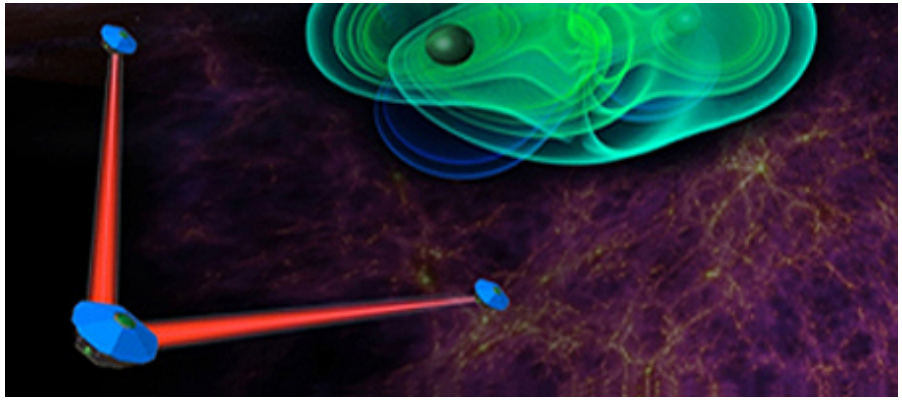
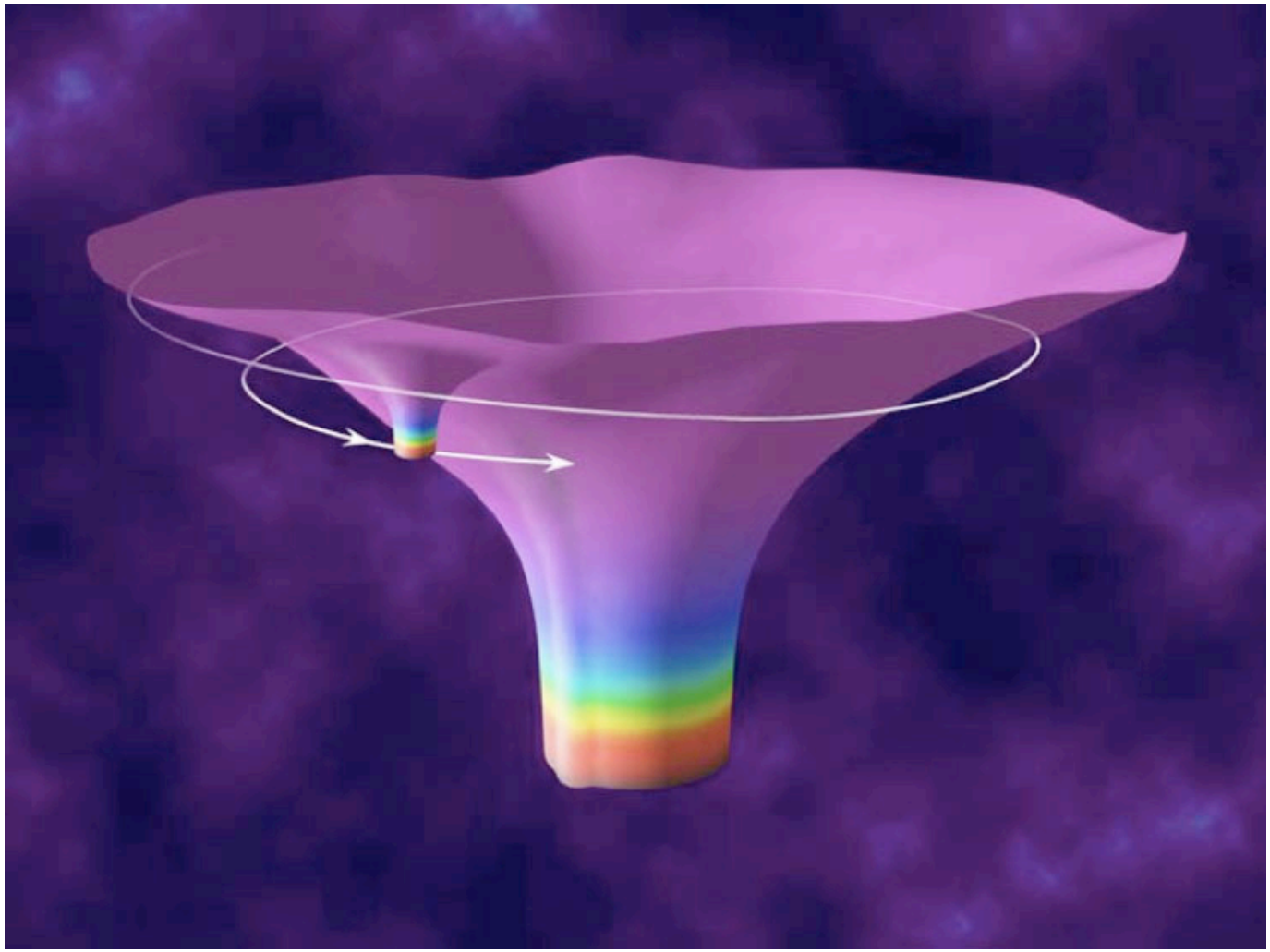
Self Force Orbit-Integrated gravitational waveforms for EMRIs

Lior Burko, Universite d'Orléans
Work with Kristen Lackeos (UAHuntsville)



