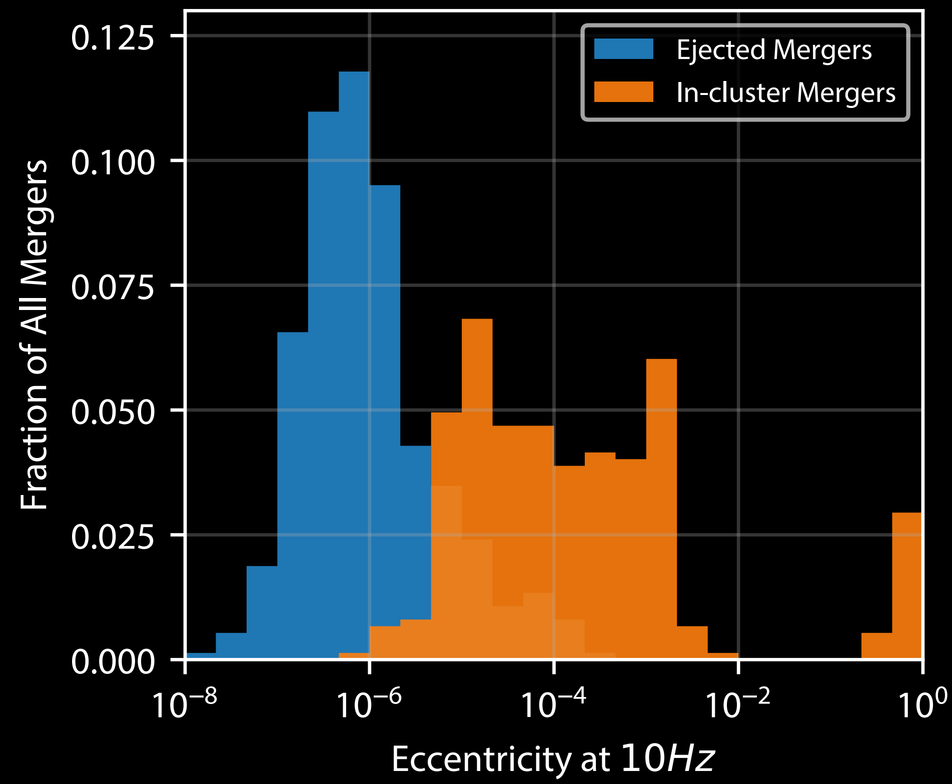
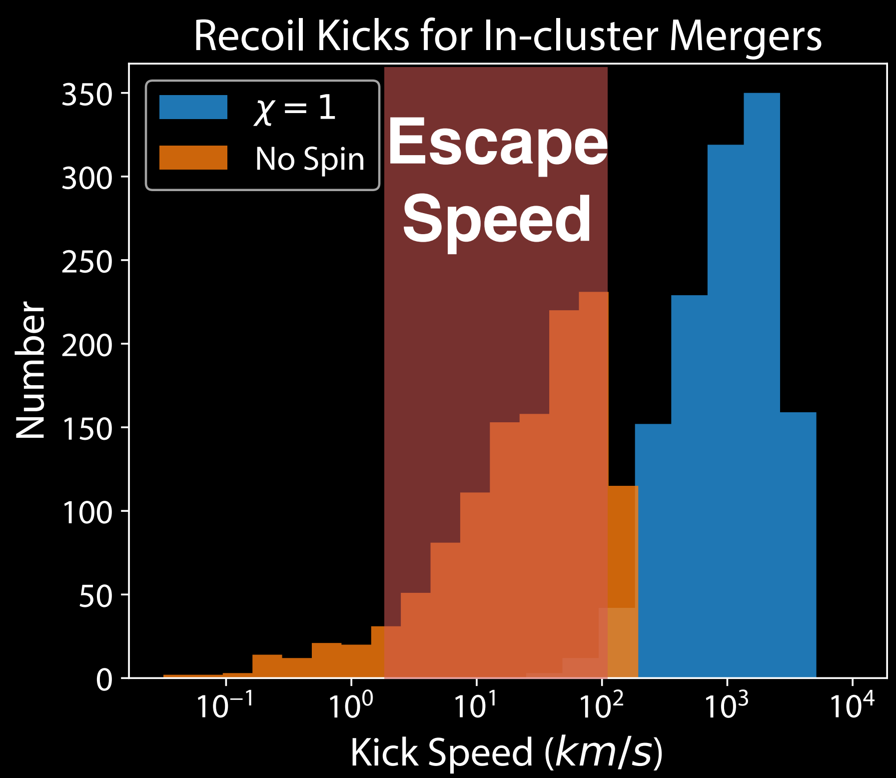
