PUBLIC LECTURE - SEDS Celestia

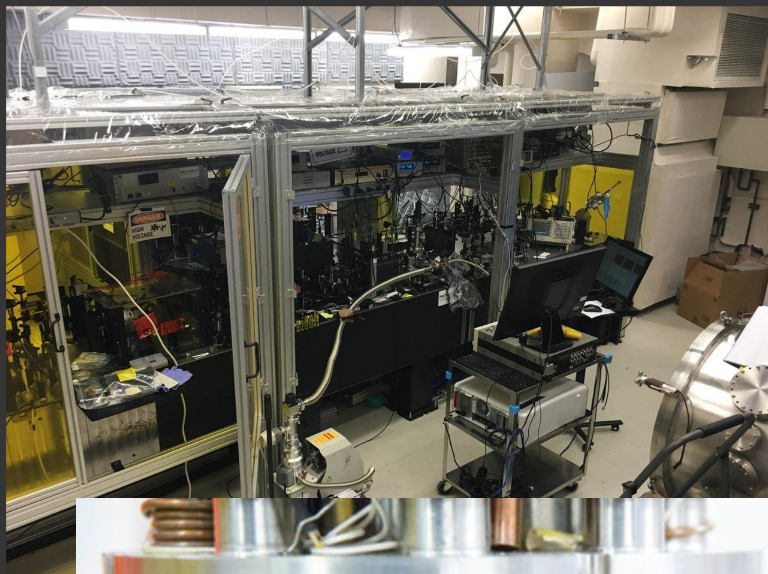
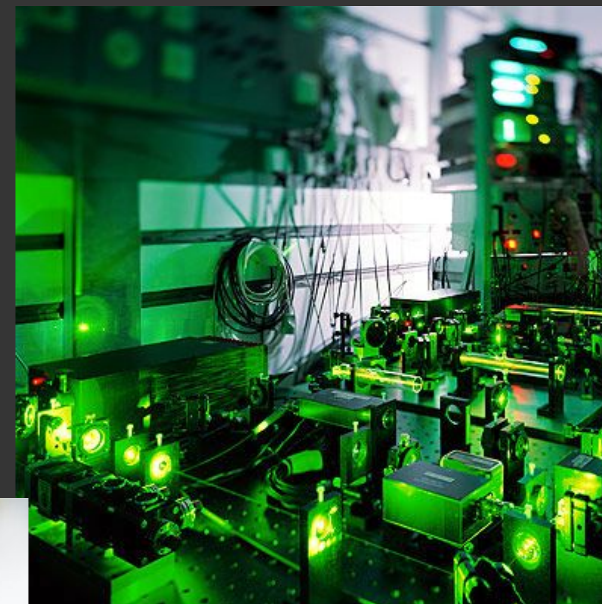
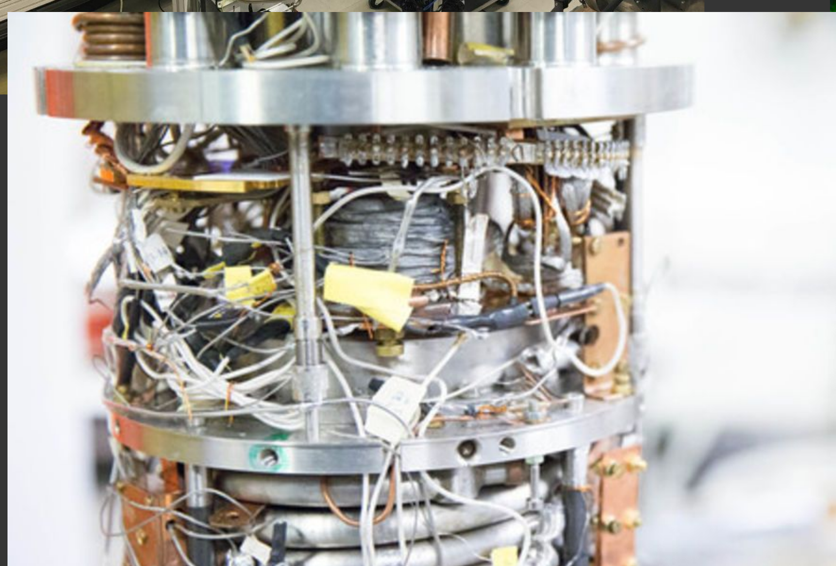
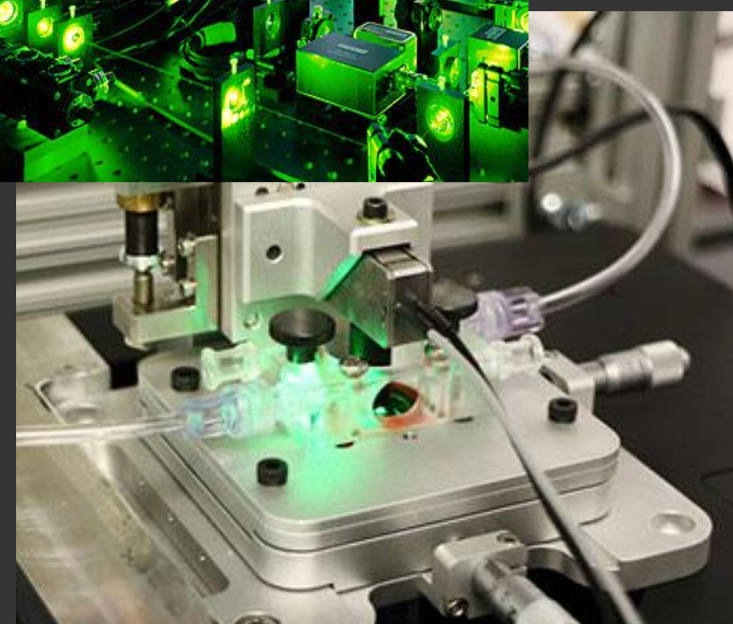
Neutron Stars - Extraordinary Cosmic Laboratories

Dr. Vanessa Graber

Institute of Space Sciences (IEC), Spain

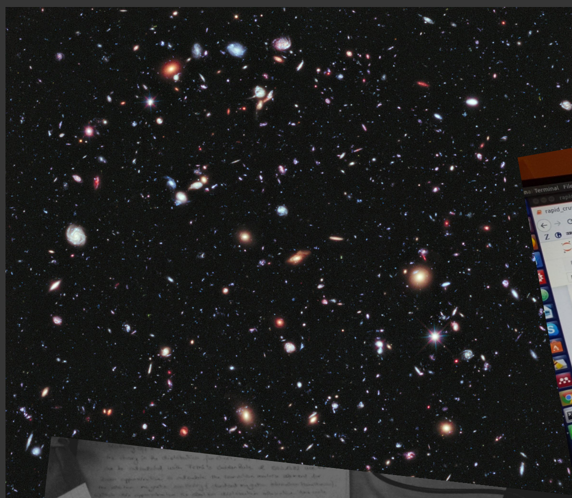
JULY 5TH, 3:30pm (CEST)

LABORATORIES

THE UNIVERSE AS A LABORATORY

Image credit: NASA



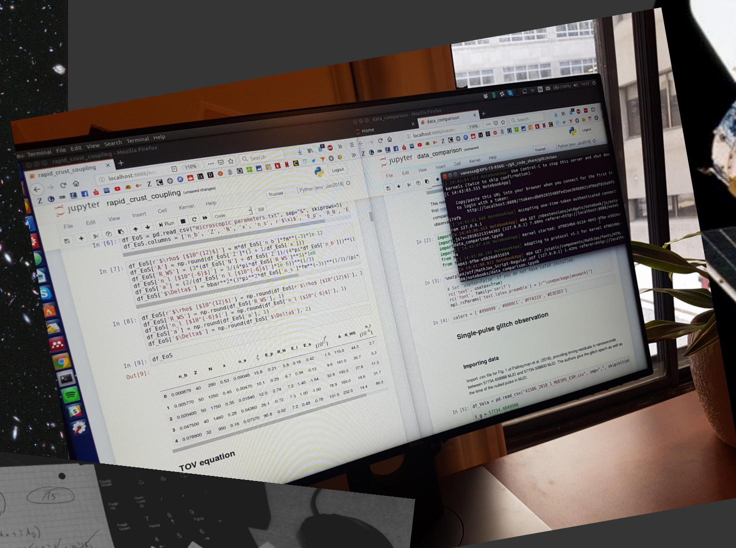
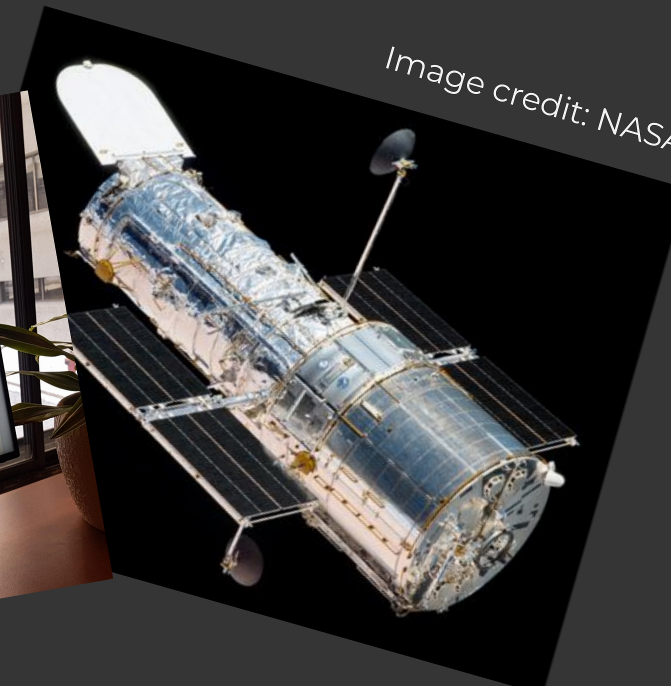
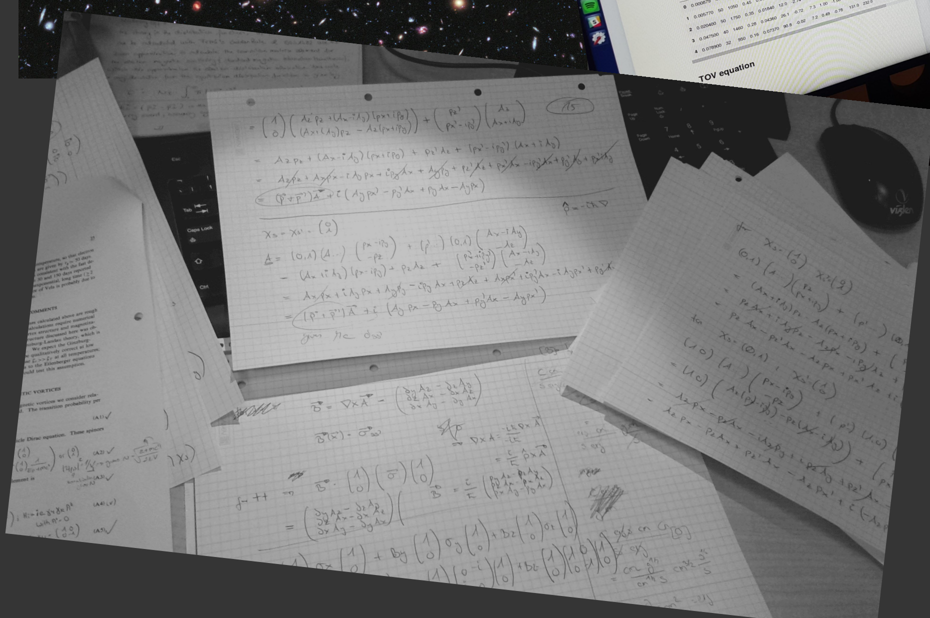


Image credit: NASA



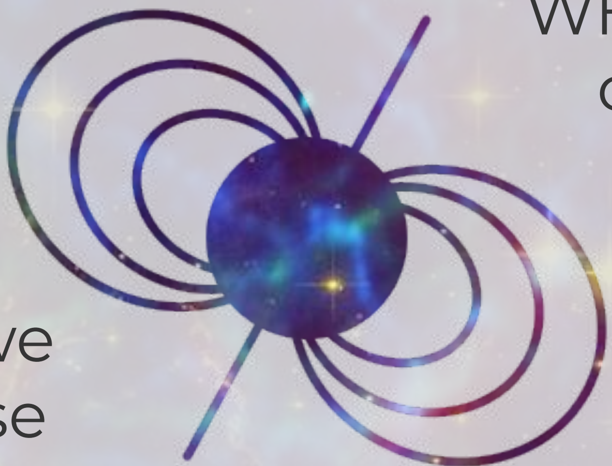


Combine observations, mathematical calculations and computer simulations to learn about the Universe.

