IRC Data Reduction Workshop 2007 Summer
The IRC Spectroscopy: Data and their Calibration

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On behalf of the IRC spectroscopy data reduction team

Today's Topics

- Quick review of the IRC spectroscopy mode
- Basic characteristics of IRC spectroscopy data
  - Raw data
  - Calibration data
- Calibrating the data
  - Overview of basic calibration processes
  - How to work with the "toolkit"
    - Descriptions of each process
    - Actual operation preview
  - More comments on the toolkit and calibration.
  - Problems/difficulties
  - FAQs (if any)
- Q/A session

If you are one of the followings, you are right place to be.

- You know the IRC, you did the observation, and you have received and seen your data, but
  - You do not know how to review the data.
- You have downloaded the "toolkit", but
  - You do not know how to work with them, or
  - You tried to reduce the data with the tools, but it failed, or
  - You finished the reduction, but
    - The results seem strange, or
    - The tools worked, but you do not know what happened, or
- You have lots of complaints/requests/suggestions on the tools.

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)
- Slit
  - Wider aperture for imaging + slit areas
  - For slit-less and slit spectroscopy
- Main Optics (Collimator/Camera)
  - same ones that for imaging mode.
- Disperser
  - prism or grism, mounted on filter wheel
- Array and its operation (clock/exposure time)
  - same ones that for imaging mode.

IRC Spectroscopy Specification

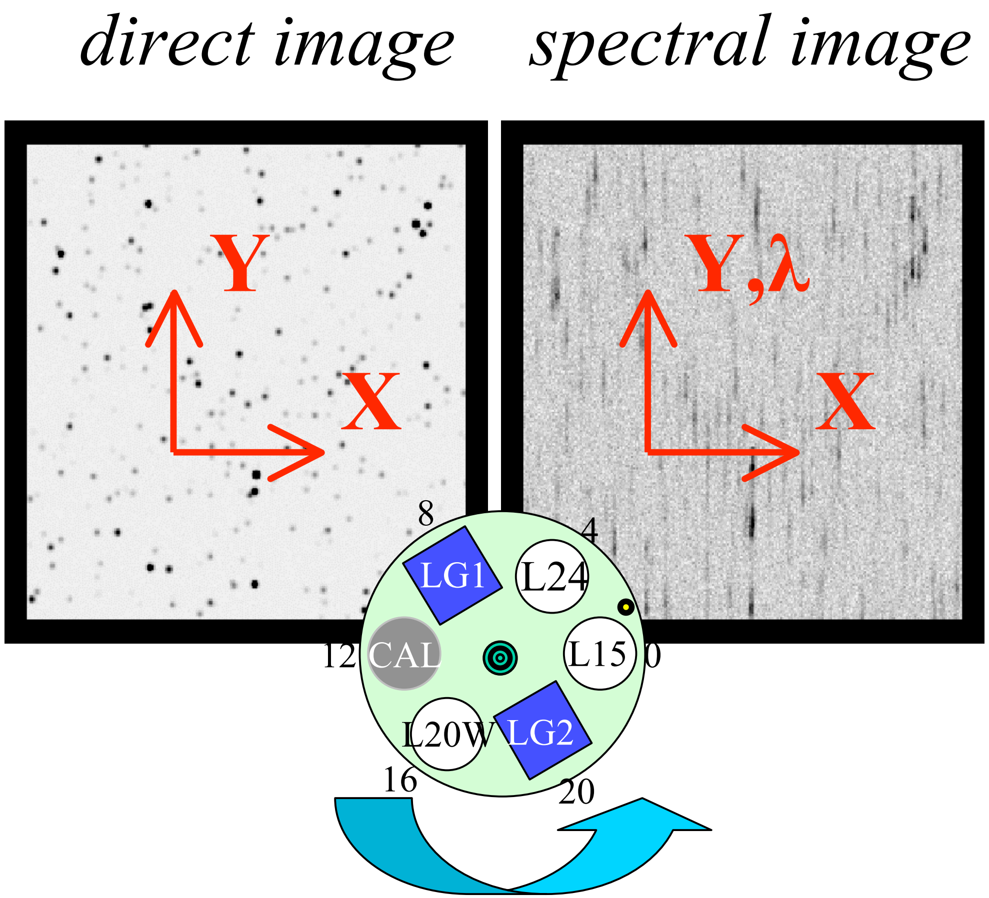
Summary on IRC Spectroscopy Capability								
Camera				Disperser				
Name	Array	FOV (arcmin^2)	Pix scale (arcsec /pix)	ID	Type	$\Delta\lambda$ (μm)	$\lambda/d\lambda$	Spec. Length
NIR	InSb 512 X412	9.5' X10.0'	1.46”	NP	prism	1.8–5.5	22 @ 3.5μm	81 pix
				NG	grism	2.5–5.0	135 @ 3.6μm	261
MIR-S	Si:As 256 X256	9.1' X10.0'	2.34”	SG1	grism	5.3–8.3	47 @ 6.6μm	85
				SG2	grism	7.5–13.5	34 @ 10.6μm	91
MIR-L	Si:As 256 x256	10.3' X10.2'	2.51” x2.39”	*LG1*	*grism*	*11–19*	*19 @ 14.4μm*	---
				LG2	grism	17.7–25.0	27 @ 20.2μm	79

The Slit-less Mode

Very Basic Ideas for Slit-less Spectroscopy

- Reference (direct) image is taken.
  - We do not have to locate target on tiny slit area. Rather
  - *<u>We need to find source locations on the reference image.</u>*
  - The 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



Selectable filter wheel

The (conventional) Slit Mode

- Observation (Satellite/Array/Filter wheel controls) will be done 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.
- Data reduction will be done 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

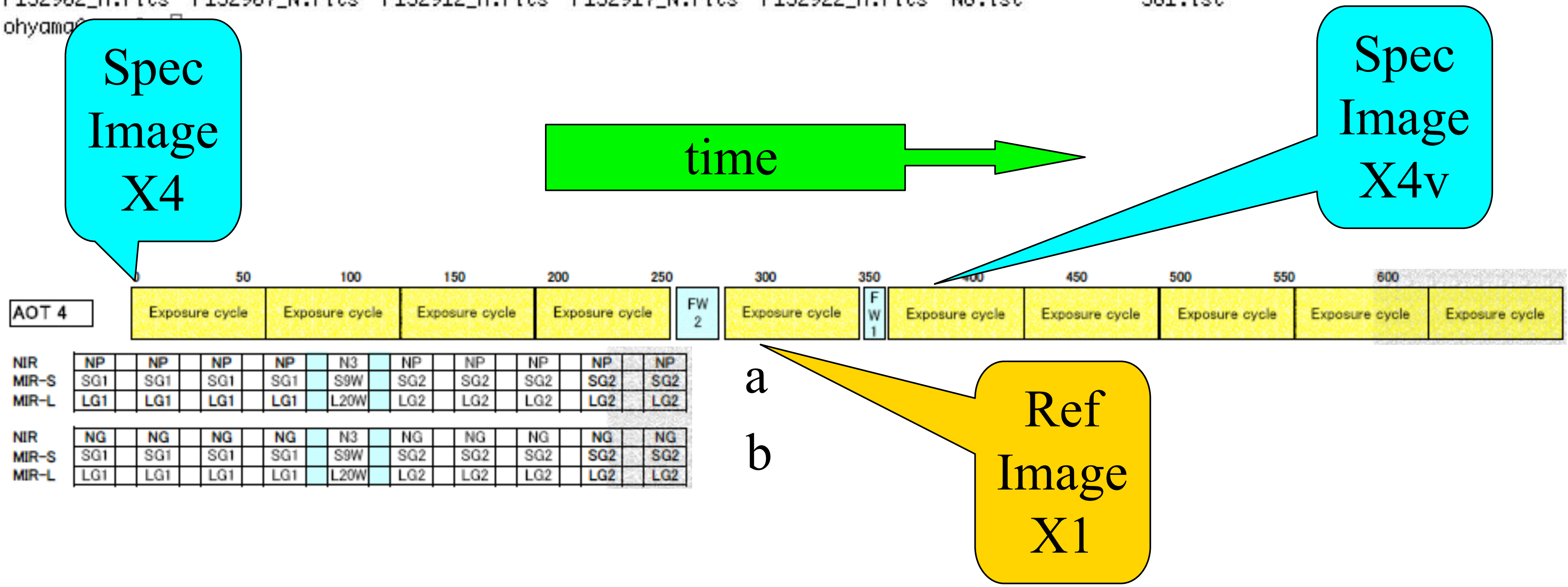
Contents of the IRC Spectroscopy Data Products

- Within single AOT, *both* direct and spectroscopy images are taken.
  - Reference (direct) image
    - For positional reference of the target
    - For wavelength reference points
  - Spectroscopy image
    - For actual science data
- Pre-/Post-dark images are taken as well.
  - This is default for all IRC observation mode.

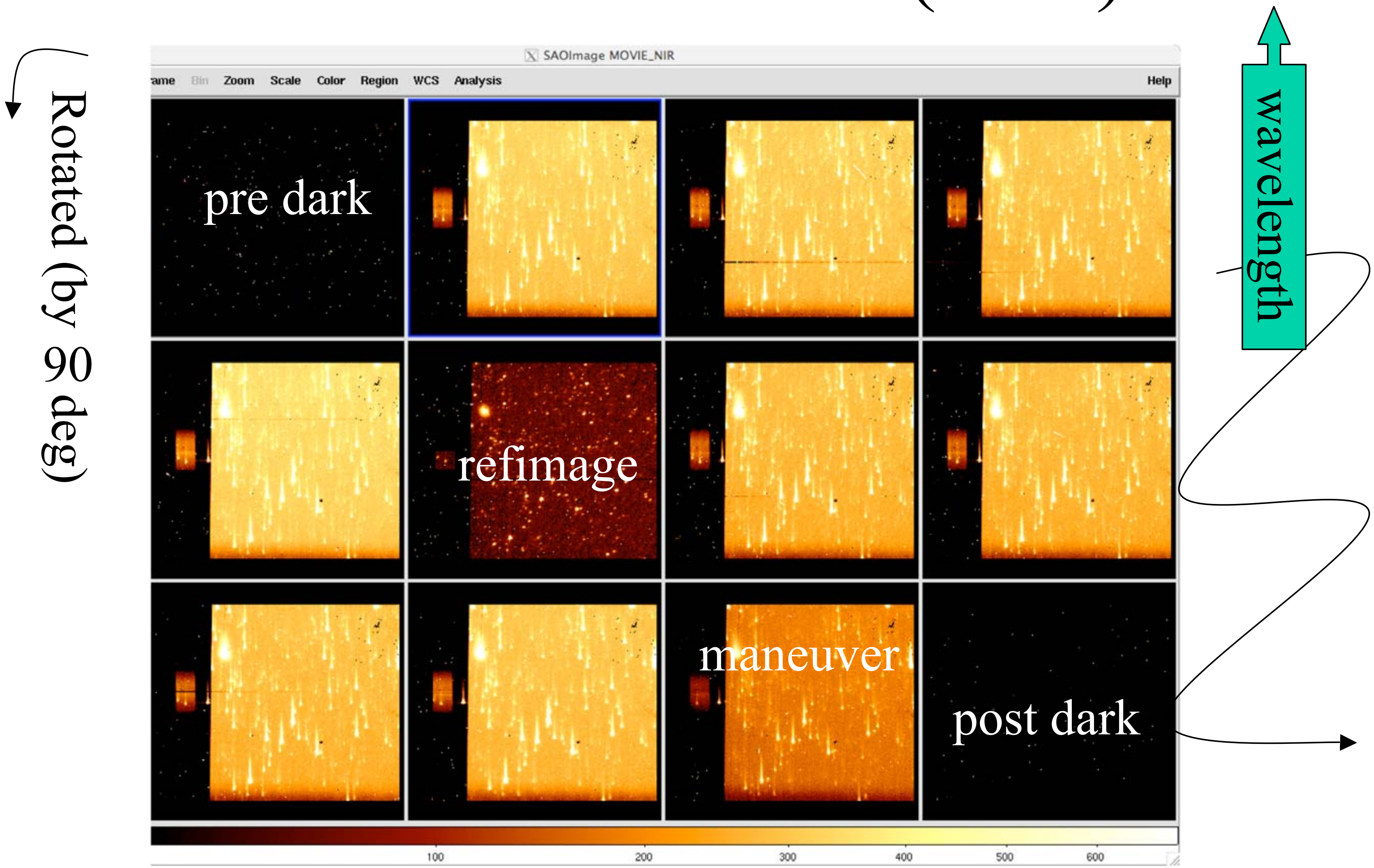
Preview of Raw/CAL Data

Rawdata in '/rawdata'

