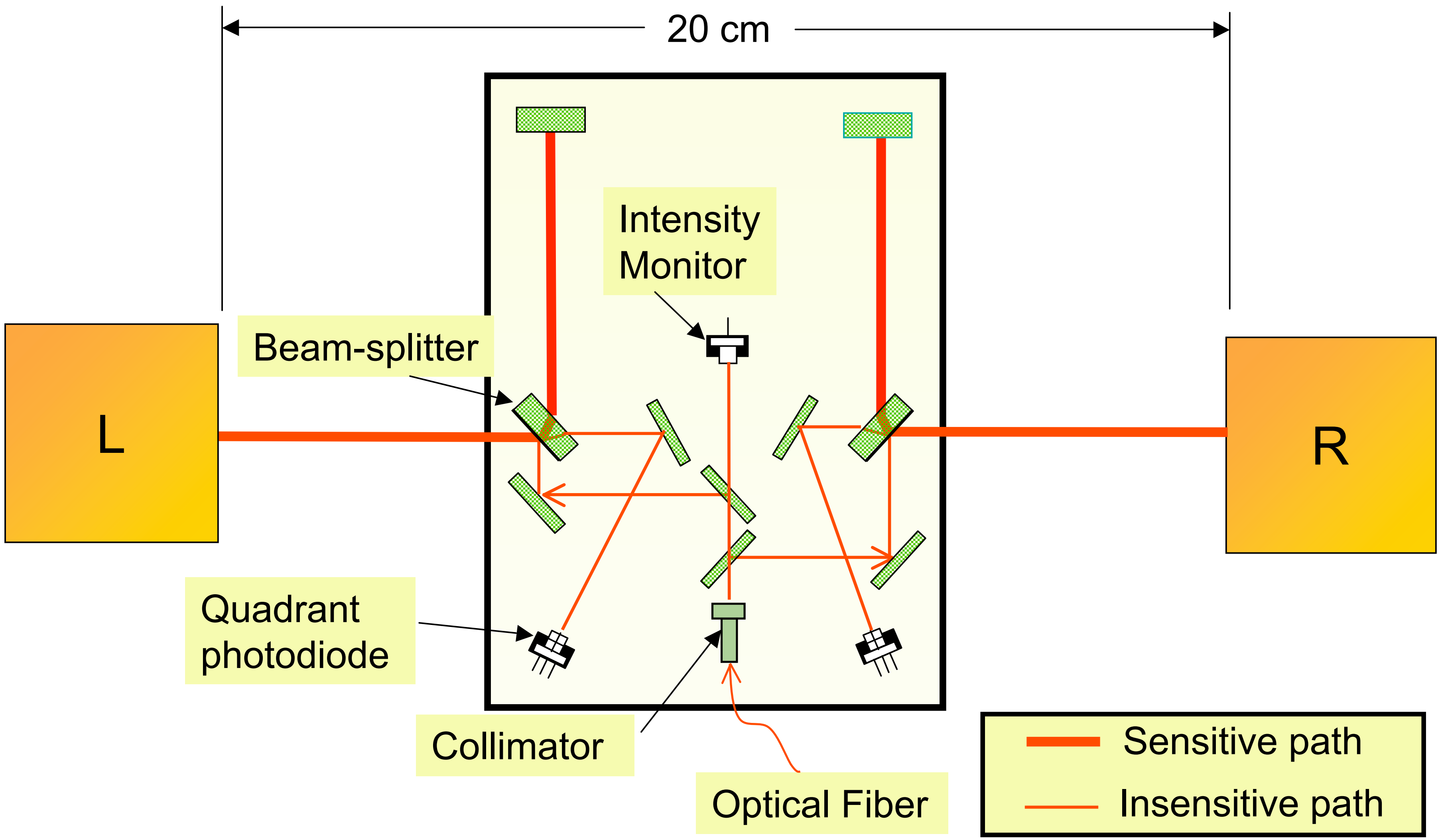
The ST7 Interferometer

Andreas Kuhnert
Robert Spero

Jet Propulsion Laboratory
California Institute of Technology

Optical Bench



Interferometer Features

Beam diameter 1 mm, Rayleigh range 70 cm, sensitive path lengths 10 cm.

No modulators, phasemeters, intensity stabilization, or frequency stabilization.