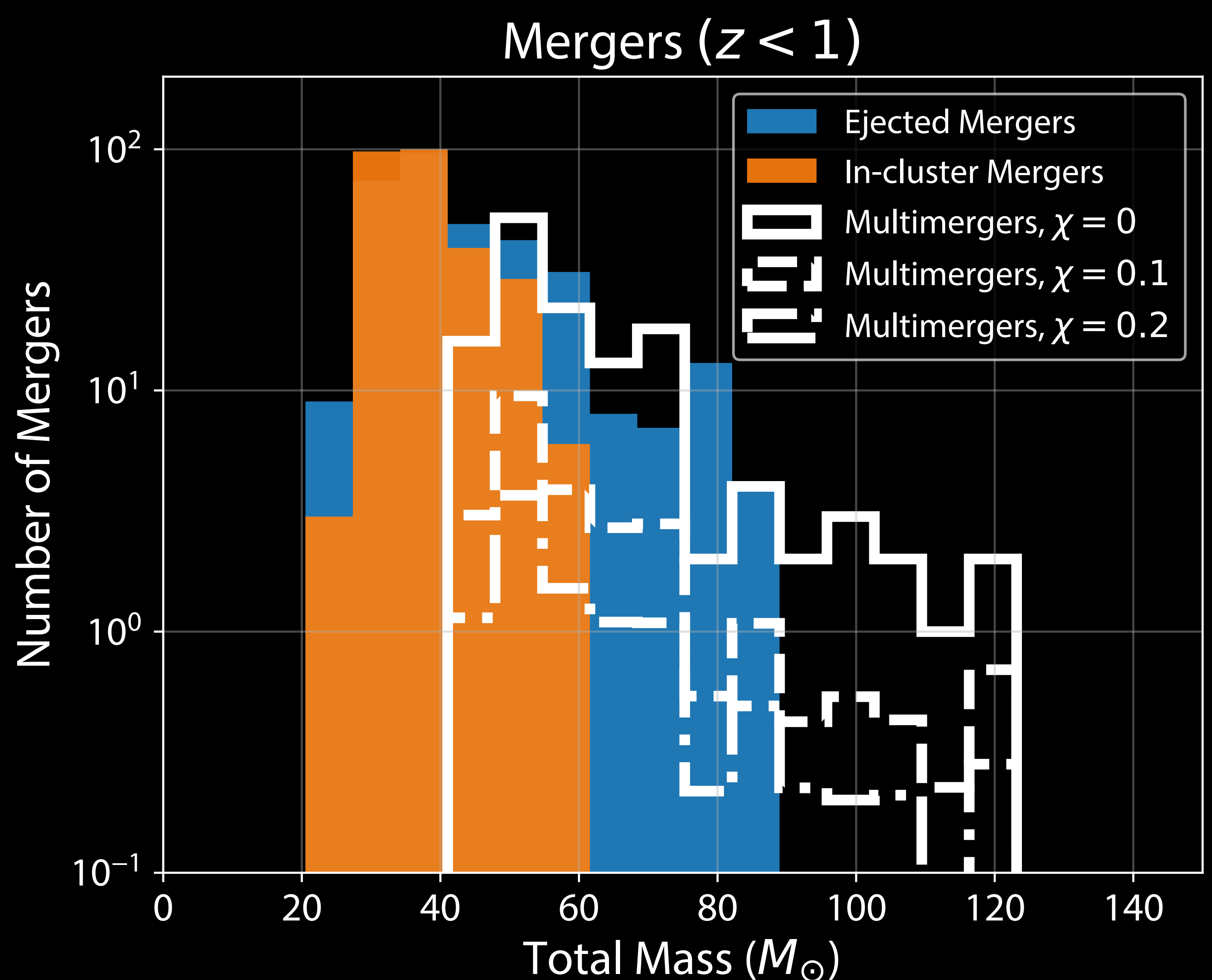
Multiple Mergers of BHs

