Black hole candidates and the Kerr bound

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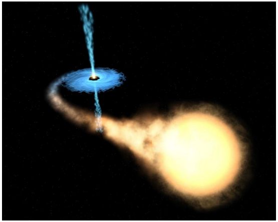
Introduction

- BH candidates are being directly observed by radio interferometers, X-ray satellites and gravitational wave detectors. To prove that BH candidates are really BHs, we have to show that the observed data cannot be explained by anything else.
- The cosmic censorship hypothesis claims that there is no naked singularity in Nature. But quantum gravity should replace classical GR in the Planckian regime. Then, a naked-singular solutions of classical GR might be physical in its low-curvature regime.



NASA & ESA

Kerr bound

- The Kerr solution

$$ds^2 = -\left(1-\frac{2Mr}{\Sigma}\right)dt^2 - \frac{4aMr\sin^2\theta}{\Sigma}dtd\phi + \frac{\Sigma}{\Delta}dr^2 + \Sigma d\theta^2 + \left(r^2+a^2+\frac{2Mra^2\sin^2\theta}{\Sigma}\right)\sin^2\theta d\phi^2,$$

  where $\Sigma = r^2 + a^2\cos^2\theta$ and $\Delta = r^2 - 2Mr + a^2$. Put $a_* \equiv a/M$.
- A curvature singularity at $r = 0$ and $\theta = \pi/2$, where $\Sigma = 0$
- $|a_*| \leq 1$: singularity covered by an event horizon
- $|a_*| > 1$: naked singularity and no event horizon
- $|a_*| \leq 1$ must be satisfied for singularity to be covered.

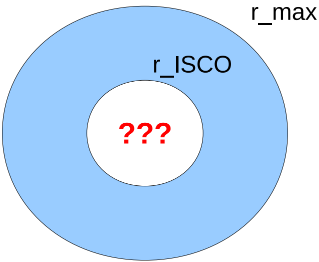
Superspinar

- The BMPV solution of supergravity in (4+1)D has a naked singularity for its super-extremal case. This singularity is excised by a domain wall of strings and D-branes, if stringy effects are taken into account. We can also assume that the naked singularity in the super-extremal Kerr solution is excised due to stringy effects (Gimon & Horava, PLB672, 2009)

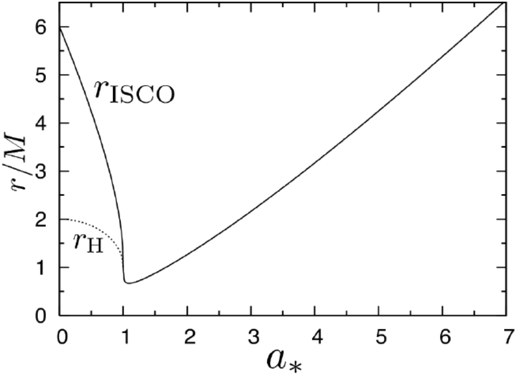
- Overspinning a black hole with a test body (Jaboson & Sotiriou, PRL103, 2009)

Accretion disk model

- We generalise the GR "standard" disk model (Page & Thorne, ApJ191, 1974) to a superspinar.
- Analytical solution: Geometrically thin and optically thick disk, Steady-state flow, Viscous torque, Local thermal equilibrium
- Torque-free inner edge given by the Innermost Stable Circular Orbit (ISCO)
- Sub-Eddington flow: $\dot{M} \leq \dot{M}_{\rm Edd} \equiv L_{\rm Edd}/c^2$

