Student questions: Edward Brown colloquium on “The Densest Matter in the Observable Universe: Accreting Neutron Stars and the Physics of Dense Matter”

1/31/18

Question 1: How do we know that a star/sun will run out of hydrogen?
We can measure the current power output (energy released per second) of the sun. We know the power source is fusion of hydrogen into helium because that fusion reaction releases neutrinos and we detect these neutrinos. From nuclear experiments, we know how much energy is released when 4 hydrogen fuse to form helium. We can therefore calculate how many hydrogen atoms are fusing each second and when they’ll be used up.

Question 2: Is there a formula to tell when a star is going to die since the only way to see them is through a telescope?
The structure and behavior of a star is described by a set of equations, which we can solve (numerically on a computer) to predict the stellar lifetime. We call these equations a stellar model. We check that our models correctly predict observations of stars.

Question 1: How do you know what is a Massive Star?
From the star’s color, we get a measurement of the surface temperature. If we know the distance, we then can infer the power output (luminosity) of the star. By knowing its luminosity and surface temperature, we can infer the structure of the star and hence its mass.

Question 2: Can a normal person tell the difference between a star and a massive star without a telescope?
Not just by looking, no. You need some additional information. For example, a star that appears bright might just be close by; but it could also be very luminous and far away.

Question 1: Can the information gathered on neutron stars be used to predict future behavior of the stars?
Yes, and that is how we test our calculations. We take the observations, and use our theoretical model to predict the future behavior. The prediction can then be tested against observations, and we then refine our theoretical models accordingly.

Question 2: Do you find it challenging to explain your work to those not in your field, and if so how do you deal with this difficulty?
It isn’t challenging, but it does require mindfulness. When I speak to specialists, we have a common base of knowledge, so I can use jargon as a shortcut that everyone understands. Because we speak to colleagues most of the time, we tend to use specialized terms without thinking, which makes the talk less clear for nonspecialists.

Question 1: Are there any hypotheses or wild guesses as to what the shallow heat source, necessary for observed phenomenon, is?
Leading guess so far is that the heating is caused by friction: the accreting matter hits the surface and causes the outermost layer to spin fast relative to the underlying crust. Friction at the base of the crust releases heat. This is still quite tentative, though.

Question 2: When looking at the theoretical structure of a neutron star, you mentioned that the core might not be simply neutrons. I understand that heavy, neutron-rich isotopes are the most likely to survive in the core, but are there any more specific hypotheses as to what the composition may be?
Neutrons are themselves made of more fundamental particles known as quarks. At very high densities, when the neutrons are packed tightly together, it is possible that the neutrons dissolve into a quark soup. But whether this occurs in neutron stars is an open question.

Question 1: If the nuclear density is fixed, does the interior have a density gradient and if not does that mean it cannot convect?
Although the nuclear density is fixed for isolated nuclei, in the neutron star interior gravity compresses the matter. So there is a density gradient; the center is at a higher density than the surface layers.

Question 2: Why are there bursts of fusion on the surface (possible requirement of a build-up of material that must reach a certain threshhold) and not a continuous low-level fusion and energy emission as material falls to the surface?
It has to do with how unstable the reactions are. At higher temperatures the reactions are less sensitive, so in this case you get low-level stable fusion. And we see this; the bursts tend to go away at higher accretion rates, when the surface temperatures are higher.

Question 1: Is the tectonic activity in the crust of a neutron star fueled by convection heat like the Earth's plate tectonics? If so, how does the transition from hydrogen fusion to helium fusion and so on affect convection?
Probably not, because we think there is little or no convection in the core. What is likely to drive tectonic motion, if there is any, is the strong magnetic field of the neutron star. For the most strongly magnetized neutron stars, we occasionally see bursts of gamma-rays, which are thought to be triggered by sudden motions of the crust.

Question 2: Could the relative thinness of the outer crust on a neutron star and the structural difference between it and the inner crust play a part in why the crust cools so quickly?
Indeed, as one makes the crust thinner it takes less time to cool.

Question 1: How does the accretion process that gives a neutron star its matter occur?
If the companion star is sufficiently close to the neutron star, then the companion will be distorted and some of its matter can be pulled onto the neutron star.

Question 2: Can black holes have any observed effects on the density of a neutron star?
If the neutron star and black hole are in a binary, they could possibly merge, in which case some of the neutron star matter will be ripped off and ejected into space.

Question 1: You mentioned that the surface of a neutron star actually is a solid crust that has plate tectonics. A little bit later you also mentioned the accretionary disk creating vorticity waves. Is this indicative that there could be faults running around the neutron star's equator, and if so does that also mean that there are large chunks of debris breaking free during the surface explosions?
Probably not breaking free—the strong gravity of the neutron star keeps the crust in place. But, the surface explosion may melt some of the crust, which allows material to move around.

Question 2: Is the nuclear pasta structure you mentioned present solely in the outer crust, or does that same structure persist throughout the entirety of the neutron star?
Solely in the inner crust, near its base.

Question 1: How does the consideration of the nuclear force affect the theoretical possible mass of a neutron star?
The stronger the pressure at high densities, the larger the maximum mass.

