IRC Data Reduction Workshop
9/18-19/2007

The IRC Spectroscopy: Data and their Calibration

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On behalf of the IRC spectroscopy data reduction team

References

- Documents on AKARI web site
  - AKARI/IRC observing manual
  - AKARI/IRC Data User Manual
  - Documents for today's workshop
    - Ita et al. for imaging (previous presentation)
    - Ohyama et al. for spectroscopy (this presentation)
- Papers
  - The Infrared Camera (IRC) for AKARI --- Design and Imaging Performance
    - Onaka et al. 2007, PASJ, in press, or astro-ph/07054144
  - Near-infrared and Mid-infrared Spectroscopy with the Infrared Camera (IRC) for AKARI
    - Ohyama et al. 2007, PASJ, in press, or astro-ph/07084290
  - Properties of UIR Bands in NGC 6946 Based on Mid-Infrared Imaging and Spectroscopy with IRC on Board AKARI
    - Sakon et al. 2007, PASJ, in press

Quick Review of the IRC Spectroscopy Mode

Infra-Red Camera (IRC) as a Spectrograph

- Telescope/Satellite operation
  - same ones that for imaging mode (pointed attitude)
- Main Optics (Collimator/Camera)
  - same ones that for imaging mode.
- Array and its operation (clock/exposure time)
  - same ones that for imaging mode.

Ita san's talk

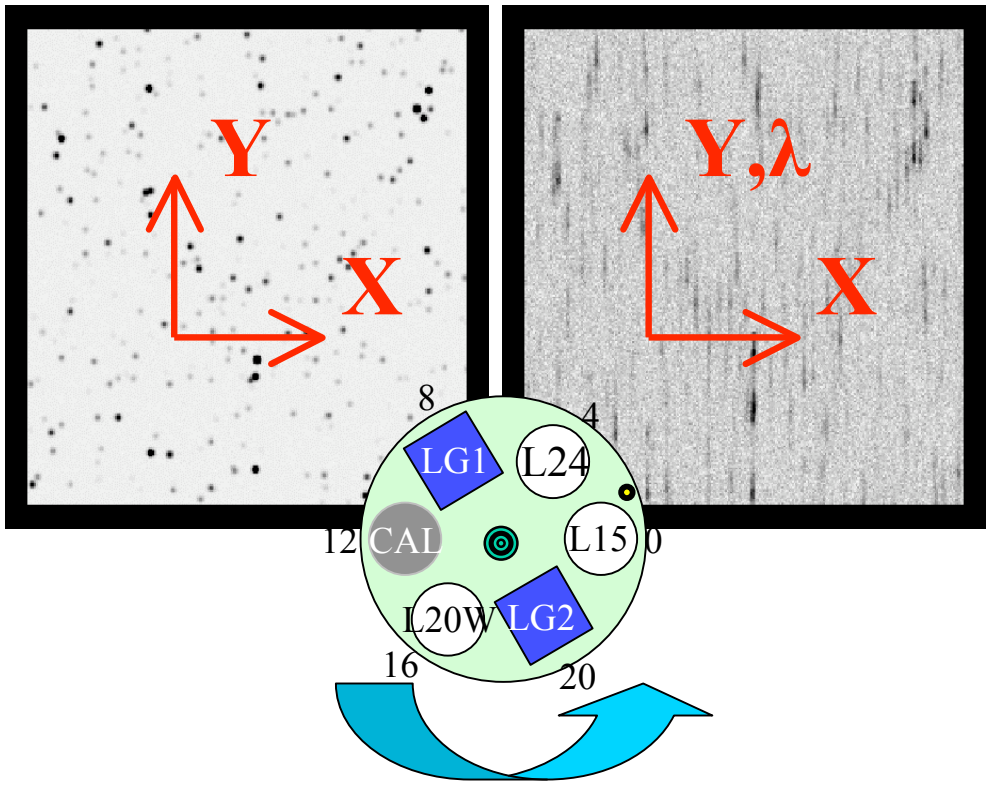
- *Slit*
  - Wider aperture for imaging + slit areas
  - For slit-less and slit spectroscopy
- *Disperser*
  - prism or grism, mounted on filter wheel

The Slit-less Mode:
Very Basic Ideas for Slit-less Spectroscopy

- Reference (direct) image is taken.
  - Source locations will be measured on the reference image.
  - The source coordinates are used as…
    - Origin of the spectral image extraction.
    - Origin of wavelength calibration.
- Spectroscopy image is reduced…
  - First in a similar way as for conventional direct imaging.
  - Then, after spectral image extraction, in a similar way as for conventional slit spectroscopy.

The “Slit-less” Concept

direct image *spectral image*



Selectable filter wheel

The (conventional) Slit Mode:

- Observation (Satellite/Array/Filter wheel controls) will be made in a *same way* as for the slit-less mode.
  - Targets are placed on some slit. *That's it!*
  - Single AOT works for both slit-less and slit modes.
    - You will obtain similar kinds of data set.
- Data reduction will be made in a *very similar way* as for the slit-less mode:
  - The same toolkit works on both slit/slit-less data…
    - With only minor changes:
      - Reference image is taken, but it is not essential to locate the slit.
      - Shift-and-coadding of individual exposure frames is disabled.
      - No local sky-subtraction is possible.
    - The toolkit accepts the option for slit-mode data reduction.

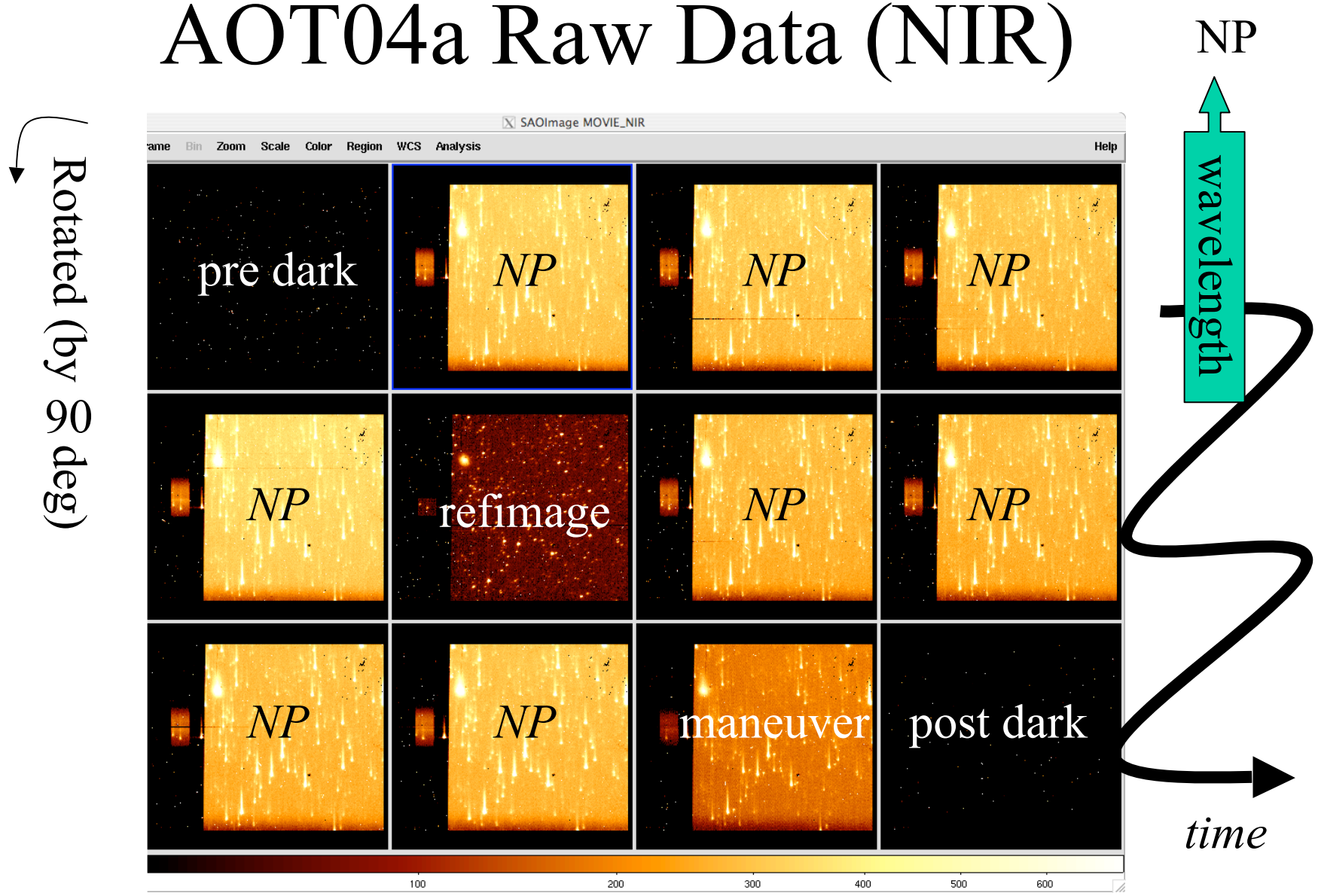
Basic Characteristics of IRC Spectroscopy Data

Review of Raw/Calibration Data

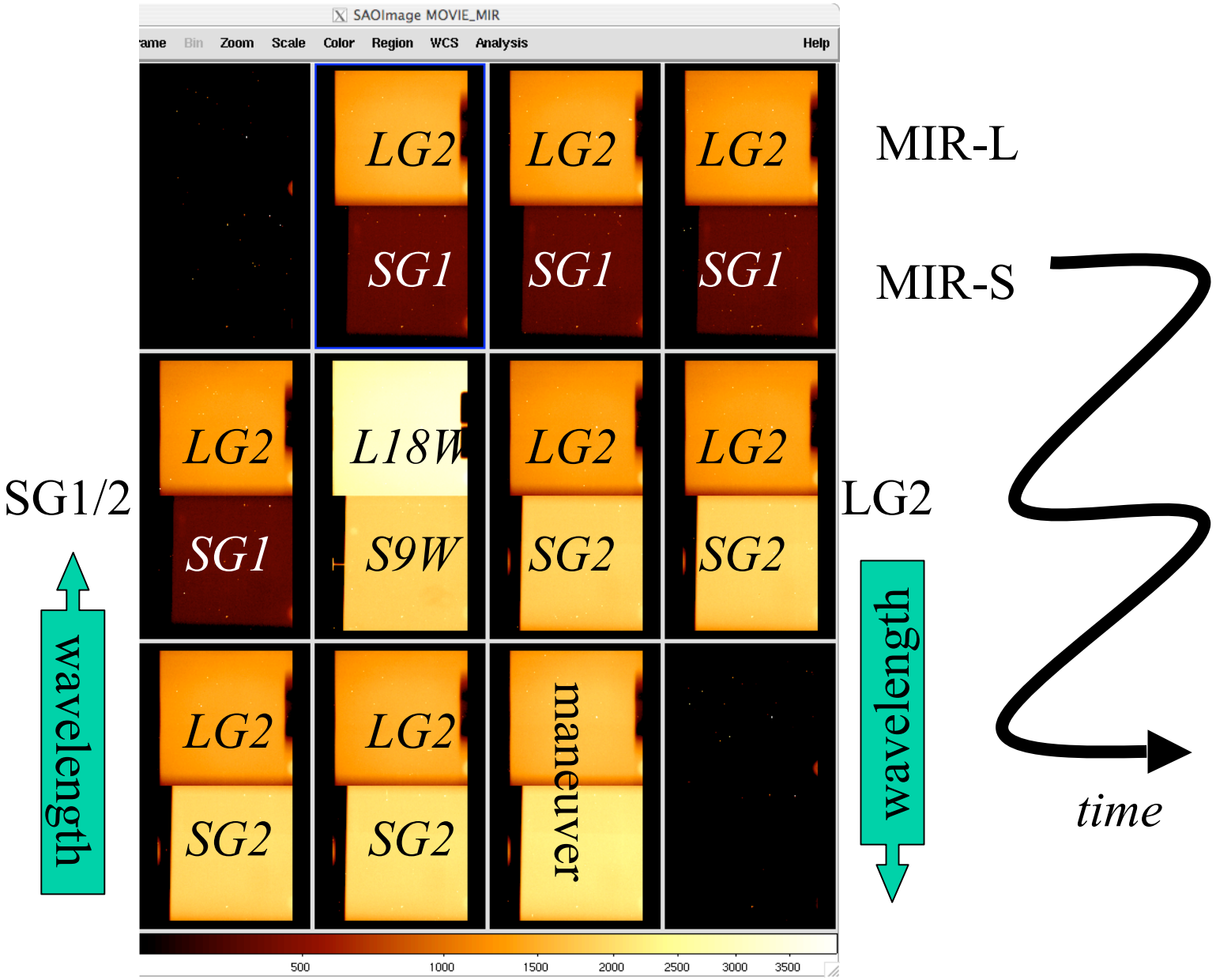
Rawdata in '/rawdata'

- Raw images (F*_[M/N].fits)
- List files (*.lst)
- Information files (README, etc.)

