

Harmonic correlators for UHECRs



Federico Urban

CEICO

Institute of Physics
Czech Academy of Sciences
Prague

*COST CA18108 Annual Conference
Napoli – Italy*

July 15, 2022



EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education



:: take home message ::

:: take home message ::



We look for UHECR anisotropies

:: take home message ::



We look for UHECR anisotropies



Harmonic space: global properties

:: take home message ::



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Cross-correlations: new angular scales

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QG-MM: energy dependence, ν , γ

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Cross-correlations: new angular scales



QG-MM: energy dependence, ν , γ

A&A 2021, arXiv:2203.09538, +ongoing x2

with D. Alonso, F. Oliveira Franco, S. Camera, K. Tanidis



some theory



:: harmonic ::

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© Tingjakov & FU, 2014

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$$\Phi(\hat{n}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\hat{n})$$

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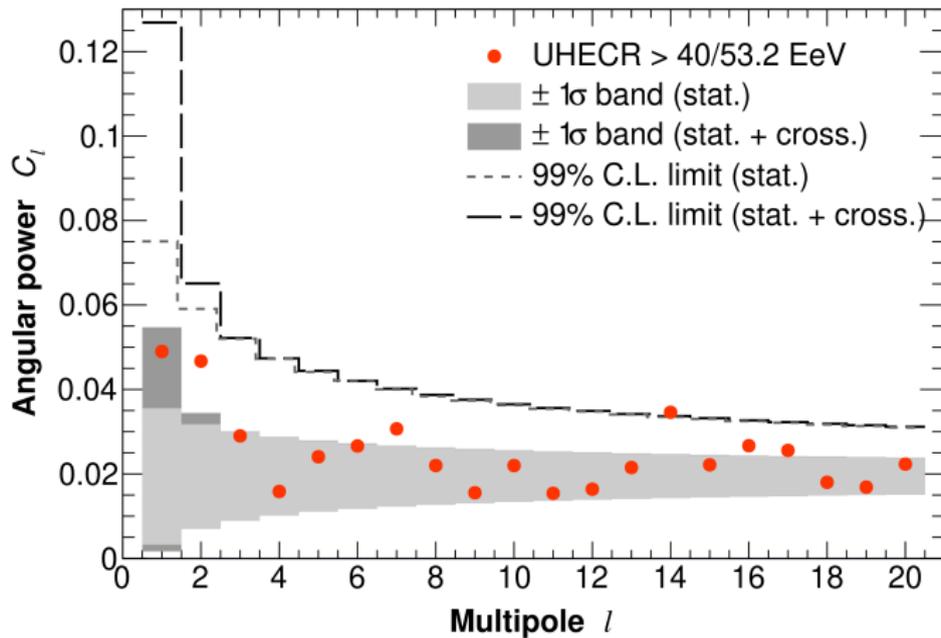
In harmonic space

$$\Phi(\hat{n}) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\hat{n})$$

we find the autocorrelation AC

$$C_{\ell} = \frac{1}{2\ell + 1} \sum_m |a_{\ell m}^* a_{\ell m}|$$

:: observations ::



:: cross correlation ::

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i. The measured UHECR flux can be written as

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Noise

$$\text{AC} \quad :: \quad \frac{1}{N_{\text{CR}}} \gg \frac{1}{N_{\text{gal}}} \quad :: \quad \text{XC}$$

:: modelling uecrs ::

:: modelling uhecrs ::



UHECR Sources

$E_{\text{cut}} = 40, 63, 100$ EeV with 1000, 200, 30 events

:: modelling uhcrs ::



UHECR Sources

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Primaries, three examples: H1, O16, Si28

Injection: $\gamma = 2.60, \gamma = 2.10, \gamma = 1.50$

© di Matteo & Tinyakov, 2018

→ for Si28 we cut at $E_{\text{max}} = 280$ EeV

:: modelling uhecrs ::



