National Aeronautics and Space Administration

Mid-IR Combs for Very High Angular Resolution Astrophysics

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Program: Strategic Initiatives

Project Objective:

This initiative explored component technologies for broadband heterodyne receivers working at mid-IR wavelengths (8-12 microns), for optical long baseline interferometry in astronomy and elsewhere. Major components are:

- **Frequency Comb Local Oscillators**: 10 micron laser frequency combs with rep. rates of 5-20 GHz with > 100 uW per comb line, for use as phase coherent local oscillators
- **Array Mixers**: High speed detectors (~10 GHz) that may be assembled in linear arrays of mixers
- **LO Lock Technology**: Means to lock independent LOs over large distances

This is a broad collaboration between researchers at JPL, Caltech, Army Research Lab, UCB-SSL, and NIST.

FY19 Results:

A breadboard optical system using our laser frequency comb, coupled to a grating monochrometer (to select comb lines), was combined with a mid-IR thermal source to generate heterodyne mixing on a 2 GHz single pixel HgCdTe mixer. Heterodyne output was detected on 60 separate comb lines to demonstrate the multi-channel system with an unprecedented bandwidth capacity of 1.5 THz.

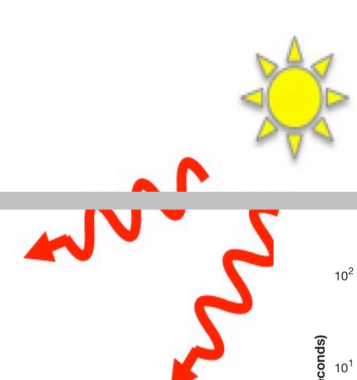
The speed of our new QWIPs arrays was measured using a rectification scheme to show total bandwidths of 1 GHz per mixer. Calculations show that we should have achieved 4 GHz speed, suggesting that the shortfall is due to a parasitic capacitance in our cyrogenic fan out card. All experimental work was done in the Exoplanet Instruments Lab in B183-219.

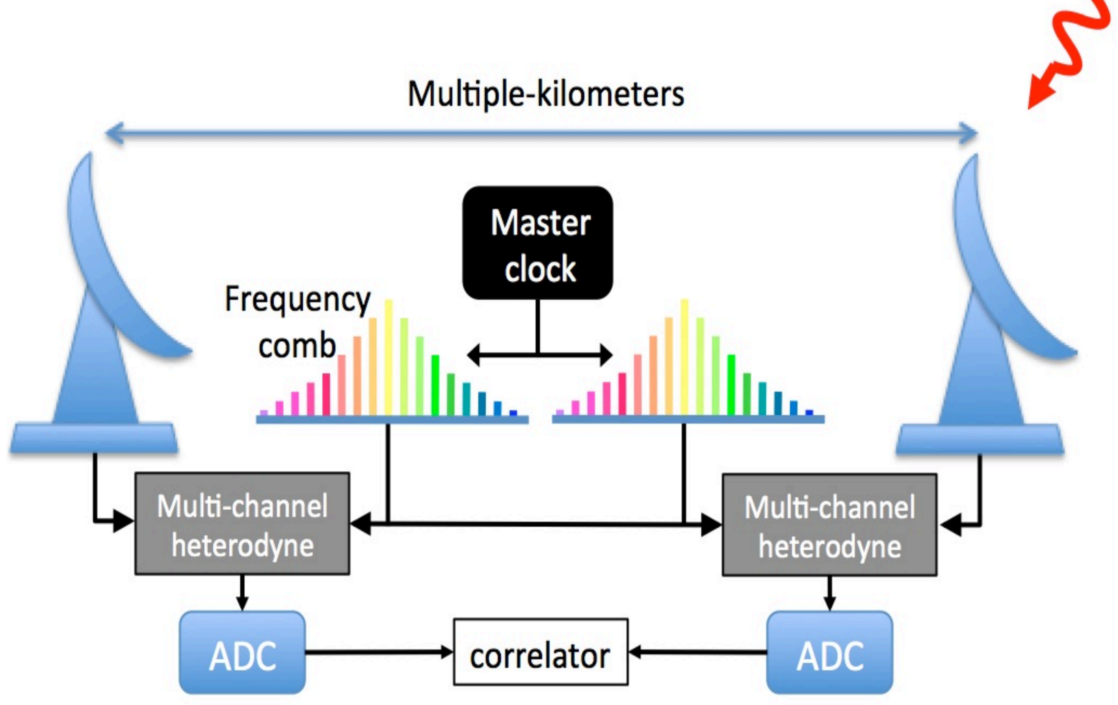
We have secured DARPA funding to study the feasibility of repurposing the existing ISI interferometer on Mt. Wilson. The goals of this study are as follows: develop a parametric model of the projected performance for a mid-IR (~10 micron) heterodyne interferometer for high angular resolution imaging of interest to DARPA, determine the system requirements for desired performance goals, and perform a detailed cost estimate of a facilities upgrade of the ISI to perform model validation.

