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Title: Jipole: An Autodiff, Julia based code, for ray tracing images in curved space time

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Jipole: An Autodiff, Julia based code, for ray tracing images in curved space time

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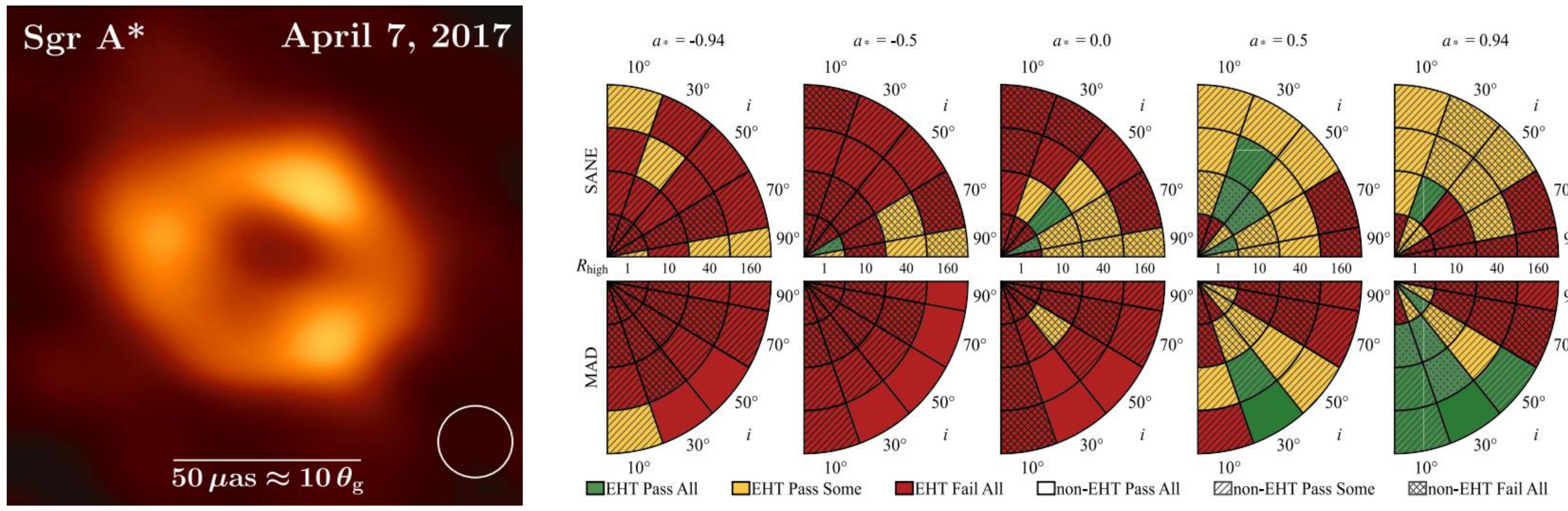
Black hole Imaging

A black hole's gravity is so strong that light cannot escape. Infalling gas forms a hot accretion disk that emits light, revealing the black hole's presence. Strong magnetic fields cause electrons to spiral and emit synchrotron radiation in radio waves, offering key insights into the black hole's environment.



(**Left**) One of the Sgr A*, the supermassive black hole at the center of our Galaxy, radio images released by the event horizon telescope (EHT) collaboration in 2022. (**Right**) The result of an extensive parametric search to properly reproduce the Sgr A* image through simulated images.

- In 2022, the EHT collaboration released a radio image of Sagittarius A*, the supermassive black hole in the center of the Milky Way.
- To interpret the image, the EHT ran a large parameter survey using general relativistic magnetohydrodynamics (GRMHD) simulations, varying properties such as spin, magnetic field strength, and orientation.
- This data analysis process was computationally expensive because generating synthetic images requires post-processing massive GRMHD datasets, limiting the number of parameter combinations that can be explored.

Our proposed approach to accelerate this challenging data analysis task

Jipole: A Julia-based code with AutoDiff

A fast, differentiable radiative transfer code built in Julia to process GRMHD simulation data, based on ipole [1].

