Title: Progress in calculating the self-force using 3D finite difference codes.

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Abstract: TBA

# Progress in calculating the self-force using 3D finite difference codes.

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# Outline

- Summary of last years status.
- Hyperboloidal slicing and matching to null infinity.
- New (and improved) results.
- Concluding remarks.

## Summary of last years status.

Implementation of regularized scalar point source for circular orbits around Schwarzschild using a 3-D multiblock finite difference code.

A couple of major problems was limiting the accuracy and usability of the code.

1. The source was specialized to circular orbits around Scharzschild black holes.
2. Lack of smoothness of the source caused high frequency noise in the extracted self force.
3. Unphysical outer boundary conditions caused reflections when the waves hit the outer boundary that would then affect the extracted self force and energy flux when the boundary came into causal contact with the extraction region.

## Hyperboloidal slicing and matching to null infinity.

The idea (from Zenginoğlu & Tiglo, Phys.Rev.D80:024044, 2009) is to compactify in the radial direction and transform the time coordinate so that the spatial slices asymptotes to $\mathscr{I}^+$.

$$\tau = t - h(r) \tag{1}$$

and

$$r = \frac{\rho}{\Omega}, \qquad \text{with} \qquad \Omega = \Omega(\rho). \tag{2}$$

Where $r \to \infty$ corresponds to $\Omega = 0$.

Choosing $\Omega(\rho) = 1 - \rho/S$ guarantees that this happens on a fixed coordinate sphere of radius $S$.

It can be shown that choosing $H = dh/dr$ as

$$H = 1 + \frac{4M\Omega}{\rho} + \frac{(8M^2 - C^2)\Omega^2}{\rho^2} \tag{3}$$

ensures that the metric is regular at $\rho = S$ such that

$$\left(\Box - \frac{1}{6}R\right)\phi = \Omega^{-3}\left(\tilde{\Box} - \frac{1}{6}\tilde{R}\right)\tilde{\phi}, \tag{4}$$





is also regular at $\rho = S$ and where $\phi = \tilde{\phi}/\Omega$.

## Hyperboloidal slicing and matching to null infinity.

We want to use standard spatial slices in the interior so we have to have a transition between standard spatial slices and hyperboloidal slices

$$\Omega(\rho) = \begin{cases} 1 & \text{for} \quad \rho \leq \rho_{\rm int} \\ 1 - f + (1 - \rho/S) f & \text{for} \quad \rho_{\rm int} < \rho < \rho_{\rm ext}\,, \\ 1 - \rho/S & \text{for} \quad \rho \geq \rho_{\rm ext} \end{cases} \tag{5}$$

$$H(\rho) = dh/dr = \begin{cases} 0 & \text{for} \quad \rho \leq \rho_{\rm int} \\ \left(1 + \frac{4M\Omega}{\rho} + \frac{(8M^2 - C^2)\Omega^2}{\rho^2}\right) f & \text{for} \quad \rho_{\rm int} < \rho < \rho_{\rm ext}\,. \\ 1 + \frac{4M\Omega}{\rho} + \frac{(8M^2 - C^2)\Omega^2}{\rho^2} & \text{for} \quad \rho \geq \rho_{\rm ext} \end{cases} \tag{6}$$

Here $f = 0$ for $\rho \leq \rho_{\rm int}$, $f = 1$ for $\rho \geq \rho_{\rm ext}$ and $f$ varies smoothly from 0 to 1 between $\rho_{\rm int}$ and $\rho_{\rm ext}$.

