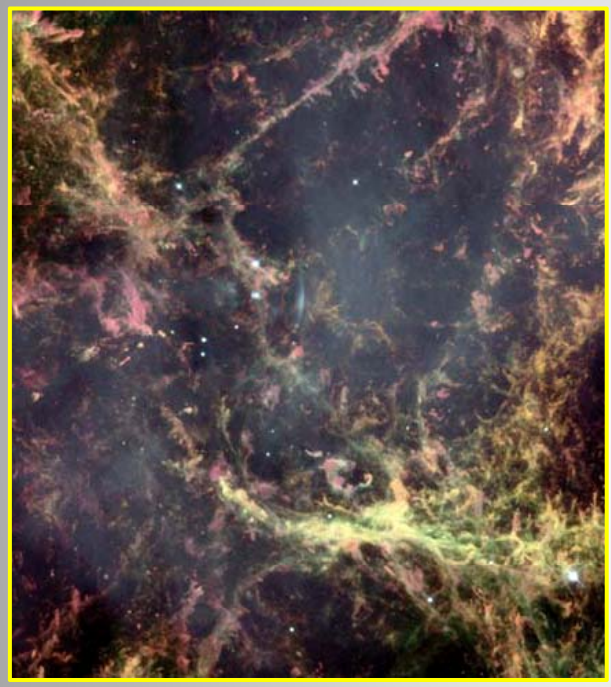
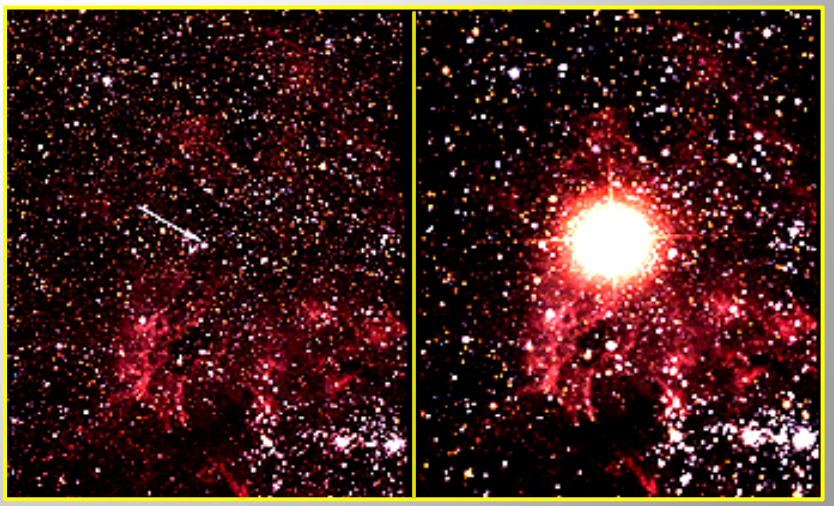
Theory Group at the University of Milano

Nuclear Astrophysics of Compact Stars



Neutron stars, the most exotic nuclear lab in the Universe



Pierre Pizzochero

EJC 2009

Lacanau, 28/9-3/10/09

Plan of the lecture

- **What are neutron stars?** Observed properties and inferred physical conditions in their interior.
- **Why stars made of neutrons?** Gravitational instability of degenerate fermions and neutronization of matter during gravitational collapse.
- **How exotic is their nuclear structure?** From the superfluid crust to the ultra-dense core: expected properties of hadronic matter with increasing density.
- **Which observations could be relevant to nuclear physics?** Three examples: maximum mass, surface cooling and pulsar glitches.
- **What could we learn about?** Some hot items: EOS of dense bulk matter, nucleon superfluidity, exotic nuclei below and above neutron drip.

Neutron stars and observations

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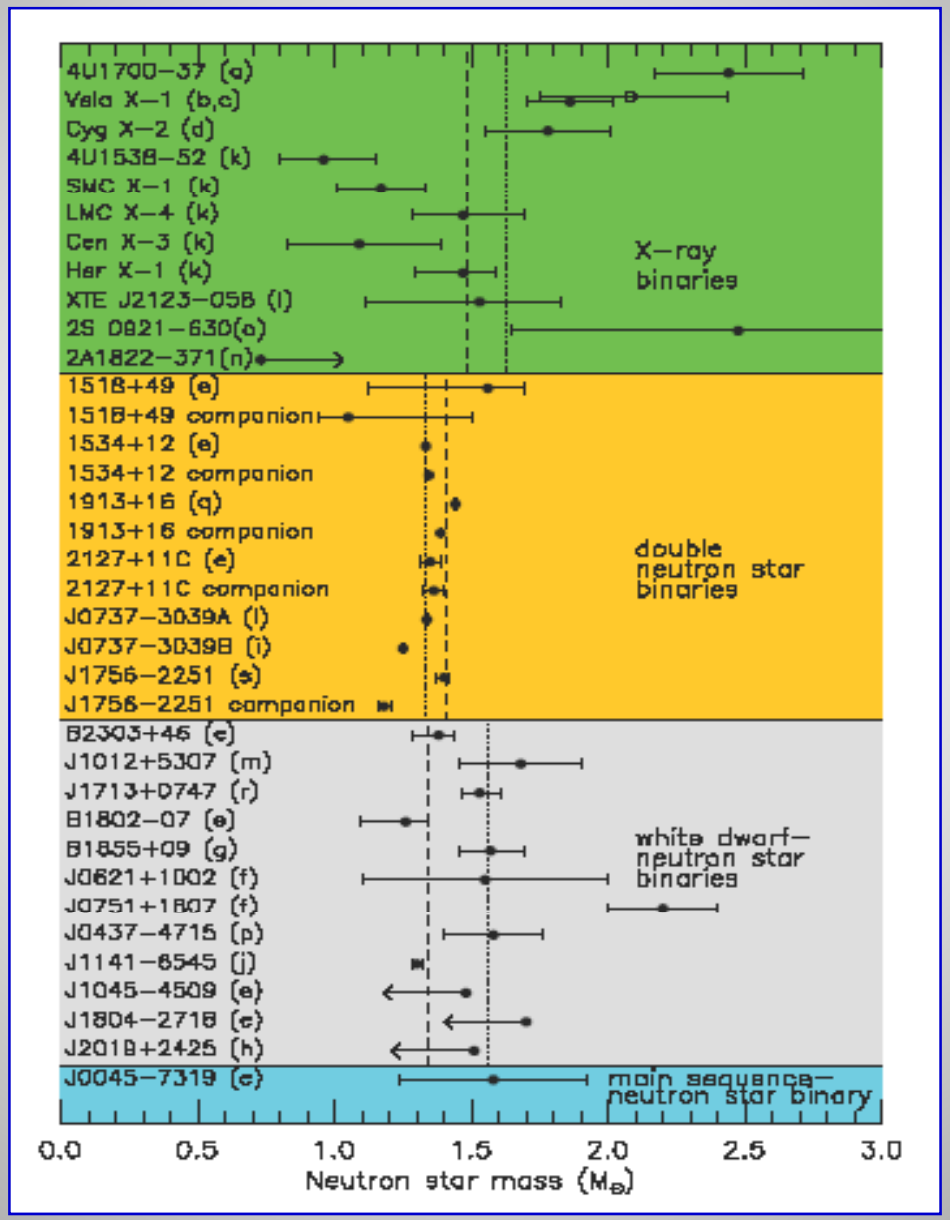
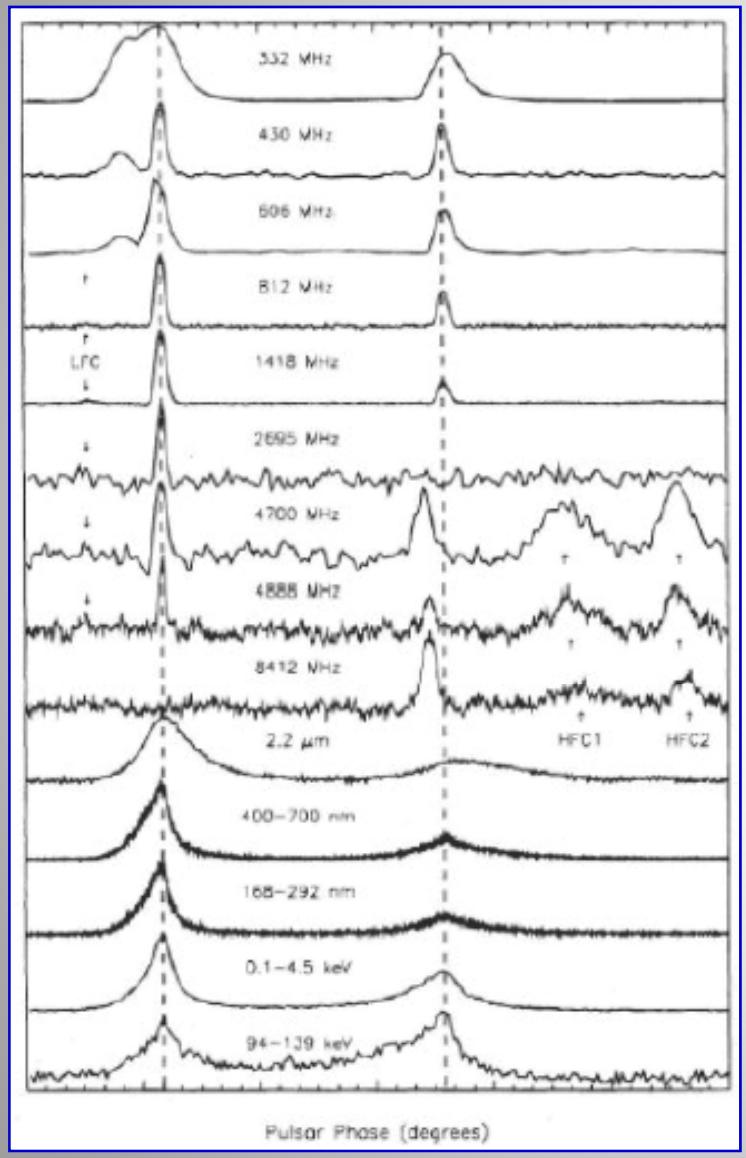
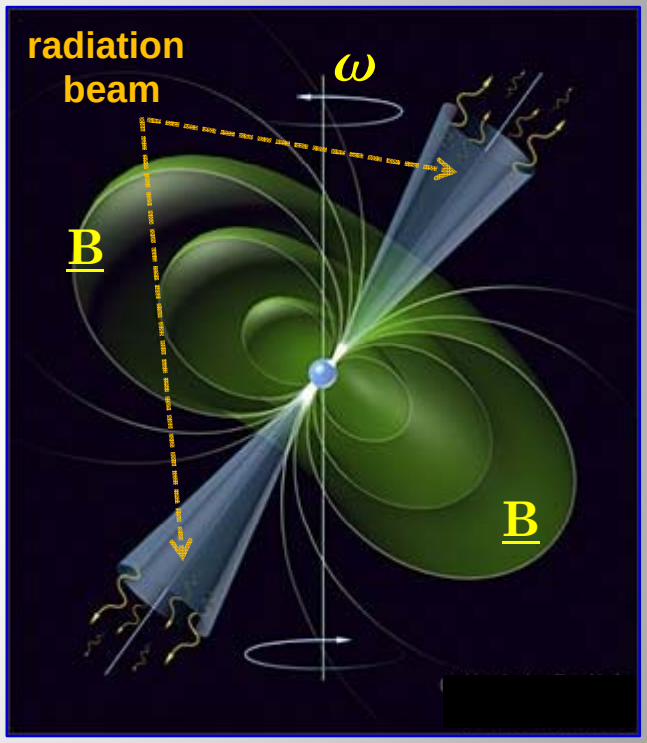