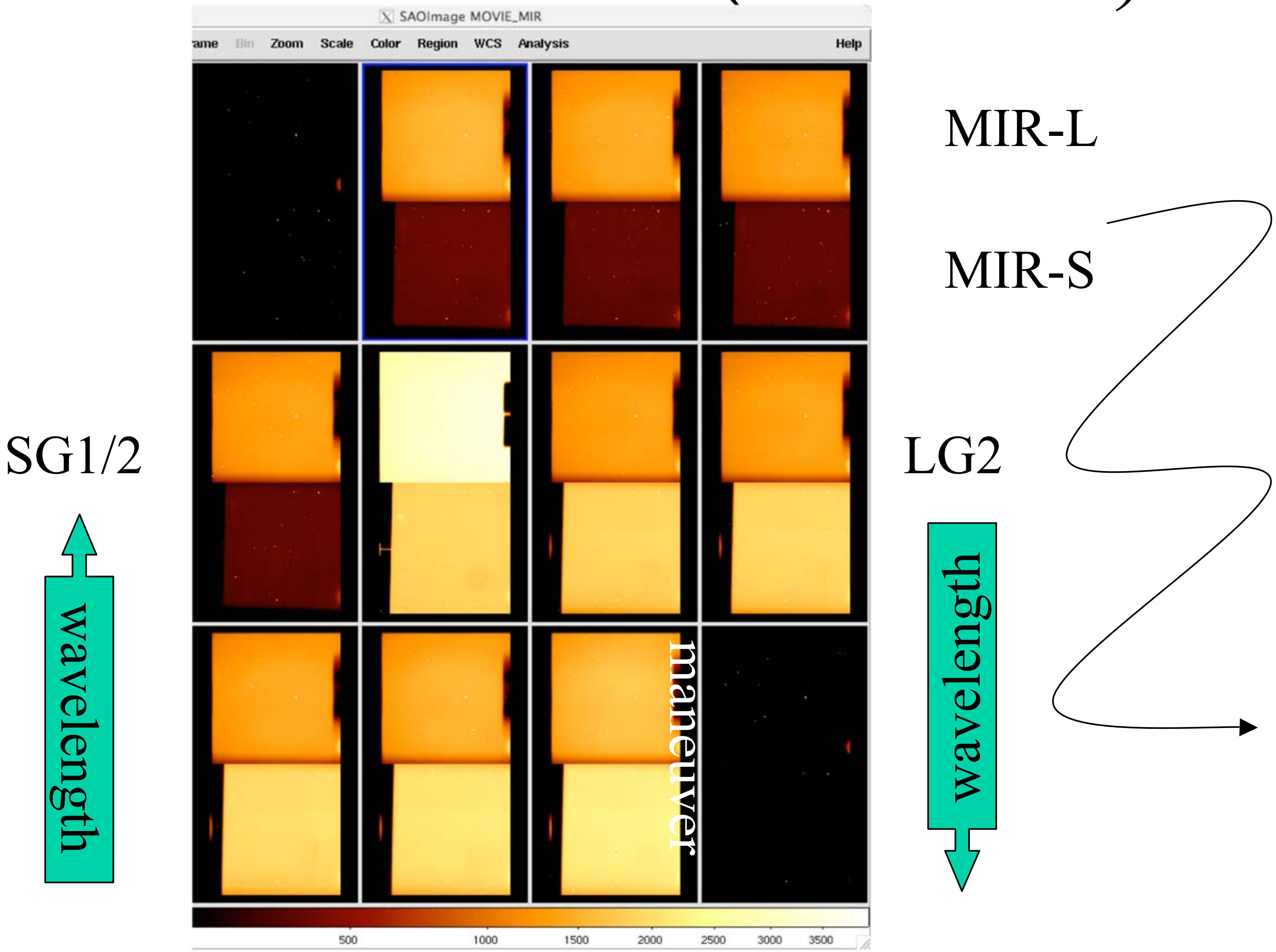
```
Terminal — ssh — 137x9
ohyama@cava3: cd ../rawdata/
/home/ohyama/hd1.cava/IRC/PV/SPEC/FLUX/5124003.1/rawdata
ohyama@cava3: ls
DARK_MIR.lst    F132903_N.fits  F132908_M.fits  F132913_N.fits  F132918_M.fits  F132923_N.fits  NP.lst            SG2.lst
DARK_NIR.lst    F132904_M.fits  F132909_N.fits  F132914_M.fits  F132919_N.fits  L18W.lst        OLD/              headerlist.tmp
F132900_M.fits  F132905_N.fits  F132910_M.fits  F132915_N.fits  F132920_M.fits  LG2.lst         README.5124003.1  headerlist_UT.tmp
F132901_N.fits  F132906_M.fits  F132911_N.fits  F132916_M.fits  F132921_N.fits  N3.lst          S9W.lst           suteki_irc.txt
F132902_M.fits  F132907_N.fits  F132912_M.fits  F132917_N.fits  F132922_M.fits  NG.lst          SG1.lst
ohyama
```



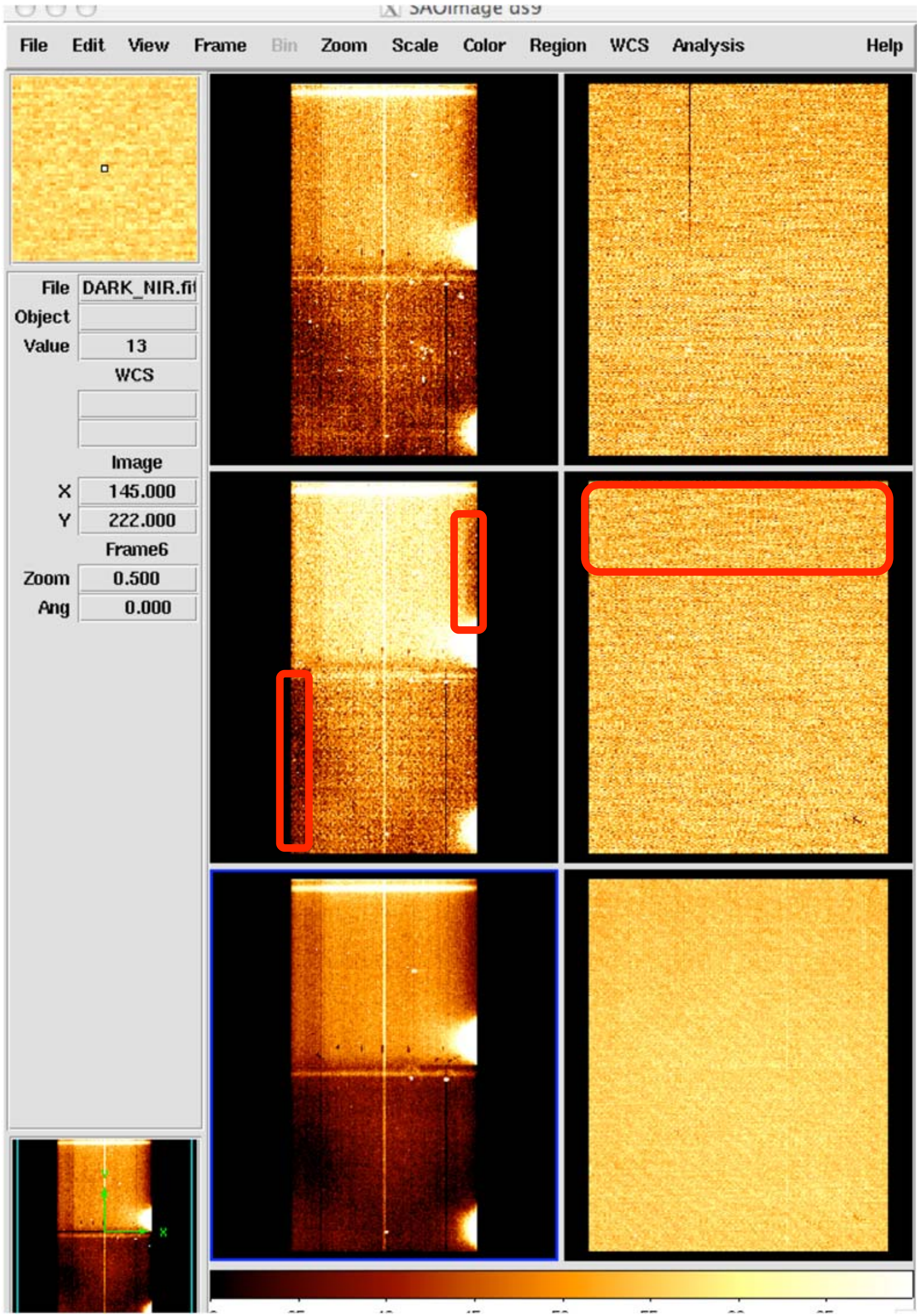
AOT04a Raw Data (NIR)



AOT04a Raw Data (MIR-S/L)



Darks (AOT04a)



Pre-dark

Slit area

Post-dark

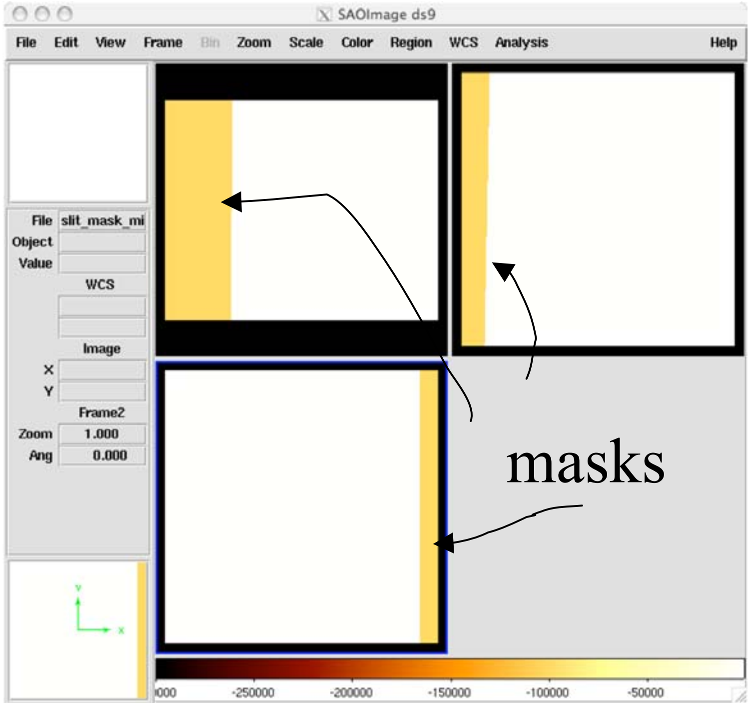
Super-dark

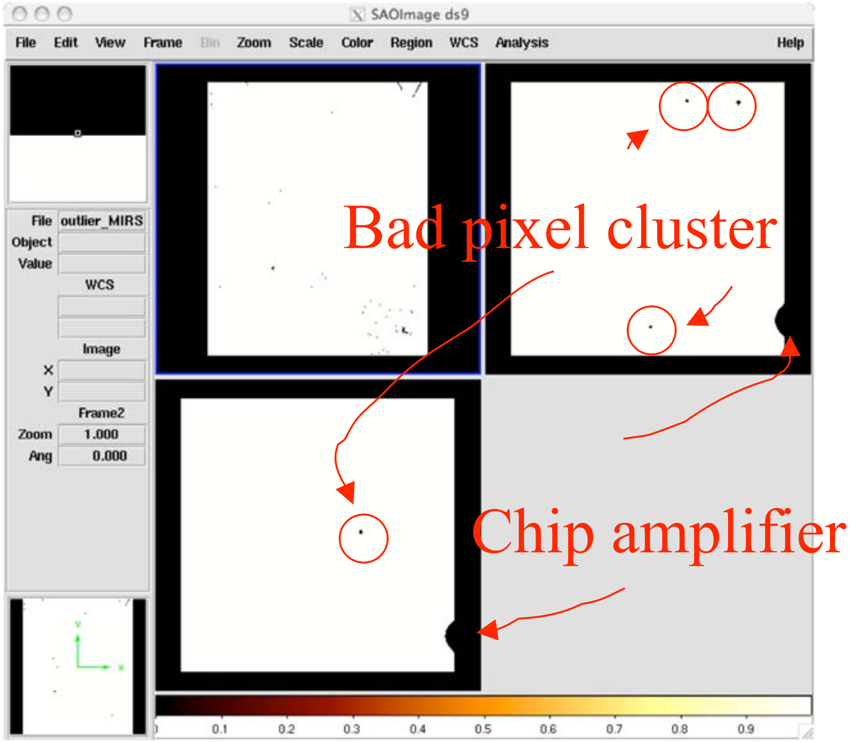
Calibration Data in '/CALIBDIR'

Terminal — ssh — 153x5

```
ohyama@cava3: pwd
/home/ohyama/ASTRO-F/IDL/ASTRO-F/IRC_SPECRED/CALIBDIR
ohyama@cava3: ls
COORDOFFSET/  DARK/  DISTPAR/  FLAT/  MASK/  OBSOLETE/  RESPONSE/  StdSpecData/  WAVEPAR/
ohyama@cava3: 
```

