Adiabatic vs Post-adiabatic

Circular Schwarzschild Orbits

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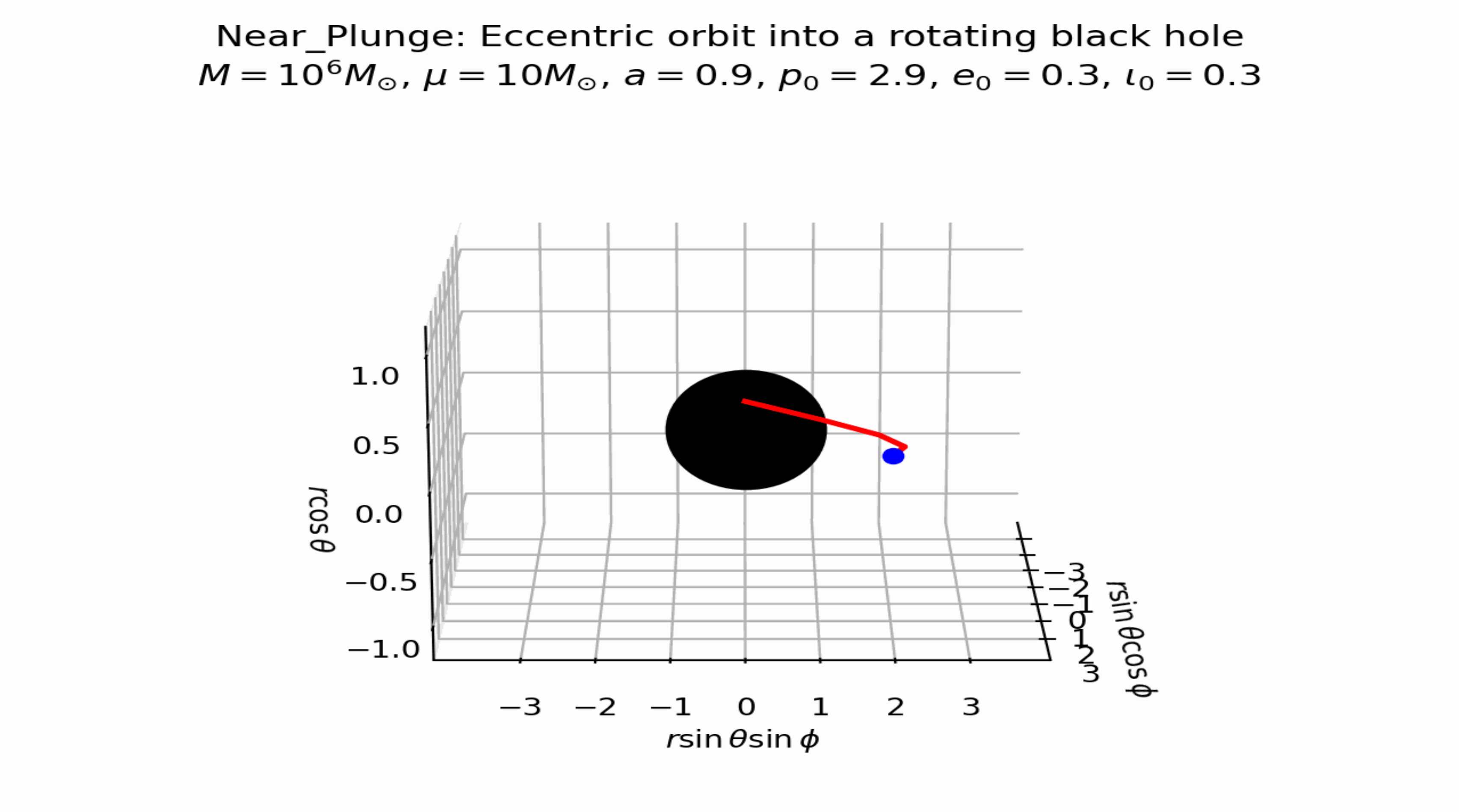
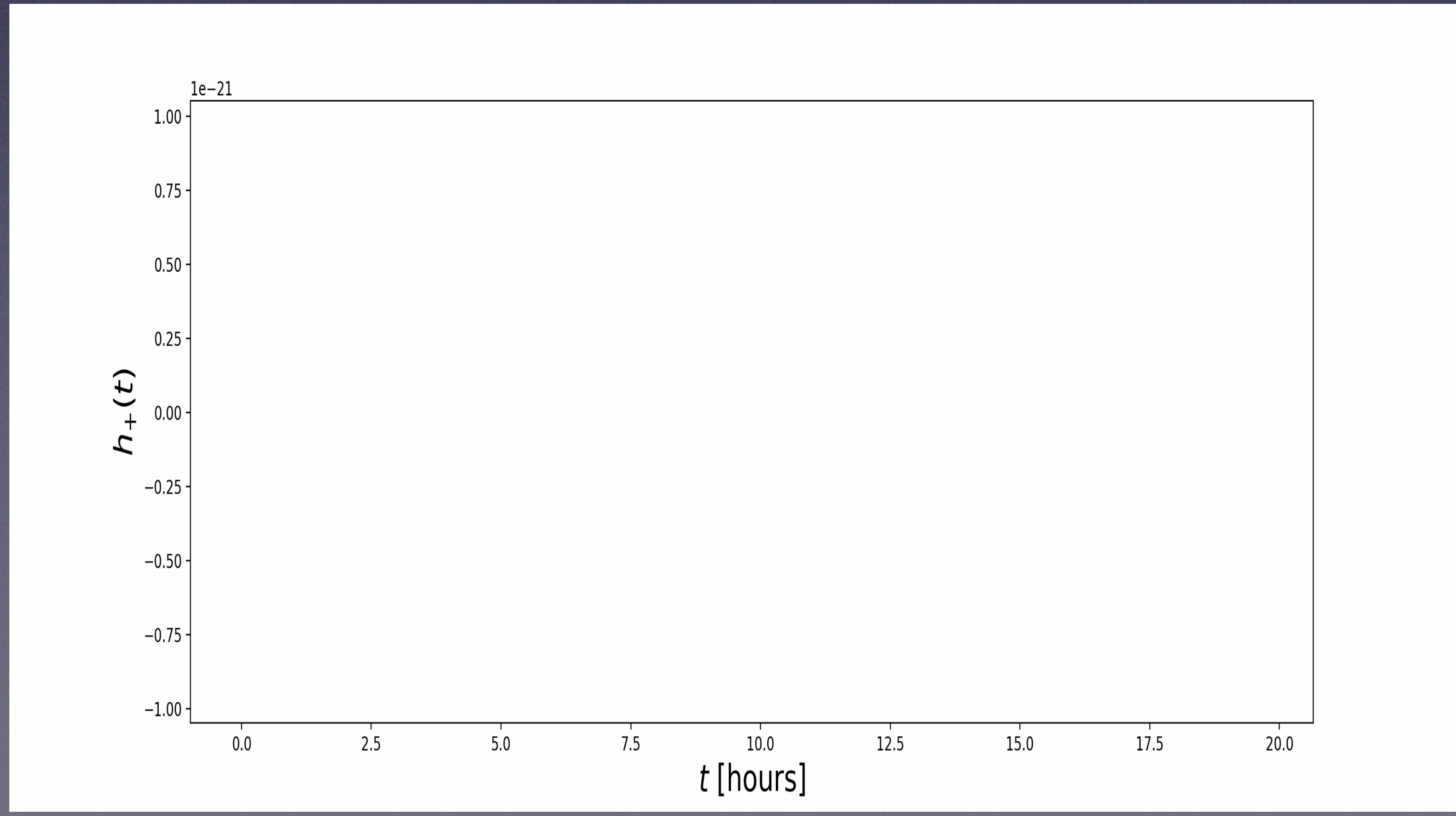


https://github.com/OllieBurke/animations

Capra, 05/07/23
Copenhagen



The structure

1. **Importance of accuracy:** The global picture
2. **Circular Schwarzschild Orbits:** 0PA vs 1PA — How well can we do?
3. **Concluding remarks :** Take home message + Discussion

Part 1: **Accuracy**

The global picture

Parameter estimation
what is important?

Cover parameter space

Why?

Failure to claim Detection

Fast to evaluate

Why?