Extreme Mass Ratio Inspirals



Credits: NASA

Sources for eLISA/NGO

- Galactic binaries
- Astrophysical black holes
- EMRIs
- GR tests
- Cosmology

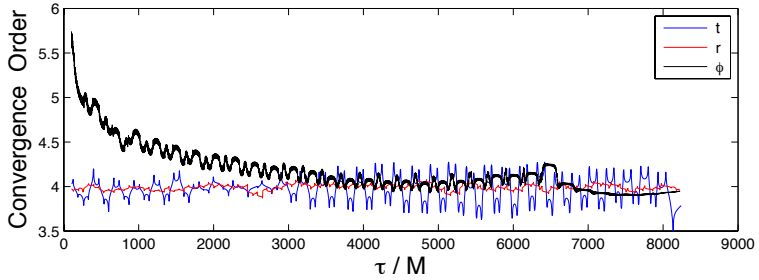
We choose mass ratio of 10^{-2}

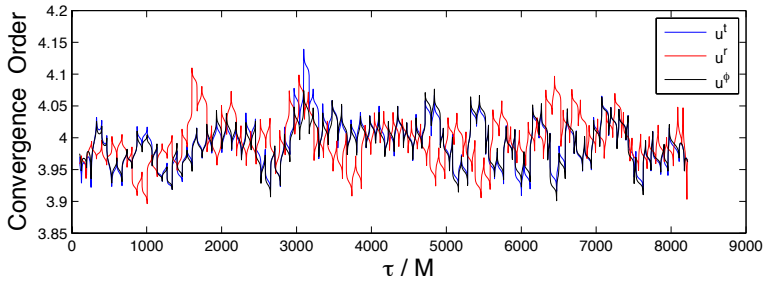
IMBH - MBH

NGO	LISA
expected rate: $1\,\mathrm{yr}^{-1}$ to $100\,\mathrm{yr}^{-1}$ expected number (2 year mission duration): 10 to 20	expected rate: $10\,\mathrm{yr}^{-1}$ to $1000\,\mathrm{yr}^{-1}$ expected number (5 year mission duration): a few tens
Capability to detect gravitational waves emitted during the last two years of inspiral for a stellar-mass compact object ($m_2 \sim 5\,\mathrm{M}_\odot - 20\,\mathrm{M}_\odot$) orbiting a massive black hole ($m_1 \sim 10^5\,\mathrm{M}_\odot - 10^6\,\mathrm{M}_\odot$) up to $z = 0.7$ with an SNR > 20. Determine the mass with an relative error smaller than 0.1 %, the spin of the MBH with an error smaller than 10^{-3}, and the mass of the compact object with a relative error smaller than 0.1 %, as well as the orbital eccentricity before the plunge with an error smaller than 10^{-3}.	Capability to detect gravitational waves emitted during the last year of inspiral for a stellar-mass compact object ($m_2 \sim 5\,\mathrm{M}_\odot \ldots 100\,\mathrm{M}_\odot$) orbiting a massive black hole (with $m_1 \sim 10^5\,\mathrm{M}_\odot \ldots$ few $\times\, 10^6\,\mathrm{M}_\odot$) at $z = 1$ with SNR > 30 (averaged over source locations and orientations)
Capability to detect gravitational waves emitted by a $10^2\,\mathrm{M}_\odot - 10^4\,\mathrm{M}_\odot$ IMBH spiralling into an MBH with mass $3 \times 10^5\,\mathrm{M}_\odot - 10^7\,\mathrm{M}_\odot$ out to $z \sim 2 - 4$ (for a mass ratio around 10^{-2} to 10^{-3}).	Capability to detect gravitational waves emitted by a $10^3\,\mathrm{M}_\odot - 10^4\,\mathrm{M}_\odot$ intermediate-mass black hole (IMBH) spiralling into an MBH with mass in the range $3 \times 10^5\,\mathrm{M}_\odot - 10^6\,\mathrm{M}_\odot$ out to $z = 3$ (with SNR ~ 30).

