

The SpECTRE CCE Module

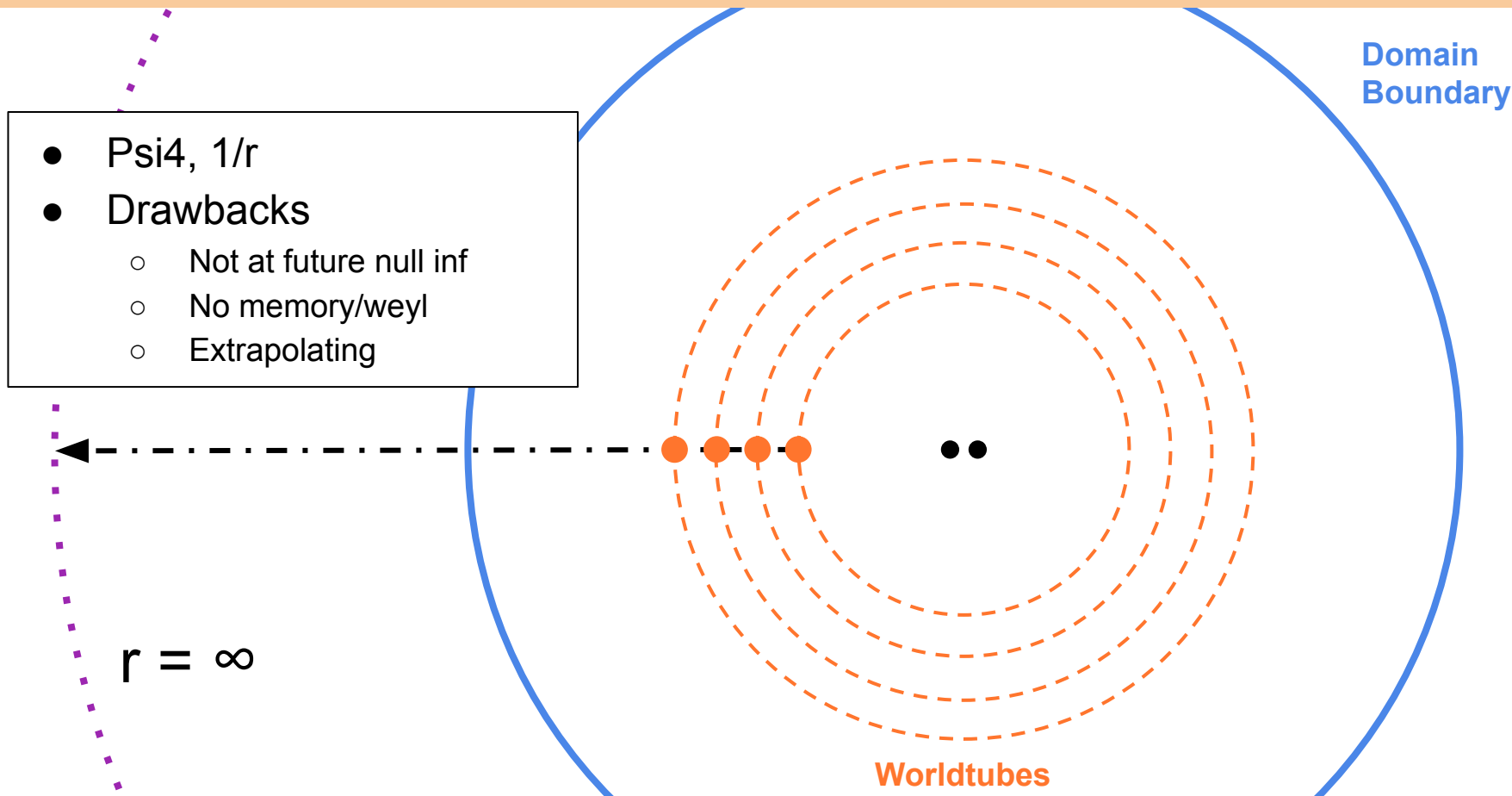


SIMULATING EXTREME SPACETIMES

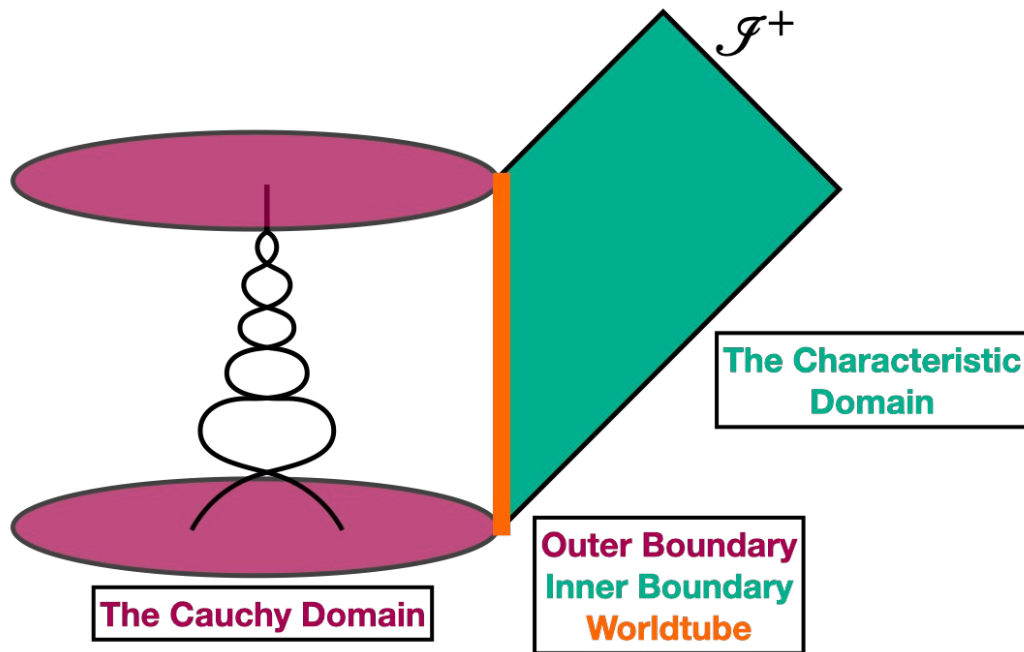
Black holes, neutron stars, and beyond...

Kyle Nelli and so many others

Extrapolation



