Lifting systematic biases in neutron star quiescent LMXBs with NewAthena to constrain the dense matter equation of state

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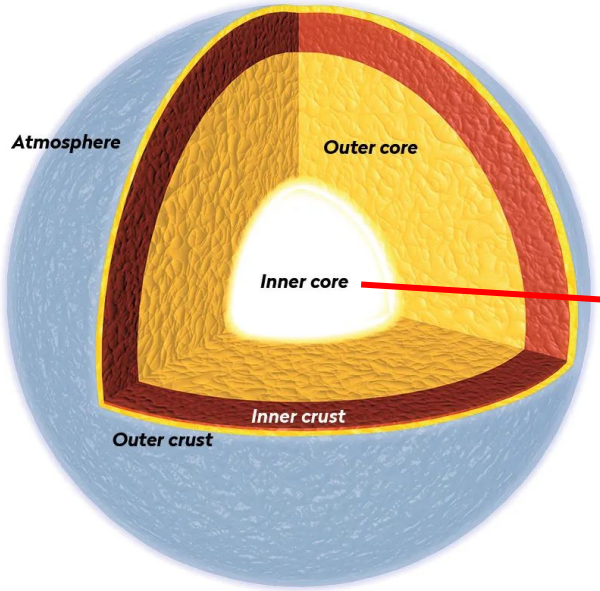
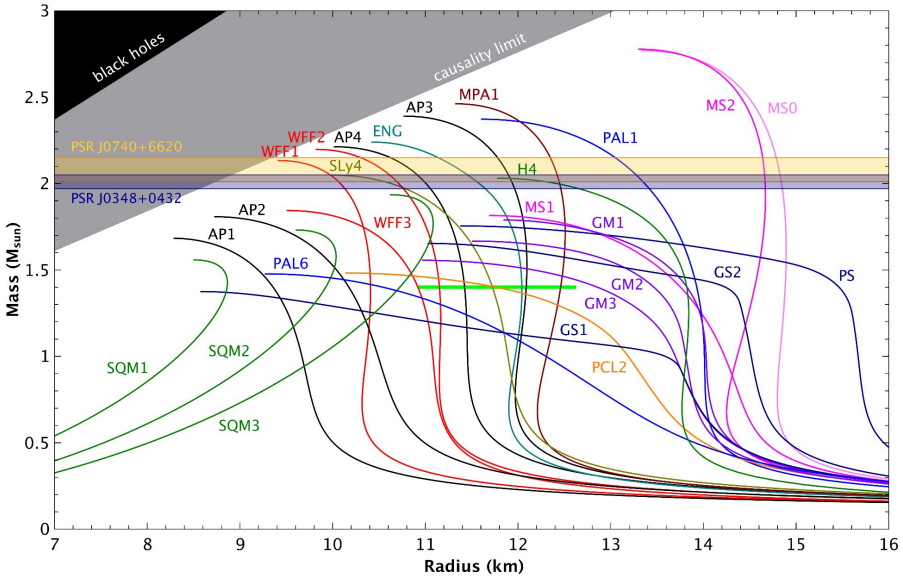
IRAP, Toulouse, France

SWG4 workshop, June 5th 2026

The dense matter Equation of State (EOS)



Credit: Paul Wootton



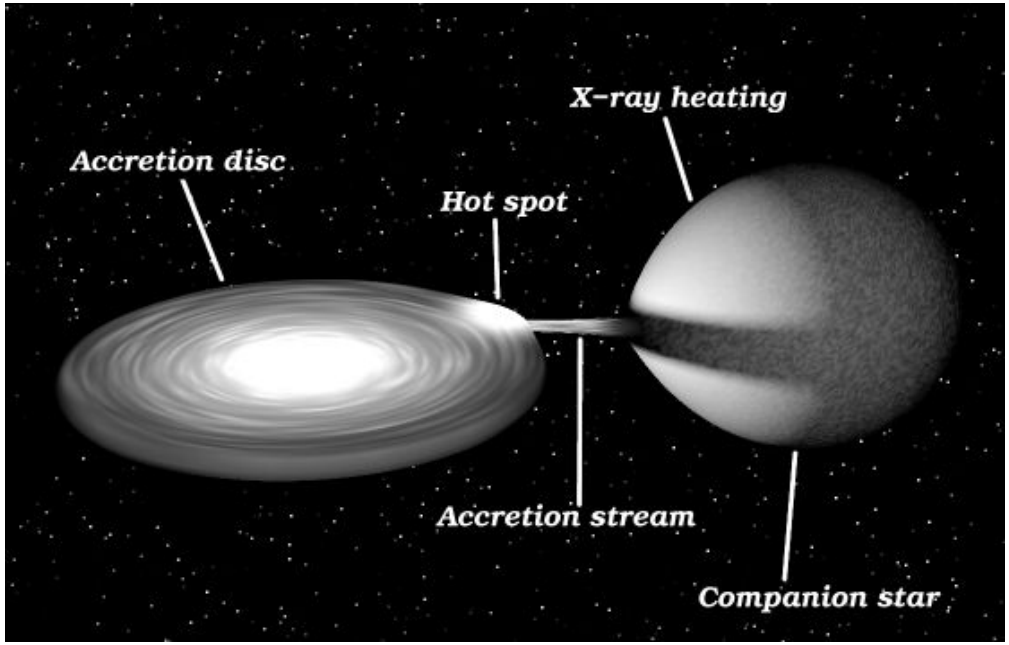
Credit: Norbert Wex

Quiescent Low-Mass X-ray Binaries (qLMXBs)

- radio emission ❌, X-rays ✅.