We want results within a Hubble time

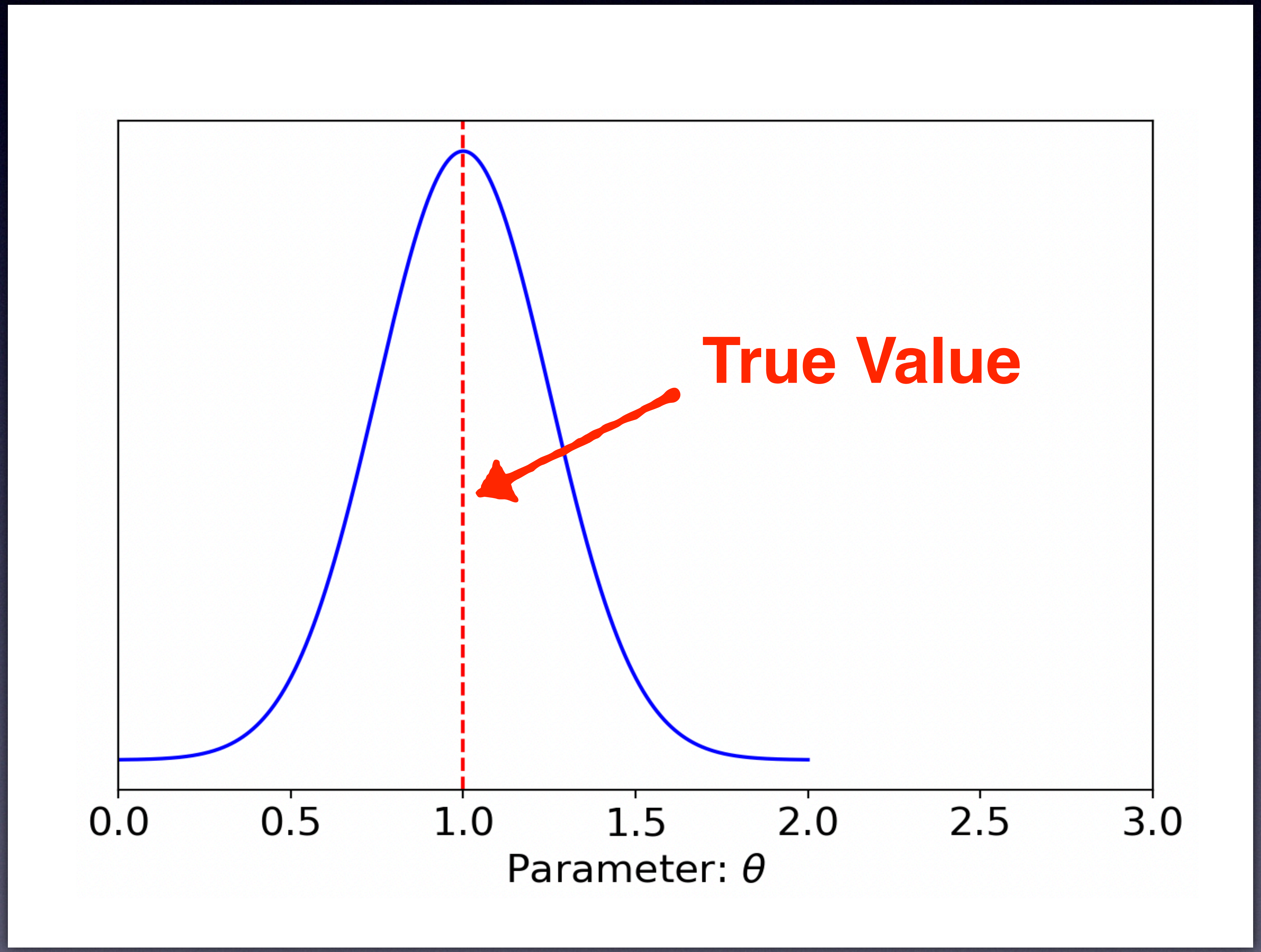
Faithful

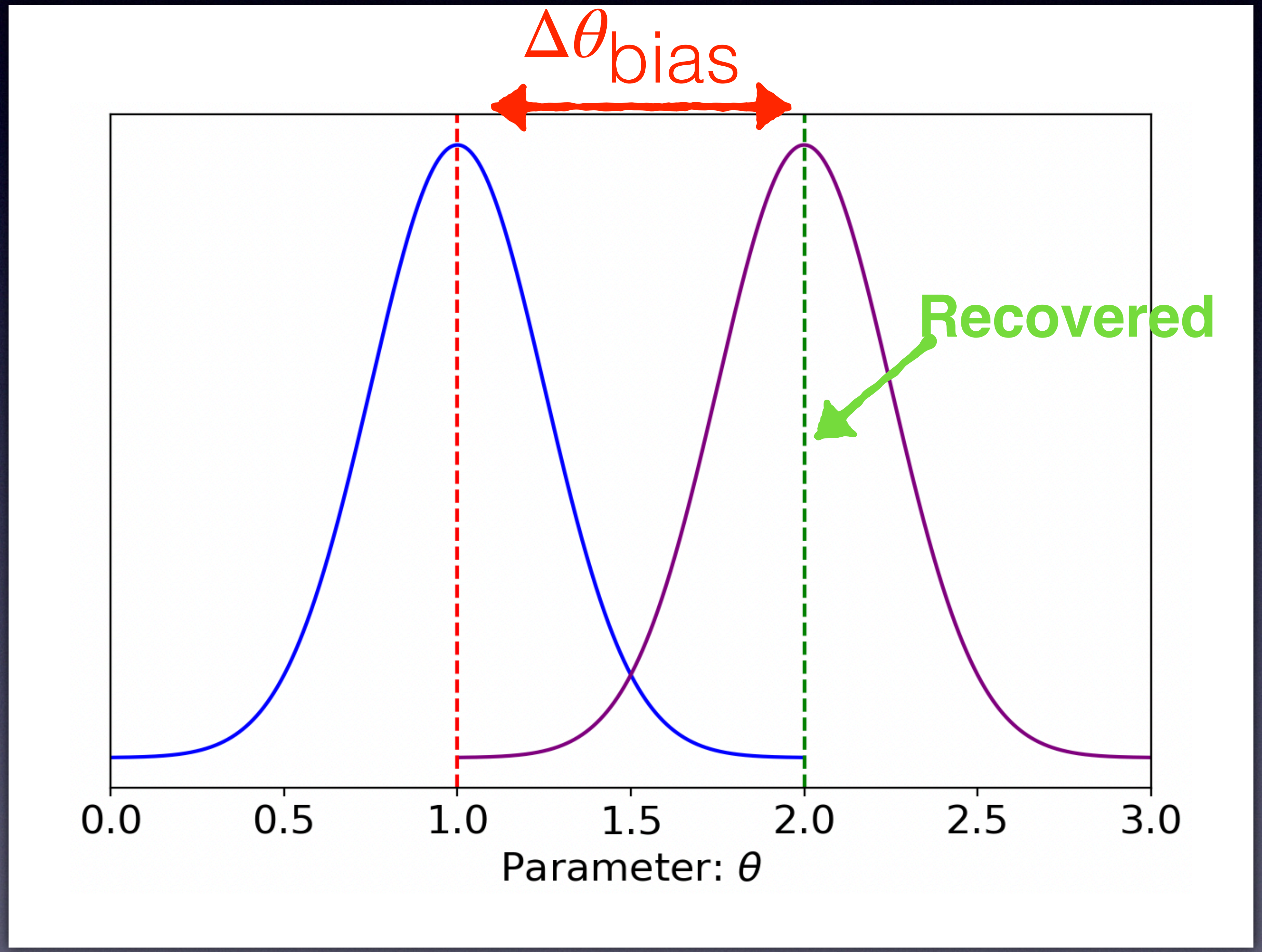
Why?

