The Herschel-PACS Point Source Catalog Feasibility Study

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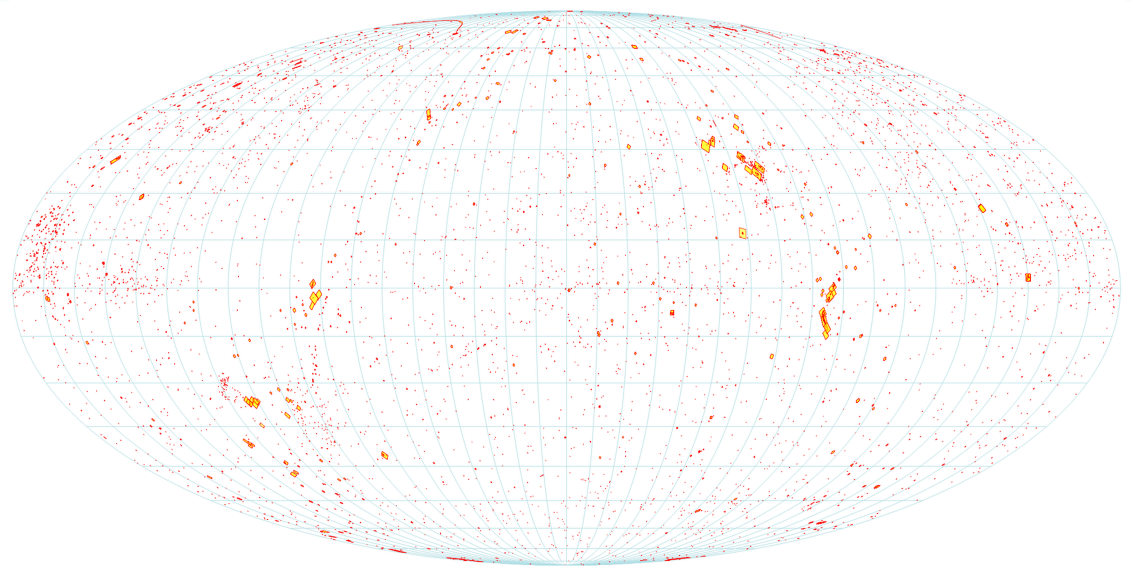
The photometer cameras of the PACS instrument collected data in two bands simultaneously (70 or 100, and 160 µm) and the >10,000 observations made cover ~10% of the sky. The outstanding sensitivity and spatial resolution allowed scientists to reveal the structure of our galaxy and to observe the most distant galaxies and their evolution. It also gave the chance to discover celestial sources that were not known before and it allowed to study astronomical sources never observed at infrared wavelengths, providing new data for the reconstruction of the spectral energy distribution of sources already observed in other wavelengths. Project-specific point source catalogs are and will be provided by the major key projects using their dedicated data. However, the different methods of source detection and photometry used by these programs make it hard to create a homogeneous source catalog and they do not cover all PACS photometer observations.

The Herschel/PACS Point Source Catalog that we are presenting here will contain point sources extracted from all possible PACS photometer measurements in a homogeneous way. The delivered positions and flux values will help the users to get information on the far-infrared characteristics of individual objects, and they help to discriminate and classify the different types of sources. Also large scale or statistical studies, like star formation rate and clustering studies will benefit from the catalog.

In this presentation we focus on the outcomes of our feasibility study, in which we studied the photometric accuracy, completeness and reliability in a variety of celestial environments. We tested numerous available source detecting and photometric algorithms and collected their advantages and disadvantages in order to build a pipeline script which will be used to build the catalog.

Sky coverage (PACS-only scan map mode)*

Scan speed	Number of observations	Covered area [°²]
10''/s	109	~5
20''/s	17517	~760
60''/s	117	~35



The PACS instrument (Poglitsch et al. 2012) on-board of the Herschel Space Telescope (Pilbratt et al.) had 3 different observing modes. The main observing modes were the scan map technique in single and parallel mode (with SPIRE), they collected data from ~10% of the sky. The figure above shows the sky coverage of the single mode in equatorial coordinates, covering ~800 square degrees. The table above details the number of observations and sky coverage per scan speed. The scanning speed mainly affects the observations performed at 60''/s, having a PSF stronly elongated towards the scanning direction.