AOT04a Raw Data (NIR)



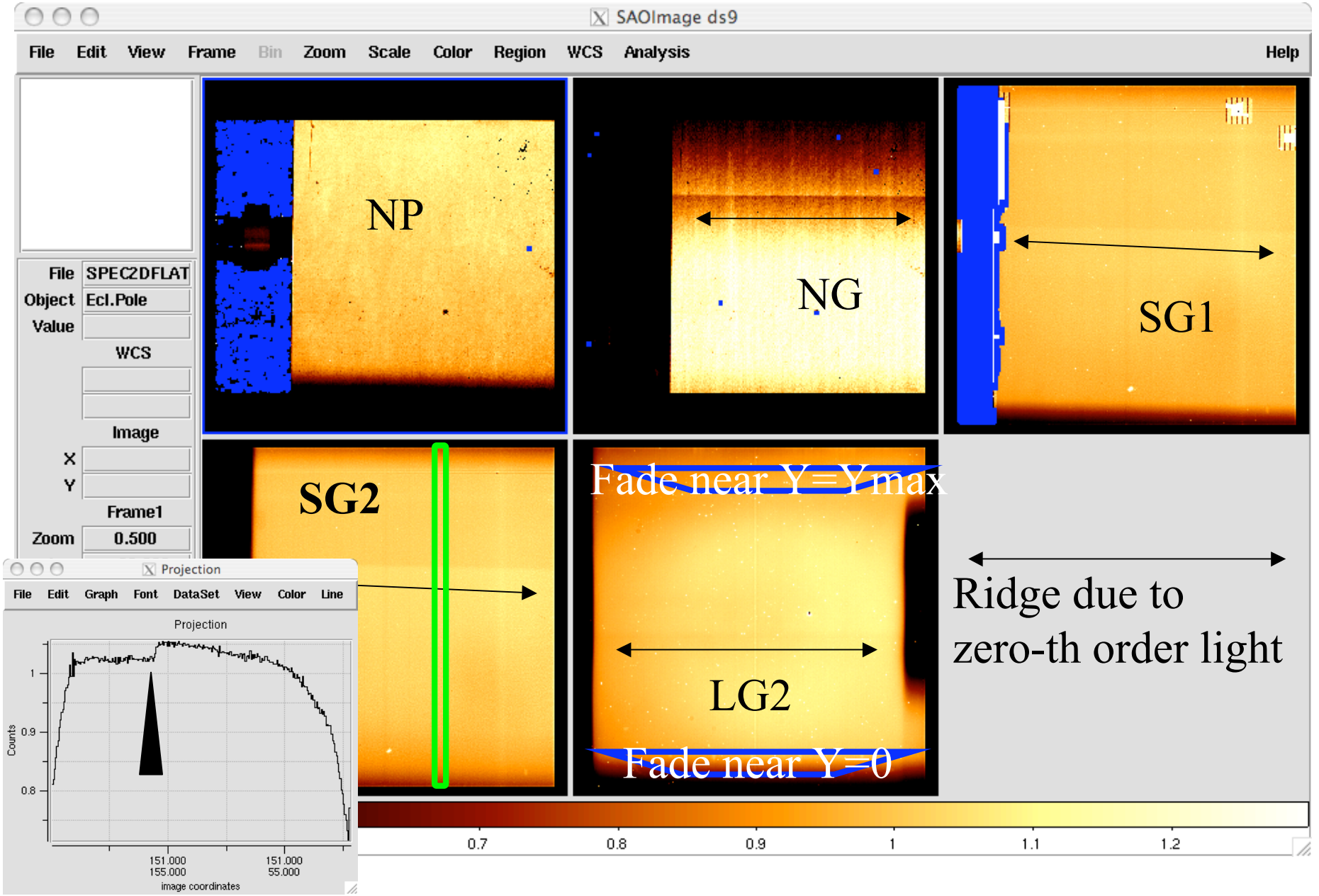
AOT04a Raw Data (MIR-S/L)



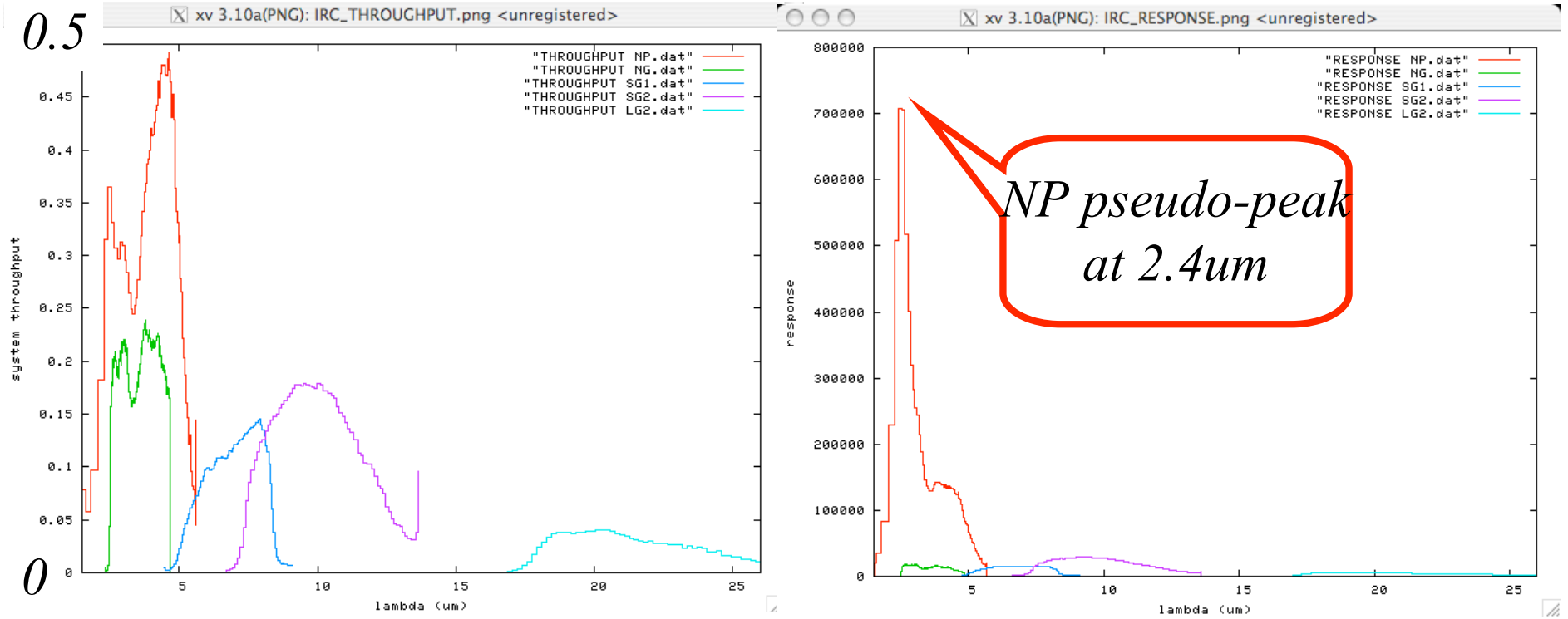
Calibration Data in ‘/CALIBDIR/*’

- DARK/ super-darks
- LINEAR/ linearity correction tables
- MASK/ mask images
- FLAT/ super-flats (imag/spec)
- RESPONSE/ spectral response tables
- APCOR/ aperture correction tables
- COORDOFFSET/ coordinate offset tables
- DISTPAR/ spectral tilt correction tables
- WAVEPAR/ wavelength calibration tables

Spectroscopy Flats

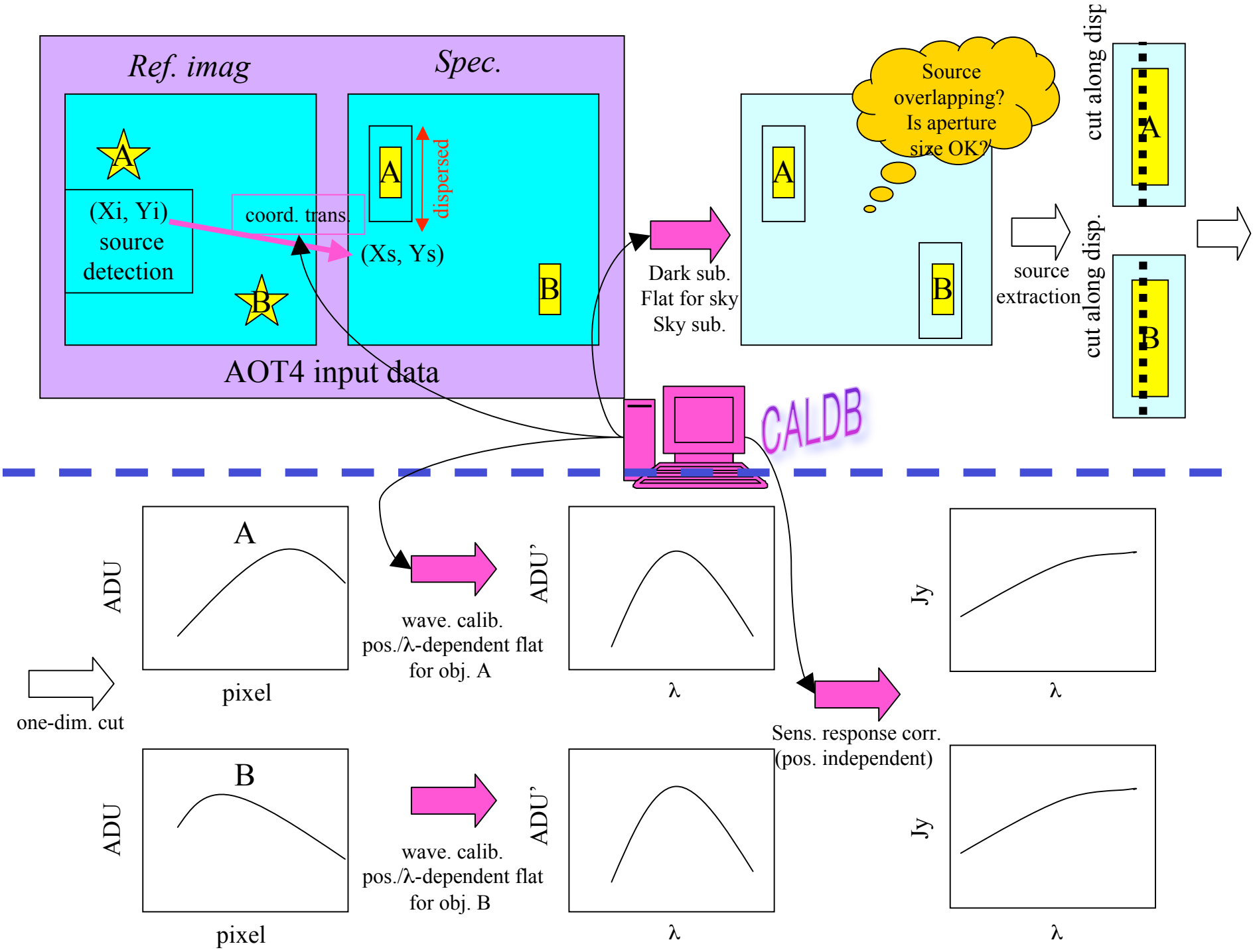


Throughput & Spectral Response



- Throughput: ratio of incident/detected photon number
- Spectral Response: data number (DN) per frame per unit incident light energy (Jy) on ***a pixel***
  - NP spectral response has a notable peak where throughput shows local maximum, due to lower dispersion (wavelength per pixel).