Neutron stars unite many extremes of physics that cannot be recreated on Earth.

WHAT are these extremes?

WHAT is going on in their interiors?



HOW do we know these extremes exist?

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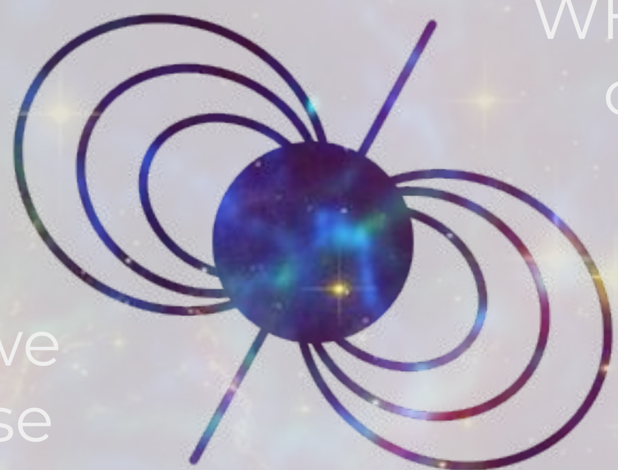


HOW do we know these extremes exist?

NEUTRON STAR EXTREMES

Neutron stars are born in supernova explosions.

Crab Nebula, 1054

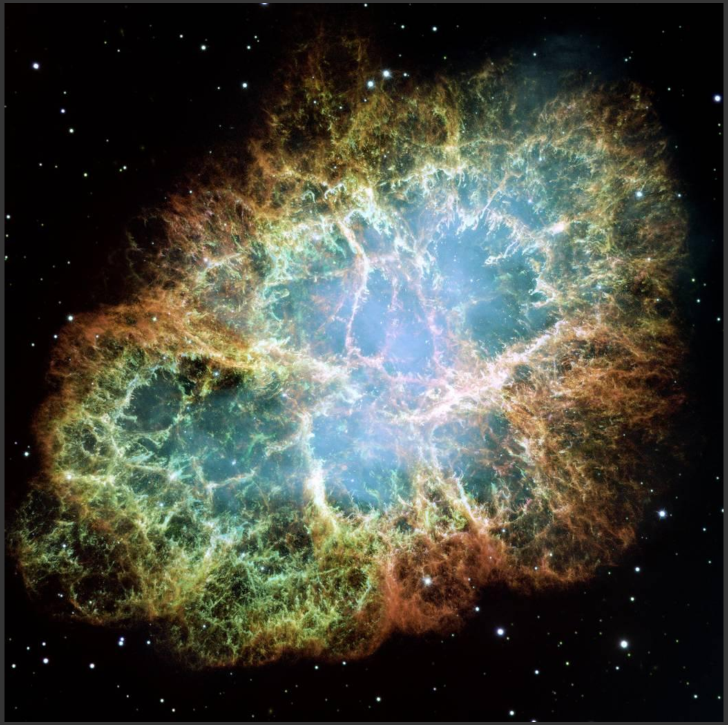


Image credit: NASA, ESA, J. Hester, A. Loll (ASU)

Cassiopeia A, ~1670

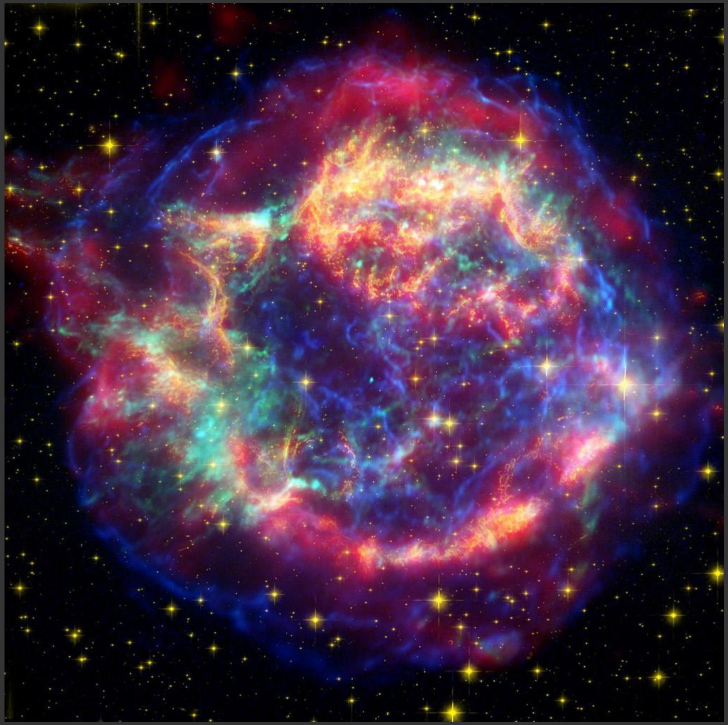


Image credit: NASA, JPL-Caltech, STScI, CXC, SAO

NEUTRON STAR EXTREMES

Neutron stars have a mass comparable to the Sun but the size of a city.

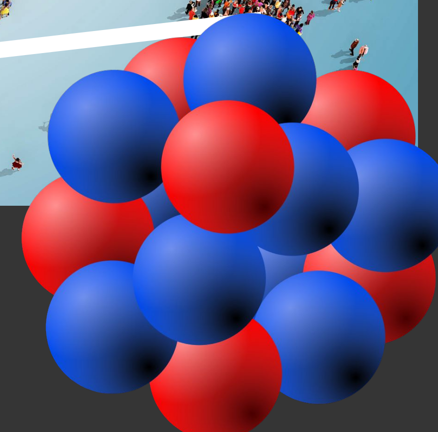
Image credit: NASA, SDO

Image credit: Google, ESO, L. Calçada

NEUTRON STAR EXTREMES

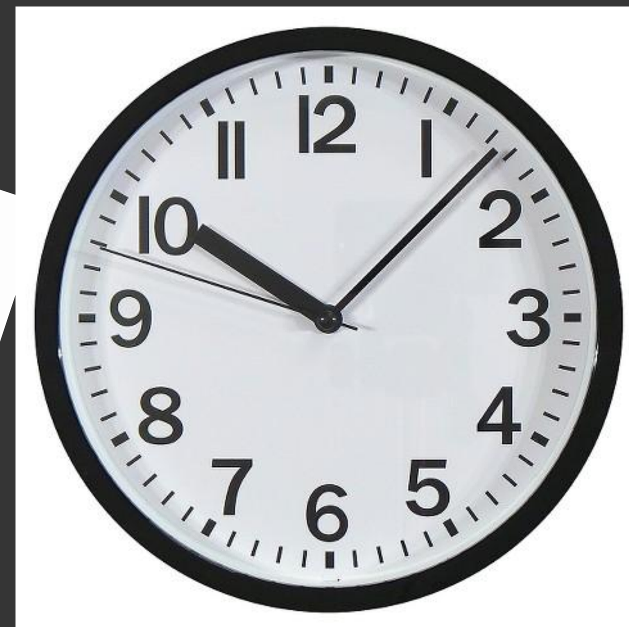
Image credit: Arthimedes/Shutterstock.com

Neutron stars mainly consist of neutrons and are the densest object we know of.



Densities up to 10^{15} g/cm^3 = 1,000,000,000,000,000 g/cm^3

NEUTRON STAR EXTREMES



Neutron stars are very fast and stable rotators.

They can rotate up to ~700 times per second.

NEUTRON STAR EXTREMES

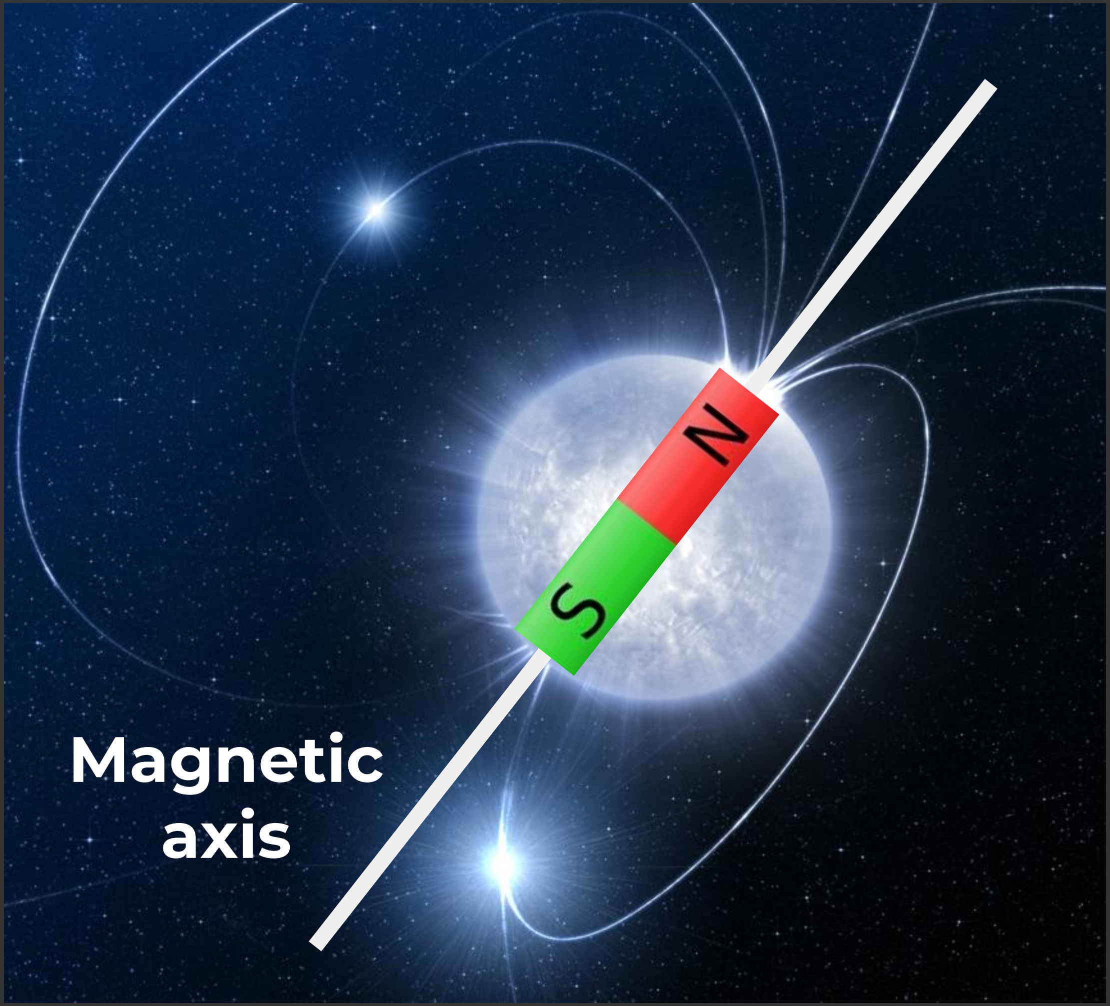


Image credit: ESO, L. Calçada

Neutron stars are the strongest magnets in the Universe.

