Stochastic gravitational wave background reconstruction for a nonequilateral and unequal-noise LISA constellation

(based on 2303.15929)

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SGWB detection in LISA TDI data

- Many potential sources (some speculative, some model-dependent)
- Instrumental noise characteristics not well known
- Two main approaches, so far:
  - Known noise, unknown SGWB (e.g. SGWBinner)
  - Unknown noise, known SGWB (e.g. Spline approach)
- Other simplifying assumptions on the LISA configuration:
  - Constant and equal arm lengths
  - Equal secondary noise levels

→ AET basis diagonal
T channel: noise dominated
A, E channels: signal dominated

Technically easy to handle
Computationally cheap
Noise estimation readily made

There are many more available TDI variables!

Unequal arms
Equal/Unequal noise

TDI response $\mathscr{R}$
for SGWB
(signal independent)

Introduce the fully symmetric
Sagnac channel ζ

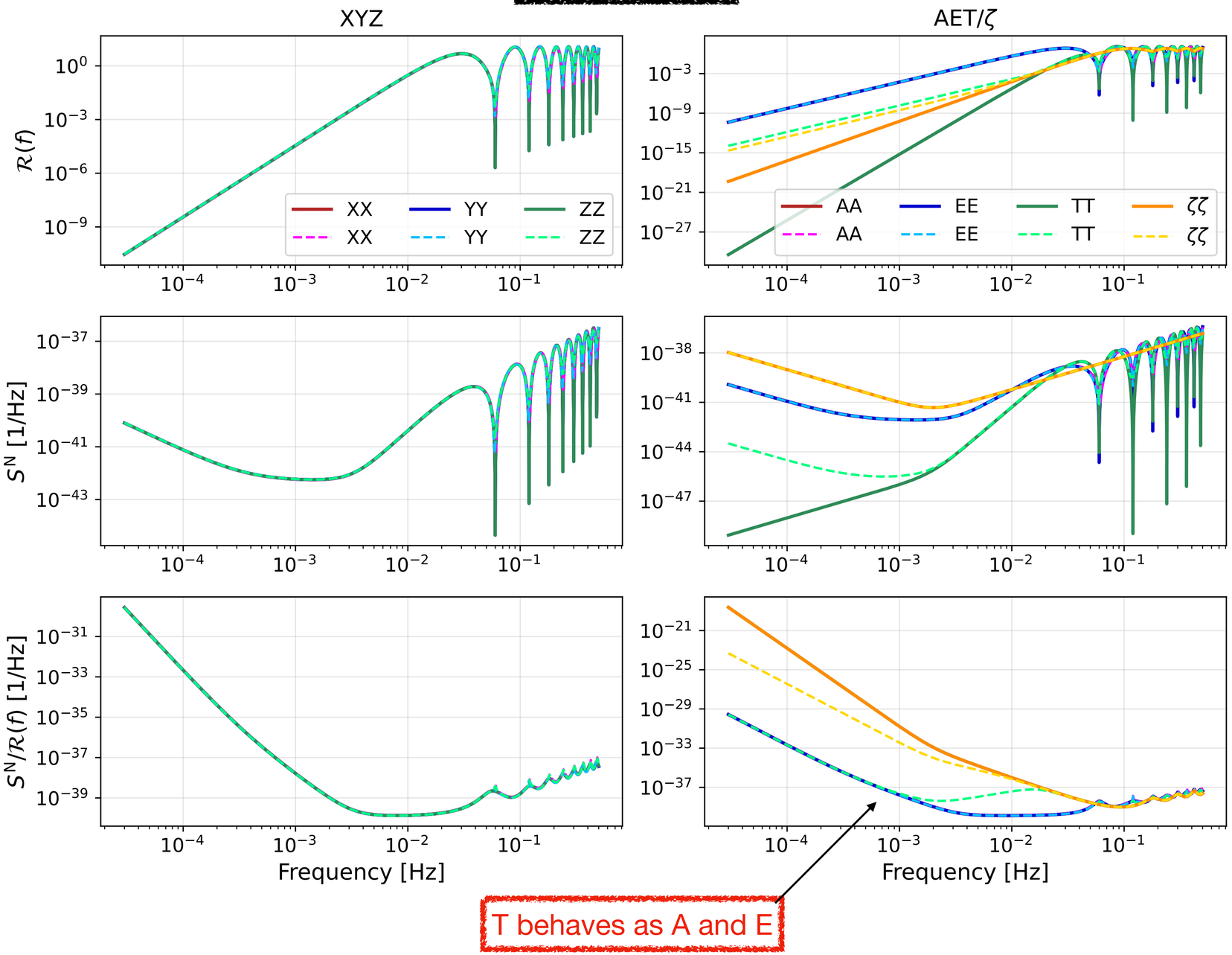
Secondary
noises PSD's
(includes noise model)

