Title: Constraining the spin parameter of near-extremal black holes using LISA

Speakers: Ollie Burke

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Abstract: We describe a model that generates first order adiabatic EMRI waveforms for quasi-circular equatorial inspirals of compact objects into rapidly rotating (near-extremal) black holes. Using our model, we show that LISA could measure the spin parameter of near-extremal black holes (for aâ‰³0.9999) with extraordinary precision, âˆ¼ 3-4 orders of magnitude better than for moderate spins, aâˆ¼0.9. Such spin measurements would be one of the tightest measurements of an astrophysical parameter within a gravitational wave context. Our results are primarily based off a Fisher matrix analysis, but are verified using both frequentest and Bayesian techniques. We present analytical arguments that explain these high spin precision measurements. The high precision arises from the spin dependence of the radial inspiral evolution, which is dominated by geodesic properties of the secondary orbit, rather than radiation reaction. High precision measurements are only possible if we observe the exponential damping of the signal that is characteristic of the near-horizon regime of near-extremal inspirals. Our results demonstrate that, if such black holes exist, LISA would be able to successfully identify rapidly rotating black holes up to a=1âˆ’1eâˆ’9 , far past the Thorne limit of a=0.998.

Constraining the Spin Parameter of Near-Extremal Black Holes

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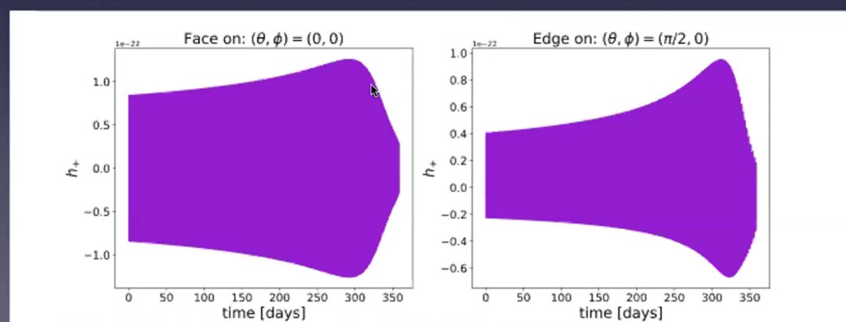
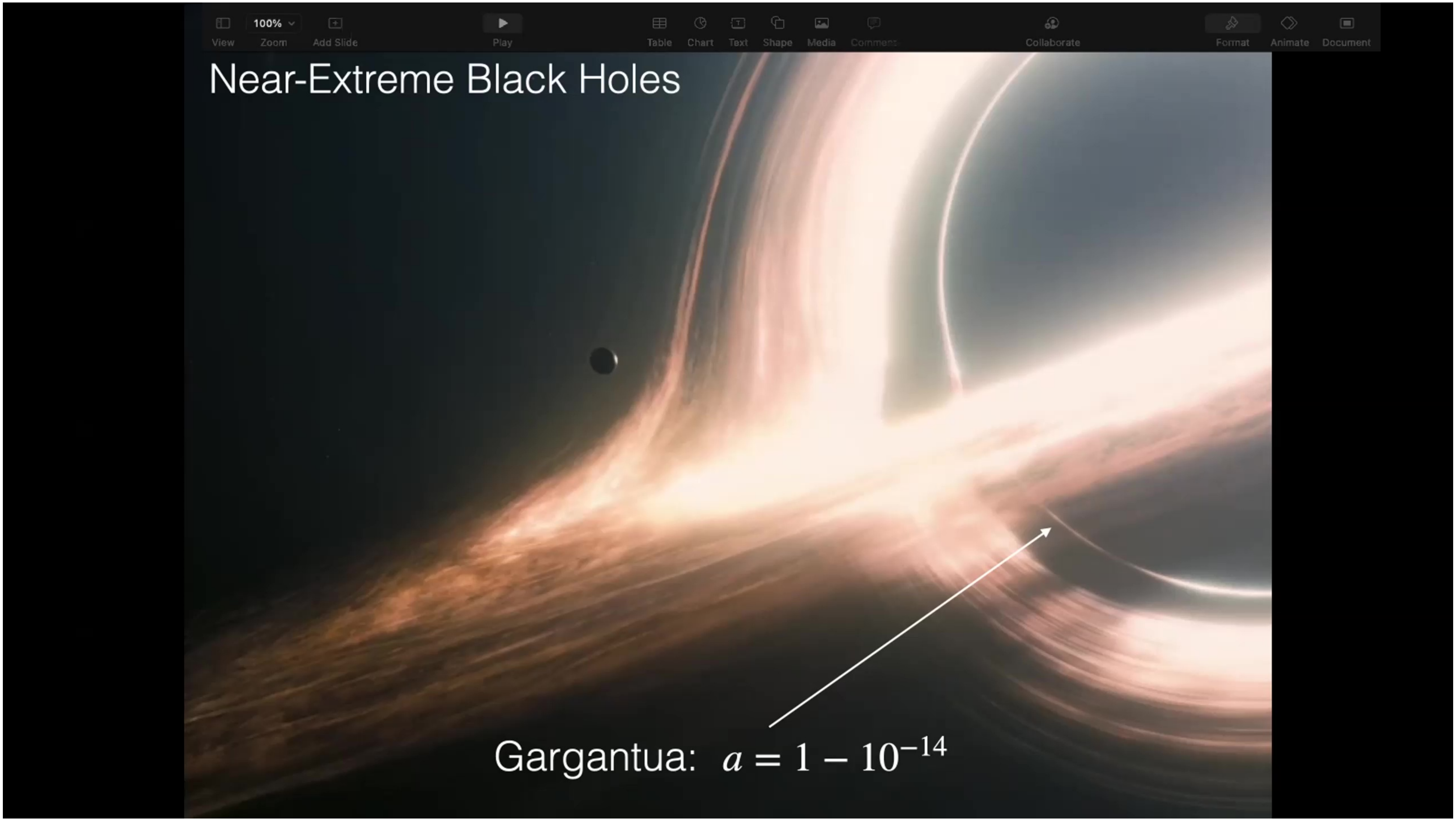