  accretion outburst ⇒ X-ray bright disk

  no accretion ⇒ **quiescence**, thermal emission from the NS surface



Credit: R. Hynes

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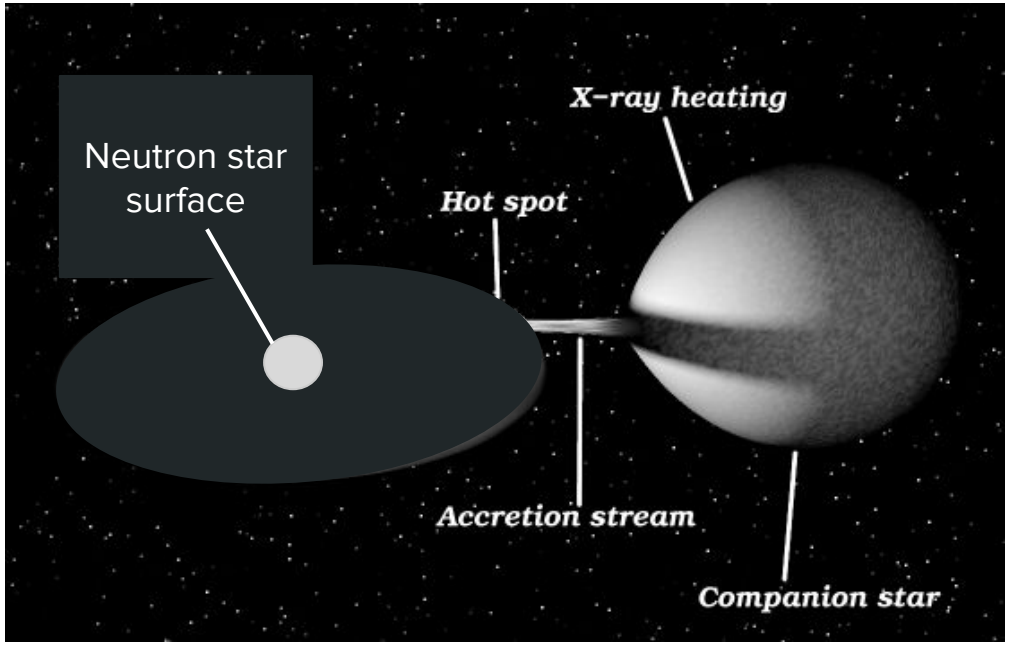


Credit: R. Hynes

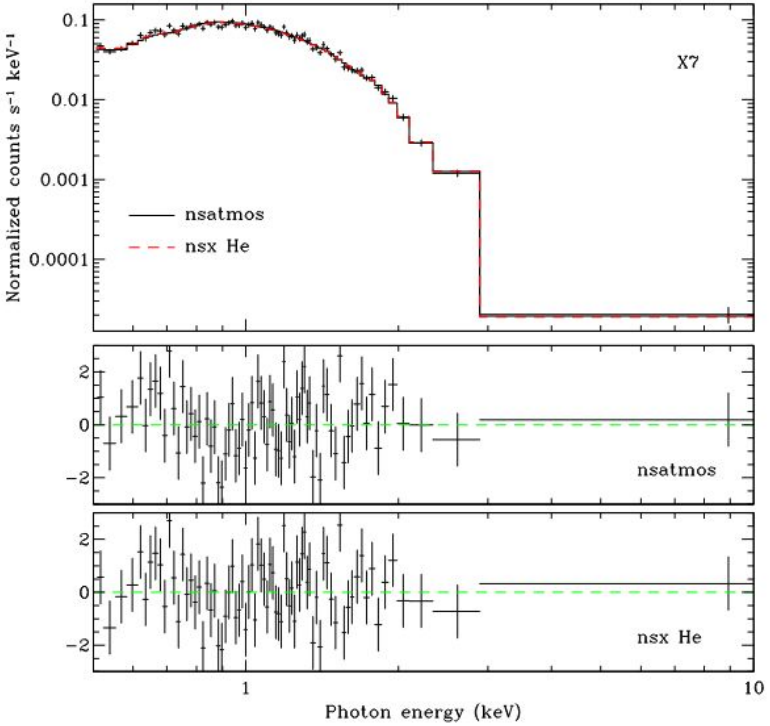
Radius measurements in qLMXBs

Uniform emission from the surface

➔ fit of T_{eff} and $F_X \propto (R_\infty/d)^2$

$$R_\infty = R_{NS}(1+z) = R_{NS}\left(1 - \frac{2GM_{NS}}{R_{NS}c^2}\right)^{-0.5}$$

↪ degeneracy between M and R



Bogdanov et al. 2016

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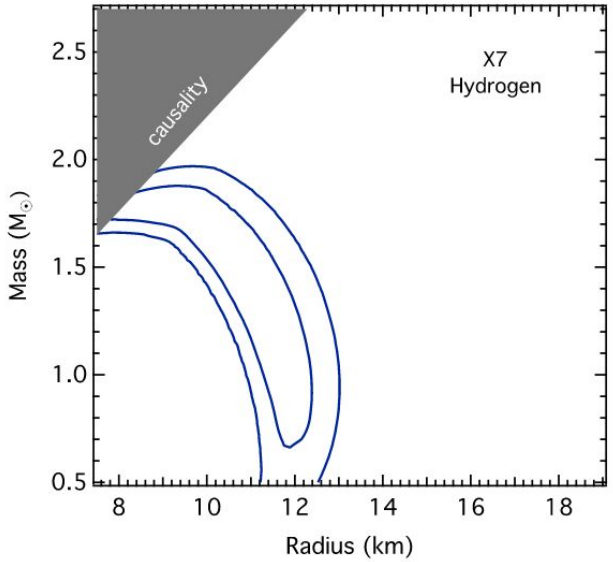
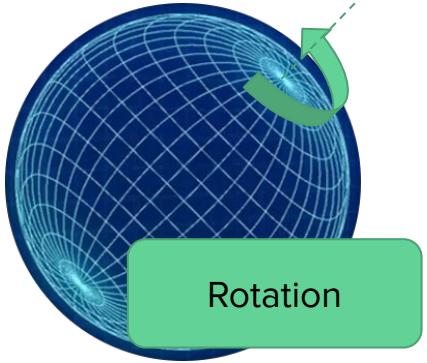


Bogdanov et al. 2016

Sources of biases in radius measurements



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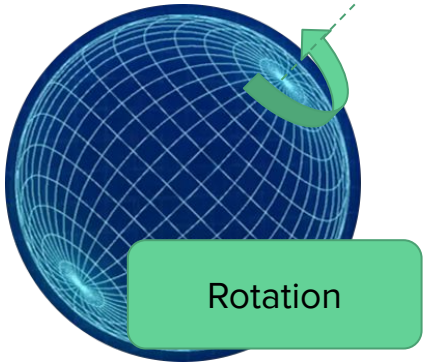

