Status of a Novel 4-Band Submm/mm Camera for the Caltech Submillimeter Observatory

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Abstract:

Submillimeter observations are important to the understanding of galaxy formation and evolution. Determination of the spectral energy distribution in the millimeter and submillimeter regimes allows important and powerful diagnostics. To this end, we are undertaking the construction of a 4-band (750, 850, 1100, 1300 microns) 8-arcminute field of view camera for the Caltech Submillimeter Observatory. The focal plane will make use of three novel technologies: photolithographic phased array antennae, on-chip band-pass filters, and microwave kinetic inductance detectors (MKID). The phased array antenna design obviates beam-defining feed horns. On-chip band-pass filters eliminate band-defining metal-mesh filters. Together, the antennae and filters enable each spatial pixel to observe in all four bands simultaneously. MKIDs are highly multiplexable background-limited photon detectors. Readout of the MKID array will be done with software-defined radio (See poster by Max-Moerbeck et al.). This camera will provide an order-of-magnitude larger mapping speed than existing instruments and will be comparable to SCUBA 2 in terms of the detection rate for dusty sources, but complementary to SCUBA 2 in terms of wavelength coverage. We present results from an engineering run with a demonstration array, the baseline design for the science array, and the status of instrument design, construction, and testing. We anticipate the camera will be available at the CSO in 2010. This work has been supported by NASA ROSES APRA grants NNG06GG16G and NNG06GC71G, the NASA JPL Research and Technology Development Program, and the Gordon and Betty Moore Foundation.

Astronomical science goals

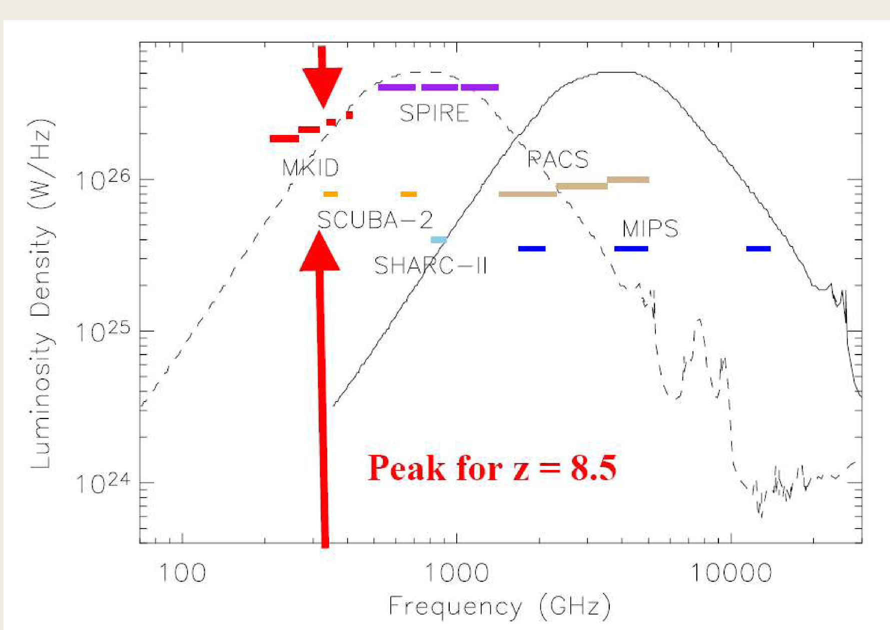

Fig. 5 The MKID cam bands measure the Rayleigh-Jeans tail of most submm galaxies and are ideal for identifying very high z galaxies whose redshifted SED peaks lies in the MKID cam bands.

- Primary goal is to **find star forming galaxies at the highest redshifts,** and to sample the spectral energy distribution (SED) in the submm and millimeter bands for spectral index and dust temperature information.
- Our final 4-color camera will provide **complementary information** in 3 colors that SCUBA-2 will not cover and will be competitive to SCUBA-2 because of the advantages of 4-color operation. It will provide the most interesting targets for follow-up with future instruments like ALMA.

