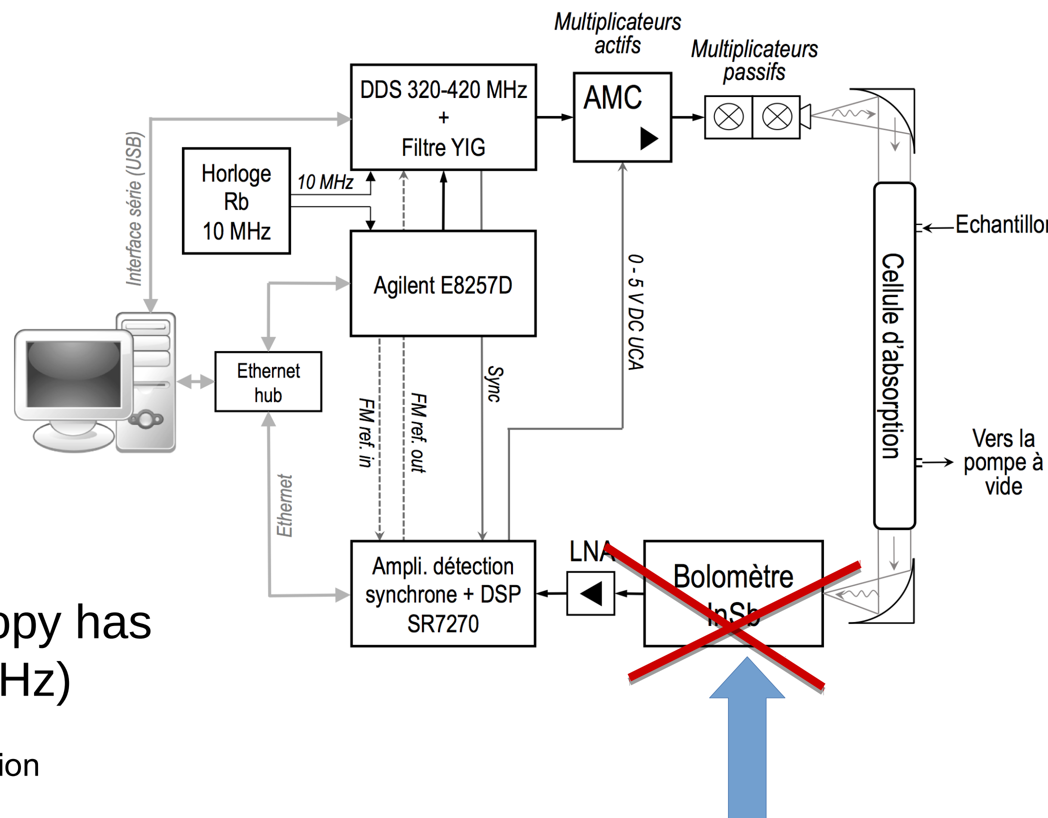
A 530-590 GHZ SCHOTTKY HETERODYNE RECEIVER FOR HIGH-RESOLUTION MOLECULAR SPECTROSCOPY WITH LILLE'S FAST-SCAN FULLY SOLID-STATE DDS SPECTROMETER

A. PIENKINA[1], L. MARGULES[1], R. A. MOTIYENKO[1],
M. WIEDNER[2], A. MAESTRINI[2], F. DEFRANCE[2]

[1]Laboratoire PhLAM, UMR 8523 CNRS - Université Lille 1, Villeneuve d'Ascq, France
[2]LERMA, Observatoire de Paris, PSL Research University, CNRS, UPMC, Paris, France

The objective of this work is to develop a 600 GHz Schottky heterodyne receiver, intended for the space mission JUICE

1) to improve the sensitivity
2) no need to use cryogenic cooling as in the case with 4K bolometer



Heterodyne submillimeter-wave spectroscopy has been performed before in Lille (74 – 400 GHz)

J. Burie, D. Boucher, J. Demaison, A. Dubrulle. Spectre de rotation millimetrique du malononitrile.
Journal de Physique, 1982, 43 (9), pp.1319-1325.

Space Heterodyne receiver

Mixer : custom microwave whisker-contact Schottky diode
Sources: klystron and Gunn diode

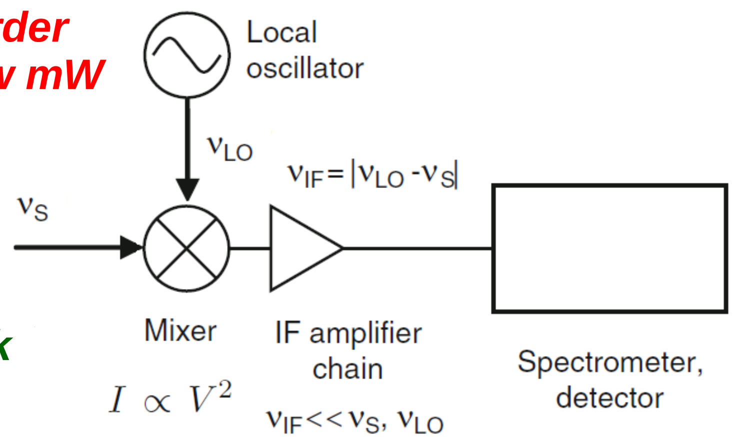
What is heterodyne detection?

frequency conversion of a (high frequency) weak signal
to lower-frequency IF range using a non-linear device (mixer)