Potentially wrong parameters recovered

The importance of accuracy

Inaccurate Waveforms $\Longrightarrow$ Biases in Parameters

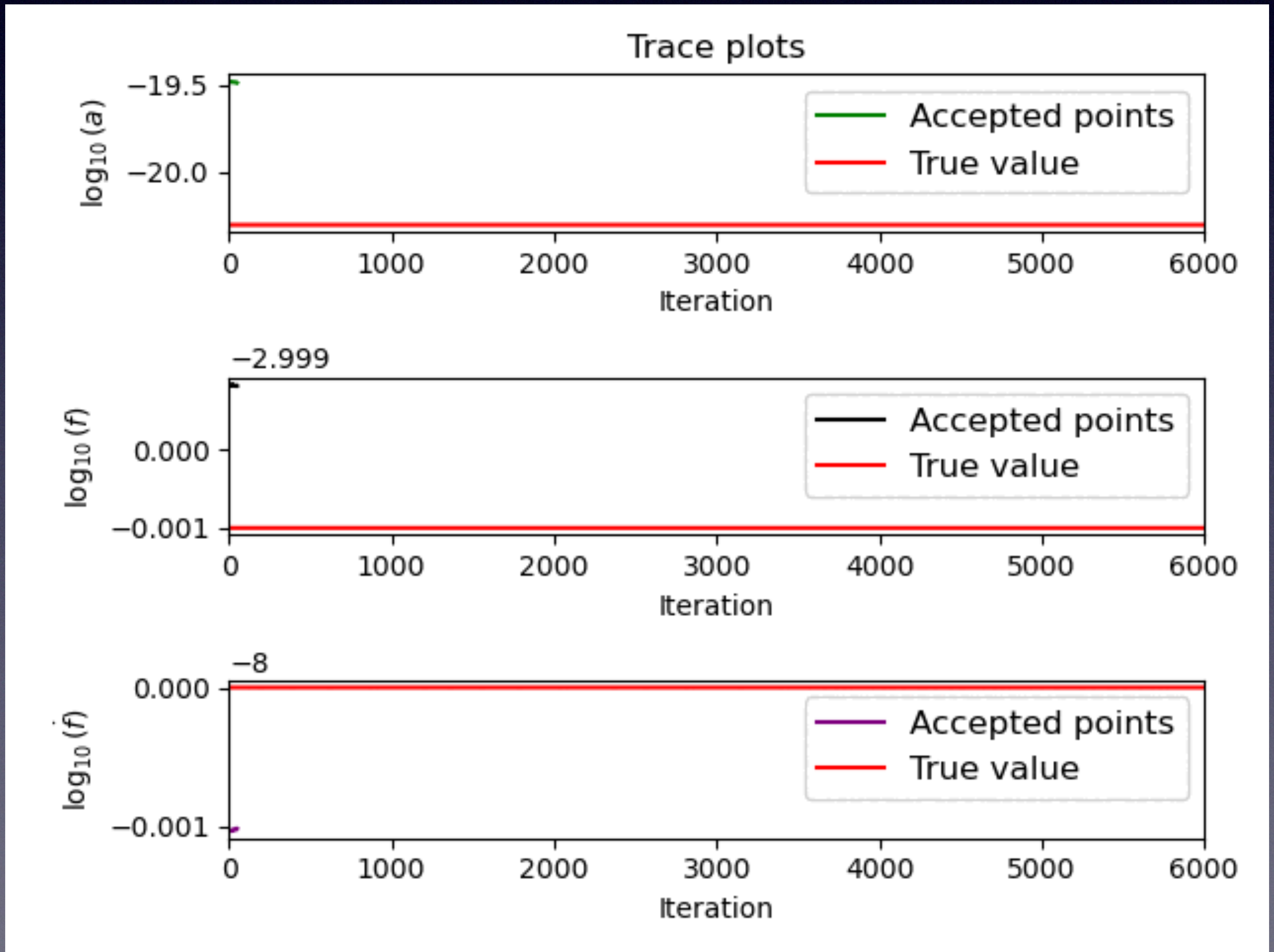


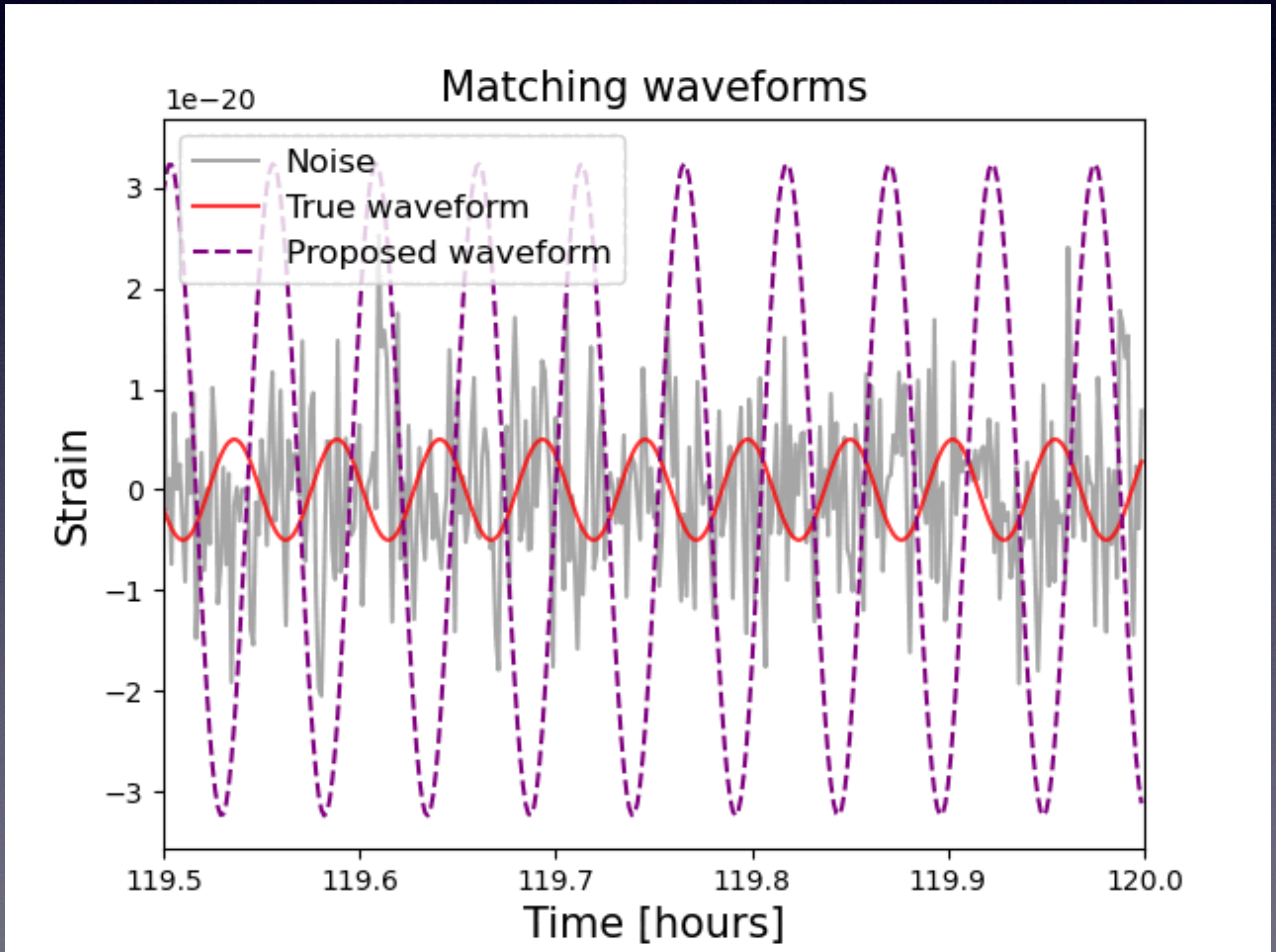


Goal: Recovered parameter within 1σ width of true distribution

Monte Carlo: finding the "best" signal

Goal: Identify parameters $\boldsymbol{\theta}$ that best match the waveform

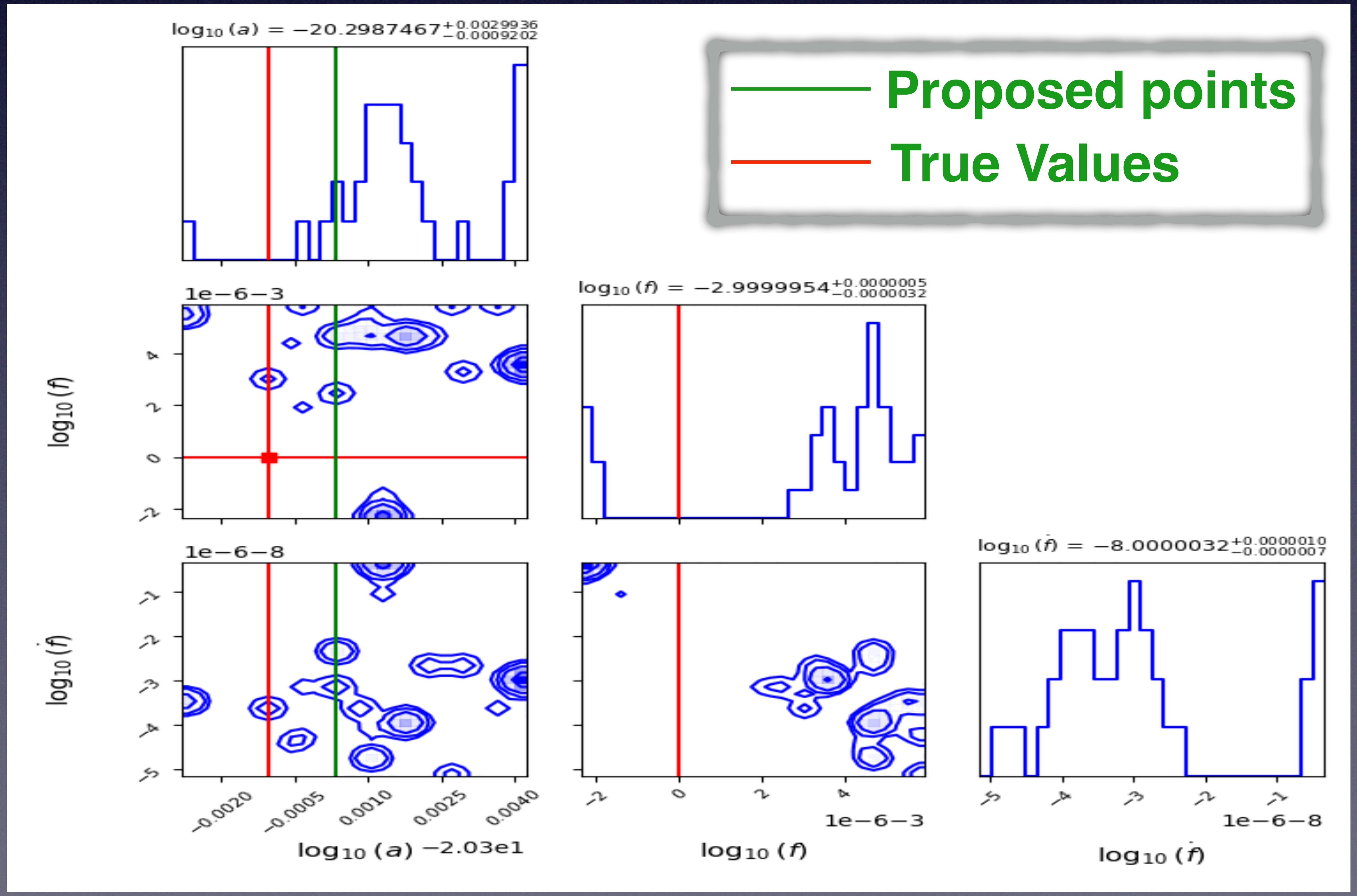


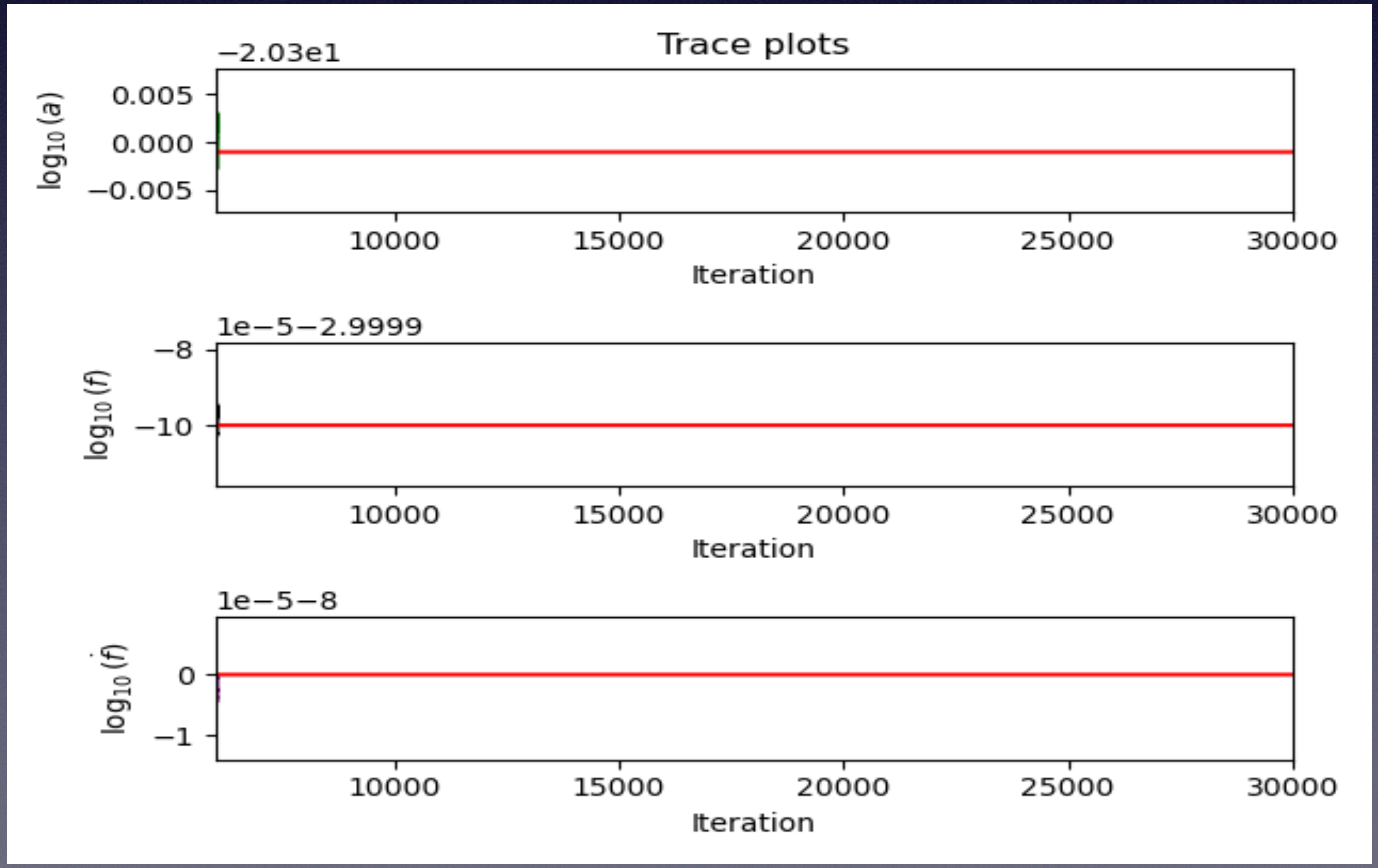


https://github.com/OllieBurke/Tutorials.git

Parameter Estimation

- Identified "best" location in parameter space
- Now sample $\boldsymbol{\theta} \sim p(\boldsymbol{\theta}\,|\,d)$ and explore posterior!
- Make statements on $\boldsymbol{\theta}$ given observed data d





https://github.com/OllieBurke/Tutorials.git

