Merger of Spinning Neutron Stars with Nuclear Physics EOS

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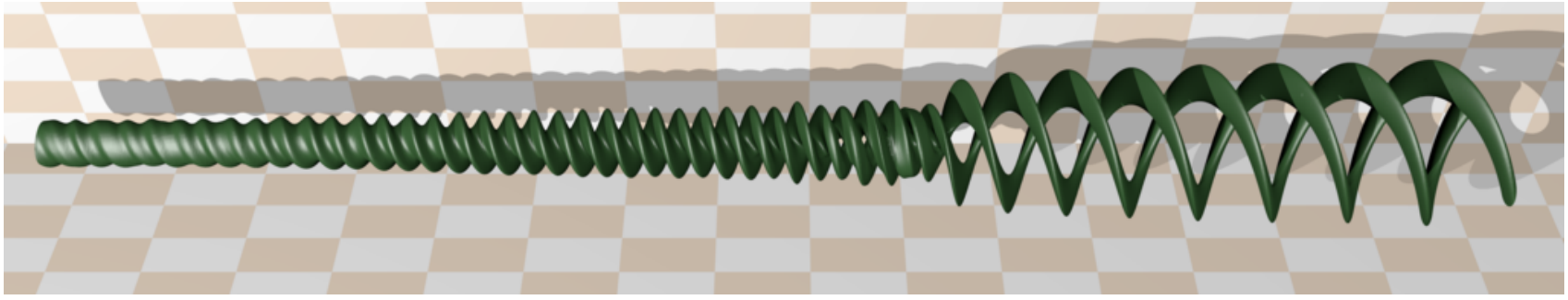
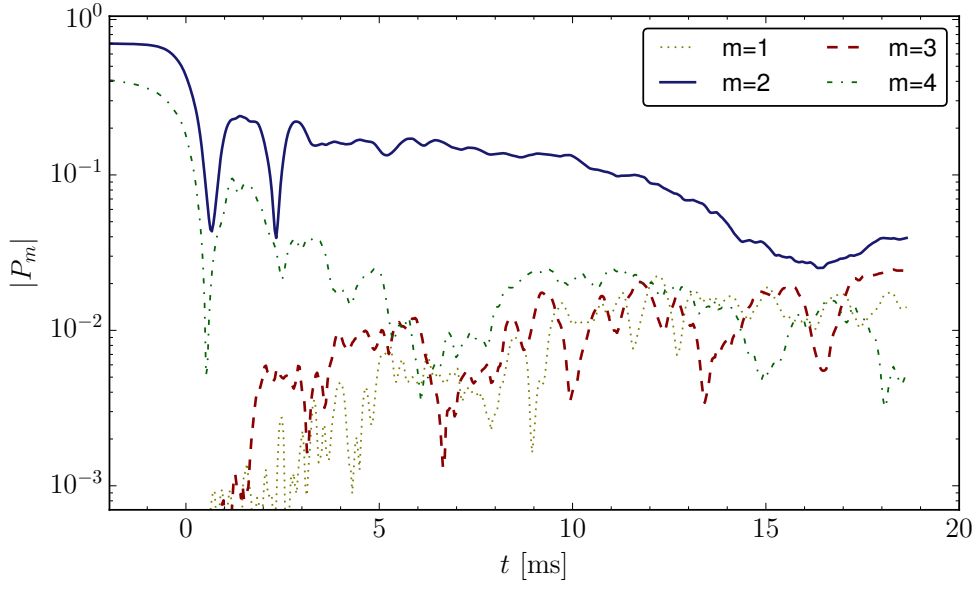
The Model

- Equal mass, $M_g = 1.4\ M_\odot$
- EOS: G. Shen, Horowitz, Teige
- Maximum TOV baryonic mass 3.33 $M_\odot$
  $\Rightarrow$ Remnant is stable !
- No magnetic field, **no neutrino radiation**
- Considered 4 spin configurations:
  - Irrotational, Up-Up, **Up-Down**, Down-Down
  - Spinup/down by $\approx$160 Hz

