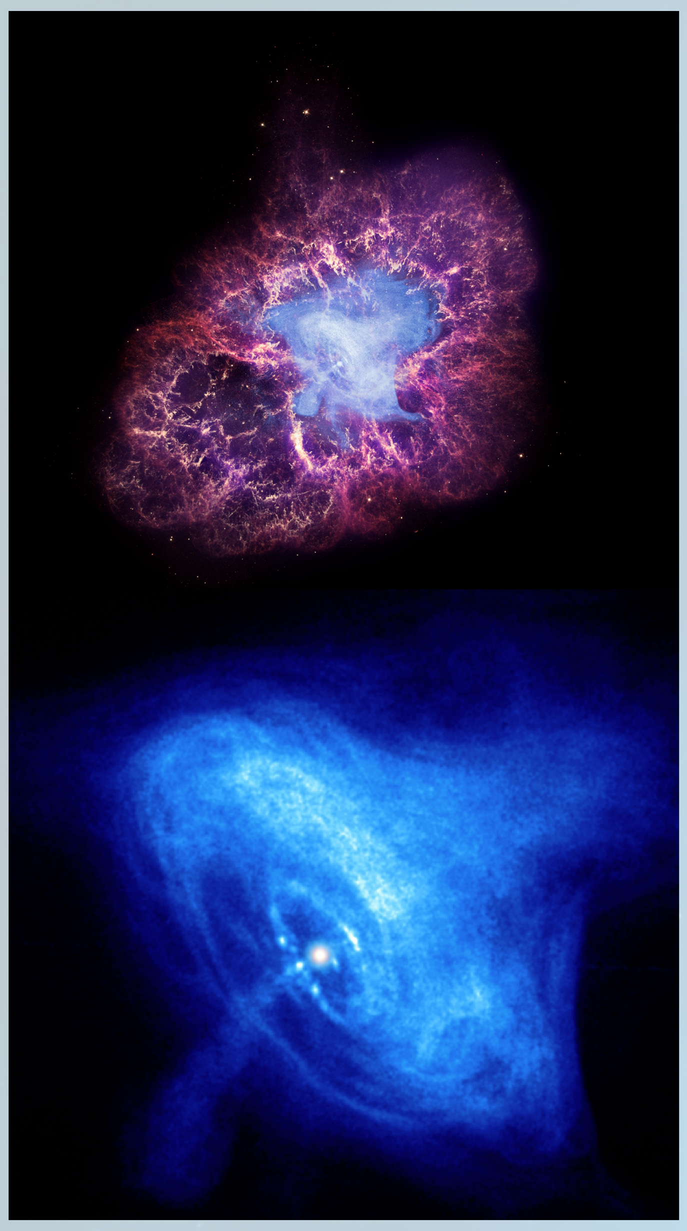
Black Hole & Neutron Star Jets

Tim Lemon
Gravity Group
www.southampton.ac.uk/stag

UNIVERSITY OF Southampton | Mathematics

1. Introduction

Black holes and neutron stars are formed from massive stars at the end of their lifetime. If the star's mass exceeds a certain threshold, then when that star goes supernova it will collapse to form a black hole. However if it is below the threshold the star will collapse to form a neutron star. A typical neutron star has a radius of about ten kilometres, whilst having between one and two times the mass of our own Sun.

