Status of the LIGO Interferometers circa 2005

Sam Waldman
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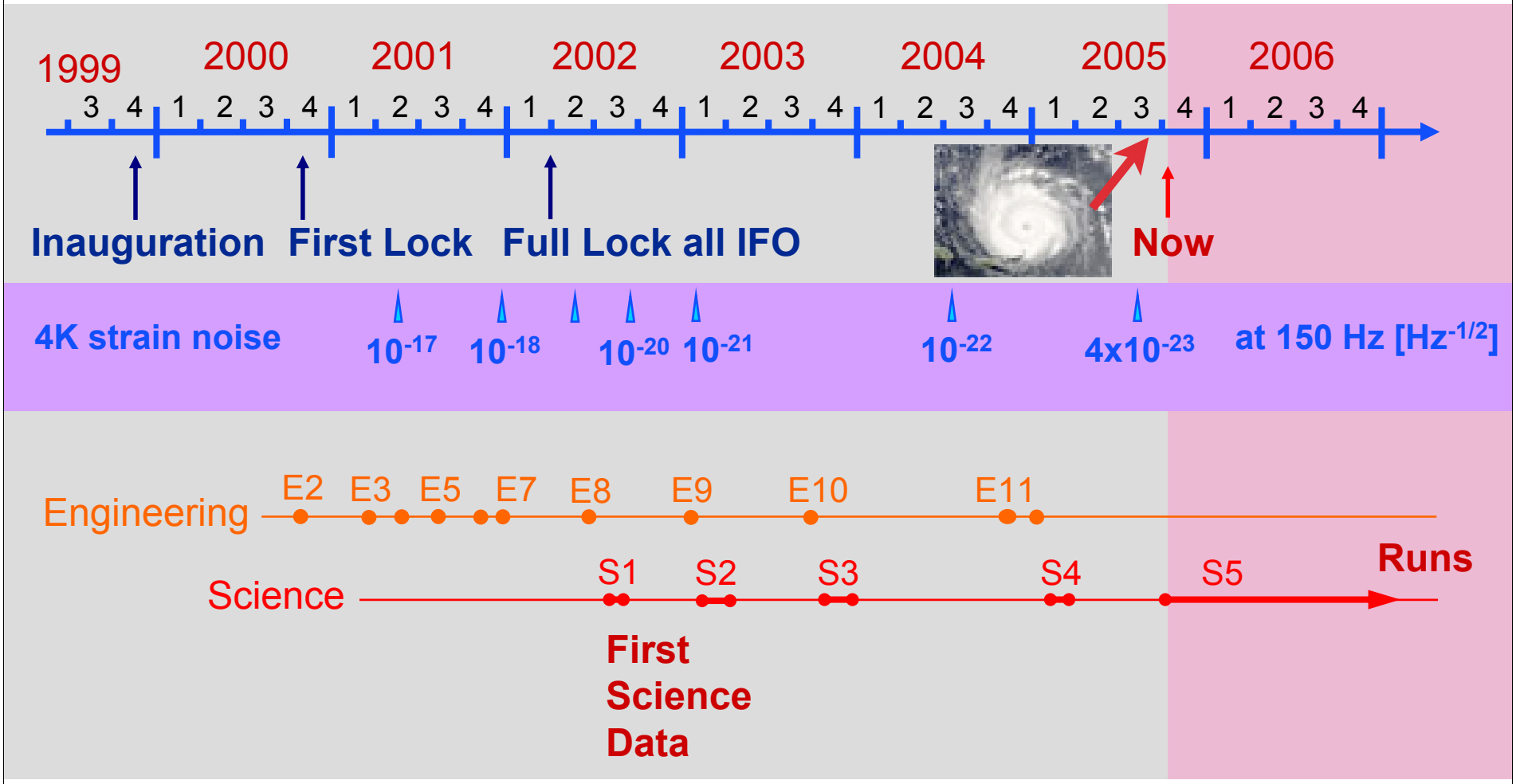
LIGO

