Implementation of ALOHA up-conversion interferometer at 3.39µm (L band)

Ludovic SZEMENDERA - Xlim Photonics
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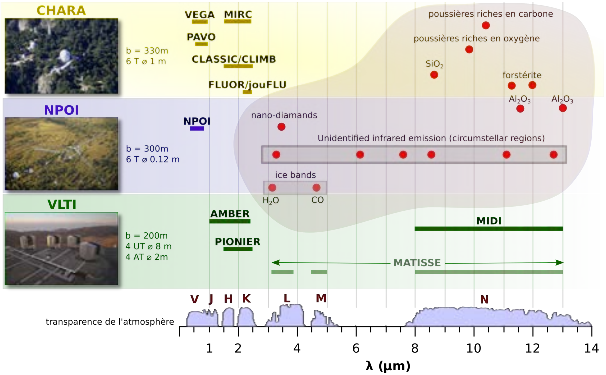
Monday 14^{th} march 2016

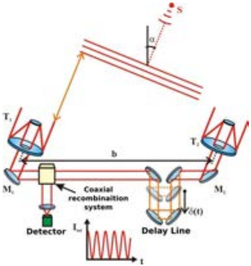
Contents

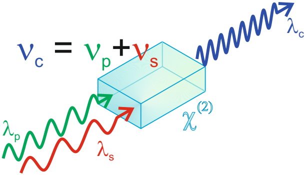
Several instrument projects adapted for MIR and FIR have already been proposed :

Their sensitivities are limited by the noise generated by optical elements (black body emissions)



Advantages of the synthetic aperture and nonlinear optics combination





Transposing infrared signal into visible or NIR domain

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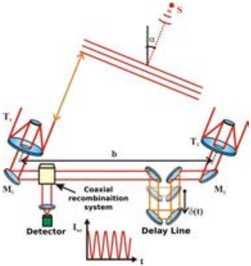

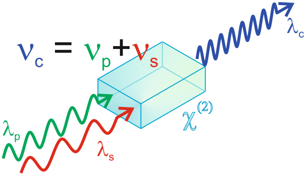

Transposing infrared signal into visible or NIR domain

- avoid noise linked to the detection chain ;

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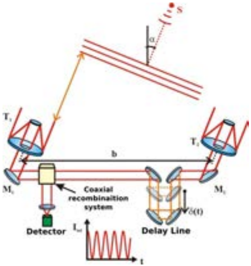

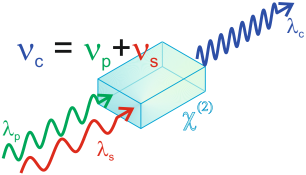

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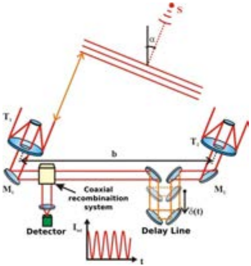

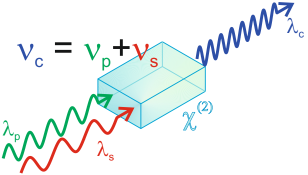

Transposing infrared signal into visible or NIR domain

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- allows to realise spectral filtering (tunable) ;

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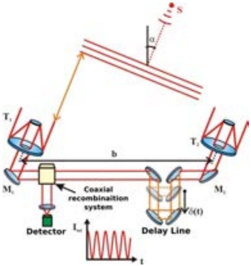
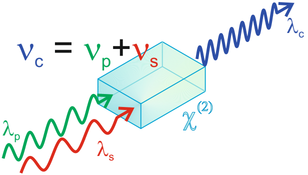
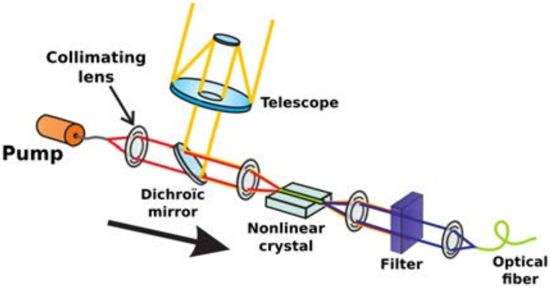




Transposing infrared signal into visible or NIR domain

- avoid noise linked to the detection chain ;
- allows to benefit optical guided elements (fibers) ;
- allows to realise spectral filtering (tunable) ;
- allows to benefit efficient detectors (silicon).