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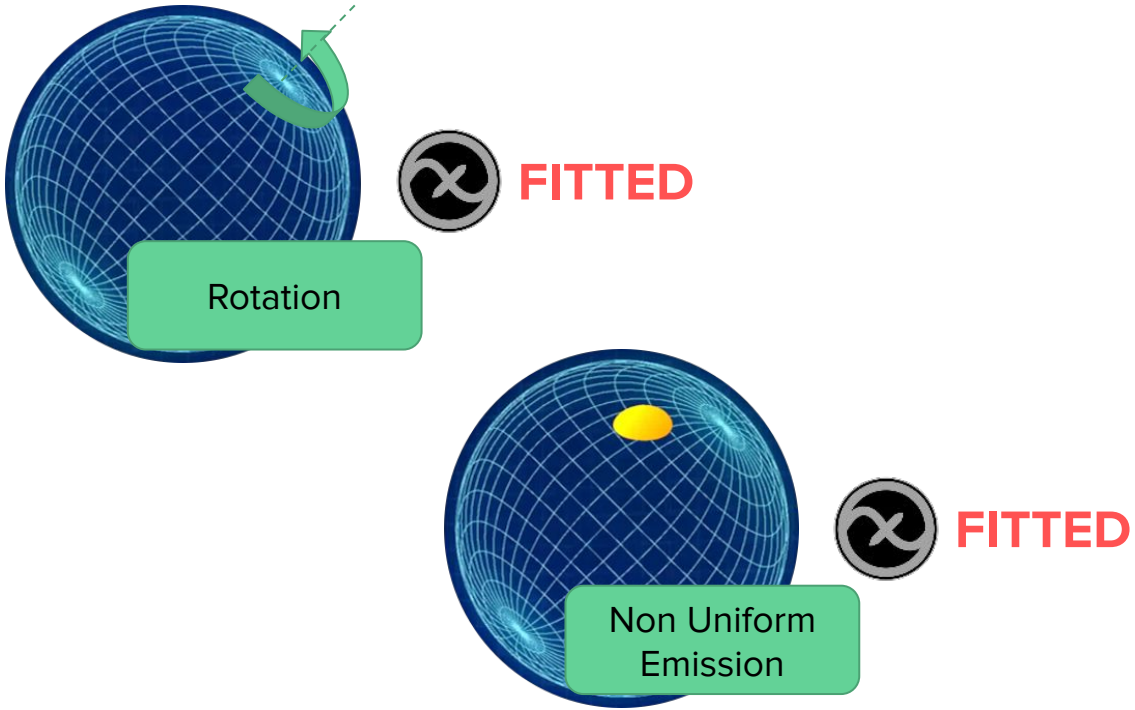

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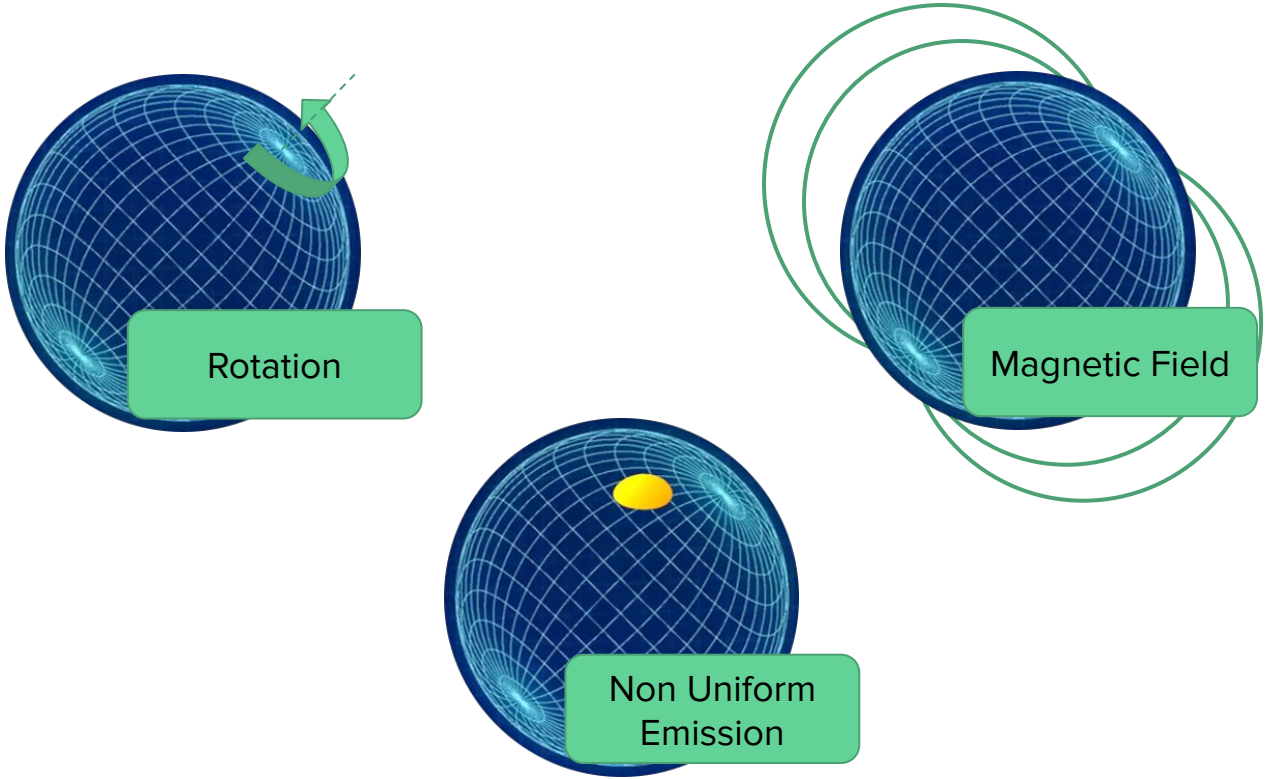

