How to measure the spin of a black hole

Daniel Plant, Astronomy Group
www.astro.soton.ac.uk/~dp1g10/index.html
d.plant@soton.ac.uk

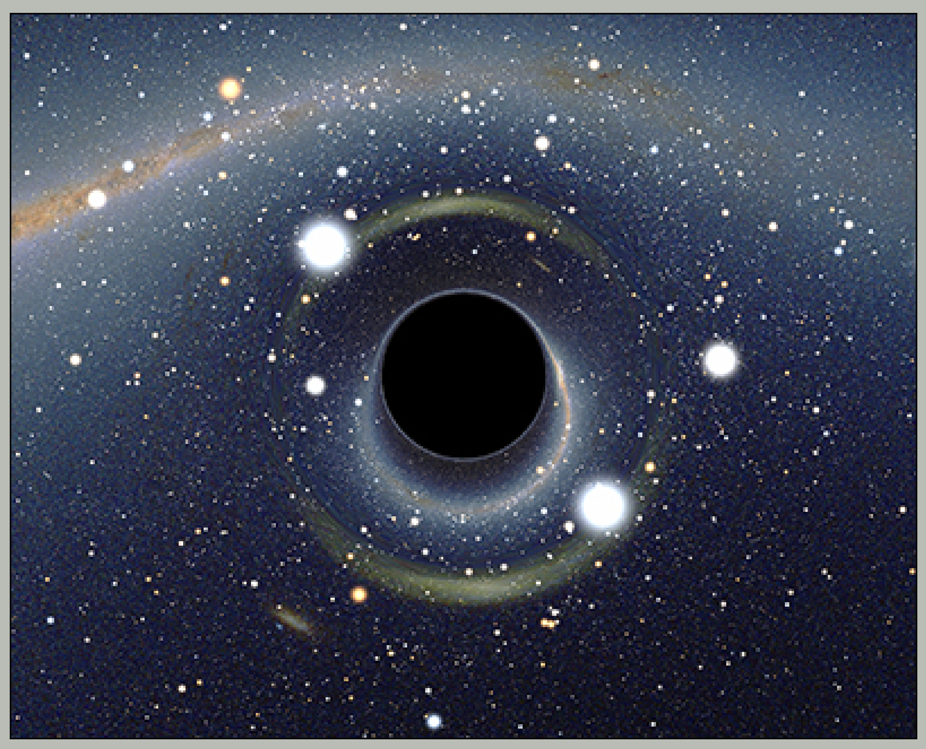
UNIVERSITY OF Southampton

Abstract

Black holes are remarkably simple, they are described by just two parameters - mass and spin. Whilst mass is fairly easy to detect, since its influence spans large distances, spin is rather subtle. The spin itself takes hold very close to the black hole, where the effects of Einstein's relativity are immense. The strength of the relativistic effects allows us to determine how fast the black hole is spinning. However, black holes are dark voids in the sky, we cannot see them, and instead we use their interaction with other objects, such as a companion star, to solve this puzzle.

