The upGREAT Spectrometer for SOFIA

Erick Young

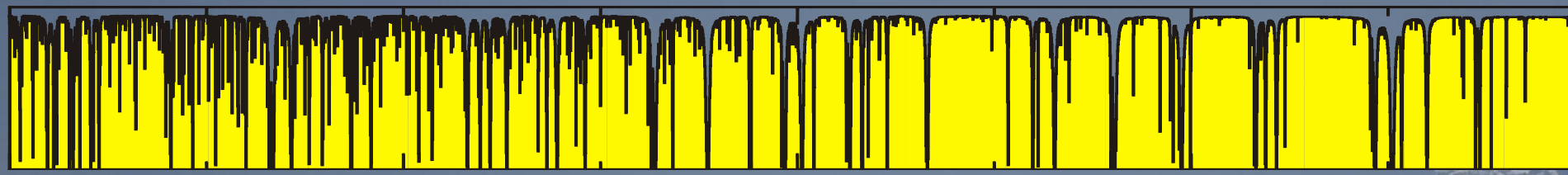
SOFIA Science Center

225th AAS Meeting 5 January 2015

SOFIA One-Minute Status

- SOFIA returned in December from an extensive Heavy Maintenance at Lufthansa Technik in Hamburg
  - Airframe inspections
  - Telescope refurbishment
- Science flights resume next week
  - GREAT Cycle 2 Series, followed by FORCAST and EXES
  - Cycle 3 observations begin in March
  - Southern Hemisphere deployment
- Cycle 4 Call for Proposals end of April, due in late June
  - upGREAT and HAWC+ will be coming on line

SOFIA Splinter Session Monday Evening



ATM 1-5 THz, 14 km altitude

German Receiver for Astronomy at THz Frequencies

GREAT

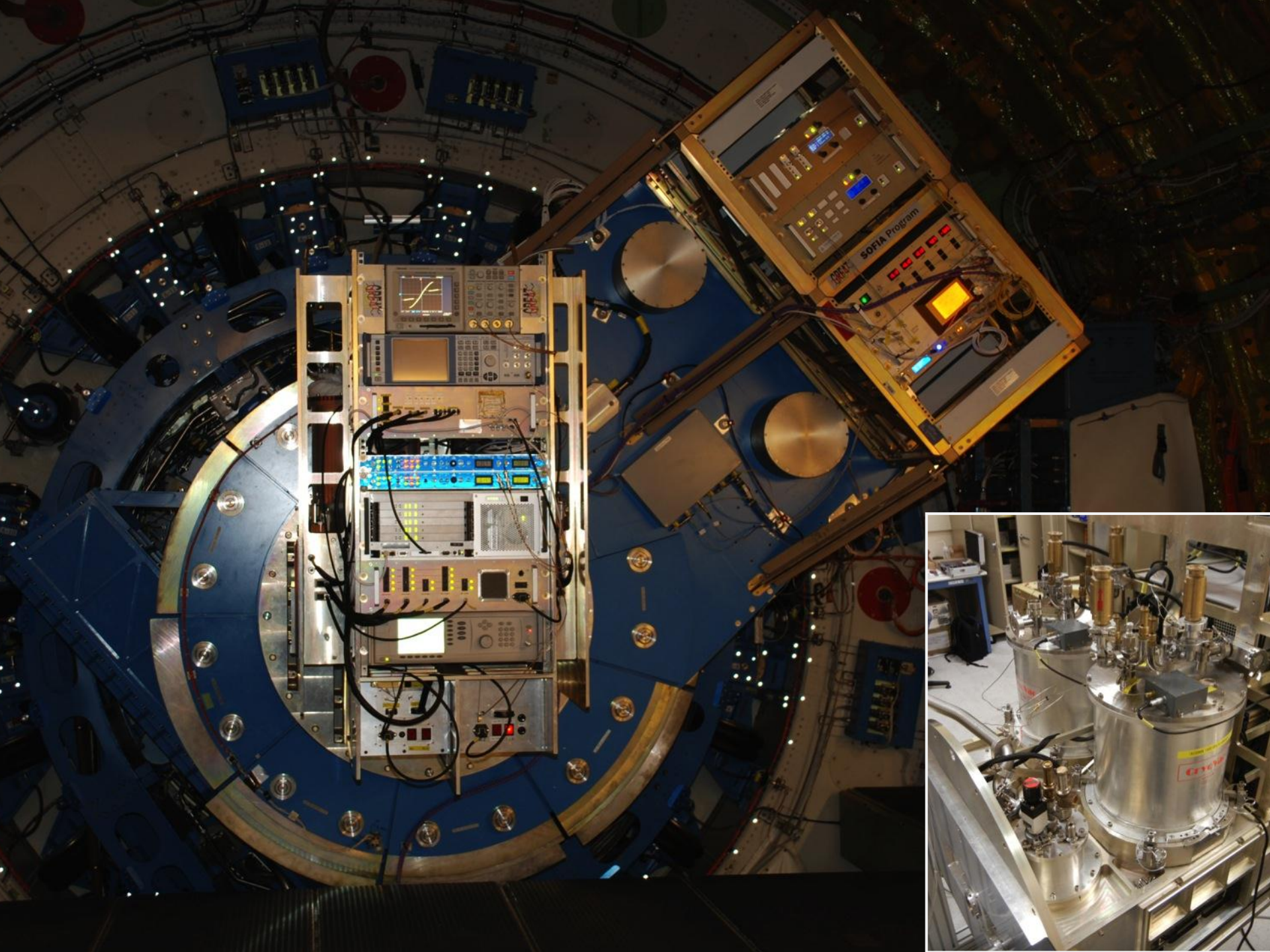
Modular dual-channel heterodyne receiver for high-resolution spectroscopy with SOFIA