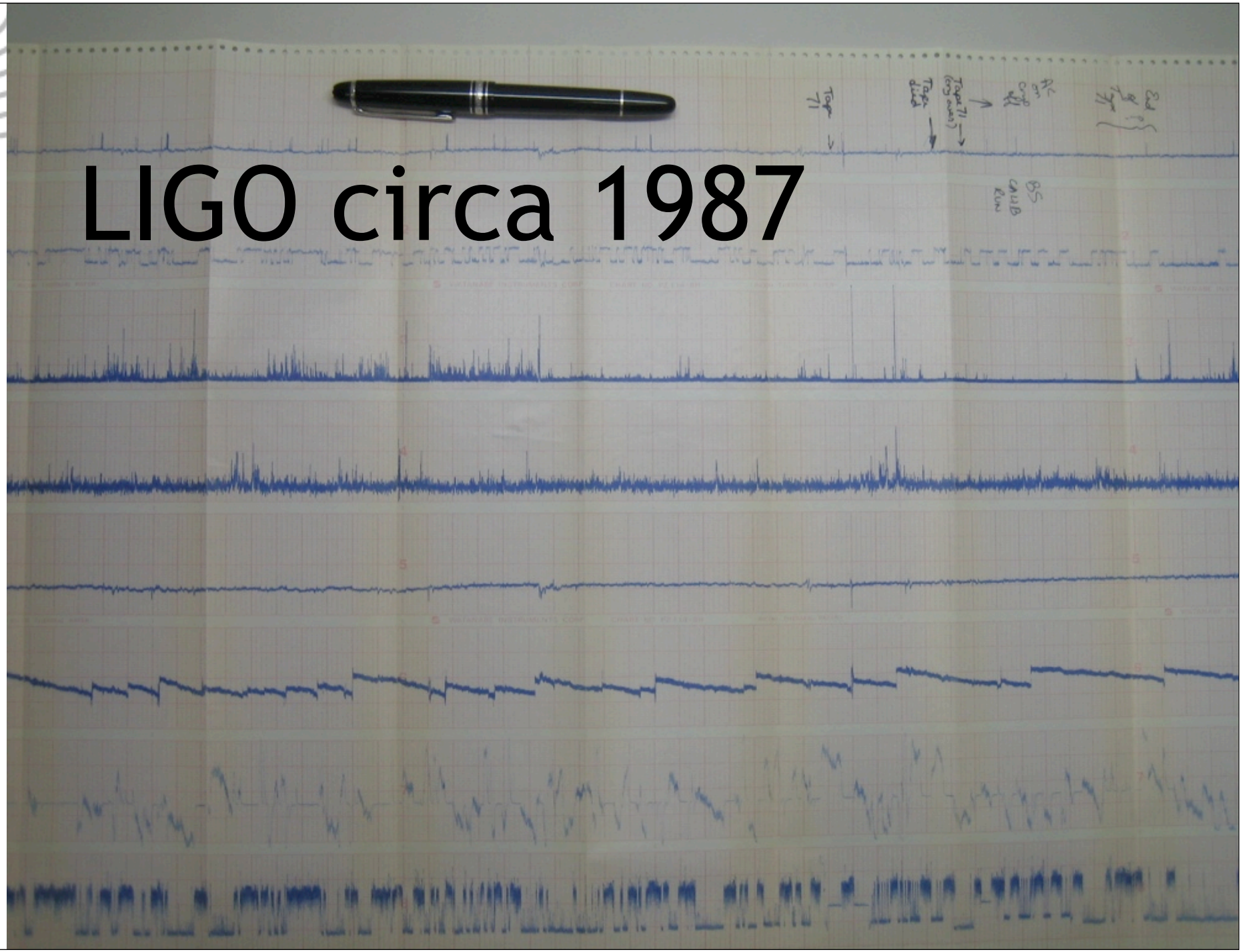
In brief

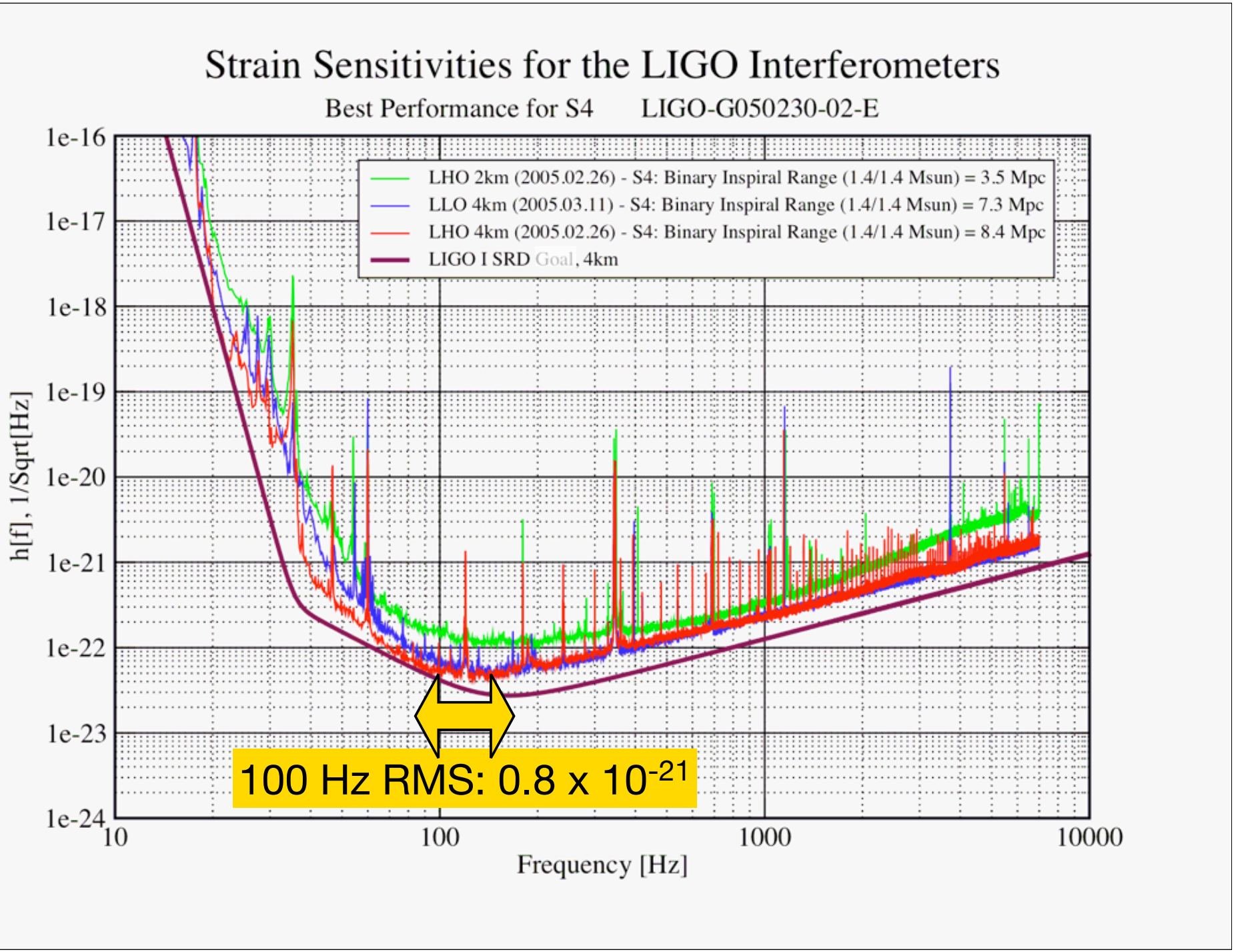
- from LIGO document E950015:
  "initial LIGO detector strain sensitivity goal of 10^{-21} RMS, integrated over a 100 Hz bandwidth"
- 2005 NSF review panel agrees - **LIGO has reached design sensitivity**

