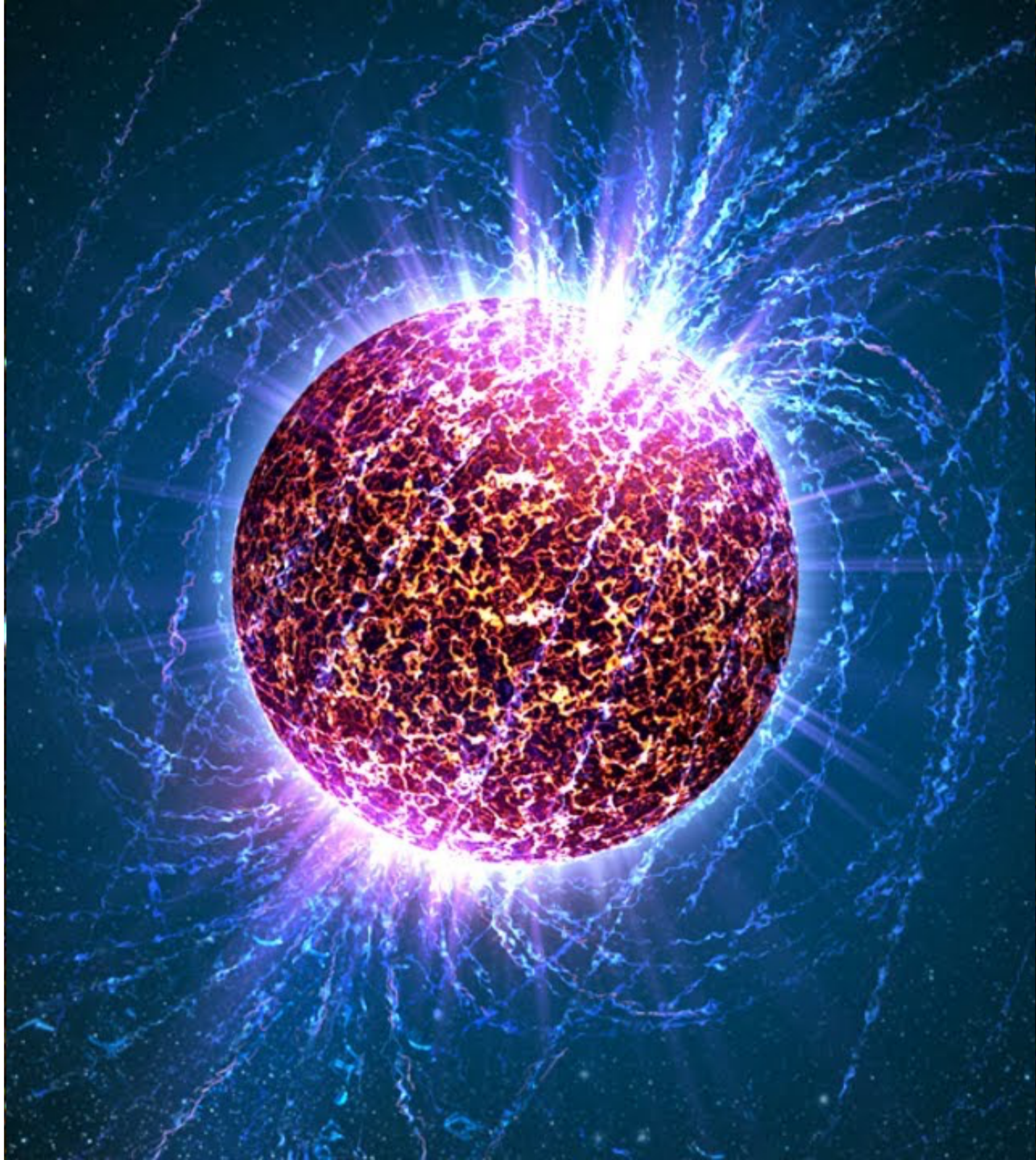
PHY 4905 | Modern Astrophysics

Lecture VIII.

Neutron stars

UF UNIVERSITY of FLORIDA

Imre Bartos | Fall 2018



Homework

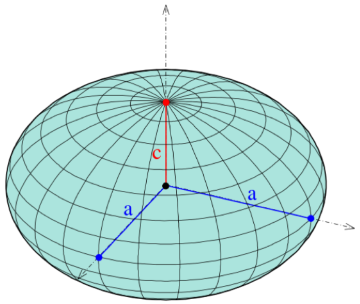
$$E_{\mathrm{GW}} \approx 10^{-2} M_{\odot} c^2 \left(\frac{\epsilon}{0.2}\right)^2 \left(\frac{f}{2\,\mathrm{kHz}}\right)^6 \left(\frac{M}{1.4\,M_{\odot}}\right) \left(\frac{R}{12\,\mathrm{km}}\right)^2 \left(\frac{\tau}{0.1\,\mathrm{s}}\right)$$

Assume realistic dependence of epsilon on f.

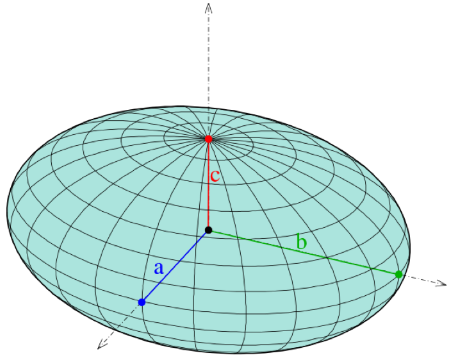
What will be the gravitational waveform?

