Impact of the noise knowledge uncertainty for the science exploitation of cosmological and astrophysical stochastic gravitational wave background with LISA

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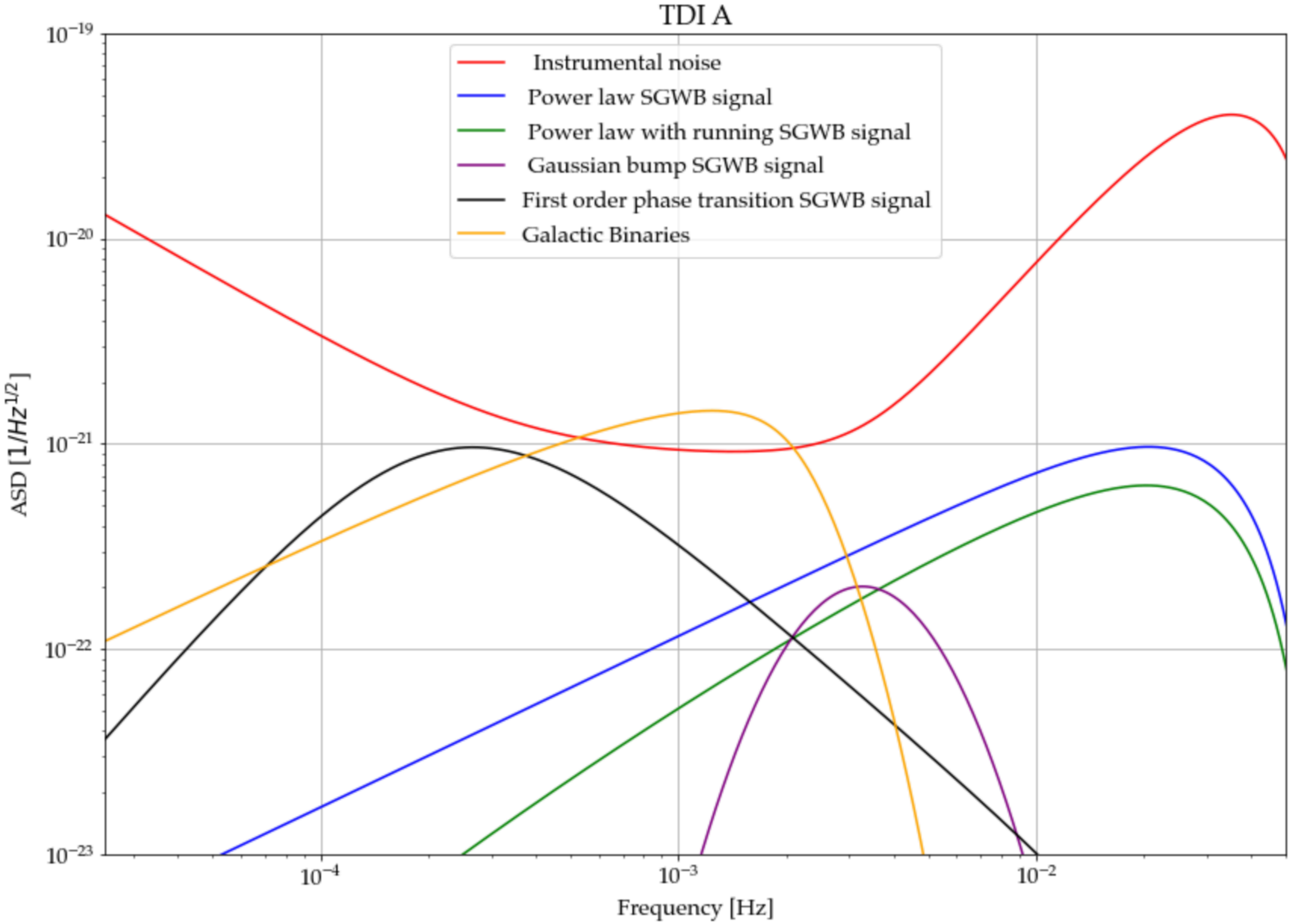
Stochastic GW backgrounds in the LISA band: brief recap

- Stochastic GW backgrounds of both **astrophysical** and **cosmological** origin are predicted in the LISA band
- These signals appear effectively as an **additional source of noise** in the detector
- **We cannot measure the noise in LISA a` la LIGO**
- We need to **distinguish SGWB from instrumental noise** in the sensitive channels
- For the high SNR individual sources, it does not make a big difference
- Remember: **LISA cannot use cross-correlation with other detectors**



* Source: LISA Redbook and C. Caprine private conversation

What does it mean LISA noise ?

$15\ \mathrm{pm/Hz^{1/2}}$

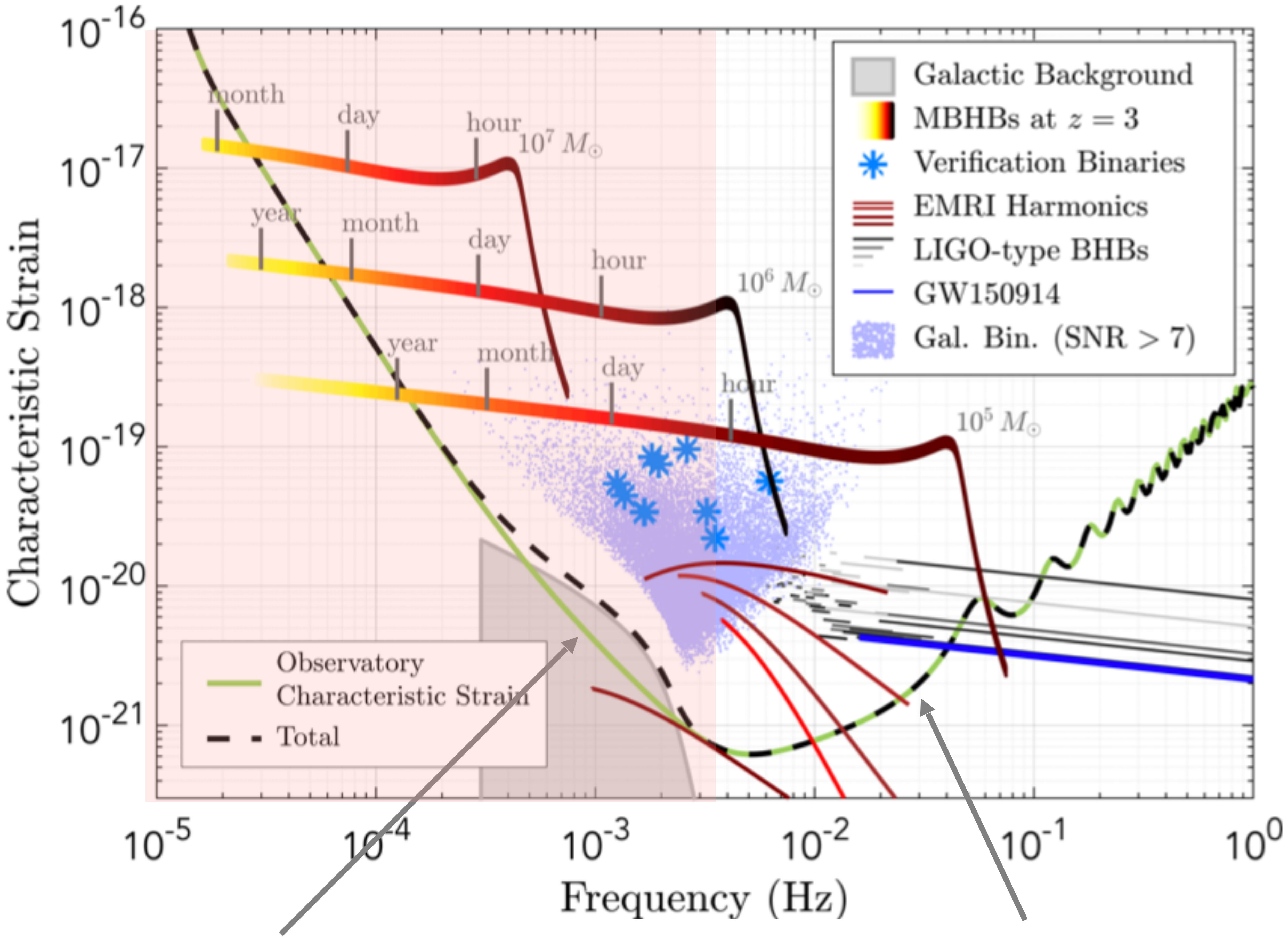
$3\ \mathrm{fm/s^2/Hz^{1/2}}$

Metrology

- Read-out
- Laser noise
- Clock noise
- Spacecraft jitter
- Tilt-to-Length

Free-falling test mass

- Actuation noise
- Brownian noise
- Stray Electrostatics Noise
- Magnetic noise
- Laser Pressure Noise
- Temperature Force Noise
- Gravitational Noise
- TM-SC/MOSA coupling Force Noise



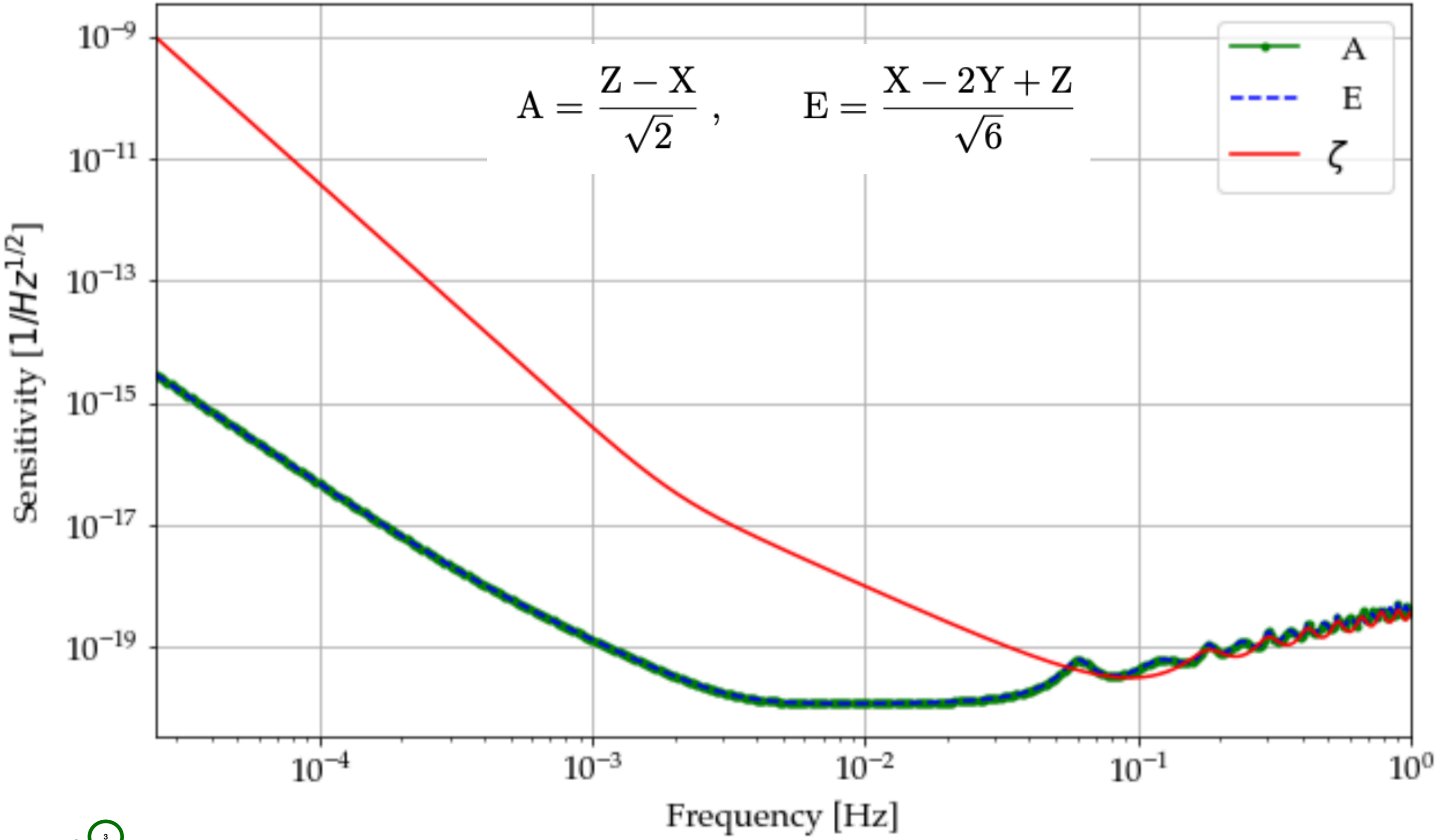
Acceleration noise

Interferometric noise after INREP

How to estimate the LISA noise ?

