A Gravitational Wave Test of The No-Hair Theorem

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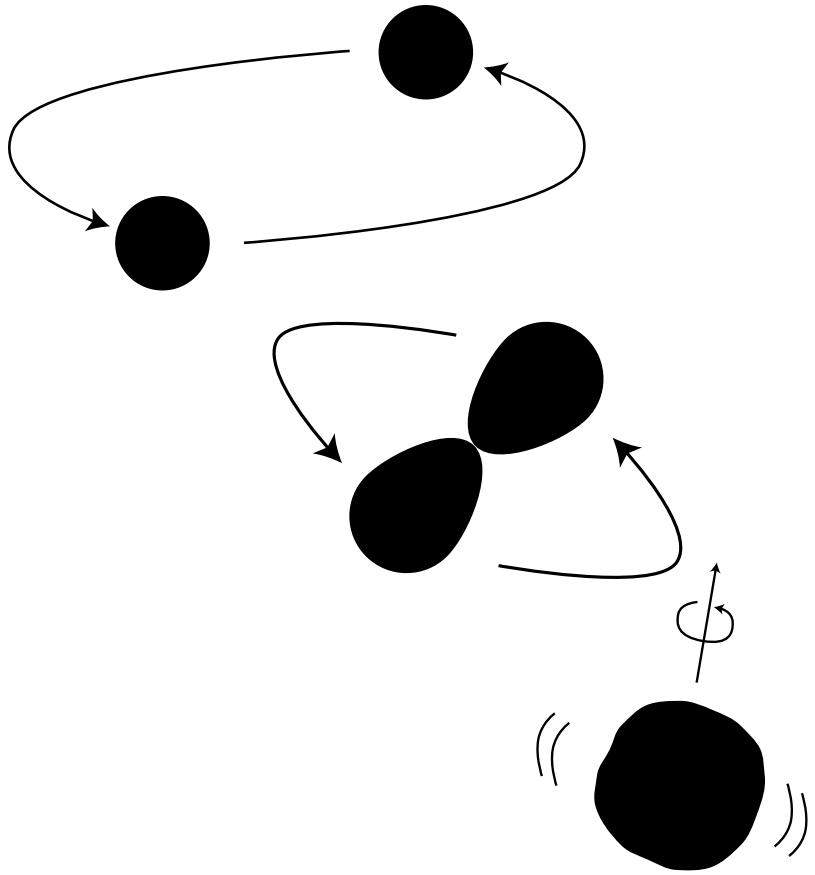
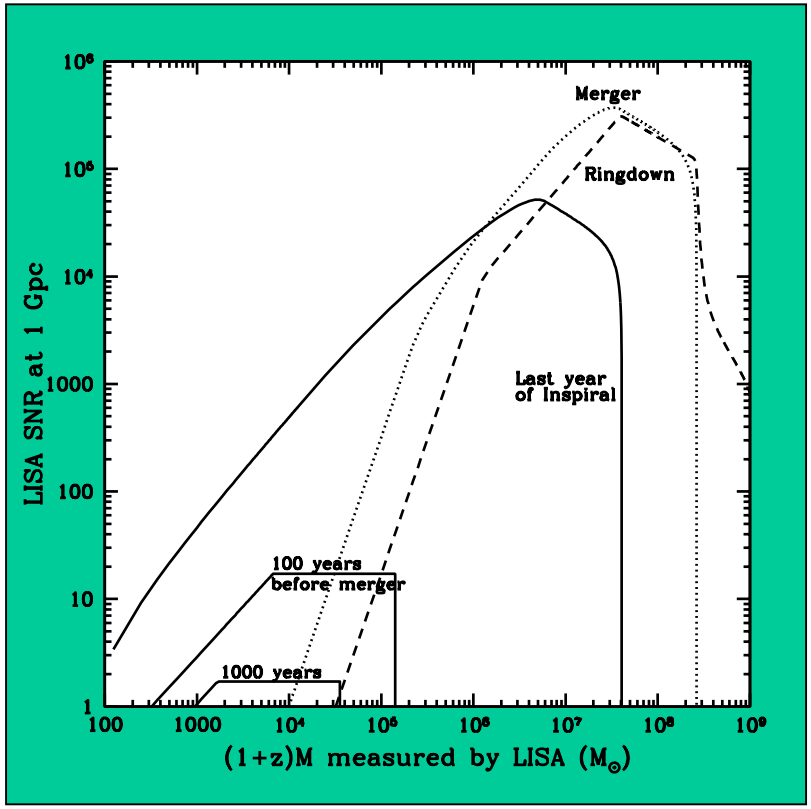
Black hole formation

