IST-PhysFront'25

Master's in Engineering Physics

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Modelling the accretion-ejection flow around the supermassive black hole at the centre of the Milky Way

Introduction

About **50 years** of observations regarding **Sagittarius A*** (Sgr A*):

- The **supermassive black hole** at the center of our galaxy was first detected in 1974 [1];
- In 2022, the first reconstructed images of Sgr A*'s close environment were made, by the Event Horizon Telescope (EHT) collaboration [2].

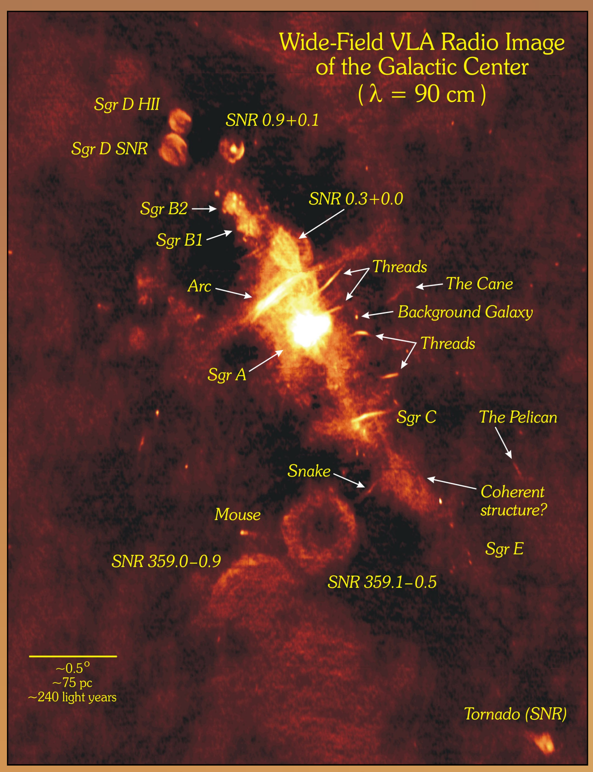


Fig1. Labeled Map of Our Galaxy's Center. https://public.nrao.edu/gallery/labeled-map-of-our-galaxys-center

Objectives

Objectives: create a new analytical model, capable of reproducing the observed spectrum, EHT images, and polarized quantites.

GYOTO

The relativistic ray-tracing code [3]

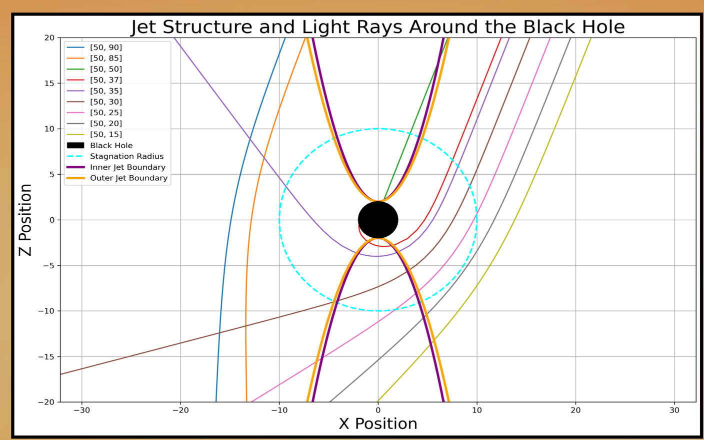


Fig2. Representation of the simulated null geodesics (path of light rays)

1. Computation of light ray geodesics;
2. Integrates over the polarized radiative transfer equations;
3. Create *synthetic images*

Torus Disk + Conical Jets Model

(by *Vincent et al 2019* [4])

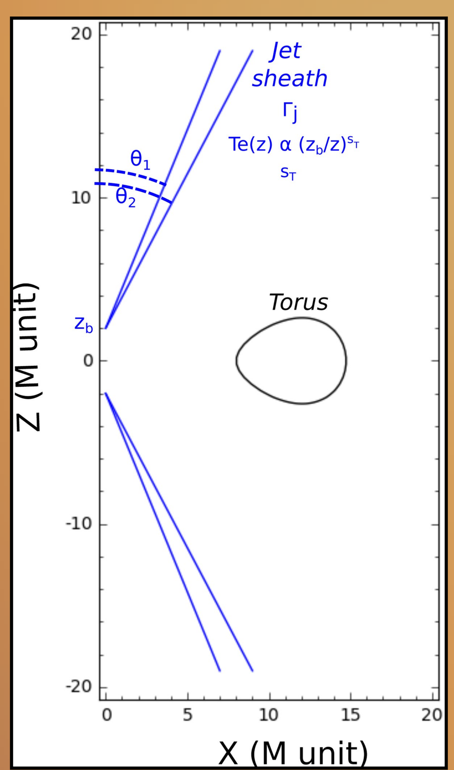


Fig3. Sketch of the ***Torus disk + conical jet model*** taken from [4]. In it we can find a representation of the front and backward jets + the torus shaped disk.

In 2019, an attempt at fitting the observed spectrum with analytical models was made.

