NEUTRON STARS :
Astrophysical probes of extreme physics

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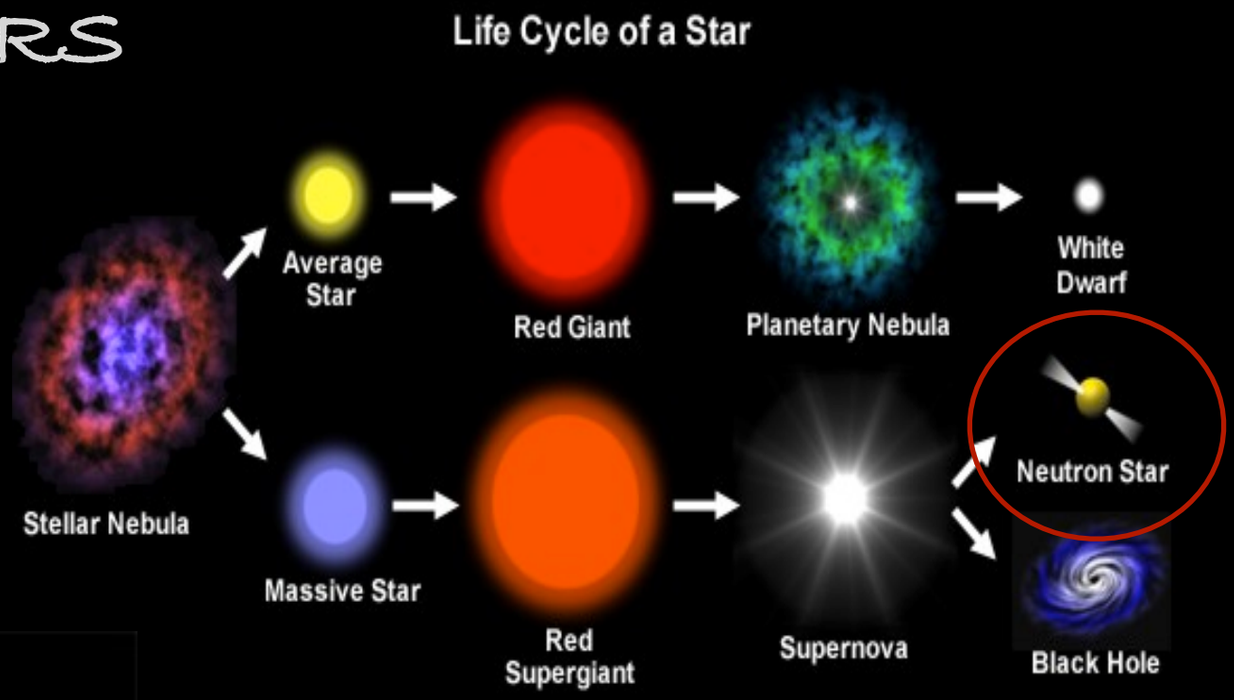
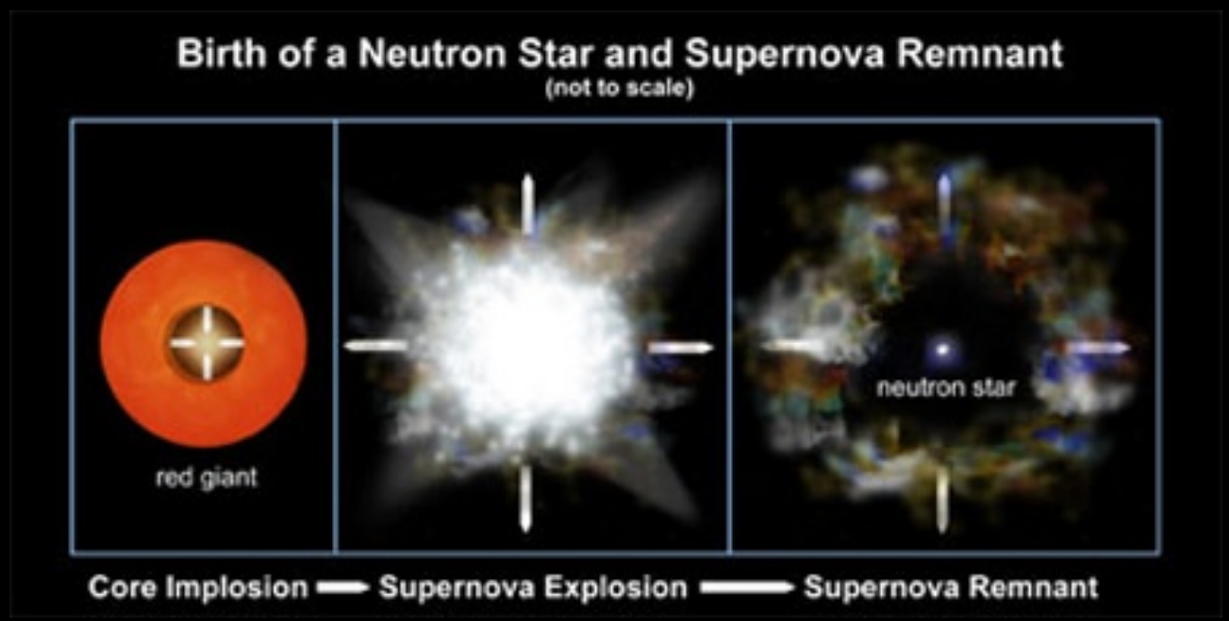
COLLABORATORS:
MICAELA OERTEL
JEROME NOVAK

Journée GPhys 2014

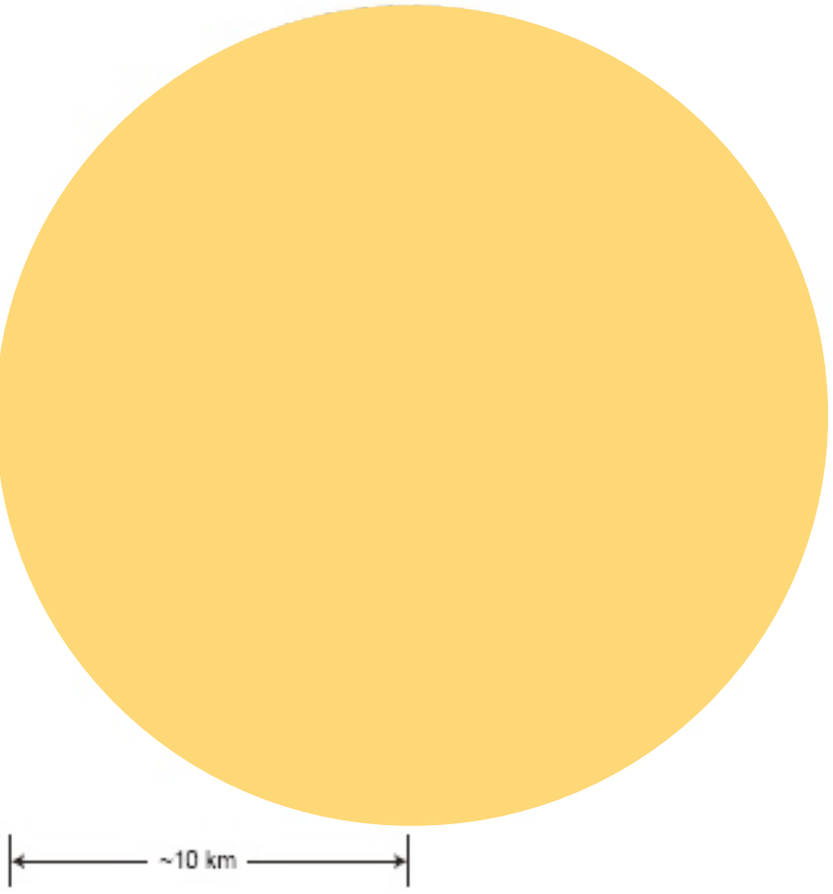
DEATH OF MASSIVE STARS





- *Massive stars end in core collapse supernova explosions*
- *Neutron stars: compact remnants*
- *$M \sim 1\text{-}2\ M_{solar}$, $R \sim 10$ km*

NEUTRON STAR STRUCTURE



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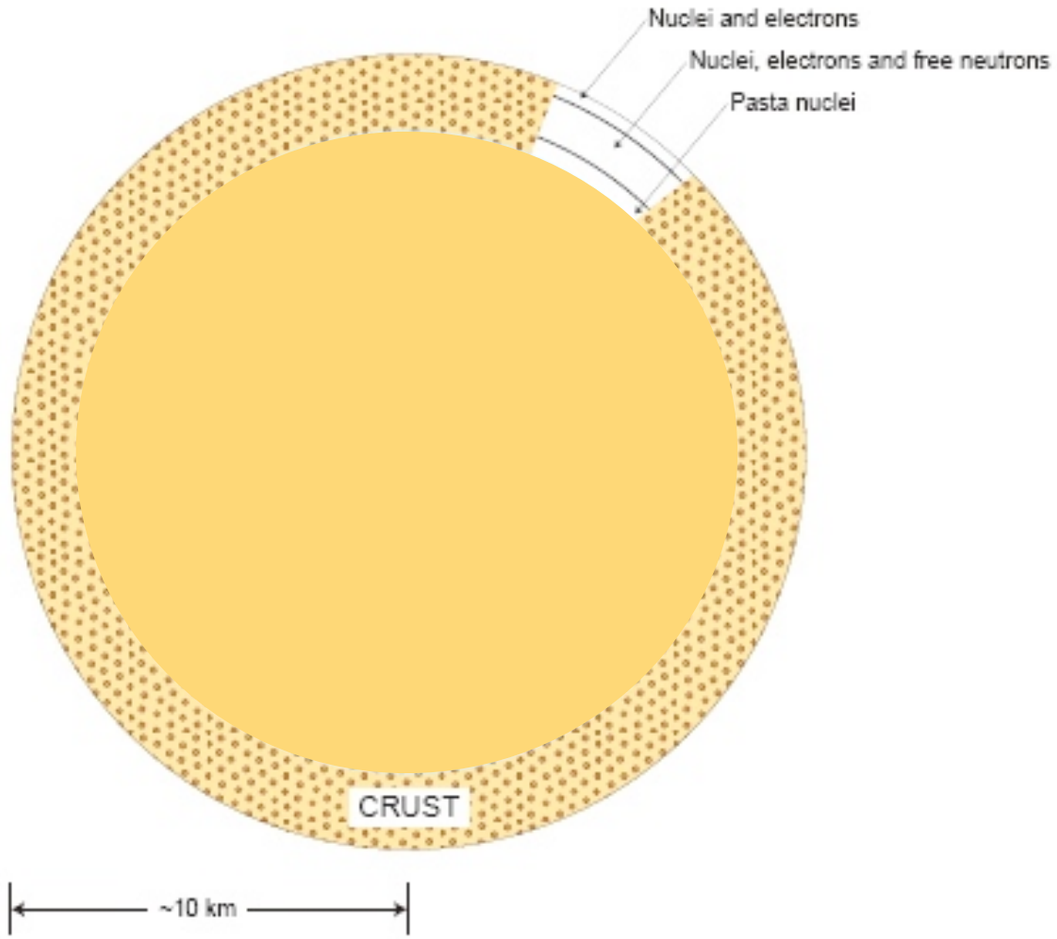

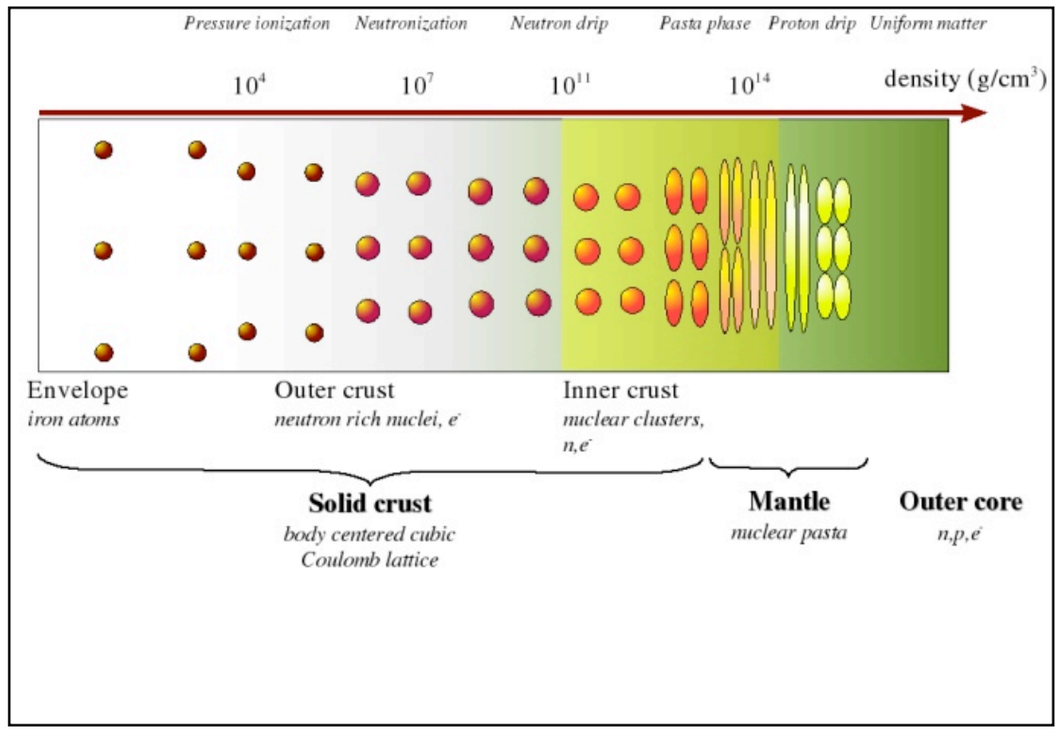

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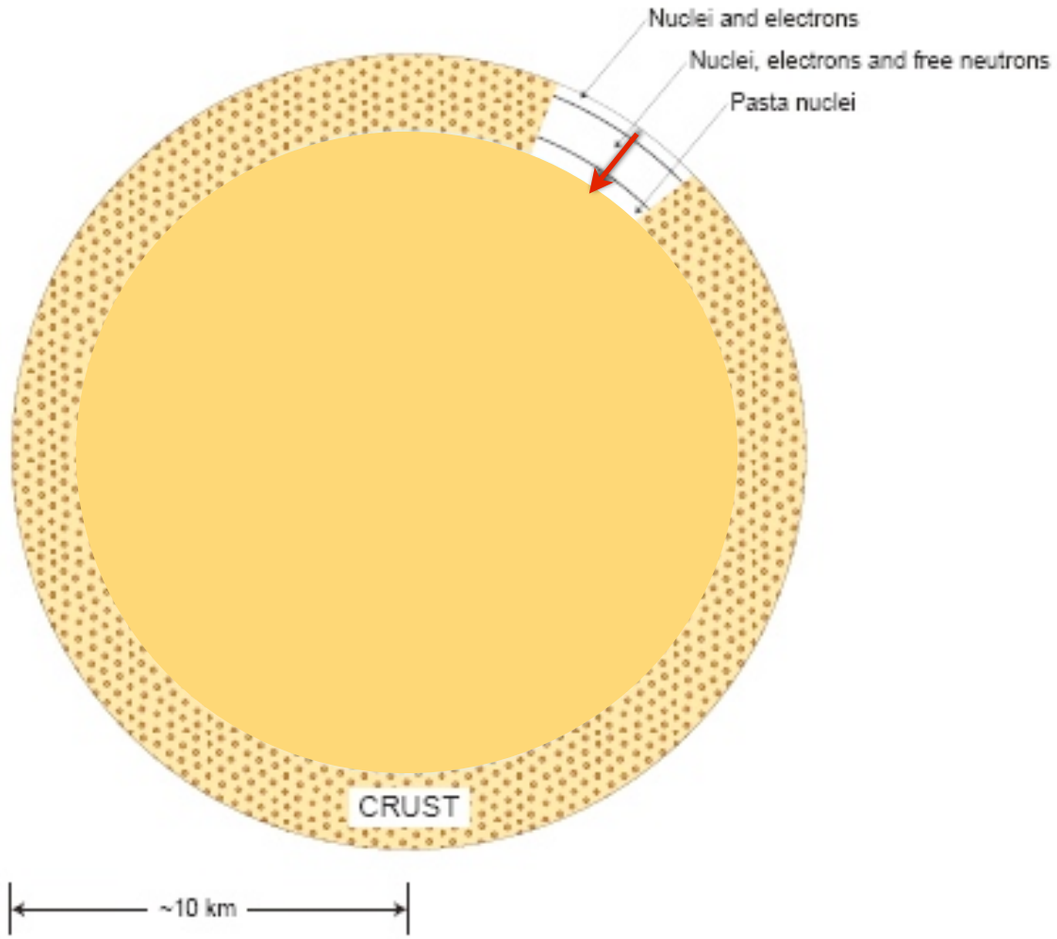