Rotating Spheroids

MacLaurin spheroids

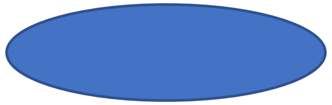


Jacobi spheroids
(or Dedekind spheroids)



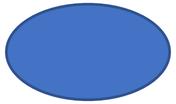
Dynamically unstable:

- $T/|W| > 2.7$
- $e > 0.95$ (1:3:3)



Secular instability:

- $T/|W| > 1.4$
- $e > 0.81$ (1:1.7)



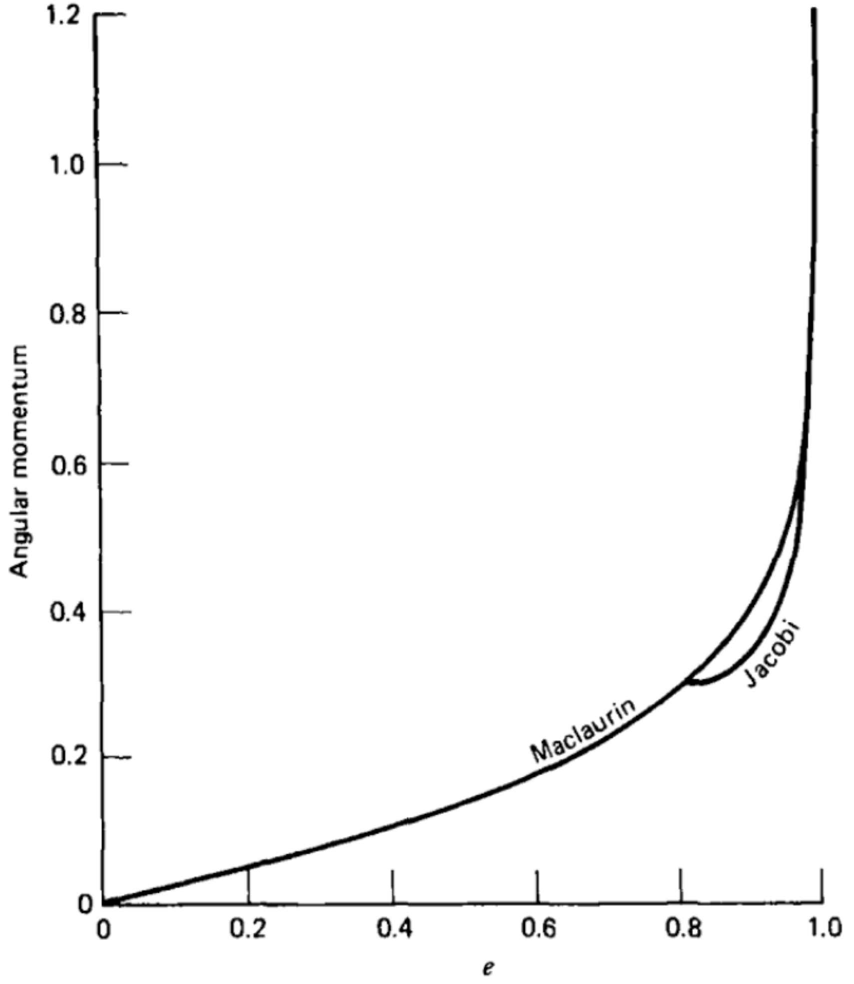


Figure 7.3 The angular momentum [in the unit $(GM^3\bar{a})^{1/2}$] along the Maclaurin and the Jacobian sequences. Here $\bar{a}$ is related to the three semimajor axes by $\bar{a} \equiv (abc)^{1/3}$; for a Maclaurin spheroid $a = b$. The abscissa in both cases is the eccentricity defined by Eq. (7.3.9). [Reproduced, with permission, from *Ellipsoidal Figures of Equilibrium* by S. Chandrasekhar, published by Yale University Press. © 1969 by Yale University.]

