WHAT'S INSIDE OF A NEUTRON STAR?

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ABSTRACT

A neutron star is the remnant of a massive star formed by a supernova explosion. Neutron stars have a radius of order 10 km and a mass of 1-2 solar masses. The interiors of neutron stars contain the densest forms of matter in the universe—so dense that they are not far from collapsing to a black hole. Neutrons stars have a solid crust as well as a so far unknown interior, and there are several candidates for the, most likely liquid, matter inside. Since neutron stars are so small, they are almost invisible. A method to observe them is: Asteroseismology. Different oscillation modes are use to get information about the star, in particular those that arise if the star rotates very fast are interesting. These can be connected to astrophysical observations of the rotation frequeny and the temperature of these source to learn about the interior of the star.

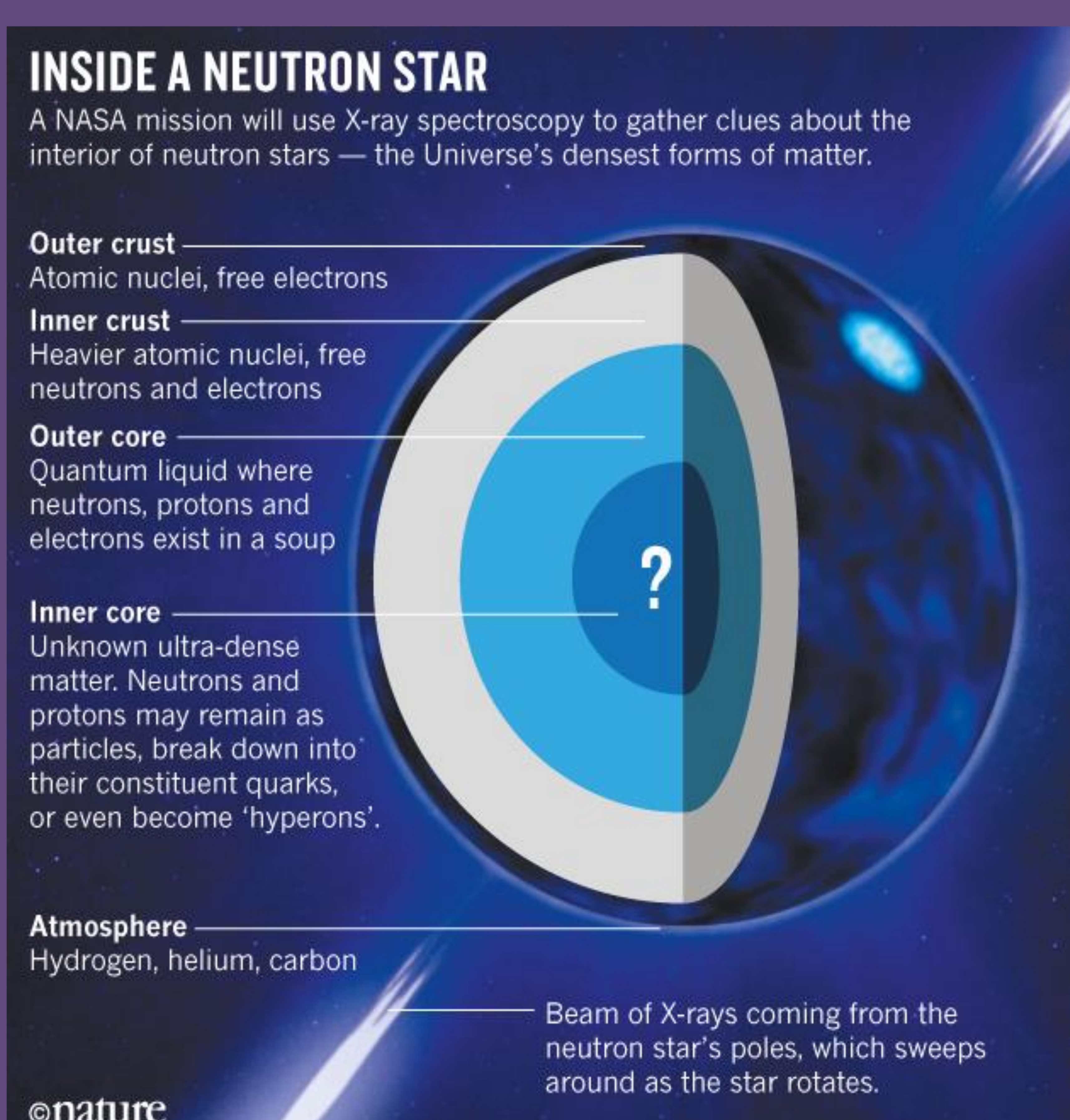
Neutron Stars

Neutron stars form from the core collapse of massive stars in the range between 10 and 25 solar masses. During their creation electrons and protons merge and form neutrons.

Even though neutron stars are naively thought to be made exclusively of neutrons, the dense matter at the center is unknown yet. Possible candidates are e.g. matter consisting of free quarks, a new kind of matter formed by heavier baryons called 'hyperons', or superfluid matter.

Neutron stars rotate really fast, nearly 1000 times a second, and some emit radiation from their magnetic poles. These type of neutron stars are known as 'pulsars'.