GREAT - the Consortium

MPIfR
KOSMA
MPS
DLR-Pf

Principal Investigator instrument - funded, developed & operated by

- MPI Radioastronomie
  - R. Güsten (PI)
  - S. Heyminck (system engineer, PA/QA)
  - B. Klein (FFT spectrometer)
  - **C. Risacher (upGREAT project manager)**
- Universität zu Köln, KOSMA
  - J. Stutzki (Co-P: software)
  - U. Graf (system engineer)
  - K. Jacobs (HEB mixers up to 2.7 THz)
- DLR Planetenforschung
  - H-W. Hübers (Co-PI: 4.7 THz HEB & QCL)
- MPI Sonnensystemforschung
  - P. Hartogh et al. (CO-PI: CTS)


SOFIA Program

GREAT - System Overview

MPIfR
KOSMA
MPS
DLR-Pf

- GREAT is a highly modular heterodyne spectrometer ($\mathcal{R} \sim 10^8$)
- operating in science-defined frequency bands $1.25 < \nu < 4.7$ THz
- 2 out of currently 4+1 cryostats can be operated simultaneously

- channel availability (as of Dec 2014)
  - 2 low-frequency channels are operational since Early Science (2011)
  - 2 mid frequency channels:
    - M_a operational; M_b on hold for mixer upgrade, waiting for commissioning slot
  - high-frequency channel commissioning in 05/14, available for cycle 3

Channel		Frequencies [THz]	Lines of interest	Status
low-frequency	L1	1.26 – 1.52	[NII], CO series, OD, H_2D^+	operational
low-frequency	L2	1.82 – 1.91	NH_3, OH, CO(16-15), [CII]	operational
mid-frequency	Ma	2.49 – 2.56	$^{(18)}OH(^2\Pi_{3/2})$,	operational
	Mb	2.67	HD	on hold
high-frequency	H	4.74	[OI]	opertional
upGREAT	LFA	14x (1.9– 2.5)	CO series, [CII], [OI], OH	commissioning Q2 15
upGREAT	HFA	7x [4.74]	[OI]	1 yr after LFA (Q1 16)

upGREAT – GREAT multiplexed…

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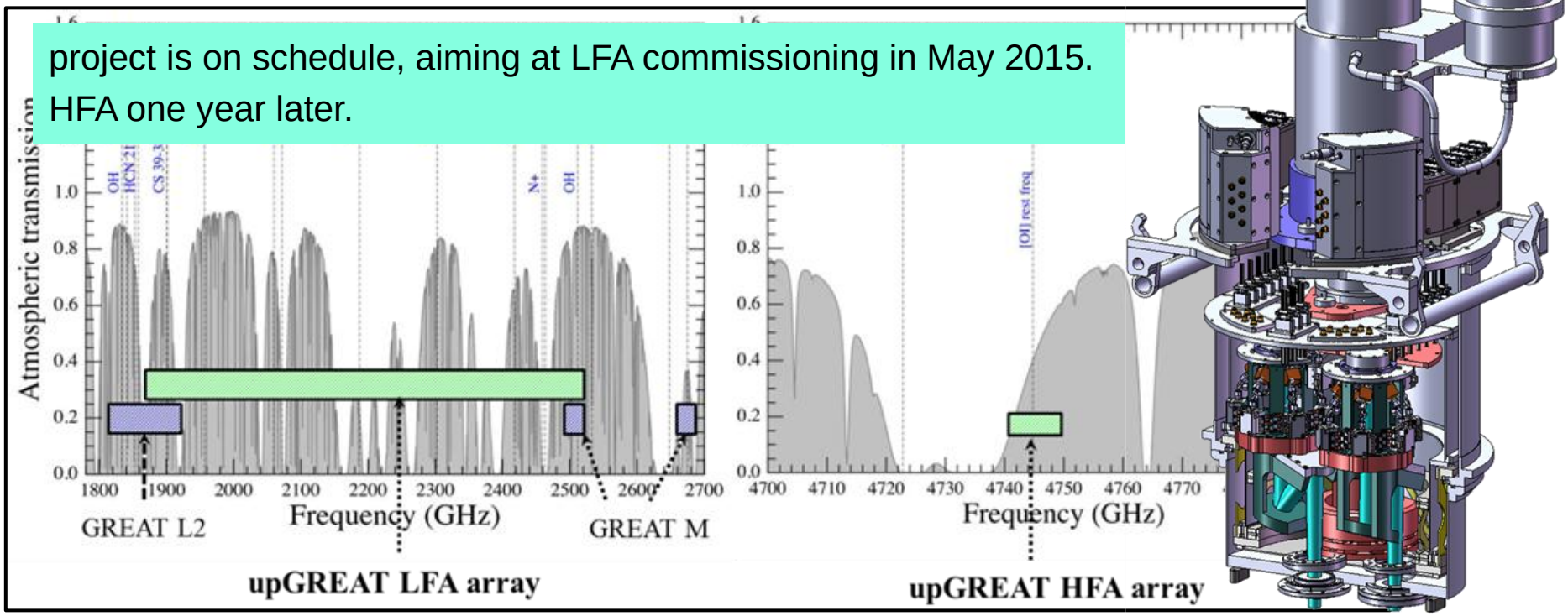
the extension of GREAT into 2 hex arrays, operating in parallel