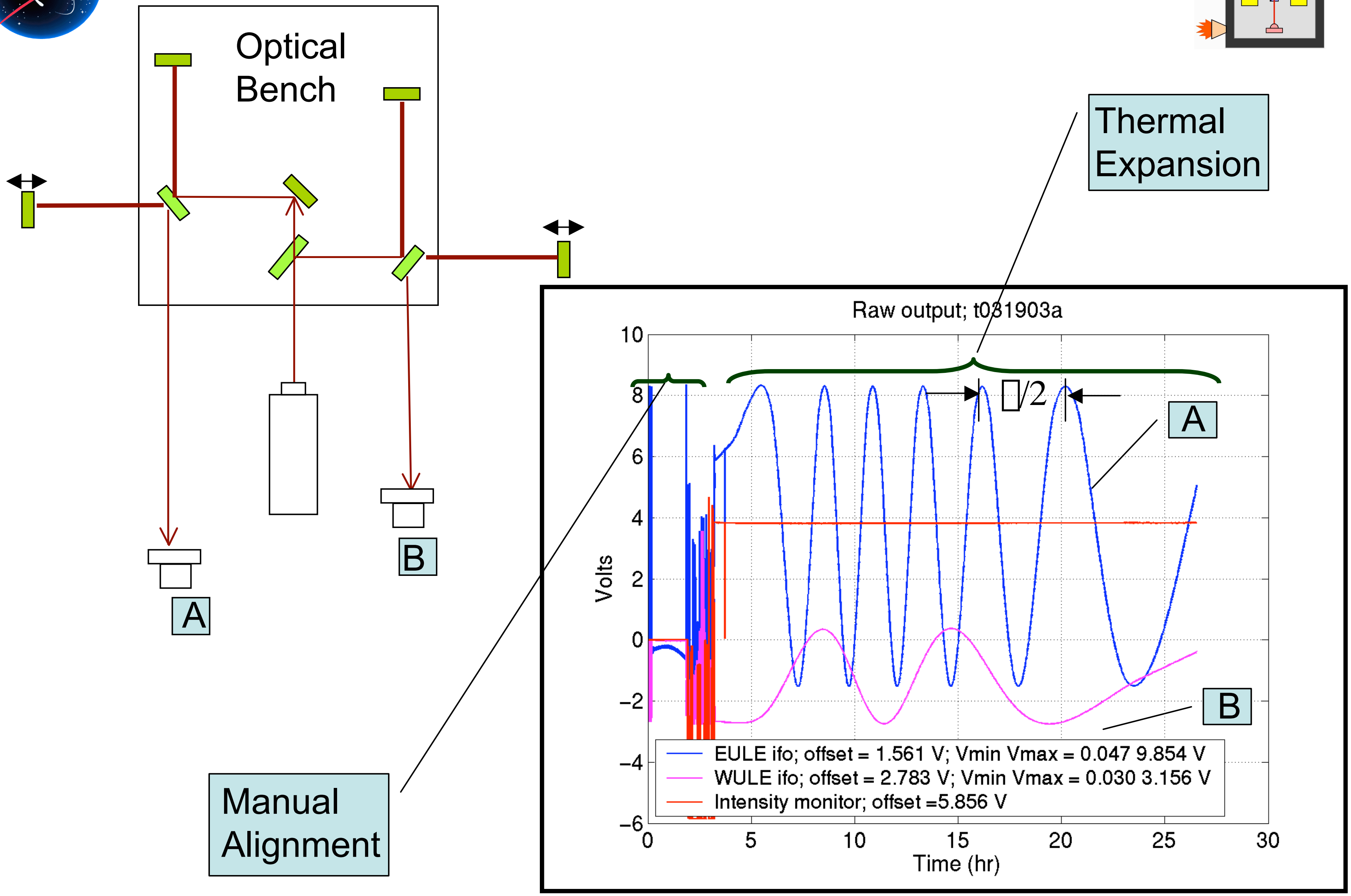
Requires test mass to be positioned near mid-fringe.

Intensity monitored, noise removed in data analysis.

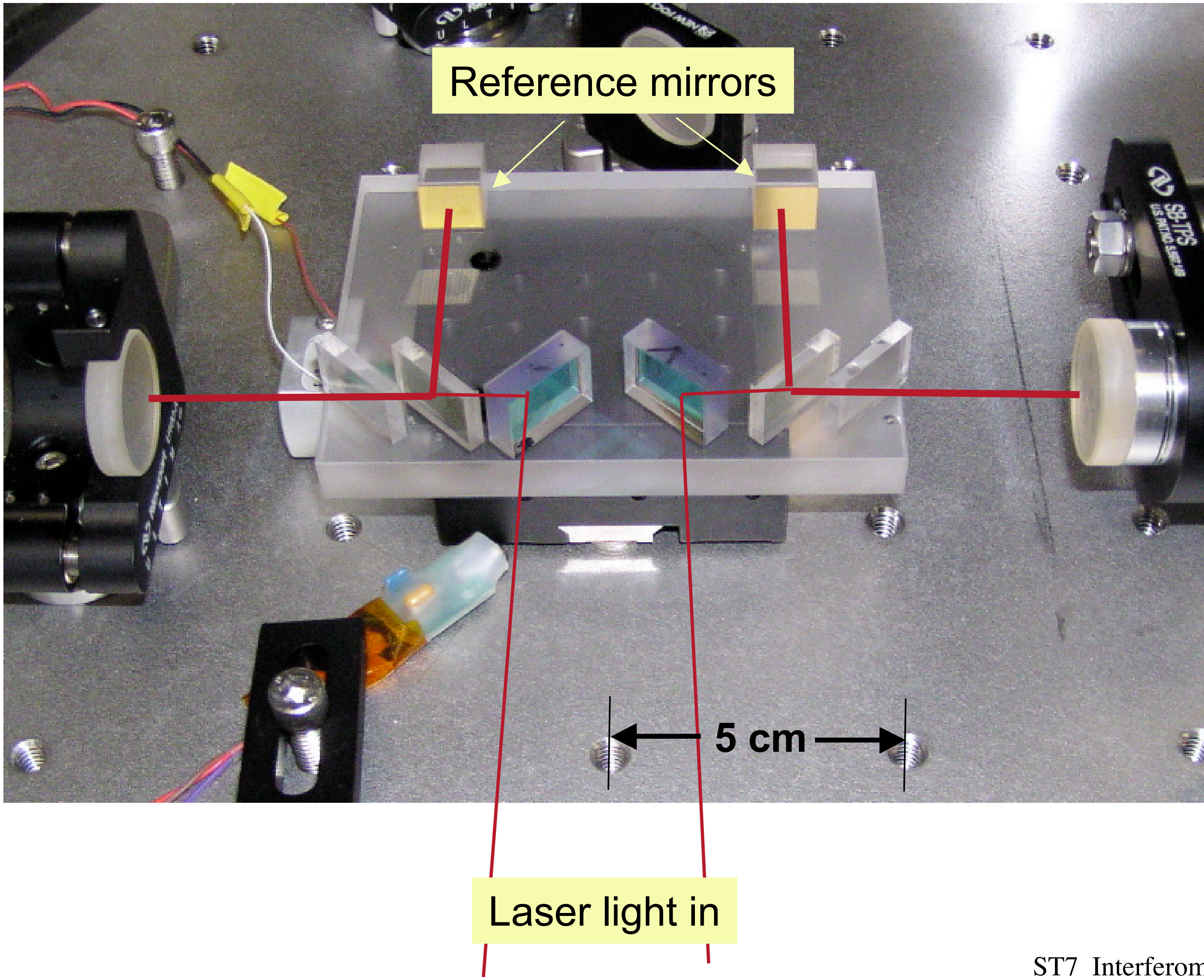
Separate measurements of both bench/test-mass distances.

