THz detector & optics developments – potential for EO applications

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CEOI-ST Emerging Technologies Workshop 30th April 2014

Outline

- THz Detector Array Development
- THz Optics
- Space Heritage & Current EO Applications
- Future Concepts

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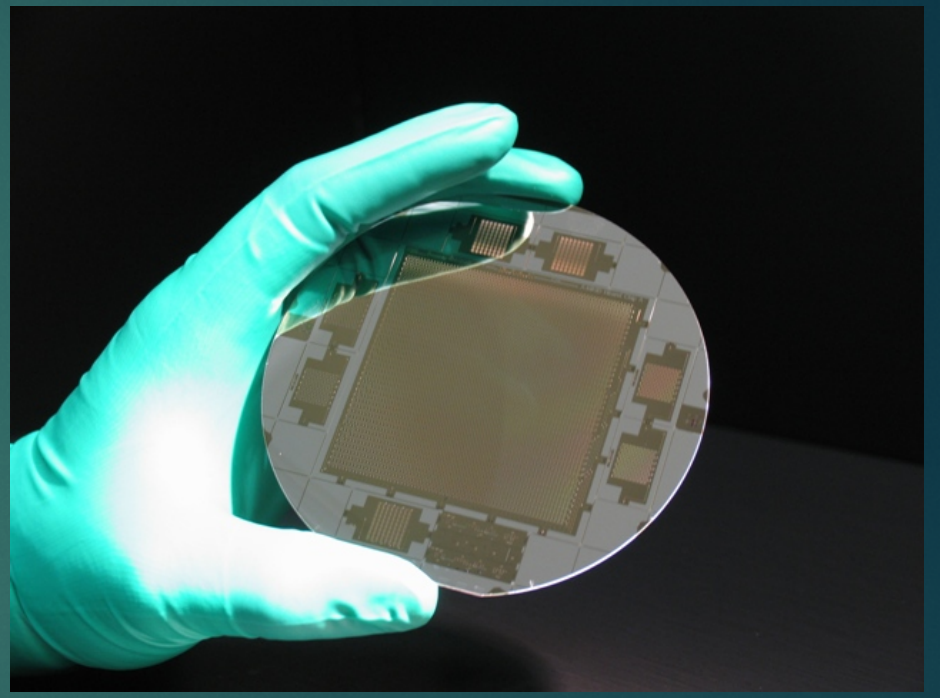
THz array development – Kinetic Inductance Detectors

- Superconducting resonator
  - Resonant frequency sensitive to relative density of paired & unpaired electrons in the superconducting material
- Incident photons $hf > 2\Delta$ breaks Cooper pairs – change inductance of resonator
- Thousands of detectors can be read out on same signal line – vary resonant frequency of each detector
- VERY simple fabrication – single photolithographic step
- Can be used as a fast & sensitive direct detector
  - Operating from mm-wave to X-ray
  - Or as an energy-sensitive particle detector
- Only 2 years from concept to 30 pixel demo system on IRAM telescope (2mm)



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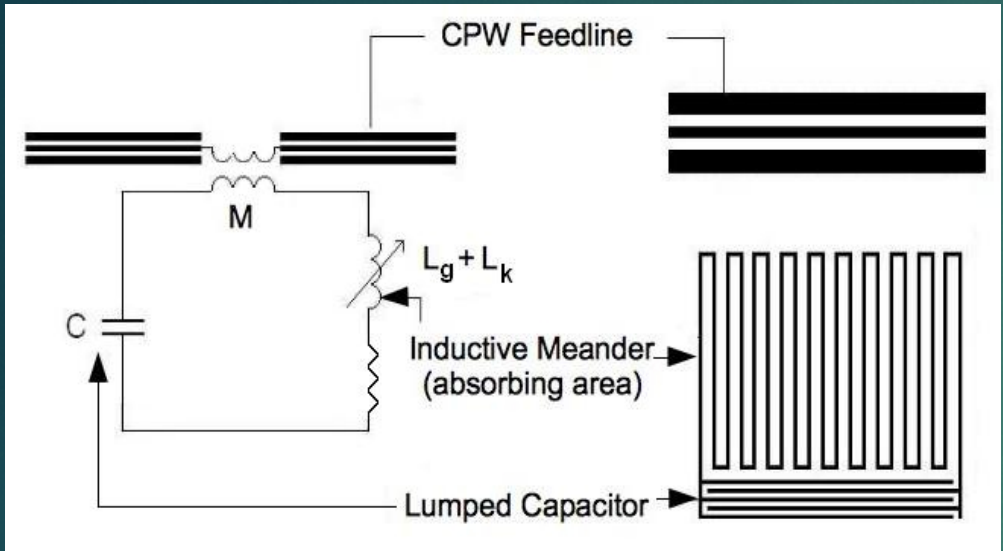
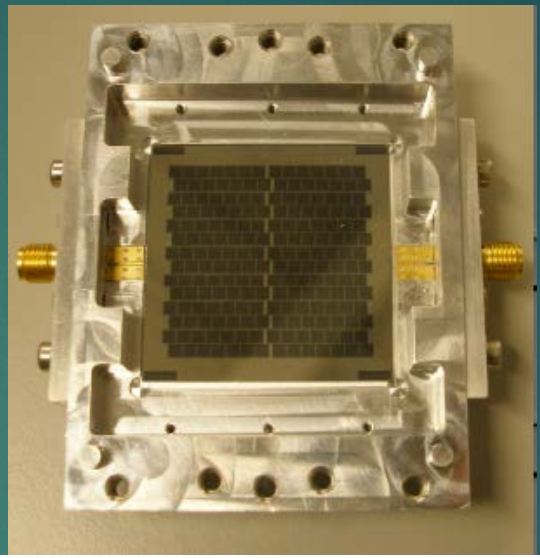
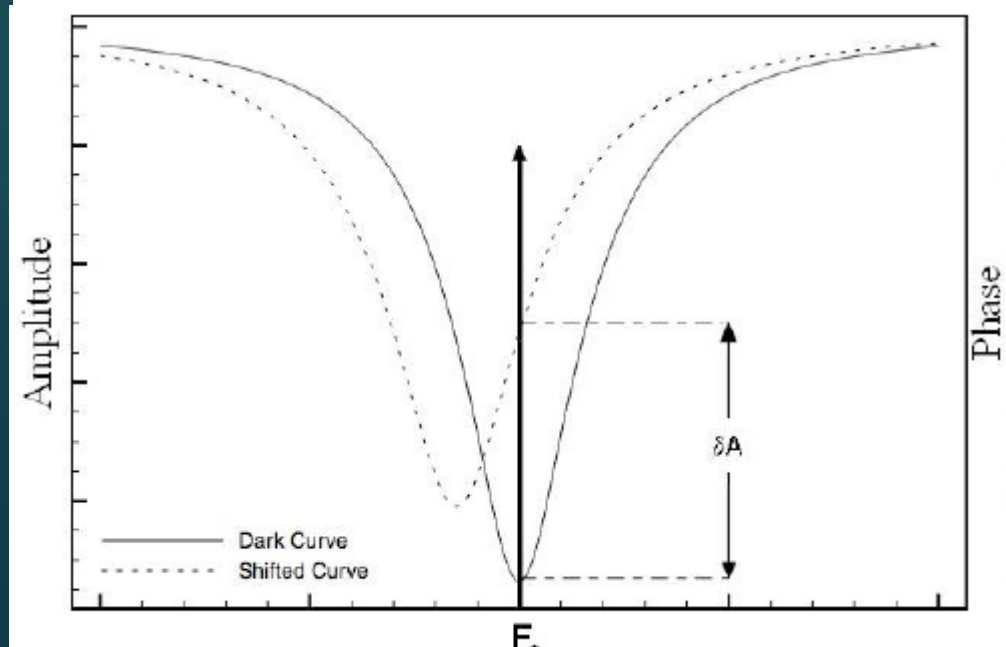
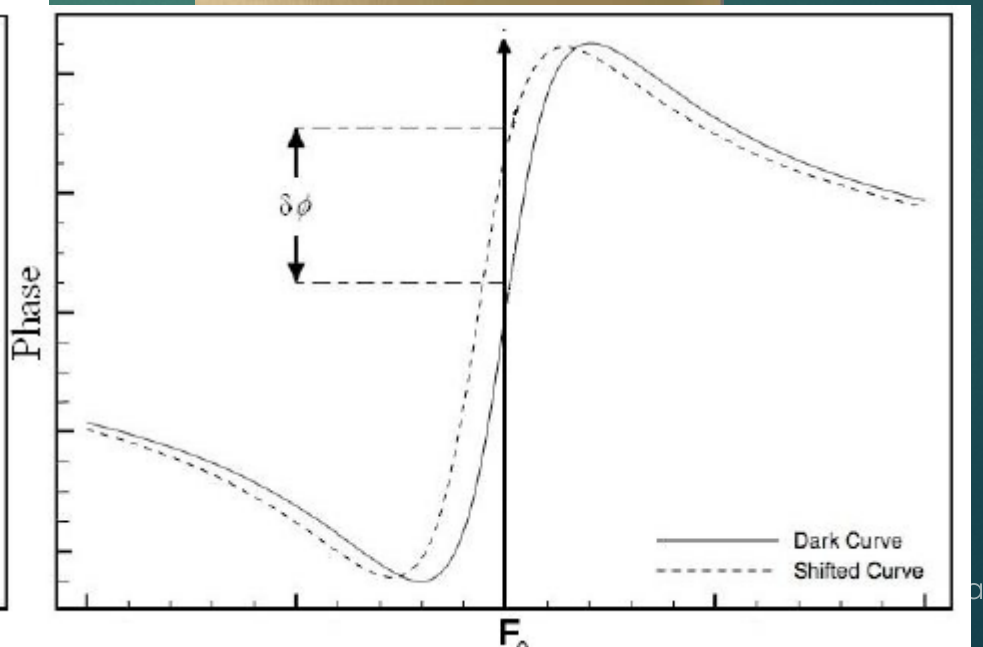
Kinetic Inductance Detectors









