SFB 956
Cologne | Bonn

CCAT-prime first-light instrumentation

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&

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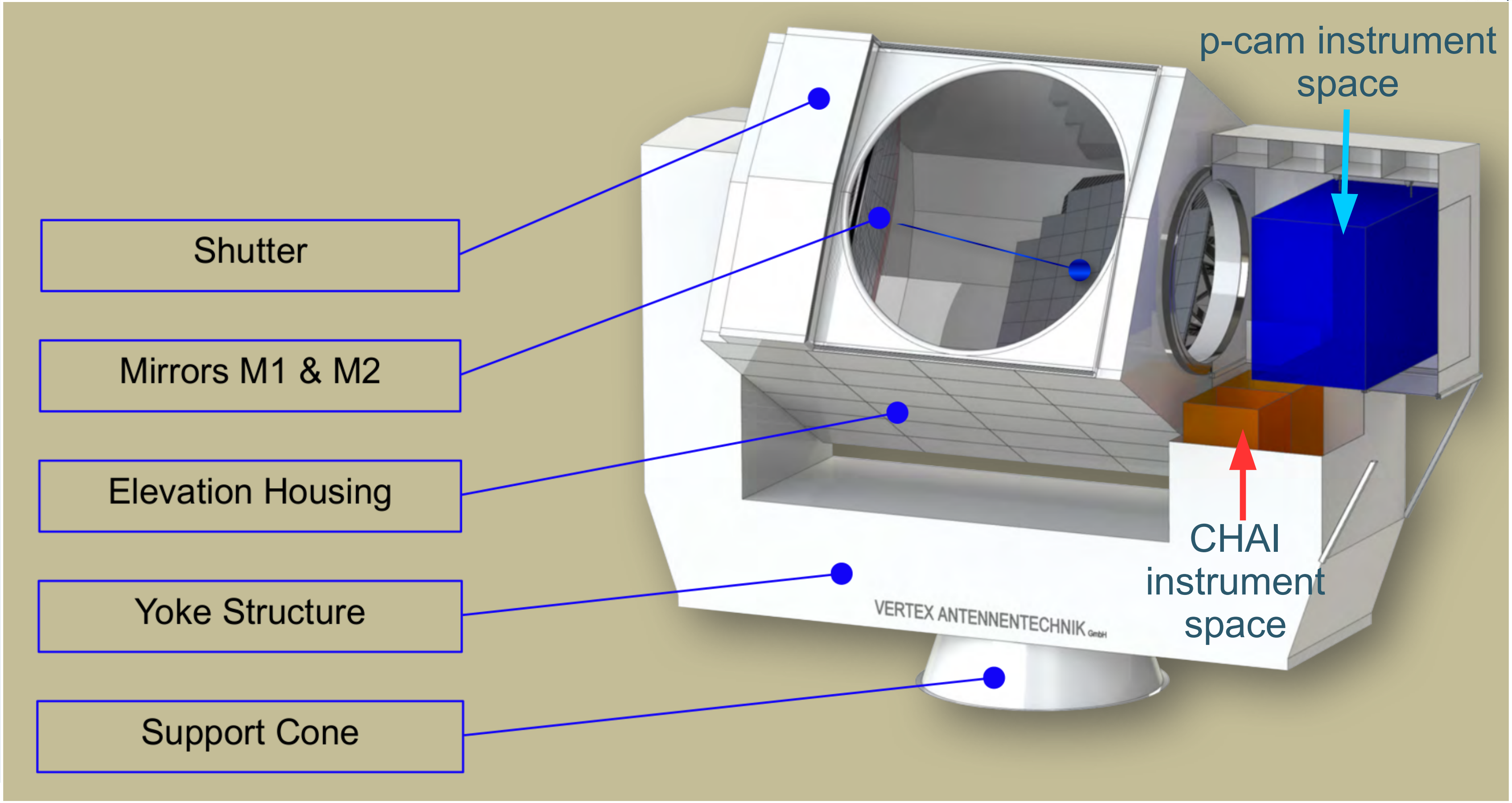
- **CHAI**
  - high spectral resolution imaging at two frequencies
  - heterodyne detection principle
  - new technology: large format array
- **p-Cam**
  - multi-wavelength large format camera
  - direct detection bolometers
  - extension with Fabry-Perot-Interferometer spectral filtering

CCAT-prime Science (priority science cases)

- **GEco:** Star formation in the Milky Way, the Magellanic clouds and other nearby galaxies through submm spectroscopy and photometry
- **kSZ:** Probing of the nature of dark energy, gravity on large scales and neutrino mass sum through kinetic SZ effect
  - *Polarization studies as well: Galactic dust science & CMB poln corrections*
- **GEvo:** Evolution of Dusty Star Forming Galaxies through submm-mm wave surveys.
- **IM-EoR:** EoR intensity mapping in [CII] at redshifts from 5 to 9.
- **Stage 4 CMB:** CMBR polarization at 10 times the speed of current facilities
  → inflationary gravity waves and the sum of the neutrino masses.