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UHECR Kernel

Attenuation $\alpha(z, E_{\text{cut}}; \gamma, Z)$ calculated with SimProp

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Magnetic beam

Smearing with $\sigma \sim 1 \text{deg} (40Z/E)/(\sin^2 b + 0.15)$ © Pshirkov, Tinyakov & FU, 2013
→ we smear with the max angle within a given sky patch



results



:: kernels ::

:: kernels ::

The 'observed' UHECR flux anisotropy is given by

$$\Delta_{\text{CR}}(\hat{n}, E_{\text{cut}}) = \int d\chi \phi_{\text{CR}}(\chi) \delta_s(z, \chi \hat{n})$$

where the radial kernel $\phi_{\text{CR}}(\chi) \sim \alpha(z, E_{\text{cut}}; \chi, Z)$

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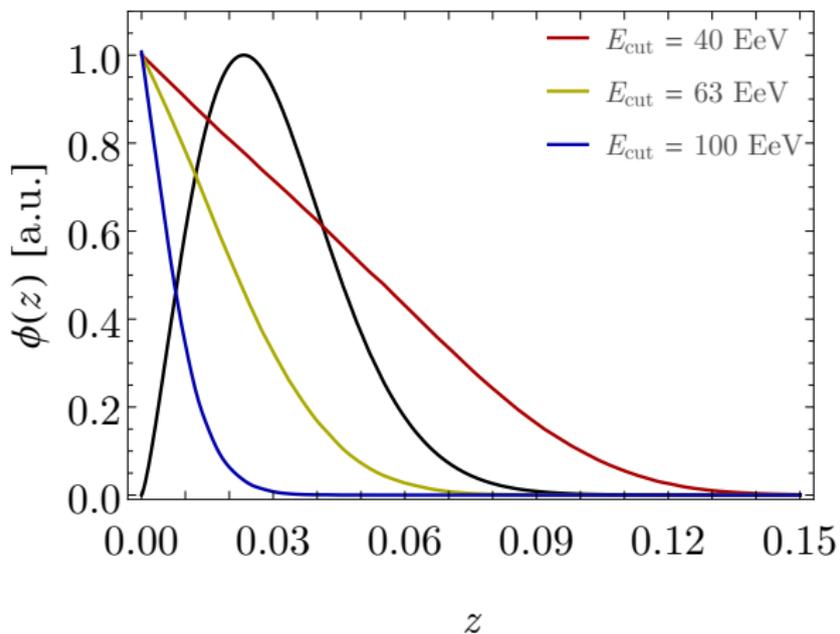
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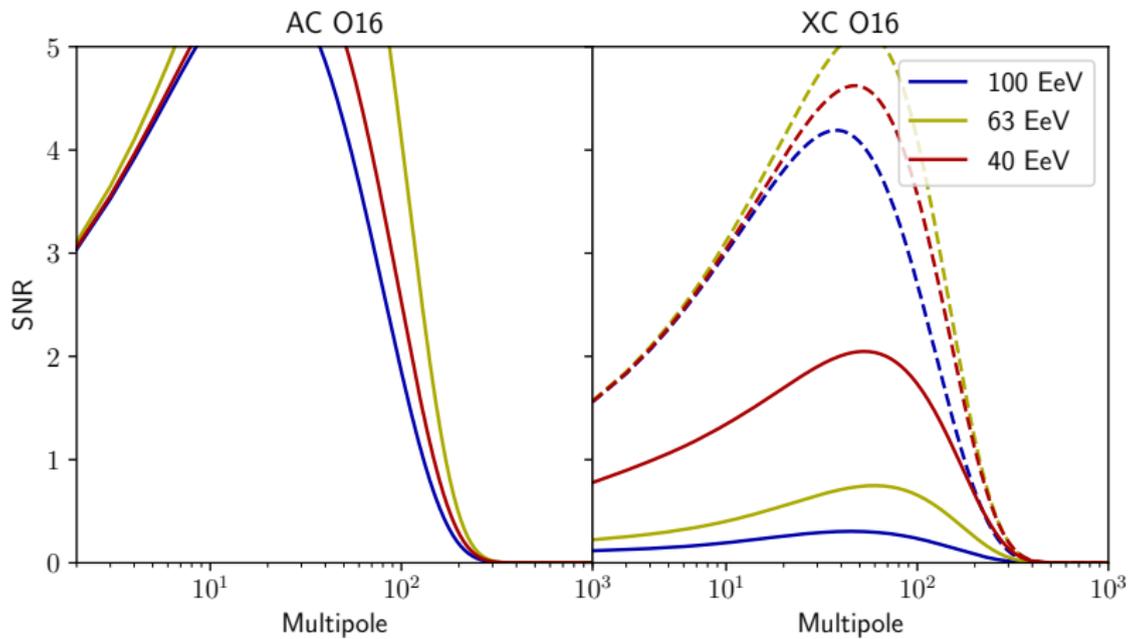
where the radial kernel $\phi_g(\chi) \sim \chi^2 w(\chi) \bar{n}_{g,c}(\chi)$