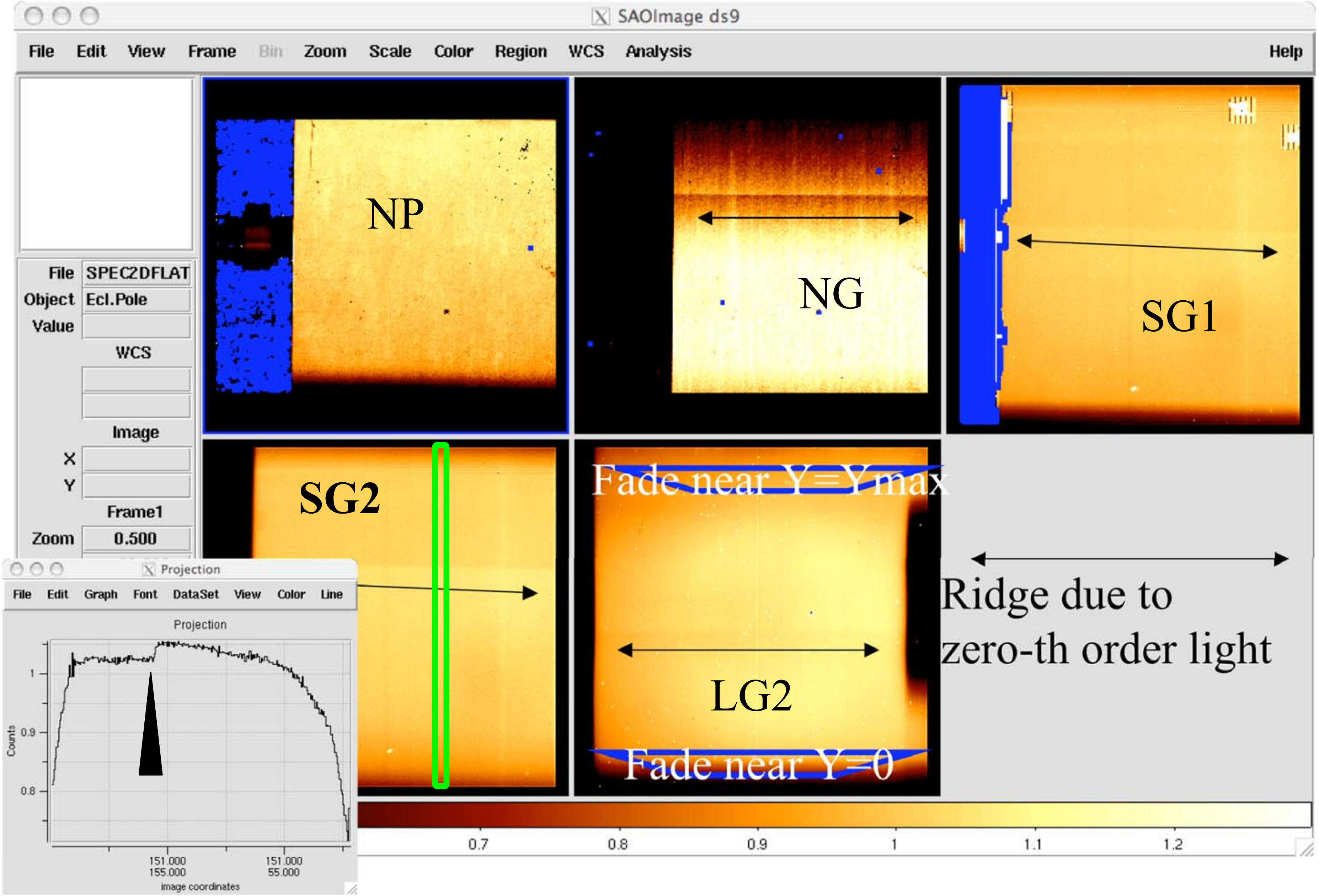
Masks
slit masks & outlier masks



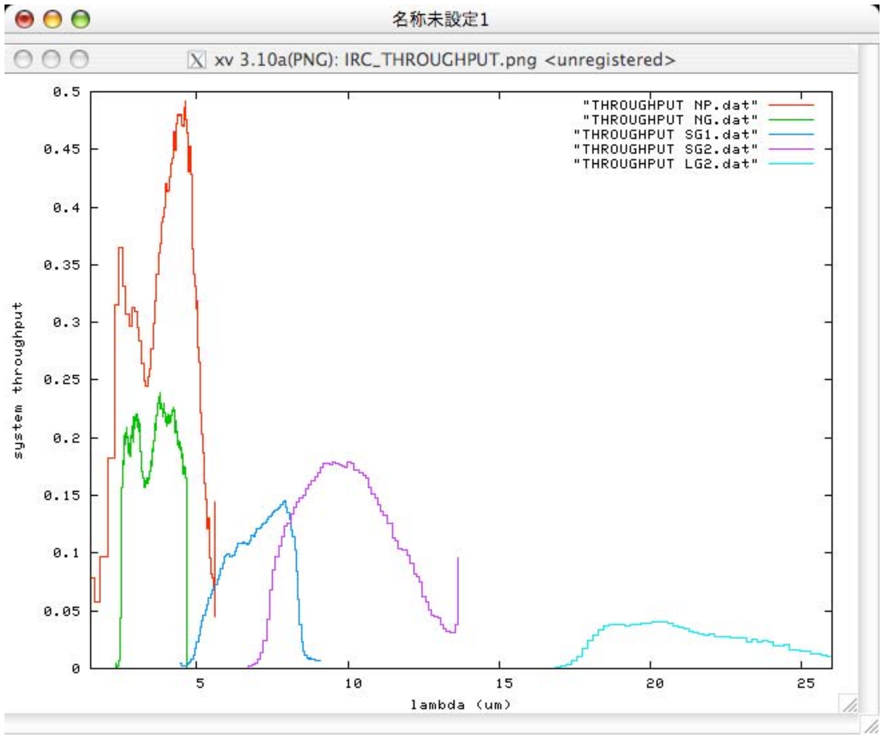


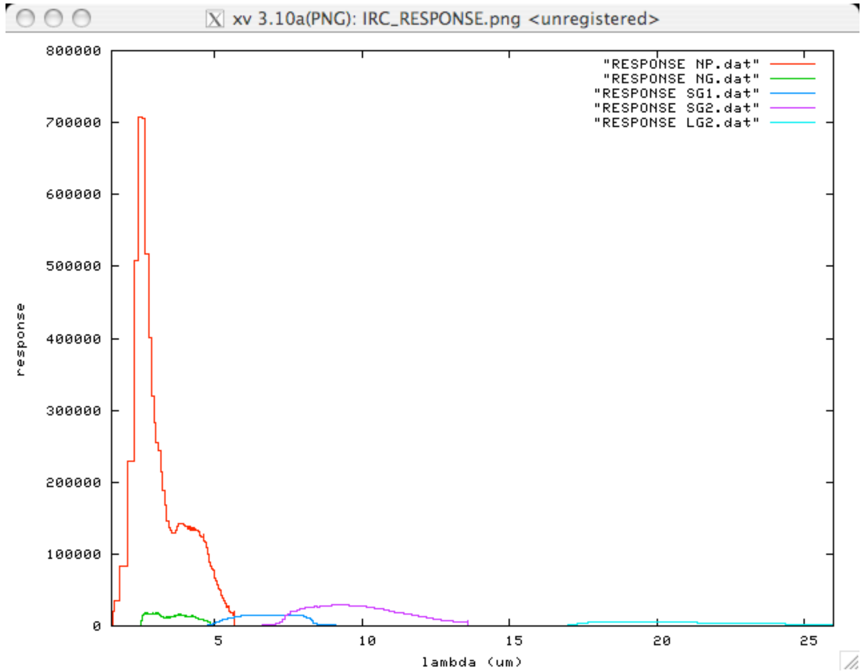
- NIR (UL), MIR-S(UR), and MIR-L(LL)

Spectroscopy Flats



Throughput & Spectral Response



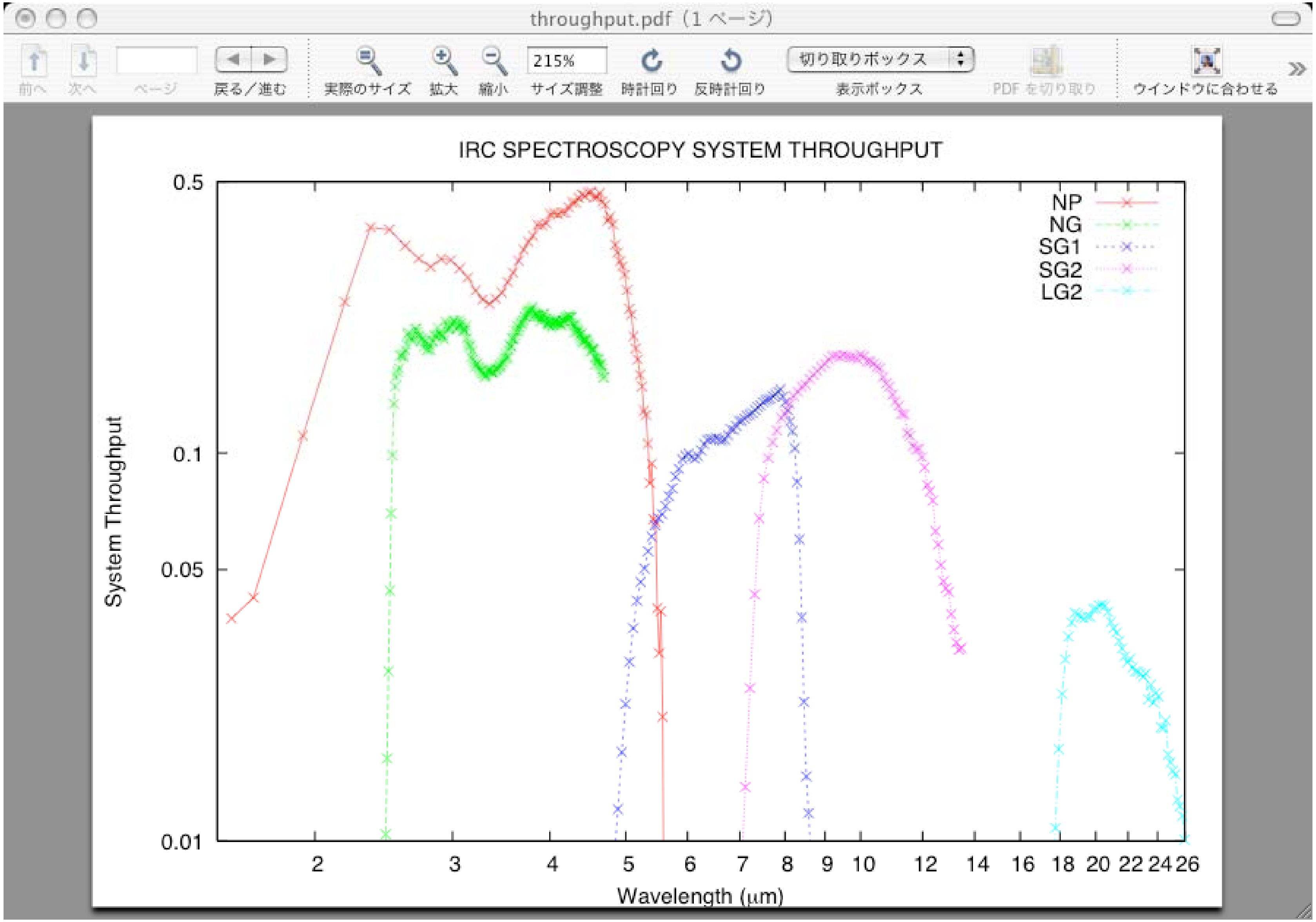


- Throughput: % including telescope/camera/array
- Spectral Response: ADU for long exposure frame/Jy

Performance Summary

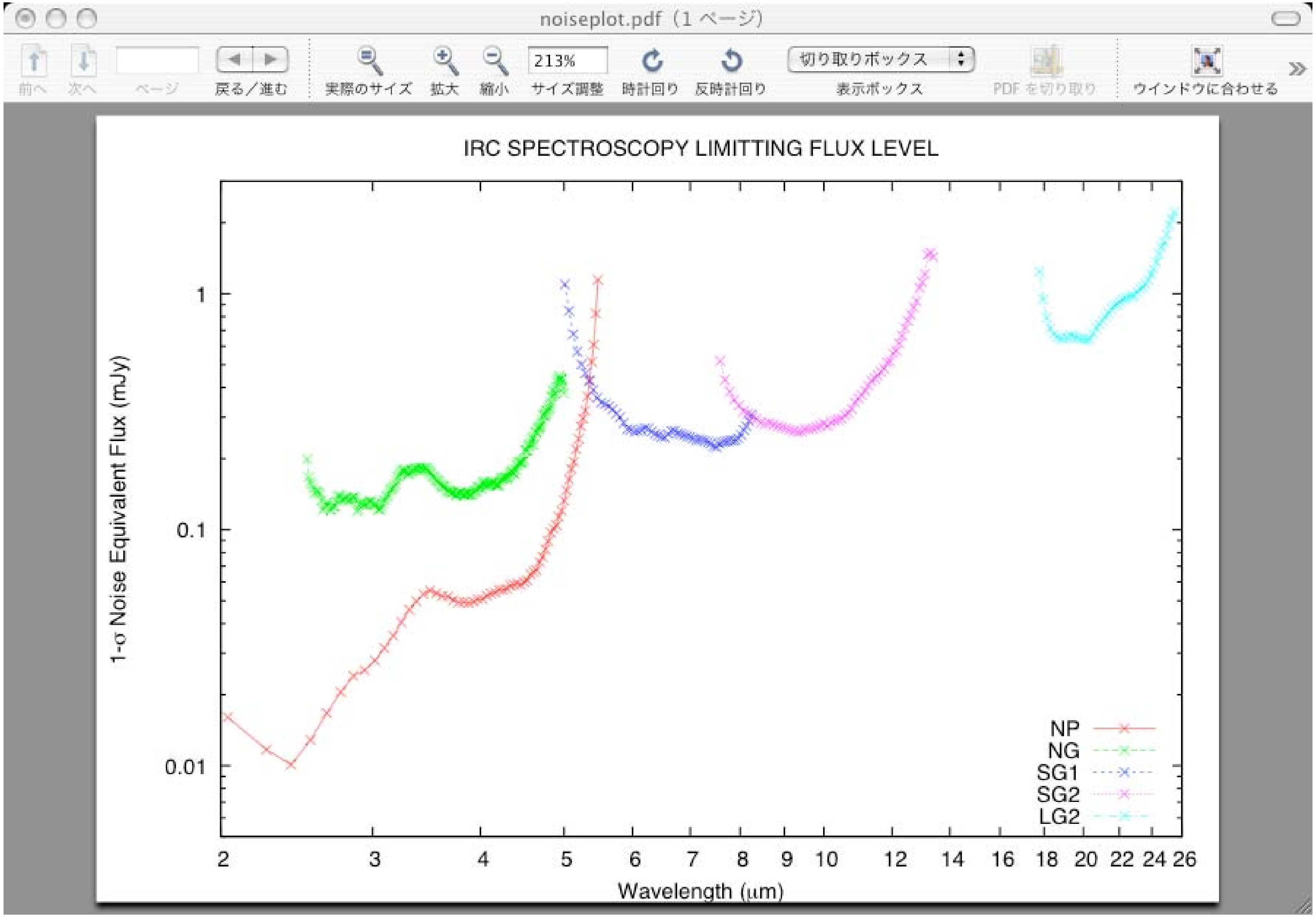
- Basically no change from the pre-launch expectation.

System Throughput

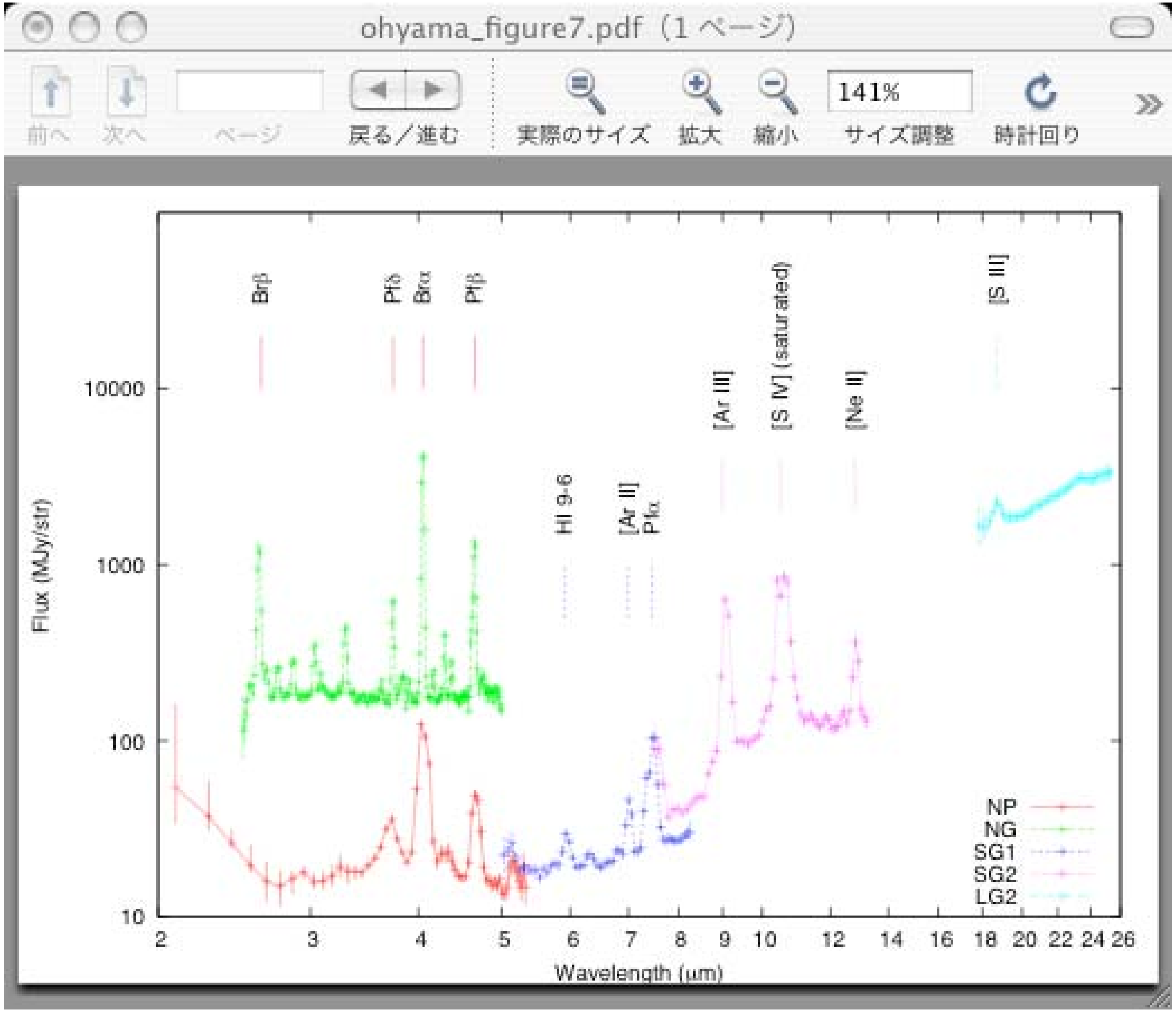


Sensitivity

(per AOT04, long, 1sigma)



Example 1: The Planetary Nebula



Example 2: The Infrared-Luminous Galaxy

- Intentionally removed. Sorry.

