Improvement of Outer Boundary Conditions for Binary Black Hole Numerical Simulations

GWANW – Virtual Meeting

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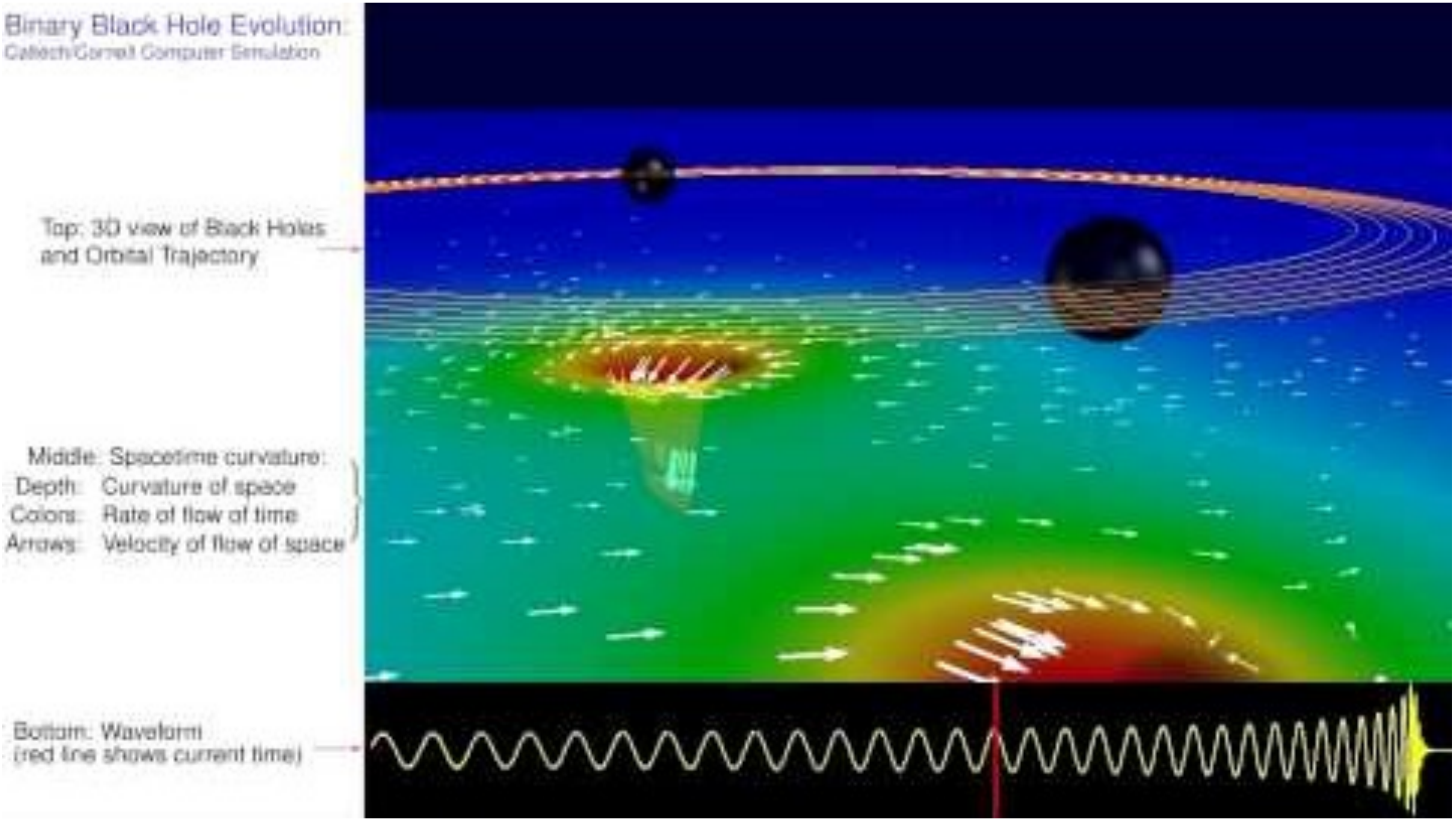
BOTHELL

