Visualizing the event horizon of a black hole

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Abstract

The “Event Horizon Telescope”, EHT, is a radio-telescope planetary network, and its goal is to reach a sufficiently high spatial resolution to obtain real images of Sgr A*, a supermassive black hole located at the core of our galaxy. Waiting for real observational data, now we can analyze predicted EHT data obtained from a simulations to "see" the event horizon and the neighborhood of Sgr A*. In this brief research note we suggest a method to improve the capabilities of our current image analyses, using a proper isometric pesudo-3D projection analysis. In fact, the details obtained are impressive and this first result suggests that the pseudo-3D isometric projection analysis could be a useful tool to better study the main properties of the surroundings of the event horizon of a black hole.

The “no hair” theorem of the black hole physics, based on General Relativity theory, predicts that the space-time around a black hole can be expressed in terms of only three physical parameters: the mass of the black hole, its intrinsic angular moment, or spin and its electric charge (if present), [1].

The strong curvature of space-time around a black hole produces a dark shadow surrounded by a bright ring of photons. The shape of this ring is approximately circular. If we will be able to detect directly that structure of a black hole using future observations, it will be possible to verify the correctness of the theory.

We know that the shadow diameter is given by: 10 m where: $m = \frac{GM}{c^2}$, is the geometrical mass of the black hole, and it is insensitive to the rotation, [1].

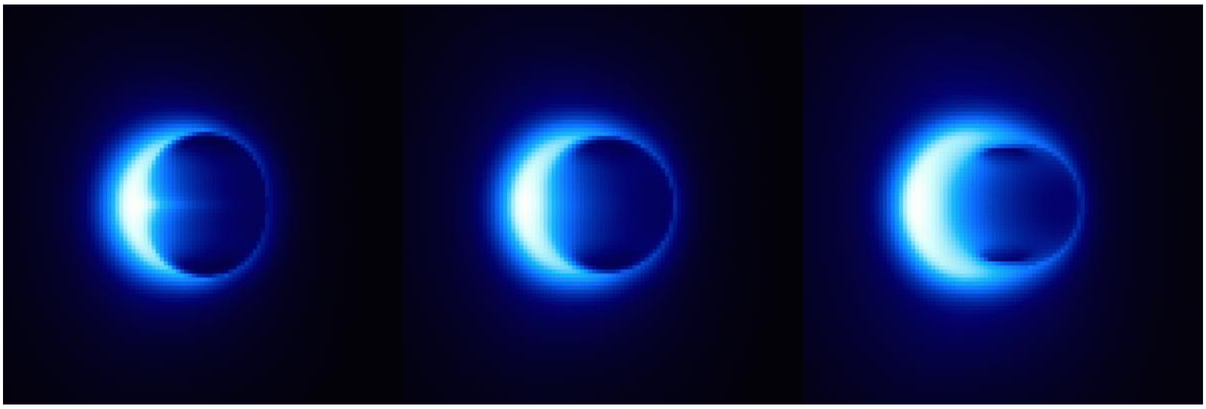

Figure 1 – Possible shadow shapes in the neighborhood of a black hole (D. Psaltis and A. Broderick, 2016).

General Relativity theory predicts that the shadow of a black hole should be circular (center image), but a black hole that violates the "no hair" theorem could have a prolate shadow (left image) or oblate (right image) . Future real “Event Horizon Telescope”, EHT, images of supermassive black hole at the center of our galaxy, called Sgr A *, with mass of 4.3×10^6 Ms and distance 26000 y.l., will verify these predictions. (ref. EHT, http://www.eventhorizontelescope.org/science/general_relativity.html. The shadow radius of Sgr A* is: ~ 3.015×10^7 km, which at the distance of the source is equal to about: 5×10^{-5} arcseconds. The radius of its event horizon is about 12×10^6 km, i.e. 17 times the equatorial radius of the Sun, [1].

We recall that EHT, is a radio-telescope planetary network, and in order to reach a sufficiently high resolution image of Sgr A*, we need to apply data interferometry using at least 7 radio-telescopes worldwide. In fact, the EHT team expects to obtain the first real image of Sgr A* in the next few years, possibly as early as 2017.

