



UNIVERSITY
OF SÃO PAULO
São Carlos Institute of Physics



Cainã de Oliveira

caina.oliveira@usp.br

Supervisor: Professor Vitor de Souza

High-energy
astrophysics in the
multi-messenger era



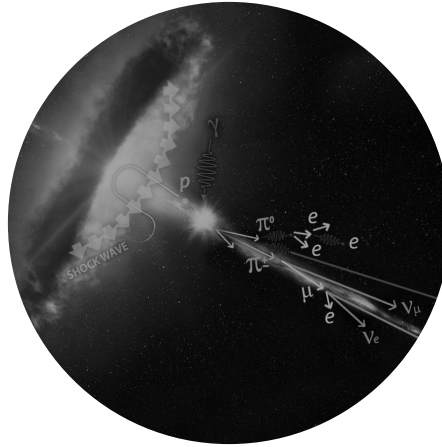
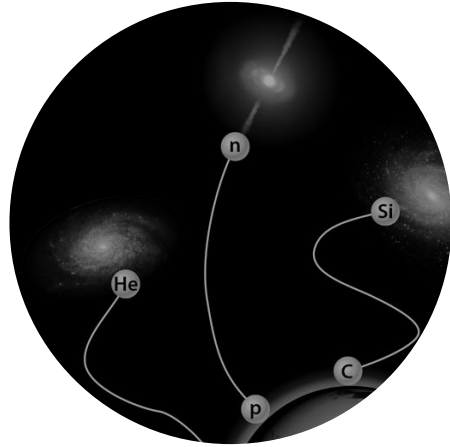


UNIVERSITY
OF SÃO PAULO
São Carlos Institute of Physics



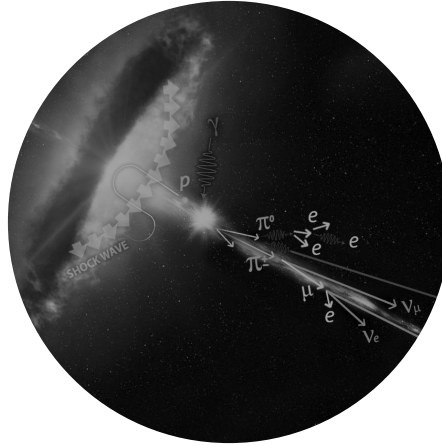
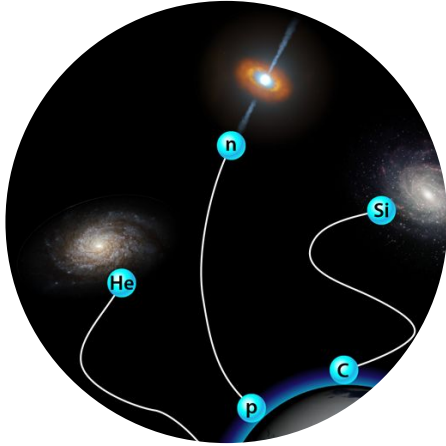
High-energy astrophysics in the multi-messenger era

Research interests



High-energy astrophysics in the multi-messenger era

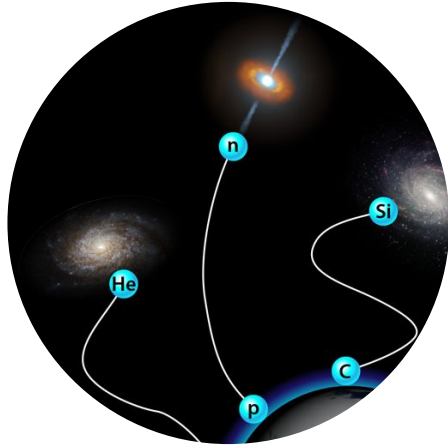
Research interests



UHECR anisotropy

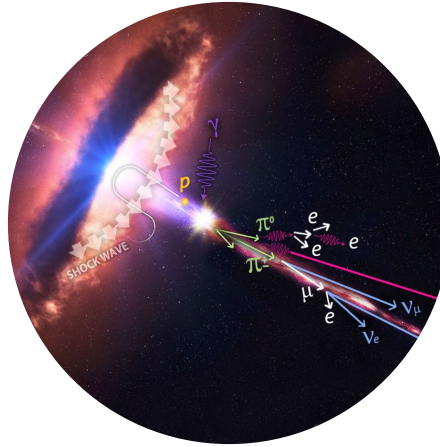
- ❑ (Nearby) sources
- ❑ Cosmic magnetic fields