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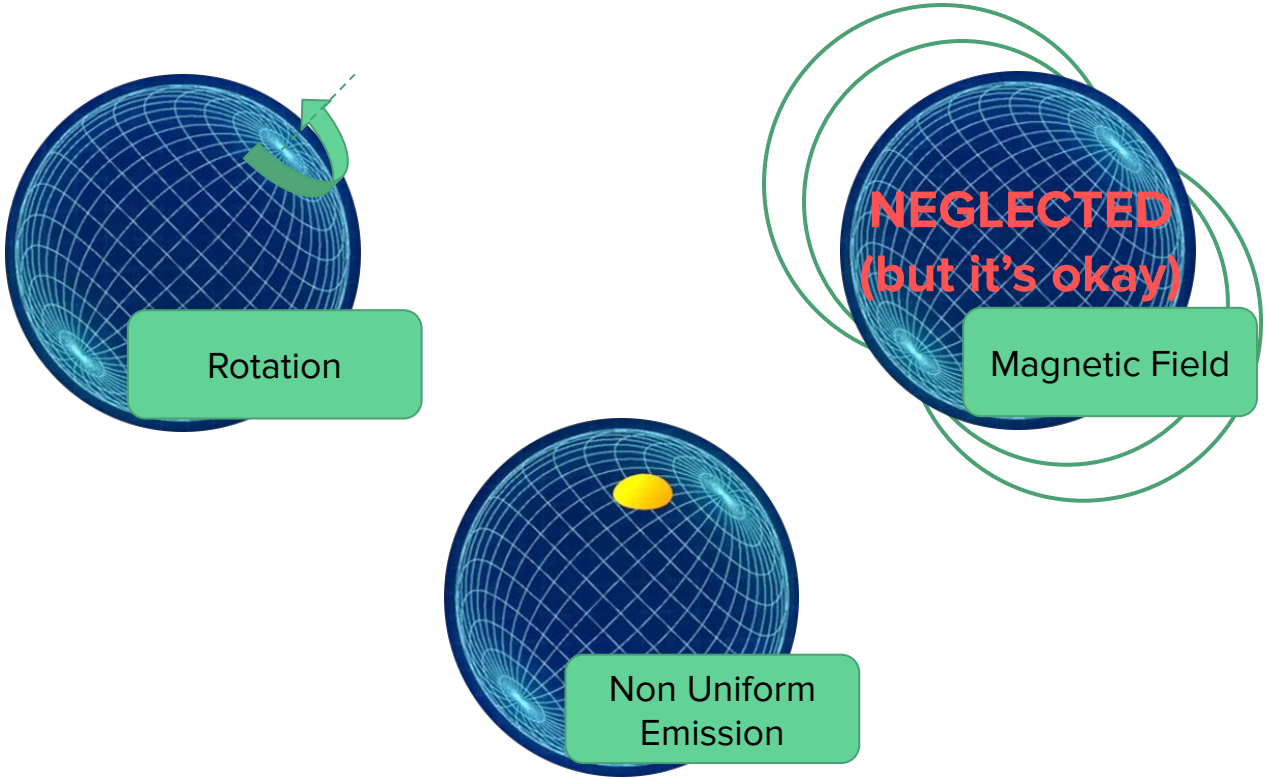

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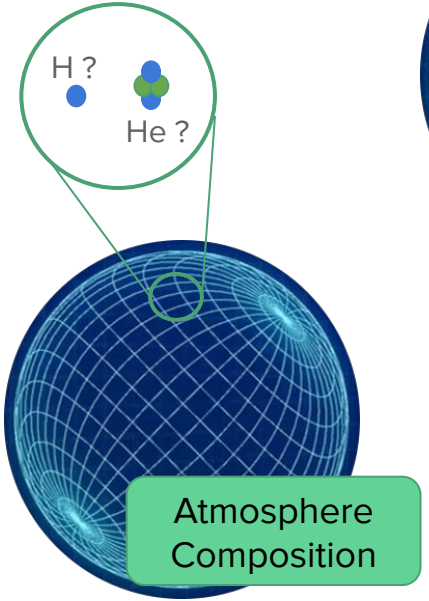

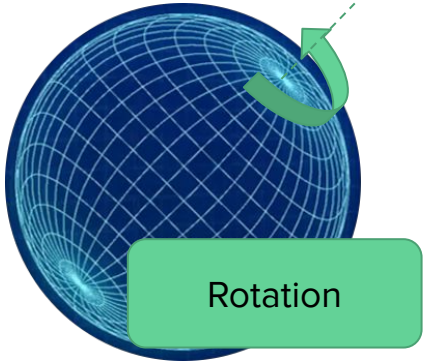

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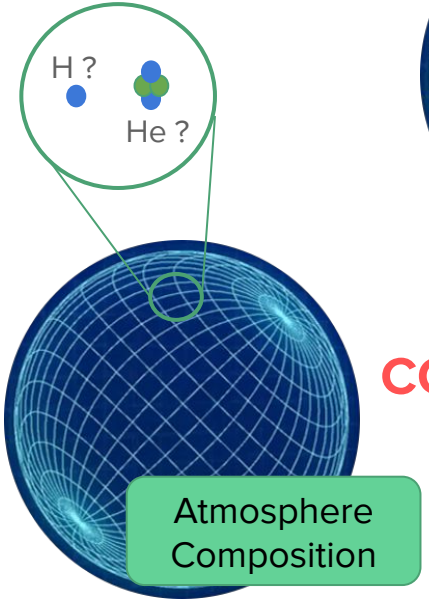

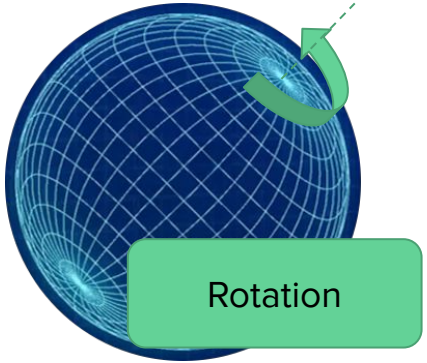

COMPANION STAR

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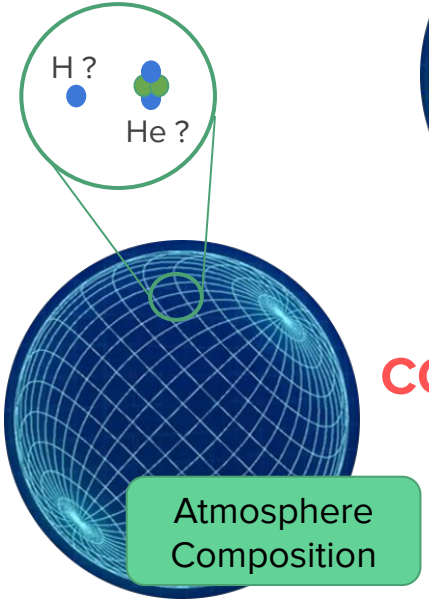

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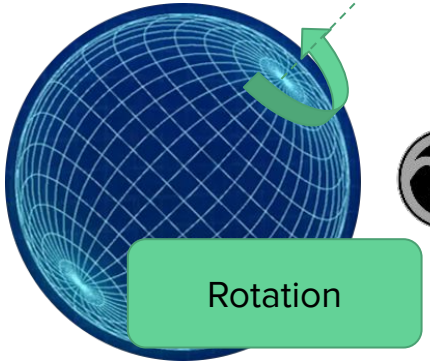