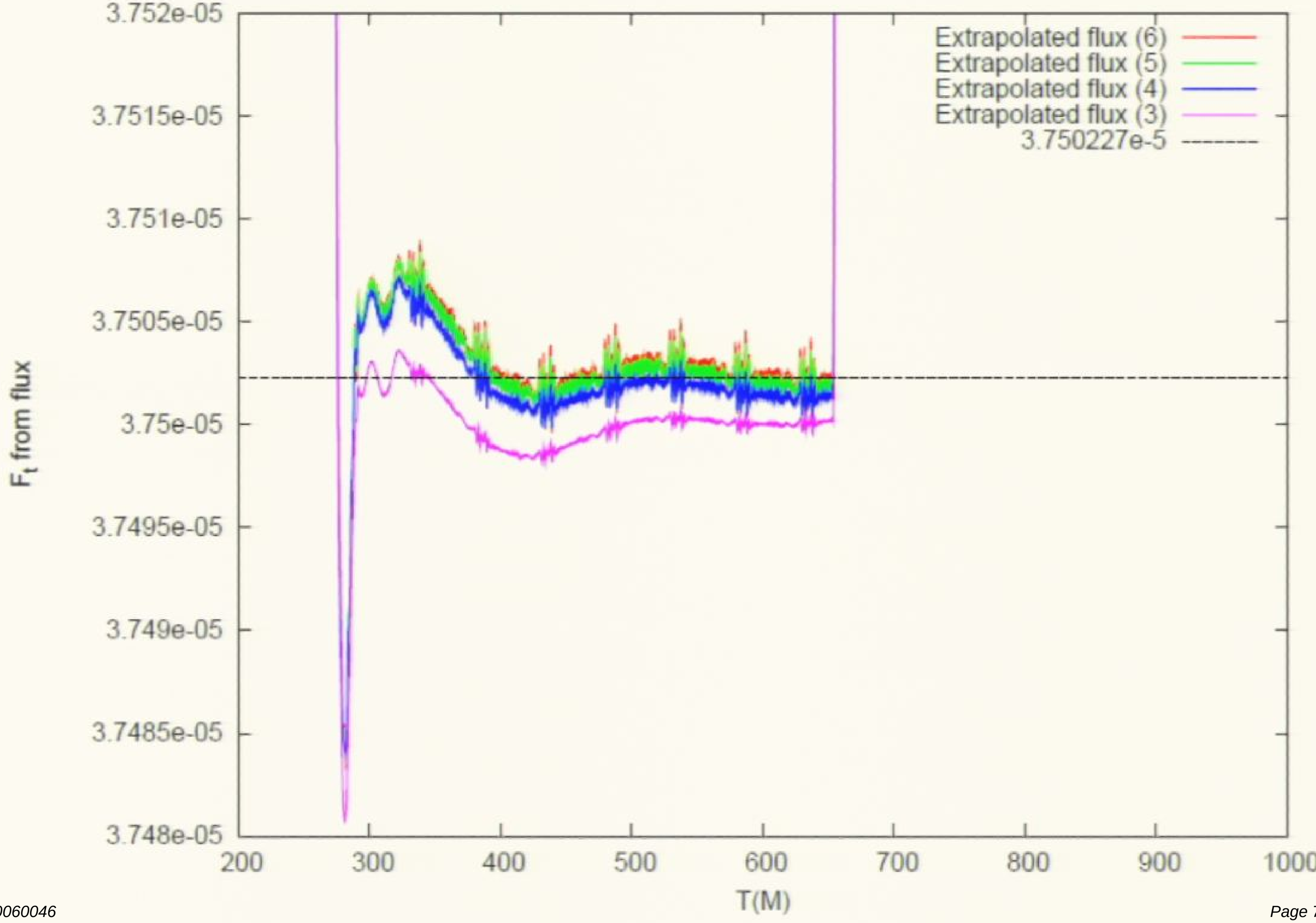
With this choice the coordinate speed of in- and outgoing null characteristics are:

$$c_- = 0, \qquad c_+ = S^2/C^2. \tag{7}$$



There are no incoming physical modes.

