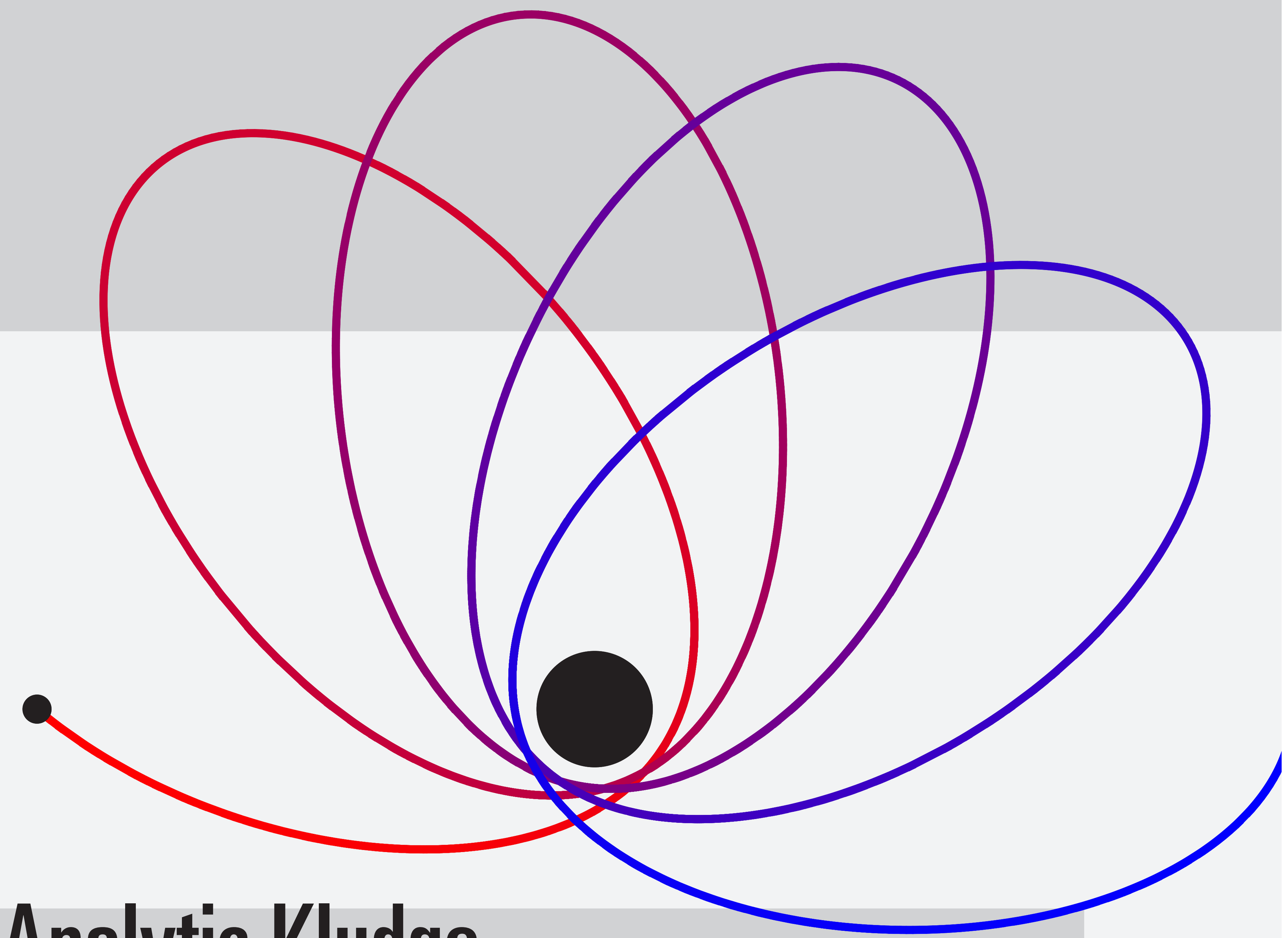
The Fast and the Fiducial

Improving kludge waveforms for EMRIs

A. J. K. Chua,* C. J. Moore† & J. R. Gair‡

*Institute of Astronomy, University of Cambridge
†Department of Applied Mathematics and Theoretical Physics, University of Cambridge
‡School of Mathematics, University of Edinburgh



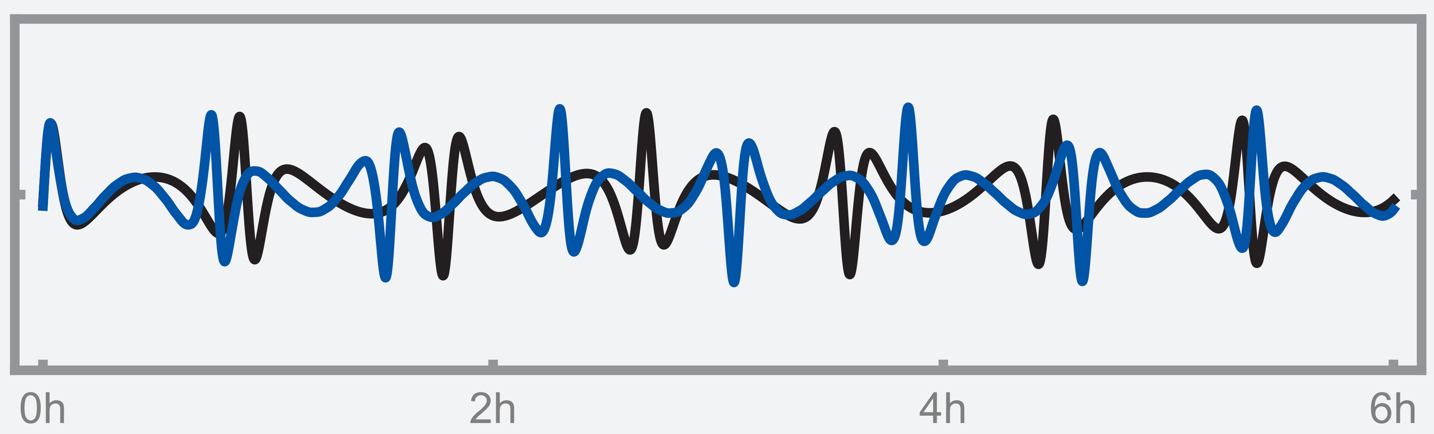
Overview

Extreme-mass-ratio inspirals will be an important class of source for LISA, but present severe challenges in data analysis due to the length and complexity of their gravitational-wave signals.

We introduce an augmentation of Barack and Cutler's analytic kludge EMRI model with a frequency map and other improvements [1,3,4]. It is hoped that the augmented model will be fast and accurate enough to provide short-duration detection templates in a hierarchical search.

After sources are localised in parameter space, longer self-force waveforms are needed to measure their parameters precisely. We propose a technique that uses Gaussian process regression to include information from fiducial waveforms when searching with faster but less accurate ones [2–4].

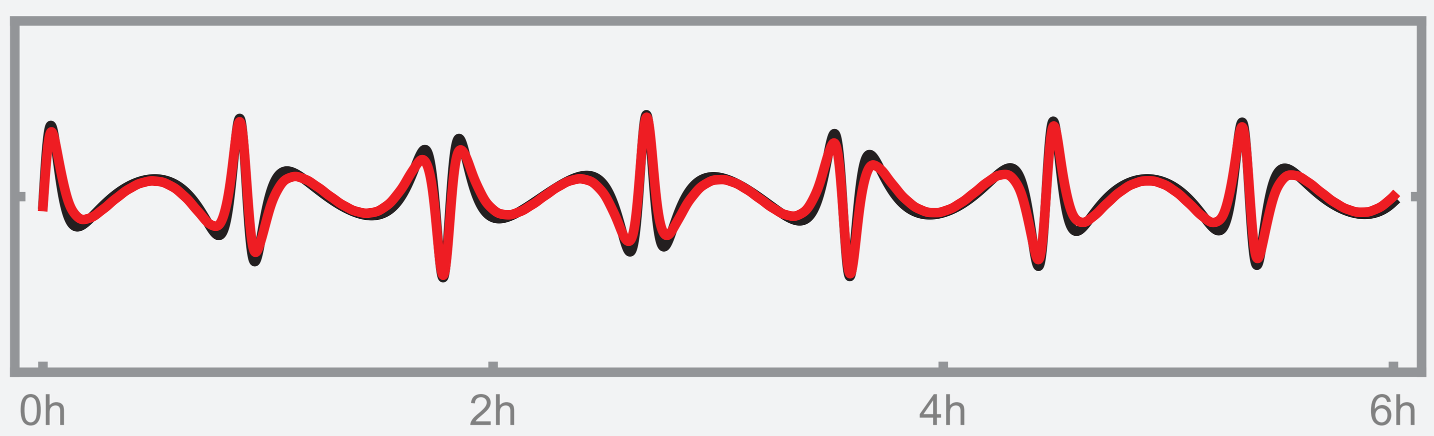
Detection: Augmented Analytic Kludge



Analytic kludge model builds orbital trajectory out of precessing Keplerian ellipses; its waveforms are fast to generate but dephase relative to more accurate waveforms within hours

Matching Keplerian, periapsis precession and Lense–Thirring frequencies of each ellipse to ***fundamental frequencies*** *of corresponding Kerr geodesic induces three-dimensional map over space of orbits; we map black-hole mass and spin, along with orbital semi-latus rectum*

$$(M, a, p) \mapsto (\tilde{M}, \tilde{a}, \tilde{p}) \qquad (\omega_{\rm Kep}, \omega_{\rm peri}, \omega_{\rm LT})\big|_{(\tilde{M},\tilde{a},\tilde{p})} = (\omega_r, \omega_\phi - \omega_r, \omega_\phi - \omega_\theta)\big|_{(M,a,p)}$$



Augmented analytic kludge uses local fit to mapped trajectory of fiducial model and higher-order post-Newtonian equations; its waveforms are still fast to generate but now dephase over months

Source code for the augmented analytic kludge and other kludge waveforms (with shared front end) is available at **github.com/alvincjk/EMRI_Kludge_Suite**

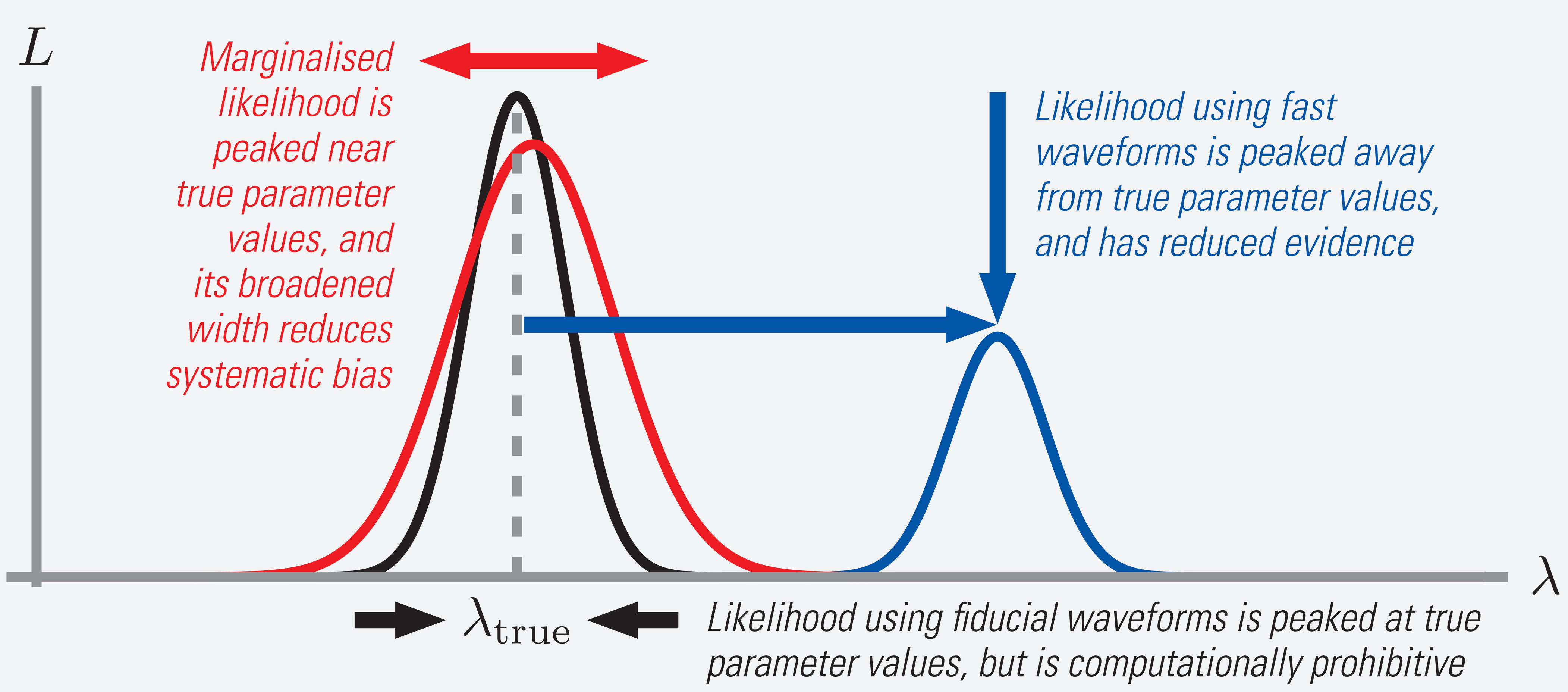
Parameter Estimation: Gaussian Process Regression

Difference between fast and fiducial waveforms is modelled by zero-mean ***Gaussian process*** *and interpolated from set of pre-computed differences in relevant region of parameter space*

$$h_{\rm fid} - h_{\rm fast} = \delta h \sim \mathcal{N}(\mu_{\rm GP}, \sigma^2_{\rm GP})$$

Waveform difference is marginalised over analytically in likelihood; ***marginalised likelihood*** *is computationally affordable as it only uses fast waveforms and Gaussian process interpolant*

$$L \propto \frac{1}{1+\sigma^2_{\rm GP}} \exp\left(-\frac{1}{2}\frac{\langle s-(h_{\rm fast}+\mu_{\rm GP})\,|\,s-(h_{\rm fast}+\mu_{\rm GP})\rangle}{1+\sigma^2_{\rm GP}}\right)$$



References

[1] A. J. K. Chua & J. R. Gair. Improved analytic extreme-mass-ratio inspiral model for scoping out eLISA data analysis. *Class. Quantum Grav.* 32:232002, 2015.

[2] C. J. Moore, C. P. L. Berry, A. J. K. Chua & J. R. Gair. Improving gravitational-wave parameter estimation using Gaussian process regression. *Phys. Rev. D* 93:064001, 2016.

[3] A. J. K. Chua. Augmented kludge waveforms and Gaussian process regression for EMRI data analysis. *J. Phys.: Conf. Ser.* 716:012028, 2016.

[4] A. J. K. Chua, C. J. Moore & J. R. Gair. The fast and the fiducial: Improving kludge waveforms for extreme-mass-ratio inspirals. In preparation, 2016.

CONTACT INFORMATION

Alvin J. K. Chua / Institute of Astronomy, University of Cambridge
Phone: +44 1223 339277 / E-mail: ajkc3@ast.cam.ac.uk

ioa

UNIVERSITY OF CAMBRIDGE