Research interests



UHECR anisotropy

- ❑ (Nearby) sources
- ❑ Cosmic magnetic fields



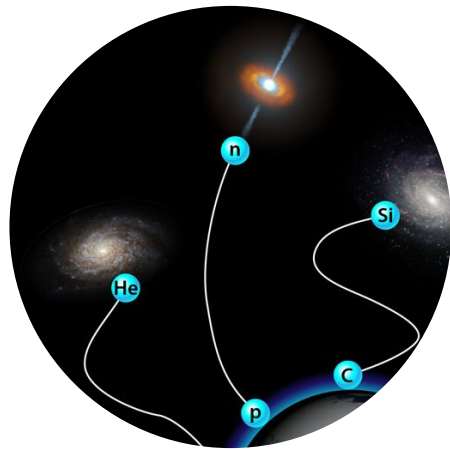
UHECR propagation & multi-messenger

- ❑ Secondary neutrino and gamma-rays



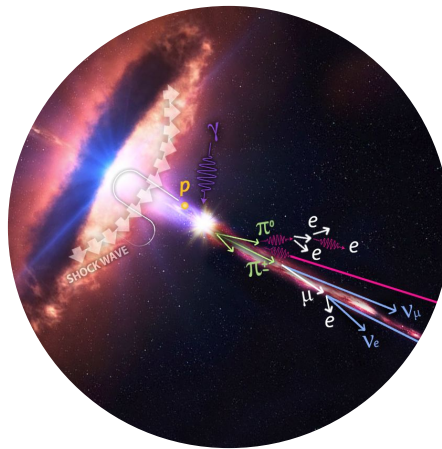
High-energy astrophysics in the multi-messenger era

Research interests



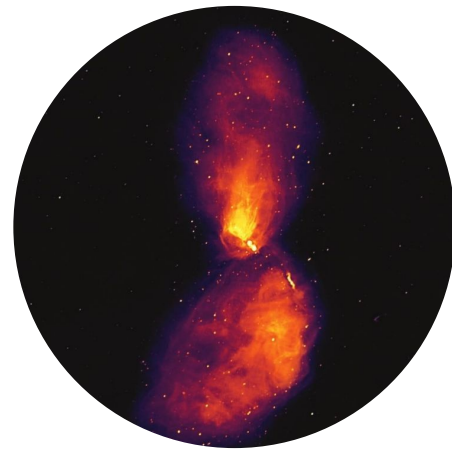
UHECR anisotropy

- ❑ (Nearby) sources
- ❑ Cosmic magnetic fields



UHECR propagation & multi-messenger

- ❑ Secondary neutrino and gamma-rays

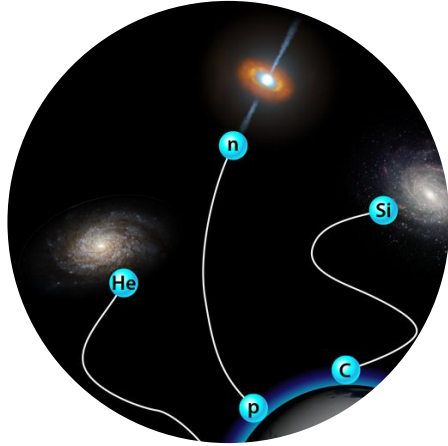


UHECR acceleration

- ❑ Centaurus A as an astrophysical lab
- ❑ Testing acc mechanisms

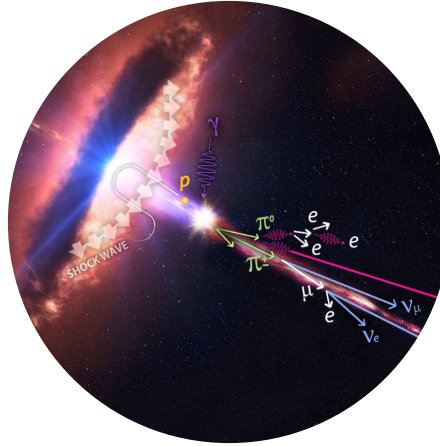
High-energy astrophysics in the multi-messenger era

Research interests



UHECR anisotropy

- ❑ (Nearby) sources
- ❑ Cosmic magnetic fields



UHECR propagation & multi-messenger

- ❑ Secondary neutrino and gamma-rays

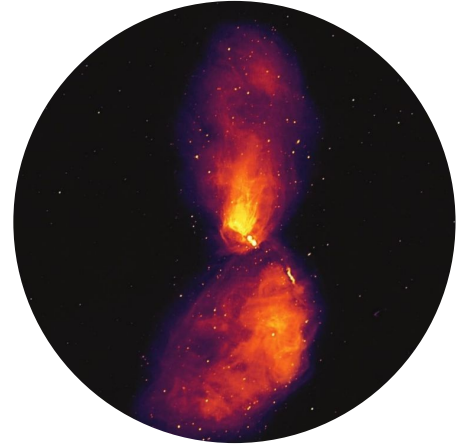
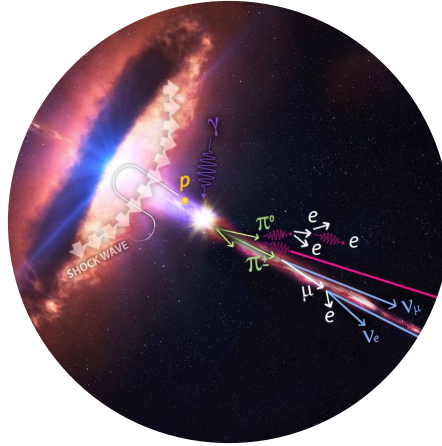
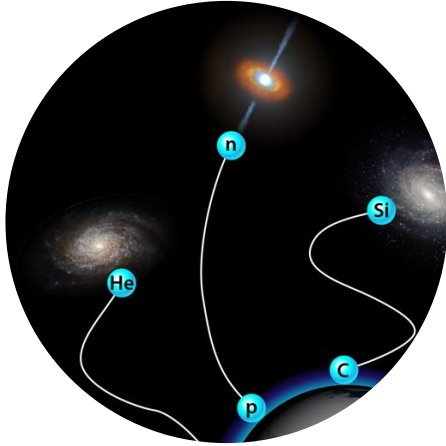


