Building the Herschel-SPIRE Point Source Catalog (SPSC)

Bernhard Schulz

on behalf of the SPSC Team

NHSC-IPAC Caltech

The SPSC Team

NASA Herschel Science Center IPAC-Caltech
Nanyao Lu
John Rector
Bernhard Schulz (PI)
David Shupe
Kevin Xu

Konkoly Observatory
Csaba Kiss
Gabor Marton

SPIRE ICC, Cardiff University
Andreas Papageorgiou

SPIRE ICC, Rutherford Appleton Labs, STFC
Chris Pearson

Herschel Science Centre, ESAC-ESA
Tanya Lim
Ivan Valtchanov

Univ. of Illinois at Urbana Champaign
Austin Edmister
Joaquin Viera

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.

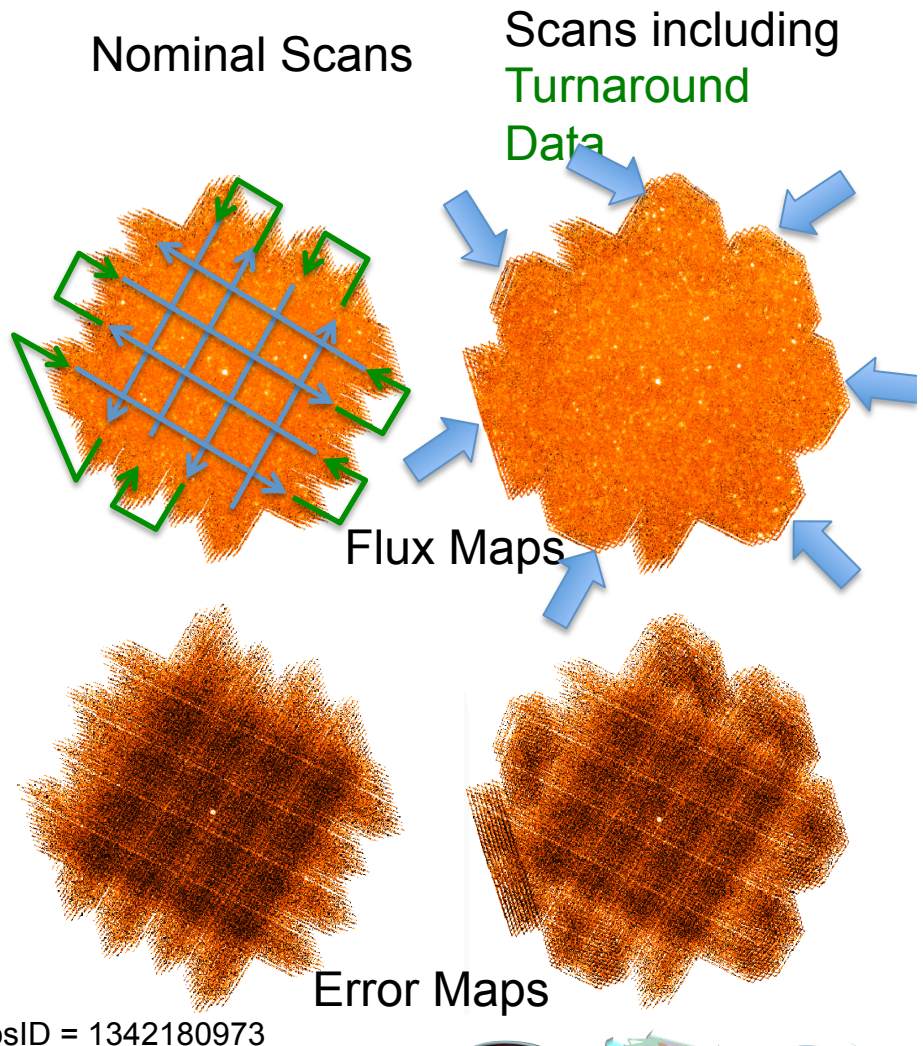
SPIRE Sky Coverage

All scan maps	squ. deg	fraction	of all sky
Total	4723		11.4%
SpirePacsParallel	2515	53%	6.1%
SpirePhotoLargeScan	2001	42%	4.8%
SpirePhotoSmallScan	208	4%	0.5%

- 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.



