FY23 Topic Areas Research and Technology Development (TRTD)

3D-HIFI: “A 3x On-Chip Diplexed Heterodyne Instrument for the Far-Infrared”

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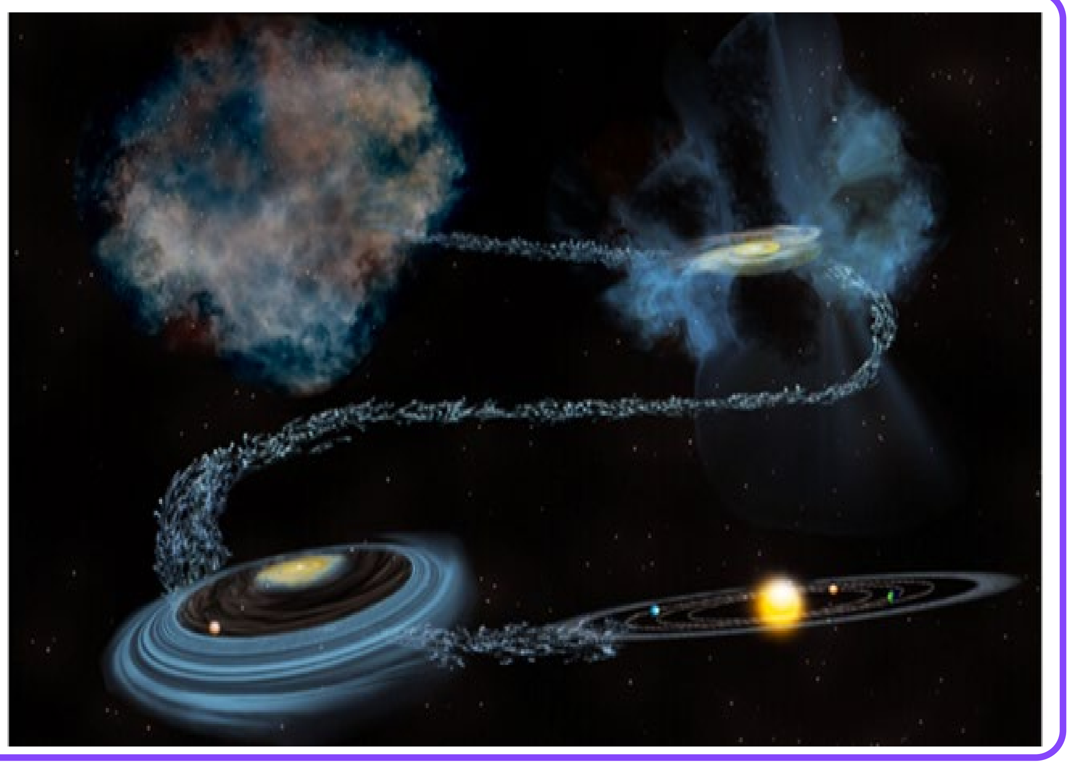
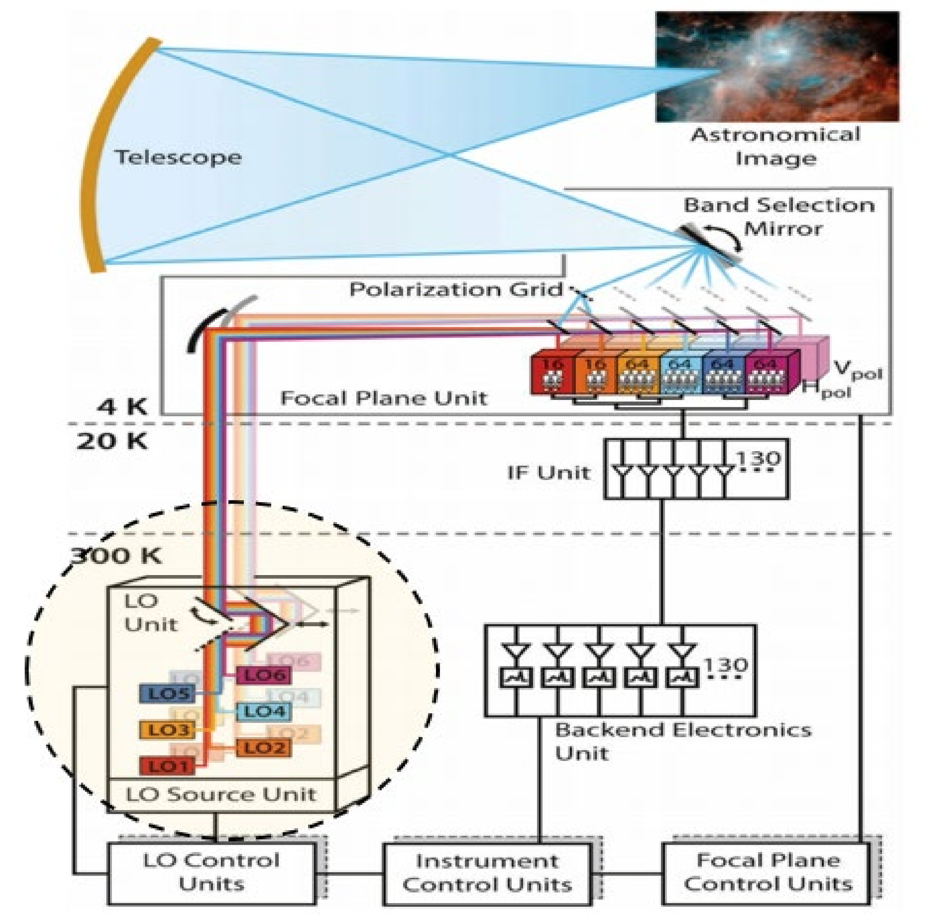
Strategic Focus Area: Direct/Coherent Detectors and Arrays