Frequency transposition thanks to sum frequency generation



We use SUM FREQUENCES (SFG)

- 2^{nd} order nonlinear process $\left(\chi^{(2)}\right)$

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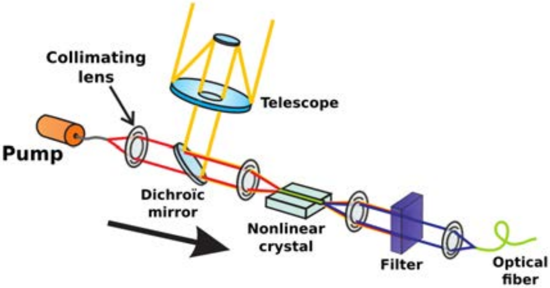

We use SUM FREQUENCES (SFG)

- 2^{nd} order nonlinear process $\left(\chi^{(2)}\right)$
- no intrinsic noise (*Louisel*)

Sum Frequency Generation (SFG)

It is led by two equations :

power conservation :

$$\nu_c = \nu_p + \nu_s$$

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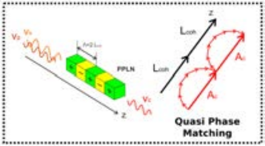

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Quasi Phase Matching condition :

$$\Delta k = \frac{2\pi n_p}{\lambda_p} + \frac{2\pi n_s}{\lambda_s} - \frac{2\pi n_c}{\lambda_c} - \frac{2\pi}{\Lambda} = 0$$

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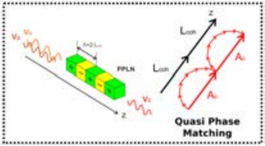
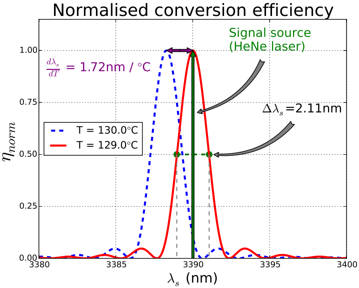
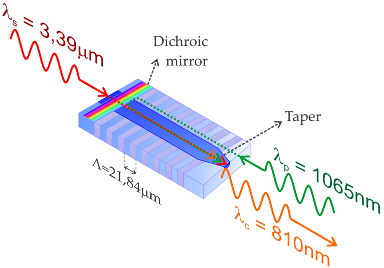
normalised efficiency is given by :

$$\eta_n(\nu_s, \nu_p) = \mathrm{sinc}^2\left(\frac{\Delta k L}{2}\right)$$





Our nonlinear crystals : PPLN



PPLN : Periodically Poled Lithium Niobate

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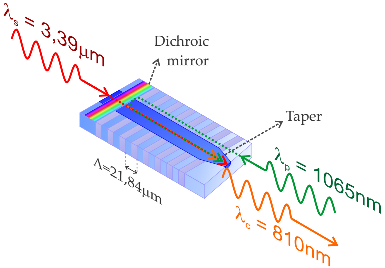

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Key features of the crystals given by the university of Paderborn (Germany) :

- they are guided (single mode @3.39 µm) ;

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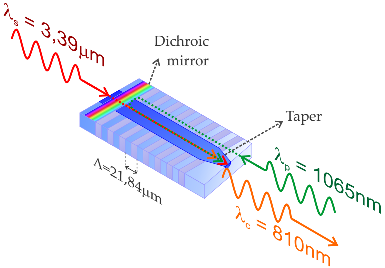

