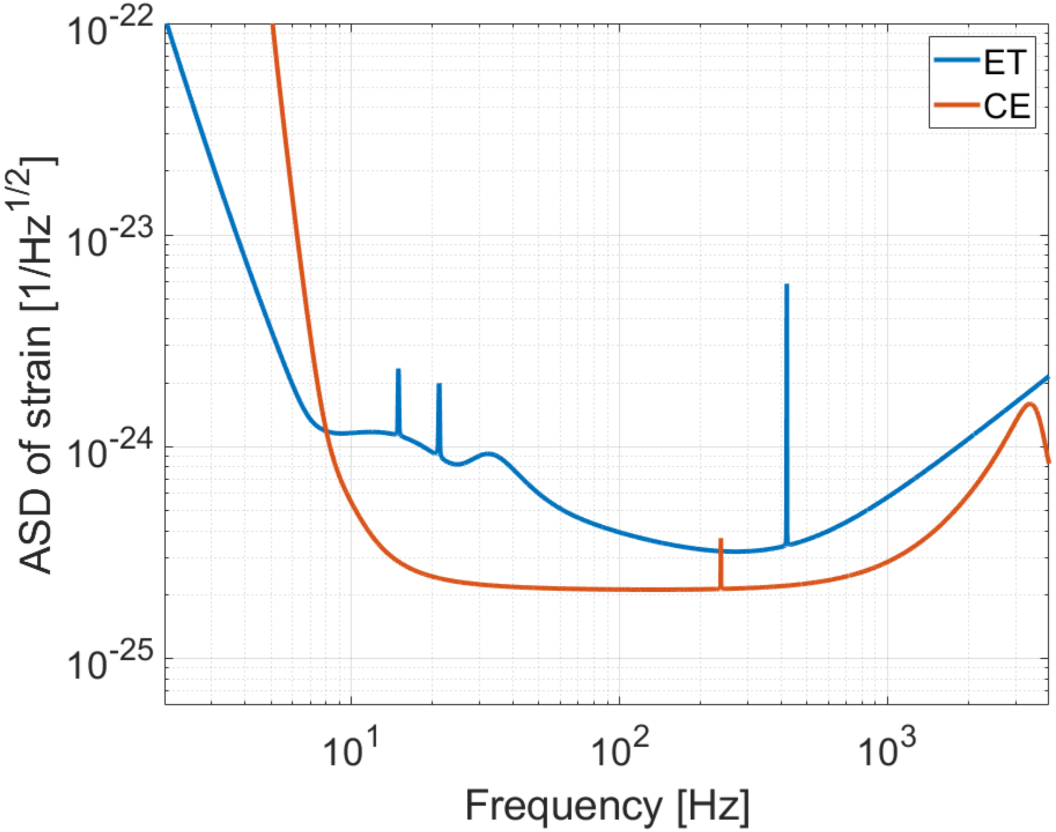
GWADW (Online) 2021
May 17-21

How to realize the ET low-frequency design?

A summary of the ET Instrument Science Board low-frequency workshop held March 2021

Conor Mow-Lowry and Kate Dooley

ET faces a particular low-frequency challenge

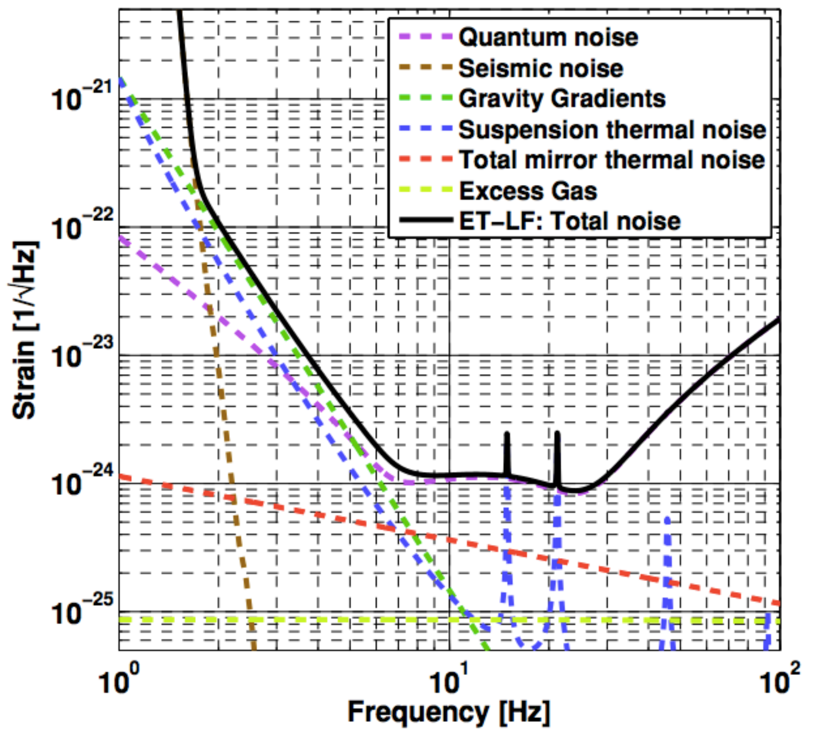


https://dcc.ligo.org/LIGO-T1500293

When does technical noise become fundamental?