Evolution – Overview

← Time ←

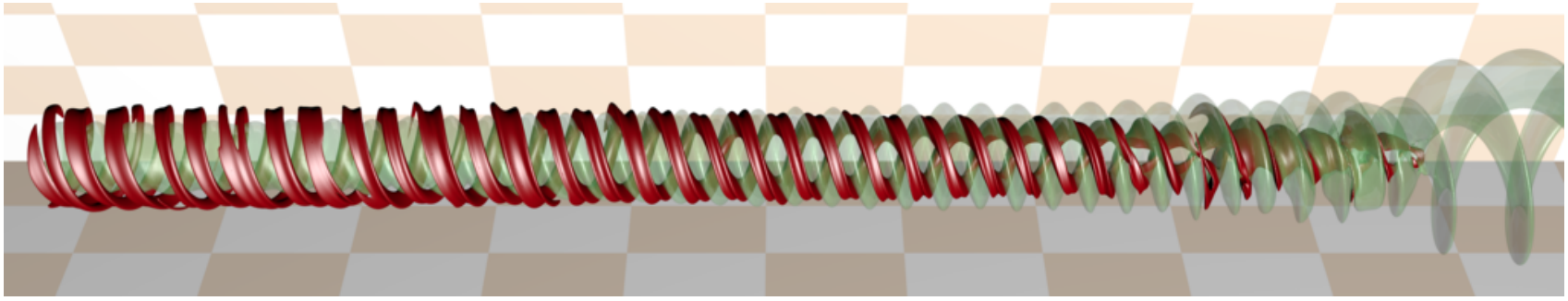


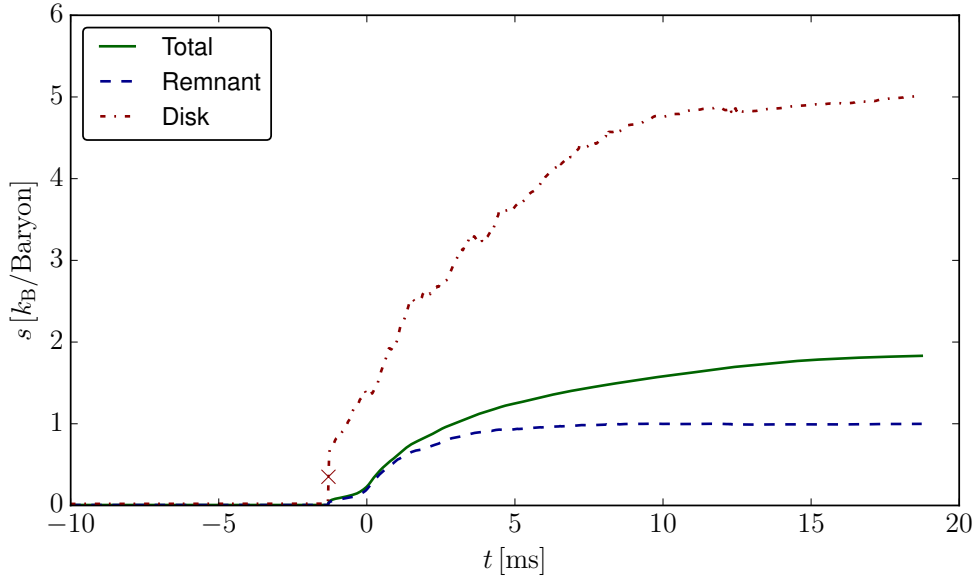


Moment decomposition

- $m = 2$ dominant
- Growing $m = 1, 3$

Evolution – Entropy

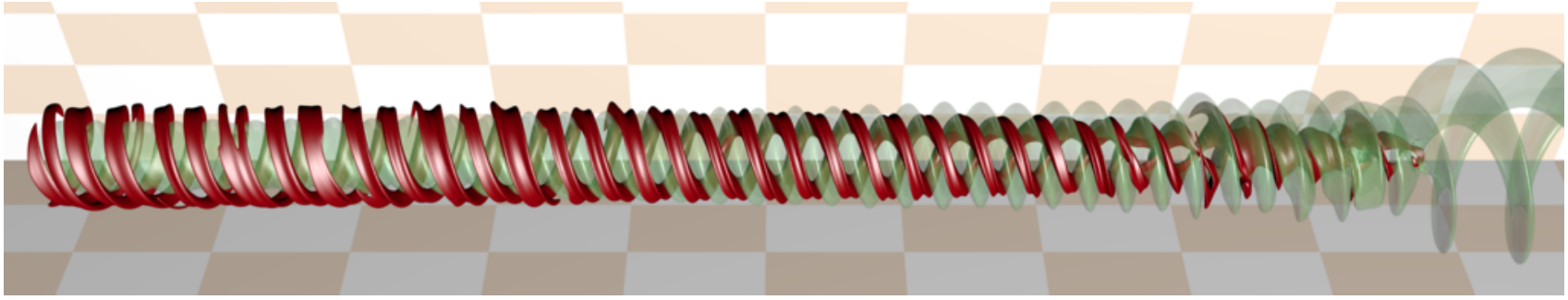




Remnant heating

- Stops after 5 ms
- Average $\bar{s} = 1 k_B$
- Not homogeneous
- Hot spots

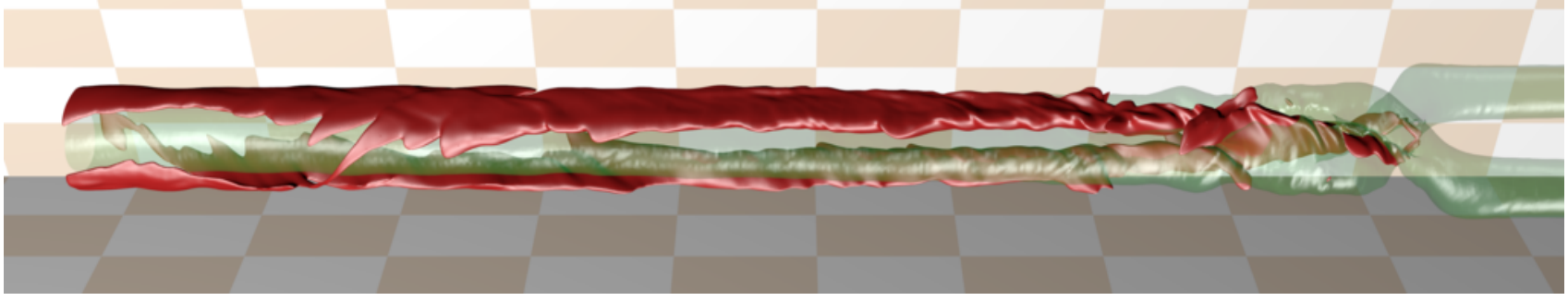
Evolution – Entropy



$\Downarrow$

Coordinates co-rotating with $m = 2$ density perturbation

