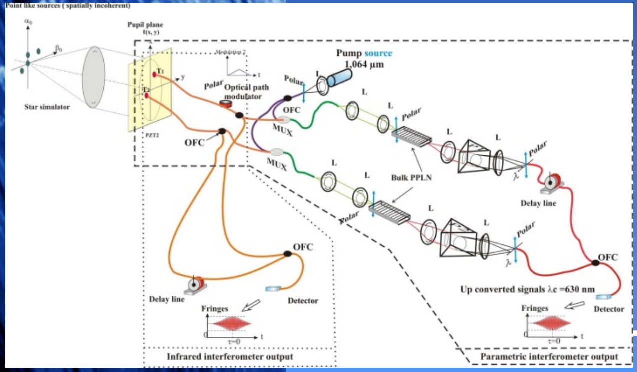
« Present status on the implementation of a up-conversion interferometer on CHARA »

François Reynaud
XLIM / Dépt. Photonique IRO Limoges

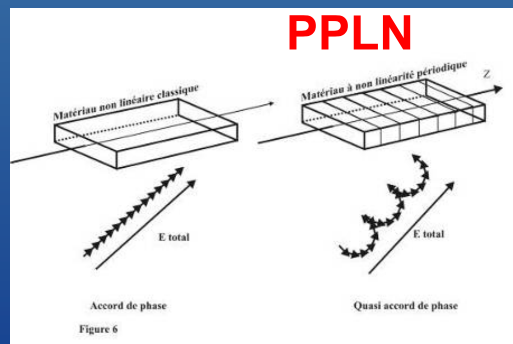
L. Delage, L. Grossard, R. Baudouin ,J.T Gomes…

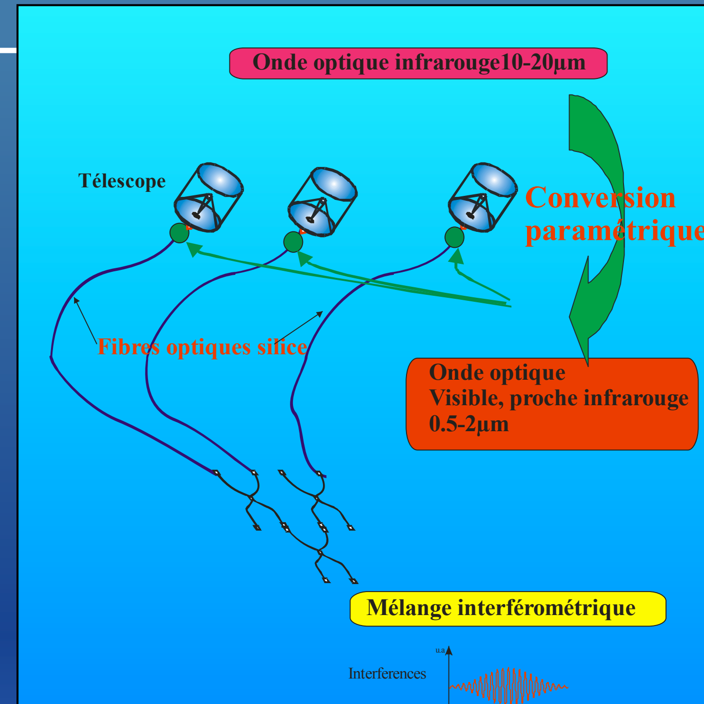


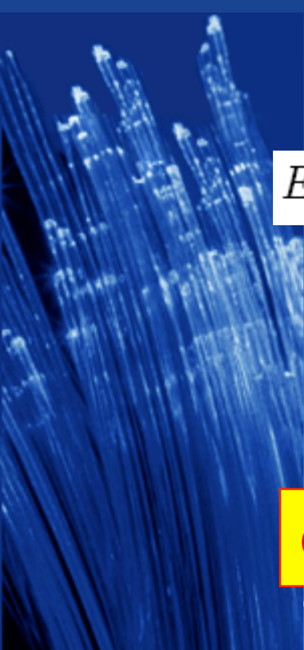
Principle of sum frequency generation: Hybrid detection

