LIGO-G1100174

DC Readout in Enhanced LIGO

Enhanced LIGO

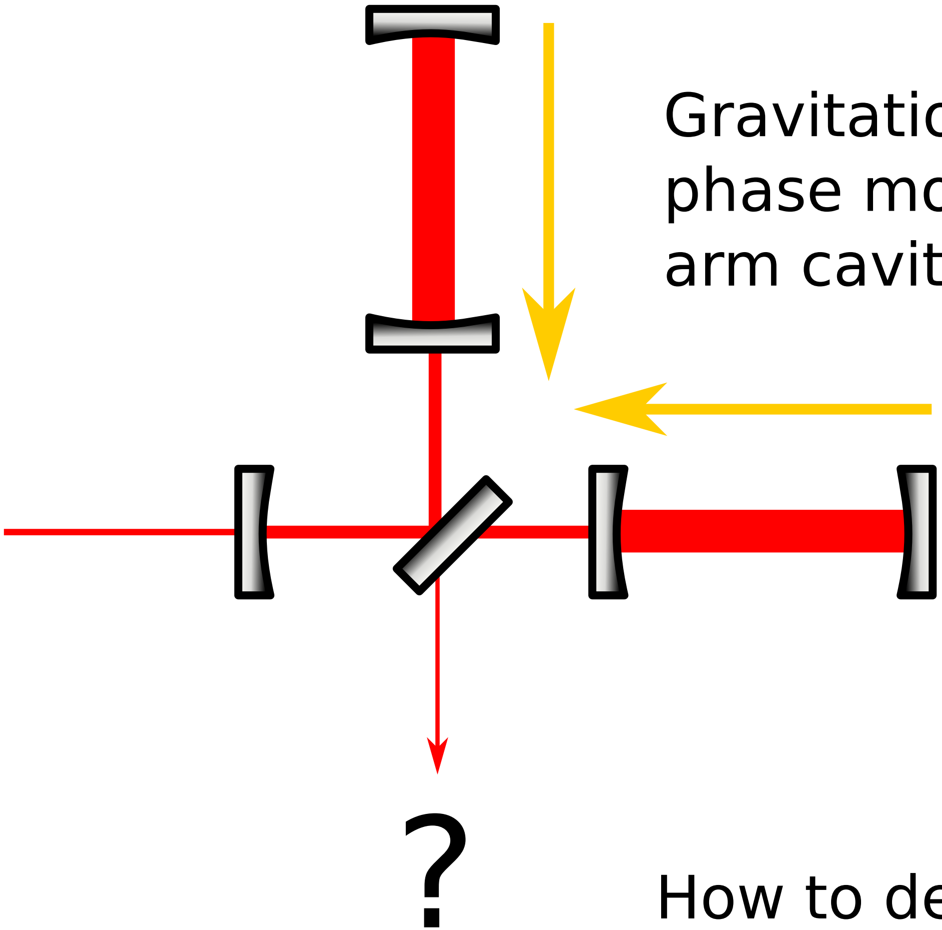
- Try out Advanced LIGO technologies

- Bet that increased sensitivity outweighs the downtime
  *exposure = time * (range)^3*

More Power → New Laser
New input optics
New Thermal Compensation
New Alignment Control

Output Mode Cleaner
DC Readout

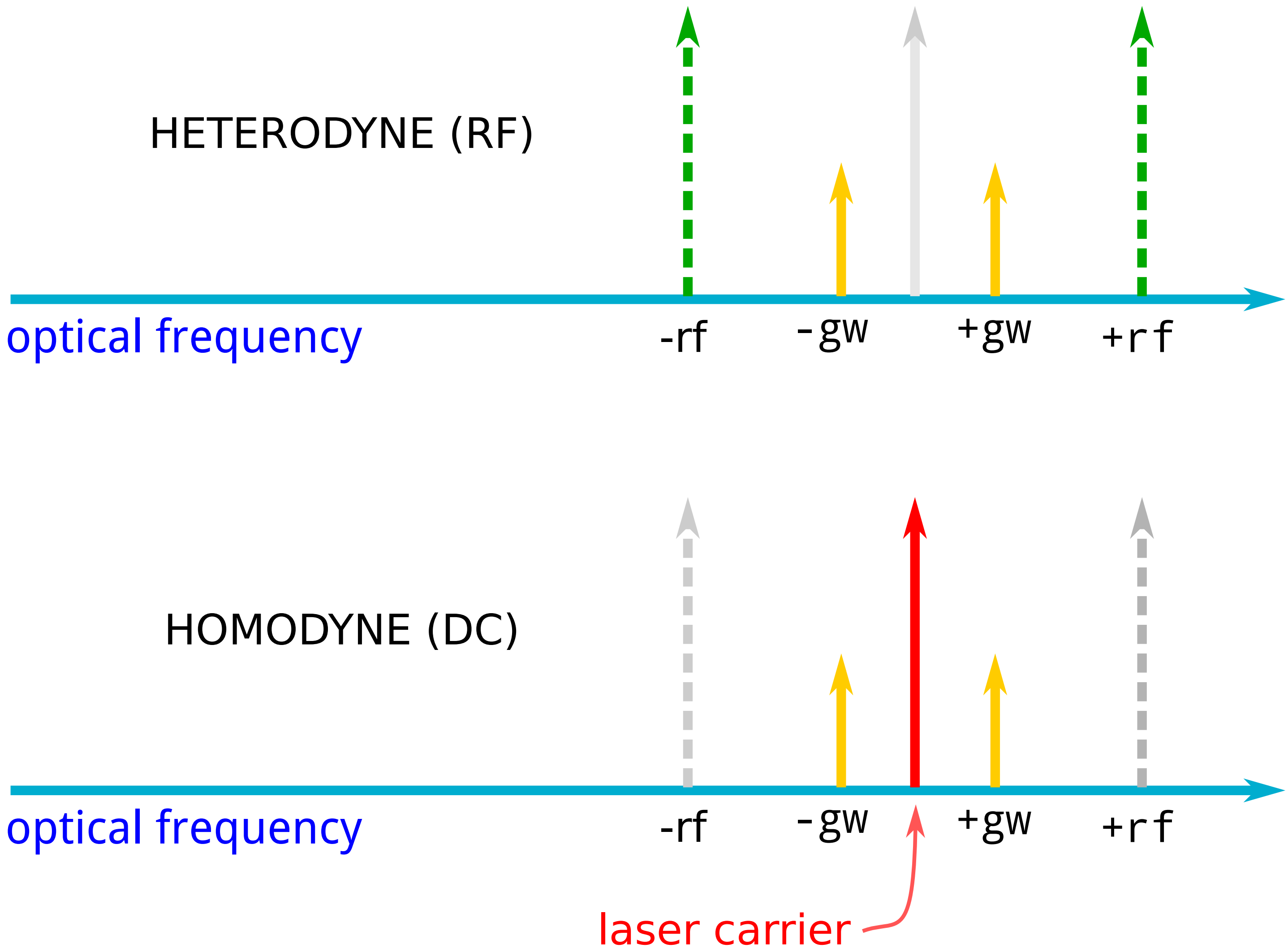
Interferometer



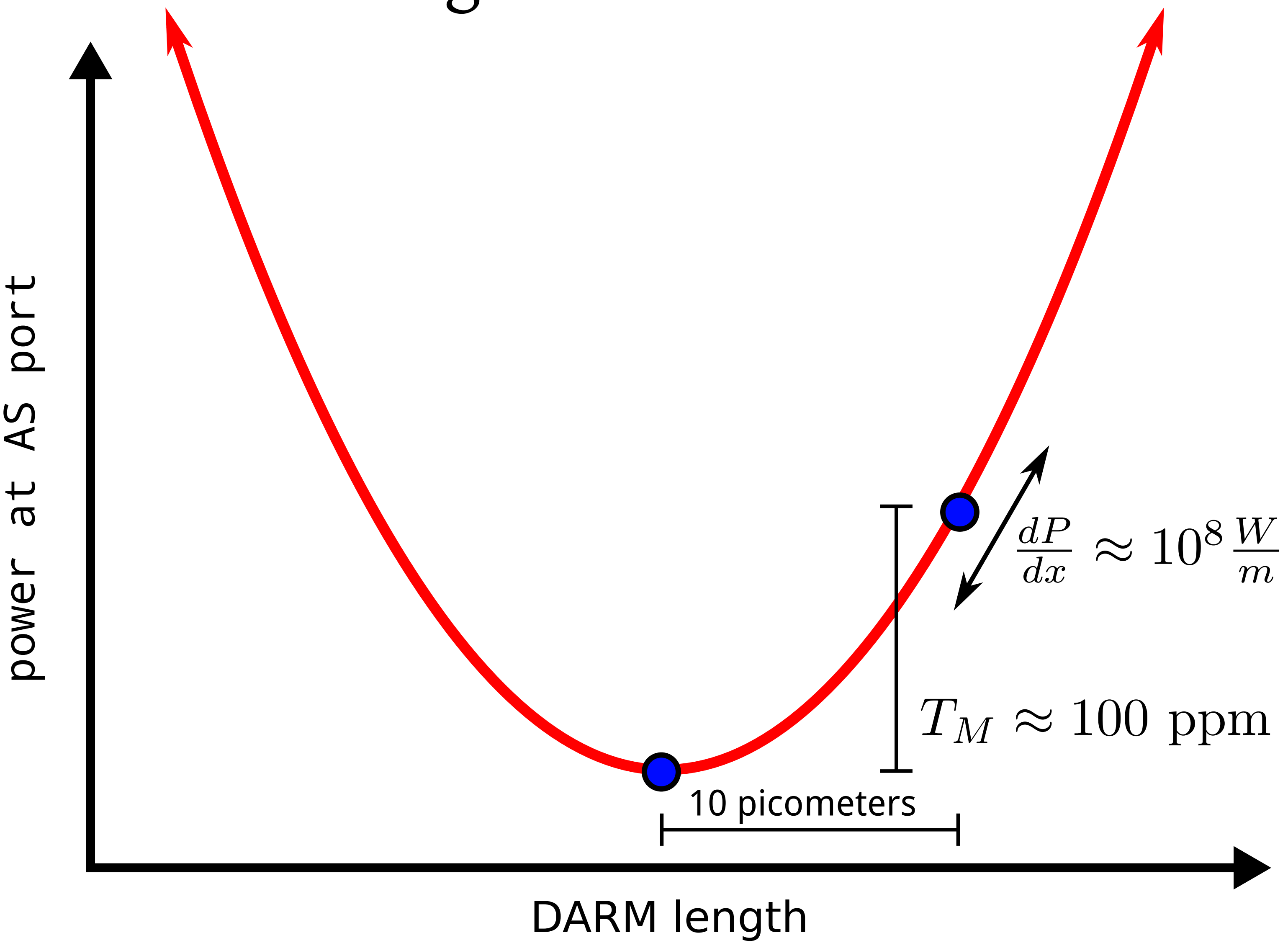
Gravitational waves produce phase modulation in the arm cavities

How to detect it?

