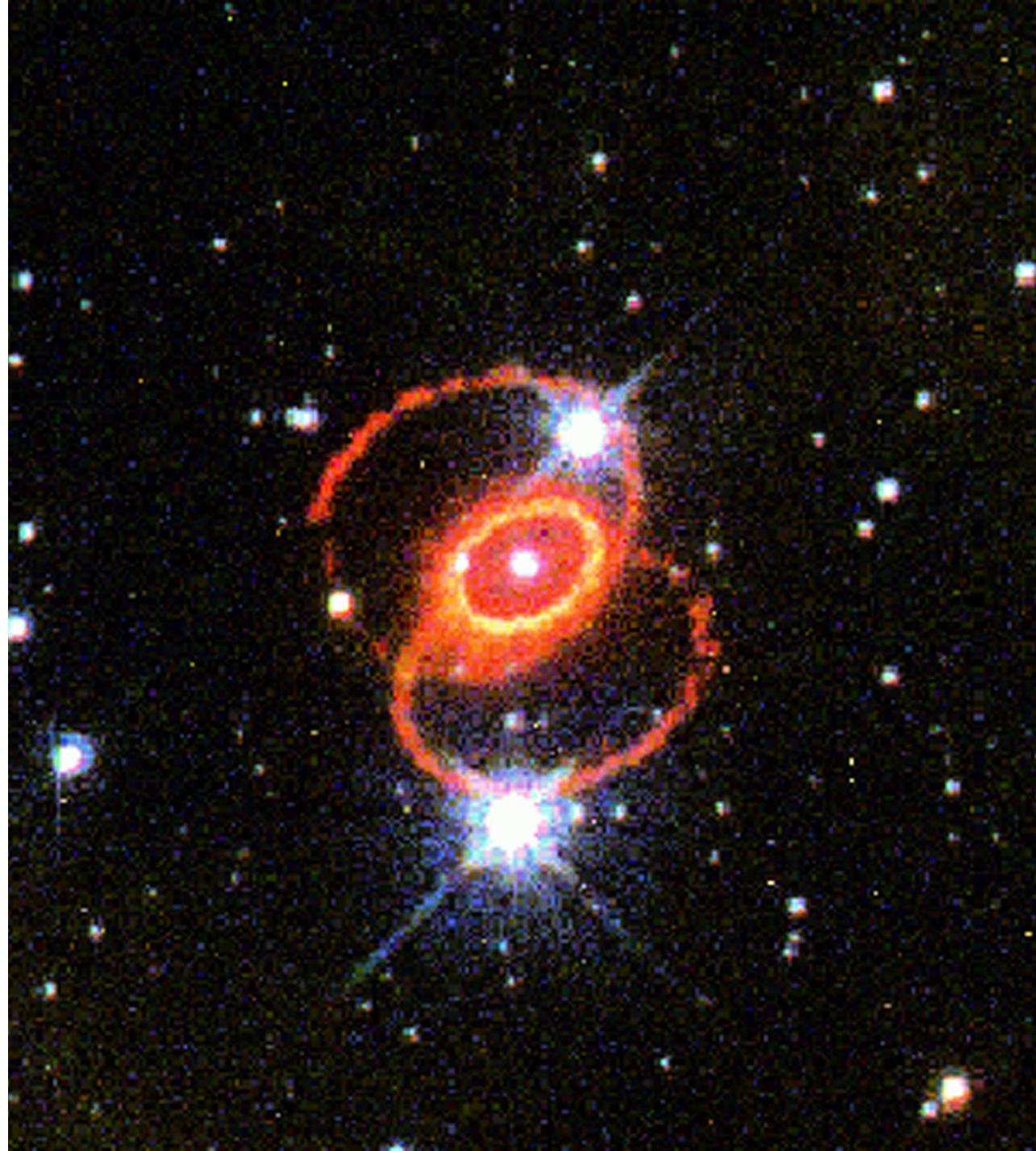


Lecture V.

