Thick disk accretion in Kerr space-time with arbitrary spin parameters

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In this paper we extend our previous works on spherically symmetric accretion onto black holes and super-spinars to the case in which the fluid has a finite angular momentum initially. We run 2.5D and 3D general relativistic hydrodynamic simulations of the accretion of a fat disk. We study how the accretion process changes by changing the values of the parameters of our model. We show that the value of the fluid angular momentum critically determines turn-on and off the production of powerful equatorial outflows around super-spinars. For corotating disks, equatorial outflows are efficiently generated, even for relatively low spin parameters or relatively large super-spinar radii. For counterrotating disks, equatorial outflows are instead significantly suppressed, and they are possible only in limited cases. We also study accretion around a tilted disk.

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I. INTRODUCTION

Today we believe that the final product of the gravitational collapse is a Kerr black hole. Nevertheless, observational evidences supporting this conjecture are still weak. Astronomical observations have led to the discovery of at least two classes of astrophysical black hole candidates: stellar-mass objects in X-ray binary systems ($M \sim 5 - 20 M_\odot$) and super-massive objects at the center of most galaxies ($M \sim 10^5 - 10^{10} M_\odot$). All these objects are supposed to be Kerr black holes because they cannot be explained by something else without introducing new physics. For example, stellar-mass black hole candidates in X-ray binary systems are too heavy to be neutron/quark stars for any reasonable matter equation of state. The super-massive black hole candidate at the center of the Galaxy is too massive, compact, and old to be a cluster of non-luminous bodies.

Gravity is relatively well tested only in the weak field limit; we do not know if our theory is still reliable in the case of strong gravitational fields. Indeed, the idea that the final product of the gravitational collapse is a Kerr black hole itself is based on a set of assumptions, which may be wrong, see e.g. the discussion in and references therein. New physics may not be so unlikely. There are a couple of fundamental problems associated with the existence of black holes when quantum effects are taken into account; several authors have thus suggested other possibilities as the final product of the collapsing matter. Lastly, quantum gravity effects may become important already at the gravitational radius of a system, $R_g = M$, rather than at the Planck scale $L_{Pl} = 10^{-33}$ cm; if this is true, astrophysical black holes might be quite different objects from the ones predicted in the classical theory.

The Kerr metric has only two free parameters, associated respectively with the mass, $M$, and the spin, $J$, of the massive object. The condition for the existence of the event horizon is $|a_\ast| \leq 1$, where $a_\ast = J/M^2$ is the dimensionless spin parameter. It is also remarkable that, at least in some circumstances, the accretion process should spin the black hole up to $a_\ast \approx 0.998$. For $|a_\ast| > 1$, there is no black hole solution, but the Kerr metric may still be used to describe the vacuum gravitational field around some very fast rotating body. If current black hole candidates are not Kerr black holes but, say, compact bodies made of some kind of exotic matter, the maximum value of the spin parameter may be either larger or smaller than 1. The determination of the spin parameter can thus be used to test the nature of these objects. If we find that one of them violates the bound $|a_\ast| \leq 1$, then the final product of the gravitational collapse is not (or not necessarily) a Kerr black hole. The possible discovery that all these objects have spin parameter significantly smaller than 1 may suggest the same conclusion. The possibility of the existence of compact objects with $|a_\ast| > 1$ (super-spinars) was first discussed in. Some basic features of the electromagnetic radiation emitted around a super-spinar were studied in, and compared with the one emitted from a Kerr black hole.

Most of the observable astrophysical phenomena occurring around a compact object are significantly determined by the exact accretion process. General relativistic effects are important only very close to the massive object, where gravity is stronger. The special case of spherically symmetric and adiabatic accretion onto a Schwarzschild black hole can be studied analytically. In general, instead, a numerical approach is necessary. The first numerical simulations in Kerr background were presented in and then in. After these works, the research on the accretion process in Kerr space-time was devoted largely to the study of black hole tori and of the associated instabilities. More recent works have investigated the role of magnetic fields and the mechanisms to generate jets; for a review, see e.g. Ref. In, we extended the study of spherically symmetric and adiabatic accretion onto Kerr black holes to the case of spin parameter $|a_\ast| > 1$. The most important result was the discovery of strong equatorial outflows by the sole gravitational force from fast-rotating super-spinars.

