Black Holes are NOT Monsters!

Black holes are getting a bad rap. For some reason, people think that when these things are created – when a massive star collapses at its end-of-life – they somehow inherit some astoundingly destructive powers. Well, when looking at the destructive power of black holes, it logical to ask "Compared to what?" and that's what we'll be looking at.

First off, there are several kinds of black holes. This discussion is limited to stellar-mass black holes. Specifically, I will *not* be discussing the super-massive black holes that are found in the center of most galaxies. In this paper, the phrase "black hole" refers to stellar-mass black holes.

To start, let's discuss a few things about gravity – the thing that makes black holes so "mean".

Gravity and You

Let's say you're standing on the surface of the Earth, and you weigh 200 pounds. The Earth's radius is about 8000 miles. These numbers are not unrelated.

Now let's say, through whatever magic, the Earth shrinks to half its size – a radius of 4000 miles – but with same mass. You are closer to the center of mass, which means your weight is going to go up. Well, you might assume that since you're twice as close to the center, your weight will double. But you would be wrong.

Gravitational force varies as the inverse of the *square* of the distance (inverse-square law). Being twice as close means the gravitational force – your weight – increases as two squared, or four. Your new weight is not 400 pounds, but 800 pounds.

And if we halved the radius of the Earth again – down to 2000 miles – your weight would increase by double-squared, or would be 3200 pounds.

(We can skip the intermediate step and follow the math. The proportional decrease in the radius is 2000/8000 = 1/4. This squared is 1/16, and the inverse is 16. This, times your original weight of 200 pounds, equals 3200 pounds.)

The point being, you don't need a black hole to get into gravity trouble. Anything very small and very massive won't be good for you. (Because it's small, there's no safe place – far enough out from the center – to "land", and you keep going toward the center, getting heavier as you go.) For example, a neutron star has a mass greater than that of the sun, but is only about the size of a city. If someone offers you a trip to a neutron star, don't go.

Making a Black Hole

You can make a black hole out of anything. You can make a black hole out of the Earth, out of the Moon, out of Cleveland, out of your neighbor’s cat – anything. First, you have to get it into the shape of a sphere. Then you have to squeeze it until its radius is below what’s called the “Schwarzschild radius”. Once the mass you’re squeezing reaches the Schwarzschild radius, it’ll keep compressing – all on its own – and it’ll be a black hole.

You can calculate this radius directly from the object’s mass with this equation:

Schwarzschild radius:
$\mathbf{r = 2.95\ M / M_{\odot}}$ kilometers

….where **M** is the mass of your object in kilograms, and $\mathbf{M_{\odot}}$ is the mass of the Sun, also in kilograms. Now, if you’re just working with a small object, using the mass of the Sun might be inconvenient, so we can remove that and just use the object’s mass:

$\mathbf{r = (1.5\times10^{-30})\ M}$ kilometers

Once you’ve compressed your object to a sphere with a radius equal to the Schwarzschild radius, it’ll keep on compressing all by itself and turn itself into a black hole.

So, if you wanted to turn your neighbor’s cat into a black hole, you’d have the impossible task of squeezing it down to something much, much smaller than a single proton, which has a radius of about 10^{-18}km. It would be a waste of time to try, which is good news for the cat.

Let’s Shrink the Sun

We can use the first equation directly to see that if we compressed the Sun into a sphere with a radius of 2.95km, it would just keep compressing on its own and it’d become a black hole. But what would happen to Earth?

The first thing, obviously, is we’d lose all light and energy from the Sun. But here’s what’s surprising – the Earth would continue to orbit the Sun just as though the Sun were at its normal size. And when you think about it, this makes sense. Orbiting bodies depend on their respective masses, and not on their sizes (radii). This is all from Newton’s Universal Law of Gravitation (which you can look up).

Although Newton has been modified by Einstein’s General Relativity, it hasn’t changed that much, but it does bring up an interesting (but unrelated) observation. The warping of space and time from the mass of the Sun at our location – 93 million miles – is unaffected by the size Sun.

Mass, Size and the "Event Horizon"

With most things, mass does not predict size and vice-versa. One has no relationship to the other. For example, a soccer ball and a bowling ball are roughly the same size, but the bowling ball is clearly more massive.

With black holes, however, they are related. According to the Schwarzschild equation earlier in this paper, if you know the mass of a black hole, you can calculate the Schwarzschild radius. And conversely, if you know the Schwarzschild radius, you can calculate the mass of the black hole.

But it would be incorrect to think of a black hole as a solid sphere with a surface at its radius. No, black holes are much more exotic than that. All of the mass of a black hole – *all* of it – is concentrated at its center, in a "singularity". And the "surface" of a black hole isn't a surface at all, at least not a solid one. This would-be surface is the "event horizon" of the black hole.