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KID performance

- Current performance details
  - Al films – NEP low x 10^{-18} W $Hz^{-1/2}$
    - Predicted ~ 10^{-20} W$Hz^{-1/2}$ at 100 mK
  - TiN films – NEP ~ 4 x 10^{-19} W $Hz^{-1/2}$
  - Readout 1000 detectors with *single* coax line and HEMT amplifier
  - Time response ~10-20 μs (300 mK)
  - Speed & noise limit governed by G-R rate of quasiparticles – scales with temperature and film volume

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SPACEKIDS

- EU-FP7 funded project
- 3 years duration, 2.6 MEuro funding. Completion December 2015.
- Project goals – to develop large (kilopixel) arrays and demonstrate their suitability and application to space-based Earth Observation and Astronomy missions

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THz Optics & Quasioptics

- Filters
- Beam dividers
- Dichroics
- Polarizers
- Half-wave plates & retarders
- Feedhorn design & testing
- Fourier transform spectrometers
- Anti-reflection coatings
- Meta-materials
- Flat lenses

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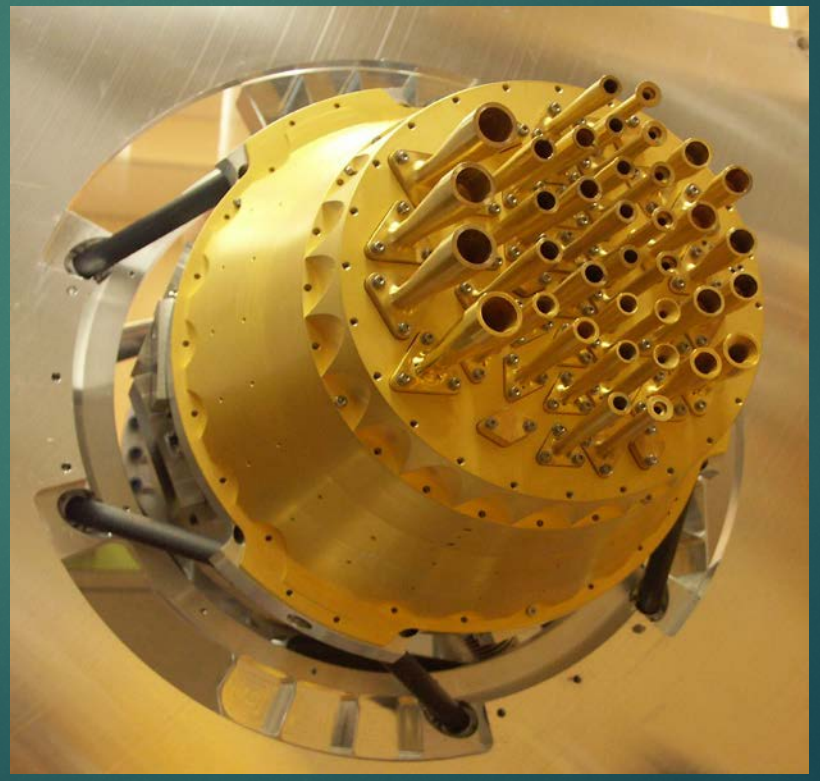
Filters

- Metal-mesh technology
- Inductive, capacitive, resonant grids
- Excellent space heritage – flown on many satellite platforms



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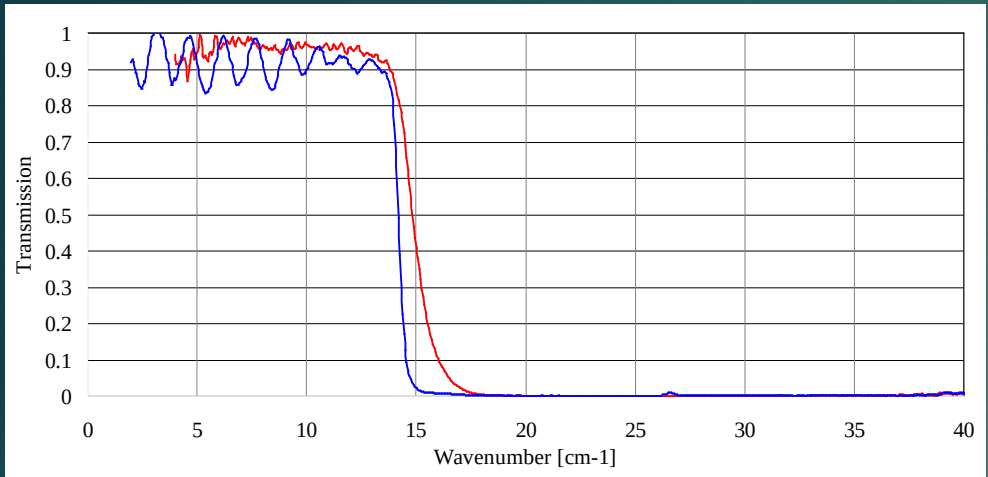
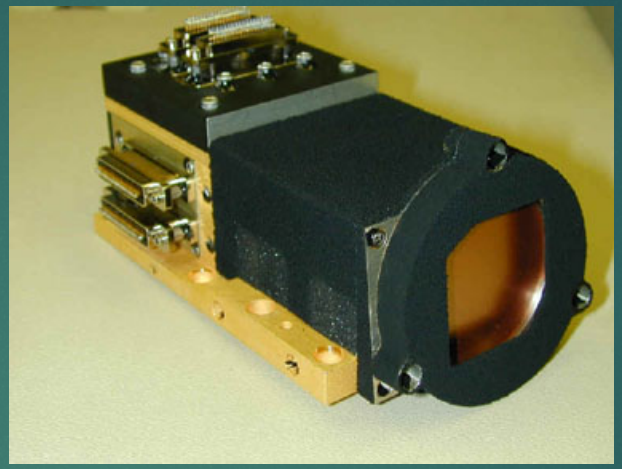
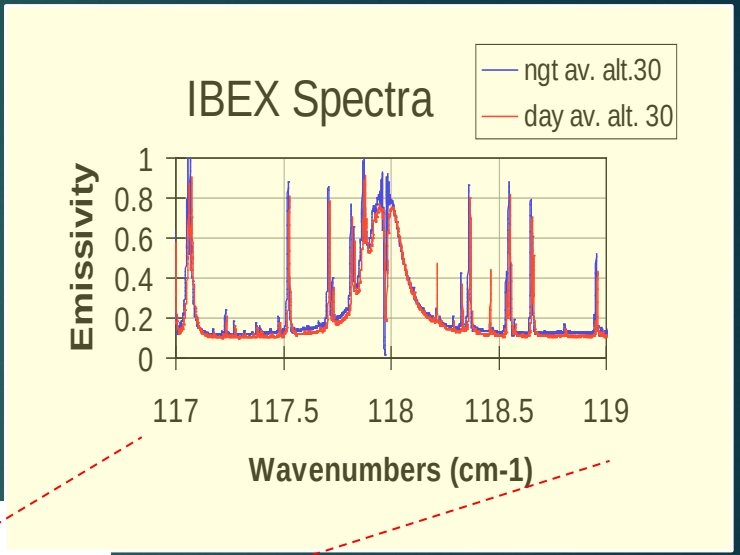
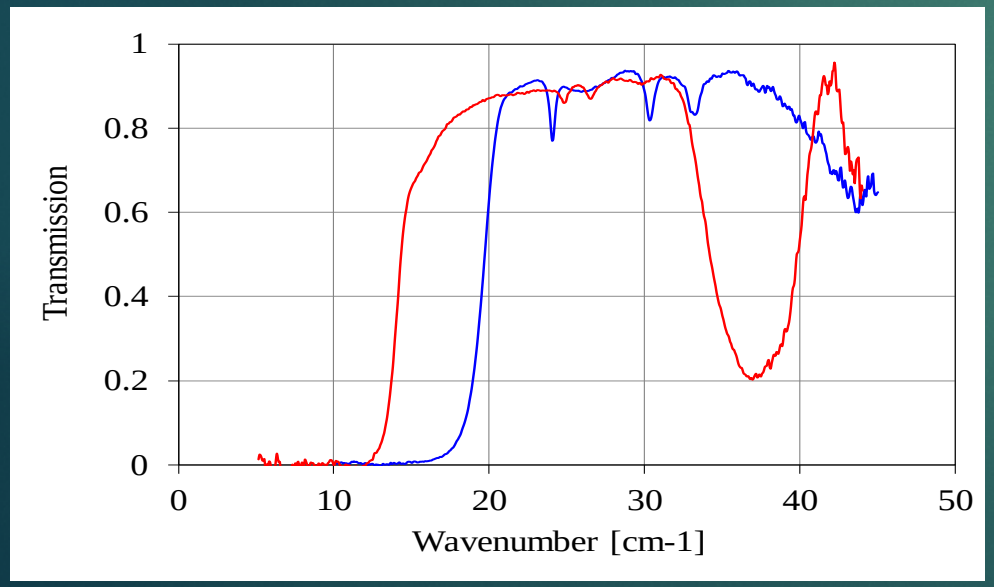
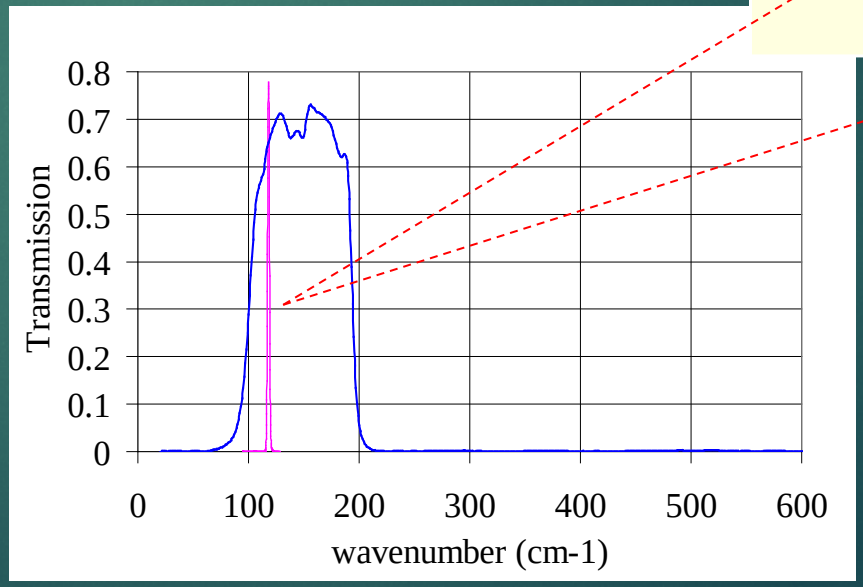
Filters – HP, LP, BP











