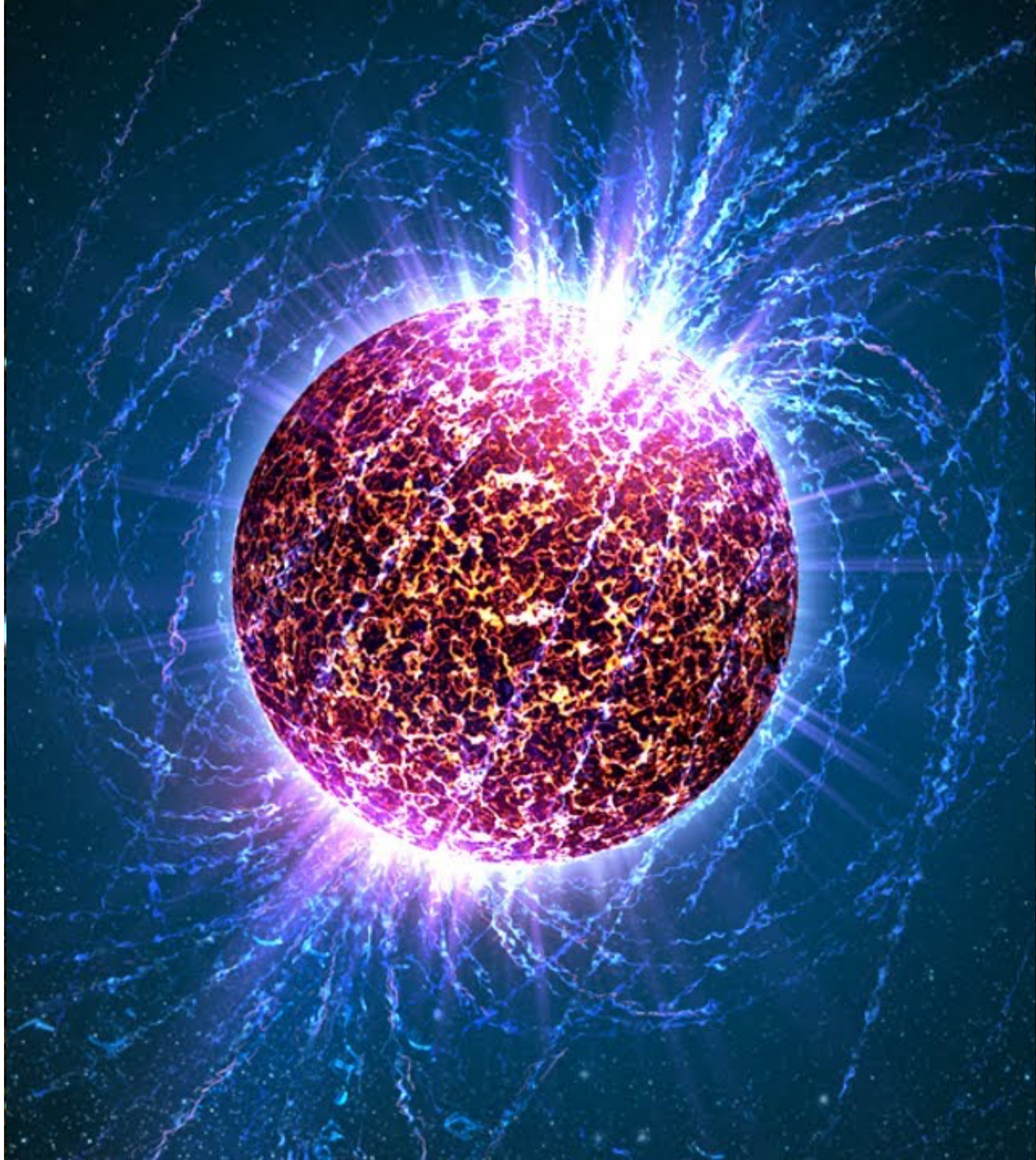
PHY 4905 | Modern Astrophysics

Lecture VII.

Neutron stars

UNIVERSITY of FLORIDA

Imre Bartos | Fall 2018



History

Background & detals: Shapiro & Teukolsky
Black Holes, White Dwarfs, Neutron strars

Proposed by Baade and Zwicky as formed in supernovae
(Baade and Zwicky coined super-novae in 1931!)

First neutron star models: Oppenheimer & Volkoff 1939

Expected to be small and hence undetectable via thermal radiation → no interest for ~30 years.

This changed with the discovery of high-energy (X-ray, 1962) emission

General acceptance: discovery of pulsars in 1967
https://www.newyorker.com/tech/elements/the-astronomer-jocelyn-bell-burnell-looks-back-on-her-cosmic-legacy