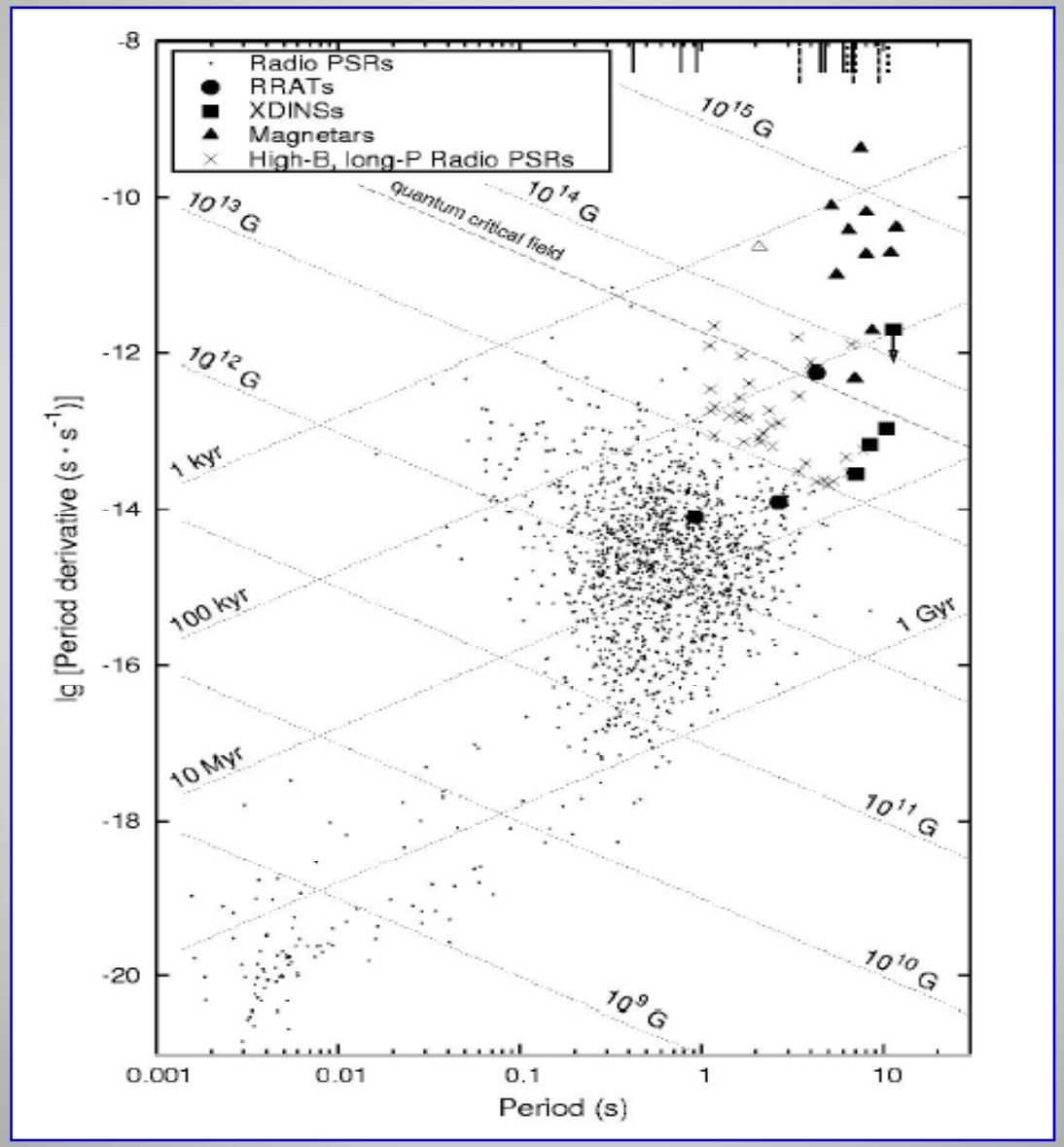
Neutron stars and observations





Lighthouse model

Neutron stars and observations