A Bit of History

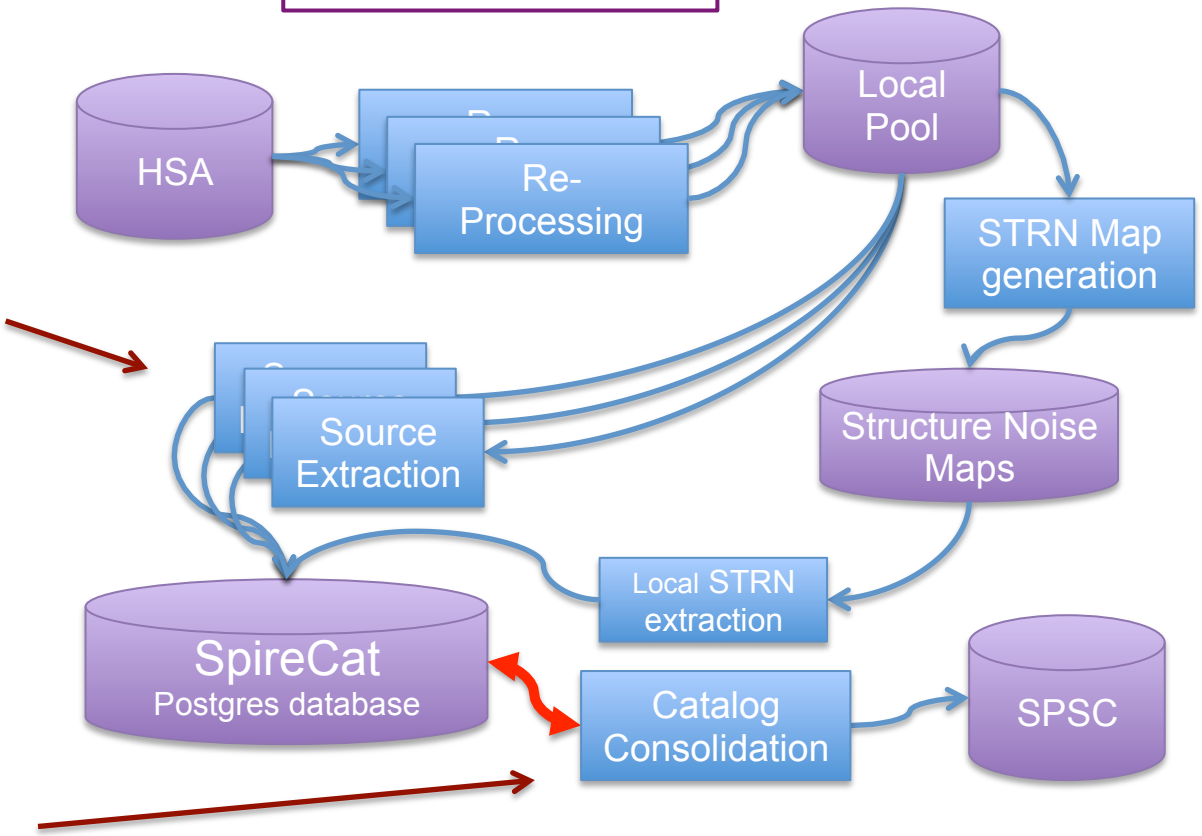
- The idea grew into a plan
  - "The Herschel-SPIRE Point Source Catalog Implementation Plan", Bernhard Schulz (NHSC) 14-Nov-2013 V0.1
- The plan called for a feasibility study
  - Tested source extraction methods
  - Improved photometric performance
  - Assessed expected completeness and reliability
  - Report
    - **The Herschel-SPIRE Point Source Catalog,** Feasibility Study Report, Bernhard Schulz[1], Gabor Marton[2], Kevin Xu[1], Nanyao Lu[1], David Shupe[1], Ivan Valtchanov[3], Babar Ali[1], Chris Pearson[4], John Rector[1], Tanya Lim[3]
      1) NHSC-IPAC Caltech, 2) Konkoly Observatory, 3) HSC-ESAC ESA, 4) RAL-STFC

Building the SPSC

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

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

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)

Relational Postgres database

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

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

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

linked by position

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

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

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

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

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

Some Other Tables

Postgres database with fast Q3C position indexing.