Part 2: **Search and Destroy**

Infrastructure

- **FastEMRIWaveforms** — GPU accelerated waveforms — **Fast** (Katz, *et al 2021*)
- ***Circular Schwarzschild Waveform Models with 0PA + (full) 1PA.*** (Pound, *et al 2019*)
- Full LISA response (TDI) including latest (mission requirements) noise model. (Katz, *et al 2021*)

Procedure: Injection with Accurate waveform then attempt recovery with innacurate waveform

1PA vs 1PA waveform

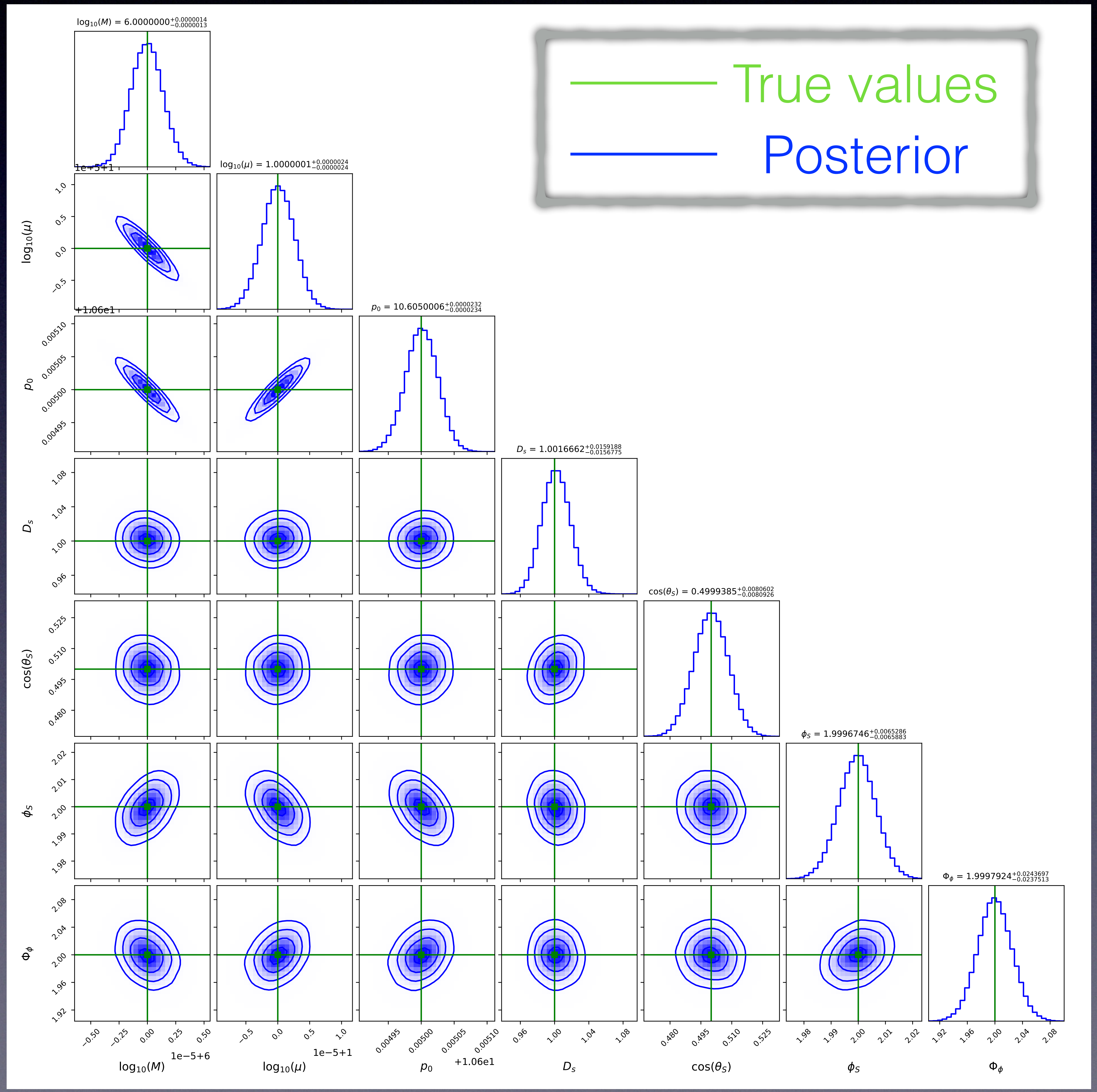
Inject waveform 1PA, **Recover with 1PA**

Quite loud: SNR ~ 62,

Strong field: $r - r_{\rm isco} \sim 0.3M$

Parameters: $M = 10^6 M_\odot, \mu = 10 M_\odot, r_0 = 10.605M$

Unbiased. As expected.



0PA vs 1PA waveform

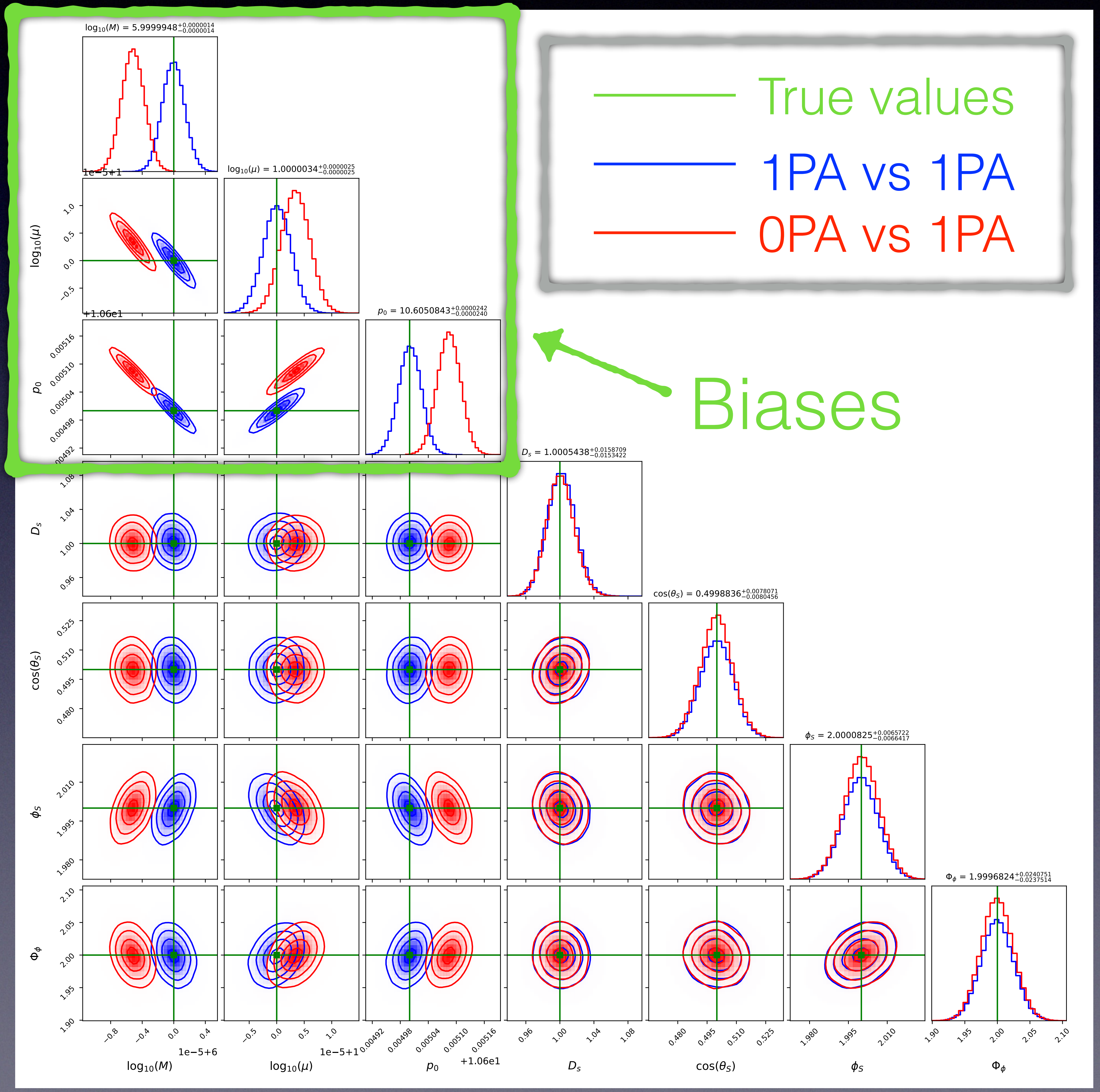
Inject waveform 1PA, **Recover with 0PA**

