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First Astronomical Use of Multiplexed Transition Edge Bolometers

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Abstract. We present performance results based on the first astronomical use of multiplexed superconducting bolometers. The Fabry-Perot Interferometer Bolometer Research Experiment (FIBRE) is a broadband submillimeter spectrometer that achieved first light in June 2001 at the Caltech Submillimeter Observatory (CSO). FIBRE's detectors are superconducting transition edge sensor (TES) bolometers read out by a SQUID multiplexer. The Fabry-Perot uses a low resolution grating to order sort the incoming light. A linear bolometer array consisting of 16 elements detects this dispersed light, capturing 5 orders simultaneously from one position on the sky. With tuning of the Fabry-Perot over one free spectral range, a spectrum covering $\Delta\lambda/\lambda = 1/7$ at a resolution of $\delta\lambda/\lambda \approx 1/1200$ can be acquired. This spectral resolution is sufficient to resolve doppler broadened line emission from external galaxies. FIBRE operates in the 350 μm and 450 μm bands. These bands cover line emission from the important PDR tracers neutral carbon [CI] and carbon monoxide (CO). We have verified that the multiplexed bolometers are photon noise limited even with the low power present in moderate resolution spectrometry.

SCIENTIFIC MOTIVATION

Spectroscopy of distant galaxies in the far-infrared and submillimeter has lagged behind continuum studies at the same wavelengths (e.g., with SHARC at the CSO [1]) and spectroscopic studies at longer wavelengths (e.g. OVRO [2]). In large part, this is due to a relative lack of available instrumentation combining high sensitivity and large bandwidth. Observing a typical galaxy, with velocity-broadened linewidth of ~300km/s, in the 350 μm and 450 μm atmospheric windows (850 GHz and 650 GHz, respectively) requires a spectrometer with bandwidth of at least 0.5 μm (1 GHz). On the other hand, obtaining a detection of this line is easiest if the spectral resolution is approximately this width. Hence, a spectrometer with a spectral resolution of slightly more than 1000 is optimal for the detection of faint galaxies in the far-infrared and submillimeter.

The Fabry-Perot Bolometer Interferometer Experiment, FIBRE, is an instrument designed to demonstrate a suite of advanced technologies suitable for sensitive detection of far-infrared light. This includes superconducting transition edge sensor (TES) bolometers, SQUID multiplexed amplfiers, and a cryogenic Fabry-Perot interferometer. These components are being developed for the SOFIA imaging Fabry-Perot spectrometer SAFIRE and for a complement of ground-based instruments.

INSTRUMENT DESIGN

Superconducting TES Bolometers and SQUID Amplifiers

The superconducting TES bolometer has been developed for use at wavelengths from the infrared to X-rays. It combines high speed with high sensitivity and can be read out by SQUID amplifiers which are well suited to multiplexing. Unfortunately, the development of these detectors is too detailed to discuss at length here. The FIBRE bolometers were used in the laboratory to demonstrate that multiplexed detection using the NIST-designed SQUID multiplexer of Chervenak et al. [3] was possible [4]. Further measurements as presented by Staguhn et al. [5] in these proceedings have verified that the noise performance of these detectors is limited by phonon and Johnson noise contributions as predicted by theory.

FIBRE features two 1×8 monolithic bolometer arrays consisting of 1 mm×1 mm absorbers with a 450 μm×450 μm Mo/Au bilayer TES. This is shown in Fig. 1.

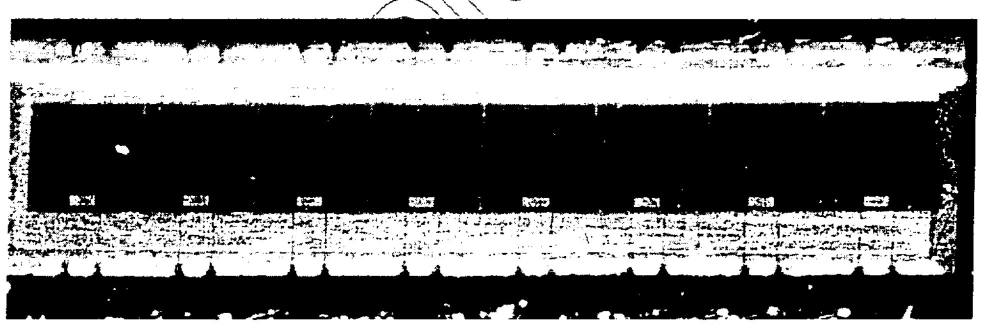

FIGURE 1. Photograph of a single 1×8 monolithic bolometer array. The 1 mm×1 mm pixels are 1 μm thick silicon membranes supported by 4 legs approximately 5 μm wide. The TES is the small pale rectangle at the bottom center of each detector.