Carl Rodriguez
MIT KAVLI INSTITUTE

Rodriguez et al., 2018
1712.04937, PRL





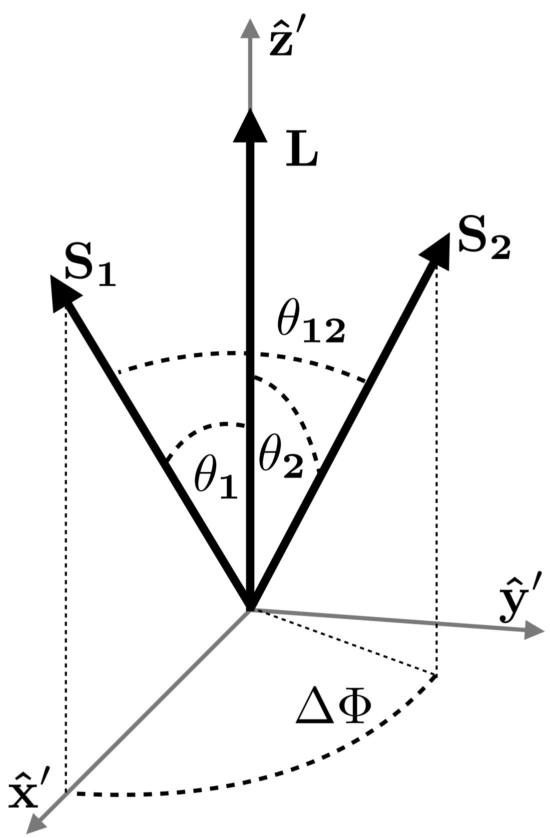


Beyond effective spins

Davide Gerosa
NASA Einstein Fellow
California Institute of Technology

1. **Orbital** motion $t_{\rm orb} \propto r^{3/2}$
2. Spin & orbital-plane **precession** $t_{\rm pre} \propto r^{5/2}$
3. GW emission and **inspiral** $t_{\rm GW} \propto r^4$

Orbit << Precession << Inspiral



…3 evolving variables $\theta_1,\ \theta_2,\ \Delta\Phi$
(more immediate)

…or equivalently $\xi\ (\chi_{\rm eff}),\ \ J,\ \ S$
(more physical! Timescale separation)

…often condensed into $\chi_{\rm eff},\ \ \chi_{\rm p}$
(useful in waveforms)

more: DG+ (2015) arxiv:1506.03492

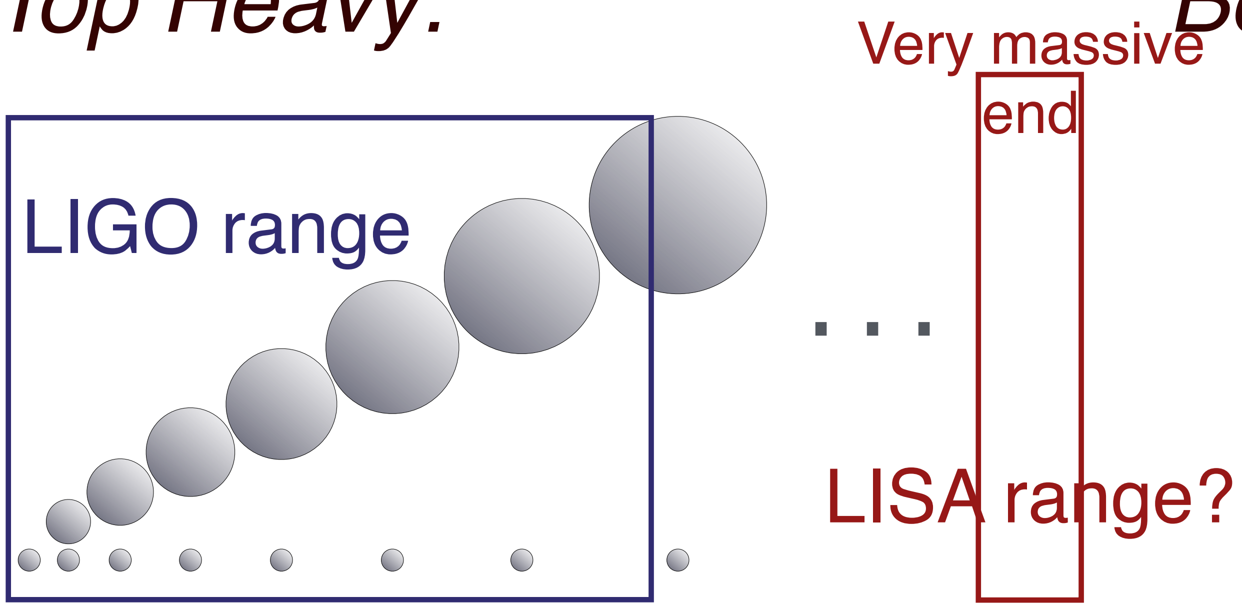
Black Holes Runaway Growth in Globular Clusters

