upGREAT: The extension of GREAT into FIR heterodyne arrays for SOFIA

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MPIfR[1]
KOSMA[2]
DLR-Pf[3]

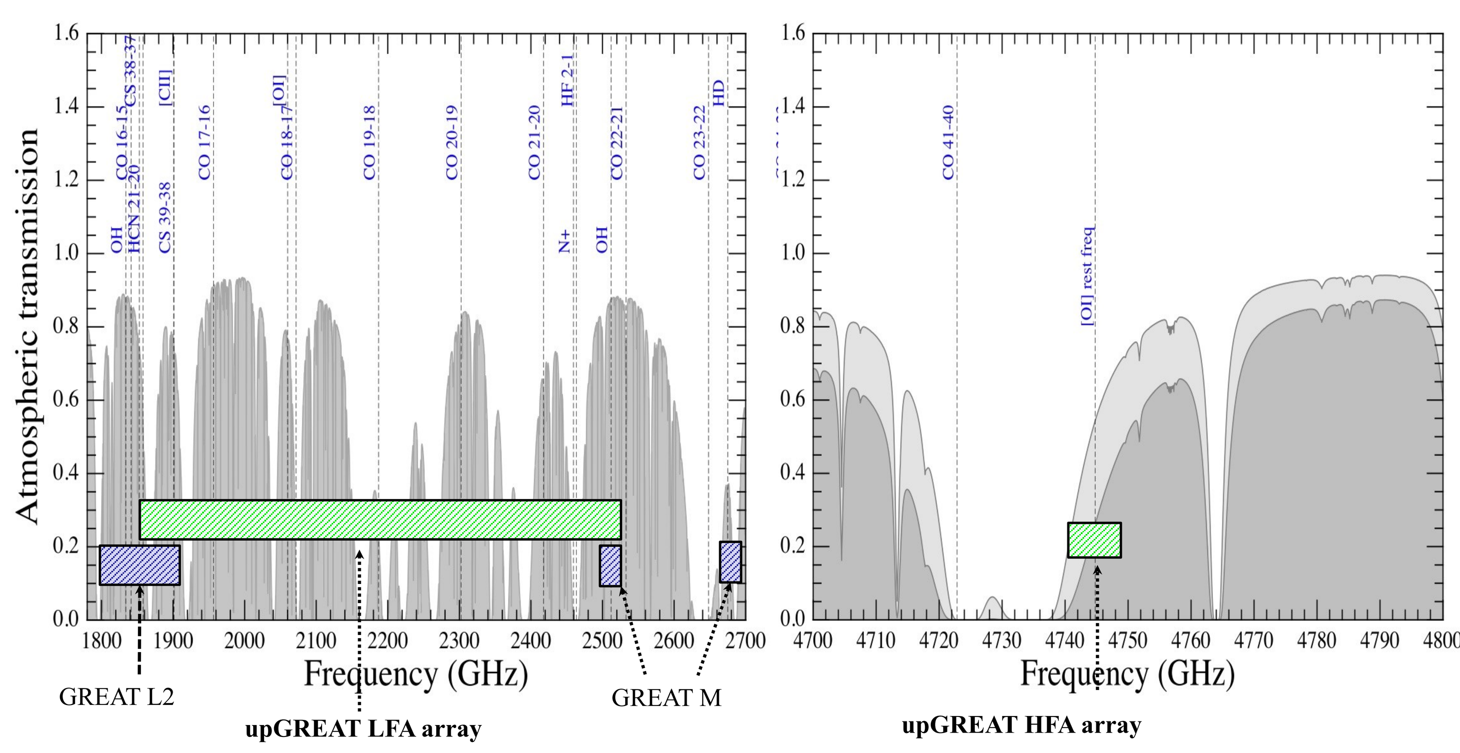
Introduction

The NASA-DLR airborne observatory SOFIA started science operations in 2011. The first-light instrument GREAT, the German REceiver for Astronomy at THz frequencies, operates heterodyne receivers in selected frequency windows between 1250 and 2700 GHz. The instrument is built in a modular fashion allowing for parallel operation of two separate, easily interchangeable cryostats. The current instrument hosts single-pixel, liquid Helium cooled HEB detectors. For upGREAT we present the design for two additional cryostats, which will be cooled using closed–cycle Pulse Tube coolers, and will operate mid-sized arrays of HEB mixers.

