Combined Fits of flux, composition and arrival directions

New possibilities with GCOS

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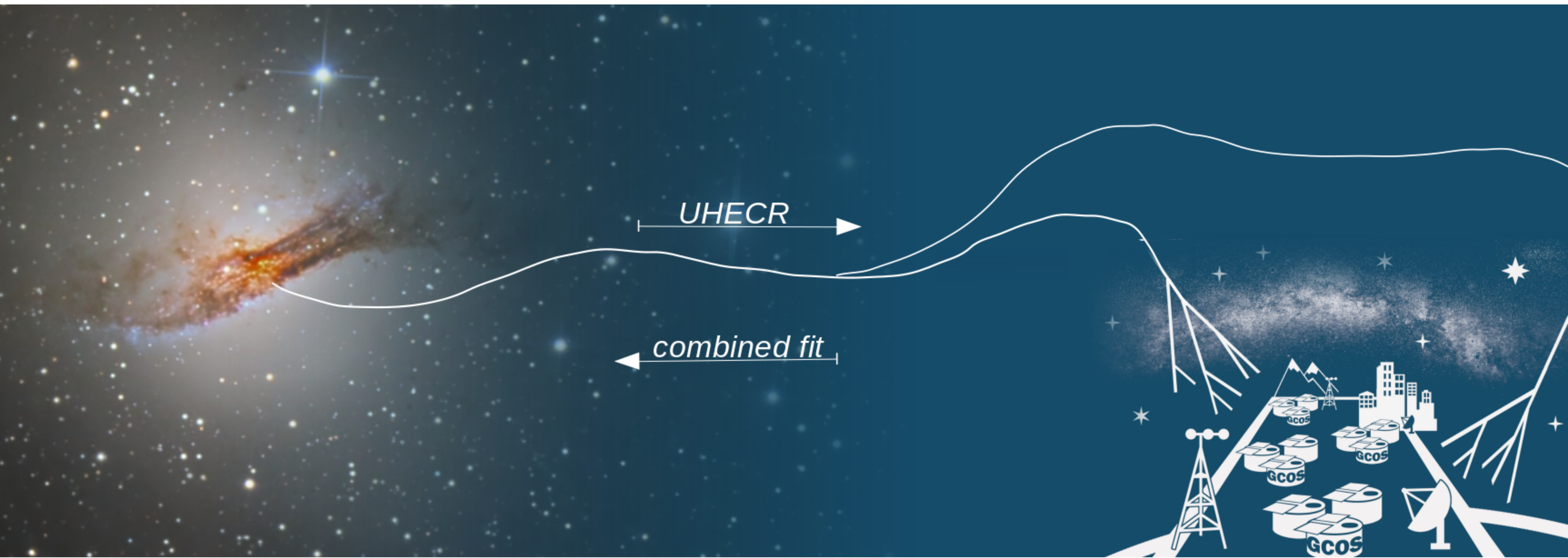


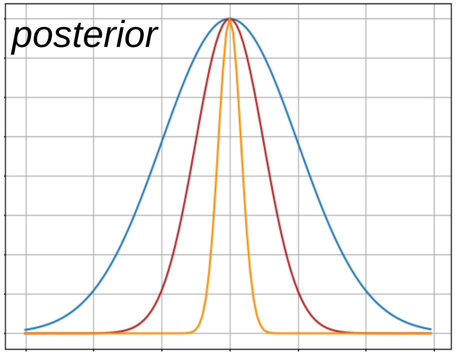
Main influences of GCOS on the combined fit

most importantly:
huge increase of statistics!

- larger detector size, whole sky exposure, Xmax / mass information for every event…?

