# Acceleration and propagation of charged cosmic ray particles

recent progress from Opava

Arman Tursunov, **Martin Kološ**,
Berenika Čermáková, Zdeněk Stuchlík, ...
Institute of Physics, Silesian University in Opava

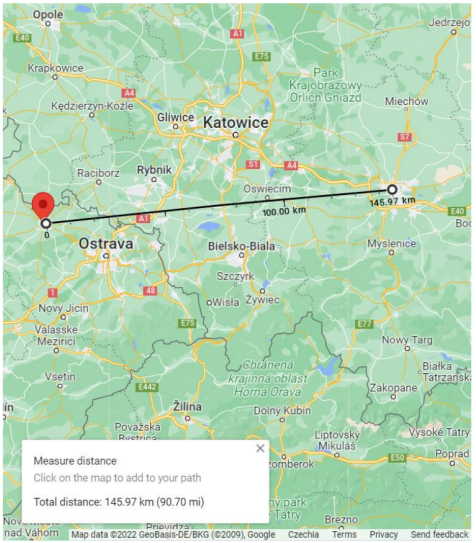
1st CREDO Visegrad Workshop,
15.-17.1.2024 IFJ PAN, Krakow

# Cosmic Rays & CREDO at Institute of Physics (Opava) 2023

- Arman Tursunov & Piotr Homola: submitted GAČR project: "Ultra high energy cosmic rays from supermassive black holes: theory and observations", not funded :-(
- Berenika Čermáková: diploma thesis - Cosmic Ray Propagation from the Galactic Center, successfully defended
- Martin Kološ, Arman Tursunov: Energy spectrum of ultra high energy cosmic rays accelerated by rotating supermassive black holes, Proceedings of RAGtime 23–25, 47–53 (2023)
- Sgr A* as a PeVatron: acceleration capability of a black hole at the Galactic centre, article in preparation

- some grants proposals in progress (OP JAK: Sun activity, radio-astronomy - connection to CREDO? - for more info: arman.tursunov@physics.slu.cz )

# Future prospects: Cracow-Opava Array (CROPA)




**CROP Array** will consist of at least 24 small, affordable, off-the-shelf radiation detectors of 3 types at our exclusive disposal:

- muon detectors such as CosmicWatch
- desktop air shower detector, as CosmicHunter
- particle camera such as TimePix or MiniPIX
- connected to CREDO

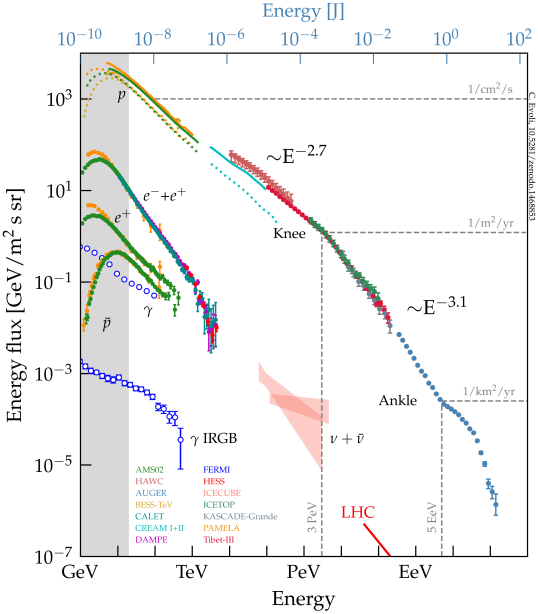
Benefits from **CROP Array**:

- Economical: testing optimization strategies
- Testing the use of diverse detector technologies
- Testing CRE scenarios with a base of 150km?
- Good training in data taking for students
- Students exchanges and mobilities
- International collaboration
- ...?

In parallel: developing algorithms that will make us prepared to notice the unexpected physics effects if they come (based on identification of anomalies in the signals).

the rest of the talk:
- some theoretical model for cosmic ray production

Galactic Cosmic Rays (classical model): charged particles (protons, electrons, ions) are accelerated to nearly the speed of light by intense magnetic fields in explosive events such as supernova.