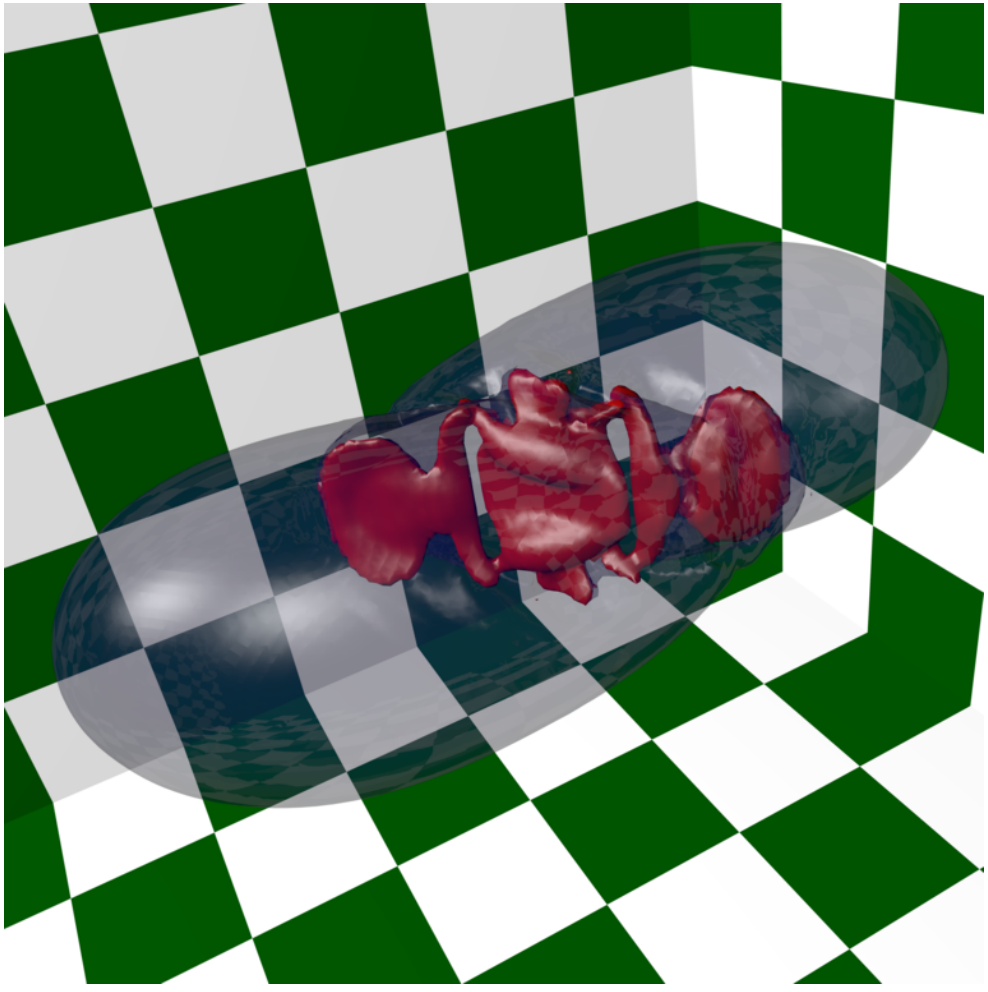
$\Downarrow$



$\Downarrow$

Hot spots are phase-locked with deformation

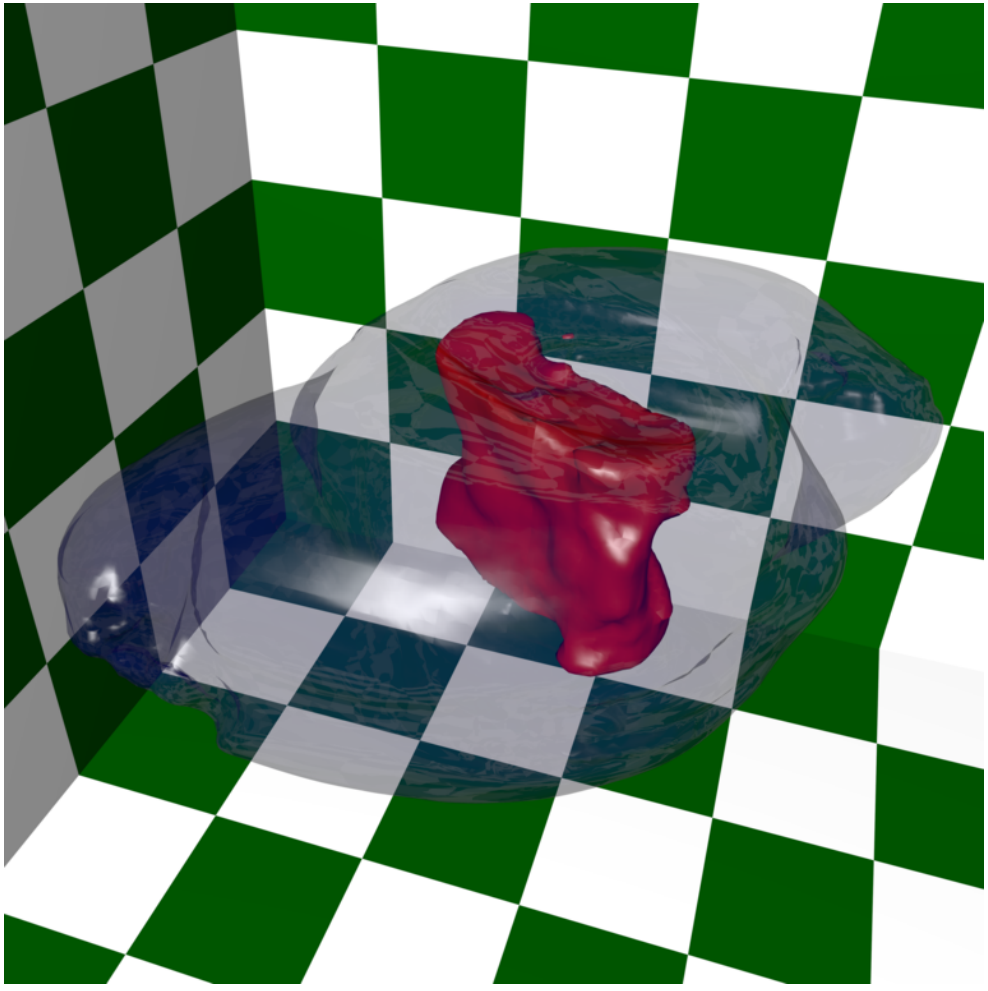
Hot Spots – Shape



$t \approx t_{\text{merger}}$

- Stars touch first off-center
- Complex shock structure

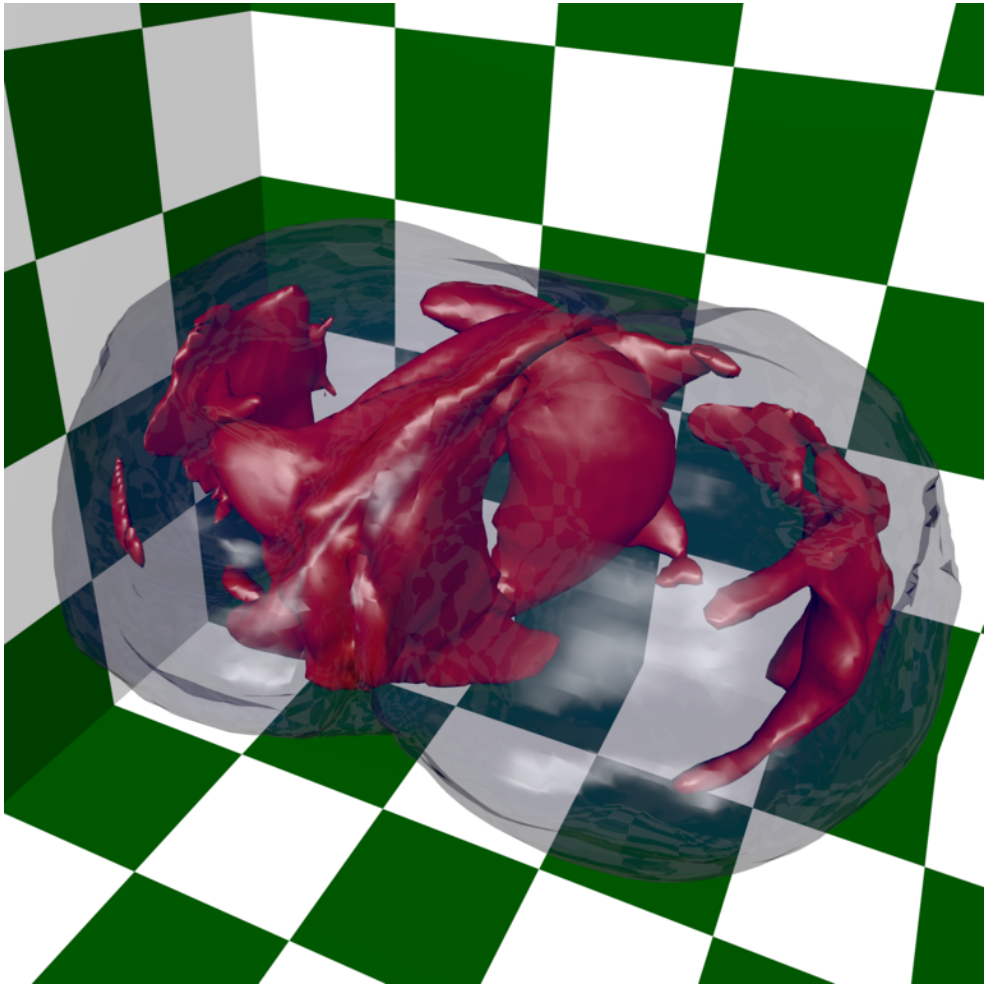
Hot Spots – Shape



$t = t_{\text{merger}} + 1.8\ \text{ms}$

- Double core phase
- Divided by heated matter
- Lasts $\approx$2 ms

