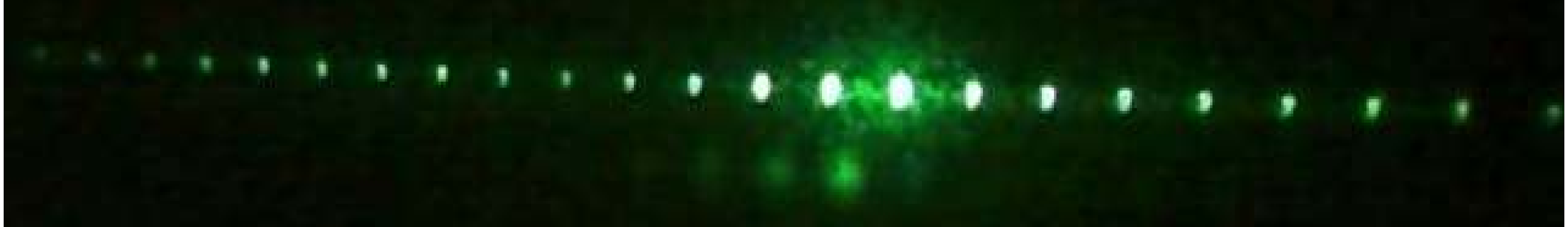
3rd. TRI-NATIONAL WORKSHOP ON STANDARDS FOR NANOTECHNOLOGIES

Diffraction-Grids Calibration at *CENAM*



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Calibration

- Operation that, under specified conditions, in a first step, establishes the relationship between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

In other words…

- *Calibration (of an instrument or standard).-* Comparison of the measurement results (of an instrument or a standard) to those of a hierarchically superior instrument or standard. In this operation a calibration uncertainty has to be established (considering the uncertainty of the reference).

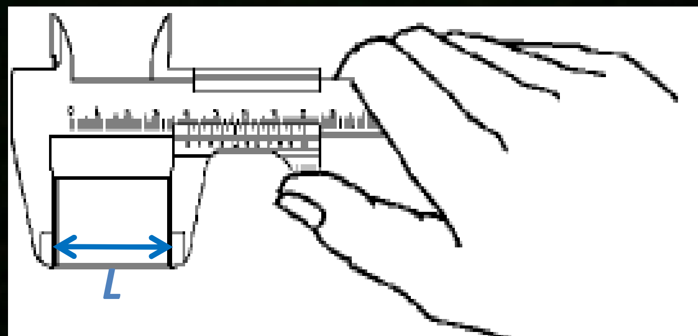
Instrument under calibration

Superior standard

Gauge Block

$L \pm U_{GB}$

L



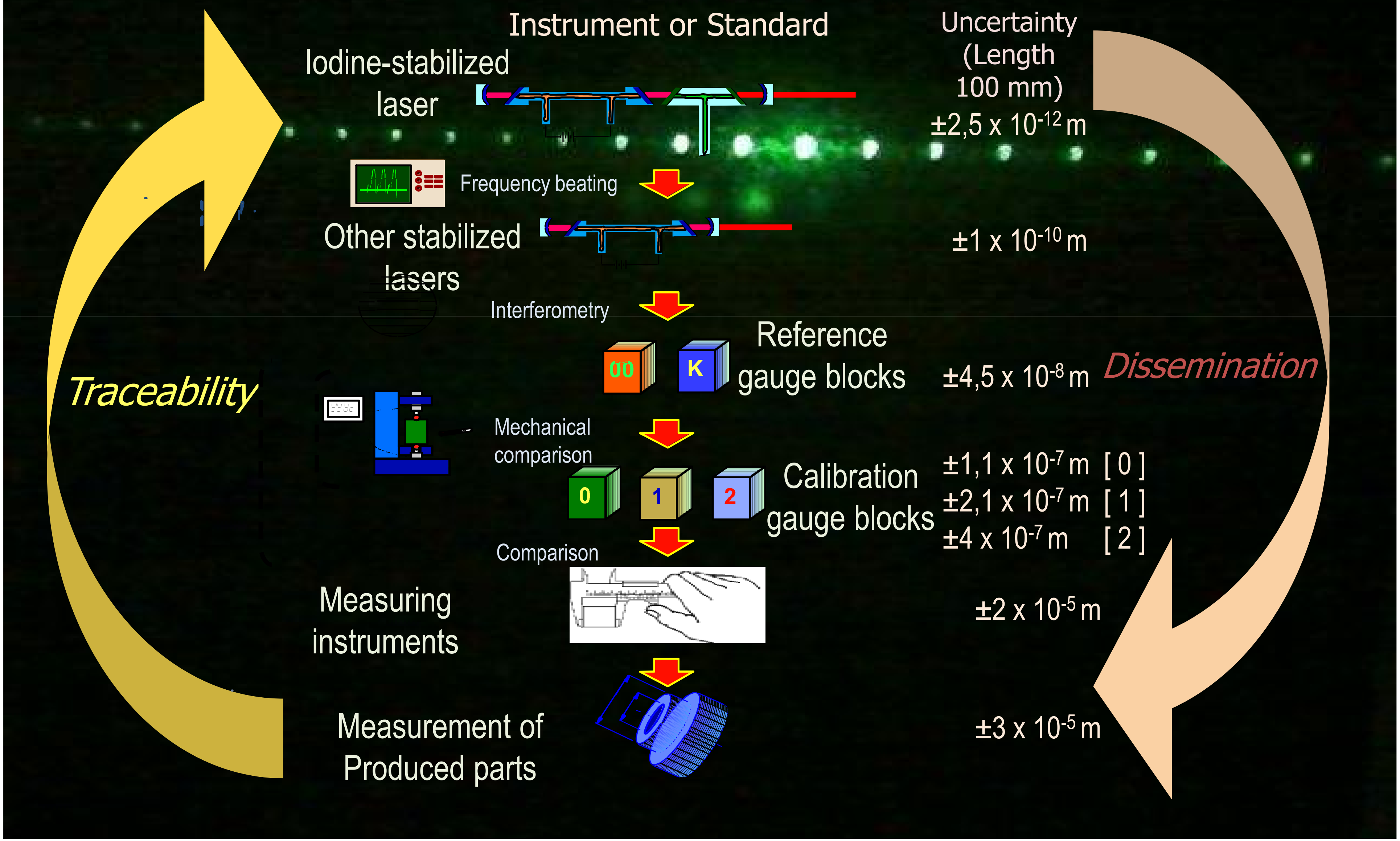
$L\ (+\ Corr) \pm U_{Cal}$

$U_{cal} > U_{GB}$

Traceability

- Property of a measurement result whereby the result may be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

Dissemination of the Unit of Length through an Unbroken Chain of Calibrations



Traceability and dissemination of the unit of length in some Nano-applications

Frequency beating

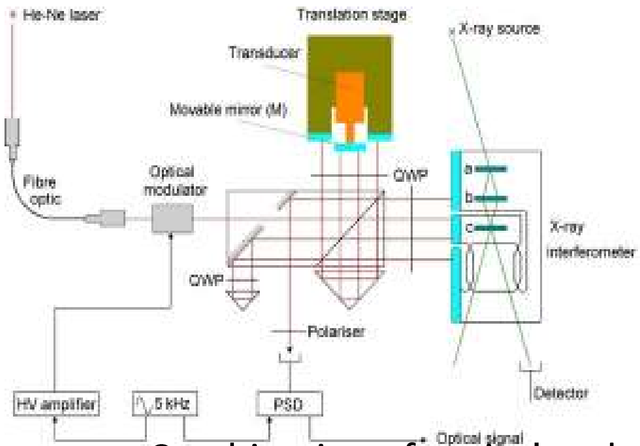
Iodine-stabilized laser by saturation spectroscopy of ^{127}I.

Measurement range	~ 473 THz
Uncertainty	24 kHz

Interferometry

Other frequency-stabilized lasers

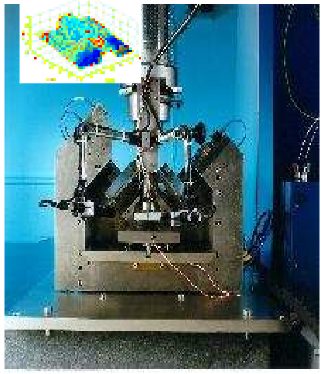
Measurement range	~ 473 THz
Uncertainty	1 MHz



Combination of optical and X-ray interferometer("COXI")

Measurement range	Uncertainty
< 10 µm	30 pm
100 µm	40 pm
1 mm	170 pm

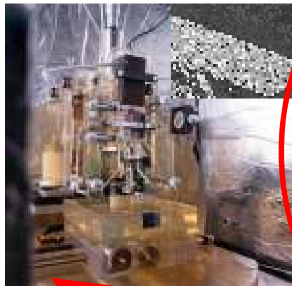
Interferometry



Small CMM

Measurement range	50x50x50 mm
Uncer-Tainty	Entre 50 y 100 nm

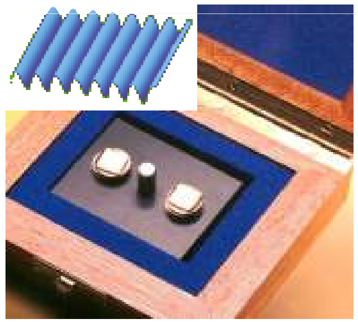
Interferometry



Sty…
instr…

	10 µm
Uncer-tainty	1.3 nm

Diffractometry

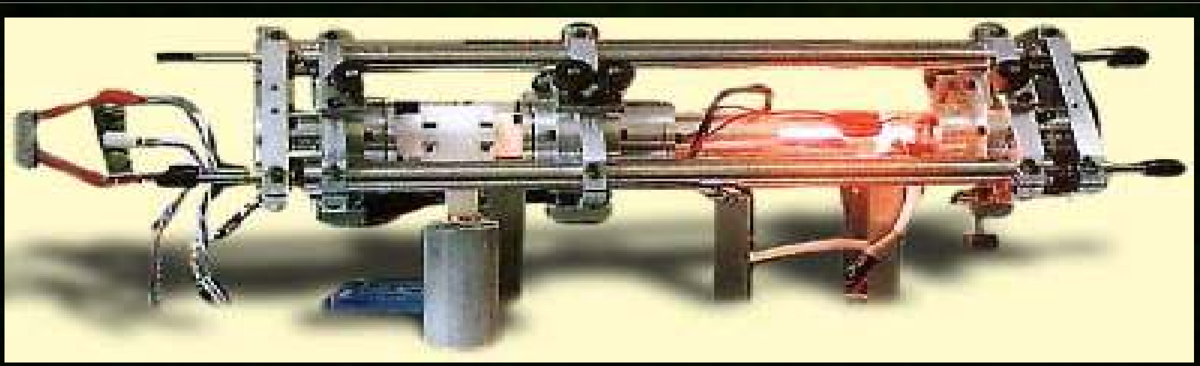


Periodic standards for SEM, EFM and SPM calibrations

Measurement range	100 µm
Uncertainty	1.3 nm

Definition of the length unit

- The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.



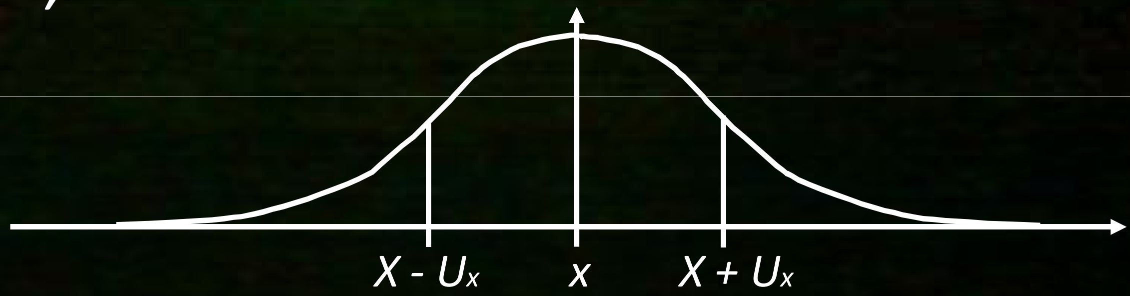
$$\lambda = \frac{c}{f}$$

- Realization at CENAM: He-Ne Iodine-stabilized laser at ~633 nm.

