

Black Holes - Any *body* out there?

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Abstract: Using analytical results from both general relativity and quantum mechanics we show that physical black holes probably do not exist. This would actually be a boon to theoretical physics, for example as:

- i) General relativity would then be globally valid in the (classical) physical universe, due to its non-singular nature.
- ii) The black hole information paradox would vanish.
- iii) No event horizon would mean no Hawking radiation, resolving the causal paradox that for an outside observer it takes an infinite time for the black hole to form whereas it evaporates in finite time.

Astrophysical applications that *seem* to require black holes (quasars/AGNs, some binary systems, stellar motions near the center of our galaxy, etc) can still be fulfilled by compact but non-singular masses, M .

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1 Newtonian intuition

We start with the strictly physical requirement that if M is to grow larger by gravitationally “eating” m , we must have

$$mc^2 + m\phi > 0, \quad (1)$$

where

$$\phi = -\frac{GM}{r}, \quad (2)$$

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is the Newtonian potential. This just means that the gravitational binding energy cannot exceed mc^2 , and results in

$$r > \frac{R_s}{2}, \quad (3)$$

where

$$R_s = \frac{2GM}{c^2}, \quad (4)$$

is the Schwarzschild radius. If m approached closer to M than $r > R_s/2$, the total energy of the whole system would decrease, i.e. M itself would shrink. Especially, m can never enter into the Newtonian singularity at $r = 0$. However, the Newtonian treatment is valid only when $|\phi| \ll c^2$, so we now turn to the general relativistic description².

2 General Relativity

It turns out that we will need only the simpler exterior, stationary solution outside mass M . Here the general relativistic equivalent of criterion (1), equally valid for radial or non-radial motion [1], is

$$mc^2 \sqrt{1 - \frac{R_s}{r}} > 0, \quad (5)$$

(1) being the weak-field limit of (5). See also [2]. Only for free-falling, geodesic motion is the energy a constant of the motion [3]. For an object M with physical extent larger than its Schwarzschild radius, the kinetic energy of m will in the non-adiabatic, non-equilibrium inelastic collision/interaction (which is non-gravitational resulting in non-geodesic motion) increase the temperature of M and be radiated away to the surrounding space.

This gives

$$r > R_s, \quad (6)$$

i.e. m can never reach the Schwarzschild radius. As we start out with a mass M below the threshold, it can never “eat” (accrete) particles to form an event horizon outside its physical extent. (Just like the Sun has a “mathematical”, but nonphysical Schwarzschild radius of approximately 3 km in its interior.) As no limits have been placed on M all masses can thus be prevented from forming black holes. The same conclusion results if m is a thin concentric shell, or several. However, as (classical) particles are corpuscles there really never is perfect spherical symmetry and continuous models can be misleading.

3 Quantum Physics

In the weak-field limit we can actually go beyond the classical picture and consider what happens in quantized gravity. For both gravity and electromagnetism static effects

² However, as is well-known the Newtonian treatment gives the “right”, *i.e.* the same results as general relativity for R_s (“escape velocity” c) and for the surface gravity $\kappa = c^2 R_s / 2r^2$, even at $r = R_s$, making Newtonian intuition remarkably accurate.

should give excellent first approximations, as the dynamical effects are negligible. This is known to be so for the electromagnetic case as the (electrostatic) Schrödinger equation for hydrogen gets just marginal corrections from dynamical effects. For gravity deviations from the static case should be even smaller. The mathematically identical form of the Newtonian and Coulomb potential means that we directly can obtain results for quantum gravity by the replacement

$$e^2/4\pi\epsilon_0 \rightarrow GmM. \quad (7)$$

All analytical results for the Hydrogen atom can then be directly lifted over to quantum gravity [4].

Semi-classical quantum gravity then predicts that m never can approach closer to M than the “gravitational Bohr-radius”, b_0 , which is non-zero making the (classical) singularity at $r = 0$ unattainable.

For the full non-classical theory, if we again impose that the binding energy

$$E_g = \frac{G^2 m^3 M^2}{2\hbar^2} = \frac{GmM}{2b_0} \quad (8)$$

cannot exceed mc^2 , we obtain [4]

$$b_0(\text{physical}) > \frac{R_s}{4}. \quad (9)$$

Furthermore, as the exact analytical form of the wavefunctions are known, we see that they are all identically zero at $r = 0$, meaning that the probability for entering the classical central singularity is strictly zero. So quantum physics does seem to avert the gravitational singularity. Only the ground state wavefunction ($n=1$, $l=0$) may peak inside the Schwarzschild radius, actually at b_0 , all the others have a negligible part of their probability density inside R_s . Also, as the wavefunctions all have a long fat tail stretching all the way out to $r \rightarrow \infty$ we see that m has vanishing probability to be inside the (classical) horizon, rendering it meaningless. If neither horizon nor central singularity survives quantization the notion black hole has no place in a fundamental description of nature. See also [5].

Admittedly, the reasoning in this section is only valid for weak-field quantum gravity, but given the very similar results of weak-field and strong-field classical gravity, sections 1. and 2., something of the same flavor can be expected to occur also for general (presently unknown) quantum gravity.

4 Conclusion and Discussion

Even though general relativity mathematically includes the possibility for black holes, it may well be that *physical* black holes never can form, just like Einstein tried to prove long ago [6]. His physical intuition was usually spot on. Black holes would then just be mathematical artifacts of general relativity with no physical counterpart.

We know from Penrose’s (classical) singularity theorem [7] in general relativity that *if* a horizon (“trapped surface”) forms, a singularity *then* is inevitable. But if a horizon

is physically forever prohibited, classical general relativity can be singularity, and black hole, free.

We also see that in the limit $r \rightarrow R_s$ all of the infalling mass/energy can be radiated out, an efficiency approaching matter-antimatter annihilation, meaning that M can still power, for instance, quasars and active galactic nuclei *without* a singular mass in the center. This would also in principle be testable as the normal rotating black hole scenario usually believed to power quasars has a maximum efficiency of around 1/3.

This would also solve the black hole “information loss” problem as all information is re-radiated back into our world before a black hole can form. Even in purely classical general relativity there is an information loss paradox if a black hole forms, as a black hole is described fully by only three parameters - its mass (M), angular momentum (J) and charge (Q) - whereas the progenitor object requires an almost innumerable number of parameters to be described in full. In the semi-classical Hawking radiation picture radiation eventually escapes the black hole, but then as thermalized black-body radiation carrying negligible information back into our universe compared to what went in.

Hawking radiation also introduces a paradox of its own. A black hole takes an infinite time to form for an outside observer. At the same time Hawking radiation predicts a finite time for the black hole to completely evaporate. Thus a black hole has to evaporate *before* it forms, violating causality.

However, if a black hole physically never can form, all these problems and paradoxes and many more, are removed. As even supermassive black holes would be very small, $R_s \simeq 3\text{km } M/M_{\text{sun}}$, there is, in fact, presently no conclusive observational evidence that black holes actually do exist. The Event Horizon Telescope [8], and its descendants, could possibly directly settle this question.

References

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