LazEv

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Numerical Relativity Community Call
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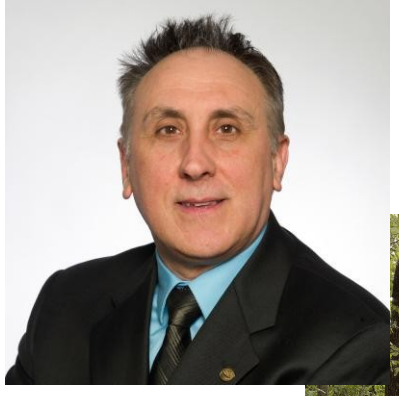
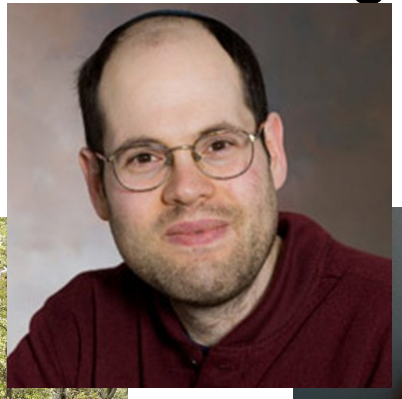
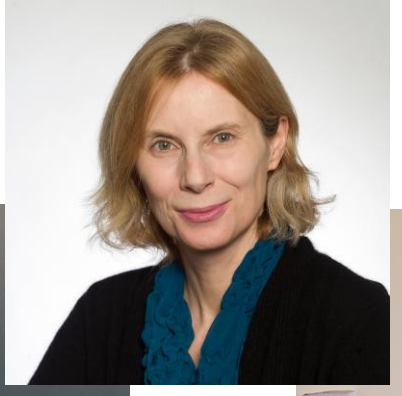
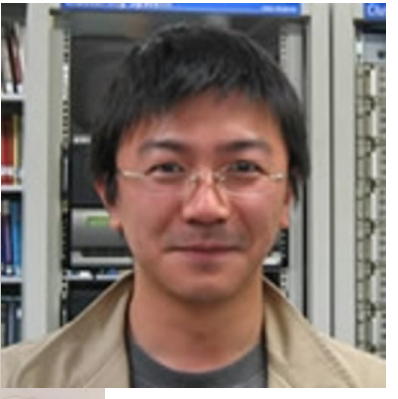
RIT Group

- Carlos Lousto, Yosef Zlochower, Jim Healy
- Frequent Collaborator: Hiroyuki Nakano
- Recent PhDs: Nicole Rosato and Ian Ruchlin
- Manuela Campanelli and TCAN collaboration
  - compact-binaries.org

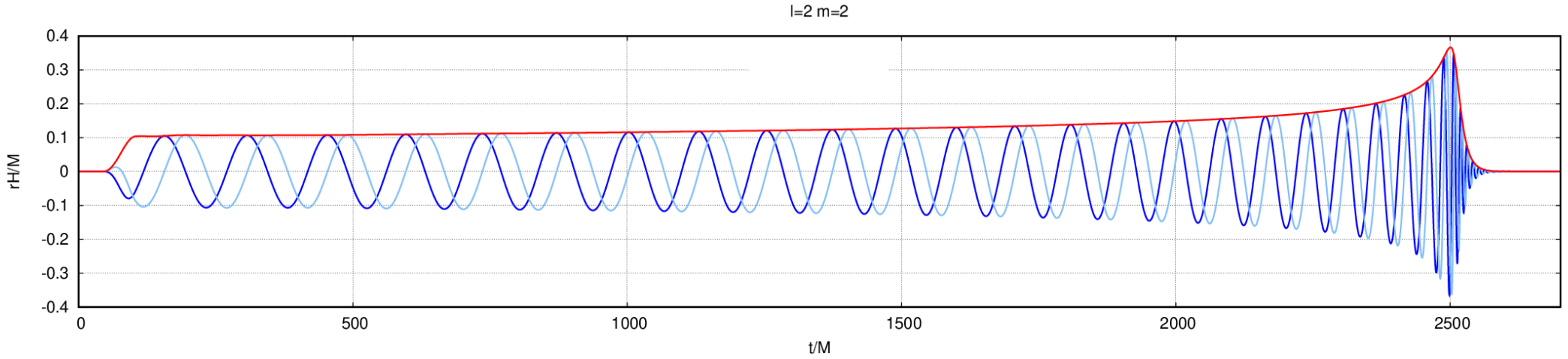






LazEv

- One of the first successful evolutions of BBHs in 2005
- ETK backbone (Cactus/Carpet)
- BSSNOK/CCZ4 Formalisms
- Internal thorns for evolution (LazEv), initial data (HiSpID) and analysis
- Very robust:
  - Black-hole binaries (BHBs)
  - 3 black-hole systems
  - 2 orbits at r=100m
  - Long-term simulations of >20,000m
  - RIT Catalog of Waveforms

RIT Catalog

- https://ccrgpages.rit.edu/~RITCatalog
- 777 quasicircular waveforms
- Applications
  - Analytic models of final state parameters
  - Correlations between final state parameters
  - Parameter estimation of LIGO-VIRGO O1/O2 runs