# How to accelerate charged particles?

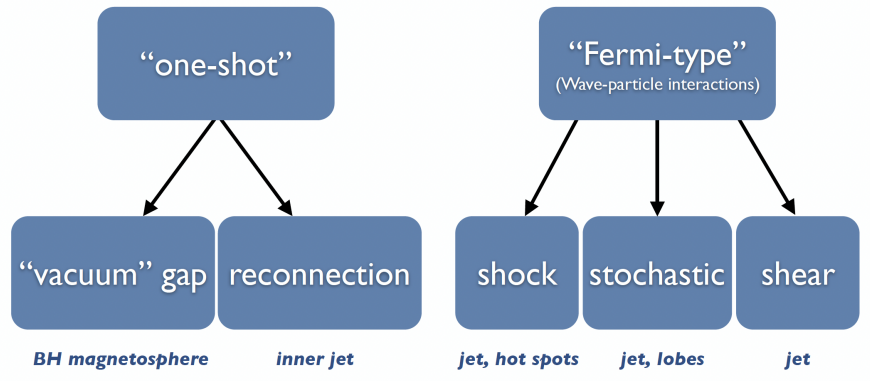



Figure taken from very nice paper:

• Frank M. Rieger: Active Galactic Nuclei as Potential Sources of Ultra-High Energy Cosmic Rays, Universe, Volume 8, Issue 11, id.607 (2022)

# Multimessenger era: Black holes as cosmic rays source

Observations of $\gamma$-ray photons from the Galactic Centre region showing acceleration of PeV particles: High Energy Stereoscopic System (H.E.S.S.) collaboration: Acceleration of PeV protons in the Galactic Centre, Nature 531, 476 (2016)

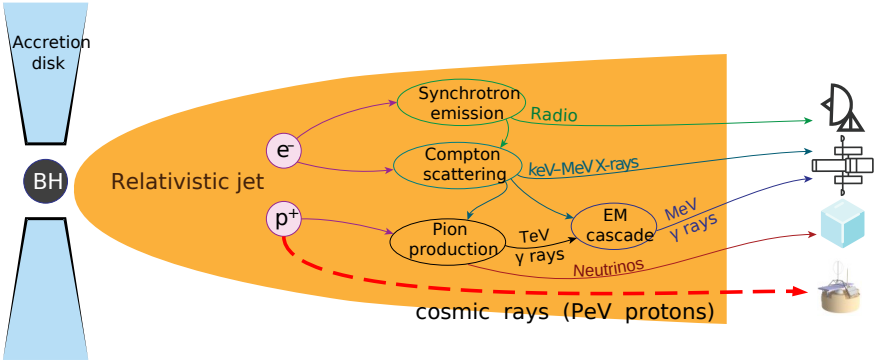
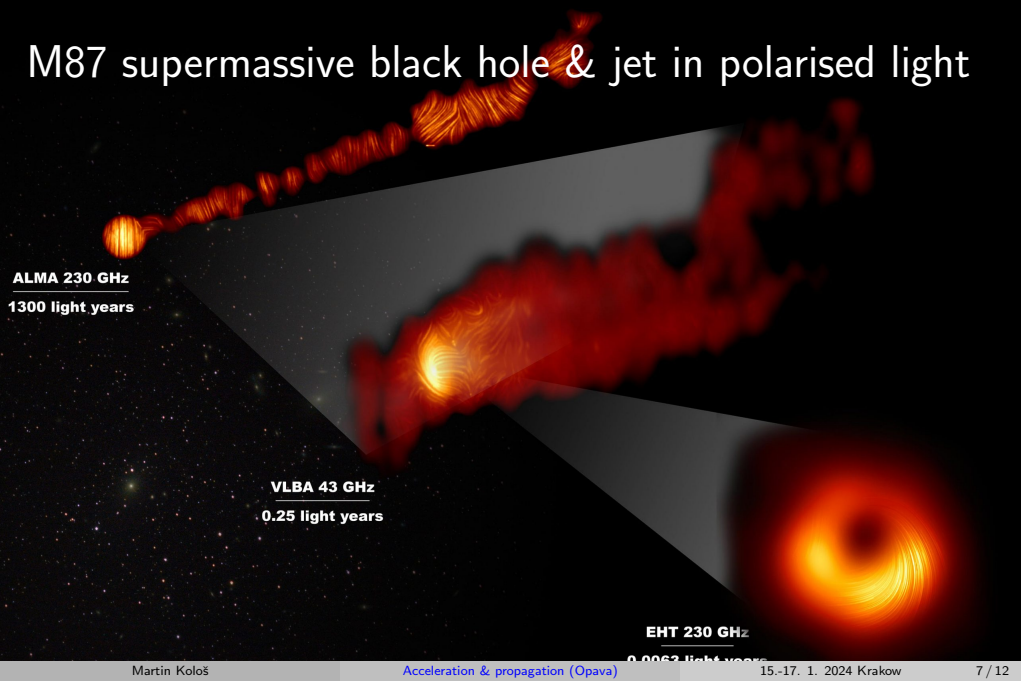
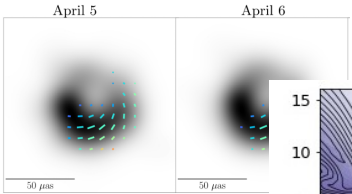