Supernovae



Imre Bartos | Spring 2018



Classification

Absorption line and light curve

Type I No hydrogen	Type Ia Presents a singly ionized silicon (Si II) line at 615.0 nm (nanometers), near peak light		Thermal runaway	
	Type Ib/c Weak or no silicon absorption feature	Type Ib Shows a non-ionized helium (He I) line at 587.6 nm		
		Type Ic Weak or no helium		
Type II Shows hydrogen	Type II-P/L/N Type II spectrum throughout	Type II-P/L No narrow lines	Type II-P Reaches a "plateau" in its light curve	Core collapse
			Type II-L Displays a "linear" decrease in its light curve (linear in magnitude versus time). ^[47]	
		Type IIn Some narrow lines		
	Type IIb Spectrum changes to become like Type Ib			

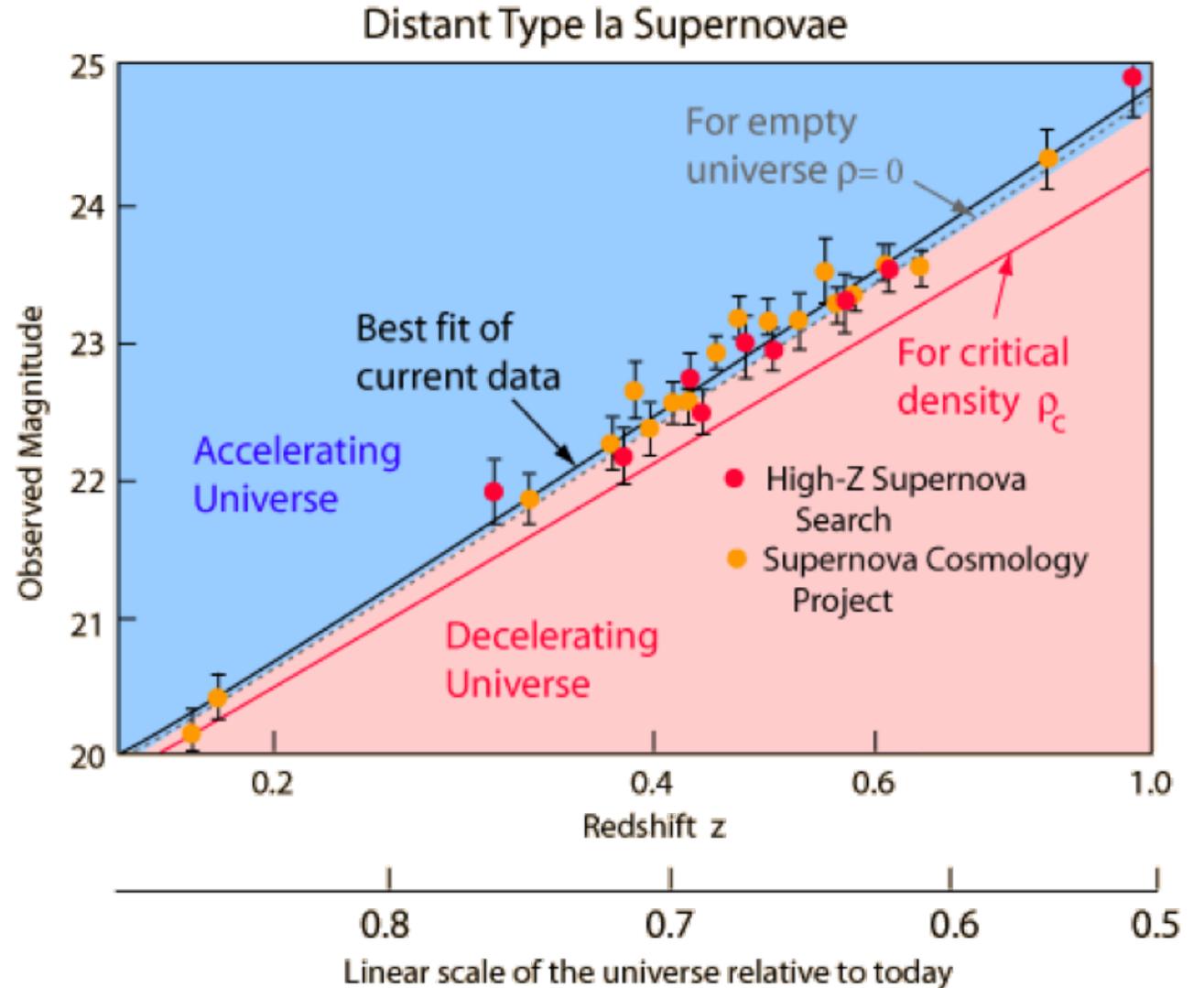
Cosmology with Type Ia Supernovae

“Standard candle”
always the same peak luminosity

Allows reconstruction of
luminosity distance

vs. host galaxy redshift

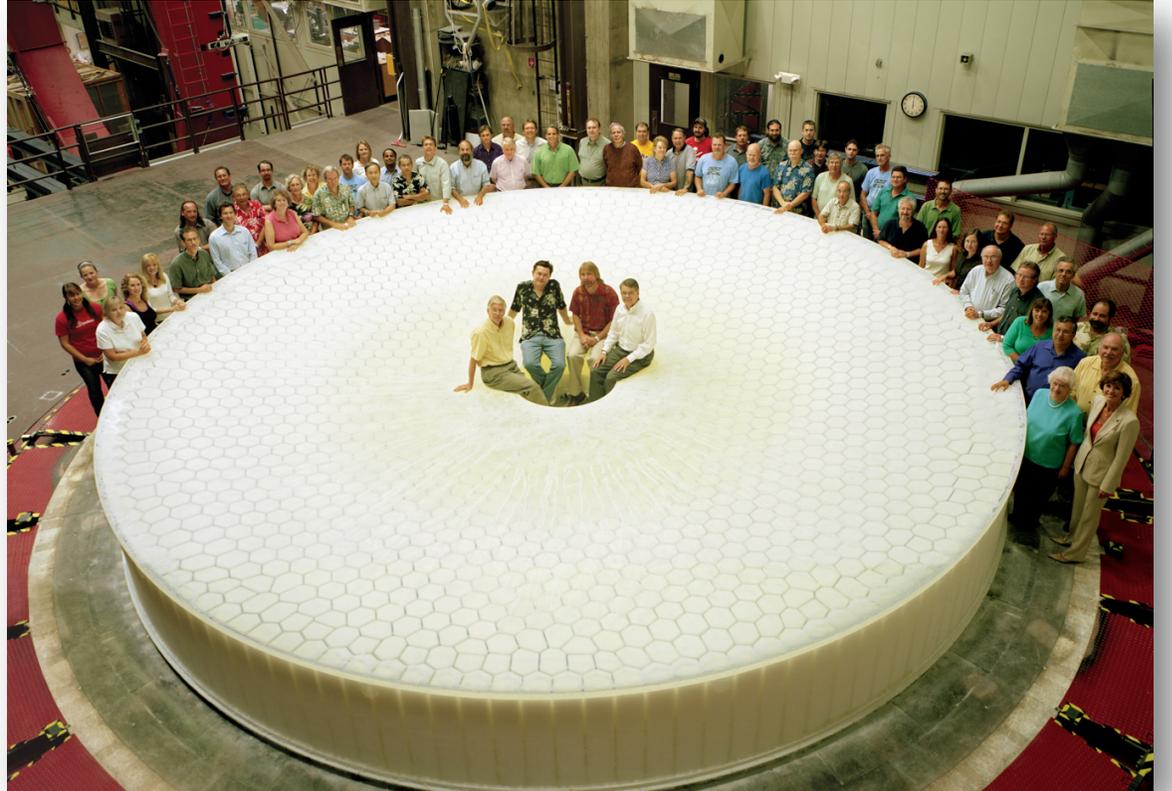
→ Rate of expansion of the universe



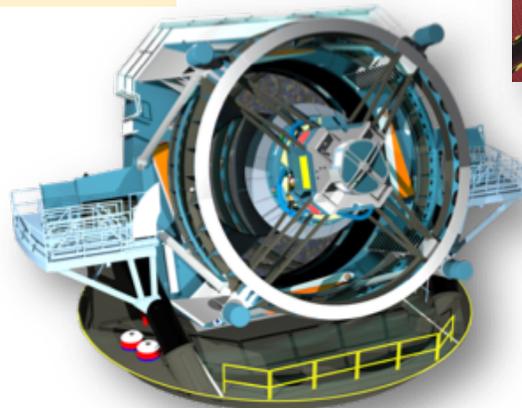
Observations



