Neutron Stars: The Basics and Beyond

Figure 1: An artist's conception of a binary neutron star system. Retrieved from https://www.psu.edu/news/research/story/seeing-light-neutron-star-collisions

By Austin, Dustin, and Yazmin

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History

First detected in 1967 by Jocelyn Bell and Antony Hewish (PBS, n.d).

Initially thought to be signals from extraterrestrial civilization, dubbed "Little Green Men" (Menezes, 2021).

By 1968, identified as a neutron star and later named Cambridge Pulsar (PBS, n.d.).

Figure 2: Bell and Hewish. Retrieved from https://doi.org/10.1038/547005b

The Fate of a Star

A star's fate depends on its mass. It may become a white dwarf, a neutron star, or a black hole (Goddard Space Flight Center, 2015).

High-mass stars, with initial mass greater than 8 times the Sun, evolve into red supergiants, which undergo a supernova event (European Space Agency, n.d).

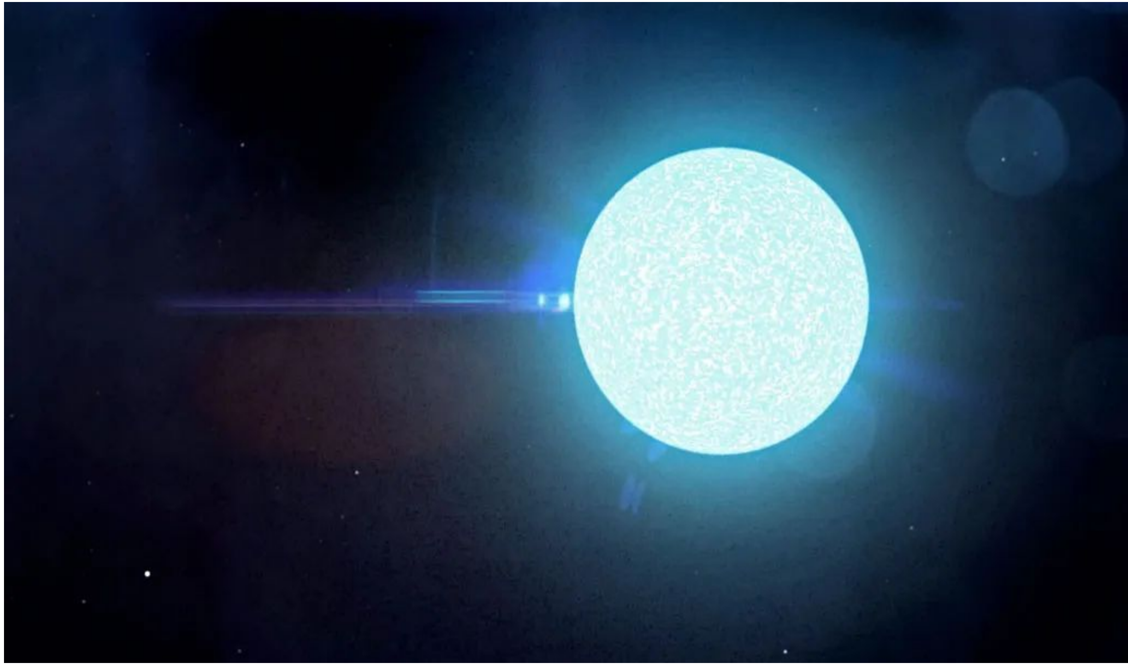

Figure 3: An artist's conception of a neutron star. Retrieved from https://www.sciencenews.org/article/neutron-stars-pulsar-density-diameter-matter

The Fate of a Star, Cont.

