Comfortable with strings? We've seen what they are, how they behave, where they live. For the remainder of this text, we'll explore how strings can help us answer the outstanding questions in physics, the physics that's not yet well understood. We'll find that strings can explain certain puzzling properties of black holes and that these tiniest of structures offer insights into the largest structure yet conceived, the multiverse beyond our universe and beyond the neighbors.

Black hole basics

Black holes exist at the frontiers of physics. In order to describe a black hole, we need the equations of general relativity, thermodynamics, and quantum mechanics. Black holes form when the most massive stars collapse in supernovas. Gigantic black holes in the nuclei of galaxies may represent the kernels of density fluctuations left over from the big bang, around which the galaxies formed. Microscopic primordial black holes also may have formed at the big bang, and physicists hope they might produce tiny black holes in the Large Hadron Collider.

First the description of black holes in general relativity. We use the Schwarzschild metric in polar coordinates. This is a simplification that assumes the black hole is radially symmetric and is not spinning, but it allows us to probe the basic physics.

$$ds^2 = -\left(1 - \frac{2GM}{r}\right) dt^{\,2} + \left(\frac{1}{1 - {}^{2GM}/_{r}}\right) dr^2 + r^2(d\theta^2 + sin^2\theta d\emptyset^2) \tag{25.1}$$

We will be interested only in the radial terms – how the metric changes with distance from the black hole – so we will ignore the last term, which describes tangential displacements at distance r.

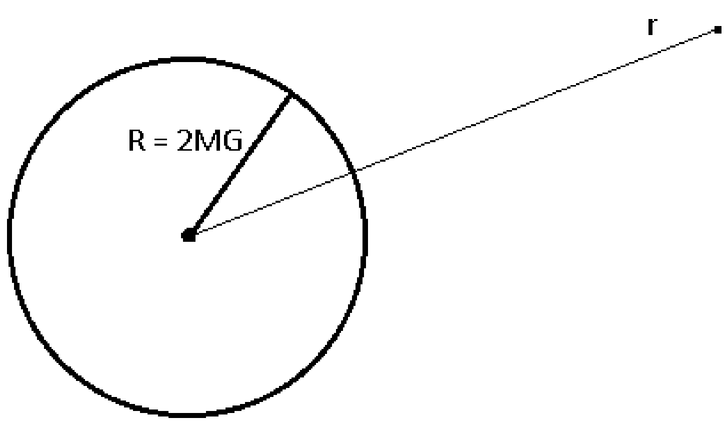

Figure 25.1. Black hole parameters. R is black hole radius. r is distance to an object outside the event horizon.

Note the relation between the metric term, $\left(1-\frac{2GM}{r}\right)$, and the good old Minkowski flat-space metric, $\left(1-\frac{v^2}{c^2}\right)$. $\sqrt{\frac{2GM}{r}}$ is the escape velocity at distance r from the black hole, so $\frac{2GM}{r}=v^2$, and, working in units where $c=1$ we recover the Minkowski metric.

Take a close look at the Schwarzschild metric. $2GM$ is the radius of the event horizon, where escape velocity is the speed of light. At the horizon, where $r=2GM$, clocks stop, and measurement of distance along the radial direction becomes indeterminate. The Schwarzschild metric also predicts bad things happen at $r=0$, the singularity at the center of the black hole. (i.e. general relativity can't describe what happens there.)

Now to the thermodynamics. The fundamental equation of thermodynamics relates the energy of a closed system to its temperature and entropy.

$$\Delta E=T\Delta S \qquad (25.2)$$

Simplistically, note that we can increase the energy of a glass of water either by increasing its temperature (roughly the average kinetic energy of all the water molecules) or by adding more molecules at the same temperature. Entropy, S , measures the amount of hidden information in a system. The concept is required for the description of systems such as the glass filled with huge numbers of water molecules where we can't keep track of all the particles individually. Entropy represents the enormous store of information in the database, if there were such a database, recording the position and momentum of each molecule.

One of the great discoveries of modern physics, by Jacob Bekenstein and Stephen Hawking, is that black holes have temperature. If they have temperature, they must radiate (and eventually evaporate), and they must have entropy. If they have entropy, they must have microscopic internal structure, containing all that hidden information. The best model so far indicates that black holes are built from strings.

Return to Table of Contents