AMSTAR*

Advanced Millimeter and Submillimeter Techniques for Astronomical Research

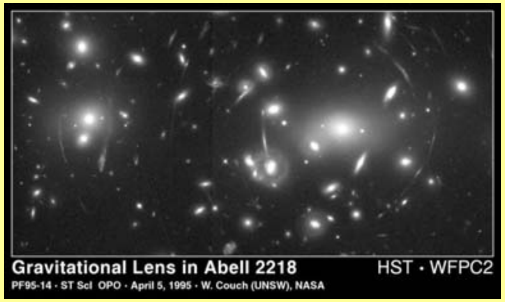
Goals and achievements during the period January 2004 – January 2006

RadioNet Mid Term Review,
Grenoble, Apr 2007

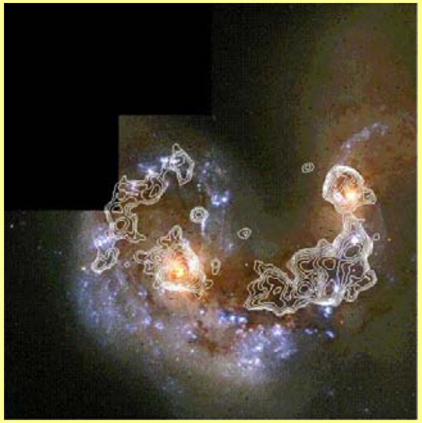
AMSTAR*: 1. goals, methods, actors

- *AMSTAR brings together Europe's foremost millimetre-wave engineering laboratories in a joint effort to improve the performance and frequency range of high frequency receivers for radio astronomy.*

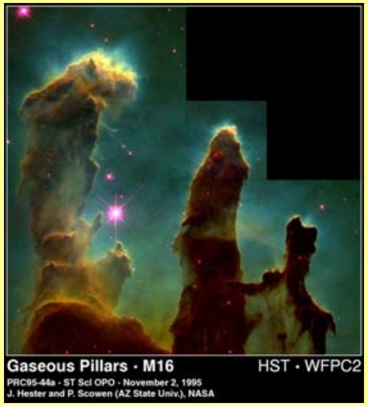
Goal: mm/submm radio astronomy



- A powerful tool for the study of the **evolution of stars and galaxies**.



- Enables to see through the cold, dense dust clouds that populate interstellar space.
- Such **dust clouds are the birth-places of stars and their planets**.



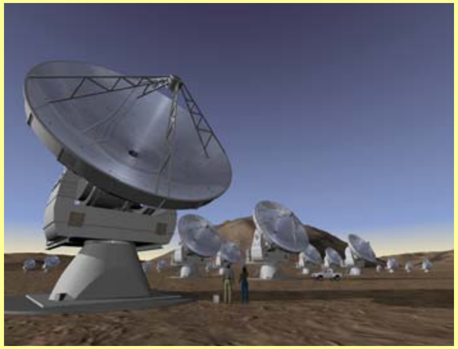
Europe's role in mm/submm radio astronomy

- Europe operates some of the **most powerful telescopes** operating in the mm/submm range
- It has built the **Herschel and Planck** submm space observatories
- It is one of the two main partners in **ALMA**

Plateau de Bure

Pico Veleta

APEX



ALMA

The actors

AMSTAR* federates 10 of the main European laboratories working on mm/submm receivers for astronomical applications: IRAM, MPIfR, SRON/ASTRON, Chalmers/OSO, KOSMA, Observatoire de Paris, RAL, TuDelft, FG-IGN

Technological needs and means

- The most crucial components of mm/submm telescopes are the **receivers front-ends** and, more specifically, the **radio-frequency mixers**, for heterodyne observations, and the **bolometers**, for direct detection.
- **AMSTAR** addresses technological solutions **micro/nano technologies** for planar circuits; **micromachining** of waveguide circuits; **quasi-optical** circuits and high frequency **LO**s

- **Wide IF-band Superconductor-Isolator-Superconductor (SIS) junction mixers for high sensitivity heterodyne observations**. Our goal is to develop several prototype receivers with the largest possible instantaneous bandwidths with little or no degradation of the receiver noise. The development involves special microelectronic processing techniques in the fabrication of the mixer chip.
- **Side-band separation mixers for heterodyne observations at submm wavelengths**. These so-called 2SB receivers combine two SIS mixers into a network and phase their outputs in such a way that it becomes possible to separate image and signal side-bands into different outputs. This type of receiver filters out the sky noise from the unwanted sideband (line work) while both sidebands may be connected to increase the bandwidth. Our goal is to develop the technique for the frequencies for the frequencies higher than 200 GHz, where the atmospheric noise is greater.
- **Hot Electron Bolometers (HEB) mixers for observations above 1 THz.** HEB mixers constitute the most promising technology for heterodyne astronomical observations above 1 THz. They consist of a thin superconducting bridge centred at a normal-metal antenna. The mixing takes place when two THz signals heat the bridge and form a hot spot, the size of which oscillates at their beat frequency. Our goal is to explore different technical solutions that will help getting a deeper understanding of these device physics and will improve their performances. This will demand in particular the development of ultra-thin films.
- **Focal plane arrays receivers for mm/submm observations**: Most mm/submm receivers detect the astronomical signals from only one pixel in the focal plane. The goal here is to develop novel technical solutions for both heterodyne and continuum receivers that would allow to build large focal plane arrays. The heterodyne system will invoke a photonic local oscillator (laser) illuminating an array of photodiodes, each integrated with an SIS mixer. Bolometric detectors will be also developed for continuum observations.