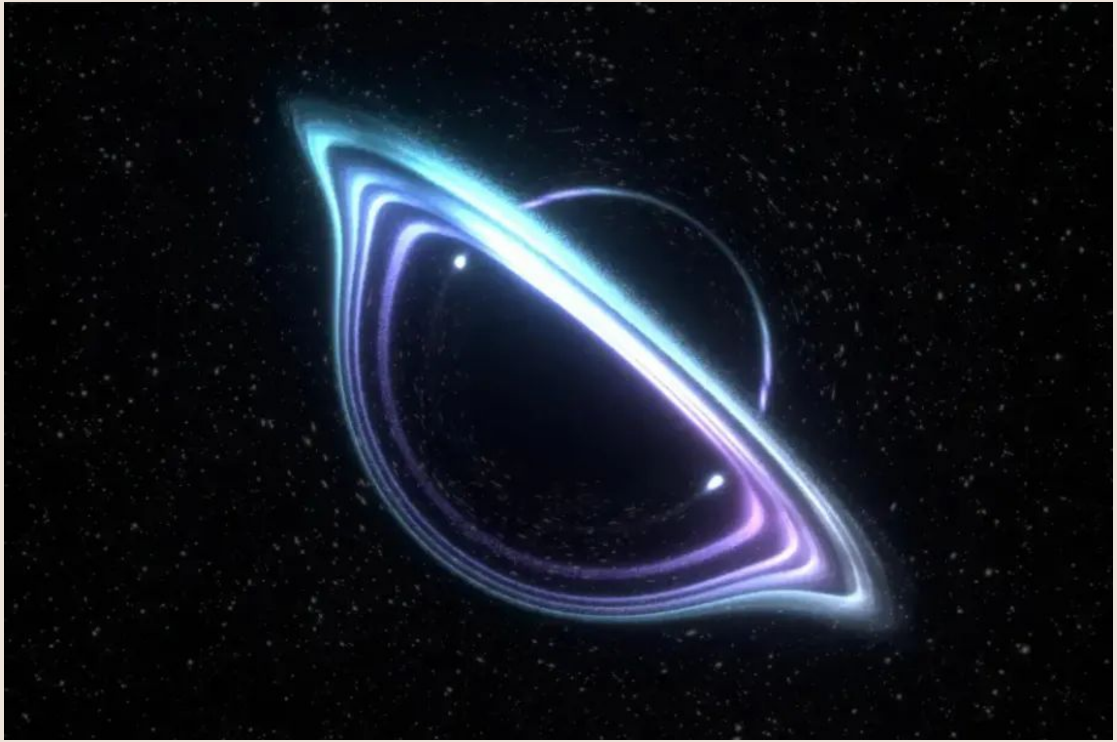

Figure 4: An artist's conception of a "New Black Neutron Star". Retrieved from https://globalnews.ca/news/7102112/black-neutron-star-ligo-hole/

If the core that is left is between 1 and 3 solar masses, it forms a neutron star; otherwise, it becomes a black hole (European Space Agency, n.d).

Formation of a Proto-Neutron Star

Strong Nuclear Force:
Binds protons and neutrons and holds the nucleus together (Nobel Prize Outreach, 2025).

Weak Nuclear Force:
Enables proton-neutron conversions via radioactive decay (Sears & Zemanski, 2010, as cited in Donev et al., 2014).