The (optional) weights $w(\chi)$ account for
the probability that a galaxy at distance χ
is the origin of an UHECR above E_{cut}

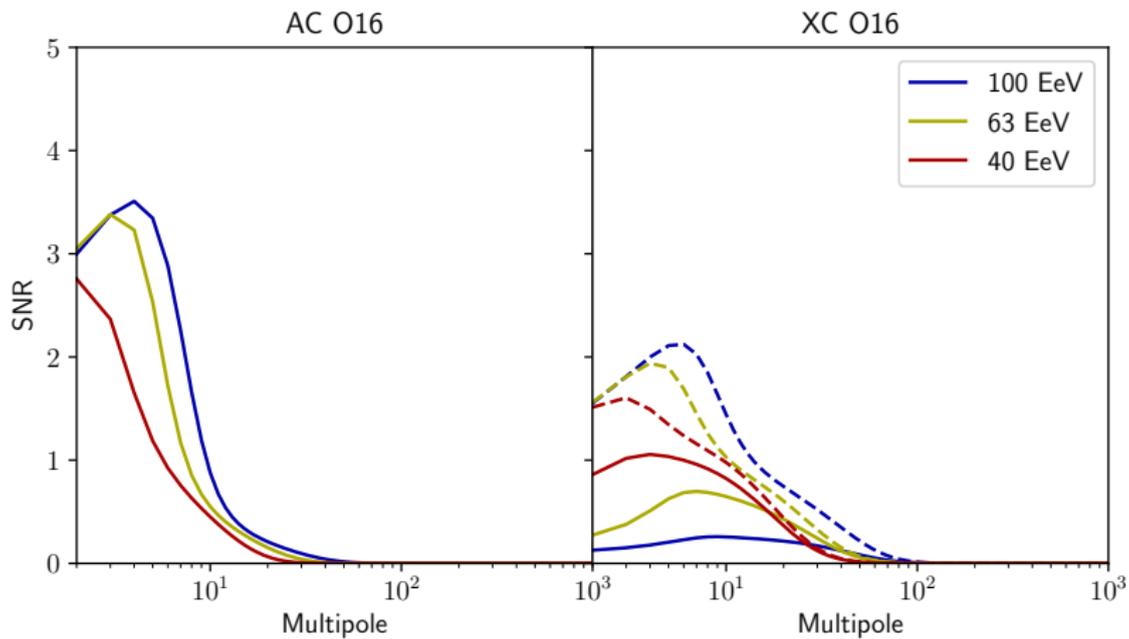
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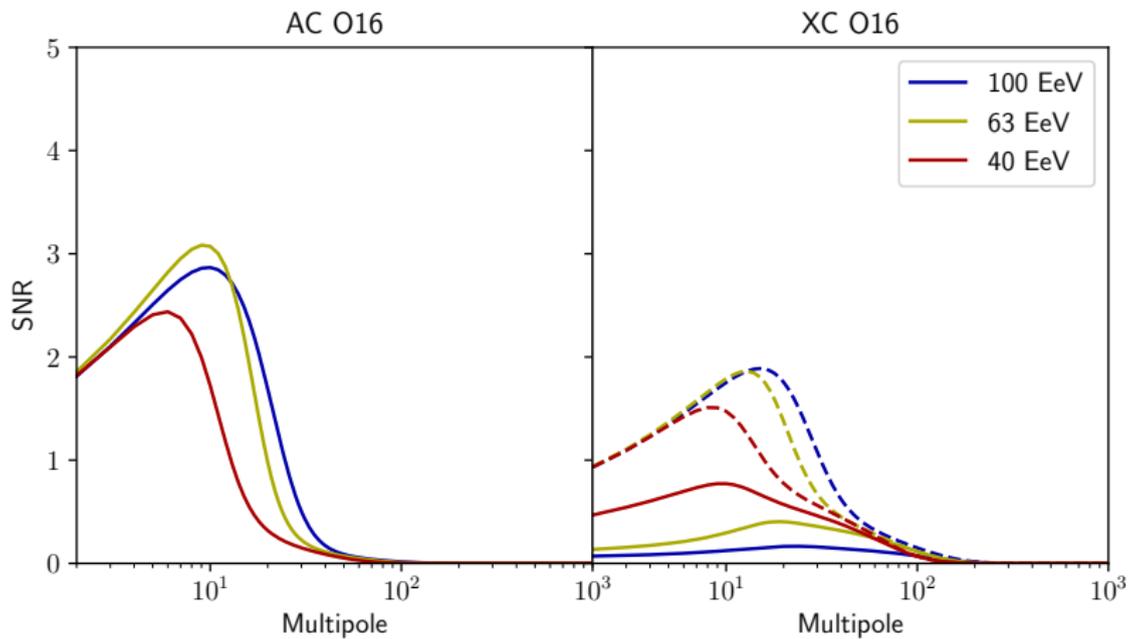
:: oxygen 16 ::