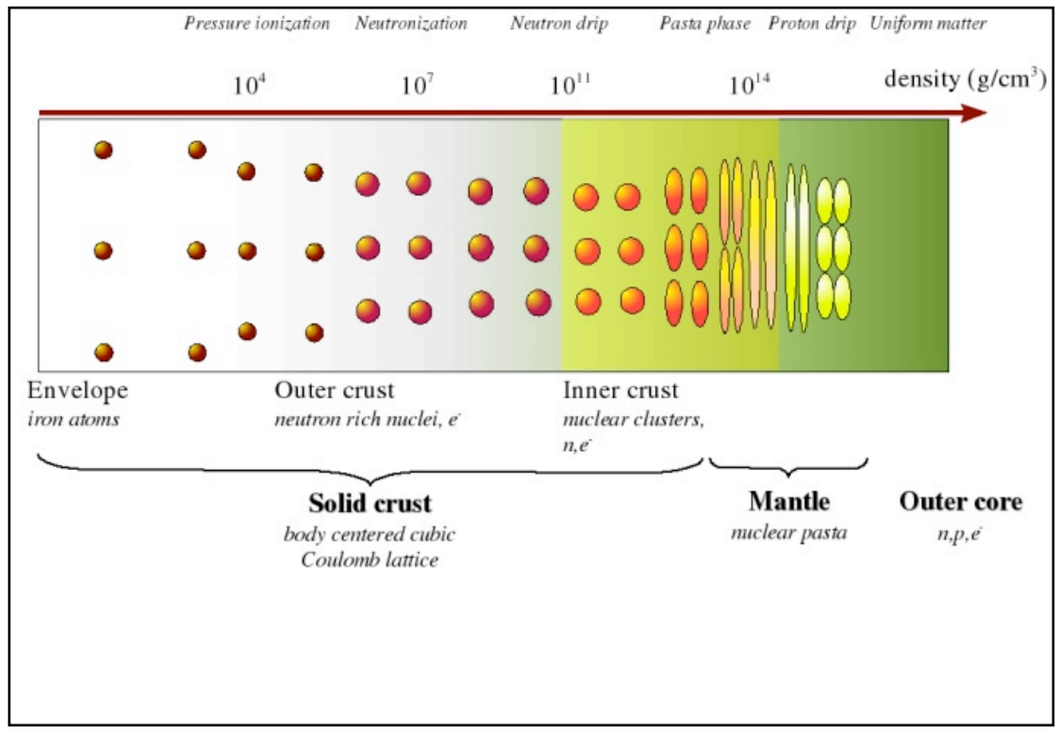

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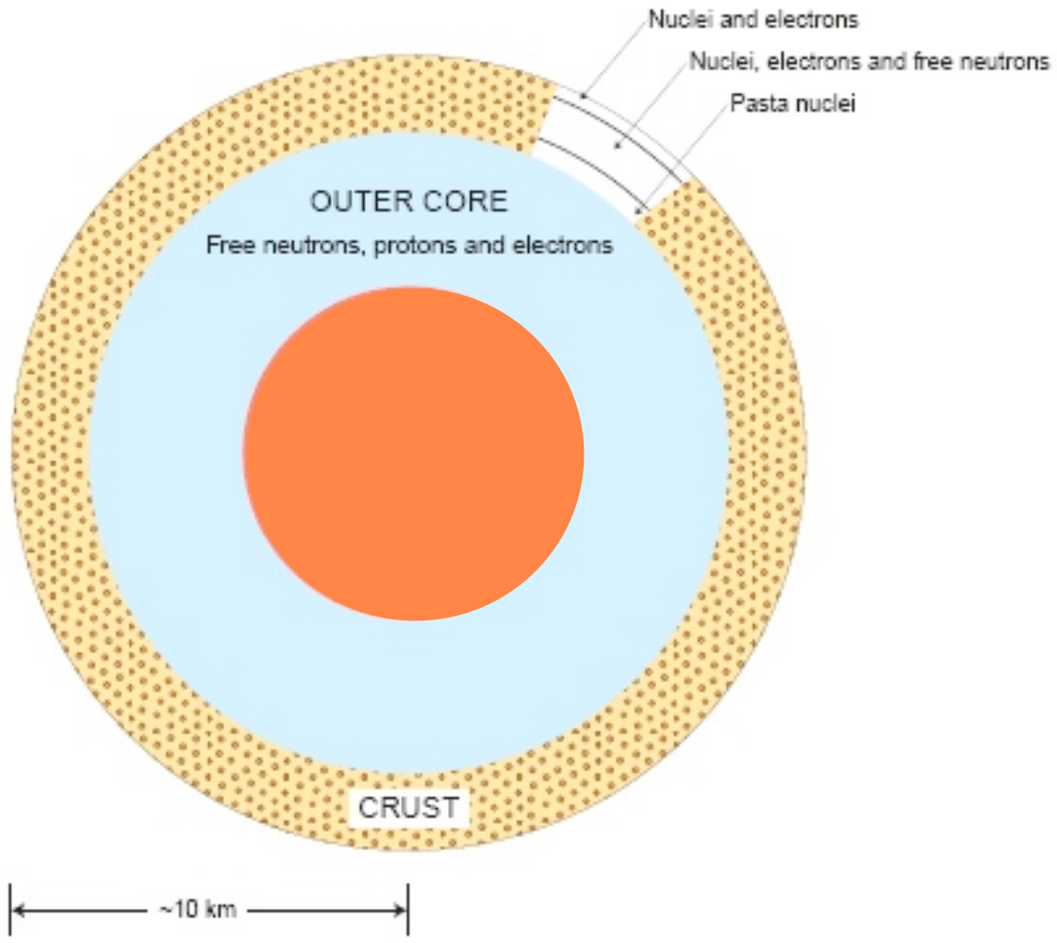

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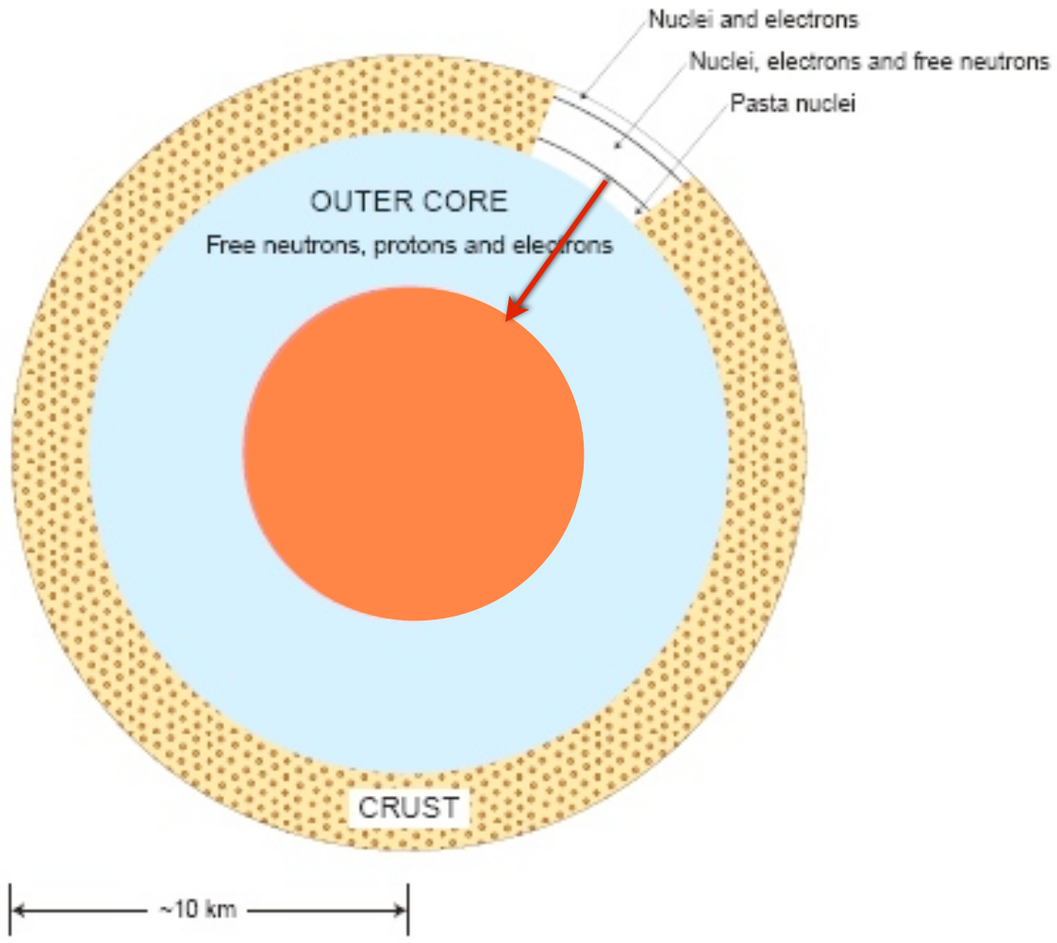

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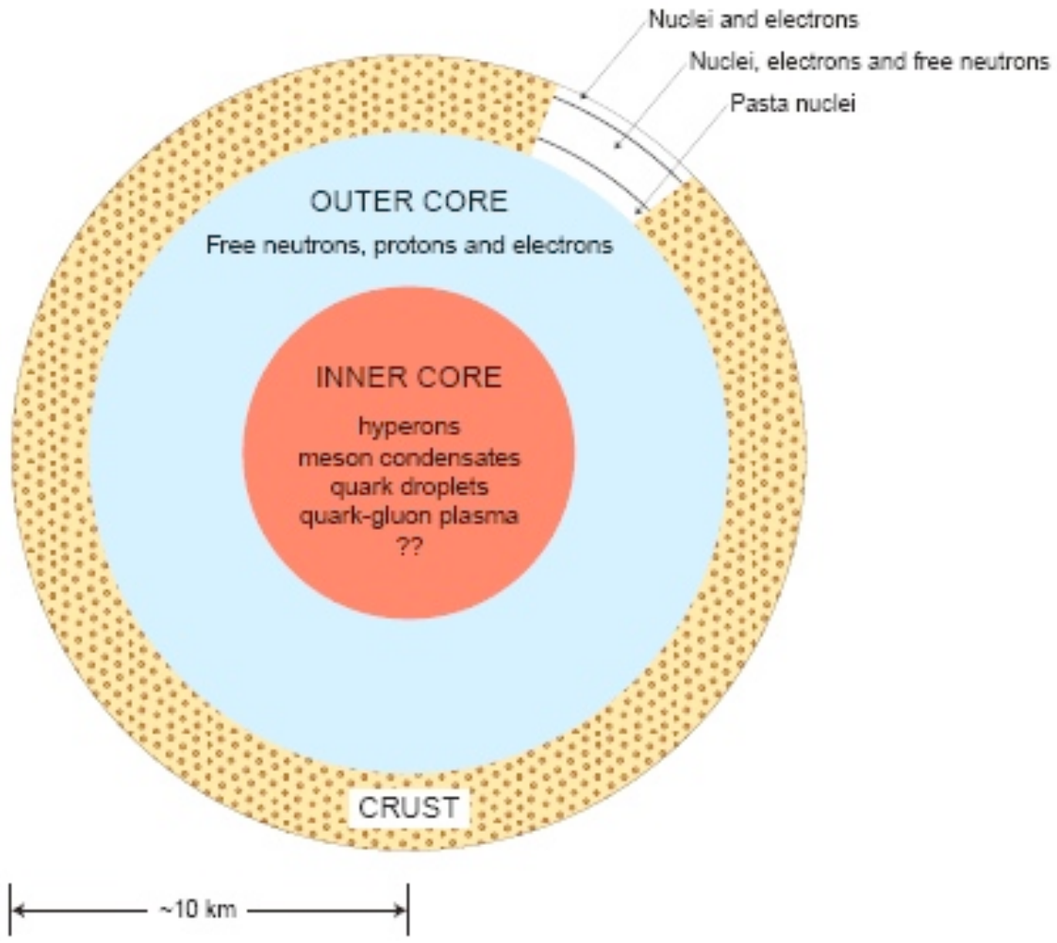