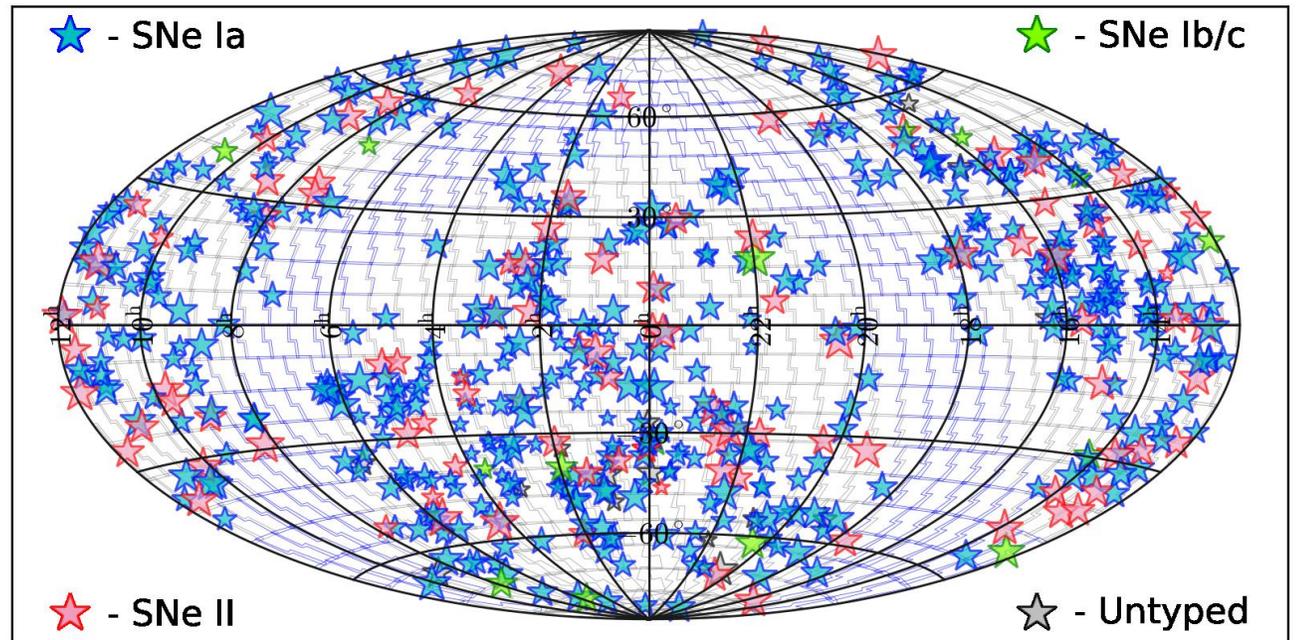
Zwicky Transient Facility (ZTF)
Regular scans of the sky, rapid ToO response



Large Synoptic Survey Telescope (LSST, 2022)
Regular scans of the sky, very high sensitivity (9m)



Observations



Multiple, very small telescopes that scan the whole sky every night.

Gravitational waves

“messy” waveform
stochastic with dominant frequency

Emission essentially stars with core bounce

Duration: 10s of ms

Waveform will depend on:

- Mass
- Nuclear equation of state (EoS)
- Rotation
- ...

