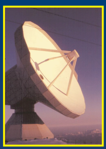

# Science Case for a 2 mm Bolometer Camera Optimized for Surveys of Dusty Galaxies in the High Redshift Universe


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We have built a bolometer camera (the Goddard-Iram Superconducting Millimeter Observer, GISMO) for operation in the 2 mm atmospheric window to be used at the IRAM 30 m telescope. The instrument uses a 16x8 planar array of multiplexed TES bolometers which incorporates our newly designed "Backshort Under Grid" (BUG) architecture. Due to the size and sensitivity of the detector array (the NEP of the detectors is $3\times10^{-17}$ W/$\sqrt{\text{Hz}}$), this instrument will be unique in that it will be capable of providing significantly greater imaging sensitivity and mapping speed at this wavelength than has previously been possible. The major scientific driver for this 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 ULIRGs and quasars even in the summer season. The 2 mm spectral range provides a unique window to observe the earliest active dusty galaxies in the universe and is well suited to better confine the star formation rate in these objects. The instrument will fill in the SEDs of high redshift galaxies at 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.


## Motivation

The 2 mm spectral range provides a unique low background window through the earth's atmosphere and allows efficient observation of 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 (Figure 1). Considering the atmospheric noise in this window (Table 1 at left),

Average winter atmosphere @ Pico Velea:
150 GHz: sky emissivity 0.1, sky noise $6\times10^{-17}$ W/$\sqrt{\text{Hz}}$
NEFD: 7 mJy/sqrt(Hz)
250 GHz: sky emissivity 0.2 sky noise $1.3\times10^{-16}$ W/$\sqrt{\text{Hz}}$
NEFD: 20 mJy/sqrt(Hz)

Average summer atmosphere @ Pico Veleta:
150 GHz: sky emissivity 0.2, sky noise $1.1\times10^{-16}$ W/$\sqrt{\text{H}}$
NEFD: 12 mJy/sqrt(Hz)
250 GHz: sky emissivity 0.4 sky noise $2.4\times10^{-16}$ W/$\sqrt{\text{Hz}}$
NEFD: 46 mJy/sqrt(Hz)

Table 1: Typical winter- and summer sky background at Pico Veleta for a λ/D sampling array with 20% bandwidth, observing in on-off mode at 50 degrees elevation. The following efficiencies were assumed: opt. throughput 0.5; detector 0.8; telescope efficiencies are from the 30m users manual.

Figure 2 demonstrates that particular at redshifts of $z > 5$ sky background limited bolometric observations at 2 mm are highly efficient as compared to observations at shorter wavelengths. In order to obtain close to sky-background-limited performance of a 2 mm camera, detectors with a noise equivalent power (NEP) of ~ 4 x $10^{-17}$ W/$\sqrt{\text{Hz}}$ are required. Our superconducting bolometers meet this requirement.

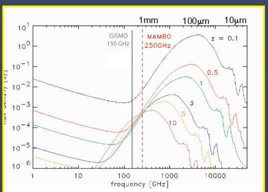


Figure 1. SEDof Arp220 at different redshifts.

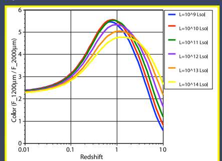


Figure 2. 1.2 mm over 2 mm color versus redshift of template galaxies with different luminosities.

## Galaxy Number Count Simulations

We have used the template SEDs from Chary & Elbaz (2001, ApJ, 556, 562) to simulate galaxy number counts from IR to millimeter wavelengths. Fig. 3 shows the galaxy templates we use for our simulations: HLIRGs (pink), ULIRGs (red), LIRGs (green), and normal galaxies (blue). Fig. 4 shows the assumed luminosity evolution in our models with a cut off at $z$=10; we assume no density evolution. Figures 5&6 show predicted vs. observed number counts for 850 μm (SCUBA, from Borys et al. 2003) and 1.2 mm (MAMBO COSMO survey, from Bertoldi, priv. comm.). Our models do agree with the observed number counts with a possible

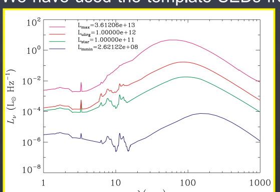


Figure 3. The galaxy SEDs from Chary & Elbaz (2001) are used for our galaxy number count calculations.

