Herschel Confusion Noise Estimator Requirements

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Change log

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Document Change Record

Issue	**Modified Pages / Paragraphs**	**Reason for change**
Draft 0	Initial issue	
Draft 1.0	All	Full revision of the initial issue
Draft 1.1	p4, p6-10	Minor corrections
Draft 1.2	insert req.13; all pages	Minor corrections
Draft 1.3	insert req.13; all pages	Minor corrections
Draft 1.4		Survey requirements have been updated
Draft 1.5		IA tool requirements are discoped
Draft 1.6		Major revision
Draft 1.7	Reference documents	Add RD-011 and RD-012
	Section 2	Extend HCNE purpose description
	Section 2.2	Confusion noise description part has been updated
	Section 2.3	Minor corrections
	Section 3	Minor corrections
	HCNE-req-4.1.11	

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1 References

1.1 Applicable Documents

AD-001	PACS-ME-RS-004	PACS Science Requirements Document
AD-002	SPIRE-UCF-PRJ-000064	SPIRE Scientific Requirements

1.2 Reference Documents

RD-001	A&AS, 127, 1 (1998)	Leinert et al., The 1997 reference of diffuse night sky brightness
RD-002	A&A, 399, 177 (2003)	Kiss et al., Small-scale Structure of the Galactic Cirrus Emission
RD-003	A&A, 430, 343 (2005)	Kiss et al., Determination of Confusion Noise for Far-IR measurements
RD-004	No ref.	Spitzer Observers Manual
RD-005	PACS-ME-PL-014	PACS Science Implementation Plan
RD-006	SCI-PT/3646	HSO Science Implementation Requirements Document
RD-007	ESA SP-460 pp. 13-20	The Herschel Mission, Scientific Objectives and this Meeting
RD-008	ESA/SPC (97) 22 rev.1	FIRST Science Management Plan
RD-009	PICC-ME-SD-004	AOT related Aspects for the PACS Spectrometer
RD-010	Sap-PACS-MS-0186-03	Preparing AOTs for the PACS Photometer
RD-011	ApJ, 585, 617 (2003)	Dole et al., Predictions for Cosmological Infrared Surveys from Space with the Multiband Imaging Photometer for SIRTF
RD-012	AJ, 129, 2869 (2005)	Tedesco et al., The Statistical Asteroid Model

2 Purpose

The purpose of this document is to summarize scientific and user requirements on the Herschel Confusion Noise Estimator (HCNE). This tool is being developed under coordination of the Herschel Science Centre (HSC) to aid Herschel observers in planning PACS and SPIRE photometer observations.

Confusion noise is a major limitation of far-infrared (FIR) imaging especially in high background regions. Comparing instrument performance to sky confusion noise will permit the observer to find an optimum AOT setup where detection limits do not get beneath the local confusion limit of no particular science reason.

It is a potential HSC responsibility to ensure the full exploitation of Herschel's scientific productivity within the given constraints. Promoting HCNE to optimize large number of observations is expected to result a more effective observatory time utilization.

The interpretation of the confusion noise usually depends on the nature of investigation. Deep extragalactic number counts are biased by unresolved sources close to the confusion limit, while cirrus dominated regions are associated with a complex diffuse FIR background making difficult the identification of faint sources. In both cases there are two important criteria to clearly detect a point (or compact) source: the source flux has to be well above the average fluctuation amplitude of the background (photometric criterium) and the source has to be far enough from sources of similar brightness so that they could be detected individually (source density criterium). These two criteria together set the *confusion limit*: above this level compact sources can be clearly detected (see e.g. Dole et al. 2003, for an introduction). The general purpose of the HCNE tool is the provision of a *confusion noise* estimate, being interpreted as the uncertainty in the determination of point source flux due to the uncertainty in the determination of the background flux. This definition of confusion noise is applicable for all measurements irrespective the science goal.

2.1 Overview on the Far-Infrared Sky Background

Thermal emission from interstellar dust the so-called interstellar cirrus dominates the FIR Sky Background (FIRSB) at lower galactic latitudes, while the Cosmic Far-Infrared Background (CFIRB) is more significant towards higher galactic latitudes also dominating the confusion noise in the PACS and SPIRE photometric bands. Intrinsically diffuse and unresolved components (see also RD-001) in descending order of their relative contribution to the FIRSB 'sandwich' can be considered as:

Diffuse Galactic Light (Interstellar Cirrus)

The infrared emission from the diffuse galactic ISM is dominated by thermal emission of dust, with some additional contributions from interstellar cooling lines, mainly from CII and NII at wavelengths <200μm. Concerning the thermal part of the IR spectrum of galactic dust it is complex in structure, suggesting significant contributions from grains covering a wide range of temperatures. In particular, there is substantial excess emission in the 5 to 50 microns spectral range. This excess is generally attributed to stochastically heated very small grains with mean temperatures in the range 100 to 500 K, while the main thermal emission peaking between 150-170 microns is attributed to classical-sized dust grains in equilibrium with the galactic interstellar radiation field, resulting in temperatures around 17.5 K. Cirrus dominates the sky brightness at wavelengths longer than 70 microns up to relatively high galactic latitudes, shifting to 45 microns at galactic latitudes around 10 degrees. In the galactic plane, the interstellar medium dominates at all wavelengths with a minimum around 20 microns. See Figure 1 for an indication of sky brightness as a function of wavelength. The filamentary cirrus spatial structure can be well described by a steep power-law (RD-002 & RD-003).