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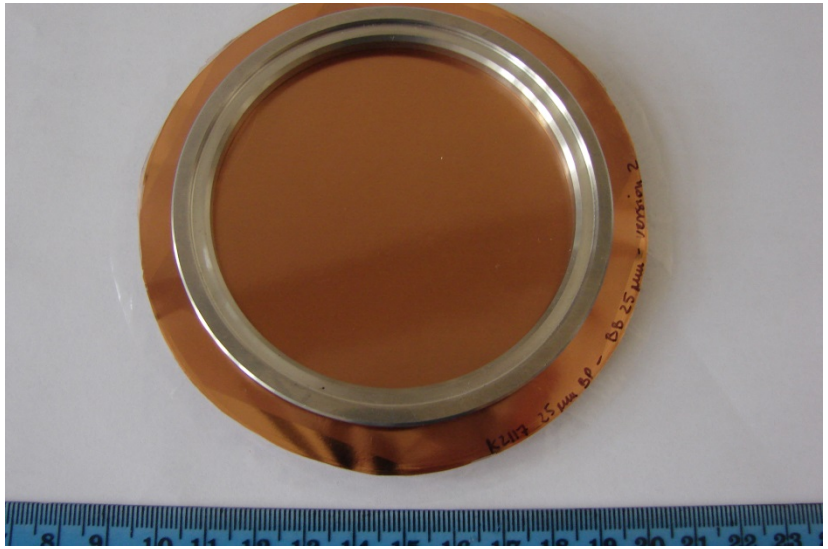
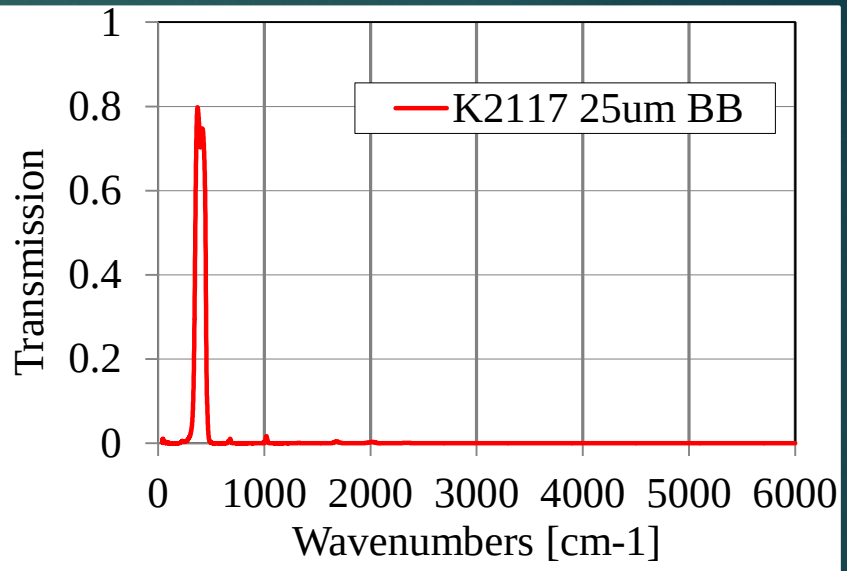
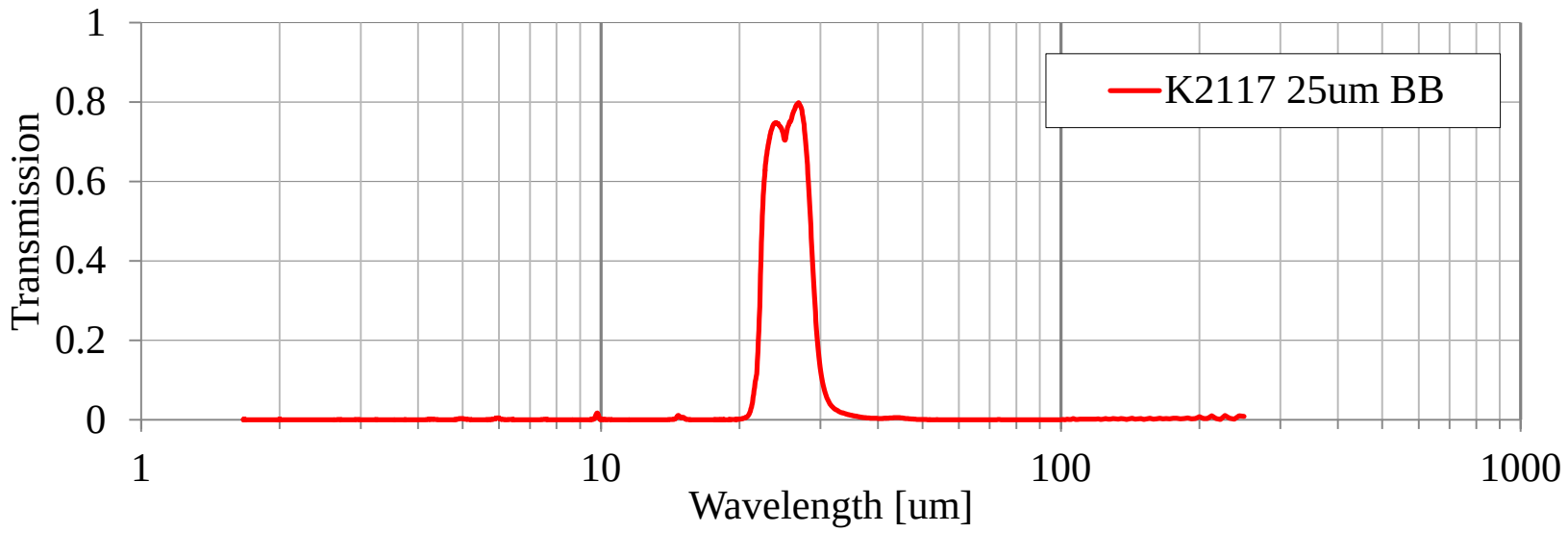
Filters







