

Measuring accretion-disk effects with gravitational waves from extreme-mass-ratio inspirals

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EMRIs as probes of supermassive black-hole's environments



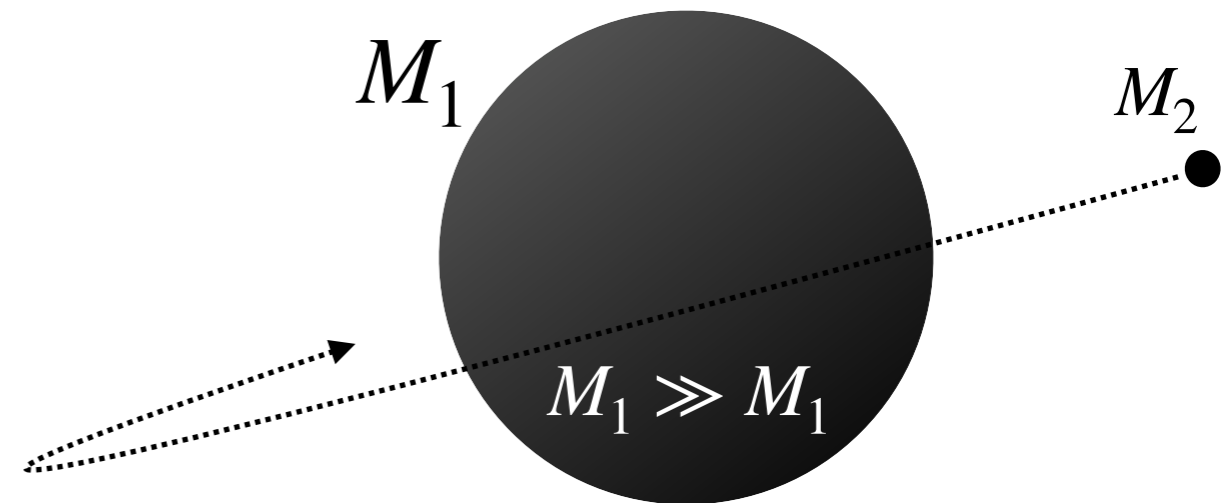
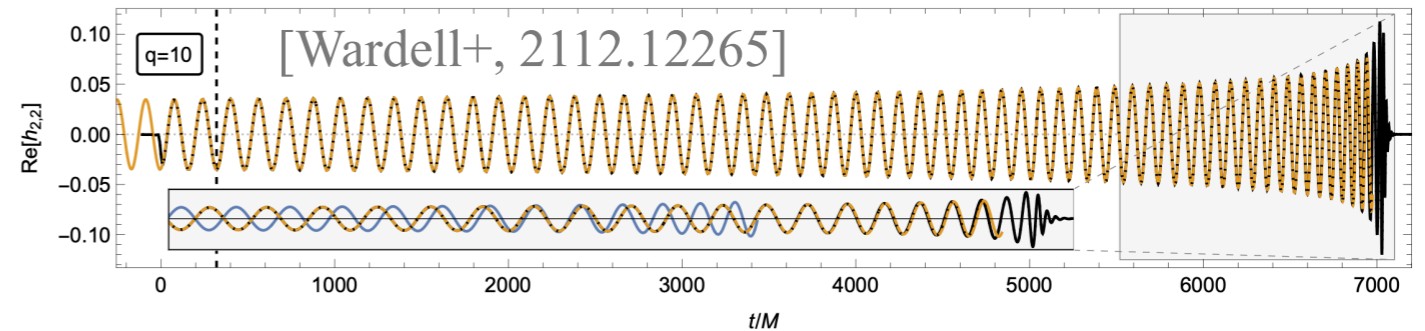
- ❖ Extreme mass-ratio inspirals (EMRIs) span many cycles in the LISA band.

Exquisite parameter estimation (if models are accurate)

System is delicate and sensitive to perturbations from vacuum GR.

For the data-analysis oriented:

- ❖ *Can we measure environmental effects with EMRI observations?*
- ❖ *Do we expect biases if we ignore them?*



For the astrophysics oriented:

- ❖ *Can we use measurements to infer physics of environment (accretion disks, dark-matter spikes, tertiary object...)*