AMSTAR: 4 main workpackages; 12 subpackages

- **Wide IF-band Superconductor-Isolator-Superconductor (SIS) junction mixers for high sensitivity heterodyne observations**.
  - **WP 2.1.1 Wide IF-band mixer: 80-116 GHz (IRAM)**
  - **WP 2.1.2 Wide IF-band SIS mixer : 385-500 GHz (OSO)**
  - **WP 2.1.3. Wide IF-band SIS Mixers: 600-720 GHz and above (SRON-TUD)**
  - **WP 2.1.4 HEMT amplifier development (FG-IGN).**

- **Side-band separation mixers for heterodyne observations at submm wavelengths**.
  - **WP 2.2.1 2SB SIS Mixer : 350-470 GHz (KOSMA)**
  - **WP 2.2.2. 2SB SIS mixer: 600-720 GHz (SRON-TUD)**

- **Hot Electron Bolometers (HEB) mixers for observations above 1 THz.**
  - **WP 2.3.1. Phonon cooled HEB mixers (SRON-TUD)**
  - **WP 2.3.2 HEBs on Si3N4/SiO2 membranes (OBSParis)**
  - **WP 2.3.3**
  - **WP 2.3.4 Ultra-thin films for HEB mixers (IRAM-CRTBT)**

- **Focal plane arrays receivers for mm/submm observations**
  - **WP 2.4.1: Focal Plane Heterodyne Array Receiver (IRAM-RAL)**
  - **WP 2.4.2. Detectors for bolometer array (SRON-TUD)**

Working Methods & Deliverables

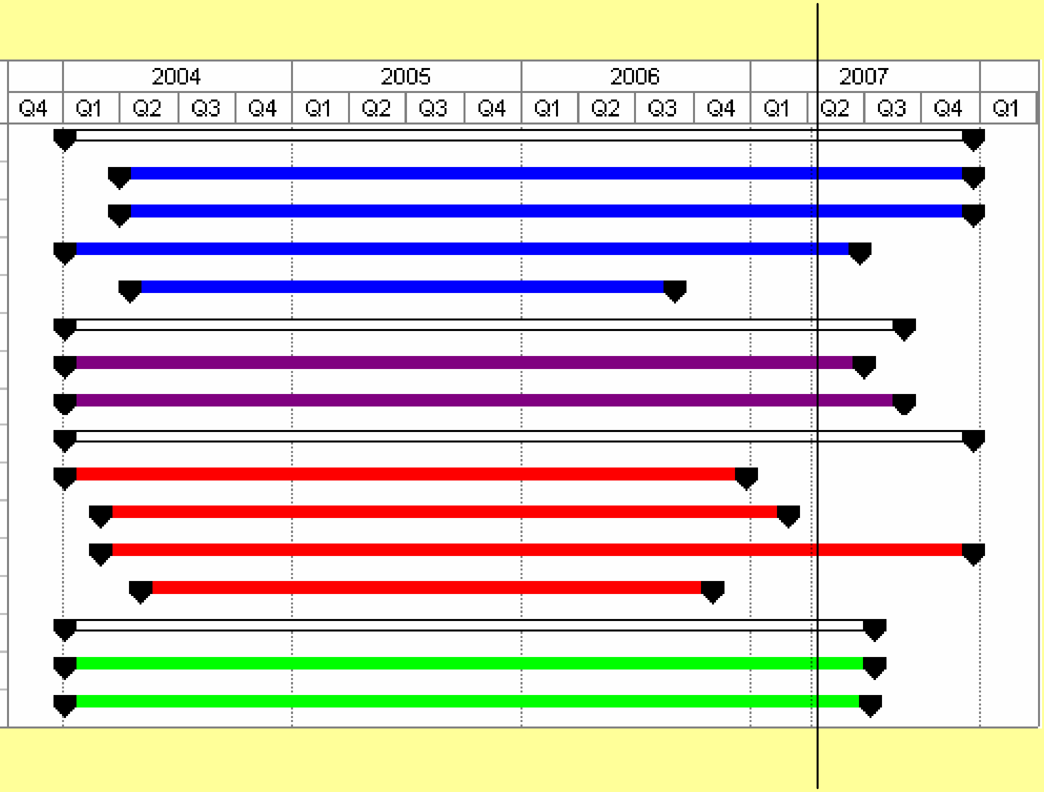
- 2 meetings each year (June and December) organized in turn by the participating institutes (RAL, IRAM, SRON, KOSMA, Chalmers, ObsParis,..)
- Progress reports issued twice a year for each of the 12 workpackges
- Common discussions on technical solutions. In some cases, exchanges of components
- Deliverables: Some prototypes. Reports on results. Design plans for duplication.

AMSTAR Status as of 31/03/07

- A large amount of work has been made since the beginning of AMSTAR (423 person-month, not counting staff of AC institutes).
- **Prototypes built**. Some in a phase of iteration aimed at getting the best performances.
- 60 publications (11 journal articles, 2 thesis, 47 confer. proceedings)
- All workpackages will be terminated by the end of 2007.