$\chi 2$ non-linear material

$E_{out} \sim E_1.E_2$

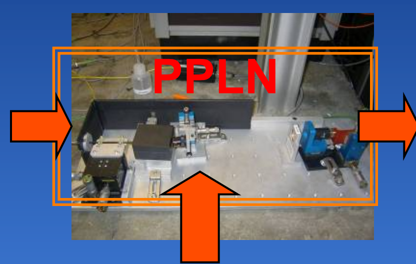






$$E_{IR1} = E_0 e^{j2\pi\nu t} e^{j\varphi_1}$$

IR spectrum



$$E_{Vis1} = E_0 e^{j2\pi(\nu+\nu_{pump})t} e^{j\varphi'_1}$$

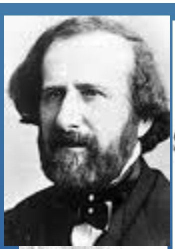
Visible spectrum

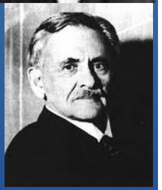
Pump

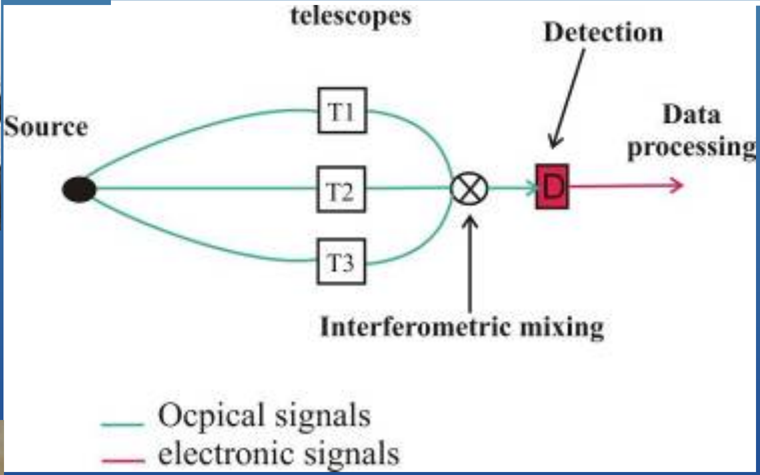
$$E_{pump} = e^{j\nu_{pump}}$$

Changing the color of ligth

A new concept for high resolution imaging based on spatial coherence analysis

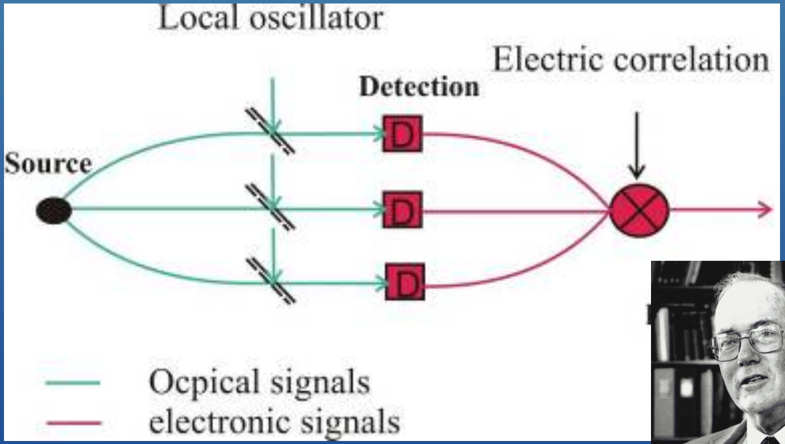






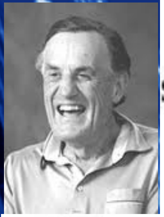
Michelson Fizeau Labeyrie

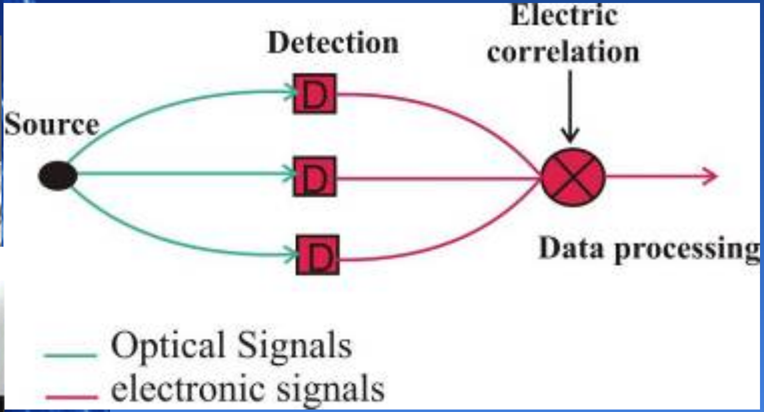
[4] : A. Michelson : *On the application of interference methods to astronomical measurements*. American journal of science, 02/1890.



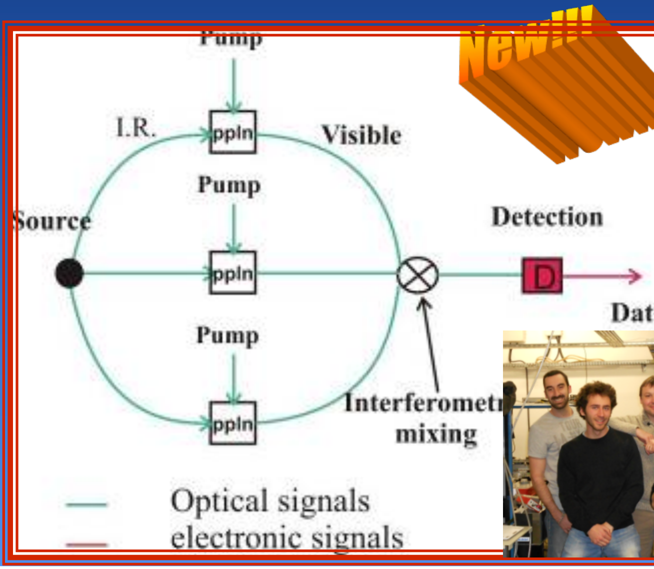
Townes

[8] : M.A. Johnson, A.L. Betz, C.H. Townes : *10 μm Heterodyne stellar interferometer*. Physical Review Letters, vol. 33 (27), pp. 1617-1620.



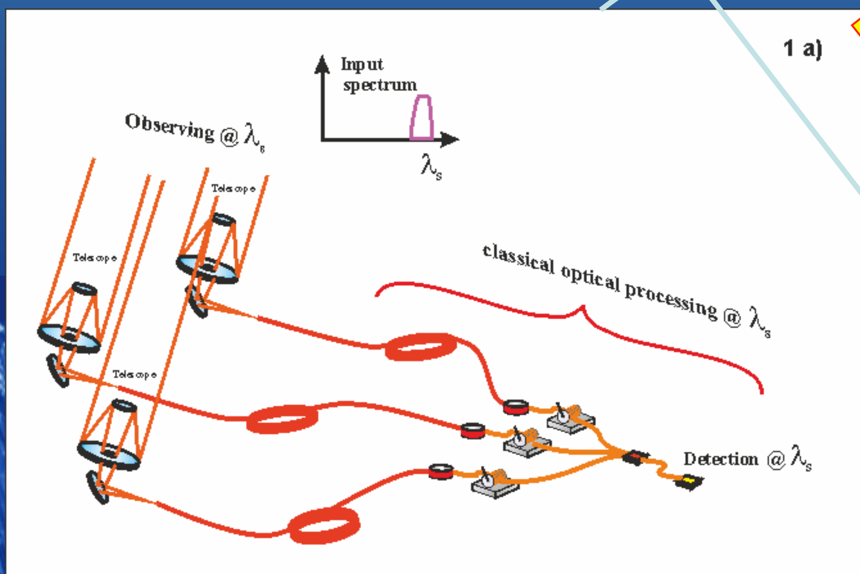


[5] : R.H. Brown, G. Twiss : *Correlation between photons in two coherent beams of light*. Nature, vol. 177, pp. 27-29, 07/01/1956.



Why it's interesting to change the color of star light

Astro target >>> wavelength



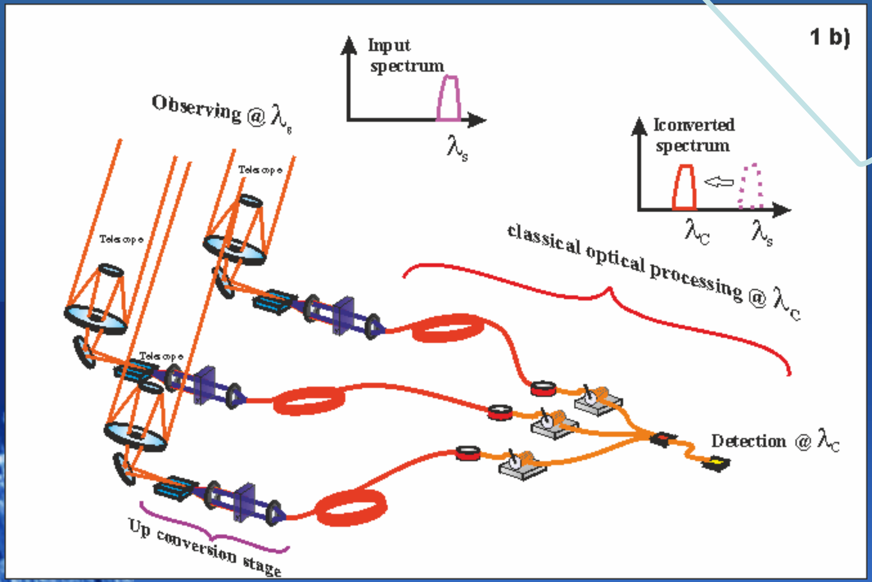
Experimental chain

Constraint for :
Transmission
Filtering
mixing
Detection…

Classical way :
All the experimental chain is design as function of the spectral domain of the source

Why it’s interesting to change the color of star light

Astro target >>> wavelength



Experimental chain

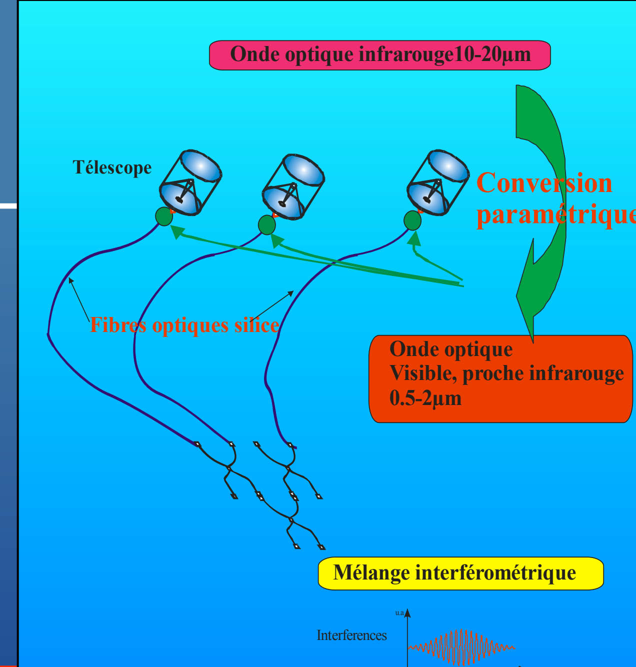
optimized for :
Transmission
Filtering
mixing
Detection…

New way :

- **All the experimental chain is designed at a given wavelength to improve the global efficiency**
- **The astro light is spectrally shifted to reach this spectral domain**

XLIM

To be checked!!!

