Spitzer 70μm Confusion and Sensitivity

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ABSTRACT

Sensitivity and confusion measurements are presented based on the ultra-deep MIPS-70μm observations of GOODS Hubble Deep Field North (HDF-N). The instrument noise for the MIPS-70μm band integrates down with nearly $t^{-0.5}$ for the low background HDF-N field. The estimated confusion level is $\sigma_c = 0.30 \pm 0.15$ mJy for the limiting flux density of 1.5 mJy ($q = 5$). For 10.6 ks of effective integration time, we estimate an instrument point source rms of 0.44 mJy and achieve a total point source rms of 0.53 mJy for the low background HDF-N field.

1. Data

The Multiband Imaging Photometer for *Spitzer* (MIPS, Rieke et al. 2004) 70μm observations of the GOODS Hubble Deep Field North (HDF-N) were carried in Cycle-1 of the General Ovsever program (*Spitzer* program 3325, PI: Frayer). The data were embargoed until after the MIPS GTO propriety period and were released to our team in 2005 August. The raw data were downloaded from the SSC archive (version S11) and were processed using the offline Germanium Reprocessing Tools (GeRT, S13 version 1.0), following the algorithms derived by the MIPS IT and IST (Gordon et al. 2005). The instrumental artifacts in the BCDs were removed adopting the filtering techniques used for the reduction of the extragalactic First Look Survey (xFLS, Frayer et al. 2006). The BCD pipeline processing and filtering procedures were optimized for these deep photometry data. We improved the sensitivity by 20% with respect to the online (version S11) filtered BCDs (fBCDs). We corrected the data for the updated calibration of MIPS (S13.2), assuming an absolute flux calibration factor of 702 MJy/sr per MIPS-70μm unit for stellar SEDs, and applied the appropriate color corrections for galaxy SEDs (color correction factor of 1.09). In comparison, the total calibration correction, including color corrections, is a factor of 1.20 times the pre-S13.2 versions of the online data products and is 3.4% larger than the calibration adopted for the xFLS analysis.

The data were combined with MOPEX and were projected, correcting for array distortions, onto a sky grid with 4$''$ pixels. The average level of the noise image was derived empirically by making multiple aperture measurements at random locations throughout the residual mosaic after

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source extraction. The standard deviation of the random aperture measurements multiplied by the appropriate aperture correction was adopted for the average point source noise level. The scale factor between the aperture derived point source noise and the pixel surface brightness noise is σ(point source) [mJy] $= (29 \pm 3)$ $\sigma(4''$ pixels) [mJy/pixel] for these data.

2. Results

Previous surveys with *Spitzer* are not deep enough to measure the confusion level at 70μm, and the published confusion estimates are based on predicted number counts from models of galaxy evolution (Dole et al. 2003, 2004). With the ultra-deep data of HDF-N, we can directly measure the confusion level at 70μm. We define the instrument noise (including photon noise, detector noise, and noise associated with the data processing) as σ_I. The total noise (σ_T) represents the noise in the mosaic after the extraction of sources above a limiting flux density (S_{lim}), and the confusion noise (σ_c) represents fluctuations due to sources with flux densities below S_{lim}. As defined here, σ_c is the "photometric" confusion noise, following the terminology of Dole et al. (2003). In the direction of HDF-N, the contribution of Galactic cirrus to the confusion noise is negligible.

The instrument noise was estimated empirically by subtracting pairs of data with the same integration time and covering the exact same region on the sky to remove sources and any remaining residuals from the sky after filtering. The error bars for the instrument noise were derived by combining different independent pairs of data with the same integration time. We found a repeatability on the noise measurements of about 5% for long observations. The measured instrument noise integrates down nearly with $t^{-0.5}$ (Fig. 1). With the current processing and at the low background level of HDF-N, $\sigma_I^2 \propto t^{-1}(1 + \beta t^{0.5})$, where $\beta \simeq 0.04$ for integration time t in units of ks. The β parameter was derived from a general weighted least-squares fit and depends on the background level and the quality of the data reduction. We used the above function to extrapolate the instrument noise from half the data to the entire data set and derived $\sigma_I = 0.0399 \pm 0.0036\,\mathrm{MJy/sr}$.

After source extraction, we measure σ_T. Since the total noise image and the instrument noise image have approximately Gaussian distributions, the confusion noise is also consistent with a Gaussian and is approximated by $\sigma_c = (\sigma_T^2 - \sigma_I^2)^{0.5}$. We iterate between source extraction at different limiting flux densities and confusion measurements until we converge to a solution with $q = 5 = S_{\mathrm{lim}}/\sigma_c$. For the $q = 5$ solution, we derive $\sigma_T = 0.0485 \pm 0.0034\,\mathrm{MJy/sr}$ and $\sigma_c = 0.0276 \pm 0.0079\,\mathrm{MJy/sr}$, for a limiting source flux density of $S = 1.5\,\mathrm{mJy}$. Including the systematic uncertainties of the absolute calibration scale and the conversion between point source noise and surface brightness noise, we derive a point source confusion noise of $\sigma_c = 0.30 \pm 0.15\,\mathrm{mJy}$.