- 2x 7 low-frequency pixels (LFA) and
- 1x 7 high-frequency pixels (HFA),
- or (m)any combination with GREAT's single pixel detectors

project is on schedule, aiming at LFA commissioning in May 2015. HFA one year later.



Multi-pixel Heterodyne Arrays will Multiply Mapping Speed >Seven-Fold

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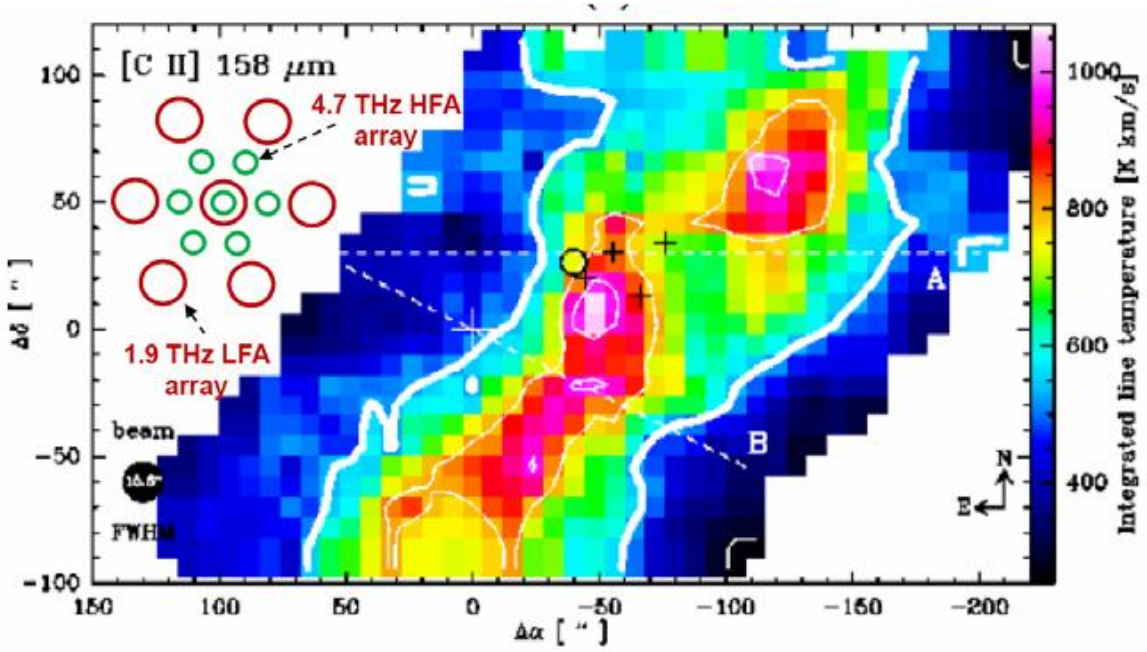
- upGREAT an enhancement of the GREAT heterodyne instrument is under development by Rolf Güsten and collaborators.
- Compact heterodyne arrays
  - 7 pixels x 2 polarizations @ 1.9 to 2.5 THz
  - 7 pixels @ 4.7 THz [O I]



upGREAT Instrument Characteristics

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MPS
DLR-Pf

	Low Frequency Array (LFA)	High Frequency Array (HFA)
RF Bandwidth	1.9-2.5 THz (goal) 1.9-2.1 THz first light	4.745 THz ± 2 GHz
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) / solid-state chains (baseline)	Quantum cascade lasers (QCL)
LO coupling	Beamsplitter or Diplexer (depending on LO power available)	Beamsplitter
Array layout	2x7 pixels for orthogonal polarizations in hexagonal configuration with central pixel	1x7 pixels in hexagonal configuration with a central pixel
T_{REC}	~600-1500K DSB 0-4GHz IF	~800-1800K DSB 0-4GHz IF
Backends	0-4 GHz with up to 128k channels	0-4 GHz with up to 128k channels