Calibrating the Data

The Spectroscopy Data Reduction ToolKit "IRC_SPECRED.pro"

- A single IRC_SPECRED works on both **<u>slit-less</u>** and **<u>slit</u>** modes.
  - Processing of the slit-mode data requires a subset of the procedures required for processing the slit-less mode data.
  - In the followings, we mainly describe the toolkit for the slit-less mode.

The Business Model of the IRC Business

- Observers observe their science targets.
- The IRC team observes calibration targets, creates standard calibration database, and provides them to observers.
- The IRC team also develops basic calibration tool (the toolkit) for general observers.
- Analyses of the basic-calibrated data will be made thoroughly by observers.
- Observers publish their results, and acknowledge us.
- The IRC team updates the calibration data and tools.

Purposes of the Toolkit

Load IRC AOT04 raw data to…

- convert input images
  - in a form of (X, Y, counts) in (pix, pix, ADU)

    To output images
  - in a form of (X, Y, wavelength, flux) in (arcsec, arcsec, um, mJy)
- based on standard calibration information (hereafter, the **CAL**),

To output

- the **basic calibrated data,** and…
- all associated information (the **AUX** output) obtained while creating the basic calibrated data.

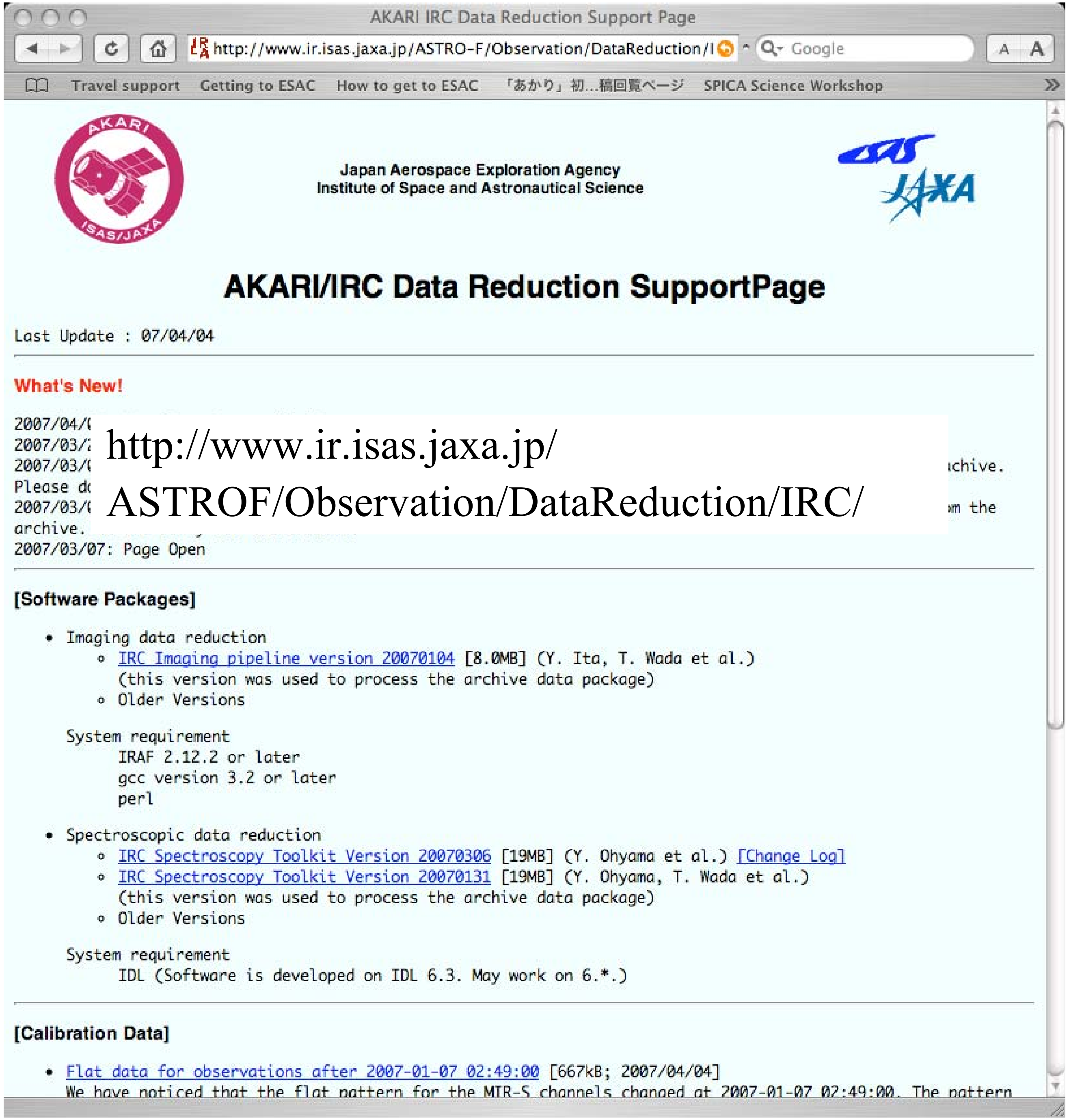
Out-of-purpose of the Toolkit

1. NOT to perform any further measurement of quantities for scientific analyses.
   - e.g., identify features, measure various kinds of quantities of the feature
2. Co-adding of more then 2 pointing data will NOT be made.

The Toolkit on the WEB

1. Download it,
2. extract it, and
3. set some environment variables

on your WS.


AKARI IRC Data Reduction Support Page

http://www.ir.isas.jaxa.jp/ASTRO-F/Observation/DataReduction/I

Travel support Getting to ESAC How to get to ESAC 「あかり」初...稿回覧ページ SPICA Science Workshop

Japan Aerospace Exploration Agency
Institute of Space and Astronautical Science

AKARI/IRC Data Reduction SupportPage

Last Update : 07/04/04

What's New!

2007/04/(
2007/03/
2007/03/(...chive.
Please d(
2007/03/(...m the
archive.
2007/03/07: Page Open

[Software Packages]

- Imaging data reduction
  - IRC Imaging pipeline version 20070104 [8.0MB] (Y. Ita, T. Wada et al.)
    (this version was used to process the archive data package)
  - Older Versions

  System requirement
  IRAF 2.12.2 or later
  gcc version 3.2 or later
  perl

- Spectroscopic data reduction
  - IRC Spectroscopy Toolkit Version 20070306 [19MB] (Y. Ohyama et al.) [Change Log]
  - IRC Spectroscopy Toolkit Version 20070131 [19MB] (Y. Ohyama, T. Wada et al.)
    (this version was used to process the archive data package)
  - Older Versions

  System requirement
  IDL (Software is developed on IDL 6.3. May work on 6.*.)

[Calibration Data]

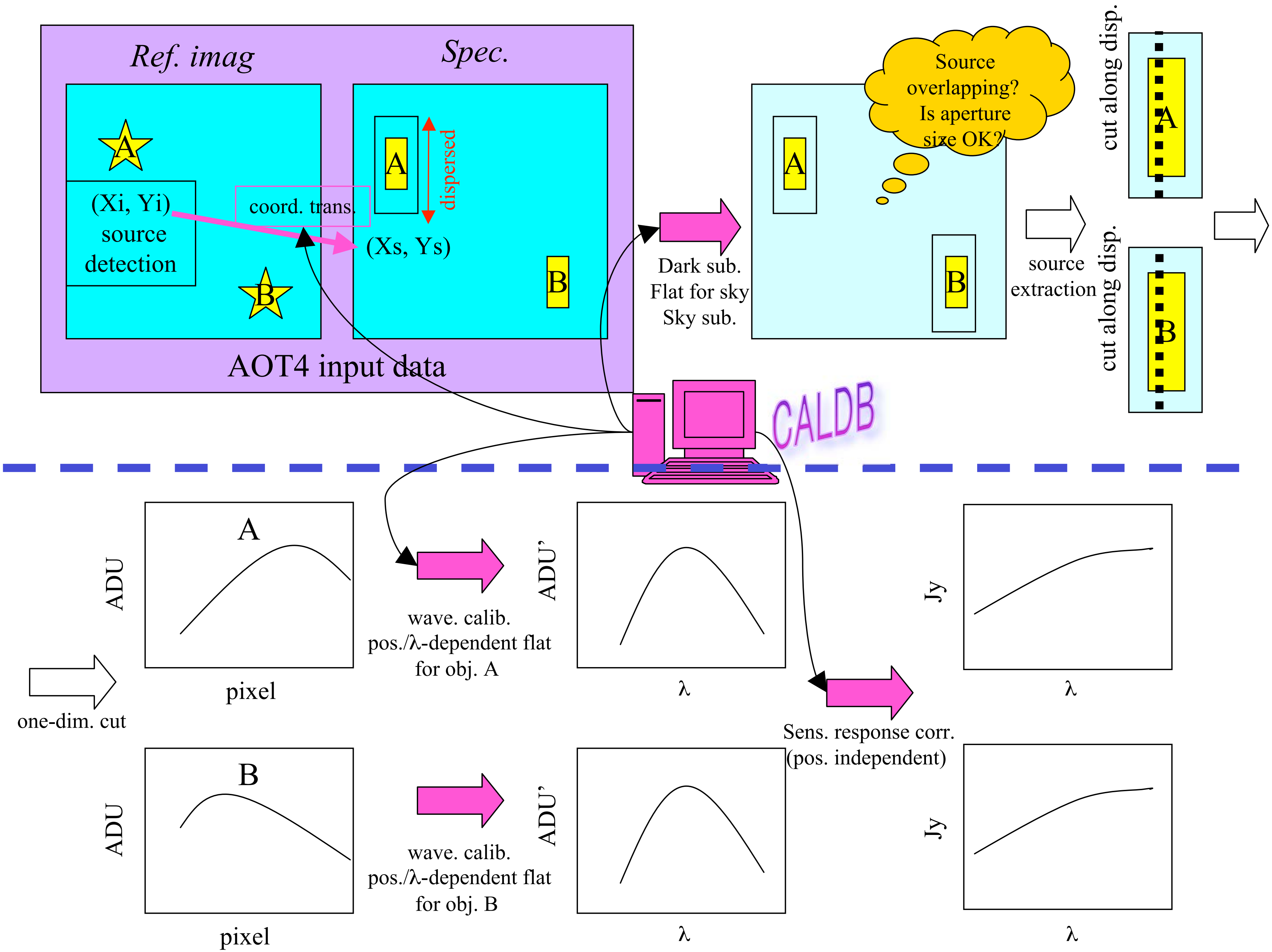
- Flat data for observations after 2007-01-07 02:49:00 [667kB; 2007/04/04]
  We have noticed that the flat pattern for the MIR-S channels changed at 2007-01-07 02:49:00. The pattern

http://www.ir.isas.jaxa.jp/
ASTROF/Observation/DataReduction/IRC/

Computer Environment for the ToolKit

- The toolkit is written with **IDL**. It also requires **DS9** FITS viewer and its associated **XPA** program.
  - The developers use IDL ver 6.1 & 6.2 on Linux PCs.
    - But IDL ver 6.3 and/or other UNIX platform should be fine.
    - It is known to work on Mac OS-X running X11.
    - No report from Windows users.
- The toolkit requires the ASTROLIB IDL library at GFSC and others, in addition to our home-made programs.
  - ${IRC_SPECRED_ROOT}/LIB/… ASTROLIB
    +${IRC_SPECRED_ROOT} /ASTRO-F/… our-own PROs.

Schematic Presentation of the Calibration Processes



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

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 is *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.

Review of Input/Output Parameters of the ToolKit

[INPUTs]

- File lists of the 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.
    - The toolkit will skip its built-in object detection procedure if the list is set.
- CAL database (mandatory):
  - The standard calibration data set is distributed with the toolkit package.
  - Directory of the CAL database should be set by computer environment parameters.

