2019 Workshop on Gravitational Waves and High-Performance Computing

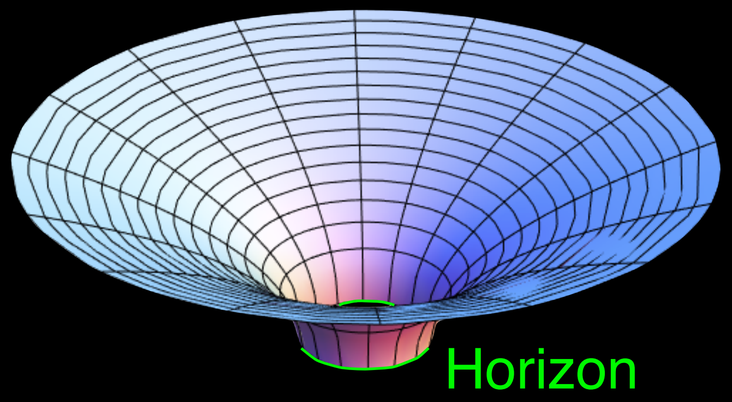
Geoffrey Lovelace

August 19, 2019 – August 23, 2019

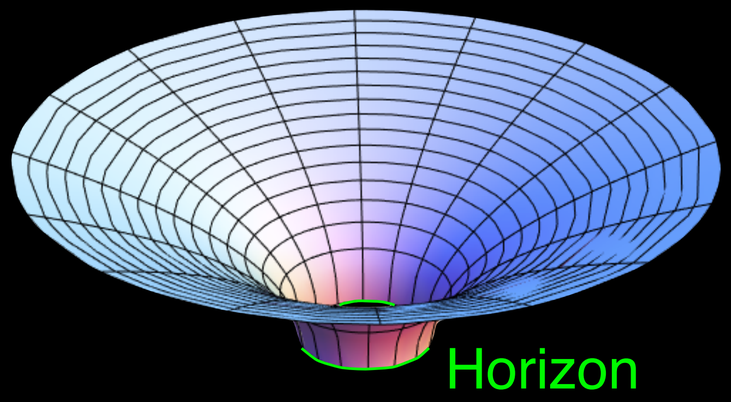
Day 4

Today's plan

- 5-minute intro to simulating gravitational waves
- CSUF student short talks on their research
- Matt Giesler, CSUF alum, talk on research
- Data center tour
- Update on your simulations
- https://geoffrey-lovelace.com/Workshop/2019/


Horizon

+


Horizon

= ?

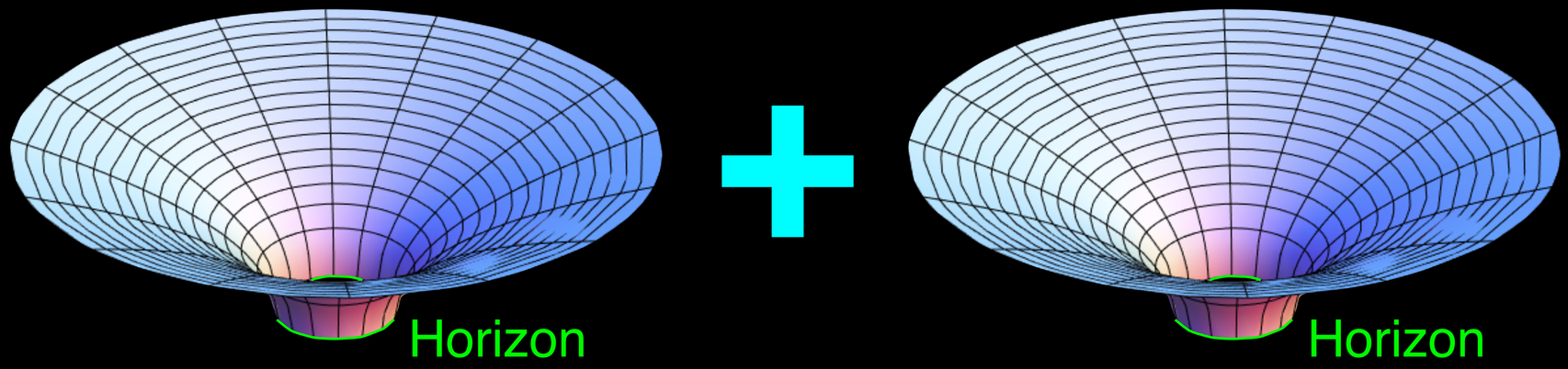
Linear and nonlinear physics

- Linear
  - Whole is sum of parts
  - Example: sound in this room
  - Total sound = sum of individual sounds
- Nonlinear
  - Whole is more than sum of parts
  - Example: water + wind
  - Example: two black holes
  - Need supercomputers