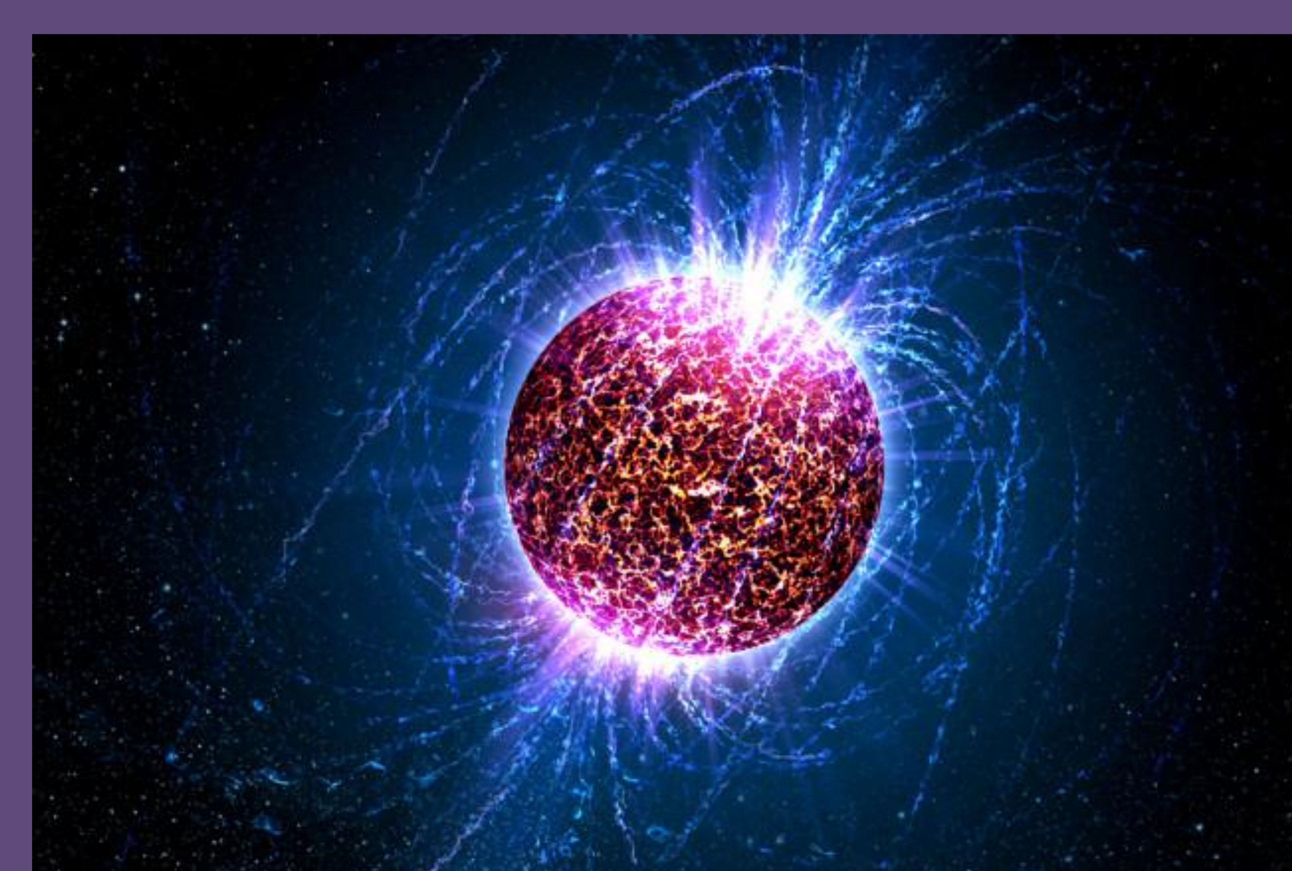
Neutron stars have an enormous temperature (around K) when they are born. They cool over time via neutrino and photon emission but many still have temperatures as high as a million Kelvin. Correspondingly they emit electromagnetic radiation in the X-ray band that can be detected if they are sufficiently nearby.



Astroseismology

Asteroseismology is the study of stellar oscillations and there are various different oscillation modes. Since Neutron stars are tiny objects, it is even hard to detect them at all and impossible to directly observe oscillations of their opaque, dense interior. However, it is possible to observe the indirect impact of seismic oscillations on their rotational frequency and temperature.
When a star rotates very fast, the liquid inner material oscillates in response and these oscillations are damped away depending on the viscosity of the liquid (i.e. its friction). Therefore the viscosity of the material gives a clue about the type of the matter inside!


Imagine a cup of honey and a glass of water. Which liquid can more easily be put into motion? This is described by the viscosity (friction) of the material, which can differ strongly for different forms of matter.



Similarly the damping of oscillations of a neutron star would be very different depending on what's inside. And the presence of these oscillations affects observational data: frequency and temperature.

Oscillations of the star would emit gravitational waves that slow down the rotation of the star. To observe the frequency change, milisecond pulsars can be used because milisecond pulsars are extremely fast and according to observations hardly slow down. This shows that the viscosity must be sufficiently large to limit these oscillations.

Similarly, neutron stars carry heat like every object in the universe. Viscous dissipation of large amplitude oscillations would strongly heat up the star. But temperature measurements of neutron stars show that they are rather cold, which likewise requires a large viscosity and tells us something about the matter inside.

Conclusion

The inner composition of neutron stars is still not fully clear, yet. A promising method to learn about the interior it is astroseismology.
For neutron stars it can be used be observing the indirect effects on the temperature and frequency of milisecond pulsars. The ratio of slowing down in milisecond pulsars and low temperature of neutron stars are used to determine inner matter. To explain current data requires a strong dissipation in the interior. Possible candidates for novel forms of mattering the interior that could provide this are: superfluids, hyperons and quark matter. Yet, there might be even other so far unknown possibilities.