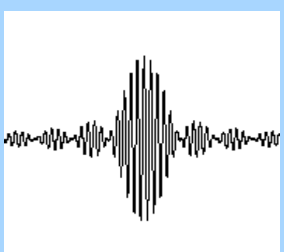


E_1 E_2

R | Up conv1

R | Up conv2

Conventional instrument: reference



Instrument under test

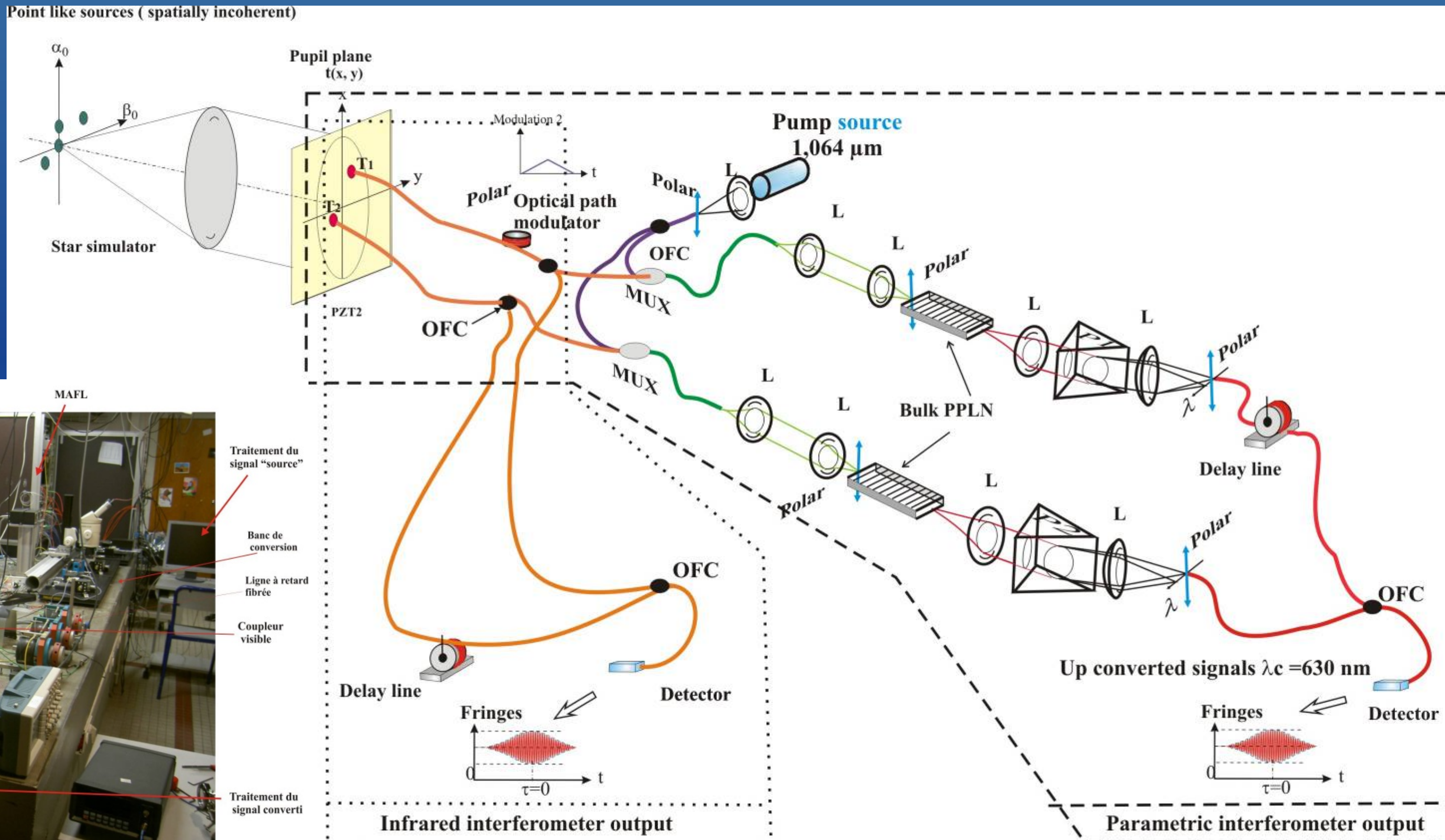
Change on the correlation between E'_1 et E'_2 ?

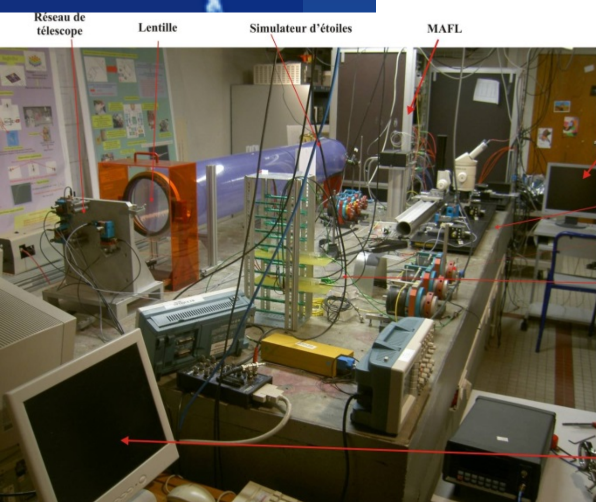
Possibility to recover C and β ?

checking the transfer of spatial coherence
High power level single line

Contrast measurement

Experimental setup :
(Thèse de Louis Del Rio
Post doc Sophie Brustlein)

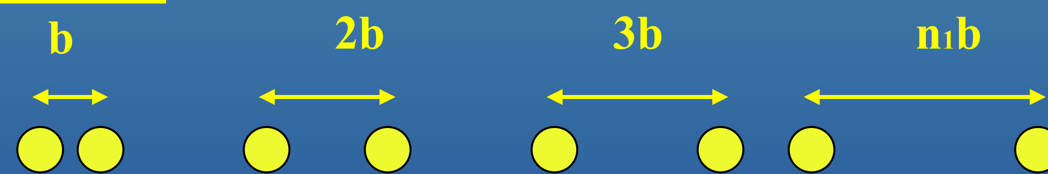




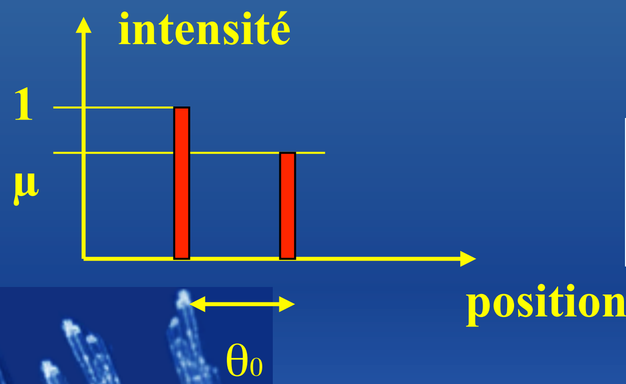
checking the transfer of spatial coherence
High power level single line