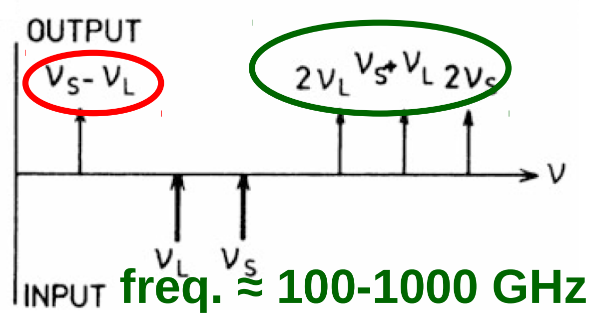
- **Signal , ν_S**
- **Local Oscillator (LO), ν_{LO}**
- **Intermediate frequency (IF), ν_{IF}**

of order a few mW

very weak



freq. ≈ a few GHz



freq. ≈ 100-1000 GHz

$$I \propto (V_S + V_{LO})^2 = [E_S \cos(\omega_S t + \phi_S) + E_{LO} \cos(\omega_{LO} t)]^2$$

$$\begin{aligned} I &\propto E_S^2 \cos^2(\omega_S t + \phi_S) + E_{LO}^2 \cos^2(\omega_{LO} t) + 2E_S E_{LO} \cos(\omega_S t + \phi_S) \cos(\omega_{LO} t) \\ &= \frac{1}{2} E_S^2 [1 + \cos(2\omega_S t + 2\phi_S)] + \frac{1}{2} E_{LO}^2 [1 + \cos(2\omega_{LO} t)] + \\ &\quad E_S E_{LO} \cos[(\omega_S + \omega_{LO}) t + \phi_S] + E_S E_{LO} \cos[(\omega_S - \omega_{LO}) t + \phi_S] \end{aligned}$$

Types of receivers:

laboratory

- incoherent (direct detectors, for example bolometers)

space

- coherent (heterodyne receivers)

Limiting Receiver's Sensitivity

Noise equivalent power, Watts $Hz^{-1/2}$

$$\mathrm{NEP_{ph}} = 2\varepsilon\, k\, T_{\mathrm{BG}} \sqrt{\Delta\nu}$$

Noise temperature, K

$$T_{\mathrm{rx}}(\mathrm{minimum}) = \frac{h\nu}{k}$$

We can't compare directly, but we may estimate (limit de Rayleigh-Jeans *hv>>kT*):

$NEP_i=(2M)^{1/2}kT(2\Delta vB)^{1/2}$~**$10^{-16}$ Watts $Hz^{-1/2}$**

Δv= 2700 GHz; spectral bandwith of bolometer

T=4 K ; t=1s ; B=1/2; M=1 at 300 GHz

$NEP_c=kT(2\Delta f_{IF}B)^{1/2}$~**$10^{-17}$ Watts $Hz^{-1/2}$**

Δf_{IF}=7 MHz ; IF band of a heterodyne receiver

T=300 K ; t=1s ; B=1/2;

$NEP_i > NEP_c$

That makes coherent system possibly more sensitive at frequencies > 300 GHz

The last space missions have driven impovement in :

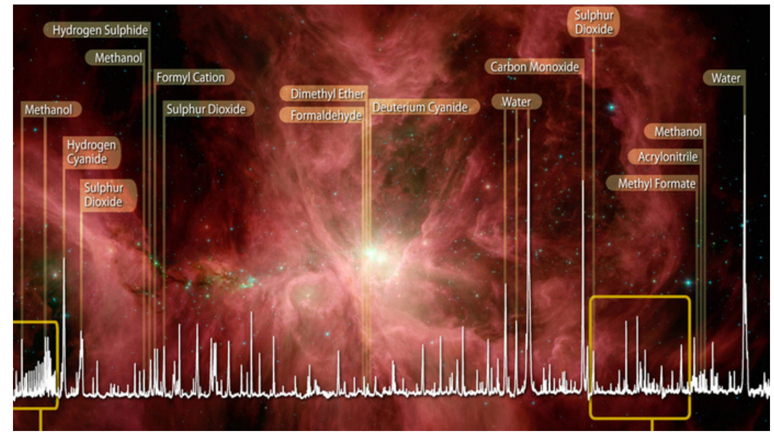
- Solid state sources
- Planar Schotky diodes

The Heterodyne Instrument for Far Infrared (HIFI) on ESA's Herschel Space Observatory observed the cold molecular clouds at frequencies impossible for ground based instrumentation

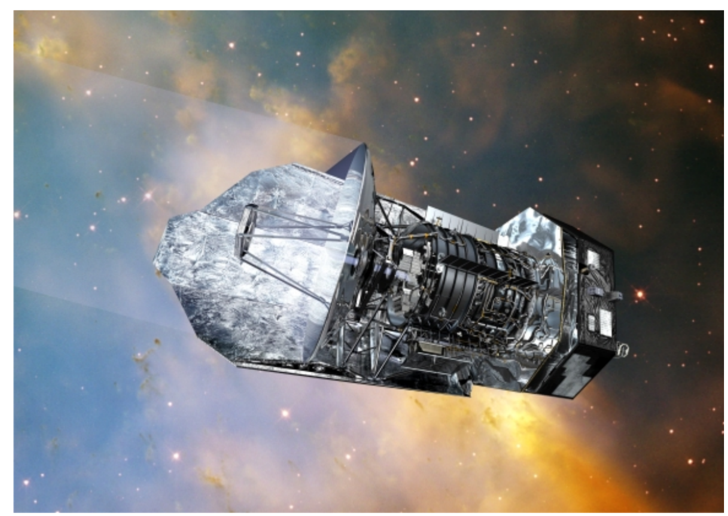
- Heterodyne astronomical receivers provide unprecedented high resolution

