Testing general relativity with gravitational waves

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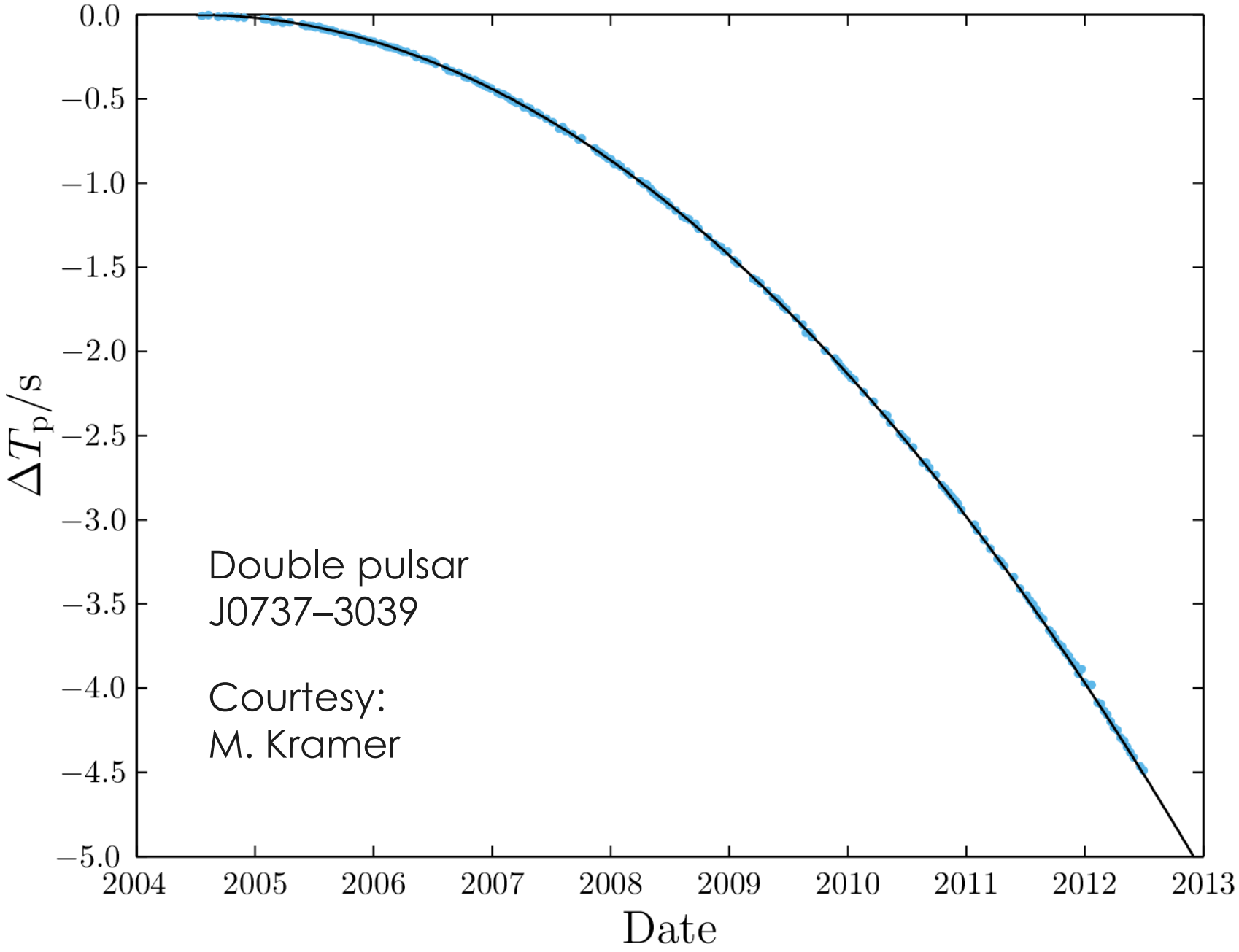
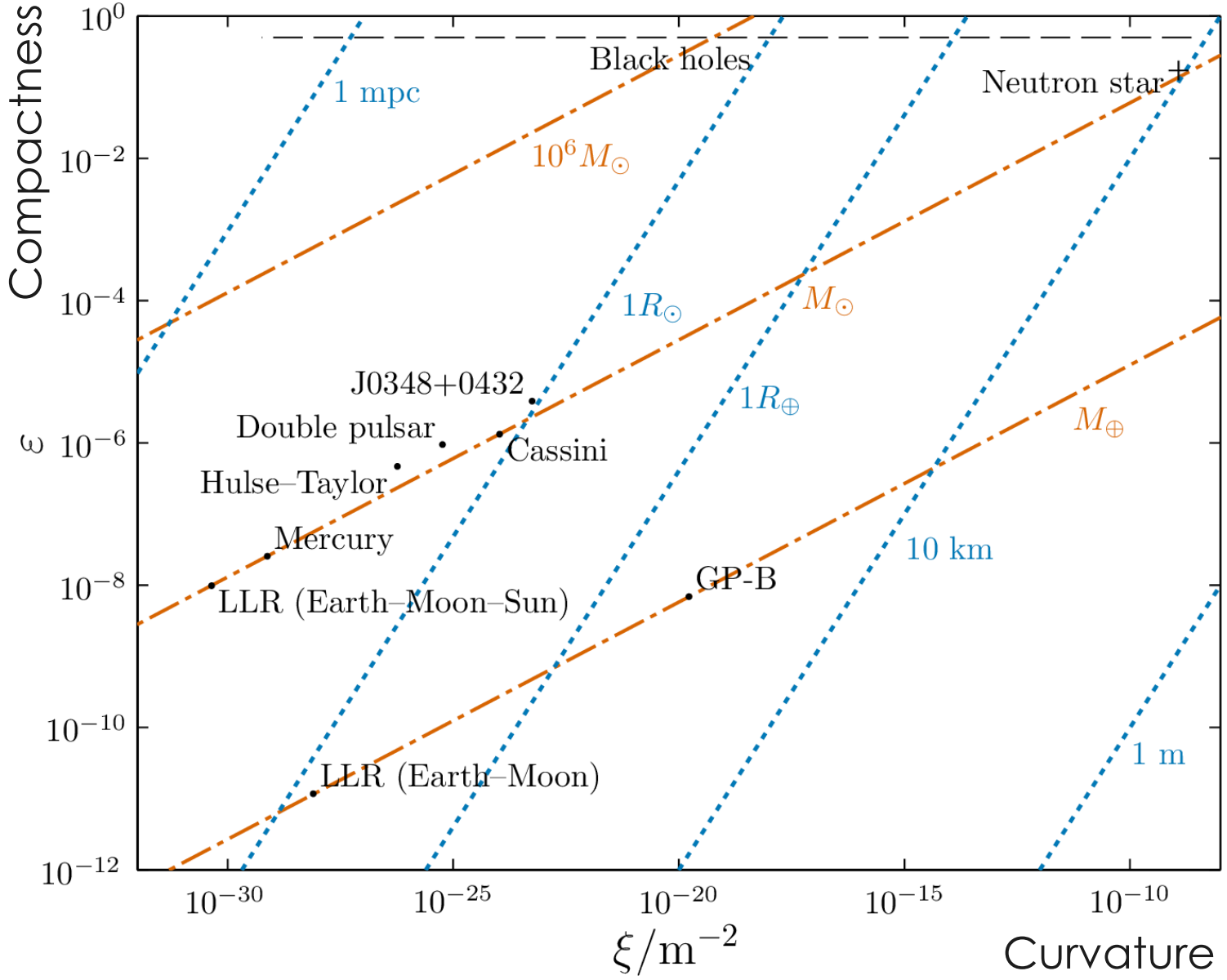
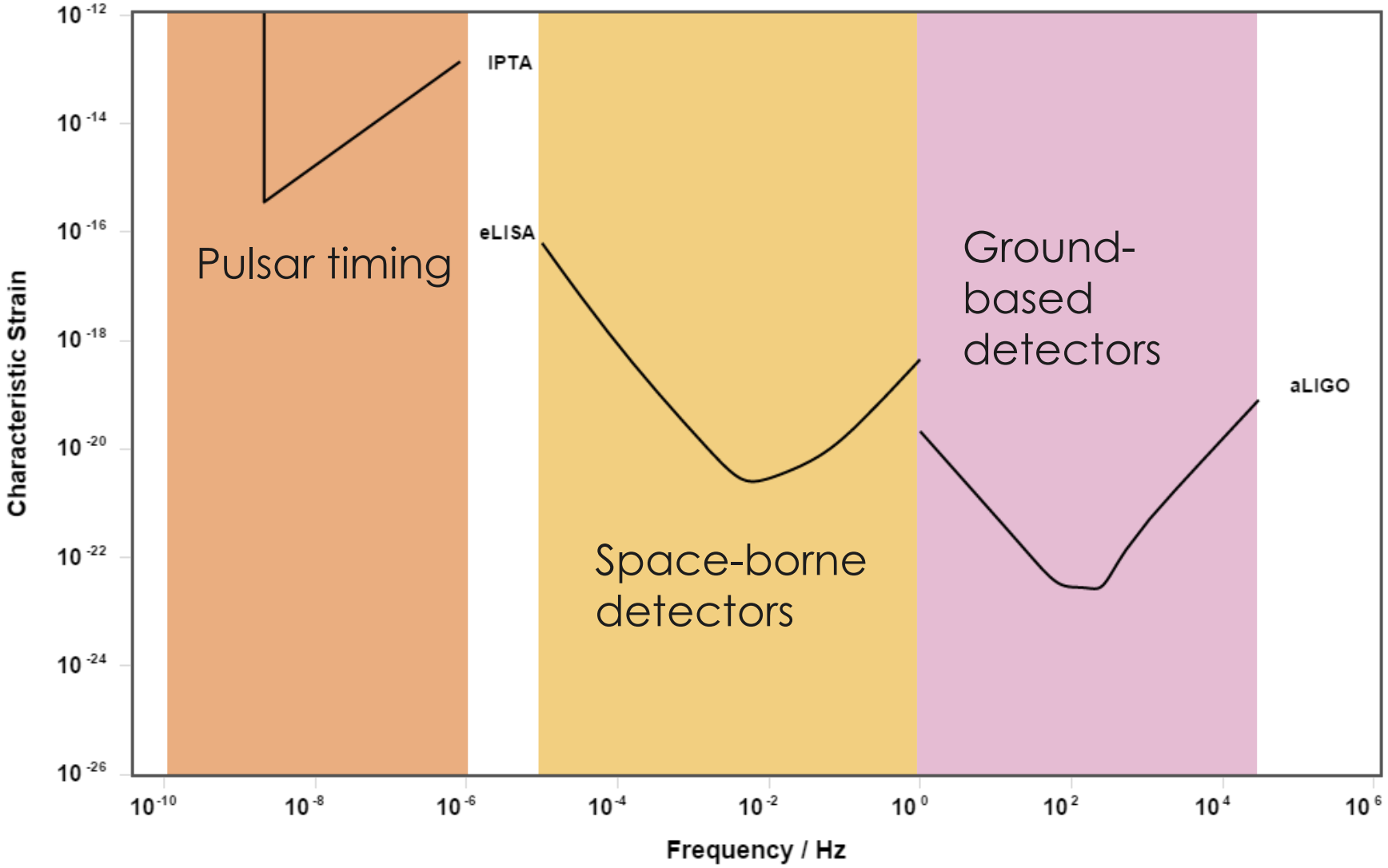
16 April 2015
eLISA Cosmology Working Group Workshop