# New (and improved) results.



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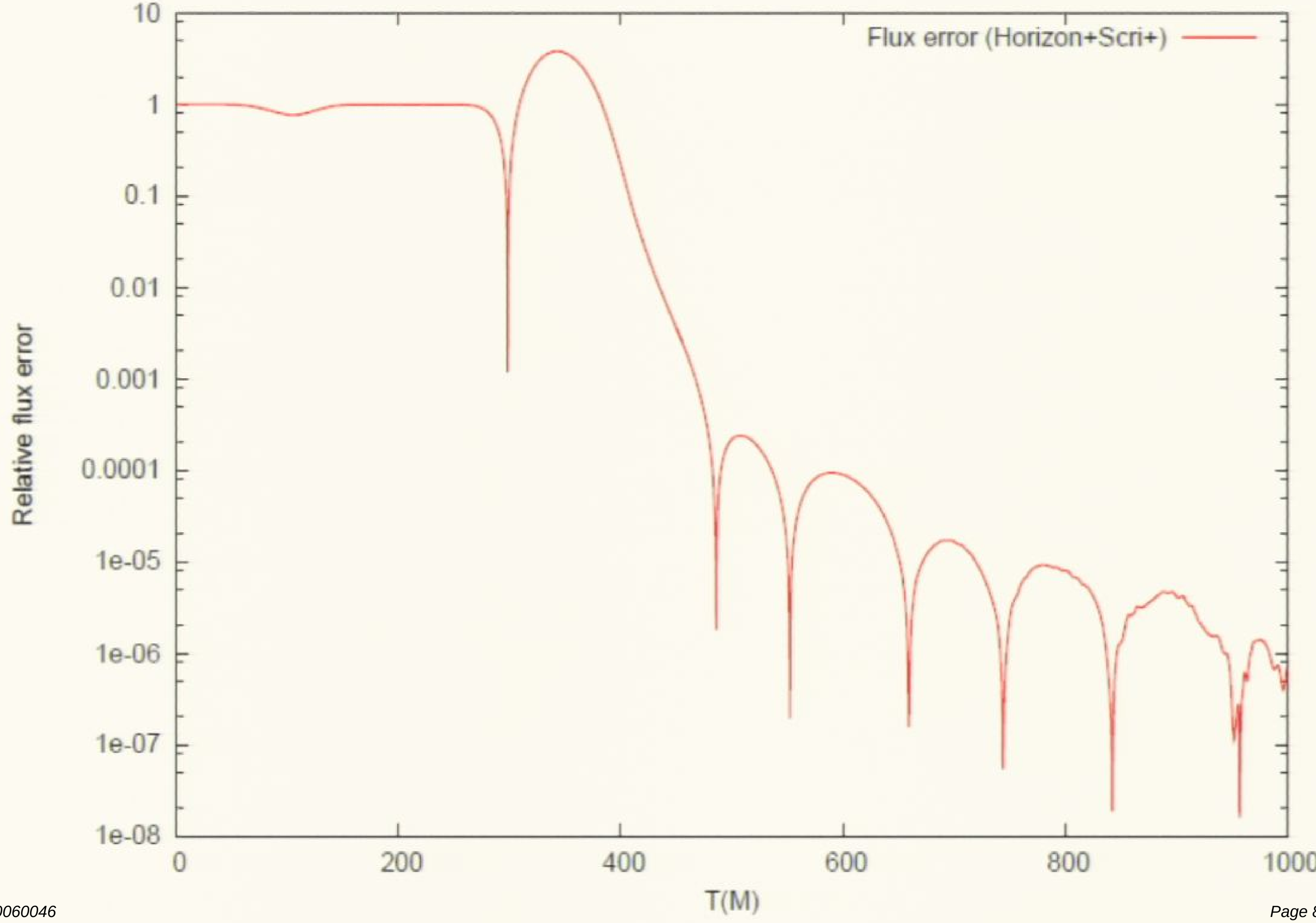

