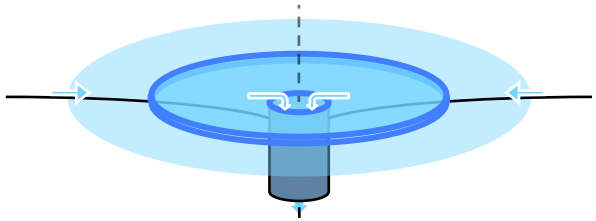
サシ → スワシ

A shallow water analog of asymmetric core-collapse, and neutron star kick/spin

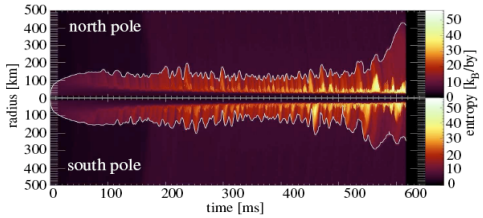


Thierry Foglizzo

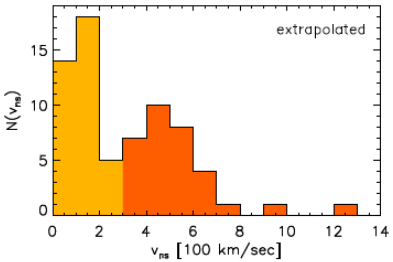
Frédéric Masset, Jérôme Guilet, Gilles Durand

The possible consequences of SASI

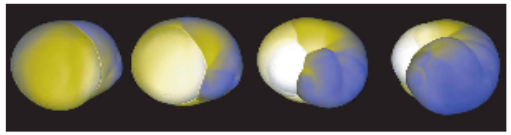
- successful explosion of $15M_{sol}$ driven by neutrino energy
  (Marek & Janka 09, Suwa et al. 10, Müller et al. 12)



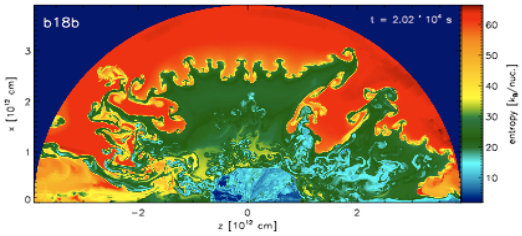
- pulsar kick
  (Scheck et al. 04, 06, Nordhaus et al. 10, 11, Wongwathanarat et al. 10)



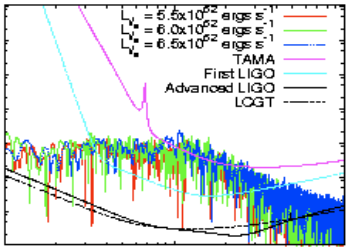
- pulsar spin ?
  (Blondin & Mezzacappa 07, Yamasaki & Foglizzo 08, Iwakami et al. 09, Rantsiou et al. 11)



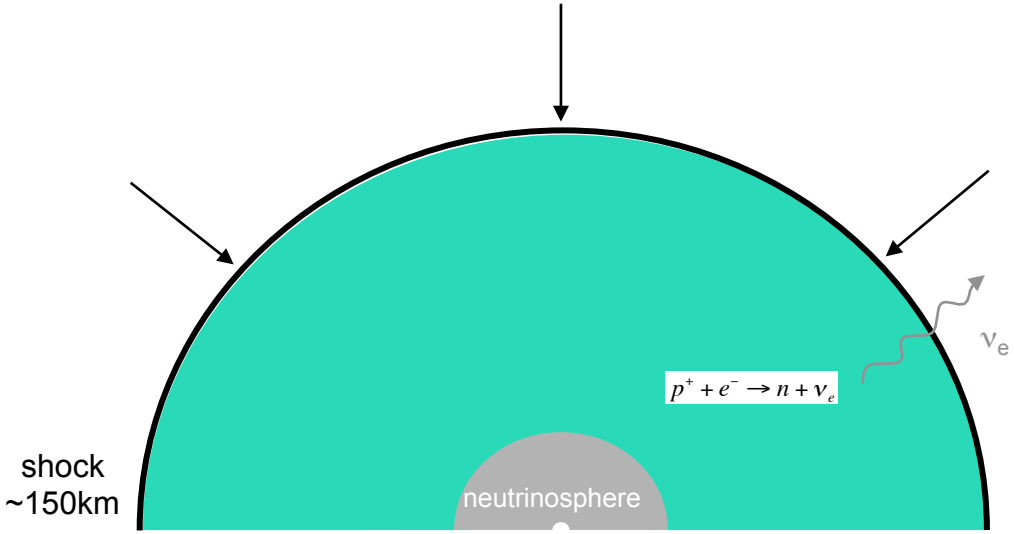
- H/He mixing in SN1987A
  (Kifonidis et al. 06, Hammer et al. 09)