Zodiacal Light

Scattered sunlight dominates this component of background at wavelengths shorter than 3.5 microns; at longer wavelengths, thermal emission from the particles themselves dominates this component. At high galactic latitudes and at wavelengths shorter than ~70 microns Zodiacal Light gets stronger than galactic diffuse emission. This component has a quite smooth spatial structure (the rms brightness fluctuation at 25 microns has been found less than 0.2% at half a degree spatial frequencies), and it was found to be stable to 1% over more than a decade.

Cosmic Far-Infrared Background

Integrated emission of unresolved redshifted galaxies. In the lowest galactic emission regions the CFIRB can dominate the background emission and background fluctuations. It has been shown that for these fields (ISOPHOT/FIRBACK) the emission coming from resolved and partially resolved sources comprises only 10% of the total emission while the rest is due to unresolved background radiation. Since the SEDs of CFIRB and interstellar cirrus show a resemblance in the far infrared where both has their emission maximum (around 150-170 microns) the separation of these two components remains difficult. Unlike cirrus, CFIRB's spatial structure can be approximated by a flat power-law, preliminary results show on arcminute scales cirrus fluctuations surpass CFIRB fluctuations. Inherently to its extragalactic nature, CFIRB has a fairly isotropic sky distribution above arcminute scales.

FIR Emission from the Asteroid Belt

The FIR emission from various asteroid populations of different size and different spatial density is expected to contribute the sky confusion noise towards low ecliptic latitudes. A statistical asteroid disk model developed by E.F. Tedesco (RD-012) based on optical data was extended to the far-infrared by the Konkoly Group using spectral energy distributions extended towards the far-infrared of modelled asteroid populations. Results show the asteroid confusion noise peaks around 0.001 mJy rms per beam in the ecliptics and decaying in an approximately ±25 degrees wide belt around. Noise slightly change over the PACS/SPIRE wavelength range but remain in the same order of magnitude. The geometry of asteroid belt model applies rotational symmetry in a solar centric coordinate system. As a consequence, the belt has its maximum width and highest confusion noise towards the L2 point seen from Earth as being the nearest point of the asteroid disk. From a perspective of a S/C centric ecliptic coordinate system the asteroid confusion noise increases with solar elongation and decays with ecliptic latitude. Since the closest point of the asteroid disk falls always within the solar visibility constraints (the solar aspect angle has to be within ±30 degrees) Herschel can never point towards the highest asteroid confusion noise part of the sky. This component is not influencing the AOR optimization since the rms asteroid confusion noise is predicted to be always beneath the instrument noise.

Resolved and Partially Resolved Galaxy and Star Light

Near-infrared imaging at the shortest wavelengths can be confusion-limited due to either galaxy or star density. Herschel imaging with the PACS blue photometer camera might be influenced by this component, especially by partially resolved redshifted galaxies at high galactic latitudes.

Cosmic Microwave Background (CMB)

The Wien-part of CMB spectrum can contribute to the IR sky background at the longest wavelength photometric bands of Herschel (SPIRE). At wavelengths >400μm the cosmic background radiation dominates over the galactic thermal radiation. CMB inhomogeneities are far below the sensitivity of Herschel.

Intergalactic Emission

Thermal dust emission from the intergalactic dust in the Local Group. Its very low surface brightness makes this component indistinguishable from cirrus on global scales.

Integrated Star Light

The combined light from unresolved stars contributes to the sky brightness from the ultraviolet through the mid-infrared, with the contribution being dominated by hot stars and white dwarfs at the shortest wavelengths, main sequence stars at visual wavelengths, and red giants in the infrared. This background component is highly concentrated to the galactic plane, its decay with galactic latitude is fairly represented by the scale height of stellar components. Integrated star light contribution to the IR sky to be seen by Herschel is probably negligible.