Measurement strategy

Telescope array



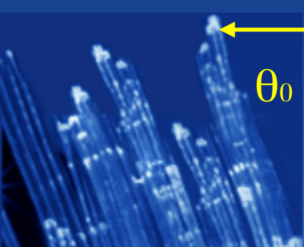
Source = steady binary star

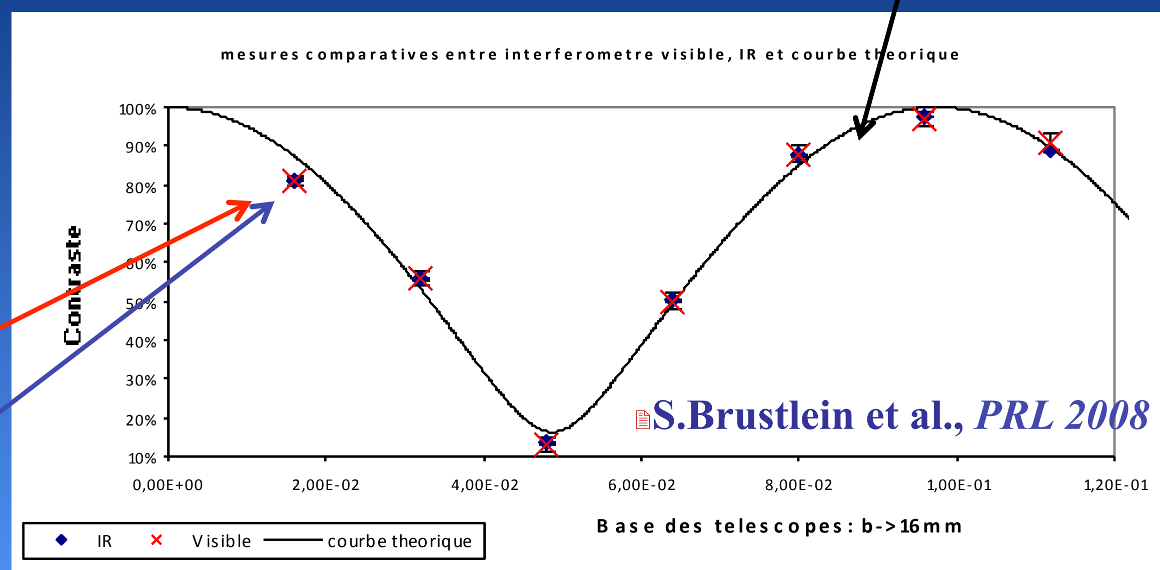


Base line variation

Theoretical contrast

$$C = \sqrt{\left[1 + \mu \cos\left(\frac{n_1 b}{\lambda}.\theta_0\right)\right]^2 + \left[\mu \sin\left(\frac{n_1 b}{\lambda}.\theta_0\right)\right]^2}$$





S.Brustlein et al., *PRL 2008*

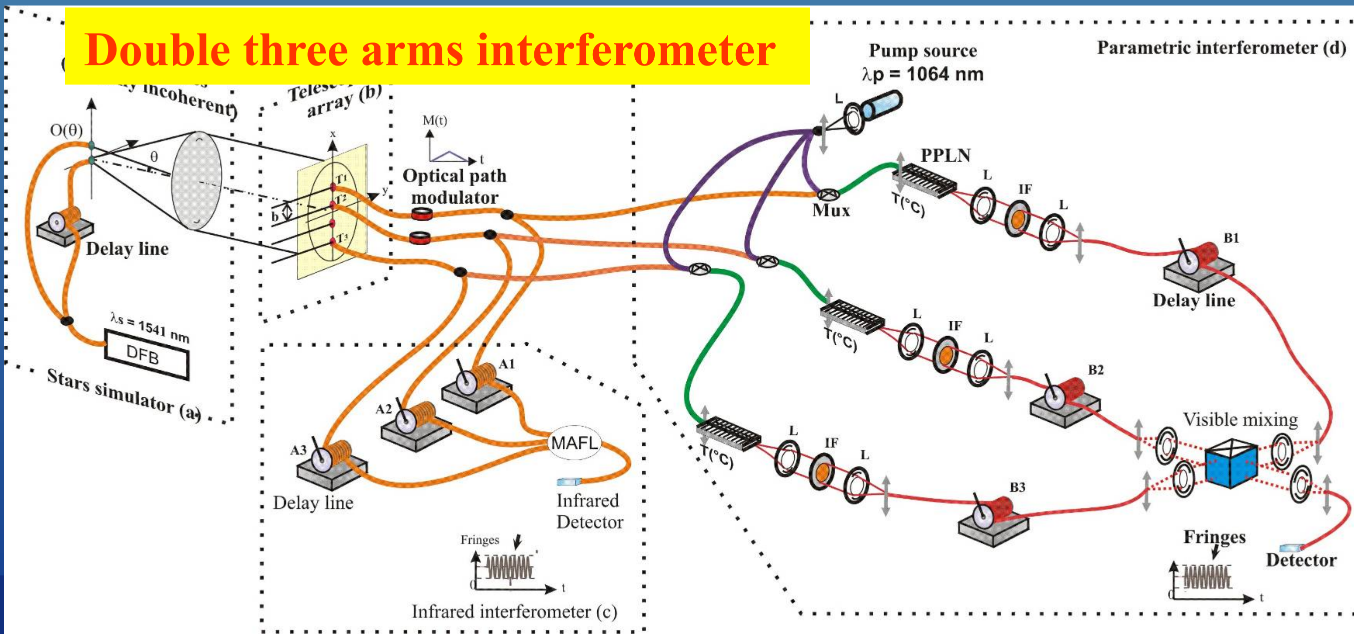
Experimental measurement

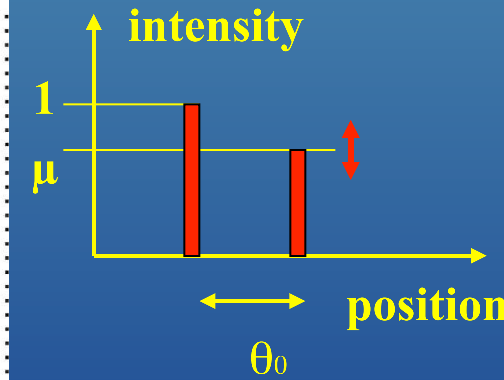
x Upconv inter

◆ IR classical inter

checking the transfer of spatial coherence
High power level single line

Double three arms interferometer



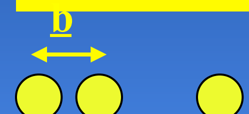


Source = variable binary star

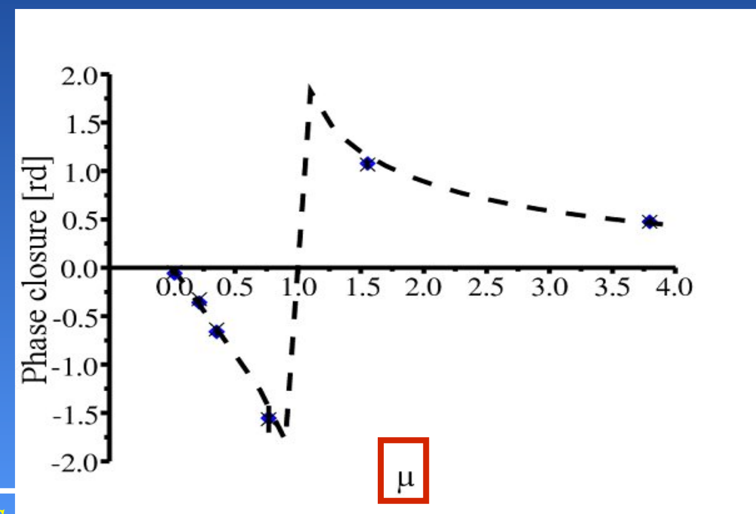
$$\beta = \arctan\left[\frac{\mu\sin(\frac{n_1 b}{\lambda}.\theta_0)}{1+\mu\cos(\frac{n_1 b}{\lambda}.\theta_0)}\right] + \arctan\left[\frac{\mu\sin(\frac{n_2 b}{\lambda}.\theta_0)}{1+\mu\cos(\frac{n_2 b}{\lambda}.\theta_0)}\right] + \arctan\left[\frac{\mu\sin(\frac{n_3 b}{\lambda}.\theta_0)}{1+\mu\cos(\frac{n_3 b}{\lambda}.\theta_0)}\right]$$