Chandrasekhar limit by Landau 1932 --- 1.5 Msun

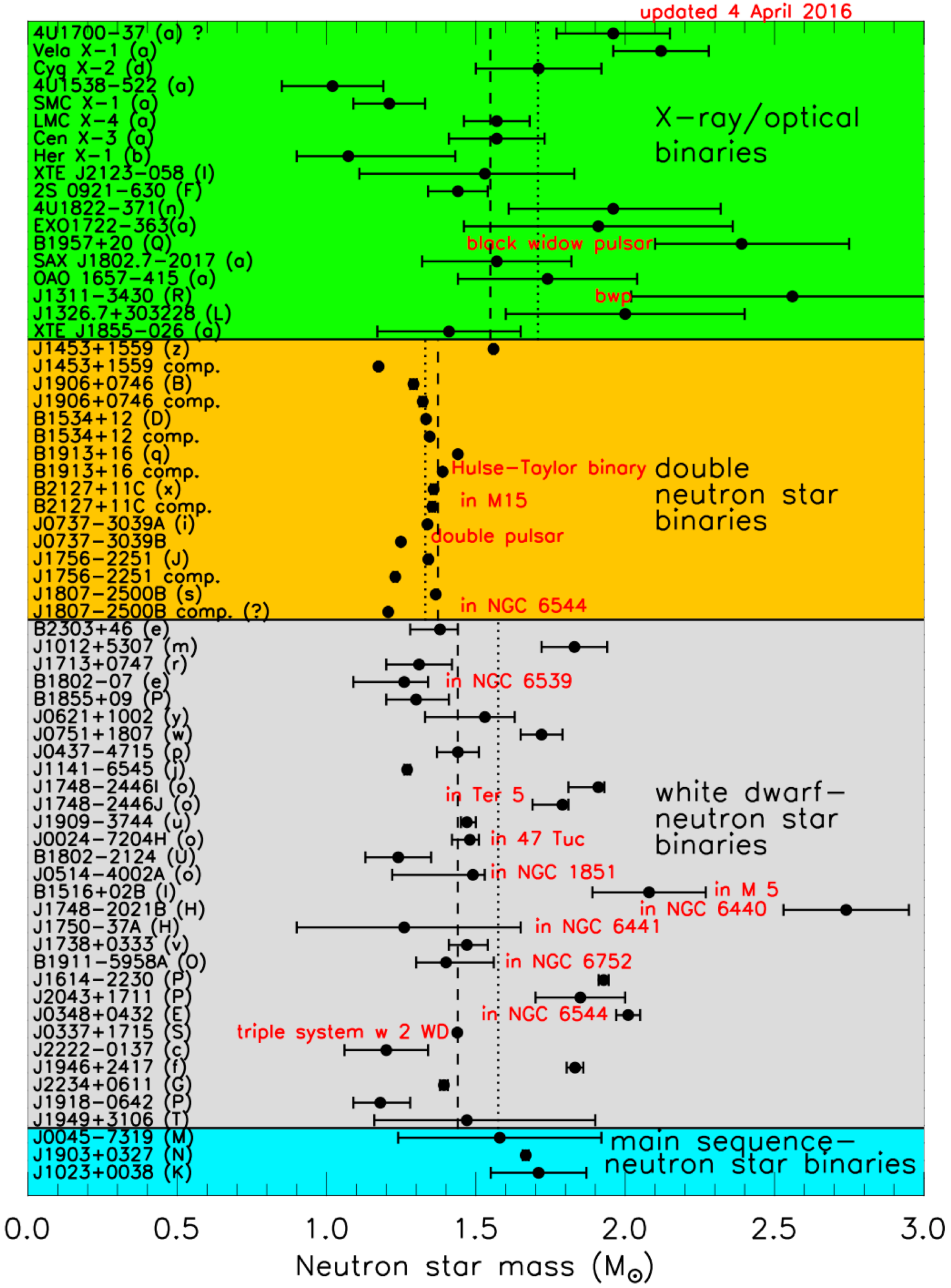
Properties - Mass

There should be a lower limit just from formation. --- 1.1 Msun

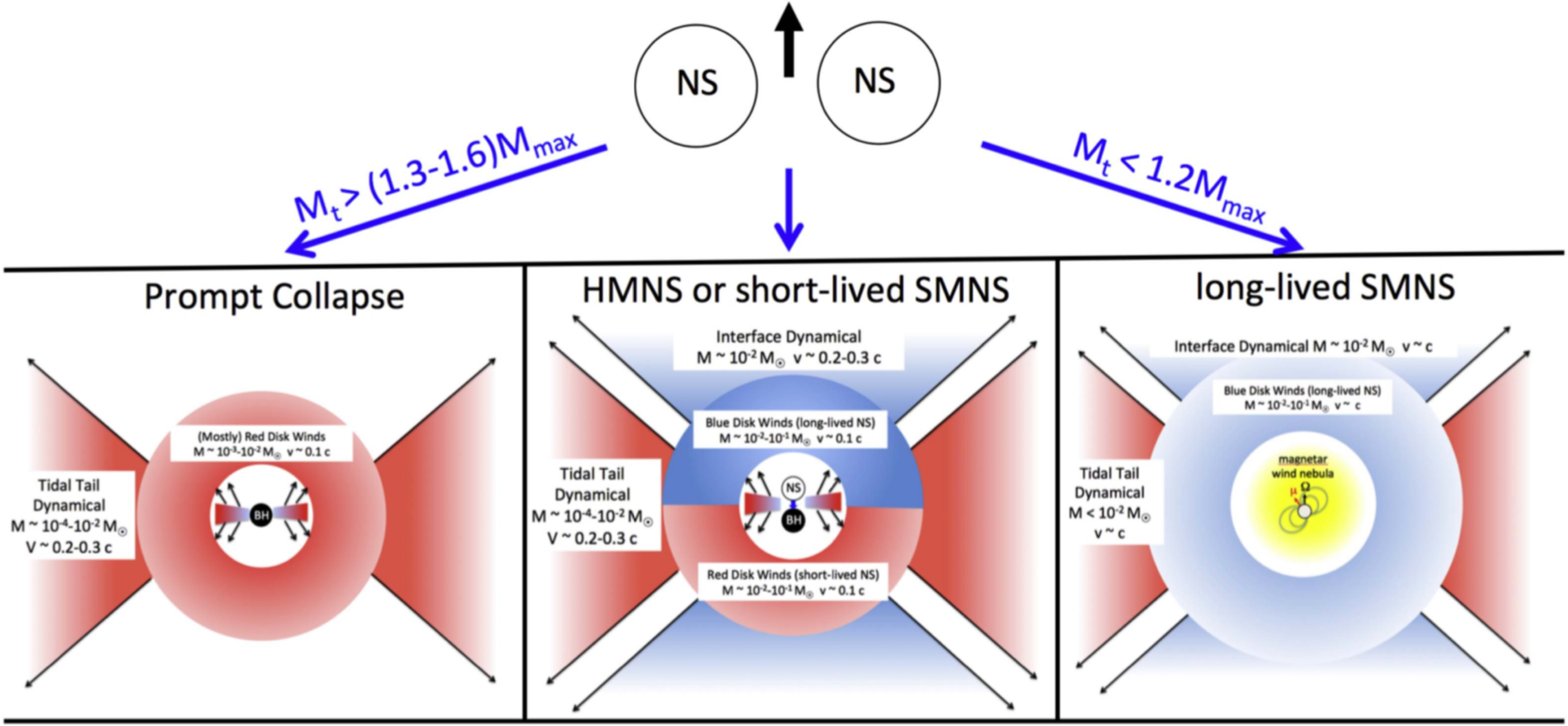
Maximum observed mass --- ~2 Msun

Maximum mass from GW170817 --- 2.17 Msun

Mass distribution depends on NS companion



https://stellarcollapse.org/nsmasses



Margalit & Metzger 2017

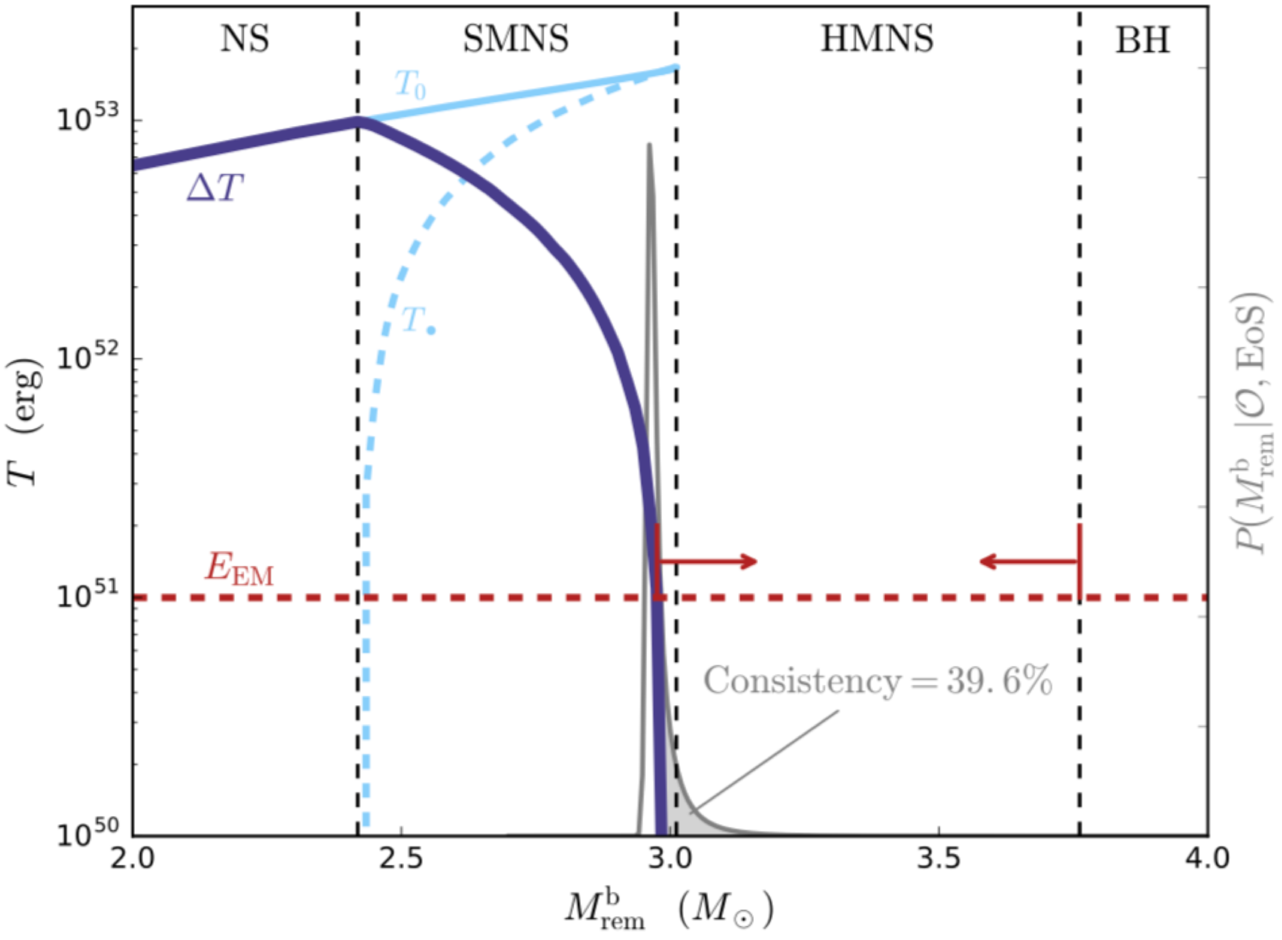
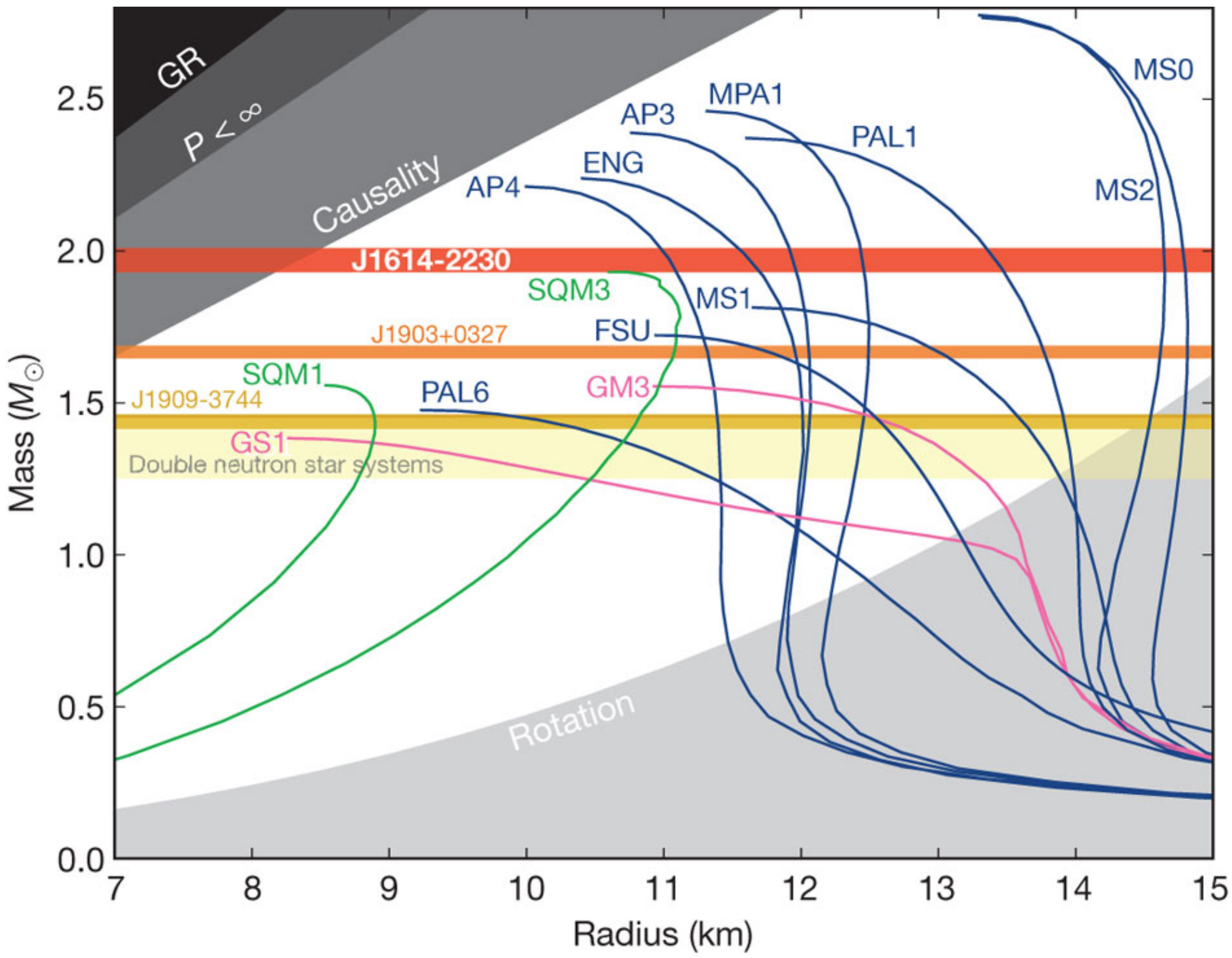


Figure 2. Maximum extractable rotational energy of the merger remnant $\Delta T = T_0 - T_*$ (Equation (1)) is shown as a dark-blue solid curve for a sample EOS. Vertical dashed curves demarcate the range of baryonic remnant masses M^b_{rem} for which the immediate post-merger compact object is a stable NS, SMNS, HMNS, or a BH (prompt collapse). A horizontal red dashed curve shows the maximal energy transferred to the environment of the merger consistent with EM observations of GW170817 for the GRB and KN emission. The parameter space where $\Delta T \gg E_{EM}$ is thus ruled out. The prompt-collapse scenario is also ruled out (see the text), such that M^b_{rem} is constrained within an "allowed" region shown by red arrows. The gray curve shows the remnant mass probability distribution function (Equation (4)), and the consistency is the integral over this distribution within the allowed region (Equation (6); shaded gray area).