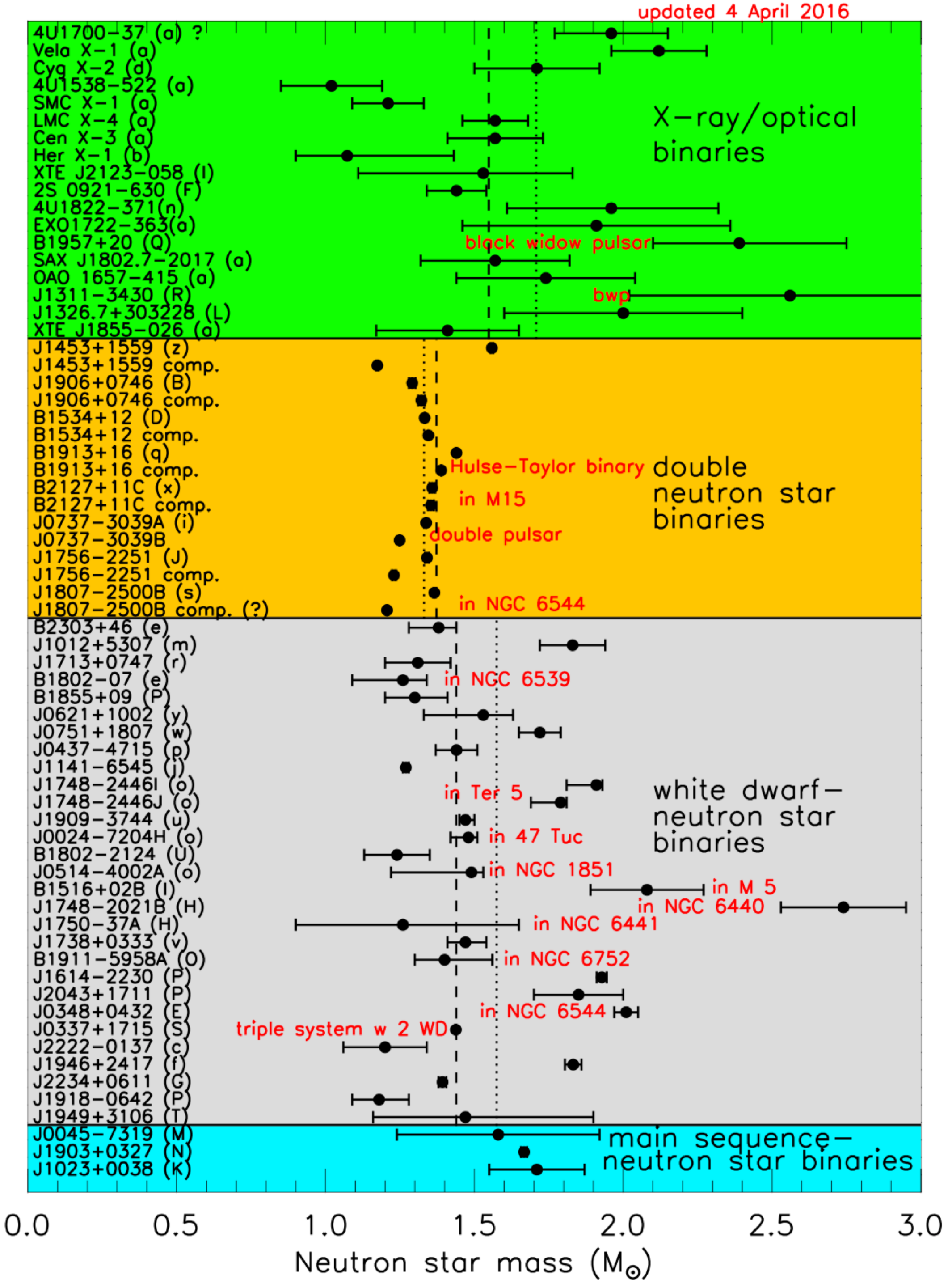
Properties - Mass

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

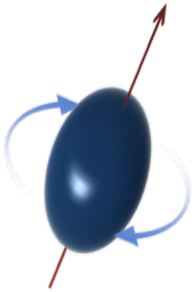


https://stellarcollapse.org/nsmasses

Magnetic field

Typically 10^4-10^{11} T

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

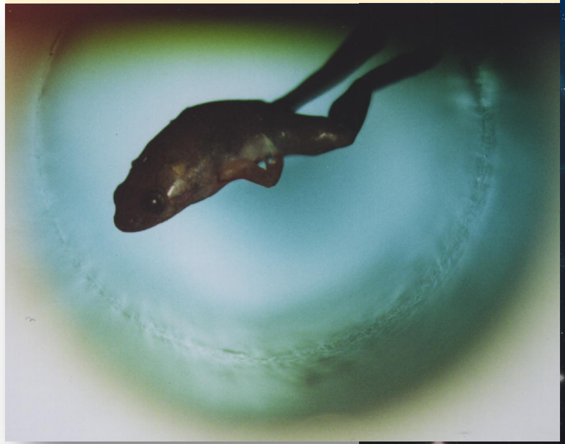


