National Aeronautics and Space Administration

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

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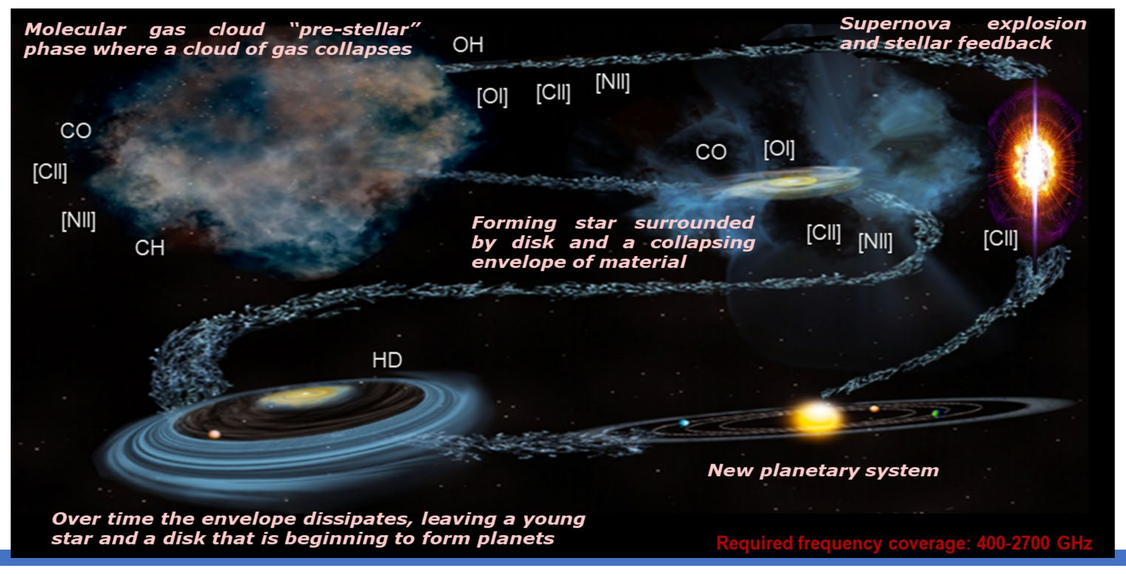
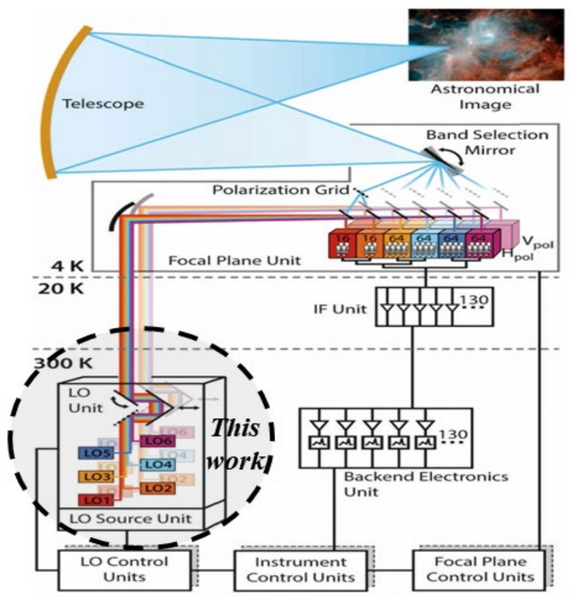
Program: FY22 R&TD Topics
Strategic Focus Area: Direct/Coherent Detectors and Arrays

Background: 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 far-infrared high-spectral resolution (R~10^6) receivers tunable to each of the key tracers the govern these processes. Current heterodyne far infrared receivers are limited by RF bandwidth to ~10%.