UHECR acceleration

- ❑ Centaurus A as an astrophysical lab
- ❑ Testing acc mechanisms

High-energy astrophysics in the multi-messenger era

Research interests



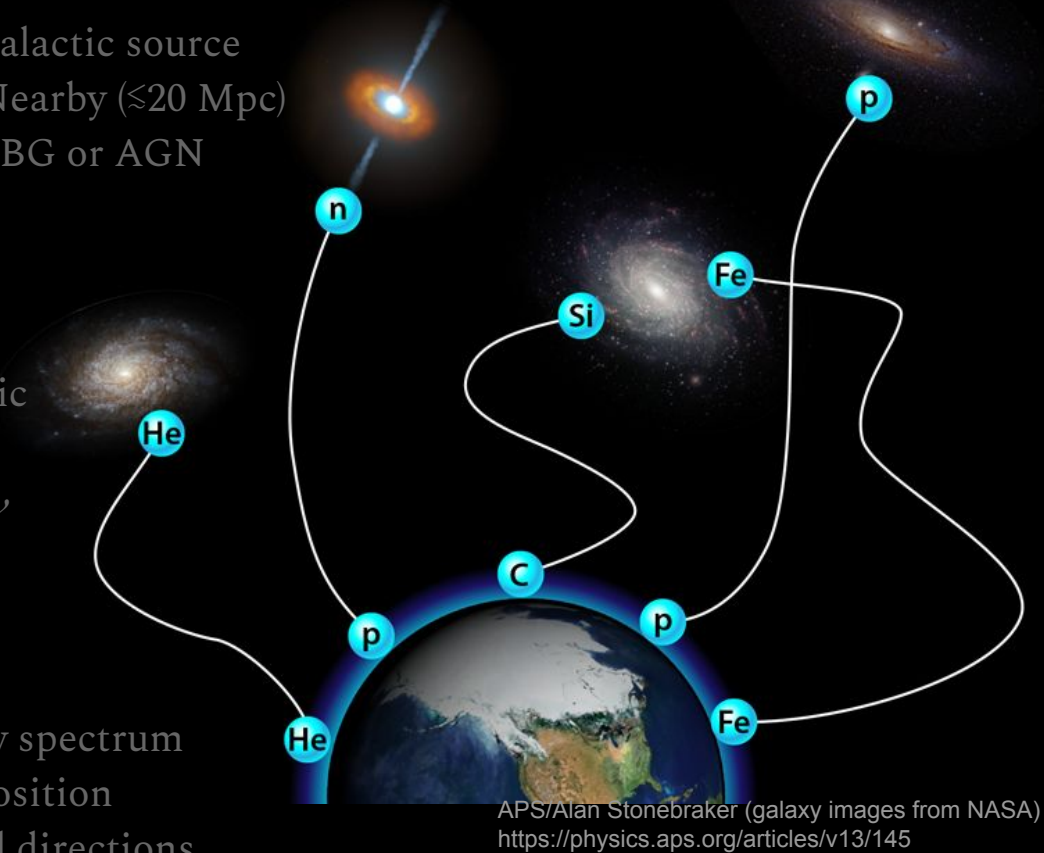
- ❑ UHECR propagation
- ❑ Interface theory & observation:
Auger, CTA

Journey from the source

- ❑ Extragalactic source
 - ✓ Nearby ($\lesssim 20$ Mpc)
 - ✓ SBG or AGN

- ❑ Propagation through the Extragalactic/
Galactic environment
 - ✓ Influence of extragalactic magnetic field
 - ✓ Interactions \rightarrow secondaries ν and γ
 - CRPropa