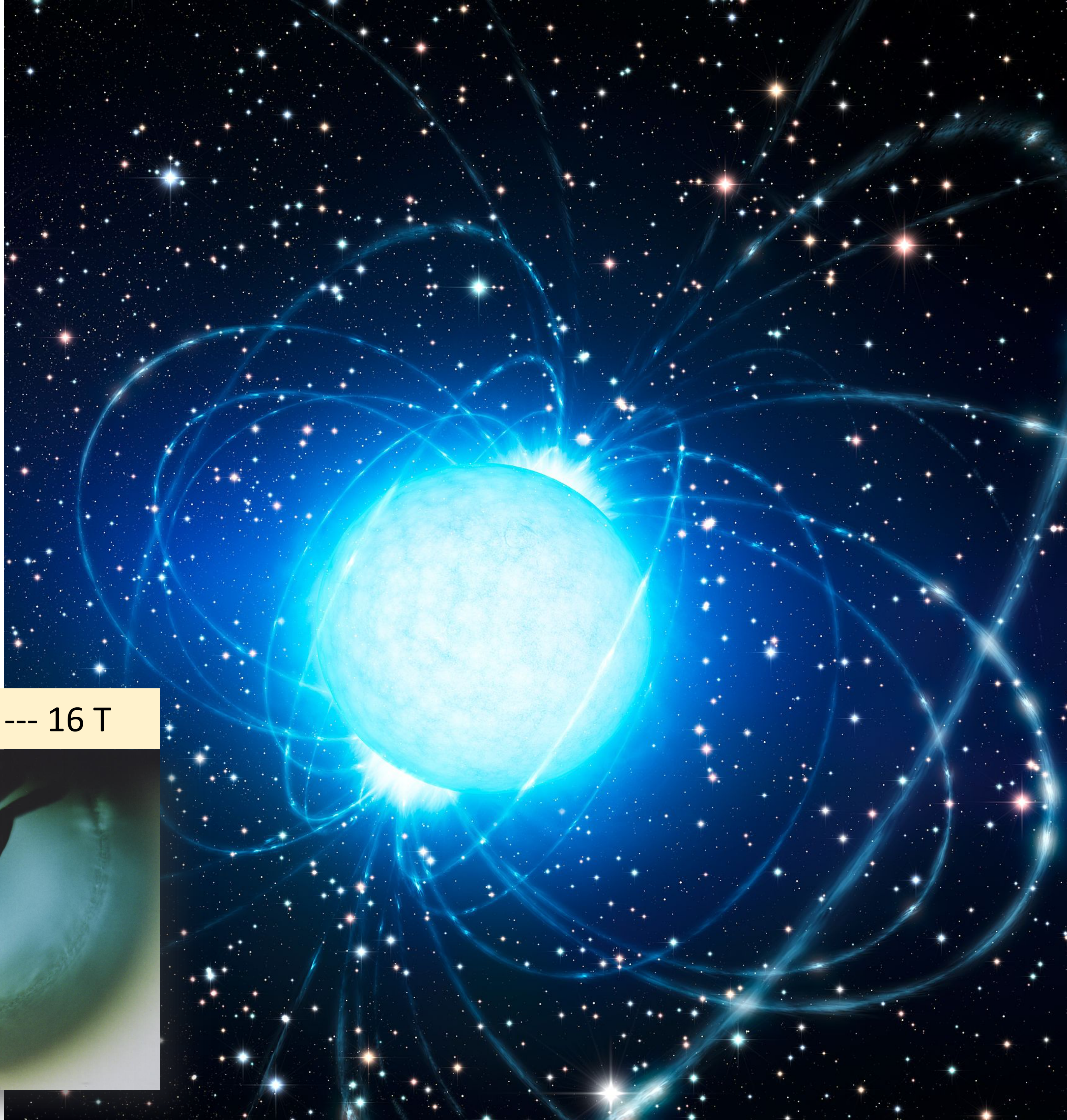
Can make NS prolate

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

NS slowly loses magnetic fields
→ weak during BNS merger

Frog levitation --- 16 T

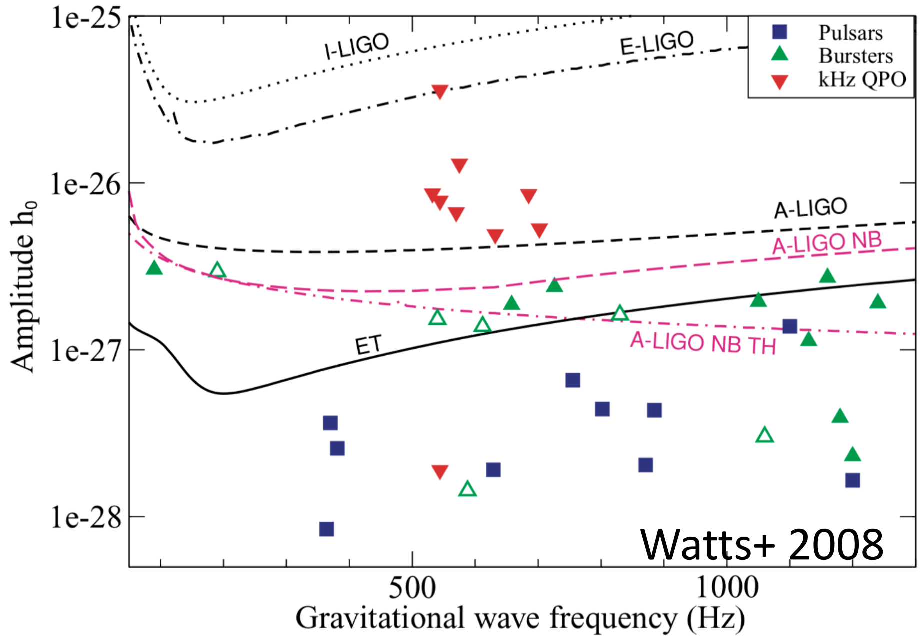


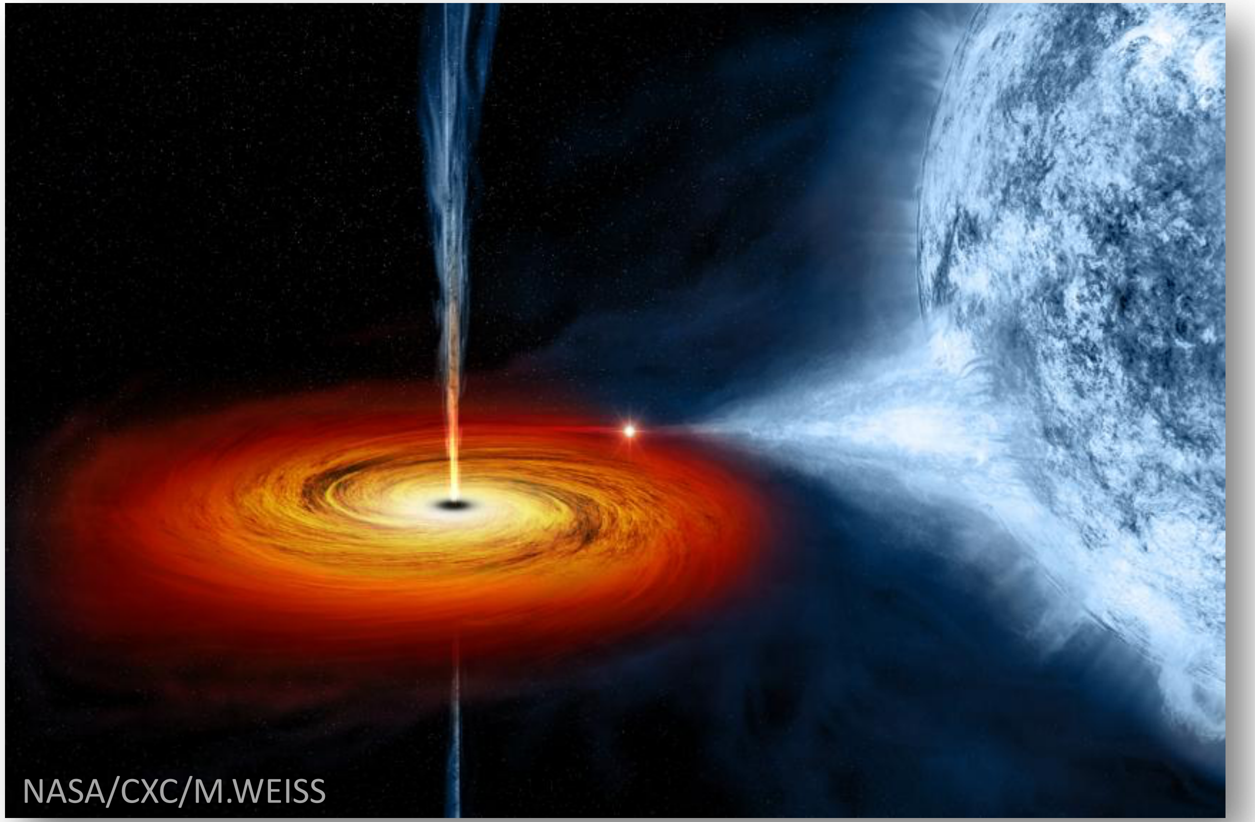


Accretion and spindown

Many accreting NSs rotate around 300 Hz

Maybe GW emission?





