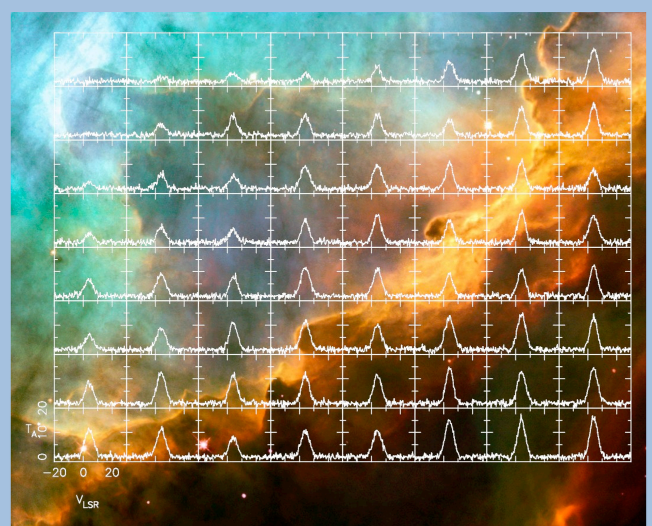
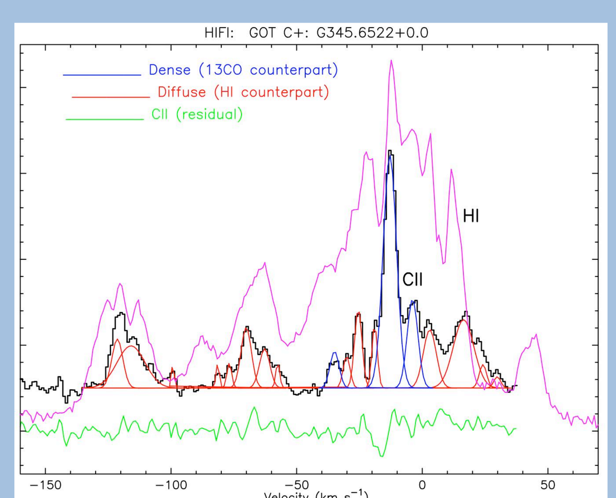
StratoSTAR
Stratospheric Submm/THz Array Receiver

Scientific Motivation



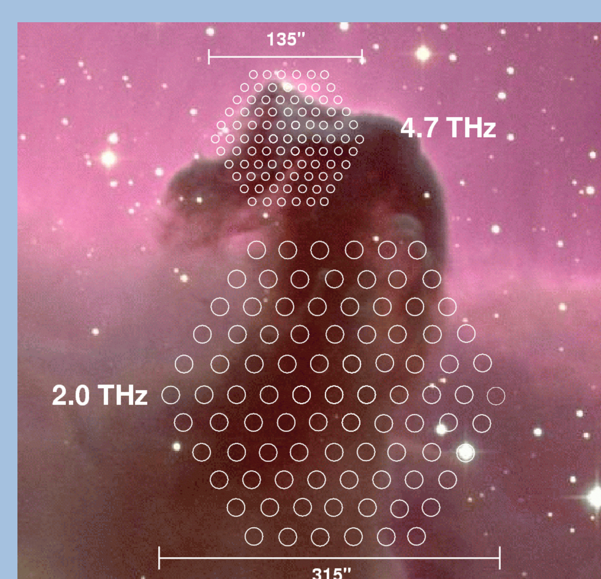
Why a Heterodyne Array?
- Emission often extended
- High spectral resolution required to disentangle emission components
- Can provide more than an order of magnitude increase in mapping speed.

Model [OI] spectra in the vicinity of M17: The THz portion of the spectrum is home to many spectral features that probe the life cycle of the interstellar medium (ISM). Three of the most important are [CII], [OI], and HD. All three are expected to extend over many arcminutes in the vicinity of star forming regions. Chemical and radiative transfer models can be used to predict how extensive the emission may be (see the [OI] emission in M17 above). THz arrays on SOFIA are essential to providing the observational feedback necessary to constrain models and test our fundamental knowledge of the composition and physics of the ISM.

