Two-In-One Observatory:

LIGO Experience with Co-linear IFOs

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LIGO

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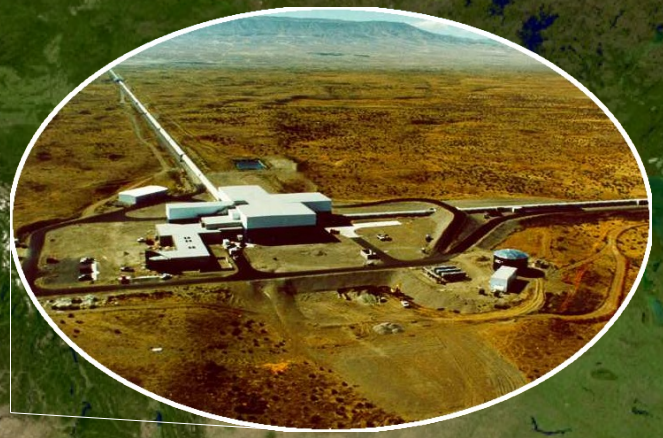
- LIGO
- Co-linear IFOs: Good and Bad
- Examples



LIGO Hanford Observatory (LHO)

2 co-linear IFOs: H1 and H2

3000km, 10 ms

LHO almost perfectly aligned with LLO

LIGO Livingston Observatory (LLO)

1 IFO: L1

- Adapted from "The Blue Marble: Land Surface, Ocean Color and Sea Ice" at visibleearth.nasa.gov
- NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights).

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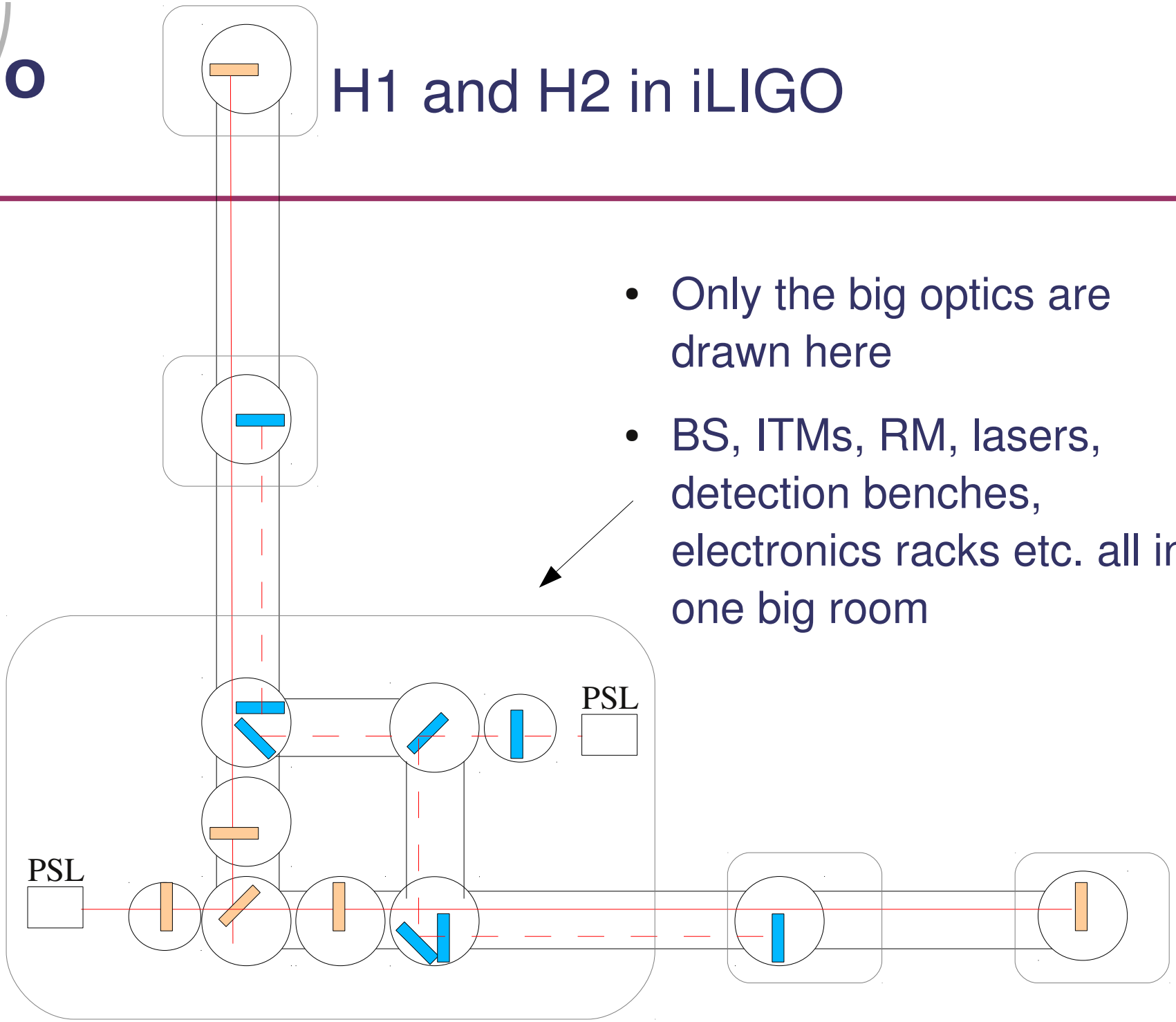
H1 and H2

- 4km and 2km instruments in a single vacuum enclosure
- ITMs, BSs, RMs, input optics and lasers in the same room.
- Operated at the same time in S5 (not in S6)
- H2 will be 'upgraded' to 4km for aLIGO

H1 and H2 in iLIGO



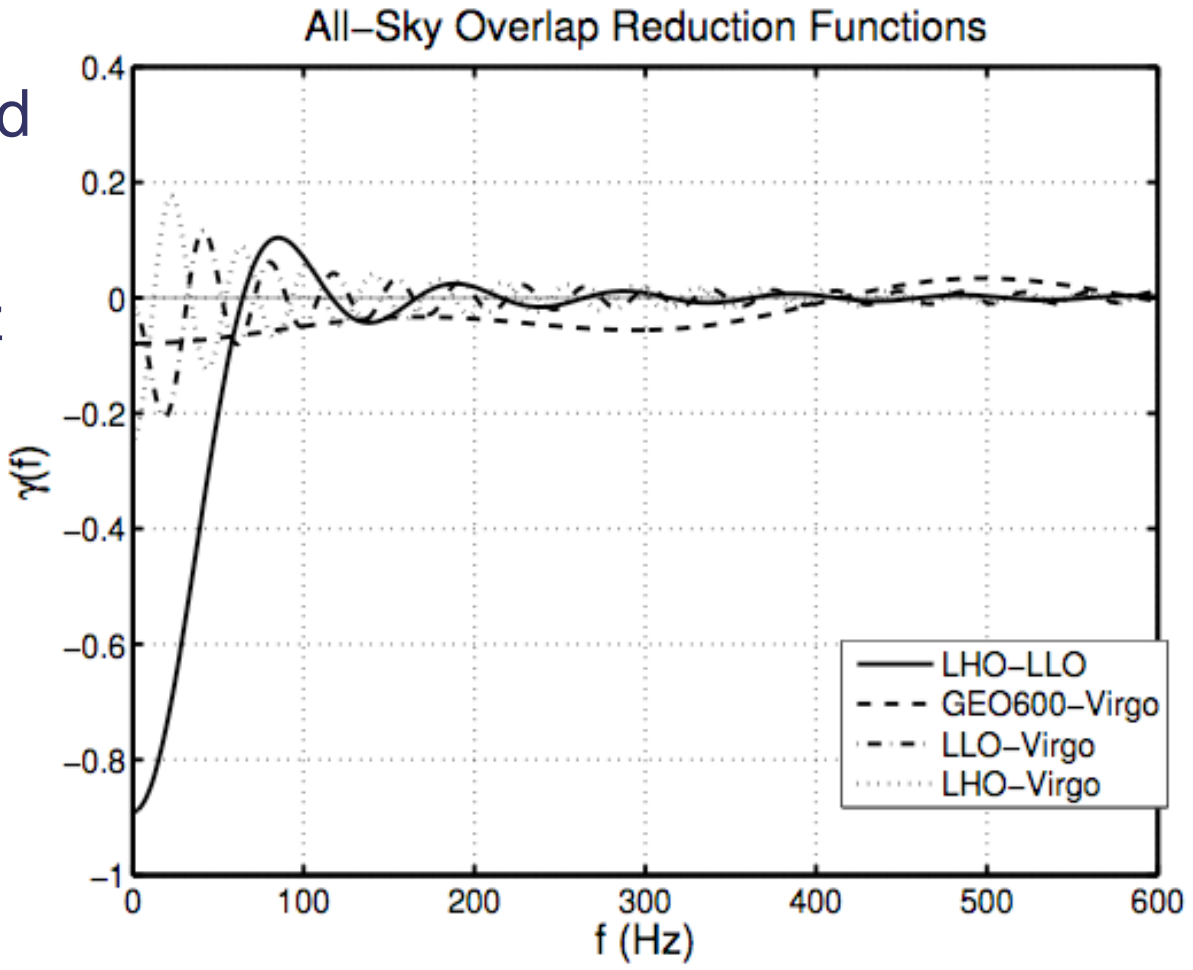
- Only the big optics are drawn here
- BS, ITMs, RM, lasers, detection benches, electronics racks etc. all in one big room