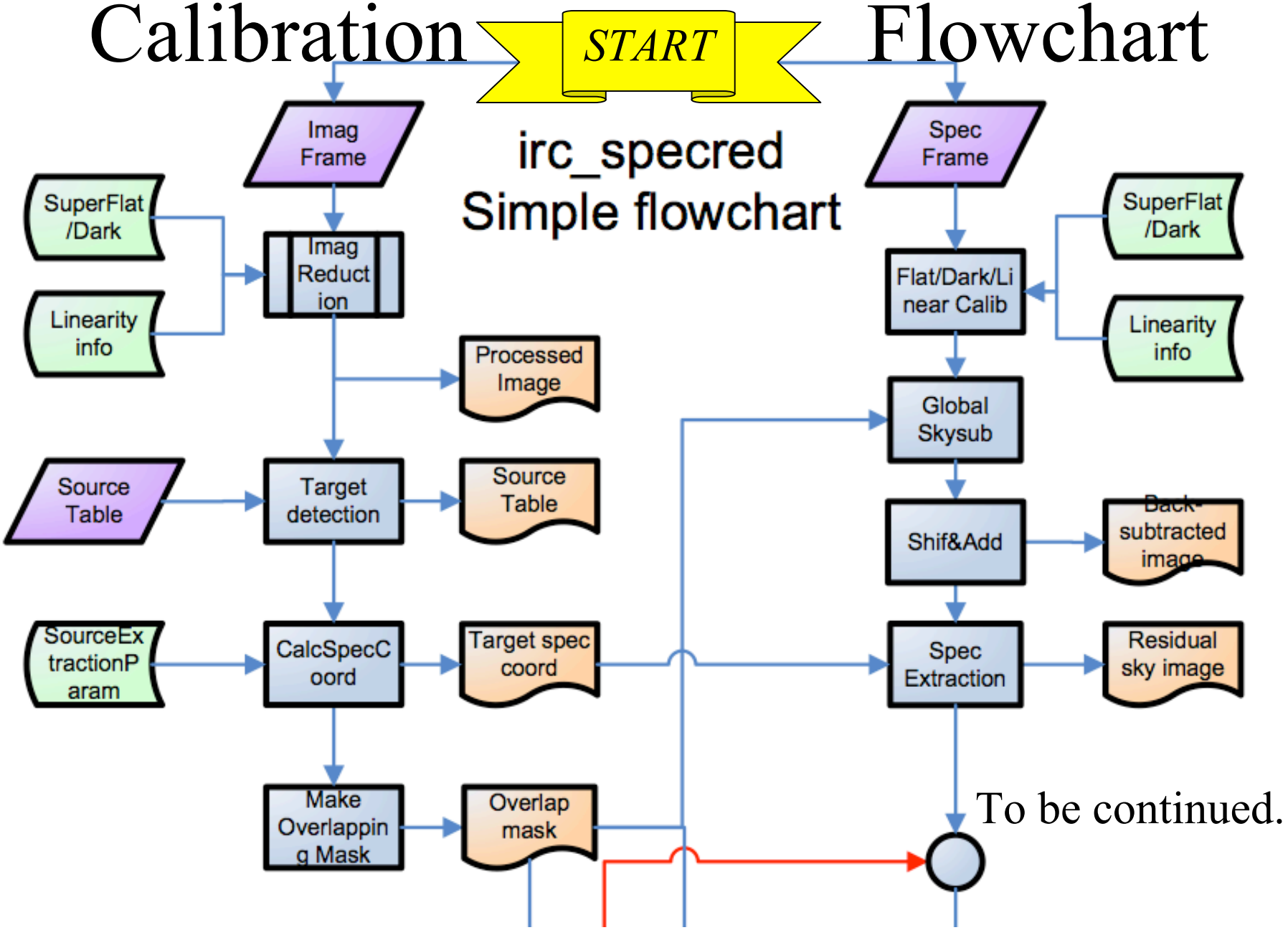
Calibrating the Data

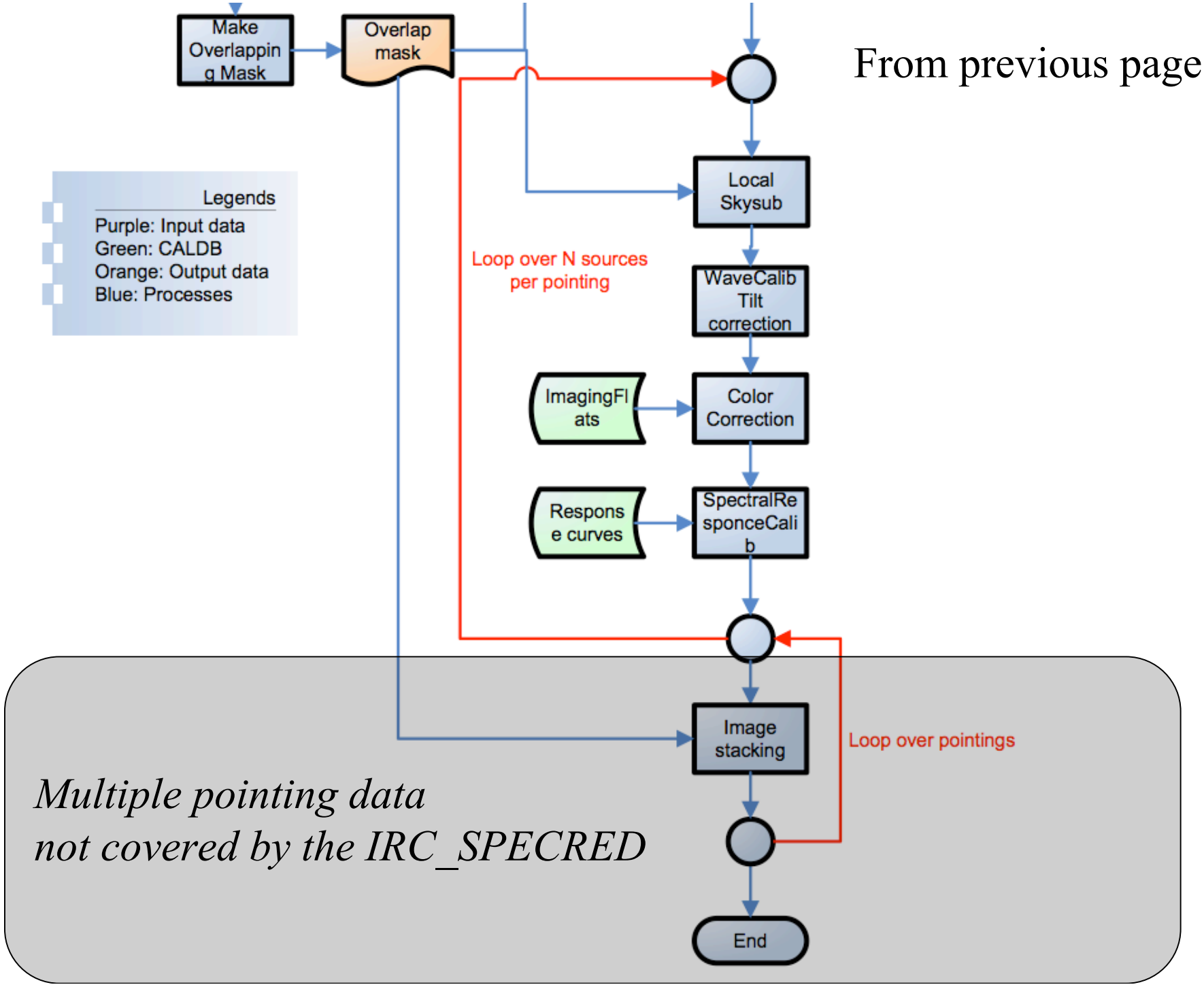

Ref. imag
Spec.
A
B
(Xi, Yi)
source
detection
coord. trans.
(Xs, Ys)
dispersed
AOT4 input data
Dark sub.
Flat for sky
Sky sub.
Source
overlapping?
Is aperture
size OK?
source
extraction
cut along disp.
cut along disp.
CALDB
ADU
pixel
one-dim. cut
wave. calib.
pos./λ-dependent flat
for obj. A
ADU'
λ
Jy
λ
Sens. response corr.
(pos. independent)
wave. calib.
pos./λ-dependent flat
for obj. B

Processes in Reducing Spectroscopy Data

- Processes common to *conventional imaging* with large-format arrays, or IRC Imaging data processing
  - Dark subtraction (hotpix subtraction)
  - Linearity correction
  - Flat fielding
  - Sky subtraction
  - Shift & add-ing individual frames
  - Source detection
- Processes common to *conventional spectroscopy*
  - Wavelength calibration
  - Flux calibration
  - Extracting 1D spectra
- Processes that are *unique to the IRC spectroscopy*
  - Measuring shift among subframes
  - Spectral image extraction
  - Flat fielding/Color correction for slit-less spectroscopy
  - Wavelength calibration for slit-less spectroscopy

Calibration Flowchart




From previous page
Make Overlapping Mask
Overlap mask
Legends
Purple: Input data
Green: CALDB
Orange: Output data
Blue: Processes
Local Skysub
Loop over N sources per pointing
WaveCalib Tilt correction
ImagingFlats
Color Correction
Response curves
SpectralResponceCalib
Image stacking
Loop over pointings
End
Multiple pointing data
not covered by the IRC_SPECRED

Overview of Basic Calibration Processes

- [REF]: procedure of reference images
- [SPEC]: procedure of spectroscopy images
- [REF/SPEC]: procedure of both

- [WHOLE]: procedures of whole image, before source extraction
- [EXTRAC]: procedures of extracted images.

Dark Subtraction [REF/SPEC/WHOLE]

- We subtract *scaled-superdark* from observed images.
  - Superdarks are in the CALIBDIR.
  - Scaling is done by measuring dark level of superdark/pre-dark/observed images.
    - At the slit-masked area.

Applying bad-pixel/slit Masks [REF/SPEC/WHOLE]

- Bad-pixel masks are provided in the CAL.
  - The same ones for the imaging data processing.
- Slit masks will be also applied for slit-less spectroscopy data.
  - This process will be skipped for slit data, of course.

Flat Fielding [*REF*/WHOLE]

- Dividing the dark-subtracted images with the super-flat for flat fielding

Sky Subtraction [*REF*/WHOLE]

- Sky is subtracted from each subframe.
  - By globally fitting the sky over the FOV,
  - With object rejecting algorithm,
  - With masks in the second path.