- ❑ Earth
 - ✓ Energy spectrum
 - ✓ Composition
 - ✓ Arrival directions

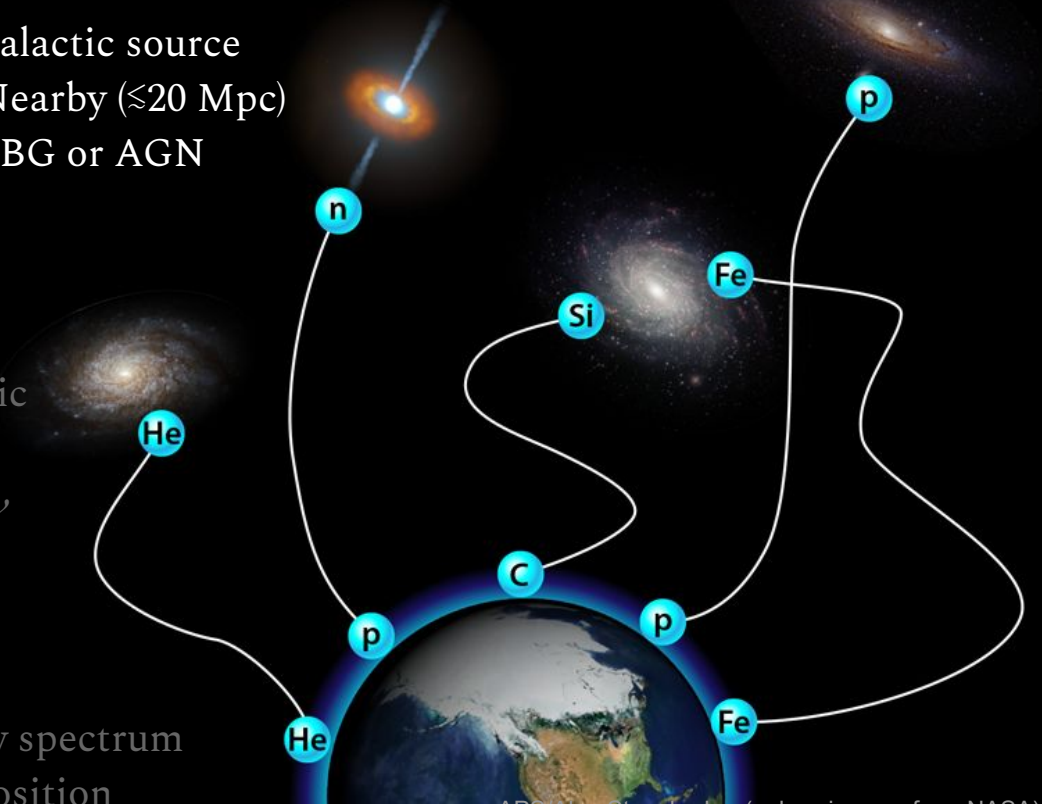


Journey from the source

- ❑ Extragalactic source
 - ✓ Nearby ($\lesssim 20$ Mpc)
 - ✓ SBG or AGN

- ❑ Propagation through the Extragalactic/
Galactic environment
 - ✓ Influence of extragalactic magnetic field
 - ✓ Interactions \rightarrow secondaries ν and γ
 - CRPropa

- ❑ Earth
 - ✓ Energy spectrum
 - ✓ Composition
 - ✓ Arrival directions



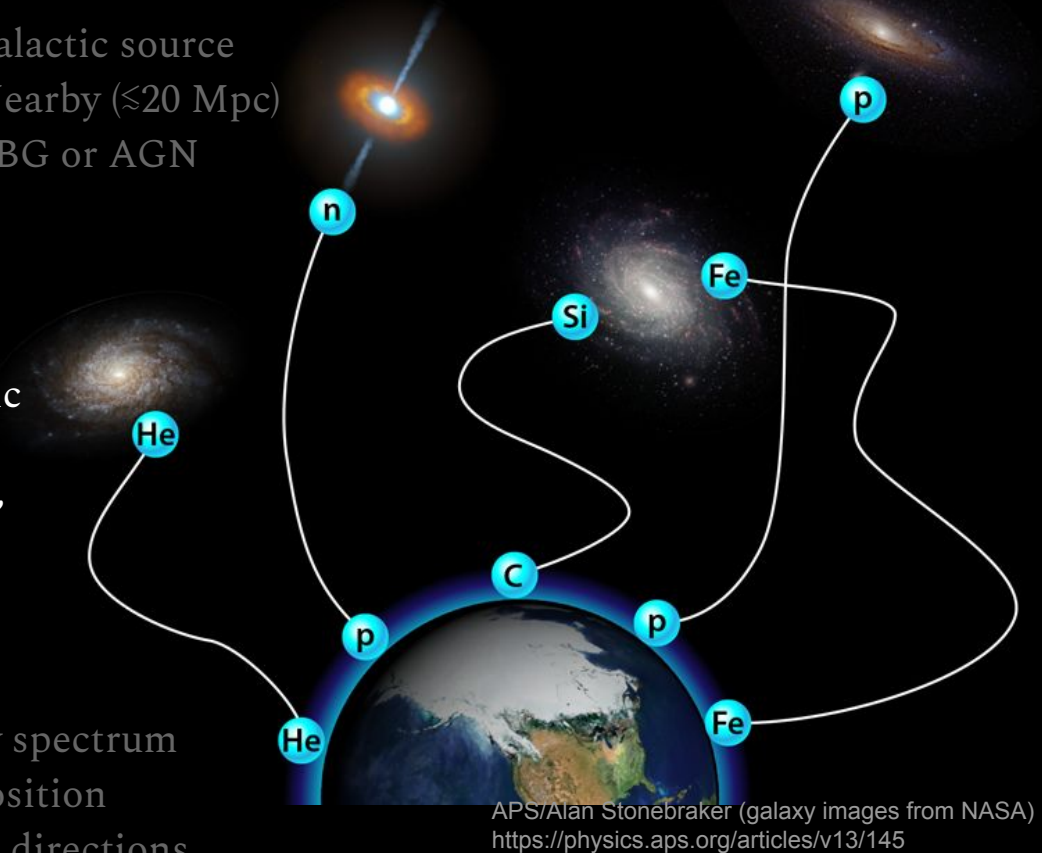
APS/Alan Stonebraker (galaxy images from NASA)
<https://physics.aps.org/articles/v13/145>