In this paper, we study the accretion process onto black holes and super-spinars when the angular momentum of the gas is initially non-negligible. We study the case of a geometrically thick disk. In our previous works, the accretion process depended on the value of the spin parameter and on the radius of the super-spinars, while other conditions, such as the gas equation of state, had a minor role. Here we show that even the gas angular momentum is very important in the accretion process. Spin-orbit interactions can indeed strongly foster the production of equatorial outflows in the case of corotating disks, while suppress it for counterrotating disks. This means that equatorial outflows can be produced even for relatively low spin parameters and/or relatively large super-spinar radii.

The paper is organized as follows. In Sec. we briefly review the basic features of spherically symmetric and adiabatic accretion onto black holes and super-spinars. In Sec. we present our new hydrodynamics simulations of thick disk accretion and we discuss our findings. In Sec. we report our conclusions. Throughout the paper we use Boyer-Lindquist coordinates to describe the Kerr background and natural units $G_N = c = k_B = 1$.

1 The existence of a third class of astrophysical black holes, intermediate objects with mass $M \sim 10^2 - 10^4 M_\odot$, is still controversial, because dynamical measurements of their masses are uncertain.
II. SPHERICALLY SYMMETRIC ACCRETION

Spherically symmetric and adiabatic accretion in Kerr space-time with arbitrary value of the spin parameter $a_*$ was studied in Refs. \[22, 23\], in 2.5 and 3 dimensions. A summary of the numerical approach and of the main results can be found in \[6\]. The behavior of the accretion process is essentially determined by $a_*$ and by the physical radius of the compact object, $R$. Because of the ergoregion instability, it is likely that super-spinars cannot be extremely compact with $R \ll M$ \[24\]. However, they can be stable if their physical radius is of the same order of their gravitational radius and, in \[24\], we assumed $R = 2.5 M$. The accretion process onto a super-spinar with smaller/larger physical radius can be easily recovered from the case with $R = 2.5 M$ by considering a super-spinar with larger/smaller spin parameter.

There are three qualitatively different kinds of accretion:

1. **Black hole accretion.** For black holes and super-spinars with $|a_*| > 1$, one finds the usual accretion process onto a compact object. The increase in $|a_*|$ makes the accretion process more difficult: in the quasi-steady-state configuration, the velocity of the gas around the compact object is lower, while the density and the temperature are higher. The gravitational field indeed becomes weaker for higher spin parameters. One can easily understand this by noticing that the radius of the event horizon of a black hole monotonically decreases with $a_*$. The difference, however, is very small and the exact value of the spin parameter does not affect significantly the process.

2. **Intermediate accretion.** As the spin parameter increases, the gravitational force around the super-spinar becomes weaker and, at some point, can become repulsive. Now the accretion process is significantly suppressed: the flow around the super-spinar becomes subsonic and the density and the temperature of the gas increase further.

3. **Super-spinar accretion.** For high values of the spin parameter, the process of accretion is quite different: matter is accreted mostly from the poles, while the repulsive gravitational field produces outflows around the equatorial plane. For $R = 2.5 M$, this occurs for $|a_*| > 2.9$, while for smaller/larger values of $R$, powerful equatorial outflows appear for lower/higher values of $|a_*|$.