Quite loud: SNR ~ 62,

Strong field: $r - r_{\text{isco}} \sim 0.3M$

Parameters: $M = 10^6 M_\odot, \mu = 10 M_\odot, r_0 = 10.605M$

Largest bias $\sim 4\sigma$ from truth



Teeny-tiny perturbations to parameters

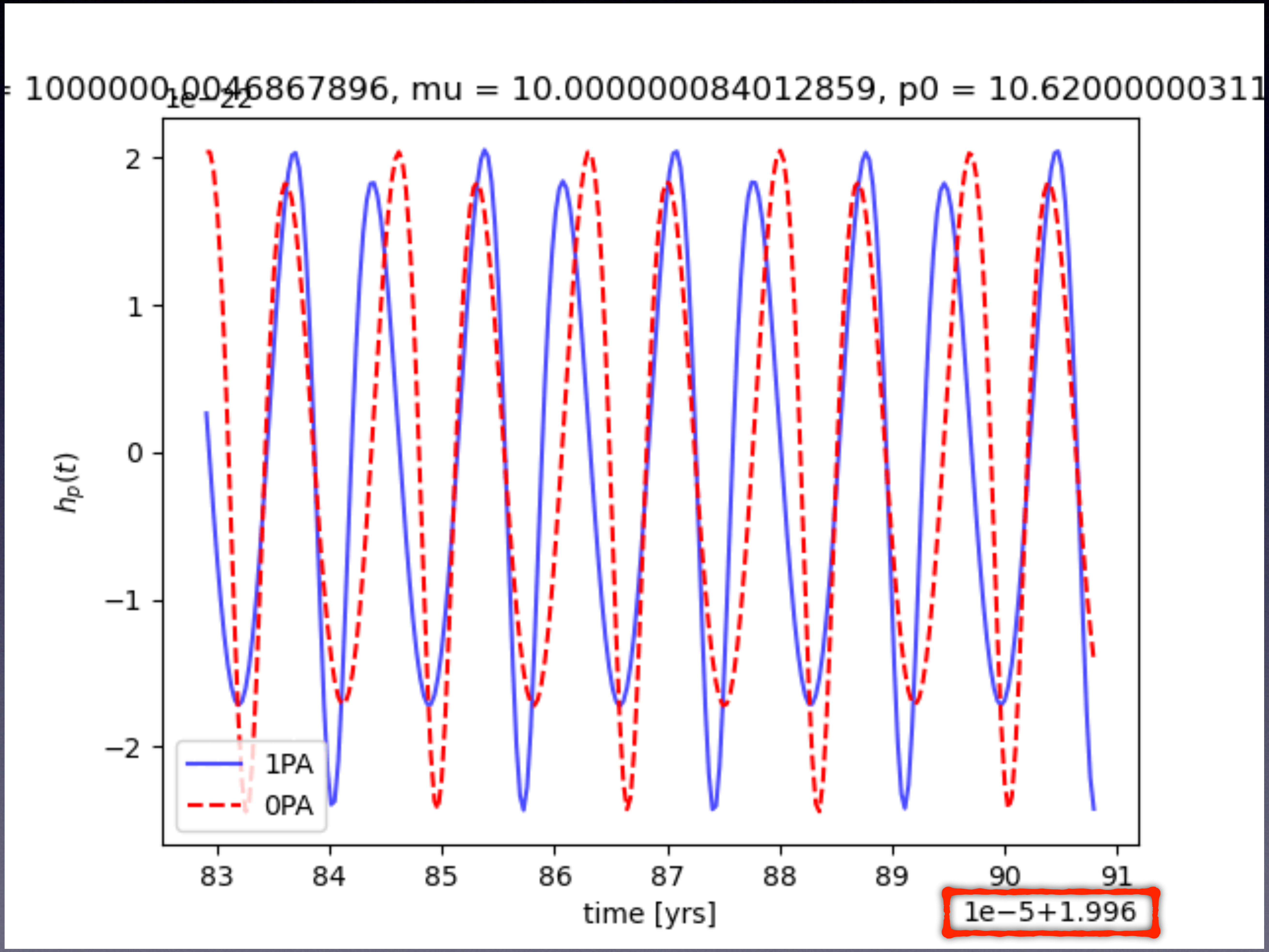
$$\mathcal{O}\left(h^{\mathrm{1PA}}(\boldsymbol{\theta}_{\mathrm{true}}), h^{\mathrm{0PA}}(\boldsymbol{\theta}_{\mathrm{true}})\right) = 0.203$$

$$\Delta\phi = \max|\phi^{(1PA)}_{\mathrm{true}} - \phi^{(0PA)}_{\mathrm{true}}| \approx 3\,\mathrm{rads}$$

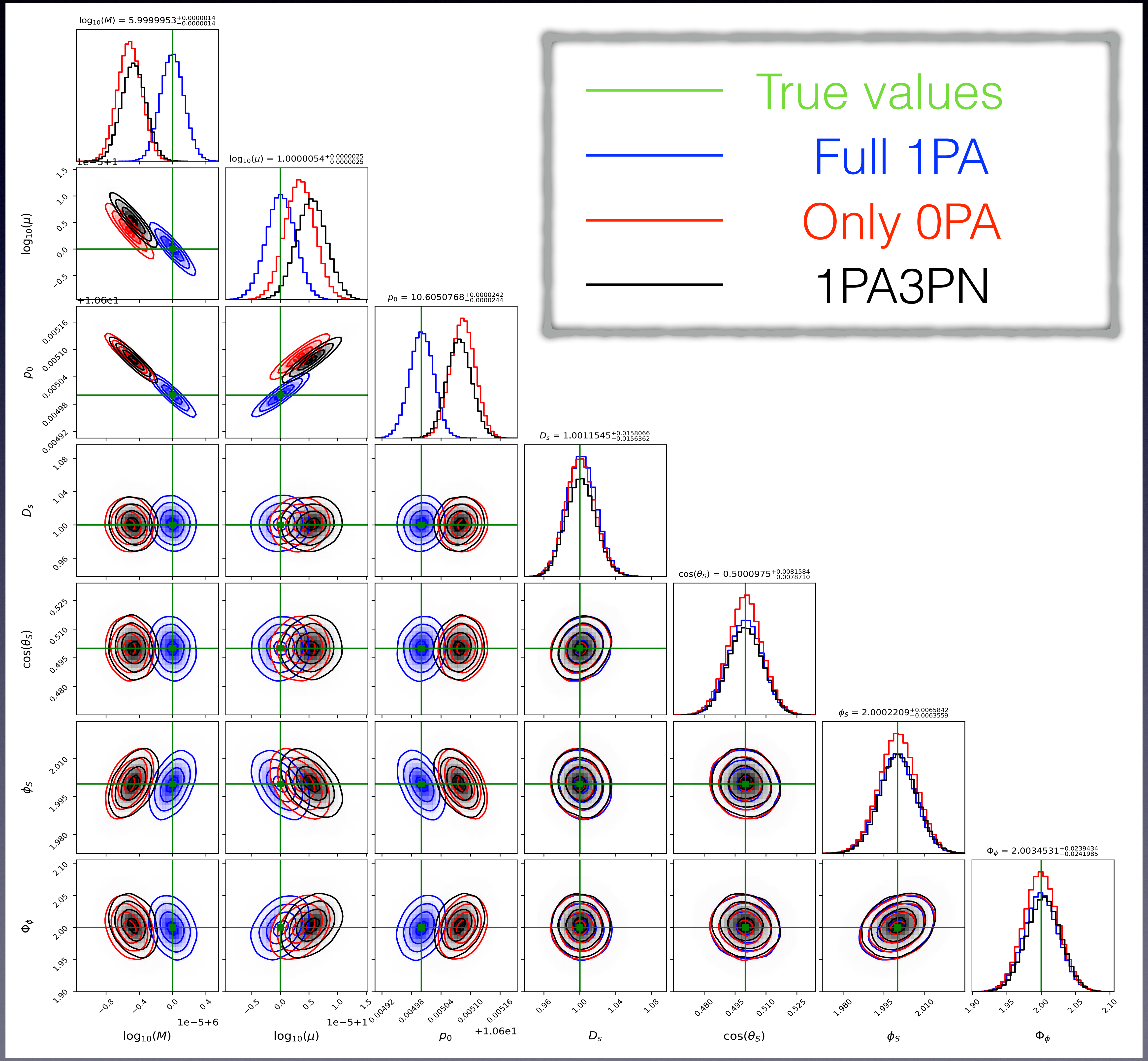
EMRIs are extremely sensitive to minor perturbations in parameters