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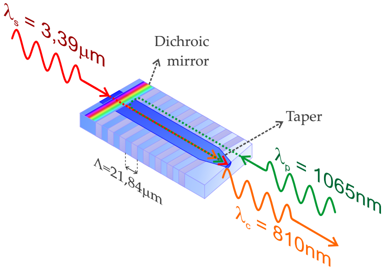

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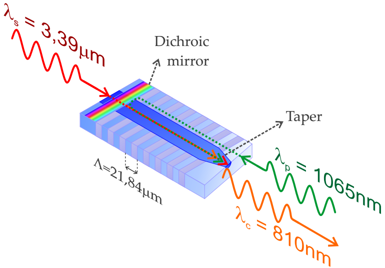

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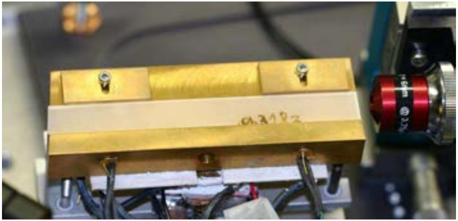
- they have got "tapers" ;
- they have an HR mirror @1064 nm ;
- their output face is slanted (Fresnel's reflection $\sim$ 14% @1064 nm).

Cristal’s temperature control

PPLN’s temperature are controlled in order to :



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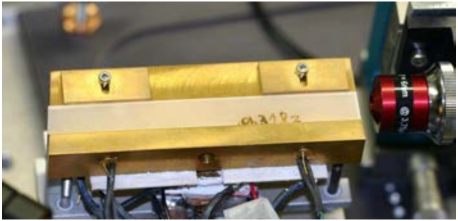

Cristal’s temperature control

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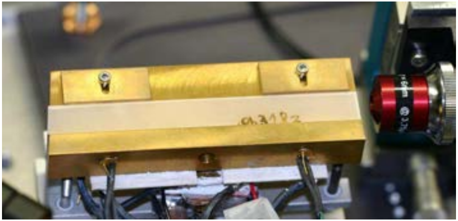
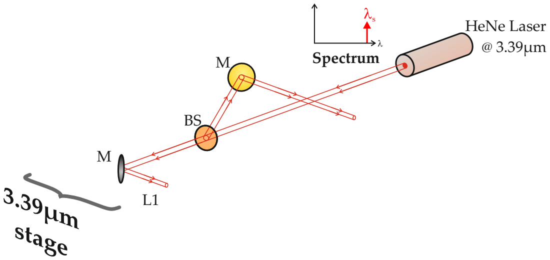
- obtain a tunable spectral filtering ;
- avoid temperature gradients (better efficiency and stability) .



In-lab setup



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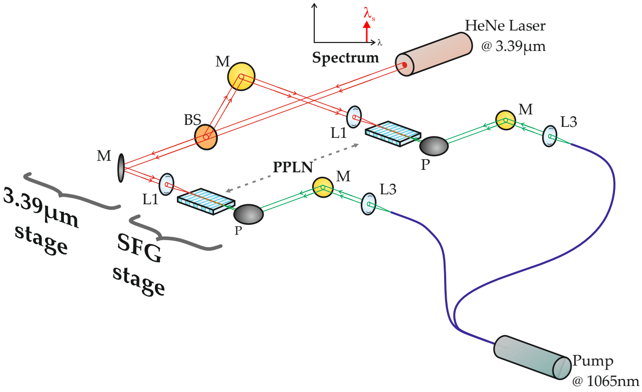
Spectrum
λ
λ_s
HeNe Laser
@ 3.39µm
M
BS
M
L1
L1
PPLN
P
P
M
L3
M
L3
3.39µm
stage
SFG
stage
Pump
@ 1065nm