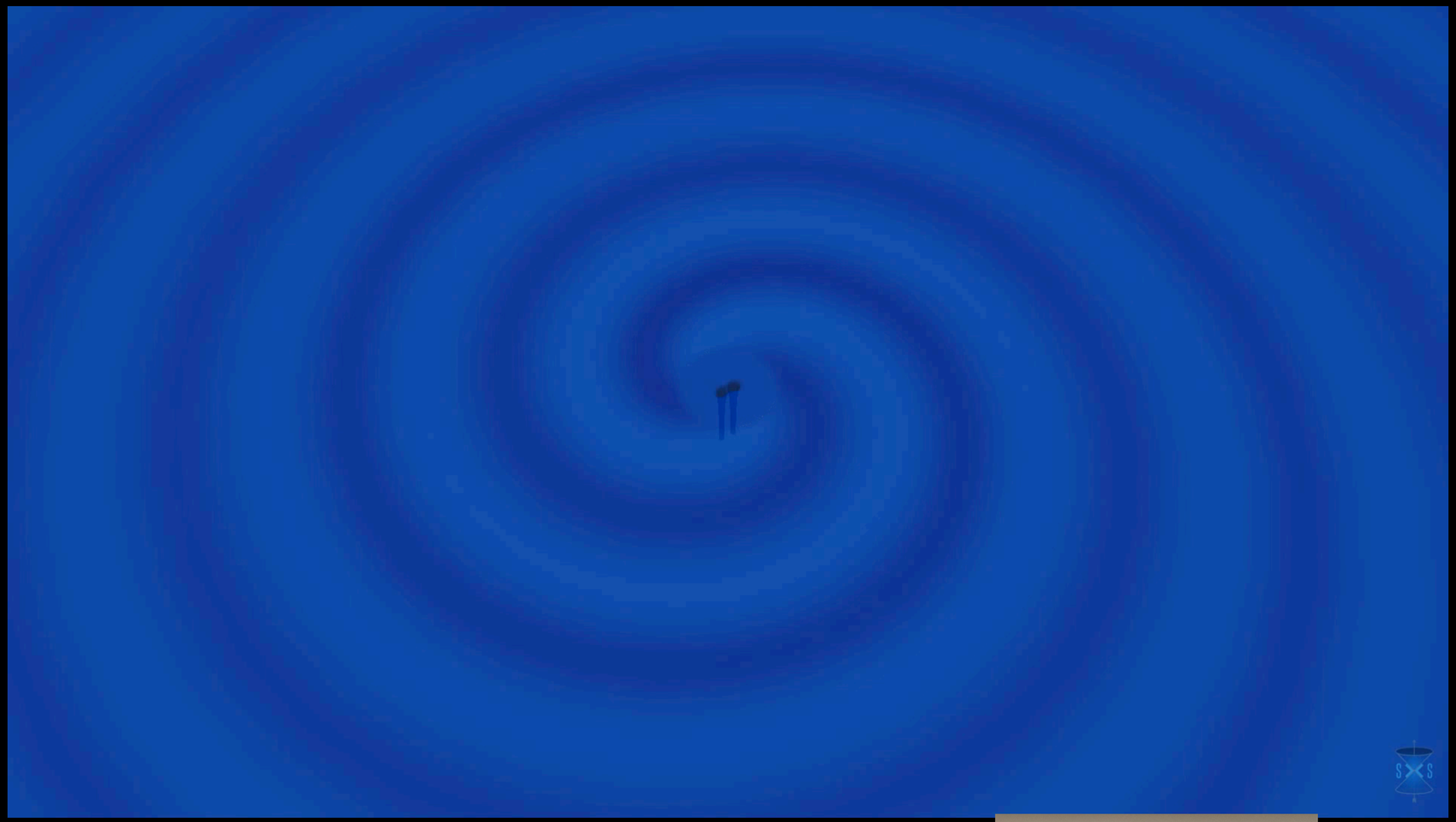
Single black hole

Colliding black holes

Images courtesy Kip Thorne



Merging black holes & gravitational waves



Simulation by Geoffrey Lovelace,
Movie by CSUF student Nick Demos,
Simulating eXtreme Spacetimes
collaboration

Supercomputer simulations of colliding black holes

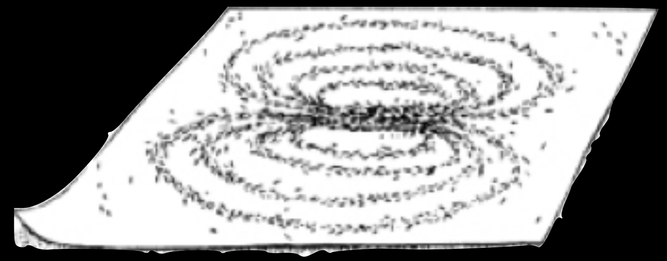
– Goal: solve Einstein's equations for warped spacetime