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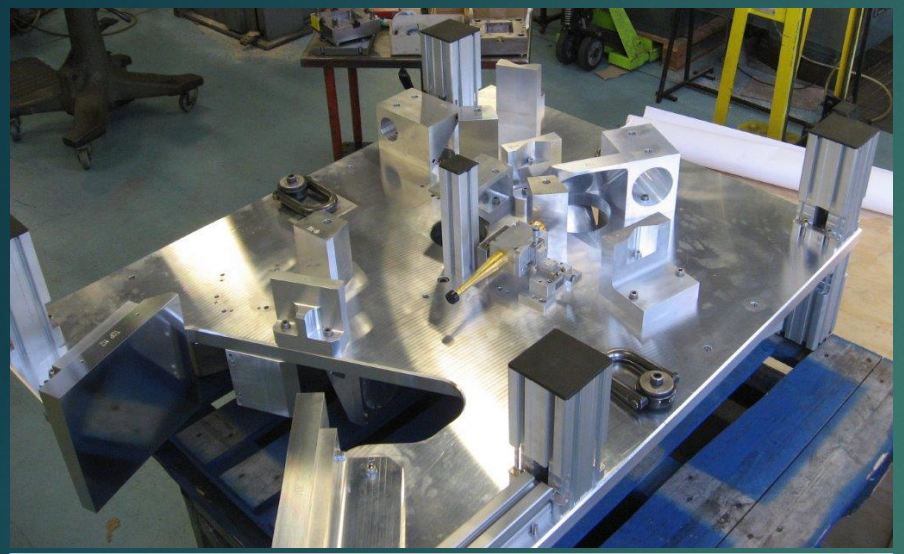
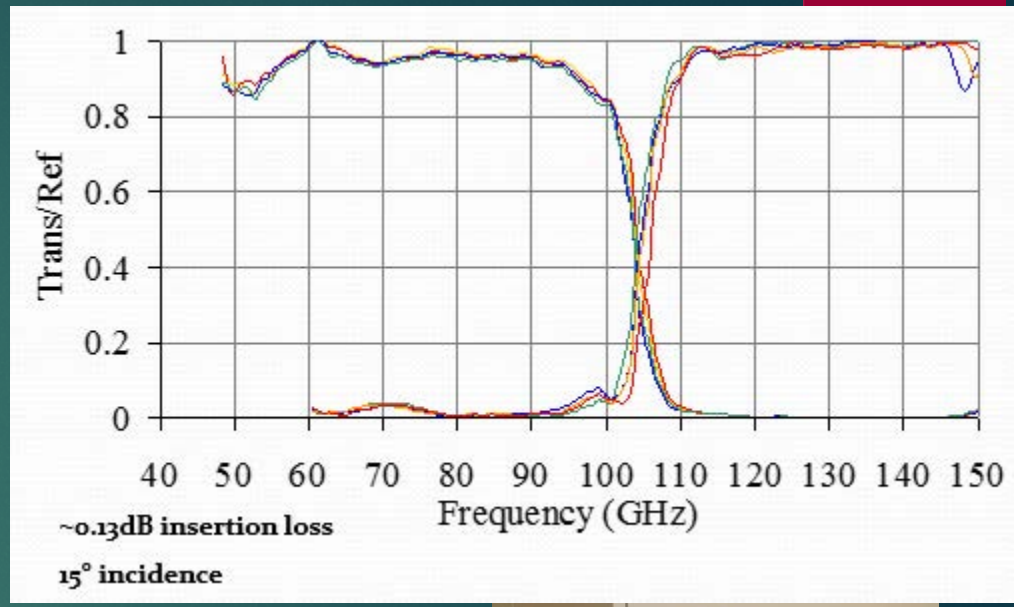
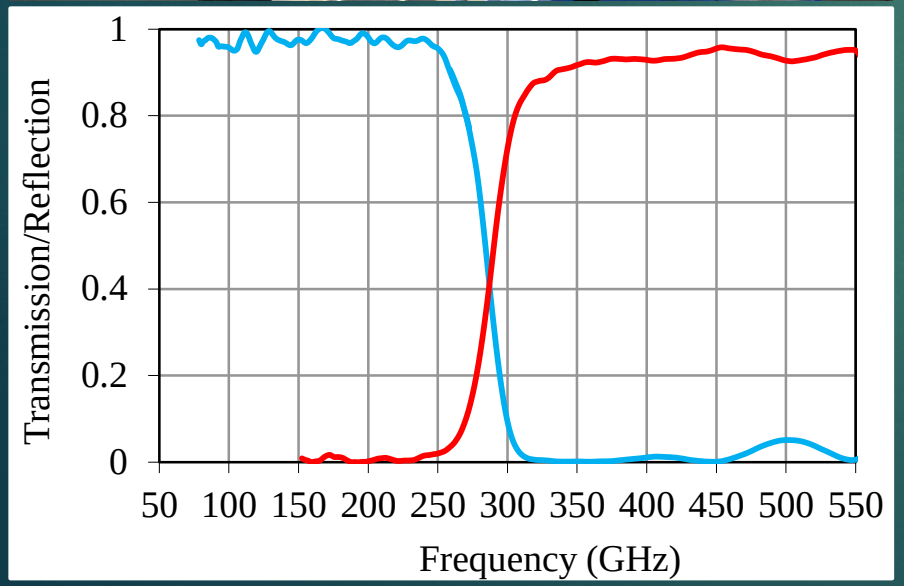
Dichroics



QO bench configured for multi-band radiometry for 50 – 600 GHz





Frequency selective dichroics for spatial separation of radiometric bands

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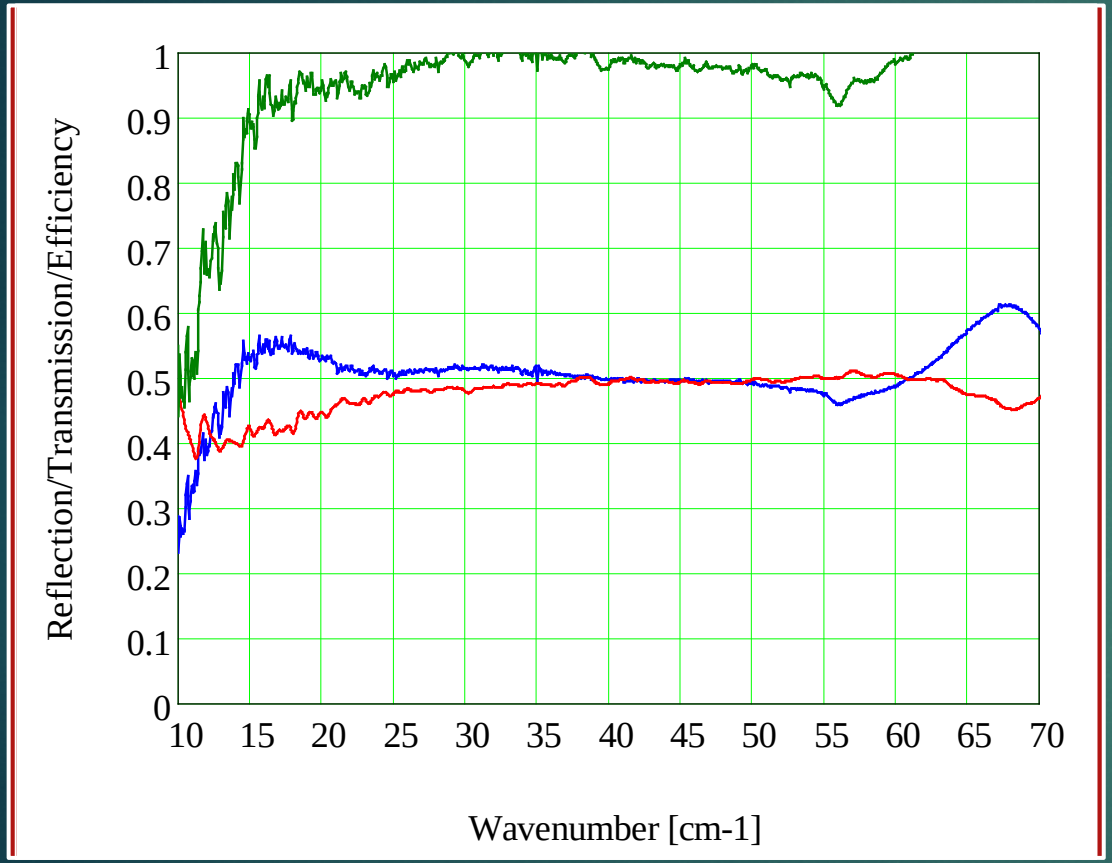
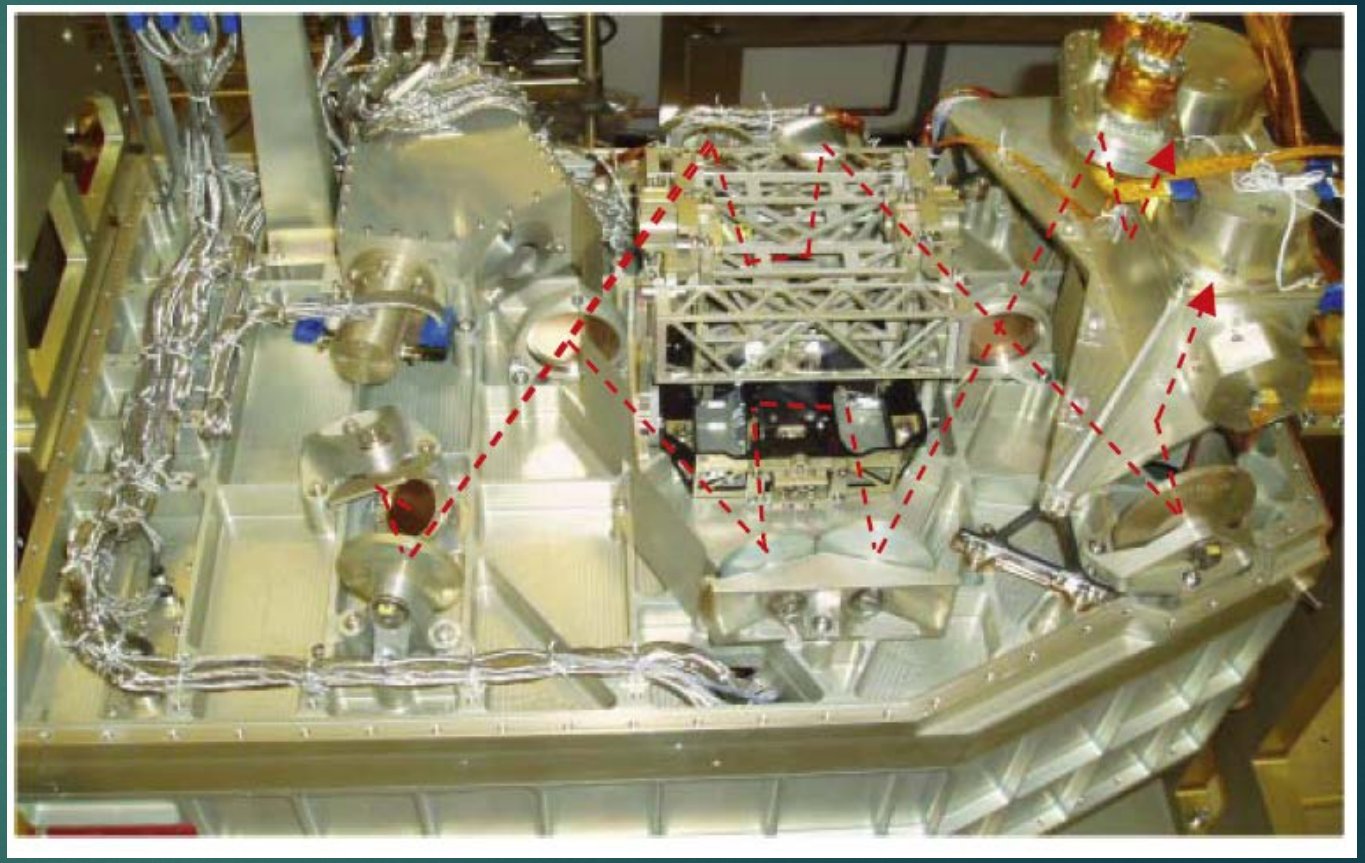
Beam dividers