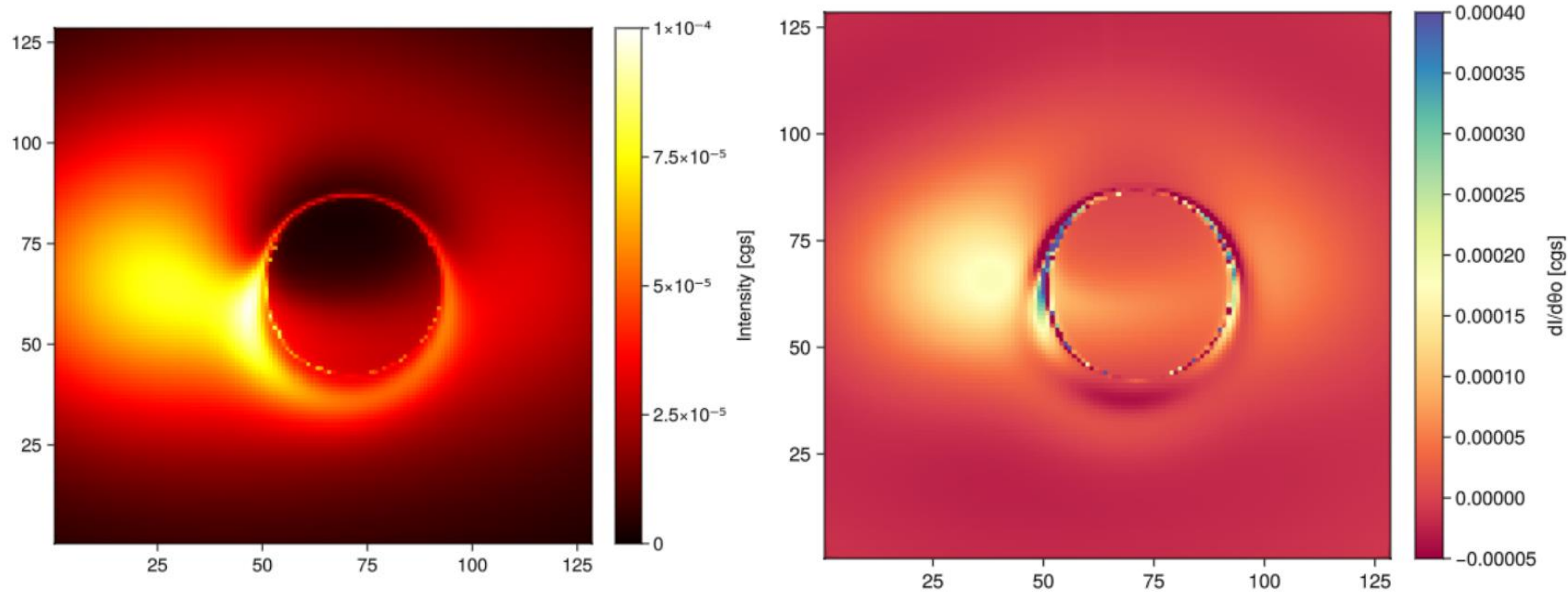
Pixel-wise Intensity Derivatives

Automatically compute the derivative of image intensity with respect to physical and observational parameters at each pixel.