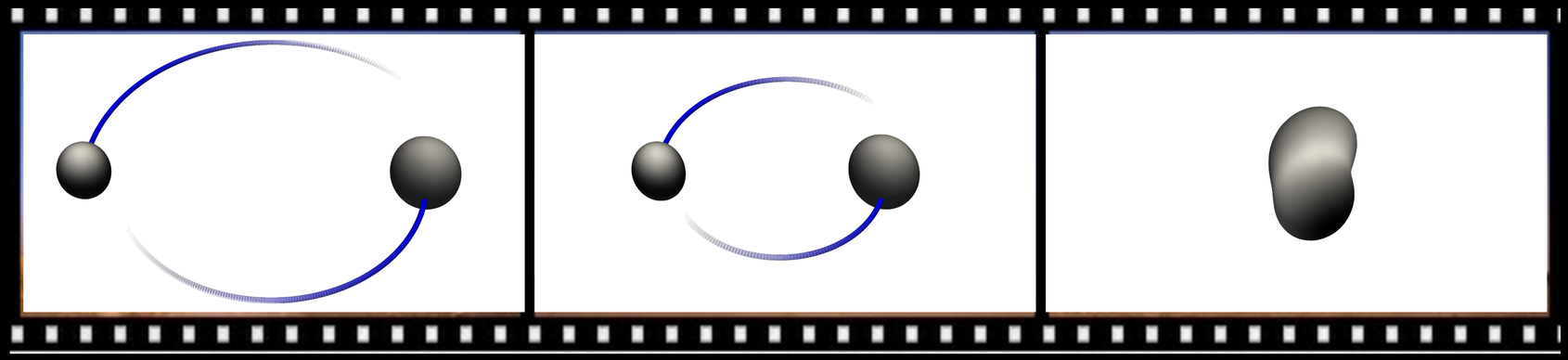
– Strategy

- 1. Solve Einstein's constraint equations for first frame
- 2. Solve Einstein's evolution equations for next frame
- 3. Go back to step 2

Example constraint:

magnetic field lines are loops with no ends



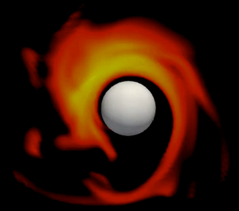


Images courtesy Kip Thorne

Clicker question #3.4

- Jennifer Sanchez (CSUF undergraduate) used numerical relativity to model a neutron star being torn apart by a black hole.

To make the data for this movie, the SpEC code solved…



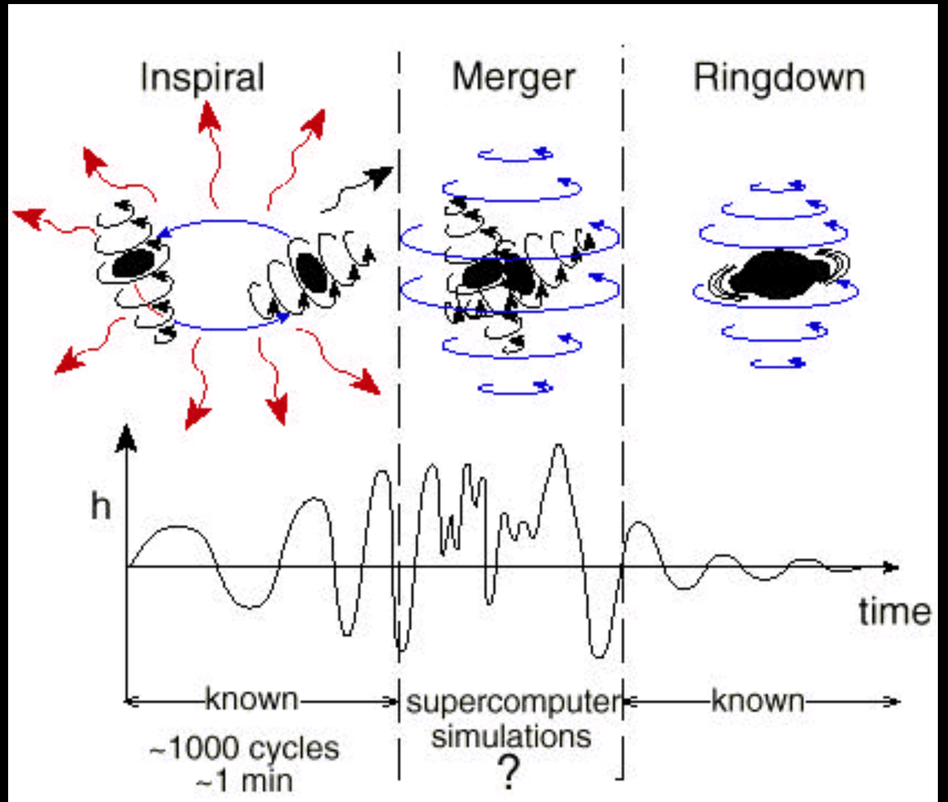
A — the Einstein evolution equations once

