On-Chip Filter Bank Spectrometer Technology for Sub-mm and FIR Surveys

CAVENDISH ASTROPHYSICS

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Cambridge On-Chip Spectrometer Team:

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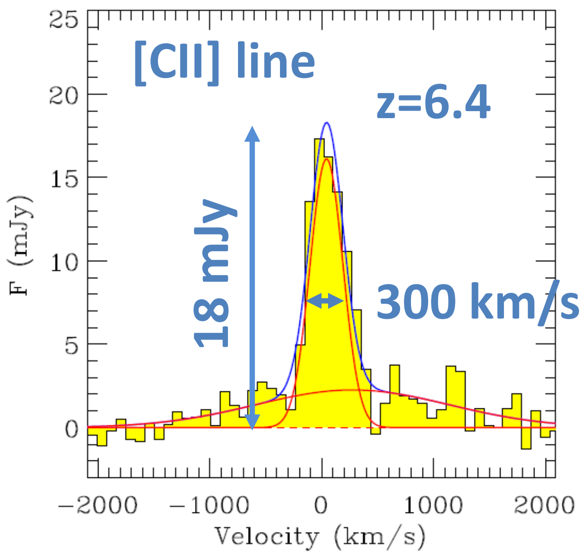
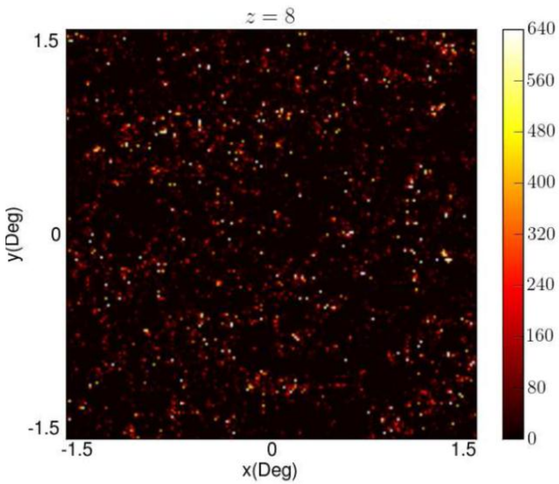
[CII] Intensity Mapping

- Complementary to [HI] mapping.
- Probe of star formation and metal production in early galaxies.
- **[CII] hyperfine structure line (1.9 THz @ z = 0) redshifted down to 200-300 GHz for z = 6-8. 'Bright' line.**
- Direct detection competitive with coherent receivers.



From 'Evidence of strong quasar feedback in the early universe' Maiolino et al. (MNRAS 425)



Simulated sky from Gong et al (z=8)

<u>Reference:</u>

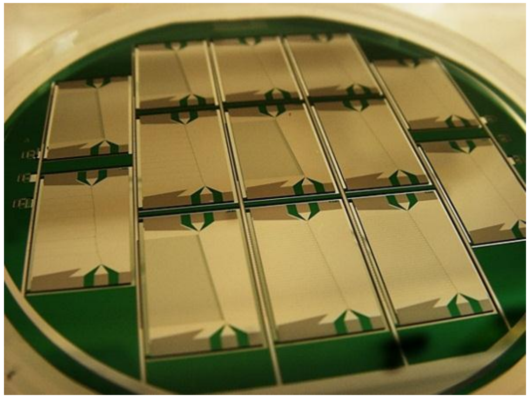
'Intensity mapping of the [CII] fine structure line during the epoch of reionisation', *Gong et al. 2012 ApJ 745 49*

On-Chip Spectrometers

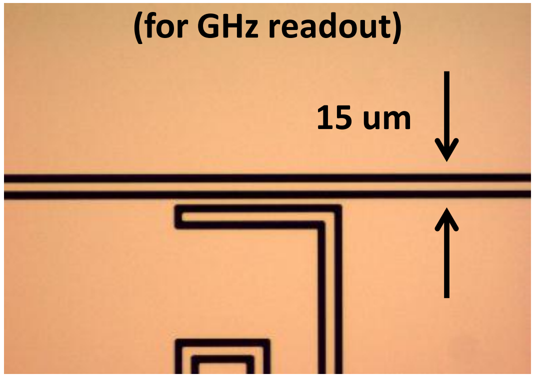
- Basic Operation:
  - Couple the radiation onto a superconducting transmission line.
  - Sort into band with electrical filters ('dispersive' spectrometer). Lumped or distributed
  - Measure the power in each band with a direct detector.

- **On-Chip spectrometers integrate all of this onto a single chip! (few cm^2 per pixel and filter bank)**

KIDs wafer

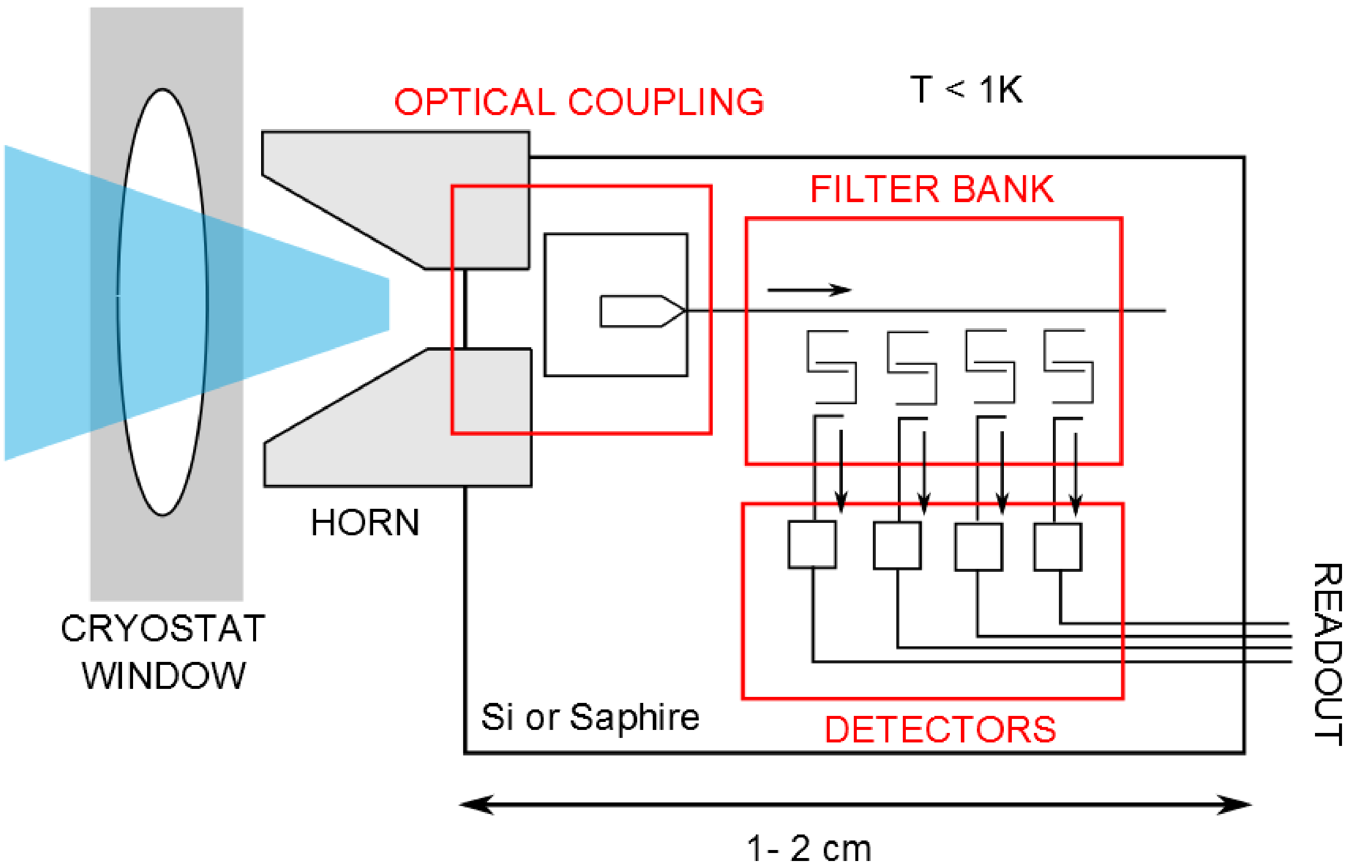


Superconducting CPW line (for GHz readout)