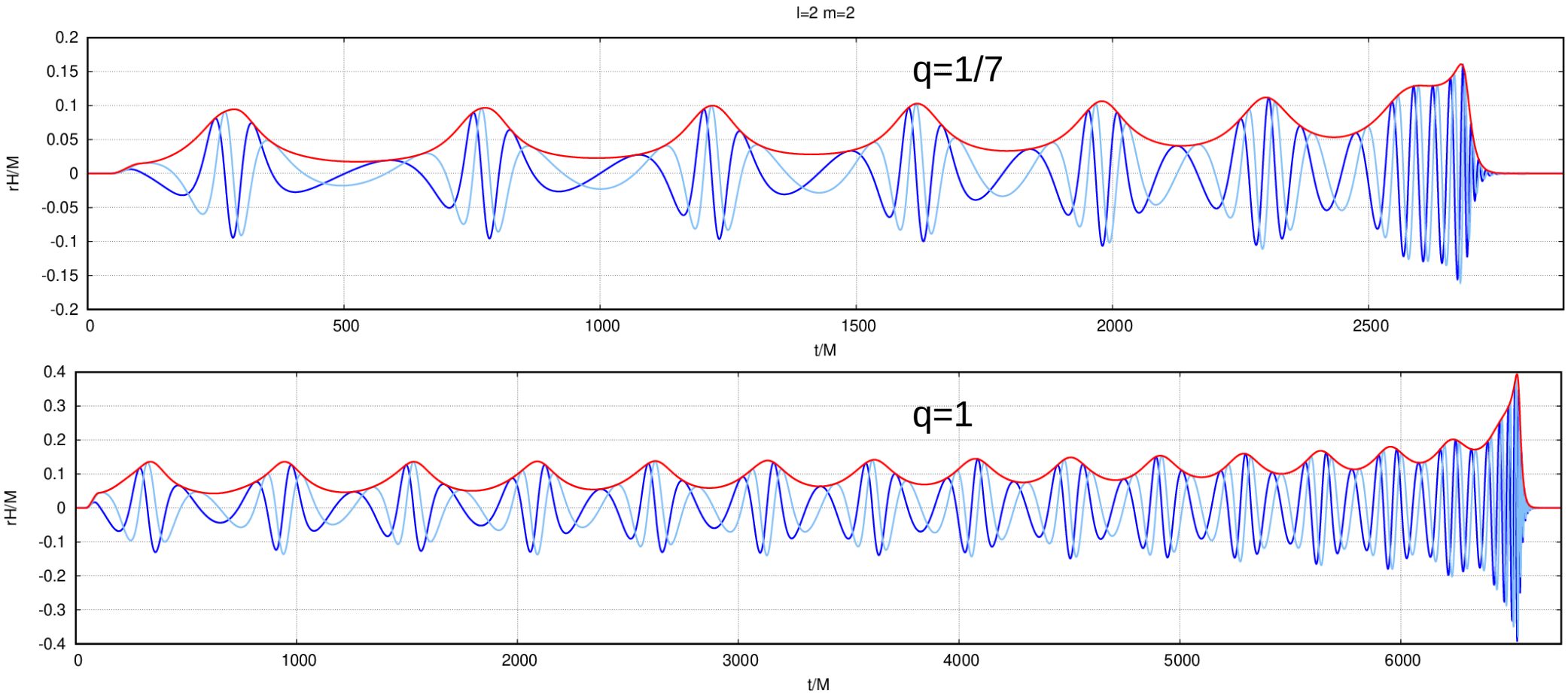


Catalog Breakdown

- Nonspinning: 13 simulations → q=1 to 1/15
  - **push to lower mass ratios (q=1/128)**
- Aligned Spins: 464 simulations
  - Lowest mass ratio with spin currently 1/7
    - **push to lower mass ratios (q=1/128)**
  - Highest spins of 0.95 for q=1 to ½
    - **push to lower mass ratios (q=1/7 currently) with 0.95 spins**
- Precessing Spins: 300 simulations
- All simulations have e~0
  - **add eccentric waveforms**

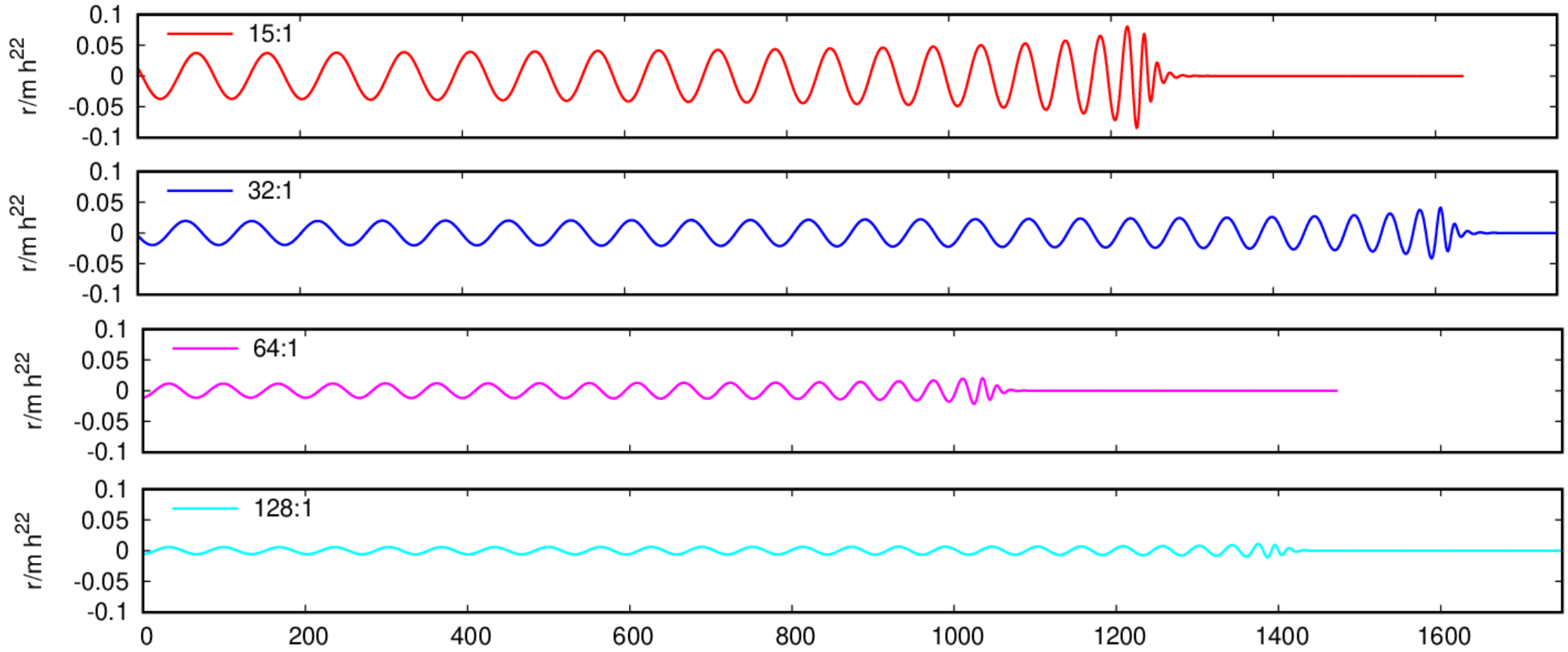
Next Catalog: Eccentric Waveforms

* With or without spins, currently down to q=1/32.



Next Catalog: Small Mass Ratios

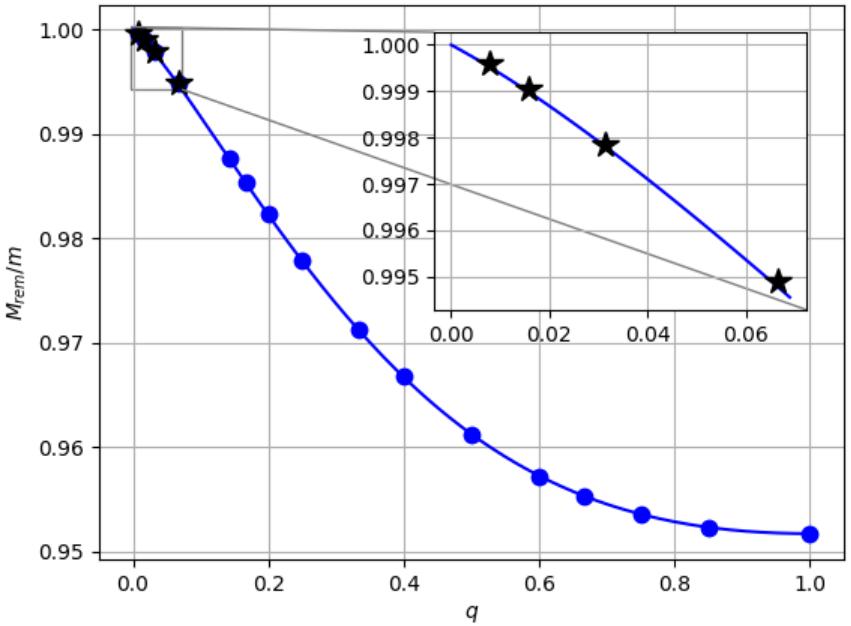
* PRD 102, 104018 (2020)
* Nonspinning simulations down to q = 1/128
* Zeno's dichotomy approach