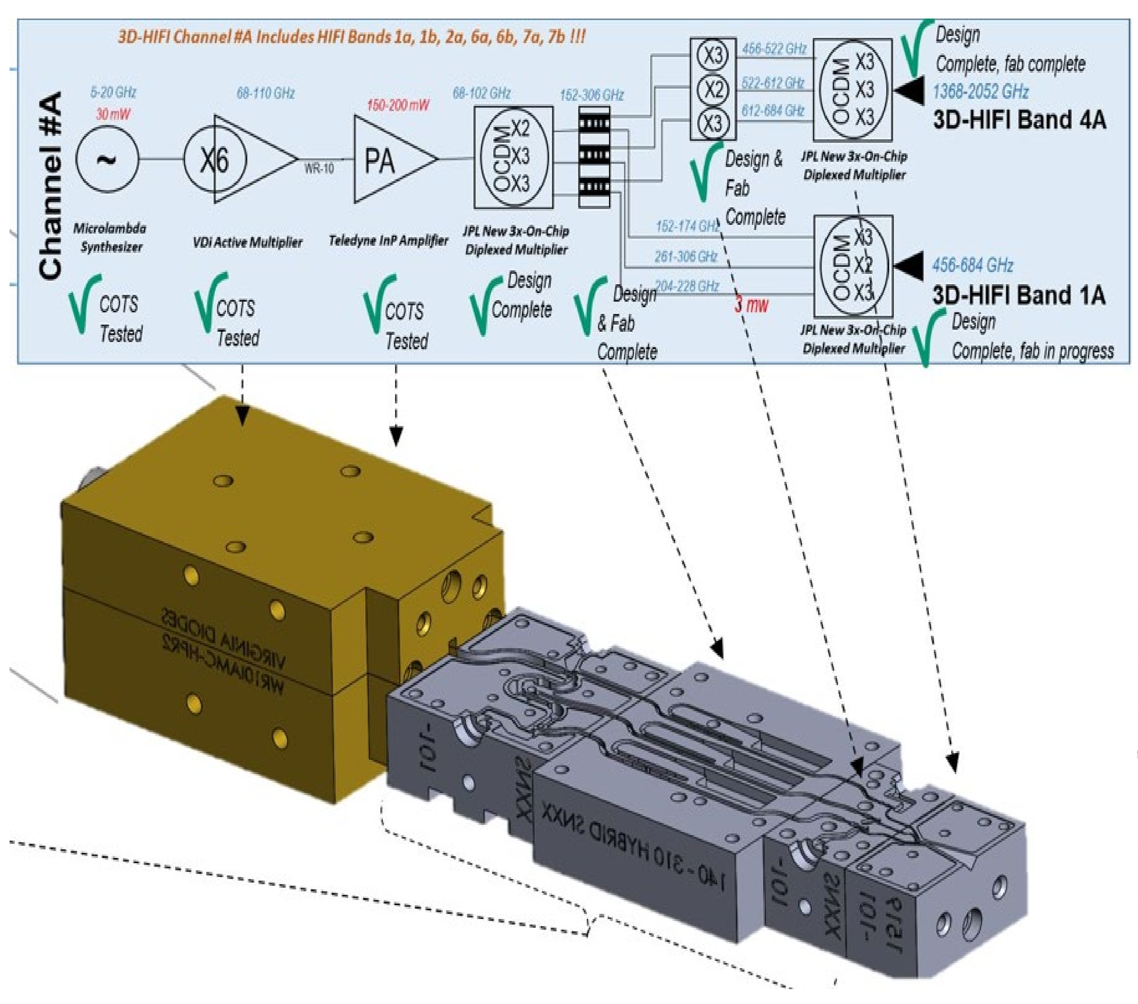
Background: Powered by the exceptional scientific findings from the HIFI instrument on Herschel, high-resolution (R>1E6) submillimeter-wave receivers continue to be essential to answer key questions in the Decadal Survey. Stars form in cores, which condense from interstellar clouds, and thereby incorporate material from their placental core. Part of this material stays in the protoplanetary disk surrounding the new star and eventually forming planets and smaller objects. The process is regulated by stellar feedback, e.g. winds from massive stars and supernova explosions that reshape these clouds. These violent outbursts can, over millions of years, disperse the surrounding material and significantly impede star formation, see figure. Without this feedback, all the available gas and dust in galaxies like our own would have coalesced into stars long ago. The dynamics of the different gas components of the ISM have to be measured with exquisite precision. Wind-resolved observations require high spectral resolution receivers tunable to each of the key tracers the govern these processes. Current heterodyne far infrared receivers are limited by RF bandwidth to ~10%. Future missions will require focal plane arrays covering the entire submillimeter- wave spectrum to observe these tracers, which is impossible with state-of-the-art heterodyne receivers.

