BLAST - A NEW BALLOON-BORNE SUBMILLIMETER TELESCOPE

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Abstract. *BLAST the Balloon-borne Large Aperture Sub-millimeter Telescope, will have three bolometer arrays operating at 250, 350, and 500 μm, with 149, 88, and 43 detectors respectively. The arrays will be cooled to 300 mK so that the receiver's noise (NEFD) will be dominated by photon shot noise and atmospheric emission. Because of the high (35 km) altitude of balloon observations, atmospheric noise will be low and we expect NEFDs less than 241 mJy/Hz*$^{1/2}$ *in all channels. A 2.0 m diameter spherical mirror will give diffraction limited resolutions of 30, 41, and 59" respectively.*

The first test flight, planned for early 2003, will last 6–24 hours across North America. Long-duration balloon flights from Antarctica will begin in late 2003 and will last 14 days. BLAST will yield data on astronomical problems as close as nearby stars and as far away as the beginnings of the Universe.

1. INTRODUCTION

The Balloon-borne Large Aperture Sub-millimeter Telescope (BLAST) is designed to produce wide (1–10 deg^2) maps of the sky at wavelengths of 250, 350 and 500 μm. Because of the dramatically increased atmospheric transmission at balloon altitudes, BLAST will be far more sensitive than existing bolometer arrays. Full advantage of the bolometric focal-plane arrays, being developed for the *Herschel* satellite [1], will be made. A 20 hour observation, during the planned long-duration balloon (LDB) flights, will map a square degree of sky to the confusion limit at each of BLAST's operating frequencies. The scientific goals [2] of these surveys include:

- The identification of galaxy populations responsible for the sub-millimeter background and measurement of their clustering on scales of 0.1–10 degrees.
- The measurement of the spectral energy distributions (SED) and colors of selected sub-millimeter galaxies to give their rest-frame luminosities and star formation rates.
- Placing constraints on evolutionary models and high red-shift star formation histories of starburst galaxies.

- Surveys of diffuse interstellar emission and dense star forming regions.
- Observations within the Solar system including planets, asteroids and Kuiper-belt objects.

Quick construction of BLAST was possible due to the use of detector assemblies and filters similar to those designed for the SPIRE instrument on *Herschel.* BLAST will provide the first "flight tests" of these critical components for the later satellite mission.

2. DETECTORS & ELECTRONICS

BLAST will have three focal plane arrays of spider-web bolometers [3]. The arrays will operate at 250, 350, and 500 μm and will have 149, 88, and 43 pixels, respectively. Each array is manufactured from a single wafer of silicon nitride and 10MΩ bias resistors are built into the array (Figure 1). The detectors have been optimized for the expected loading at balloon altitudes. Their predicted NEPs are 3×10^{-17} W/Hz$^{1/2}$, which is less than the expected photon shot-noise from the telescope. They have time constants between 5 and 20 ms, fast enough for efficient mapping. Each array is fed by close-packed 2fλ conical feedhorns with λ/4 backshorts for efficient coupling of the bolometers to the telescope. The field of view of each array is 13″ by 6.5″ and they observe the same patch of sky simultaneously.

The bolometers and the horn feeds are cooled to <0.28 K by a helium-3 absorption refrigerator [4] and are mounted in the SPIRE instrument's detector array assembly, shown in Figure 1. This assembly minimizes the heat load on the helium-3 refrigerator by suspending the detectors using Kevlar string from a 2K support structure. Heat conduction down the >300 wires needed to read out the bolometers is minimized using cables made of constantan traces deposited on a Kapton support structure.

Each bolometer is read out using the circuit shown in Figure 2. The bolometers are AC biased at 400 Hz. Spiderweb bolometers have a high impedance (10 MΩ when cold) so to prevent noise from stray capacitance in the wiring, a matched pair of cooled (120 K) JFET amplifiers with a gain of 0.98 is placed as close to each detector as possible. Room temperature electronics amplifies this signal and a 100 Hz wide bandpass filter removes excess noise. The signal is then digitized. A lock-in to the 400 Hz bias signal is carried out using software. To prevent RF from entering the cryostat, (which would then be dissipated as heat in the bolometers), the cables from the cryostat and the room temperature electronics lie in RF-tight conduit. RF filters separate the analog preamplifier circuits from the digital stages.

Because BLAST has 280 detectors wiring is non-trivial. The electronics and cabling are modular, each unit serving 24 bolometers. To save space in the cryostat, the JFET units are constructed from bare die, bonded to FR4 circuit boards. One such module is shown in Figure 2.