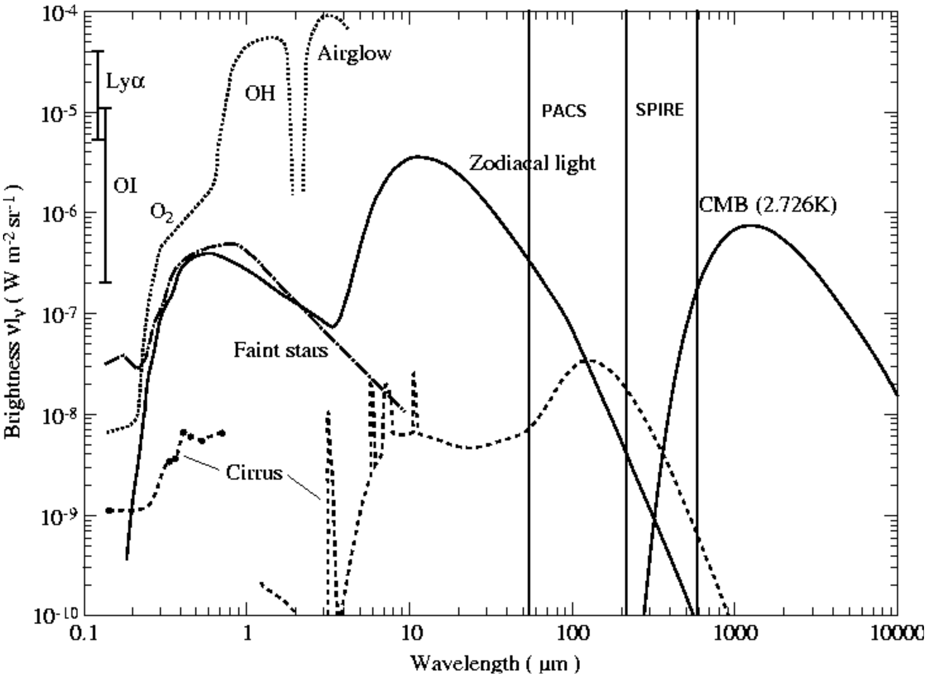

Fig.1 Qualitative overview on the IR sky spectrum outside the lower terrestrial atmosphere and at high ecliptic and galactic latitudes (RD-001). The zodiacal emission and scattering as well as the integrated light of stars are given for the South Ecliptic Pole. The plot does not show the contribution of CFIRB and partially resolved sources.

In addition to the sky background, the astronomical signal seen by PACS and SPIRE on Herschel is masked by the emission from the passively cooled telescope. In fact, despite the very low emissivity of its optical surfaces, the thermal emission from the telescope at the operational temperature will be the totally dominating signal; the total of the sky background plus source emission will only add a very small fraction. The variation of telescope primary mirror average temperature as well as temperature gradients on its surface (only considered along the S/C Z-axis) are very small, typically a small fraction of a Kelvin over a representative observing day. The telescope background is therefore expected to be a stable and very smooth component of the FIR light illuminating the detectors. It has no expected structure on mJy level, fluctuations can be neglected.

2.2 Background Complexity and Confusion Noise

Homogeneous background can be effectively removed applying spatial chopping or different mapping configurations. When background has a complex inhomogeneous spatial structure, the observed brightness fluctuations increase its noise contribution depending on the fluctuation amplitude within the beam. The structure contributes directly to the variance of the background degrading the photometric accuracy and sensitivity as a payoff. In such a case, background noise exhibits spatial but not temporal variations what makes ineffective the application of chopping or other beam modulation attempts in order to get rid of confusion. Indeed, chopping has an inverse effect, if absolute values of signal levels on target and chopped positions are not known but only the difference between them then the confusion limit is increasing leading to worse point source detectability compared to an unchopped image.

In general, the term ‘confusion-limited’ refers to images in which there are so many detected point sources or filamentary cirrus fine-structures that determining whether a particular faint source is part

of the background or is a target can be difficult. The confusion noise refers to the uncertainty in the determination of point source flux due to the uncertainty in the determination of the background flux, therefore the confusion limit arise a natural boundary of photometric accuracy. At near-infrared wavelengths confusion noise is dominated by unresolved distant galaxies at higher galactic latitudes and by stars at low galactic latitudes. With increasing wavelengths from near-infrared towards the far-infrared the importance of point source confusion turns down while the background can also contain a significant contribution from galactic cirrus emission and unresolved galaxies (see Figure 2).
Decomposition of cirrus confused maps (most recently RD-002 & RD-003) show a steep Fourier power spectrum indicating a $1/f$ type noise where f refers to spatial frequencies. In general, $1/f$ noise represents a process with a frequency spectrum such that the spectral energy density is proportional to the reciprocal of the frequency - or in terms of sky confusion - interstellar cirrus emission scales up with lower spatial frequencies (larger beams). Observing such a power-law structured cirrus background one could emphasize the advantage of small Herschel (especially PACS) beams. Higher spatial resolution results less confusion noise, due to high power at high spatial frequencies the noise from cirrus confusion is largely dependent on the beam diameter. In addition, the fluctuation power is clearly correlated with the average cirrus surface brightness. The finding of power-law correlations indicates the presence of scale-invariant, fractal structures where the underlying generator process can be either pure fractal or a self-affine multifractal. These processes are assumed to be closely related to stochastic phenomena such as turbulent flows.
The extragalactic confusion of discrete sources is due to the effect that fluctuations of point sources in the beam increase the uncertainty of background flux determination. Estimating point source confusion noise requires the knowledge of the integral source density and the effective solid angle of the instrument in a given filter. The integral source counts go approximately as a power law with a constant index. The confusion noise limit scales as the square of the beam diameter approximatively. There are two different criteria to measure the confusion noise. The ‘photometric criterion’ is derived from the fluctuations of the signal due to the sources below the detection threshold S_{lim} in the beam; it was well adapted for the first generation of space IR telescopes (*IRAS*, *COBE*, *ISO*). The ‘source density criterion’ is derived from a completeness criterion and evaluates the density of the sources detected above the detection threshold S_{lim}, such that only a small fraction of sources are missed because they cannot be separated from their nearest neighbor (RD-011).