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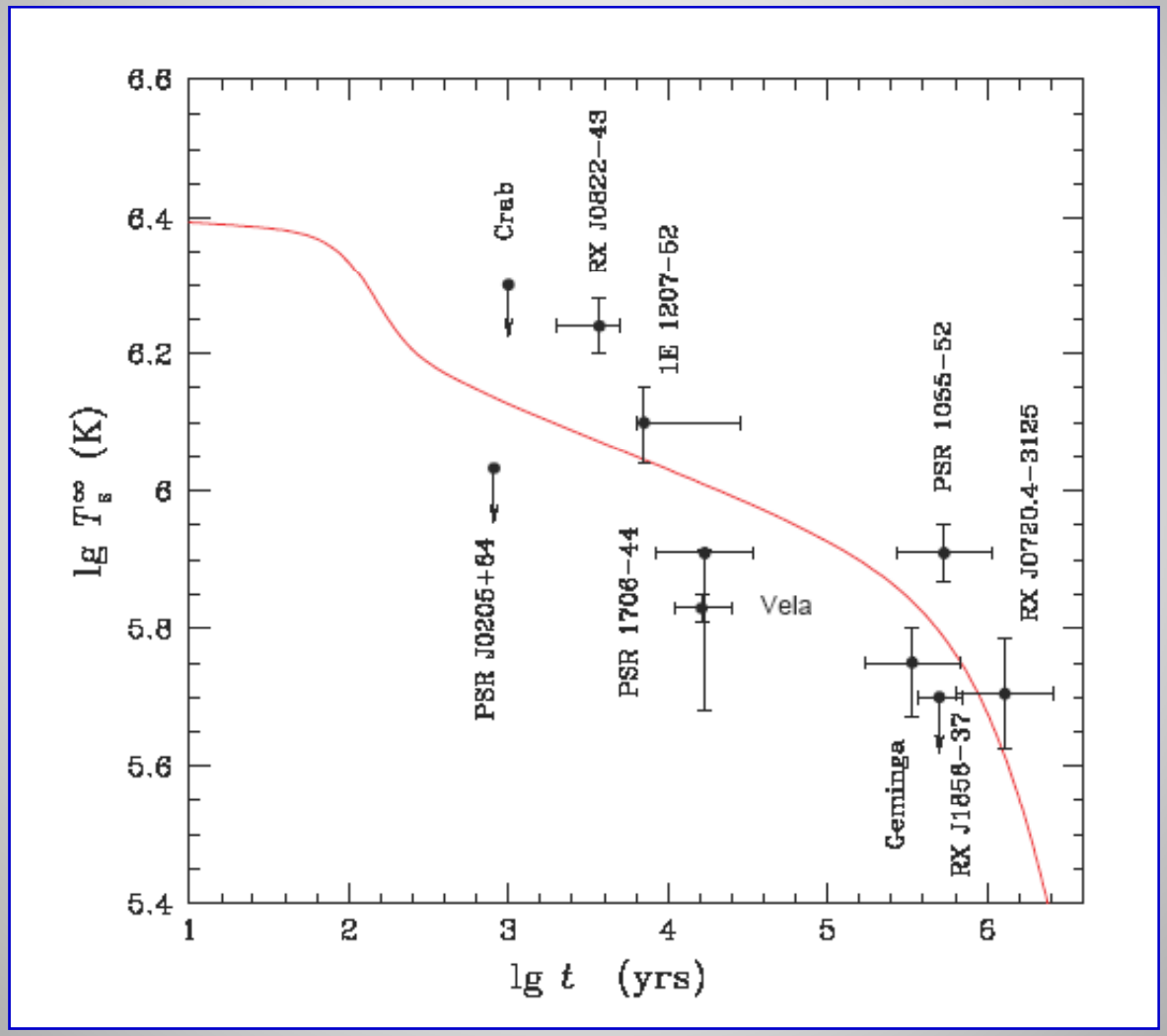
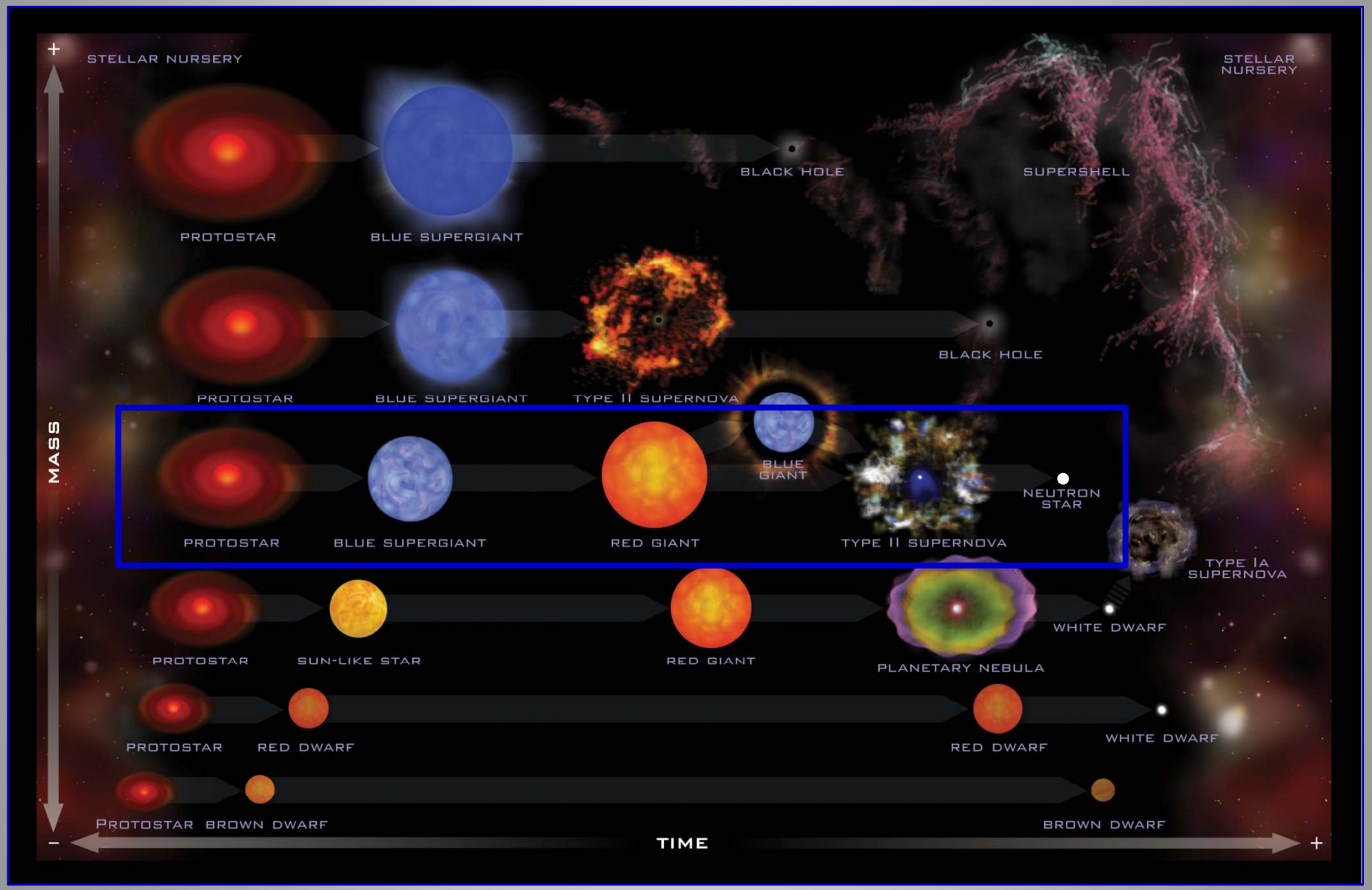
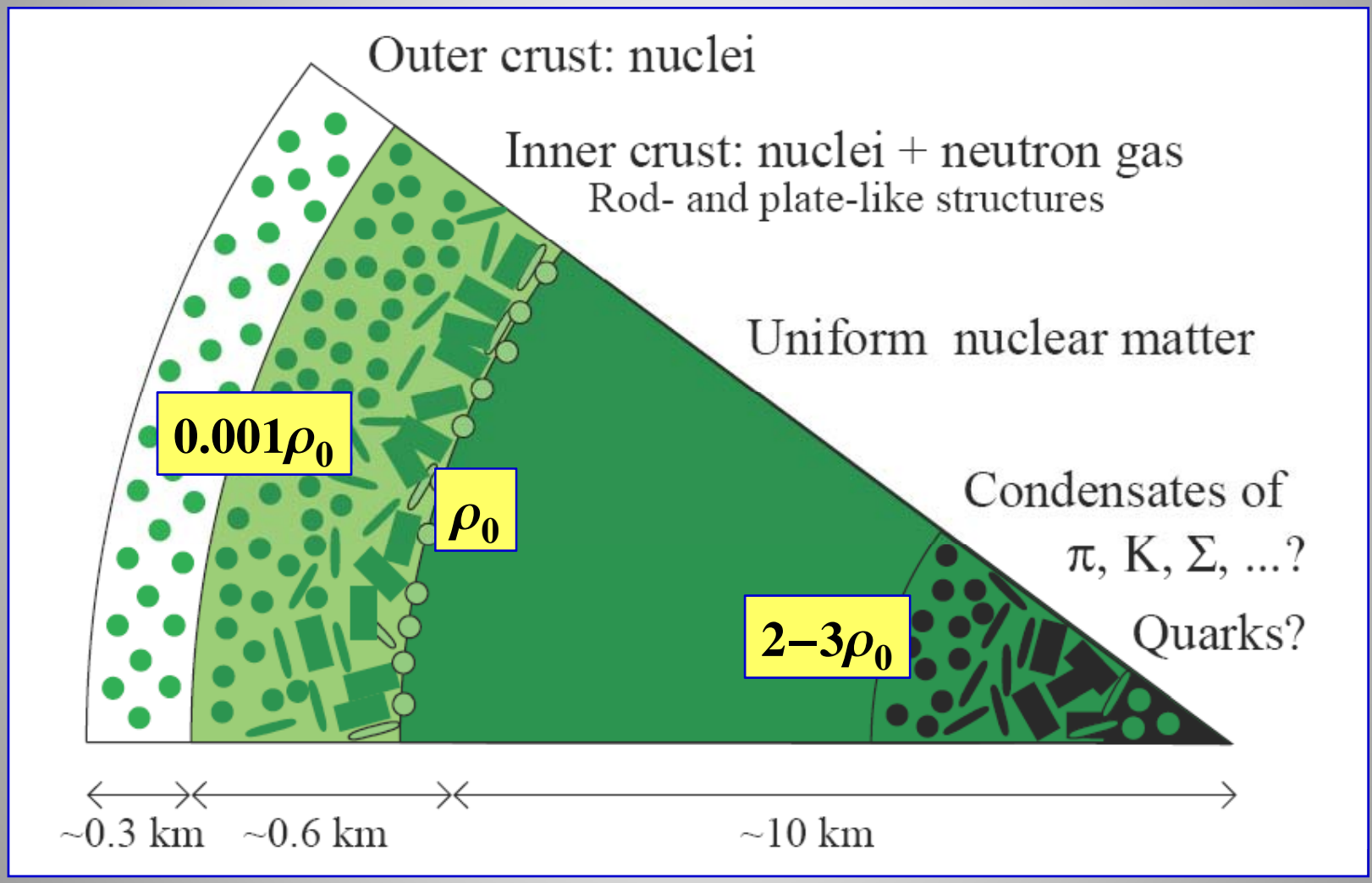


