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Latest Advances in THz Heterodyne Receivers for Space Probes

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The Herschel satellite (2009–2013) carried, besides two other instruments, the very successful Heterodyne Instrument for Far Infrared (HIFI) that opened the 480 to 1910 GHz window for observations of celestial sources. Since then, several satellite missions for astronomy using heterodyne receivers have been proposed and some very detailed studies for the NASA probe call are currently taking place. All build on the success of HIFI/Herschel but push the technology one step further. Some proposals aim for high spatial resolution and propose submm/THz interferometry either between space and ground or between two space satellites, such as THEZA or Millimetron. For these missions, accurate time keeping and position knowledge are essential. To compensate for the small collecting area in space, large frequency bandwidths are used. Recent SIS mixers have demonstrated 2 x ~20 GHz.

Other satellite missions desire mapping capabilities and suggest heterodyne arrays. These include Origins (proposal submitted to the US Astronomy Decadal Review 2020), the Millimetron mission, as well as mission studies submitted [but not selected] to the ESA M7 call) and two proposals for the US Probe: the Far Infrared Spectroscopy Space Telescope (FIRSST) and the Single Aperture Large Telescope for Universe Studies (SALTUS). The first heterodyne arrays have been built and demonstrated for ground-based telescopes, onboard the SOFIA aircraft and the STO balloons. The GUSTO (balloon mission scheduled for flight in December 2023) with 24 HEB mixers in 3 channels of 8 pixels each will further exploit the potential of heterodyne cameras. We have carried out the first detailed study of a heterodyne camera for Origins, the HEterodyne Receiver for Origins (HERO), and are in the process of adapting it for FIRSST. The biggest challenge is to keep the required cryogenic heat lift low. The first stage low noise amplifiers (LNAs) contribute the most to the cryogenic thermal budget. As the number of LNAs rises with the number of pixels in an array, we have selected very low heat dissipating SiGe amplifiers. In the HERO design they are connected directly to the mixers at 4.5K, for FIRSST we decided to move the amplifiers to the next warmer stage at 18K, at which temperature the cryocoolers can remove heat more easily. The other challenge is to keep the electrical power consumption low, which is dominated by the spectrometers for heterodyne array receivers. Standard DFT spectrometers for ground-based instruments consume ~70W per pixel. For a space mission that amount of power becomes prohibitive even for small arrays. We have therefore identified CMOS spectrometers as a very promising alternative. They only consume 1 to 2 W for 6 GHz bandwidth. They will be validated on the balloon experiment ASTHROS but need to be space qualified. Last but not least, the local oscillators need to be powerful enough to pump a whole array rather than an individual pixel. Fortunately, the Schottky multiplier technology has advanced tremendously in recent years, so that powerful multiplier chains up to nearly 3 THz are now available (e.g. JUICE 1.2 THz channel of SWI). The LO beam is then split into as many beams as pixels either in waveguide or via phase gratings.

For space interferometry or small to medium arrays (of few to tens of pixels) HIFI/Herschel components could be used for all other parts. However, there has been important progress since Herschel: Superconducting mixers have become much more sensitive, in particular, HEB mixers with noise temperatures below 500K have been demonstrated. An IF bandwidth of up to 7.5 GHz has been measured for HEB mixers, and their operation at 4.7 THz proven. Amplifier multiplier LOs have tuning ranges of ~30% and can be designed for 45% to 50%. The highest multiplier chain to date operates at 2.7 THz, but designs are taking place for 3.4 THz and 4.7 THz. An alternative LO is the Quantum Cascade Laser (QCL), which has already been optimized for use on an airplane, though the cooling resources required are still too large for satellite operation. In addition, prototypes of miniaturized IF chains with a tenth of the weight and size have been demonstrated.

In summary, with the recent developments we are now capable to build excellent single pixel and heterodyne array receivers for space and we are looking forward to provide another heterodyne instrument for astronomy.