LIGO

A brief history of LIGO

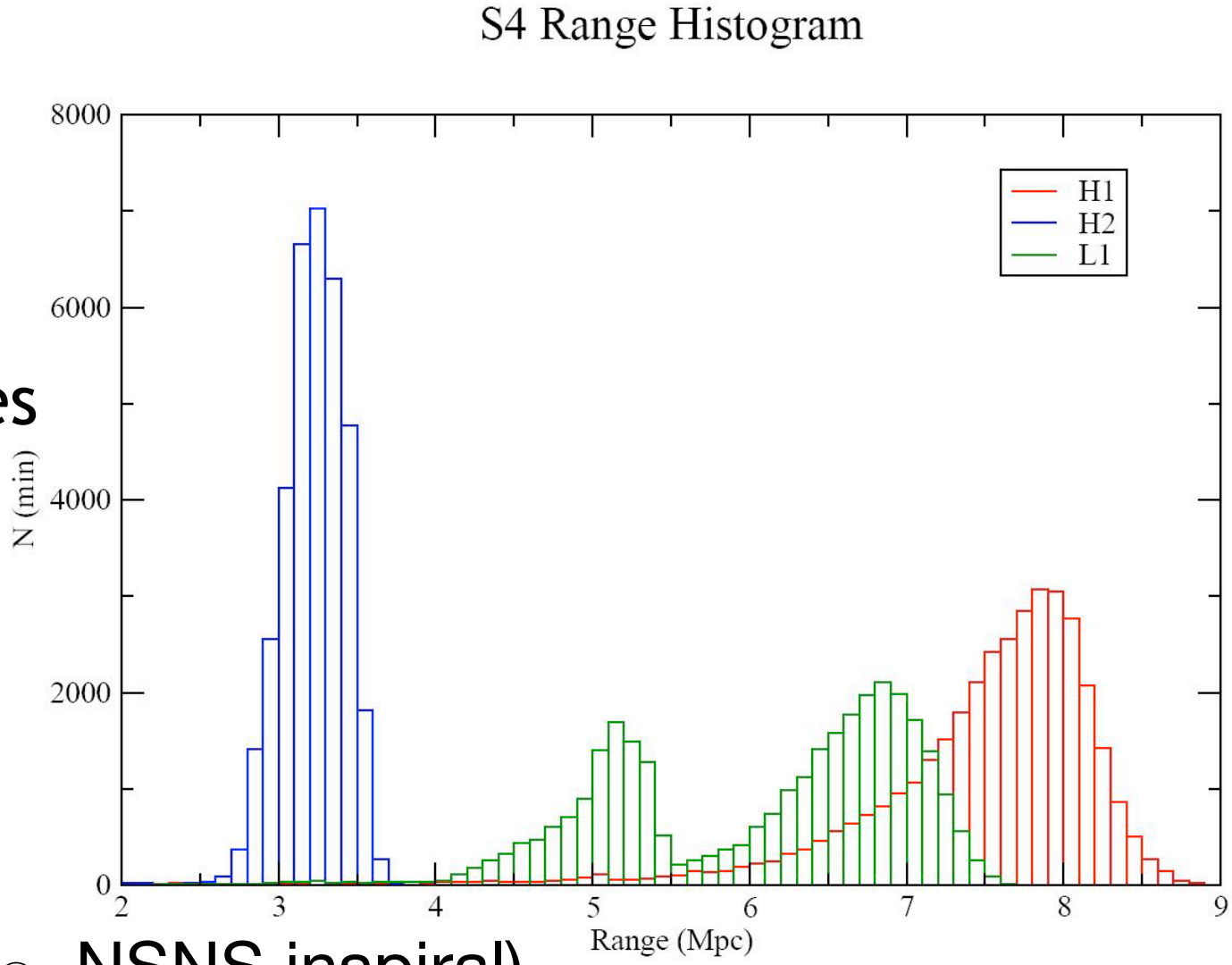



LIGO circa 1987


Strain Sensitivities for the LIGO Interferometers
Best Performance for S4
LIGO-G050230-02-E
LHO 2km (2005.02.26) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 3.5 Mpc
LLO 4km (2005.03.11) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 7.3 Mpc
LHO 4km (2005.02.26) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 8.4 Mpc
LIGO I SRD Goal, 4km
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
100 Hz RMS: 0.8 x 10-21