Bildsten ApJ Lett 1998

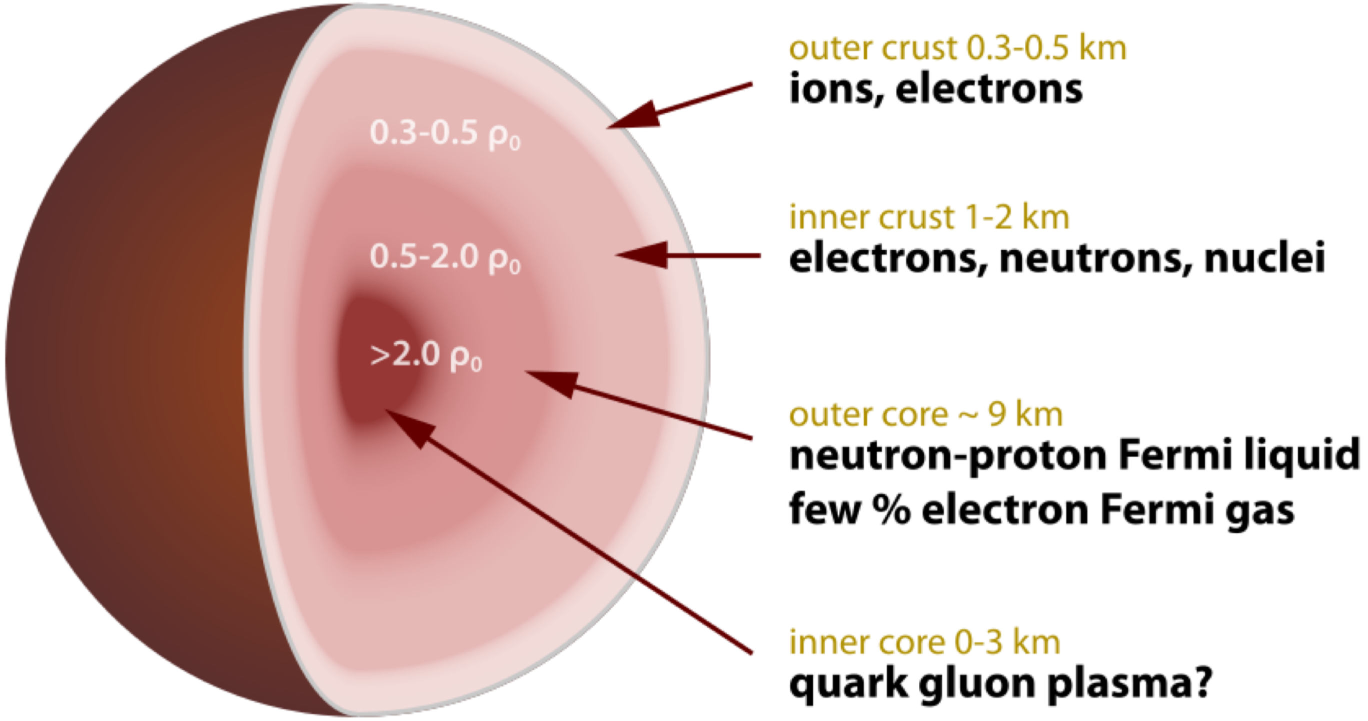
Structure

Mostly unknown

There is likely a NS “crust”

There is likely a NS “crust” and core

Quark-gluon plasma in core?



Robert Schulze

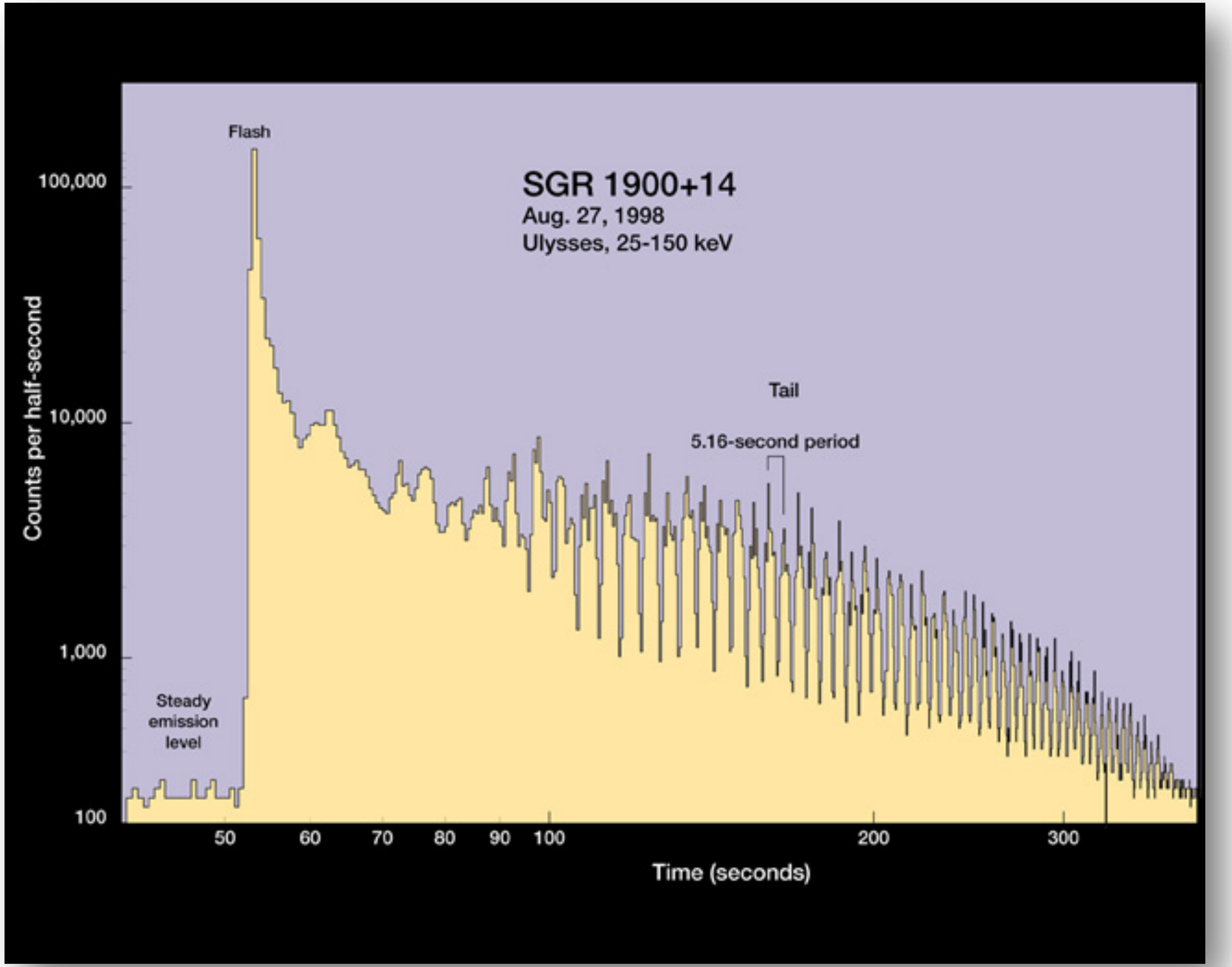
Soft gamma repeaters

Occasional outbursts of gamma rays

Quasi-periodic oscillations

Starquakes??

Magnetic field reorganization?