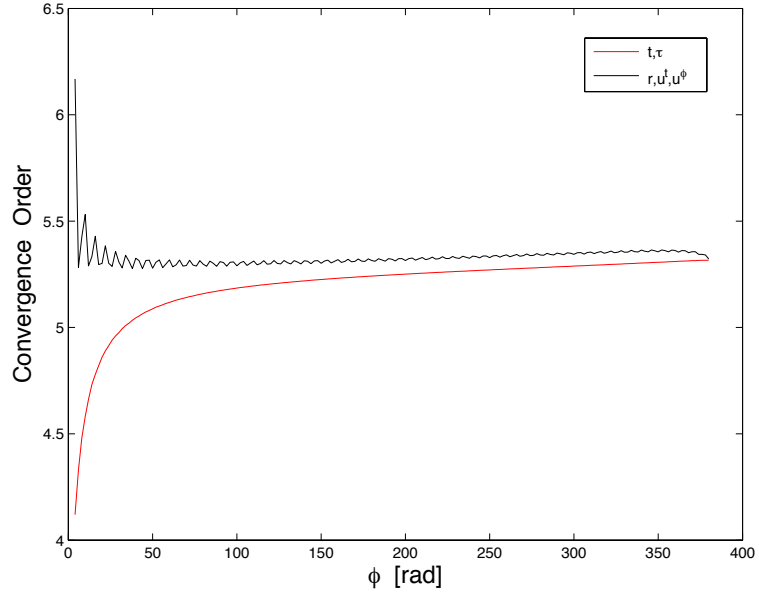
Credits: eLISA/NGO

Code development: convergence

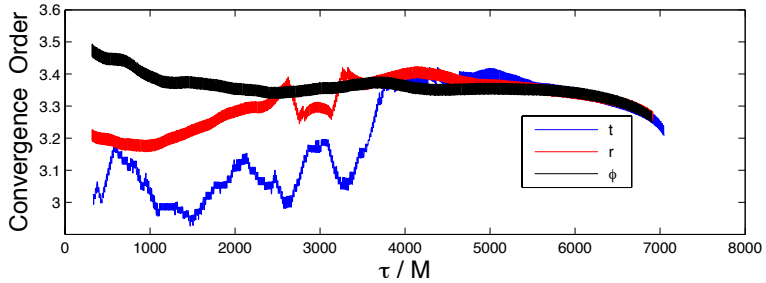


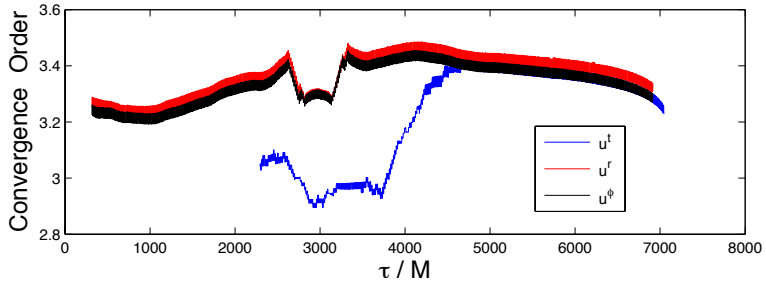


Direct Code



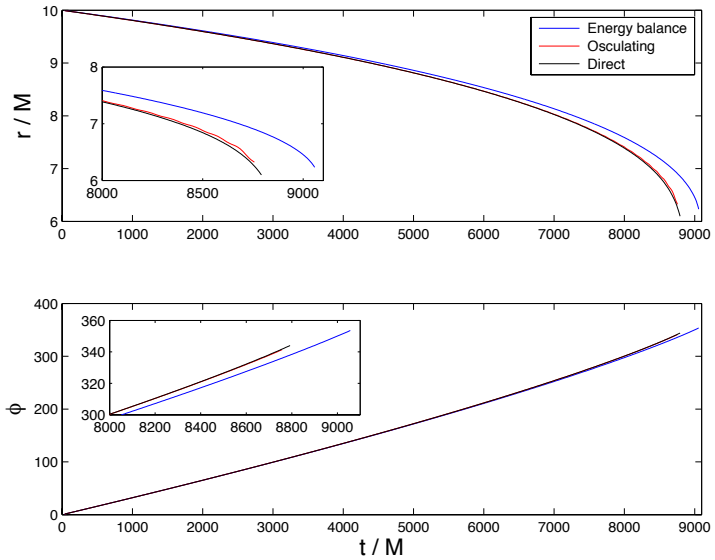
Osculating Code

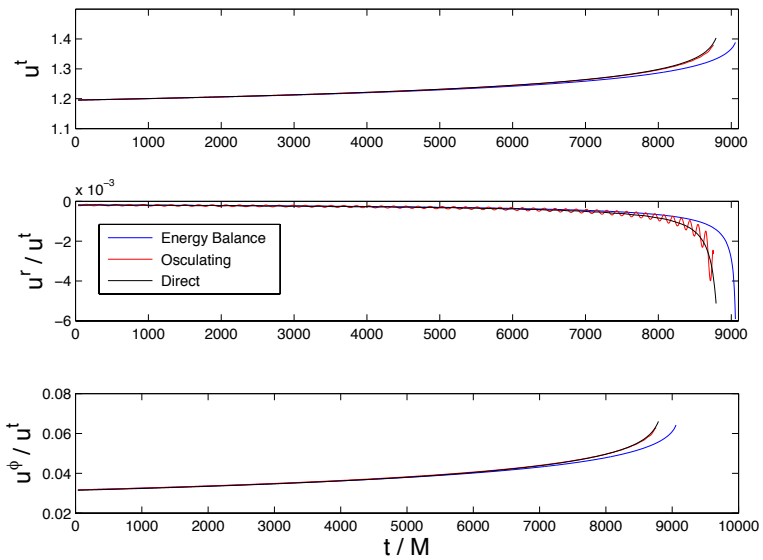


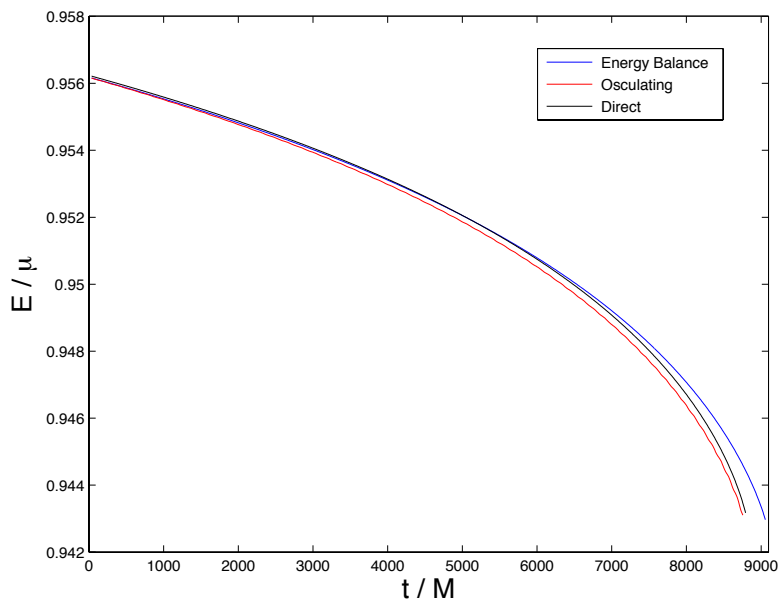


Energy Balance Code

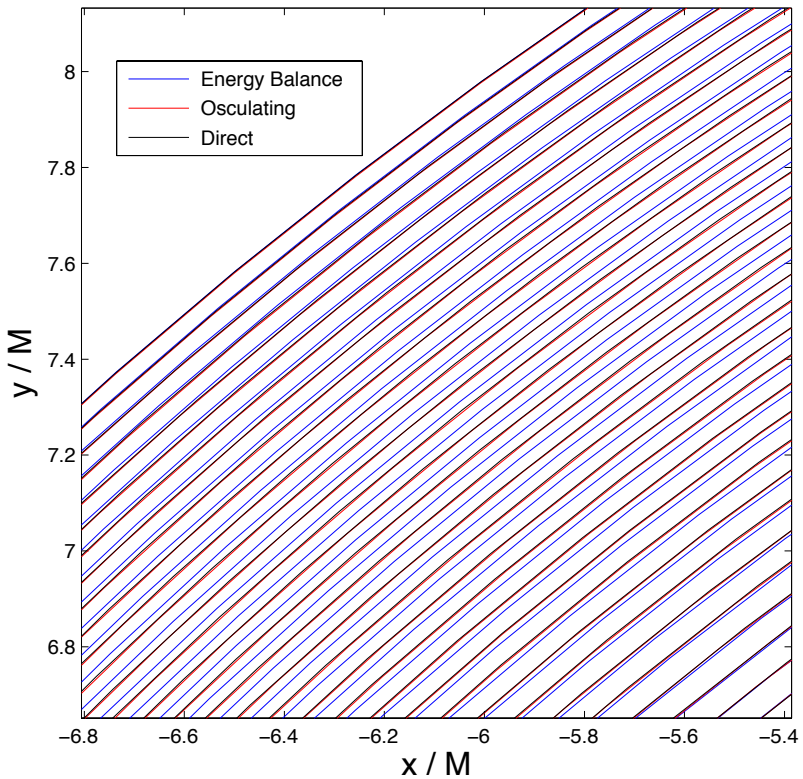