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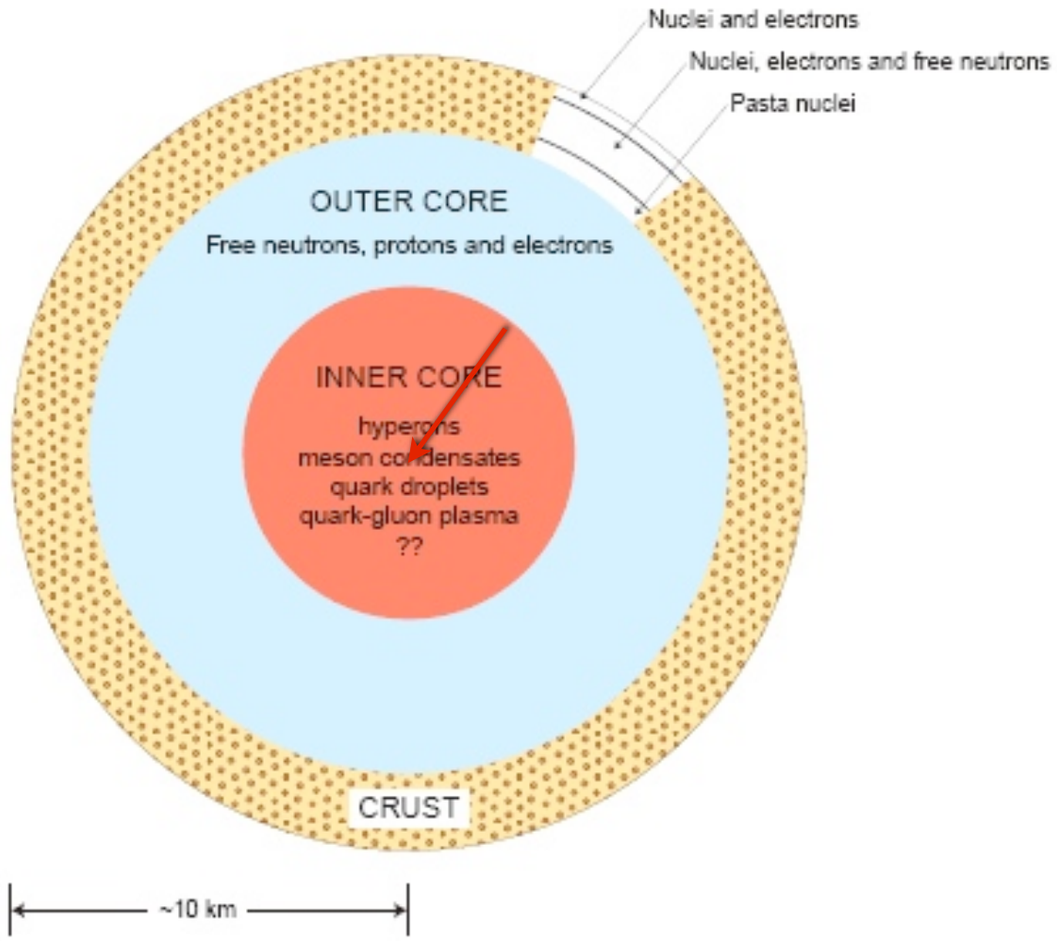

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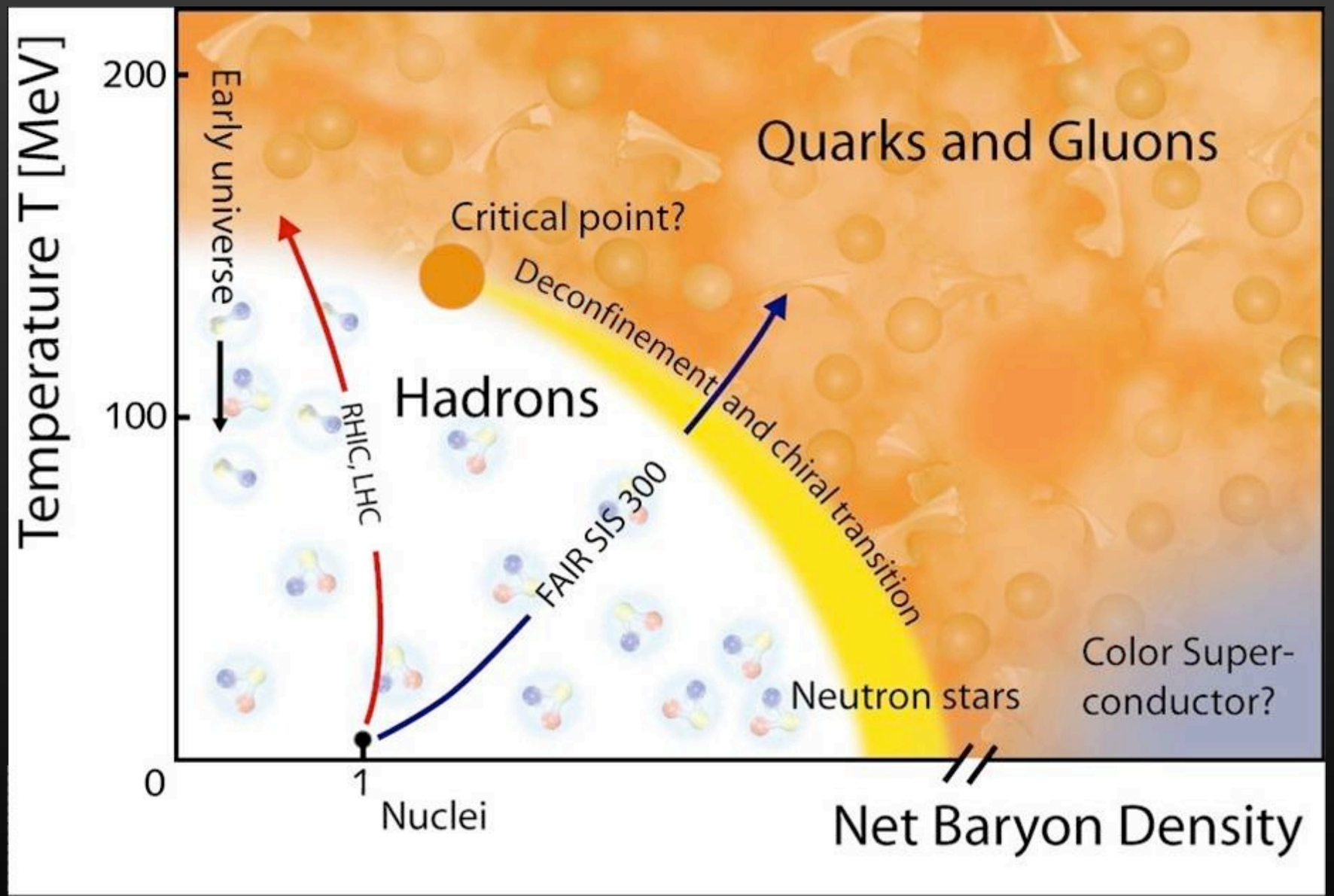
Dense Nuclear Matter



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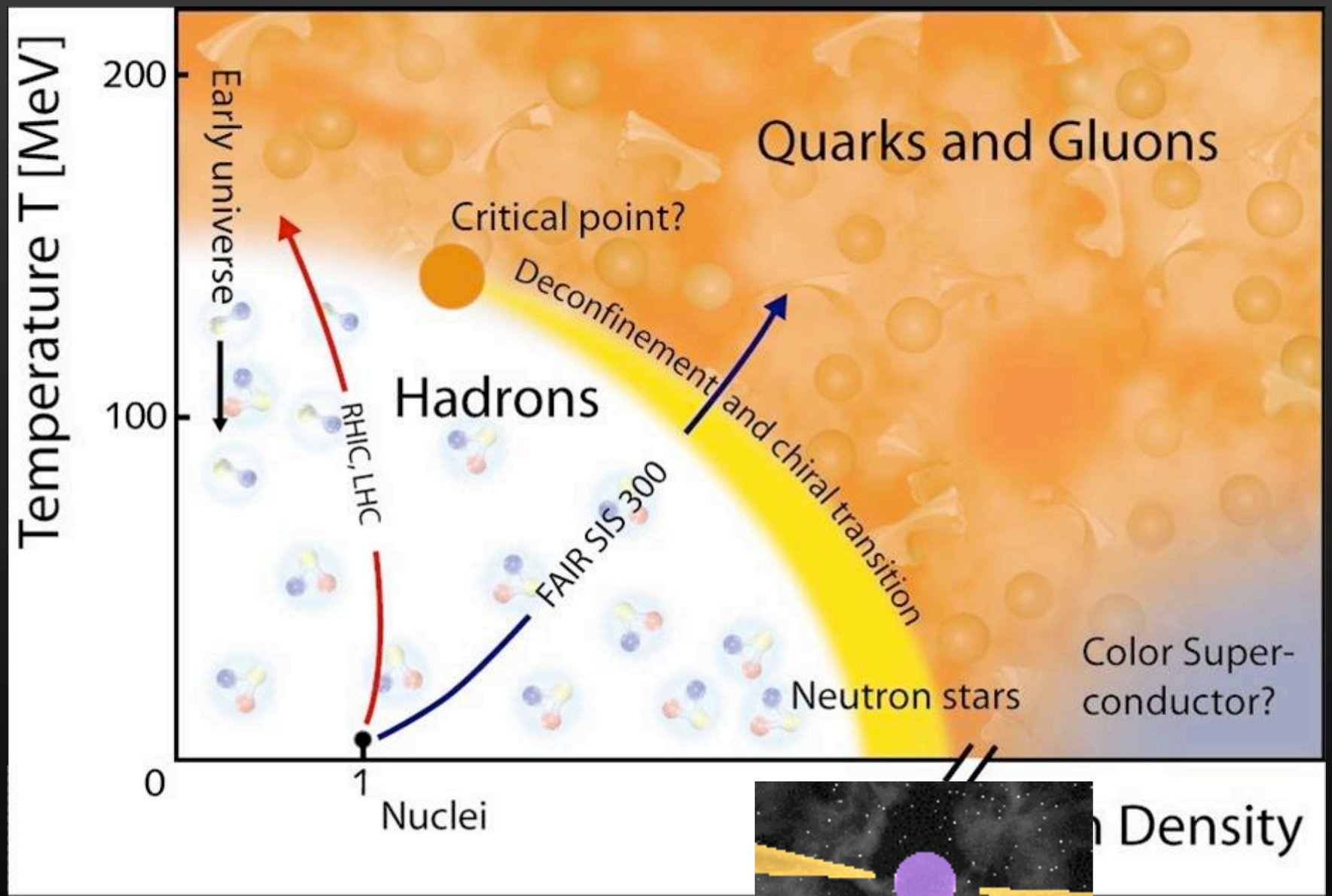

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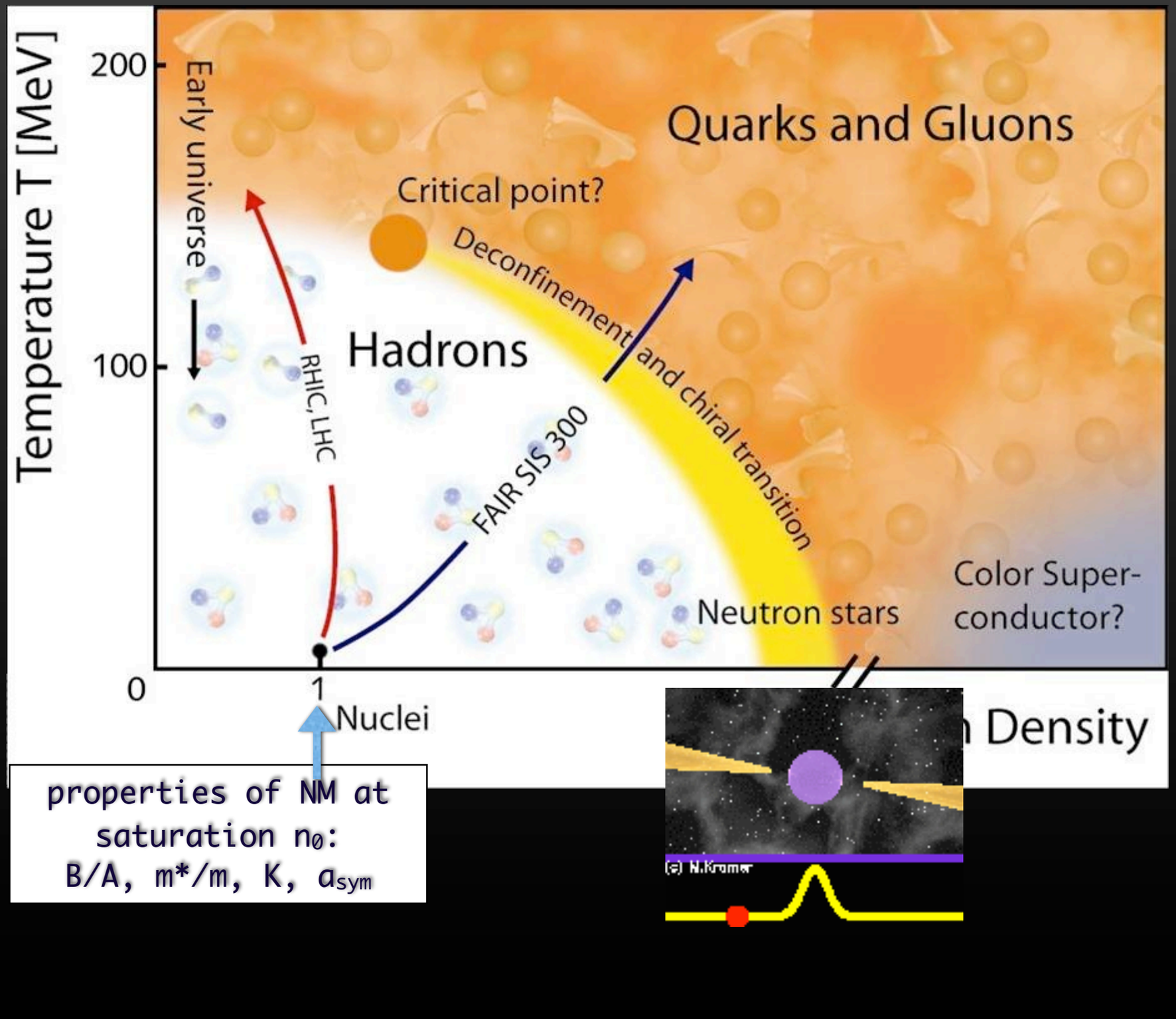