Benefits to NASA and JPL:

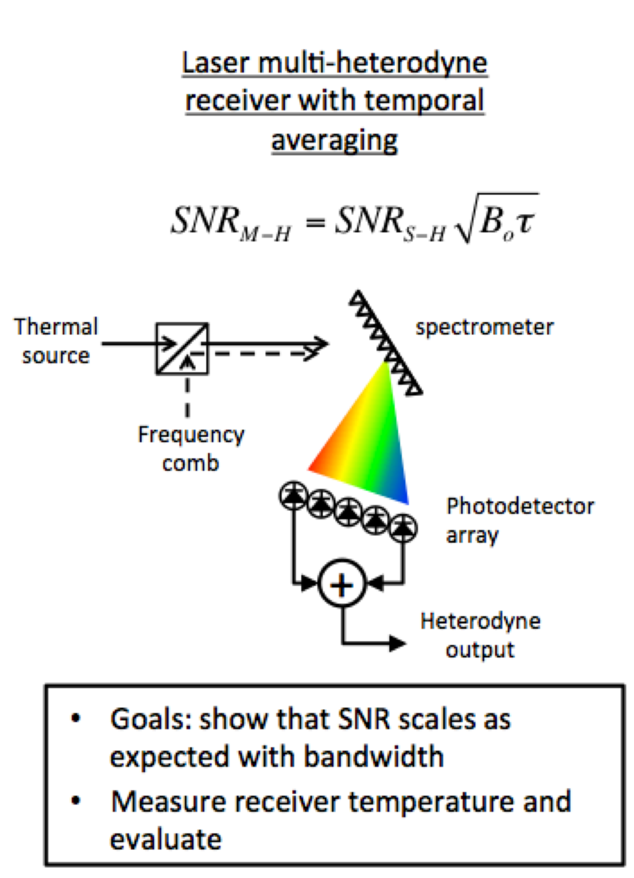
This work can dramatically extend the state-of-the-art for optical heterodyne detection by enabling total bandwidths that compete with direct detection methods. Heterodyne interferometers in the mid-IR compete well with direct detection interferometers in terms of SNR, but enable extremely long baselines and very high angular resolution. These capabilities can be used for imaging planet formation scenes at large distances. Baselines could be extended to ~100-500 km to resolve the surfaces of temperate exoplanets orbiting nearby stars. Other applications include the remote sensing and imaging of Earth orbiting structures such as Geosats.

