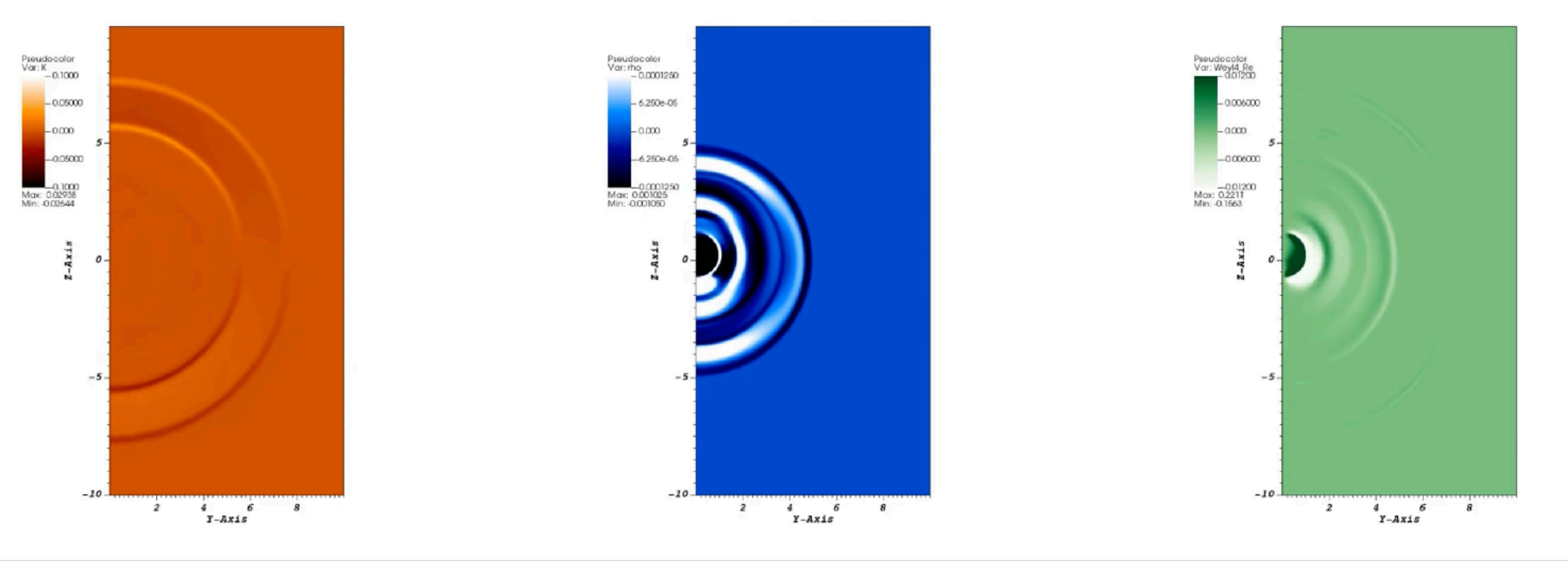
What no one has seen before: gravitational waveforms from warp drive collapse

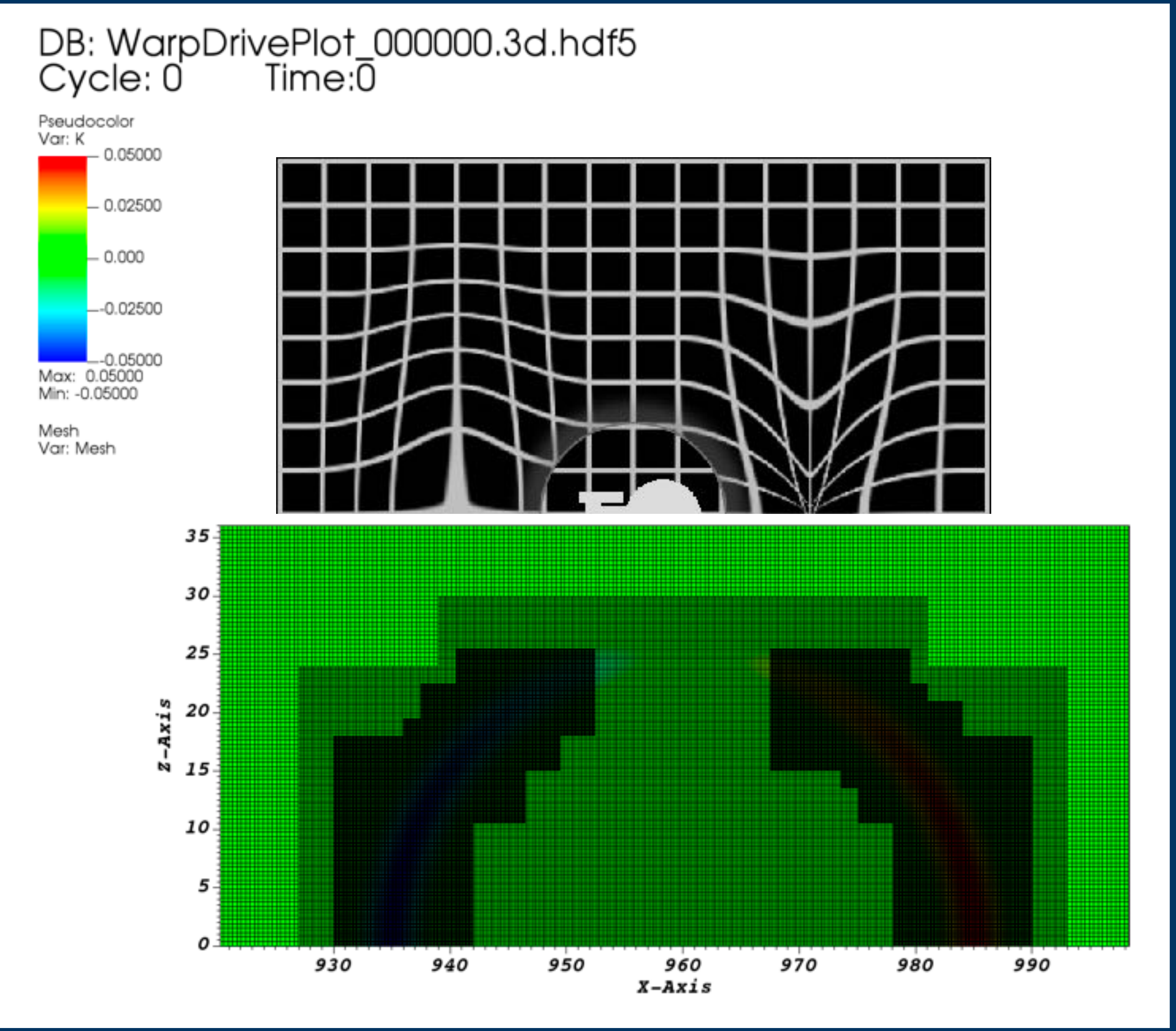
Katy Clough



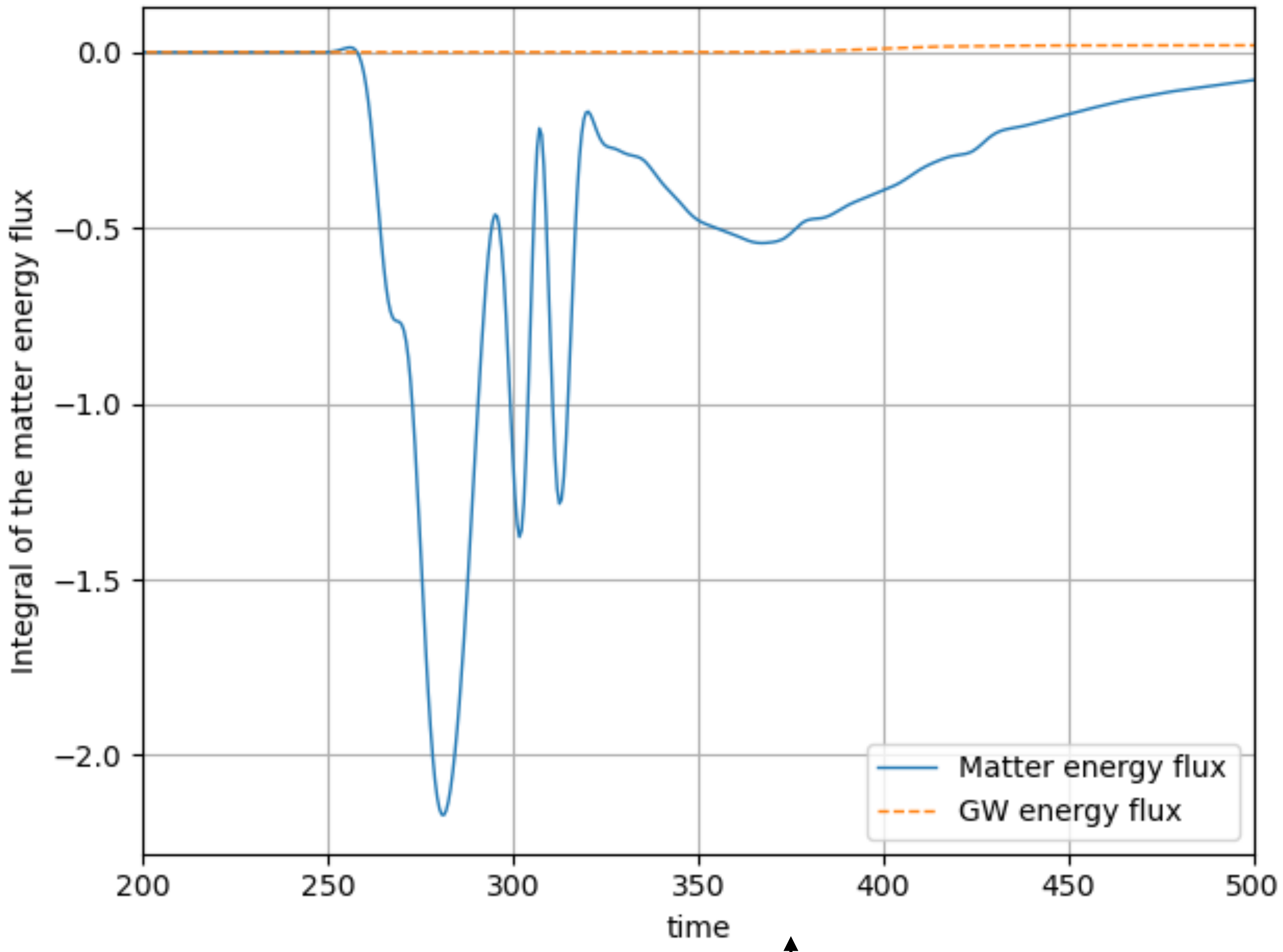
Last time on ETK, the next generation…

Adaptive mesh refinement (and warp drives)

Katy Clough



Some rather dodgy looking plots followed…



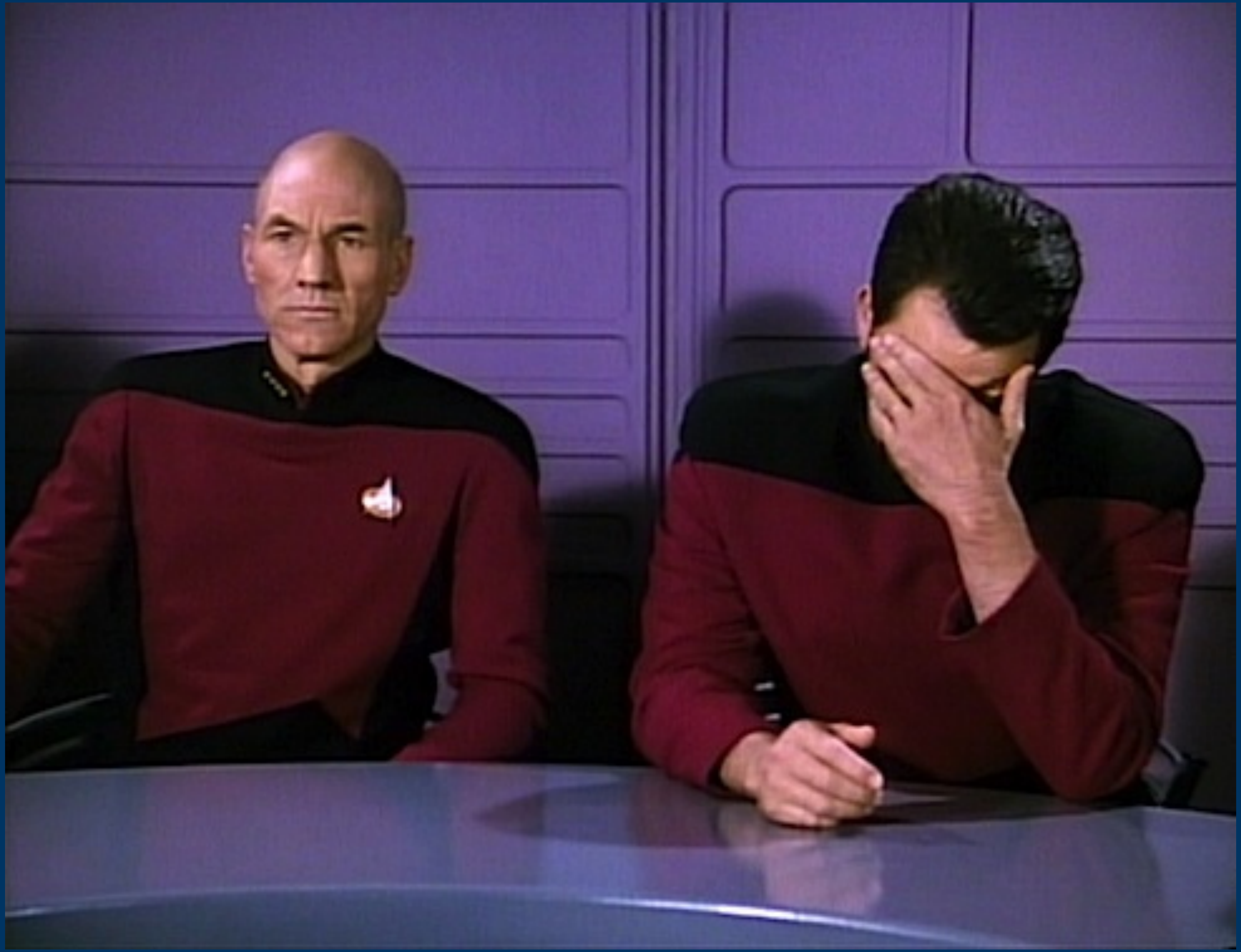
Total matter flux of energy of order -0.07M