Question 2: What causes the variation in the thickness of a neutron star's crust?
More massive neutron stars have a stronger gravity, which makes the crust thinner.

Question 1: What is the maximum mass for a neutron star, at which point will more mass create a Black Hole?
This is currently unknown. We know it is more than 2 solar masses (we observed a pulsar with 2 solar masses) and likely less than about 2.7 solar masses (the recent gravitational wave detection was caused by the merger of two neutron stars—which appear to have then collapsed into a black hole—with a combined mass was 2.7 solar masses.).

Question 2: If Neutron Stars can be cooling for 12 years like you said. Could they have the capability of having more then one heating and cooling cycles? And how would the crust respond to multiple heating cycles?
Yes, we think the neutron star undergoes multiple cycles. We haven't had X-ray telescopes for a long enough time to see multiple cycles, though. Over many cycles, the crust settles into a steady rhythm in which its temperature cycles up/down during heating/cooling.

Question 1: Do we know what causes quakes in magnetic neutron stars? What are the typical observational signatures to detect such quakes and can they be inferred from emission spectra?
We think the quakes occur in strongly magnetized neutron stars: as the magnetic field changes, it exerts a force on the crust that may cause it to fracture. When this happens, the abrupt reconfiguration of the magnetic field causes a a discharge in the plasma surrounding the neutron star and the emission of a burst of gamma rays.

Question 2: What is the eventual fate of neutron stars, if they are stable against beta decay and have no other forms of decay?
In the absence of accretion, the neutron star simply cools and becomes a cold, dense lump of matter.

Question 1: In the diagram you showed us, showing the composition of massive stars mostly being comprised of magnesium, helium, hydrogen, silica and an iron core, where do all of those atoms go when the star compresses and forms the neutron star? Is it all condensed into the 6 mile wide star or does some of it get sent out during this compression?
Much of the iron core is compressed into the neutron star. The other layers get ejected into space: this matter eventually collects in clouds of gas and dust that form new stars, planets, and in at least one case, life.

Question 2: On average, how often do massive stars turn into neutron stars vs. black holes? And how often do we " see" this happening in both cases?
This is unclear. One thing astronomers have tried is to monitor many massive bright stars to see if any disappear without a supernova.

Question 1: Whats the closest (if any) observed star that has been observed going through the process of accretion?
The nearest neutron star is Centarus X-4, which is about 3000 light-years away (these are relatively rare systems!)

Question 2: Are any computational algorithms used to verify the accuracy of the models like the ones for the fractions in solid and liquid?
Verification of algorithms is an important component of numerical simulation. Some checks are making sure that the simulation conserves energy. Once can also devise test calculations for which there is an analytical solution and verify that the numerical computation gets the correct solution.

Question 1: Do you think that there will be advances in the field of astronomy to the point where mathematical constants like the speed of light will change With all the new skepticism of how the universe is expanding?
No, the speed of light being constant has been verified by many experiments.

Question 2: ve always argues about the word "universe." Do you believe in a uni as in one or could it be in fact a multiverse of many different collections of different worlds?
Agnostic, not enough data.

Question 1: What type of equipment/software do you use to make these observations?
We observe neutron stars with X-ray telescopes that are on satellites (X-rays don't penetrate Earth's atmosphere—luckily for us!). The calculations I showed of cooling neutron stars run on my laptop. The pasta simulations that were done by Prof. Horowitz (Indiana) are run on a cluster of computers.

Question 2: Does the crust of a neutron star act as one solid shell or are there individual pieces that can move independently of each other like the plates on earth?
This is currently a topic of debate. It is unlikely that the crust can act as a solid shell, but whether it forms large-scale plates, as on Earth, or a multitude of small "platelets" is unknown.

Question 1: Is it bad that neutrinos are released during a super nova and formation of neutrino star and are there any negative consequences for this release?
The neutrinos do blow away the outer parts of the star. If you are asking about the effect on Earth, then no—the supernova would have to be extraordinarily close (a few light years I think) for there to be an effect. There are no massive stars that close to us.

Question 2: In the detection slide, the signal for neutron star appears and disappears. Why does this occur and does it have any major implications on the neutron star?
Are you referring to the pulsations from the Crab nebula? The strong magnetic field of the neutron star accelerates particles, which emit radiation that is beamed along a particular direction (like a flashlight). As the star spins, we see pulsations as the beam is swept into, and out of, our line of sight. These pulsations are carrying energy away from the neutron star, so it is gradually spinning slower and slower.

Question 1: For someone who isn't familiar with this field of study, what can you tell me about the fate of the neutrinos after a supernova occurs, such as do they simply dissipate or do they contribute to the formation of a new solar system via the stellar disk?
Yes, the neutrinos gradually spread out in all direction and basically just fly away. The gas that is ejected in the supernova is mixed into the ambient gas in the galaxy, and it is eventually incorporated into newly forming stars.

Question 2: You spoke about the different types of "pasta" formations later in your talk. What other forms of this "pasta" zexist that you didn't talk about?
For the nuclear pasta, the images I showed basically cover the forms seen in the simulations. Note that an actual star, there may be many different shapes coexisting, so it could be rather messy.