Quadrant photodiodes monitor total fringe signal, and two axes of alignment.

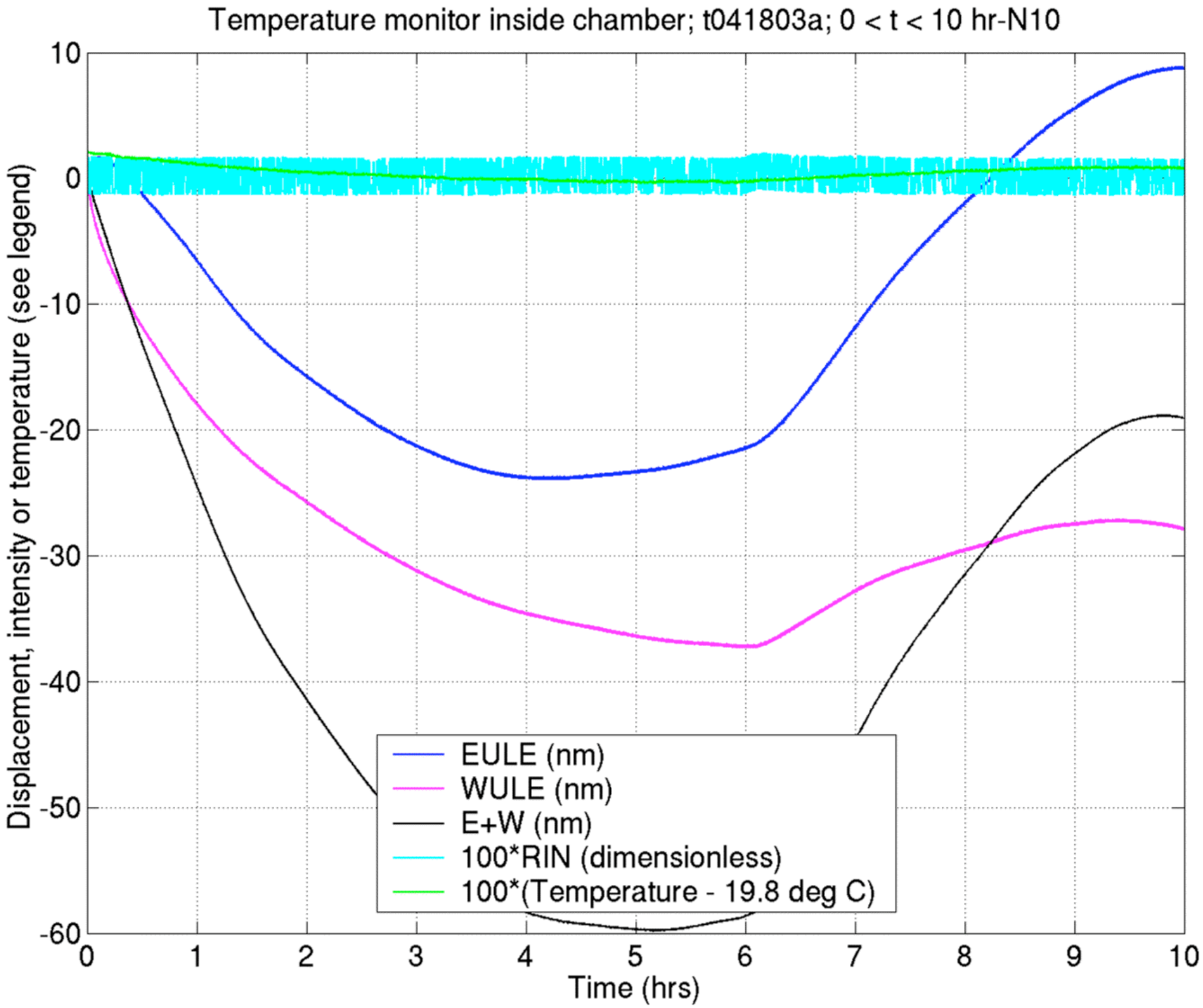
Homodyne Signal



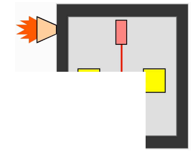
Contacted Optics in Vacuum Chamber

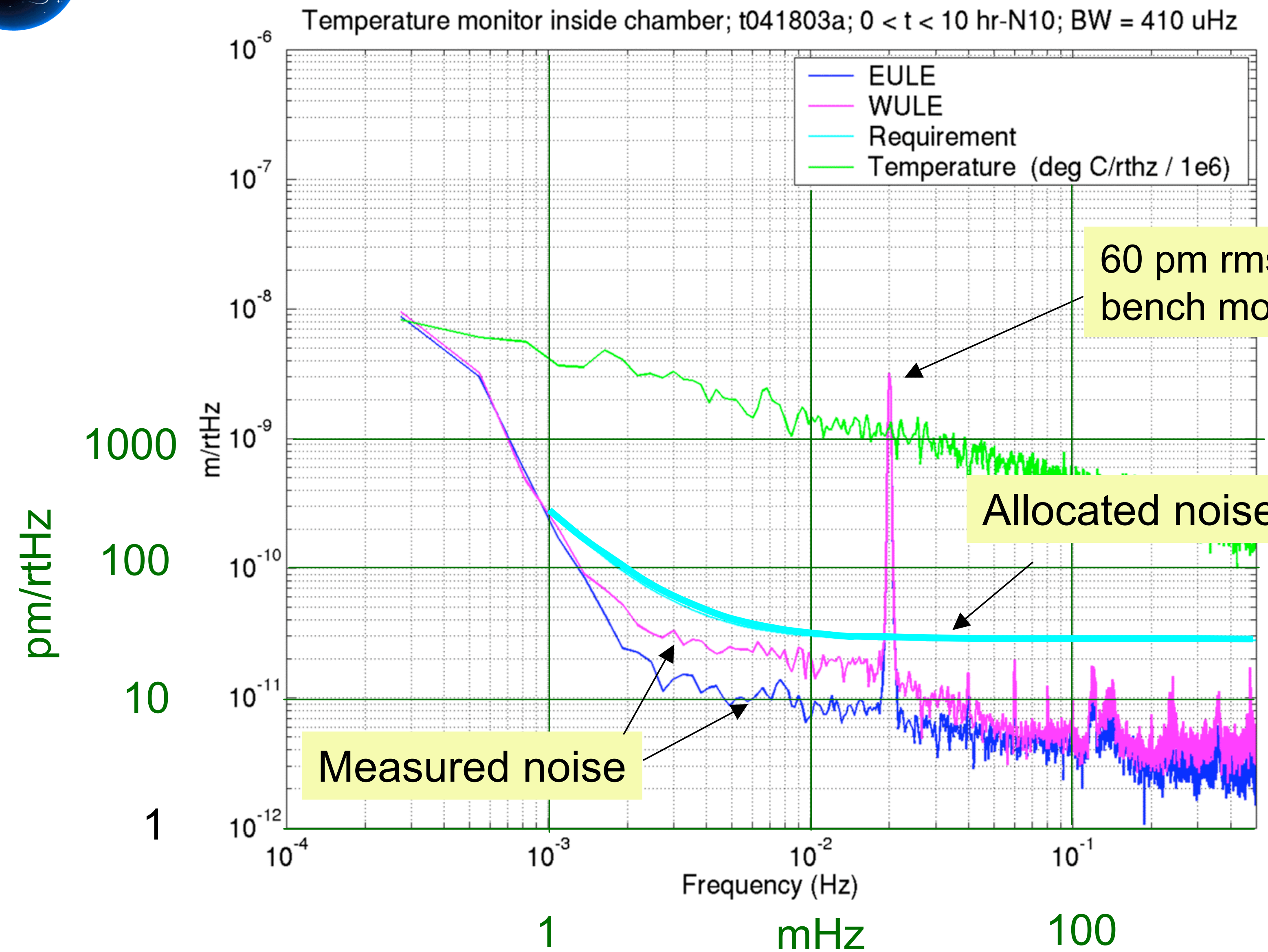


Testbed Drift



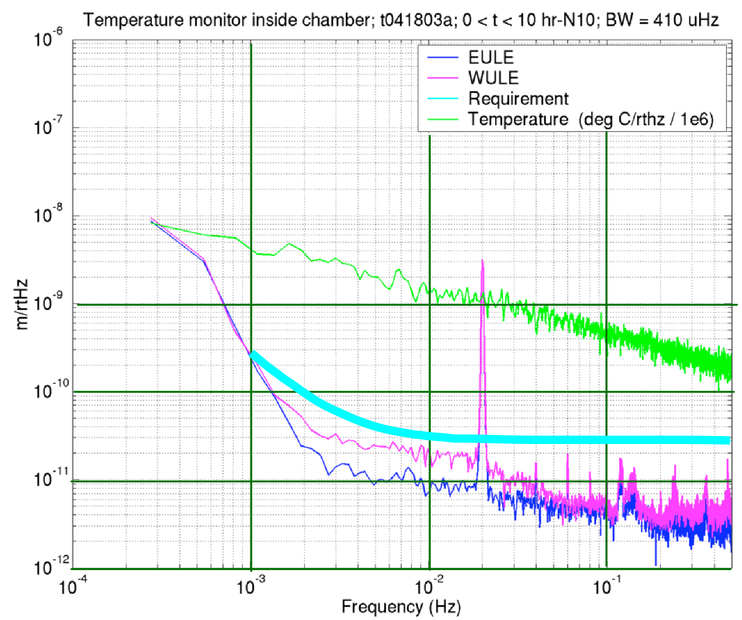
Testbed Noise



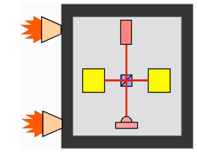


