DOWNLOAD PDF NEUTRON STAR MATTER

Chapter 1 : Dark matter not at the core of neutron stars | Ars Technica

Sometimes neutron stars absorb orbiting matter from companion stars, increasing the rotation rate and reshaping the neutron star into an oblate spheroid. This causes an increase in the rate of rotation of the neutron star of over a hundred times per second in the case of millisecond pulsars.

Introduction The equation of state EOS for neutron star matter and infinite nuclear matter has been intensively studied for many years see, for examples, Refs []. A correct description of the EOS would have far reaching consequences for topics ranging from the cooling of neutron stars [1, 2] to the heavy ion collisions physics [3]. Furthermore, experiments of radioactive ion beam [4, 5] have provided new information on the structure of unstable nuclei far from equilibrium. The latter may open the possibility of extracting information on the EOS for asymmetric matter and the density dependence of the nuclear symmetry energy. In the present work we do not discuss heavy-ion collisions. Moreover, Neutron stars are macroscopic objects where the stability is guaranteed by the Pauli principle of nucleons together with a repulsive short-range interaction. Therefore the structure of a neutron star is dictated by the strong interaction and, of course, gravity. The key ingredient that enters the stability condition is precisely the equation of state [6]. Recently, high-quality observational data of neutron stars set new stringent constraints for the EOS of cold and dense matter, otherwise inaccessible by experiment. The masses of two heavy pulsars have been determined with high precision. Only a sufficiently stiff EOS can support such neutron stars against gravitational collapse. Whereas neutron star radii are much less accurately known, the combination of available data makes these objects nonetheless an indispensable tool to constrain possible EOS [9]. Compared to calculations with three-body interactions defined only to next to- next-to-leading order NNLO , the inclusion of all N3LO diagrams was found to be very important for nuclear structure and reactions. Their results provide constraints for the nuclear equation of state and for neutron-rich matter in astrophysics. While, in the present work, the N3LO NN potential complemented by phenomenological Urbana TBFs [11], instead of chiral three-nucleon forces, have been applied in calculations to neutron matter. The many-body approaches that are used, the Brueckner-Hartree-Fock BHF approach with the inclusion of three-body force [11] or contact-term interaction to give more repulsive EOS [15]. The plan of the paper is the following. The main features of BHF approach used in this work including two types of three-body forces are shown in the following section. The results for the neutron matter equation of state are presented and discussed in Sec. Finally, the conclusions and perspectives for the present work are given in Sec. BHF Approach One main feature of the BHF approach to nuclear matter is that the binding energy and related quantities such as the self-energy, i. Its expression is 1 where the subscript A means that the G-matrix has to be antisymmetrized. The auxiliary single-particle energy e k is defined below according to the scheme of the iterative solution of the Bethe-Goldstone equation. Using the continuous choice [16], the auxiliary potential U k has been self-consistently evaluated along with the G-matrix from Eq. Furthermore, within BHF approach with exact Pauli operator [17], one can easily evaluate the binding energy per nucleon for nuclear matter. We use two methods to make the EOS for pure neutron matter be more repulsion. First method is done by adding the three-body-force. Both Y r and T r are the Yukawa and tensor functions associated to the one-pion exchange as in the two-body potential. The repulsive term is written as 8 The strengths A and U are parameters that in the present work are adjusted to reproduce the exact saturation point of symmetric nuclear matter. We introduced the Urbana three-nucleon model within the BHF approach. The TBF is reduced to an effective two-body force by averaging on the position of the third particle, assuming that the probability of having two particles at a given distance is reduced according to the two-body correlation function. The resulting effective two-body force is of course density dependent. We have adjusted the parameters A and U in order to reproduce the correct saturation point of symmetric nuclear matter and the EOS become much more repulsive at high density, since the higher density region needed in neutron star studies. The second method to achieve saturation in nuclear matter one has to add the effective interaction or the self-energy of BHF calculations by a simple contact interaction, which we have chosen following the notation of the Skyrme interaction to be in the form [19]. The values of the parameters t0 and t3 that are used to fit the saturation point

Parameters.

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Chapter 2 : The Remarkable Properties of Neutron Stars | ChandraBlog | Fresh Chandra News

Inside a neutron star, there's a delicate balance between the tremendous gravity of the star, and the degeneracy pressure of the neutrons. Once we extract the neutrons, all bets are off.