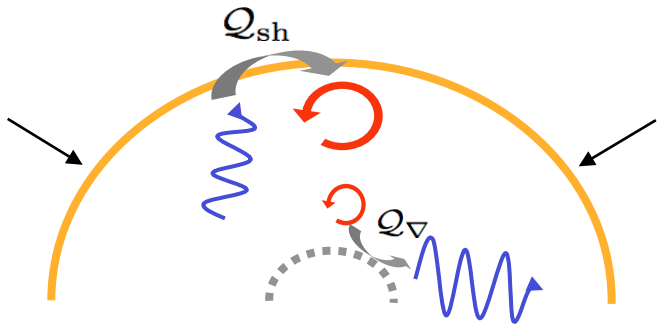


- gravitational waves
  (Ott et al. 06, Kotake et al. 07, Marek et al. 09, Ott 08, Murphy et al. 09, Kotake et al. 11)

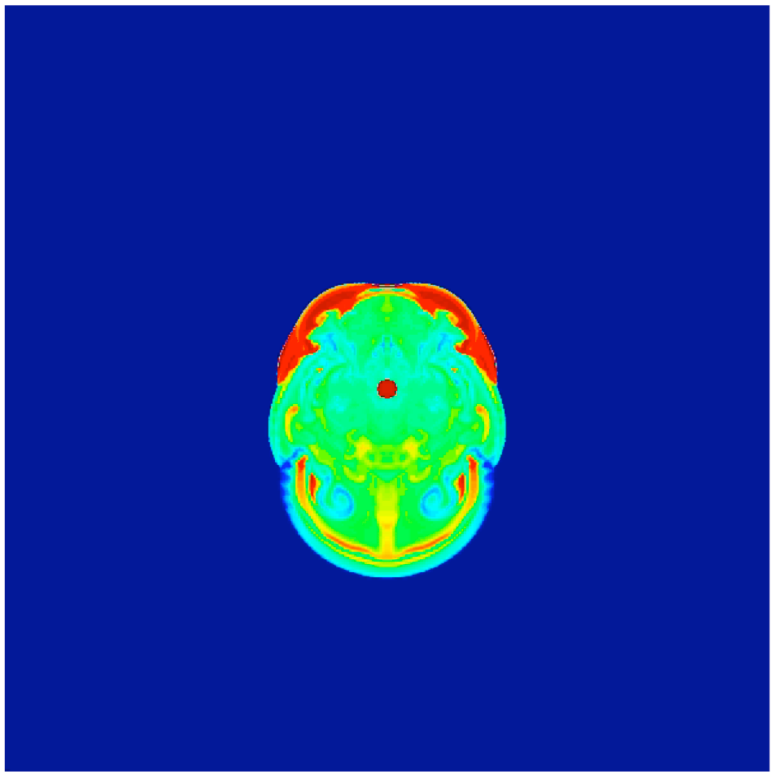


Stationary Accretion Shock Instability : SASI





Blondin et al. 03

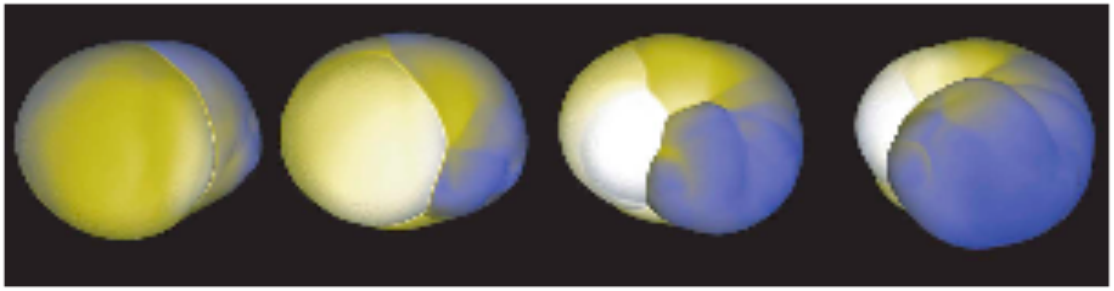


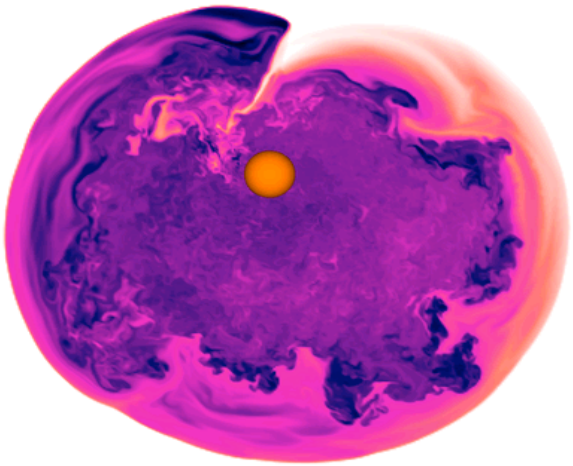
Mechanism of SASI: advective-acoustic cycle

