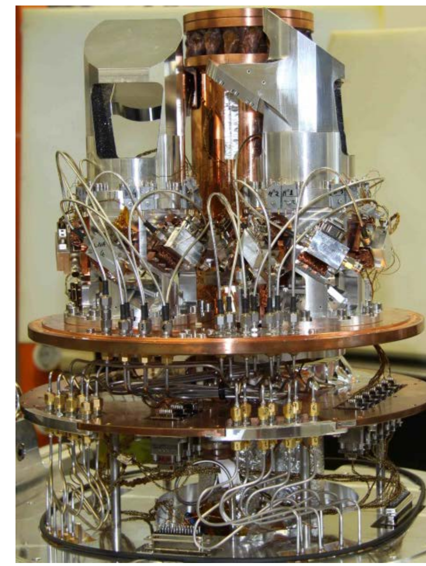
upGREAT : Status of the 1.9-2.5 THz heterodyne array receivers for SOFIA



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Outline

- upGREAT instrument overview
- upGREAT LFA performance, subsystems
- Karl J.: HEB mixer developments
- Objectives for commissioning, timelines
- Status of development, issues
- Availability of LFA, and operational constraints

GREAT/upGREAT Instrument Overview

MPIfR
KOSMA
DLR-Pf

Channel	Frequencies (THz)	Lines of Interest
low-frequency L1 a,b	1.25-1.50 (single pixel)	[NII], CO series, OD,HCN,H_2D^+
low-frequency L1 a,b	1.81-1.91 (single pixel)	NH_3,OH,CO(16-15),[CII]
mid-frequency M a,b	2.5 – 2.7 (single pixel)	OH($^2\pi_{3/2}$),HD
high-frequency H	**4.7 (single pixel)**	**[OI]**
upGREAT Low Frequency Array (LFA)	1.9 – 2.5 (14 pixels)	OH,[CII],CO series, [OI]
upGREAT High Frequency Array (HFA)	4.7 (7 pixels)	[OI]

- Two out of the 6 cryostats can be used simultaneously
- Channel availability:
  - All of the low frequency and mid frequency receivers are available and were used so far
  - High frequency single pixel channel commissioned successfully in May 2014 and first science observations performed in 05/14 and 01/15 with excellent instrument performance and science observations


GREAT receivers
Liquid Helium based cryostats
CryoVac


upGREAT receivers
Closed-cycle cooler (Pulse Tube)
CryoVac

upGREAT instrument 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) / solid-state chains (baseline)	Quantum cascade lasers (QCL)
LO coupling	Beamsplitter	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_{REC}	~600-1200K DSB 0-4GHz IF	~800-1600K DSB 0-4GHz IF
Backends	0-4 GHz with 16k channels	0-4 GHz with 16k channels

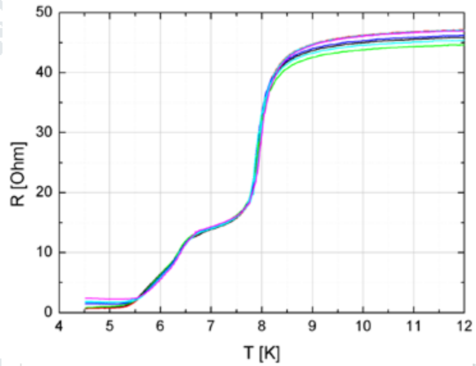
upGREAT HEB detector development

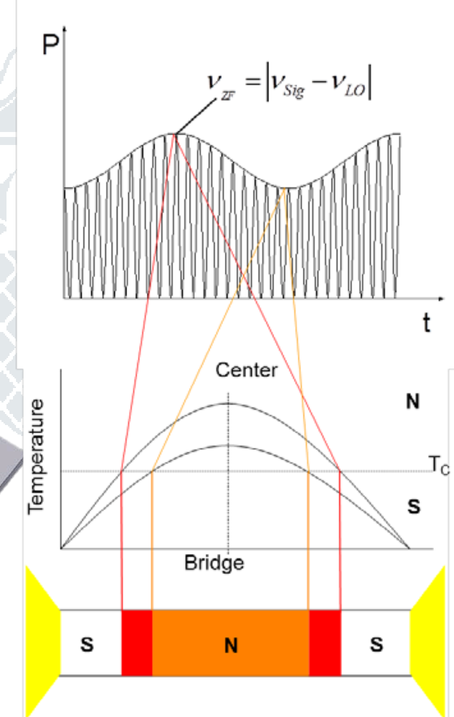
KOSMA, I. Physikalisches Institut,
Universität zu Köln
Netty Honingh, Denis Büchel, Patrick Pütz, Michael Schultz, Karl Jacobs

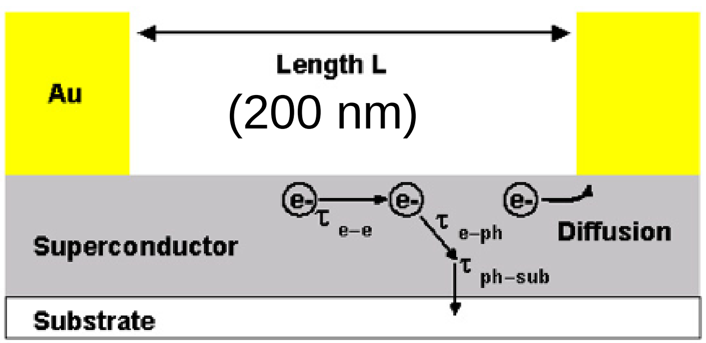
Superconducting HEB mixer

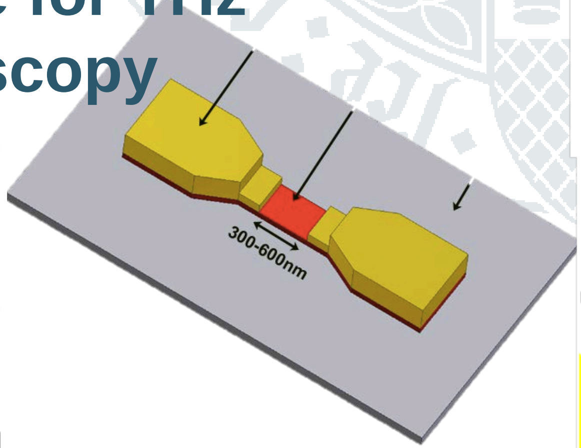
SIS mixers do not work above ~1.5THz !