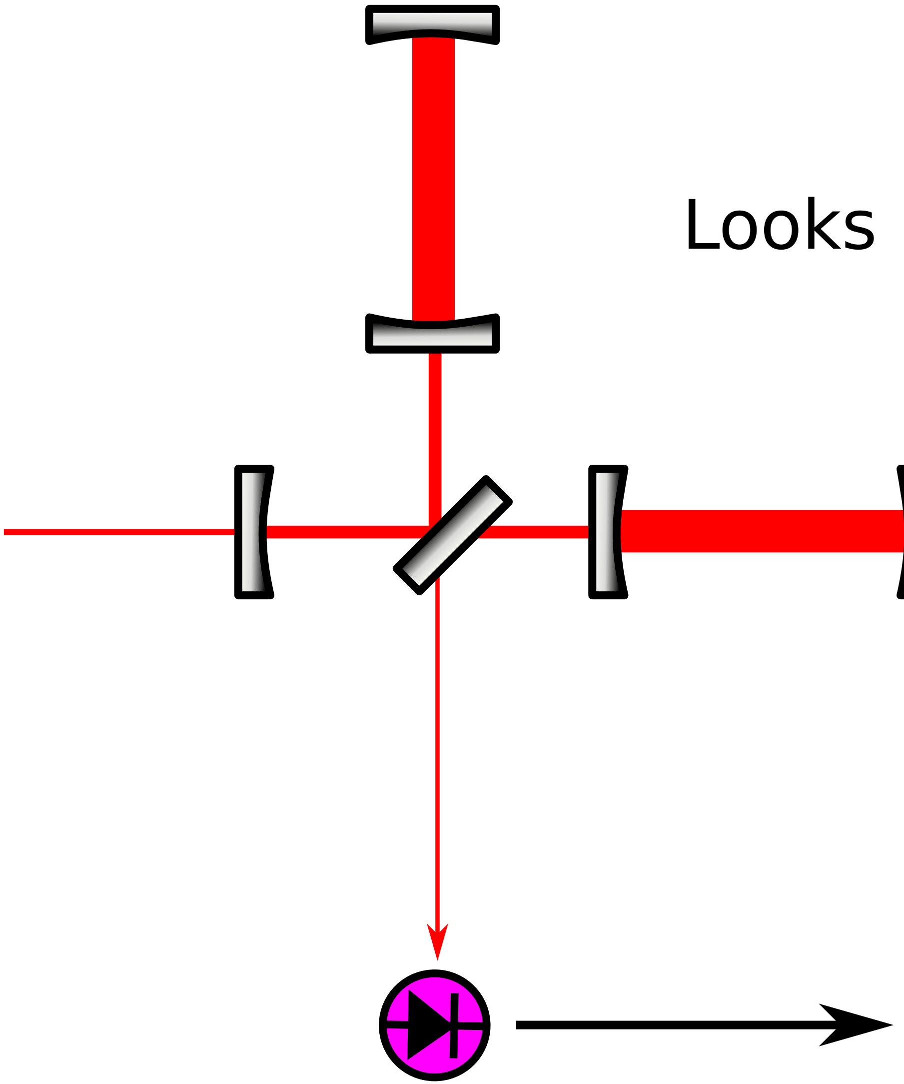
DC Readout: sideband view



DC Readout: fringe view

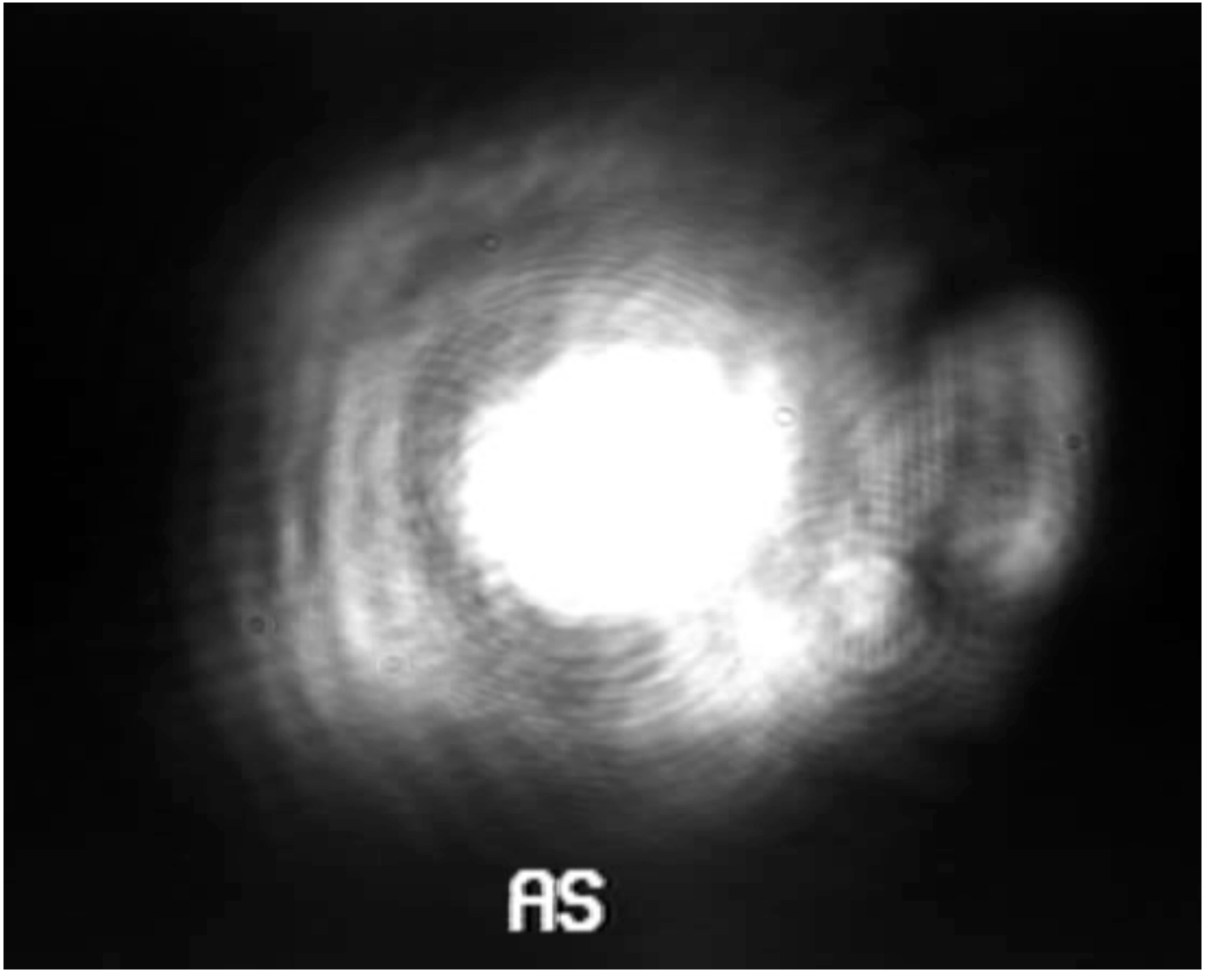


DC Readout



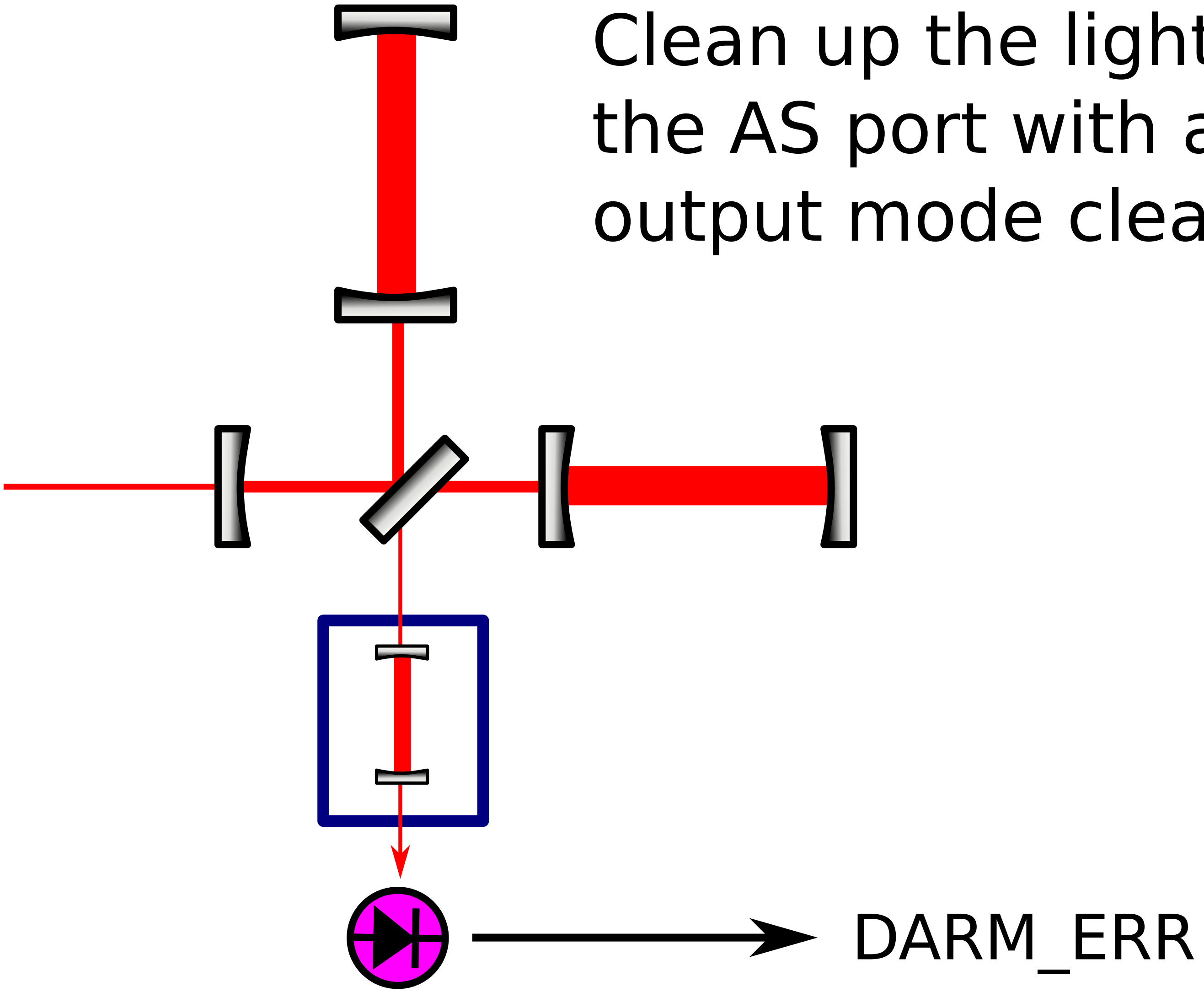
Looks pretty simple...

Junk Light



DC Readout with OMC

Clean up the light at the AS port with an output mode cleaner.



DC Readout promises

- fundamental improvement in SNR

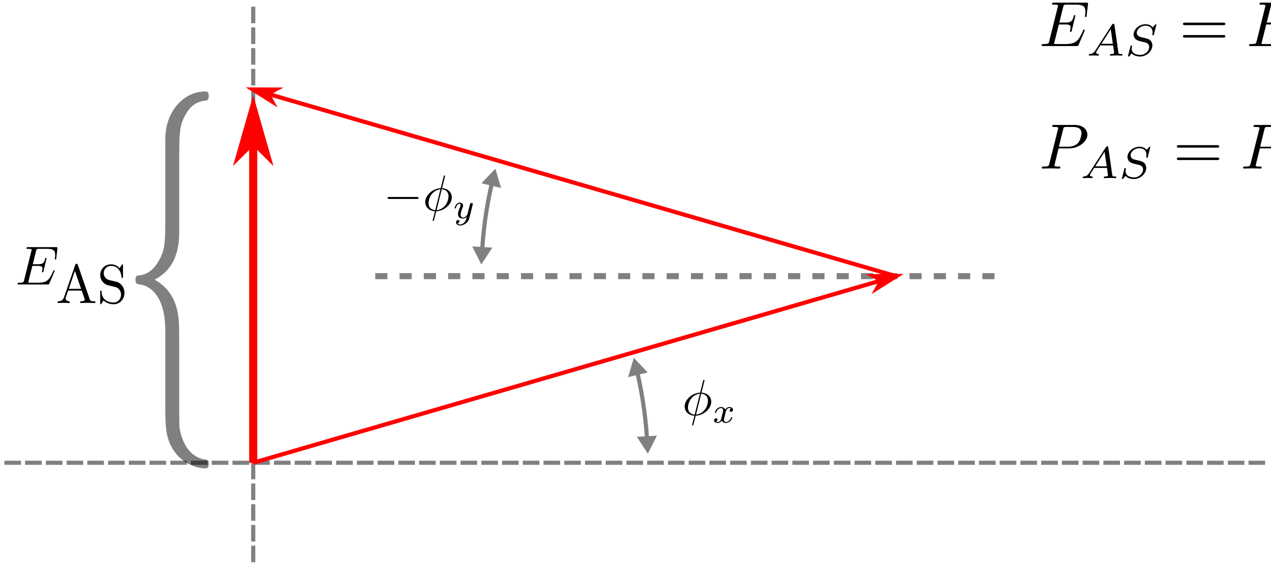
- technical improvement in SNR
  - perfect overlap of local oscillator and signal beams
  - junk light removal by OMC

- independence from RF oscillator noises
  - exploit the amazing filtering ability of the interferometer

- Easier platform for squeezed light injection

- Easier to handle higher power

DC Readout: phasor view



$$E_{AS} = E_{BS}\sin\left(\delta\phi\right)$$

$$P_{AS} = P_{BS}\sin^2\left(\delta\phi\right)$$

optical gain: $S_{DC} = \frac{\partial P}{\partial x} \approx 2\sqrt{P_{BS}P_{AS}}\,(137)\left(\frac{f_c}{f}\right)\left(\frac{2\pi}{\lambda}\right)$

How do we choose the DARM offset?

