Kicks in charged black hole binaries

Raimon Luna, University of Valencia

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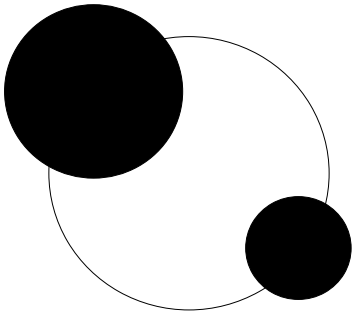

Based on:
Raimon Luna, Gabriele Bozzola, Vitor Cardoso, Vasileios Paschalidis, Miguel Zilhão:
Phys.Rev.D 106 (2022) 8, 8 • e-Print: 2207.06429 [gr-qc]

What are kicks?

Inspiralling black hole binaries emit:

- Energy
- Angular momentum

} → Leading to merger

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These are emitted in the form of:

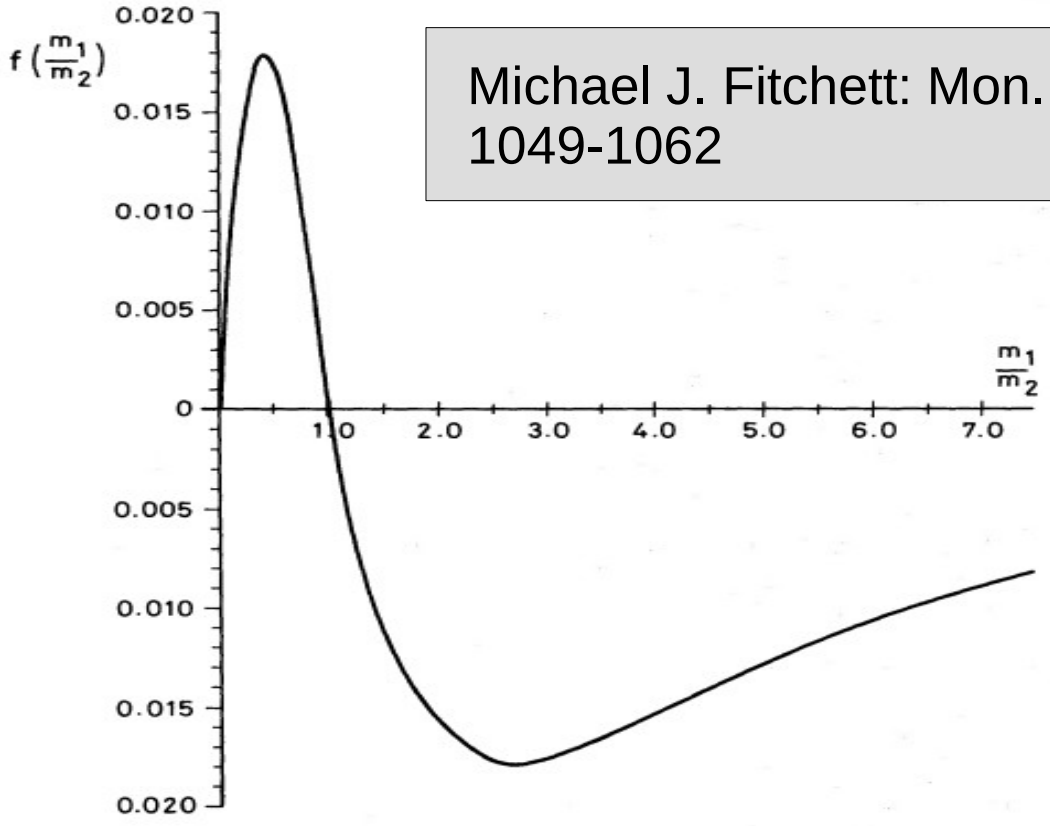
- Gravitational waves
- If charged: Electromagnetic waves
- Possibly other fields

Gravitational wave kicks

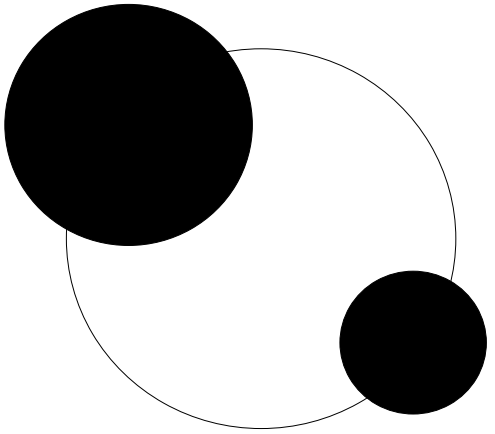
$$I^i = G(945c^6)^{-1}(22Q^{jk}B^{jki} - 12Q^{jk}B^{jik} - 12Q^{ji}B^{jkk})$$