- **Science Case 1** enabled by heterodyne instrument and first light camera
- **Science Cases 2, 3, and 4** are enable by first light camera

- **Science Case 5** will be enabled by the second generation camera and the large FoV of the telescope itself

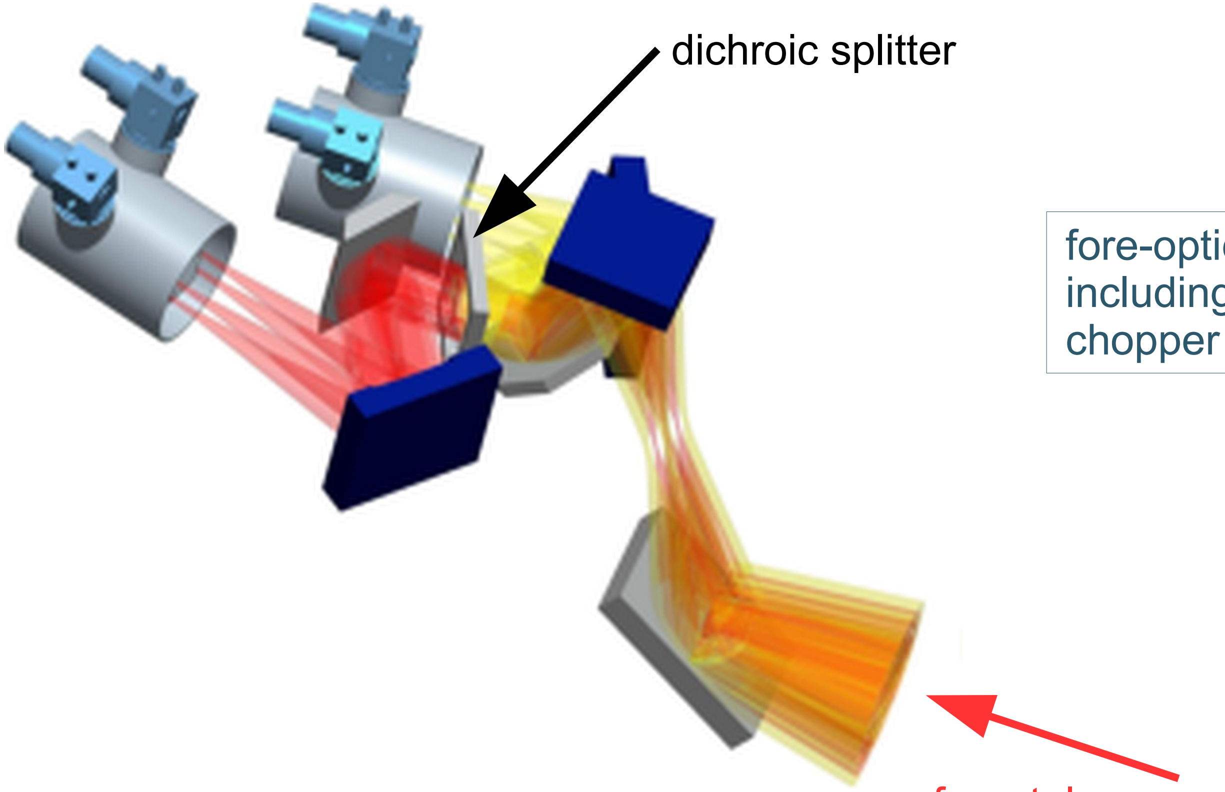

Shutter
Mirrors M1 & M2
Elevation Housing
Yoke Structure
Support Cone
p-cam instrument space
CHAI instrument space
VERTEX ANTENNENTECHNIK GmbH

CHAI – CCAT Heterodyne Array Instrument

- high spectral resolution mapping of ISM in Milky Way and nearby galaxies
- simultaneously two frequency bands
  - 460-490 GHz (600 µm): CO J=4-3 and [CI] J=1-0 (either/or)
  - 800-830 GHz (370 µm): CO J=7-6 and [CI] J=2-1 (simultaneously within 4 GHz IF) band)
- 2 x 64 pixels in total (expandable by modular design; limited by cost)

- lead by Universität zu Köln
  - collaboration with
    - MPIfR Bonn (digital backends)
    - Universidad de Chile t.b.d. on funding availability
  - Cologne/Bonn funding DFG/SFB 956