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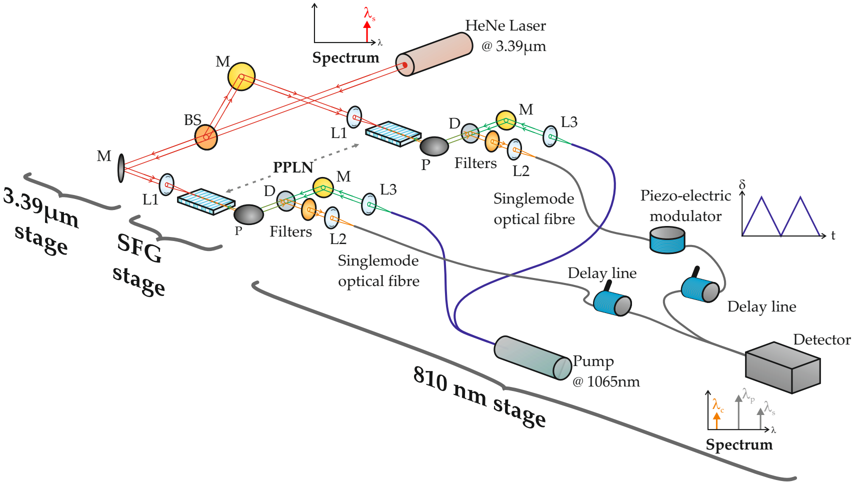
Spectrum
HeNe Laser
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M
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L1
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P
D
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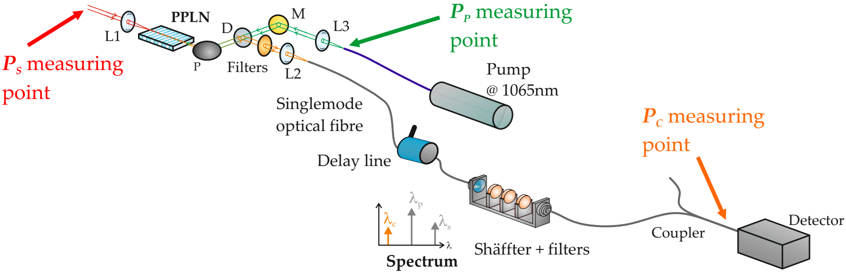
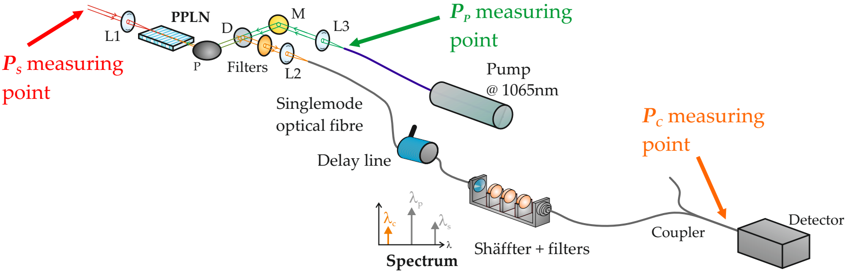
Filters
L2
Singlemode
optical fibre
Piezo-electric
modulator
Delay line
Delay line
Detector
Pump
@ 1065nm
Spectrum
3.39µm
stage
SFG
stage
810 nm stage

Efficiency measurement



- P_S : signal power (λ_S = 3.39 µm)
- P_C : converted signal power (λ_C = 810 nm)
- P_P : pump power (λ_p = 1064 nm)

Efficiency measurement



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According to this definition, η includes :

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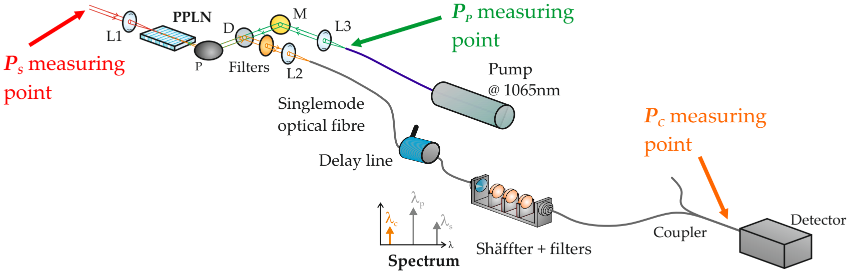
Efficiency measurement