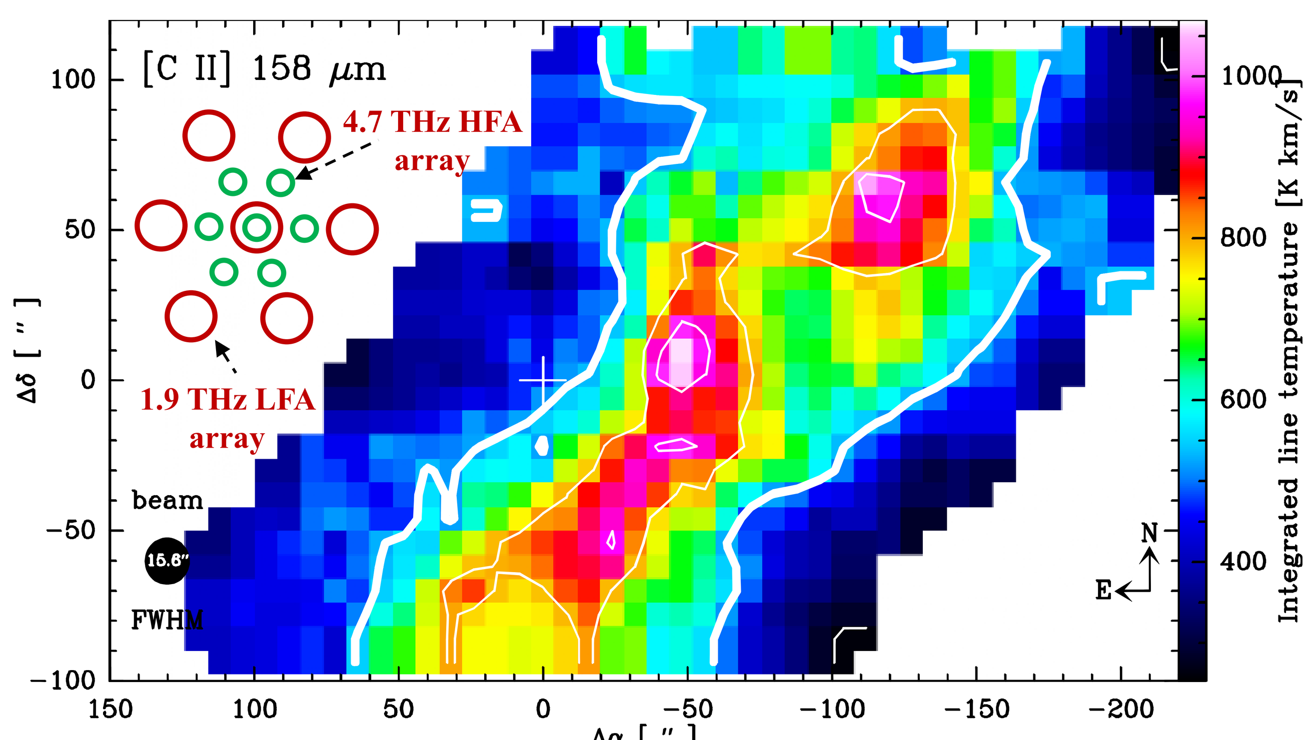
Characteristics

	Low Frequency Array (LFA)	High Frequency Array (HFA)
RF Bandwidth	1.9-2.5 THz (goal)	~4.745 THz
IF Bandwidth	0.2-4 GHz	0.2-4 GHz
HEB technology	Waveguide-based HEB NbN on Si membrane	Waveguide-based HEB NbN on Si membrane
LO technology	Cooled photonic mixers (goal) or solid-state chains (backup)	Quantum cascade lasers (QCL)
LO coupling	Beamsplitter (goal) or Diplexer (backup)	Beamsplitter
Array layout	2x7 pixels for orthogonal polarizations in hexagonal configuration with central pixel	1x7 pixels in hexagonal configuration with a central pixel
Expected T_{SYS}	Goal ~3000K SSB	Goal ~5000K SSB
Backends	0-4 GHz (goal) with 128k channels	0-4 GHz (goal) with 128k channels

The atmospheric transmission at flight altitude of 41000 feet (typical for SOFIA) is shown on the right-hand plots. Some of the most important atomic and molecular transitions are superimposed. The upGREAT-LFA will cover most of the L2 and M bands (current GREAT single pixel receivers). The atmospheric transmission is shown for an average precipitable water vapour of 15 µm (left plot), and 10 and 20 µm (right plot).