Measurements Demonstrate:

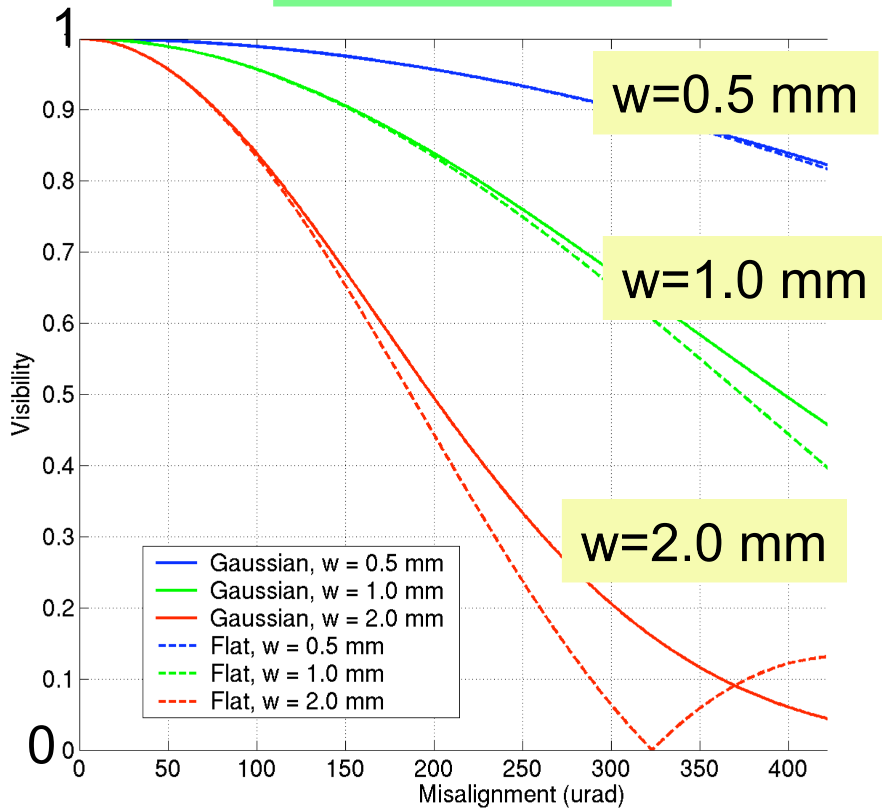
1. Analog electronics and ADC noise adequately low
2. Thermal sensitivity probably adequately low
3. Bench motion suppression typically x200, without calibration (x1000 needed)
4. Frequency stabilization not needed
5. Intensity noise can be suppressed in data analysis