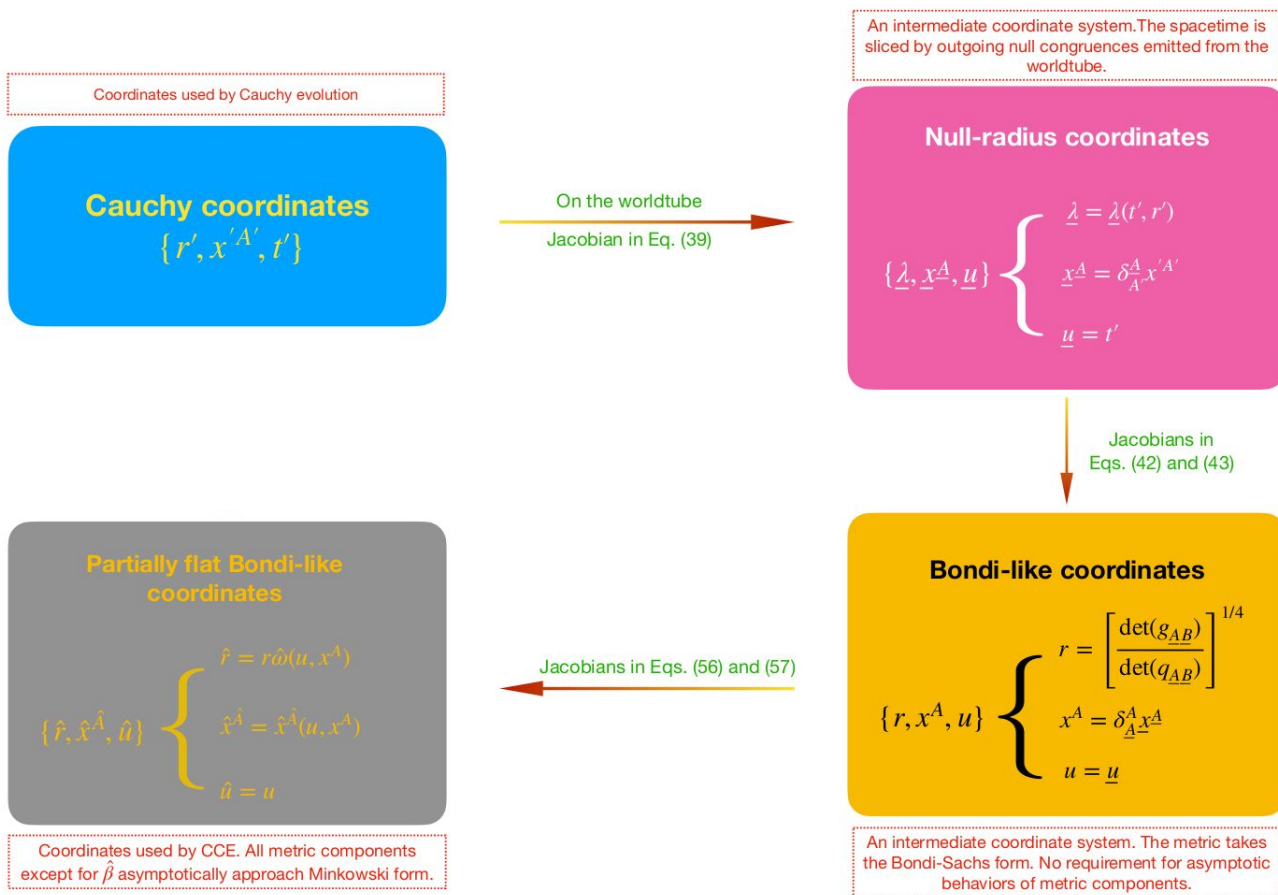
Cauchy-Characteristic Evolution





$$ds^2 = - \left(e^{2\beta} \frac{V}{r} - r^2 h_{AB} U^A U^B \right) du^2 - 2e^{2\beta} dudr \\ - 2r^2 h_{AB} U^B dudx^A + r^2 h_{AB} dx^A dx^B.$$