Microwave kinetic inductance detection principle

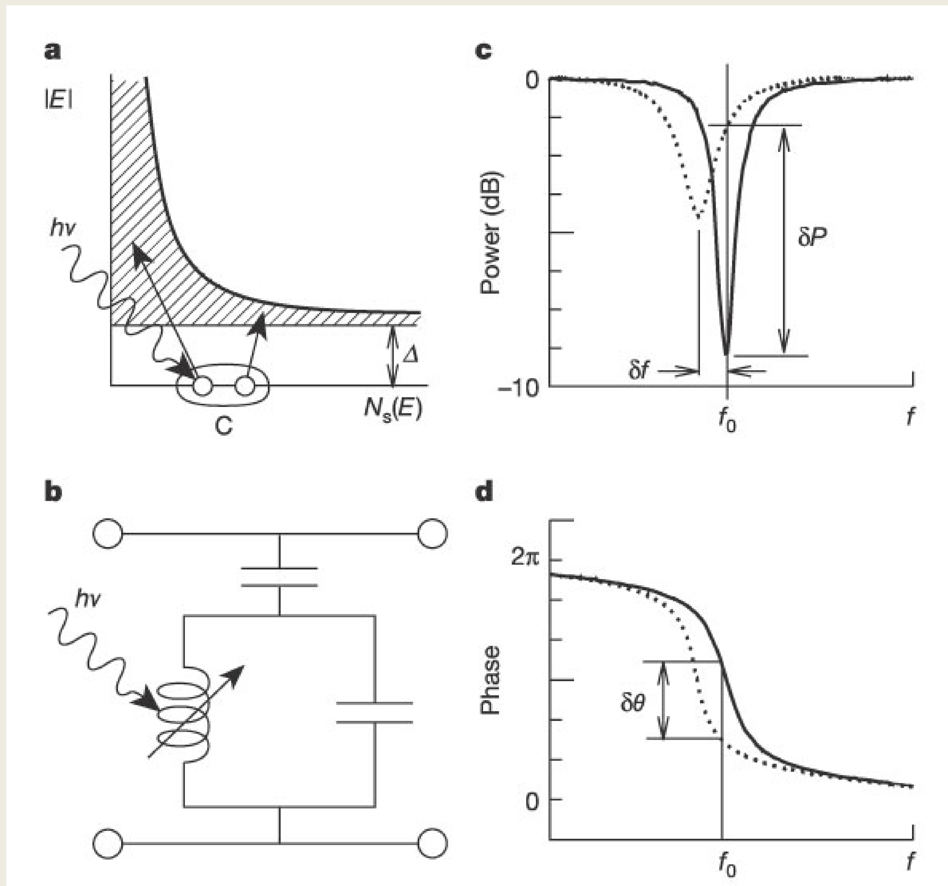

Fig. 1 a) Photons break Cooper pairs creating quasiparticles. b) Increase in quasiparticle density changes surface inductance (Ls) and resistance (Rs) of superconducting film used as a microwave resonant circuit depicted as a parallel LC circuit. This moves resonance to lower frequency (due to Ls) and makes the dip broader and shallower (due to Rs). These effects change the amplitude (δP) (c) and phase (d) of a microwave probe signal transmitted through the feedline, which is read out.