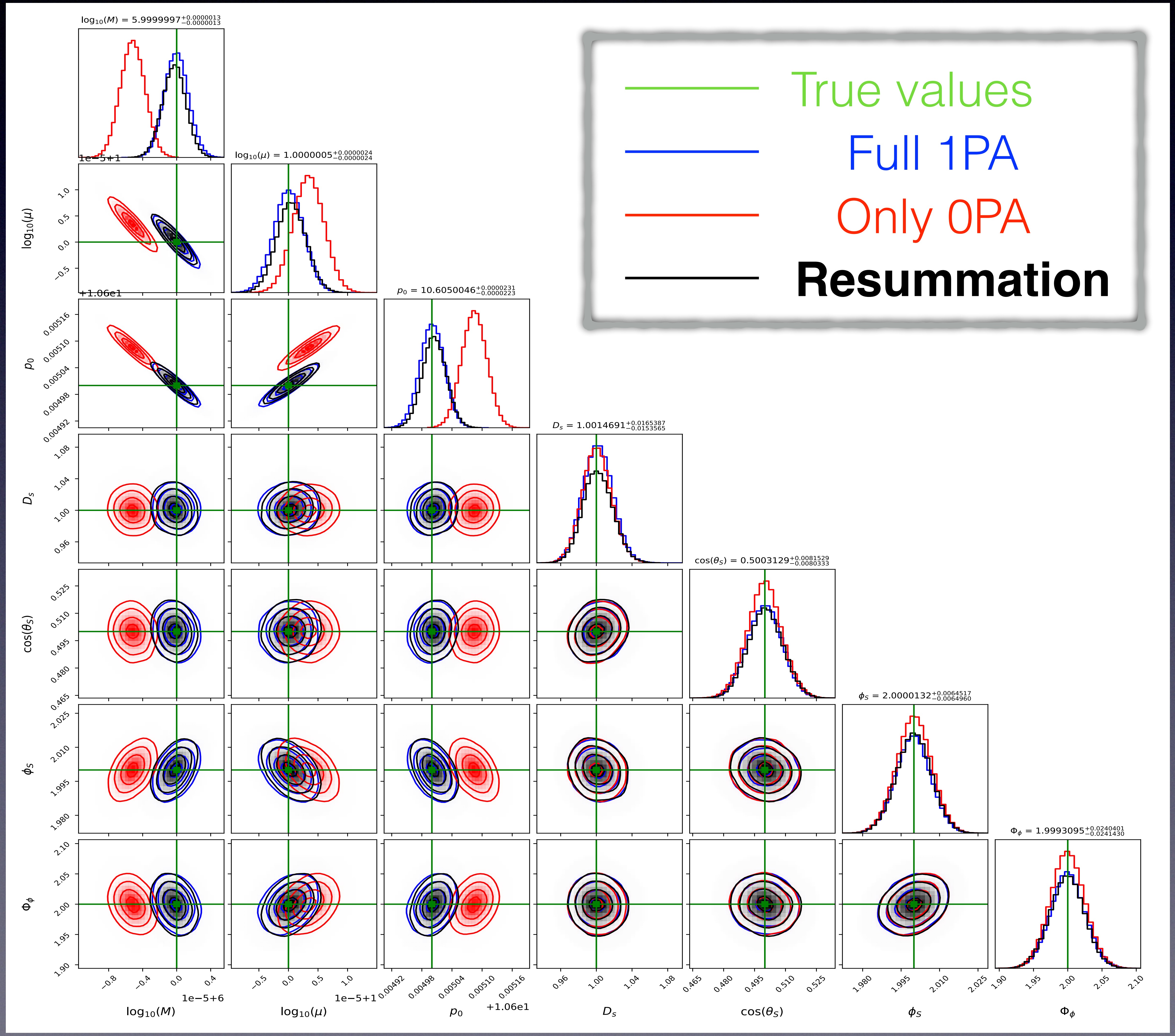
$$\mathcal{O}\left(h^{\mathrm{1PA}}(\boldsymbol{\theta}_{\mathrm{true}}), h^{\mathrm{0PA}}(\boldsymbol{\theta}_{\mathrm{bf}})\right) = 0.9999\ldots$$

$$\Delta\phi = \max\left|\phi^{(1PA)}_{\mathrm{true}} - \phi^{(0PA)}_{\mathrm{bf}}\right| \approx 0.003\,\mathrm{rads}$$



Can we do better with PN?

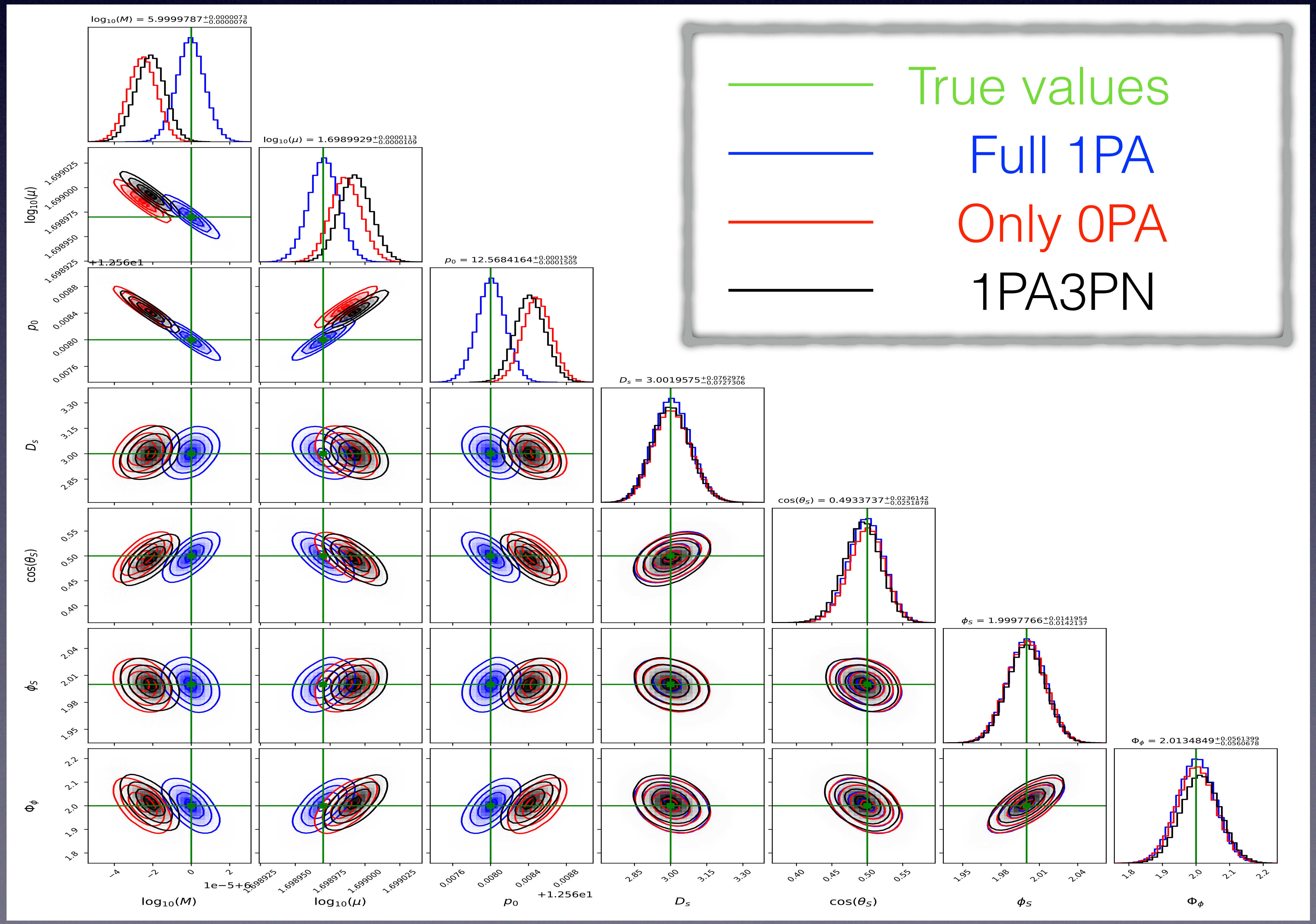




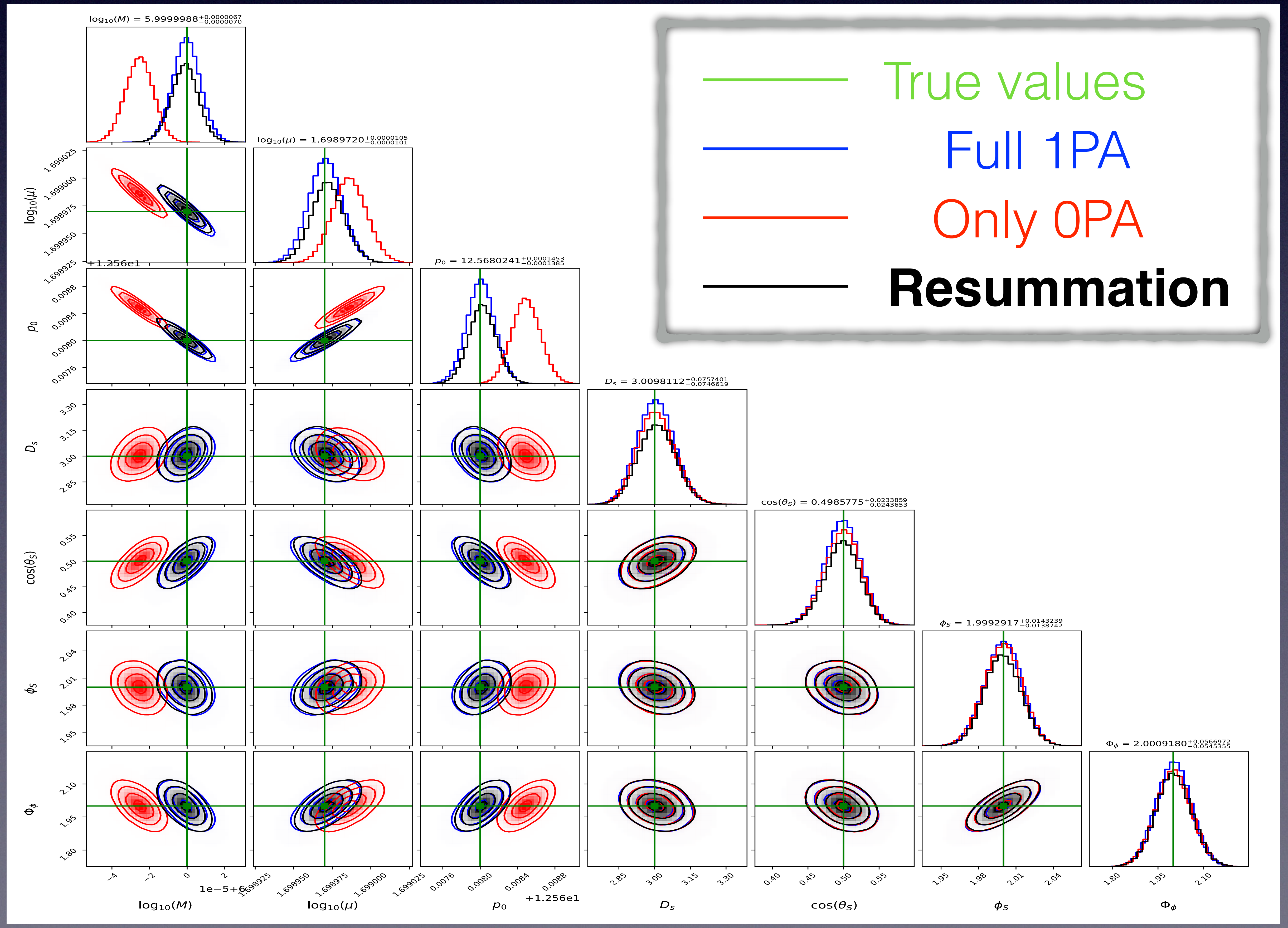
Increase mass-ratio?

