Aligning Advanced Detectors

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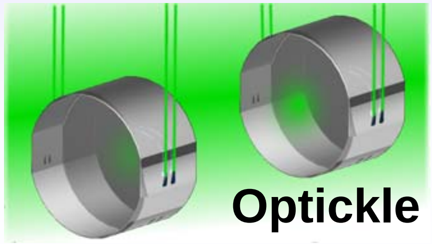
Understanding Detector Performance and Ground-Based Detector Designs

LIGO-G0900604-v1

Outline

- Alignment Sensing and Control hard(er) for Advanced Detectors

- ASC in Advanced LIGO:
  - Impact on optical design
  - Lessons from Enhanced LIGO
  - *Preliminary* results from modeling

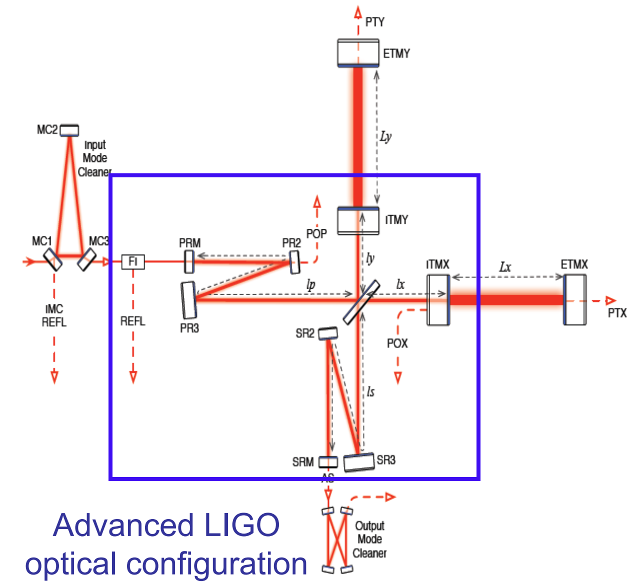


Radiation pressure effects included

Why Aligning Advanced Detectors is Hard

- More mirrors, more **degrees of freedom**
- **High power** operation complicates the problem:
  - radiation pressure modifies the opto-mechanical TFs (Sidles-Sigg instabilities)
  - Thermal compensation to keep a good mode shape
- **Stable cavities** are good…
  (previous talk by Muzammil Arain)

  …but they make alignment error signals smaller..



