ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

e-Workshop 2020 – October 27-29

JcUVa

Measuring a neutron star radius from ultraviolet and X-ray observations

(González-Caniulef et al. 2019, MNRAS, 490, 5848)

Denis González-Caniulef, CITA national fellow, UBC, Canada

Sebastien Guillot, IRAP, France

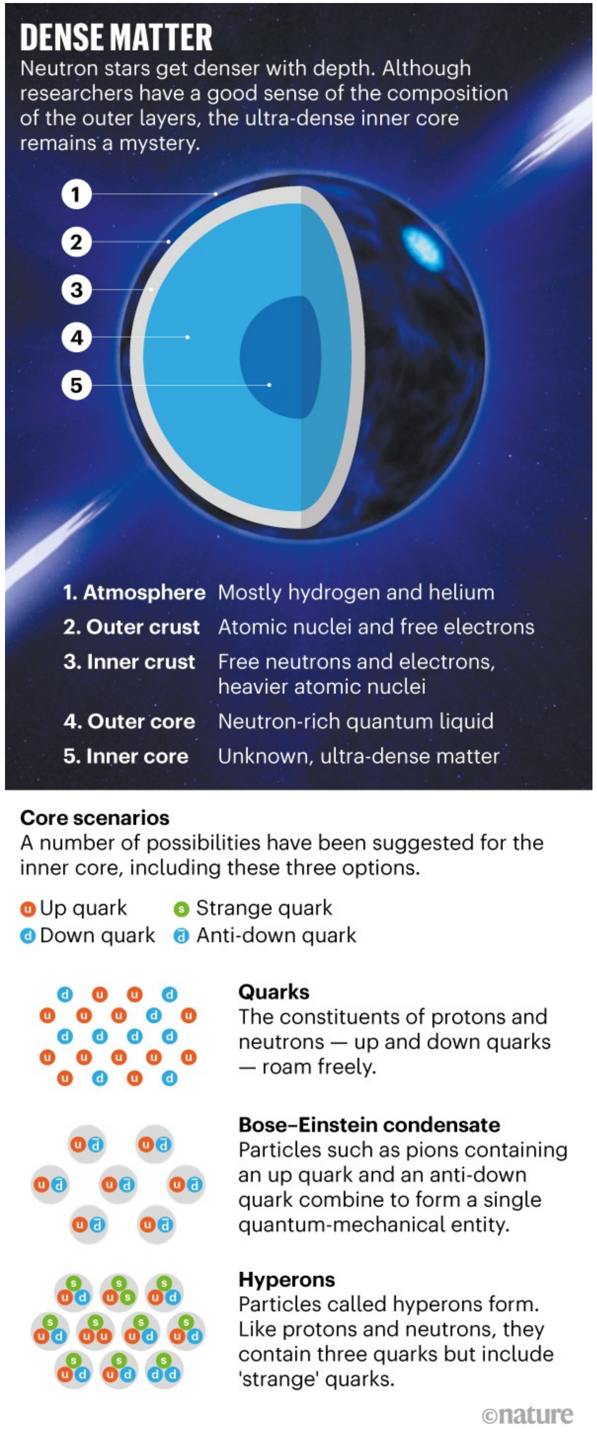
Andreas Reisenegger, Departamento de Física, UMCE, Chile

(Acknowledgements: FONDECYT Regular Projects 1171421 and 1201582)

5th Workshop of the Network for Ultraviolet Astronomy, Virtual meeting 27th – 29th October 2020