Jacob, D. Bekenstein: Astrophys.J. 183 (1973) 657-664

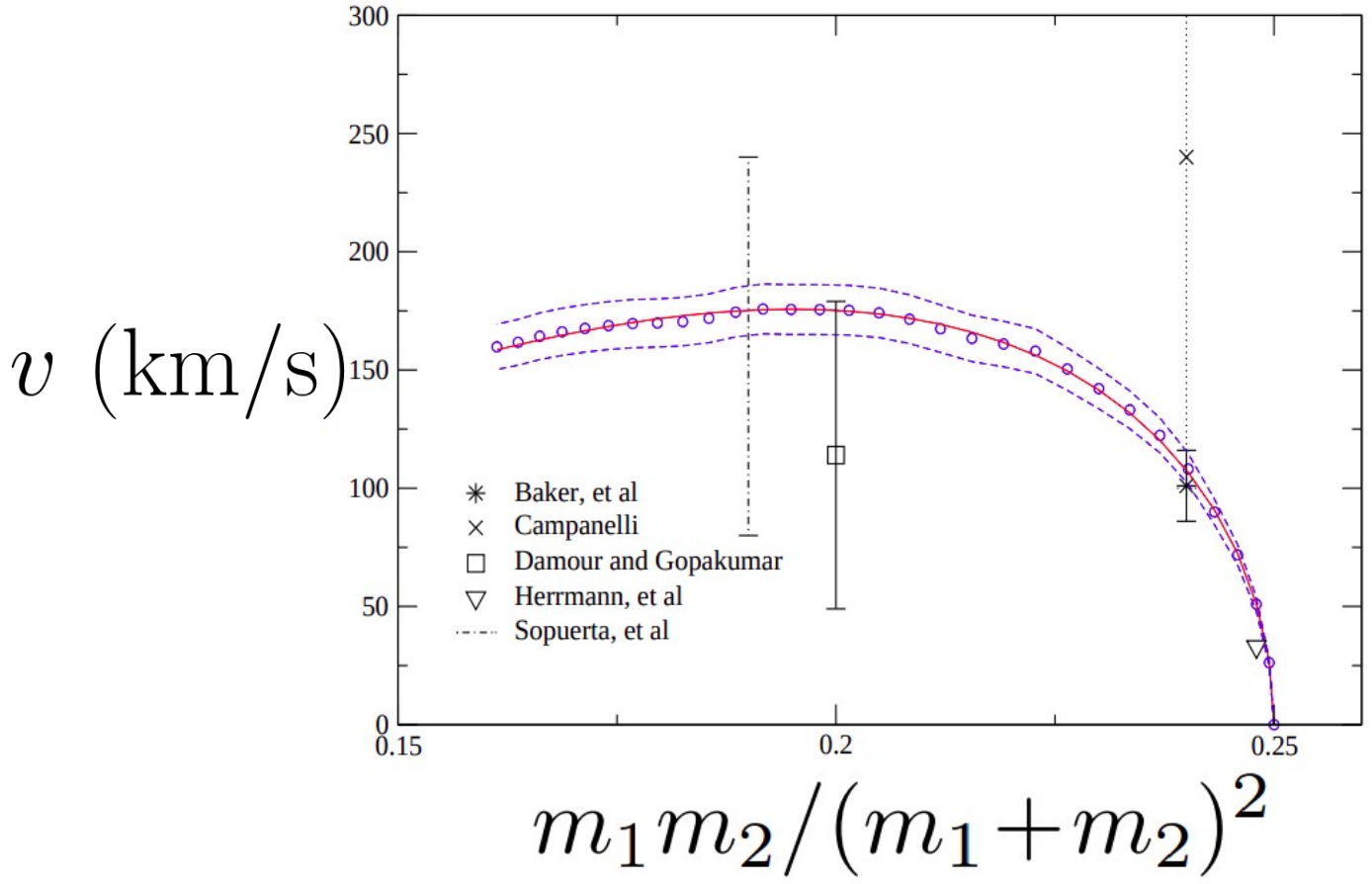
$$f(m_1/m_2) = (1 + m_2/m_1)^{-2}\,(1 + m_1/m_2)^{-3}\,(1 - m_1/m_2)$$



Michael J. Fitchett: Mon. Not. R. astr. Soc. (1983) 203, 1049-1062



Gravitational wave kicks: numerical simulations



Jose A. Gonzalez, Ulrich Sperhake, Bernd Bruegmann, Mark Hannam, Sascha Husa: Phys.Rev.Lett. 98 (2007) 091101 • e-Print: gr-qc/0610154 [gr-qc]

