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Krang: Kerr Raytracer for Analytic Null Geodesics

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Summary

`Krang` is a Julia (Bezanson et al., 2017) package that implements efficient algorithms for raytracing emission geometries in the Kerr black hole space time. It is GPU compatible and is specialized for studies of sub-image contributions from gravitationally lensed sources (Johnson et al., 2020). Such algorithms are of interest for modeling the sources seen by Very Long Baseline Interferometry (VLBI) observations of Low Luminosity Active Galactic Nuclei (LLAGN) such as those imaged by the Event Horizon Telescope Collaboration (EHTC).

Statement of need

Studies of electromagnetic signatures around black holes have increased in interest due to results from the horizon-scale observations of supermassive black holes by the Gravity Collaboration, the Atacama Large Millimeter Array (ALMA), and the EHTC. The Event Horizon Telescope, in particular (EHT, Event Horizon Telescope Collaboration, 2019b), produced the first images of the shadows of the supermassive black holes in the centers of M87 (Event Horizon Telescope Collaboration, 2019a) and the Milky Way (Event Horizon Telescope Collaboration, 2022) at event-horizon scales, with emission being sourced from the interactions of accreting relativistic plasmas and magnetic fields within the vicinity of the black holes. Scientific analysis of the data from these sources often requires complicated source modelling that includes various relativistic effects that can leave characteristic signatures in the observed images. The large scale of the black holes allows for many of these effects to be described within the geometric optics limit of electro-magnetism. Raytracing techniques thus present viable options for modeling images of supermassive black holes.

A relativistic image feature that has been theorized to exist, but is yet to be resolved, are the individual sub-image contributions to the overall image structure known as photon-rings, (Johnson et al., 2020). Photon rings are of particular interest because of their strong dependence on gravitational effects and their insensitivity to variations in the emission physics around the black hole. The observation of a photon ring would therefore serve as effective probe for measurements of black hole characteristics like spin or help facilitate tests of gravity. This feature could potentially be seen in the near future with a recently proposed space extension to the EHT aimed at detection and measurement (Lupsasca et al., 2024).

Scientific studies of black hole images within the current software landscape often require great compromise due to the computational complexity of the problem. Other difficulties can arise from interfacing existing raytracing software with the wider ecosystem of tools; it is difficult, for example, to apply machine learning optimization algorithms to existing Python raytracing codes since they typically rely on special functions that are not implemented within current machine learning frameworks. Existing Python implementations are also bounded to CPU evaluations, limiting their capability of accessing acceleration from specialized hardware. A Julia implementation of raytracing algorithms is thus beneficial because of the language's modular design, differentiable programming and efficient execution. Krang therefore benefits from the ‘plug and play’ nature of the Julia programming language, allowing for easy development and synergy with existing analysis pipelines, and fast CPU/GPU executions.

Similar Packages

- `AART` (Cárdenas-Avendaño et al., 2023): An adaptive analytical raytracing code for geodesics in the Kerr space time in Python.
- `KerrBam` (Palumbo et al., 2022): An analytical raytracing code for equatorial synchrotron models in Python.
- `Gradus` (Baker & Young, 2022): A Julia implementation of a numeric, general relativistic raytracer with radiative transfer.

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