upGREAT Cryostats

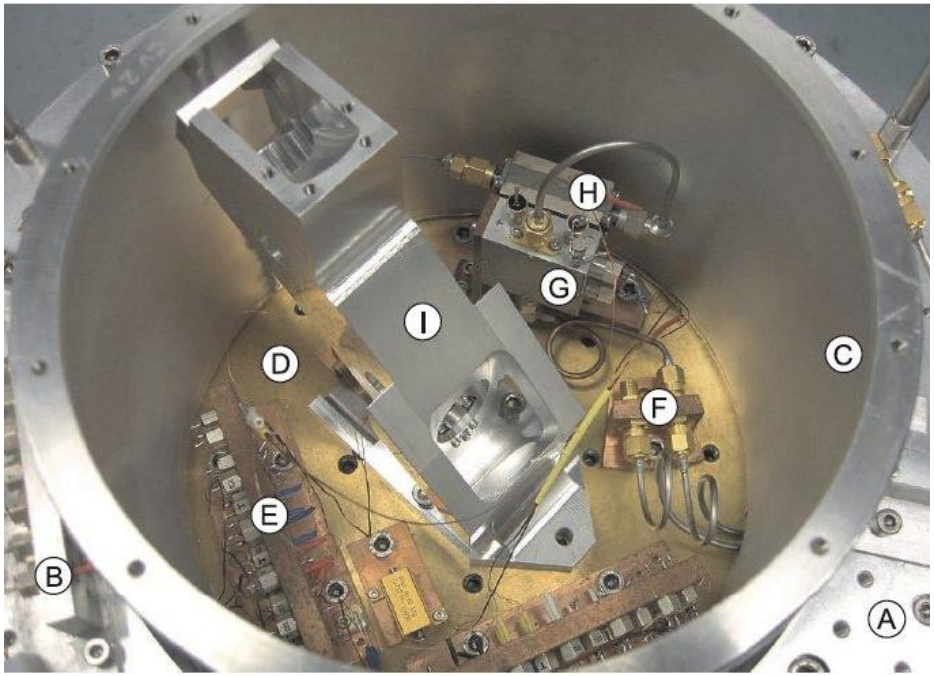
LFA cryostat fully assembled

Pulse tube PTD-406C

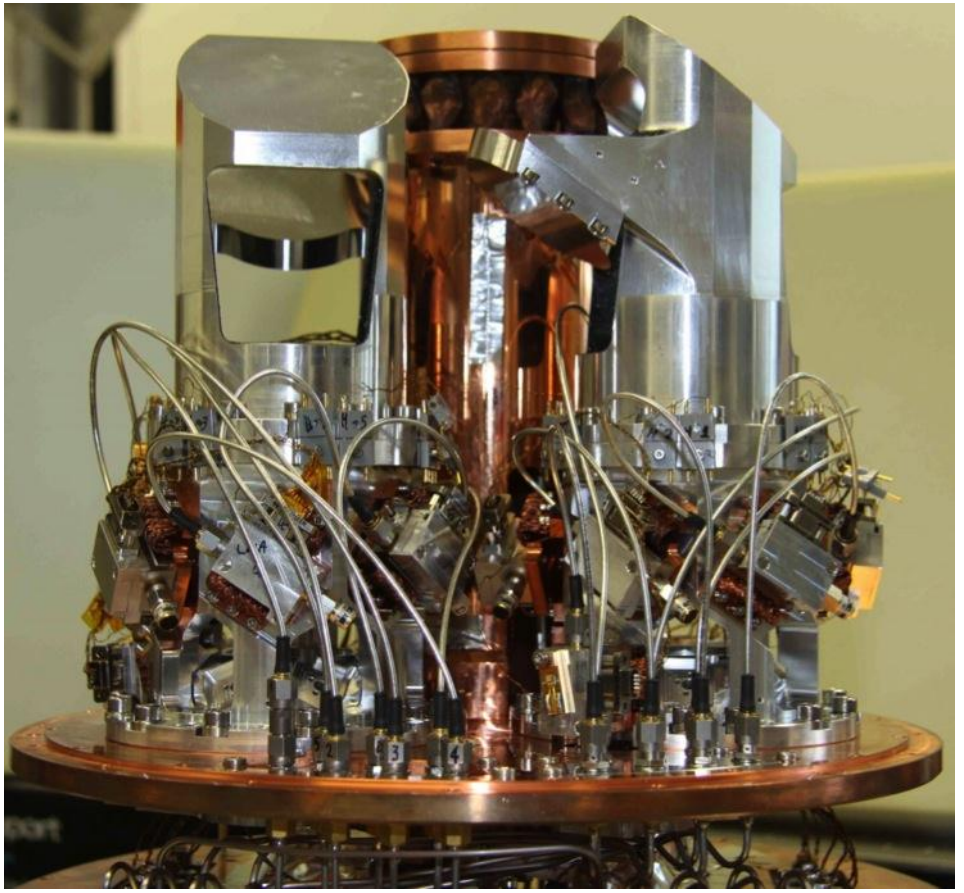
Pre-amplifiers for
HEB biasing

Warm IF LNAs
0-4 GHz