[OUTPUTs]

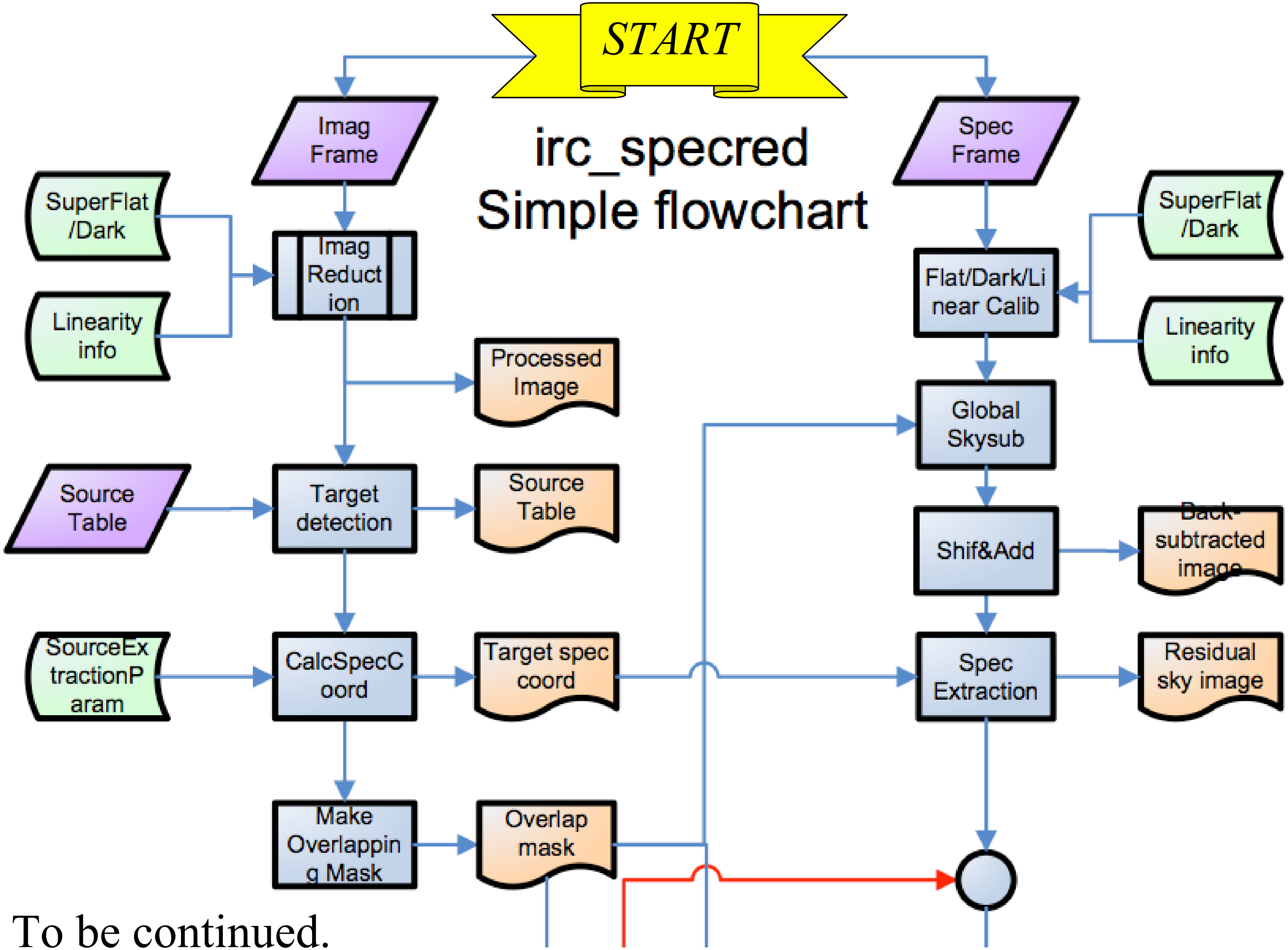
Main outputs:

- Object catalogue:
  - A table of object information, including target location, brightness, size, coordinates of the spectroscopy apertures, etc.
- Processed WHOLE images of reference/spectroscopy images:
  - Co-added images of input frames after calibrated for flat, dark, and background.
- A series of EXTRACTED reference/spectroscopy images of each object:

Auxiliary outputs:

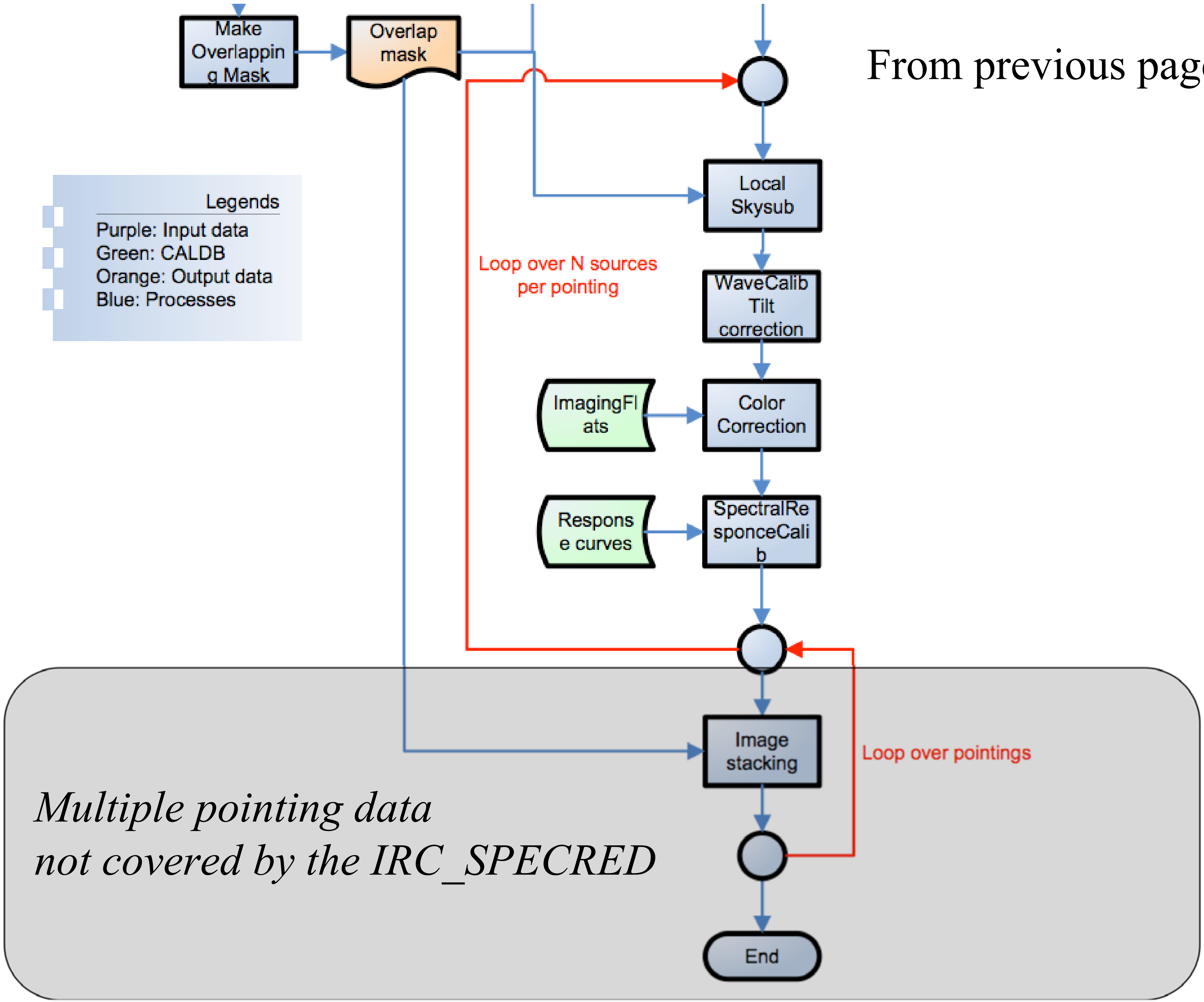
- WHOLE Mask images:
  - Images showing the object occupation on reference/spectroscopy images.
- WHOLE Images after removing (masking) detected objects:
  - Combined images masked for the detected objects.
  - The images could be useful to examine object detection completeness, background subtraction quality, total noise quality, etc., of the toolkit.
- A series of 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.
- DS9 region files for identifying extraction area, zero-th order light occupation, etc.

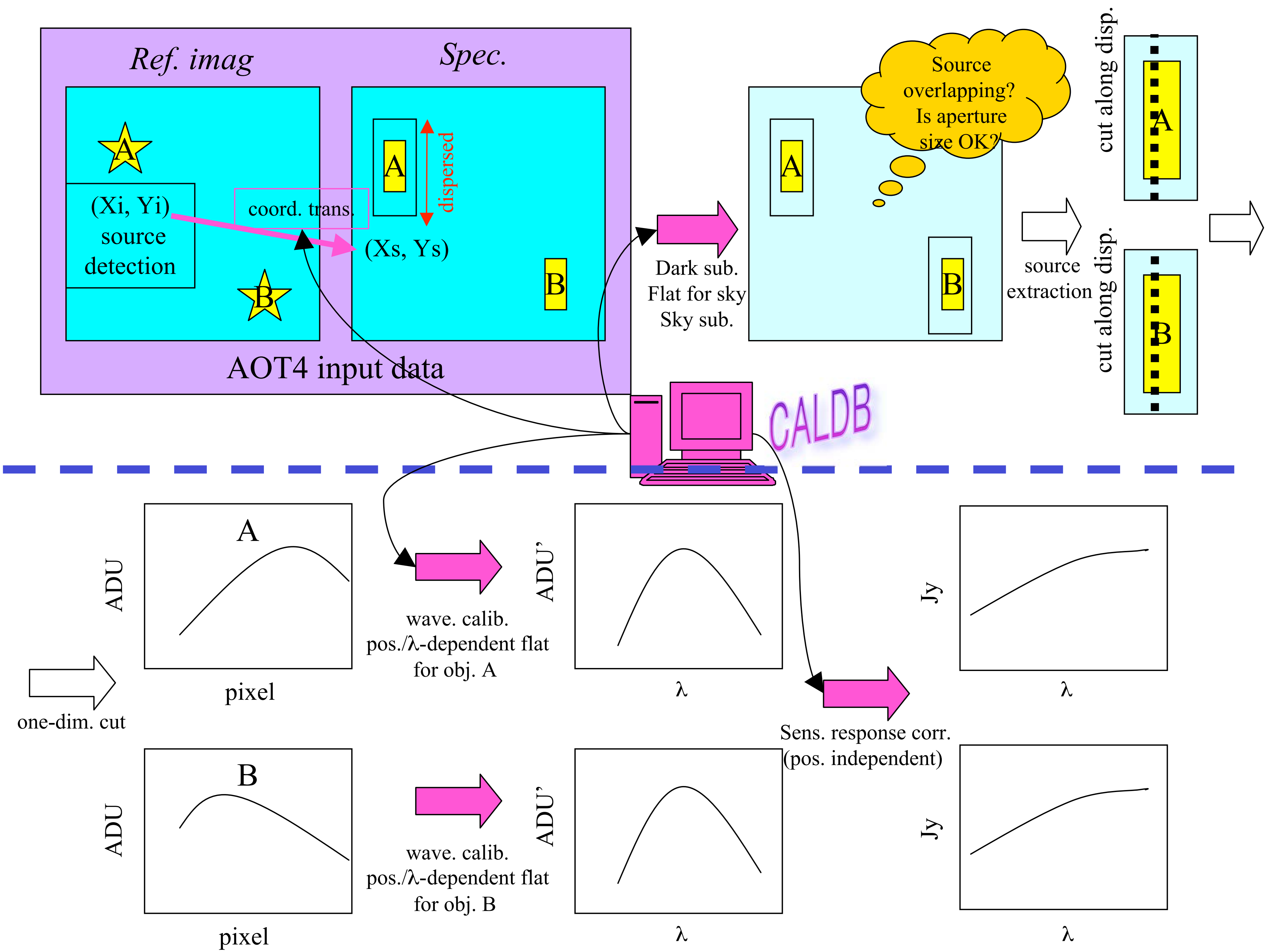
The Calibration Flowchart



To be continued.

From previous page





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

Review of Basic Calibration Processes in the ToolKit

- [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]

- The standard dark images will be provided in the CAL database.
- Note, however, simple subtraction of the standard dark image may fail to work correctly because of dark level fluctuation among frames
  - Due to both the memory effects and the 1st frame effect.
- The toolkit measures the dark count level in each image, and then subtracts the scaled standard dark images.
  - The measurement will be made on a small area where the focal-plane slit mask shadows the background light.

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

- Standard bad-pixel masks will be provided in the CAL database.
  - Some bad pixels (mostly hot pixels) and small clusters of them are known to exist on both the NIR and MIRS/L chips.
- The masks will be taken into account in all toolkit procedures.
  - Such bad pixels cannot be subtracted off properly with the dark subtraction procedure.
- 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]

- Flat fielding will be made by dividing the dark-subtracted images with the flat images.

Sky Subtraction [REF/WHOLE]

- Sky will be removed from each subframe.
  - By locally fitting the sky image,
  - With object rejecting algorithm.

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.
- The toolkit converts their coordinates into that in the spectroscopy images based on the CAL database information.
    - In the slit-less mode, wavelength zero point and location of the spectroscopy apertures are determined by the object location on the reference images.
  - No source detection will be made on the spectroscopy images.
  - This is because all the sources detected in the spectroscopy images should also be detected on the reference images.
- The toolkit utilizes the DAOFIND code to automatically detect objects in the reference images.
  - The detection parameters (noise level, detection threshold over the noise level, and source size) can be changed interactively and iteratively within the toolkit.
- The toolkit also has a capability to accept a user-created target table as an input.
  - 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]

- Local sky is measured by fitting with
  - Source rejection algorithm
  - Masks made based on detected sources on the reference image

Frame Stacking [SPEC/WHOLE]

- Shift-and-adding sub-frames
- While removing cosmic-ray events.

Spectral Extraction [SPEC/WHOLE]

- Spectral images of each source are extracted
  - Extraction box coordinates (Xs, Ys) are calculated based on
    - source coordinates on reference image (Xi, Yi)
    - coordinate offset (dX, dY)

    and
  - Extraction box size (width, length)
- Extracted images cover both
  - Source area
  - Surrounding sky area
- Spectral masks will be also created.

Wavelength Calibration [SPEC/EXTRC]

- Basically no image transformation will be made.
- Rather, wavelength array will be created.
  - For grisms…
    - Wavelength=linear_function(dY, d_lambda, lambda0)
      - dY: pixel increment along Y, w.r.t. center of extracted spectral image.
      - D_lambda: wavelength inclement per pix (um per pix)
      - Lambda0: wavelength (um) at reference position (image center)
  - For prism…
    - Wavelength=3rd-order-poly(Y)
      - Function is measured based on pre-launch laboratory test.
  - Single wavelength array per whole image
    - That is common to all extracted spectral images.

Sky Subtraction [EXTRAC/SPEC]

- Any remaining sky is subtracted.
  - Sky is an average of surrounding sky area of each extracted spectral image.

Color Correction [SPEC/EXTRAC]

- Ideally, flat response is a function of
  - Pixel (X and Y)

    And
  - Wavelength (lambda)
- Spectral flat correction applied at the early stage of calibration over the whole image was
  - a function of pixel, but
  - not a function of 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 plot routine.

Recommended Processing 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.