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Large anti-reflection coated lenses

- ESA TRP contract. Completed 2013.

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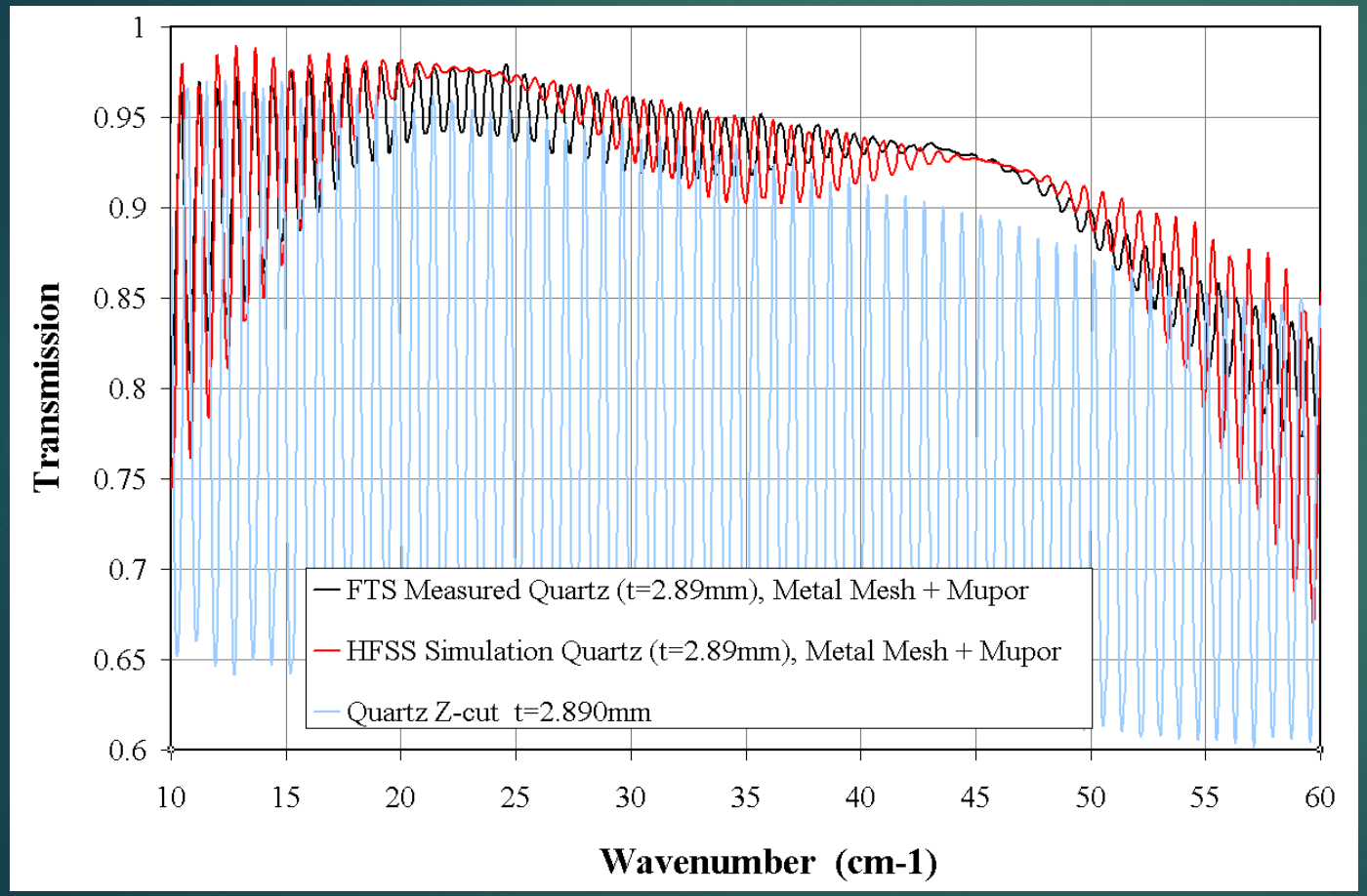
Artificial dielectric materials – anti-reflection coating applications



- black line – FTS transmission spectrum of the stack (PPTFE-ADM-QUARTZ-ADM-PPTFE)
- red line – HFSS simulation of the complete ARC quartz plate
- blue line – measured data of the uncoated quartz substrate.

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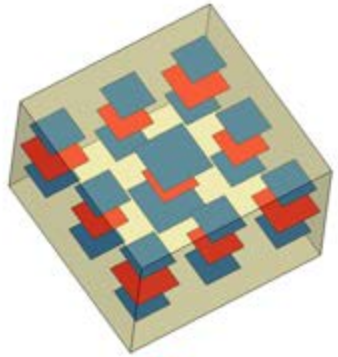
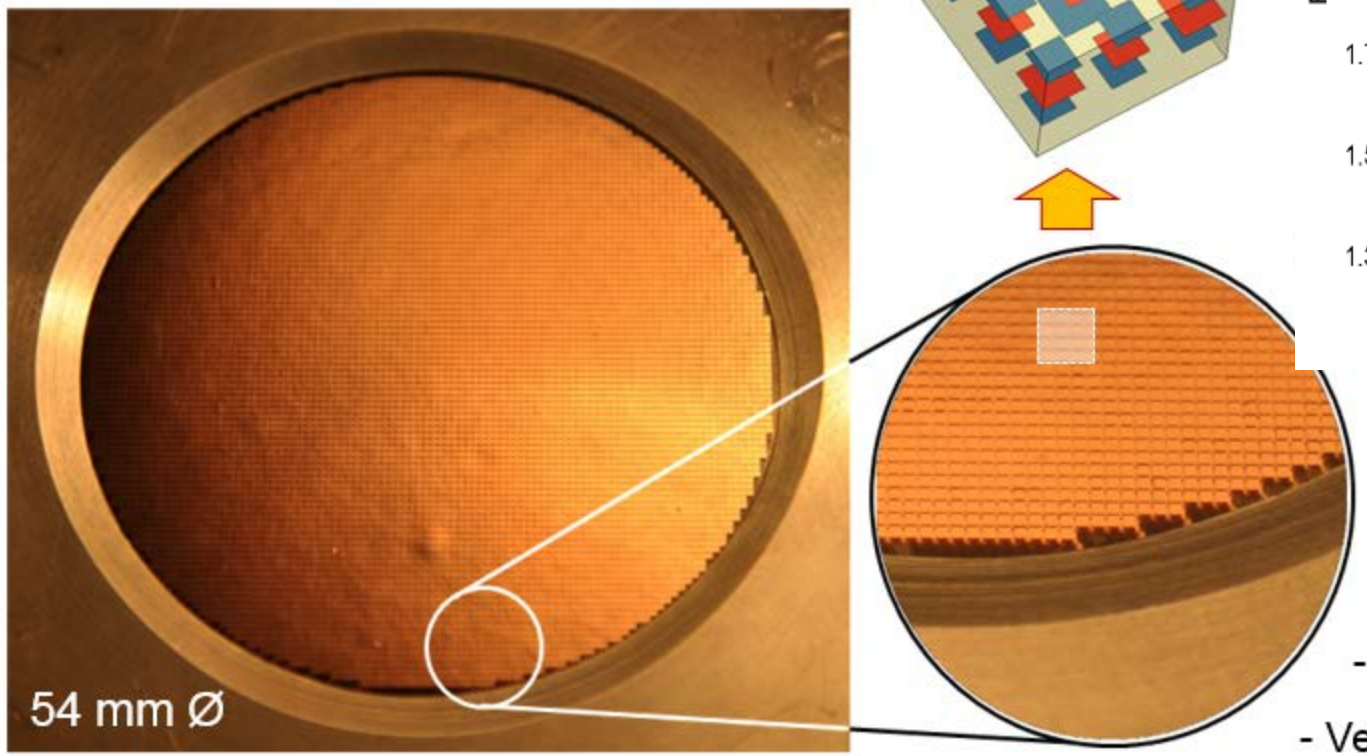
Flat lenses – GrIn

