Partially accreted crusts of neutron stars

Journée du LUTH

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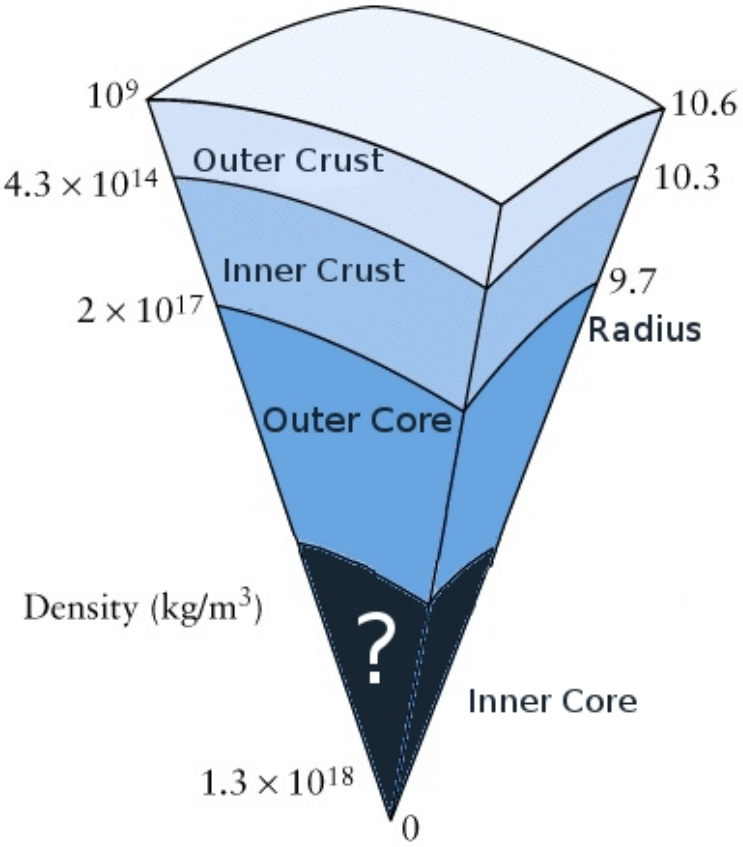
10/11/2021

Neutron star's main characteristics

- Compact objects :
  $M \simeq 1 - 2\mathrm{M}_{\odot}$
  $R \simeq [9 - 15]$kms
- Structure in layers
- So dense : no core equation of state !
  - Nuclear constraints
  - Observables constraints: via reltivistic equations (hydro, cooling, k love numbers...)
- Multi-messaging information:
  - NICER telescope - M(R)
  - LIGO/Virgo/KAGRA - Λ
  - Luminosity observations: neutrino emissive processes
    + **crustal heating**