Operation of the Toolkit

Input Information

- File lists

ohyama@cava: ls *lst

DARK_MIR.lst L18W.lst N3.lst NP.lst SG1.lstDARK_NIR.lst
LG2.lst   NG.lst S9W.lst SG2.lst

ohyama@cava: ls *tbl

target_MIRS.tbl

target_MIRL.tbl

5020056_5_N3_NP_target_table.tbl

5020056_5_S9W_SG1_target_table.tbl

5020056_5_S9W_SG2_target_table.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

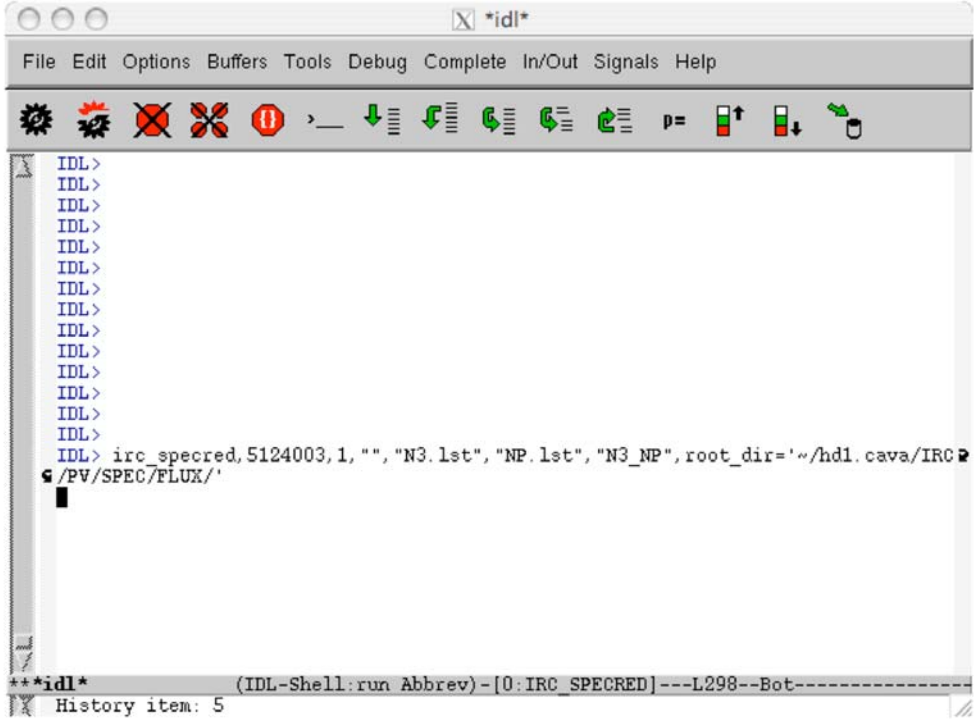
F54927_N.fits

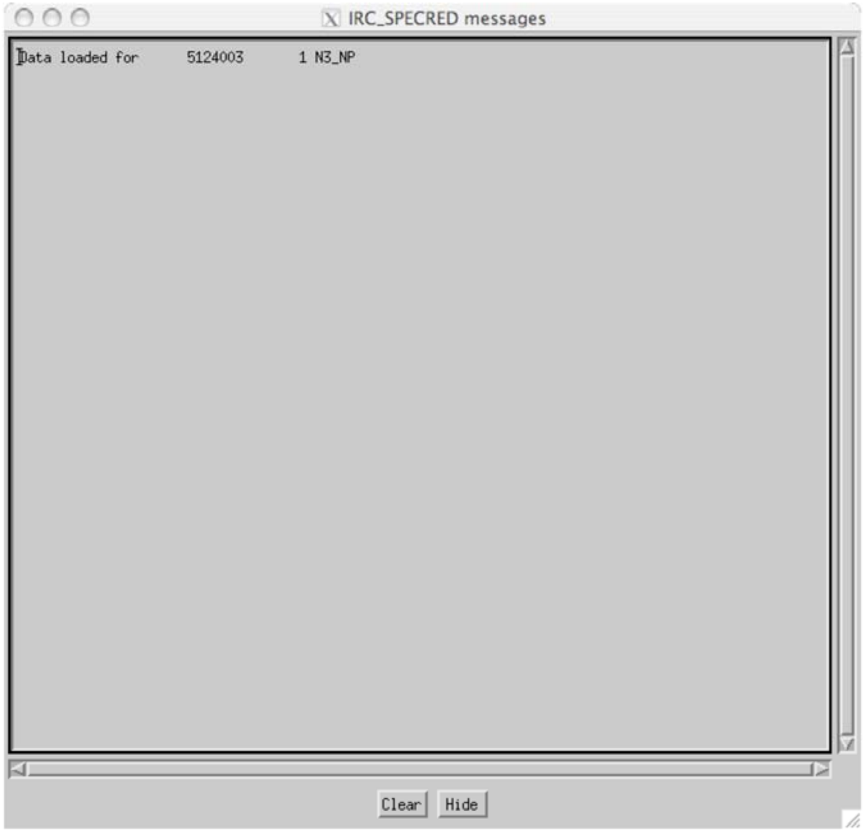
- Source Table

ohyama@cava: more 5020056_5_S9W_SG1_target_table.tbl

52.1651	17.7651
73.3098	25.5560
32.2403	113.417
94.7317	78.1639
114.406	74.0791
129.454	100.110
159.639	62.0461
213.167	23.4816
212.757	85.6808
206.567	127.160
167.850	221.823
167.850	221.823
222.679	234.424

Step 1:
Start the Pipeline
The case of NP/no source table



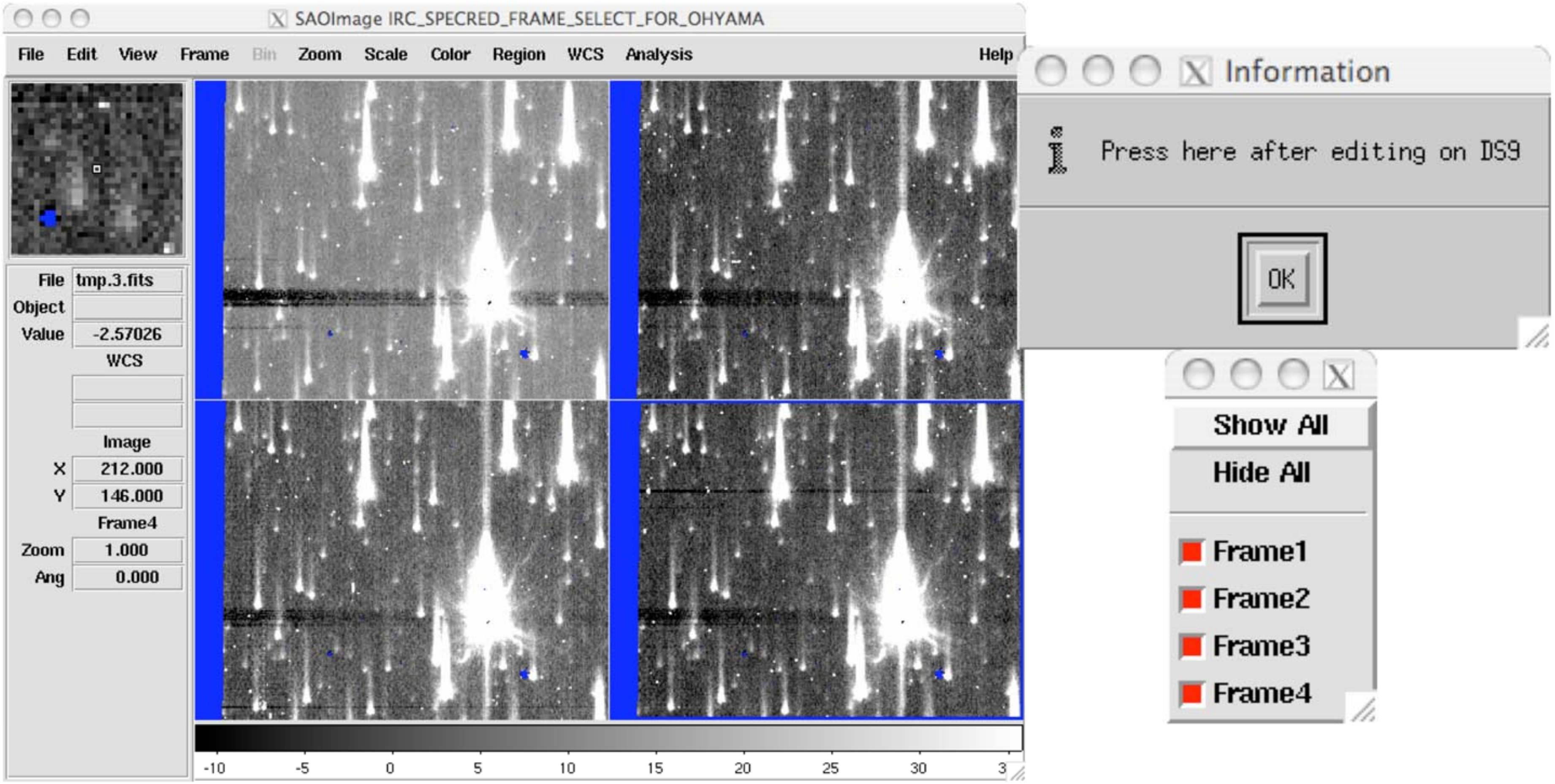


- Left: Issue a pipeline command at the IDL command line.
- Right: A log window will show up.

Example of IRC_SPECRED Commands

- Slit-less
  - irc_specred,5020056,1,"","N3.lst","NP.lst","N3_NP",root_dir='/data/IRC/TEST/'
- 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",root_dir='/data/IRC/TEST/',/NS_spec

Step 2: Screening sub-frames



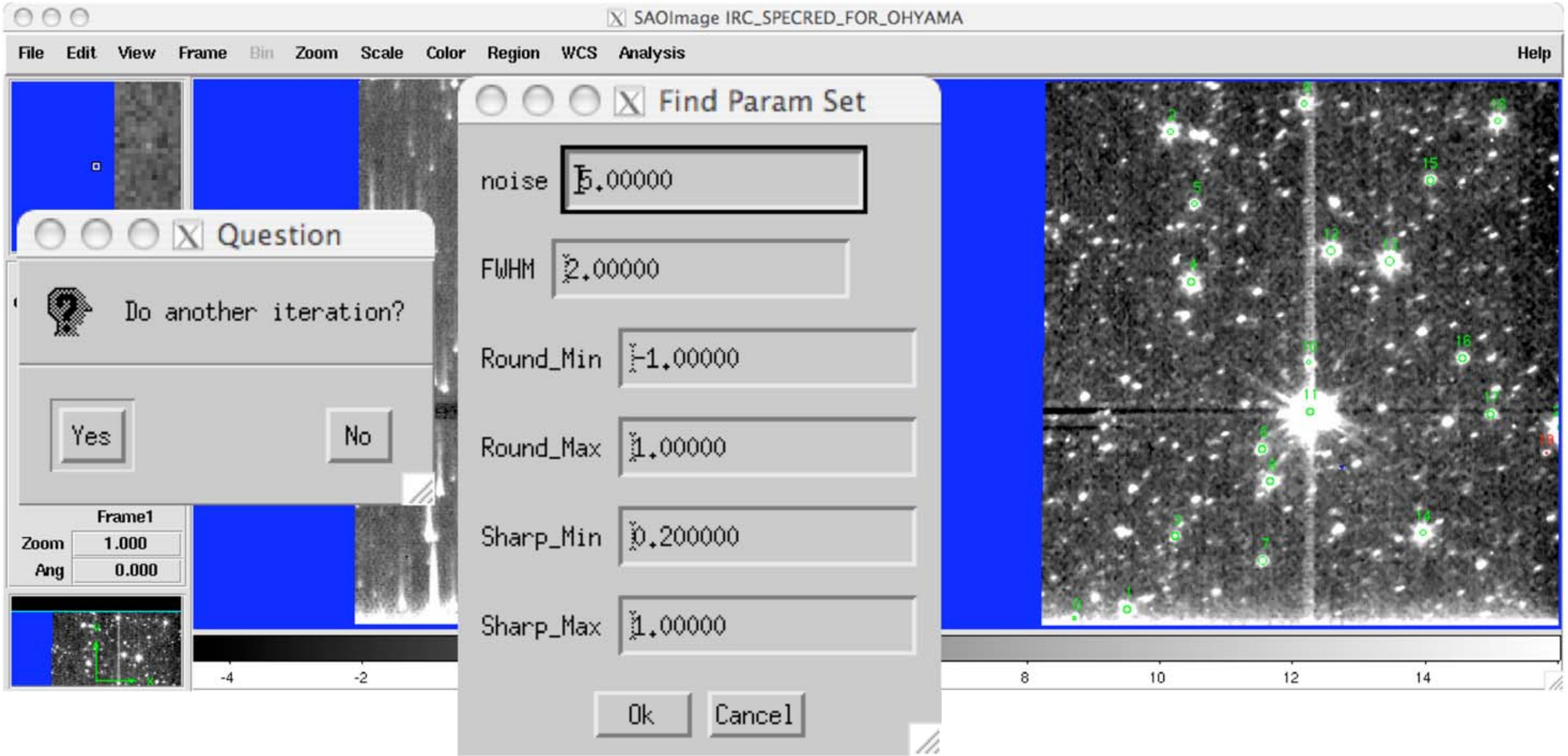
- NIR sub-frames are shown on ds9.
  - Note: Typical AOT04a gives 8 or 9 sub-frames.