Co-linear IFOs: Potential scientific benefits still look attractive

- Narrow coincidence window
- Overlap reduction function=1 (isotropic stochastic search)
- Telling GW and common length change apart by 4km and 2km difference
  - There are tons of disturbances acting differently on 2 IFOs, though

Overlap reduction function?

- Important for cross-correlation analysis of stochastic search
- Represents an overlap of antenna patterns of a pair of IFOs at different locations and orientations.
- L1-H1 attenuated for f>50 Hz despite a good alignment of the two IFOs



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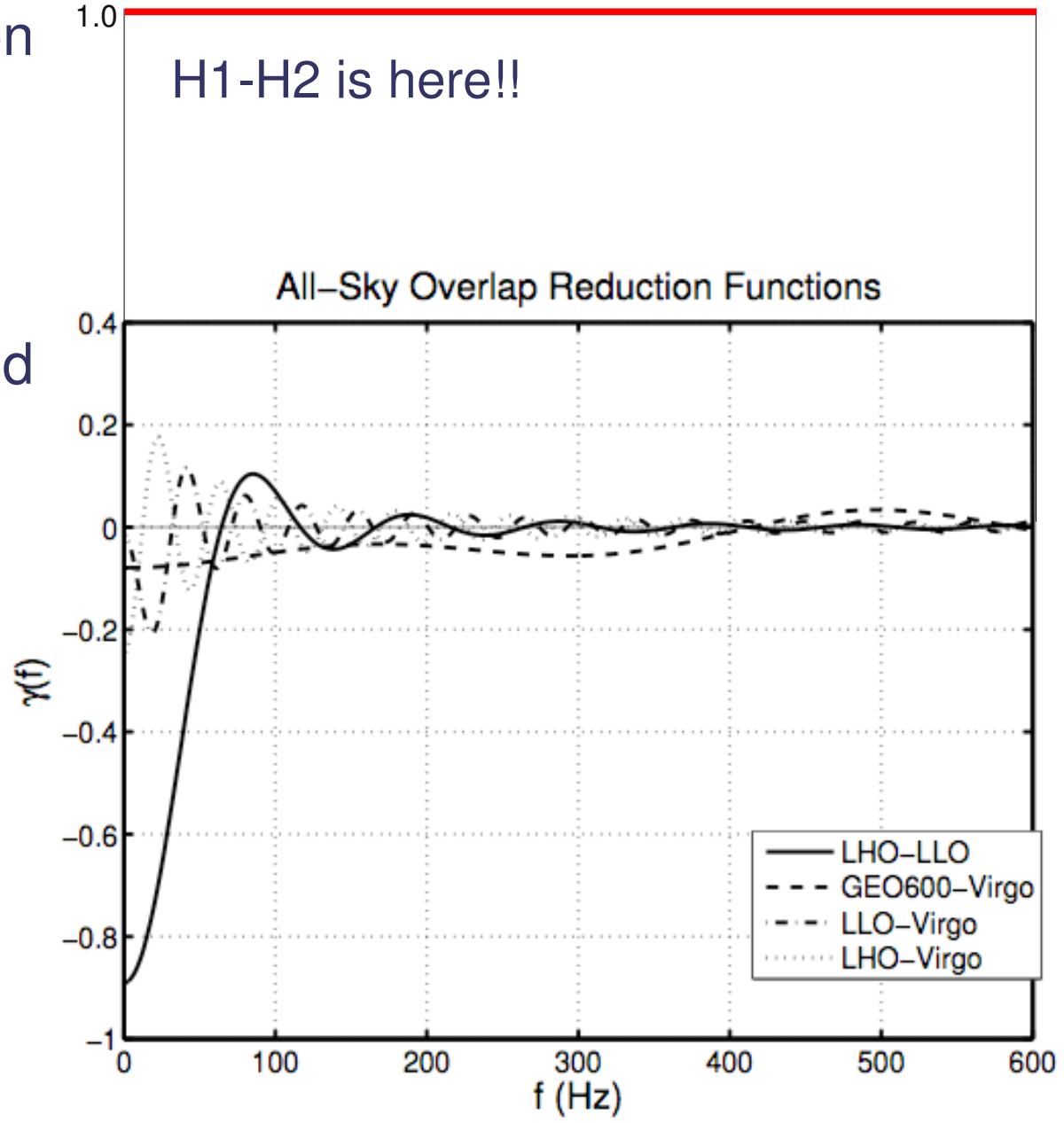


Co-linear IFOs: Could be bad, not because of science but pesky thing called reality

- Lots of things cause common noise
  - Seismic: EQs, local traffic, wind, air conditioning turbine, air conditioning flow, cooling water lines, water pumps, LN2 dewer/insulation slippage, dams discharging, firing etc.
  - Acoustic: Fans, air conditioning flow etc.
  - Magnetic: 60Hz and its harmonics etc.
  - RF: Various electronics e.g. proximity reader, cpu clock etc.