Start of GW flux

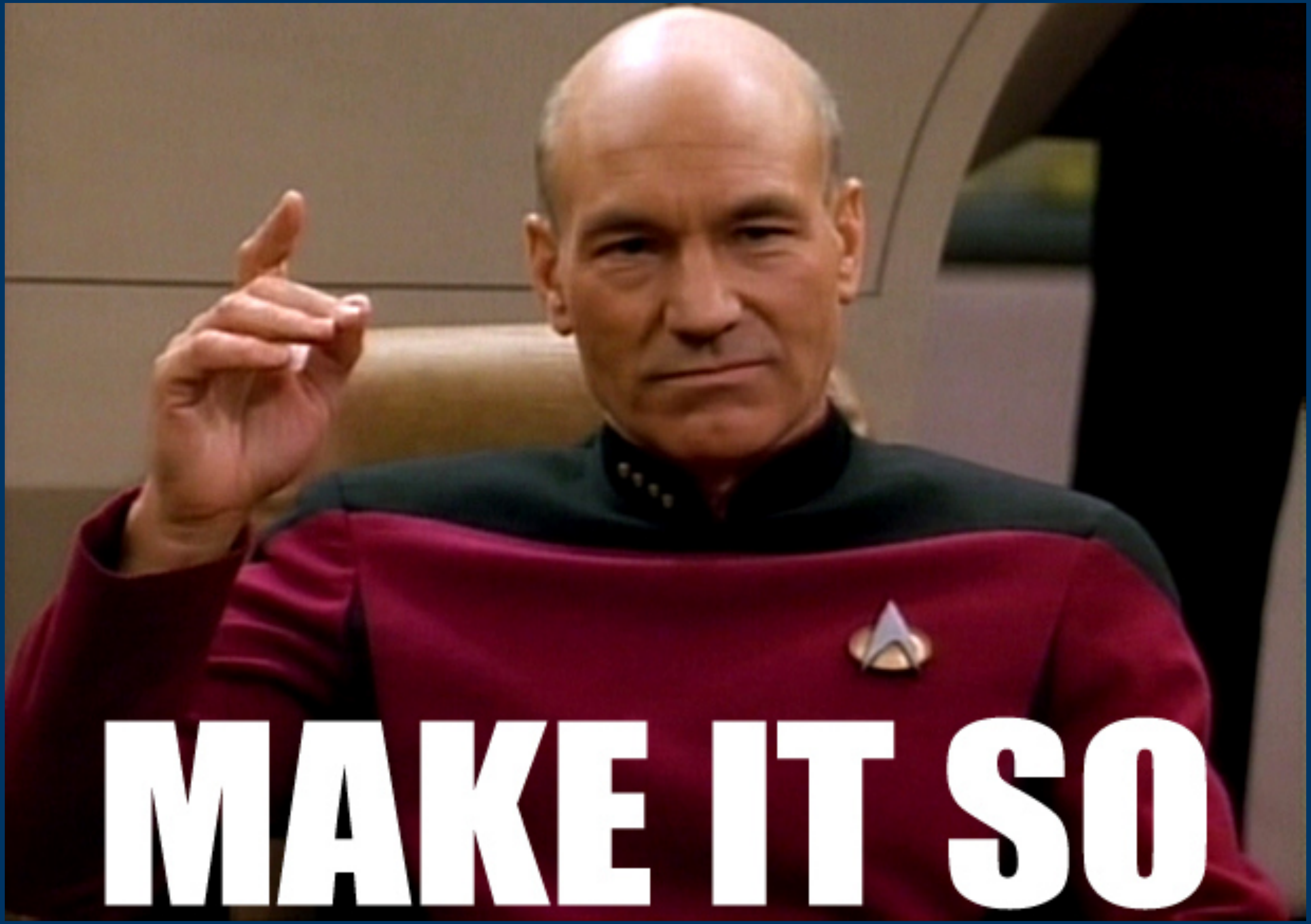
Conclusion:

Still many questions…
Not sure it is actually working…
Does this even make sense?

Other conferences were like…

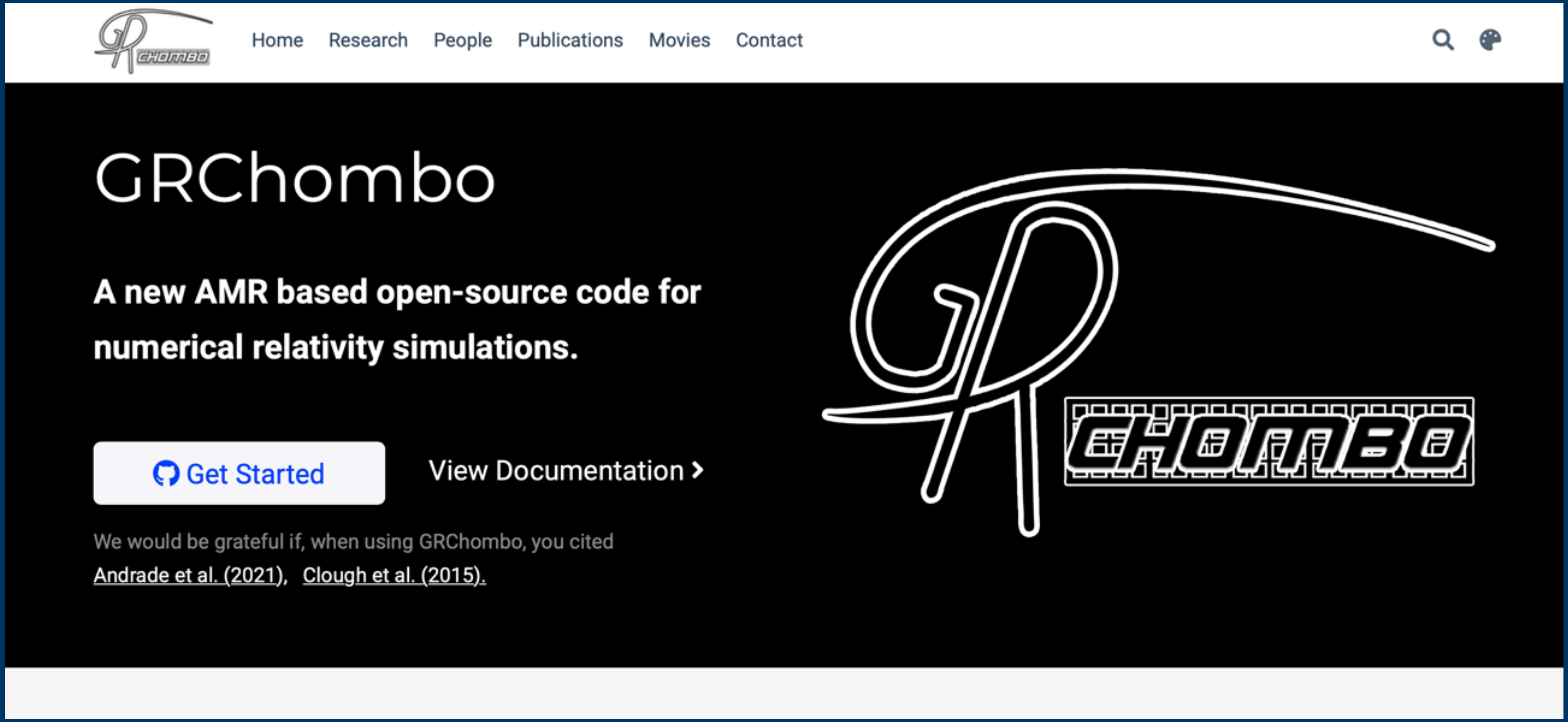


ETK were like…



And now the conclusion…

About me: a friend of ETK



I do have some more serious projects:

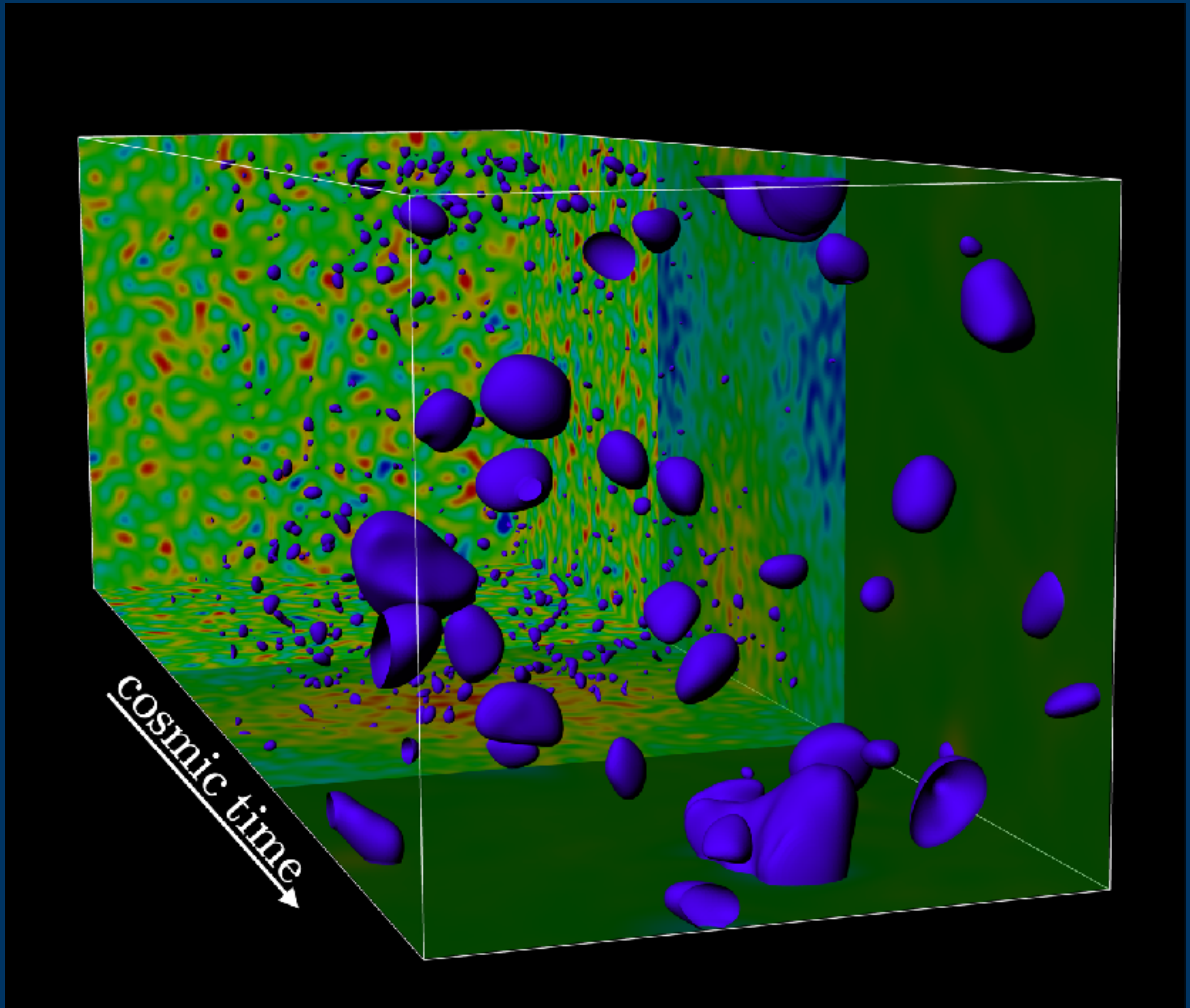
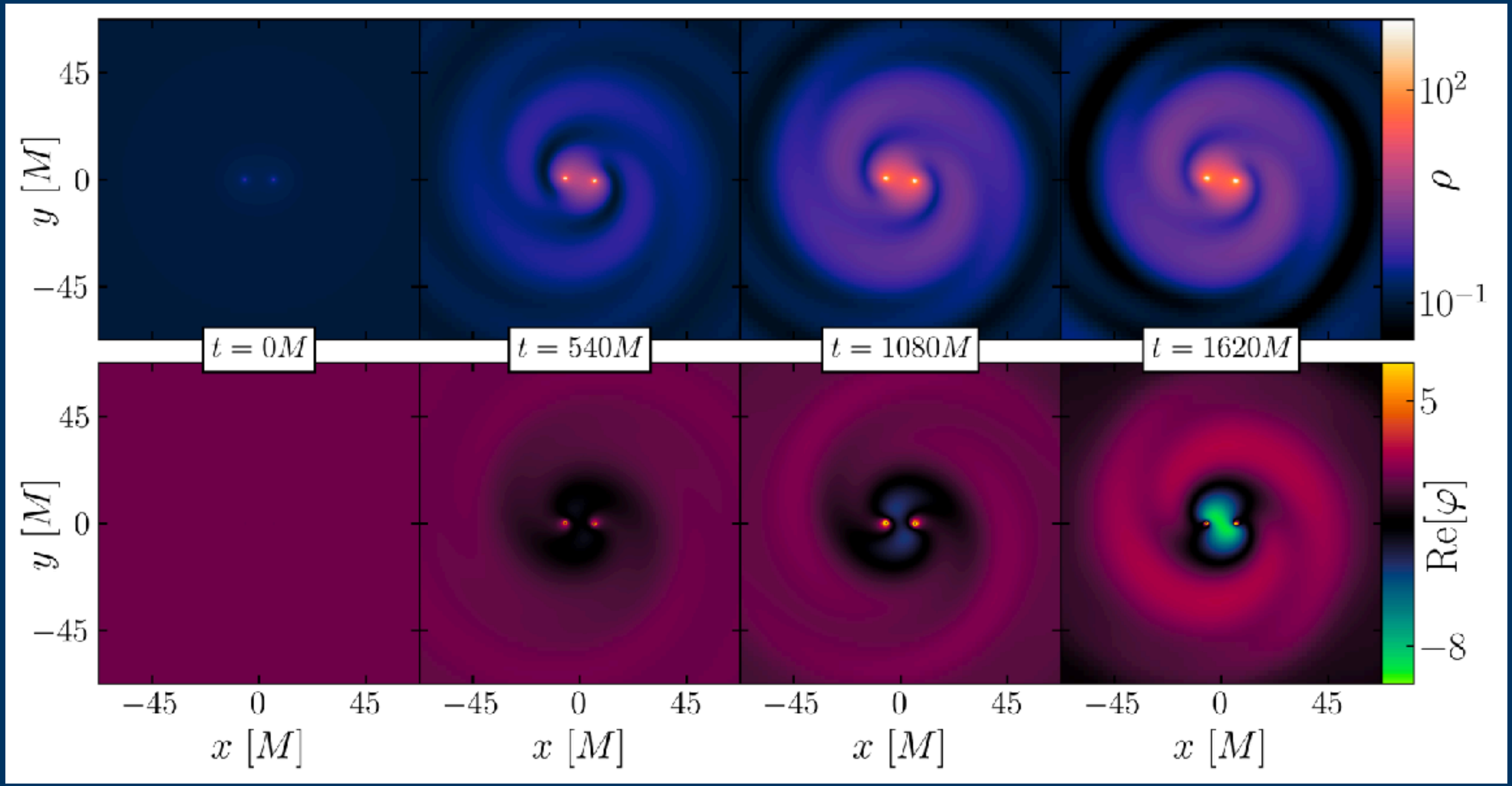