- **hot-electron bolometer (HEB) (ultra-fast bolometer with strong electron-phonon coupling) used for mixing**
  - $\tau \approx$ 1E-10 s range (limit for IF bandwidth)
  - <5 nm NbN, NbTiN (~~Nb~~), quality crucial
- **breakthrough device for THz heterodyne spectroscopy**



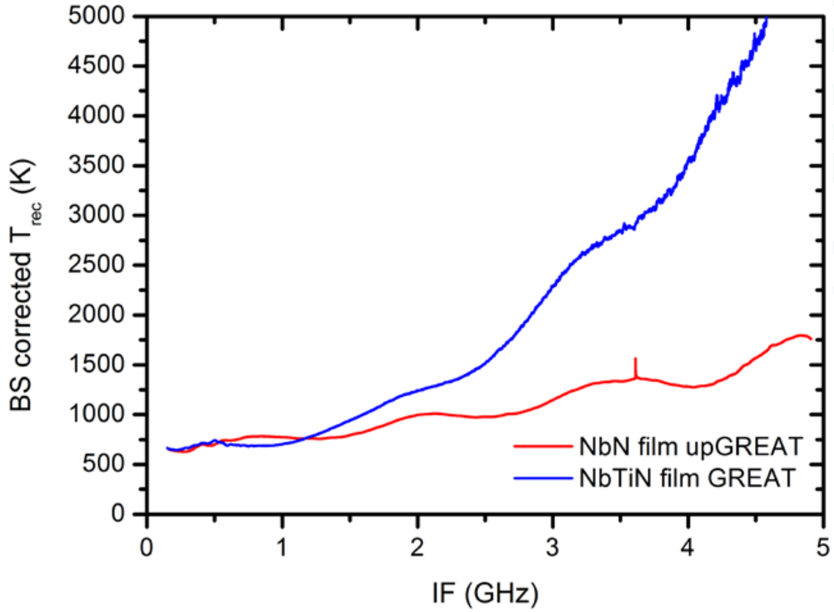






from GREAT to upGREAT:

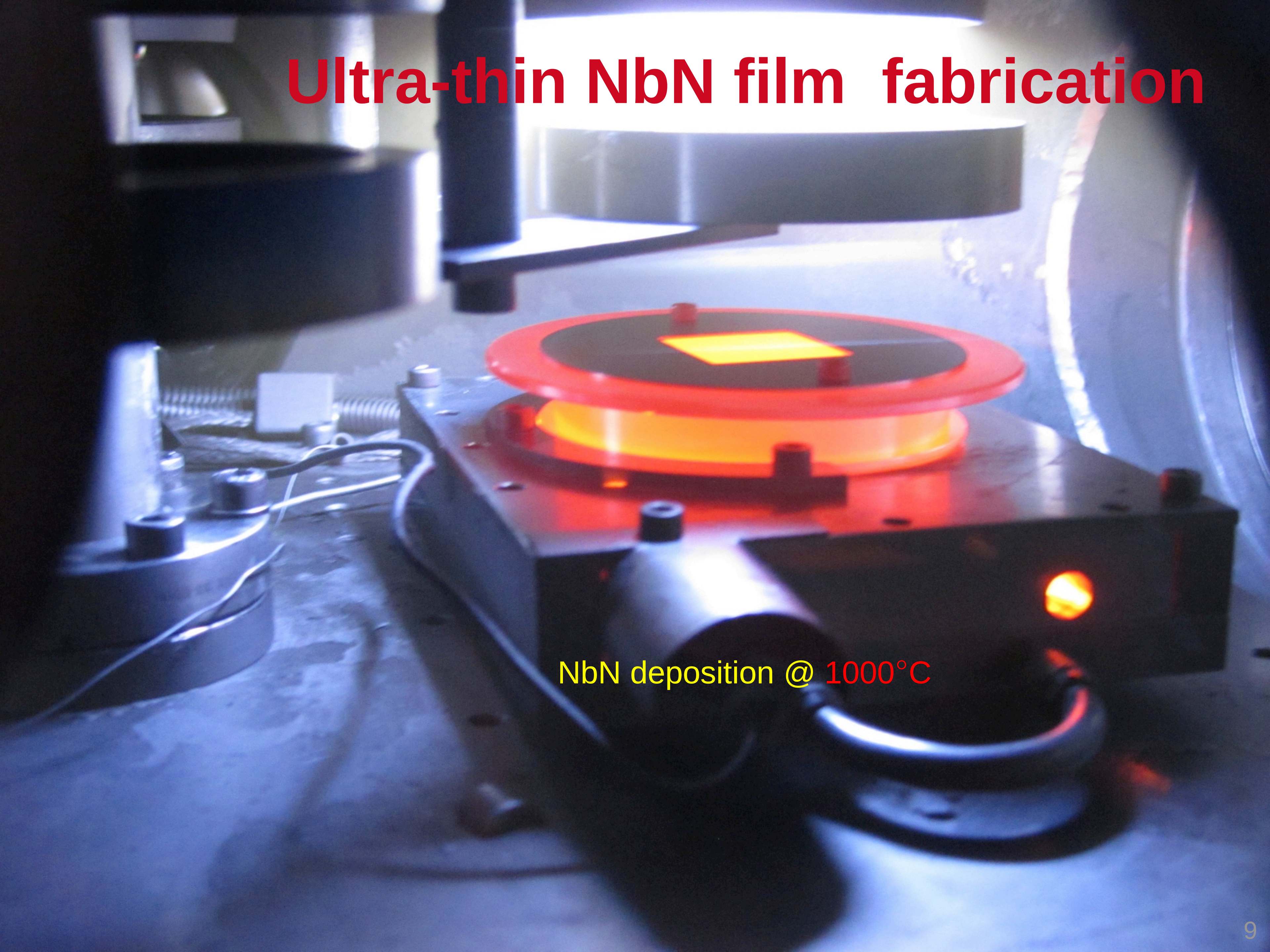
- selection process within consortium: stick with waveguide mixer concept (even at 4.7 THz) for beam quality, array capability
- wider IF bandwidth: switch from NbTiN to NbN