✓ **decrease uncertainties on fitted source parameters**, e.g. spectral index

→ new constraints for theory / source modeling…



e.g. spectral index γ

comparison on simulation
→ posterior uncertainties from MCMC sampler:

with Auger statistic:

$\langle\gamma\rangle = -2.399\,^{+0.289}_{-0.264}$
$\langle\log_{10}(R_{\mathrm{cut}}/\mathrm{V})\rangle = 18.163\,^{+0.023}_{-0.022}$
$\langle I_{\mathrm{H}}\rangle = 0.063\,^{+0.016}_{-0.012}$
$\langle I_{\mathrm{He}}\rangle = 0.187\,^{+0.020}_{-0.023}$
$\langle I_{\mathrm{N}}\rangle = 0.642\,^{+0.027}_{-0.026}$
$\langle I_{\mathrm{Si}}\rangle = 0.080\,^{+0.020}_{-0.020}$
$\langle I_{\mathrm{Fe}}\rangle = 0.028\,^{+0.005}_{-0.007}$

with Auger statistic + Xmax for every event:

$\langle\gamma\rangle = -2.247\,^{+0.141}_{-0.134}$
$\langle\log_{10}(R_{\mathrm{cut}}/\mathrm{V})\rangle = 18.177\,^{+0.015}_{-0.017}$
$\langle I_{\mathrm{H}}\rangle = 0.059\,^{+0.011}_{-0.010}$
$\langle I_{\mathrm{He}}\rangle = 0.191\,^{+0.017}_{-0.017}$
$\langle I_{\mathrm{N}}\rangle = 0.637\,^{+0.022}_{-0.022}$
$\langle I_{\mathrm{Si}}\rangle = 0.087\,^{+0.015}_{-0.014}$
$\langle I_{\mathrm{Fe}}\rangle = 0.026\,^{+0.004}_{-0.004}$

→ **~1/2 uncertainties**

with 10x Auger statistic: + Xmax for every event:

$\langle\gamma\rangle = -2.018\,^{+0.045}_{-0.043}$
$\langle\log_{10}(R_{\mathrm{cut}}/\mathrm{V})\rangle = 18.197\,^{+0.005}_{-0.006}$
$\langle I_{\mathrm{H}}\rangle = 0.055\,^{+0.004}_{-0.004}$
$\langle I_{\mathrm{He}}\rangle = 0.218\,^{+0.006}_{-0.006}$
$\langle I_{\mathrm{N}}\rangle = 0.585\,^{+0.007}_{-0.007}$
$\langle I_{\mathrm{Si}}\rangle = 0.115\,^{+0.004}_{-0.005}$
$\langle I_{\mathrm{Fe}}\rangle = 0.027\,^{+0.001}_{-0.001}$

→ **~1/6 uncertainties**

Main influences of GCOS on the combined fit

most importantly:
huge increase of statistics!

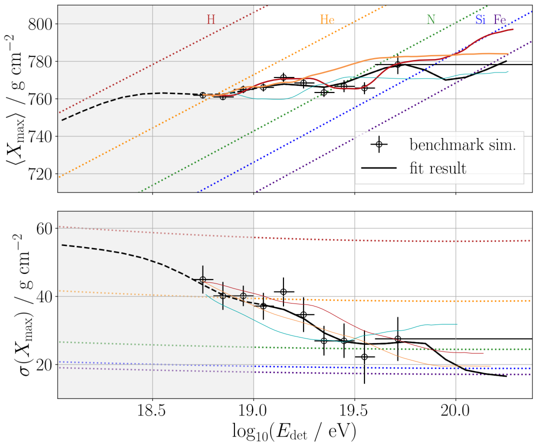
- larger detector size, whole sky exposure, Xmax / mass information for every event…?

✓ **decrease uncertainties on fitted source parameters**, e.g. spectral index

→ new constraints for theory / source modeling…

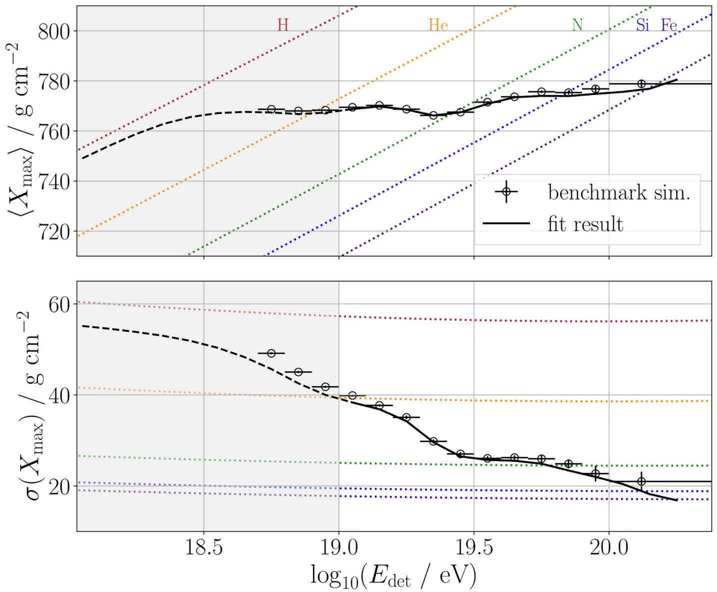
✓ **exclude large parts of the parameter space** which does not describe observables