Image credit: Josu Aurrekoetxea, KC, Francesco Muia

Inhomogeneous inflation

I do have some more serious projects:



Fundamental fields and BHs

But today: A fun(damental) example

Preview Abstract

What no one has seen before: gravitational waveforms from warp drive collapse

Katy Clough, Tim Dietrich and Sebastian Khan

Despite originating in science fiction, warp drives have a concrete description in general relativity, with Alcubierre first proposing a spacetime metric that supported faster-than-light travel. Whilst there are numerous practical barriers to their implementation in real life, including a requirement for negative energy, computationally, one can simulate their evolution in time given an equation of state describing the matter. In this work, we study the signatures arising from a warp drive "containment failure", assuming a stiff equation of state for the fluid. We compute the emitted gravitational-wave signal and track the energy fluxes of the fluid. Apart from its rather speculative application to the search for extraterrestrial life in gravitational-wave detector data, this work is interesting as a study of the dynamical evolution and stability of spacetimes that violate the null energy condition. Our work highlights the importance of exploring strange new spacetimes, to (boldly) simulate what no one has seen before.

Comments: 12 pages, 6 figures, plus appendix. Comments welcome!

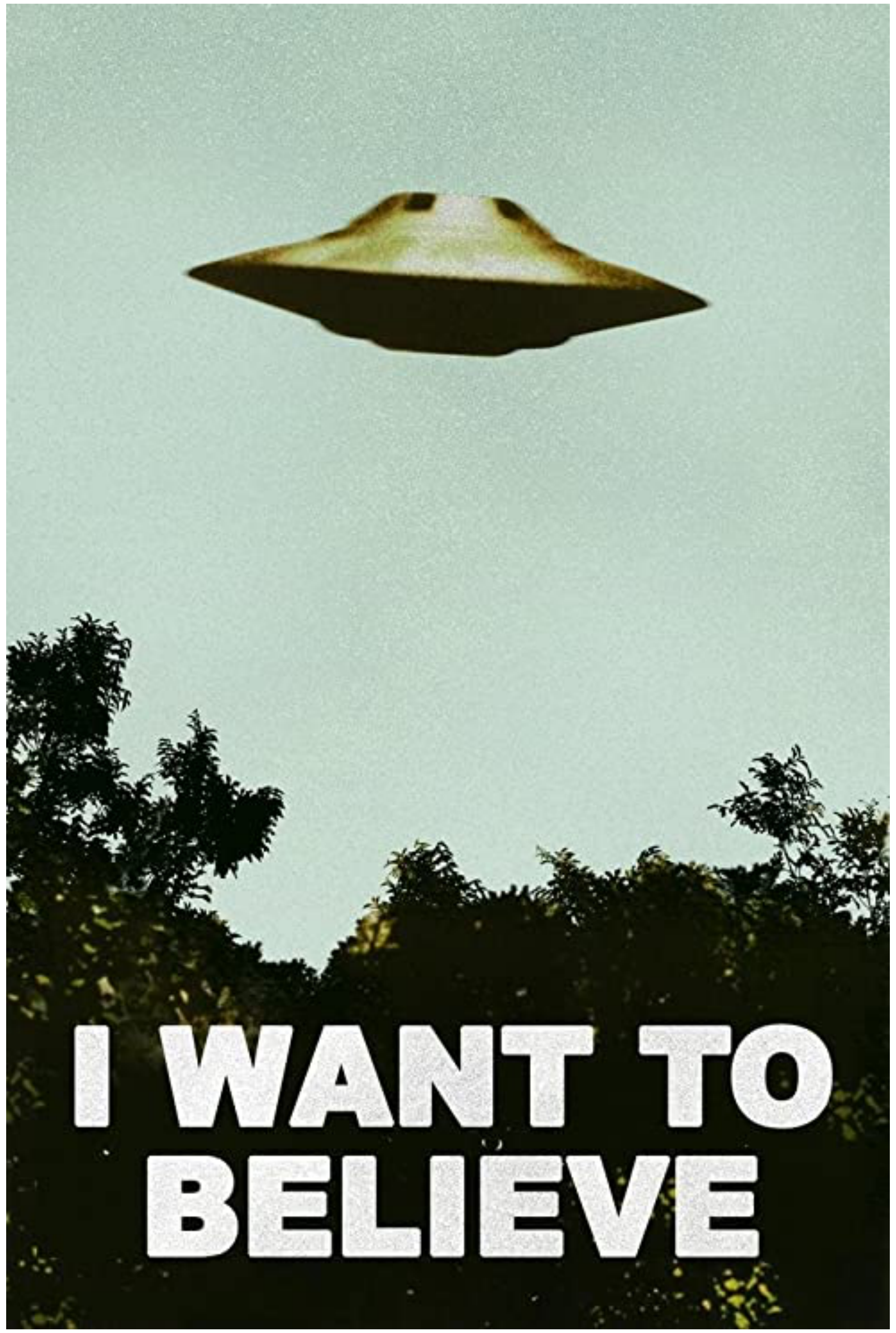
Categories

The crew

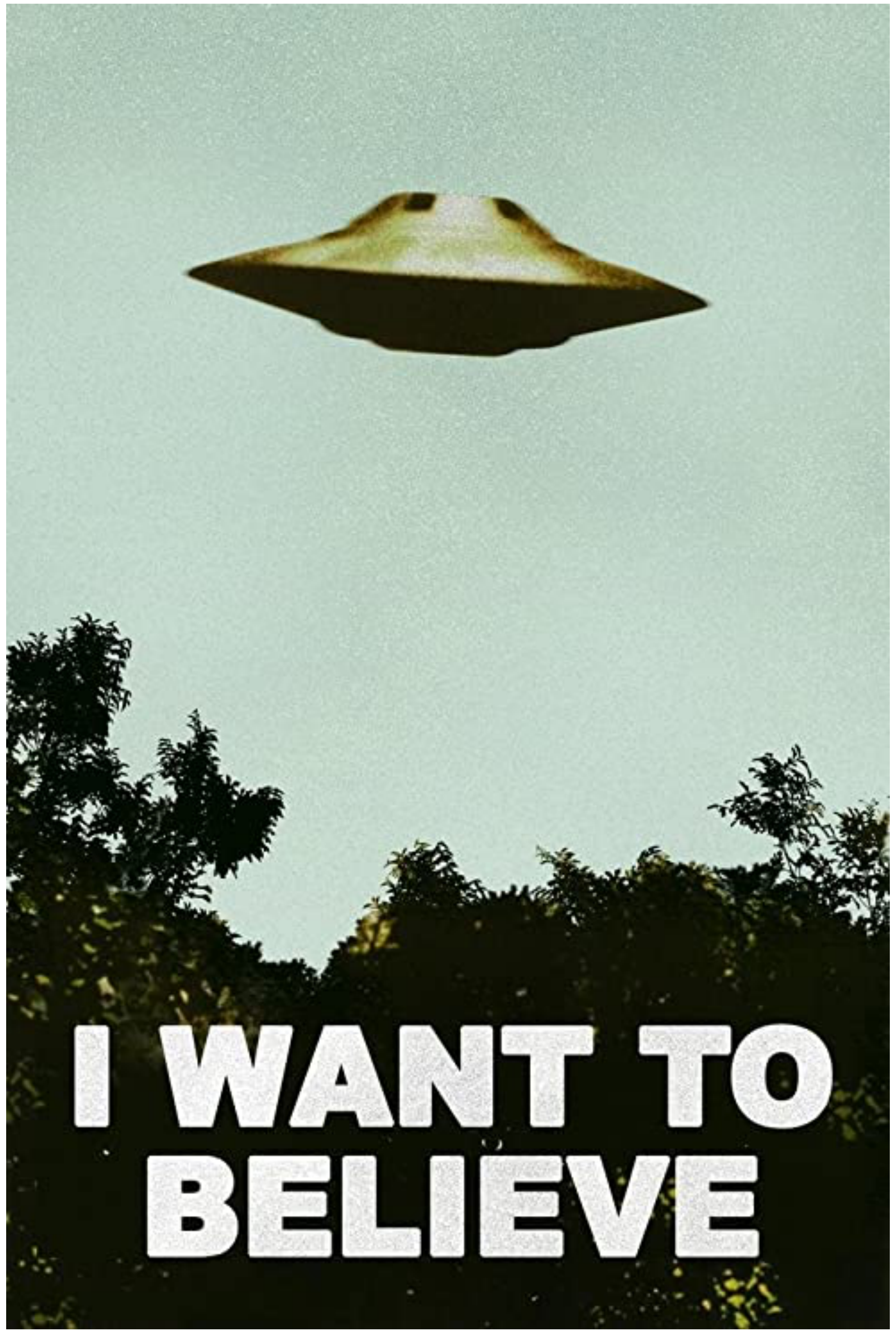
Katy "I cannae do it Captain" Clough

Captain Tim "Jim T." Dietrich

Sebastian "Wrath of" Khan

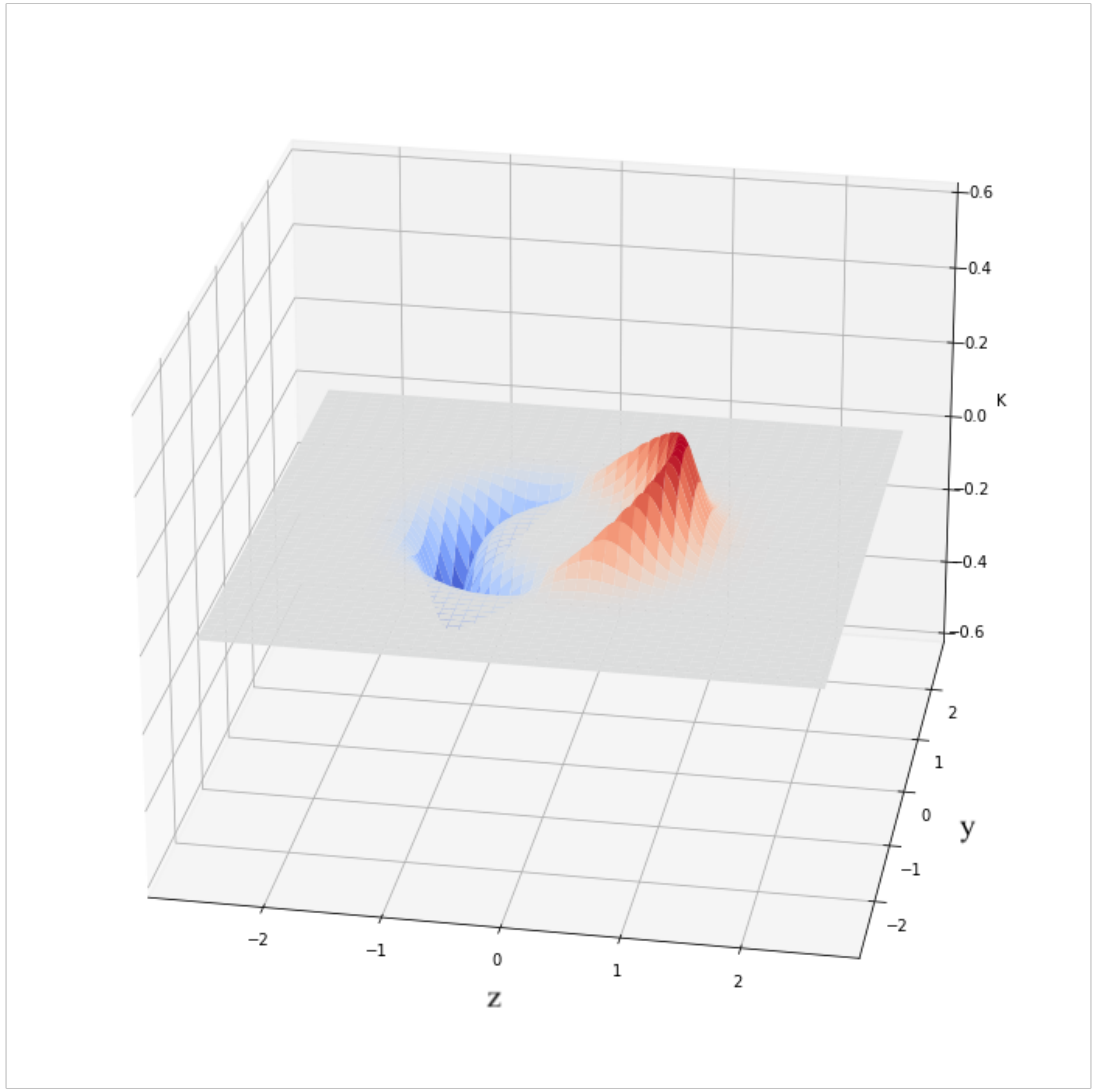


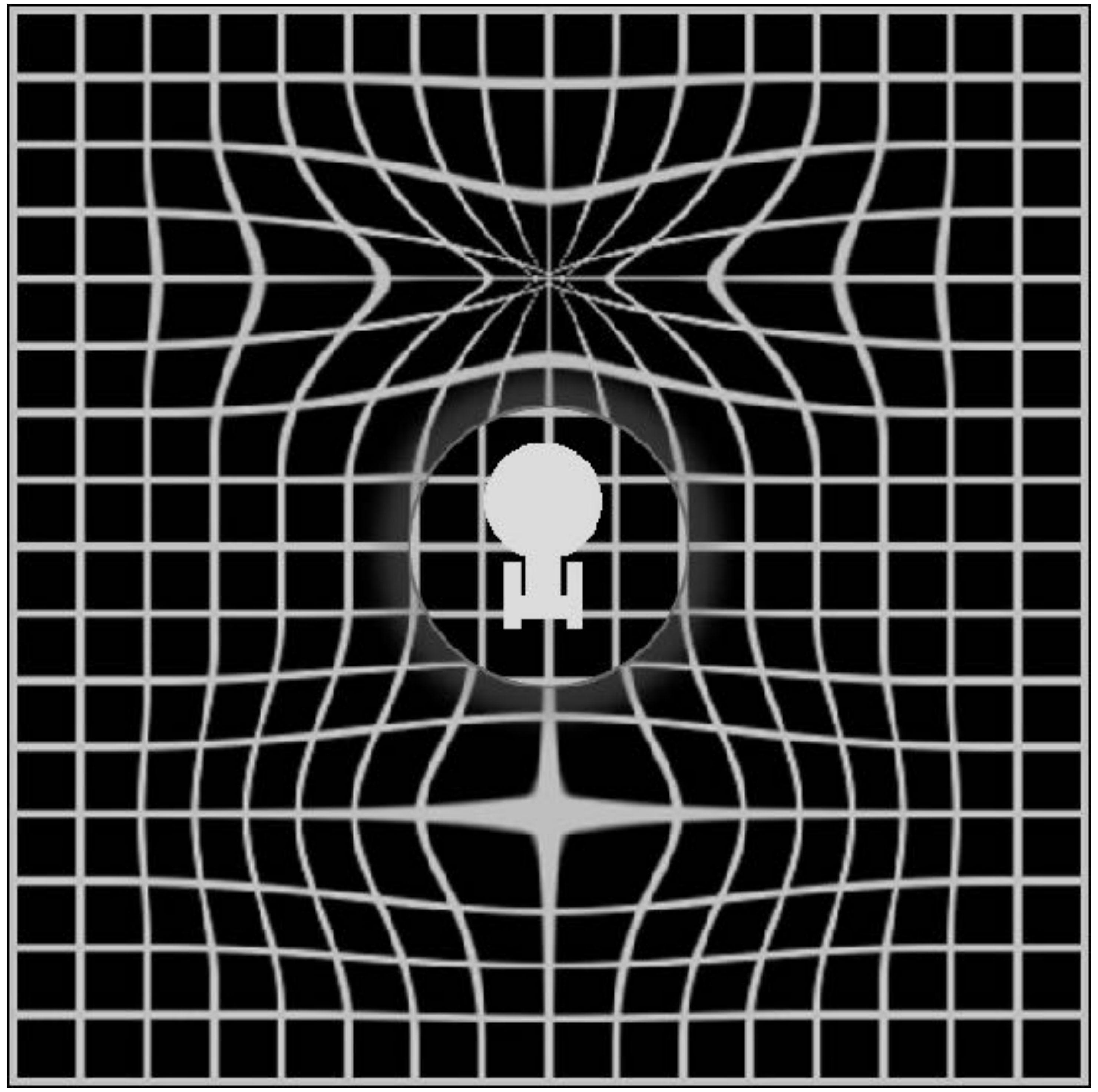
Question 1: Could we see gravitational waves from alien warp drive ships?



Question 2: Can asympotically zero ADM mass spacetimes radiate?

A warp drive metric exists





Alcubierre, The warp drive: hyper-fast travel within general relativity, CQG 1994

Tasks for the chief engineer:

- Initial conditions - for metric and fluid
- Evolution equations - for metric and fluid
- Specify coordinates / gauge
- Diagnostics - what to measure?

Initial conditions for the spacetime metric

$$\gamma_{ij} = \delta_{ij}$$

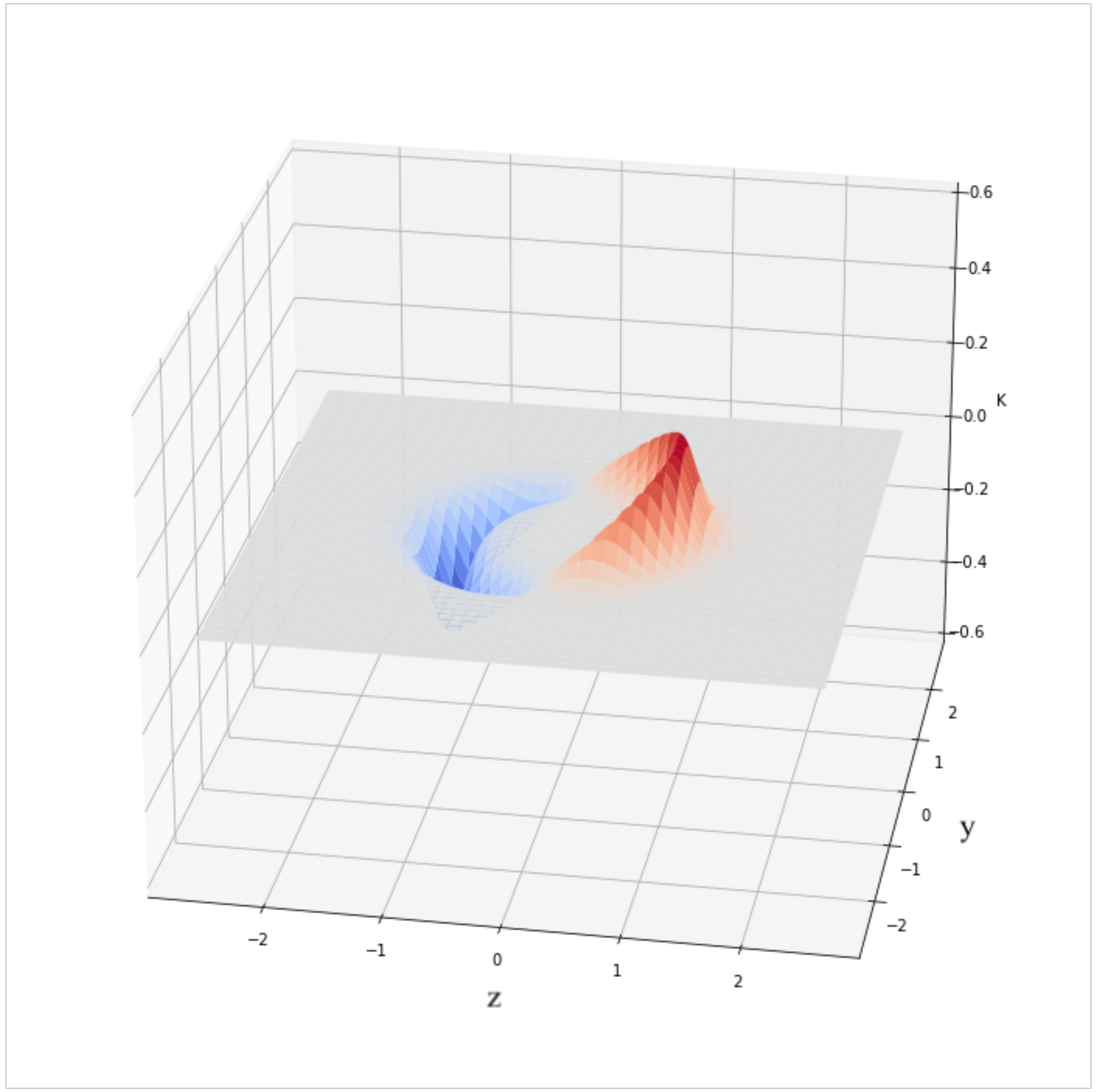
$$\alpha = 1$$

$$\beta^z = f(r - R)$$

$$K = \partial_z \beta^z$$

This requires matter that violates the Null Energy Condition,

(ie negative energy density)



Initial configuration for the matter

$$T_{\mu\nu}(t=0) = G_{\mu\nu}^{alcubierre}(t=0)/(8\pi)$$

This requires matter that violates the Null Energy Condition,

(ie negative energy density)

Metric evolution - just GR

The Einstein equation

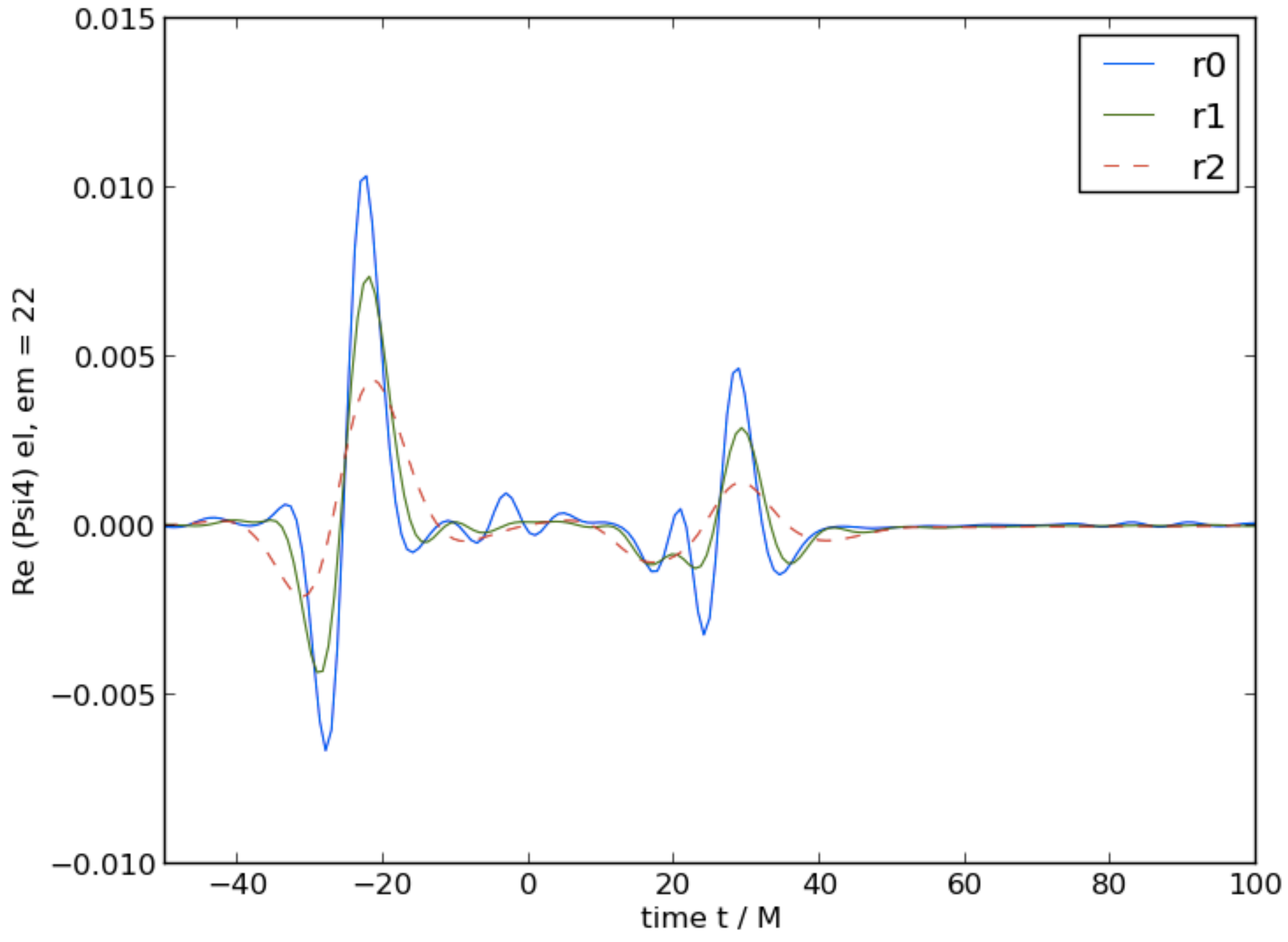
$$R_{ab} - R/2\, g_{ab} = 8\pi\, T_{ab}$$