S4 performance

- Feb 22 to Mar 23
- Duty Cycles
  - H1: 80%
  - H2: 81%
  - L1: 74%
  - 3x: 57%



(1.4 $M_\odot$ NSNS inspiral)

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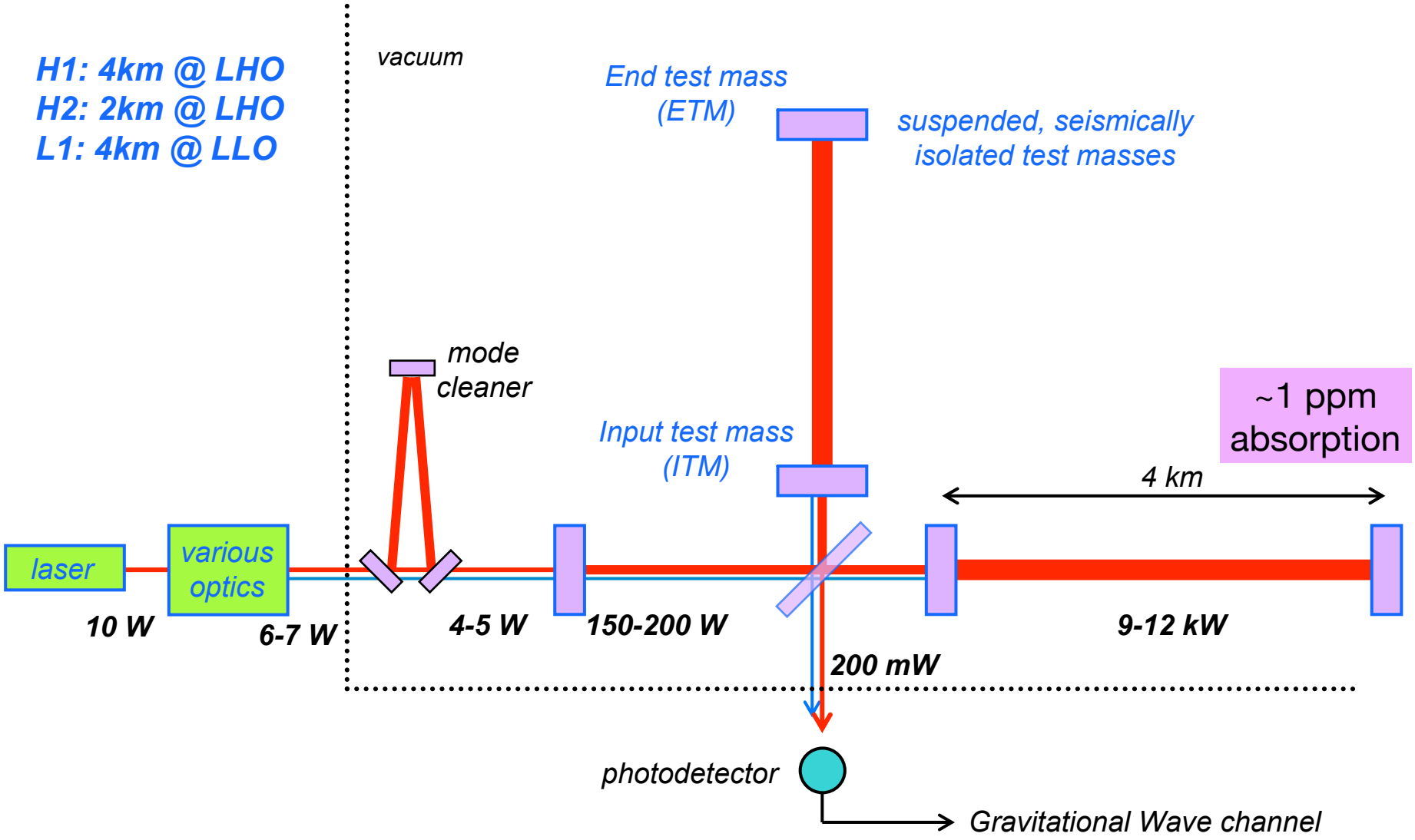
Post-S4 improvements