Margalit & Metzger 2017

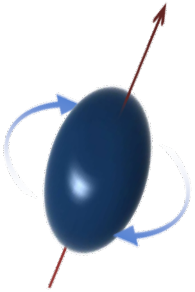
Properties – Equation of state



Magnetic field

Typically 10^4-10^{11} T

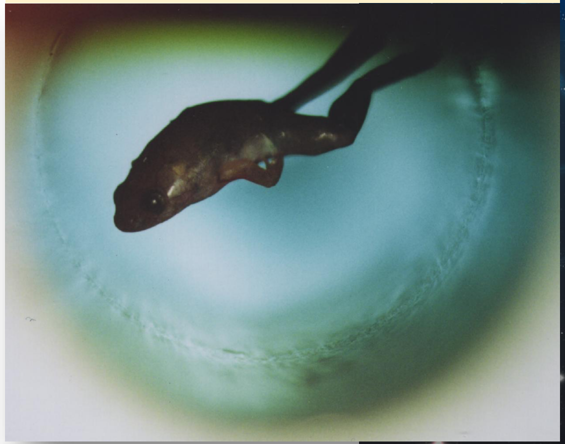
Newly born magnetars --- 10^{15} T



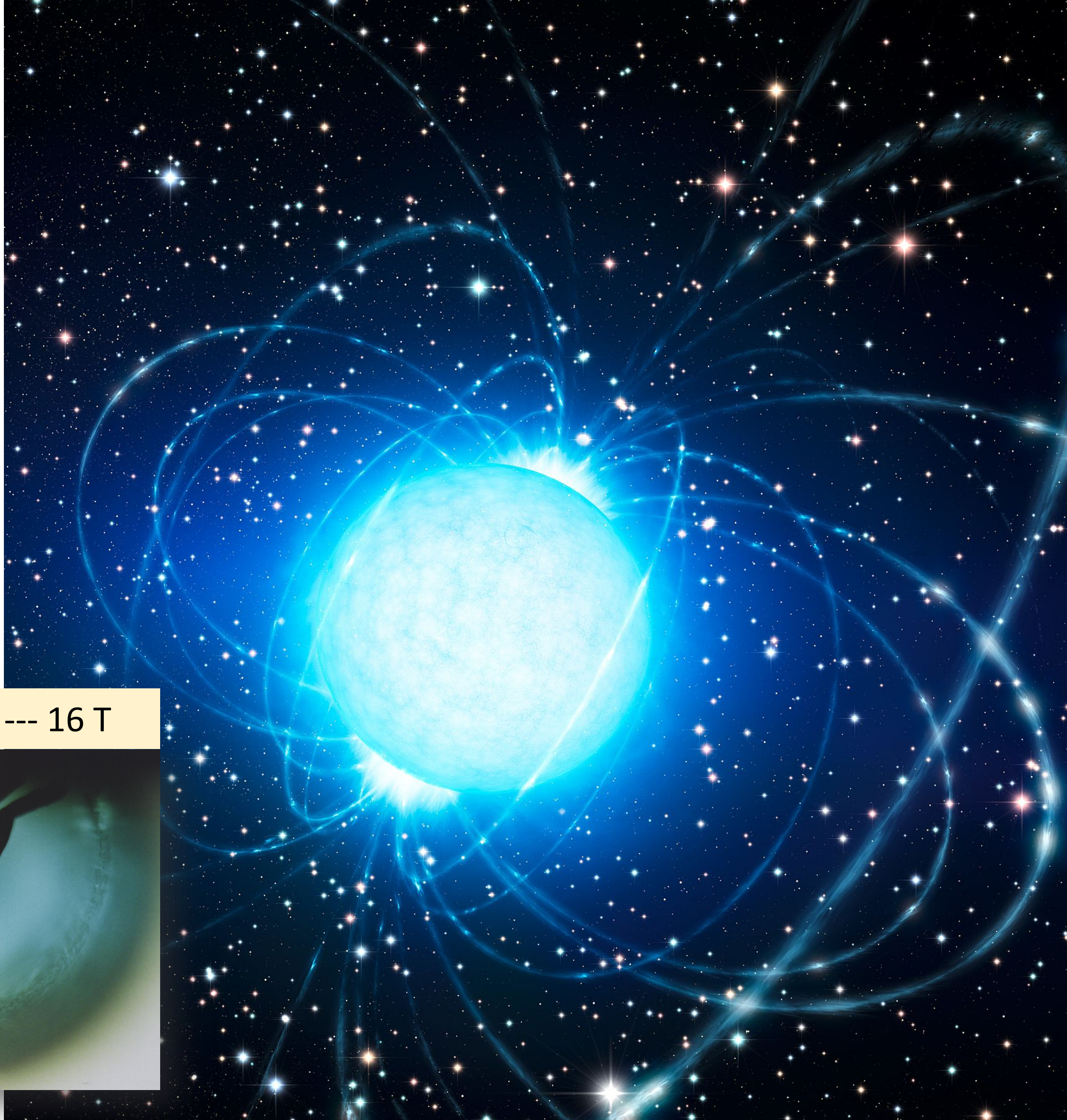
Can make NS prolate

After formation → dynamo effect
→ loss of angular momentum
←→ competing effect with GWs

Frog levitation --- 16 T



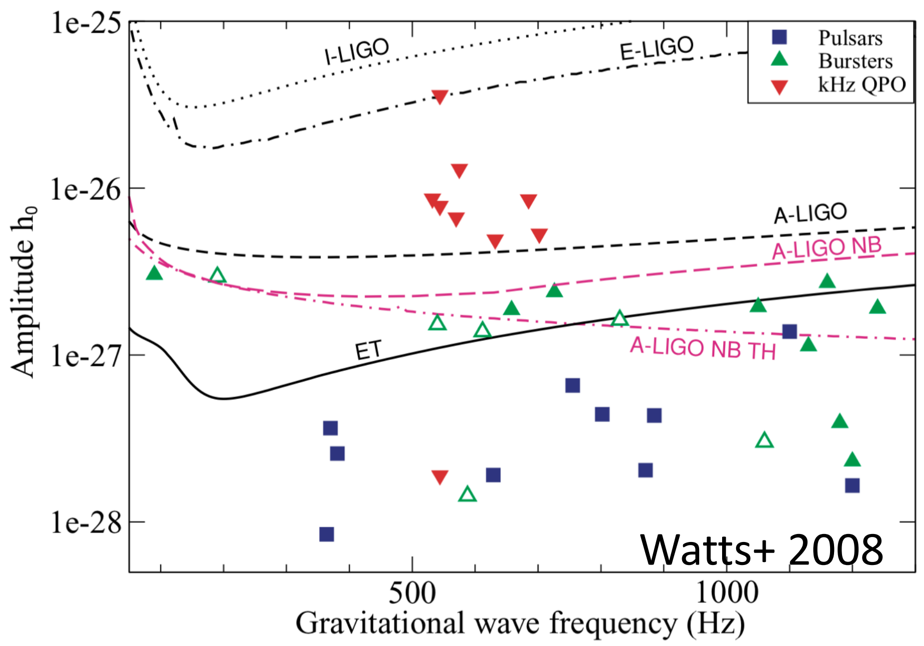
NS slowly loses magnetic fields
→ weak during BNS merger