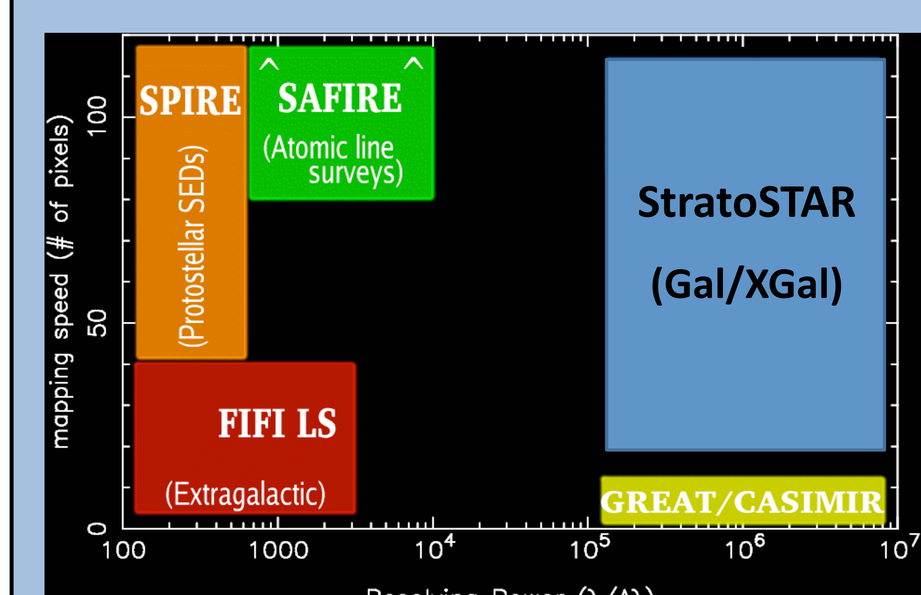


CII from Herschel HIFI's **G**alactic **O**bservations of **T**erahrertz **C+** Key Program (Langer et al. 2010, ESLAB 2010 Conference) along with HI.

HIFI Observation of [CII]: The complexity of [CII] emission is illustrated in this spectrum from the HIFI Got C+ Survey. A number of peaks can be seen indicating the presence of multiple emission regions along a single line of sight. Only heterodyne arrays can provide the high spectral resolutions (>10^5) needed to disentangle the emission from neutral and ionized gas over extended regions.



StratoSTAR Beams on the Sky: SOFIA's optics can support a large number of THz array beams. Pictured are the beam footprints of 121 pixel THz heterodyne arrays near the frequency of the [CII] and [OI] lines. Each circle represents a diffraction limited beam. The separation between adjacent pixels is ~2 full-width-half-maximums (FWHM).



Exciting Astronomy at 2-6 THz

...a diverse, rich, and unexplored wavelength frontier...

Species	Transition	THz	Importance
[C II]	$^2P_{3/2\to1/2}$	1.9013	Probe energetic PDR
[O I]	$^3P_{0\to1}$	2.06007	surfaces of molecular clouds,
[N II]	$^3P_{2\to1}$	2.4622	UC HII regions, AGB stars,
H I	n=14 → 13	2.6811	protoplanetary disks
[O III]	$^2P_{3/2\to1/2}$	3.3940	& molecular clouds.
[O I]	$^3P_{1\to2}$	4.74580	
CO	J=17 → 16	1.9560	Trace energetic molecular
	J=21 → 20	2.4139	gas in star-forming regions,
	J=25 → 24	2.8703	PDR's, SNR's, AGB ejecta.
o-$H_2^{18}O$	$2_{21}\to1_{10}$	2.7416	Probe enhanced H_2O
p-$H_2^{18}O$	$2_{20}\to1_{11}$	2.9389	in shocks, outflows, disks.
HD	0-0 R(0)	2.67499	Cosmological nucleosynthesis, deuterium fractionation, thermal history of starforming regions, abundance of H_2.
OH	$\Pi_{3/2\to1/2}$	1.83	Ground state OH; general
	$\Pi_{7/2\to5/2}$	2.60	H_2O and oxygen chemistry.