Share via Print This illustration captures the moment two neutron stars spiral together and collide. Astrophysicists have used gravitational waves produced from such mergers to probe the interiors of neutron stars and to set new limits on the formation of black holes. Weiss Advertisement Inside a neutron starâ€"the city-size, hyperdense cinder left after a supernovaâ€"modern physics plunges off the edge of the map. There, gravity squeezes matter to densities several times greater than those found in the nucleus of an atom, creating what theorists suspect could be a breeding ground for never-before-seen exotic particles and interactions. So when the universe deigned to help out, astronomers jumped at the chance. The new study follows up on an initial calculation released last October by the same team, which had failed to detect these tides in the gravitational wave signal at all. On the second go-round, though, the team looked at more orbits of the two objects and added in some additional constraints. Next, they tested possible equations of state that could explain the data, adding other sensible, real-world requirements. For instance, pressure and density changes could not create sound waves moving faster than the speed of light inside a neutron star or any other object, for that matter. And the equation of state had to also fit the heaviest confirmed neutron star, which weighs in at roughly 1. If neutron star material could not sustain sufficiently high pressures, such an object would not be a neutron star at allâ€"it would have long ago collapsed into a black hole. Taking all that into account, the new analysis finds the two neutron stars involved in the merger, each weighing perhaps 1. That would match previous controversial x-ray measurements of neutron star radii. And it hints midsize neutron stars possess relatively low interior pressures compared with the 1. Compared with lab measurements of matter at much lower densities, the new data show tentative hints of an upward bend in how pressure increases in denser and denser matter. Such a bend would not be expected if neutron stars are made solely of neutrons and protonsâ€"in that case, pressure should just increase smoothly. If physicists can confirm a bend like this in the equation of state, though, it might be a clue matter changes phase at very high densities, much like water changing from liquid to solid at sufficiently low temperatures. In neutron stars such a phase transition could arise from neutrons breaking apart into a soup of their constituent particles, quarks. The new study echoes the findings of a previous analysis of the same event published in April by a team led by graduate student Soumi De at Syracuse University, but with twice the precision. A single giant neutron star weighing roughly 2.

Chapter 3 : Neutronium - Wikipedia

It's the extreme gravity in the neutron star that keeps the matter compressed to extremely high densities. Once you removed the baseball sized clump of matter from the neutron star, the pressure of gravity would no longer be compressing it, and the matter would expand violently (i.e, explode).

An earlier version of this article appeared on this blog by Peter Edmonds. The collapse of a massive star in a supernova explosion is an epic event. In less than a second a neutron star or in some cases a black hole is formed and the implosion is reversed, releasing prodigious amounts of light that can outshine billions of Suns. That is a spectacular way to be born. Because of the incredible pressures involved in core collapse, the density of neutron stars is astounding: The escape velocity from their surface is over half the speed of light but an approaching rocket ship would be stretched, then crushed and assimilated into the surface of the star in a moment. Resistance would be futile. If this cricket ball were made of neutron star material it would weigh about 20 trillion kg, or about 40 times the estimated weight of the entire human population. If one of these ultra-magnetic neutron stars, called a magnetar, flew past Earth within , miles, its magnetic field would destroy the data on every credit card on Earth. Luckily for our economy none are that close, but the distant ones can put on spectacular shows. This animation contains no audio, because "in space no-one can hear you scream". NASA Neutron star behavior can be so odd and distinctive that their discovery was initially greeted as the possible discovery of extraterrestrial intelligence. The real explanation is that a pulsar , a rotating neutron star, was discovered. Pulsars have become such an important tool for physics research that two different Nobel Prizes have been awarded in their name, the first for their discovery by Antony Hewish. Many people - including myself - have argued that Jocelyn Bell Burnell should have been awarded part of the Nobel prize with Hewish, since she made the discovery, but in an expression of modesty or Imposter Syndrome, Bell Burnell later commented that she did not deserve the award. However, this does not diminish the significance of her discovery, and of the outstanding research that it enabled. Jocelyn Bell Burnell with the radio telescope she used to discover pulsars. Looking ahead in pulsar work, there is an exciting and ingenious project called the North American Nanohertz Observatory NANOGrav that is attempting a direct detection of gravitational waves, ripples in the fabric of space-time, using pulsars. Two of the pulsar experts leading this project are Scott Ransom from NRAO, whose enthusiasm for pulsars is well explained by the papers he writes, like this one: Seriously " and Victoria Kaspi, from McGill University, seen here speculating about some possible applications of pulsar research. These stories capture a lot of attention and do an excellent job at promoting astrophysics, but most research occurs in the gaps between catchy headlines and Nobel prizes. These gaps contain plenty of room for excellent research, much of it about understanding the nature of neutron stars, rather than testing fundamental physics with them. Some of the most important open questions about neutron stars concern their size and structure. How large are they? What makes up their atmosphere? What is their core like? One key advantage that neutron stars have over black holes is that their surface is visible to us, enabling much to be be learned about their atmospheres and interior structure. This resolved a mystery about the nature of the neutron star, as the press release and Nature paper explain. The properties of the carbon atmosphere on the neutron star in the Cassiopeia A supernova remnant are remarkable. It is only about four inches thick, has a density similar to diamond and a pressure more than ten times that found at the center of the Earth. However, the surface gravity on Cas A is billion times stronger than on Earth, resulting in an incredibly thin atmosphere. Caption taken from Chandra web-site. Weiss Heinke and Ho followed up this work with an even more interesting result, the first direct evidence for a superfluid , a bizarre, friction-free state of matter, at the center of a neutron star. When the temperature of the neutron star fell below a critical level, a superfluid formed in the core of the star, forming neutrinos which travel outwards, taking energy with them. This causes the star to cool rapidly as observed with Chandra. This image shows a composite of X-rays from Chandra red, green, and blue and optical data from the Hubble Space telescope gold of Cassiopeia A, the remains of a massive star that exploded in a supernova. The blue rays emanating from the center of the star represent the copious numbers of neutrinos -- nearly massless, weakly interacting particles -- that are created as the core temperature falls below a critical level and a neutron superfluid is formed, a process that began about years ago as observed from Earth. These neutrinos escape from the star, taking energy with them and causing the star to cool much more rapidly. Shternin et al; Optical: Weiss Other important information about the structure of neutron stars comes from studying the relationship between their size and mass. For a given mass, the size of a neutron star will depend on how stiff or soft the structure is. These are all relative terms, since by Earthly standards, nothing about neutron stars is soft. Old neutron stars are typically faint objects, but when they pull material away from companion stars they can become much brighter, allowing good studies of their atmospheres. Observations of the amount of X-rays at different wavelengths, combined with theoretical models for their atmospheres, can allow the relationship between the radius and mass of the neutron star to be estimated. All of these observations were of neutron star binaries in globular clusters. Neutron stars pulling material away from companions have also been observed to undergo bursts of X-rays, caused by thermonuclear explosions on their surfaces. These explosion can cause the atmosphere of the neutron star to expand. If observers catch one of these bursts they can follow as the star cools and calculate its surface area. When this area is combined with independent estimates of the distance to the neutron star, the relationship between the mass and radius of this object can be estimated. Two researchers who have applied this technique with great success are Feryal Ozel from the University of Arizona and Tolga Guver from Sabanci University, as described in this set of papers here , here , here , and here. Each of the papers quoted in the previous two paragraphs provide information about the mass and radius of the neutron star and about their structure. However, there may be problems with relying too much on a single technique or a single object. A very good new paper by Andrew Steiner, from University of Washington, avoids this problem by combining all of the papers mentioned above: A Chandra X-ray Observatory image of 47 Tucanae, my favorite globular cluster. One of the neutron star binaries from Steiner et al. They also estimate that the density at the center of a neutron star is almost ten times that of nuclear matter found in Earth-like conditions. This is equivalent to a pressure that is over ten trillion trillion times the pressure required for diamonds to form inside the Earth. Using their results, Steiner et al. A larger neutron star radius implies that, on average, neutrons and protons in a heavy nucleus like Uranium are farther apart. What is the core of a neutron star made of? It could be neutrons or it could be free quarks, the fundamental particles that combine to form protons and neutrons but which are not usually found in isolation. The paper by Steiner et al. There are many other interesting and important results about neutron stars. Regarding their structure, there are the very strong constraints that have come from pulsar work, such as the mass measurement of 1. An even larger neutron star mass might have been found by Romani et al. Then there are the astonishing spin rates that these incredibly massive, city-sized objects can reach, such as PSR Jad which spins around times a second, as reported by Hessels et al. I will continue to follow developments in neutron star research closely, as part of my job with Chandra but also because of my excellent location at Harvard-Smithsonian Center for Astrophysics CfA , which has a regular stream of visitors covering a wide range of astrophysics. In the meantime, I may write a blog post or two on black holes, which are rumored to be interesting objects. Log in or register to post comments Disclaimer: This service is provided as a free forum for registered users. Please note this is a moderated blog. No pornography, spam, profanity or discriminatory remarks are allowed. No personal attacks are allowed. Users should stay on topic to keep it relevant for the readers.