The Question: Are Globular Clusters the birthplaces of merging BHs—> GWs?
If yes, then for ~10% of these systems (the most massive and dense) we expect to have a runaway process.

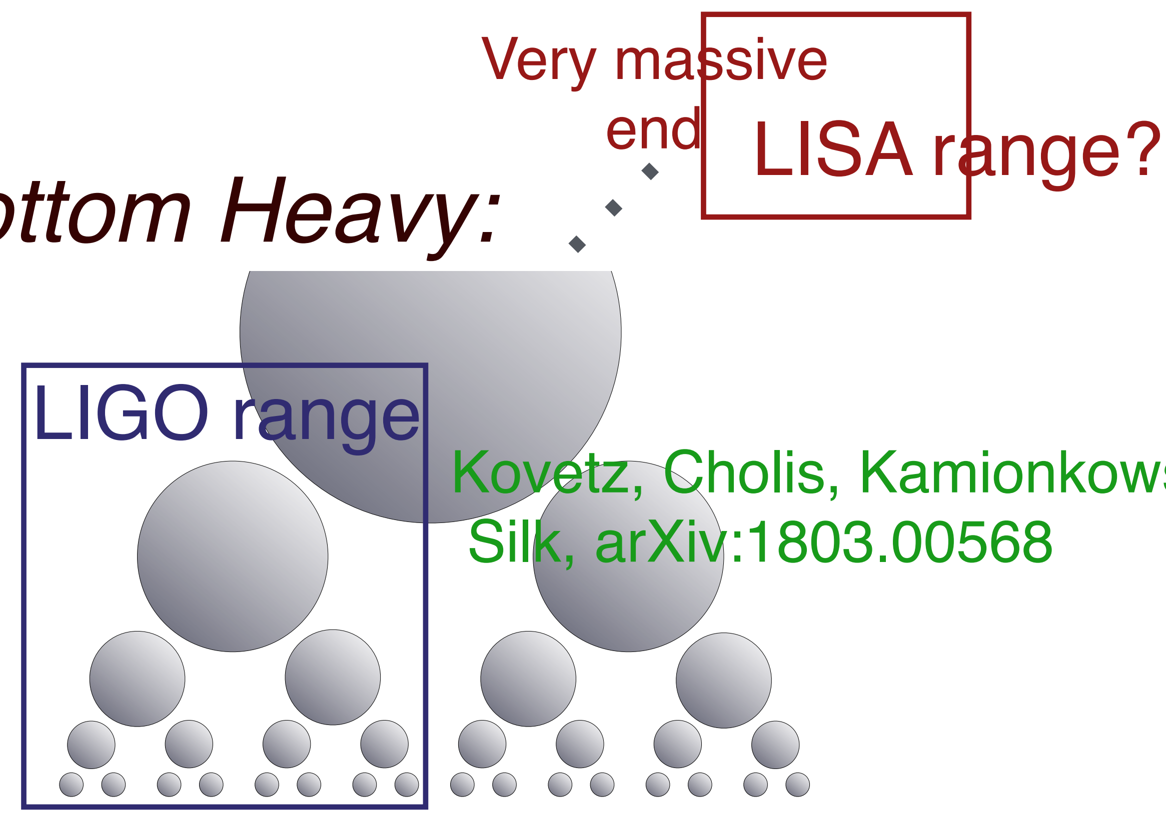
Cholis, Kovetz, Kamionkowski in prep 2018