theory

Fixed telescope array

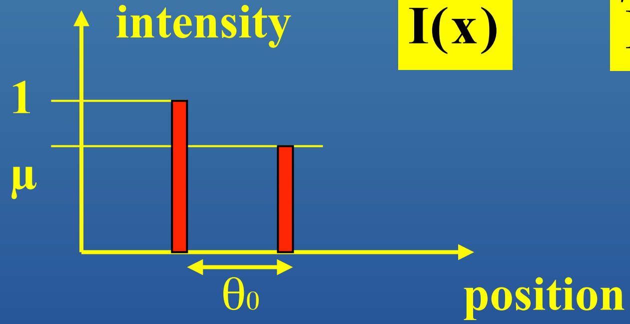


-1 0 2



" Phase Closure Retrieval in an Infrared-to-Visible Upconversion Interferometer for High Resolution Astronomical Imaging", Optics Express 2011

checking the transfer of spatial coherence
very low power level single line

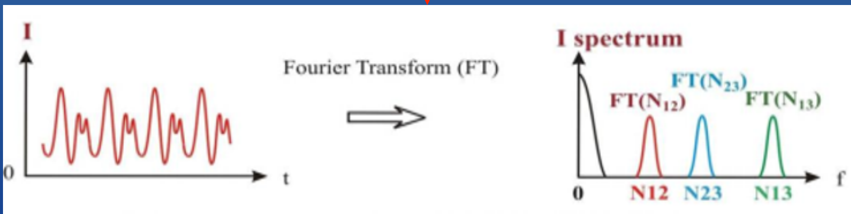


I(x)

$$\tilde{I}(u) = FT(I)$$

Zernike and Van Cittert Theorem

$$\tilde{I}(u) = V(u)$$

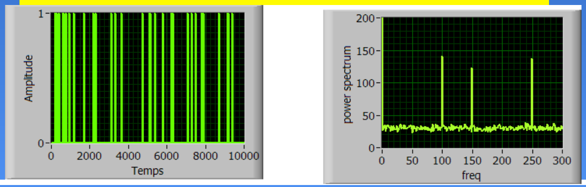


High flux level

$$\tilde{I}^{(2)}(u) = |V(u)|^2 = C^2(u)$$

up to the photon counting regime

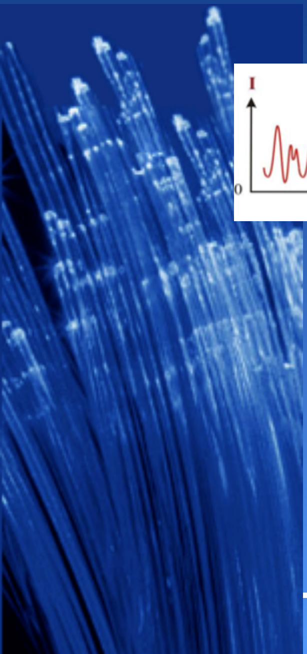
Photon counting regime



$$\tilde{I}^{(2)}(u) = |\tilde{I}(u)|^2 = \langle |V(u)|^2 \rangle - \langle N \rangle$$

Photon noise correction

B. Wirnitzer
JOSA Vol 2 n°1 pp 14-20
Jan. 1985

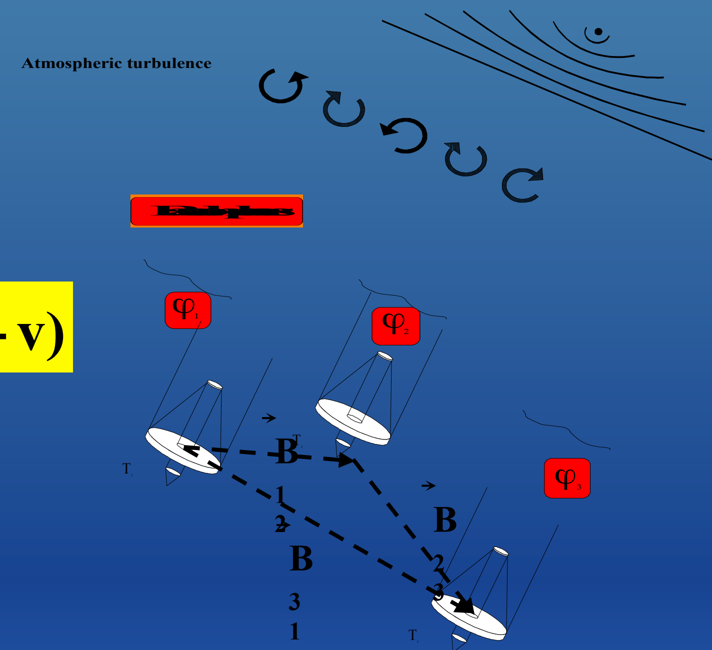


checking the transfer of spatial coherence very low power level single line

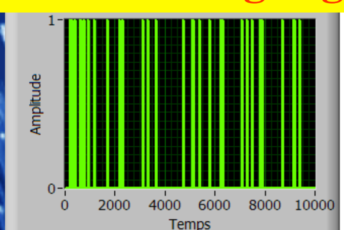
High flux level

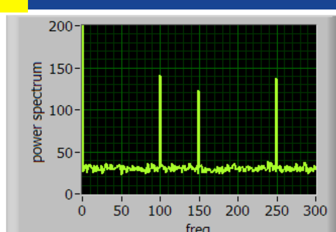
$$\tilde{I}^{(3)}(u,v) = \tilde{I}(u).\tilde{I}(v).\tilde{I}(-u-v) = V(u).V(v).V^*(u+v)$$

$$\beta = \arg(\tilde{I}^{(3)}(u,v)) = \arg(\tilde{I}(u).\tilde{I}(v).\tilde{I}^*(u+v))$$