- Assumptions of ET-LF design curve are the classical fundamental noises:
  - Gravity gradient noise
  - Suspension thermal noise
  - Quantum (radiation pressure) noise
  - Seismic noise

- But we know no detector to date has ever reached this 'fundamental' noise floor at low frequencies



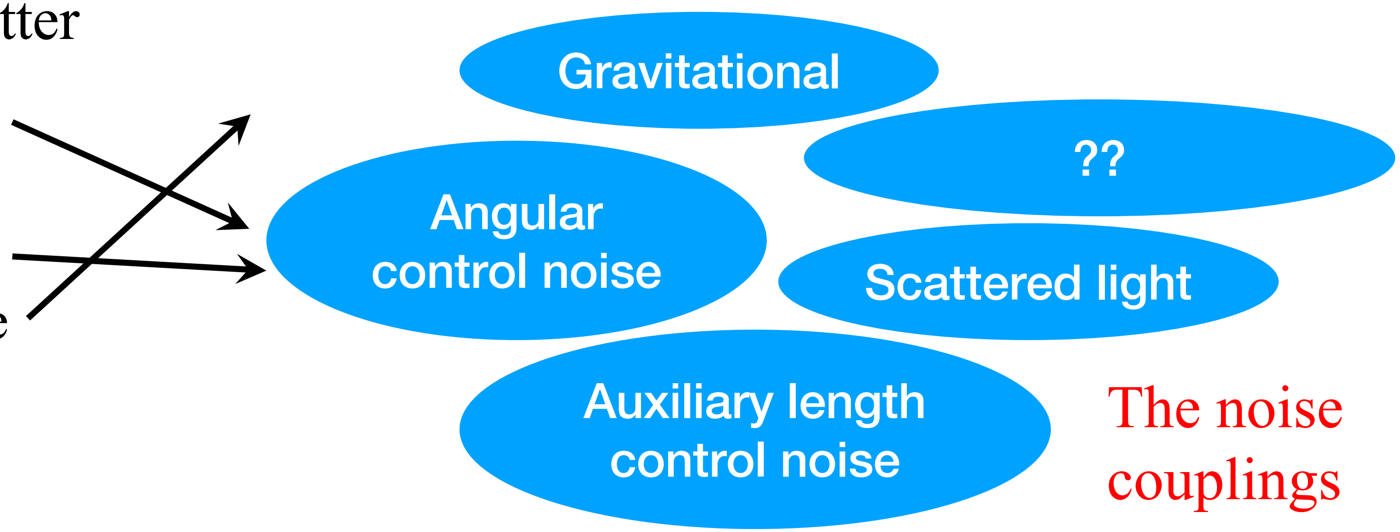
Class. Quantum Grav. 28 (2011) 094013

Approach for avoiding this same fate in ET

1. Identify key LF noise drivers in current detectors, i.e. things that make noise couplings matter

- RMS mirror motion
- Actuation forces
- Imperfect sensors
- Environmental noise
- …

