

GISMO, a 2 mm Bolometer Camera Optimized for the Study of High Redshift Galaxies

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Received: 23 July 2007 / Accepted: 5 October 2007 / Published online: 29 January 2008
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Abstract The 2 mm spectral range provides a unique terrestrial window enabling ground based observations of the earliest active dusty galaxies in the universe and thereby allowing a better constraint on the star formation rate in these objects. We have built GISMO (the Goddard-IRAM Superconducting 2-Millimeter Observer), a 2 mm, 128 element superconducting Transition Edge Sensor (TES) based bolometer camera for the IRAM 30 m telescope in Spain. The camera uses an 8×16 planar array of multiplexed TES bolometers, which incorporates our recently designed Backshort Under Grid (BUG) architecture, described elsewhere. The optical design incorporates a 100 mm (4 inches) diameter silicon lens cooled to 4 K, which provides the required fast beam of $0.9 \lambda/D$. With this spatial sampling, GISMO will be very efficient at detecting sources serendipitously in large sky surveys, while the capability for diffraction-limited observations is preserved. With the background limited performance of the detectors, the camera provides significantly greater imaging sensitivity and mapping speed at this wavelength than has previously been possible. The major scientific driver for the instrument is to provide the IRAM 30 m telescope with the capability to rapidly observe galactic and extragalactic dust emission, in particular from high-z Ultra Luminous Infrared Galaxies (ULIRGs) and quasars, even in the summer season. The instrument will fill in the SEDs of high redshift galaxies at

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the Rayleigh-Jeans part of the dust emission spectrum, even at the highest redshifts. Our source count models predict that GISMO will serendipitously detect one galaxy every four hours on the blank sky, and that one quarter of these galaxies will be at a redshift of $z > 6.5$. We expect to install GISMO at the 30 m telescope in the second half of 2007.

Keywords Millimeter astronomy · Bolometer array · Dust emission · Galaxies

PACS 07.57.Kp · 85.25.-j · 95.55.Jz · 98.70.Lt · 95.85.Bh · 98.80.Es

1 Motivation

The 2 mm spectral range provides a unique low background window through the earth's atmosphere and allows to efficiently observe the earliest active dusty galaxies in the universe. Continuum measurements of galaxies at this wavelength are well suited to determine the star formation rate and the total energy output in these objects. 2 mm observations will complement existing SEDs of high redshift galaxies at the Rayleigh-Jeans part of the dust emission spectrum, even at the highest redshifts. In particular at redshifts of $z > 5$ sky background limited bolometric observations at 2 mm are highly efficient as compared to observations at shorter wavelengths, and the low confusion flux limit allows very deep integrations. In order to obtain close to sky background limited performance of a 2 mm camera, detectors with a noise equivalent power (NEP) of $\sim 4 \times 10^{-17} \text{ W}/\sqrt{\text{Hz}}$ are required.

2 GISMO: A 2 mm Bolometer Camera for the IRAM 30 m Telescope

At NASA's Goddard Space Flight Center we are now building the bolometer camera GISMO (Goddard-IRAM Super-conducting 2-Millimeter Observer), optimized for operating in the 2 mm atmospheric window. We have negotiated an opportunity to operate the instrument on the IRAM 30 m telescope on Pico Veleta in Spain [1]. The instrument is primarily aimed at surveying the first dusty galaxies in the universe. The camera is built around an 8×16 pixel array of 2 mm pitch, close-packed superconducting Transition Edge Sensor (TES) bolometers. Our source count models predict that GISMO will serendipitously detect one galaxy every four hours on the blank sky, and that one quarter of these galaxies will be at a redshift of $z > 6.5$ (Fig. 1).

3 Detectors, Dewar, Optics, Electronics, Performance

In GISMO we use a 2-dimensional planar bolometer array architecture, which separates the array and the backshort production, allowing a straightforward way to provide bolometer arrays for a wide range of wavelengths [2]. A 16×8 Backshort Under Grid (BUG) array is used in GISMO [3]. Figure 2 shows an image of the 8×16 BUG array that is installed in the camera.