t

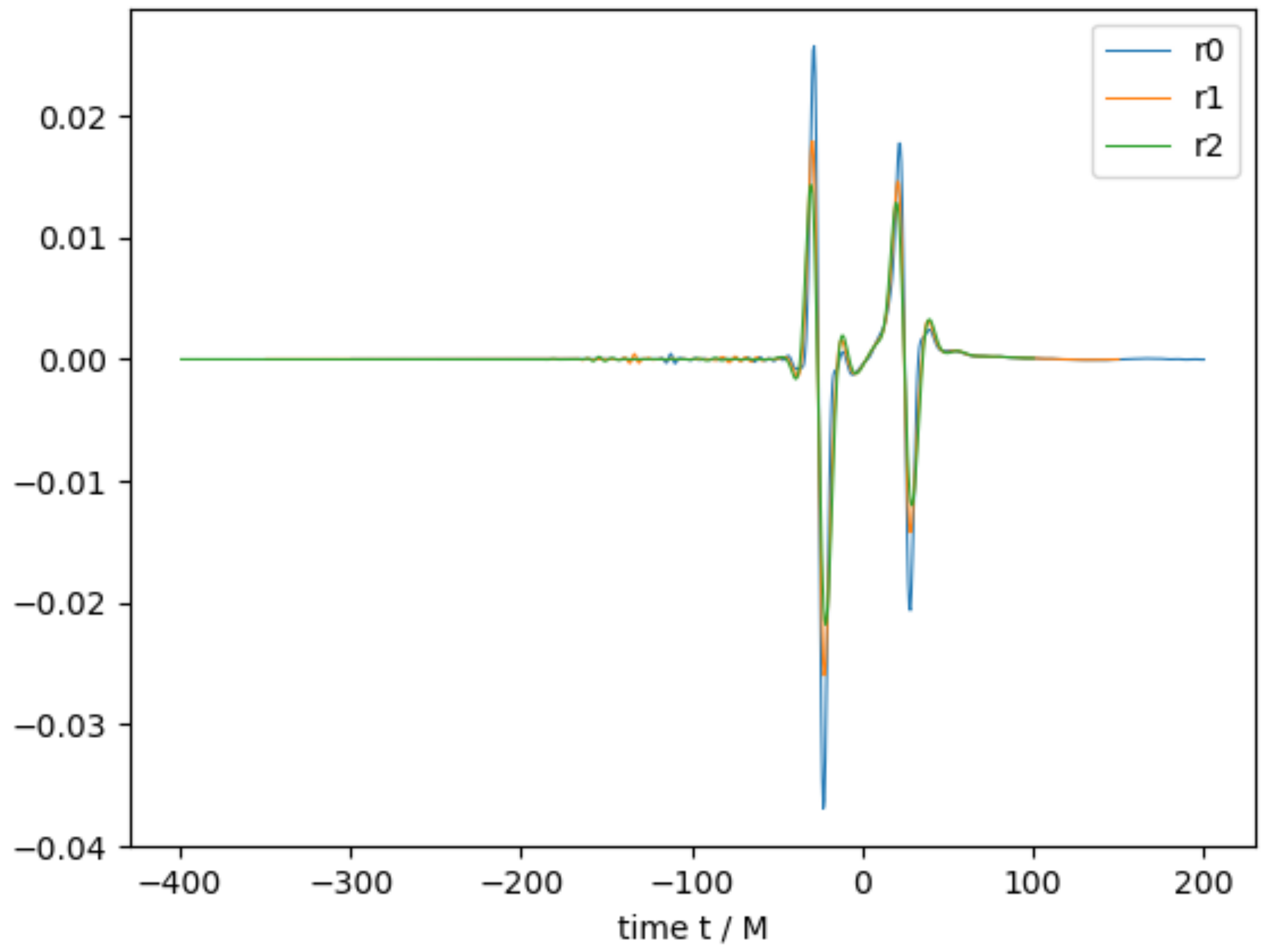
$f(\partial^2 g_{ab}, \partial g_{ab}, g_{ab})$
"Curvature"

"Energy-Momentum"

But finding good coordinates is a challenge



Bad gauge choice



Better gauge choice

But finding good coordinates is a challenge

Shock-avoiding slicing conditions: Tests and calibrations

Thomas W. Baumgarte and David Hilditch
Phys. Rev. D **106**, 044014 – Published 4 August 2022

Article | References | Citing Articles (4) | PDF | HTML | Export Citation

ABSTRACT

While the $1+\log$ slicing condition has been extremely successful in numerous numerical relativity simulations, it is also known to develop "gauge shocks" in some examples. Alternative "shock-avoiding" slicing conditions suggested by Alcubierre prevent these pathologies in those examples, but have not yet been explored and tested very broadly. In this paper we compare the performance of shock-avoiding slicing conditions with those of 1+log slicing for a number of "text-book" problems, including black holes and relativistic stars. While, in some simulations, the shock-avoiding slicing conditions feature some unusual properties and lead to more "gauge dynamics" than the $1+\log$ slicing condition, we find that they perform quite similarly in terms of stability and accuracy, and hence provide a very viable alternative to $1+\log$ slicing.

Matter evolution

Local energy conservation tells us how 4 components evolve:

$$\nabla^\mu T_{\mu\nu} = 0$$

$\implies \partial_t \rho = f(\rho, S_i, S_{ij}, g_{\mu\nu})$ energy density

$\implies \partial_t S_i = f(\rho, S_i, S_{ij}, g_{\mu\nu})$ momentum density

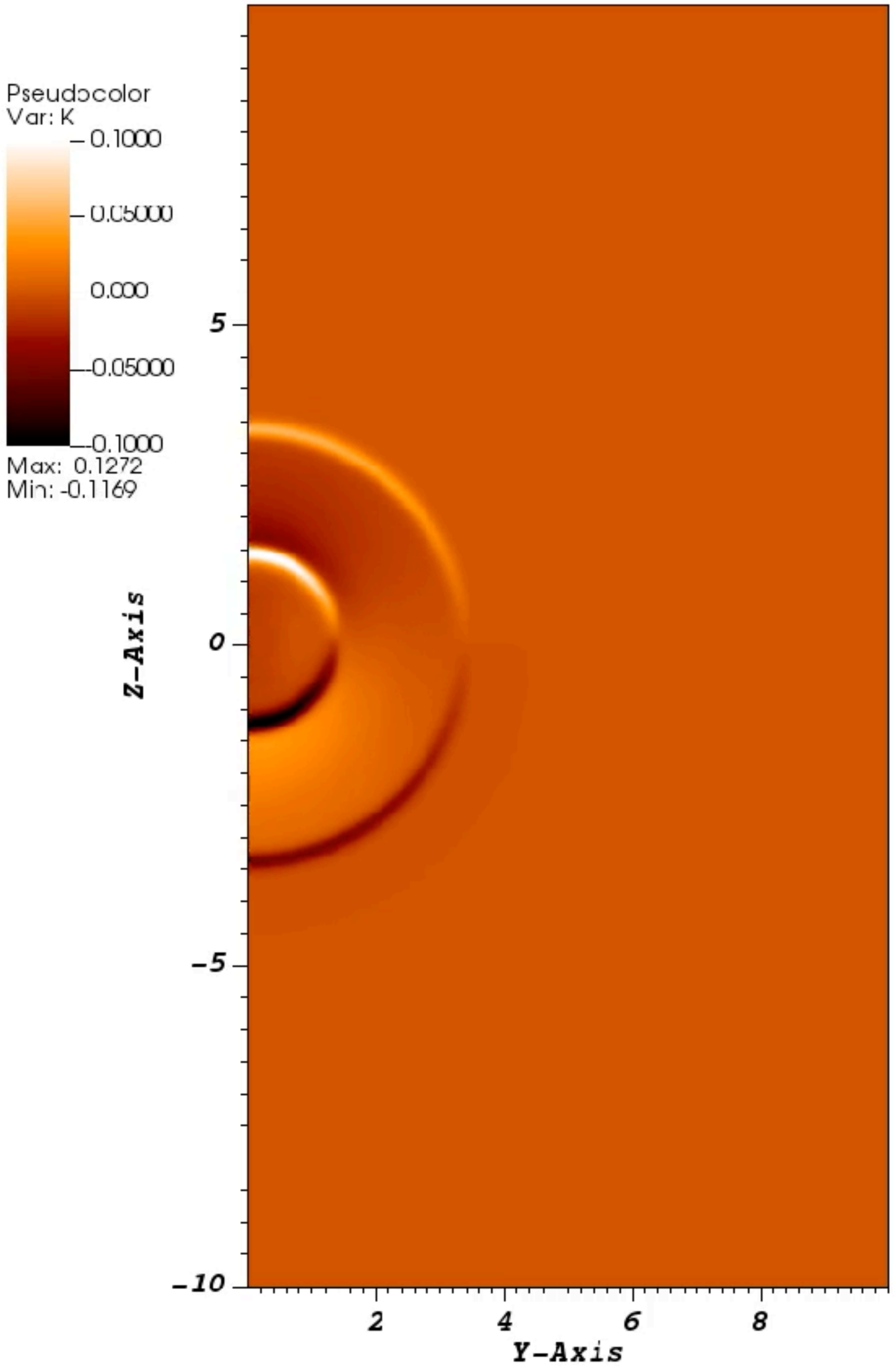
Matter evolution

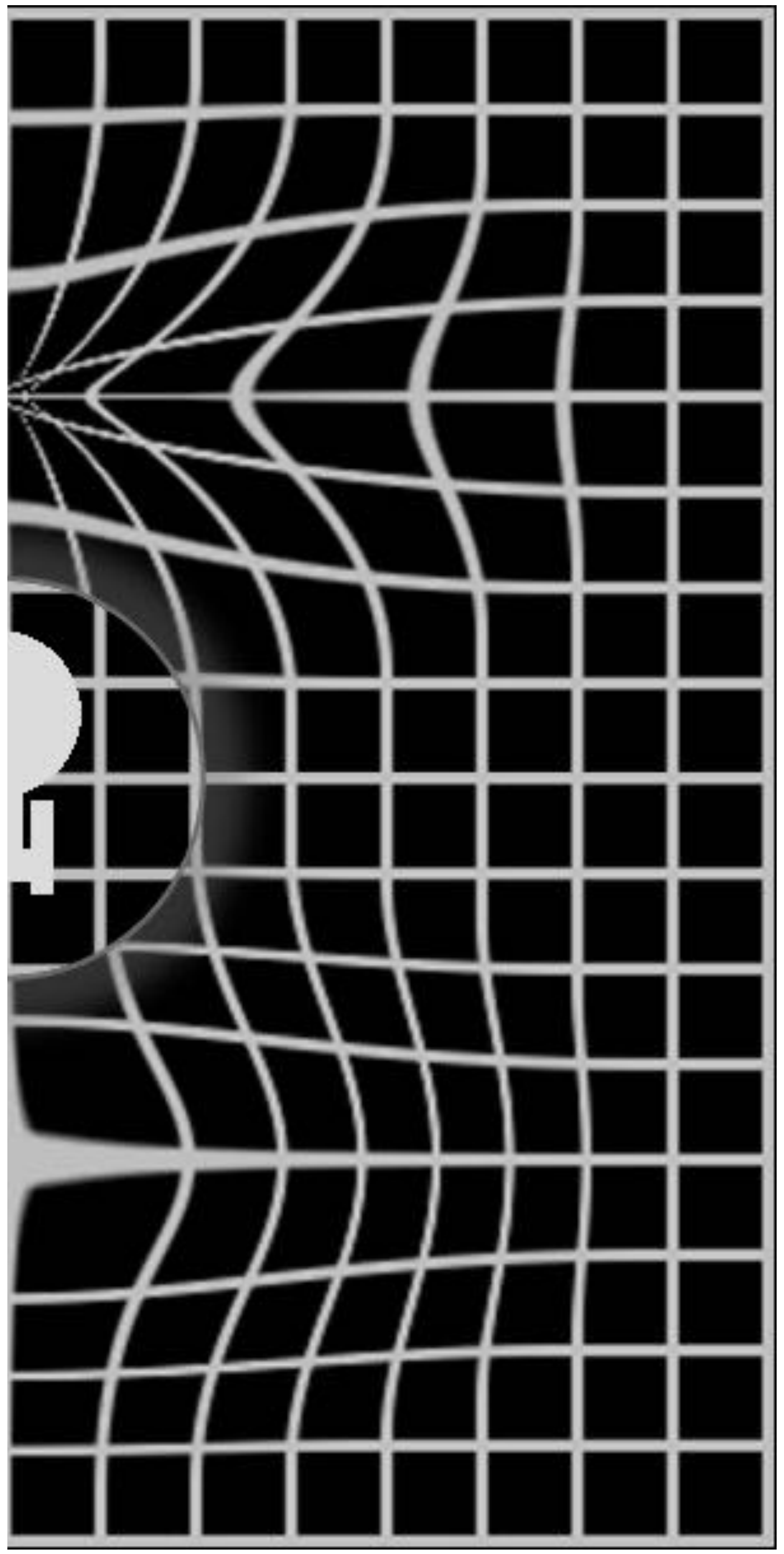
Still need eom for anisotropic stresses and pressures T_{ij} (effectively the fluid equation of state)

Bit of a hack:

Choose that anisotropic stresses decay in time, and a stiff equation of state $\bar{p} = \rho$.