Journey from the source

- Extragalactic source
 - ✓ Nearby ($\lesssim 20$ Mpc)
 - ✓ SBG or AGN

- Propagation through the Extragalactic/
Galactic environment
 - ✓ Influence of extragalactic magnetic field
 - ✓ Interactions \rightarrow secondaries ν and γ
 - CRPropa

- Earth
 - ✓ Energy spectrum
 - ✓ Composition
 - ✓ Arrival directions

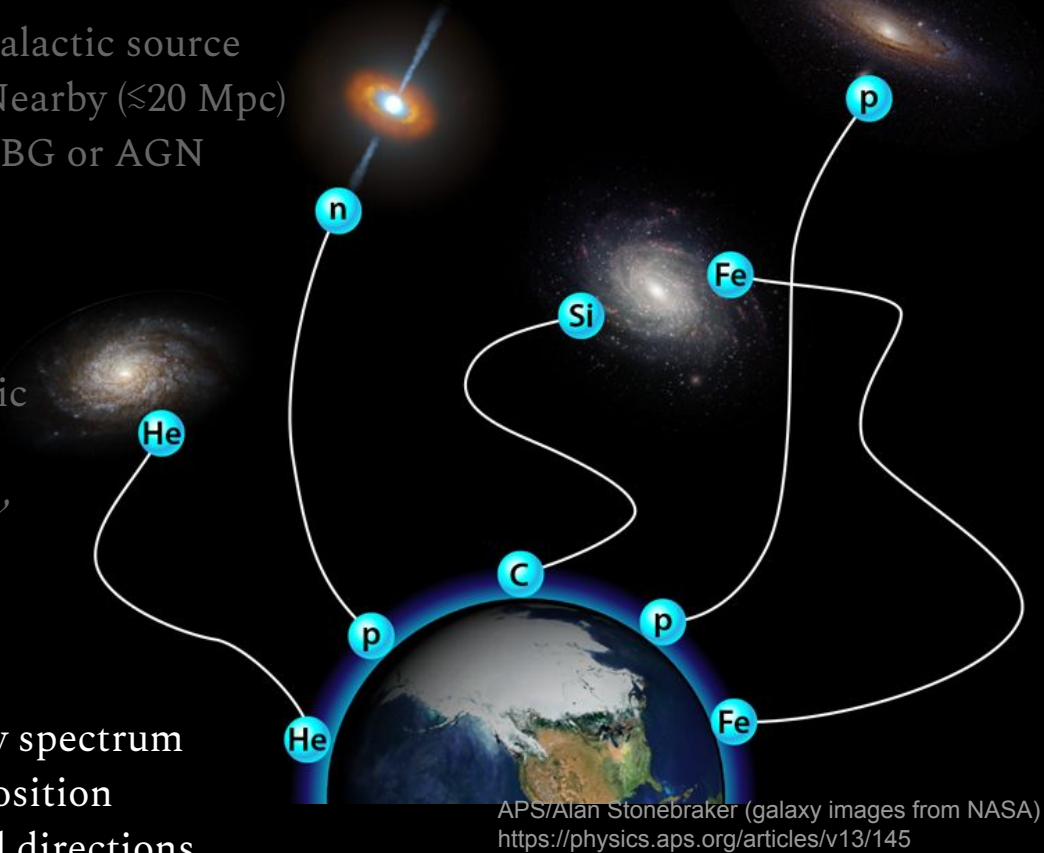


Journey from the source

- ❑ Extragalactic source
 - ✓ Nearby ($\lesssim 20$ Mpc)
 - ✓ SBG or AGN

- ❑ Propagation through the Extragalactic/
Galactic environment
 - ✓ Influence of extragalactic magnetic field
 - ✓ Interactions \rightarrow secondaries ν and γ
 - CRPropa