The outflows generated around super-spinars have no counterpart in the case of black holes. When $|a_*| \leq 1$, jets and outflows cannot be produced in spherically symmetric and adiabatic accretion. The most popular scenarios to generate jets around astrophysical black holes require the presence of magnetic fields and outflows cannot be produced in spherically symmetric and adiabatic accretion. The most popular scenarios to extract energy from the black hole and produce relativistic jets. For slow-rotating or Schwarzschild black holes, jets may indeed be powered by the Blandford-Payne mechanism \[28\]. Current studies, however, are controversial, and there is not a common agreement on the efficiency of these processes, see e.g. Refs. \[29, 30\]. If the mass accretion rate is close or exceeds the Eddington limit, quasi-steady outflows with high velocity ($v \sim 0.25$) can also be driven by the force of the radiation pressure (radiation driven outflows) \[31, 32\]. A model in which jets are driven by the force of the radiation pressure and collimated by the magnetic field has been recently proposed in \[33\]. In all these models, matter should be ejected parallel to the spin of the massive object and/or perpendicular to the accretion disk.

The outflows found in our hydrodynamics simulations in the case of super-spinars are instead gravitationally-driven outflows: they are produced by the peculiar features of the gravitational field in the Kerr metric when $|a_*| > 1$. These outflows can thus be generated even when the accretion process is adiabatic and (at large radii) spherically symmetric. Here matter is ejected on and around the equatorial plane; that is, perpendicular to the spin of the massive object. In some circumstances, the amount of matter in the outflow is considerable, which can significantly reduce the mass accretion rate onto the central object.

III. THICK DISK ACCRETION

To study the thick disk accretion, we use the same set-up adopted in Ref. \[25\]. The accreting matter is modeled as an ideal fluid with polytropic index $\Gamma = 5/3$. Its gravitational field is neglected. Mass increase and the variation in spin of the massive object, as a consequence of the accretion process are also neglected. Our study is based on simulations in 2.5 dimensions, and the computational domain is $2.5 M < r < 40 M$ and $0 < \theta < \pi$. So, we are

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2 In the case of stellar-mass black holes in X-ray binary systems, one can expect that the spin of the black hole is usually perpendicular to the accretion disk, on the basis of binary population synthesis \[34\]. For super-massive black holes, at least the central part of the accretion disk may lie on the equatorial plane of the black hole because of the Bardeen-Petterson effect \[35\]. However, there are observational data \[36\] and theoretical arguments \[37\] suggesting that tilted disks may instead be common.
interested only in the innermost part of the accretion disk, where the properties of the gravitational field are more important. We run a few simulations in full three dimensions in order to check that our main conclusions based on 2.5 dimensions are robust. The initial configuration and the boundary conditions are different from Ref. [25]. Here, the computational domain is initially empty. We inject gas from the outer boundary for $\pi/4 < \theta < 3\pi/4$. For $\theta < \pi/4$ and $\theta > 3\pi/4$, we impose free-outflow boundary conditions, i.e. we set zero gradient across the boundary: this condition allows for both outflow and inflow and it is a quite common choice for this kind of simulations [20]. The gas is injected with non-zero radial and azimuthal velocity. Our default choice at the beginning of the simulations is $v_r = -0.15$ and $v_\phi = 0.0010/\sin \theta$, corresponding to a gas angular momentum per unit mass $l_0 = 1.6 M$. The polar velocity, $v_\theta$, is set to be zero. Snapshots of the gas density at $t = 50 M$, 75 $M$ and 100 $M$, are shown in Fig. 1, for the case of $a_*=0$.

A. Black holes

We first discuss the case $a_*=0$. The accretion process is determined by the gas angular momentum, which is controlled by the injection azimuthal velocity at the outer boundary. For low specific angular momenta, the gas reaches the inner boundary and is swallowed by the black hole. As the angular momentum increases, the height of the effective potential barrier increases as well. At some point, the gas cannot reach the central object and there is not accretion any more. The critical value of the specific angular momentum depends on the accretion rate and on the mechanism responsible for transporting angular momentum to larger radii. If the infall gas velocity is too low, the gas injected from the outer boundary clashes with the one already present in the computational domain, generating turbulences and random motions, a part of which leaves the computational domain. In this case, the gas has not the time to lose angular momentum to fall to the central object. On the other hand, if angular momentum transport by turbulent motions is efficient, the gas can reach quickly the black hole and new gas can enter easily into the computational domain. For higher specific angular momenta, the gas is confined at larger distance from the black hole. In all these simulations, the exact value of the injection radial velocity is not very important. For higher $v_r$, the gas reaches the central object somewhat quicker, but for reasonable choices of its value we do not see a significant difference.