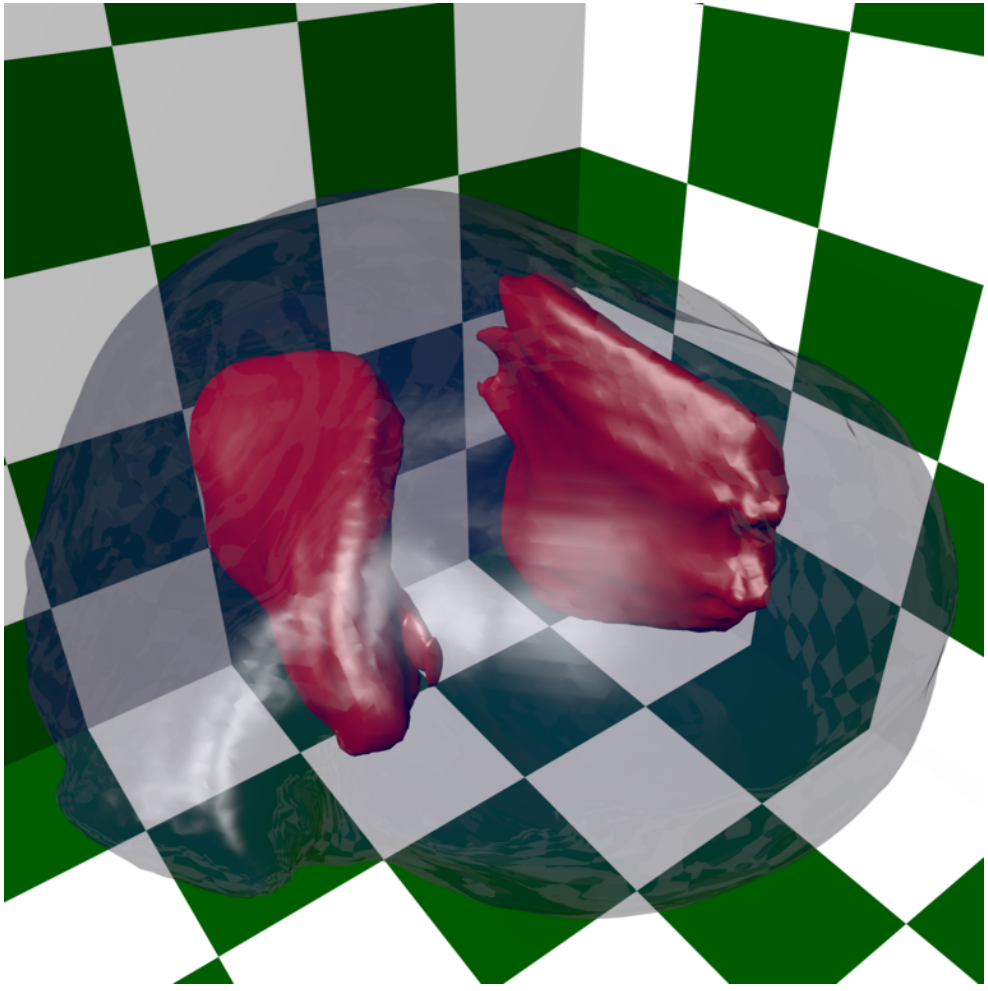
Hot Spots – Shape



$t = t_{\text{merger}} + 3.5\ \text{ms}$

- Transition phase
- Entropy rearranged
- Short

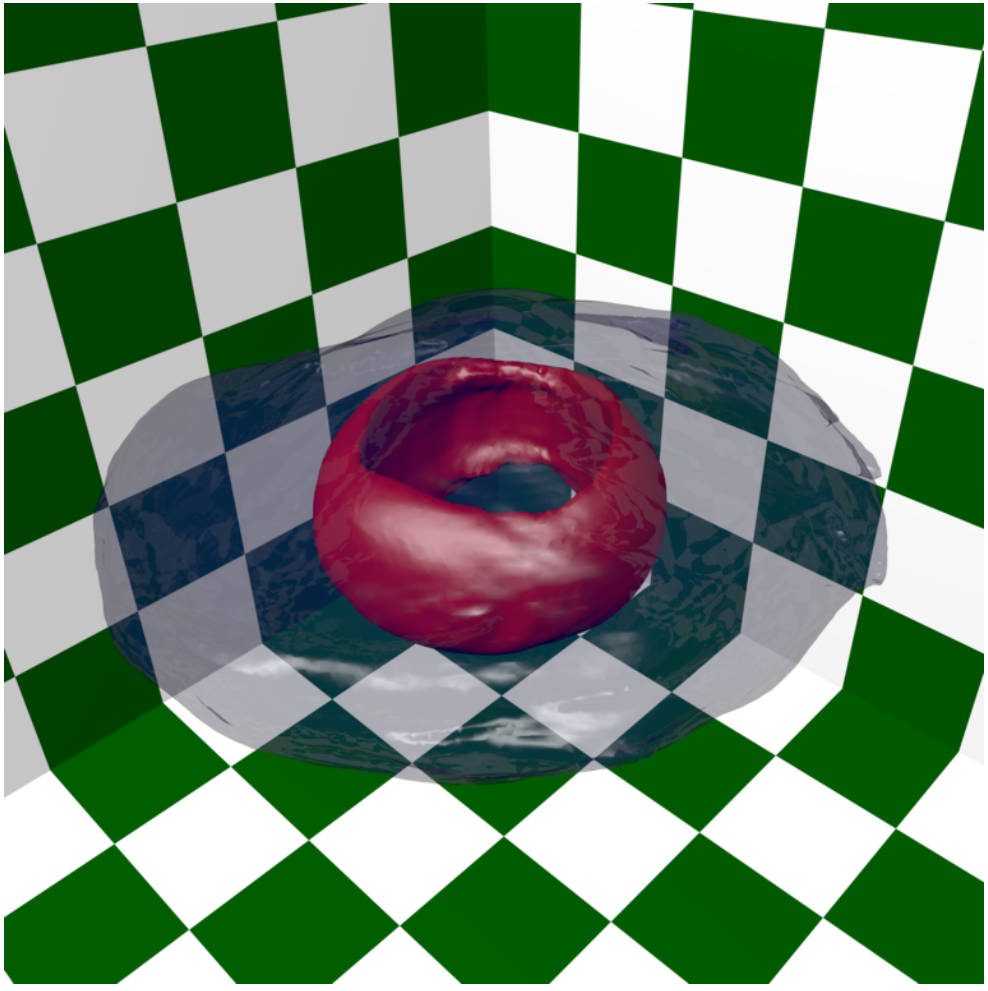
Hot Spots – Shape



$t = t_{\text{merger}} + 8.5\ \text{ms}$

- Hot spots formed
- Relatively stable
- Lasts $\approx$10 ms

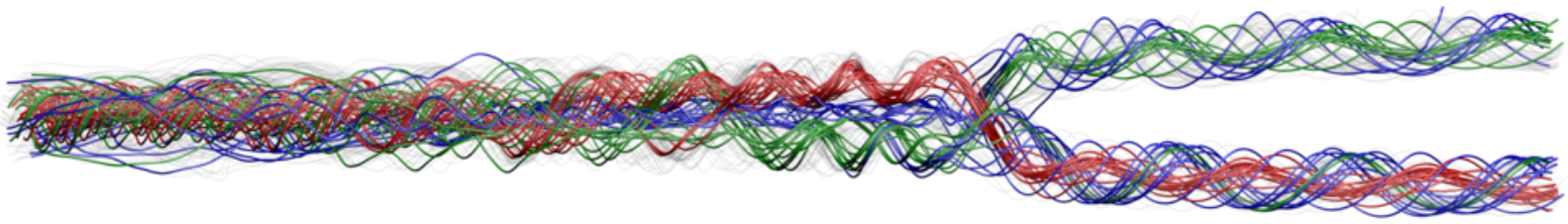
Hot Spots – Shape



$t = t_{\text{merger}} + 18\ \text{ms}$

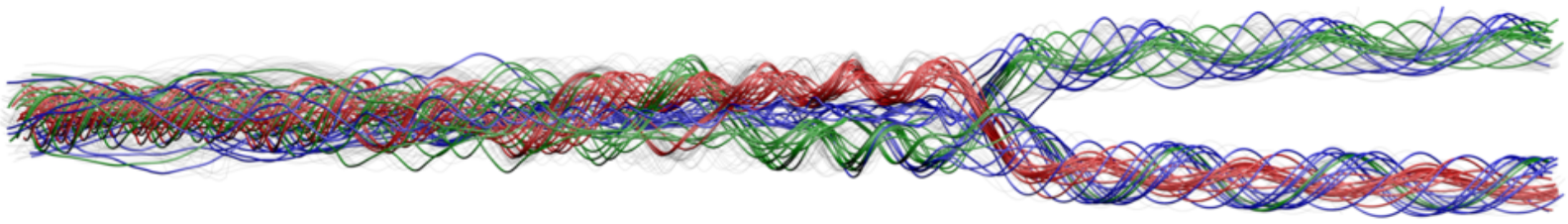
- Hot spots dissolved into hot ring