Fig. 1 Cumulative redshift dependent $N(>S)$ at 2 mm versus flux for GISMO's instantaneous sky coverage

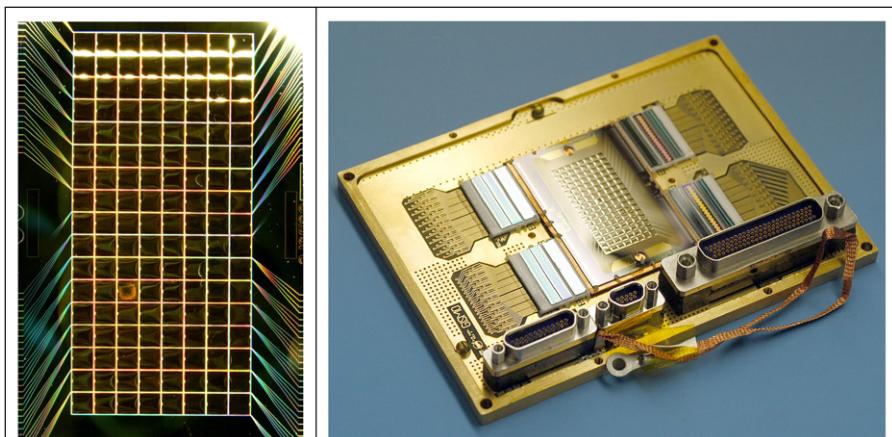
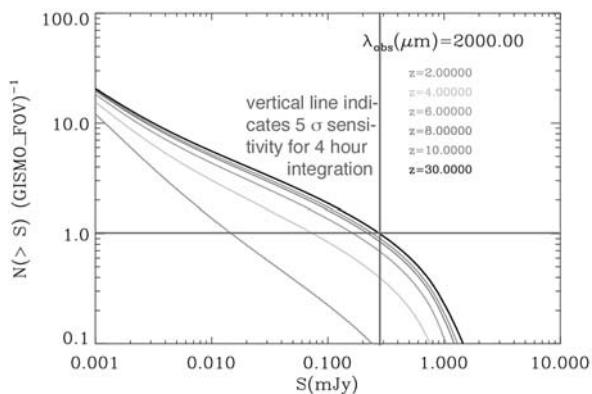


Fig. 2 (Color online) (Left): detailed view of the 8×12 BUG TES array used in GISMO. Due to the long wavelength of the observed radiation, the pixel pitch of the array is 2 mm. (Right): the GISMO detector box. The four readout columns with (from inside to out) SQUID multiplexer chip, Nyquist Inductor chip, and Shunt chip can be seen in the picture

A photograph and drawing of the dewar and the optics is shown in Fig. 3. The dewar has a combination of ${}^4\text{He}$ and ${}^3\text{He}$ evaporation coolers, which are assembled into the pocketed baseplate of the dewar, providing a base temperature of 260 mK for the detector array.

A 110 mm wide anti-reflection coated silicon lens (Fig. 4) provides the required $f/1.2$ of the optics for a $\sim 0.9 \lambda/D$ sampling, intended to optimize the efficiency of GISMO for large area blank sky surveys, without compromising the achievable point source signal-to-noise ratio. The silicon lens is cooled to 4 K.

The TES arrays are read out by four 32-channel SQUID multiplexers provided by NIST/Boulder [4]. Both the read out electronics [5] and the IRC control- and data acquisition software [6] are used in other instruments such as the GBT ~ 3 mm bolometer camera [7].