0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
−5.0
$\Delta T_{\rm p}/{\rm s}$
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Date
Double pulsar
J0737–3039
Courtesy:
M. Kramer



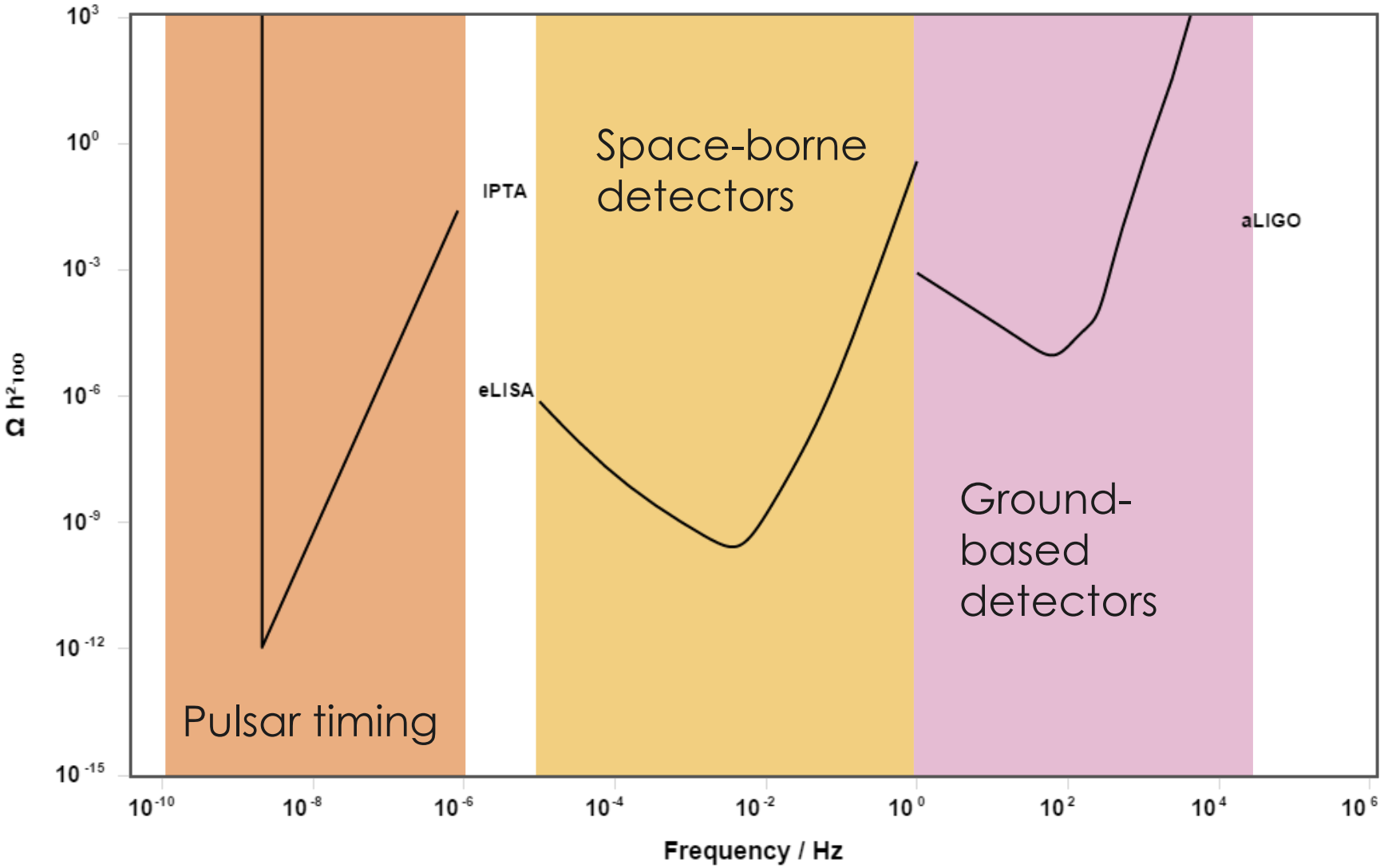
Strong-field gravity

Gravitational-wave spectrum



Credit: rhcole.com/apps/GWplotter/

Gravitational-wave spectrum

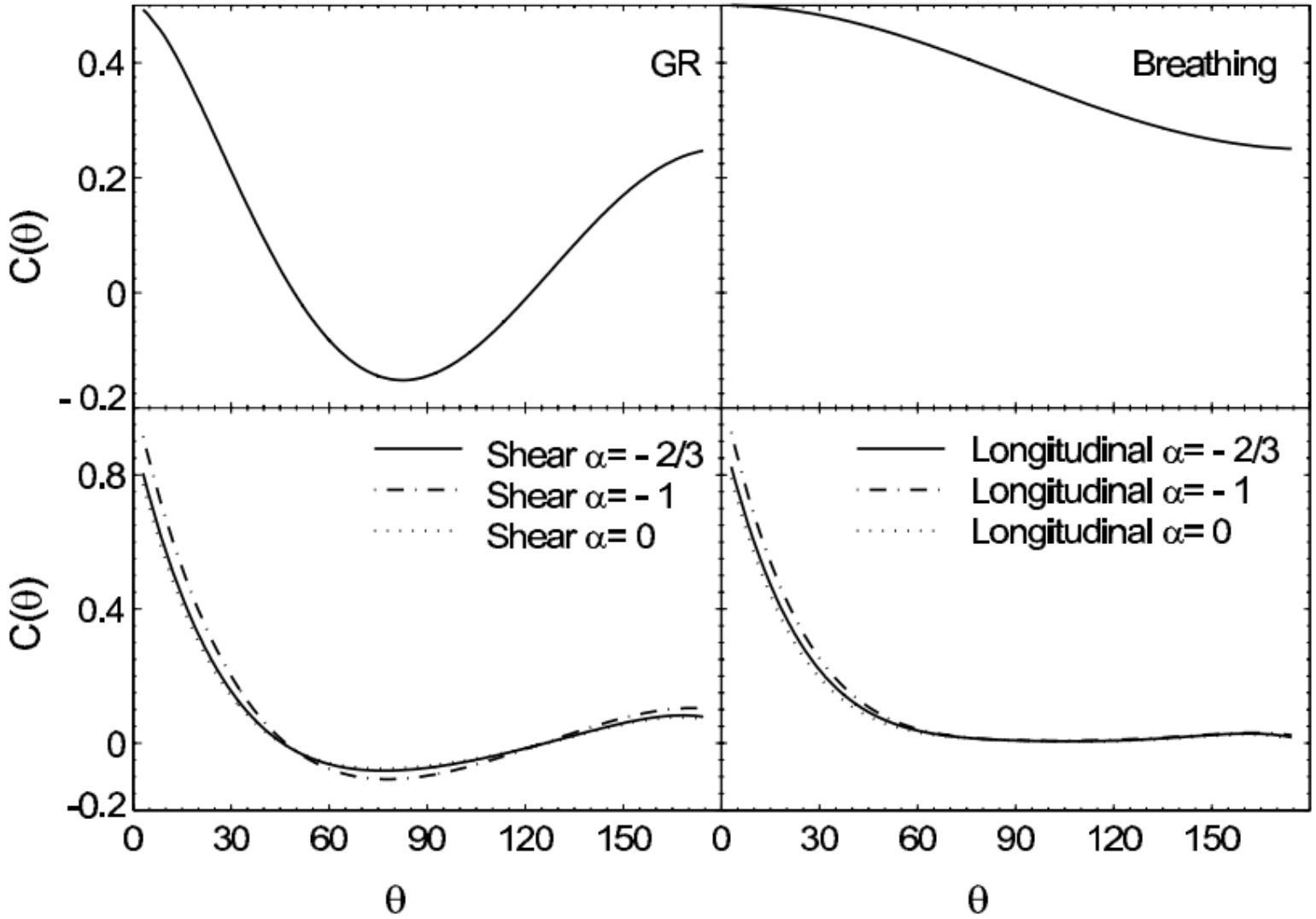


Credit: rhcole.com/apps/GWplotter/

PTAs & alternative polarizations

Alves & Tinto (2011)
arXiv:1102.4824 [gr-qc]
Chamberlin & Siemens (2012)
arXiv:1111.5661 [astro-ph.HE]