Fluid Flow

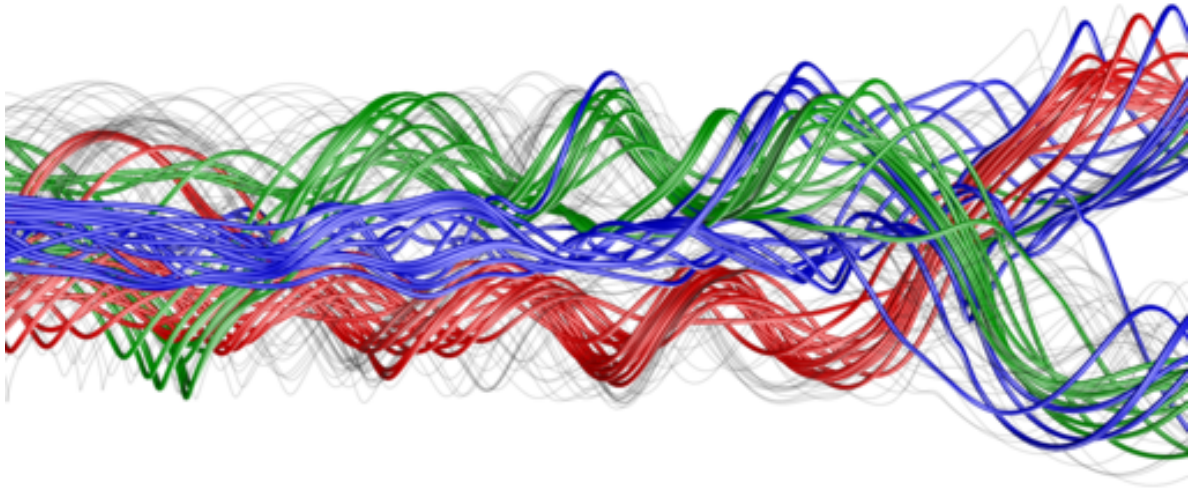


Traced fluid trajectories backward in time

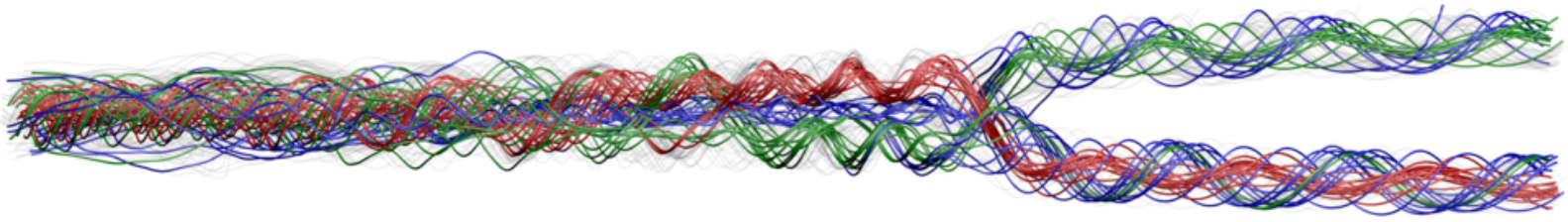
Fluid Flow



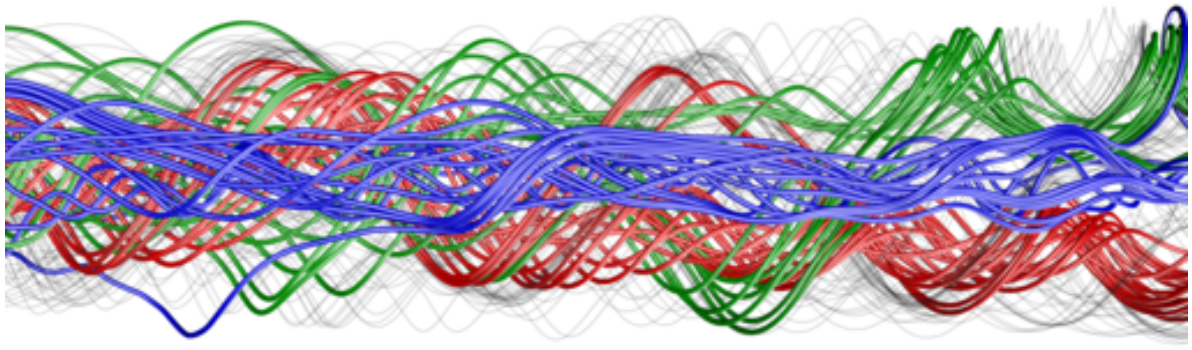
- Cores remain independent for a while
- Rotate against each other
- Secondary vortices formed



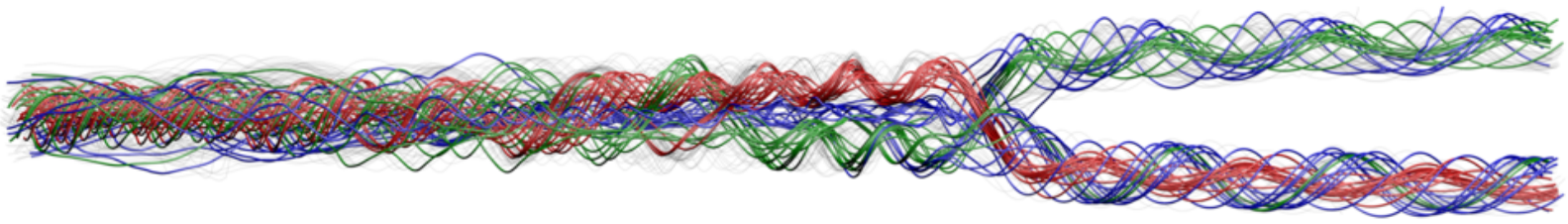
Fluid Flow



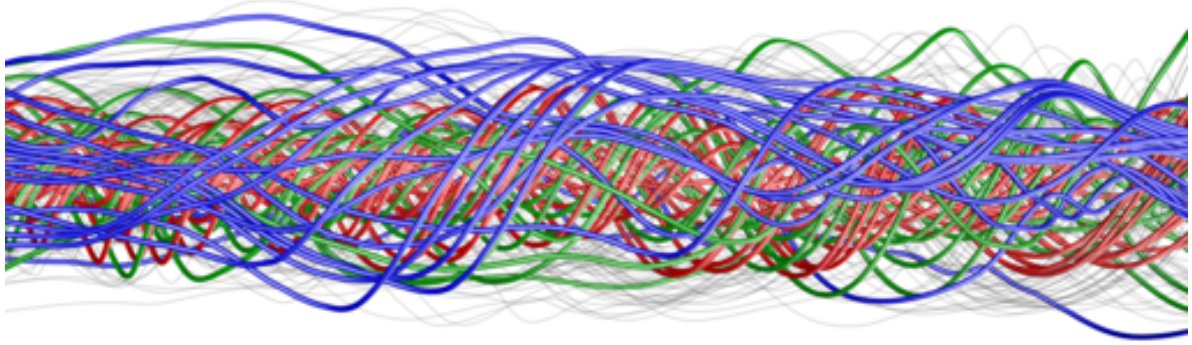
- Shear layer dissolves
- Cores unite
- Secondary vortices remain