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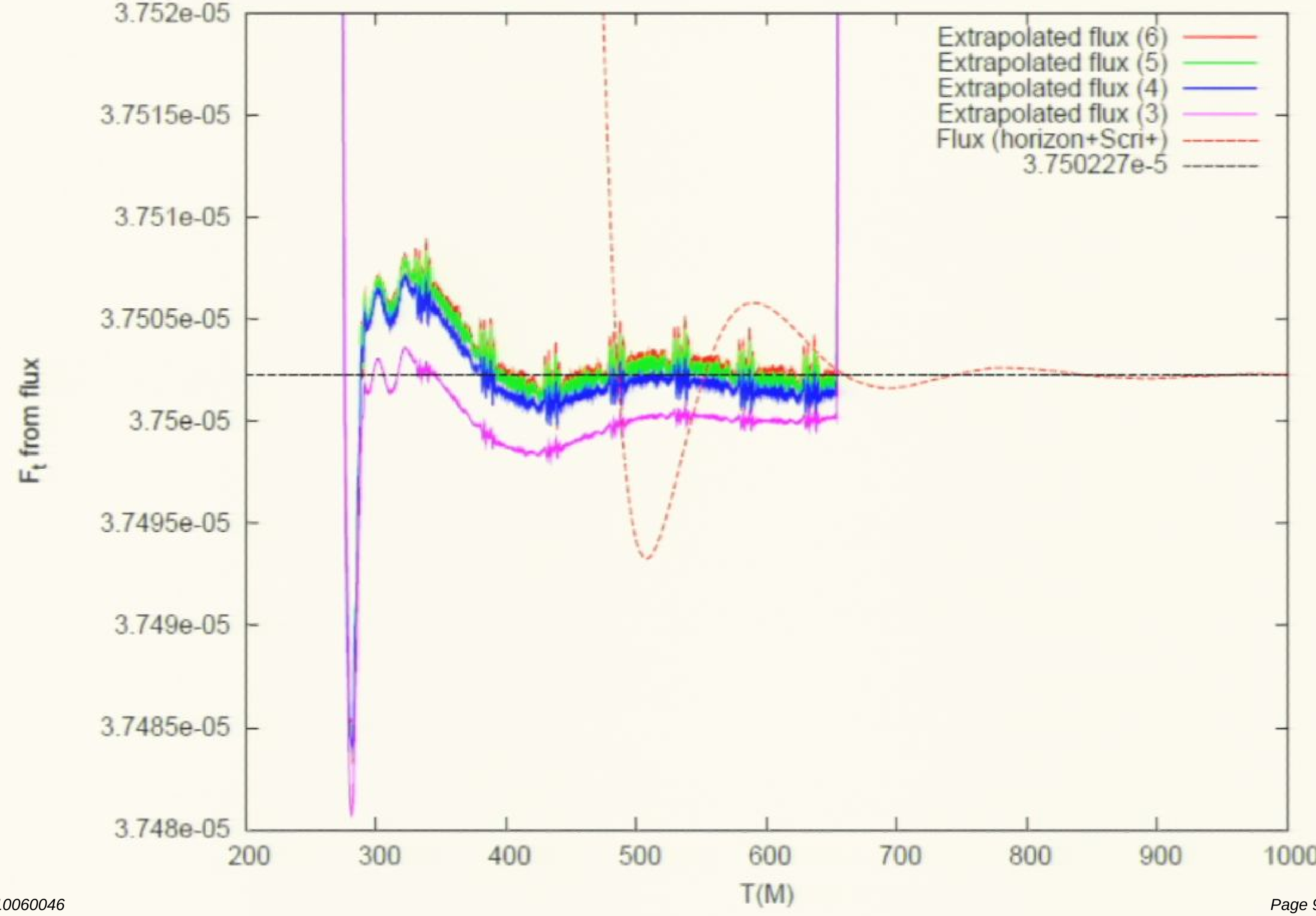