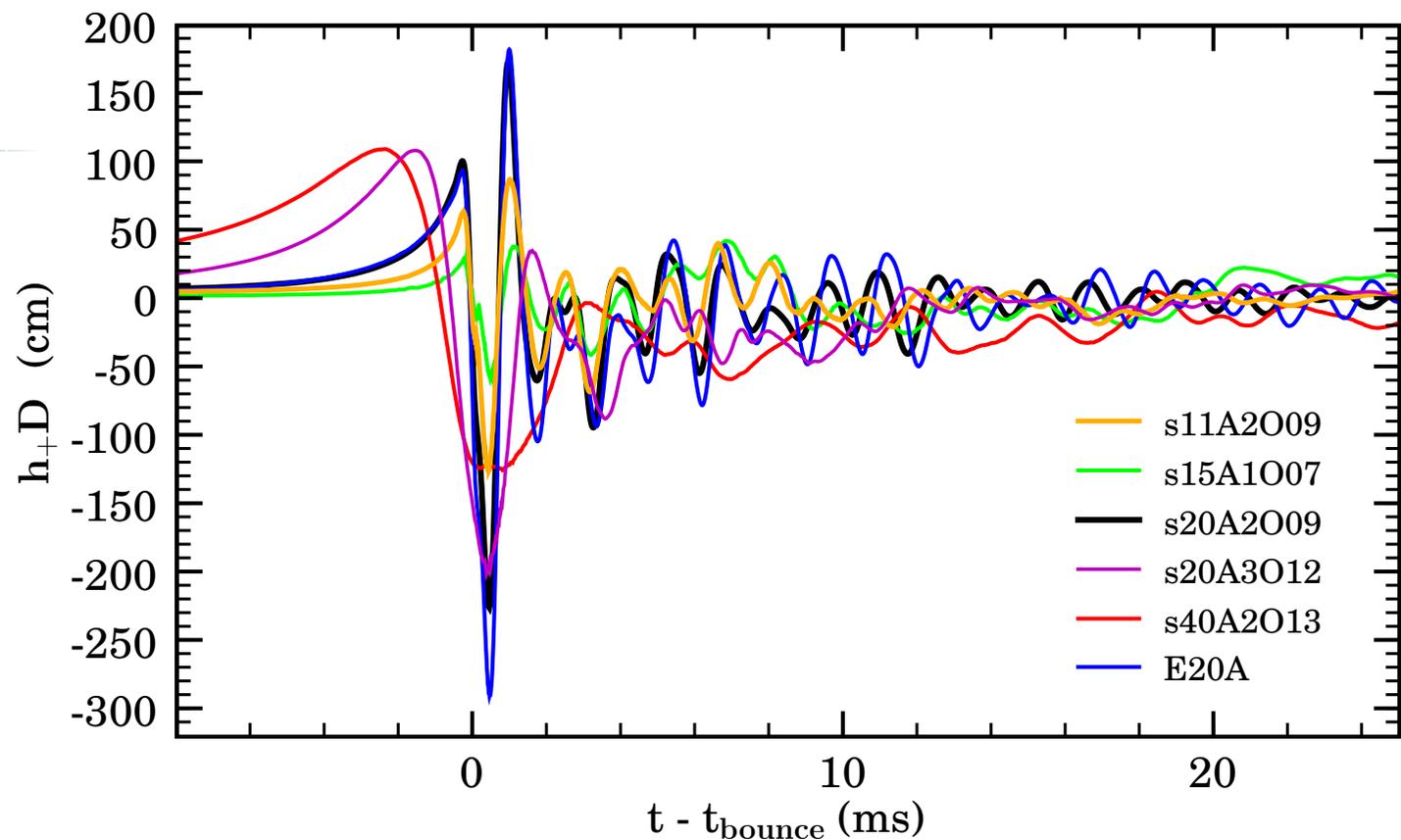


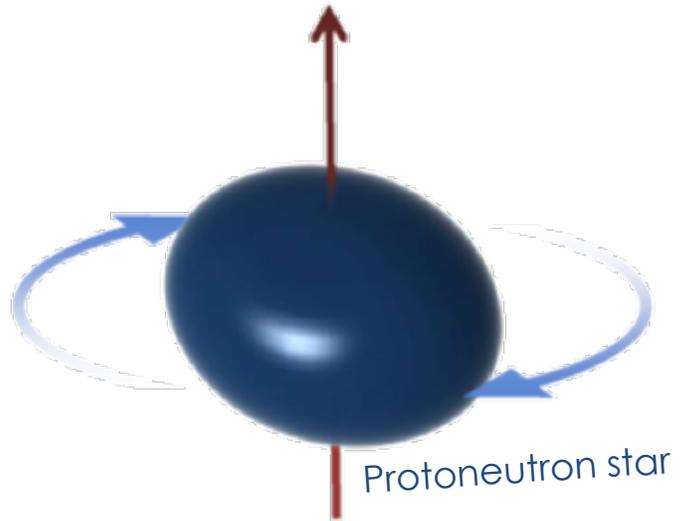
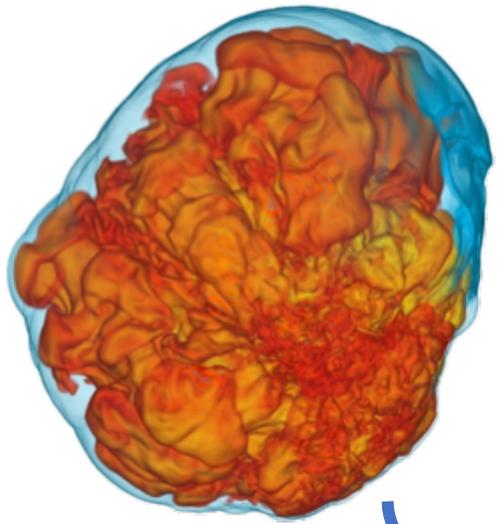
Figure 2. GW signals ($h_+ D$ in units of cm, where D is the distance of the source) for a few examples from the 2D GR model set of Dimmelmeier et al. [108]. The models shown here were computed with the Shen EOS [135, 136] and employ 1D presupernova models of [137], spanning the progenitor mass range from $11.2 M_\odot$ (s11) to $40 M_\odot$ (s40). The models were set up with precollapse central angular velocities $\Omega_{c,i}$ from $\sim 1.5 \text{ rad s}^{-1}$ to $\sim 11 \text{ rad s}^{-1}$. For details of the rotational setup, see [108]. Model E20A uses a $20 M_\odot$ presupernova model that was evolved by [138] with a 1D prescription for rotation. Note the generic shape of the waveforms, exhibiting one pronounced spike at core bounce and a subsequent ring down. Very rapid precollapse rotation ($\Omega_{c,i} \gtrsim 6 \text{ rad s}^{-1}$; models s20A3O12 and s40A2O13 in this plot) results in a significant slow-down of core bounce, leading to a lower-amplitude and lower-frequency GW burst. The GW signal data are available for download from [126].

Gravitational wave production

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

Unclear, but likely only detectable from the Milky Way

Rapidly rotating core



GWs from rapidly rotating cores?

Relevant distance scale:

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

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

(Beaming factor ~ 10)