Photon counting regime





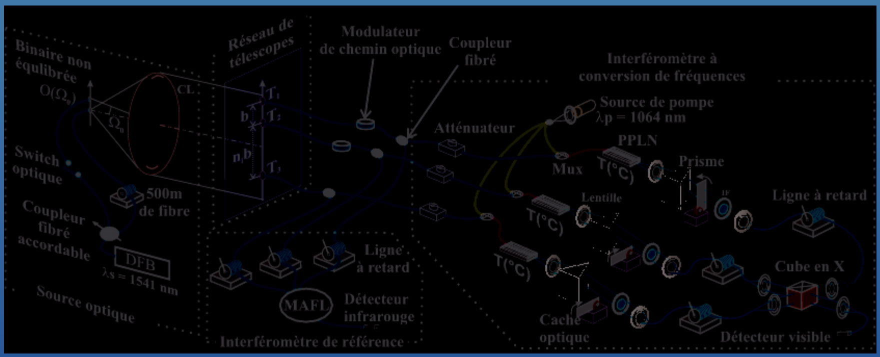
Photon noise correction

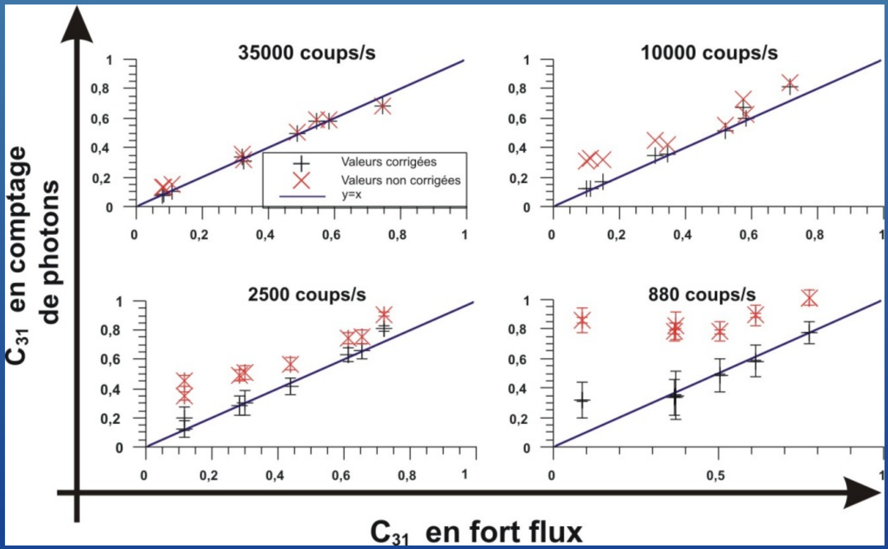
$$\tilde{I}^{(3)}(u,v) = \left\langle V(u).V(v).V^*(u+v)\right\rangle + 2\langle N\rangle - \left\langle |V(u)|^2\right\rangle - \left\langle |V(v)|^2\right\rangle - \left\langle |V(u+v)|^2\right\rangle$$

$$\beta = \arg\left[\left\langle V(u).V(v).V^*(u+v)\right\rangle + 2\langle N\rangle - \left\langle |V(u)|^2\right\rangle - \left\langle |V(v)|^2\right\rangle - \left\langle |V(u+v)|^2\right\rangle\right]$$

B. Wirnitzer JOSA Vol 2 n°1 pp 14-20 Jan. 1985

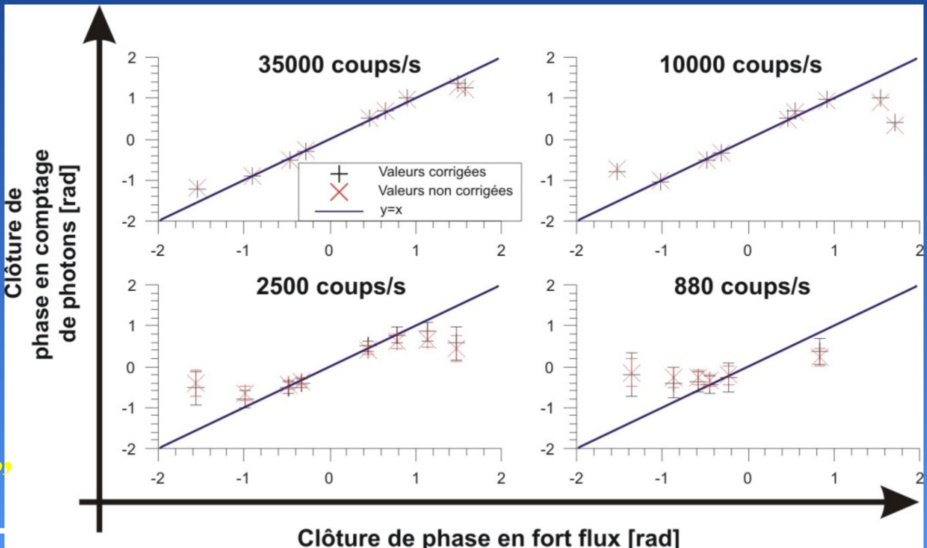
checking the transfer of spatial coherence very low power level single line





Contrast measurement

Phase closure measurement

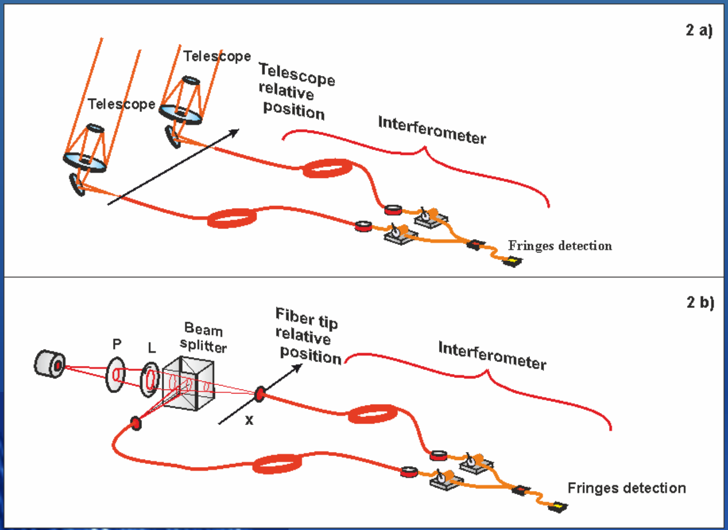


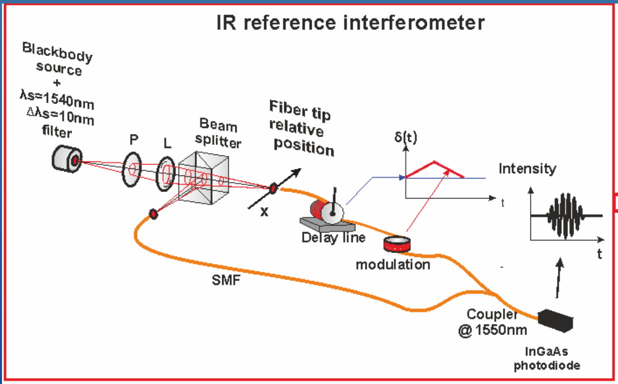
MNRAS 2013
"Contrast and phase closure acquisitions in photon counting regime using a frequency upconversion nterferometer for high angular resolution imaging "

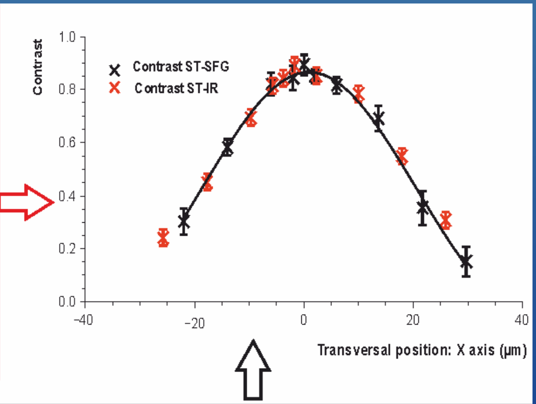
checking the transfer of spatial coherence very low power level black body