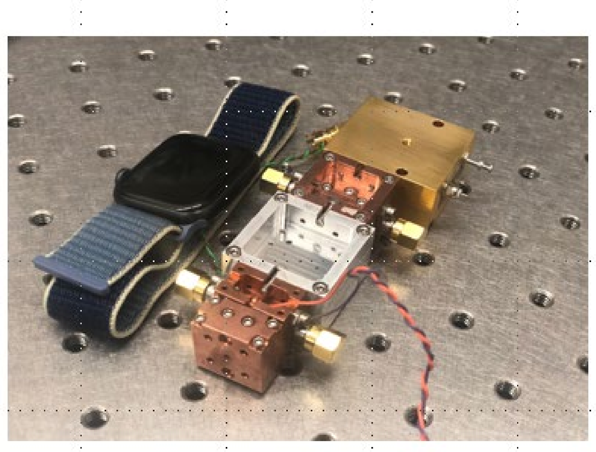


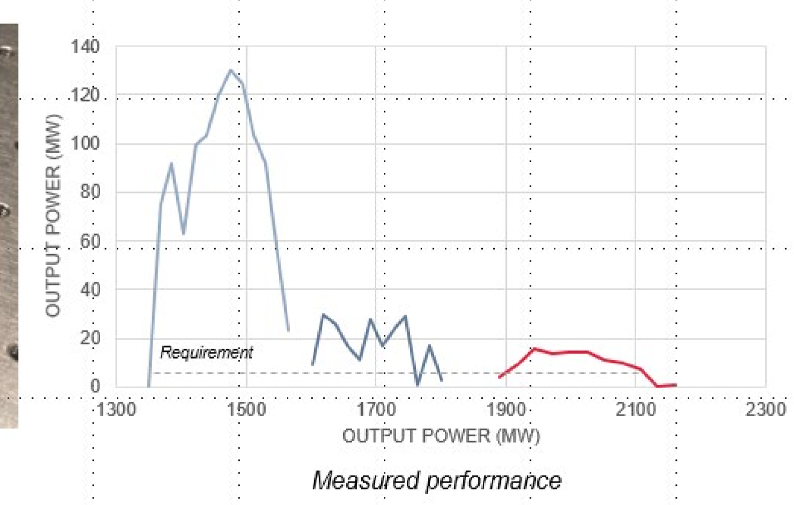
Objectives: A typical high-spectral resolution heterodyne receiver consists of an antenna, a frequency mixer (SIS or HEB), a Schottky based LO source, and the IF processor, see Fig. below. Primarily, the bottleneck is the RF bandwidth of the LO (~15% only). We propose to maximize the LO bandwidth up to the limit (full-band waveguide coverage, 40% RF bandwidth) by using a radically new concept consisting of on- chip diplexing three bands into one with a novel design in which a single frequency multiplier chip can cover three bands (3OCDM). With a thorough design of the multiplier diodes and matching circuitry, 3 different multiplier “cells” on a chip can work together as one, multiplying the he bandwidth by a factor for 3 (from 15 to 45%).