As detailed in the previous section the CFIRB, partially resolved galaxies and the foreground components of Zodiacal light, asteroid FIR emission and the thermal emission by interstellar dust contribute to the infrared sky brightness with varying importance over the whole wavelength range. Apart from the Zodiacal light, all these components are increasing the confusion noise but the main driver remains the interstellar cirrus emission and the extragalactic background in the far-infrared. Since there is no distinct spectral signature known in the CFIRB, the separation of the foreground components has to be based on modeling and measurements of their different spatial structure. This technique is being worked out as a part of the Herschel Confusion Noise Model development.

2.3 Impact of Confusion on Herschel Science

In addition to detector/photon noise, imaging surveys in the far-infrared spectral range are limited in depth by the two significant components as describe in the previous sections: structure in the infrared cirrus emission and confusion by extragalactic sources. The first of these limitations can be avoided for some programs by observing in particularly low-background regions on the sky The second limitation arises because the high density of faint (partially resolved or unresolved) distant galaxies creates signal fluctuations in the telescope beam (RD-011).

Confusion due to cirrus is a major limitation of far-infrared surveys especially in high background regions (AD-001). Several mJy rms (at 170 microns) can be easily encountered towards high-surface brightness molecular fields. The detailed survey layouts are TBD and could focus on high density regions as well as cover larger areas in an unbiased way, but obviously PACS/SPIRE shall be capable to integrate to the (local) confusion limit in order to detect lowest mass star or brown dwarf progenitors. The higher confusion noise suggests that these surveys will typically be shallower than the extragalactic ones. To be unbiased is a key requirement on large surveys for both galactic and extragalactic fields, statistical studies (e.g. IMF, clustering, galaxy counts) can be highly hampered by variation in confusion. Extragalactic surveys in low surface brightness extragalactic windows might be influenced by CFIRB and confusion of (partially) resolved extragalactic sources. In general, longer wavelength surveys more quickly run into the confusion limit set by their larger beams and the number counts, while shorter wavelength surveys are unconfused but will miss many higher redshift targets. These effects would be more pronounced when surveys over the full Herschel spectral range are planned. The wavelength dependent power of confusion noise leads to another concern using multiband imaging: the source SED can influence its detectability. PACS will have the highest, diffraction limited spatial resolution on Herschel in its photometric bands; this will be essential not only in terms of FIR source confusion, but also in terms of identification of sources with known IR/radio counterparts. In such a case, the PACS photometry can reach or can perform even beneath the local confusion limit.