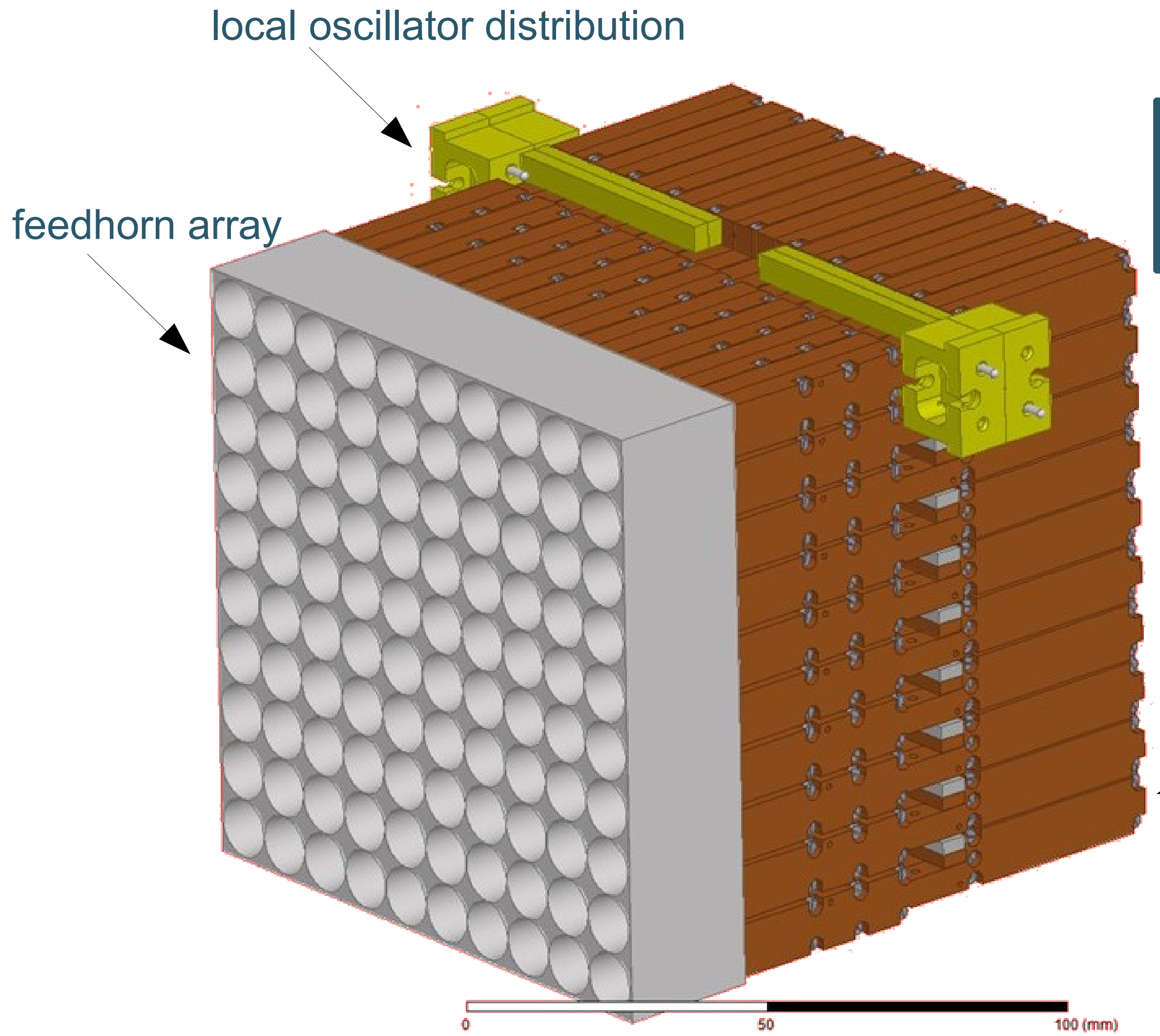
CHAI optics layout (U. Graf, UzK)



fore-optics possibly including focal-plane chopper

CHAI Optics for L-band and H-band Dewar

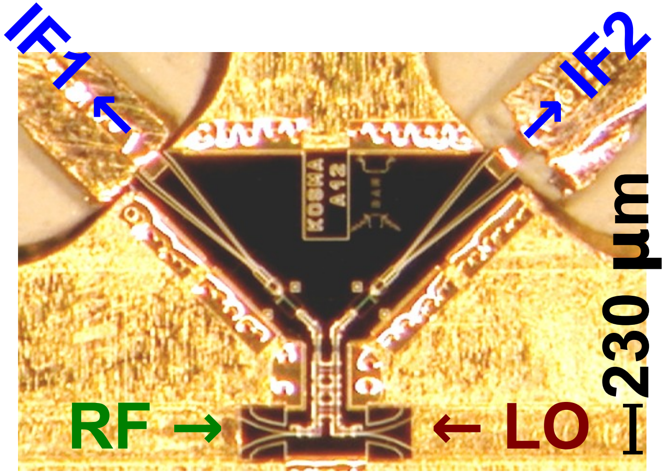
CHAI detector block (64 pixels) (N. Honingh, K. Jacobs)