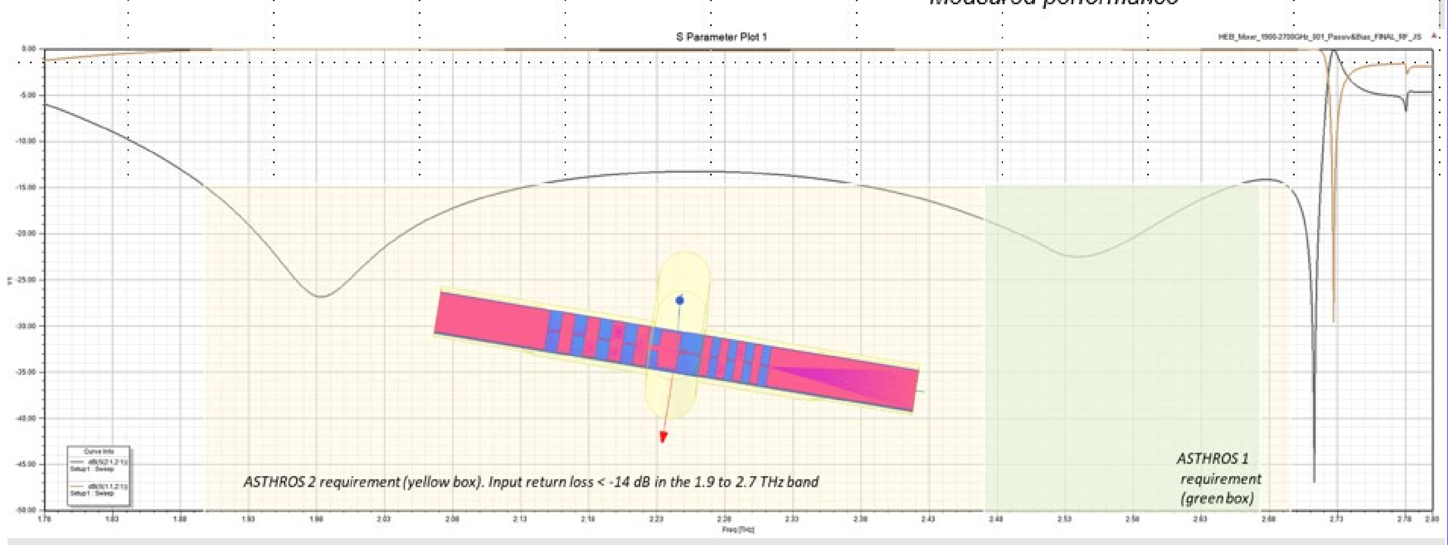


Objectives: The approach consisted in implementing a novel and very innovative “3x on-chip diplexed frequency multiplier” concept. It is based on a single-substrate multiplier chip with one third of the diodes tuned to the lower side of the target frequency band, and the rest tuned to the mid and upper part of the band, resulting in the on-chip diplexing and an increase in bandwidth from 10-15% (current state-of-the-art) to at least 40%. We take advantage of the broadband power amplifiers currently available (70-130 GHz InP Teledyne chips) to drive the JPL frequency multiplied LO chain featuring the novel 3x-on-chip diplexed JPL frequency multipliers (this work’s novel approach). The devices are based on the mature GaAs Schottky diode process developed at JPL. The circuit block diagram is shown in the figure below (left). For channel A, the 68-110 GHz is diplexed on the multiplier chips into three sub- bands. The 68-76 signals are multiplied X3X3X3, the 76-87 GHz signals are multiplied X2X3X3, and the 88-102 GHz inputs are multiplied X3X2X3. This yields a full coverage between 1368 GHz and 2052 GHz. The measured results are summarized in the figure below (right). This increases RF bandwidth of traditional multipliers by a factor of 3 (reaching full waveguide band operation without compromising conversion efficiency). A four-pixel version of such LO system has been also fabricated. In order to complete a full waveguide band receiver, we designed and fabricate HEB mixers providing full waveguide coverage to match the new LO system developed. The predicted performance is also shown below. Final tests are being done. Preliminary results show the mixer RF bandwidth is as expected. Regarding superconductive HEB mixers (for receivers > 1.2 THz), it is often claimed that quasi-optical mixers are









Significance of the results: 3D-HIFI will allow, with a single tunable receiver channel to cover all key tracers of star formation ([CII], [NII], water, OI, HD, OH, HDO, HF, HD, CO, etc.), by increasing the bandwidth of current receiver technology from ~12% to ~40%. Thus, our results alters the trade-space and enables a drastic increase in science throughput without increasing system complexity. Current JPL balloon mission ASTHROS aims to provide NASA with a low-risk and low-cost stepping-stone platform for future heterodyne space flight missions. ASTHROS will fly as payload a 4-pixel dual band cryogenic superconducting heterodyne array camera for high-spectral resolution imaging at 1.4-1.5 THz and 2.4-2.7, focused on [NII] and HD observations. This is a further step with regards to HIFI due to the multi-pixel receivers and the operation over 2 THz, but the RF bandwidth per channel is still ~15%. For future ASTHROS flights, JPL can now offer much more advanced science capabilities. This is even more important without, since ASTHROS will be the only platform available to perform heterodyne FIR science. With 3D-HIFI, JPL will lead the field during many years to come, owning an extremely powerful technology ready for future suborbital and space missions. The results of this task represent a major breakthrough for far infrared astronomy and this technology can be baselined in future ASTHROS flights or SMEX or MIDEX Far-Infrared Space Missions.

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J.V. Siles, at al. "Ultra-broadband integrated room-temperature Schottky diode based local oscillators for line surveys in the 400-2070 GHz range", 32nd Int. Symposium on Space THz Technology, Oct. 2022.

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