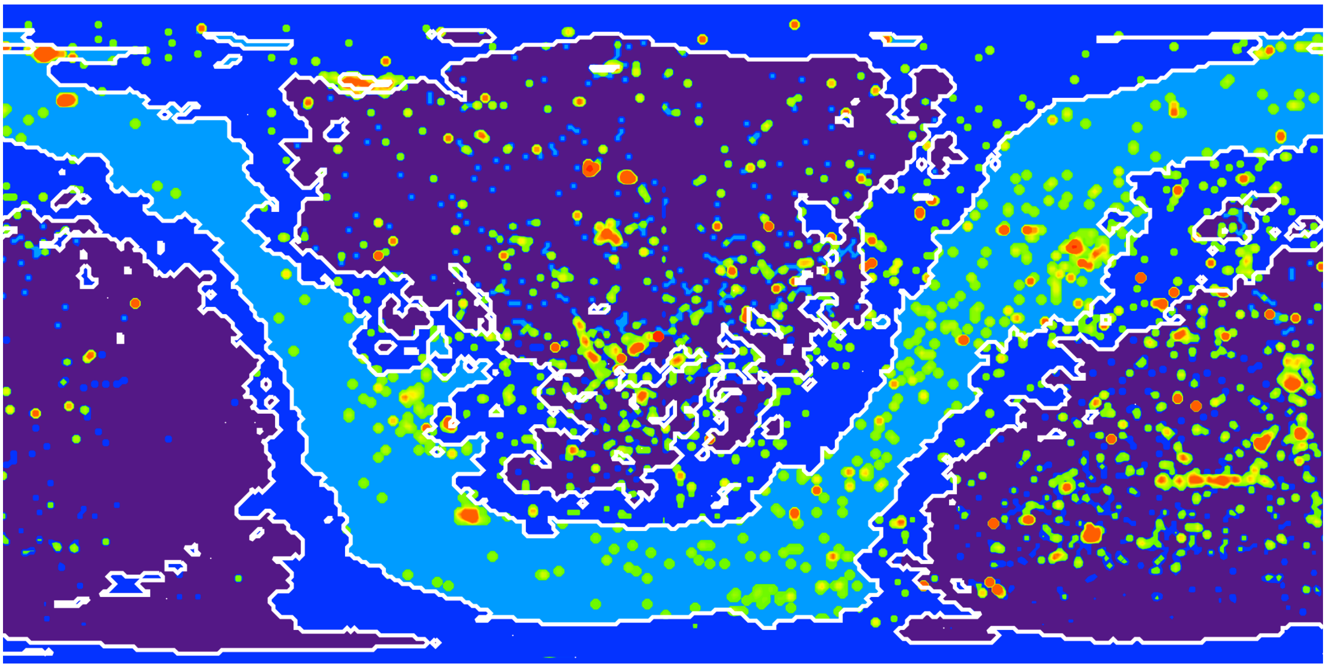

Fig.2 All-sky confusion noise distribution estimate in the PACS red band, projection is based on FK5 equatorial coordinates. Contours discriminate three regions according to the local cirrus to extragalactic confusion noise ratio. These are respectively: [deep blue] extragalactic confusion dominated regions, [medium blue] the extragalactic and cirrus confusion is in the same order, [light blue] cirrus dominated regions. Overlays show the ISO pointing density distribution where red colour indicates the most frequently visited positions and blue dots are for single pointings. (Courtesy of Cs. Kiss)

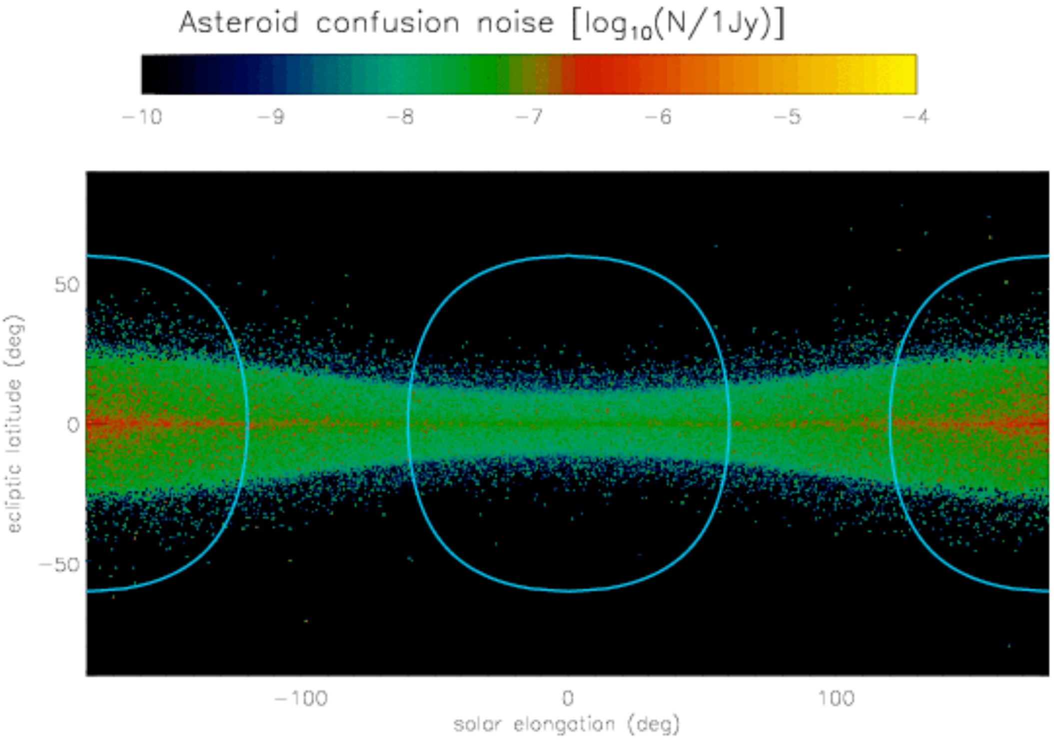

Fig.3 Predicted asteroid confusion noise map in the PACS red band shown in a S/C centric ecliptic coordinate system where X-axis represents the solar elongation and Y-axis shows the ecliptic latitude. Blue circles indicate the borders of solar visibility constraints. (Courtesy of Cs. Kiss)

3 Scope

In the present version of this document requirements are not considered to be specific for various scientific goals of Herschel. For instance, interstellar confusion could inherently show a variety of spatial structures from faint high latitude filamentary cirrus to dense molecular clouds. The tool within its boundary conditions is expected to accumulate all these particularities into a few parameters; further characterization of bright cirrus confusion over the specified surface brightness limit (e.g. for most of the star forming regions) is beyond the scope of HCNE.

Measurement configurations are important in calculating the confusion noise values, each measurement configuration has a different confusion noise level, even when using the same instrument/filter setup (RD-003). As an example, due to the expected steep power-law of cirrus emission the chop/nod throw amplitude has a significant impact of detected confusion noise. HCNE attempts to provide the confusion noise values of the different sky components (CIB and cirrus) customized for the AOT configuration of the observer's request.