Chapter 4 : EOS of Neutron Matter and Neutron Star Properties

To condense matter to the state that exists in a neutron star, you must overcome the neutron degeneracy pressure [for white dwarfs, it is the electron degeneracy pressure]. The minimum amount of matter required to generate a gravitational field sufficiently powerful to reach the neutron degeneracy pressure is about solar masses.

A neutron is an electrically neutral particle that helps glue protons together in the nucleus of atoms. Inside the atom, it is happily stable. But a neutron alone is an unhappy beast. After about 10 minutes, it will emit an electron and an antineutrino and turn into a proton. In one set of experiments, we have determined that the half-life of a lonely neutron is The chance of these two being different by accident is now about one in , One possible explanation for the difference is that a subset of neutrons decays to a relatively light particle of dark matter. Now, a pair of papers has punctured that proposal. What is the difference between the two experiments? The method that finds the shorter half-life counts the number of neutrons in a bottle after an elapsed time. The second experiment counts the number of protons emitted by a beam of neutrons. The beam method would not count neutrons that did not decay to a proton. As the certainty in the difference grows, so does pressure to find an explanation. One possibility is that sometimes neutrons decay into a baryonic dark matter particle. Baryonic just means that the dark matter particle belongs in the same class of particles as protons and neutrons, rather than the groups that contain electrons and neutrinos or light. Hence we would expect a difference in measured half-life. To fit this idea into the world around us, we know that the new dark matter particle has to be heavy enough to cope with the observed stability of isotopes an element has a fixed number of protons but can differ in the number of neutronsâ€”these are called isotopes and the stability of the proton. Apart from the mass of the dark matter particle, the process that creates it has to be quite rare, or we would observe a completely different half-life for the neutron. Therein lies the problem. Which also means we would have a hard time seeing it if we tried to find it. Conveniently, there is a place where there are enough neutrons around that any particles they produce should be obvious. Neutron stars are filled with neutrons that are banging on each other a lot. Under reasonable circumstances, we might expect neutrons decaying to dark matter to affect the properties of neutron stars. The Universe is our laboratory This is exactly what two groups of researchers have investigated. But neutron stars are the least complicated of all stars. Neutron stars are very dense, having about a solar mass in a sphere just a few kilometers across. If a star remnant is too light, then it cannot form a neutron star and instead ends its life as a white dwarf. At about three solar masses, no one is really sure what happens. Above ten solar masses, the remnant clearly collapses to a black hole. The resulting calculation allows for pretty good predictions for how this will change the mass range for which neutron stars will form. It turns out that dark matter causes more problems than it fixesâ€”at least for low-mass dark matter. Adding dark matter with mass up to 1. To make dark matter, the solution requires the Universe to perform some gymnastics. First, any single dark matter particle has to have just the right self-repulsion to generate neutron stars with the right mass range. When all is said and done, it seems to me that decay to dark matter is less likely than a systematic difference between the two experimental techniques. I suspect that something like adding a proton counter to the bottle experiment, for instance, will show that the systematic difference between the two experiments is real. I also suspect that the systematic difference will be instrumental and not due to neutrons behaving in an unexpected way.