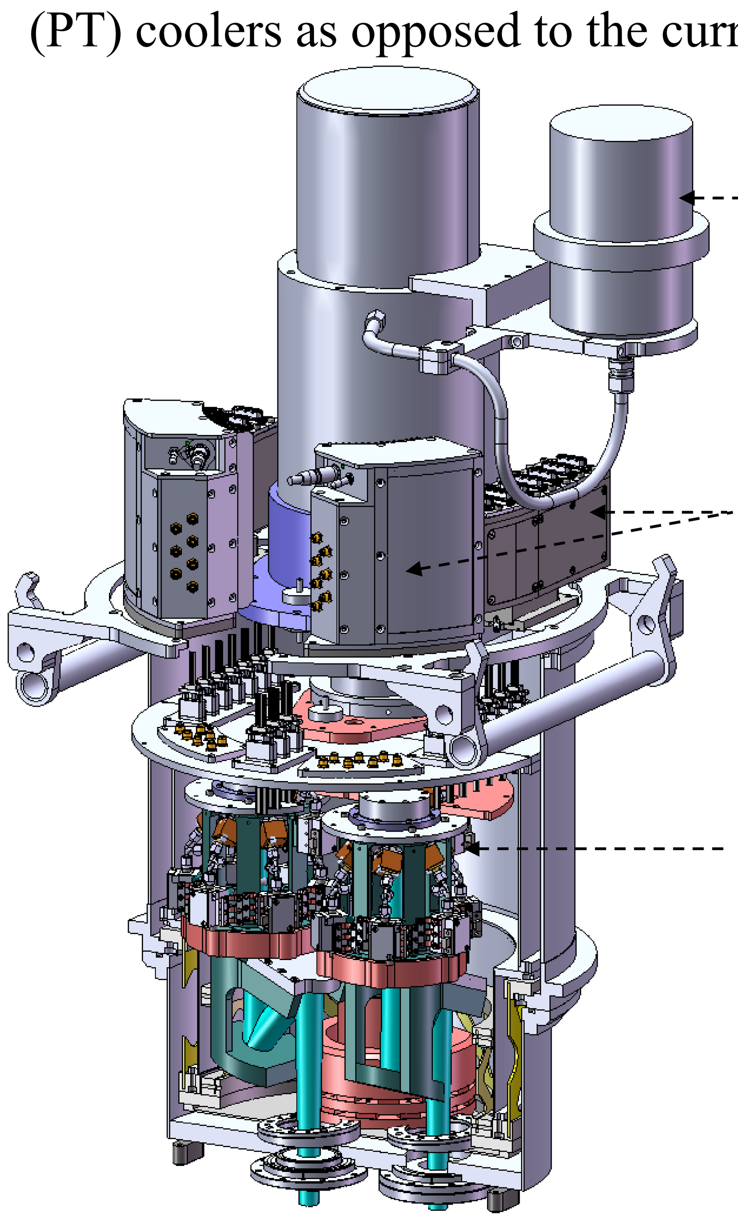


The overall improvement in mapping speed compared to a single pixel receiver is expected to be about 10 times faster. The right-hand plot shows an example of a [CII] map at 158 µm wavelength observed with the 1.9 THz single pixel receiver of GREAT. The source is the PDR region M17SW. The insert in the left hand corner displays the footprints of the upGREAT LFA and HFA arrays. The original map took ~60 minutes on-target time with the single pixel receiver whereas with the LFA array it would take only about ~5 minutes.



Cryostats with closed-cycle coolers

These new receivers dissipate more power in the coldest stage due to the larger number of pixels (mainly low noise amplifiers dissipation). Therefore the new cryostats will incorporate Pulse Tube (PT) coolers as opposed to the current GREAT cryostats which use liquid Helium and Nitrogen.