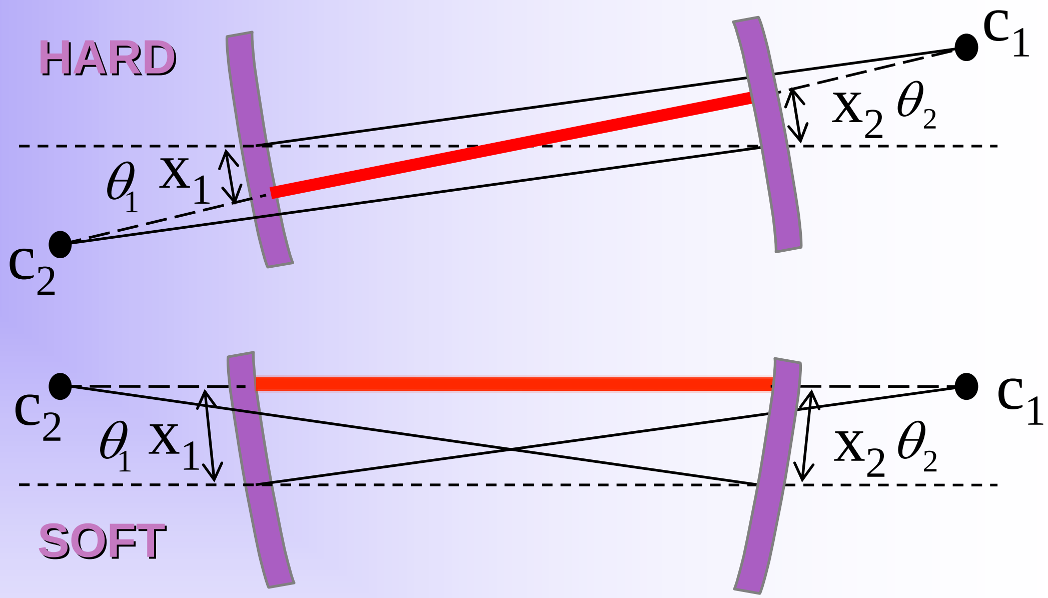
Advanced LIGO optical configuration

Sidles-Sigg Instabilities

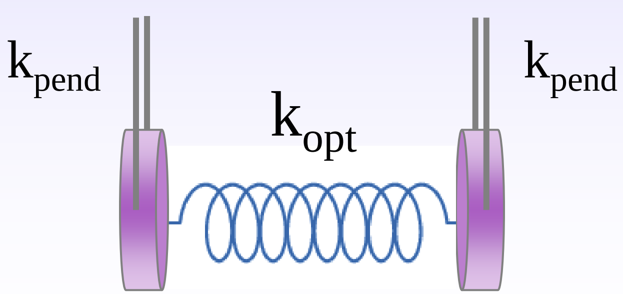
Physics Letters A 354 (2006) 167–172

Torque induced by radiation pressure

$$\tau = \hat{k}_{opt}(g_1, g_2, L, P)\begin{pmatrix}\theta_1 \\ \theta_2\end{pmatrix}$$



❖ Modification of the pendulum resonance frequencies:

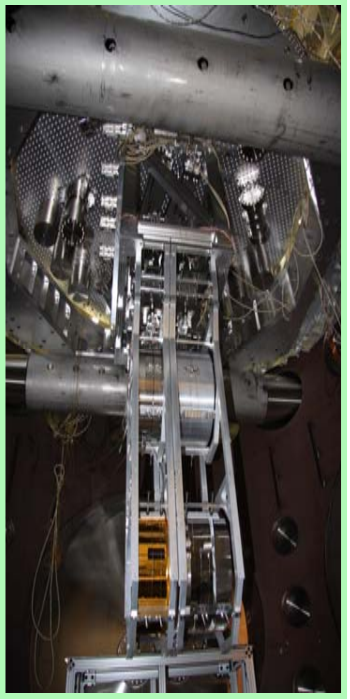


$$f_{Hard} = \frac{1}{2\pi}\sqrt{\frac{k_{Hard} + k_{pend}}{I}}$$

$$f_{Soft} = \frac{1}{2\pi}\sqrt{\frac{k_{Soft} + k_{pend}}{I}}$$

High Power in LIGO detectors

- **Initial LIGO**: maximum input power **~7 W**
  → radiation pressure already important
- **Enhanced LIGO**: same optical parameters / suspensions as in Initial LIGO, **35 Watts** input power
  **New ASC design in the *hard* and *soft* angular mode basis
- **Advanced LIGO**: g factors chosen for low radiation pressure impact, **+50% restoring torque** from Quadruple suspensions



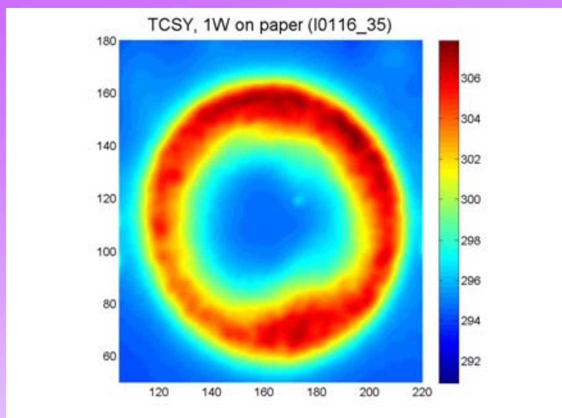
	P_cavity (kW)	**f_pend (Hz)** PITCH	YAW	**f_hard (Hz)** PITCH	YAW	**f_soft (Hz)** PITCH	YAW
Initial LIGO	15	0.6	0.5	0.69	0.60	-0.25	-0.42
Enhanced LIGO	87.5	0.6	0.5	1.00	0.95	-1.46	-1.49
Advanced LIGO	770	0.57	0.6	2.85	3.05	-0.17	-0.21