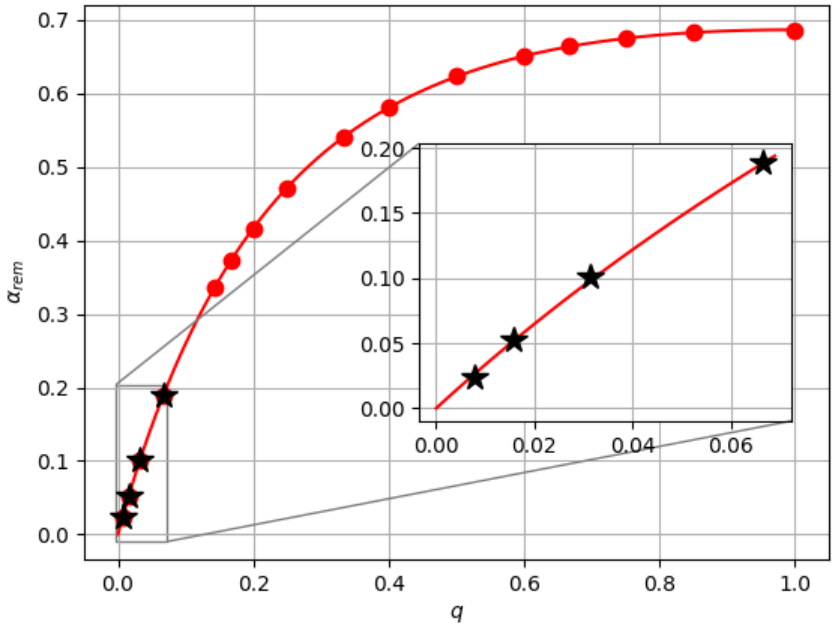


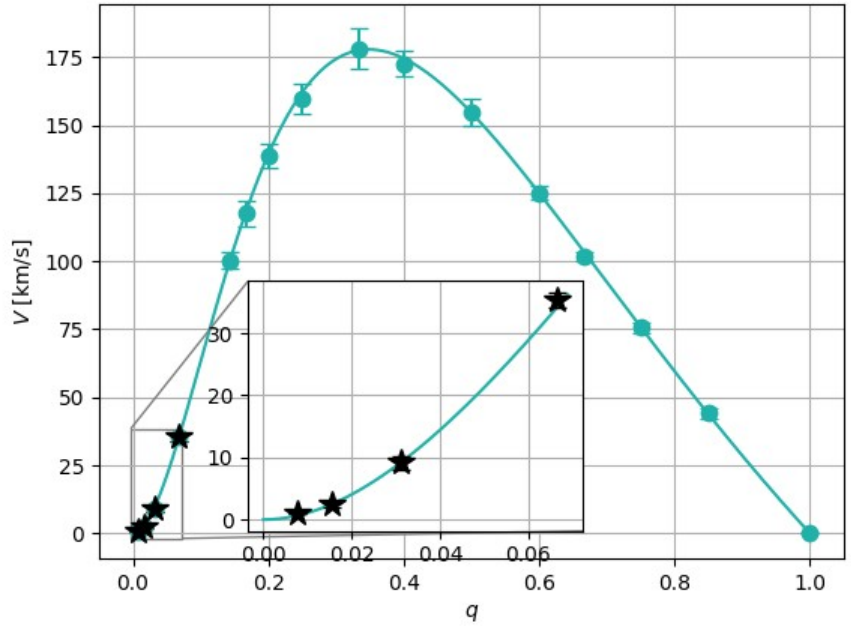
SMR grid construction

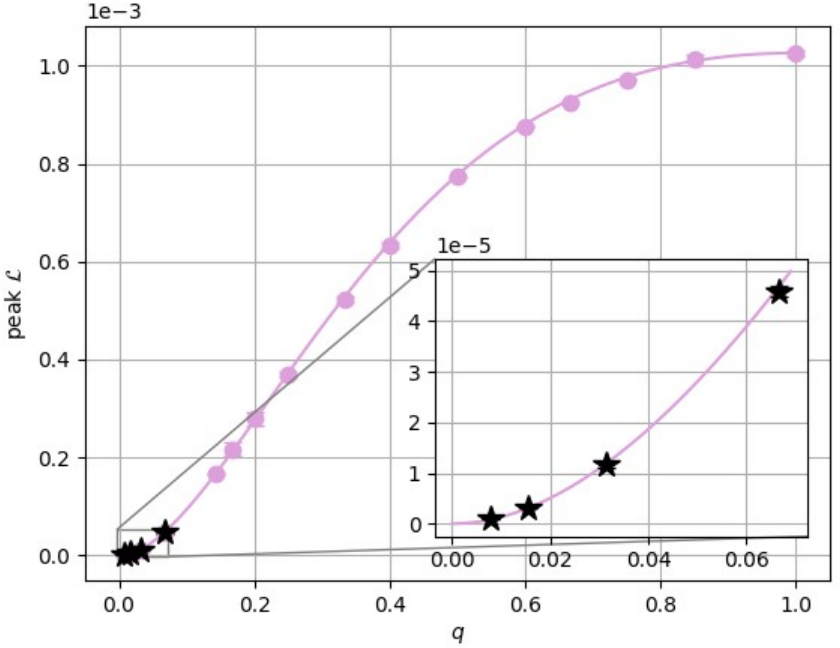
- Start with the q=1/15 case and show convergence
- Halving the mass-ratio adds an additional grid around small BH
- Large BH grid stays the same (m2~1 since m=m1+m2=1)
- Resolutions for q=1/128: m/4096

Analytic fits









Limitations

- Temporally expensive – since **dt = cfl*dh**
  - q=1/128 ran for 7 months on 8 frontera nodes
  - Need 3 resolutions for convergence study
- Solutions?
  - Better code scaling
    - Different implementations of MPI?
    - Long term: CarpetX AMR?
  - Gauge choices