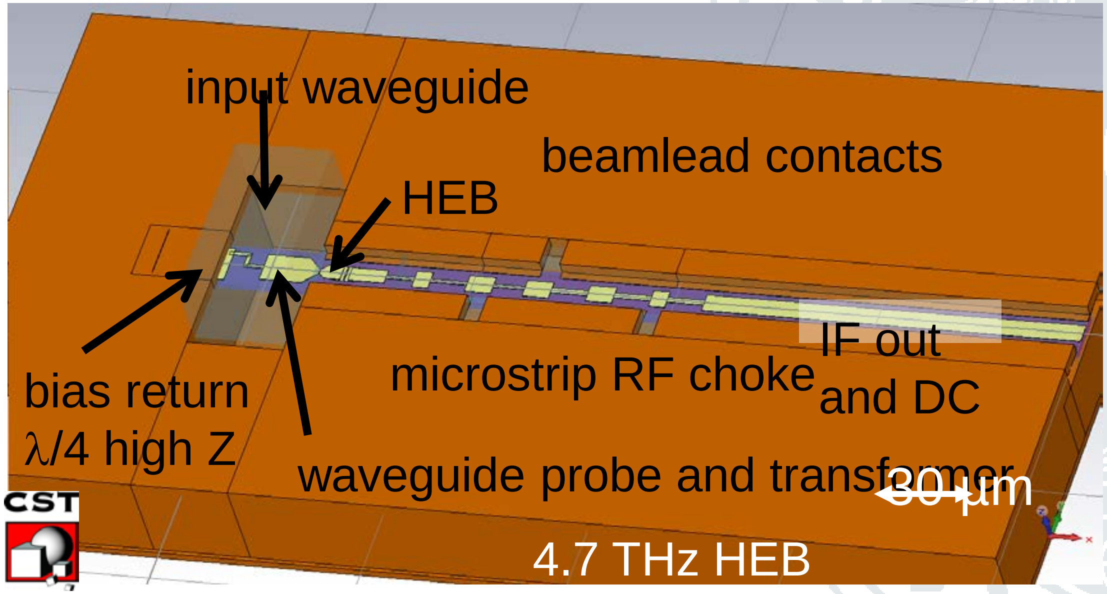
price to pay:
more LO power

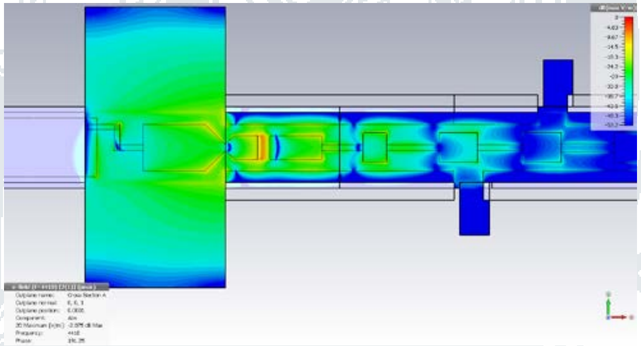
- All fabrication, including NbN films, at KOSMA