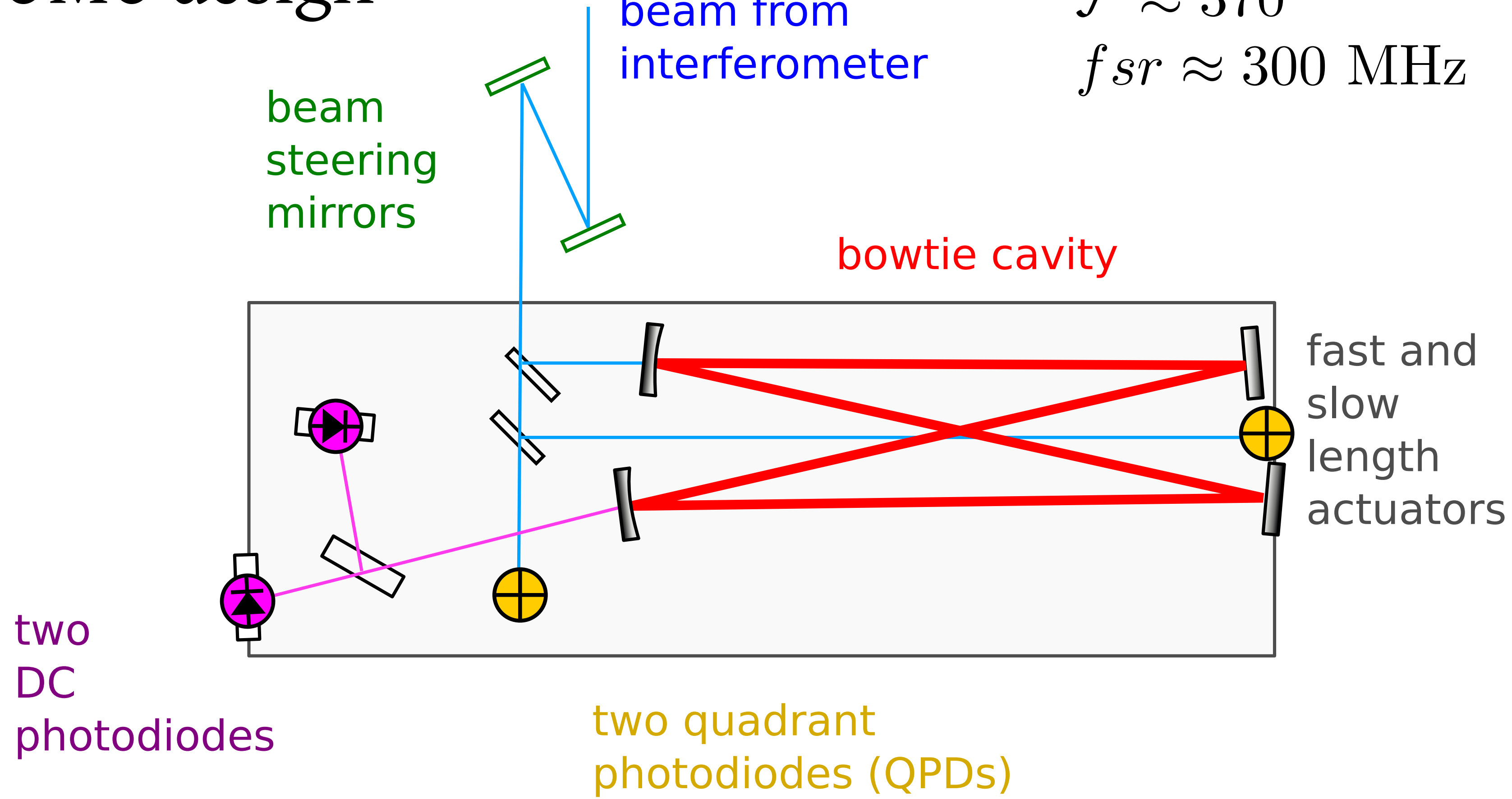
- Must be much greater than residual DARM displacement
- Must overcome contrast defect and electronics noise
- But not excessively detrimental to power recycling

In practice: turn the knob to get the best sensitivity

OMC design

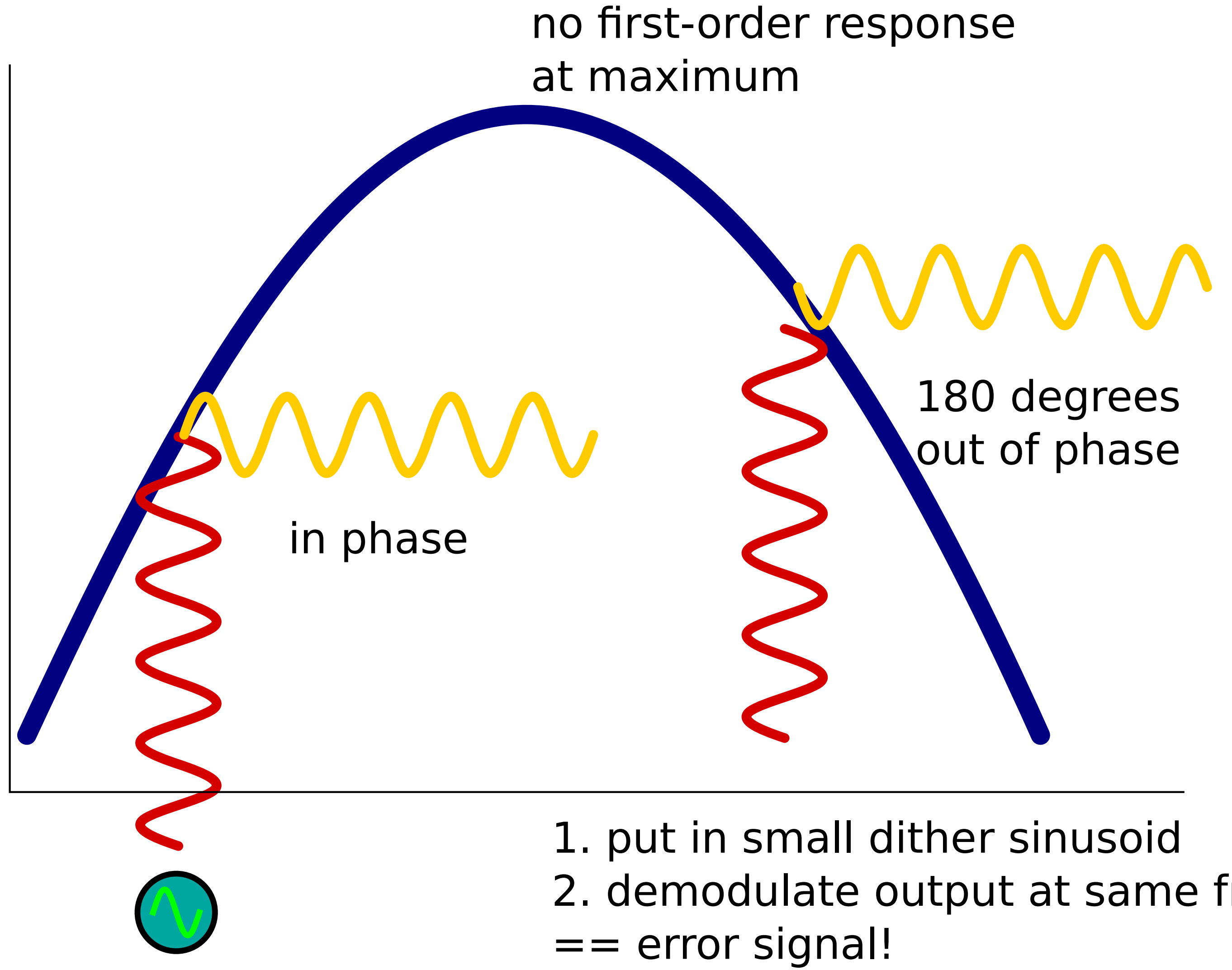
$\mathcal{F} \approx 370$

$fsr \approx 300\ \mathrm{MHz}$



monolithic, suspended, in-vacuum

Dither Locking

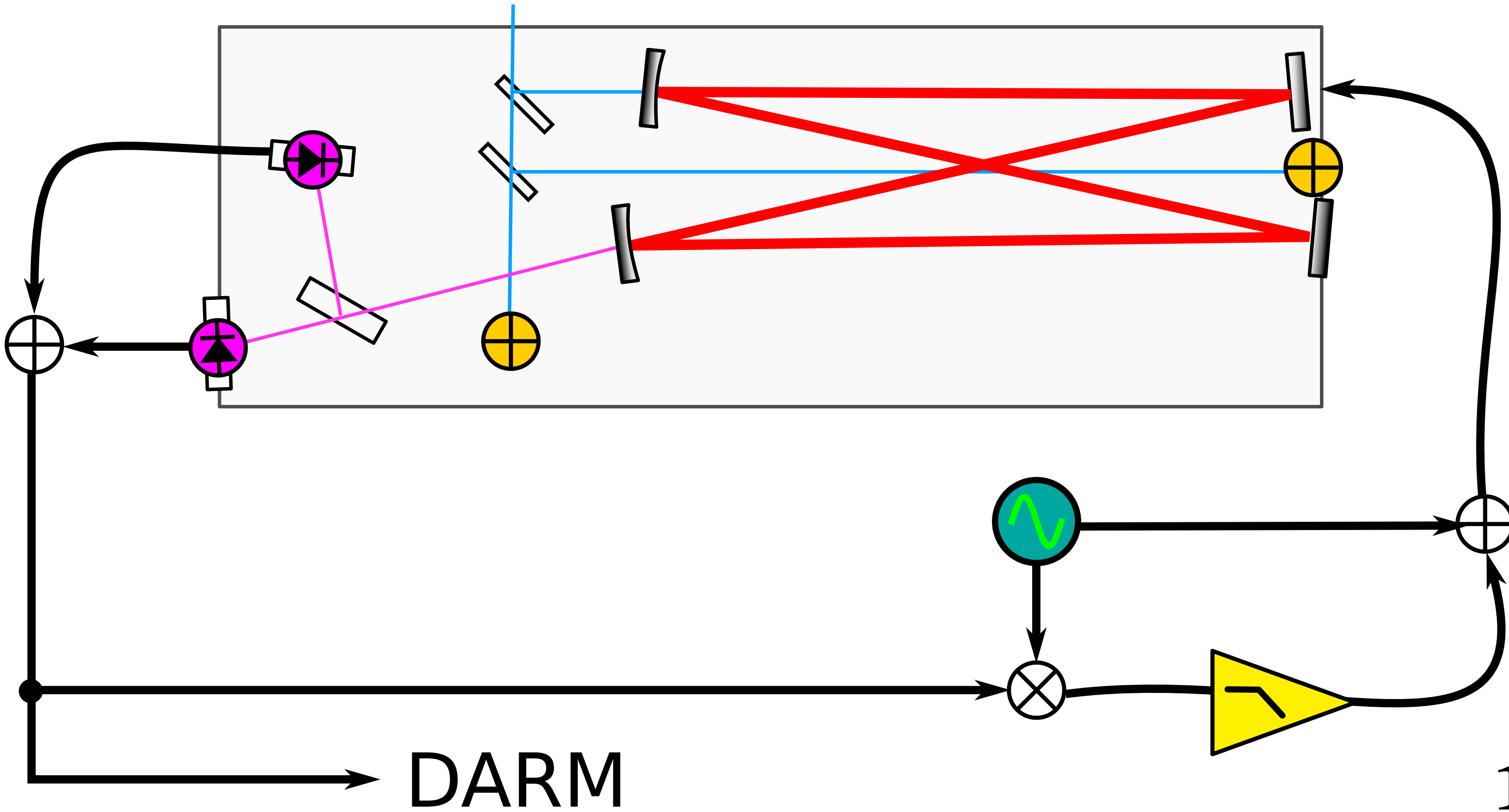


1. put in small dither sinusoid
2. demodulate output at same freq
== error signal!