The origin of neutron stars



Internal structure of neutron stars



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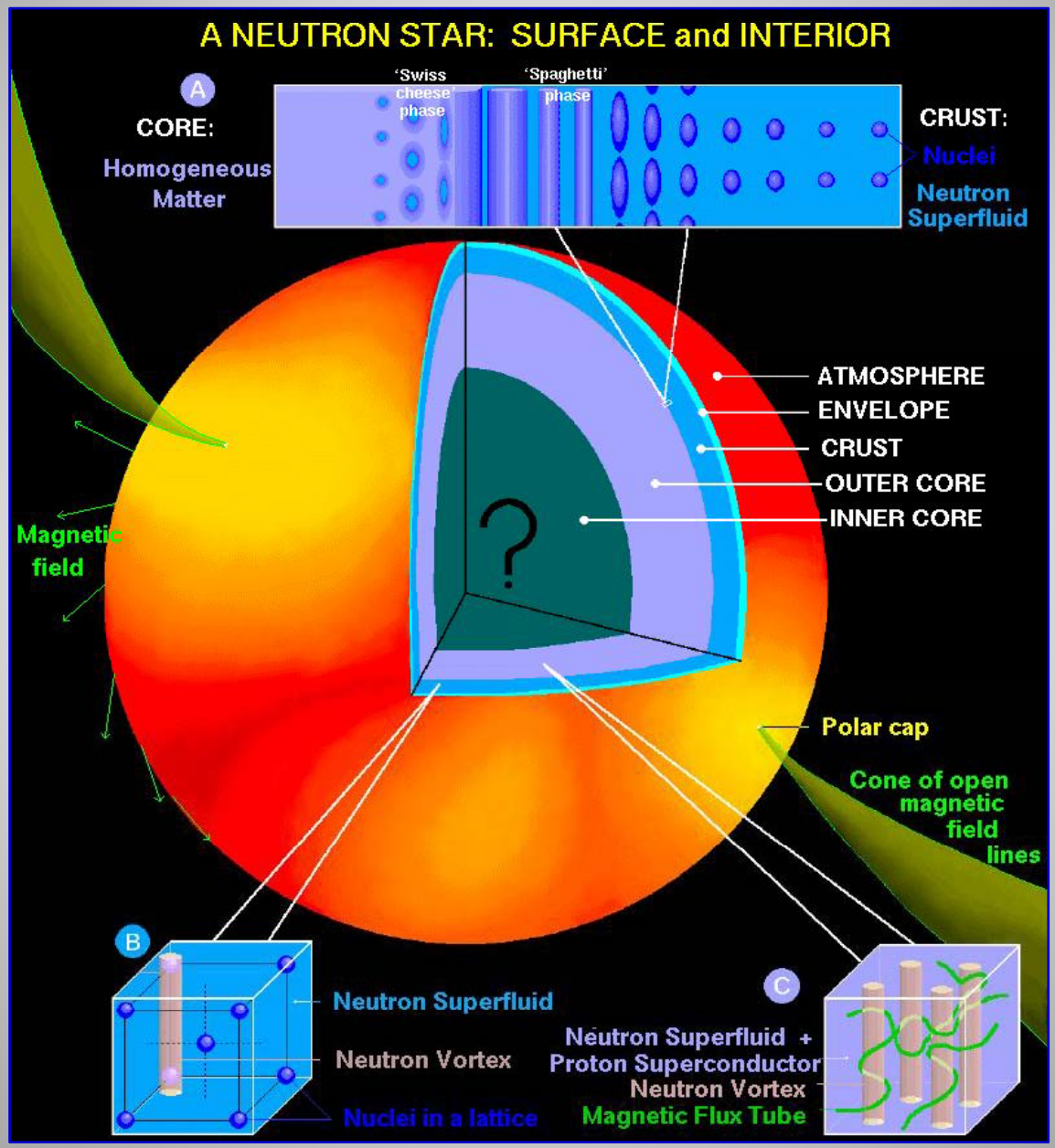

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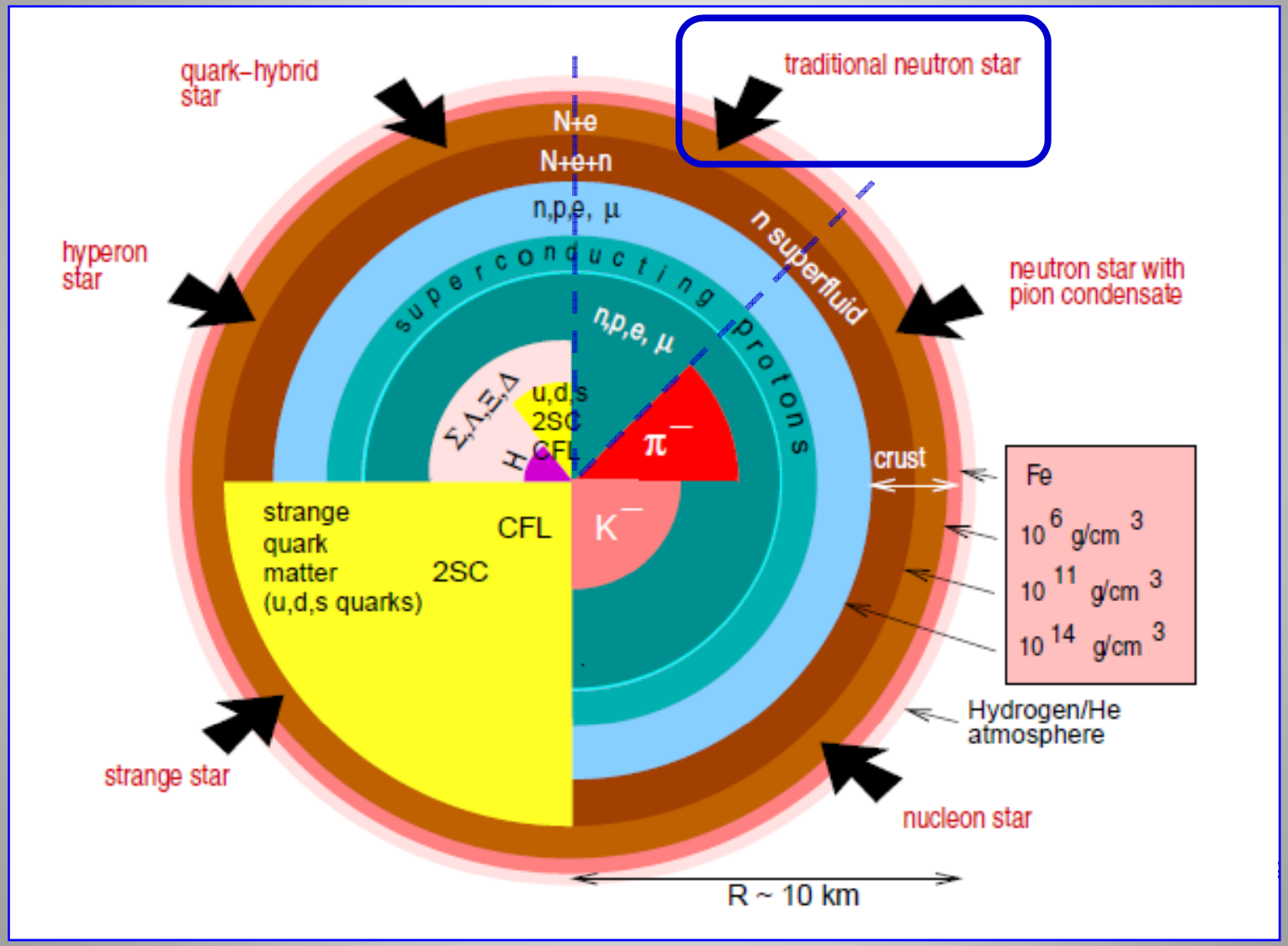