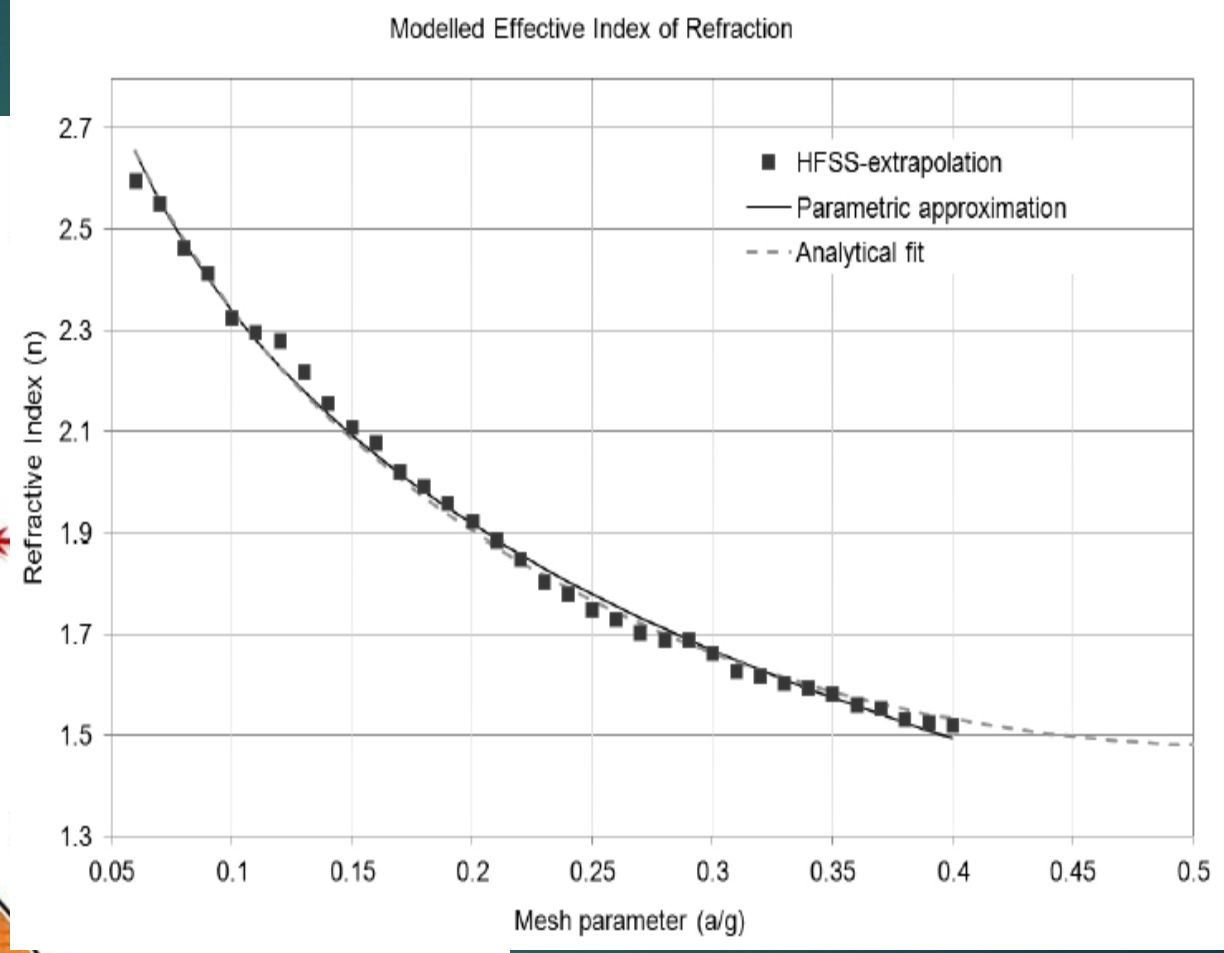
Inhomogeneous Phase Delays: Mesh Lenses

Locally variable
grid geometries





W-Band f/3 lens prototype (1.4mm thick)



- Very thin and robust
- Very light and low loss
- No Anti Reflection Coatings required

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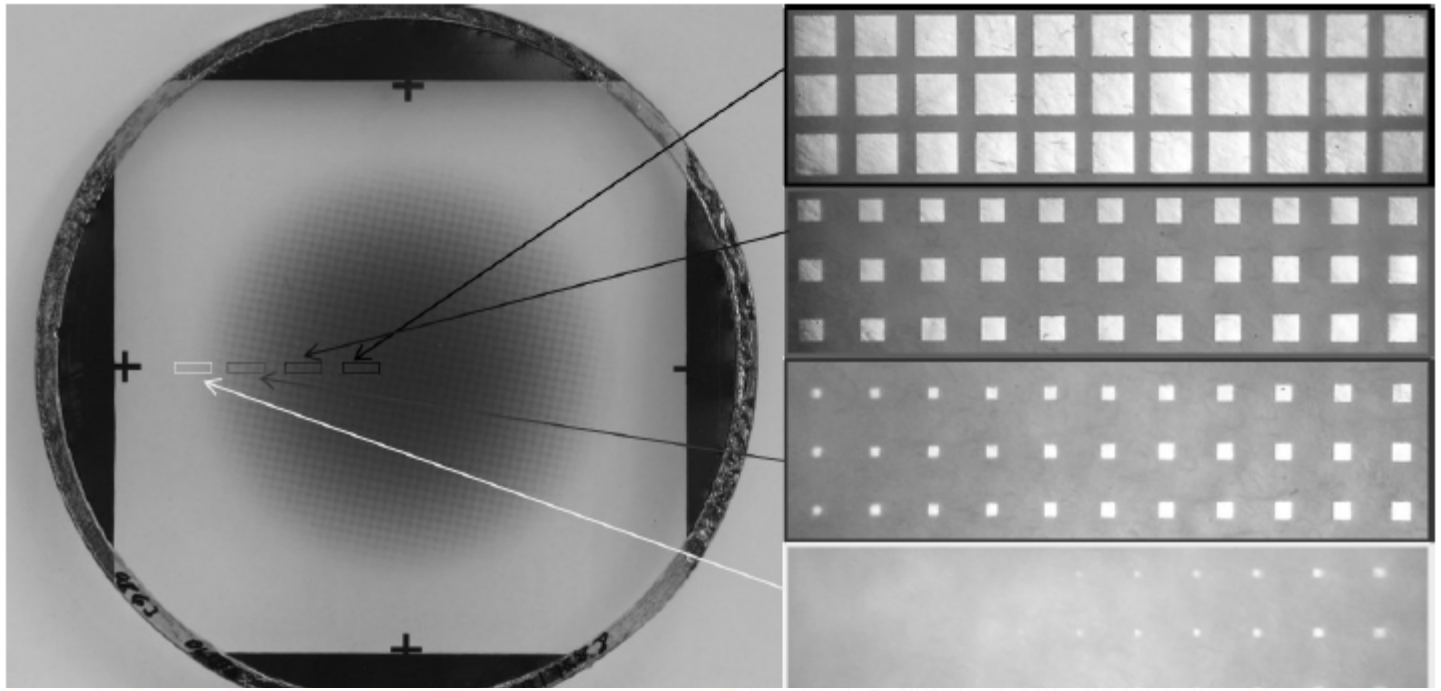