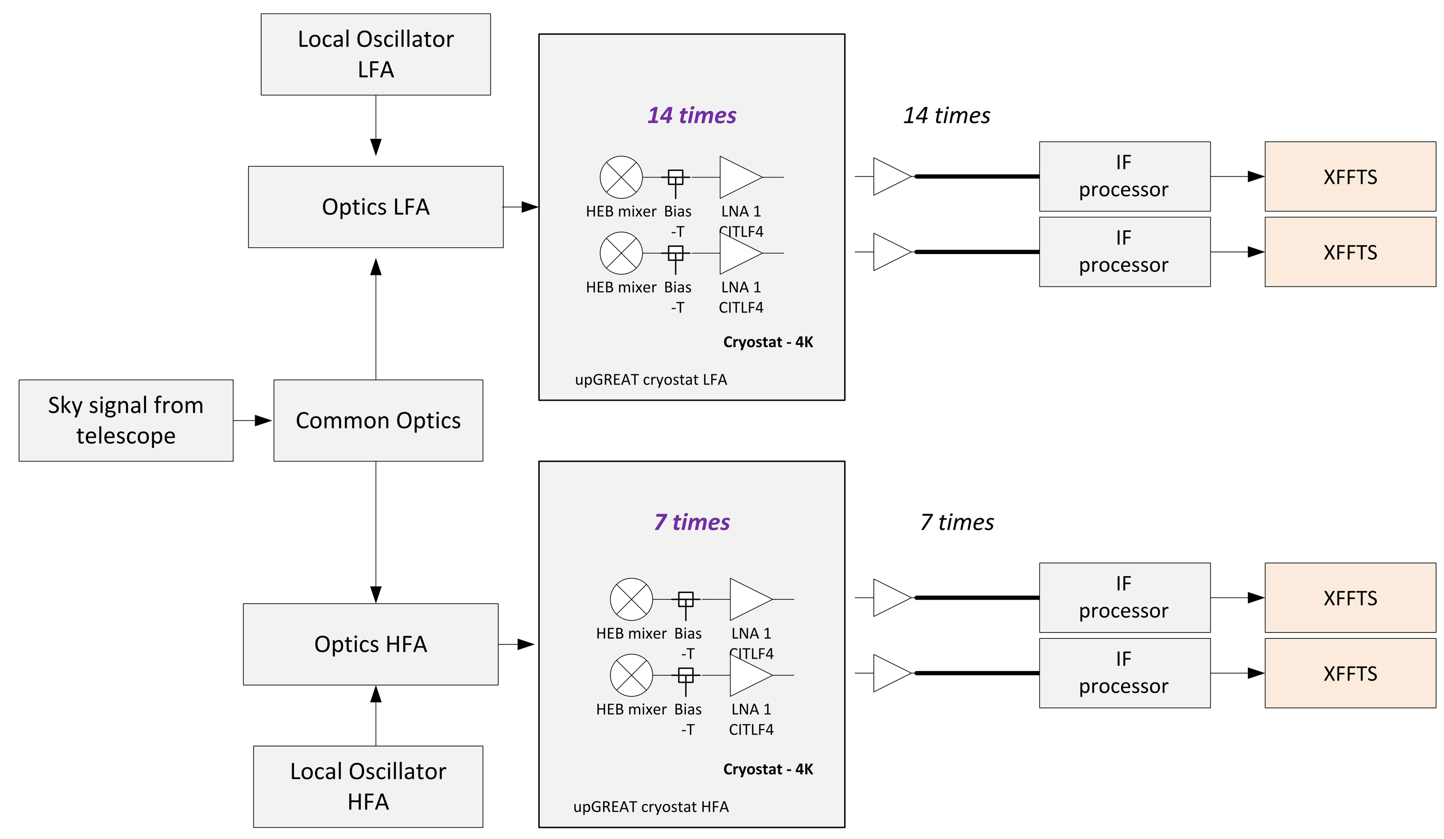
upGREAT cryostat using a PT cold head connected to the rotary valve and to a He compressor

Warm electronics for cryogenic components biasing and warm IF amplifiers.