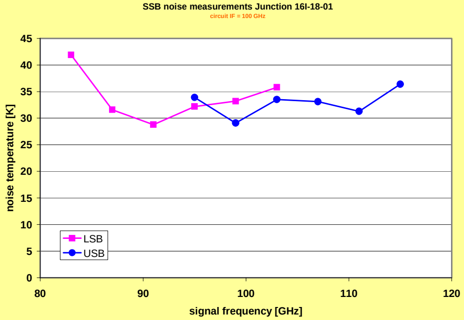
AMSTAR* timeline

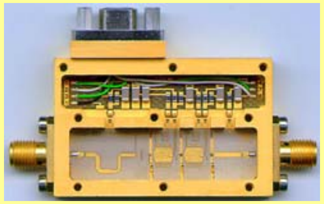
ID	Task Name
1	**Wide IF-band SIS mixers**
2	**2.1.1 Wide IF-band 3mm mixer**
13	**2.1.2 wide IF-band 0.6mm mixer**
23	**2.1.3 wide IF-band 0.5mm mixer (SRON)**
38	**2.1.4 HEMT amplifier devlopment**
44	**2SB SIS mixers**
45	**2.2.1 350 GHz 2SB mixer for FPA**
56	**2.2.2. 600-720 GHz 2SB mixer**
66	**HEB THz mixers**
67	**2.3.1. Phono-cooled HEBs**
80	**2.3.2. HEBs on Si3N4/SiO2 membranes**
85	**2.3.3. Balanced 1.3 GHz HEB mixer**
93	**2.3.4. Ultra-thin film HEB mixers**
103	**Focal Plane Array receivers**
104	**2.4.1 Heterodyne Array**
125	**2.4.2. bolometer array detectors (SRON)**



Main AMSTAR Results (& Plans)- I

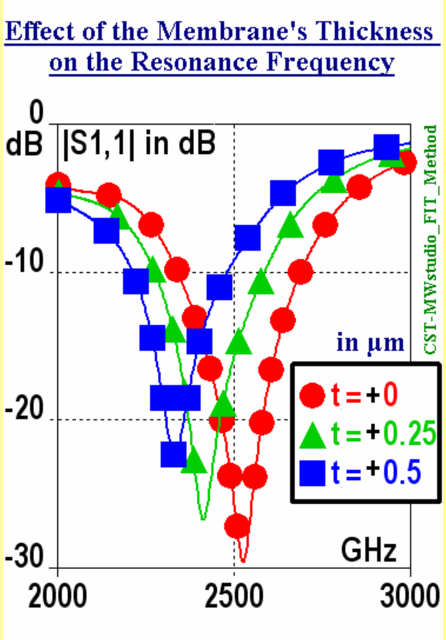
- **SIS mixers**
  - First 3-mm SSB mixers with 4 GHz-wide IF band derived from prototype **in operation on IRAM interferometer**. Noise similar to or lower than ALMA specs. Development of 8 GHz-wide band 2SB prototype mixer.
  - 0.5 mm prototype DSB mixer built according to OSO design and tested (200 K). SSB mixer in construction.
  - First 2SB prototype mixer operating at 0.4 mm built and being tested. SSB Receiver noise 300 K. Rejection >7dB.
  - Two 4-8 GHz and two 4-12 GHz low noise cryogenic amplifiers developed and delivered.





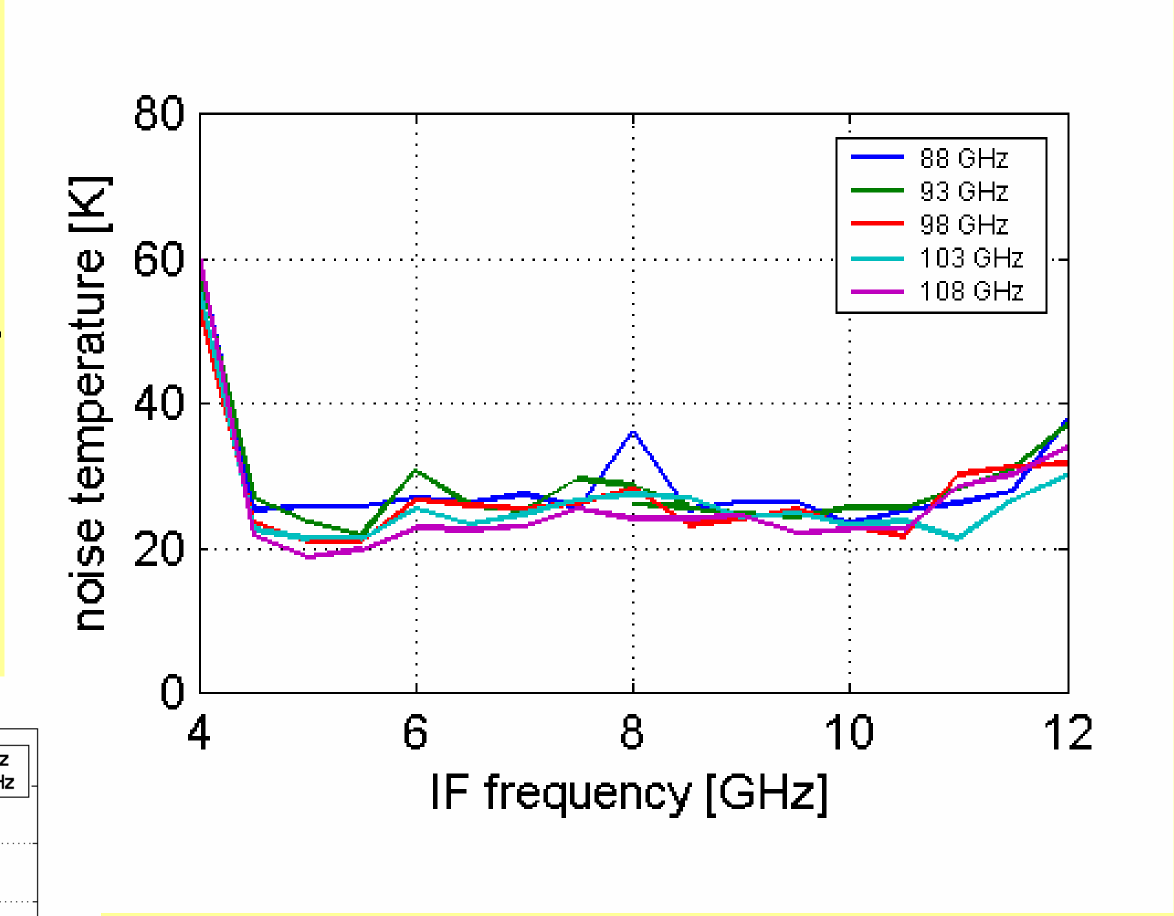
Main AMSTAR Results (& Plans) - II

- **HEB mixers**
  - First demonstration of a all solid-state HEB mixer receiver above 2 THz.
  - Effect of membrane nature and thickness studied
  - Structure of ultra-thin films investigated at ESRF

