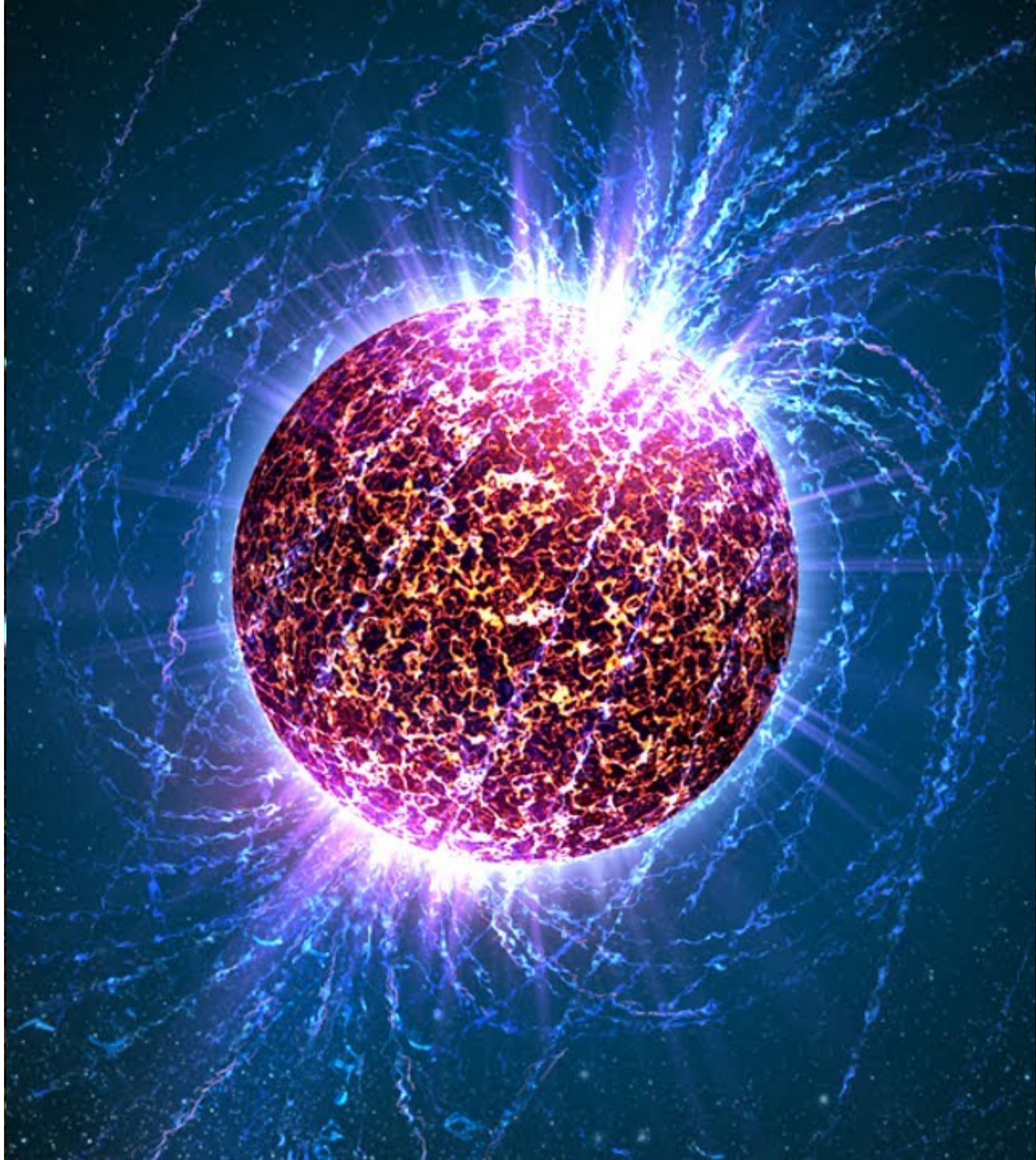
PHY 7097 | Modern Astrophysics

Lecture VI.