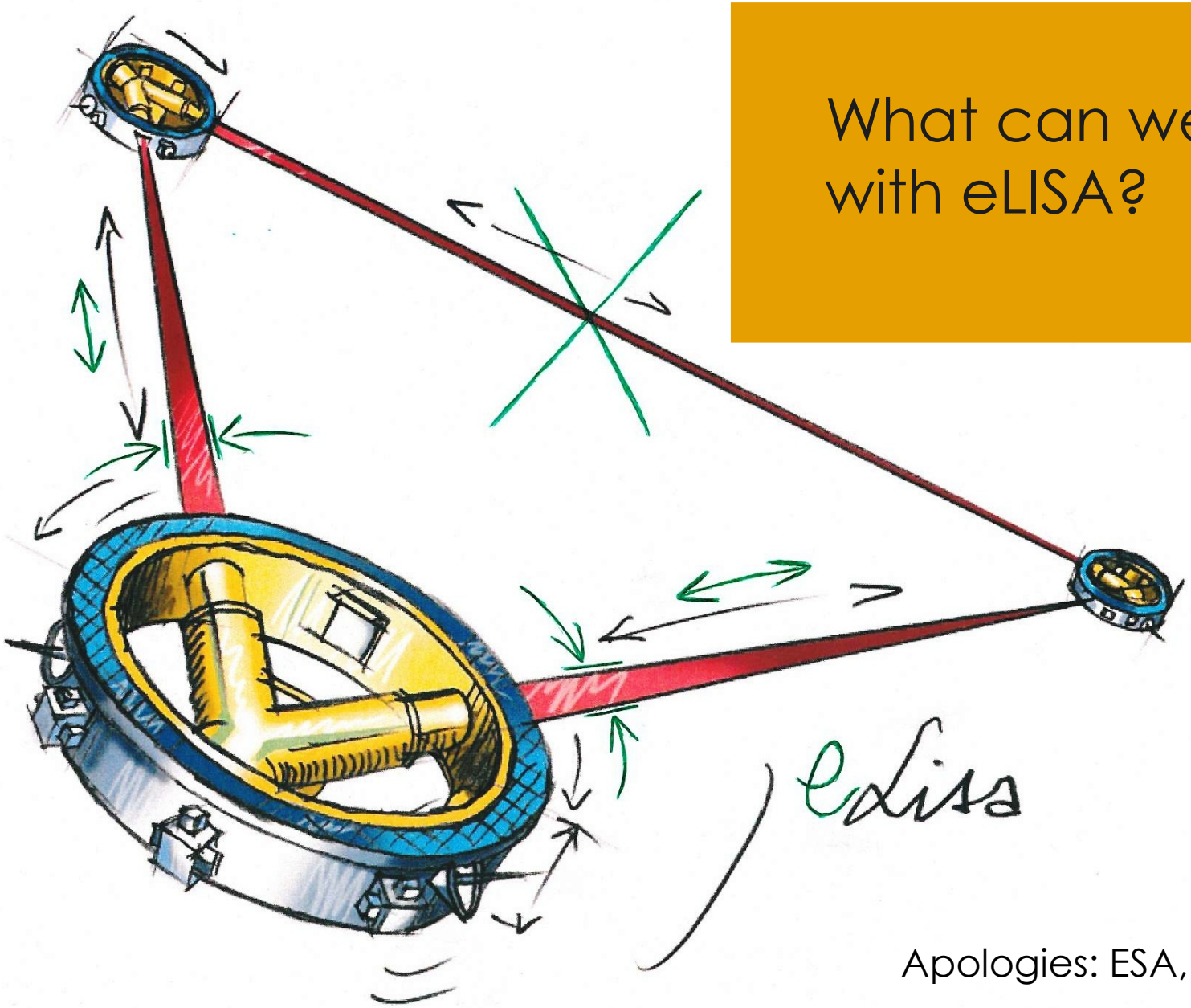
Credit:
Lee, Jenet & Price (2008)



Gravitational-Wave Tests of General Relativity with Ground-Based Detectors and Pulsar-Timing Arrays
Yunes & Siemens; Living Rev Relativity; **16**:9; 2013
arXiv:1304.3473 [gr-qc]

Testing General Relativity with Low-Frequency, Space-Based Gravitational-Wave Detectors
Gair, Vallisneri, Larson & Baker; Living Rev Relativity; **16**:7; 2013
arXiv:1212.5575 [gr-qc]

What can we do with eLISA?



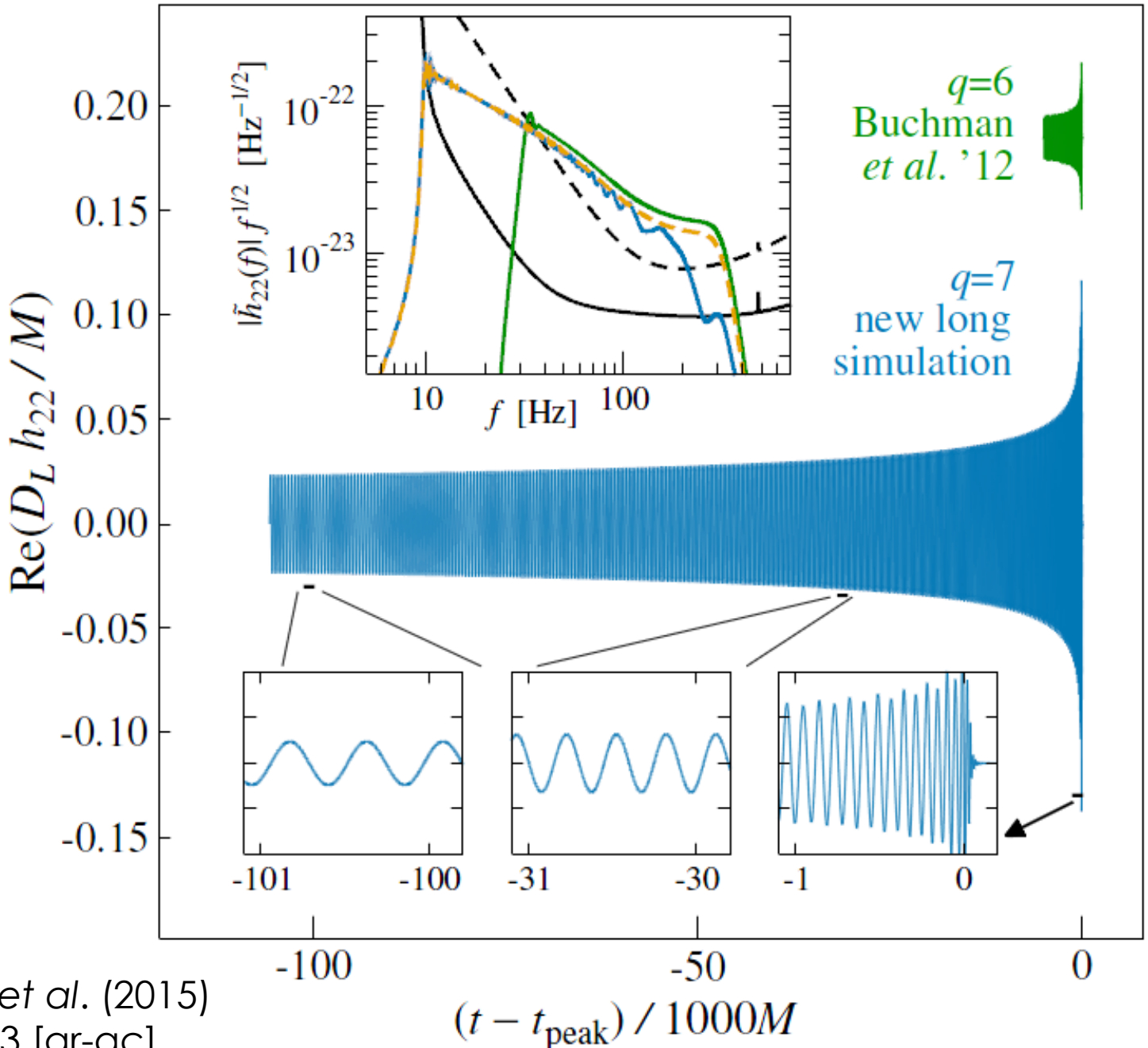
Apologies: ESA, C. Vijoux

Massive black-hole binaries – inspiral, merger and ringdown

Extreme-mass-ratio systems – evolution and background

Galactic binaries – inspiral

Inspirals are well under-stood



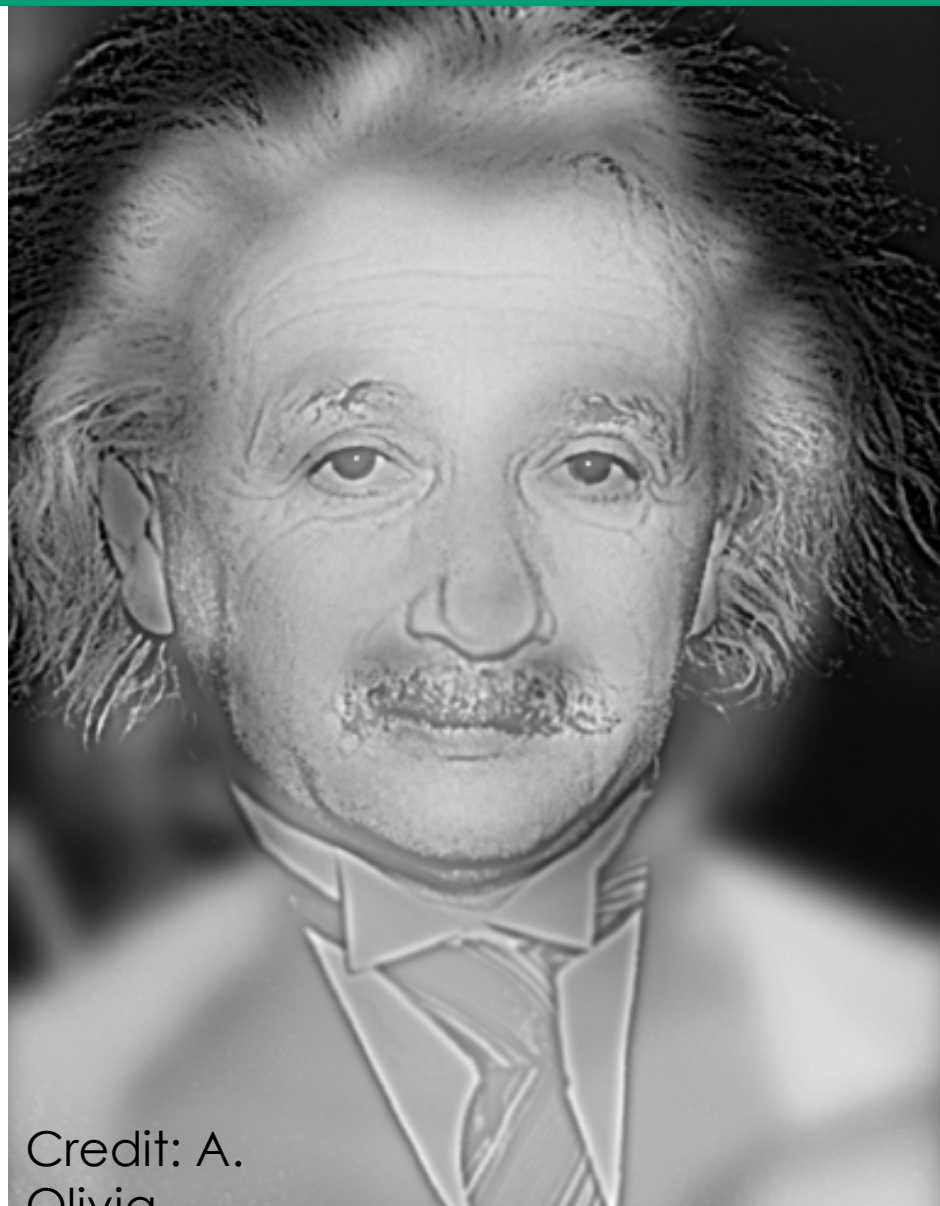
Credit: Szilàgyi *et al*. (2015)
arXiv:1502.04953 [gr-qc]