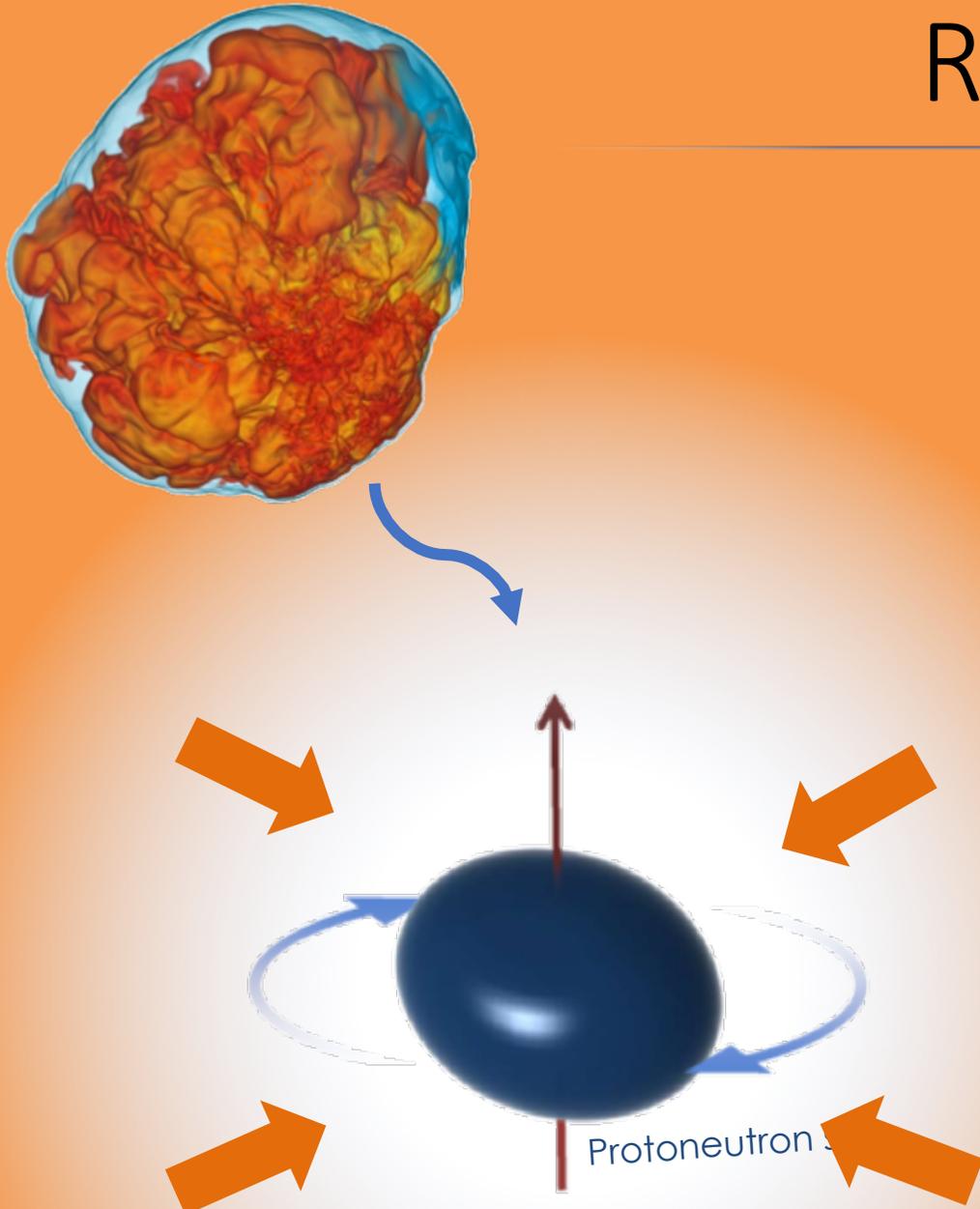
→ 50-100 Mpc

Differential rotation (e.g. Corvino+ 2010)

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

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

Rapidly rotating core



GWs from rapidly rotating cores?