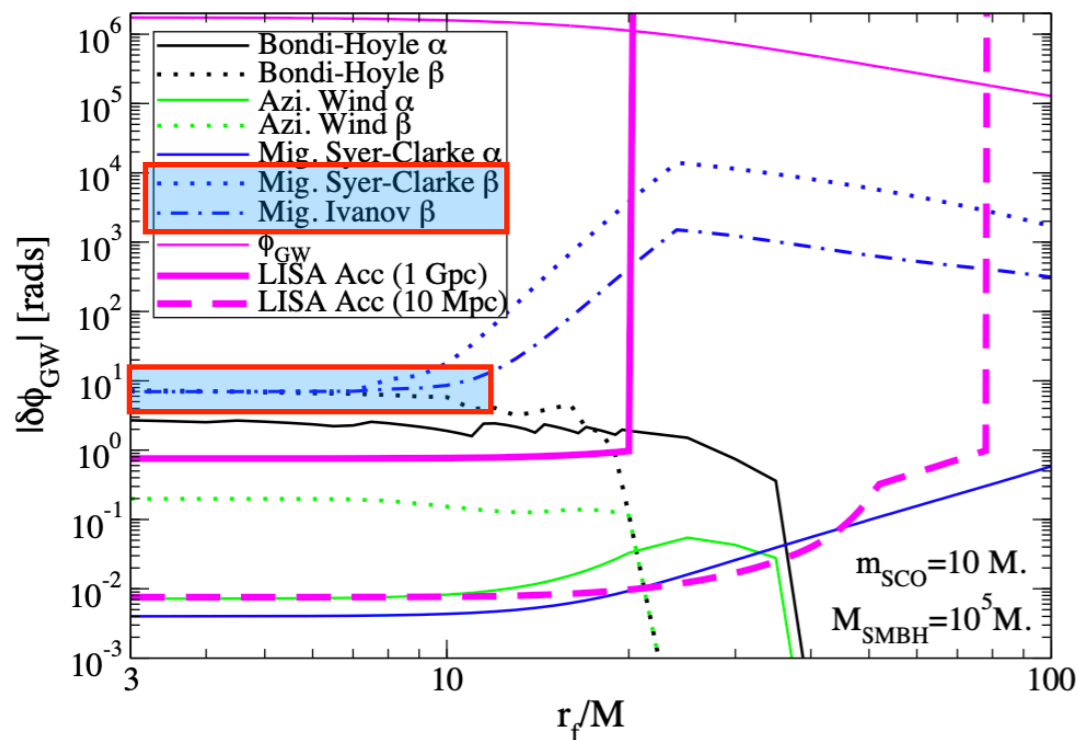
EMRIs embedded in accretion disks



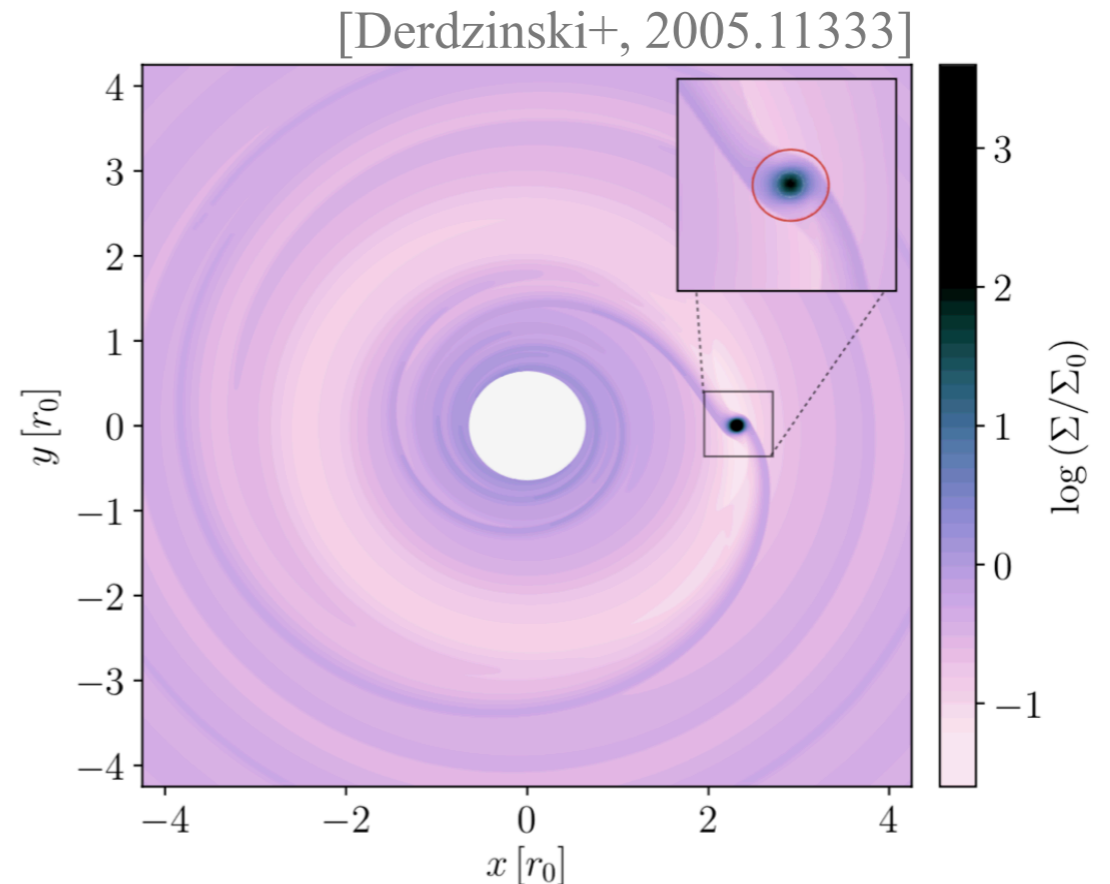
Why looking at accretion disks?

- ❖ A fraction of EMRIs is expected to be embedded in an AGN.
- ❖ Effects that may be important: dynamical friction, migration, accretion winds etc.

[Kocsis+, 1104.2322; Barausse+, 1404.7149]



[Yunes+, 1103.4609]



- ❖ Dephasings show that planetary-type migration is potentially detectable.

[Yunes+, 1103.4609;
Kocsis+, 1104.2322;
Barausse+, 1404.7149;
Derdzinski+, 2005.11333]

Dirty EMRI waveforms



FastEMRIWaveforms (FEW):
(<https://bhptoolkit.org>)

PRECISE

(adiabatic)

FAST

(enough for MCMC)

MODULAR

(easy to modify)

❖ We add torques as modifications of \dot{L} for winds and migration (α and β disks)

