Release Note

Herschel Confusion Noise Estimator update patch v015

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1 Background

The Herschel Confusion Noise Estimator (HCNE) is accessible via the PACS and SPIRE Astronomical Observation Templates in HSpot [1]. HCNE provides the photometric accuracy of a detected point source related to the sky background fluctuation. This uncertainty in the measured point source flux is due to the presence of infrared sources in the beam fainter than the survey limit. The confusion noise in this interpretation depends on the instrument noise obtained in a given observation setup.

The previous version of HCNE (v013) provided unexpectedly low confusion noise numbers especially in the SPIRE bands for the Cosmic Infrared Background (CIB) component. This problem was related to the survey limit settings in HCNE. The ambitious 3.5 mJy in the SPIRE bands and 6.0 mJy in the PACS bands were resulting HCNE numbers somewhat lower than usually reported in the literature.

With the current v015 update HCNE survey limits are adjusted to the theoretical confusion noise limit of a given photometric band. Consequences are summarized in this release Note.

[1] The HCNE scientific concept is developed by the Konkoly Observatory, Budapest with the coordination of the Herschel Science Centre. The HCNE server is provided by the NASA Herschel Science Center.

Band (μm)	S_{lim}^{phot} (mJy)	σ_{phot} (mJy)	S_{lim}^{sd} (mJy)	σ_{sd} (mJy)
75	0.022	0.004	0.190	0.024
110	0.676	0.135	3.822	0.521
170	4.858	0.972	9.993	1.757
250	25.15	5.030	16.92	4.034
350	29.21	5.839	15.97	4.868
500	24.60	4.919	9.775	4.203

Table 1: Sensitivity limits and corresponding extragalactic confusion noise values for PACS and SPIRE.

2 Calculation of the confusion noise

In HCNE the confusion noise is performed on the pixel scales. This is necessary, since at least one component of the sky background, namely the Galactic cirrus, is intrinsically diffuse, and cannot be considered as an ensemble of point sources. The cirrus confusion noise is calculated as described in Kiss (2007).

For the extragalactic background – or for any other background made of the light of unresolved individual sources – the confusion noise is calculated by the following equation (for the definition of the units and further explanation see e.g. Dole et al., 2003; Lagache et al., 2003):

$$\sigma_{\rm conf} = \int {\rm f}^2(\theta,\phi){\rm d}\theta{\rm d}\phi \int_0^{\rm S_{lim}} {\rm S}^2 \frac{\rm dN}{\rm dS}{\rm dS} \tag{1}$$

As described e.g. in Lagache et al. (2003) S_{lim} can be set either according to the photometric criterion (S_{lim}^{phot}), the source density criterion (S_{lim}^{sd}) or could be defined by the "high" instrument noise (S_{lim}^{inst}). The actual value is the highest of the three S_{lim}-s above. Setting S_{lim} to the instrument noise is necessary when (S_{lim}^{inst}) is higher then the others (usually defined as $5\sigma_{inst}$) since sources between S_{lim}^{inst} and S_{lim}^{sd} or S_{lim}^{phot} still remain unresolved.

The same is true for the relationship of S_{lim}^{sd} and S_{lim}^{phot}, i.e. we apply the highest of these two in the calculation of the confusion noise. Below the calculation of the confusion noise is according to this scheme above, i.e. the highest of the three S_{lim}-s is taken and the second integral is approximated by the sum of the flux sqares of all the sources below the limit. The first integral defines an "effective beam" for the noise calculations, and can be derived by assuming e.g. an Airy-beam. For the PACS and SPIRE bands sensitivity limits in Table 1 could be derived using the Lagache et al. (2003) model (version as of December 2006).

3 Dependence of the confusion noise on the instrument noise for the PACS and SPIRE photometric bands

The instrument noise is time dependent, in the first approximation it scales with $t^{-1/2}$ for a specific AOR and band (t is the integration time). We use this scaling in the following. Since in the calculation of the confusion noise the actual value of S_{lim} depends on the instrument noise, the confusion noise also depends on the instrment noise and hence on the integration time. Below on Figures 1-6 we present the confusion noise vs. time relationship for the PACS and SPIRE photometric bands, using the Lagache et al. (2003) CIB model and the calculations described above. *The confusion noise values presented here are 1σ point source confusion noise values.* Instrument noise values corresponds to those in HSpot version v2.0 provided for the Phase 1 of the Announcement of Opportunity (GT/OT KP).