Frame Stacking [*REF*/WHOLE]

- NIR: no image stacking is possible.
- MIR-S/L: shift-and-coadd three subframes with median combine mode.
  - To remove cosmic rays

Object Detection [*REF*/WHOLE]

- Objects will be detected on the reference images with *DAOFIND* (IDL version).
  - The detection parameters can be changed interactively and iteratively within the toolkit.
    - noise level, detection threshold over the noise level, and source size
- The toolkit accepts a user-created *source table* as an input, if supplied.
  - If the list is set, the toolkit skips the object detection procedure.

Flat Fielding [*SPEC*/WHOLE]

- Divide each subframe by spec-flat images.
  - This would create globally-flat background.

Sky Subtraction [*SPEC*/WHOLE]

- Sky is subtracted from each subframe.
  - By globally fitting the sky over the FOV,
  - With object rejecting algorithm,
  - With masks in the second path.

Frame Stacking [*SPEC*/WHOLE]

- Shift-and-adding sub-frames
  - While removing cosmic-ray events.
- Shift value is measured on the NIR
  - Even for MIR-S/L
  - Based on pseudo features in NP or NG spectra.

Spectral Extraction [*SPEC*/WHOLE]

- Spectral images of each source are extracted
  - The toolkit converts source coordinates on the REFIMAGE into that in the SPECIMAGE.
    - based on the CAL information.
  - Extraction boxes include surrounding sky area.
- Spectral masks will be also created.
  - To find possible source overlapping.

Wavelength Calibration [*SPEC/EXTRC*]

- Basically no image transformation is made, rather
- Wavelength array will be created to relate Y pixel and wavelength in um.
  - For grisms…
    - Wavelength=linear_function(dY, d_lambda, lambda0)
  - For prism…
    - Wavelength=3rd-order-poly(Y)
- Single wavelength array for all extracted spectral images.

Sky Subtraction
[*EXTRAC/SPEC*]

- Any remaining sky is subtracted locally.
  - *Note: The sky is close to zero for most cases.*
  - Sky is an average of surrounding sky.

Color-term Correction [*SPEC/EXTRAC*]

- Ideally, flat response is a function of both
  - Pixel (X and Y) and Wavelength (lambda)
- But, spectral flat-fielding applied over the whole image was a function of
  - Pixel, but ***not*** Wavelength.
- We need somehow correct color-dependence of the flat response.
  - After calibrating wavelength.

Flux Calibration [*SPEC/EXTRAC*]

Or spectral response correction

- Flux(mJy, lambda)

  =count(ADU,lambda)/response(lambda)

- Response is a 1D function, but actual flux calibration is made on wavelength-calibrated 2D images.
  - Then, extract 1D spectra in the plotting program.

The IRC_SPECRED Data Reduction Toolkit

- The toolkit is called ‘IRC_SPECRED’.
  - The toolkit can be used for both ***reducing*** and ***reviewing*** the data
  - The toolkit needs some interactive operations.
- A single toolkit works on both ***slit-less*** and ***slit*** modes.
  - Processing of the slit mode data requires a subset of the procedures for processing the slit-less mode data.

- In the followings, I mainly describe the toolkit for the slit-less mode.

Computer Environment for the ToolKit

- The toolkit is written with **IDL**.
- It also requires
  - **DS9** FITS viewer
  - **XPA** program for communication between IDL and DS9.
- It is developed with IDL ver 6.1 & 6.2 on Linux PCs, but…
  - IDL ver 6.0 or later should be fine.
  - Solaris/other UNIX platform should be fine.
  - Mac OS-X seems OK.
- The toolkit requires the ASTROLIB IDL library at GFSC and others.

Review of Input/Output Params/Products of the ToolKit

[INPUTs]

- File lists of raw data to be processed (mandatory):
  - Lists of a reference image and spectroscopy images.
- Target table (optional):
  - If users want to create their own target list with their favorite source detection programs, a target table should be specified as a toolkit option.

[OUTPUTs]

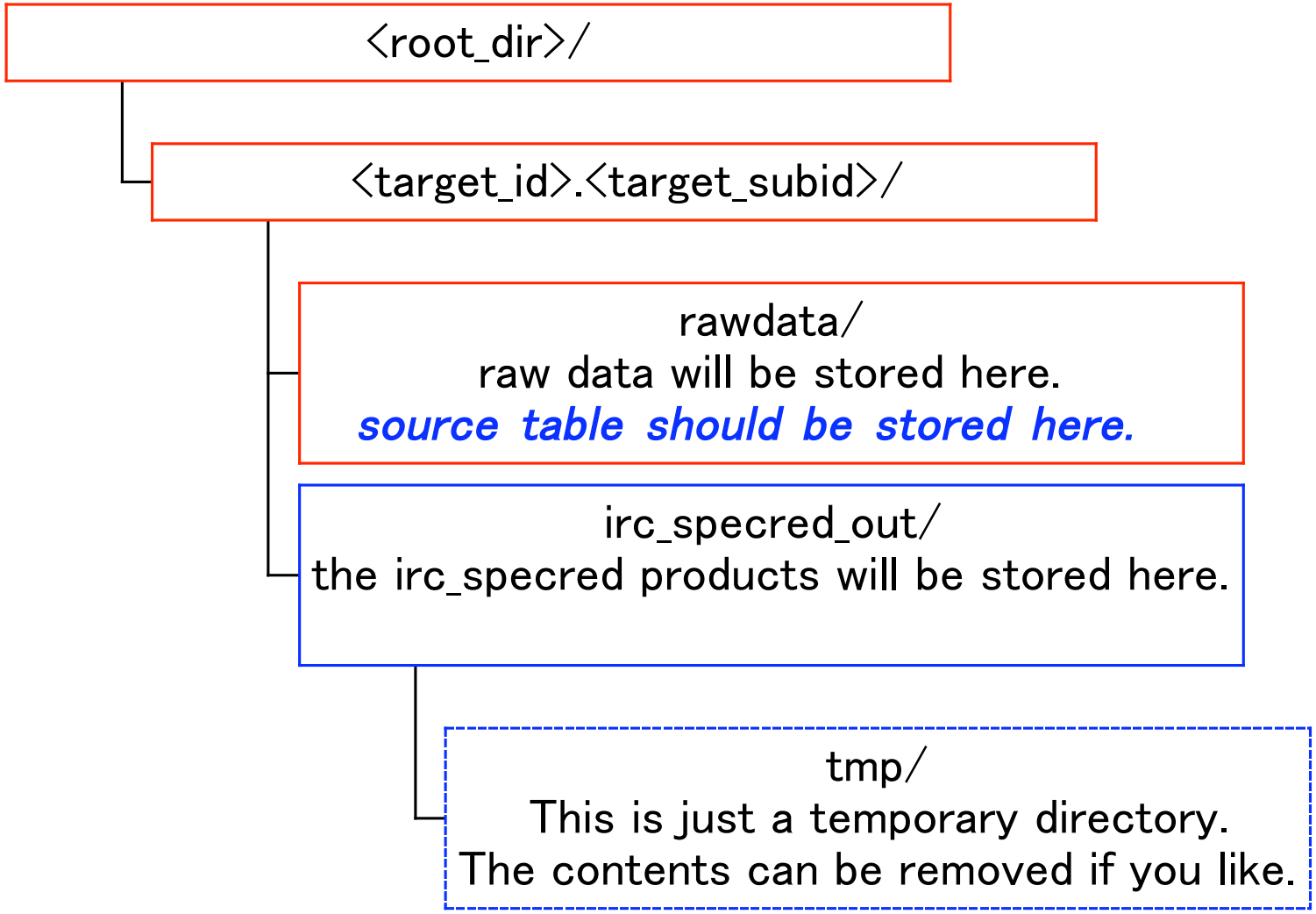
Main outputs:

- Object catalogue, or table of object information
  - ***target location, brightness, size, coordinates of the spectroscopy apertures, etc.***
- Processed **WHOLE** reference/spectroscopy images:
  - ***dark-subtracted***, ***flat-fielded***, ***background-subtracted***, ***stacked.***
- Processed **EXTRACTED** reference/spectroscopy images of each object:
  - ***Wavelength calibrated/color corrected/flux calibrated.***
- IDL save files

Auxiliary outputs:

- Masks
  - WHOLE mask images:
    - Images showing the object occupation on reference/spectroscopy images.
  - EXTRACTED mask images for each object:
    - Images showing location of object overlapping, area of lost information either due to out-of-chip or bad pixels.
- Residual images (after masking detected objects):
  - Combined images masked for the detected objects.
  - The images could be useful to examine object detection completeness, background subtraction quality, total noise quality, etc., of the toolkit.
- DS9 region files
  - for identifying extraction area, zero-th order light occupation, etc.

The IRC_SPECRED Directory



Processing ‘Filter-Grism’ Order

NIR data provide some basic information for processing MIR-S/L data.

1. NP or NG, without source table.
2. (NP or NG, with source table)
3. SG1 with or without source table.
4. (SG2 with or without source table.)
5. LG2 with or without source table.

Examples:

- If you want to reduce MIR-S data, first reduce NIR, then SG1/2.
- If you want to reduce MIR-L data, first reduce NIR and SG1, and then MIR-L.

Preview of the Toolkit Operation

- Input list files for this operation example

```
ohyama@cava: ls *lst
L18W.lst N3.lst NP.lst SG1.lst LG2.lst NG.lst S9W.lst SG2.lst DARK_NIR.lst
    DARK_MIR.lst
ohyama@cava: ls *tbl
target_MIRS.tbl target_MIRL.tbl MYOBJECTS.tbl
ohyama@cava: cat N3.lst
F54919_N.fits
ohyama@cava: cat NP.lst F54911_N.fits
F54913_N.fits
F54915_N.fits
F54917_N.fits
F54921_N.fits
F54923_N.fits
F54925_N.fits
F54927_N.fits
```

The default list files work just fine for most cases.

Example of IRC_SPECRED Commands

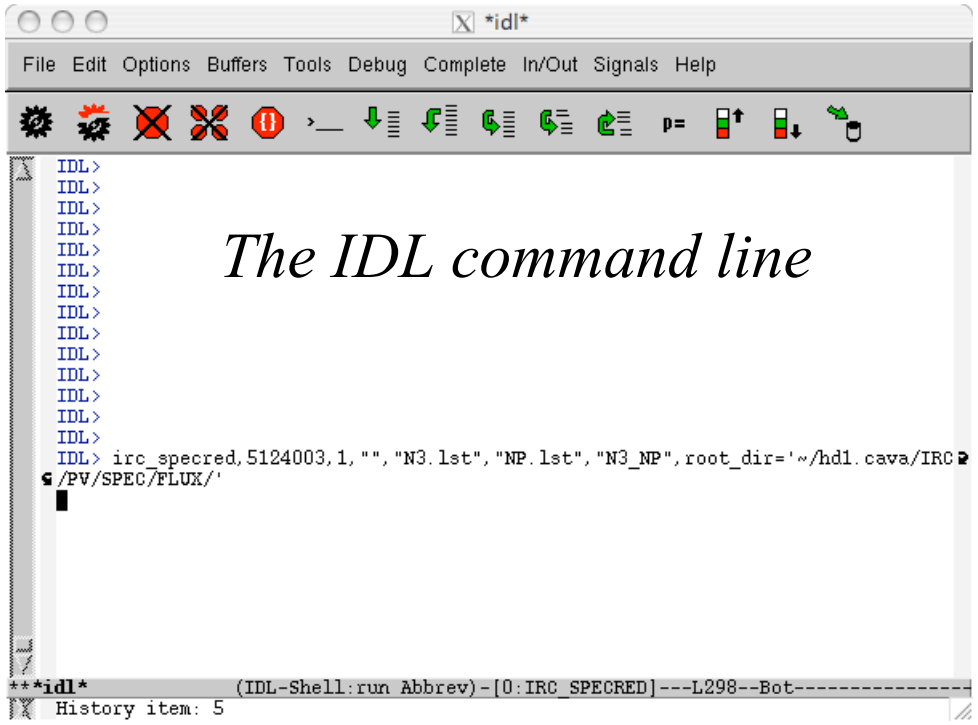
- Slit-less
  - irc_specred,5020056,1,’’,’N3.lst’,’NP.lst’,’N3_NP’
- Slit-less + target table
  - irc_specred,5020056,1,’MYOBJECT.tbl',’S9W.lst’,’SG1.lst’,’S9W_SG1’,root_dir=’/data/IRC/TEST'
- Slit
  - irc_specred,1400043,1,’’,’N3.lst’,’NG.lst’,’N3_NG’,/Ns_spec,savefile=savefile