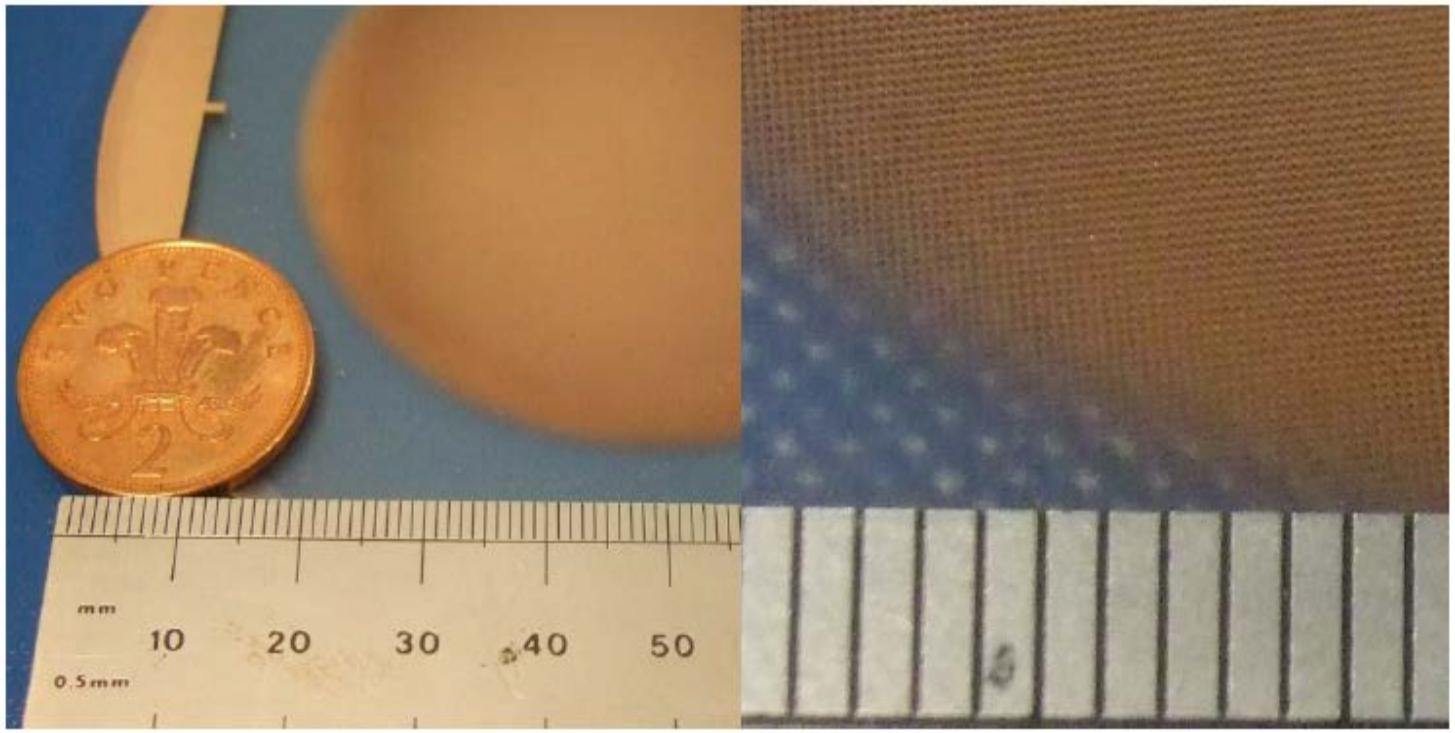

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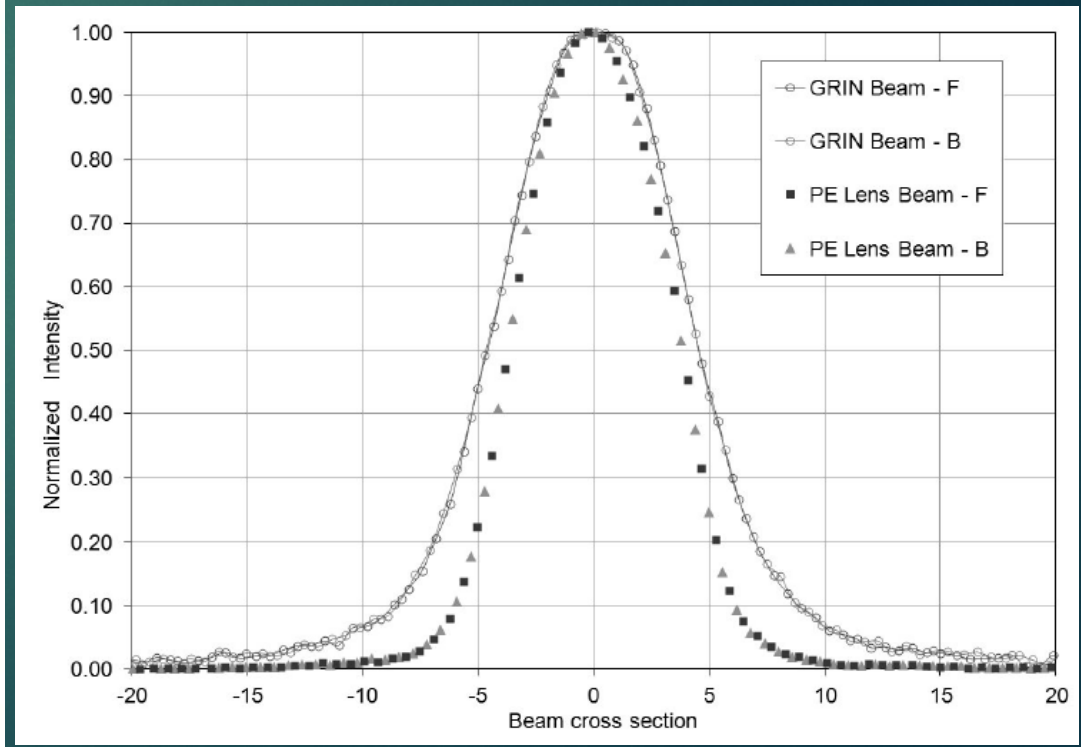
G. Savini, P. Ade, and J. Zhang, "A new artificial material approach for flat THz frequency lenses,"

Opt. Express 20, 25766-25773 (2012).

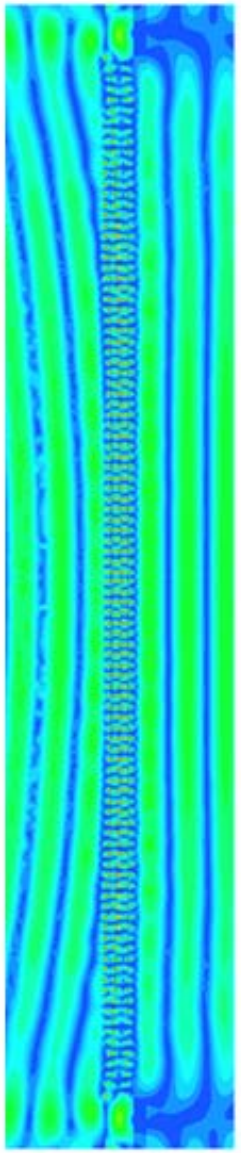


Flat Mesh Lens: Finite-element modelling check

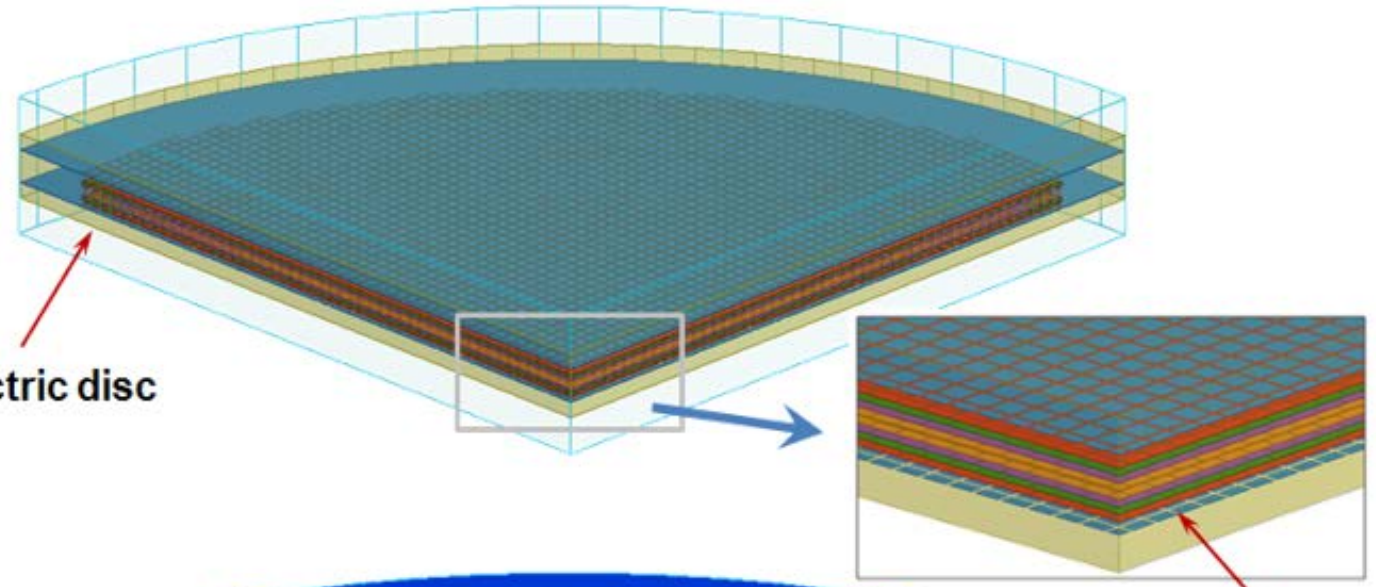
G. Pisano et al.
Applied Optics **52**,n.11, (2013)