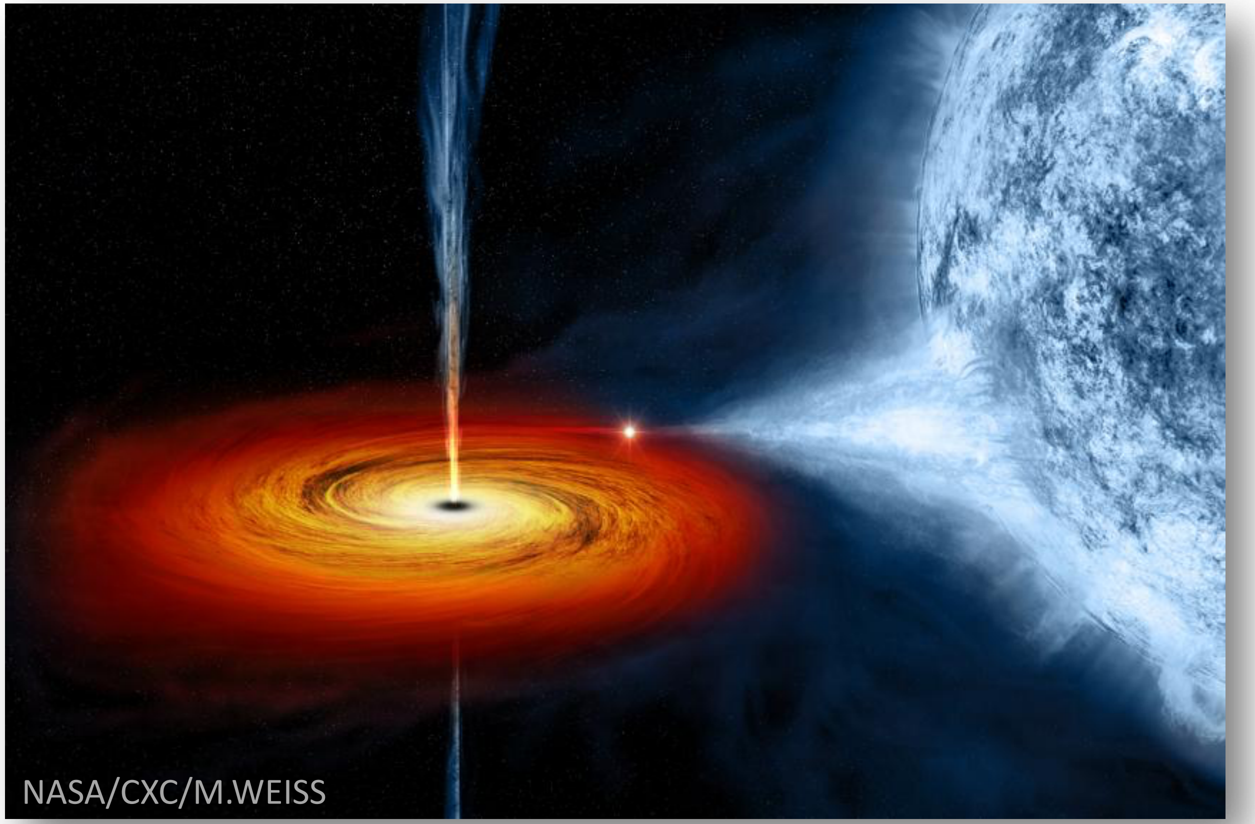


Accretion and spindown

Many accreting NSs rotate around 300 Hz

Maybe GW emission?





Bildsten ApJ Lett 1998

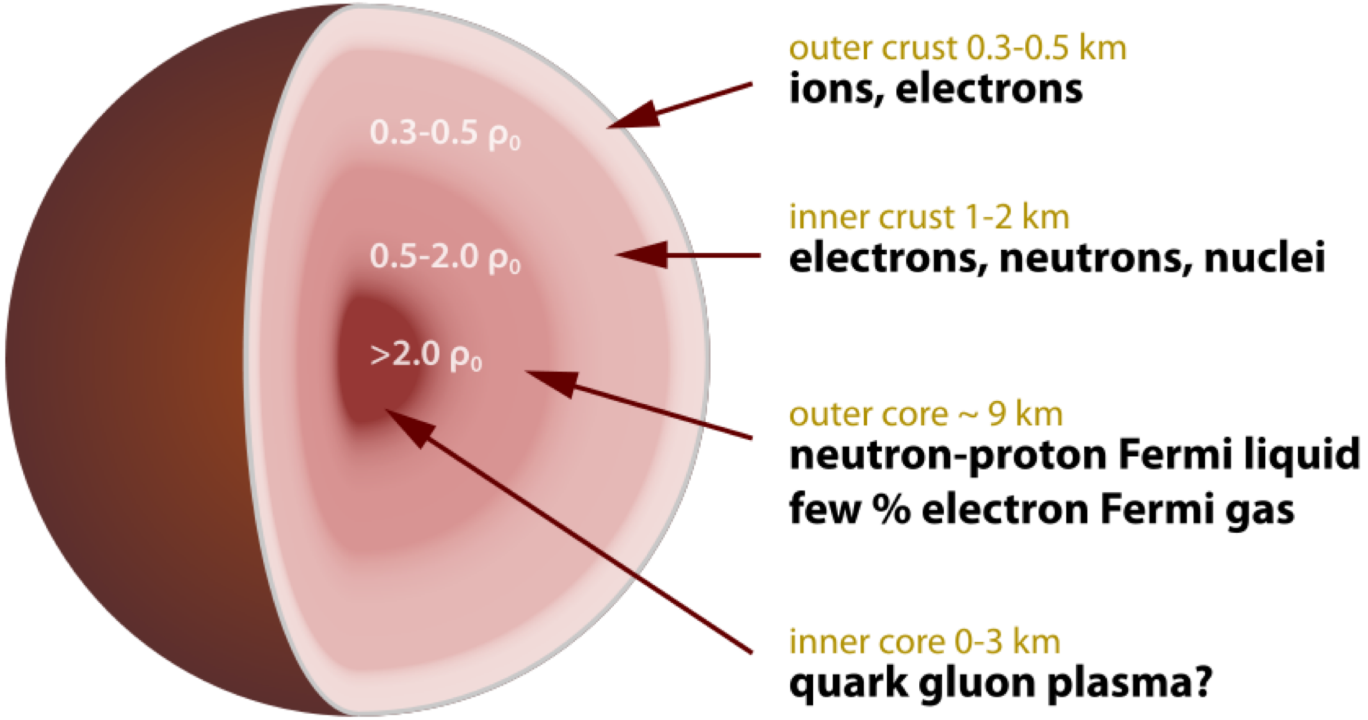
Structure

Mostly unknown

There is likely a NS “crust”

There is likely a NS “crust” and core

Quark-gluon plasma in core?