Antenna coupling and on-chip band-defining filters

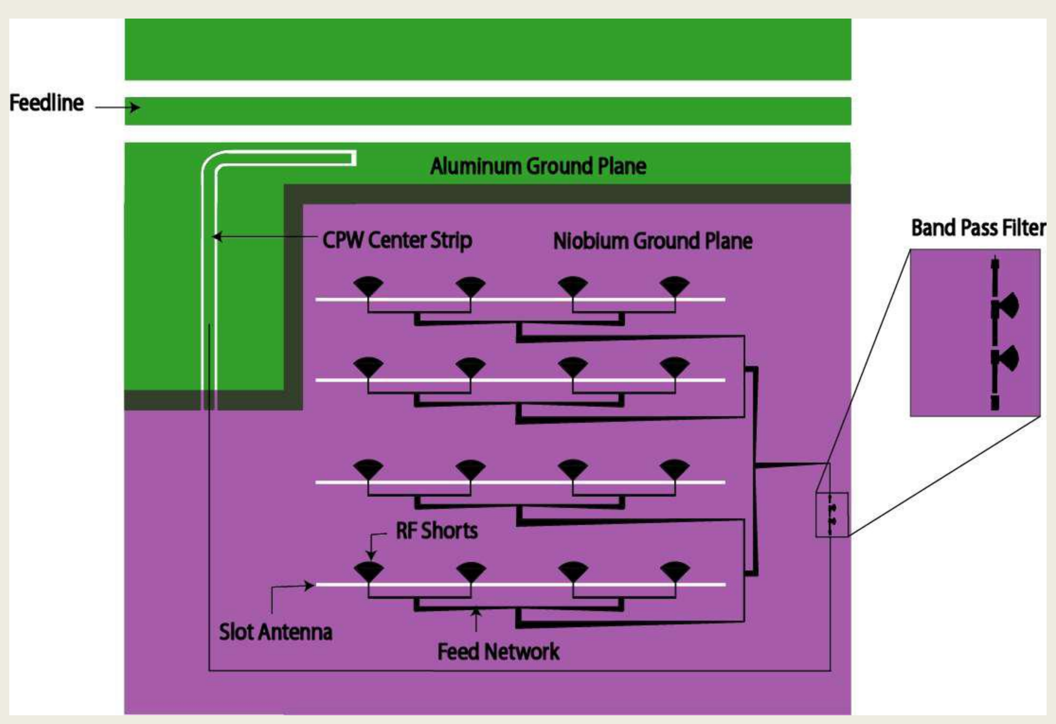

Fig. 2 Figure shows one pixel containing a slot-dipole phased-array antenna, a filter and a MKID. Submillimeter power exits the array on a transmission line, passes through the band-pass filter and terminates in the MKID. The MKID is a quarter-wave CPW resonator capacitively coupled to a microwave feed-line.

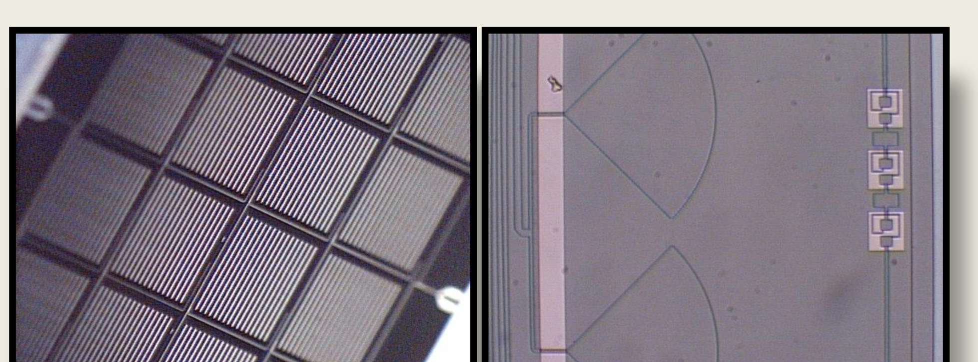

Fig. 3 (Left) Fabricated 16-pixel array for the demonstration camera. Each pixel has a 16-slot phased array antenna. (Right) A 3-stage in-line band-pass filter is shown on the right.