StratoSTAR complements 1st Generation Instruments: StratoSTAR brings an exciting, new suite of capabilities to SOFIA. With the array pictured above, ~1 square degree of sky can be Nyquist sampled in the [CII] line in one flight.

THz Line List: There are many important atomic and molecular species that can be surveyed with StratoSTAR. Such surveys are essential to our understanding of the complex interplay between different components of the ISM.

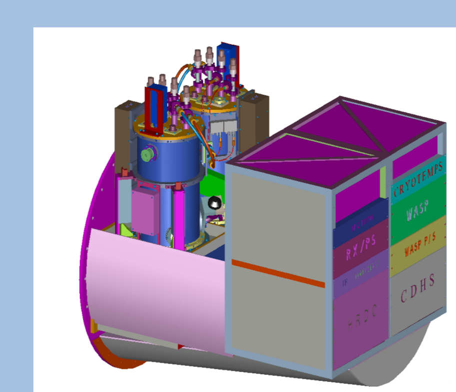
ABSTRACT

In the wavelength regime between 60 and 300 microns there are a number of atomic and molecular emission lines that are key diagnostic probes of the interstellar medium. These include transitions of [CII], [NII], [OI], HD, H_2D+, OH, CO, and H_2O, some of which are among the brightest global and local far-infrared lines in the Galaxy. In Giant Molecular Clouds (GMCs), evolved star envelopes, and planetary nebulae, these emission lines can be extended over many arc minutes and possess complicated, often self absorbed, line profiles. High spectral resolution (R> 10^5) observations of these lines at sub-arcminute angular resolution are crucial to understanding the complicated interplay between the interstellar medium and the stars that form from it. This feedback is central to all theories of galactic evolution. Large format heterodyne array receivers can provide the spectral resolution and spatial coverage to probe these lines over extended regions.

The advent of large format (~100 pixel) spectroscopic imaging cameras in the far-infrared (FIR) will fundamentally change the way astronomy is performed in this important wavelength regime. While the possibility of such instruments has been discussed for more than two decades, only recently have advances in mixer and local oscillator technology, device fabrication, micromachining, and digital signal processing made the construction of such instruments tractable. Recent advances in these technologies can be implemented to construct a sensitive, flexible, heterodyne array facility instrument for SOFIA. The instrument concept for **StratoSTAR: Stratospheric Submm/THz Array Receiver** includes a common user mounting, control system, IF processor, spectrometer, and cryogenic system. The cryogenic system will be designed to accept a frontend insert. The frontend insert and associated local oscillator system/relay optics would be provided by individual user groups and reflect their scientific interests. Rapid technology development in this field makes SOFIA the ideal platform to operate such a modular, continuously evolving instrument.