The Orbit

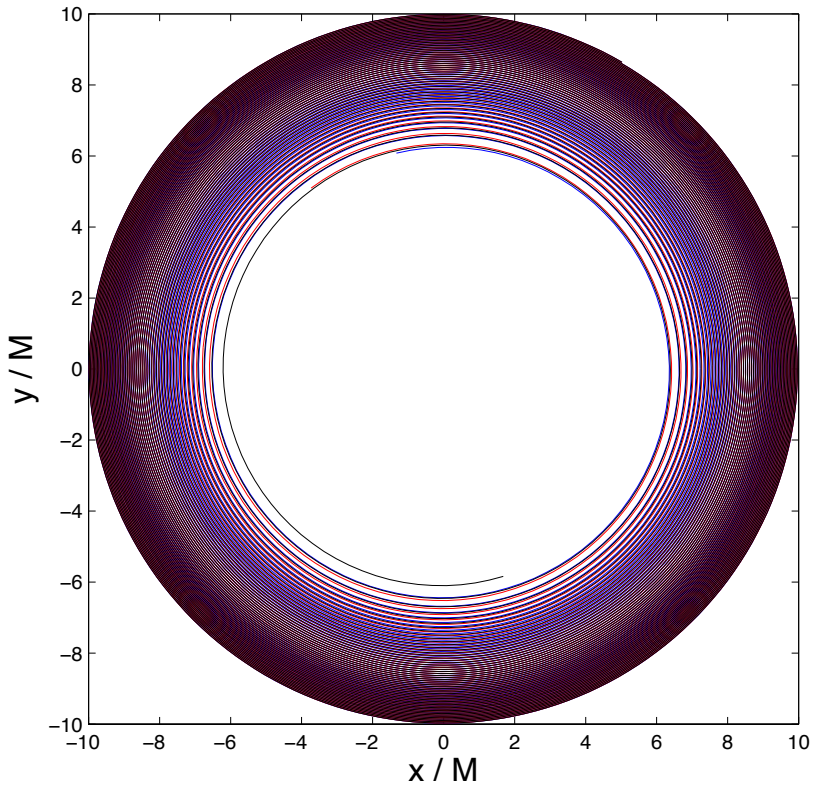

Energy balance
Osculating
Direct
r / M
ϕ
t / M


u^t
u^r / u^t
x 10^{-3}
Energy Balance
Osculating
Direct
u^ϕ / u^t
t / M

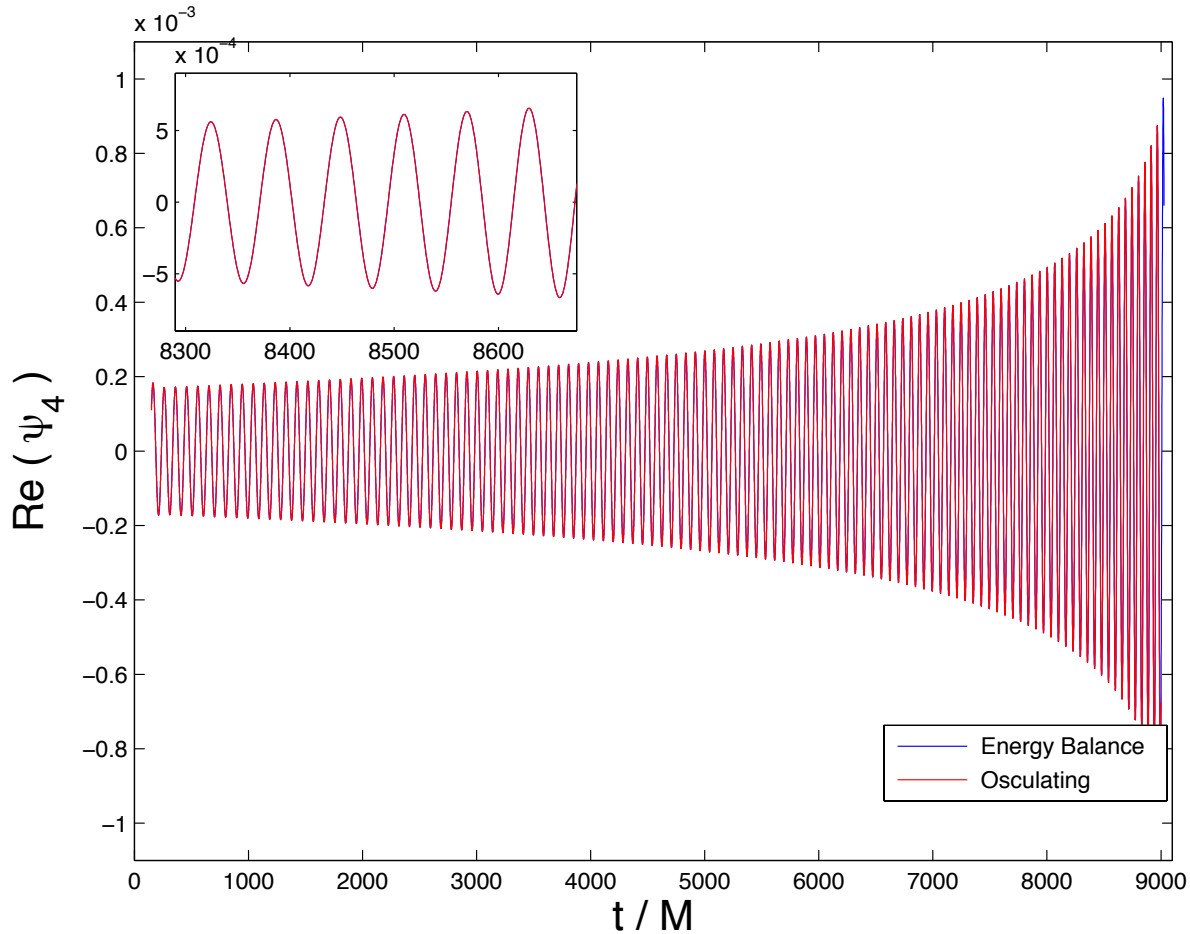

Energy Balance
Osculating
Direct
E / μ
t / M

The Orbit


Energy Balance
Osculating
Direct
y / M
x / M
8
7.8
7.6
7.4
7.2
7
6.8
−6.8
−6.6
−6.4
−6.2
−6
−5.8
−5.6
−5.4