- Space missions require the best sensitivity possible

- Components must be state-of-the-art

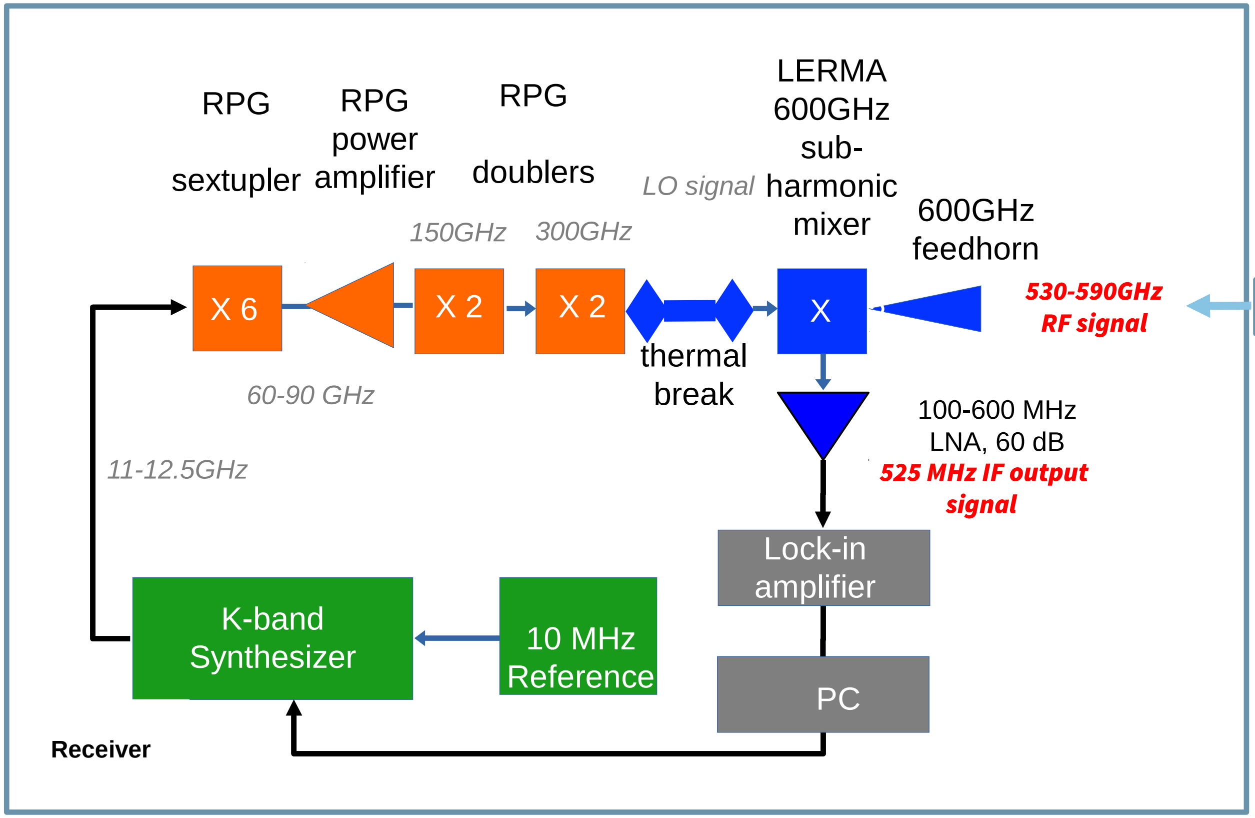


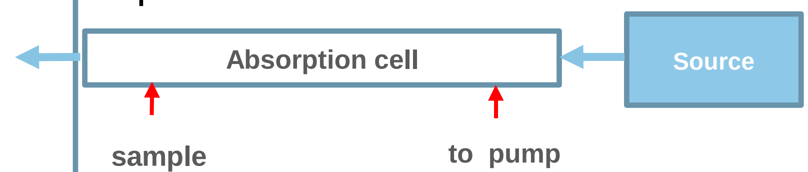
Observations from 1.5 million km from Earth.



Herschel Spacecraft ;
cost of the mission 1,1 billion €

Our spectroscopy team in laboratory PhLAM, Lille had a unique opportunity to use and test a prototype of a Schottky heterodyne receiver, specially developed in LERMA, Observatoire de Paris for space mission JUICE





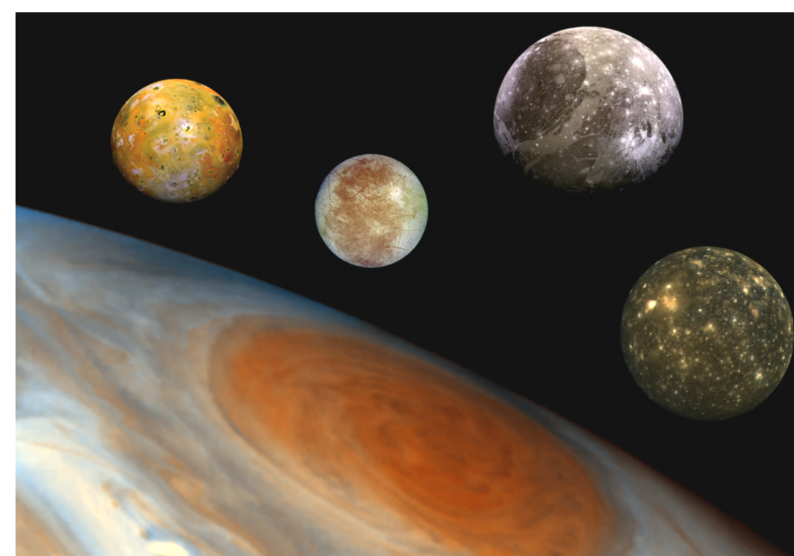
experimental schematic setup
of a prototype* of JUICE 600 GHz receiver**,
tested with Lille's fast scan DDS spectrometer
configuration is not final

*The current prototype was kindly provided by Alan Maestrini

**described in details in [Treuttel, J., et al., IEEE Transactions on Terahertz Science and Technology, 6148-155, 2016] and [Maestrini, A., et al. the 27th ISSTT 2016, Nanjing, China, 12-15 April 2016.]