Optical Design

The optical design uses a single Fabry-Perot etalon followed by an order sorting grating. The grating is blazed to operate in one order, where up to 6 orders of the Fabry-Perot are transmitted to the detector arrays with a dispersion of approximately 5 μm/mm. In this manner, a spectrum consisting of several orders of the Fabry-Perot is collected instantaneously. By stepping the Fabry-Perot over one free spectral range, a complete spectrum is accumulated.

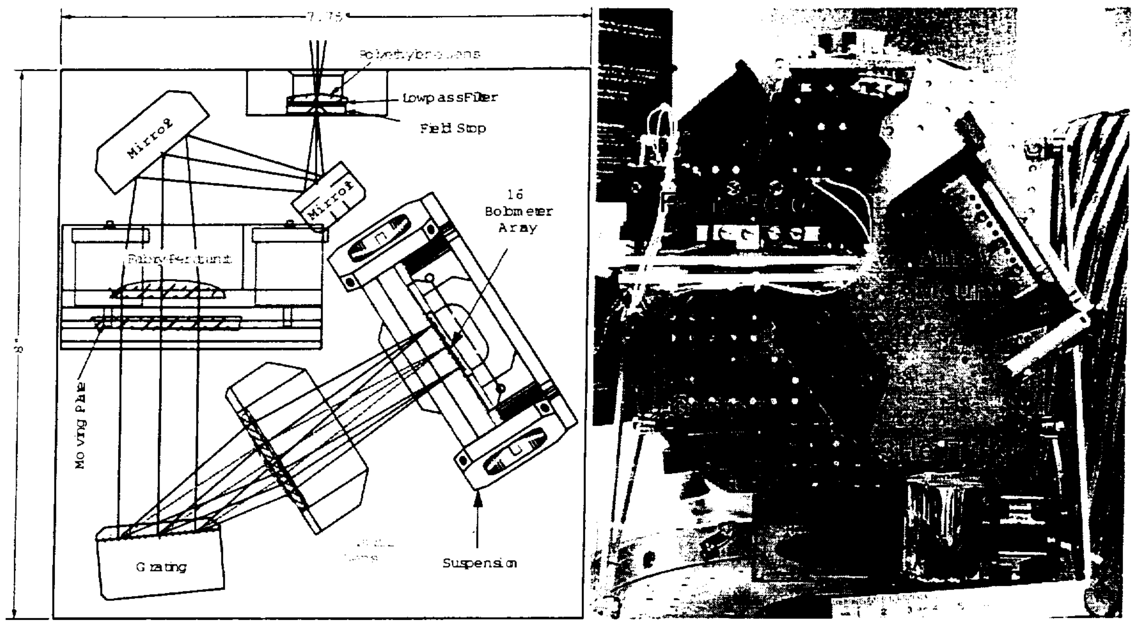

FIGURE 2. (Left) Diagram of spectrometer optics, showing three orders being dispersed onto the bolometer array. (Right) Optics being assembled, with the detector array and baffles yet to be added.

Commissioning Observations

FIBRE was delivered to the Caltech Submillimeter Observatory on Mauna Kea, Hawai'i in May 2001 (Fig. 3). During 6 nights of poor weather, the instrument was tested and found to work very well. The bolometers were read out in multiplexed fashion (Fig. 4). Those bolometers which were illuminated at a given Fabry-Perot tuning were found to have ~20 times the noise of the dark bolometers. The expected photo noise contribution is approximately 10 times the intrinsic (phonon plus Johnson) noise of the detectors, so the system noise is near the theoretical performance and the bolometers are background-limited with a net NEP of 3×10^{-17} W/$\sqrt{\text{Hz}}$. A spectrum (Fig. 5) was taken using a local oscillator source operating at 365 μm (822 GHz). The spectral resolving power was measured to be 1200, for a velocity resolution of 250 km/s, as predicted from the known performance of the Fabry-Perot.