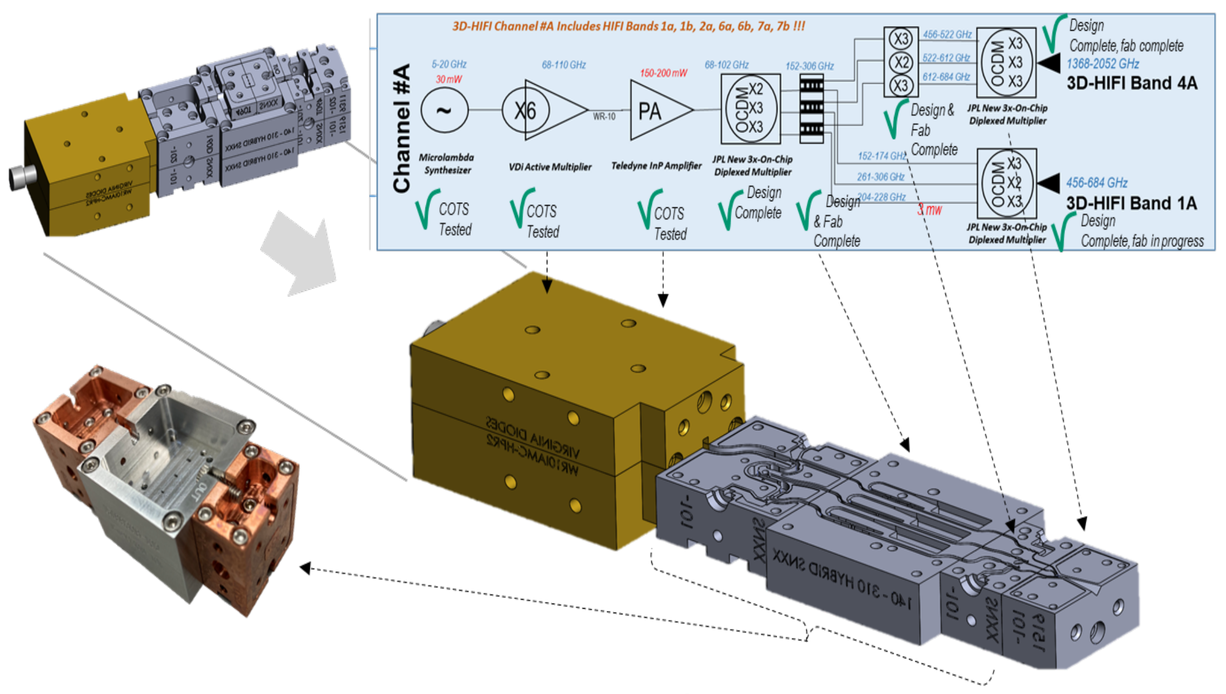
Objectives: A typical high-spectral resolution heterodyne receiver consists of an antenna, a frequency mixer (SIS or HEB), a Schottky based LO source, and the IF processor, see Fig. below. Since HEB mixers are inherently broadband, if the proper antenna structure is used, the bottleneck is the RF bandwidth 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 in 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 bandwidth by a factor of 3 (from 15 to 45%).



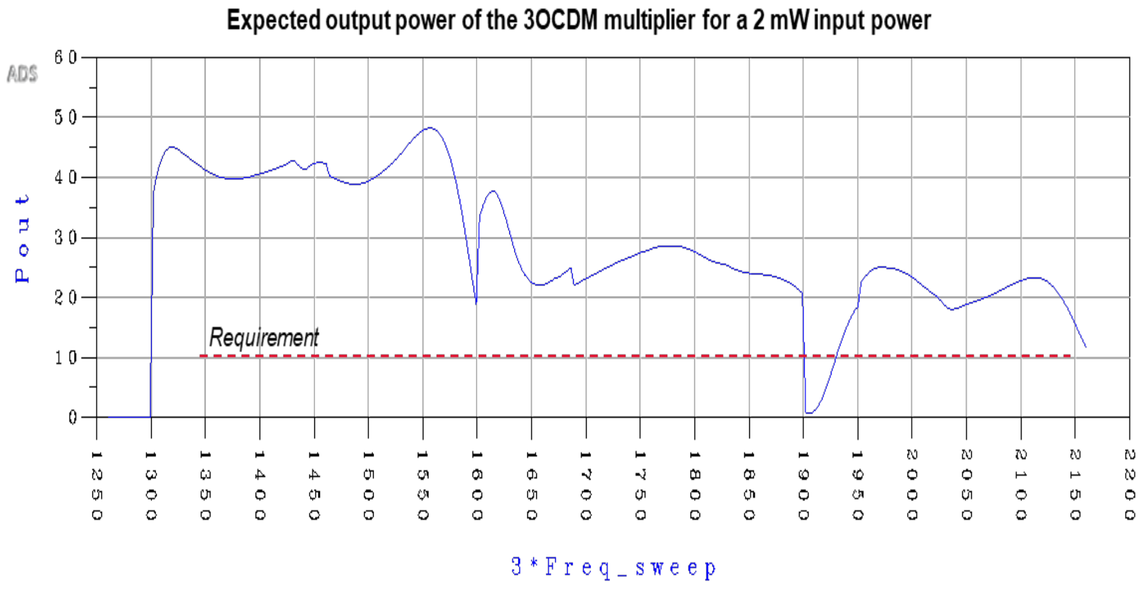
Significance to JPL and NASA: 3D-HIFI will allow with a single tunable receiver channel to cover many key tracers of star formation ([CII], [NII], water, OI, HD, OH, HDO, HF, HD, CO, etc.), by increasing the bandwidth of current receiver technology from ~12% to ~40%. Our proposed task fundamentally alters the trade-space and enables a drastic increase in science throughput without increasing system complexity. JPL ASTHROS 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, focusing on [NII] and HD observations. For future ASTHROS flights, JPL will have to offer much more advanced science capabilities. With SOFIA finishing operations in 2023, 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.

Approach and Results: 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. 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 plus 456 GHz to 685 GHz using the intermediate multiplication stages.

The circuit selectively routes the input signal to a certain number of diodes, doubling or tripling the signal depending on the frequency sub- band. The figure on the right show the 3D model of the complete 3D-HIFI LO chain, as well as a photo of the fabricated stages ready to test. The predicted performance for the complete system is also shown



DESIGN & FABRICATION & ASSEMBLYCOMPLETE, ASSEMBLY IN PROGRESS → THIS CAN BE A MAJOR BREAKTHROUGH FOR FAR INFRARED ASTRONOMY



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