Building the Herschel-SPIRE Point Source Catalog (SPSC)

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Goal

• Build a homogeneous point source catalog from all SPIRE scan map observations, geared primarily at the extragalactic community, that can serve as a pathfinder for ALMA and other Submm and Far-IR facilities.

• Use the combined expertise of specialist teams before they dissolve.
**SPIRE Sky Coverage**

<table>
<thead>
<tr>
<th>All scan maps</th>
<th>sq. deg</th>
<th>fraction</th>
<th>of all sky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4723</td>
<td>11.4%</td>
<td></td>
</tr>
<tr>
<td>SpirePacsParallel</td>
<td>2515</td>
<td>53%</td>
<td>6.1%</td>
</tr>
<tr>
<td>SpirePhotoLargeScan</td>
<td>2001</td>
<td>42%</td>
<td>4.8%</td>
</tr>
<tr>
<td>SpirePhotoSmallScan</td>
<td>208</td>
<td>4%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

- There are three relevant SPIRE scan map observing modes:
  - **Parallel Mode**: SPIRE and PACS observing larger portions of the sky simultaneously.
  - **Large Scan Mode**: SPIRE scanning the sky in several scan legs, normally followed by scans in a perpendicular direction.
  - **Small Scan Mode**: SPIRE scanning across a single coordinate in two perpendicular directions.
Scan Maps and Coverage

- SPIRE scans the sky with its 4’ x 8’ detector arrays at an angle close to 45 deg in almost perpendicular directions.
- Very few observations exist without a cross-scan direction.
- Parallel Mode observations normally are linked to another observation in cross-scan direction.
- Turnaround data exist but will only be introduced in HIPE 13 processing.

ObsID = 1342180973 nominally 20’ x 20’
A Bit of History

• The idea grew into a plan
  – “The Herschel-SPIRE Point Source Catalog Implementation Plan”, Bernhard Schulz (NHSC) 14-Nov-2013 V0.1

• The plan called for a feasibility study
  – Tested source extraction methods
  – Improved photometric performance
  – Assessed expected completeness and reliability
  – Report

  • The Herschel-SPIRE Point Source Catalog, Feasibility Study Report, Bernhard Schulz, Gabor Marton, Kevin Xu, Nanyao Lu, David Shupe, Ivan Valtchanov, Babar Ali, Chris Pearson, John Rector, Tanya Lim
  1) NHSC-IPAC Caltech, 2) Konkoly Observatory, 3) HSC-ESAC ESA, 4) RAL-STFC
Building the SPSC

Source Extraction
- Detection
- Photometry
- Determine source extension
- Pointing correction

Catalog Consolidation
- Resolve source multiplicities
- Error analysis
- Catalog statistics
- Flags

Re-Processing
- TwoPass Pipeline
- Incl. Turn-around data

HSA
Re-Processing
Local Pool
STRN Map generation
Structure Noise Maps
Local STRN extraction
Catalog Consolidation
SPSC
SpireCat Postgres database

Catalog Consolidation
- Resolve source multiplicities
- Error analysis
- Catalog statistics
- Flags
Important Work Ahead

• Data Reprocessing Phase
  – Data Reprocessing with HIPE 13 (under way)

• Source Extraction Phase
  – Source extraction
  – Assessment of Photometric Accuracy, Completeness and Reliability
  – Generation of Structure Noise Maps and values
  – Position corrections

• Consolidation Phase
  – Database setup and ingestion
  – Consolidation of source extractions into single objects
  – Statistical analysis of database contents
  – Derivation of best flux estimate

• Quality Assessment and Documentation Phase
  – Derive specific flags like semi-extended source, map edge, etc.
  – Determine overall quality flag
  – Explanatory Supplement
Database Schema (SpireCat)

Sources are extracted from observations (maps) and consolidated into groups or objects (catalog entries). Other tables provide additional information.

Observation Table
- Obs ID: Primary Key
- List of all scan map observations

Source Table
- Source ID: Primary Key
- Obs ID: Foreign Key
- List of source detections with different algorithms

Group/Object Table
- Group ID: Primary Key
- Obs ID: Foreign Key
- List of groups of source detections belonging to the same source

Position Corrections
- Obs ID: Primary Key
- List of position offsets from WISE point source stacking

Structure Noise Table
- Source ID: Primary Key
- List of structure noise numbers for each source position in SPIRE filters

Nearby Galaxies
- Galaxy ID: Primary Key
- List of encircling ellipses of galaxies >1' from 2MASS Catalog

SSO Tracks
- SSO ID: Primary Key
- List of start and end positions and estimated fluxes in SPIRE filters