Comparison single pixel vs array receivers



GREAT L2 receiver 1.9THz
single pixel



upGREAT LFA receiver 1.9-2.5THz
14 pixels

upGREAT LFA Cryostat

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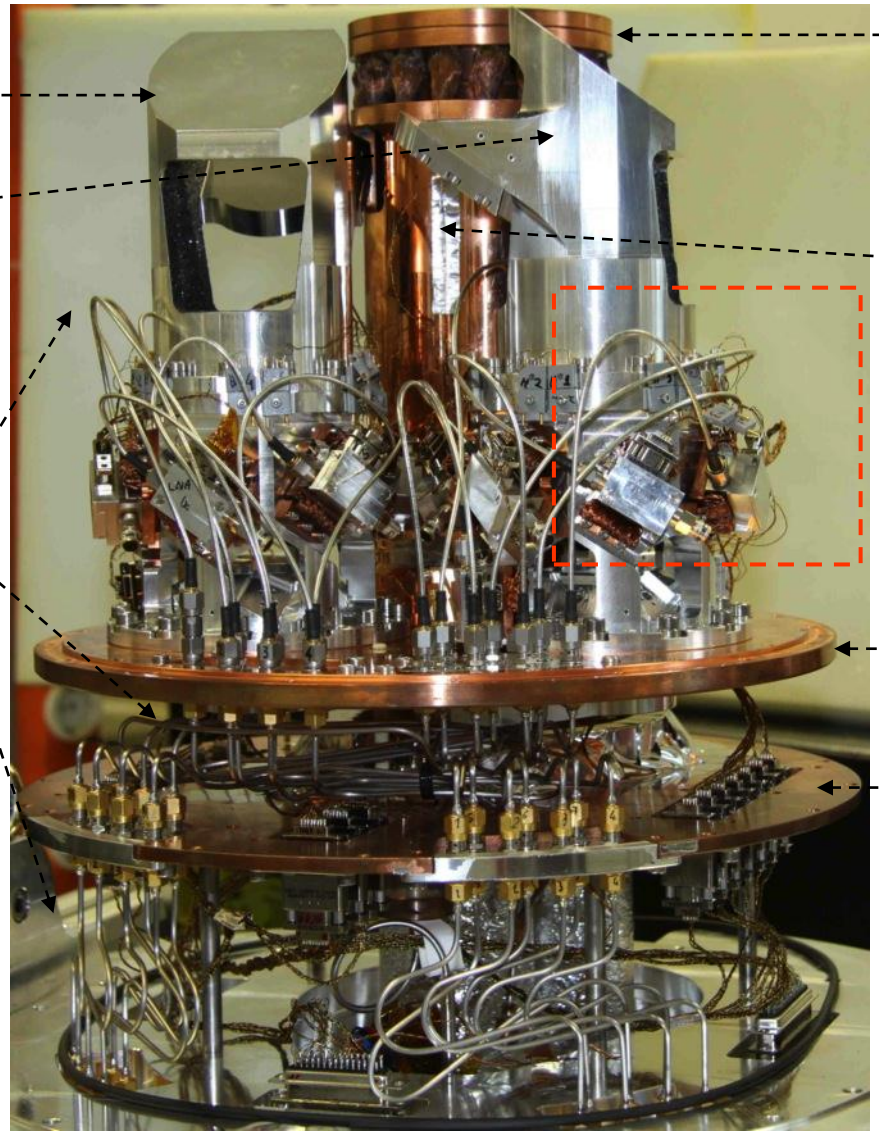