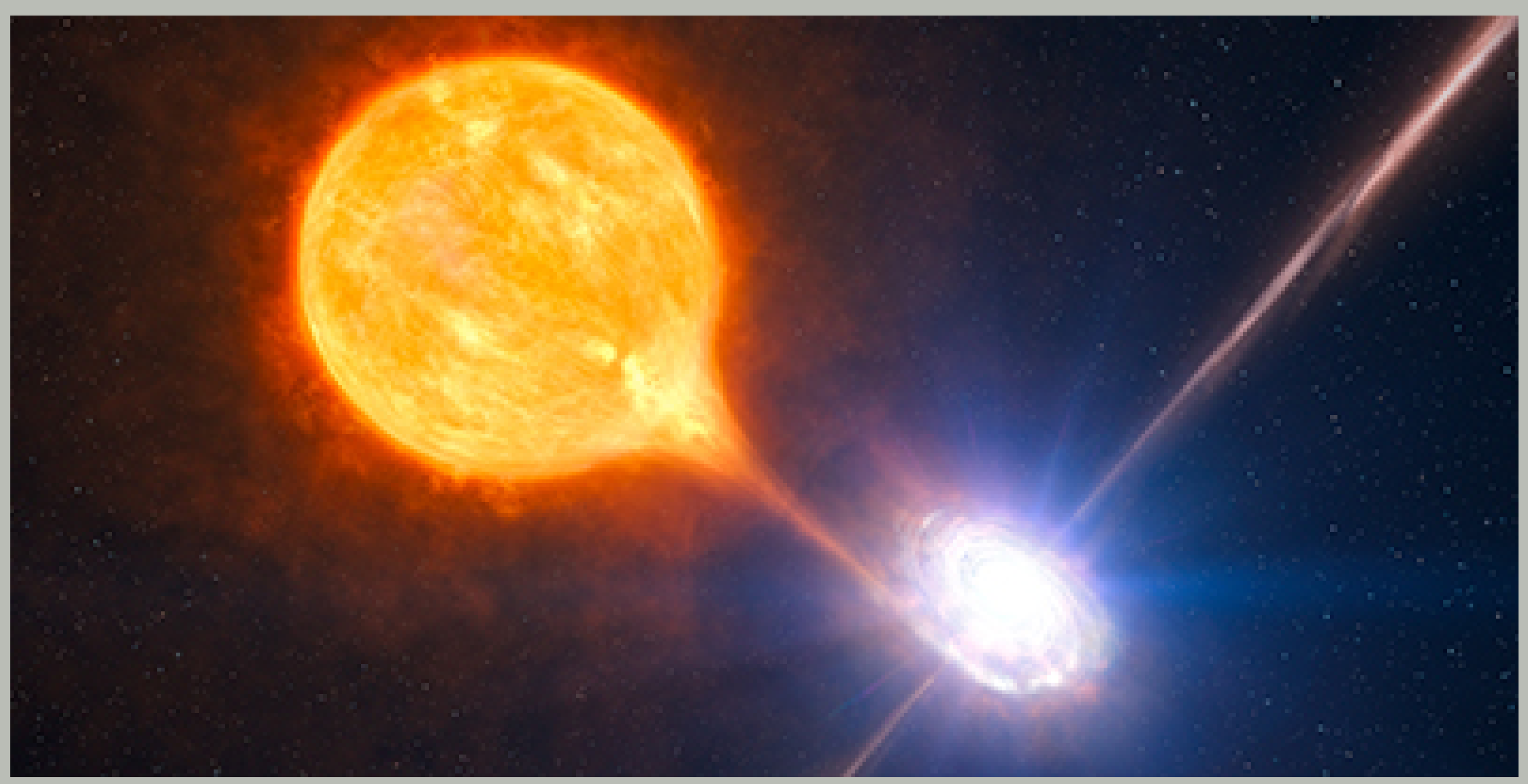
1. But first...what is black hole?

A star spends most of its life in equilibrium - gravity tries to make the star collapse whilst all the radiation attempts to force its way out. When a massive star dies it no longer radiates and hence collapses upon itself, compressing all the remaining matter into a tiny space. The gravity of such an object is immense and consumes anything nearby with ease. Close by (3km per Sun mass) even light cannot escape, and without light we cannot see it. All that remains is a dark void, a 'black hole'.



A simulation of a black hole placed in between us and a nearby galaxy. Image credit: Alain Riazuelo.