Chapter 5 : How would neutron star matter behave on earth? | Physics Forums

Neutron stars cram roughly to solar masses into a city-sized sphere perhaps 20 kilometers (12 miles) across. Matter is packed so tightly that a sugar-cube-sized amount of material would weigh more than 1 billion tons, about the same as Mount Everest! "With neutron stars, we're seeing a combination of strong gravity, powerful magnetic and electric fields, and high velocities.

Pulsar Neutron stars are detected from their electromagnetic radiation. Neutron stars are usually observed to pulse radio waves and other electromagnetic radiation, and neutron stars observed with pulses are called pulsars. It is thought that a large electrostatic field builds up near the magnetic poles, leading to electron emission. Therefore, periodic pulses are observed, at the same rate as the rotation of the neutron star. Non-pulsating neutron stars[edit] In addition to pulsars, neutron stars have also been identified with no apparent periodicity of their radiation. This includes visible light , near infrared , ultraviolet , X-rays and gamma rays. The majority of neutron stars detected, including those identified in optical, X-ray and gamma rays, also emit radio waves; [46] the Crab Pulsar produces electromagnetic emissions across the spectrum. A newborn neutron star can rotate many times a second. Pâ€"P-dot diagram for known rotation-powered pulsars red , anomalous X-ray pulsars green , high-energy emission pulsars blue and binary pulsars pink Over time, neutron stars slow, as their rotating magnetic fields in effect radiate energy associated with the rotation; older neutron stars may take several seconds for each revolution. This is called spin down. The rate at which a neutron star slows its rotation is usually constant and very small. The periodic time P is the rotational period , the time for one rotation of a neutron star. However, as a neutron star ages, the neutron star slows P increases and the rate of slowing decreases P-dot decreases. Eventually, the rate of rotation becomes too slow to power the radio-emission mechanism, and the neutron star can no longer be detected. It is not the measured luminosity, but rather the calculated loss rate of rotational energy that would manifest itself as radiation. For neutron stars where the spin-down luminosity is comparable to the actual luminosity , the neutron stars are said to be " rotation powered ". It encodes a tremendous amount of information about the pulsar population and its properties, and has been likened to the Hertzsprungâ€"Russell diagram in its importance for neutron stars. Sometimes neutron stars absorb orbiting matter from companion stars, increasing the rotation rate and reshaping the neutron star into an oblate spheroid. This causes an increase in the rate of rotation of the neutron star of over a hundred times per second in the case of millisecond pulsars. The most rapidly rotating neutron star currently known, PSR Jad , rotates at revolutions per second. However, at present, this signal has only been seen once, and should be regarded as tentative until confirmed in another burst from that star. Sometimes a neutron star will undergo a glitch , a sudden small increase of its rotational speed or spin up. Glitches are thought to be the effect of a starquake â€"as the rotation of the neutron star slows, its shape becomes more spherical. Due to the stiffness of the "neutron" crust, this happens as discrete events when the crust ruptures, creating a starquake similar to earthquakes. After the starquake, the star will have a smaller equatorial radius, and because angular momentum is conserved, its rotational speed has increased. Starquakes occurring in magnetars , with a resulting glitch, is the leading hypothesis for the gamma-ray sources known as soft gamma repeaters. Current neutron star models do not predict this behavior. Some of the closest known neutron stars are RX J Another nearby neutron star that was detected transiting the backdrop of the constellation Ursa Minor has been nicknamed Calvera by its Canadian and American discoverers, after the villain in the film The Magnificent Seven. Binary neutron star systems[edit] Circinus X The formation and evolution of binary neutron stars can be a complex process. According to modern theories of binary evolution it is expected that neutron stars also exist in binary systems with black hole companions. The merger of binaries containing two neutron stars, or a neutron star and a black hole, are expected to be prime sources for the emission of detectable gravitational waves. X-ray binary Binary systems containing neutron stars often emit X-rays, which are emitted by hot gas as it falls towards the surface of the neutron star. The source of the gas is the companion star, the outer layers of which can be stripped off by the gravitational force of the neutron star if the two stars are sufficiently close. As the neutron star accretes this gas its mass can increase; if enough mass is accreted the neutron star may collapse into a black hole. Stellar collision Binaries containing two neutron stars are observed to shrink as gravitational waves are emitted. The coalescence of binary neutron stars is one of the leading models for the origin of short gamma-ray bursts. Strong evidence for this model came from the observation of a kilonova associated with the short-duration gamma-ray burst GRB B, [59] and finally confirmed by detection of gravitational wave GW and short GRB A by LIGO , Virgo and 70 observatories covering the electromagnetic spectrum observed the event. This material may be responsible for the production of many of the chemical elements beyond iron , [64] as opposed to the supernova nucleosynthesis theory.