upGREAT LFA Focal plane components

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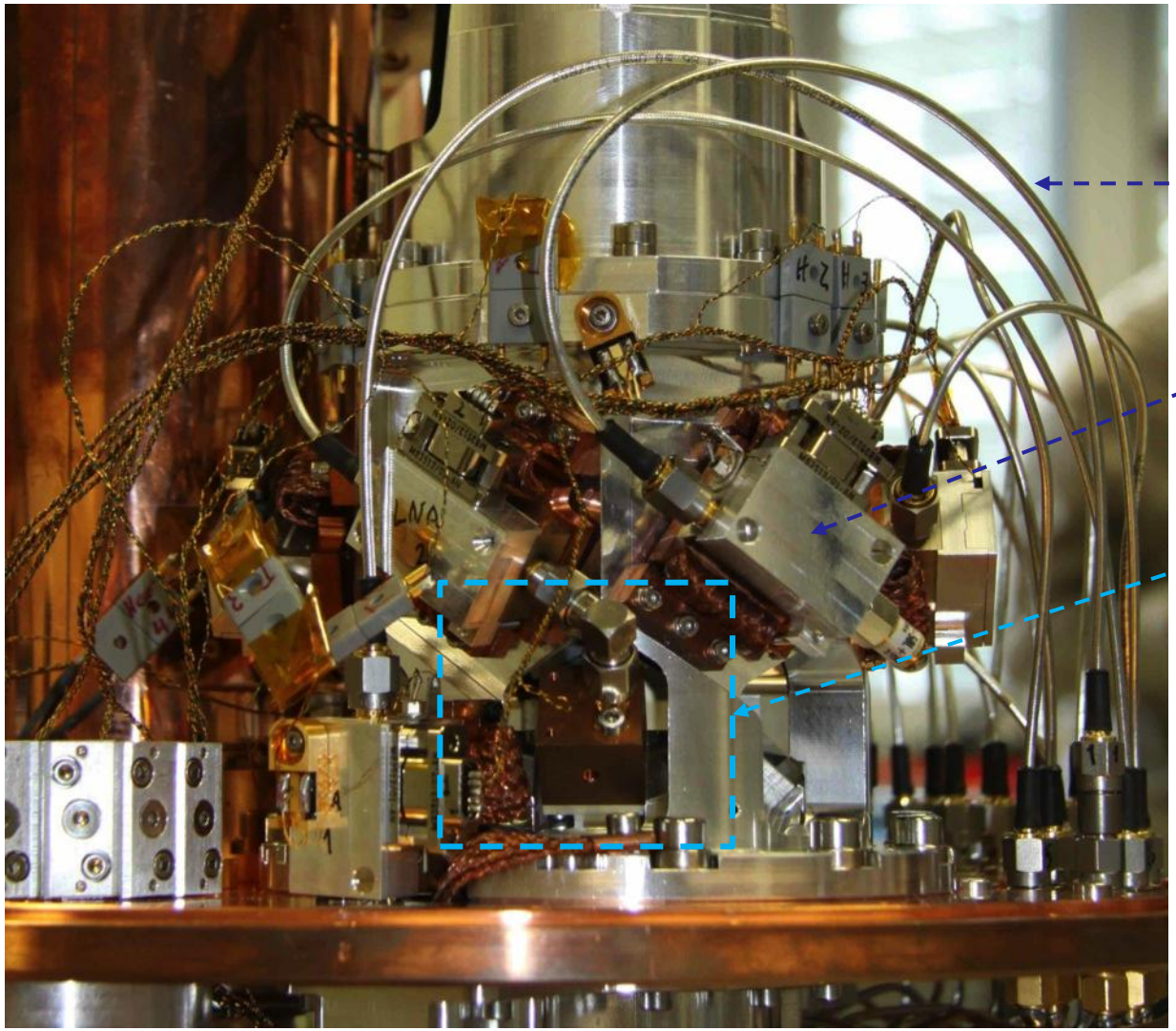
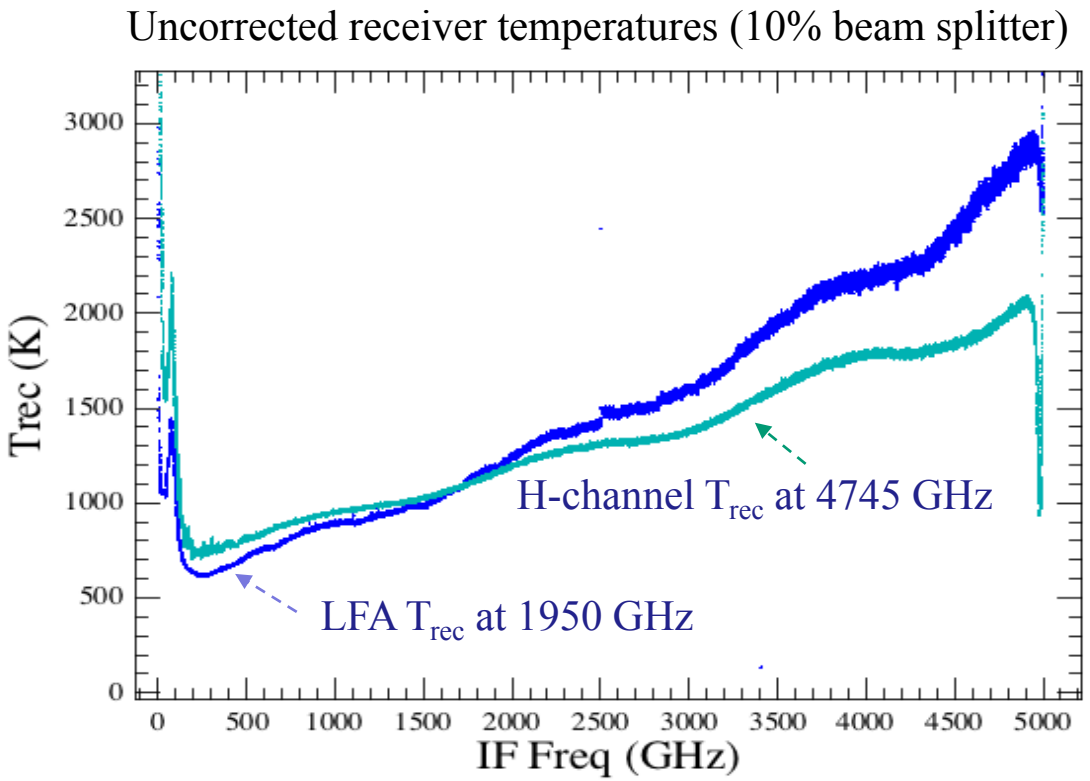