2. How to observe a black hole.



An illustration of a black hole (right) feeding off a companion star (left). Note the bright accretion disc which has formed around the black hole. Image credit: ESO/L. Calcada

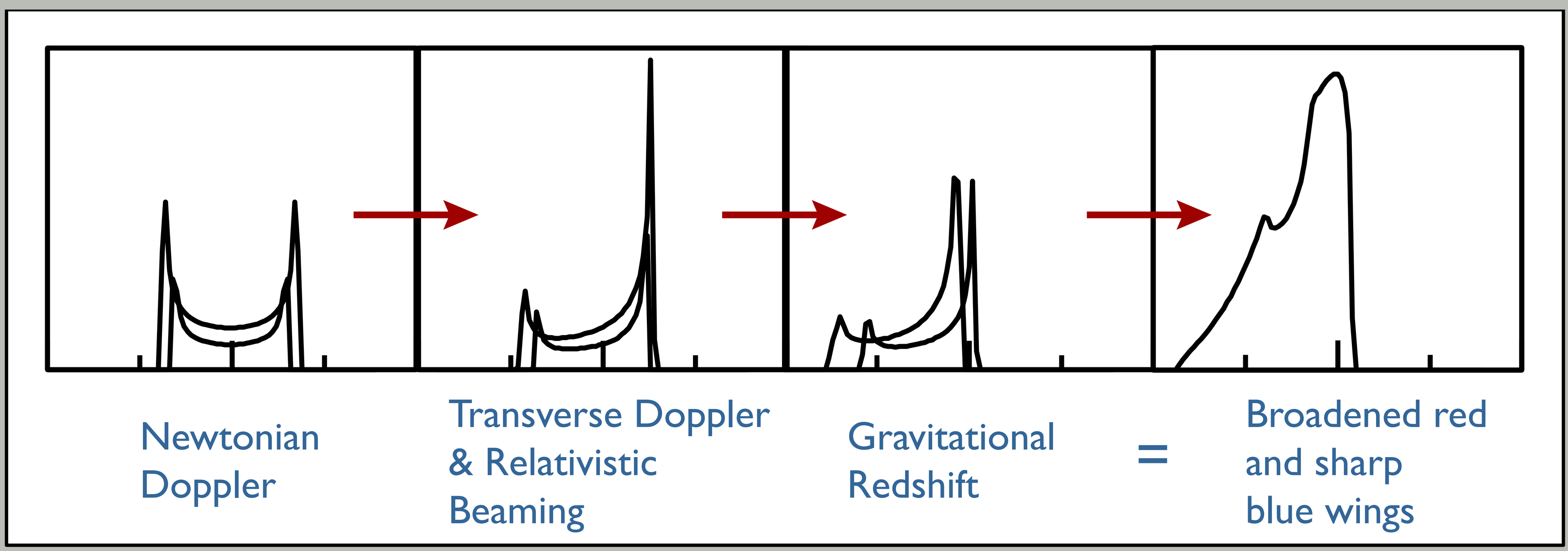
Astronomers use light to observe objects, therefore we cannot 'see' a black hole. However it is believed that at least half of the stars in our galaxy are systems of two or more stars. This means that if a black hole is formed there is a good chance there is a star nearby, and the intense gravitational might of the black hole will tear gas from the star towards it (see the illustration above). This process is called accretion, and since the star and black hole are orbiting each other, the matter cannot fall directly onto the black hole. Instead it spirals, forming an 'accretion disc' around the black hole. Matter in the disc is gradually devoured by the black hole, and as it moves closer it heats up more and more as gravitational energy is lost. The inner regions reach millions of degrees, making the disc visible to us through X-ray telescopes.