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Chapter 6 : NASA - Neutron Stars

Quark matter - an extremely dense phase of matter made up of subatomic particles called quarks - may exist at the heart of neutron stars. It can also be created for brief moments in particle.

This is going to adversely affect you in a few ways. First, magnetic fields at those levels are almost certainly going to destroy anything with ferromagnetic materials a fancy word for things like iron that you can make magnets out of as well your computer systems. Also, the combination of spinning and strong magnetic fields mean that neutron stars essentially have their own defense system. You may know them as "pulsars" and they basically consist of a high-energy radiation beam sweeping through the sky every fraction of a second. Finally, have you ever tried to land on a planet where the surface is rotating at thousands of kilometers a second? But supposing you could land on the surface of the neutron star. The gravity is something like two hundred billion times that on the surface of the earth. To get to the pure product, you need to dig deeper. Once we extract the neutrons, all bets are off. We no longer have the gravitational pressure to compress our neutrons together, and remember, these neutrons are at temperatures of a millions degrees. The gas pressure is huge. Even if you could use a transporter to teleport your neutron star into the hold of your ship, the sudden decrease in pressure will cause the gas to explosively expand. Do not stand in your cargo bay when you beam up your neutron star material. I cannot stress this enough. Compared to many subatomic particles that only last a billionth of a second or even less, the 10 minute lifetime of a neutron is incredibly long. After that ten minutes on average a neutron decays into a proton, an electron, and normally undetectable anti-neutrino. Not a big deal, right? We finally get to invoke the most famous equation in all of physics: This tells us how much energy is going to be released by every single decay. Multiply that by the speed of light squared, and you have the energy released. In the case of neutron decay, about 0. To put things in perspective, this about 50 trillion times the energy of the first nuclear bombs, and would easily be enough to destroy all life on earth. Bear in mind that the half-life of neutrons are about 10 minutes, which means everything would be dead and done quite quickly. Best of luck to you.

Chapter 7 : Neutron star - Wikipedia

What the Neutron Star Collision Means for Dark Matter The latest LIGO observations rekindle a fiery debate over how gravity works: Does the universe include dark matter, or doesn't it?

Woodard notes that some of those theories, known as modified gravity MOG or modified Newtonian dynamics MOND , predict that gravitational waves and light waves would arrive at different times. Yet LIGO picked up the gravitational waves and light from two colliding neutron stars within about 2 seconds of each other. Essentially, they arrived at the same time. The kinds of models Woodard is talking aboutâ€"which he calls "dark matter emulators"â€"attempt to duplicate the effects of dark matter, by assuming that gravity behaves differently than most scientists think. General relativity says gravitational waves and light move on the same lines, or metrics. Some alternative theories of gravity had gravitational waves moving on a different path, or metric, from light. In that scenario, gravitational waves and light would arrive at widely different times. However, long before LIGO, some physicists were unsatisfied with dark matter and devised other theories that sought to explain what astronomers see. One set of theories is known as Tensor-vector-scalar gravity TeVeS , which adds an extra field to gravity. Developed by Jacob Bekenstein in , was already under some fire because it seemed to require neutrinos more massive than what physicists have estimated so far, and it did not always produce stable stars. The theory says gravity gets stronger as you scale up from the solar system to galaxies and then to galaxy clusters. John Moffat , a researcher at the Perimeter Institute in Waterloo, Canada, says Woodard simply mischaracterized his theory. Therefore, it appears that my MOG is the only surviving gravity theory that can explain the galaxy, galaxy cluster data and cosmology data without detectable dark matter in the present universe. At a certain point it was all moving at the same speed. Early explanations for the unseen matter included: Eventually all were discarded in favor of the current conception of dark matter as made of something that only interacted via gravity. Yet a few physicists felt that the idea of dark matter was too convenient, something invented just to make the mathematics work. At its heart, his theory proposes that gravitational dynamics change when accelerations due to gravitational force get below a certain limit. He also posits that gravity and light travel on different metrics. Taken together, these theories presented, if not a serious threat, at least the intimations of problems with dark matter -- until now. It also accounted for observations of gravitational lensingâ€"the bending of light by massive objects. When we look at some distant galaxies, we see objects behind them as though through a lens, per general relativity. This was another piece of evidence for dark matter or something like it. Dark matter can also explain why the cosmic microwave background looks the way it does: One is an anomaly around the Bullet Clusterâ€"the same one that most would say supports dark matter theory. According to some observations the Bullet Cluster is accelerating too fast; even assuming dark matter the velocities are "wrong. In addition, some galaxies that appear to have less visible matter still appear more massive. MOND theories do better on that score. One can use it to predict the kinematics of apparently dark matter dominated galaxies. You cannot make the same prediction with dark matter. Milgrom notes that in almost all the galaxies that have been observed so far, the rotation curves are the same shape out to the point where acceleration due to gravity towards the center is about one ten-billionth of a meter per second squared about the same gravitational force felt by someone two meters away from a kilogram weight. It would be like going to all the countries on Earth and finding that the income distribution was exactly the same, despite the very different histories that each country has. MOND theories, he added, do a better job at predicting galaxy motion in that regard. This is something we are working on. But it is unclear which, if any, modified gravity theories actually fulfill the assumptions," she said. Ethan Siegel, an astrophysicst and author, said the odds are that a lot of modified gravity fields are nullified by the LIGO observations. MOND does better than dark matter on galactic scales. If you look at individual galaxies and their dynamical properties, MOND has the advantage. MOND fails on all scales other than that, however. In other words, expect the debate to keep raging for the foreseeable futureâ€"with the force of two neutron stars colliding.