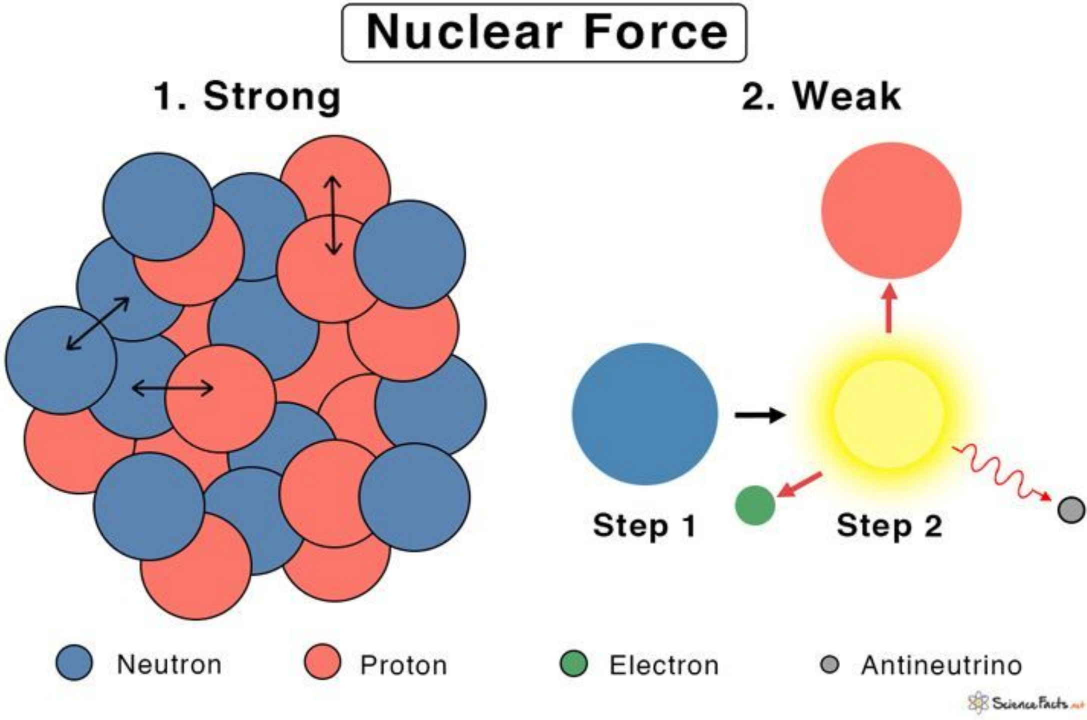

Figure 5: Illustration of the strong and weak forces. Retrieved from https://www.sciencefacts.net/nuclear-force.html

Formation of a Proto-Neutron Star, cont.

Timeline

Within 10 seconds of core collapse:
PNS forms, neutrino emissions, and rapid contraction. (Camelio, 2017)

After 10 seconds:
Becomes quasi-stationary with strong thermodynamic gradients and neutrino emissions (Martinion et al., 2014).

Contracts and cools

Forms into a full neutron star.

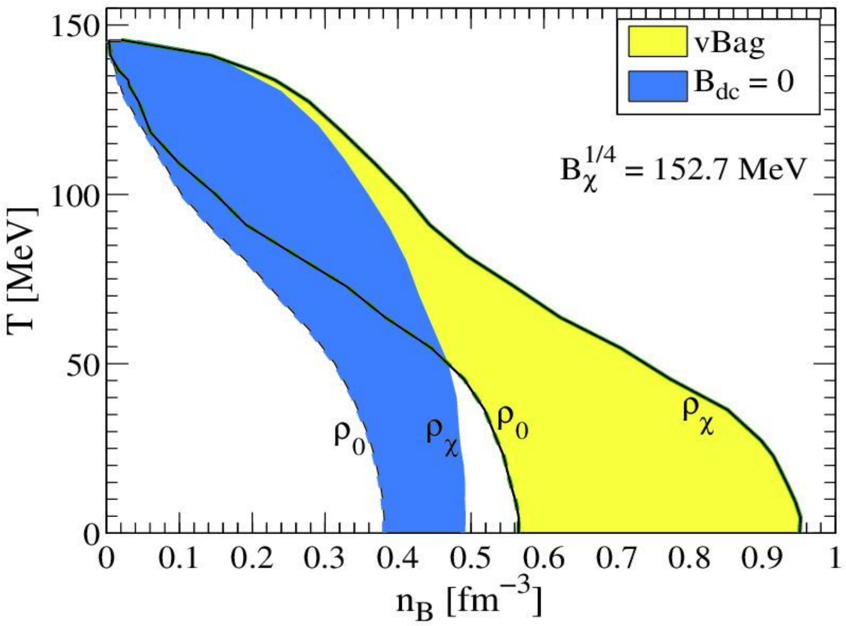

Figure 6: Illustration of a density vs. temperature graph for proto-neutron states. Retrieved from https://doi.org/10.1088/1742-6596/861/1/012026

Physical Qualities of a Neutron Star

Density

Neutron stars are extremely compact, spanning just 10 - 20 km in diameter (Alfredo, 2023). They typically have a mass 1.1 to 2.3 times that of the Sun.