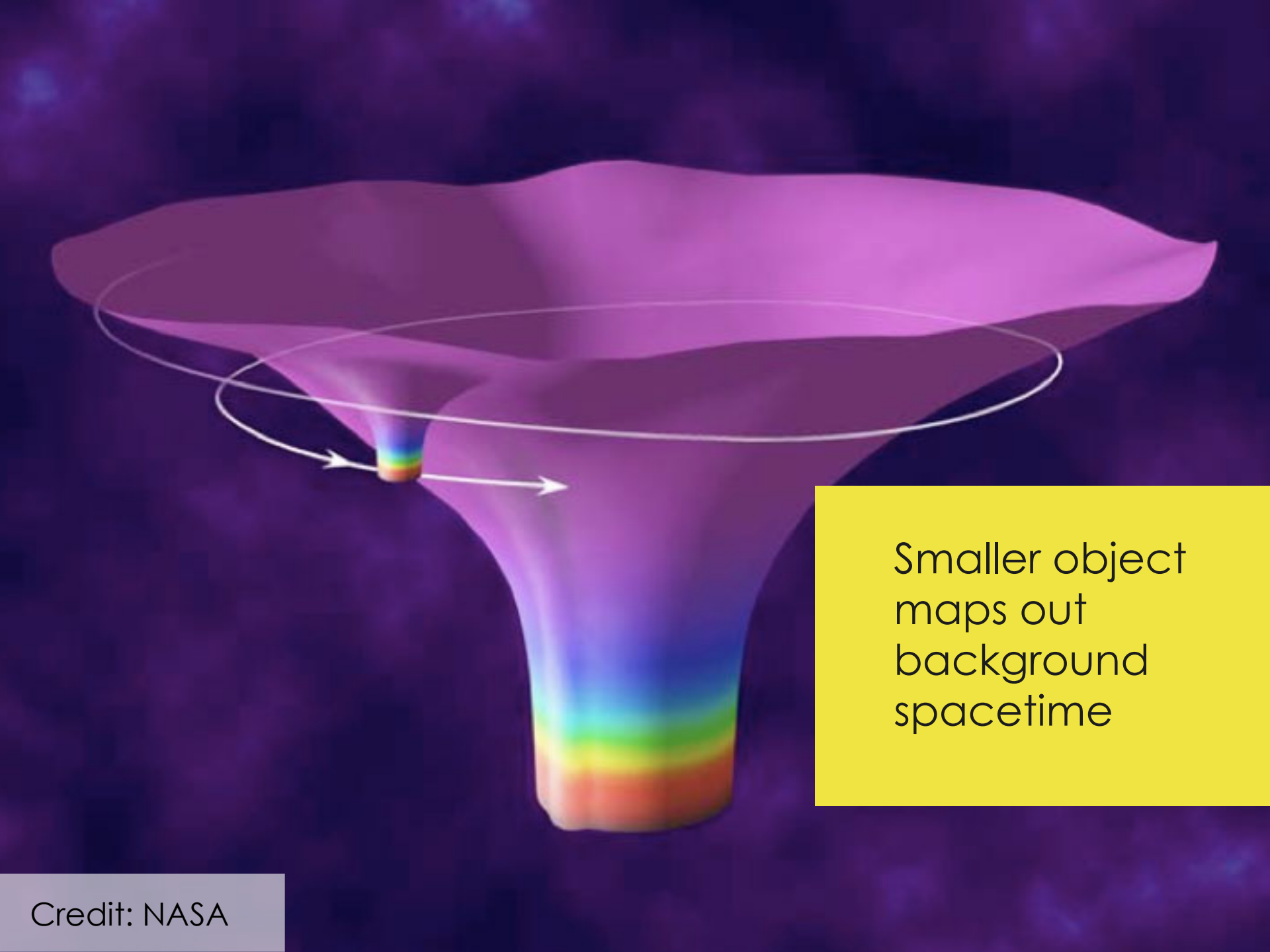
Deviations from Einstein

Parameterized post-Einsteinian (PPE) framework
Yunes & Pretorius (2009)
arXiv:0909.3328 [gr-qc]
Cornish *et al*. (2011)
arXiv:1105.2088 [gr-qc]
Sampson, Yunes & Cornish (2013)
arXiv:1307.8144 [gr-qc]
Huwyler, Porter & Jetzer (2015)
arXiv:1410.8815 [gr-qc]

Massive gravity
Berti, Gair & Sesana (2011)
arXiv:1107.3528 [gr-qc]

$$\lambda_{\rm g} > 10^{19}\ {\rm m}$$

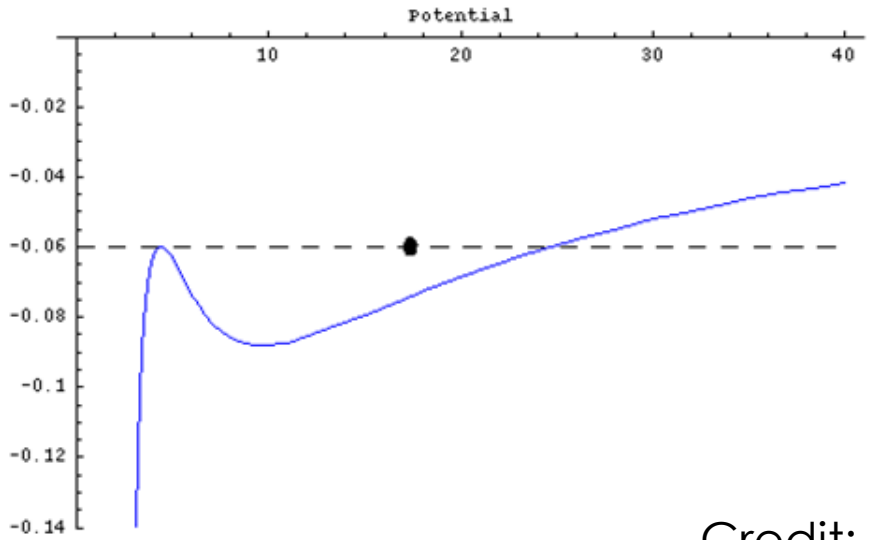

Credit: A. Olivia

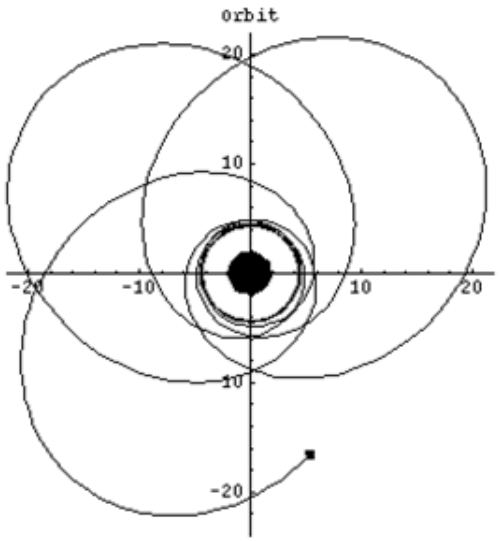


Smaller object maps out background spacetime

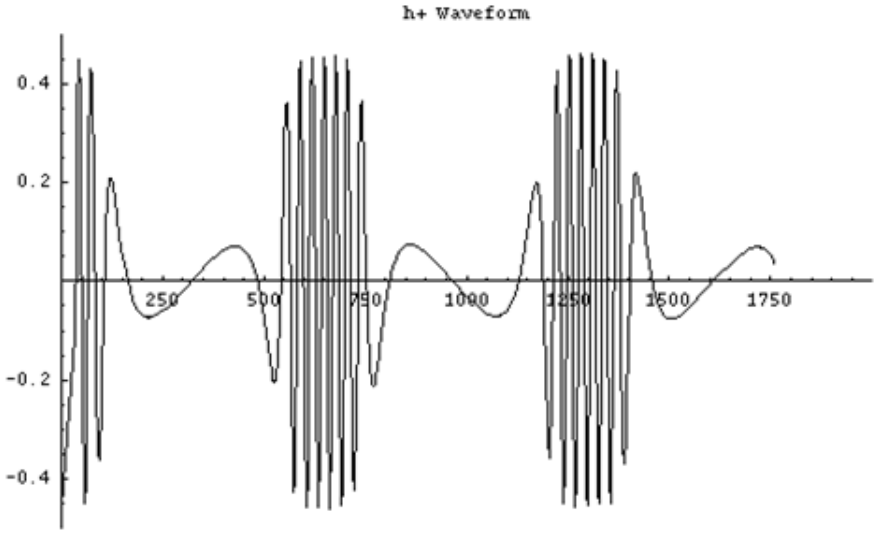
Credit: NASA

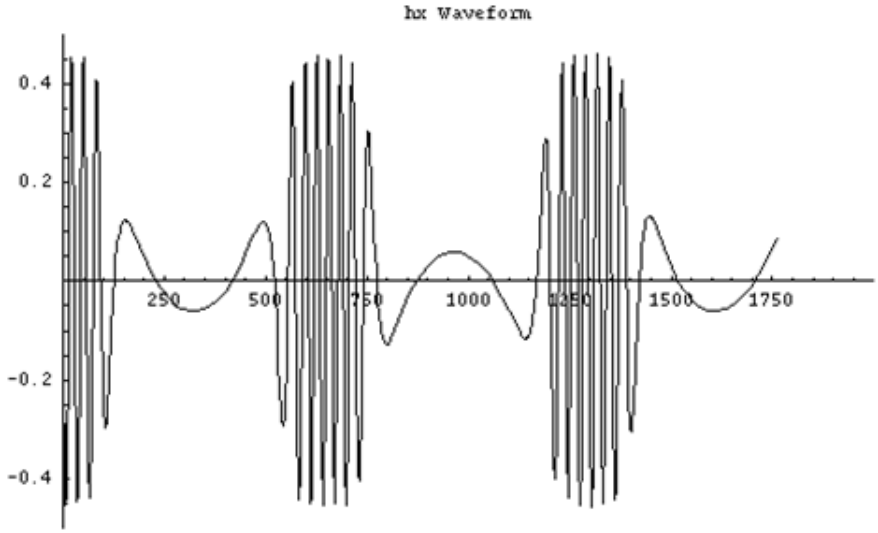
Intricate orbits





Credit: J. Gair





Dynamical Chern–Simons

$$S_{\rm EH} = \kappa \int {\rm d}^4x \sqrt{-g} R$$

$$S_{\rm CS} = \frac{\alpha}{4} \int {\rm d}^4x \sqrt{-g} \vartheta \, {}^*RR$$

$$S_\vartheta = -\frac{\beta}{2} \int {\rm d}^4x \sqrt{-g} g^{\mu\nu} \nabla_\mu \vartheta \nabla_\nu \vartheta$$

$$\xi = \frac{\alpha^2}{\kappa\beta}$$

$$\delta g_{t\phi} = \frac{5}{8} \frac{\xi a_\bullet}{r^4} \left(1 + \frac{12 M_\bullet}{r} + \frac{27 M_\bullet^2}{10 r^2} \right) \sin^2\theta$$

$$\xi^{1/4} < 10^4 \ {\rm km}$$

Canizares, Gair & Sopuerta (2012) arXiv:1205.1253 [gr-qc]