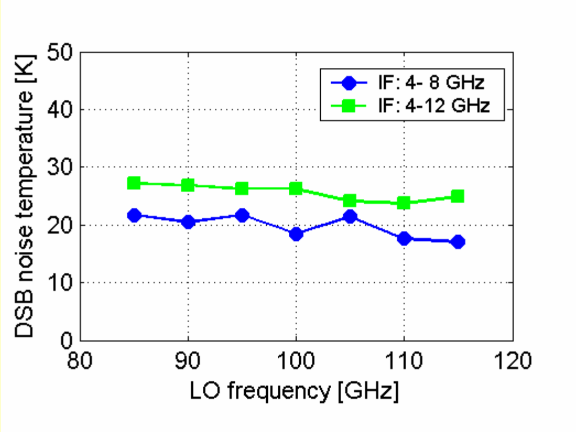


- **Focal Plane Arrays**
  - First tests of SIS mixer with photonic LO. 4 element test array of SIS mixers built. Their performances tested with conventional LO are good. First tests of complete system done. Tests on telescope planned

Excepts from 2007 results: WP 2.1.1
8 GHz-Wide IF band SIS mixer @ 3mm



<u>IF bandwidth reaches 9% of RF @88 GHz</u>



<u>See demo</u>

Excerpts from results (WP 2.1.2): 0.5 mm Wideband Mixer

The mixer chip with on-chip integrated local oscillator (LO) injection was fabricated in-house by in the Chalmers MC2 clean room facility. First DSB measurements yielded a Trec (DSB)=200 K.

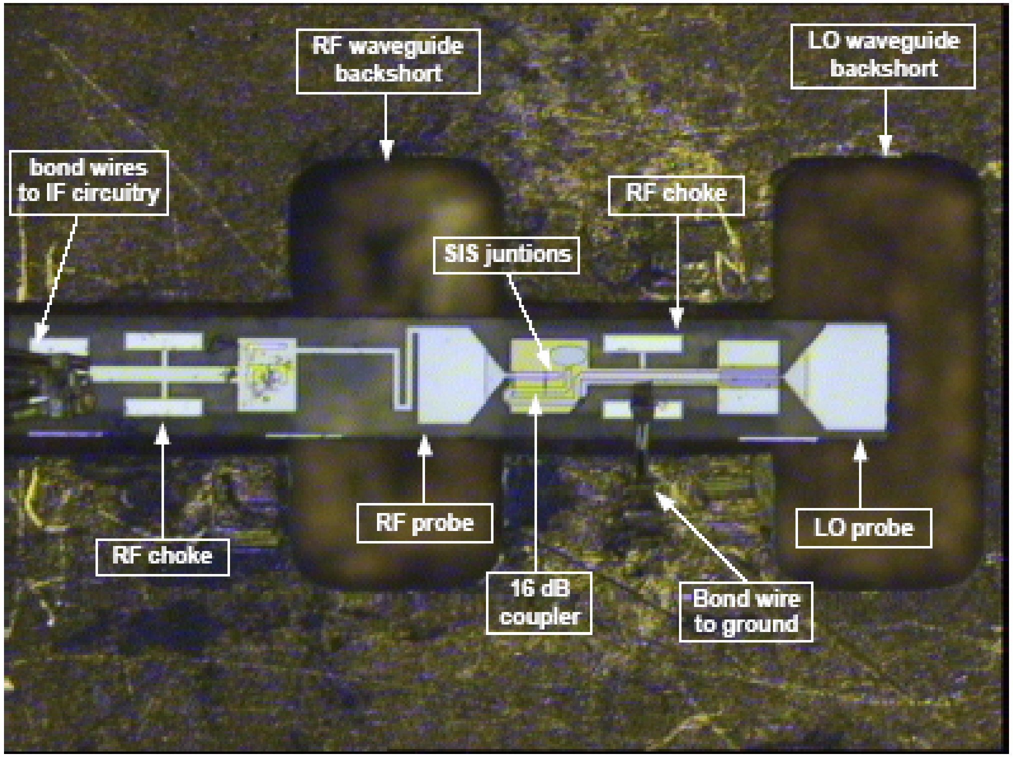
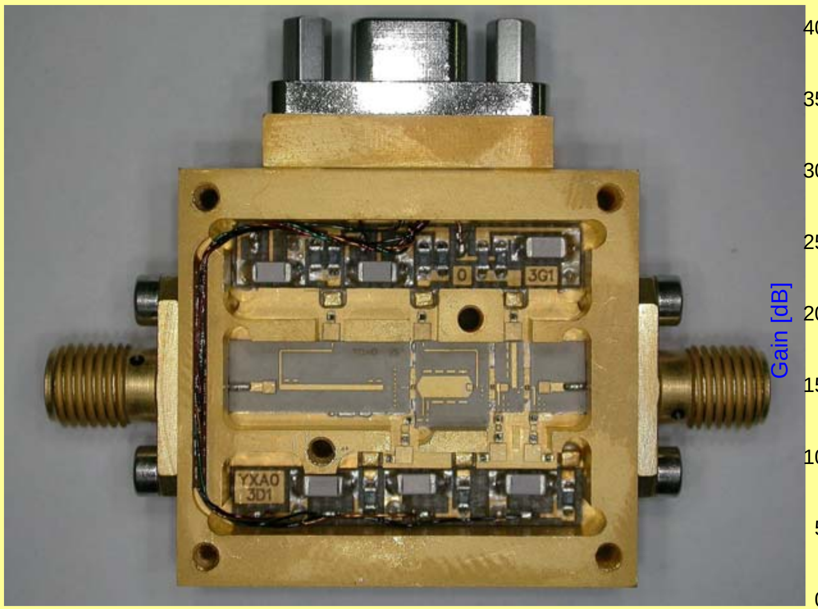
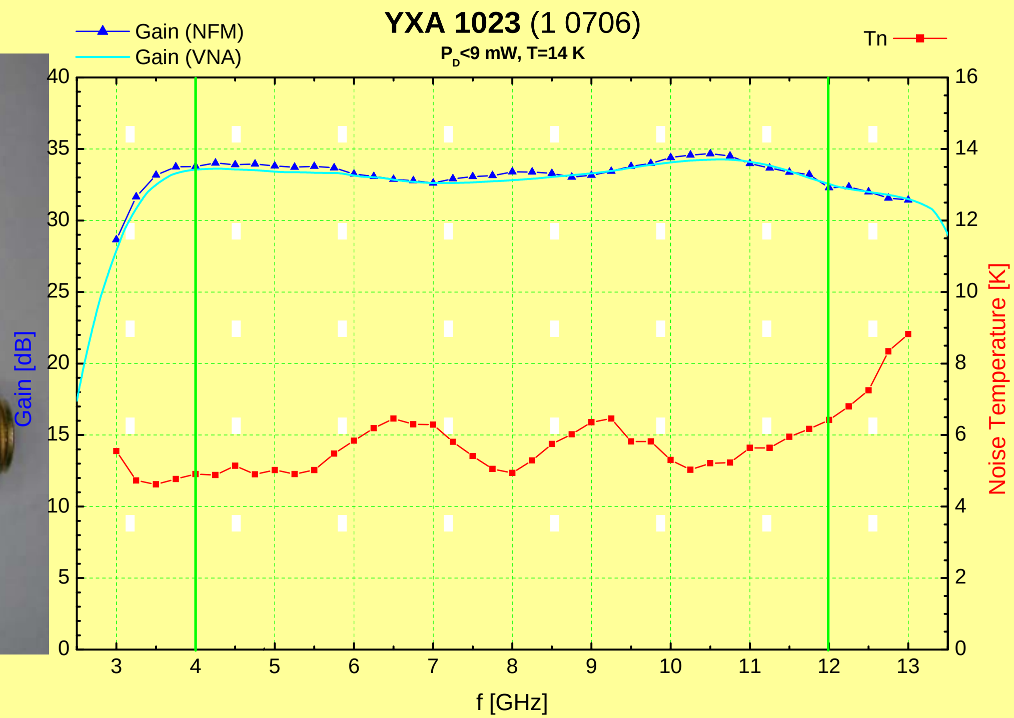


