Using CompOSE cold EOSs for rotating neutron star models in lorene

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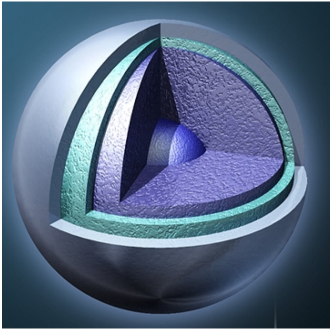
The complex physics of neutron stars

The description of neutron stars involves many different fields of physics, with overall conditions that can hardly be tested on Earth:



- cold, highly asymmetric nuclear matter,
- very strong gravitational field (last stage before black hole),
- intense magnetic field, up to $\sim 10^{17}$ G,
- rapid rotation, implying relativistic fluid velocities.

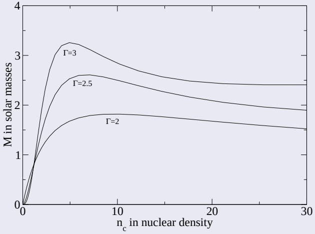
$\Rightarrow$need for theoretical models, often involving numerical simulations

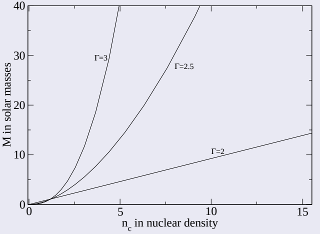
Need for GR

Influence of general relativity (GR) can be measured by the compactness ratio:

$$\mathcal{C} = \frac{GM}{Rc^2}. \qquad \mathcal{C} = 0.5 \iff \text{black hole.}$$

GR makes qualitative difference:





No maximal mass in Newtonian theory!

⇒General Relativity is absolutely necessary…

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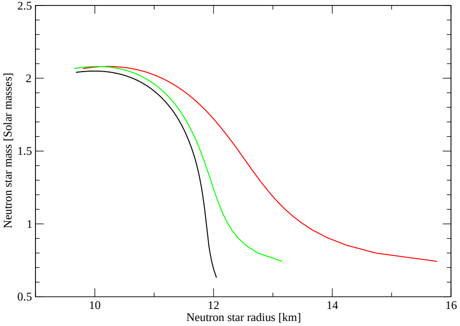
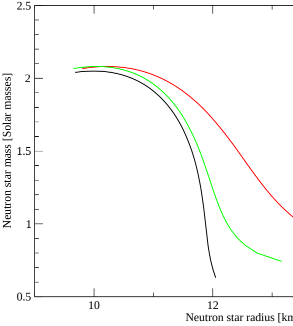
Need for rotation?

Three different EoSs ... One Eos : SLy4 Douchin & Haensel (2001)





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Rotation is important when dealing with radii. ⇒Need for

Brief history

rotating neutron star models

- Hartle & Thorne (1968) : slow rotation approximation,
- Bonazzola & Maschio (1971) : Lewis-Papapetrou coordinates,
- Wilson (1972) : differentially rotating stars
- Butterworh & Ipser (1975) : Bardeen-Wagoner formulation,
- Friedman *et al.* (1986) and Lattimer *et al.* (1990) : realistic EoSs,
- Bocquet *et al.* (1995) : (electro)magnetic field,
- ...

Some codes:

- Komatsu *et al.* (1989) ⇒KEH,
- Bonazzola *et al.* (1993) ⇒ `nrotstar` (LORENE)
- Stergioulas & Friedmann (1995) ⇒ `rns`
- compared in Nozawa *et al.* (1998)
- Ansorg *et al.* (2002) ⇒ AKM

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nrotstar

NROTSTAR

- solves for the equilibrium of a self-gravitating perfect fluid in general relativity under the assumptions of: stationarity, axisymmetry and circularity
- comes with LORENE ⇒uses spectral methods to solve PDEs: rapid ($\sim$ 10 s $\rightarrow$ 1 min) with low errors given by independent virial indicators: GRV2 and GRV3
- can be installed on any linux-like system (and on Mac. . .), see instructions at `http://www.lorene.obspm.fr`
- physical inputs: central enthalpy (equivalent to central density/pressure), rotation frequency . . .
- . . . and an equation of state for cold matter at β-equilibrium

⇒the EoS can be provided as a table in LORENE-like format and units

or

with the CompOSE files `xxx.nb` and `xxx.thermo`, for 1-parameter EoSs

IN PRACTICE

- login as `lorene@lyopc428.in2p3.fr`
- `mkdir Yourdirectory`
- `cp -r Lorene/Codes/Nrotstar Yourdirectory/`
- `cd Yourdirectory/Nrotstar` then `make`
- download some cold EoS table from CompOSE to `Yourdirectory`
- copy parameter files from `Parameters/GR/CompOSE` to `Yourdirectory/Nrotstar`
- modify `par_eos.d` to include path to your CompOSE tables
- run the code (`./nrotstar`)
- look at the results : text file `result.txt` and profiles `prof_XXX.d` to be visualized with `gnuplot` or `xmgrace`

Don't hesitate to ask me. . .

CONCLUSIONS

- How much does the star deviate from spherical symmetry @700 Hz?
- Try a `time ./nrotstar >& /dev/null`...
- Consider adding your tables to the CompOSE database ...and using `nrotstar` to get rotating compact star configurations.

More possibilities (improvements from `nrotstar`):

- Magnetized EoS $p(n_B, B)$: see tomorrow's talk and `arXiv:1410.6332`
- Two-fluid EoS with entrainment $p(n_B^1, n_B^2, \Delta_v)$: under testing...
- Hot EoS $p(n_B, T)$: under development
- ...

References

- Ansorg, M. *et al.*, Astron. Astrophys. **381**, L49 (2002)
- Bocquet, M. *et al.*, Astron. Astrophys. **301**, 757 (1995)
- Bonazzola, S. *et al.*, Astron. Astrophys. **278**, 421 (1993)
- Bonazzola, S. & Maschio, G., Proc. IAU Symp. **46**, 346 (1971)
- Butterworth, E.M. & Ipser, J.R., Atrophys. J. **200**, L103 (1975)
- Douchin, F. & Haensel, P., Astron. Astrophys. **380**, 151 (2001)
- Friedman, J. *et al.*, Astrophys. J. **304**, 115 (1986)
- Gourgoulhon, E. arXiv:1003.5015
- Hartle, J.B. & Thorne, K.S., Astrophys. J. **153**, 807 (1968)
- Komatsu, H. *et al.*, Month. not. Roy. Astron. Soc. **239**, 153 (1989)
- Nozawa, T. *et al.*, Astron. Astrophys. Suppl. **132**, 331 (1998)
- Stergioulas, N. & Friedmann, J., Astrophys. J. **444**, 306 (1995)
- Wilson, J.R., Astrophys. J. **176**, 195 (1972)