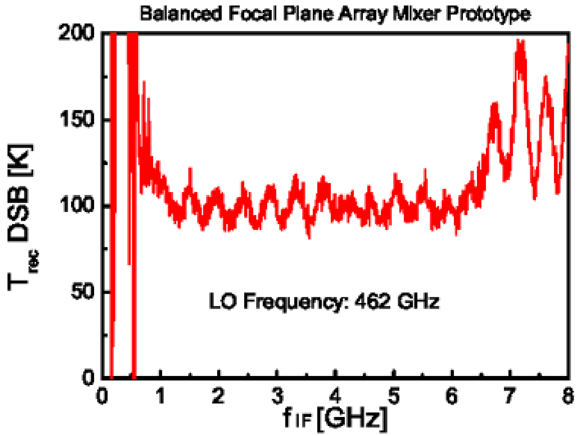


very challenging
ultra compact design

On-chip balanced SIS at 490 GHz

under development
- SSB
- 810 GHz balanced

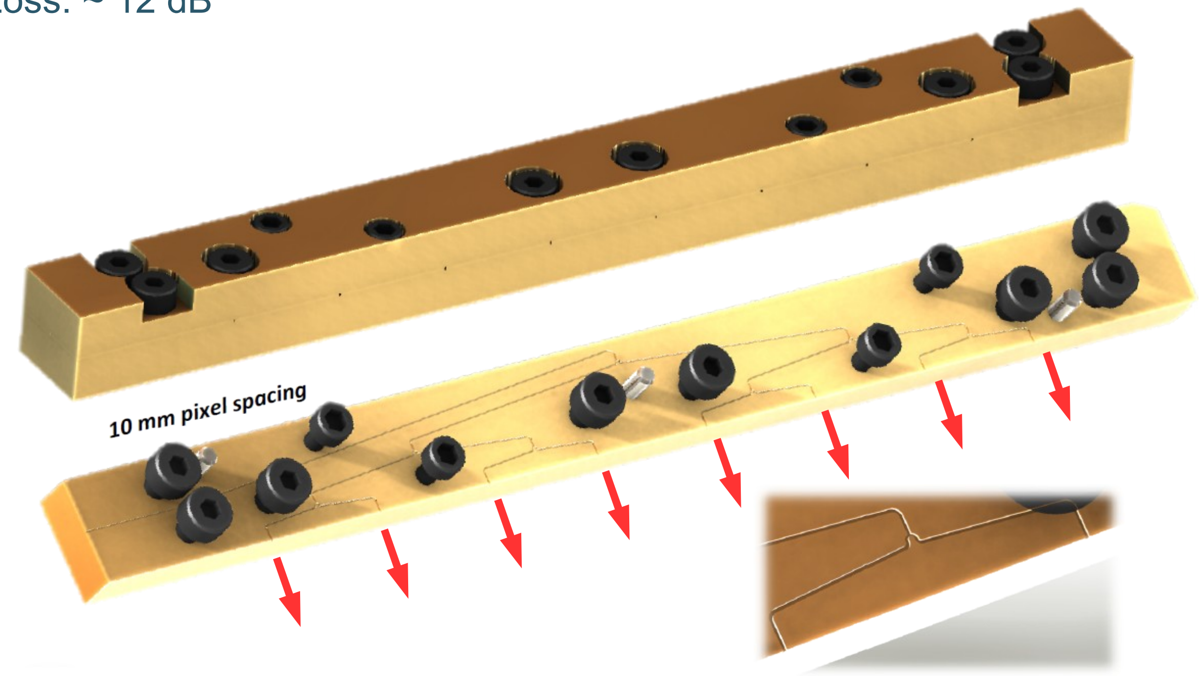




Local Oscillator distribution

pictures:
concept study by JPL (former partners)

Overall dimensions: 100mm x 8.5 mm x 8mm
Bandwidth: 730-900 GHz
Insertion Loss: ~ 12 dB



CCAT-prime first-light instrumentation
(AG-2017; CCAT-prime splinter meeting)

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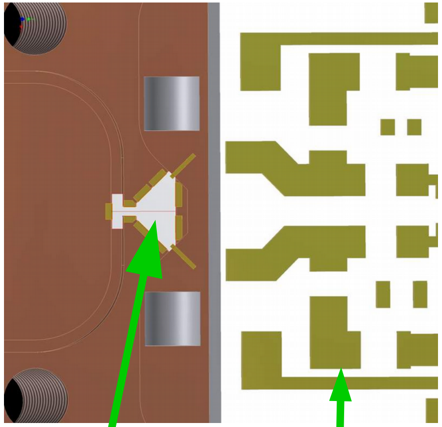
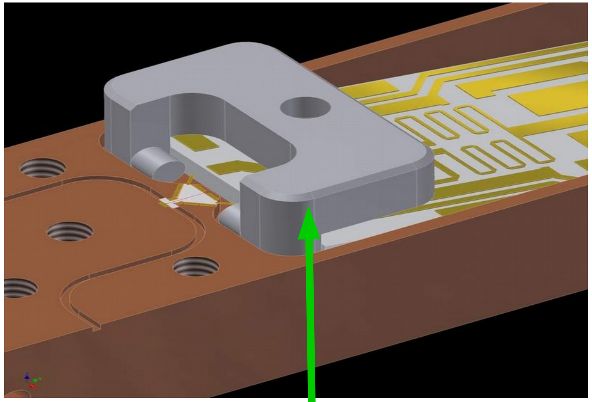
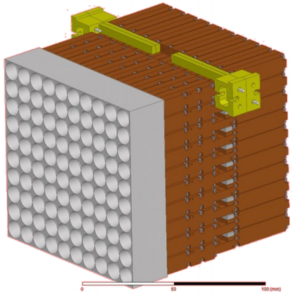
Universität zu Köln

mixer block (details)