Waiting for the real observational data, Tim Johannsen of the Perimeter Institute for Theoretical Physics, Canada, and his colleagues, analyzed predicted EHT data obtained from a **simulation** to "see" the event horizon and the neighborhood of Sgr A*. The result is shown in the following figure: [2]

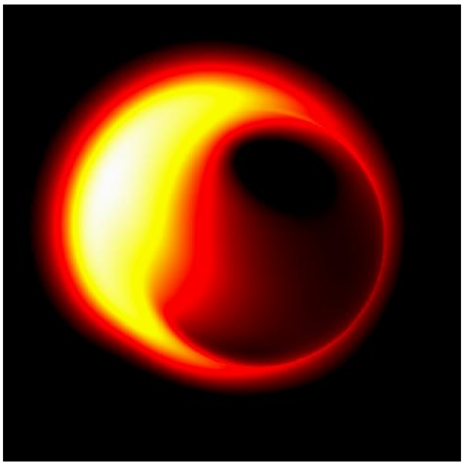

Figure 2 – Image simulation of the event horizon and the neighborhood of Sgr A* (Tim Johannsen et al., 2016)

The image size dimensions are 100x100 micro-arcseconds. The arbitrary color map is related to the emission intensity at 230 GHz.

In the above image it is visible a dark region surrounded by a light ring (accumulated photons) and a very bright region corresponding to a peak of emission due to the matter spiralling inside the gravitational field of the huge black hole. (see also: https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.116.031101).

In order to highlight even better the features and structures inside the images provided by EHT in the neighborhood of the event horizon of Sgr A*, here we applied an **isometric projection analysis** to the above simulated image, after a proper transformation to gray levels:

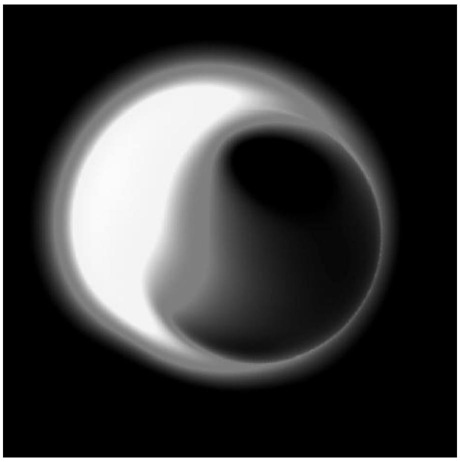

Figure 3 – BW version of the image simulation of Figure 1.

Since the introduction of the famous VP8 image analyzer in the 70s and 80s that allowed useful analyses of NASA's planetary images, the isometric projection method has proven very effective to transform any flat BW image in a **pseudo-3D image** on the basis of the intensity values of the gray levels in the original image. The resulting 3D structure allows to better study the details and the features in the original image even in the presence of regions hardly detectable and/or distinguishable and, if there is a direct correlation between light intensity and physical elevation, also provides a real 3D image, [3].

Based on these properties, we applied the isometric projection method to the simulated 2D BW image by Johannsen et al., Figure 3, to visualize the neighborhood of the Sgr A* black hole. More precisely, assigning suitable values to the two main parameters, (ρ,θ), of the basic transformation function:

$$\eta(y_{ij};\rho,\theta) = (\rho / \sqrt{y_{ij}} + \theta)^{-1}$$

where: y_{ij} is the i-th row and j-th column of the gray levels square matrix (475x475) and: $\eta = \eta_{ij}$ is the pseudo 3-D isometric projection value, we obtained the following result:

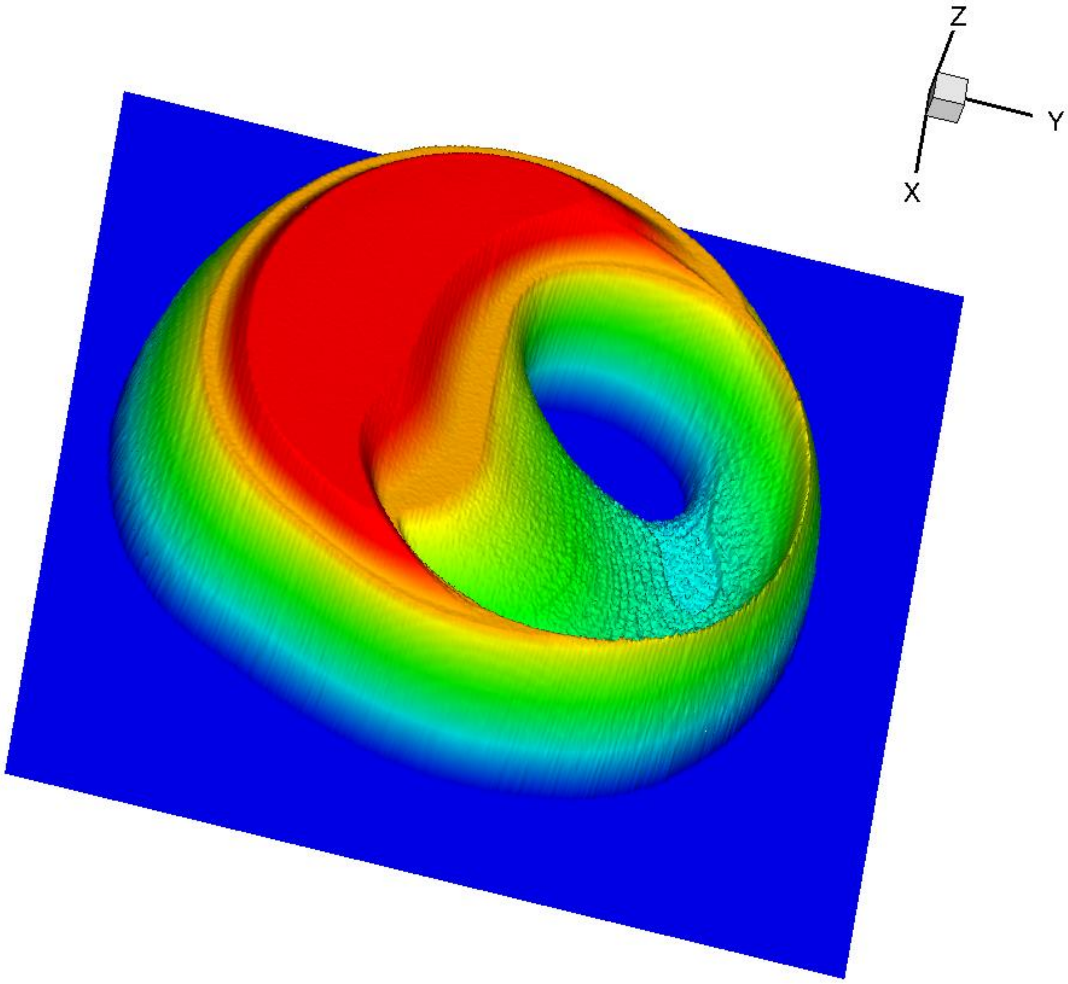

Figure 4 – Isometric pseudo-3D reconstruction of Figure 2 in order to better see the main properties of the surroundings of the event horizon of black hole Sgr A*.

The richness of details is now impressive: indeed we can appreciate, through this pseudo-3D map, the local fine structure of the surroundings of a black hole and we can follow accurately the spatial gradients of the various regions that are related to the emission intensity, and how these are distributed near the event horizon surrounding the "hole", here represented in dark blue color within the "pancake". Note that in the original image it is not so easy to detect this feature. We recall that the event horizon here has a radius less than half the radius of the black hole shadow. The high colorful red plateau, corresponds to a maximum emission of matter falling into the black hole by an accretion process.

It will be very interesting to apply **the same analysis to a real EHT image** of Sgr A* that we will obtain in the next few years and to compare it with that of the above simulation. The result obtained suggests that the pseudo-3D isometric projection analysis will be of great help to better study the main properties of the surroundings of the event horizon of a black hole.

References

[1] Derek Raine and Edwin Thomas: Black Holes, An Introduction, 2nd ed., Imperial College Press, 2010.

[2] Tim Johannsen, Avery E. Broderick, Philipp M. Plewa, Sotiris Chatzopoulos, Sheperd S. Doeleman, Frank Eisenhauer, Vincent L. Fish, Reinhard Genzel, Ortwin Gerhard, and Michael D. Johnson: “Testing General Relativity with the Shadow Size of Sgr A*”, arXiv:1512.02640v2, 19 Jan 2016.

[3] Peter M. Shumacher: http://shroudnm.com/docs/1977-08-VP8ImageAnalyzerBrochure.pdf