→ exclude models for source distribution, magnetic fields...



simulation with Auger statistic

→ many models fit

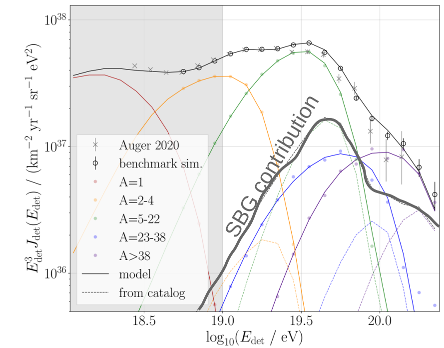


simulation with 10x Auger statistic

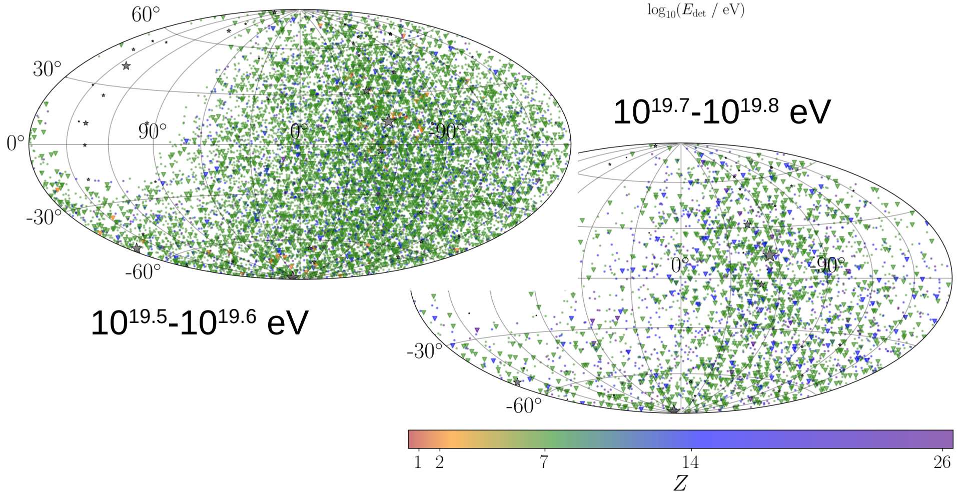
→ exclude most models

Source identification in the fit with arrival directions

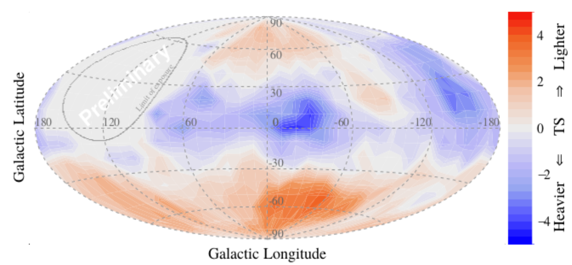
- fit with arrival directions can **differentiate between different source catalogs**
  - other sources at different directions & distances cannot describe spectrum / Xmax / arrival directions as functions of energy



- **example simulation with SBGs as sources:**
  - logL ratio SBG model / AGN model: **5.4σ**
  - *with 10x statistics:*
    logL ratio SBG model / AGN model: **22.4σ**



- **Outlook:**
  - may benefit additionally from full-sky exposure
  - use Xmax / logA maps in E bins
    (currently not enough statistics)
    → composition anisotropy?
  - also reconstruct magnetic field parameters at the same time?