Scientific requirements summarized in Chapter 4 are provided to constrain key elements of scientific implementation. These requirements are considered to be relevant in preparing Herschel Astronomical Observation Requests (AORs) and implementing HCNE software components.

4 Requirements

4.1 HCNE Scientific Requirements

- **[HCNE-req-4.1.01]** HCNE should provide confusion noise estimates for the following components of the far-infrared sky:
    - diffuse galactic light (interstellar cirrus)
    - cosmic far-infrared background
    - asteroid confusion (IMPLEMENTATION IS NOT REQUIRED for the HCNE version to be provided for the AO of Key Programmes, relevant requirements are kept tracked under this section)
- **[HCNE-req-4.1.02]** The response of HCNE has to be specific for a given noise component in the sense
    - confusion noise of diffuse galactic light has to be provided as a function of sky position and/or surface brightness
    - confusion noise of cosmic far-infrared background has to be characterized by a canonical value representative for the all sky
    - confusion noise of asteroid disk FIR emission has to be provided as a function of solar elongation and ecliptic latitude (to be calculated for a given date of observation)
- **[HCNE-req-4.1.03]** The estimator should provide a breakdown of sky confusion noise rms in units of flux density mJy/pixel and mJy/beam (for point sources) and rms surface brightness fluctuation in units of MJy/sr for each component.
- **[HCNE-req-4.1.04]** The model should be able to provide confusion noise estimates for all PACS and SPIRE photometric bands.
- **[HCNE-req-4.1.05]** Highest spatial frequencies relevant for a given photometric band have to be determined as the representative beam size in a given band. These are respectively:

Band (μm)	75	110	170	250	360	520
	PACS			SPIRE		
Beam (″)	3.5	5.2	8.0	11.8	17.1	24.4

HCNE has to provide confusion estimates on these spatial frequencies.

- **[HCNE-req-4.1.06]** The spatial resolution of confusion estimates for the FIR cirrus and asteroid disk components has to be in the order of 1 arcminute.
- **[HCNE-req-4.1.07]** The surface brightness range should cover 1.5-100 MJ/sr after removal of Zodiacal Light. The estimation of Zodiacal light should consider seasonal and other inhomogeneity effects.
- **[HCNE-req-4.1.09]** The calculation of average surface brightness values of sky background components (Zodiacal Light, Interstellar Cirrus, CFIRB) for a given wavelength, epoch and line-of-sight is a dedicated task of the IPAC background tool provided by NHSC. The HCNE engine has to use the IPAC background tool to obtain surface brightness values for the applicable confusion noise components over the required wavelength range. On spatial frequencies higher than the background tool’s resolution the HCNE pre-flight version has to consider a constant background surface brightness.

- **[HCNE-req-4.1.10]** For the cirrus and asteroid noise components a spatial scaling model has to be established and represented for each individual bandpasses and for a set of surface brightness values (see HCNE-req-4.1.05 and HCNE-req-4.1.07). The spatial scaling model has to show the fluctuation powers as a function of spatial frequency.
- **[HCNE-req-4.1.11]** The predicted scaling model should have to refer to dedicated measurements from preceding and ongoing missions (e.g. ISO, Spitzer) and other follow-up measurements (e.g. extinction in the near-infrared or optical reflection on diffuse fields).
- **[HCNE-req-4.1.12]** Predictions should have to investigate the applicability of a variety of (nonlinear) power spectra. Impact of cosmological models (e.g. clustering) has to be considered when CFIRB dominates confusion. The obtained spatial scaling model should have to be extrapolated down to Herschel's resolution (see HCNE-req-4.1.05).
- **[HCNE-req-4.1.13]** This is a nice to have requirement, an alternative statistical interpretation of confusion noise has to be established e.g. source density criterion defined by the probability of separation two sources closer than a given radius.
- **[HCNE-req-4.1.14]** The quality assessment of confusion noise measurement techniques (see Chapter 4.4) have to include spatial characterization of simulated cirrus fields. The spatial complexity of simulated maps have to be similar to the predicted cirrus scaling function andthe simulated spectral shape has to follow the observed cirrus SED. The confusion noise measurement technique is assumed to be reliable if the measured scaling function of simulated fields could reproduce their generator parameters up to an acceptable accuracy. The robustness of the applied measurement technique has to be investigated by varying generator parameters of the simulated cirrus field.

[HCNE-req-4.1.15] The observing mode specific confusion noise estimates have to be produced by using PCSS software:

a) the PACS scientific simulator to mimic AOT logic and instrument signatures on a typical AOT type observation. Th background image cube
b) and the standard product generation software in order to investigate the impact of data reduction algorithms on

4.2 User Interface and AOT Specific HCNE Functionalities

- **[HCNE-req-4.2.01]** The HCNE has to be accessible through two user interfaces:
  - **4.2.01-a)** User interface (HCNE-UIf-H) built in the client S/W of the Proposal Handling System (HSPOT). This interface provides confusion estimates based on a user defined Astronomical Observation Request (AOR) configuration.
  - **4.2.01-b)** User online web interface (HCNE-UIf-W) accessible from or linked to the HSC web site. This flexible interface allows the user to query HCNE without reference to a certain observation request or a specific AOT configuration.