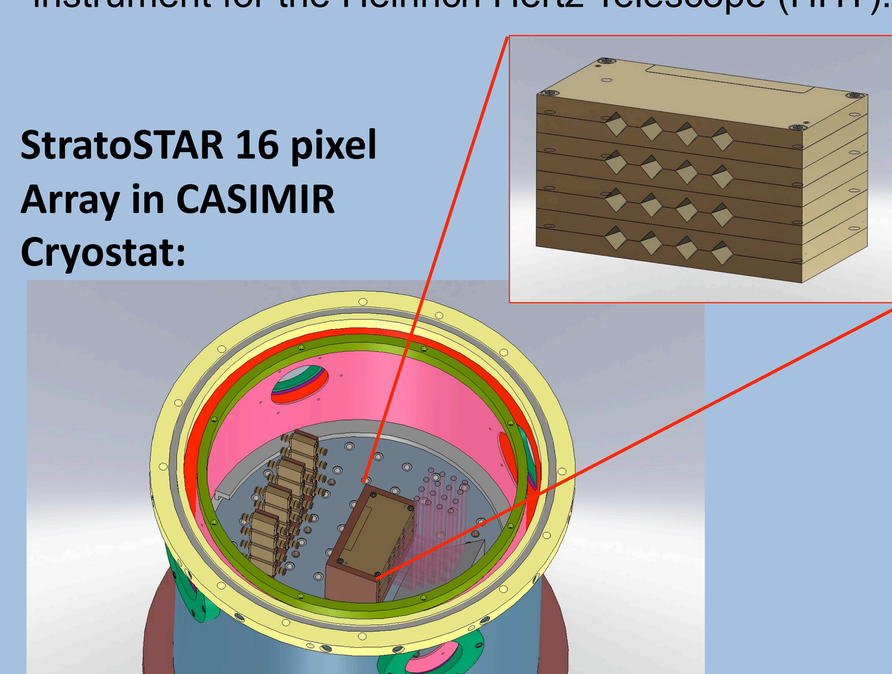
Pathfinder: 16 Pixel StratoSTAR Array

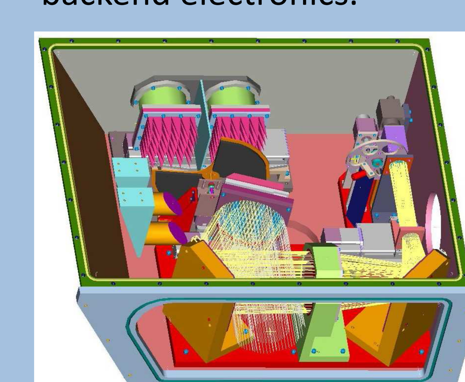
Recent design studies have shown that CASIMIR, *as is*, could host a pathfinder, 16 pixel StratoSTAR array. The array (shown below) is composed of four, 1x4 subarrays of Hot Electron Bolometer (HEB) waveguide mixers optimized for the [CII] line at 1.9 THz. The mixer array can mount directly in a standard CASIMIR cryostat. The existing Optics Box can support the passage of all sixteen beams. The required mixer technology and all associated electronics (bias, IF amplifiers, IF processors, spectrometers) have already been developed either for CASIMIR, the Stratospheric THz Observatory (STO), or the 64 pixel- 345GHz SuperCam instrument for the Heinrich Hertz Telescope (HHT).



CASIMIR Instrument: Instrument package supports two cryostats per flight and all associated frontend and backend electronics.

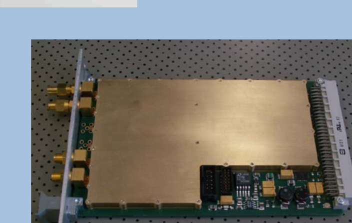
StratoSTAR 16 pixel Array in CASIMIR Cryostat:





CASIMIR Optics box: The telescope beam enters from the front of the figure. The calibration chopper wheel and the two loads are shown in the rear of the figure. The relay optics and loads are large enough to accommodate 16 THz beams. The box forms part of the pressure interface between the aircraft cabin and the exterior.

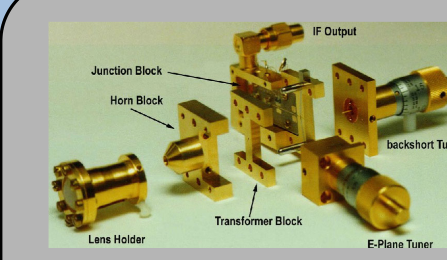
StratoSTAR 16 pixel FFT Spectrometer:
- Built by Omnisys AB for CASIMIR and SuperCam
- Real-Time FFT system
- Virtex 4 SX55 FPGA
- 2x 1GHz per board
- 1024 channels
- 25W per board
- Ethernet interface
- StratoSTAR spectrometer would use 16 identical boards for 16 x 2GHz operation



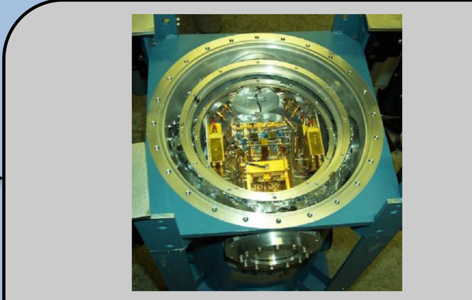
Single FFT Board

16 x 1GHz Spectrometer

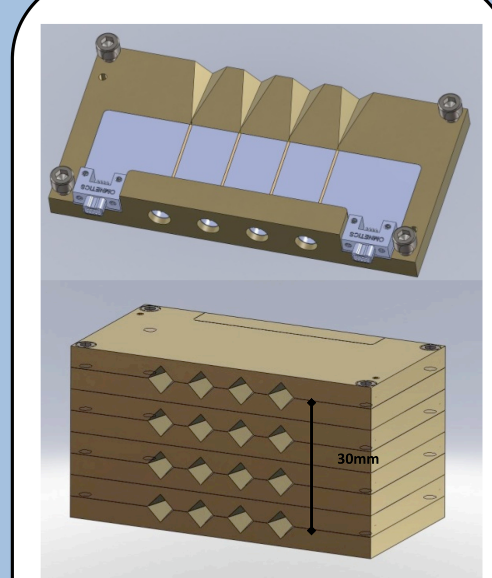
THz Receiver Evolution



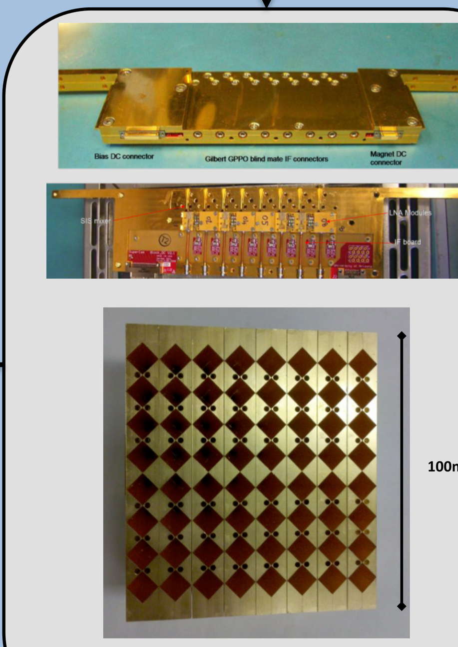
CSO Mixer @ 492GHz: 1990



4 pixel AST/RO array @ 810GHz : 2000

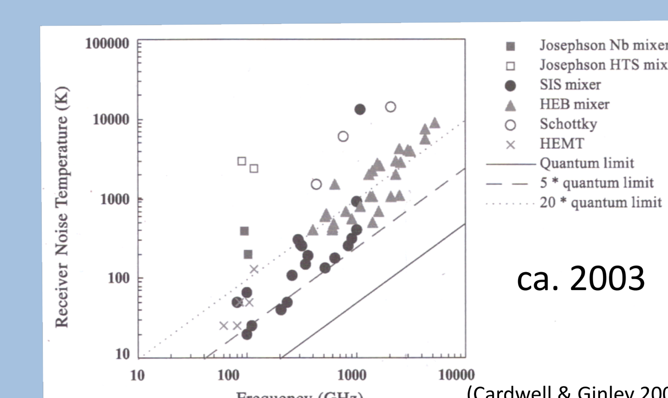


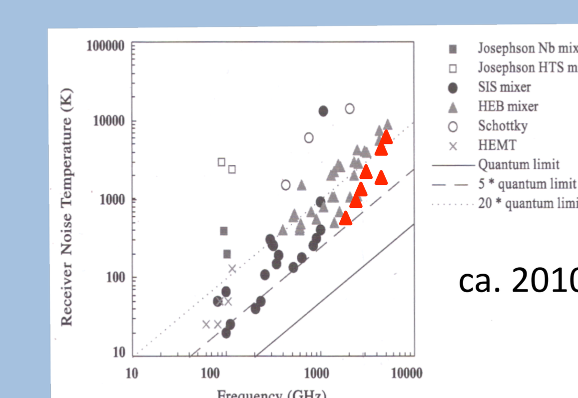
StratoSTAR Prototype: 2 THz Stacked Linear Arrays