Readout and multiplexing many pixels

Hundreds to thousands of resonators tuned to slightly different frequencies may be coupled to a single feed-line which results in an elegant multiplexing scheme. (fig.4)

IQ homodyne mixing is used to read out the resonators. MKIDs are excited with a comb of frequencies . The output is mixed with a copy of the excitations which results in an in-phase (I) and out-of-phase signal (Q) which contain the change in surface impedance of the resonators. (fig. 4 (down))

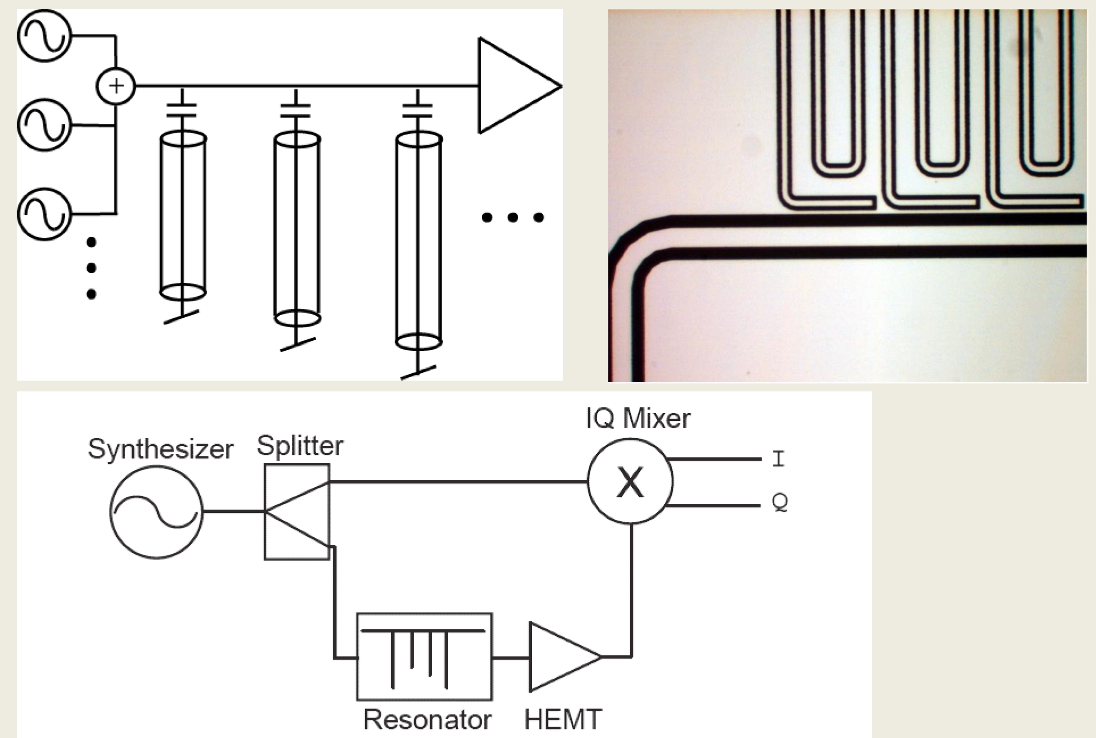

Fig. 4 (Left) Schematic view of multiplexing scheme. (Right) Actual picture of resonators coupled to a single feed-line. (Down) IQ homodyne readout.

