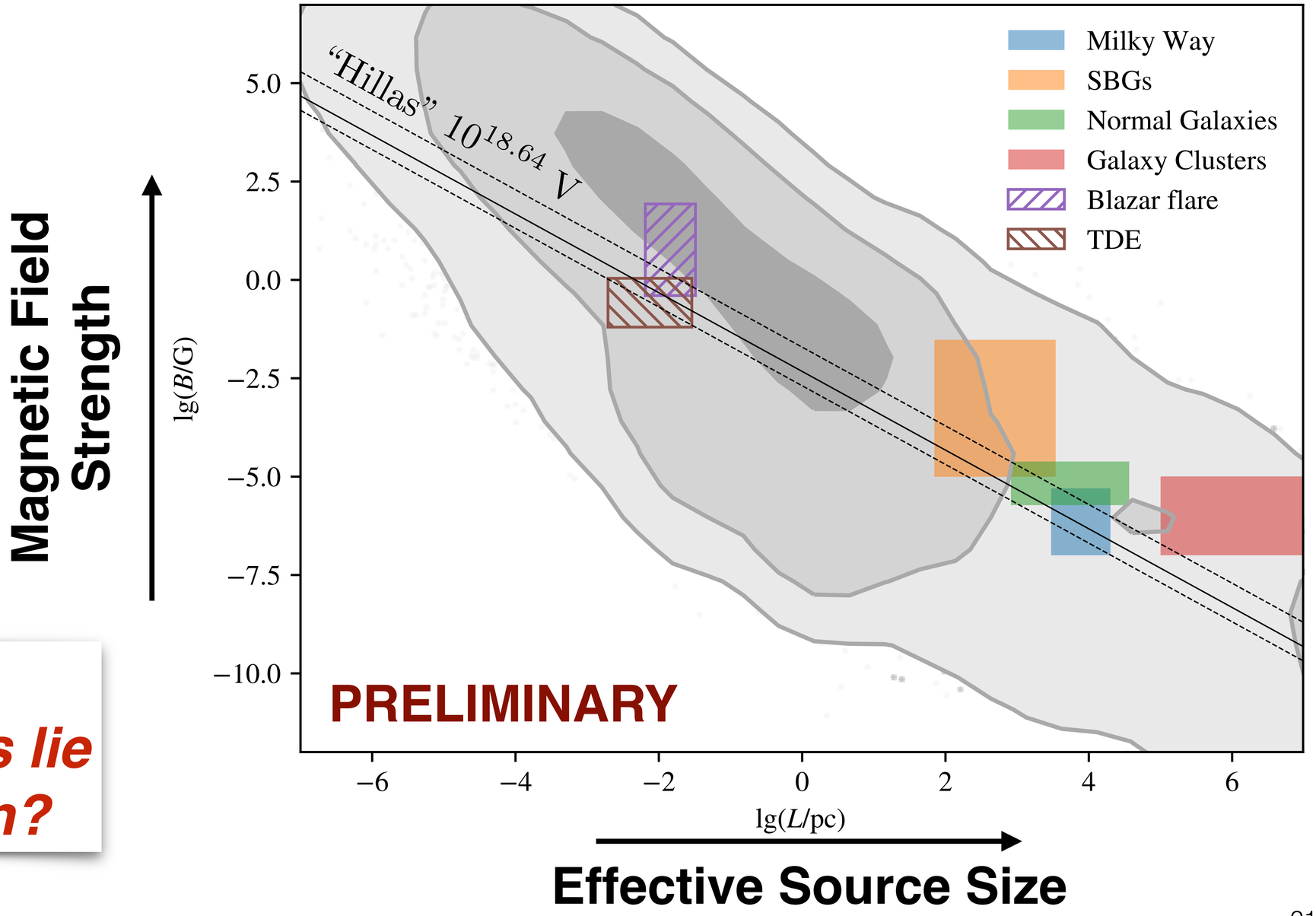


Work in Progress: the Not-Hillas Plot

Posterior distribution constrains source size *L* and magnetic field strength *B*