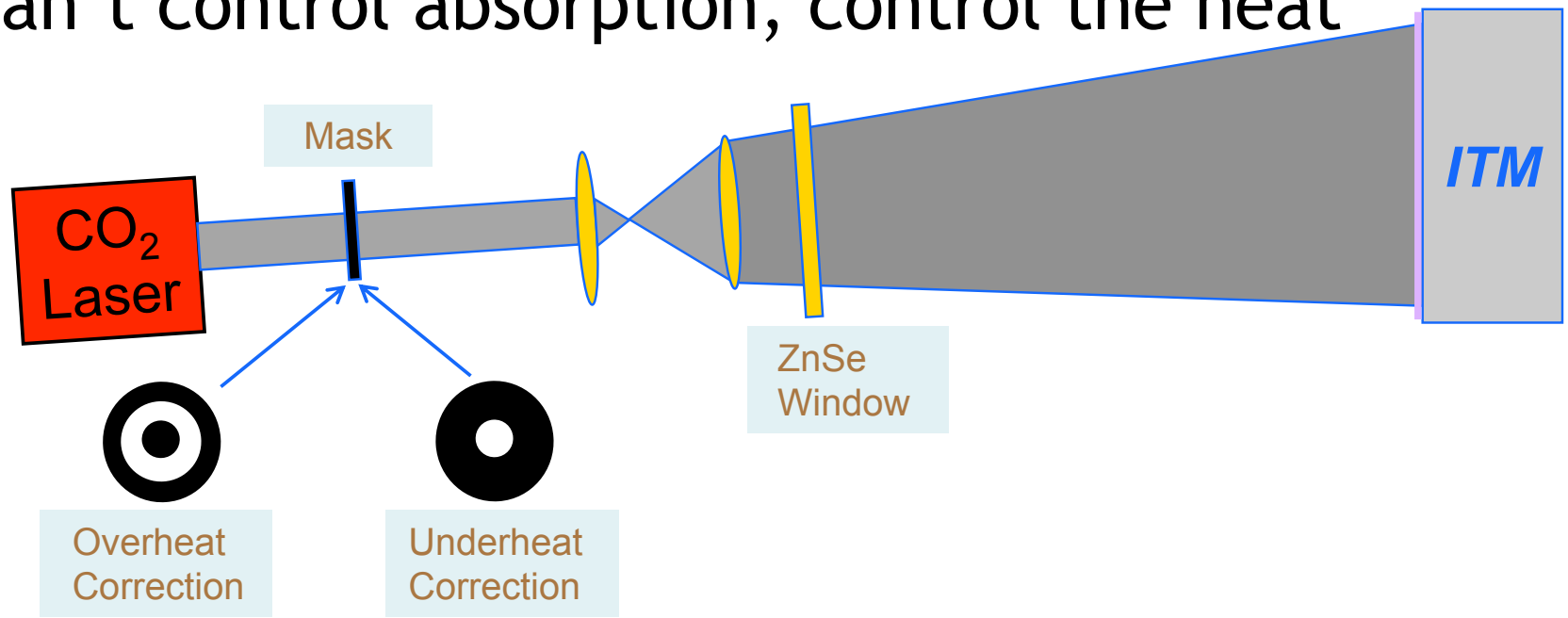
- Thermal Compensation System (TCS)
- Fixed H1 ITM absorption
- Improved Angular Sensing & Control (WFS)
- Hydraulic External Pre-Isolator (HEPI) fine-tuning

IFO Layout


H1: 4km @ LHO
H2: 2km @ LHO
L1: 4km @ LLO
vacuum
End test mass
(ETM)
suspended, seismically
isolated test masses
mode
cleaner
Input test mass
(ITM)
~1 ppm
absorption
4 km
laser
various
optics
10 W
6-7 W
4-5 W
150-200 W
9-12 kW
200 mW
photodetector
Gravitational Wave channel

Thermal Compensation

- Cold power recycling cavity is unstable
- Requires 10's of mW absorption for optimal thermal lensing
- Can't control absorption, control the heat