Fluid Flow

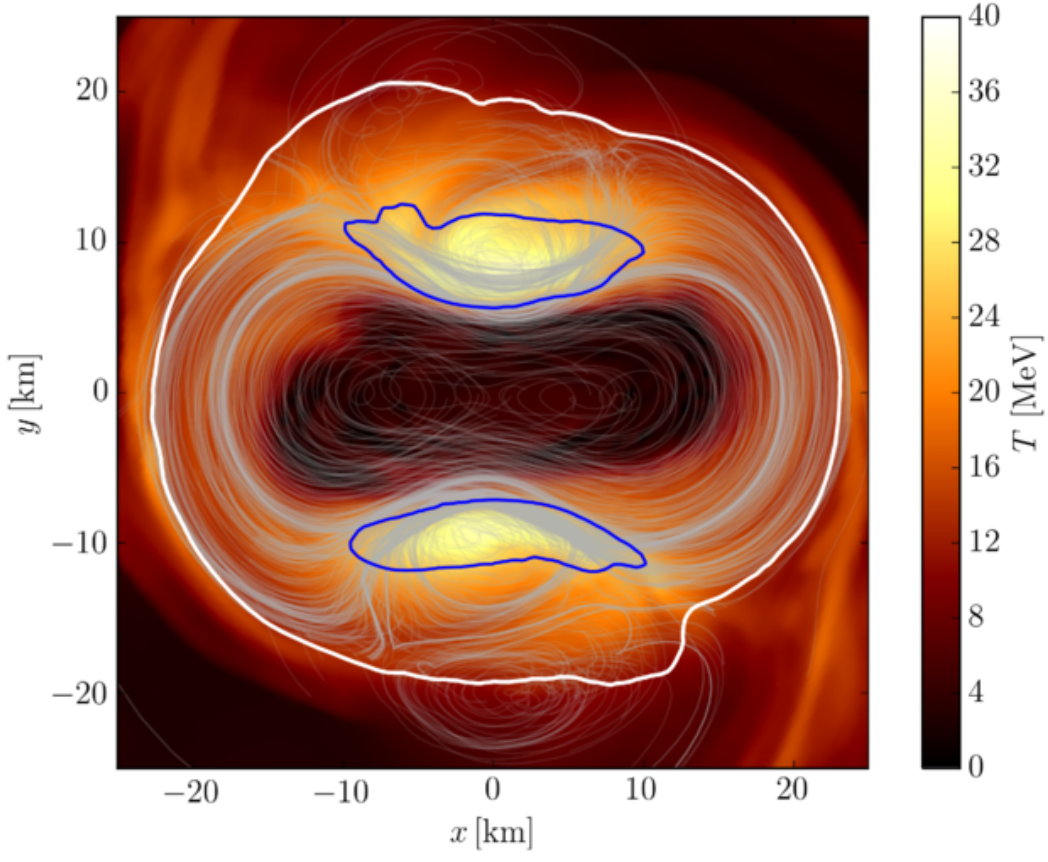


- Deformation decreases
- Secondary vortices squeezed

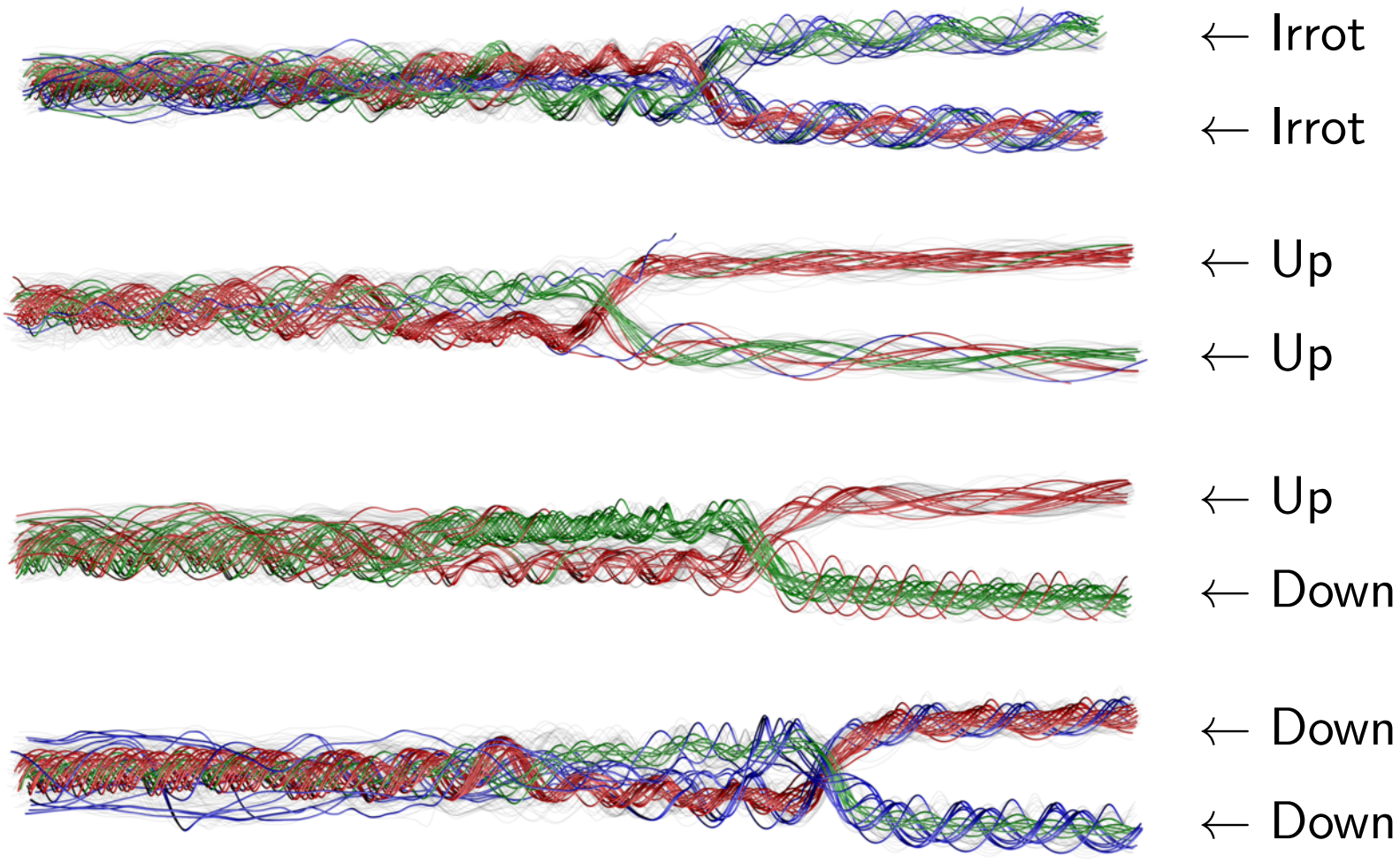


Hot Spots and Fluid Flow

- Partially trapped in stationary vortices
- Part due to adiabatic compression in fluid flow
- Vortices and hot spots relevant for deformation