Self-measured Information or DATABASE

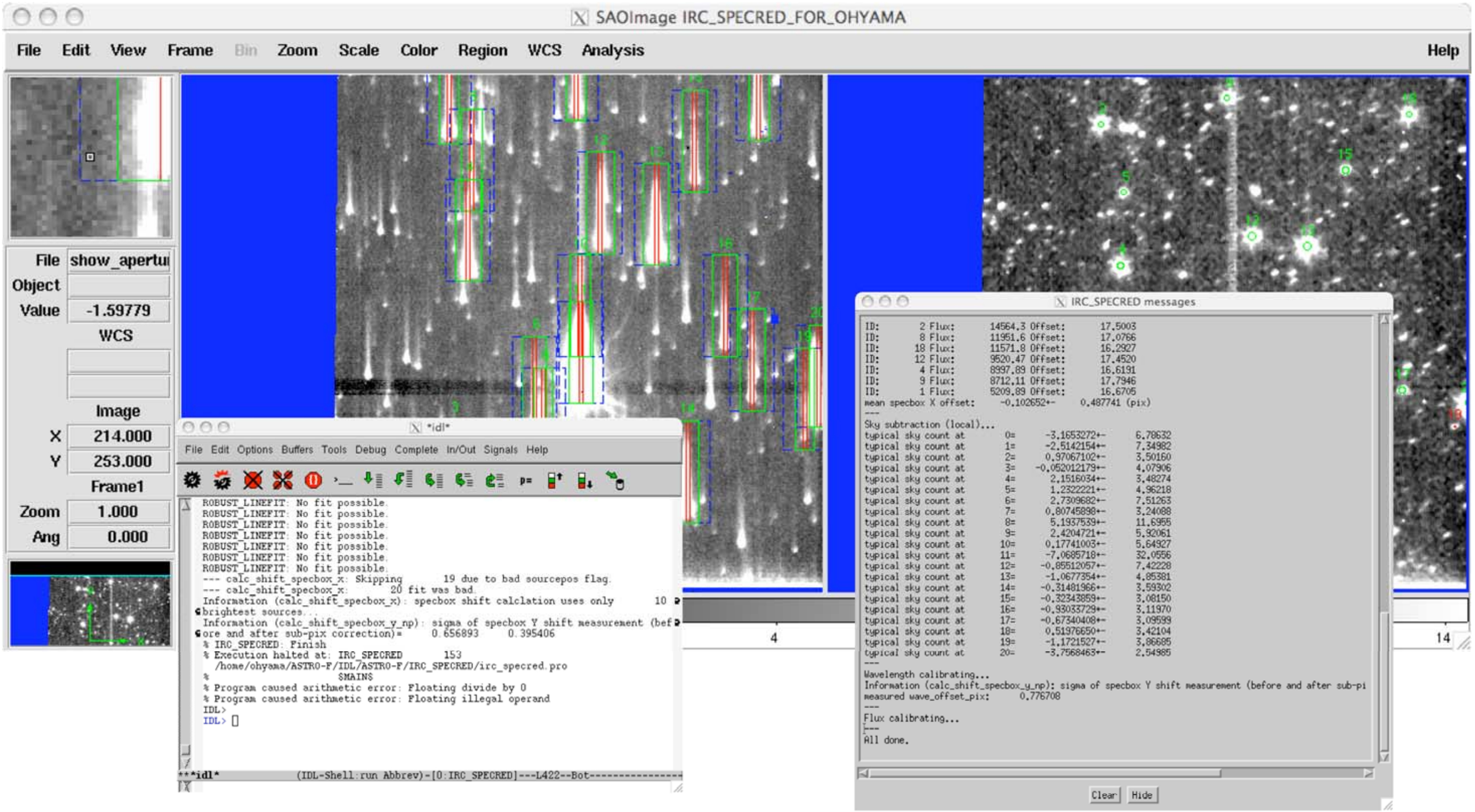
```
ohyama@cava: ls *dat
NP_SHIFT_XY.dat
NP_SPECBOX_SHIFT_X.dat
NP_SPECBOX_SHIFT_Y.dat
ohyama@cava: cat NP_SHIFT_XY.dat
0      0.00000      0.00000
1      0.00000      0.00000
2      0.00000      0.00000
3     0.00000      0.00000
4     -1.00000      0.00000
5     -1.00000      0.00000
6     -1.00000      0.00000
7     -4.00000      0.00000
ohyama@cava: cat NP_SPECBOX_SHIFT_X.dat
     0.00000
ohyama@cava: cat NP_SPECBOX_SHIFT_Y.dat
   -0.573364
```

This information will be used for coming MIR-S/L processing.

Step 3:
Tweak 'find' parameters
(with auto-detection sub-program)

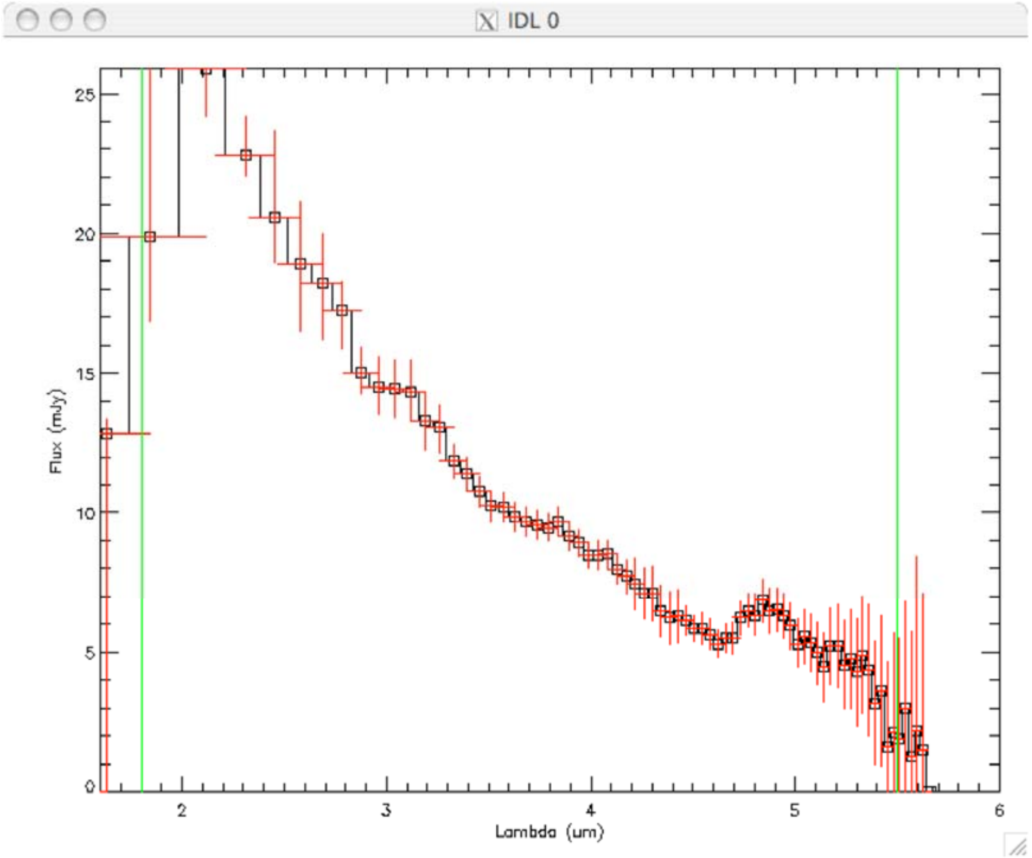


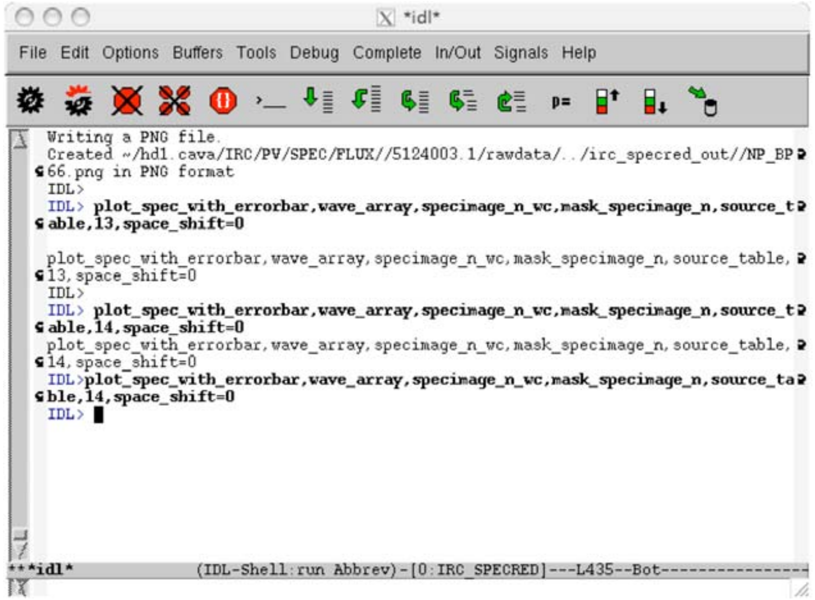
Step 4:
‘All done’/’Finish’



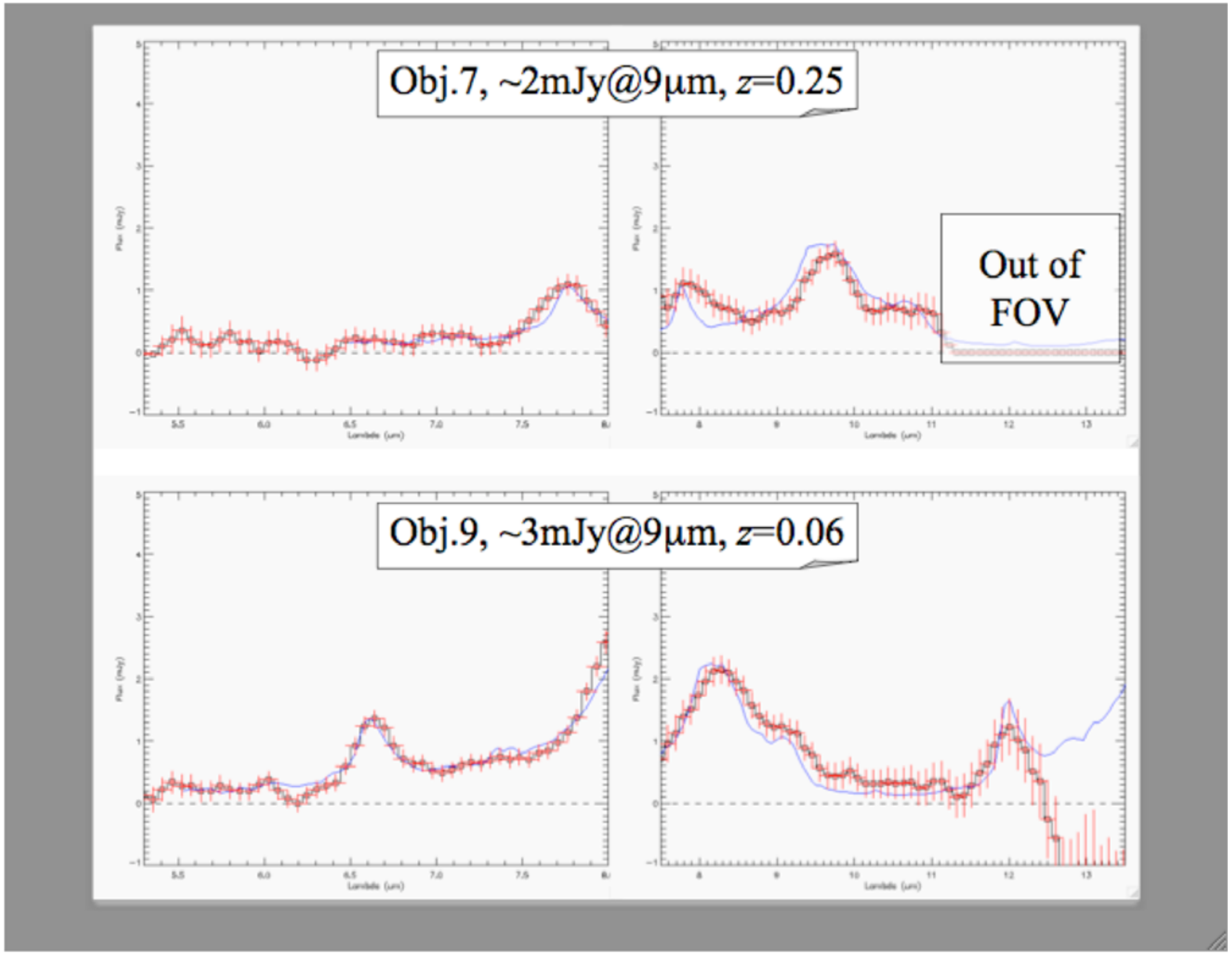
Step 5: Examine Spectra

with plot_spec_with_image





… And more spectra (SG1/2)



Working with the Plotting Tool

- Basic (for plotting spectrum of source_id=1):
  - plot_spec_with_image,wave_array,specimage_n_wc,mask_specimage_n,source_table,1
- Options:
  - Plotting related
    - yrange=[-1,5]: plotting range along Y axis
    - Space_offset=1: move plotting region along X (space)
    - Nsum: plotting width
    - Smooth=3: box smoothing along wavelength.
    - /no_mask: plot without masking
  - With_image related
    - /with_image: show an extracted image along with spectra.
    - tvtop=10,tvbottom=-2: display range (top and bottom)
  - Output related
    - Png='PNG file', ps='ps file', ascii='ascii-table file'

List of Output Products

Terminal — ssh — 136x22

```
ohyama@cava3: pwd
/home/ohyama/hd1.cava/IRC/PV/SPEC/FLUX/5124003.1/irc_specred_out
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
ohyama@cava3:
```

Review of FITS Outputs

<u>REFIMAGE</u>

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

<u>SPECIMAGE</u>

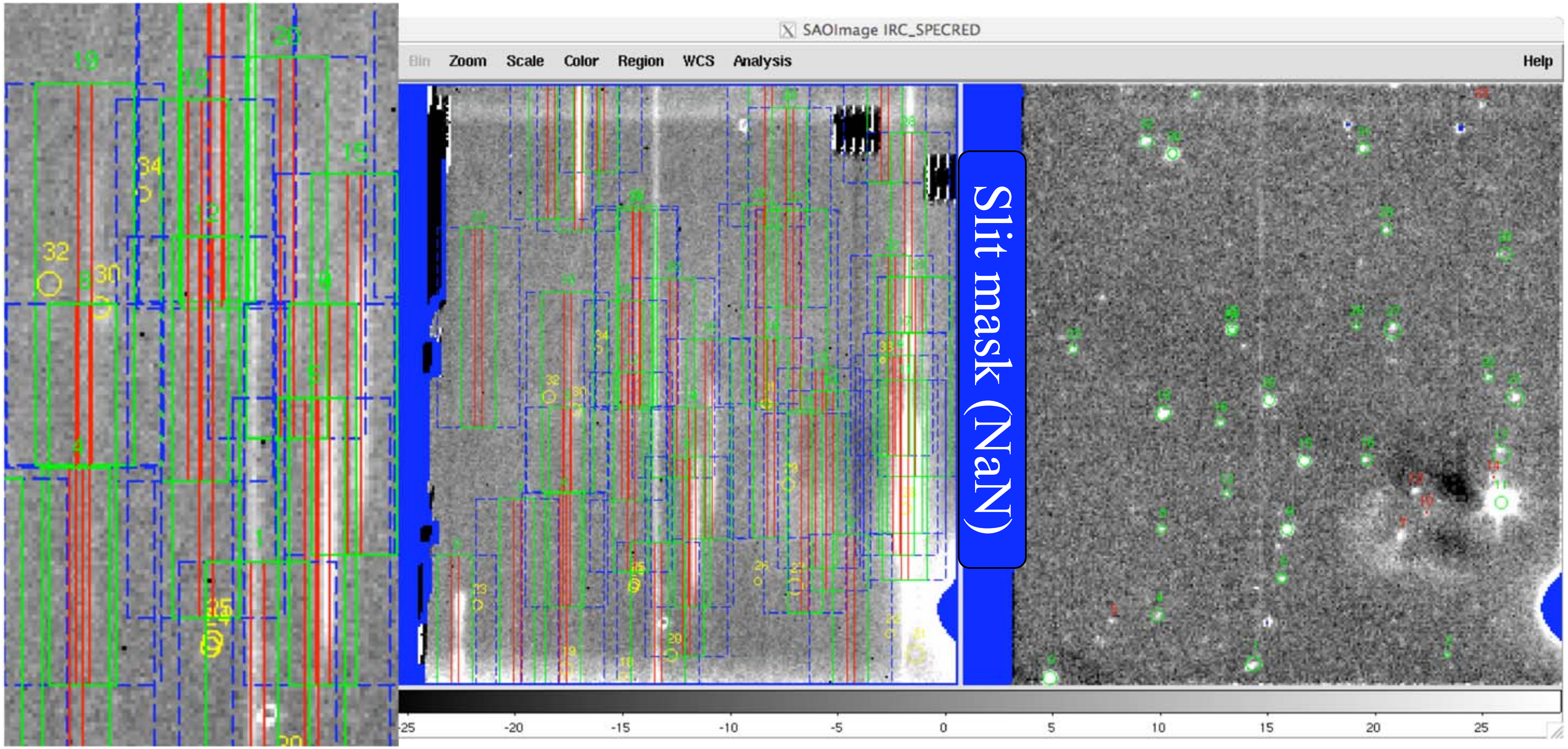
- Whole:
  - Specimage_bg
  - Specimage_mask
  - Residual_specimage_bg
- Extracted:
  - Specimage_wc_indiv
  - Specimage_fc_indiv
  - Specimage_mask_indiv
- Region file
  - Specimage.reg