Ultra-thin NbN film fabrication



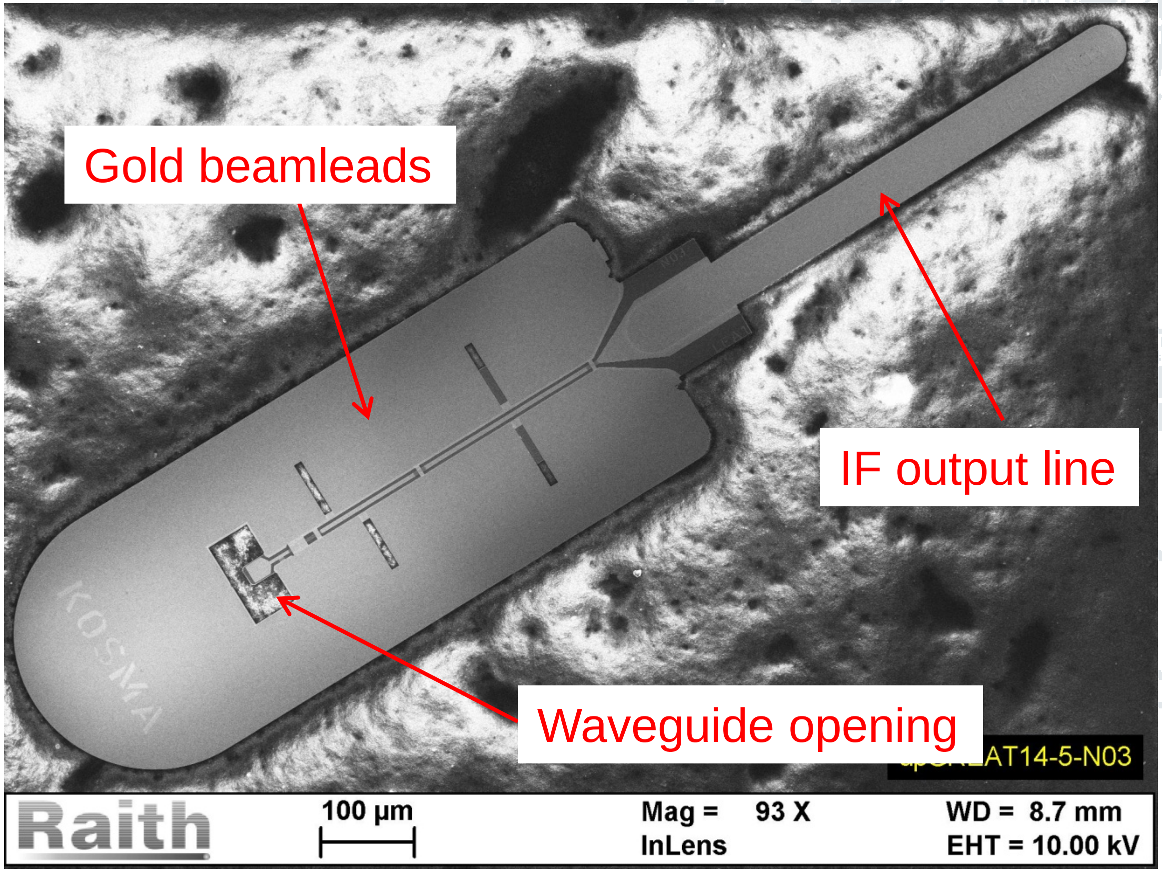
3D-EM THz circuit simulation



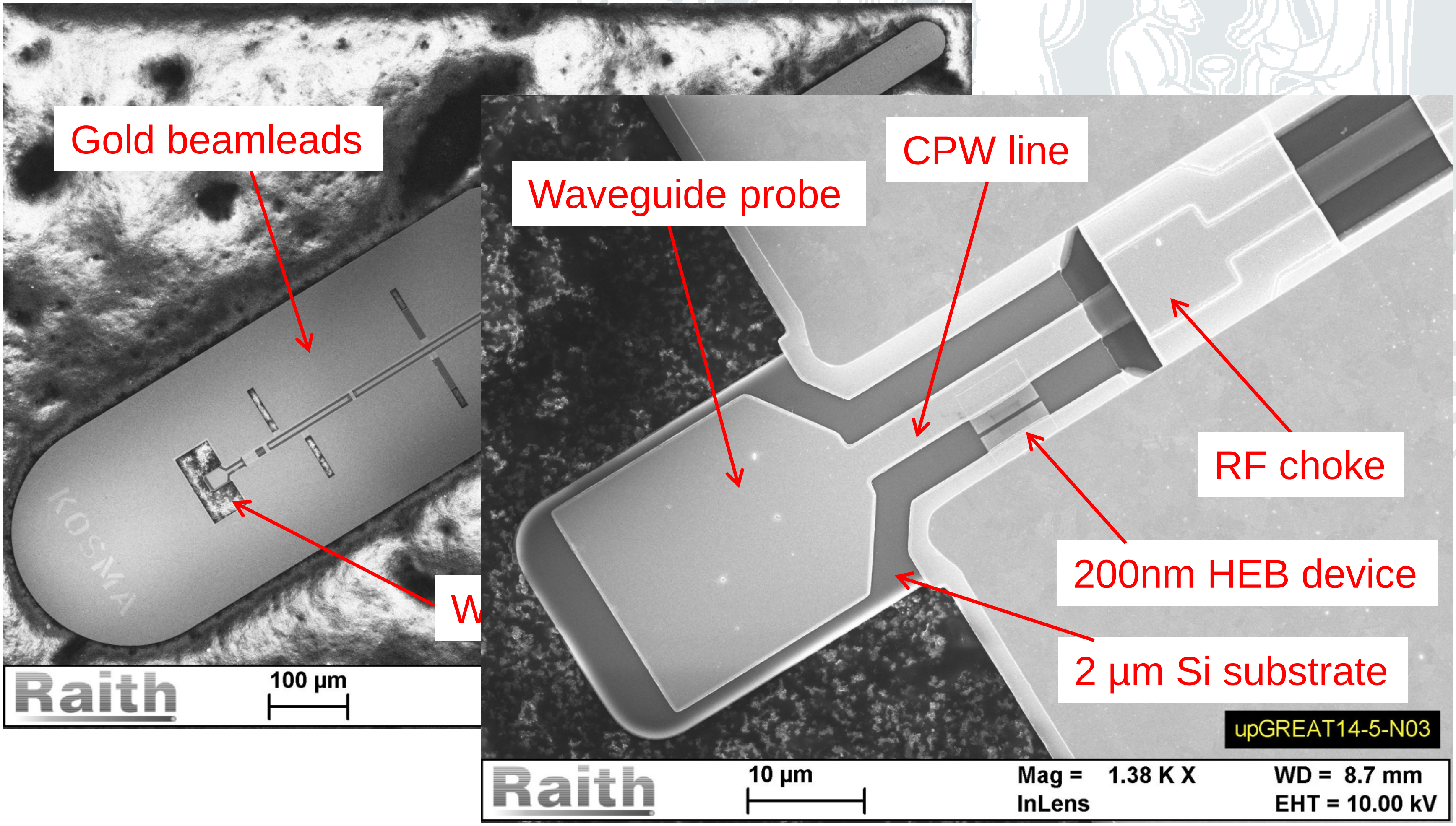


Thorough RF circuit design is crucial
THz characteristics of materials not well known
Physics of nonequilibrium NSN systems not well known
-> THz detector development still is its own research field