The density of the gas around a Schwarzschild black hole is shown in Fig. 2 for three different values of the initial specific angular momentum, $l_0$. The exact value of $l_0$, however, should be taken with caution. It is model-dependent, and also it specifies only the specific angular momentum of the gas injected from the outer boundary at the beginning of the simulations. As the system evolves, such a quantity changes its value according to the density and the pressure of the gas which is already inside the computational domain. If it were not so, we would obtain an unphysical gas configuration. In practice, the value of $l_0$ indicates the initial degree of gas rotation. The corresponding direction of the velocity of the gas is shown in Fig. 3. In these picture, we clearly see that accretion from a thick disk is characterized by chaotic outflows, a feature absent in the case of negligible angular momentum of the gas. The existence of outflows resulting from fluid rebounding at the centrifugal barrier is a well known phenomenon in the case of accretion from thick disk and was already found in [16, 18].

A reasonable estimate of the critical value of the specific angular momentum separating the case of accretion from the one of non-accretion onto a Schwarzschild black hole can be obtained by considering the motion of a test-particle
in the Schwarzschild space-time. The effective potential for a test-particle with specific angular momentum $l$ is

$$V_{\text{eff}} = -\frac{M}{r} + \frac{l^2}{2r^2} - \frac{Ml^2}{r^3}.$$  

(1)

The shape of the potential depends on the value of $l$. For $l/M < \sqrt{12} \approx 3.46$, $V_{\text{eff}}$ is a monotonically increasing function of the radial coordinate $r$ and a test-particle coming from infinity is swallowed by the black hole. A comparison with the case of accreting gas is not straightforward. Moreover, the initial specific angular momentum tends to increase in our simulations. Nevertheless, we find a similar behavior for the accreting gas.

For rotating black hole, the behavior of a corotating disk is different from that of counter-rotating one, since spin-orbit interactions determine the height of the effective potential barrier. For given values of $|a_\ast|$ and $|l|$, the barrier is lower for counter-rotating gas, which can thus reach the central object even if it has higher angular momentum.

In Fig. 4, we show the gas velocity at the time $t = 1000 M$ around black holes with $a_\ast = 0, \pm 1$, for $l_0/M = 1.6$. The three cases do not present substantial differences. The high velocity gas in the region along the symmetry axis is a numerical artifact and should be ignored. There, the gas density is very low and the boundary is not fully under control. Fortunately, it does not significantly affect the rest of the evolution.

### B. Super-spinars

As discussed in [24, 25], spherically symmetric and adiabatic accretion onto super-spinars can generate outflows because the gravitational field is axisymmetric and, at very small radii, the force can be either attractive or repulsive. In particular, the radial gravitational force is strong and repulsive near, but outside, the equatorial plane; for this reason the matter in the outflows is ejected perpendicular to the spin of the super-spinar. The effective gravitational force acting on the falling gas depends, however, even on the gas angular momentum, which becomes thus an important parameter in the dynamics of the accretion process.