Concept

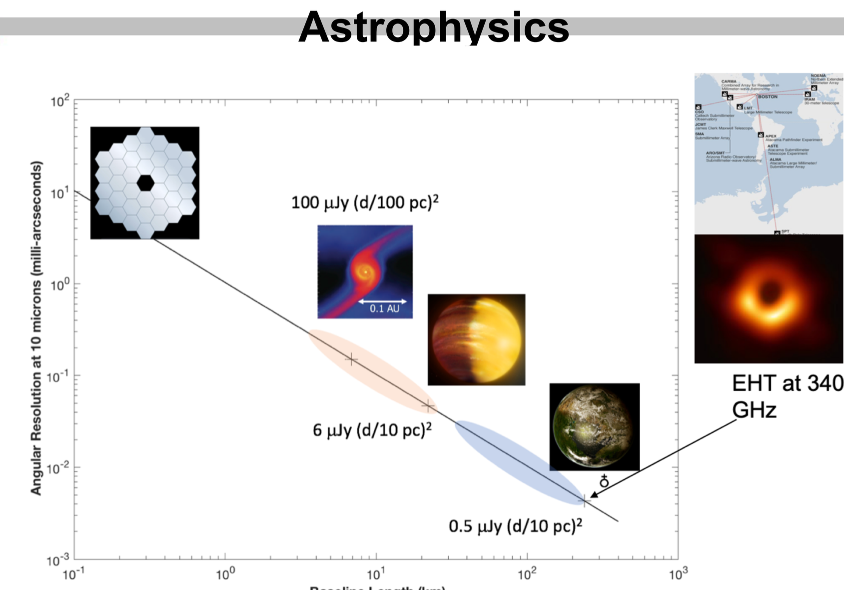




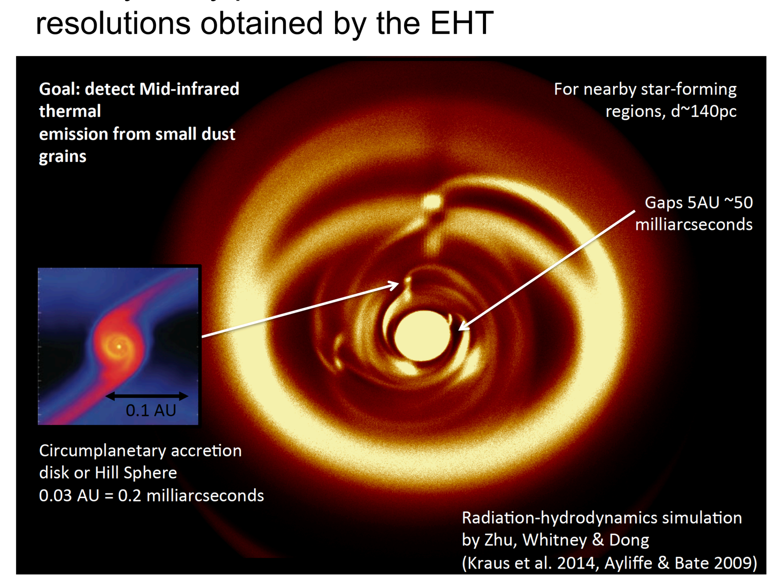
The schematic shows a conceptual application for THERM technology. It depicts two unconnected telescopes -- each with a commonly stabilized THERM receiver powered by a mid IR frequency comb local oscillator. Signal outputs at each telescope are digitized and combined in a fast cross-correlator. Multiple km baselines are required for sub nano-radian angular resolution on the sky.



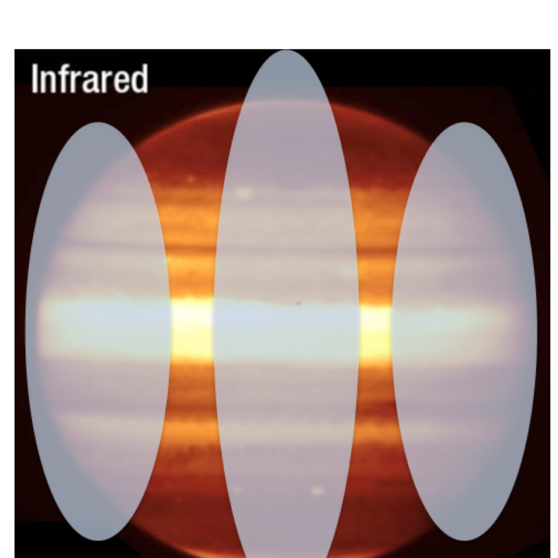
Astrophysics



Exoplanet imaging across the angular scales. Nearby rocky planets can be resolved at the resolutions obtained by the EHT