- E.g., by binary coalescence
- Inspiral, merger, ringdown
  - Inspiral
    - Very sensitive to initial conditions
  - Merger
    - Pattern unknown, very possibly messy
  - Ringdown
    - Discrete normal mode spectrum



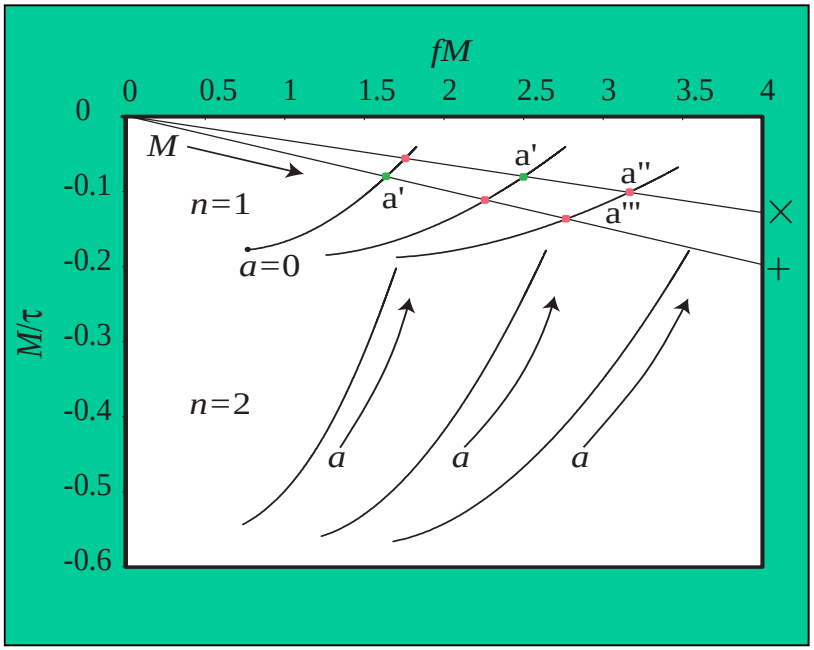
Ring-down and the No-Hair Theorem

- Ringdown
  - Discrete quasi-normal mode spectrum
  - High S/N: for LISA
    - ρ ~ 100 at rate 10/y, 10 at rate 100/y
    - Flanagan & Hughes Phys. Rev. D57 (1998)
- No-hair theorem:
  - (f, t) fixed by M, J, "quant." #'s (n, l, m)
- Are observed modes consistent with single M, J?



BH Normal Mode Spectrum

- Observe ringdown
  - $s(t) \sim \Sigma \exp(-t/\tau_k) \sin 2\pi f_k t$
- Estimate (f,t) pairs
  - Each pair suggests set of (M,J,n,l,m) n-tuples