B — the Einstein evolution equations many times

C — the Einstein constraint equations many times

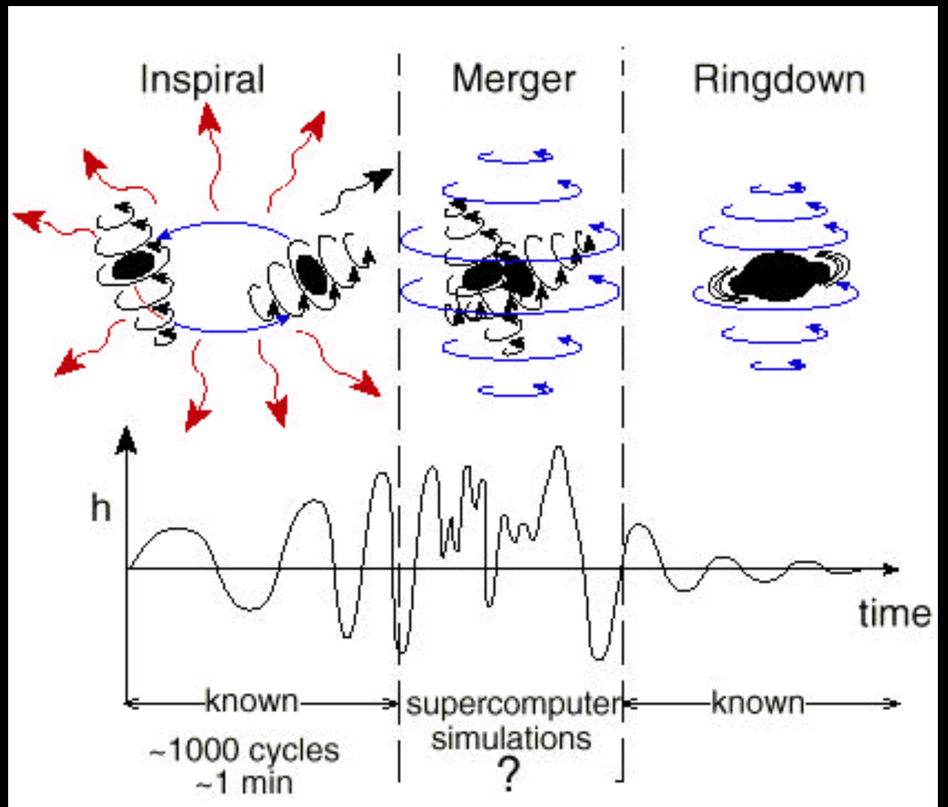
D — None of ABC

Time: 8365.000000



KS Thorne, "Spacetime warps and the quantum world: speculations about the future", in RH Price, ed, *The Future of Spacetime* (WW Norton, NY, 2002)

"I have bet these numerical relativists that gravitational waves will be detected from black-hole collisions before their computations are sophisticated enough to simulate them. I expect to win, but hope to lose, because the simulation results are crucial to interpreting the observed waves." —Kip Thorne



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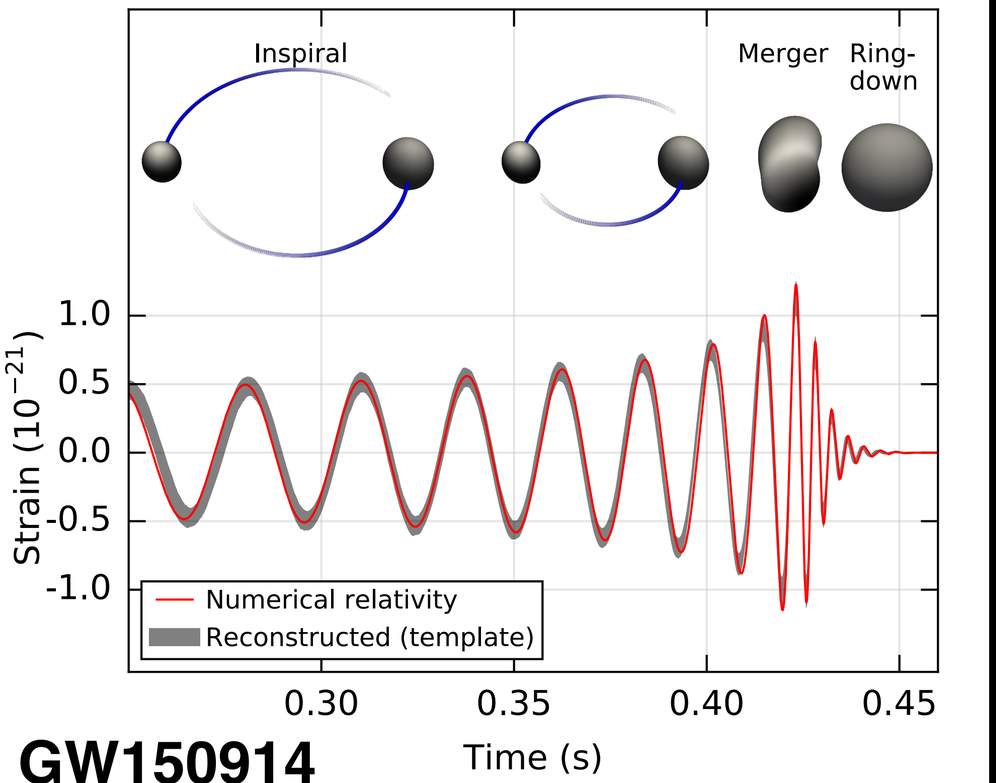
Abbott+, PRL **116**, 061102 (2016)