Temperature

The temperature of a proto-neutron star is measured to be between 10^{11} - 10^{12} Kelvin. Because of the neutrinos emissions, the temperature falls and settles to about 10^{6} Kelvin (Camelio, 2017) for a neutron star.

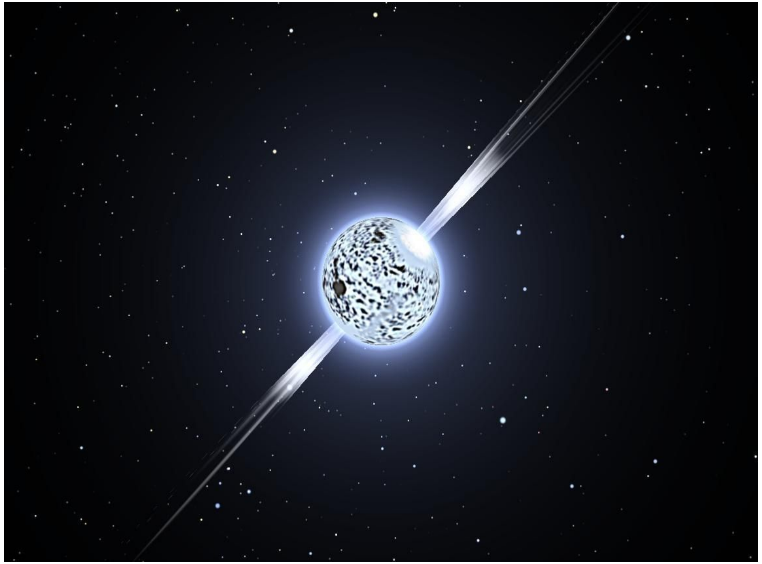

Figure 7: An artist's conception of a neutron star. Retrieved from http://www.orionsarm.com/eg-article/46d4bf6c4e652

Physical Qualities of a Neutron Star, Cont.

Magnetic Fields
Neutron stars have magnetic fields ranging from 10^8 to 10^{15} G (Reisenegger, 2001). These intense magnetic fields can emit bursts of radiation, influencing their surrounding environments (Vigano, 2013, as cited in Alfredo, 2023).

Rotation
Neutron stars can rotate up to hundreds of times per second due to angular momentum conversion during the core collapse of the previous star (Ordaz, 2019, as cited in Alfredo, 2023).

Interior Composition
Neutron stars contain superfluids and superconductors in their internal environment (Page et al., 2014, as cited in Chamel, 2017)

Main types: (Jet Propulsion Laboratory, 2020)

I. Magnetars
II. Pulsars
III. Isolated Neutron Stars

Pulsar Subtypes: (Center for Astrophysics: Harvard & Smithsonian, n.d.)

I. Millisecond
II. Ordinary

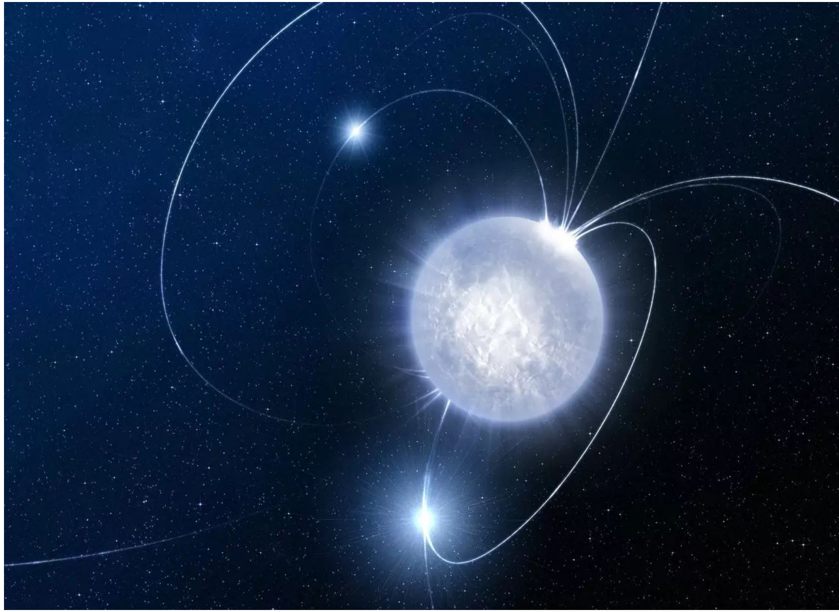

Figure 8: An artist's conception of neutron star. Retrieved from https://rndmcanada.org/2023/12/11/neutron-star/

Classifications

Clicker Question

What force is primarily responsible for holding a neutron star together?