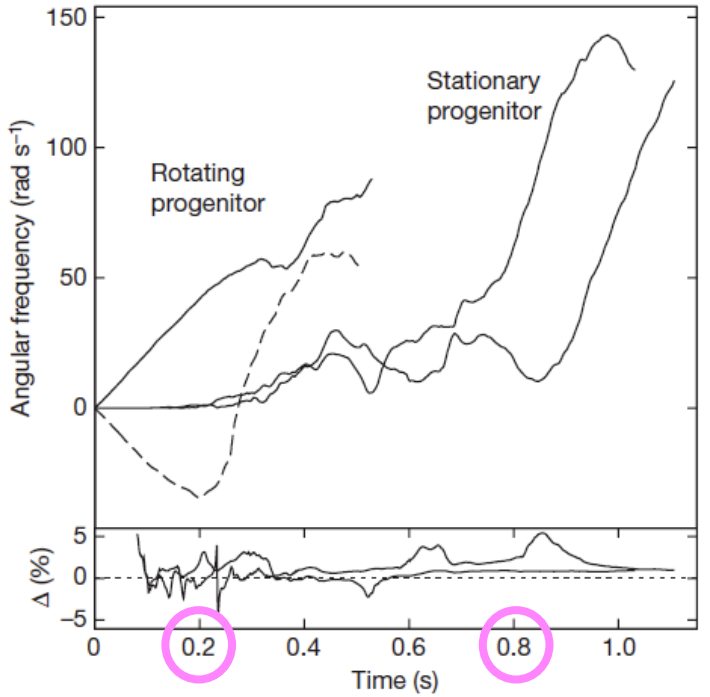
(Foglizzo 02, Foglizzo et al. 07, Scheck et al. 08,
Fernandez & Thompson 09, Guilet & Foglizzo 12)

surprising spiral mode of SASI in 3D

Blondin & Mezzacappa 07







Timescale for symmetry breaking ?

-too slow for slow rotators ?
(Iwakami et al. 08, Wongwathanarat et al. 10, Rantsiou et al. 11)

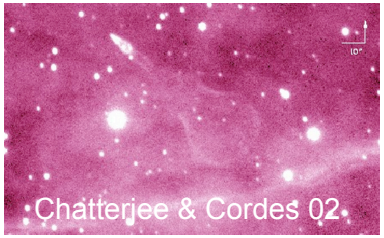
→ Need for 3D simulations of a rotating progenitor
(Iwakami et al. 09)

From SN explosions to a shallow water experiment

realism & complexity

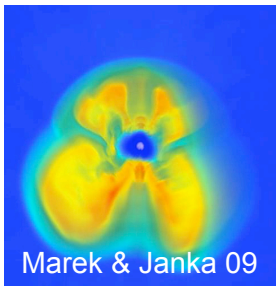
simplicity & understanding

Observations of SN and pulsars



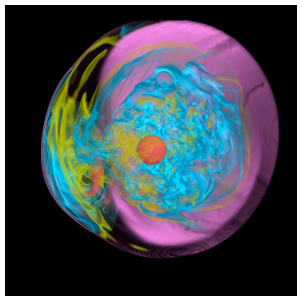
- SN light curve, polarimetry, neutrinos, grav. waves, nucleosynthesis,
- Pulsar kick and spin

Complex comprehensive simulations
(Marek & Janka 09, Burrows et al. 06, Wongwathanarat 10, Suwa et al. 10, Müller et al. 12, Kuroda et al. 12, Sumiyoshi & Yamada 12)



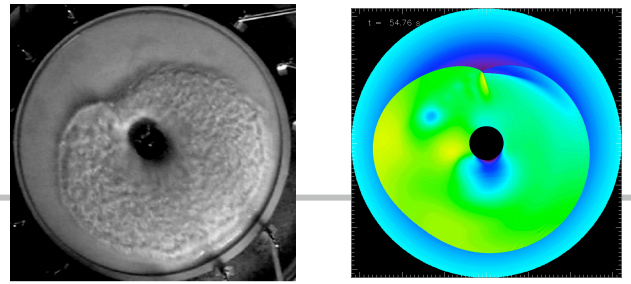
progenitor structure + nuclear EOS
+ neutrino "transport" & interactions
+ "GR" + "multi-D" hydro
(no magnetic field)