Measurement uncertainty

- Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

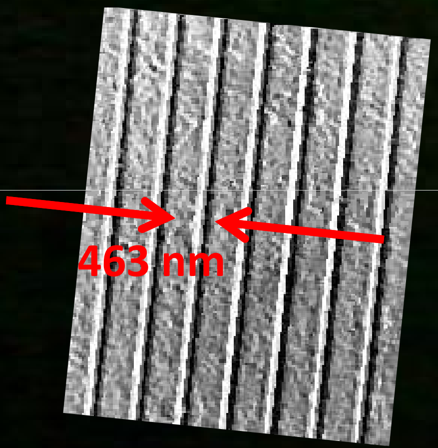
$$x \pm U_x$$



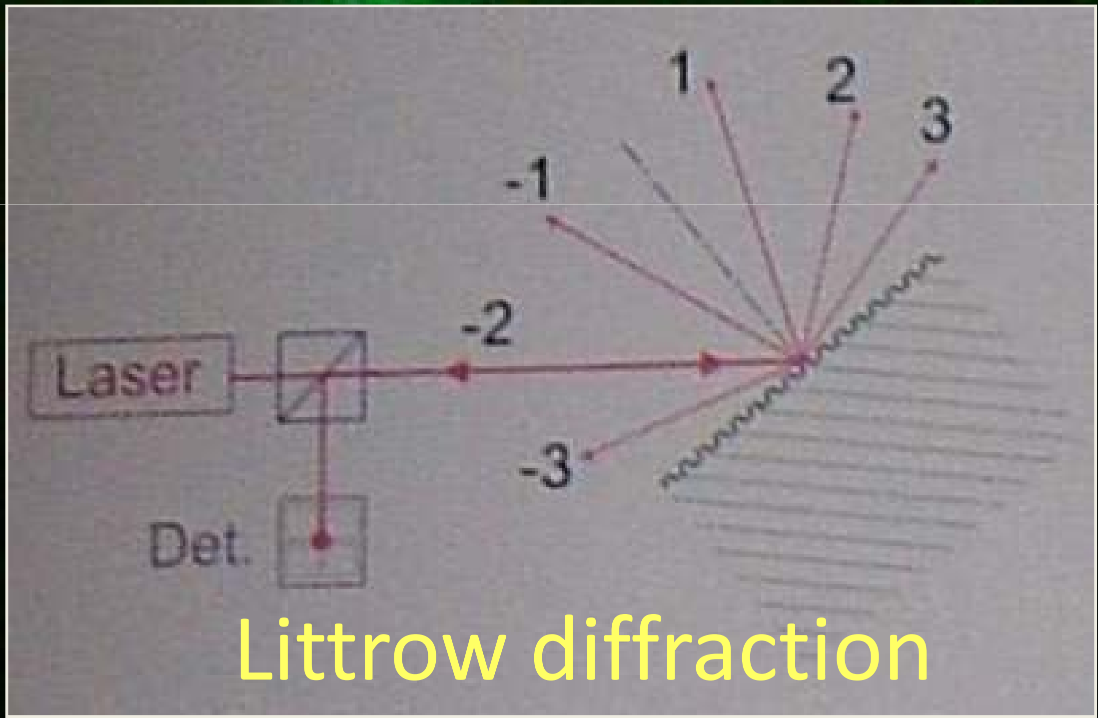
In other words...

- It is an interval (U_x) around the best estimate of a measurand (x) where the true value of the measurand should lie with a specified confidence level.

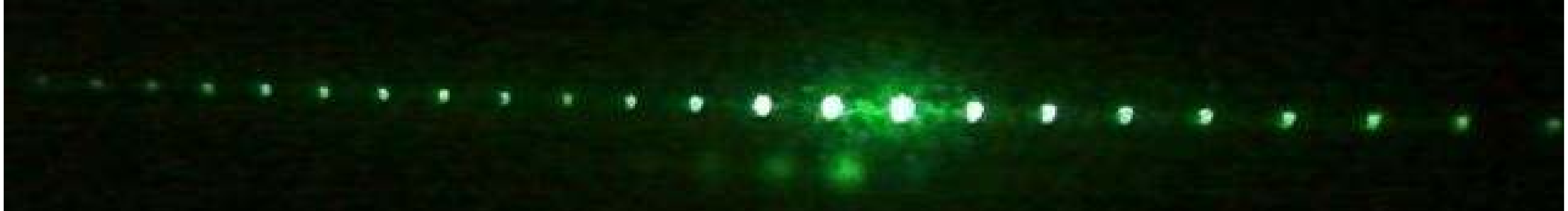
Diffractometer principle



Example of a commercial grating: 2,160 lines/mm



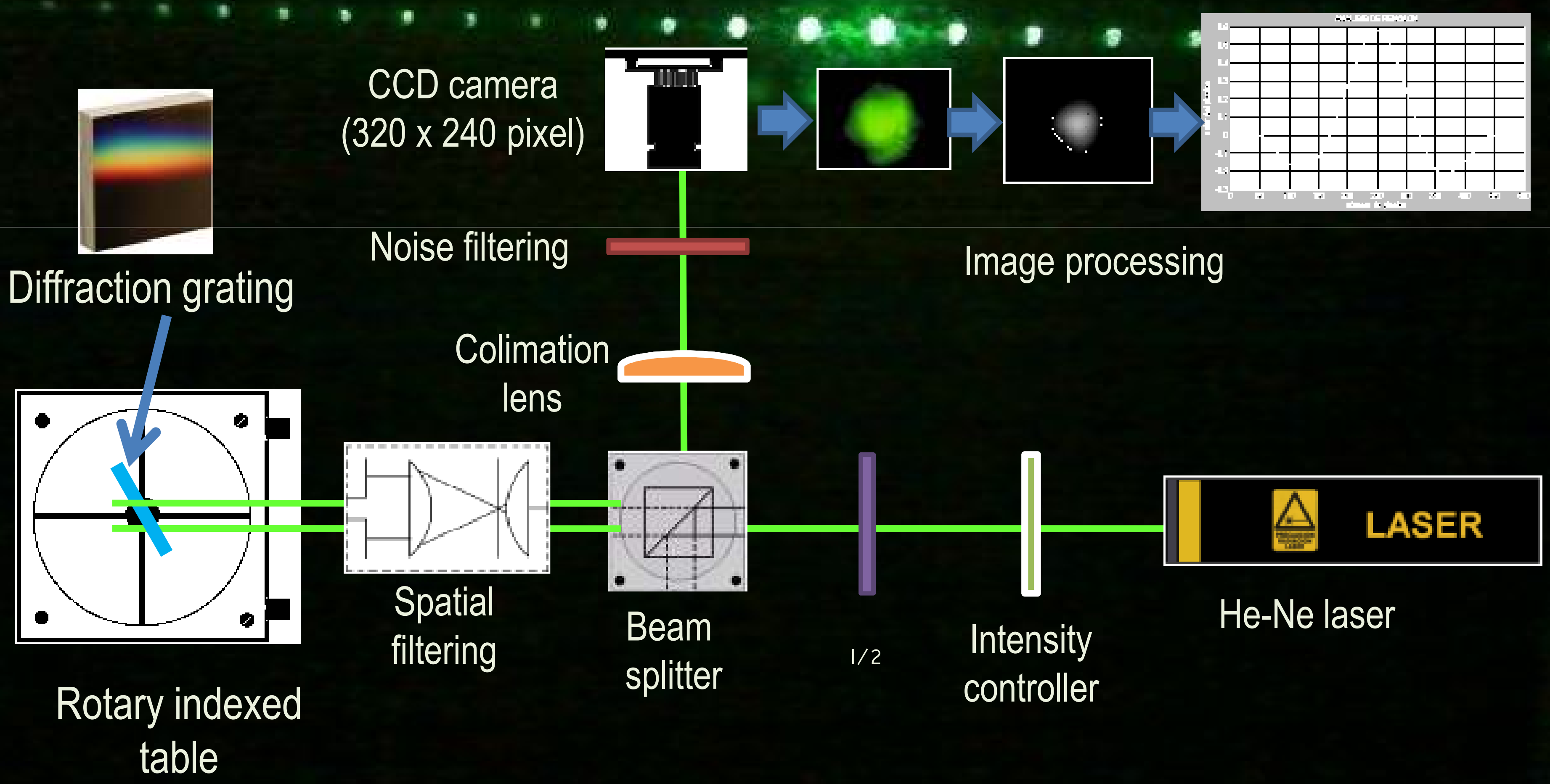
Diffractometer principle



$$p = \frac{m\lambda}{2\sin\theta}$$

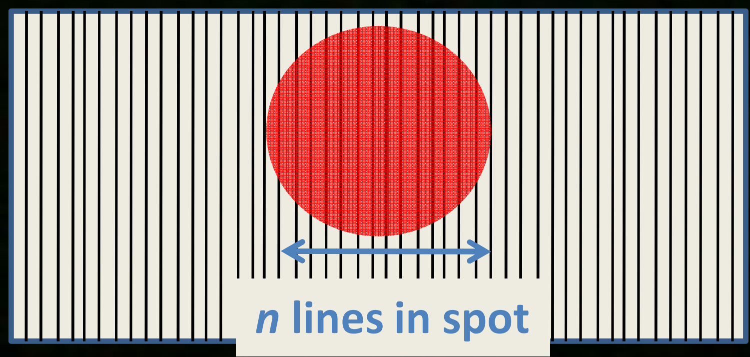
m, diffraction order (m = 1, 2, 3...) ;
λ, Light wavelength
θ, measured angle

Measurement set-up



Some considerations…

- Calibration of a bundle of lines (between 2 000 and 15 000 depending on the grating and the laser beam spot size) whereas the grating is used to measure between individual lines.



Some considerations…

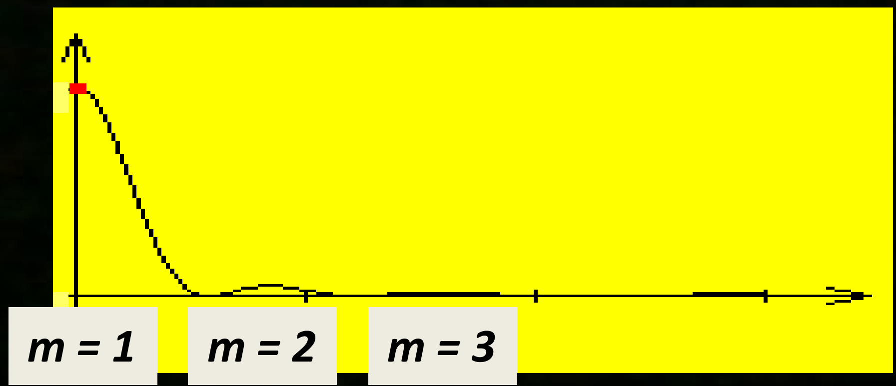
- Smallest pitch that can be calibrated limited by half of the wavelength applied (318 nm red, 272 nm green).

$$p = \frac{\lambda}{2}$$

And only one order of diffraction (*m = 1*) may be observed under this condition.

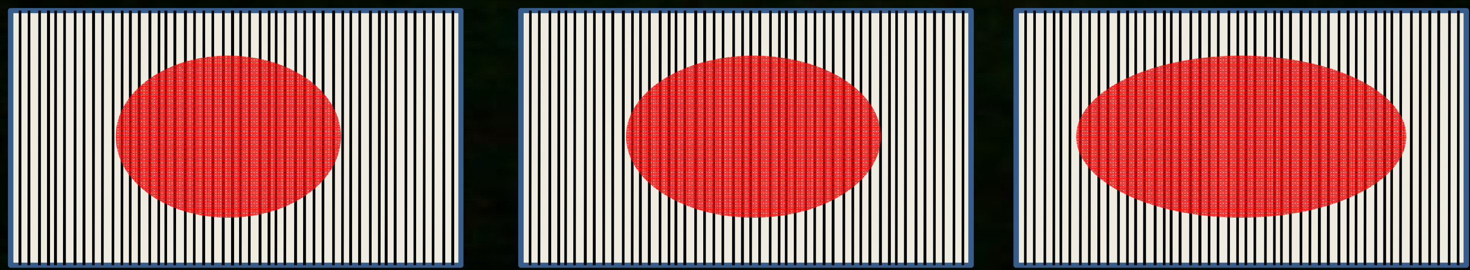
Some considerations…

- Number of diffraction orders that can be measured limited by the decreasing intensity of light with diffraction order (only the two first orders are usually measured).



Some considerations…

- Number of lines in the averaging spot is a function of the Littrow condition angle.



n_1 lines on spot
Smaller angle

n_2 lines on spot

n_3 lines on spot
Larger angle

$$n_1 < n_2 < n_3$$

Uncertainty of measurement

$$U_p = 2\sqrt{\left(\frac{\partial p}{\partial \lambda}\right)^2 u_\lambda{}^2 + \left(\frac{\partial p}{\partial \theta}\right)^2 u_\theta{}^2}$$

Where:

$$\frac{\partial p}{\partial \lambda} = \frac{m}{2\,sen\,\theta}$$

$$\frac{\partial p}{\partial \theta} = -\frac{m\lambda\cos\theta}{2\,sen^2\theta}$$

Uncertainty of measurement

40 μm grating

θ = 0,40°

Contrib.	Type of Unc.	Uncertainty Value	Sensitivity Value	Unc. Cont.	Variance	%
~~λ~~	~~B~~	~~5,44 x 10^{-7} μm~~	~~71,6~~	~~1,51 x 10^{-5} μm~~	~~3,78 x 10^{-10} μm²~~	~~0~~
θ	A	10" (4,85 x 10^{-5})	5,57 x 10^{3} μm	2.70 x 10^{-1} μm	7,29 x 10^{-2} μm²	100
				u² =	7,29 x 10^{-2} μm²	100
				u =	2,70 x 10^{-1} μm	
				U =	**0,54 μm**	

⇒ p = (39,91 ± 0,54) μm

1,66 μm grating

θ = 9,65°

Contrib.	Type of Unc.	Uncertainty Value	Sensitivity Value	Unc. Cont.	Variance	%
~~λ~~	~~B~~	~~5,44 x 10^{-7} μm~~	~~2,98~~	~~1,62 x 10^{-6} μm~~	~~2,62 x 10^{-12} μm²~~	~~0~~
θ	A	10" (4,85 x 10^{-5})	9,53 μm	4,62 x 10^{-4} μm	2,14 x 10^{-7} μm²	100
				u² =	2,14 x 10^{-7} μm²	100
				u =	4,62 x 10^{-4} μm	
				U =	**0,00094 μm**	

⇒ p = (1,65016 ± 0,00092) μm

Working prototype

Conclusions

- Diffraction gratings may be calibrated by a simple set-up of diffractometer.
- The light source frequency stability has negligible impact in the quality of the measurement. An un-stabilized laser may be used.
- The measurement of angle is almost the only source of uncertainty.
- Angle measurement with an uncertainty of 10” seems to be enough.
- Uncertainty is a function of angle and angles larger than 10° are desirable to keep uncertainty low. To be able to get adequate diffraction angles to have a set of different wavelengths available is recommended.
- It is also recommended to measure higher diffraction angles to get larger angles to measure as long as the intensity of the signal is enough.
- The present prototype and experiments will lead to the design of a compact low cost diffractometer to calibrate diffraction gratings. It is the continuation of this project.