A): Electromagnetic force

B): Weak nuclear force

C): Strong nuclear force

D): Gravitational force

Analyzing the Properties of Neutron Stars

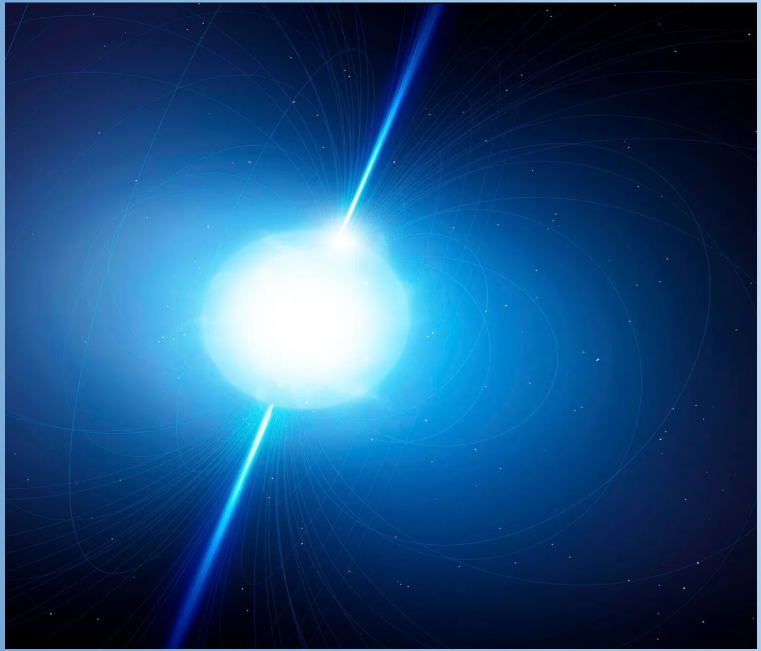

Figure 9: An artist's conception of a neutron star. Retrieved from https://www.cnet.com/science/this-astounding-neutron-star-spins-faster-than-a-blender/

Superconductivity allows for:

- Phones that never die (U.S Department of Energy, n.d.).
- Computers that never overheat (U.S Department of Energy, n.d.).

Superconductivity is a highly sought-after property for a material, but we've only achieved it at very low temperatures (Wu et al., 1987).

Well, Neutron Stars are superconductive, and certainly not at low temperatures...

What if We Built a Computer Out of Neutron Stars?

- iPhone 15 Pro Max's chip has 19 billion transistors (CNET, n.d.)
- No sources on transistor volume, so let's say 1 cubic micrometer to keep things simple.
- 1 cubic micrometer times 19 billion gives us 0.019 cubic centimeters of materials we need to supplant with Neutron Star stuff. A single M&M is 33 times the size (Wolfram Alpha, n.d.)
- Now we have an electronic device that will never die!

Clicker Question

How Might You Realistically Befriend a Worm?

A) Be a good conversationalist.

B) BYOB!

C) Forage huckleberries and blackberries from the mountain as a gift

D) err::MicrosoftInjectionError! [Please log out of the program.]