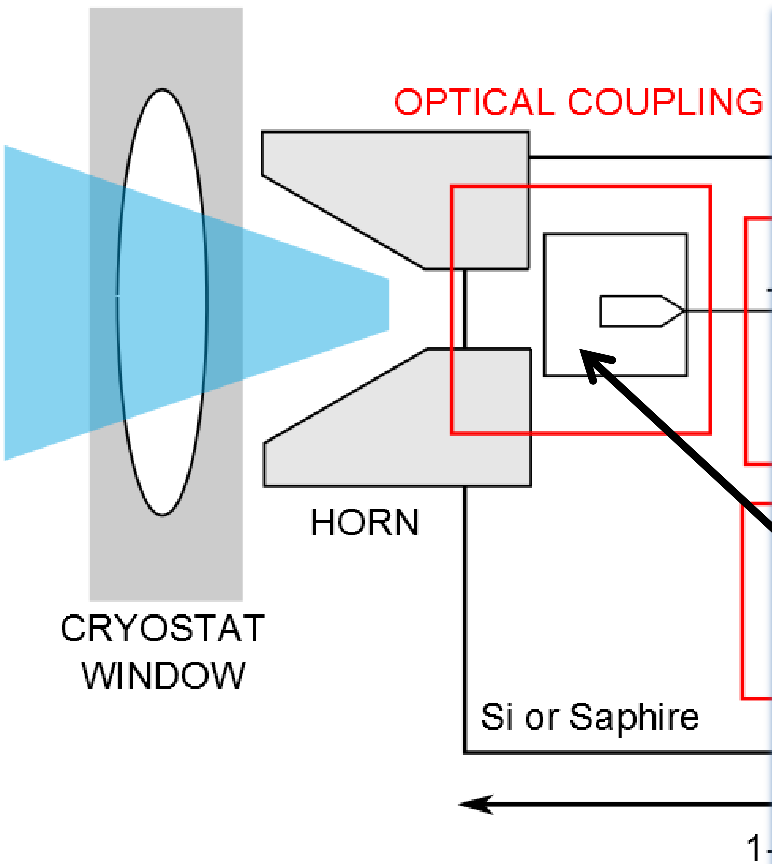


Wavelength 2.5x shorter on SC microstrip than freespace (aids miniaturisation)

Schematic of Operation

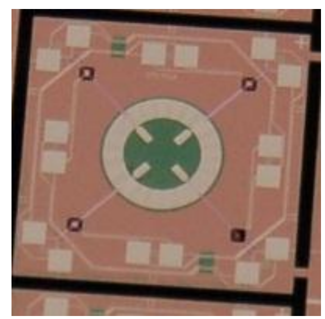


Schematic of Operation



Horn-coupled device illustrated...

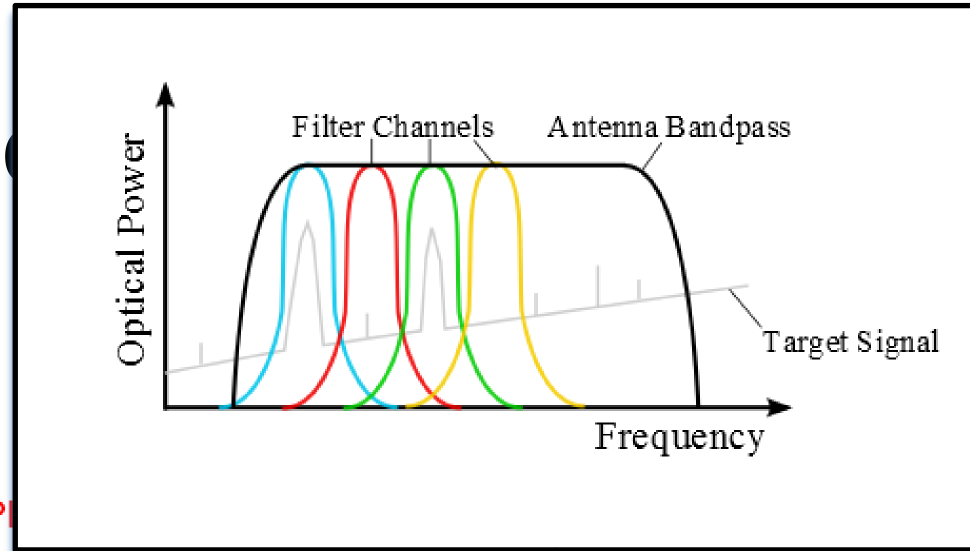
Possibility of using dual-polarisation probes, then having either different or interlaced filter-banks on the two polarisations channels