Simplified paths:

Top Heavy:

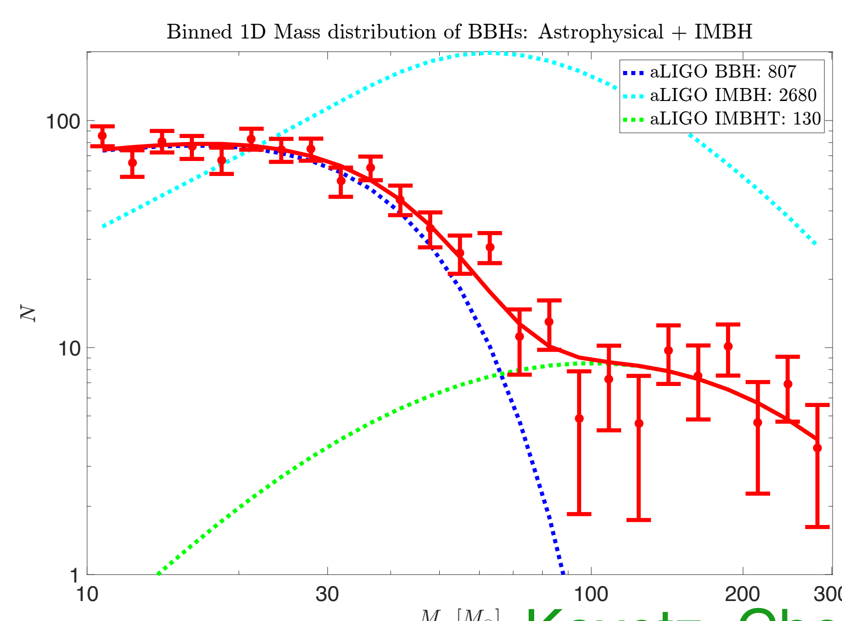


Bottom Heavy:



Kovetz, Cholis, Kamionkowski, Silk, arXiv:1803.00568

From LIGO obs. we will be able to derive limits on the occupation fraction of IMBHs in GCs:



	Right Triangle			
Background Model	O1+O2	O3 (1 yr)	Design (6 yrs)	with $R(z)$
$P(M) \propto \exp(-(M/40)^2)$	470% (0.2)	38% (3)	3.1% (47)	2.9% (53)
$P(M) \propto \exp(-(M/60)^2)$	760% (0.2)	68% (3)	7.4% (47)	6.8% (53)
$P(M) \propto \mathcal{H}(50-M)$	220% (0.2)	17% (3)	1.3% (47)	1.2% (53)
$P(M) \propto \exp(-M/40)$	890% (0.2)	120% (3)	19% (47)	18% (53)
$\bar{R}_{BG} = 103 + 110 = 213$	470% (0.2)	41% (3)	3.4% (47)	3.1% (53)
$\beta = -1$	430% (0.2)	34% (3)	2.8% (47)	2.7% (53)
$\beta = 1$	480% (0.2)	34% (3)	3.3% (47)	3.1% (53)

Kovetz, Cholis, Kamionkowski, Silk, arXiv:1803.00568

Next-Gen Numerical Relativity: More Science at Less Cost

Zachariah B. Etienne

Reducing human expense

- Lowering learning curve
  - Excellent texts on NR & GW astrophysics
  - Texts on NR codes & algorithms?
    - *Need to improve our code documentation*
- Automatic code generation
  - Input: Eqs in Einstein-like notation
  - Output: Optimized C code
  - Open-source packages
    - Kranc (kranccode.org)
      - Mathematica-based
    - NRPy+ (tinyurl.com/nrpyplus)
      - Python/SymPy-based