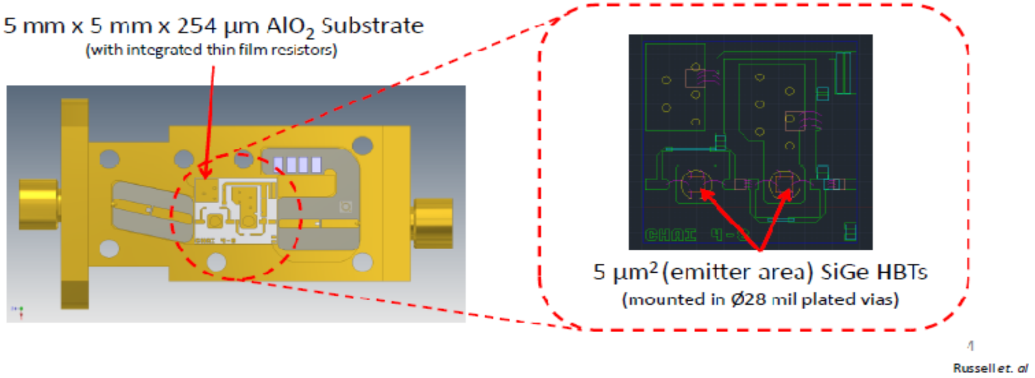




cryogenic amplifier (CalTech)

fits behind 10x10mm footprint

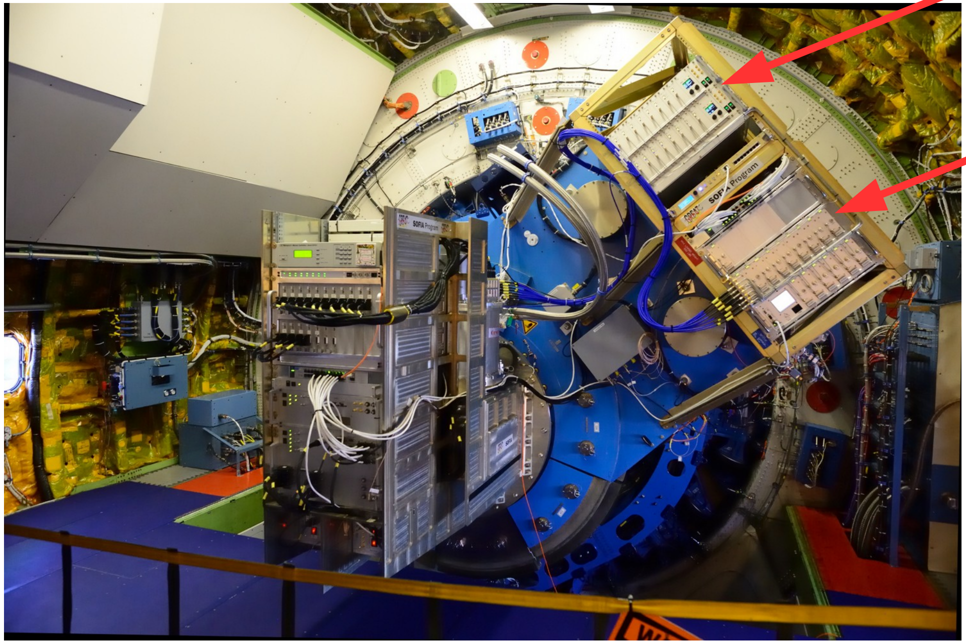
SIGe LNA



digital Fast-Fourier Transform spectrometer backends

- rapidly progressing technology
- in routine operation at APEX and on upGREAT/SOFIA (21 units)
- 2 x 4 GHz IF coverage, 16k channels each

upGREAT on SOFIA



dFFTS backends (16 units)

warm IF processor

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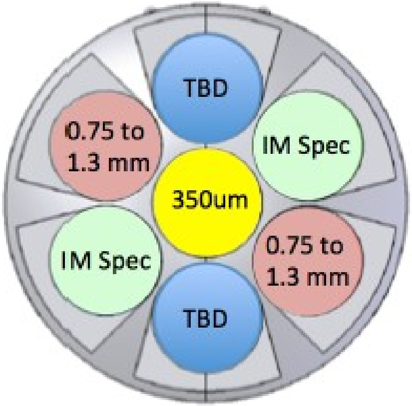
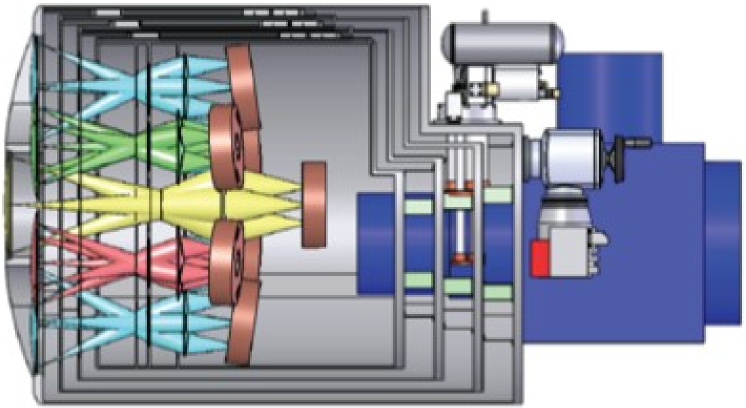
- **CCAT-p/CHAI science perspectives**
  - **see follow-up talks and posters**
    - **talk by R. Simon: CCAT-prime GEco science case**
    - **posters by M. Ziebart and C. Bruckmann**
    -

