

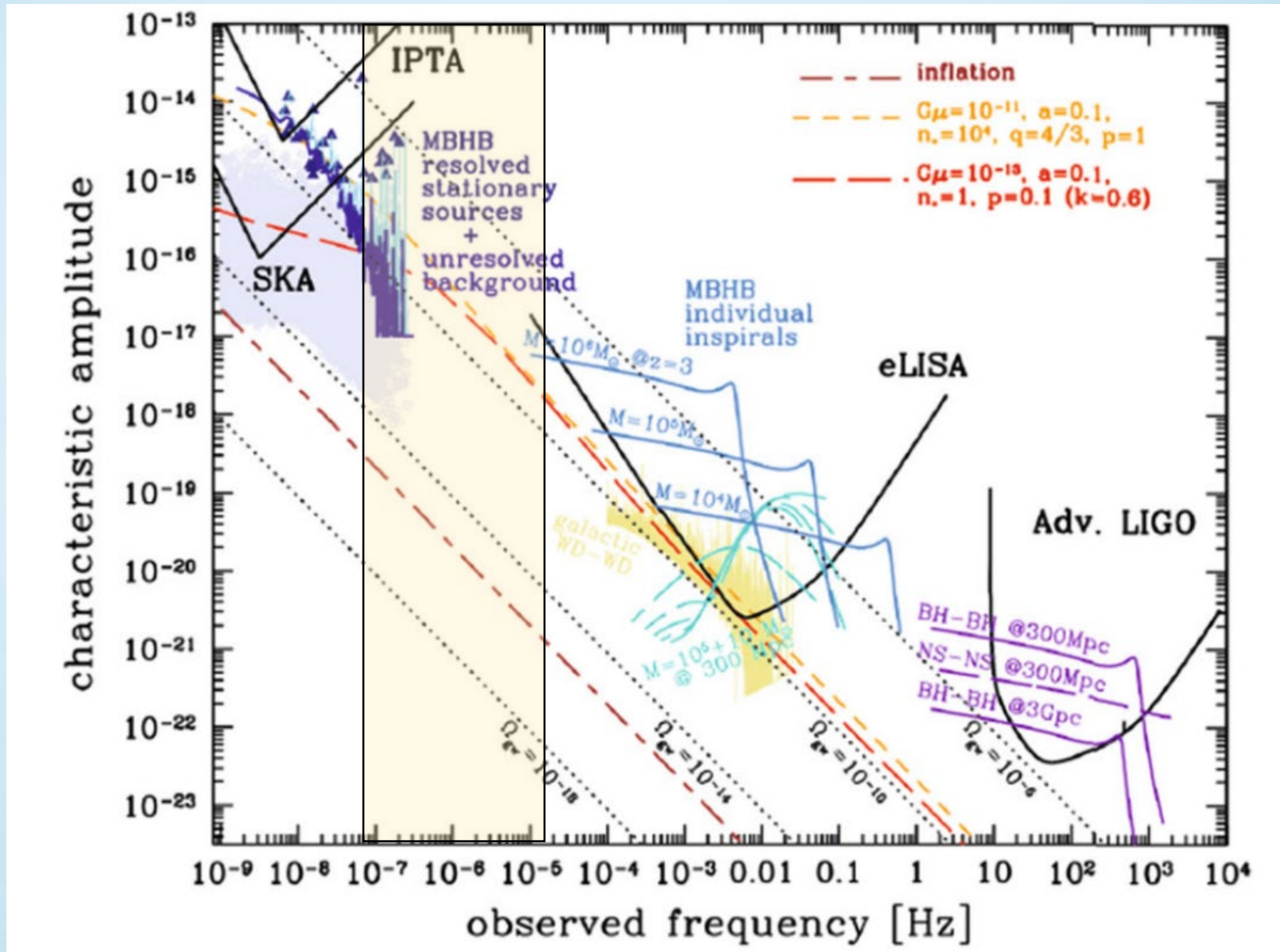
uHz gravitational wave searches

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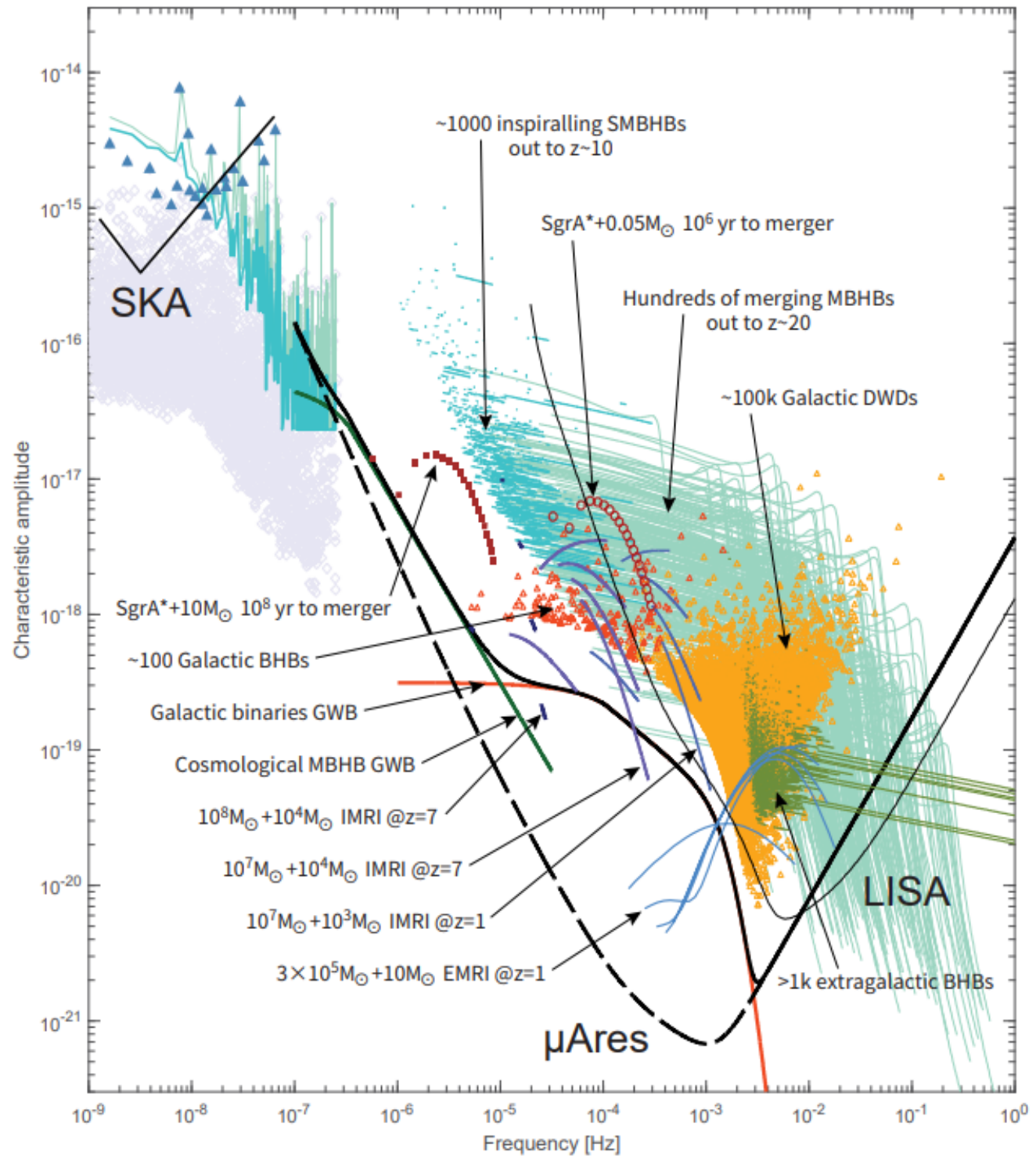
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Something for uHz?



The μ Ares detection landscape



Sesana et al., 2019
In Voyage 2050 white paper

Two key question:

Can we fill the uHz gap to see the full merger processes of SMBHBs? SMBHB at high Z . From PTA to LISA?

Where are the seeds of SMBHs controlling the cosmic structure formation (MBH)? Can we really probe those low mass BHs?

How? Do we need to wait until have a laser interferometer in the Martian orbit?

Yes --- Expected to be very sensitive and need to be patient

No --- Can we do it easier?

Coherent radar for GW searching?



$$\frac{S}{N}_{\text{radiometer}} = 1.7 \times 10^{12} \frac{\eta}{0.1} \frac{P}{1 \text{ MW}} \left(\frac{D_{\text{recv}}}{100 \text{ m}} \right)^2 \left(\frac{t}{1 \text{ hr}} \right)^{\frac{1}{2}} \left(\frac{T}{35 \text{ K}} \right)^{-1} \left(\frac{B_i}{\text{kHz}} \right)^{-\frac{1}{2}} \left(\frac{R}{3.8 \times 10^8 \text{ m}} \right)^{-2}$$

$$\sigma_{\text{radiometer}} = \lambda / \sqrt{\text{SNR}_{\text{radiometer}}}$$



$$\sigma_{\text{radiometer}} = 28 \text{ nm} \left(\frac{\eta}{0.1} \right)^{-1/2} \left(\frac{P}{1 \text{ MW}} \right)^{-1/2} \left(\frac{D_{\text{recv}}}{100 \text{ m}} \right)^{-1} \left(\frac{t}{1 \text{ hr}} \right)^{-\frac{1}{4}} \left(\frac{T}{35 \text{ K}} \right)^{1/2} \left(\frac{B_i}{\text{kHz}} \right)^{\frac{1}{4}} \left(\frac{R}{3.8 \times 10^8 \text{ m}} \right)$$

How well we can detect GW?

GW sensitivity – distance measurement error transfer function

$$S_h(f) = \frac{1}{4} \frac{1}{R^2 \text{sinc}^2\left(2\pi f_{\text{GW}} \frac{R}{c}\right)} S_{\text{noise}}(f),$$

$$\sigma_h \equiv \sqrt{S_h(f) f} = \frac{1}{2} \frac{\sigma}{R} \frac{1}{\text{sinc}(2\pi f_{\text{GW}} R/c)}$$

$$\sigma_h = \frac{1}{2} \frac{\sigma}{R} = 1.3 \times 10^{-15} \left(\frac{\sigma}{\mu\text{m}}\right) \left(\frac{R}{3.8 \times 10^8 \text{m}}\right)^{-1} \quad \text{For } f < 0.5 \text{ Hz}$$

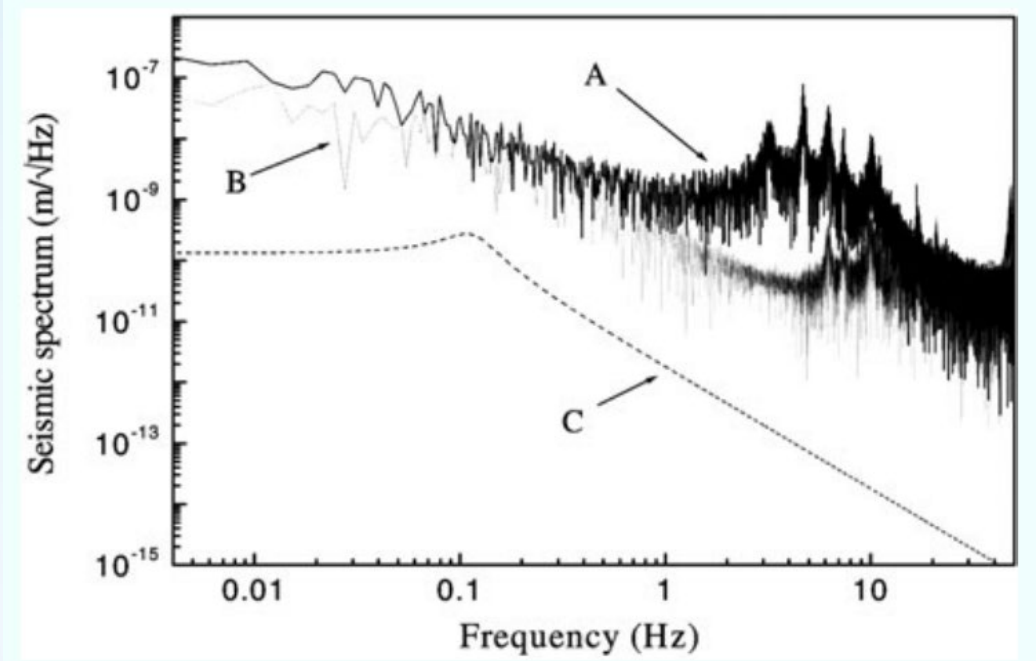
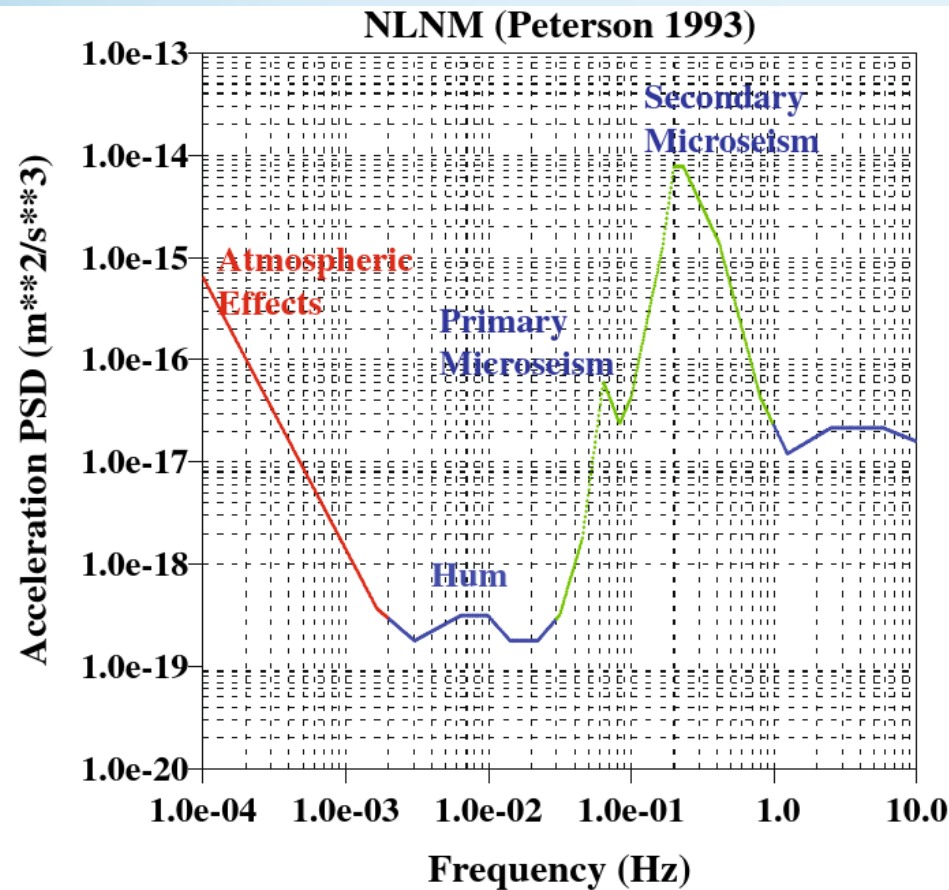
Radiometer noise of GW sensitivity

$$\sigma_h = 3.6 \times 10^{-17} \left(\frac{\eta}{0.1}\right)^{-1/2} \left(\frac{P}{1 \text{ MW}}\right)^{-1/2} \left(\frac{D_{\text{recv}}}{100 \text{ m}}\right)^{-1} \left(\frac{f}{1 \text{ hr}^{-1}}\right)^{1/4} \left(\frac{T}{35 \text{ K}}\right)^{1/2} \left(\frac{B_i}{\text{kHz}}\right)^{1/4}$$

Seismic noise

$$S_{\text{seismic}}(f) \sim 1 \text{ nm}^2 \text{ Hz}^{-1} \left(\frac{f}{\text{Hz}} \right)^{-2}$$

$$\sigma_h = 1.3 \times 10^{-15} \left(\frac{f}{\mu \text{ Hz}} \right)^{-1}$$

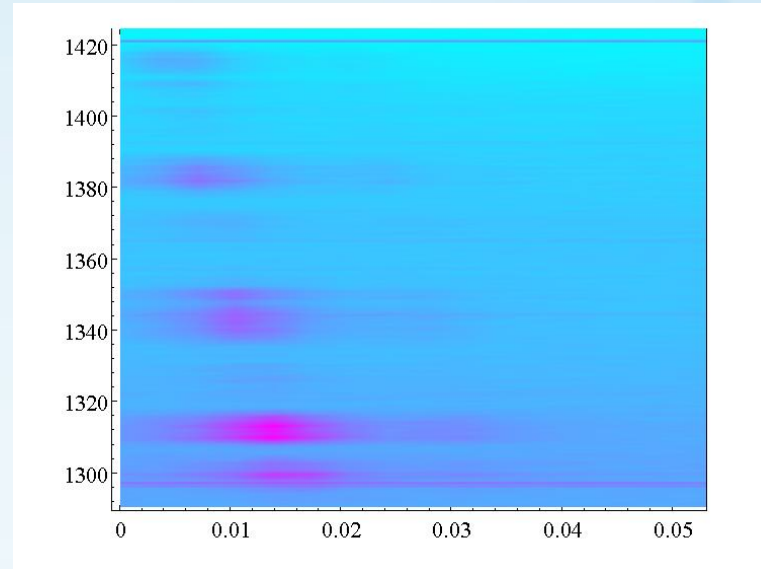
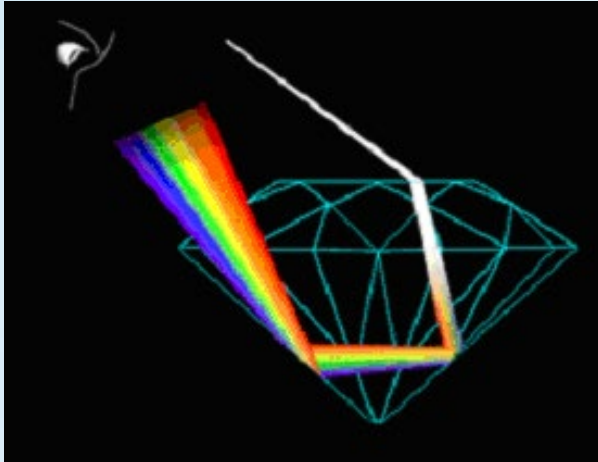