:: oxygen gmfoo ::



:: oxygen gmf 40 ::

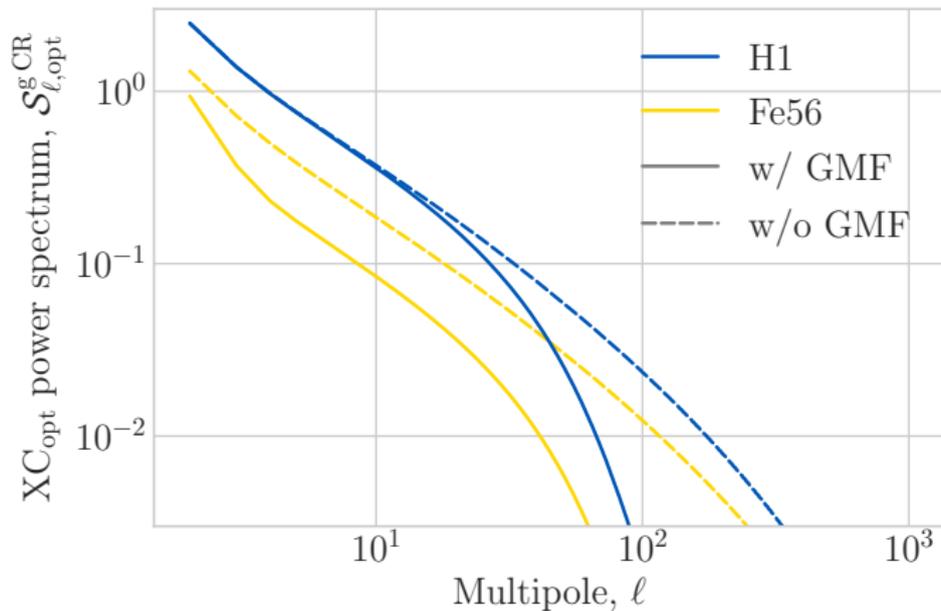




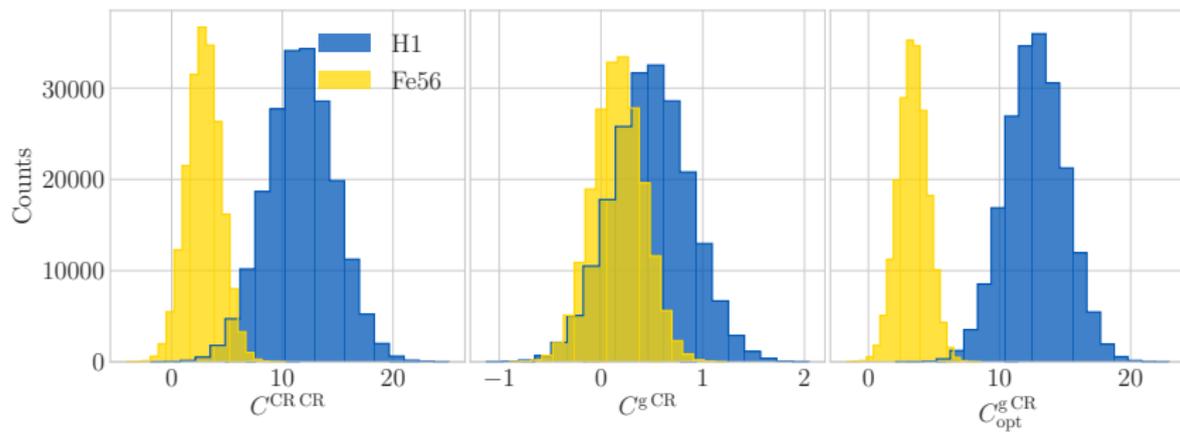
chemistry



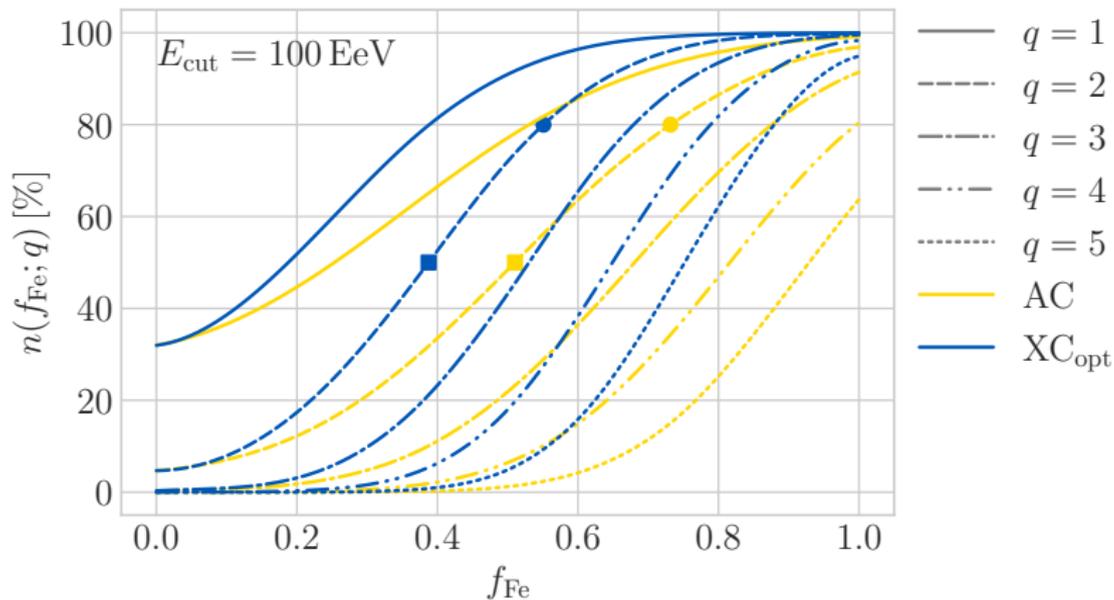
:: hydrogen or iron ::



:: total power ::



:: how much iron ::



:: Summary ::

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w/Camera+Alonso

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:: w/Tanidis+Camera

arXiv:2203.09538

...and work in progress...