The noise drivers

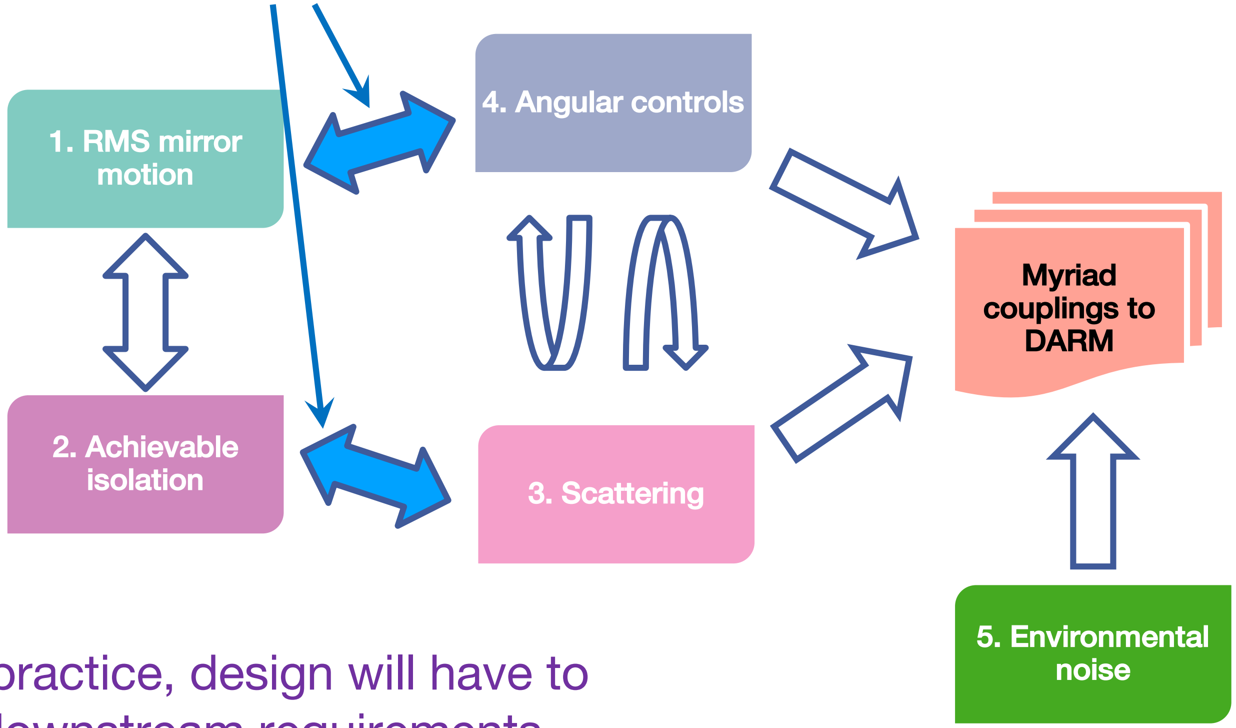


The noise couplings

2. Identify strategies to mitigate noise drivers by design.

ET LF workshop focused on 5 themes

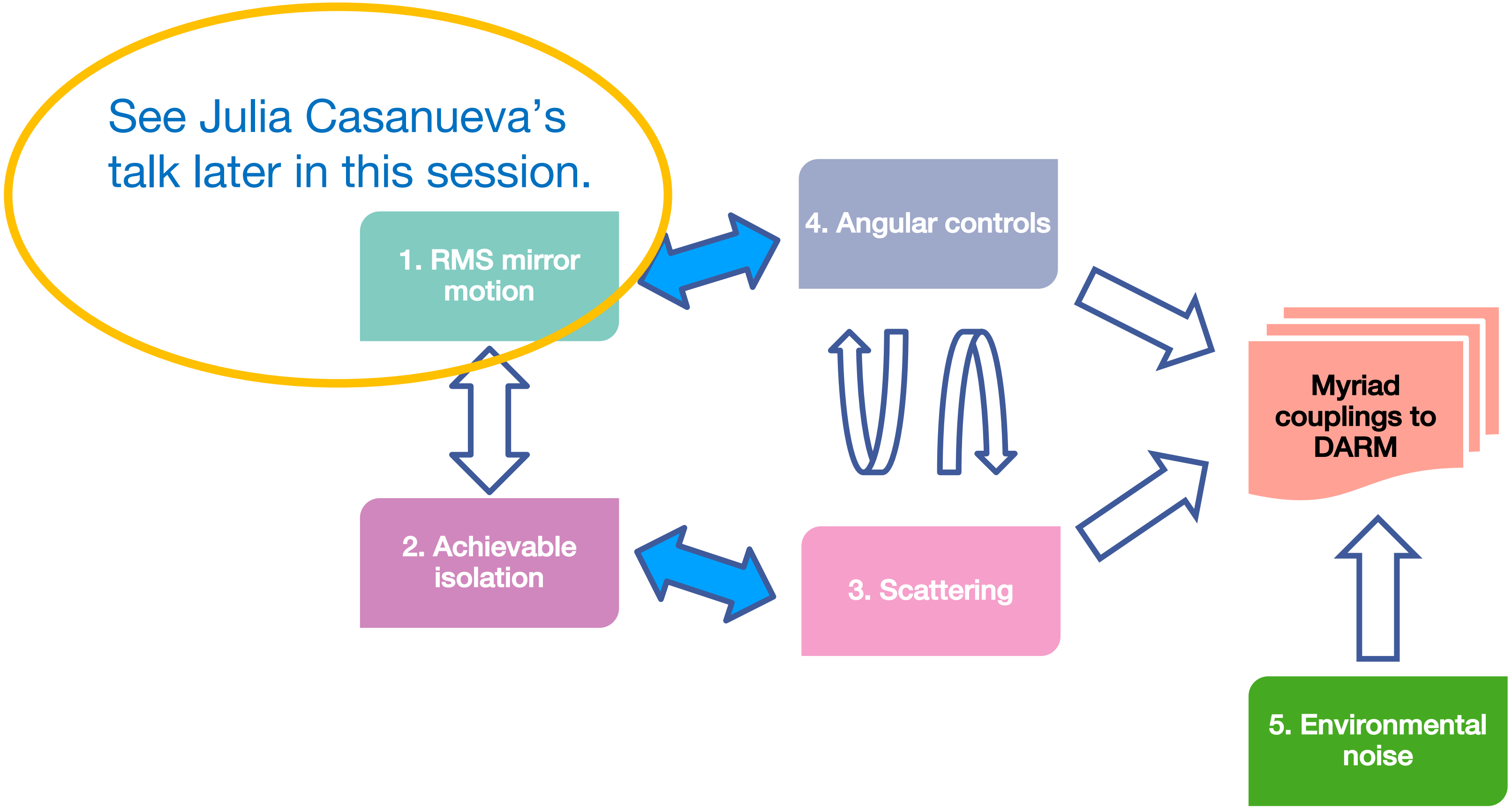
Conor had used one-way arrows here to simplify the thinking for the workshop



