Laser interferometry

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Content

Introduction

Famous applications of optical interferometry

Practical applications of optical interferometry

Detection/locking schemes

Mechanical stability

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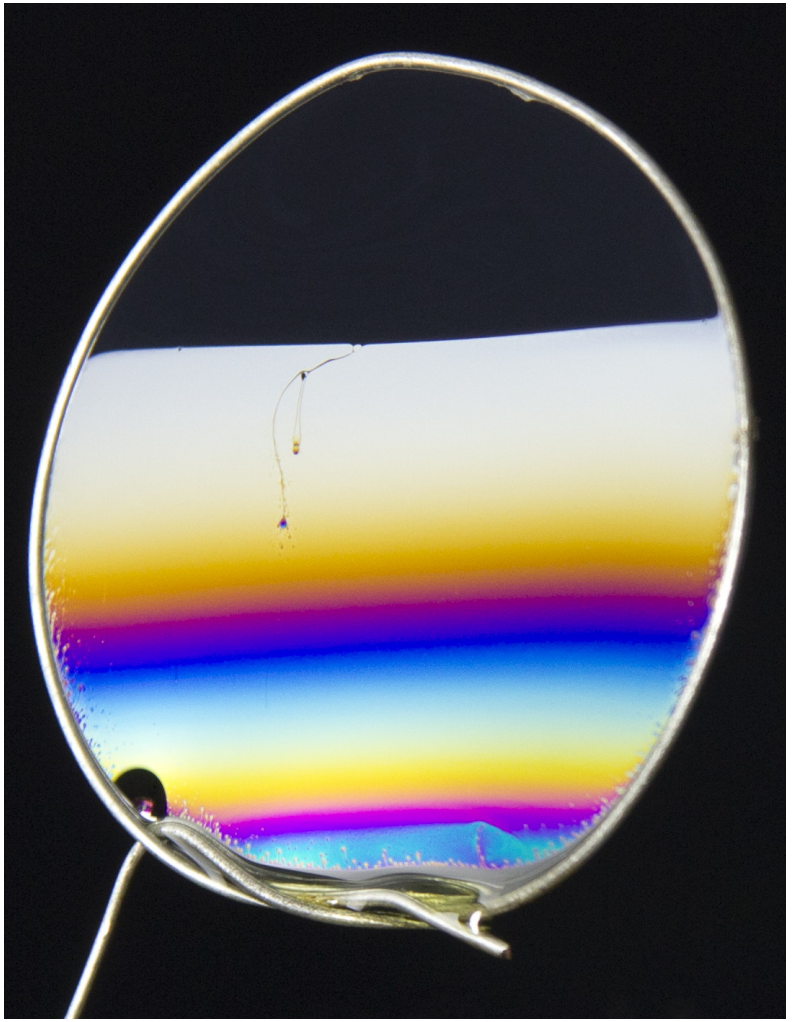
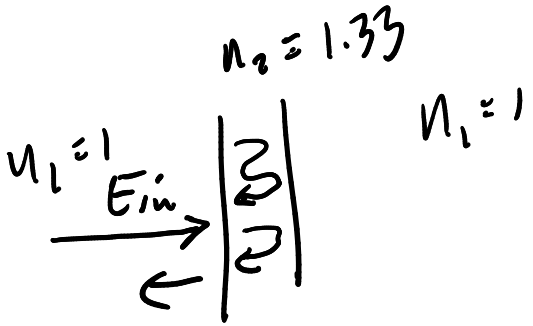
The etalon





$$r_{12} = \frac{n_1 - n_2}{n_1 + n_2}$$

$$t_{12} = \frac{2n_1}{n_1 + n_2}$$

$$r_{21} = -r_{12} = -r$$

$$r^2 + t_{12}\, t_{21} = 1$$

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The etalon

Let's do the math

$$E_{refl} = -r E_{in} + E_{in}\, t_{12}\, e^{i\delta}\, r\, e^{ik_0 n_2 L}\, t_{21}$$
$$+ E_{in}\, t_{12}\, e^{i\delta}\, r\, e^{i\delta}\, r\, e^{i\delta}\, r\, e^{i\delta}\, t_{21}$$
$$+ \dots$$
$$= -r E_{in} + r E_{in}\, t_{12} t_{21}\, e^{2i\delta} \sum_{n=0}^{\infty} \left(r^2 e^{2i\delta}\right)^n$$

$$\frac{E_{refl}}{E_{in}} = r_{FP} = \frac{-r(1-e^{2i\delta})}{1-r^2 e^{2i\delta}}$$

$$\left|\frac{E_{out}}{E_{in}}\right|^2 = |r_{FP}|^2 = R_{FP} = \frac{4R\sin^2\delta}{(1-R)^2 + 4R\sin\delta}$$

$$R = |r|^2$$

$$\nu_{FSR} = \frac{c}{2n_2 L}$$

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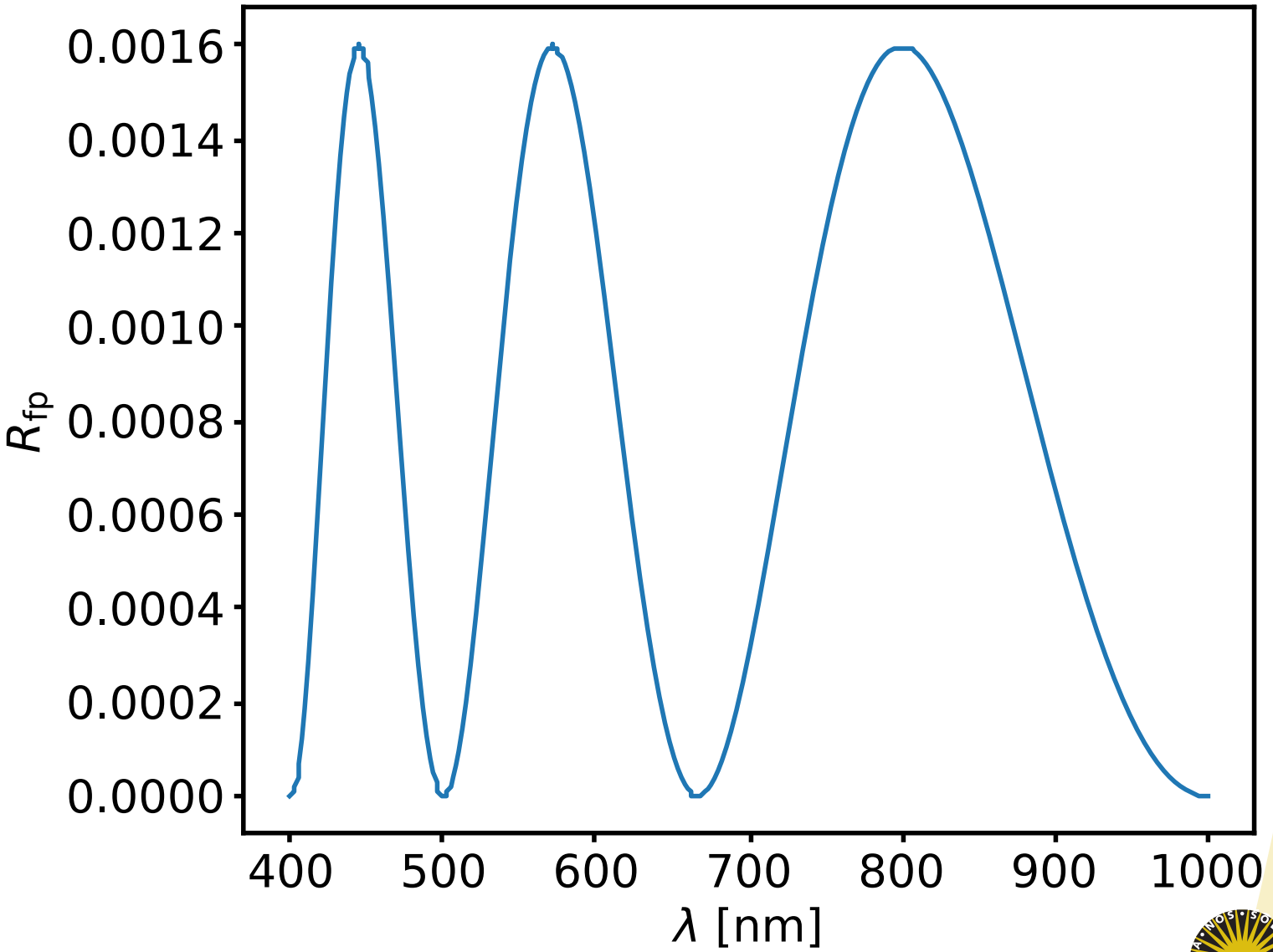
The etalon