LISA is expected to be a signals dominated detectors

- ➢ Look for **TDI combinations that have *suppressed* sensitivity** to gravitational wave **(GW)** signals
- ➢ but still carry some information on the instrumental noise
- ➢ **TDI null-channels** (see talk from O.Hartwig)



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

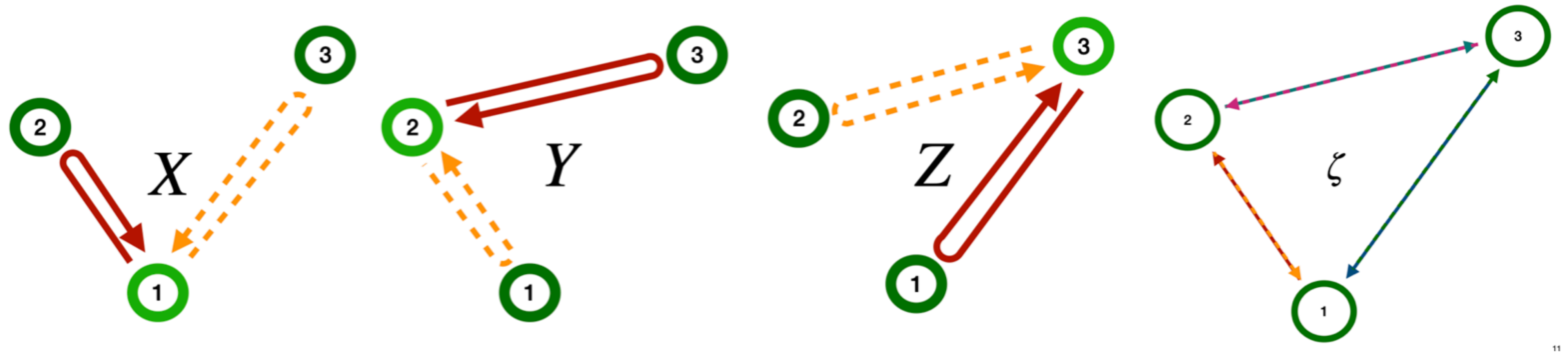


Image curtesy of O.Hartwig

M. Muratore et al, Time Delay Interferometry combinations as instrument noise monitors for LISA. Phys. Rev. D 105, 023009

Muratore et all, On the effectiveness of null TDI channels as instrument noise monitors in LISA e-Print: 2027.02138

Separation of instrumental noise and stochastic backgrounds requires assumptions

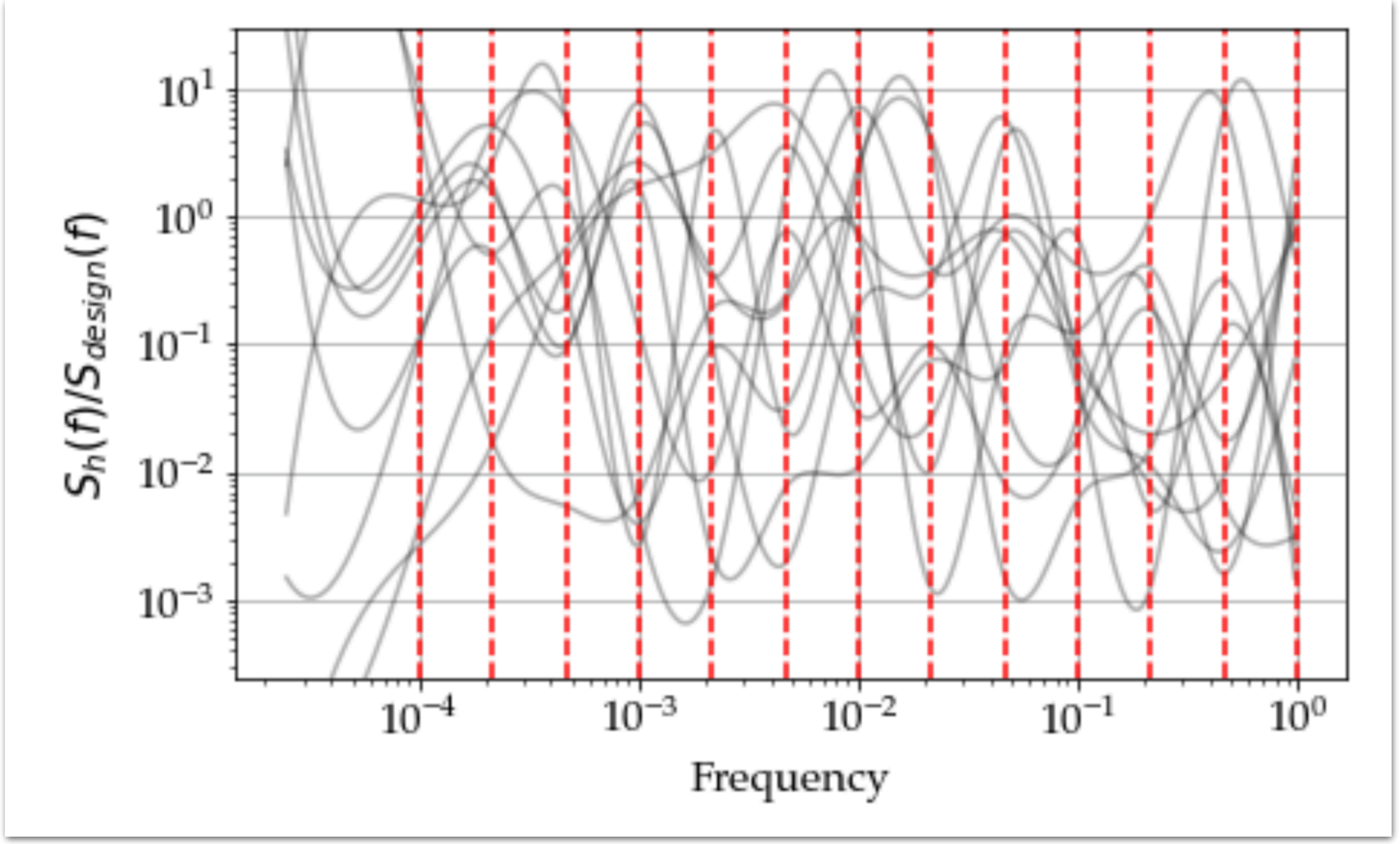
- We use splines to model the noise uncertainty **generic, slowly varying, fluctuations in the PSD and CSD**

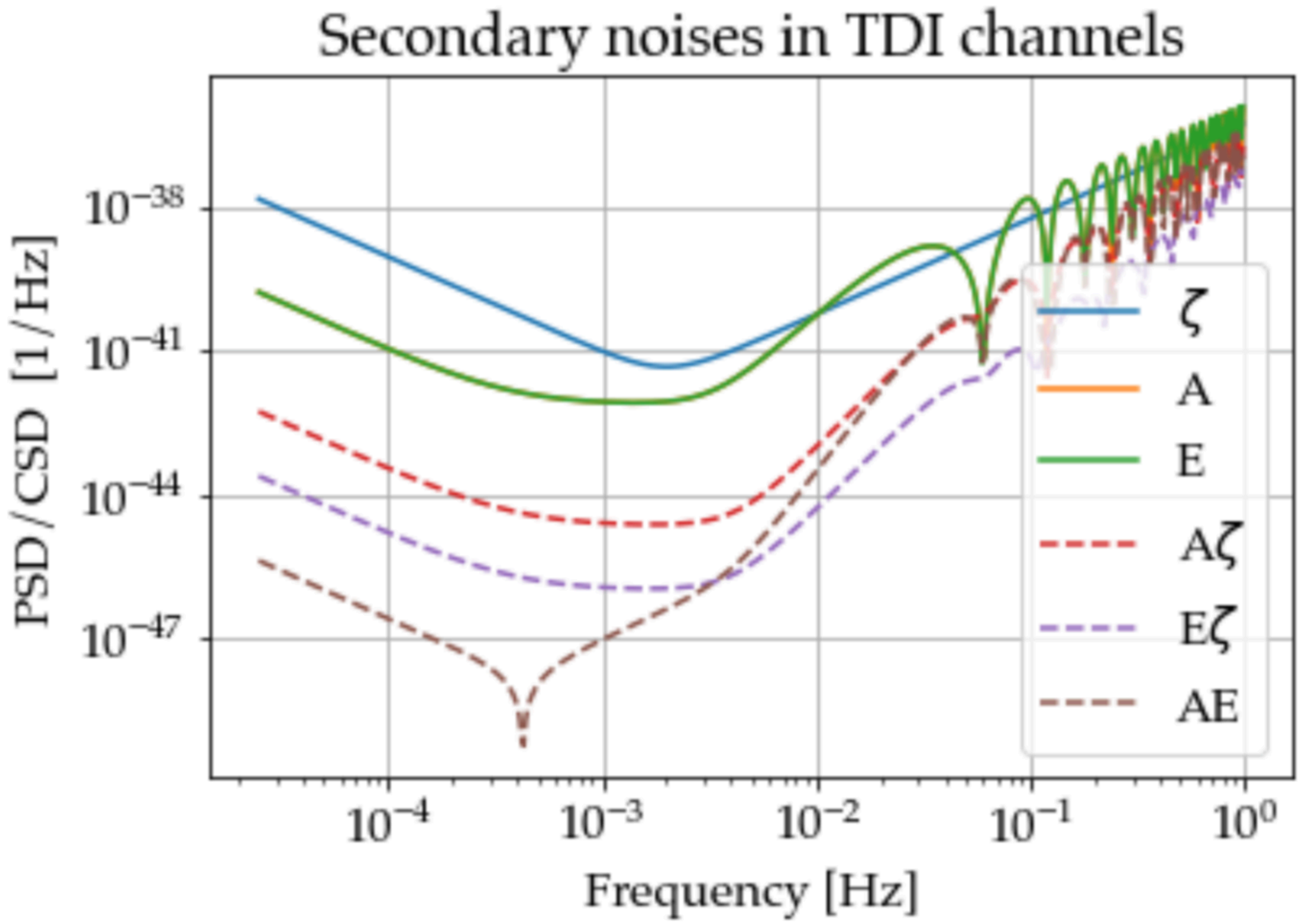
- We consider **templates** for SGWB

- We look for optimal TDI combinations to do the analysis (See M. Lilley talk)

$$S(f) = S_{ref}(f)10^{C(f,w,k)}$$

  - *k are 13 equally spaced knots*
  - *w are the weights*
  - *1 order of magnitude variation in the PSD/CSD*
  - *f is the frequency*




Secondary noises in TDI channels

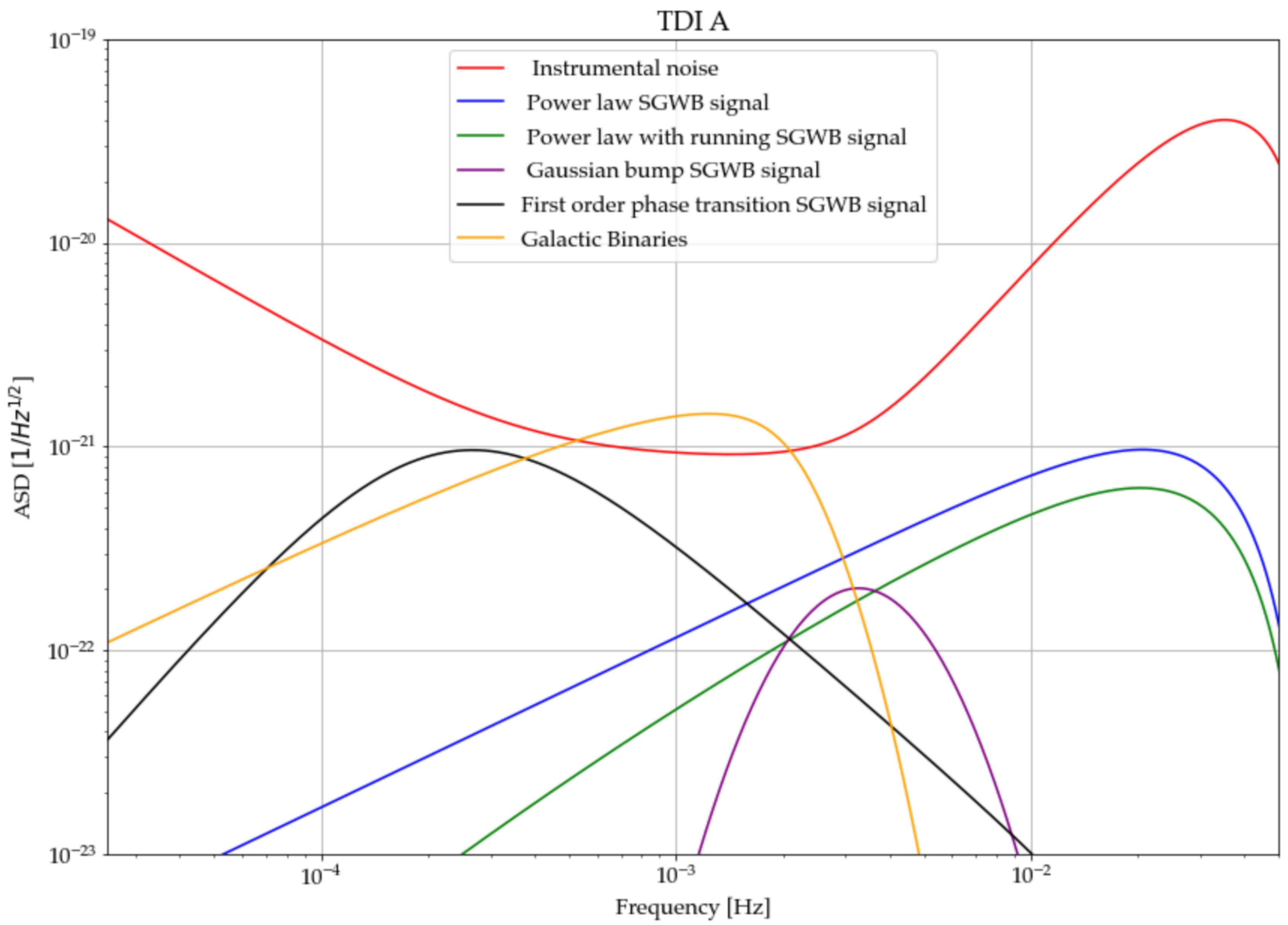
**Source: Muratore, Gair and Speri, in preparation*