Multi-D hydro processes only
Blondin & Mezzacappa 07

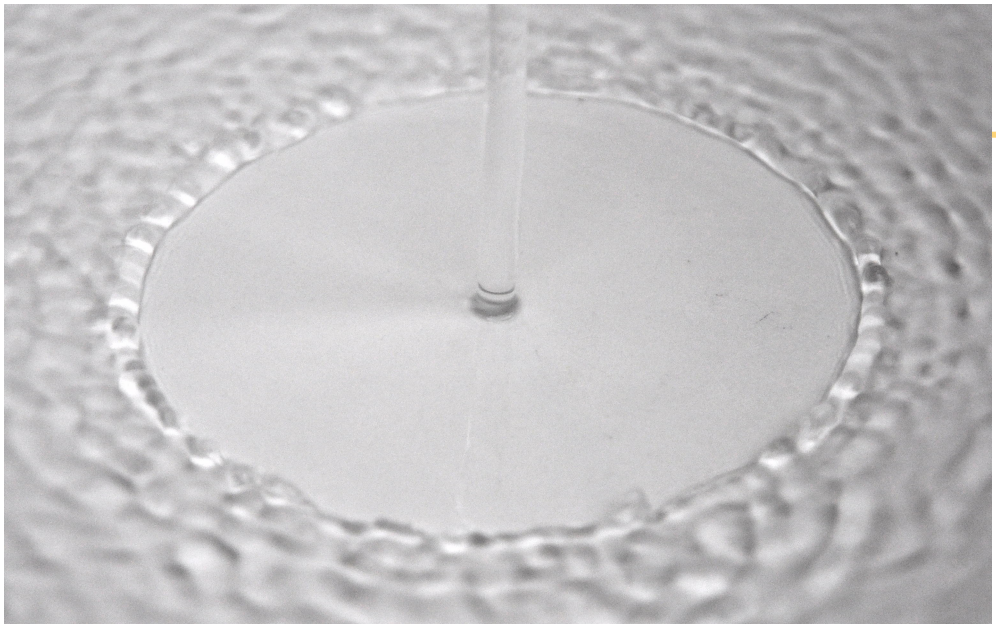


stationary accretion,
ideal gas,
3D adiabatic

SWASI experiment
Foglizzo et al. 12