16-pixel demonstration camera

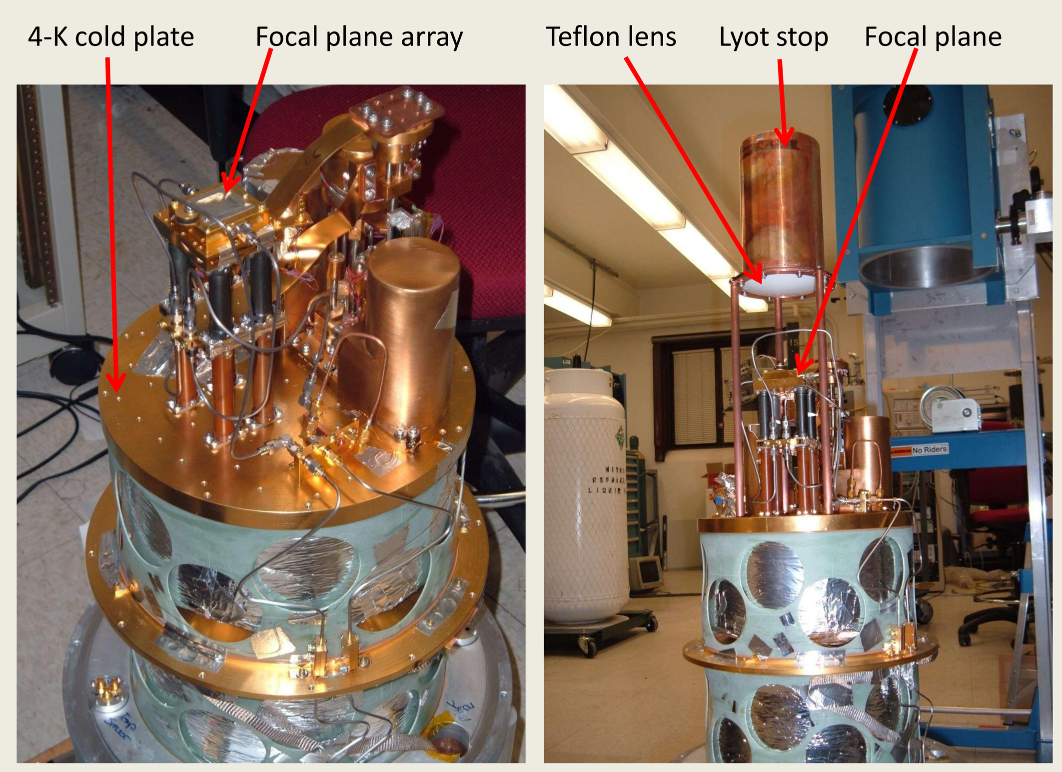

Fig. 6 The 16-pixel 2-color/pixel (850um and 1.3 mm) demonstration camera tested at CSO . Optics is similar to Bolocam, but uses purely dielectric filters (no metal mesh) for much greater bandwidth.