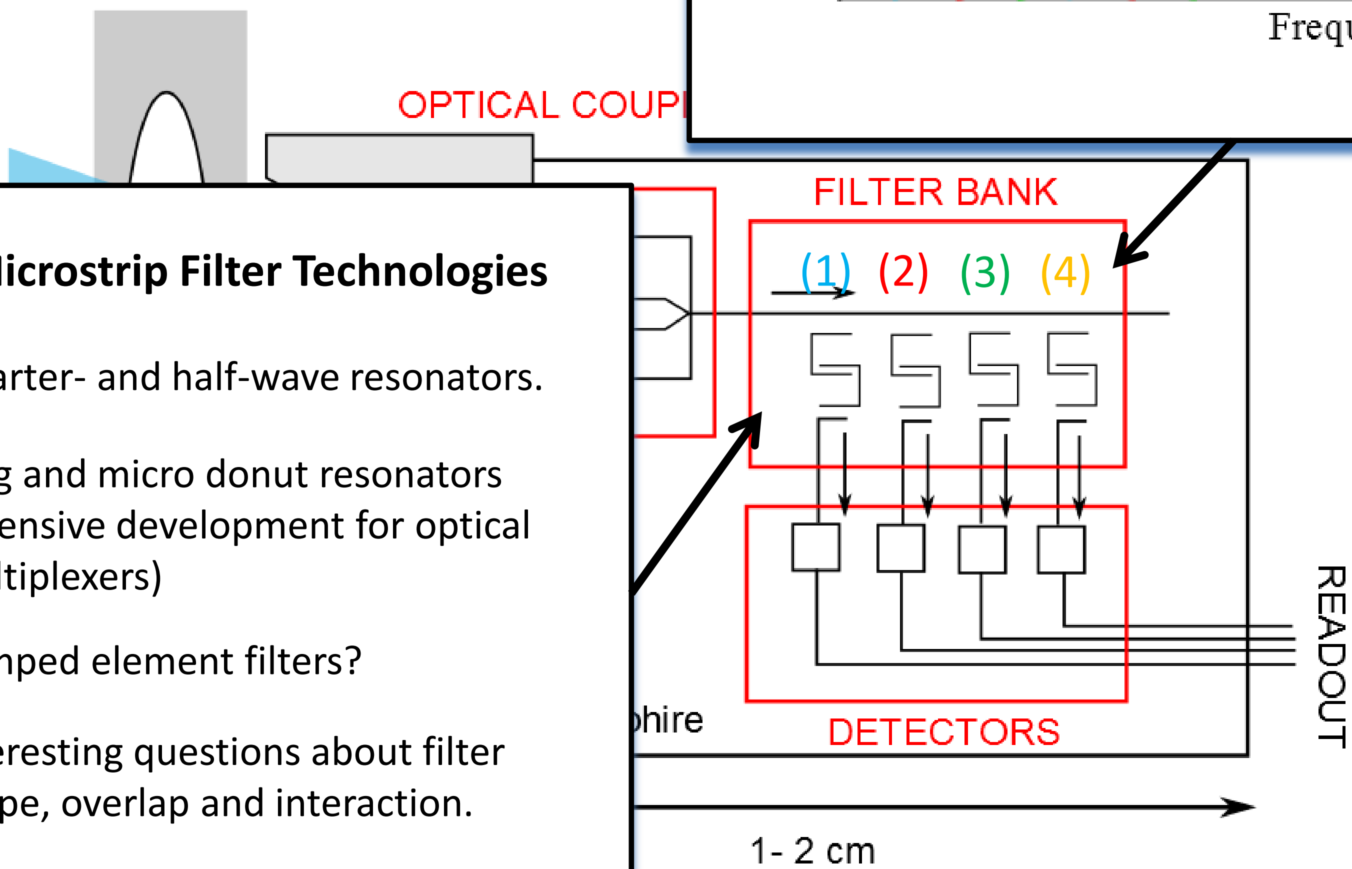


Four-probe OMT technology developed for Clover

Planar antennas with lenselet arrays also applicable at higher frequencies...