**Katherine Dooley, Controlling the Sigg-Sidles Instability in Enhanced LIGO (Poster)

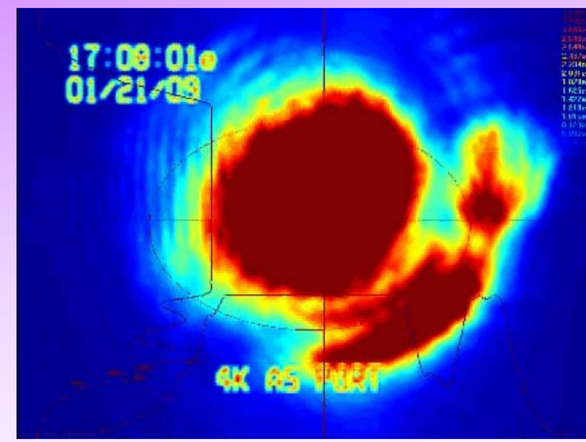
ASC vs Thermal Compensation

- **Lesson from Enhanced LIGO:** it is crucial to have a good TCS for alignment stability

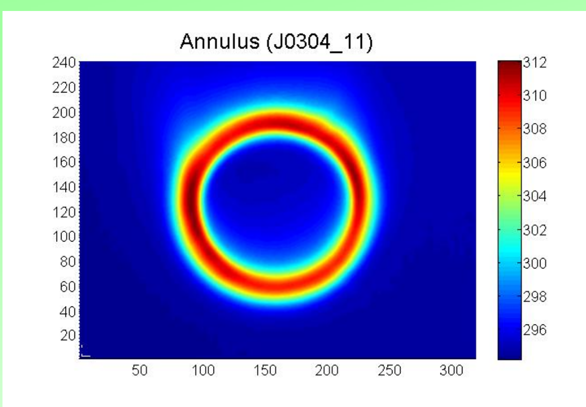
TCS Annulus pattern (January 2009)



AS port in 20 minutes with 14W input power



TCS Annulus pattern (March 2009)



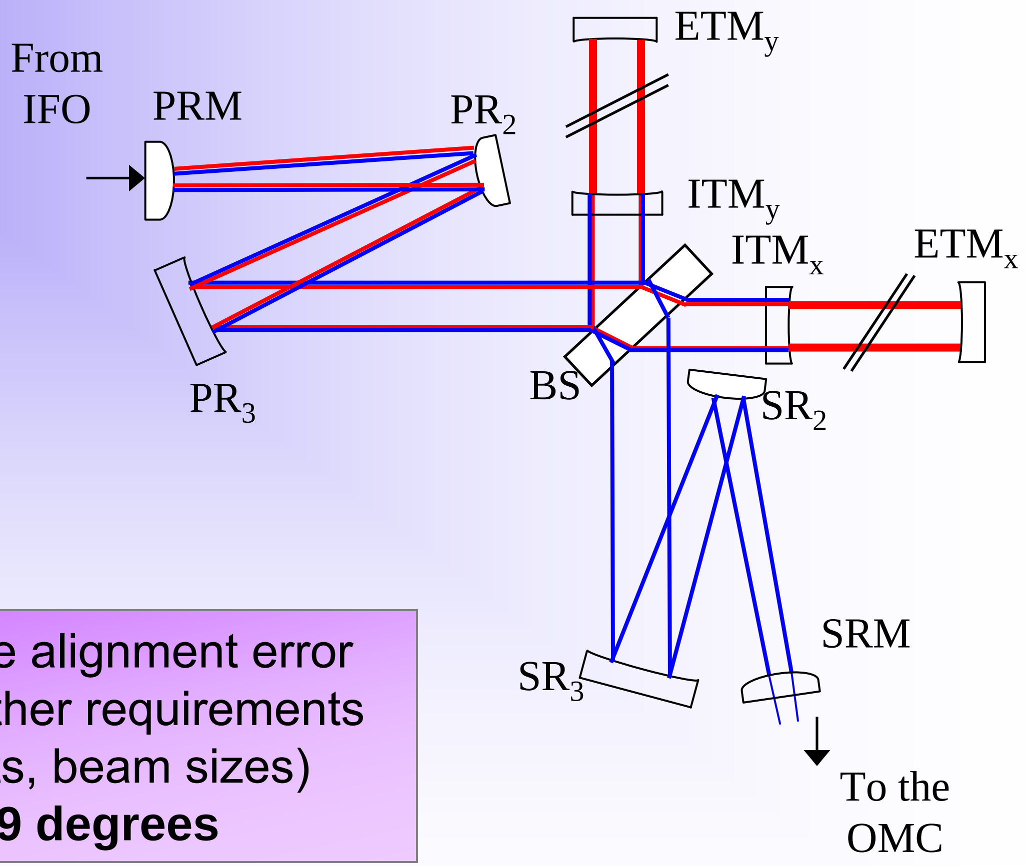
Stable Recycling Cavities

Plot by
Muzammil Arain

❖ Alignment signals are conceptually:

$$A_{00}^{CA} A_{01}^{SB} + A_{01}^{CA} A_{00}^{SB}$$

❖ 01 modes not resonant in stable recycling cavities → **small alignment error signals**