3.1 Notes on the confusion noise vs. instrument noise figures

- The AOR settings considered in the analysis are coded with the following convention:
  - PACS:
    - solid: point source photometry
    - dotted: scan map, high speed
    - dashed: scan map, low speed
    - dash-dot: scan map, medium speed
    - dash-triple-dot: small source photometry
  - SPIRE:
    - solid: large map
    - dotted: small map
- Black line represent the instrument noise (simple $t^{-1/2}$ scaling). Red line represent the confusion noise due to the sources below $5\sigma_{inst}$. Blue line represent the confusion limit (1σ), either using the sensivitiy limit due to the photometric or to the source density criteria (whichever is higher). *All values presented by the curves are 1σ, point source uncertainty values.* **Selecting a low cirrus position in HSpot (where the CIB dominates the infrared background) HCNE will provide confusion noise estimates matching the blue limit.**
- The intersection of **red** and **black** lines represent the integration time and the corresponding confusion noise value, where confusion noise of sources below the instrument noise becomes dominant. This point defines the "classical" photometric confusion limit and the corresponding time limit. After this point the further integration does not improve the signal-to-noise ratio any more. If the photometric criterium was used to set the confusion limit, the blue line goes through this intersection too. If the sensitiviy limit was set with S^{sd}_{lim}, then the blue line intersects the black line *above* the red-black intersection. Although the signal-to-noise ratio still can be improved below this limit, the completeness of the source counts below this limit drops rather rapidly.
- The confusion limits set here are somewhat different from those presented in Lagache et al. (2003). The reason behind this is that the confusion limits in Lagache et al. (2003) can be reproduced using the PACS pixel sizes ($3''.3$, $3''.3$, and $6''.6$) and SPIRE pixel sizes that are smaller than the ones presently applied ($\sim 9''$, $14''$ and $19''$).

3.2 Conclusions

- The PACS 75 μm band is practically never confusion noise limited (at least due to the CIB) – there is no intersection of the red and blue curves with the black instrument noise curve.
- The PACS 110 μm band is limited by the source density criterion for very long integration times. This limit is reached in $\sim 10^4$ s for the scan map mode, but the photometric limit is not reached in the timescales investigated.
- The PACS 170 μm band is limited by the source density criterion for integration times shorter than $\sim 10^3$ s, and the photometric limit is reached in $\sim 5 \cdot 10^3$ s.
- All SPIRE bands show a similar behaviour, reaching the sensitivity limit in $\sim 10^2$ s, which is set by the photometric criterion in all cases.
- It has to be noted, that the source density criterion is defined with in a rather conservative way in the present calculations. We used $P = 0.1$ here for the probablilty to have the nearest source with $S > S_{lim}$ in the beam. In prartical applications, however, one can integrate below this limit and still have reliable

photometry – if $S_{lim}^{phot} > S_{lim}^{sd}$ – especially if the position of the target is known (e.g. from shorter wavelength measurements). The "final" limit in this case is rather defined by the photometric criterion and would accordingly give lower confusion noise values for the PACS photometric bands (for SPIRE it is the photometric criterion which sets the sensitivity limit anyhow).

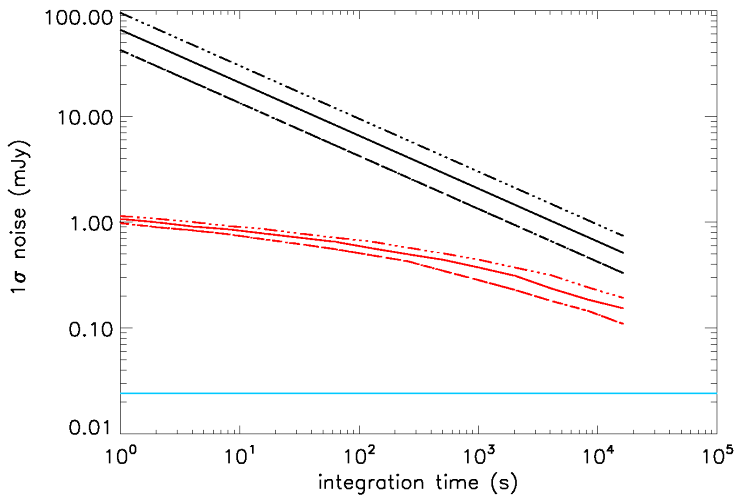

Figure 1: Confusion noise and instrument noise for the PACS 75 μm filter, for various AOR settings (see Section 3.1 for details).