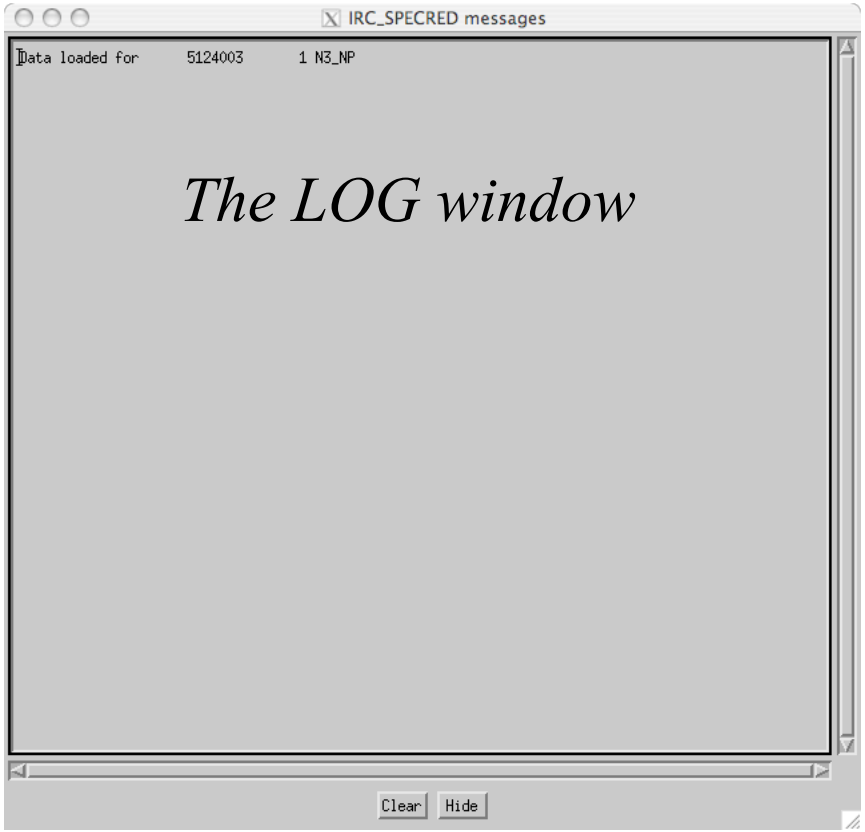
’’=Null string

single quotation, not double!

One command per line!

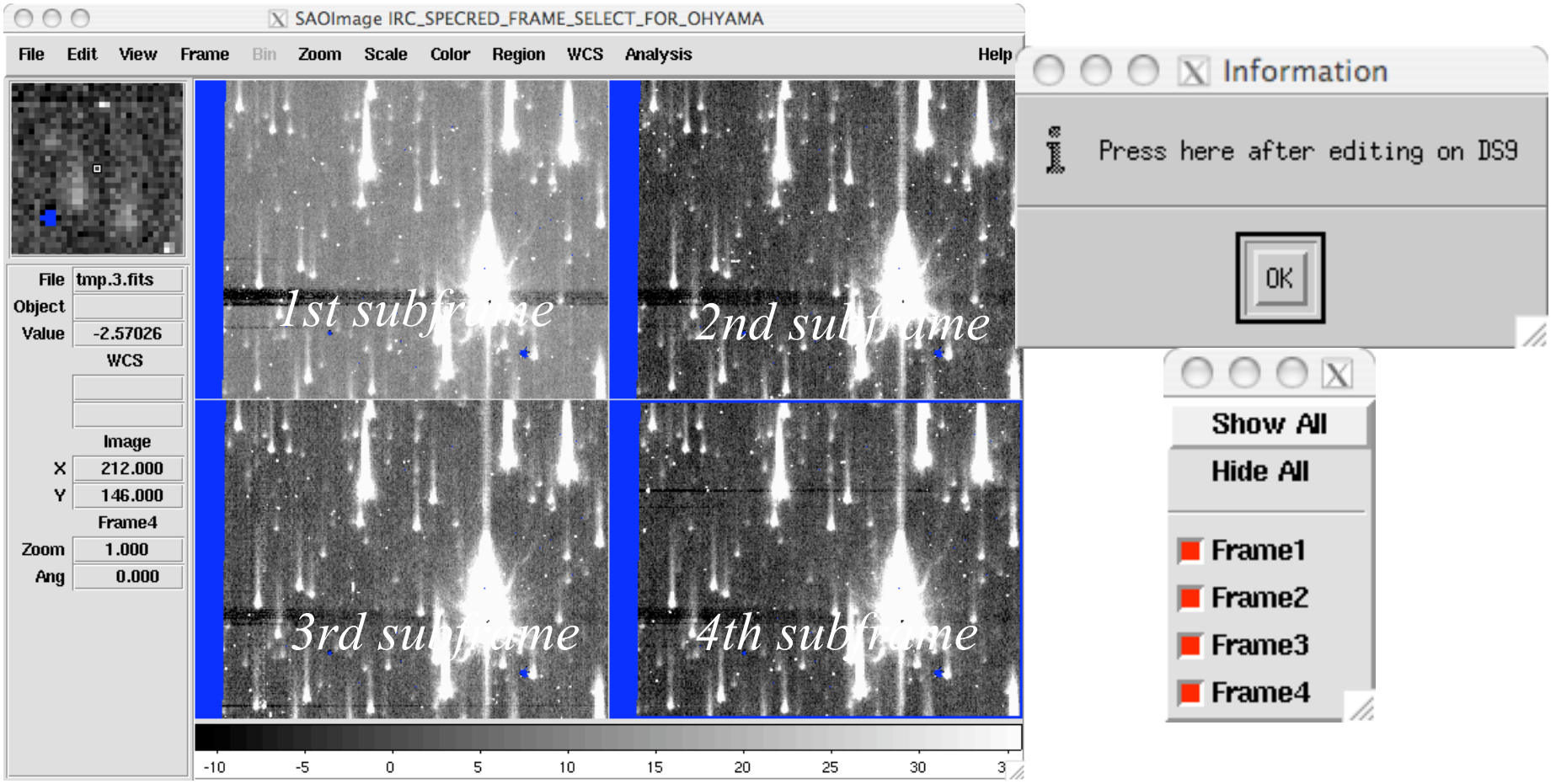
Step 1: The case of NP/no source
Issue the ‘irc_specred’ command





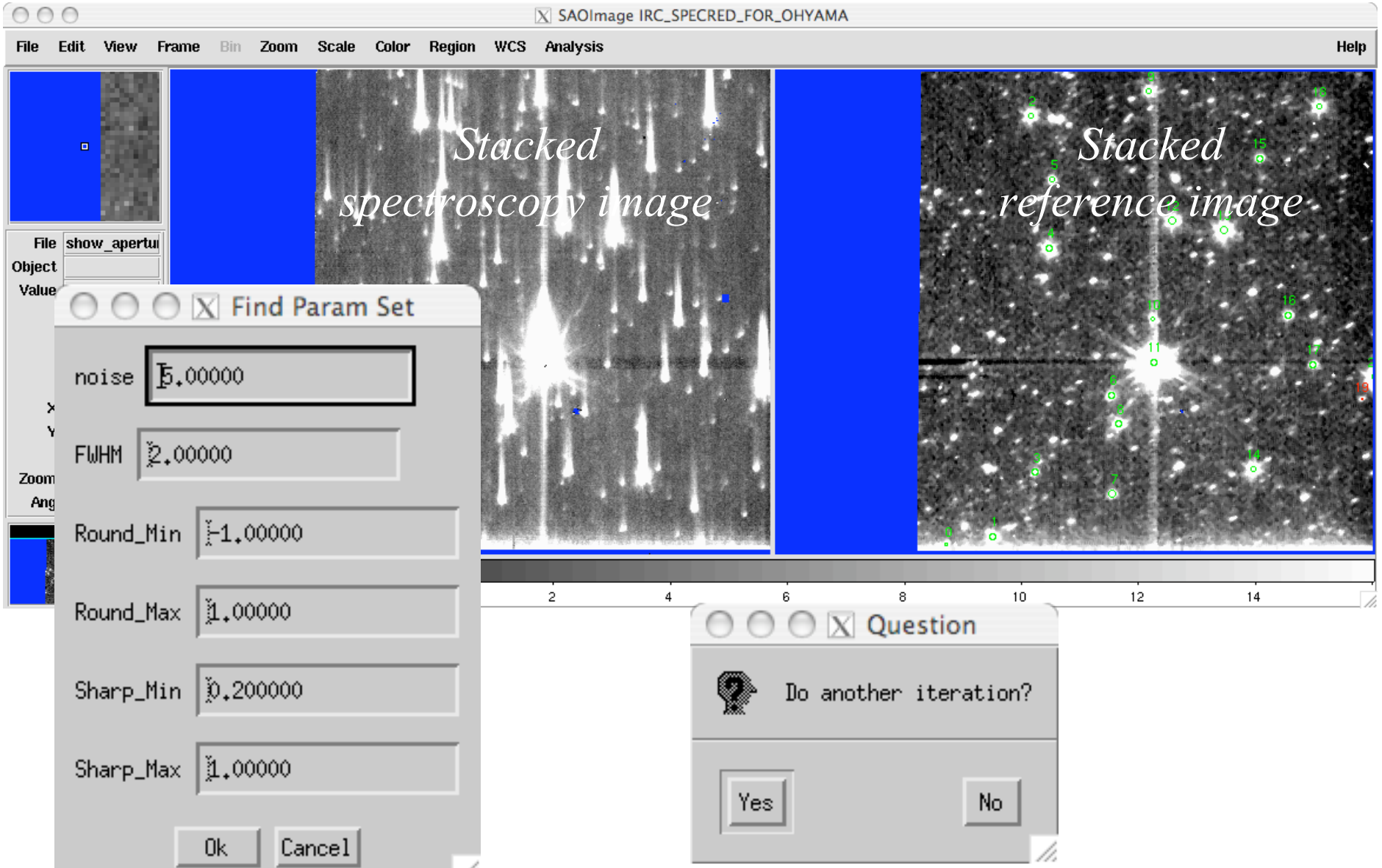
- Left: Issue a toolkit command at the IDL command line.
- Right: A log window will show up.

