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

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1 General framework

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4 Conclusion and broad perspectives
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

\[ \nu_c = \nu_p + \nu_s \]

Transposing infrared signal into visible or NIR domain

Implementation of ALOHA up-conversion interferometer at 3.39\(\mu\)m (L band)
Advantages of the synthetic aperture and nonlinear optics combination

Transposing infrared signal into visible or NIR domain

- avoid noise linked to the detection chain;
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- allows to benefit optical guided elements (fibers);
Advantages of the synthetic aperture and nonlinear optics combination

- Transposing infrared signal into visible or NIR domain
- Avoids noise linked to the detection chain
- Allows to benefit optical guided elements (fibers)
- Allows to realise spectral filtering (tunable)

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Advantages of the synthetic aperture and nonlinear optics combination

\[ n_c = n_p + n_s \]

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).

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Frequency transposition thanks to sum frequency generation

We use SUM FREQUENCES (SFG)

- 2nd order nonlinear process ($\chi^{(2)}$)
Frequency transposition thanks to sum frequency generation

We use SUM FREQUENCES (SFG)

- 2\textsuperscript{nd} order nonlinear process (\(\chi^{(2)}\))
- no intrinsic noise (Louisel)
Sum Frequency Generation (SFG)

It is led by two equations:

\[ \nu_c = \nu_p + \nu_s \]
Sum Frequency Generation (SFG)

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- **Power conservation:**
  \[ \nu_c = \nu_p + \nu_s \]

- **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:

\[ \eta_n(\nu_s, \nu_p) = \text{sinc}^2 \left( \frac{\Delta k L}{2} \right) \]
Our nonlinear crystals: PPLN

PPLN: Periodically Poled Lithium Niobate
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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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- they have an HR mirror @1064 nm;

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

- they are guided (single mode @3.39 µm);
- they have got "tapers";
- they have an HR mirror @1064 nm;
- their output face is slanted (Fresnel’s reflection ∼ 14% @1064 nm).

PPLN: Periodically Poled Lithium Niobate
Cristal’s temperature control

PPLN’s temperature are controlled in order to:

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Cristal’s temperature control

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Cristal’s temperature control

PPLN’s temperature are controlled in order to:

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

- $P_S$: signal power
  ($\lambda_S = 3.39 \, \mu m$)

- $P_C$: converted signal power
  ($\lambda_C = 810 \, nm$)

- $P_P$: pump power
  ($\lambda_P = 1064 \, nm$)

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$$\eta = \frac{P_C}{P_S}$$

According to this definition, $\eta$ includes:
- SFG efficiency
Efficiency measurement

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$$\eta = \frac{P_C}{P_S}$$

According to this definition, $\eta$ includes:

- SFG efficiency
- Insertion losses
- Losses due to filtering
First in-lab results with a high flux MIR source

Experimental time fringes

Fringes SPD

Experimental conditions

- \( P_s \approx 500\mu W \)
- \( \eta \approx 1 \cdot 10^{-5} \)
First in-lab results with a high flux MIR source

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

We got first interferometric fringes from a converted signal at $810\,\text{nm}$ from a MIR signal at $3.39\,\mu\text{m}$

$$C_{DSP}^2 = \frac{2 \cdot \sum B(v_i)}{B_0}$$

Measured contrast is 97.2%.

Publication: In-lab ALOHA mid-infrared up-conversion interferometer with high fringe contrast @$\lambda = 3.39\,\mu\text{m}$ - MNRAS vol.457 - n°3 - fev.2016
Method of contrast measurement in photon counting regime

- Time interferogram

Mesures du contraste

1. time frame acquisition (single photon counting module)
Method of contrast measurement in photon counting regime

\[ |\text{FFT}(P_s)|^2 = B(v) \]

1. time frame acquisition *(single photon counting module)*
2. calculation of the SPD on each frame *(VI LabView©)*

**Mesures du contraste**

- Time interferogram
- Spectral Power Density
- Fringes peack
- Frequency
- Noise

