Student questions: James Stone colloquium on "Using Computation to Understand Why Black Holes Shine"

11/6/19

Question 1: How do kinetic effects change the distribution of the plasma discharged?
This is a very complicated question. There is additional viscosity and heat conduction in a weakly collisional plasma, and both are only along the direction of the magnetic field. In addition, the electron and in temperatures may not be the same. This affects the plasma dynamics in fundamental ways.

Question 2: How does Ligo estimate the mass and distance of a black hole?
The amplitude and especially the frequency and how it changes in time of the gravitational waves observed by LIGO give the distance and mass repectively.

Question 1: What is the function of disk-jets around the black hole?
I'm afraid I don't understand the question.

Question 2: What are some examples of how the fastest computer in the world is being used?
In addition to astrophysics, the fastest computers are also used to predict the weather, understand climate change, to design new materials and new drugs by studying molecular structure, and to design new airplanes. In short, an enormous range of problems.

Question 1: How did you find the measurements of these black holes compared to the sun?
The black hole observed in M87 is several billion times more massive than the sun.

Question 2: If the two black holes merge together will they produce more light because there are more photons involved?
Without plasma in the surroundings, they will not produce any light, only gravitational waves. If there is plasma, then the merger would likely generate more light, but only for a short amount of time.

Question 1: Does mass or angular momentum of a black hole change with the addition of plasma?
Yes, both change, but only by a very small amount.

Question 2: How do kinetic effects change the distribution of plasma?
(see previous answer)

Question 1: Is the orientation of a black hole determined by the angular momentum/orientation of its host galaxy?
No, observations show that the spin of the BH can be orientated at any direction compares to the host galaxy.

Question 2: What is the primary limiting factor on improving processing power in newer computers?
The power consumption. It is difficult to build bigger computers because of the amount of electricity and cooling they would require.

Question 1: Thanks for the great talk! I'm not an astronomer, so my questions are quite of basic: How fast do black holes rotate?
Thanks! They can spin almost at the speed of light.

Question 2: Does the speed a black hole rotates ever change? Or is it a steady rate?
It can change. It will slow down if the BH has a jet and loses energy, and it will speed up if the BH accretes matter and gains energy.

Question 1: Will large scale quantum computing be helpful in your simulation work?
No, quantum computers can only work on very specialized problems, at least for the forseeable future.

Question 2: Is there such a thing as an anti blackhole?
No, since there is no anti-gravity (too bad, since that would make space flight easier!), there are no anti-BHs.

Question 1: How do the gravitational wave detectors work?
By measuring the change in distance between two points very precisely as gravitational waves pass by. The LIGO website has lots of material explaining how it works in detail.

Question 2: Why are black holes surrounded by a disk of plasma?
Most of interstellar space is filled with plasma that comes from stars and other sources. Some of this plasma gets captured and accreted by the BH.

Question 1: How well do we understand plasma mechanics around these black holes?
We think we understand the plasma physics quite well. We are now using observations and simulations to test whether thus true.

Question 2: How could we increase the resolution of future images with the limitations we currently have with our technology?
Better resolution requires longer baselines (larger distance between receivers). Since the EHT now covers the entire Earth, anything better will require launching radio telescopes into space, and using those combined with the receivers on Earth to get longer baselines.

Question 1: Is the mass density of a super massive black hole more than that of a smaller black hole?
Since the size of the BH is proportional to mass, the density gets smaller. But we don't really think of the density inside of a BH as being important, all that really matters is mass, spin, and charge.

Question 2: What originated first, a super massive black hole or a galaxy?
We don't know. We think they might have formed together. It is one of the biggest mysteries about galaxy formation.

Question 1: Is it possible to form gravitational waves (possibly with an interfering force) strong enough to push two wave peaks together, and cause two portions of space time to intersect? If so, what are the predicted effects?
I don't think so, but perhaps I don't understand the question.

Question 2: What method did you use to determine that the object in the center of galaxy M87 was indeed a relativistic jet from a black hole, and not a stellar feature such as a Harbig-Haro object?
Over the course of the last few decades, we have detected the motion of the jet away from the BH at the center of M87 and that shows the plasma in the jet is moving at very close to the speed of light. That means it must be coming from a BH and not a low-mass star (which observations have shown drive Herbig-Haro objects).

Question 1: With computation, will it be possible to derive universal equations for plasma dynamics near black holes?
Yes, these equations are already known, and were derived analytically. Solving them requires computers.

Question 2: Is there a limit to how much plasma a black hole can accrete?
No, in principle it could keep accreting matter for ever. However, the age of the universe puts a limit on how large BHs could have grown by today. In addition, the supply of mass puts another limit on the mass of the biggest BHs. They cannot be more massive than the galaxy that contains them.

Question 1: With this new technology have there been other black holes discovered that "shine"?
Yes, the BH at the center of the Milky Way also shines in the same way as M87.