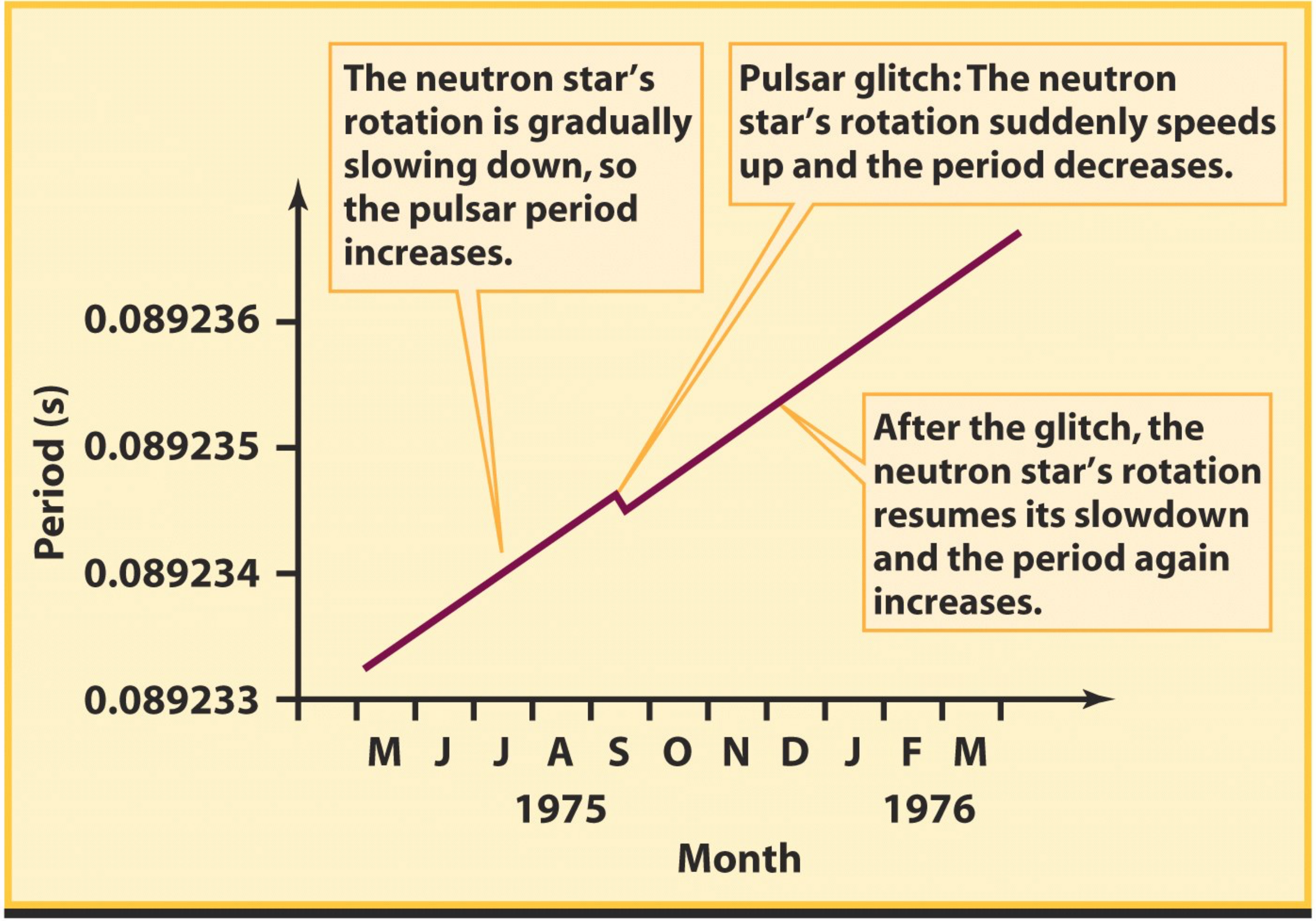
Glitches

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

Core reorganization that releases energy?

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

Bad for pulsar timing



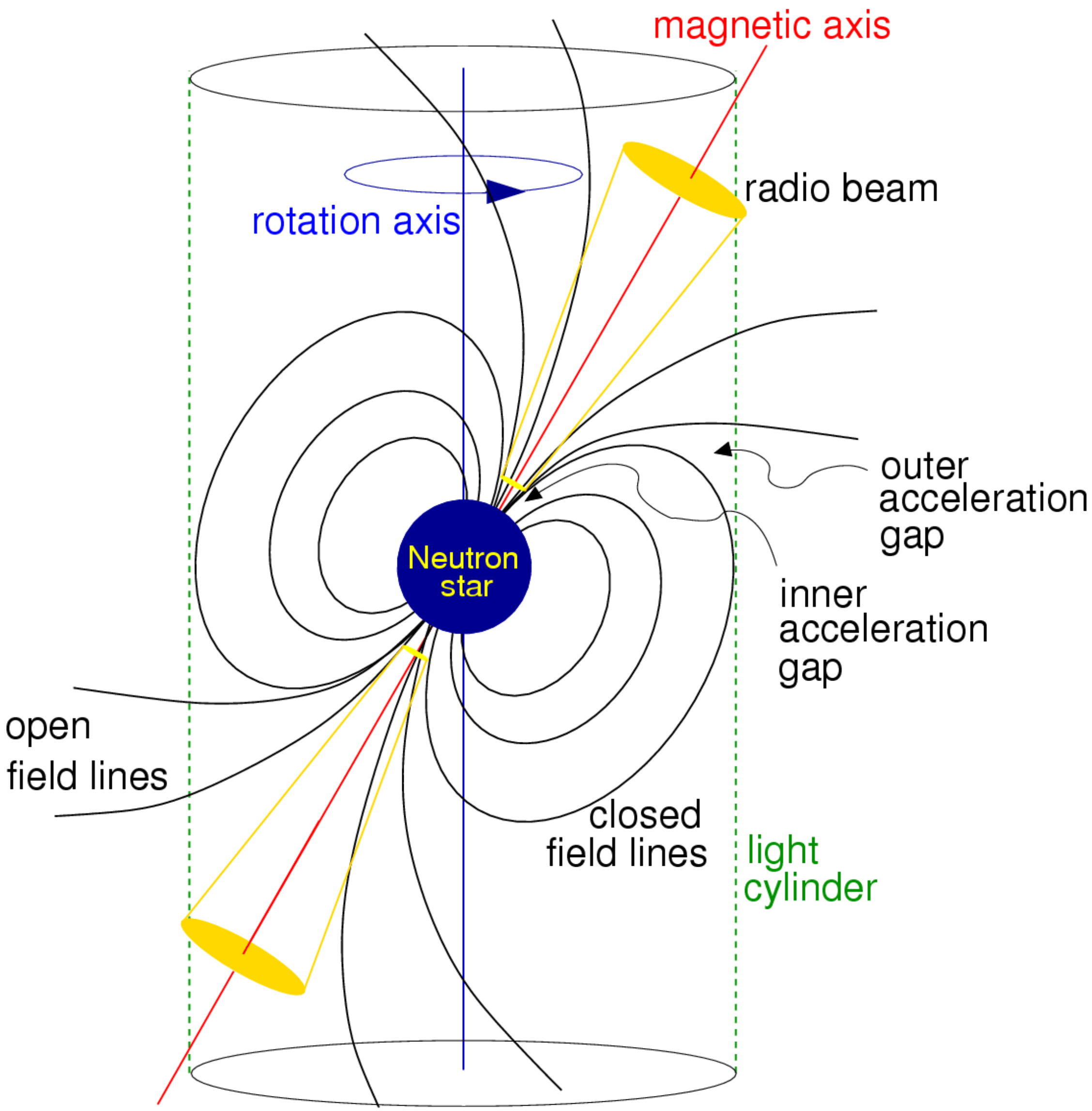
Pulsars

Very regular period

Formed in a supernova

After sufficient slowdown the radio pulsar mechanism is turned off.