Parameters: $M = 10^6 M_\odot, \mu = 50 M_\odot, r_0 = 12.568M,$ SNR ~ 48

One year long inspiral



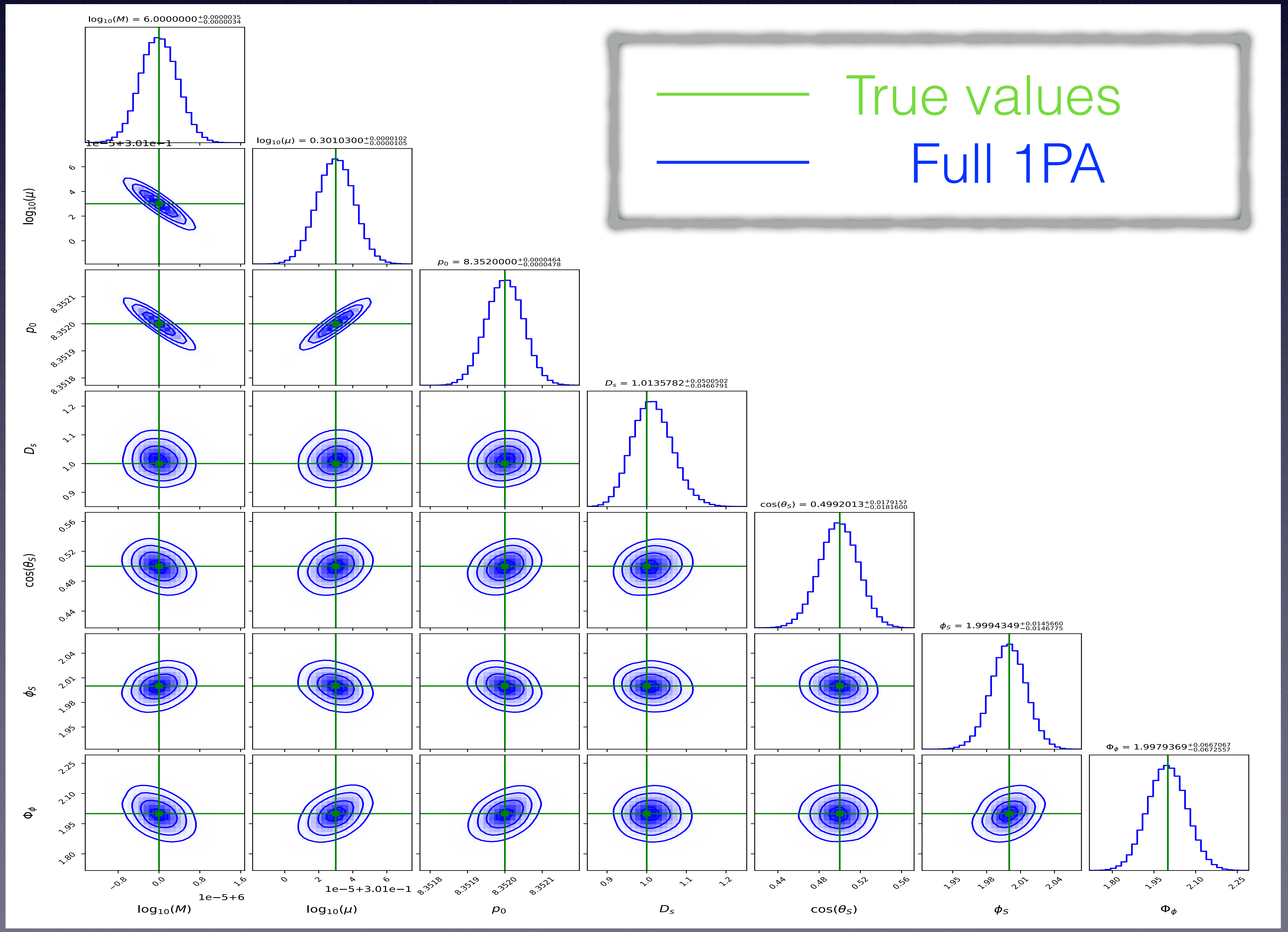
Strong field: $r - r_{\text{isco}} \sim 0.2M$



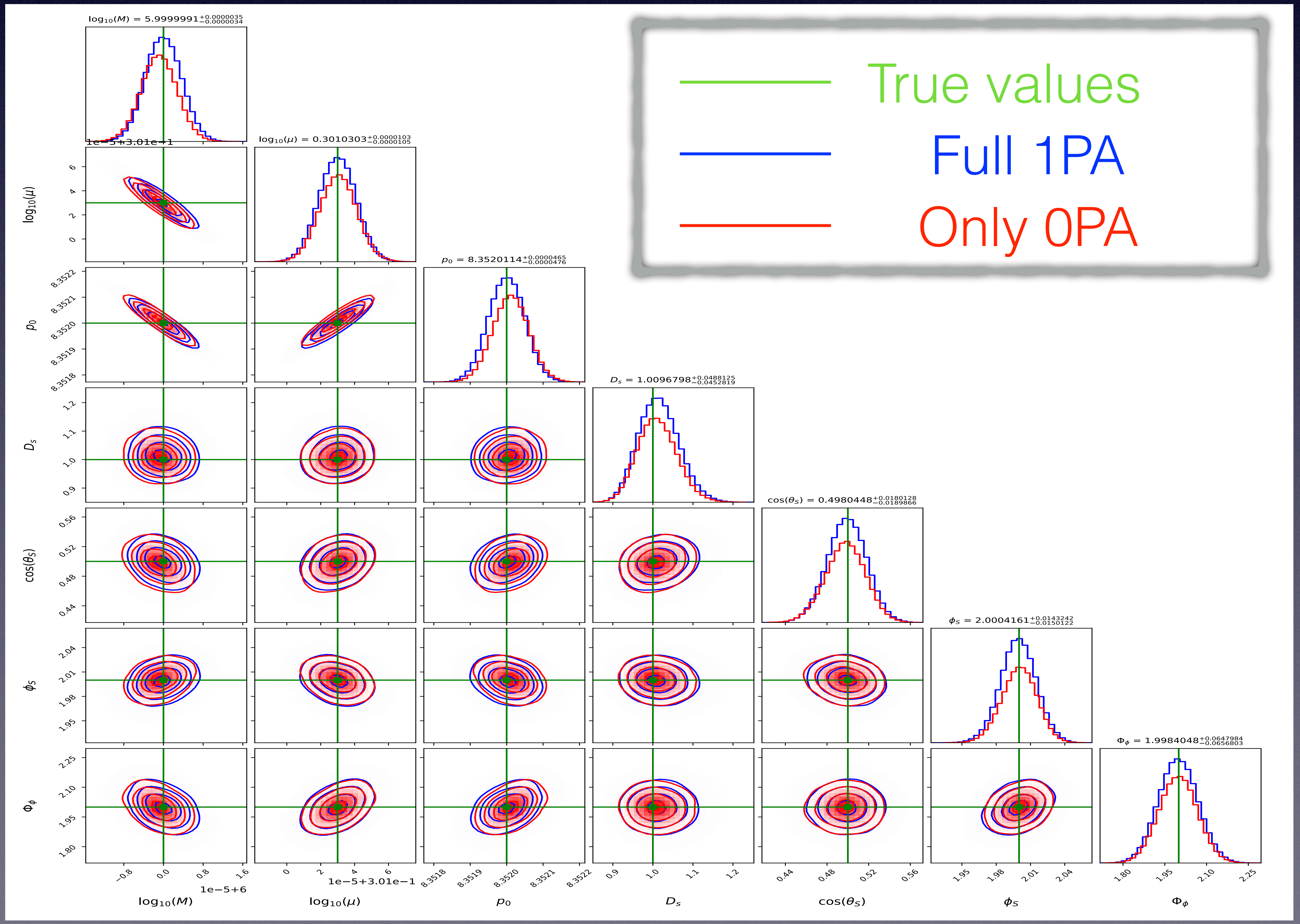
Decrease mass-ratio?