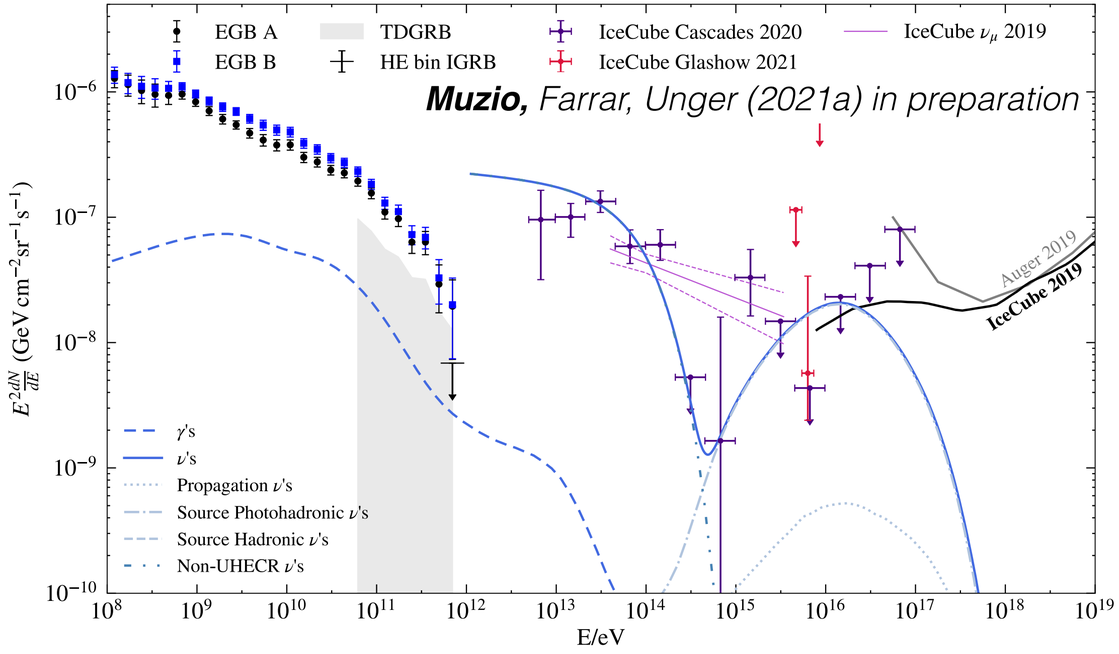
Source regions indicated represent fiducial values from literature, plot still being populated

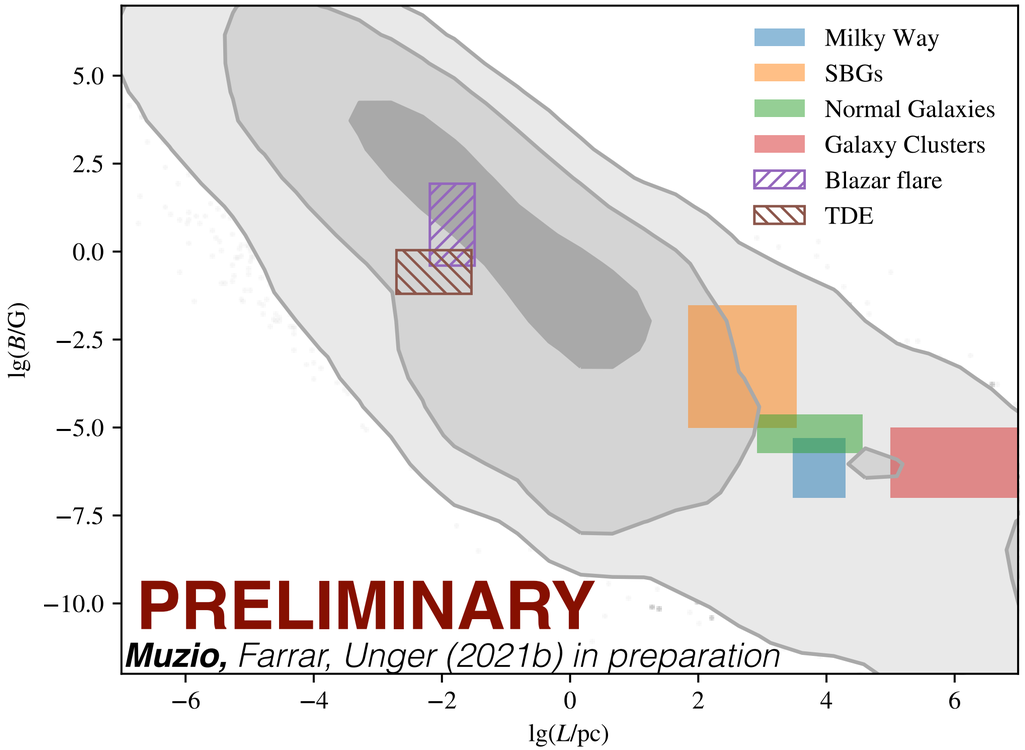
What known astrophysical sources lie in the favored region?



Summary

- **Gas & photon interactions** in source environment can **explain UHECR data**
- **Gas dominated source** environments **in tension with EHE neutrinos**
- **Viability of soft spectral indices** like ~E^{-2} **determined by** accurate measurement of **neutrino flux at ~10 PeV**
- **High energy astrophysical neutrinos** can be **explained by UHECR sources**
- Analysis **constrains astrophysical source properties**, potentially determines preferred source types






Thank you!