*The figure and the table was produced based on the Herschel Footprint Database. Uploading the Herschel Data to the database is in progress and details on the parallel mode observations will be available soon. The database is available at: http://herschel.vo.elte.hu/Observations

Tested extraction procedures

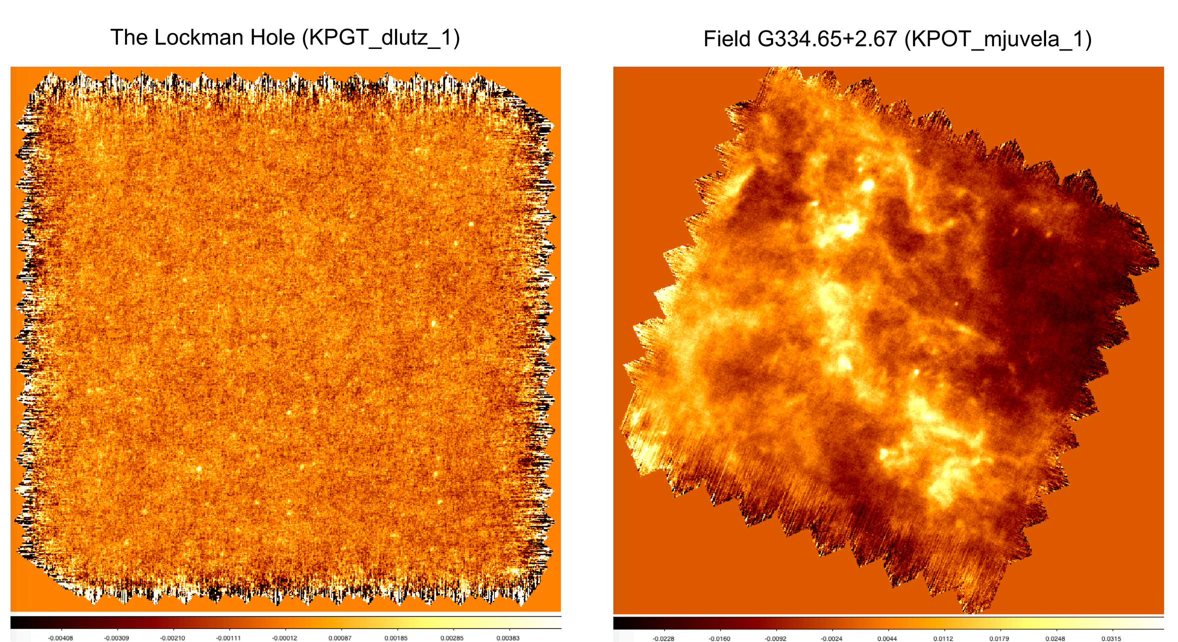
	Environment	Detection performance	Photometry	Speed	Easy to use & to implement
Sussextractor	HIPE	5	4	5	5
Daophot	HIPE	2	5	5	5
Starfinder	IDL	5	5	3	2
Getsources	FORTRAN	5	5	1	1
Cutex	IDL	5	3	5	3

Numerous algorithms are available for source detection and photometry. These algorithms are often tuned for special fields, like crowded ones with clusters of objects, or complex ones with structured background emission. We tested 6 of the methods to identify their advantages and drawbacks.

Our experience is that these algorithms are comparable in terms of detection and photometric performance. However, Getsources (Men'shchikov et al., 2012), Cutex (Molinari et al., 2011) and Starfinder (Diolaiti et al., 2000) are more sophisticated and they need more interaction to set the correct parameters. They also need more computational time to reach the optimal result. Implementation of these algorithms into the pipeline is also problematic since they are running outside the HIPE (Ott, 2010) and in some cases they need additional preparation of the maps.