OMC Length Control

Cavity length dithered at ~10 kHz via PZT actuator

PZT offloaded onto slow, long-range thermal actuator



OMC Alignment Control

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The mode cleaner will clean the modes if you can
identify what mode you want to keep.
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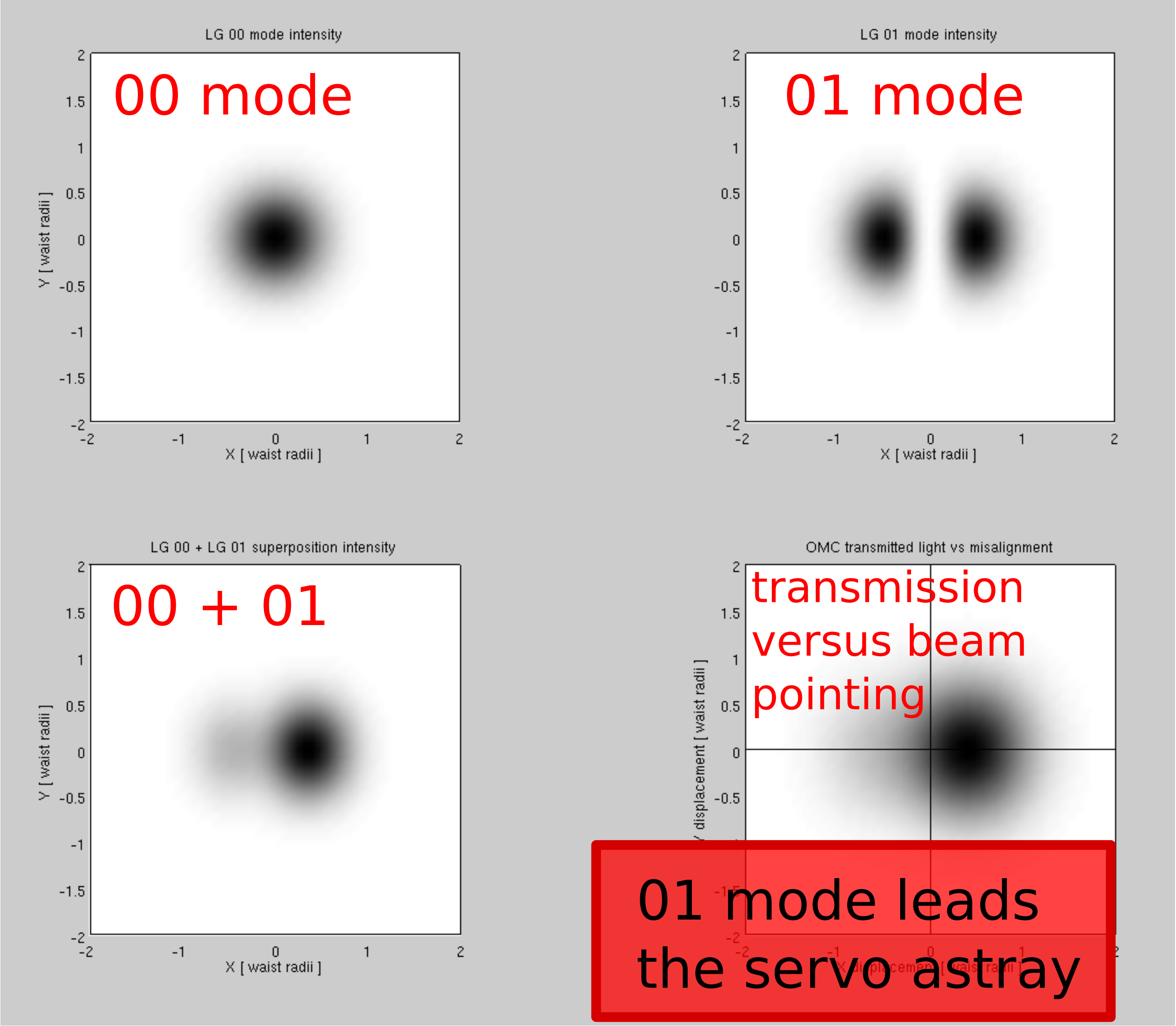
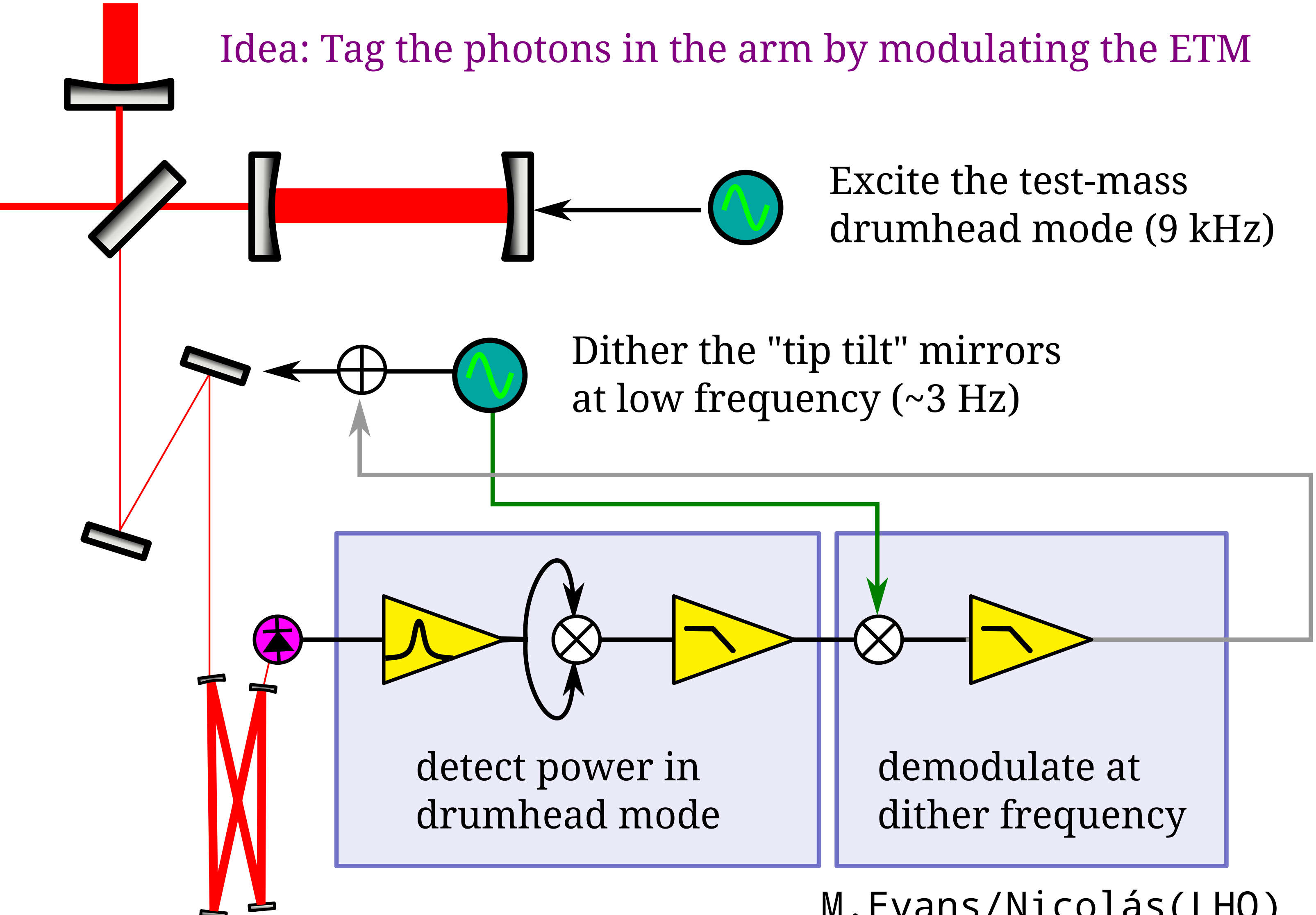
Initial idea: maximize transmission through the OMC

Junk light confuses simple servo



Drumhead Beacon Dither

Idea: Tag the photons in the arm by modulating the ETM



Optical Gain vs Jitter

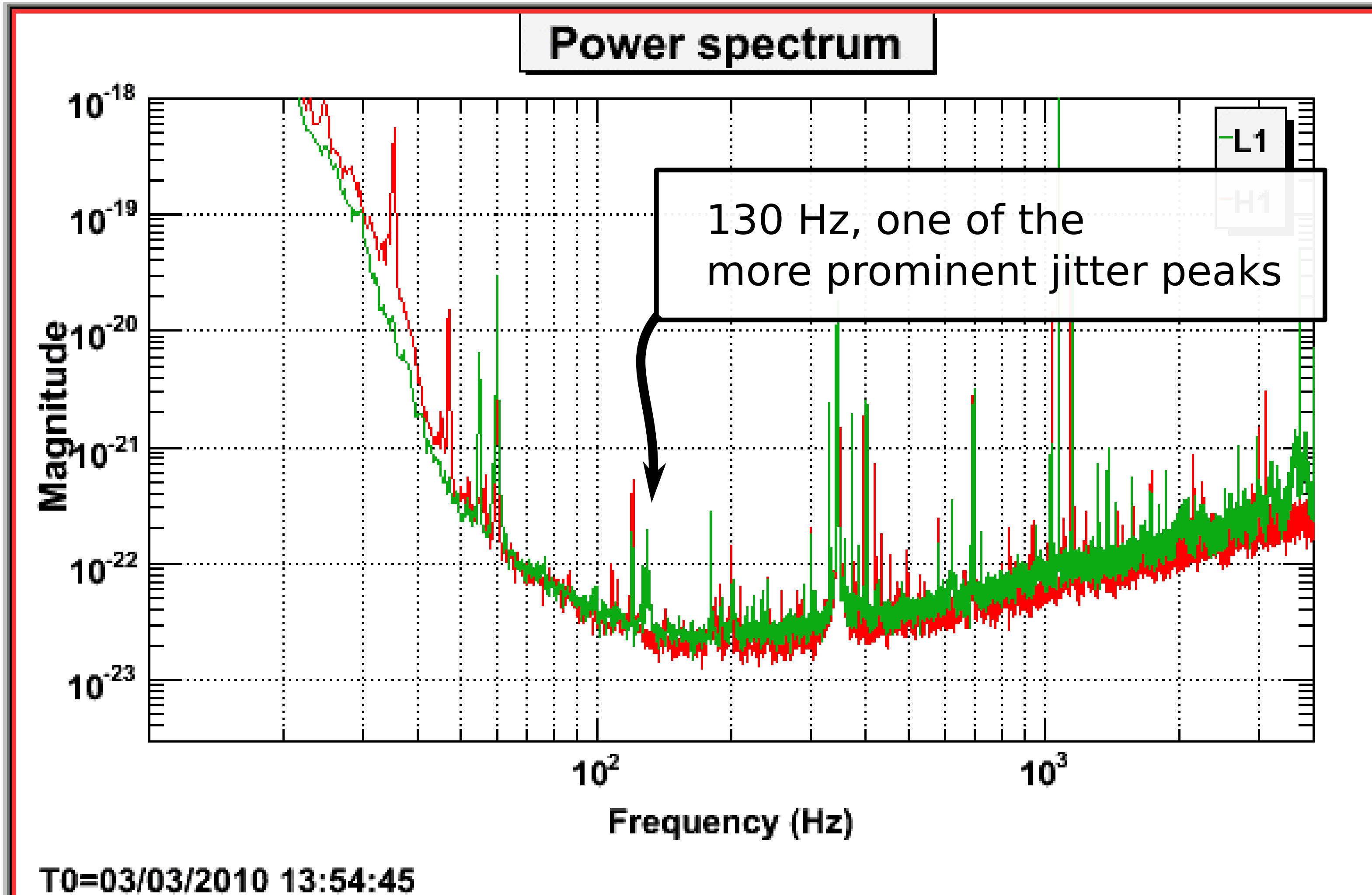
But if we optimize alignment for optical gain...