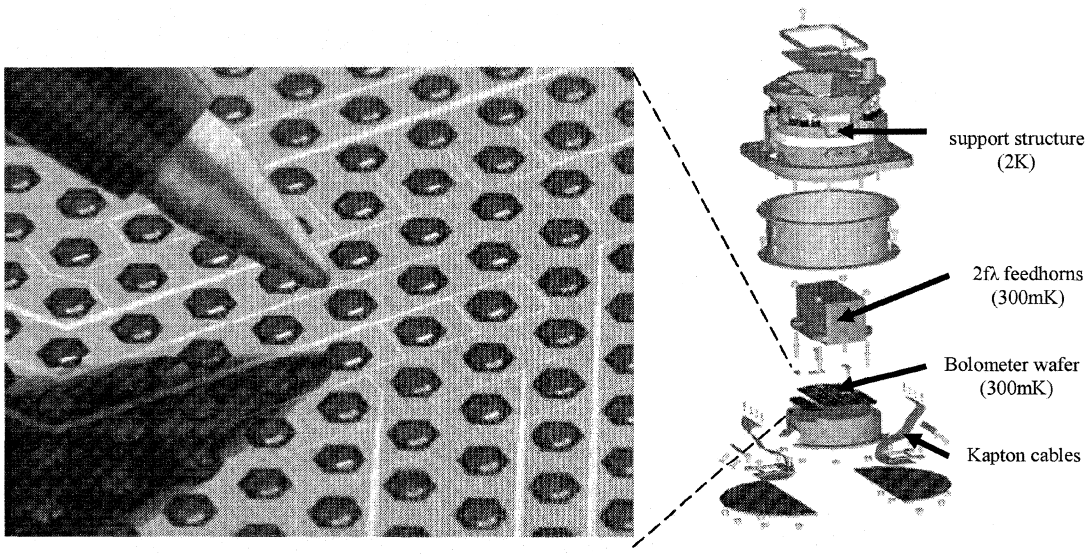

Figure 1. The array of 350 μm detectors to be used on BLAST is shown on the left and on the right is the SPIRE detector assembly that will house the wafer.

Band (μm)		250	350	500
Number of pixels		149	88	43
Beam FWHM	(″)	30	41	59
Background Power	(pW)	26	18	14
Background NEP	($\times 10^{-17}$ W/√Hz)	20	14	10
NEFD	(mJy/√s)	236	241	239
SCUBA's NEFD	(mJy/√s)	-	*1100*	*1001*
SOFIA's NEFD	(mJy/√s)	*550*	-	-
ΔS (1σ, 1hr, 1 deg^2)	(mJy)	38	36	36

Table 1. : Beam and sensitivity parameters for BLAST. The sensitivities obtainable by the SCUBA and SOFIA receivers have been added for comparison.

3. CRYOSTAT & CRYOGENICS

The blast cryostat has a 53.1 *l* nitrogen tank, a 30 K vapor-cooled shield and a 36.7 *l* helium tank. The expected hold time is 12 days, limited by the nitrogen. To achieve this hold time, essential for LDB balloon flights, the JFET modules are mounted on a G10 tube suspended from the nitrogen tank. In this way the ~3 mW of heat produced by the JFETs is dissipated to the liquid nitrogen. Dissipating this much heat to the helium bath would shorten the hold time to 4 days.

Since the total loading on the helium-3 refrigerator is estimated to be <30 μW it will have a hold time more than 40 hours. When exhausted, the refrigerator is recycled off a pumped helium-4 bath in a process that takes less than an hour. To conserve liquid helium, the main helium tank is not pumped. Instead, the helium-3 refrigerator is recycled off a small pumped helium pot connected to the main helium bath by a capillary [4].

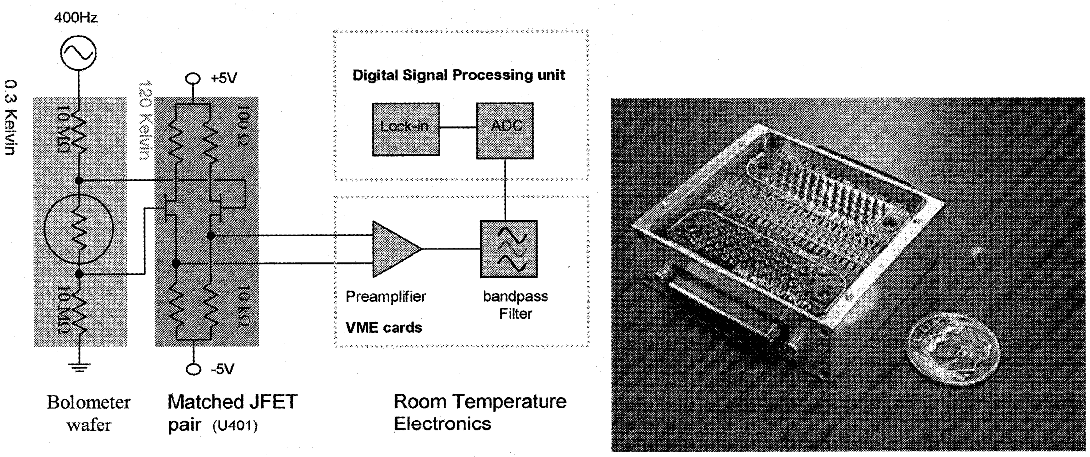

Figure 2. The electronics used to read out a single bolometer. To fit cold electronics for 255 bolometers in the cryostat, miniaturization was needed. On the right is a 24 channel JFET module.