24th CAPRA meeting, 11th of June, 2021

The Roadmap

- **A Review:** Near-Extreme EMRIs
- **Analytic Results:** Why expect high precisions?
- **Numerical Results:** parameter space precision
- **Future:** Conclusions, Future work + Discussion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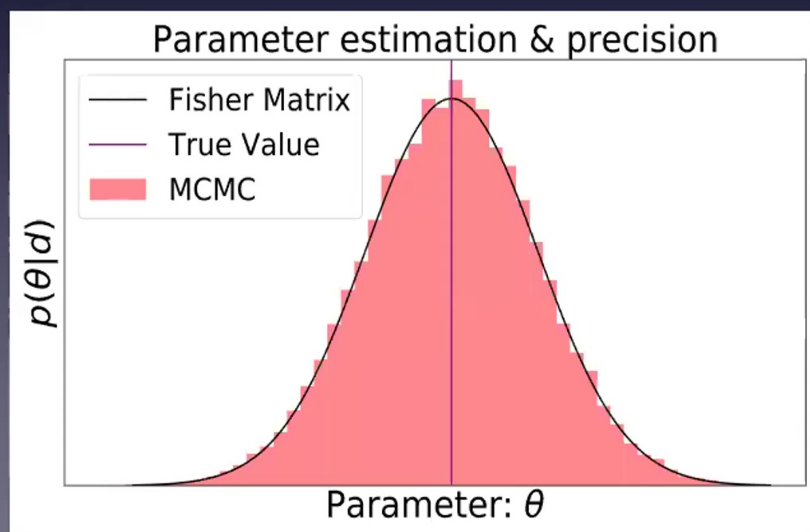
Near-Extreme Black Holes
Gargantua: $a = 1 - 10^{-14}$

The Fisher Matrix

Fisher Matrix: $\Gamma_{ij} = (\partial_i h \,|\, \partial_j h)$. Where Precision in $\theta^i \approx \sqrt{(\Gamma^{-1})^{ii}}$

Inverse $\Longleftrightarrow$ Precision on parameters!