...and best optical gain does not correspond to maximum transmission

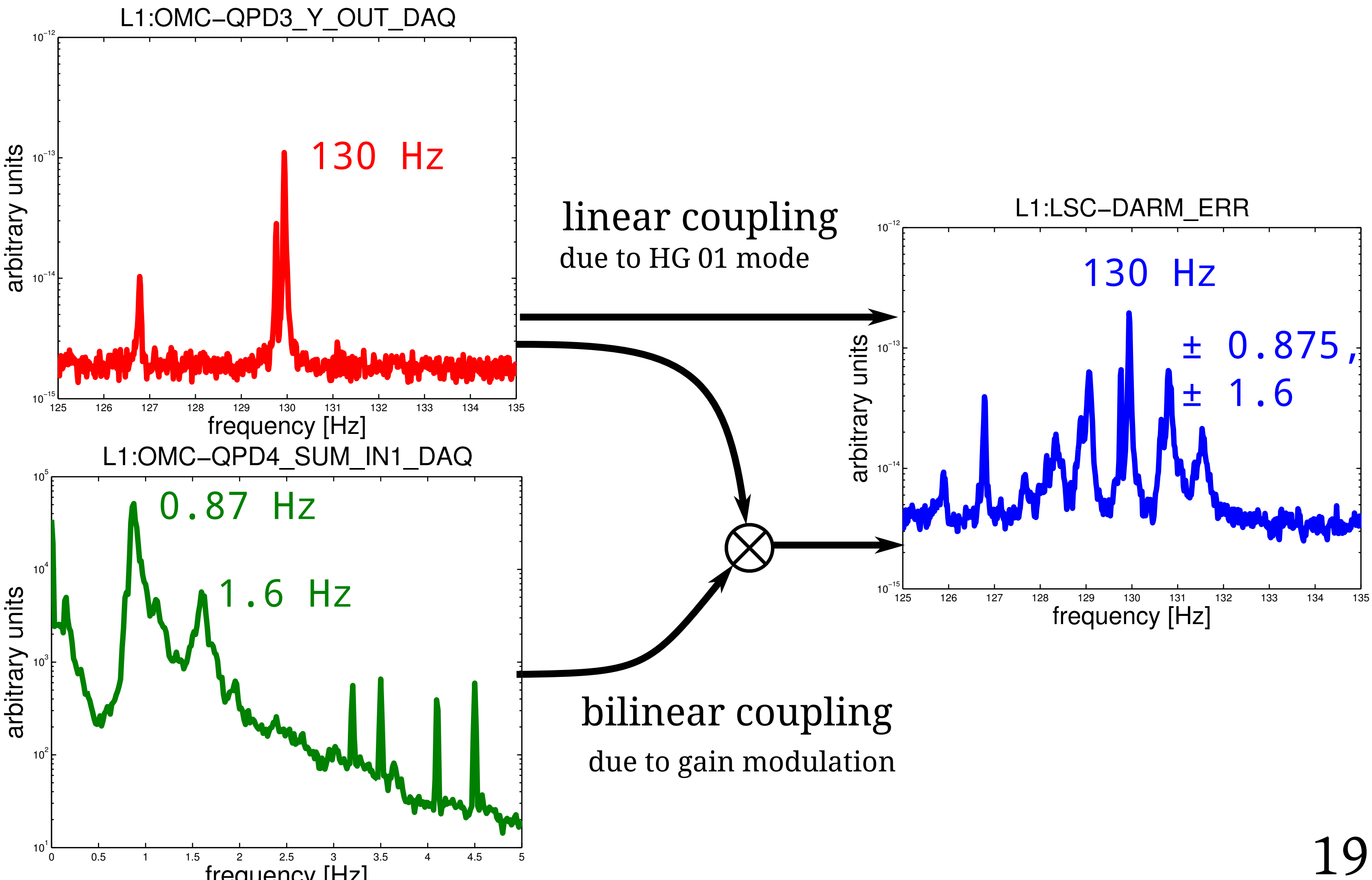
...then we introduce a beam jitter coupling

Beam Jitter Noise

Most significant new noise source

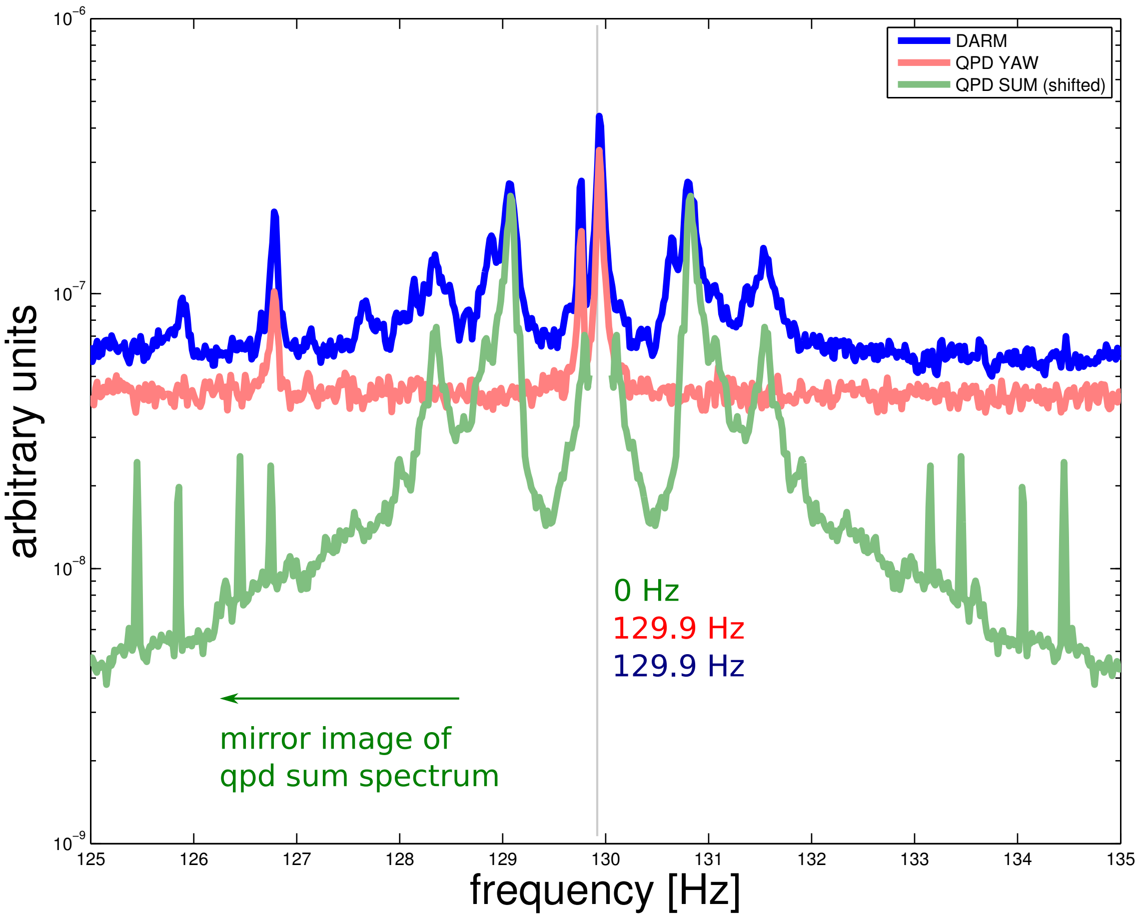


A closer look at 130 Hz

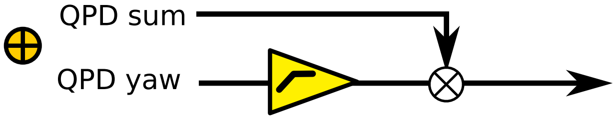


A closer look at 130 Hz

Quick check: overlay the spectra



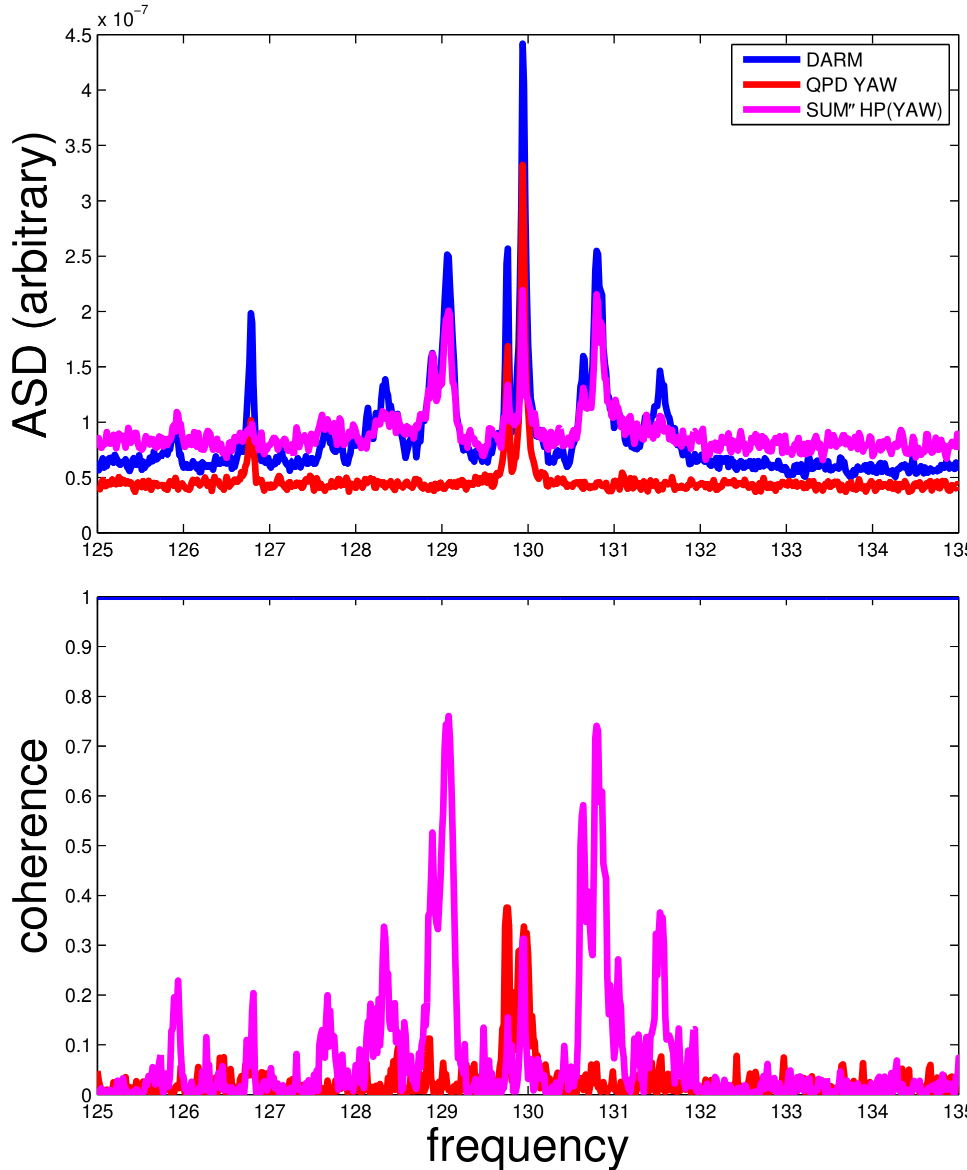
Can we predict the timeseries?



One of several possible bilinear couplings.

Yes. Good coherence shows this is a real coupling.