7-pixel sub-arrays for orthogonal polarizations showing the HEB mixers low noise amplifiers and cold optics

Main characteristics of the PT coolers
Coolers are model PTD-406C from transMIT (Giessen, Germany)
2nd stage cooling power : • 0.9 W@4.2K with a ~7 kW compressor • 0.6 W@4.2K with a ~4 kW compressor
Customized to include a small Helium pot (0.2L) to stabilize the lowest temperature.
Vibrations are minimized by separating the rotary valve from the cold head by a ~70 cm Helium line.
Tilting by ±45º will be possible with low impact on cooling power (10%)

General layout



The above diagram shows the general layout of the upGREAT receivers when used simultaneously, illustrating the main components. A maximum of 14+7 channels will be used, therefore innovative development of new electronics is needed to bias the active cryogenic components (21 mixers and low noise amplifiers) and to process the signals (IF processors and digital spectrometers).

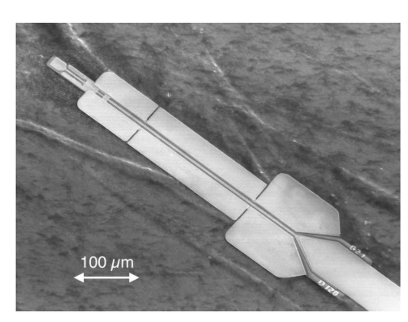
Detectors

For the upGREAT-LFA:

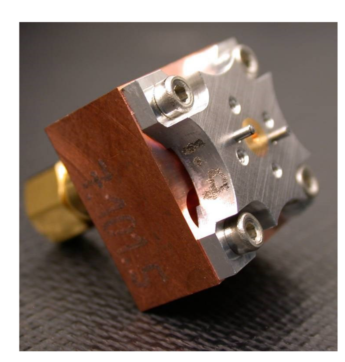
- Waveguide-based Hot Electron Bolometers (HEB) mixers
- HEB based on NbN on Si membrane for larger IF bandwidth
- 3 hν/k quantum noise limited sensitivities achieved

For the upGREAT-HFA:

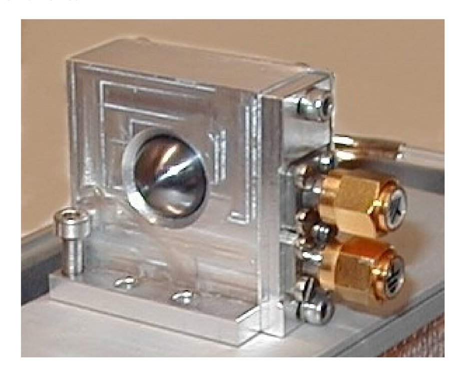
- Parallel development of waveguide (KOSMA) and open-structure (DLR-Pf) mixers
- Waveguide-based Hot Electron Bolometers (HEB) mixers selected
- 3 hν/k quantum noise limited sensitivities achieved



Example of a 2.5 THz waveguide HEB mixer using beam-leads (KOSMA)



Example of a 2.5 THz waveguide HEB mixers mixer block (KOSMA)



Example of 4.7 THz open-structure HEB mixer using hemispherical lens on a spiral antenna (DLR-Pf)

Local Oscillators

For the upGREAT-LFA:

- based on photonic mixers. Two tunable LASERs are combined, amplified and mixed in a cooled photomixer. Phase-locking of the LASERs is realized by a comb generator with kHz resolution. The minimum output powers needed to operate the arrays are in the µW range.
- Solid state sources from Virginia Diodes Inc.

For the upGREAT-HFA:

- based on Quantum Cascade Lasers (QCL). Output powers in the range of a few 100µW at 4.7 THz have already been demonstrated. The LO will then be coupled with beam-splitter foils and the frequency stabilization can be performed using a gas-cell. Tuneability is limited to a few GHz but could be increased using external resonators. This technology is being developed in parallel at Kosma and DLR-Pf.

Backends - XFFTS

The backends for the arrays will be Fast Fourier Transform Spectrometers developed at the Max Planck Institut für Radioastronomie. 21 boards will be fabricated, allowing directly sampling the IF bandpass from 0-4 GHz with 128K channels thereby providing a velocity resolution of less than 10 m.s^{-1} at 1.9THz.

Timeline for first flights

- ❑ 1.9-2.5 THz LFA array → Q1 2015
- ❑ 4.7 THz HFA array → Q1 2016