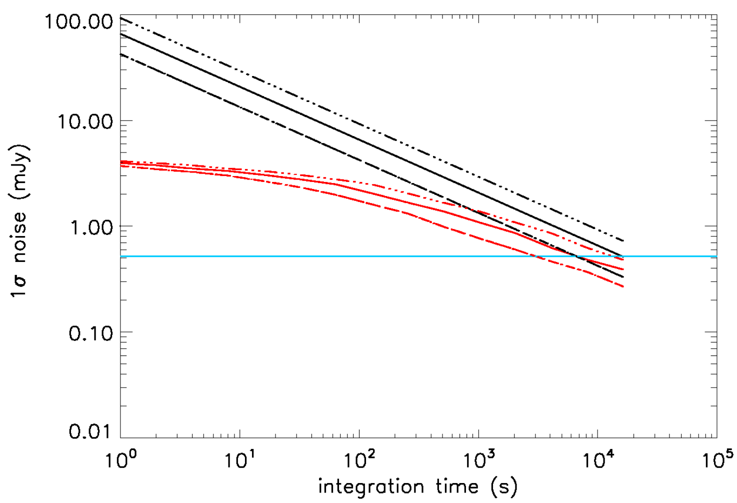

Figure 2: Confusion noise and instrument noise for the PACS 110 μm filter, for various AOR settings (see Section 3.1 for details).

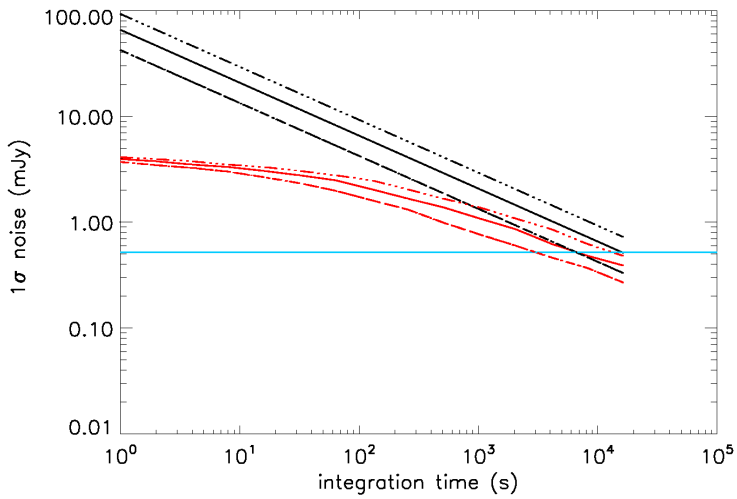

Figure 3: Confusion noise and instrument noise for the PACS 170 μm filter, for various AOR settings (see Section 3.1 for details).

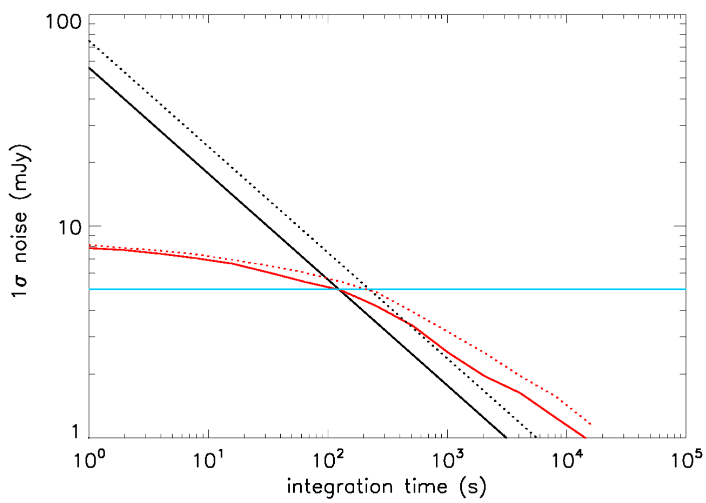

Figure 4: Confusion noise and instrument noise for the SPIRE 250 μm filter, for various AOR settings (see Section 3.1 for details).