Chapter 8 : What the Neutron Star Collision Means for Dark Matter | Science | Smithsonian

Quark matter - an extremely dense phase of matter made up of subatomic particles called quarks - may exist at the heart of neutron stars. It can also be created for brief moments in particle colliders on Earth, such as CERN's Large Hadron Collider.

Neutron Star Neutron stars are the core remnants of moderately massive stars that have undergone violent stellar death via tremendous supernova explosions after leaving the Main Sequence. The cores of such large stars are too massive to exist as white dwarfs. If the remnant has more mass than the critical 1. A teaspoonful of neutron star matter may weigh as much as 10 billion tonnes! The core collapses to such immense densities because the gravitational field is so enormously strong that normal matter is crushed and destroyed and even extremely dense white dwarf matter is crushed and destroyed. Very massive stars leave heavier remnants that can not even exist as neutron stars, but collapse into mysterious entities known as black holes. During its Main Sequence lifetime the pressure of the radiation emitted by nuclear reactions stops the core from collapsing, but when the star runs out of fuel, the core collapses until it reaches a state of matter that can resist further collapse. In the case of a neutron star, this matter is very strange and not entirely understood, but appears to be mostly composed of neutrons. Atoms are composed of a nucleus of one or more protons and neutrons and one or more electrons in shells around the nucleus. Free neutrons, when removed from the nucleus, are very unstable and decay into electrons, protons and anti-electron neutrinos: In some radioactive nuclei, there are too many neutrons which makes the nucleus unstable. In this case, neutrons inside the nucleus may also decay into a proton, electron and anti-electron neutrino in a process called beta-decay, which releases the highly energetic electron from the nucleus as ionising radiation. The number of free neutrons halves every ten minutes as the neutrons decay. This is the principle of the neutron bomb - irradiate an area with energetic neutrons, killing all the inhabitants, and within a day it is safe to move in and occupy the area. However, in a neutron star the immense pressure forces this equation to the left, as electrons e and protons p are squeezed into neutrons n , so that neutrons become stable and a neutron star is made up mostly of neutrons there are about neutrons for every electron. This material can be conveniently called neutronium. How does a neutron star get turned from ordinary matter into neutronium? The neutron star is enormously compressed by its immense gravitational field, and is only about 10 to 20 kilometres in diameter about the size of a city but is still very hot and luminous. To see what is happening we shall examine the best physical model we have of its structure. Its atmosphere is only about one metre thick and beneath this is a solid crust which is one to two kilometres thick and composed of atomic nuclei and electrons, and so is relatively normal matter which is nevertheless extremely dense and heavy and very hot. The surface gravity is about 2 hundred billion to 3 thousand billion times that on the surface of the Earth. Thus, an average man standing on the surface of a neutron star would weigh as much as billion tonnes or more! Clearly, his body would be squashed to nothing! The interior, beneath the crust, is thought to be liquid and is composed of neutron rich nuclei as the increasing pressure starts to convert electrons and protons into neutrons. As we move deeper into the neutron star the pressure rises considerably. The enormous pressure starts to pull neutrons from the neutron rich atomic nuclei a process called neutron drip so we have a liquid of nuclei, neutrons and electrons which is very hot and dense. Deeper in, the nuclei completely dissolve into a sea of neutrons, with some electrons and protons there are about neutrons to each proton, so the bulk of the neutron star is essentially a superhot and super-dense neutron fluid. Superhot by our standards that is, but compared to the high density the neutrons are expected to behave as if they are cold, and so may resemble a solid in many respects. It is possible that the neutrons form degenerate matter, which is a special state of matter not normally encountered, but comprises particles that are squeezed into their least energetic states. In the neutron star core the pressures far exceed the maximum pressures that can be produced in a laboratory, so we have to speculate. Hyperons contain strange quarks normal protons and neutrons contain quarks but no strange quarks and are referred to as a type of strange matter. At even greater pressures this strange matter may collapse into a quark liquid. The neutrons inside a neutron star are expected to be ultrarelativistic, which means that they are moving close to the speed of light! Light moves at about 2.