3. Black holes are just mass and spin.

Image credit: scottamus @ flickr

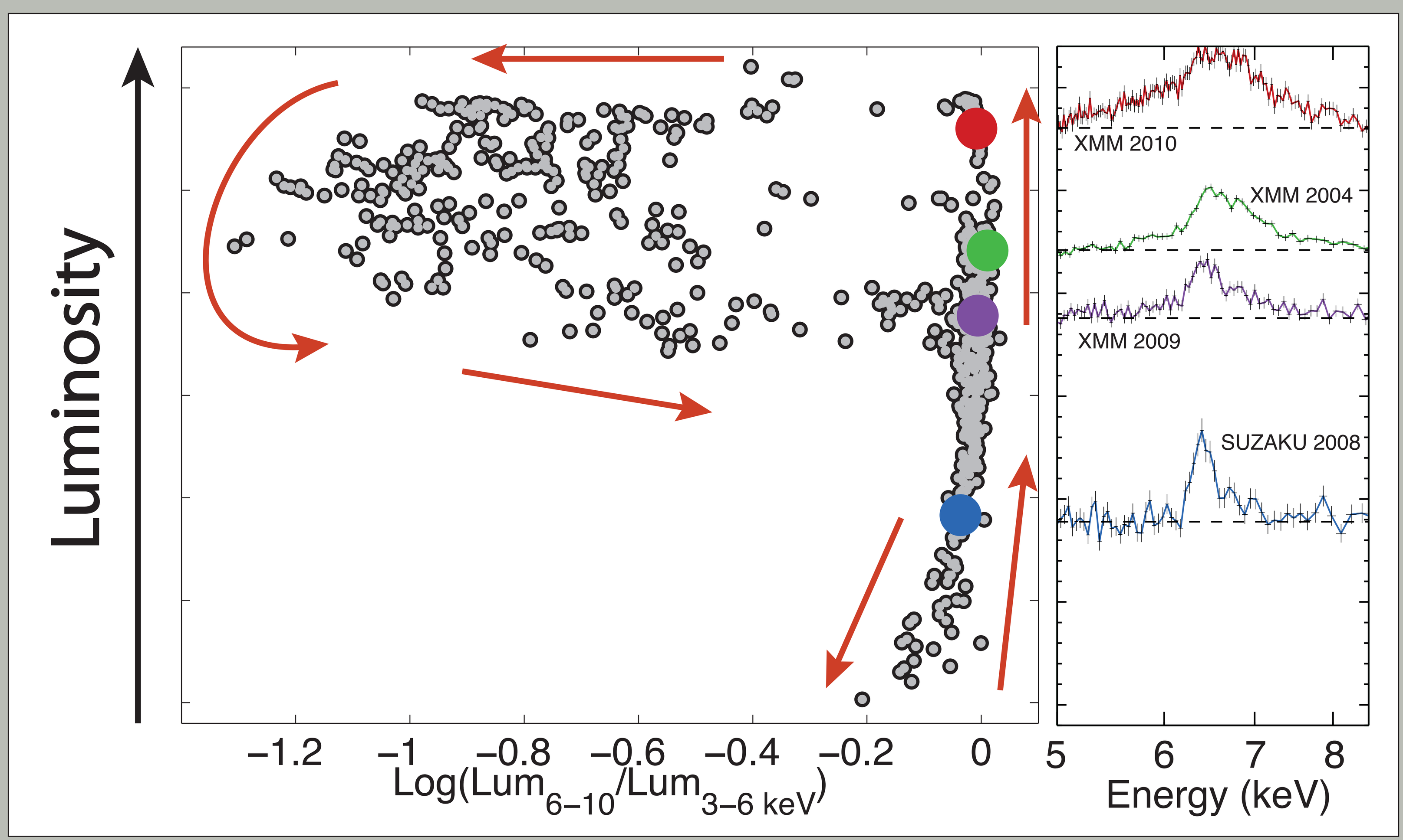
Whatever makes its way into a black hole is converted into just mass and spin. Think of all the ways to describe yourself - the colour of your hair, eyes, skin, your weight, height...the list is endless, and makes black holes quite remarkable. Measuring the mass and spin is therefore much less complicated. Mass is simple to determine, since more mass increases the scale of the gravitational influence. Spin though is more subtle. Imagine you are on a merry-go-round (left), it is spinning faster and faster with every turn, you have to grab tighter and tighter to stay on. A black hole drags space around with it as it spins, so whilst gravity is pulling you towards the black hole the spin is essentially pushing you away. **The faster a black hole spins, the closer you can get to it without falling in.**

4. Measuring black hole spin.



The inner part of the disc is travelling at extreme relativistic velocities (more than 10,000 km each second). For a black hole with no spin it orbits ~200 times a second, and this increases to over 1000 times a second for maximal spin. Furthermore, light emitted close to the black hole will be stretched out to longer wavelengths by the gravity trying to pull it in. Elements emit radiation at specific energies leading to sharp lines in the spectra we observe, and such effects distort these spectral lines (see above), and are more severe with increasing spin. By modelling this we can fit the observed spectral profile to measure the spin of the black hole.