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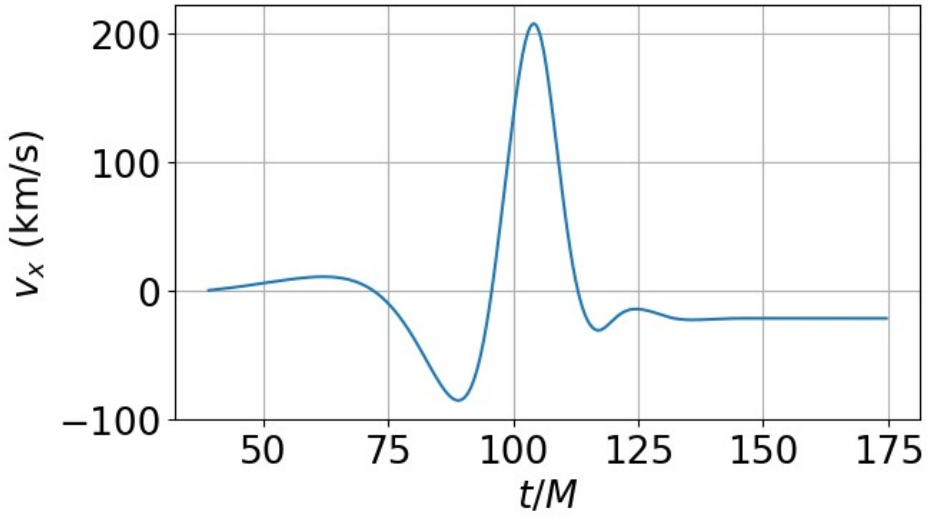