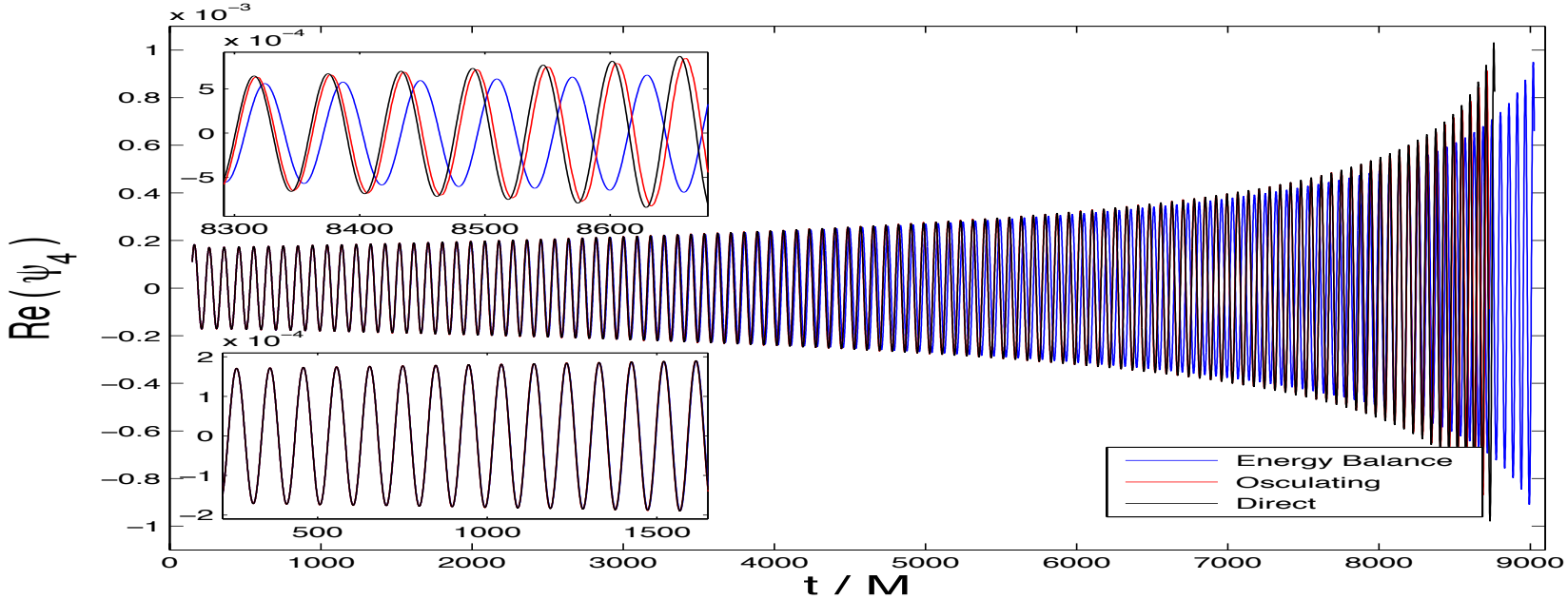

y / M
x / M
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10

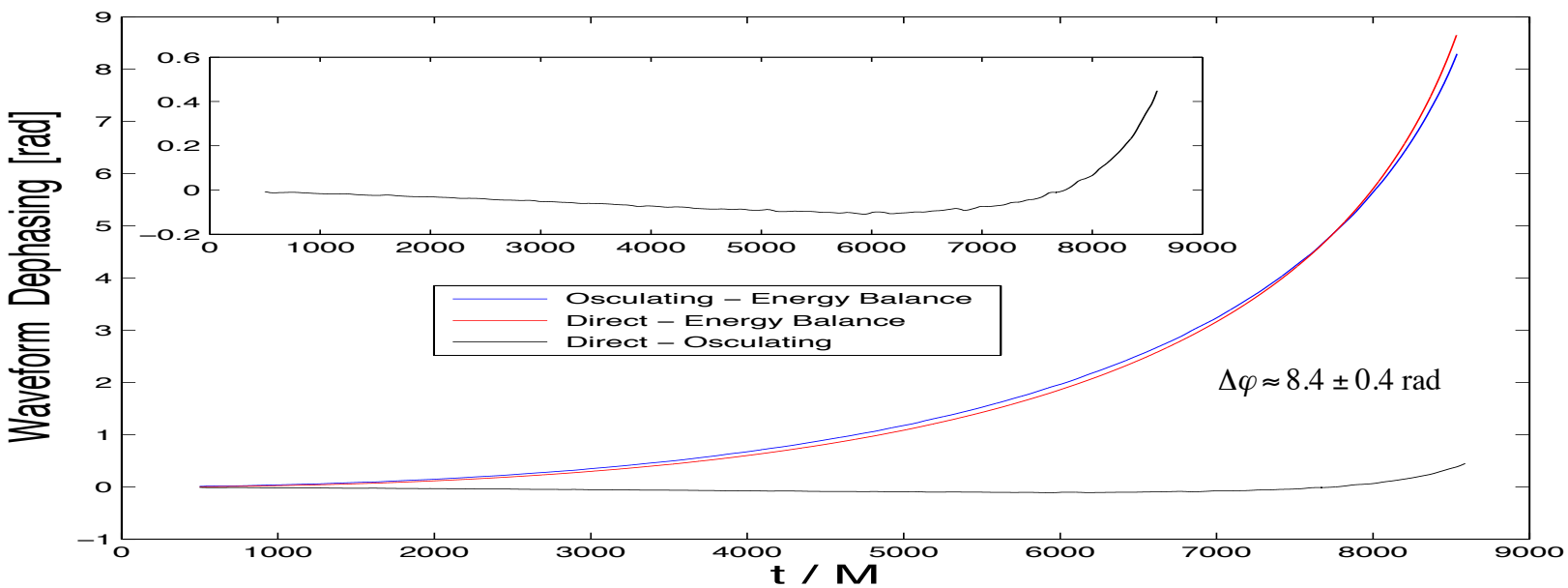
Testing the waveforms: Conservative effects turned off