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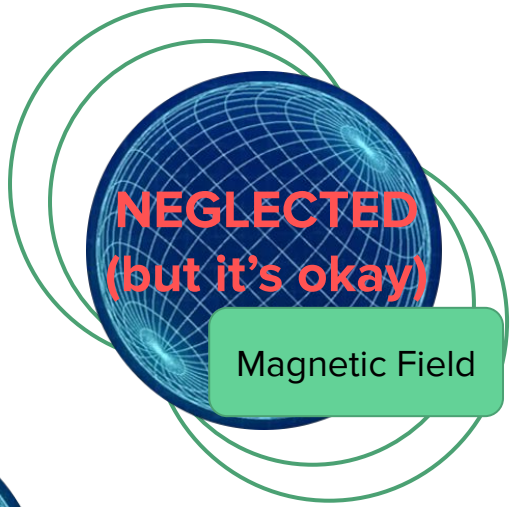

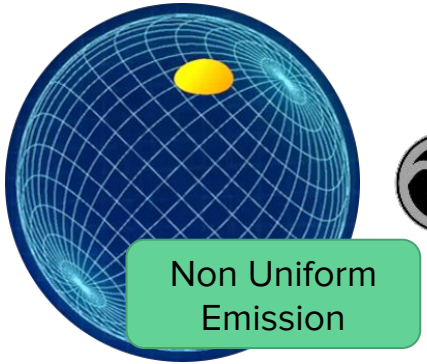

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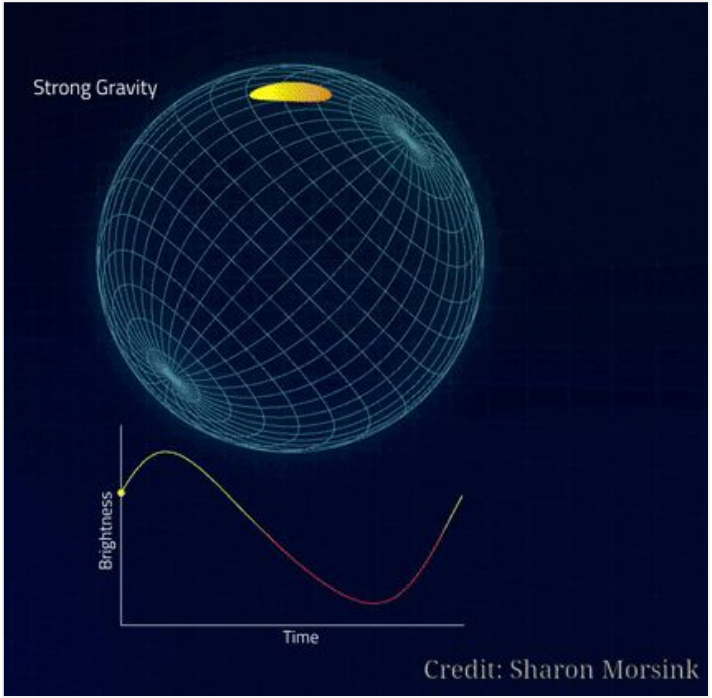
X-ray Pulse Simulation and Inference (X-PSI)

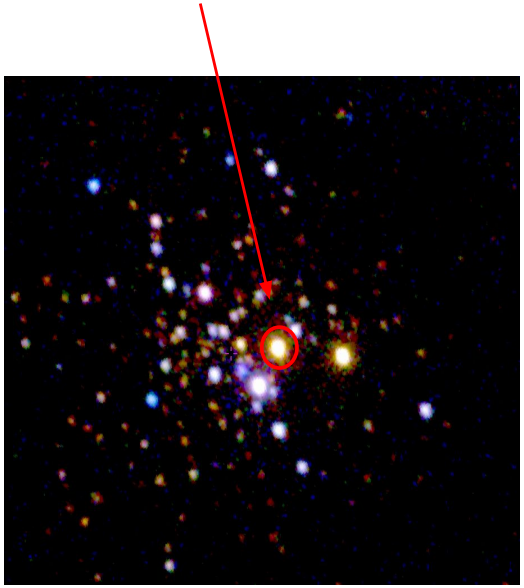
simulation of surface X-ray emission from rotating neutron stars

- ✅ Bayesian inference to infer M,R..
- ✅ rotation effects: Doppler, oblateness
- ✅ gravity: Schwarzschild spacetime



Application to 47Tuc - X7

- highest X-ray flux from a globular cluster qLMXB
- 560 ks of Chandra observation



from ESASky, Chandra image

Application to 47Tuc - X7

- highest X-ray flux from a globular cluster qLMXB
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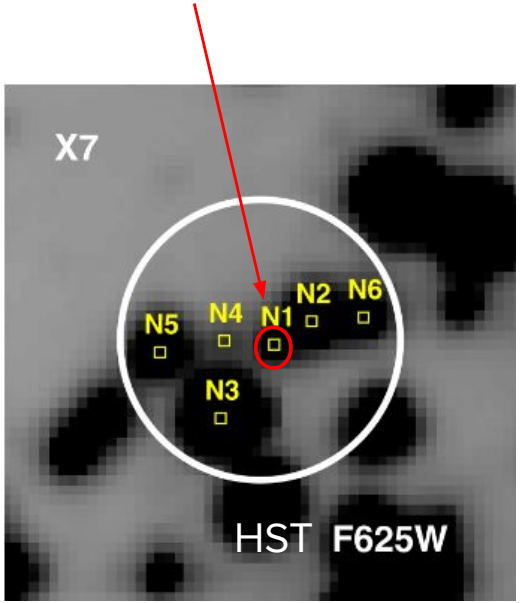
- atmosphere model : Hydrogen