- **[HCNE-req-4.2.02]** The HCNE user interface HCNE-UIf-H has to be integrated into the client software (HSPOT) of the proposal handling System (PHS) and should be directly accessible from PACS/SPIRE photometry AOT front-ends. A confusion noise estimation request initialize an interaction between HSPOT and the HCNE engine. The HCNE user interface in HSPOT has two layers (similar to the PACS/SPIRE time estimator):

a) Summary table of confusion and instrument noise in the time estimation GUI
b) Detailed HCNE report in a pop-up window

The summary table has to show the overall confusion noise budget as a sum of the superimposed components. Confusion noise has to be provided in the same unit used by the instrument time estimator. The detailed HCNE report has to include:

- HCNE version number
- a table of confusion noise estimates per band and for each noise component in units of:
    - MJy/sr (rms)
    - mJy/pixel (rms)
    - mJy/beam (rms)
- user guidelines if applicable (how to influence the measured confusion noise with AOT parameters like chopping, nodding)

Calculating the noise in different units requires the same procedure what instruments are using within their time and sensitivity estimators. The same formula has to be implemented in HCNE to perform a conversion from noise/pixel unit to noise/beam unit applicable to represent confusion noise for partially resolved point sources.

- **[HCNE-req-4.2.03]** The HSPOT user interface HCNE-UIf-H has to provide the confusion noise estimation based on AOT and target/background parameters (e.g. photometric band ID, chopper throw, scan speed, nodding, pointing mode etc.). This interface should not require any further user input in addition to the AOR front-end parameters. Estimation can be done only for valid and for single AORs. In case of mosaic or linked observations of multiple AORs which include overlapping regions (e.g. PACS 3 band photometry where the red channel observations are duplicated) HCNE is not supposed to provide a combined noise estimate.

[HCNE-req-4.2.04] The HCNE server satisfying HCNE-UIf-H will accept multiple positions for confusion noise estimation using a single call to from HSPOT to HCNE server.

4.2.04-a) The HCNE server will compute minimum, maximum, mean and standard deviation of estimated confusion values when this information is requested for multiple sky positions.

- **[HCNE-req-4.2.05]** HCNE should consider target types of fixed single (in the HSpot terminology this category includes mapping observations as well) and moving objects (SSOs).
- **[HCNE-req-4.2.06]** In case of SSO observations the cirrus background and asteroid confusion has to be reported for each day (TBC) of the visibility window(s). A graphical representation of component’s confusion noise against time is a *nice to have* option.
- **[HCNE-req-4.2.07]** In case of large map AOT configurations (raster or scan map) the HCNE should provide multiple estimates if the confusion noise varies above 5% (TBC) over the map area or one of the map dimensions is larger than 30 arcminutes. Locations where confusion noise estimates are

provided have to be distributed in a reasonable way (e.g. corners and center of the map) or alternatively, the variation of confusion noise over the map area has to be calculated. This requirement applies only when the confusion model is updated and extended towards spatial scales below few arcminutes using Herschel's own measurements.

[HCNE-req-4.2.08] The HCNE online web interface (HCNE-UIf-W) requires photometric band ID and beam average background surface brightness, or alternatively, photometric band ID and source coordinates in TBD system. In the first case, the noise report has to include the cirrus and CFIRB components, in the second case the asteroid confusion has to be provided as well (TBC). This web interface estimates sky confusion irrespective of AOT parameters, it can be considered as a 'light version' of HCNE in HSPOT. The main goal of this second front-end is to allow the user to browse HCNE for various background levels. In HSPOT this functionality is not provided directly since the background level is inherently locked to the AOR's target location. A confusion noise estimation request initialize an interaction between the web interface and the HCNE engine.

[HCNE-req-4.2.09] The HCNE must be able to respond to TBD number of concurrent requests.

4.2.09-a) The HCNE must continue to function under the required load

4.2.09-b) The response time under full load must be within a factor TBD of single query/request time.

4.3 The HCNE Engine

- **[HCNE-req-4.3.01]** Both user interfaces (HCNE-UIf-W and HCNE-UIf-H) have to be connected to a backend application- the HCNE engine (HCNE-En-W and HCNE-En-H). The HCNE engines are responsible for confusion noise calculations and for connections to the user front-ends, look-up tables and also to the background estimator. Responses of these two engines referring to common functionalities have to be identical. Depending on the engines architecture, the distinction between HCNE-En-W and HCNE-En-H could remain virtual in terms the same engine serves both user interfaces through different application layers.

[HCNE-req-4.3.02] The HCNE engine codes and auxiliary data (look-up tables) have to be under configuration control.. The location of the CVS server will be in the HCNE document provided by the NHSC (see section 4.5).

