GISMO, a 2 mm Camera for the IRAM 30 m Telescope

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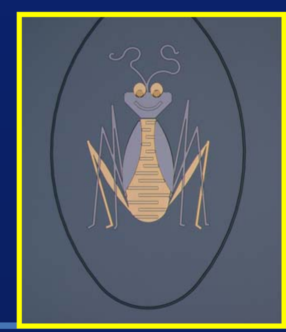

We have demonstrated a monolithic 8x16 Backshort Under Grid (BUG) array with superconducting Transition Edge Sensors (TES), using our 2 mm wavelength imager GISMO (Goddard IRAM Superconducting 2 Millimeter Observer) at the IRAM 30 m telescope in Spain for astronomical observations. The 2 mm spectral 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. The optical design incorporates a 100 mm diameter silicon lens cooled to 4 K, which provides the required fast beam yielding 0.9 lambda/D pixels. With this spatial sampling, GISMO is optimized for detecting sources serendipitously in large sky surveys, while the capability for diffraction limited imaging is preserved. The camera provides significantly greater detection sensitivity and mapping speed at this wavelength than has previously been possible. The instrument will fill in the spectral energy distribution of high redshift galaxies at the Rayleigh-Jeans part of the dust emission spectrum, even at the highest redshifts. Here we present results from our observing runs with the first fielded BUG bolometer array.

Motivation

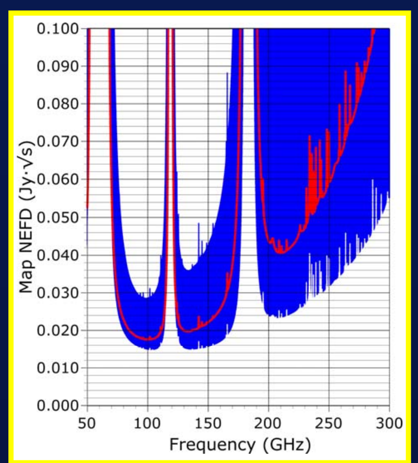

Fig.1: Total GISMO and IRAM 30m telescope Noise Equivalent Flux Density (NEFD) in typical weather (red line) ranging from good winter conditions (90% transmission) to normal summer conditions at 2 airmasses (60% transmission), shown in blue . The predicted range of NEFDs is between 16 and 44 mJy/rt(s).

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. The achievable sensitivities at the IRAM 30m telescope (Fig. 1) in combination with the expected colors of high redshifted galaxies (Fig. 2) implies that at redshifts of $z > 5$ sky background limited bolometric observations at 2 mm are highly efficient as compared to observations at shorter wave-lengths. Detectors with a noise equivalent power (NEP) of ~ 4 x 10^{-17} W/ˆHz are required for background limited observations at 2mm. Our superconducting bolometers meet this requirement.

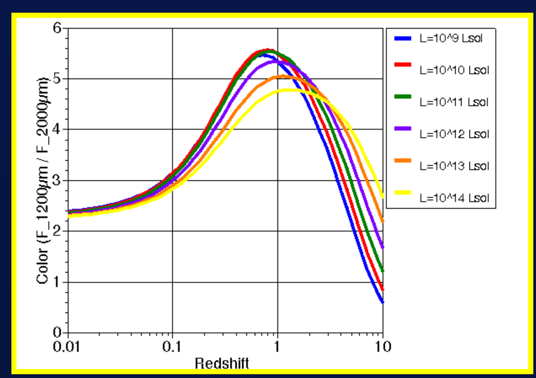

Figure 2. 1.2 mm over 2 mm color versus redshift of template galaxies with different luminosities.

We have used the template SEDs from Chary & Elbaz (2001, ApJ, 556, 562) to simulate galaxy number counts from IR to millimeter wavelengths. Figure 3 demonstrates the accuracy of our predicted vs. observed number counts a 1.2 mm (counts from MAMBO COSMOS survey, Bertoldi et al. 2007, ApJS, 172, 132). The low confusion limit at 2 mm for the 30m telescope will allow blank sky detections of LIRGS and even less luminous galaxies at high redshifts. Fig. 4 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 2 mm background-limited camera at the IRAM 30m telescope will serendipitously detect 2 sources per observing night, of which one will be at z > 6.5.