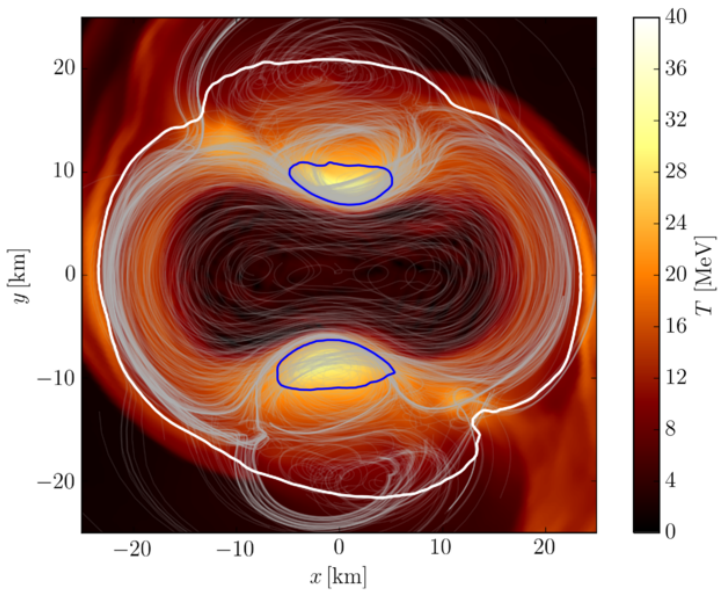


Spin – Fluid Flow

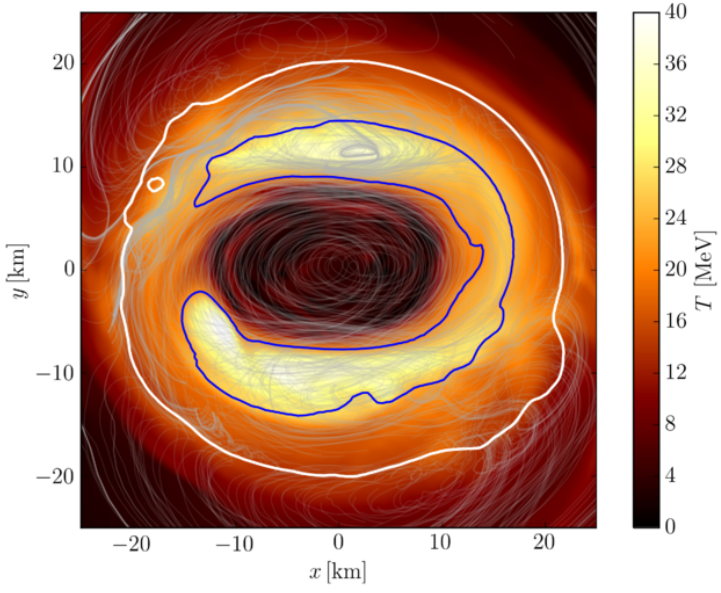


Spin – Deformation Pattern

Up-Up



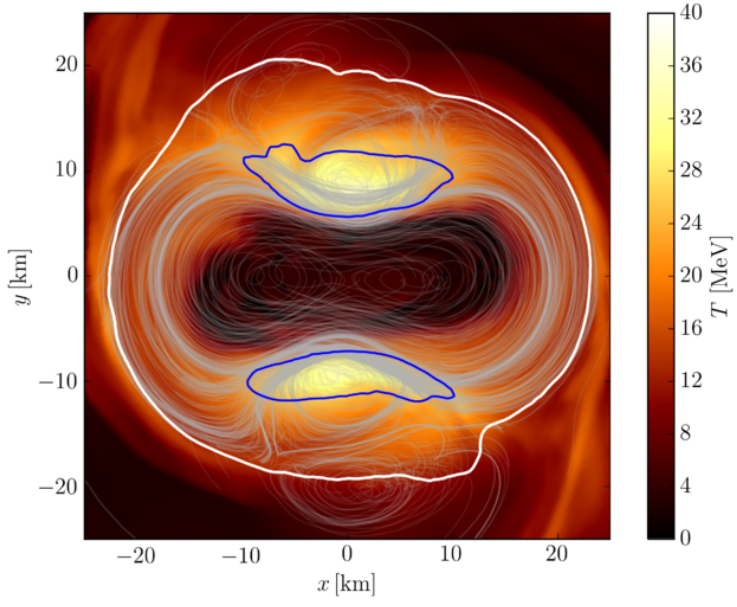
Down-Down



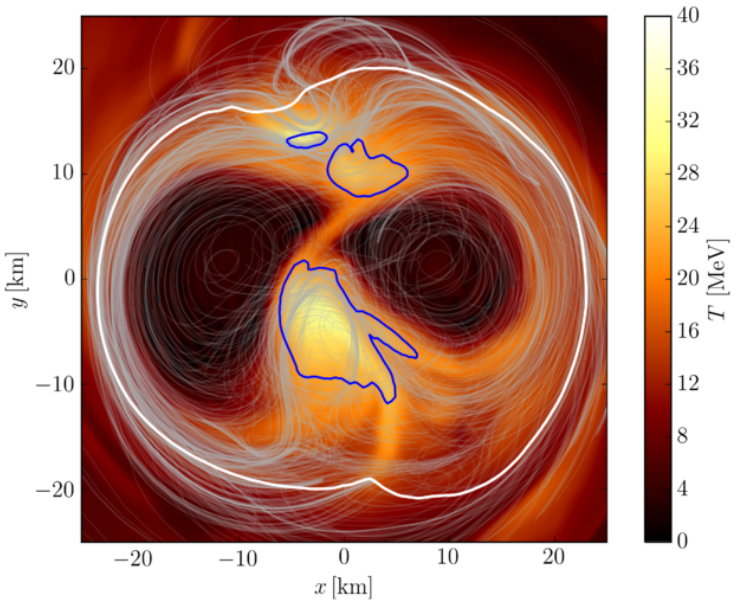
- Symmetric spin changes influence of secondary vortices

Spin – Deformation Pattern

Irrotational

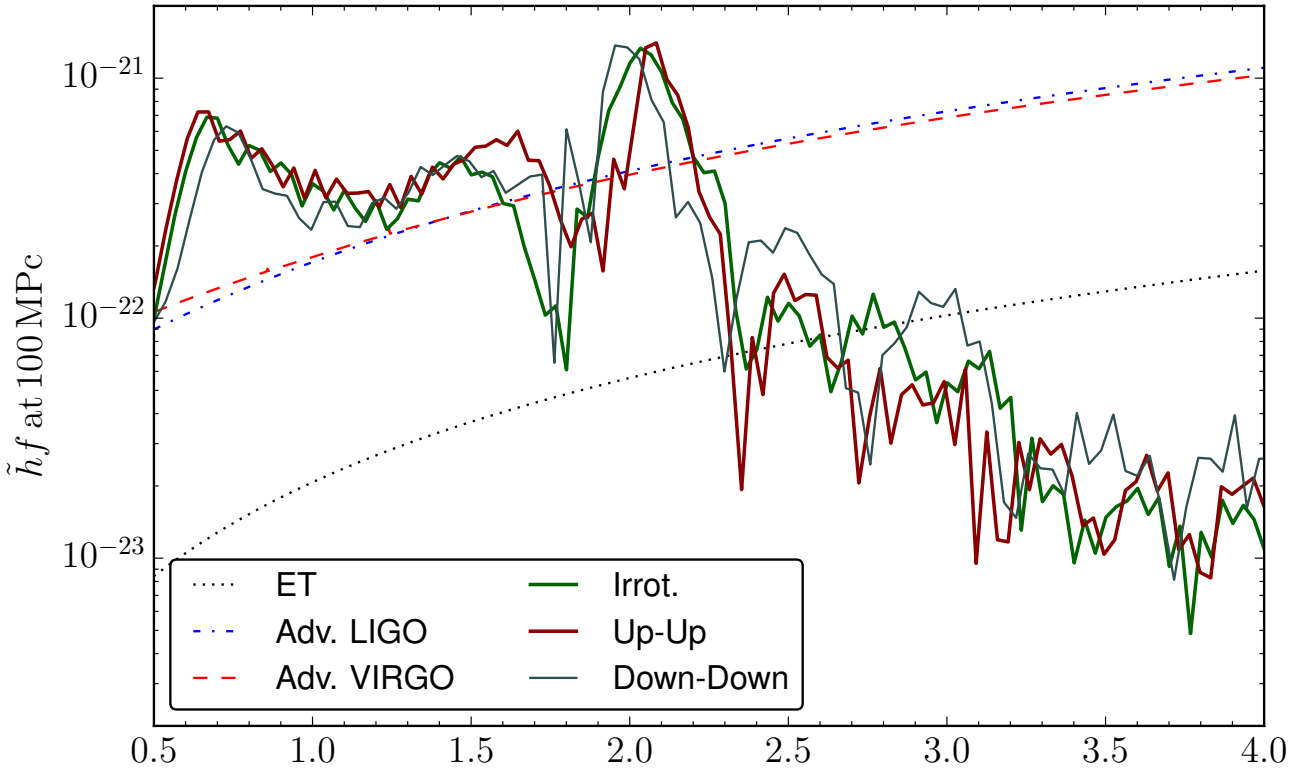


Up-Down



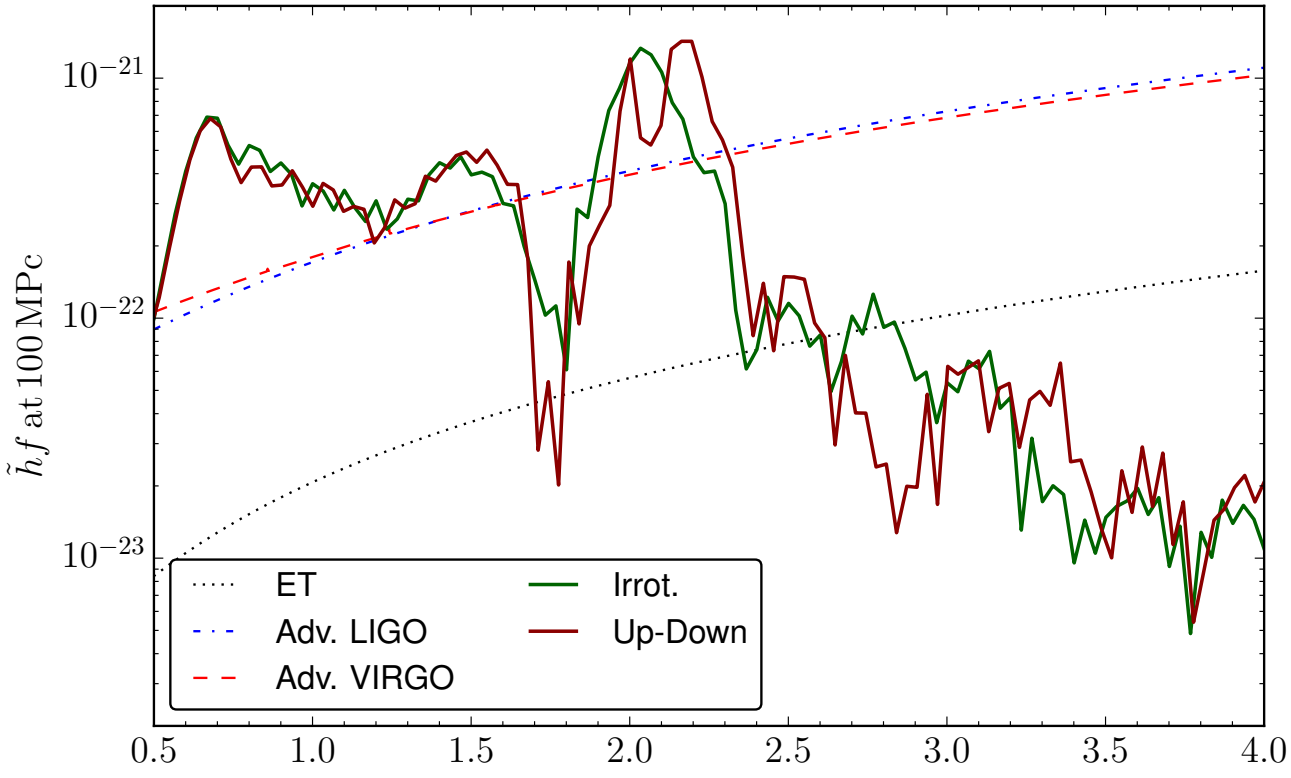
- Symmetric spin changes influence of secondary vortices
- Asymmetric spin creates asymmetric deformation