Let's do the math

Soap film



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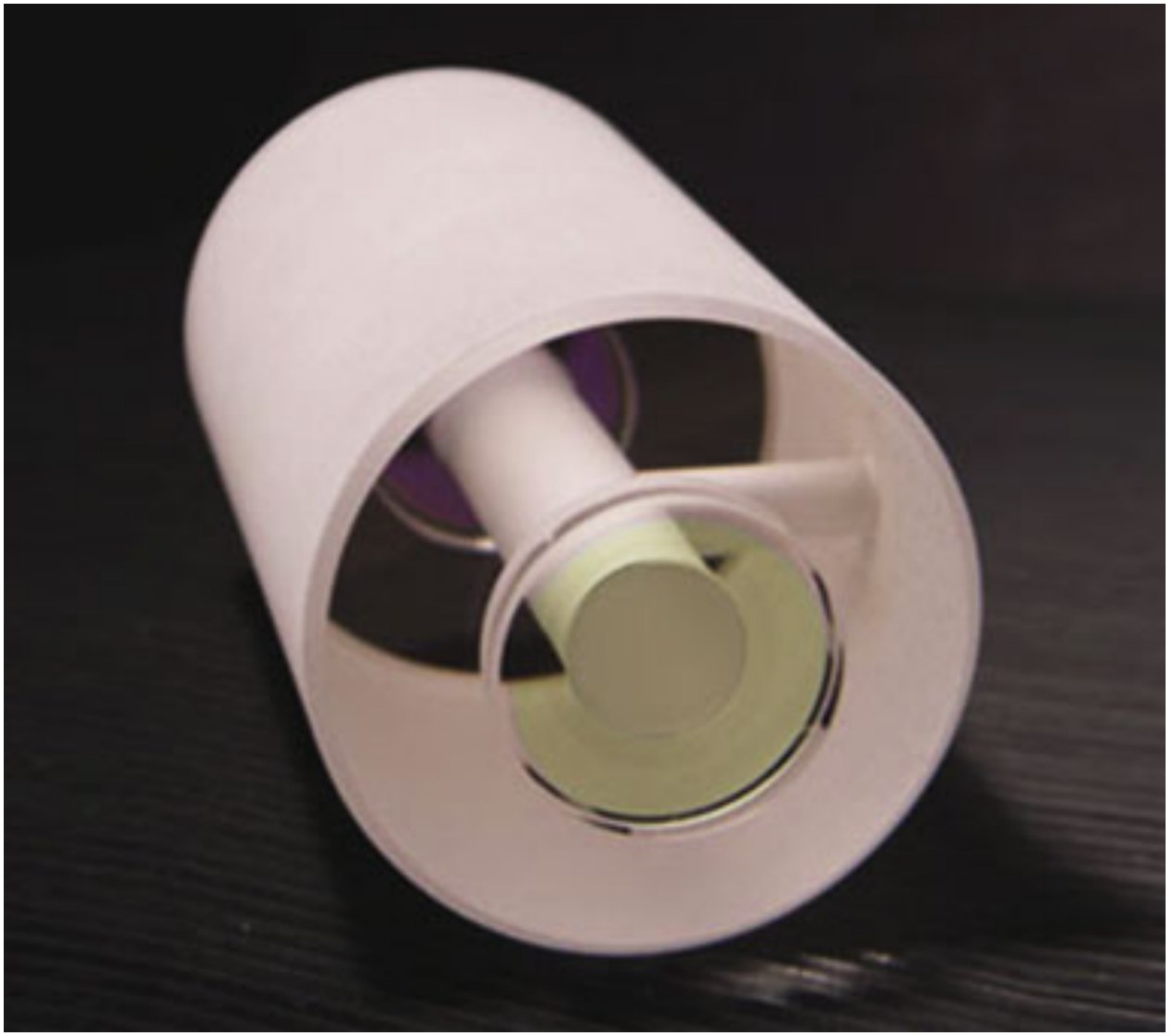
Fabry-Perot