AS port modes

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Matching SB & carrier modes

CO2 heating

Sideband images

none

90mW

carrier

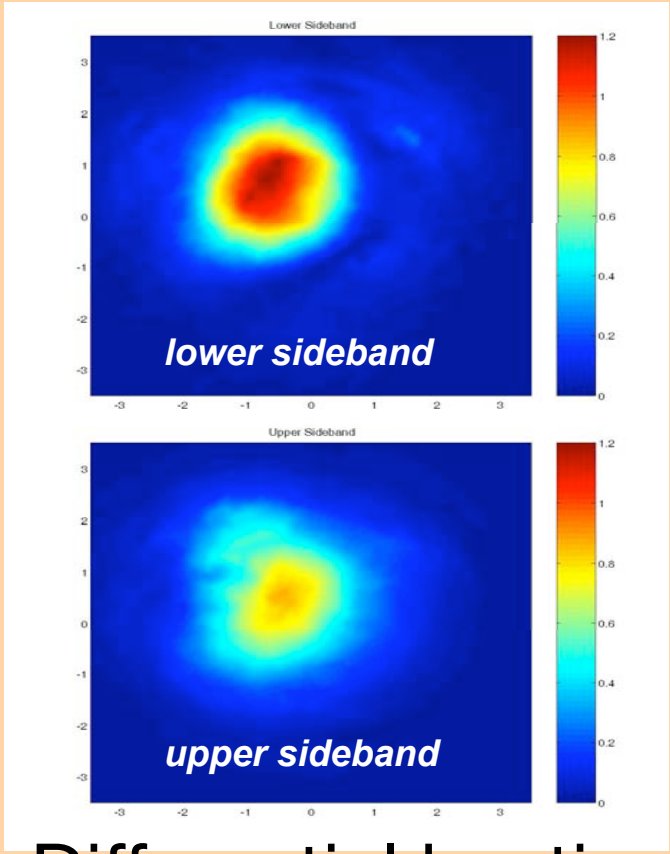
Best match

180mW

Common heating

Servo controlled

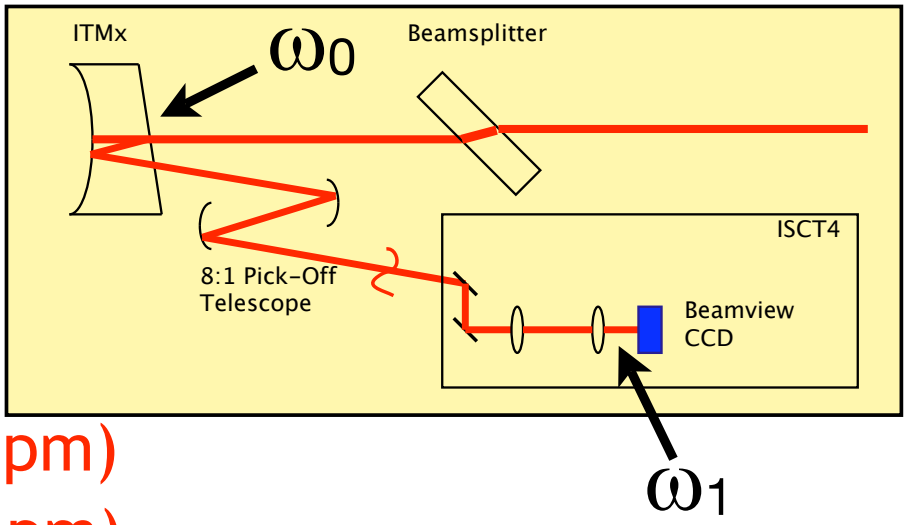
Symmetrizing the SBs to minimize the orthogonal-phase signal: controlling RF saturation



Differential heating

H1 characterization

- S4: 3W input required 1.5W CO_2 annulus compensation
- Post-S4: *in situ* measurements of the ITMs
  - Arm cavity g-factor
  - Beam size changes
  - Results:
    - ITMX = 35 mW/W (20 ppm)
    - ITMY = 13.5 mW/W (6 ppm)
- High power attempts failed



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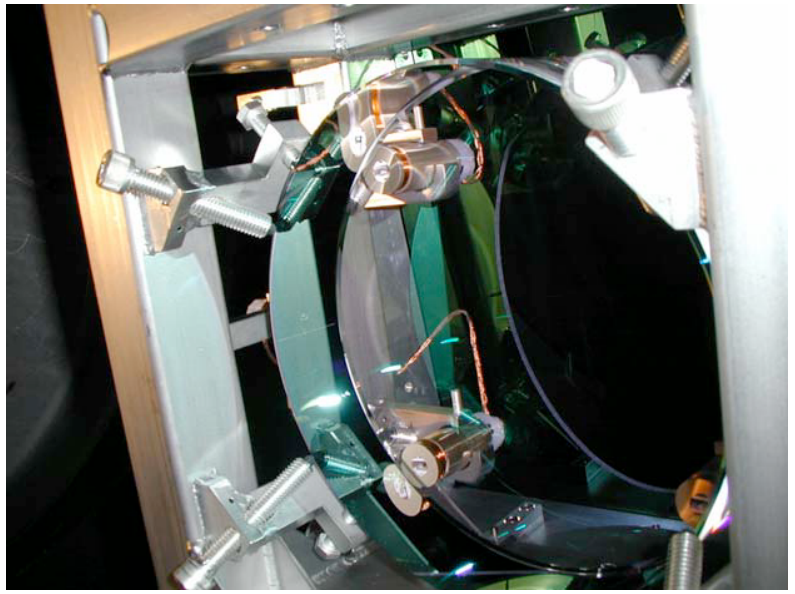
H1 replacement

- Couldn't run at high power
- In mid-June decided to replace ITMX
  - Fully characterized spare
  - *In situ* cleaning of ITMY
  - Vent on June 29, 4 wks pump
- Dragwipe ITMY