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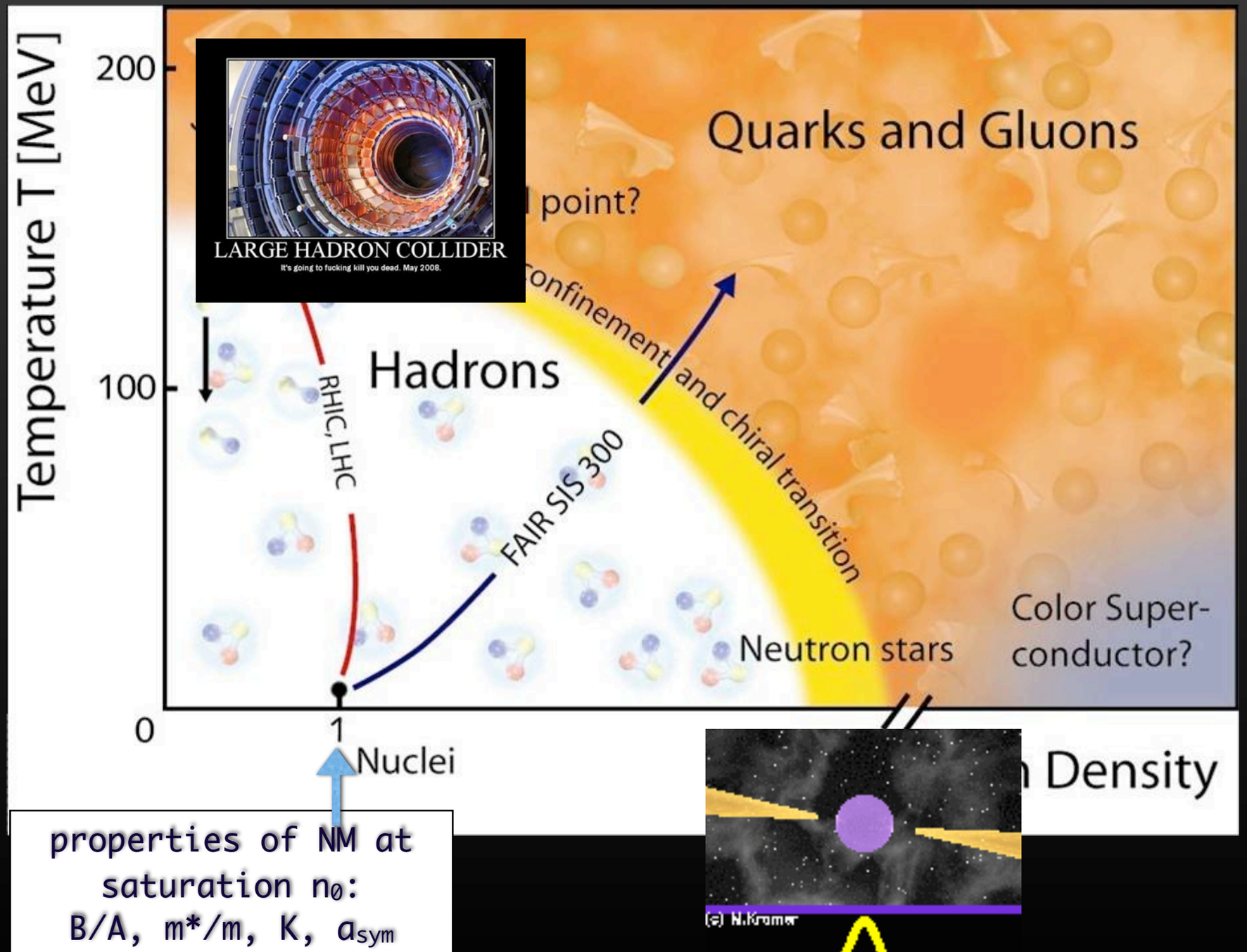
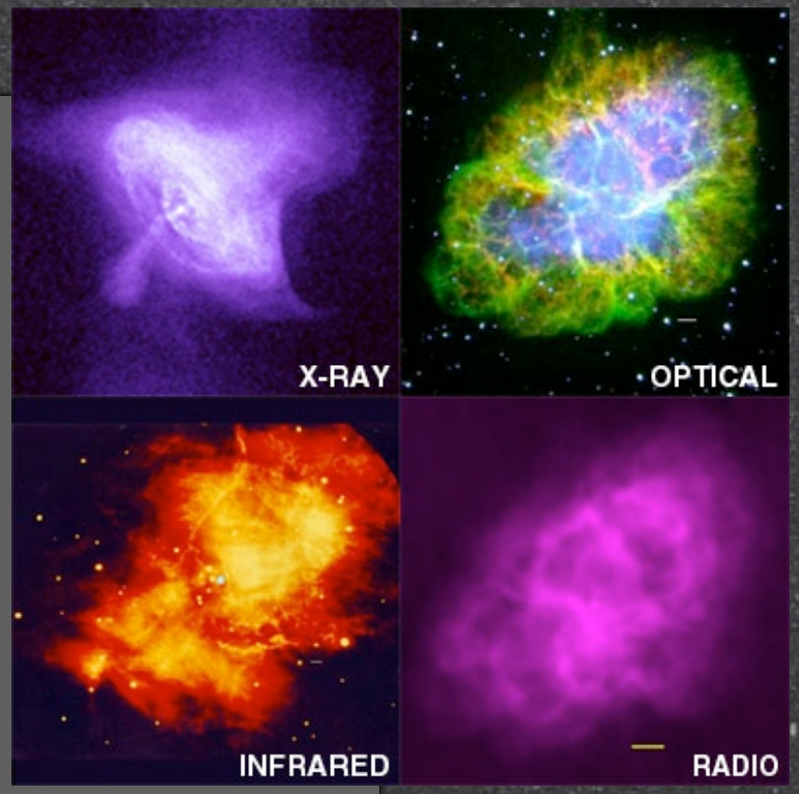
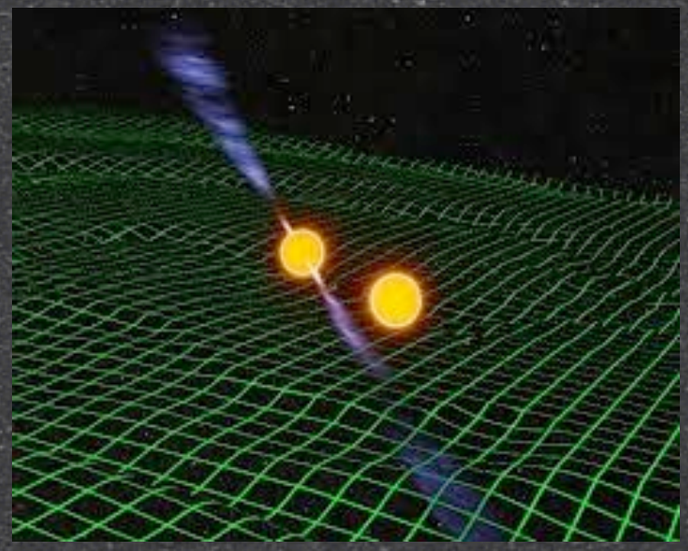
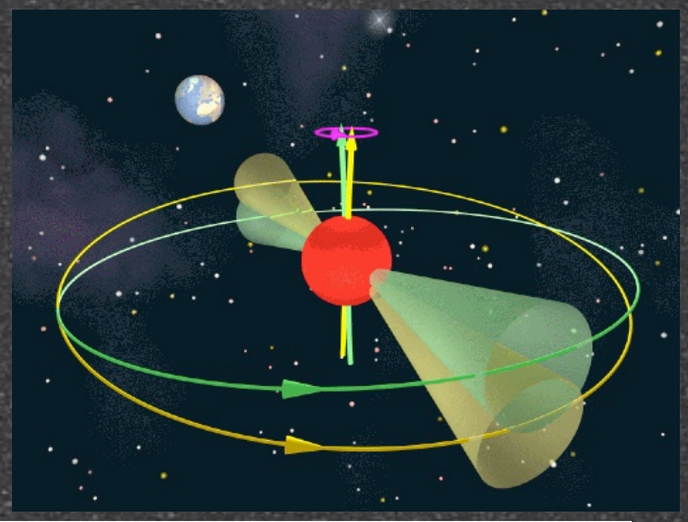


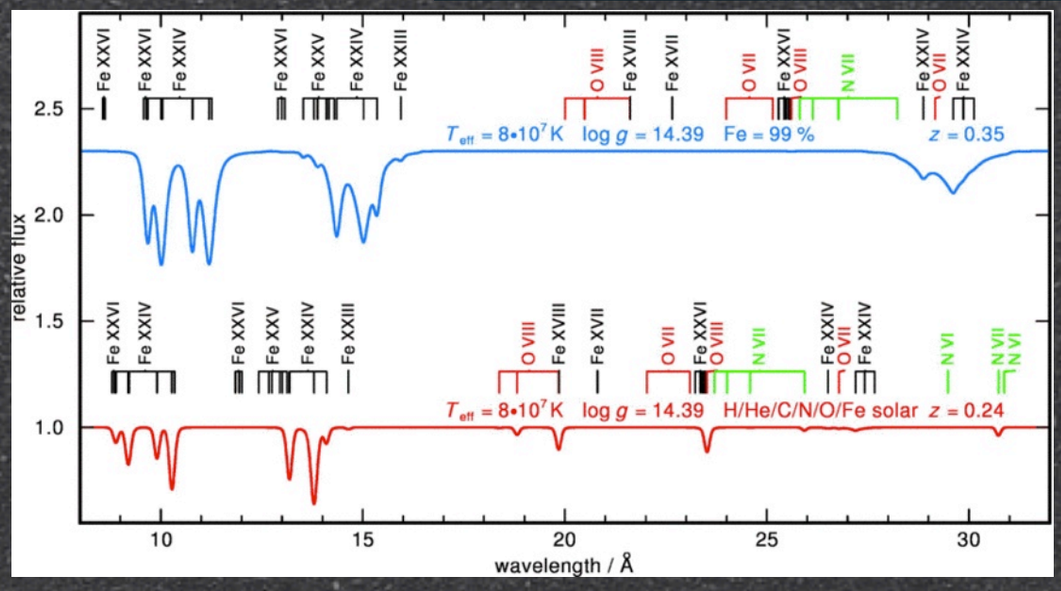
Astrophysical Observables

- *Period*
- *Mass M*
- *Radius R*
- *Moment of inertia $I \sim MR^2$*
- *Gravitational redshift $z \sim M/R$*
- *Cooling*

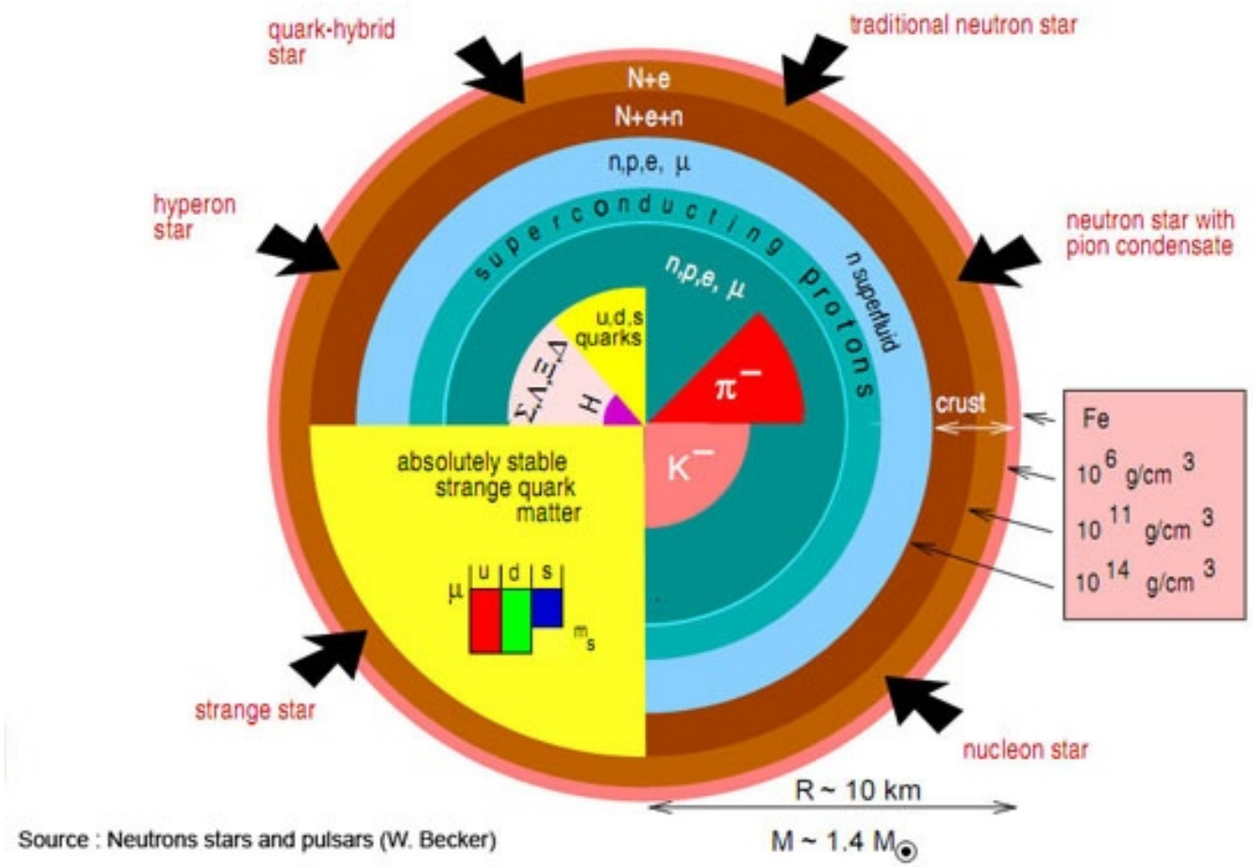








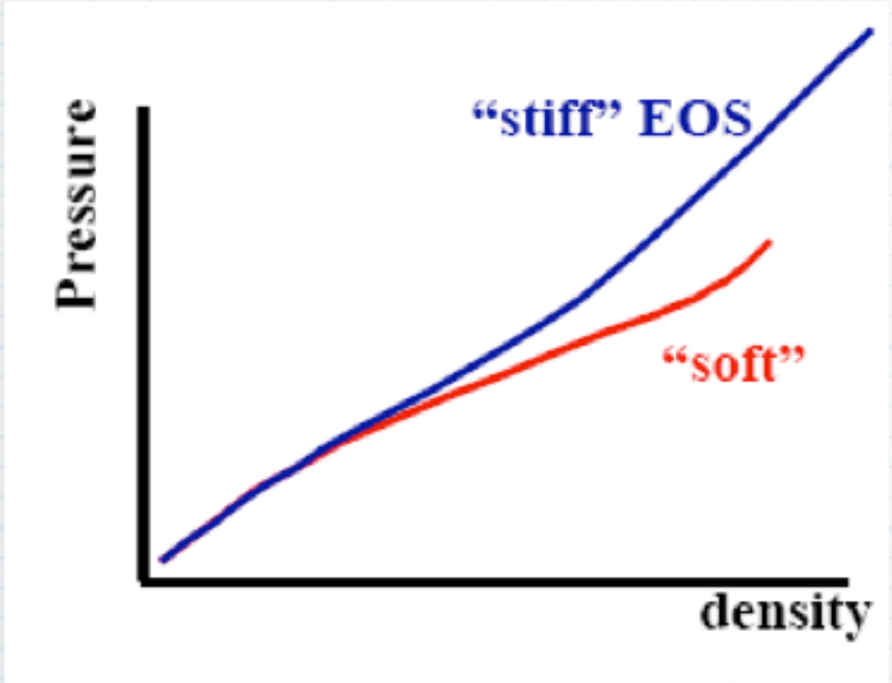
MODELING NEUTRON STARS



Source : Neutrons stars and pulsars (W. Becker)

- *Astrophysics*
- *General Relativity*
- *Atomic Physics*
- *Nuclear Physics*
- *Particle Physics*
- *Condensed Matter Physics*

Equation of state (EoS)