Jupiter and the four Galilean moons

Copyright: NASA/JPL/DLR



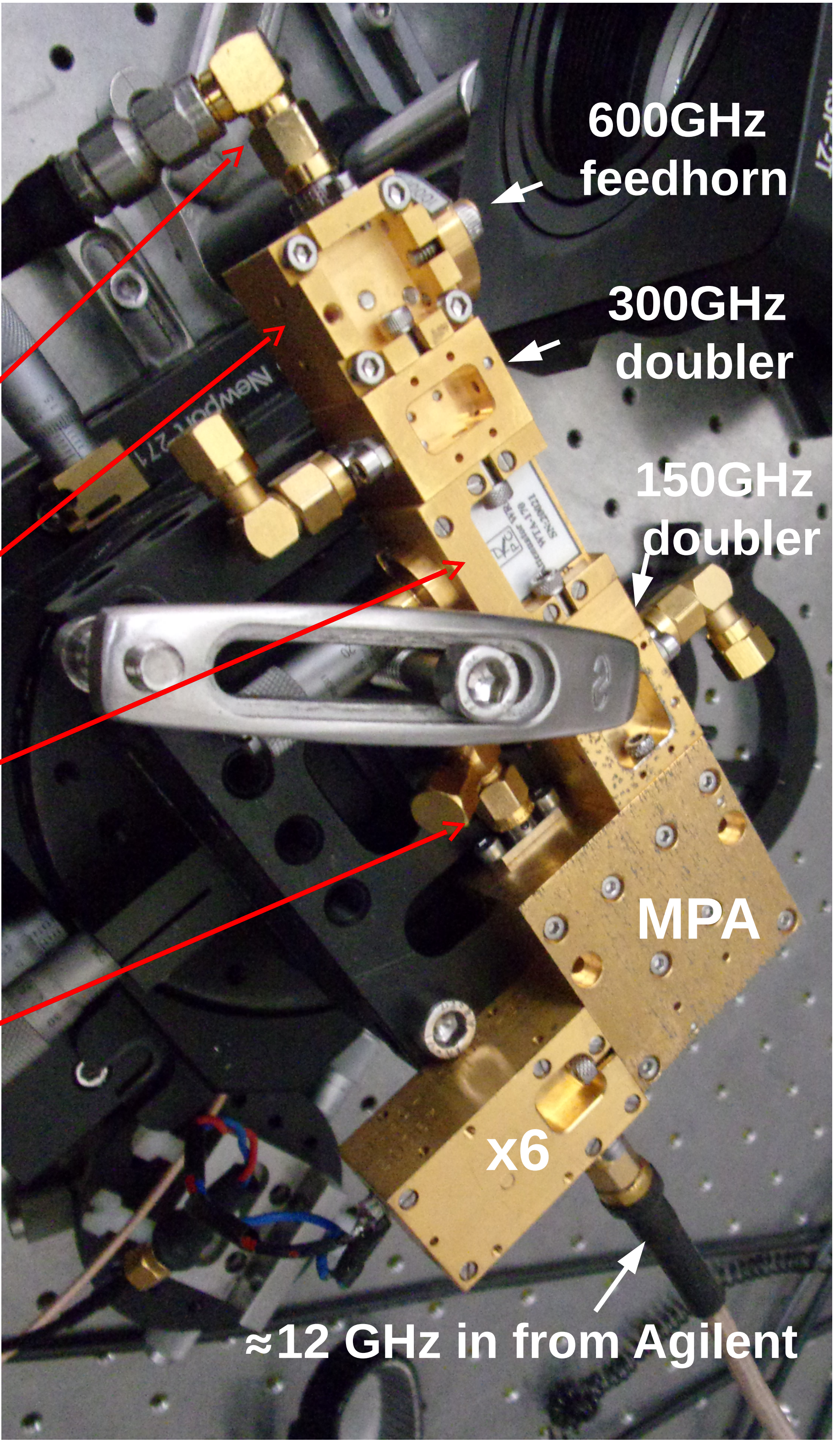
LERMA 530-590GHz Prototype Schottky Receiver

IF output

600GHz subharmonic mixer

Waveguide Tunable Attenuator

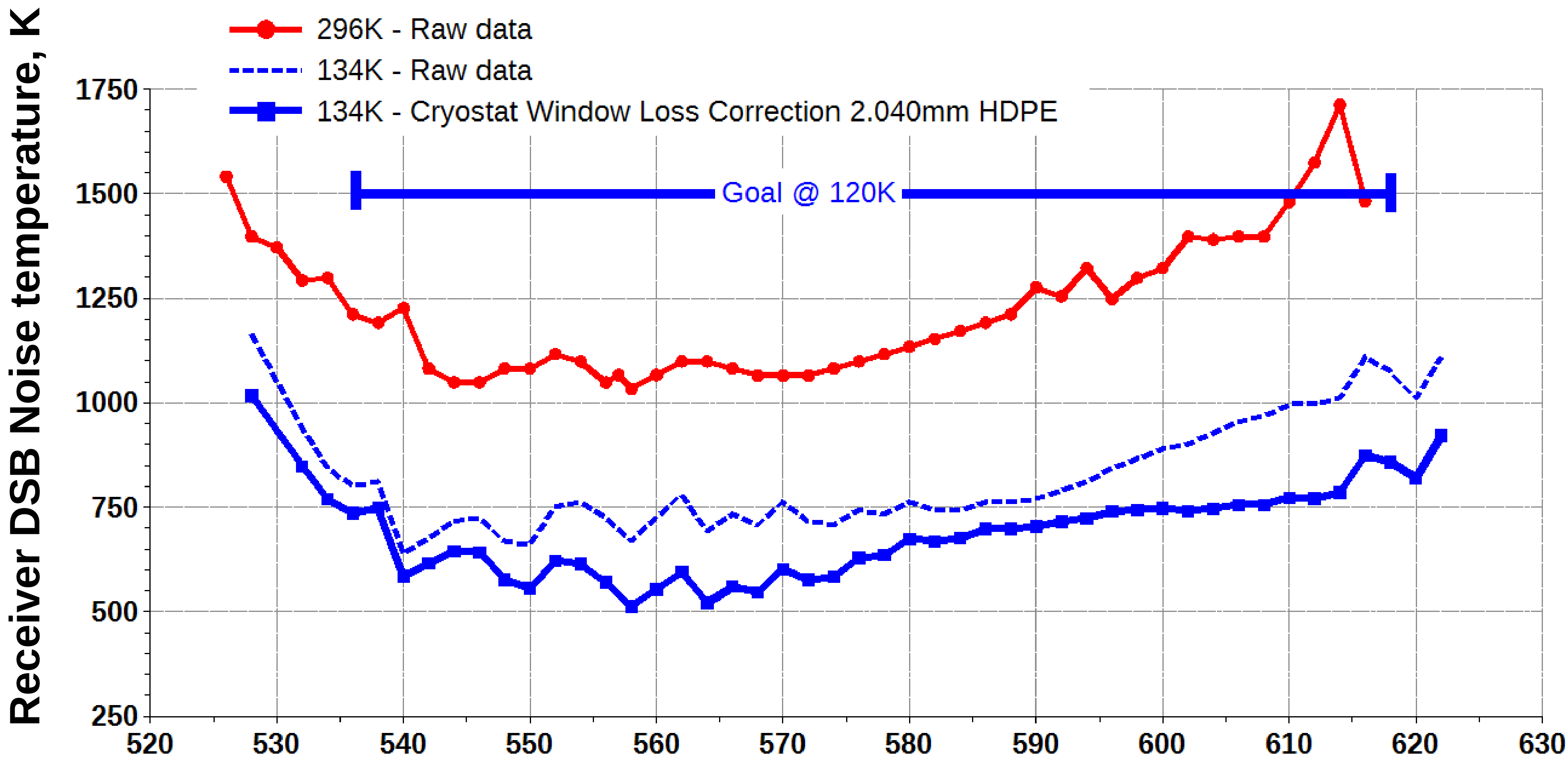
300GHz Local Oscillator chain
(to be replaced for final test in July)