Fig. 1. Mixer chip layout.

A sideband separation (SSB) mixer, which consist of two mixers and an RF 90-degrees 3-dB hybrid and the LO power divider is being manufactured.

Excepts from recent results (WP 2.1.4)
4 -12 GHz Cryogenic Amplifier





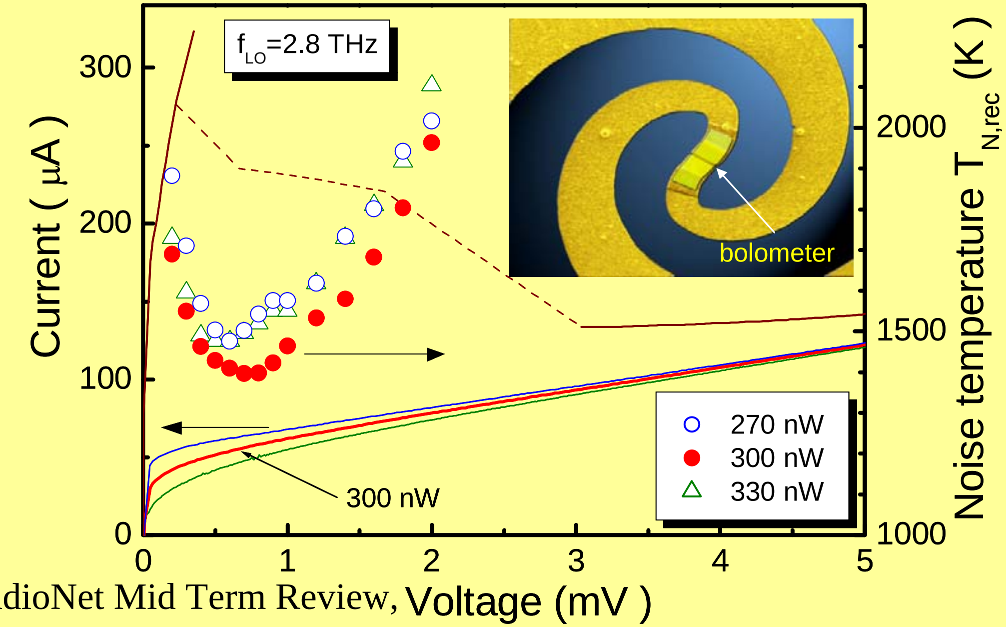
Measured performance of amplifier YXA 1023 **(FG-IGN)** at cryogenic temperature. The average noise temperature in the band is 5.6 K. The input reflection is better than -3 dB and the output reflection better than -15.5 dB. The other fabricated units have very similar results. **One such LNA is integrated in the demo of WP 2.1.1.**

Excerpts from results (WP 2.3.1):