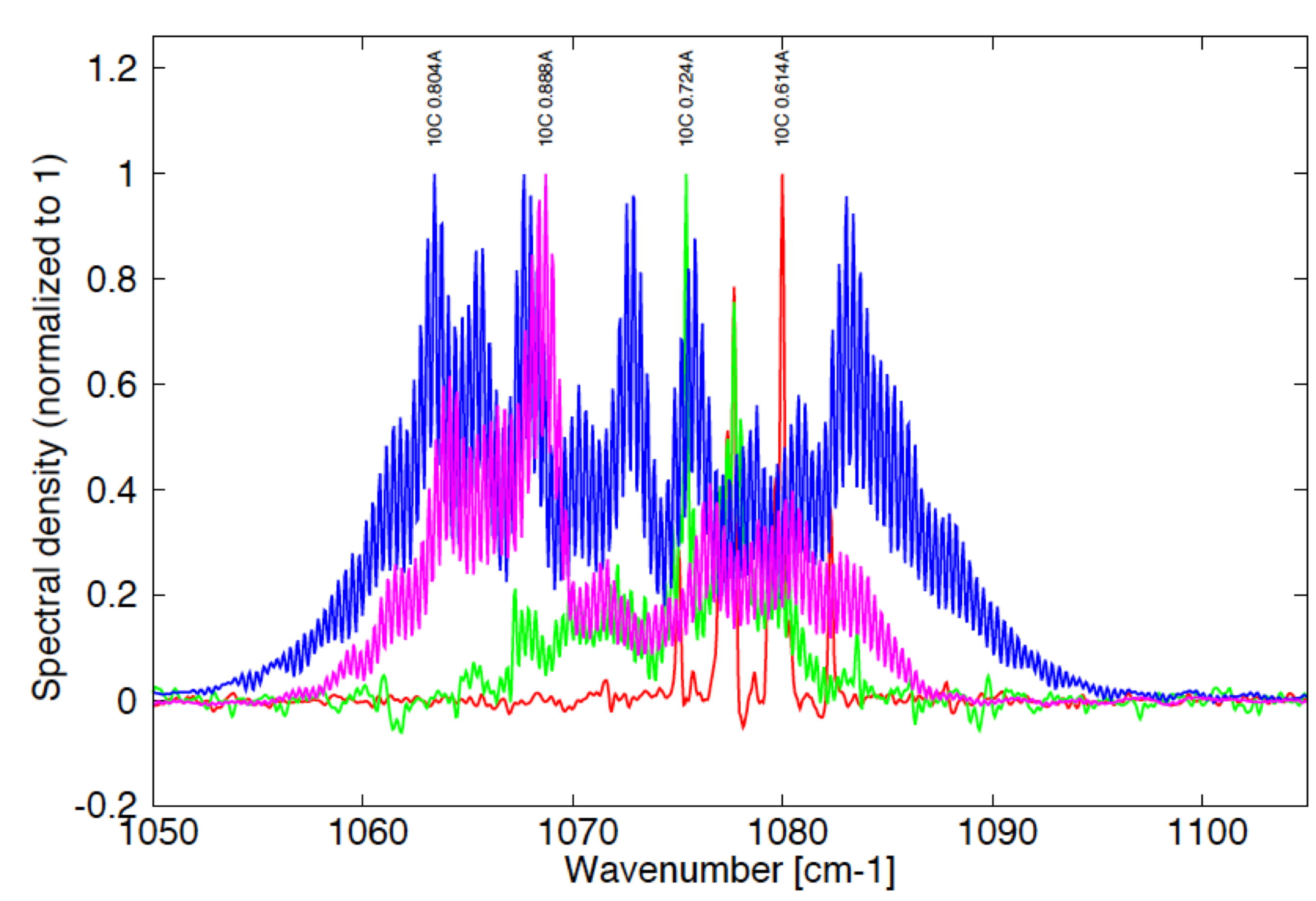


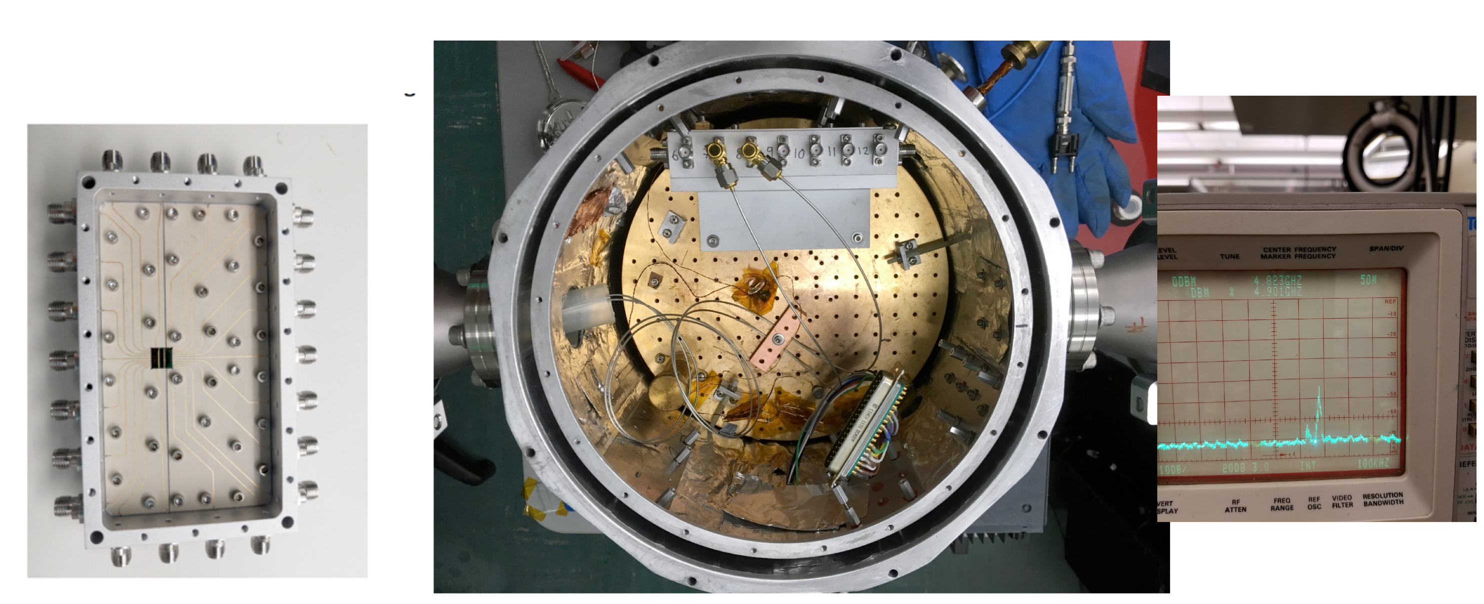
Imaging giant planets on a Hill sphere scale in planet forming disks at distances to Taurus requires an angular resolution of 0.5 nanoradian or 500 uas.
See: www.planetformationimager.org



Resolving the disks of the nearest giant planets (d < 10 pc) is a potentially groundbreaking application. Baselines of ~10 km can resolve giant planet photospheres at 5-10 pc distances.

Technology





Left – R-QWIPs mixer array and fan out Middle – Co-I Wollman's mixer test cryostat
Right – 6 GHz 2 QCL beat not with Karasik's MgB2 mixer (see his poster)

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