Step 2: Screen sub-frames

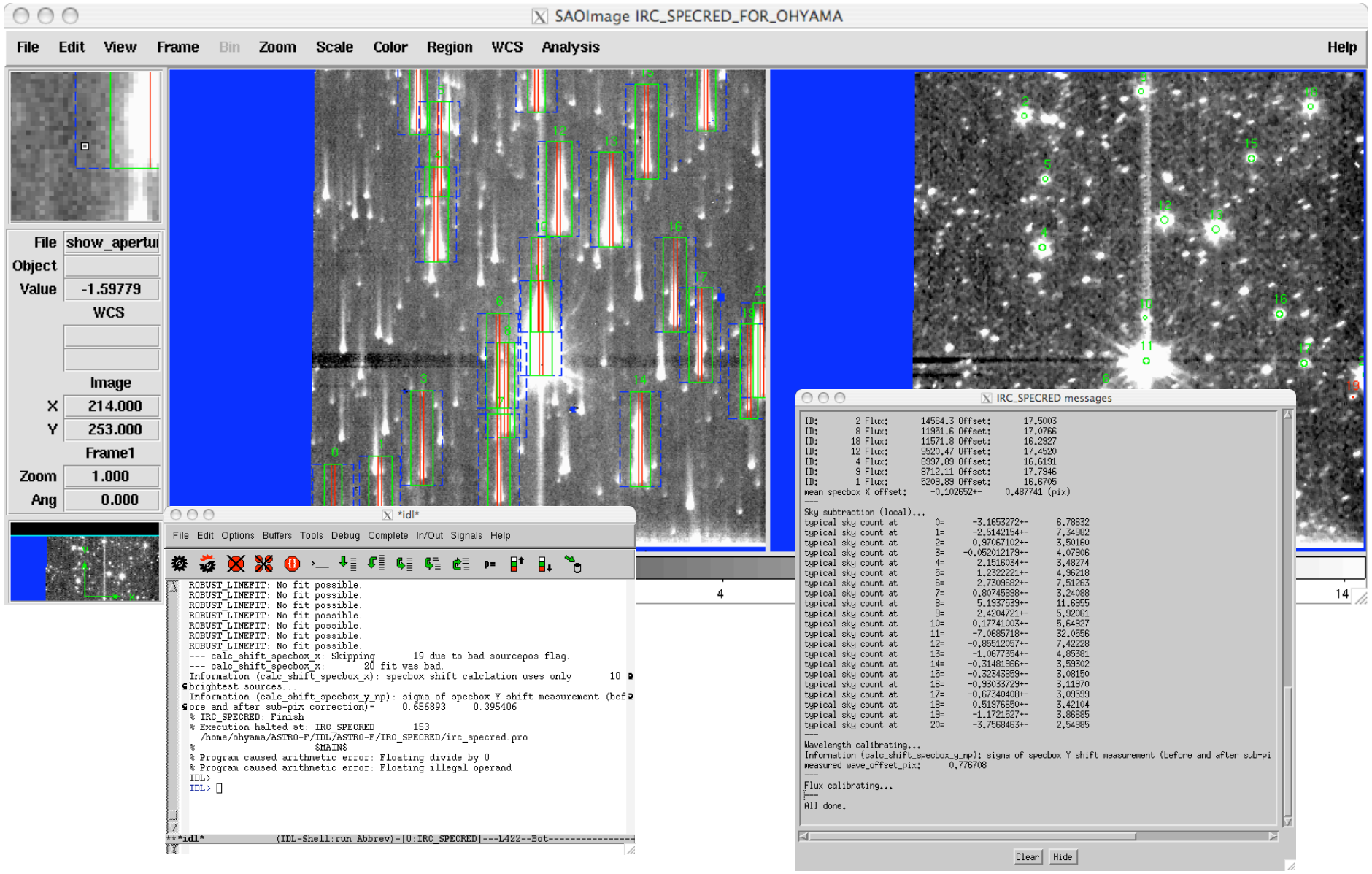


- All sub-frames are shown on ds9 for *eye*-screening.
  - Note: Typical AOT04a gives 8 or 9 sub-frames.

Step 3: Tweak ‘find’ parameters

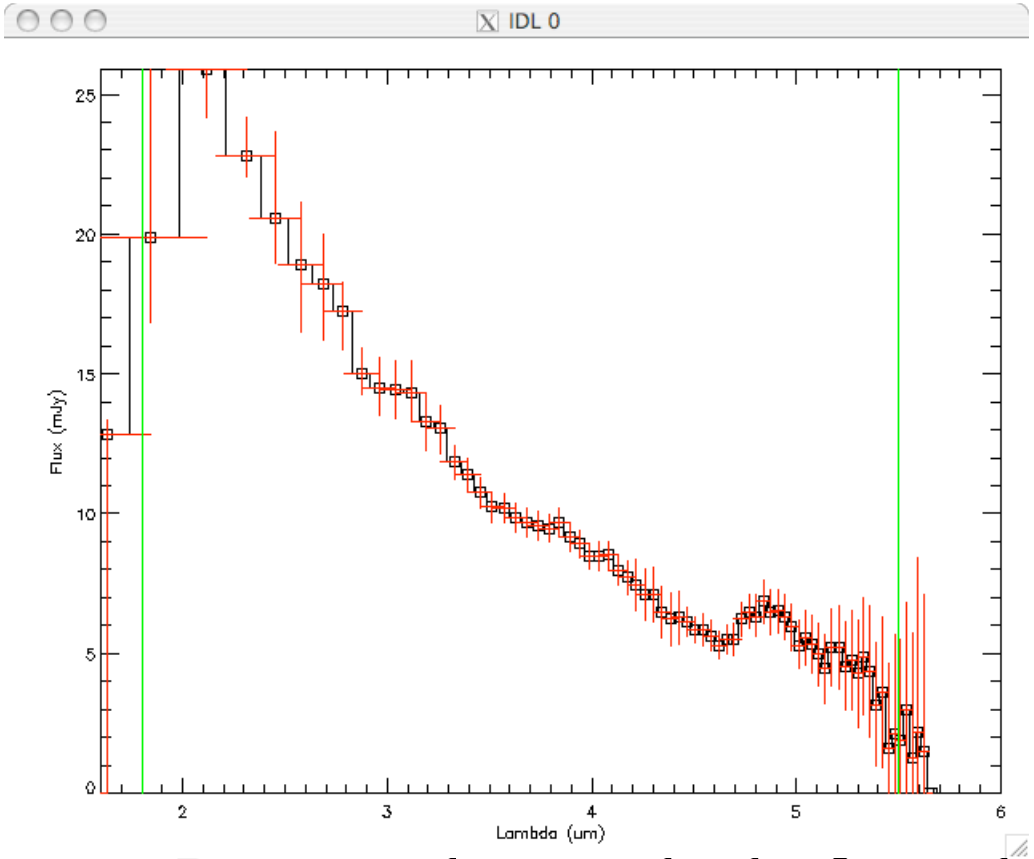


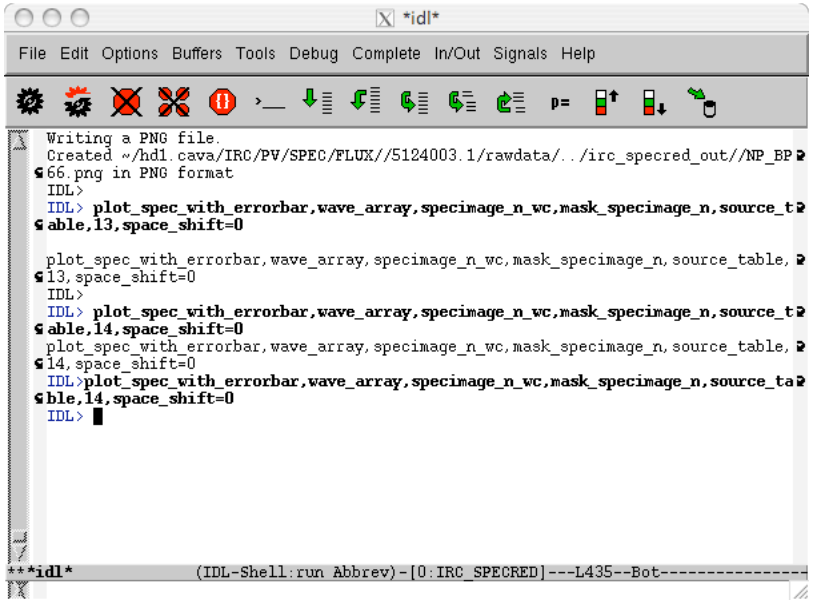
Step 4: ‘All done’



Step 5: Examine Spectra

with *plot_spec_with_image*





- Restore the results before plotting by issuing

  restore,savefile

Contents of ‘irc_specred_out’ Dir.

```
ohyama@cava3: ls
5124003.1.N3_NG.refimage_bg.fits            5124003.1.N3_NP.residual_specimage_bg.fits   5124003.1.S9W_SG1.specimage_mask.fits
5124003.1.N3_NG.refimage_bg_indiv.fits      5124003.1.N3_NP.source_table.tbl             5124003.1.S9W_SG1.specimage_mask_indiv.fits
5124003.1.N3_NG.refimage_mask.fits          5124003.1.N3_NP.specimage_bg.fits            5124003.1.S9W_SG1.specimage_wc_indiv.fits
5124003.1.N3_NG.residual_refimage_bg.fits   5124003.1.N3_NP.specimage_fc_indiv.fits      5124003.1.S9W_SG1_refimage.reg
5124003.1.N3_NG.residual_specimage_bg.fits  5124003.1.N3_NP.specimage_mask.fits          5124003.1.S9W_SG1_specimage.reg
5124003.1.N3_NG.source_table.tbl            5124003.1.N3_NP.specimage_mask_indiv.fits    5124003_1_N3_NG_target_table.tbl
5124003.1.N3_NG.specimage_bg.fits           5124003.1.N3_NP.specimage_wc_indiv.fits      5124003_1_N3_NP_target_table.tbl
5124003.1.N3_NG.specimage_fc_indiv.fits     5124003.1.N3_NP_refimage.reg                 5124003_1_S9W_SG1_target_table.tbl
5124003.1.N3_NG.specimage_mask.fits         5124003.1.N3_NP_specimage.reg                NG_SHIFT_XY.dat
5124003.1.N3_NG.specimage_mask_indiv.fits   5124003.1.S9W_SG1.log                       NG_SPECBOX_SHIFT_X.dat
5124003.1.N3_NG.specimage_wc_indiv.fits     5124003.1.S9W_SG1.refimage_bg.fits           NG_SPECBOX_SHIFT_Y.dat
5124003.1.N3_NG_refimage.reg                5124003.1.S9W_SG1.refimage_bg_indiv.fits     NP_BP66.png
5124003.1.N3_NG_specimage.reg               5124003.1.S9W_SG1.refimage_mask.fits         NP_SHIFT_XY.dat
5124003.1.N3_NP.log                         5124003.1.S9W_SG1.residual_refimage_bg.fits  NP_SPECBOX_SHIFT_X.dat
5124003.1.N3_NP.refimage_bg.fits            5124003.1.S9W_SG1.residual_specimage_bg.fits NP_SPECBOX_SHIFT_Y.dat
5124003.1.N3_NP.refimage_bg_indiv.fits      5124003.1.S9W_SG1.source_table.tbl           tmp/
5124003.1.N3_NP.refimage_mask.fits          5124003.1.S9W_SG1.specimage_bg.fits
5124003.1.N3_NP.residual_refimage_bg.fits   5124003.1.S9W_SG1.specimage_fc_indiv.fits
```

- Processed FITS images (*.fits)
  - <target_id>.<target_subid>.<filter-grism>.<image type>.fits
- DS9 region files (*.reg)
- Source tables (*.tbl)
- Processing logs (*.log)
- Database for next processing (*.dat)

Review of FITS Output

REFIMAGE

- Whole:
  - Refimage_bg
  - Refimage_mask
  - Residual_refimage_bg
- Extracted:
  - Refimage_bg_indiv
  - Refimage_mask_indiv
- Region file
  - Refimage.reg