In comparison, Dole et al. (2003) predict a $q = 5$ photometric confusion level of $\sigma_c = 0.224\,\mathrm{mJy}$ and based on the updated predictions of Dole et al. (2004), one would expect $\sigma_c \simeq 0.28\,\mathrm{mJy}$

($q = 5$), depending on the exact shape of the differential source counts. The measured confusion level of 0.3 mJy from the ultra-deep HDF-N data agree well with the predicted photometric confusion levels ($q = 5$). The 3.2 mJy confusion limit based on the source density criterion (SDC) adopted by Dole et al. is about a factor of two higher than the limiting flux density derived here. The Dole et al. SDC limit corresponds to $q \simeq 7$ and a high completeness level of $> 90\%$.

In summary, for 10.6 ks of integration time, we achieve a point source instrument noise level of 0.44 mJy and a total point source rms of 0.53 mJy after the extraction of sources. In the low background region of HDF-N, we find that the instrumental noise integrates down nearly with $t^{-0.5}$. Analysis is ongoing for regions of higher backgrounds, but there are indications that the ability to integrate down with long exposure times depends to some degree on the background (i.e., increased "β" values with larger backgrounds). The effects of background on sensitivity are still being quantified for long integration times.

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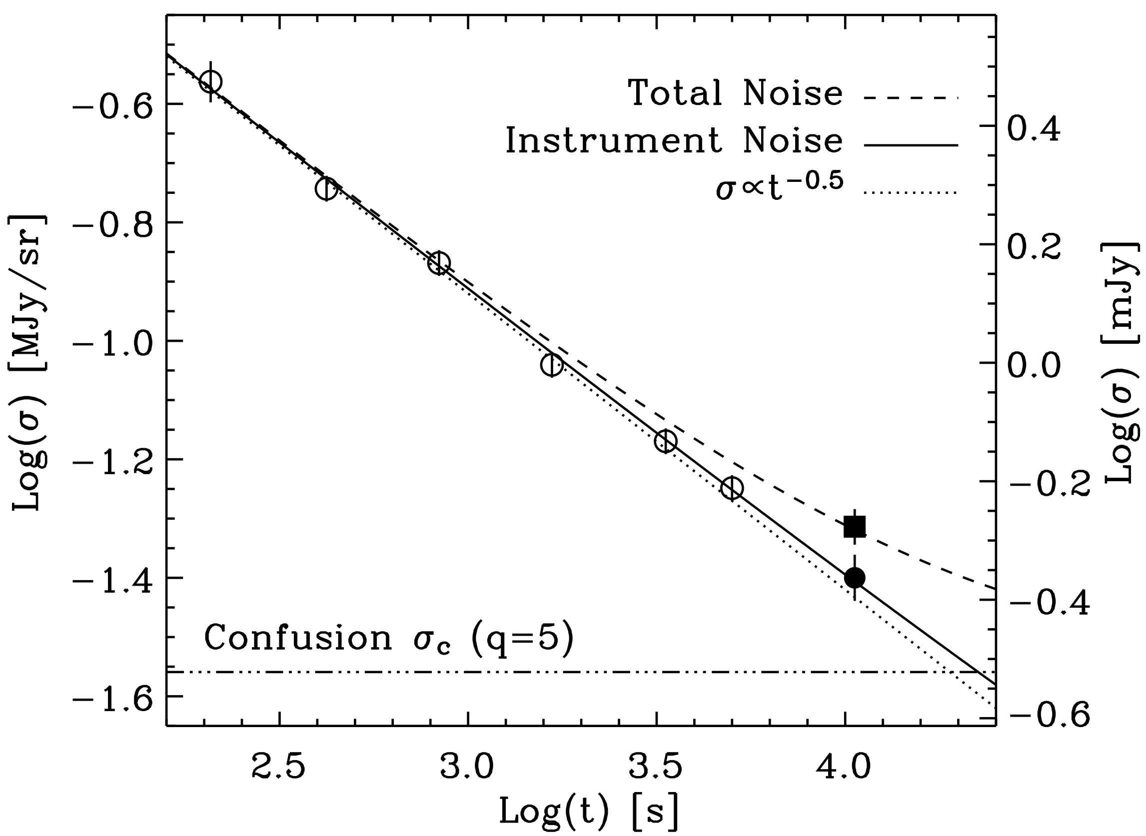

Fig. 1.— Measured rms noise for 4″ pixels as a function of integration time (1σ). The corresponding point source noise level in mJy is shown at the right. Instrument noise measurements are shown by the open circles and are represented by the solid line. For comparison, the dotted line shows a $t^{-0.5}$ function. The derived confusion level (σ_c) is shown by the dashed-dotted line, and the total noise after the extraction of sources with $S70 > 5\sigma_c$ is shown by the dashed line. The total noise and instrument noise for the HDF-N mosaic is shown by the solid square and solid circle respectively.