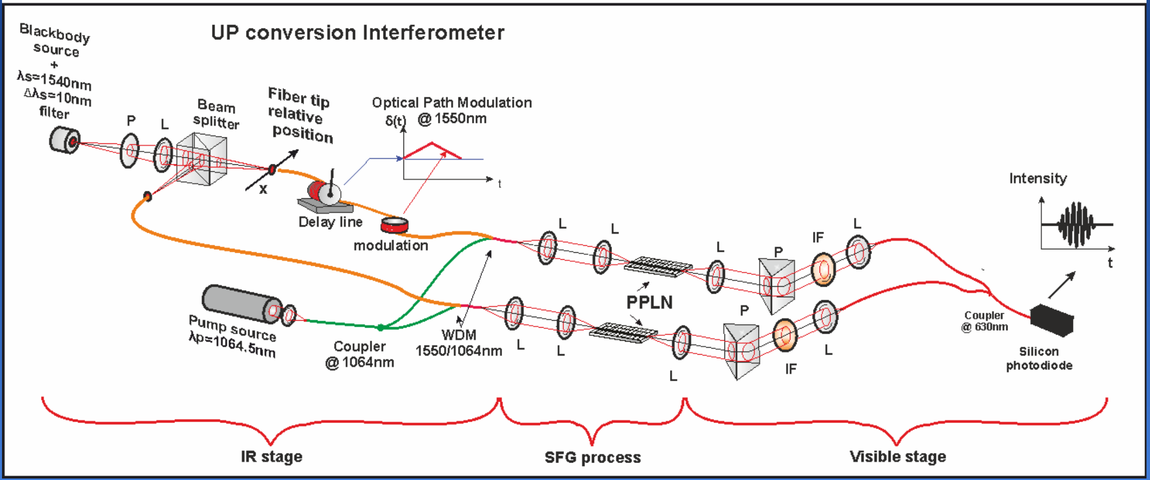
Changing the source >>> black body

In lab experiment









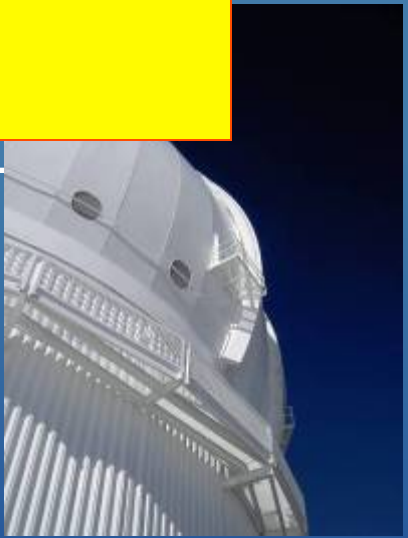
Ultra fine servo control of the SFG

" Spatial coherence analysis of a blackbody through an up conversion interferometer. A future for astronomical imaging ? "

to be submitted to Nature photonics

XLIM

checking the sensitivity of ALOHA On the"CFHT" telescope

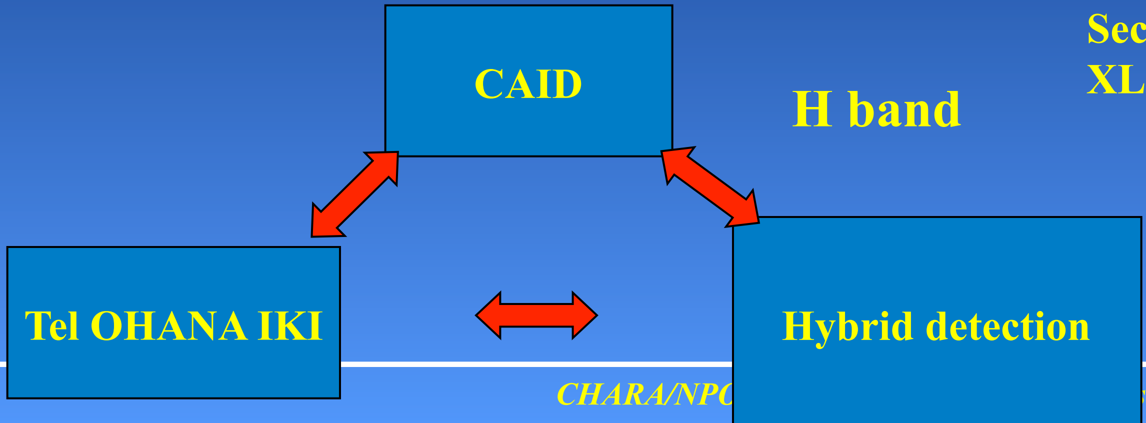


Astronomical
Light
Optical
Hybrid
Analysis

Optical hybrid detection
Use of a PPLN and a YAG Laser
to convert IR to the visible
(red light)

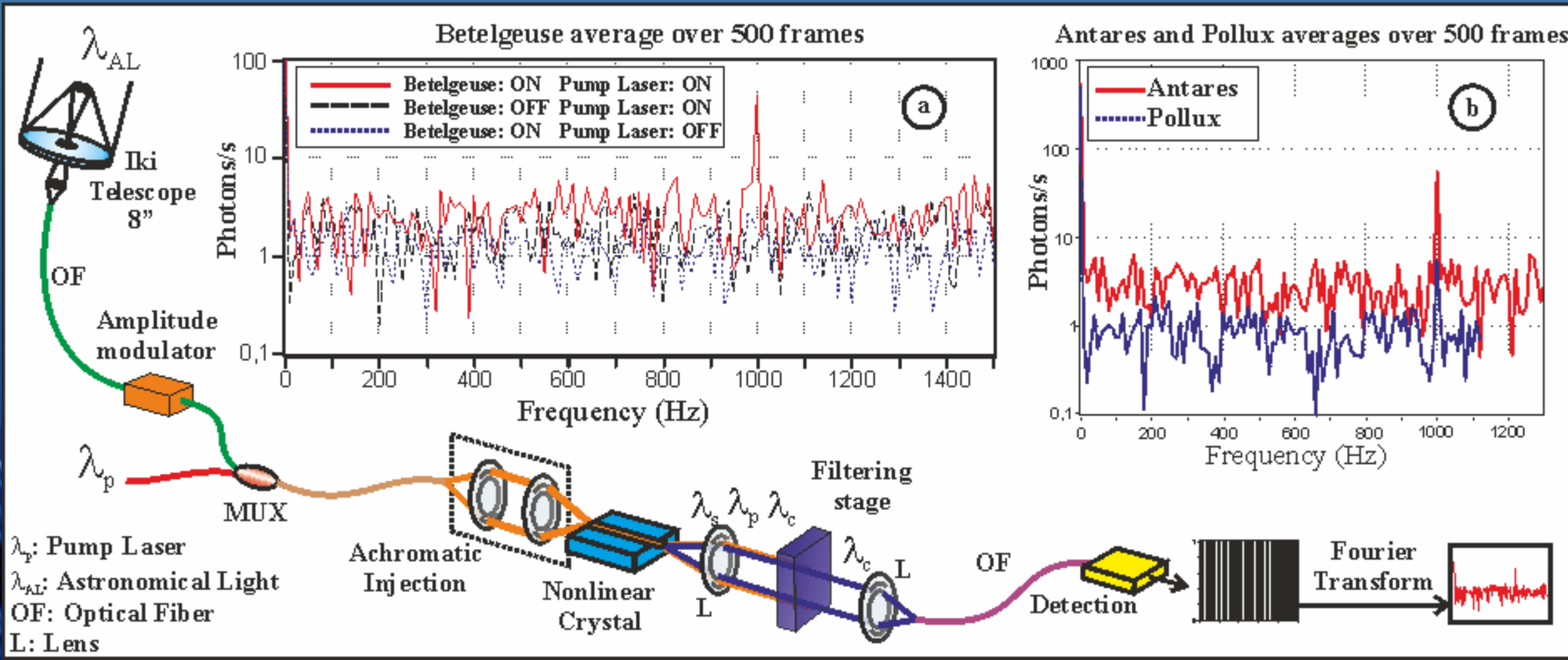
- First step: only energy conversion to scale the problem in situ (flux ; coupling on site constraints…)
  (In parallel with OHANA IKI)
  first tests on a small Celestron with a very low SNR (CFHT)

Second generation of
XLIM non linear modules



On site tests with CFHT: ALOHA 0.2

Accepted for publication in MNRAS



Betelgeuse mag H=-3.9 NSR =30 over 50s
Antares H=-3.6
Pollux H=-0.9
Epsi Scor H=-0.2 NSR =2 over 1500s

Collaboration with CHARA

- **First mission ALOHA / CHARA**
  - First preliminary internal tests
  - Operating wavelengths around 1.5 µm (H band)
  - 2 beams Mach Zehnder to test the vibrations environment

Collaboration with CHARA

- First mission ALOHA / CHARA

  Second preliminary internal tests

  –Operating wavelengths around 1.5 µm (H band)