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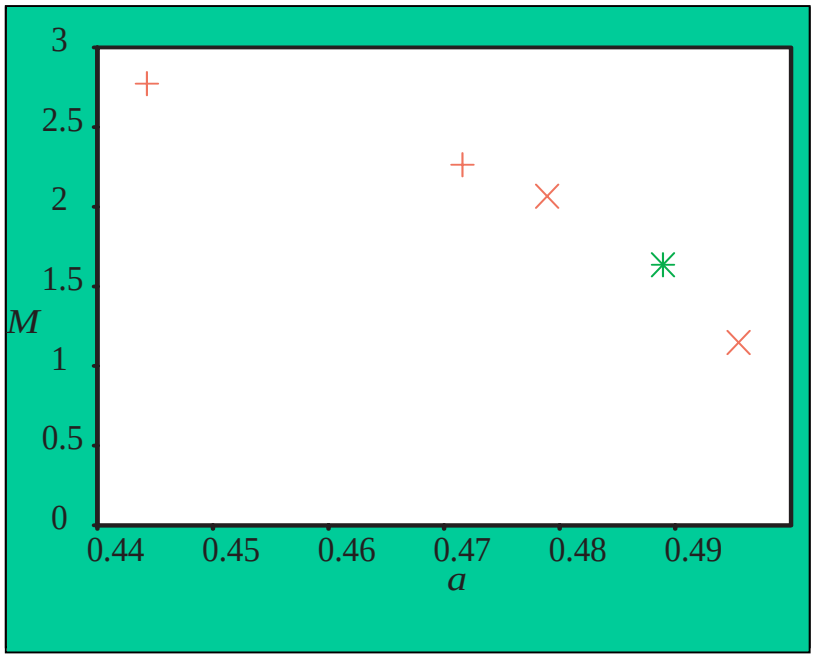
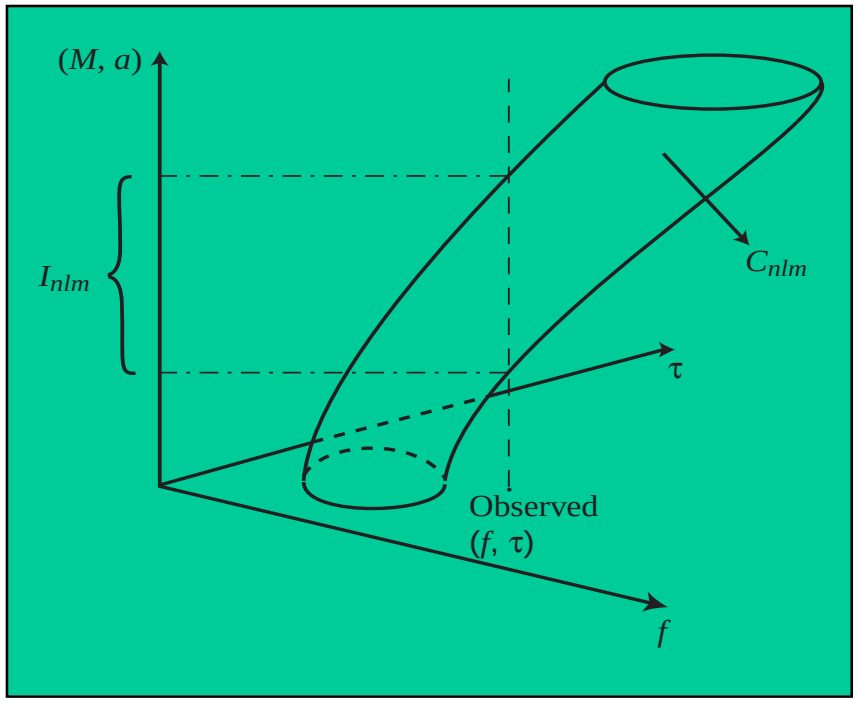
- No-hair theorem?
  - Consistent (in M, J) set of n-tuples



Making Consistency Quantitative

- Observe signal+noise
- Fixed (n,l,m) tracks become "snakes"
  - Girth determined by S/N, confidence level q
- Consistency: observed $\{(f,t)\}$ intersects sausage
  - Even if no-hair true a prob. $p(q)$ that doesn't
- Conclude (in)consistent
  - (Fails to) intersect snake
- Note: construction gives M, J confidence region if assume GR



Summary

- A quantitative test of general relativistic gravity
  - High rate, S/N ring-down observations allow precision test of GR
- LISA expected to observe
  - S/N 100 black hole formations at rate 10/y;
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- If observe a single QNM, likely to observe several
  - $l = 2$ loudest (m depends on formation mechanism)
  - No-hair theorem predicts unique relationship between mode frequency, damping time and black hole M, J
    - Alternatives? E.g., boson stars
  - Test of consistency is test of no-hair theorem