SEEING THE INVISIBLE – THE SEARCH FOR BLACK HOLES.

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In this article we briefly discuss how black holes are discovered, some of their basic characteristics. Most of the discussion will concern what are called "stellar mass" black holes - black holes only ~5-10 times heavier than our Sun. Almost all of the black holes in our Galaxy (the Milky Way) are of this type. These objects have been under intensive study by several research groups over the last few years, including the group at UCC.

A Brief History of Black Holes

It was one George Michell who suggested, in the late 1700's, that a star 500 times larger than the Sun (but of the same density) would have a gravitational pull sufficiently strong that not even light could escape from it. The existence of stars so extreme was largely discounted until, some 150 years later, Einstein's Theory of General Relativity was brought to bear on the final evolution of massive stars. Here it was shown by Oppenheimer and collaborators that black holes were the inevitable result of the collapse of certain types of stars.

Black Holes represent Nature at her most extreme. The average density of material within the "typical" black hole found in our Galaxy is one hundred million million tonnes per cubic metre. A teaspoonful (say 1 cubic cm) of material at this density would weigh of order one hundred million tonnes (imagine the weight of one hundred million cars in a teaspoon !). Such a high density results from the fact that black holes are very compact objects: those in our Galaxy weigh ~5-10 times that of our Sun, but have volumes very much smaller - e.g. sizes comparable to cities on the Earth.

The distance at which not even light can escape from the black hole is called the Schwartzchild Radius. All points at this distance from the black holes are said to lie on an imaginary surface called the Event Horizon: anything that happens within this region is forever hidden from us on the outside.

Such is the enhanced strength of gravity approaching the Event Horizon that even time itself slows down enormously. We will return to some of these effects later.

We mention in passing that Einstein's theory is not just confined to black holes: its applicabilty ranges from the expansion of the Universe to the successful operation of the Global Positioning System (GPS) system (because of its ability to explain how gravity affects time) - but that's another story.

Finding Black Holes

The search for such exotic objects in our Galaxy depends on two branches of Astronomy - X-ray astronomy and optical astronomy. Very generally, the techniques of X-ray astronomy can be used to find the black holes, whereas the techniques of optical astronomy can be used to weigh them.

Optical Astronomy

As the name implies, optical astronomy largely involves the study of the visible light that is generated by stars (or any other astronomical object). It is arguably the oldest of the sciences, as stars have been the subject of idle fascination and systematic study for thousands of years. Nowadays large telescopes are used in place of the eye to record light from stars with unprecedented detail. These measurements usually take the form of either (a) determining the brightness of a star (e.g. by taking images) or (b) measuring the spectrum of star. The latter is an especially powerful tool of the astronomer. It involves looking at how the intensity of light from a star depends on the colour of that light (or more specifically, the wavelength), and enables astronomers to measure such things as the temperature, speed, and chemical composition of the star.

Optical Telescopes

Up until the middle of the 16th century, the only tool for gathering the light from stars available to an astronomer was the human eye. With a typical pupil diameter of (say) 1/2 cm, one can see how the construction of a telescope with a lens of a few cm in diameter increased the sensitivity of the astronomical observation. The lens also allows objects to be resolved from each other that would otherwise be impossible with the naked eye. From the observations of Galileo onwards, these devices revolutionised our perception of the Cosmos.

The power of modern telescopes can be gauged by the fact that the largest today have mirrors ~10 m in diameter (e.g. the size of a large house), and are capable of resolving the disk of a 5 cent coin in Dublin from, say, London. Such telescopes can study in detail stars thousands of millions of times fainter than the unaided eye can see.

X-ray Astronomy.

This is a relatively recent development of astronomy, involving the detection of X-rays from stars. These X-rays are much the same as those received by a patient during an "X-ray" at hospital. They are a type of radiation, similar to visual light, but much more energetic - it is because of this higher energy that they can penetrate matter.

If turns out that very hot objects emit copious X-ray. By "hot", we mean *really* hot - temperatures of millions of degrees, or higher. By contrast, a comfortable temperature would be ~20^{o}C, whereas at the surface of the Sun the temperature is (a slightly less comfortable) ~5500^{o}C. As most stars are thought to be similar to our Sun, it came as a big surprise to astronomers to find many astronomical objects thousands of times hotter again. How can this be?

The secret behind "X-ray bright" stars lies in their compactness. We've seen already how black holes in our Galaxy have a mass comparable to that of our Sun, but are much smaller in size. Now imagine a black hole (weighing, say, 8 times that of our Sun) onto which we accidentally drop some matter - say this book. Because the black hole is so compact, the gravitational force near it is extremely strong: indeed, near the Event Horizon it is one hundred thousand million times more than you are experiencing right now – i.e. an average size person would weigh ten thousand million tonnes. Because of this force, it turns out that this book would be accelerated to a speed comparable to that of light itself - 186,000 miles per second (i.e. a trip on a light beam from Cork to Dublin would take three thousandths of a second). Hence, if a black hole *accretes* nearby gas, the gas is accelerated to extremely high speeds, and this heats the gas to very, very, high temperatures - hot enough indeed for it to generate copious X-rays.

What is the source of this gas? It turns out that many of the black holes in our galaxy orbit a companion star (often a star pretty much like out own Sun). The black hole accretes gas from its companion, over the eons draining the star of gas. This gas is accreted onto the black hole generating X-rays.

Hence these black holes are X-ray bright, and many of them stand out conspicuously in the "X-ray sky". Now all we need is a way to see the sky in X-rays.

X-ray telescopes

Unlike the optical telescopes mentioned earlier, X-ray telescopes must be launched into space - the Earth's atmosphere does a very good job of absorbing most of the high energy radiation from space, including X-rays (luckily for us). These telescopes can be used to produce images of the sky, in much the same way as optical telescopes do: the difference is these are images using X-rays. It turns out that, to do this properly, the mirrors of the X-ray telescope have to be extremely smooth - so smooth, in fact, that they are amongst the smoothest surfaces made by man (with a roughness of no more than a few atoms above nominal).

These telescopes can be used to provide X-ray images of the sky, and hence we have a way of finding black holes.

Weighing Black Holes

We've mentioned that many of the black holes in our Galaxy orbit companion stars. It turns out that, by measuring the speed of the companion star as it orbits the black hole, we can constrain the black hole mass. For example, all other things being equal, the more massive the black hole, the more rapidly its companion star will have to orbit. By measuring the speeds of companion stars in this way, some ~dozen black holes have been found in our Galaxy, mostly weighing ~6-8 times that of our Sun.

Recently, dramatic evidence has been found of a more massive black hole lurking in the centre of our Galaxy. Astronomers have been able to measure the speed of stars as they orbit the centre of the Galaxy. They have found evidence that some stars orbit at very high velocity, very close to the centre. These measurements show that a black hole weighing ~three million of our Suns must reside in the core of our Galaxy. It is thought that similar mass black holes reside in the cores of other galaxies like our own, and that even more massive black holes lurk in more distant galaxies.

Conclusions

Astronomy is one of the most dynamic of the sciences, as abundantly exemplified by the discovery of black holes. However, much has to be done to improve our understanding of these extreme objects - and this requires "extreme" Physics, pushing to the limit our understanding of the fundamental workings of Nature. And from this, no doubt, other discoveries are bound to follow.

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