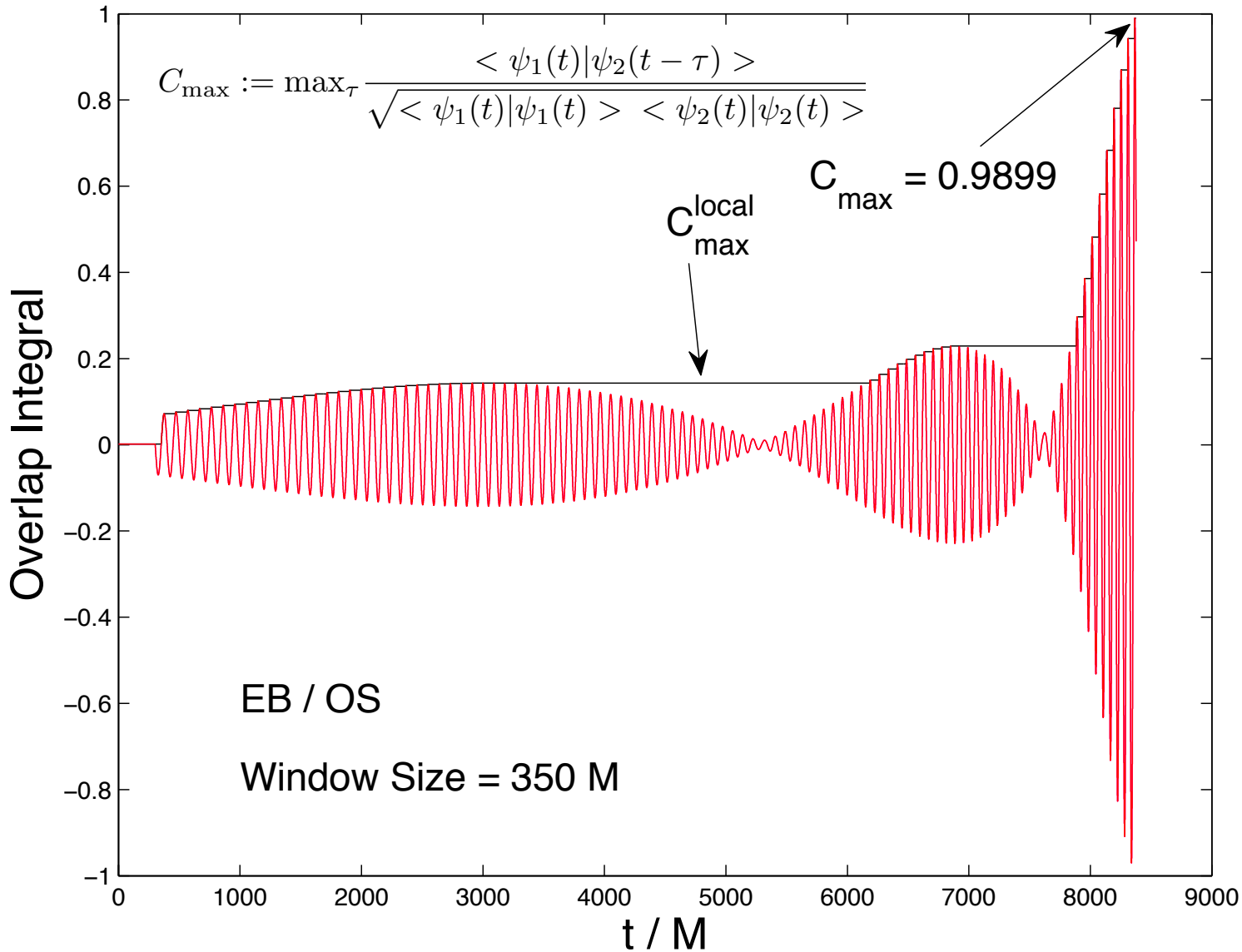
$$f_\mu^{\rm SF} = \underbrace{f_t\,\delta_\mu^t + f_\phi\,\delta_\mu^\phi}_{\text{dissipative}} + \underbrace{f_r\,\delta_\mu^r}_{\text{conservative}}$$