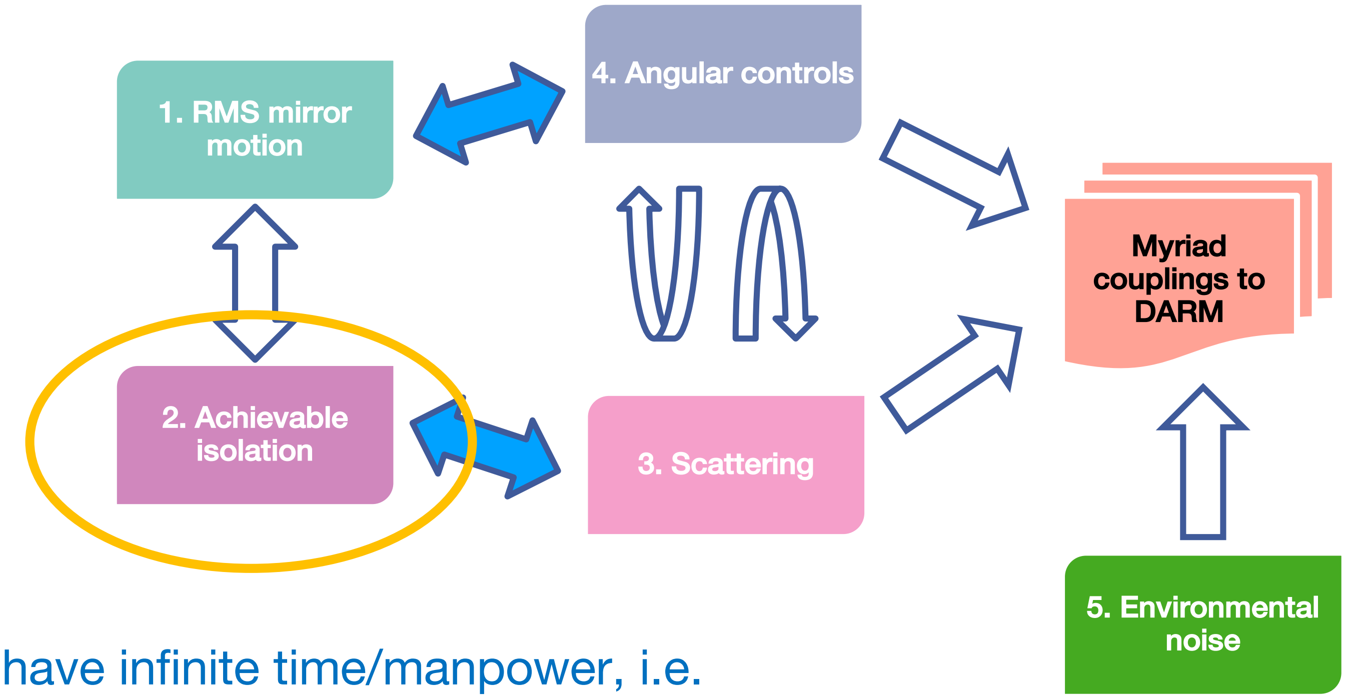
(does not affect controls design)

Comment: In practice, design will have to be driven by downstream requirements dictating what matters most.

Theme 1: RMS mirror motion



Theme 2: Achievable isolation



We don't have infinite time/manpower, i.e. to make isolation 'as best as possible'.

Theme 2: Achievable isolation

To what extent does ET need to use active isolation on top of a passive inverted pendulum design?