Phonon-cooled HEB mixer with a quantum cascade laser (QCL) LO

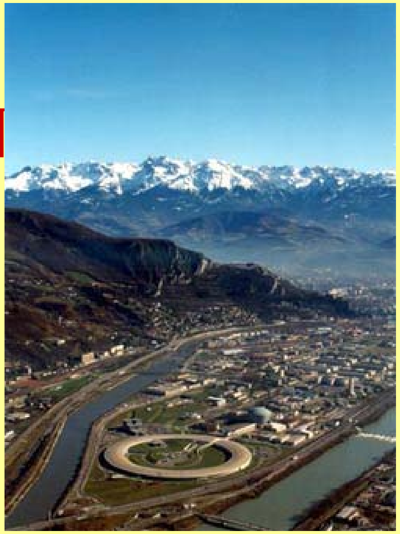
First demonstration of an all solid-state heterodyne receiver for spectroscopy above 2 THz. The receiver uses a NbN HEB as mixer and a QCL operating at 2.8 THz as LO. The Noise temperature is T_N=1400 K @ 2.8 THz and a physical temperature of 4.2 K.

Figure: Measured receiver noise temperature $T_{N, rec}$ versus the bias voltage for different LO power levels at the HEB mixer without and with radiation from the QCL at 2.814 THz

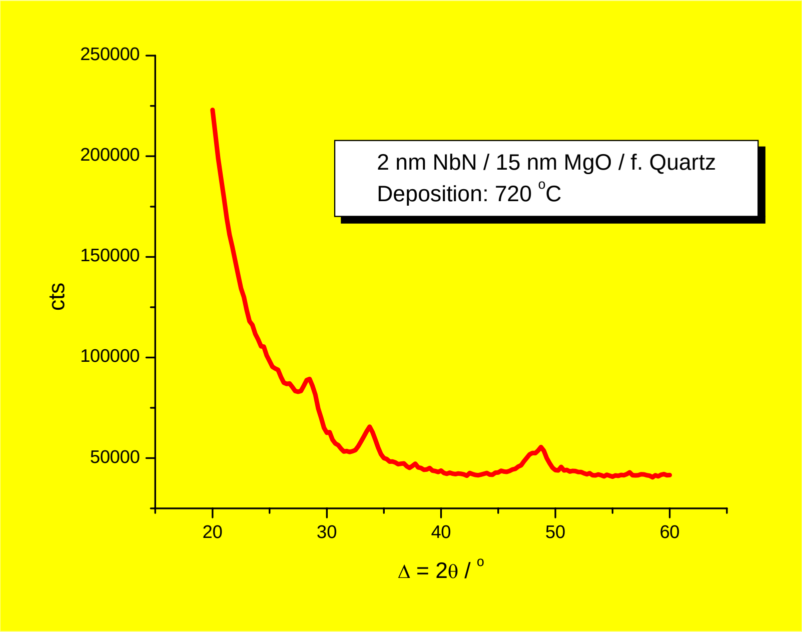


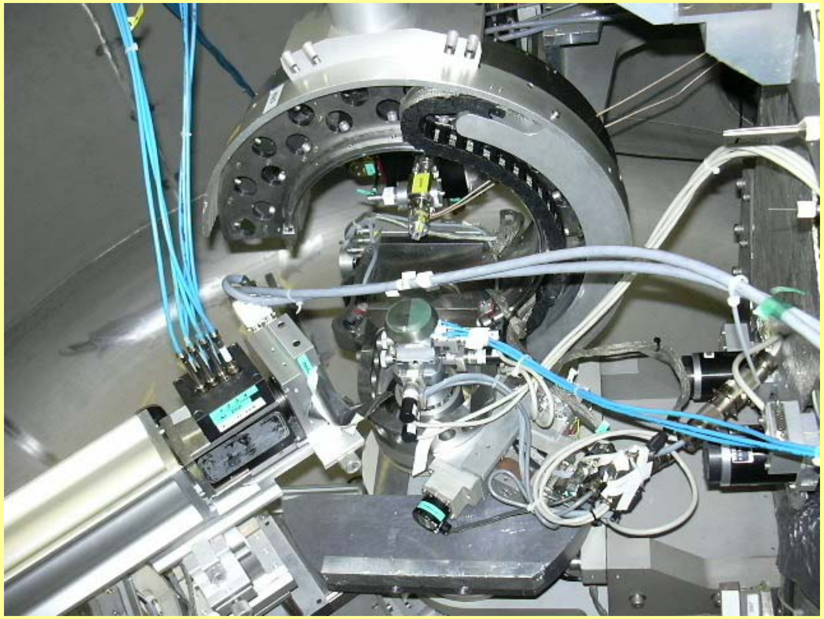
Excerpts from results (WP 2.3.4):

Small angle X-Ray scattering of ultra-thin NbN films using synchrotron radiation @ the European Synchrotron Radiation Facility



ESRF (Grenoble)





Left Figure: Small angle X-Ray scattering of ultra-thin NbN films using synchrotron radiation

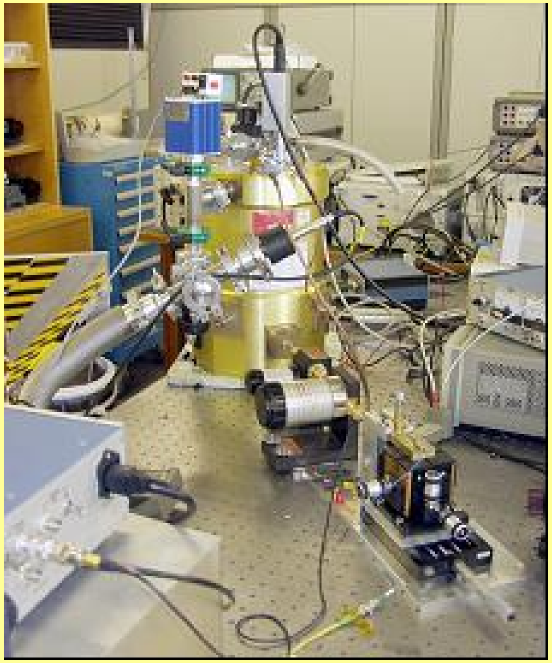
Excerpts from recent results (WP.2.4.1):