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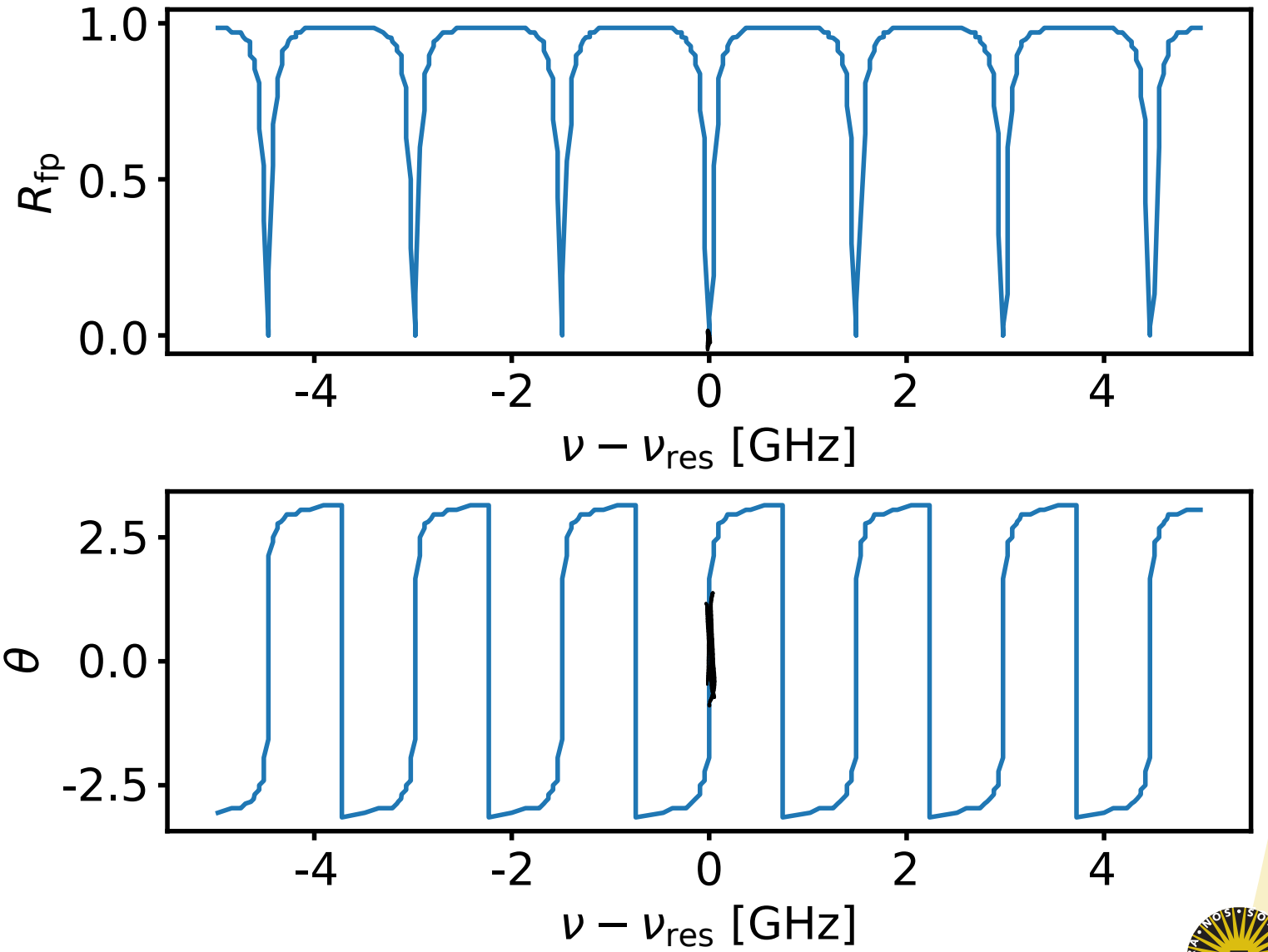
Fabry-Perot



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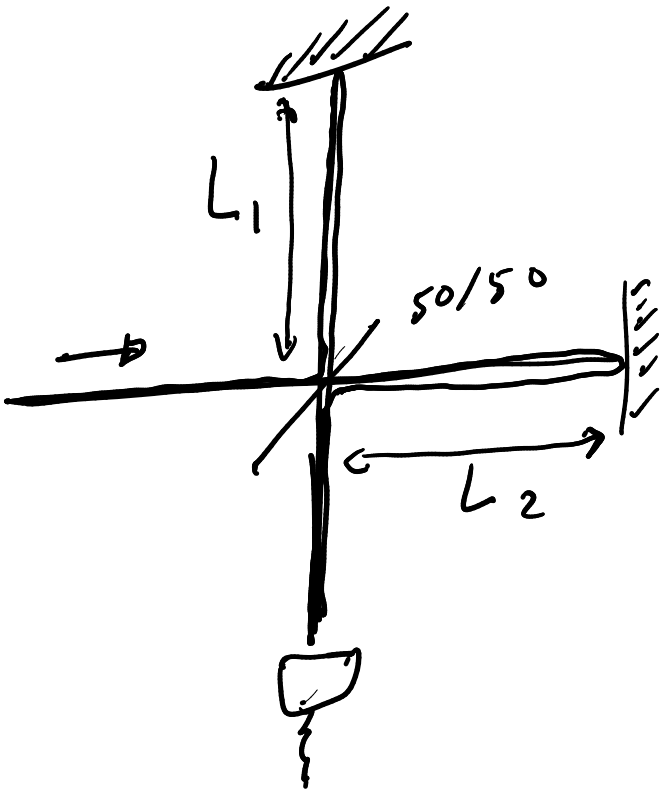
Content

The Michelson-Morley interferometer



$$E_{in} = E_0 e^{-ikx}$$

$$E_1 = E_{in}\, r\, e^{-2ikL_1}\, t$$

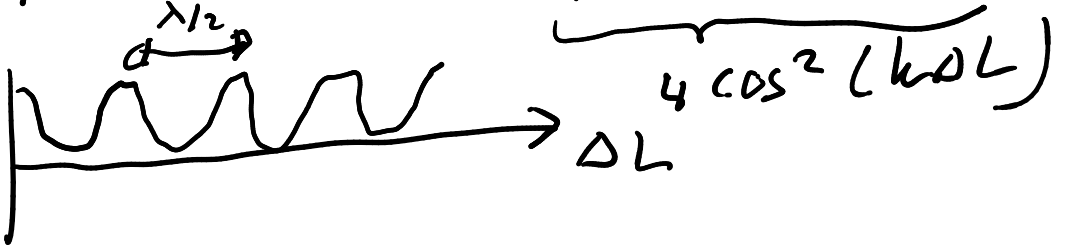
$$E_2 = E_{in}\, r\, e^{-2ikL_2}\, t$$

$$E_{det} = E_1 + E_2$$

$$= E_{in}\, r \cdot t\, e^{-2ikL_1} \times \left(1 + e^{-2ik\Delta L}\right)$$

$$\Delta L = L_2 - L_1$$

$$|E_{det}|^2 = |E_{in}|^2 t^2 r^2 \underbrace{\left|1 + e^{-2ik\Delta L}\right|^2}_{4\cos^2(k\Delta L)}$$



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The Michelson-Morley interferometer