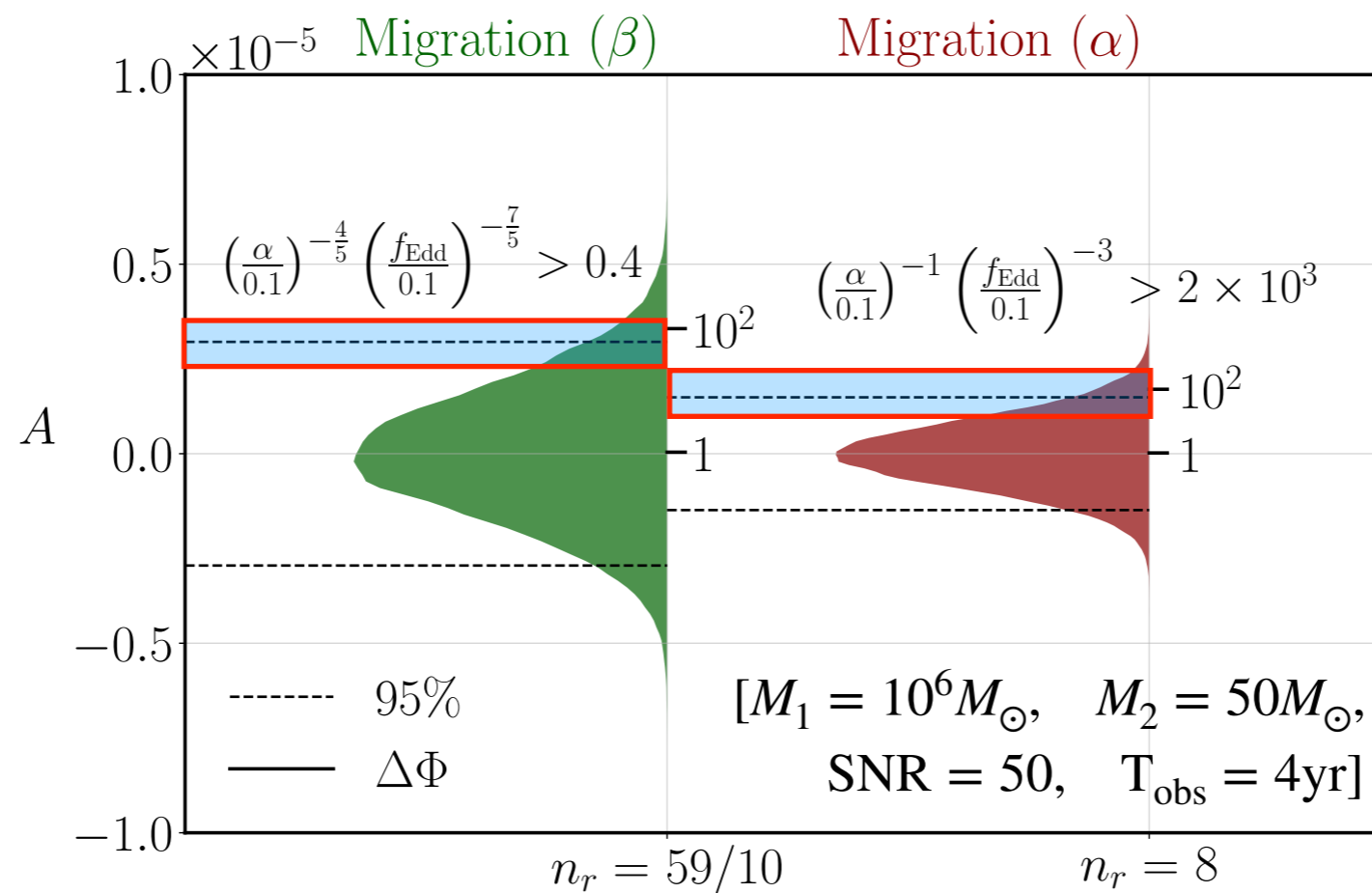
[Kocsis+, 1104.2322]

$$\frac{\dot{L}_{\text{environment}}}{\dot{L}_{\text{GW}}} = A(f_{\text{edd}}, \alpha; M_i) r^{n_r}$$

$f_{\text{edd}} = \text{accretion rate}$
 $\alpha = \text{viscosity}$

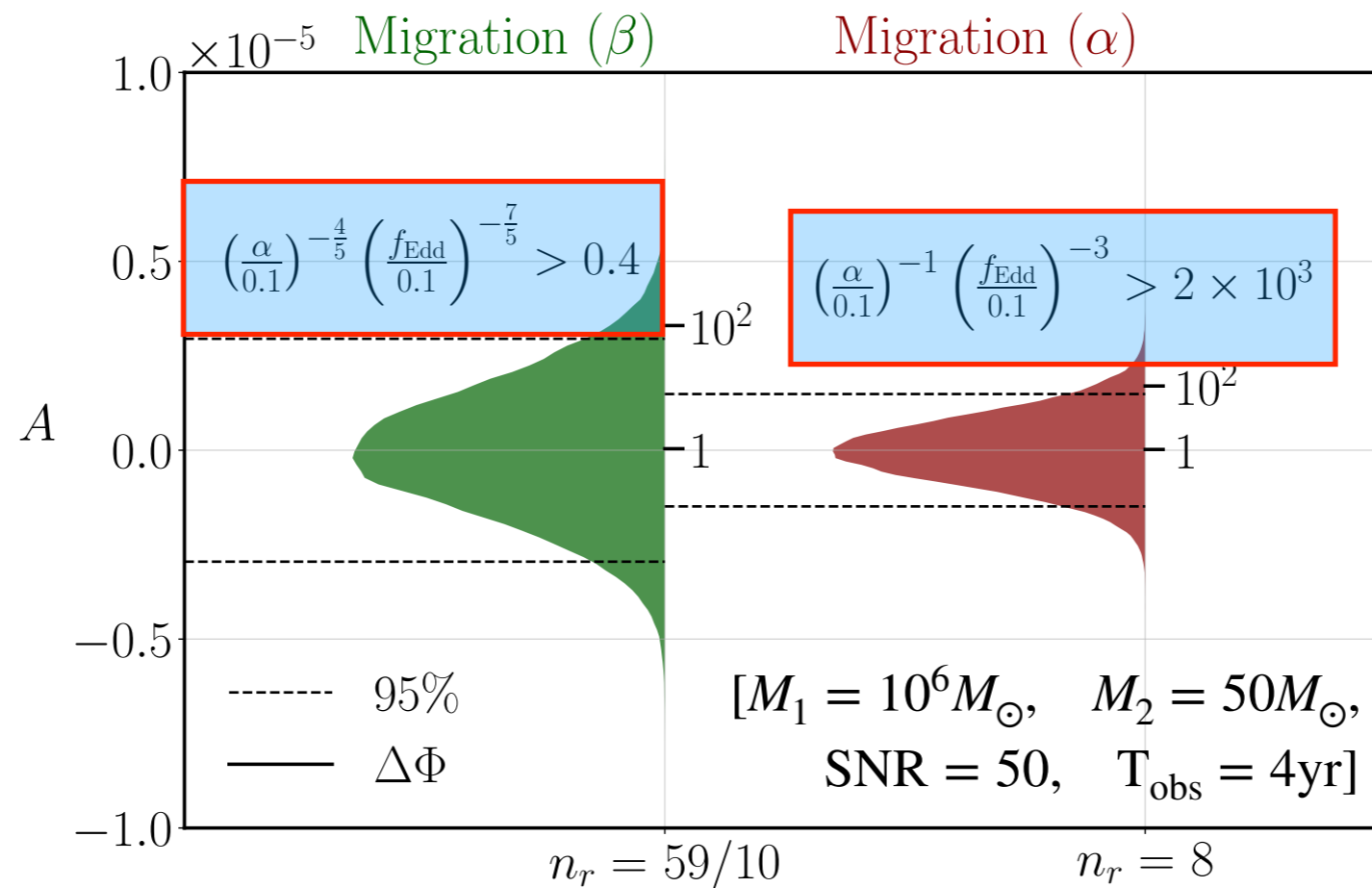
❖ Leave out interesting phenomenology (no stochasticity, quasi-circular inspirals, ...)