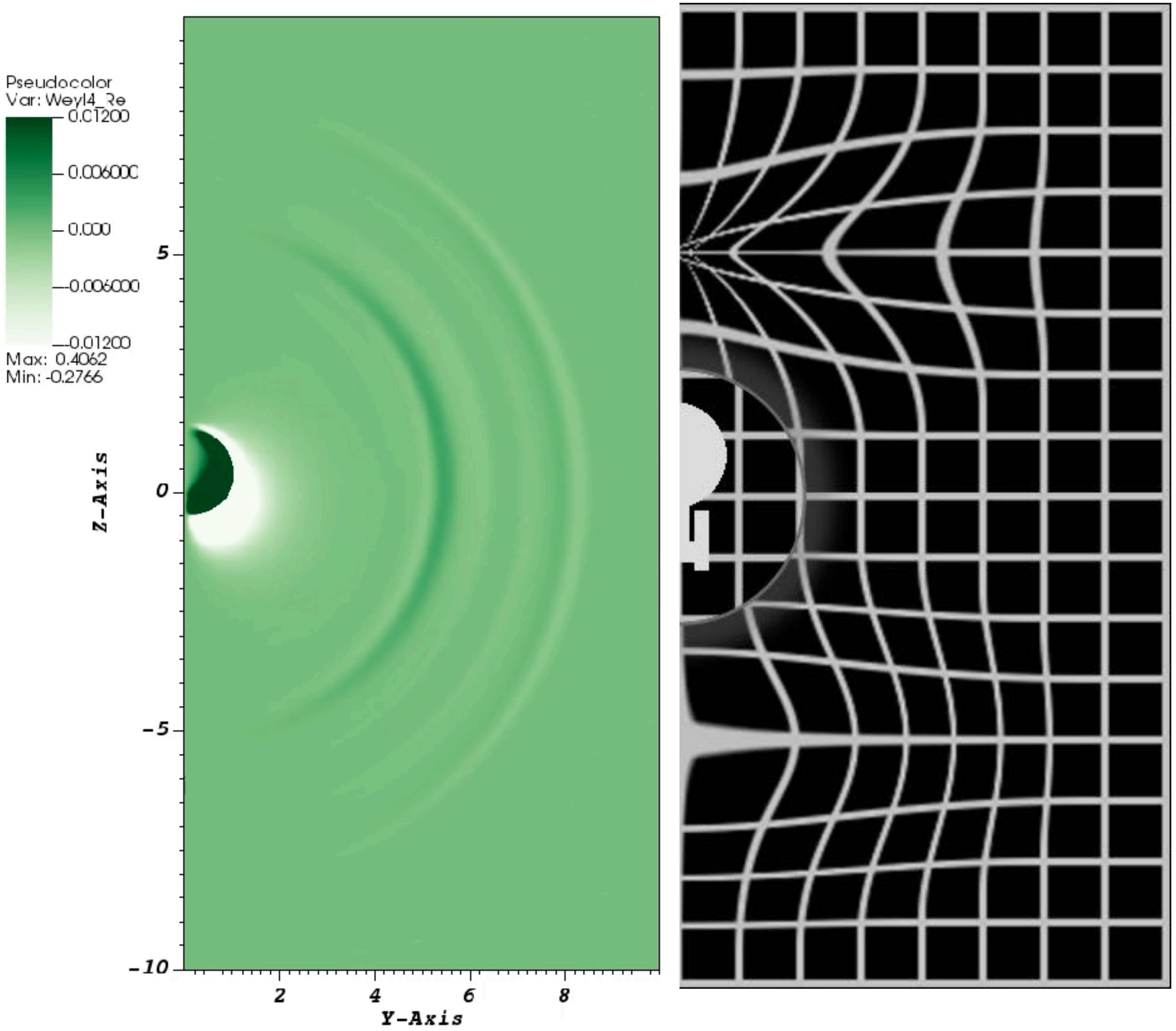
What no one has seen before…





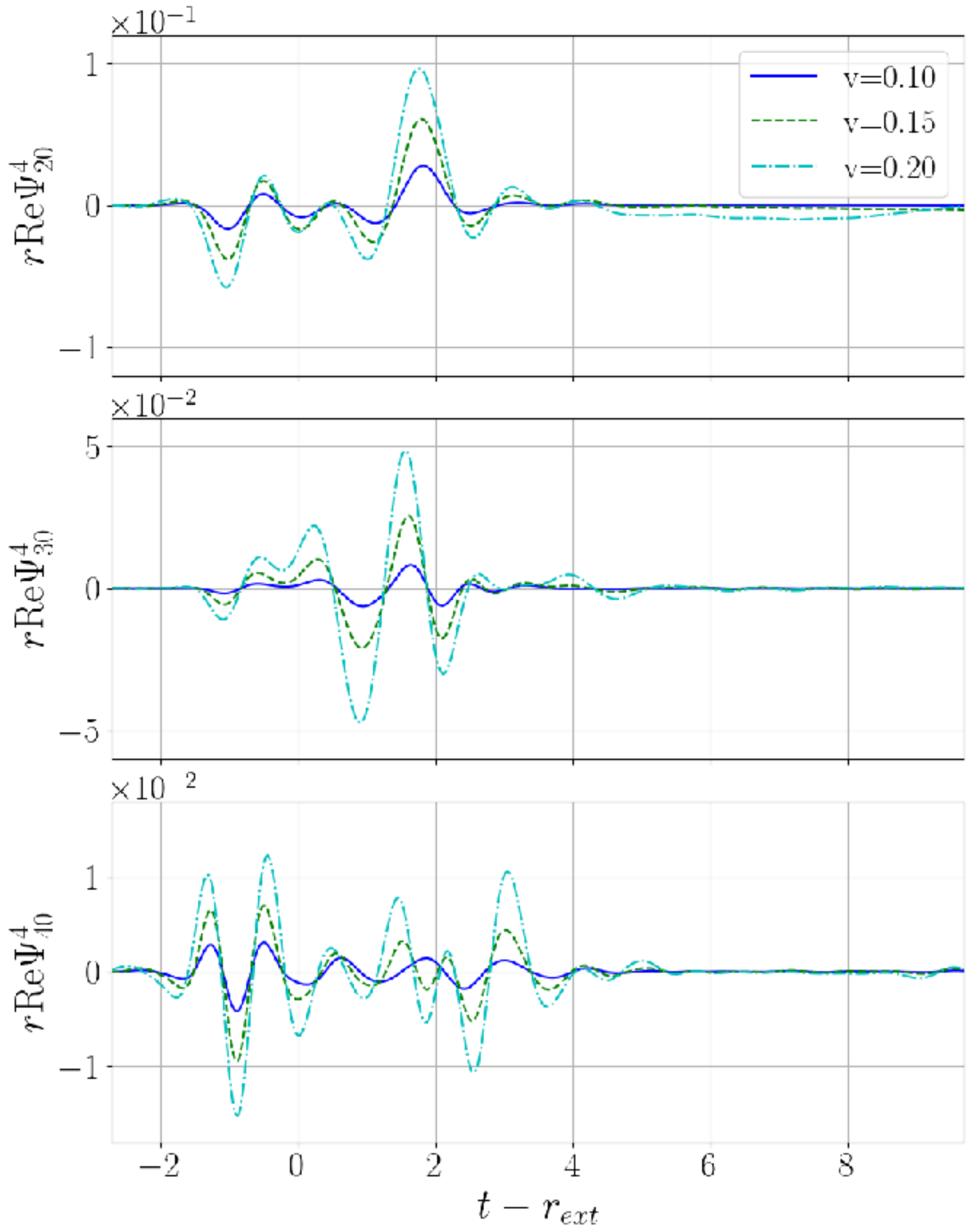
K
(Trace of extrinsic curvature of spatial slice)

One can extract the gravitational wave signals



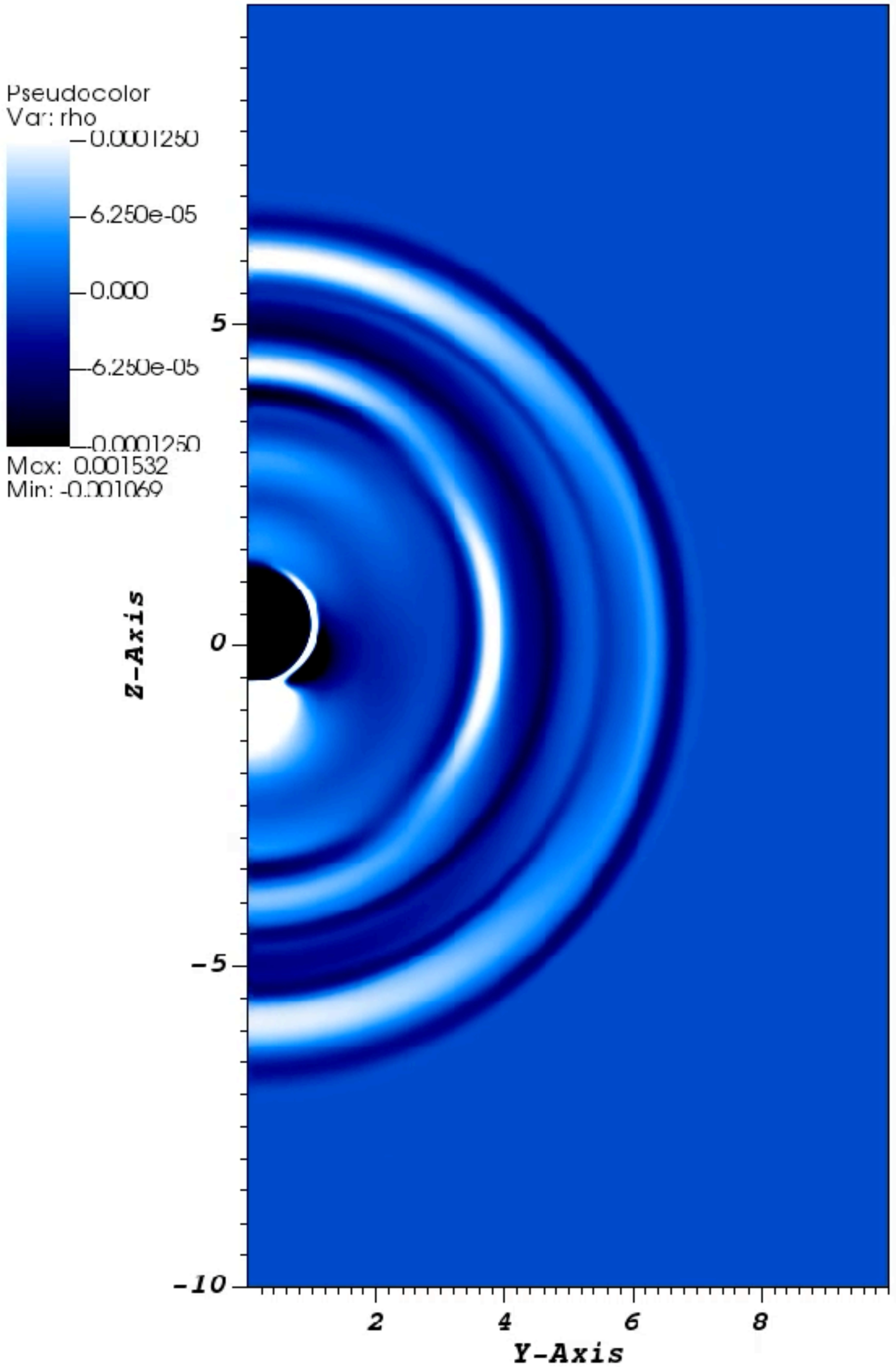
Weyl4 scalar

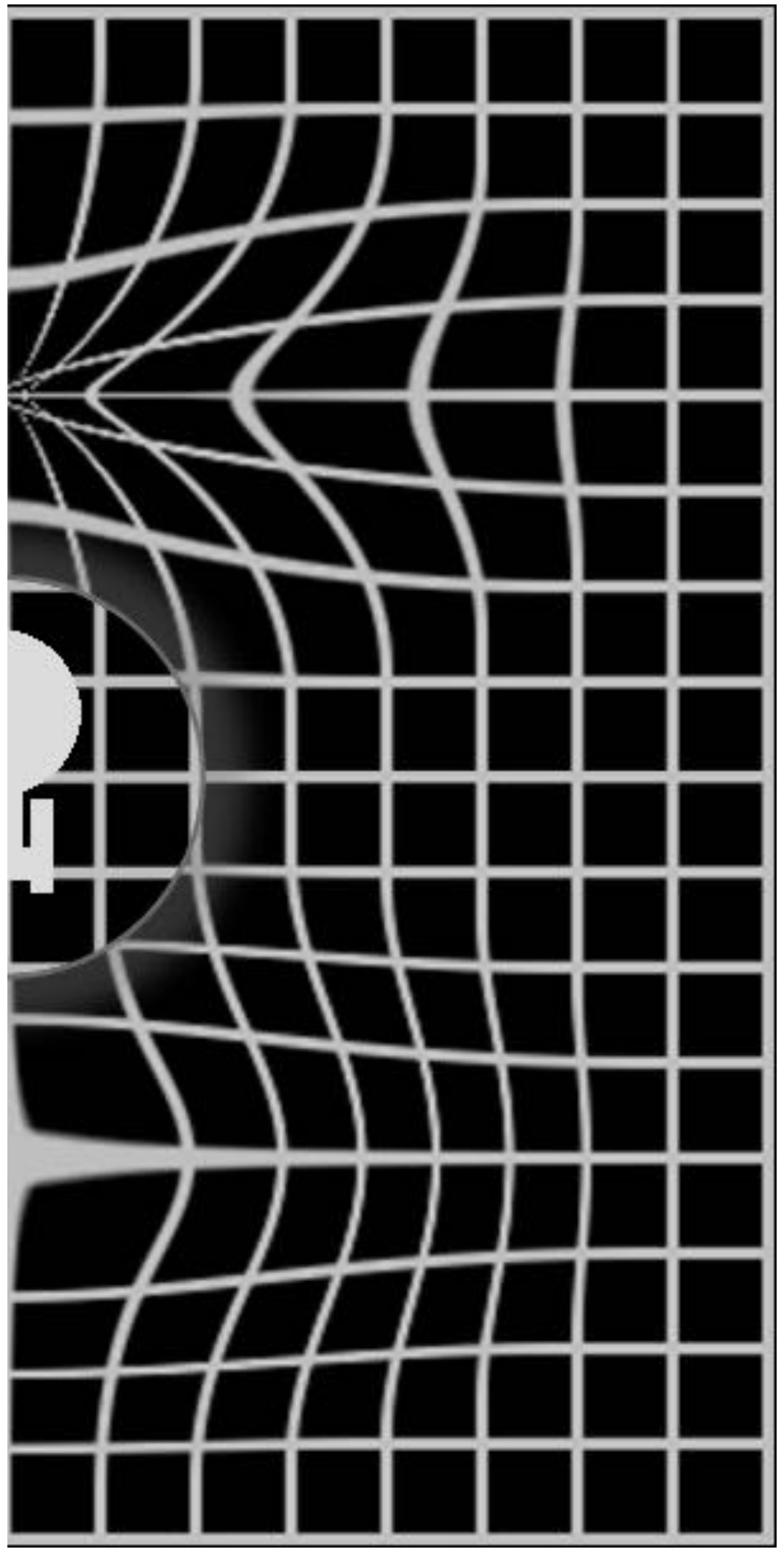
One can extract the gravitational wave signals