- ❑ Earth
 - ✓ Energy spectrum
 - ✓ Composition
 - ✓ Arrival directions



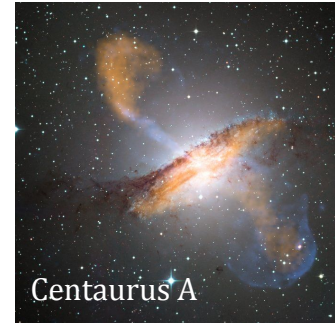
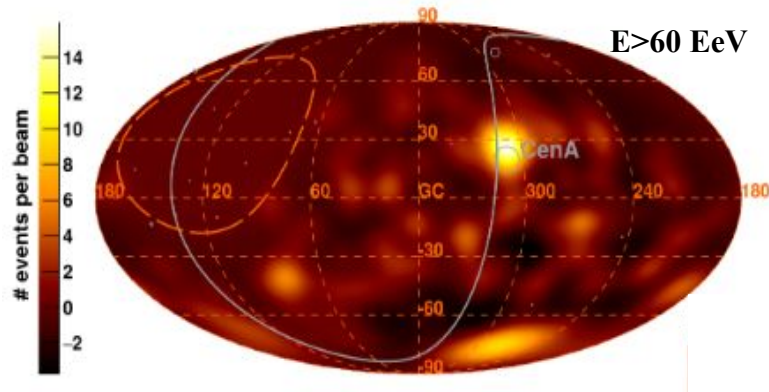
Probing UHECR production in Centaurus A using secondary neutrinos and gamma-rays

[Cainã de Oliveira](#) ✉ & [Vitor de Souza](#)

[The European Physical Journal C](#) **81**, Article number: 517 (2021) | [Cite this article](#)

669 Accesses | 9 Altmetric | [Metrics](#)

<https://link.springer.com/article/10.1140/epjc/s10052-021-09278-3>



The Pierre Auger Collaboration. AJL, 2018

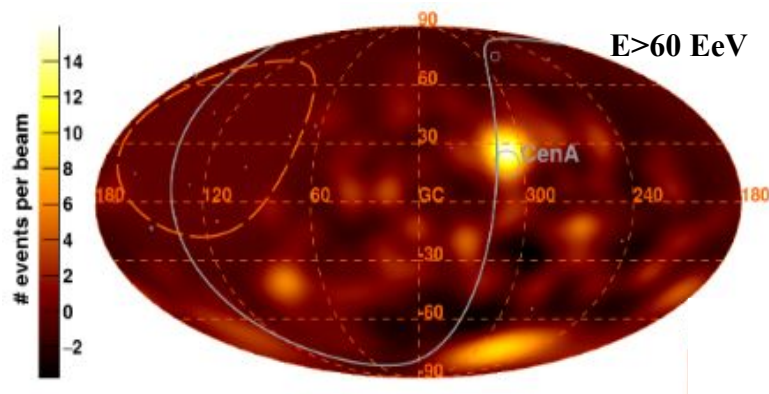
Probing UHECR production in Centaurus A using secondary neutrinos and gamma-rays

[Cainã de Oliveira](#) ✉ & [Vitor de Souza](#)

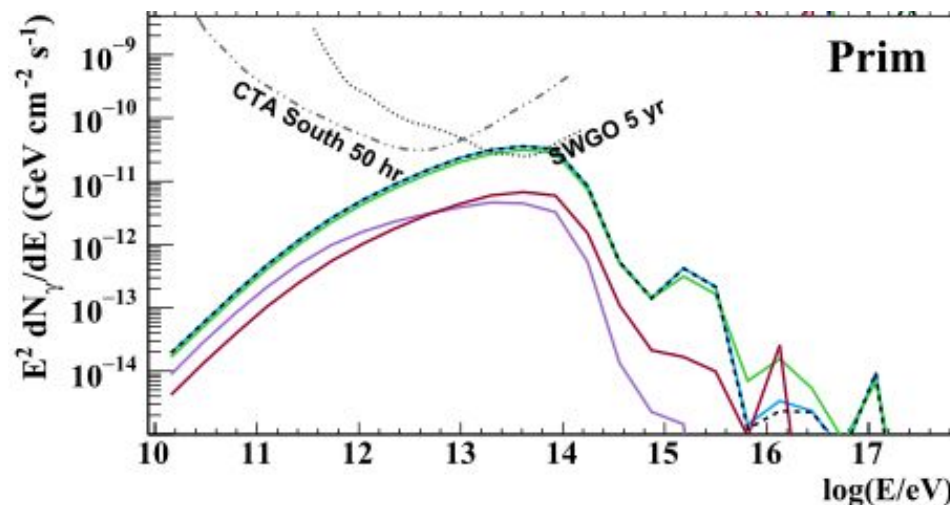
[The European Physical Journal C](#) **81**, Article number: 517 (2021) | [Cite this article](#)

669 Accesses | 9 Altmetric | [Metrics](#)

<https://link.springer.com/article/10.1140/epjc/s10052-021-09278-3>



The Pierre Auger Collaboration. AJL, 2018



Magnetically Induced Anisotropies in the Arrival Directions of Ultra-high-energy Cosmic Rays from Nearby Radio Galaxies