Cooling of neutron stars

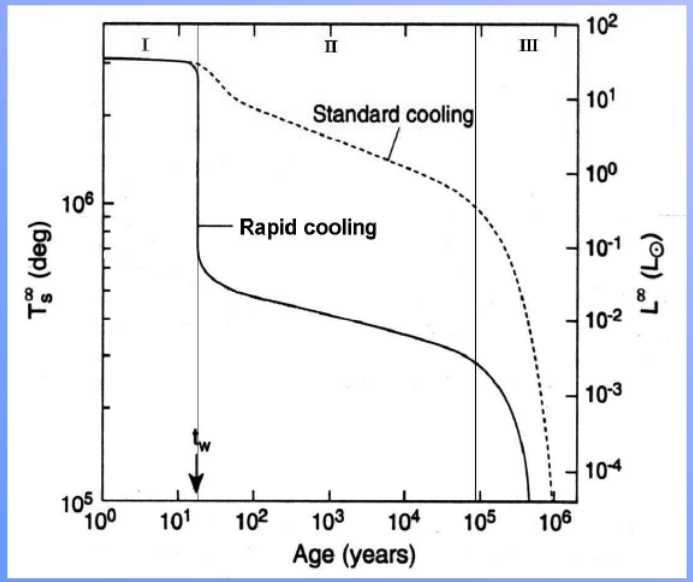
Cooling scenarios: depend on the physics and constitution of NS core ⇒ diagnostic tool

Standard
(low core density)

low mass NS with stiff EOS

Rapid or **exotic**
(high core density)

high mass NS or
low mass NS with soft EOS

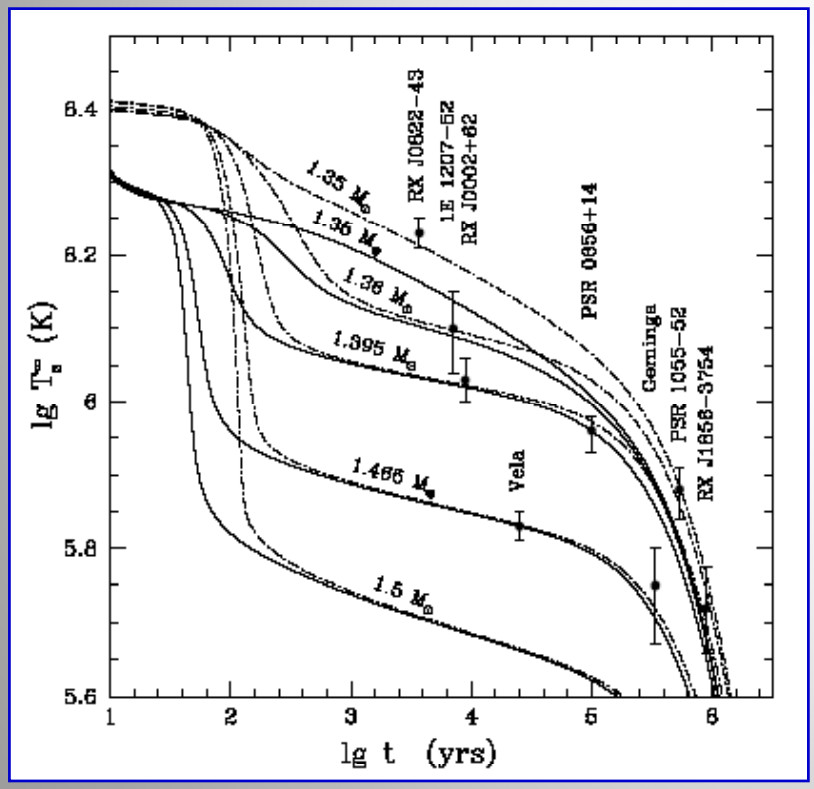


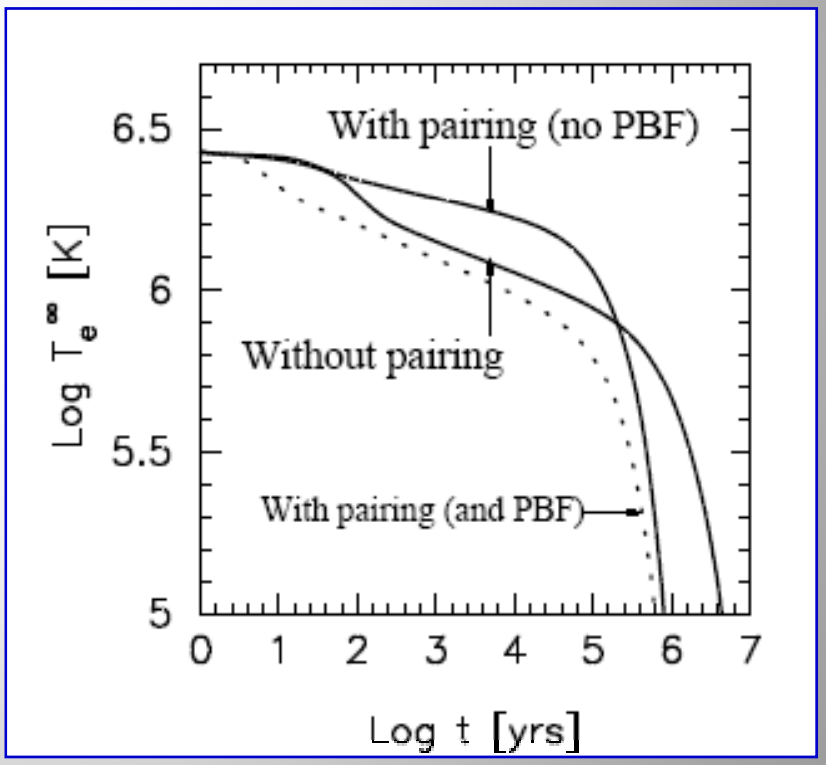
I. Core relaxation epoch
II. Neutrino cooling epoch
III. Photon cooling epoch