Array of SIS mixer receivers driven by photonic LOs

Four pixel-RF module, comprising corrugated horns (front), LO coupler (middle), DSB mixer blocks (left rear) and photomixer (rear right).
Right: 4-pixel module inserted in the demonstration cryostat

Excerpts from recent results (WP.2.4.1):

Results for the Array of SIS mixer receivers driven by photonic LOs



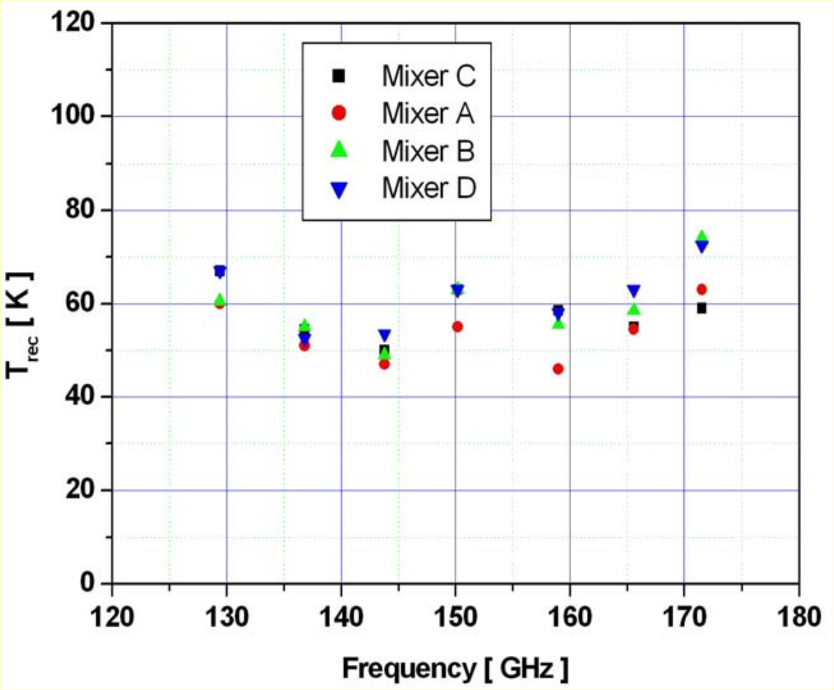
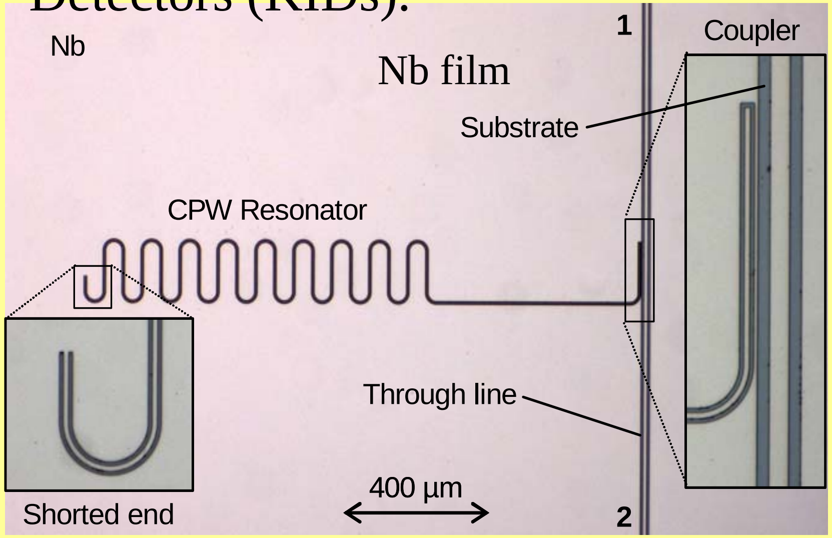


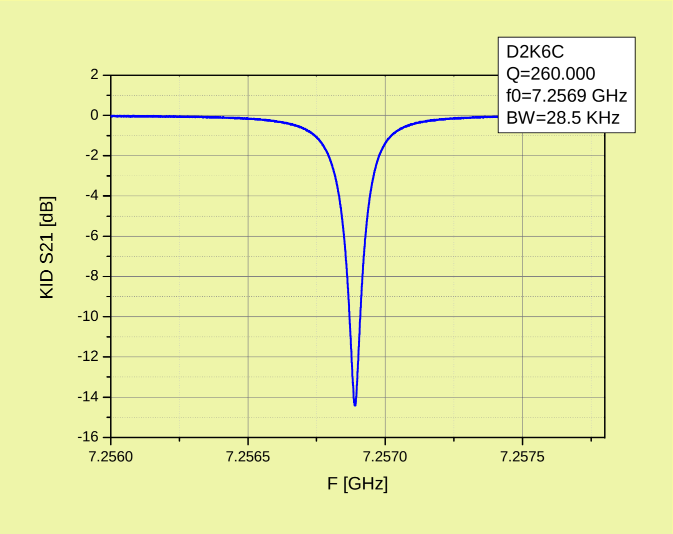
Figure: Noise performance of 4-pixel SIS mixer array pumped a by cooled photomixer (first test, RAL/IRAM)

(See live demo)

Excerpts from recent results (WP.2.4.2):

Goal: Novel solution for the construction of inexpensive detectors fitted for large-format bolometer arrays, namely superconducting Kinetic Inductance Detectors (KIDs).