T channel no longer
noise-dominated
below 0.01 Hz

"Strain sensitivity":
$$\frac{S^N}{Signal\ TF}$$

ζ channel
robust to arm
length mismatch

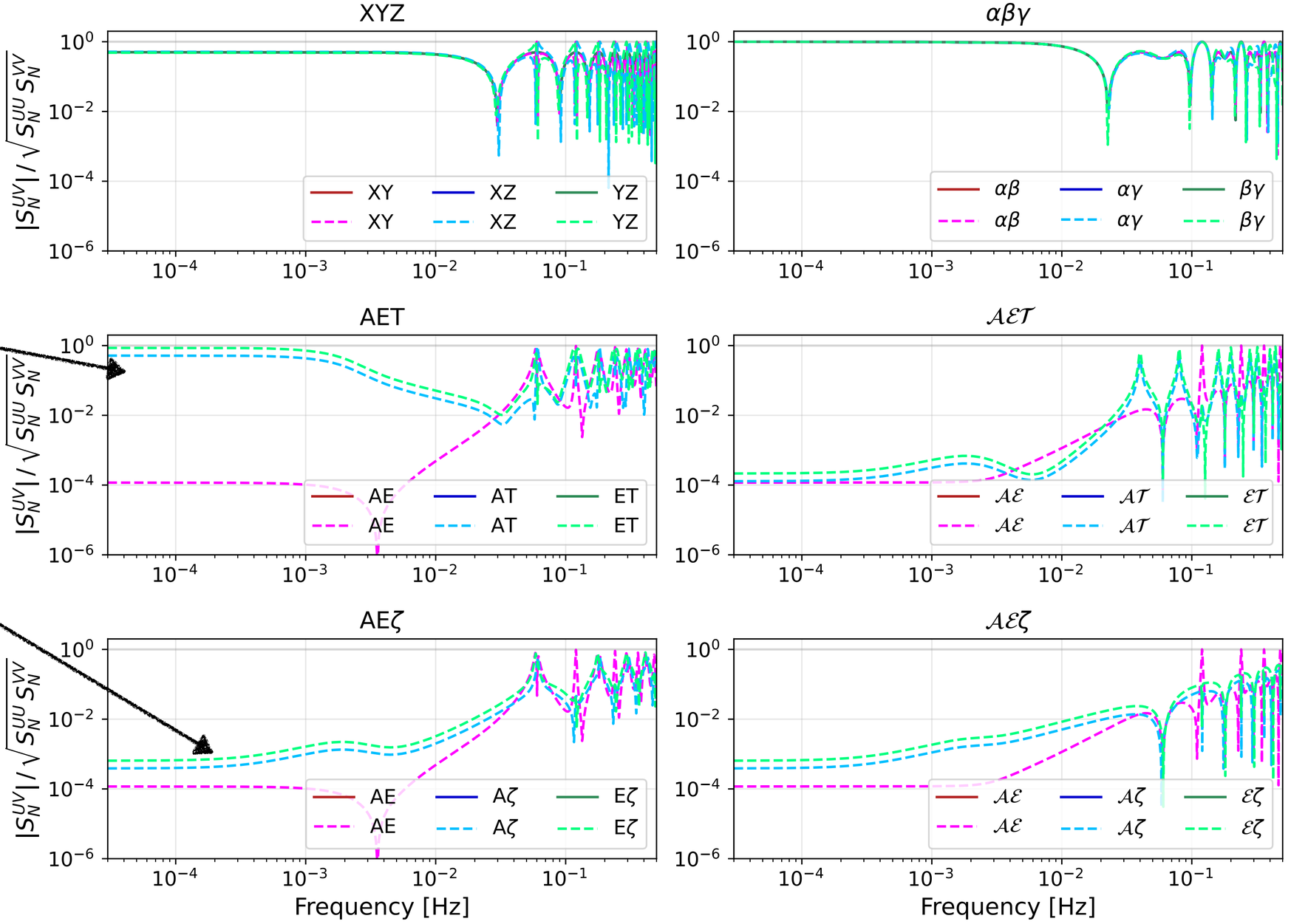
Diagonal terms



T behaves as A and E

Unequal arms
Equal noise

Noise cross-correlations



Michelson AT and ET no longer zero

Aζ and Eζ remain small

Use AEζ or Sagnac channels but not AET

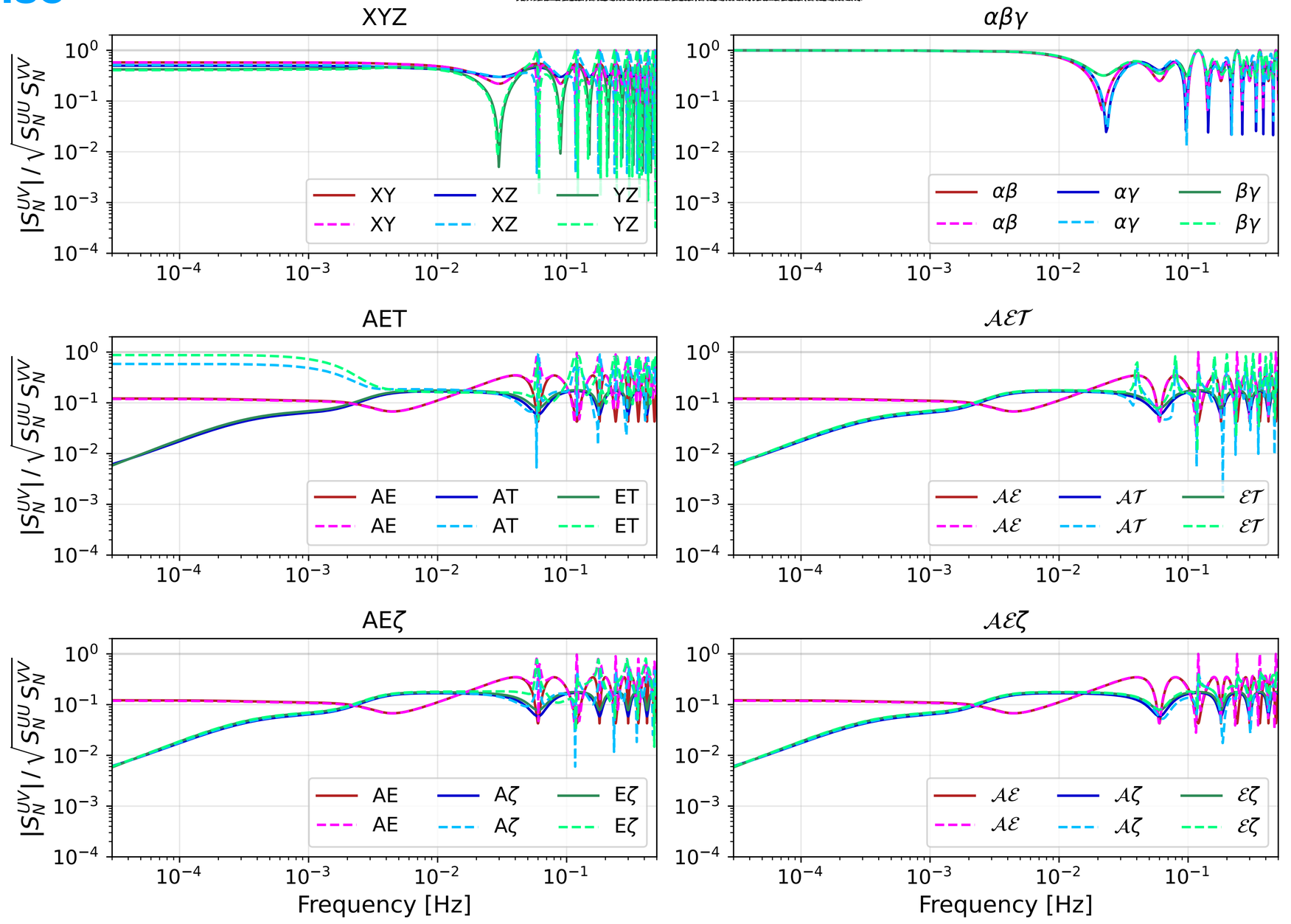
Unequal arms, unequal noise vs. equal arms unequal noise