In Figs. 5 and 6 we show respectively the velocity and the density of the accreting gas around super-spinars with $a_\ast = \pm 2$ and $\pm 3$, with our default boundary conditions. In all these cases, the gas reaches the central object and there is accretion. However, the accretion process for corotating and counterrotating disks presents a significant difference: for $a_\ast = 2$ and 3, we see equatorial outflows characterized by gas with high velocity and low density, for $a_\ast = -2$ and $-3$, the accretion looks more like the one onto black holes, with chaotic and turbulent motion of the gas, but without equatorial outflows. In our earlier work [25], we found that outflows were generated for $|a_\ast| \geq 2.9$ with the same conditions (in particular $R = 2.5 M$), but injecting gas with zero angular momentum. Fig. 6 shows clearly that

3 Let us remind the reader that the geodesic equations in Kerr space-time contain, in addition to the Newtonian centrifugal term, other contributions proportional to $L_z$, $L_z^2$, and $Q$, where $L_z$ is the component of the particle angular momentum at infinity parallel to the spin of the massive object and $Q$ is the Carter constant. The latter reduces to $L_z^2 + L_y^2$ in the Schwarzschild case $a_\ast = 0$.  

FIG. 2. Snapshot at $t = 1000 M$ of the gas density (in arbitrary units) around a Schwarzschild black hole for three different values of the initial specific angular momentum $l_0$. For $l_0 = 1.6$ there is accretion; in the other cases there is no accretion. In the case of higher specific angular momentum, $l_0 = 6.4$, the gas is confined far from the black hole. The unit of length along the axes is $M$; $l_0$ in unit $M = 1$. 

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FIG. 3. Directional velocity of the gas in the three cases presented in Fig. 2. Only the region of the computational domain with density $\rho > 0.1$ is considered. The unit of length along the axes is $M$.

FIG. 4. Snapshots at $t = 1000$ $M$ of the gas velocity $v = \sqrt{\gamma_{ij} v^i v^j}$ around black holes with spin parameter $a_* = 0$ and $\pm 1$. In these simulations, the accretion process onto Schwarzschild and extreme Kerr black holes is qualitatively identical. The unit of length along the axes is $M$.

a corotating accretion disk favors the production of outflows, while a counterrotating accretion disk suppresses it. To be more quantitative, we plot the accreted mass of gas in the volume $r < 5$ $M$ for black holes and super-spinars, i.e. the quantity

$$ M_{\text{acc}}(t) = \int_0^t \int_{r=5M} \rho u^r \sqrt{-g} d\theta d\phi d\tau. \quad (3) $$

Such a quantity is not associated with a conserved current. From this point of view, the relativistic accreted mass should be defined as

$$ Q(t) = \int_0^t \int_{r=5M} \rho u^r \sqrt{-g} d\theta d\phi d\tau, \quad (2) $$

where $u^r$ is the $r$-component of the gas 4-velocity. However, here we can use the definition given in Eq. (3) to interpret the data without a significant difference. $M_{\text{acc}}(t)$ is closer to the Newtonian concept of accreted mass.
The left panel of Fig. 5 shows the case $l_0/M = 1.6$: as the value of the spin parameter decreases, the amount of gas which can reach the central object is larger. For $a_* = 2$, the production of equatorial outflows reduces considerably the accretion rate onto the super-spinar. For a lower specific angular momentum, we find a trend consistent with the case of spherically symmetric flow discussed in [25]: the difference between the cases $a_* = 0$, $±1$ and $−2$, is apparently very small. When $a_* = 2$ the accretion is much suppressed, but there are no equatorial outflows (Fig. 5 right panel). Comparing the left and the right panels of Fig. 5 we recover the quite obvious result that a lower gas angular momentum increases the mass accretion rate, simply because the effect of the centrifugal force is less important.

Overall, the generation of outflows requires that the super-spinar is sufficiently fast-rotating and compact, i.e. the mechanism works for sufficiently high spin parameters $|a_*|$ and small physical radii $R$. The effect of the gas angular momentum is instead more complex. For corotating gas, the height of the effective potential barrier is not a monotonic function of $a_*$, but first increases and then decreases as $a_*$ increases. A higher gas angular momentum favors the production of equatorial outflows, but, if it is too high, the gas cannot overcome the effective potential barrier and thus cannot reach the region close to the compact object where outflows can be produced. For counterrotating disks, the behavior of the accretion process seems to be easier to predict, because a higher angular momentum increases the barrier and makes the ejection of matter inefficient.