Catalog Entries

Object ID	Filter	RA	DEC	σ RA	σ DEC	Δ RA	Δ DEC
		Position		Errors		Offsets	
	λ	Position Information					

Flags
Extended Source
SSO Contamination
Map Edge
Variability
Nearby Galaxy

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).

Flux	σ Flux	σ Instr.	STRN Category	Flags	Quality	ObsIDs
Flux	Noise					List of ObsIDs
Flux Information				Quality Info		Link to HSA

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.
- **Photmetric 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

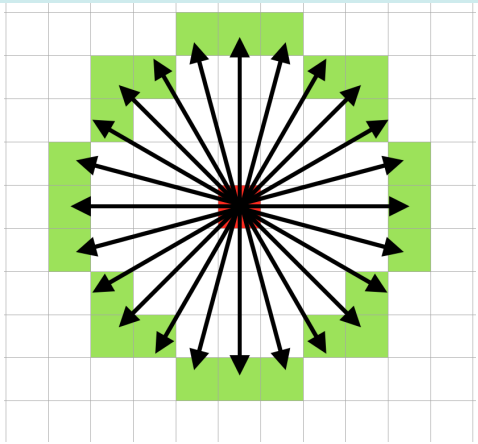
- A SPIRE point source catalog is being built as an additional legacy product that can be used as pathfinder by other submm facilities like ALMA.
- We expect a total of ~ $3*10^6$ point sources from ~12% of the sky at 250, 350 and 500μm.
- Wavelength cross identification is not planned although some 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.

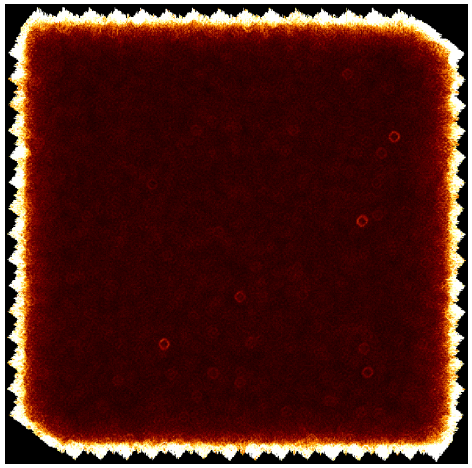


For each pixel of the map the structure noise (N_S) is calculated as the mean deviation of the pixel's (green) flux with respect to the reference pixel (red). It is calculated as follows:

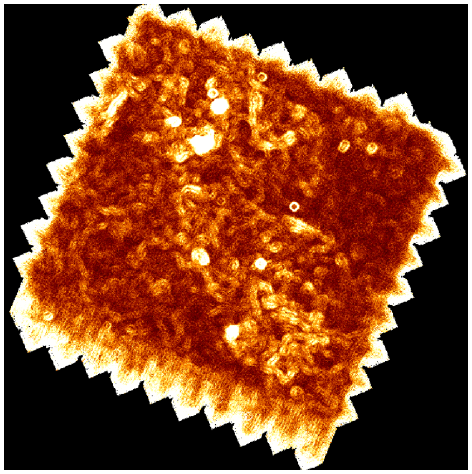
$$N_S = \sqrt{\frac{1}{24}\sum_{i=1}^{24}(d_i - \mu)^2} \quad \text{, where} \quad d_i = |F_{x_t,y_t} - F_{x_i,y_i}|$$

and μ is the mean value of the d_i values.

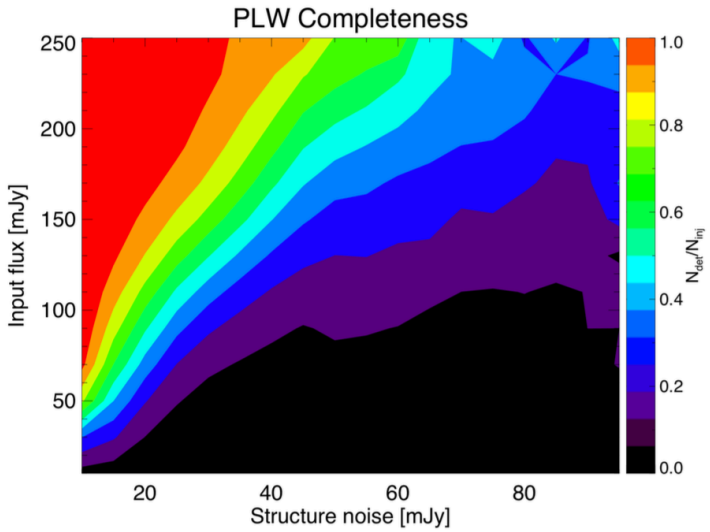
The Lockman Hole (KPGT_dlutz_1)

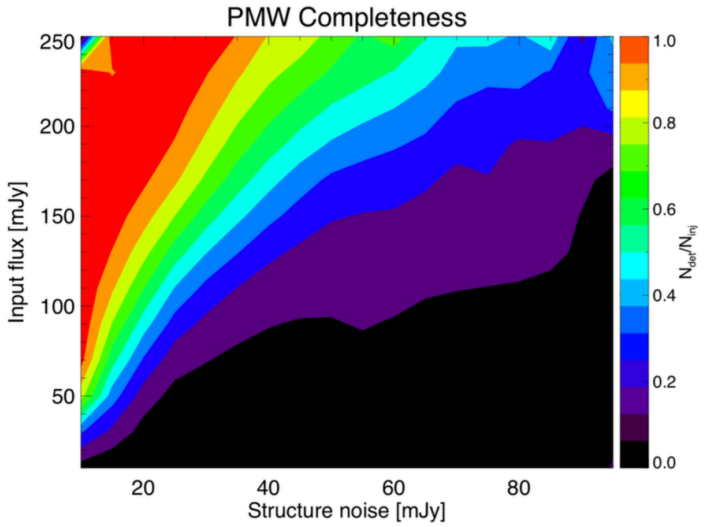


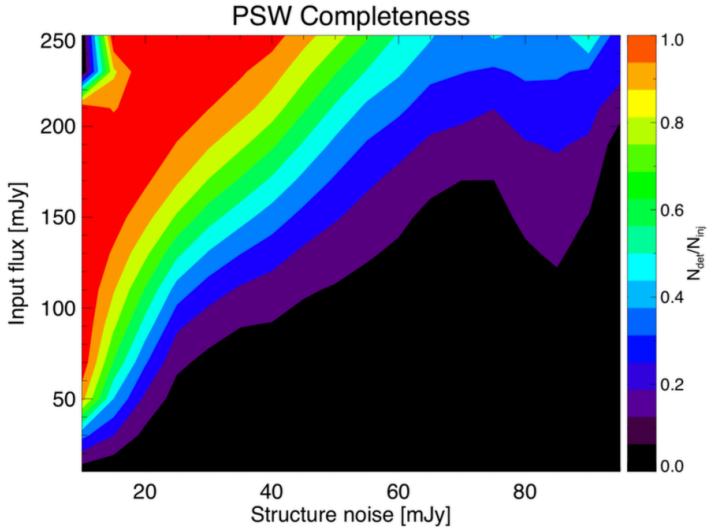
Field G334.65+2.67 (KPOT_mjuvela_1)



Completeness vs. Structure Noise vs. Input Flux





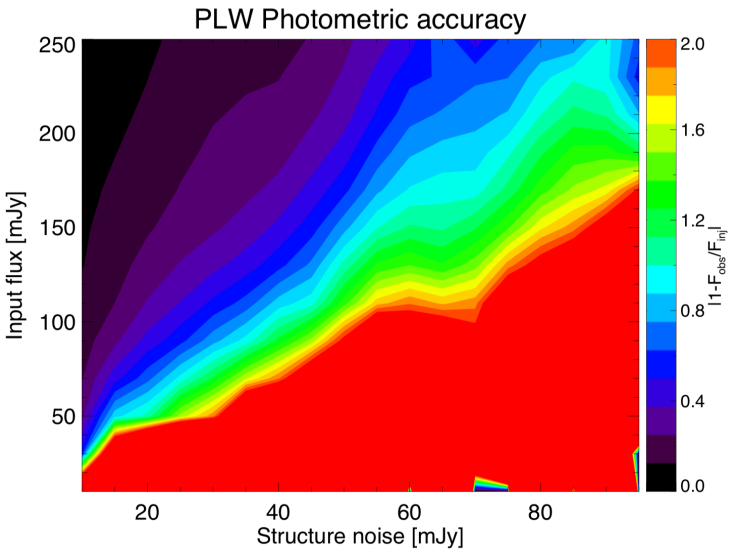


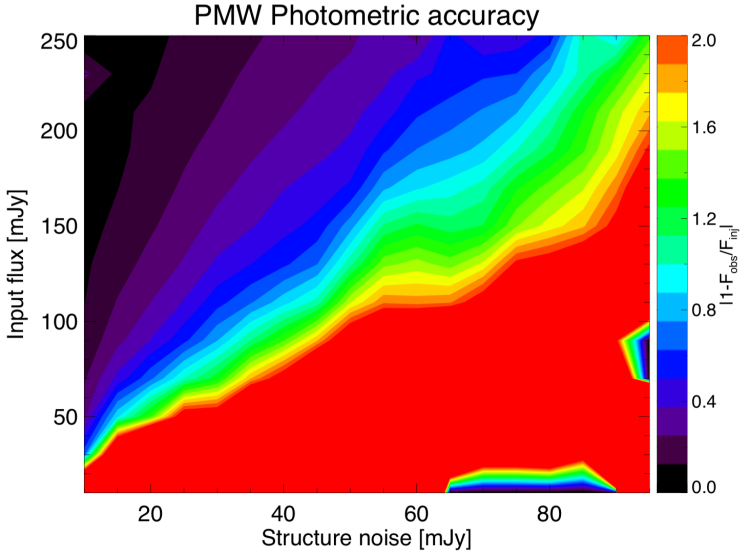
Flux levels: 250, 230, 210, 190, 170, 150, 130, 110, 90, 70, 50, 30 & 10 mJy

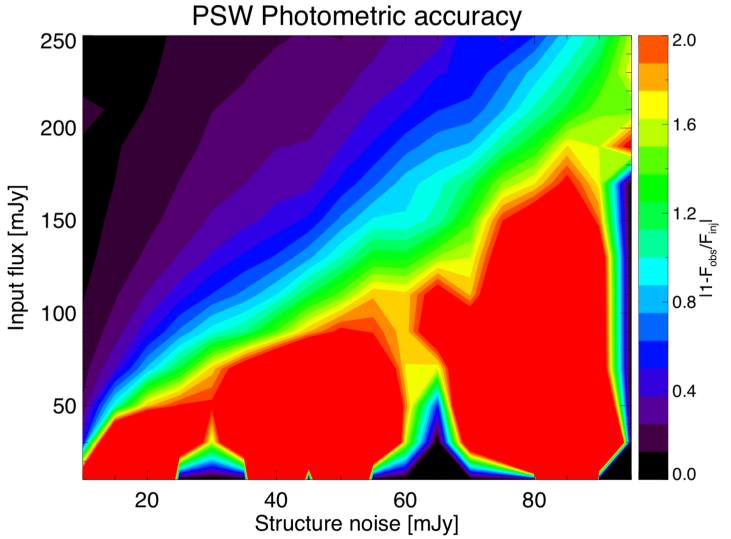
At low structure noise levels sources above 60 mJy can be detected reliably

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

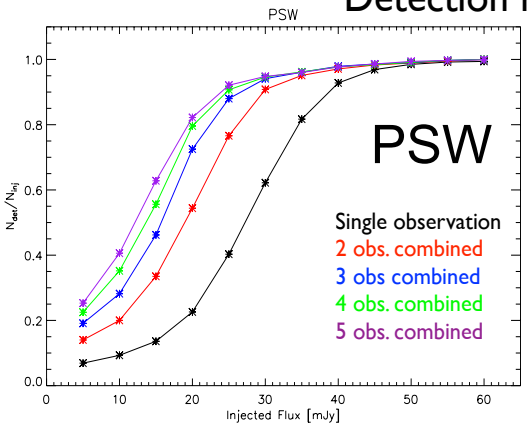
At low structure noise levels sources above ~40 mJy can be measured accurately

At high structure noise levels the photometry is not reliable

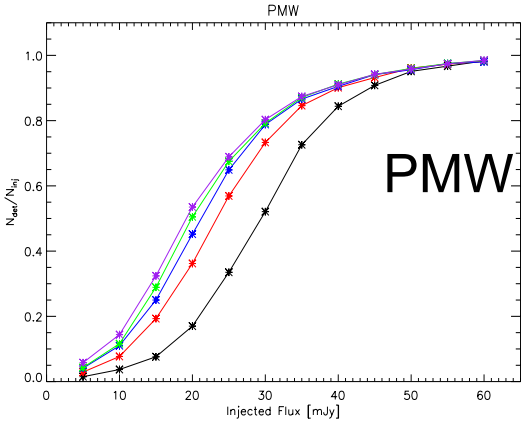
Completeness and Reliability

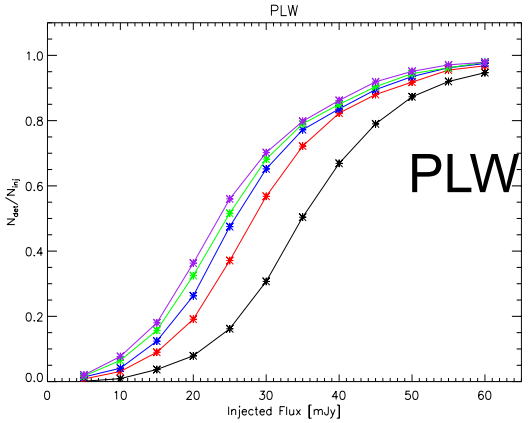
- Completeness:
  - Injection and recovery of artificial sources into real maps at different structure noise levels.
- Reliability:
  - small thanks to low instrument noise and high confusion noise.
  - From Jackknife tests following Smith et al. 2012.

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:

Object ID	String	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.
RA	Double	Right Ascension expressed in decimal degrees in a J2000 reference system.
Dec	Double	Declination expressed in decimal degrees in a J2000 reference system.
RA Err.	Float	One sigma uncertainty of Right Ascension [deg].
Dec Err.	Float	One sigma uncertainty of Declination [deg].
Flux	Float	Point source flux [Jansky/beam].
Flux Err.	Float	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).
S/N	Float	Signal to noise = Flux/ Flux Err.
Instr. Err.	Float	One sigma instrumental uncertainty [Jansky/beam]
# Detections	Integer	Number of contributing source detections.
Time	String	Standard date string expressing start time of first contributing observation. More contributing observations may have to be covered in a separate catalog product.
Extended source	Flag	Flag indicating that a source is potentially wider than a typical point source at the given wavelength.
SSO contamination	Flag	Flag indicating potential SSO confusion [Yes/No type]
Nearby Galaxy	Flag	Flag indicating that source is located within the encircling ellipse of a nearby galaxy [Yes/No type].
Variability	Flag	Flag indicating discrepant flux results of more than one contributing observation that are further apart than 5 sigma [Yes/No type].
STRN Category	Flag	Structure noise category indicating one of several TBD intervals. [several categories indicated by letters A,B,C…].
Cirrus Category (??)	Flag	Cirrus noise category derived from SQRT(STRN^2 – Instr_Err^2) [several categories indicated by letters A,B,C…].
Map Edge	Flag	Flag indicating proximity to map edge (TBD) [Yes/No type].
Quality	Flag	Overall quality flag being a synthesis of several of the preceding columns [several categories indicated by letters A,B,C…].