The waveforms: Effect of the conservative self force

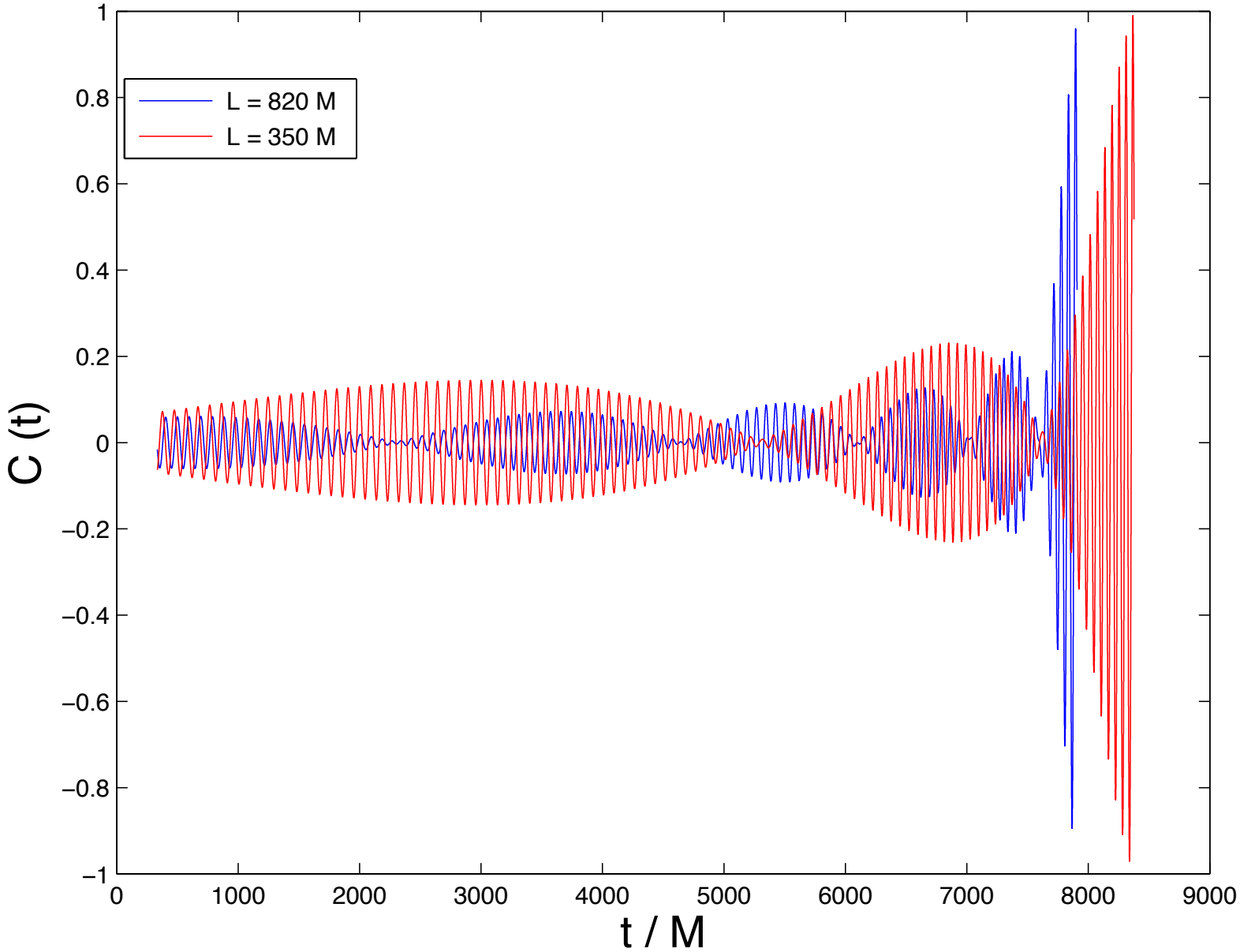




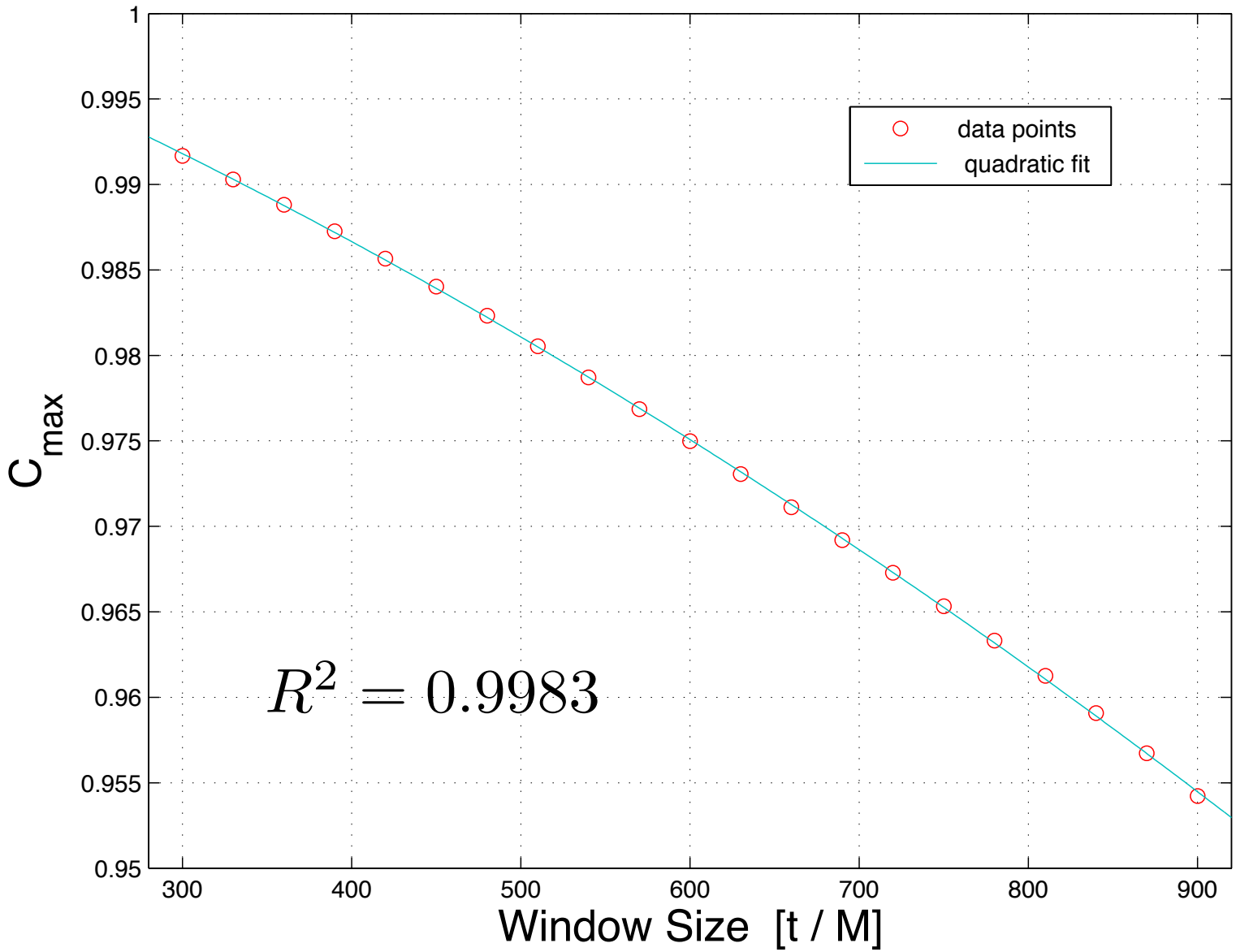
The waveforms: Effect of the conservative self force