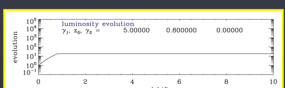


Figure 4. Luminosity evolution used in our simulations.

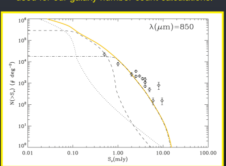


Figure 5. Calculated 850 μm number counts with superimposed SCUBA observations (Borys et al., 2003). Dash-dotted line: ULIRGs and brighter, dashed: LIRGS, dotted: normal galaxies.

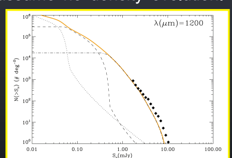


Figure 6. Calculated 1.2 mm number counts with superimposed MAMBO dobservationsata (Bertoldi, priv. comm.). Dash-dotted line: ULIRGs and brighter, dashed: LIRGS, dotted: normal galaxies.

number counts. However, there is a tendency of our simulations to underpredict slightly the number of the brightest sources. Figure 7 shows the expected number counts at 2 mm wavelength. The 2 mm confusion limit for a 30m telescope is ~40μJy, which will allow blank sky detections of LIRGS and even less luminous galaxies at high redshifts. Fig. 8 shows the redshift distribution of the sources comprising the integrated background radiation at different observing frequencies. The plot demonstrates that at 2mm in a dark sky survey virtually all galaxies that will be detected have a redshift of $z > 2$. In detail, our model calculations predict that under winter weather conditions a 2mm background-limited camera at the IRAM 30m telescope will serendipitously detect 4 sources per observing night, of which one will be at z > 6.5, the current QSO redshift record.

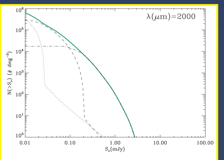


Figure 7. Predicted 2 mm number counts. Dash-dotted line: ULIRGs and brighter, dashed: LIRGS, dotted: normal galaxies. On a 30 m telescope a 2mm camera has a confusion limit of ~40 μJy, which will allow serendipious observations of LIRGS at high redshifts.

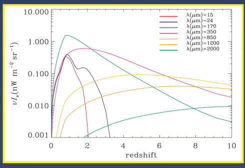


Figure 8. Redshift distribution of the sources that cmprise the integrated background at different wavelengths. At 2mm the contribution from galaxies at z<2 is negligible.

## GISMO: A 2 millimeter bolometer camera for the IRAM 30m Telescope

We have developed a new type of 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. A 16 x 8 Backshort Under Grid (BUG) array is installed in our 2mm bolometer camera GISMO (Fig. 9) . Fig. 10 shows an image of the detector array. The TES arrays are read out by four 32-channel SQUID multiplexers provided by NIST/Boulder. The detector array is coolded to 260 mK by a combination of $^4$He and $^3$He evaporation coolers, which are recessed into the dewar cold plate. Fig. 11 shows an enlarged photo of one pixel which shows the integrated Transition Edge Sensor (TES) bolometer in more detail. The normal metal "Zebra" structure on the device, which is used to suppress excess noise, is clearly visible in this image. This design provides background-limited observing capabilities for the IRAM 30m telescope at 2 mm. A 10 cm wide anti-reflection coated silicon lens provides the required $f$/1.2 of the optics for a ~0.9 λ/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. Dithering will be used to recover the full angular resolution of the telescope. We expect to install GISMO at the IRAM 30m telescope in November of 2007.

Figure 9. The GISMO dewar in the lab at NASA/GSFC.

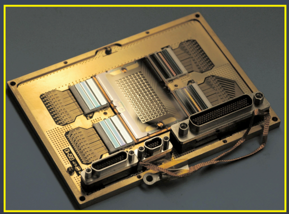

Figure 10. Image of the GISMO 8x16 planar array in the detector package. SQUID multiplexers, shunts and Nyquist inductors are integrated in the package.

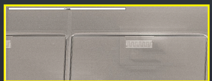

Figure 11. Photograph showing part of one pixel of the BUG array in detail. The TES sensor with its meandering "Zebra" normal metal layer can be seen at the top center of the pixel.

Figure 12. GISMO will be installed at the IRAM 30m Telescope in the Fall of 2007.