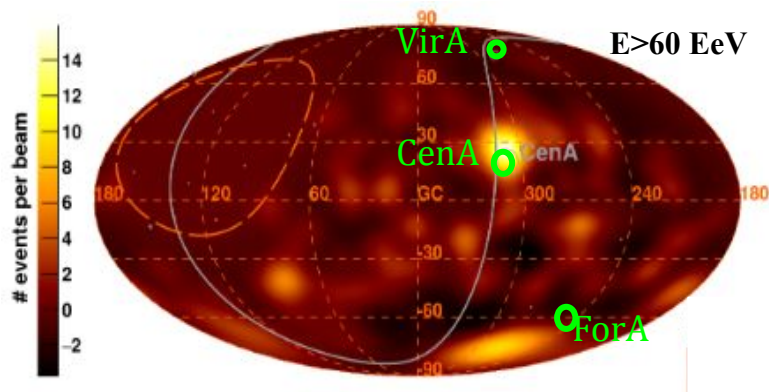
Cainã de Oliveira¹  and Vitor de Souza¹ 

Published 2022 January 24 • © 2022. The Author(s). Published by the American Astronomical Society.

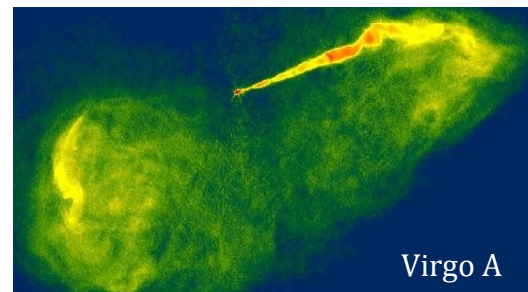
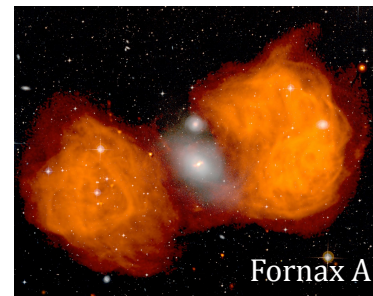
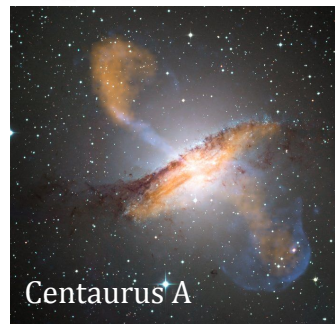
[The Astrophysical Journal](#), Volume 925, Number 1

Citation Cainã de Oliveira and Vitor de Souza 2022 *ApJ* **925** 42

<https://iopscience.iop.org/article/10.3847/1538-4357/ac3753>



The Pierre Auger Collaboration. AJL, 2018



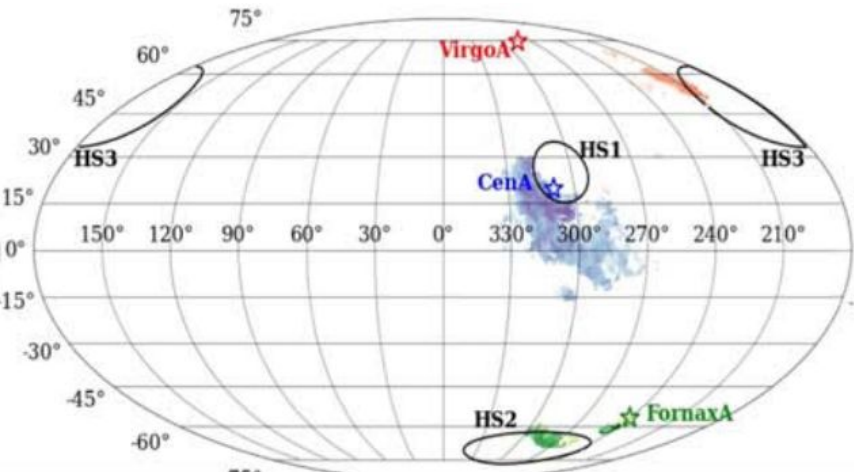
Magnetically Induced Anisotropies in the Arrival Directions of Ultra-high-energy Cosmic Rays from Nearby Radio Galaxies

Cainã de Oliveira¹  and Vitor de Souza¹ 

Published 2022 January 24 • © 2022. The Author(s). Published by the American Astronomical Society.

[The Astrophysical Journal](#), Volume 925, Number 1

Citation Cainã de Oliveira and Vitor de Souza 2022 *ApJ* **925** 42



Some results...