No-hair theorem

Is the background Kerr?

$$M_\ell + iS_\ell = (ia_\bullet)^\ell \, M_\bullet^{\ell+1}$$

For LISA:

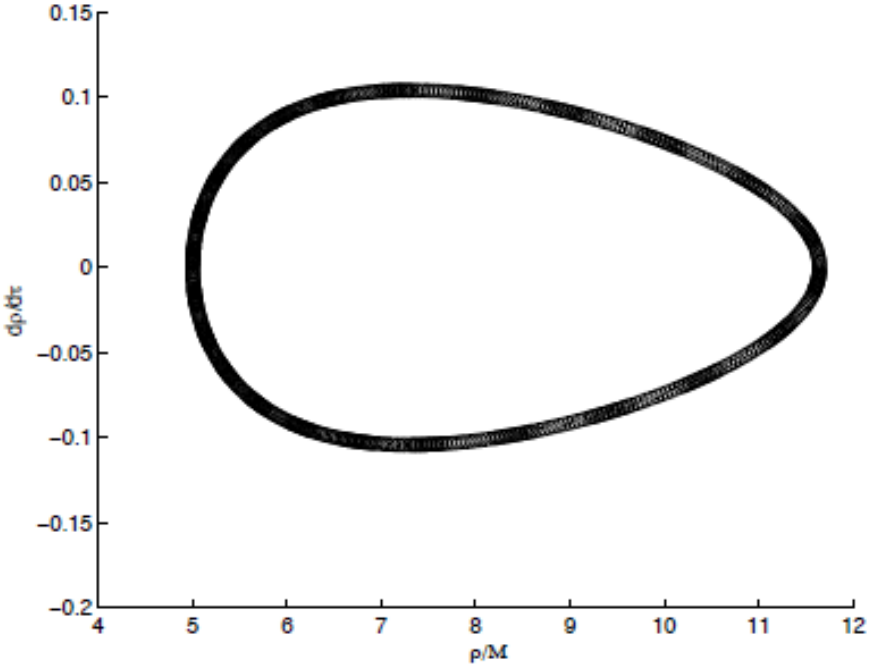
$$\Delta\left(\frac{M_2}{M_\bullet^3}\right) \sim 10^{-4}\text{–}10^{-2}$$

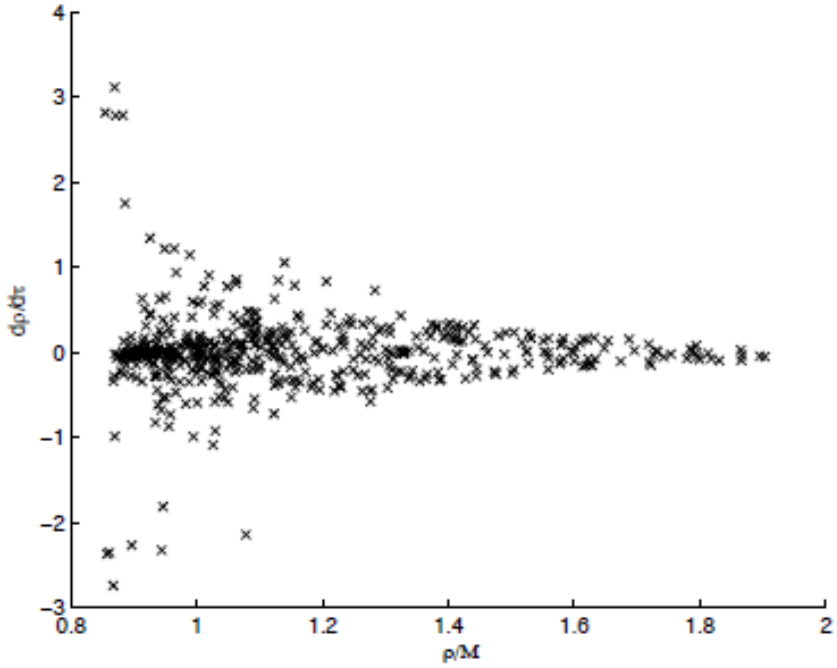
Barack & Cutler (2007)
arXiv:gr-qc/0612029

Credit: M. Groening

Bumpy spacetimes

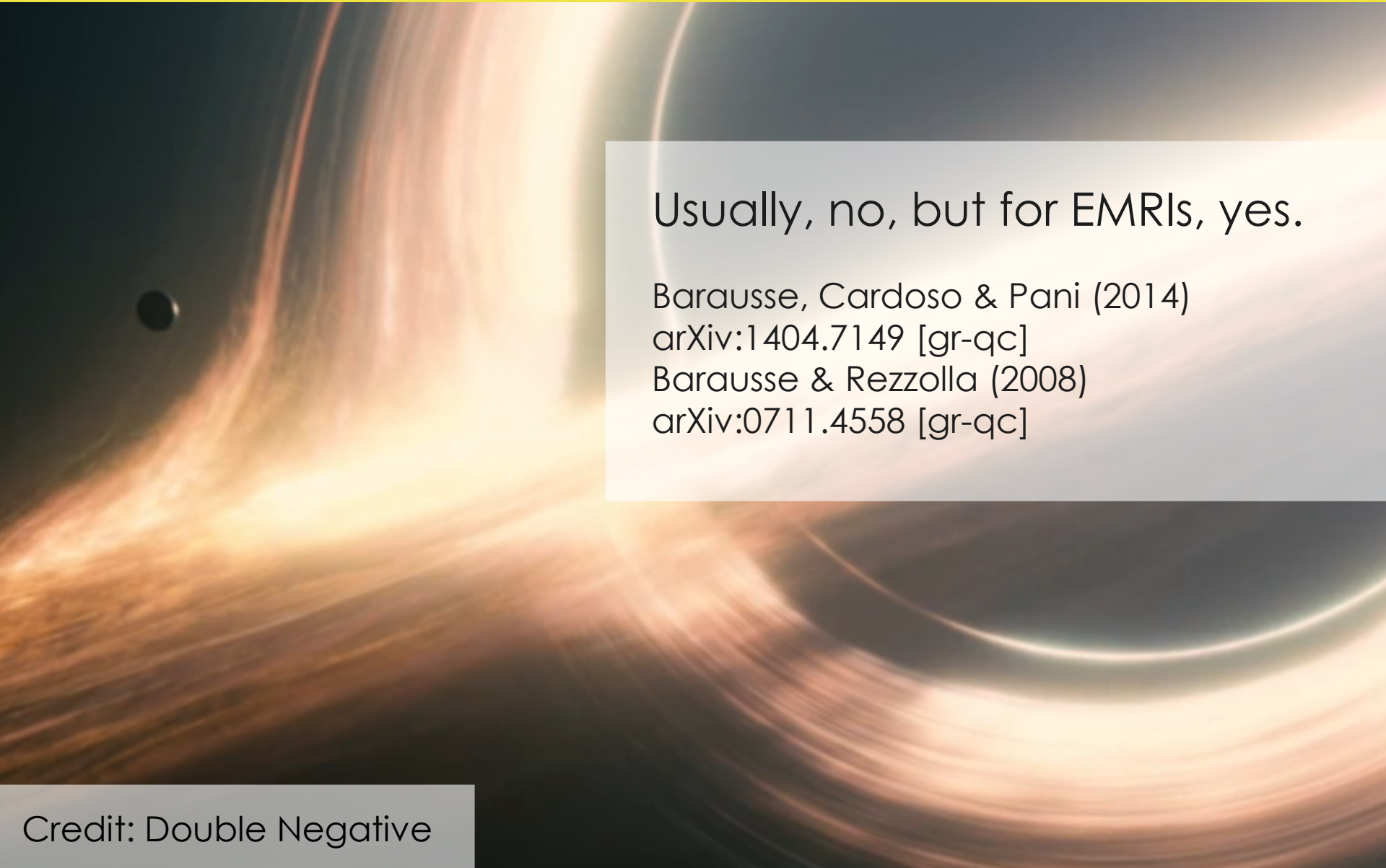
Lose nice properties of Kerr





Credit: Gair, Li & Mandel (2008) arXiv:0708.0628 [gr-qc]

Does matter matter?



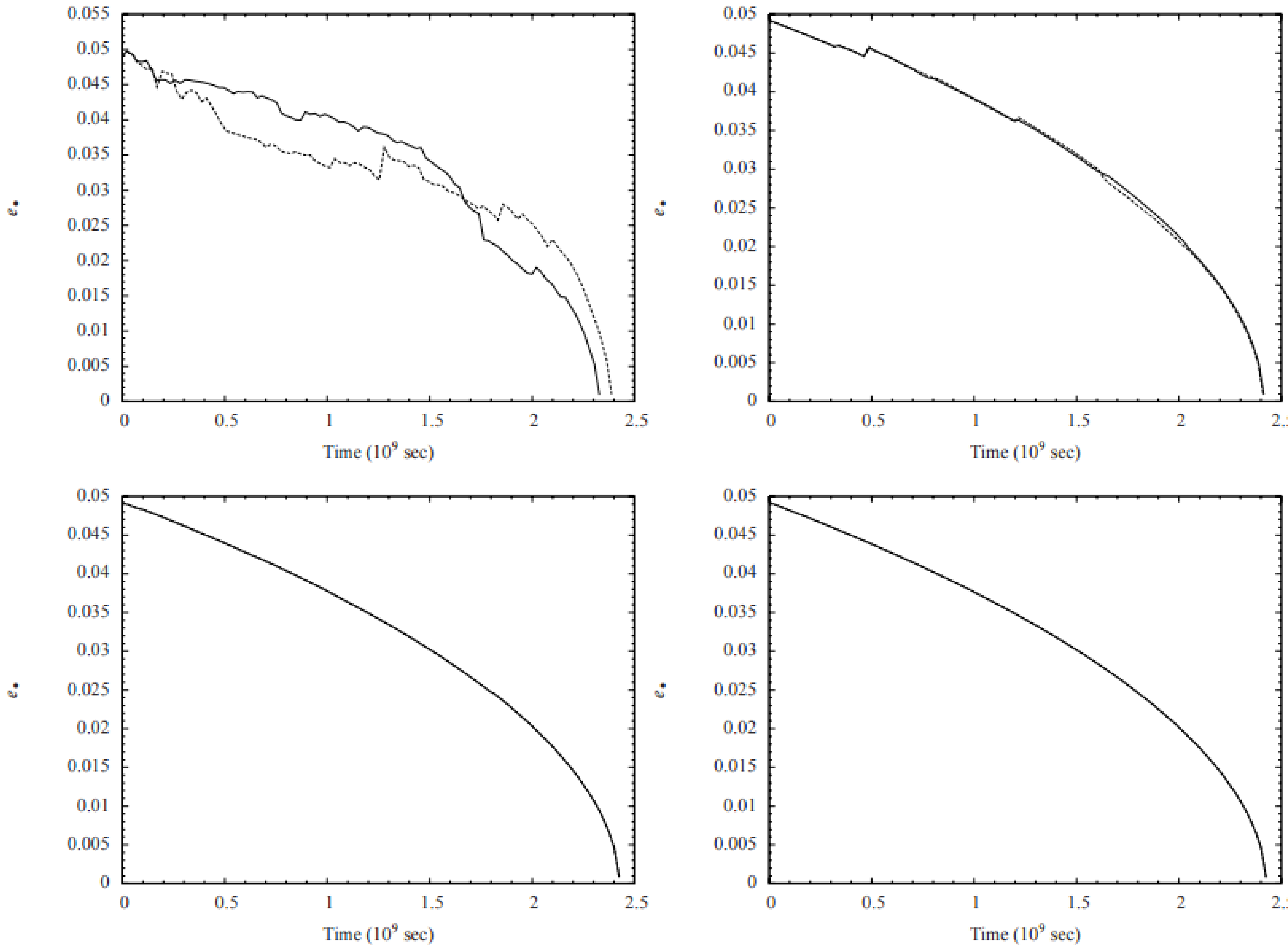
Usually, no, but for EMRIs, yes.

Barausse, Cardoso & Pani (2014)
arXiv:1404.7149 [gr-qc]
Barausse & Rezzolla (2008)
arXiv:0711.4558 [gr-qc]

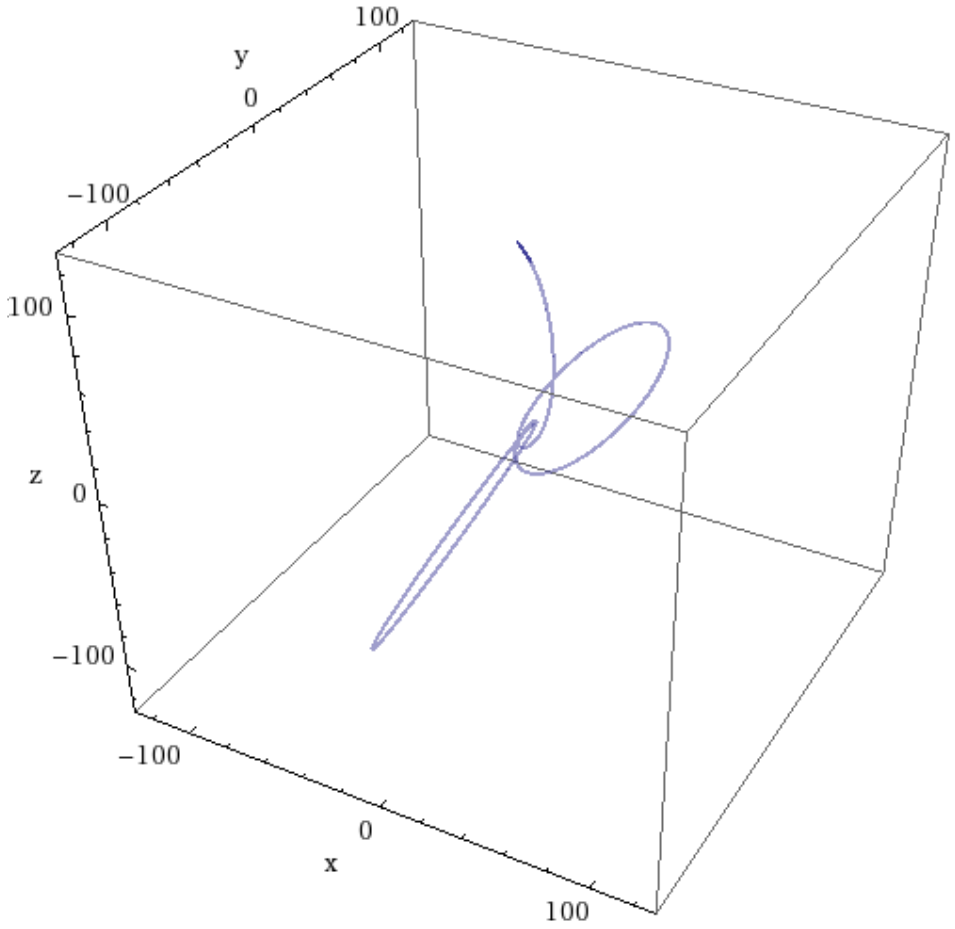
Credit: Double Negative

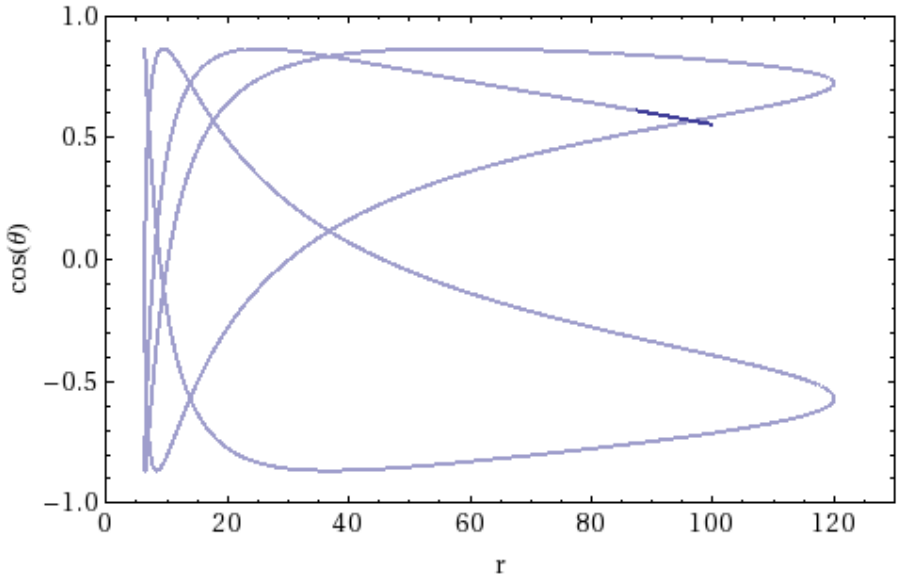
Effect of a perturbing object

Credit: Amaro-Seoane, Brem, Cuadra & Armitage (2012) arXiv:1108.5174 [astro-ph.CO]



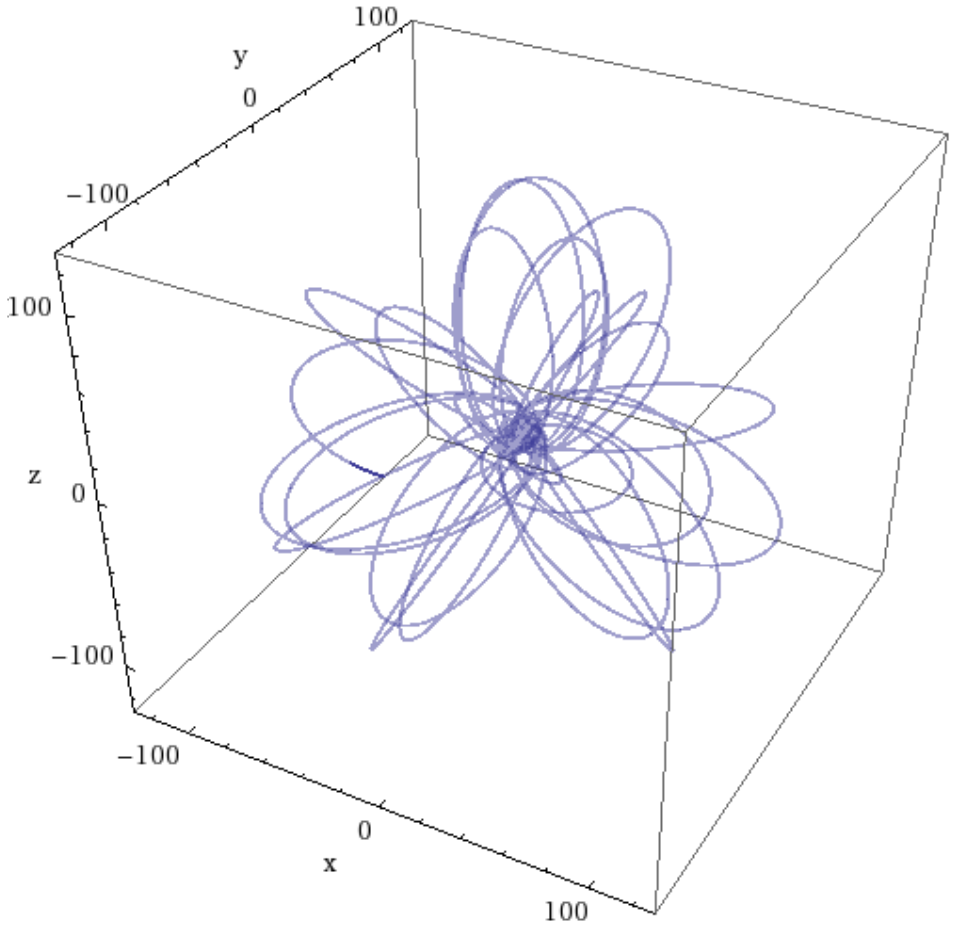
Adiabatic evolution

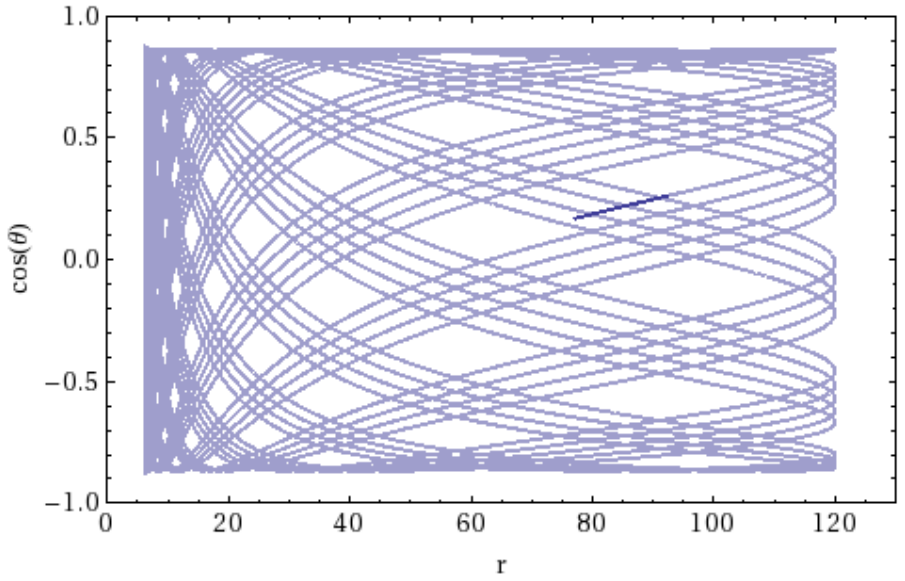




Credit: R Cole

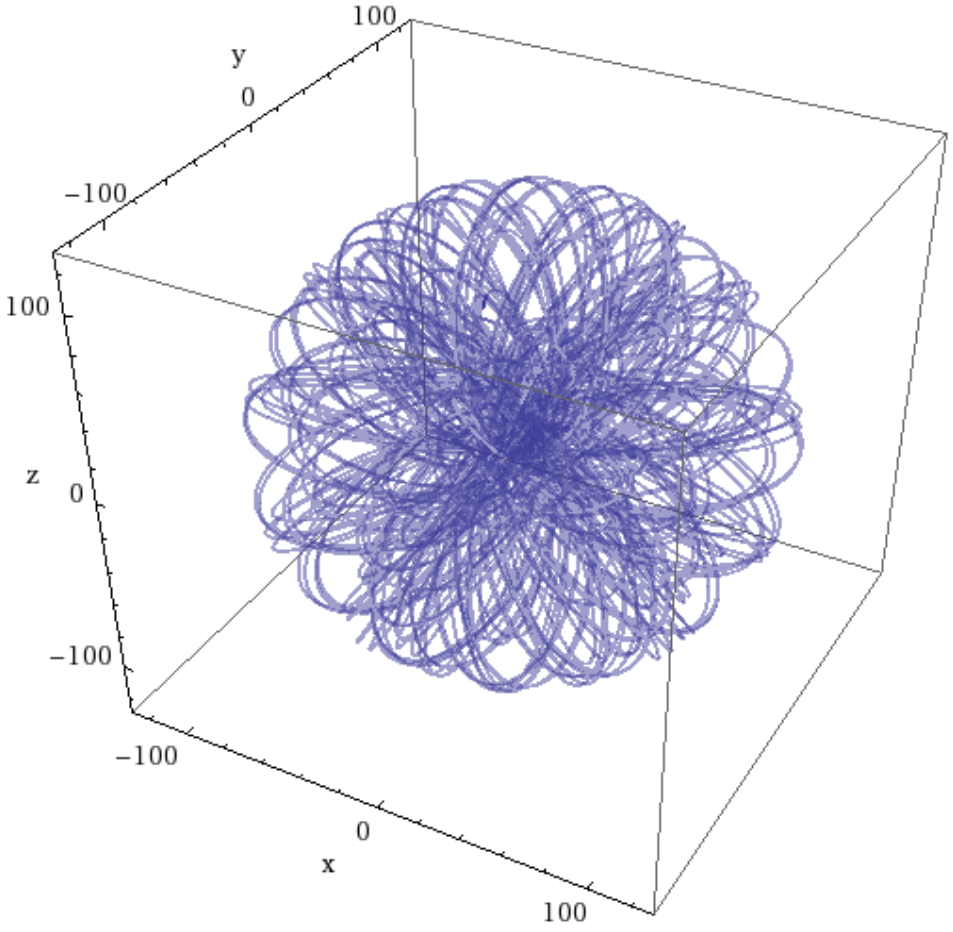
Adiabatic evolution

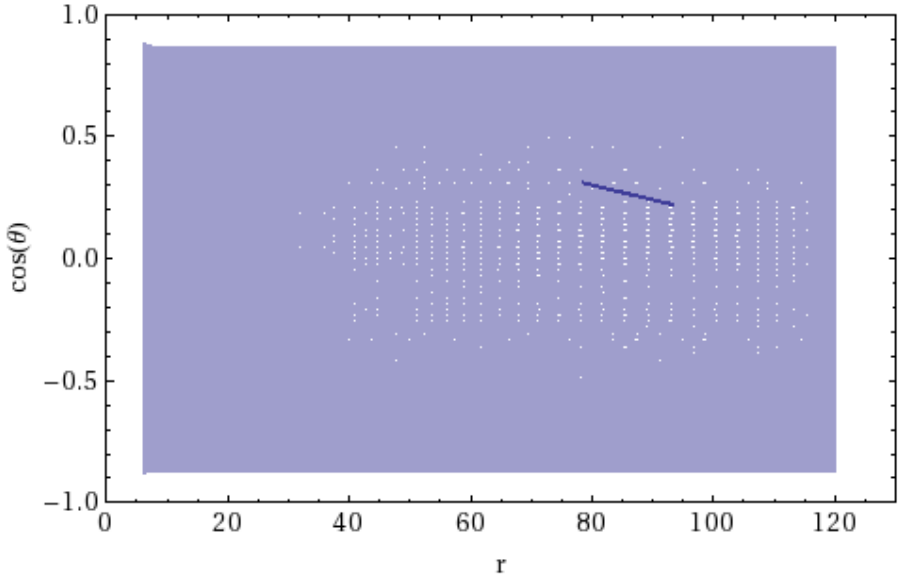




Credit: R Cole

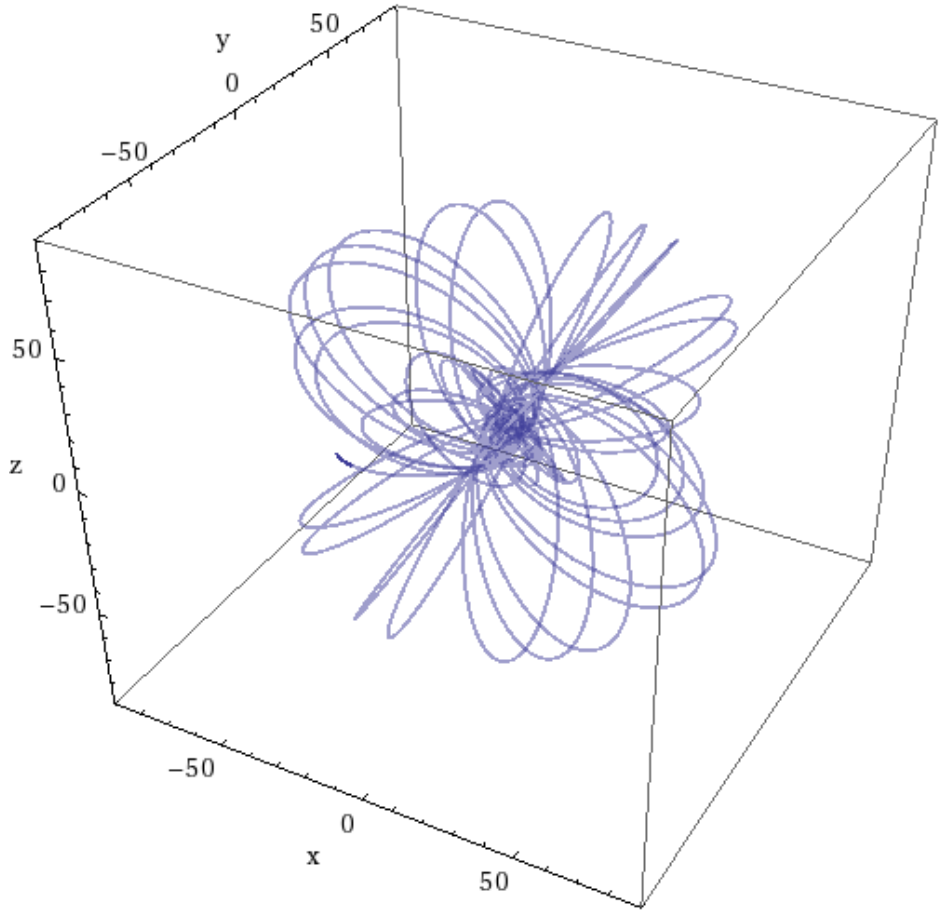
Adiabatic evolution

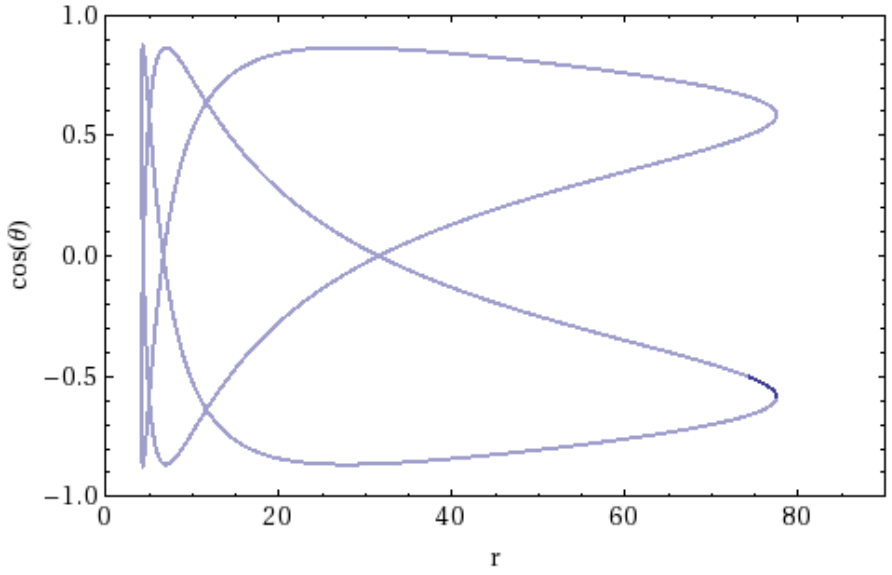




Credit: R Cole

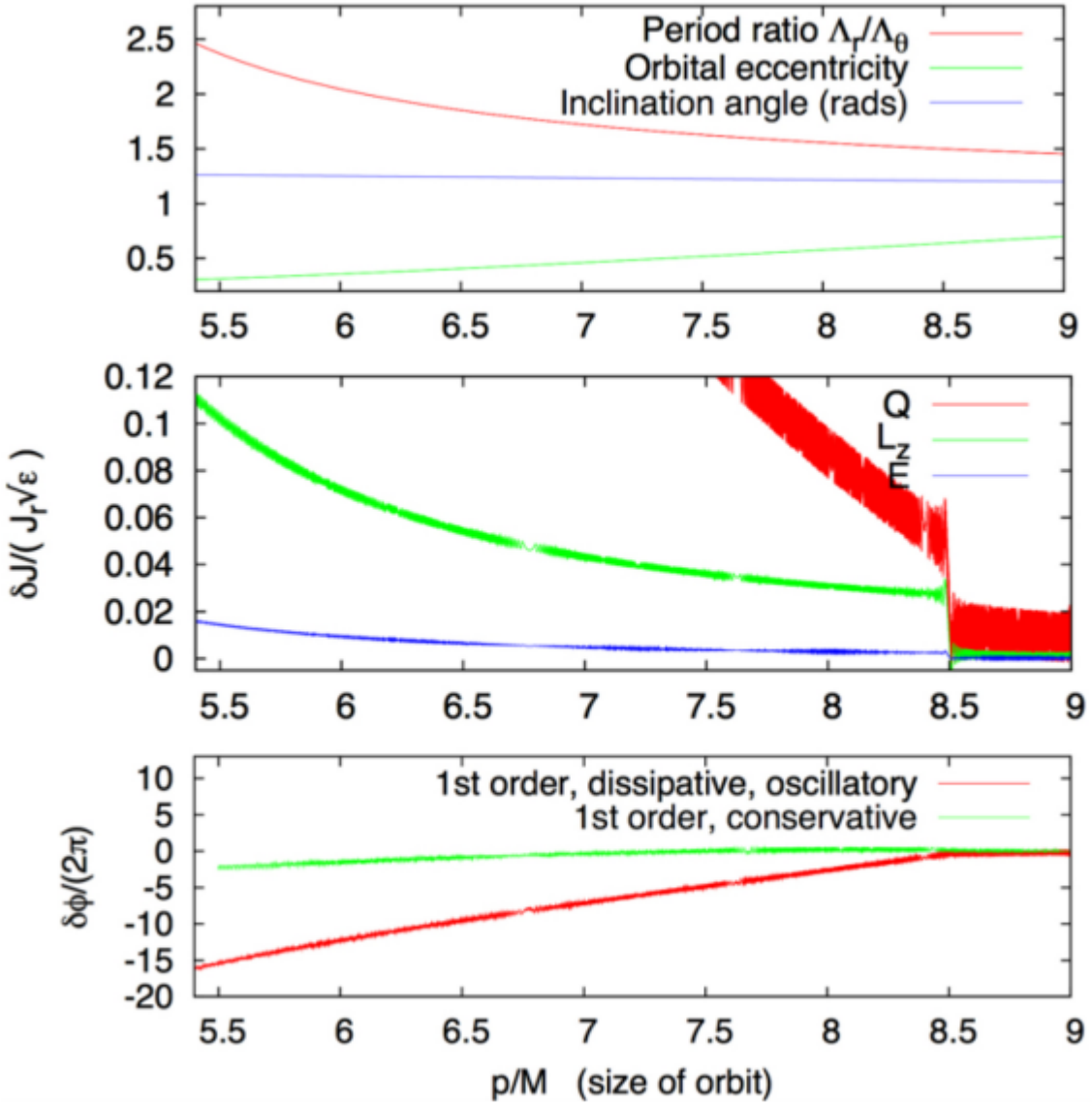
Resonant trajectory





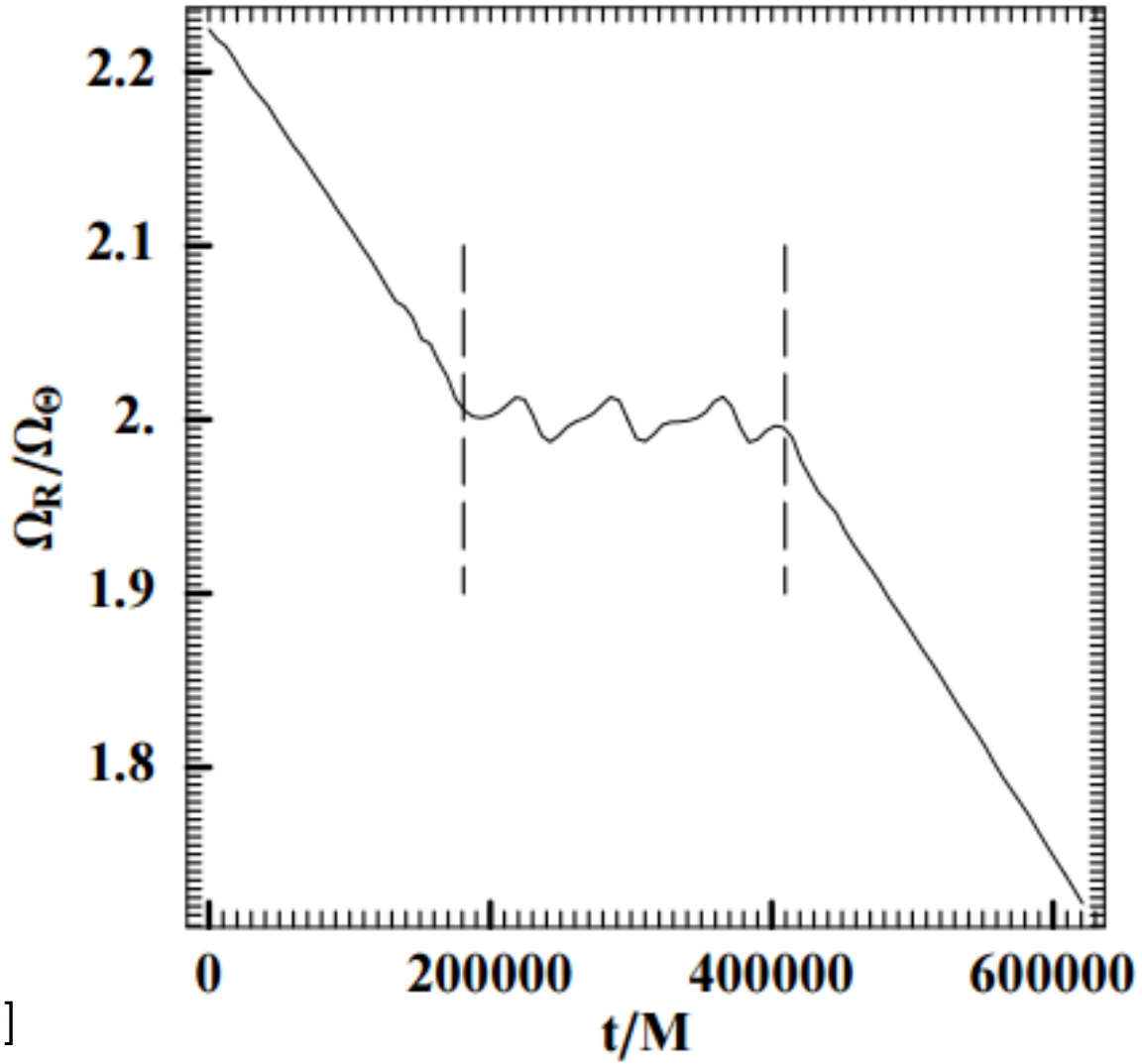
Credit: R Cole

Transient resonances



Credit: Flanagan & Hinderer (2012) arXiv:1009.4923 [gr-qc]

Resonant islands



Credit: Lukes-Gerakopoulos, Apostolatos & Contopoulos (2010) arXiv:1003.3120 [gr-qc]

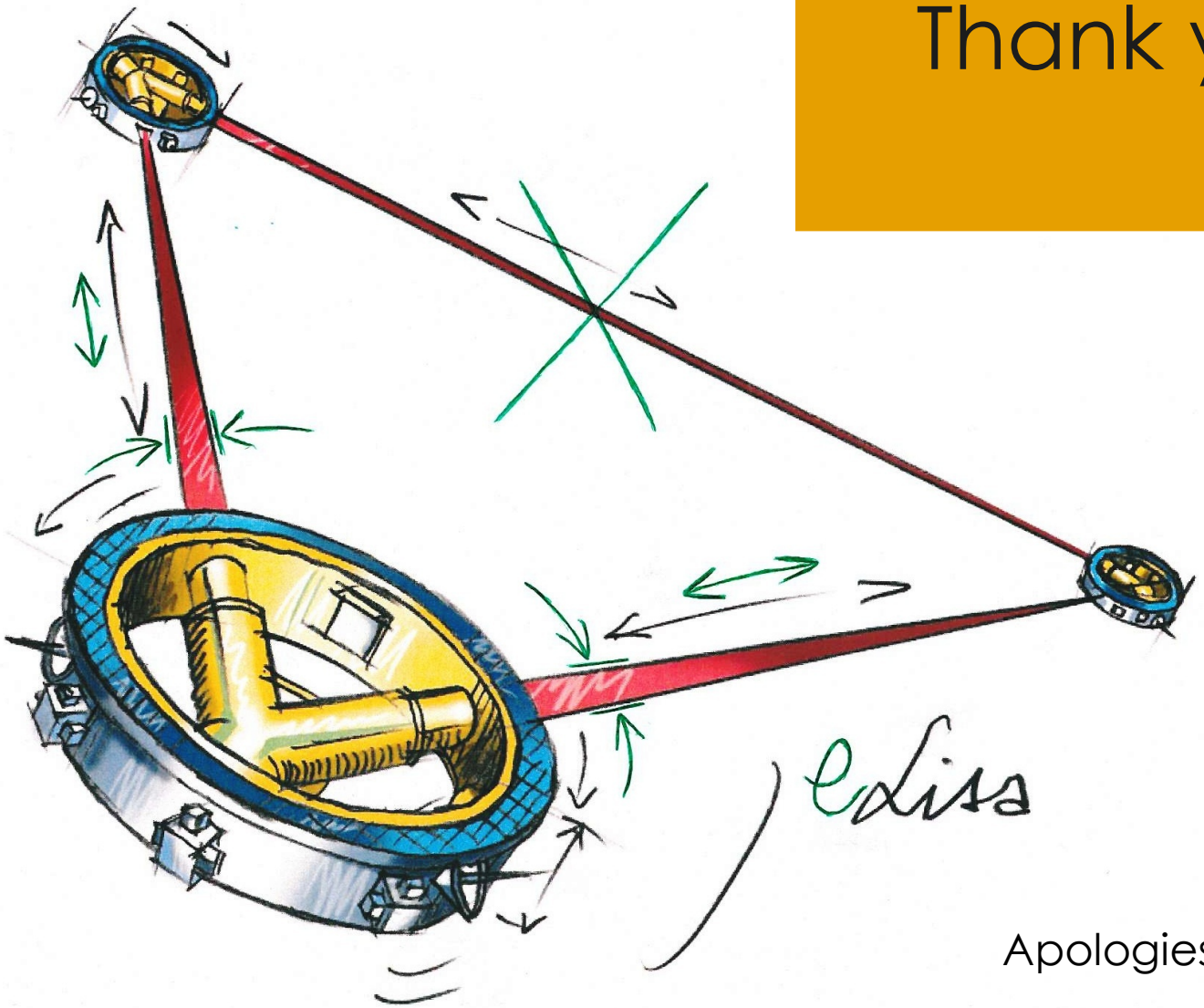
Gravitational waves probe strong-field gravity

Different detectors measure different effects

EMRIs provide detailed spacetime maps

EMRIs waveforms need to be accurate

Thank you



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