CCE Coordinates



$$\partial_{\check{y}} \check{\beta} = S_{\check{\beta}}(\check{J}),$$

$$\partial_{\check{y}} ((1 - \check{y})^2 \check{Q}) = S_{\check{Q}}(\check{J}, \check{\beta}),$$

$$\partial_{\check{y}} \check{U} = S_{\check{U}}(\check{J}, \check{\beta}, \check{Q}),$$

$$\partial_{\check{y}} ((1 - \check{y})^2 \check{W}) = S_{\check{W}}(\check{J}, \check{\beta}, \check{Q}, \check{U}),$$

$$\begin{aligned} & [\partial_{\check{y}} ((1 - \check{y}) \check{H}) + L_{\check{H}}(\check{J}, \check{\beta}, \check{Q}, \check{U}, \check{W}) \check{H} \\ & + L_{\check{\check{H}}}(\check{J}, \check{\beta}, \check{Q}, \check{U}, \check{W}) \check{\check{H}}] \\ & = S_{\check{H}}(\check{J}, \check{\beta}, \check{Q}, \check{U}, \check{W}), \end{aligned}$$

$$\partial_{\check{u}} \check{J} = \check{H}.$$

Compactified radial coordinate

“Time” derivative

What does CCE give you?



h , News, Ψ_0 , Ψ_1 , Ψ_2 , Ψ_3 , Ψ_4

- In atmosphere



- Self-gravitation

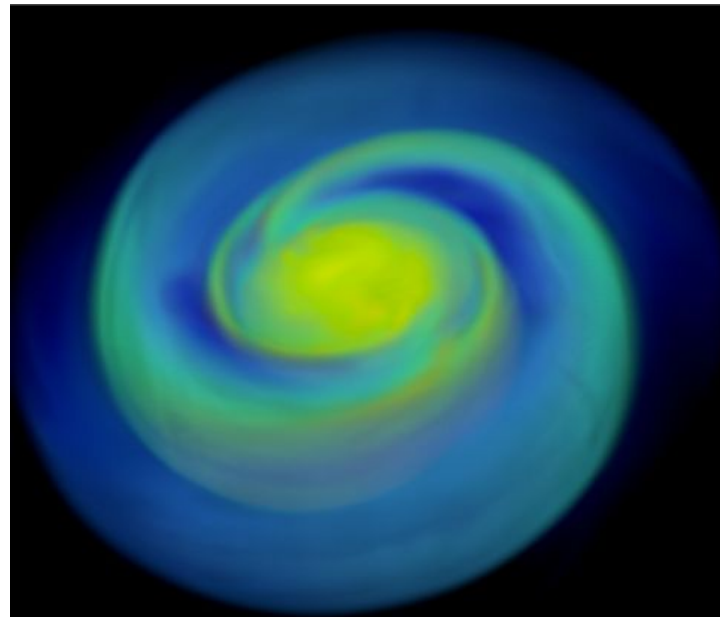


Image credit: Francois Foucart



All info available in CCE tutorial: https://spectre-code.org/tutorial_cce.html

SpECTRE v2024.05.11

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Introduction

license MIT C++ 17 Tests failing codecov 96%

What is SpECTRE?

SpECTRE is an open-source code for multi-scale, multi-physics problems in astrophysics and gravitational physics. In the future, we hope that it can be applied to problems across discipline boundaries in fluid dynamics, geoscience, plasma physics, nuclear physics, and engineering. It runs at petascale and is designed for future exascale computers.

Developed in support of our collaborative Simulating eXtreme Spacetimes (SXS) research

messenger astrophysics of neutron star mergers, core-collapse supernovae, and gamma-ray bursts.

Citing SpECTRE

Please cite SpECTRE in any publications that make use of its code or data. Cite the latest version that you use in your publication. The DOI for this version is:

- DOI: [10.5281/zenodo.11180072](https://doi.org/10.5281/zenodo.11180072)

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Obtaining the CCE module



- From source?