At this point, one can check numerically the features of the accretion process by changing $a_*$, $R$, or $l_0$. We find that the production of outflows is significantly suppressed when the disk is counterrotating: for fixed $R = 2.5 M$ and $l_0/M = 1.6$, outflows are possible only for $a_* \lesssim −5.5$. Contrarily, outflows are produced very easily for corotating disks: for $a_* = 2$ and $l_0/M = 1.6$, we find the production of powerful outflows for $R \lesssim 4 M$.

C. Tilted accretion disk

In the previous sections, we have adopted the standard assumption that the accretion disk is symmetric with respect to the equatorial plane. There are a couple of astrophysical arguments suggesting that this is the most likely configuration, see e.g. the footnote in Section II. However, more recently, some authors have argued that tilted disks may not be rare [36, 37]. Numerical simulations of tilted accretion disks were presented in [38, 39]. It is interesting to study the case with a small but non-zero disk misaligned angle with respect to the rotation axis of the compact object. In principle, for 2.5D simulations, the choice of the boundary conditions at $\theta_{\min}$ and $\theta_{\max}$ along the symmetry axis may be problematic, because now we lose the axial symmetry and therefore the axisymmetric boundary conditions are not strictly appropriate. Here we consider small tilt angles. We have checked that our results are essentially the same for axisymmetric, periodic, or outflow boundary conditions. In the rest of this section, we show the results obtained by imposing outflow boundary conditions, which have some advantages from the computational point of view. At the beginning of the simulations, we inject gas into the computational domain for $\pi/4 − i < \theta < 3\pi/4 − i$, while for $\theta < \pi/4 − i$ and $\theta > 3\pi/4 − i$ we impose free-outflow boundary conditions. This is our definition of tilt angle $i$.

For systems without equatorial outflows (black holes, super-spinars with small value of the spin parameter, super-spinar with a counterrotating accretion disk), we do not see any new feature associated with the presence of a tilted
FIG. 6. Gas density (in arbitrary units) at $t = 1000 \, M$ around super-spinars with $a_* = \pm 2$ and $\pm 3$. Comparing these plots with the ones in Fig. 5, we see that in the outflows produced in the cases $a_* = 2$ and $3$ the gas has low density. The unit of length along the axes is $M$.

FIG. 7. Accreted mass as a function of time $t$ of the space region inside the radius $r = 5 \, M$ for $a_* = 0, \pm 1$ and $\pm 2$. The injection initial angular momentum per unit mass of the gas is respectively $l_0 = 1.6$ (left panel) and $l_0 = 0.8$ (right panel). Accreted mass in arbitrary units; the time $t$ and the specific angular momentum $l_0$ are in unit $M = 1$.

disk. Here the Bardeen-Petterson effect cannot be seen because the gas is too energetic and turbulent, the disk is too thick, and the mechanism responsible for the transportation of angular momentum to larger radii is too inefficient. These are all ingredients preventing the observation of an accretion disk forced to rotate in the same plane of the compact object.