p-Cam First Light Instrument

- Design is similar to SWCam (CCAT-25 m), but likely with 45 cm rather than 30 cm diameter field lenses ↔ 0.9° (30 cm) or 1.5° (45 cm) FoV per tube
- First light instrument to have 7 optics tubes illuminating up to 3 or 4 - 15 cm diameter detector wafers each
  - Initial version likely has 3 to 5 tubes due to limited resources but is upgradeable to 7 tubes in a tube by tube manner *on the telescope*.
  - 2 to 4 tubes with 4-color (0.75, 0.86, 1.1 & 1.3 mm) bolometers
    - 1-2 tubes for [CII] intensity mapping z = 3.3 to 9
    - 1-2 tubes for multiband polarimetry for cluster science
  - Central tube for 350 μm work (Dusty Star Forming Galaxies and cluster)

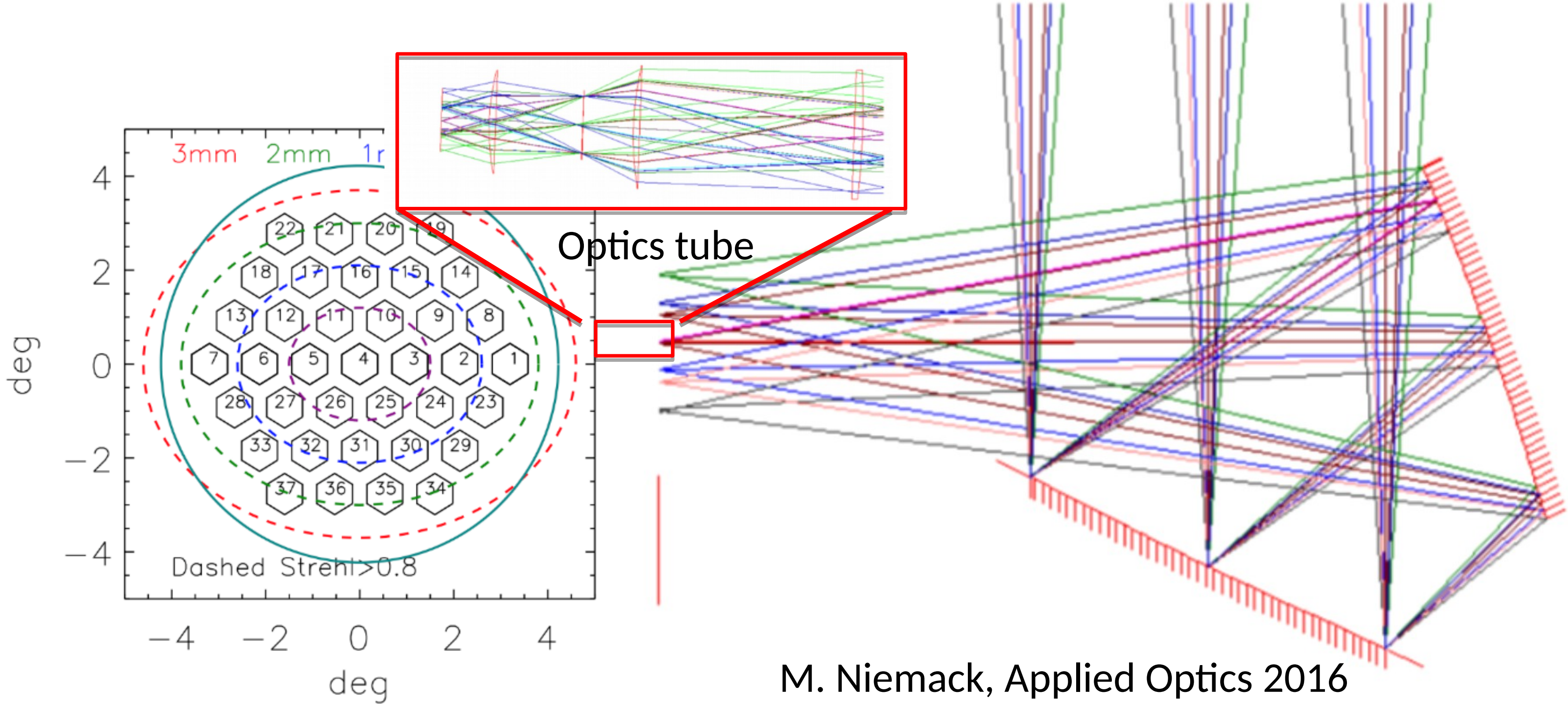




0.9 m diameter optics tubes are mostly enclosed in Strehl>0.8 (diffraction-limited)

3 mm = 37 OT	26,000 pixels
2 mm = 33 OT	58,000 pixels
1 mm = 19 OT	110,000 pixels
0.35 mm = 7 OT	400,000 pixels

"Ultimate Instrument"