Required:

- [GCC](#) 9.1 or later, [Clang](#) 13.0 or later (see [here](#) for how to get newer versions of clang through apt), or AppleClang 13.0.0 or later
 - [CMake](#) 3.18.0 or later
 - [Charm++](#) 7.0.0, or later (experimental) [\[96\]](#) [\[97\]](#) [\[95\]](#)
 - [Git](#)
 - BLAS (e.g. [OpenBLAS](#))
 - [Blaze](#) v3.8. It can be beneficial to install Blaze with CMake so some configuration options are determined automatically, such as cache sizes. [\[92\]](#) [\[91\]](#)
 - [Boost](#) 1.60.0 or later
 - [Catch2](#) 3.4.0 or later. Install from your package manager or do a standard CMake build and installation (as detailed in the [Catch2 docs](#)). Compile with `CMAKE_POSITION_INDEPENDENT_CODE=ON`.
 - [GSL](#) [\[71\]](#)
 - [HDF5](#) (non-mpi version on macOS) [\[179\]](#)
 - [jemalloc](#)
 - LAPACK
 - [LIBXSMM](#) version 1.16.1 or later [\[86\]](#)
 - [yaml-cpp](#) version 0.6.3 or later. Building with shared library support is also recommended. [\[18\]](#)
 - [Python](#) 3.8 or later.
 - Python dependencies listed in `support/Python/requirements.txt`. Install with `pip3 install -r support/Python/requirements.txt`. Make sure you are working in a [Python venv](#) before installing packages. Alternatively, you can set `BOOTSTRAP_PY_DEPS=ON` when configuring a build with CMake to install missing Python packages into the build directory automatically.
- Details

Obtaining the CCE module



spectre Public

v2024.06.05 2 Branches 45 Tags

Go to file

Code

About

SpECTRE is a code for multi-scale, multi-physics problems in astrophysics and gravitational physics.

spectre-code.org

Readme

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Activity

Custom properties

148 stars

16 watching

184 forks

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Releases 45

Release 2024.06.05 Latest

6 hours ago

+ 44 releases

Release 2024.06.05 Latest

sxs-bot released this 6 hours ago · 0 commits to 6219c51f2eb4b7b2ec5a

Upgrade instructions

From [#5978](#) (Add CLI to plot basic control system quantities):

To use, build the CLI then run

Contributors

nilsvu, geoffrey4444, and 10 other contributors

Assets 3

CceExecutables.tar.xz

Source code (zip)

Source code (tar.gz)



```
knelli@quigon:~/CceExecutables$ ls
BondiSachsCceR0200.h5
CharacteristicExtract
CharacteristicExtractReduction_Expected.h5
CharacteristicExtract.yaml
CheckCceOutput.py
ReduceCceWorldtube
```



- Natively
 - Expanse
 - Anvil
 - Stampede3
 - Delta (must set LD_LIBRARY_PATH first)
 - Perlmutter
 - Ubuntu 18.04 LTS or later (LTS version only)
- Through the `sxscollaboration/spectre:dev` container
 - All of the above
 - Frontera
 - Delta

How to run CCE



```
apptainer exec spectre_dev.sif \
```

```
./CharacteristicExtract --input-file CharacteristicExtract.yaml
```

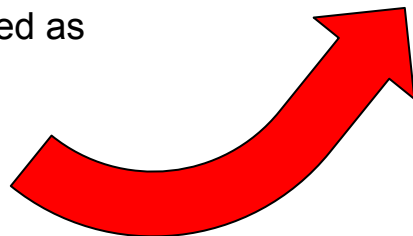


Cartesian Metric

- Components
 - Spatial metric
 - Lapse
 - Shift
 - Time and radial derivs
- Cartesian components represented as spherical harmonic coefs
- Less space efficient
- Deborah!

Bondi-Sachs

- Components
 - Bondi “alphabet soup” (H, J, Q, R, U, W...)
- Spherical harmonics
- More space efficient (4x)