Energy source:
- Rotation
- Accretion
- Magnetic fields



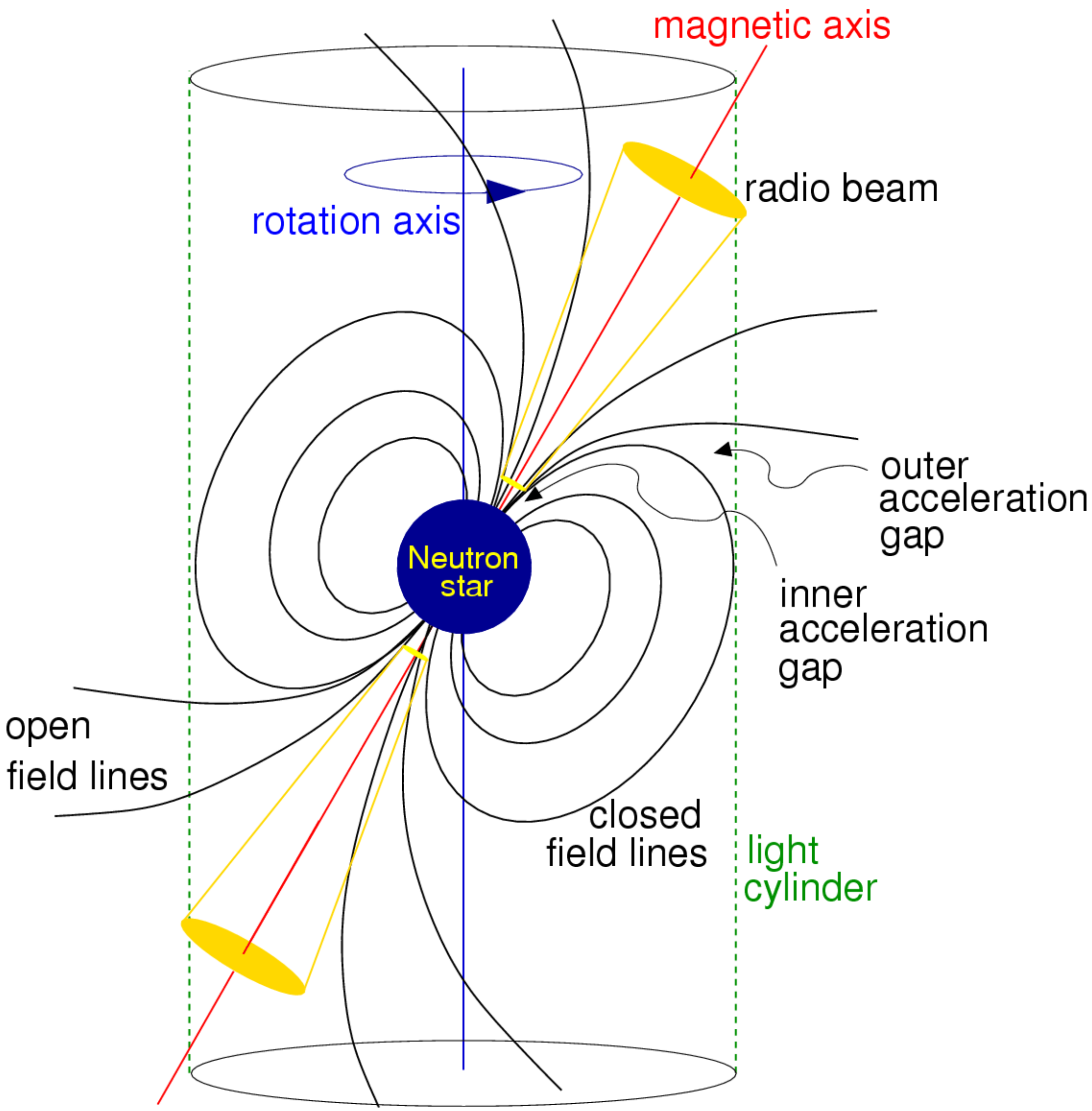
http://www.cv.nrao.edu

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.