GW150914

Warped spacetime dynamics

Horizons shaded by their curvature
Orbits as black holes spiral together

Waveform prediction

Calibrate, validate analytic templates used in template reconstruction

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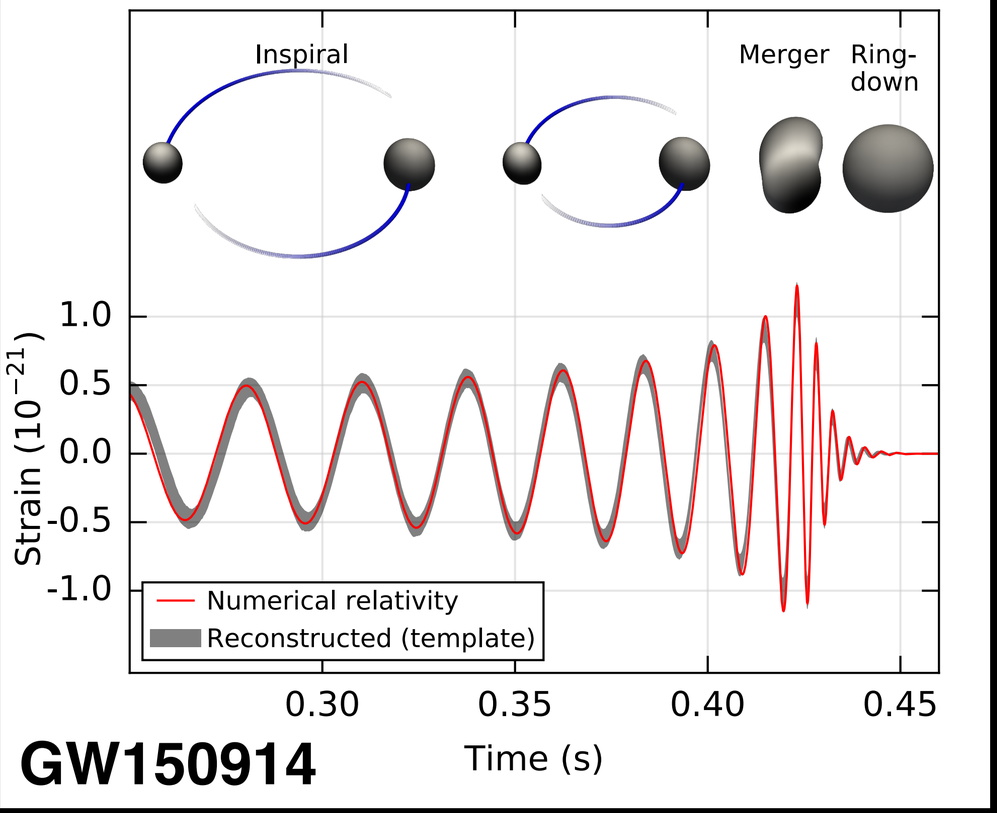
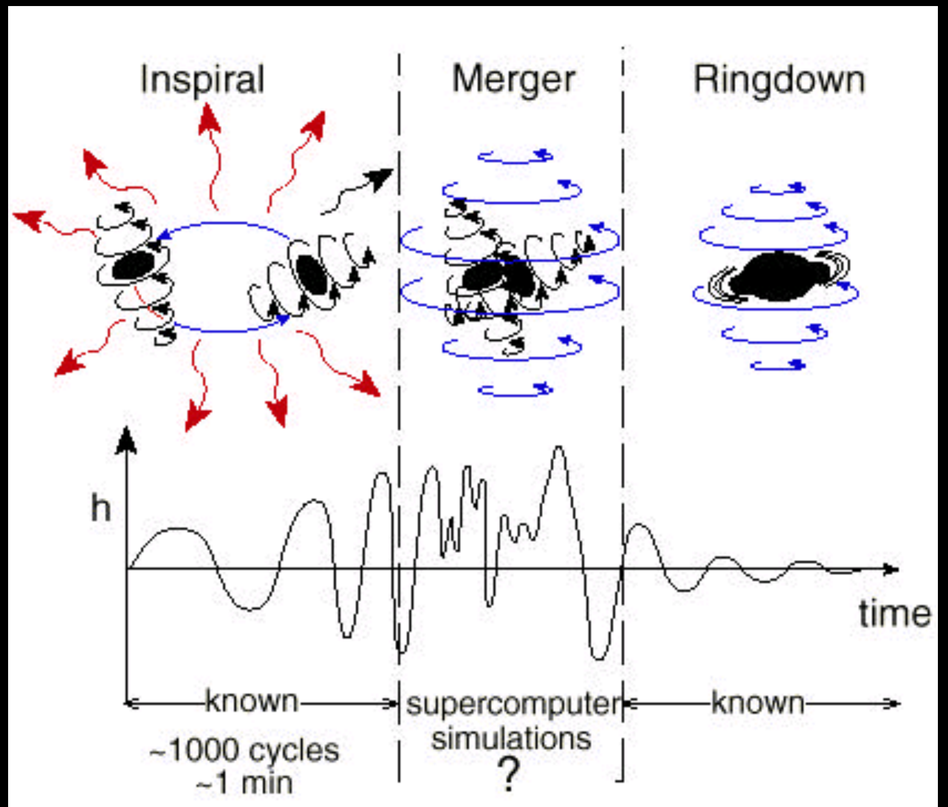


Fullerton's role

Students, GL: perform the supercomputer calculations

Solve Einstein's equations for merging black holes + gravitational waves
Create movies visualizing this computation