The opacities at the zenith during the observing run were measured by skydips using both FIBRE and the CSO facility 350 μm taumeter. These measurements yielded zenith opacities of $\tau_{350\mu m}$ ~4 during most of the run. No scientific data could be taken in such poor conditions, but in order to demonstrate a multiplexed detection using TES bolometers, we observed the limb of the Moon while chopping the telescope. The chopping enabled the subtraction of the atmospheric contribution, enabling a high signal-to-noise detection of the Moon emission, although the atmospheric transmission was ~1% during the observation (Fig. 6).

FIGURE 3. FIBRE on the CSO. Don't know if we need this one.

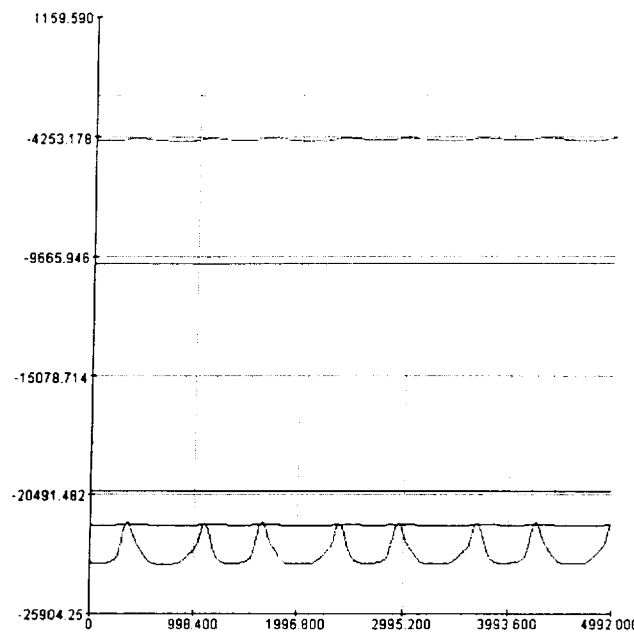

FIGURE 4. Multiplexed readout of the FIBRE bolometers; the signal can be seen strongly on one channel, weakly in two others, and is not seen in the remaining channels.

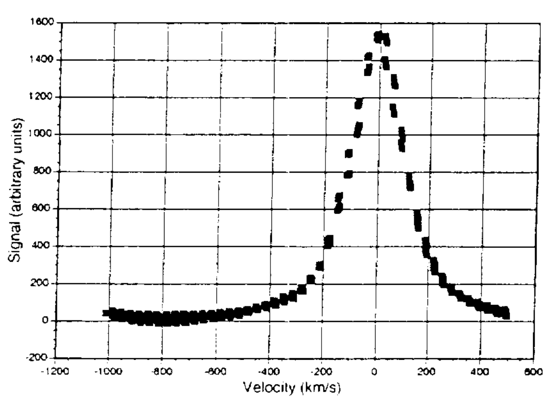

FIGURE 5. Calibration spectrum taken using a local oscillator operating at 365 μm (822 GHz), calibrated in velocity units. The resolution is 250 km/s , for a resolving power of 1200.

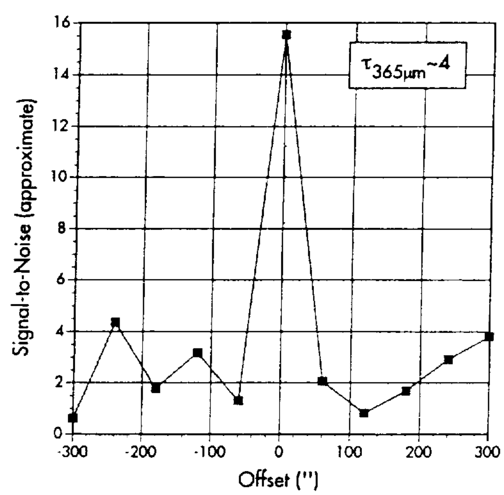

FIGURE 6. Detection of the limb of the Moon at 365 μm. The measurement was taken while chopping on and off the limb so that signal is seen only when exactly on the limb. Each data point contains 3 seconds of on-source time.

CONCLUSION

FIBRE went to the telescope. Success was achieved in a limited fashion.

ACKNOWLEDGMENTS

We thank the staff of the Caltech Submillimeter Observatory and George Voellmer for making the observations described here possible; their support was crucial in the commissioning of FIBRE. We owe a debt of gratitude to Troy Ames at NASA's Goddard Space Flight Center and his team for their dedication to developing the Instrument Remote Control (IRC) software framework that FIBRE uses.

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