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Visualizing Binary Black Hole Simulations in the SXS Collaboration Catalog

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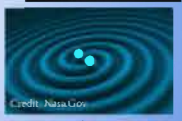
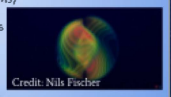
Introduction

- **Gravity** — warped spacetime
- **Black holes** — regions of warped spacetime where gravity is so strong that nothing can escape from inside the surface (horizon)
- **Binary black holes** — two black holes that orbit each other, emitting gravitational waves
- **Gravitational waves** — ripples of warped spacetime that travel at the speed of light
  - **A new way to observe the universe** since Laser Interferometer Gravitational-wave Observatory (LIGO)'s first detection of gravitational waves in 2015
- **Visualizing simulated binary black holes** — share excitement of discoveries with the public, refine scientists' intuition



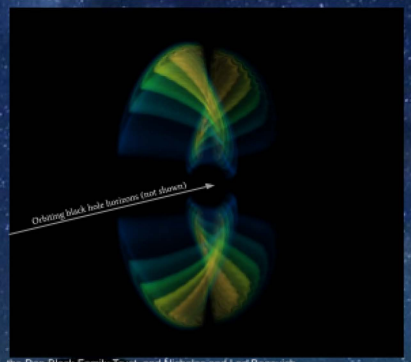
Methods

- **Simulate merging black holes** — solve Einstein's equations of relativity on supercomputers
- **Simulating eXtreme Spacetimes (SXS) Catalog** — catalog of simulated merging black holes. Includes gravitational-wave strength at different points in space and time.
- **Spectral Einstein Code (SpEC)** — created simulations in SXS Catalog, black-holes.org/waveforms)
- **ParaView** — open source software used for making 3D visualizations of scientific data/simulations
- **GWPV** — open-source python script by Nils Fischer
  - Uses paraview to visualize simulated gravitational waves from SXS catalog
  - Fetch and interpolate gravitational-wave data, uses color and opacity to show the wave strength as a function of position and time



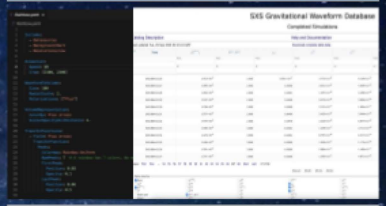
Abstract

Gravitational Waves provide us with an new way of observing our universe and are changing the ways we observe the universe. Creating visualizations of these gravitational waves is important for not only creating excitement and knowledge for the public, but as well as assist scientists on polishing their knowledge and intuition on what these simulations mean. In my work for the summer, I created visualizations of merging black holes from the Simulating eXtreme Spacetimes (SXS) Catalog using an open source python code gwpv.



Methods II

- **Configure GWPV by editing yaml files**
- **Choose simulation to visualize, options controlling e.g. what times render as frames, how many frames total, resolution, colors, etc**
- **Make images** — run paraview python script in a docker container
  - **Docker** — program that uses containers to set up known environments, to run things (like GWPV) without having to install a bunch of stuff
- **FFmpeg** — Combine images into movie
- **ezgif.com** — Convert movie into gif



Conclusion & future work

- First at Cal State Fullerton to use GWPV to visualize gravitational waves
- Documentation of how to use the tool, filling in specific details not outlined in GWPV docs could be found at https://github.com/anthonyarata/GWPV/instructions
- **Future work** — render a full movie, render different binary-black-hole simulations, multiple binaries in one movie

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References:
[1] M. Boyle et al. "The SXS Collaboration of binary black hole simulations." Class. Quantum Grav. **36**, 195006 (2019). https://doi.org/10.1088/1361-6382/ab34e2
[2] gwpv. Nilsleiffischer. "Nilsleiffischer/Gwpv: Visualize Gravitational Wave Data With Paraview." *GitHub*, github.com/nilsleiffischer/gwpv
[3]"Animated Gif Editor and GIF MAKER." *Online Animated GIF Tools*, ezgif.com/.

My task this summer was to create visualizations of merging binary black holes from the Simulating eXtreme Spacetimes (SXS) collaboration website using python.

Alternate Text:

Anthony Arata

Quote: "My task this summer was to create visualizations of merging binary black holes from the Simulating eXtreme Spacetimes (SXS) collaboration website using python."

Image of Anthony Arata

Image of text and graphic laden project presentation entitled "Visualizing Binary Black Hole Simulations in the SXS Collaboration Catalog. Anthony Arata, Dr. Geoffrey Lovelace"