The **Sp**ectral **E**instein **C**ode - SpEC



Video from https://www.black-holes.org/explore/movies

Computational domain

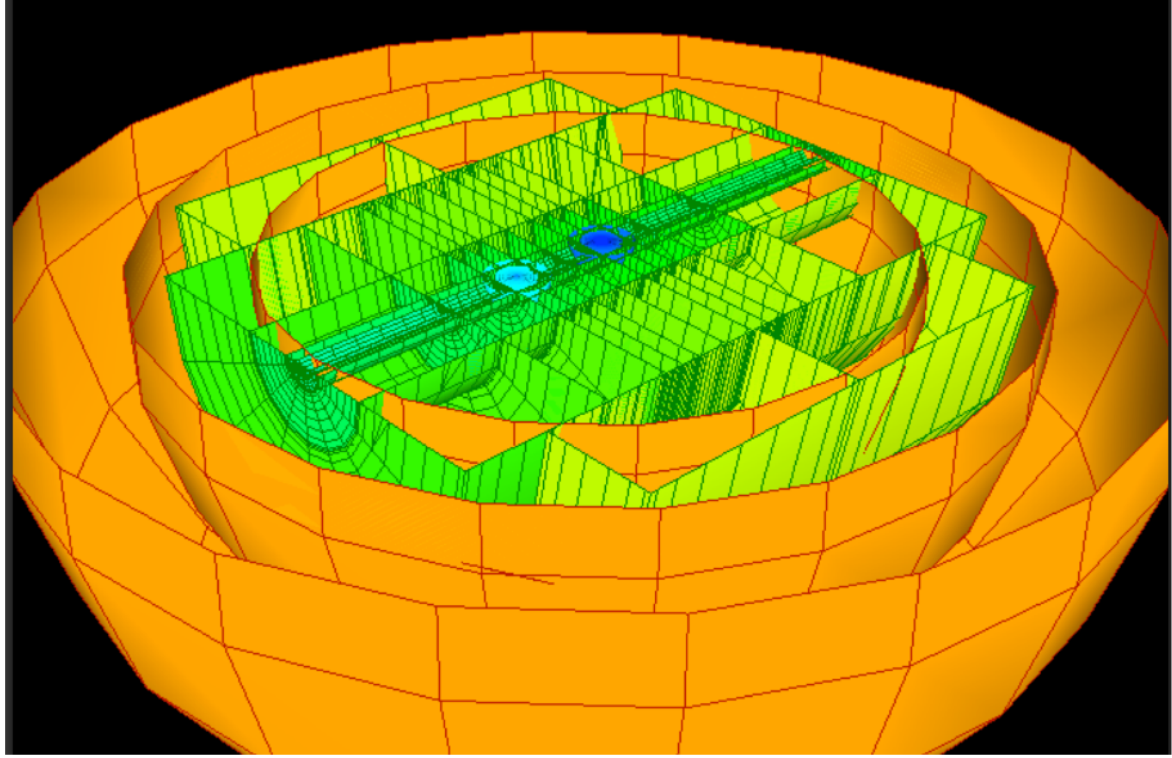


Image from the SXS Collaboration

Cauchy (3+1) formulation

- Solve EEs on spatial hypersurface
- Evolve in time (the +1)

Outer boundary: spherical domain

- Artificial time-like boundary
- Where GW are calculated ($\mathbf{\Psi_4^{\ell,m}}$ & $\mathrm{h}_{\ell,m}$)
- Requires boundary conditions
- Freezing $\mathbf{\Psi_0^{\ell,m}}$