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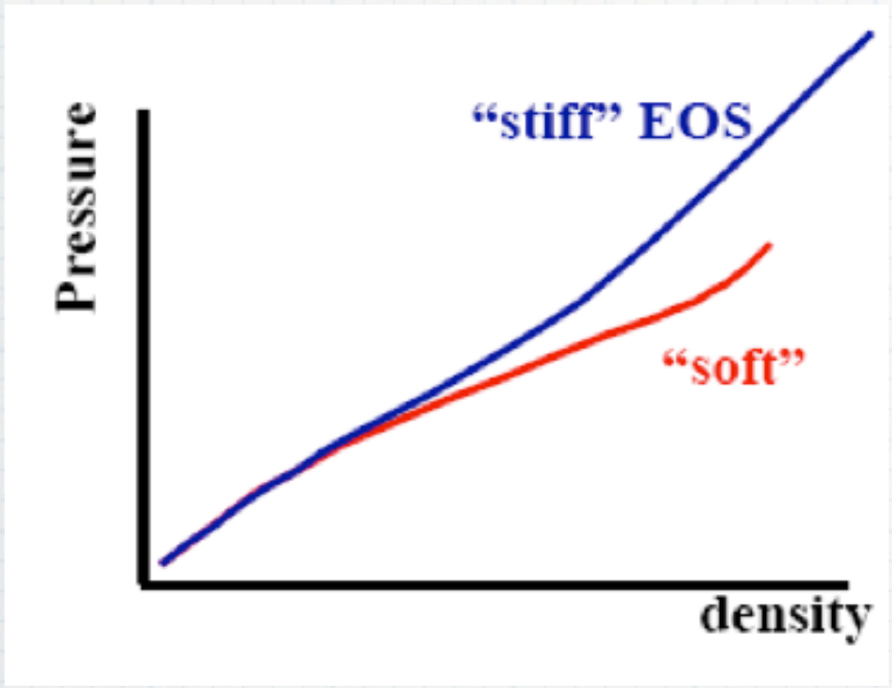

Tolman-Oppenheimer-Volkov equations of relativistic hydrostatic equilibrium:

$$\frac{dp}{dr} = -\frac{G}{c^2}\frac{(m+4\pi pr^3)(\epsilon+p)}{r(r-2Gm/c^2)}$$

$$\frac{dm}{dr} = 4\pi\frac{\epsilon}{c^2}r^2$$

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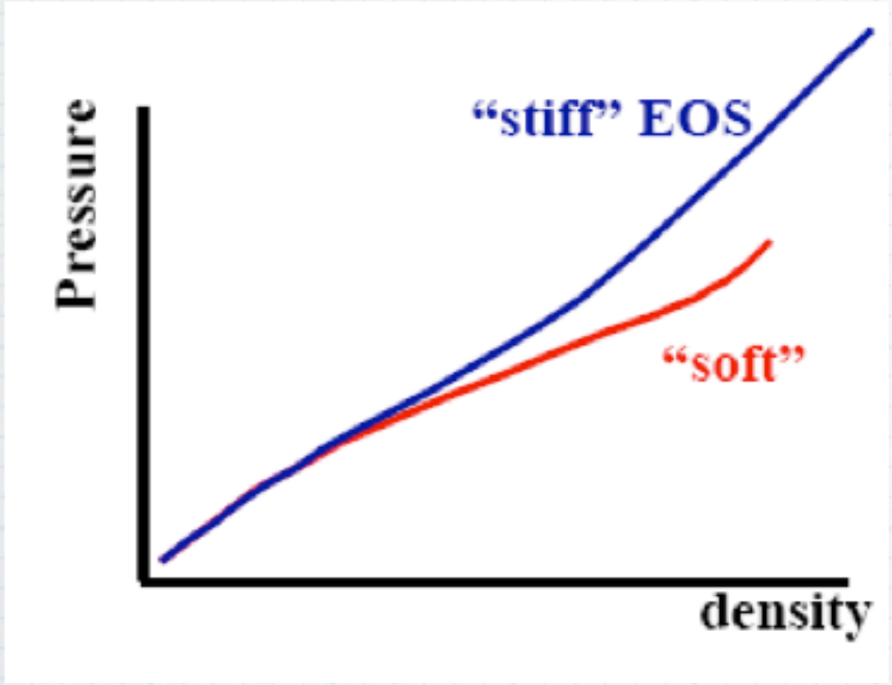

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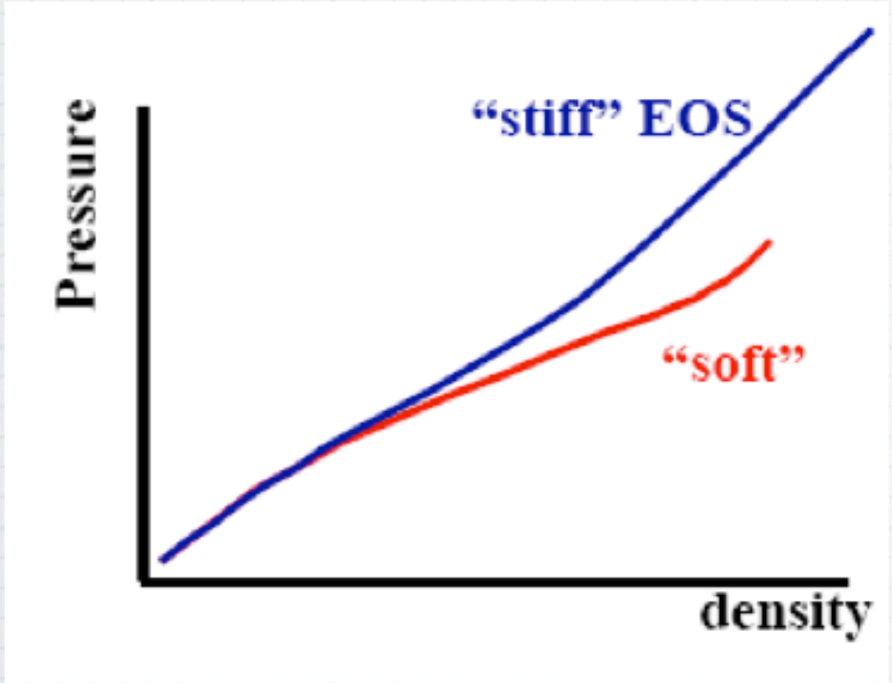

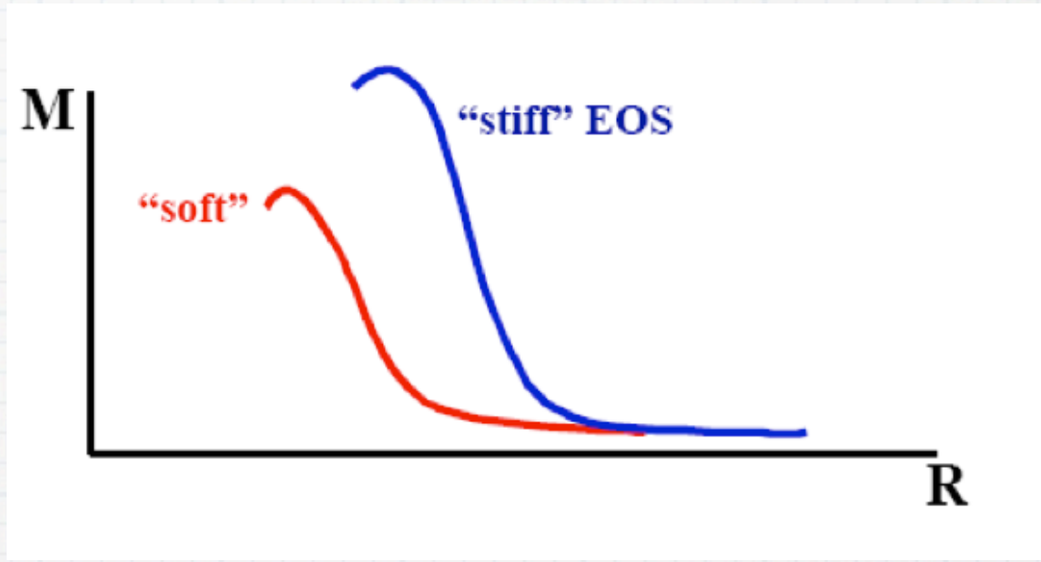

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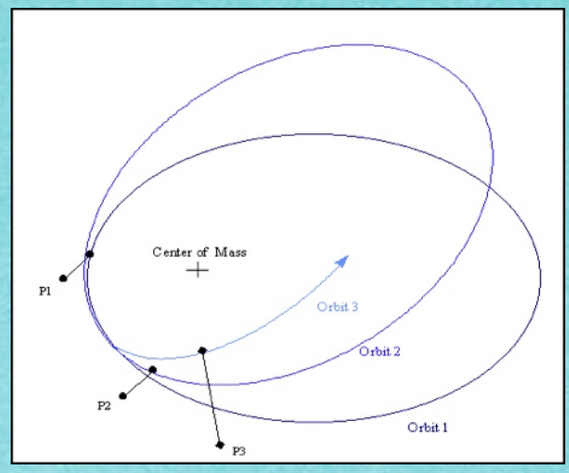
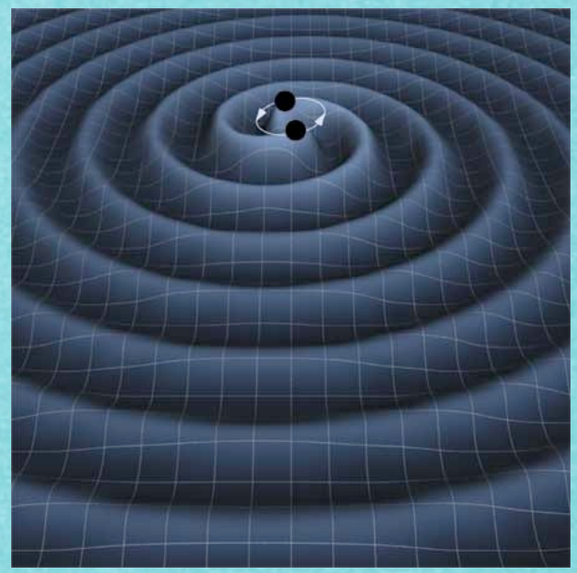
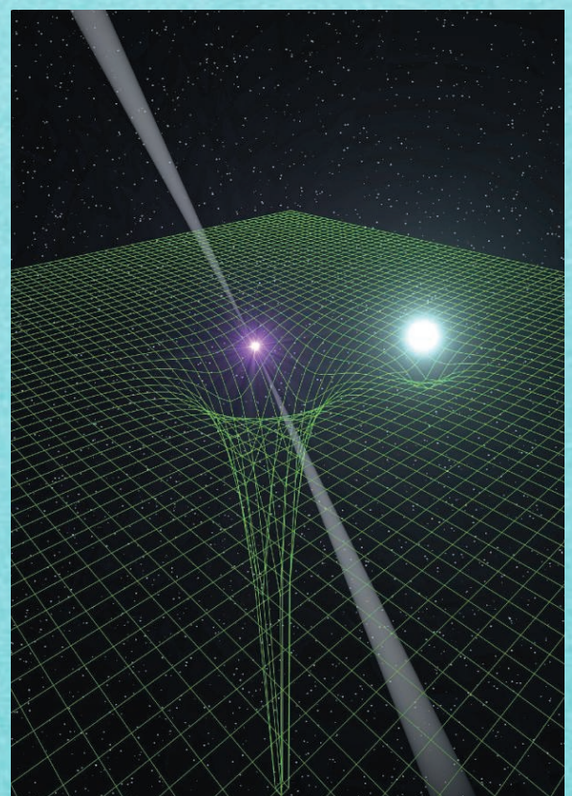
Neutron stars in Relativistic binaries

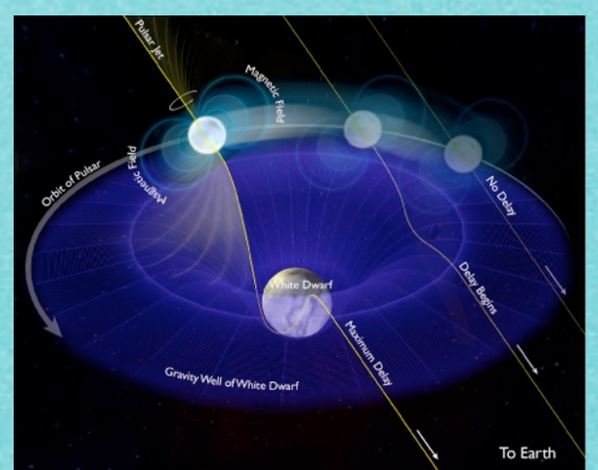
Post-Keplerian Parameters

- *Relativistic advance of periastron $\dot{\omega}$*
- *Gravitational redshift and time dilation γ*
- *Orbital decay in period $\dot{P}_b$*
- *Shapiro time delay (range r and shape s)*









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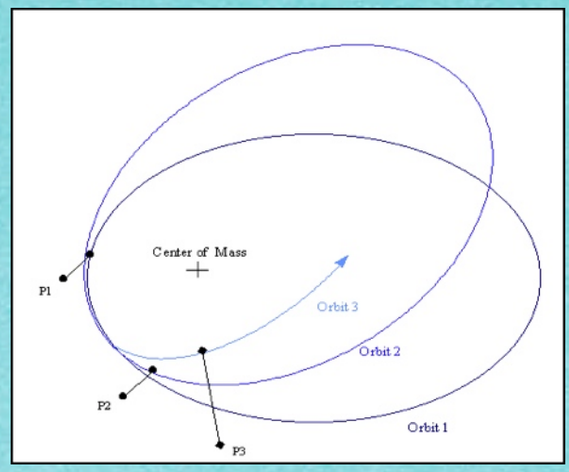