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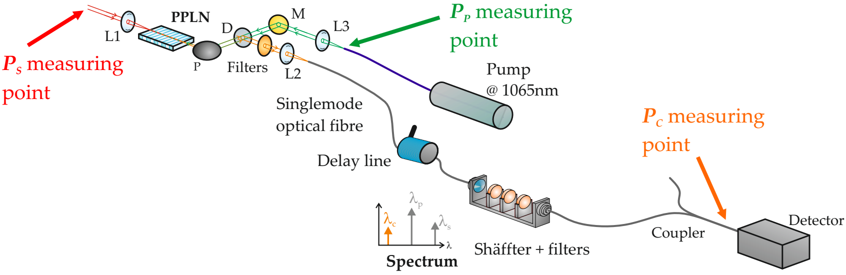

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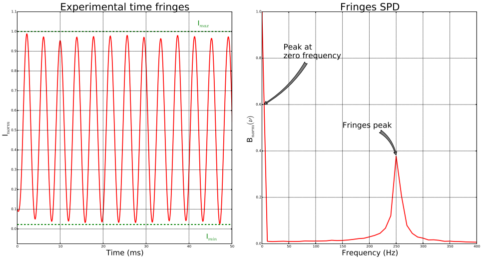
- losses due to filtering

First in-lab results with a high flux MIR source



Experimental conditions

- $P_s \approx 500\mu W$
- $\eta \approx 1 \cdot 10^{-5}$

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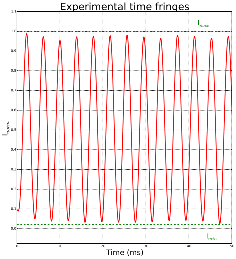

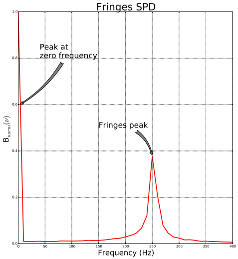

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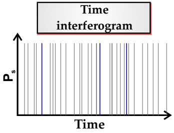
We got first interferometric fringes from a converted signal at 810 nm from a MIR signal at 3.39 µm

$$C^2_{DSP} = \frac{2 \cdot \sum B(\nu_i)}{B_0}$$

Measured contrast is 97.2%.

Publication : In-lab ALOHA mid-infrared up-conversion interferometer with high fringe contrast @$\lambda = 3.39$ µm - MNRAS vol.457 - n°3 - fev.2016

Method of contrast measurement in photon counting regime



Mesures du contraste

1. time frame acquisition *(single photon counting module)*

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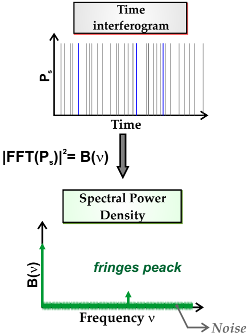

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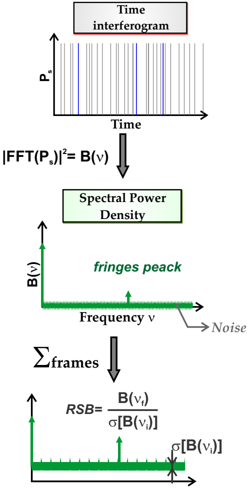

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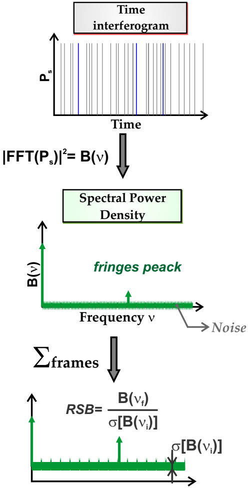