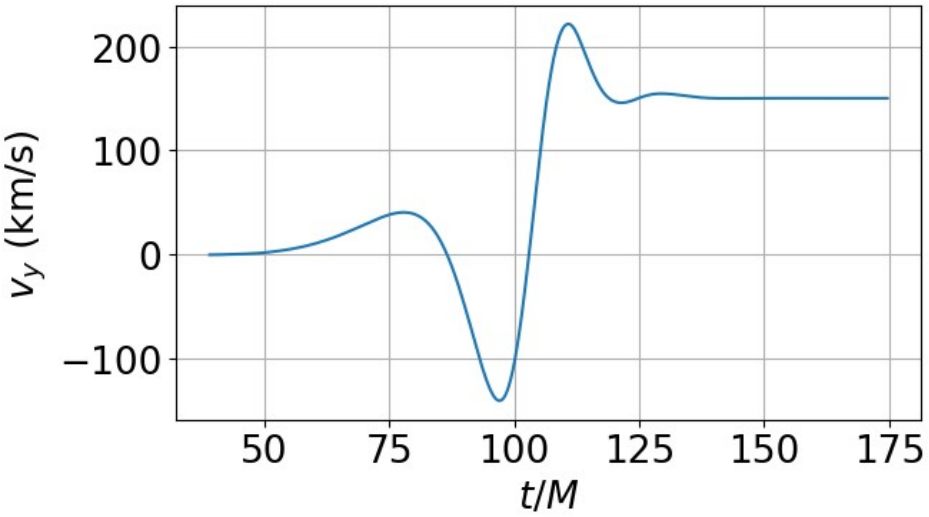
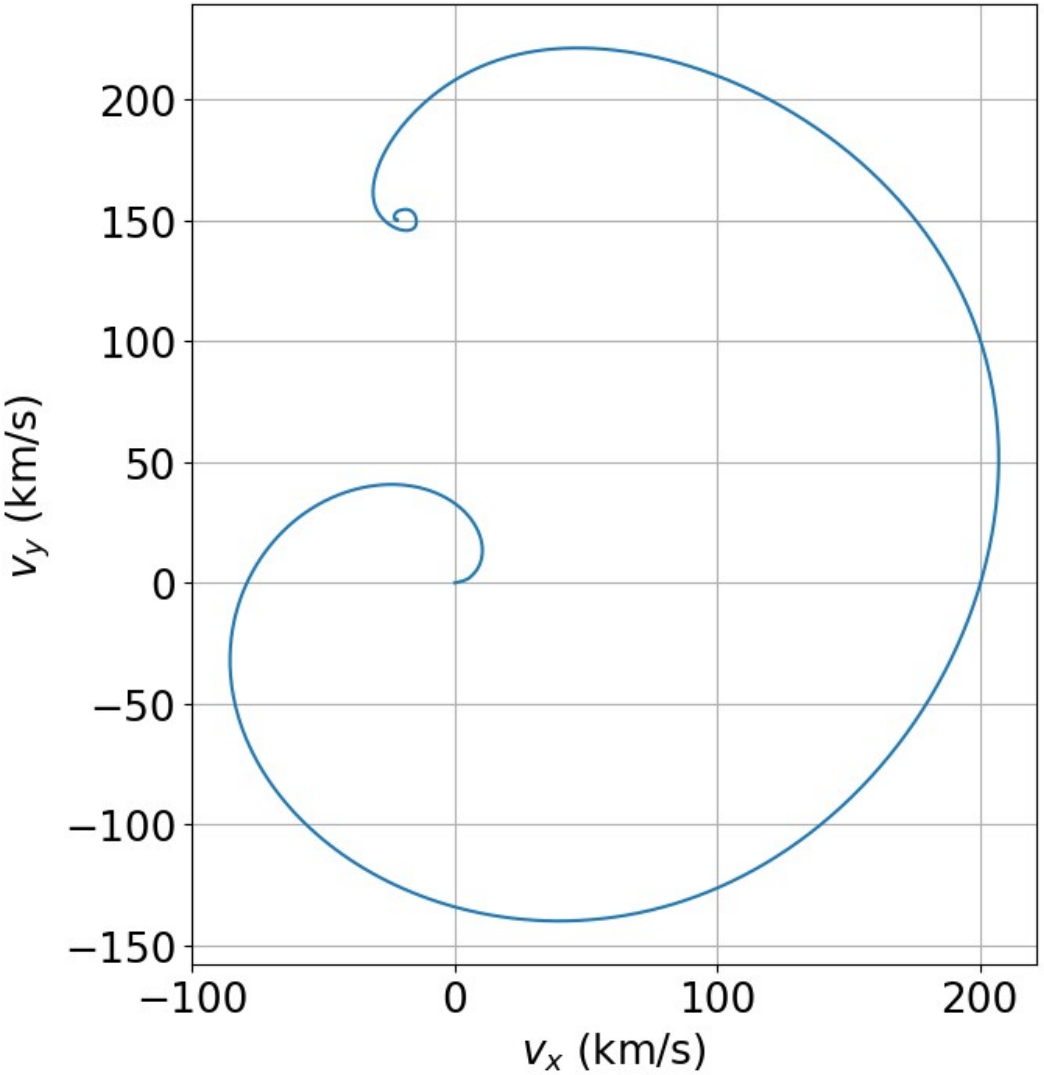
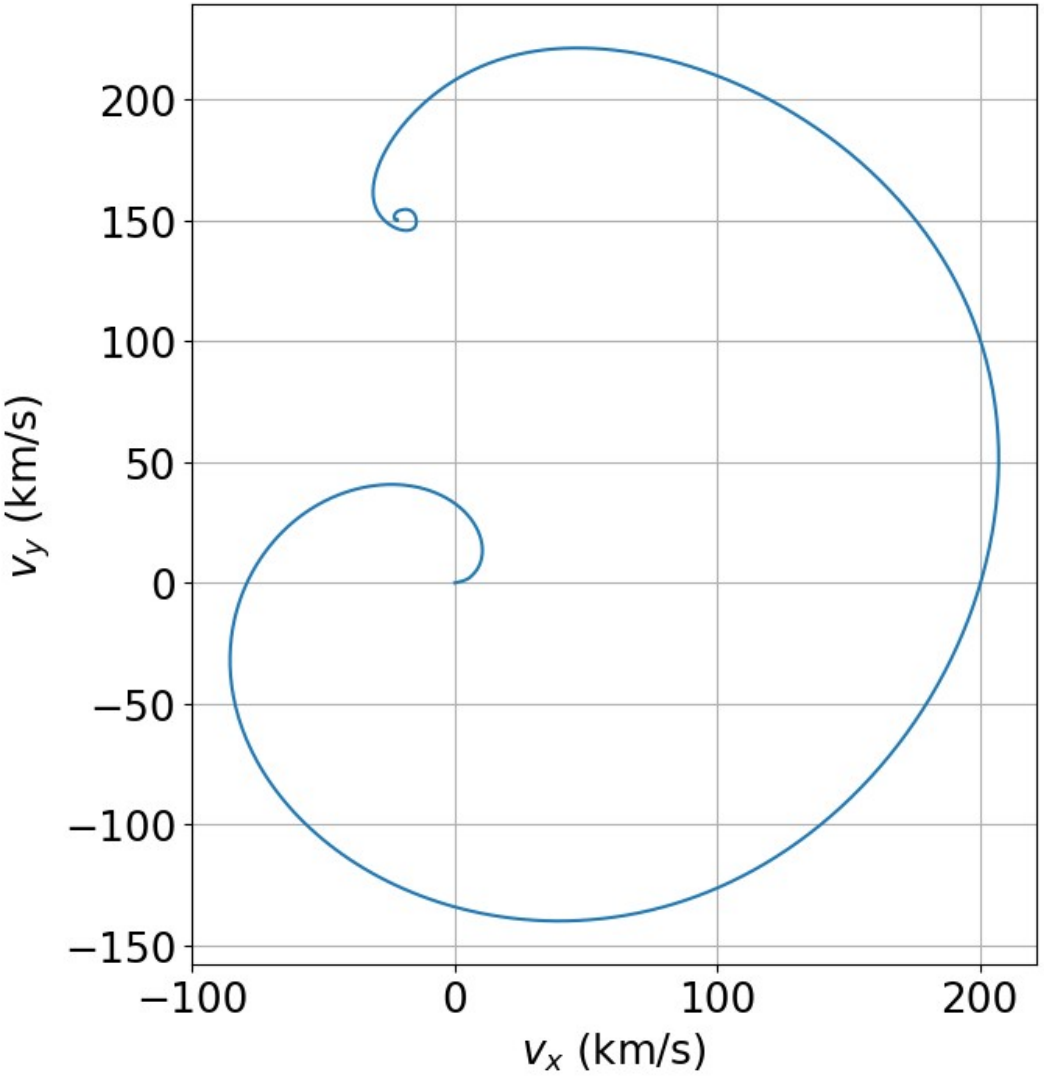


