Measuring the Spin of Sgr A* with the EHT

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Abstract
We simulate EHT observations of infalling gas clouds embedded in a black hole accretion disk and then use the power spectrum density and shot analysis to investigate whether we can detect the orbital period of photons, which depends on the black hole spin. Both methods successfully obtained the expected orbital period of photons, and thus the spin of the black hole.

Motivation
1. Black hole spacetime is predicted by general relativity to be uniquely determined by the black hole mass and spin (normalized angular momentum of a black hole).
2. Spin is hard to measure, as it requires observations from extremely close to the black hole.

Background
While black hole masses are often measured by observing the motions of orbiting stars or gas, spin measurements are much harder because they require observations of material very close to the black hole. The Event Horizon Telescope (EHT, [1]) provides the necessary angular resolution to see close enough to nearby black holes, including the galactic center’s black hole Sgr A*, to infer their spin.

Methods
We used a two-component model, with an inner component of infalling gas clouds, and an outer component of a slower orbiting hot spot. Observations were simulated using the 2017 EHT array [1] with an eight-hour observation period. The synthetic observational data was processed using an imaging package called SMILI [4-6]. SMILI is a new imaging package developed for the EHT, implementing dynamical imaging algorithms that reconstruct movies of rapidly changing structures. Currently needed only for Sgr A*, but as the EHT acquires more data, dynamical imaging may need to be used to image other black holes. Dynamical imaging reconstructs movies directly without any segmentation of data by regularizing the frame-to-frame variations, providing much higher-fidelity images than the traditional snap-shot imaging.

Model & Imaging

Power Spectrum Density
Power spectrum density: Performs a Fourier analysis on the data and returns the frequencies of the dominant periodic functions.

Shot Analysis
Shot analysis: A way of extracting the periodic behavior out of a chaotic system. Performed on data between two telescopes.
1. Breaks data into time frames of 50 $r_g/c$ long.
2. Finds maximum peak in each time frame.
3. Aligns maximum peaks to combine frame data into one plot to make periodic behavior more prominent.

Results
Power spectrum density: The power spectrum density was able to extract the frequencies of both the inner and outer component of the model. The inner component frequency matched both the period from the shot analysis and the expected period, giving confidence to the result that we can measure the orbital period of photons and thus measure the spin.

Shot analysis: The ALMA-JCMT baseline shot analysis calculated a period of 20 $r_g/c$, agreeing with the expected value. Furthermore, the location of the two peaks aligned with where they were expected to be.

References