Mesures du contraste

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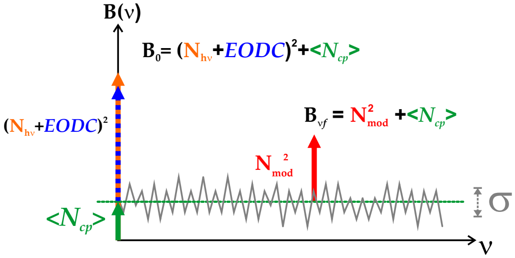
Experimental conditions

- Frame time : 400 ms
- Number of frames : from 300 to 1200

Contrast calculation



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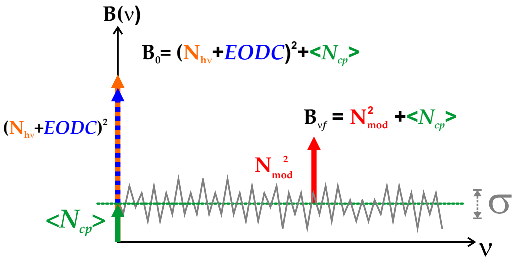

$B(\nu_f)$

- N_{mod} : converted photons (on fringe channel)

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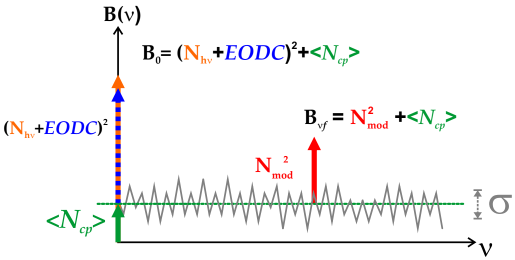

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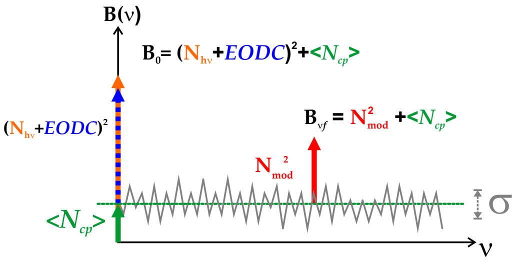

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B_0

- $N_{h\nu}$: converted photons

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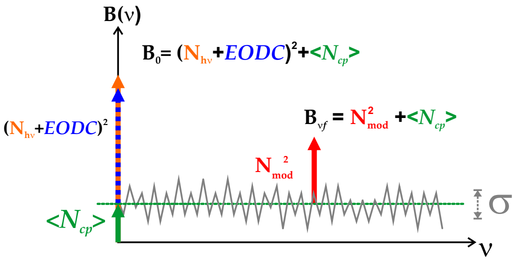

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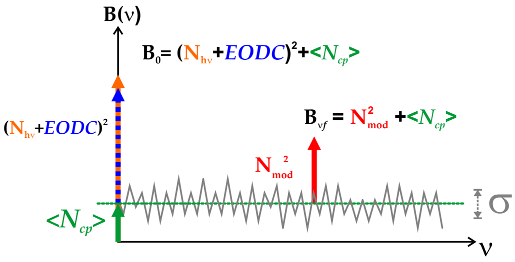

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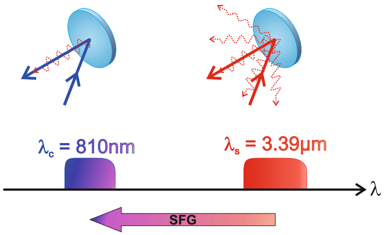
Contrast calculation

$$C = \frac{\sqrt{B_{\nu_f} - \langle N_{cp} \rangle_t}}{\sqrt{B_0 - \langle N_{cp} \rangle_t} - EODC}$$

Thermal background



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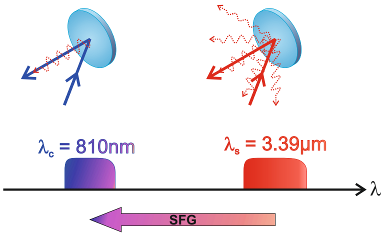