Field strengths of ~10^{12} Gauss = 2,000,000,000,000 x Earth's magnetic field

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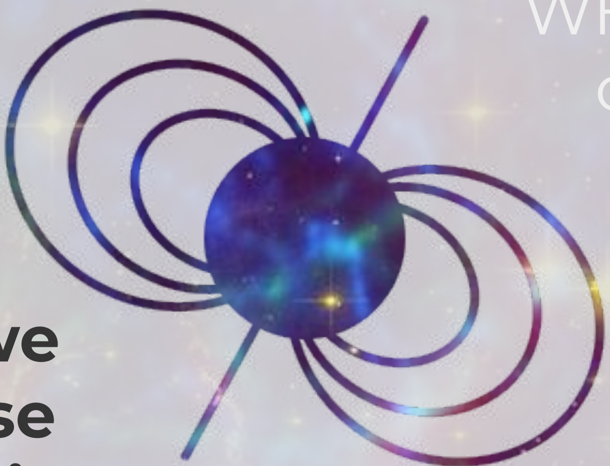
WHAT are these extremes?

WHAT is going on in their interiors?



HOW do we know these extremes exist?

OBSERVING NEUTRON STARS

Neutron stars emit light in different parts of the electromagnetic spectrum.

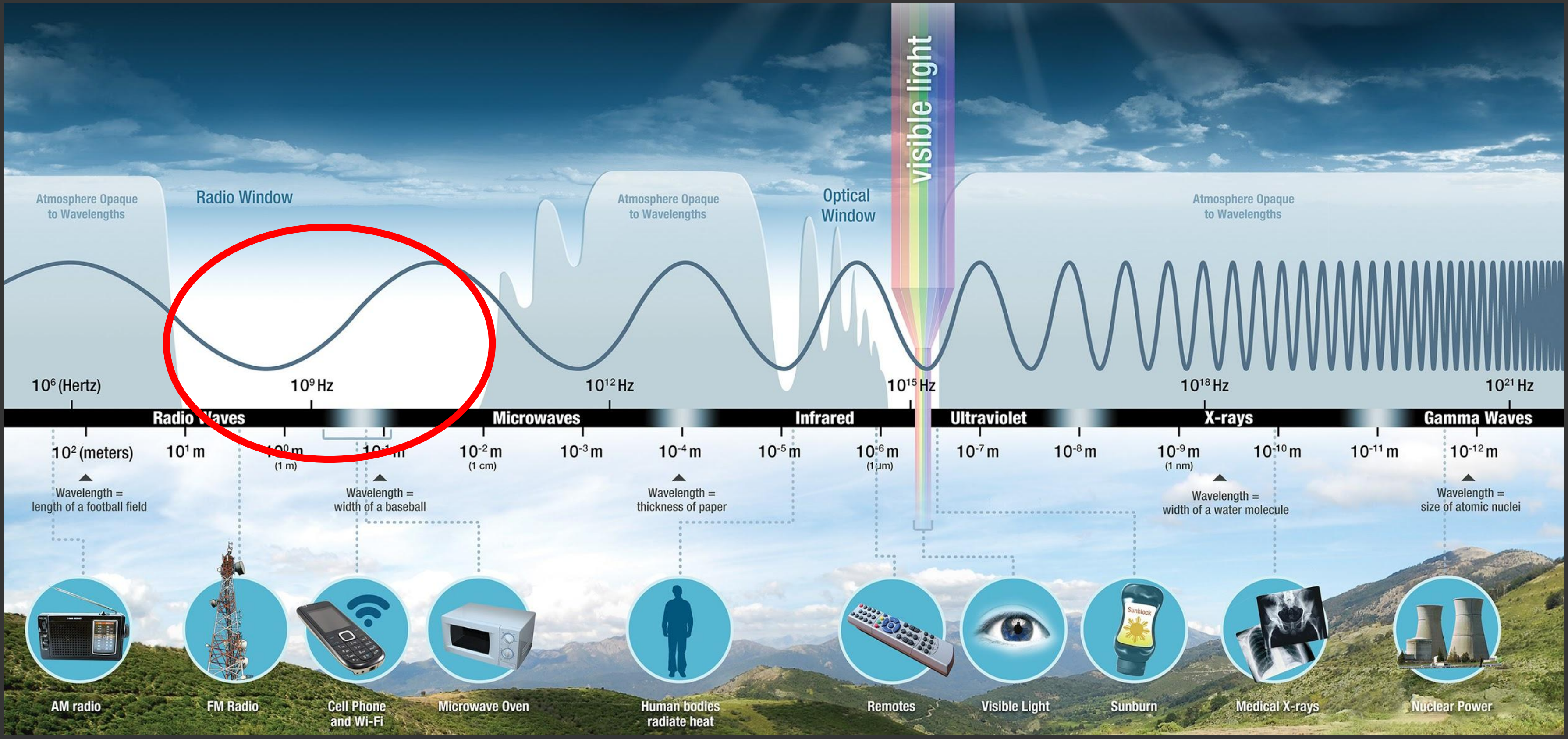


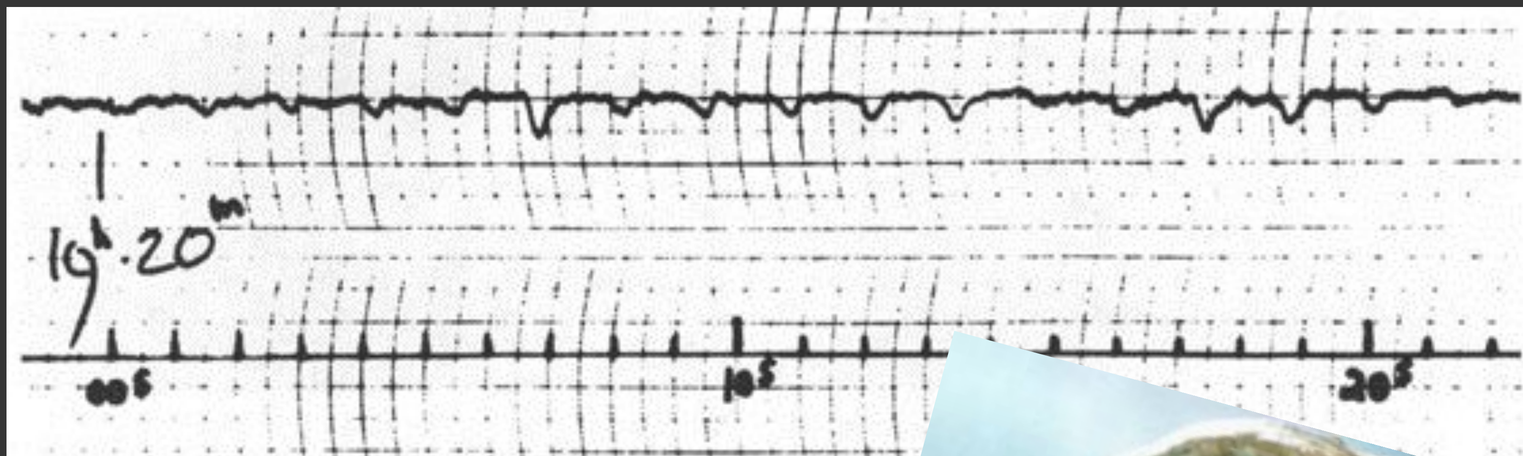
Image credit: NASA

OBSERVING NEUTRON STARS

They were first observed in the radio band in 1967 by Jocelyn Bell Burnell.

Neutron stars emit radiation like a lighthouse - they pulse.

OBSERVING NEUTRON STARS



The first source had a period of ~1.3 seconds and was nicknamed LGM-1, which stands for ‘Little Green Man’.

OBSERVING NEUTRON STARS

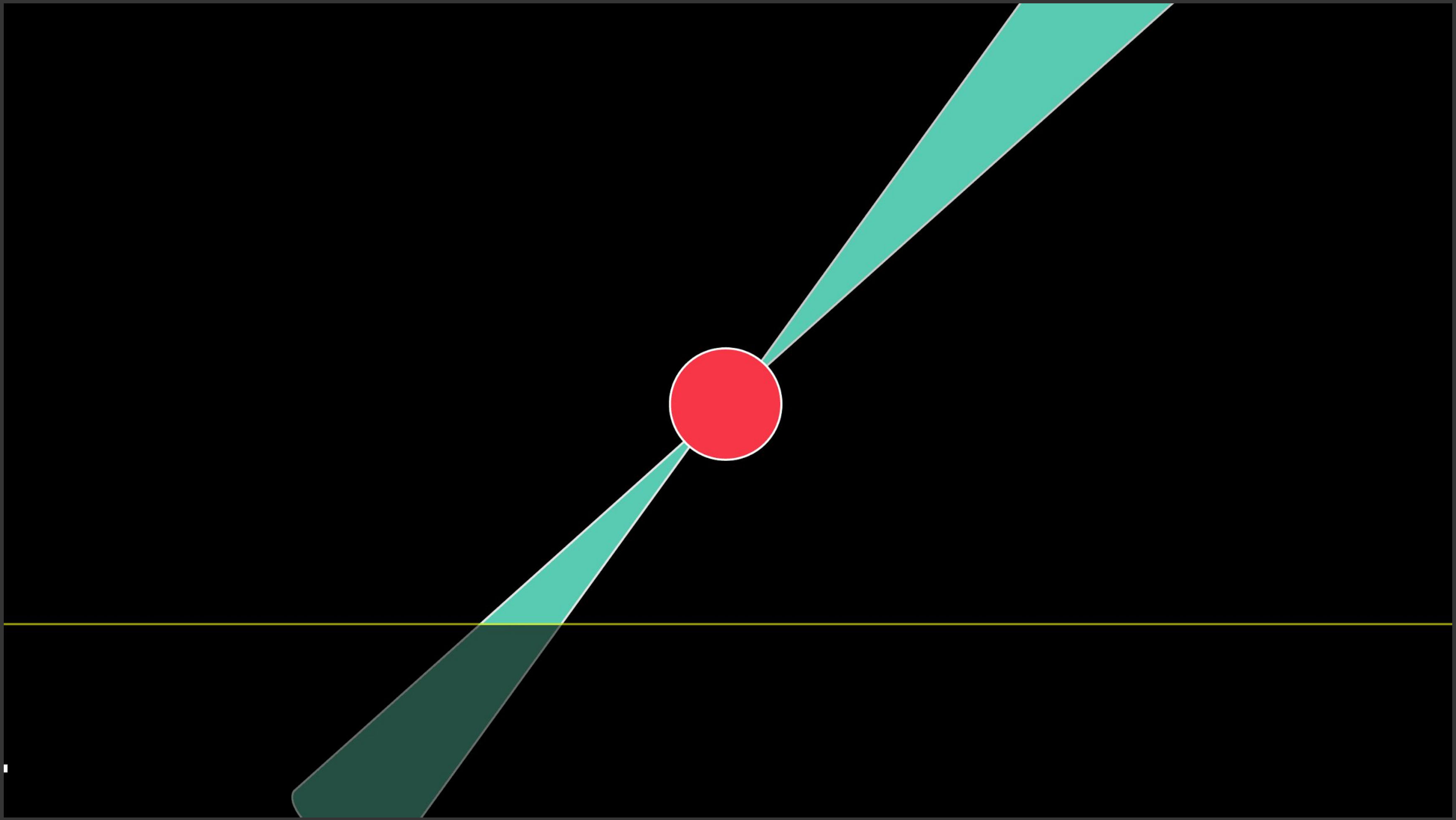
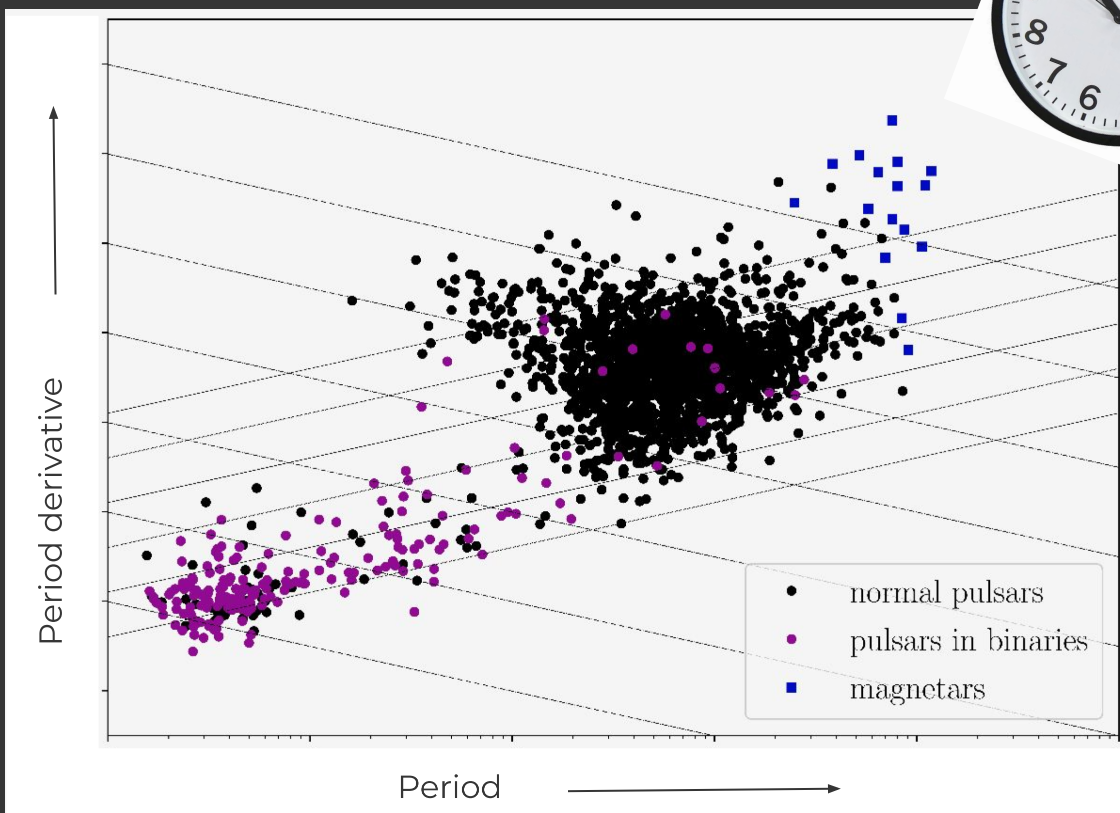