- It was a simple and purely analytical solution;
- Capable of reproducing the black hole's close environment;
- Was able to fit very accurately the observed spectrum.

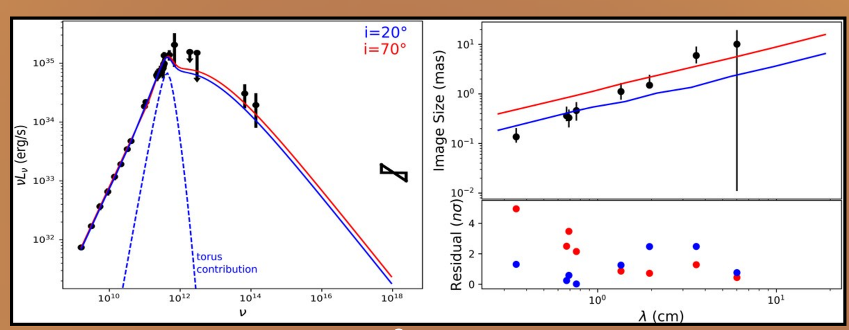


Fig4. Best fitting results ($\chi^2 = 0.54$) using the torus disk + conical jets model taken from [4].

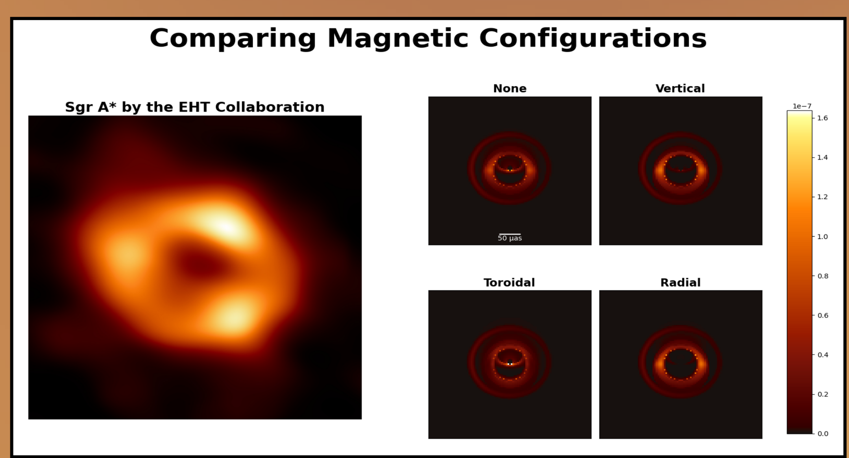


Fig5. Simulated images of the relativistic jets with different geometries/shapes and magnetic configurations. Comparison being made with 2022 image of Sgr A* [2].

A few key points to improve on:

- Ring structure from **Fig6.** rises from disk's shape;
- Brightness found in the center of the image (where it should be dark);
- Conical jets' shape is not very realistic.

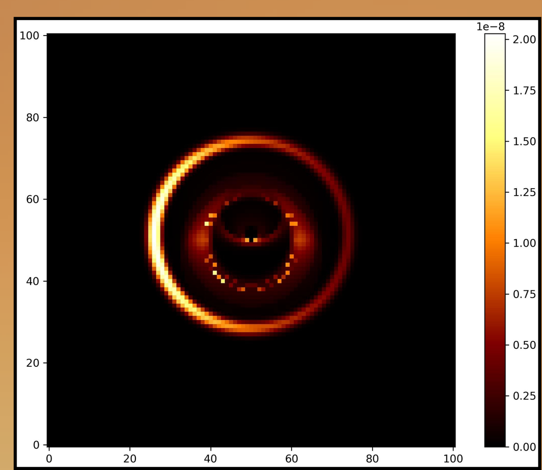


Fig6. Synthetic image of the Torus disk and conical jets model at *230 GHz.*

Thick Disk + Parabolic Jets Model

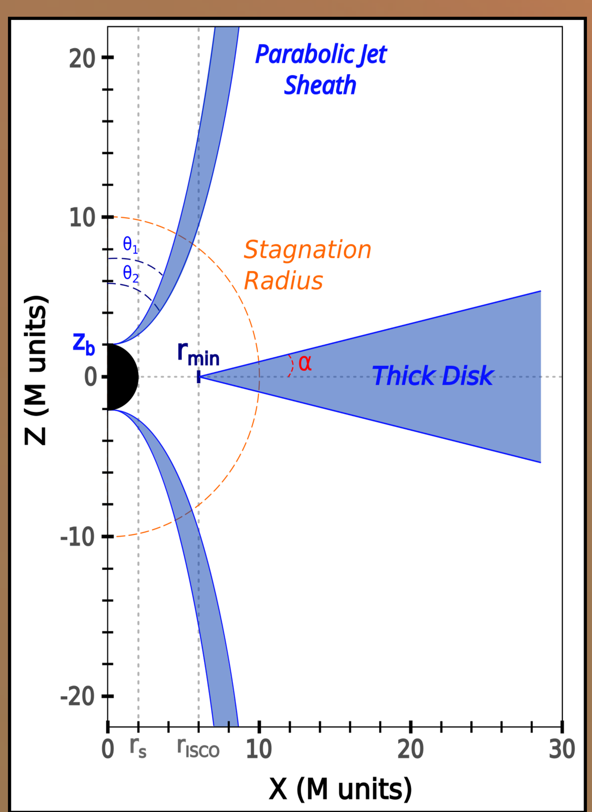


Fig7. Sketch of the ***Thick Disk + Parabolic Jets model***. The profile picture shows us the two parabolic shaped jets and the thick disk (with a "triangular" profile appearance). The jets' and disk's interior is in blue.