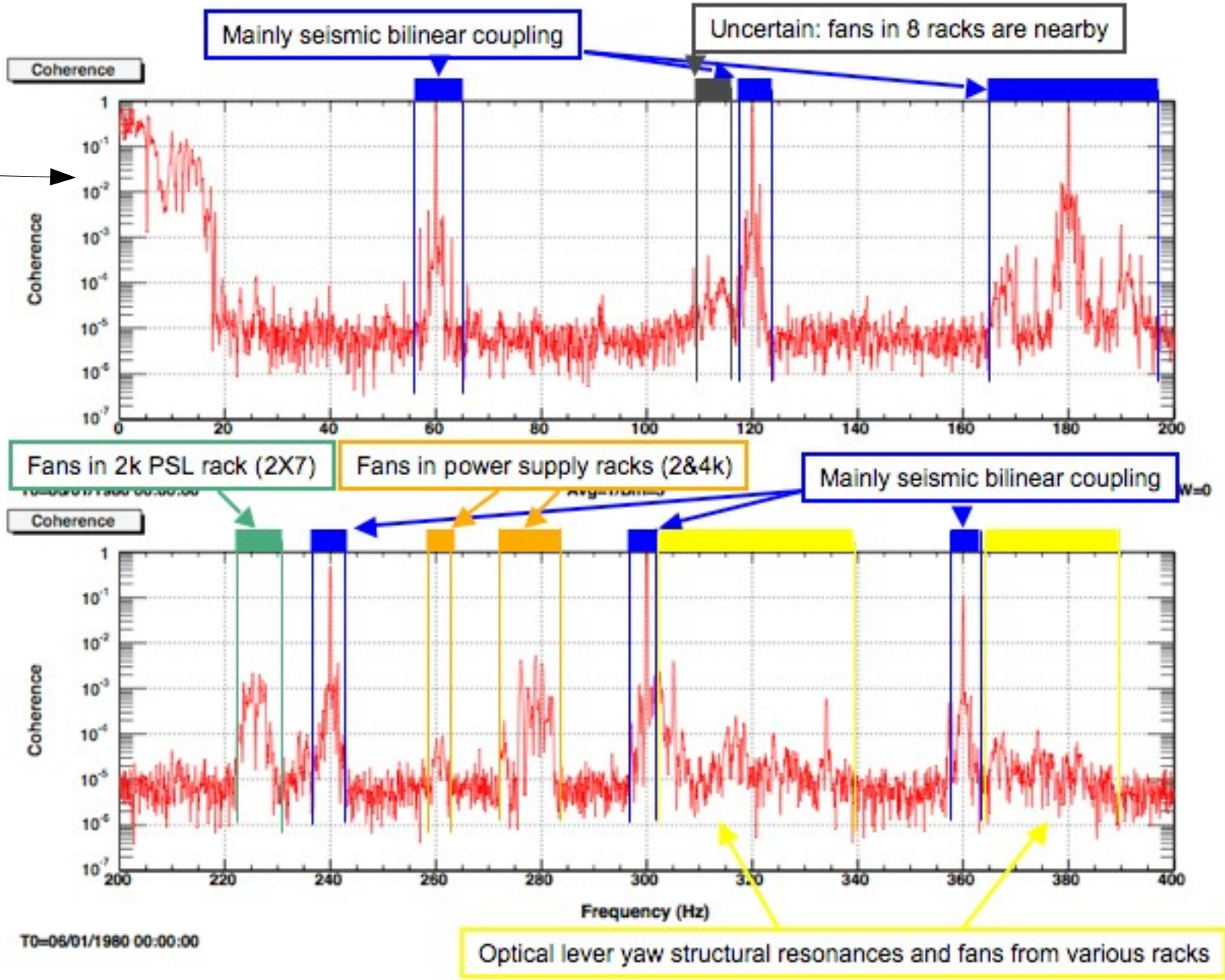
This is in no way a comprehensive list

Co-linear IFOs: Could be bad, not because of science but pesky thing called reality

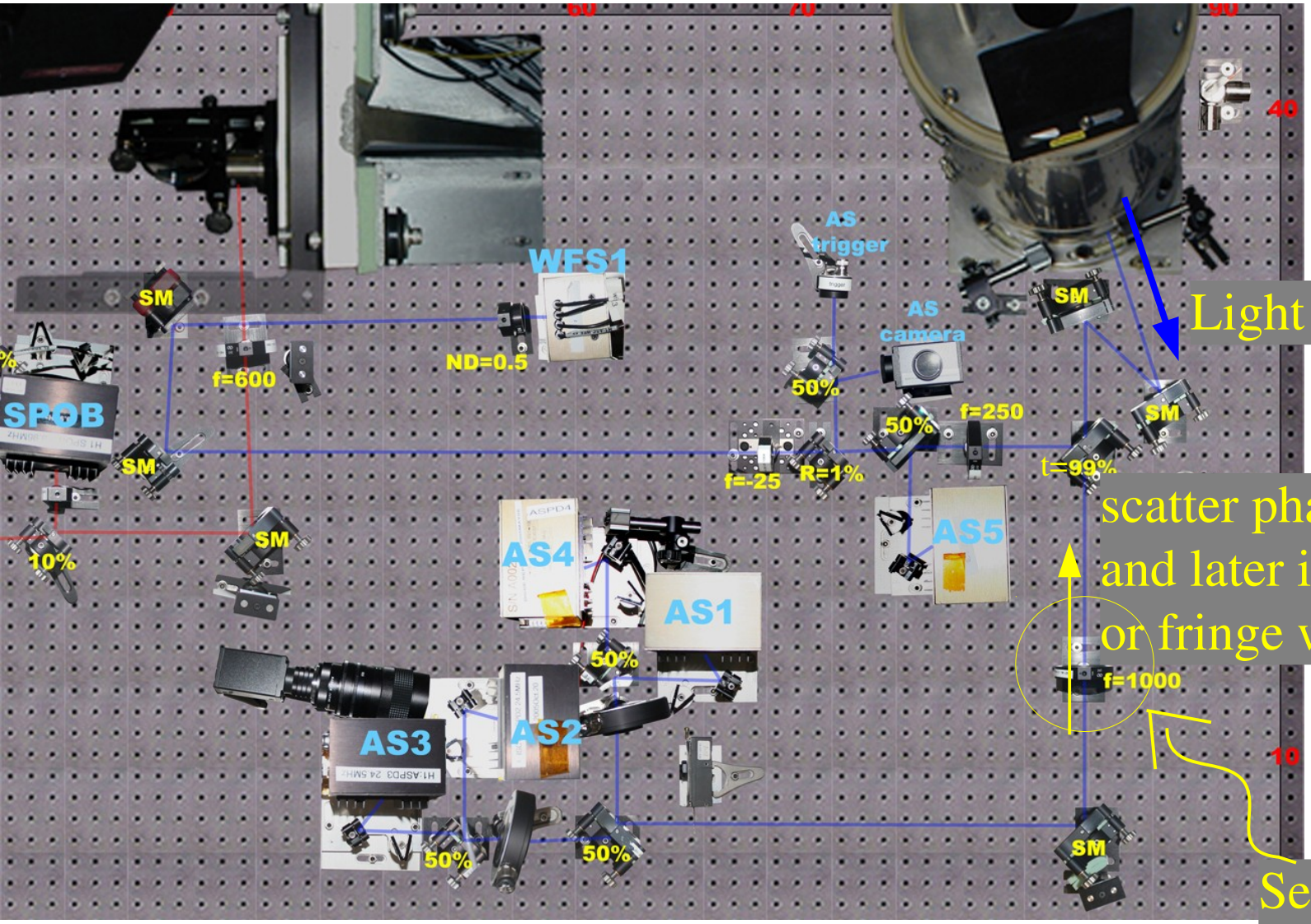
- Upconverted (bi-linear, fringe wrapping, Barkhausen etc.) as well as linearly coupled
- Can be coherent (small motion scatter, bi-linear around lines etc.), or incoherent but coincident
- We found nothing that cannot be mitigated/vetoed, but these are serious problems nevertheless
- Difficult to predict, mitigation strategy case-by-case

Ex) H1-H2 coherence from seismic and acoustic: problem for S5 stochastic search

Log scale: subtle thing!



I cannot talk about all coupling paths, but I'll give you some idea anyway, 1

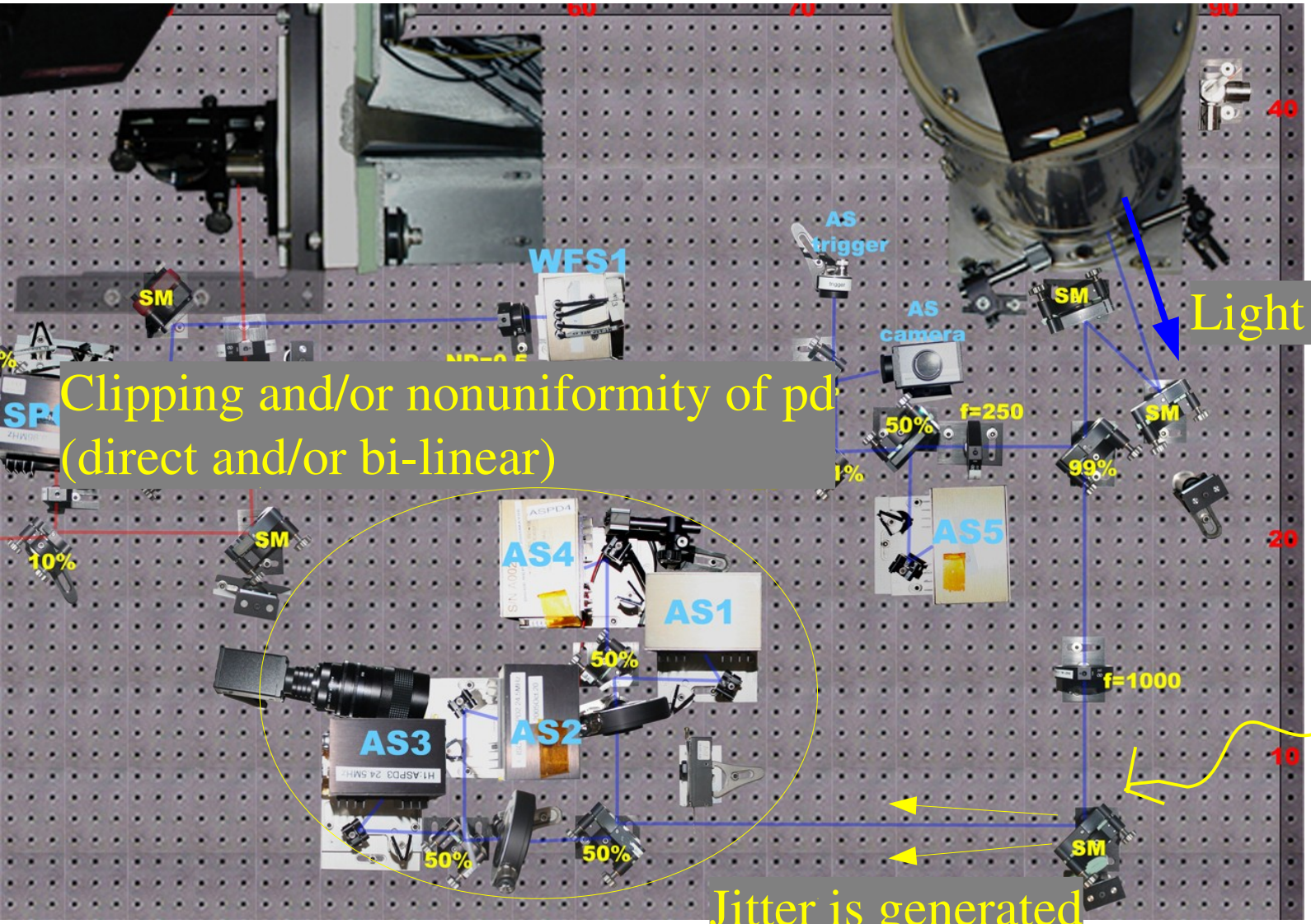


Light from IFO

scatter phase is modulated and later it comes back (direct or fringe wrapping)

