



# Analysing with(out) LISA's noise asymmetries

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# Background & previous work

# Introduction to LISA

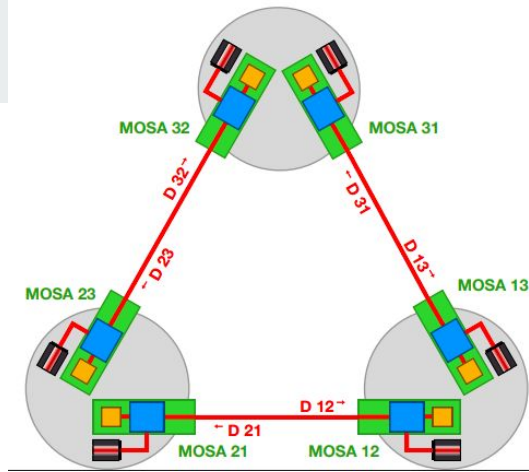
## LISA is not a normal Michelson interferometer

- Arms are too far away
- Single link response no longer holds LFA
- First order correction made:

$$y_{IJ}(t) = \frac{1}{2(1 - \hat{k} \cdot \hat{n}_{IJ}(t))} \left[ H_{IJ} \left( t - \hat{k} \cdot \vec{x}_J(t) - L_{IJ}(t) \right) - H_{IJ} \left( t - \hat{k} \cdot \vec{x}_I(t) \right) \right].$$

To replicate physical interferometers and eliminate laser-frequency noise, Time Delay Interferometry (TDI) is performed

- Turns 6 single link data streams to 3 TDI channels
- Multiple combinations possible to suppress laser frequency noise
  - Michelson (XYZ), Sagnac ( $\alpha\beta\gamma$ )
- Noise becomes highly correlated but can become diagonalised after coordinate transformation



$$A = \frac{Z - X}{\sqrt{2}},$$
$$E = \frac{X - 2Y + Z}{\sqrt{6}},$$
$$T = \frac{X + Y + Z}{\sqrt{3}},$$

# Asymmetries in LISA

## 2 Noise sources modelled in LISA:

- test mass (TM) & optical metrology system (OMS) noise

- Associated noise parameters  $A_{IJ}$ ,  $P_{IJ}$  
$$n_{IJ}(t) = n_{IJ}^{\text{TM}}(t) + n_{IJ}^{\text{OMS}}(t) + n_{JI}^{\text{TM}}(t - L_{IJ}(t))$$

- Usually set to  $A_{IJ} = 3, P_{IJ} = 15$

- From single link to TDI noise

→ stationarity:  $S^{XX}$  possible

$$(\text{Re}[\tilde{\mathbf{n}}(f)], \text{Im}[\tilde{\mathbf{n}}(f)]) \sim \mathcal{N}\left(0, \frac{1}{2\Delta f} \begin{pmatrix} \text{Re}[\mathbf{S}(f)] & \text{Im}[\mathbf{S}(f)] \\ -\text{Im}[\mathbf{S}(f)] & \text{Re}[\mathbf{S}(f)] \end{pmatrix}\right)$$

- Further assumption of symmetry

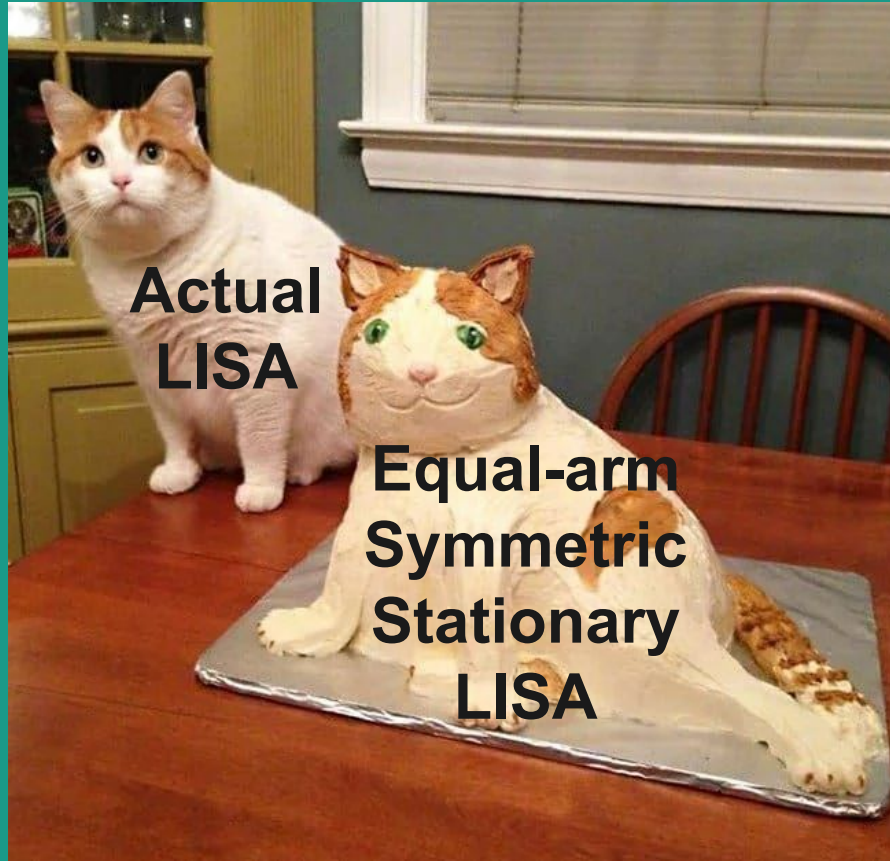
$$((L_{IJ}, A_{IJ}, P_{IJ}) = (L, A, P))$$

→ Transform to the AET base, contains no correlations

$$\mathbf{S}^{\text{AET}}(f) = \begin{pmatrix} S^{XX} - S^{XY} & 0 & 0 \\ 0 & S^{XX} - S^{XY} & 0 \\ 0 & 0 & S^{XX} + 2S^{XY} \end{pmatrix}$$

# Asymmetries are guaranteed!

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**Actual  
LISA**

**Equal-arm  
Symmetric  
Stationary  
LISA**

# Why will LISA have asymmetries?

- A and P parameters only known up to factor 2 before launch
- Noise will deviate over time already for Mojito data sets
- Orbits known to be non-equilateral

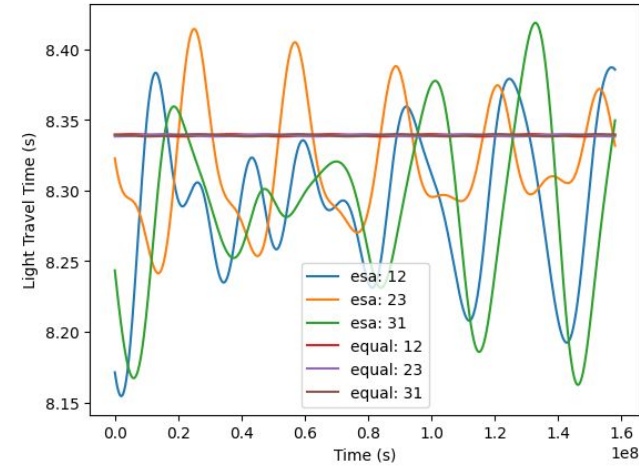


Image taken from LisaAnalysisTools documentation

$$n_{IJ}(t) = n_{IJ}^{\text{TM}}(t) + n_{IJ}^{\text{OMS}}(t) + n_{JI}^{\text{TM}}(t - \underbrace{L_{IJ}(\quad)}_{\text{circled}}))$$

# Previous work on asymmetries

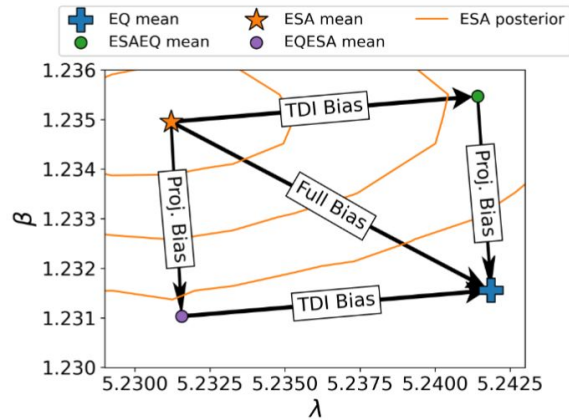


Figure taken from (Katz+ 2022)

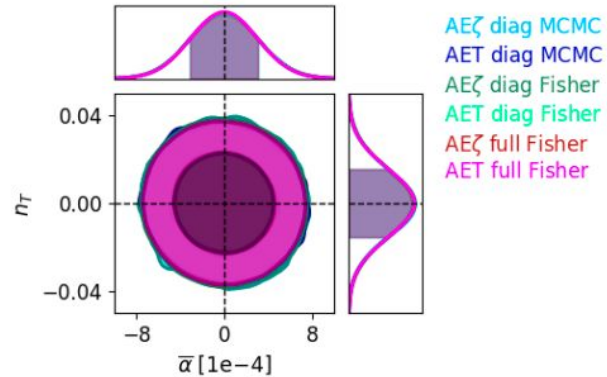


Figure taken from (Hartwig+ 2024)

# Limitations of previous studies



## Katz et al. (2022)

- Only treats asymmetries from the orbits, no noise included

## Hartwig et al. (2024)

- Different likelihood for background estimation
- **Disregarded AET noise correlation terms!**
- **Limited frequency range (~1-10 mHz)**
  - Suggested higher frequencies
- **For Einstein Telescope, Correlations very important! (Cireddu+ 2023)**

→ Full analysis of the noise asymmetries across the LISA band yet to be done

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# Methods and Results

# Methods: Noise models and chosen waveform

3 noise models in AET channels

- Asymmetric

$$A_{IJ} \sim \mathcal{N}(3; 0.6^2), P_{IJ} \sim \mathcal{N}(15; 3^2)$$

- Diagonal

$$A_{IJ} \sim \mathcal{N}(3; 0.6^2), P_{IJ} \sim \mathcal{N}(15; 3^2)$$

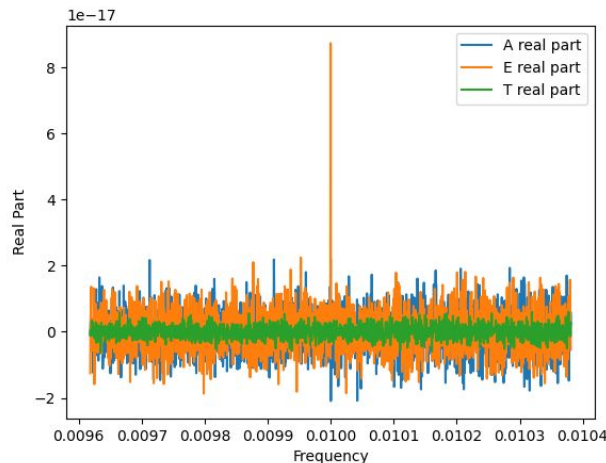
$$S^{AE} = S^{ET} = S^{AT} = 0$$

- Symmetric  $A_{IJ} = 3, P_{IJ} = 15$

In all cases, we use equal-arm orbits and  
TDI-1

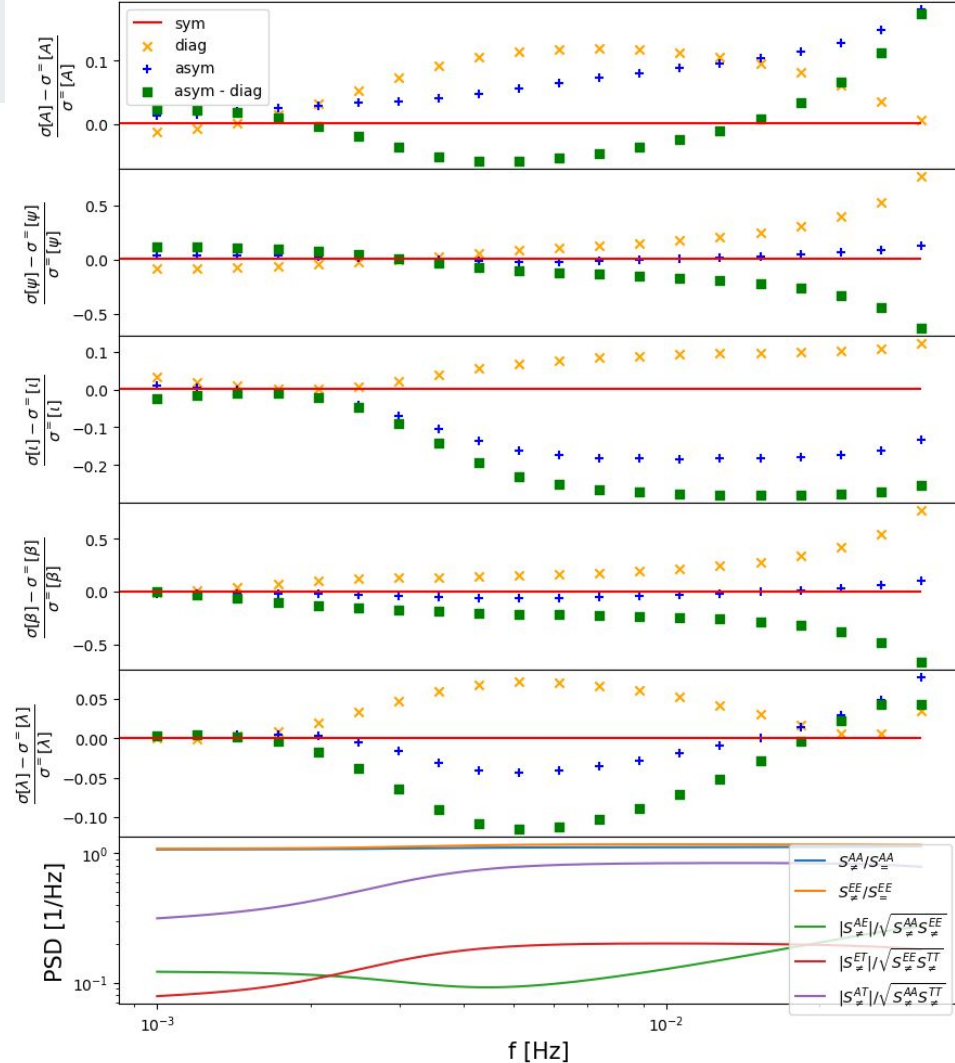
Galactic binary

- Fast frequency domain waveforms (JaxGB) that deals with orbit
- Quasi-monochromatic  
→ Prod local noise asymmetries



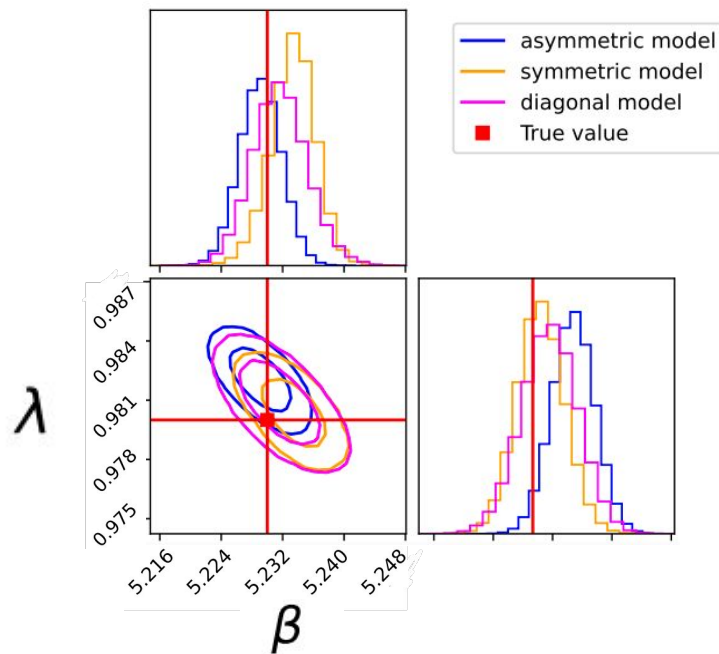
# Results (i): Fisher analysis

- Calculated Fisher matrices (fixed  $f_0$  and  $\dot{f}$ , and phase)
- SNR set to 100 (for symmetric detectors)
- $T_{\text{obs}} = 1$  year
- Frequency dependency very clear
- Mismatch in uncertainties quite clearly due to correlations
- Asymmetries seem to become significant from 5-10 mHz?  
→ Perform PE at  $f = 10$  mHz



## Results (ii): Bayesian analysis

- Injected a GB signal with asymmetric noise
  - SNR  $\sim 110$ , observation time = 1 yr
- Performed PE with FlowMC (strong recommend for anyone programming with JAX!)
- Analysed with likelihoods based on 3 noise models
- Not only smaller posterior, but also shifted MAP
- True value still within 2 sigma, so no bias
- Generally, diagonal and symmetric match up quite well
  - PSDs are quite similar

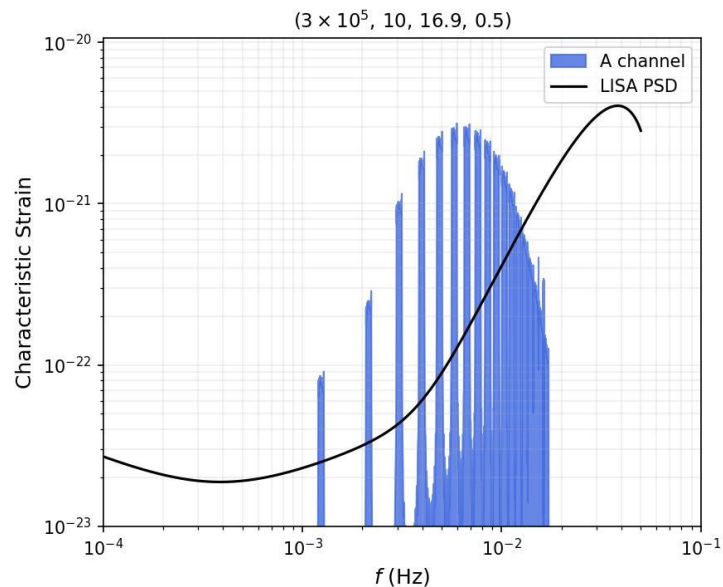


# Conclusions and Future work

- Noise asymmetries are important and non-negligible
- Good understanding of noise required
- But with asymmetric correlations, you have tighter error bars
- T-channel correlations seem to play important part here, for  $f > 10$  mHz
- Asymmetries have different effects for different waveforms!

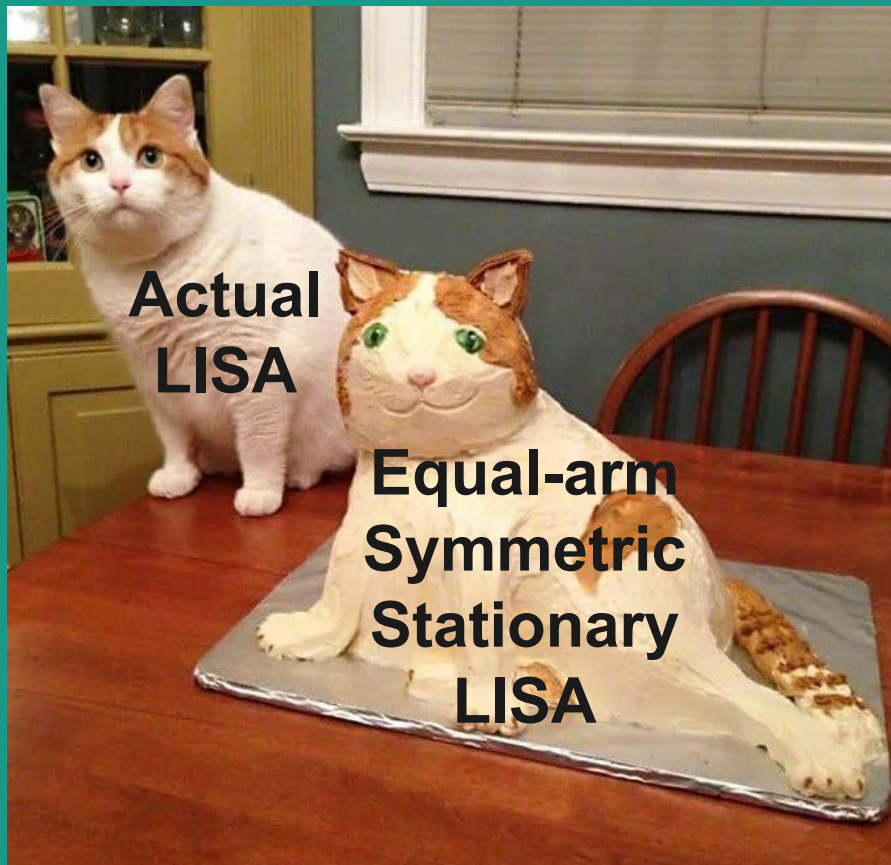
## FUTURE WORK:

- Perform similar analyses for different waveforms (specifically EMRIs, MBHBs)
- Analyses to fit asymmetric noise (work in progress: Shivani Harer)
- Instrumental noise nonstationarities?



# Questions?

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**Actual  
LISA**

**Equal-arm  
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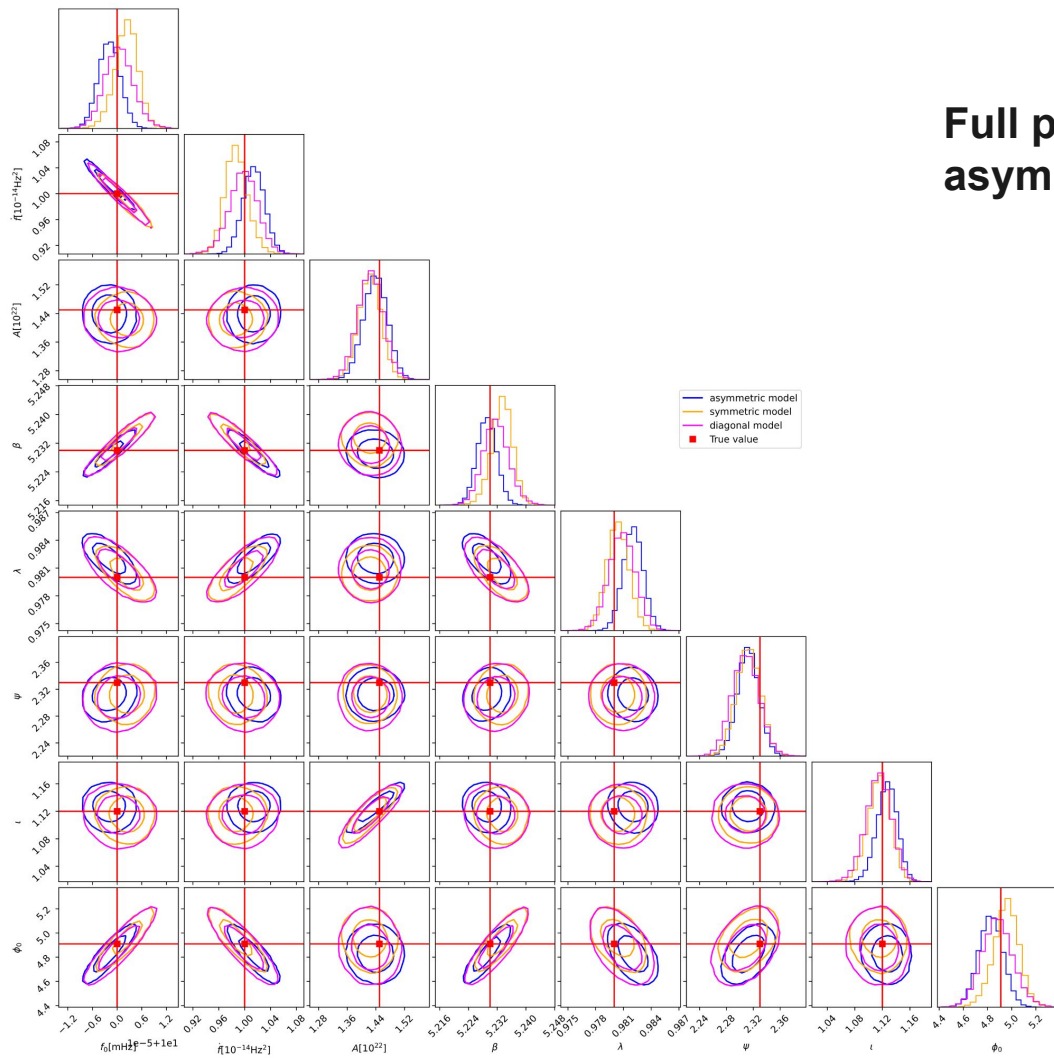
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**Extra slides**

# Full posterior plot with SNR 110 and asymmetric noise (1 yr observation time)



**Full posterior plot with SNR 110 and no noise (1 yr observation time)**