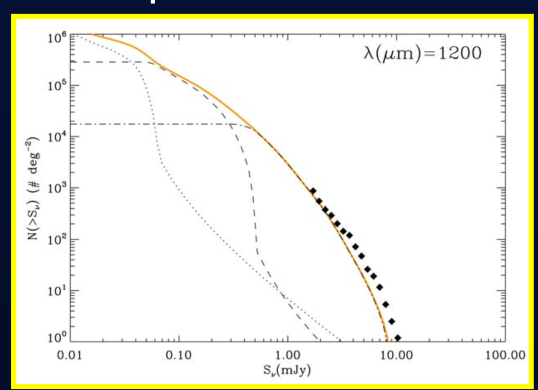

Figure 3. Calculated 1.2 mm number counts with superimposed MAMBO dobservations (Bertoldi et al. 2007). Dash-dotted line: ULIRGs and brighter, dashed: LIRGS, dotted: normal galaxies.

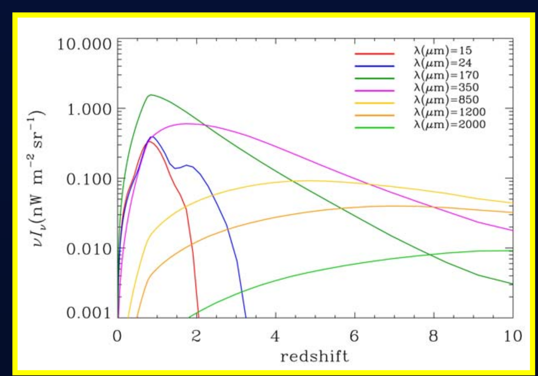

Figure 4. Redshift distribution of the sources that comprise the integrated background at different wavelengths. At 2mm the contribution from galaxies at $z<2$ is negligible.

GISMO - a 2mm Bolometer Camera for the IRAM 30 m Telescope

GISMO uses a 16 x 8 Backshort Under Grid (BUG) array of superconducting Transition Edge Sensors (TES), shown in Fig. 5. The TES array is read out by four 32-channel SQUID multiplexers provided by NIST/Boulder. The normal metal "Zebra" structure on the device, which is used to suppress excess noise, provides near fundamental noise limited device performance (Fig. 6). An 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 sky surveys. *Lissajous* observations provide the diffraction limited angular resolution, reduce correlation times between different regions on the sky, and provide for optimal separation of the source from other signal variations.

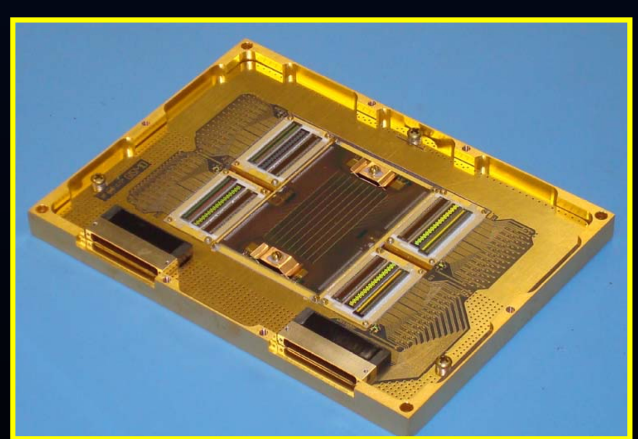

Figure 5. The GISMO 8x16 planar array in the improved detector package used during our second observing run in 2008. SQUID multiplexers, shunts and Nyquist inductors are integrated in the package.

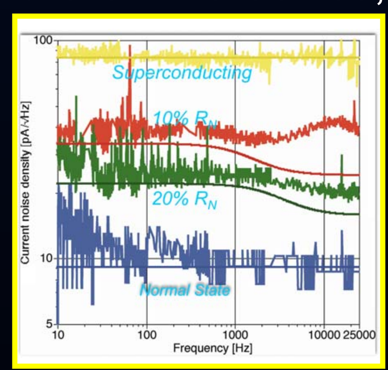

Figure 6. Noise spectrum of a BUG device in its superconducting state (yellow), on the transition (red and green), and in its normal state (blue). Superimposed is the expected fundamental thermodynamic noise limit.

