An Introduction to photometry and spectroscopy with PACS

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&

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Outline of the Webinar

- Quick Instrument Overview: PACS photometer & spectrometer
- PACS Data: download and visualization in HIPE
- Review of PACS Products
- PACS Calibration
- When to reprocess PACS data
- How to reprocess PACS data
- Documentation & Additional Resources

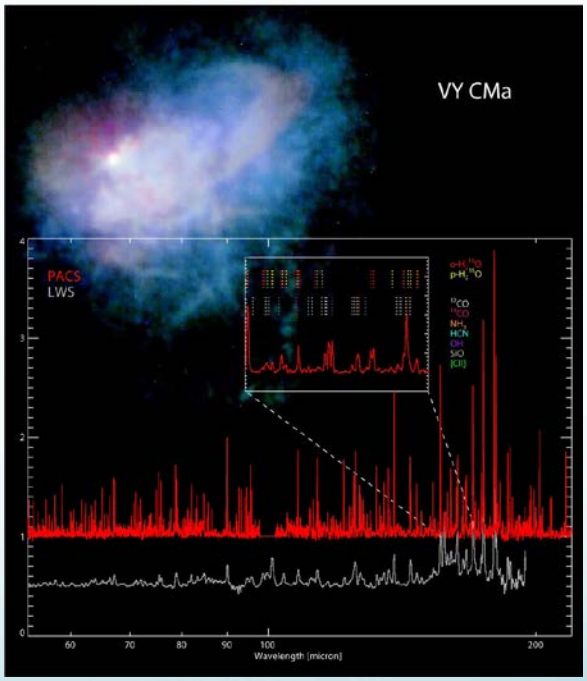
Quick Instrument Overview

PACS (PI. Albrecht Poglitsch, MPE, Germany)

A Photodetector Array Camera & Spectrometer for Herschel

Image Credit: ESA and PACS Consortium

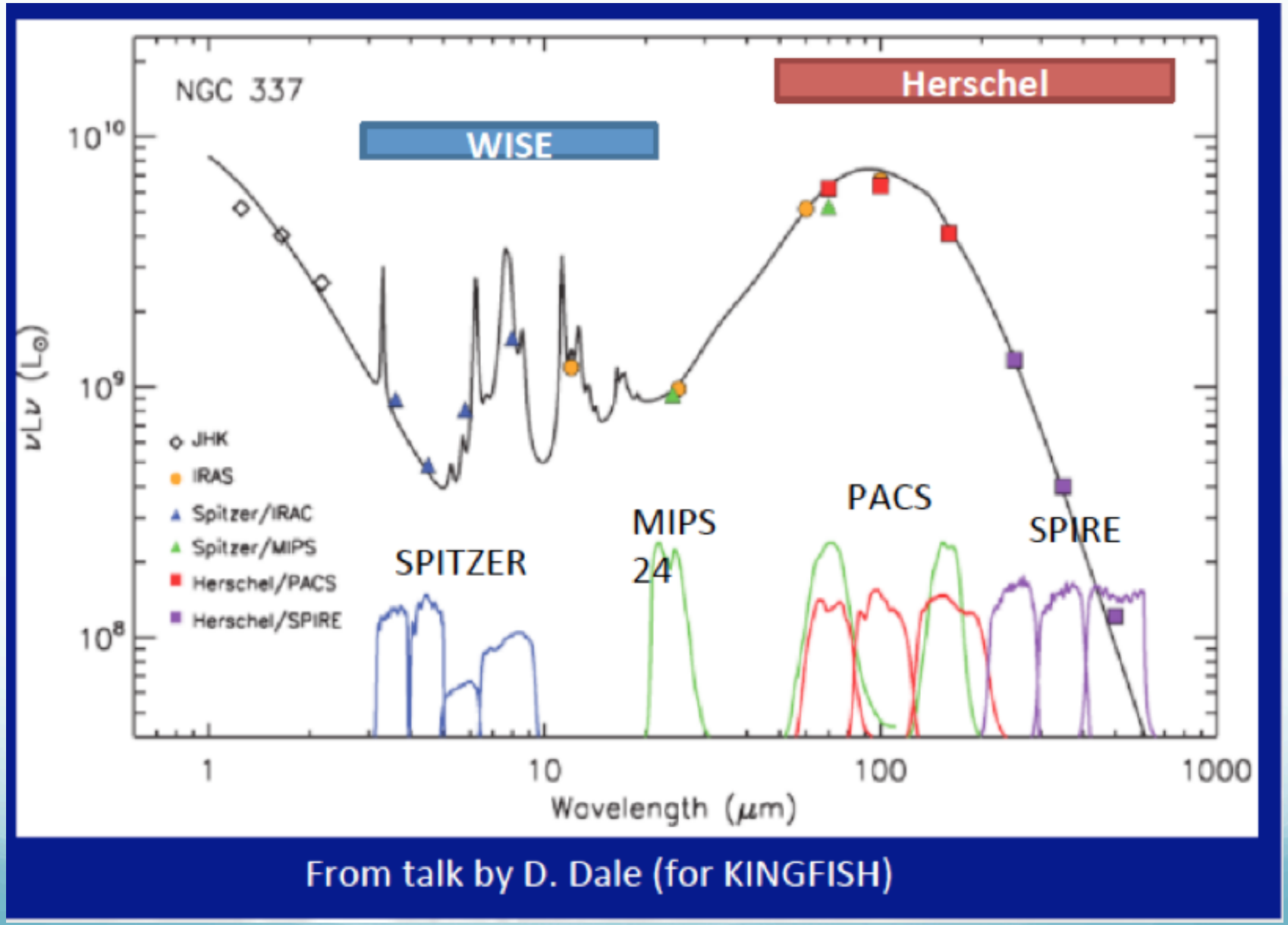
Image Credit: MESS Consortium



Imaging ⟷ bolometers

Spectroscopy ⟷ Ge:Ga array

PACS Instrument Overview: photometer

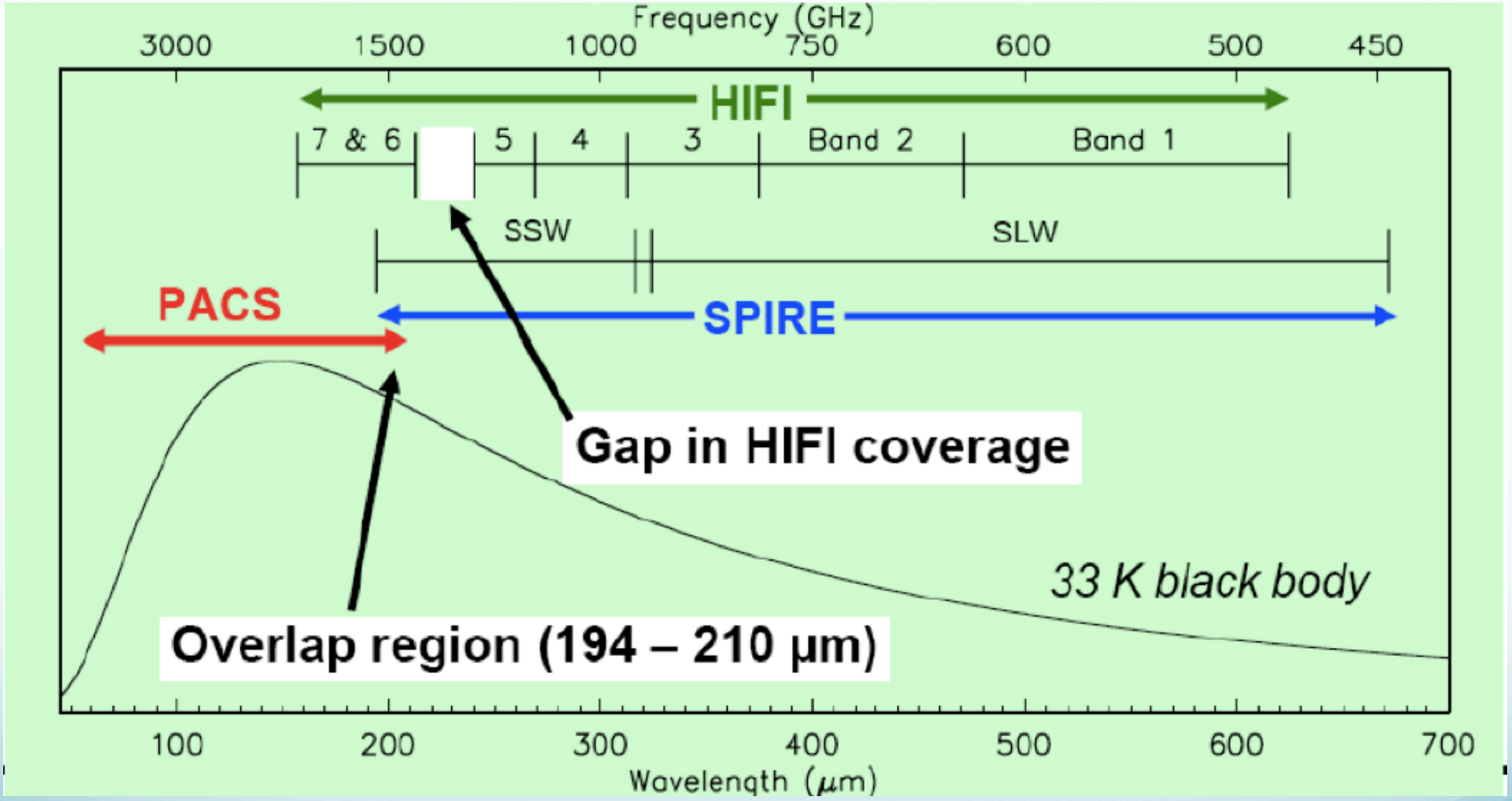


From talk by D. Dale (for KINGFISH)

Wavelengths & Resolution: PACS photometer

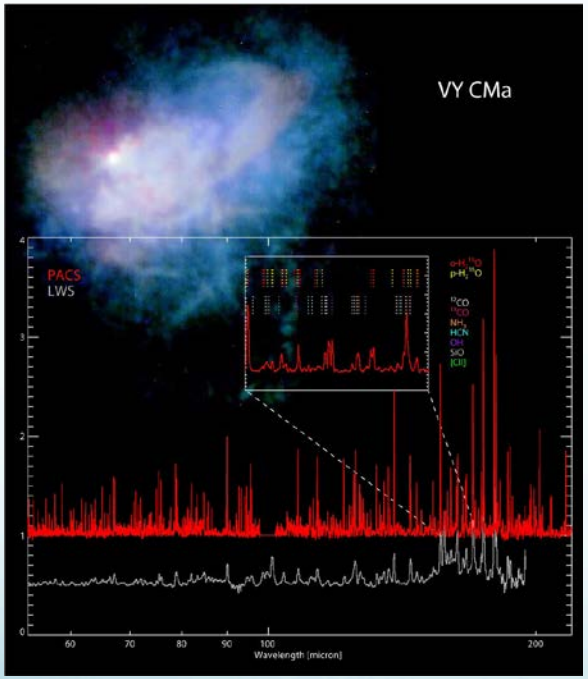
- Simultaneous (→ same FOV) 60-85 μm or 85-130 μm and 130 – 210 μm imaging
- FWHM: 5.5”, 6.7”, 11.5”
- 1.7’ X 3.5’ FOV with a 64 X 32 and 32 X 16 arrays
- Point source detection limit: ~3mJy (5σ, 1h)

PACS Instrument Overview: spectrometer



(slide courtesy of David Ardila)

Wavelengths & Resolution: PACS spectrometer



"Integral Field" (IFU) Spectrometer (3D-spectroscopy)

- Simultaneous (→ same FOV) 57-105 μm (B3A, B2B) & 105-210 μm (R1) spectroscopy
- FWHM from 9.4" to 13"
- 47" X 47" FOV re-arranged via an image slicer on two 16 X 25 arrays
- $\lambda/\Delta\lambda$ ~ 1500
- Sensitivity: ~ 5 X 10^{-18} W/m^2 (5σ, 1h)

Data Download and Visualization in HIPE

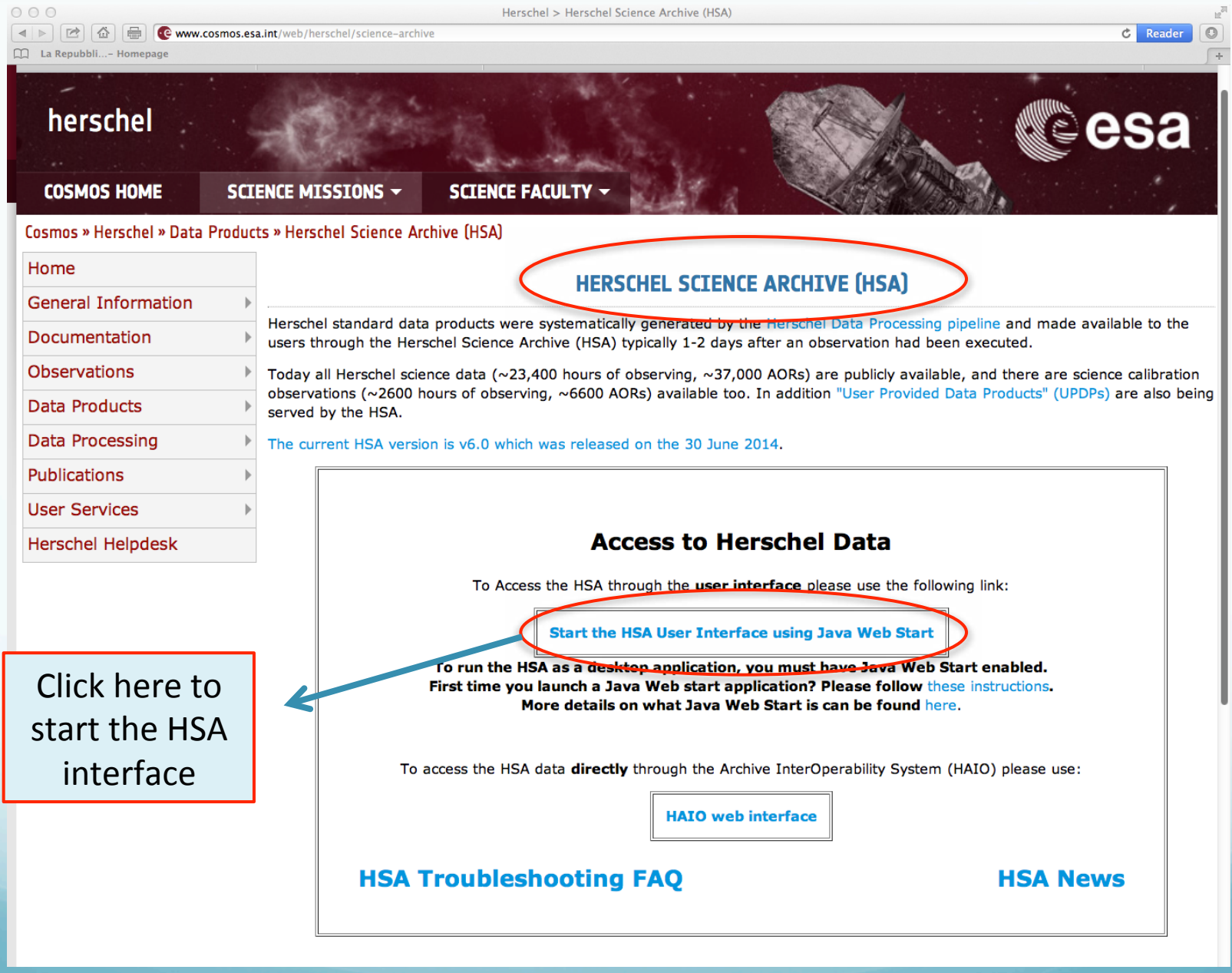
How do I find the PACS data I need ?