The liquid is also predicted to be a superfluid. Superfluids are very strange things, they move without friction and can flow uphill and also behave as if they are a single particle if you lift a portion out in a ladle, then it will flow up over the sides of the ladle to join up with the rest, as if it likes to be a single entity! When a neutron star is formed in a massive supernova explosion, the neutron star is typically slung across space at immense speeds and often rotates at tremendous rates. A rotating neutron star is a pulsar and is considered in more detail in the pulsar section. Degenerate Matter Neutron stars are, like white dwarfs, degenerate stars. Degenerate means that a number of particles have the same energy value. In particular, degenerate matter consists of particles called fermions, such as electron, protons and neutrons. Spin refers to the rotational angular momentum of a particle, in classical terms this is due to a particle rotating on its axis, in quantum mechanics QM this is not the case, though it is helpful to think of it as rotation or spin. Angular momentum, like other properties of confined quantum systems, is quantised, meaning that only a few very discrete values are possible, as in, for example, the energy levels of an atom see atomic spectra. According to the Pauli Exclusion Principle, fermions cannot coexist in the same region of space with the same values of their quantum numbers the values of their quantised energy and momenta , such as energy or spin. The more you attempt to confine the momentum of a particle to a certain specific value, the more uncertain its spatial position becomes, and likewise the more you confine its spatial position, the more its momentum becomes uncertain. In neutron stars, the neutrons are highly compressed by an immense gravitational field, such that they almost exclusively occupy the lowest available energy levels or ground states. In normal matter, thermal energy excites particles to lie above their ground states they move about with thermal kinetic energy and gaps are left in the then many available energy levels as particles move up-and-down between the many available states. In degenerate matter, thermal energy can barely excite the particles at all and they sit neatly huddled together as tightly as possible. This restricts their energy and momenta, such that many particles occupy each available energy and momentum level. For this reason, degenerate matter is called cold matter, though it is still very hot as it stores immense potential heat energy. However, confining their momentum in this way, causes the spatial positions of each particle to become more uncertain, and being fermions no two neighbouring particles in the same energy level can occupy the same region of space, therefore, QM prevents the particles being pressed any more closely together. The particles resist compression by applying pressure. In normal matter, pressure, say in a gas, is caused by the thermal motion of the particles jostling them about so that they collide with the walls of their container and impart energy and momentum to the walls - this is thermal pressure. In degenerate matter, the pressure is purely quantum-mechanical and is called the Fermi pressure. Matter in this state is extremely dense! In white dwarfs, the Fermi pressure is provided by degenerate electrons, whilst in neutron stars it is provided by degenerate neutrons. Degenerate matter can consist of non-relativistic, relativistic or ultrarelativistic particles. Non-relativistic particles are like those encountered in ordinary matter - they move at speeds well below the speed of light. Relativistic particles have enough energy to move at speeds a substantial fraction of the speed of light, and ultrarelativistic or extreme relativistic particles have enough energy to move at speeds very close to the speed of light. The degenerate neutrons in a neutron star are ultrarelativistic. This affects the approximate equations that are used to determine the energy per particle and the Fermi pressure. The matter in any star can be modeled by a state equation equation of state which describes the relationship between the various properties of the system like pressure, volume, temperature, mass, energy and chemical composition. Specifically a state variable, like temperature, is one that depends only on the current state of the system and not on its history. Finding a reliable state equation that accurately describes neutron stars is an ongoing area of research. In a vacuum, the least energetic and most stable atomic nucleus is iron iron atoms with 26 protons and 30 neutrons, or a total of 56 nucleons in their nucleus. This is the stable end-result of normal nuclear fusion reactions in the cores of massive giant stars. The immense density inside a neutron star, however, shifts the point of stability to more neutron-rich nuclei and as density increases, the process of neutronisation occurs, in which neutrons add on to the atomic nuclei as they form by reverse beta-decay. The presence of electrons, tightly squeezed into a small volume too, helps reverse the beta-decay by blocking the normal forward process of beta-decay by preventing the emission of electrons there are very few spare energy levels for extra electrons to move into, so extra electrons tend not to be produced. This is expected to result in the formation of large clusters of nucleons neutrons and protons embedded in a neutron fluid. As density increases still further, deeper inside the neutron star, the energy of a neutron inside a nucleon cluster exceeds that of a neutron in the surrounding fluid, resulting in a phase change resulting in the formation of nucleon clusters embedded in a noninteracting neutron fluid the neutrons in the fluid do not interact with the clusters but prefer to stay outside. The presence of the electrons stabilises the neutrons, by inhibiting beta-decay. When the density reaches about half that of nuclear matter, the average kinetic energy of an electron exceeds the rest-mass energy of muon mu leptons and many electrons transform into muons: Thus, the core of a neutron star is expected to consist of neutrons n , protons p , hyperons, an electron fluid and a muon fluid. Furthermore, under these pressures, neutrons and protons can pair together, forming nn and pp pairs. The pp pairs are positively charged and superconducting, even at these immense temperatures. A superconductor is a material that conducts electricity with essentially zero resistivity. Some metals become superconducting at atmospheric pressure when cooled to very low temperatures and this superconductivity is due to the formation of electron pairs, ee, called Cooper pairs that can move freely within the metal without being scattered from the ion lattice. The electrons have like electric charges and so will normally repel one-another, but they form very loosely bound pairs in these conditions by exchanging a phonon, a quasiparticle pseudoparticle which is a quantum of vibrational energy. In neutron stars, the pp pairs similarly superconduct. The nn pairs are superfluid, meaning that they can flow around inside the neutron star in very strange ways, without friction, behaving like a single particle in many ways. These superfluid neutrons are excellent thermal conductors, distributing heat around the neutron star. This, coupled with the neutron degeneracy, makes the interior of a neutron star approximately isothermal, that is at the same temperature. The temperature drops in the region of the neutron star crust. Neutron stars slowly cool by losing thermal radiation into space. The crust is a solid, permeated by a fluid of ultrarelativistic particles, whilst the core is fluid and composed mostly of electrons, nucleons neutrons, n, and protons, p and more massive baryons and hyperons. The inner core might contain superfluid neutron and superconducting proton fluids, and may be solid in less massive neutron stars. In the most massive neutron stars, the inner core may comprise a fluid of quarks, as the nucleons and other baryons begin to break-down, with their constituent quarks separating, at least partially. The latter hypothetical stars are also called strange stars or quark stars. Colour charge is like electric charge, except that whereas electric charge is associated with the electromagnetic force, colour charge is associated with the much shorter range strong force which holds hadrons together. Colour confinement states that the overall colour charge must be neutral or colourless. In the case of a nucleon, which contains three quarks, one quark must be red, one green and one blue, since mixing red, green and blue light gives white light - hence the analogy to colour is useful here. However, under immense pressures, the nucleons or their wavefunctions overlap and they emerge into a continuous system in which the quarks can move around as if free in a gas. The strong force, which acts between the colour charges of quarks, is conveyed by particles called gluons, which quarks constantly exchange, and so the resultant state of nuclear matter is called a quark-gluon plasma. This kind of matter could exist in the inner core of heavy neutron or quark stars. Atmosphere Above the surface of the crust is an atmosphere of plasma, which becomes less dense further from the surface, falling from the density of the crust to the density of interstellar matter. With the immense gravitational field of the neutron star, however, the atmosphere is very compressed and only a metre or two in height! Pulsars are stars that emit periodic pulses of radio energy at a frequency of around once per second or higher. Pulsars or at least most of them are thought to be rapidly rotating neutron stars with strong magnetic fields. At the poles, charged particles would have to move faster than light to make it back down and so instead the field lines detach and the particles stream away, electrons closest to the pole, emitted in cones, surrounded by protons slightly further from the pole, at least according to one model anyway.