SPECIMAGE

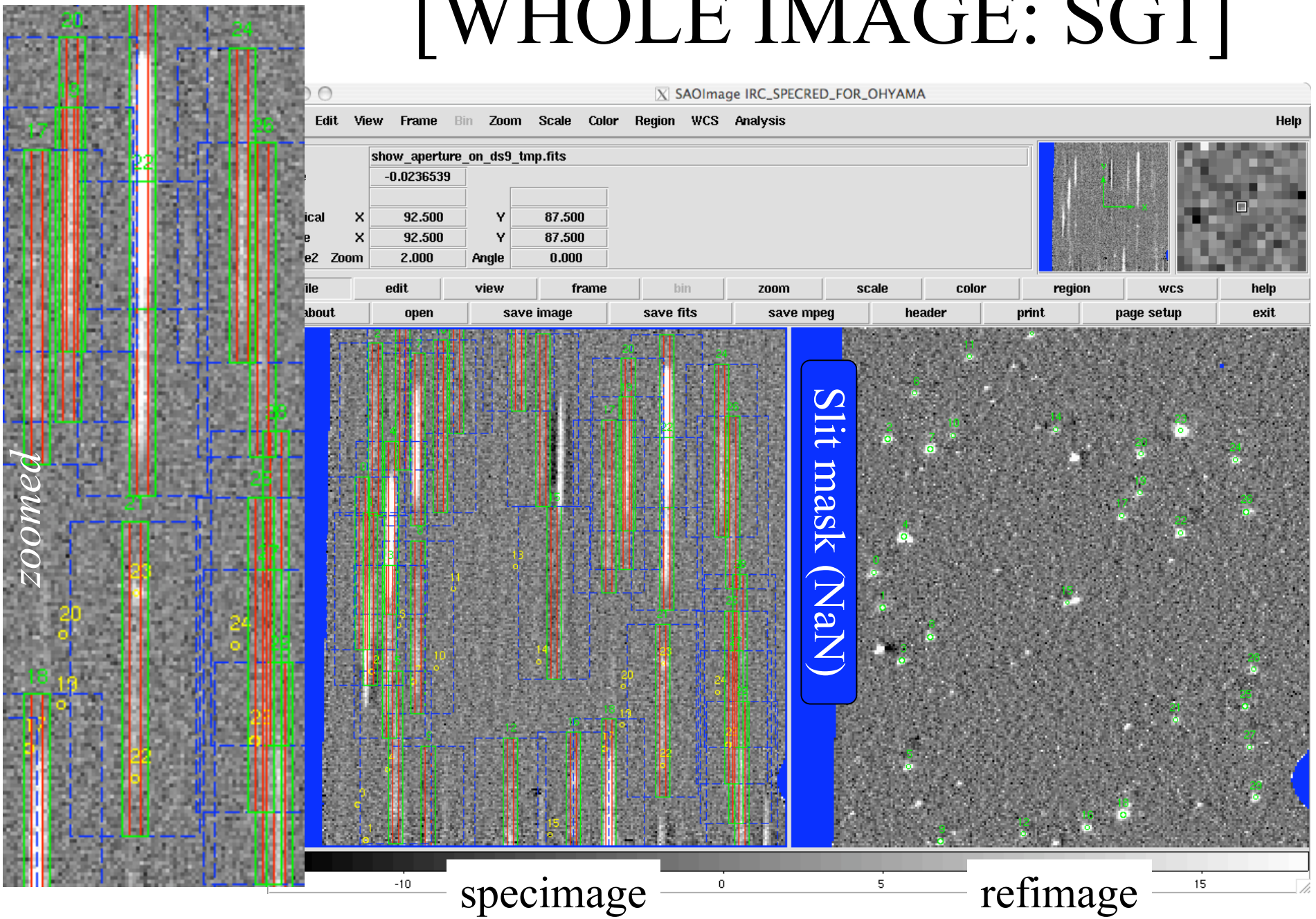
- Whole:
  - Specimage_bg
  - Specimage_mask
  - Residual_specimage_bg
- Extracted:
  - Specimage_wc_indiv
  - Specimage_fc_indiv
  - Specimage_mask_indiv
- Region file
  - Specimage.reg

Others

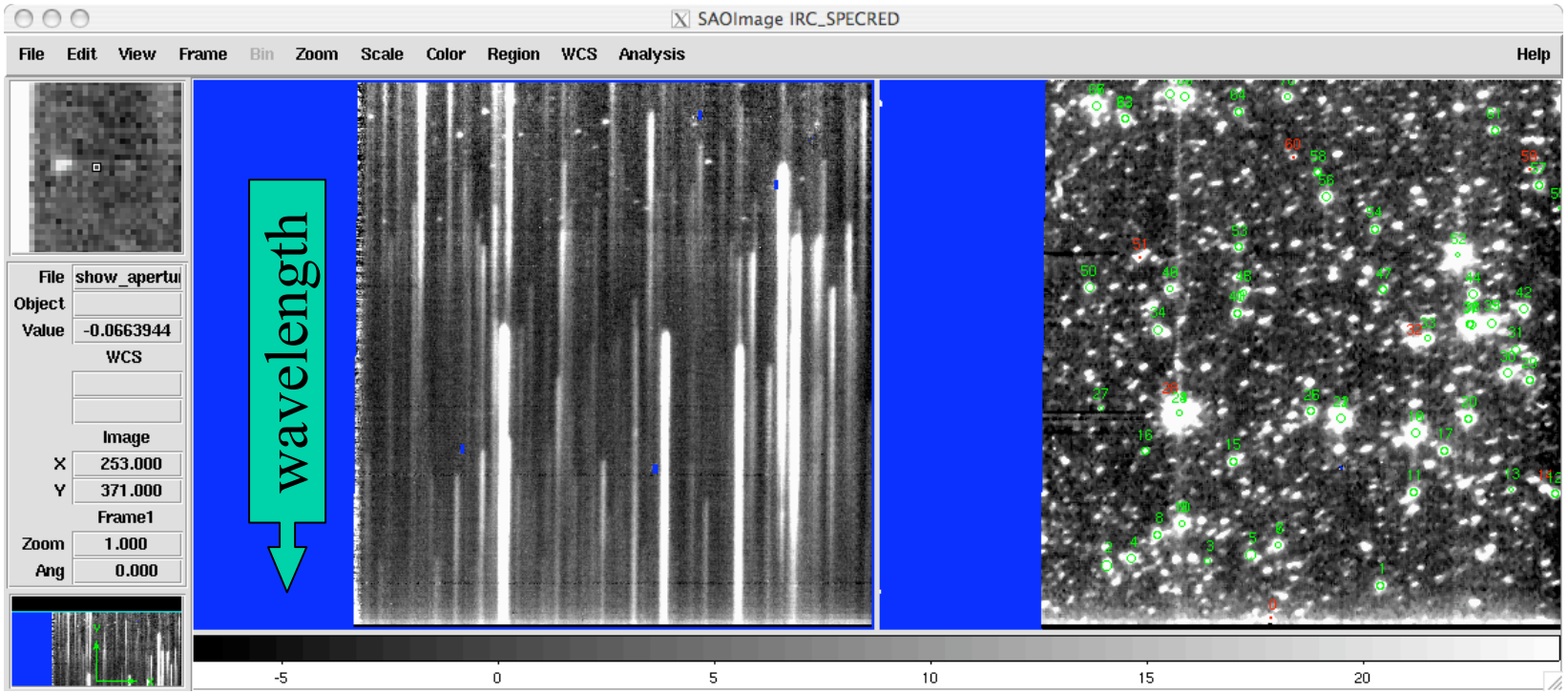
Source table.tbl

Processing log.log

[WHOLE IMAGE: SG1]



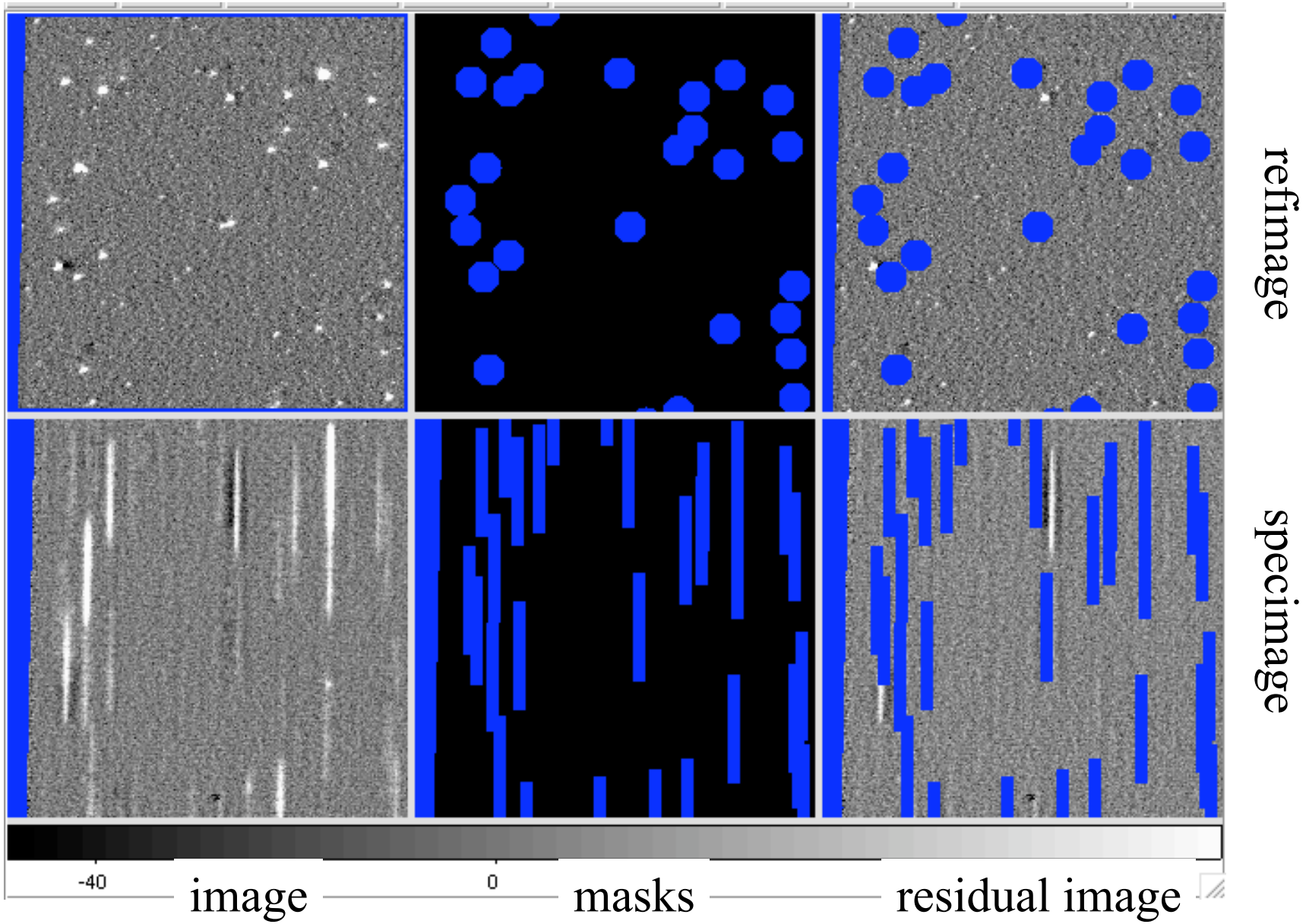
[WHOLE IMAGE: NG]