4. OPTICS AND GONDOLA

BLAST is a Casigrain telescope with a 2 m primary mirror. The mirror, which is on loan to the project from NASA, is made of carbon fiber and weighs only 32 kg. The mirror has a f/2 spherical shape and a surface rms of 5 μm. The secondary mirror and reimaging optics in the cryostat correct for the spherical shape of the primary to give diffraction limited performance over a 14′ by 7′ field-of-view. To prevent spill-over from the ground only 1.9 m of the primary mirror is illuminated. The antenna efficiency is estimated to be over 80% and its emissivity is below 0.04. When the coupling efficiency of the bolometers and reflections from the filters are taken into account a telescope efficiency of 30% is achieved.

The BLAST reimaging optics, shown in Figure 3, are cooled to 2 K. All the mirrors and the detector arrays are mounted on a vertical "optics bench", enclosed in a light tight box. Where the beam enters the box, capacitive mesh filters define a band of 208 to 588 μm. The Casingrain focal plane is reimaged onto each array by two elliptical mirrors with a reflecting Lyot stop between them. After the second mirror, dichroic beam splitters (capacitive mesh) split the beam into the individual bands which are directed to their arrays via optical flats. Additional filters over each array are used to sharpen the edges of the bands. This design allows easy alignment before installation into the cryostat and shields the detectors from stray light.

The BLAST gondola consists of a precision-pointed inner frame on which the primary and secondary mirrors, a near-field baffle and the cryostat are mounted. The inner frame is supported by a stiff outer frame that is suspended from the gondola by four cables. Both frames are made of welded aluminum. The outer frame will be pointed in azimuth by a flywheel and an active pivot. The inner frame has an elevation mount with direct-drive servo motors that turn it relative to the outer frame. Three orthogonally-mounted laser-ring gyros provide high bandwidth motion sensing, and a daytime CCD star camera, capable of seeing magnitude +7 stars, is used to update the gyros and provide pointing measurements to an accuracy of 4″ (after data analysis). Crude pointing of the outer frame will be provided by a combination of magnetometers and sun sensors. The whole gondola is surrounded by a sunshield made of mylar sheet stretched over an aluminum frame.

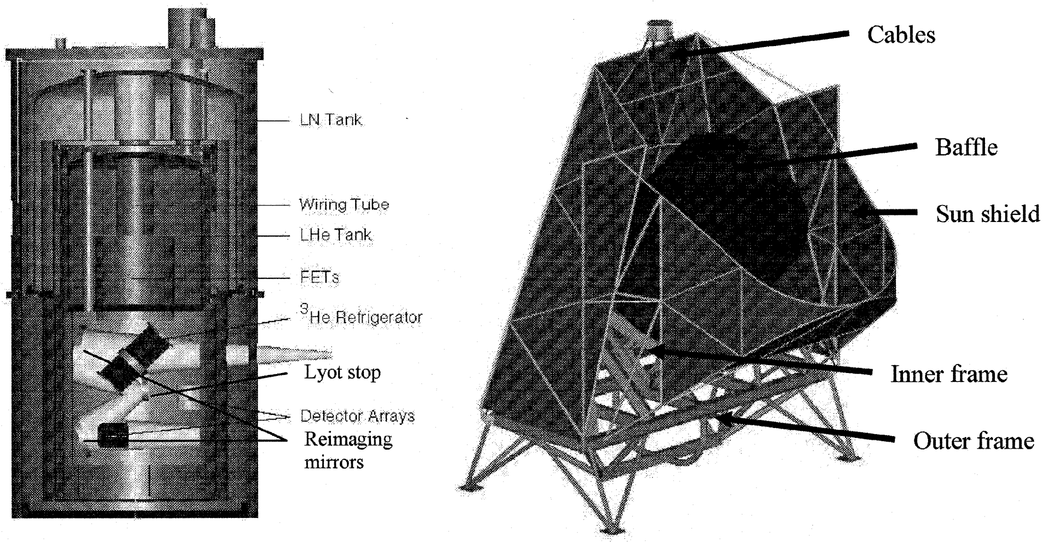

Figure 3. On the left is a cutaway view of the blast cryostat, showing the positions of the reimaging optics, the arrays and the helium-3 refrigerator. On the right the BLAST gondola is shown. The base of the gondola is 14 by 9.5 ft, the structure is 25 ft high, and the total mass is 4300 lbs (loaded).

5. CONCLUSIONS

BLAST will first fly overnight across N. America. Later Artic and Antarctic LDB flights will provide sub-millimeter maps much more cheaply and more quickly than those produced by the planned *Herschel* instrument. An upgrade to a 2.5 m mirror is also possible. BLAST will observe areas of the sky that are accessible by other lower frequency instruments such as SCUBA on the JCMT telescope. Such complementary observations will allow a greater range of science to be carried out. When SPIRE is launched BLAST observations will also be very useful for planning surveys.

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