Schematic





Microstrip Filter Technologies

Quarter- and half-wave resonators.

Ring and micro donut resonators (intensive development for optical multiplexers)

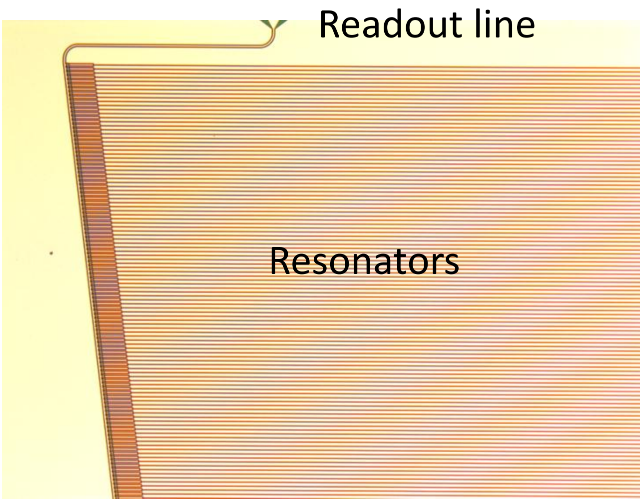
Lumped element filters?

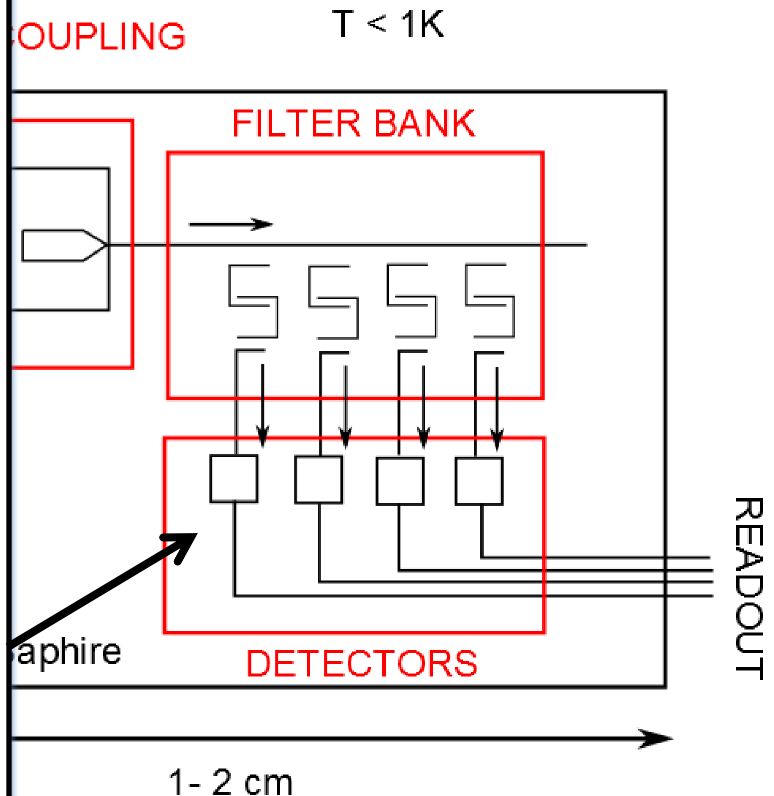
Interesting questions about filter shape, overlap and interaction.

Schematic of Operation

Detectors:

Kinetic Inductance Detectors favoured due to ease of multiplexing (intrinsically frequency multiplexed)





Advantages (1)

- Greatly **reduced size** compared with a grating of FTS spectrometer:
  - Easier to accommodate at telescope.
  - Reduced cryogenic requirements.
- **Ruggedness**:
  - No moving parts.
- Straightforward to fabricate **multiple pixels** with filter banks on same chip/wafer. Large imaging arrays with spectroscopic capability!

Ideal for balloon- and space-borne platforms!