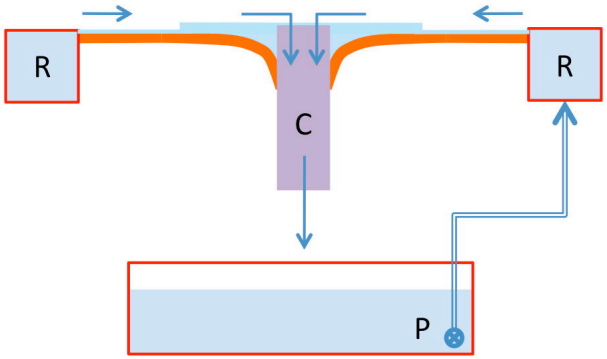


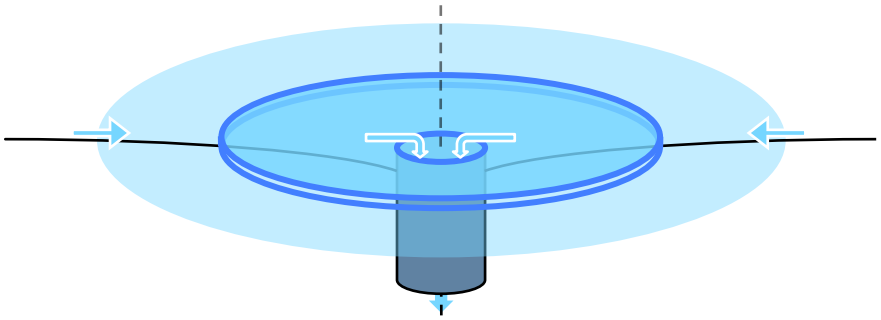
- 2D shallow water
inviscid



SWASI

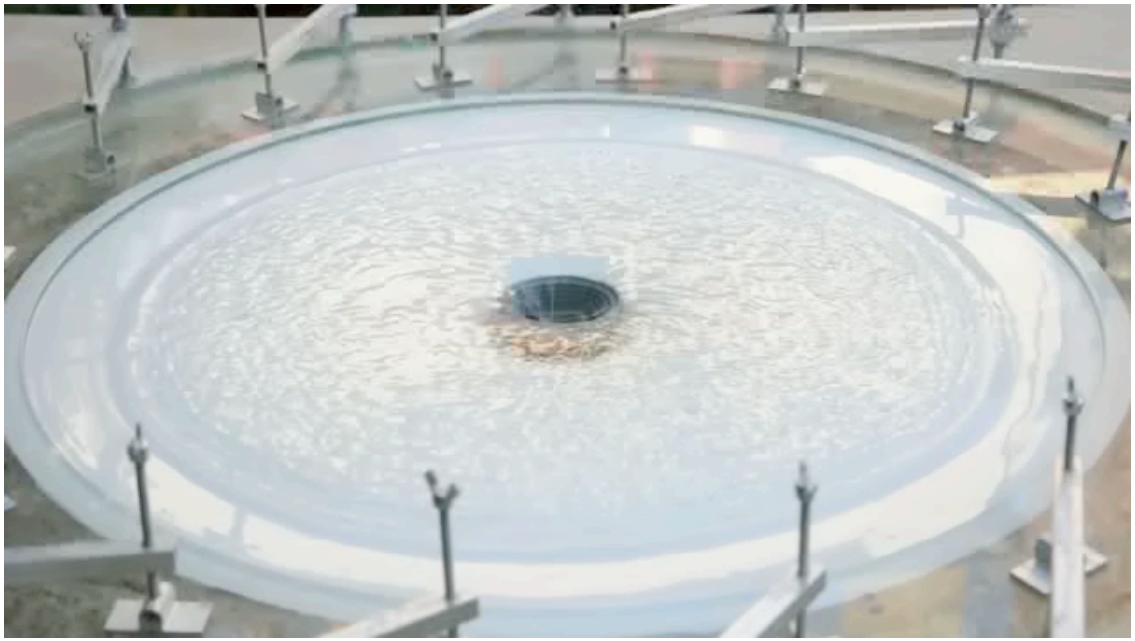
Shallow Water Analogue of a Shock Instability