Image credit: J. Christiansen

OBSERVING NEUTRON STARS

700 neutron stars have been observed as radio pulsars.

Image credit: Arecibo Obs., NSF



We time pulsars to measure the period and its derivative.

Obtain age and magnetic field strength estimate.

OBSERVING NEUTRON STARS

If the pulsar is in a binary, the arrival time of the pulses is altered as the two stars orbit around each other.

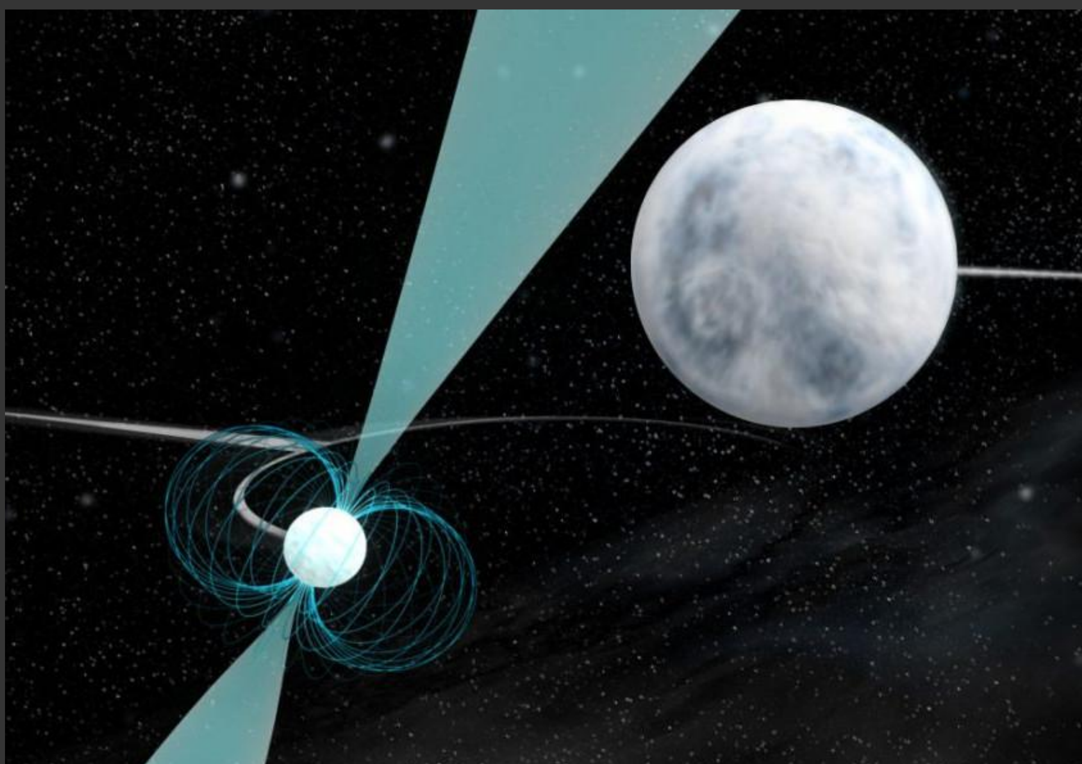


Image credit: B. Saxton, NRAO, AUI, NSF

High precision measurements allow us to extract the neutron star mass.

OBSERVING NEUTRON STARS

Neutron stars emit light in different parts of the electromagnetic spectrum.

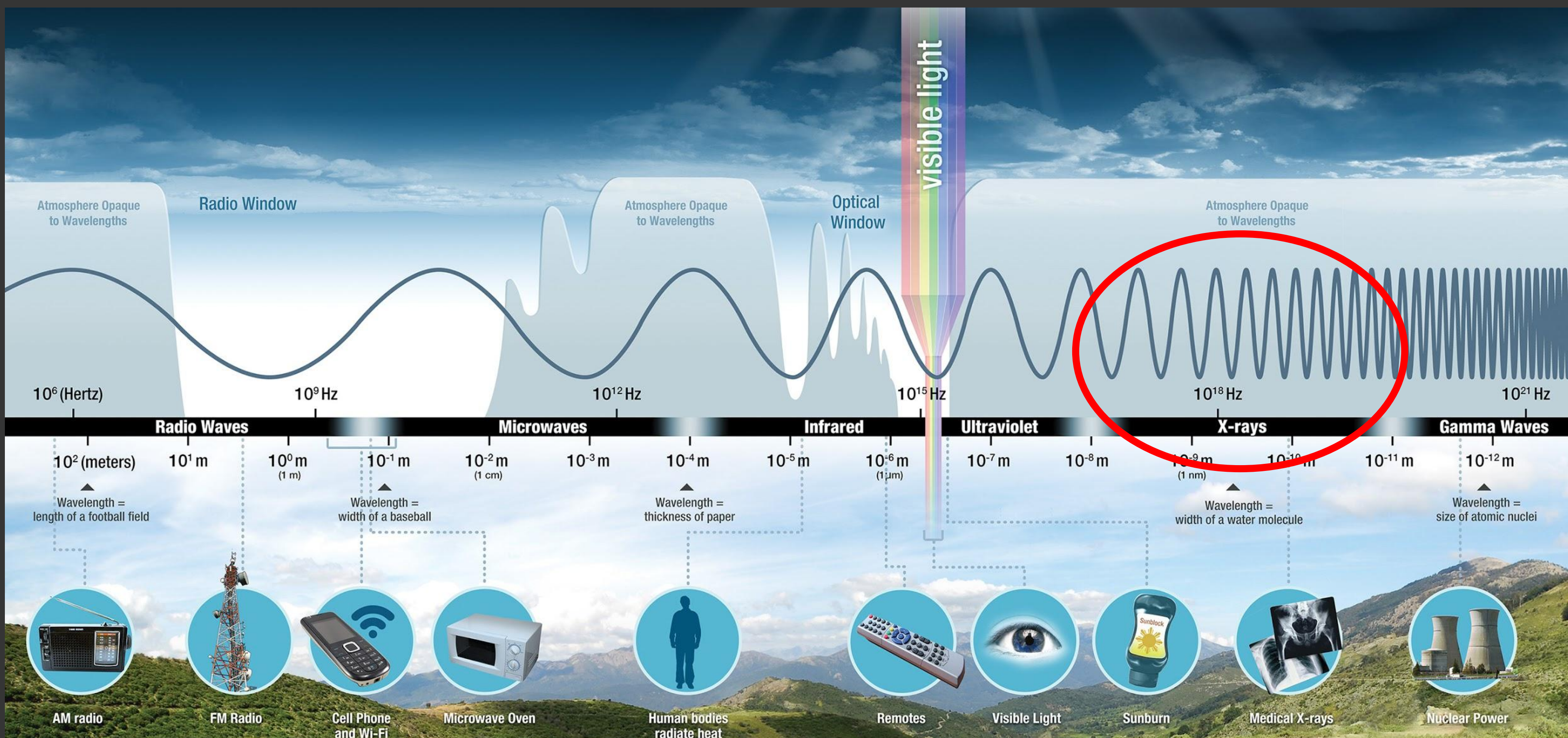
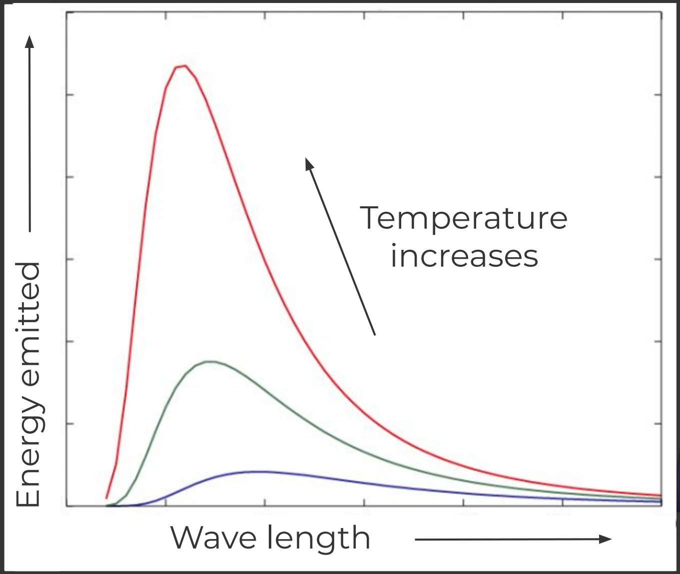


Image credit: NASA

OBSERVING NEUTRON STARS

With temperatures of ~10^7 °C = 10,000,000 °C, they emit thermal black-body radiation in the X-rays.