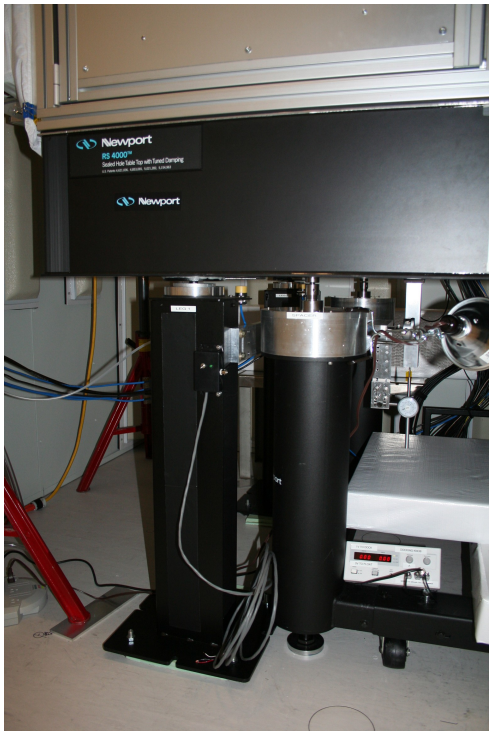
Seismic or acoustic shakes things

I cannot talk about all coupling paths, but I'll give you some idea anyway, 2



You could make the coupling smaller,

- “Meat locker” acoustic enclosure in addition to the smaller enclosure on the table
- Moving electronics racks away
- etc.



- Floating the table
- Larger optics
- Better quality components (beam dumps etc.)

or make the source smaller (if it's your fault)

- Putting big turbine on a spring,
- Lowering the air flow of HVAC system,
-

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or make the source smaller (if it's your fault)

- Putting big turbine on a spring,
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- Making the road less bumpy,
- Etc., you're already getting the full picture.

Another Example: Cross-IFO Scattering

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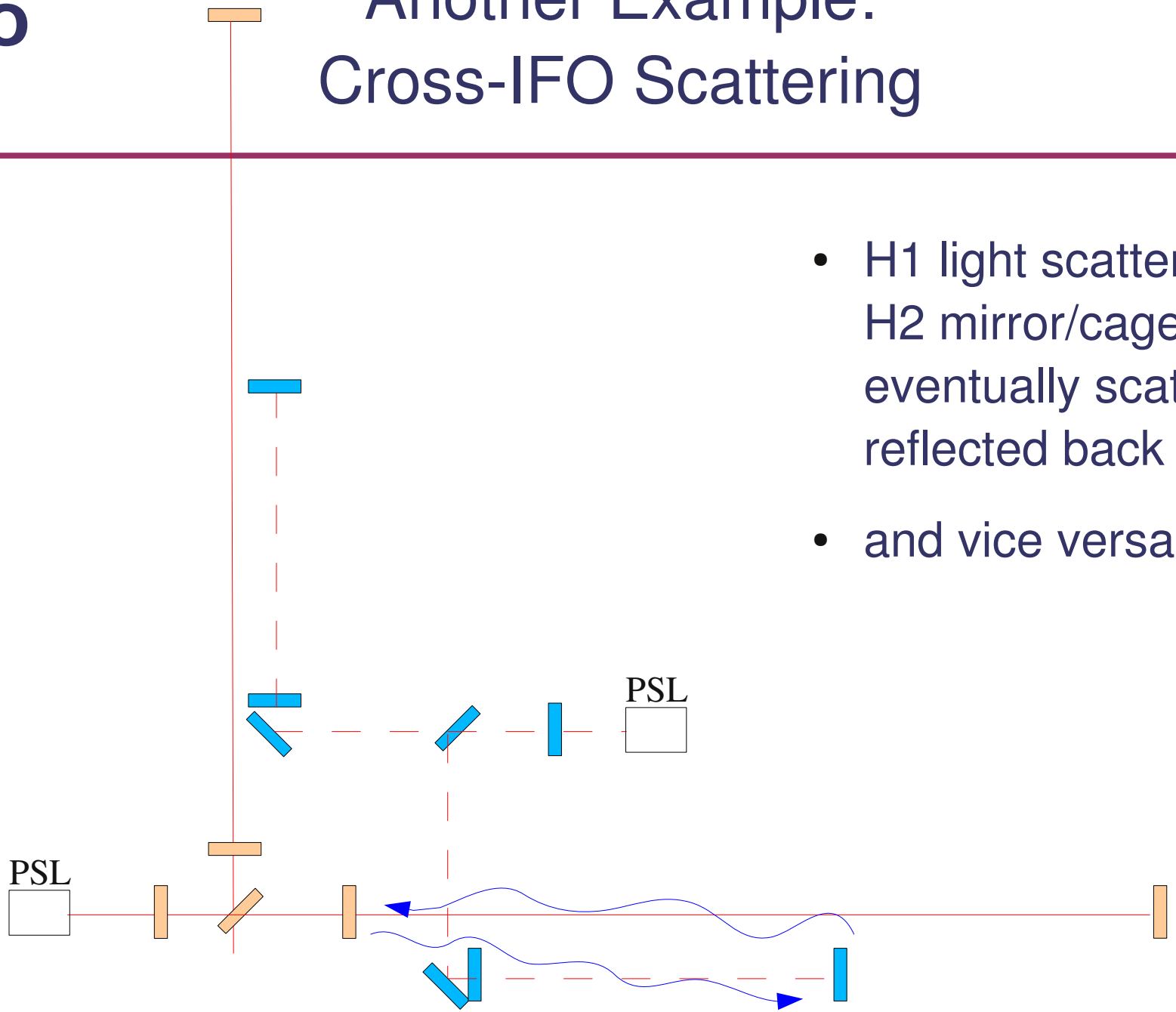


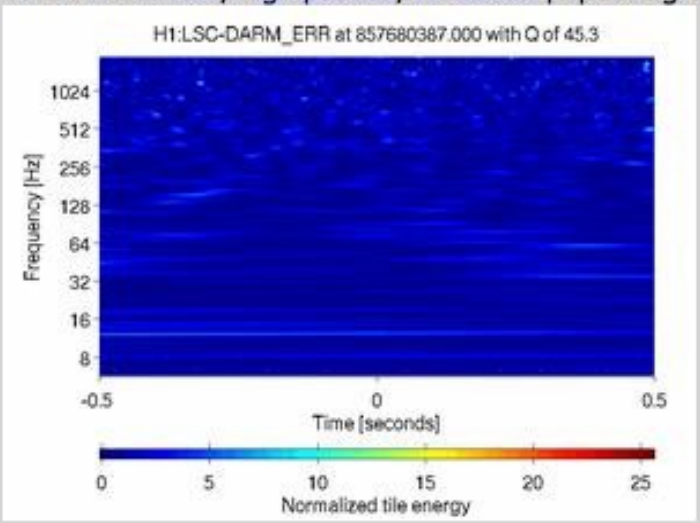
- H1 light scattered into H2 mirror/cage etc., eventually scattered or reflected back to H1,
- and vice versa.