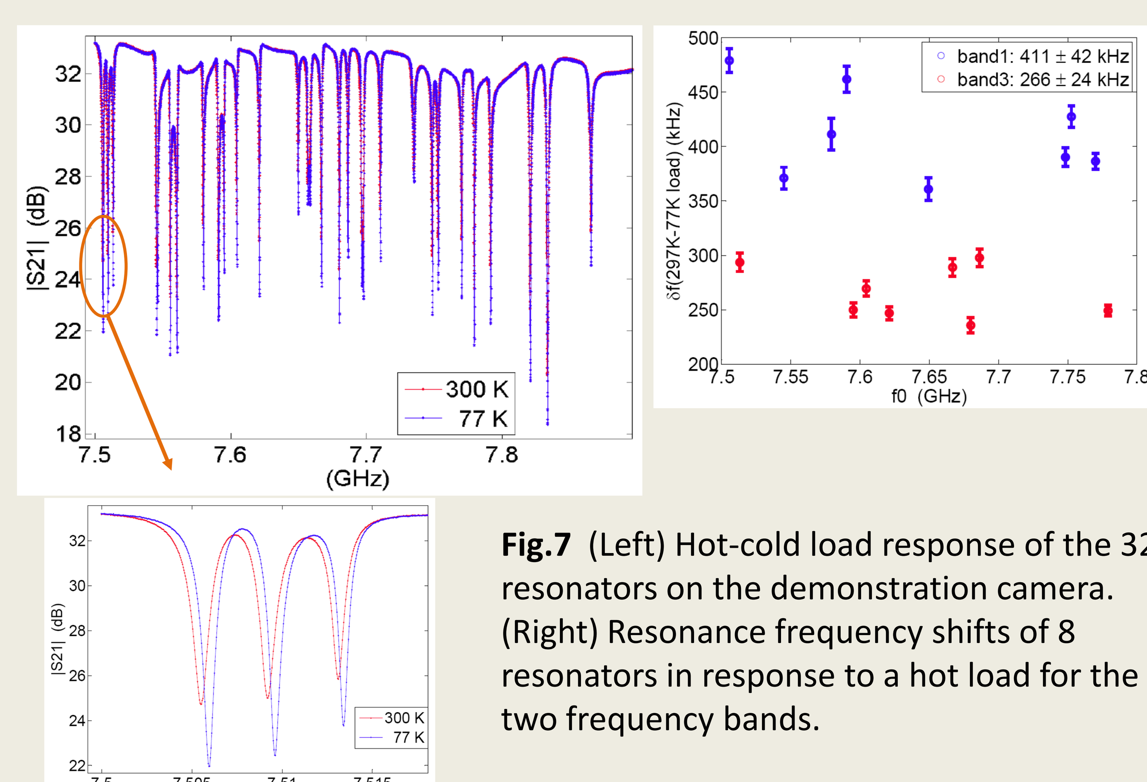

Fig.7 (Left) Hot-cold load response of the 32 resonators on the demonstration camera. (Right) Resonance frequency shifts of 8 resonators in response to a hot load for the two frequency bands.

Final 600 pixel 4-color MKID camera

- Final cryostat being built by High Precision Devices, Inc.
- Focal plane consists of 16 tiles each having 36 4-color pixels. A total of 2304 resonators in 576 pixels.
- 8 separate coaxes and 8 separate HEMTs for readout.
- Replaceable focal plane for future observations.

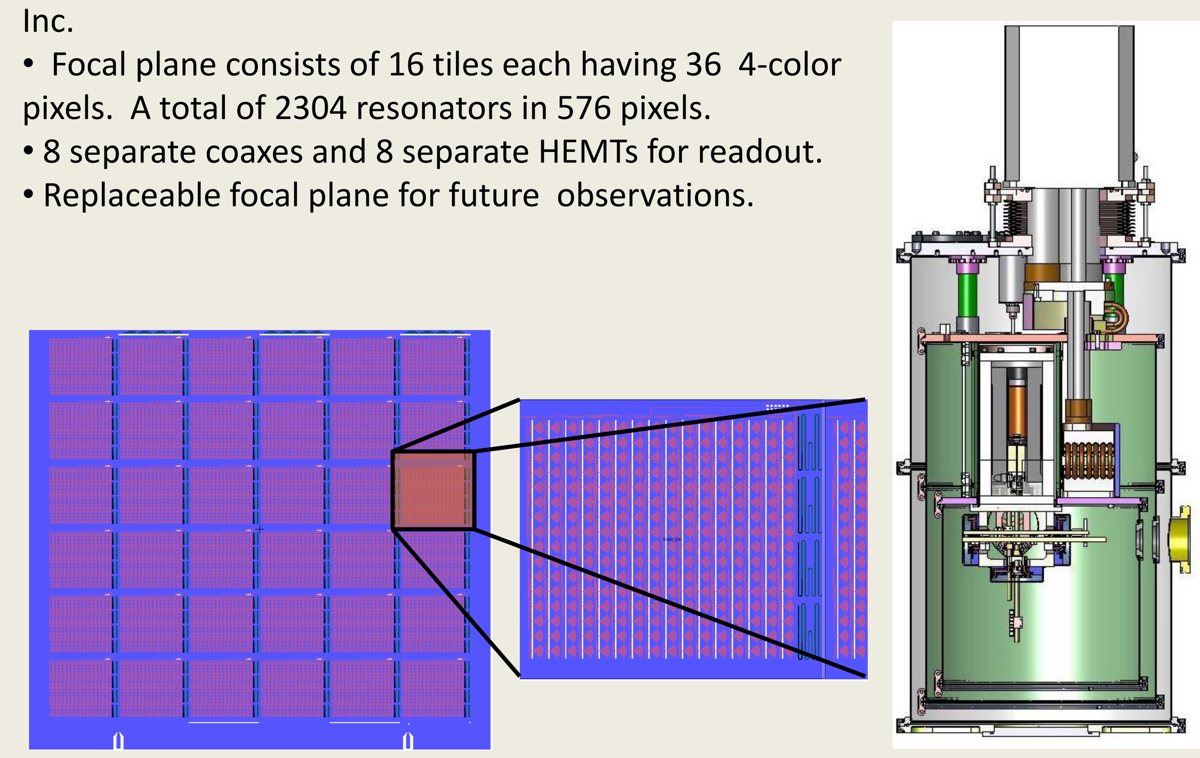

Fig. 8 (Left) Schematic of a 36 pixel 4-color tile in L-Edit. (Right) HPD cryostat