Image credit: D. Bice



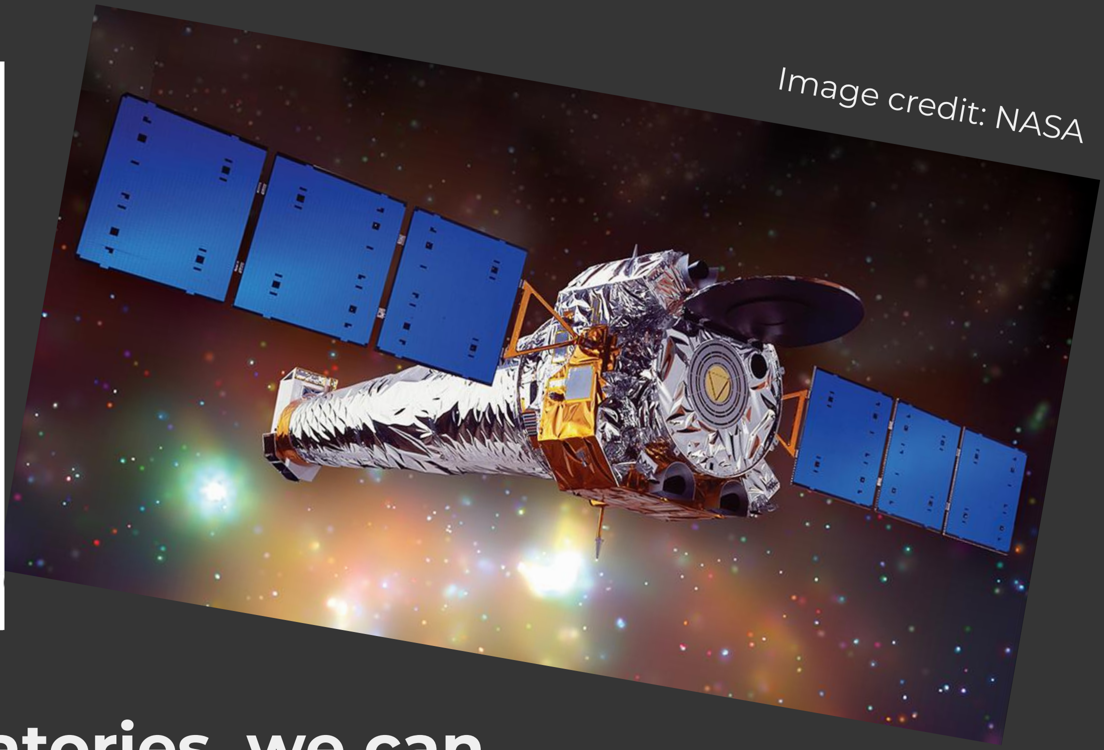
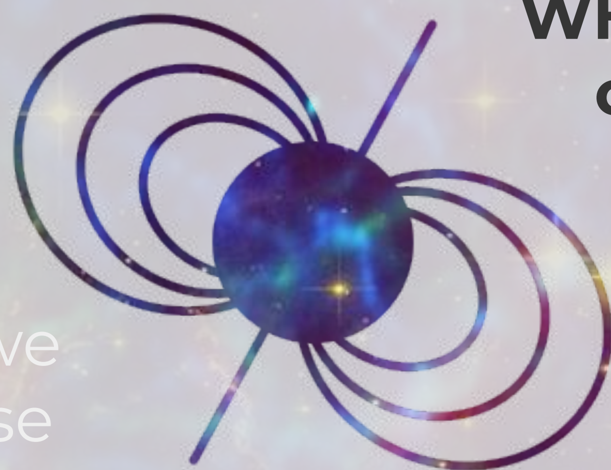


Image credit: NASA

Using X-ray observatories, we can learn about their temperatures and radii.

Neutron stars unite many extremes of physics that cannot be recreated on Earth.

WHAT are these extremes?

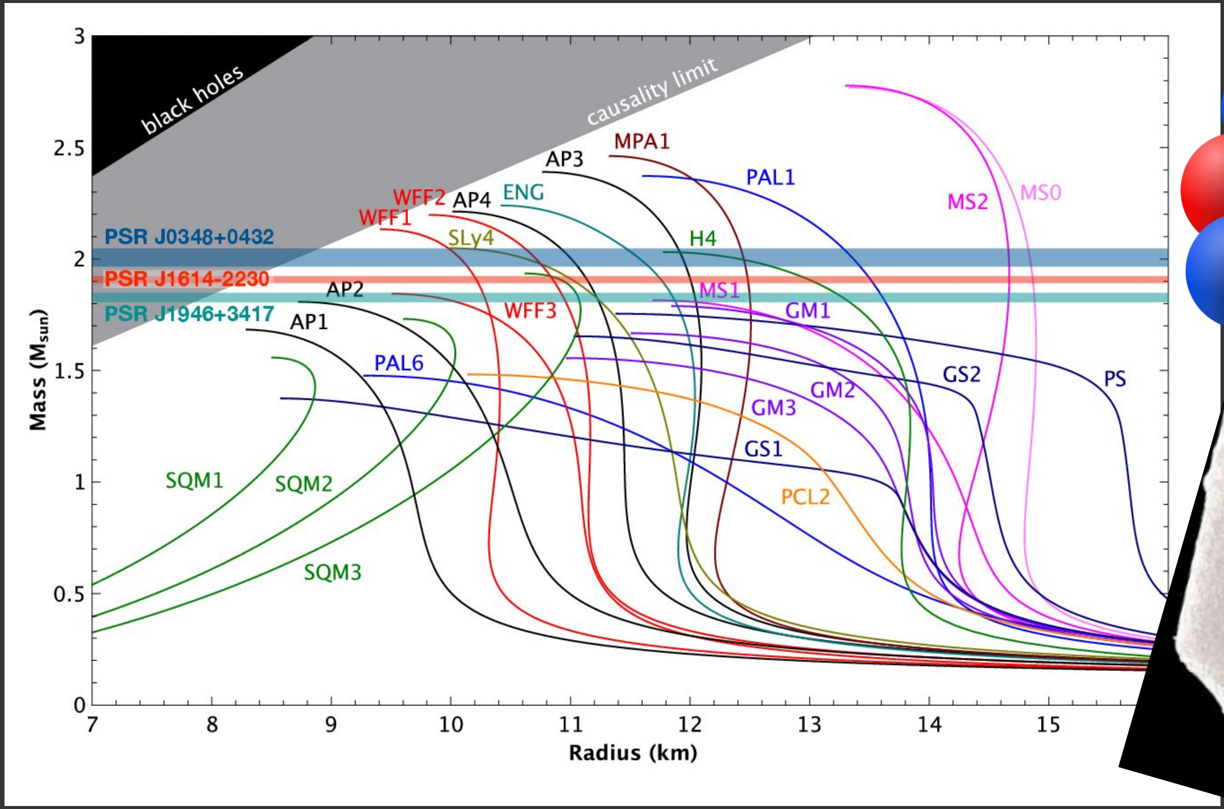


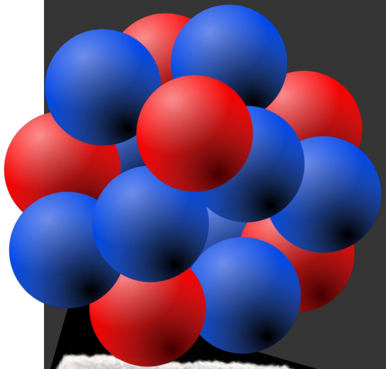
WHAT is going on in their interiors?

HOW do we know these extremes exist?

EQUATION OF STATE

Neutron star conditions are so extreme that the equation of state of matter is unknown.





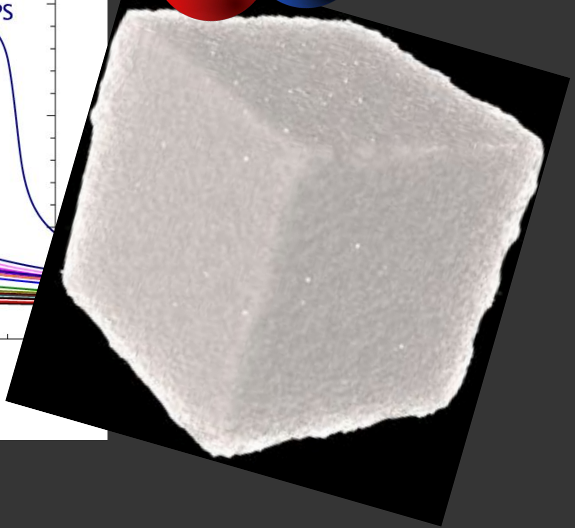


Image credit: N. Wex

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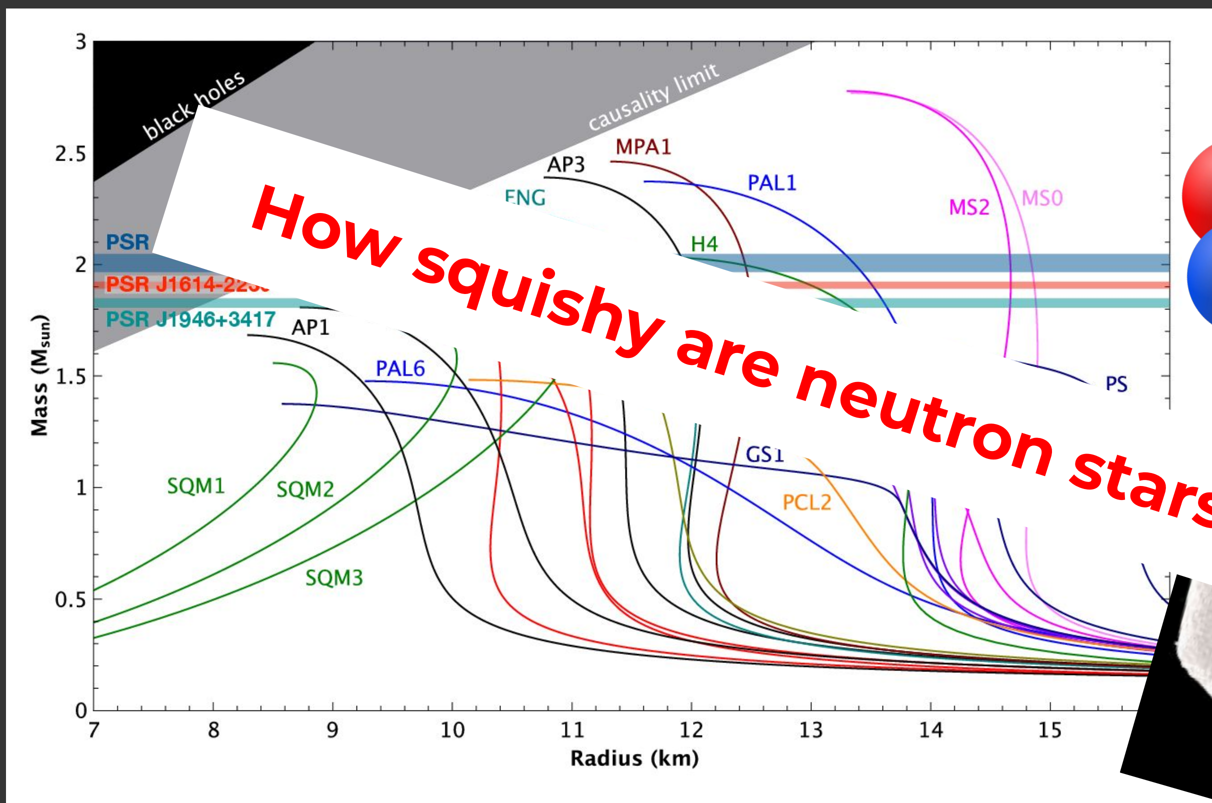
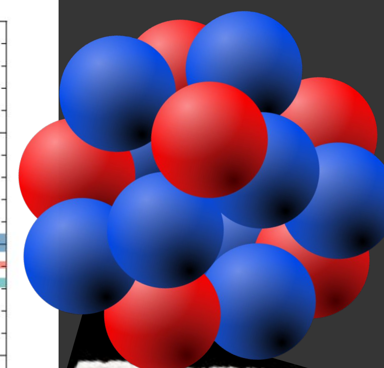
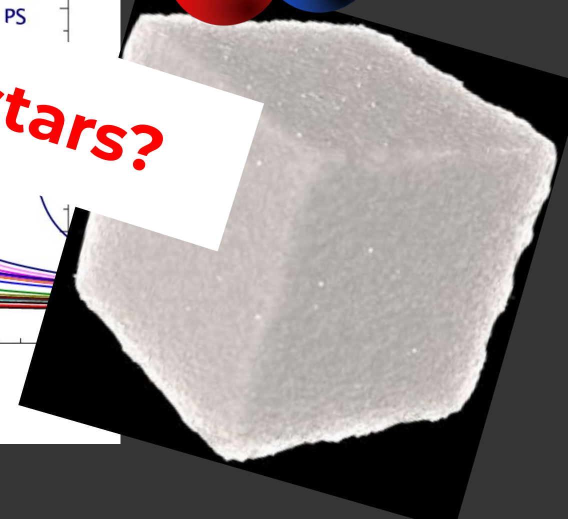


How squishy are neutron stars?