The case of super-spinars capable of generating outflows is more interesting. In Figs. 8 and 9 we show respectively the velocity and the density of the gas for a tilt angle $i = 5^\circ$, $10^\circ$, and $15^\circ$ and a spin parameter $a_* = 2$. In these plots, the spin vector of the massive object is still along the y-axis. The outflow is not on the equatorial plane any more. It is generated close to the equatorial plane, but then the gas moves to the side opposite to the disk. The reason is that the outflow is not stable and tends to follow the easiest way to reach the outer boundary where the density of the falling gas is lower. For higher values of the spin parameter, the outflow is more energetic. The result is that, for very small tilt angles, the outflow can still propagate on the equatorial plane; for more misaligned disks, it propagates out of the equatorial plane at higher velocities (Fig. 10). At least in the cases considered here, characterized by small tilt angles, we do not see any clear difference in the mass accretion rate with respect to the configurations with a disk on the equatorial plane.
FIG. 8. Snapshots at $t = 1000 \ M$ of the gas velocity $v = \sqrt{\gamma_{ij}v^iv^j}$ around a super-spinar with spin parameter $a_* = 2$. In these simulations, the corotating disk has a tilt angle $i = 5^\circ$ (left panel), $i = 10^\circ$ (central panel), and $i = 15^\circ$ (right panel). The unit of length along the axes is $M$.

FIG. 9. Snapshots at $t = 1000 \ M$ of the gas density (in arbitrary units) around a super-spinar with spin parameter $a_* = 2$. In these simulations, the corotating disk has a tilt angle $i = 5^\circ$ (left panel), $i = 10^\circ$ (central panel), and $i = 15^\circ$ (right panel). The unit of length along the axes is $M$.

FIG. 10. Snapshots at $t = 1000 \ M$ of the gas velocity $v = \sqrt{\gamma_{ij}v^iv^j}$ around a super-spinar with spin parameter $a_* = 3$ and tilt angle $i = 5^\circ$ (left panel), $a_* = 3$ and $i = 10^\circ$ (central panel), and $a_* = 4$ and $i = 5^\circ$ (right panel). The unit of length along the axes is $M$. 
IV. CONCLUSIONS

If current black hole candidates are not Kerr black holes, but compact bodies made of some kind of exotic matter, the Kerr bound $|a_*| \leq 1$ does not hold. The maximum value of the spin parameter may be either smaller or larger than 1, depending on the properties of these objects. The study of the accretion process for different value of the spin parameter may thus shed light on the nature of the black hole candidates.

In this work we have studied the accretion process in Kerr space-time with arbitrary value of the spin parameter $a_*$. As already noticed in our previous papers [12, 21], the accretion process onto objects with $|a_*| > 1$ can generate equatorial outflows that can be unlikely produced around Kerr black holes. This phenomenon can be used as observational signature to look for compact objects with $|a_*| > 1$. Here we have extended our previous studies on spherically symmetric accretion to the case of thick disk accretion, which is a more likely situation for a binary system, in which the compact object strips matter from the stellar companion due to tidal effects. Current numerical studies are not yet capable of simulating geometrically thin disks; we can however consider geometrically thick disks, which is expected when the heat generated by the viscous stress is not radiated away efficiently.

Accretion occurs only when the gas can overcome the centrifugal barrier, which is determined both by the spin of the compact object and by the angular momentum of the gas. For corotating disks, the centrifugal barrier is higher; that is, accretion requires either a lower gas angular momentum, or a more efficient mechanism to lose angular momentum. For counterrotating disks, the centrifugal barrier is lower and the gas can reach easier the central body.

When $|a_*| > 1$, another effect has to be taken into account. The gravitational force at small radii and near, but outside, the equatorial plane can be strongly repulsive and generate powerful equatorial outflows. For non-zero gas angular momentum, spin-orbits interactions cannot be ignored and the region with repulsive gravity is not given by the simple expression $r^2 < a^2 \cos^2 \theta$, as in the case of spherically symmetric accretion. Now, equatorial outflows are more easily generated when the gas angular momentum is parallel to the spin of the super-spinar, while strongly suppressed in the opposite case. The production of outflows is determined by the spin parameter $a_*$ and by the physical radius of the object $R$, i.e. outflows are possible for high values of $a_*$ and low values of $R$. The main result of this paper is that in a typical binary system, where the gas angular momentum cannot be neglected, the accretion makes outflows possible even for significantly lower $a_*$ and larger $R$ for corotating disks, while the production of outflows becomes unlikely for counterrotating disks.

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