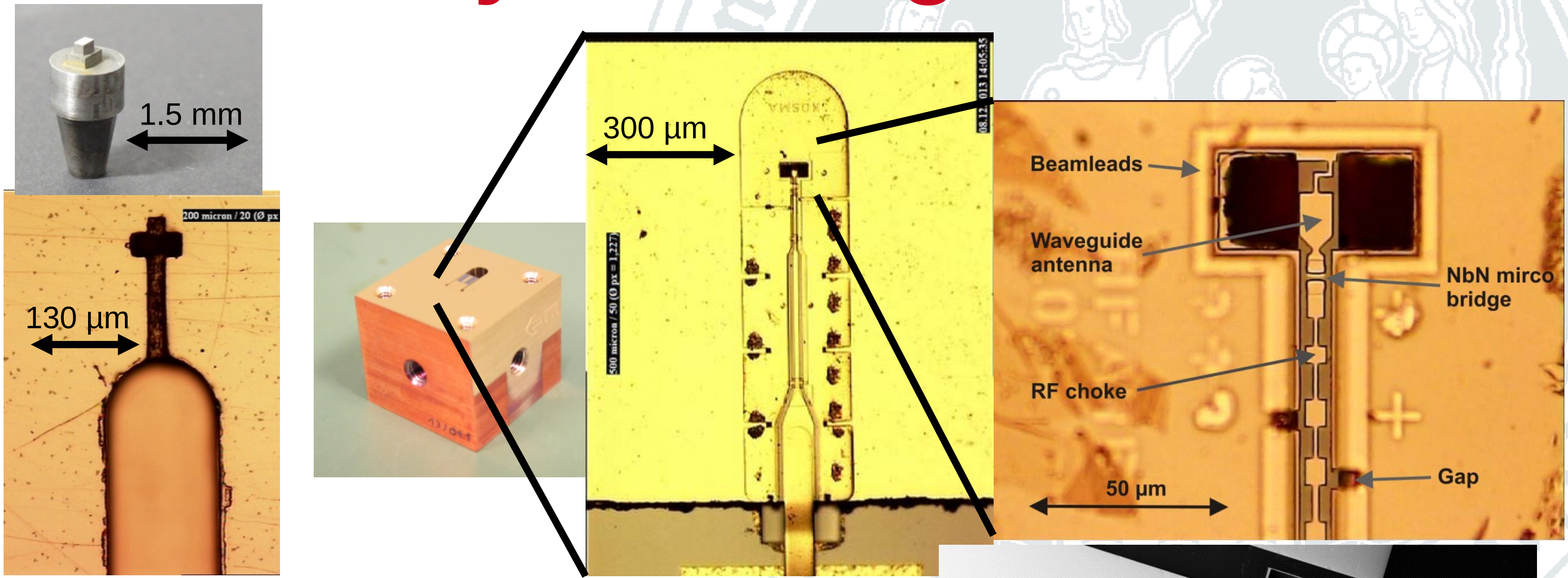
SEM picture: LFA Device



SEM picture: LFA Device

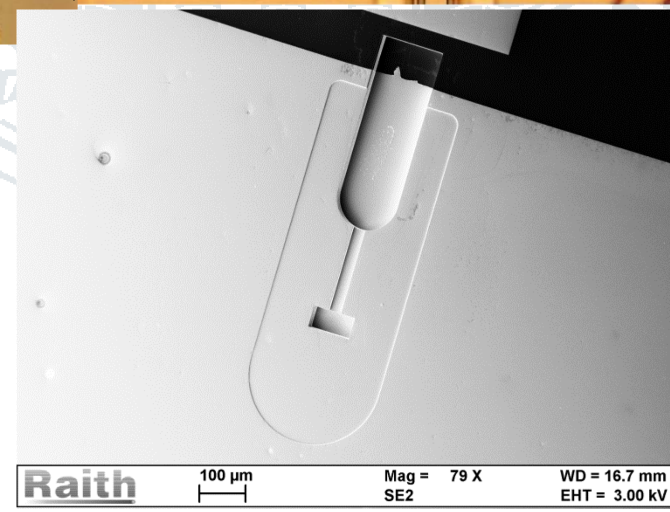


Assembly in waveguide block

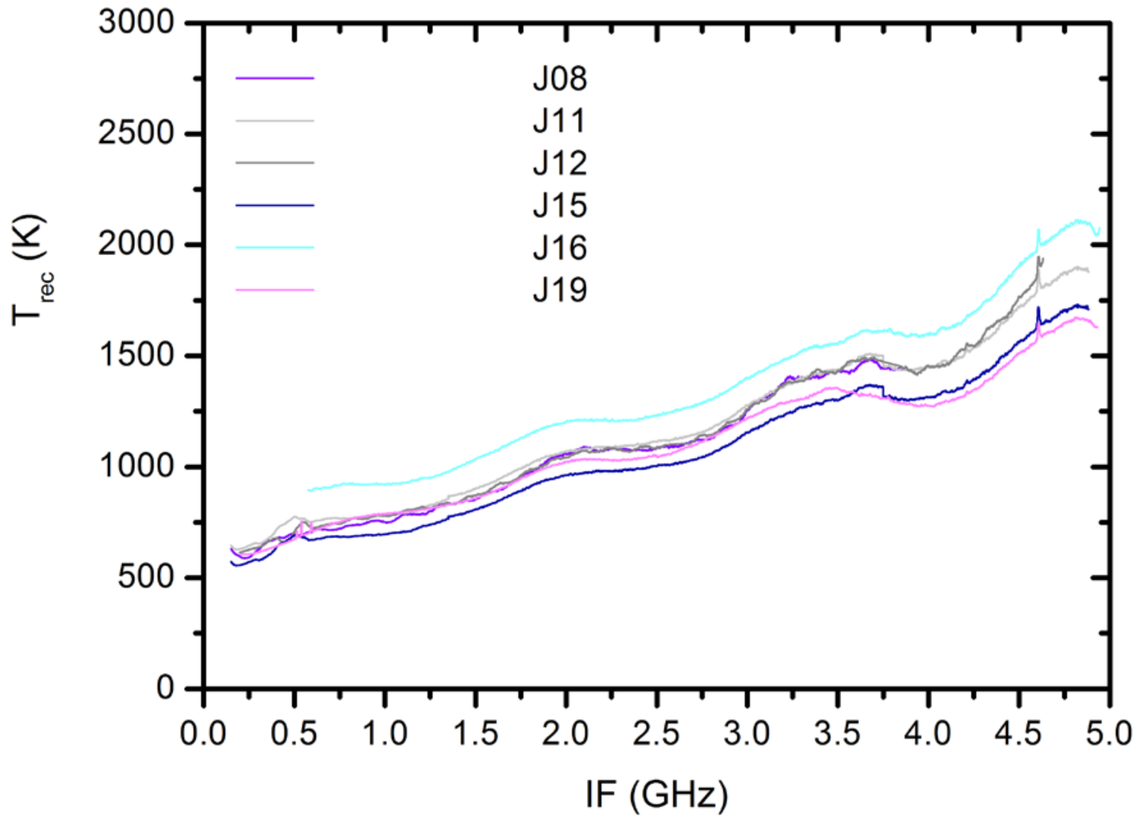


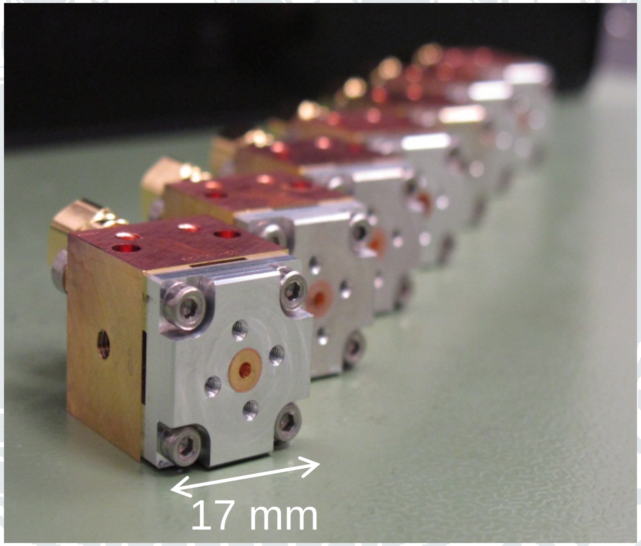
Waveguide 4.7 THz (50µm x 25µm)