Improvements made:

- Thick Disk's & Parabolic jets' shape corresponds to their expected shape.
- Deals with extra brightness and expected observations from a distance.

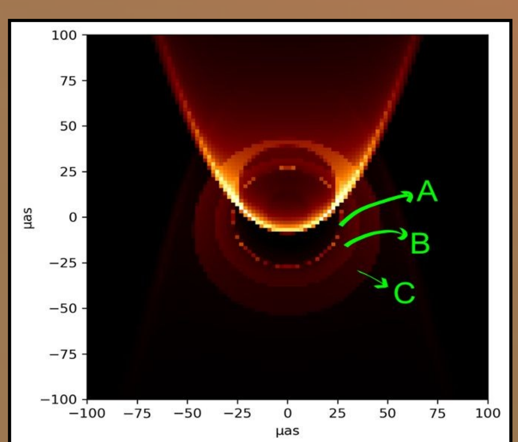


Fig8. Synthetic image of the parabolic jets. **Region A:** Photon ring. **Region B:** Beamed in-falling particles. **Region C:** Backward Jet's primary image.

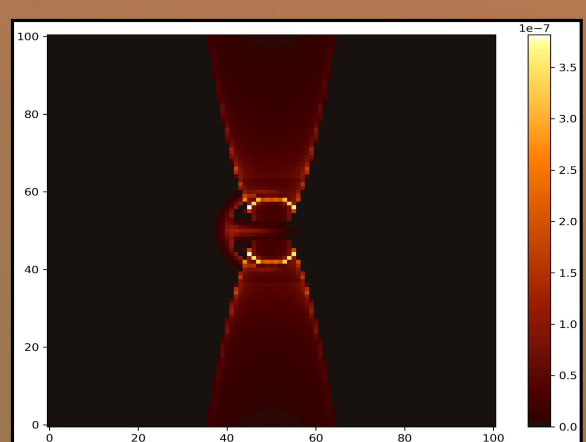
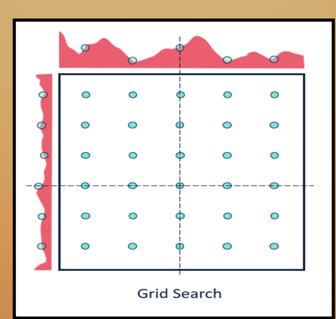


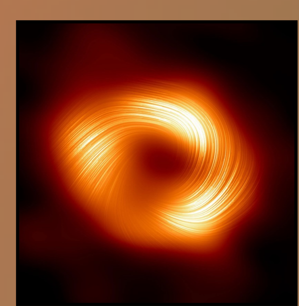
Fig9. Synthetic image to represent the Thick Disk and parabolic jets model at 91° inclination.

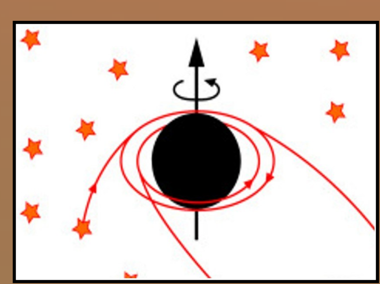
Conclusions & Future Work



A fitting of the spectrum is to be made to find the best/closest physical parameter values.

Attributes to analyse are, for example, the polarized quantities or the visible shadow radius.





How do different initial values of the spin parameter — *a* — change the results?

Using GYOTO, we aim to **fit** all observational data of Sgr A*, **including *EHT* image, spectra and polarization** to produce the best "quiescent" model.

References:

- [1] B. Balick and R. H. Sanders, "Radio Fine Structure in the Galactic Center," *Astrophysical Journal*, vol. 192, pp. 325–336, Sep. 1974.
- [2] The Event Horizon Telescope Collaboration et al. "First Sagittarius A* Event Horizon TelescopeResults. VII. Polarization of the Ring". In: The Astrophysical Journal Letters 964.2 (Mar. 2024),p. L25. DOI: 10 . 3847 / 2041 - 8213 / ad2df0. URL: https : / / dx . doi . org / 10 . 3847 / 2041 -8213/ad2df0.
- [3] F. H. Vincent, T. Paumard, E. Gourgoulhon, and G. Perrin, "Gyoto: A new general relativistic ray-tracing code," Classical and Quantum Gravity, vol. 28, no. 22, p. 225 011, Oct. 2011.
- [4] Vincent, F. H. et al. "Multi-wavelength torus–jet model for Sagittarius A*". In: A&A 624 (2019),A52. DOI: 10 . 1051 / 0004 - 6361 / 201834946. URL: https : / / doi . org / 10 . 1051 / 0004 - 6361 /201834946.

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