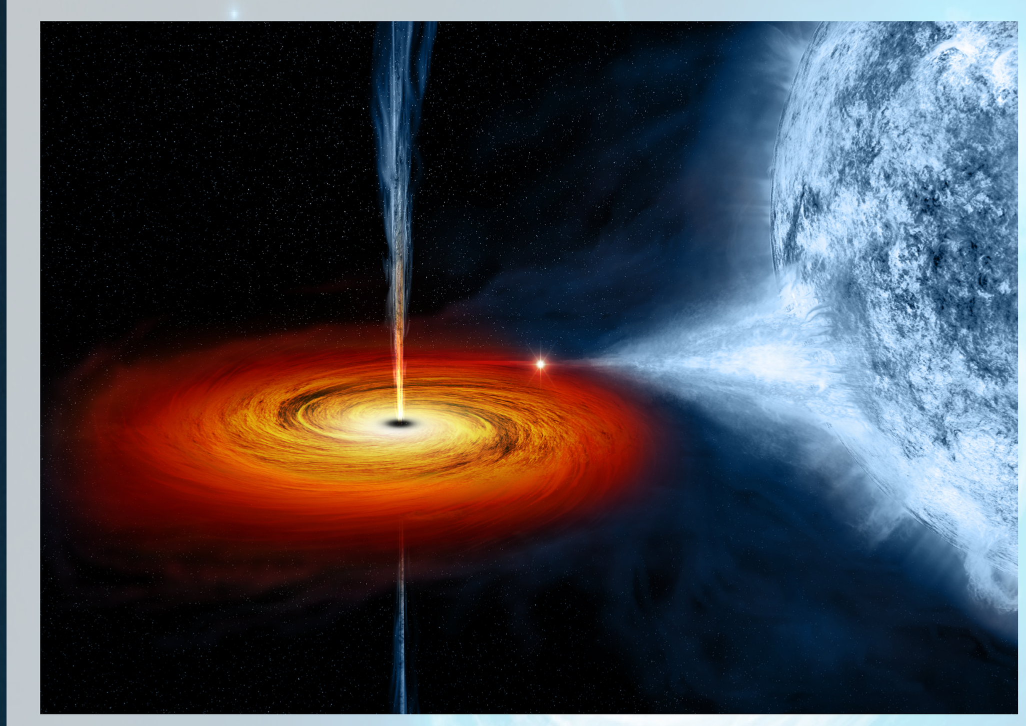


Astrophysical jets are spectacular and powerful phenomena. They are believed to be formed when matter flows onto a compact star, such as a black hole or neutron star. This matter is then ejected at the poles of the star at velocities close to the speed of light. They are thought to be the cause of gamma-ray bursts, one of the most powerful phenomena ever discovered in the Universe.

2. X-Ray Binaries

X-ray Binaries (*below*) consist of an ordinary star transferring stellar matter onto its companion compact star, as they rotate around each other. This accreted matter then forms an accretion disk around the compact star which then releases its potential energy in the form of X-rays.

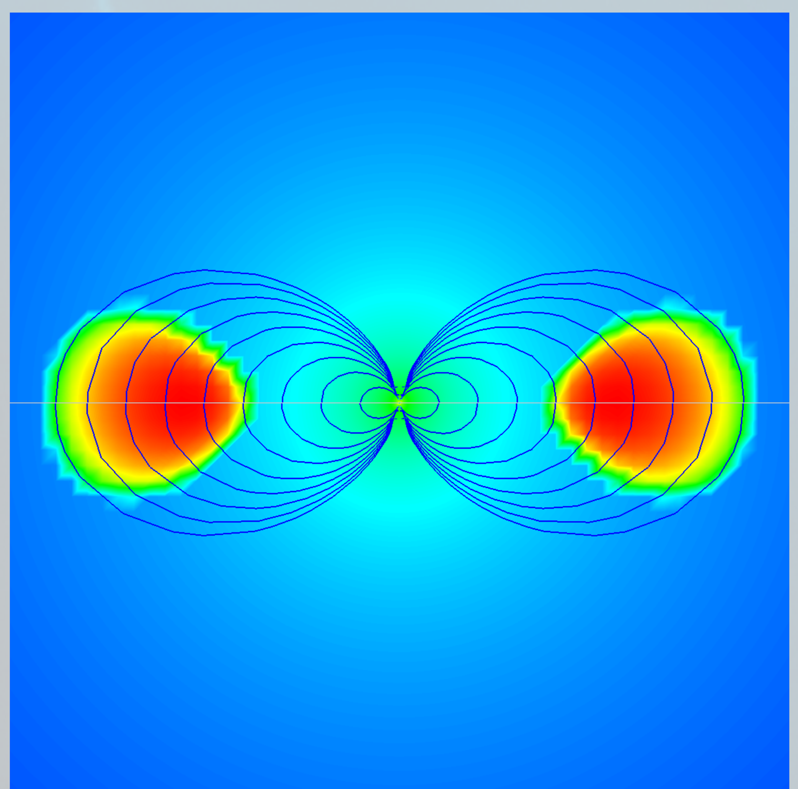
Within X-ray Binaries, a link has been established between X-ray observations of the accretion disk and the radio emission from the jet. This suggests that jets are powered by this accretion process.