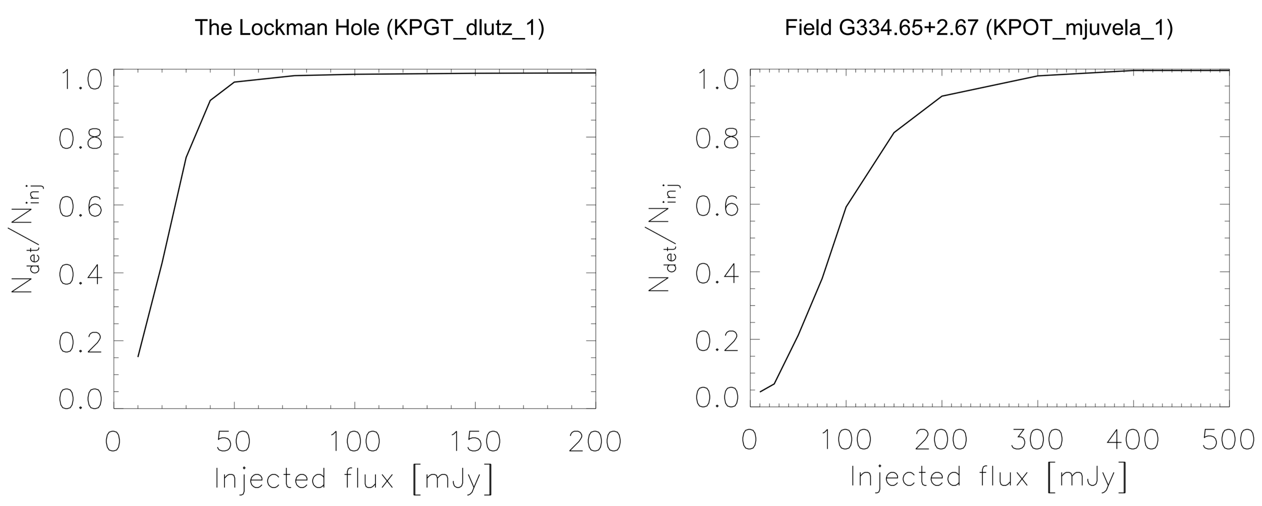
Based on our test results we decided to create our prototype pipeline by using Sussextractor (Savage & Oliver, 2007) as the source detector and Daophot (Stetson, 1987) to measure the flux density of sources detected by Sussextractor, all inside HIPE.

Different celestial environments



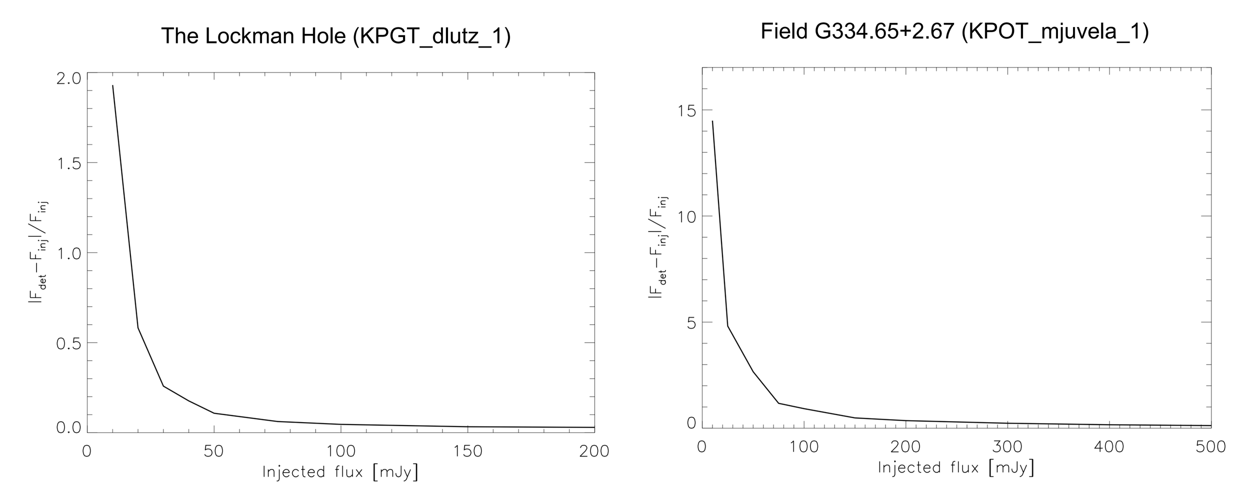
The PACS observations cover a wide range in terms of complexity and different levels of extended emission. The figures above represent two extreme cases: on the left the Lockman Hole is an extragalactic field with very low extended emission, while on the right the field G334.65+2.67 shows highly structured background with embedded point- and compact sources. These two fields are our test cases.