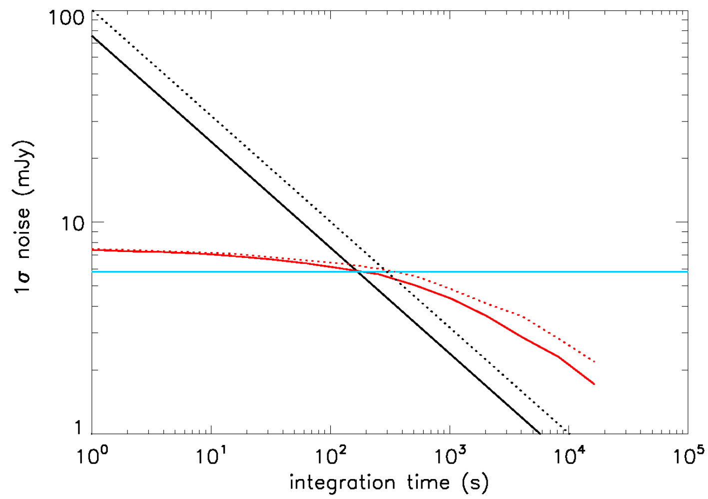

Figure 5: Confusion noise and instrument noise for the SPIRE 350 μm filter, for various AOR settings (see Section 3.1 for details).

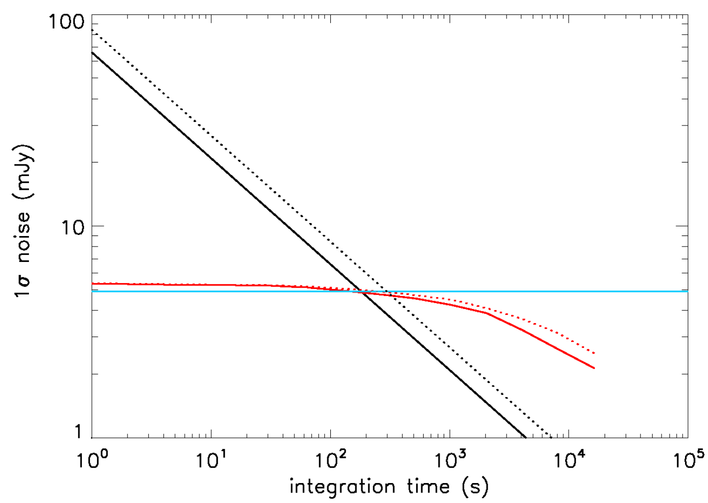

Figure 6: Confusion noise and instrument noise for the SPIRE 500 μm filter, for various AOR settings (see Section 3.1 for details).

Band (μm)	σ_{ps} (mJy)	σ_{pix} (mJy)
75	0.024	0.016
110	0.521	0.235
170	1.757	0.996
250	5.030	4.558
350	5.839	5.558
500	4.919	4.457

Table 2: HCNE lookup table V015 extragalactic background confusion noise values

4 HCNE update patch v015 summary

In HCNE lookup table version V015 a constant confusion noise is considered for each PACS and SPIRE band, independent of the instrument noise. These values are set to the confusion noise values of the prior sensitivity limit of each band, as discussed above. These 1σ points source and 'per pixel' extragalactic confusion noise values are listed in Table 2.

References

Dole, H., Lagache, G., Puget, J.-L., 2003, ApJ, 585, 617

Lagache, G., Dole, H., Puget, J.-L., 2003, MNRAS, 338, 555

Kiss, Cs., "The Herschel Confusion Noise Estimator Science Implementation Document", Version February 1, 2007, available at: *http://kisag.konkoly.hu/pkisscs/HCNE_v2007Jan30a.pdf*