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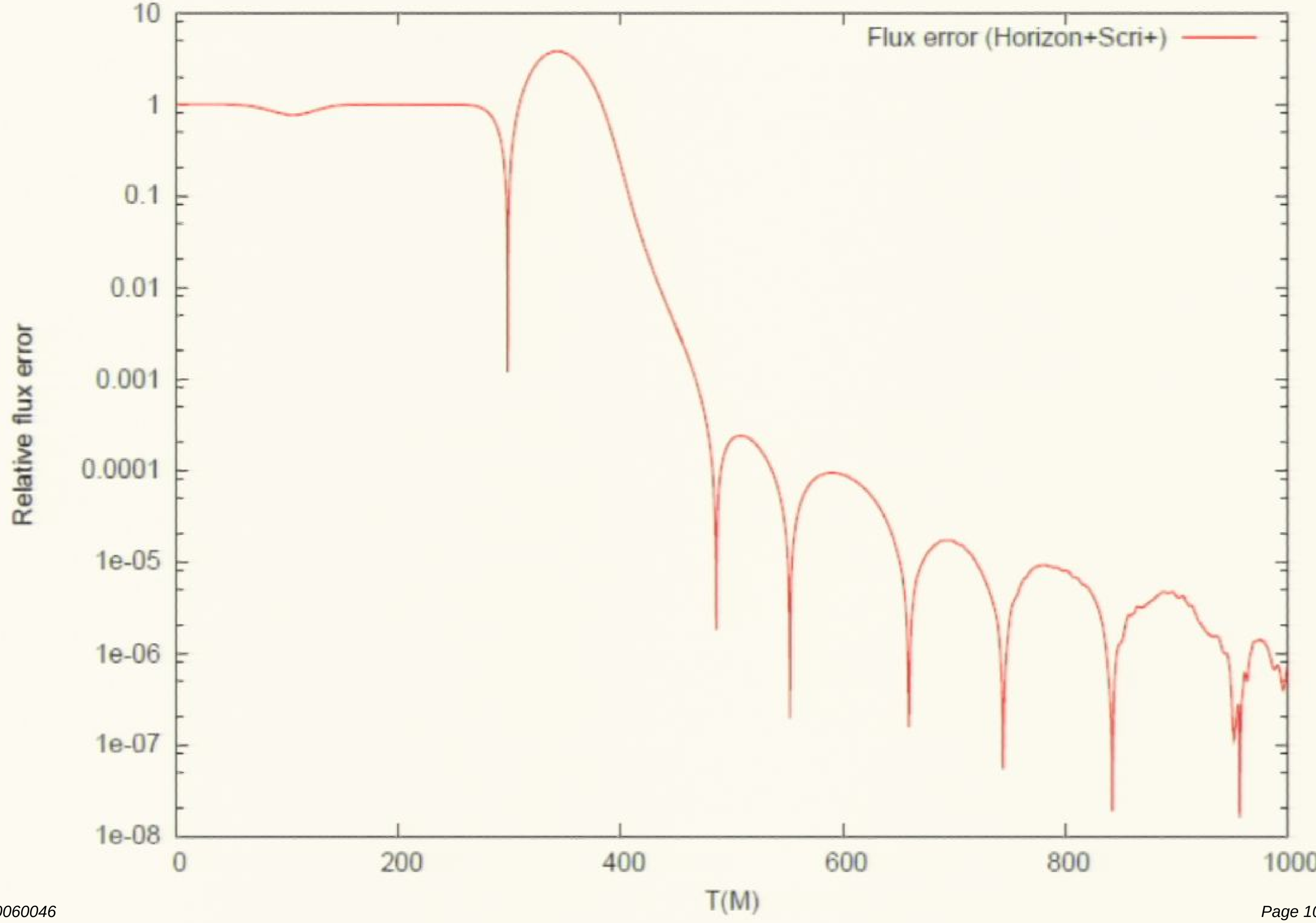

## Concluding remarks

- With the outer boundary located at $\mathscr{I}^+$ all fields are outgoing and no boundary conditions are necessary.
- The computational domain can be made quite small with no risk of reflections from the outer boundaray regardless of the length of the simulation.
- Running for longer times does not require a larger domain.
- All background curvature information needed to account for the late part of the tail is included on the computational domain.
- The source need not be modfied as long as $\rho_{\rm int}$ is chosen large enough that the source is zero in the transition region.
- The hyperboloidal slices are already implemented and tested for Kerr.
- I'm now ready for a general source (in both Schwarzschild and Kerr) to tackle eccentric orbits and (hopefully soon) long evolutions with the self-force calculated and taken into account at every timestep.