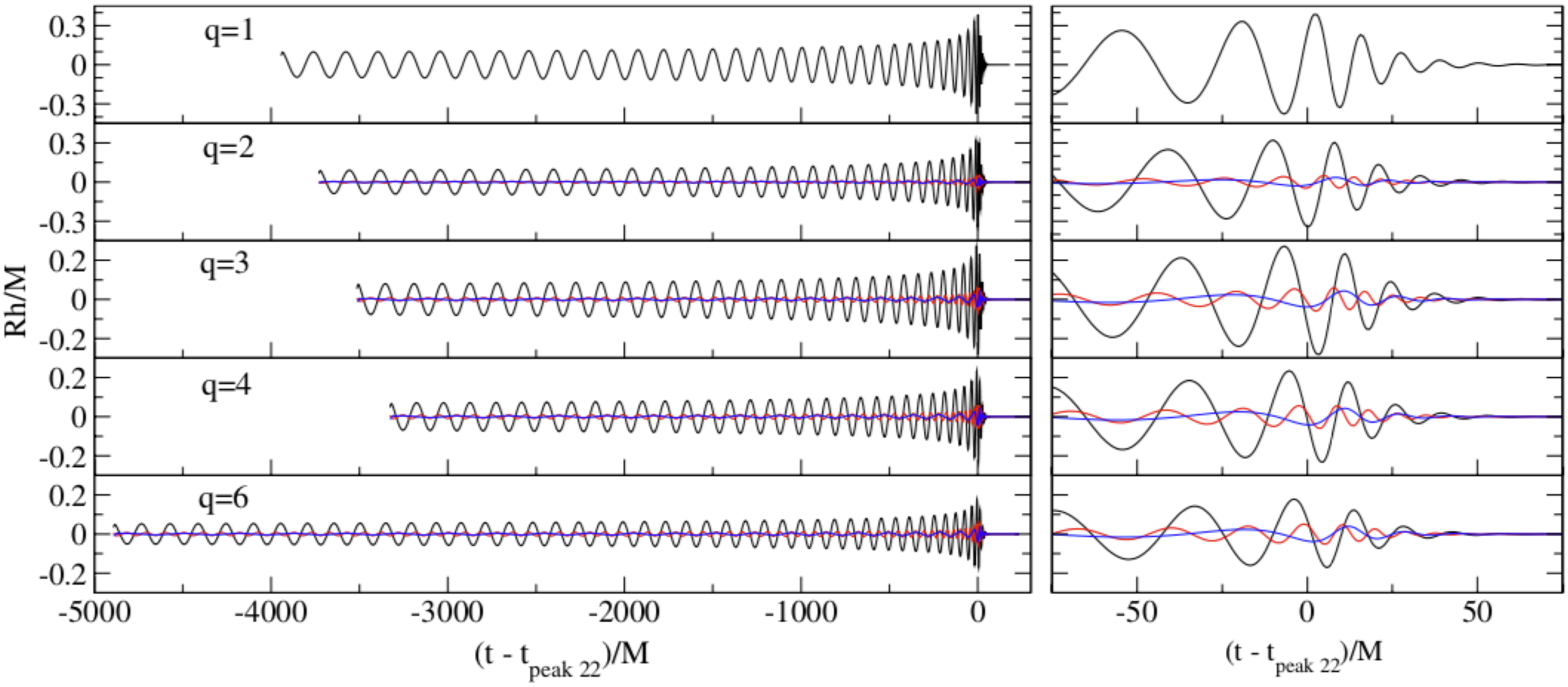
Boundary conditions (BCs) for the GWs

Angular momentum number (ℓ) of GWs

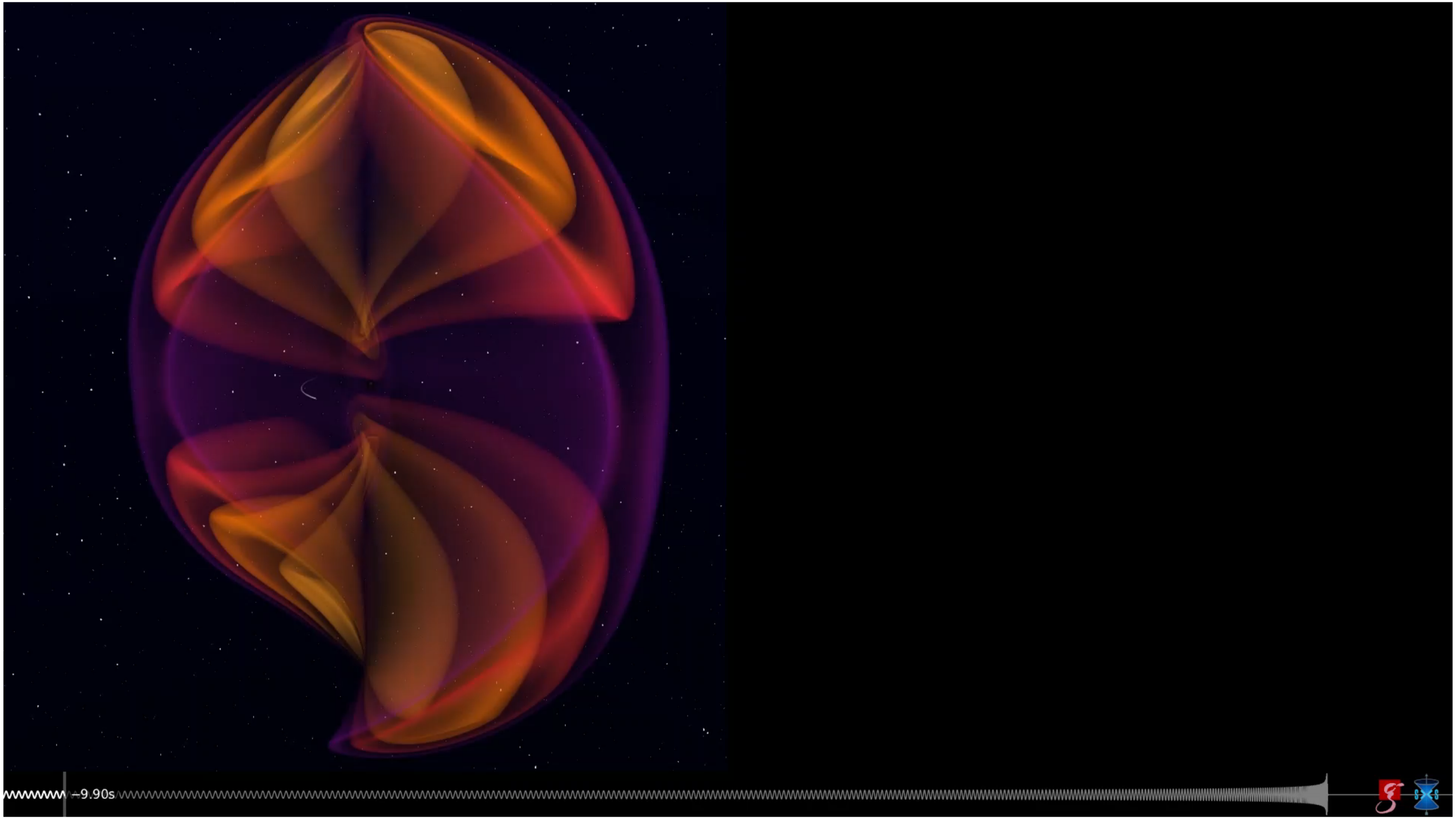
- ℓ = 2 is the dominant mode
- ℓ = 3, 4, … are called the higher multipoles

Spurious reflections occur for higher multipolar GWs with freezing $\boldsymbol{\Psi_0^{\ell,m}}$ BC

- Important for unequal mass BBHs
- GW190814


q=1
q=2
q=3
q=4
q=6
Rh/M
0.3
0
-0.3
0.2
-0.2
-5000
-4000
-3000
-2000
-1000
0
-50
50
(t - t_peak 22)/M
(t - t_peak 22)/M