Differences in jet observations indicate that different types of stars also have an important effect on the structure and formation of jets. A major issue is whether the mechanism, which causes the jet, is the same for all of these objects. A cross comparison of these different systems is vital to understanding the mechanisms behind jet formation.

3. Simulations

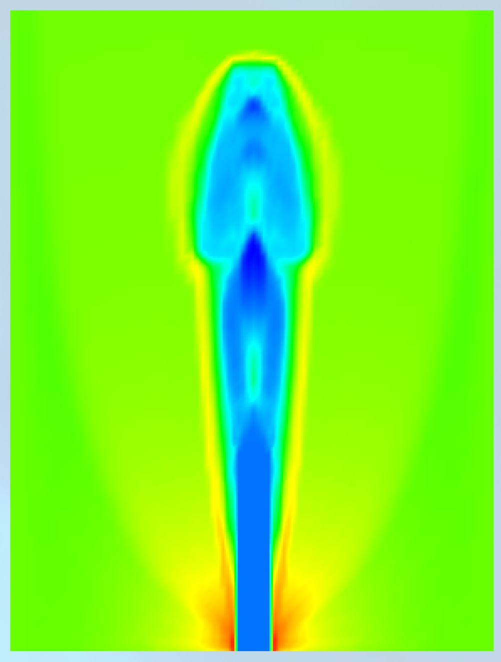
To study the formation of jets, I need to simulate how a jet interacts with its environment. However the environment where jets are formed is very complicated and is not well understood. For this reason the initial simulations were basic and just focused on how a relativistic jet travels through a denser material.



Later the more advanced simulations included an accretion disk with a magnetic field around a compact star. My cross-section image (*right*) shows the initial density of the accretion disc around a black hole. The high density areas, such as the disk, are coloured red, whilst the low density ambient medium is blue.

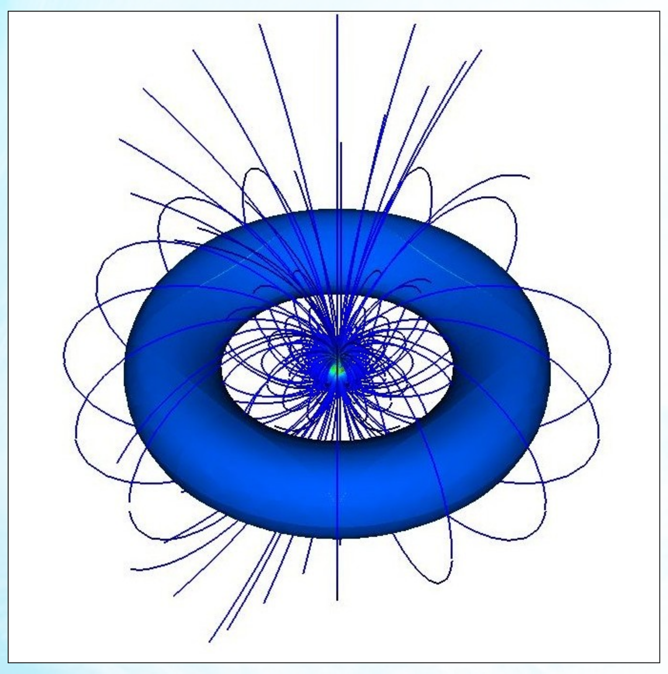
4. Jet Modelling

The first jet simulations were achieved by taking some initial properties of relativistic jets within an ambient medium and then letting the simulation evolve over time. With the jet material travelling at close to the speed of light this produced a turbulent flow of material, with shocks occurring inside the high density structure around the jet itself.



This model was then improved upon by including the gravitational field from a compact star at the origin of the jet structure. This introduced strong gravitational effects from the star pulling most of the matter from the jet back to the origin, creating a high density area near the base. My figure to the *right* shows such an example of jet originating from a rotating black hole. The actual black hole cannot be seen in the figure, as it is just a single pixel in the simulation.