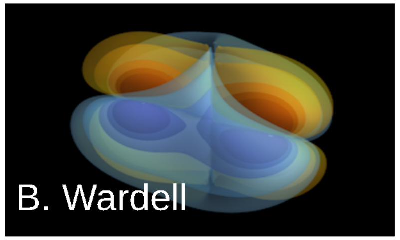
Reducing computational expense

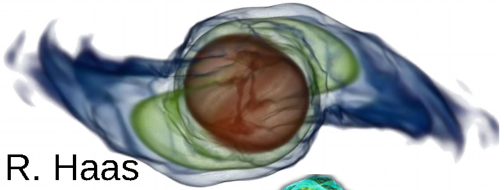
- Moore's Law is slowing
  - Cannot rely on continued CPU speed boosts
- Path forward = more efficient algorithms
  - Better sampling of our spacetimes
    - Beyond Cartesian AMR for CB inspirals:
      - Bispherical-like coords
      - Patches of curvilinear grids
    - Toward implicit timestepping
      - Corotation / dual frame approach
  - More scalable algorithms
    - DG methods
    - Few-patch grids

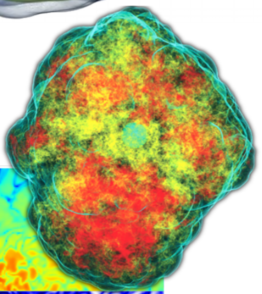
Einstein toolkit based results

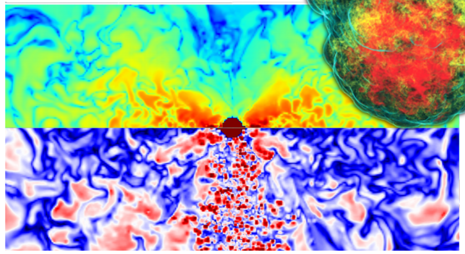
- binary black hole mergers
- binary neutron star mergers
- mixed binaries
- supernovae
- accretion disks
- boson stars
- cosmology

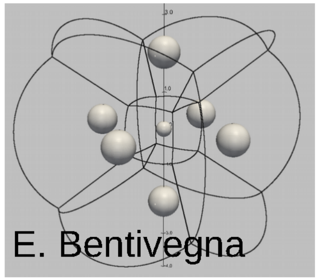
- GRMHD simulations
  - 2 free, open source, mature codes for ideal MHD simulations
  - force-free MHD code available
  - support for tabulated hot EOS
  - neutrino transport: leakage and M1 moment scheme
  - fully dynamic gravity solver