Noise cross-correlations

Michelson AT and ET
mainly affected by unequal arms

Aζ and Eζ
mainly affected by unequal noise

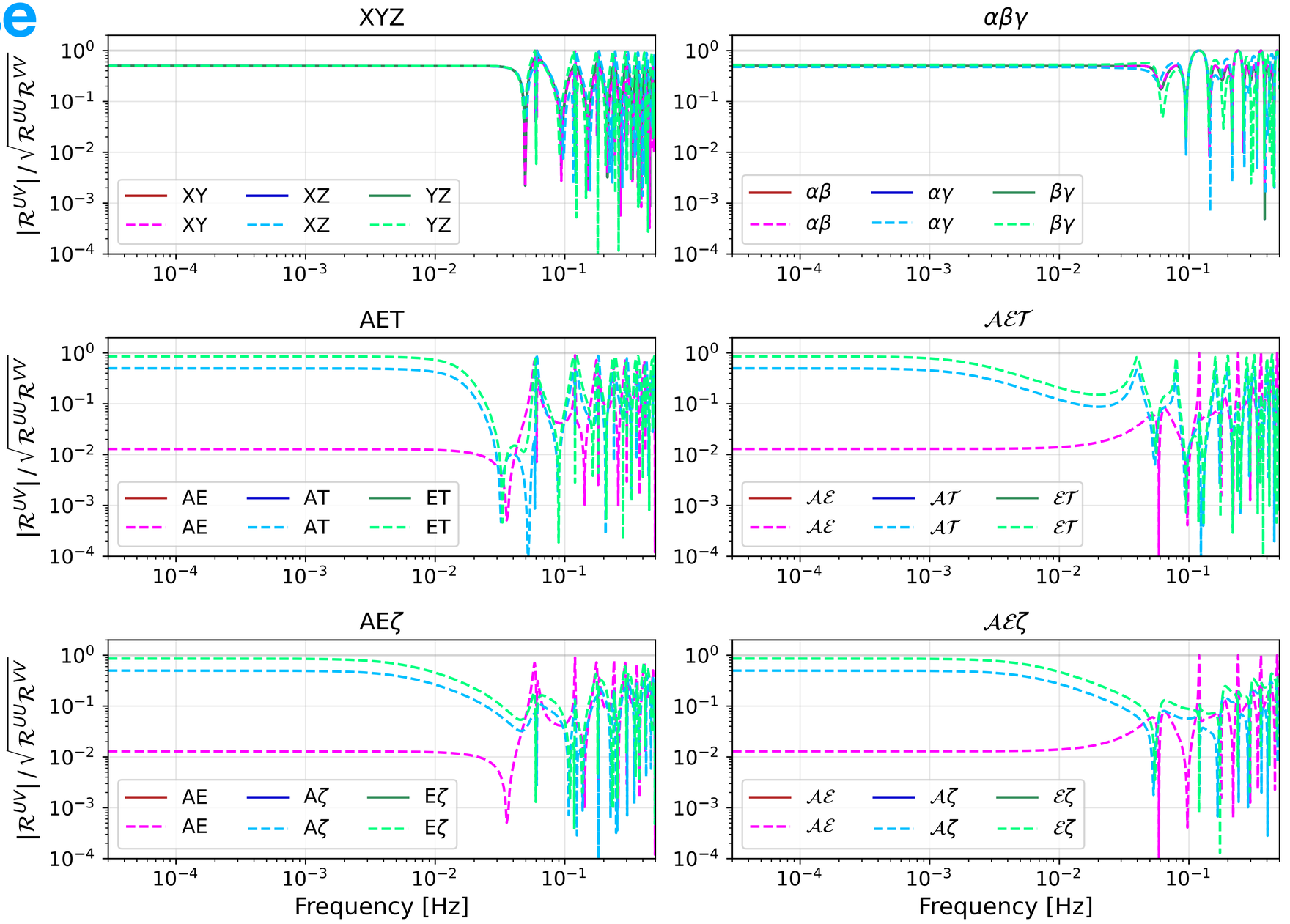
No diagonal basis for noise



Unequal arms
Equal/Unequal noise

No diagonal basis for signal

Signal transfer function cross-correlations



Intermediary comments

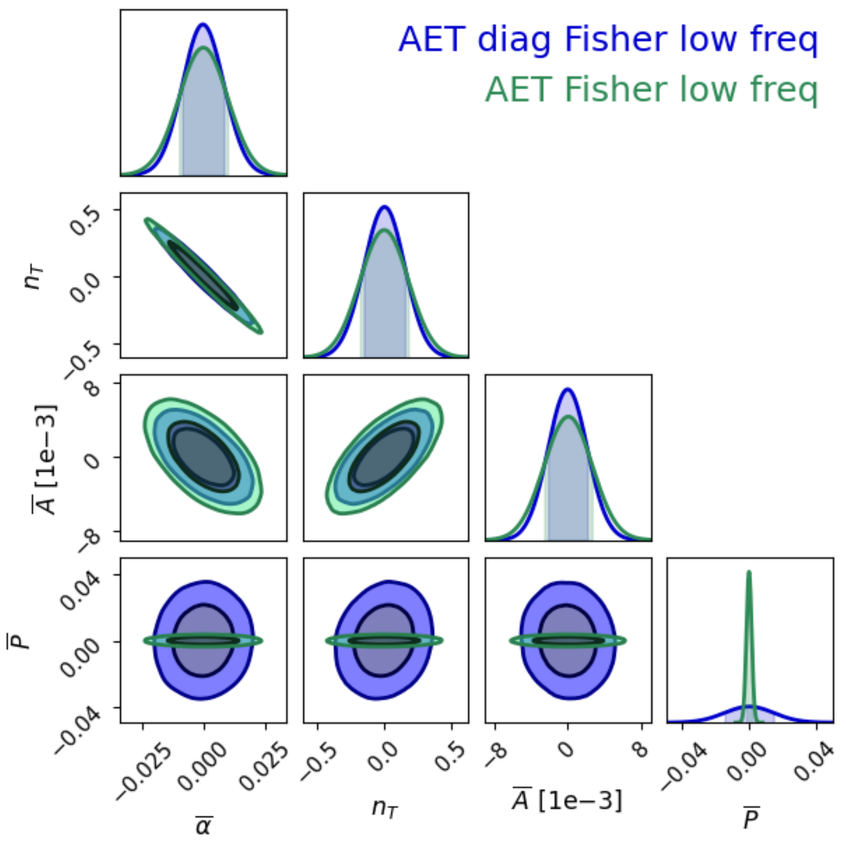
- We have established that in a semi-realistic setting (arm lengths are still time independent), there are no null channels, and there is no diagonal basis.
- This introduces computational and modelling complexity.
- We have seen in previous talks there the noise has to be estimated at the same time as the SGWB.
- The spline approach, for e.g., takes seriously the fact that noise models established on-ground will not be reliable in flight, i.e., noise estimation has to be kept very flexible.
- Can we get away with neglecting off-diagonal terms in the covariance?

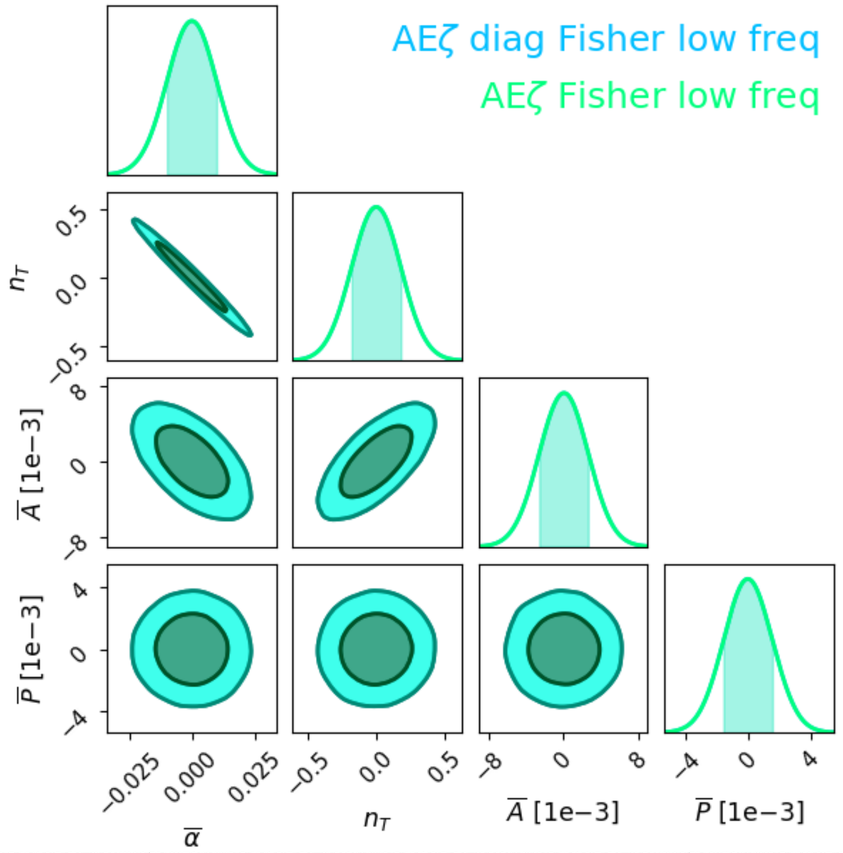
In general, we expect that neglecting off diagonal terms will result in the following:
- some degeneracies which could be broken will remain
- the dominant components will have artificially smaller error bars
- the subdominant components will have enlarged error bars

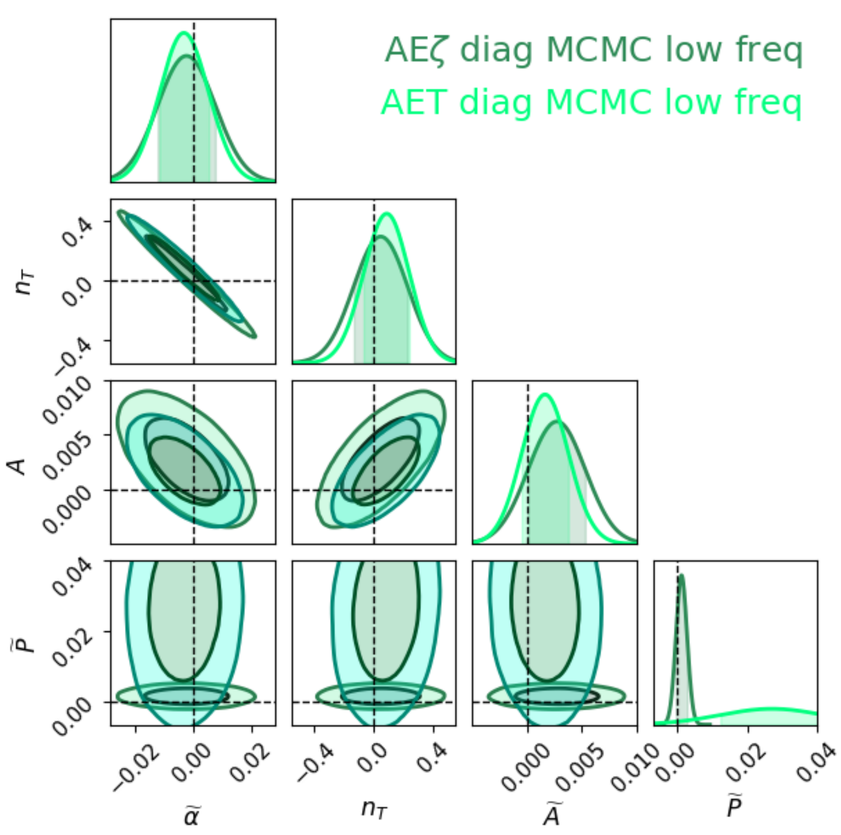
Case study

- Signal as a simple power law: spectral index n_T, spectral slope α
- Noise functional forms known, but amplitudes unknown (with some priors)
- Access the determination of signal and noise parameters
- Compare diagonal-only AET and AEζ with full-matrix AET and AEζ using Fisher information (access to uncertainties only).
- MCMC runs diagonal-only (access to biases and uncertainties).
- Unequal arms, equal and unequal noise, low frequency or full frequency range.
- High SNR over the full frequency range

Low frequency, equal noises



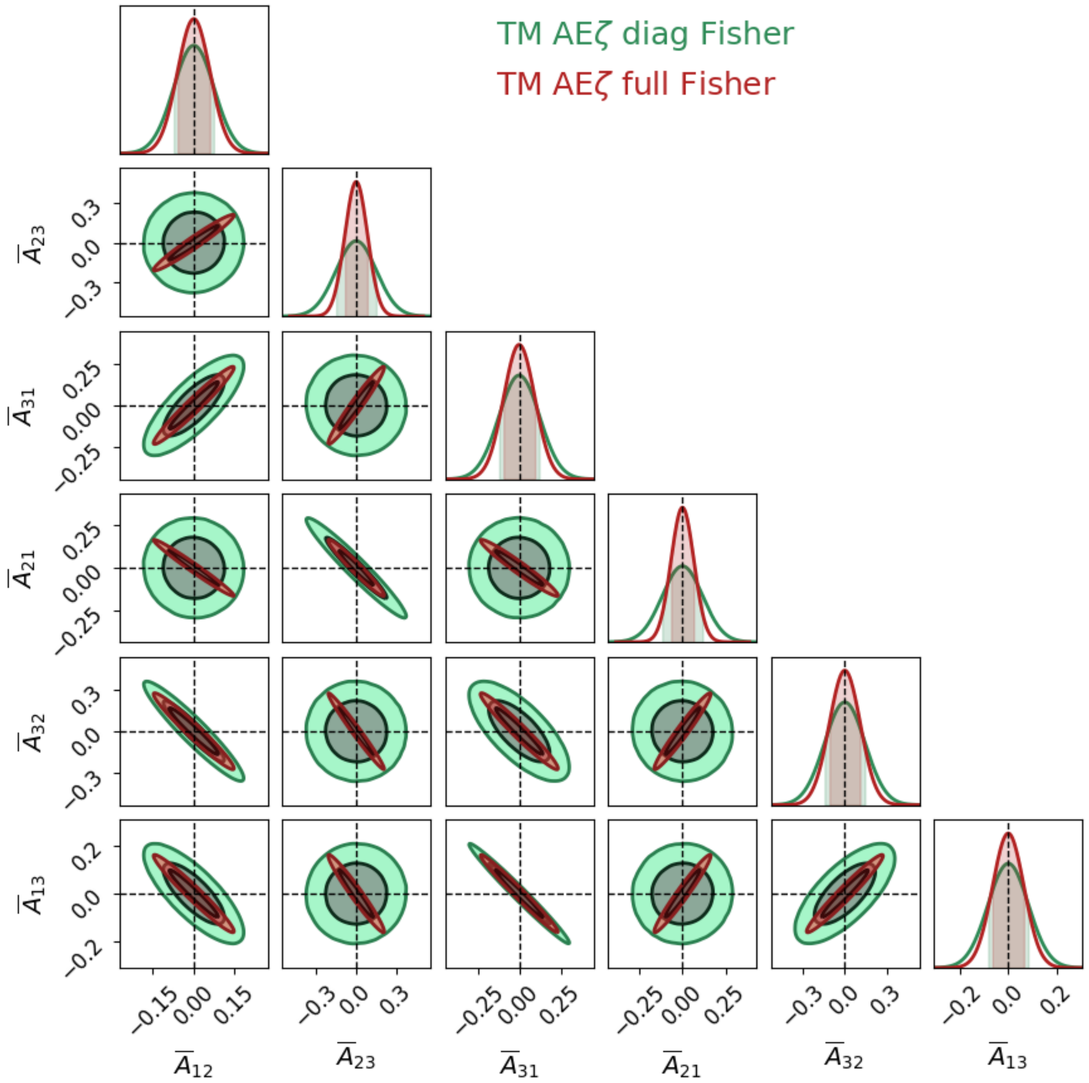


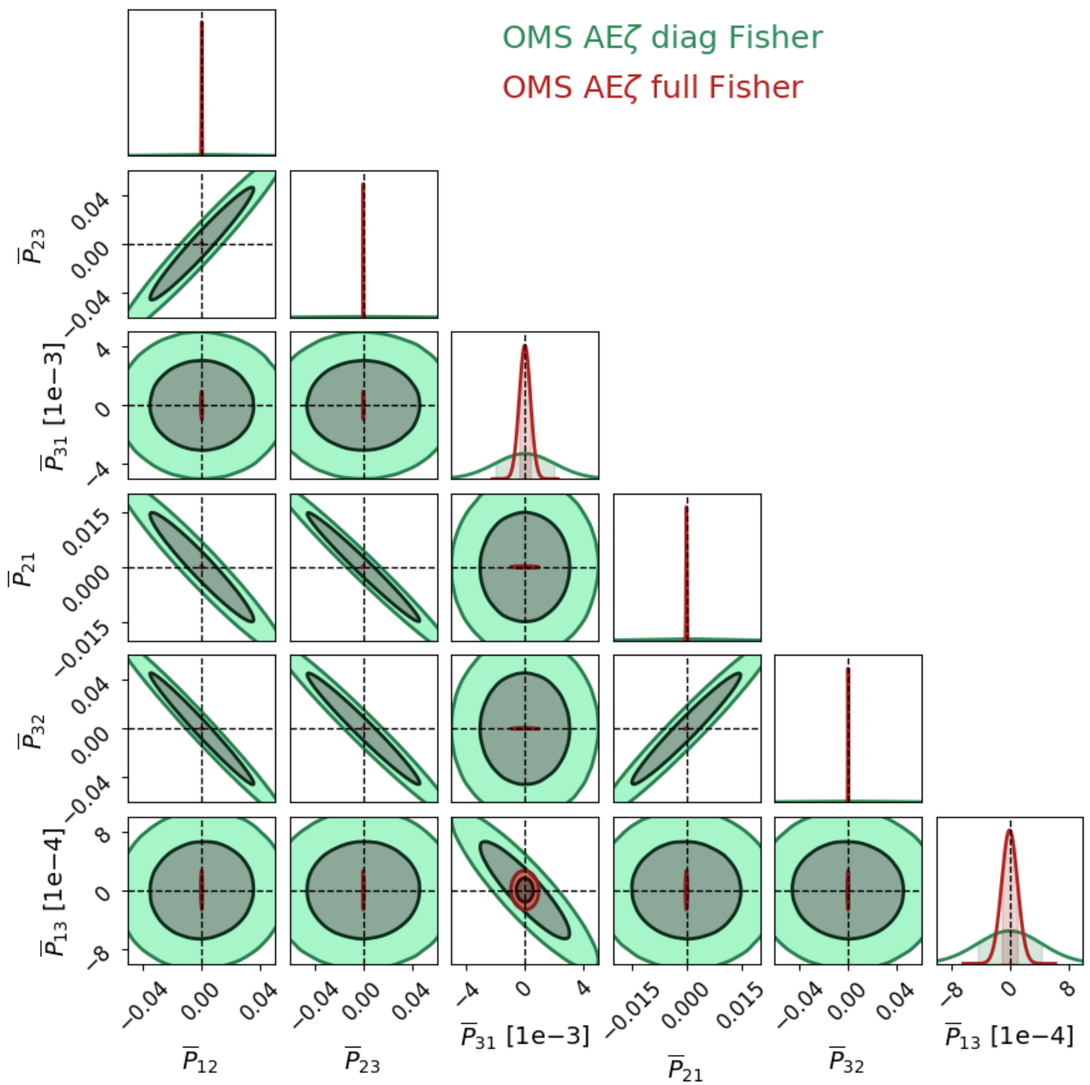


From Fisher forecast: Off-diagonal terms matter for AET but not for AEζ

From MCMC: AET performs much worse than AEζ. In particular P is wrong.