The radial trajectory

- $\tilde{E} = \tilde{E}_{\text{circ}}(\tilde{r}, a) \Rightarrow \dfrac{d\tilde{r}}{d\tilde{t}} = -\dfrac{\dot{\tilde{E}}_{\text{GW}}}{\partial_{\tilde{r}}\tilde{E}}$

$\dot{\tilde{E}}_{\text{GW}} \leftarrow$ Dynamical (Radiation)

$\partial_{\tilde{r}}\tilde{E} \leftarrow$ Kinematical (Geodesic)

- Two choices for $\dot{\tilde{E}}_{\text{GW}}$

  1. **Numerical**: $\dot{\tilde{E}}_{\text{GW}} =$ Maarten + BHPT

Spin Parameter Fisher Matrix

spin precision $\approx (\Gamma_{aa})^{-1/2}$, with

$$\Gamma_{aa} \approx \frac{8M}{\tilde{D}^2 S_n(f_{\mathrm{O}})} \sum_m \int_{\tilde{t}_0}^{\tilde{t}_{\mathrm{cut}}} d\tilde{t}\, \dot{\tilde{E}}_m^{\infty} (\tilde{\Omega}\tilde{t})^2 \left(1 + \frac{3}{2}\sqrt{\tilde{r}}\,\partial_a \tilde{r}\right)^2$$

Spin Parameter Fisher Matrix

spin precision $\approx (\Gamma_{aa})^{-1/2}$, with

$$\Gamma_{aa} \approx \frac{8M}{\tilde{D}^2 S_n(f_{\rm O})} \sum_m \int_{\tilde{t}_0}^{\tilde{t}_{\rm cut}} d\tilde{t}\, \dot{\tilde{E}}^{\infty}_m (\tilde{\Omega}\tilde{t})^2 \left(1 + \frac{3}{2}\sqrt{\tilde{r}}\,\partial_a \tilde{r}\right)^2$$

Outgoing Flux

#No. Cycles (squared)