Receiver noise temperatures

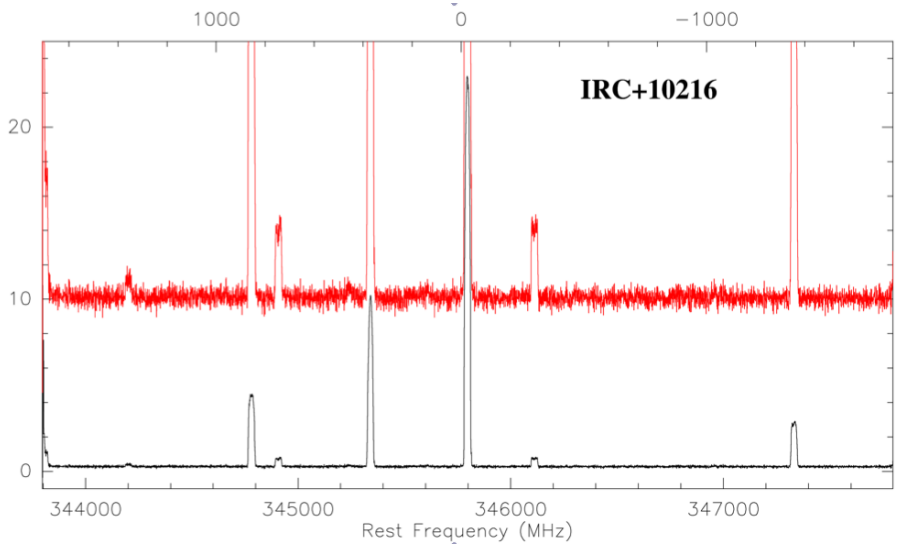
Novel mixers: waveguide-based HEB NbN devices on thin Si membrane (KOSMA)

- LFA: depending on available LO power, beam splitter or diplexer will be used
- HFA: beam splitter is baseline (based on successful operation of H-channel)



Key Technologies

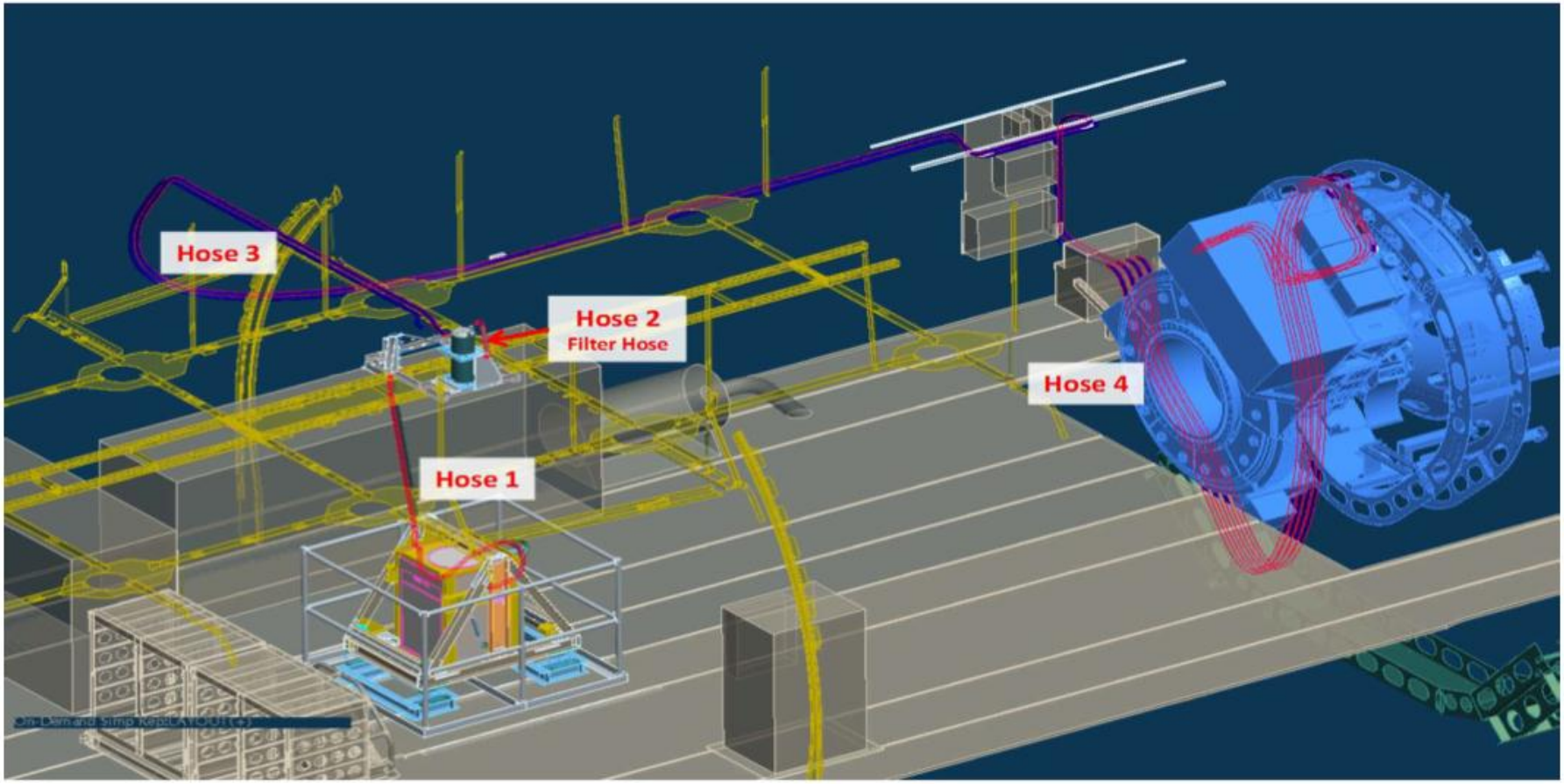
- Local Oscillators
  - Low Frequency Array
    - Photonic LO's (MPIfR)
    - Solid State LO's (Virginia Diode)
  - High Frequency Array
    - Quantum Cascade LO's (DLR & KOSMA)
- Wide Band FFT Spectrometers
  - Developed by MPIfR
  - 0 – 4 GHz Bandwidth
  - 64K Channels