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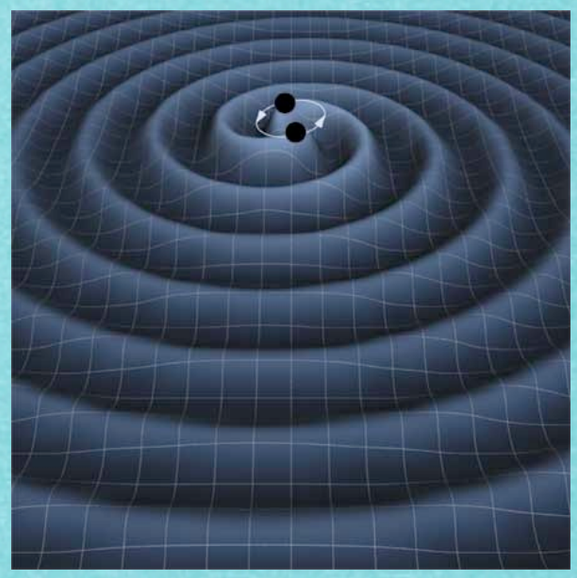
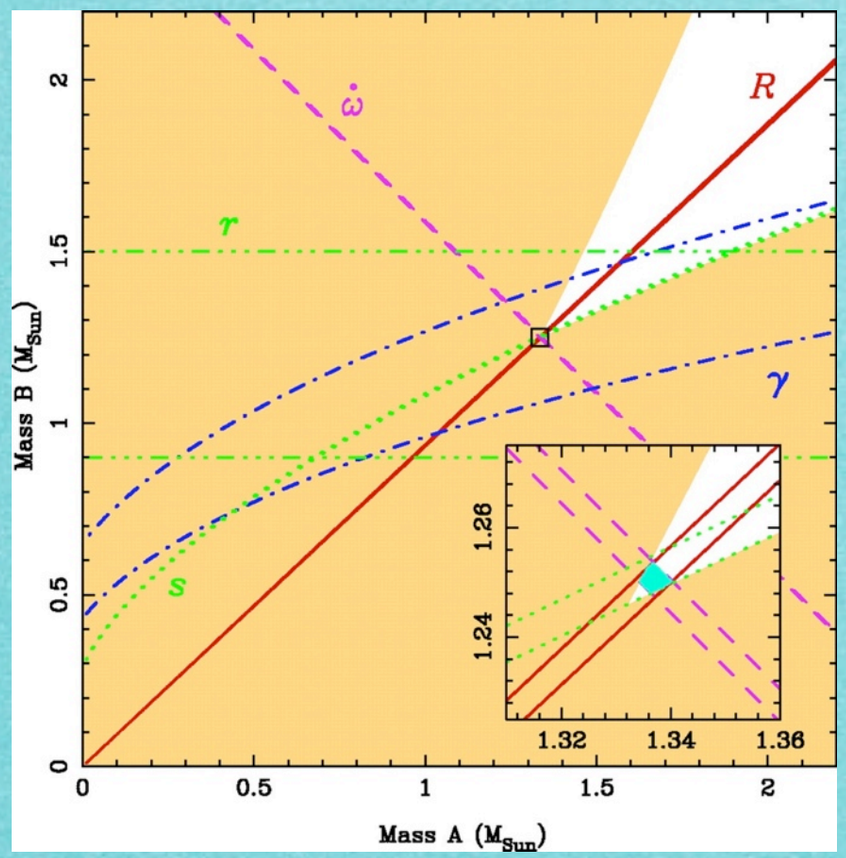
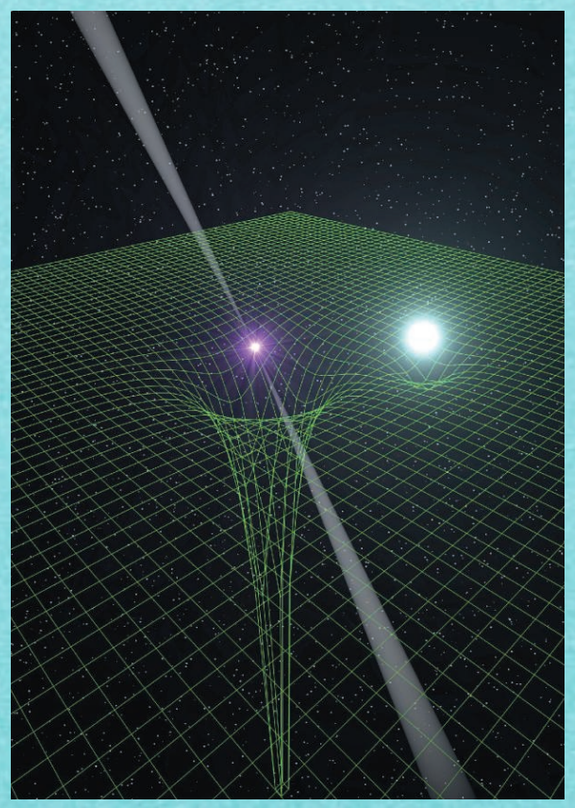
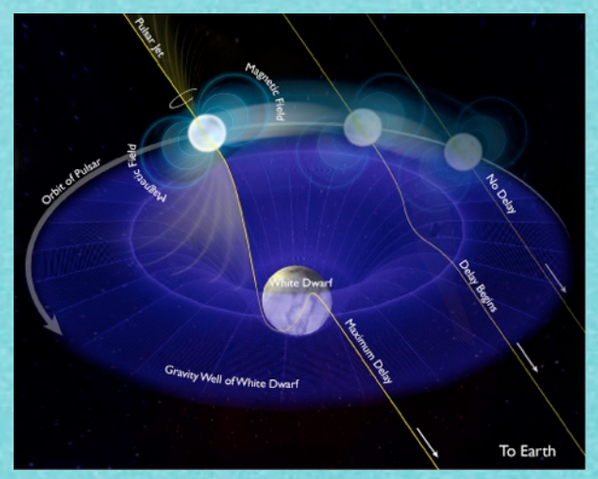


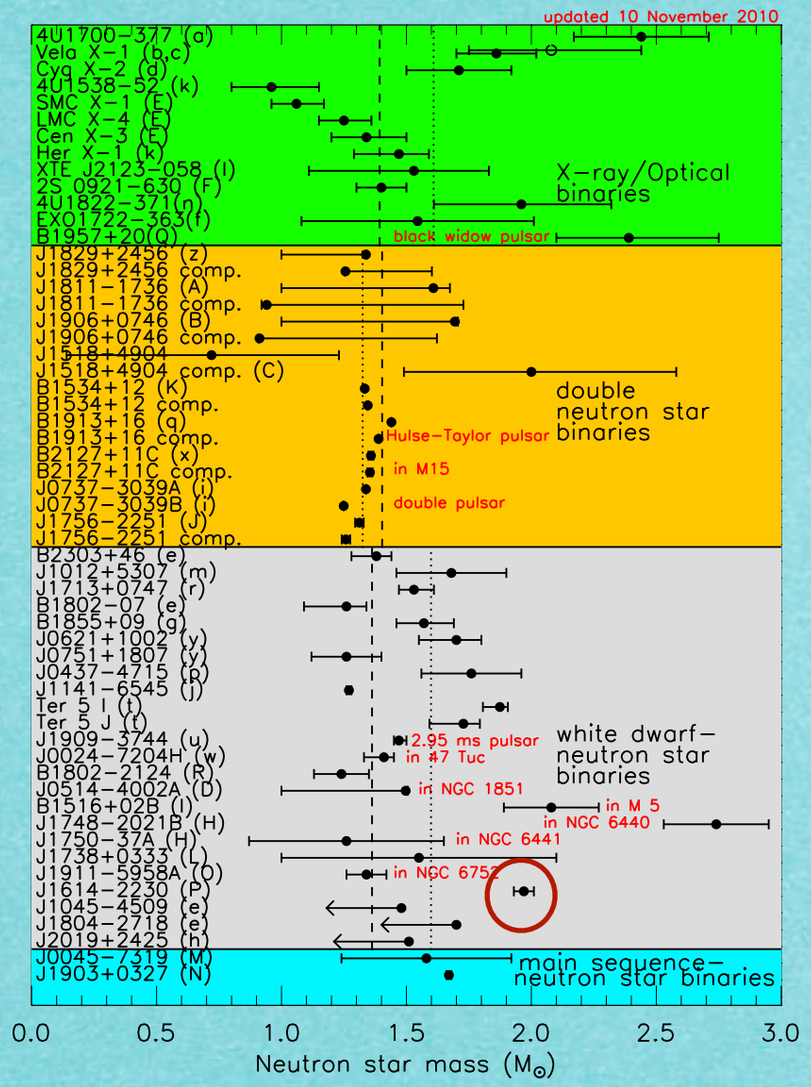


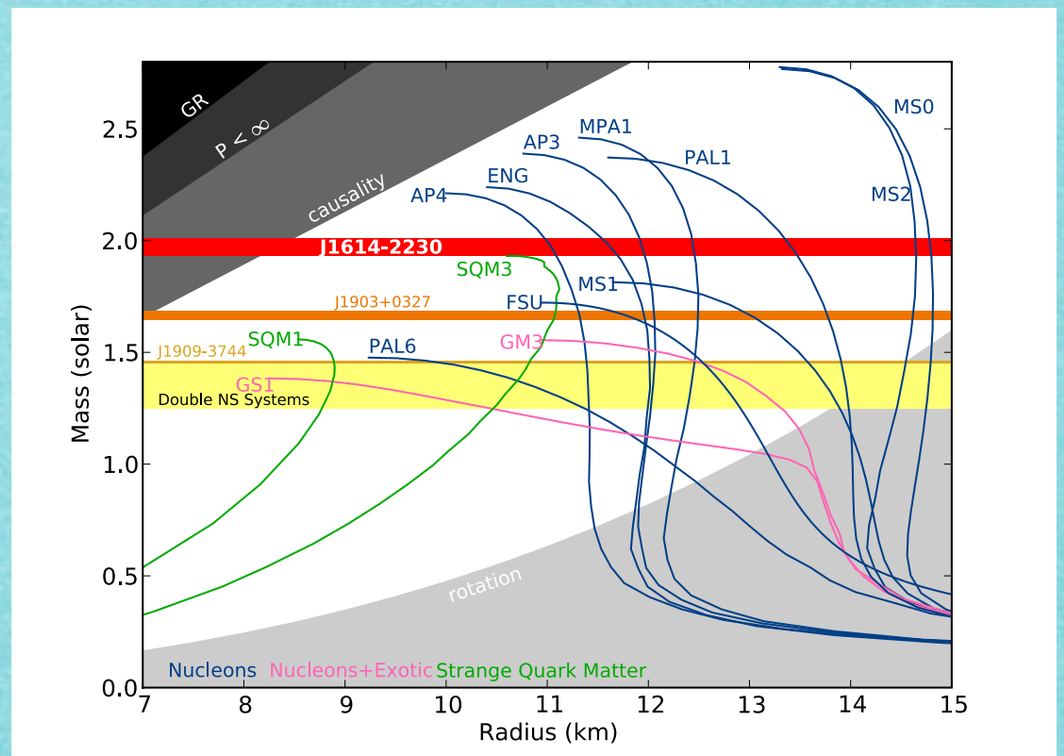




Constraining the EoS

$$M^{max}(theo) > M^{max}(obs)$$



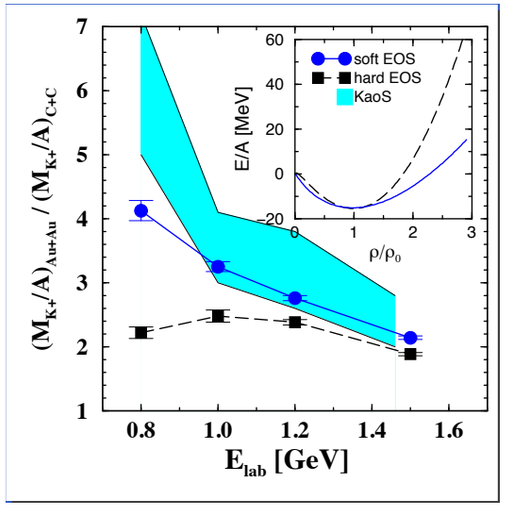


Lattimer and Prakash, arXiv:1012.3208

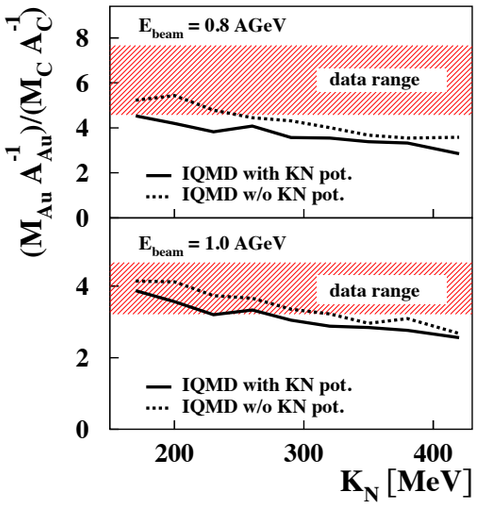
Soft equation of state from heavy-ion data

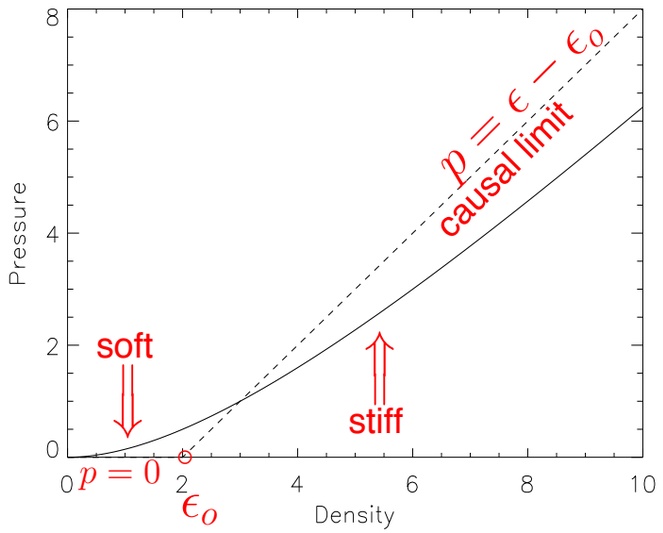
KaoS experiment,
GSI Darmstadt

Hartnack, Oeschler, Aichelin, PRL 2006

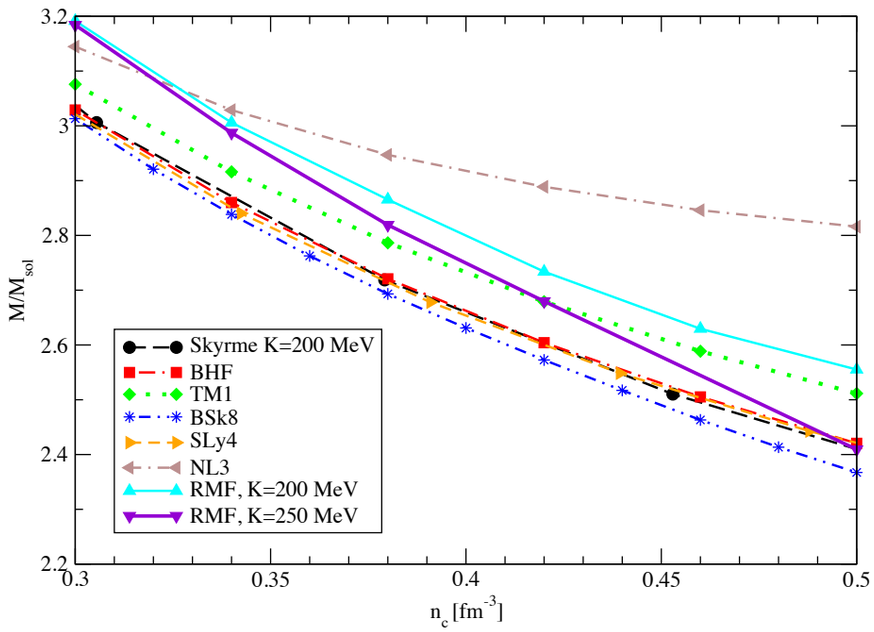


Sturm et al. (KaoS collaboration), PRL 2001





Lattimer, GSI, 2010



I. Sagert, C. Sturm, D. C., L.Tolos and J. Schaffner-Bielich, 2012, Phys. Rev. C 85, 065802

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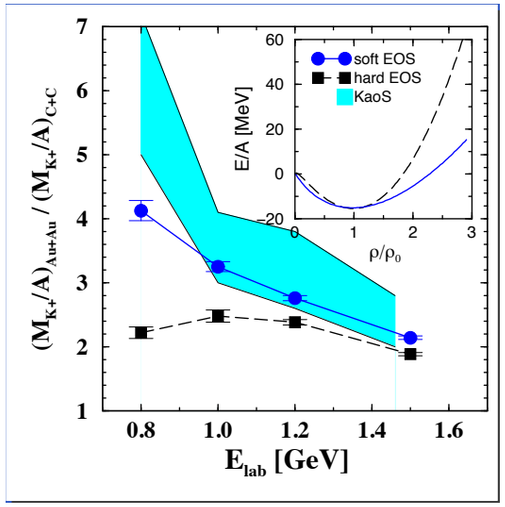