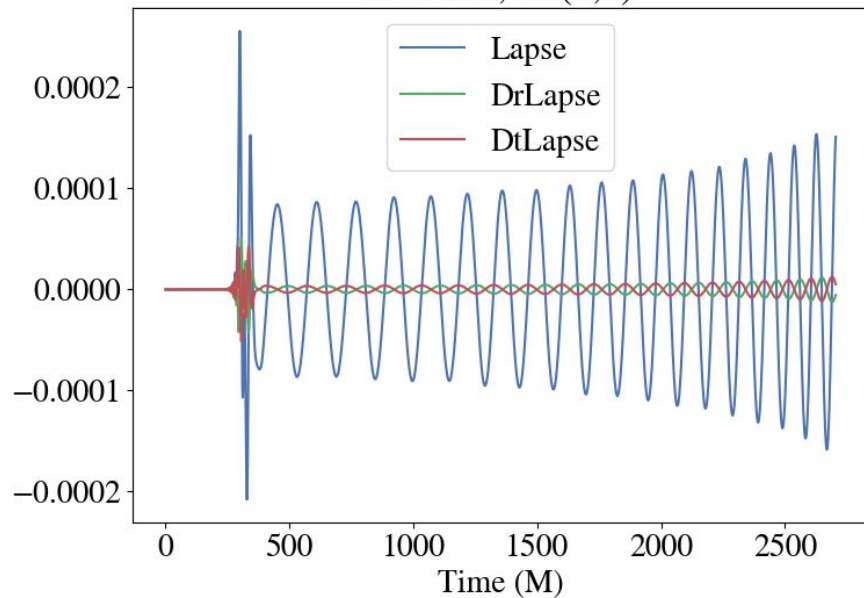


ReduceCceWorldtube

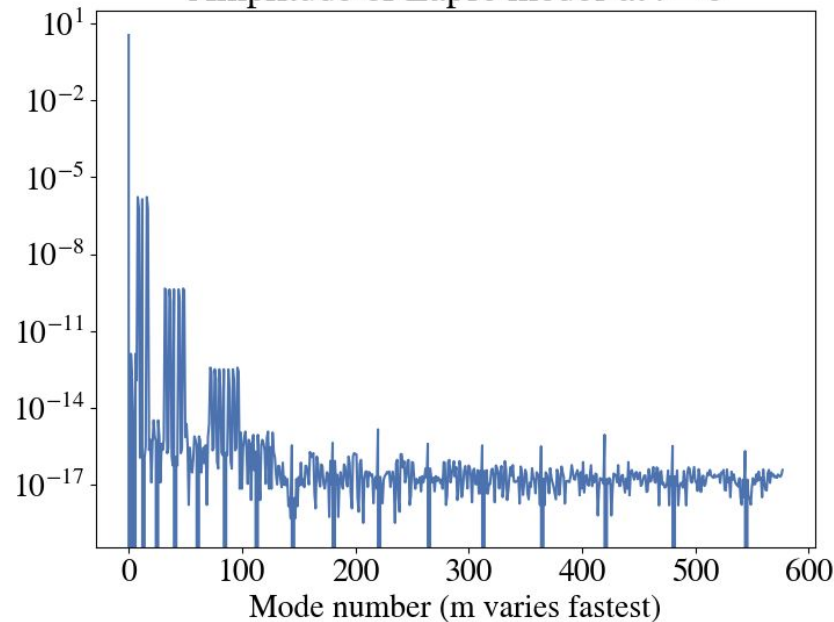
Example Worldtube Data: Lapse



$R = 292, \text{Im}(2,2)$



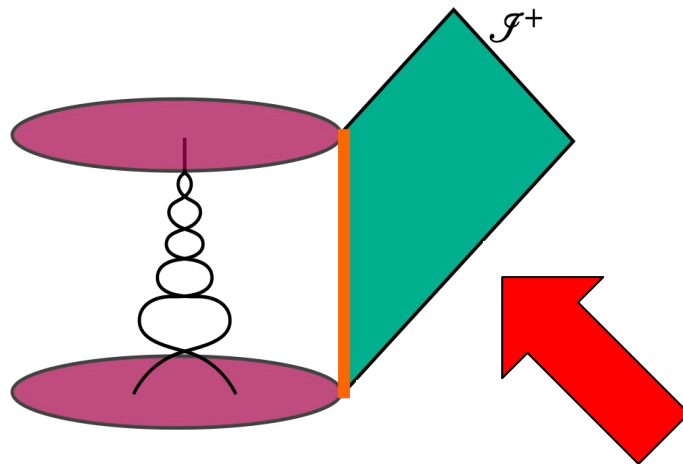
Amplitude of Lapse modes at $t = 0$



Initial Data on Null surface

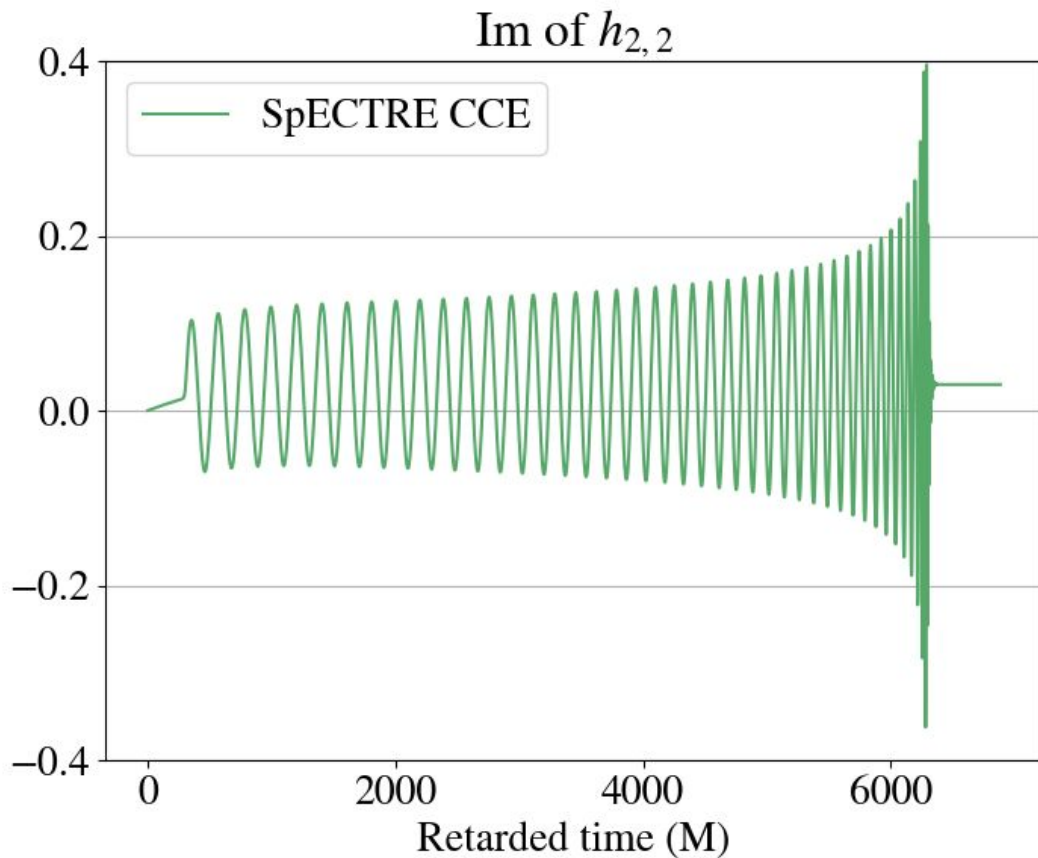


- Bondi J only
- Active area of research
- Several types
 - Conformal J
 - Inverse cubic
- CCE Junk