Zhou et al., 2003

Earth tides, complicated, but due to the Q value, does not affect much

Ionosphere correction

Ionosphere delay:



$$\delta = 80.6 m \left(\frac{f_{\text{radio}}}{\text{GHz}} \right)^{-2} \left(\frac{\text{TEC}}{100 \text{ TECU}} \right)$$

$$\sigma = 0.4 \text{ nm} \left(\frac{\eta}{0.1} \right)^{-1/2} \left(\frac{P}{1 \text{ MW}} \right)^{-1/2} \left(\frac{D_{\text{recv}}}{100 \text{ m}} \right)^{-1} \left(\frac{t}{1 \text{ hr}} \right)^{-1/4} \left(\frac{T}{35 \text{ K}} \right)^{1/2} \left(\frac{B_i}{\text{kHz}} \right)^{3/4} \left(\frac{R}{3.8 \times 10^8 \text{ m}} \right) \left(\frac{f_{\text{radio}}}{\text{GHz}} \right) \left(\frac{\text{BW}}{100 \text{ MHz}} \right)^{-3/2}$$

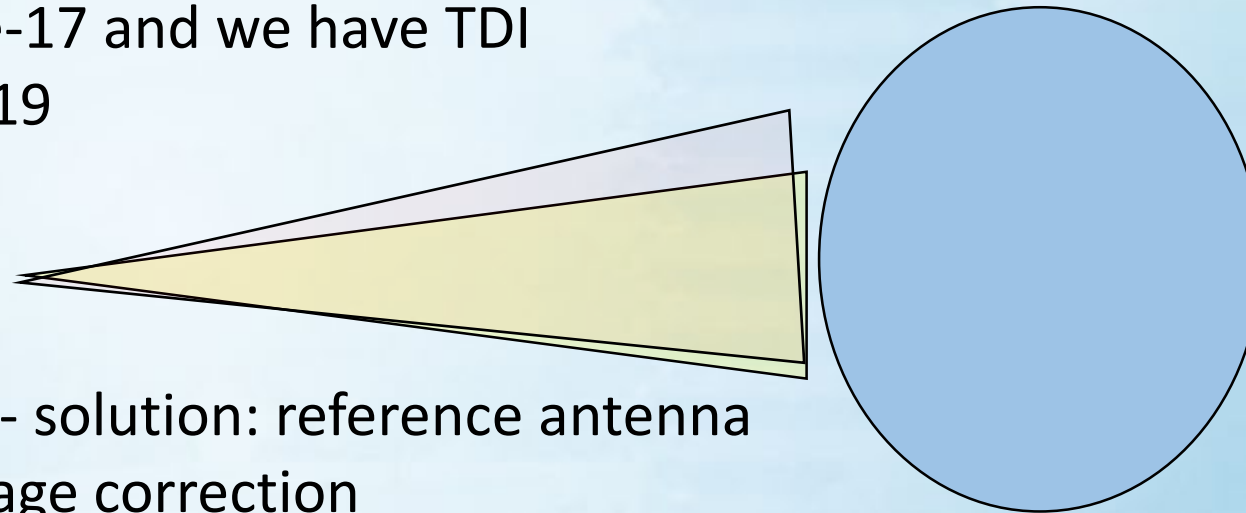
$$\sigma_h = 1 \times 10^{-18} \left(\frac{\eta}{0.1} \right)^{-1/2} \left(\frac{P}{1 \text{ MW}} \right)^{-1/2} \left(\frac{D_{\text{recv}}}{100 \text{ m}} \right)^{-1} \left(\frac{t}{1 \text{ hr}} \right)^{-1/4} \left(\frac{T}{35 \text{ K}} \right)^{1/2} \left(\frac{B_i}{\text{kHz}} \right)^{3/4} \left(\frac{R}{3.8 \times 10^8 \text{ m}} \right) \left(\frac{f_{\text{radio}}}{\text{GHz}} \right) \left(\frac{\text{BW}}{100 \text{ MHz}} \right)^{-3/2}$$

