Beam Shape Reconstruction Using Synchrotron Radiation Interferometry

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ALBA-CELLS

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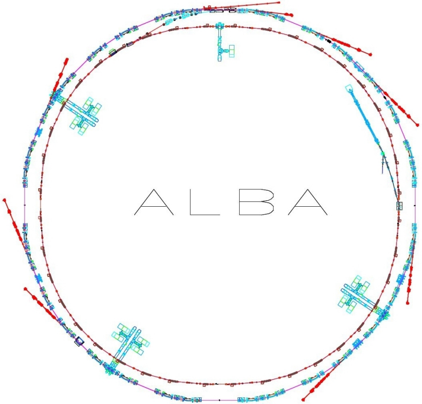
ALBA

The Facility

- Energy: 3 GeV
- Current: 130 mA
- RF-Frequency 500 MHz
- Eight active beamlines
  - +1 Optical beamline
  - +1 x-ray Fronted



Transverse Beam Characteristics

The emittance is a key parameter in every accelerator machine:

$$\varepsilon = \frac{1}{\beta}\left(\sigma^2 - \mathcal{D}^2\left(\frac{\Delta E}{E}\right)^2\right)$$

σ is measured

Machine parameters obtained from LOCO

Assuming that the intensity distribution of the electron on the transverse plane is Gaussian, the beam size is defined as the standard deviation of the electron distribution

TRANSVERSE BEAM CHARACTERISTICS

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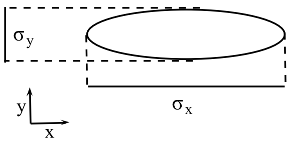

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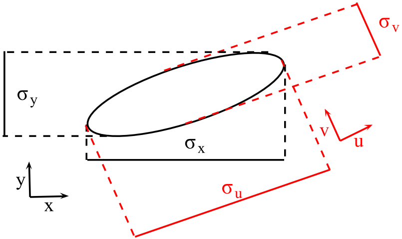


Machine parameters obtained from LOCO

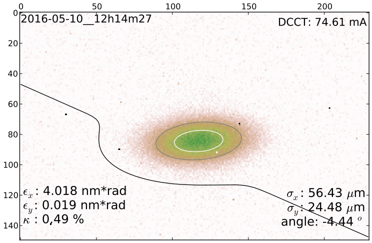
In many accelerators the beam is tilted

$\Downarrow$

$\sigma_x \neq \sigma_u$ and $\sigma_y \neq \sigma_v$

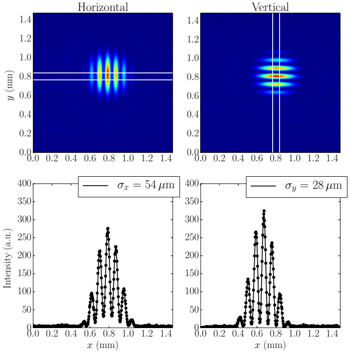
TRANSVERSE MEASUREMENTS AT ALBA

X-Rays Pinhole



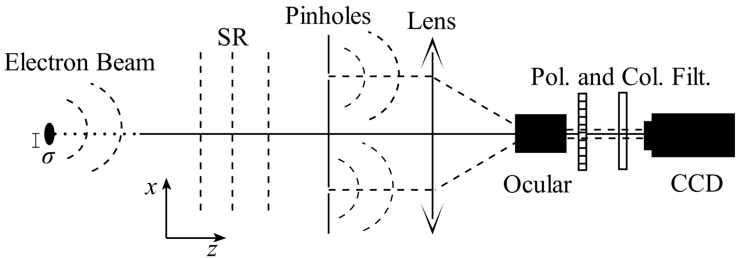
Two dimensions direct image of the beam using x-rays

Synchrotron Radiation Interferometry



Measurement of the projection of the beam in one dimension

SYNCHROTRON RADIATION INTERFEROMETRY (SRI)