Static Misalignment and Static Longitudinal Error

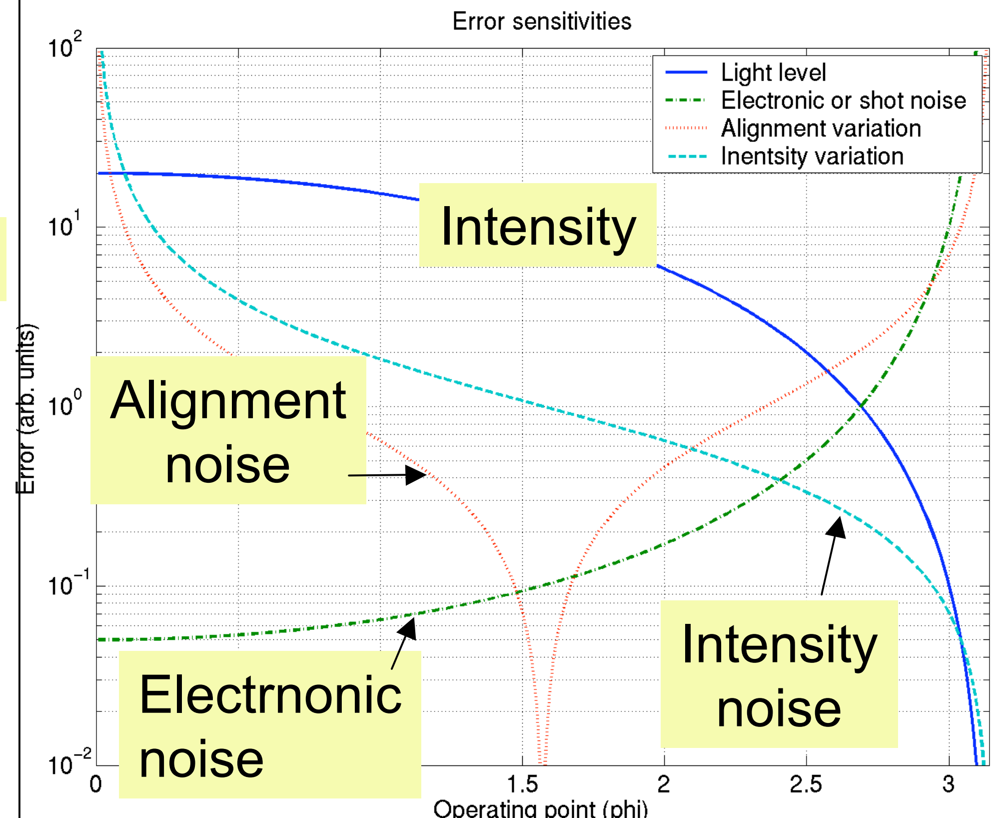


Fringe Visibility



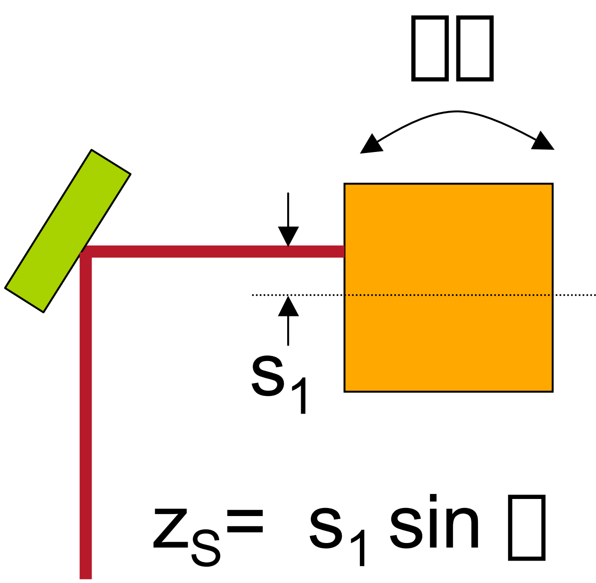
Misalignment (□rad)