Gauge Choice

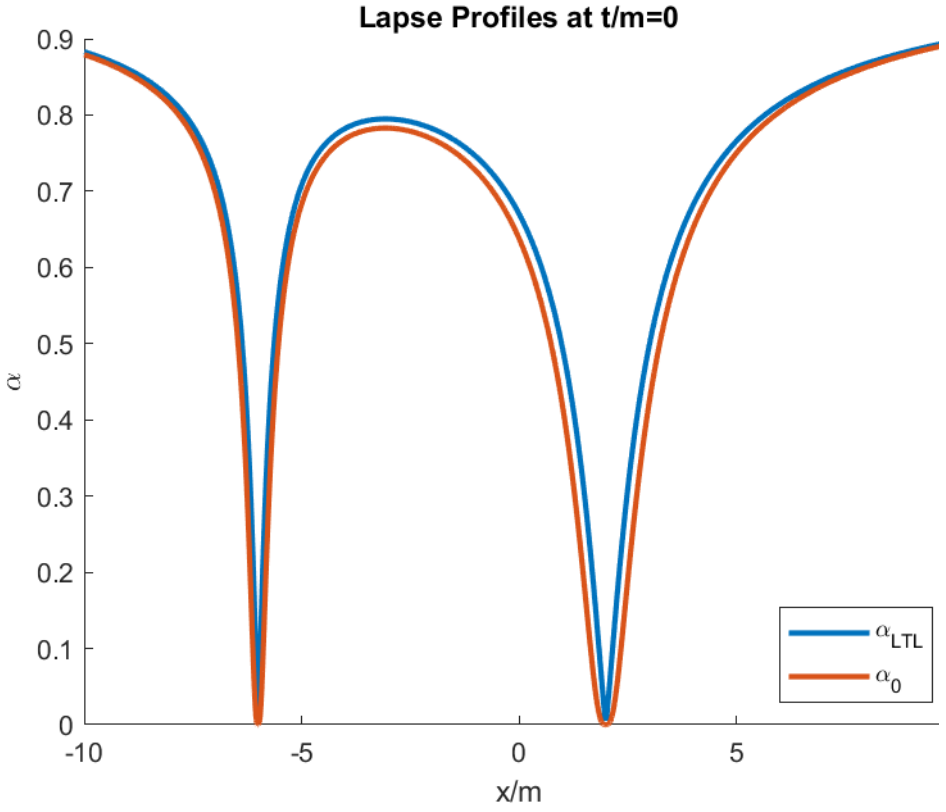
$$\partial_0 \alpha = (\partial_t - \beta^i \partial_i)\alpha = -2\alpha K,$$

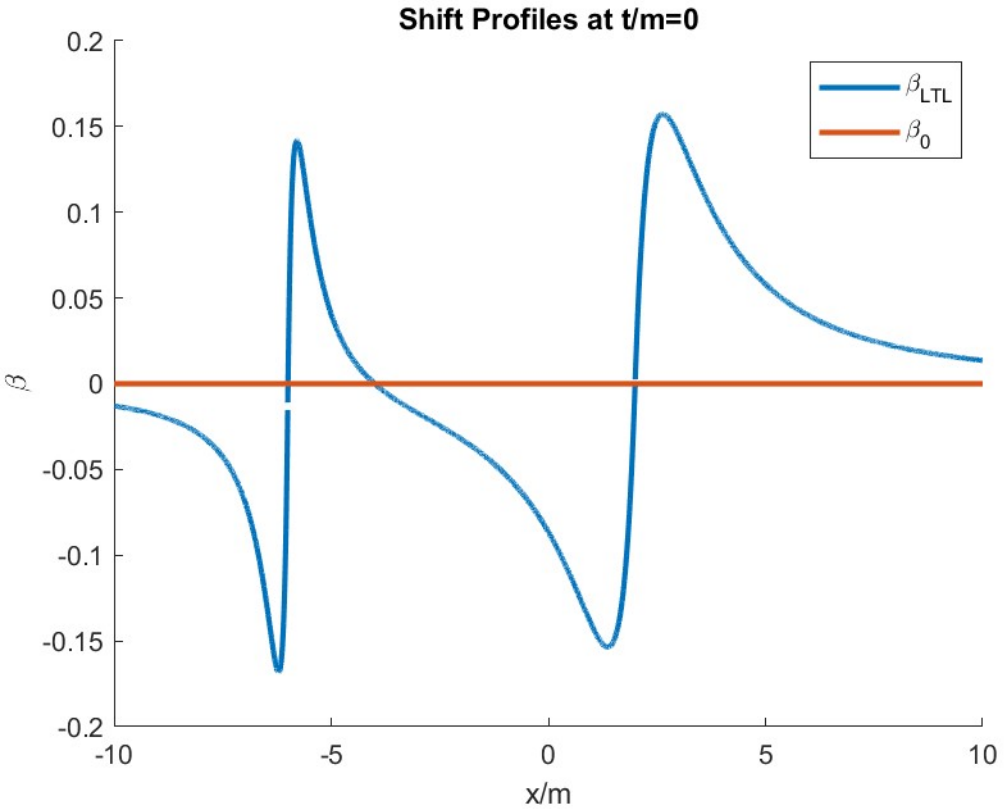
$$\partial_t \beta^a = \frac{3}{4}\tilde{\Gamma}^a - \eta(x^k, t)\,\beta^a$$

- PRD 103, 104068 (2021)
- Initial Lapse/Shift profile
- Shift Evolution parameter, η

Initial Gauge

$$\alpha_{LTL} = \alpha_0(\psi_0) = \frac{a}{1 + b\psi_0^n + c\psi_0^{n+1} + d\psi_0^{n-1}}$$