Astronomical Observations with GISMO

GISMO was installed at the IRAM 30 m telescope (Figs. 7, 8) three times between 2007 and 2010. In order to accomodate for all weather conditions, a 40% transmission neutral density filter was installed in the instrument. As a result, the photon noise limit for those observations was about 50% higher than the numbers shown in Figure 1. Starting with our next run, the last before the instrument becomes accessible to the astronomical community, we will use a cold mechanism that can move out the neutral density filter during good weather conditions. Figure 9 shows current noise density spectra observed on the sky under different weather conditions, and the dewar window blanked off. Figs. 10 through 17 show examples of GISMO's astronomical observations.

Figure 7. The GISMO dewar at the IRAM 30m telescope.

Figure 8. The IRAM 30m Telescope on Pico Veleta, Spain.

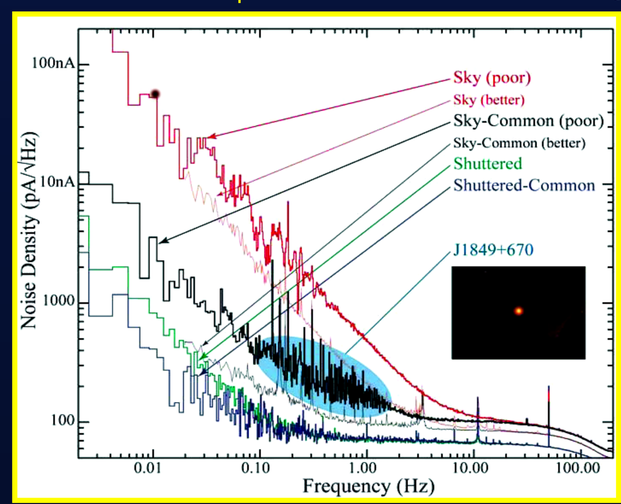

Figure 9. Detector current noise density on and off the sky under different conditions.

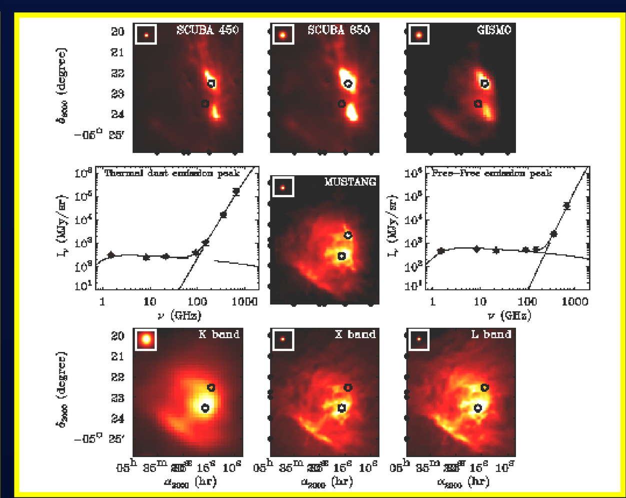

Figure 10. Multi color images of Orion . The spectrum on the left is for the peak of the dust-dominated region and the spectrum on the right is for a free-free dominated region (Dicker et al. 2009, ApJ 705, 226).

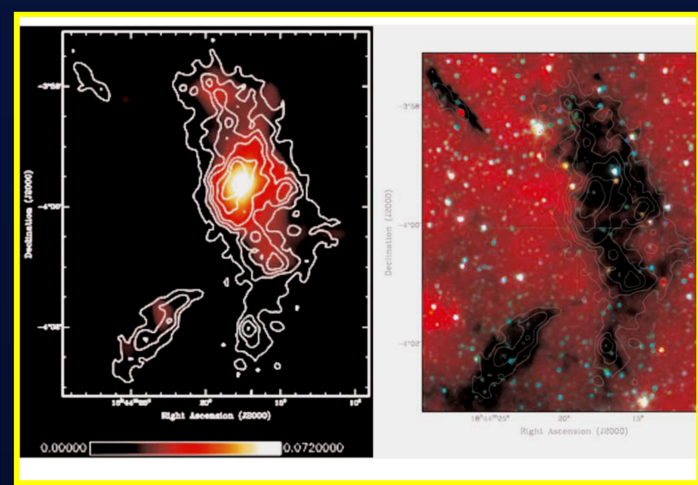

Figure 11. *Left:* GISMO (colors) and Mambo (contours) observations of Infrared Dark Cloud IRDC30. *Right:* Mambo Contours superimposed on IRAC data.