Josh Smith, Jocelyn Read, GL: design, create the figure



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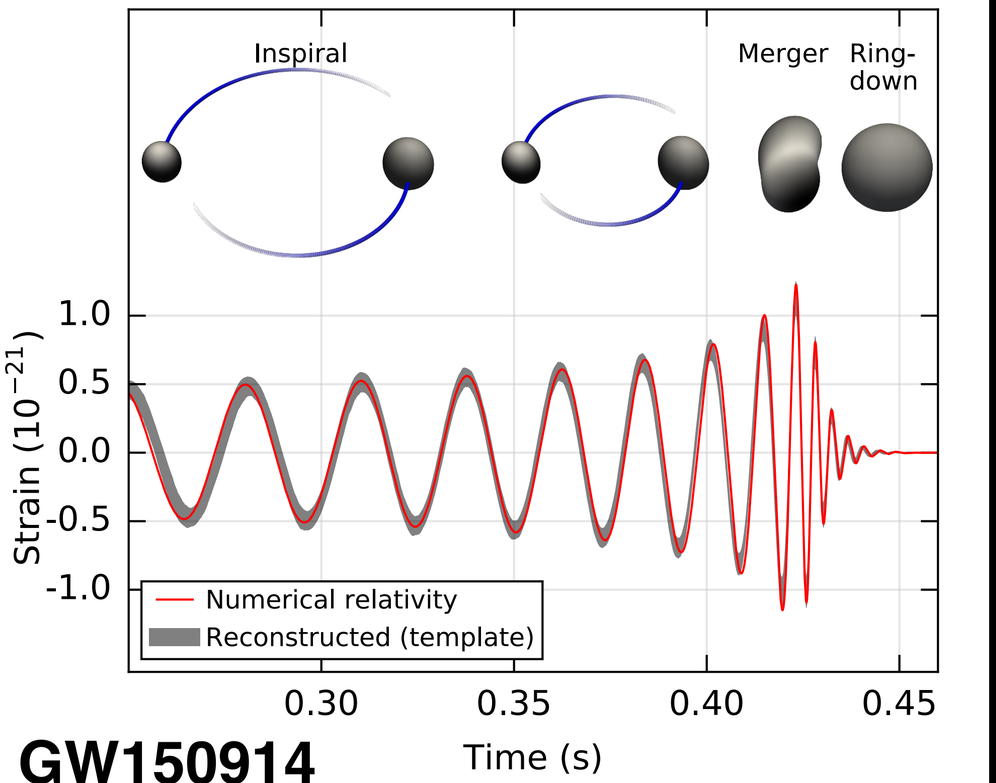

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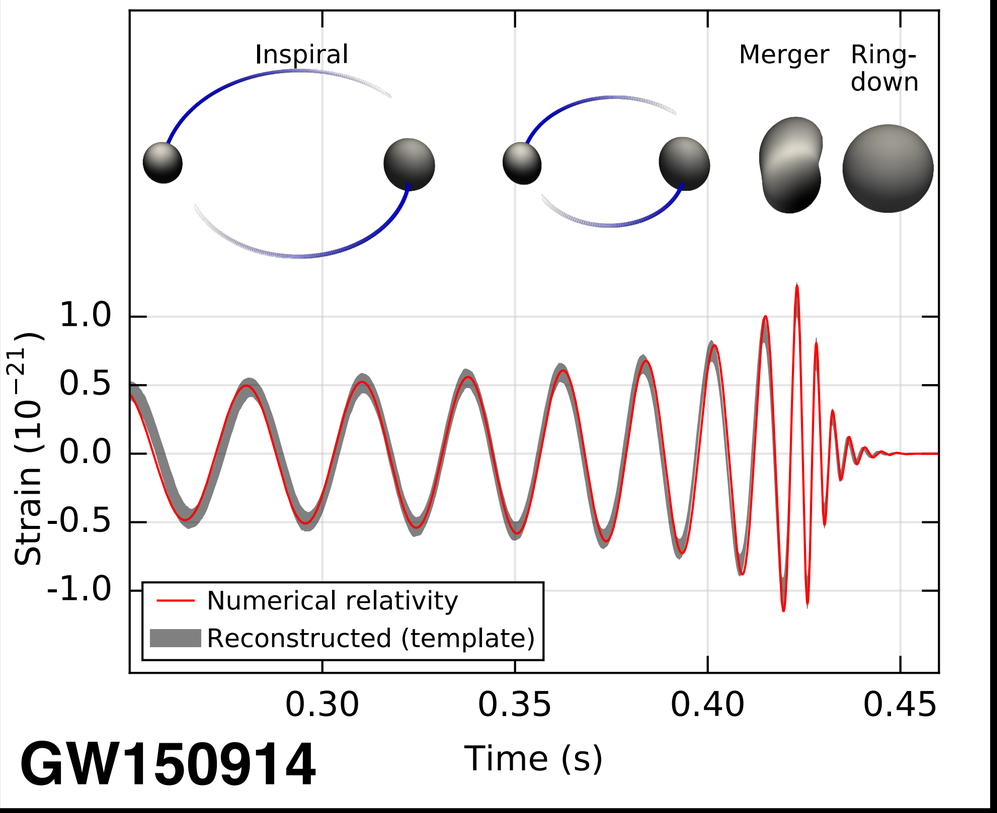

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Clicker question #3.7

- A gravitational-wave detector detects 4 waves. Each wave came from binary black holes that are identical except for how far away they are. Which wave's source was **closest** to the detector?