Let's do some math

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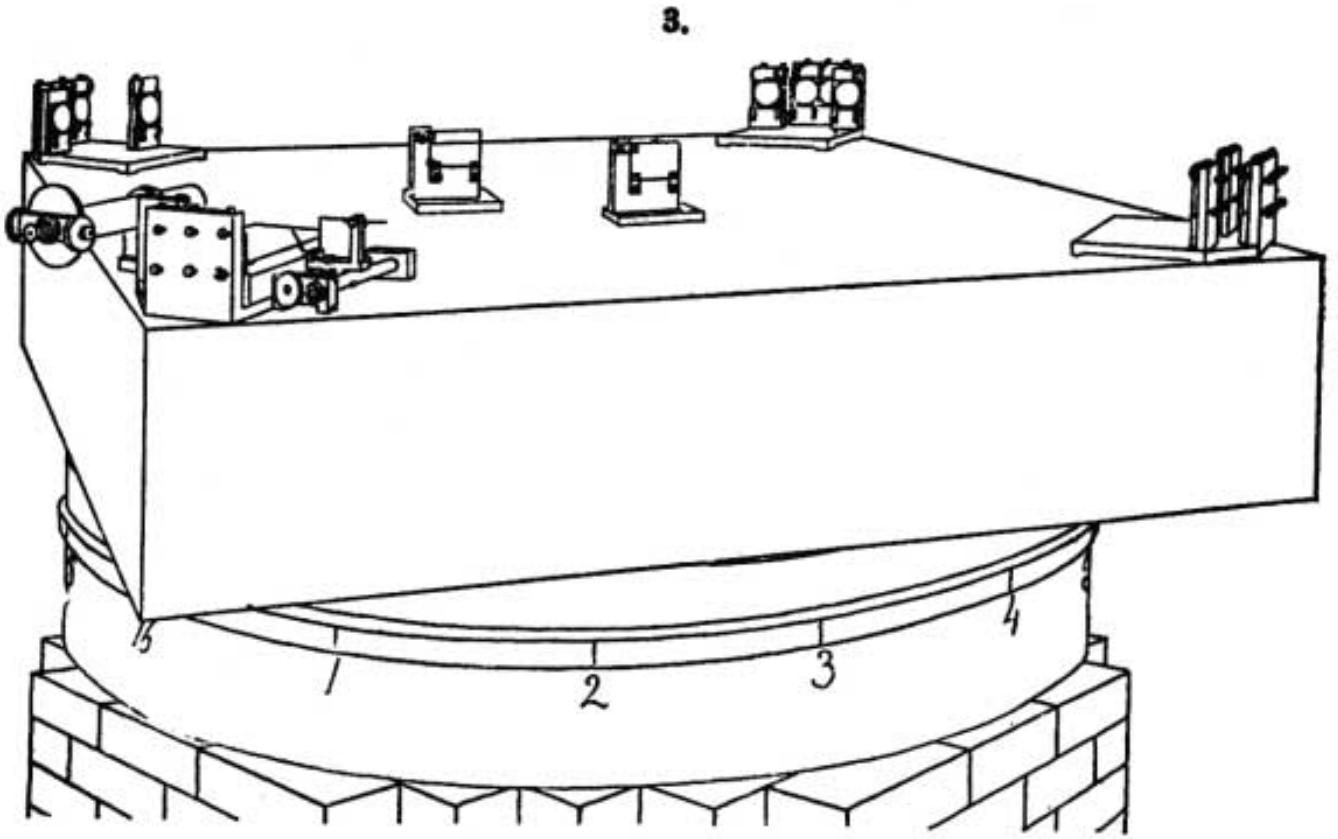
The Michelson-Morley experiment



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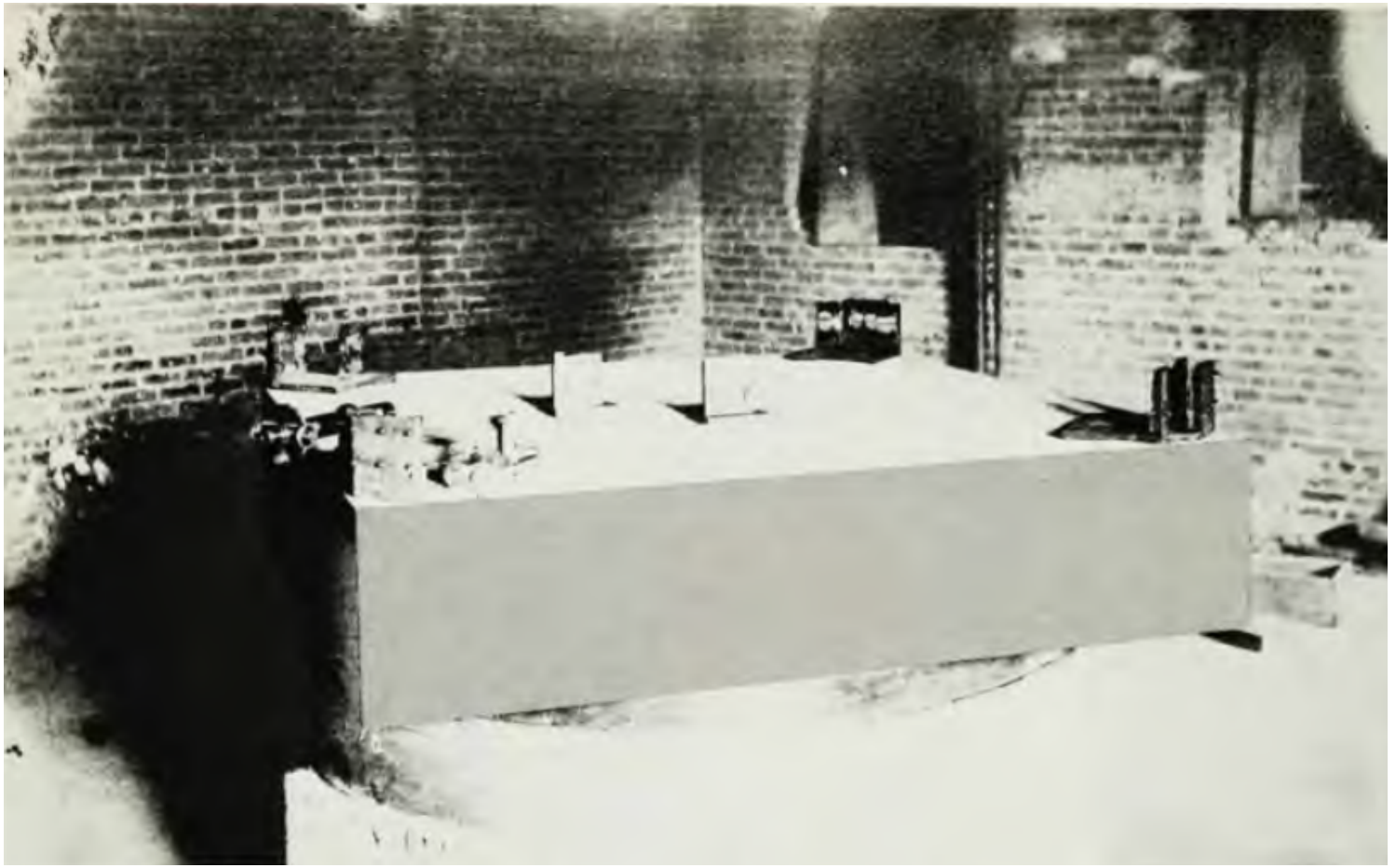
The Michelson-Morley experiment



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LIGO/VIRGO: preposterously big Michelson-Morley experiments