LERMA 600GHz Receiver Sensitivy

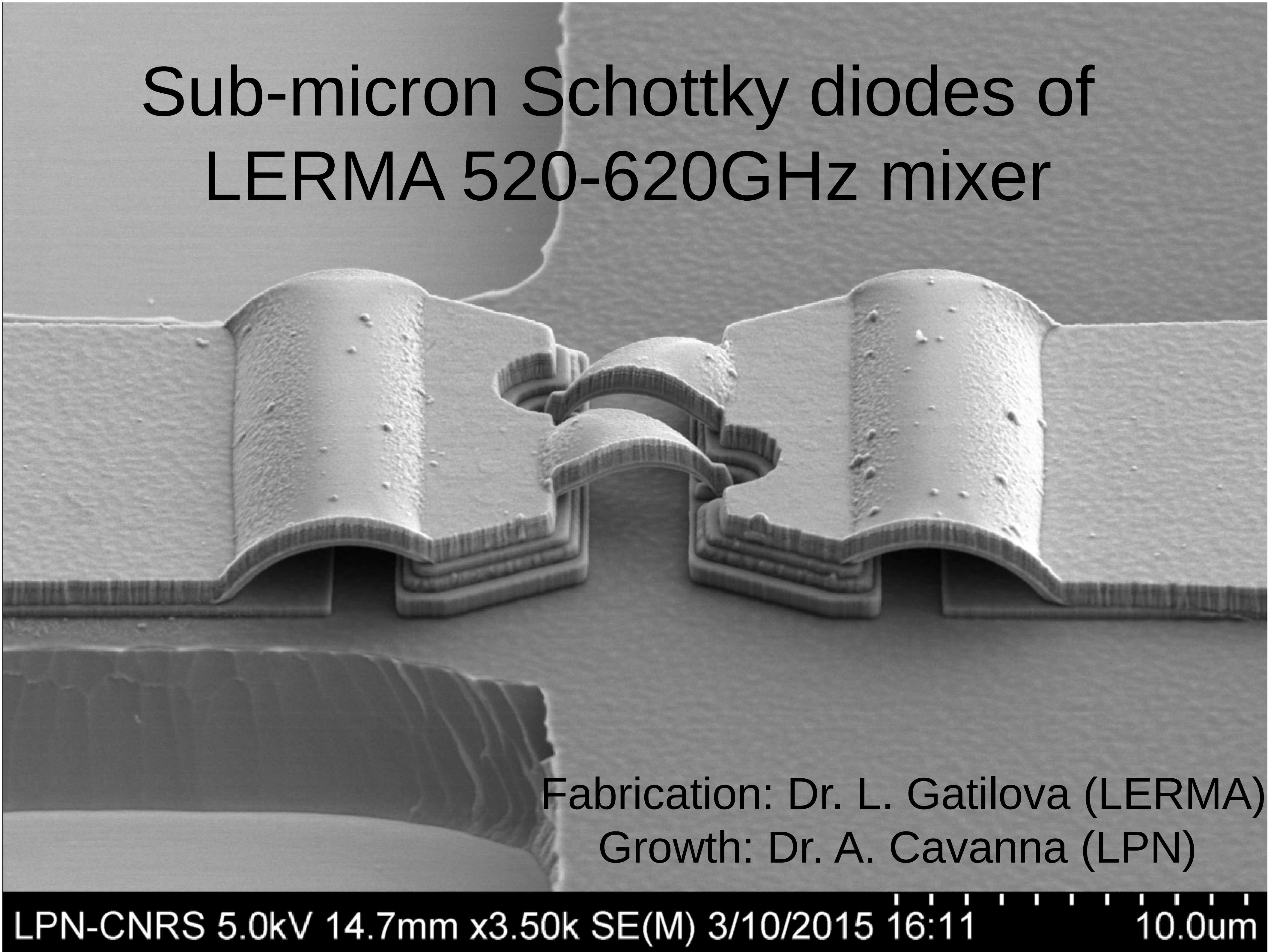
With Miteq 4-8GHz AFS4-0400 0800-07-10P (296K) / Low Noise Factory 1-12GHz LNF-LNC1_12A (134K) & 4.0-8.0GHz Intermediate Frequency Filter

No correction for water vapor absorption - 6.5cm (296K) / 3cm (134K) optical path in air