specimage

refimage

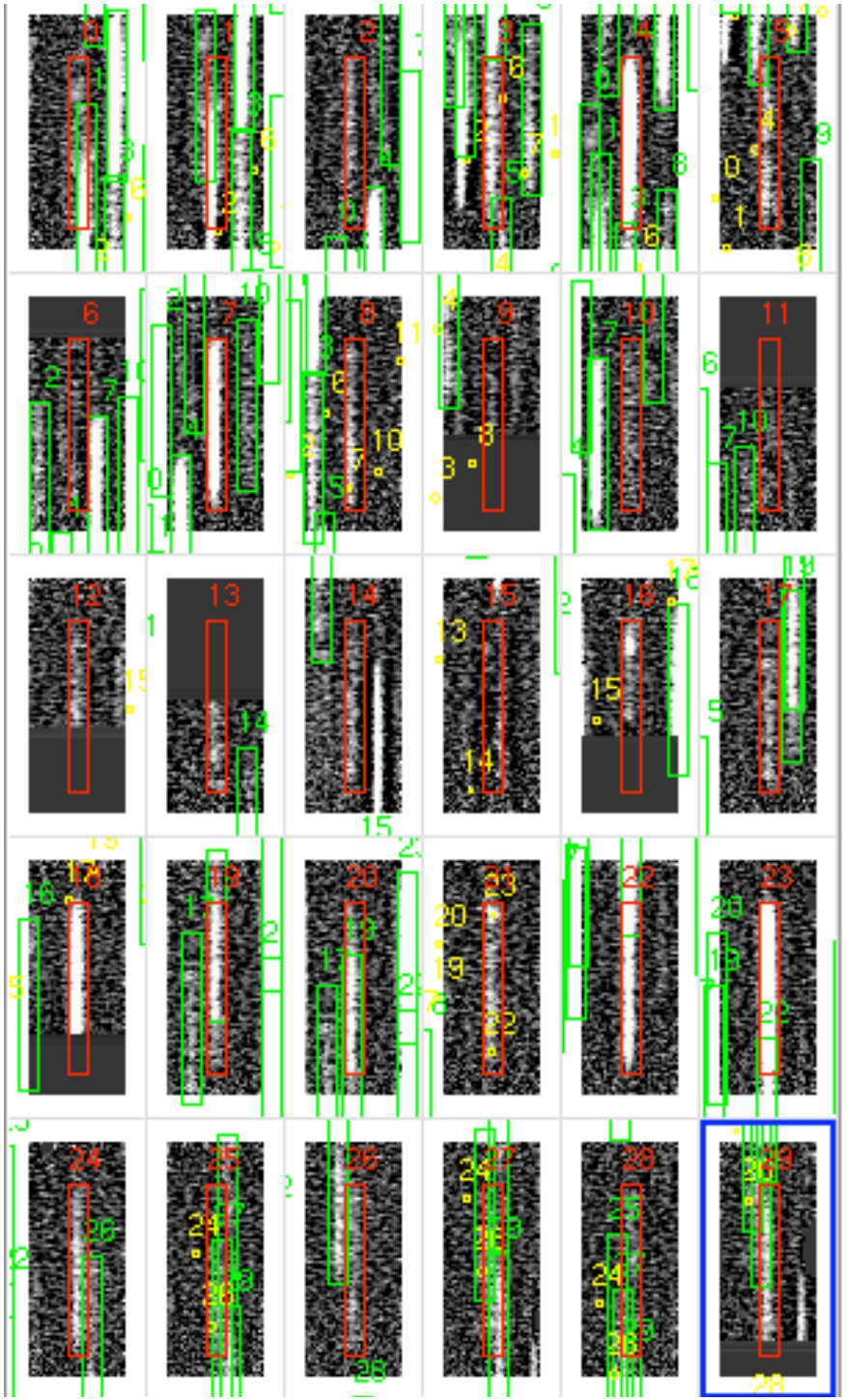
[WHOLE IMAGE: SG1 Masks]



[EXTRACTED : SG1]

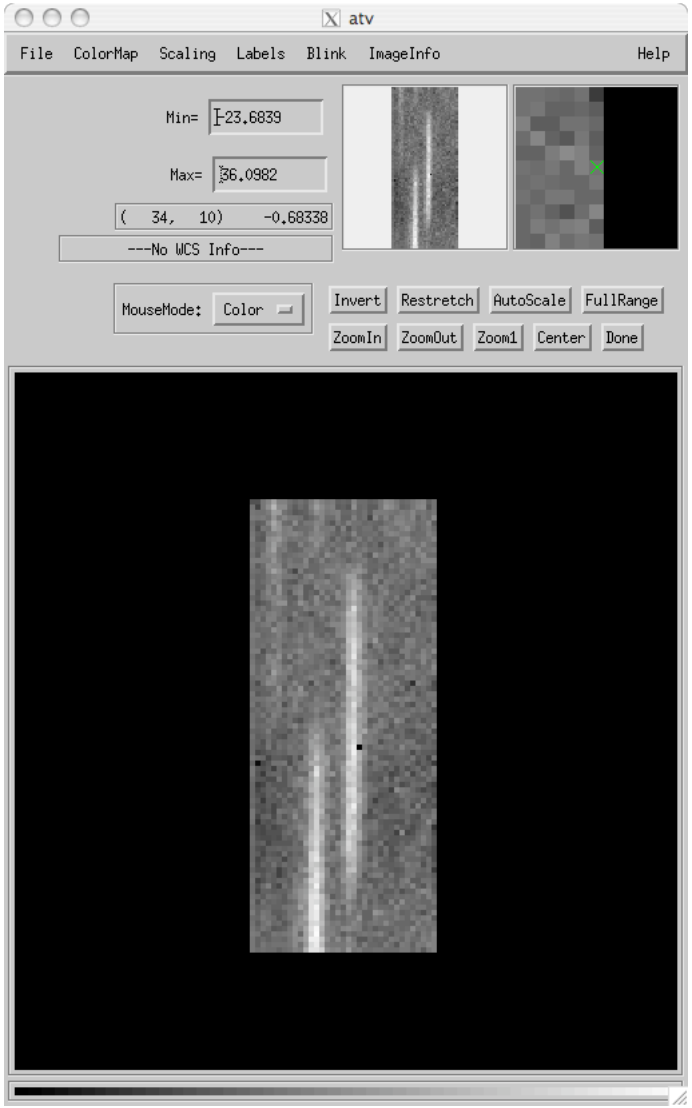
2D spectra of wavelength-calibrated extracted sources (_WC)

30 objects in this example.

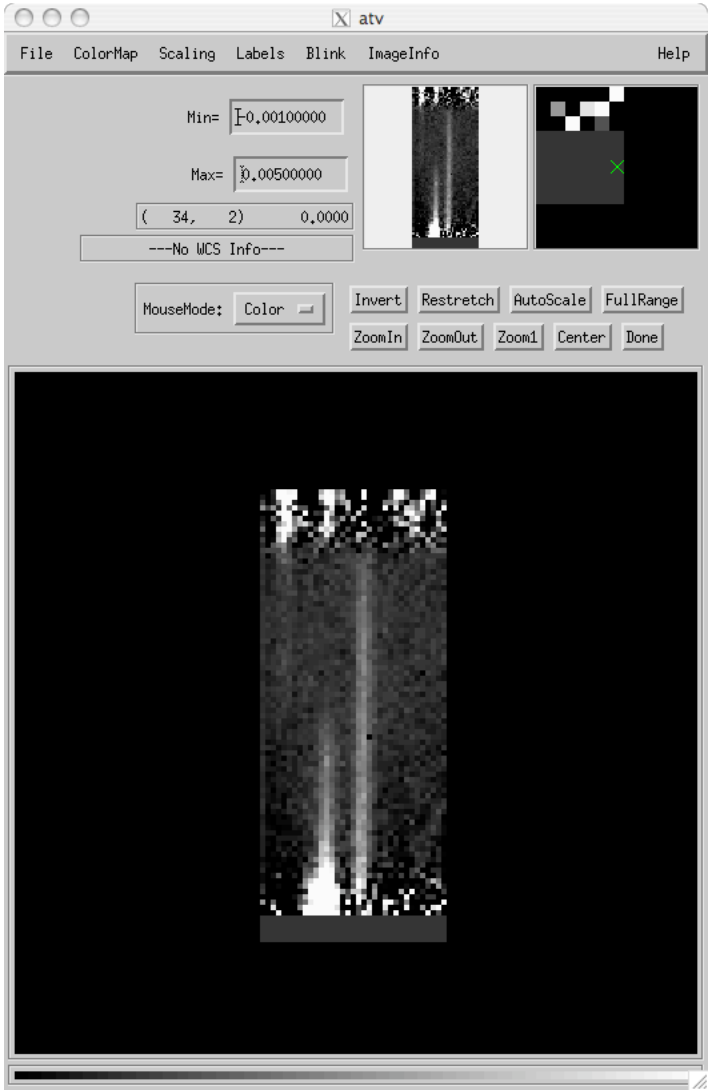


Extracted specimage: _wc vs. _fc

WC=Wavelength Calibrated



FC=Flux Calibrated



Example of the Spectra

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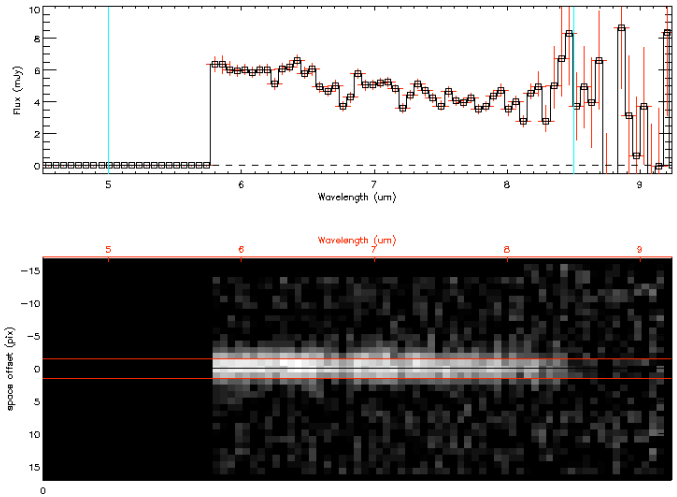

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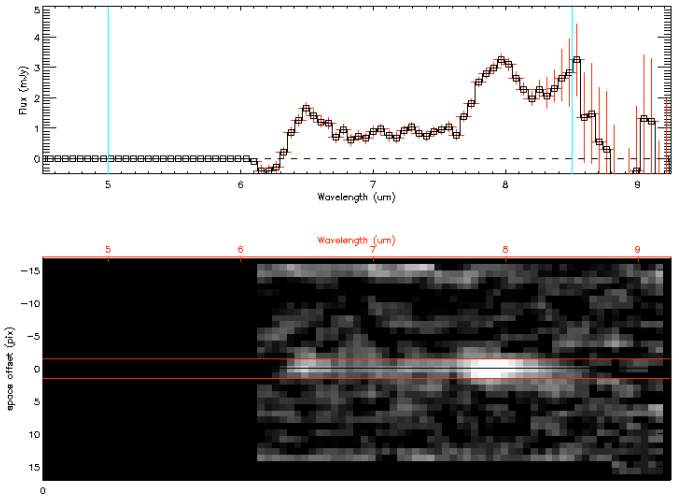

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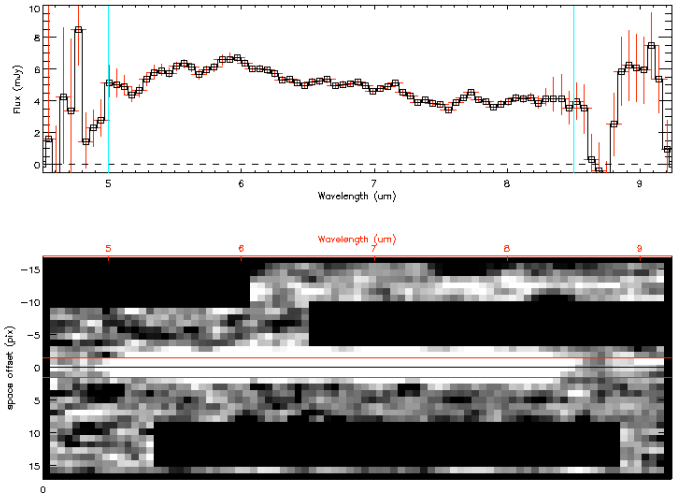

Demonstration