The look-up table version number has to refer to the corresponding HCNE version number. The HCNE version number has to appear in both the server and the client API. A server won't accept requests from a client with a version less than a specified value because that indicates a fundamental difference between the two pieces of software. (This prevents people from using an old version of HSPOT that doesn't work, for whatever reason, with the current hcne server.)

The version number has to be "double hcne_version." The integer portion is the major release number, and the first three decimal numbers are the minor release number.

The hcne result object has to return the server's version number.

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- **[HCNE-req-4.3.03]** Confusion noise coefficients should have to be provided as look-up tables in a TBD format: (i) tables searchable by surface brightness (ii) all-sky tables searchable by equatorial[1] coordinates.

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[1] The reference coordinate system in HSpot is Equatorial J2000 (FK5)

- **[HCNE-req-4.3.04]** The surface brightness resolution in the look-up table should be adjusted to at least 5% (TBC) variation in the calculated confusion noise.
- **[HCNE-req-4.3.05]** An optimized interpolation method has to be specified to refine the look-up table's grid.
- **[HCNE-req-4.3.06]** Model upgrade, code and documentation maintenance and HSC helpdesk service remains the responsibility of HCNE scientific developers

HCNE-req-4.3.07] Test cases. [BA note: Lets pick ~8 locations and get the results for these locations. We will make sure that who ever is testing can verify that these test cases produce the right results.
4.3.07-a) The test cases must be regression tested with each new version/update of the code.
[BA note: NHSC devs plan to use JUNIT for automatic regression testing]

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[HCNE-req-4.3.08] It is the responsibility of HCNE engine maintainers to generate version numbers of defined format (see requirement HCNE-req-4.3.02) [BA note: whoever is writing the documentation].

This is to ensure that (HSpot) documentation uses the right version identifications when describing HCNE.

4.4 PV Phase and Early Mission Activities – Measuring Confusion and Relation to Key Program Surveys (TBC)

- **[HCNE-req-4.4.01]** During early mission phases (Comissioning, PV phase, Science Demo) and as early as possible during Key Programme implementation, a suitable set of measurements have to be identified to characterize confusion noise at Herschel's resolution. Data have to be used to improve the HCNE confusion model and induce updates of HCNE.. The layout of these observations do not need to be optimized for confusion noise characterization but the following goals or part of them should be achieved:
    - Mapping of low surface brightness (high galactic latitude) extragalactic fields which can serve for CFIRB characterization. In ideal case the turnover point in surface brightness when CFIRB starts to dominate confusion can be measured
    - On low surface brightness fields completeness limit, source density and photometric accuracy have to be determined via source counts
    - Characterization of high surface brightness cirrus on low galactic latitudes
    - Derivation of confusion spatial scaling law as a function of galactic latitude
    - Isotropy characterization on fields of various surface brightnesses (e.g. measuring long strip – quasy 1D – maps)
    - Comparison to preceding (ISO, Spitzer FLS) measurements, surveys.
    - Characterization of detectability of point sources on various surface brightness values.
    - Size of individual fields should provide a large enough coverage of spatial frequencies: high frequency cutoff at pixel-size, low freq cutoff at map size.

- **[HCNE-req-4.4.02]** Layout of survey measurements has to be based on PACS/SPIRE photometry AOTs with 'large map' option in a TBD pointing mode (e.g. scan, raster, jiggle map). The precise AOT configuration is TBD.
- **[HCNE-req-4.4.03]** By its nature, the cirrus confusion noise measurement technique(s) must be rotation and scale invariant on all scales.

- **[HCNE-req-4.4.05]** Measurement techniques should have to deal efficiently with edge effects. Distortion on the spatial model should not occur by reason of map geometry.

4.5 Documentation

- **[HCNE-req-4.5.01]** The HCNE User Documentation has to consist two separate issues:
    - Model description, validity, limitations, applicability, reference parameters, results of follow-up observations and other relevant considerations should have to be provided in a HCNE Science Implementation Document. Characterization of detectability of point sources on various surface brightness values. A full and detailed description of HCNE scientific implementation with emphasis on Herschel specific aspects of confusion noise estimation and models. This document can refer to or include scientific publications on the topic.
    - A shorter user manual explaining the HCNE interface in HSPOT and the influence of AOT parameters on the confusion noise estimation. This information has to be sufficient for the observer to optimise an AOR where confusion noise is an issue. The manual should have to be written in XML what enables HSC to directly include this text in the PACS/SPIRE Observers Manuals as a dedicated section.
- **[HCNE-req-4.5.02]** A HCNE/HSPOT ICD has to be provided to HSC. This document has to give a list of AOR parameters required as input for the HCNE engine, it has to describe relevant API signatures describing and integration and handling of look-up tables in the HCSS/HSPOT environment.
- **[HCNE-req-4.5.03]** Model upgrades which influence the confusion noise estimation has to generate a new release of HCNE Science Implementation Document.
- **[HCNE-req-4.5.04]** A user information web page hosted by HSC (or linked to the HSC website) has to be launched. This page can provide further links to documentation and to scientific developer’s pages.