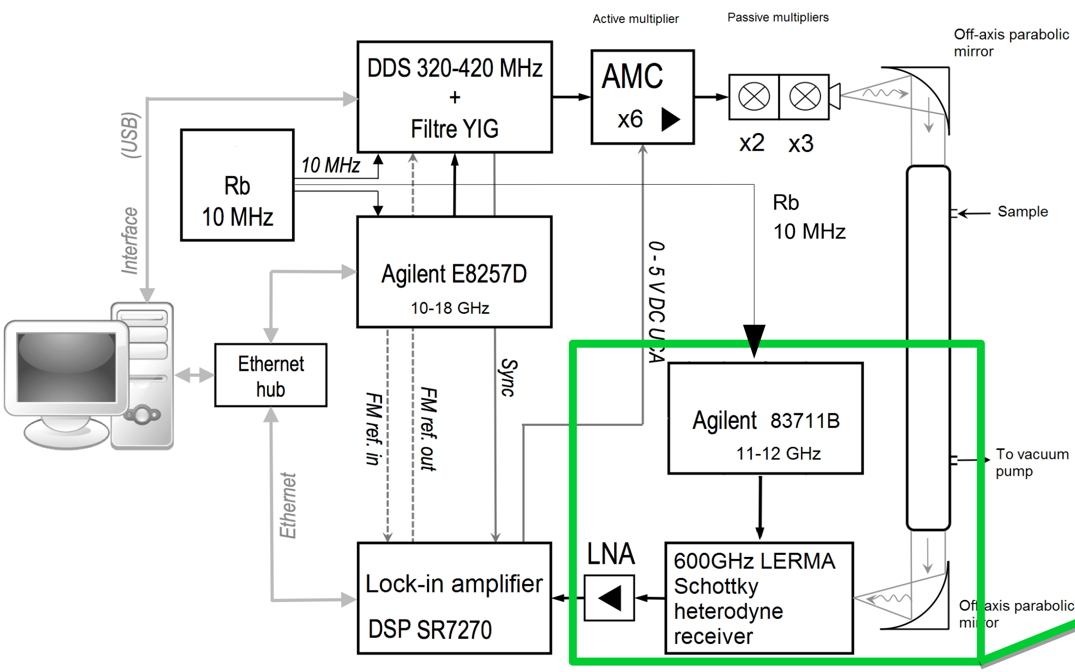


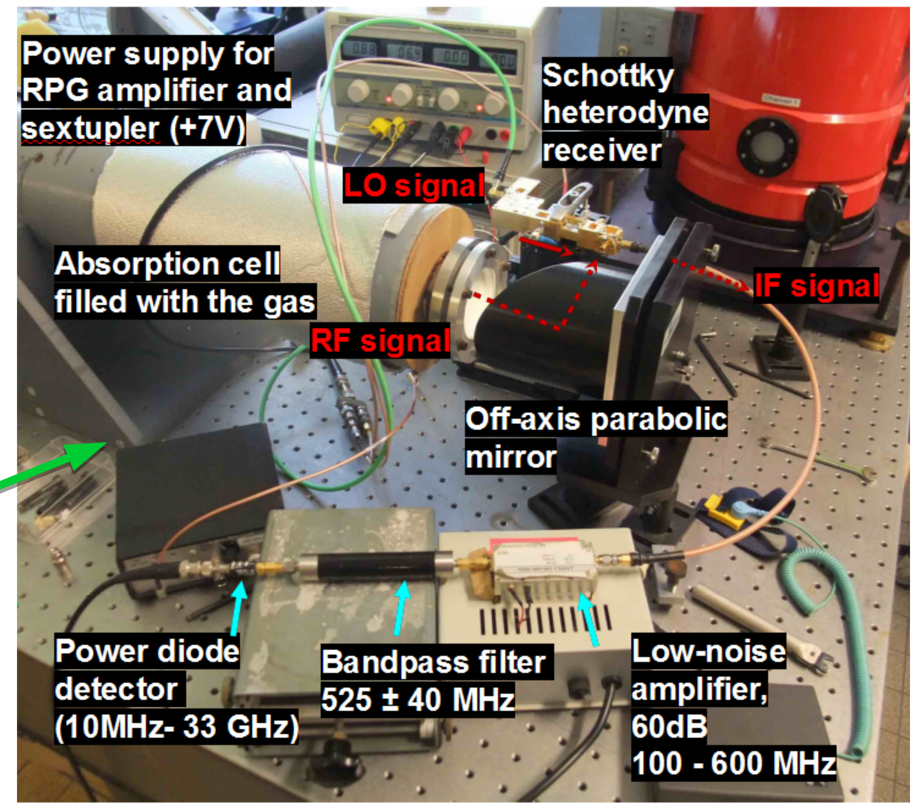
SHM600GHz SN03 Measured at LERMA by F. Tamazouzt, A. Féret, A. Maestrini, Diego Moro Melgar & Raffaello Ferone - April-September 2015

Sub-micron Schottky diodes of LERMA 520-620GHz mixer



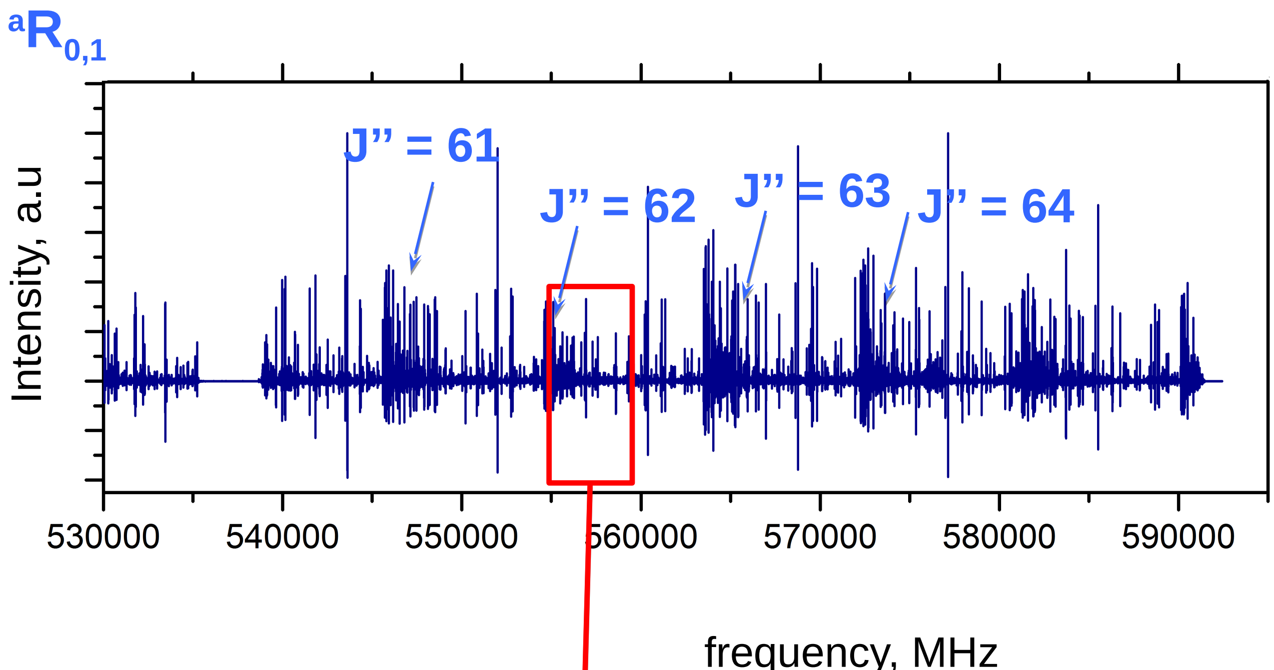
Heterodyne fast-scan all solid state DDS Lille's spectrometer (test setup)





Front-end of a 530-590 GHz heterodyne spectrometer in PhLAM, Lille.