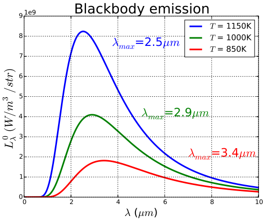

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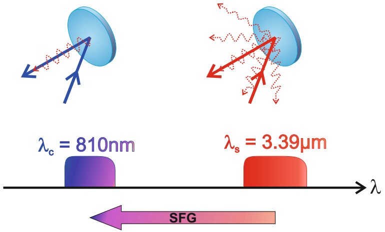

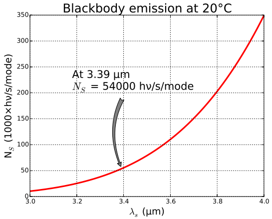

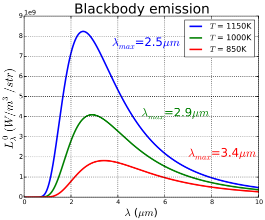

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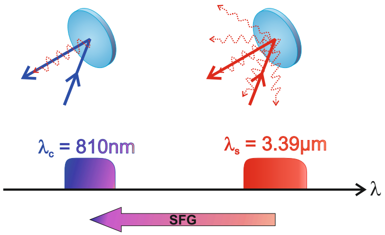
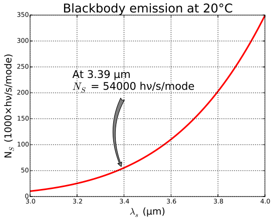
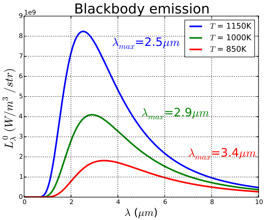


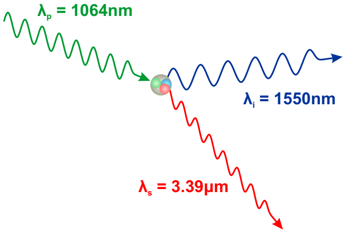




Experimentally

With $100\,\mathrm{mW}$ pump power, we observe 20cp/s due to thermal effects.

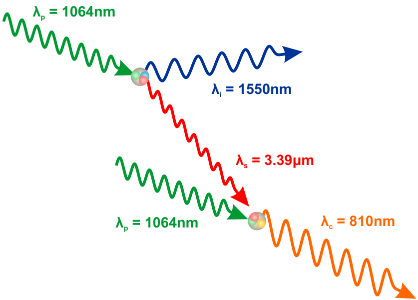
Parametric fluorescence and cascading effect



Principal

1. a pump photon generates a signal photon and an idler one

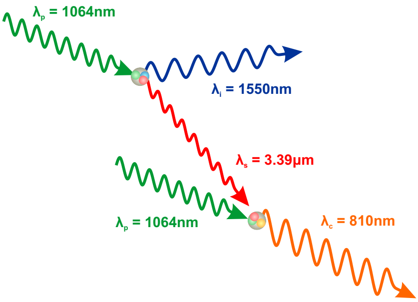
Parametric fluorescence and cascading effect



Principal

1. a pump photon generates a signal photon and an idler one
2. the signal photon is recombined with a pump photon (SFG) to produce a photon at 810 nm

Parametric fluorescence and cascading effect



Principal

1. a pump photon generates a signal photon and an idler one
2. the signal photon is recombined with a pump photon (SFG) to produce a photon at $810\ \mathrm{nm}$

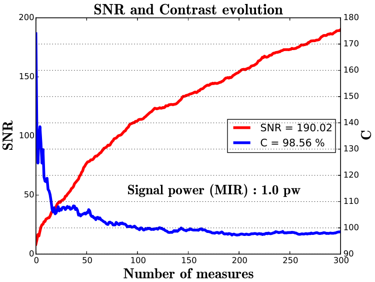
Experimentally

With $100\ \mathrm{mW}$ pump power, we observe 20cp/s due to parametric fluorescence.