Successful spectrometer demonstration on APEX telescope with a 345 GHz receiver

Cryo-cooler infrastructure

First closed-cycle cryo-cooler operation. Pulse tube coolers from TransMIT (Giessen, Germany) are customized for operation on board of SOFIA. Certification is ongoing.



Summary & Outlook

- The spatial multiplexing of GREAT (14x L2, 7x H) will greatly boost the science productivity of SOFIA
- SOFIA/GREAT will outperform Herschel/HIFI by an order of magnitude, and will carry spectroscopy into frequency regimes uncovered by HIFI.
- The next steps:
  - Shipment to Palmdale mid of March
  - Integration of upGREAT components in April 2015
  - Commissioning of 2x7 LFA pixels in May 2015 (flying with L1-channel)
  - HFA expecting commissioning slot in Q1/2016


http://www.sofia.usra.edu

Backup

Local Oscillators

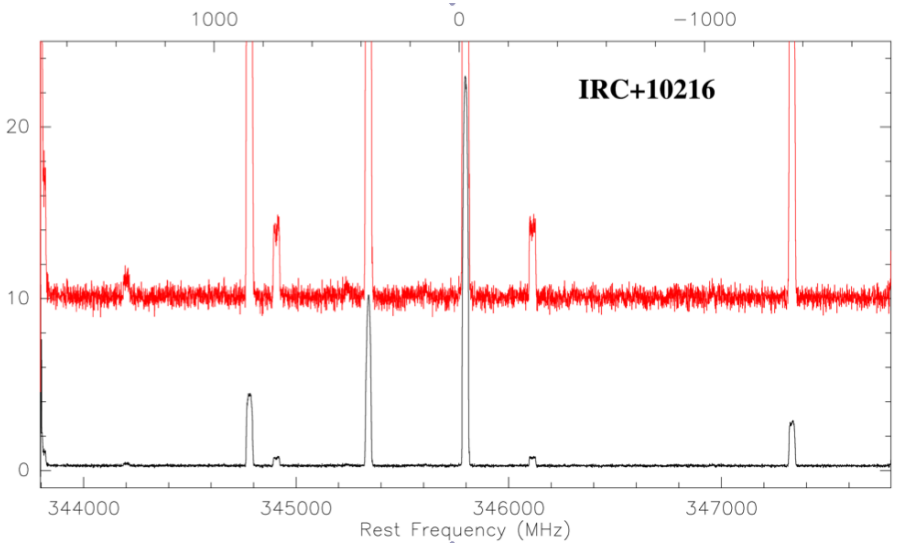
- For the upGREAT LFA, two developments are done in parallel:
  - Photonic local oscillators (MPIfR) – for wideband operation (1.9-2.5 THz)
    - current devices reach a few µW of output power
    - new design tests are ongoing – goal is >4 µW per HEB mixer
  - Solid-state LOs (VDI) for the lower band: 1.9-2.1 THz
    - 2 units operated in parallel, each pumping one sub-unit of 7 mixers
    - required power >30µW for 7 pixels, LO distribution via phase gratings
    - baseline configuration for LFA commissioning
- For the upGREAT HFA band, parallel developments of QCL technology by DLR-Pf and KOSMA groups:
    - LO power should be >100-200 µW
    - Successfully demonstrated in-flight operation of prototype in GREAT H-channel

wide-band FFT spectrometers

MPIfR
KOSMA
MPS
DLR-Pf

New generation of monolithic 4 GHz wide FFT spectrometers (MPIfR)

- design successfully verified during field operation at APEX
- works with 0-4 GHz instantaneous bandwidth with 64k channels
- production of boards completed, 21 units in final integration.



Successful demonstration on APEX telescope with a 345 GHz receiver