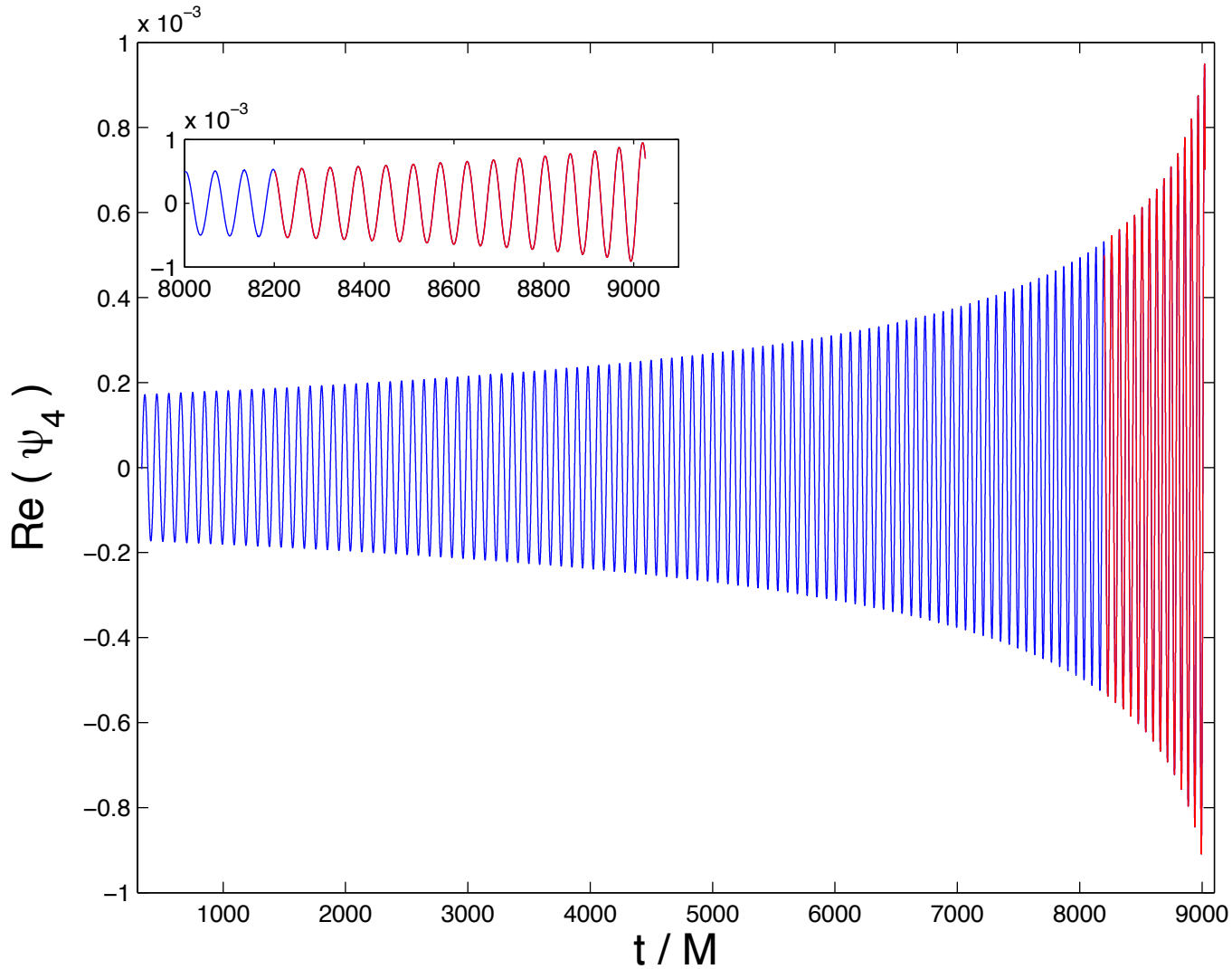
The waveforms: Effect of the conservative self force



The waveforms: Effect of the conservative self force



The waveforms: Effect of the conservative self force



Future Directions

- Eccentric orbits in Schwarzschild (straightforward – Warburten et al.)
- Kerr orbits
- (True) self consistent waveforms