Approach:

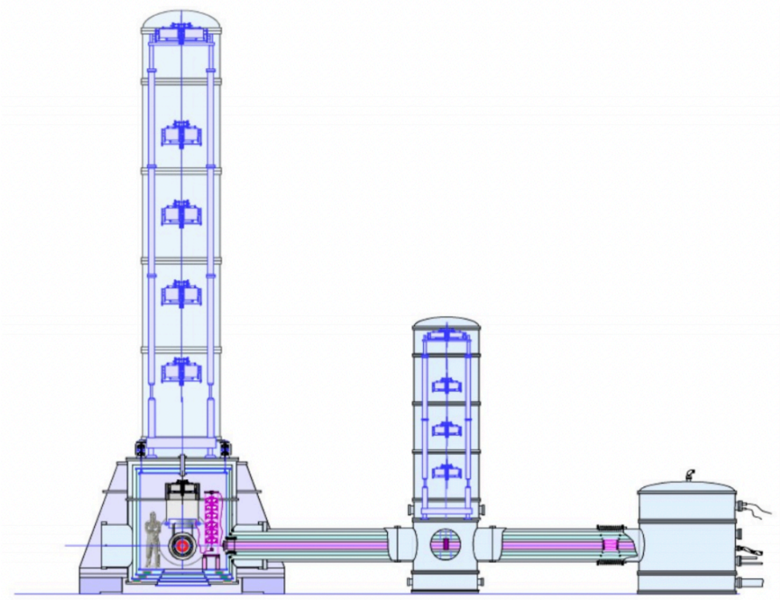
- Express requirements as a spectral density + RMS, not as a transfer function or attenuation factor

Theme 2: Achievable isolation

To what extent does ET need to use active isolation on top of a passive inverted pendulum design?

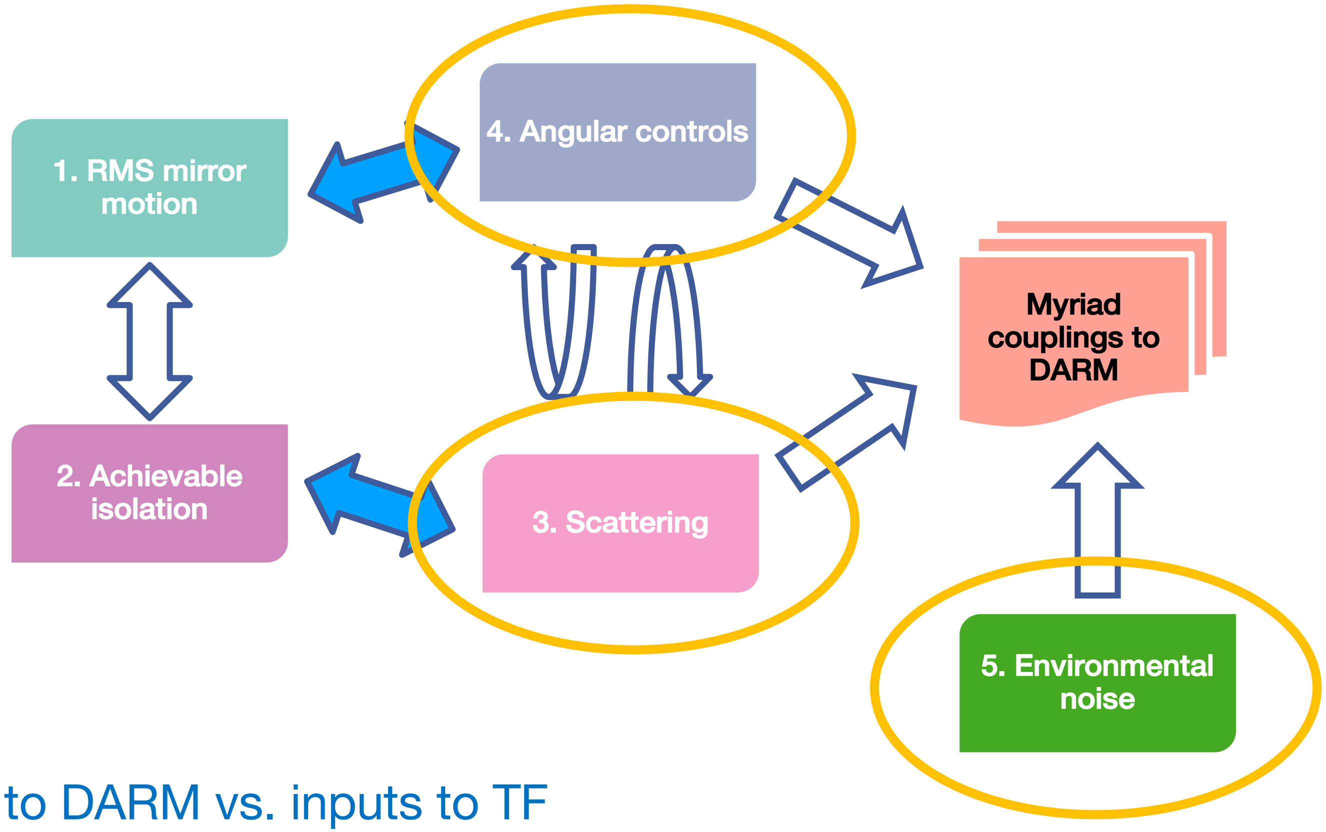
Questions:

- Are 12m suspensions sufficient?
- What are some of the practical limitations we have understood from Advanced instruments, especially concerning tilt and cross-couplings?
- Not discussed, but noted as very important: coupling with cryogenics



