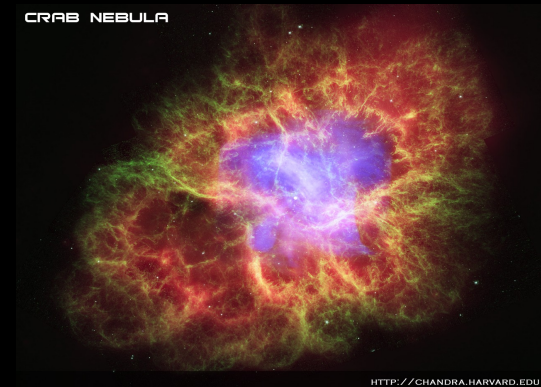
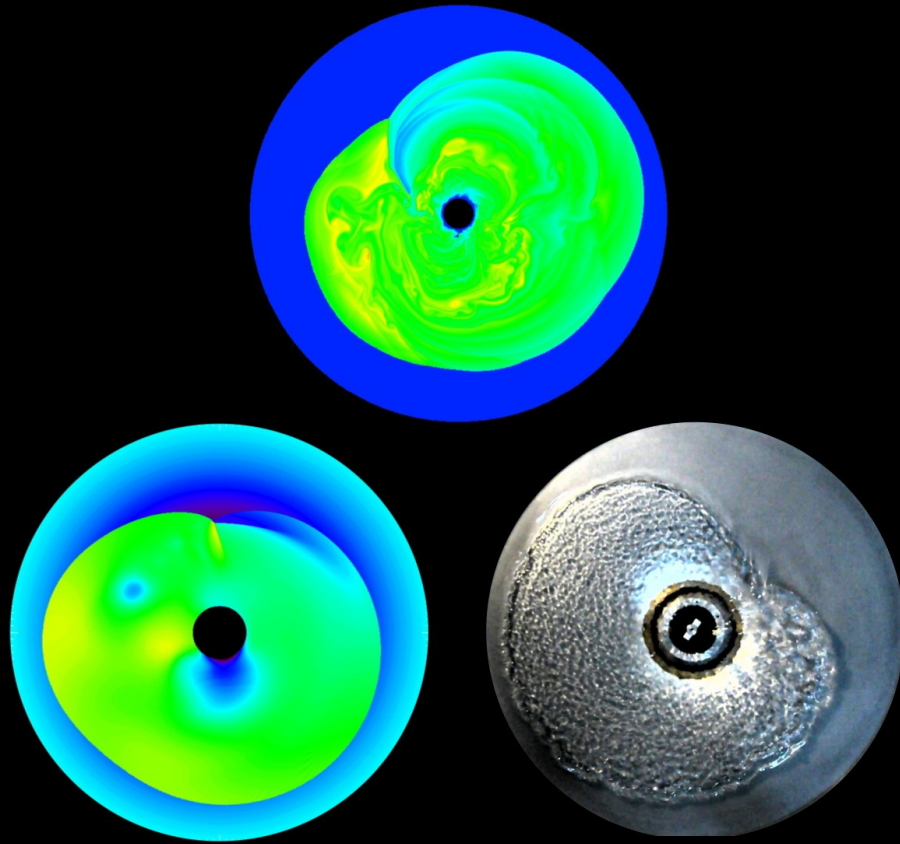