A

B

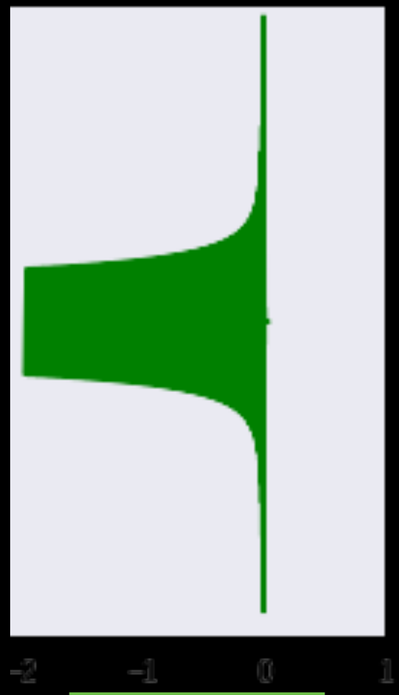
C

D

Clicker question #3.8

- A gravitational-wave detector detects 4 waves. Each wave came from binary black holes that are identical except for how far away they are. Which wave's source was **farthest** from the detector?

A



B

C

D

Simulations help LIGO observe more waves

- Compare LIGO observations to predictions of relativity
- Help LIGO observe more waves
  - We help LIGO know what the waves will “sound like”
  - Like hearing your name in a crowded room