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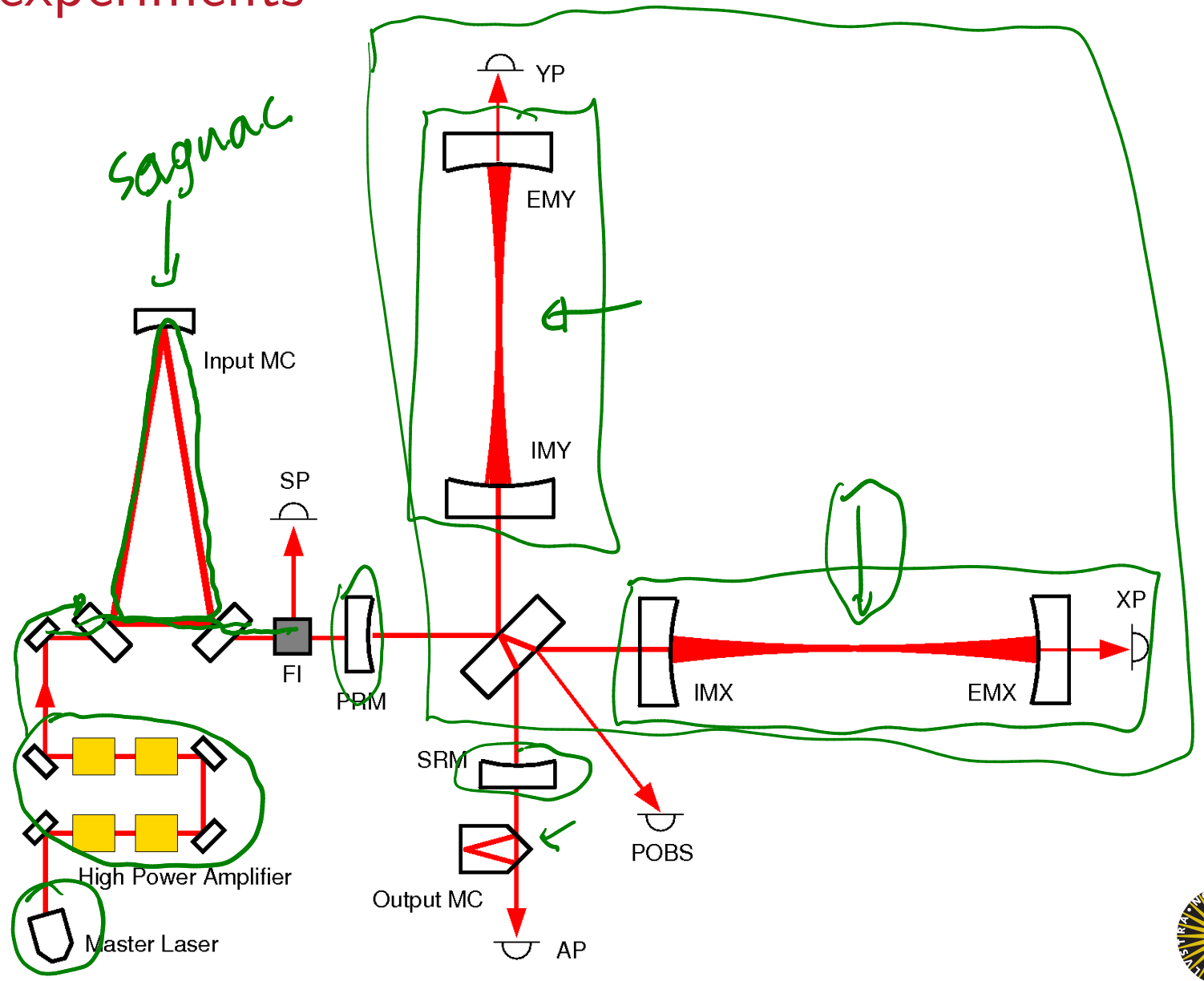
LIGO/VIRGO: preposterously big Michelson-Morley experiments



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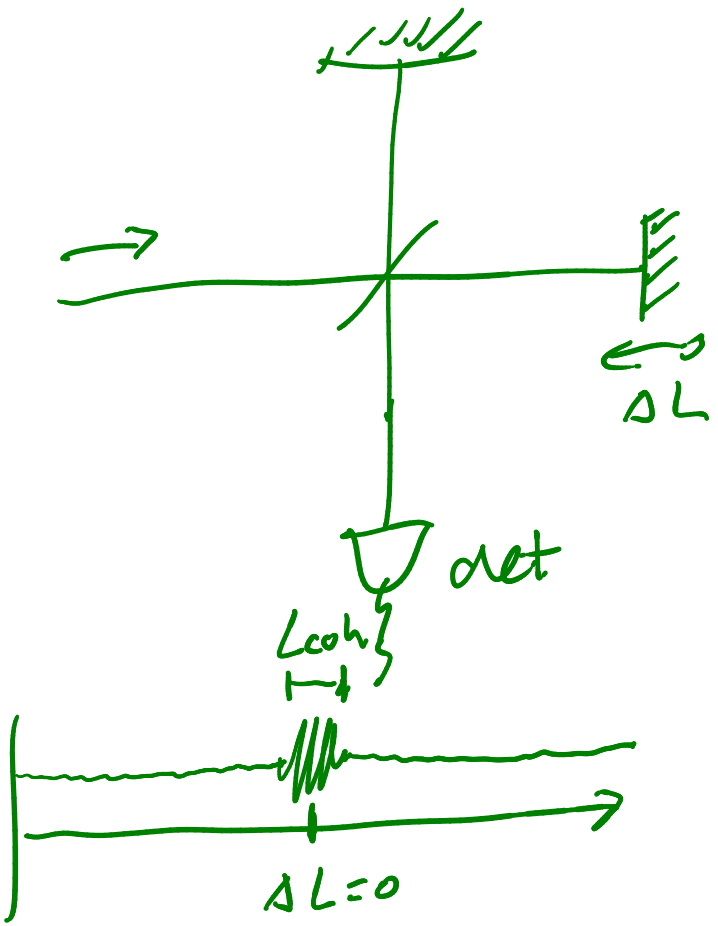
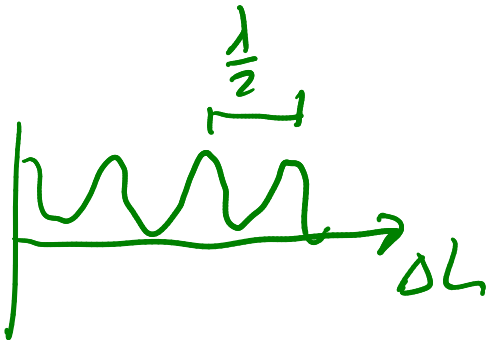
- We obviously not going to detect gravity waves during this course
- Even repeating the Michelson-Morley experiment is extremely difficult
- Let's look at some applications for mere mortals

Content

Fourier transform spectroscopy





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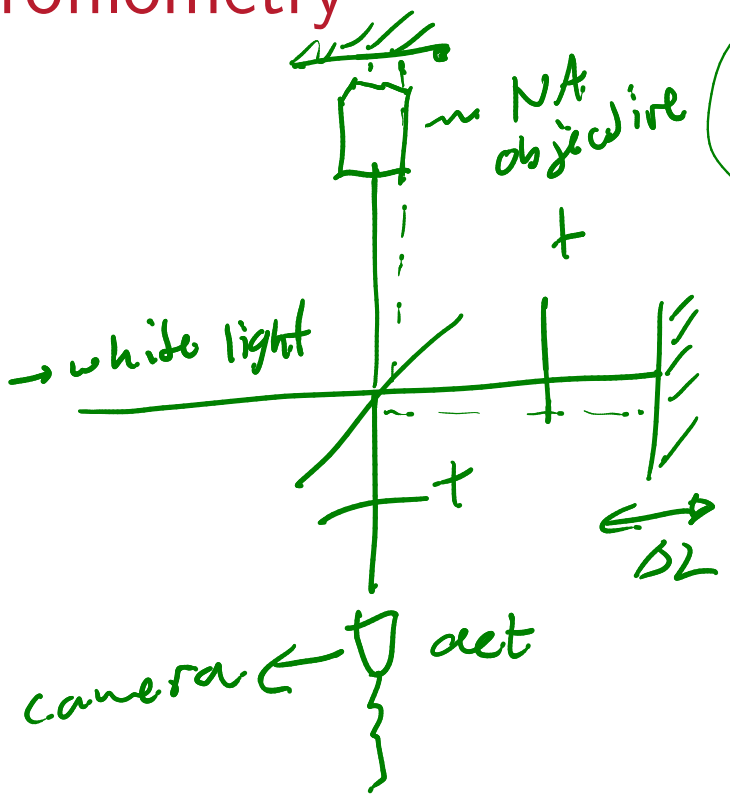
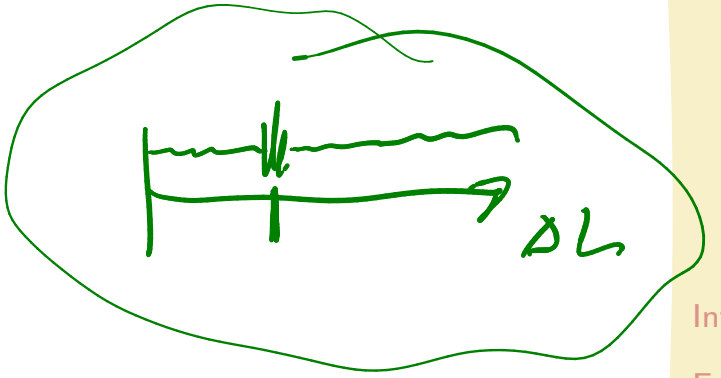
Optical profilometry





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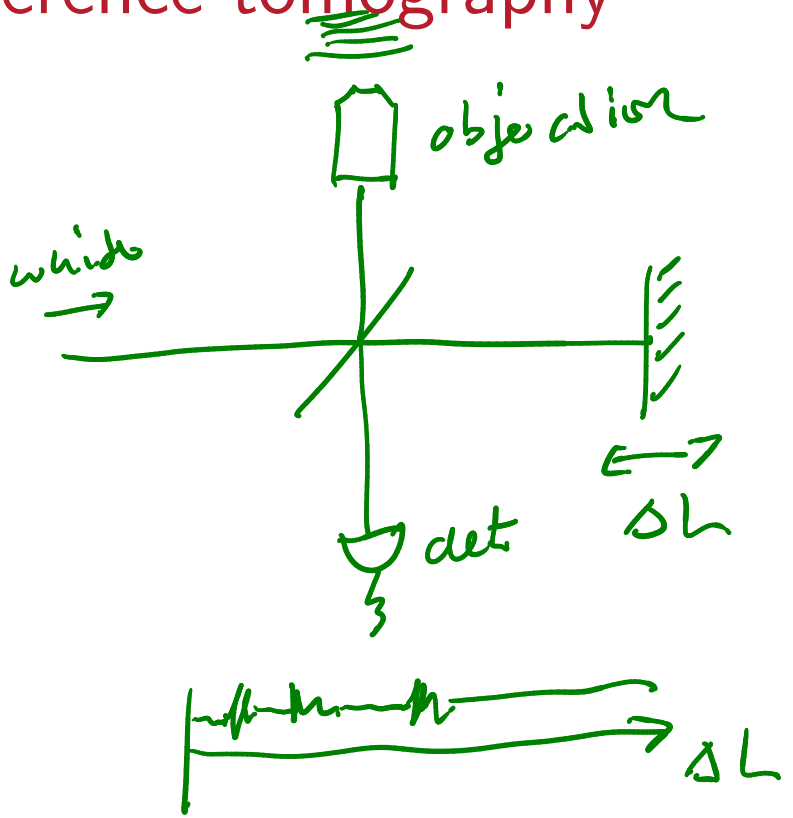
Optical coherence tomography



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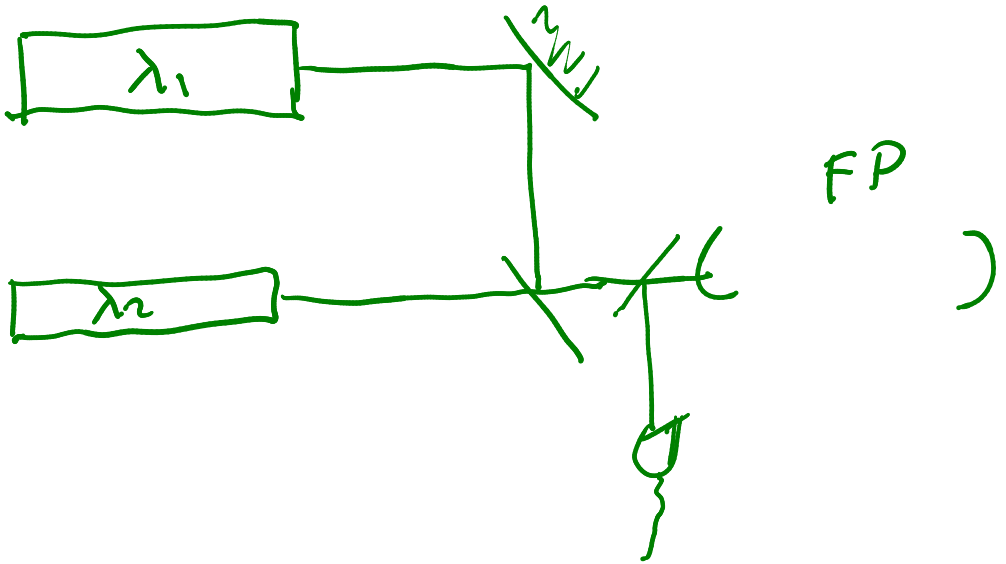
Laser stabilisation