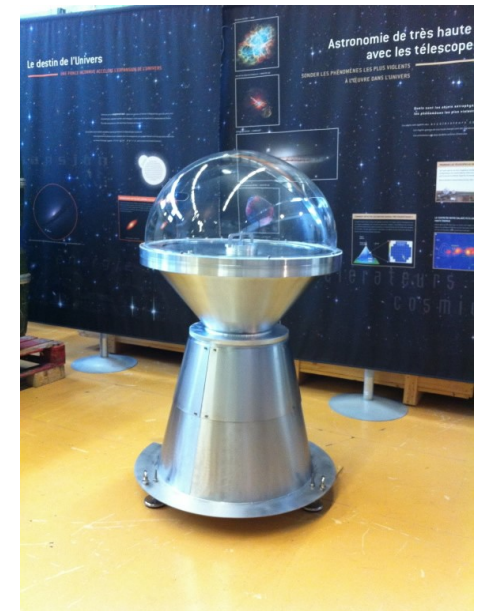
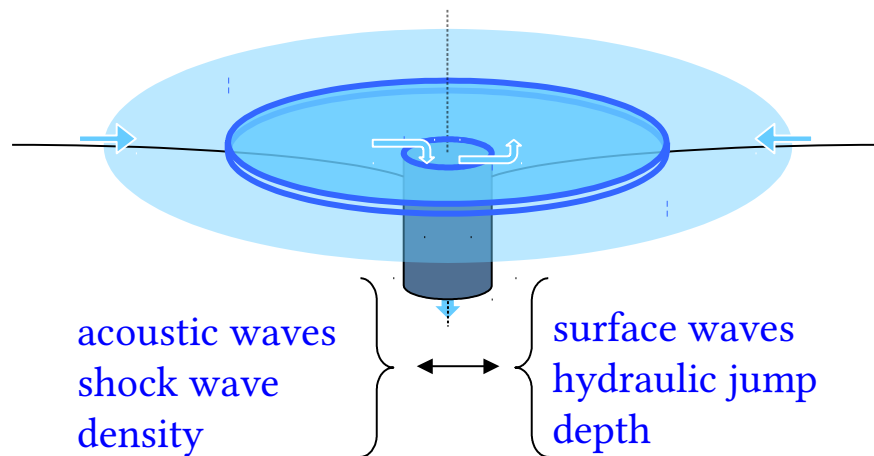
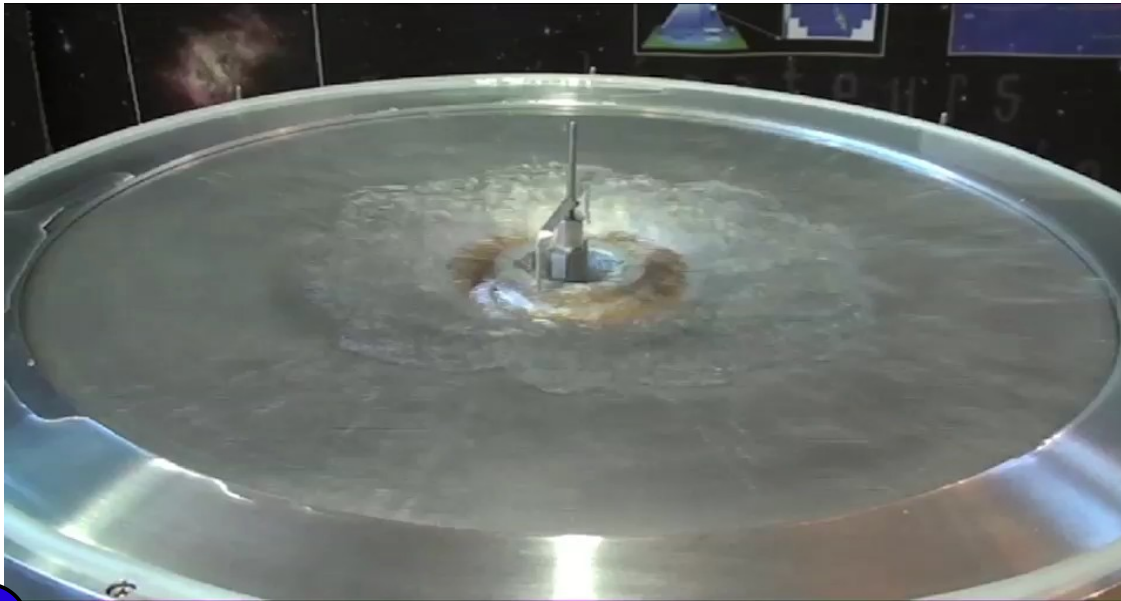
Are pulsars spun up or down by the spiral modes of the SASI?



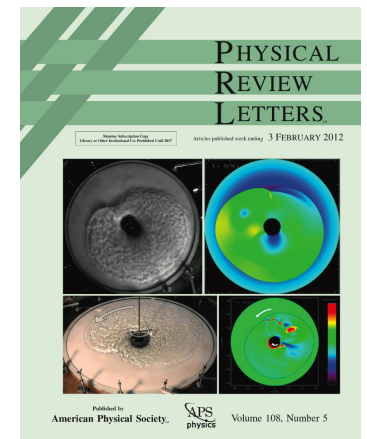
Rémi Kazeroni (CEA)
Thierry Foglizzo (CEA), Jérôme Guilet (MPA)

Shallow Water Analogue to Shock Instability (SWASI)