Cooling of neutron stars

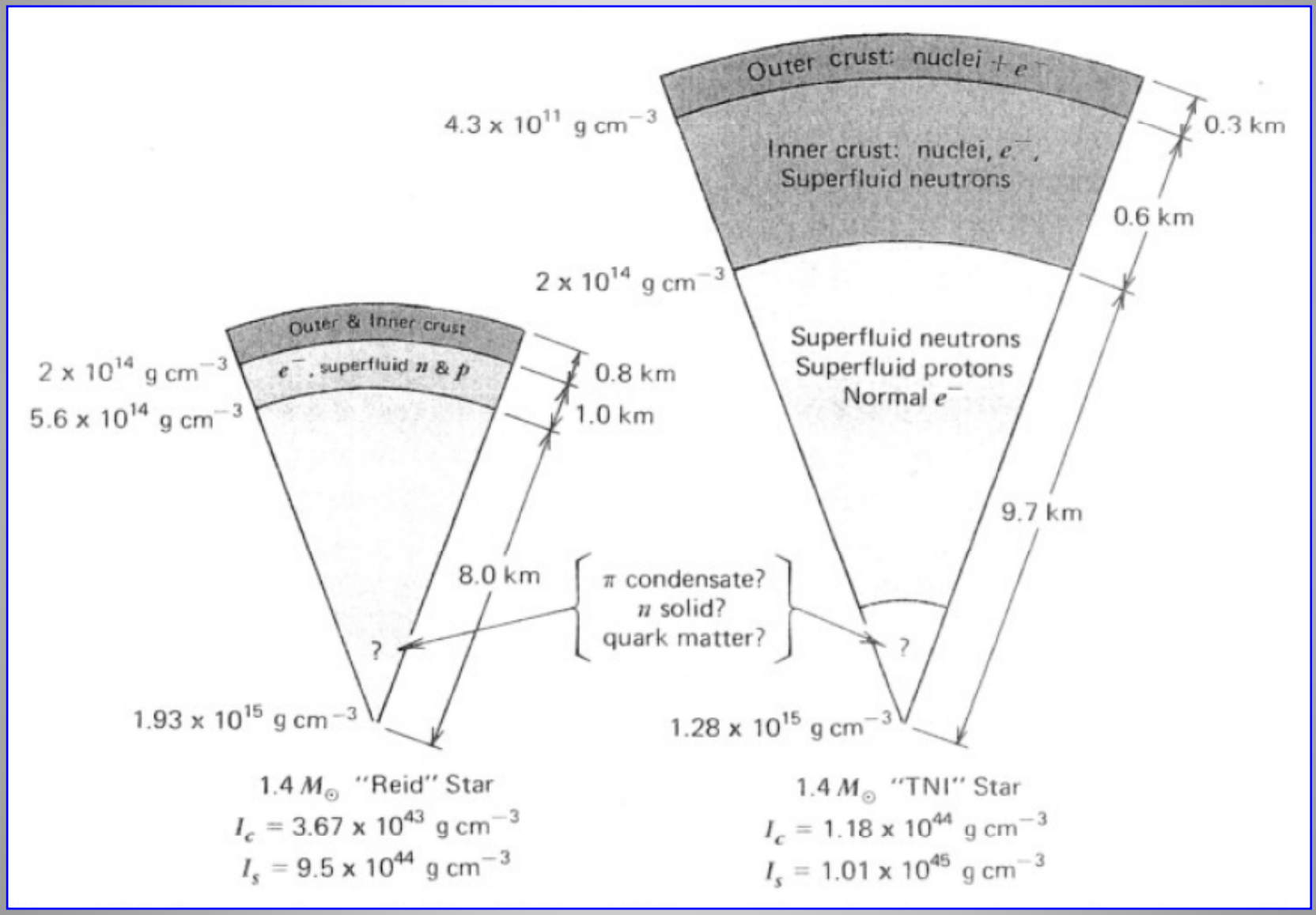
The program: cooling as a probe of NS structure

One of the problems to solve: effects of superfluidity in the crust and in the core





Neutron stars and EOS of dense matter



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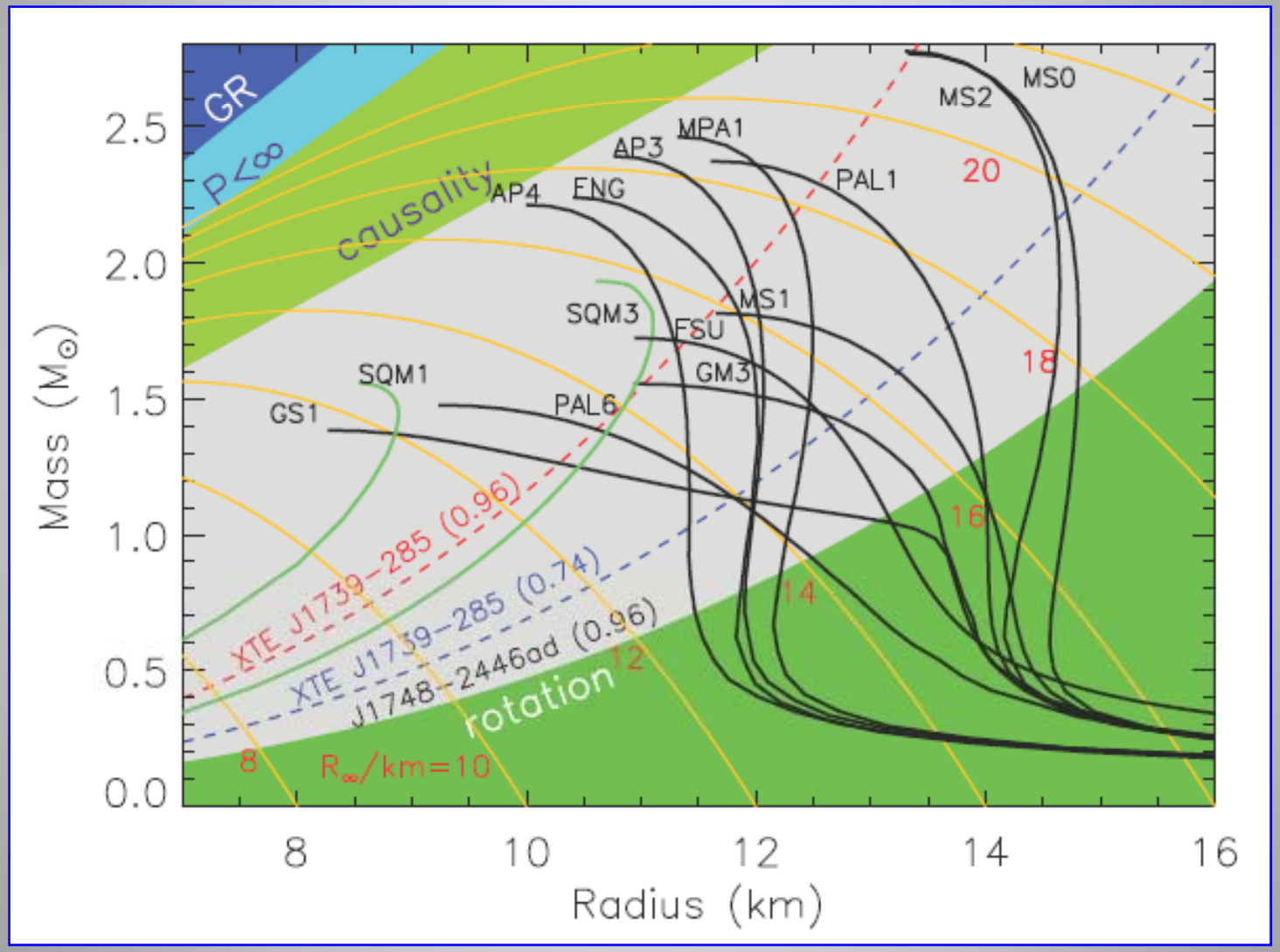