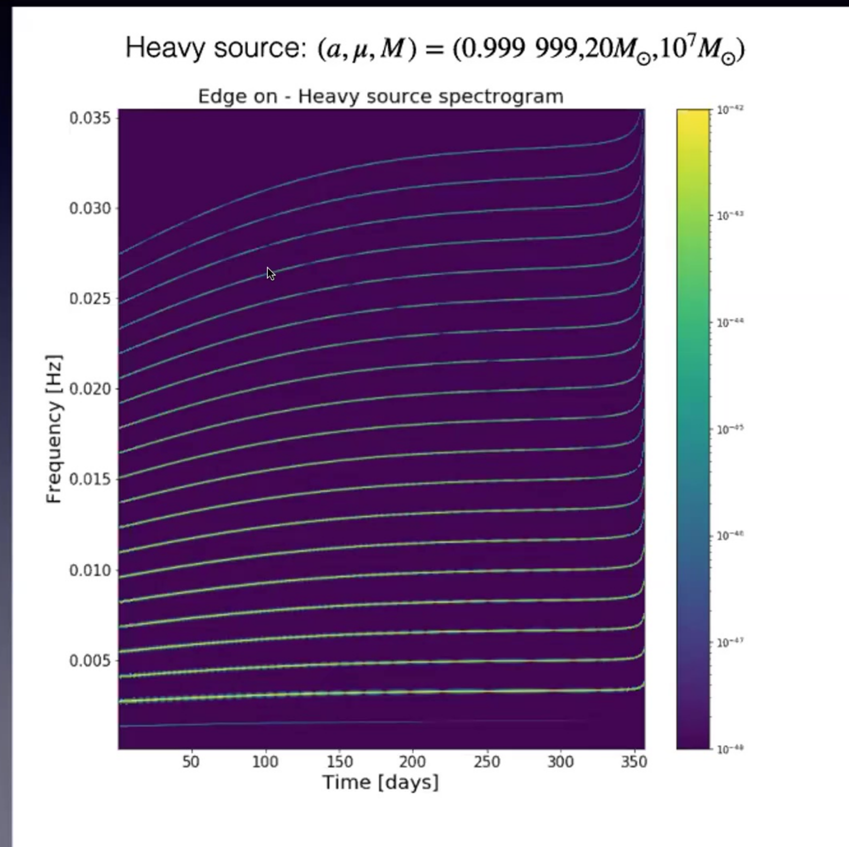
Spin Dependence Radial Trajectory

Teukolsky based waveform

Teukolsky based Waveforms

Edge on:
Require $|m| \leq l = 20$

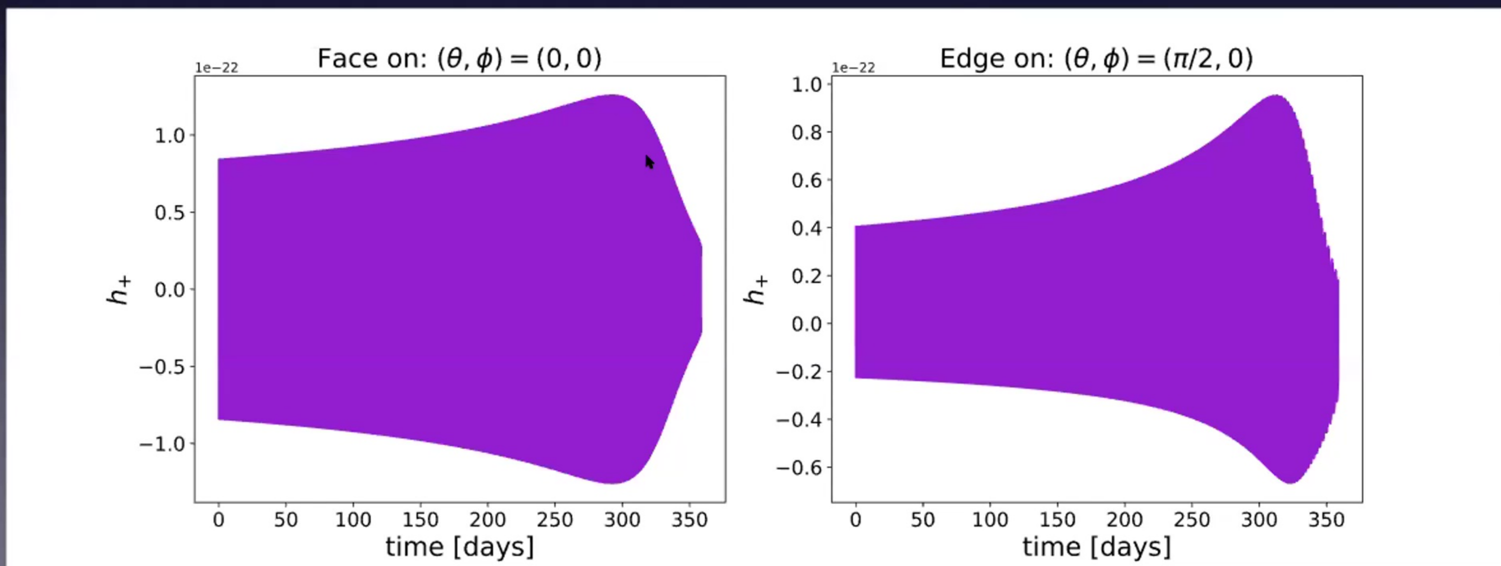
Complicated Harmonic Structure!