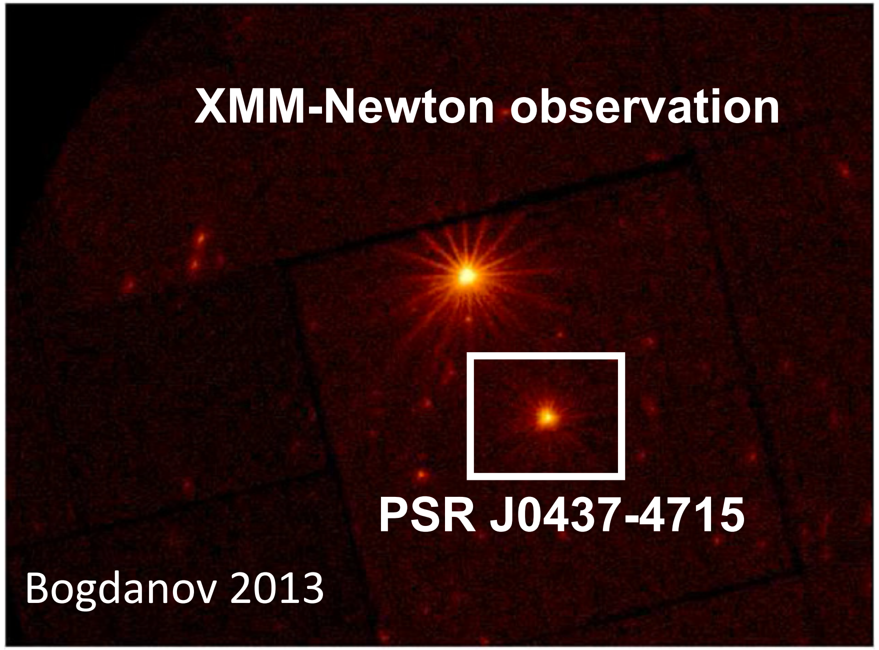
Motivation

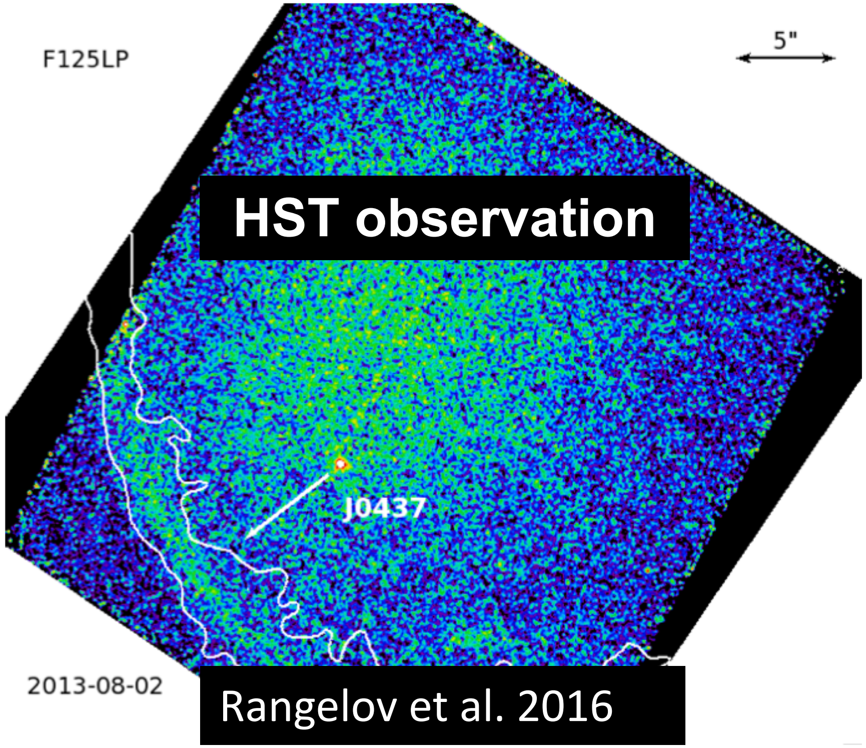
- Both from a theoretical and experimental point of view, the properties of matter at very high densities, above the nuclear saturation density $\rho_0 = 3 \cdot 10^{14}\ \mathrm{g\ cm^{-3}}$, are highly unknown.
- The density in the interior of neutron stars can exceed several times ρ_0. Therefore, they are unique laboratories to study matter in extreme conditions.
- Radius and mass measurements of neutron stars can allow us both to infer the equation of state (EOS) of super-dense matter and to establish constraints on fundamental physics.
- Different techniques have been proposed to determine radii and masses of neutron stars. We performed spectral fits to the emission from the surface of the millisecond pulsar PSR J0437-4715, in order to measure its radius [1].