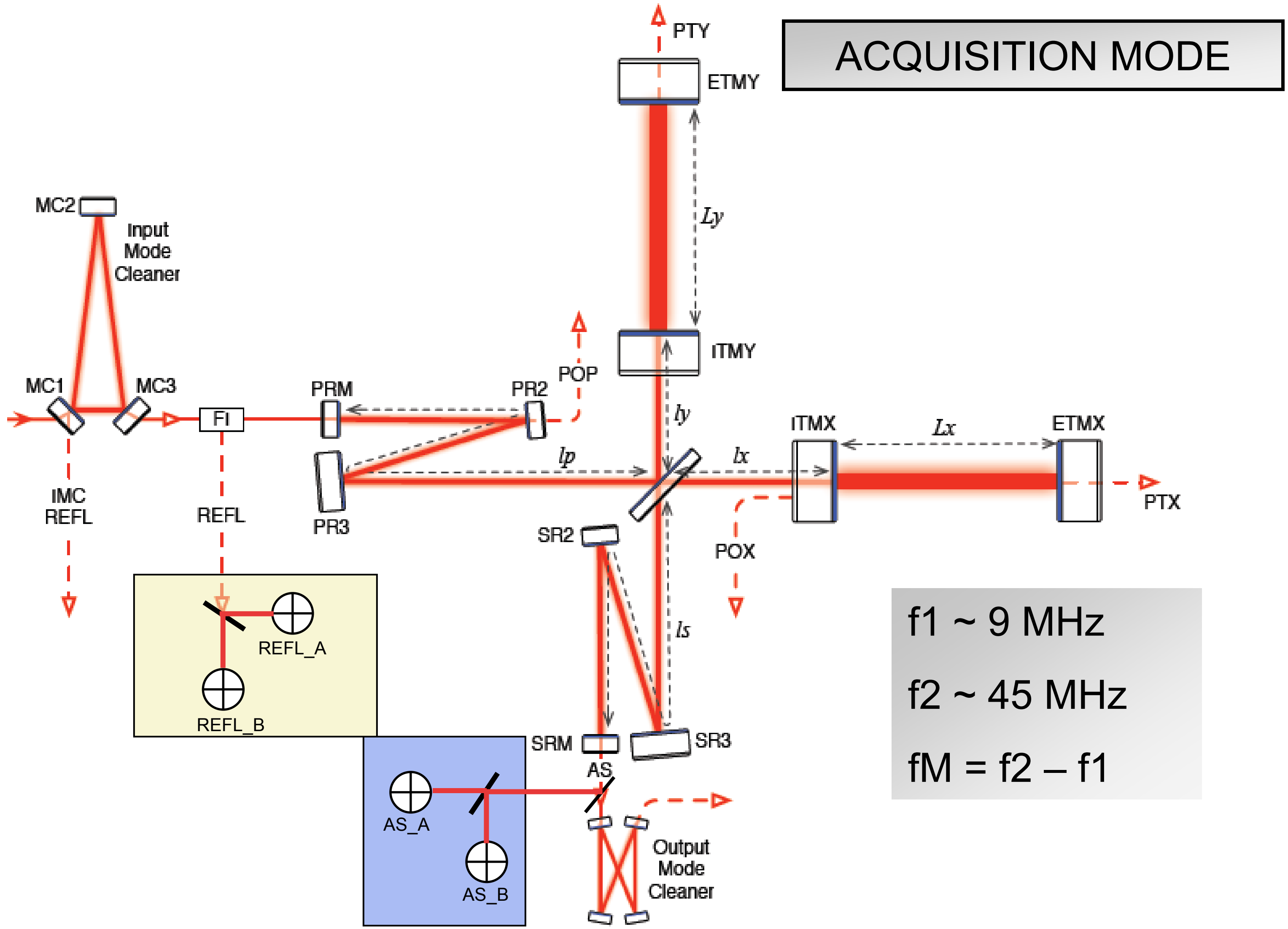


Gouy phases chosen to maximize alignment error signal for SRC, compatibly with other requirements (mode matching, thermal effects, beam sizes)
PRC: 25 degrees, SRC: 19 degrees