Telescope deformation calibration and phase center:

$$\sigma = 20 \text{ nm} \left(\frac{N}{50} \right)^{-1}$$

LOSC: Frequency stability: $1\text{e-}17$ and we have TDI

Solar acceleration noise: $1\text{e-}19$

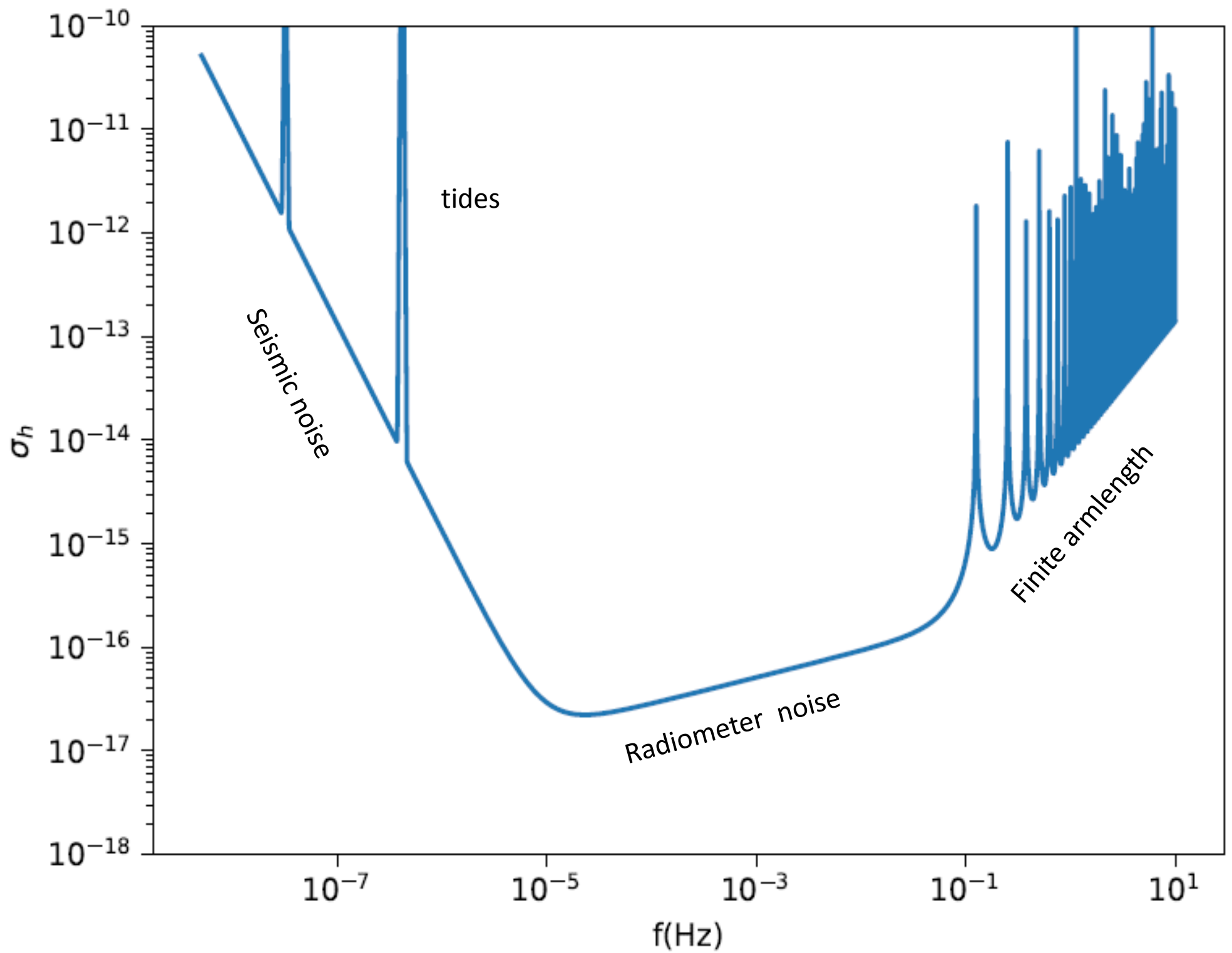


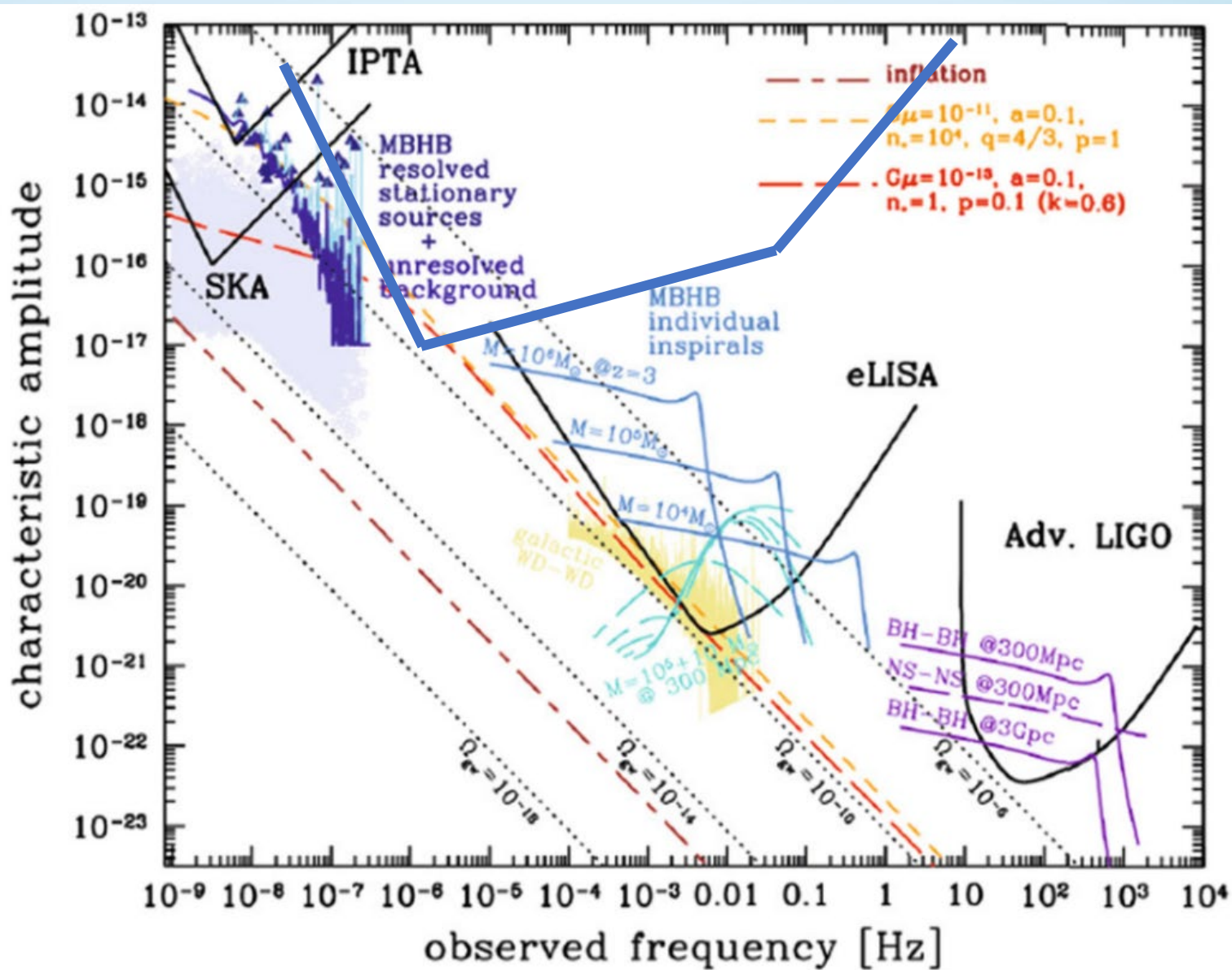
Potential issues:

Stochastic wind disturbing --- solution: reference antenna

Pointing error --- radar image correction

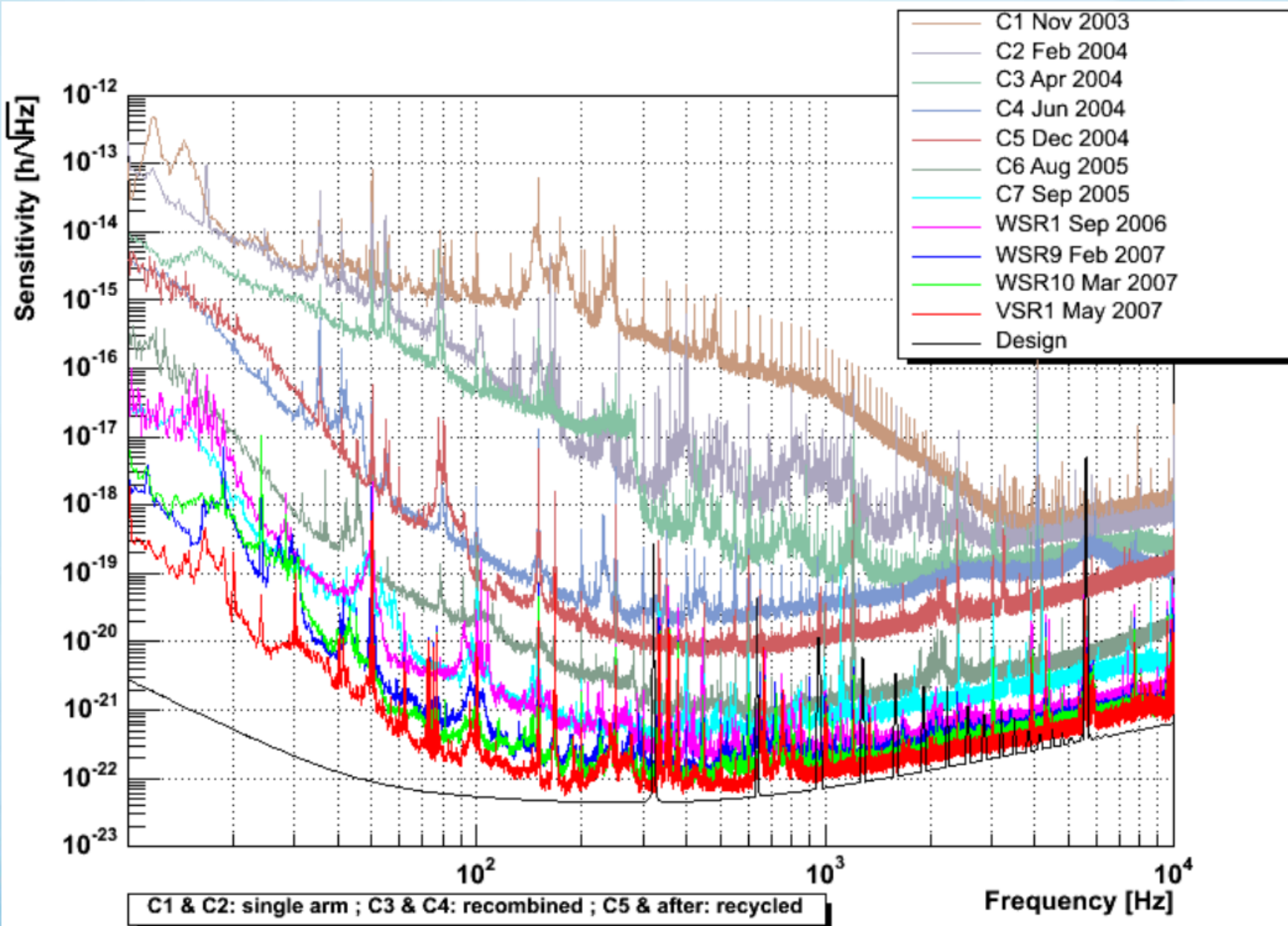
Phase noise of radar amplifier --- TDI or active correction





Is the idea too crazy?

- 1) If it is not limited by the S/N, then it is possible.
- 2) All systematics are useful sciences.



So...

Instead of sending laser to the Mars, you want a 1 MW radar?

Note: 1 MW is not a very bad number, 1/2000 of 大亚湾

1MW power station



- 1.Expected to run in 2030
- 2.We are in the initial stage to propose radar –GW detector experiment.
- 3.Anyone is welcome to join the science / engineering team.



- Expected GW sources (astronomer)
- Searching algorithm (astronomer, data analyst, statistician)
- Noise and mitigation (mechanic engineer, geophysist, space scientist)
- Solar system dynamics (astronomer)
- Radio engineering (electric engineer)
- Radar experts



Thanks