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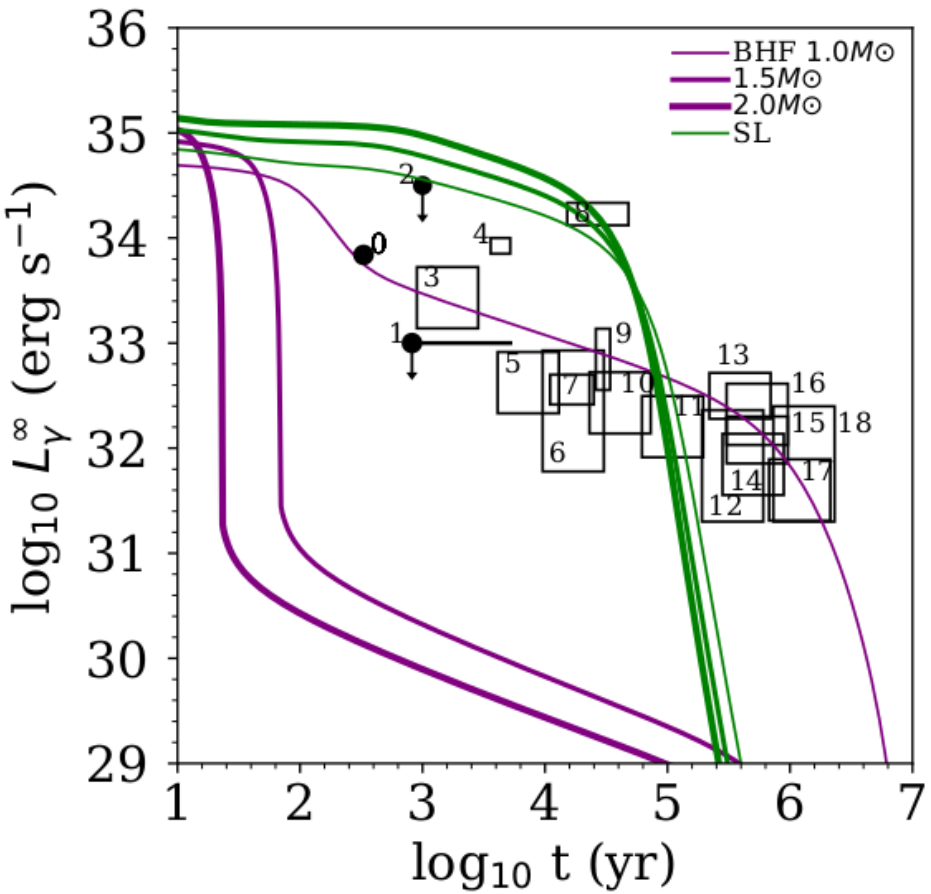
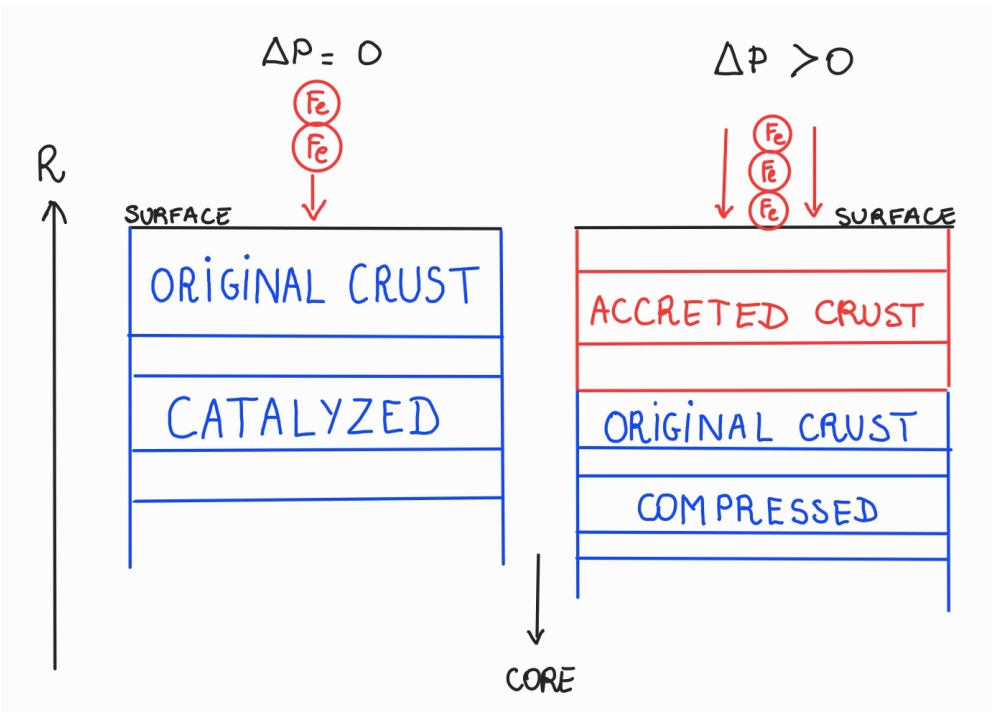