ASC modeling for Advanced LIGO

- *Hard* and *soft* degrees of freedom for the arms
- Control loops
- ASC noise coupling to DARM due to:
    - **shot noise**
    - **seismic noise**
- *Acquisition* Mode (before the OMC is locked)
- *Science* Mode: low noise

Alignment Sensors

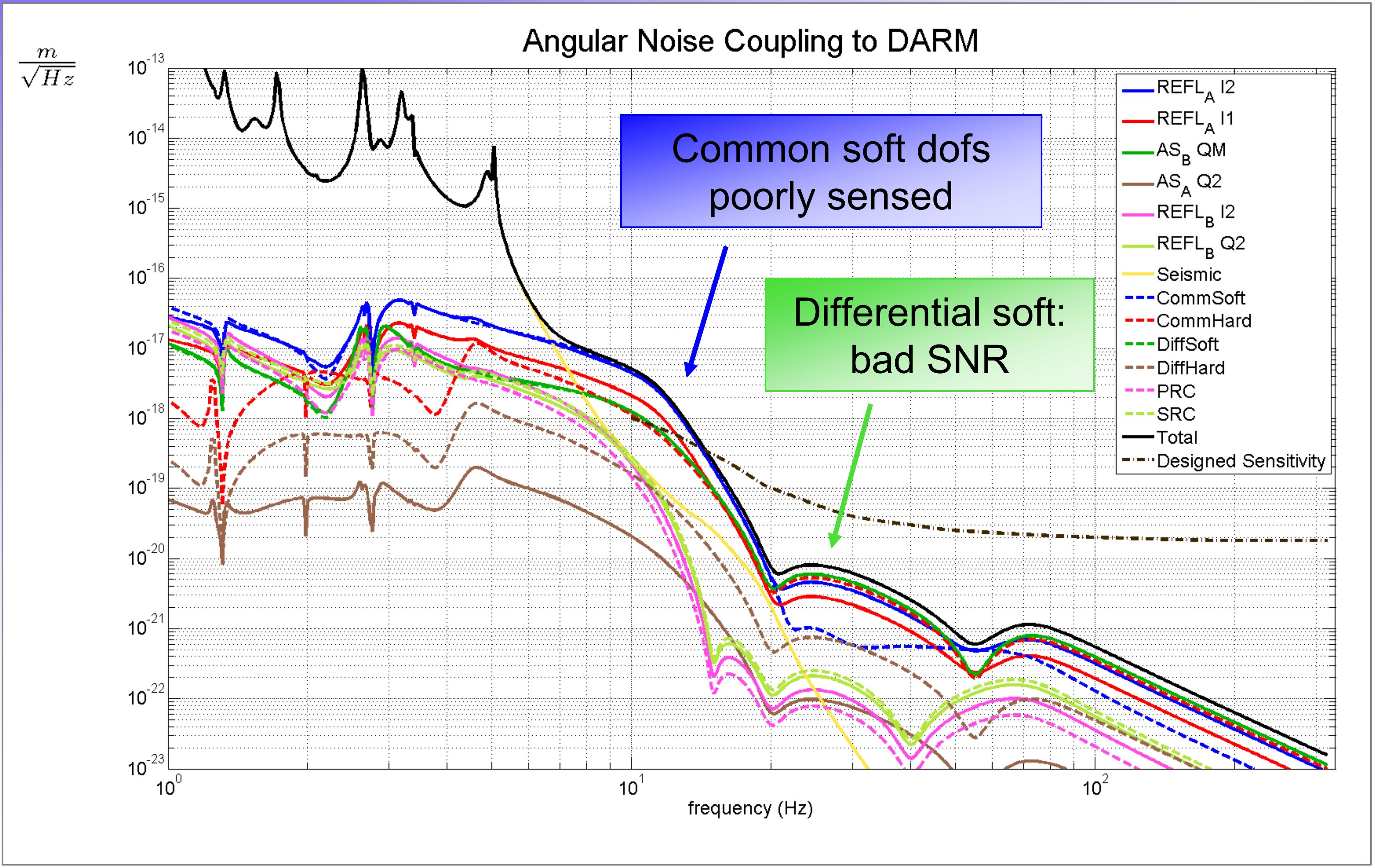