2D model (cylindrical)

Central TL array

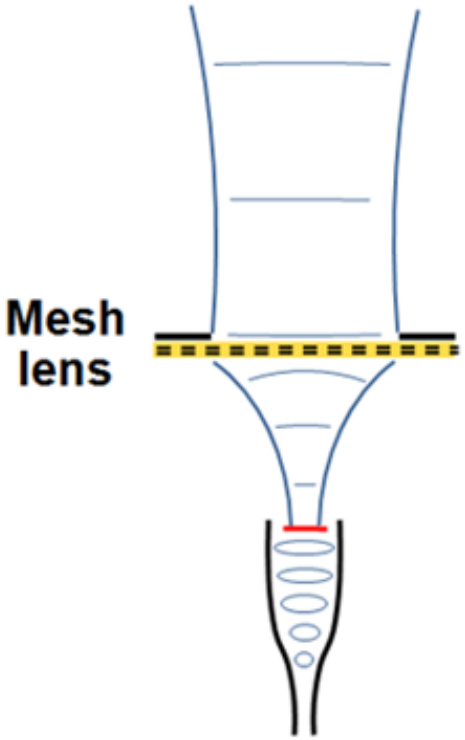


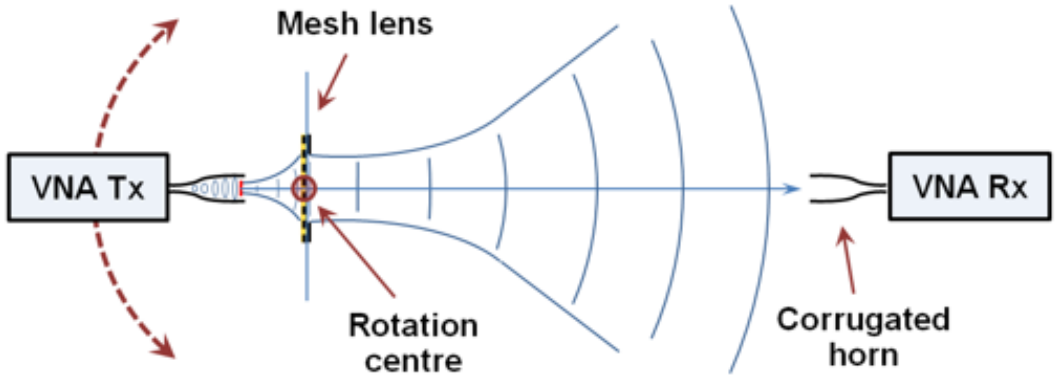
3D full model

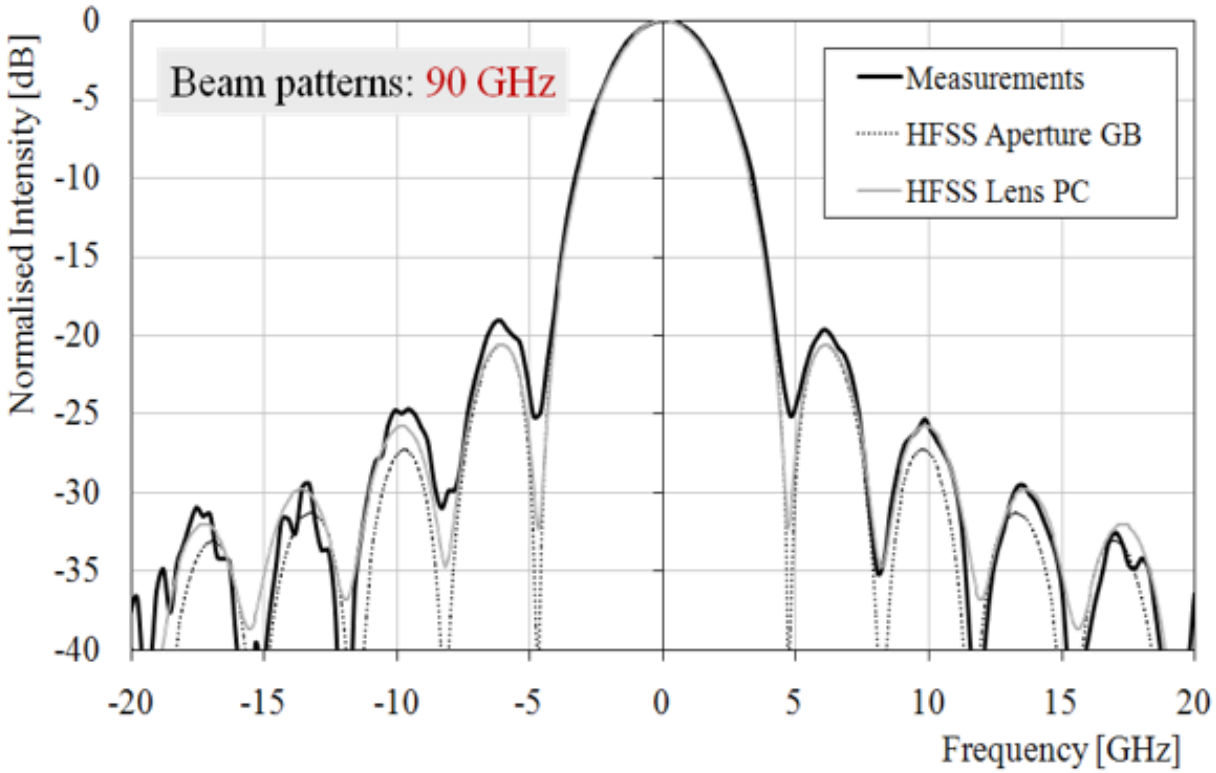


Flat Mesh Lens: VNA beam tests

G. Pisano et al.
Applied Optics **52**,n.11, (2013)

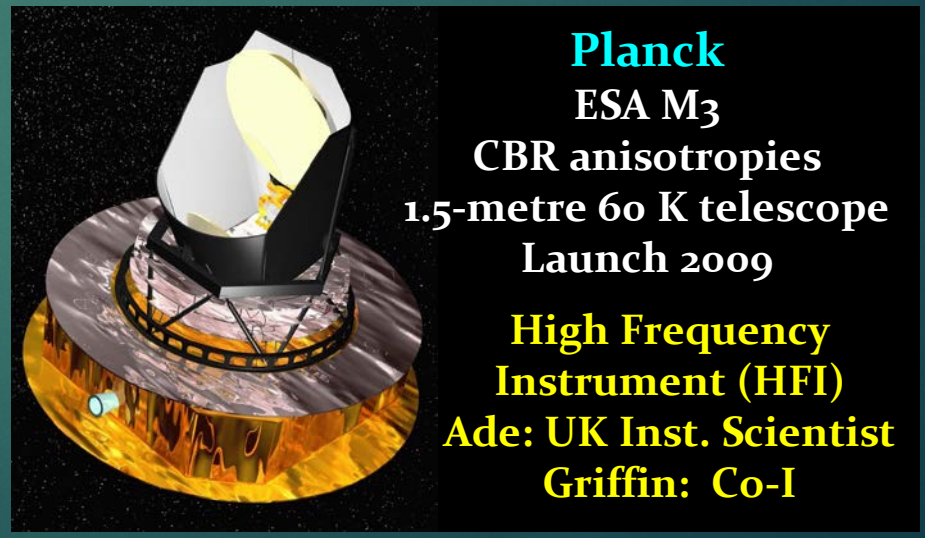






→ Experimental agreement down to the 4th side lobes

Space Heritage



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EO applications

- GEO satellite for temperature/humidity, cloud water & ice, & precipitation
  - Provision of quasi-optical bench
  - Far Eastern Customer
- Novel instrument concepts enabled by wide field optics & mm-/sub-mm arrays

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ICEMuSIC – Ice Cloud Explorer Multi-Spectral Imaging Camera

- Instrument study funded by CEOI-ST
- Pushbroom multispectral imager based on submm superconducting detector arrays – operation from 300 mK
- Wide field optics – no mechanical scanning – 3-4 x 25° modules
  - Could integrate flat lenses
- Huge sensitivity improvement c.w. ICI
- Good scientific arguments for sun-synch or ISS-type orbits (diurnal cycles)