"ET design report update 2020"
Virgo TDS: ET-0007A-20

Remaining 3 themes: dividing the thinking

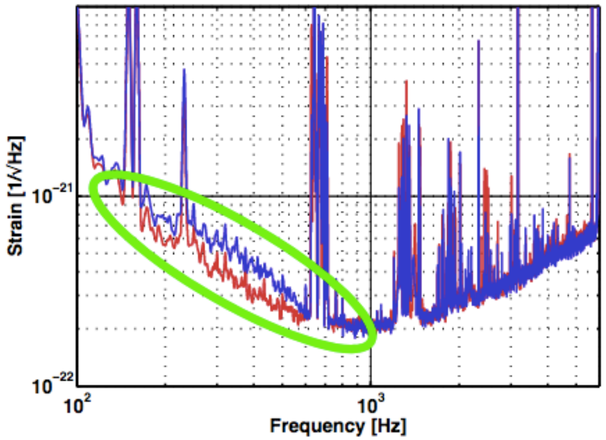


Transfer function to DARM vs. inputs to TF

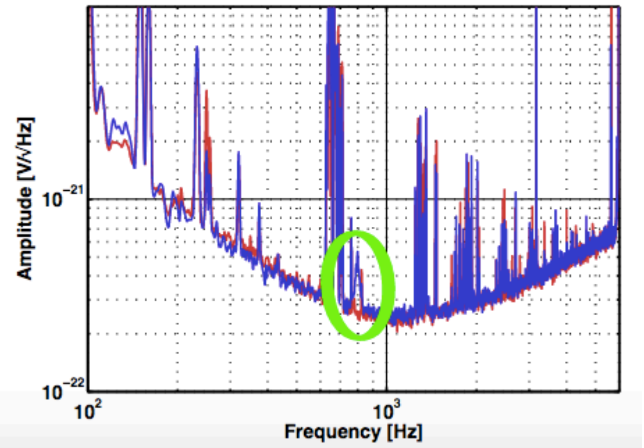
Theme 3: Scattering

	Transfer function to DARM	Input to transfer function
3. Scattering	• More of a coefficient (unless scatter path length controlled)	• Surface motion (i.e. baffles, vacuum tubes) • Amount of scattered light that couples to main beam path
4. Angular sensing and control	• Bi-linear coupling of angular mirror motion and beam spot motion	• Wavefront sensor noise (i.e. shot noise) • Mirror angular motion
5. Environmental noise	• Magnetic susceptibility • Gravitational coupling • Mechanical coupling	• Schumann resonances • Man-made EM fields • Seismic and acoustic noise from machines (i.e. HVAC system) • Vibrations (i.e. traffic, wind, seismic activity)

Theme 3: Scattering



Non-linear coupling (scatterer with large amplitude motion)



Linear coupling (scatterer with small amplitude motion)

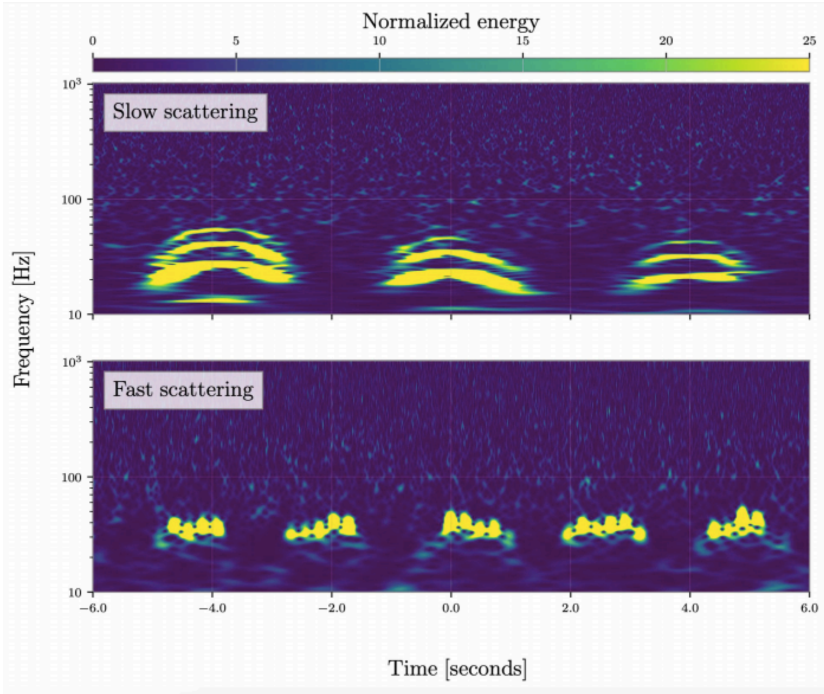
To keep the scattering shoulder out of the ET band (>2 Hz), speed of baffle/tube/etc. has to be below one wavelength per second.