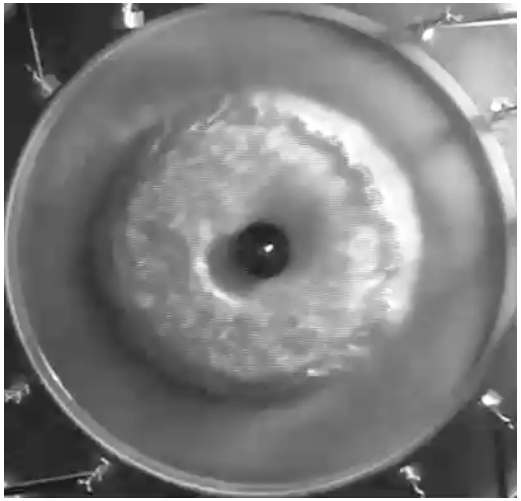


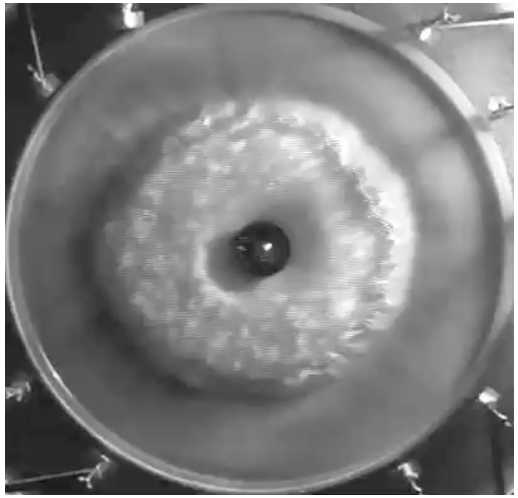
acoustic waves
shock wave
pressure

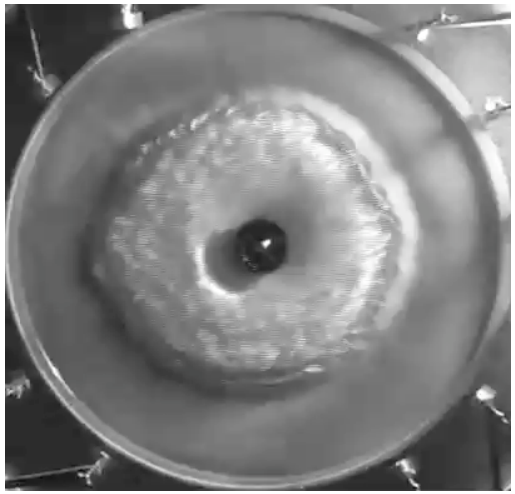
surface wave
hydraulic jump
depth

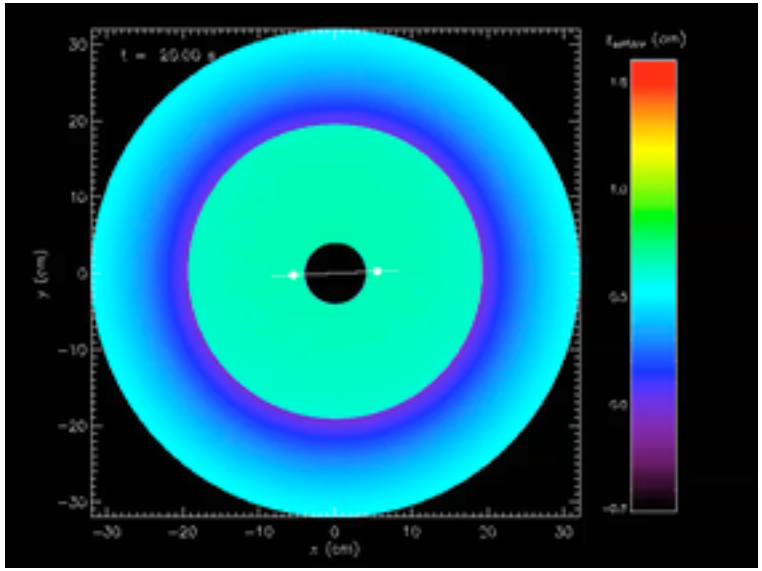


unstable oscillation and nonlinear symmetry breaking









Formal similarity between SASI and SWASI

accretion of gas (on a cylinder)

density ρ, velocity v, sound speed $c \propto \rho^{\frac{\gamma-1}{2}}$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho v) = 0$$

$$\frac{\partial v}{\partial t} + w \times v + \nabla \left(\frac{v^2}{2} + c^2 \log \frac{\rho}{\rho_0} + \Phi \right) = 0 \qquad \text{isothermal}$$

$$\frac{\partial v}{\partial t} + w \times v + \nabla \left(\frac{v^2}{2} + \frac{c^2}{\gamma - 1} + \Phi \right) = \frac{c^2}{\gamma} \nabla S \qquad \text{adiabatic}$$

inviscid shallow water accretion

depth H, velocity v, wave speed $c = (gH)^{\frac{1}{2}}$

$$\Phi = gz$$

$$c^2 = gH$$

$$\frac{\partial H}{\partial t} + \nabla \cdot (Hv) = 0$$

$$\frac{\partial v}{\partial t} + w \times v + \nabla \left(\frac{v^2}{2} + c^2 + \Phi \right) = 0$$