Gas dynamics in the supernova core: 1 000 000 x bigger and 100 x faster

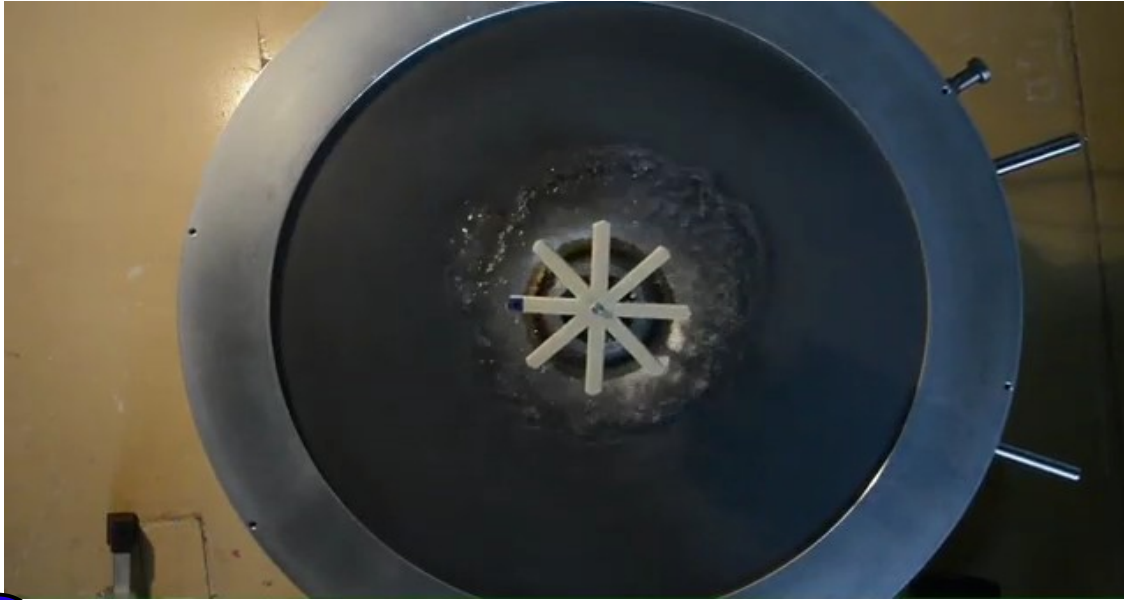


*Now at Palais de la
Découverte, Paris*



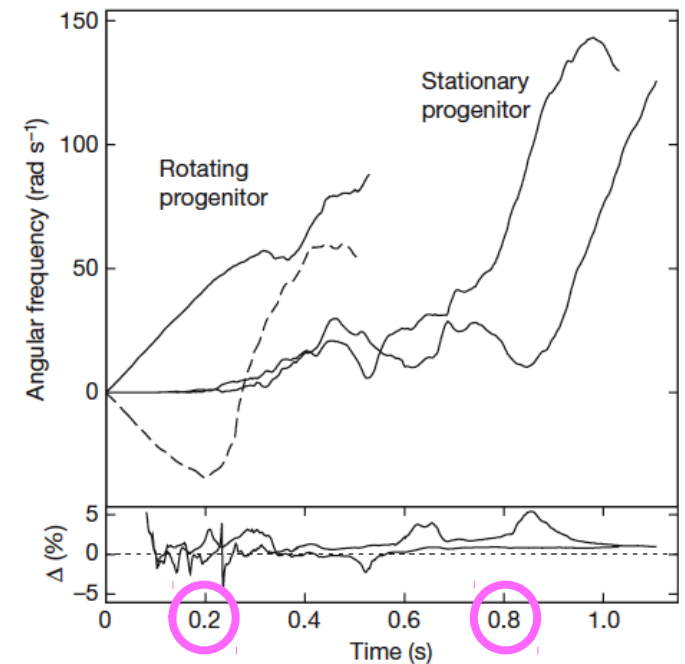
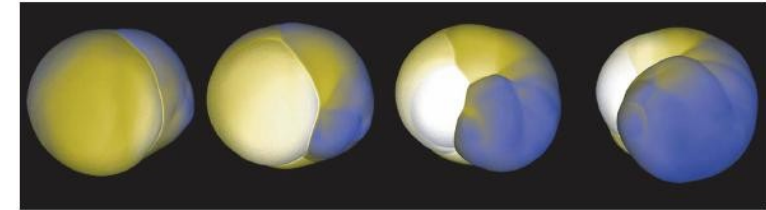
*Foglizzo, Masset, Guilet,
Durand, PRL 2012*

Rotating progenitor: accreted angular momentum changes its sign as SASI grows



see Foglizzo, RK, Guilet et al. 15

- Spin-up of a neutron star (NS) born from a non-rotating progenitor
- Spin-down a NS born from a rotating progenitor?
Counter-rotating NS?