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NEUTRON STAR STRUCTURE

Like the Earth, neutron stars are composed of distinct layers.

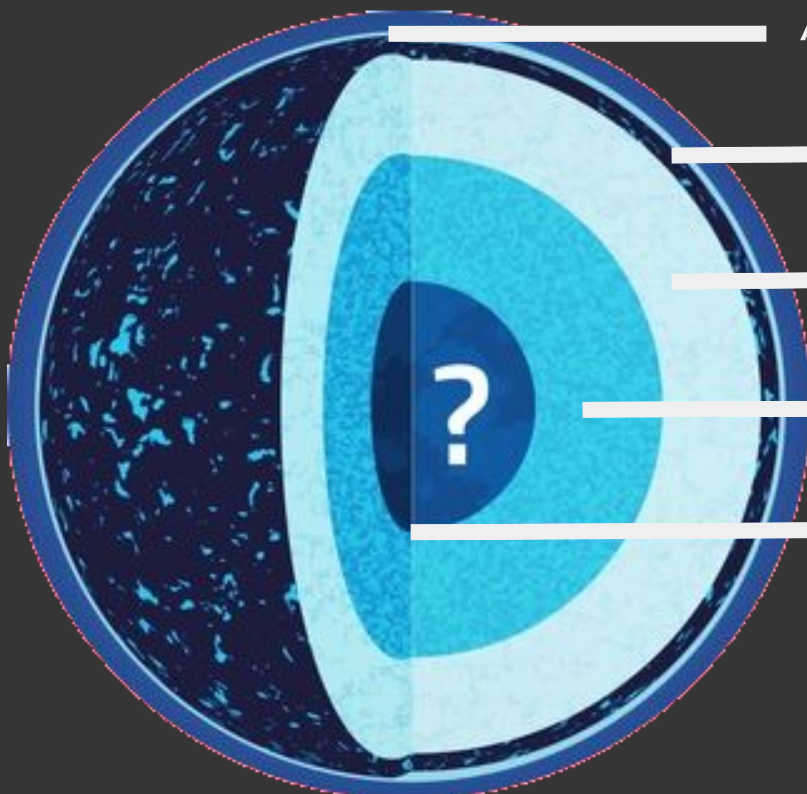

Image credit: NASA GSFC, Conceptual Image Lab

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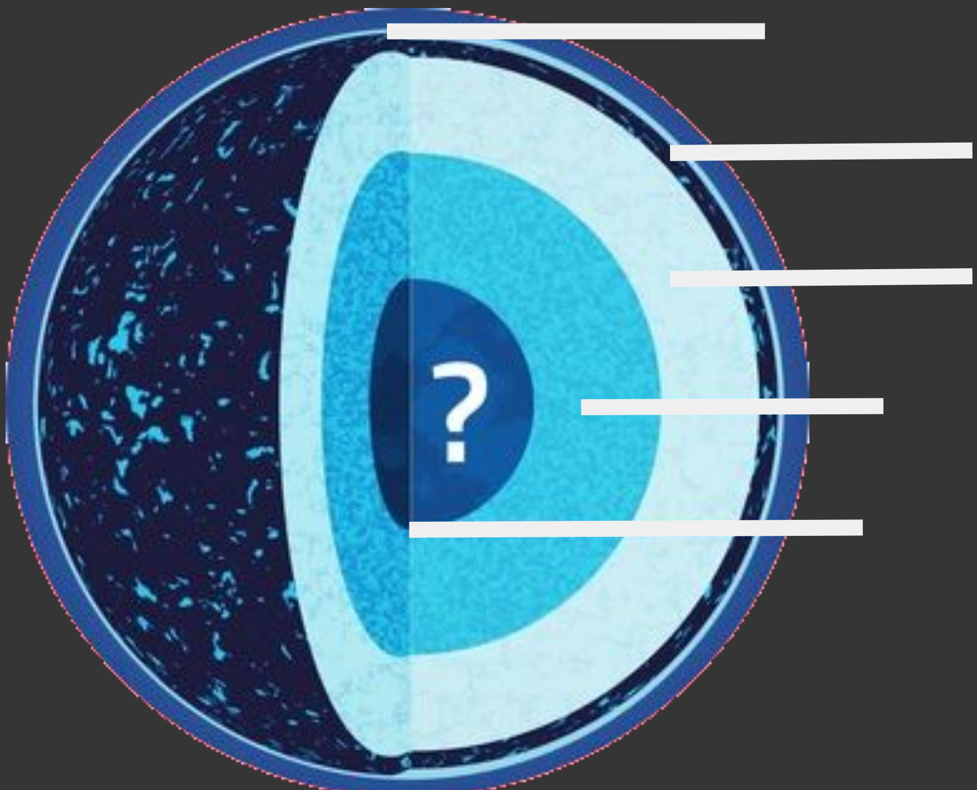


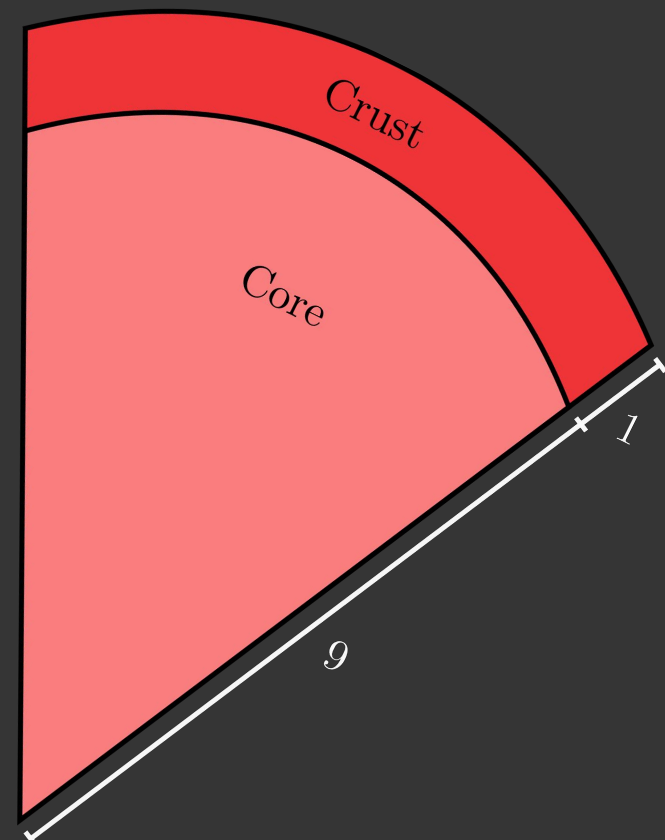
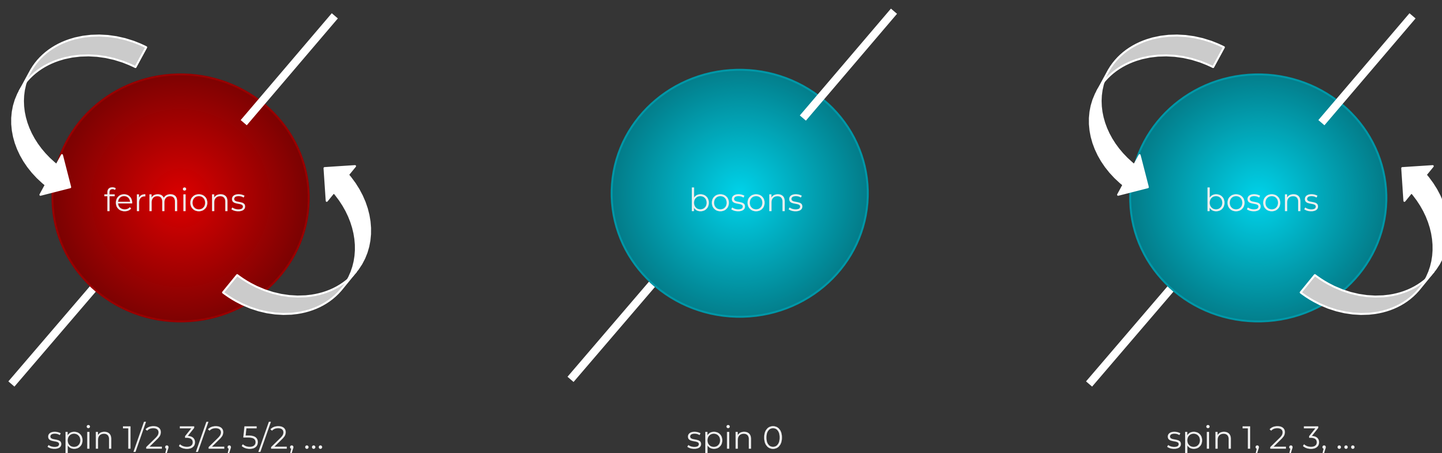


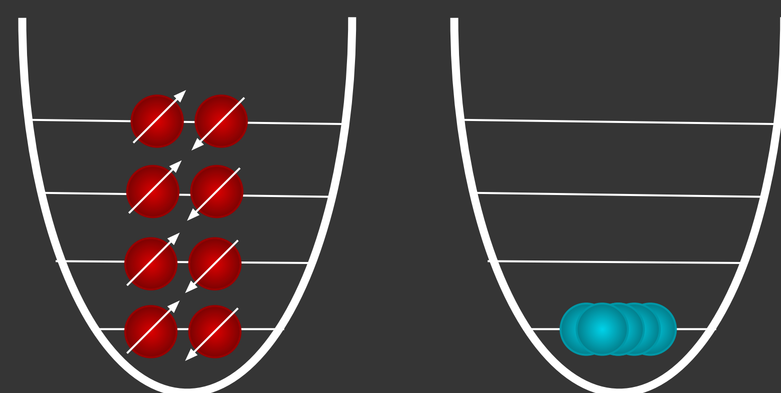
Image credit: NASA GSFC, Conceptual Image Lab

FERMIONIC PARTICLES

Neutrons, protons and electrons are fermions - elementary particles with spin 1/2.



Fermions have to obey the Pauli exclusion principle.



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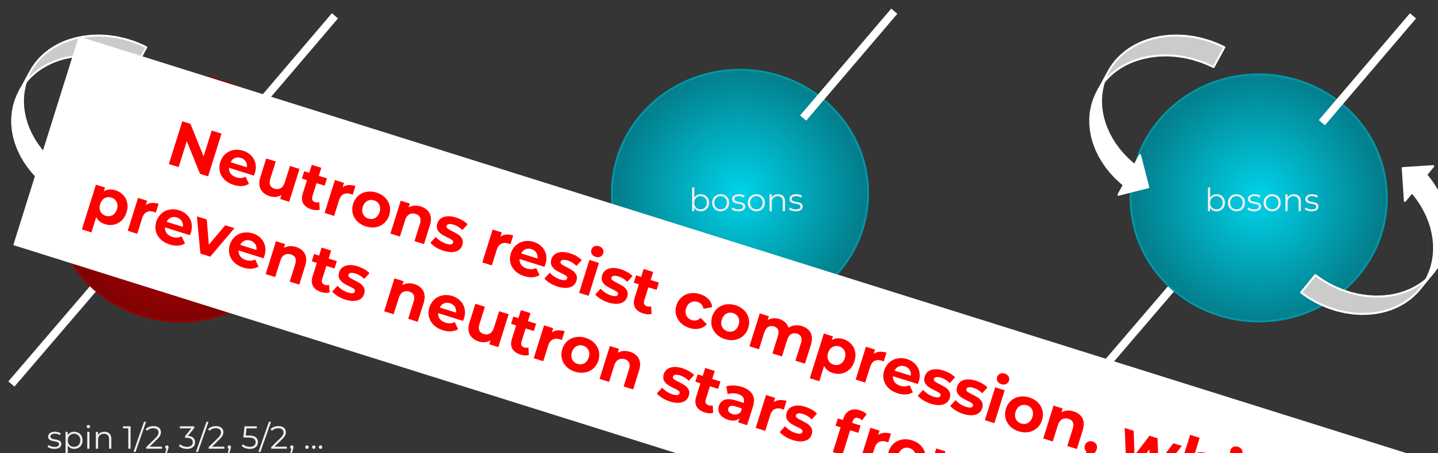
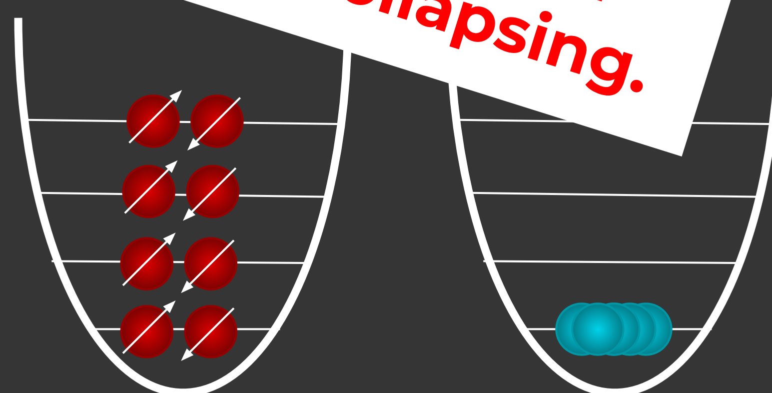


Neutrons resist compression, which prevents neutron stars from collapsing.