  –Use of the CHARA internal source and FLUOR launching device

  –Photometric scaling >>> sources to be reached on CHARA/ALOHA

H m= -4 (CHARA internal source)

Coupler
Home made InGaAs
XLIM

Learn a lot about CHARA

XLIM

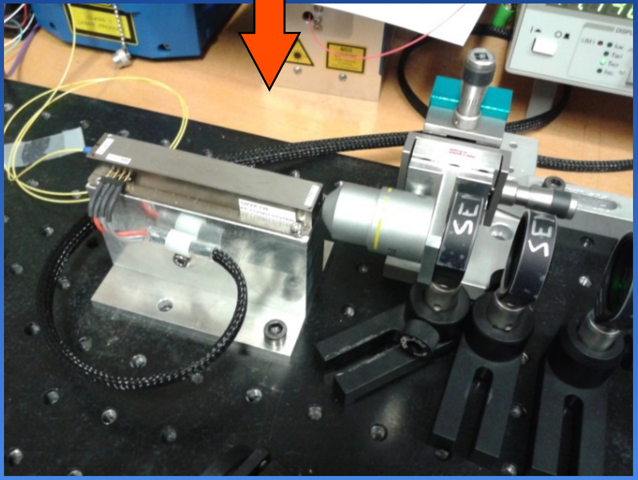
ALOHA

Collaboration with CHARA

Upgrading the SFG modules (In progress in Limoges)

- SFG Outline dimensions:
  (34x21 cm + launching assemblies V2
  smaller for V3 + simplification of fiber coupling)
- Thermal regulation rack
  From the previous version
- Current performances V2
  - The conversion efficiency
    (in the range of 1-5%)
  - The thermal stability
    (under test better than 10^{-2} °C)
  - The noise
    dark count 20/s with pump

  V3 under test



Collaboration with CHARA

To be achieved………….

2 SFG module (new generation) implementation (mid 2013)

2 Thermal regulation rack completion using V2 prototypes

Implementation of the "visible" interferometer (in progress)

Scale the Limoges experiment on the CHARA photometry

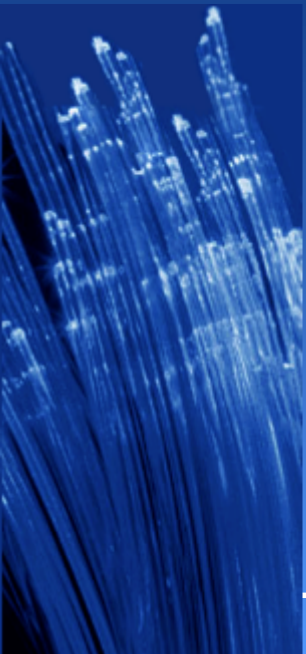
Etc.…

First mission in march 2013

The next ones to be discuss….

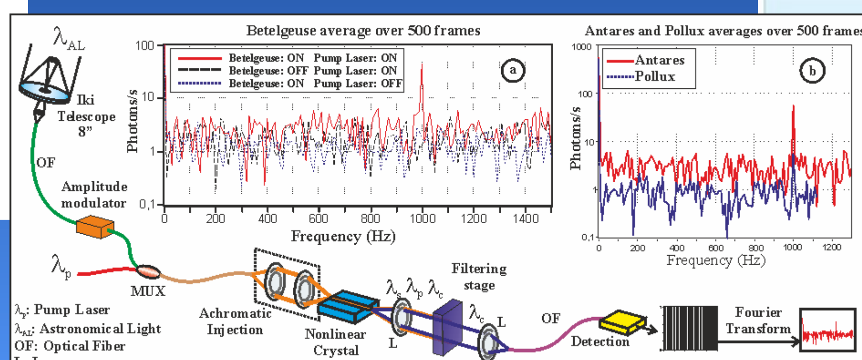
Goals: Conversion on sky..

Fringes on sky….



The end

Astronomical
Light
Optical
Hybrid
Analysis



XLIM

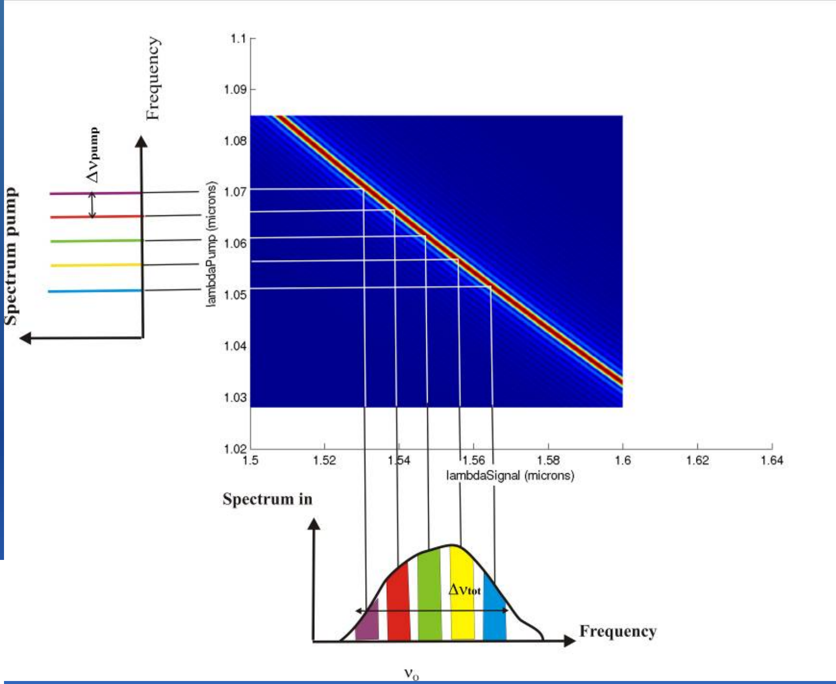
Perspective for broadband and conversion

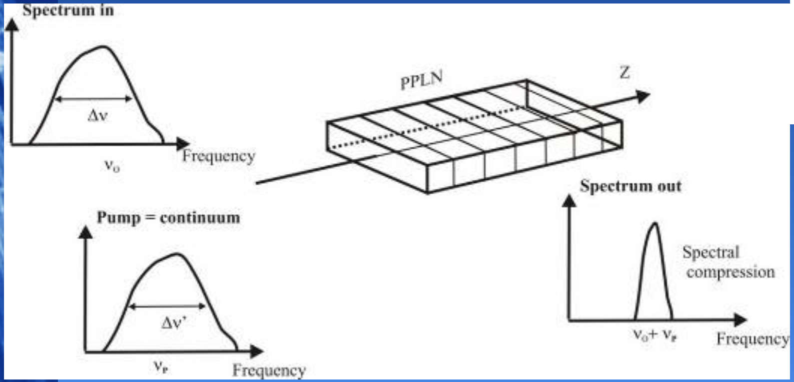
Collaboration with Paderborn

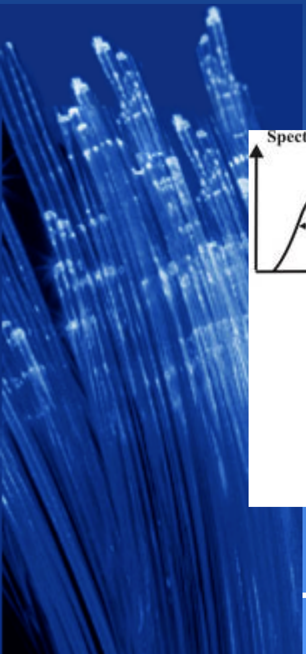
PPLN >>>
Limited spectral acceptance

pump = spectral comb
PPLN

Under progress







Under study

Preliminary results:
J. Guillot et al; XLIM
Optics Comm283 (2010), pp. 442-446