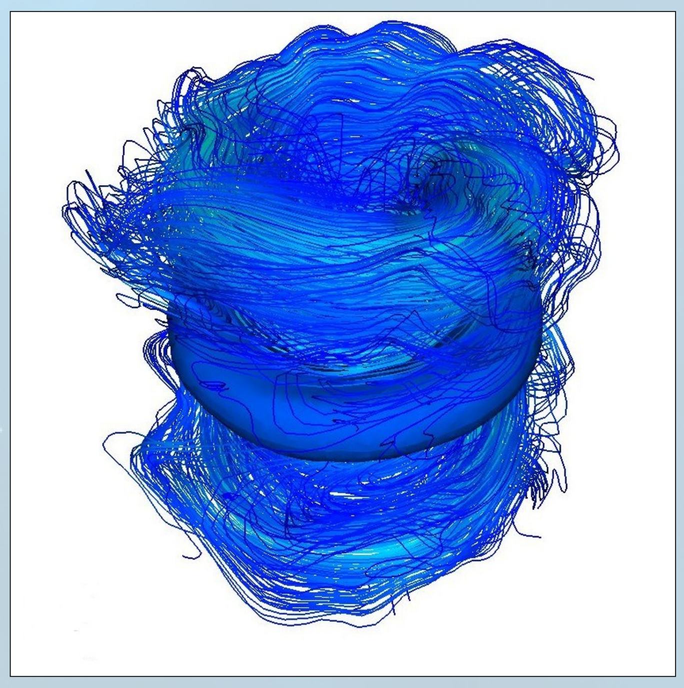
5. Accretion Disks



The next set of simulations were designed to try and create a jet directly from a compact star and its accretion disk. This time I would need to take into account the effects of magnetic fields as well as general relativity. My figure (*left*) shows a 3D density plot of an accretion disk around a black hole, viewed in the initial state of the simulation. In the figure it is also possible to see the field lines of the magnetic field loop around the disk.

During the simulation the matter in the accretion disk rotates around the star, falling more and more inwards. The rotation in the disk twists the magnetic field lines around with it, as they are anchored into the disk. The matter will eventually reach the innermost stable circular orbit. Past this point the matter should flow along the magnetic field lines to the black hole, and then be ejected outwards at the poles.

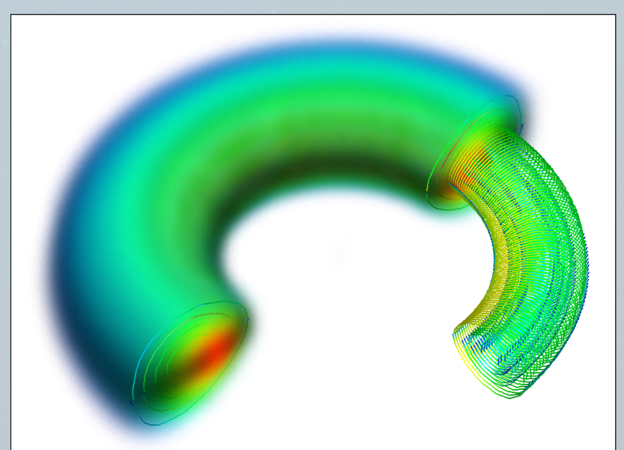
By the end of the simulation the system has ended up in a very complex state as seen in my figure (*right*). Simulations so far have been carried out with both black holes and neutron stars, that were either rotating or non-rotating. These simulations also included magnetic fields of varying strengths. The results from these do show matter flowing along the field lines and accumulating at the poles. However this matter is not being accelerated to high enough velocities to escape the gravitational attraction of the compact object and launch a jet.



6. The Future

The simulations now include all the main features associated with launching a relativistic jet from a compact object. This gives me a good starting model to improve on and to match a more realistic jet launching environment.

The next step is to fine-tune the initial conditions to more closely resemble those found within X-ray binaries. This would include using a different structure for the magnetic field within the accretion disk, shown *right*.



The way the simulation evolve the system over time could also be altered to use the computer resources more efficiently. This should lead to more accurate results.

Images courtesy of NASA. The author acknowledges support from the University of Southampton.

Supervisor: Ian Hawke   Tim.Lemon@soton.ac.uk   STAG Website: