Constraining EMRI Population using Hierarchical Bayesian Inference

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LISA Astrophysics Working Group Meeting
5 Nov 2024

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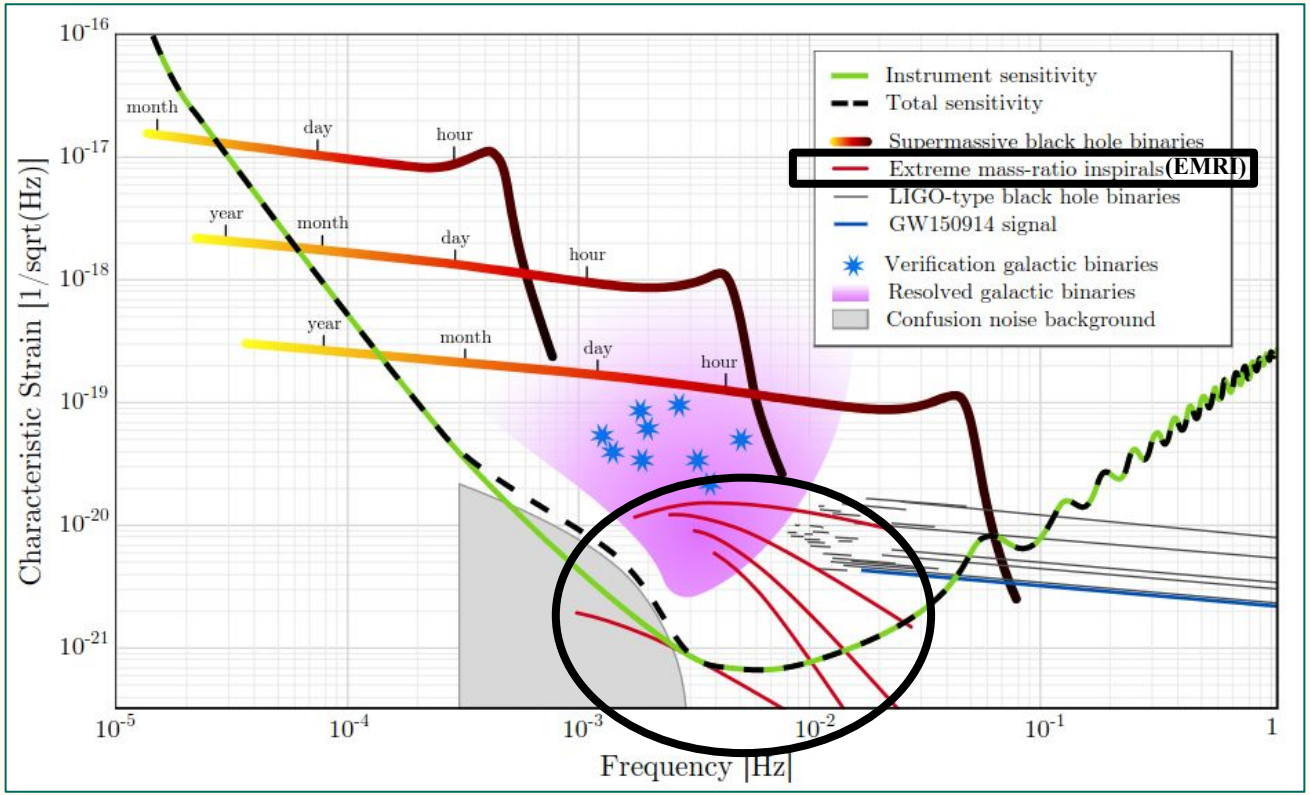
LISA and its sources



Amaro-Seoane *et al.* arXiv:1702.00786

What is an EMRI ?

Inspiral of compact objects with large mass ratio

complex dynamics ⇒ rich in information

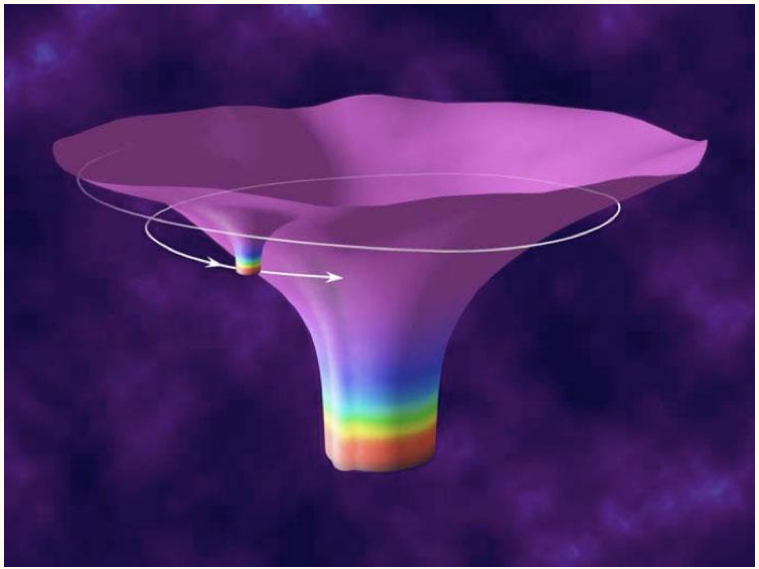
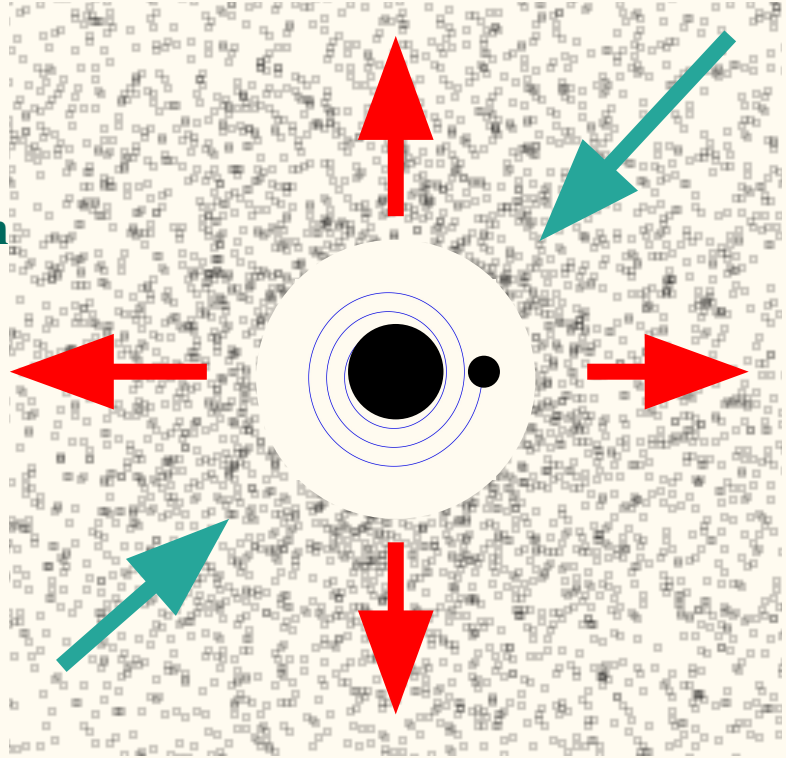


Image Credit: NASA

Cusp erosion

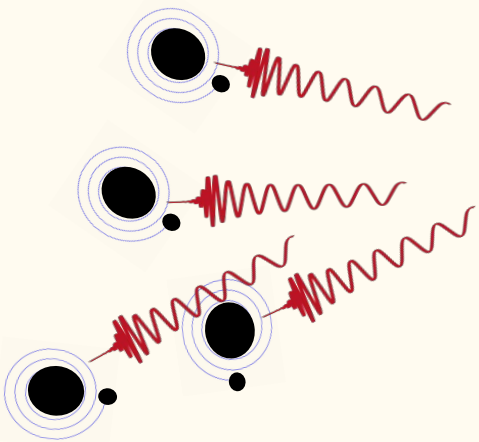
Mass segregation

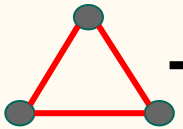


Astrophysical processes affecting formation

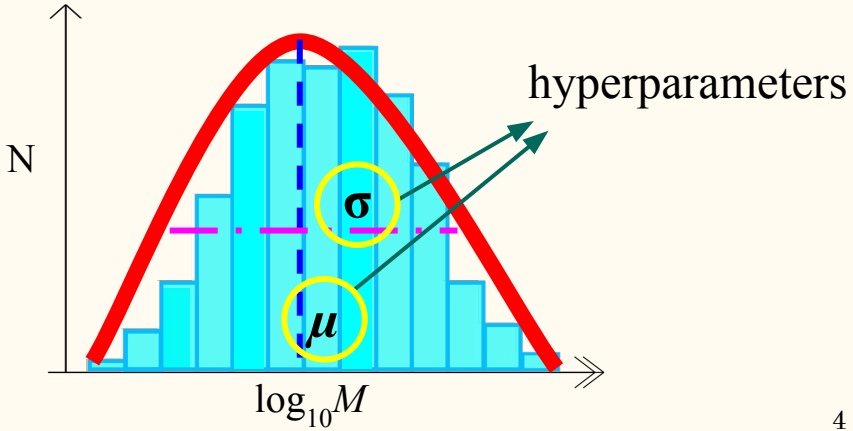
Constraining the astrophysical parameters

EMRI detections → Astrophysical processes





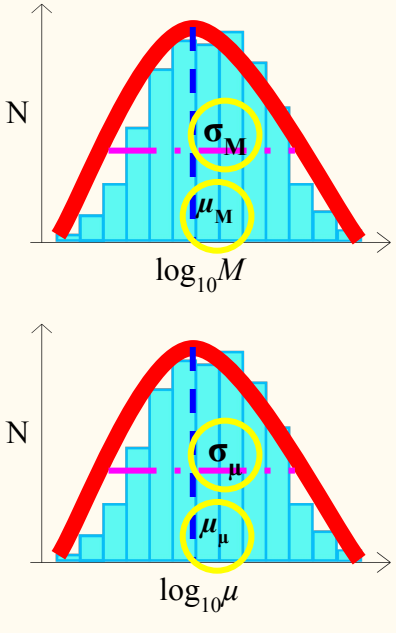
Inference

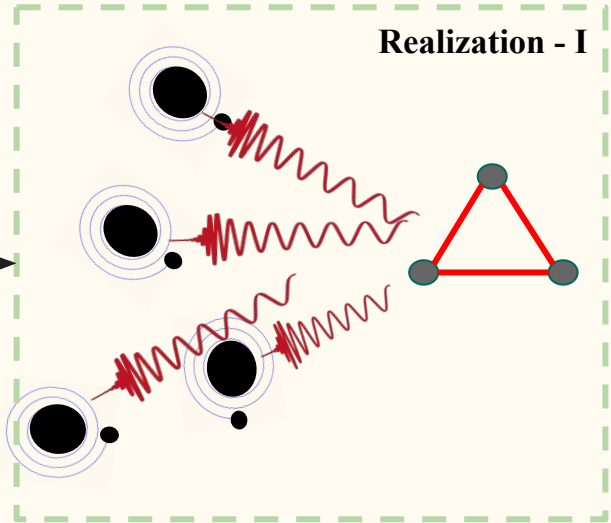


Our analysis

Astrophysical processes

EMRI detections





Inference

$\text{SNR} > \rho_{\text{th}}$

Hierarchical Inference – estimating hyperparams

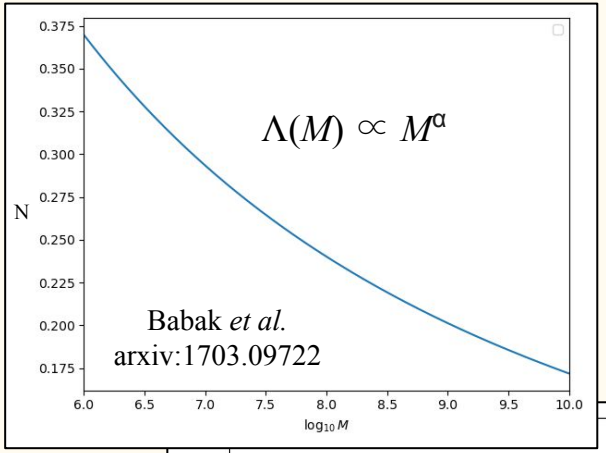
σ_M

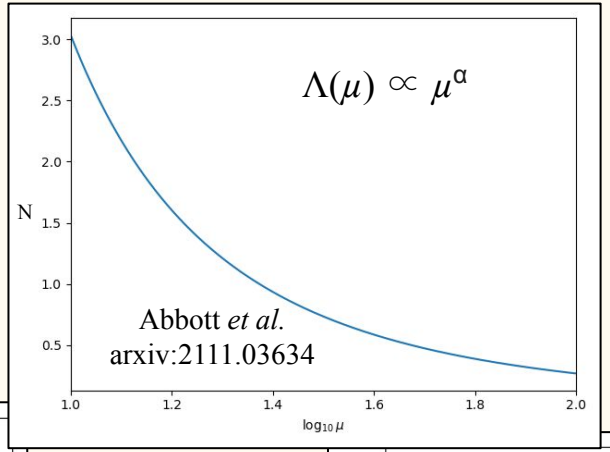
μ_M

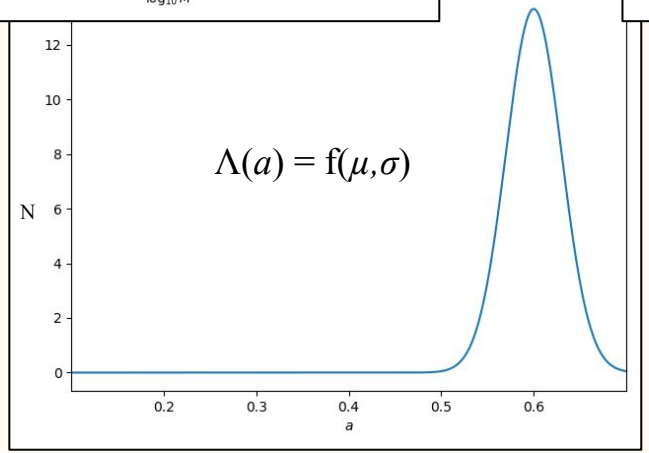
σ_μ

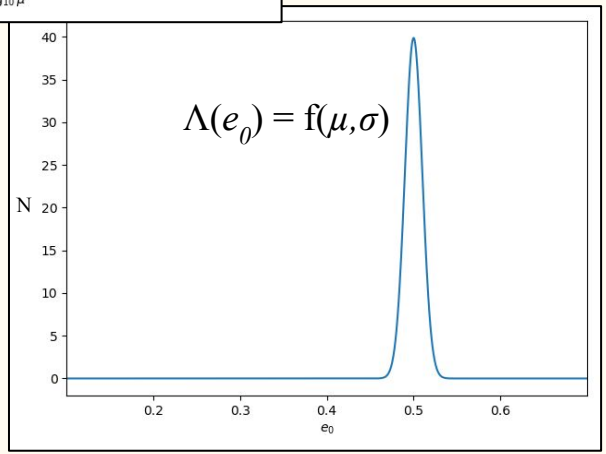
μ_μ

Our analysis – distributions

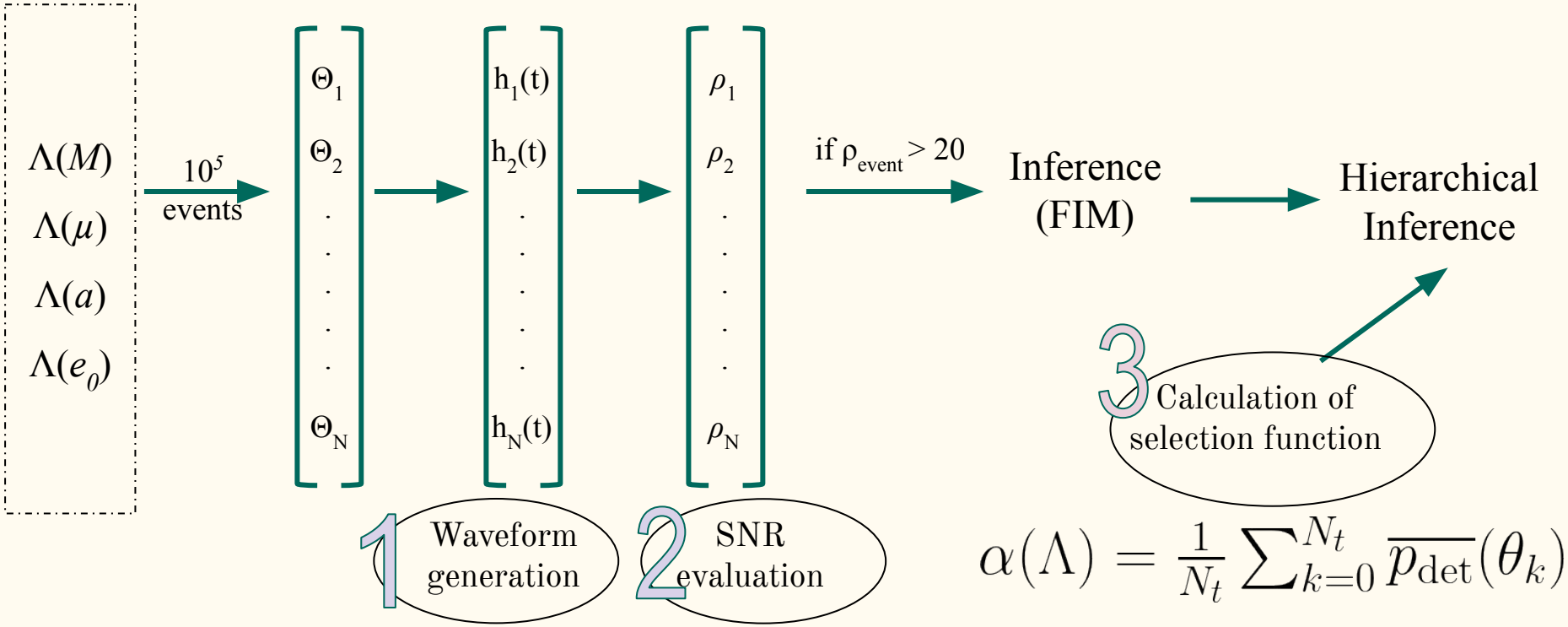






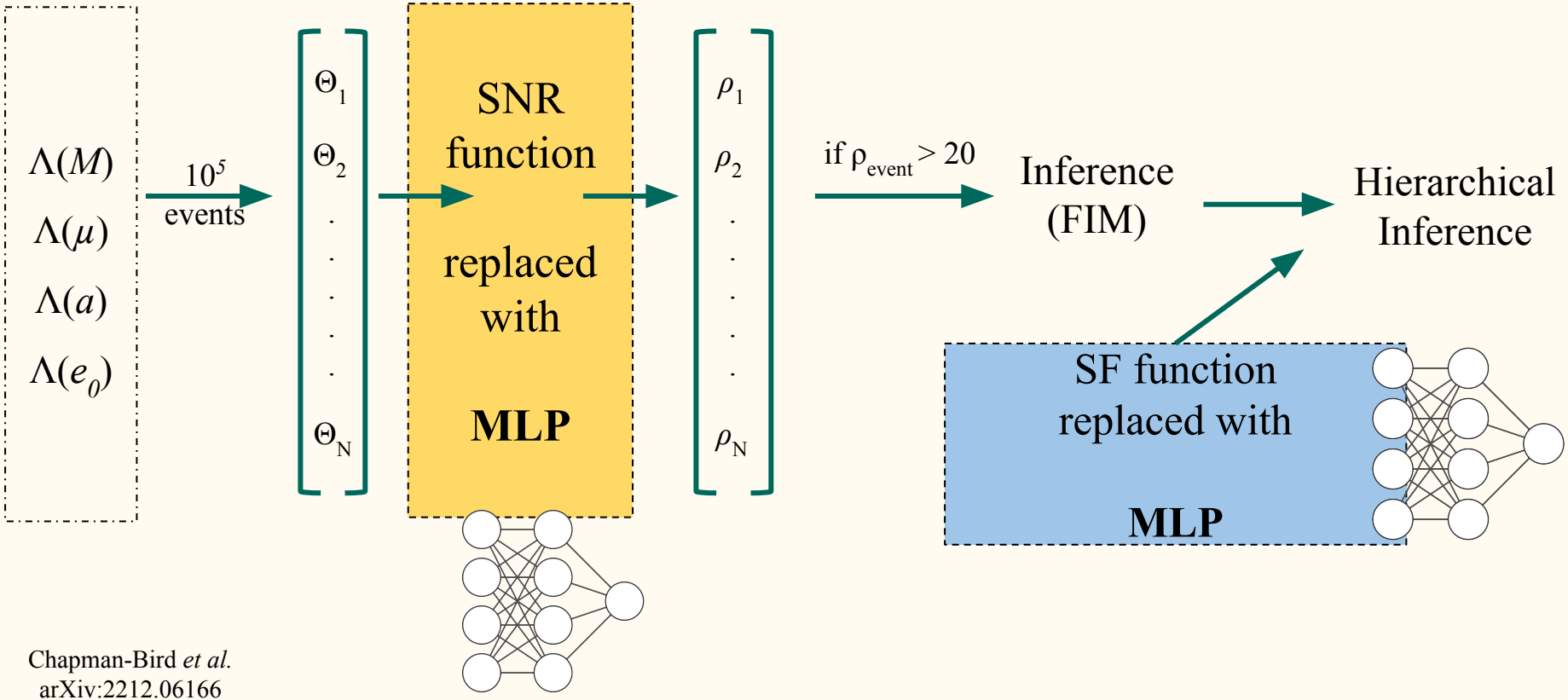


Our analysis



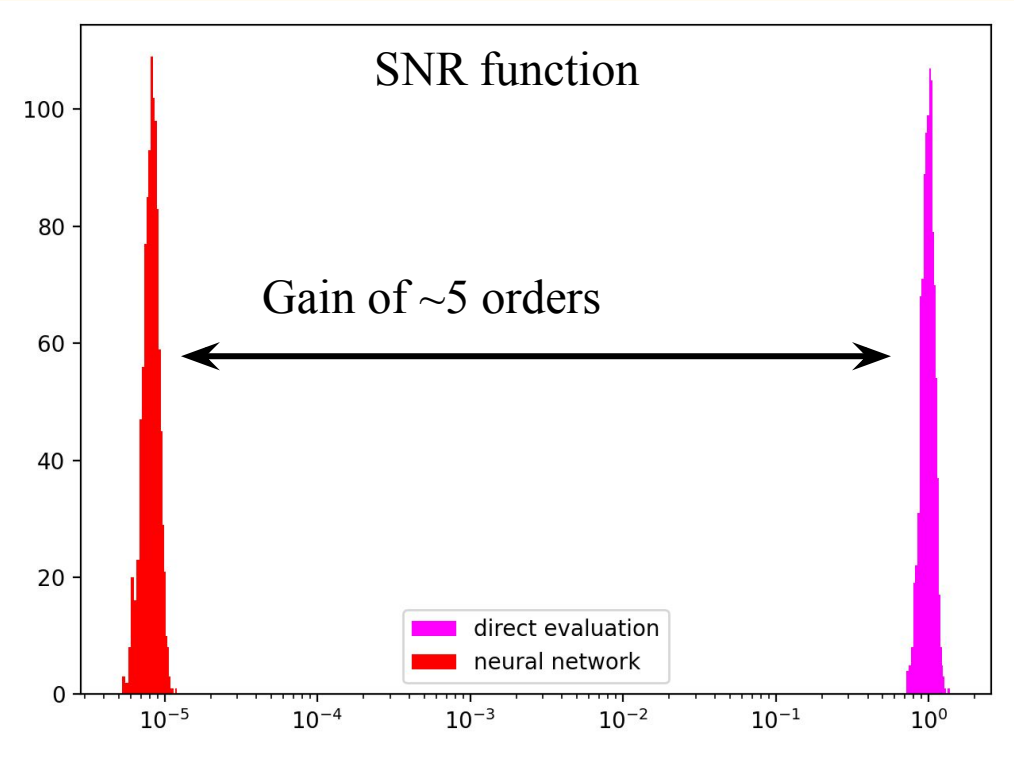
Katz *et al.* arXiv:2104.04582, 2204.06633

Our analysis – speed up



Chapman-Bird *et al.*
arXiv:2212.06166

Our analysis – speed up



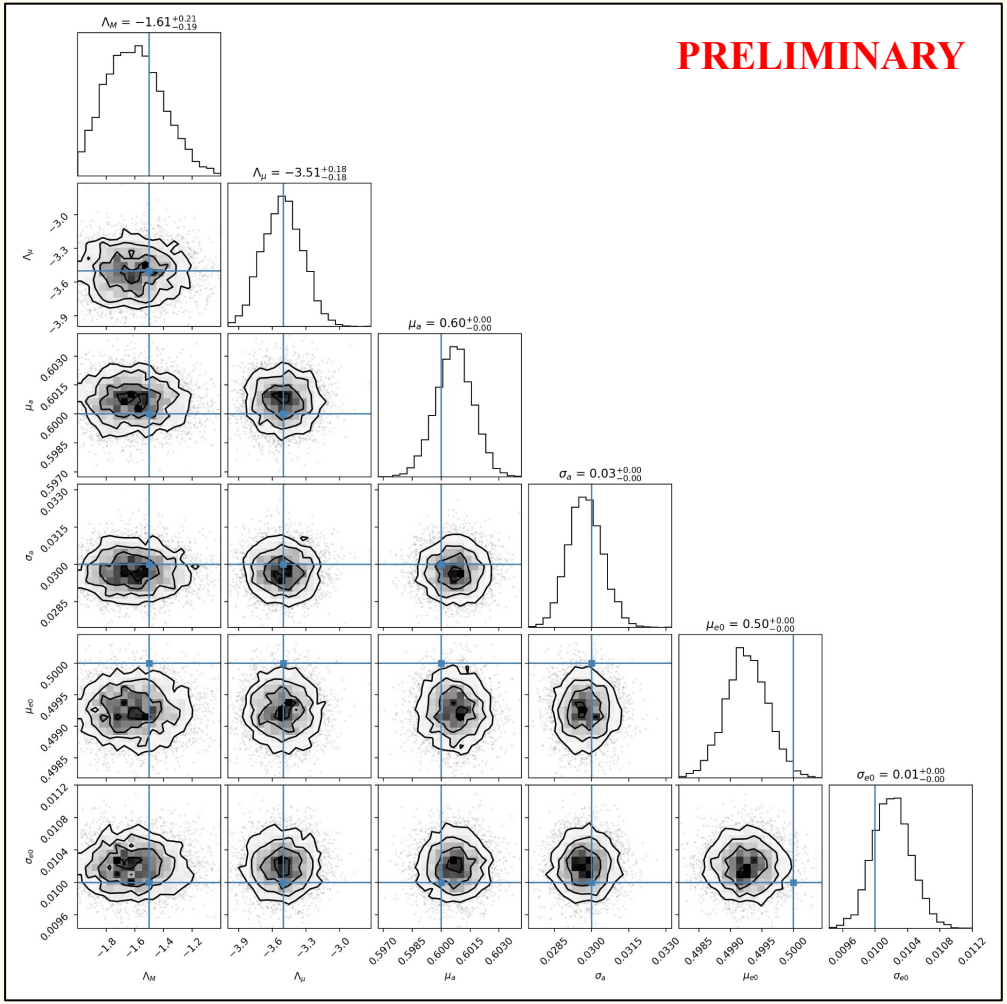
Gain in SF

Direct evaluation

10^4 events ⇒ 1000s ~ 16 mins

Neural network

10^4 events ⇒ .1s



Results

- Slope of ***mass function*** *of* **MBH** and **CO** are constrained within **15%** and **5%**. **Spin** & **eccentricity** are within **5%**.

- Inference on ~2.10^2 events out of 10^4 injections for SNR threshold of 20.

- We are able to speed up the
  - SNR analysis
  - SF evaluation

  using neural networks.

Conclusion

- With multiple EMRI detections, it will be possible to constrain EMRI population parameters.
- Formation mechanism is affected by various astrophysical processes which are hard to infer with the current detections.
- Using MLP it is possible to speed up the SNR evaluation upto 5 orders of magnitude and consequently likelihood evaluation.
- With our method it is possible to constrain the population parameters and consequently study the formation mechanism.

END

Our analysis – *hierarchical inference*

Prior

Likelihood function

$$p(\lambda \mid d_i) = \pi(\Lambda) \prod_{i=1}^{N_{\rm obs}} \frac{\frac{1}{S_i}\sum_{j=1}^{S_i} \frac{p_{\rm pop}(\theta_i^j|\Lambda)}{\pi(\theta)}}{\int {\rm d}\theta\, p_{\rm det}(\theta)\, p_{\rm pop}(\theta|\Lambda)} \times e^{-N_{\rm det}} (N_{\rm det})^{N_{\rm obs}}$$

selection function

$$\alpha(\Lambda) = \frac{1}{N_t} \sum_{k=0}^{N_t} \overline{p_{\rm det}}(\theta_k)$$