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CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

Testing the No-Hair Theorem with IMRIs in Advanced LIGO

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Overview

- Prospects for IMRI detection
- Why IMRIs?
- Tests of General Relativity:
  - Null test of No-Hair theorem
  - Super-compact objects
- Fisher matrix formalism
  - Post-Newtonian waveforms
- Results

IMRIs in Advanced LIGO

- IMRI = Intermediate Mass Ratio Inspiral
    - 1.4/50 to 1.4/350 solar masses
- Expected from core-collapsed globular clusters
- Current estimates place an upper limit of ~10 detections per year
- On average, we hope to see one IMRI every 3 years *--Mandel et al. 2008*

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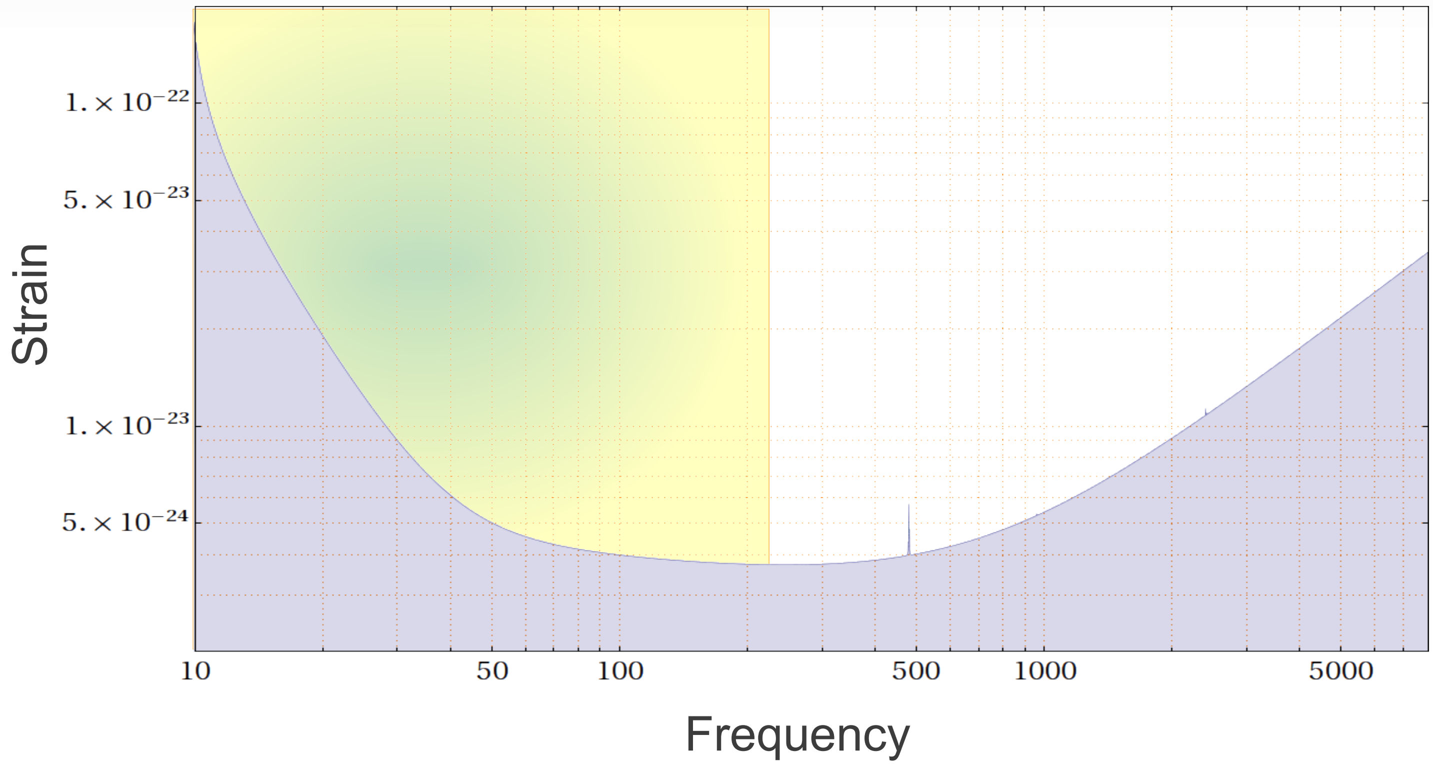
Why IMRIs?