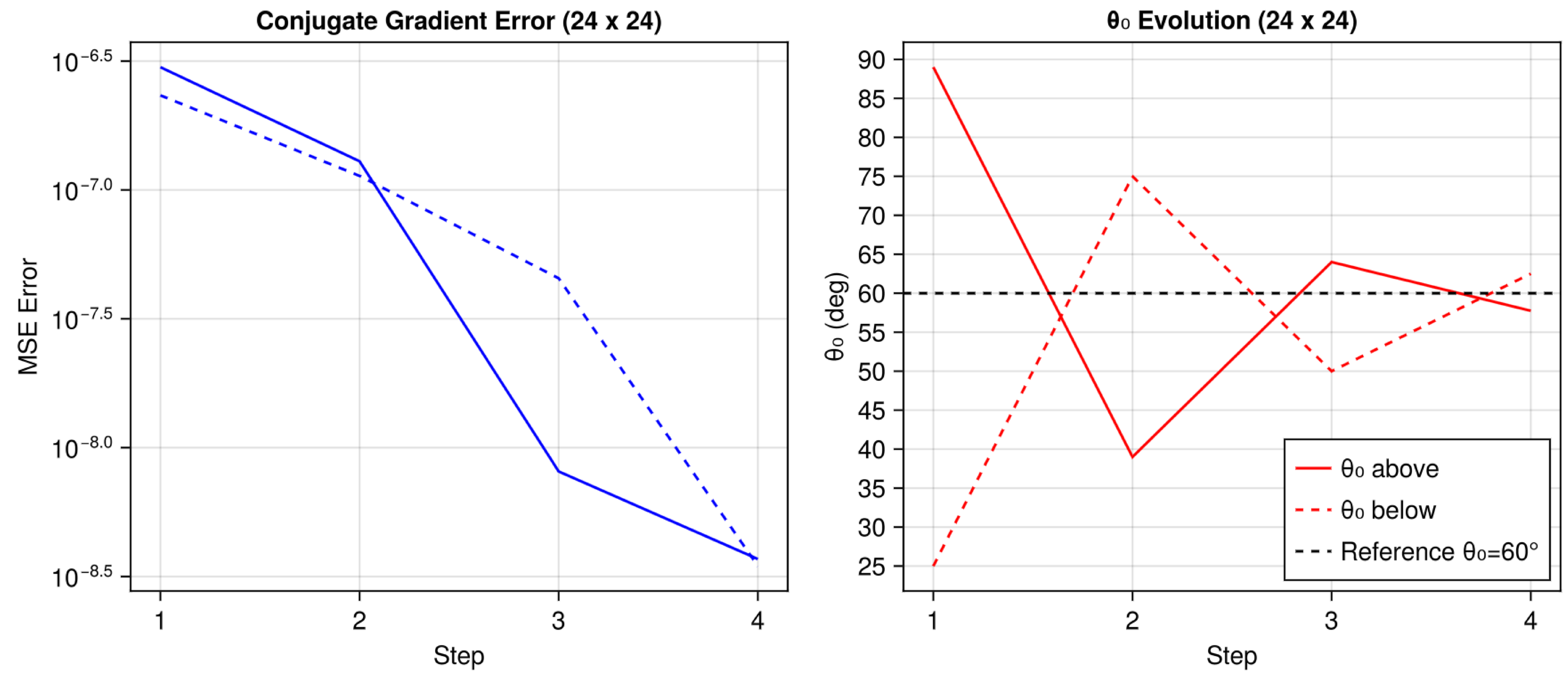
Gradient-Based Optimization

Use these derivatives in algorithms like gradient descent or conjugate gradient to efficiently infer model parameters.

Preliminary Results



(**Left**) A black hole imaging simulation as depicted in [2]. (**Right**) Colormap depicting dI/dθo, i.e., the derivative of intensity with respect to θo, the inclination angle, for each pixel.



(**Left**) Gradient descent method mean squared error. (**Right**) Value of θo for each step. Showcases the convergence to the reference inclination angle value.

- **Takeaways**: Using a phenomenological plasma model [2], we can generate images of black holes and their corresponding dI/dθo map, where θo is the observer's inclination angle, highlighting Jipole's approach to speed up data analysis.
- We apply gradient descent from two initial angles to test convergence toward the true inclination. Both tests converge in a small number of steps.

References

[1] M Mościbrodzka, C F Gammie. 2018,MNRAS 475 <https://doi.org/10.1093/mnras/stx3162>

[2] Gold et al. 2020, ApJ, 897, 148 <https://doi.org/10.3847/1538-4357/ab96c6 >