Neutron stars



Imre Bartos | Spring 2018

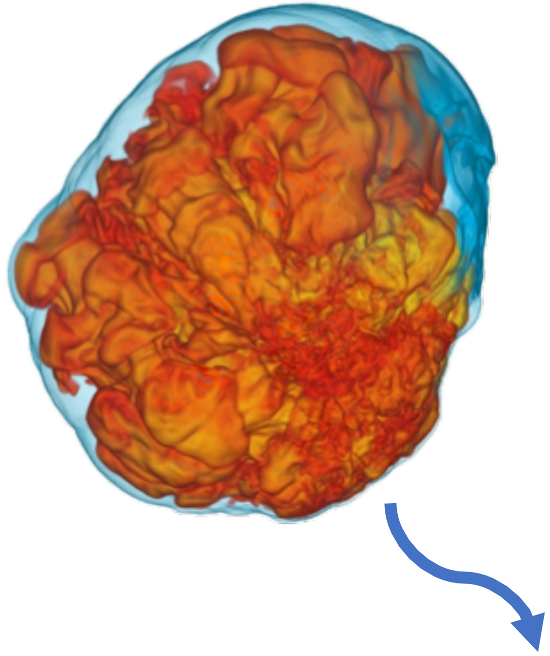
Gravitational wave production

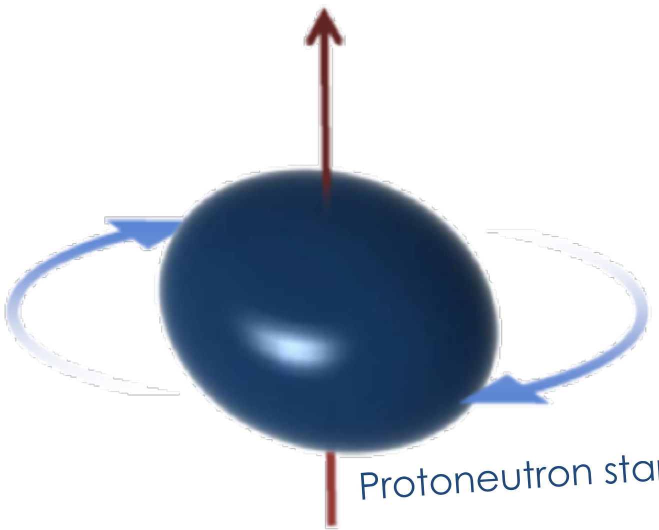
Process	Typical $\lvert h\rvert$ (at 10 kpc)	Typical f (Hz)	Duration Δt (ms)	E_{GW} $(10^{-10} M_\odot c^2)$	Limiting Factors or Processes
Prompt Convection	$10^{-23} - 10^{-21}$	$50 - 1000$	$0- \sim 30$	$\lesssim 0.01 - 10$	Seed perturbations, entropy/lepton gradient, rotation
	(Emission characteristics depend on seed perturbations.)				
PNS Convection	$2 - 5 \times 10^{-23}$	$300 - 1500$	500 – several 1000	$\lesssim 1.3(\frac{\Delta t}{1s})$	rotation, BH formation, strong PNS g-modes
Neutrino-driven Convection and SASI	$10^{-23} - 10^{-22}$ (peaks up to 10^{-21})	$100 - 800$	$100- \gtrsim 1000$	$\gtrsim 0.01(\frac{\Delta t}{100ms})$ $\lesssim 15(\frac{\Delta t}{100ms})$	rotation, explosion, BH formation

Unclear, but likely only detectable from the Milky Way

Ott 2008

Rapidly rotating core





Bartos, Brady, Marka 2013

GWs from rapidly rotating cores?