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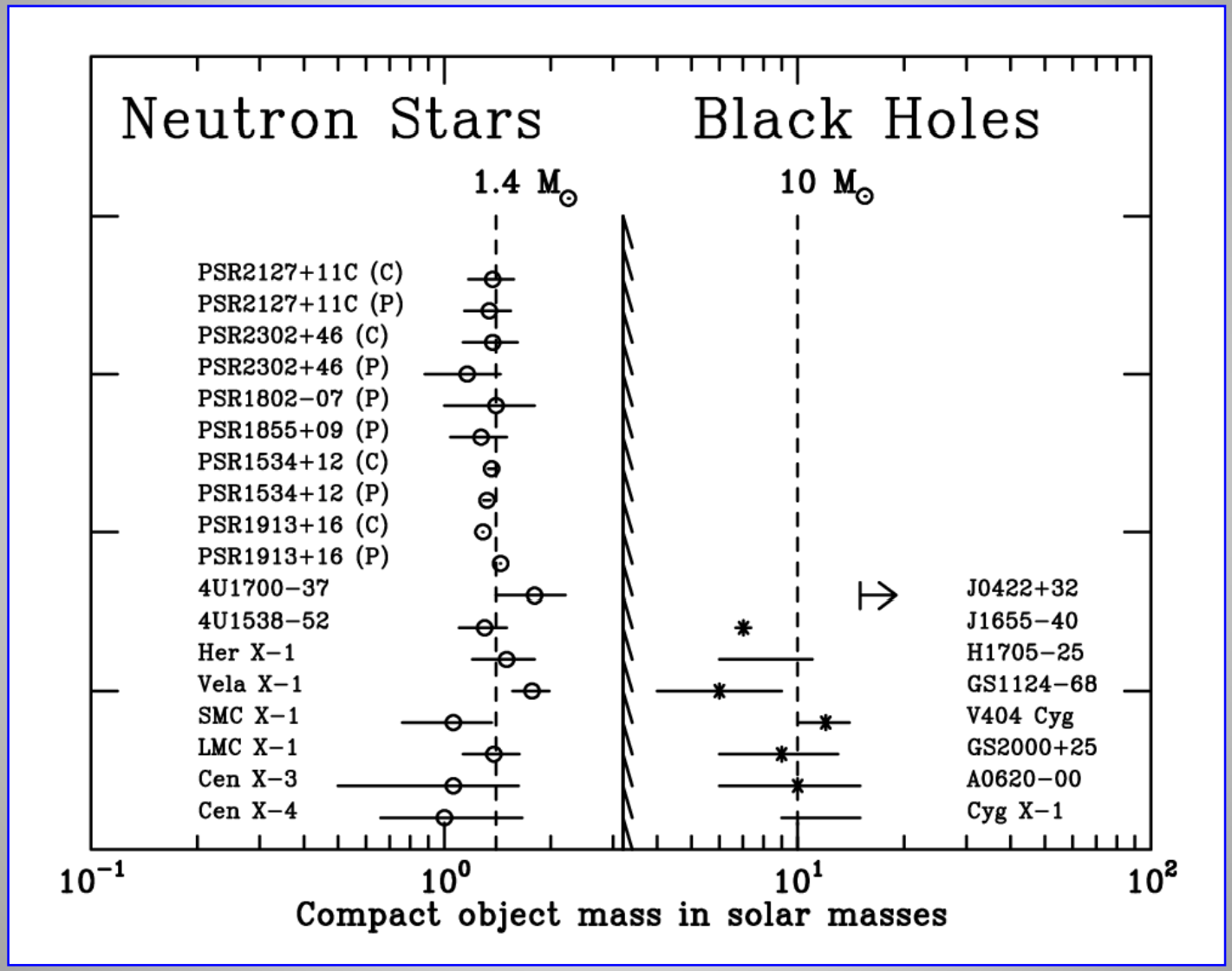
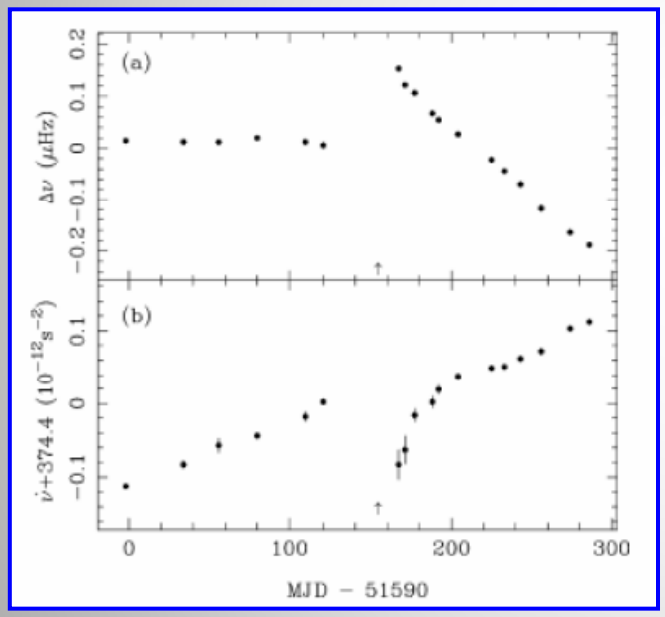
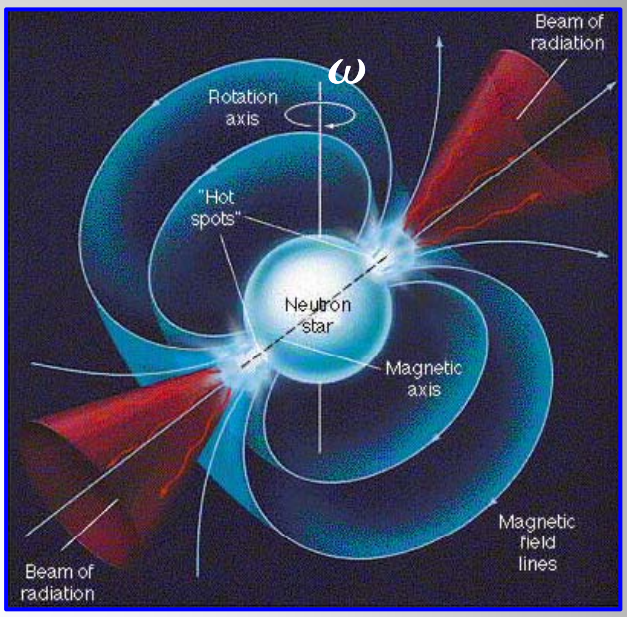


Pulsar glitches

Steady rotational slow-down of Pulsar due to emission of e.m. and gravitational waves

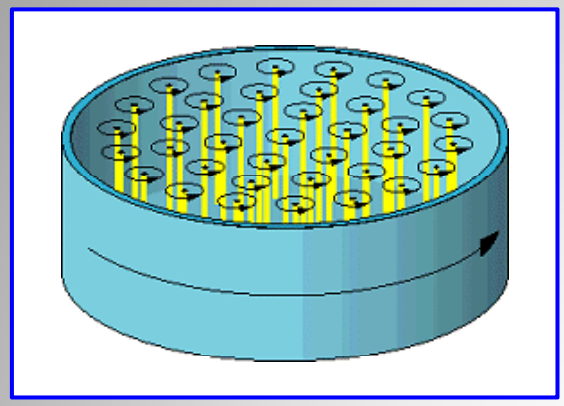




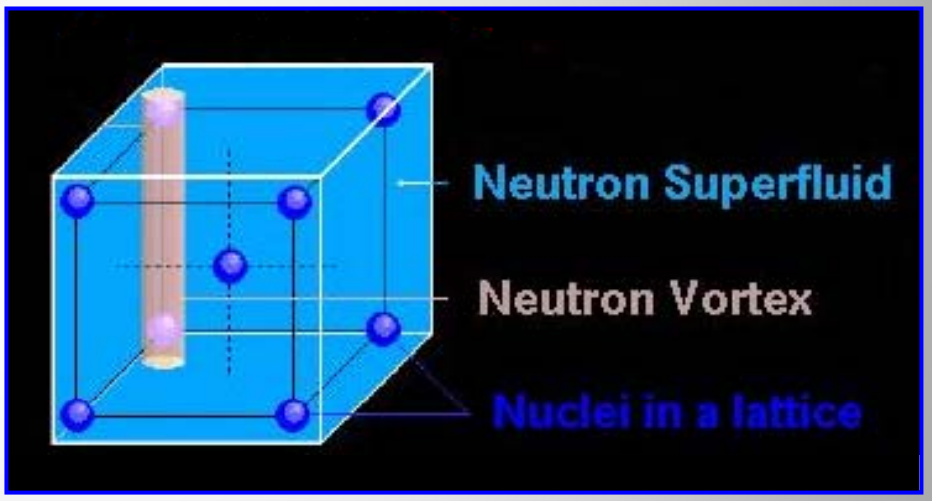
Pulsar glitches are recurrent spin-ups of rotational frequency ($\Delta\omega \sim 10^{-8}$- $10^{-6}\,\omega$) without external forces

Glitches as direct observational evidence of the existence of macroscopic (km-sized) **nucleon superfluidity** inside NS

Vortex theory of glitches



Angular momentum of rotating neutron superfluid is quantized in parallel array of vortex lines



Collective vortex depinning by hydrodynamical forces

⇓

Transfer of angular momentum from superfluid to star surface

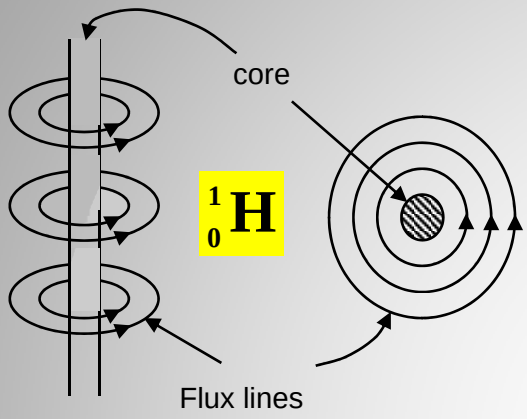
⇓

Glitch in rotational frequency

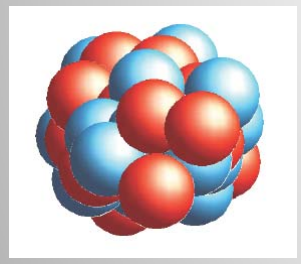
Microscopic input
pinning energy

Vortices in the Inner Crust pin to lattice of exotic nuclei ⇒ angular momentum of neutron superfluid is frozen