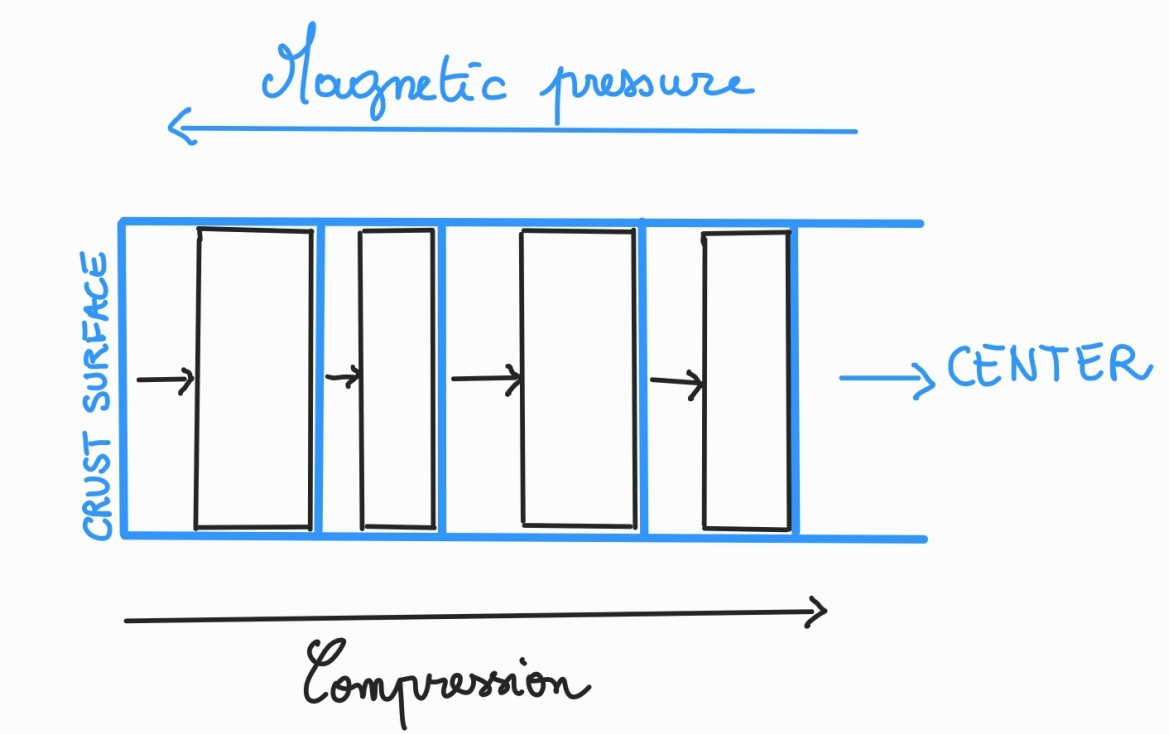
Astrophysical phenomenon concerned

- **Partially accreted crusts**
  - Accretion mechanism in a binary
  - Beyond fully accreted crust approximation for small accretion
  - Motivation: IGR J17480 − 2446, 1RXS J180408 − 342058 = low level of accretion
  - Original crust compressed under accumulating accreted material