(bilinear wiener filtering?)
have to be careful to not subtract DARM from DARM



Beam jitter mitigation

- Remove the offending resonance or increase isolation
  i.e. tip-tilt blade springs, no fixed mirror

- Reduce sensitivity to the motion
  i.e. clever telescope design

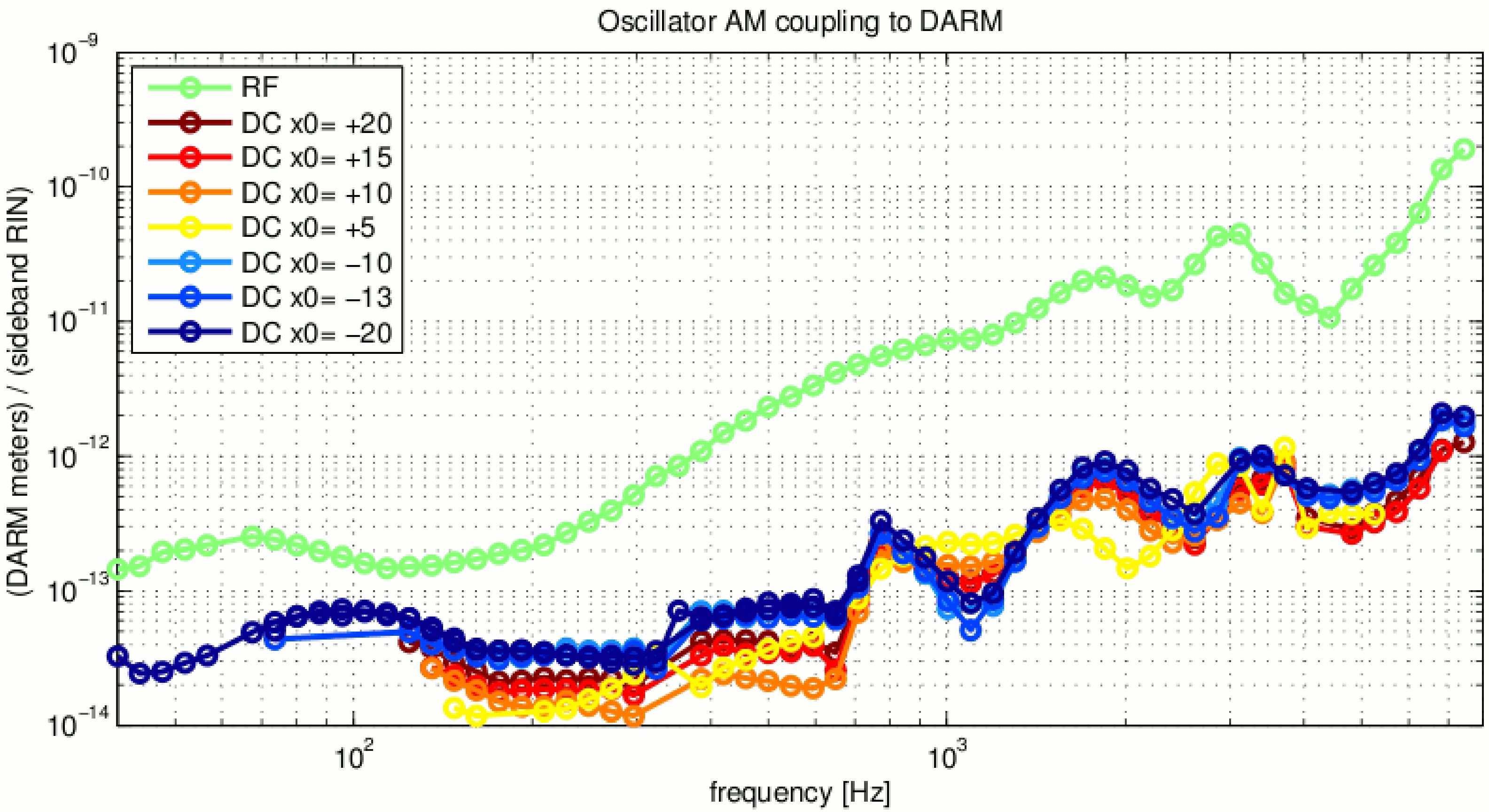
- Cancel the motion (feedback/forward)
  i.e. 60 Hz magnetometer FF