**Implementation**

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Method of contrast measurement in photon counting regime

Mesures du contraste

1. time frame acquisition \textit{(single photon counting module)}

2. calculation of the SPD on each frame \textit{(VI LabView©)}

3. integration: summation on all SPD \textit{(VI LabView©)}
Method of contrast measurement in photon counting regime

Mesures du contraste

1. time frame acquisition *(single photon counting module)*
2. calculation of the SPD on each frame *(VI LabView©)*
3. integration : summation on all SPD *(VI LabView©)*

Experimental conditions

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

\[ B_0 = (N_{hv} + EODC)^2 + \langle N_{cp} \rangle \]

\[ B_{vf} = N_{mod}^2 + \langle N_{cp} \rangle \]
Contrast calculation

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\[ B(v_f) \]

- \( N_{mod} \): converted photons (on fringe channel)
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\[ B(v_f) = N_{mod} \] converted photons (on fringe channel)

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\[ B_0 = (N_{hv} + EODC)^2 + \langle N_{cp} \rangle \]

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B(ν_f)
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B_0
- N_{hv} : converted photons
- EODC : electro-optic dark count

\[ B_0 = (N_{hv} + EODC)^2 + \langle N_{cp} \rangle \]

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Contrast calculation

\[ B(v_f) = (N_{hv} + EODC)^2 + \langle N_{cp} \rangle \]

\[ B_0 = N_{hv} \nu + EODC \]

\[ B_{vf} = N_{mod}^2 + \langle N_{cp} \rangle \]

\[ C = \frac{\sqrt{B_{vf} - \langle N_{cp} \rangle_t}}{\sqrt{B_0 - \langle N_{cp} \rangle_t - EODC}} \]

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- \( \langle N_{cp} \rangle_t \): average number of photons
- \( N_{hv} \): converted photons
- \( EODC \): electro-optic dark count

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Thermal background

\[ \lambda_c = 810\text{nm} \quad \lambda_s = 3.39\mu\text{m} \]

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\[ \lambda_c = 810 \text{nm} \quad \lambda_s = 3.39 \mu \text{m} \]

Blackbody emission

\[ T = 1150 \text{K} \quad T = 1000 \text{K} \quad T = 850 \text{K} \]

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Blackbody emission

\[ T = 1150\text{K} \quad T = 1000\text{K} \quad T = 850\text{K} \]

\[ \lambda_{\text{max}} = 2.5\mu\text{m} \quad \lambda_{\text{max}} = 2.9\mu\text{m} \quad \lambda_{\text{max}} = 3.4\mu\text{m} \]

Experimentally

With 100 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

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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.

Implementation of ALOHA up-conversion interferometer at 3.39 µm (L band)
Parametric fluorescence and cascading effect

Principal

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

With 100 mW pump power, we observe 20 cp/s due to parametric fluorescence.
Results on the photon counting regime

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

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

SnR and Contrast evolution

Implementation of ALOHA up-conversion interferometer at 3.39\text{µm} (L band)
Results on the photon counting regime

Signal power @1pW on each interferometric arm
(≈ 2 × 10⁷ photons/s)
- contrast : 98.6%
- signal to noise ratio : 190

Signal power @80fW on each interferometric arm
(≈ 10⁶ photons/s)
- contrast : 94%
- signal to noise ratio : 6.7

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Implementation of ALOHA up-conversion interferometer at 3.39µm (L band)
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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MNRAS February 2016
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2. first fringes with a high flux source \(\rightarrow\) MNRAS February 2016
3. first fringes on the photon counting regime

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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 $\rightarrow$ MNRAS February 2016
3. first fringes on the photon counting regime $\rightarrow$ publication in progress
New tracks for the future:

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

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New tracks for the future:

1. Improvement on performances (new crystals, architecture, etc)
2. Fringes with a blackbody source
3. Implementation on site

Implementation of ALOHA up-conversion interferometer at 3.39μm (L band)
Thank you for your attention