Blondin & Mezzacappa 07

Modeling: 2D framework

- What is the flow pattern in the non-linear regime: spiral mode or sloshing mode?
- Can we define a timescale to reach a robust spiral mode?

Simplified setup

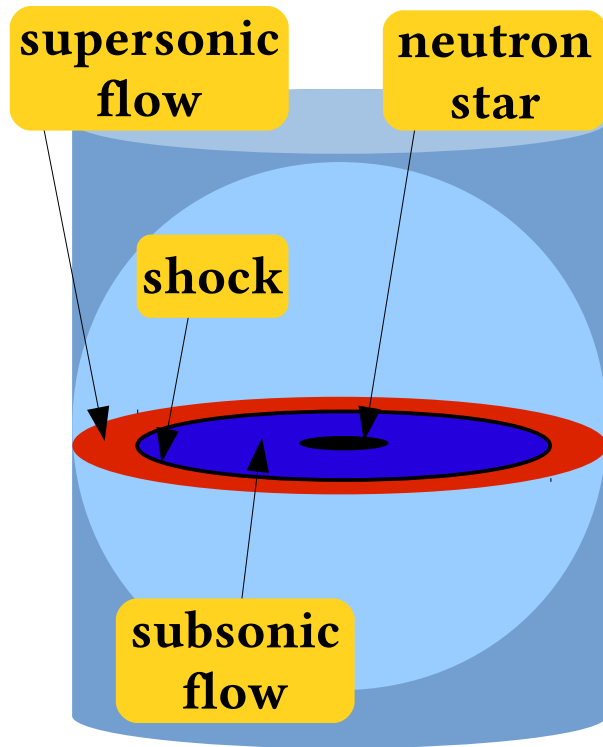
- Perfect gas equation of state ($\gamma=4/3$)
- Approximation of the neutrino cooling (*Blondin & Mezzacappa 06, Fernández & Thompson 09*)
- No heating
- Constant accretion rate

Numerical simulations

- RAMSES code: MHD code using Godunov type method
- Parametric study

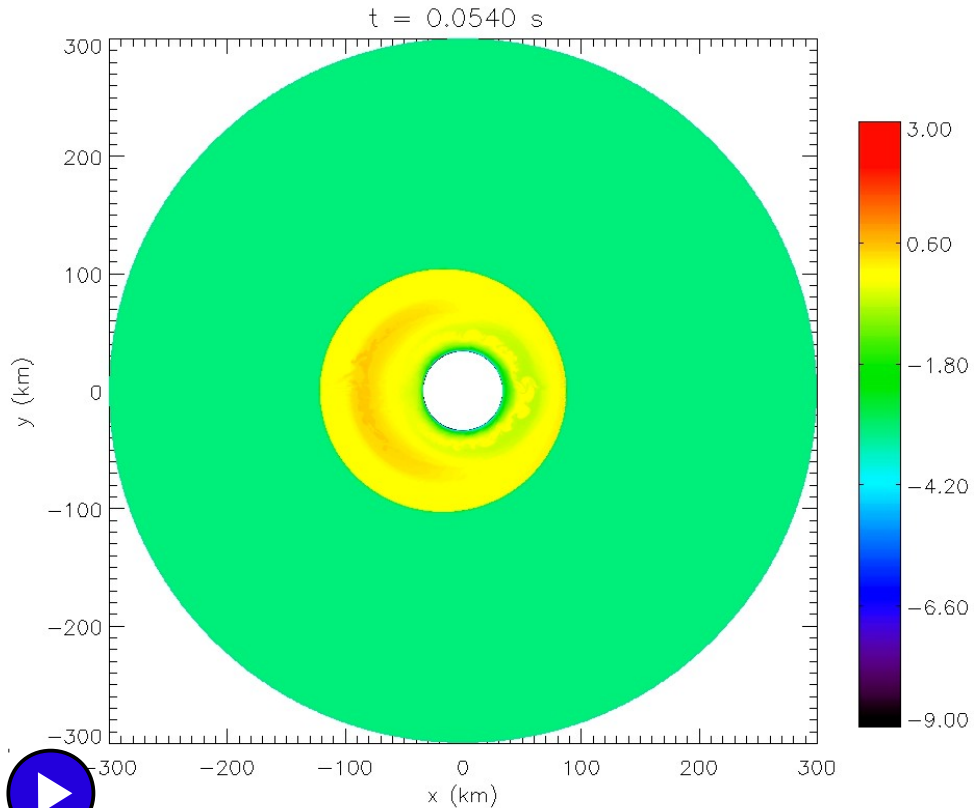
$$R = r_{\text{sh}} / r_* \quad (\text{e.g. } r_{\text{sh}} = 150 \text{ km} \ \& \ r_* = 50 \text{ km})$$