- Importance of Extragalactic Magnetic Field
 - Virgo A absence
- CenA, VirA, and ForA and Auger dipoles directions

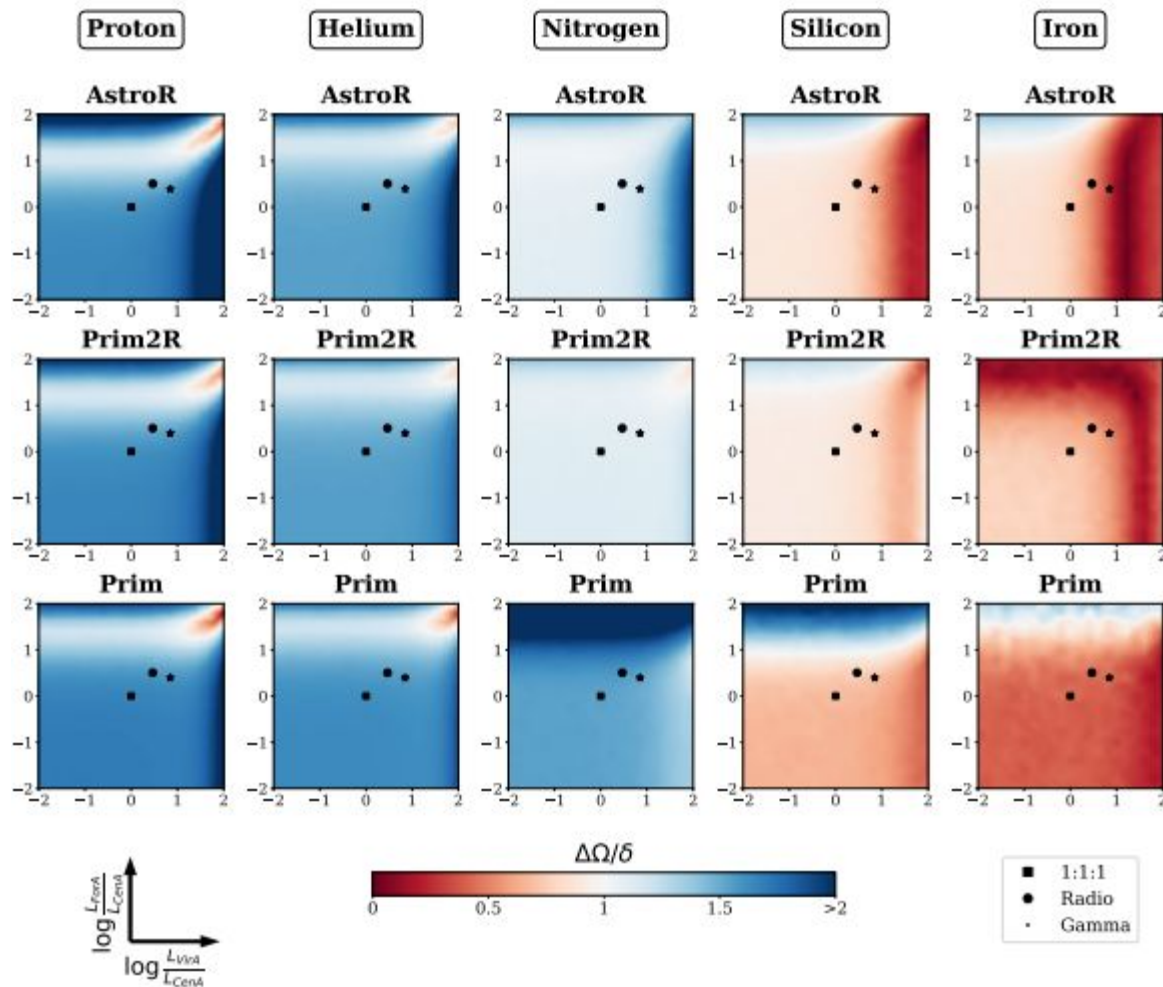
Nearby active galactic nuclei and starburst galaxies as sources of the measured UHECRs anisotropy signal

Cainã de Oliveira and Vitor de Souza

Instituto de Física de São Carlos, Universidade de São Paulo, Av. Trabalhador São-carlense 400, São Carlos, Brasil.

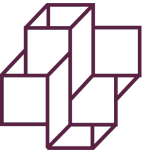
E-mail: caina.oliveira@usp.br, vitor@ifsc.usp.br

Abstract. The Pierre Auger and the Telescope Array observatories have measured independent and statistical significant anisotropy in the arrival direction of ultra-high-energy cosmic rays (UHECR). Three hotspot regions with relative excess of events and a dipole signal have been identified in different regions of the sky and energy ranges. In this paper, we investigate the conditions under which these anisotropy signal could be generated by nearby (<23 Mpc) active galactic nuclei (AGN) and/or starburst galaxies (SBG). We studied a wide range of possibilities including injected nuclei (p, He, N, Si, and Fe), three UHECR luminosity proxies and three extragalactic magnetic field models. The results shows that both local AGN and SBG are needed to describe all the anisotropy signal. The contribution of AGN to hotspots and to the generation of the dipole is dominant in most cases. SBG is required only to explain the hotspot measured by the Telescope Array Observatory.





UNIVERSITY
OF SÃO PAULO
São Carlos Institute of Physics



LABORATÓRIO NACIONAL
DE COMPUTAÇÃO CIENTÍFICA
LNCC

Contact me! We can collaborate!

caina.oliveira@usp.br