- Each PACS data set (photometer or spectrometer) is uniquely associated with a 10 digit number, i.e. an OBSID. Ex: 1342191353

- Therefore, we always first need to identify the OBSID or list of OBSIDs which correspond to the data set we are interested in

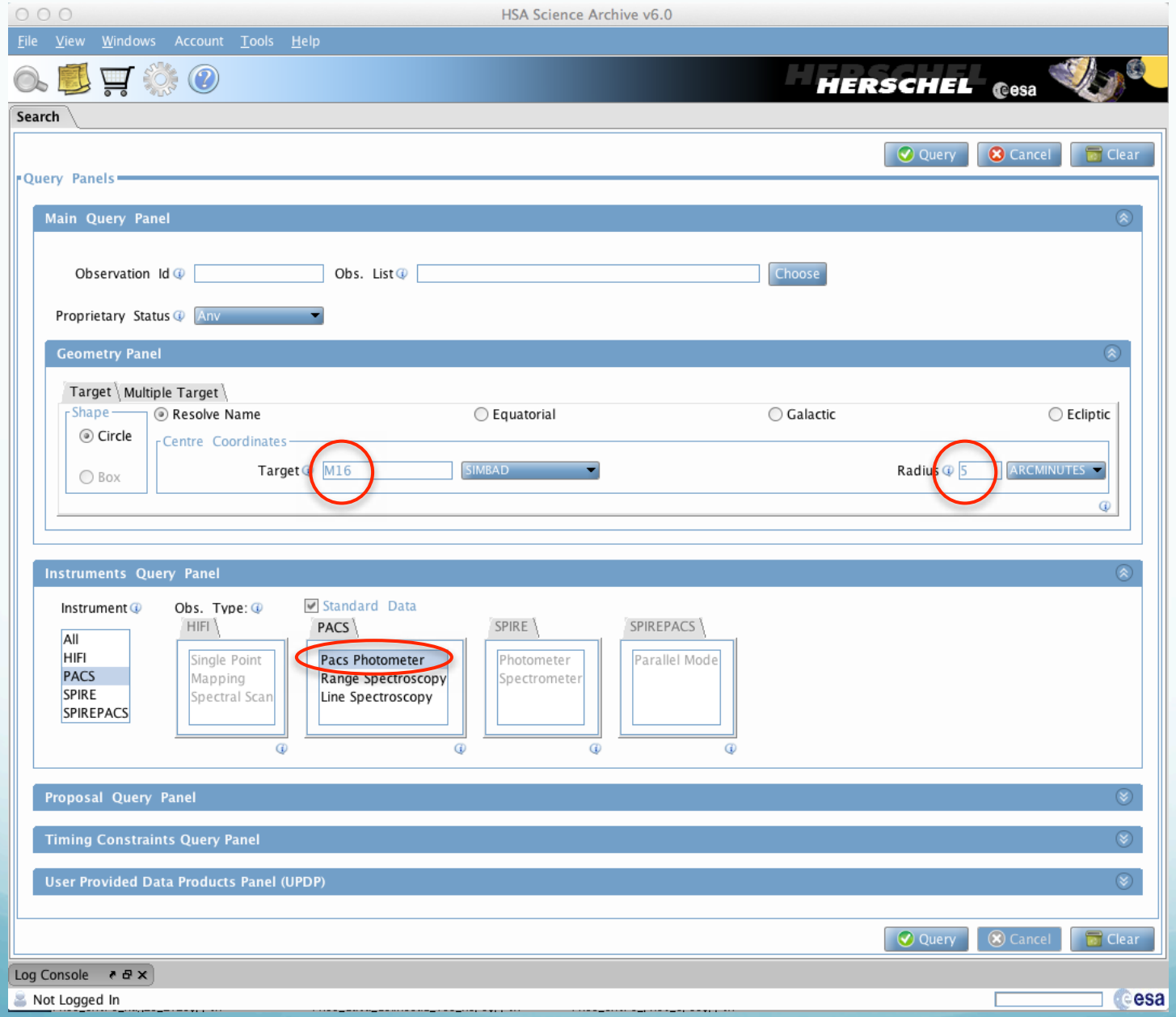
- To this end, we go to the Herschel Science Archive (HSA)

PACS Data Download & Visualization



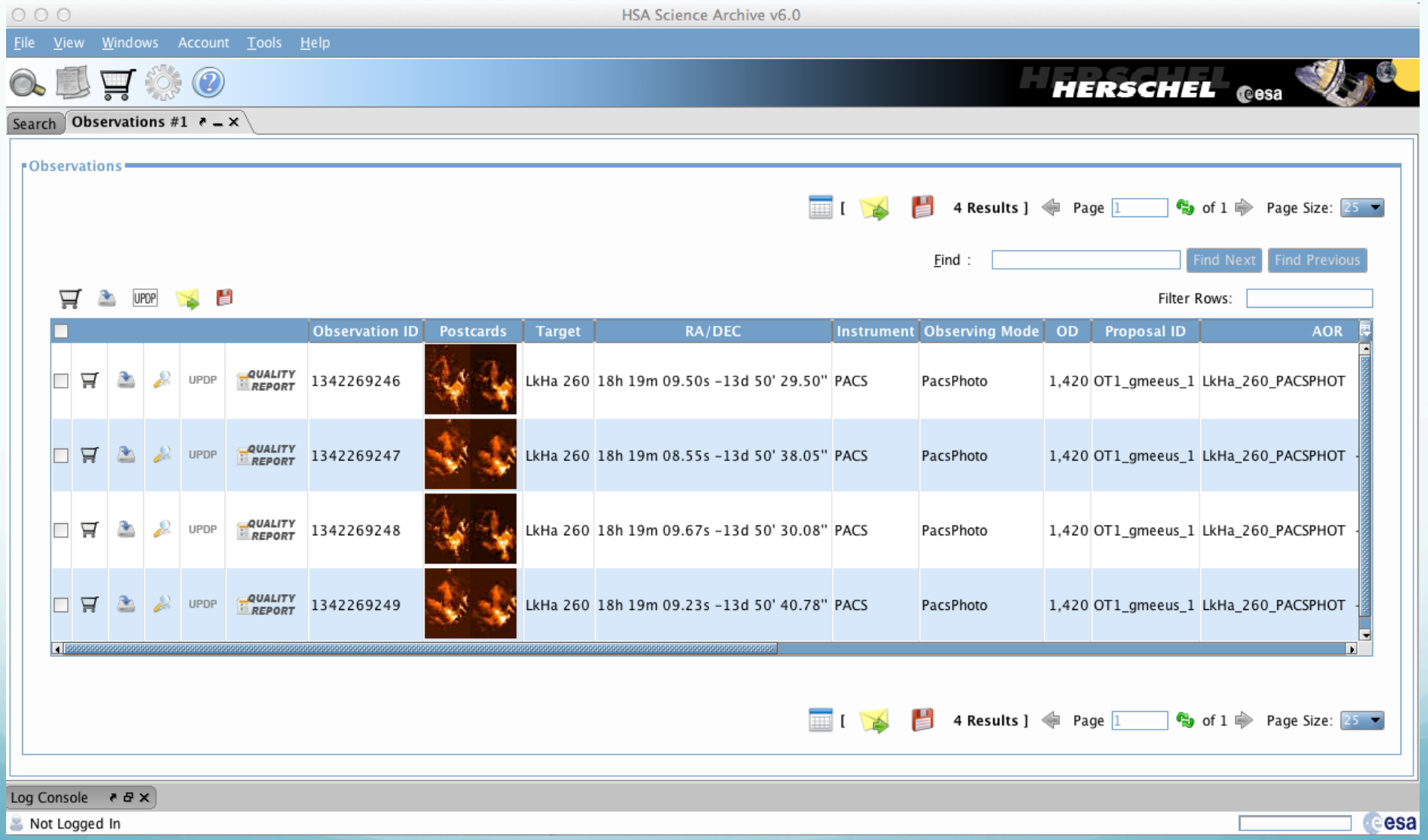
Click here to start the HSA interface

PACS Data Download & Visualization



Ex:
Search in the HSA for PACS photometer data for M16 within a 5’ radius

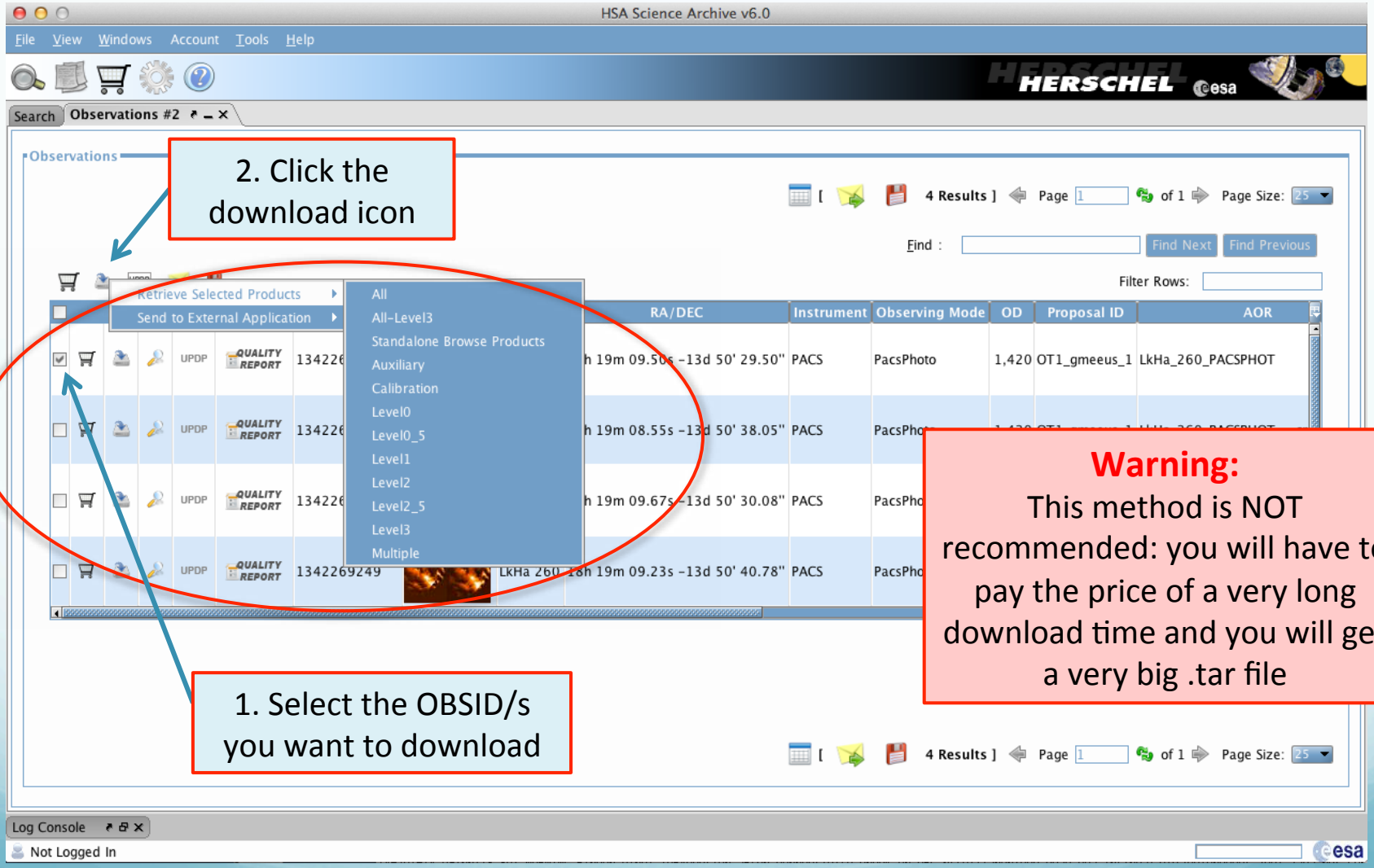
Result of the query:



Now that I have identified the OBSID/s I need: how do I download the data?

The best way to download PACS data is from HIPE

Before showing how to download the data from HIPE, for completeness….



What is HIPE ?

The Herschel Interactive Processing Environment (HIPE) is a software package that allows Herschel users to: 1) download; 2) visualize; 3) analyze the data

Where do I find it ?

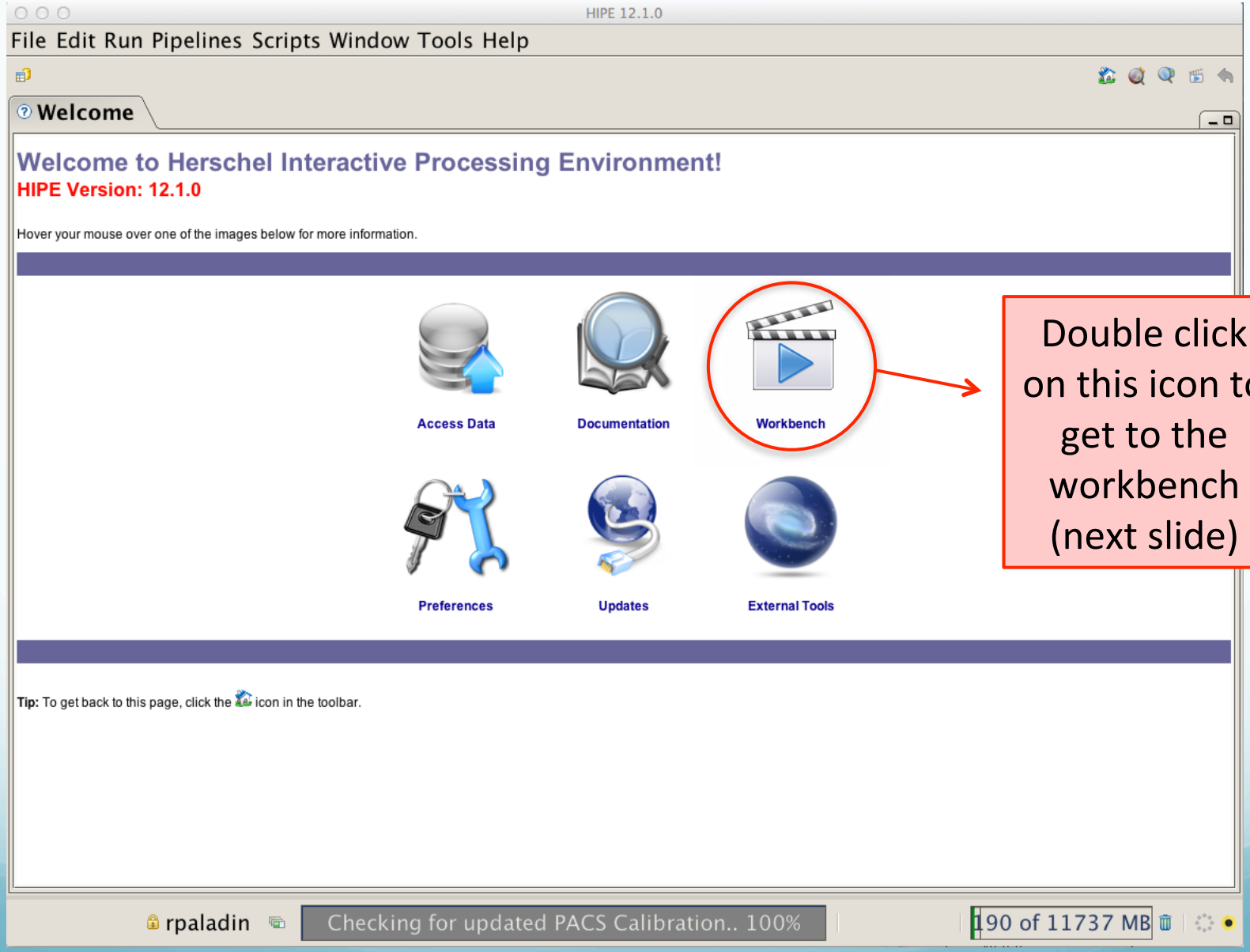
- To download HIPE, go to:

http://www.cosmos.esa.int/web/herschel/hipe-download

- HIPE is developed for different platforms: Windows, MacOSX and Linux
- Installation instructions are provided at the above link
- During the Herschel mission (2009 – 2013), a new version of the software was released every six months (HIPE 1 to HIPE 11). Since September 2013, HIPE is released once per year. The current released version is HIPE 12.1. The next release will occur ~end of 2014

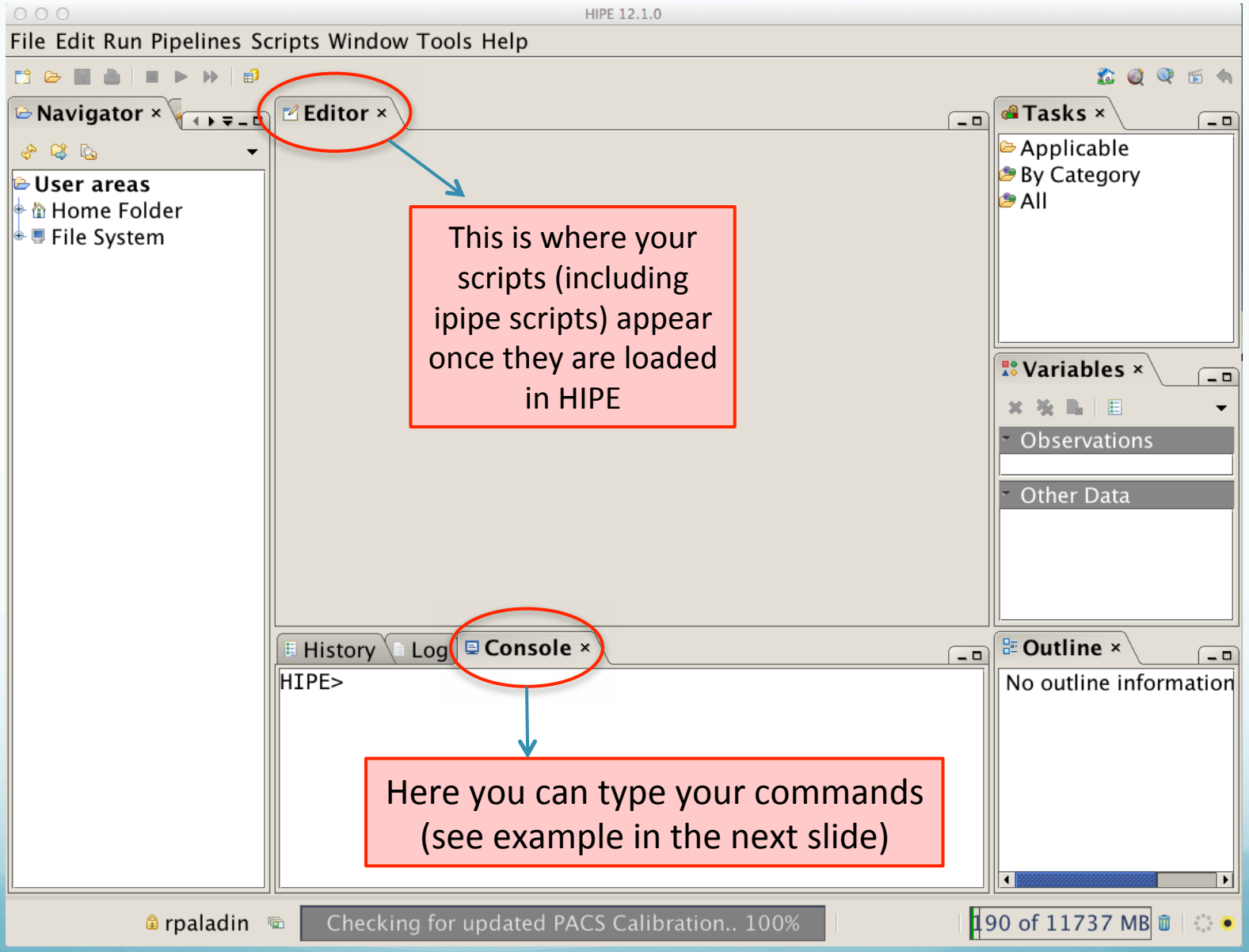
Always process your data with the last HIPE release