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



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

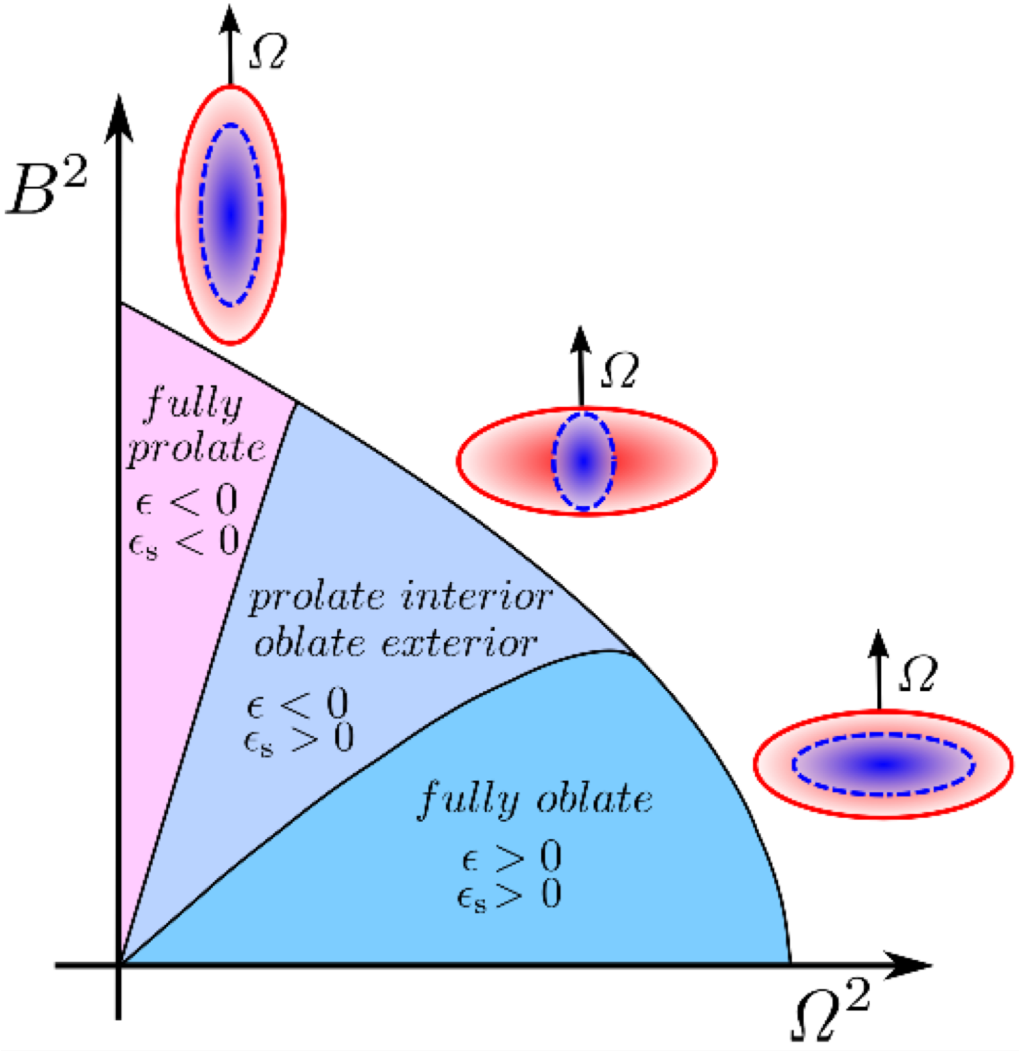
Magnetic deformation

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.

$$\epsilon = -\frac{3}{2}\varepsilon = \frac{1}{18}\frac{B^2 R^4}{G M^2}$$
$$\approx 10^{-12}\left(\frac{R}{10\,\mathrm{km}}\right)^4\left(\frac{M}{1.4\,\mathrm{M}_\odot}\right)^{-2}\left(\frac{\bar{B}}{10^{12}G}\right)^2$$

Haskell+ 2002



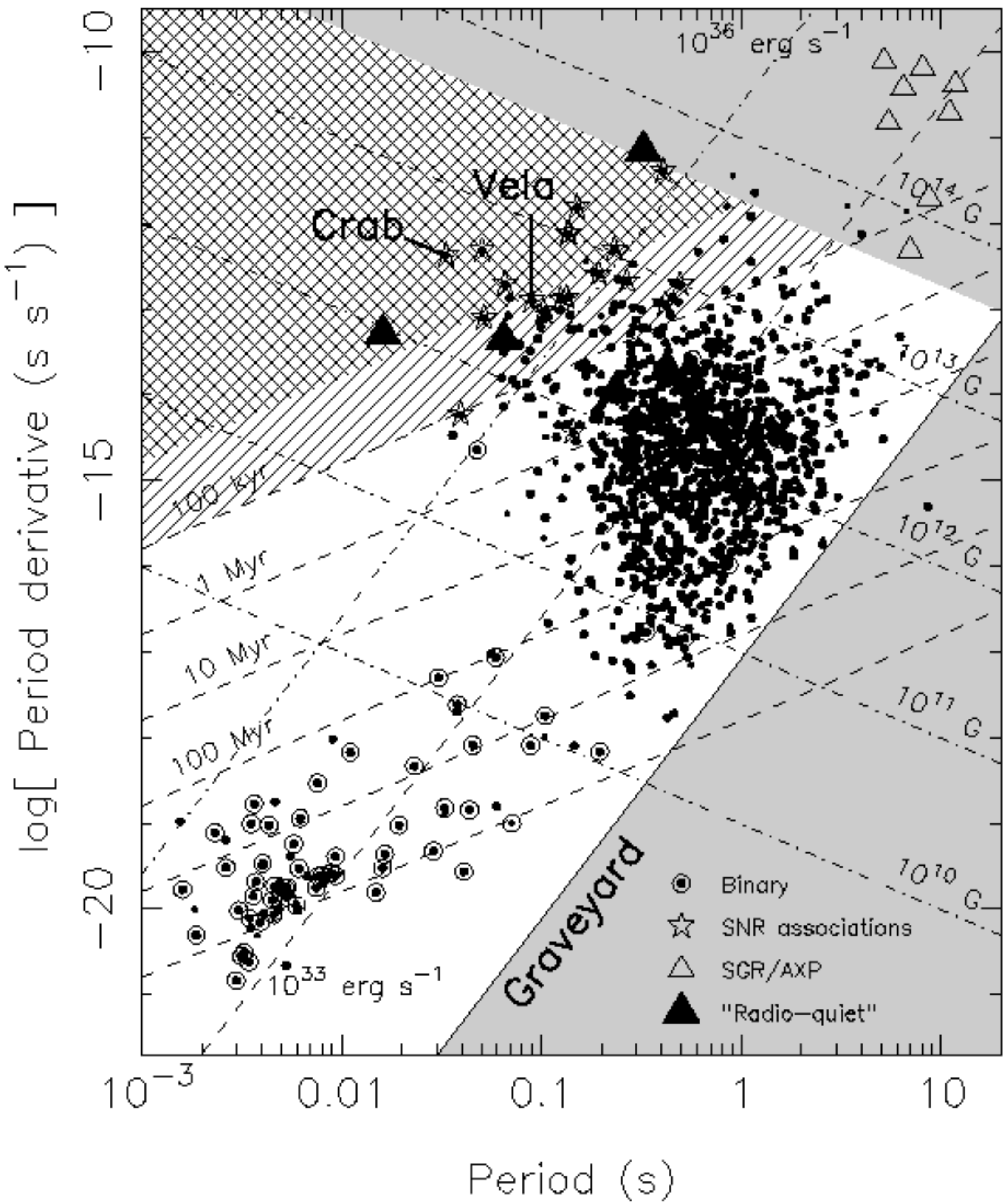
Fieben & Rezzolla 2014

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