5. Or measuring the disc inner radius.



Increasing spin decreases the inner radius of the accretion disc (*i.e.* allowing the disc closer to the black hole), but what if the inner radius was changing for a different reason? Black holes conserve their spin very well, so this will not change. Therefore if we see the spectral profiles broaden then it is a very good indication that the inner radius of the disc is moving closer to the black hole (or visa versa). Above (left) is a plot of how a black hole evolves, the y-axis indicating how luminous it is, with coloured circles for four high resolution observations able to resolve the spectral profiles. Grey points are from monitoring of the black hole. On the right are the corresponding spectral profiles which show a clear difference between observations.

6. The inner radius of the disc is changing!

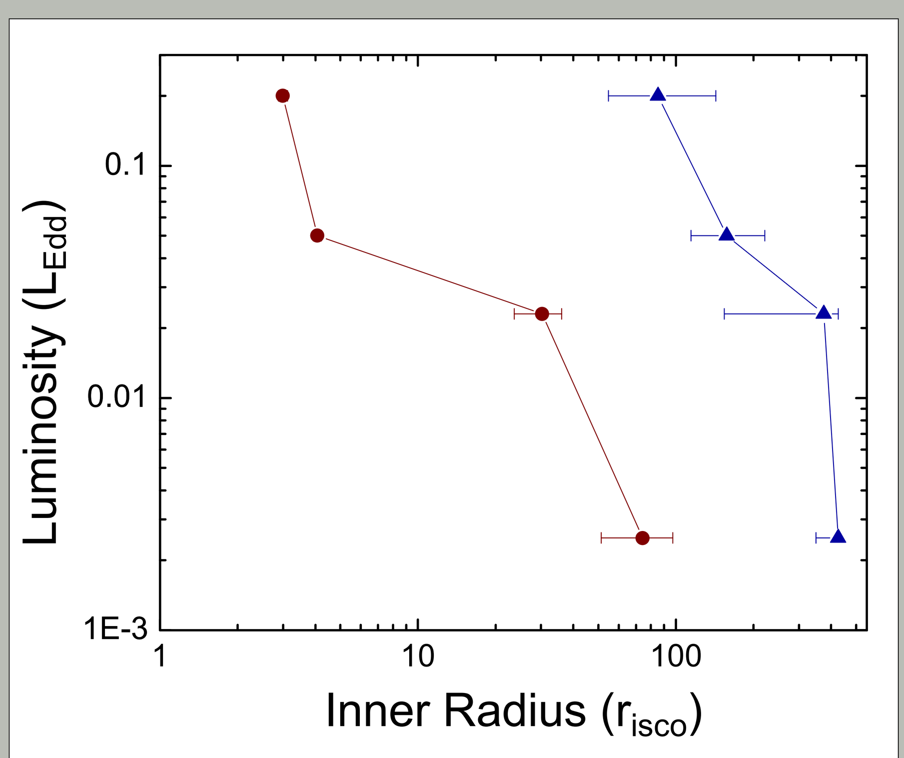


Figure 4 adapted from Fabian+2000. Figures 5 and 6 are from Plant+2013

The plot to the left shows the inner radius (x-axis) against luminosity (y-axis). We find that as the black hole increases in luminosity the disc is moving closer to the black hole, and this explains a lot about how the accretion disc evolves. Many black holes are transient, they are not always accreting in the same way. If the disc is moving inwards and outwards, as we have found, then it is much easier to understand their behaviour.