Vortex-nucleus interaction

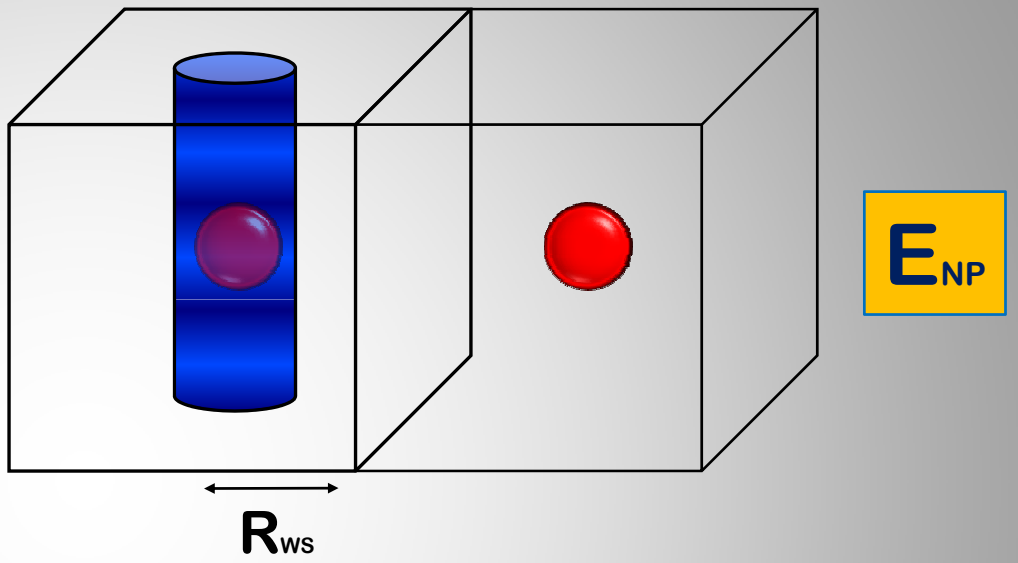


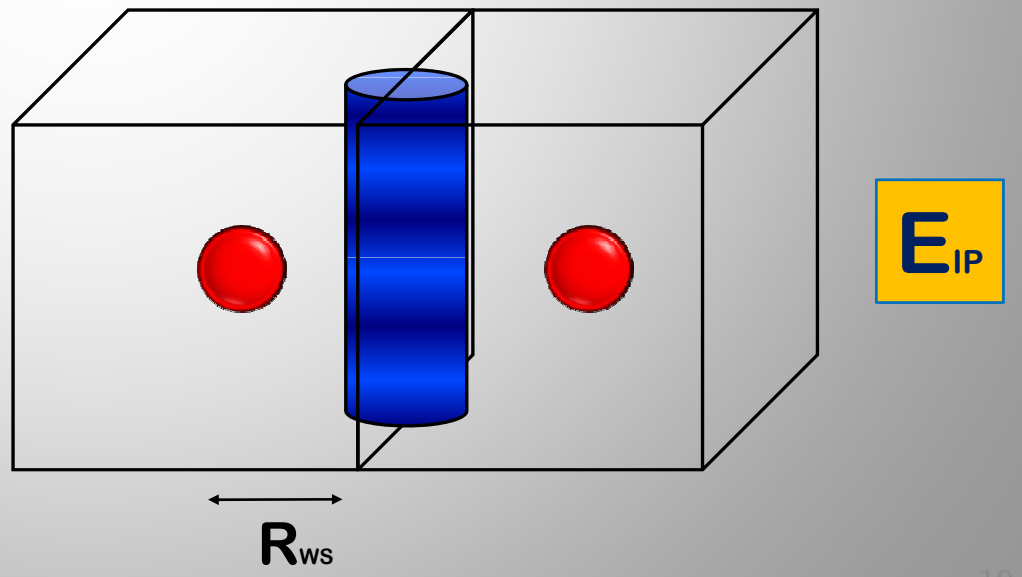
$^{1}_{0}H$



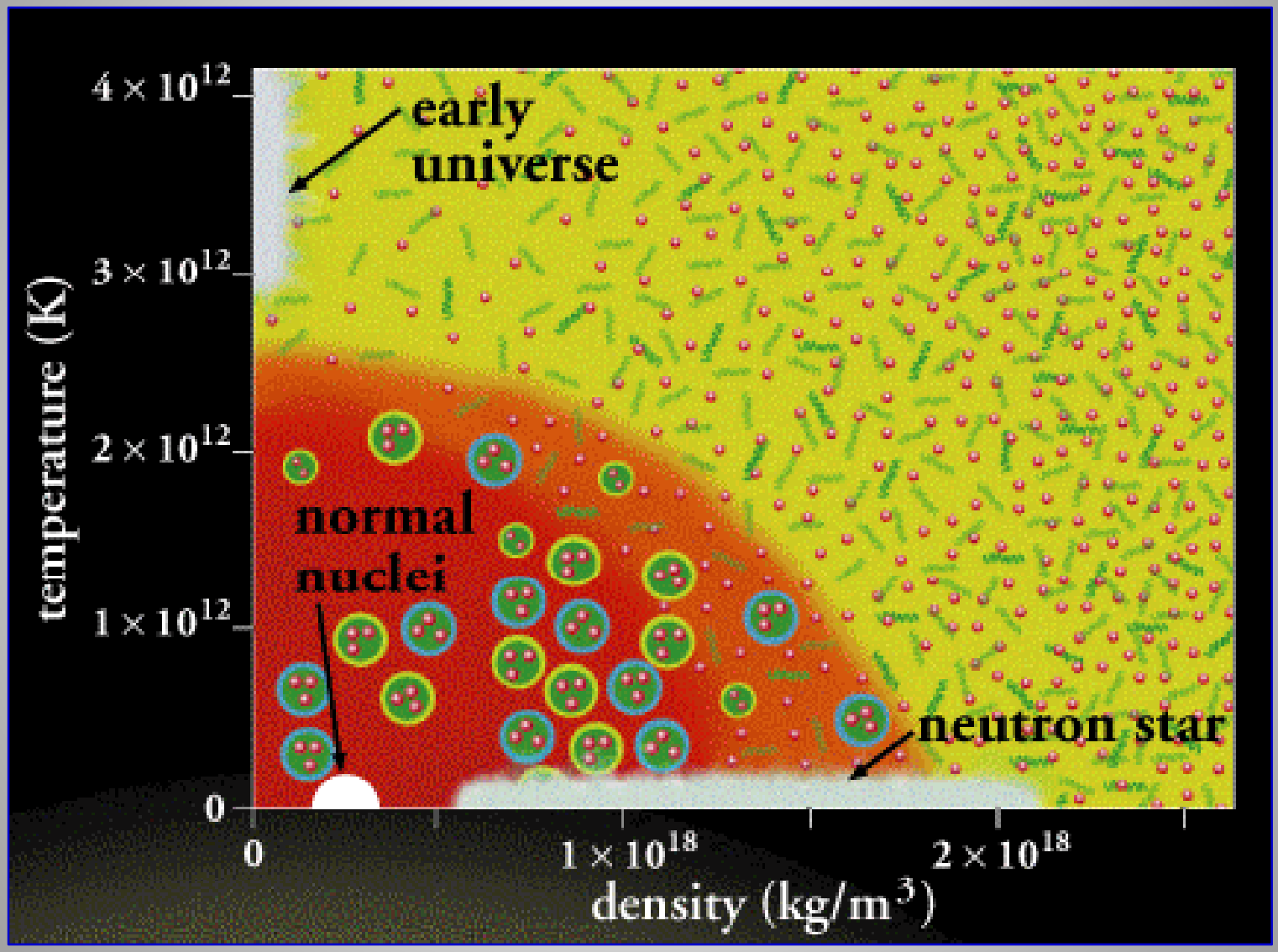
$^{1800}_{50}Sn$

$$E_{pin} = E_{NP} - E_{IP}$$





Neutron stars and hadronic matter




"That's all Folks!"