Error Sensitivity



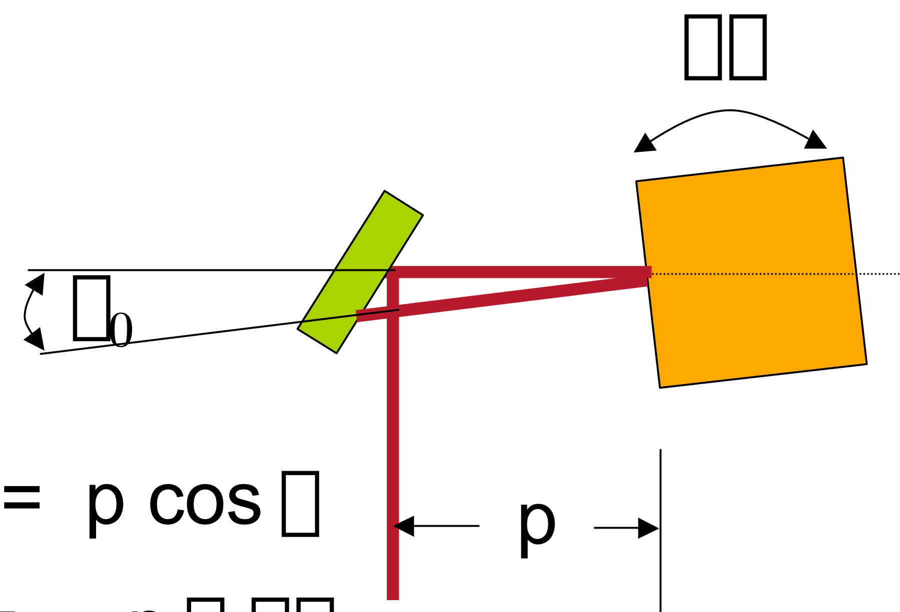
Bright Mid Dark

Alignment Sensitivity 1:
Geometric Errors



$z_S = s_1 \sin \square$

$\square z_S = s_1 \square\square$



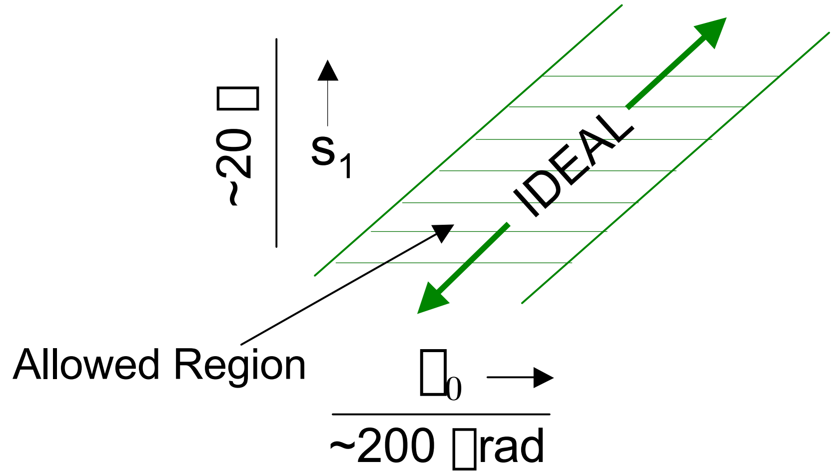
$z_c = p \cos \square$

$\square z_c = p\, \square_0 \square\square$

Errors are correlated, and of same order: $s_1 \sim p\, \square_0$

Cancellation of Geometric Errors

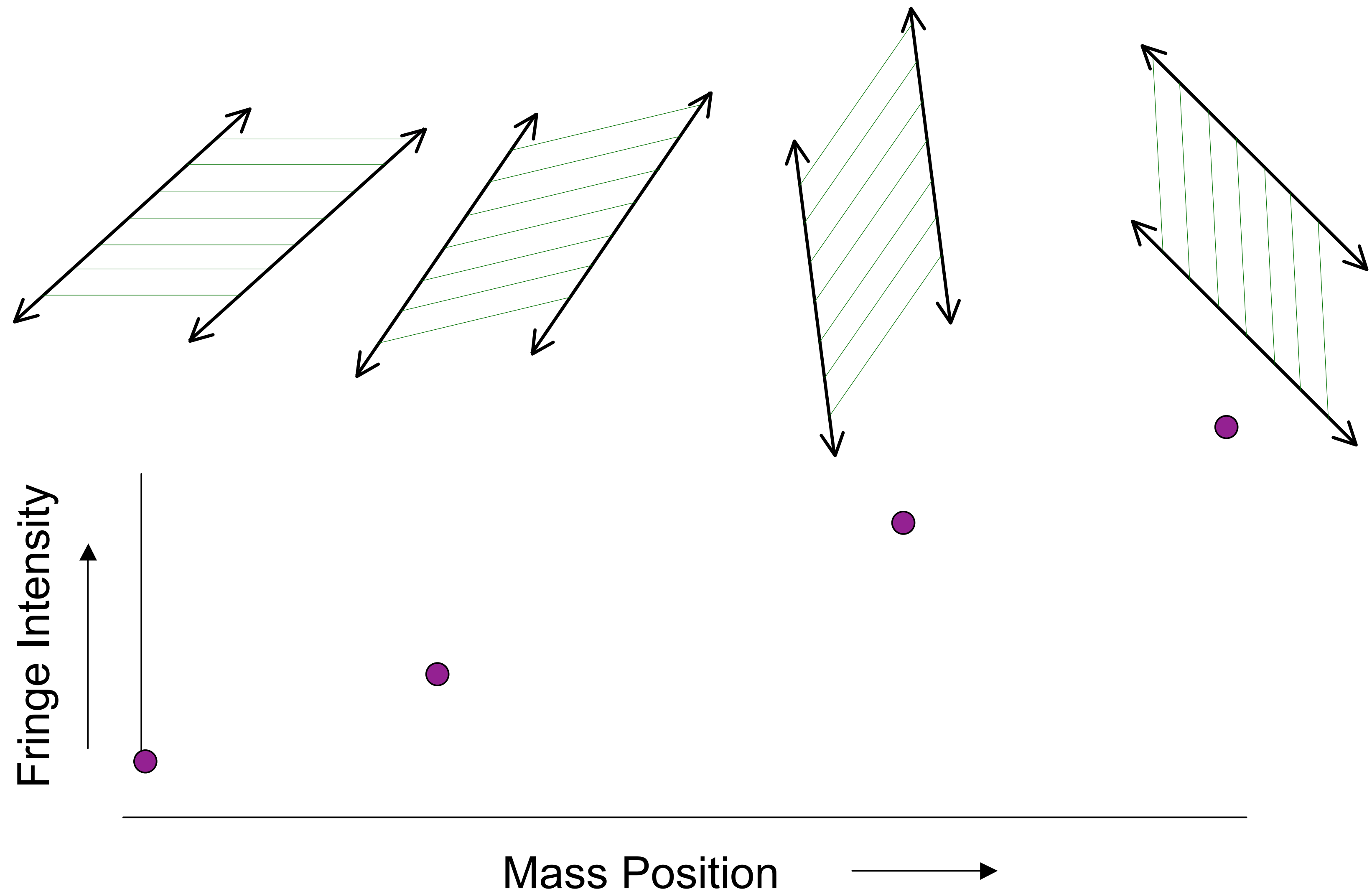
□z_s + □z_c = 0 when s_1 = -p□$_0$,
eliminating sensitivity to □□.