Relevant distance scale:

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

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

(Beaming factor ~ 10)

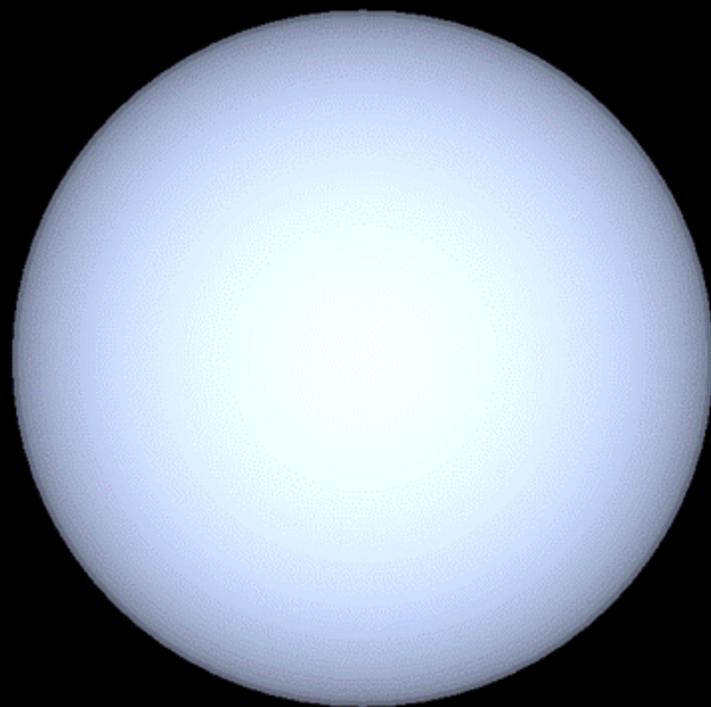
→ 50-100 Mpc

Differential rotation (e.g. Corvino+ 2010)

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

Fallback accretion? (Piro, Thrane, 2012)

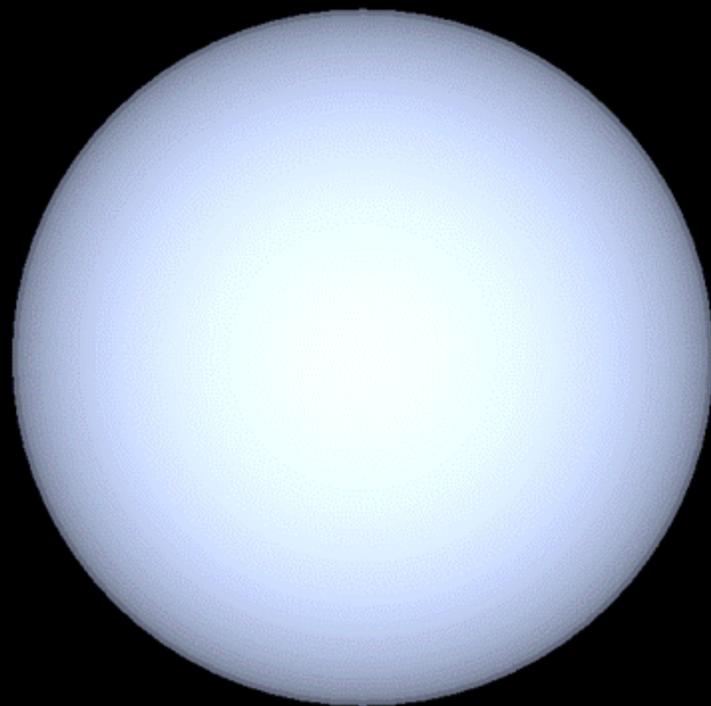
$$E_{\text{GW}} \approx 10^{-2} M_{\odot} c^2 \left(\frac{\epsilon}{0.2} \right)^2 \left(\frac{f}{2 \text{ kHz}} \right)^6 \left(\frac{M}{1.4 M_{\odot}} \right) \left(\frac{R}{12 \text{ km}} \right)^2 \left(\frac{\tau}{0.1 \text{ s}} \right)$$



$$M \approx 1.0 M_{\text{sun}}$$

$$R \approx 5800 \text{ km}$$

$$V_{\text{esc}} \approx 0.02c$$



$$T = 2\pi \sqrt{\frac{a^3}{G(M_1 + M_2)}}$$

$$M \approx 1.0 M_{\text{sun}}$$

$$R \approx 5800 \text{ km}$$

$$V_{\text{esc}} \approx 0.02c$$