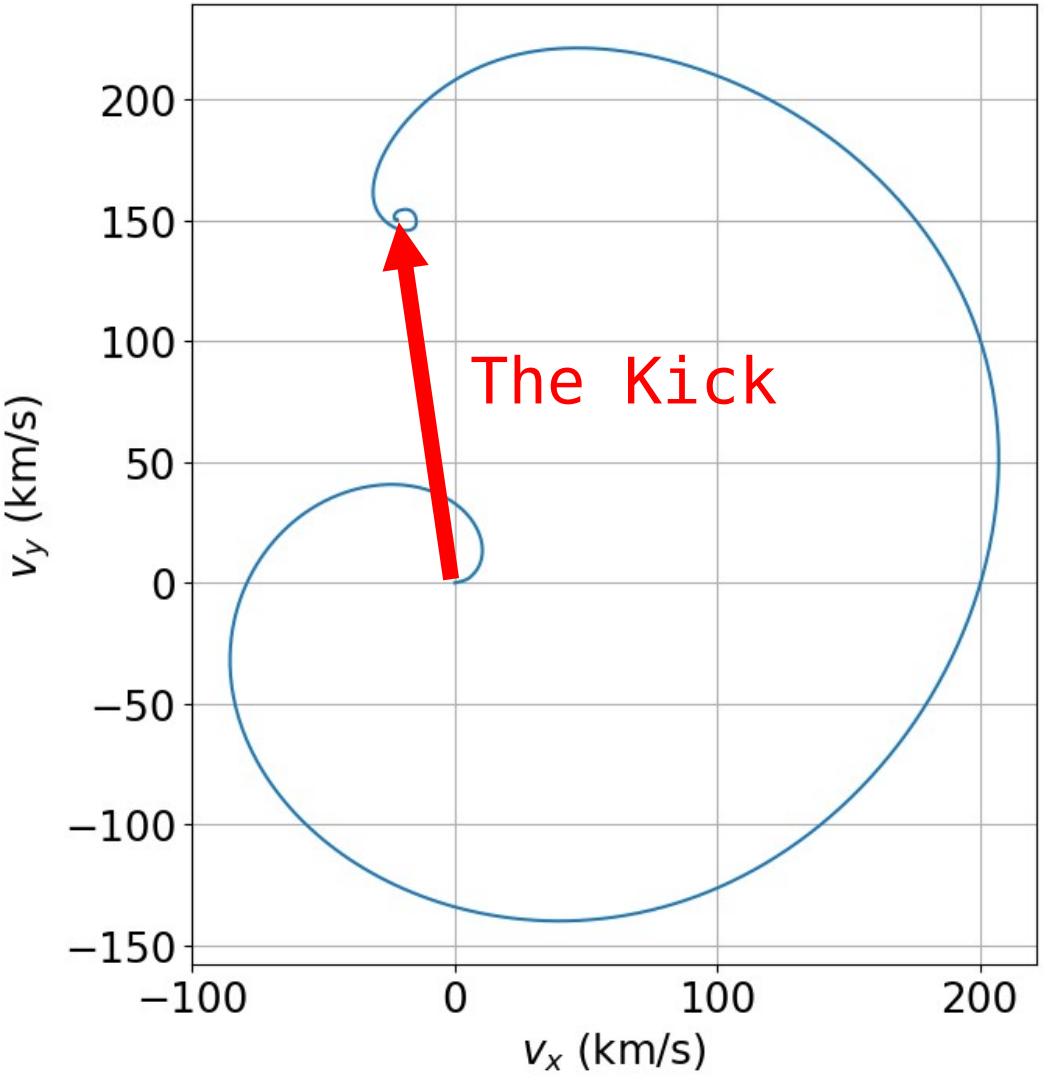




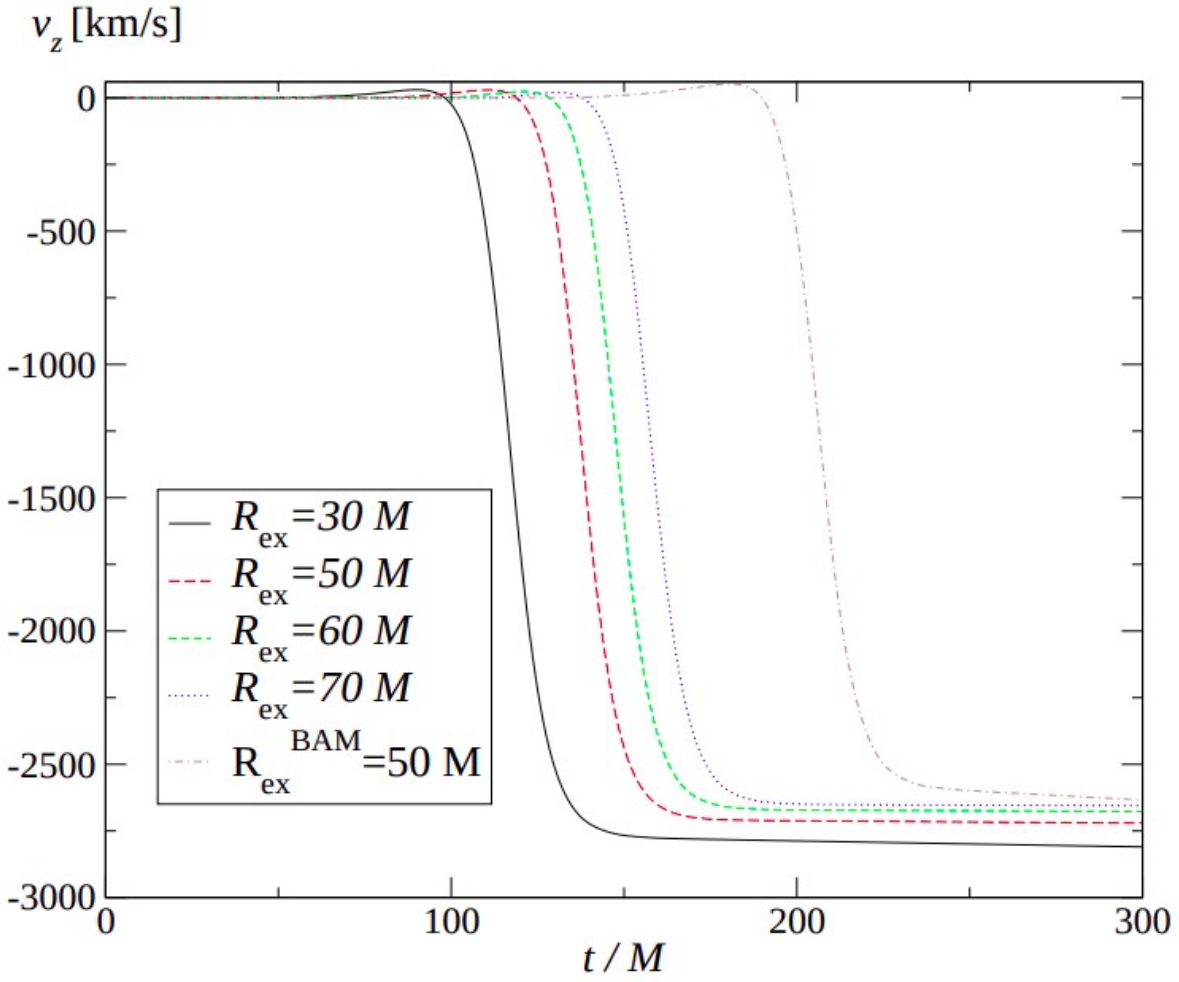
Gravitational wave kicks: numerical simulations



Gravitational wave kicks: numerical simulations



Adding spin: Superkicks



Jose A. Gonzalez, Mark Hannam, Ulrich Sperhake, Bernd Bruegmann, Sascha Husa: Phys.Rev.Lett. 98 (2007) 231101 • e-Print: gr-qc/0702052 [gr-qc]

Adding charge: Electromagnetic kicks

$$\frac{dP^i_{\rm EM}}{dt} = \frac{1}{15}\ddot{D}^j\dddot{Q}^{ji} - \ddot{D}^j\ddot{M}^{ji}$$

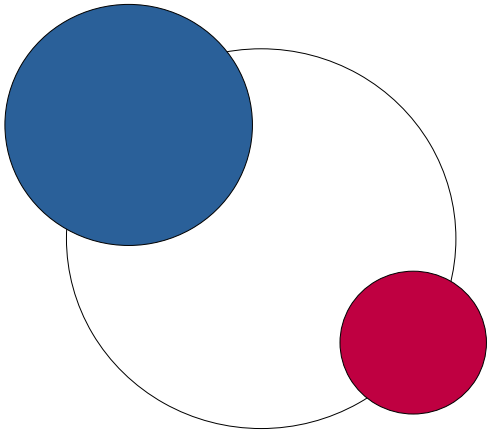
$$\frac{dP_{\rm EM}}{dt} = \frac{4}{5}\left(\frac{M}{d}\right)^{9/2}\frac{(1-\lambda_1\lambda_2)^{5/2}\rho^2}{(1+\rho)^5}(\lambda_1-\lambda_2)(\lambda_1+\rho\lambda_2)$$

$$M = m_1 + m_2\,, \quad \rho = \frac{m_1}{m_2}\,, \quad \lambda_i = \frac{q_i}{m_i}$$

Then the zeros should be at

$$\lambda_2 = \lambda_1, -\lambda_1/\rho$$

Are they?