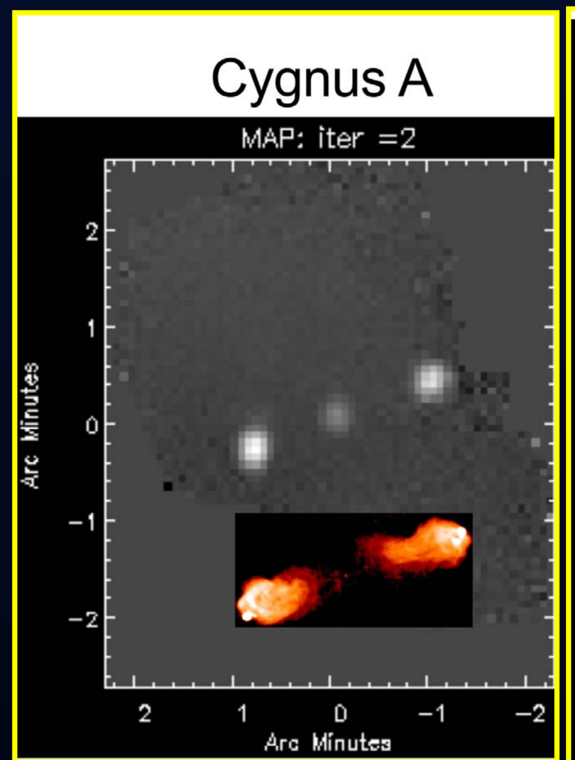

Figure 12. Cygnus A: Grey scalie: GISMO 2mm, Color insert: VLA 21 cm.

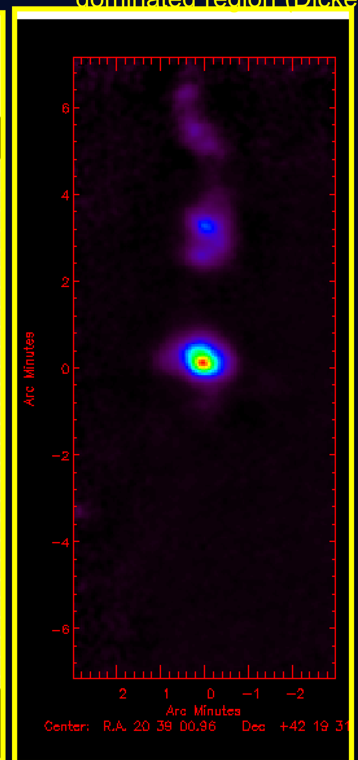

Figure 13. The star forming region Dr 21.