May be replaced by Si micromachining for HFA array



LFA performance

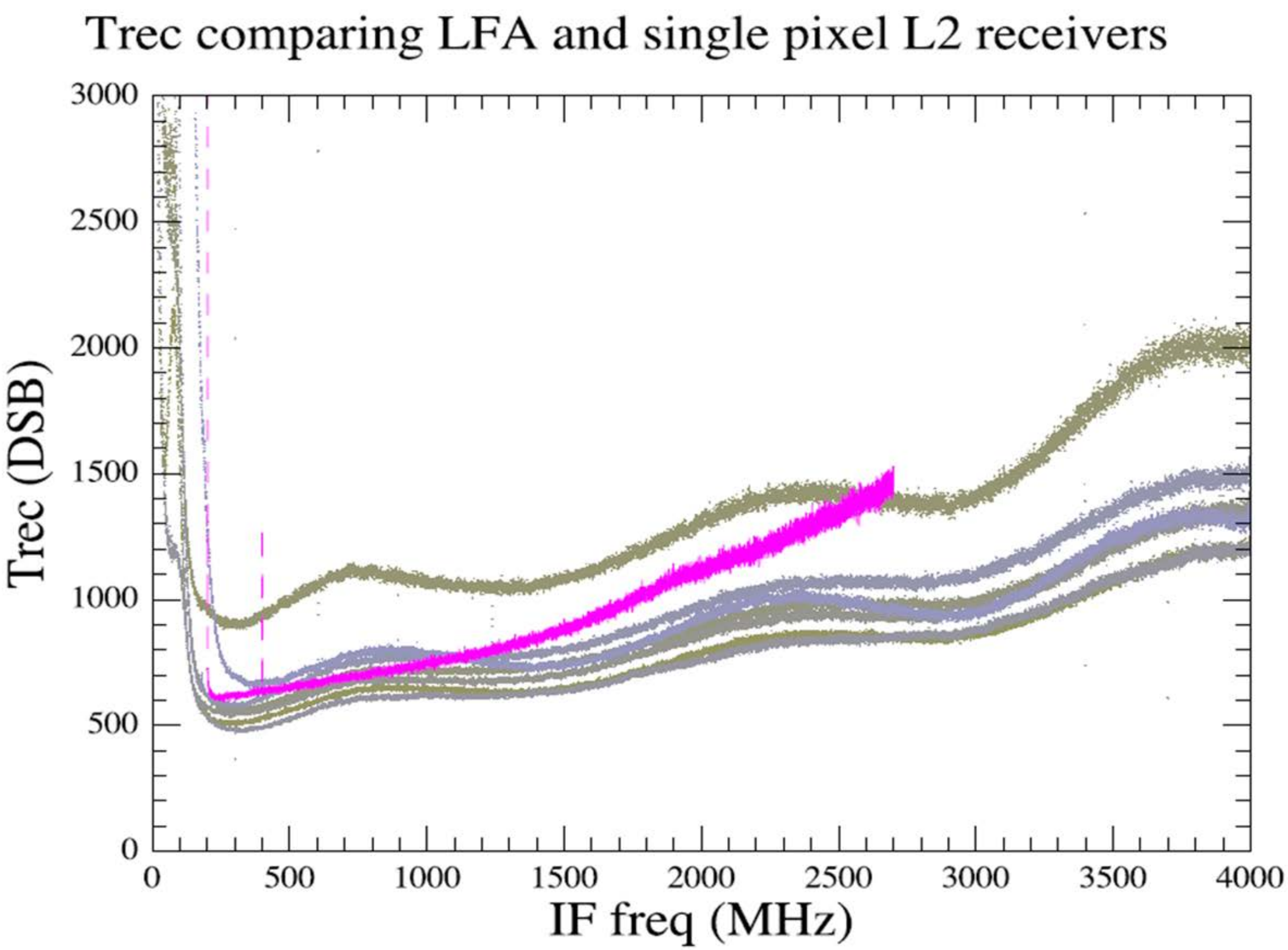




Performance better than our GREAT single pixel mixer (IF bandwidth larger!)
Largest collection of working 1.9 THz HEB mixers on this planet
(15 mixers delivered to project)

upGREAT LFA T_{rec} Characterization

MPIfR
KOSMA
DLR-Pf



Uncorrected noise temperatures for the 7 pixels in the H-polarization at ~1.9THz are 600-1400K between 0-4 GHz

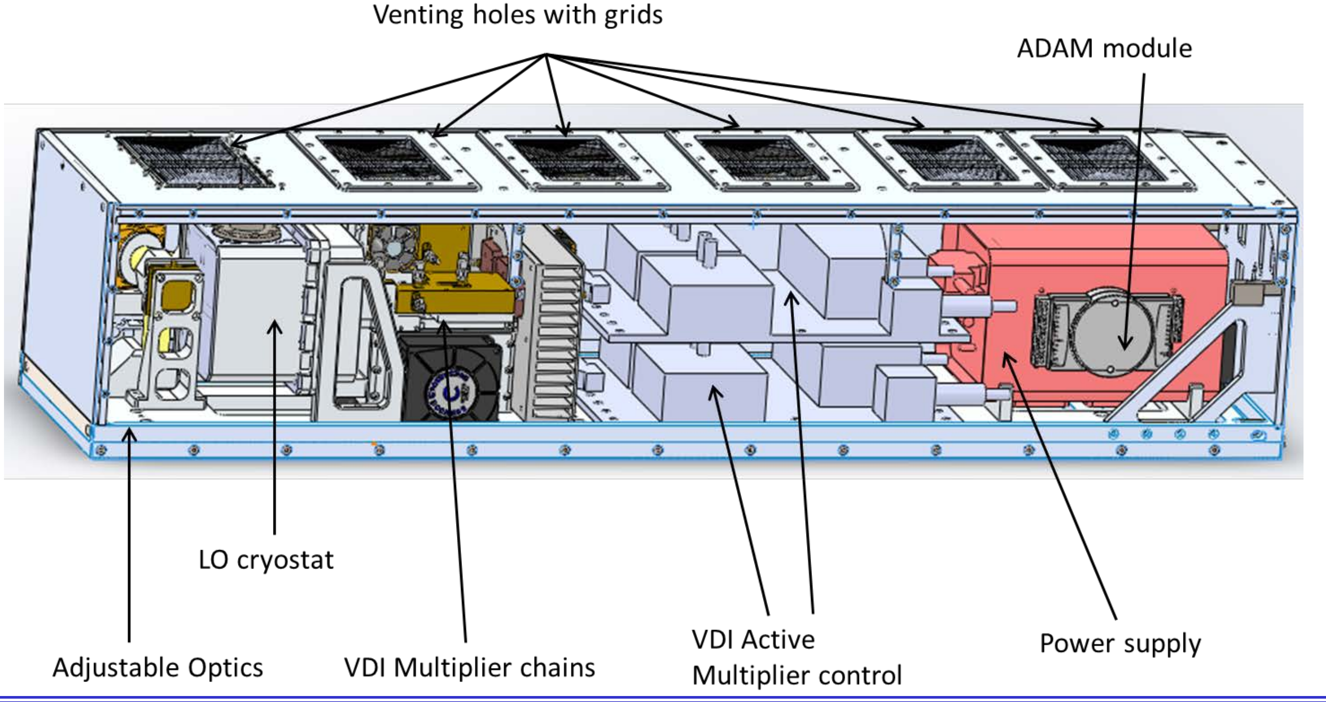
LO coupling is ~15% with beam splitter optics

A phase grating is used to separate the LO beam into 7 equal beams

LFA Local Oscillators

For the upGREAT LFA, two development are done in parallel:

- Photonic local oscillator – for 1.9-2.5 THz
  - current devices reach few µW of output power –
  - tests of new designs ongoing – goal is >4 µW for the LFA (per mixer)
- 2 solid-state LOs from VDI, for the lower band at 1.9 THz (CII line)
  - 20-30 µW available and close to 40-50 µW when cooling the last triplers