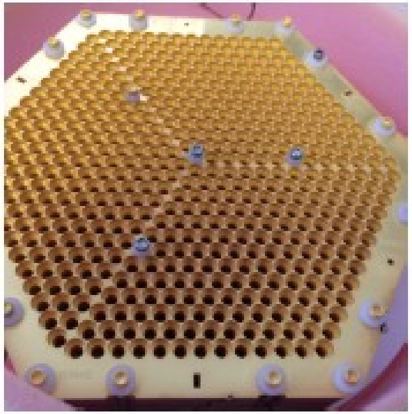


M. Niemack, Applied Optics 2016

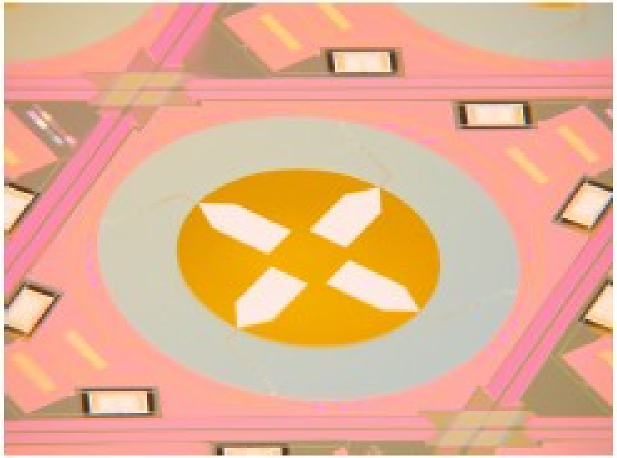
The Focal Plane

- TES bolometers with simultaneous feeds to 740 µm, 860 µm, 1.1 mm and 1.3 mm
- Being developed by McMahon at U. Michigan who is collaborating on program
- Polarization sensitive with 4 bands per feedhorn: requires 8 TES detectors per horn
- Microwave SQUID readout being worked on in Niemack's group (Cornell)
- Still need to nail down things like pixel spacing for optimizing science
- 350 um band requires different technology, e.g. MKIDs

Multichroic feedhorn array

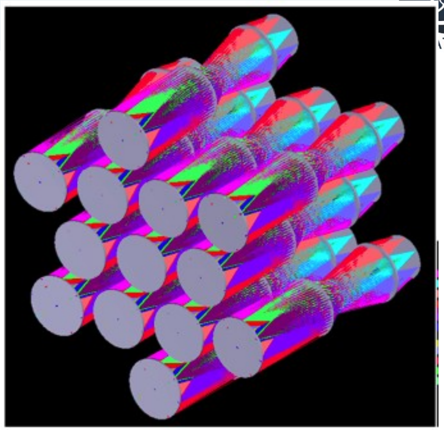


2 band multichroic detector



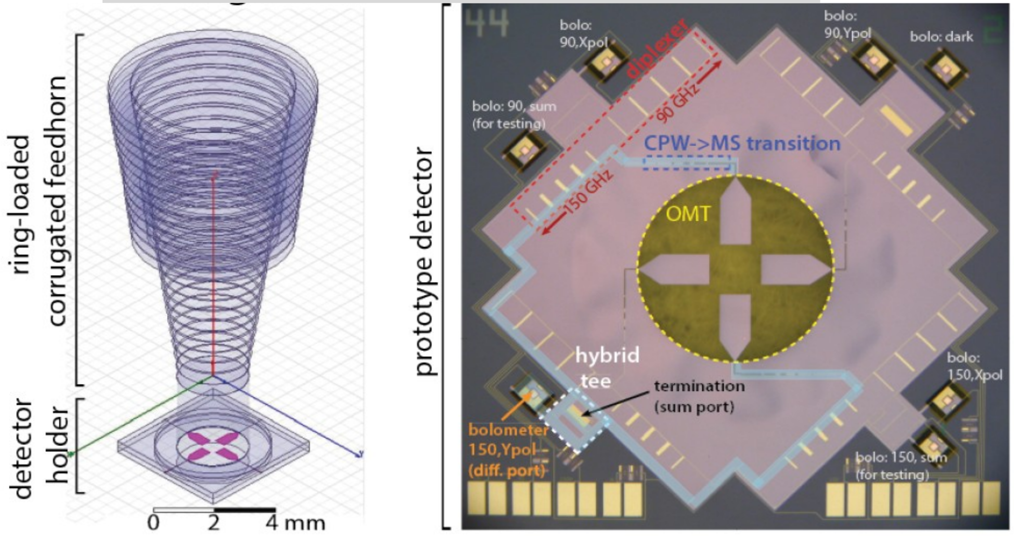
Datta et al. 2016. J Low Temp Phys.
doi:10.1007/s10909-016-1553-5

- Currently looking at a system with 13 ⌀45cm optics tubes designed for SO. 7 central tubes good for submm bands.
- Feedhorn-coupled multichroic polarimeter arrays with 4 bands per feedhorn: 740, 860, 1100, 1300mm (NIST, McMahon et al.)
- 3-4 15cm 400 feed detector arrays tiled in each optics tube.
- Add FP on two tubes for intensity mapping.
- Cryogenics arranged such that tubes
telescope from the back.



