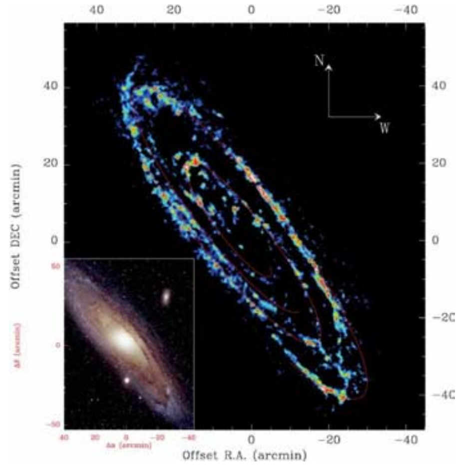
AMSTAR (Advanced Millimeter and Submillimeter Techniques for Astronomical Research)

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.



The Andromeda Galaxy (insert) observed in the J=1-0 line of CO with the Pico Veleta 30-m telescope.

Millimetre/submillimetre wavelength astronomy is a powerful tool for the study of the evolution of both stars and galaxies, enabling astronomers to see through the cold, dense dust clouds that populate interstellar space. Such dust clouds are the birth-places of stars and their planets. Their observation holds great promise for understanding

- *The formation of stars and their planetary systems in the Milky Way,*
- *Star formation in external galaxies,* which controls their evolution,
- *Early Universe research* **-** using the large European mm-wave telescopes, astronomers have shown that molecular lines and dust emission may be seen in regions of star formation with red-shifts as great as 6.4, so remote that they give us a glimpse of the Universe when it was but 10% of its present age.
- *Interstellar chemistry***-** understanding how interstellar molecules, in particular pre-biotic organic molecules, form and survive in interstellar clouds , a grand scheme for which the great Astrophysicist F. Hoyle had a stunning intuition in his science-fiction book *The Black Cloud.*

Such is the promise of this field of research that ESA will launch in 2007 a satellite (Herschel) devoted to mm/submm observations, and ESO, in collaboration with the United States and Japan, is building the Atacama Large Millimetre Array (ALMA), a giant array of ground-based telescopes in the high Andes of Northern Chile.

For now, European astronomers own the world largest and most powerful telescopes operating at mm/submm wavelengths. These are located in France, Spain, Sweden, Hawaii, and Chile. The receivers developed in the Joint Research Activity AMSTAR will be used on these telescopes, as well as in space. The highest frequency receivers will be used to extend the frequency range of millimetre astronomy to close the gap between radio and infrared wavelengths.

Left: the Plateau de Bure mm-wave interferometer (French Alps). **Right**: the new submm telescope APEX (Atacama, Chile)

Two kinds of receivers are used for astronomy at mm/submm wavelengths:

- Classical bolometer, where the radiant energy heats a thin metallic layer,
- Coherent heterodyne receivers that amplify the incoming signals before detection.

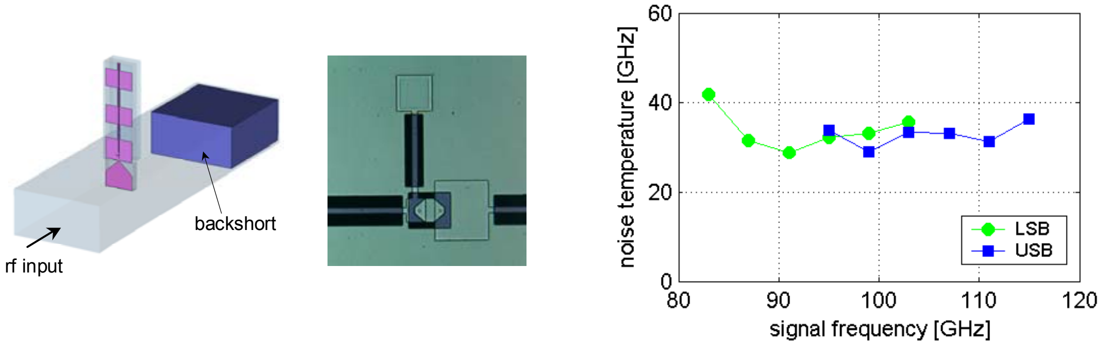
Classical bolometers have wide instantaneous bandwidths, but no spectral resolution; they can be very sensitive for detecting wide-band continuum signals but are not usable for spectroscopy or for instruments requiring phase coherence such as interferometers . The best results are obtained with detectors based on thin cryogenically cooled semi-conductor or superconductor thermometric elements.