Simulation of GW190814 (SXS collaboration)



Improved Boundary conditions

Higher Order Boundary condition on $\Psi_0^{\ell,m}$ (Buchman and Sarbach 2006)

- Freezing $\Psi_0^{\ell,m}$ is the lowest order
- Higher orders reduce spurious reflections for ℓ = 3, 4, …

SpEC implementation (Rinne et al 2009)

BCs reformulated:

- Now able to apply tricks developed in applied mathematics for numerical implementation

Rinne et al 2009

Successful implementation for multipolar wave initial data

- Evolved in the full SpEC code (non-linear, Einstein equations)
- This is a simple non-rotating computational grid with spherical shells

Goal now is for a successful implementation for Binary Black Hole inspiral and merger simulations

Towards BBH simulations

Adaptation of HOBCs to BBH infrastructure

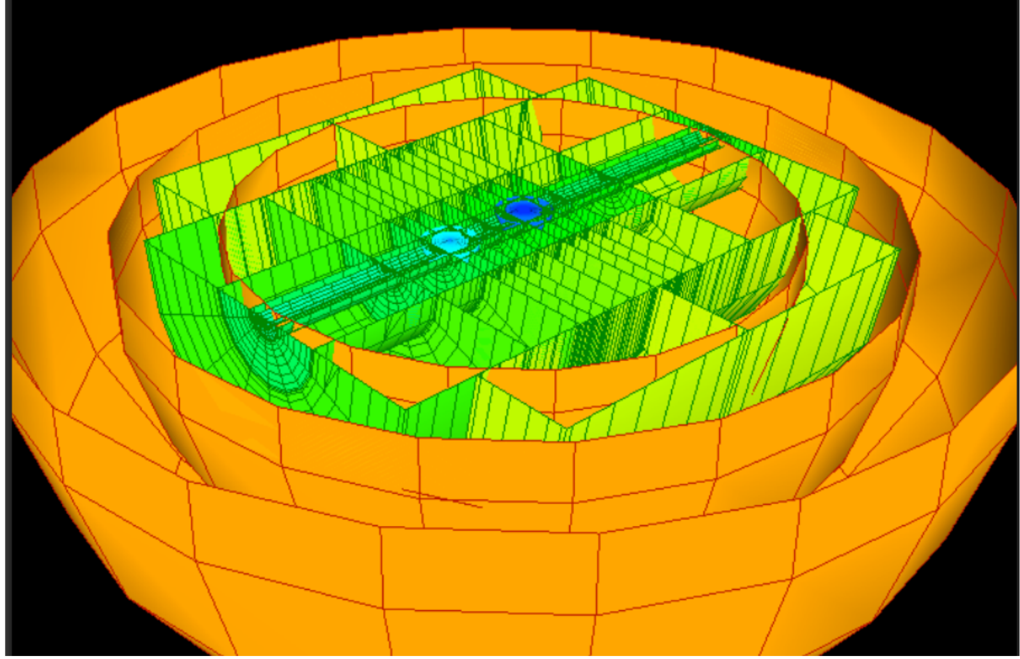
- Dual frame *
- Rotating *

Repeating tests of Rinne et al in the new infrastructure

- Multipolar wave initial data ($\ell = 2, 3, 4$)
- Compare with exact solution
- Compare numerical and theoretical reflection coefficients

* Previously completed by Scheel and Buchman

BBH Simulations



- Initial data of a BBH system
- Evolved in BBH infrastructure

Difficulties:

- Analytic solution is unknown -> no comparison can be done

Solutions:

- Calculate reflection coefficient (Buchman & Sarbach 2006)
- Compare to the numerical to the theoretical ($\frac{\Psi_0}{\Psi_4}$)

Next steps

- Testing of recent sign changes
- Multipolar wave tests (in dual frame rotating code)
- BBH coalescence tests

References

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7. LIGO Document G2000730-v3