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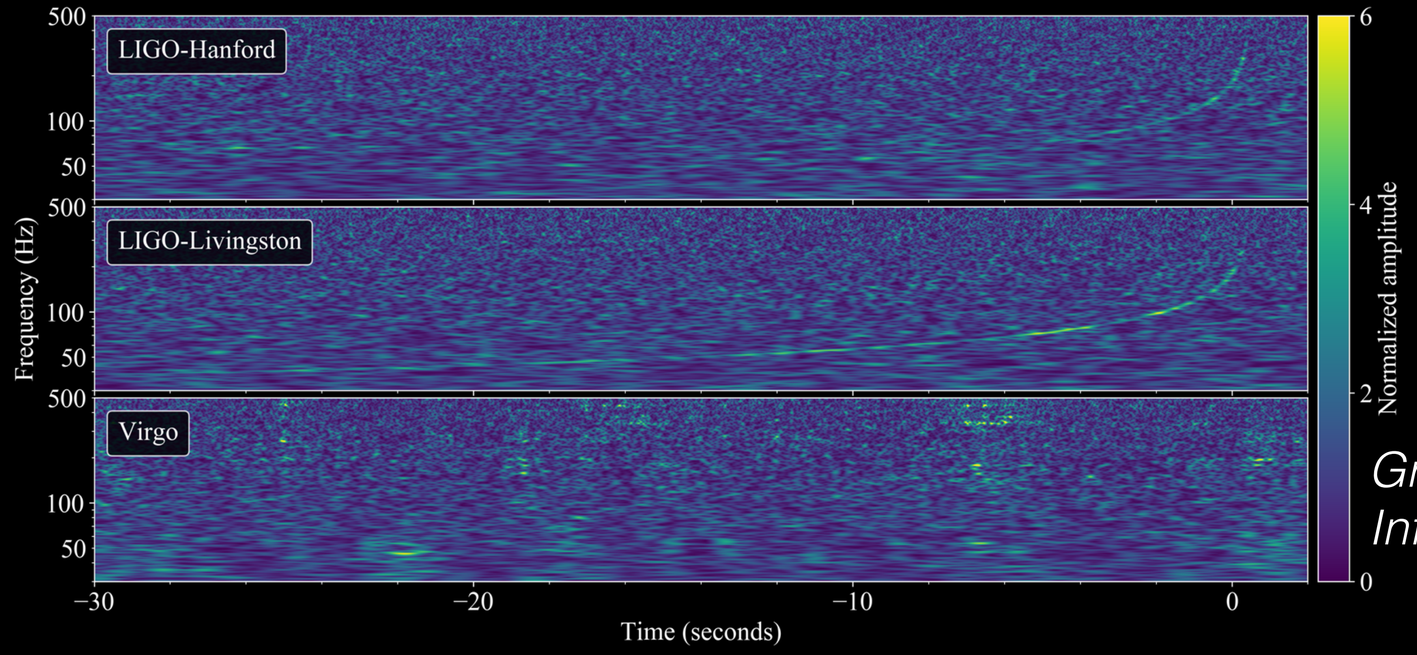
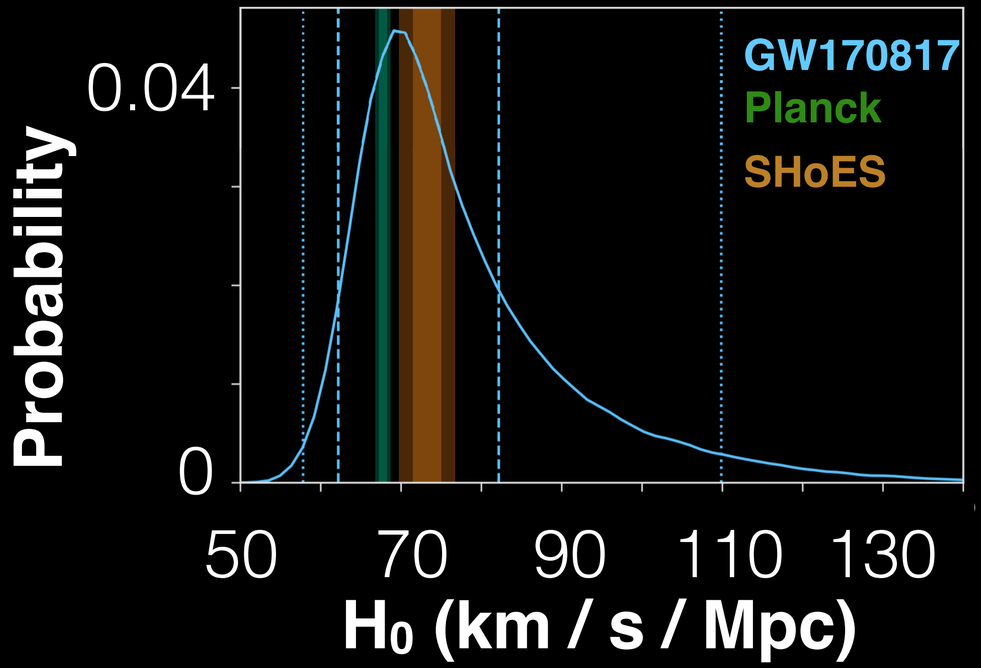
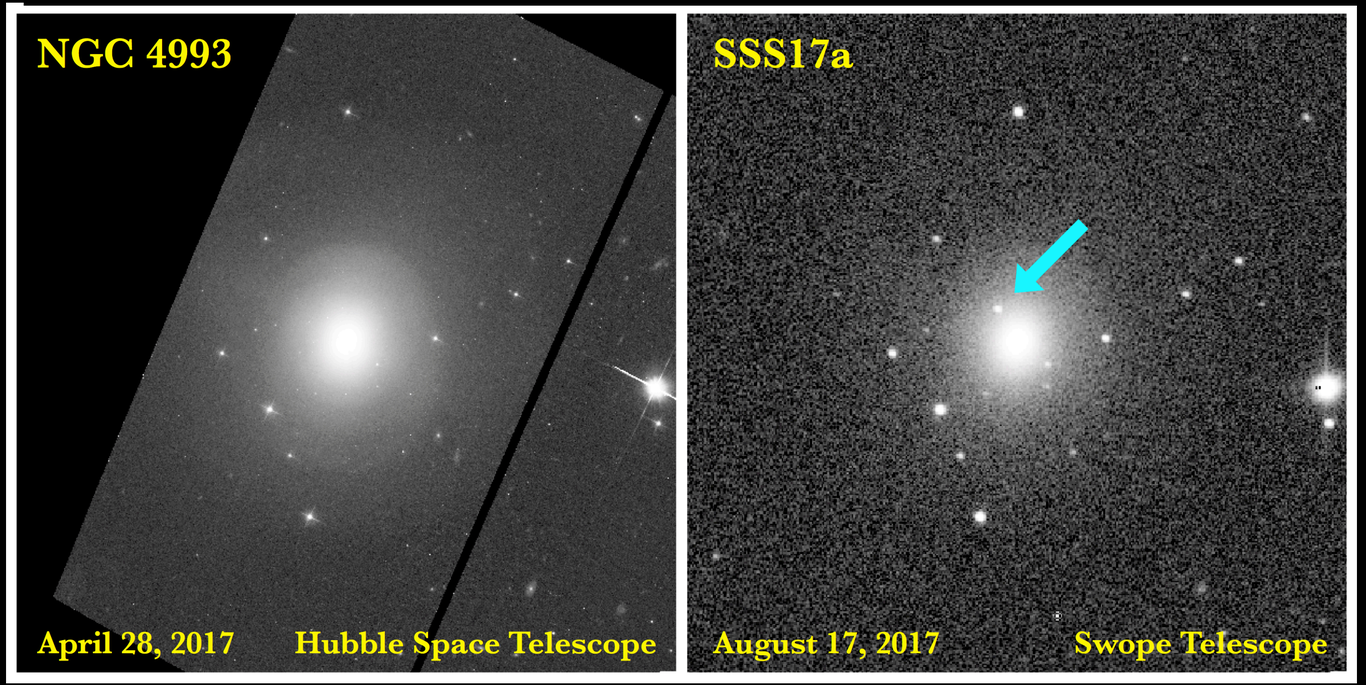


Numerical relativity: *model tidal deformability's effect on waveform, radiated energy*

Gravitational waves: Infer distance



LSC/VSC/DEC/GW-EM/DES, Nature (2017)



Host galaxy: Infer velocity

LSC/VSC/Fermi/INTEGRAL, ApJL (2017)