Question 2: This particular black hole you discussed has a shadow, which is uncommon, but how would one normally find a black hole in outer space?
We can only find them if they accrete matter. Then they produce light which we can detect. Some BHs are extremely bright and easy to find, for example quasars and X-ray binaries.

Question 1: How parallel is your code (can you quote a percentage)?
It is about 85% efficient on up to 500,000 cores.

Question 2: What is the dynamical time for modeling accretion disks using 3d mhd?
The dynamical time is the time to make one orbit aroun d the BH near its surface. This is about 1 millisecond in the case of a stellar mass black hole, and about one day in the case of M87.

Question 1: How large is the most impactful observed singularity ?
I don't think we have ever observed a singularity, but perhaps I didn't understand the question.

Question 2: With black holes that shine, how much radiation does it take to pass into the "observable" shine?
We can detect a very, very small amount of radiation coming from accreting BHs. Our telescopes are very, very sensitive.

Question 1: To what degree of magnitude would modeling plasma to have weak interaction instead of strong interaction improve the accuracy of black hole measurements, and can this be quantified or are we lacking in computing power to do so?
If you mean the weak and the strong interaction of nuclear physics, neither really plays a role in BH accretion. Instead the particles interact mostly through electromagnetic forces, and through gravity.

Question 2: Do you believe the implementation of addition baselines in orbit or on the moon is essential in improving the event horizon "telescope" and do you think the cost of implementation would be worth it to improve resolution of these images?
Adding telescopes in space is indeed essential to improve the images. I am not sure what would be the cost, so I cannot comment on whether it would be worth it.

Question 1: Why doesn't the entire rotating disk of plasma get sucked into the black hole?
It has angular momentum (rotation) and this prevents it from falling inwards. It is the same physics that prevents the Earth from falling into the Sun.

Question 2: I understand massive stars form stellar mass black holes but what forms supermassive black holes?
It requires the merger of many smaller BH to build up the mass over time, or the addition of mass through accretion through processes such as I presented in my talk.

Question 1: How could quantum computing improve the visualization of black holes?
Quantum computers are very specialized and so probably will not help the observations or modeling of BH accretion flows, at least in their current designs. Perhaps this will change in the far future.

Question 2: How do you go about stitching together the data received from each different array?
This is a very complicated process. It requires recording all the data with a very precise time stamp at each receiver, and then trying to find the time off-set required to make each signal agree exactly. That then gives the time delay of the signal between the two telescopes, and that gives the direction on the sky from which the radiation arrived. Doing this with many telescopes then makes a picture of the sky. However, you should look-up how "interferomentry" works to get a better answer.

Question 1: How are you able to validate the output from plasma dynamics simulations?
We test our codes on many know simple problems. Only once we know it gives the right answer for all the simple problems do we apply it to the full calculations.

Question 2: Given the large team of developers, how do you manage the scientific software development lifecycle for Athena++ so that software engineers can better integrate themselves with the team?
Currently we do not have any software engineers on the team, only scientists. In the future we hope this changes. For now we use distributed development tools like git, regression testing, and continuous integration. We also use interaction tools like slack.

Question 1: Why are there peaks and valleys in the time progression graph of your code that showed how much of your code was in each language?
Sometimes when someone adds a lot of code at once, that produces a peak.

Question 2: Is the red/orange in the black hole image false color or the heat of the accelerating plasma you mentioned?
No, the color of the image is not related to the temperature of the plasma. It is a "false color" image.

Question 1: How do you predict adding kinetic effects to your accretionary plasma models will change your simulated image?
(see earlier answers)

Question 2: Do you think that software can help smooth out images, to get a higher-resolution image much like upscaling is done on 4k TV's, instead of a bigger dish for higher resolution
No, since we can only interpolate the images, that adds no new information, so that will not give us a better image. We need new information that can only come from higher-resolution observations in order to improve the image.

Question 1: Once we detect gravitation waves associated with fusion of black holes, can we measure dimensions of each participating black hole.
Yes, the GW signal tells us the mass and size of the merging BHs.

Question 2: In a case where black holes merge, do they form one homogeneous large black hole, or they can form a pair of independent black holes, and do they ever burst ("supernova" for black holes)?
They always produce one larger BH.

Question 1: Is there enough parallax between the different radio telescopes to resolve out any depth in your images?
No, the image only shows the distribution of emission on the sky, not the depth.

Question 2: Is the super computer processing just used to aggregate all of the data from the telescopes or is it also used to filter out noise?
It is used for both. Filtering out the noise is very important.

Question 1: How can we estimate the rate of the black hole growth?
That depends on how quickly matter can be fed into the center. This in turn depends on where the BH is located, and what processes control the inflow of matter from large scales. So this depends very much on the environment of the BH.

Question 2: Does the rate of accreting matter into the black hole control the brightness of the black hole we see?
Yes, the rate at which mass is accreted directly controls the brightness we see. It is the most important factor, along with the mass of the BH itself.