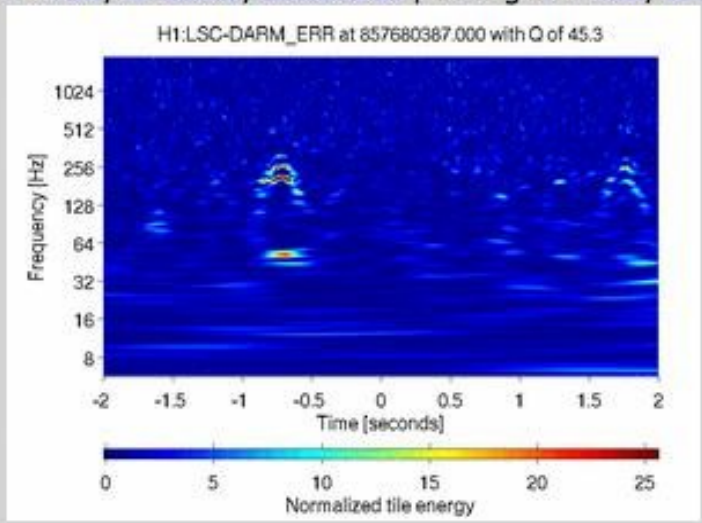
Another Example: Cross-IFO Scattering

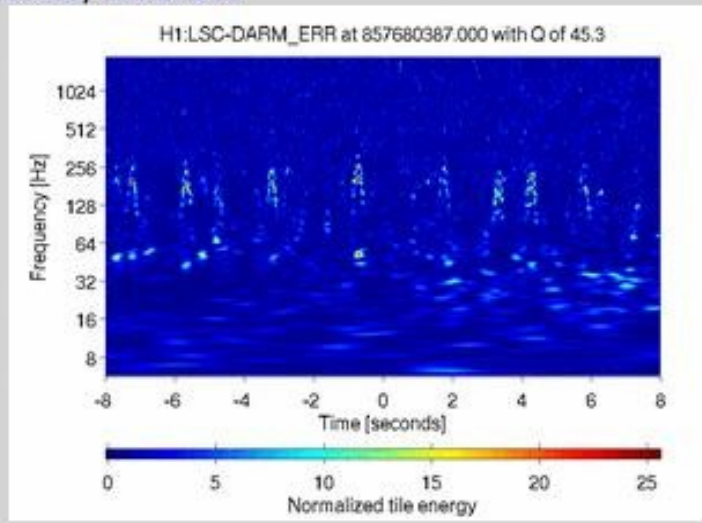
- Interference of the main beam and a beam with uncontrolled phase
  - $\alpha \sin\phi(t)$: α coupling, ϕ phase
  - Potentially both small amplitude (linear) and fringe wrapping (upconversion)
- Many possible paths, simple ones reasonably understood (e.g. H1 ITM- H2 ETM – H1 ITM)
- Multiple bounce path exists, fringe wrapping observed when both IFOs are in lock, paths not well understood

H1:LSC-DARM_ERR (t = 857680387.078 s, f = 1.9×10^{3} Hz, Q = 4.5×10^{1}, Z = 7.7×10^{0}, X = 3.0×10^{-8} $Hz^{-1/2}$)

time series: raw, high passed, whitened | spectrogram: raw, whitened, autoscaled | eventgram: raw, whitened, autoscaled

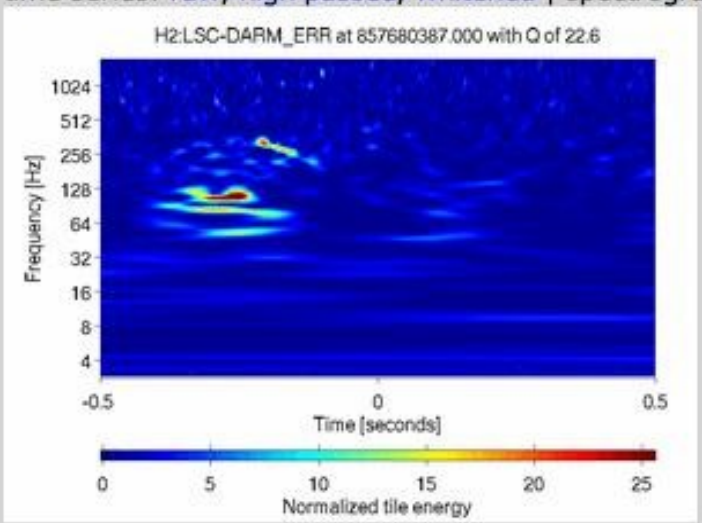


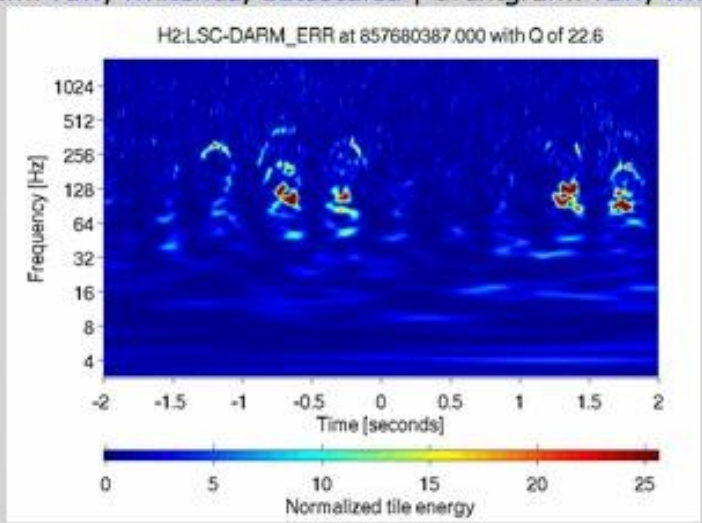


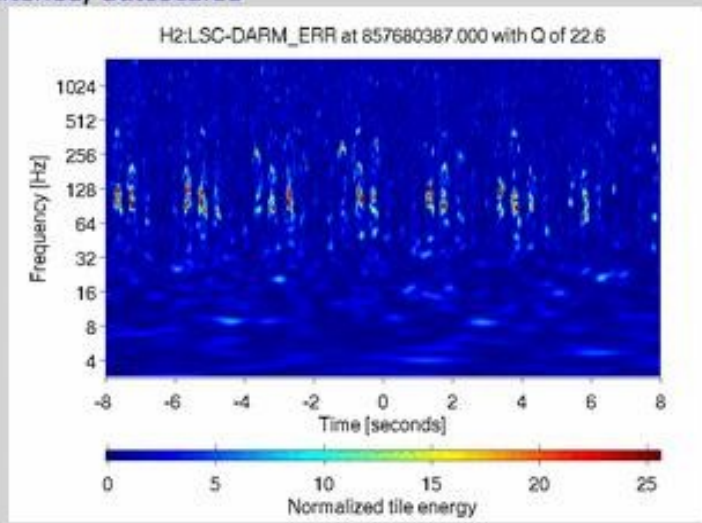


H2:LSC-DARM_ERR (t = 857680386.750 s, f = 1.1×10^{2} Hz, Q = 2.3×10^{1}, Z = 3.2×10^{1}, X = 4.8×10^{-6} $Hz^{-1/2}$)

time series: raw, high passed, whitened | spectrogram: raw, whitened, autoscaled | eventgram: raw, whitened, autoscaled







Multiple-bounce fringe wrapping event. Characteristic time-frequency feature. Caused by O(10) bigger motion than usual.