Results on the photon counting regime

Signal power @1pW on each interferometric arm ($\approx 2 \times 10^7$ photons/s)

- contrast : 98.6%
- signal to noise ratio : 190



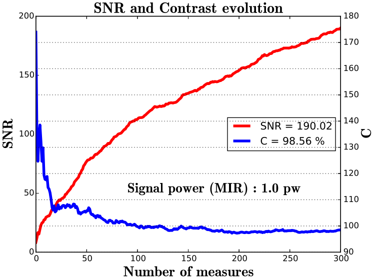
Results on the photon counting regime

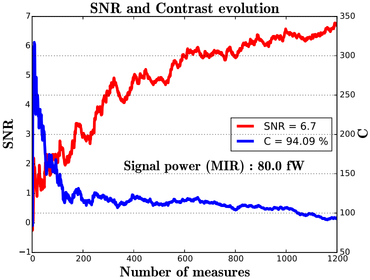
Signal power @1pW on each interferometric arm ($\approx 2 \times 10^7$ photons/s)

- contrast : 98.6%
- signal to noise ratio : 190

Signal power @80fW on each interferometric arm ($\approx 10^6$ photons/s)

- contrast : 94%
- signal to noise ratio : 6.7





1 General framework

2 Theory and technologies

3 In-lab results

4 Conclusion and broad perspectives

Conclusion : overview of done work

At the moment, ALOHA project has a promising balance :

1. building and tests with the in-lab set up

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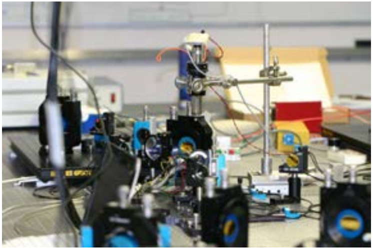
At the moment, ALOHA project has a promising balance :

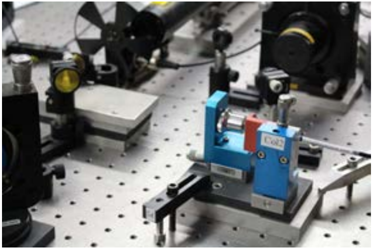
1. building and tests with the in-lab set up
2. first fringes with a high flux source $\longmapsto$ MNRAS february 2016
3. first fringes on the photon counting regime $\longmapsto$ publication in progress

Broad perspectives

New tracks for the future :

1. improvement on performances (new crystals, architecture, etc)





Broad perspectives

New tracks for the future :

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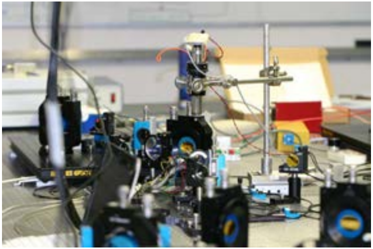
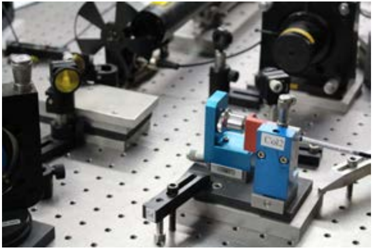
2. fringes with a blackbody source

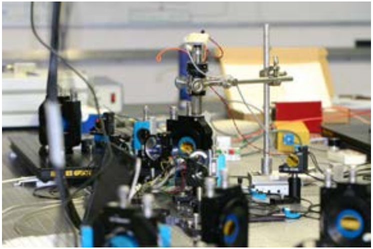


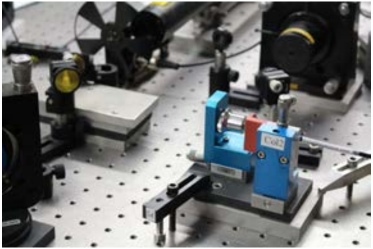


Broad perspectives

New tracks for the future :

1. improvement on performances (new crystals, architecture, etc)
2. fringes with a blackbody source
3. implementation on site





Thank you for your attention