When can we detect environmental torques?



- ❖ Recovery of a “null” injection (with $A=0$): precision with which we can *rule out* the presence of an environmental effect.

When can we detect environmental torques?



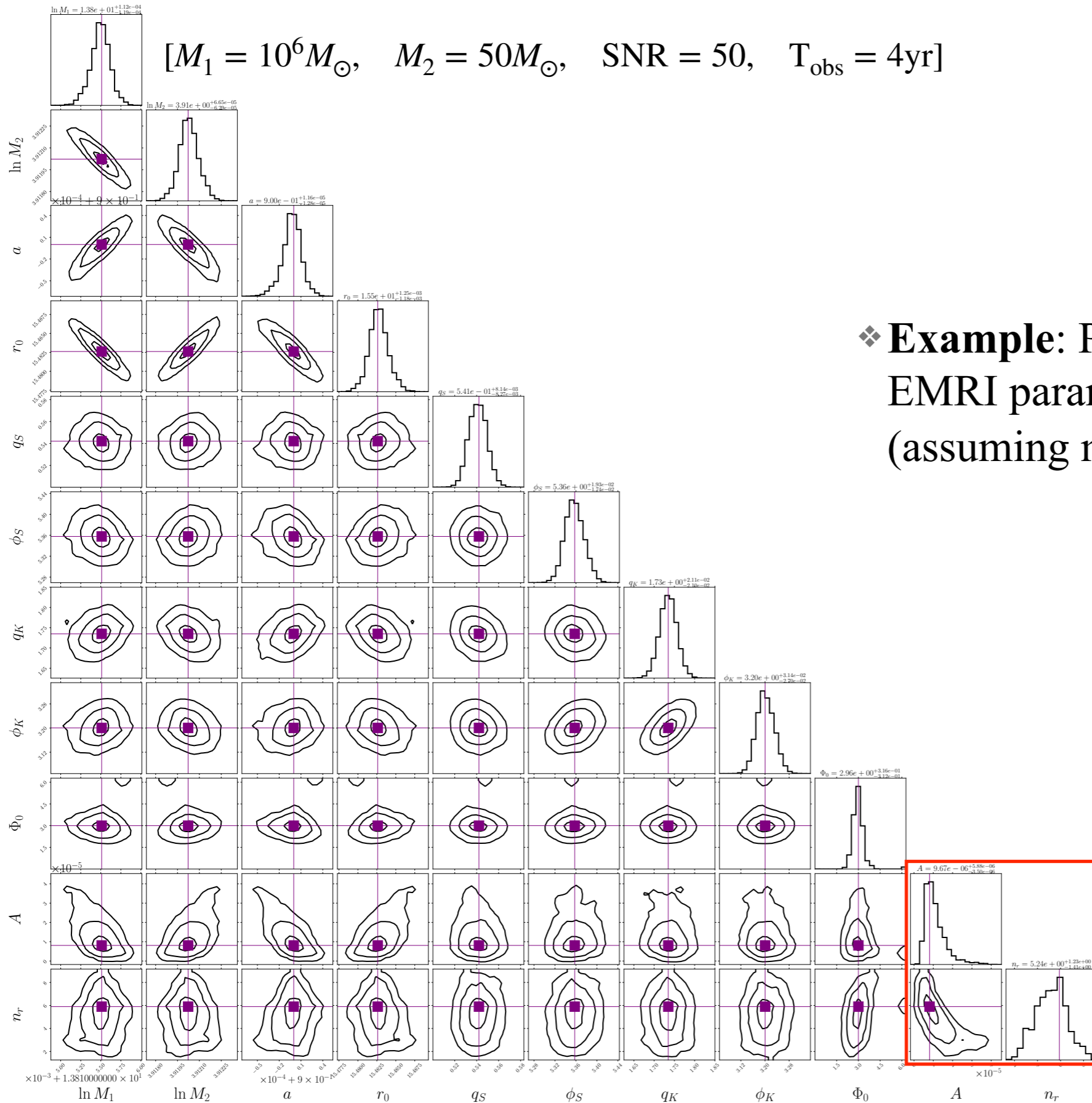
❖ Recovery of a “null” injection (with $A=0$): precision with which we can *rule out* the presence of an environmental effect.

❖ One can turn this into accretion model-dependent statement a posteriori.

Measuring migration torques

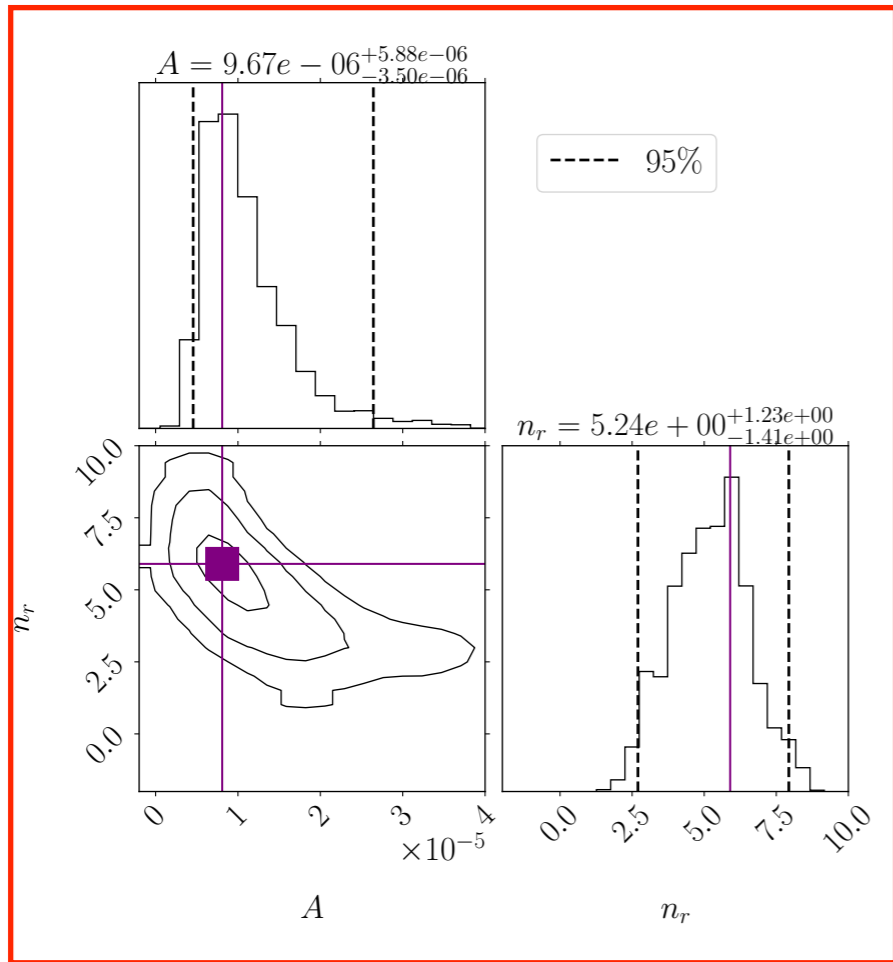
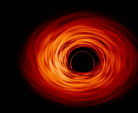


$[M_1 = 10^6 M_\odot, M_2 = 50 M_\odot, \text{SNR} = 50, T_{\text{obs}} = 4\text{yr}]$

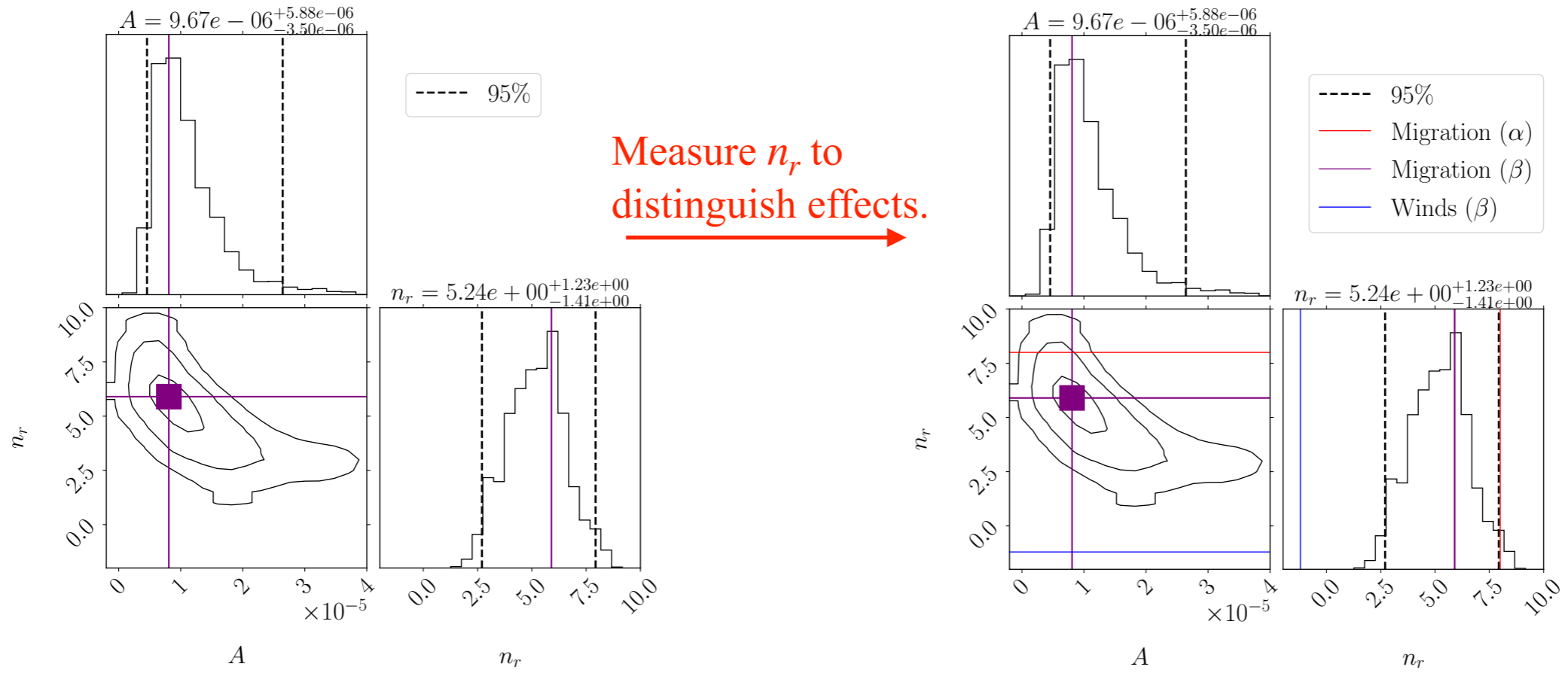
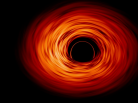


❖ **Example:** PE performed on all EMRI parameters, A and n_r (assuming migration in β -disks).

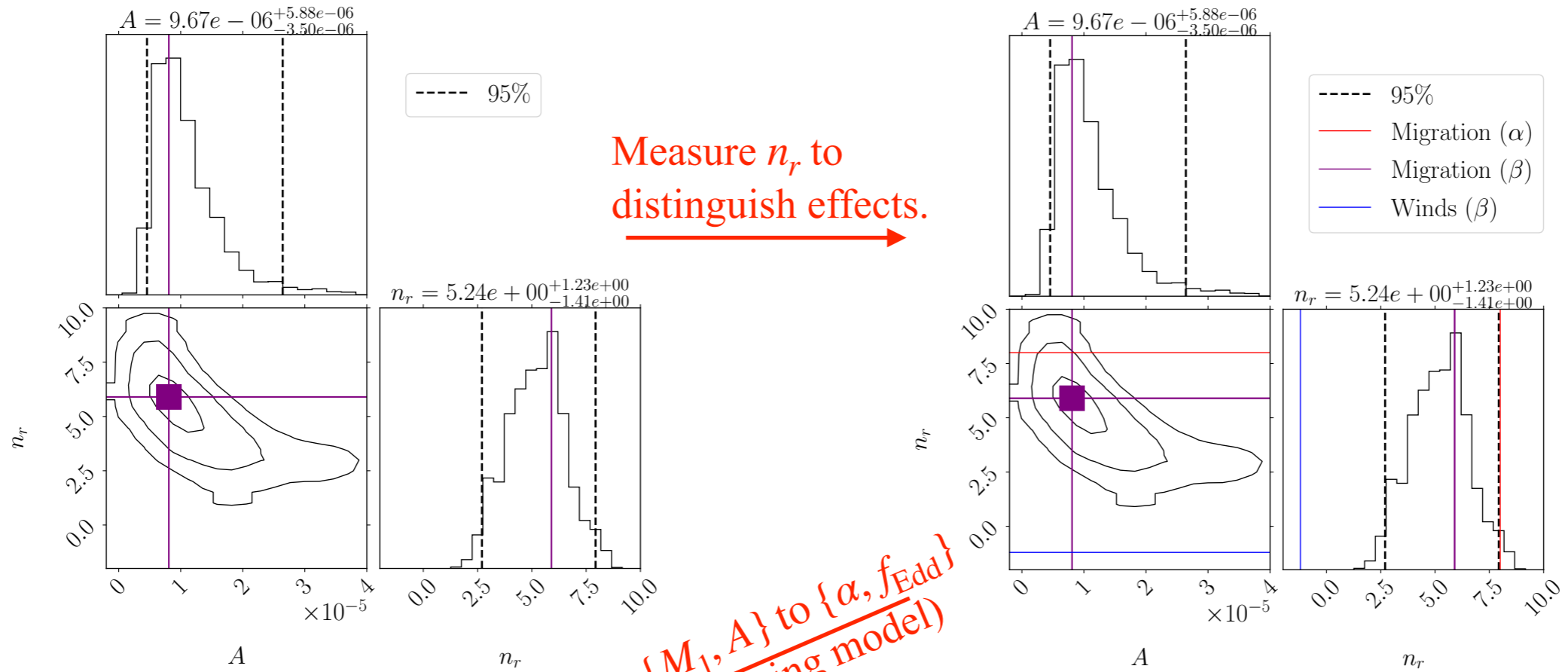
Measuring migration torques



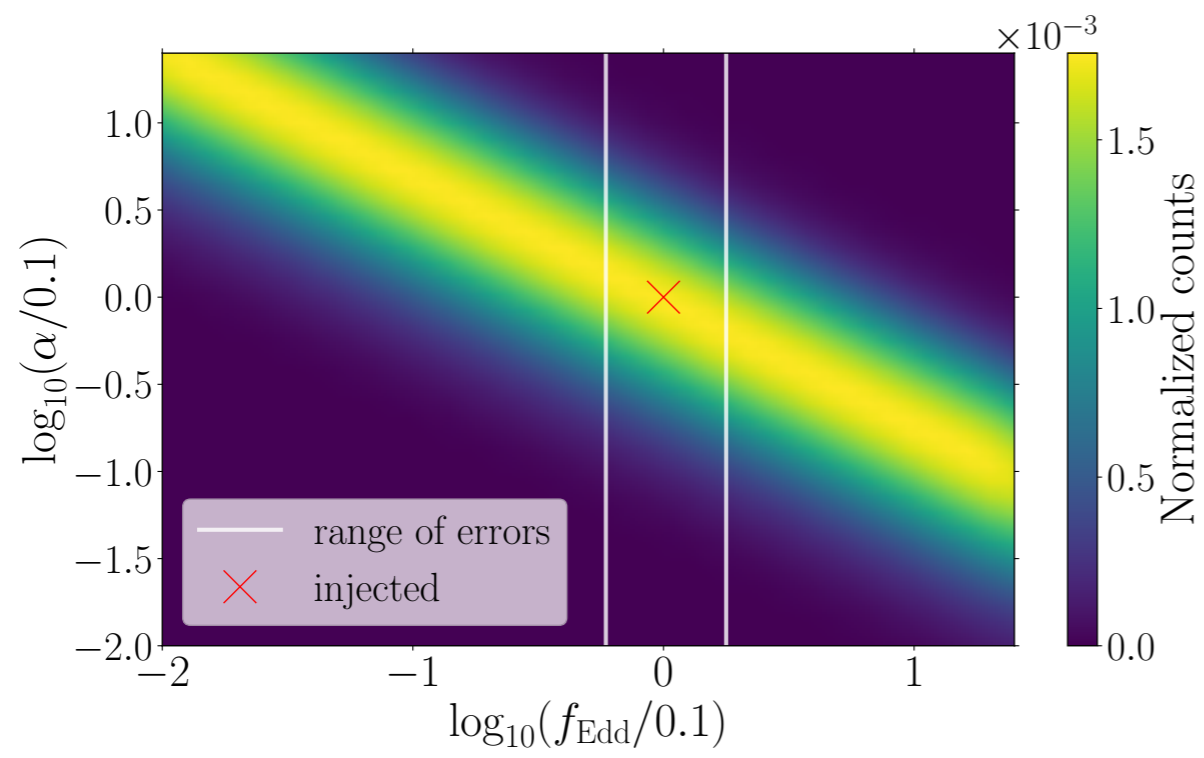
Measuring migration torques



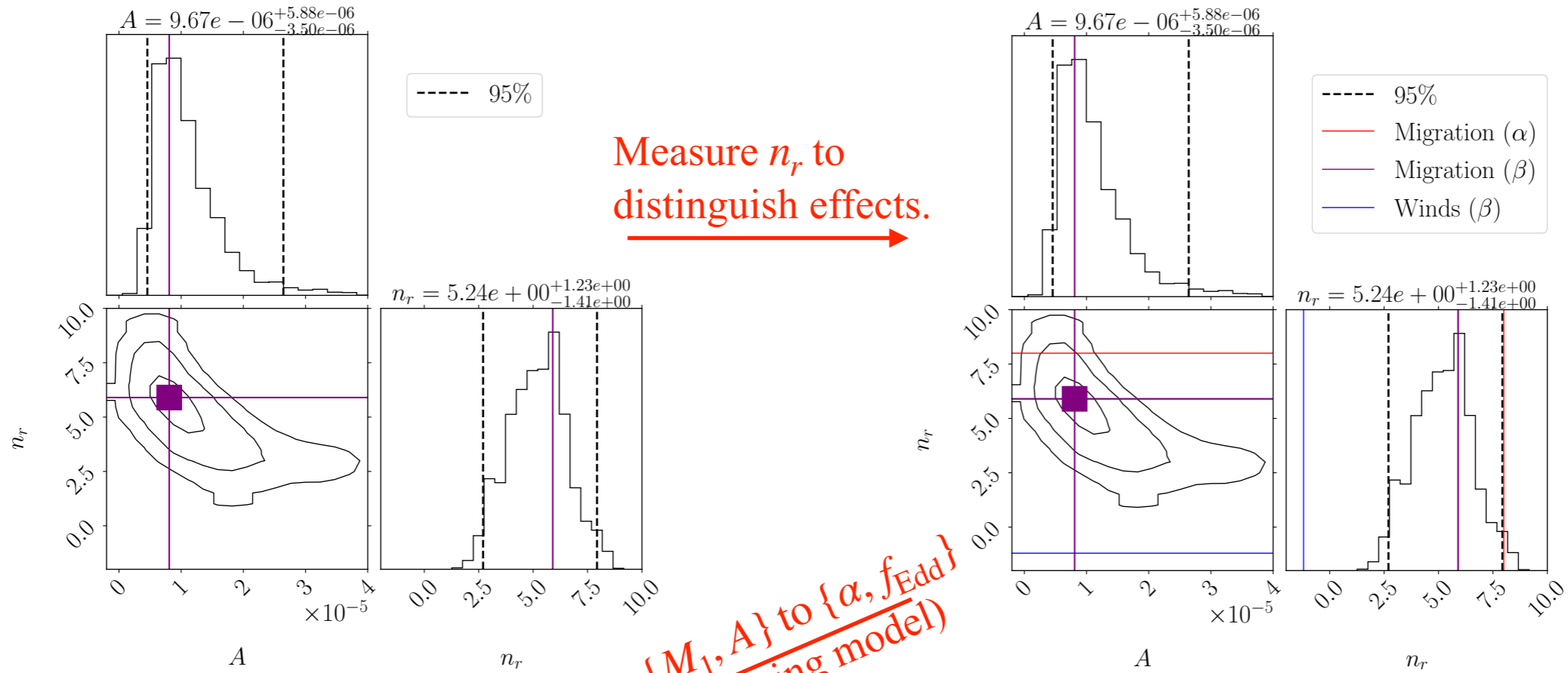
Measuring migration torques



$\{M_1, A\}$ to $\{\alpha, f_{\text{Edd}}\}$
 (assuming model)



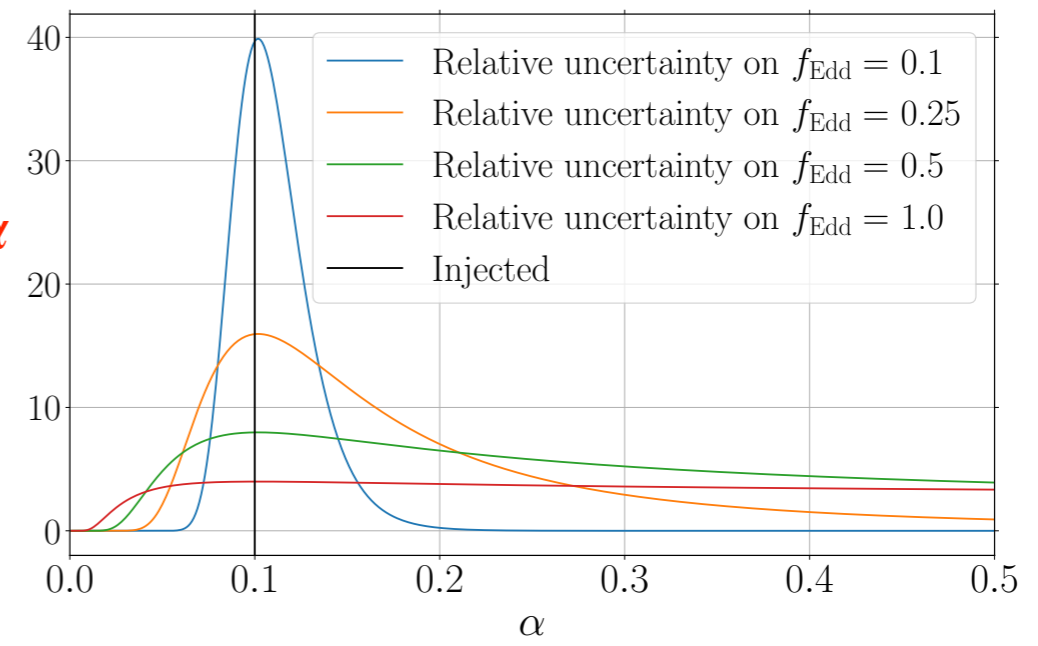
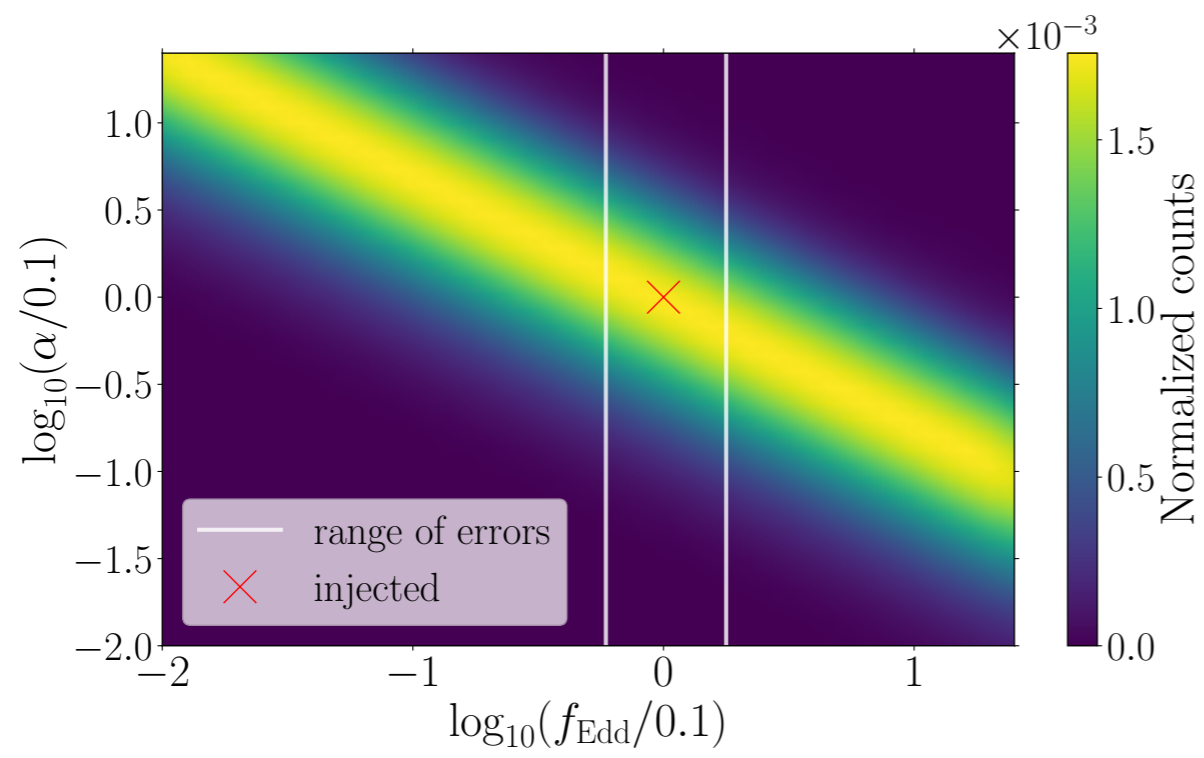
Measuring migration torques