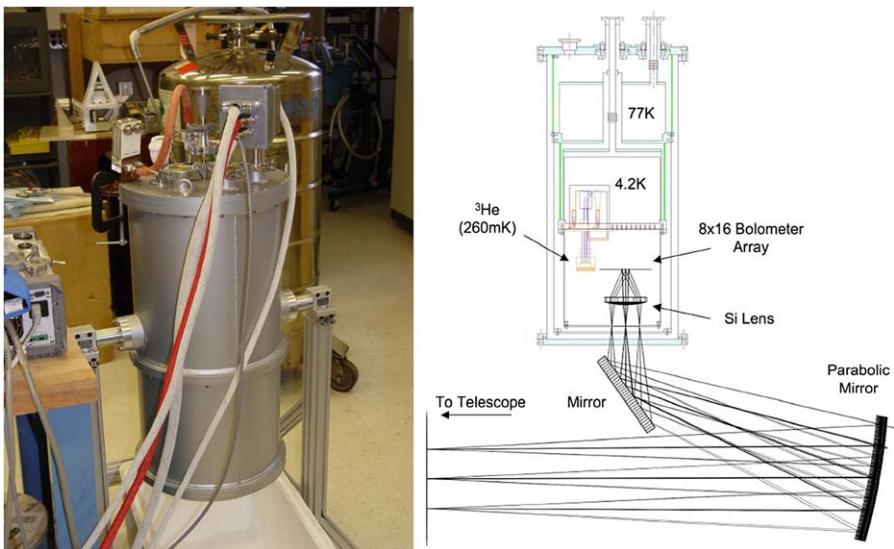


Fig. 3 (Color online) Photograph and drawing of the GISMO dewar. The diameter of the cold plate is 10 inches. For clarity the baffling of the optical train is not shown in the drawing



Fig. 4 (Color online) The 10 cm silicon lens used in GISMO before (*left*) and after (*right*) the AR coating which applied at Princeton University

4 Optical Tests

Figure 5 presents optical tests obtained with an internal blackbody source. A uniform gain of the detectors was observed. A fit to the data allowed us to verify the performance of the bandpass filter on the detector package. Figure 6 shows measurement of two of the authors' hands in front of the camera's window. Similar measurements of blackbody thermal loads at different temperatures are used to determine the optical efficiency of the instrument.

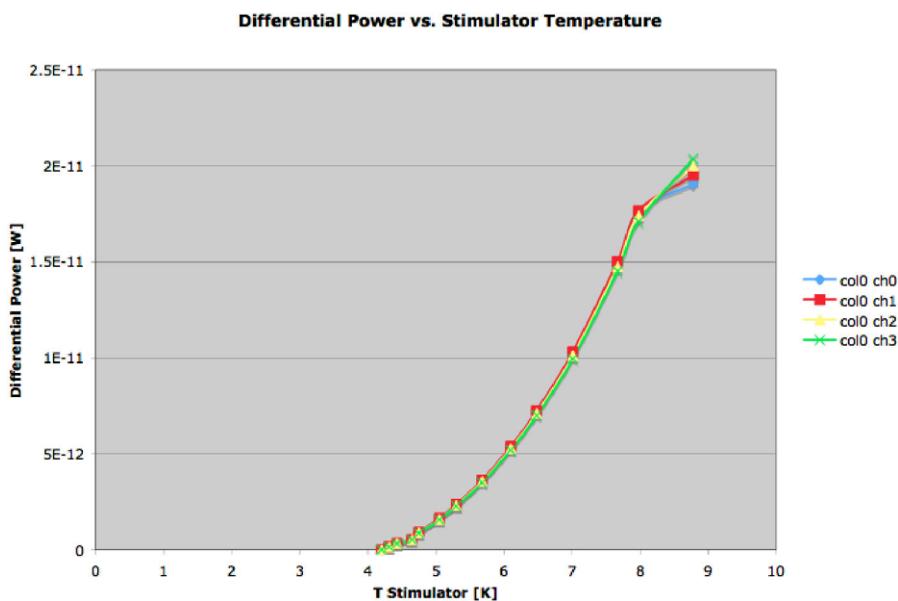
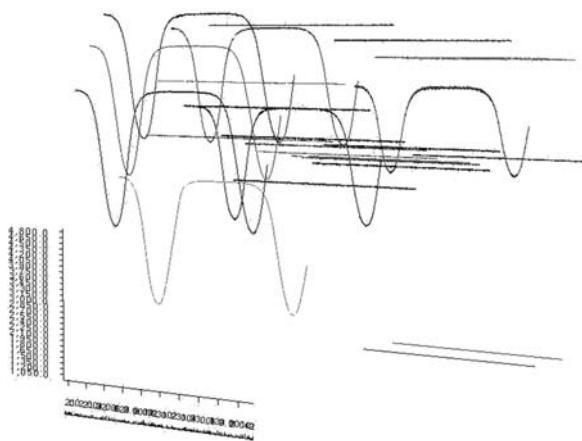


Fig. 5 (Color online) GISMO detectors detect blackbody radiation from an internal blackbody source

Fig. 6 GISMO observes waving hands outside the dewar from one of the authors of this article



5 Conclusion

We have built a 2 mm bolometer camera for the efficient detection of extremely high redshift galaxies. The camera is currently undergoing a variety of optical performance tests and we anticipate the deployment of GISMO at the IRAM 30 m telescope in 2007.

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