Weyl4 scalar

One can also study the fluxes of the matter content

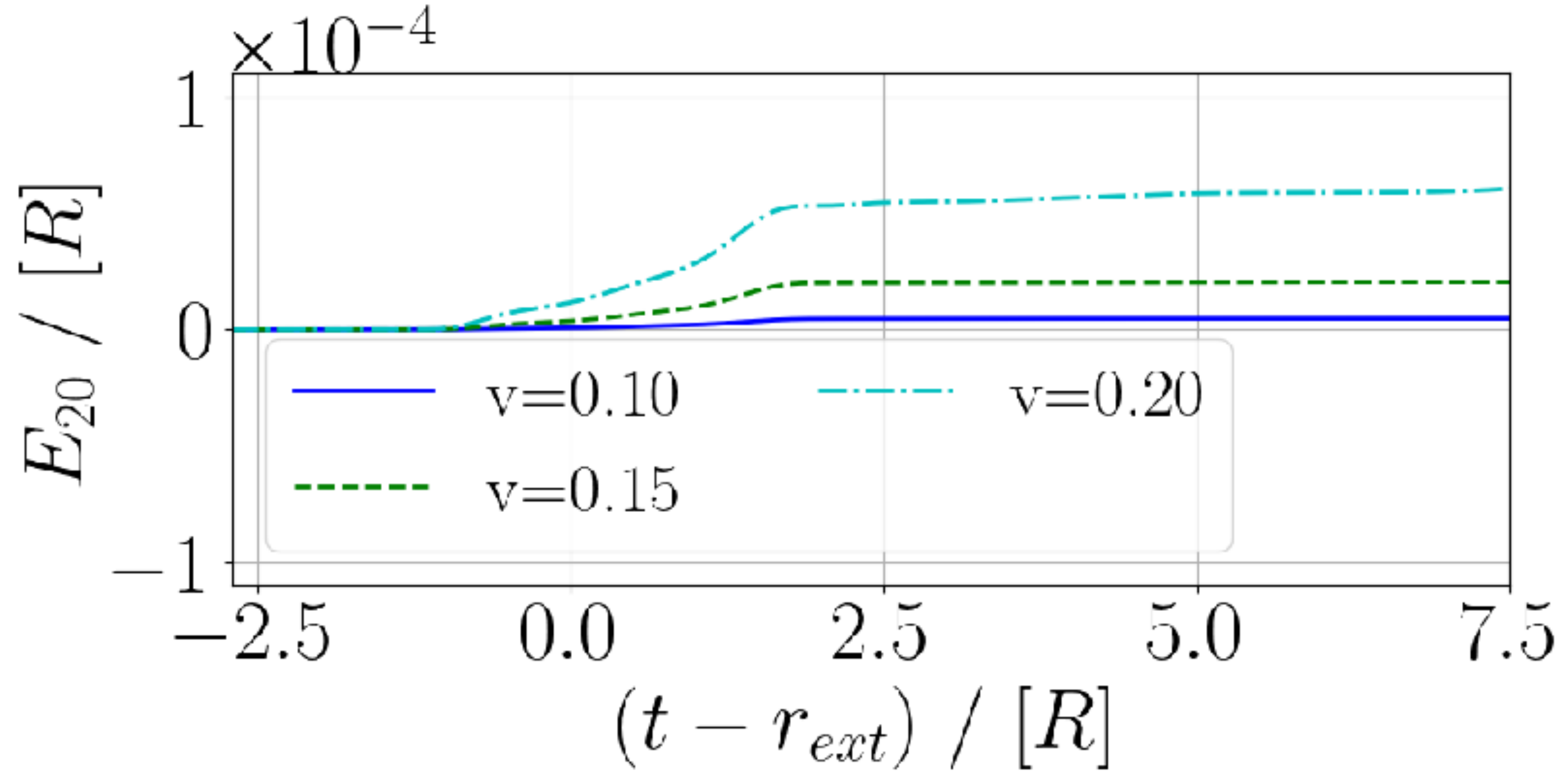


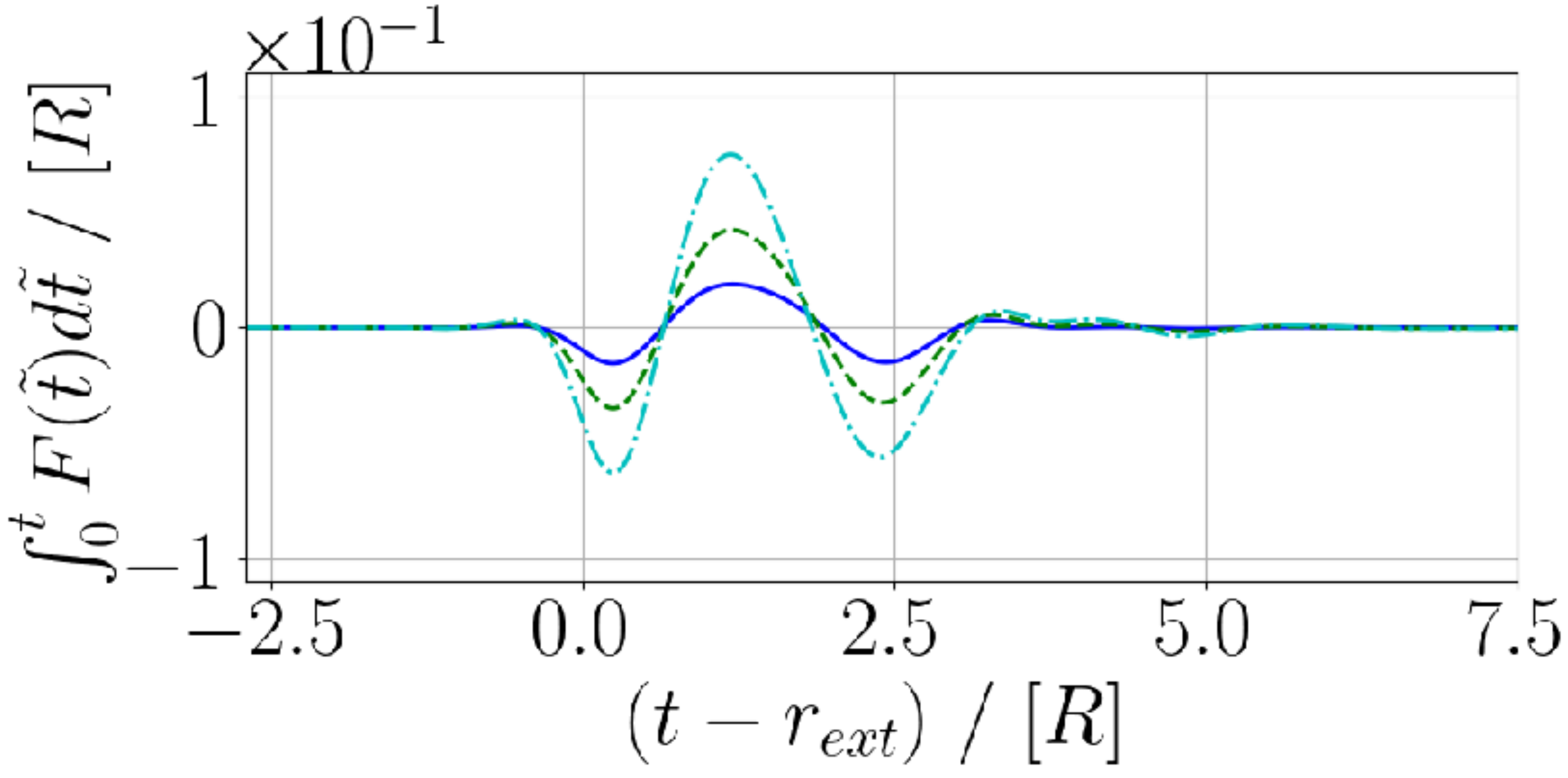


Energy density of warp fluid

See: Negative Mass in General Relativity (Bondi 1957)

Matter energy radiation is both negative and positive

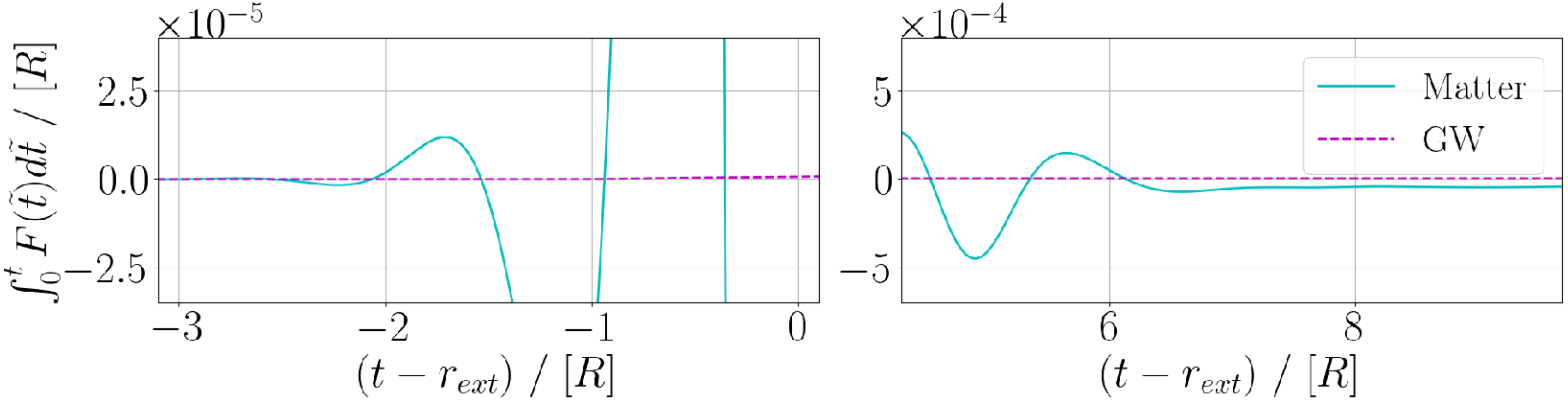




Energy flux of GWs

Energy flux of warp fluid

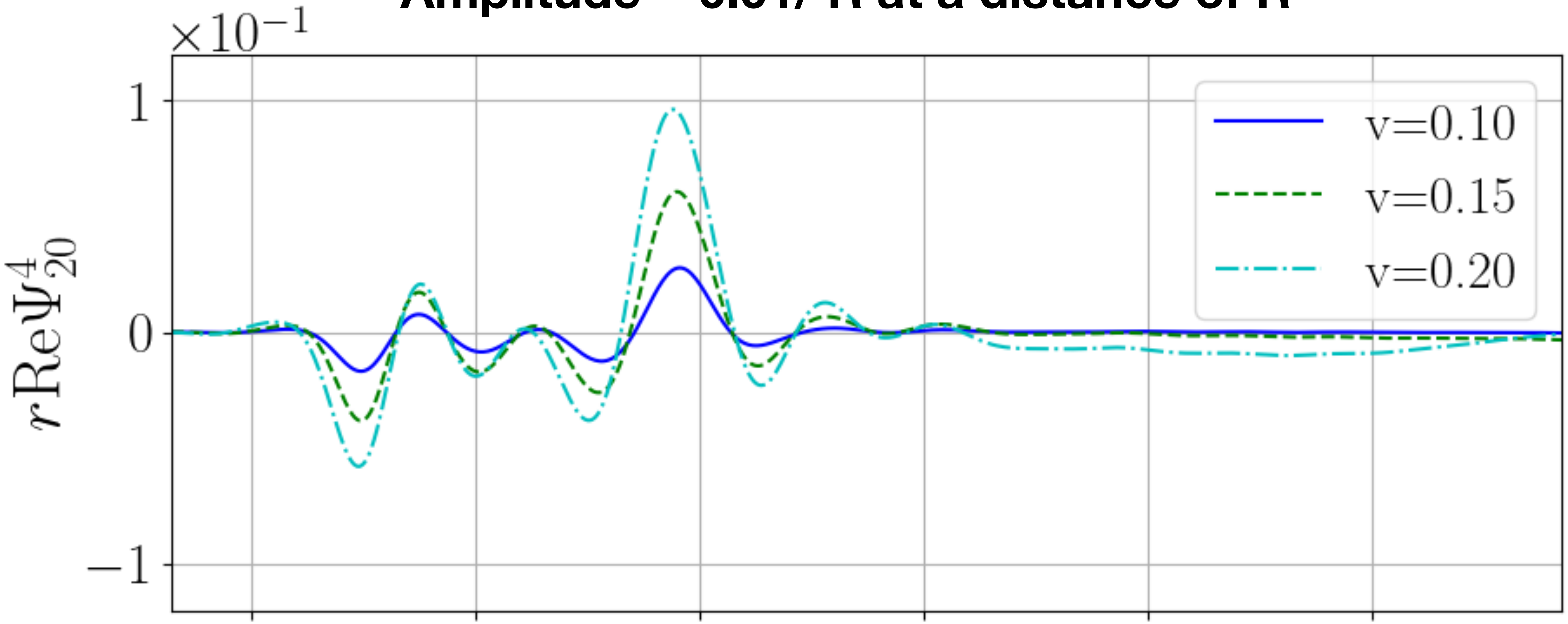
Final result is a loss of negative energy, so a positive ADM mass



Energy fluxes

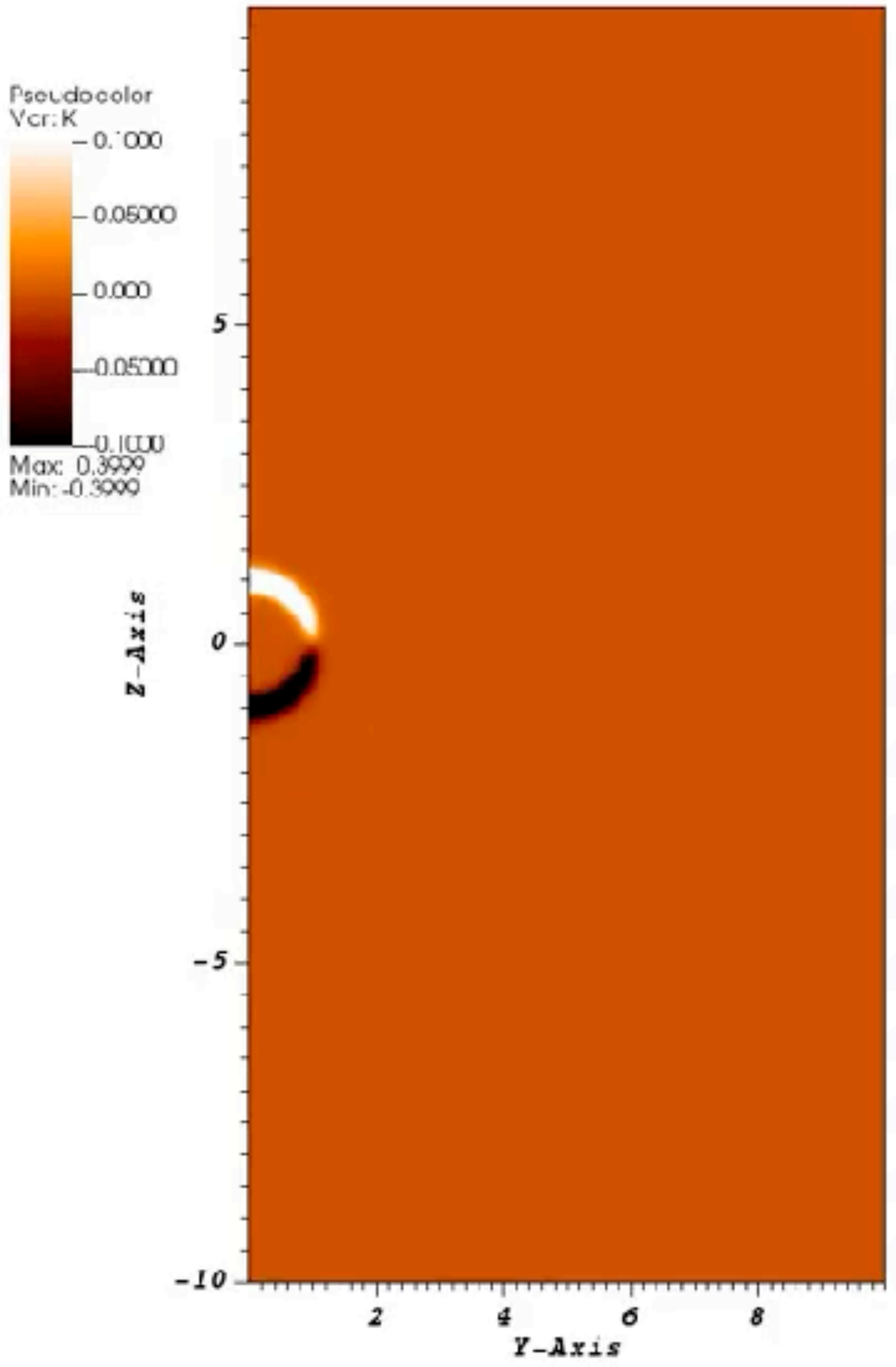
Can it be detected?