PACS Data Download & Visualization

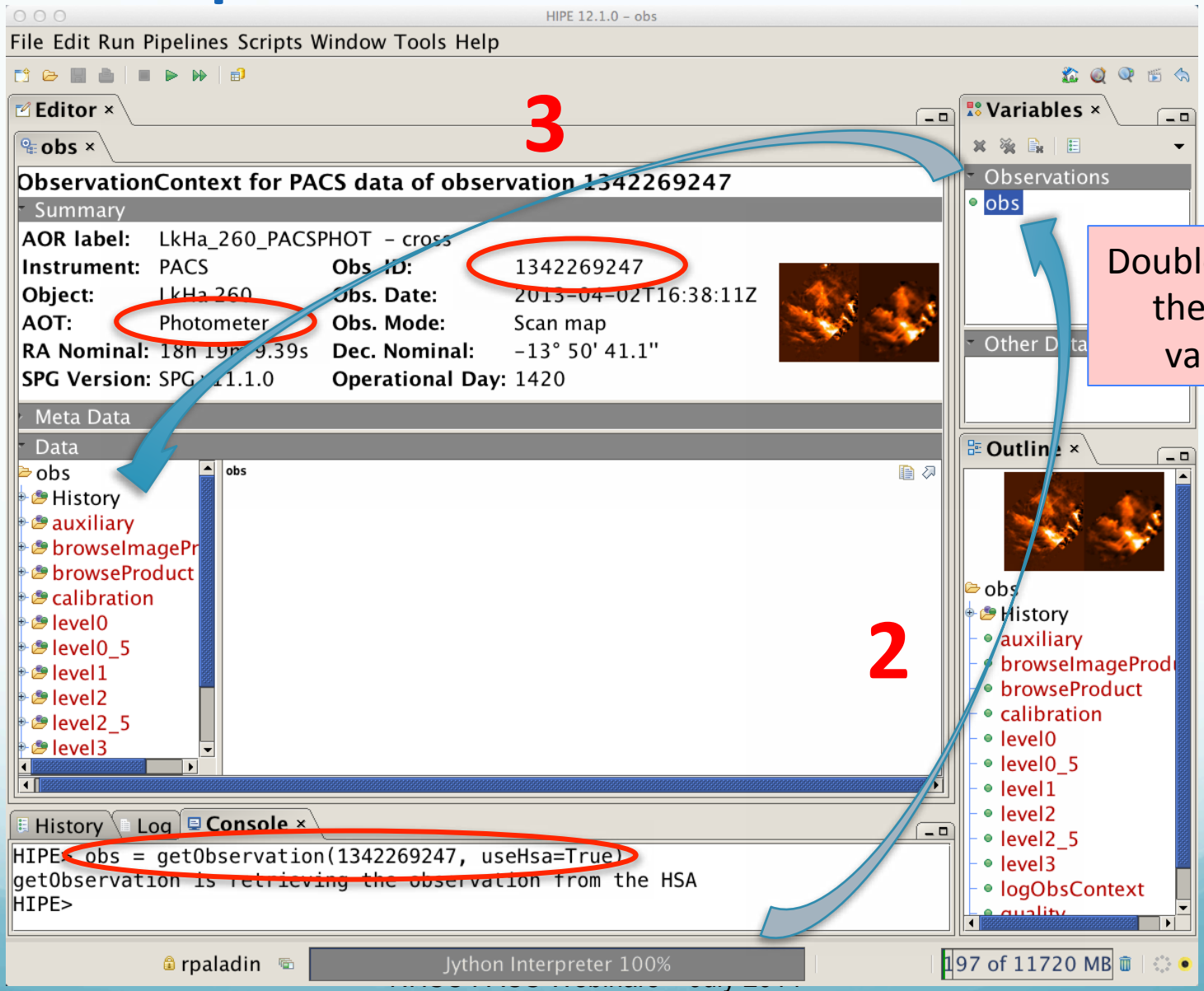


Double click on this icon to get to the workbench (next slide)

PACS Data Download & Visualization



Example: M16 – OBSID: 1342269247



PACS Data Products: Photometer & Spectrometer

Note on PACS archived data

- Every time a new version of HIPE is publicly released, all the Herschel data in the archive (HSA) are reprocessed with it (→ Standard Processing Generation (SPG) *bulk-reprocessing*)
- the current version of the bulk reprocessing in the HSA is: SPG 11.1
- when you use PACS data for your science, always make sure you are using the last processed version
- this will assure that the data have been processed with the most updated calibration files and pipeline

PACS photometer products

PACS Photometer Archived Products

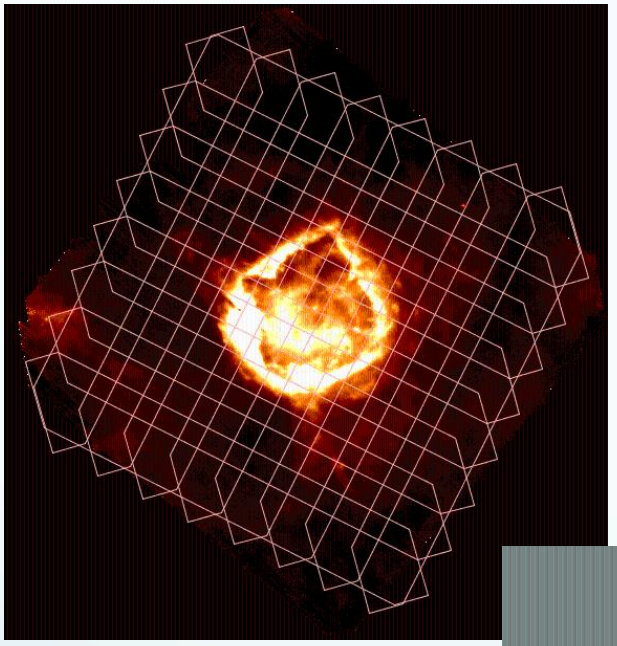
- There are 3 PACS photometer observing modes:
  - Chop-Nod mode → this mode was deprecated in Cycle 1/ Cycle 2 and only used for calibration purposes
  - Scan map mode
  - Parallel mode

  Here, we will only talk about these two modes

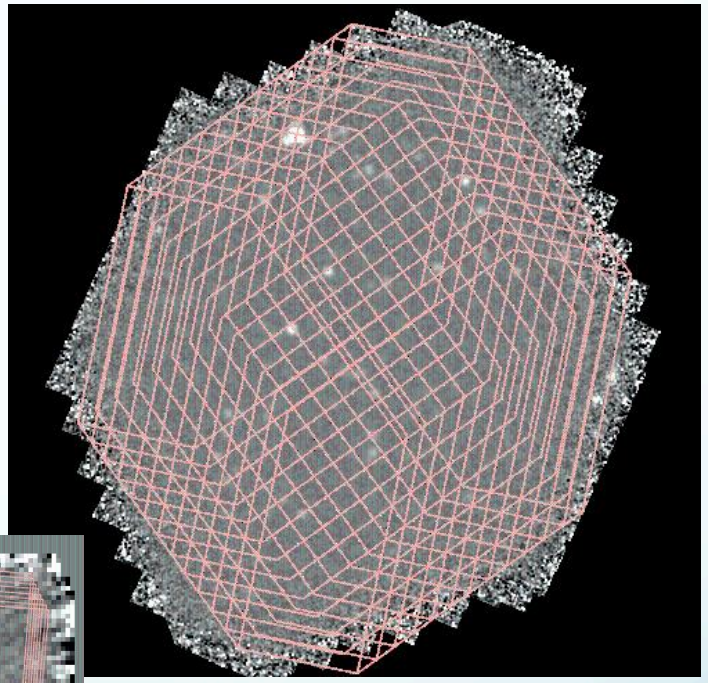
- For any observation performed in a given mode (scan map or parallel), the archive contains different *processing levels (level 0, level 1, etc.)* of the data

Scan Map Mode

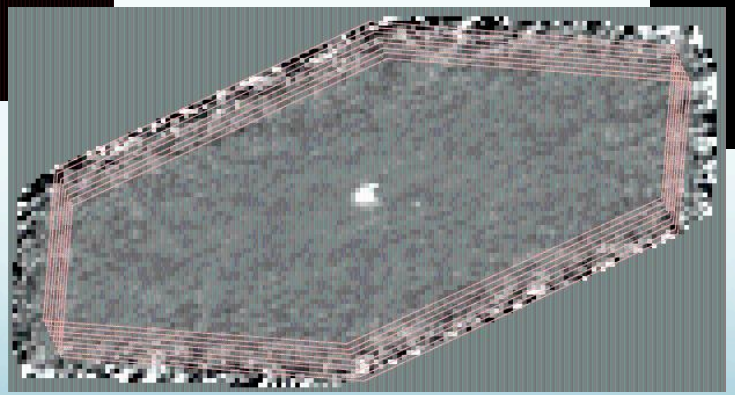
Large Galactic fields



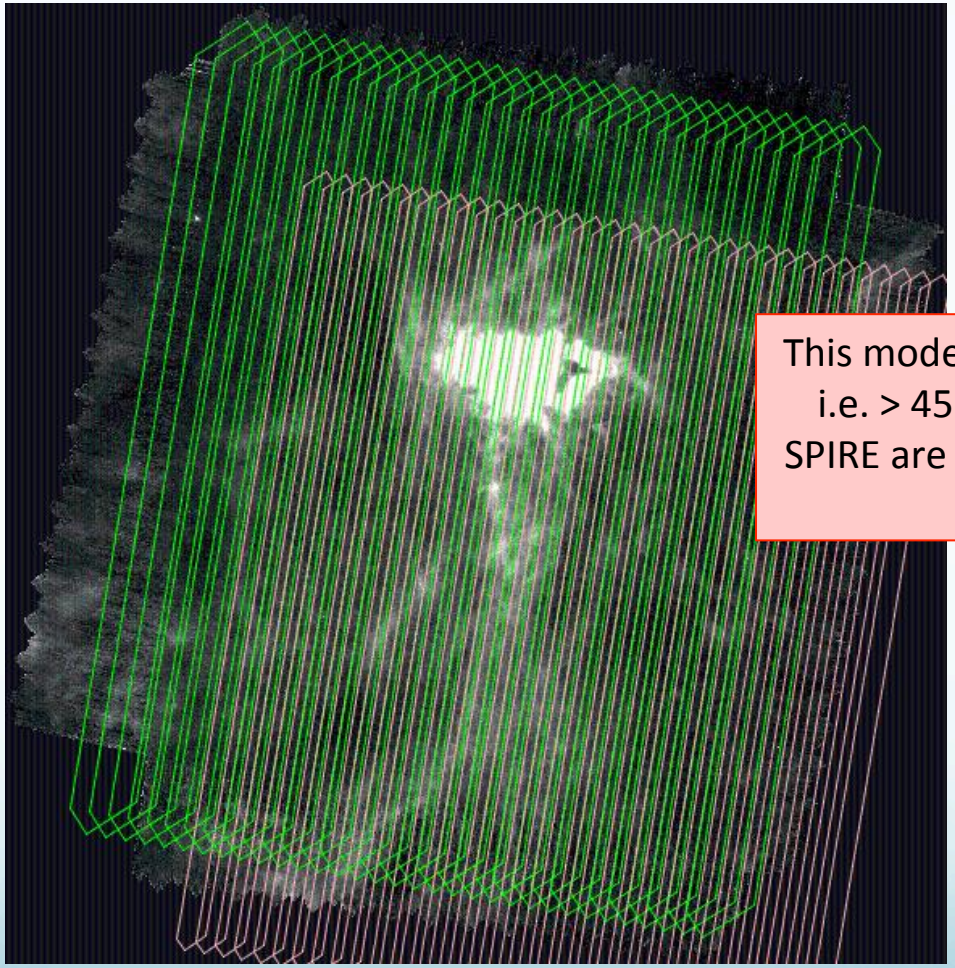
Deep cosmological fields



Small fields centered on point-sources

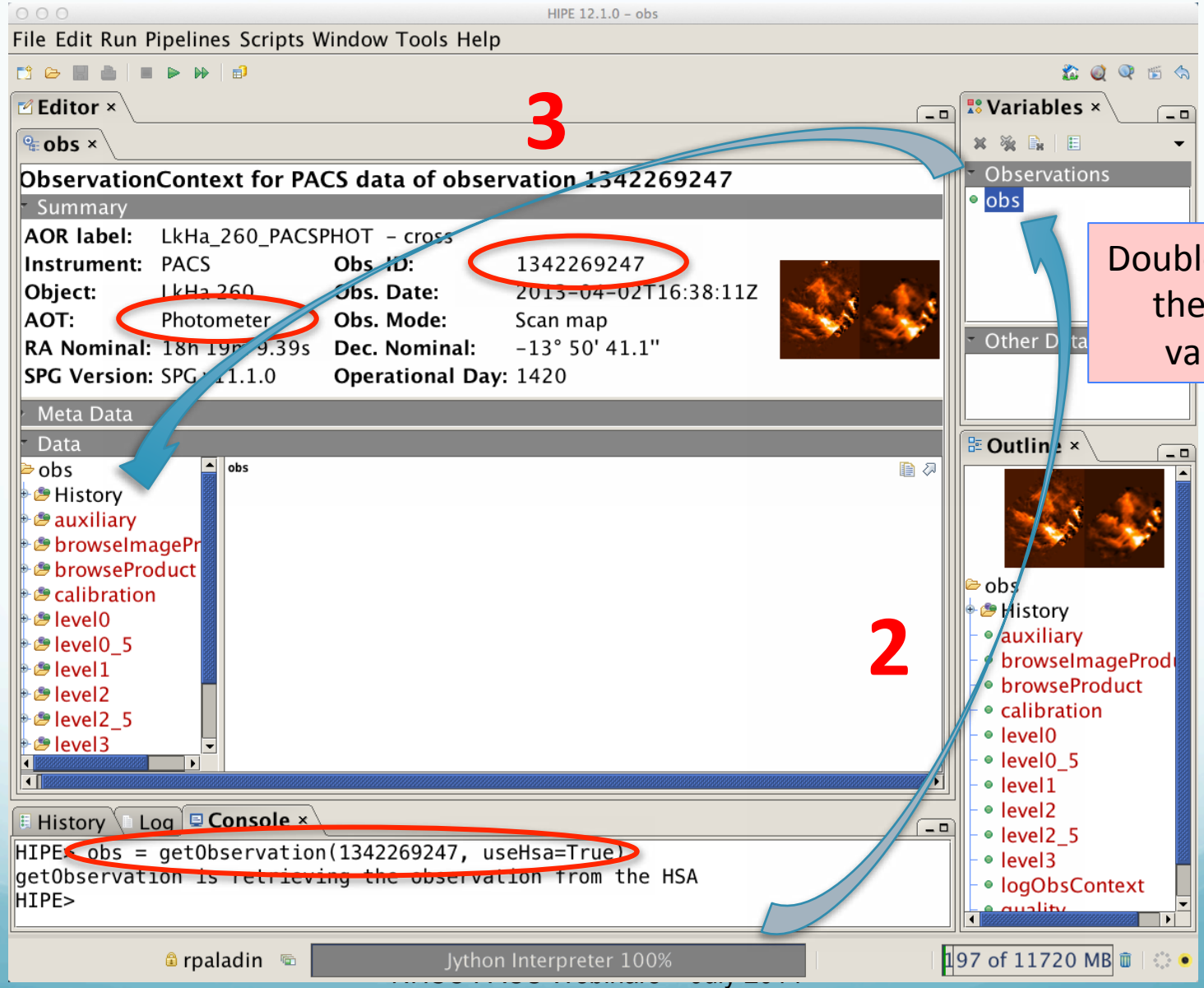


Parallel Mode: PACS & SPIRE



This mode is efficient for large maps, i.e. > 45 arcmin in size (PACS and SPIRE are separated by 21 arcmin on the focal plane)