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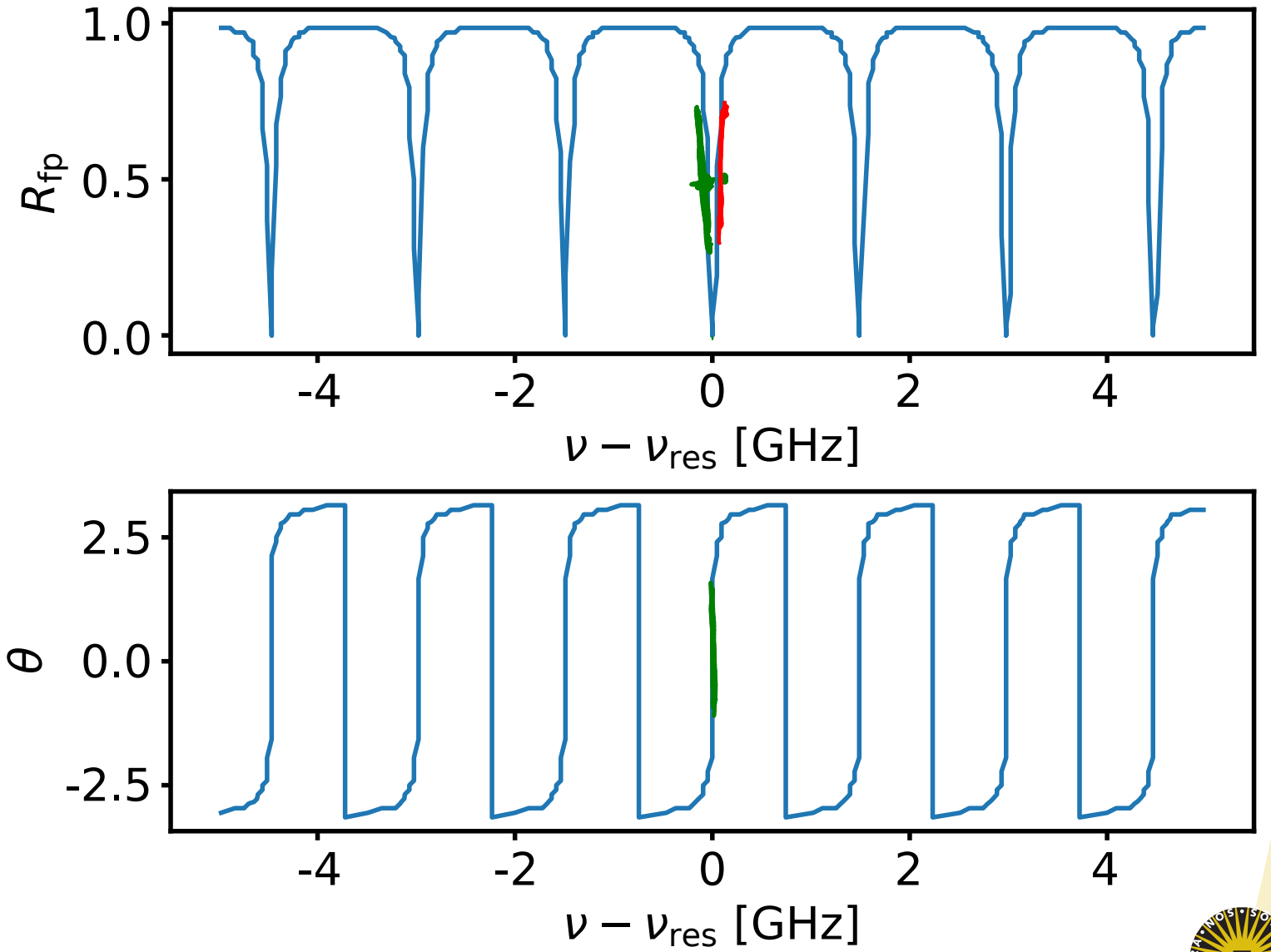
Transfer cavity



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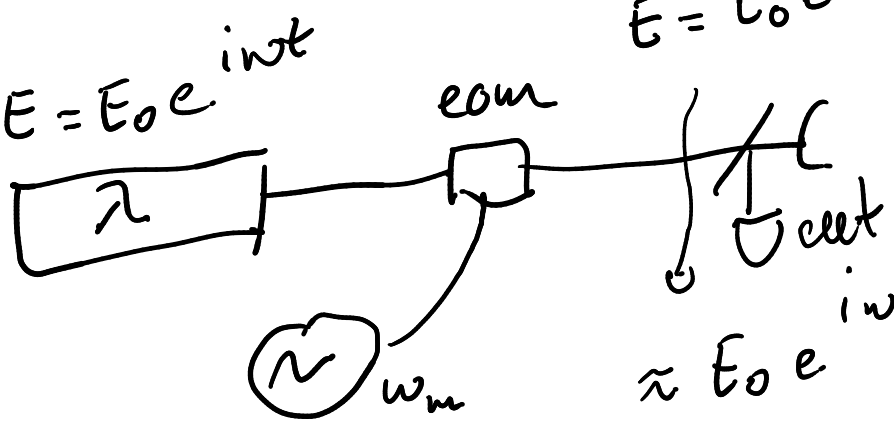
Error signal

- Error signal: is zero when you are at the target
- How?
- Detect the slope: slope is zero at maximum or minimum

Pound Drever Hall



$E = E_0 e^{i(\omega t + \beta \sin \omega_m t)}$

$\beta << \omega_m << \omega$

$\approx E_0 e^{i\omega t}(1 + i\beta \sin \omega_m t)$

$= E_0 e^{i\omega t}\left(1 + \frac{\beta}{2} e^{i\omega_m t} - \frac{\beta}{2} e^{-i\omega_m t}\right)$

$$r_{FP} = \frac{-r(1 - e^{2i\delta})}{1 - r^2 e^{2i\delta}} \longrightarrow \delta(\omega)$$

$$E_{FP} = E_0 \left\{ r_{FP}(\omega) e^{i\omega t} + \frac{\beta}{2} r_{FP}(\omega + \omega_m) e^{+i(\omega+\omega_m)t} - \frac{\beta}{2} r_{FP}(\omega - \omega_m) e^{+i(\omega-\omega_m)t} \right\}$$

$$P_{FP} \propto E_{FP}^* E_{FP} = \frac{\beta}{2} |E_0|^2 \left(\chi(\omega) e^{i\omega_m t} + \chi^*(\omega) e^{-i\omega_m t} \right) + \text{const. terms} + e^{\pm 2i\omega_m t} \text{ terms}$$

$$\chi(\omega) = r_{FP}^*(\omega) r_{FP}(\omega + \omega_m) - r_{FP}(\omega) r_{FP}^*(\omega - \omega_m)$$

Pound Drever Hall

Let's do the math

$$\chi = \chi' + i\chi''$$

$$\beta |E_0|^2 \left(\chi' \cos\omega_m t - \chi'' \sin\omega_m t \right)$$

$$\times \cos(\omega_m t + \varphi)$$

$$\cos\omega_m t \cos(\omega_m t + \varphi) = \frac{1}{2}\cos(2\omega_m t + \varphi) + \frac{1}{2}\cos\varphi$$

$$\sin\omega_m t \quad " \quad = \quad \ldots \quad - \frac{1}{2}\sin\varphi$$

$$\alpha \quad \frac{1}{2}\chi' \cos\varphi + \frac{1}{2}\chi'' \sin\varphi$$

$\varphi = 0 \rightarrow$ measurement χ'