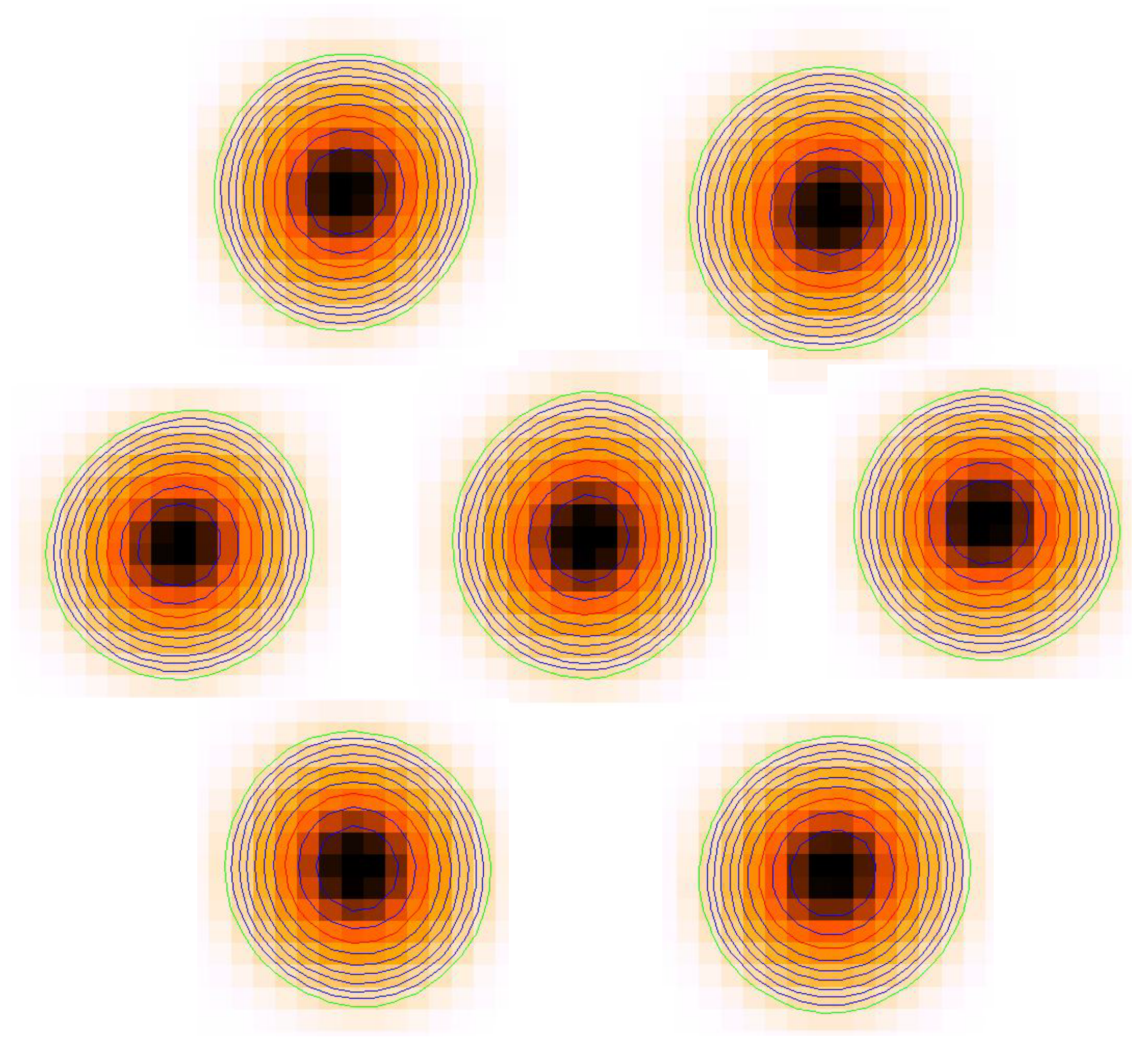


IF Processors – FFT4G spectrometers

The spectrometer technology developed at MPIfR now **achieves 0-4 GHz instantaneous bandwidth** with up to 64K channels (16K used for the commissioning).

The IF processor is capable to handle 21 channels with an IF from 0-6 GHz. To accommodate the 0-4 GHz FFT4G spectrometers, 4 GHz low pass filters will limit the IF input range to 0-4 GHz

Beam characterization

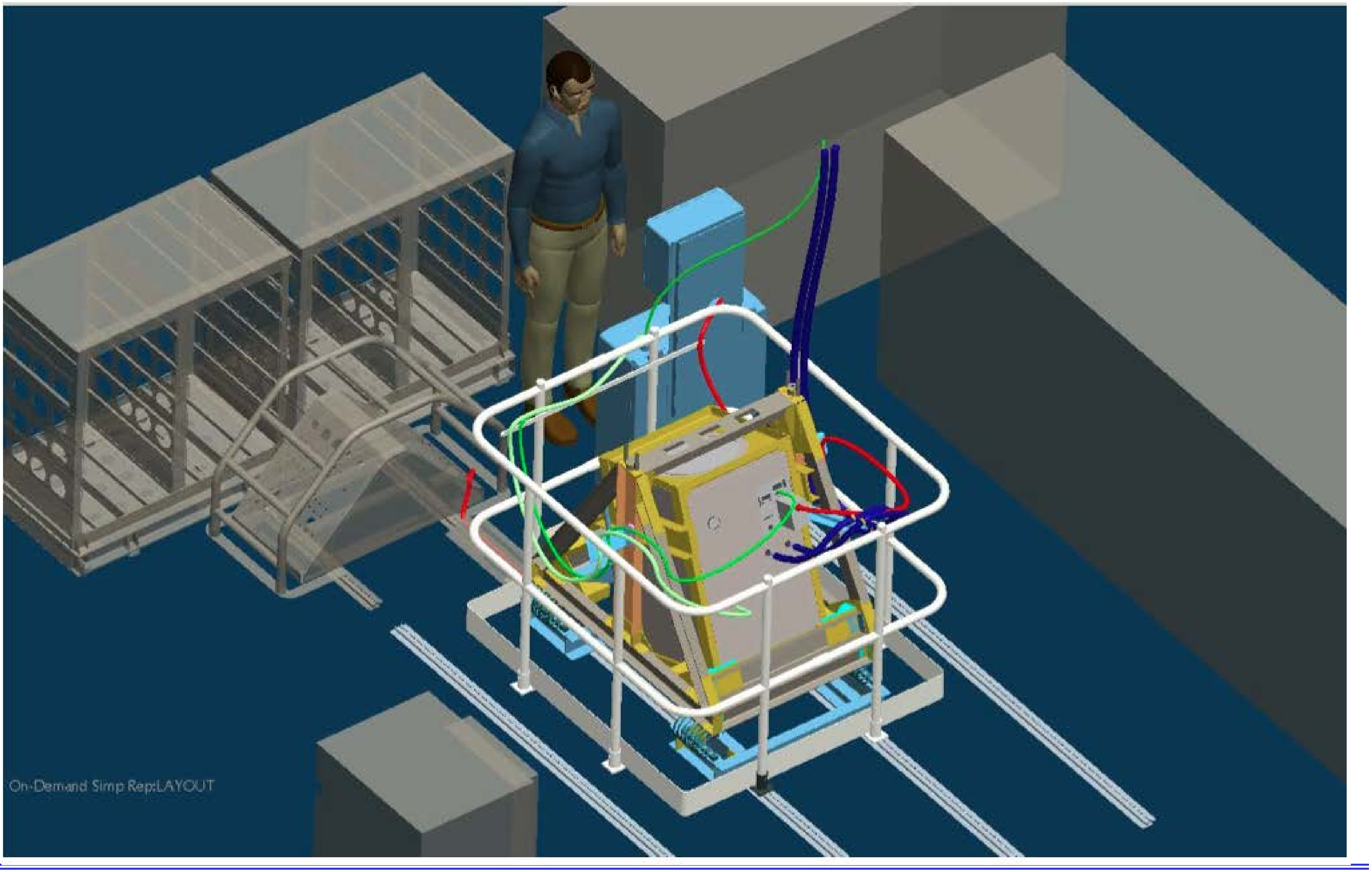


Optics beam verification confirms that beam waists and positions are as designed (13dB edge taper chosen)