f1 ~ 9 MHz

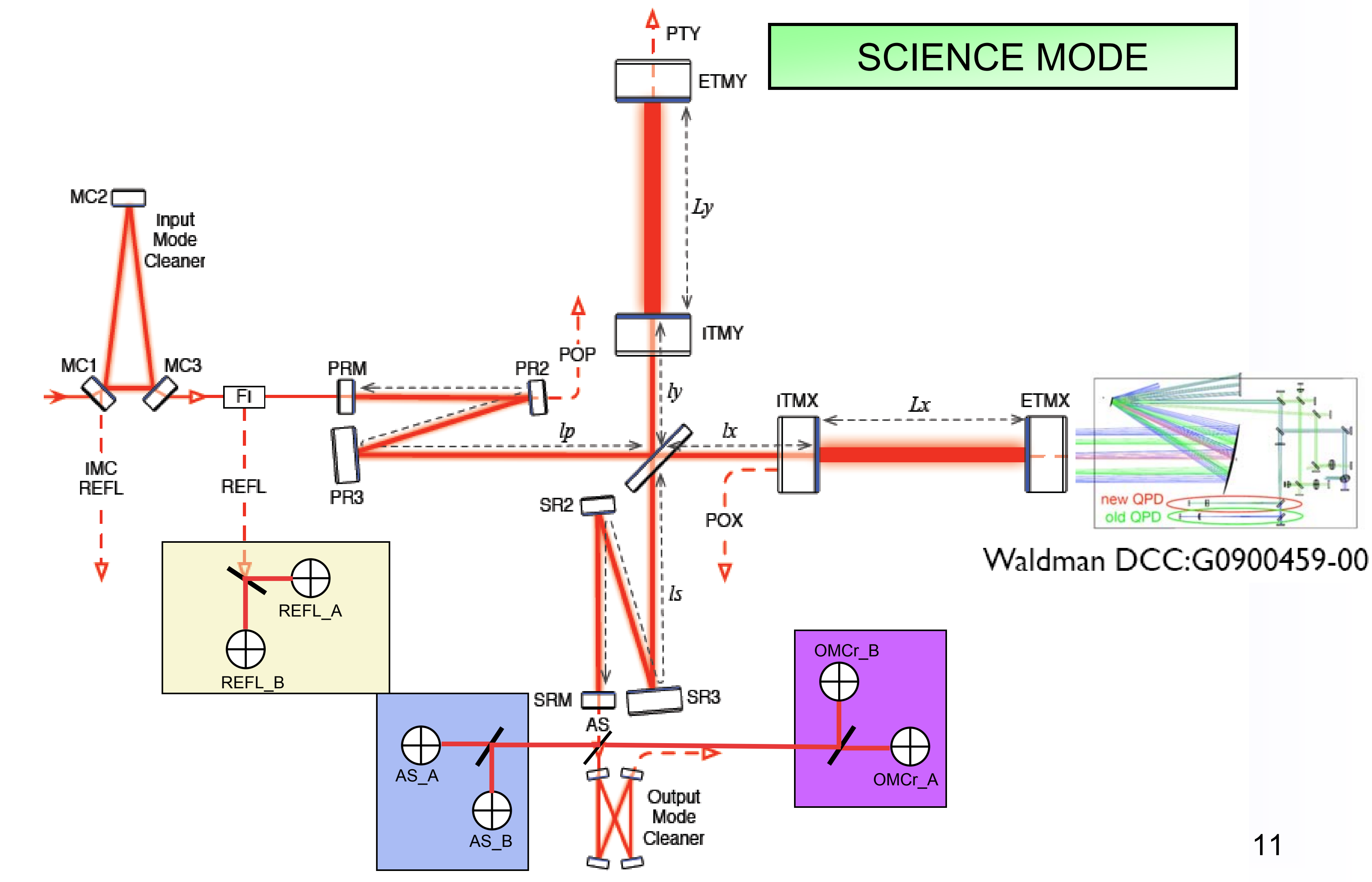
f2 ~ 45 MHz

fM = f2 – f1

Acquisition Mode

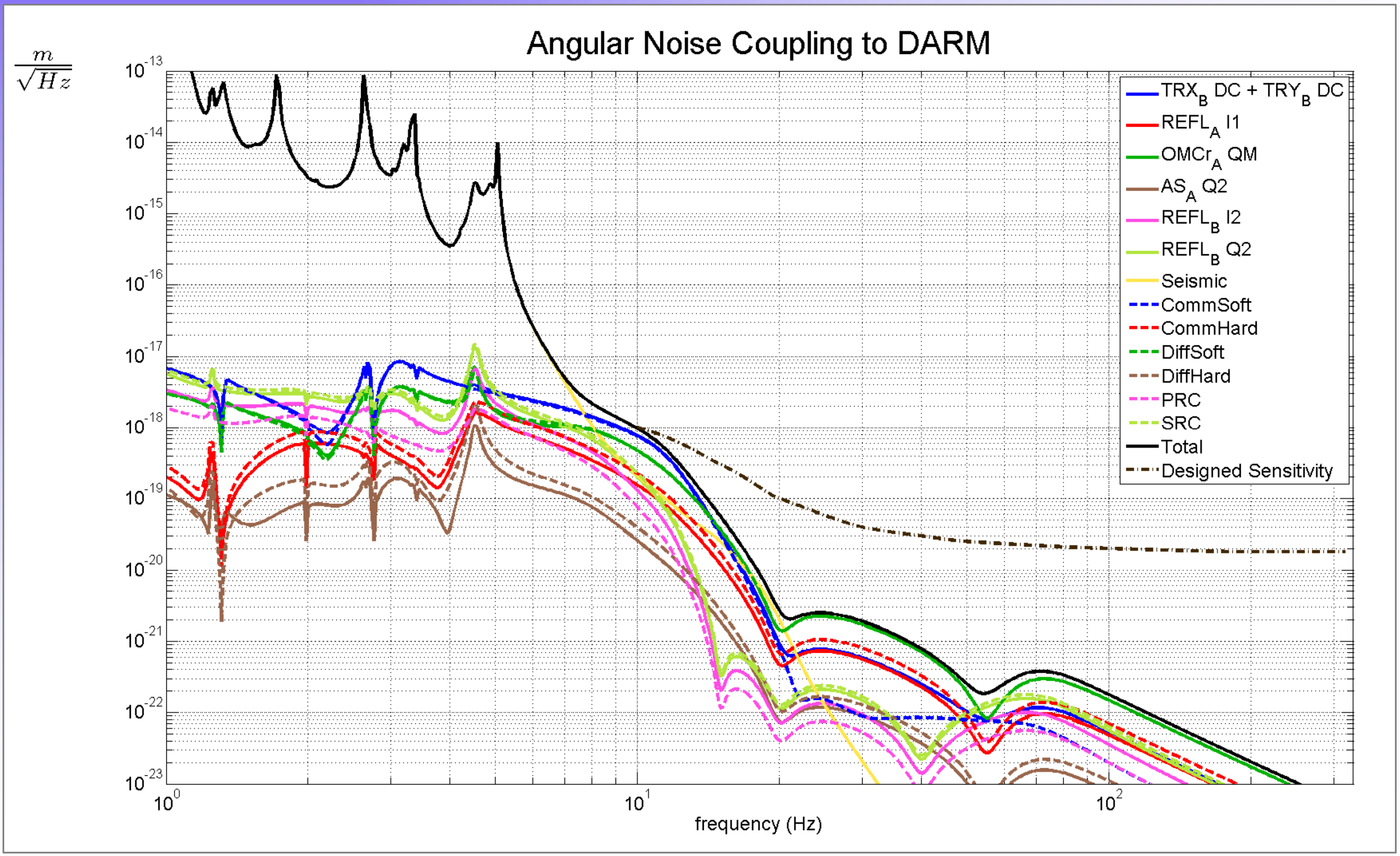


Alignment Sensors



Waldman DCC:G0900459-00

Science Mode



The Message

- Convenient to work in the basis which diagonalizes the opto-mechanical system (*hard* and *soft*)
- Greater stability → poorer sensing
- Evaluation of the ASC scheme needs to take into account the whole system:
    - sensor noise, seismic noise
    - control bandwidth
    - stability in the presence of thermal effects
    - noise coupling to DARM

Dark Fringe