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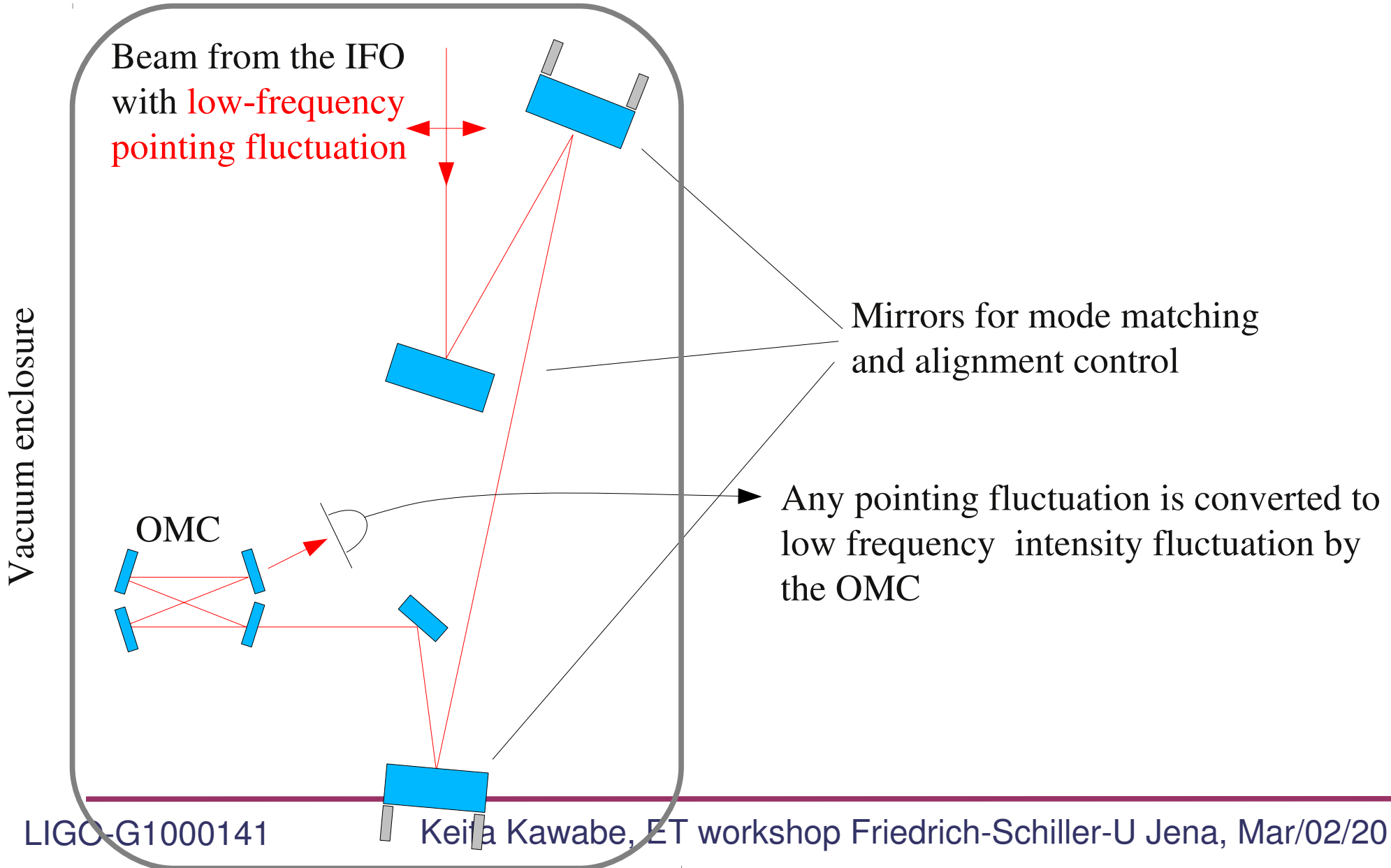
Cross-IFO scattering

- Events as bad as shown here can be (and was in S5) vetoed using optics motion amplitude
- Usual level for this specific path is much smaller than the back ground noise
- New baffle installed after S5: Baffling will make it OK for aLIGO
- Caution: Scattering areas/sites should be vibrationally isolated.

Magnetic Coupling Ex: OMC Alignment (in S6, no H1-H2 comparison)



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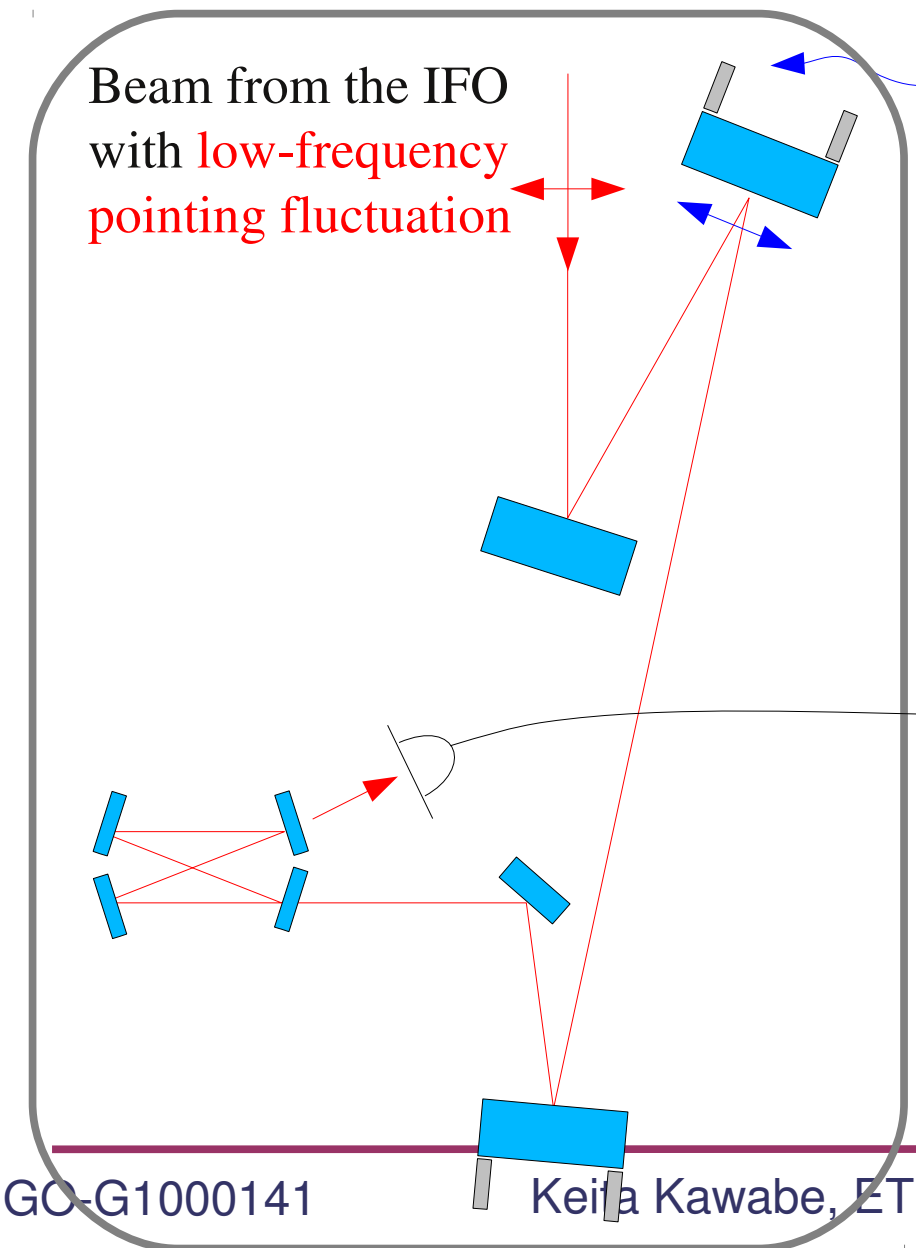
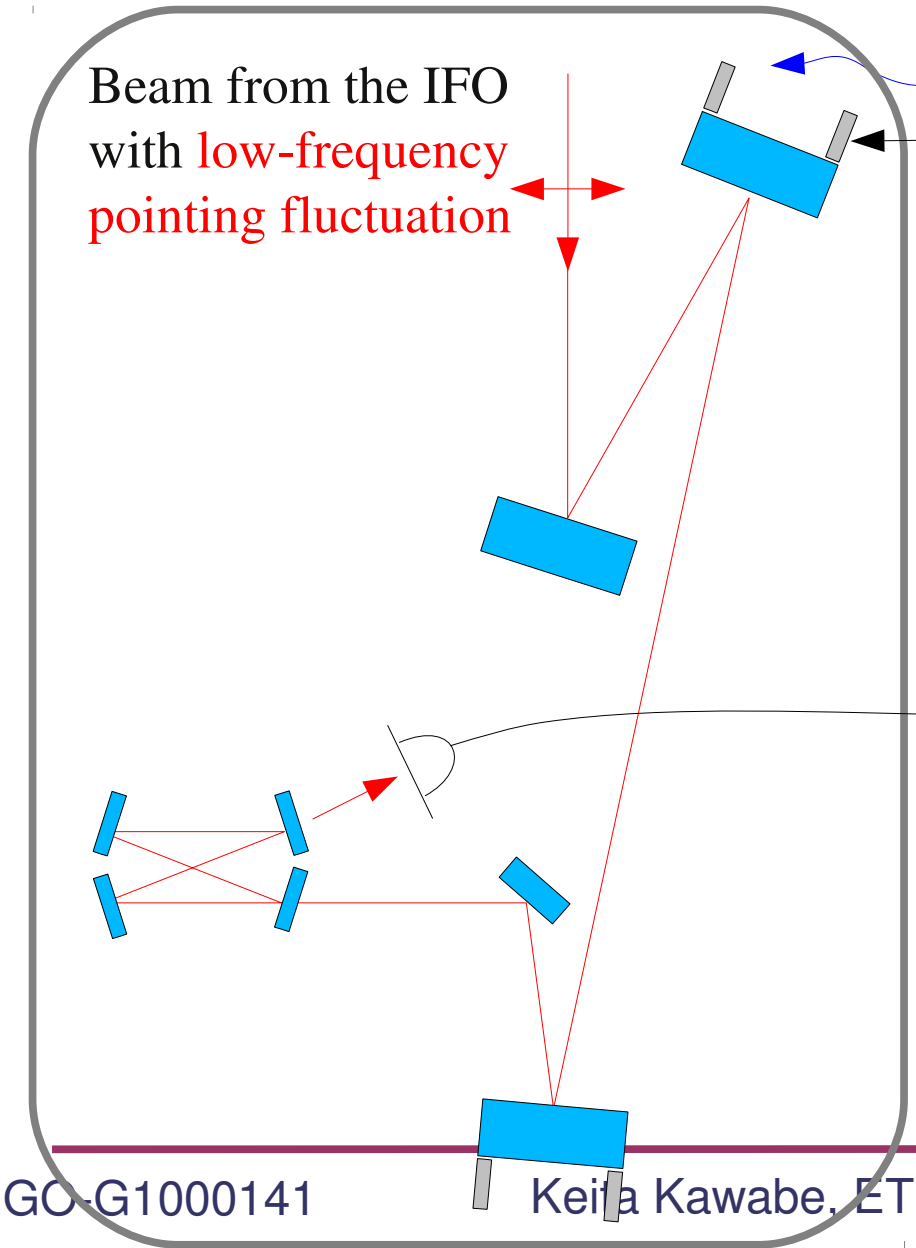