Beams are nicely circular, confirming that the smooth walled spline horns built by RPG are performing as expected

Left: superimposed beam profiles for the 7 pixels in the H-polarization sub-array

Cryocooler Infrastructure aboard SOFIA



Readiness for Commissioning

- pre-shipment tests successfully completed (ex LO cross-talk, see below)
- upGREAT/LFA currently being packed, shipment end of this week
- April & early May: de-install GREAT and re-integrate with new hardware

- 4 commissioning flights in mid May 2015
- if commissioned successfully, LFA (7) can be conditionally included in call for cycle 4 proposals

- post-flight: re-install single channels (L2, H) for NZ deployment

- Δ-commissioning of LFA in Dec 2015 (optional, goal: 7+7 pixels)

- HFA commissioning only 2Q/ 2016 (flying LFA cryo-infrastructure)
- pending installation of full cryo infrastructure by NASA, combined LFA&HFA flights in 2nd half 2016 will conclude upGREAT commissioning

Status of instrument

- All subsystems comply to baseline requirements, except the LO units:
  - In autumn we noticed spures/excess noise in the new solid-state local oscillators from VdI, traced back to an oscilling doubler. Corrective action (processing new design) by VdI failed last week.
  - In effect, this means we can operate the 2 LO chains separately, but not in parallel (cross-talk between carrier and oscillations).
- We should still be able to achieve our commissioning objectives, but we cannot operate the two sub-arrays (7+7) simultaneoulsy on sky.
- Timeline for repair of the 2 LO units by VdI is summer/autumn. They share a strong commitment to have these issues solved in time for the first science operation of upGREAT (as early as Dec 2015)
- recovery plans, should there be a fundamental design issue:
  - modify foreoptics to avoid overlapping LO beams
  - use both GREAT instrument ports to operate sub-arrays independently

What to expect for Cycle 4 ?

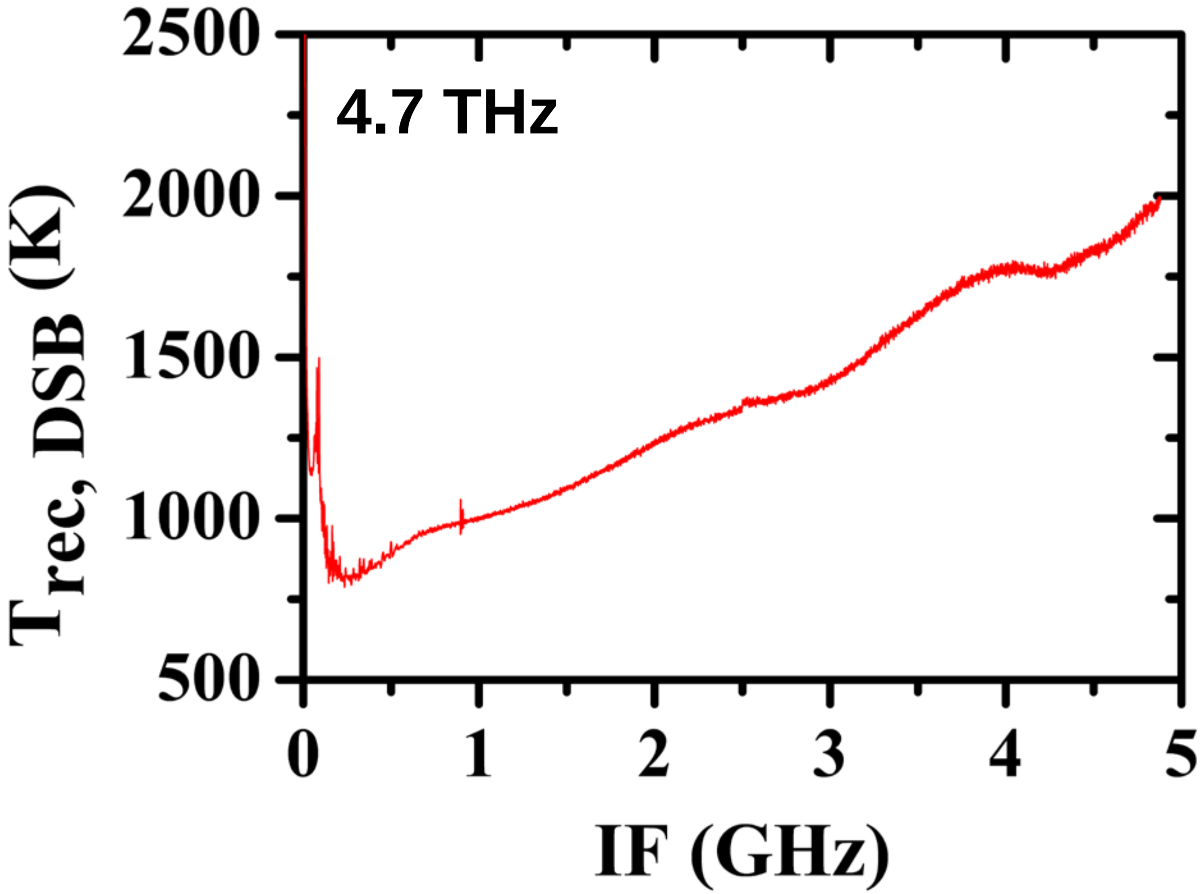
- Pending agreement about new MoU, you may assume that upGREAT/LFA will be included in the Cycle 4 call for proposals (shared risk).
- Use uncorrected Trec at 1.9 THz of 500-1000K DSB between 0 – 4 GHz IF range, but as baseline assume only one polarization will be operational.

Given its superior performance per pixel, for observations of the [CII] line the upGREAT/ LFA will be more than 7x faster than the current L2 channel

Observing modes: assume that upGREAT/LFA will be operated much like the CHAMP array at the APEX

- de-rotating on sky (here with a K-mirror)
- in the standard observing modes (OTF, position and beam switched)

HFA prototype (GREAT H channel)



Compare to Trec ~ 70.000K of Boreiko & Betz (1996)