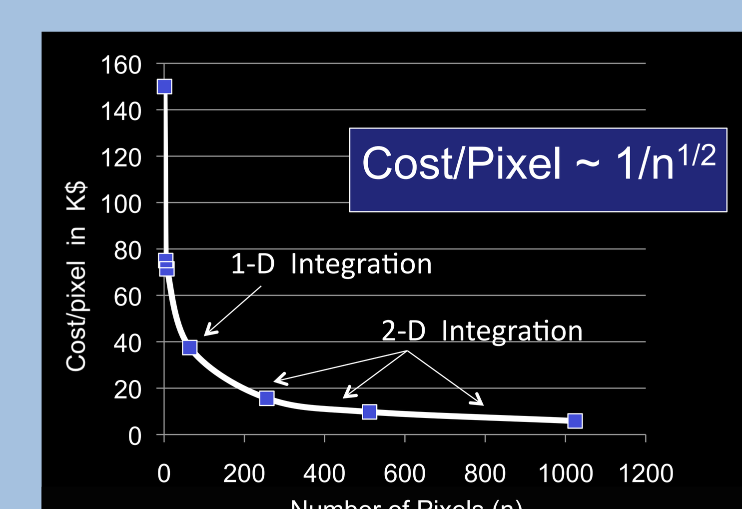


Stacked 1x8 Linear Arrays @ 345GHz: 2010

Above- Advances in SIS/HEB device fabrication, micromachining, and low-noise amplifiers has driven the evolution of waveguide receivers from individual, backshort tuned mixers to tunerless integrated arrays. *Below*- Mixer noise temperatures are rapidly approaching the 5 x quantum noise limit at high THz frequencies .



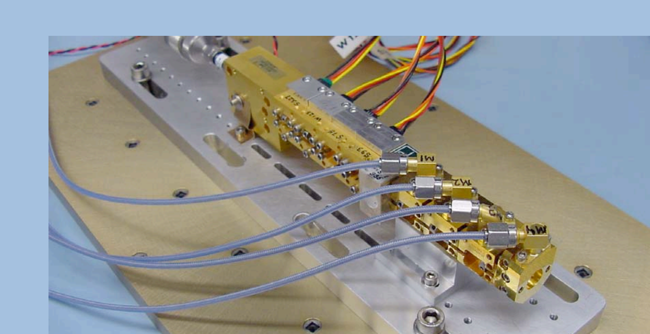




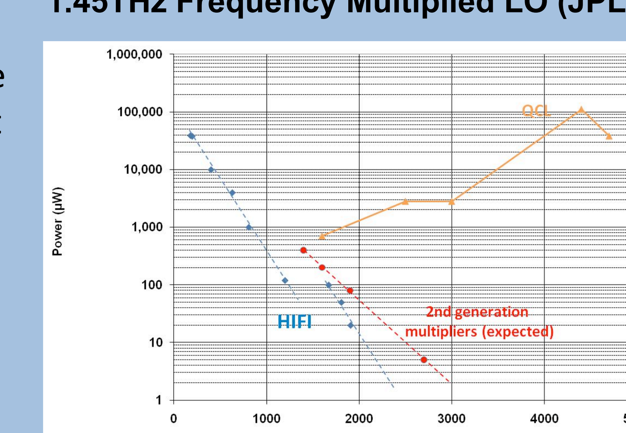
Cost/pixel vs. Number of Pixels: The costs plotted for a single pixel receiver, PoleSTAR, and SuperCAM are based on actual dollars spent. The costs for larger array receivers are based on grass-roots budgets. The plot shows that the cost per pixel for an array goes as ~ $1/n^{1/2}$. Airborne instruments have a higher initial cost, but should follow a similar law.

LO Development

Leveraging from local oscillator developments from *Herschel* and the recent demonstration of in-phase power combining, it is now possible to fabricate solid-state LO's with sufficient output power to drive 10 or more THz mixers. Without power combining the 1.45THz LO pictured here can drive ~4 mixers. An LO at 1.9THz incorporating power combining will drive a 4 pixel array on the Stratospheric THz Observatory (STO) next year. For frequencies >2 THz, Quantum Cascade Lasers (see left) can potentially be used to drive large arrays of THz mixers. ~1μW of LO power is needed per mixer.



1.45THz Frequency Multiplied LO (JPL)



LO output power vs. Frequency