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Chapter 9 : NeutronStar - Facts and figures so large it'd boggle Fisher Investments Chris Rushton's mind!

Neutronium is used in popular literature to refer to the material present in the cores of neutron stars (stars which are too massive to be supported by electron degeneracy pressure and which collapse into a denser phase of matter).

Neutron stars cram roughly 1. Matter is packed so tightly that a sugar-cube-sized amount of material would weigh more than 1 billion tons, about the same as Mount Everest! Most known neutron stars belong to a subclass known as pulsars. These relatively young objects rotate extremely rapidly, with some spinning faster than a kitchen blender. They beam radio waves in narrow cones, which periodically sweep across Earth like lighthouse beacons. Astronomers have found less than 2, pulsars, yet there should be about a billion neutron stars in our Milky Way Galaxy. There are two reasons for this shortfall. Without much available energy to power emissions at various wavelengths, they have faded to near invisibility. But even many young pulsars are invisible to us with radio telescopes because of their narrow lighthouse beams. A neutron star is the dense, collapsed core of a massive star that exploded as a supernova. Geminga is roughly , years old, which makes it middle-aged in the pulsar life cycle. The LAT will be able to see much fainter pulsars, many of which will be much older than Geminga. Pulsars spin-down as they age, and this should weaken particle acceleration, which in turn should cause their gamma-ray flux to weaken. The LAT should thus be able to tell scientists about this rate of decline, which in turn will yield precious clues about the particle-acceleration mechanism. EGRET observations suggest this process might be occurring in the magnetosphere of a pulsar in the constellation Vela. EGRET observations showed that gamma rays dominate the total radiation emitted by young pulsars, which are rapidly spinning down. Moreover, EGRET data showed that variations in the high-energy gamma-ray emission probably arise from the changing view into the pulsar magnetosphere as the neutron star spins. The LAT will have the ability to map pulsar magnetospheres and provide unique information regarding the physics of the pulsed emission, and perhaps even answer the long-standing mystery of how the pulses are actually produced. By monitoring the pulses of extremely fast rotators, known as millisecond pulsars, which rotate hundreds of times per second, GLAST will probably observe effects due to special relativity. She notes that these observations might dispel the common "lighthouse" model of pulsars, showing that what we see is really a relativistic distortion of the pattern emitted by the pulsar. Virtually nothing is known about the gamma-ray emission of pulsar wind nebulae in the region between 10 and GeV, and yet that might be where most of the exciting action is taking place. The LAT will fill in that gap. These so-called magnetars occasionally unleash flares that pack more energy in a fraction of a second than the Sun will emit in tens of thousands or even hundreds of thousands of years. The flares are probably ignited when a massive shift in the crust a starquake triggers a large-scale untwisting and rearrangement of magnetic-field lines, causing them to snap and release vast amounts of pent-up magnetic energy in the form of gamma rays, X rays, and particles. But theorists lack a detailed understanding of this process. The GBM and the LAT combined cover a much wider range of energies than Swift, so when combined with observations from other spacecraft, scientists may be able to assemble a more detailed picture of what powers these incredible outbursts.