The black hole horizon

An old song claims "I've looked at clouds from both sides now." In this chapter, we'll look at the event horizon of a black hole from both sides. An observer outside the black hole sees events different from an observer in free fall through the horizon. Like the holographic principle, the two different perspectives give us different tools to describe the same phenomena.

As we've seen, the simplest description of a black hole derives from the Schwarzschild metric.

$$ds^2 = -\left(1 - \frac{2GM}{r}\right) dt^{\,2} + \left(\frac{1}{1 - {2GM}/{r}}\right) dr^2 \tag{30.1}$$

We have suppressed the tangential components in order to concentrate on radial motion, i.e. objects and observers falling into the black hole. First we take the perspective of an observer, Bob, outside the black hole watching a second observer, Alice, falling toward the event horizon.

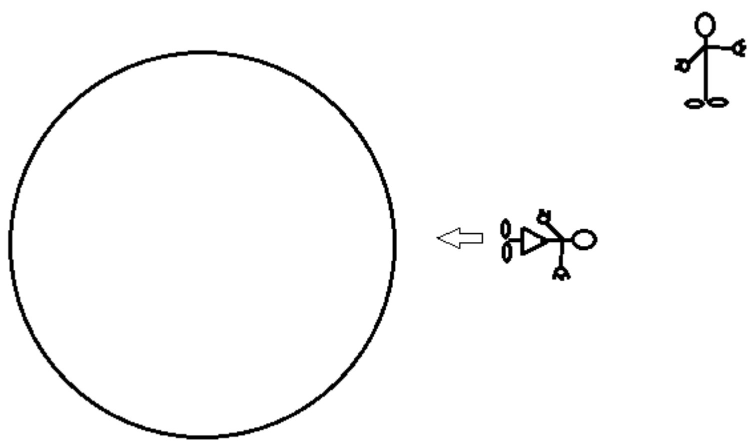

Figure 30.1. Bob, hovering above a black hole, watches Alice falling toward the event horizon.

As r, Alice's distance from the (center of the) black hole, approaches $R = 2GM$, the radius of the black hole, Bob sees Alice's clocks slow and her meter sticks shorten along the direction of motion. From Bob's perspective, Alice never reaches the horizon. Her clock ticks (and she moves) slower and slower and slower and slower . . . And as she approaches the horizon, it Bob watches in horror as she gets squashed against it. Poor Alice!

But wait. What does Alice herself experience?

Nothing unusual. It's ho-hum free-fall, just like sky diving. No bumps or jostles or discomfort along the way. How can this be?

Take a look again at the Schwarzschild metric. That first term on the right

$$\left(1-\frac{2GM}{r}\right)dt^{\,2} \tag{30.2}$$

is the square of the proper time, the time Alice reads on her wristwatch.

$$\left(1-\frac{2GM}{r}\right)dt^{\,2}=\left(1-\frac{v^2}{c^2}\right)dt^{\,2}=d\tau^2 \tag{30.3}$$

because

$$\frac{2GM}{r} \tag{30.4}$$

is the square of the escape velocity at distance r from a center of mass (in this case, the black hole).

Similarly

$$\left(\frac{1}{1-{}^{2GM}\!/_{r}}\right)dr^2=d\rho^2 \tag{30.5}$$

is the square of the proper distance. Combine these, and the Schwarzschild metric reduces to

$$ds^2=-d\tau^2+d\rho^2 \tag{30.6}$$

This is good ol' Minkowski flat space. Alice sees no r dependence for her clocks and meter sticks. Nothing strange happens as she falls through the event horizon. She doesn't even know when she crosses it.

Here we have another kind of duality. Bob sees terrible things happening to Alice (although it takes an infinitely long time for them to happen). Alice encounters nothing unusual on her trip through the event horizon and into the black hole. Different observers, dual descriptions of the same physics.

Return to Table of Contents