Let's go back to our example: M16 – OBSID: 1342269247



Currently available from the HSA (SPG 11.1)

- Level 0: raw data cubes → we will not talk about these: users never need to go back to Level 0 in the case of PACS photometer data (..different story for the spectrometer)

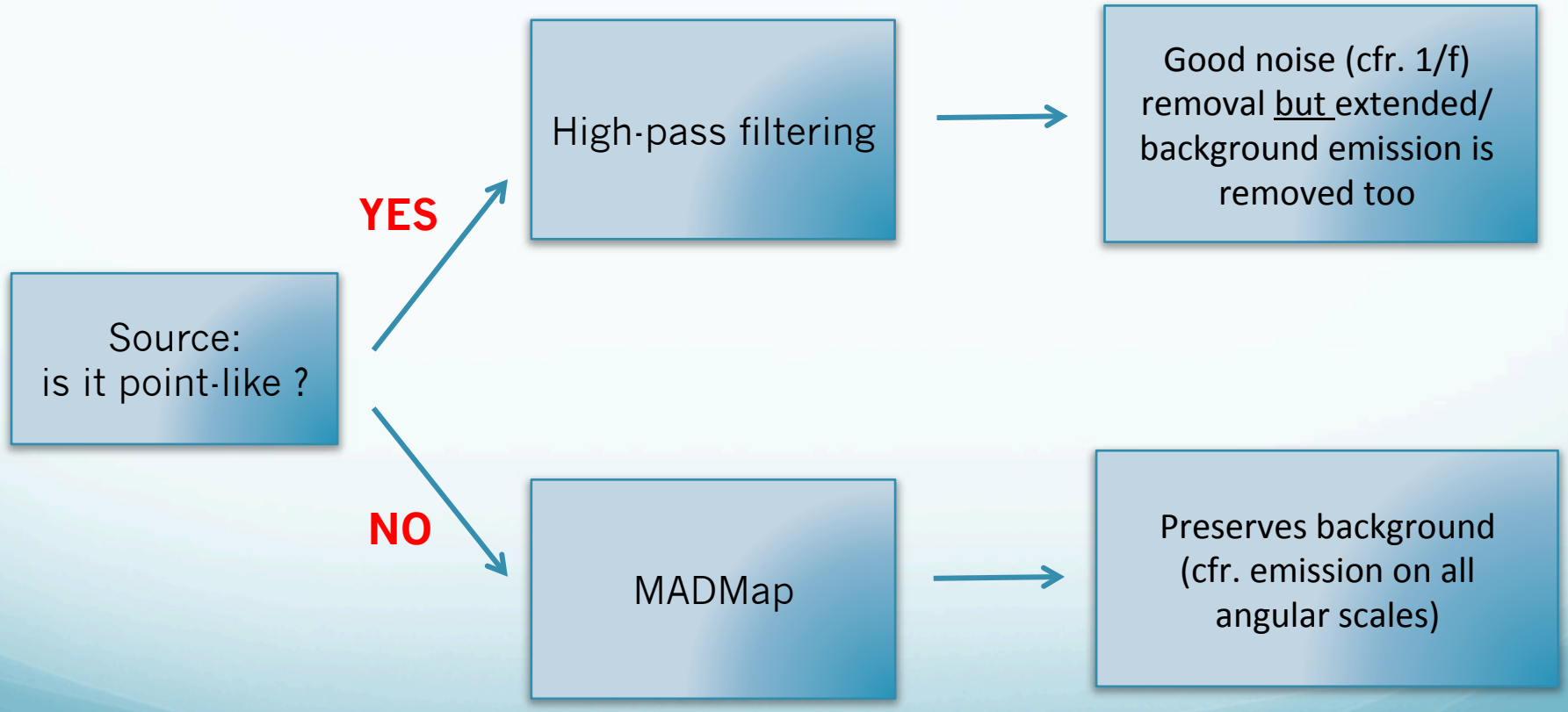
- Level 1: data cubes calibrated in Jy/pixel, instrument effects removed and propagation of "flagged pixels" (cfr. masks). Astrometry (cfr. pointing) attached
  NOTE: Level 1 is the typical starting point for re-processing

- Level 2: maps created by projecting high-pass filtered (HPF) data cube on a grid using pointing information
  NOTE: one map per OBSID / extended emission is filtered out

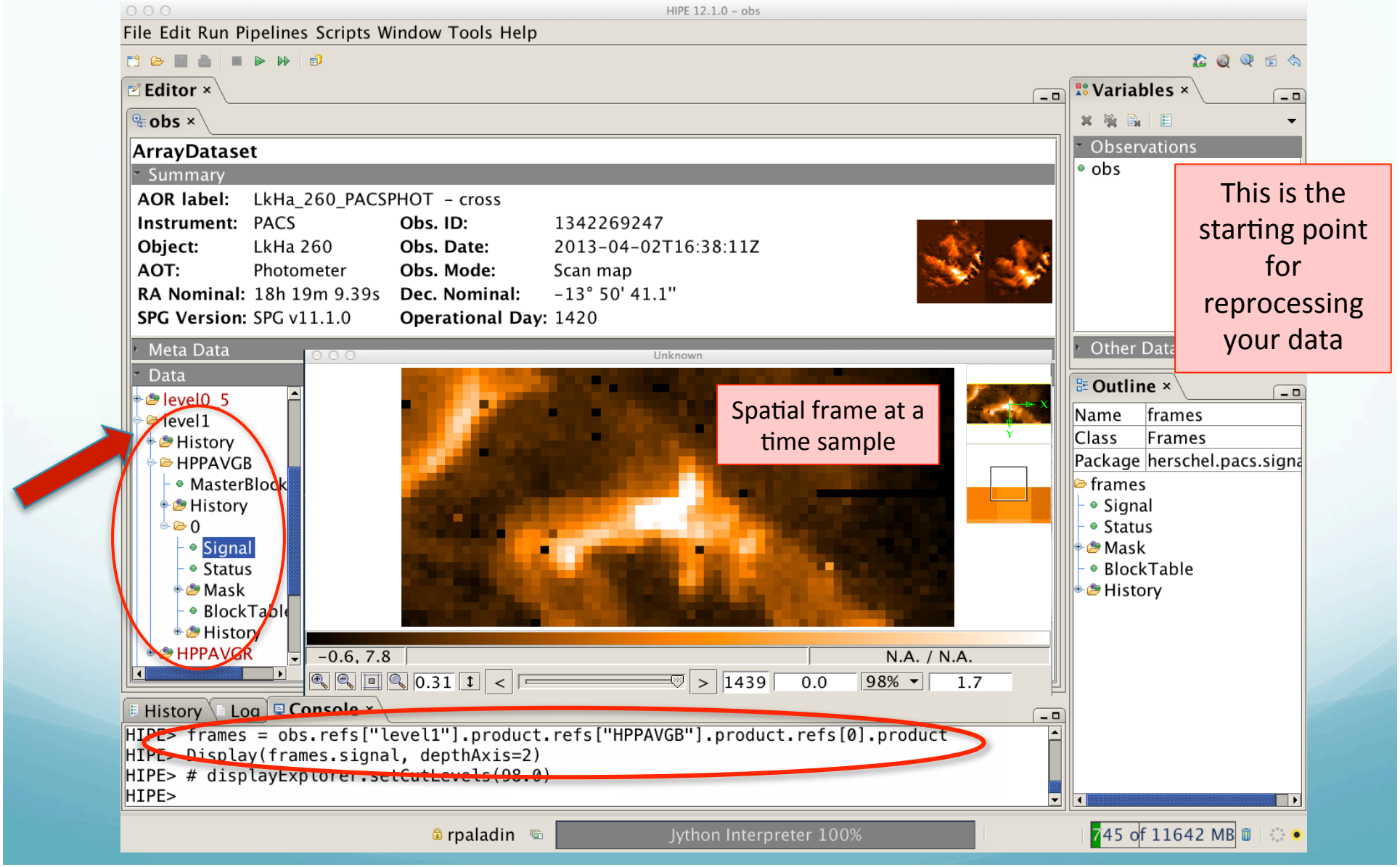
- Level 2.5: maps obtained by combining *pairs* (cfr. Scan/X-scan) of OBSIDs – Both MADmap and HPF maps
  NOTE: MADMap preserves emission on all angular scales

- Level 3: maps obtained by combining all observations of a given field from the same program – HPF only

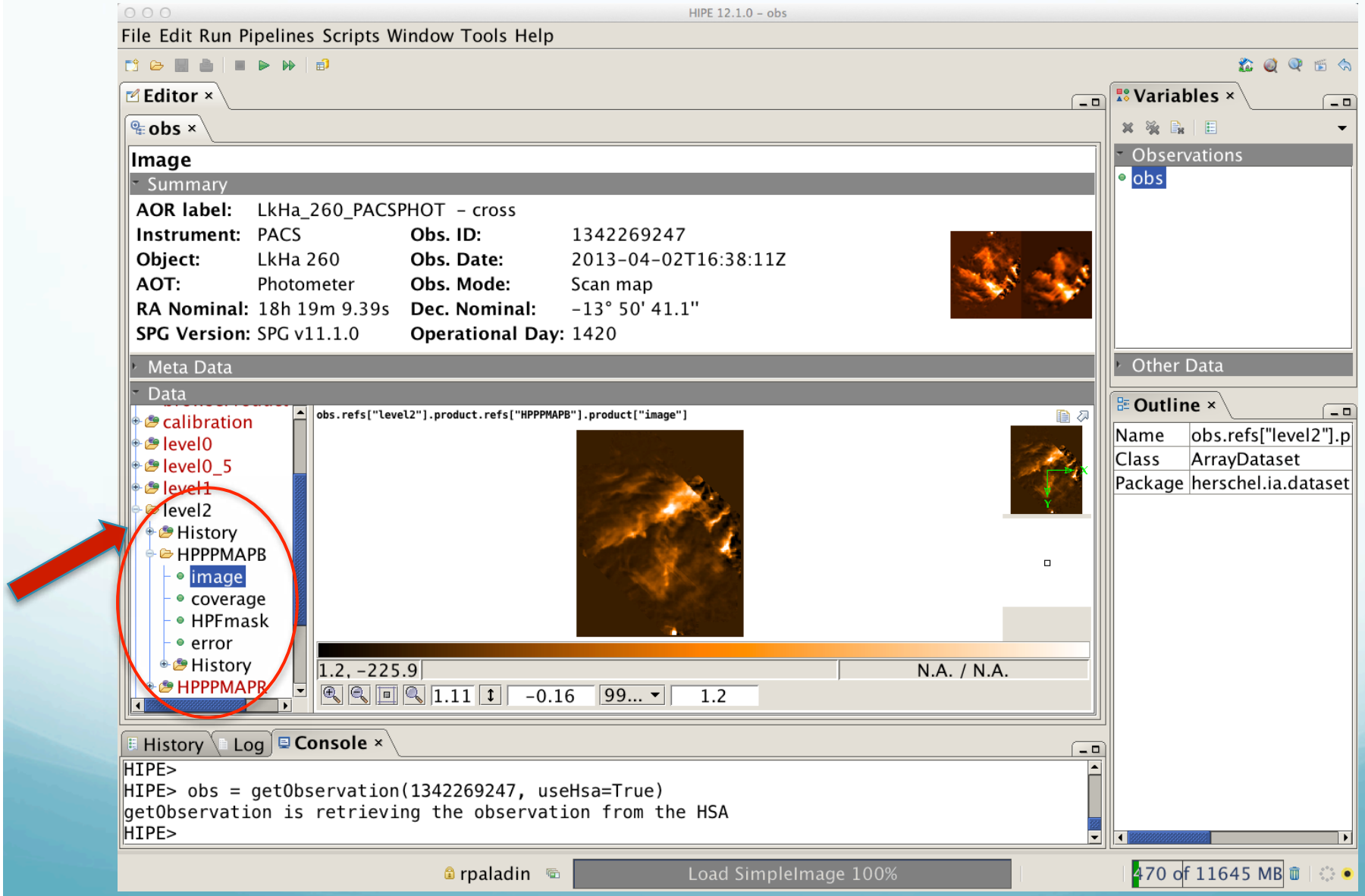
The PACS photometer pipeline has 2 branches starting from Level 1:



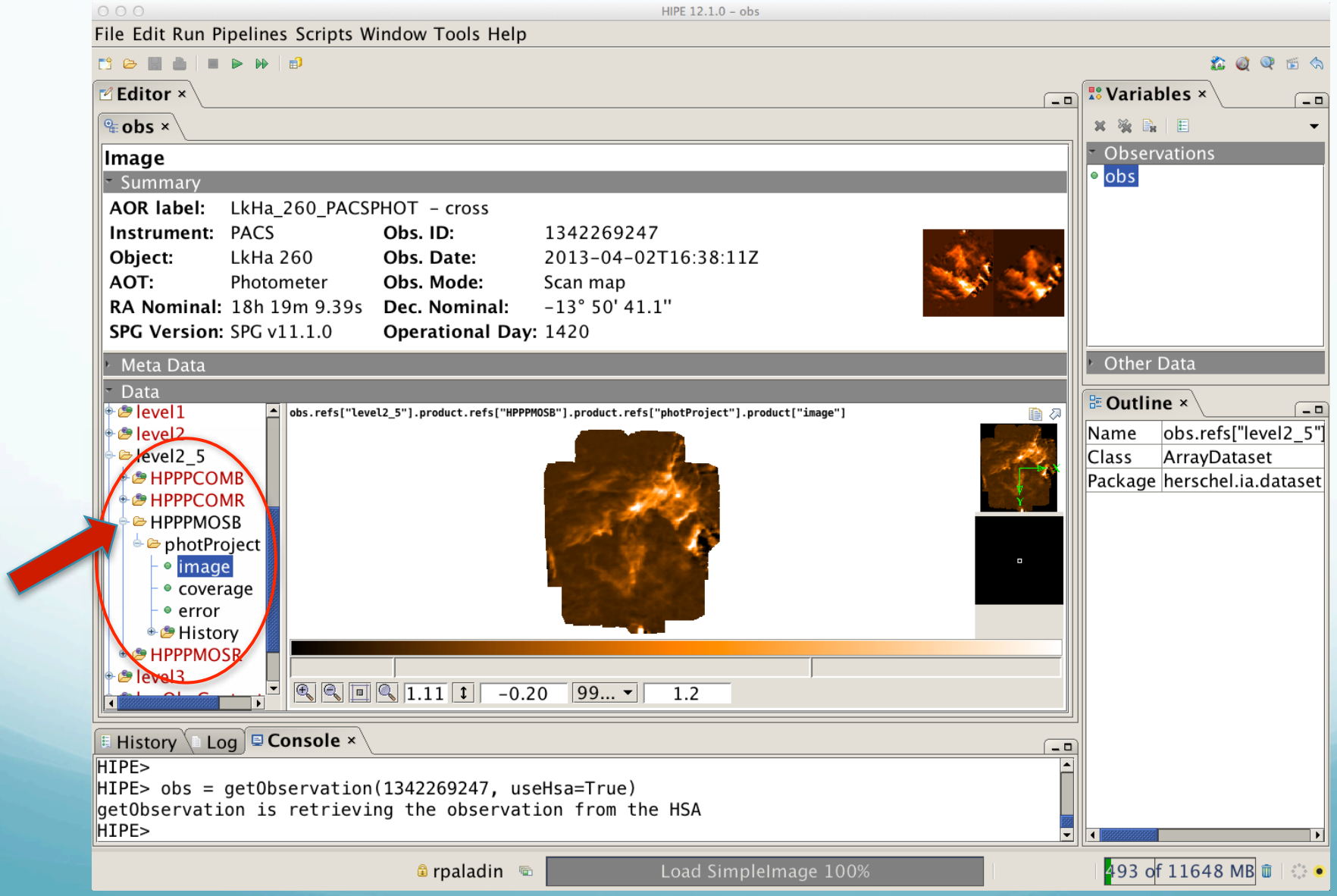
Level 1: calibrated frames



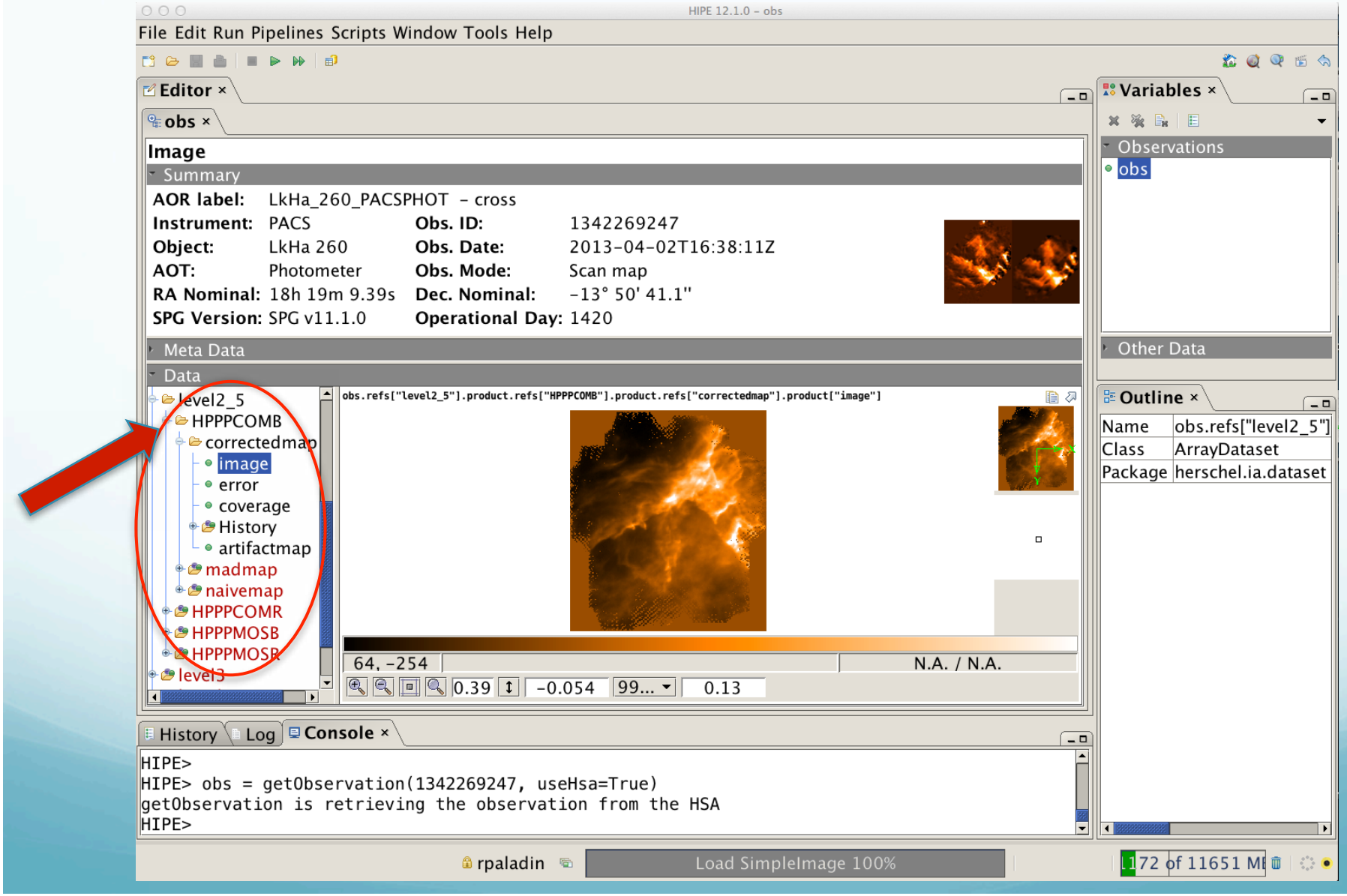
Level 2: per-OBSID map



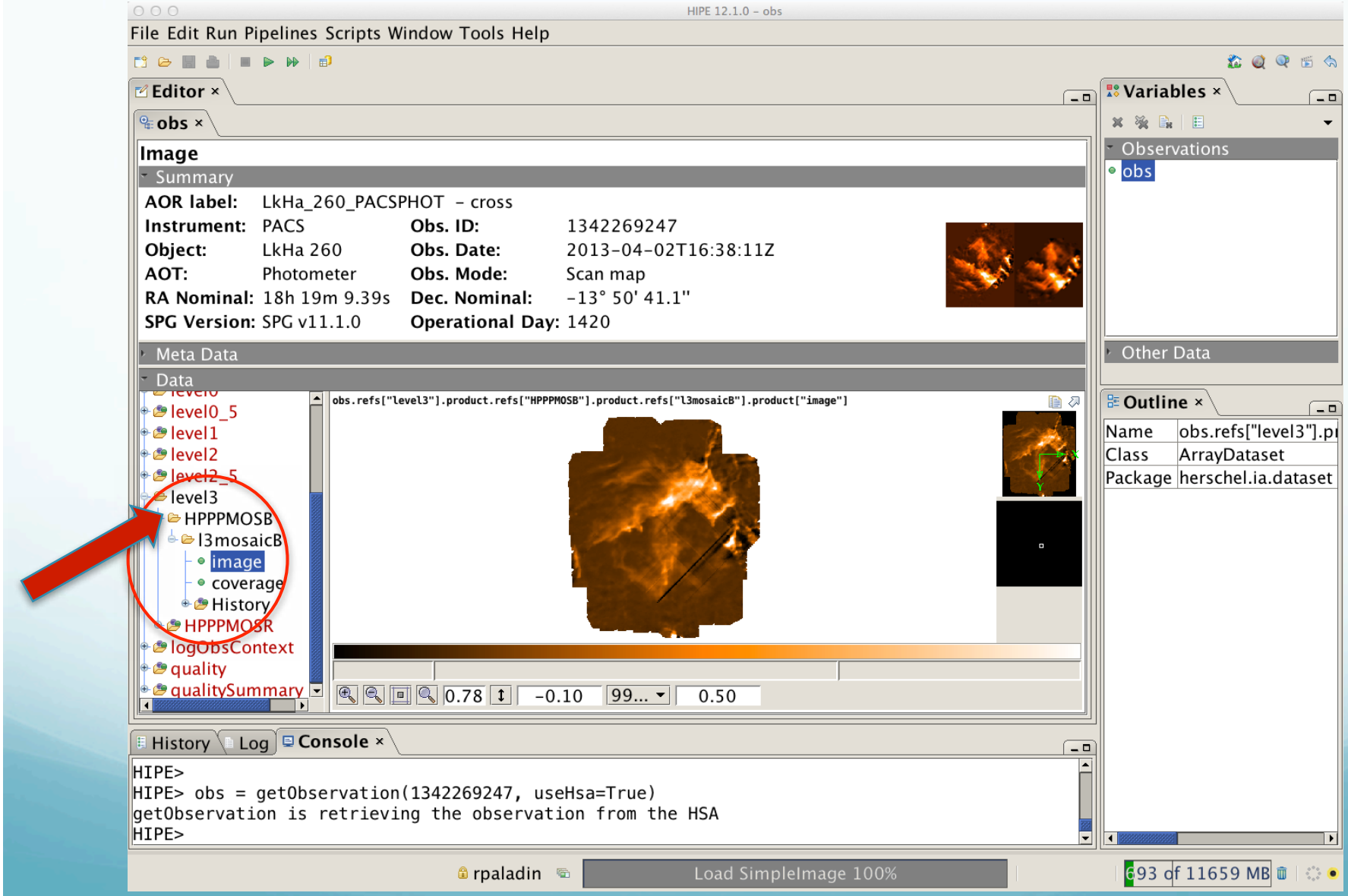
Level 2.5: OBSID pair (scan/X-scan) HPF map



Level 2.5: OBSID pair (scan/X-scan) MADMap map



Level 3: all OBSID pairs from the same program / HPF



Summary of PACS photometer archived products

- level 0:

  HPENG: engineering
  HPGENHK: housekeeping
  HPPAVGB/HPPAVGR: Herschel PACS Photometer Averaged Blue/Red Data (→ "Signal" in /0)
  HPPDMCB/HPPDMCR: raw data (blue/red)
  HPPHK: housekeeping

- level 1:

  HPPAVGB/HPPAVGR: Herschel PACS Photometer Averaged Blue/Red Data (→ "Signal" in /0)

- level 2:

  HPPPMAPB/HPPPMAPR: Herschel PACS Photometer Phot-project Map Blue/Red
  (→ "image", "error", "coverage")

- level 2.5:

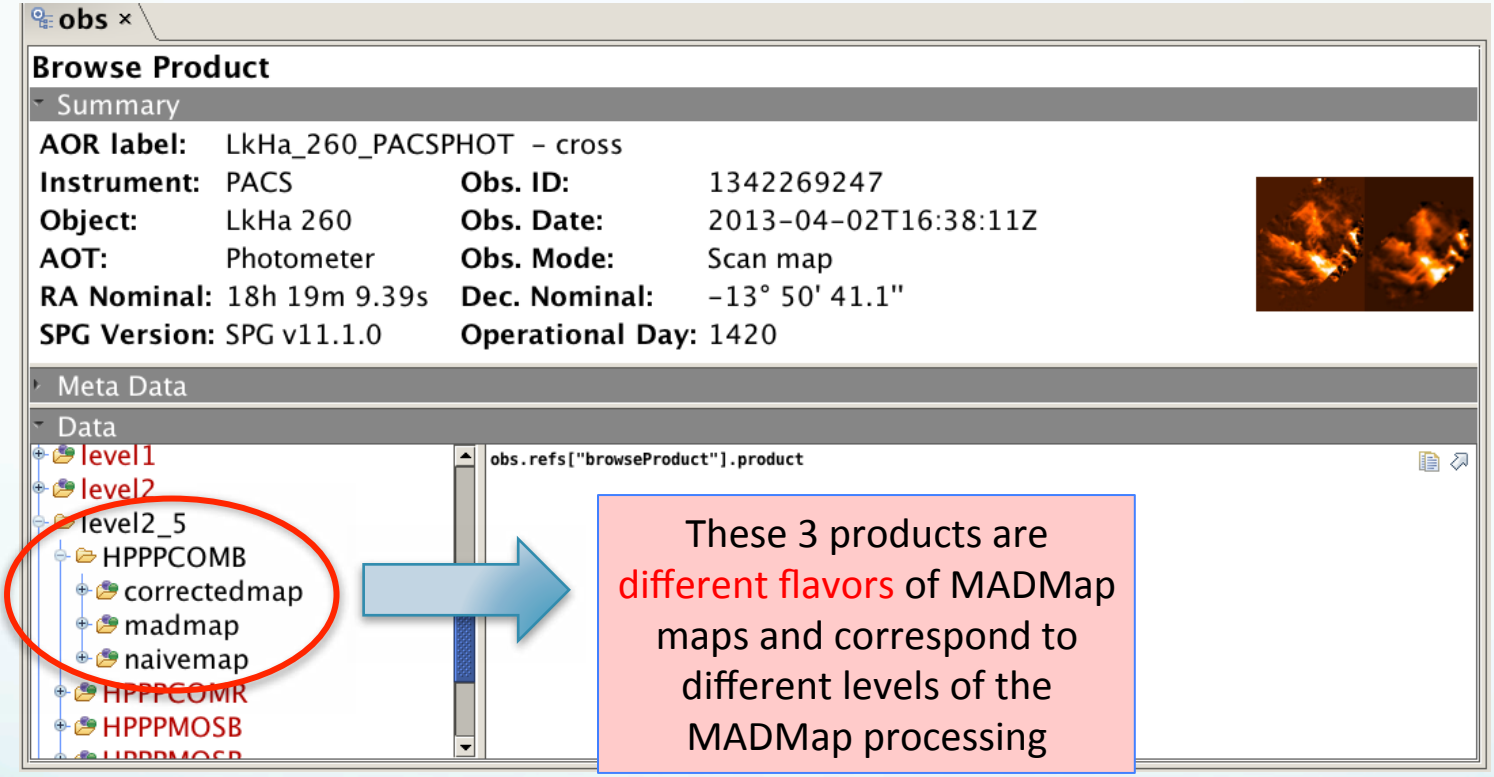
  HPPPCOMB/HPPPCOMR: Herschel PACS Photometer Combined MADMap Blue/Red
  (→ "image", "coverage", "error" in /correctedmap, /madmap, /naivemap)
  HPPPMOSB/HPPPMOSR: Herschel PACS Photometer Phot-project Mosaic Blur/Red
  (→ "image", "coverage", "error" in /photProject)

- level 3:

  HPPPMOSB/HPPPMOSR: Herschel PACS Photometer Phot-project Map Blue/Red
  (→ "image", "error", "coverage")

Note about MADMap products

(..this is a recurrent question)



- correctedmap: MADMap map after PGLS correction
- madmap: MADMap map before PGLS correction
- naivemap: MADMap naïve map, i.e. map not corrected for uncorrelated 1/f noise but corrected for drift

Heads up: different photometer products in the HSA soon..

SPG 11
(currently in HSA)

Photometer Products:
- ✓ HPF (up to Level 3)
- ✓ MADmap

SPG 12
(end of Summer/Fall 2014)

Photometer Products:
- ✓ HPF (up to Level 2.5)
- ✓ JScanam (up to Level 3)
- ✓ MADmap (up to Level 3)

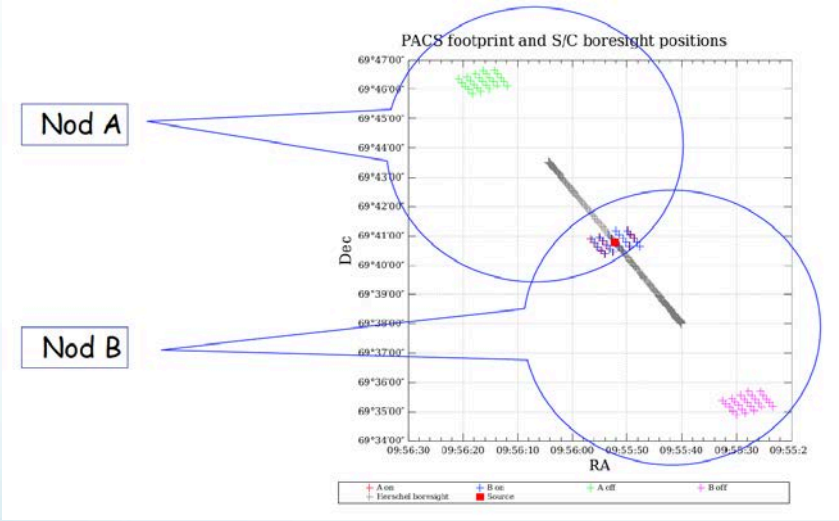
PACS spectrometer products

PACS Spectrometer Archival Products

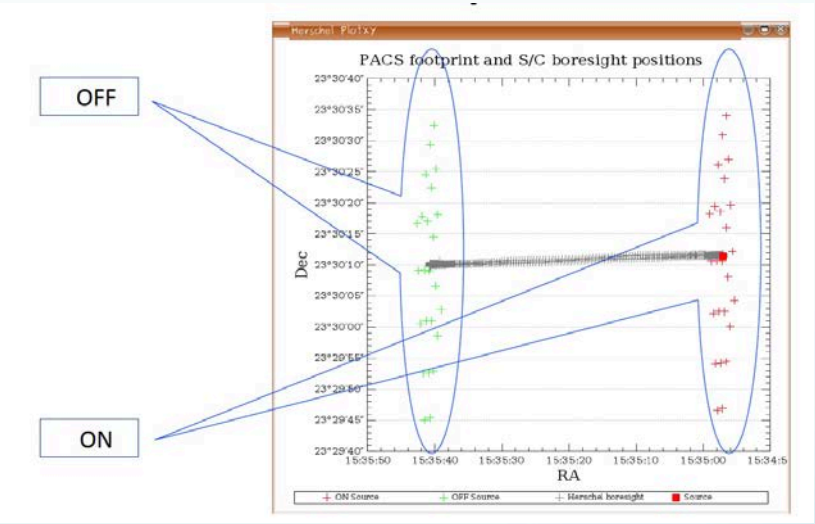
- There are 2 PACS spectrometer observing modes:
  - Chop-Nod mode
  - Un-chopped mode

- For any observation performed in a given mode (chop/un-chopped), the archive contains different *processing levels (level 0, level 1, etc.)* of the data

