SWCam: The Short Wavelength Camera for CCAT

SWCam is a short submm-wave camera designed for the CCAT telescope. SWCam provides diffraction limited imaging in the 200, 350, and 450\,µm telluric windows. We plan 6 off-axis 350/450\,µm sub-cameras (54,000 pixels total) surrounding an on-axis 200\,µm camera (26,000 pixels total) providing a 13’ diameter effective field of view. It is expected that SWCam will deliver background-limited performance at all wavelengths, attaining a mapping speed faster than 0.05 deg/hr and 0.013 deg/hr for sources at the 3\,σ level of 1\,mJy/pixel, and 1\,mJy/beam, respectively. The primary science goal for CCAT is to investigate star, galaxy and structure formation over cosmic time through large scale (10s of \(10^3\)) surveys in the sub-mm continuum bands. SWCam is a key part of a triad of instruments including LWCam and X Spec (Posters 150.08 and 150.09) that enable this science.

G.J Stacey for the SWCam team (see team list below)

SCIENCE DRIVERS

The COBE satellite discovered that half the optical radiation ever produced by stars over cosmic time is absorbed locally by interstellar dust, and then reradiated. Cosmic expansion delivers this light to us in the obscured star and galaxy formation history of the Universe. To date, most of the far-IR background remains unresolved into its individual sources – there is so many far-sources that their distribution is “confused” with the modest angular resolution available to current sub-mm telescopes. With its large aperture and small beam at 350/450\,µm, CCAT breaks through the confusion limit, resolving most of the far-IR background into its constituent sources so that we can then trace star formation over cosmic time (Fig. 1).

Fig. 1. Simulated Herschel (25’ beam) and CCAT (3.5’ beam) surveys for the same region of sky at 350\,µm. The much smaller CCAT beam resolves the cosmic infrared background (CIB) that heavily confused in the Herschel image.

Fig. 2. Arp 220 and Milky Way dust SEDs at various redshifts from 1 to 20. CCAT cameras sample near the SED peak, yielding estimates of source luminosity. Note that the 850\,µm flux is insensitive to source redshift \(\Rightarrow 350\,µm\) “drop-outs” will tend to be high redshift sources.

Fig. 3. 350\,µm detection, 350\,µm non-detections, or “drop-outs” can be useful in constraining the level of background sources.

SWCam is key to this discovery space: (1) the small beam and high sensitivity of the 350/450\,µm surveys will resolve 90% of the CIB, delivering much higher source density than the larger beam sub-mm surveys. SWCam will reach the confusion limit in 2-8 hours integration time; (2) the dust SED peak is redshifted into the 200 to 450\,µm SWCam bands for redshifts \(\sim 1-5\) (Fig. 2), so that SWCam samples \(\lambda_{\text{red}}\) and (3) combined SWCam/LWCam (850\,µm) images will reveal the high-z sources as 350\,µm “drop-outs” (Fig. 3). These drop-out IDs will need spectroscopic verification (see poster 150.09)

HIGHLIGHTS

CAMERA

- Diffraction Limited imaging at 200, 350, and 450\,µm
- Beam size \(\sim \frac{\lambda(\mu\text{m})}{100}\) : 2’ at 200\,µm \& 40 pc @ M83
- 80,000 MKID pixels spanning 13’ diameter Eq. FoV
- NEFD \(\sim 180, 42, \& 28\,mJy/beam\) at 200, 350 & 450\,µm

Optical Design

- Resolve the CIB through a simulator that will detect 160,000 high redshift IR bright galaxies per year
- 3\,σ confusion limited (0.5-1\,mJy/beam) \(\Rightarrow 450\,µm\) in < 8-2 h rms
- Mapping speed >0.013’/hr @ 350/450\,µm to 1\,mJy (3nJ/beam)
- Confusion (1mJy at 3\,σ) limited @ \(\sim 7’/\text{yr}\)

SWCam is designed with transmissive optics to ensure excellent image quality over its entire field of view in a compact configuration. Due to the large curvature of the CCAT focal plane, the best image quality is obtained by sub-dividing the field into 7 sub-cameras. The outer 6 cameras will each contain 9000 pixel 350/450\,µm sensitive arrays, while the inner camera contains a 26,000 pixel 200\,µm array. Lens material is base-lined as silicon which has smaller absorptive losses than our backup option, HDPE. The silicon lenses must be AR coated due its high index. We are pursuing A/R coatings by softening the index transition geometrically via dicing saws or silicon etching techniques.

Fig. 4. Cu-away schematic of the SWCam cryostat and re-imaging optics. Lenses are green (field lens array on the left), the LP filter is red, located at the Lyot stop. Detector arrays are blue, dual stage He refrigerators are yellow, and our three pulse tubes are orange. Dewar diameter is 1.2 m. Several filters are excluded for clarity.

Fig. 5. Optical ray trace for off-axis 350\,µm camera. Field lens is plano-convex silicon, camera lens doublet is plano-convex silicon and HDPE.

Fig. 6. Ensquared energy per pixel for optical system above. Our pixel size is 1\,mm square (~1.2’, or 2.9’ at 350\,µm). This plate scale is near optimal for point source detection. With diffraction limited performance, 60% of the light from a point source falls on a single pixel. Our ray trace shows that all pixels have been fabricated at JPL (Fig. 7) using super-conducting TiN thin film detectors. Resonant frequencies are in the 125-250 MHz range, which reduces TLS noise, enabling photon noise limited performance in a laboratory setting (Fig. 8). On sky tests with the CISO are expected soon.

Fig. 7. 432 pixel TiN lumped element array exposed to the 350\,µm photon backgrounds expected for the SWCam on CCAT.

READOUT

A set of tones matching the resonator frequencies are generated by a D/A converter and transmitted in to the array. The modified probe signals are complex sampled by an A/D converter and processed to extract the signals. TIN film’s high responsivity requires multi-tone probing as opposed to single tone per resonator probing for Al resonators. Two prototype systems are under development: one using a COT transceiver and GPU cards and another using a ROACH board with Xilinx FPGA. We are also designing a custom low cost, low power board with suitable data converters and FPGA.

Fig. 9. ROACH board approach: Ryan Monroe & Loren Swenson, Caltech

Fig. 10. Xilinx Vertex 5 FPGA based ROACH-I board with open source SW/FW (Fig. 11)
- Lower resonator frequencies and large number of tones demand very high resolution and large memory.
- Algorithms developed to test two different solutions.
- Tests with MAKO at CISO soon.

Fig. 11. Custom Board Design: Ganesh Rajagopalan, Cornell, Ryan Monroe, et al.
- Initial testing with the latest Xilinx 7 series Kintex FPGA kit (Fig. 11)
- Evaluating different approaches to high speed data transfer from A/D to FPGA.
- Cost and Power optimized final design to be contracted out to partner institution / private industry.

Fig. 8. Noise performance for TiN lumped element array exposed to the 350\,µm photon backgrounds expected for the SWCam on CCAT.

CTT Engineering Design Phase is partially supported by funding by the National Science Foundation’s Division of Astronomical Sciences

www.CCATObservatory.org

Canadian Consortium