$$\varepsilon = (A_p^2 - A_{-p}^2) / (A_p^2 + A_{-p}^2) \quad A_p: \text{ mode amplitude}$$

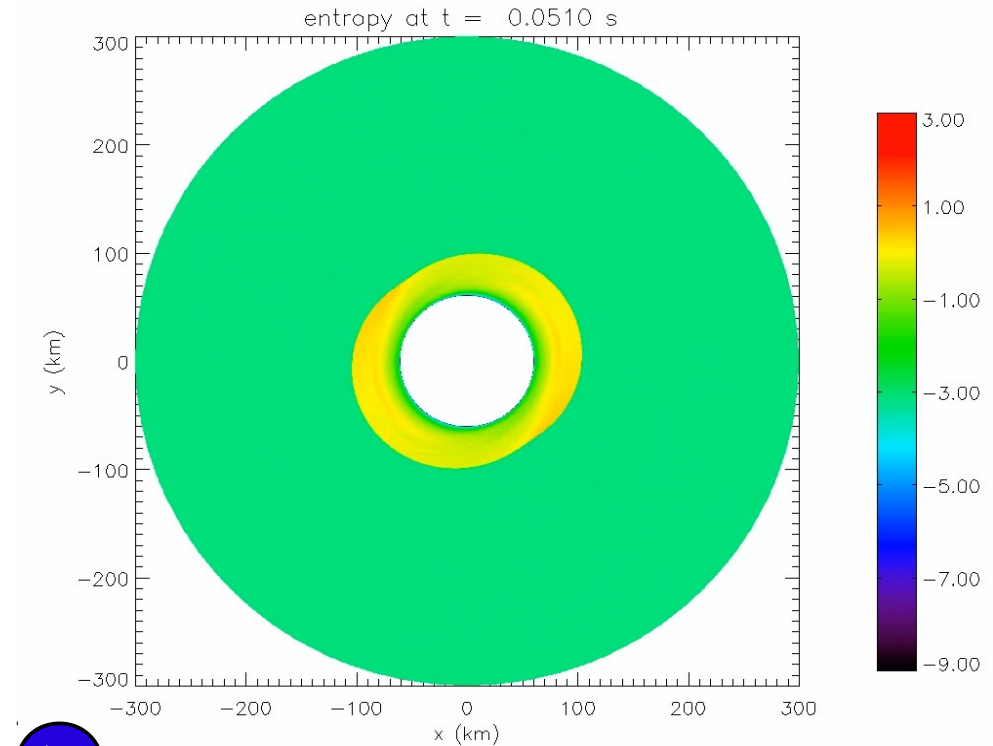


2D cylindrical domain

Symmetry breaking threshold



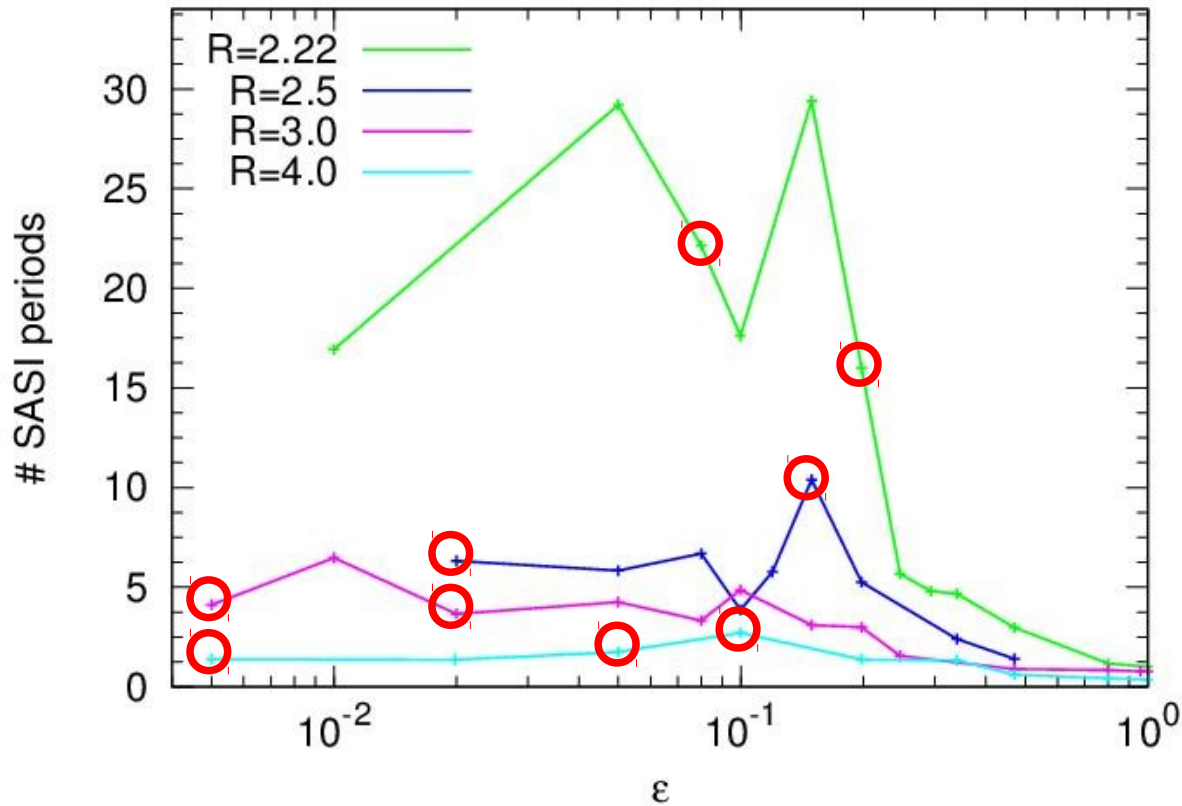
R=3
early spiral mode