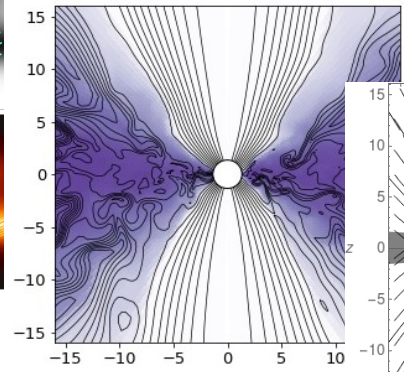

figure from: A.V.Plavin et al., The Astrophysical Journal, Volume 908, Issue 2, id.157 (2021) + my small update

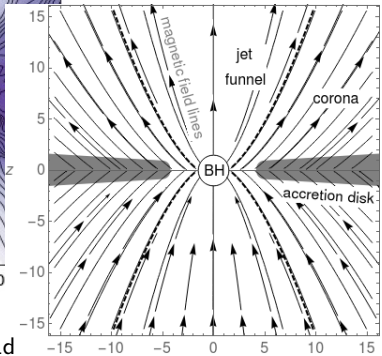
# M87 supermassive black hole & jet in polarised light



# Black hole, accretion disk and electro**magnetic** field:
observation || numerical experiment || analytical model




$B_{\mathrm{M87}} \sim 10$ Gs

from "Polarization of the Ring": 10.3847/2041-8213/abe71d

# Charged particle acceleration - magnetic Penrose process

- How to populate BH magnetosphere with charged particles (particle injection): neutral particle split - ionization or decay
- neutral particle (1) $\rightarrow$ charged (2) + (3)

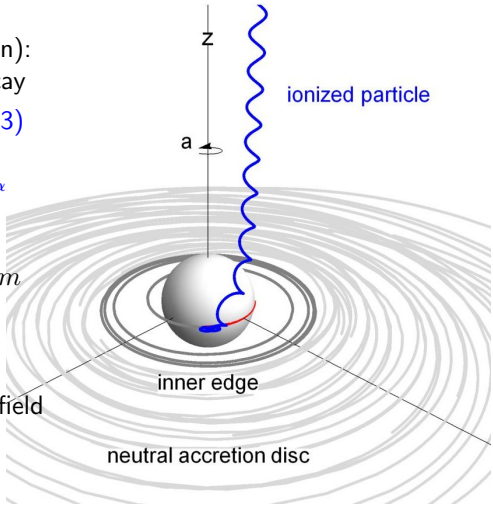
$$p_{\alpha(1)} = p_{\alpha(2)} + qA_\alpha + p_{\alpha(3)} - qA_\alpha$$

- axial symmetry $A_\alpha = (A_t, 0, 0, A_\phi)$
- $A_t$ can change particle energy $\mathcal{E} = E/m$

$$\boxed{\mathcal{E} = -g_{t\alpha}u^\alpha + (q/m)A_t}$$

- BH rotation $g_{t\phi}$: electric $\leftrightarrow$ magnetic field

selective accretion
$\rightarrow$ BH with Wald charge $Q_{\rm W} = 2aMB$




• A.Tursunov,Z.Stuchlík,M.Kološ,N.Dadhich,B. Ahmedov,: *Supermassive Black Holes as Possible Sources of Ultrahigh-energy Cosmic Rays*, The Astrophysical Journal, Volume 895,

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- available energy (BH rotation) ✓
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  one-shot acceleration model
  proton and $M_{\mathrm{SgrA}} = 4.3{\times}10^{6}\,\mathrm{M}_{\odot}$

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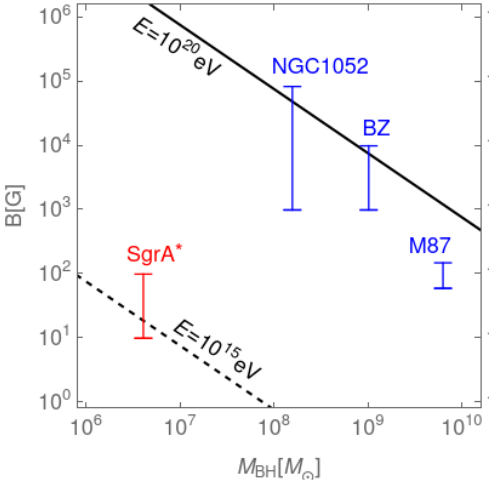

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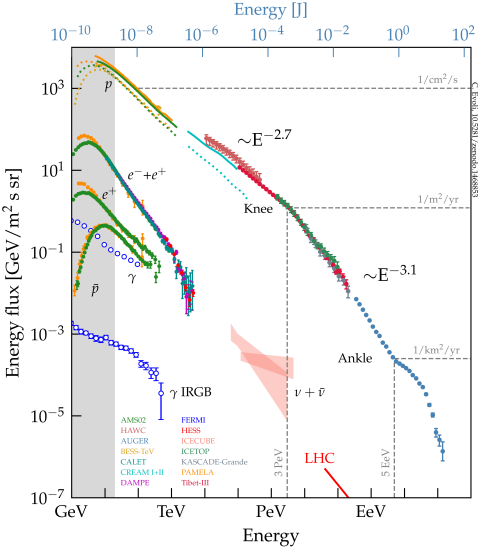