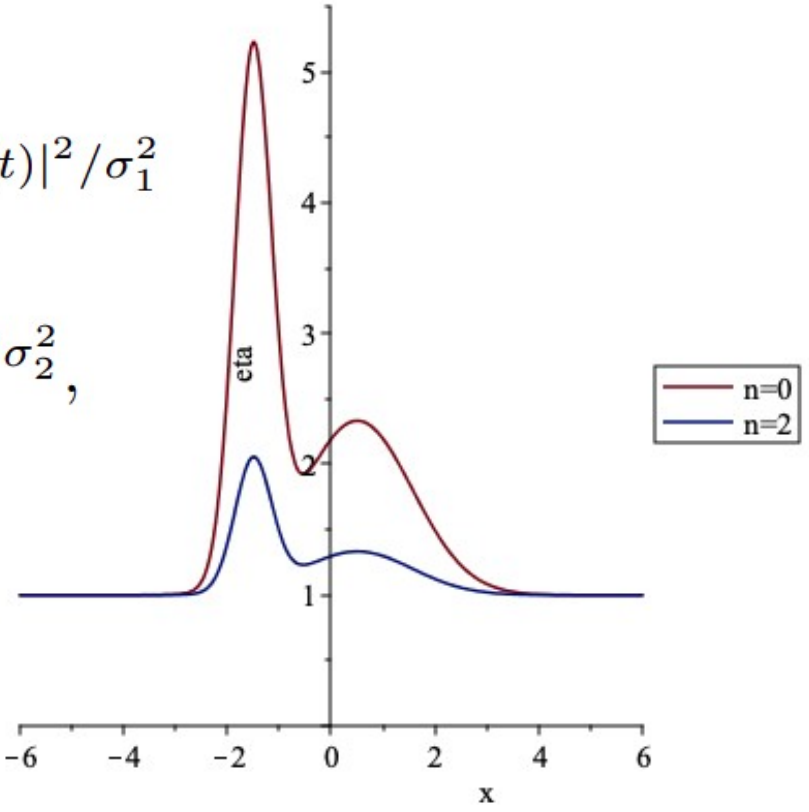




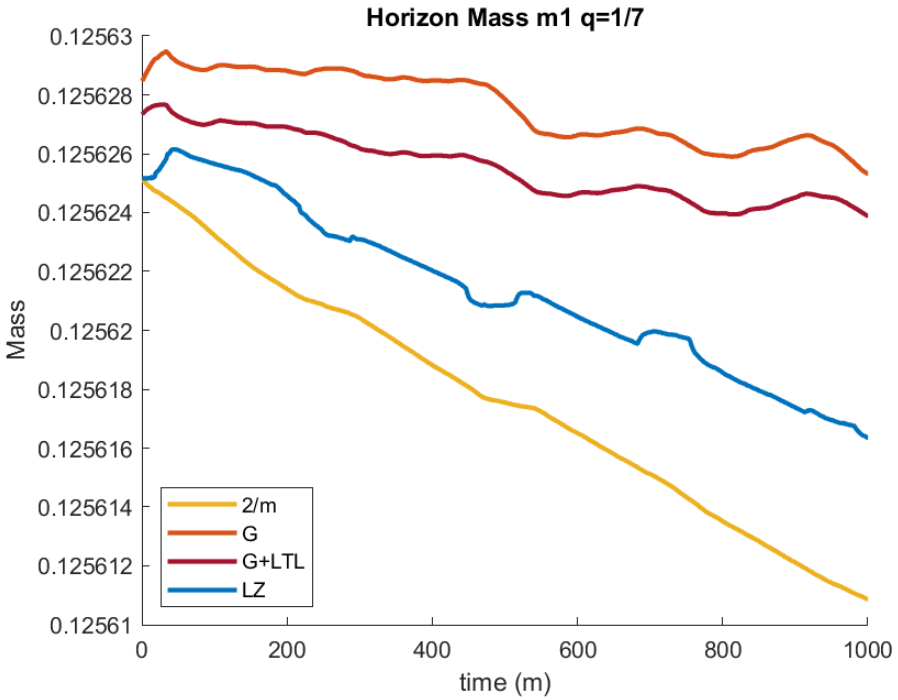
$$\beta_0^r(\psi_0) = \frac{a(\psi_0 - 1)^2}{1 + b\psi_0 + c\psi_0^2 + d\psi_0^3}$$

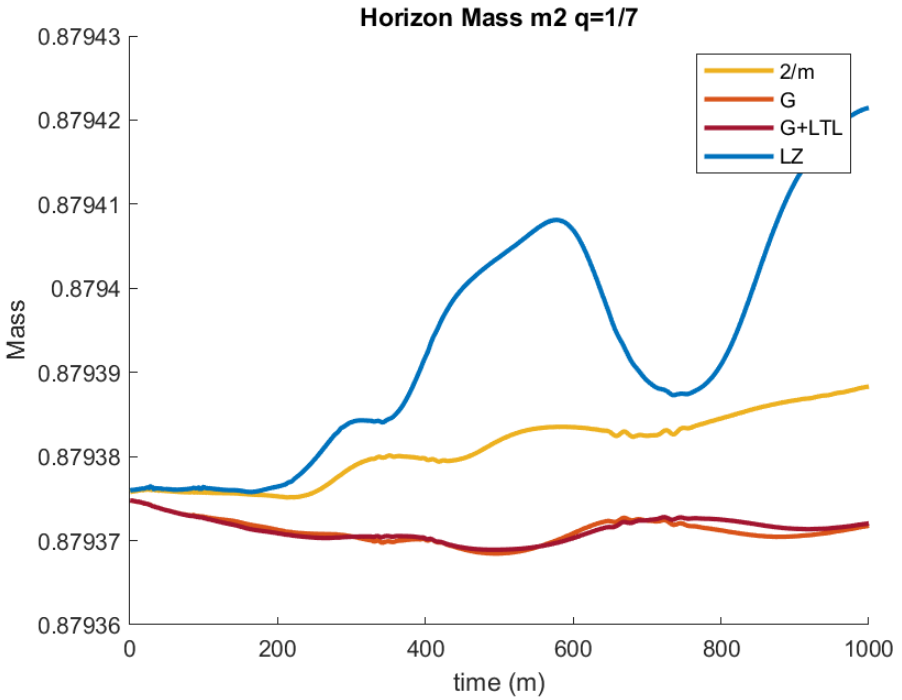
Spatially dependent η

- $m\eta=2$
- $m\eta_\psi = \mathcal{A} + \mathcal{B}\,\dfrac{\sqrt{|\vec{\nabla}_r \psi_0|^2}}{(1-{\psi_0}^a)^b}$
- $\eta_G = \dfrac{\mathcal{A}}{m} + \dfrac{\mathcal{B}}{m_1}\left(\dfrac{\vec{r}_1(t)^2}{\vec{r}_1(t)^2+\sigma_2^2}\right)^n e^{-|\vec{r}-\vec{r}_1(t)|^2/\sigma_1^2}$
$+\dfrac{\mathcal{C}}{m_2}\left(\dfrac{\vec{r}_2(t)^2}{\vec{r}_2(t)^2+\sigma_1^2}\right)^n e^{-|\vec{r}-\vec{r}_2(t)|^2/\sigma_2^2},$