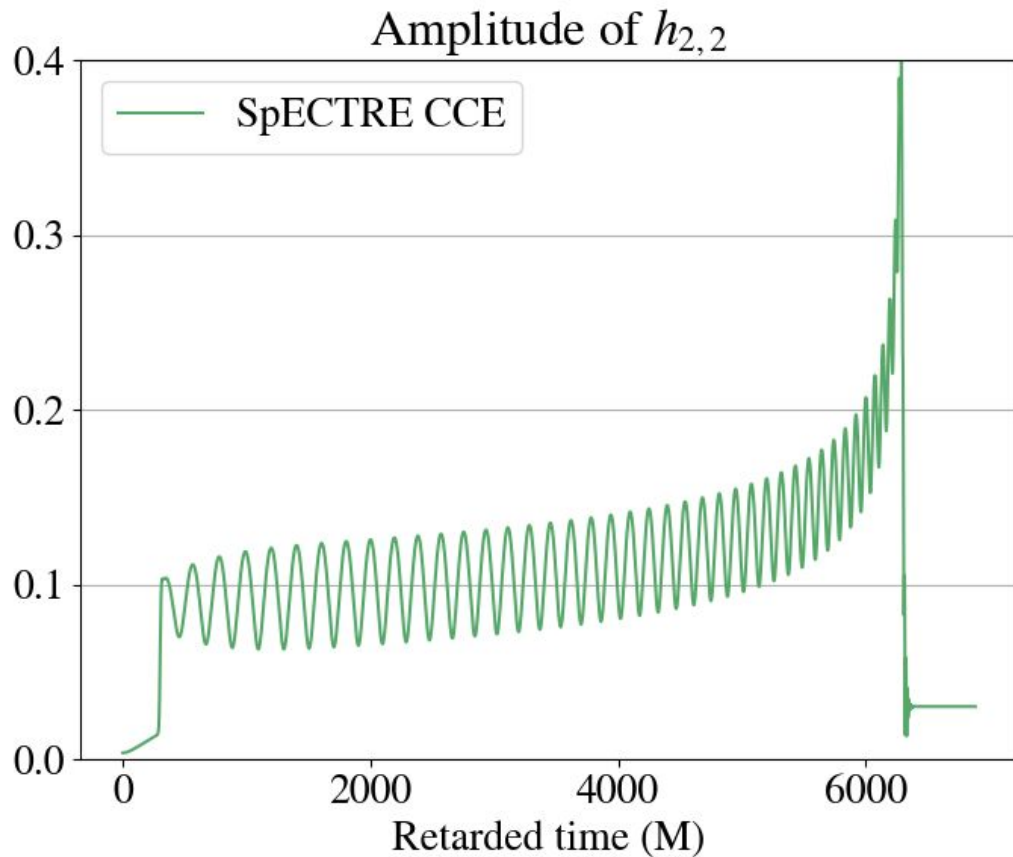


$$\partial_{\check{u}} \check{J} = \check{H}.$$

Raw CCE output



Raw CCE output

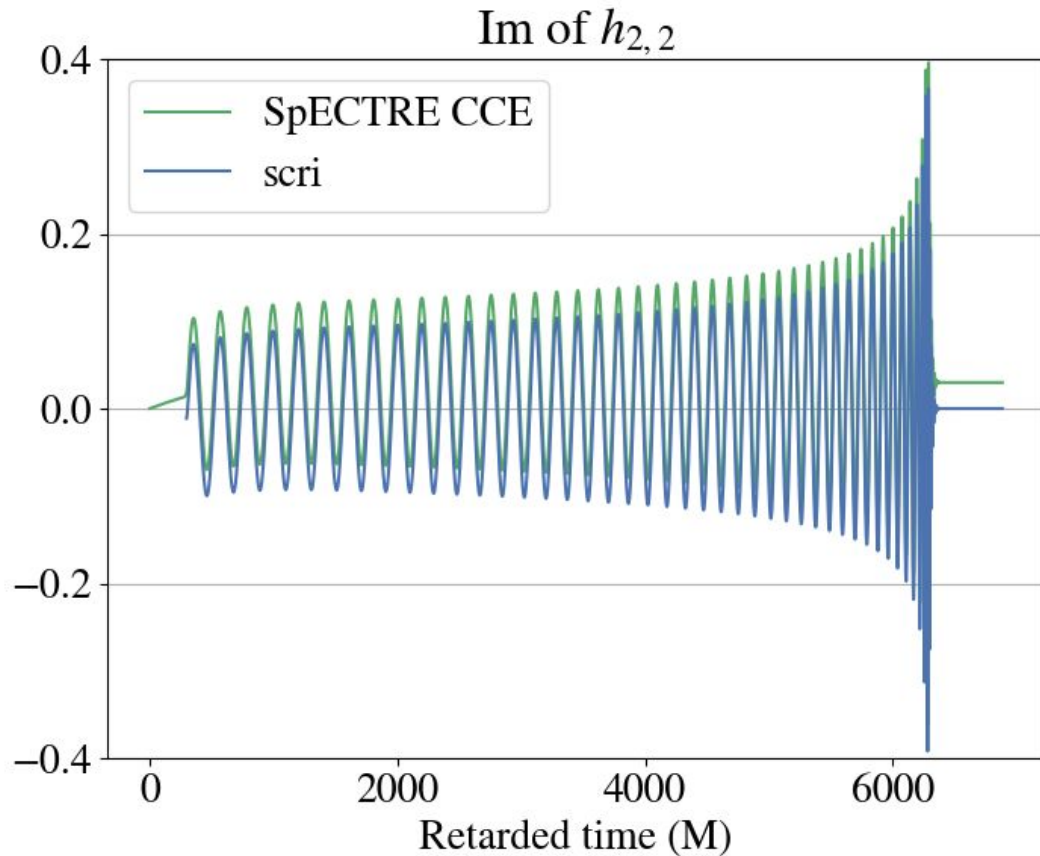


What is Frame Fixing?

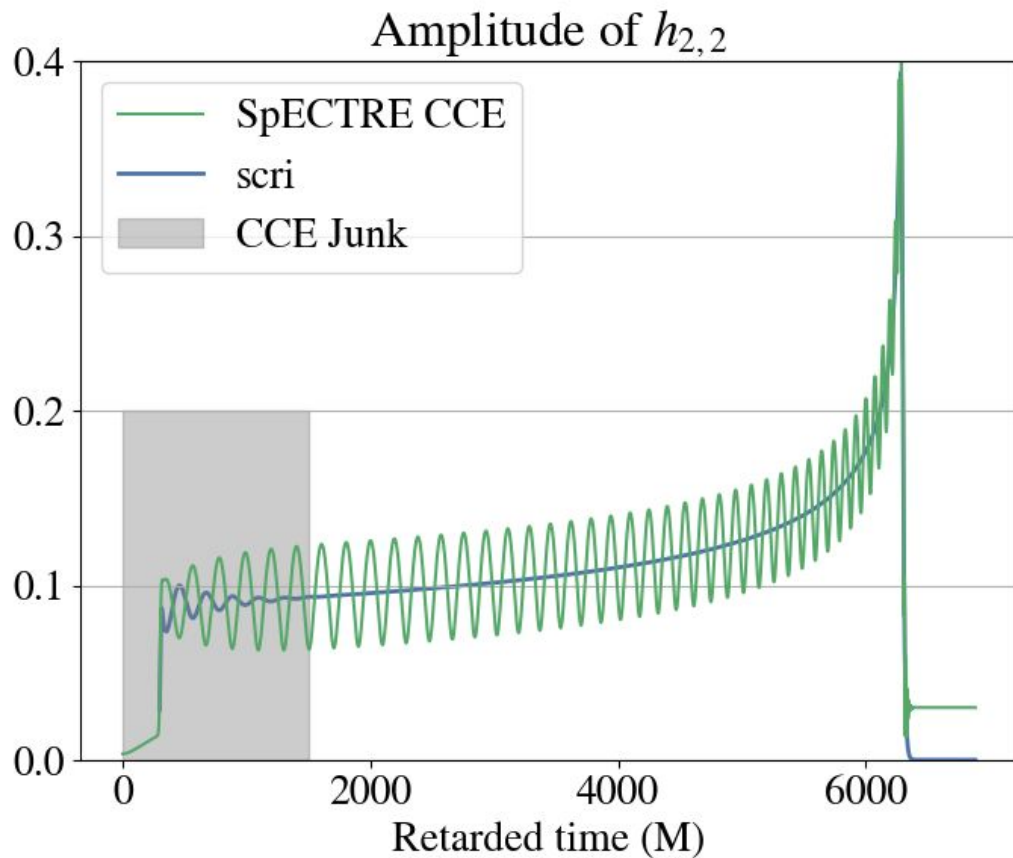


- Covariant = No preferred frame
- BMS group/symmetries
- “Superrest frame”
 - Supertranslation
 - Rotation
 - Boost
- Necessary for ALL analyses
 - QNMs
 - Comparing waveforms
 - Convergence tests
- <https://github.com/moble/scri>

