IS THE CARTER-ISRAEL CONJECTURE CORRECT?

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According to the Carter-Israel conjecture, the end-state of the gravitational collapse of matter is a Kerr-Newman black hole. Nevertheless, neither the theory nor observations can confirm that. In this talk, we discuss the possibility that the collapsing matter can create a super-spinning compact object with no event horizon, and we show how future observations at sub-millimeter wavelength of SgrA* can test this scenario for the black hole candidate in the Galactic Center.

1 Introduction

The question about the nature of the end-state of the gravitational collapse of matter is a long-standing issue which is still unsolved. At the theoretical level, the question might be addressed by general relativity (GR), our current theory of gravity. Here we know some singularity theorems which show that collapsing matter leads to the formation of singularities. Basically there are two possibilities: if the singularity is hidden behind an event horizon, the final product is a black hole (BH), if it is not, we get a naked singularity (NS). However, the true question is if “real matter” can form a NS. That is unknown, even because it is not so easy to say what “real matter” must be. In addition to this, it is not obvious that GR can address the issue: the theory has been tested only in the weak field limit and we do not know if it works in the case of strong gravity.

As for observations, today we have clear evidences supporting the existence of super-massive bodies at the center of many galaxies and compact stellar-mass bodies in the Galaxy. These objects are very likely the final product of the gravitational collapse of matter and are believed to be BHs, but actually there are no evidences that they have an event horizon and we do not know if the spacetime around them is like the one predicted by GR.

Even if GR allows for the creation of NSs, their existence seems to be problematic: in a spacetime containing a NS, it is typically possible to go back in time and therefore to violate causality. So, it is common opinion that NSs cannot be created by any physical process (Cosmic Censorship conjecture). When we consider the case of collapsing matter, this idea leads to
the Carter-Israel conjecture: the final product of the gravitational collapse of matter is a Kerr-Newman BH. The latter is an object characterized by just three parameters; that is, the mass $M$, the electric charge $Q$, and the spin $J$ (or the Kerr parameter $a = J/M$). These three parameters are not completely free, but must satisfy the relation $M^2 > Q^2 + a^2$, which is just the condition for the existence of the horizon. In what follows, we can restrict our discussion to the case $Q = 0$, because the electric charge is usually negligible for large astrophysical bodies.

2 Motivations for new physics

It is well known that simple considerations suggest that the Planck scale, $E_{Pl} \sim 10^{19}$ GeV, is the natural UV cut-off of classical GR. In this case, the theory would be unable to describe phenomena in which the characteristic energy exceeds $E_{Pl}$. If we apply this idea to the case of a Kerr spacetime with $M < |a|$, where observer-independent quantities like the scalar curvature diverge at the singularity, it is at least questionable to expect that the GR prediction of the violation of causality is reliable: the latter requires that a particle coming from infinity “enters” into the singularity. On the other hand, new physics may replace the singularity with something else and Nature may conserve causality not because it is impossible to create a NS, but because there is no singularity in the full theory. Adopting this point of view, there are no fundamental reasons that forbid the creation of a super-compact object with $M < |a|$ in the Universe.

3 Direct image of the accretion flow of SgrA*

In this talk, we discuss the possibility of testing the Carter-Israel conjecture by observing the direct image of the accretion flow onto the BH candidate in the Galactic Center. This is a short summary of the material presented in Bambi and Freese and Takahashi et al.

3.1 Present observations

Because of the strong gravitational field, the light passing near compact objects does not go along straight lines, but bends. The result is that the apparent size of a compact object seen by a distant observer is always larger than the real size of the object.

In Doeleman et al., the authors reported the observation at the wavelength of 1.3 mm of the radio source SgrA*, which is coincident with the position of the BH candidate in the Galactic Center at the level of 10 mas. Modeling SgrA* as a circular Gaussian brightness distribution, they find that the intrinsic diameter of the radio source is $37^{16}_{-10} \mu$as at $3\sigma$. Nevertheless, if SgrA* were a spherically symmetric photosphere centered on the BH, one would expect that the minimum apparent diameter would range from 52 $\mu$as (Schwarzschild BH) to 45 $\mu$as (Kerr BH with $|a| = M$ for an observer on the equatorial plane). Although the current data are not yet capable of absolute confirmation of such a measurement, its implications could be intriguing. One possibility is that the radio source is not perfectly centered on the BH. A second possibility is that SgrA* is centered on the compact object, but the latter is a super-rotating object with $|a| > M$. In the latter case, the emission region could have a smaller apparent size: since the compact object has no event horizon, the actual size of the photosphere could be very small. That is impossible for the case of BH, just because the photosphere has to be out of the event horizon.

3.2 Future observations

It is common opinion that, for frequencies larger than about 500 GHz (wavelengths smaller than 0.6 mm), the plasma around the BH candidate in the Galactic Center becomes optically thin.
At such frequencies, one should observe the “shadow” of the BH, a dark area over a bright background.

Assuming that the particles of the accreting gas follow marginally bound time-like orbits of the background metric, have zero component of the angular momentum along the BH spin at infinity, and an emissivity function independent of frequency and proportional to $1/r^2$, the image of the accretion flow onto a BH with $a/M = 0.9999$ would look like the pictures in the top panels of Fig. 1. Very long baseline interferometry observations are expected to be able to see the shadow of the BH candidate in the Galactic Center in a few of years.

However, if the super-massive object in the Galactic Center is not a BH, the image of its accretion flow at sub-millimeter wavelengths would be different. Fig. 1 shows the image of a super-spinning object with $a/M = 1.0001$ (central panels) and $a/M = 2$ (bottom panels), assuming that the NS is replaced by a spherical object with radius $0.1M$ and a perfectly absorbing surface.

The exact prediction of the intensity map of the accretion flow around a compact object depends on the features of the accretion flow. Nevertheless, there is an important difference between BH and super-spinning object. If the first case, there is always the shadow, i.e. the dark region over the bright background. In the second case, the absence of the event horizon let the observer see radiation coming from regions at very small radii: the result is the presence of some brighter spots inside the shadow. Indeed, close to the singularity, the gravitational redshift is negligible and one would even expect that the temperature of the plasma is higher. Both features imply a higher luminosity in the region where instead one should expect lower luminosity in the case of BH.

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Figure 1: Images of the accretion flow around a black hole with $a/M = 0.9999$ (top panels) and super-spinning black objects with $a/M = 1.0001$ (central panels) and $a/M = 2$ (bottom panels). The viewing angle is $i = 5^\circ$ (left column), $i = 45^\circ$ (central column), and $i = 85^\circ$ (right column).