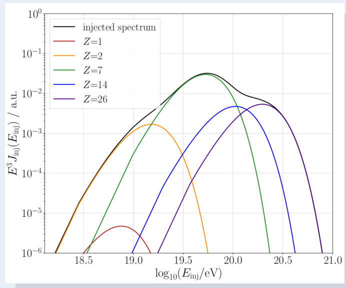
E. Mayotte / Pierre Auger Collaboration ICRC 2021

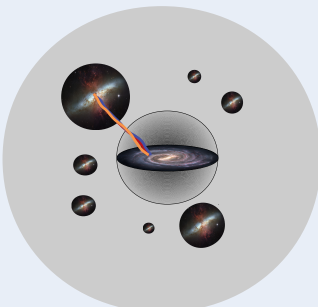
Backup

Combined fit of spectrum, Xmax and arrival directions

Set up a universe model:

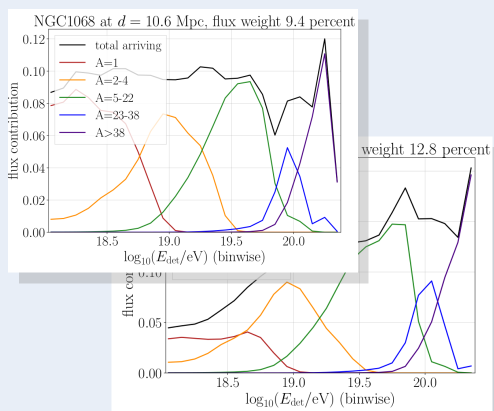
- injected spectrum:
  γ, R_{cut}, int. fractions





- ***catalog sources***
  (SBGs / AGNs / Cen A)
  & background

- **source contributions** depending on source distance + propagation



- **signal fraction** at $10^{19.5}$ eV: f_0

- rigidity- (and distance-) dependent **magnetic field blurring**

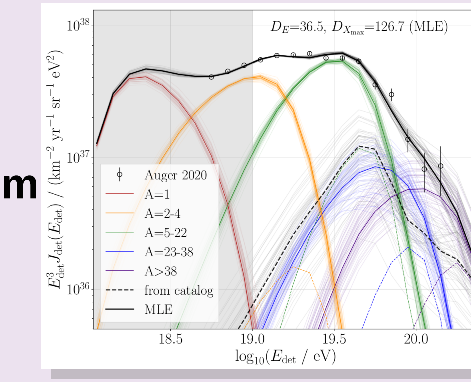
$$\delta_S = \delta_0 \, Z_{det} \, \frac{10 \text{ EeV}}{E_{det}}$$

propagation

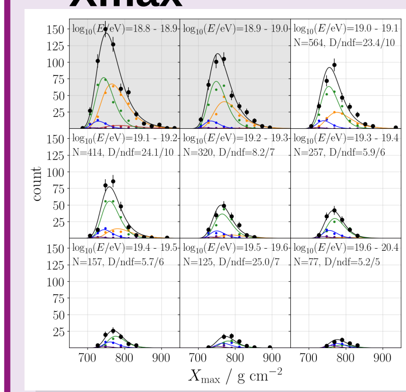
(CRPropa3 database)

Observables:

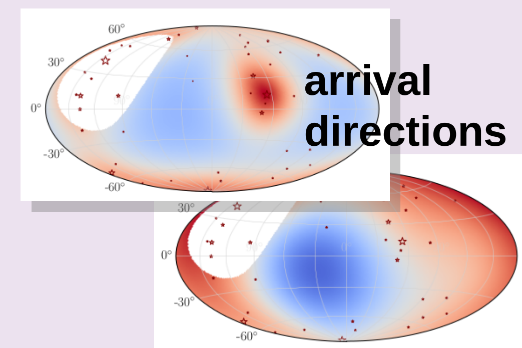
energy spectrum



Xmax



arrival directions



Combined Fit (with 2 methods):

- **MCMC sampler** for posteriors / uncertainties
- **minimizer** for best-fit / MLE
- AD likelihood: $\mathcal{L}_{AD} = \prod_e \prod_p \mathrm{pdf}^{e,p}(v^{e,p})$