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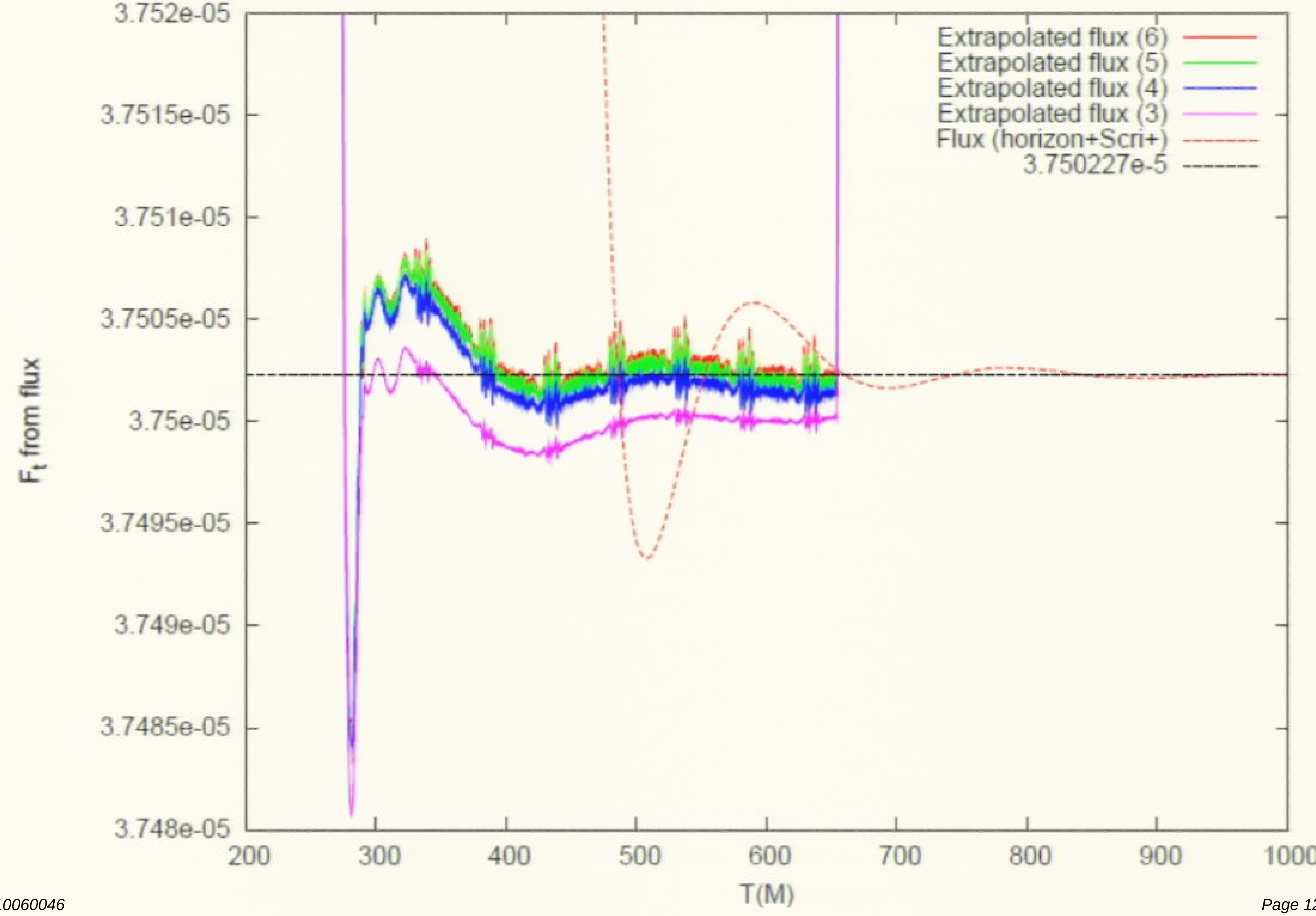

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