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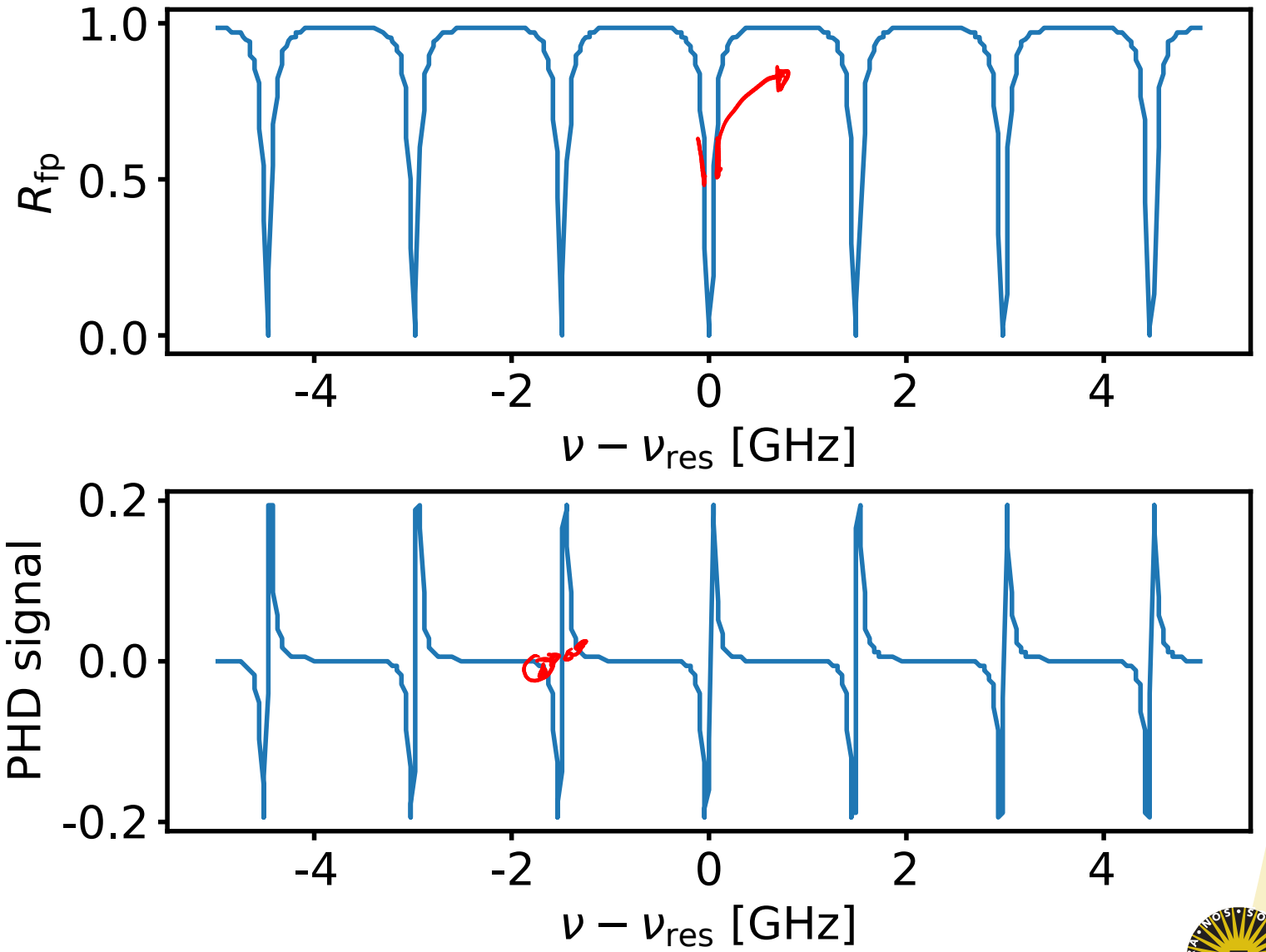

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Laser locking

- now we have an error signal
- tells us in which direction the correct frequency/length is
- feed into an integrator, feed integrator signal into actuator

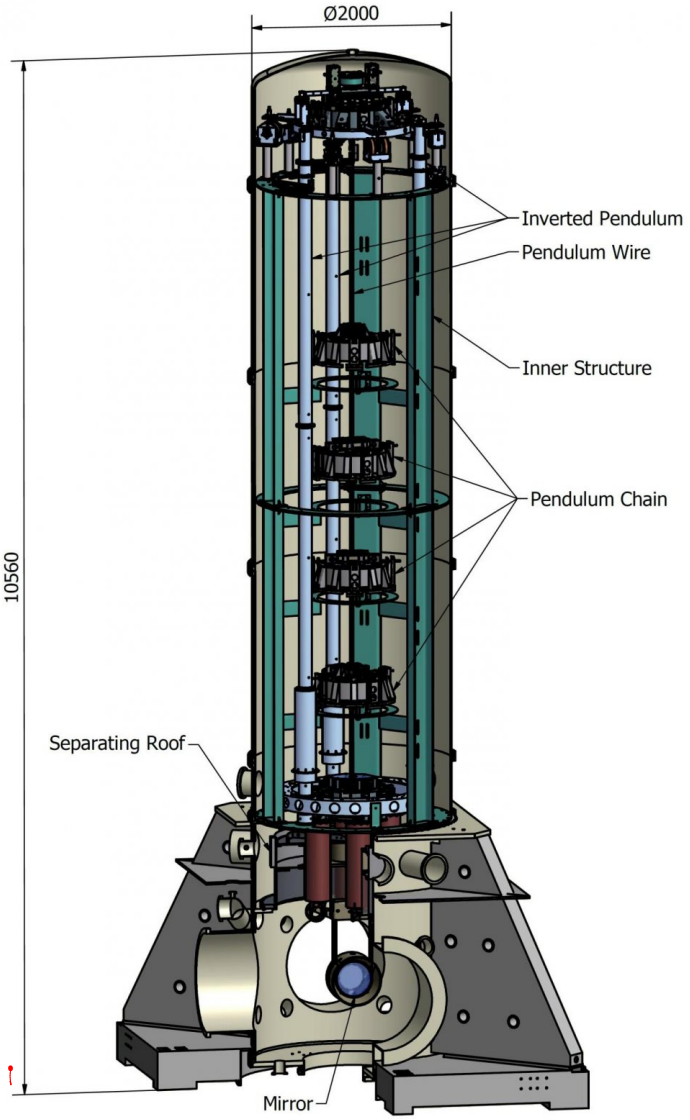
Pound Drever Hall

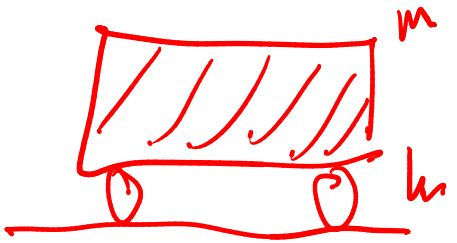
Laser locking

Mechanical stability

- Interferometers: sensitive to vibration, both seismic and acoustic
- Isolate your setup: heavy optical table air cushion (tennisballs, bicycle tires, ...)
- Active feedback: measure acceleration and cancel it using some actuator (piezo, solenoid, ...)

Mechanical stability: VIRGO





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