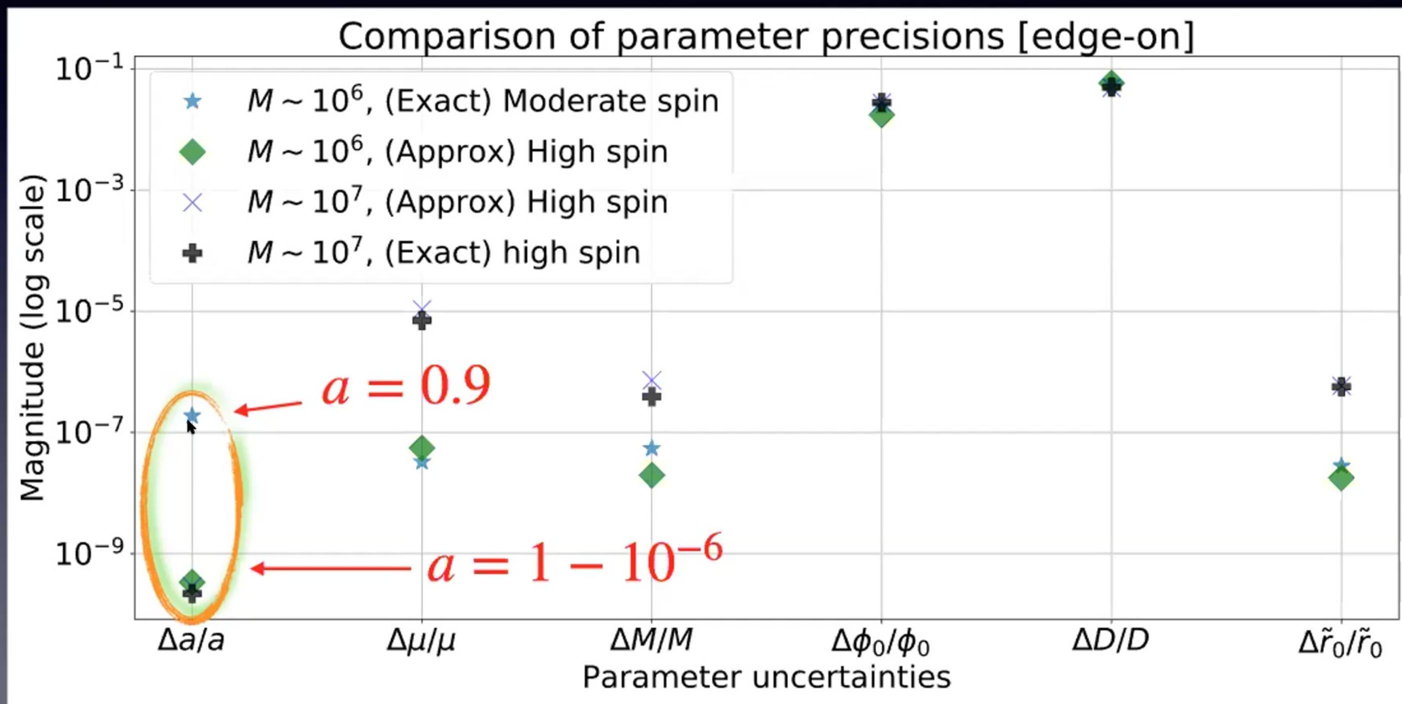
Inspiral + Dampening

Light source: $(a, \mu, M) = (0.999\ 999, 10M_{\odot}, 2 \cdot 10^6 M_{\odot})$

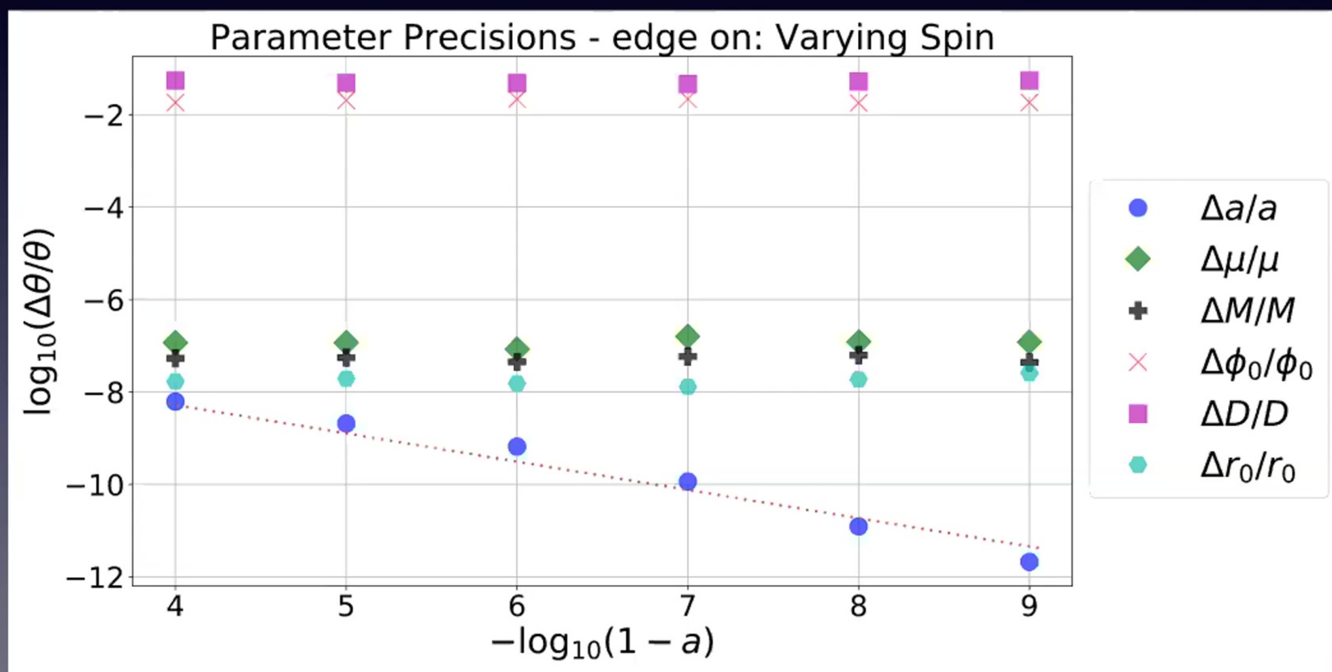
SNR ~ 20



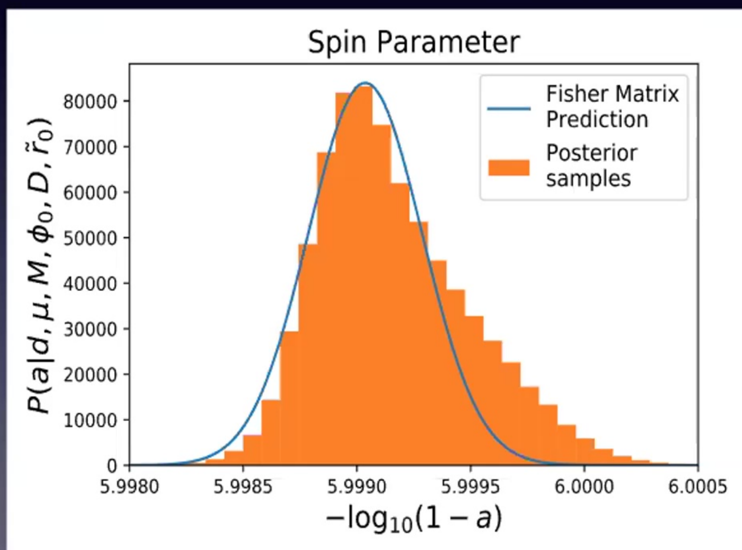
Constraints on spin parameter



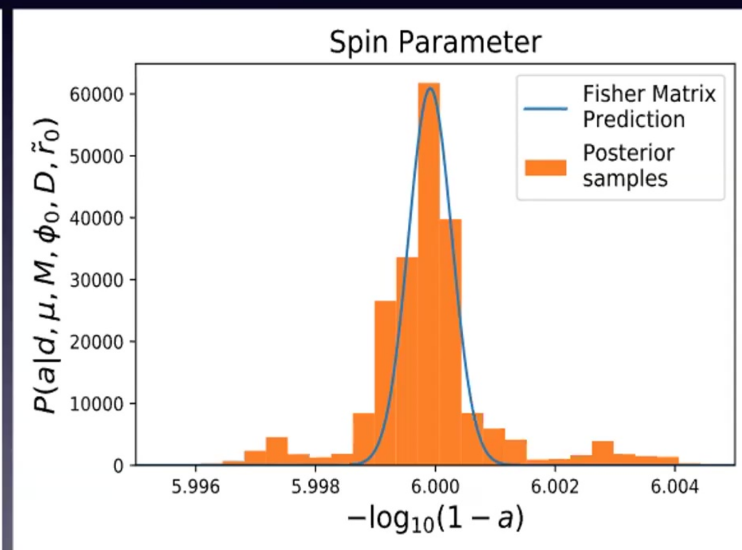