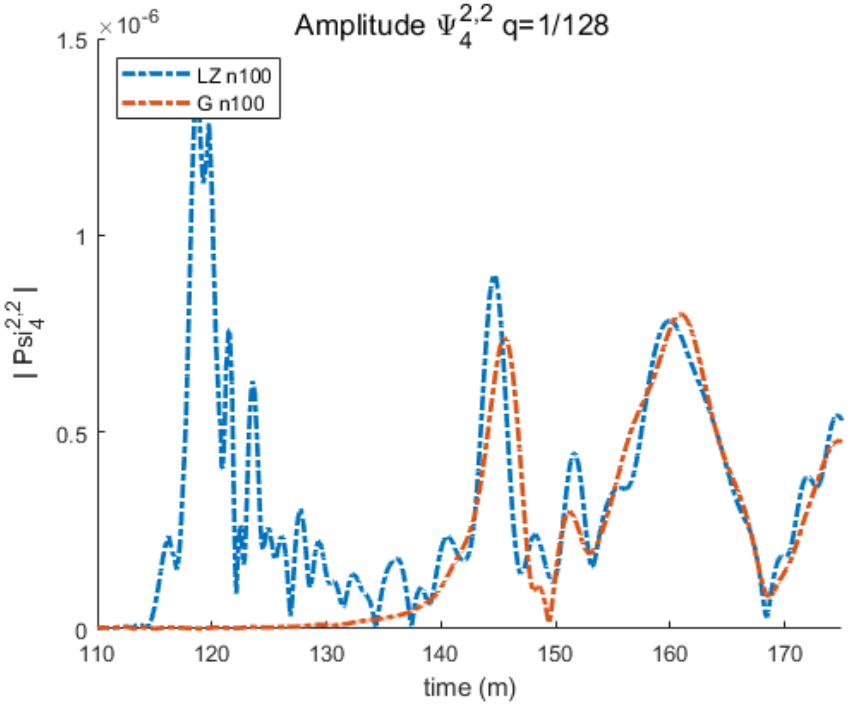
Results

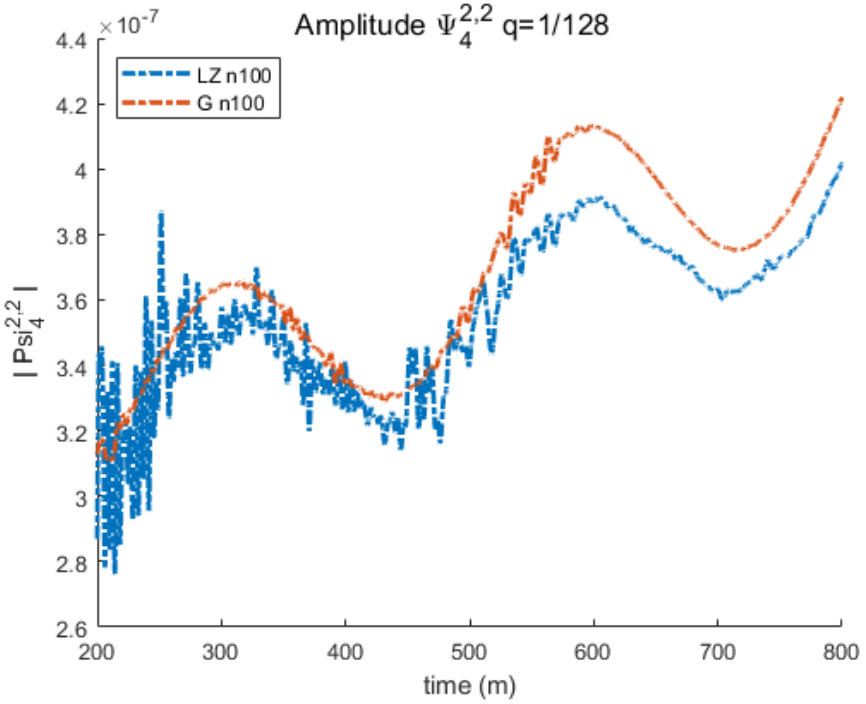




- q=1/7 nonspinning
- Better mass retention with G