<u>Relevant distance scale:</u>

Low-luminosity GRB / CCSN with jets: 10^2-10^3 Gpc^{-3} yr^{-1}

(Guetta & della Valle 2006; Soderberg+ Nature 2010)

(Beaming factor ~ 10)

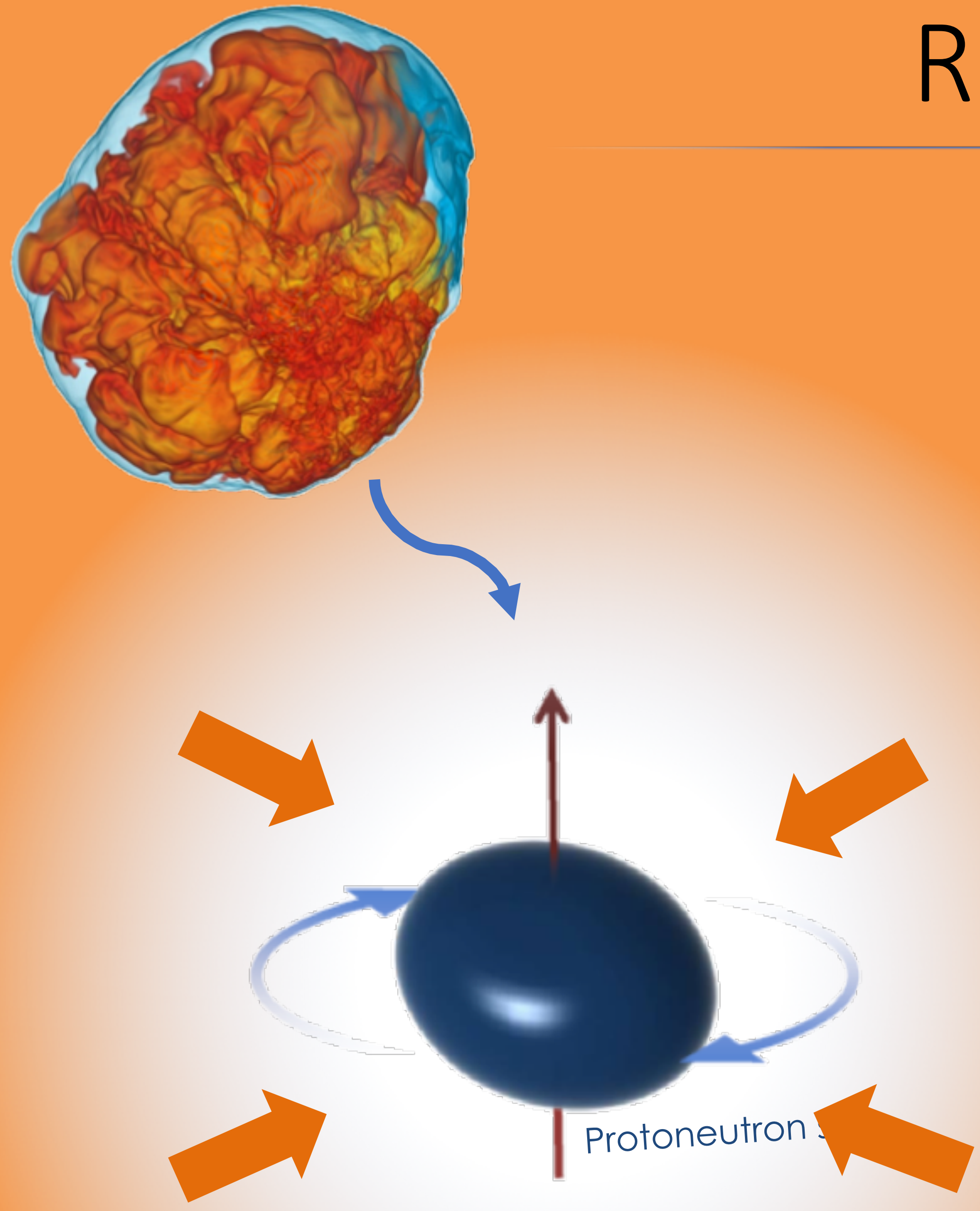
→ **50-100 Mpc**

Differential rotation (e.g. Corvino+ 2010)

- **Dynamical instabilities** *(shorter time scale)*
- **Secular instabilities** *(longer time scale)*
- **Magnetic distortion**

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

Rapidly rotating core



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Fallback accretion? *(Piro, Thrane, 2012)*

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Homework

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

Assume realistic dependence of epsilon on f.

What will be the gravitational waveform?

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