Some Other Tables

Relational Postgres database

Postgres database with fast Q3C position indexing.
Catalog Entries

<table>
<thead>
<tr>
<th>Object ID</th>
<th>Filter</th>
<th>RA</th>
<th>DEC</th>
<th>σ RA</th>
<th>σ DEC</th>
<th>Δ RA</th>
<th>Δ DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

| λ         |        |      |       |      |       |      |       |

Position Errors Offsets

**Catalog entries aim to provide the best position and flux values for a given object, based on the source extractions from one or several observations (maps).**

<table>
<thead>
<tr>
<th>Flux</th>
<th>σ Flux</th>
<th>σ Instr.</th>
<th>STRN Category</th>
<th>Flags</th>
<th>Quality</th>
<th>ObsIDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux</td>
<td>Noise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>List of ObsIDs</td>
</tr>
</tbody>
</table>

**Flux Information**

Quality Info Link to HSA

Flags

- Extended Source
- SSO Contamination
- Map Edge
- Variability
- Nearby Galaxy
Catalog Derivation Procedures

- **Source detection**: HIPE Sussextractor.
- **Position offsets**: Stacking of 250µm maps on WISE point sources.
- **Group/Object Consolidation**: Position matching using Q3C indexing.
- **Source photometry**: Timeline Fitter
- **Extended source discrimination and artifact rejection**: Second Timeline Fitter run and aperture photometry (Daophot) -> Statistical database analysis.
- **Photometric uncertainties**: Function of local structure noise.
- **Instrumental noise**: Instrument model.

- **SSO Contamination Flag**: SSO track position matching.
- **Map Edge Flag**: Coverage map analysis.
- **Variability Flag**: Statistical database analysis.
- **Nearby Galaxy Flag**: Position match with nearby galaxy ellipses.
- **Structure Noise Flag**: Local structure noise.

- **List of source ObsIDs**: Position matching using Q3C indexing.
- **Quality Index**: Combination of quality indicators.
Progress I

• Reduced full SPIRE scan map dataset (few exceptions) to Level 2 and Level 2.5 (finished Jan 2015).
  – Problem with destriping in pre-version of HIPE 13 caused some artifacts.
  – Currently being repeated with released HIPE 13 version.
• Relational Postgres database with source ingestion scripts for SPIRE created at IPAC in Feb.
  – Successfully ingested all representative dataset sources (158607).
  – Work on access outside IPAC and Q3C indexing in progress.
• Performed point source extraction on representative dataset (160 obsIds) (04-Mar-2015)
• Workpackage document since March 2015.
Progress II

• PSC Coordination Meeting with PACS 24-26. Feb at IPAC.
  – Coordination of SPIRE and PACS.
  – Preliminary catalog columns defined.
  – Fundamental importance of structure noise maps for photometric accuracy and completeness agreed.
  – Defined format of structure noise maps.
  – Defined format of SSO contamination tables.

• Position corrections for representative dataset with improved position correction tool through stacking on WISE sources 13-Mar-2015.

• List of 2MASS large galaxies with semi major axis > 1’ obtained from NED (Thanks to Joe Mazzarella, Ben Chan) 26-Mar-2015
  – exclusion/flagging of intra galaxy sources

• Currently reprocessing all SPIRE scan maps from HIPE 12.1 Level 0 to Level 2 with HIPE 13.0
Conclusions

• A SPIRE point source catalog is being built as an additional legacy product that can be used as pathfinder by other submm facilities like ALMA.
• We expect a total of ~ $3 \times 10^6$ point sources from ~12% of the sky at 250, 350 and 500$\mu$m.
• Wavelength cross identification is not planned although some cross association should be possible in a future version.
• A comprehensive planning phase and feasibility study is now being followed by actual production phases.
• A team of instrument experts will ensure a high quality level of the photometric and positional data.
• The catalog will be based on HIPE 13 maps.
• Through team coordination a maximum of similarity should be achieved between the PACS and SPIRE catalogs.
• Distribution through ESA HSA and NASA/IPAC IRSA.
• This project has already now greatly benefitted the quality of HIPE 12-14 data products and documentation.
That’s all Folks!
Additional Slides
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 neighbouring areas, but it gives local information instead of a general number. We use this quantity to describe the background noise in 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:

\[
N_S = \sqrt{\frac{1}{24} \sum_{i=1}^{24} (d_i - \mu)^2},
\]

where \( d_i = |F_{x_i,y_i} - F_{x_i,y_i}| \)

and \( \mu \) is the mean value of the \( d_i \) values.
Completeness vs. Structure Noise vs. Input Flux

Flux levels: 250, 230, 210, 190, 170, 150, 130, 110, 90, 70, 50, 30 & 10 mJy

At low structure noise levels sources above 60 mJy can be detected reliably

At high structure noise levels completeness becomes lower
Photometry vs. Structure Noise vs. Input Flux

Flux levels: 250, 230, 210, 190, 170, 150, 130, 110, 90, 70, 50, 30 & 10 mJy

At low structure noise levels sources above ~40 mJy can be measured accurately

At high structure noise levels the photometry is not reliable
Completeness and Reliability

- **Completeness:**
  - Injection and recovery of artificial sources into real maps at different structure noise levels.

- **Reliability:**
  - Small thanks to low instrument noise and high confusion noise.
  - From Jackknife tests following Smith et al. 2012.

Detection rate in Cosmos

- 1000 sources injected
- Flux range: 5-60 mJy
- Interval: 5 mJy
- Algorithm used for detection: Sussextractor
- Detection Threshold: 5
# Catalog Entries

A preliminary catalog definition:

<table>
<thead>
<tr>
<th>Column</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object ID</td>
<td>String</td>
<td>Unique identifier that designates the object at a given location in the sky for which one or more source detections exist. The values given in the additional columns represent a synthesis of all information from all contributing sources. The name format should conform to general astronomical standards and is still TBD.</td>
</tr>
<tr>
<td>RA</td>
<td>Double</td>
<td>Right Ascension expressed in decimal degrees in a J2000 reference system.</td>
</tr>
<tr>
<td>Dec</td>
<td>Double</td>
<td>Declination expressed in decimal degrees in a J2000 reference system.</td>
</tr>
<tr>
<td>RA Err.</td>
<td>Float</td>
<td>One sigma uncertainty of Right Ascension [deg].</td>
</tr>
<tr>
<td>Dec Err.</td>
<td>Float</td>
<td>One sigma uncertainty of Declination [deg].</td>
</tr>
<tr>
<td>Flux</td>
<td>Float</td>
<td>Point source flux [Jansky/beam].</td>
</tr>
<tr>
<td>Flux Err.</td>
<td>Float</td>
<td>One sigma uncertainty of point source flux [Jansky/beam]. This number may be derived from the structure noise value for this source, its total flux, the total number of contributing readouts, the number and uncertainties of contributing source detections, (TBD).</td>
</tr>
<tr>
<td>S/N</td>
<td>Float</td>
<td>Signal to noise = Flux/ Flux Err.</td>
</tr>
<tr>
<td>Instr. Err.</td>
<td>Float</td>
<td>One sigma instrumental uncertainty [Jansky/beam]</td>
</tr>
<tr>
<td># Detections</td>
<td>Integer</td>
<td>Number of contributing source detections.</td>
</tr>
<tr>
<td>Time</td>
<td>String</td>
<td>Standard date string expressing start time of first contributing observation. More contributing observations may have to be covered in a separate catalog product.</td>
</tr>
<tr>
<td>Extended source</td>
<td>Flag</td>
<td>Flag indicating that a source is potentially wider than a typical point source at the given wavelength.</td>
</tr>
<tr>
<td>SSO contamination</td>
<td>Flag</td>
<td>Flag indicating potential SSO confusion [Yes/No type]</td>
</tr>
<tr>
<td>Nearby Galaxy</td>
<td>Flag</td>
<td>Flag indicating that source is located within the encircling ellipse of a nearby galaxy [Yes/No type].</td>
</tr>
<tr>
<td>Variability</td>
<td>Flag</td>
<td>Flag indicating discrepant flux results of more than one contributing observation that are further apart than 5 sigma [Yes/No type].</td>
</tr>
<tr>
<td>STRN Category</td>
<td>Flag</td>
<td>Structure noise category indicating one of several TBD intervals. [several categories indicated by letters A,B,C…].</td>
</tr>
<tr>
<td>Cirrus Category (?,?</td>
<td>Flag</td>
<td>Cirrus noise category derived from SQRT(STRN^2 – Instr_Err^2) [several categories indicated by letters A,B,C…].</td>
</tr>
<tr>
<td>Map Edge</td>
<td>Flag</td>
<td>Flag indicating proximity to map edge (TBD) [Yes/No type].</td>
</tr>
<tr>
<td>Quality</td>
<td>Flag</td>
<td>Overall quality flag being a synthesis of several of the preceding columns [several categories indicated by letters A,B,C…].</td>
</tr>
</tbody>
</table>