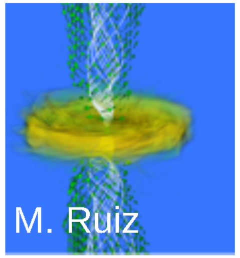

B. Wardell

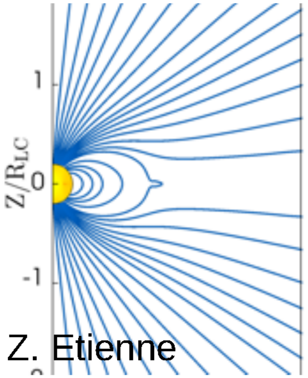

R. Haas


C. Ott

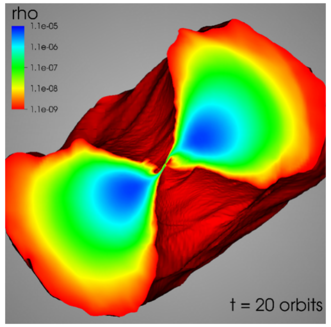

D. Siegel


E. Bentivegna


M. Ruiz

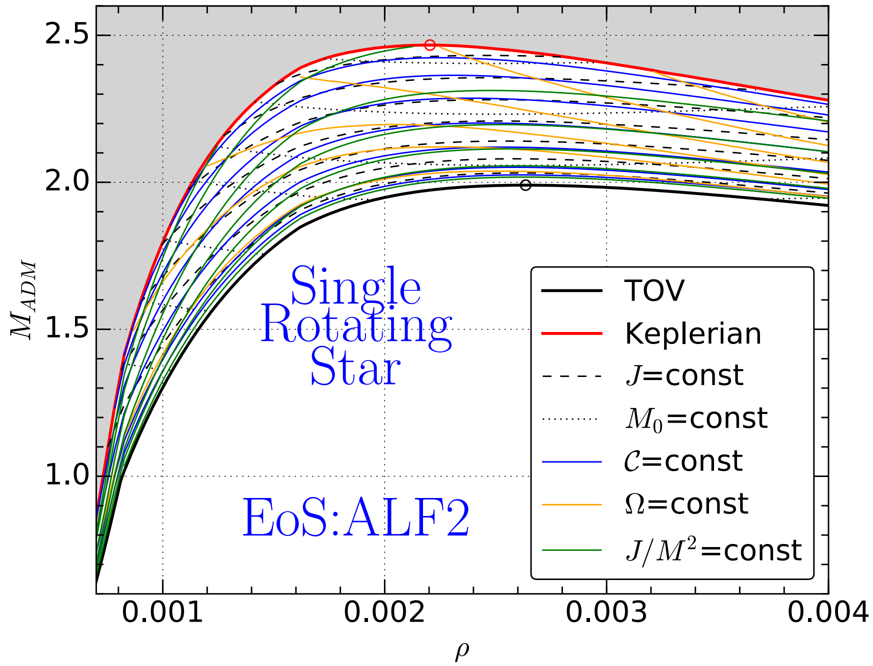


Z. Etienne



V. Mewes

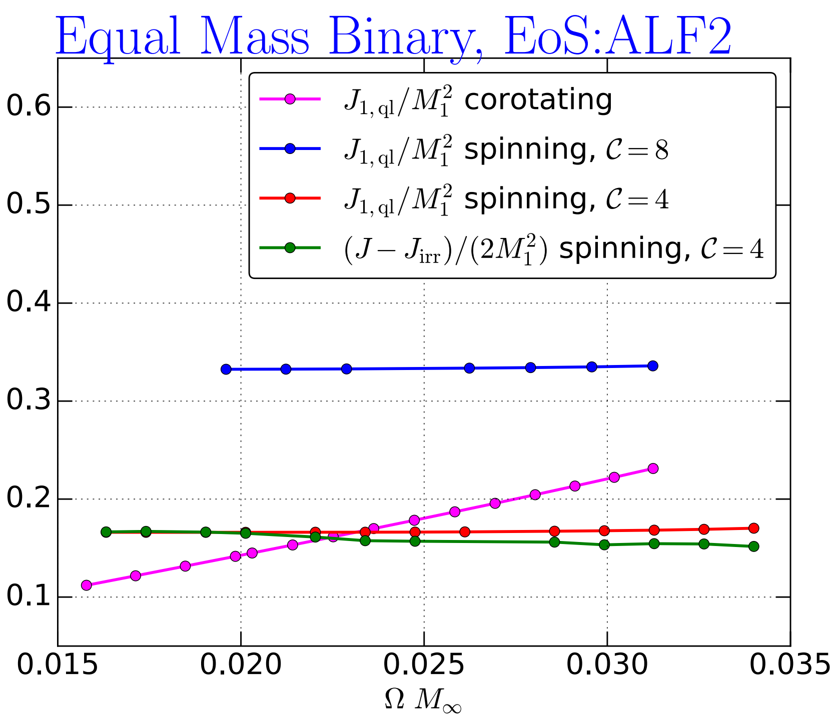
Sequences of spinning binary neutron stars: circulation & spin



Generally lines of constant $\mathcal{C}$, J/M^2 are distinct.

For slow rotations, they nearly coincide (up to a constant) $\Rightarrow$

Moving along a $\mathcal{C} = const$ curve is almost equivalent to moving along a $J/M^2 = const$ curve.