Other Things We Could Do with Neutron Stars

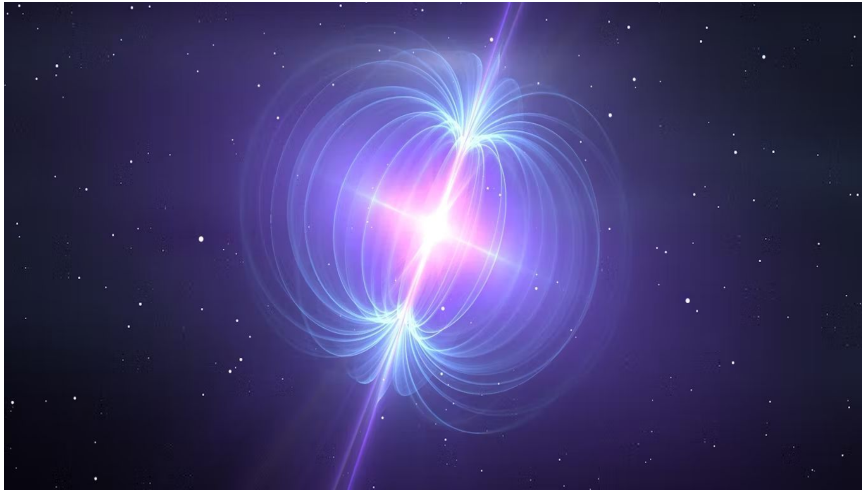

Figure 10: An artist's conception of a neutron star. Retrieved from http://theconversation.com/this-newly-discovered-neutron-star-might-light-the-way-for-a-whole-new-class-of-stellar-object-184050

Frictionless nature of neutron star material;

Frictionless high speed modes of travel?

Airliners, high-speed rail?

Neutron Star Applications

Possibly frictionless airplanes?

Concorde reborn? But faster and more efficient?

Maybe not burning 25,000 L of fuel per hour? Mother Nature rejoice!

Figure 11: The Concorde. Retrieved from https://www.popularmechanics.com/flight/airlines/a27206102/concorde-badass-plane/

Why These Ideas Are Totally Infeasible

The nearest Neutron Star is 130 parsecs away, or 424 light years (Posselt et al., 2008).

Although we'd need only 1/33rd of an M&M's worth of material for an iPhone, it would weigh as much as the Great Pyramid of Giza (Wolfram Alpha, n.d.)

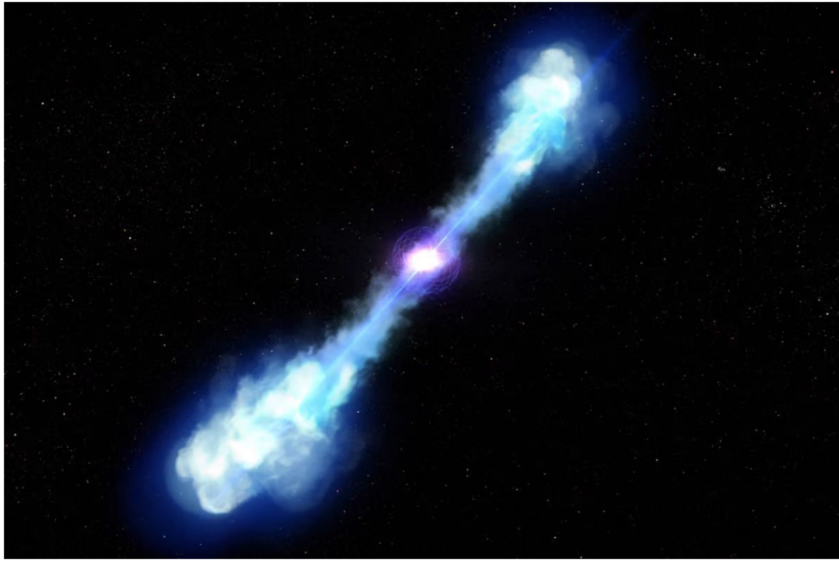

Figure 12: An artist's conception of gamma ray bursts from neutron stars. Retrieved from https://newatlas.com/space/neutron-star-collision-short-gamma-ray-burst/

Why It Is Not Happening, Cont.