Numerical framework: Einstein Toolkit / Cactus

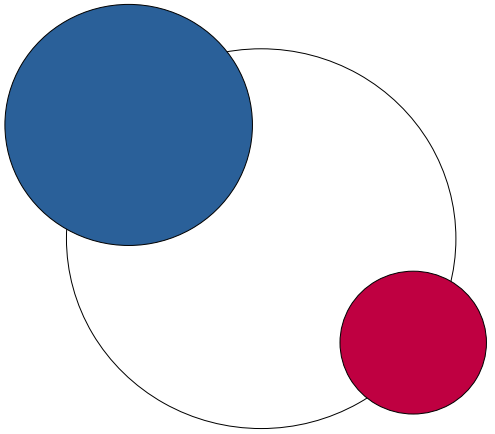
Initial data for black hole binaries:
TwoChargedPunctures

Analysis of quasilocal quantities:
QuasiLocalMeasuresEM

> Gabriele Bozzola, Vasileios Paschalidis:
> Phys.Rev.D 99 (2019) 10, 104044
> e-Print: 1903.01036 [gr-qc]

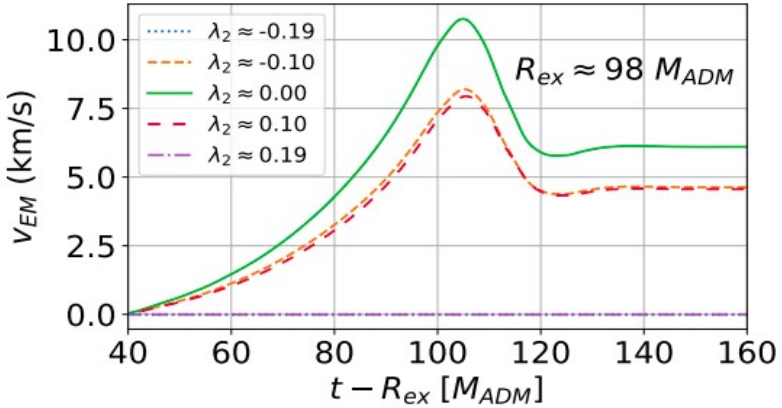
3+1 BSSN evolution of Einstein-Maxwell:
Lean, Proca

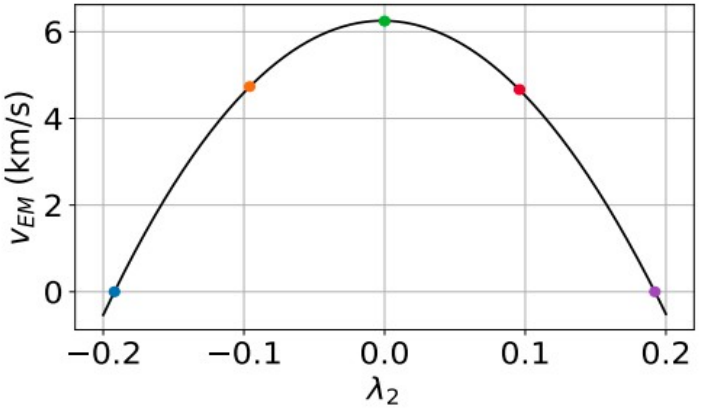
> Miguel Zilhão, Helvi Witek, Vitor Cardoso:
> Class.Quant.Grav. 32 (2015) 234003
> e-Print: 1505.00797 [gr-qc]



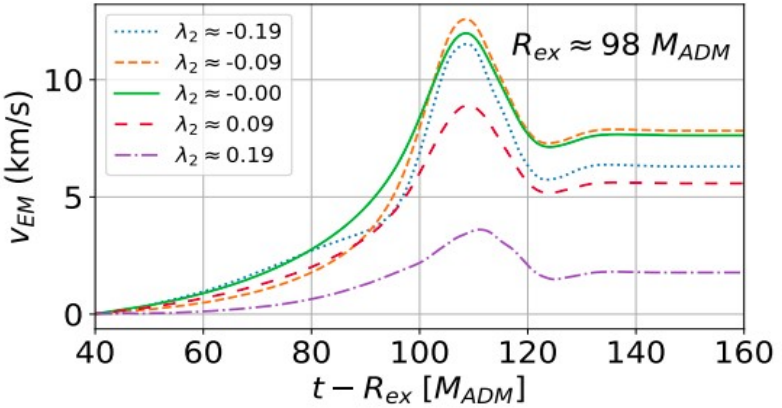
Adding charge: Electromagnetic kicks

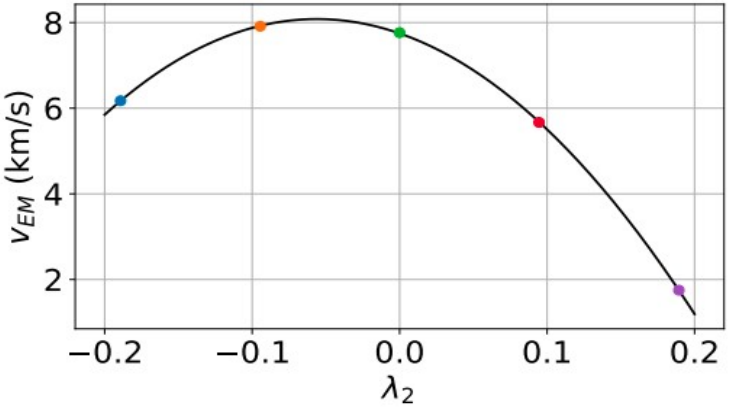
Newtonian / Keplerian prediction: $$\left.\frac{d\vec{P}}{dt}\right|_{\rm EM} \sim \underbrace{\left(\frac{q_1}{m_1}-\frac{q_2}{m_2}\right)}_{\rm Dipole}\underbrace{\left(\frac{q_1}{m_1^2}+\frac{q_2}{m_2^2}\right)}_{\rm Quadrupole}$$