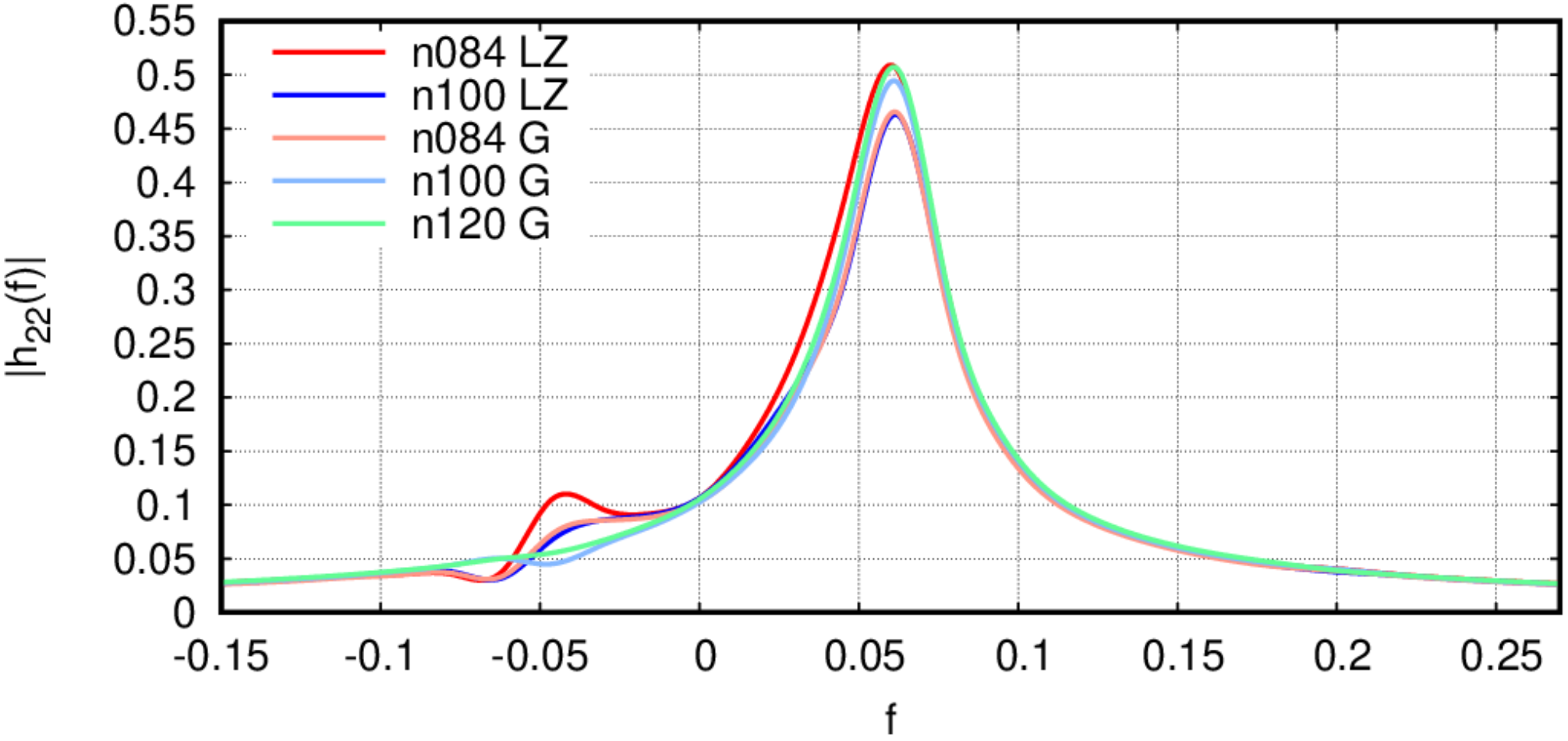
Results





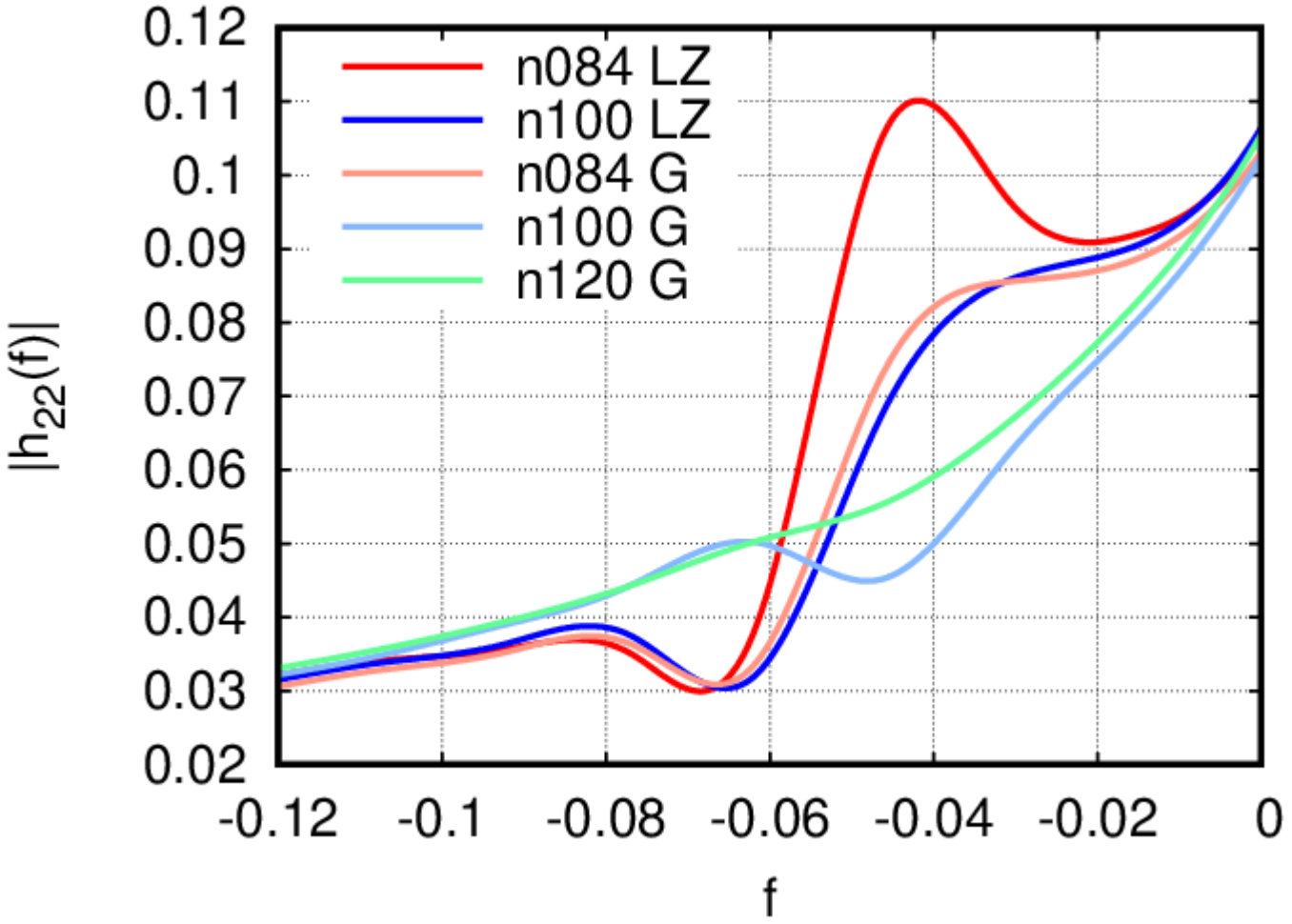
- q=1/128 nonspinning
- Reduced noise with G