Completeness and photometric accuracy in different celestial environments



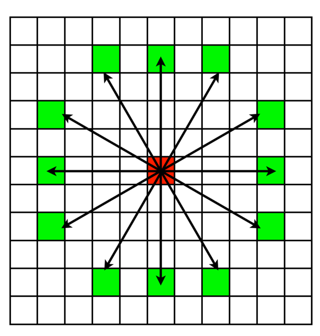
The completeness in our test fields is calculated as the fraction of the injected and detected artificial sources. These sources were back-projected into the observational timeline and then projected onto Level2.5 maps with JScanam. This allowed us to simulate any possible effects on source photometry by the mapmaker which will be used during the process of catalog creation.

The figures above show the completeness for our two test cases. In the Lockman Hole field (left) we were able to detect >90% of the 1000 injected sources above ~40 mJy. In the field G334.65+2.67, which is a highly structured region, for 250 injected sources 90% completeness was reached at the flux level of ~200 mJy. Since the complexity of the field scales with the background brightness, these results clearly show that completeness is highly dependent on the extended structures observed in the field.



For the same fields the photometric accuracy was also tested based on the photometry of sources artificially injected into the timeline. Photometric accuracy is calculated as a fraction of the injected and measured flux. The curves in the figures above show that at the faint end of the injected flux levels we experience large photometric inaccuracy. In the Lockman Hole (left) 5% accuracy is reached at ~100 mJy. In case of Field G334.65 (right) an 10% accuracy is reached at 500 mJy. These results clearly suggest that in highly fluctuating environment the photometry needs to be treated with special attention.