60Hz magnetic field interacts with the magnets on the steering mirror(s), modulating the pointing

Low frequency + 60Hz pointing fluctuation is converted to intensity fluctuation by the OMC, generating sidebands around 60 Hz

Mitigation: Feed forward of the magnetometer signal

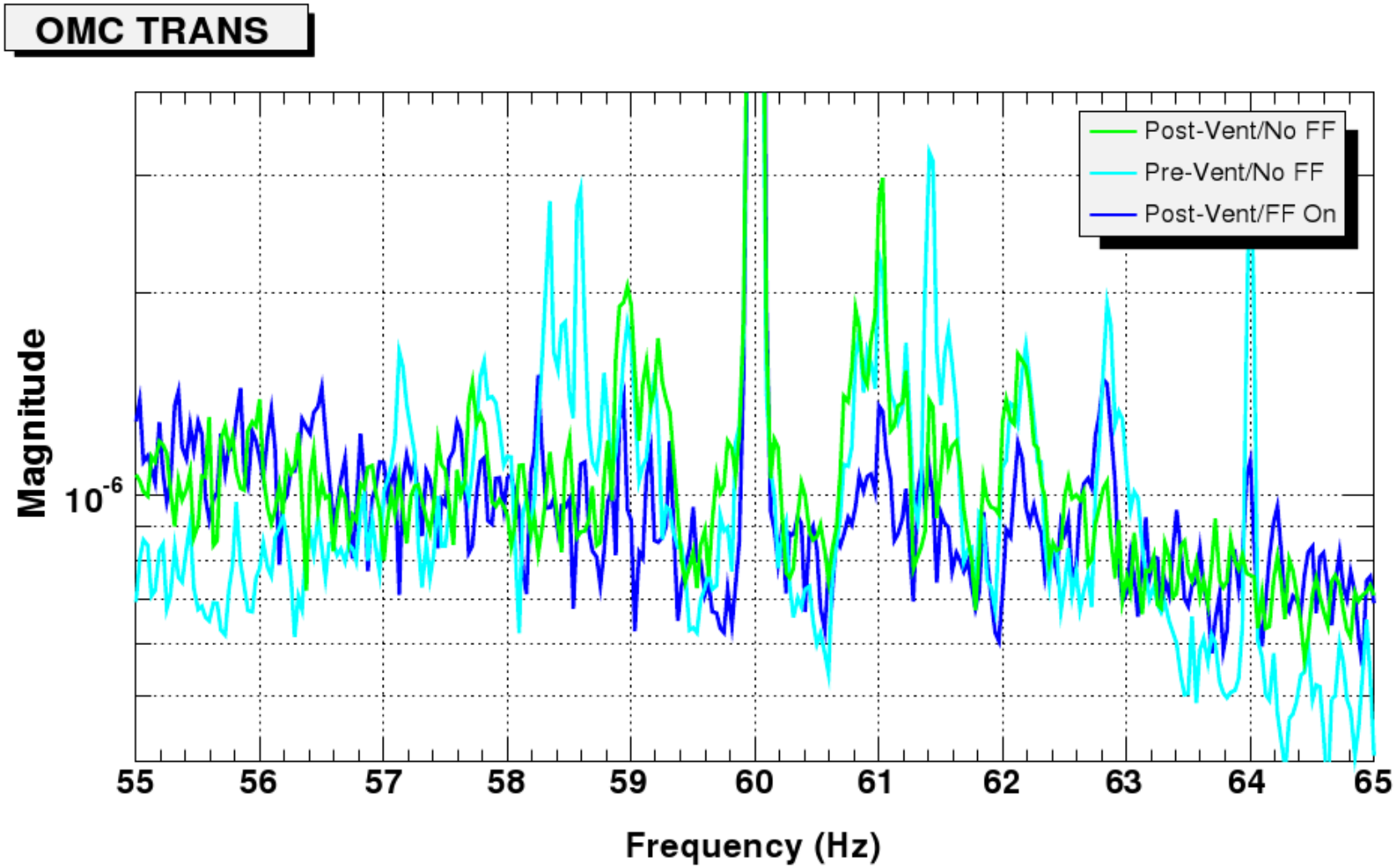


Magnetometer

60Hz magnetic field is monitored with a magnetometer, and is fed forward to the angle of the steering mirror, eliminating the 60Hz modulation.

Only low frequency pointing fluctuation is present, no 60 Hz sidebands!

Magnetometer Feed Forward: Works



LIGO Magnetic Coupling to the OMC Alignment

- In this case the magnets were much stronger than necessary.
- But you'd have never thought that this would happen, and it would have been difficult to predict before seeing it.
- Another “oops” moment.

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Summary

- There are benefits of co-located, co-linear IFOs
  - In the end we'll still have H1 and H2 in aLIGO
- Many difficult-to-predict common noise sources
  - Nothing that we couldn't mitigate/veto was found.
  - We WILL find more in aLIGO, though it looks OK for now.
- Unfortunately environmental noise matters. You should get worried even if you are not directly shaking the test masses.
- For some of the problems (e.g. cross-IFO scattering) some quantitative projection is possible
  - You should start thinking about the requirement for 3rd generation IFOs now.