Results



- Ringdown q=1/32 nonspinning

Results

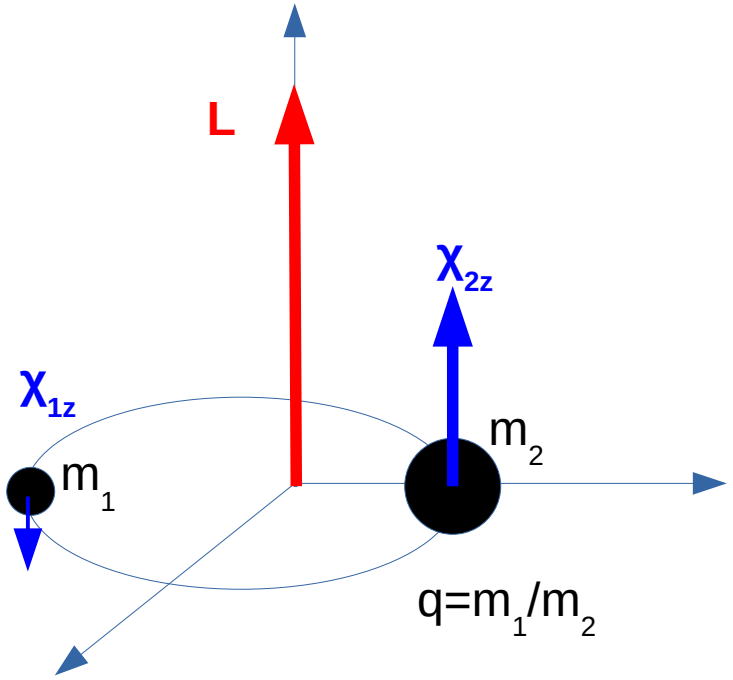


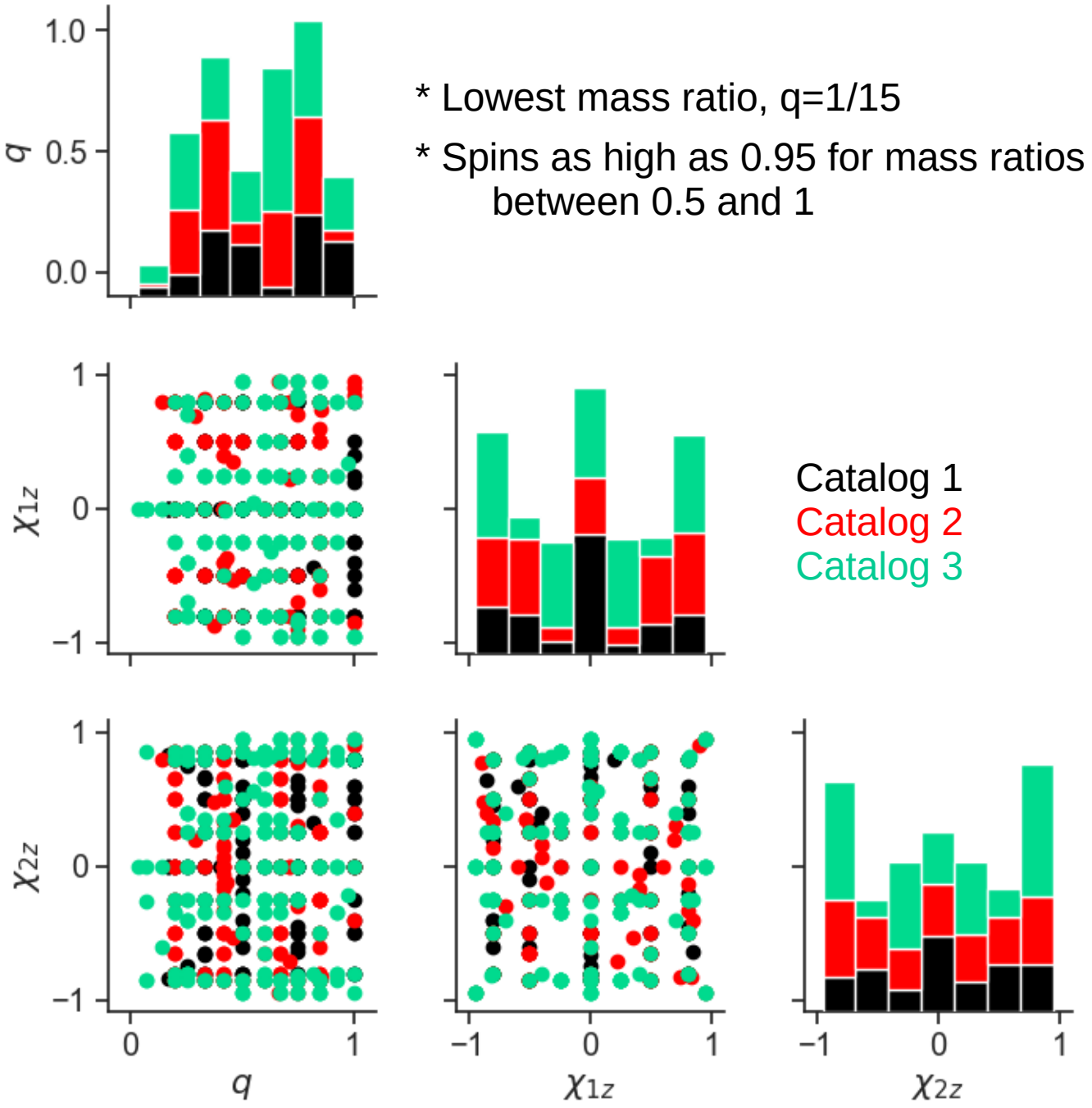
- Higher effective resolution with G

Conclusion

- LazEv is a very robust code used to run a myriad of vacuum black hole simulations
- We are pushing the code to unexplored limits with great results
- Gauge choices can help reduce numerical noise initially and give a higher effective resolution

Catalog: QC Aligned Systems

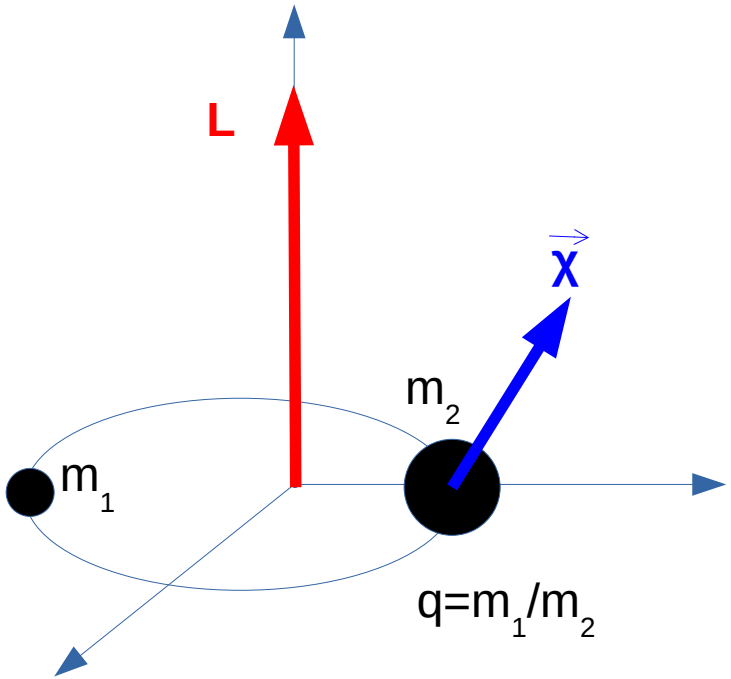


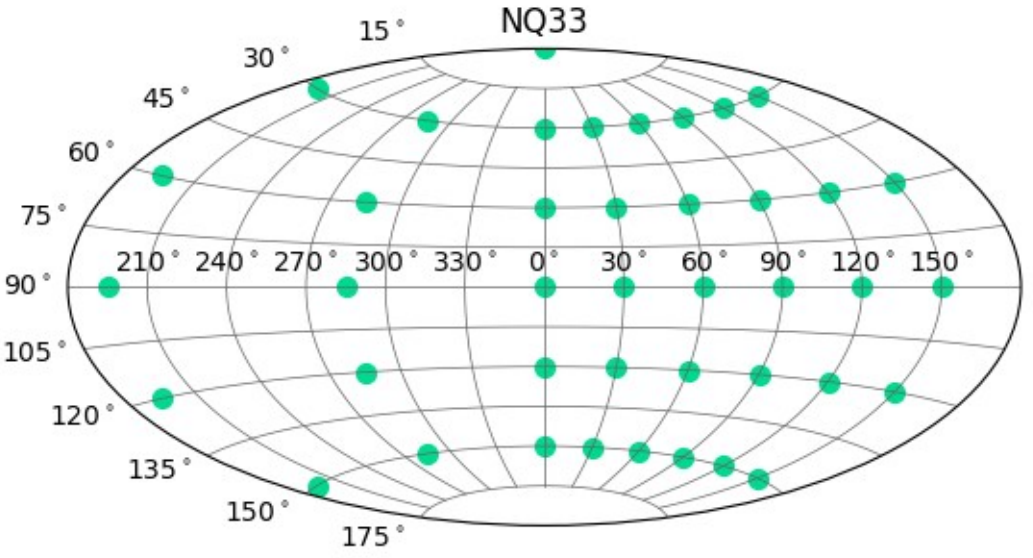


* Lowest mass ratio, q=1/15
* Spins as high as 0.95 for mass ratios between 0.5 and 1

Catalog 1
Catalog 2
Catalog 3

Catalog: Precessing Systems





* One BH spinning
* Either large or small
* Continuous q:
  q<1 if large BH is spinning
  q>1 if small BH is spinning

* Spin magnitude fixed at 0.8
* Vary spin angles, θ and ϕ
* Typical coverage for a given q
* 9 q's between 0.2 and 2.0