Spectroscopy of CH_3CH_2CN with 530-590 GHz Schottky receiver – tests on 14/02/2017

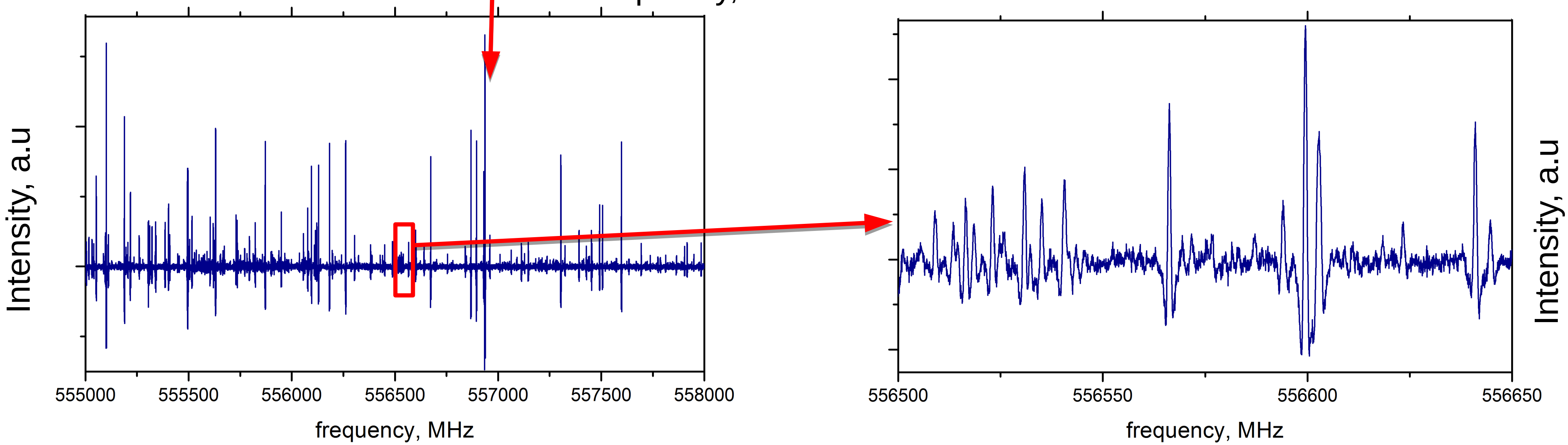


Experimental conditions:

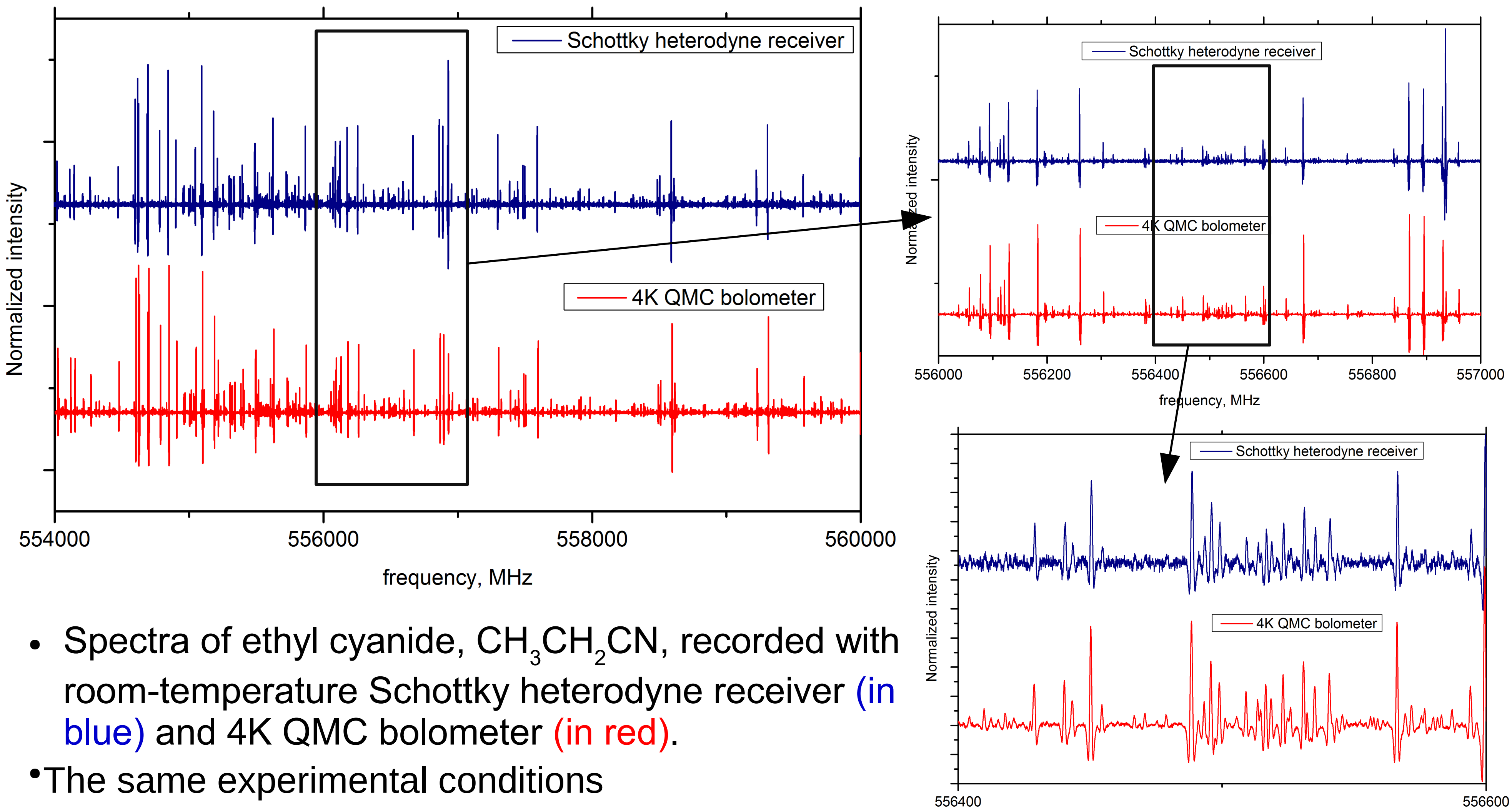
frequency step 81 kHz ;