Implementation: Adjust translational or angular offset for extremum of interferometer response (intermittently or in control loop, depending on drift rates).

The catch (for homodyne interferometer): Cancellation fails if mirror position drifts.

Cancellation of Geometric Errors Spoiler: Dependence on Fringe Position

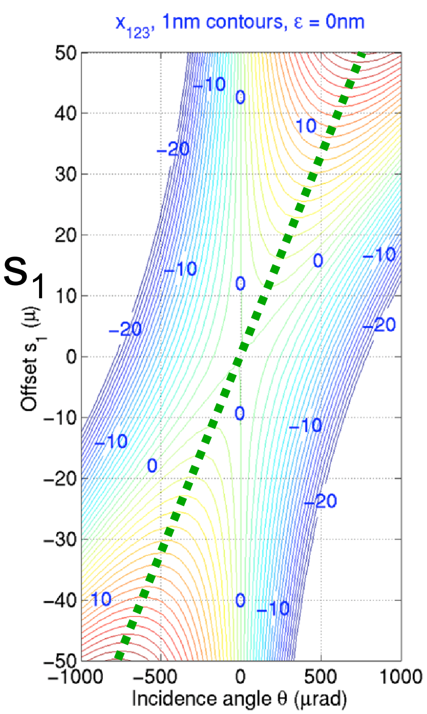


Alignment Sensitivity 2:
Readout Errors

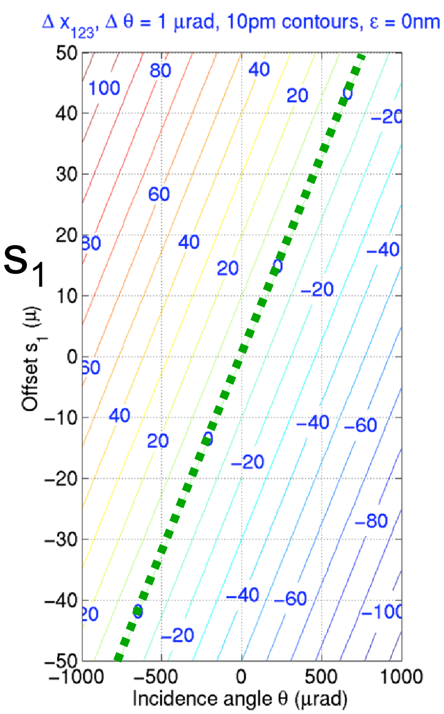
Fringe Center:
saddle in z(□)