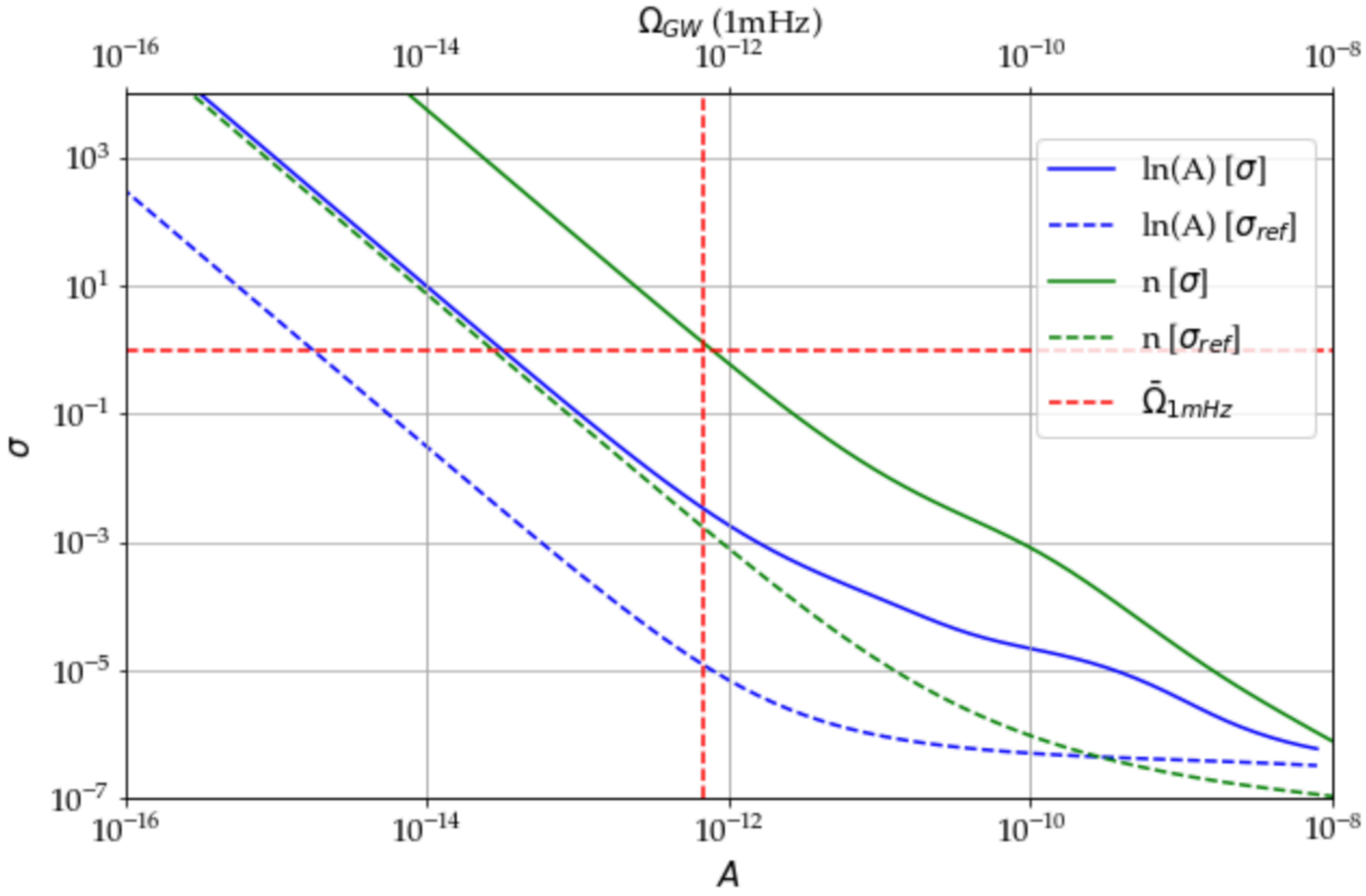
Power law SGWB from sBHB binaries with SNR 43 with 4 years of data

$$h^2\Omega_{GW}(f) \approx \underbrace{6.9 \times 10^{a}}_{\mathbf{A}}\left(\frac{f}{f_p}\right)^{n}$$

With a = -13, $n = 2/3$ *and* $f_p = 0.003Hz$

* Source: LISA Redbook





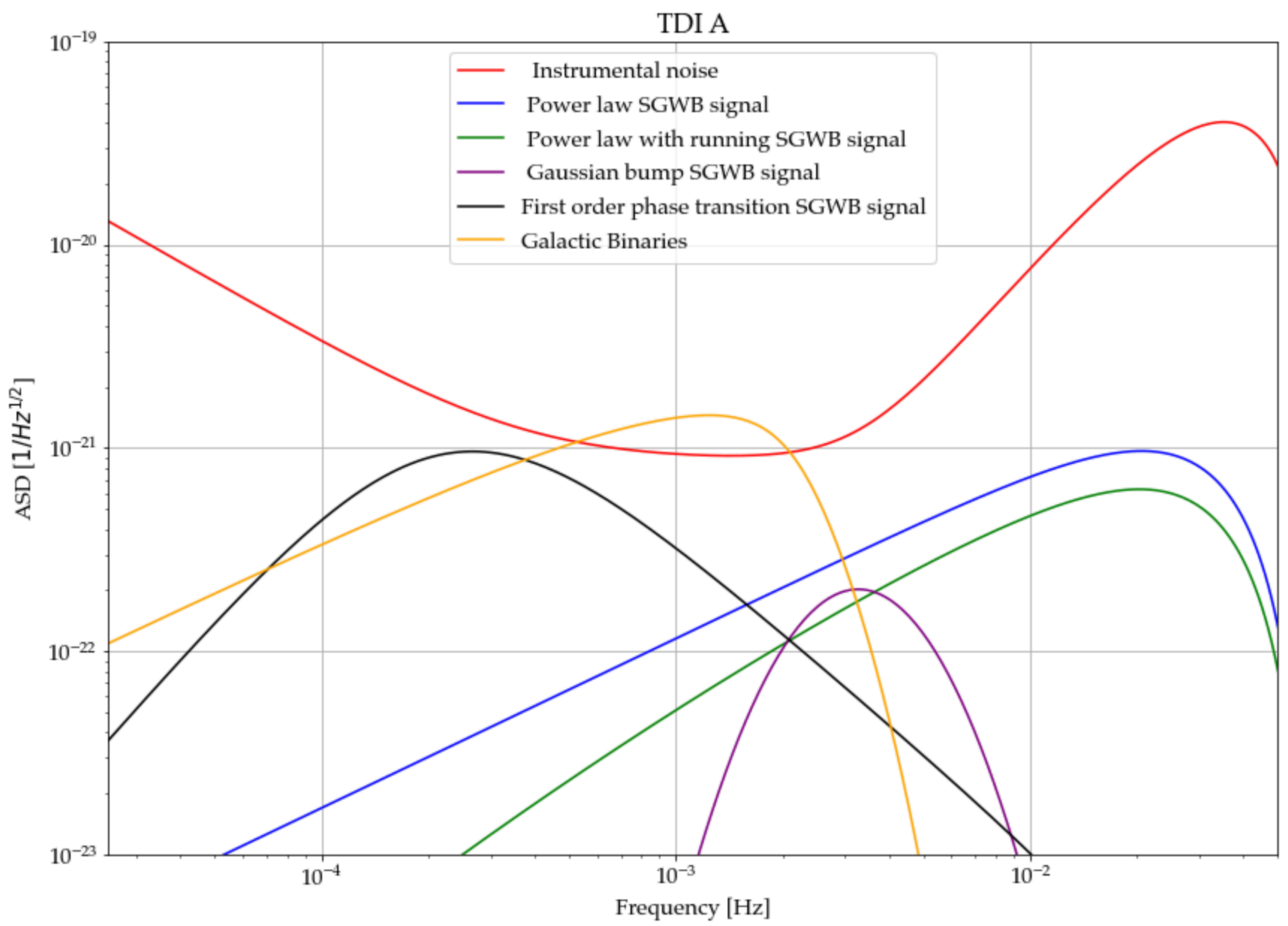
PRELIMINARY

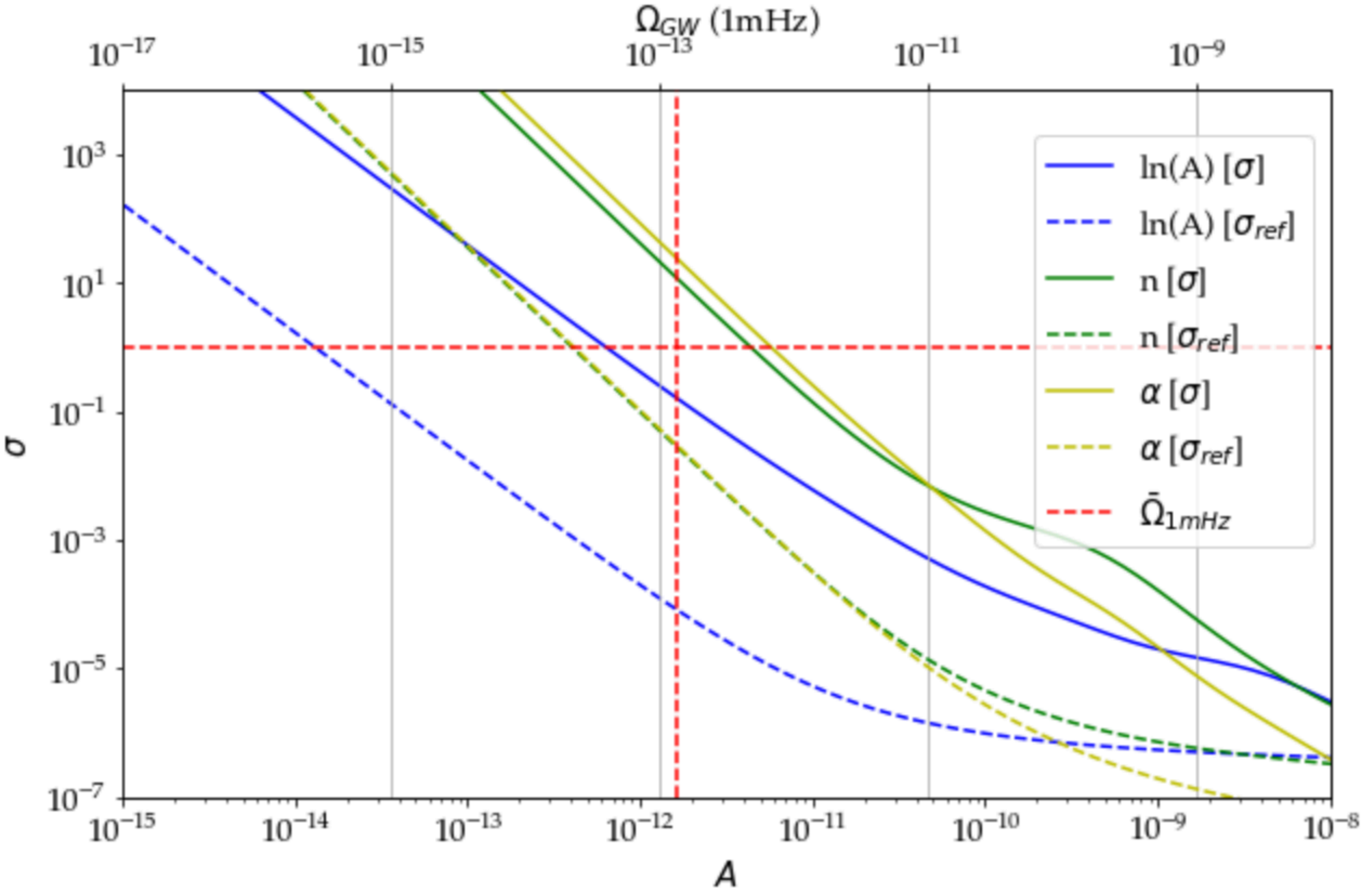
Power law with running (non-standard inflation) SNR 14 with 4 years of data

$$h^2\Omega_{GW} = \overset{A}{\boxed{10^{a}}}\left(\frac{f}{f_p}\right)^{n+\alpha\times ln(\frac{f}{f_p})}$$

With $n = 1$, $\alpha = -0.1$ and $f_p = 0.003Hz$

* Source: C. Caprini notes





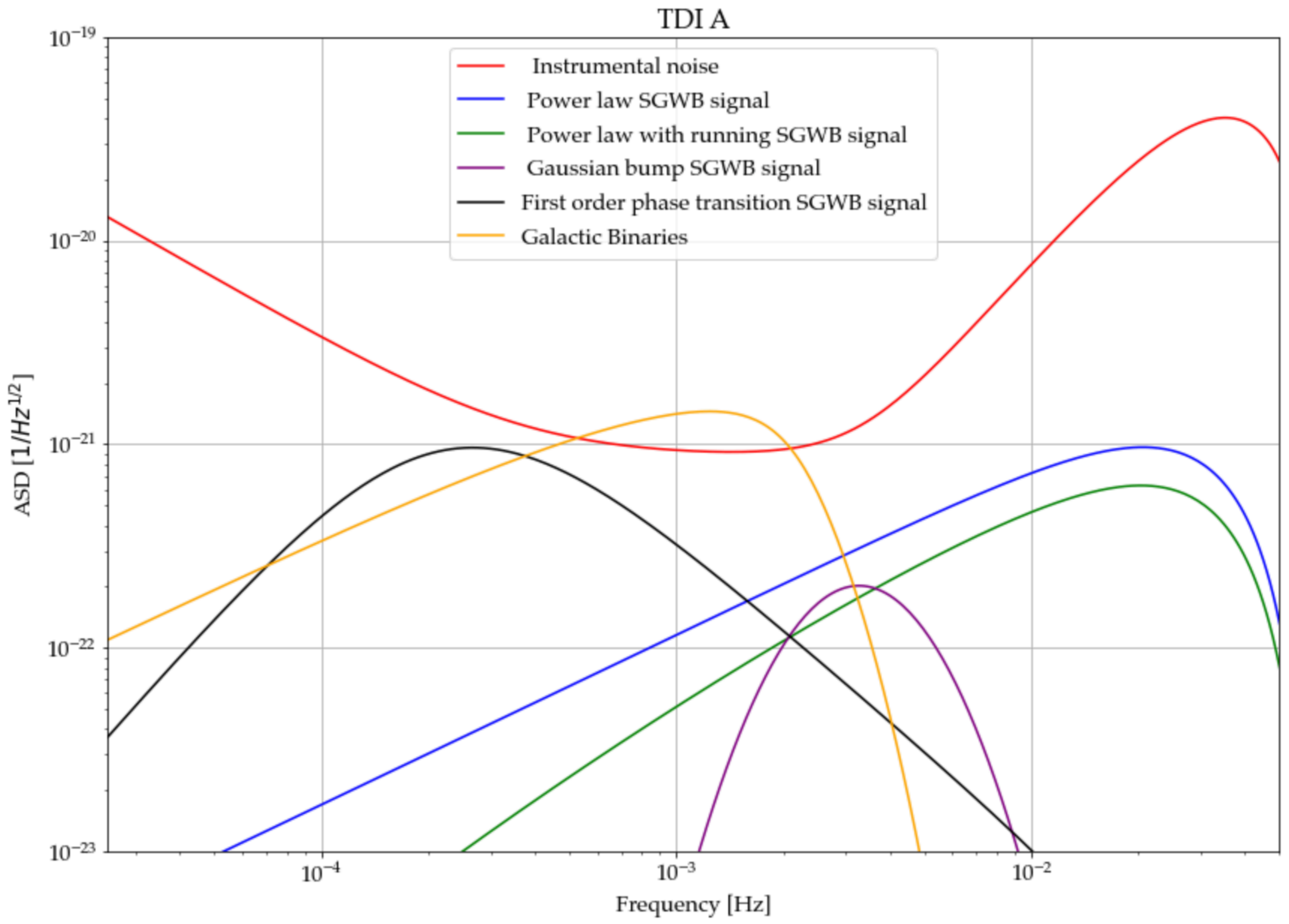
PRELIMINARY

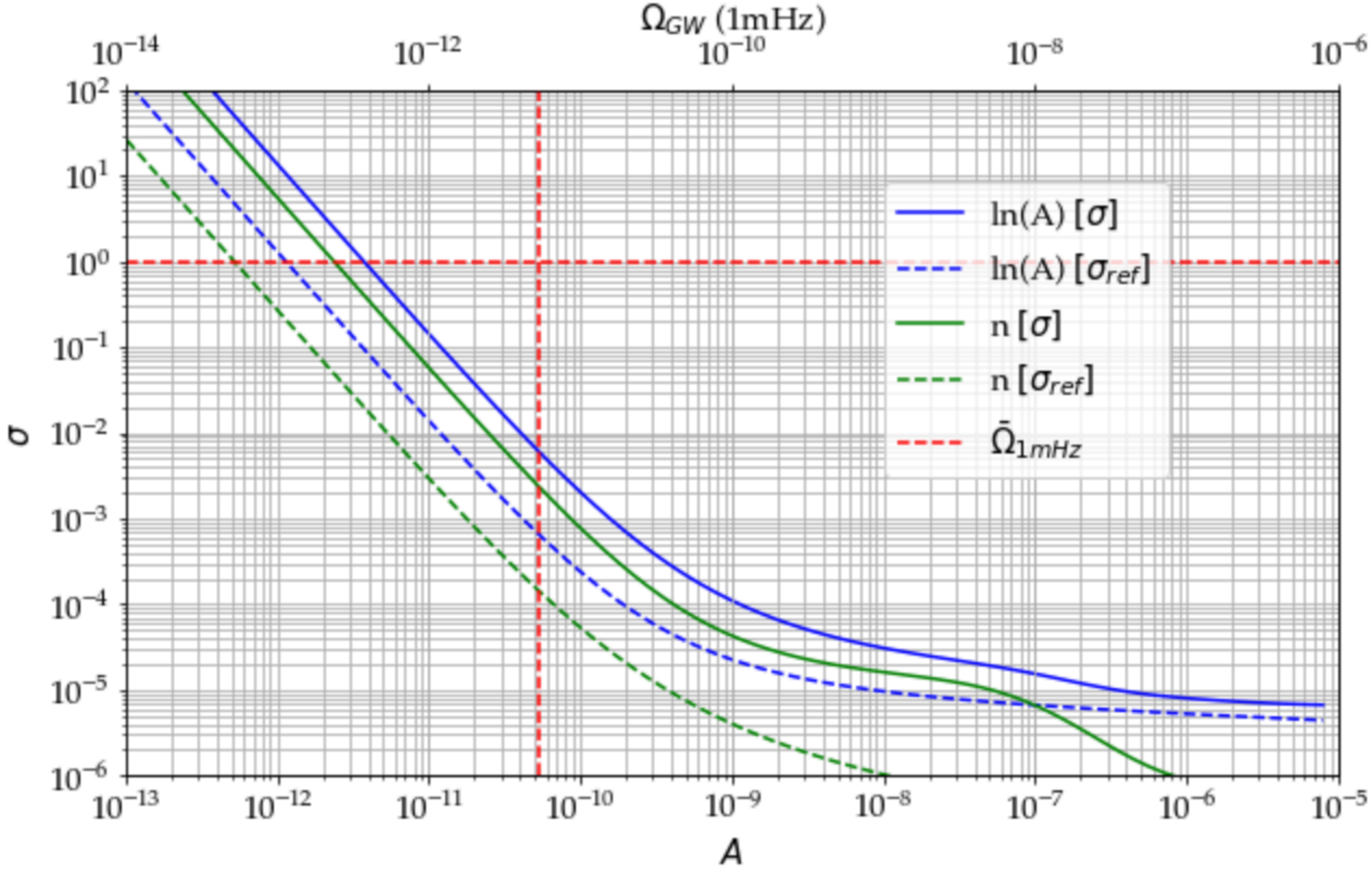
First order phase transition with SNR 119 with 4 years of data

$$h^2\Omega_{\rm PT}(f) = \overset{A}{\boxed{h^2\Omega_p}}\left(\frac{f}{f_p}\right)^3\left(\frac{7}{4+3\left(\frac{f}{f_p}\right)^2}\right)^{n}$$

With $n = 7/2$, $h^2\Omega_p = 10^{-10}$ *and* $f_p = 2\times 10^{-4} Hz$

* Source: LISA Redbook





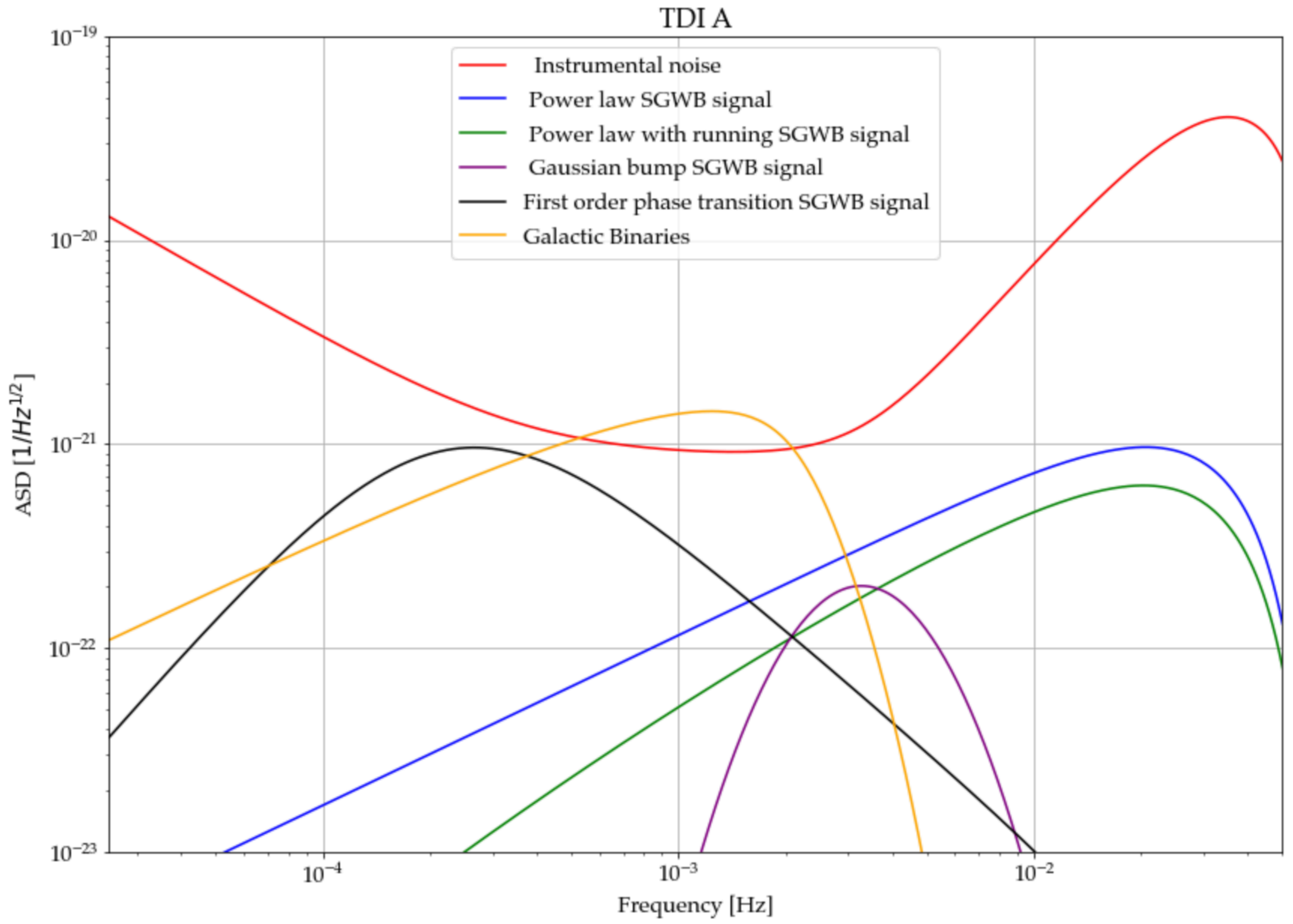
PRELIMINARY

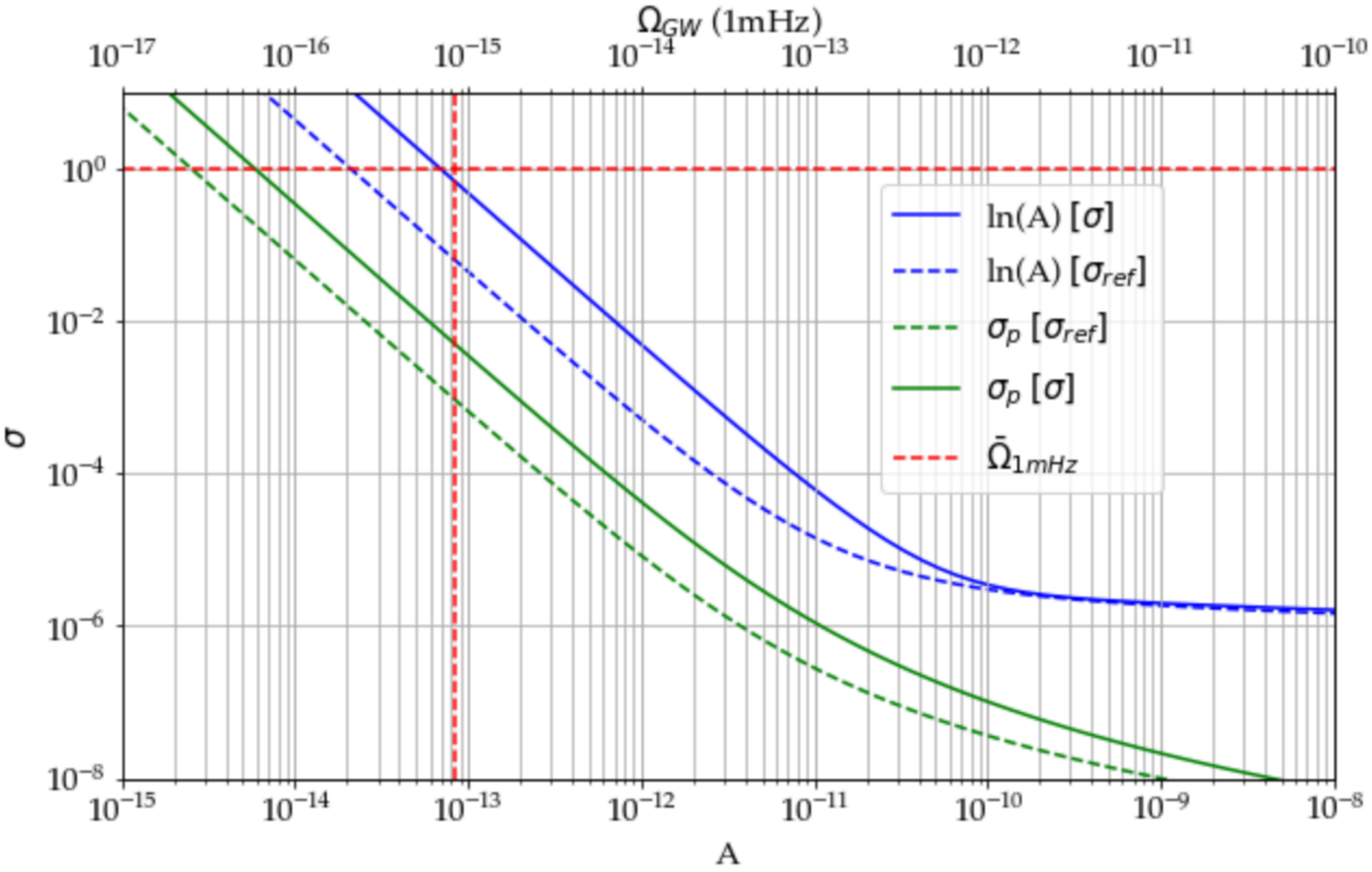
Gaussian bump (primordial BHs generation) with SNR 13 with 4 years of data

$$h^2\Omega_{GW} = \overset{A}{\boxed{10^a}} e^{-\frac{1}{2\sigma^2} ln(\frac{f}{f_p})^2}$$

With $a = -12.48$, $\sigma = 0.3$ and $f_p = 0.003Hz$

* Source: C. Caprini notes

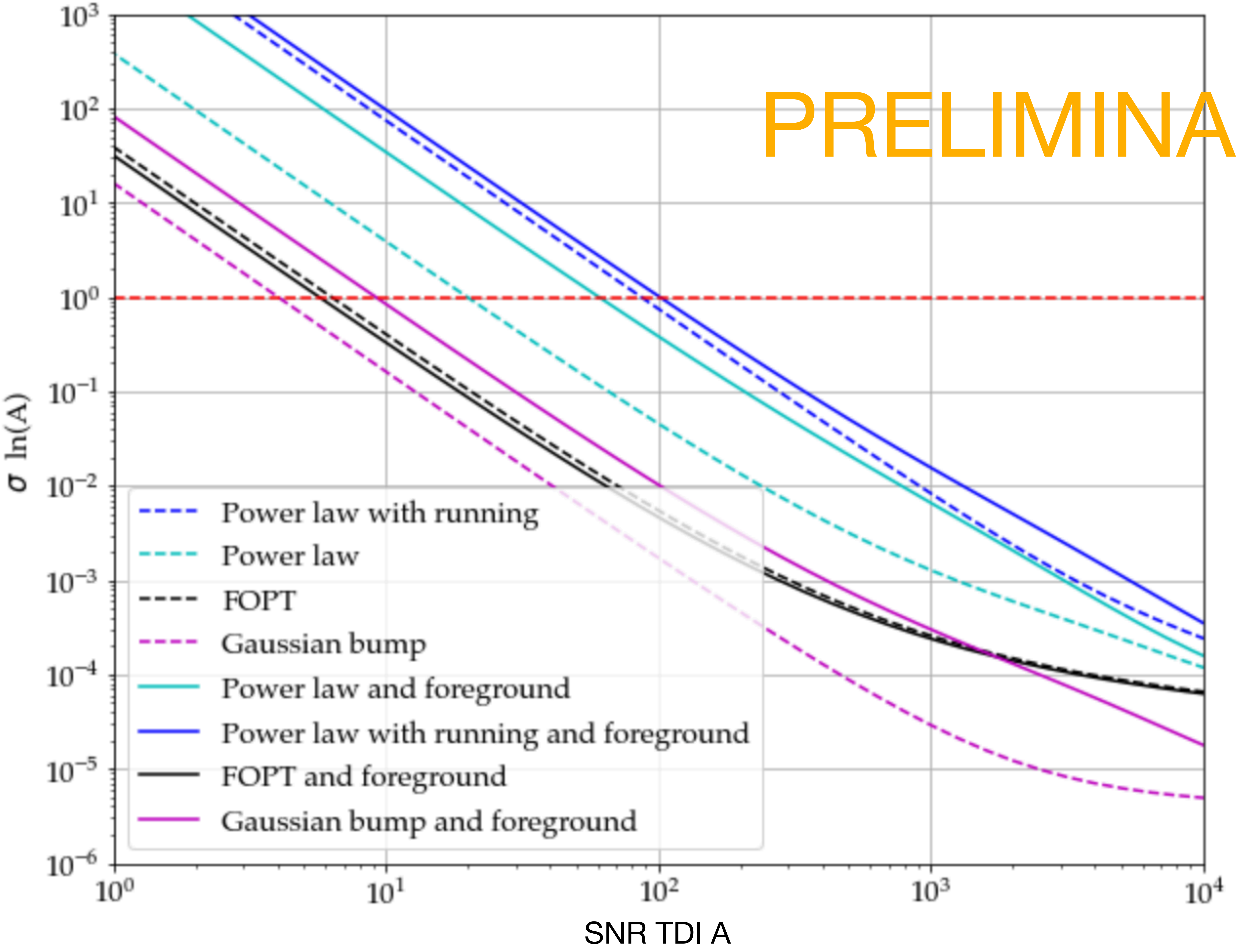


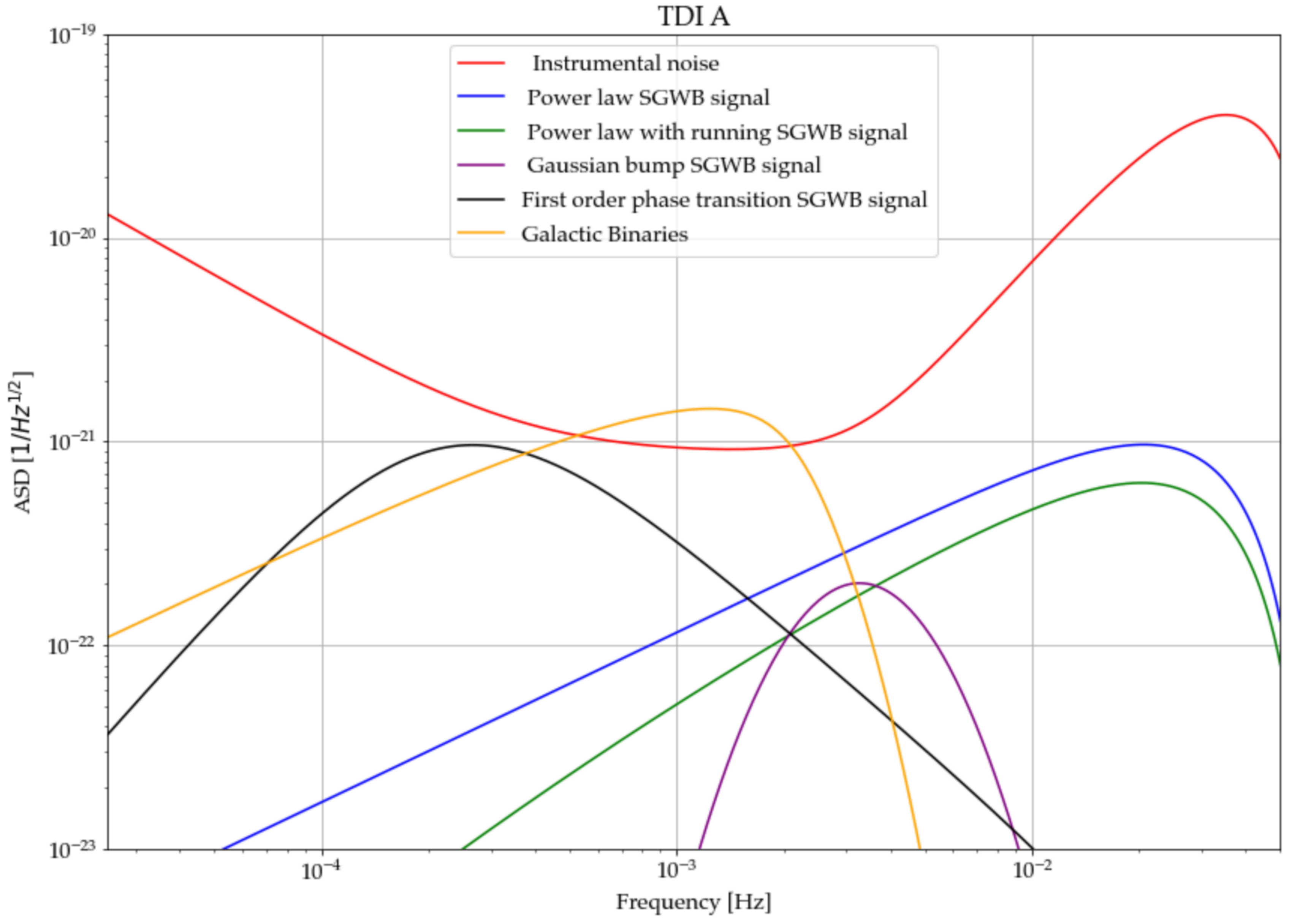


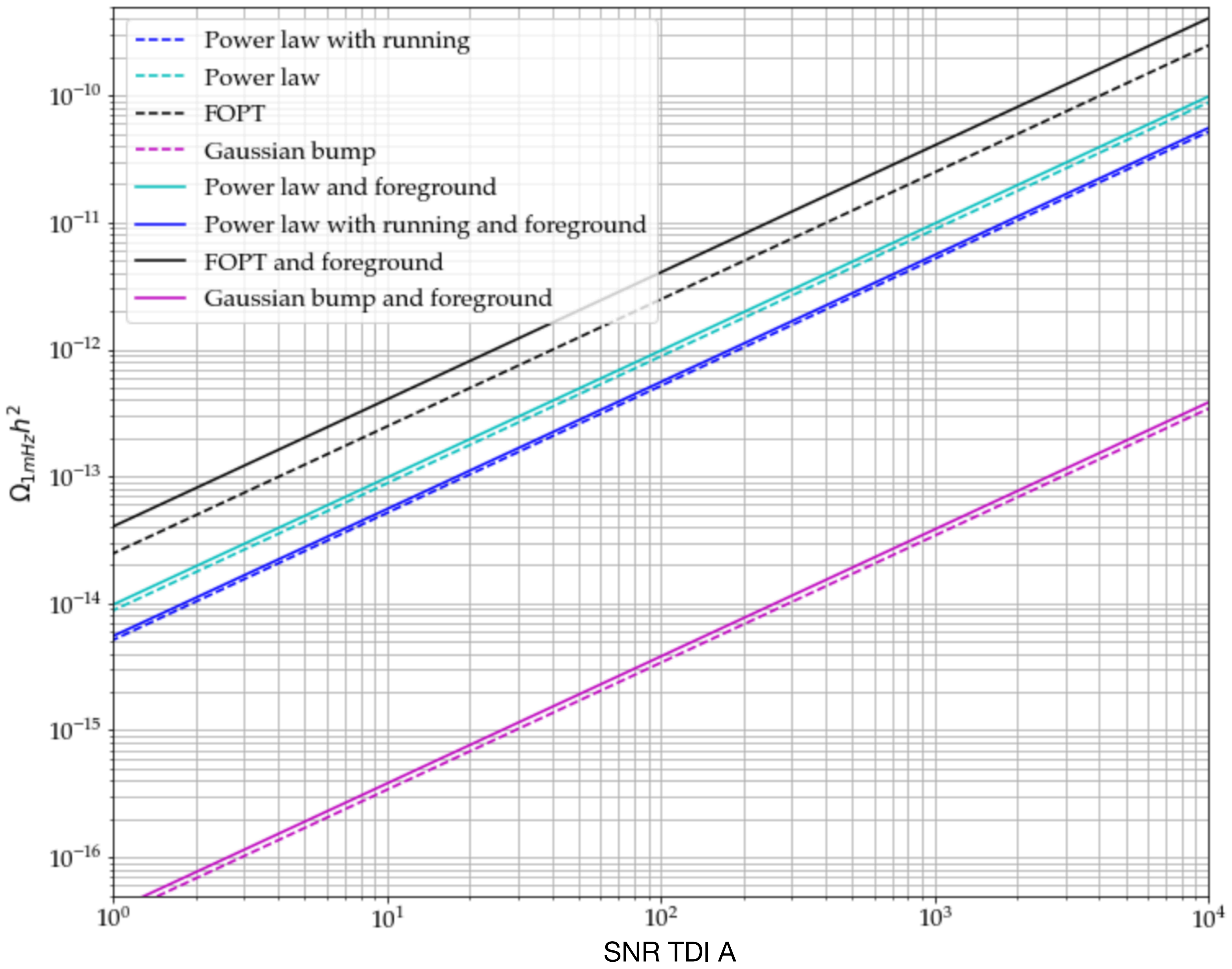
PRELIMINARY

SNR TDI A vs. σ and SNR TDI A vs. energy density

PRELIMINARY







Conclusion and few ‘’caveats”

- Things ***are measurable*** as we are allowing **generic, slowly varying, fluctuations in the PSD and CSD**

- We have **modelled SGWBs**

- We don't know for sure that those assumptions are valid. So, **would be challenging to claim a detection of an SGWB.**

Future activities

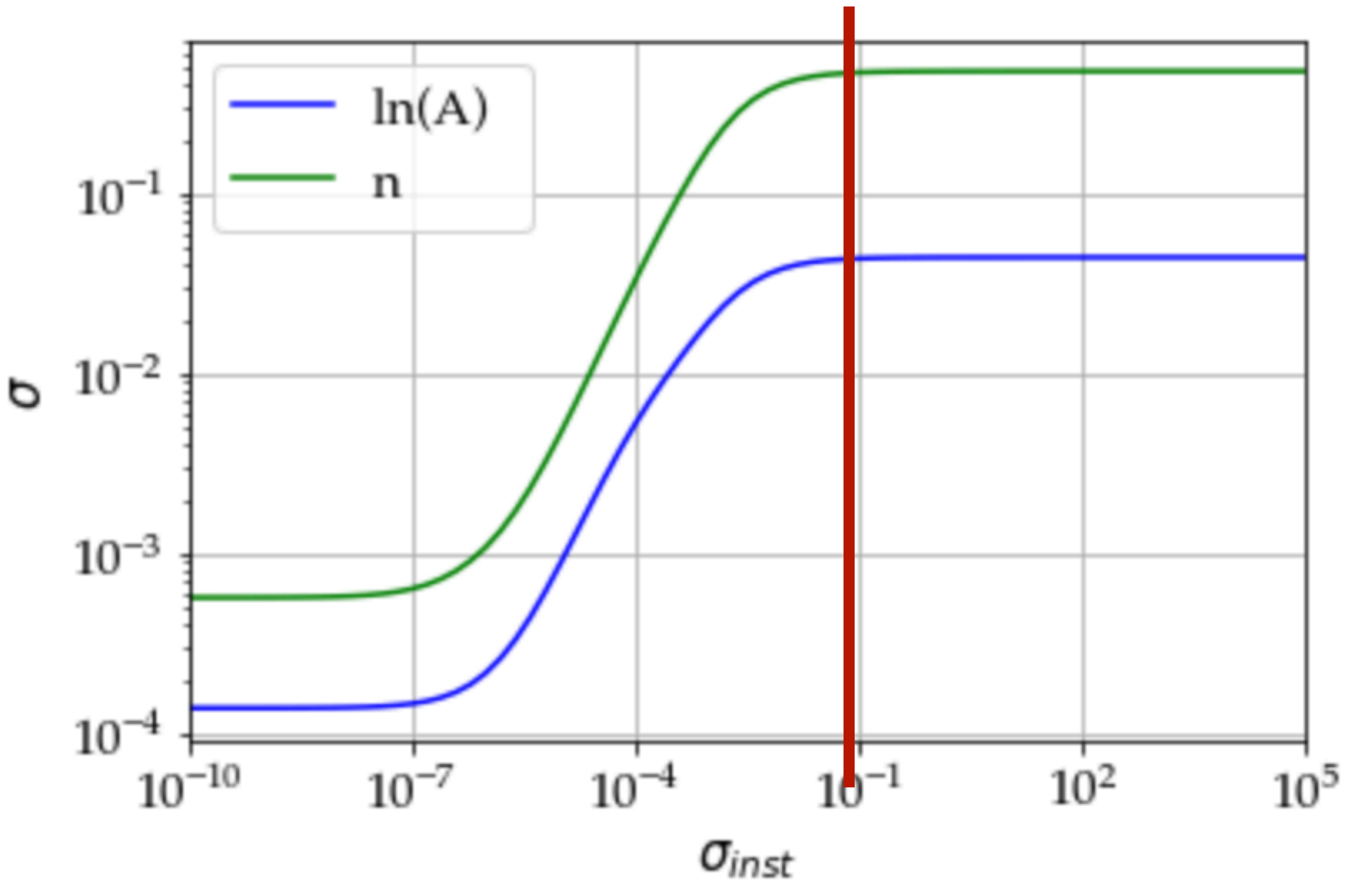
- Studying the case of **un-modelled SGWB** (more likely PE precision will be degradated)

- Need a **more flexible noise model**: the current model for the CSD (for instance) would not be suitable to use when analysing the data

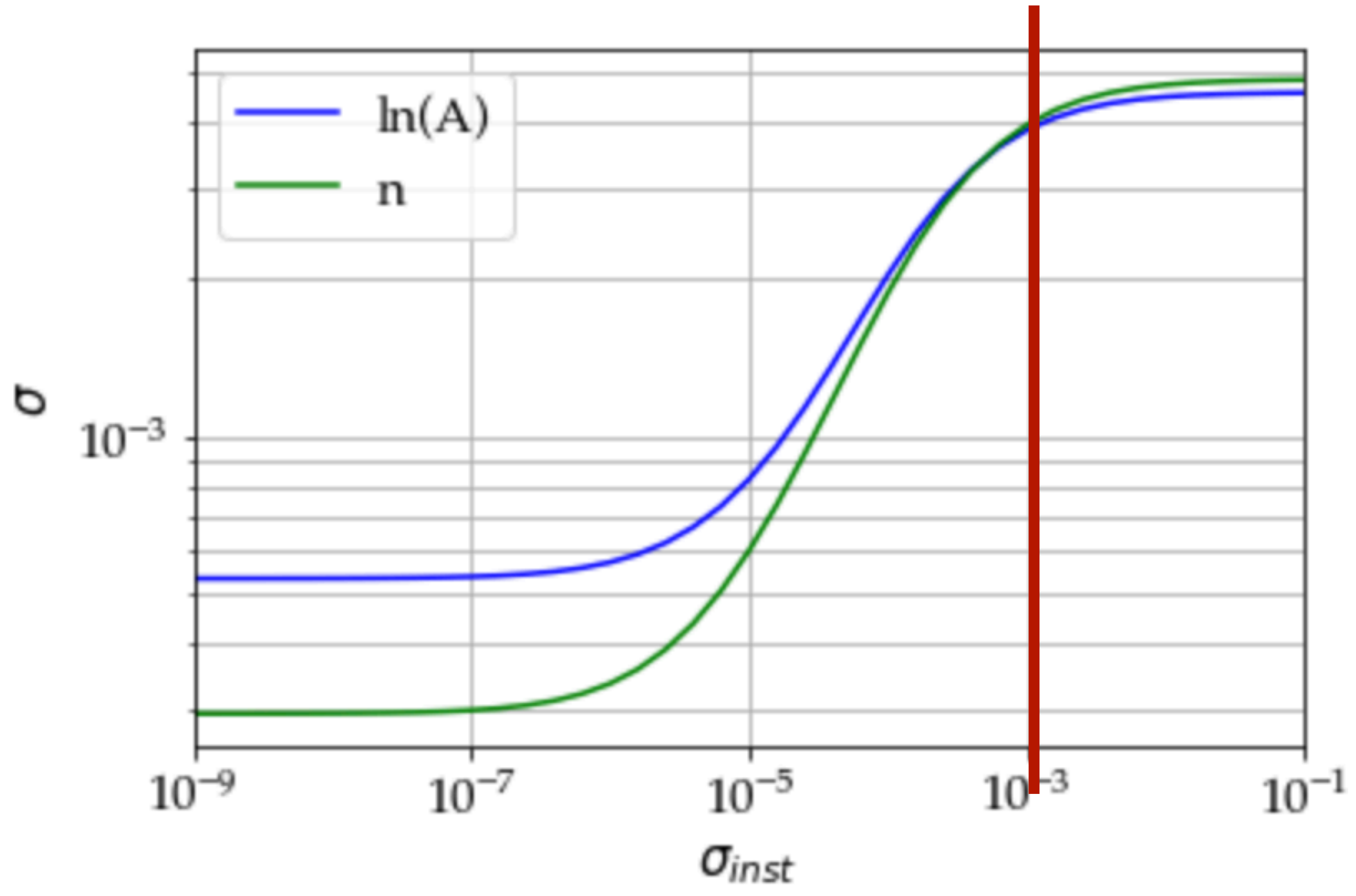
- Longer term plans is **finding** (and implementing) **the best way to model noise uncertainties** in the framework of LISA data analysis and global fit

Varying the prior uncertainty on the spline weights

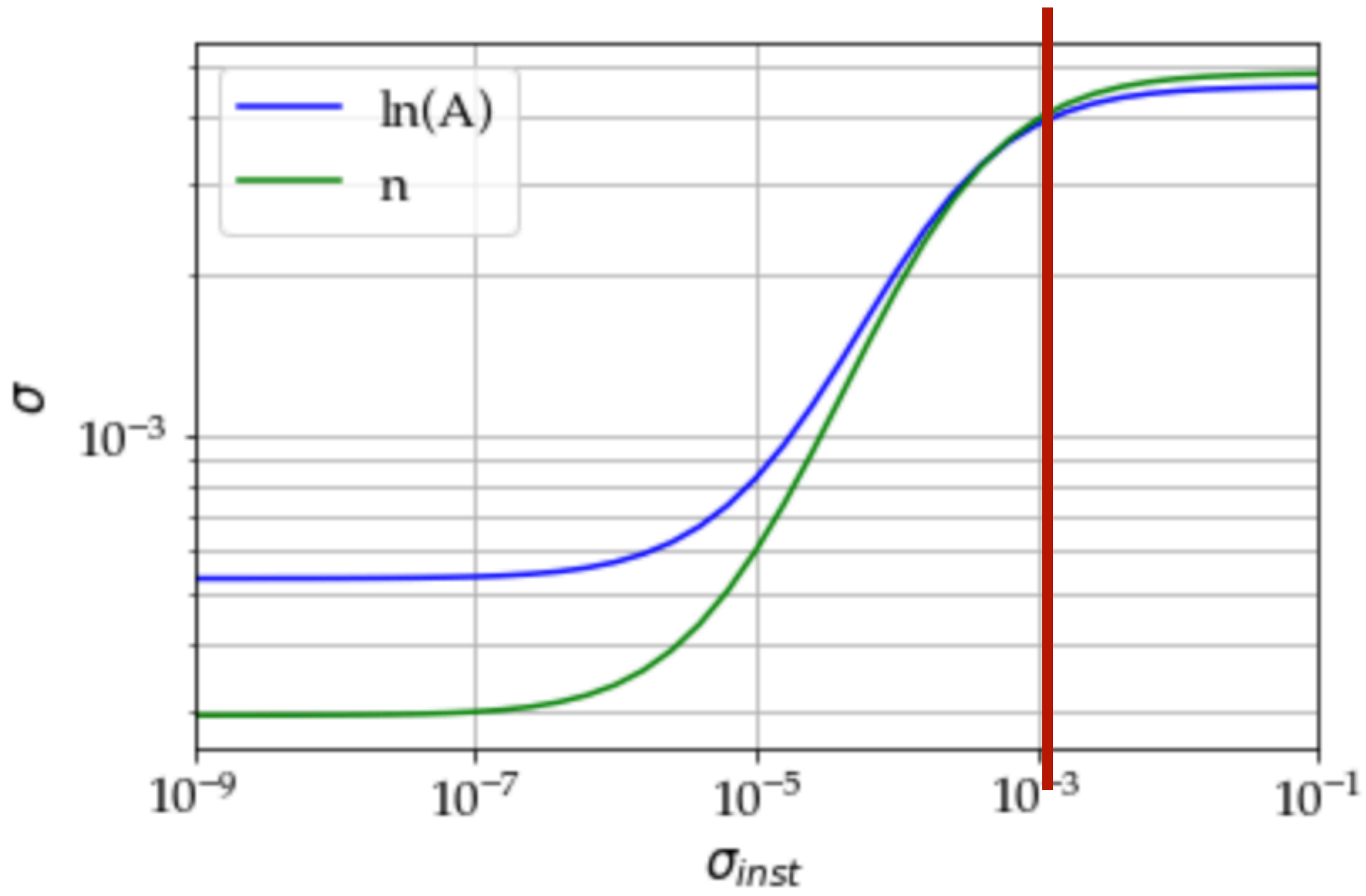
Power law



First order phase transition



Power law and Foreground



- To which accuracy we need to get to constrain the models (SNR = 100) ?

Measurement principle

Beam Propagation

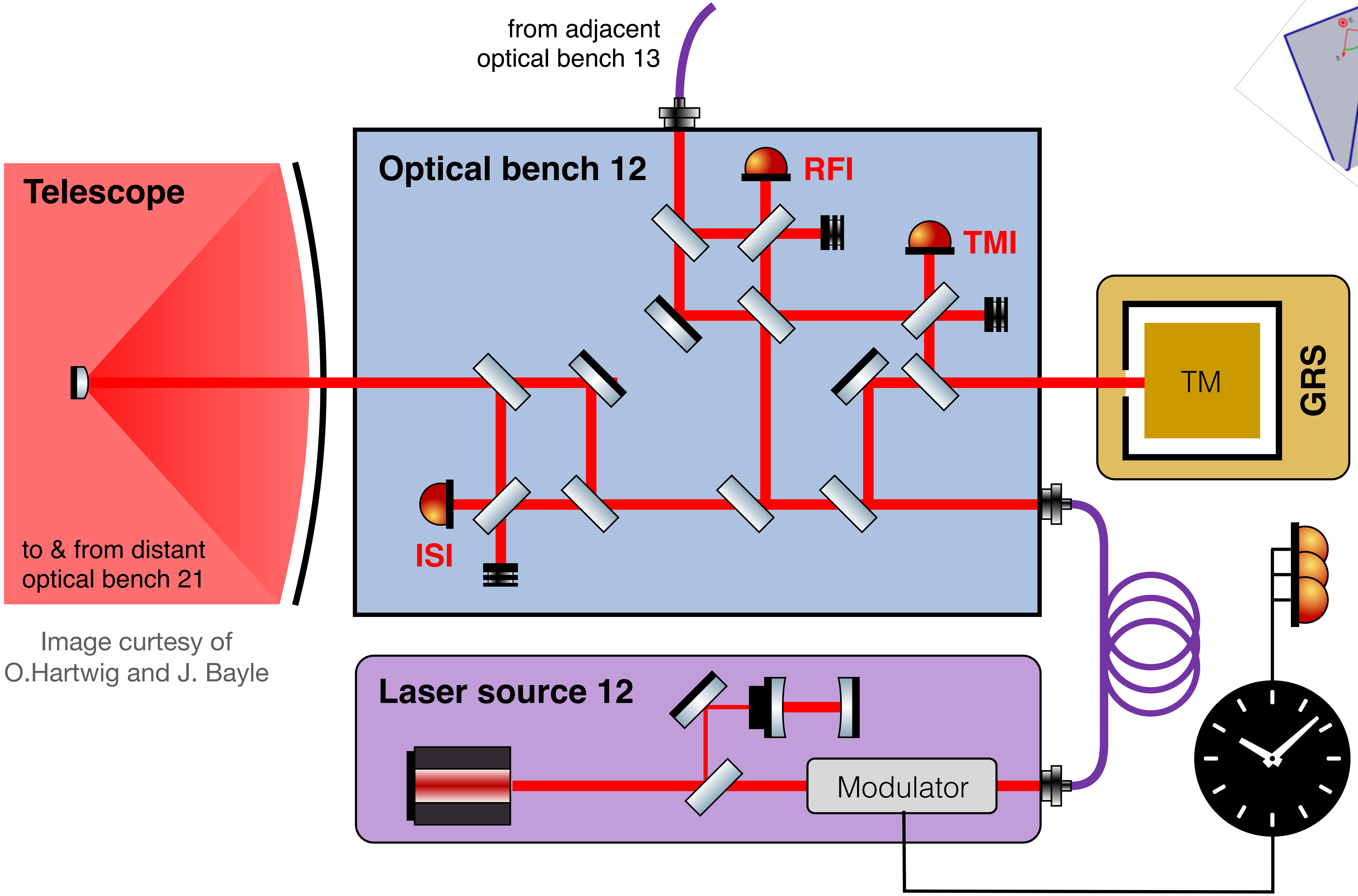
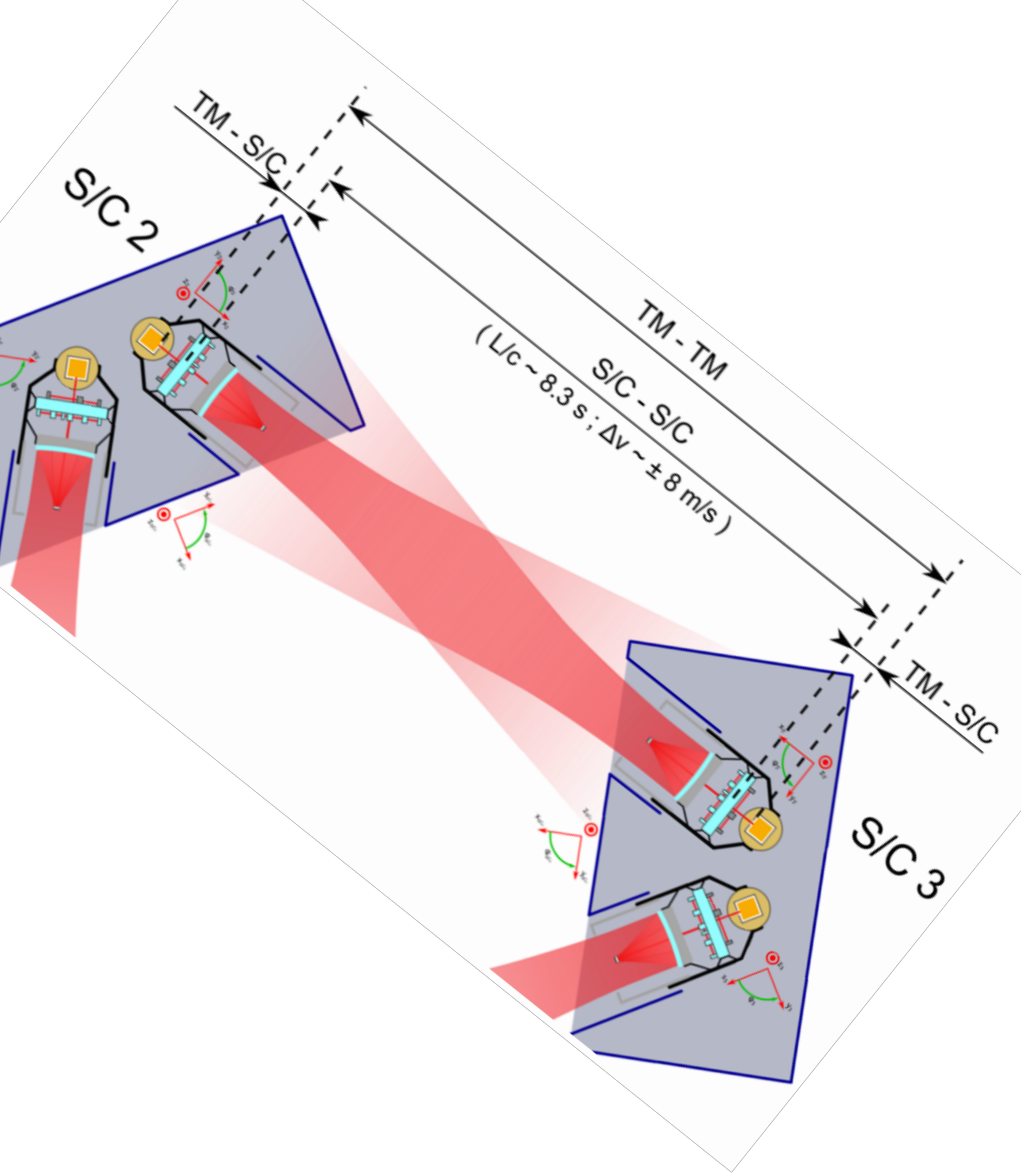
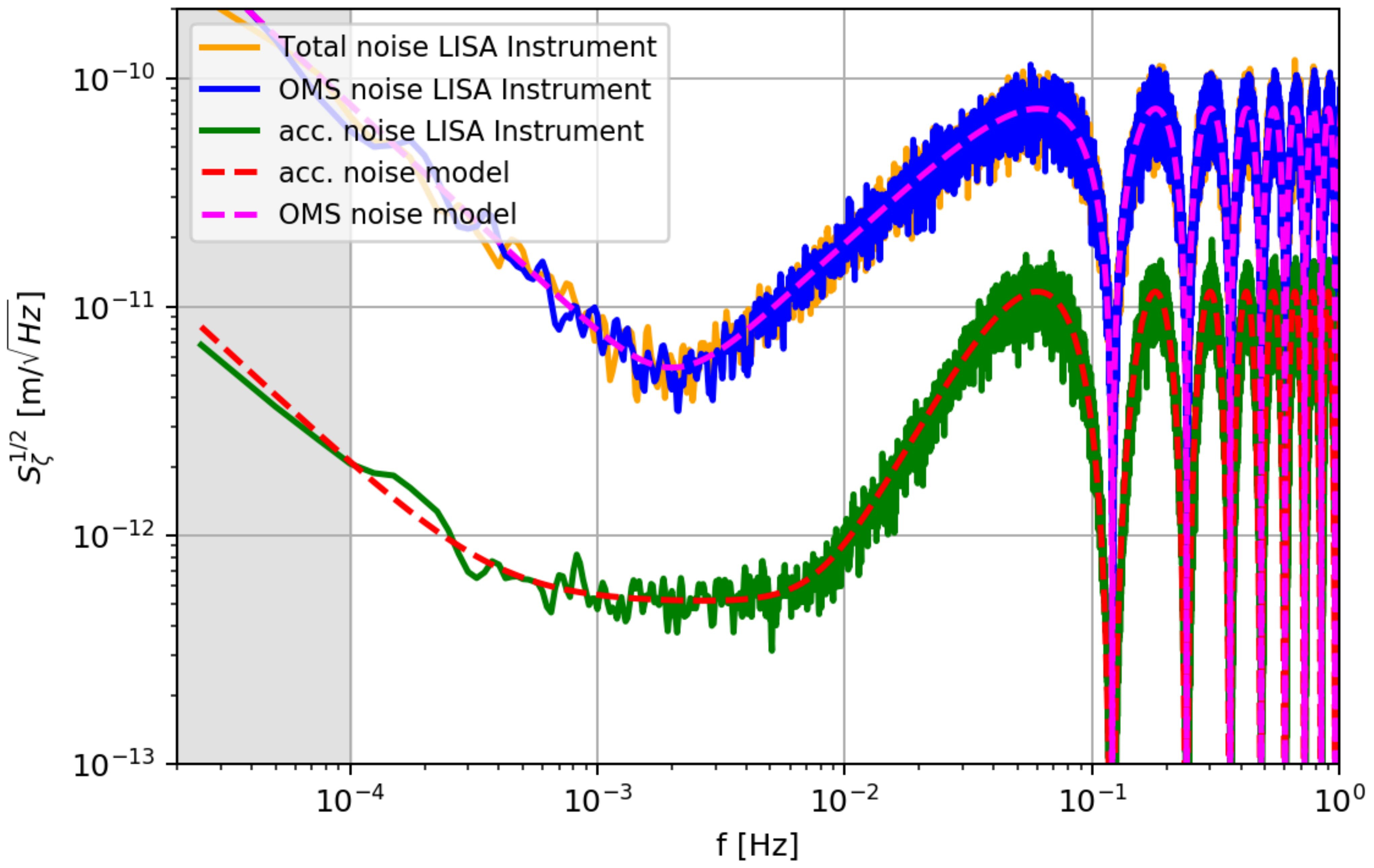


Image curtesy of
O.Hartwig and J. Bayle



Secondary noises in the TDI channels

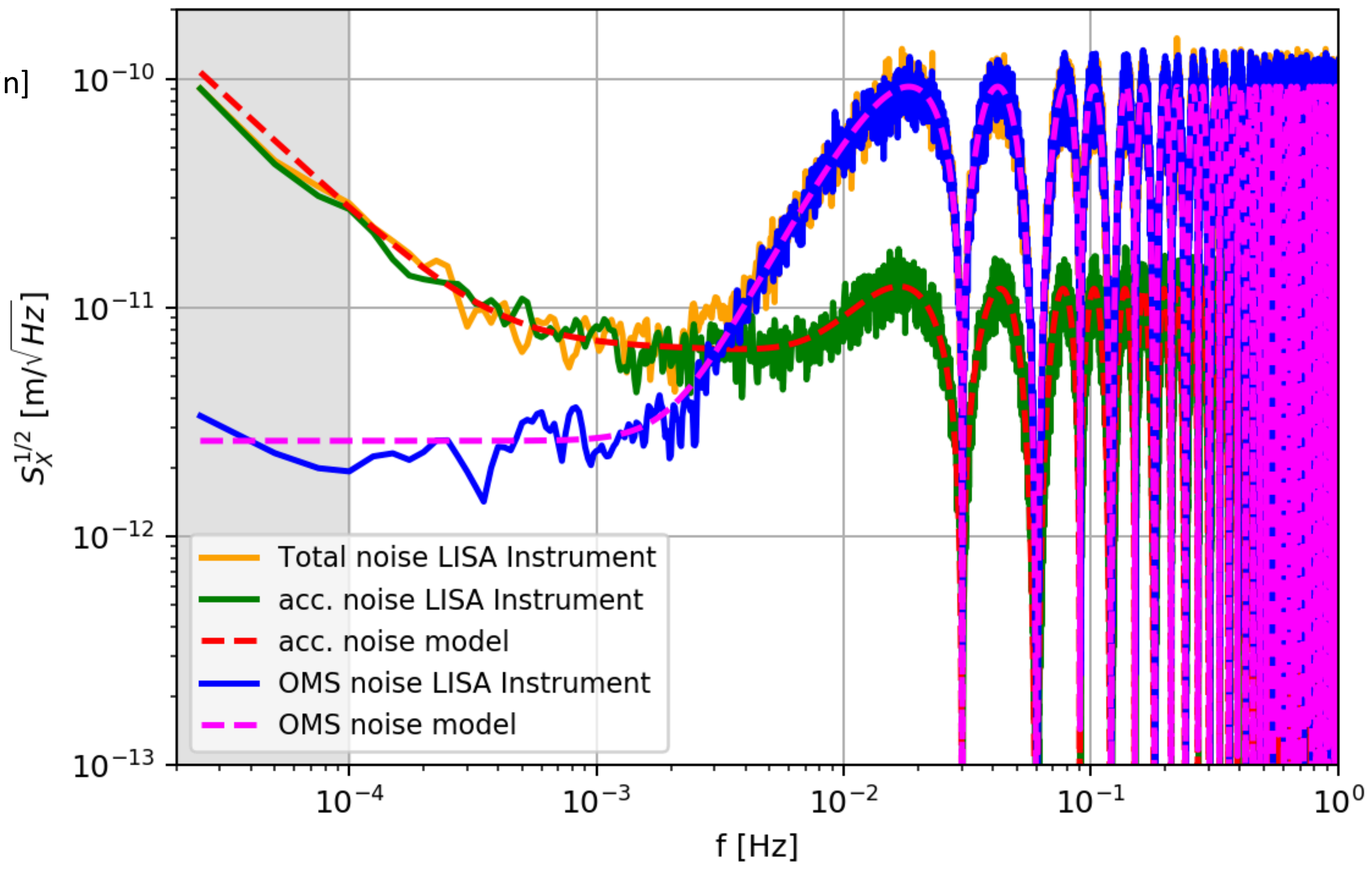
Null channel



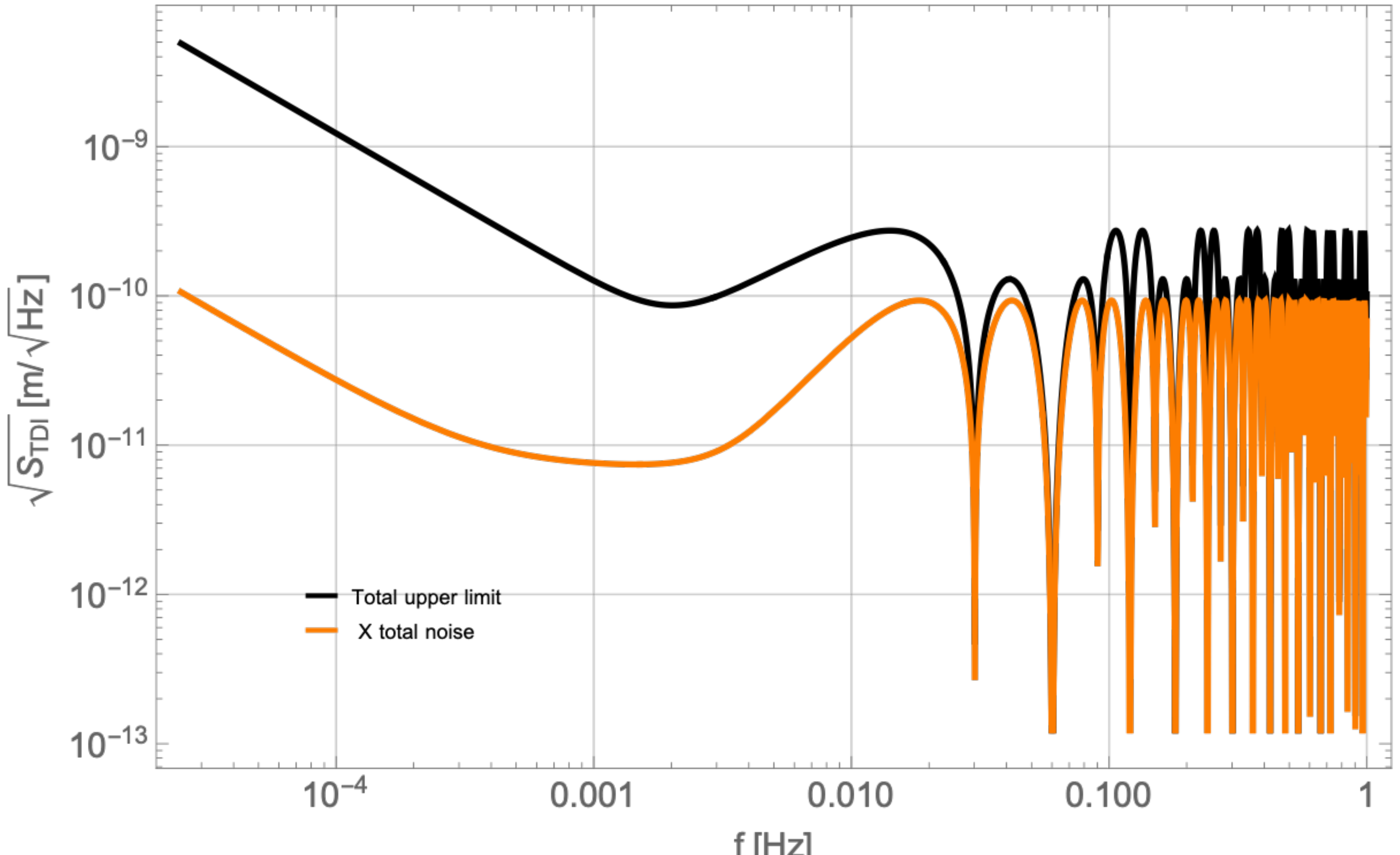
Credit: LISA Instrument [Bayle, Jean-Baptiste, Hartwig, Olaf, & Staab, Martin]

Muratore et al. On the effectiveness of null TDI channels as instrument noise monitors in LISA, eprint : 2207.02138

Sensitive channel

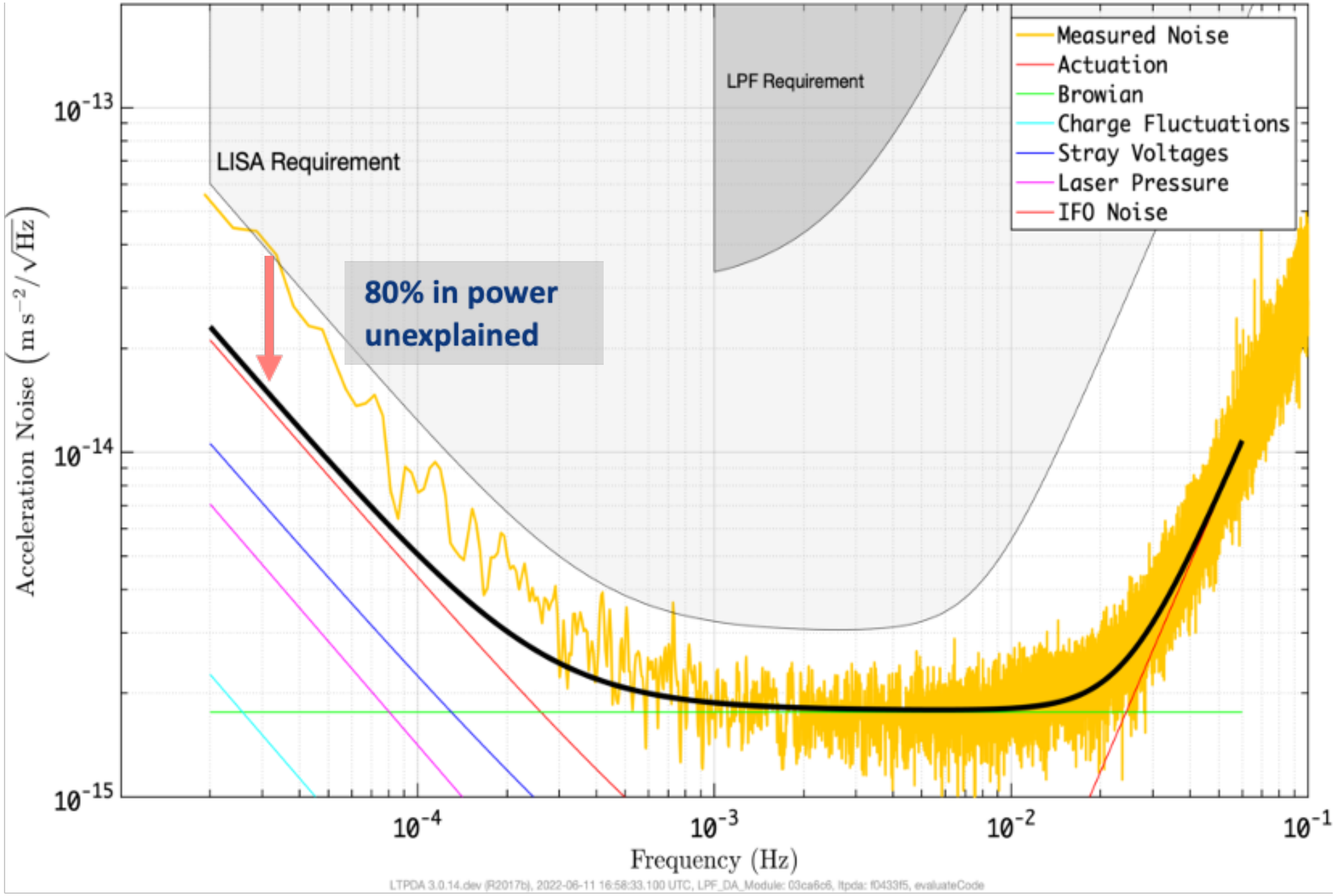


We will not know the instrumental noise but generally **we can‘‘establish”un upper-bound**



We can report a **measured spectral density in all channels** and translate that into an **upper limit on the SGWB amplitude**

Pre-flight modelling LISA Pathfinder: Modeled forces do not fully explain noise



80% in power unexplained

- Various key parameters of the LISA noise (**DC residual forces, magnetic field gradients, residual stray electrostatic fields, optical alignments, among others)**, are all designed to be ideally zero
- but with uncertainties that make their residual contribution **both difficult to predict and likely different among the different LISA TM or optical readouts**
- Existing noise model consists of many components which depend on physical parameters which cannot be measured directly (e.g., the Brownian force noise or the optical interferometry shot noise)

Muratore et all, On the effectiveness of null TDI channels as instrument noise monitors in LISA e-Print: 2027.02138