R=1.67
a sashing mode dominates:
no NS spin-up!

Symmetry breaking occurs only if $R=r_{\text{sh}} / r_* > 2$

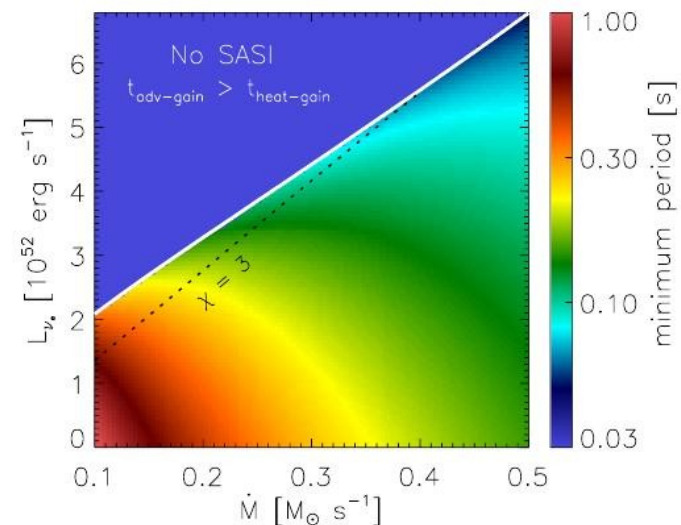
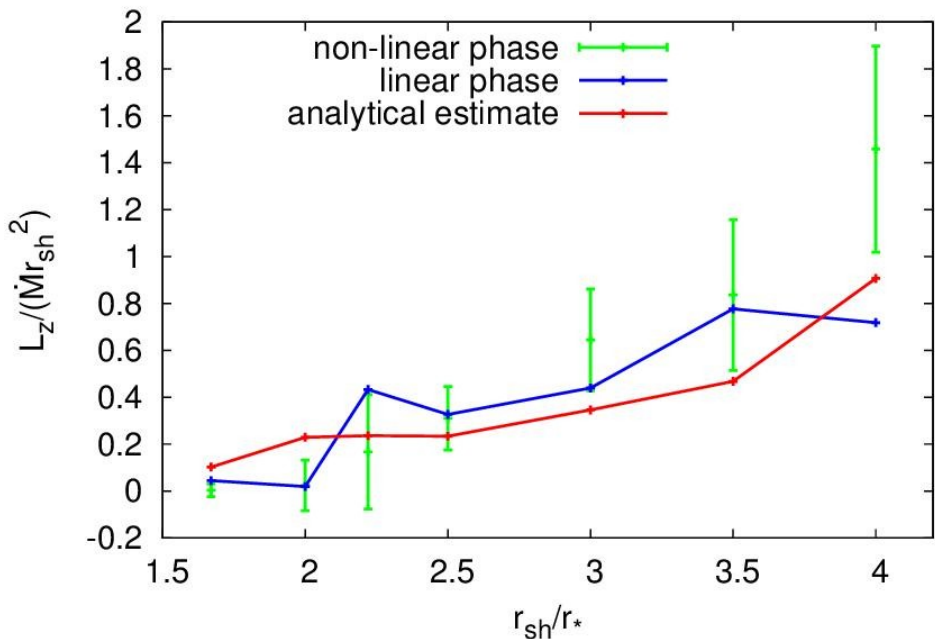
Timescale to reach a spiral mode (T_{sp})