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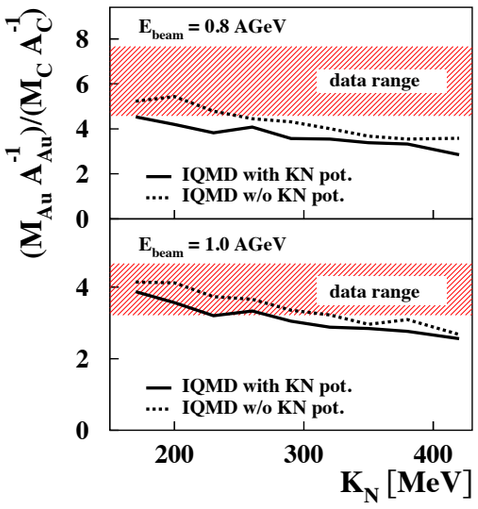

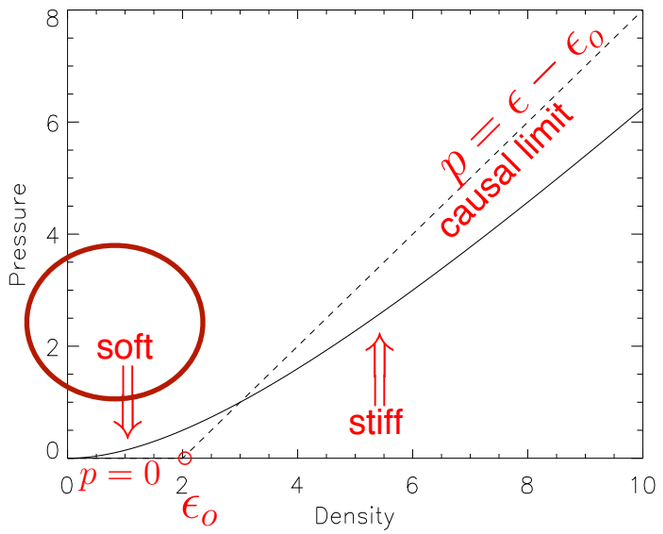

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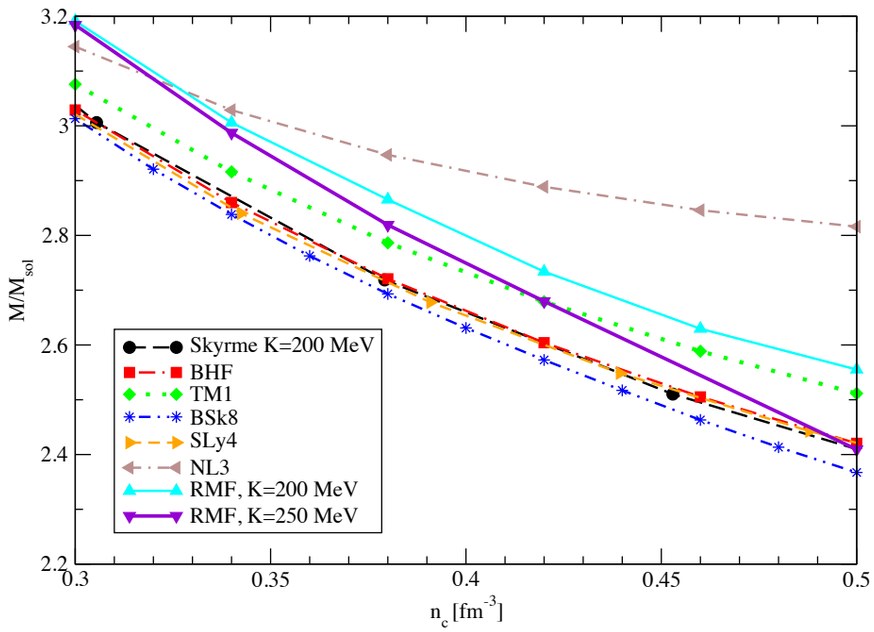

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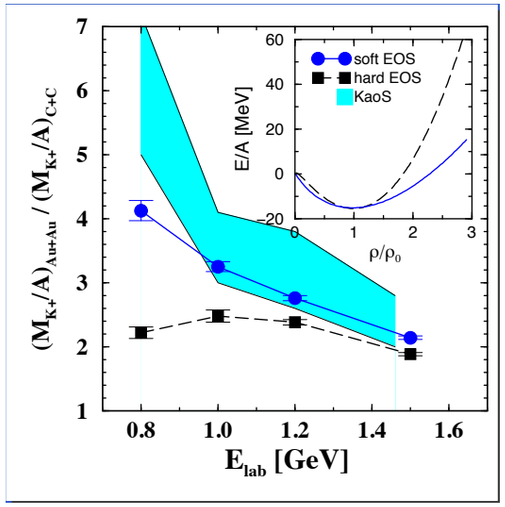

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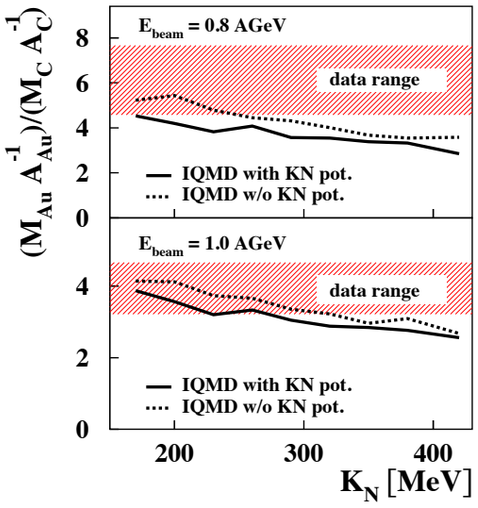

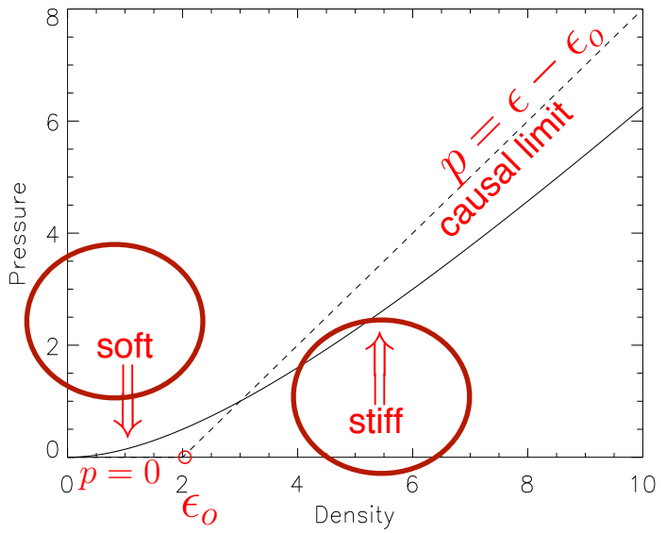

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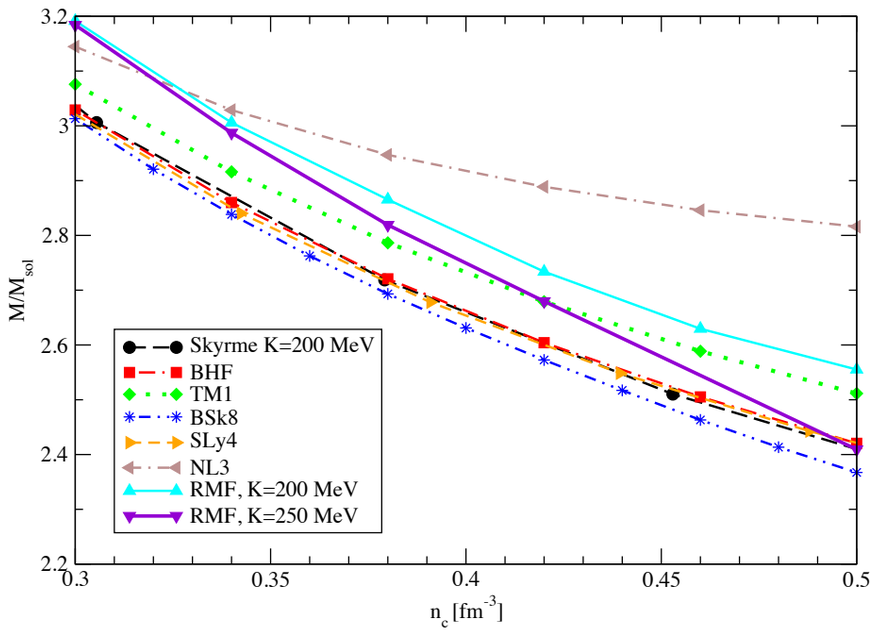

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Neutron Star Oscillations : Asteroseismology

Non-radial Oscillations:
f-modes: fundamental
g-modes: buoyancy
p-modes: pressure
R-modes: Coriolis force
w-modes: space-time

G W detectors

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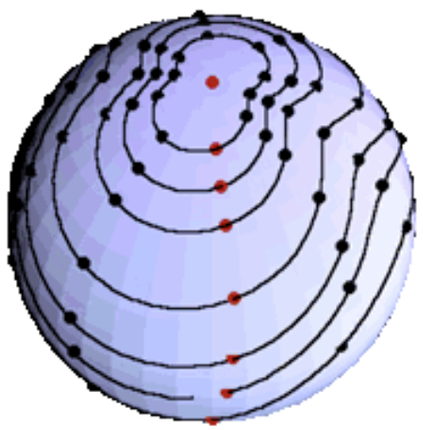
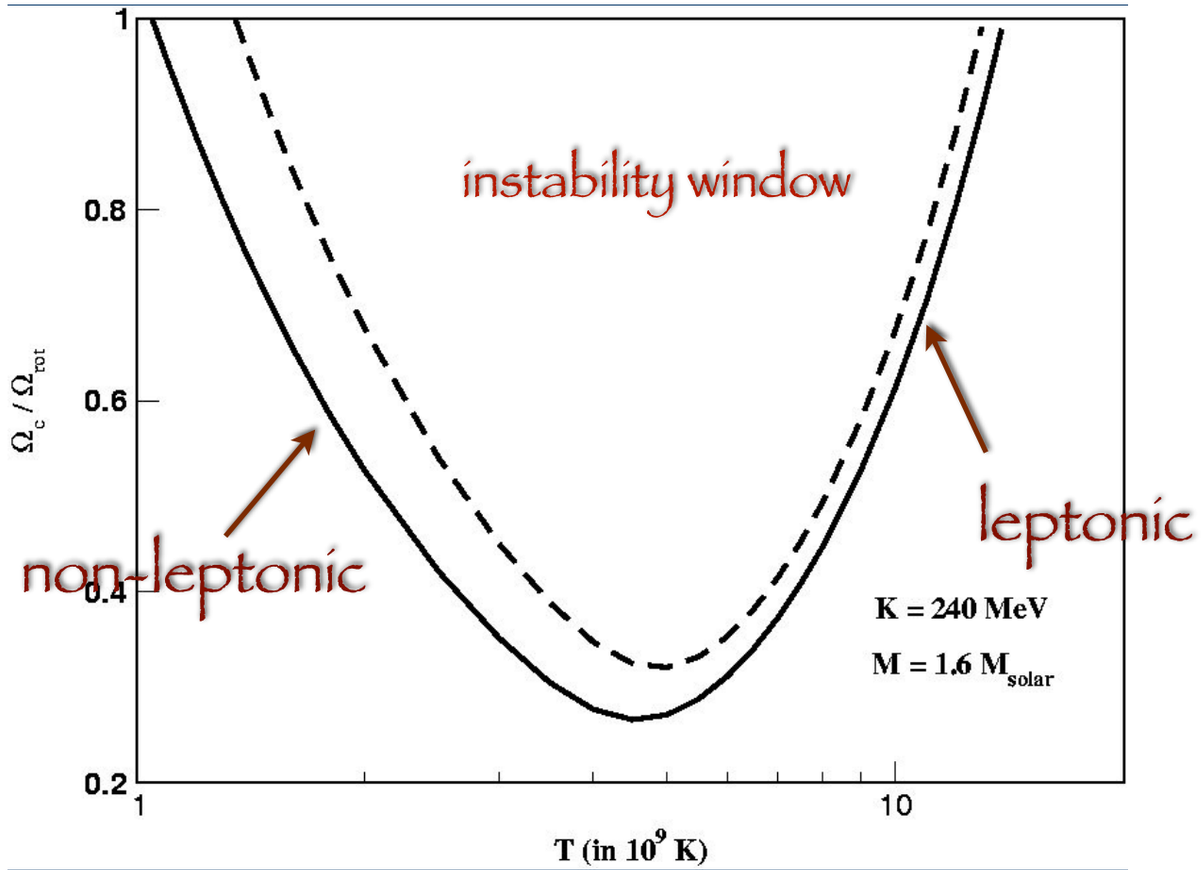