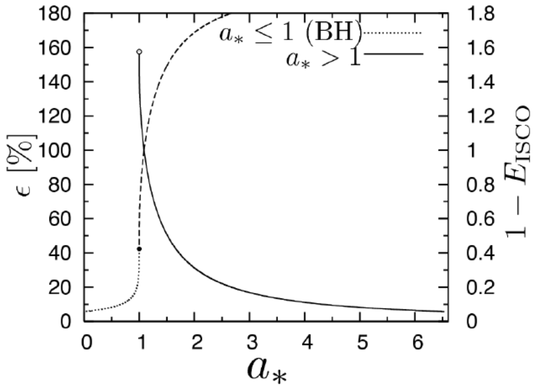


ISCO in the Kerr metric



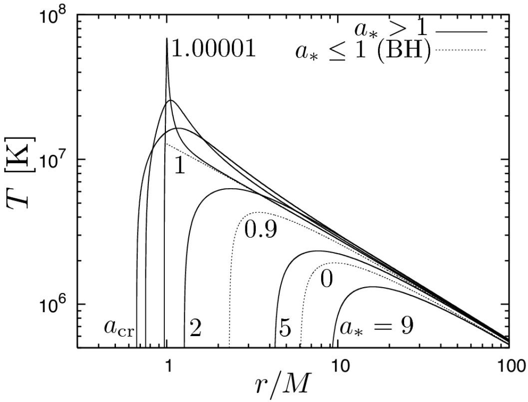
- There is an ISCO even for the superspinar.
- The minimum $(2/3)M$ for $a_* = 4\sqrt{2}/(3\sqrt{3}) \simeq 1.09$
- $r_{\rm ISCO} > 6M$ for $a_* > 8\sqrt{6}/3 \simeq 6.53$

Radiation energy efficiency



- $\epsilon = 1 - E_{\rm ISCO} > 100\%$ for $1 < a_* \lesssim 1.09$.
- The maximum 157.7% achieved for $a_* = 1^+$
- $\epsilon \sim 42\%$ for $a_* = 1^-$ and $a_* = 5/3 \simeq 1.67$

Temperature structure of the accretion disk



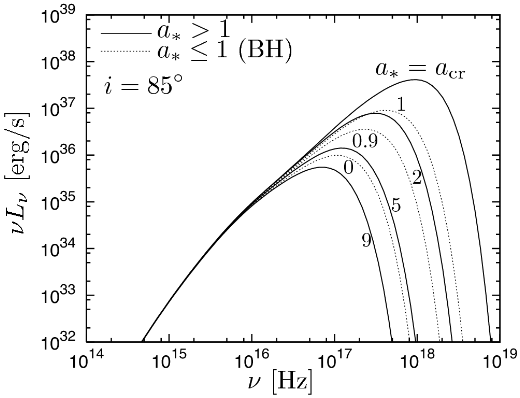
- A peaky spike appears near the inner edge for $1 < a_* \lesssim 1.09$.
- For a superspinar with $1.09 \lesssim a_* \lesssim 6.53$, there is a BH counterpart with very similar structure.

Emission from the accretion disk

List of assumptions

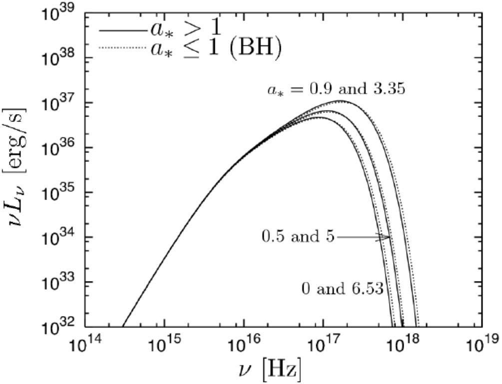
- Energy release fully converted to local black-body radiation due to viscous torque
- GR radiative transfer, including all kinematical GR effects
- Absorption, emission and reflection by gases surrounding the disk neglected
- No emission and no absorption by the superspinar

Observed energy spectrum



- For $1 \lesssim a_* \lesssim 1.67$, the spectrum extends to higher energy compared to BHs.
- For $a_* \gtrsim 6.53$, the photon energy is lower compared to BHs.

Superspinar counterpart



- Surprisingly, any BH has its superspinar counterpart which gives very similar X-ray specturm. In contrast, for a superspinar with $1 \lesssim a_* \lesssim 1.67$ or $a_* \gtrsim 6.53$, there is no BH counterpart.

Summary

- In the present setting, it is very challenging to distinguish BHs from superspinars only by the X-ray spectrum observation.
- In contrast, some of the superspinars can be clearly distinguished from BHs. In other words, we can potentially find the violation of the Kerr bound by the X-ray spectrum observation.
- The present disk and radiation model might be too simple. It is interesting to study with other accretion models, such as Radiatively Inefficient Accretion Flow (RIAF).
- See Takahashi & Harada CQG**27**, 075003 (2010) for details.