Chop-nod

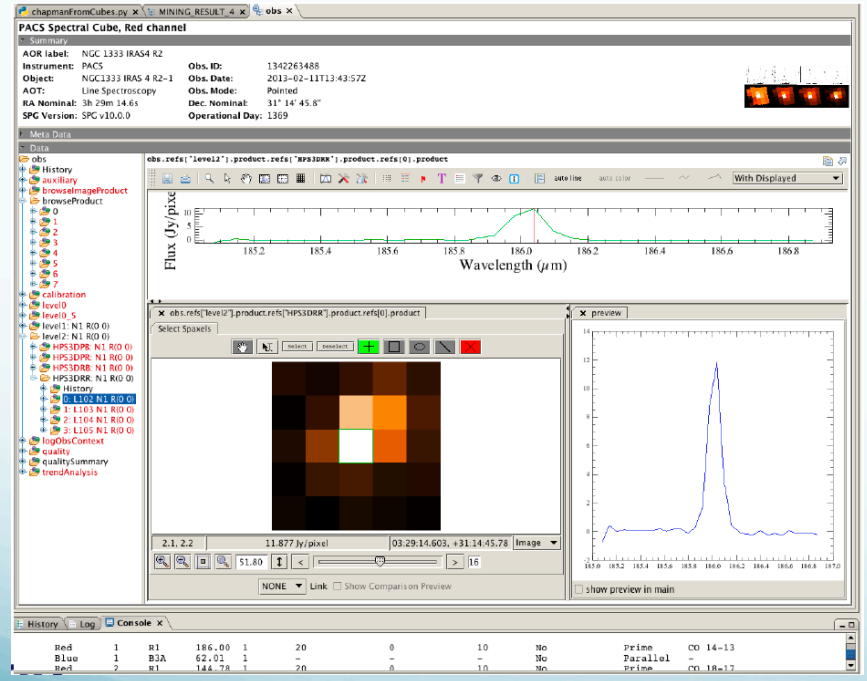


Un-chopped

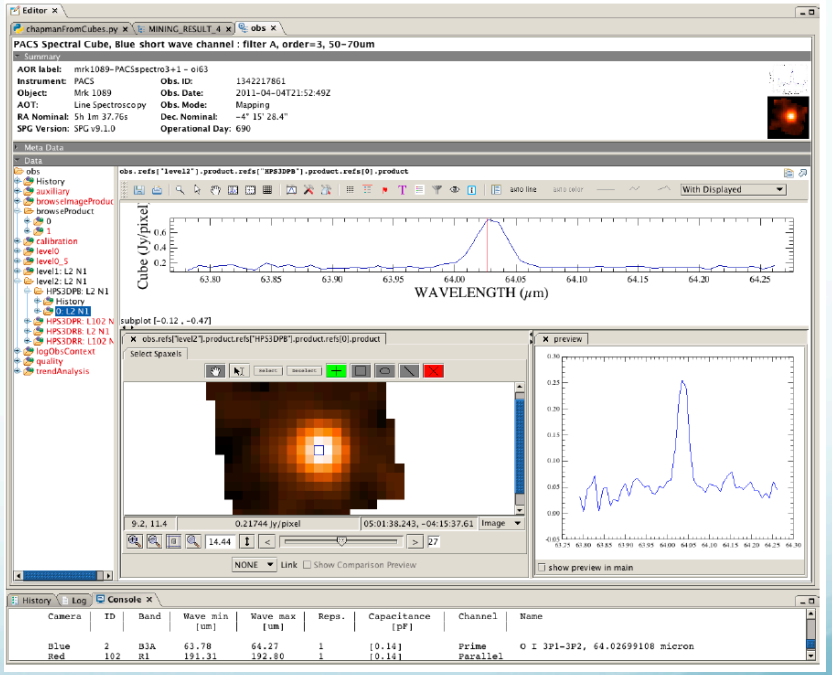


Both chop and un-chopped observations can be pointed or mapping

Pointed



Mapping



Both chop-nod and un-chopped observations can be line or range

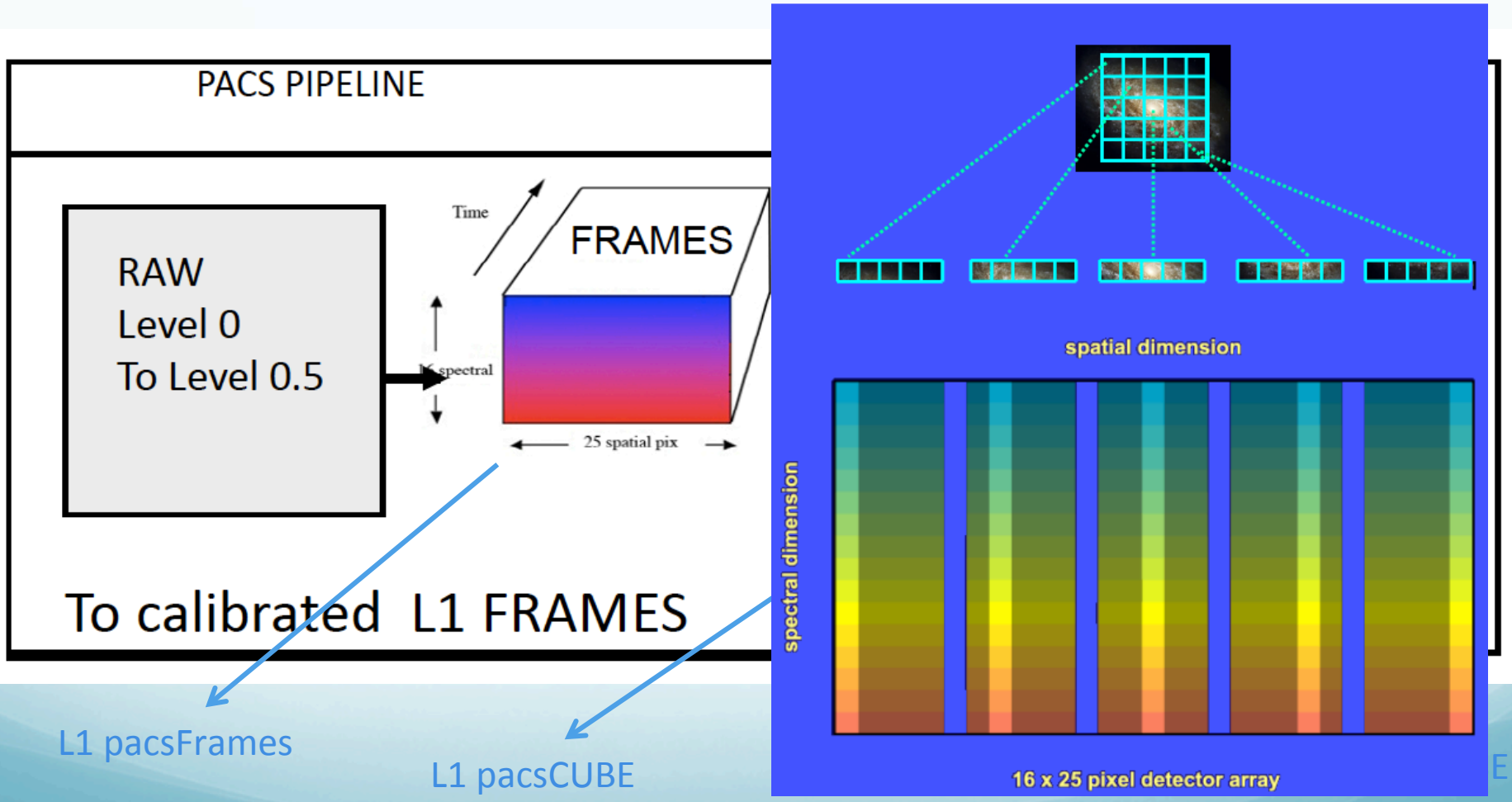
- Line Spectroscopy - short wavelength coverage, multiple lines
- Range Spectroscopy - broader wavelength coverage, multiple ranges

In Summary:

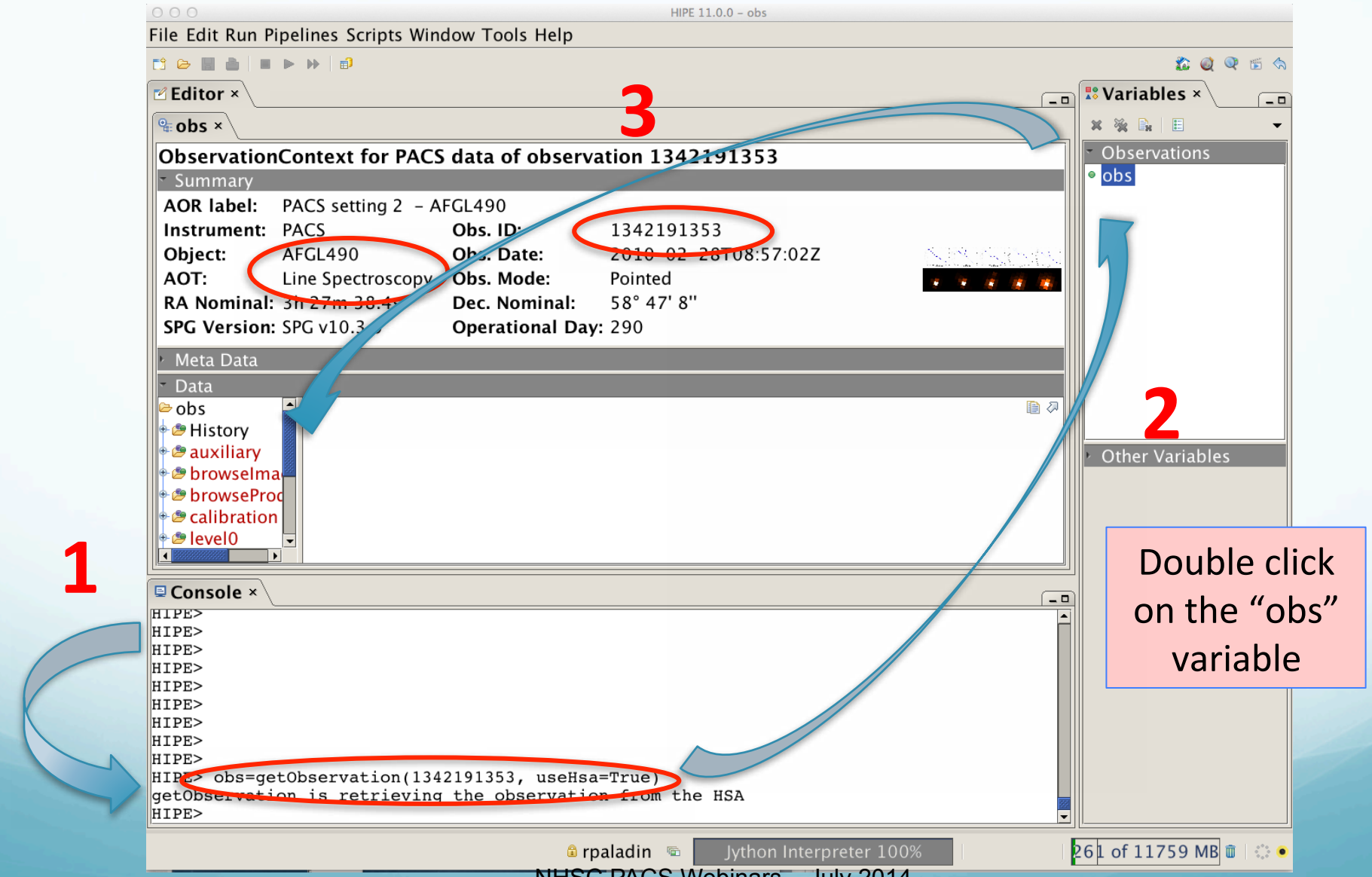
A PACS spectrometer observation can be any combination of the following:

→ line/range, chop/un-chopped, pointed/mapping

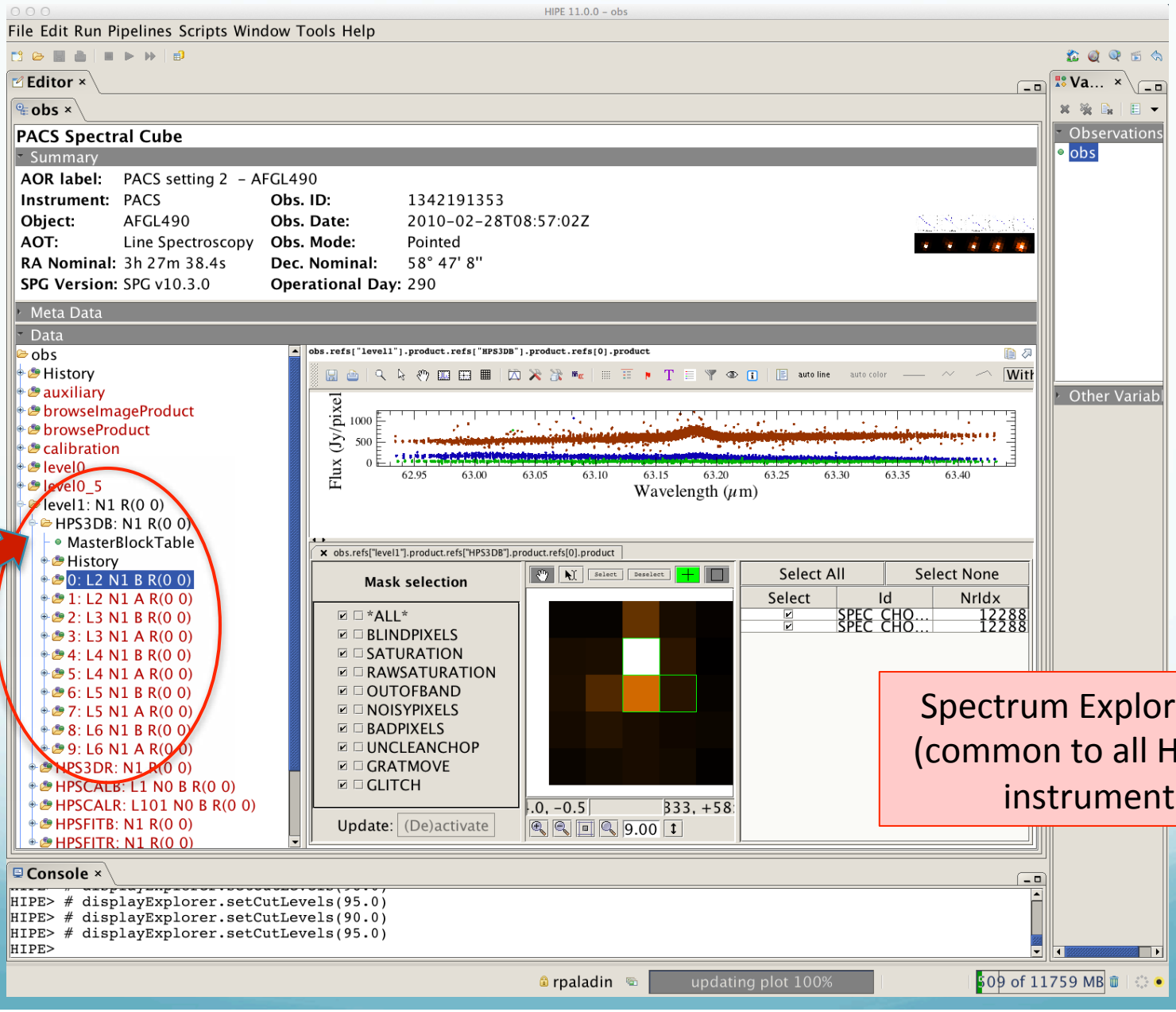
PACS Spectrometer Archived Products



Example: AFGL490 – OBSID: 1342191353

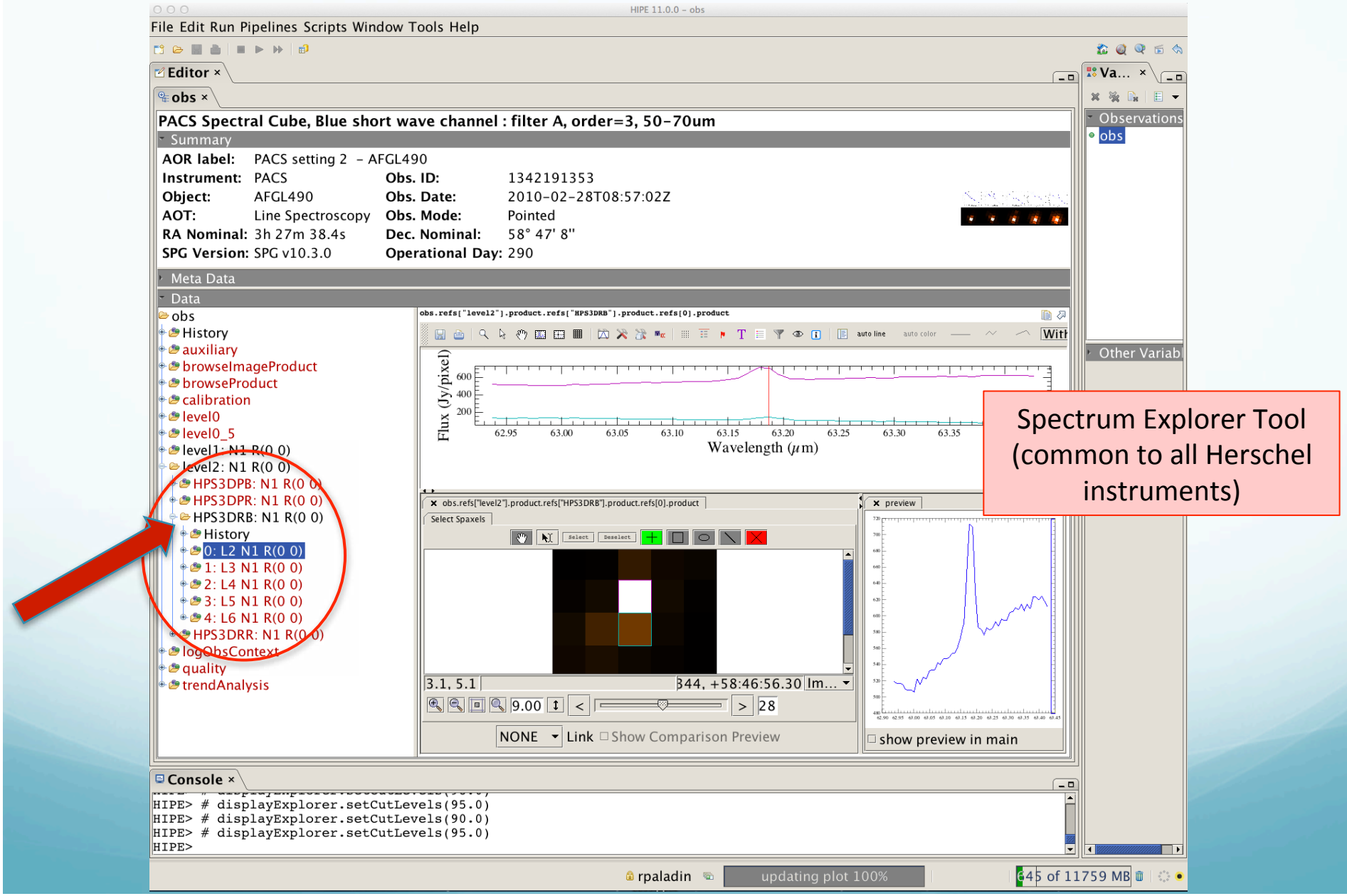


Level 1: PacsCube



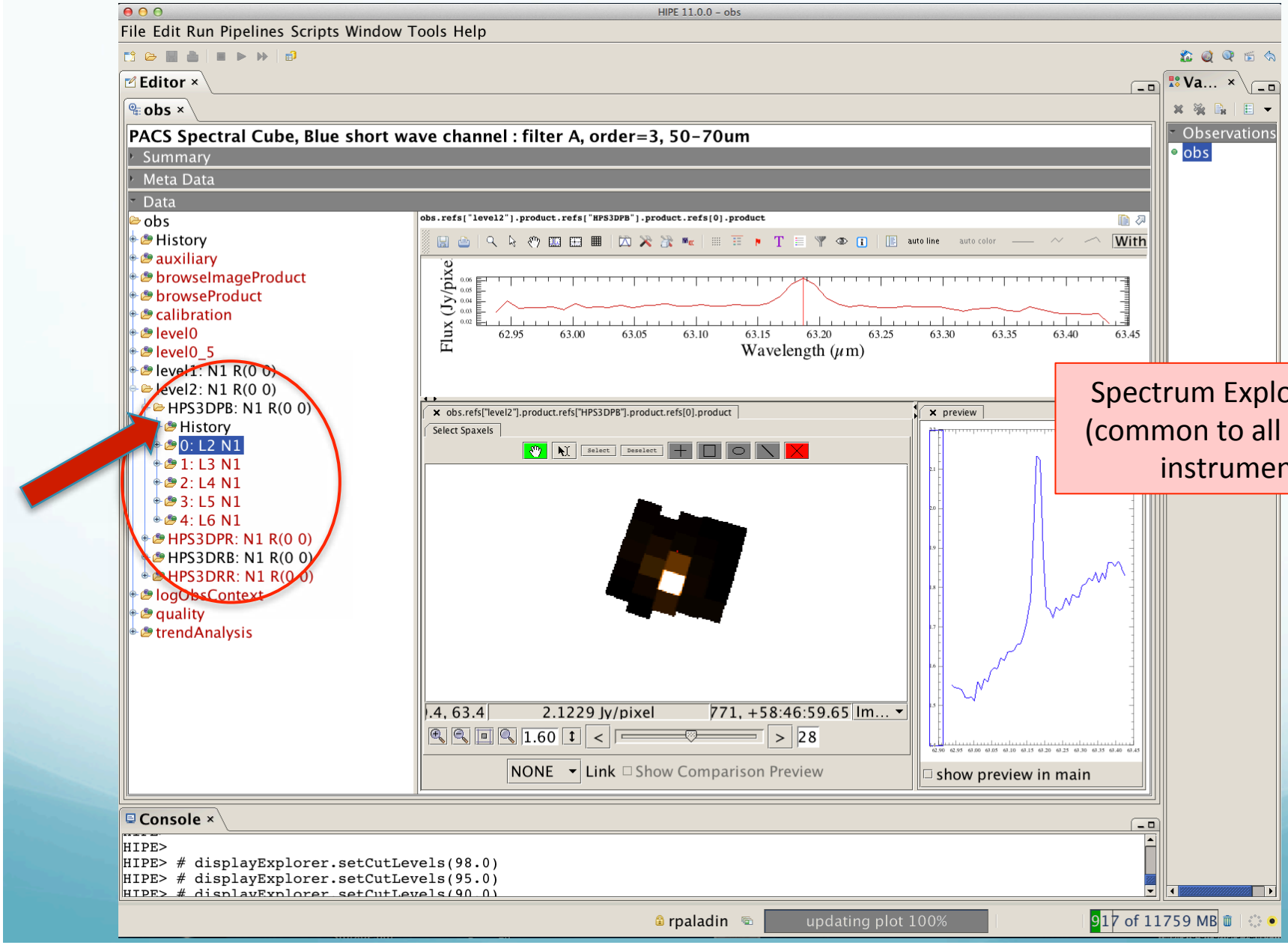
Spectrum Explorer Tool (common to all Herschel instruments)

Level 2: Rebinned Cube



Spectrum Explorer Tool (common to all Herschel instruments)

Level 2: Projected Cube



Spectrum Explorer Tool (common to all Herschel instruments)

Summary of PACS spectrometer archived products

- Level 0:

  HPENG: engineering
  HPGENHK: housekeeping
  HPSDMCB/HPSDMCR: raw DecMec (blue/red)
  HPSFITB/HPSFITR: Herschel PACS Spectrometer Fitted Blue/Red (→ "Signal" in /0)
  HPPHK: housekeeping
  HPSRAWB/HPSRAWR: raw data (blue/red)

- Level 1:

  HPS3DB/HPS3DR: Herschel PACS Spectrometer 3D Spectral Cube Blue/Red
  (→ "flux", "wave", "ra", "dec" in, e.g., /0: L2 N1 B R(0 0))
  HPSCALB/HPSCALR: calibration (response/dark)
  HPSFITB/HPSFITR: fitted slopes

- Level 2:

  HPS3DPB/HPS3DPR: Herschel PACS Spectrometer 3D Projected Cube Blue/Red
  (→ "image", "coverage" in, e.g., /0: L2 N1 A R(0 0))
  HPS3DRB/HPS3DRR: Herschel PACS Spectrometer 3D Rebinned Cube Blue/Red
  (→ "image", "ra", "dec", "stddev", "exposure", "wavegrid" in, e.g., /0: L2 N1 R(0 0)

- Level 2.5: (only for range un-chopped): on and off positions are in different OBSIDs. In Level 2.5, the off is subtracted from the on

PACS Calibration

A word about calibration…

➢ Photometer:

- Point-source flux calibration is estimated from a set of 5 fiducial stars (primary calibrators). Additionally, a set of asteroids and planets is also used (secondary calibrators);

- Based on this set of calibrators, the point-source flux calibration error is ~5% in all bands, with 1-2% reproducibility;

➢ Spectrometer:

- Flux calibration is estimated from a set of ~30 absolute flux sky calibrators (fiducial stars, asteroids and planets);

- Based on this set of calibrators (and using the 3X3 *calibration block scheme*), the flux calibration error is ~7% in all bands, with 3-4% reproducibility

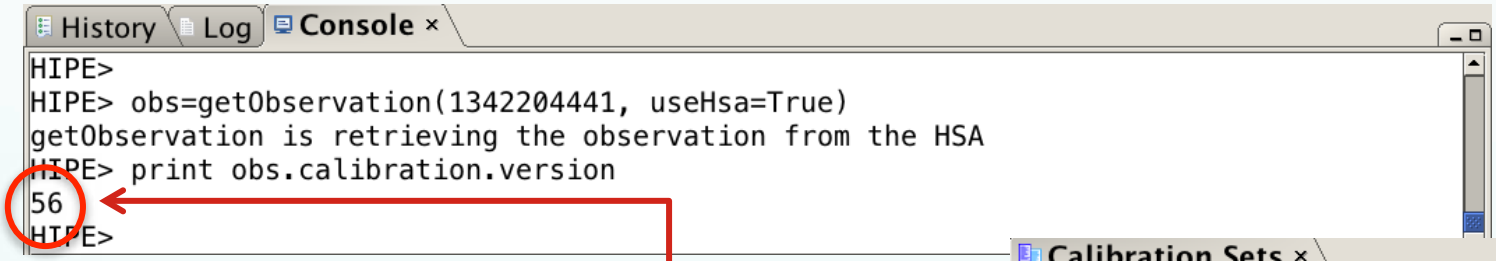
http://herschel.esac.esa.int/twiki/bin/view/Public/PacsCalibrationWeb

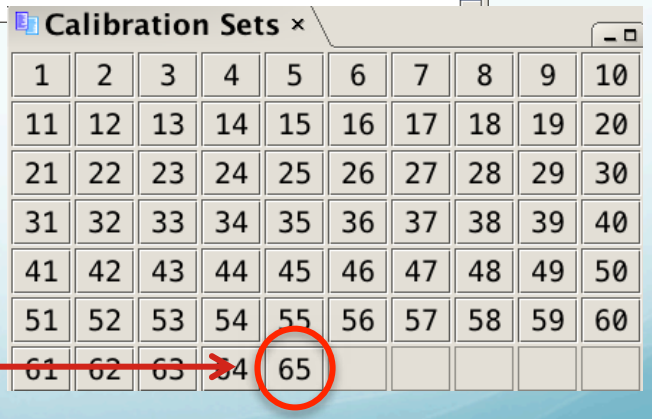
When to reprocess PACS data

IMPORTANT

One of the most important reasons to reprocess your PACS data is to make sure that you are using the latest versions of the calibration files. This is true for both the photometer and spectrometer

- To check the calibration files version of the data downloaded from the HSA, first load your OBSID into HIPE and then type the command below:



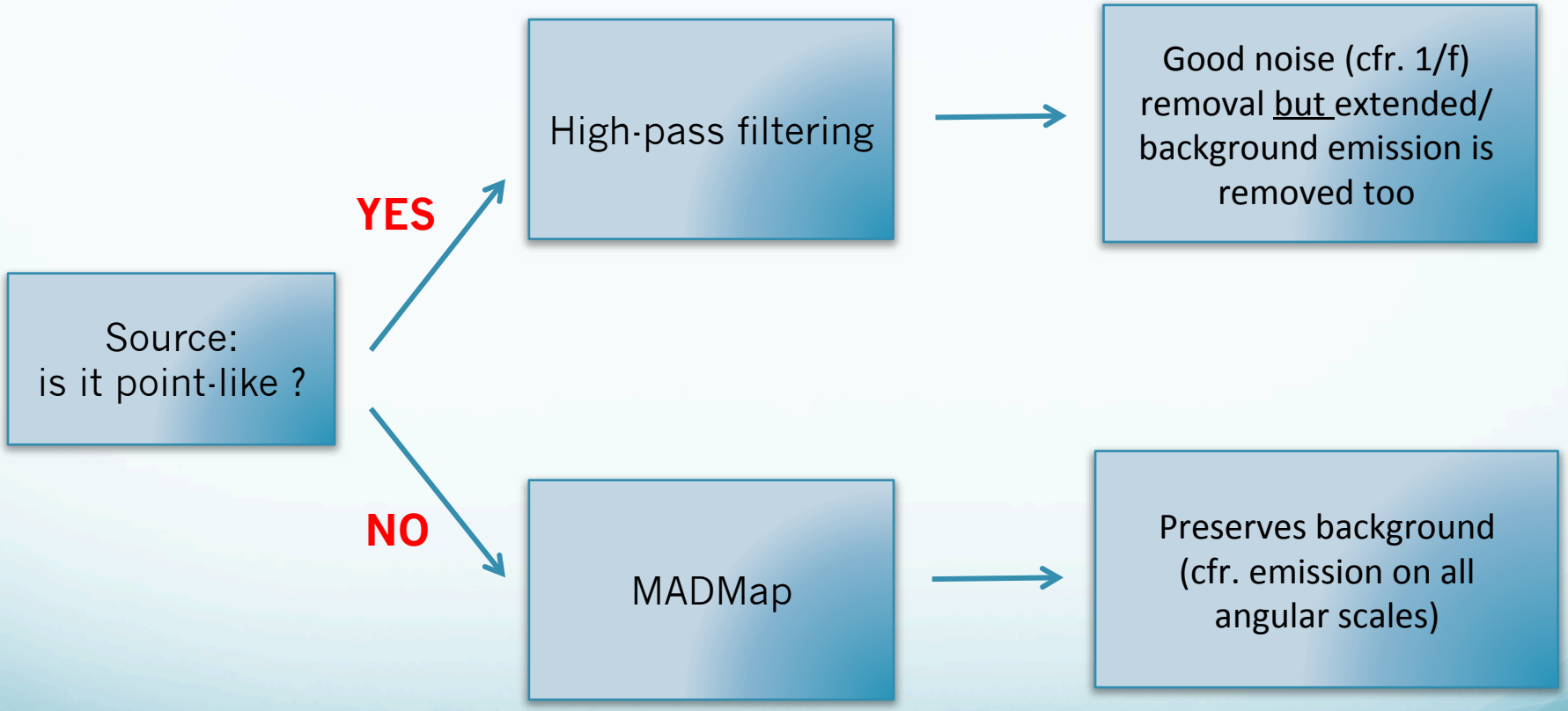


Compare the number you get (e.g. 56) from running the command above with the last number (e.g. 65) showing in the Calibration Sets table in HIPE

Window → Show View → Workbench → Calibration Sets

PACS Photometer

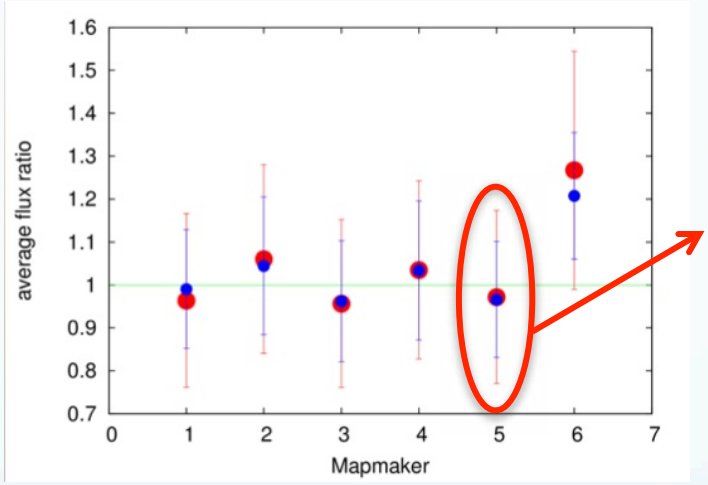
..we have seen that the photometer pipeline has 2 branches



PACS Photometer

Both HPF and MADMap products provide reliable point-source photometry

1) Scanamorphos
2) Jscanam
3) UNIMAP
4) Tamasis
5) MADMap
6) SANEPIC

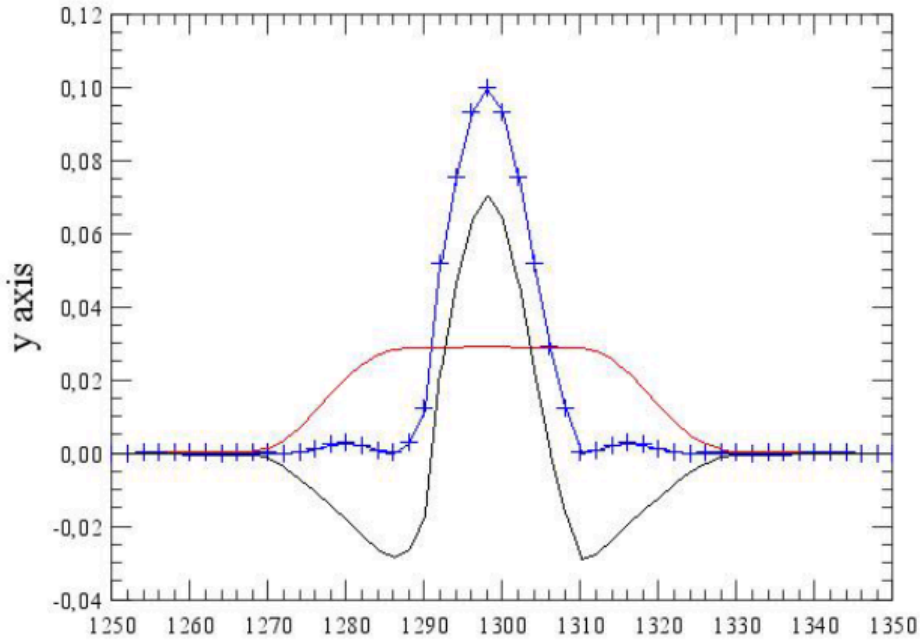


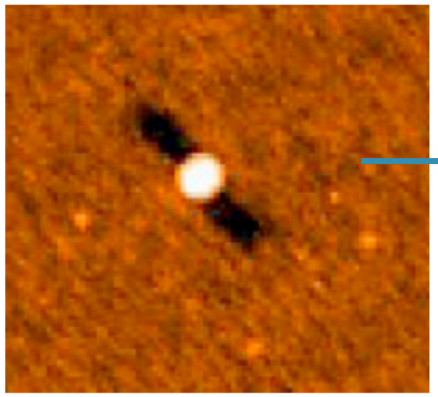
The aperture photometry ratio for calibration stars performed on HPF and MADmap maps is within 5%

NOTE: the agreement between HPF and the new MADMap released in HIPE 12 is even better: 1% !!