First light observation results with demonstration camera

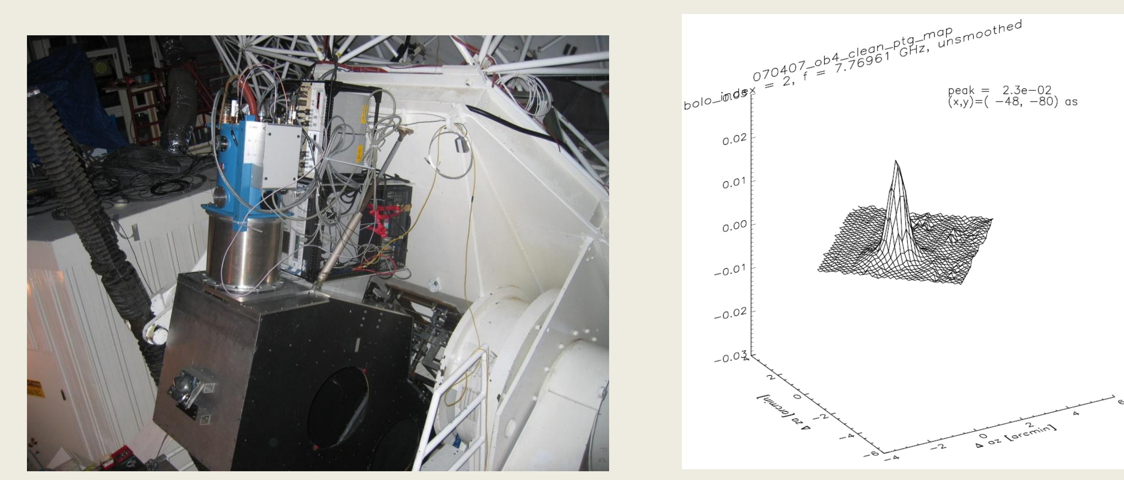

Fig. 9 (Left) Democam dewar mounted on CSO telescope optics box (Right) First light detection of Jupiter with the 16-pixel demo camera on April 2007.

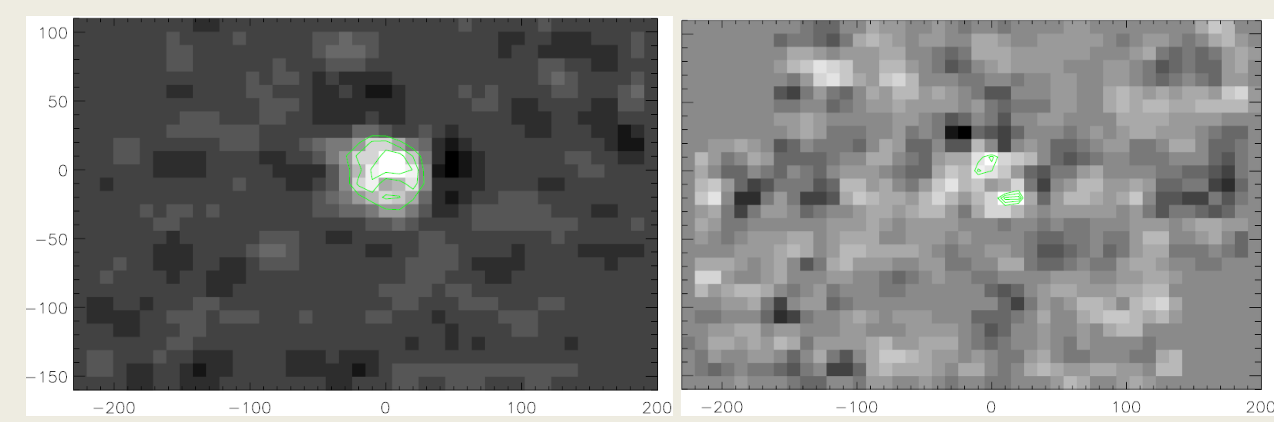

Fig. 10 (Left) Image of G34.3 from two pixels in two colors during the same observation. This observation involved drift scanning over the source for roughly 20 minutes, leading to a detection at 25σ at 240GHz (left) and 4.9σ at 350 GHz (right). Contours are at 10,15, 20σ and 3.5, 4, 4.5σ, respectively.