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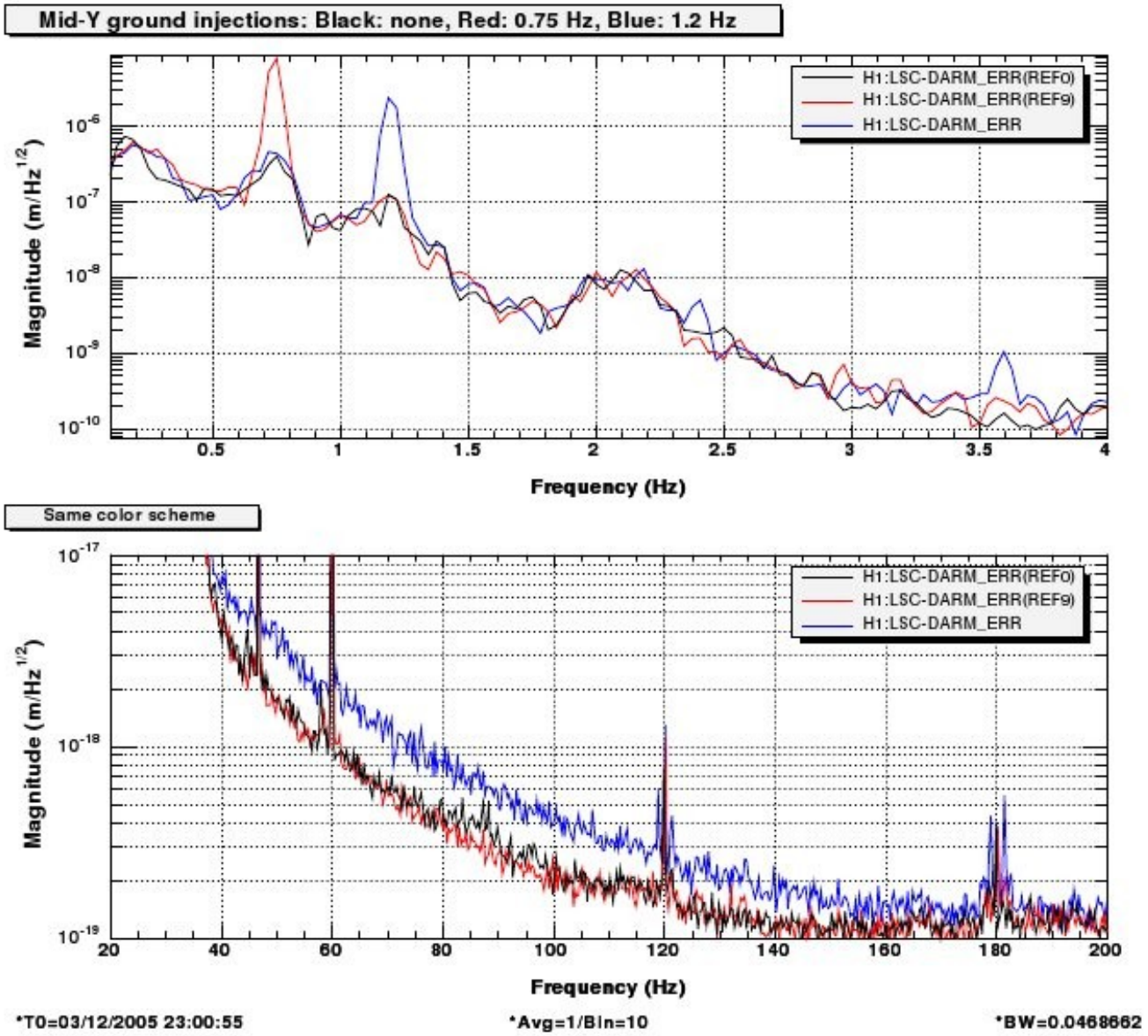
The talk ends here

- If you really want to know more about the environment noise, you want to talk to Robert Schofield. He's THE environment guy.

http://www.ligo-wa.caltech.edu/~robert.schofield/iLIGOenvironmentalInflueinces.htm

Another example: coil current upconversion

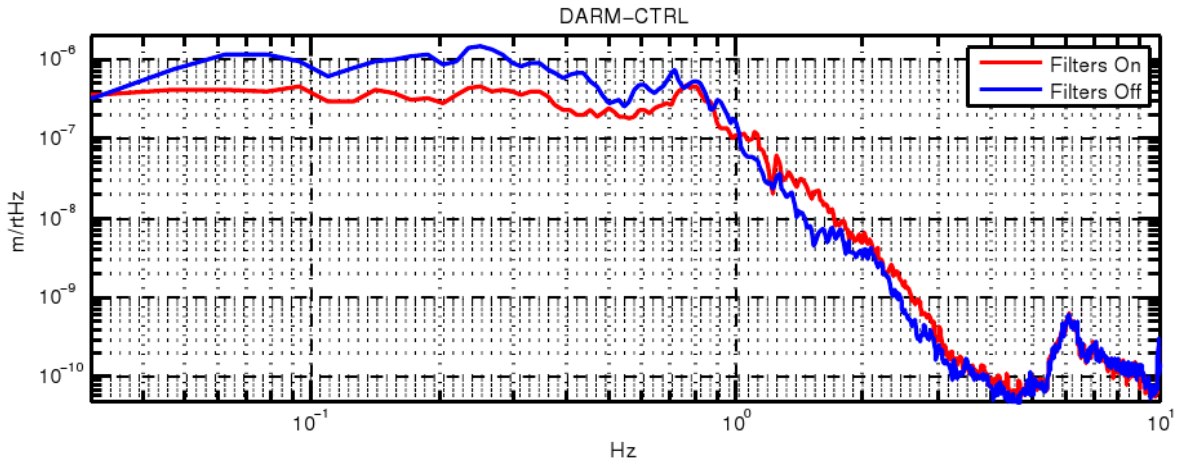
- When we push the voice-coil actuator hard at low frequency, we observe a broad high frequency noise.
- It's the current, not the displacement.

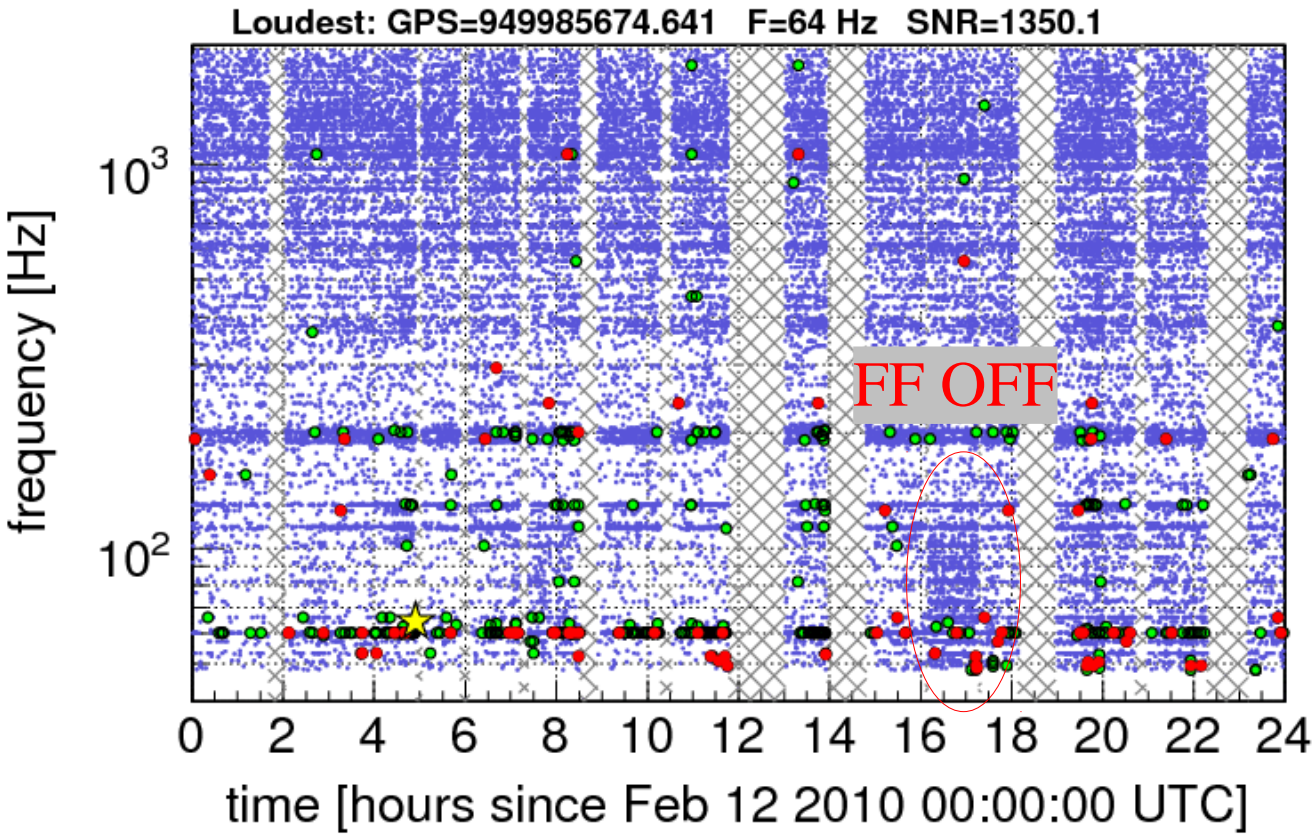


Coil current upconversion

- Barkhausen? Magnet swapped (not all), not much change
- Bad electronics? Was fixed (upconversion test yet to be done)
- Something else? Bad wire stand-off?
- Offloading coil to pzt (H1) and HEPI (L1) works.
- Nothing conclusive yet.
- aLIGO probably better
  - no coil
  - monolithic suspension
- Incoherent between 2 IFOs

Offsetting current to external actuators





- "On" and "Off" represents with/without feed forward of seismometer signals
- Current is offset to the external actuator (top plot)
- This is reducing number of glitches in L1 (bottom plot, omega glitchgram)

Dams!?
Who would have thought that!