Millisecond Pulsars

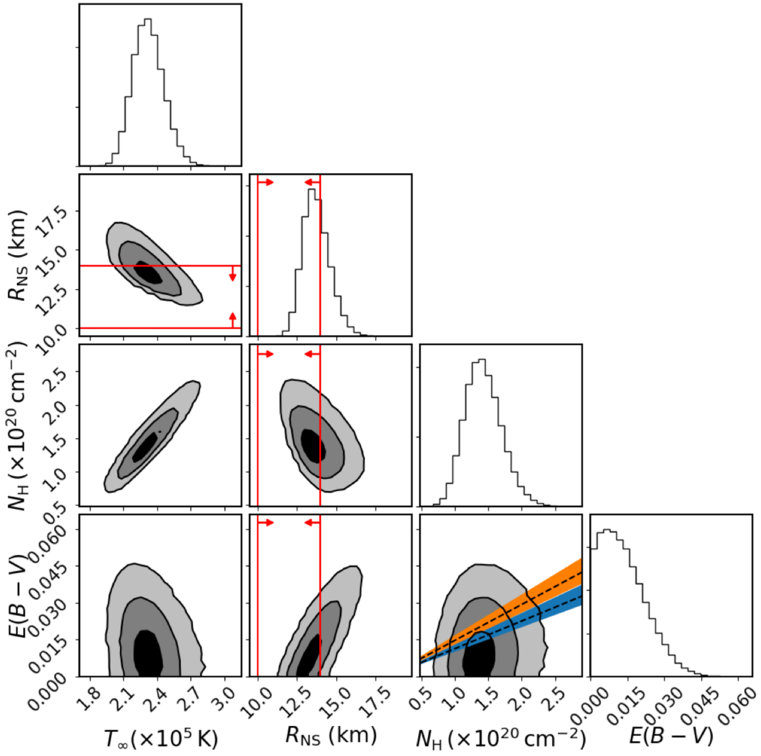
- Millisecond pulsars (MSPs) are fast spinning neutron stars, with typical periods of few millisecond.
- They are thought to have been spun up by accretion of matter from a binary companion.
- PSR J0437-4715 is the brightest and nearest millisecond pulsar, at a well-measured distance $\boldsymbol{d = 156.79 \pm 0.25\ \mathrm{pc}}$ [2]. In addition, this MSP is in a binary system (with a white dwarf companion), which has allowed to measure its mass with high precision: $\boldsymbol{M = 1.44 \pm 0.07\ M_\odot}$ [3]
- Ultraviolet and X-ray observations have revealed thermal emission from the entire surface of PSR J0437-4715 [4,5].

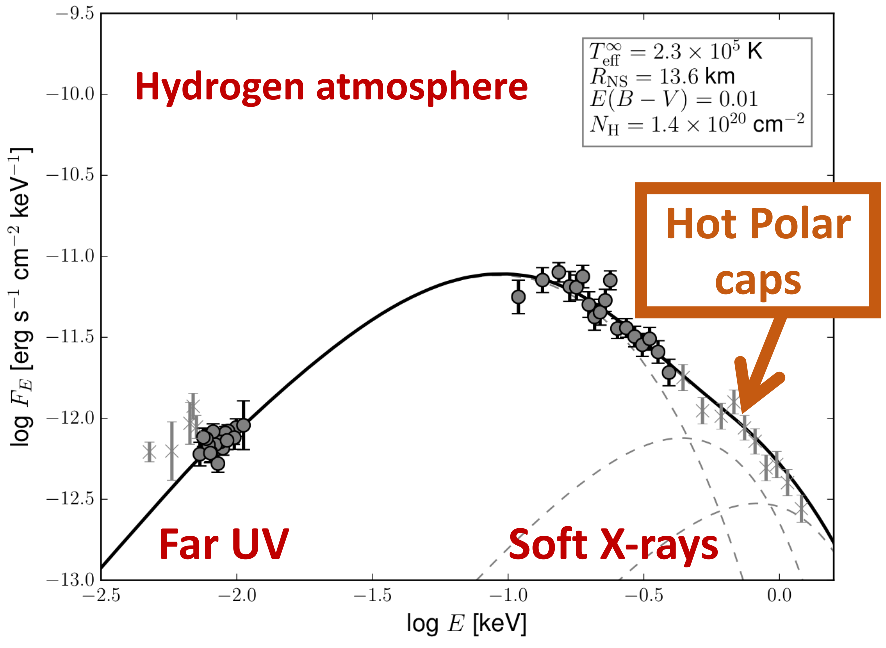




Spectral fit PSR J0437-4715

- We modelled the cool thermal component observed in the UV (HST [4]) and soft X-rays (ROSAT [5]), considering realistic atmosphere models of neutron stars for H, He, Fe composition, as well as blackbody emission
- We perform a MCMC analysis considering four parameters: radius, temperature, dust extinction, and neutral hydrogen column density.
- We found that a ***hydrogen atmosphere*** yields the best spectral fits.
- By considering a prior in the dust extinction, based on 2D and 3D maps of galactic dust, we measure a neutron star radius $\boldsymbol{R = 13.6 \pm 0.9\ \mathrm{km}}$