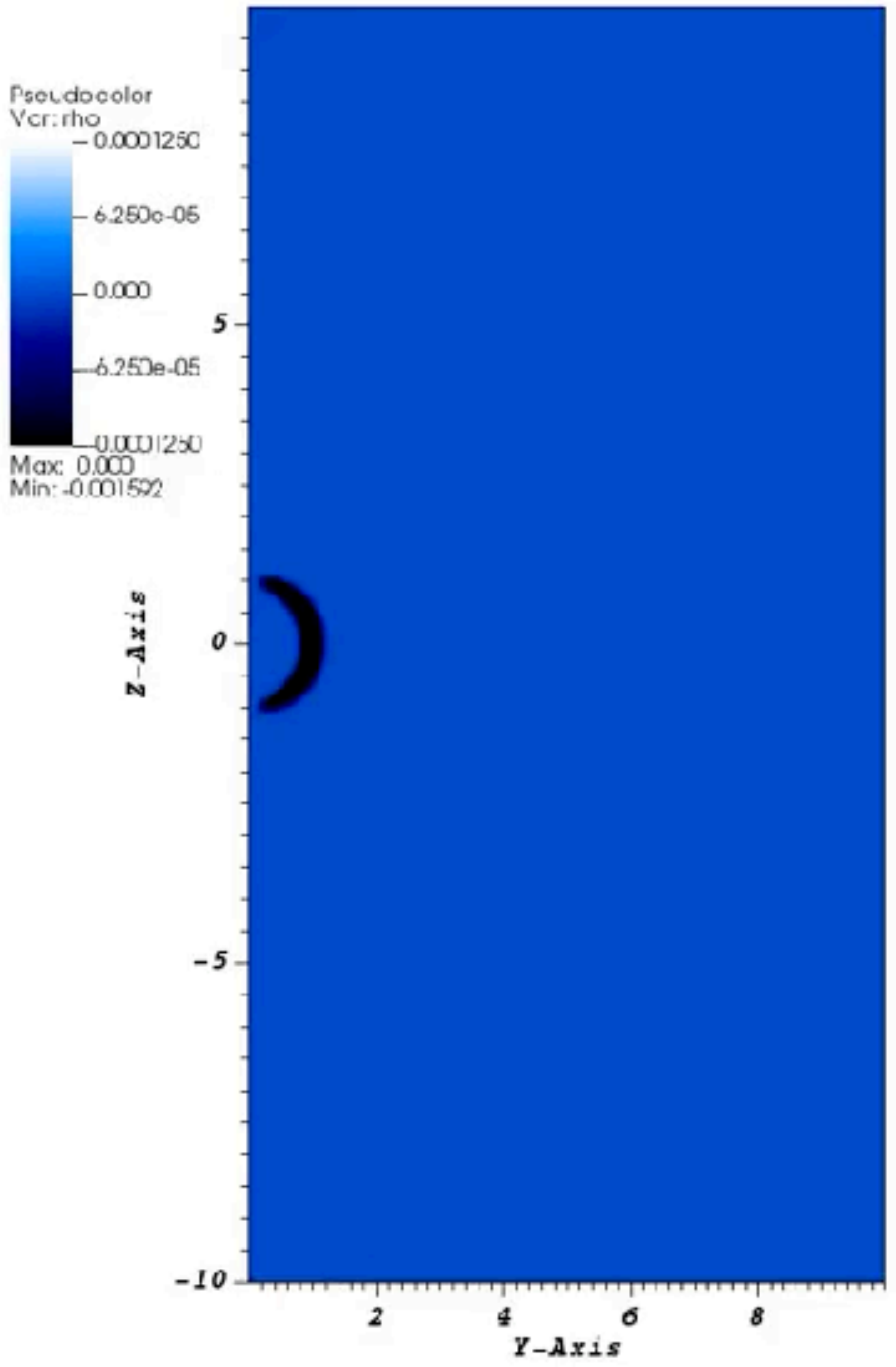
Amplitude ~ 0.01/ R at a distance of R

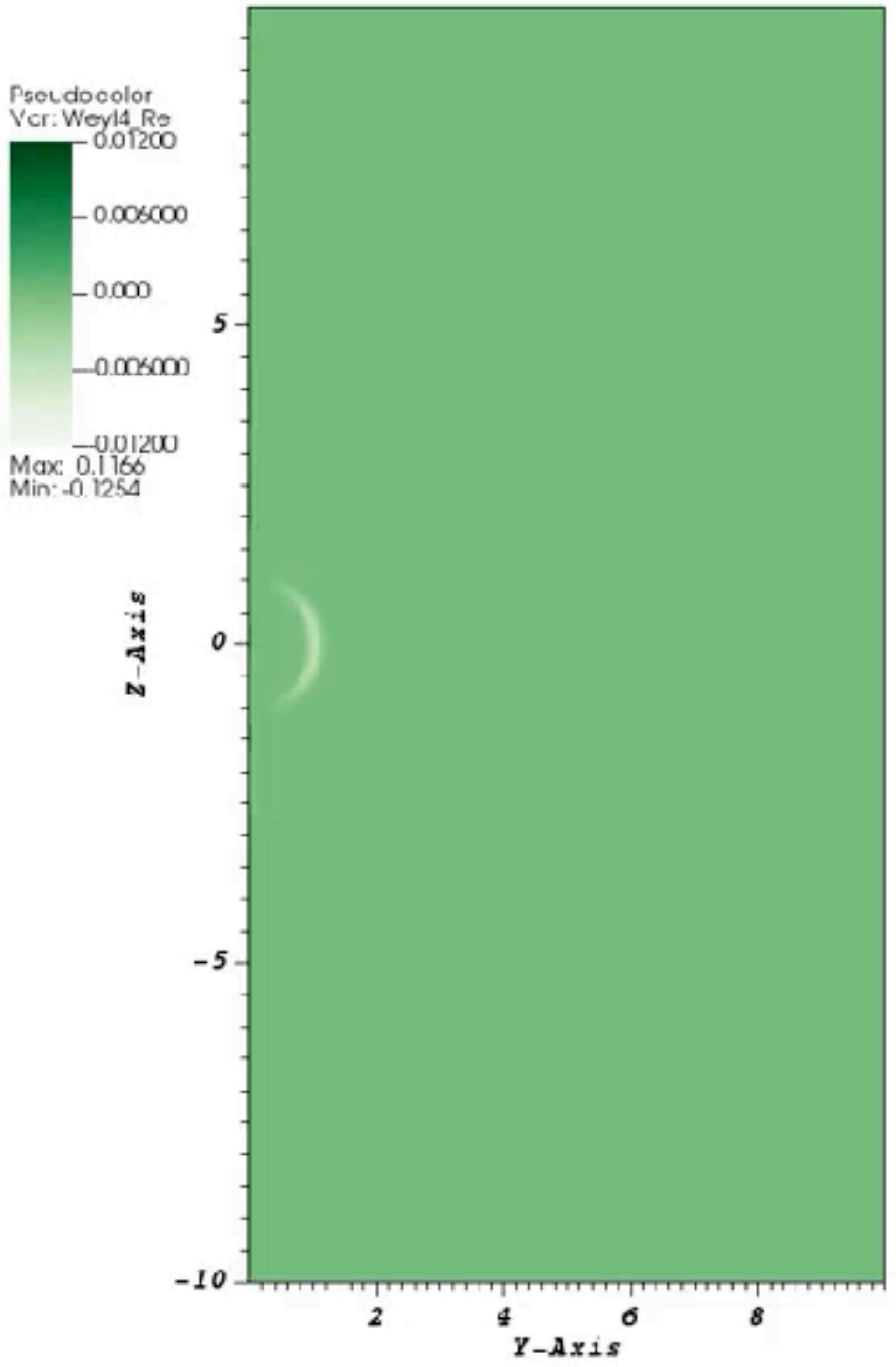


Frequency ~ 1/R

Maybe it’s not the destination that matters… it’s the journey

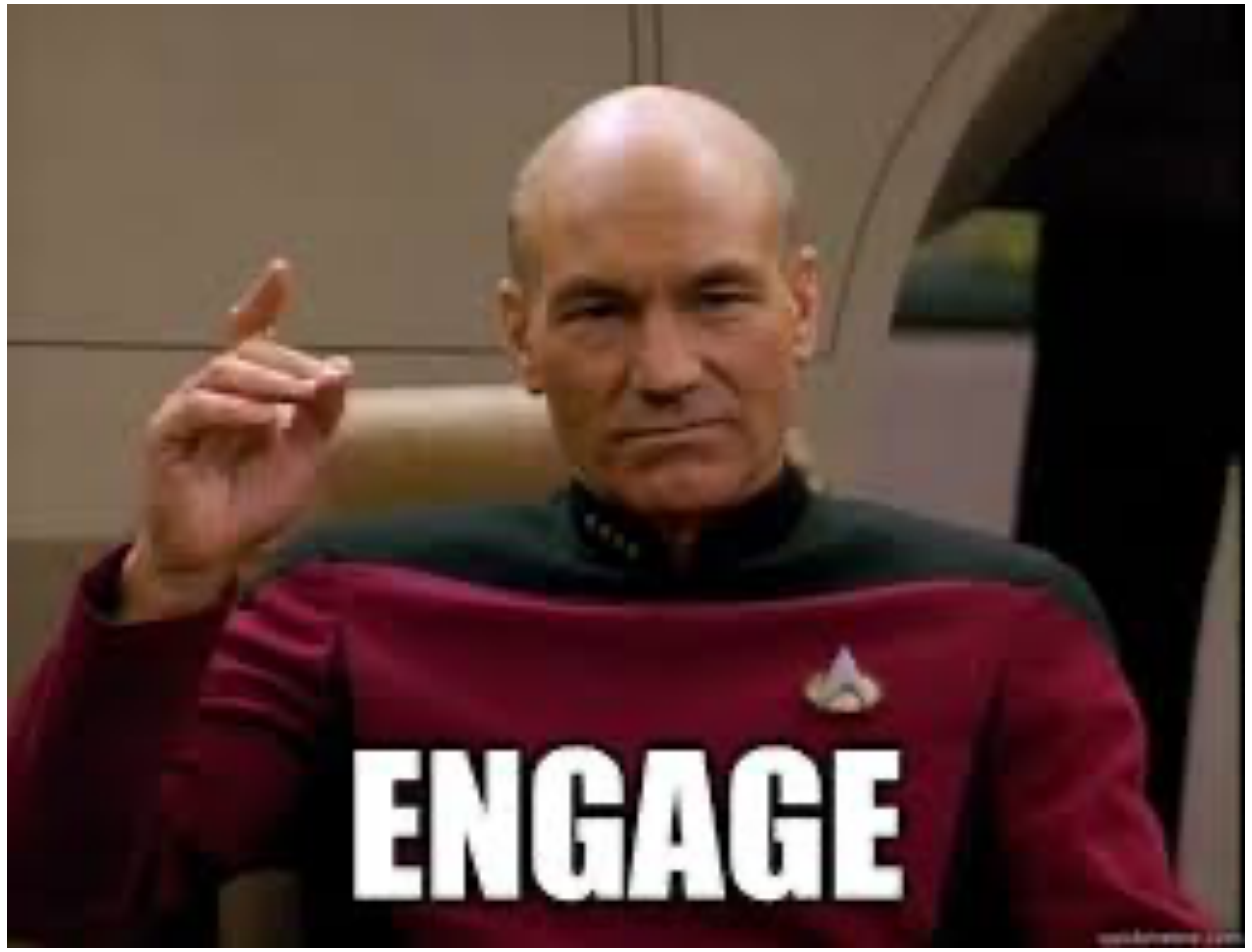






Summary

- Don’t give up on your crazy ideas (but maybe wait to get a permanent job before publishing them)
- LIGO has not ruled out post warp civilisations
- Future high frequency detectors may be able to!



Further questions

- Is this behaviour generic to negative energy spacetimes?
- What is the impact of the equation of state?
- What happens beyond v=c?

If you are on twitter please repost @KatyAClough


Katy Clough
@KatyAClough

Breaking my twitter vow of silence to announce https://arxiv.org/abs/2406.02466 using gravitational waves to detect warp drive containment failure. With fellow numerical relativists Tim "Jim T" Dietrich and Sebastian "Wrath of" Khan @noworkwednesday. @StarTrek @GRChombo @QMULMaths

arxiv.org
What no one has seen before: gravitational waveforms from
Despite originating in science fiction, warp drives have a concrete description in general relativity, with Alcubierre ...

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