Robert Schulze

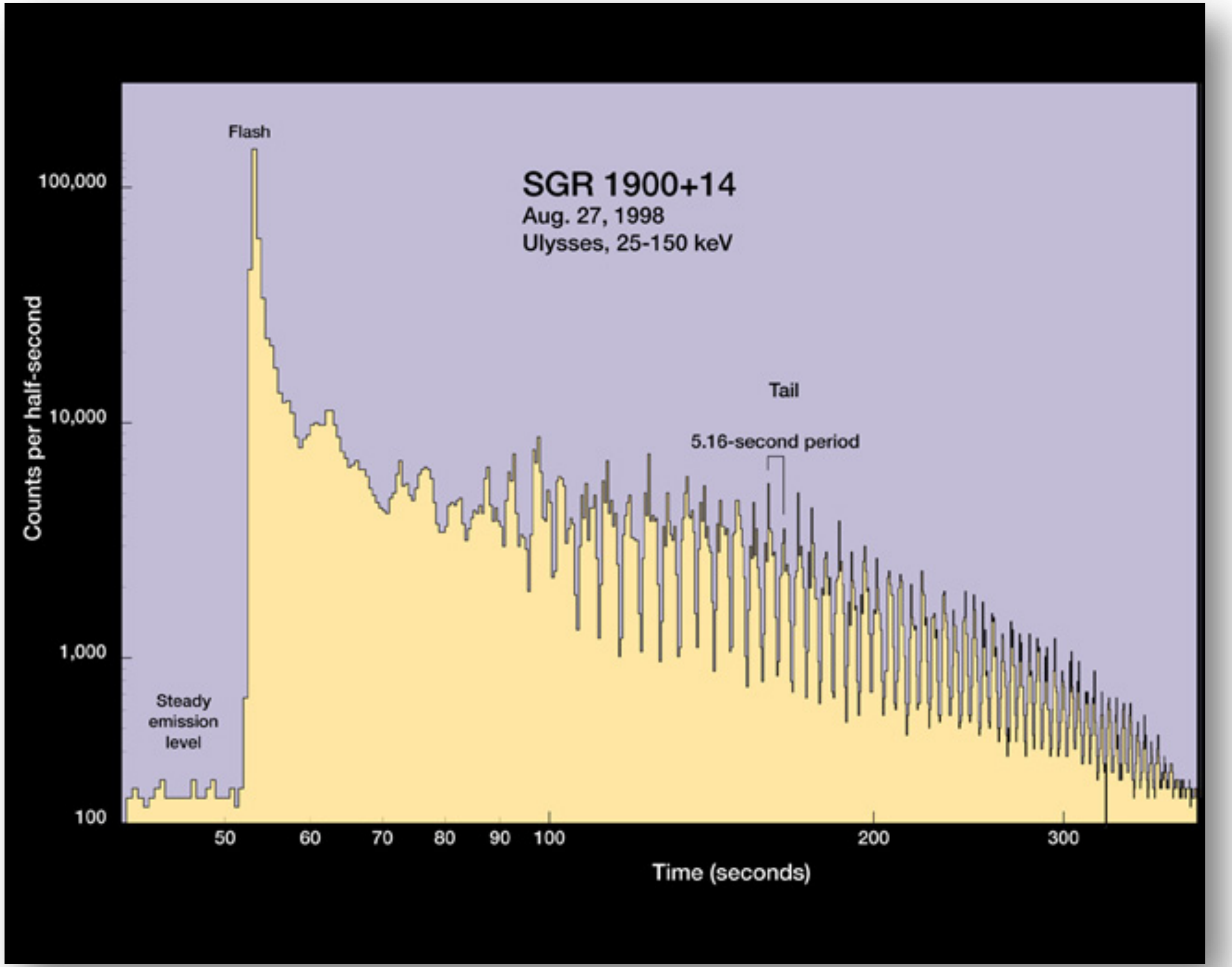
Soft gamma repeaters

Occasional outbursts of gamma rays

Quasi-periodic oscillations

Starquakes??

Magnetic field reorganization?