- IMRIs make our lives more difficult
  - Large uncertainty in waveforms
  - Sensitivity is poor in the IMRI range



Why IMRIs: Three Reasons

- Large mass ratio isolates properties of single object *--Brown et al. 2008*
- IMRIs spend many orbits near ISCO
- Don't need to wait for LISA

--Barack and Culter, 2005

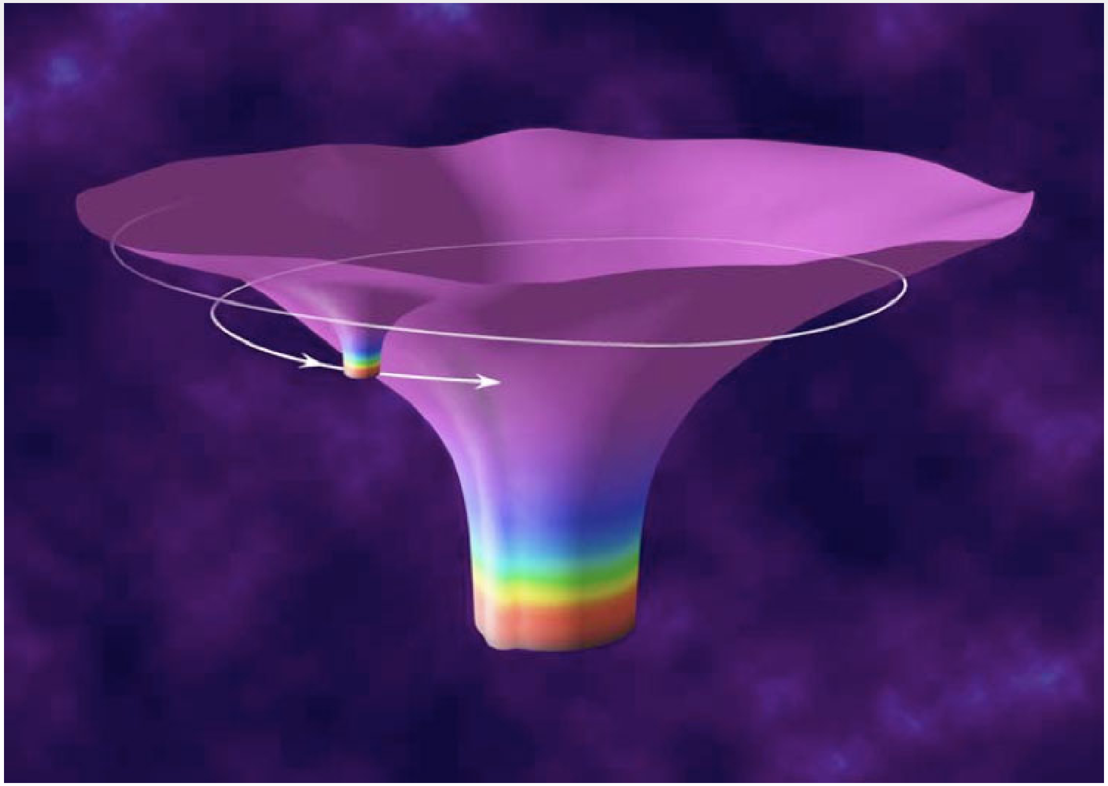


Photo: lisa.nasa.gov

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Null Tests of GR

- The well known No-Hair theorem
  - All Kerr multi-pole moments can be specified by mass and spin
  - Mass quadrapole moment, given by

$$Q_{\text{kerr}} = -a^2 m^3$$

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- Introduce a deviation:

$$Q_{\mathrm{mod}} = Q_{\mathrm{kerr}} + Q_{\mathrm{anom}}$$

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Exotic Matter Stars

- Massive, horizon-less objects:
- Boson Stars:
    - Expected to have $Q \in [15, 100]a^2m^3$

      --Ryan, 1997
- Soliton stars
- Naked singularities
- Something completely different?

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Determining Uncertainties

- Via the Fisher Information Matrix
  - Defining $\langle a, b \rangle \equiv \sum_{\alpha} \left(4 \int_0^{\infty} \frac{a_{\alpha}(f) b_{\alpha}^{*}(f)}{S_h(f)} df \right)$
  - And $F_{ij} \equiv \left\langle \frac{\partial h}{\partial \theta^i}, \frac{\partial h}{\partial \theta^j} \right\rangle$
  - Then $\sigma_i^2 = (\Gamma_{ii})^{-1} \left[1 + \mathcal{O}(\mathrm{SNR}^{-1}) \right]$

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Using the pN Waveform

- A first pass with 2pN SPA Waveforms
- Replace quadrapole-monopole interaction in phase with

--Poisson & Will, 1995
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$$-\frac{5}{2}\sum_{\alpha}\frac{Q_{mod}}{m_{\alpha}M^{2}}\left[3(\hat{L}\cdot\hat{s}_{\alpha})-1\right]$$

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$$\Downarrow$$

$$-5(-a^2+Q_{anom})\left(\frac{m_\alpha}{M}\right)^2$$

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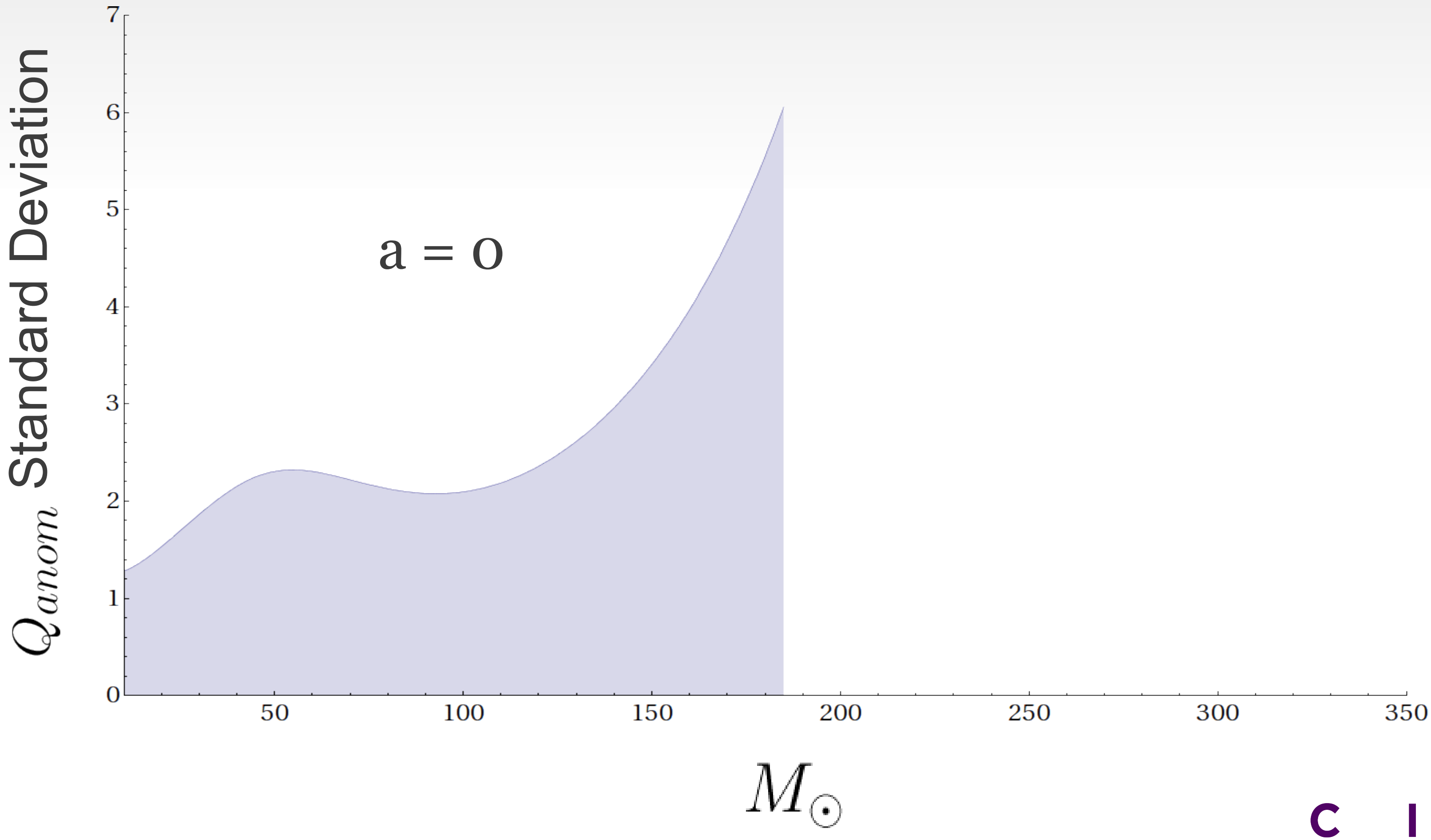

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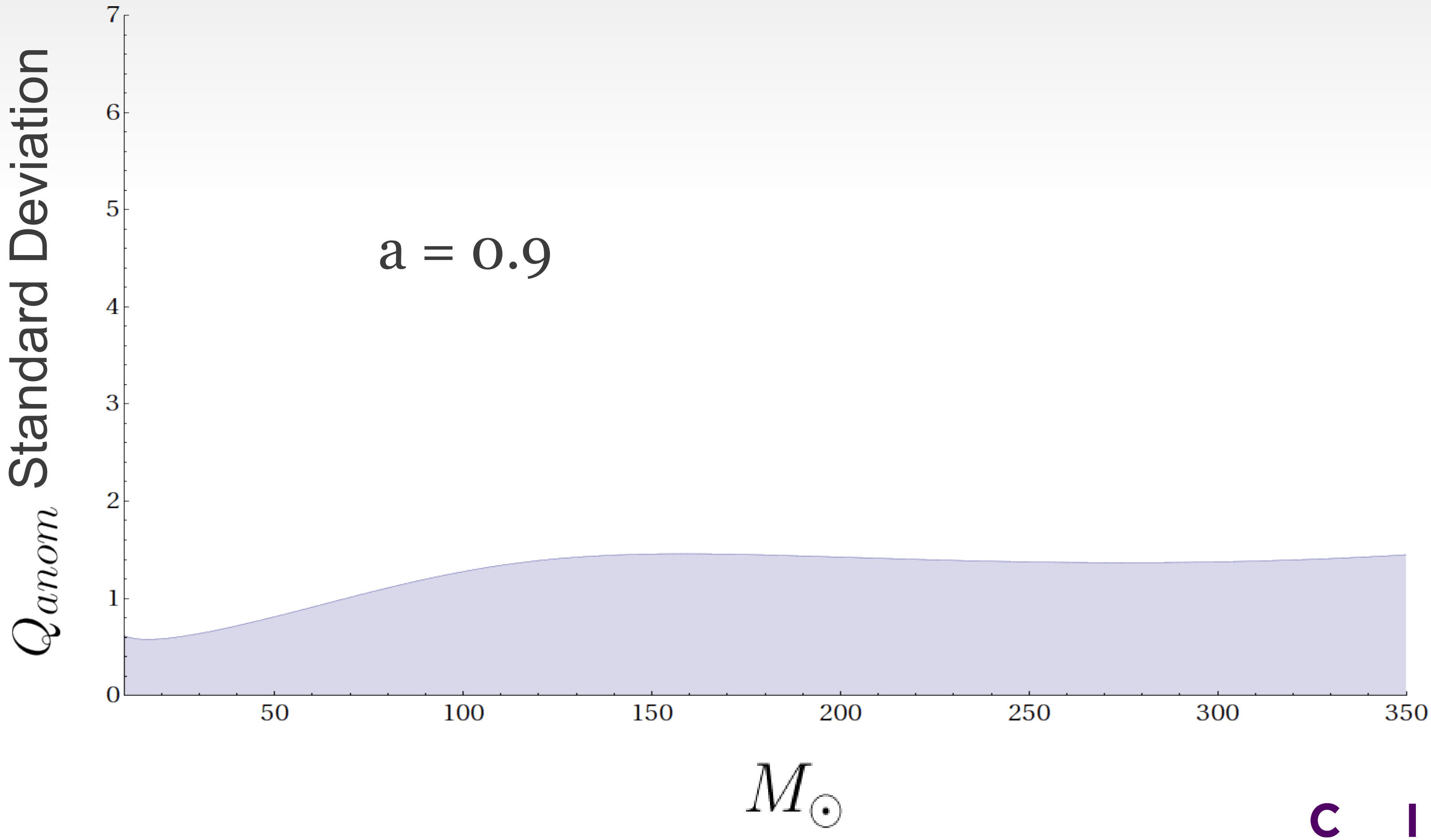

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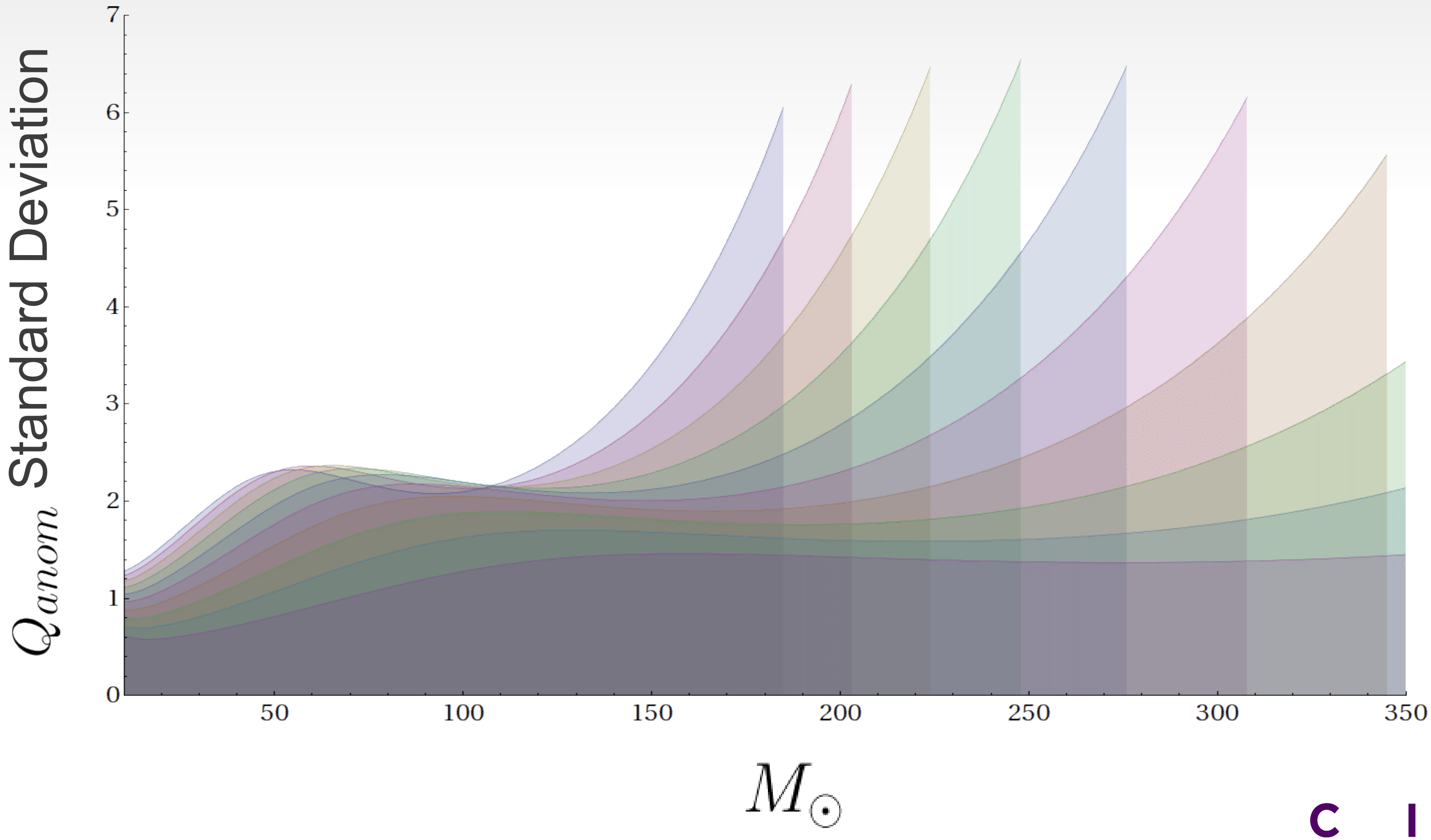

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Summary/Future Work

- Advanced LIGO will be able to statistically test IMRIs for any off-Kerr quadrupole moment
- It will be possible to discern different types of massive objects: black holes, boson stars, etc.
  - At least until LISA arrives
- Including priors in the Fisher matrix will serve to increase the theoretical sensitivity
- Results will be more realistic with next generation waveforms
  - Leading to parameter estimation

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References

- Rates Paper:
  - Mandel et al., 2008 arXiv:astro_ph/0705.0285
- Previous LIGO/LISA work:
  - Brown et al., 2008 arXiv:gr-qc/0612060
  - Barack & Cutler, 2006 arXiv:gr-qc/0612029
- 2pN SPA waveforms:
  - Poisson & Will., 1995 arXiv:gr-qc/9502040
  - Will, 1997 arXiv:gr-qc/9707032