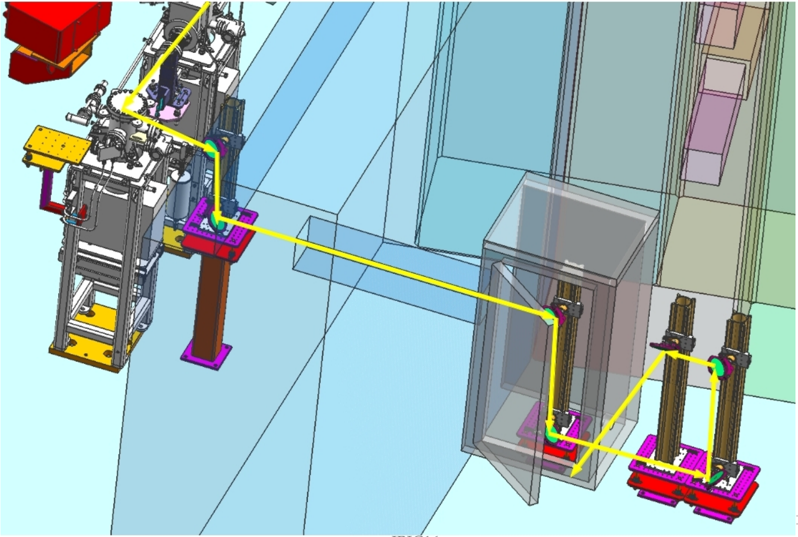


$$I = I_0 \left\{ \frac{J_1\left(\frac{2\pi a x}{\lambda f}\right)}{\left(\frac{2\pi a x}{\lambda f}\right)} \right\}^2 \times \left\{ 1 + V \cos\left(\frac{2\pi D x}{\lambda f}\right) \right\}$$

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

- I_0: Intensity
- a: Pinholes radius
- λ: SR wavelength
- f: Focal distance of the optical system
- D: Pinholes distance
- V: Visibility
- L: Distance from the source

SRI AT XANADU



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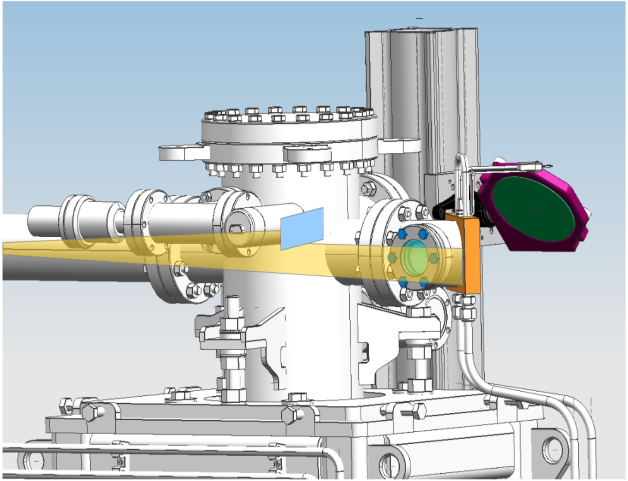
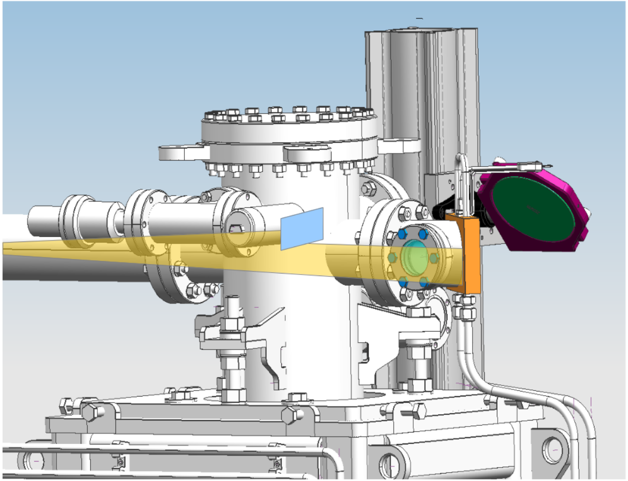


The characteristics of the SRI are limited by the "half mirror"