Spin – GW Spectrum



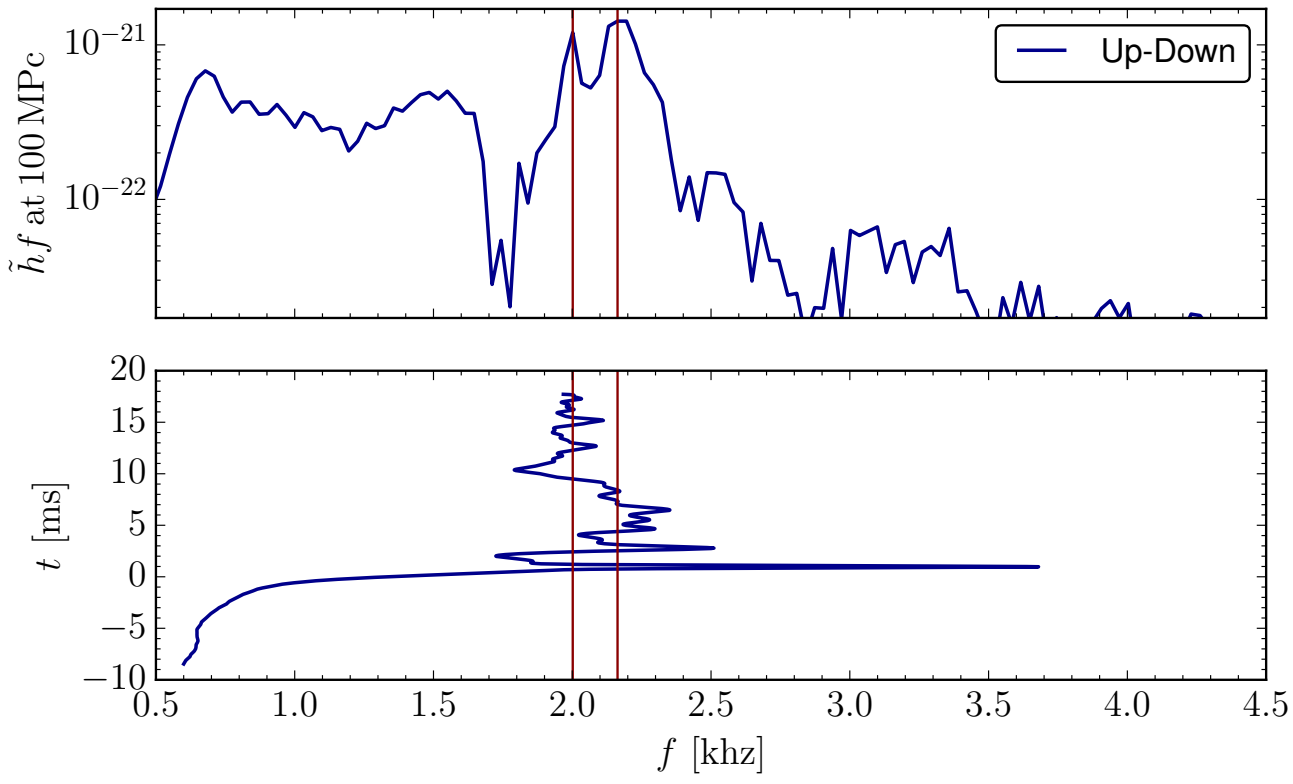
- Post-merger peak detectable if merger is detectable.

Spin – GW Spectrum



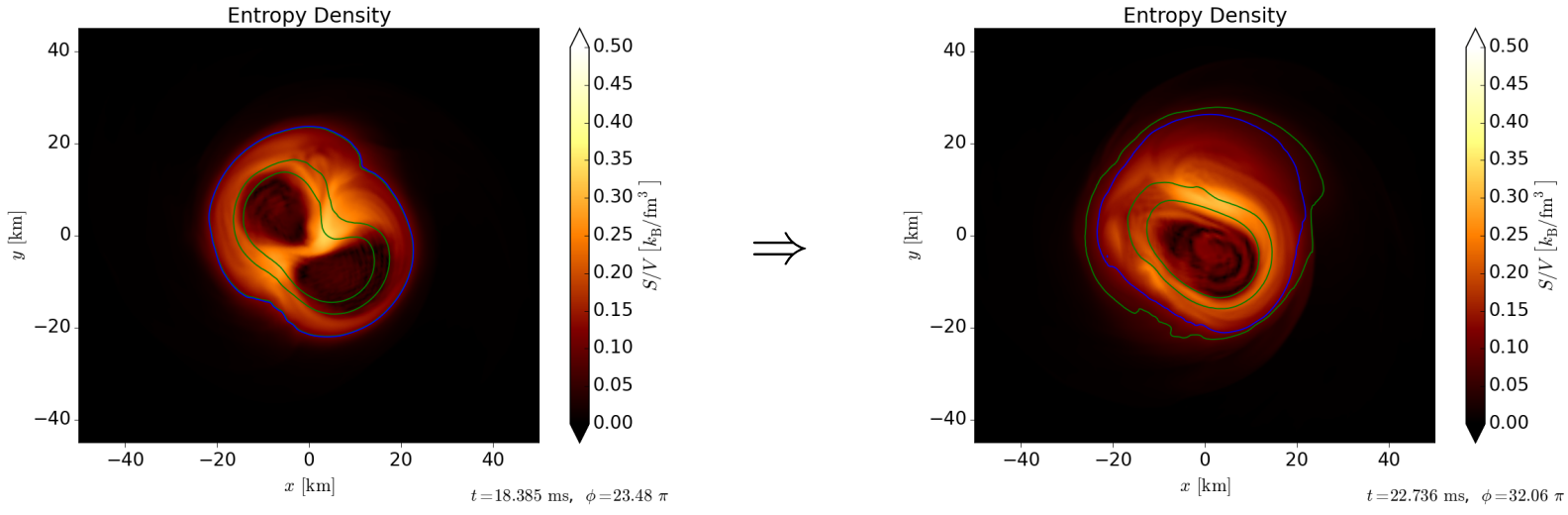
- Largest difference for Up-Down orientation
- Appearance of strong second peak

Spin – GW Spectrum



- Largest difference for Up-Down orientation
- Appearance of strong second peak
- Due to sudden frequency change.

Spin – GW Spectrum



- Frequency change when vortices rearrange.
- Yet another cause for side-peaks..

Thanks!

Read more:

W. Kastaun, R. Ciolfi, B. Giacomazzo, *Structure of Stable Binary Neutron Star Merger Remnants: a Case Study*, **arxiv 1607.02186**

Appendix

- Rotation profile 9 ms after merger