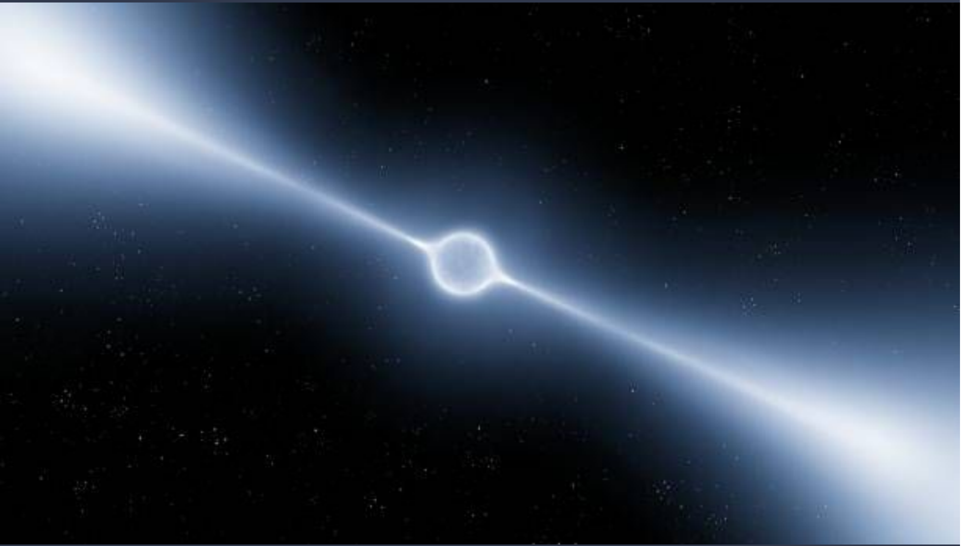

Figure 13: Neutron star stock photo. Retrieved from https://www.istockphoto.com/photos/neutron-star

Also, Neutron Stars only have these qualities (superfluidity, superconductivity) due to the immense pressure and temperature of their cores (Lombardo & Schulze, 2000).

Image: Neutron Star Trajectory

Figure 14: Photo of a neutron star trajectory in visible light. Retrieved from https://hubblesite.org/contents/news-releases/2000/news-2000-35.html

Figure 15: A lone neutron star in space. About 28 km across. Retrieved from https://esahubble.org/images/opo9732a/

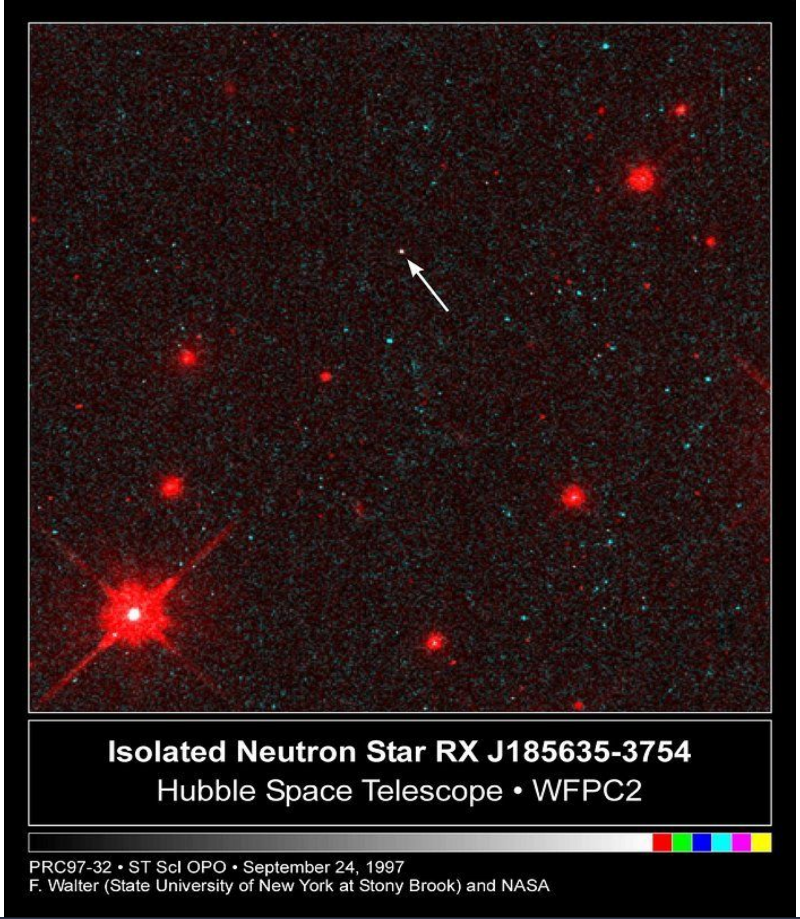

Image: Isolated Neutron Star

Clicker Question

What property of neutron star material would be beneficial for aircraft fuel efficiency?