PACS Photometer

Signs I need to re-process my HPF map..





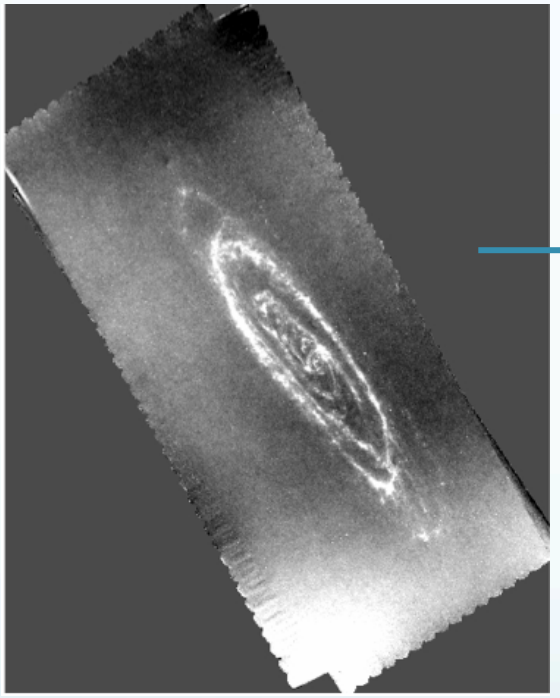
credit: Bruno Altieri

These dark blotches are due to a too small high-pass filter radius causing flux removal in the wings of the source

Solution: reprocess HPF map with larger filter radius (see slide)

PACS Photometer

Signs I need to re-process my MADMap map..



Gradient across the map due to inaccurate drift removal

Solution: reprocess with new MADMap in HIPE 12.1 or with another mapper (Jscanam, Unimap, etc.)

PACS Photometer

If I do not need to reprocess my photometer data:

- I can use HPF Level 3 (if available) or Level 2.5 maps if I am interested in point sources
- I can use MADMap Level 2.5 maps if I am interested in both point sources and extended emission or extended emission only

NOTE ON EXTENDED EMISSION: the zero level of PACS photometer maps is not set. Therefore, if you are using MADMap/Jscanam/Unimap/etc. maps remember that the absolute level of the maps is arbitrary.

PACS Spectrometer

Signs I might have to re-process my spectrometer data ...

- With respect to photometer data, PACS spectrometer data do not show *evident signs* that I need to re-process them
- However, this does not mean that "since the data look fine, *they are fine*"
- In general, we always recommend re-processing PACS spectrometer data

PACS Spectrometer

Reasons I always need to reprocess my spectrometer data:

- In the SPG bulk-reprocessing (i.e. the data in the HSA), only *one flavor* of the spectrometer pipeline per observing mode (e.g. chop nod) is run
- However, *other flavors* of the pipeline might be more appropriate for your specific science case (depending on the brightness of your source and duration of your observation)
- Also, for a given pipeline flavor, not all tasks are run in the SPG bulk-reprocessing (e.g. drizzling)

PACS Spectrometer

Different pipeline flavors (for chop-nod modes)

- lineScan: calibration blocks + RSRF flux calibration (this is the standard pipeline run in SPG bulk reprocessing) → *recommended for bright sources*
- Background Normalization: uses telescope background for flux calibration → *recommended for faint sources or long duration observations or when broad band features are present*
- Split On-Off: allows to compare on-source/off-source spectra
- Point Source Background Normalization: uses telescope background for flux calibration + correction for pointing jittering → *recommended for very bright point sources*

NOTE: for the unchopped mod, line or range, there is only one *flavor* of the pipeline and this is run in the SPG bulk reprocessing (→ but the transient correction task is not automatically run)

PACS Spectrometer

Not all pipeline tasks are run in the bulk reprocessing

- Point sources: the re-binned cubes (HPS3DRB/R) are calibrated for extended emission by default. For point sources centered in the IFU (i.e. on spaxel (2,2)) run the task *extractCentralSpectrum.* The task works well for bright sources, i.e. continuum flux level in the range 5 – 10 Jy

- Slightly Extended Sources: the re-binned cubes (HPS3DRB/R) are calibrated for extended emission by default. For slightly extended sources (slightly bigger than the beam size at a given wavelength) centered in the IFU (i.e. on spaxel (2,2)), apply the task *pacsExtendedToPointCorrection*. You need to know the geometry of your source to successfully apply this task

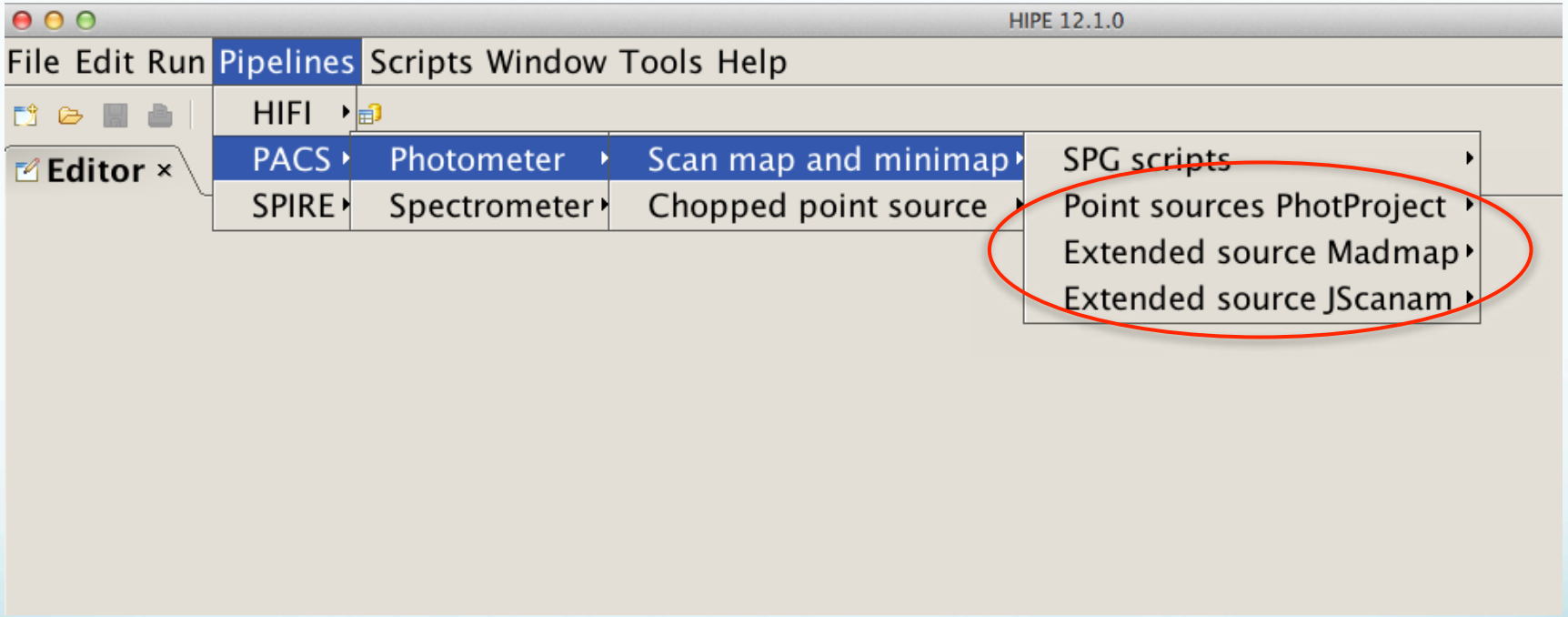
- Extended sources – mapping: for well-sampled (i.e. Nyquist) line or short-range raster observations, the best projected cubes are obtained by running the *drizzling* task which is not automatically run in the SPG bulk reprocessing

NOTE: for extended sources observed without mapping (i.e. in pointed mode), use the rebinned cubes to extract your science, NOT the projected cubes.

How to reprocess PACS data

PACS Photometer

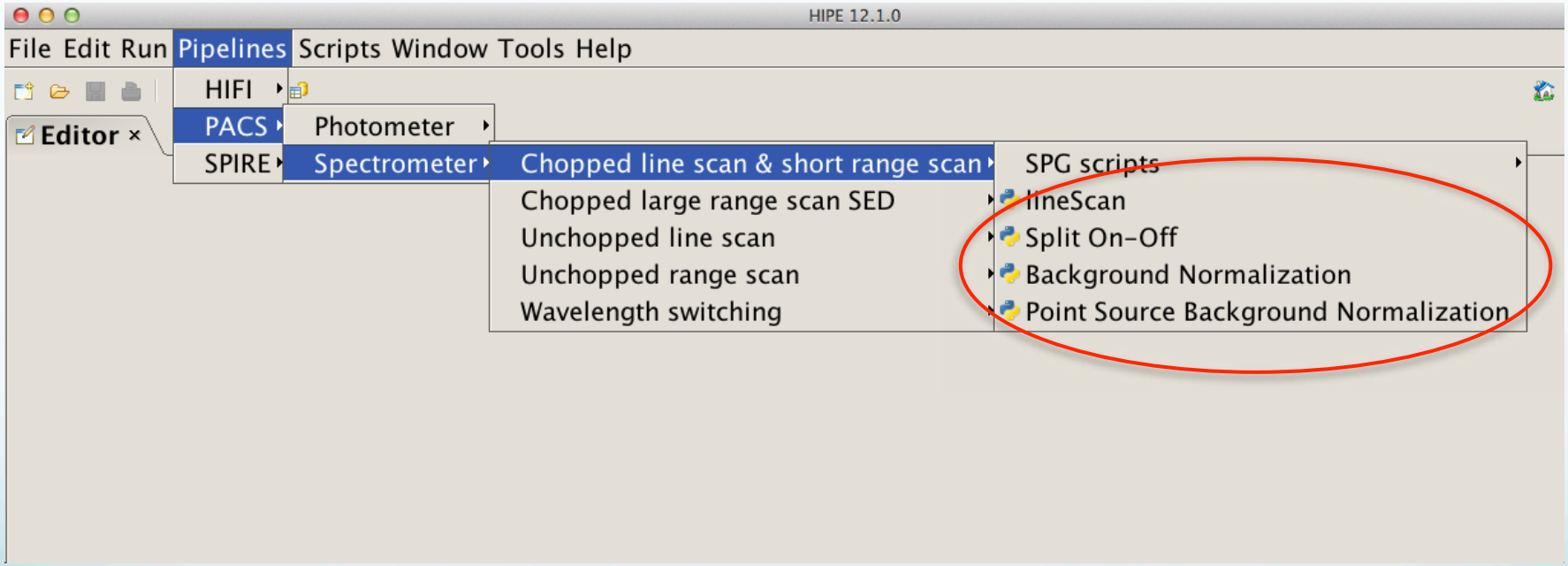
PACS photometer *ipipe* scripts



NOTE: ipipe scripts are in jython

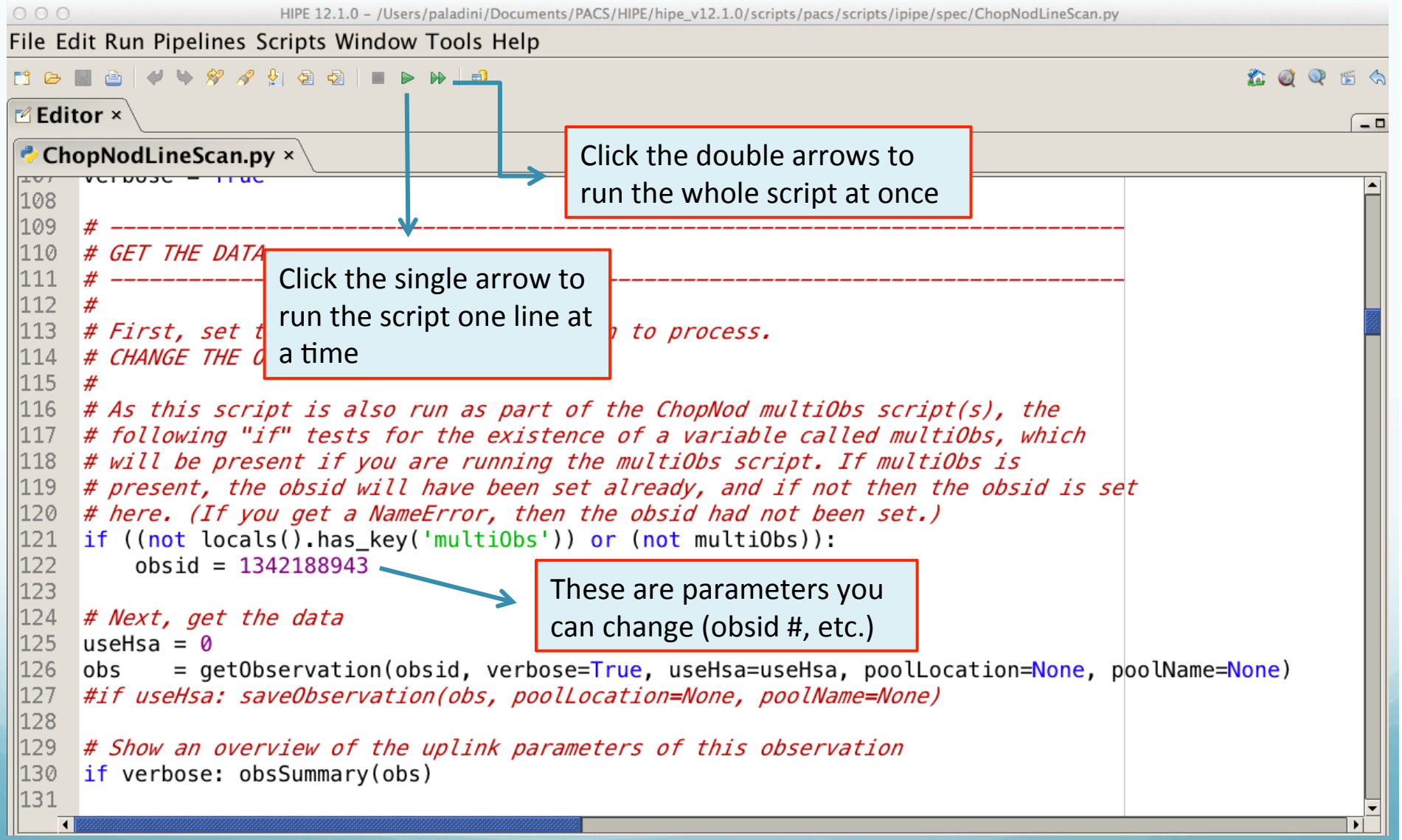
PACS Spectrometer

PACS spectrometer *ipipe* scripts



NOTE: ipipe scripts are in jython

Ex: ChopNodLineScan.py (*flavor* of spectrometer pipeline)



PACS
Documentation & Additional Resources

PACS Documentation
(updated in Jan – Mar '14)

- PACS Observer's Manual (last update: July '13)
  http://herschel.esac.esa.int/Docs/PACS/pdf/pacs_om.pdf

- PACS Data Reduction Guide: Photometer
  http://127.0.0.1:8082/print/pacs_phot/pacs_phot.pdf#pacs_phot

- PACS Data Reduction Guide: Spectrometer
  http://127.0.0.1:8082/print/pacs_spec/pacs_spec.pdf#pacs_spec

- NHSC PACS tutorials:
  https://nhscsci.ipac.caltech.edu/sc/index.php/Pacs/DataProcessing

PACS @ NHSC

Roberta Paladini (Lead, calibration scientist, photometer)
Dario Fadda (calibration scientist, spectrometer)
Jeff Jacobsen (developer, spectrometer)
Cate Liu (developer, photometer)
Yi Mei (system engineer, photometer & spectrometer)
Dave Shupe (calibration scientist, spectrometer)

For any questions and help with your PACS data, contact the NHSC Help Desk:

http://nhsc.ipac.caltech.edu/helpdesk/index.php

Additional Resources

- Processing large PACS data sets, especially for the photometer, requires large memory allocations (64 GB or more). You can request a remote user account on our virtual system at NHSC. For more information, visit:

https://nhscsci.ipac.caltech.edu/sc/index.php/CompSupport/ExternalUsers

- Our remote user accounts come automatically with a multi-threaded version of the PACS spectrometer pipeline. This means that you can speed up your spectrometer data processing by a factor 4 !

- For PACS photometer data processing, we encourage the use of SIMPLE (*Simplified Interface Making PACS Look Easy).* For ore information, visit:

https://nhscsci.ipac.caltech.edu/sc/index.php/Pacs/Simple

NOTE: SIMPLE will be extended to the spectrometer pipeline in the near future.

Thank You !