z(□) dz/d□

s_1

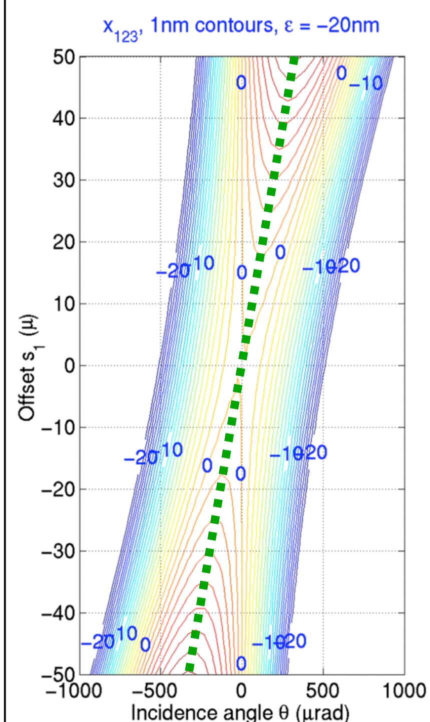


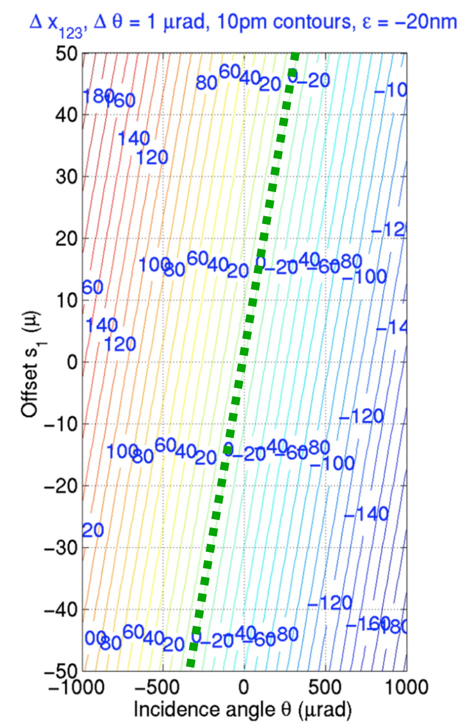
s_1



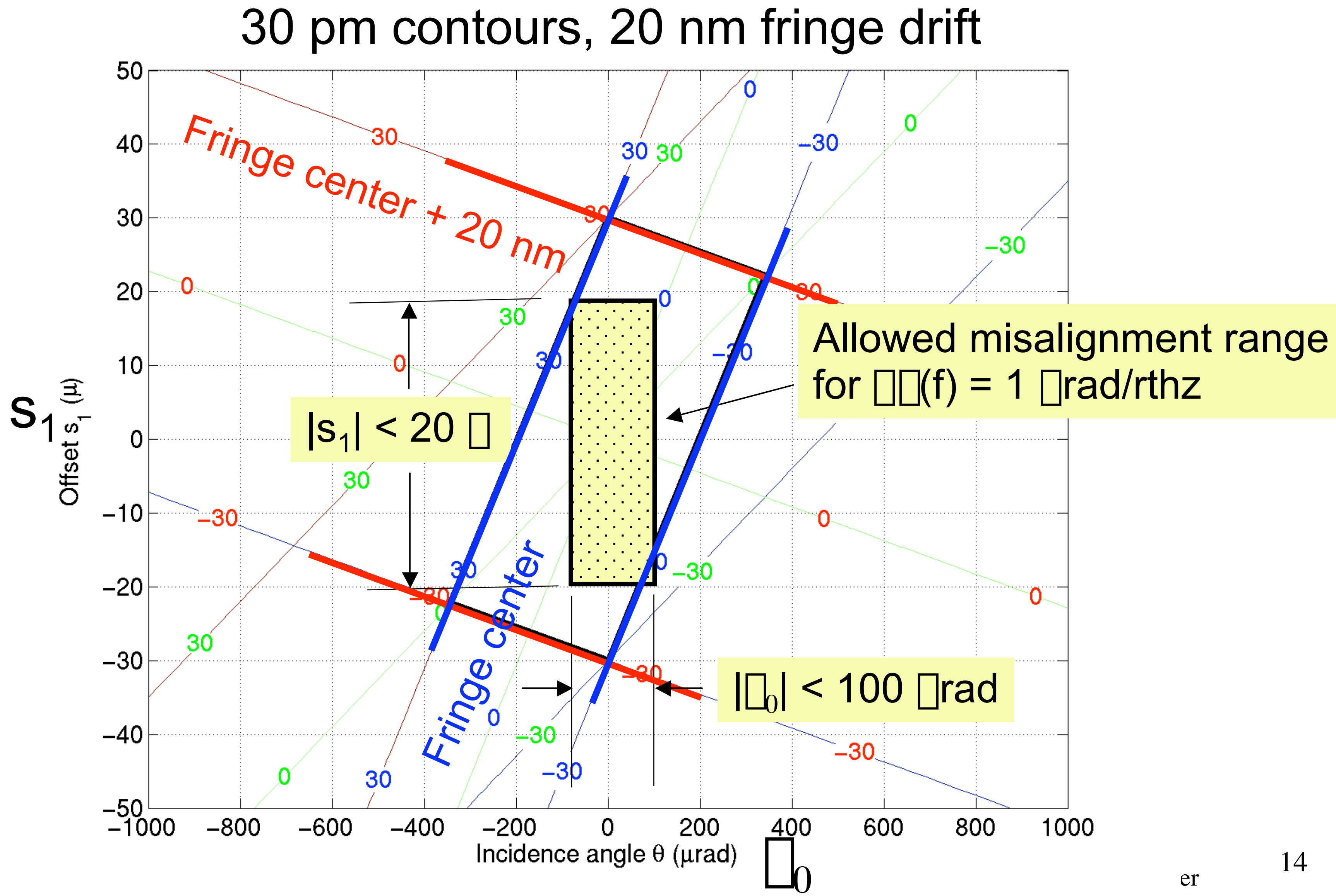
□ □

Fringe Center +20 nm:
saddle shifts





Misalignment and Fringe Drift Together



Formulae for Cosine Error

$$I_{\rm sum} = \frac{1}{2}\left[1+\sin\phi\,\exp(-k^2w^2\theta^2/8)\right]; \qquad \phi = 2kz.$$

$$\frac{dI_{\rm sum}}{d\theta} = \frac{k^3w^2\theta z}{4}; \qquad \frac{dI_{\rm sum}}{dz} = k$$

$$\frac{dz}{d\theta} = \frac{dI_{\rm sum}/d\theta}{dI_{\rm sum}/dz} = \frac{k^2w^2}{4}\theta z; \qquad \text{allowed } \tilde{\theta}(f) = \frac{\tilde{z}(f)}{k^2w^2\theta z}$$

$$I_{\rm diff} = \frac{I_1 - I_2}{(I_1+I_2)/2} = 2\sqrt{\frac{2}{\pi^3}}k\theta w,$$

$$\frac{dI_{\rm diff}}{d\theta} = 2\sqrt{\frac{2}{\pi^3}}kw$$

displacement signal = 130
□ = 100 □rad,
z = 100 nm

jitter

angle signal,
= 1505

Alignment sensitivity formulae – p.1/1

Options for Reduction of Alignment Noise

1. Tighten tolerances on □(f) itself, alignments s_1, $□_0$, or test mass position drift □z .
2. Fringe-tracking interferometer to force □z = 0. Requires actuated reference mirrors or feedback to hold both test masses on fringe center.
2. Intermittent calibrations to find optimum s_1 or $□_{0.}$
3. Monitor □(f) with quadrant photodiodes, and subtract scaled version of measured noise from main displacement signal.
4. Correct □(f) with electrostatic feedback.

Intensity Pattern with Misalignment

- Horizontal misalignment shown.
- Pattern insensitive to fringe offset near mid-fringe.
- Sample with 4 pixels (quadrant photodiode). Difference/sum response:

$dQ/d\square = \mathrm{sqrt}(8kw/\square^3)$