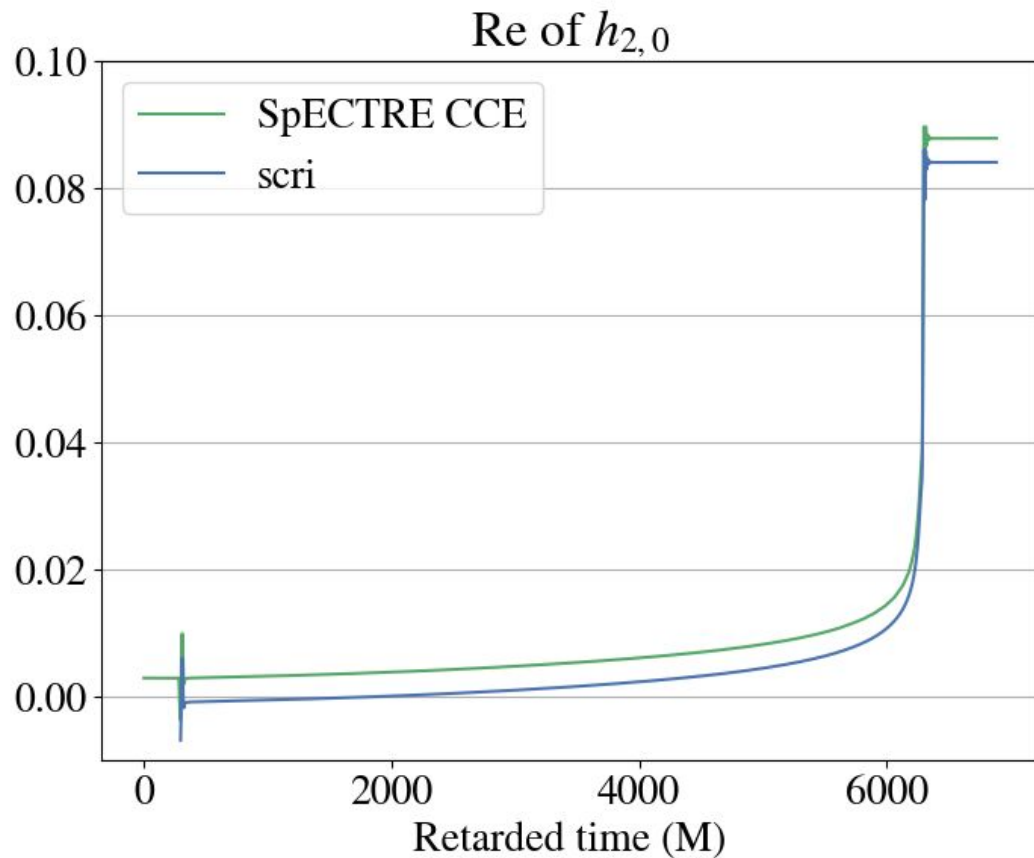
Frame-fixed output



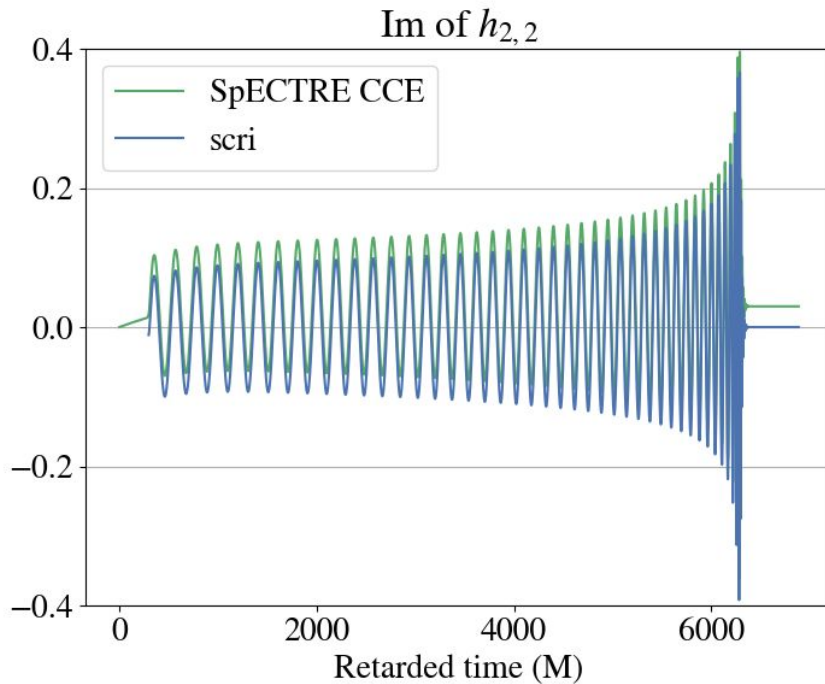
Frame-fixed output



Gravitational Memory!



Summary



Up next: Deborah Ferguson!