- Reshape the output beam
  i.e. use WFS1 to push on the ASC

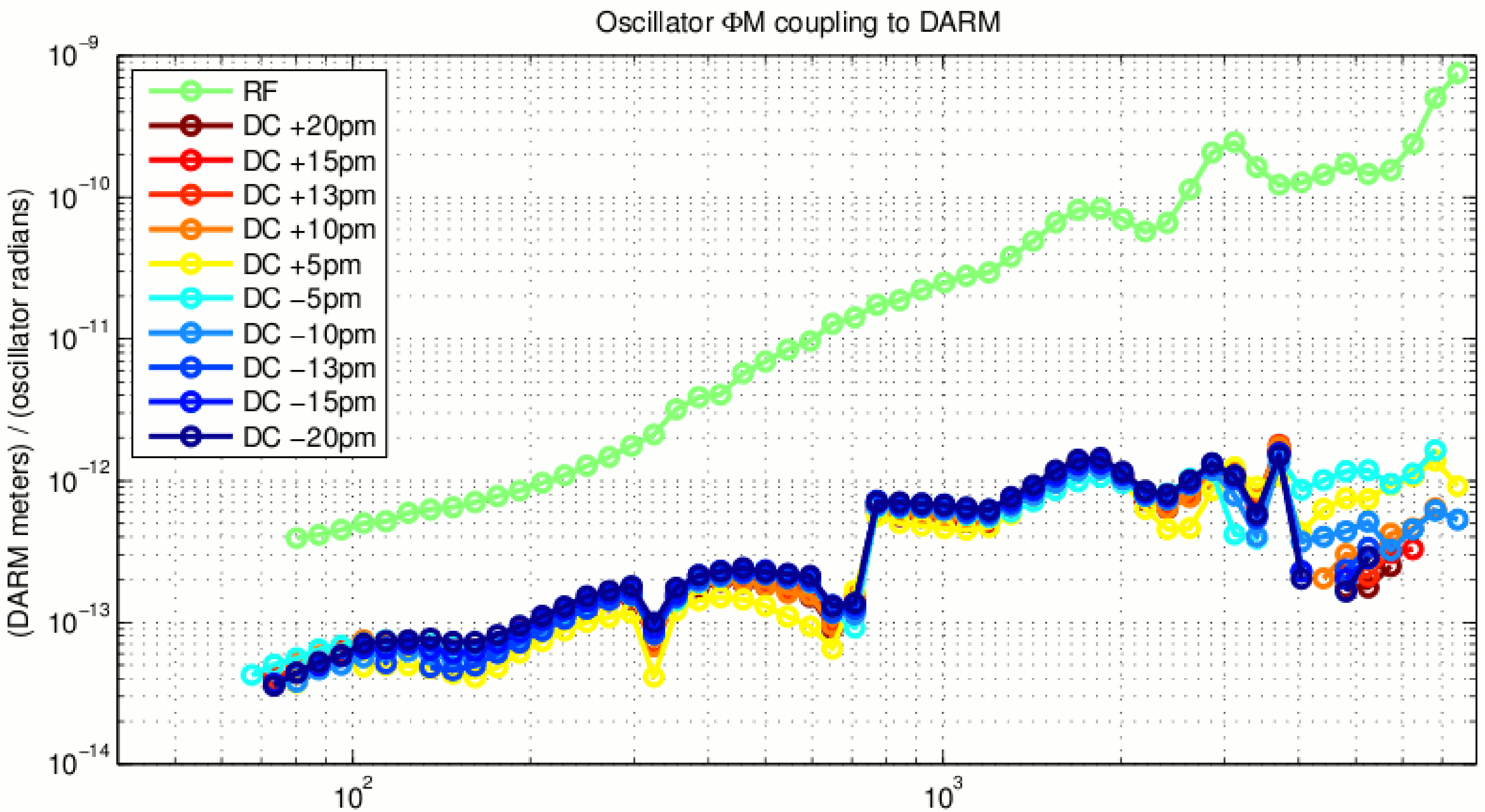
Noise Couplings

* Oscillator amplitude
* Oscillator phase
* Laser intensity
* Laser frequency

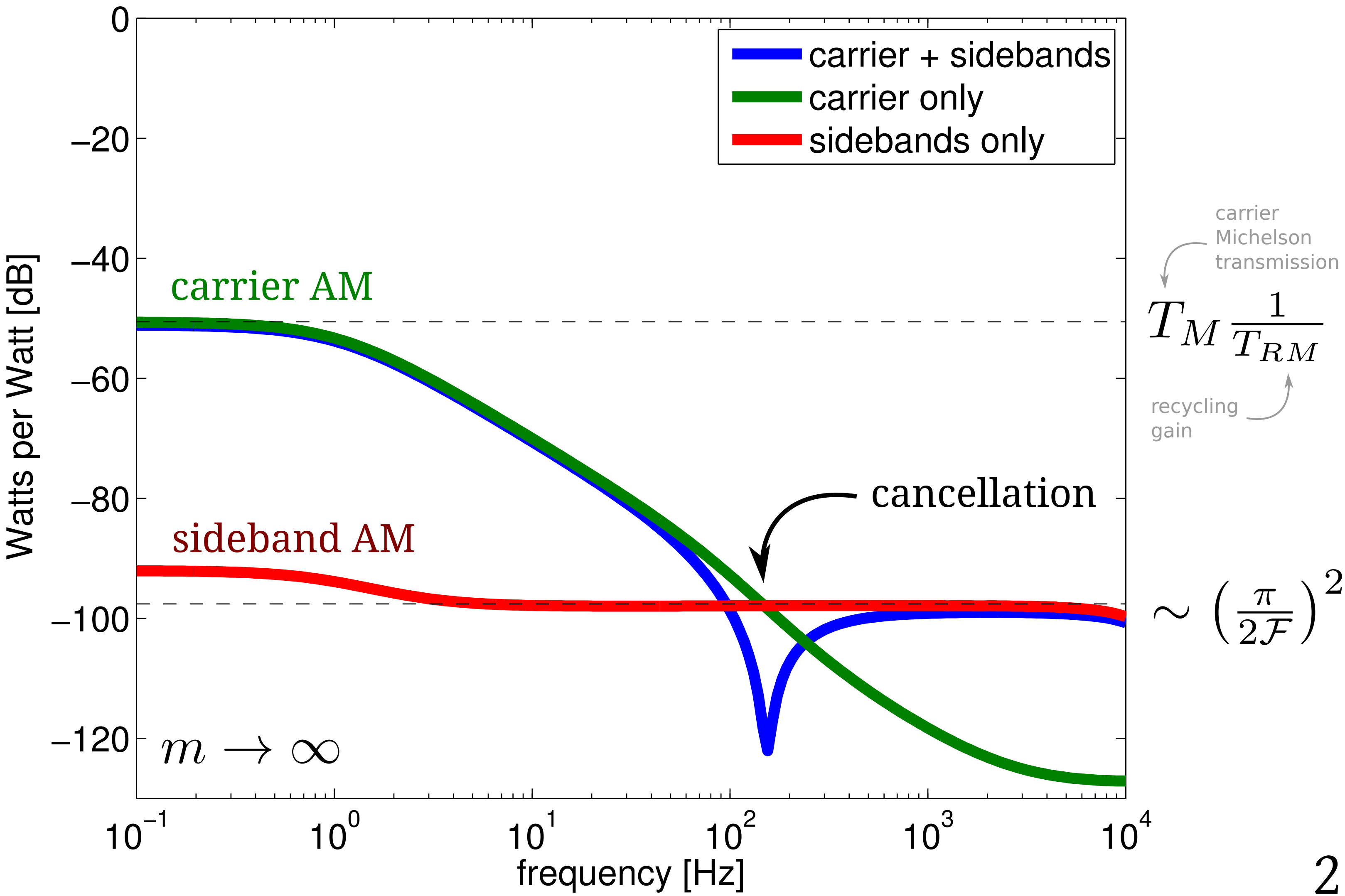
Oscillator Amplitude noise



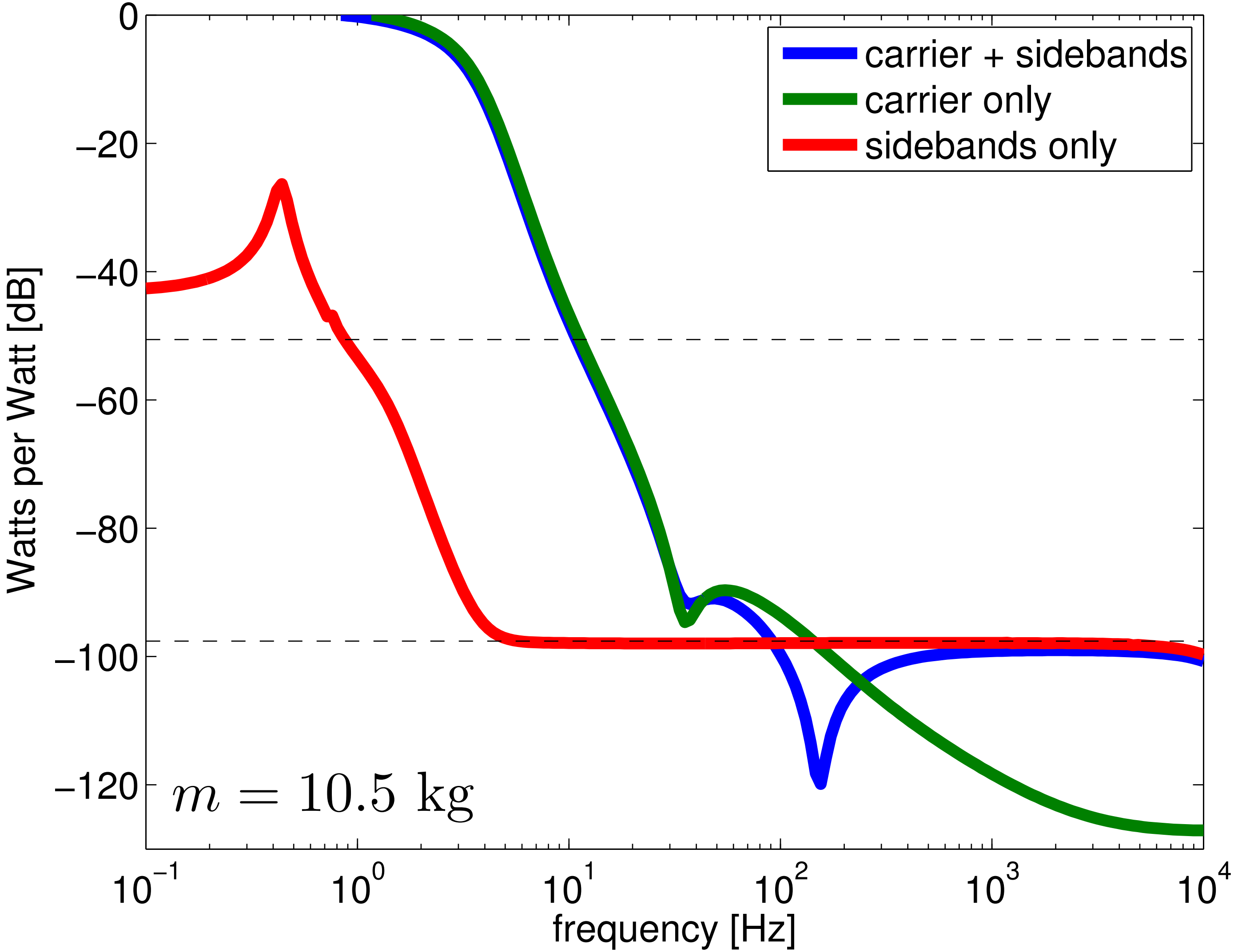
Oscillator Phase noise



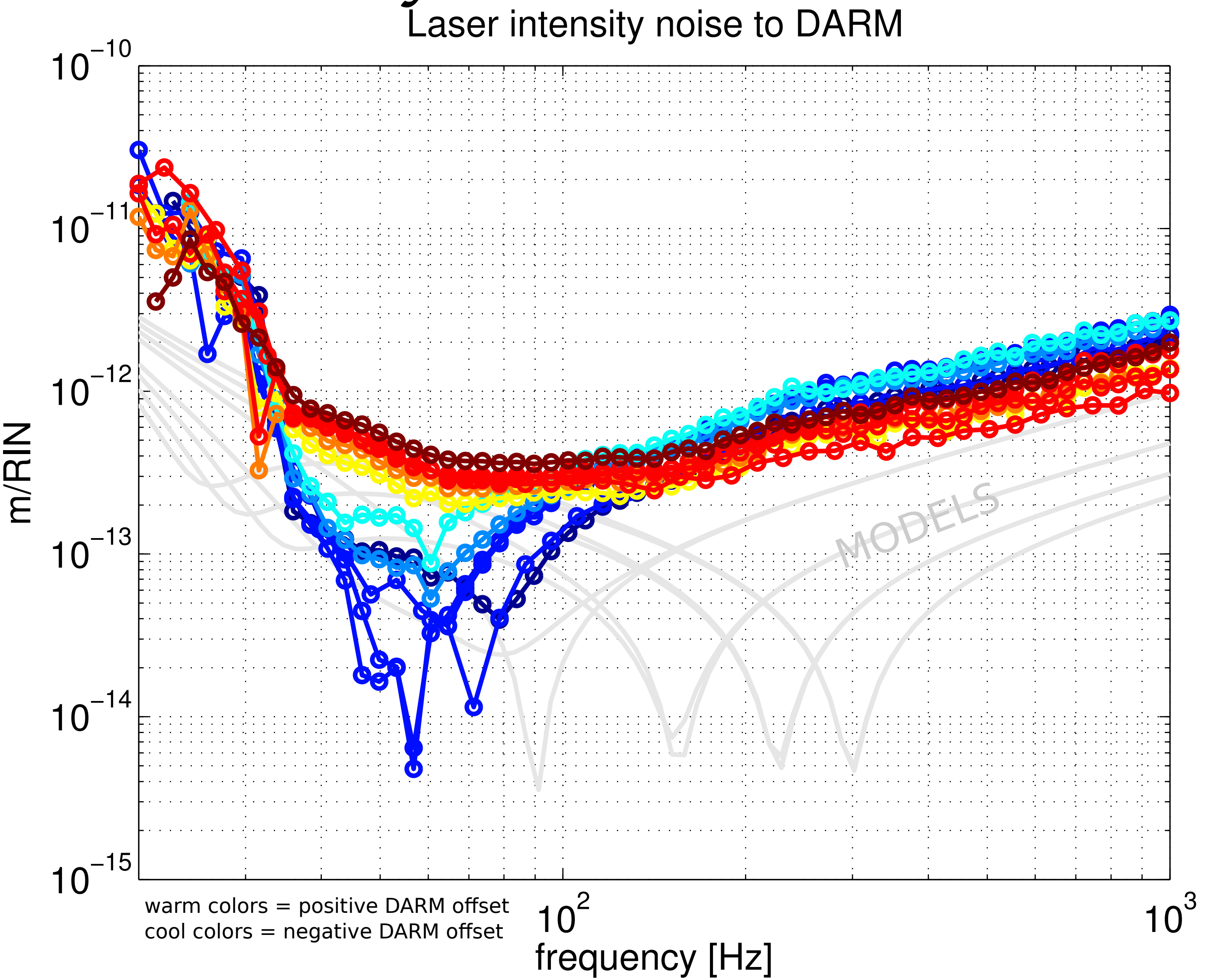
Anatomy of intensity noise coupling



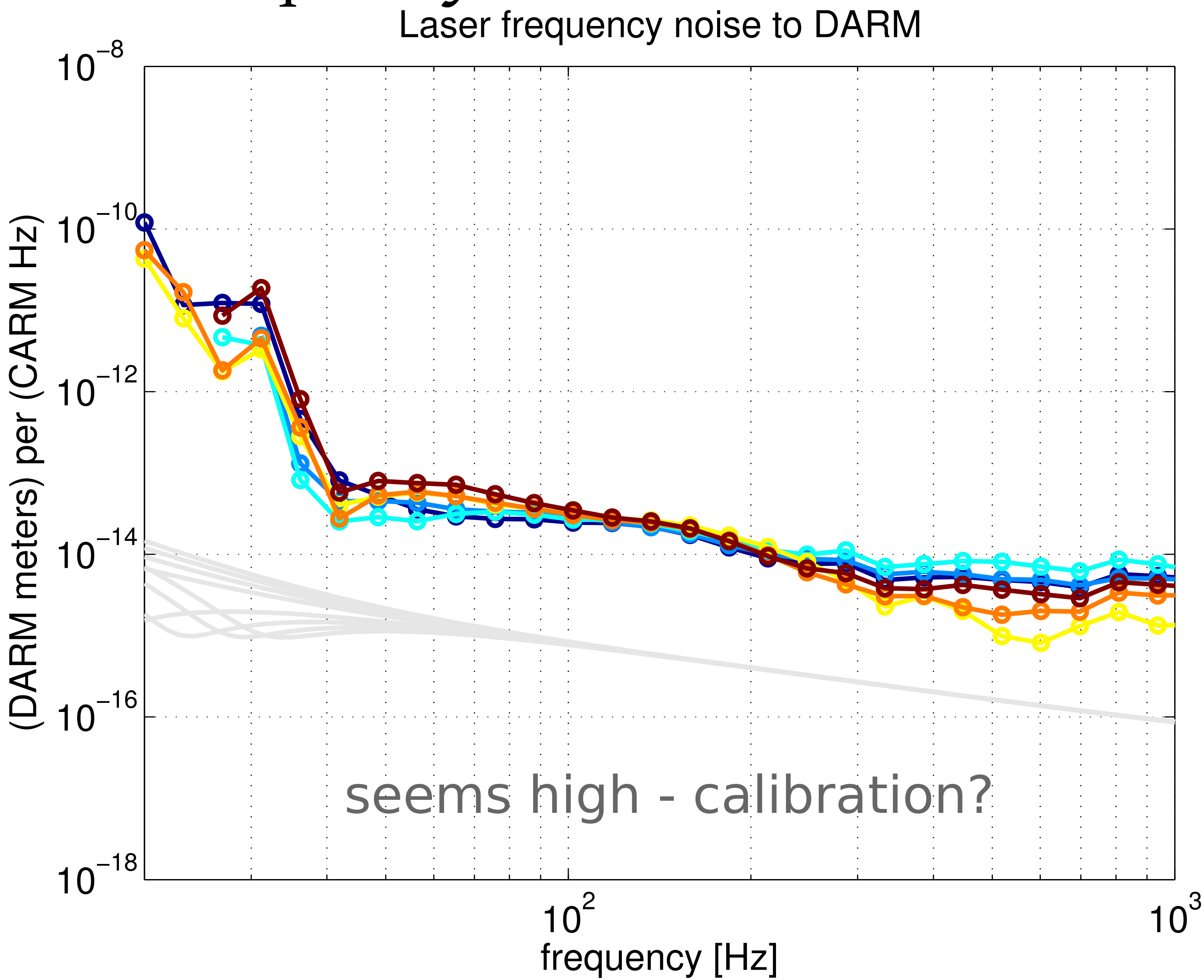
Anatomy of intensity noise coupling II



Laser intensity noise



Laser frequency noise



Noise Couplings To-Do

- Wrap control loops around Optickle results (Pickle) and around measured results to see effect of cross-coupling.