The difference between the surface of a star and the event horizon of a black hole is, if you go into the surface of a star, you can still turn around and get back out (assuming, of course, you have a high tolerance for heat). But for a black hole, if you cross the event horizon, it's a one-way trip – you are now permanently part of that black hole with no hope for getting out. Exactly what happens to you in that black hole is beyond the scope of this discussion, and no one really knows for sure anyway; but it's safe to assume that it's predictable only to the point you won't like it.

From Star to Black Hole

During their normal life, stars keep their equilibrium by keeping their nuclear furnace just hot enough to counteract the crushing force of gravity. Once the nuclear fuel runs out (or low), gravity starts to win. But this isn't like a light switch. Like a car running out of gas, the star will "sputter" – gravitational pressure builds up and temporarily restarts the fusion process, which puffs out the star, and throws off a lot of the stars mass as clouds of ejecta. This can happen multiple times in its dying process, throwing off an awful lot of the star's original mass. Once nuclear fusion is no longer possible, the star simply collapses.

What it collapses into depends on the mass that left. A relatively low mass collapsing star will wind up as a white dwarf. More massive stars compress into neutron stars. And a high mass stars will just keep going – with a supernova being a probable event, which blows away a LOT more mass – and then it compresses down below the Schwarzschild radius, and becomes a black hole.

Now, I know I'm skipping some pretty significant stuff, but I'm doing this to stay on topic.

The point is, the mass of the black hole is going to be significantly less than the mass of the star that created it. According to estimates I’ve found, somewhere around 80% of a star’s mass will have been blown away (puffing, supernova) by the time what’s left collapses into a black hole.

Do Black Holes Eat Stars?

Actually, black holes are omnivorous – you name it, they’ll eat it. This certainly includes stars, but most of this happens in the center of galaxies that have supermassive black holes (which, again, is not part of this paper).

But do stellar-mass black holes eat stars? Yes, they do, but probably not in the way you think. It’s not like these black holes roam the galaxy looking for stars to eat. Remember the black hole was once a high-mass star, doing what stars do for millions of years, and managed to do this without running into anything. Collapsing into a black hole in no way imparts some kind of speed on this thing. For the most part, it’ll keep moving the same way the original star was moving – only with a lot less mass, almost no light at all.

But this is for a star just sitting there, and believe it or not, there are relatively few of these. Most stars are part of what’s called a “binary system”, meaning two stars are circling each other around a common center of mass, and this center is typically outside of both stars, somewhere in between.

Now, the following isn’t the only thing that can happen, but it’s an example. Let’s say you have two high-mass stars in a binary system:

- One star goes through its life, puffing out a lot of gas on dying, and eventually collapses into a black hole.
- The puffed-out gas from this star is gravitationally attracted to the companion, and it starts to gain mass, which you would think would be good for star, but it’s not. The more massive a star, the shorter its life.
- Eventually the companion starts its end-of-life, puffing out outer layers of gas.
- This gas is gravitationally attracted to the black hole, which sucks what it can get into its event horizon.

The black hole is eating its companion star, or parts of it at least. This increases its mass, which increases the event horizon and its gravitational influence. And on it goes.

(Since I brought up binary systems, I might as well complete the thought. There are also multiple star systems – more than two stars – all orbiting a common center of mass. I avoid this because it introduces the “three-body” problem, which has confounded mathematicians for centuries. Also note that any or all stars in the system can be normal-life, white dwarfs, neutron stars, or black holes, with any and all combinations allowed.)

Star vs. Black Hole – Which Wins?

This is easy – the black hole wins, and the reason why is simple. The star has no way of un-blacking the hole, but the black hole can certainly tear the star apart. Just how badly the star is torn up depends on how long the black hole has it "in range" and the relative speed and trajectories.

For example, let's suppose the black hole hit the star perpendicular and dead-center. It would travel through the star, sucking the star's mass into the event horizon and therefore growing as it goes. The slower it goes, the more time the black hole has time to gain mass, and since it will go through the star's nuclear core (which is very dense), this will be a real feeding frenzy. Eventually, the black hole will exit – a whole lot fatter – and the star will be stuck with a conical-shape perforation right through its center.

I bet it'd be fun to watch.

So the Black Hole *Is* the Monster!?

That certainly would be easy to assume, based on the above discussion. But do this – take out pencil and paper and draw a fairly small Solar System in the center. Now take out a ruler so that it passes near, or through, part or all of your Solar System.

Now think about what might happen if a 5 solar-mass black hole followed this trajectory at whatever speed you like. Estimate the disruption. Now, without moving the ruler, estimate the impact of a 25 solar-mass star coming through there (which is what this black hole was generated from, very roughly speaking). This thing has five times the mass and five times the gravitational effect. A *lot* more of the Solar System will be in gravitational range of the star than in the range of the black hole.

Black holes aren't monsters. They're just black.

Credits

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