Advantages (2)

- Large instantaneous bandwidth possible with appropriate readout (though smaller R than coherent receivers).
  - Comes down to how many detectors can be read out simultaneously
- Background limited performance achievable
  - Cooled bolometric systems can achieve lower receiver noise temperatures than coherent receivers.
  - **For example, the ZEUS grating spectrometer has an equivalent SSB receiver temperature of 20K at 350um (~250K for coherent system)**
  - High mapping speeds.

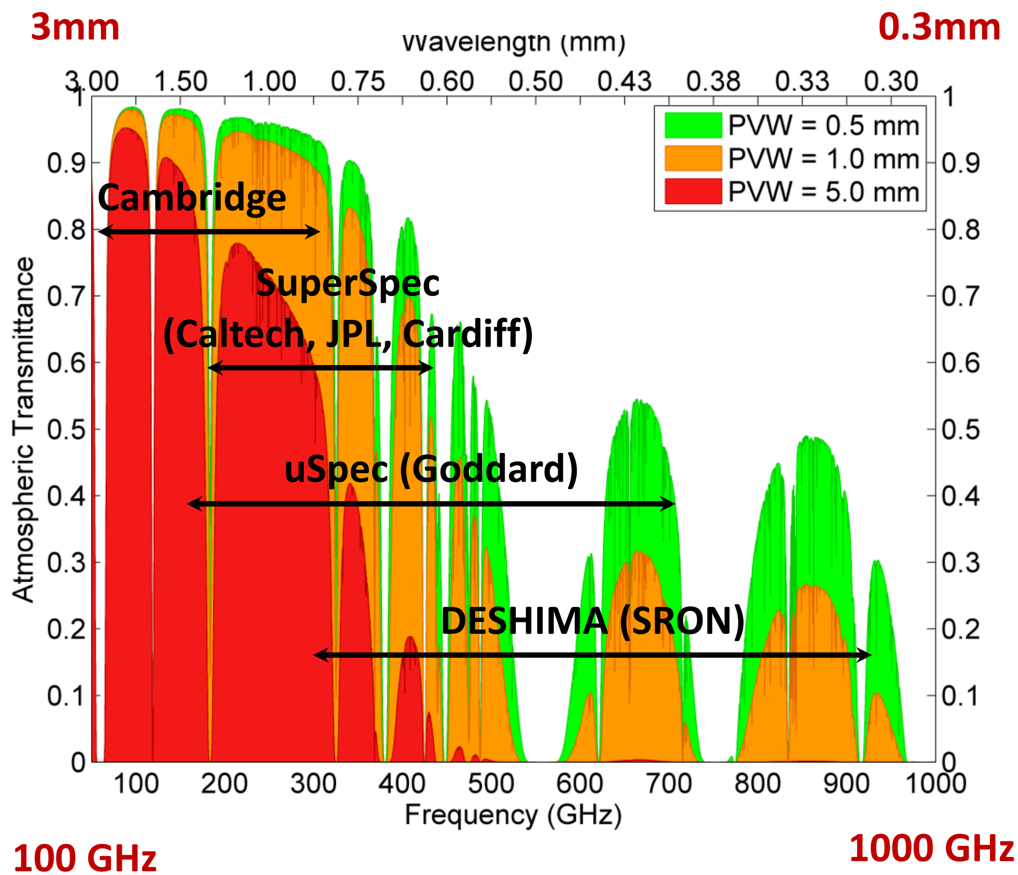
Technology Development at Cambridge

- **Focusing on 3mm (74 – 110 GHz) and 1mm (200 – 300 GHz) bands**
- **Initial science: redshift surveys. [CII] intensity mapping also feasible.**
- **Spectral resolution of 300 km/s (R = 1000)**
- **Aiming for BLIP performance**

- Key technologies
  - Microstrip filter banks
  - High sensitivity RF Kinetic Inductance Detectors (KIDs) to simplify multiplexing.
  - Integration of single pixels into blocks that can be positioned on the focal plane (multi-object spectrometer)

Conclusions

- Demonstrator is about proving key technologies.
- It should subsequently be straightforward to scale to different frequencies and filter bandwidths.
- Other groups are working on prototypes at different wavelengths.



Technology offers the possibility of large imaging areas with wide instantaneous bandwidths at moderate spectral resolution.