Theme 3: Scattering

Perhaps one of the low frequency challenges we have the best understanding and experience of how to address. (See Monday's workshop.)

Can we:

- Measure and control inter-platform motion with new sensors (i.e. SPI)?
- Damp resonant frequencies of vacuum tubes?
- Suspend all phase-sensitive elements and baffles?



Siddarth Soni, G2100105

Theme 4: Angular sensing and control

	Transfer function to DARM	Input to transfer function
3. Scattering	• More of a coefficient (unless scatter path length controlled)	• Surface motion (i.e. baffles, vacuum tubes) • Amount of scattered light that couples to main beam path
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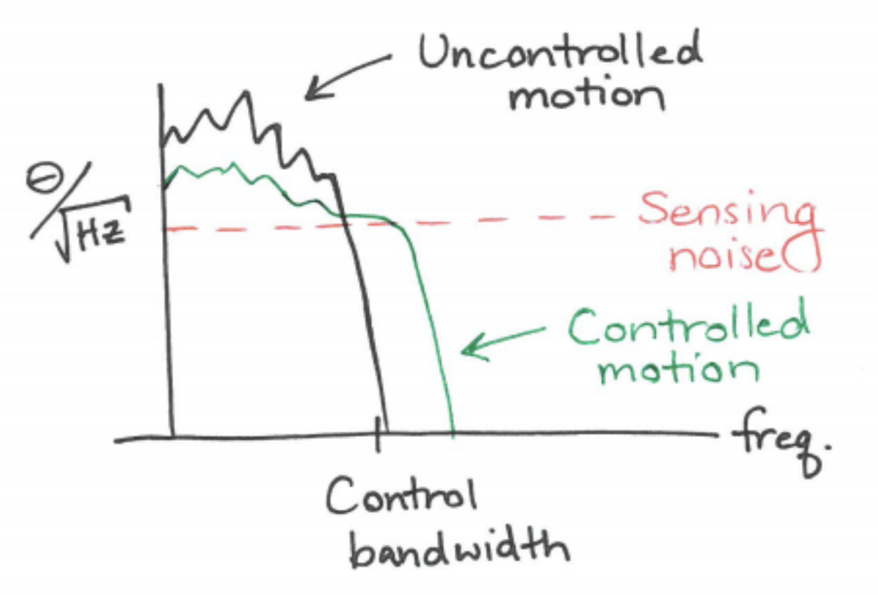
Theme 4: Angular sensing and control

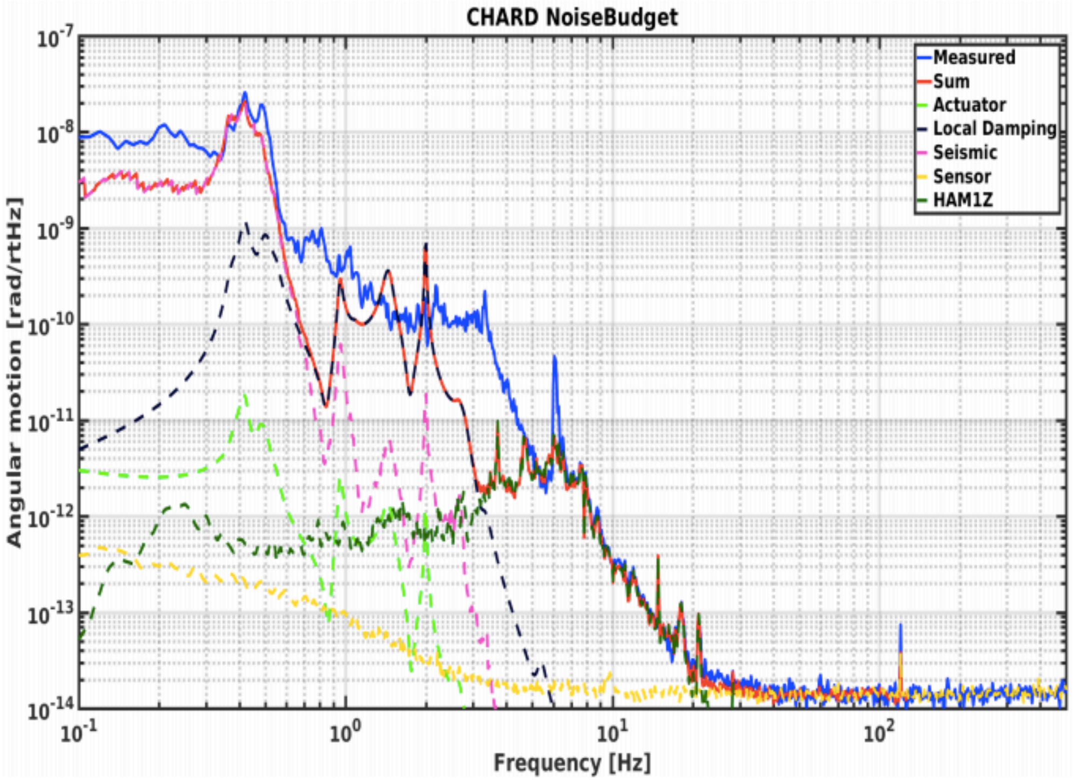
Outcome of discussions:

- The big picture (idealized!) solution: reduce mirror motion so we don't need control
- The reality: Focus will be on how we best deal with the residual mirror angular motion that we are given



Theme 4: Angular sensing and control

- Where does the noise seen by the wave-front sensors come from (electronic noise, scattered light, beam jitter wrt sensor, phase noise, ...)?
- Sidles/Sigg limits to UGFs? Ans: For ET-LF, hard mode yaw = 240 mHz
- How can modern controls help, i.e. can we define a cost function for designing control loops?



LIGO WFS budget from Marie Kasprzack:
https://dcc.ligo.org/LIGO-G1801648
And for Virgo…?

Theme 5: Environmental noise

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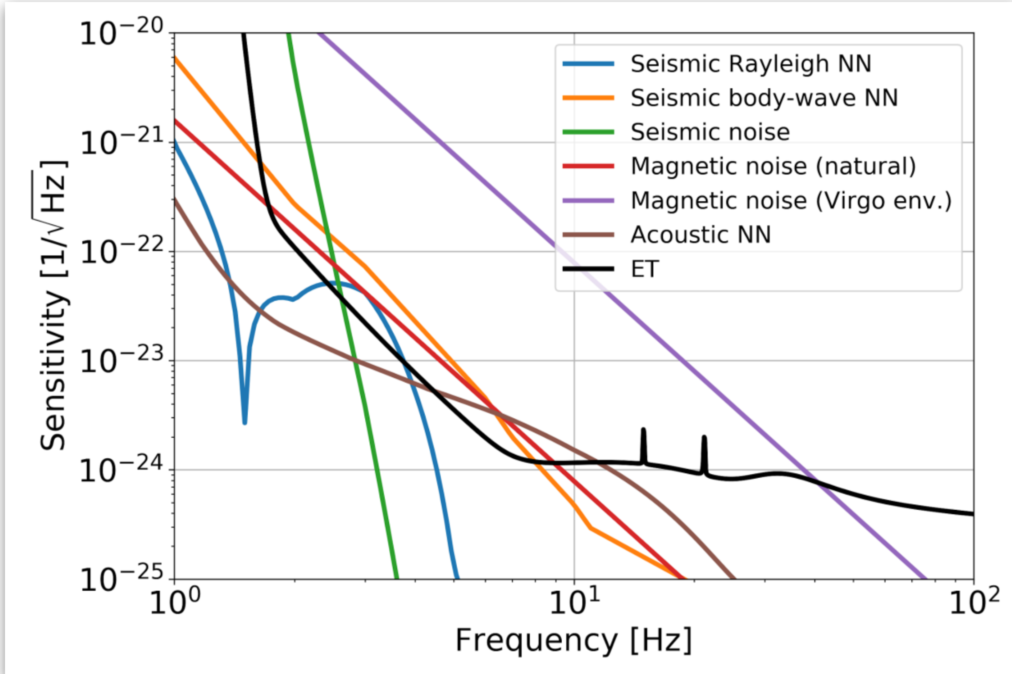
Theme 5: Environmental noise

Noise type	Origin related to infrastructure	Origin related to site properties
Fluctuations of EM field	Source: Electronics/electrical system Mitigation: Stricter control and better guidelines for electronics designs; design electrical system	Source: High-voltage power lines Mitigation: Noise cancellation with magnetometers, payload design, magnetic shielding, RF antenna arrays
Vibrations and deformations	Source: Vacuum pumps, cryo-coolers, ventilation and temperature stabilization; detector depth Mitigation: Keep machines far from test masses; put machines on dampers	Source: Traffic, wind farms, industry and farming; seismic activity, weather, topography, geology Mitigation: seismic isolation, inter-platform motion control
Gravitational fluctuations	Detector depth	Source: Geology, topography; polarizations of seismic waves; propagation directions of seismic and acoustic waves, wind speeds, surface structures and forests; precipitation Mitigation: Noise cancellation using seismic sensors, microphones, LIDAR

Theme 5: Environmental noise

A big challenge: What will the environmental noise actually be?

- Lack of understanding of underground environmental fields, especially at ET depths and at frequencies of 3-10 Hz.
- Tilt might be very small underground; if so, noise would depend only on self-noise of sensor
- Different mirror material for ET + cryogenics makes EM field coupling a current unknown
- Numerical models can provide important insight, but need to be compared to measurements for validation. Use existing detector sites.



Jan Harms

“Problem is not that people don’t know what they’re doing, but that sometimes shared designs could have helped.”