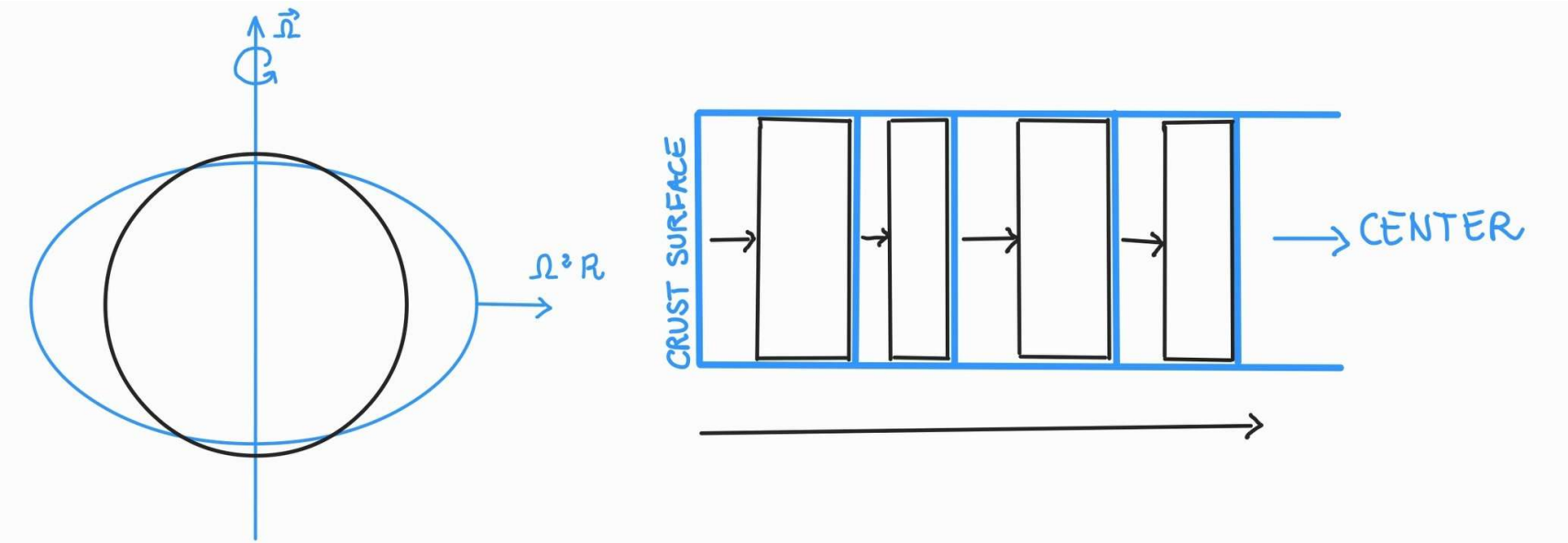
Astrophysical phenomenon concerned

- Magnetar's decay:
  - [Chamel, Fantina, Suleiman, Zdunik, Haensel 2021]
  - Magnetars : high magnetic field $\simeq 10^{17}$G
  - Loss of magnetic pressure: equivalent to a compression of the crust



Astrophysical phenomenon concerned

- Spinning down neutron stars:
  - Rotating neutron star : equator and polar radius not the same
  - Slow down: from high spin to non-rotating = asymmetry diminished