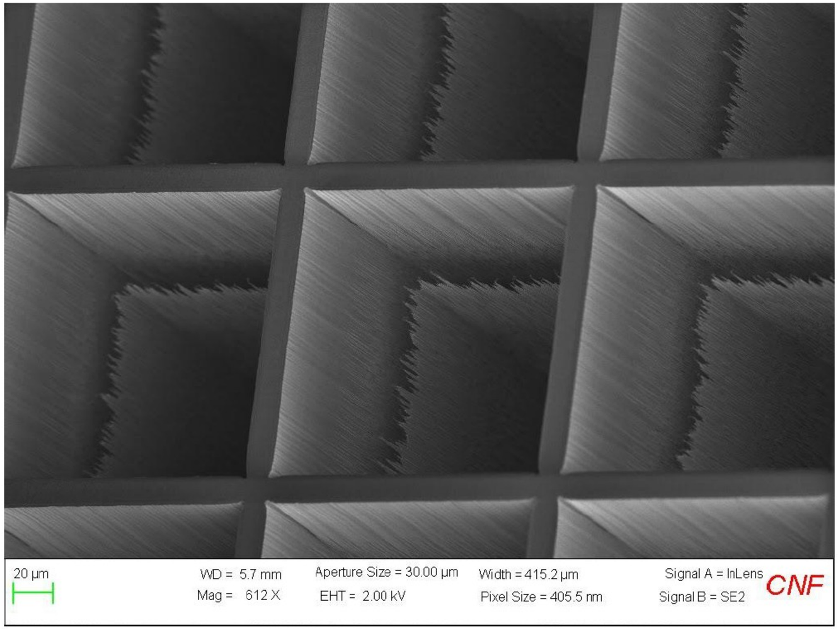
P. Mauskopf , SO

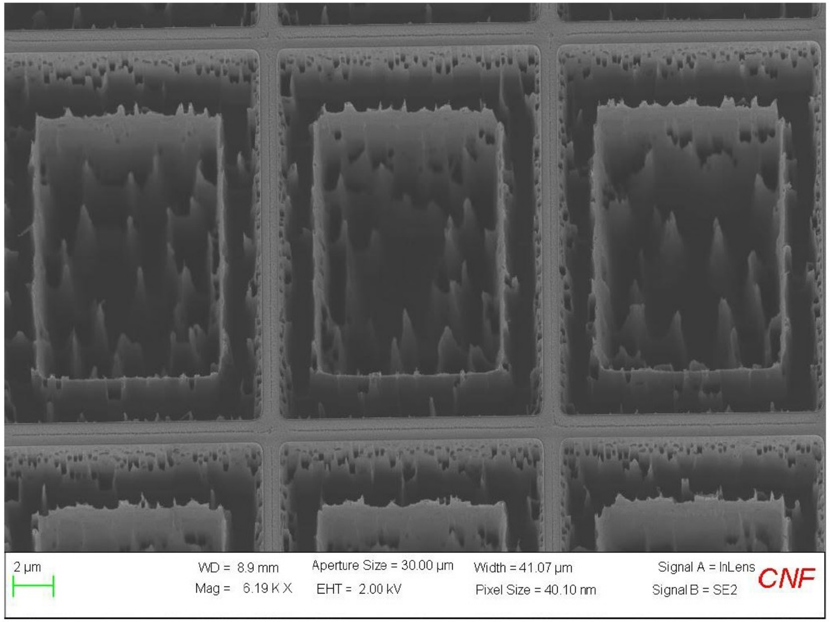
Datta et al. 2016. J Low Temp Phys.



Cost-effective, low-risk technology for CCAT-p first light science

FPIs for Intensity Mapping: reflector development





5° Tilt

R = 10^6 FPI at 112 um for HIRMES on SOFIA

- these are based on free-standing metal mesh
- developing silicon substrate-based FPI:
    - Silicon AR coatings (dual layer) with microstructures
    - Metalized (superconducting) broad-band reflectors
- mechanically more robust
- potentially superconducting surfaces at mm-waves → no Ohmic losses

T. Nikola, C. Henderson,
G. Douthit, N. Cothard, K. Vetter

- CCAT/p-Cam science perspectives
  - see follow-up talks and posters
    - talks by B. Magnelli, D. Riechers, K. Basu and J. Erler
    - poster by C. Karoumpis

Challenges

- high-altitude operation
  - requires reliable remote-control
  - minimum servicing
  - thermal control/cooling
- constraints on available power
  - initially on generators (?)
  - connection to ALMA power grid
- data transfer
  - raw data stored at fast rate
    - atmospheric correction
    - de-glitching
    - positional association with telescope
    - → up to 1 to several TB/day
  - → glass-fibre link to ALMA network
    - initial start with disk-storage/transport

Summary

- instrumentation program builds on long-term heritage on ground-based, airborne and space instruments
- two first light instruments in mature design stage
  - challenging design, but
  - no major show-stoppers identified
- first light instrument suite covers 4 out of 5 science cases
- let's get to work....