A): Super Conduciveness

B): Superfluidity

C): Superconductivity

D): Super super super supper

References

Center for Astrophysics: Harvard & Smithsonian. (n.d). *Millisecond pulsars.* https://www.cfa.harvard.edu/news/millisecond-pulsars

Chamel, N. (2017). Superfluidity and superconductivity in neutron stars. *J Astrophys Astron* 38, 43. https://doi.org/10.1007/s12036-017-9470-9

CNET. (n.d). *Apple a17 pro: The new chip brain in the iPhone 15 pro, pro max.* https://www.cnet.com/tech/mobile/apple-a17-pro-the-new-chip-brain-in-the-iphone-15-pro-pro-max/

Collazos, J. A. (2023). *Structural characteristics and physical properties of neutron stars: Theoretical and observational research*. https://doi.org/10.48550/arxiv.2303.08734

Donev, J.M.K.C., et al. (2024). Strong nuclear force. *Energy Education*. https://energyeducation.ca/encyclopedia/Strong_nuclear_force

European Space Agency. (n.d). Neutron star. *ESA/Hubble*. https://esahubble.org/wordbank/neutron-star/

References Cont.

Goddard Space Flight Center. (2015). *The Life Cycles of Stars. NASA.* https://imagine.gsfc.nasa.gov/educators/lifecycles/LC_main3.html

Jet Propulsion Laboratory. (2020). *Different types of neutron stars (illustration)*. https://www.jpl.nasa.gov/images/pia23863-different-types-of-neutron-stars-illustration/

Lombardo, U., & Schulze, H. J. (2000). *Superfluidity in neutron star matter.* https://doi.org/10.48550/arXiv.astro-ph/0012209

Martinion, G., Maselli, A., Gualtieri, L., & Ferrari, V. (2024). *Rotating proto-neutron stars: Spine evolution, maximum mass and l-love-Q relations.* Ithaca: Cornell University. https://doi.org/10.48550/arxiv.1406.7661

Menezes, D.P. (2021). A neutron star is born. *Universe, 7, 267.* https://doi.org/10.3390/universe7080267

Nobel Prize Outreach. (2025). *Forces*. https://www.nobelprize.org/prizes/themes/forces

PBS. (n.d). *A Science odyssey: People and discoveries.* https://www.pbs.org/wgbh/aso/databank/entries/dp67be.html

References Cont.

Posselt, B., Neuhäuser, R., & Haberl, F. (2008). *Searching for substellar companions of young isolated neutron stars.* Ithaca: Cornell University. https://doi.org/10.48550/arXiv.0811.0398

Reisenegger, A. (2001). *Magnetic fields of neutron stars: An overview*. Ithaca: Cornell University. https://doi.org/10.48550/arxiv.astro-ph/0103010

U.S Department of Energy. (n.d). *DOE explains... superconductivity*. https://www.energy.gov/science/doe-explainssuperconductivity

Wolfram Alpha. (n.d.). *0.019 cubic centimeters*. https://www.wolframalpha.com

Wolfram Alpha. (n.d.). *(0.019 cubic centimeters) (3.7x10^17 kg/m^3)*. https://www.wolframalpha.com

Wu, M. K., Ashburn, J. R., Torng, C. J., Hor, P. H., Meng, R. L., Gao, L., Huang, Z. J., Wang, Y. Q., & Chu, C. W. (1987). *Superconductivity at 93 K in a new mixed-phase Y-Ba-Cu-O compound system at ambient pressure. Physical Review Letters, 58*(9), 908–910. https://doi.org/10.1103/PhysRevLett.58.908

Image References

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Question Period

Please ask better questions than they do in the real Question Period in Parliament.

I beg of you