van den Berg+2024

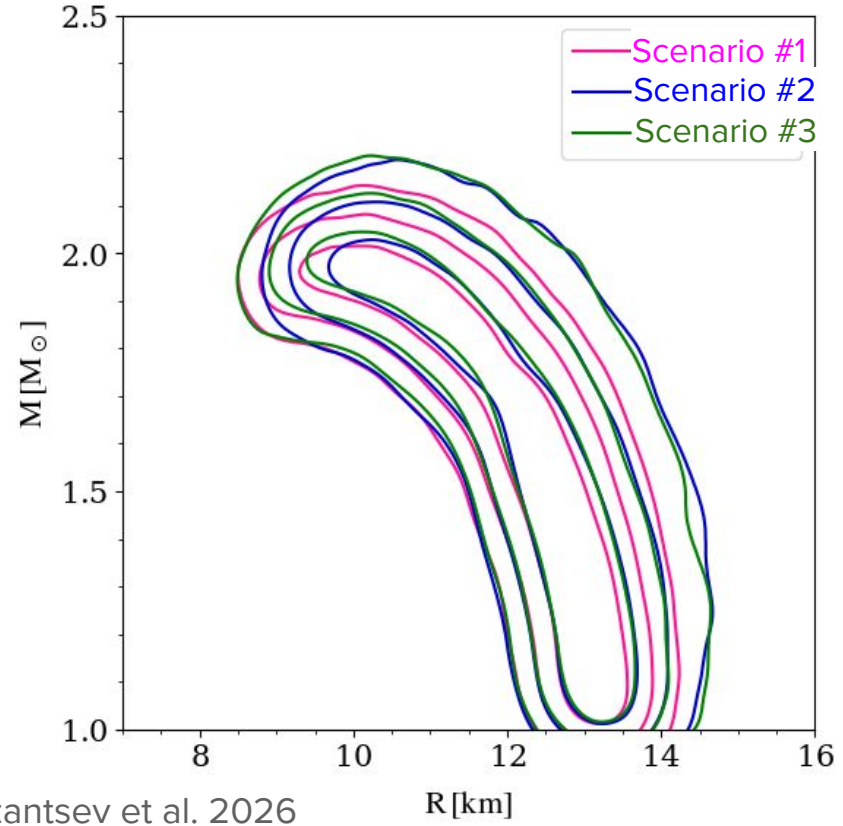
Application to 47Tuc - X7

Scenario #1: Uniform surface, no rotation

Scenario #2: Uniform surface, **rotation**

Scenario #3: **Non uniform** surface, **rotation**

68% CI: $R_{1.4\,M_\odot} = 12.9 \pm 0.4\,\mathrm{km}$



C. Kazantsev et al. 2026

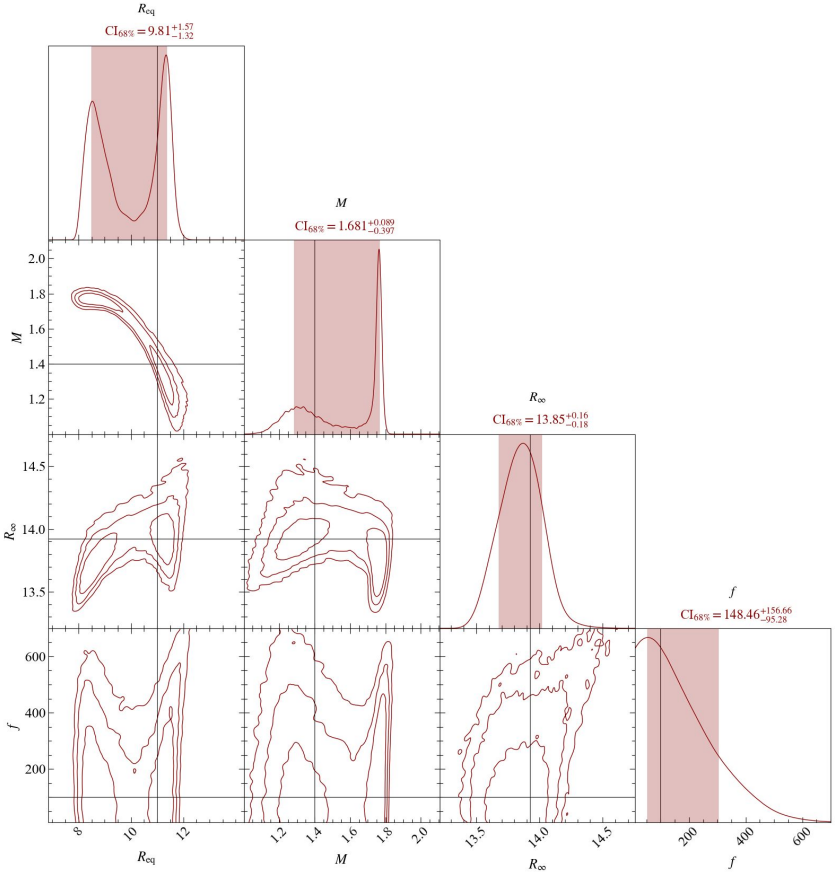
NewAthena Simulations

➜ 500ks simulation with WFI

for M=1.4Msun, R=11km, f=100Hz

➜ inference with Scenario #2 (free f)