Nuclear model for the partially accreted crust

Compression = exothermic reactions electron captures + pycno fusions

Heat deposited = source of luminosity

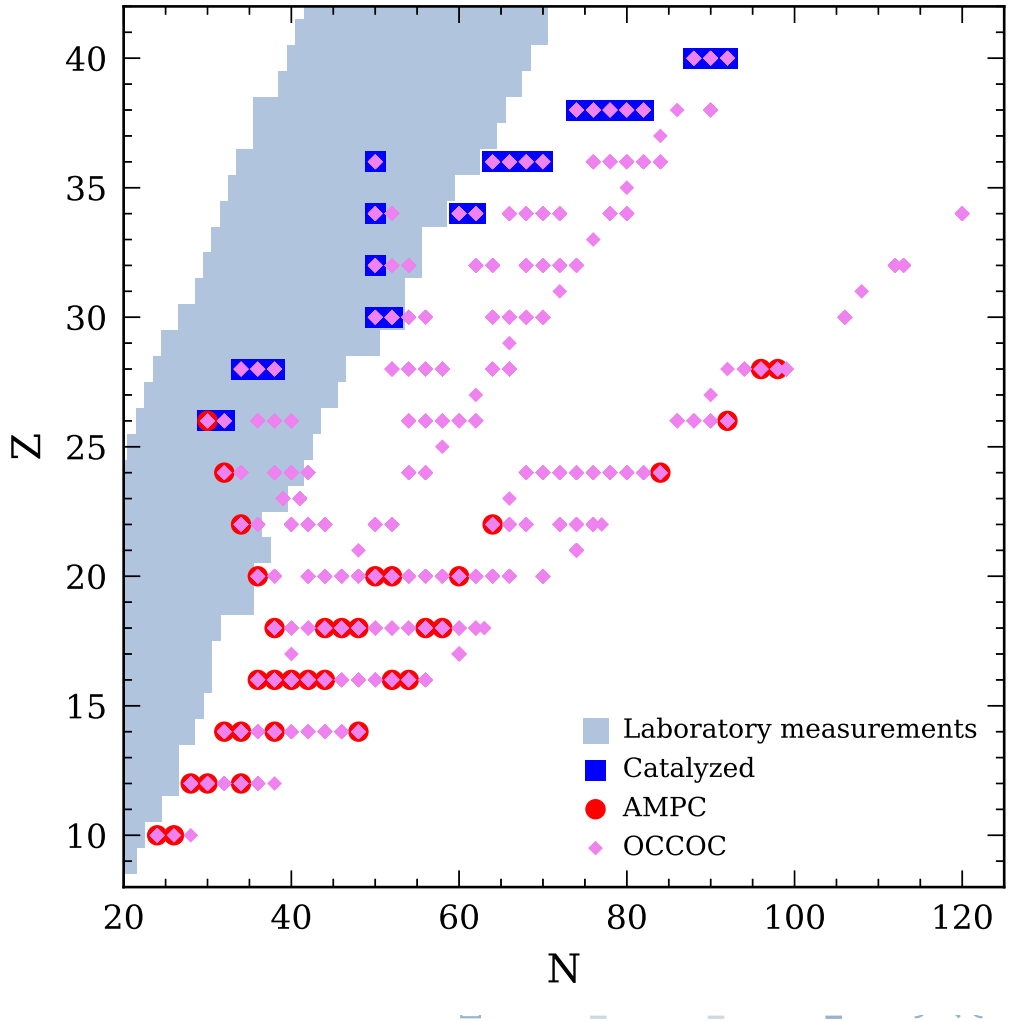
How to treat partially accreted crusts ?

Establish the (CLDM) equation of state for:

- Catalyzed matter
- Accreted matter
- Compressed original crust as a function of ΔP

Establish a catalog of heat sources as a function of ΔP for:

- Accreted material part: permanent heat sources
- Compressed original crust: temporary sources



Punctal sources

Partially accreted crusts

- Heat for accreted outer crust and underneath compressed originally catalyzed: 2.2×10^{46}erg and 1.3×10^{46}erg
- Originally catalyzed outer crust vs originally accreted outer crust both pushed to inner crust: practically the same $\sim 2 \times 10^{45}$ erg

Decaying magnetars

- Amount of heat independent of the magnetic field
- Location of heat sources: strongly depend on the magnetic field
- Sources located deeper than accretion related deep crustal heating

Spinning down neutron stars

- Recycled pulsars $\sim$ 1ms frequency
- Relative compression of 40%
- Heat sources for the deepest layers of the outer crust

Properties of compressed crusts

Neutron drip anomaly + Density related instability

Ongoing and additional work

- Need to put the heat sources in a cooling code
- Time dependant heat sources might be difficult to treat...

Additional work

- Role of non-unified equations of state in the modelisation of macroscopic parameters of neutron stars [Suleiman, Fortin, Zdunik, Haensel 2021]
- Revision of analytical representation of equations of state based on unified equations of state [Suleiman, Fortin, Zdunik in prep]
- Neutrino emissivity of the Modified Urca process
- Virgo collaboration LUTH/Caen