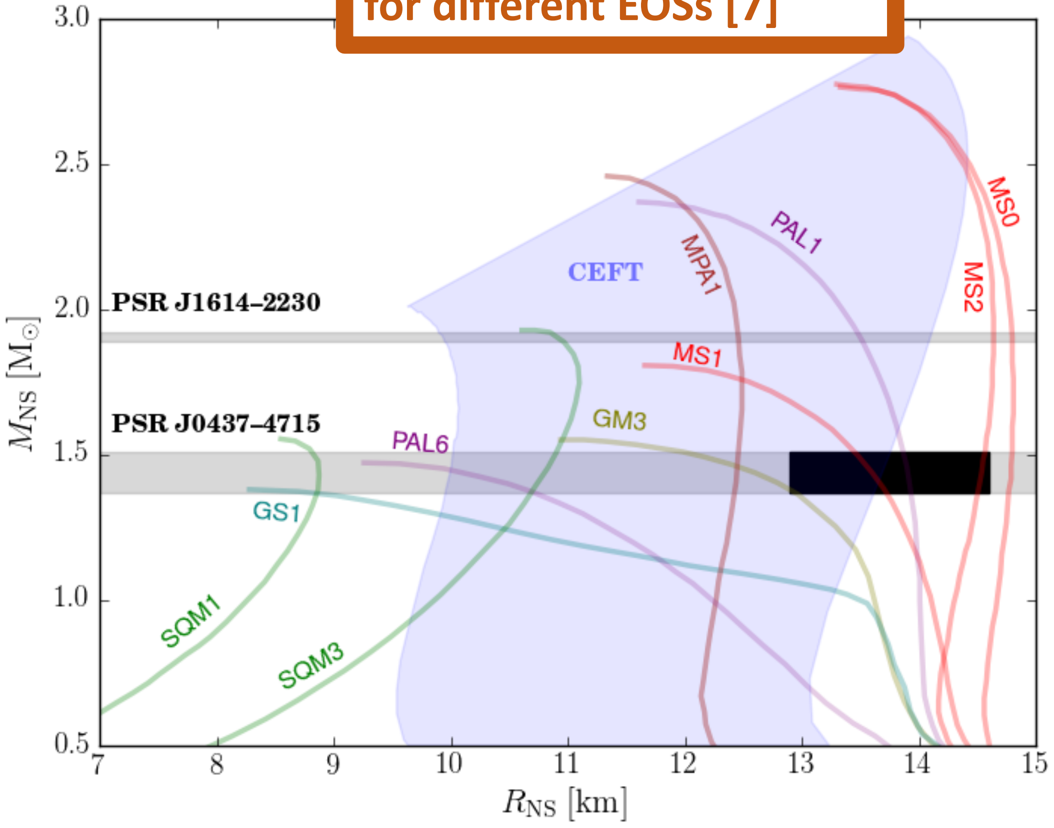




Conclusions and future prospects

- The radius measurement for PSR J0437-4715, combined with its well-measured mass, allows us to establish one of the tightest constraints on the EOS for ultra-dense matter to date.
- Our results, combined with the largest measured masses for a pulsar (PSR J1614-2230 [6]), favour a stiff EOS and disfavour a strange quark composition inside neutron stars.
- This research demonstrates that ***combined ultraviolet and X-ray observations*** of neutron stars can allow us to study the properties super-dense matter in conditions that cannot be reproduce by terrestrial laboratories. Future observations of neutron stars will help us to establish further constraints on the EOS. Currently, only HST has the required capabilities to observe this kind of sources in the far ultraviolet.

Radius and mass relation for different EOSs [7]



Bibliography

[1] *González-Caniulef, Guillot, and Reisenegger 2019, MNRAS, 490, 5848*

[2] *Deller, Verbiest, Tingay, and Bailes, 2008, ApJL, 685, L67*

[3] *Reardon, et al., 2016, MNRAS, 455, 1751*

[4] *Durant, et al., 2012, ApJ, 746, 6*

[5] *Guillot, et al., 2016, MNRAS, 463, 2612*

[6] *Arzoumanian, et al., 2018, ApJS, 235, 37*

[7] *Lattimer and Prakash, 2001, ApJ, 550, 426*