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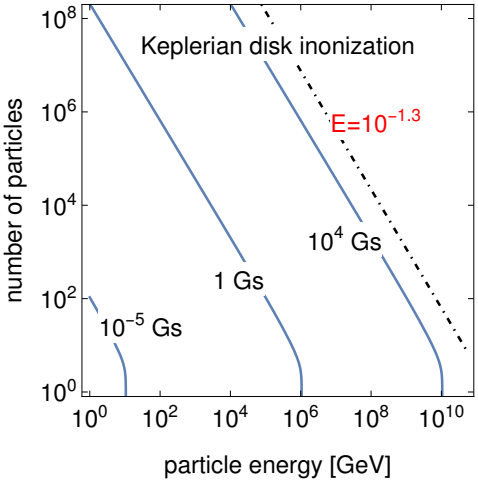

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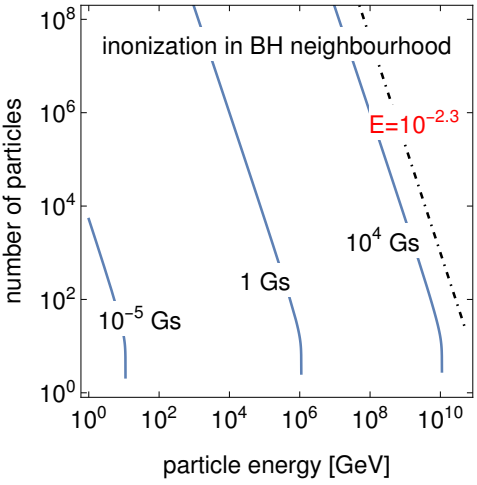
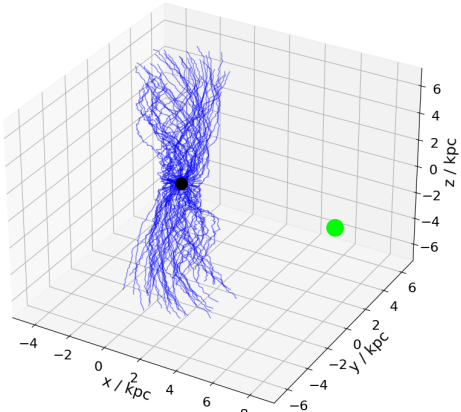
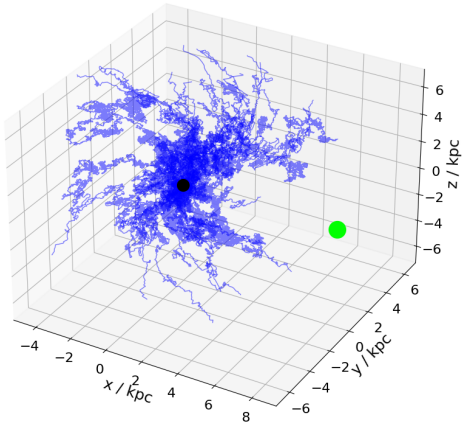


# PeV proton propagation from Sgr A* to Earth (Berenika Čermáková)

fast particle / more energy




slow / less energy (no incoming direction)




toy model: Sgr A* BH - isotropic source shooting protons with 50 PeV energy
CRPropa / GALPROPa = charged particle propagation: https://crpropa.desy.de/

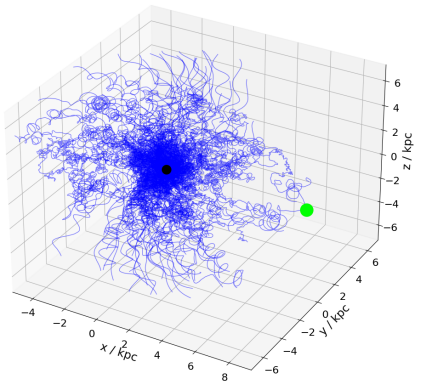
# Summary & we are working...

CREDO collaboration

- detector field Cracow-Opava Array
- data analysis (nonlinear methods)

theoretical models

- black hole as particle accelerator
- SgrA* BH as PeVatron, CR propagation




## Thank you for your attention

• A. Tursunov, M. Kološ, Z. Stuchlík: *Constraints on Cosmic Ray Acceleration Capabilities of Black Holes in X-ray Binaries and Active Galactic Nuclei*, Symmetry 14 (3), 482 (2022)