Measure n_r to distinguish effects.

$\{M_1, A\}$ to $\{\alpha, f_{\text{Edd}}\}$
(assuming model)

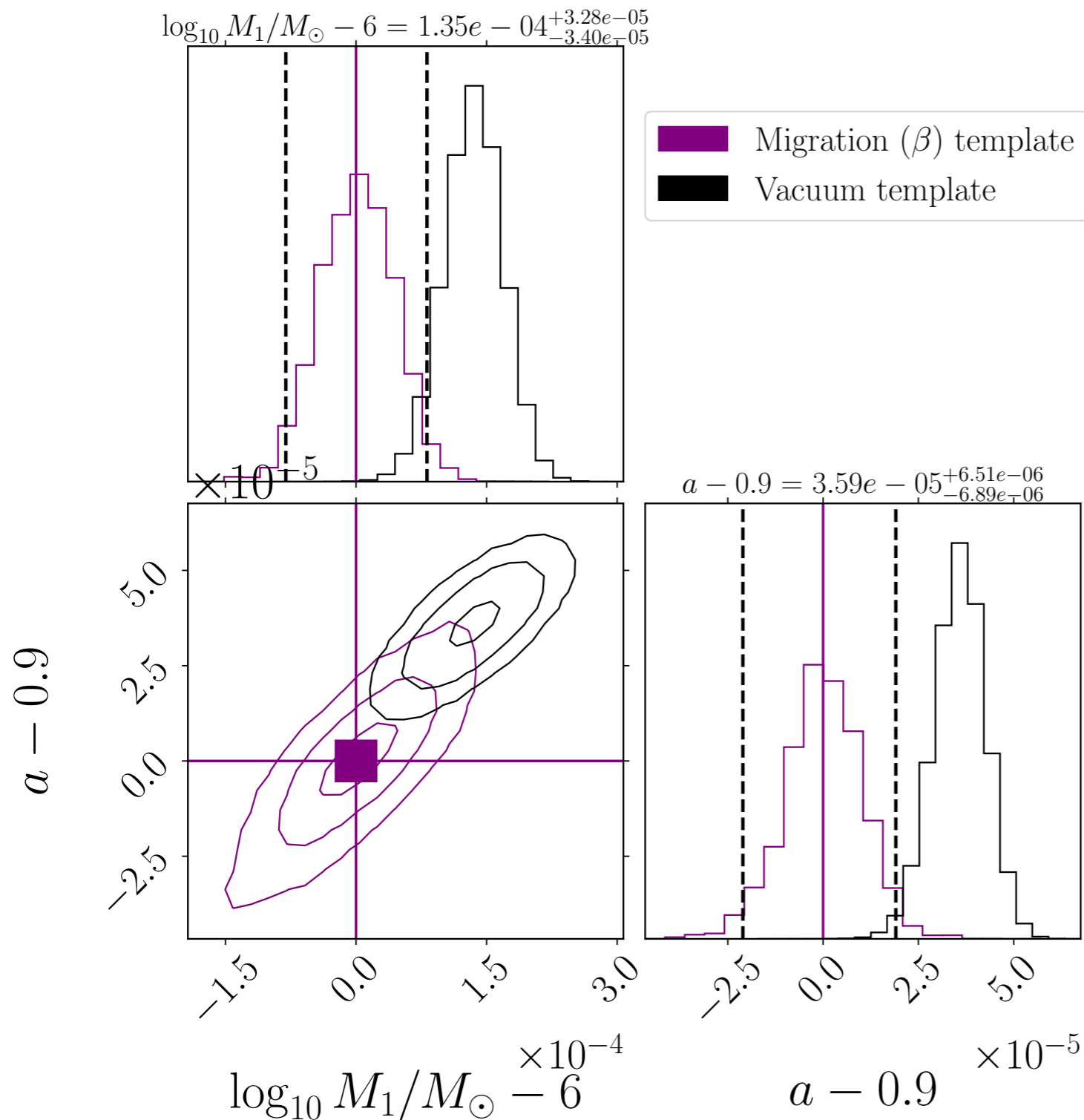
Get α



Ignoring environmental effects



$[M_1 = 10^6 M_\odot, M_2 = 50 M_\odot, \text{SNR} = 50, T_{\text{obs}} = 4\text{yr}]$



❖ Inject an EMRI system affected by β -disk migration.

❖ Search for it with a template in vacuum GR.

Ignoring environmental effects can lead to biases in the estimation of quantities of interest (e.g. masses and spins).



- ❖ *Can we measure environmental effects with EMRI observations?*
- ❖ Shown how to do this within a realistic EMRI data analysis scenario.
- ❖ *Do we expect biases if we ignore them?*
- ❖ We do expect biases from reasonable environmental effects that affect tests of GR, but possibly not astrophysics.
- ❖ *Can we use measurements to infer physics of environment (accretion disks)?*
- ❖ We can infer interesting accretion-disk physics, whether we detect the effect of a torque or not.