Fermions have to obey the Pauli exclusion principle.



PHASE TRANSITIONS

Neutron stars are cold enough to contain new quantum phases of matter.

Neutrons (protons) can form pairs and undergo phase transitions into superfluid (superconducting) states.

SUPERFLUIDITY/SUPERCONDUCTIVITY

Superfluid are fluids that flow without viscosity.

Superconductors have zero electrical resistivity and try to expel their magnetic field.

Their existence is a direct result of quantum mechanics.

Neutron stars are the largest superfluids and superconductors in the Universe.

SUPERFLUID VORTICES

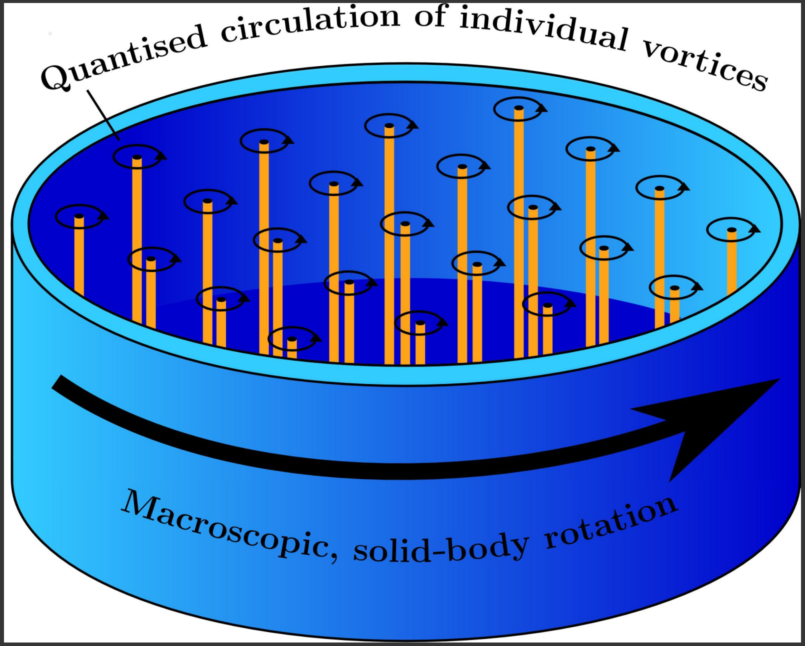
Superfluids cannot rotate like classical fluids.

Image credit: NOAA Photo Library

They have to form vortices, which can be envisaged as tiny, rapidly rotating tornadoes.

SUPERFLUID VORTICES

Each vortex carries a unit of circulation, adding up to mimic classical rotation.



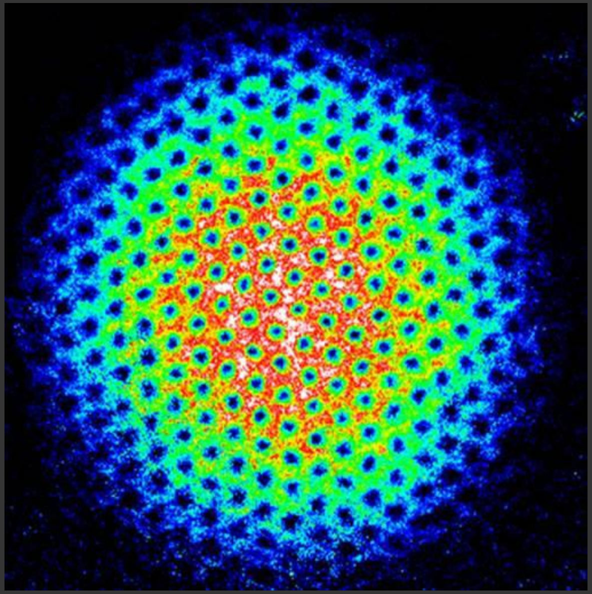


Image credit: Peter Engels, JILA

Neutron star interiors contain ~10^5 = 100,000 vortices per square centimetre.

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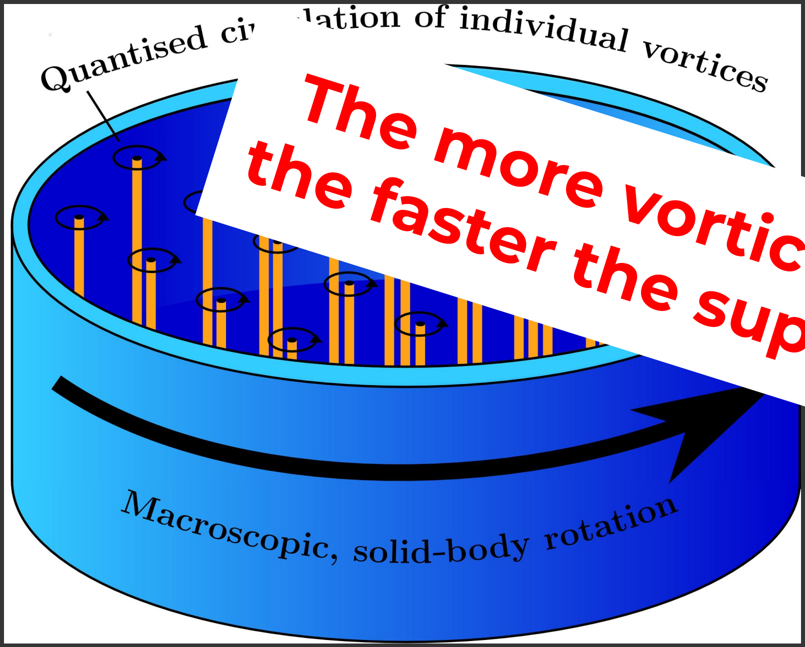


The more vortices are present, the faster the superfluid rotates.

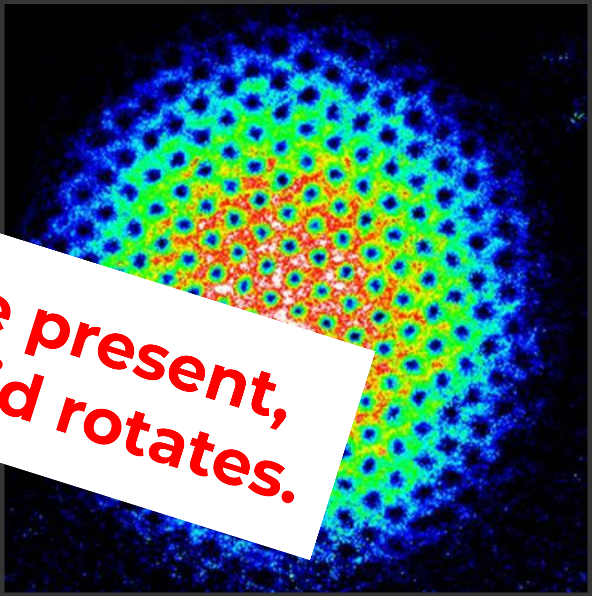


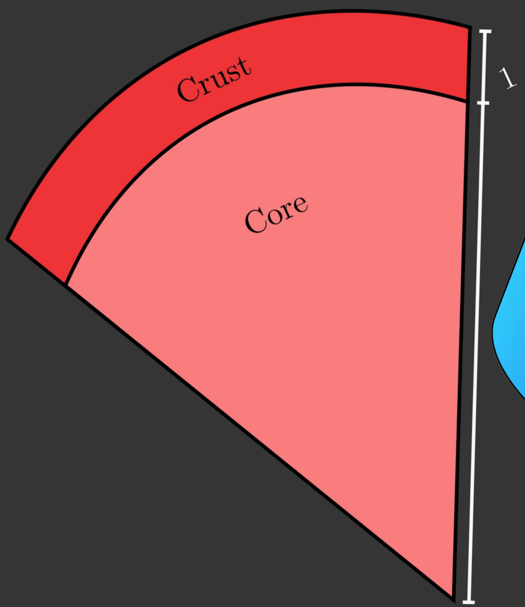
Image credit: Peter Engels, JILA

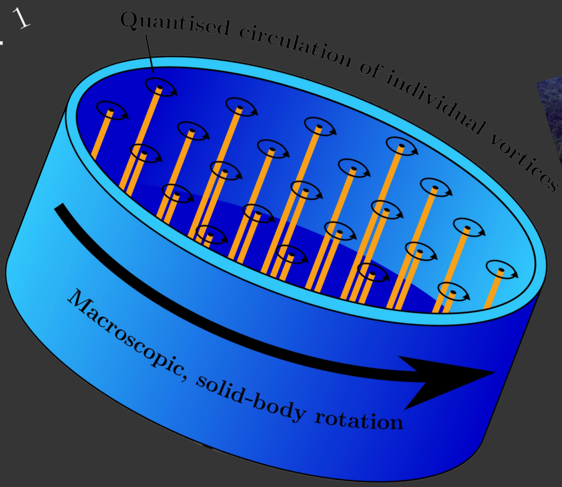
Neutron star interiors contain ~10^5 = 100,000 vortices per square centimetre.

PULSAR GLITCHES

Over a long time, the neutron star loses energy and will rotate slower and slower.

Sudden glitches interrupt the regular spin-down of pulsars.