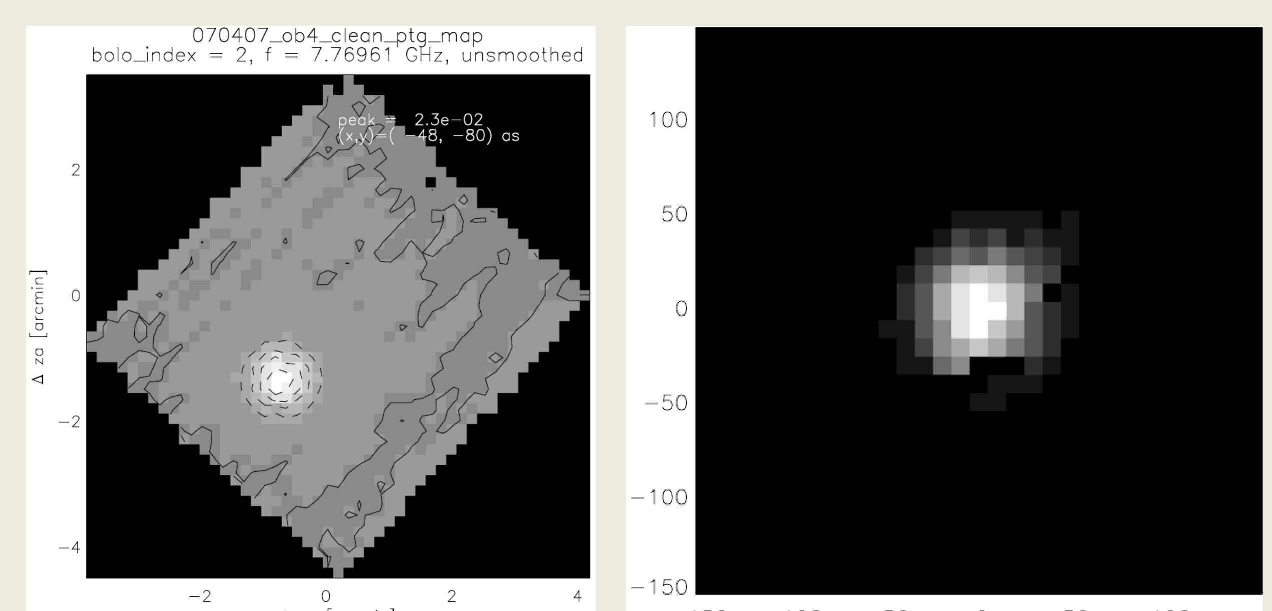

Fig. 11 An approximately 15 minute raster scan image of Jupiter at 240 GHz with contours detected at >1000σ. Right map units are in arcseconds.

We measured the system's **Noise Equivalent Flux Density (NEFD)** using numerous observations of planets and G34.3 :

- For raster scans of planets → NEFD of 1.3 Jy $s^{1/2}$ at 240 GHz, and 8 Jy $s^{1/2}$ at 350 GHz.
- For drift scans of G34.3 → NEFD of 1.6 Jy $s^{1/2}$ at 240 GHz, and 14 Jy $s^{1/2}$ at 350 GHz. (values higher due to 1/f drift noise)

Eventhough sensitivities roughly 20 times worse than background limit of ~50 mJy $s^{1/2}$ in 240 GHz band, **performance is acceptable for an engineering run designed to simply demonstrate the concept.**