Since low-noise amplification is difficult to achieve above 100 GHz, coherent mm/submm receivers use heterodyne down-conversion as the first step in signal processing. This is achieved in a low-noise mixer element, usually cooled to 4K, fed by a local oscillator (LO), that produces an intermediate frequency (IF) signal in the range 4-12 GHz. Up to 1 THz, the best results are obtained with SIS junctions consisting of two thin layers of superconducting metal separated by few nanometers of insulator. SIS mixers fall short of their performances above 1 THz and are replaced by Hot Electron Bolometer (HEB) mixers based on a superconducting bridge centred on a normal-metal antenna.

The most critical parts of mm/submm receivers are the multi-layer junctions or bolometers that are embedded in planar circuits or waveguide structures. Their dimensions can be as small as a fraction of a µm and their fabrication requires up to date micro/nano technologies, such as electron-beam lithography. Their operation requires extremely low temperatures (e.g. 0.1 K or 4 K), hence heavy cryogenic equipment.

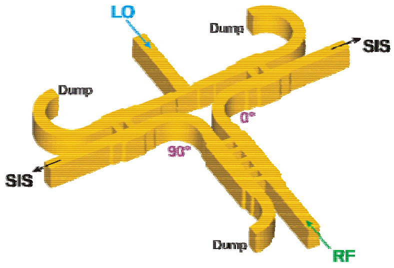
Class 100 Clean Room at IRAM for the fabrication of SIS junctions and HEBs

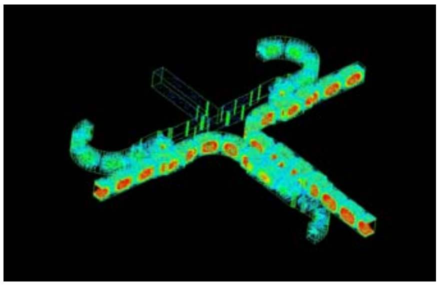
The main goals of AMSTAR are ***a)*** to develop SIS junction mixers with the largest possible instantaneous bandwidth and the lowest noise, operating through the frequency range 100-1000 GHz (3-mm to 0.3 mm wavelength), ***b)*** to get a deeper understanding of HEBs' physic and to improve their performances for astronomical applications in the range 1-4 THz, and ***c)*** to develop innovative solutions for the realization of multi-pixel heterodyne and bolometer receiver arrays.



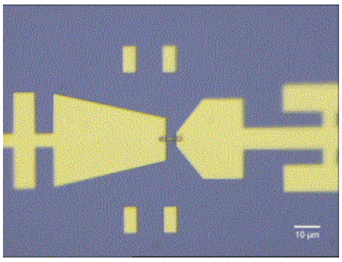
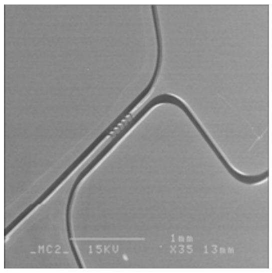
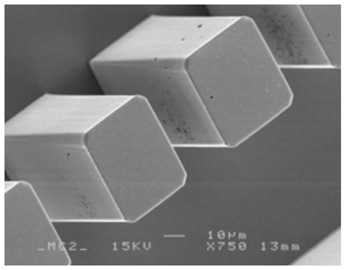
Wide IF-band SIS junction mixer for high sensitivity heterodyne observations in the 3-mm range (83-115 GHz). Left: Design of a waveguide to microstrip transition. **Middle**: Close-up of the junction tuning structure. **Right**: Noise measurements on a first prototype with a 4 GHz IF-bandwidth (IRAM). The mixer is equipped with a backshort that insures a high image sideband rejection. The HEMT 4-8 GHz preamplifier was developed by FG-IGN. The achieved receiver noise is below the specifications requested for the ALMA project.

Design of a 2-sideband SIS junction mixer block for heterodyne observations at 0.5 mm (600-720 GHz) and simulation of the electro-magnetic field generated by the incoming radio signal (SRON-TuD).





Hot Electron Bolometers (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. The figure shows two critical components of a balanced HEB mixer developed at OSO/Chalmers: the HEB mixer chip (left) and the 3 dB quadrature waveguide directional coupler providing LO injection and RF signal distribution (middle and right).

Focal plane array of SIS receivers driven by a photonic local oscillator. 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 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. The right figure shows the SIS junction and its matching circuit mounted in the mixer waveguide (IRAM) and the left figure a prototype photomixer developed at RAL.