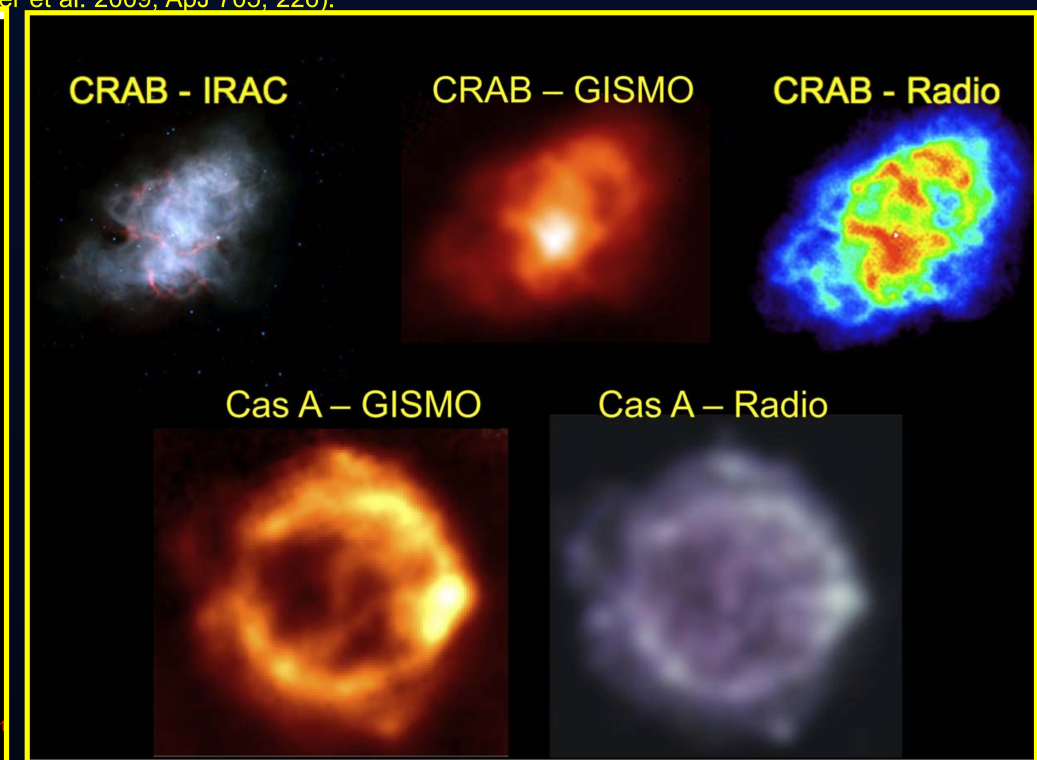

Figure 14. Multi Color images of Supernovae remnants Crab and Cas A.

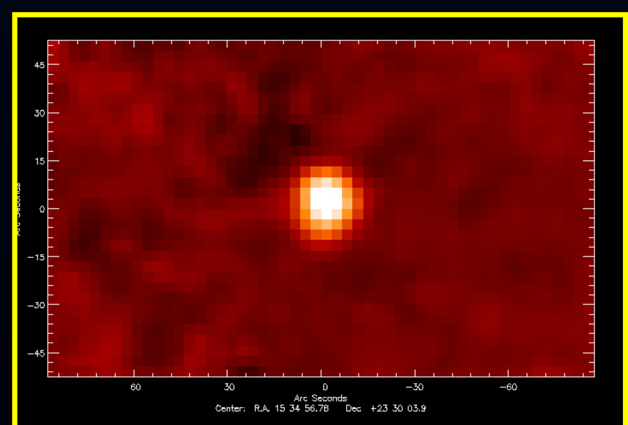

Figure 15. Image of Arp 220. The measured flux is 70 mJy.

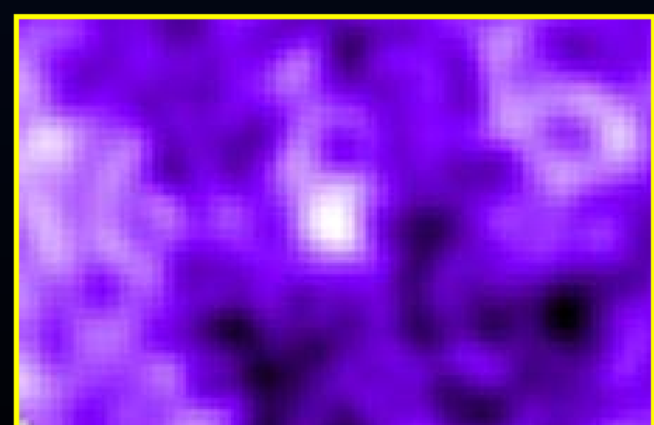

Figure 16. S/N Image of the high-z quasar APM 08279+5255. The measured flux is ~ 8 mJy.

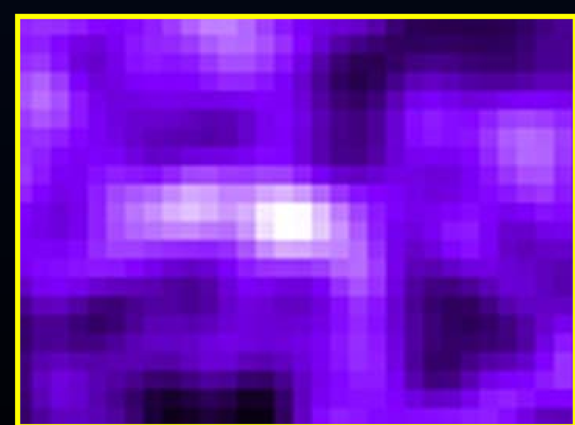

Figure 17. S/N Image of the high-z source AzTEC3. The measured flux is ~2.5 mJy.