Parameters: $M = 10^6 M_\odot, \mu = 2M_\odot, r_0 = 8.32M,$ SNR ~ 21

Two year long inspiral



Strong field: $r - r_{\text{isco}} \sim 0.22M$

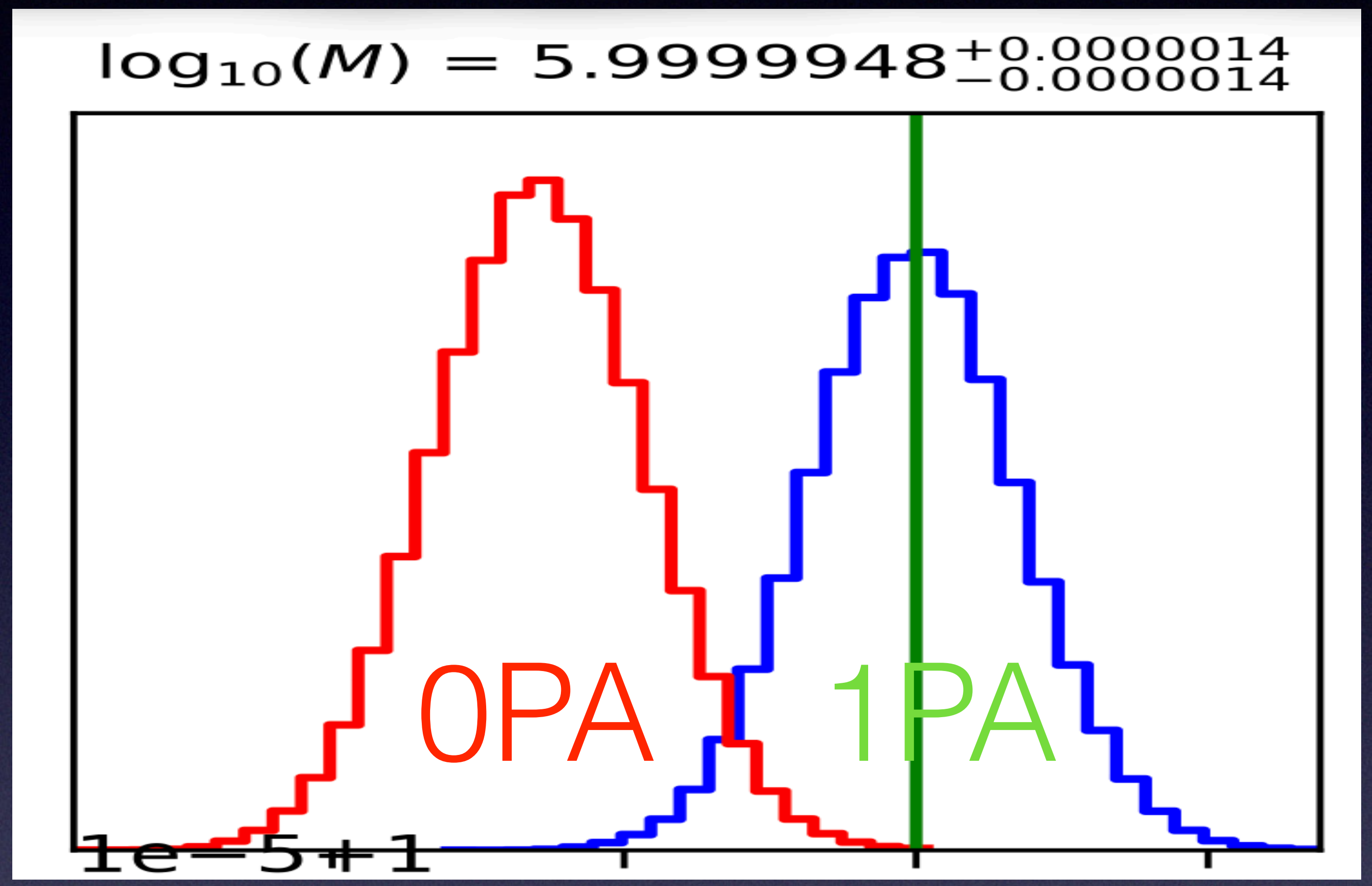


Final thoughts + musings

Neglecting post-adiabatic $\Longrightarrow$ Biases!

Biases "not as bad" as expected.

PN "tricks" could help!

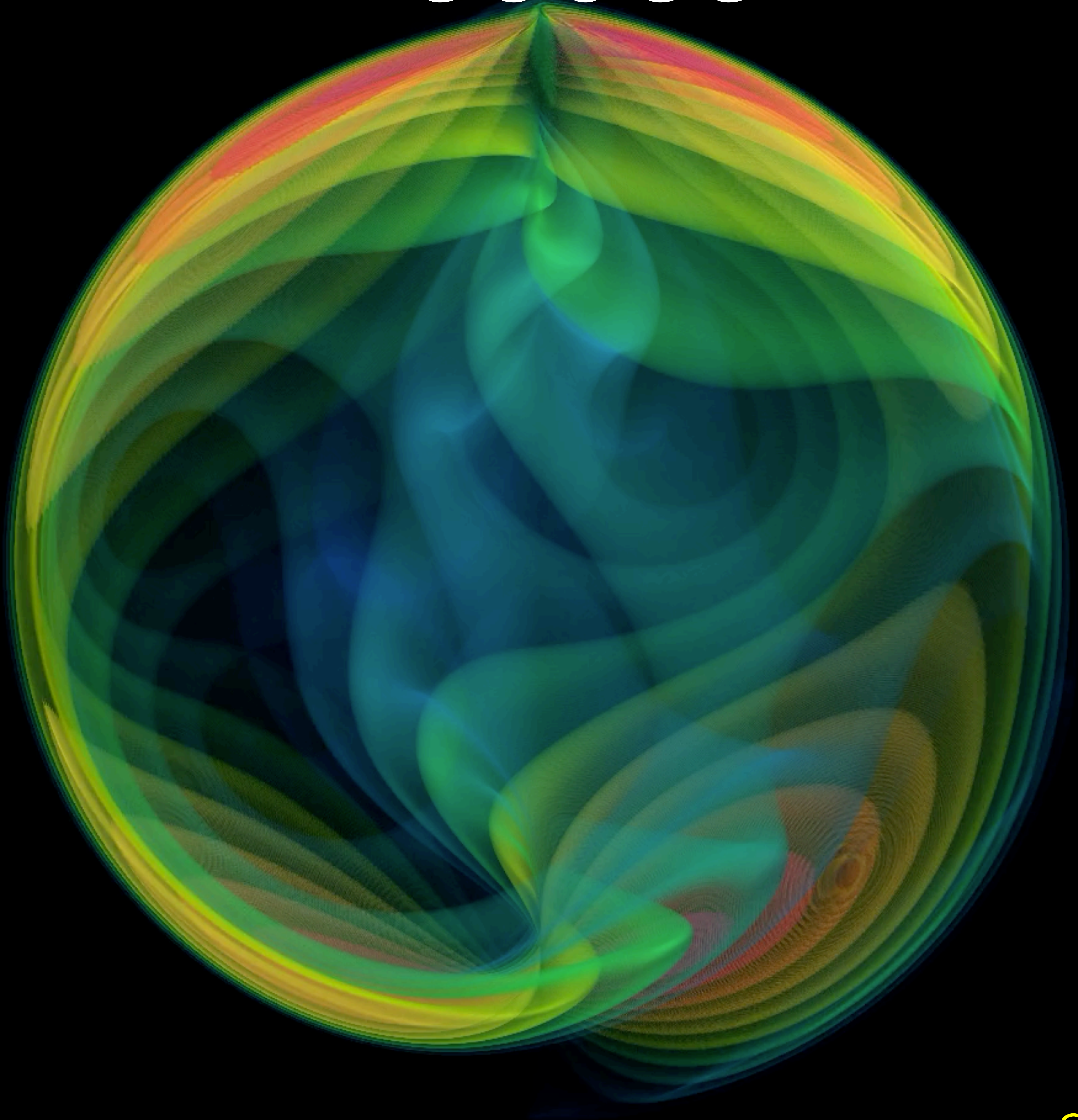


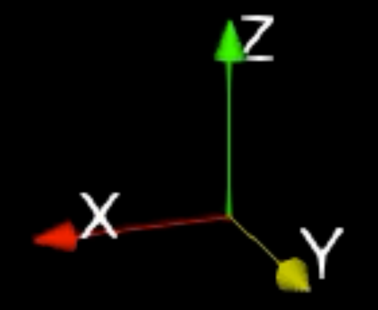
- Impact on **tests of GR** + **astrophysics**?
- Work only possible through **Self-force community** + **FEW**

Results may not extend for generic orbits / Kerr

Time: 0s

Discuss.





(Credit: Nils Fischer)

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Why?

$$\mathcal{O}\left(h^{\text{1PA}}(\boldsymbol{\theta}_{\text{true}}), h^{\text{0PA}}(\boldsymbol{\theta}_{\text{true}})\right) = 0.203$$

$$\Delta\phi = \max|\phi^{(1PA)} - \phi^{(0PA)}| \approx 3\ \text{rads}$$

$$\text{Lindblom} = \left(h^{(\text{1PA})} - h^{(\text{0PA})} | h^{(\text{1PA})} - h^{(\text{0PA})}\right) \approx 3900$$

$$\mathcal{O}\left(h^{\text{1PA}}(\boldsymbol{\theta}_{\text{true}}), h^{\text{0PA}}(\boldsymbol{\theta}_{\text{recovered}})\right) = 0.99990043$$

$$\Delta\phi = \max|\phi^{(1PA)} - \phi^{(0PA)}| \approx 3 \cdot 10^{-3}\ \text{rads}$$

$$\text{Lindblom} = \left(h^{(\text{1PA})} - h^{(\text{0PA})} | h^{(\text{1PA})} - h^{(\text{0PA})}\right) \approx 0.17$$