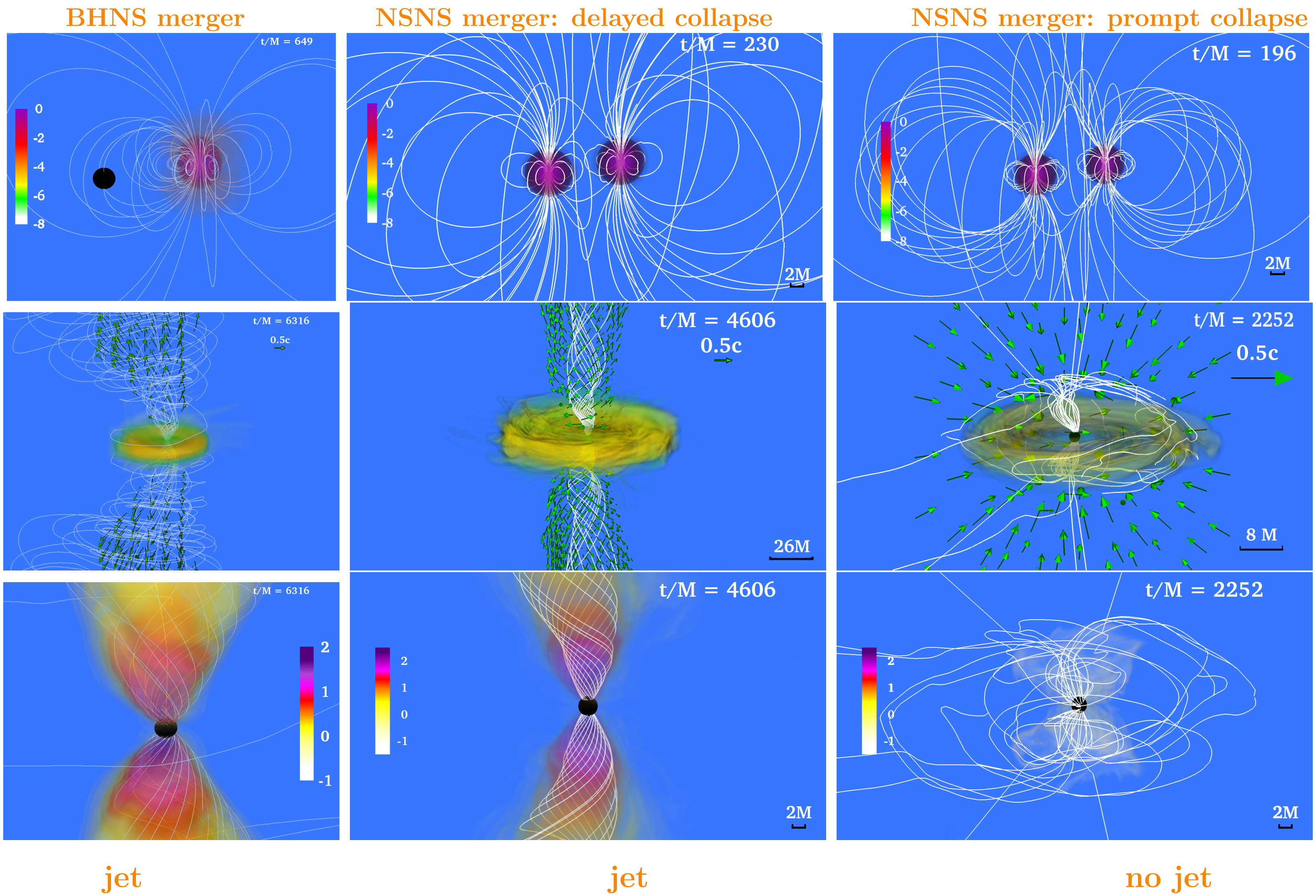


($J_{1,\mathrm{ql}}$: Quasi-local angular momentum of one star, J: Total angular momentum, J_{irr}: Total angular momentum of irrotational binary.)

$\Rightarrow$ Corotating sequences can have low spin ≤ 0.3 even for close binaries.

$\Rightarrow$ Constant circulation sequences preserve quasi-local spin (for low spins) similarly to single rotating stars.

GW170817 + GRMHD ⇒ NS Maximum Mass[◇]



$$\beta M_{\rm max}^{\rm sph} \approx M_{\rm max}^{\rm sup} \lesssim 2.74 \lesssim M_{\rm thresh} \approx \alpha M_{\rm max}^{\rm sph}.$$

$$2.74/\alpha \lesssim M_{\rm max}^{\rm sph} \lesssim 2.74/\beta$$

EOS causal limit ⇒ $\beta \approx 1.27$ ⇒ $\boxed{M_{\rm max}^{\rm sph} \lesssim 2.16}$

◇ M. Ruiz, S. Shapiro, A. Tsokaros, Phys. Rev. D 97, 021501(R) (2018)