Structure noise calculation

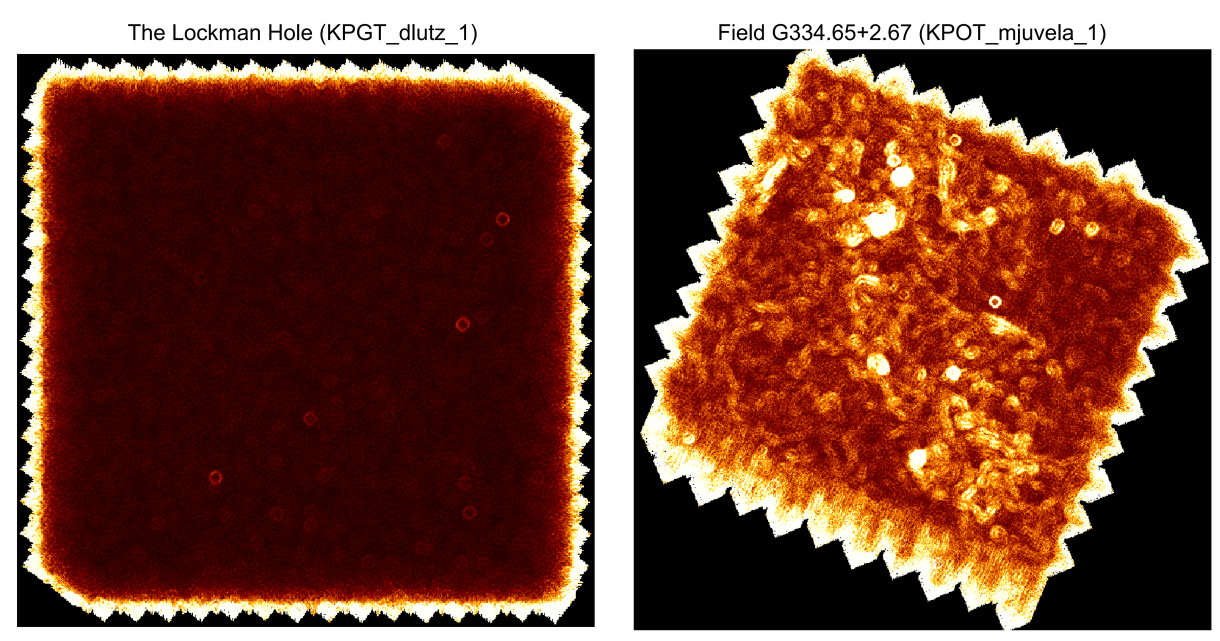


The structure noise measures the fluctuation around a given point in the sky. This measure can be translated into the power spectrum of the neighboring areas, but it gives a local information instead of a general number. We use this quantity to describe the close vicinity of each detected source.

For each pixel of the map the structure noise (N_S) is calculated as the mean deviation of the pixel's (green) flux with respect to the reference pixel (red). It is calculated as follows:

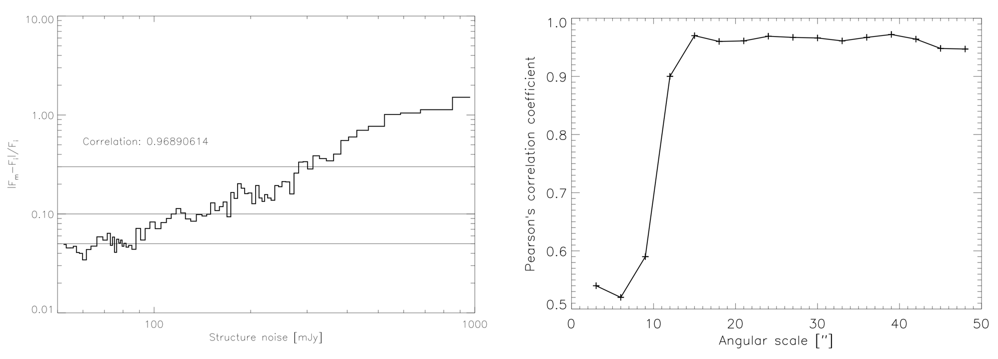
$$N_S = \sqrt{\frac{1}{24}\sum_{i=1}^{24}(d_i - \mu)^2}, \text{ where } \quad d_i = |F_{x_t,y_t} - F_{x_i,y_i}|$$

and µ is the mean value of the d_i values.



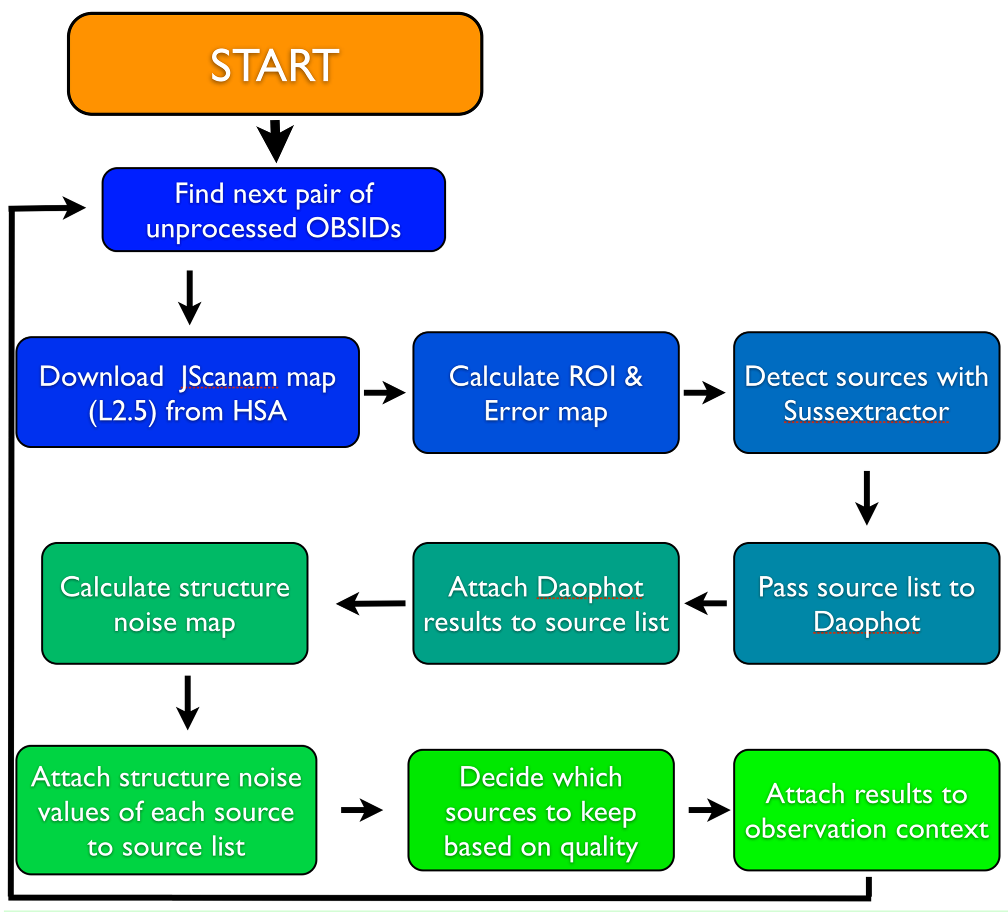
As demonstrated above, structure noise maps are capable of revealing the complexity of the observed fields. On the left the structure noise is very low and homogeneous. Bright sources manifest themselves as compact bright rings in the structure noise maps, suggesting that if another source is located on the ring, the bright source contributes to the background of the other source and affects the photometry. In the case of the Galactic field (right) more structures are revealed. Features in the extended emission (like filaments) appear on the structure noise images as bright curves. They also have an impact on the photometric accuracy. The same scaling is used for both images.

Photometric accuracy in correlation with structure noise



The photometric accuracy was investigated as a function of the structure noise measured on several angular scales. The angular scale was changed between 3″ and 48″ with an interval of 3″. 1590 sources with 1 Jy flux were injected into maps with different level of complexity to cover a wide range of structure noise values. On the left figure the photometric accuracy is plotted as a function of the structure noise calculated on 24″ angular scale around the sources. The accuracy is averaged in bins of 20 sources. The Pearson's correlation coefficient gives a number on the correlation strength. In the plotted case this value was 0.97. Using a Student's T test we found that this correlation is clearly significant. The correlation coefficient was investigated on other angular scales, too. The figure on the right shows the correlation coefficient as the function of the angular scale. On scales lower than the beam FWHM (12″ in this case for the red PACS band) the correlation is weak, but it becomes and stays strong on larger scales. Around 40″ the correlation starts to become weaker.

The prototype point source extraction pipeline



The schematic workflow of our prototype PACS PSC pipeline is shown in the figure above. We are using Level2.5 maps (created from pairs of observations) to detect the sources with Sussextractor and the photometry is made with the Daophot task. The structure noise is also calculated and the value for each detected source is attached to the source list. Both Sussextractor and Daophot provide quality flags for the sources which we use along with the structure noise to decide if we keep it or flag it as bad detection. For each map the source list will be attached to the observation context. This workflow allows us to stay within the HIPE. Later the collected data will be structured in a database. For more details on the database see the SPIRE PSC poster of B. Schulz et al.

Summary & Conclusions

- The possibility and feasibility of the general Herschel-PACS Point Source Catalog was investigated
- The catalogue aims to include data from all PACS scan map observations, which cover about 10% of the sky, including the PACS/SPIRE parallel observations
- Five methods were tested for source detection and photometry. We selected Sussextractor for source detection and Daophot for photometry.
- A prototype pipeline was created. It uses tasks inside the HIPE which allows us to optimize the speed of the process and it is the easiest way to access the Herschel PACS data
- The completeness and photometric accuracy was tested in different celestial environments
- Calculating the structure noise for each source is an excellent way to determine wether the photometry of the sources are reliable or not
- The main benefit for the astronomy community is a well-characterized far-infrared point source catalog including homogeneously extracted sources derived by instrument experts

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