- Inviscid shallow water: analogue to an isentropic gas γ=2

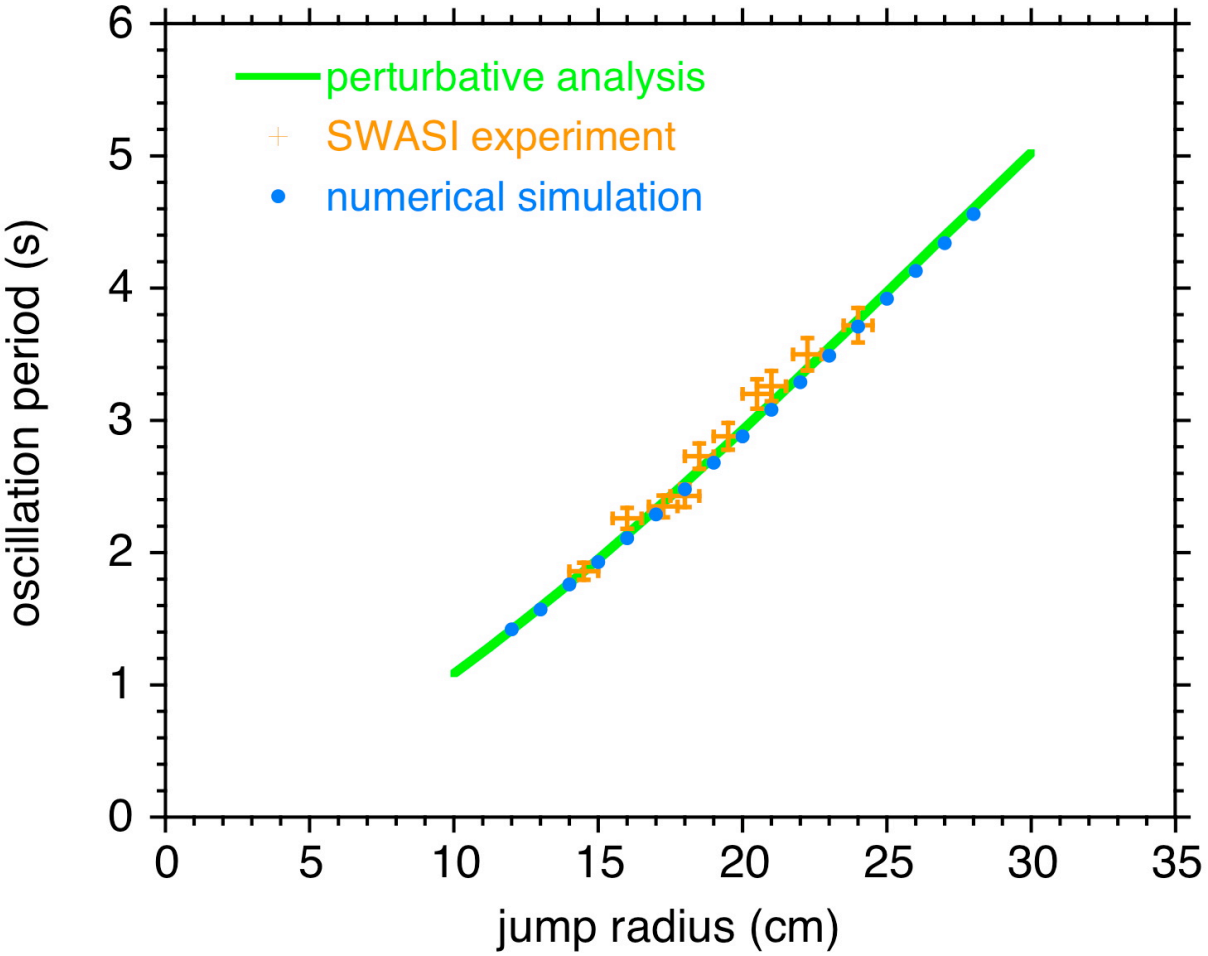
(intermediate between "isothermal" and "γ=2 without entropy")

expected scaling $\frac{t_{\rm ff}^{\rm sh}}{t_{\rm ff}^{\rm jp}} \equiv \left(\frac{r_{\rm sh}}{r_{\rm jp}} \right) \left(\frac{r_{\rm sh} g H_{\rm jp}}{G M_{\rm NS}} \right)^{\frac{1}{2}} \sim 10^{-2}$

shock radius $\times 10^{-6}$ 200 km → 20 cm

oscillation period $\times 10^{2}$ 30 ms → 3 s

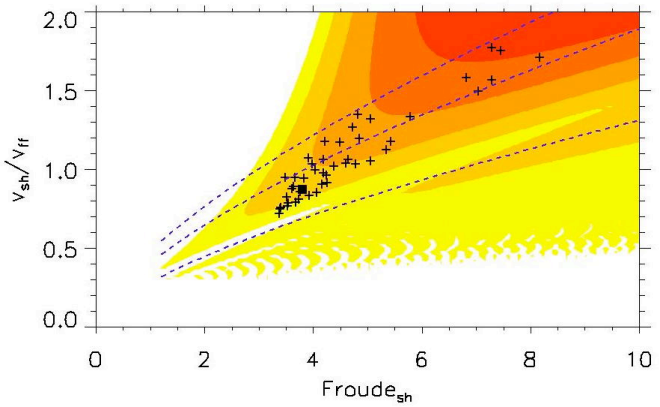
Comparrison to a 2D shallow water model



No free parameter:

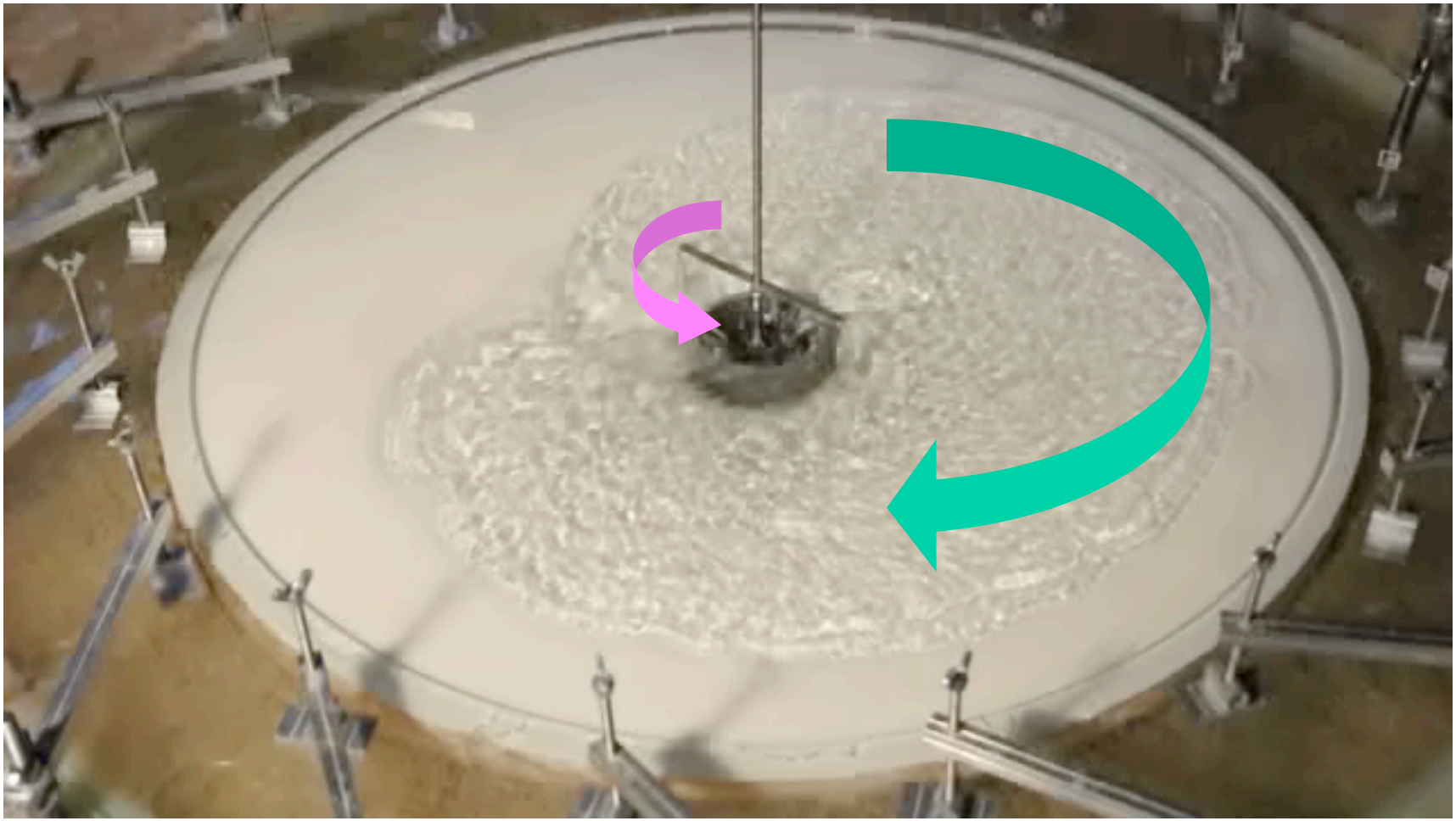
- laminar viscous drag measured in the stationary flow
- inner boundary: free spillover

robust m=1 instability



Angular momentum budget

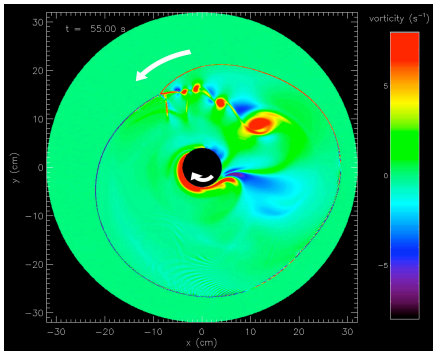
rotating wave + advected vorticity = 0



Conclusions

SWASI: first experimental view on SASI

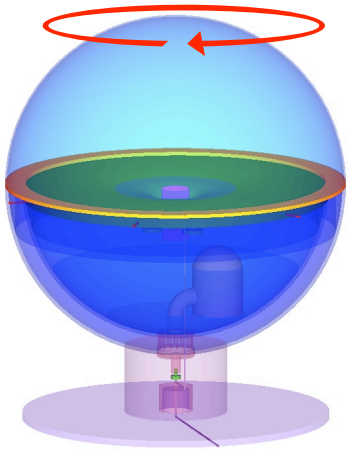
- complementary to analytical and numerical approaches
- makes asymmetric explosions more intuitive



PRL (2012)
108, 051103

Astrophysical questions:

- saturation mechanism ?
- inner boundary ?
- spiral domination ?
- destabilized by rotation ?



Two new prototypes built at CEA Saclay (sept 2012)

- improved accuracy + global rotation for research
- simplified model for public outreach

http://irfu.cea.fr/Projets/SN2NS/outreach.html