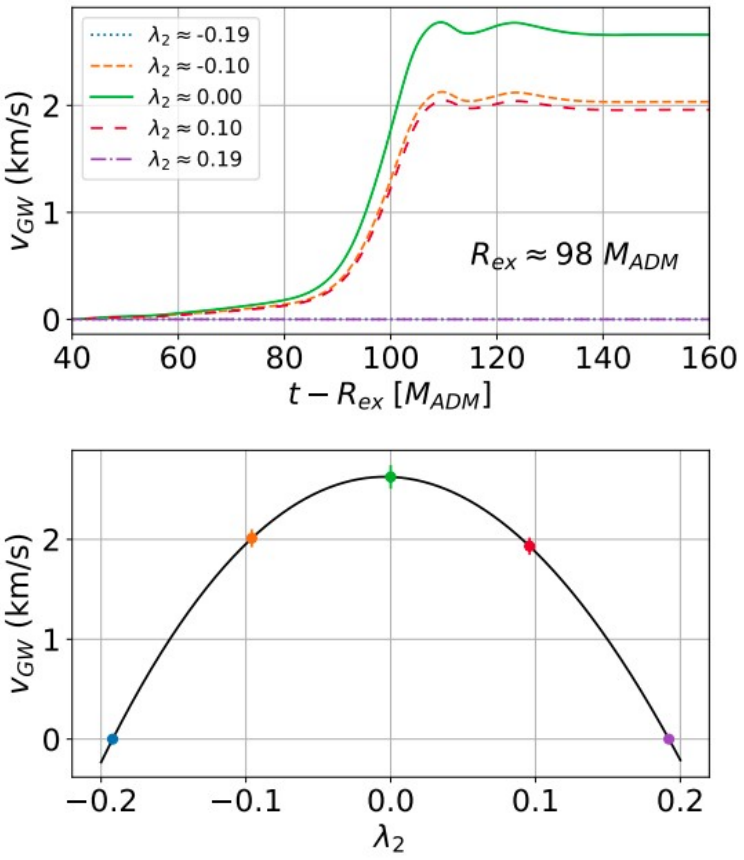
Equal masses: The Newtonian prediction for the zeros holds



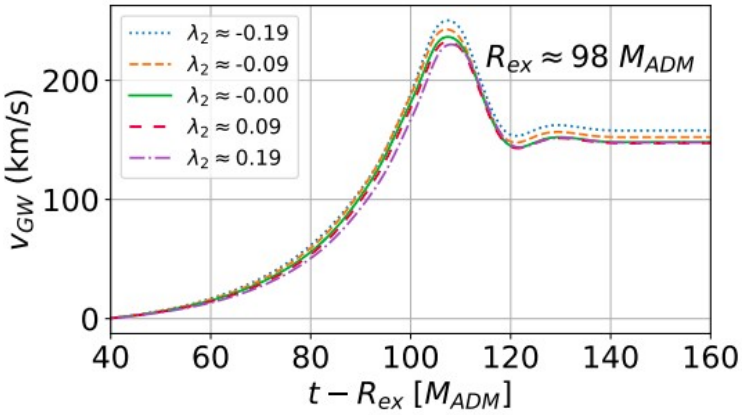


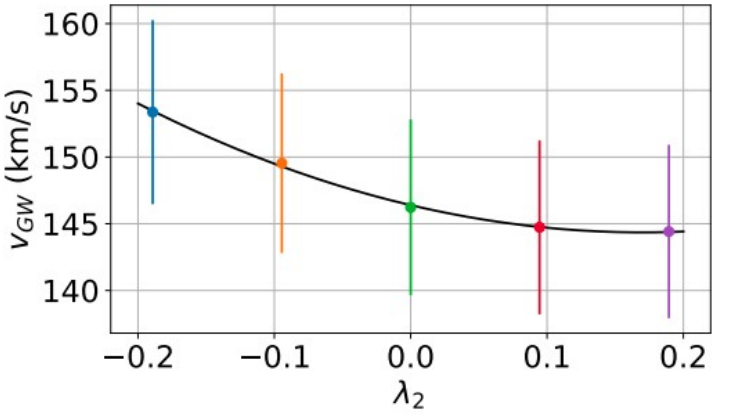
$m_1 = 2m_2$: Deviation from the Newtonian prediction

Adding charge: Gravitational kicks



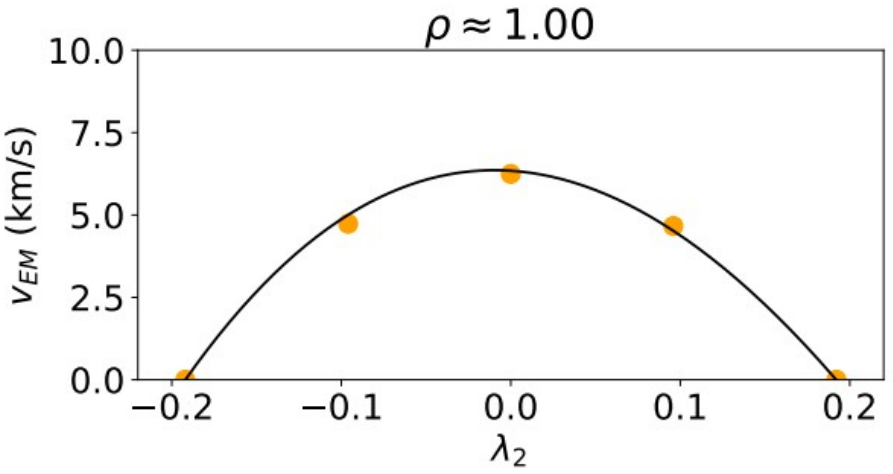
Equal masses: We now have nonzero kicks in the gravitational channel!