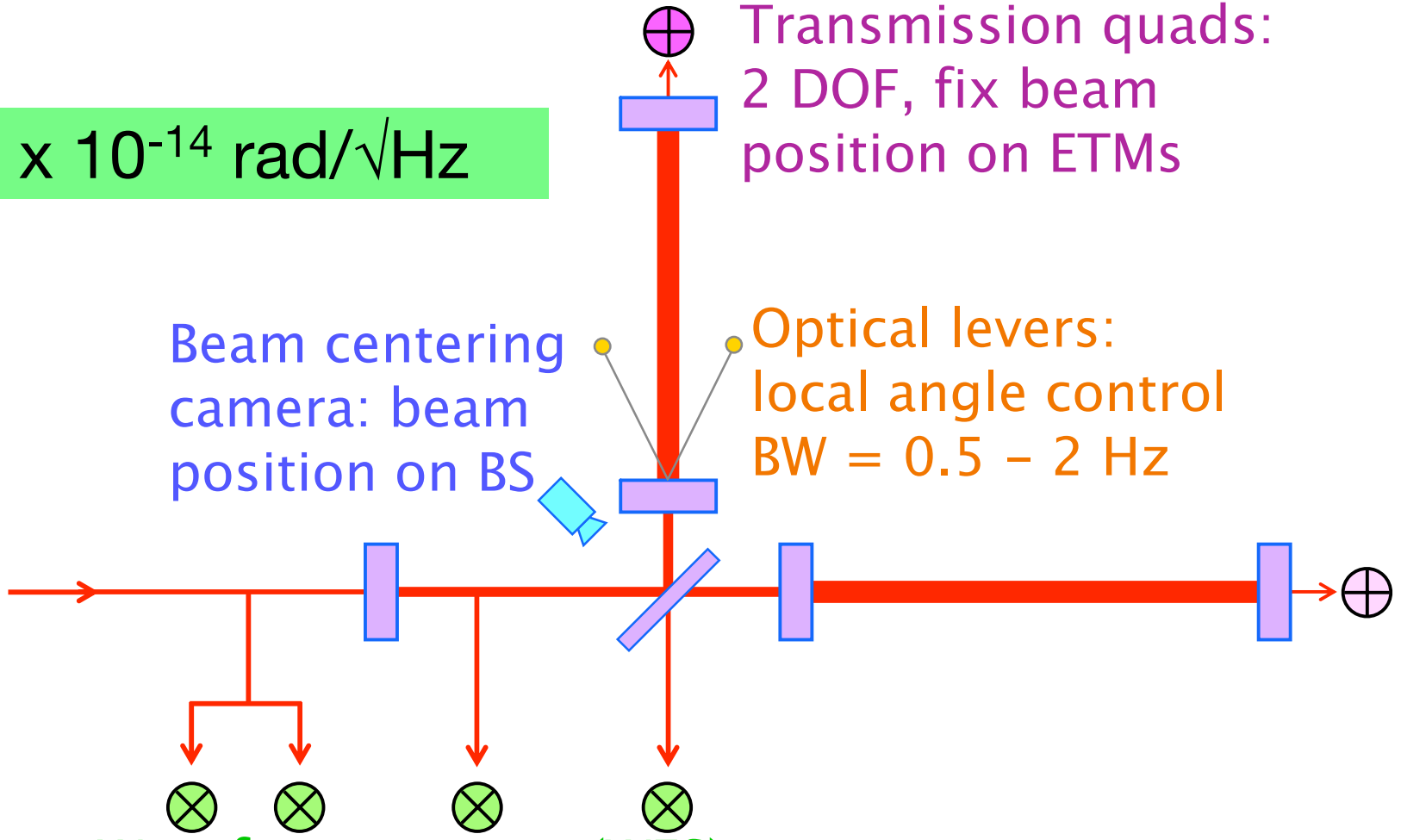


	ITMX	ITMY
Before	35 mW/W	14 mW/W
After	< 3 mW/W	3 mW/W

4k IFOs at full power

Angular Sensing

~1 x 10^{-14} rad/√Hz



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WFS diagonalization

- Each sensor detects multiple optics
- Previously, stabilized w/ gain heirarchy
- Now, output matrix diagonalized

	WFS1	WFS2a	WFS2b	WFS3	WFS4
ETMX	1.0	0.35	0.50	-0.50	-1.0
ETMY	-1.0	0.35	-0.50	-0.50	-1.0
ITMX		-1.0	-1.0	1.0	0.35
ITMY		-1.0	1.0	1.0	0.35
RM		-0.25		0.75	0.25