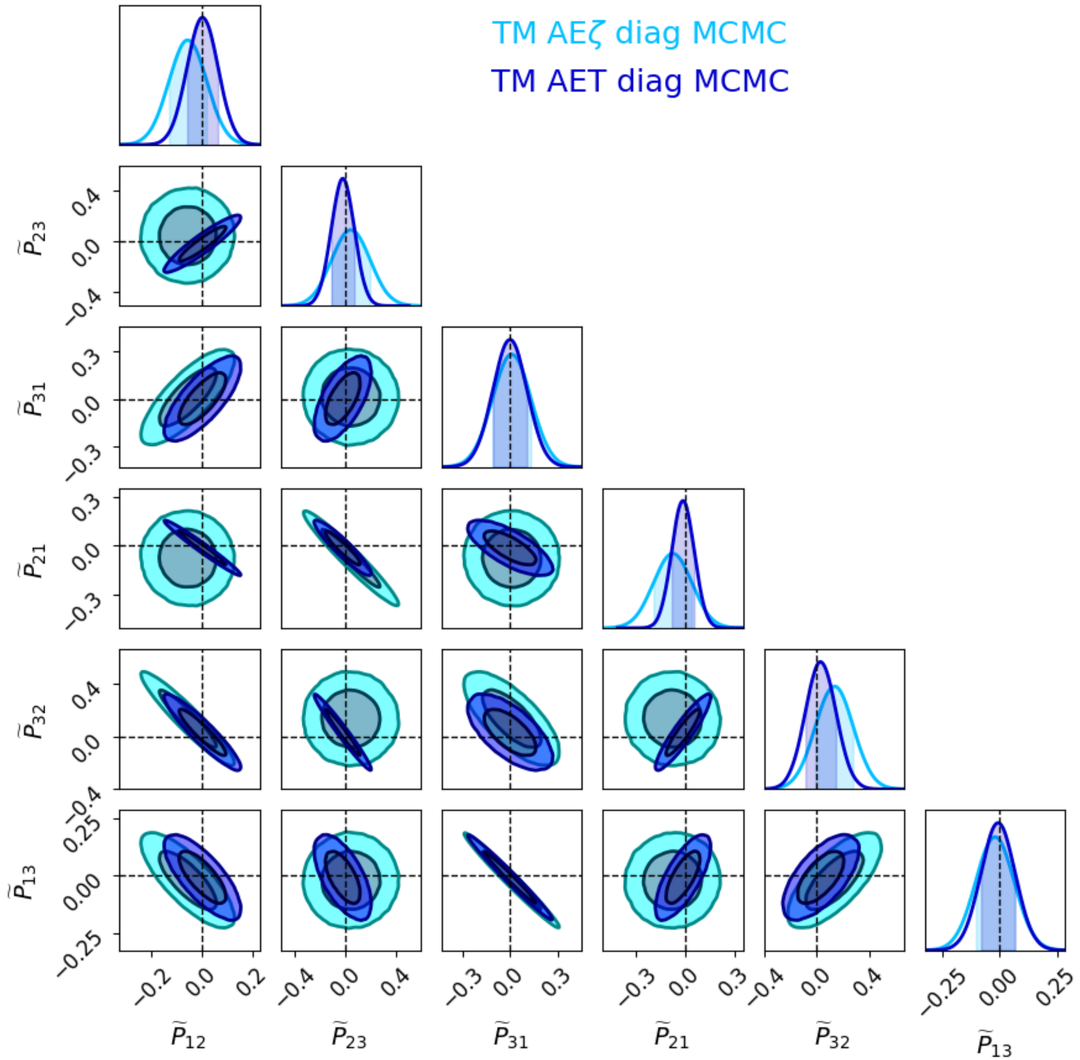
Full frequency, unequal noises

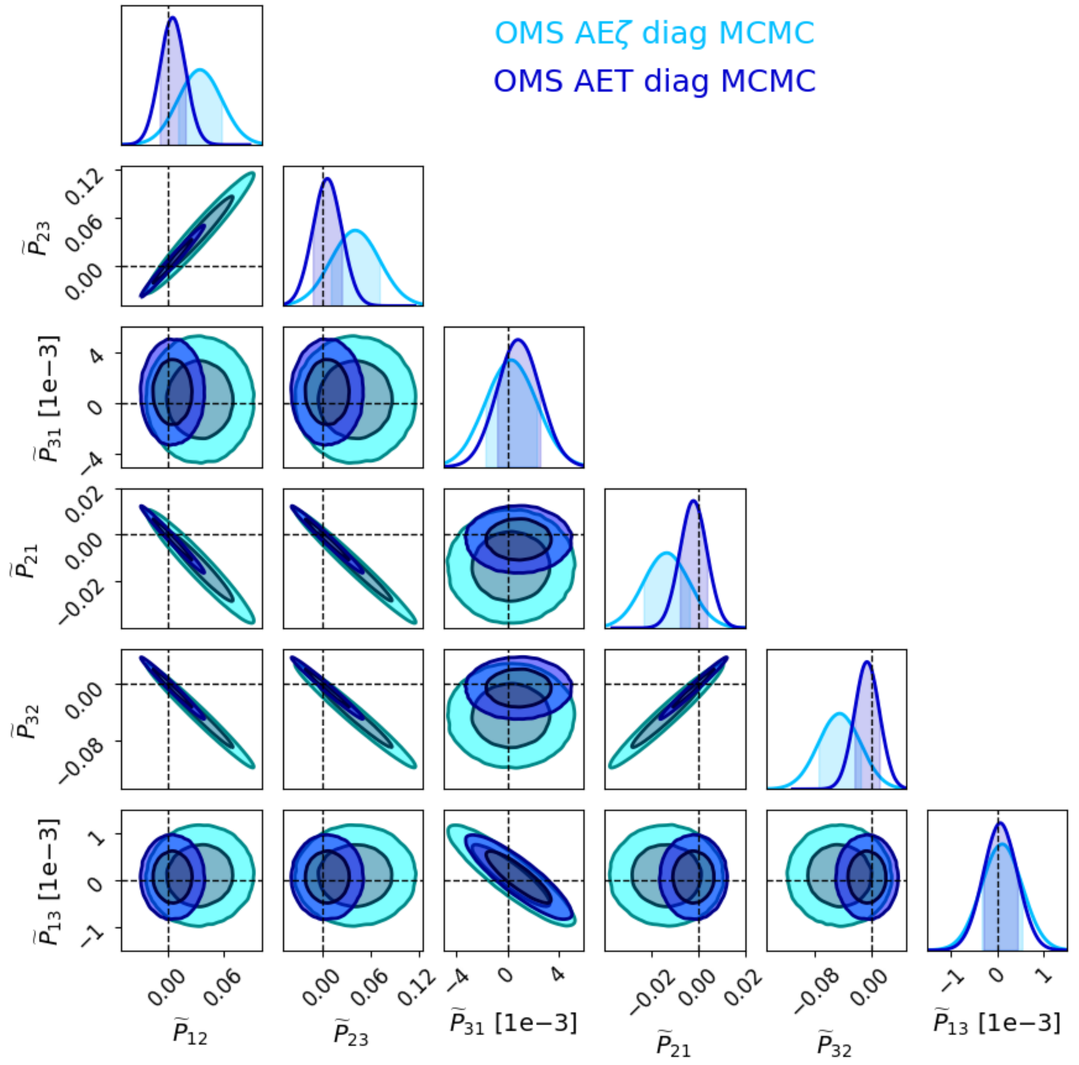




From Fisher forecasts: Off-diagonal terms matter for AEζ (and for AET, not shown)

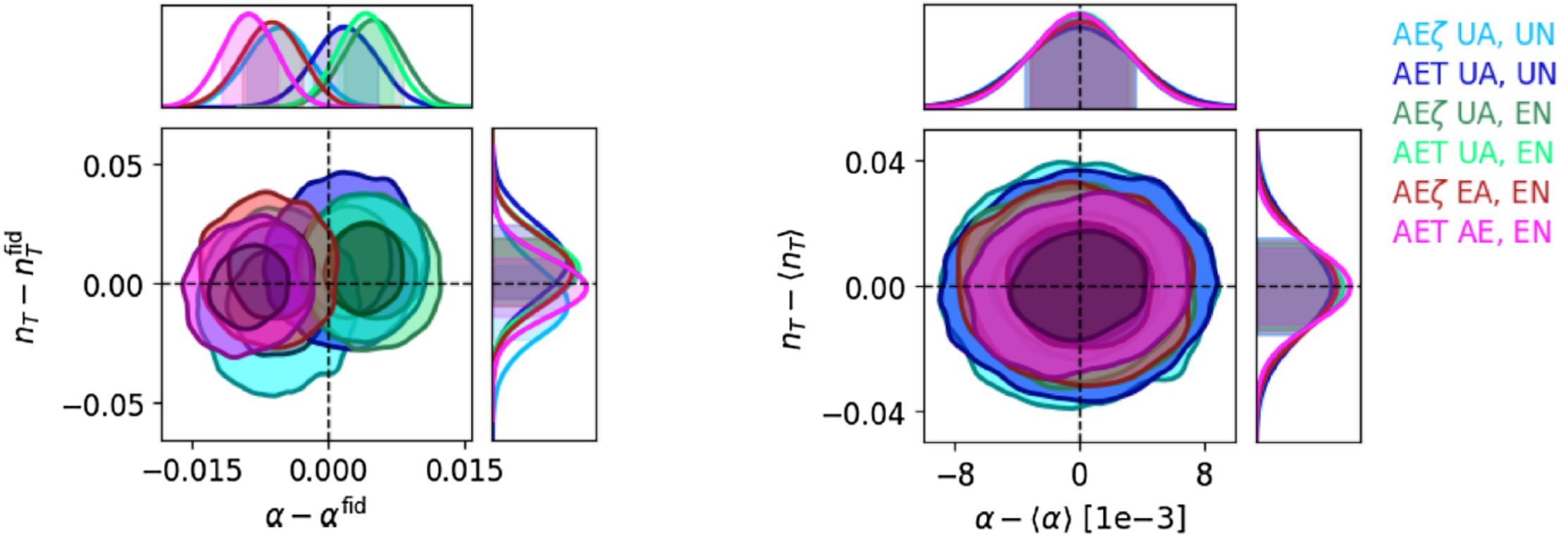
Full frequency, unequal noises





These corner plots are an example of variance under-estimation for AET noise parameters
The best fit values also shift by up to 1 sigma for 3 OMS noise parameters

SGWB parameters for 6 LISA configurations



The cosmological parameters for this specific power law model are not very sensitive to the details of the LISA configuration.
But:

- This is a high SNR case
- The noise and SGWB functional forms are precisely defined (provides strong handle)

Conclusions

We studied secondary noises and SGWB power law for a semi-realistic LISA configuration. All detailed analytic formulae are available in 2303.15929 and supplementary material as Mathematica notebooks)

- TDI variables:
  - Unequal arms: T is no longer a null channel, AET no longer diagonal.
  - AEζ robust to unequal arms.
  - No null channels or diagonal basis for unequal arms and unequal noise.
- Parameter estimation:
  - Frequency range matters
  - Off-diagonal terms matter, as demonstrated for the noise in this study
  - Noteworthy that here, we found insensitivity of the SGWB parameter to the details of the LISA configuration. Not believed to be generic.
- General comments:
  - Important to go beyond diagonal AET and beyond the fully symmetric LISA configuration
  - Important to recognise that the noise is not going to be well known: innovative and agnostic approaches are needed.
  - This will have an impact on forecasts and the ability to reconstruct SGWBs.