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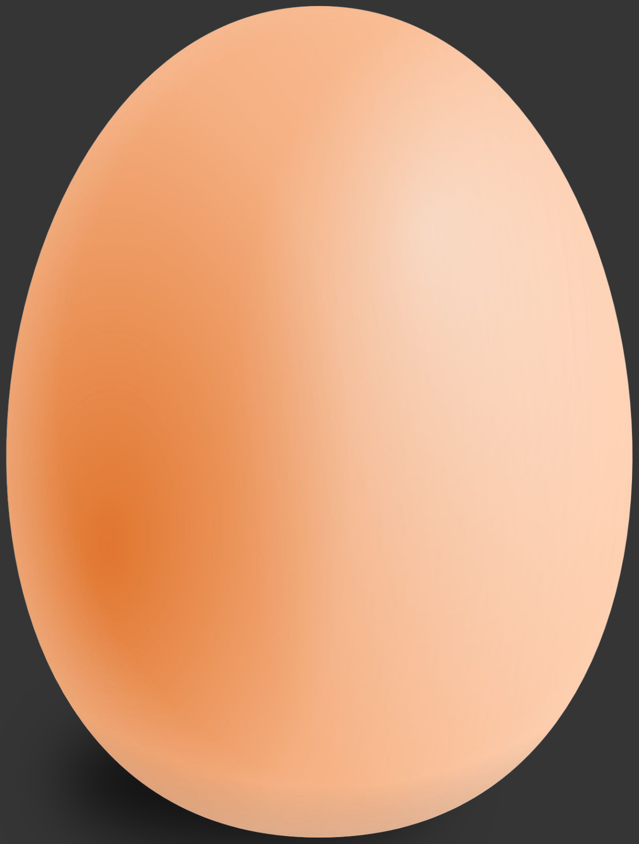
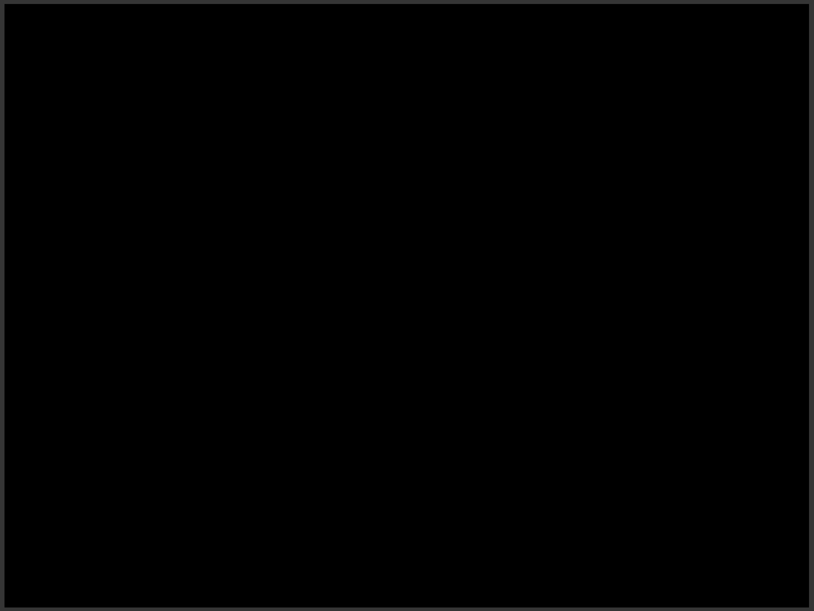


PULSAR GLITCHES

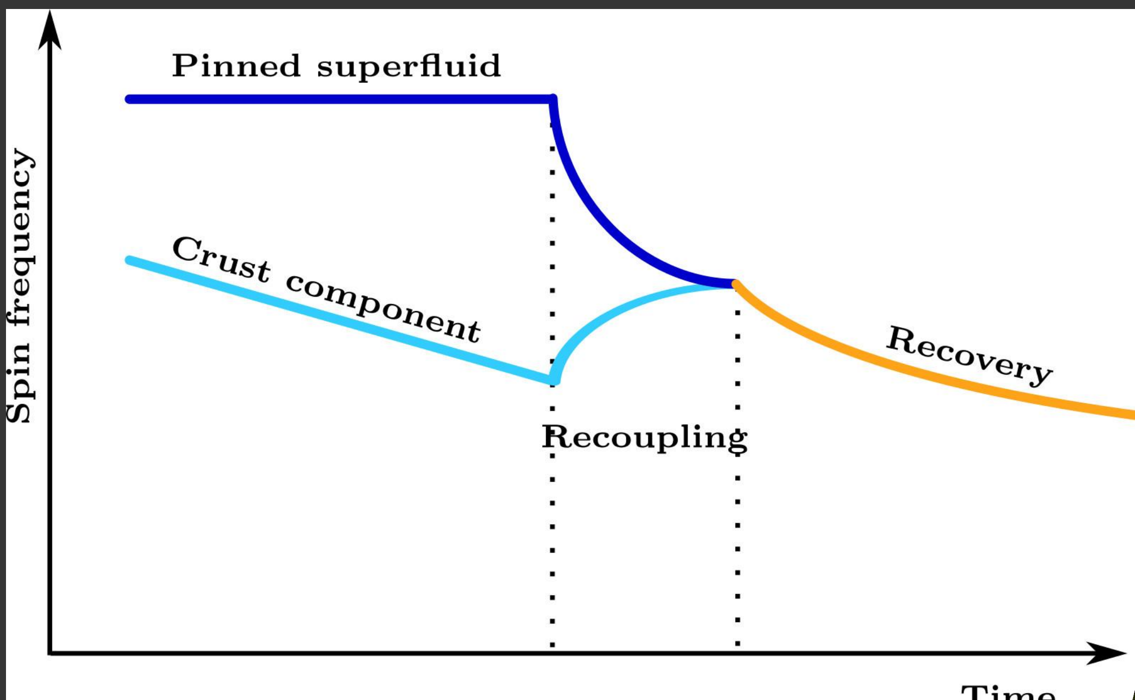
To illustrate the concept: what happens when a rotating cooked / raw egg is stopped?

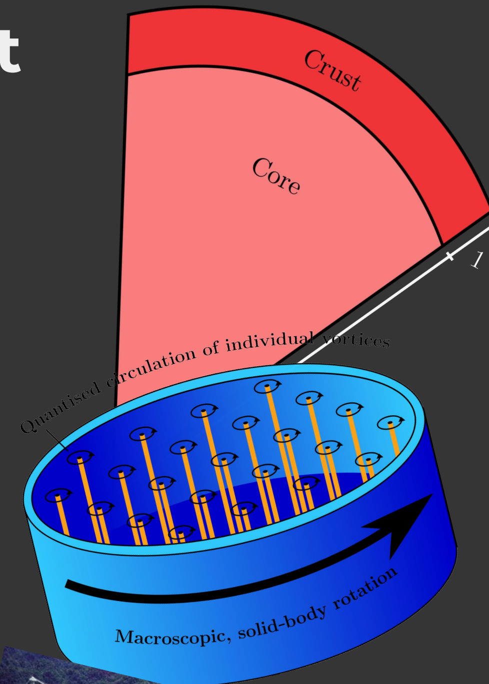


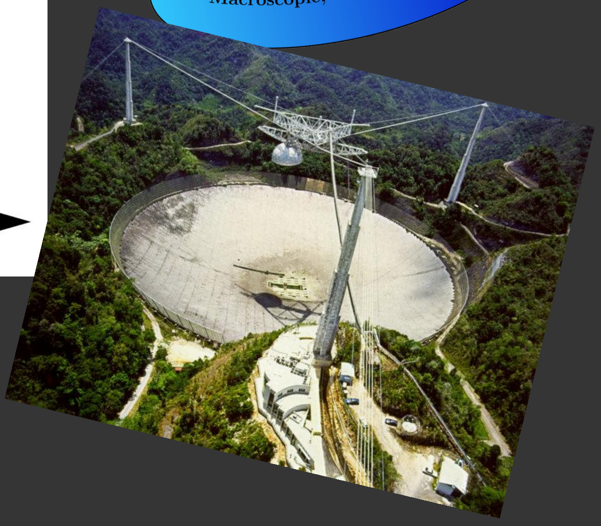
Transfer of angular momentum!

PULSAR GLITCHES

Sudden spin-ups (glitches) interrupt the regular spin-down of pulsars.



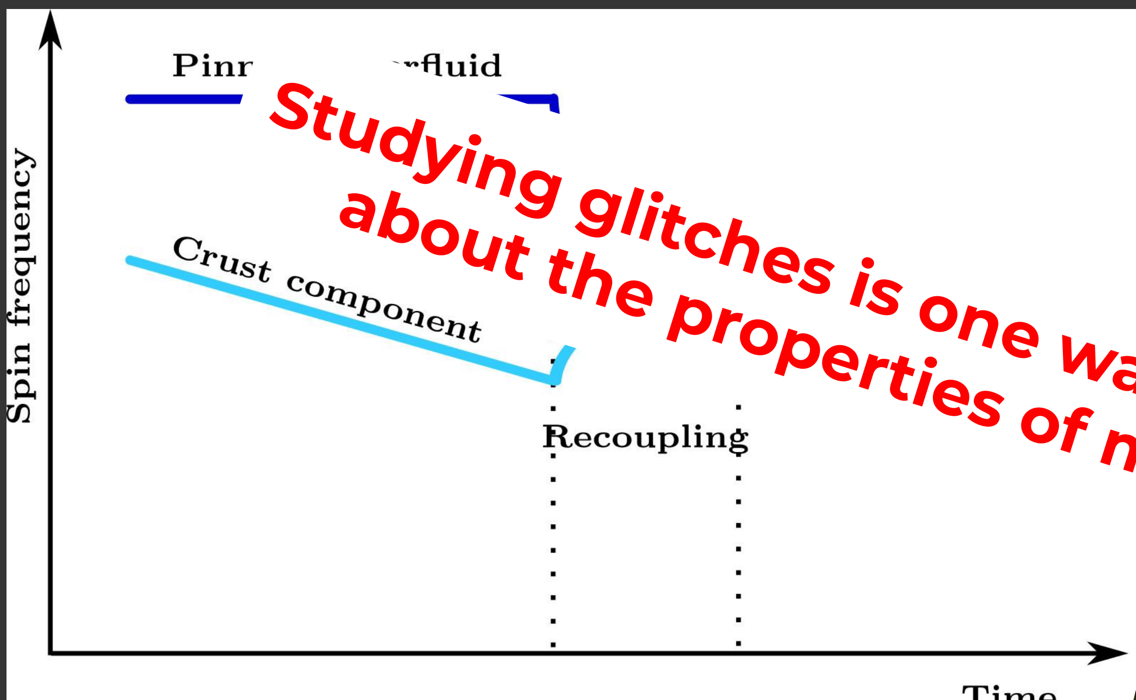


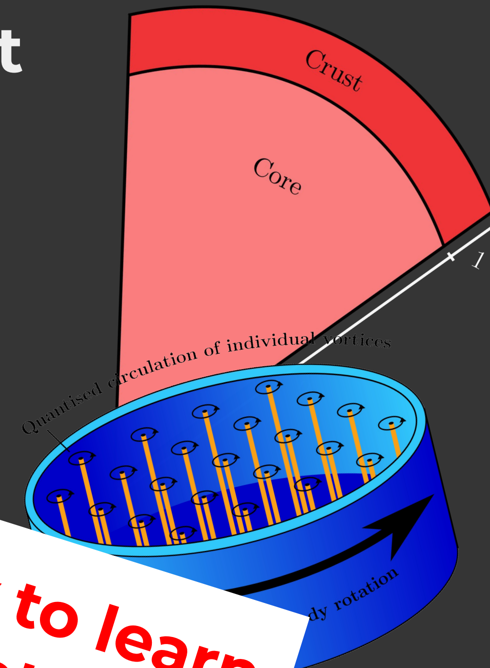


Glitches are a manifestation of quantum mechanics.

PULSAR GLITCHES

Sudden spin-ups (glitches) interrupt the regular spin-down of pulsars.



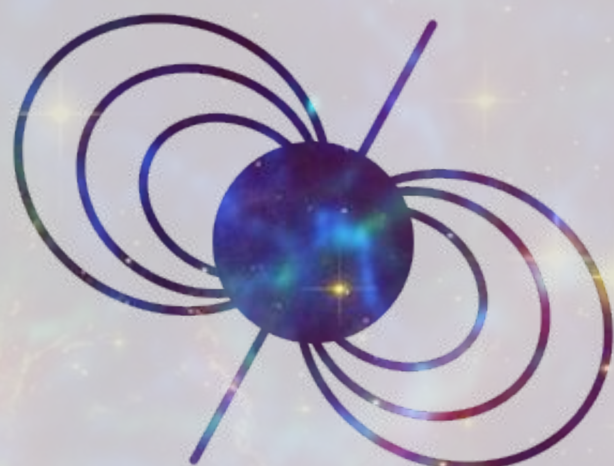


Studying glitches is one way to learn about the properties of matter.

Glitches are a manifestation of quantum mechanics.

Because neutron stars unite many extremes of physics that cannot be recreated on Earth, they are ...

GREAT COSMIC LABORATORIES!!



THANKS FOR **LISTENING.**