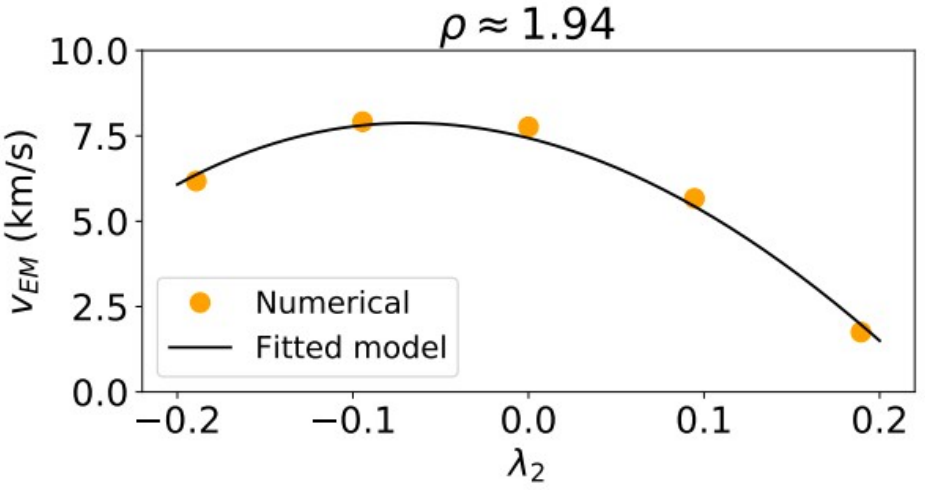




$m_1 = 2m_2$: Charge contributes (weakly) to the magnitude of the gravitational kick

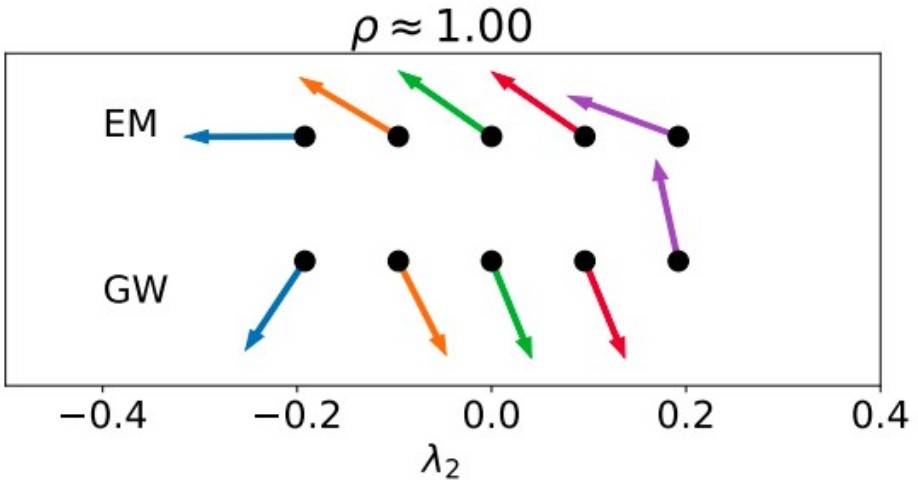
Trying to explain the deviation...

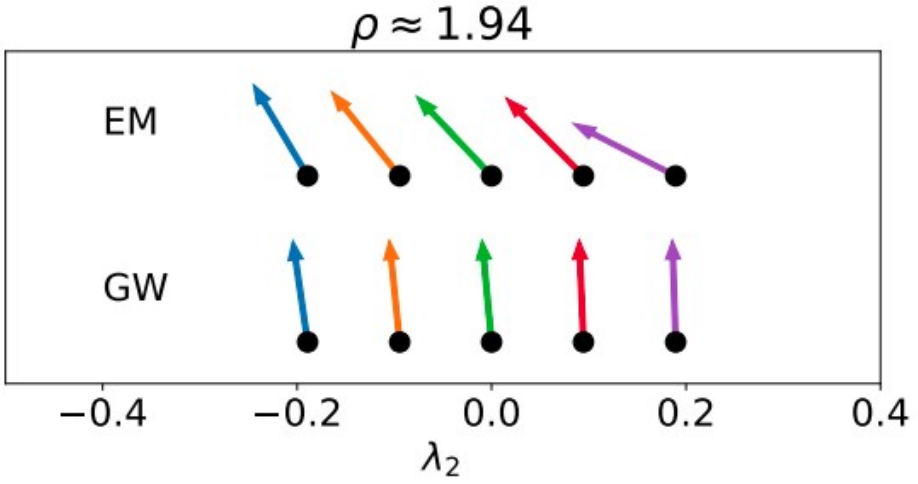




$$v_{\mathrm{EM}} = \alpha \frac{(1-\lambda_1\lambda_2)^{5/2}\rho^2}{(1+\rho)^5}(\lambda_1-\lambda_2)(\lambda_1+\rho\lambda_2) + 2\beta(1-\gamma\lambda_2)v_{\mathrm{GW}}.$$

Relative direction of kicks





Conclusions

- Charged black hole binaries have kicks both in the gravitational and electromagnetic channels
- For reasonable values of the charge, the maximum EM kicks are about 5% of the maximum GW kicks
- Charge induces GW kicks even for equal masses
- The Newtonian / Keplerian approximation for EM kicks holds when the masses are equal, but not when they are different
- More research is needed to understand this effect

Thank you for
your attention