- Tune parameters to fit results as well as possible

- Be informed by / compare with other methods:
  - Zach's mode tracking absorption msmts
  - Mode scans
  - Arm cavity pole (ringdown) measurements

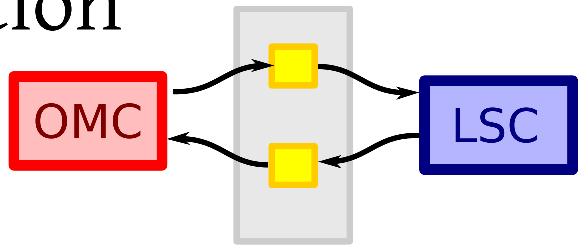
Digital Gotchas

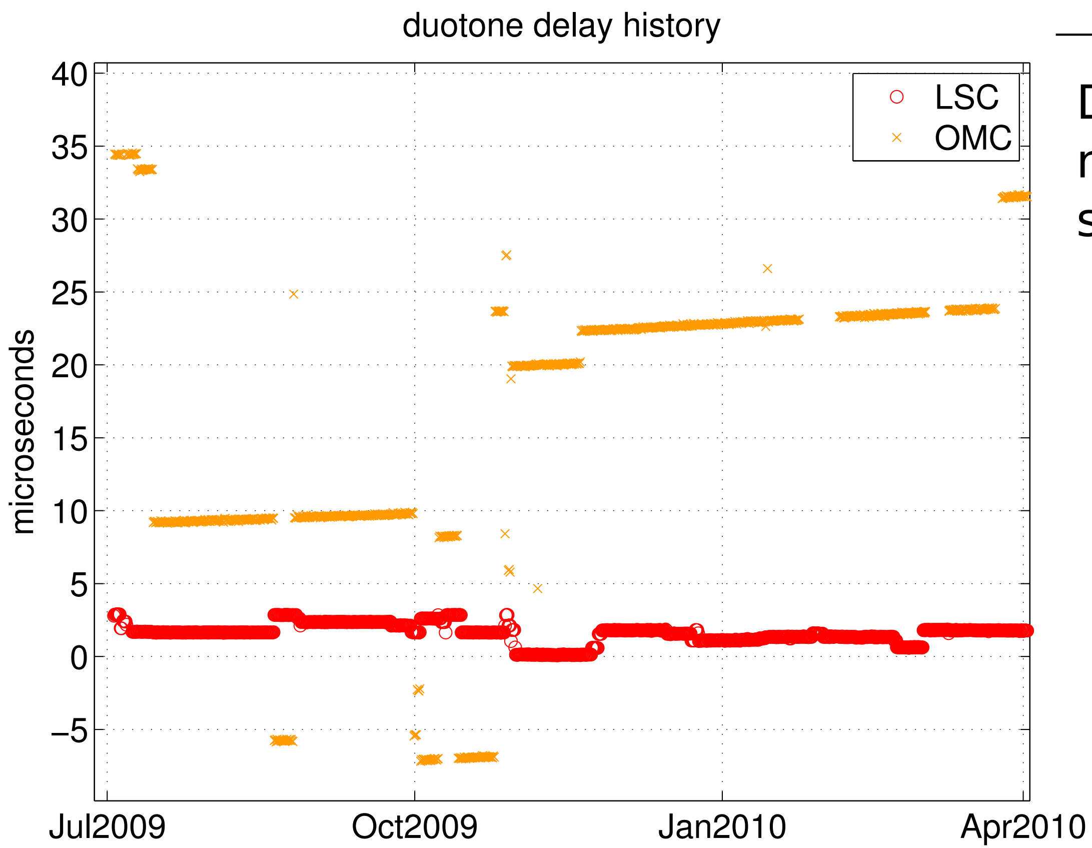
* Not new!

* But we keep 'rediscovering' them!

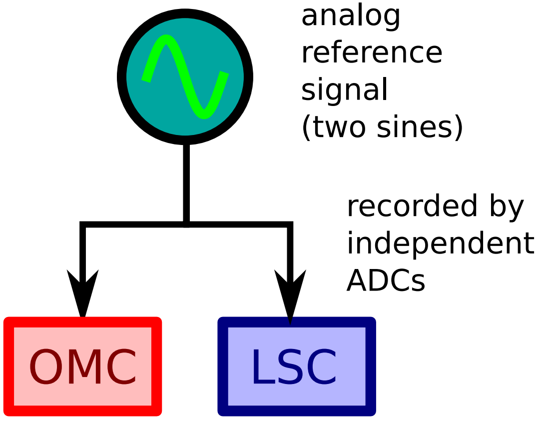
Digital Gotchas: Synchronization

* synchronization of communication
* ADC timestamp synchronization





Duotone tracking shows nondeterministic ADC startup and drift.



phase of timestamped digital signals compared (in plot to the left)

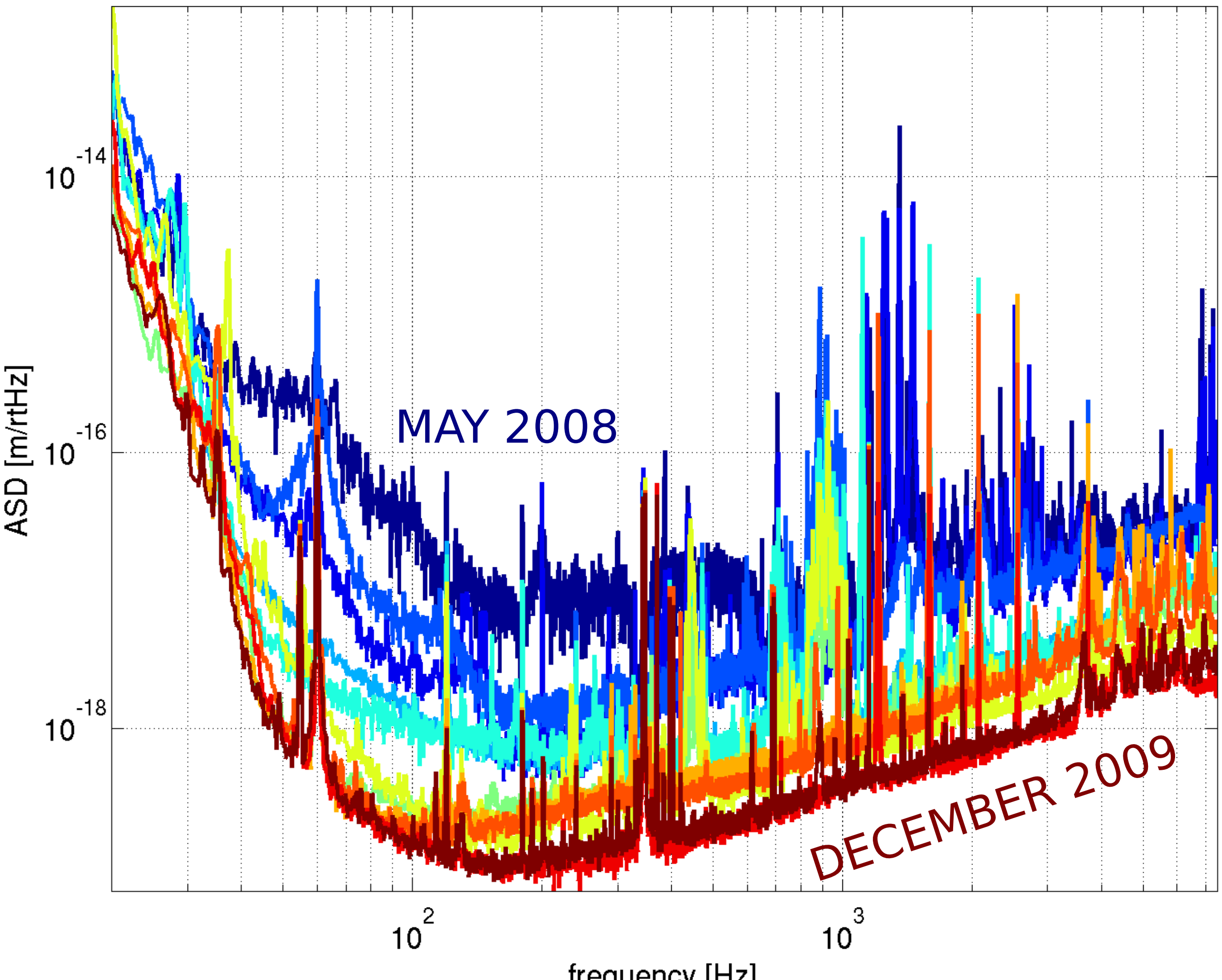
Digital Gotchas: Other

* Quantization noise in DACs
  -- "dark noise" not enough

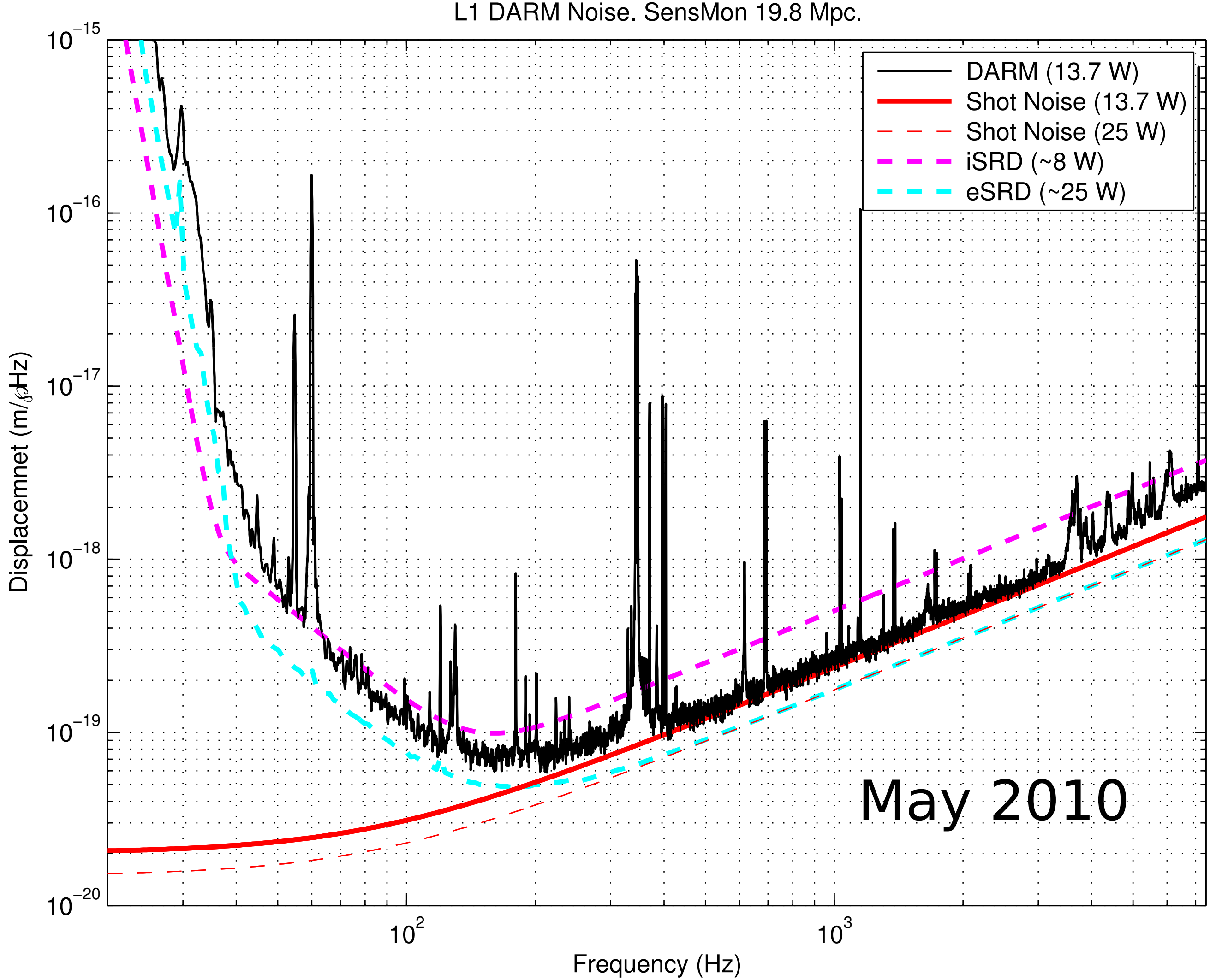
* Floating point dynamic range/oddities
  -- don't add small numbers to big numbers
  -- use double precision
  -- beware denormalized numbers (slow)

* Nondeterministic runtimes
  -- need to leave headroom in cycle time

Commissioning



Shot noise



V.Frolov

Thanks for listening!