60 GHz spectra is recorded in 52 min ;

Measurement rate : 1 ms/point
740000 points



Schottky heterodyne receiver sensitivity in comparison with 4K QMC bolometer in 600 GHz frequency range – preliminary results



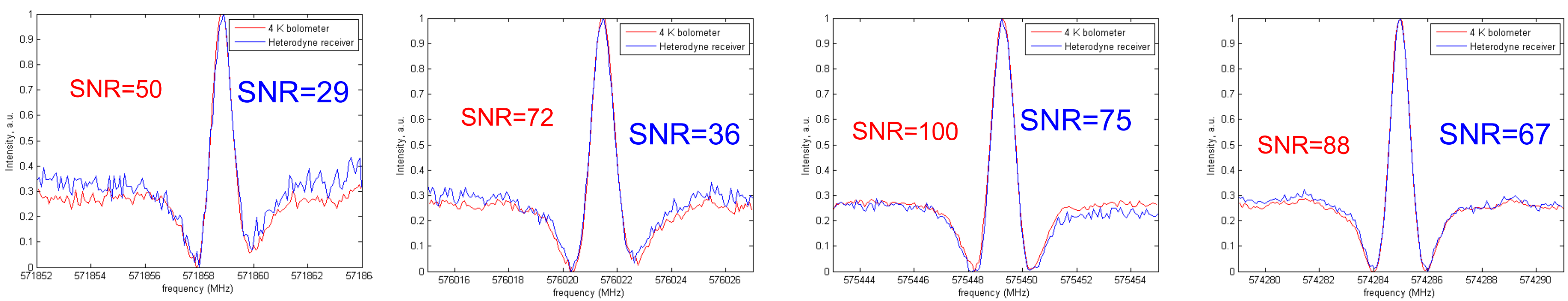
- Spectra of ethyl cyanide, CH_3CH_2CN, recorded with room-temperature Schottky heterodyne receiver (in blue) and 4K QMC bolometer (in red).
- The same experimental conditions
- Even with this sensitivity we can use Schottky heterodyne receiver (which is not in its final configuration) for high-resolution laboratory spectroscopy.

Schottky heterodyne receiver sensitivity in comparison with 4K QMC bolometer in 600 GHz frequency range – <u>preliminary results</u>

To compare the sensitivity of QMC bolometer and Schottky heterodyne receiver, we calculated the Singal-to-noise ratio, which we took as a ratio between signal maximum intensity (normalized) of a molecular line, and noise standard deviation.

$$SNR = \frac{Signal\ (max)}{noise\ (std)}$$

SNR (4K bolometer) /SNR (Schottky heterodyne receiver)~2.00



Some of the observed transitions of CH_3CH_2CN, recorded with 4K QMC bolometer (in red) and non-cryogenic Schottky heterodyne receiver (in blue), are given with calculated SNR.

Schottky heterodyne receiver provide the same order of SNR as QMC bolometer in 600 GHz frequency range, but in addition it operates at a room temperature → **no helium needed!**

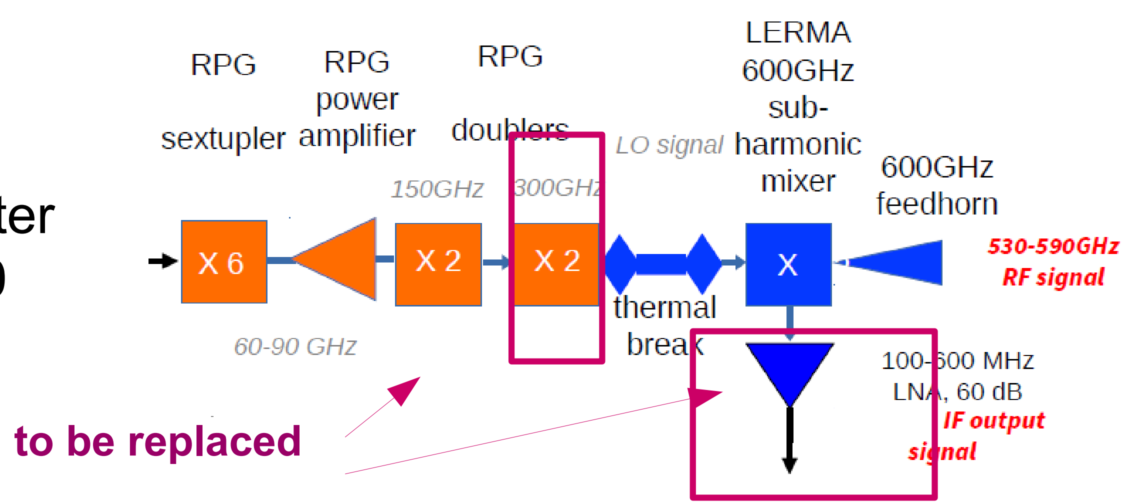
Conclusions

- A prototype of a Schottky heterodyne receiver for JUICE-SWI, has been implemented for laboratory spectroscopy of with Lille's Fast-Scan DDS Spectrometer.

- Room-temp. Schottky receiver's (not in the final configuration) sensitivity is comparable with 4K InSb QMC bolometer (relative SNR is only a factor of 2!)

Future prospectives:

- Test a Schottky receiver in final configuration of the Local oscillator chain: use (buy) components with better performances: LERMA 300 GHz doubler, Miteq IF amplifier, K&L filter.



Acknowledgements

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