- $a = 2.5\,\mathrm{mm}$
- $\lambda = 538\,\mathrm{nm}$
- $f = 500\,\mathrm{mm}$
- $f_{oc} = 18\,\mathrm{mm}$
- $D = 16\,\mathrm{mm}$
- $L = 15\,\mathrm{m}$

SRI at Xanadu



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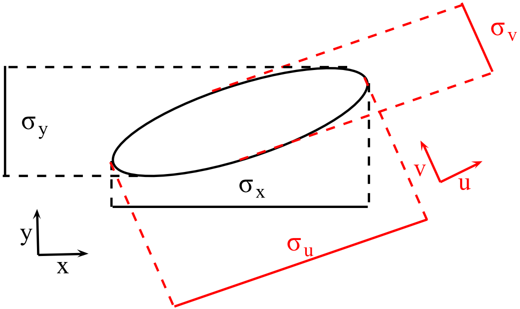
LIMITATION OF SRI

SRI only measures the length of the one dimensional projection of the beam shape on the pinholes axis

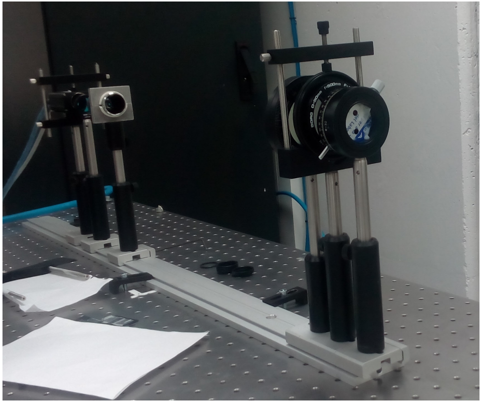


If the beam is tilted the measurement of the beam size is incomplete

Is it possible to measure beam sizes and tilt using SRI?

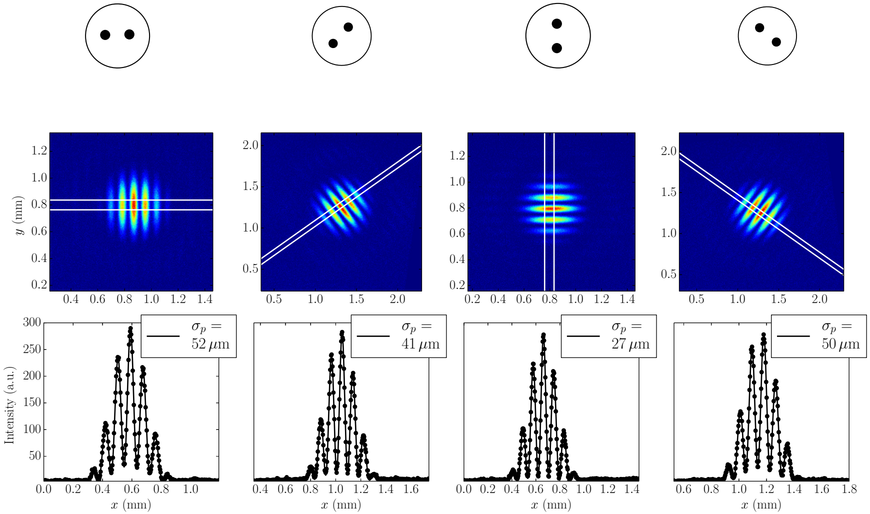
Transverse Beam Reconstruction

It is possible to obtain projections of the beam on different axis by rotating the double pinholes system



Double-Pinhole system mounted on a graduate rotational stage

Transverse Beam Reconstruction



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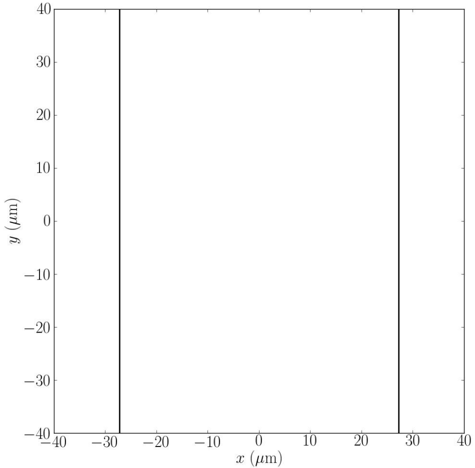

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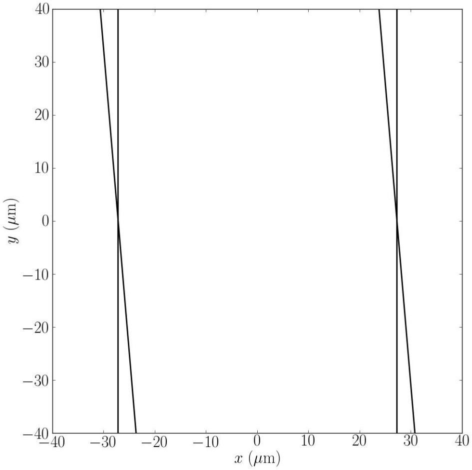

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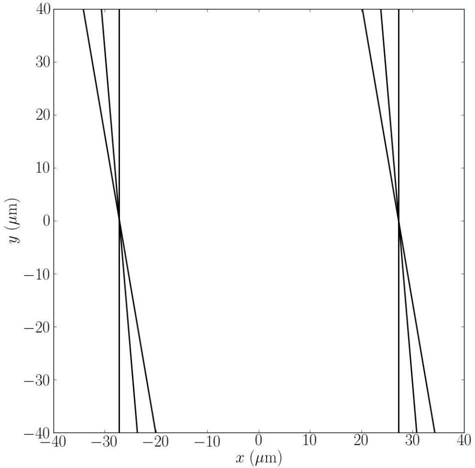
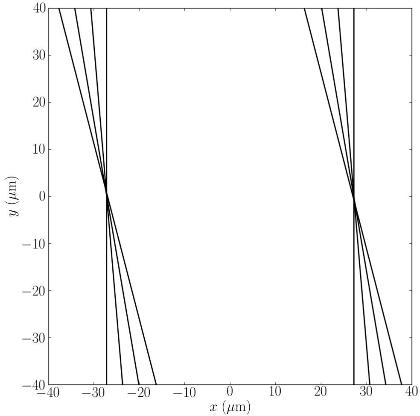
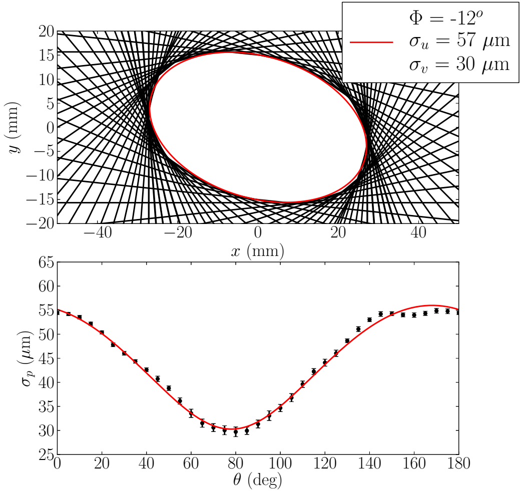


TRANSVERSE BEAM RECONSTRUCTION



Elliptic Beam



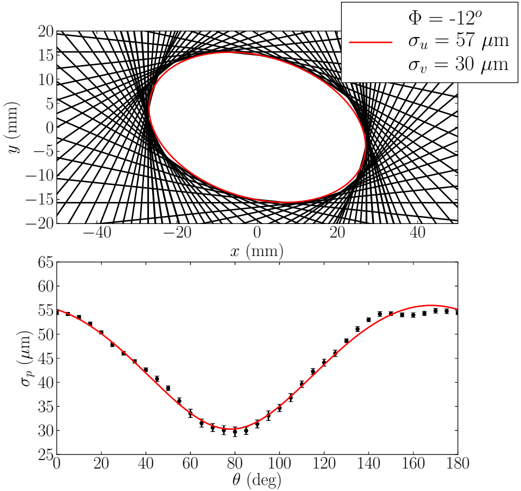
The beam reconstruction shows clearly that the beam can be approximated as an ellipse.

$$x(\theta) = \sigma_u \cos(\theta + \Phi)$$

$$y(\theta) = \sigma_v \sin(\theta + \Phi)$$

$$\sigma_p(\theta) = \sqrt{\sigma_u^2 \cos^2(\theta + \Phi) + \sigma_v^2 \sin^2(\theta + \Phi)}$$

ELLIPTIC BEAM



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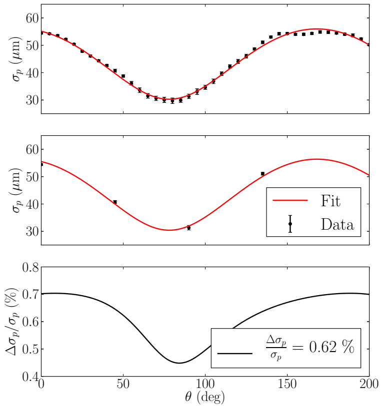
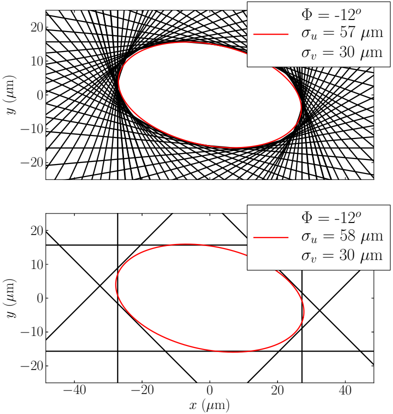
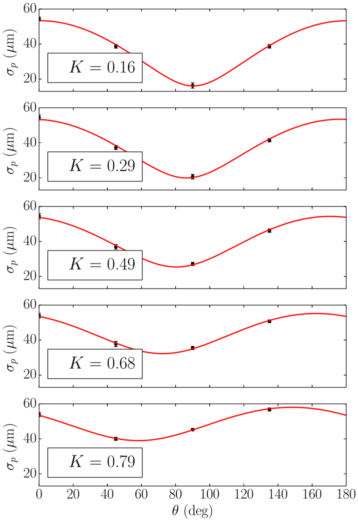
Simplification

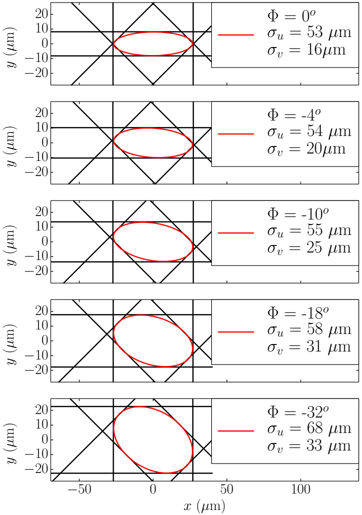
It is possible to exploit the ellipticity of the beam and reduce the number of necessary measurements to 4.





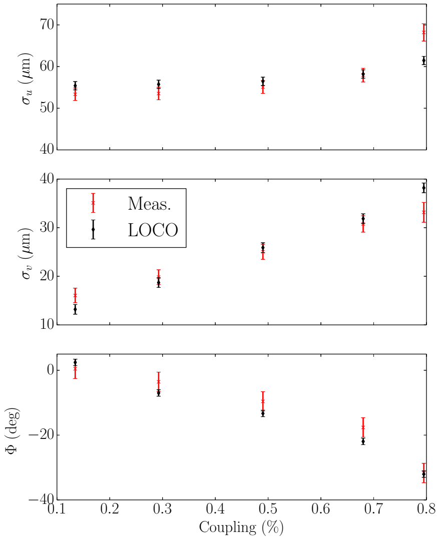
Results at Different Couplings



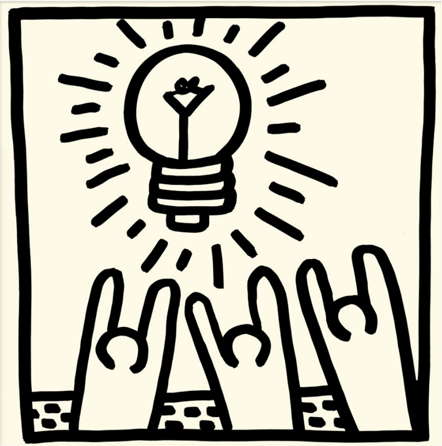


Comparison with LOCO

A LOCO was applied at each coupling. The beam sizes and the tilt at for each settings has been extracted.



Further Applications



Using a **Fitting Method** we can infere beam sizes at any angle

We can use the same technique used for the full beam reconstruction to infere ultra-low beam sizes!

ULTRA-LOW BEAM SIZES

In future light sources the vertical beam size will be so small that it will be difficult to measure it with interferometry technique.

A possibility to obtain the vertical beam size is to reconstruct the beam ellipse using SRI reconstruction, without directly measure the smallest beam size.

SRW simulations has been performed to proof the effectiveness of the technique:

Beam characteristics:

- $\Phi = 0$
- $\sigma_x = 55\,\mu\text{m}$
- $\sigma_y = 2, 5, 7, 10\ \mu\text{m}$

ALBA Diagnostic Beamline:

- $a = 2.5\,\text{mm}$
- $\lambda = 538\,\text{nm}$
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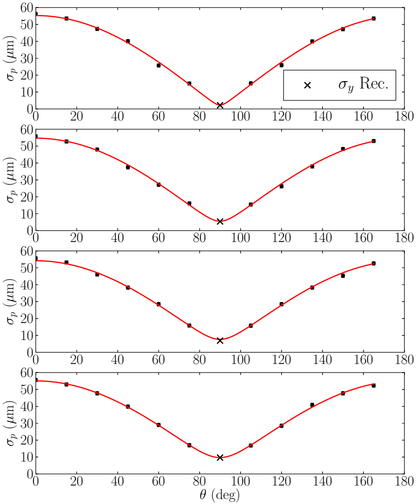
Results



σ_y	
Theo. (μm)	Rec. (μm)
2	2.2
5	5.4
7	6.9
10	9.7

Conclusions

A method to perform a full beam reconstruction in transverse using the SRI has been proposed and successfully tested at ALBA. As a further application the same technique can be used to measure ultra-small beam sizes.

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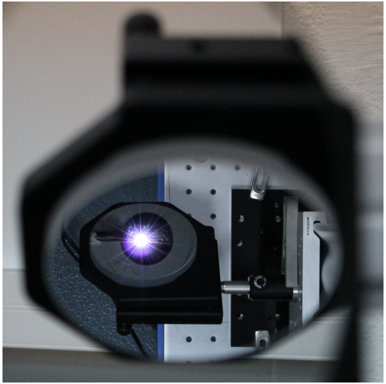
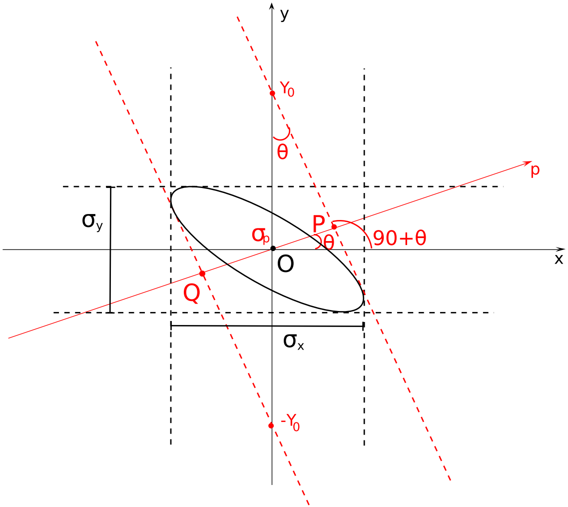


We want to acknowledge the ALBA accelerator division, and all the ALBA staff for the efforts to maintain and improve the facility. Many thanks to the “synchrotron radiation diagnostic community”.

Beam Reconstruction



$$y = mx \pm Y_0,$$

$$\begin{cases} m = \tan(\theta + 90^\circ) \\ \pm Y_0 = \pm \frac{\sigma_p}{2\sin(\theta)} \end{cases}$$

4-PINHOLE INTERFEROMETRY AT ALBA