○ Unexpected direction of rotation

- T_{sp} decreases with R
- For $R=2.22$, $T_{sb} \approx 1s$
- Direction of rotation unpredictable if $\epsilon \ll 1$
 \Rightarrow stochasticity

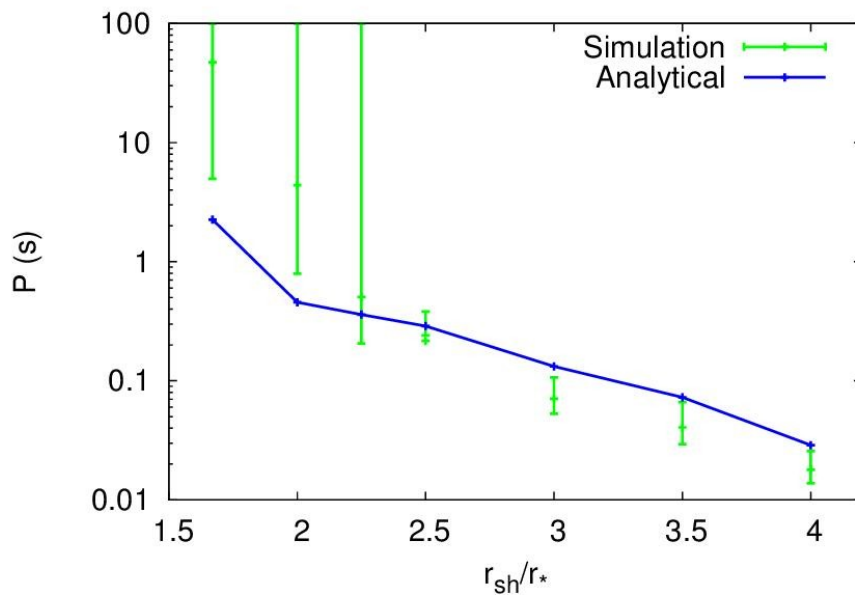
Pulsar spin estimates from analytical calculations and numerical simulations



Minimal period: $50\text{ms} \leq P \leq 1\text{s}$

Guilet & Fernández 14

results similar to Fernández 10, Guilet & Fernández 14



- SASI may spin-up the NS if $R \geq 2.5$
- SASI may not impact the spin if $R < 2.5$

Role of the initial rotation

Properties of the rotation

- SASI growth rates increase linearly with angular momentum (*Yamasaki & Foglizzo 08*)
- Prograde spiral modes are favoured and impact the NS spin (*Blondin & Mezzacappa 07*)
- Reduces the critical neutrino luminosity required for explosion (*Nakamura+14, Iwakami+ 14*)

SASI & rotation

- Effect on the saturation amplitude?
- Angular momentum accreted by the PNS?
- Maximal rotational energy available to match with pulsar spin observations?

Summary

- SWASI experiment to help understanding SASI in the presence of rotation
- Spiral vs sloshing mode in the non-linear regime: depends on the radii ratio
- SASI has the potential to spin-up the NS for an identified set of parameters
- Role of the initial rotation: ongoing work to characterize the non-linear dynamics of SASI and its impact on the neutron star spin at birth

Thanks for your attention!