68% CI: $R_{1.4\,M_\odot} = 11.09 \pm 0.15\,\mathrm{km}$

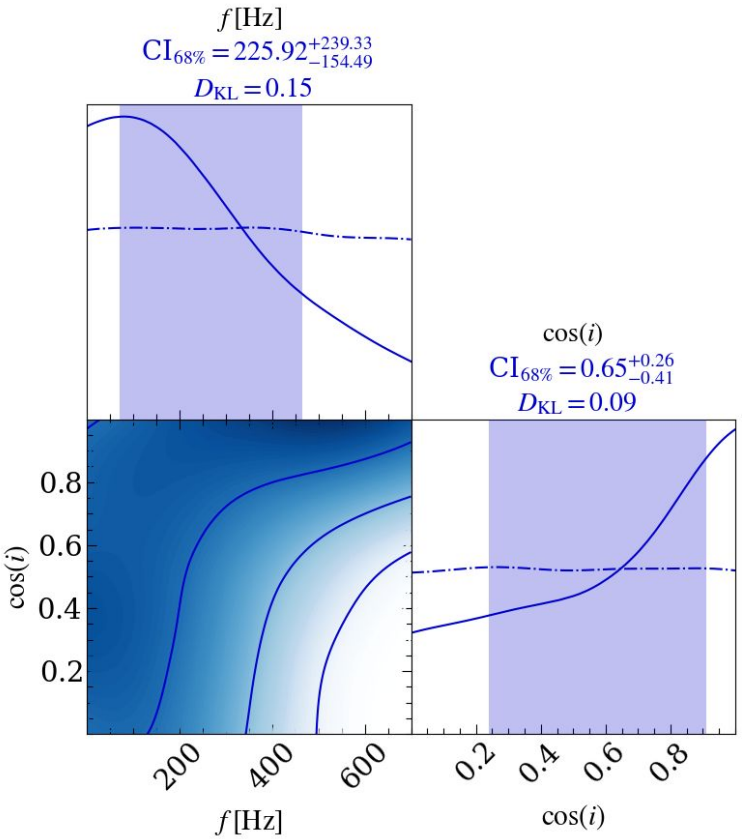


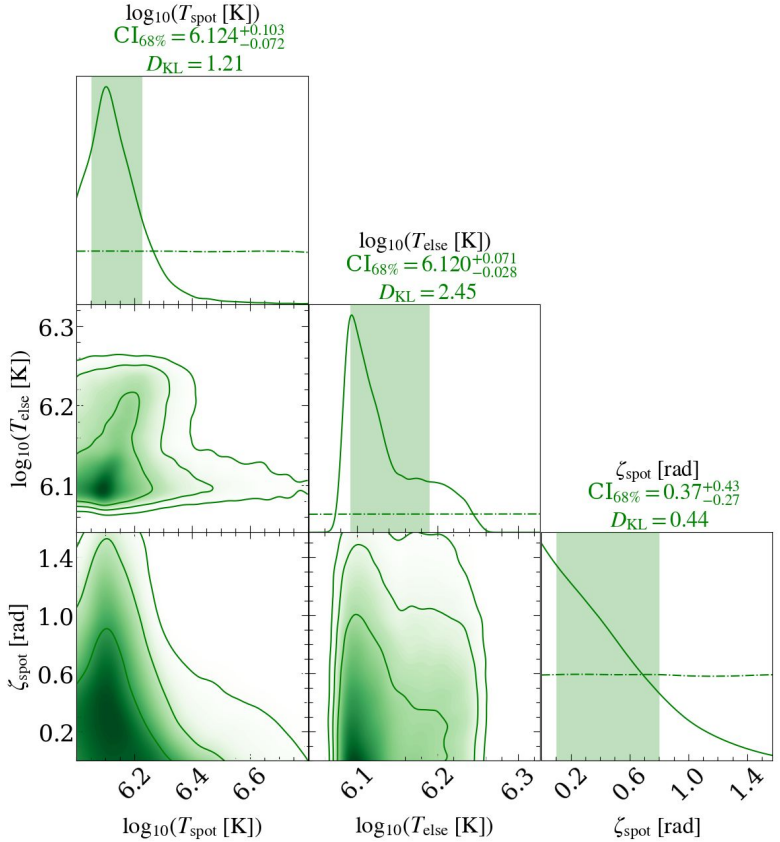
Conclusions

- ➔ New method developed to include systematics in MR measurements of qLMXBs ➔ paper on arxiv for details (arXiv: 2605.28411)
- ➔ NewAthena will greatly improve our measurements of M-R in qLMXBs
- ➔ WIP: Additional simulations to investigate hot spots:
  - ◆ look for possible detection of pulsations or constrains on pulse fraction
  - ◆ simulation with uniform surface + fit with a hot spot
  - ◆ simulation with a hot spot (parameters to be decided) + fit with uniform or hot spot

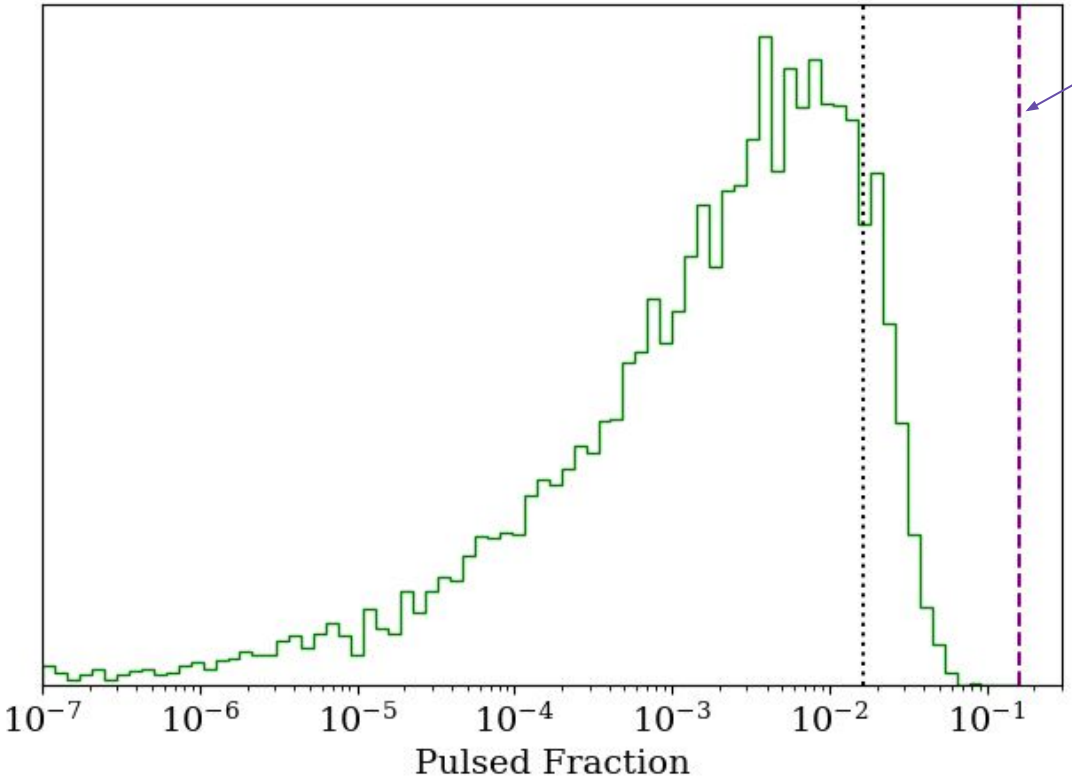
Thank you for your attention !

47Tuc - X7


f [Hz]
$\mathrm{CI}_{68\%} = 225.92^{+239.33}_{-154.49}$
$D_{\mathrm{KL}} = 0.15$
$\cos(i)$
$\mathrm{CI}_{68\%} = 0.65^{+0.26}_{-0.41}$
$D_{\mathrm{KL}} = 0.09$
$\cos(i)$
0.8
0.6
0.4
0.2
200
400
600
f [Hz]
0.2
0.4
0.6
0.8
$\cos(i)$