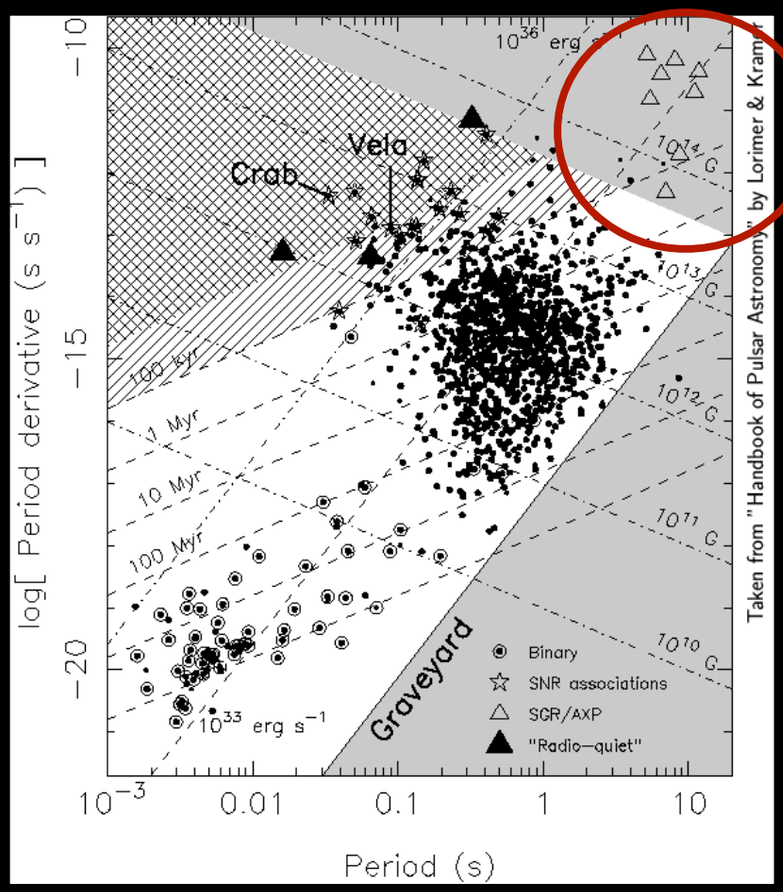
R-mode



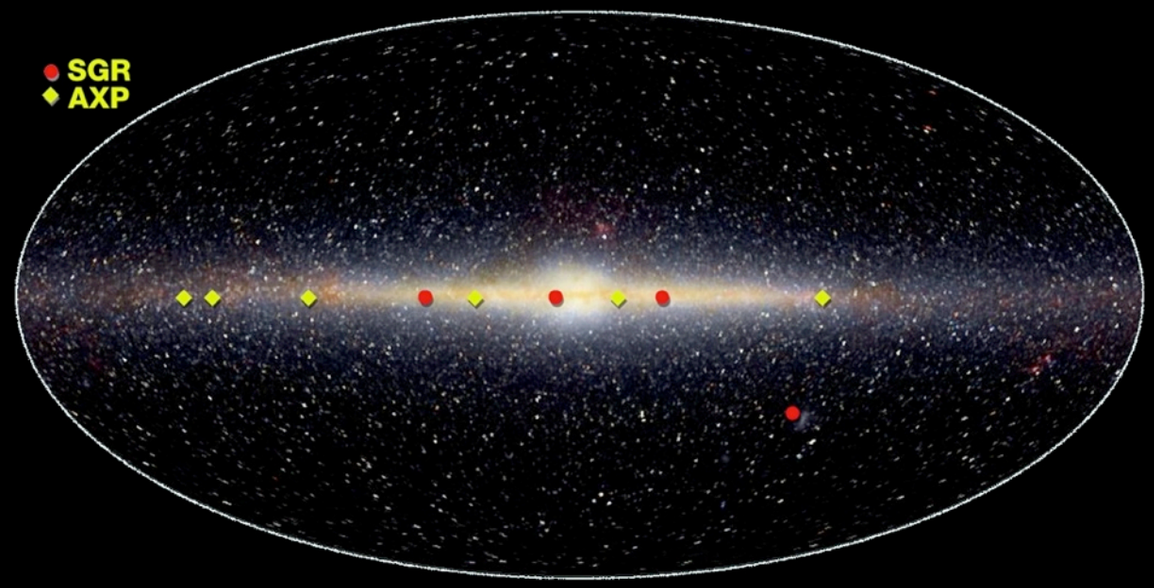
D.C. and D. Bandyopadhyay, Phys. Rev. D 74 (2006) 023003

Magnetars

Ultra strong magnetic field $B \sim 10^{15}$ G



Known magnetar candidates



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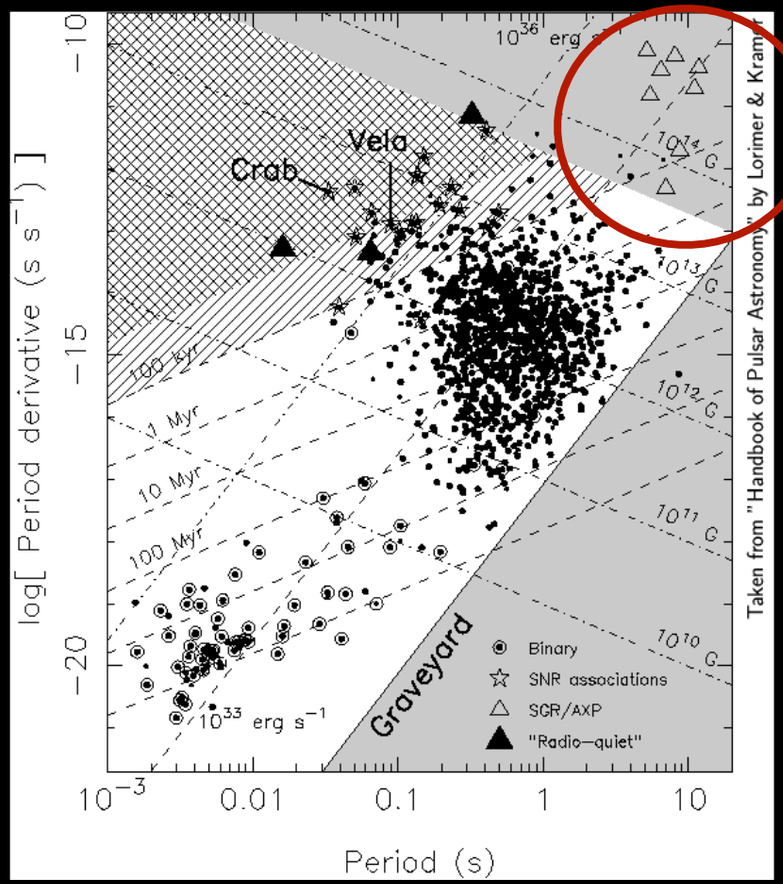
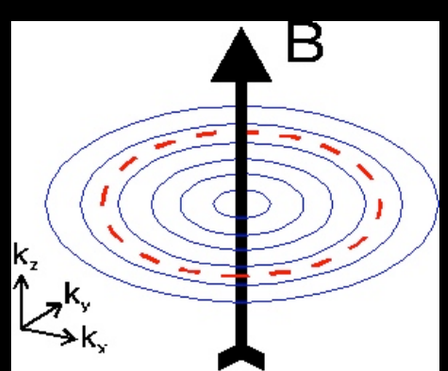
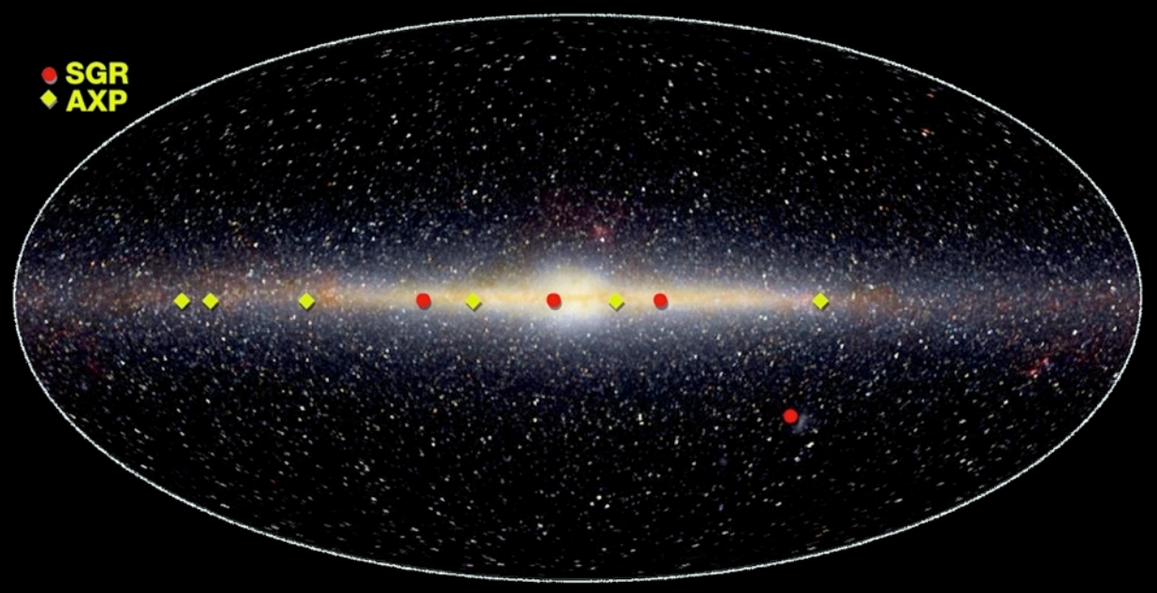
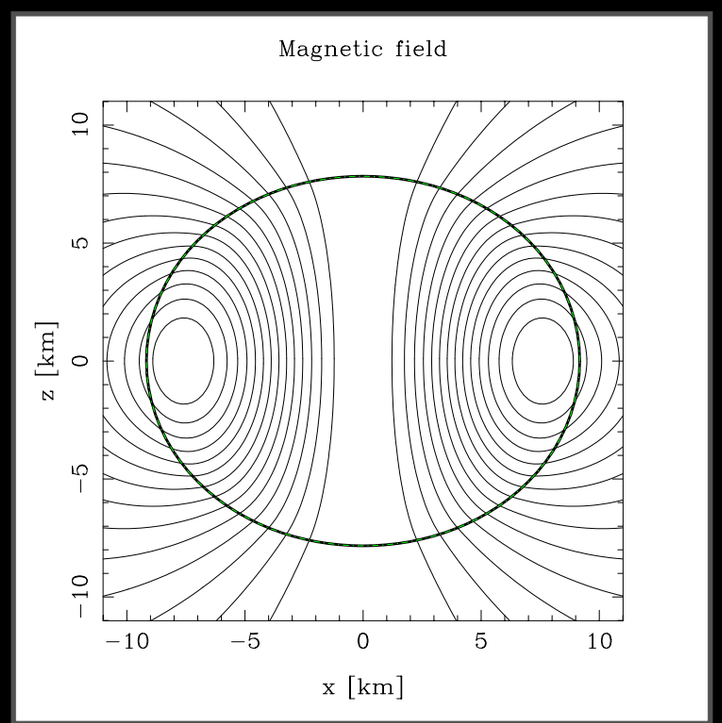
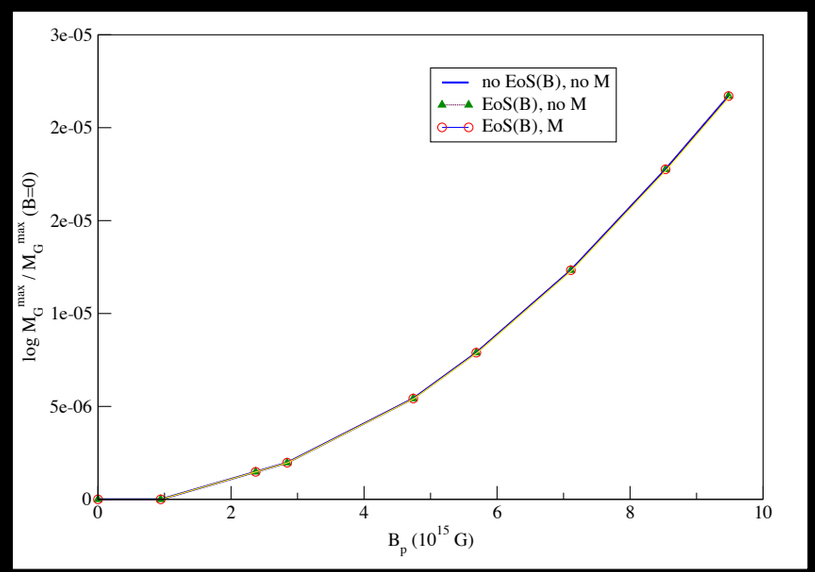




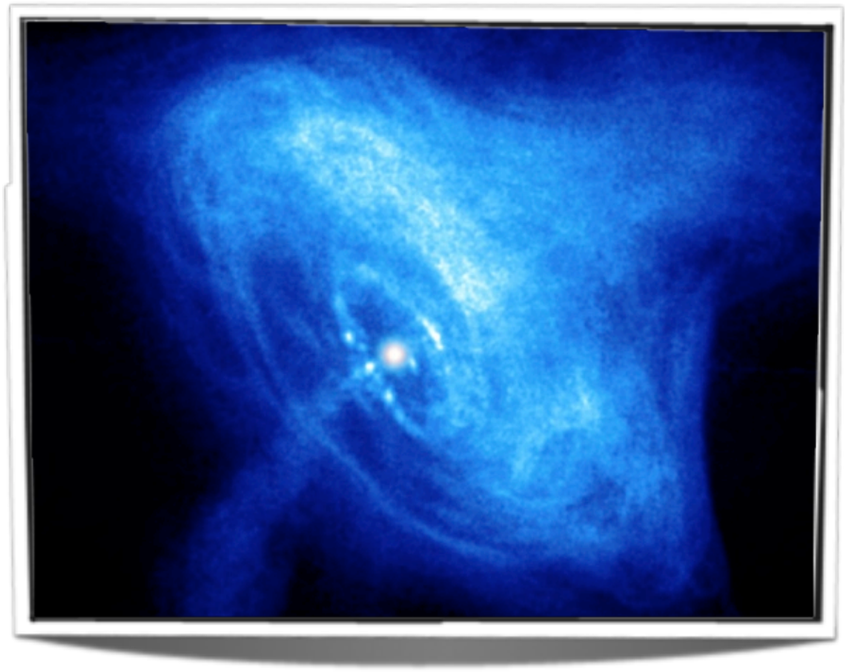






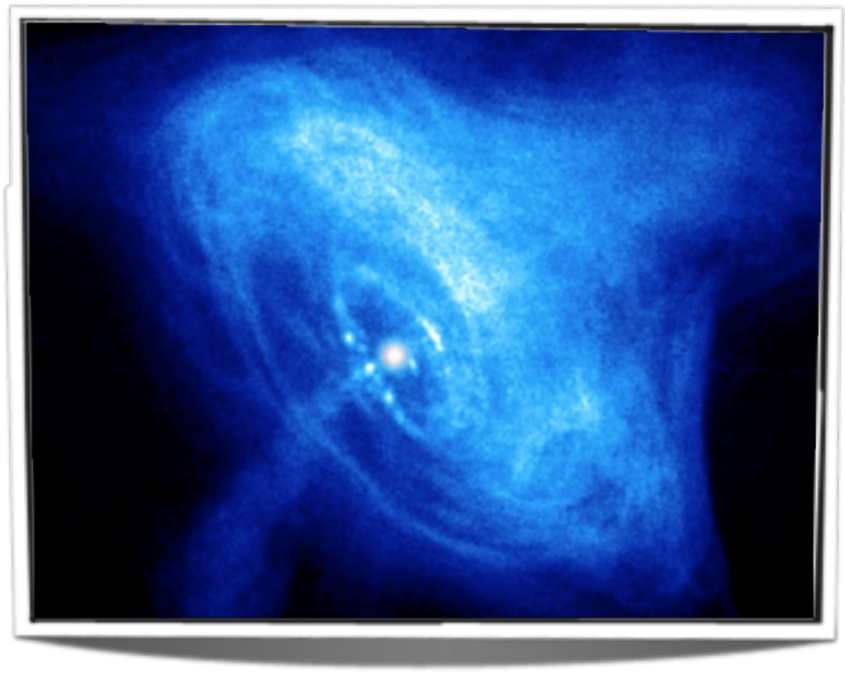
D.C., M. Oertel and J. Novak, in preparation

Neutron stars are perfect astrophysical laboratories for ..



- Composition of cold and dense matter
- tests of general relativity
- oscillation modes and gravitational waves
- physics in ultra strong magnetic fields
- ....

Neutron stars are perfect astrophysical laboratories for ..



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Thank you!