Loop BW $\lesssim$ 5 Hz

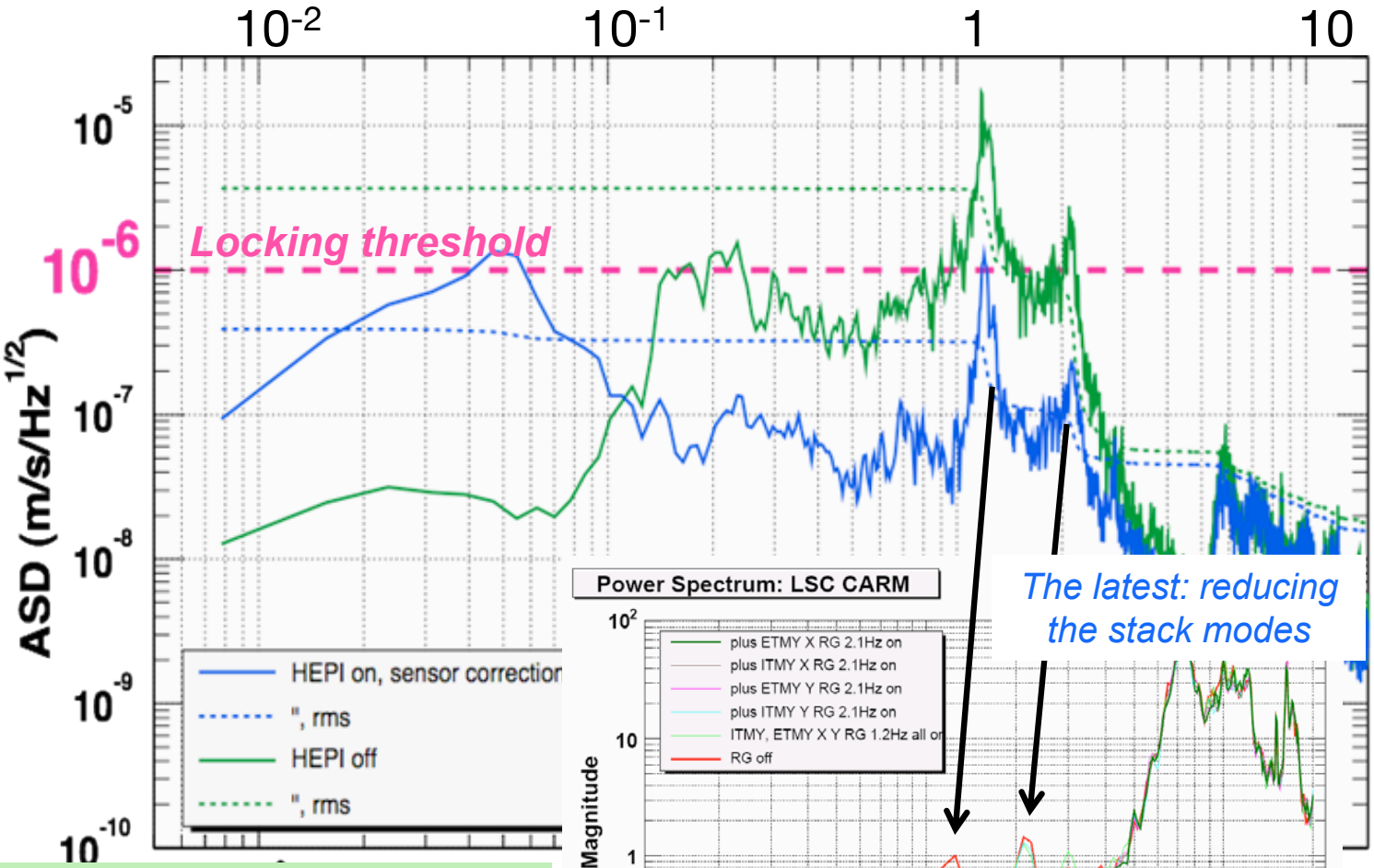
Decrease orthogonal phase AS signal

LIGO

Hydraulic External Pre-Isolator

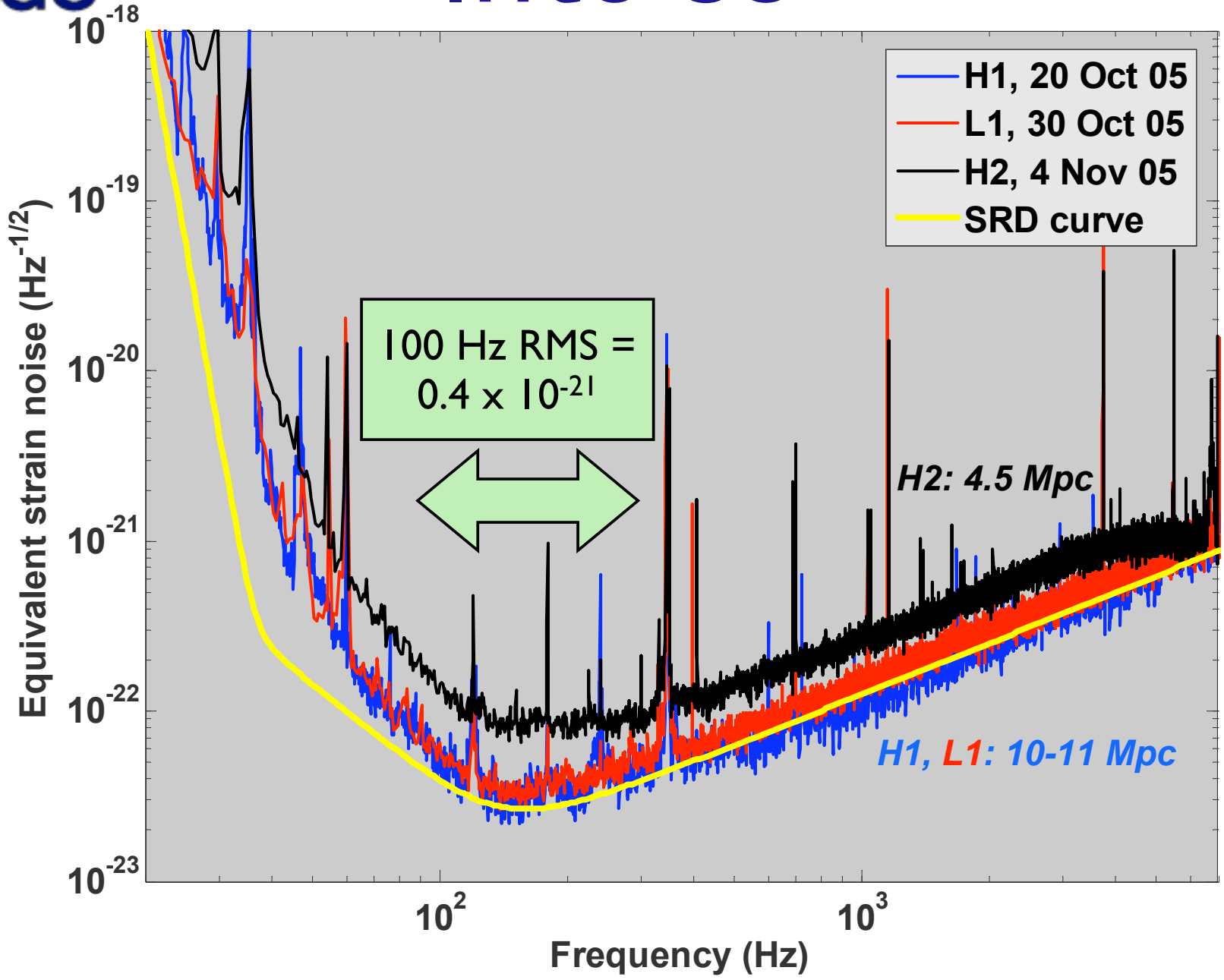
- Spring-supported payload
- High force, low noise hydraulic bridges
- Sensor blending
- ~10x vel. reduction

HEPI results



Allows L1 to lock during "typical" noisy days

Into S5


H1, 20 Oct 05
L1, 30 Oct 05
H2, 4 Nov 05
SRD curve
100 Hz RMS =
0.4 x 10-21
H2: 4.5 Mpc
H1, L1: 10-11 Mpc
Equivalent strain noise (Hz-1/2)
Frequency (Hz)
10-18
10-19
10-20
10-21
10-22
10-23
102
103