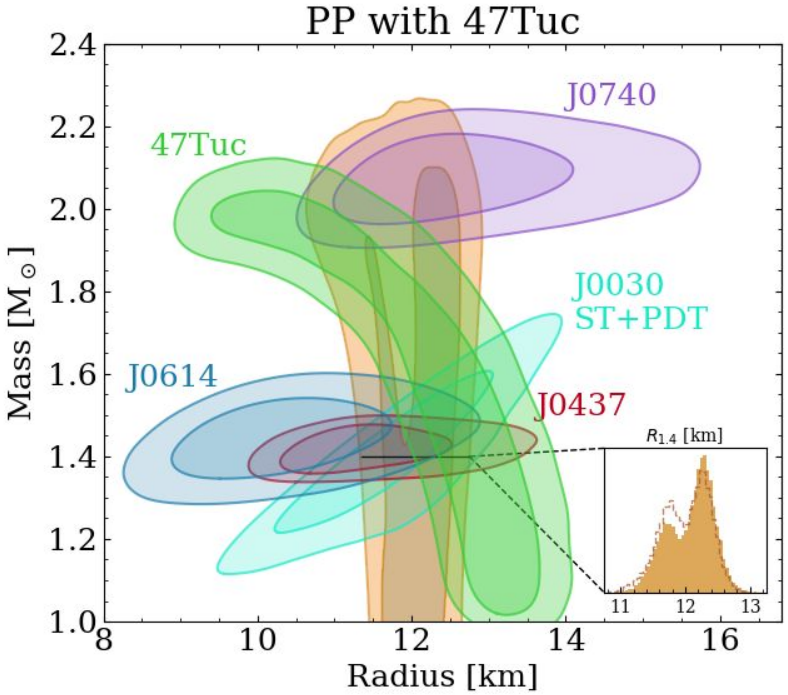

$\log_{10}(T_{\mathrm{spot}}\ [\mathrm{K}])$
$\mathrm{CI}_{68\%} = 6.124^{+0.103}_{-0.072}$
$D_{\mathrm{KL}} = 1.21$
$\log_{10}(T_{\mathrm{else}}\ [\mathrm{K}])$
$\mathrm{CI}_{68\%} = 6.120^{+0.071}_{-0.028}$
$D_{\mathrm{KL}} = 2.45$
ζ_{spot} [rad]
$\mathrm{CI}_{68\%} = 0.37^{+0.43}_{-0.27}$
$D_{\mathrm{KL}} = 0.44$
$\log_{10}(T_{\mathrm{else}}\ [\mathrm{K}])$
6.3
6.2
6.1
ζ_{spot} [rad]
1.4
1.0
0.6
0.2
6.2
6.4
6.6
$\log_{10}(T_{\mathrm{spot}}\ [\mathrm{K}])$
6.1
6.2
6.3
$\log_{10}(T_{\mathrm{else}}\ [\mathrm{K}])$
0.2
0.6
1.0
1.4
ζ_{spot} [rad]

47Tuc - X7

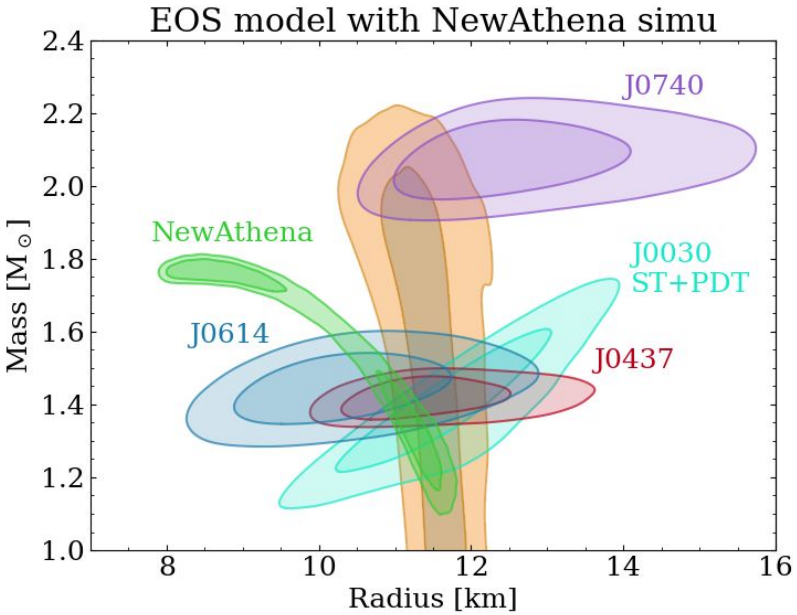


Elshamouty+2016 90% UL

EOS inference - Comparison

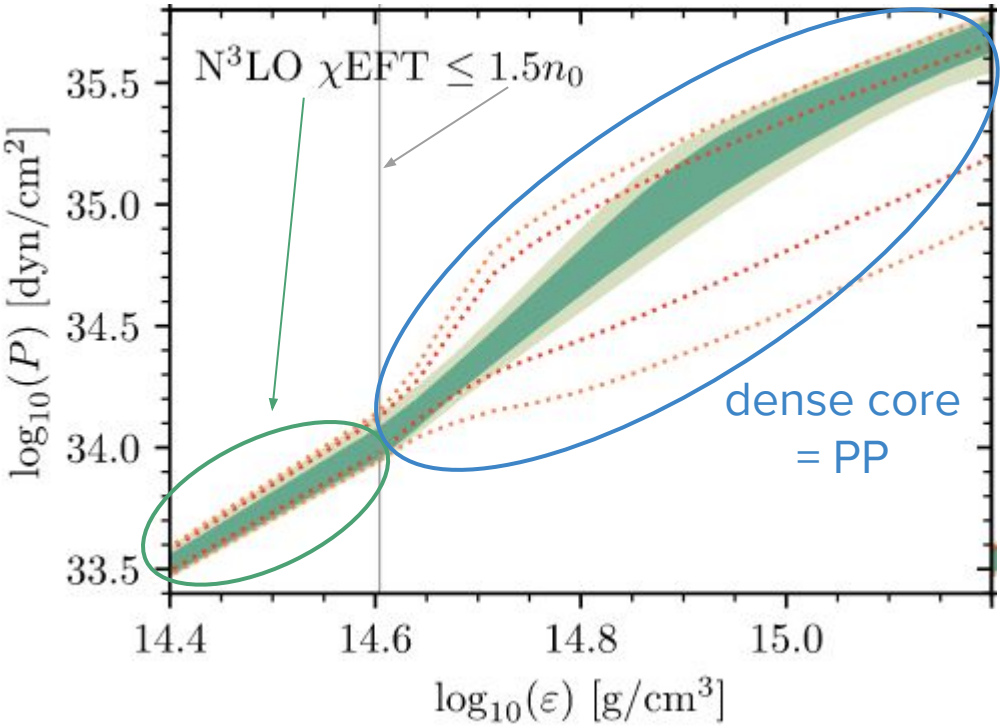


C. Kazantsev et al. 2026



Preliminary simulation

EOS model : the piecewise polytrope model (PP)



from Rutherford et al. 2024