Question 1: Is the disk of material around a black hole in the same orientation as the spin axis of the black hole?
Not always. If the angular momentum of the infalling matter at large scales is not the same as the spin of the BH, then you can form a disk that spins in any direction in relation to the BH.

Question 2: How are the jets actually formed?
Magnetic fields in the plasma are twisted by the spin of the BH, and this twisting produces an outward force along the magnetic field lines that produces a jet.

Question 1: How do you determine the mass of the two types of black holes?
For stellar mass BHS, we use the properties of the orbits when they are found in binary systems with other stars to measure mass. For supermassive BHs, we use a variety of techniques to infer the mass. It is very difficult to measure the mass directly. For example, we use the brightness of the radiation they produce, or the timescale for variation of radiation around the BH to infer mass. The only exception is the center of our own galaxy, where we can see the orbits of individual stars to again measure the mass very accurately.

Question 2: How is the distance to black holes determined based on their frequency and wavelength?
The distance can be anything, and does not depend on the frequency or wavelength of light that they produce.

Question 1: Can Athena ++ be run on normal computers, or does it require super-computing?
No, it can be run on anything from a laptop to a supercomputer.

Question 2: What would happen if one of the black hole-generated plasma jets were to hit Earth?
It would be very bad for the Earth. It might strip off our atmosphere over time, and would certainly irradiate the planet with high-energy particles that would be bad for life.

Question 1: When two black holes merge, does the resulting mass equal to the two masses combined, or is there mass loss?
There is a mass loss. That mass is carried away in the energy of the graviational waves produced. It can be very substantial, so BH mergers are in fact the most powerful events in the unvierse.

Question 2: Why do we not observationally see intermediate mass black holes?
We still don't know. We are looking very hard to find them. There is some evidence that a few objects that have been observed might be IMBH, but the evidence is not certain. This is a puzzle that astronomers are very actively trying to solve.

Question 1: What is the difference between a stellar blackhole and a supermassive blackhole?
Mostly only their mass, but also the processes by which they form.

Question 2: What is the big picture goal and significance of figuring out and tracking relative spin effects of all blackholes, and is that big picture goal different for each stellar black holes and supermassive blackholes?
Our only goal is to understand the universe and the objects it contains. BHs are some of the most exotic objects we have found, so understanding them will help us understand physics in extreme conditions, and also the history and properties of our universe.

Question 1: What are arc seconds?
It is a unit of measurement for angles. One degree = 3600 arc seconds.

Question 2: How long does it take to compute a synthetic image of a black hole?
Roughly one day, depending on how many computer cores you use at once (much, much longer than one day if you only use one core!)

Question 1: How is a black hole formed, and if it the same for the supermassive and the stellar black hole why do they have different densities than each other - is it the way they form or the age ?
Different mass BHs form by very different processes. Stellar mass BHs form during the death of massive stars by collapse of their central regions. We are not entirely certain how supermassive BHs form, but it must be via the merger of many smaller ones, plus the accretion of considerable amounts of matter in stars or plasma.

Question 2: Why was a ring of light shown in Telescope (EHT) when it should be black ??
The ring should be bright since it is formed by photons emitted by the plasma falling into the BH. Once the plasma falls in then light can no longer escape, so the central regions are dark (thus it looks like a ring).

Question 1: Based on so many variables and instabilities in regards to LIGO, how are we able to accurately use and process the data gathered from it with reasonable certainty; in other words, how do we know what we're seeing isn't just more random noise?
The scientists involved in LIGO have spent many decades testing the instrument and getting the noise to be as small as possible. Only over all these years of testing are the results believable. There is much more information on the LIGO website on how it works and how it was tested.

Question 2: How do black holes generate these plasma jets and what useful information can we glean from them?
(see answer to previous questions)

Question 1: Are both an accretion disc and relativistic jet needed to know the geometric orientation of a black hole?
Yes. In principle if we could measure the "shape" of the ring very precisely we could get the orientation of the spin, but in practice this is very difficult. The existence of the jet in M87 makes the measurement much more reliable.

Question 2: Has Athena++ been used to model/understand neutron stars?
Yes, we are using it to study several different problems related to accretion onto neutron stars as well.

Question 1: Has the real data obtained from black holes influenced parameters of simulations, necessitating changes to the source code and how they are modeled?
Yes, as new data is collected it has led to new improvements to the codes in order to model new physics (such as radiation transport) that is required to accurately model the images. The interplay of observations and theory is very important to help us improve our understanding of what it is that we are seeing.

Question 2: Given the high computational power required to run the simulations, was Athena++ developed and optimized for a specific system, necessitating changes to the code to run on different computational systems?
We worked very hard to make Athena++ run on any computer. That way we can run simulations on any system to which we have access. This has proved very important. If you optimize for only one computer, then you can only do all your work on that computer, and you are stuck if it is busy, or if becomes no longer avaialble in the future.