Increasing the spin parameter



Verification - Tight Precision



Heavy Source



Light Source

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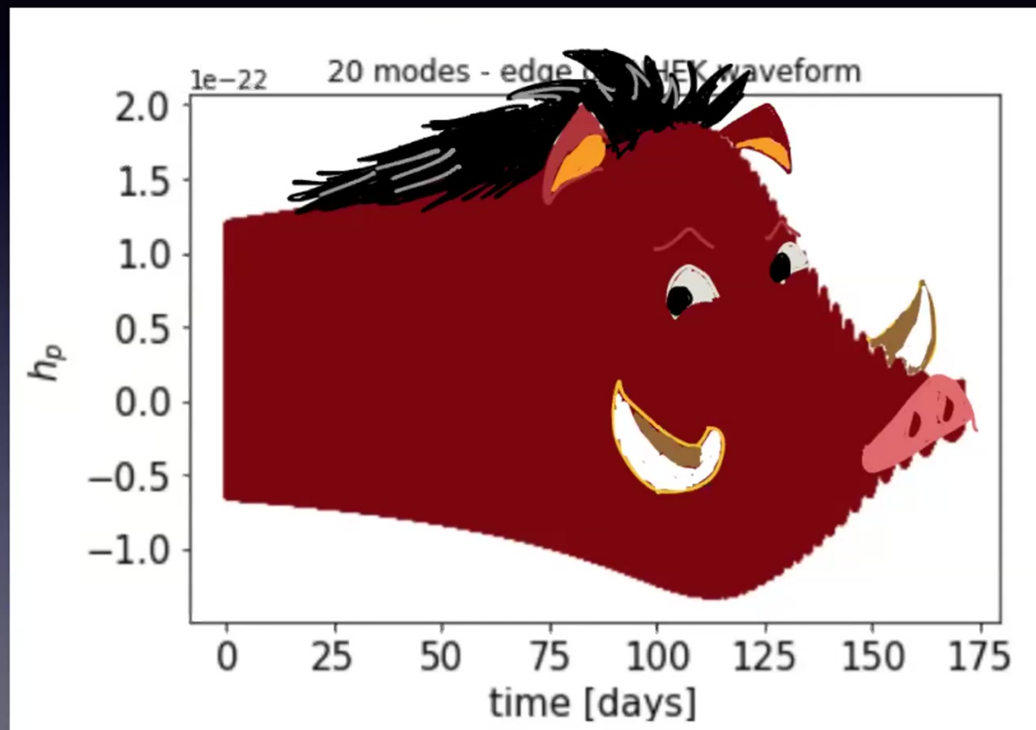
A natural extension…
Full near-extremal GW
ISCO
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
$h \times D/\mu$
0
2
4
6
8
10
$\tilde{t} \times \eta$
(Burke, Gair, Simón, 2020)
Constraints on spin?

Further extensions…

- Multiple (analytical) parameter analysis.
- Extend the parameter space.
- Systematic (faithfulness) waveform study.

Questions?



Credit:
Andrea Antonelli

Constraints on spin parameter