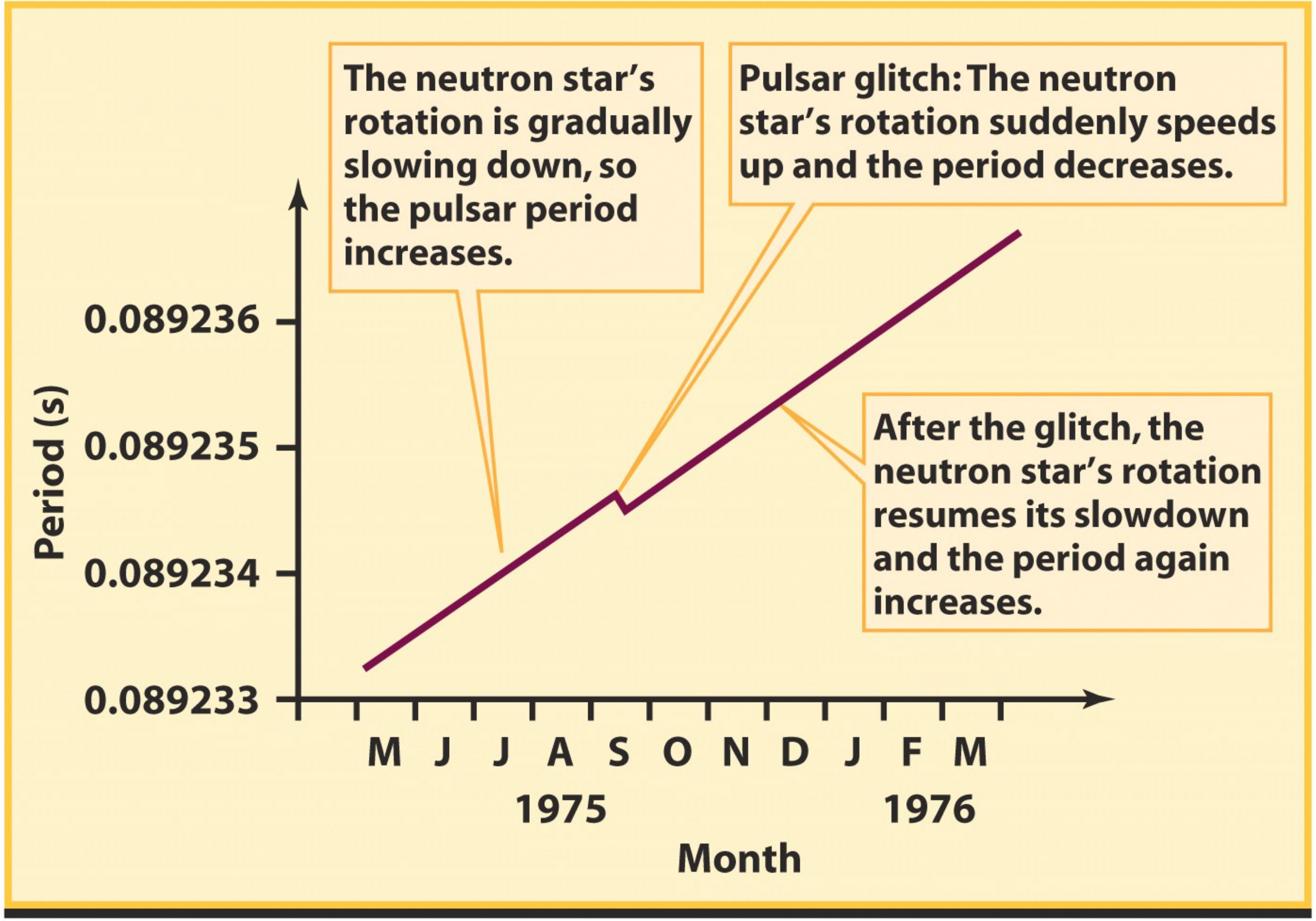
Glitches

<u>Starquakes?</u>
NS crust ruptures
→ radius decreases
→ faster rotation

Core reorganization that releases energy?

<u>Anti-glitches</u>
Unclear??

Bad for pulsar timing



Pulsars

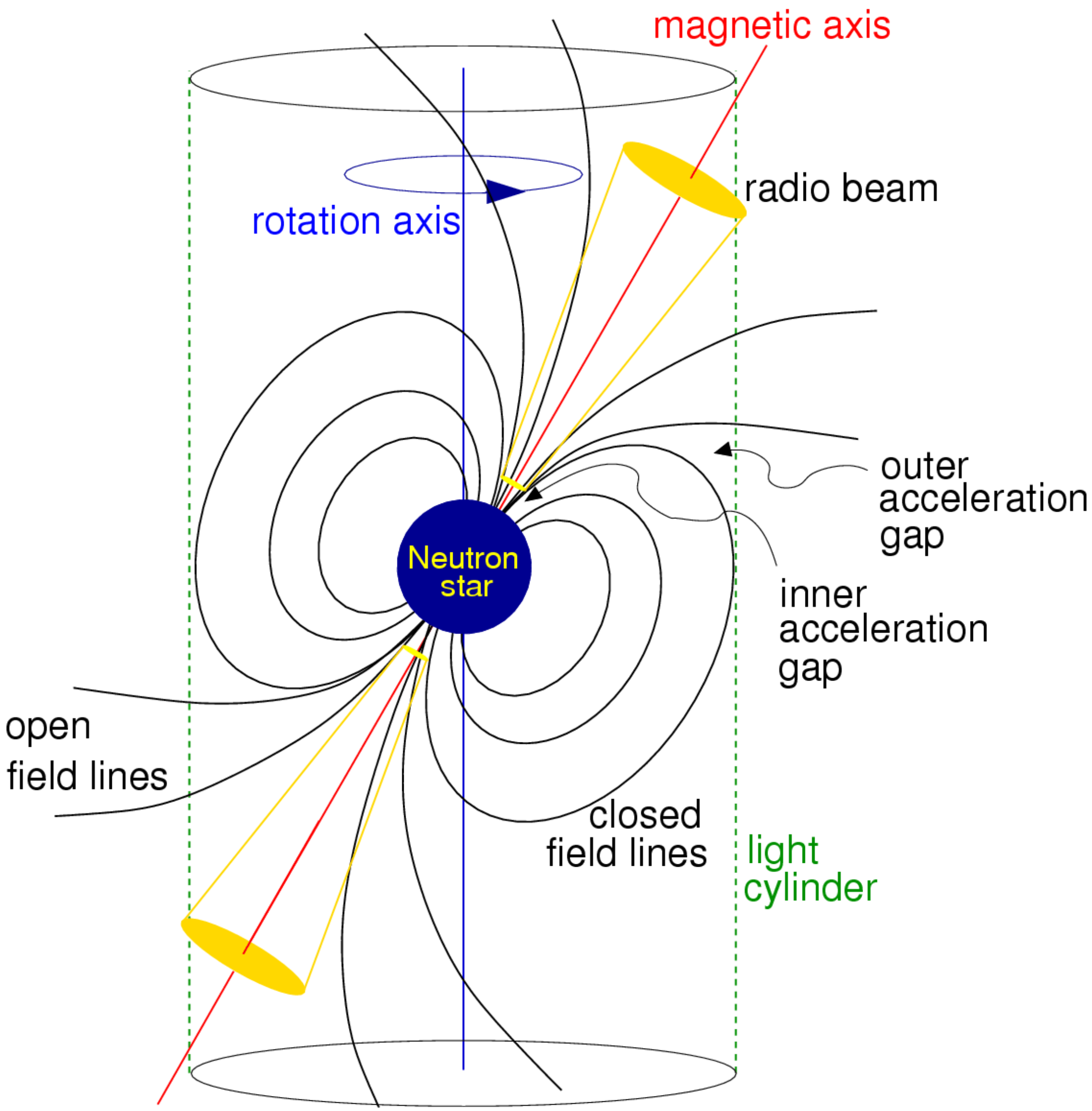
Very regular period

Formed in a supernova

After sufficient slowdown the radio pulsar mechanism is turned off.

Energy source:

- Rotation
- Accretion
- Magnetic fields



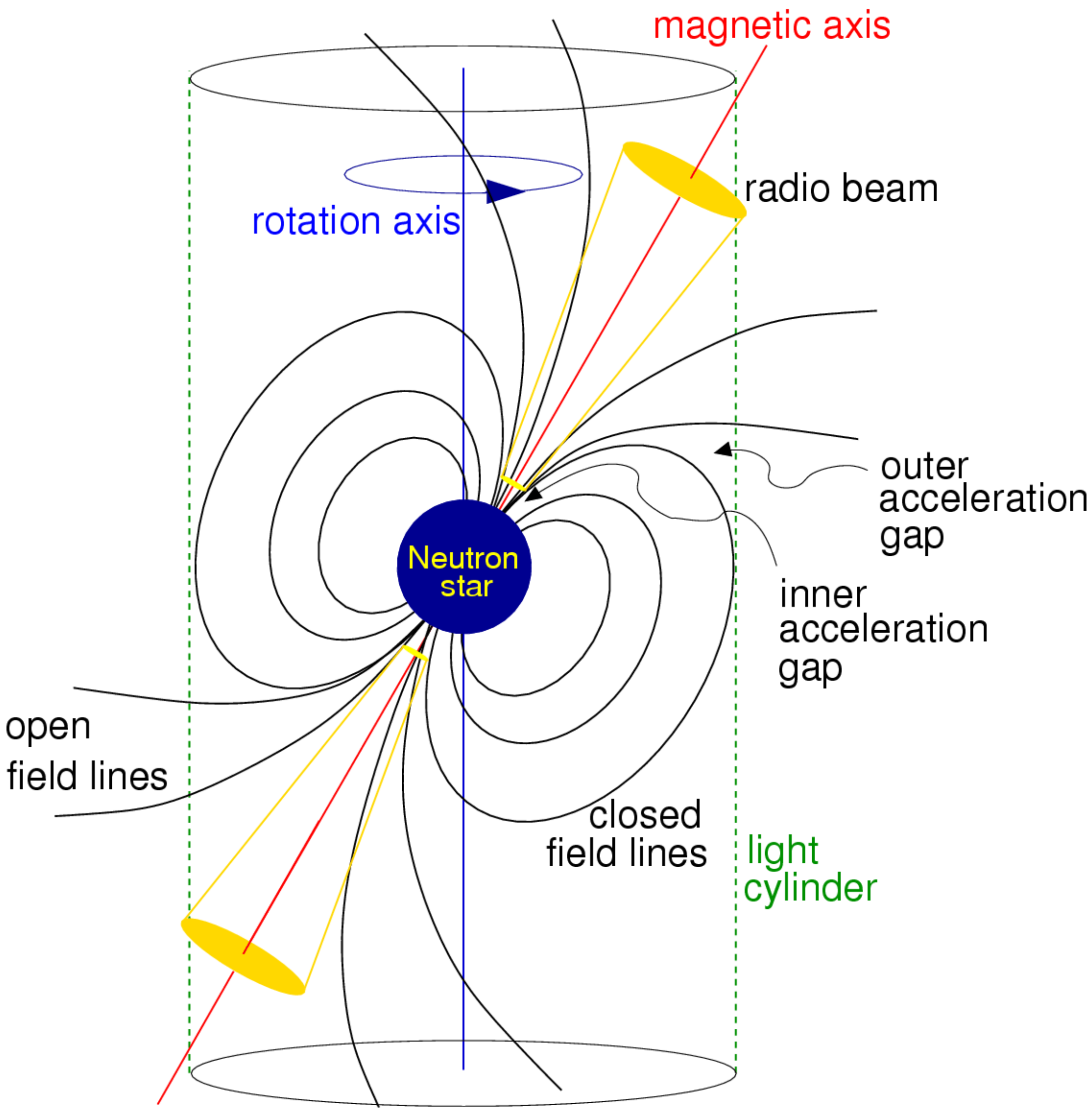
http://www.cv.nrao.edu

Pulsars

If the magnetic dipole is inclined from the rotation axis
→ Magnetic dipole radiation

We can find the magnetic field strength of the NS from the spindown rate.

$$\left(\frac{B}{\text{Gauss}}\right) > 3.2 \times 10^{19} \left(\frac{P\dot{P}}{\text{s}}\right)^{1/2}$$



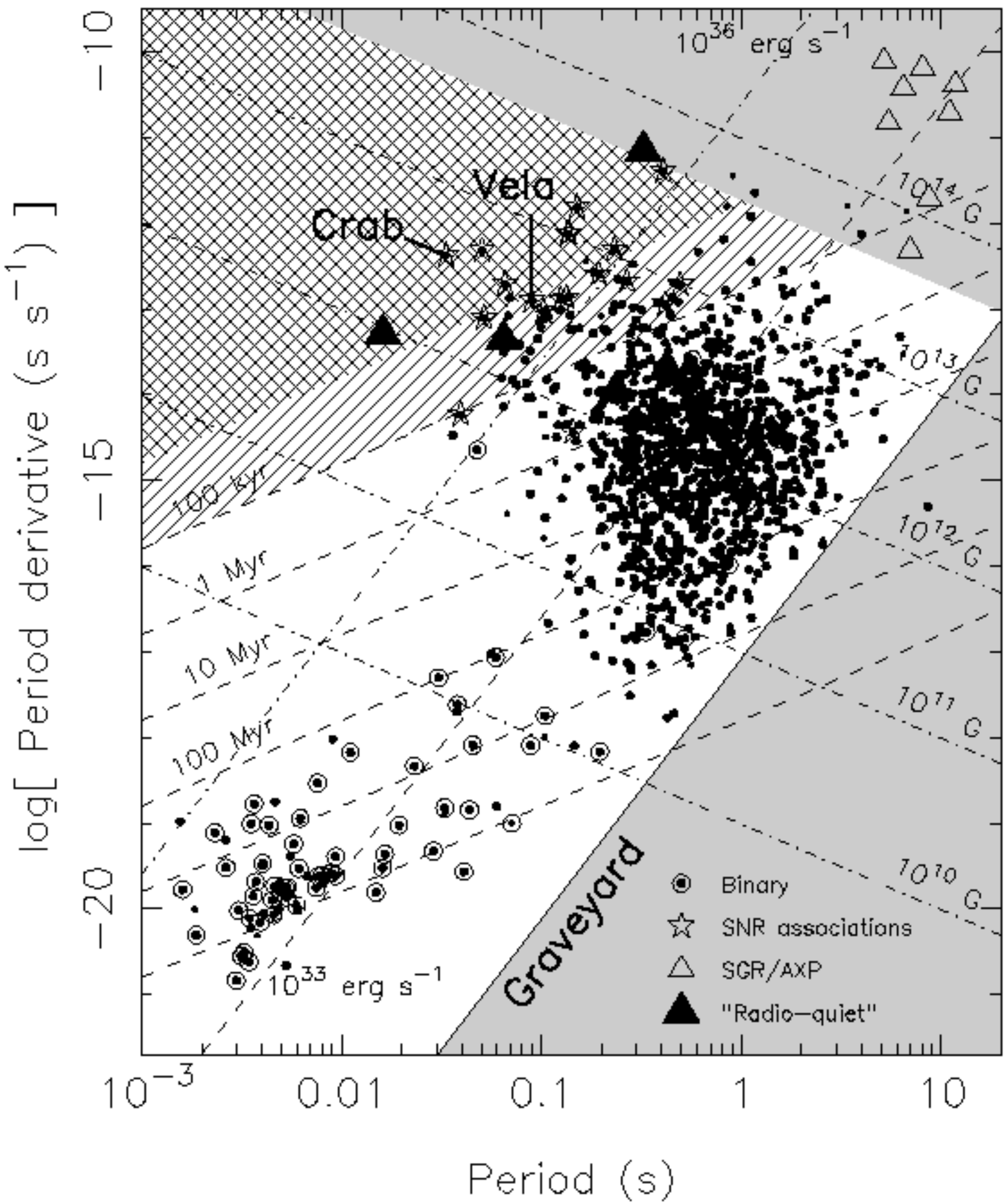
http://www.cv.nrao.edu/course/astr534/Pulsars.html

Spin Down

Longer period typically means higher spindown rate.

If luminosity ~ spin down power
→ rotation powered

Spindown rate and period gives us an estimate on the characteristic age of the pulsar.



Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer