Product decision trees

An explanation of the PACS spectroscopy products to use for different types of science case

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Introduction

In this set of product decision trees, we show which of the various products of PACS spectroscopy to use when working with different science cases. The information here is a condensed version of the **Quick Start Guide (QSG)** which itself is a condensed version of the **PACS Handbook (PH)**, and the **PACS Products Explained (PPE)**; these documents should be consulted for more information, particularly on: the different types of cubes produced by the pipeline, how the data are organised in the spectrum tables produced by the pipeline, how to identify the type of observation you are working with, what the FITS files that are the cubes and tables are called and where they can be found in a downloaded observation, and how to use the various tasks or pipelines mentioned here. These documents can be found on the Herschel Explanatory Library (HELL), PACS Level 1. In addition, working with point sources, semi-extended sources, and extended sources with PACS spectroscopy are covered in three documents **Dealing with [Point/Semi-extended/ Extended] Sources observed with PACS spectrsocopy** (**DWPS**, **DWSS**, **DWES**) that can be found on HELL (PACS Level 2). All of these same subjects are also covered by video tutorials that can be found on the Herschel Academy YouTube channel.

In the following, RED boxes are questions the user has to ask themself, BLUE boxes are explanations, actions, or options, and GREEN boxes are the products to use or advice to follow.
In the next pages are:

- PP 2-4 : an introduction to the terminology of PACS spectroscopy: the names of the different types of observation, cube, and table.
- P 5 : a list of the the science cases that are considered in the decision trees.
- PP 6-8 : a sketch of the the types of cubes and tables to use for different sorts of observations.
- P 9 : information about making your own cubes in HIPE.
- P 10 : what information you need to gather before reading the decision trees.
- PP 11-14 : the decision trees themselves.

All documentation are linked to from the Instrument Overview page: https://www.cosmos.esa.int/web/herschel/pacs-overview

Terminology

AOT

Astronomer observation template, shorthand for the observing mode of the observation.
For PACS spectroscopy the modes were:

- *chop-nod* or *unchopped* : refers to the way the telescope background was sampled during an observation
- *line-scan* or *range-scan/SED* : refers to the spectral coverage
- *mapping*[*Nyquist, oversampled*, or *tiling*] or *pointed* : refers to the type of pointing

The unchopped mode was used for crowded fields with no clean nearby background sky. Mapping modes were used to improve the spatial sampling or the spatial coverage. The pointed mode was recommended for point sources, but in fact many extended sources were also observed in this mode; do not confused the "pointed" AOT with a "point source".

Level 2, 3, or Level 2.5?

The Levels of an observation indicate how far the pipeline processing has reached. For most AOTs, *Level 2* is the level with the science-use products (cubes and tables). Only for unchopped range-scan AOTs should you look at *Level 2.5* instead: the same range of cubes and spectral tables are found the two levels, but for the unchopped range-scans, only the Level 2.5 data are background subtracted. In *Level 3* we have placed a spectral table, created from the Level 2 tables from multiple observations; this is only provided for pointed, chop-nod, SED AOTs.
For more information, including the FITS filenames of all products in an observation, see the **PPE**.

Spaxel or Spatial pixel

A spaxel or spatial pixel is the pixel unit of a cube, containing the spectrum from one small patch of sky in the observed field. "Spaxel" is usually used when referring to native cubes that have the sky footprint of the instrument, which for PACS means the rebinned cubes. "Spatial pixel" is more often used when talking about mosaicked or spatially-resampled cubes, which for PACS are created from the rebinned cubes.

Terminology

Rebinned cubes

There are various types of cubes produced by the pipeline. Rebinned cubes are provided for every type of observation, and they are the first science-use cubes of the pipeline. The name comes from the fact that they are the spectrally-*rebinned* version of the previous class of cube in the pipeline. These cubes have the spatial grid of the PACS IFU, i.e. a slightly irregular 5x5 spaxel grid with spaxels of 9.4”.

Mosaic cubes

Mosaic cubes are created from the rebinned cubes.
For mapping observations: they are the combination of the individual pointings (each providing a single rebinned cube) in the raster. Three types of mosaic cubes are created − *interpolated*, *projected*, or *drizzled* − depending on the mapping mode. Their spatial grid is regular, with spatial pixels of size between 1.5” and 3”.
For pointed observations: interpolated and projected cubes are also created − here they are not a mosaic, but rather a spatially-resampled single pointing. This is done to turn the irregular grid of the rebinned cubes into a regular grid, which makes the cubes easier to view in various software, and makes it easier to inspect the appearance of your source. The spatial pixels of the projected cubes created for pointed observations are 0.5”, for interpolated cubes they are 3”.
The **PH** should be consulted to learn about the algorithms used to create the different types of cube: not all types of cube are suitable for all types of observing mode.

Equidistant cubes

All mosaic cubes are also offered in an “equidistant” version. The spatial grid is the same as its parent mosaic cube, but the spectral grid has been resampled to have equal-sized bins across the spectral range of the cube, rather than bins that scale in size with the spectral resolution (i.e. get larger with increasing wavelength, which is the case for all other cubes produced by the pipeline). These were created because some software cannot read cubes with a non-equidistant wavelength grid. The data look the same as in the parent cube, however it should be remembered that the spectral sampling is very much finer than the spectral resolution warrants.

Terminology

Mapping mode key

Three mapping mode were offered: *oversampled, Nyquist*, and *tiling.* These refer to the density of the raster: steps that are smaller than a spaxel (9.4”) are oversampled, steps which are no more than 2 or 3 spaxels in length are Nyquist, and those that are a considerable fraction of the cube’s FoV (47”) are tiling. The key to identifying the mapping mode for any cube from its FITS header keywords can be found in the **PH** (in the chapter on PACS Data Products) and the **PPE**. Several types of cube are produced for all observations, and all are useable; on pp 6-7 we give some recommendations.

Cube names

The cubes are called *HPS* (Herschel PACS Spectroscopy) + *3D* (3 dimensions)) + *[EQ]* if equidistant + *[R|P|I|D]* (rebinned, projected, interpolated, or drizzled) + *[BS]* if Level 2.5 (background subtracted) + *[R|B]* (red or blue). The directory and file names will include this combination of letters. Here we will exclude the [BS][R|B] when referring to the cubes.

Spectral tables

Two types of spectral table are offered: point-source tables and rebinned cube tables. The first contains point-source calibrated spectra for pointed observations (whether or not the source is a point). The second is provided for all observations, and each table contains the spectrum of each spaxel of each raster position (wavelength, flux, error, coordinates…), for one requested wavelength range in the observation: so multiple tables are provided where multiple wavelength ranges exist, but each table contains all raster positions. The organisation of the data in the tables is explained in the **PH** and **PPE**.

Slices and cameras in the FITS filenames

For observations with multiple wavelength ranges, a separate cube (all types of cube) or table (both tables) is created for each range: these are aka “slices”. For mapping AOTs, the rebinned cubes are sliced on wavelength range and also raster position. The mosaic cubes, which are the combined rebinned cubes from the raster, are only sliced on wavelength range. Slice numbers are indicated in the FITS filename as _s##. Each cube and table also has a red (R) and a blue (B) camera version.

Information: Types of sources considered in the decision tree

Point Source

Any unresolved source. (The FWHM of the PACS beam is ~9” in the blue and ~14” in the red.)

Small source

Any source that has a diameter of <30”, i.e. that fits fully within the central 3x3 spaxels of the rebinned cubes.

Extended source

Any source is larger than a point and which is not fully flat over the observed field. This can include irregular sources larger than the mapped field, those with a varied morphology, or many smaller sources blended together.

Flat source

Any source that has at most a shallow gradient over the FoV of a single pointing (approx. <20% gradient).

Information: Mapping AOTs and the recommended mosaic cubes

Tiling

Interpolated cube (**HPS3DI**…), or **Projected** cube (**HPS3DP**...) for very large-step tiling observations

Nyqist

Projected cube (**HPS3DP**…) for range scan AOTs; **Projected** or **Drizzled** (HPS3D**D**…) cube for line scan AOTs. Note that where a drizzled cube is provided in an observation, it and the projected cube have a spatial pixel size that is optimised for the wavelength: hence two cubes of different wavelength will have different-sized spatial pixels

Oversampled

Projected cube (**HPS3DP**…) for range scan AOTs; **Projected** or **Drizzled** (**HPS3DD**…) cube for line scan AOTs. (See note above)

Alternative for all three above

For all observations, one of the mosaic cubes is also offered in an equidistant version (...**EQ**), but this is only intended for external software that cannot read the standard cubes

Alternative (for any AOT)

If working in HIPE and using one of the Useful scripts to create fitted line intensity or velocity maps, this can be done with the **projected, drizzled, and interpolated** cubes *and* also with the **rebinned** cubes (**HPS3DR**…).

Information: Pointed AOTs and recommended products

Rebinned cube **(HPS3DR...)**

These cubes are the science product to be used for observations of point or semi-extended sources, as the point and semi-extended source corrections are done on these cubes. However, they have an irregular spatial grid (5x5 of 9.4" spaxels) and can be difficult to properly visualise in software other than HIPE.

Interpolated cube **(HPS3DI...)** or the equidistant version **(HPS3DIEQ...)**

Interpolated cubes are also provided for pointed observations. They have a regular spatial grid, with spatial pixels of 3" size. They are therefore easier to load into software other than HIPE, and for extended sources it is easier to visualise the morphology of these target. For extended sources these and the rebinned cubes are both useful – it depends on what type of data analysis you wish to do. Line fitting can be done on both, aperture extraction is best done on the interpolated cubes.
The equidistant cubes are only intended for use in software that cannot read the spectral grid of the standard (interpolated) cubes.

Information: Type of tables for any AOT

Pointed AOT

Point sources

Point-source table: **HPSSPEC**… (Level 3 for chop-nod pointed SEDs, Level 2 or 2.5 otherwise). Read the PPE to learn about the data layout.

Any source

Rebinned cube table: **HPSTBR**… *However*, this table is awkward to read, as the entire spectrum from all the spaxels from the cube are contained in a single table, in single columns. This table is intended for those who cannot read cubes at all. Read the PPE to learn about its layout.

Mapping AOTs

Rebinned cube table: **HPSTBR...** (each table conains the entire raster). *However*, note that there is no mosaicking of the individual pointings before the table is created – a single table contains the entire spectrum from each spaxel from *each* rebinned cube in the raster. Hence this table is not recommended for use with mapping observations, unless you cannot read the cubes at all. Read the PPE to learn about its layout.

Information: Creating your own cubes in HIPE

Creating cubes which are not provided or changing the size of the spatial pixel

Users may wish to create mosaic cubes for mapping or pointed observations themselves, if

1. the type of cube they want to use is not provided
2. the spatial pixel size of two cubes to compare are different, but they need to be compared directly to each other (this is common when dealing with cubes created for line scan Nyquist and oversampled observations)
3. for tiling observations with a very large step, with very little or no overlap between pointings, the default cubes may look “smeared out”: projected cubes with spatial pixels of 1.5” seem to work better than that provided by default

For these cases there is a user script offered in HIPE (in the Scripts menu) that starts from a downloaded observation, takes the necessary Level 2 or 2.5 rebinned cubes, and creates a new mosaic cube. Very little expertise with HIPE is necessary to run this script.

Creating cubes from separate observations which overlap spatially and spectrally

Mosaic cubes are only created per observation. It is, however, possible to combine separate observations that overlap spatially and spectrally using a user script in HIPE. Again, very little expertise with HIPE is necessary, although some experience interacting with PACS cubes will be helpful.

These scripts are well annotated, and can be found in the HIPE Scripts menu. The PACS Data Reduction Guide, which can be accessed from the HIPE Help menu, can be consulted for help.

Preliminary step: Information to gather about the observation

Step 1: determine the AOT of the observation

- Chopnod or Unchopped
- LineScan or RangeScan [full SED or shorter range?]
- Pointed or Mapping [Tiling,Nyquist,Oversampled?]

Step 2: determine which Level to work from

Is a Level 2.5 present?

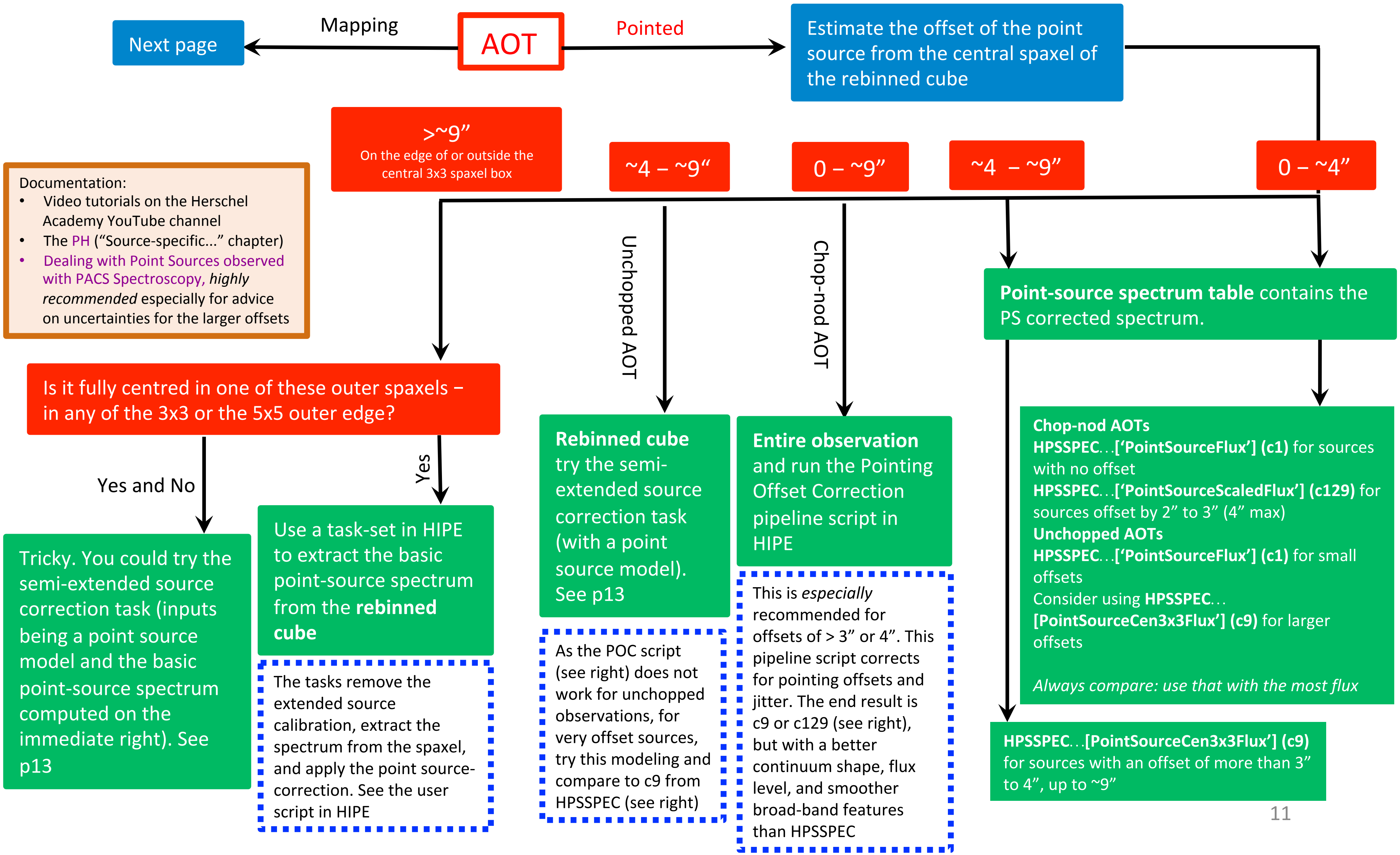
- Yes: **Use Level 2.5** (the background-subtracted on-source observation from an unchopped range scan on/off pair)
- No: **Use Level 2** (but if the AOT is unchopped range scan, note that the data will not be background subtracted)

Step 3: which camera and which "slice" covers the wavelength range you are interested in? That is, which are the cubes you want?

This information can be found in the FITS keyword of any cube in Level 2 or 2.5. The necessary keywords are documented in the PPE

In HIPE, the product viewers list this information. Outside of HIPE, consult the HSA search results panel (observation summary) or the CSV file with the values of these header keywords for all PACS spectroscopy observations. The file is explained in the PPE which can be found on https://www.cosmos.esa.int/web/herschel/legacy-documentation-pacs-level-2

Decision tree for point sources: running the point-source corrections



Decision tree for point sources: running the point source corrections

AOT

Pointed → previous page

Mapping → Can you locate the **rebinned** cube in which the point source is centred in the central 3x3 spaxels?

Yes → Estimate the offset of the point source from the central spaxel of the cube. → Follow the steps outlined for pointed observations (p. 11).

No → If the source is located on the very edge of, or outside, the 3x3 spaxel box of *all* the rebinned cubes in the raster, you can try the option for point sources offset by >9" outlined on p. 12.
If that is not possible, the only option is to perform an aperture spectro-photometry of your source from your mosaic cube.

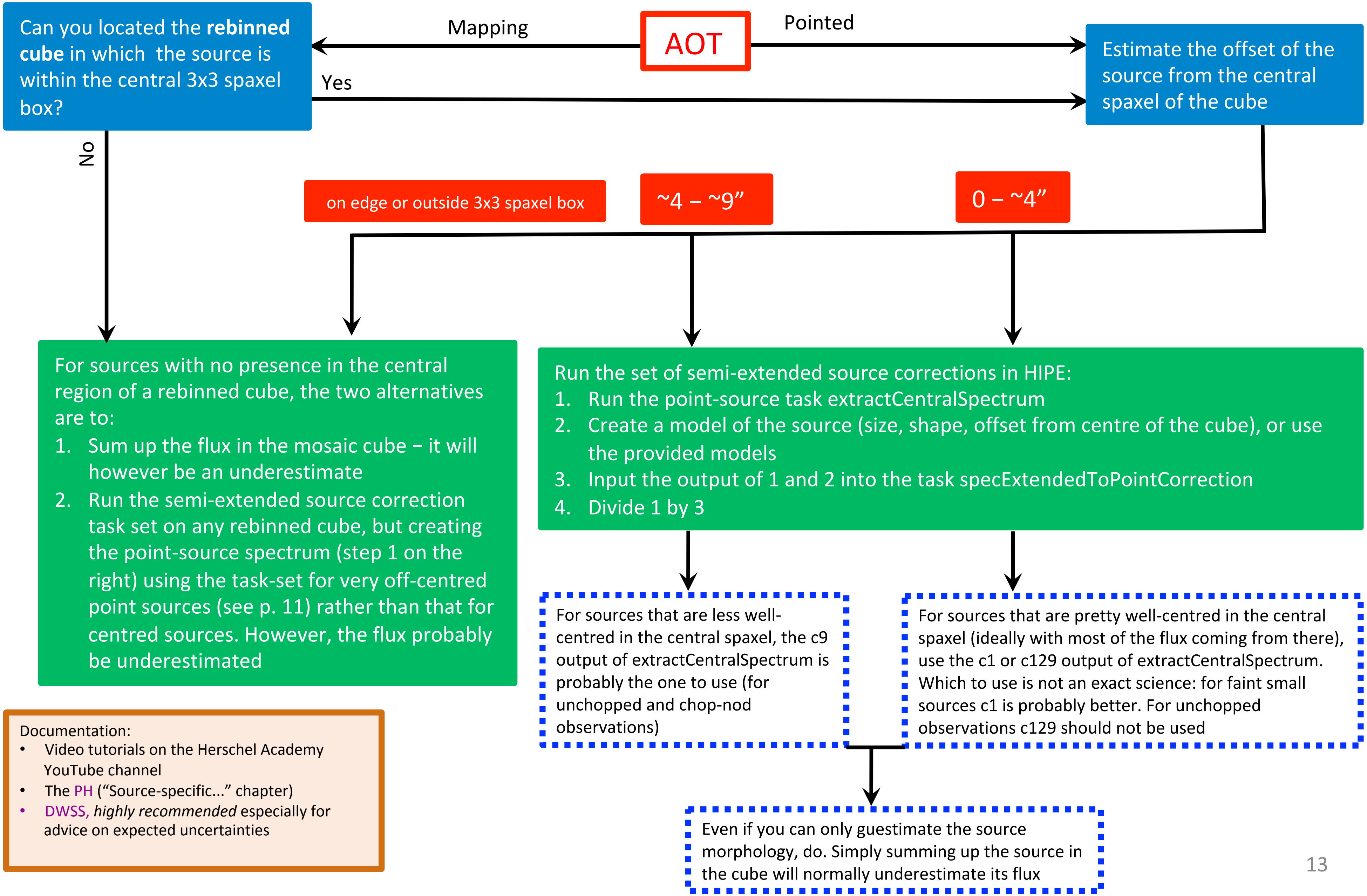
Extracting the flux from the mosaic cube with aperture spectro-photometry will underestimate the flux, by a degree that depends on the spatial sampling, location of the source in the instrument plane, and its brightness. There are no aperture corrections provided by PACS to compensate for this.

If you can find mapping observations of point sources in the archive (standard or calibration data), you can try compute appropriate aperture corrections. However, it should be born i mind that such corrections have a strong dependence on the mapping pattern of the observation and location of the source in the instrument plane, and so to some level are unique to each observation.

Documentation:

- Video tutorials on the Herschel Academy YouTube channel
- The PH ("Source-specific..." chapter)
- DWPS, *highly recommended* especially for advice on expected uncertainties

Decision tree for semi-extended sources (<30” full size)



Decision tree for extended and flat sources