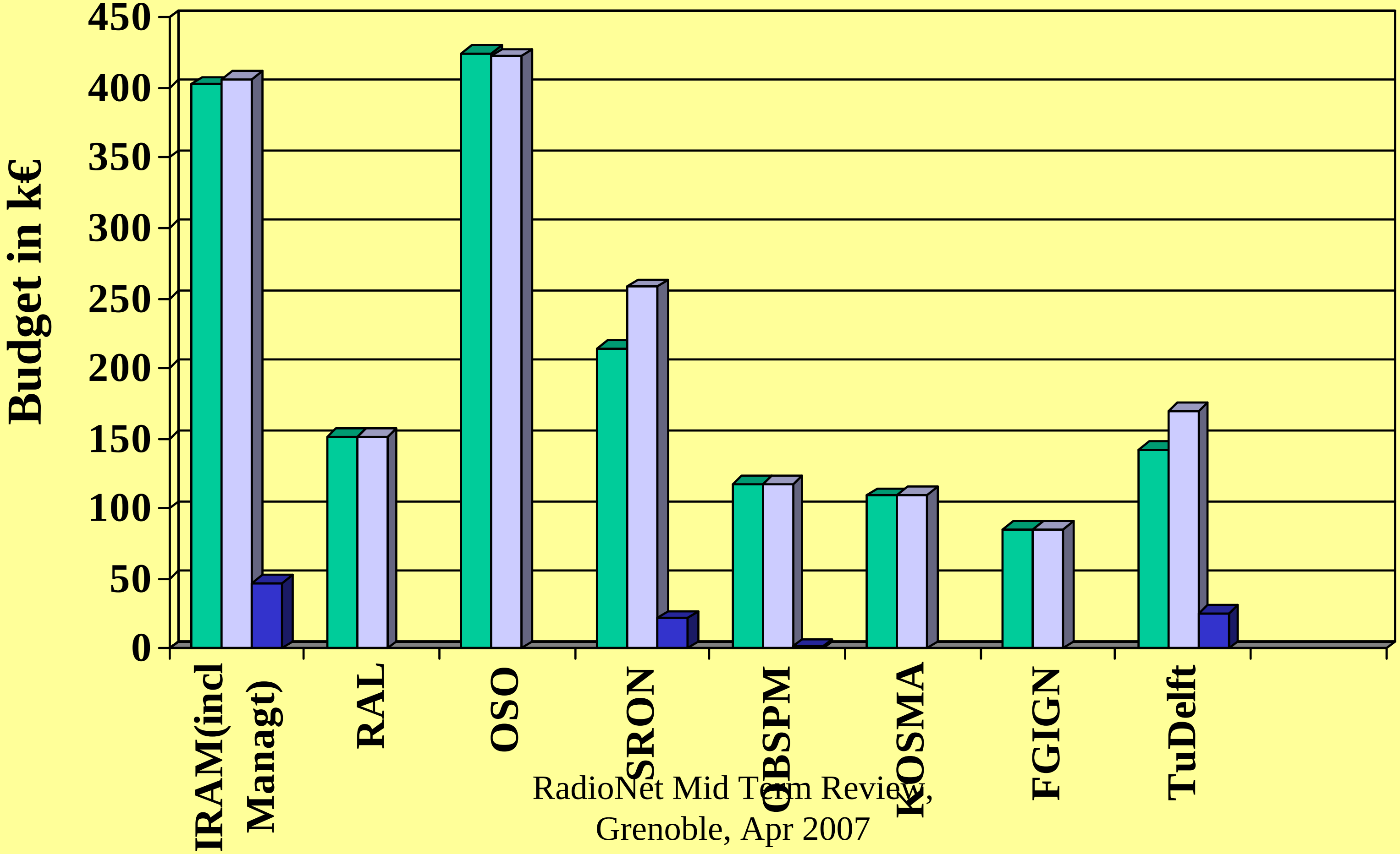
Left: Coplanar Waveguide Transmission (CPW) resonator structure built at TuDelft and a zoom of the part of a Nb resonator.

Right: The measured resonance at 7.2 GHz and around 300 mK.

Workpackage	**Initial Goal**	**Status (03/07)**	**Comments**
WP 2.1.1	IF band >3% RF	achieved	Go to 9% IF band
WP 2.1.2	2SB mixer @0.6mm	DSB proto made	Go to 2SB
WP 2.1.3	DSB mixer @0.5mm	achieved	Go to 0.4 mm
WP 2.1.4	2 LNA units 4-8 GHz	delivered	2 LNA 4-12 GHz
WP 2.2.1	SIS mix@0.8mm for FPA	Only parts made	Lack of manpower
WP 2.2.2	2SB @0.5 mm	1st Proto made	Being improved
WP 2.3.1	2.8 THz HEB mixer	achieved	T(DSB)= 1050 K
WP 2.3.2	HEB on membranes	Test performed	Wide band not achieved
WP 2.3.3	1.3 THz balanced HEB	1st proto	Not satisfactory
WP 2.3.4	Thin film properties	Tests made	Raman @ ESRF
WP 2.4.1	FPA with photonic LO	Built. Under test	Tests on telescope
WP 2.4.2	KID development	First devices built	

AMSTAR Budget breakdown as of Dec, 31st 2006:

- EC-contribution for 2004, 2005 and 2006 expenditures (Green)
- Original budget (light grey)
- Planned in 2007 (blue)



Budgetary considerations

- All groups had already spent (or almost spent) their budget by Dec 2006.
- Some groups have extended their activities to reach upgraded goals.
- Several groups will overspend their allocated budget by the end of the JRA