<u>Others</u>

Source table.tbl

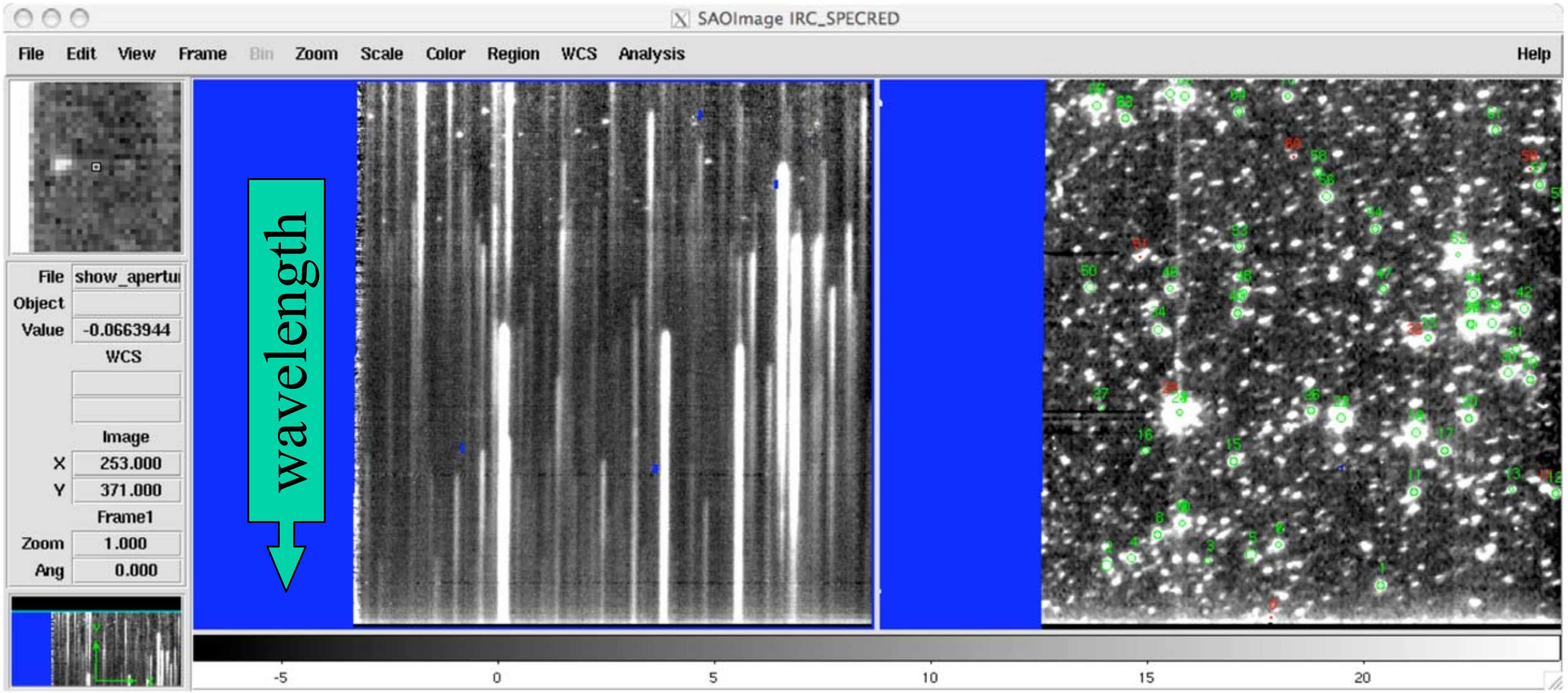
Processing log.log

[WHOLE IMAGE PRODUCTs]
SG1



specimage refimage

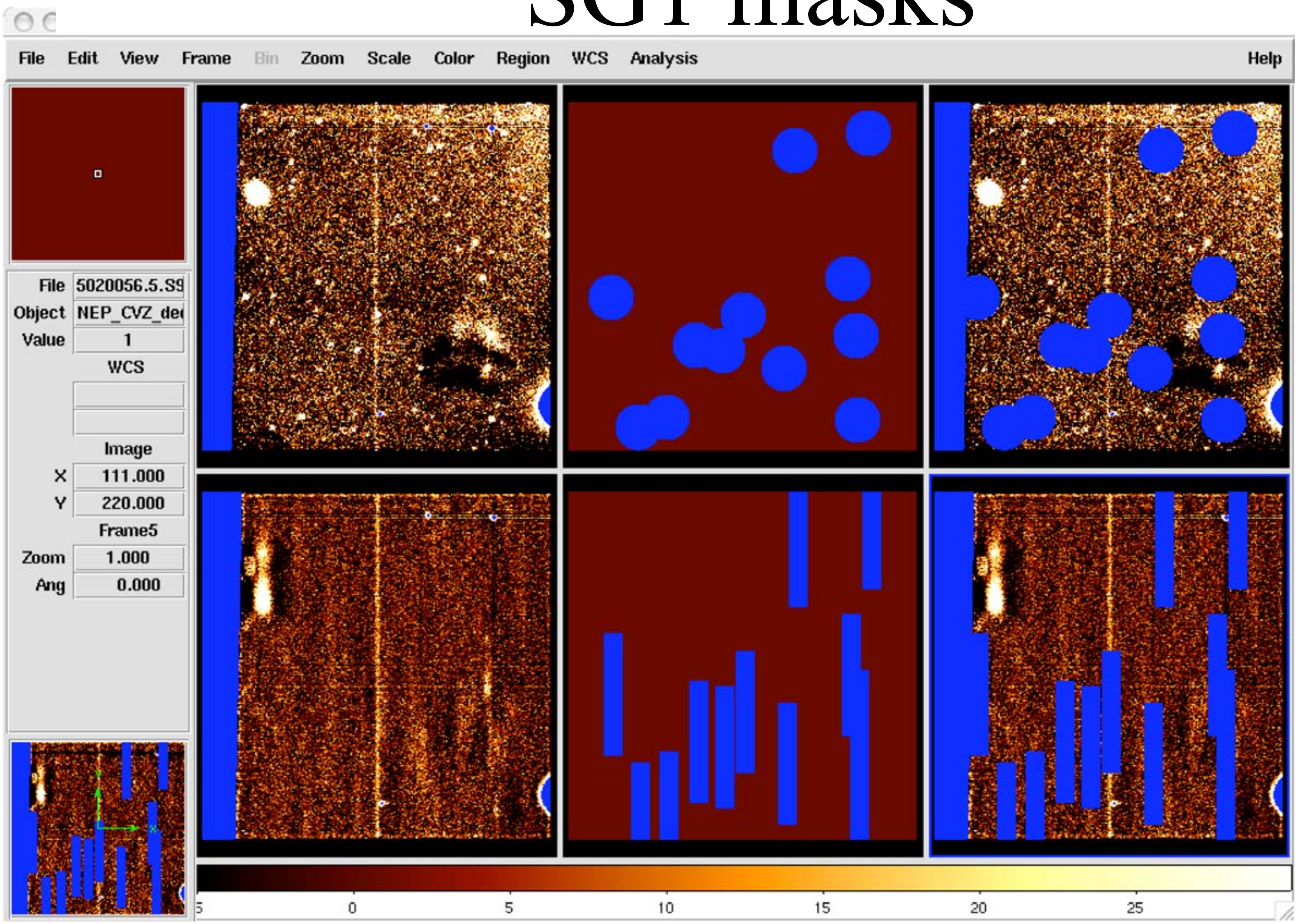
[WHOLE IMAGE PRODUCTs] NG



specimage

refimage

[WHOLE IMAGE PRODUCTs]
SG1 masks



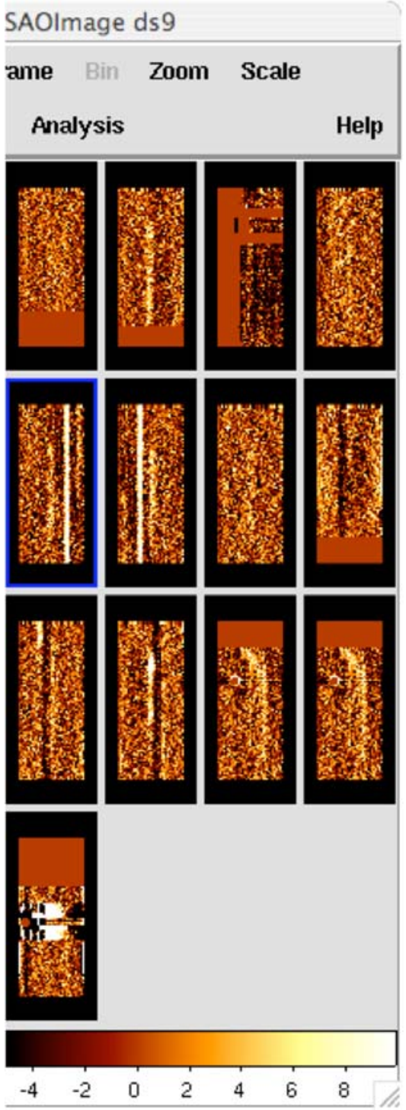
refimage

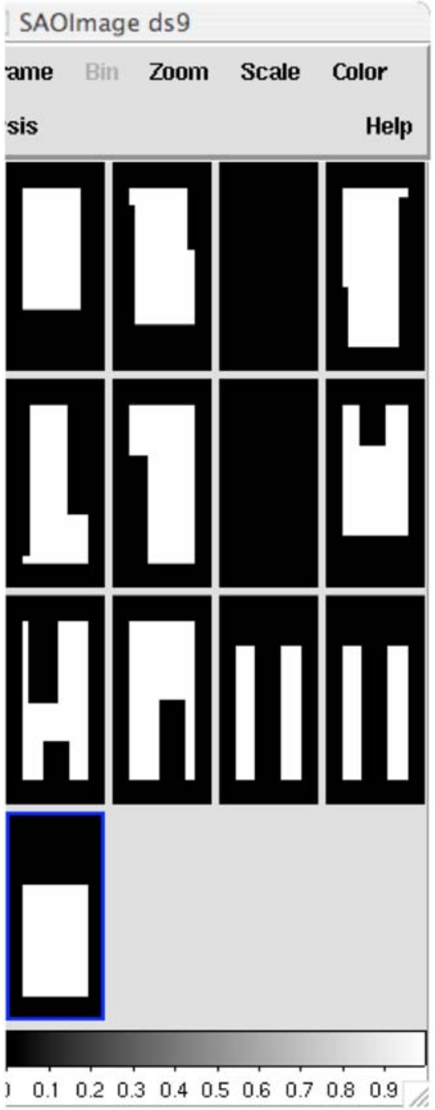
specimage

image masks residual image

[EXTRACTED PRODUCTs]
SG1

2D spectra of extracted sources (_WC)
(13 objects in this case)

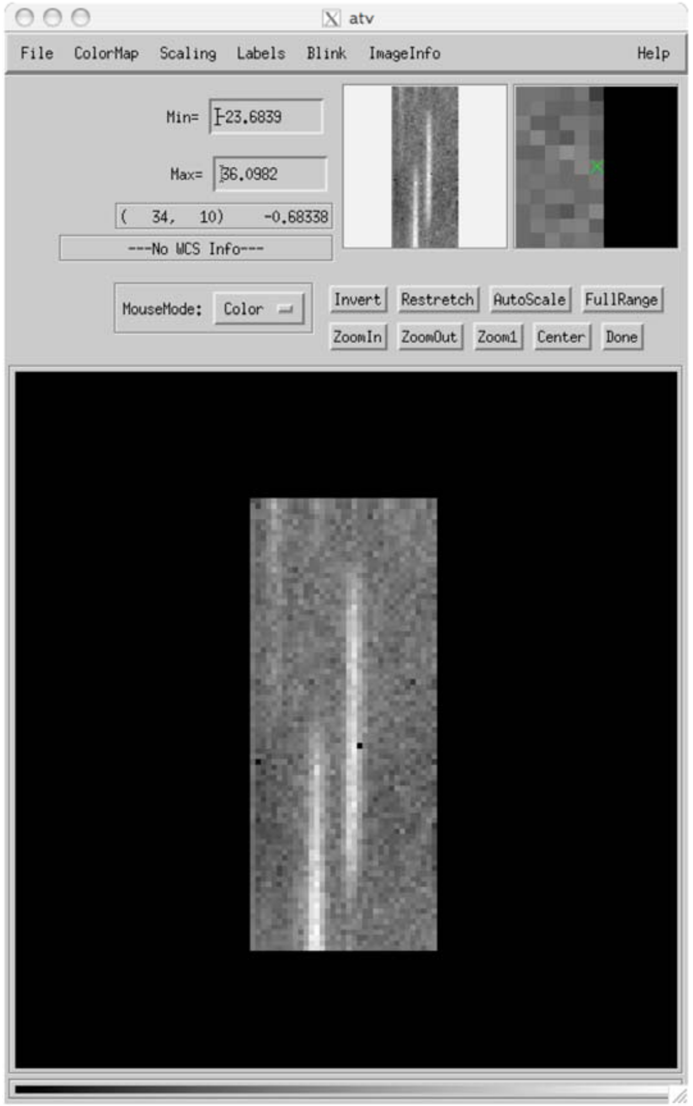




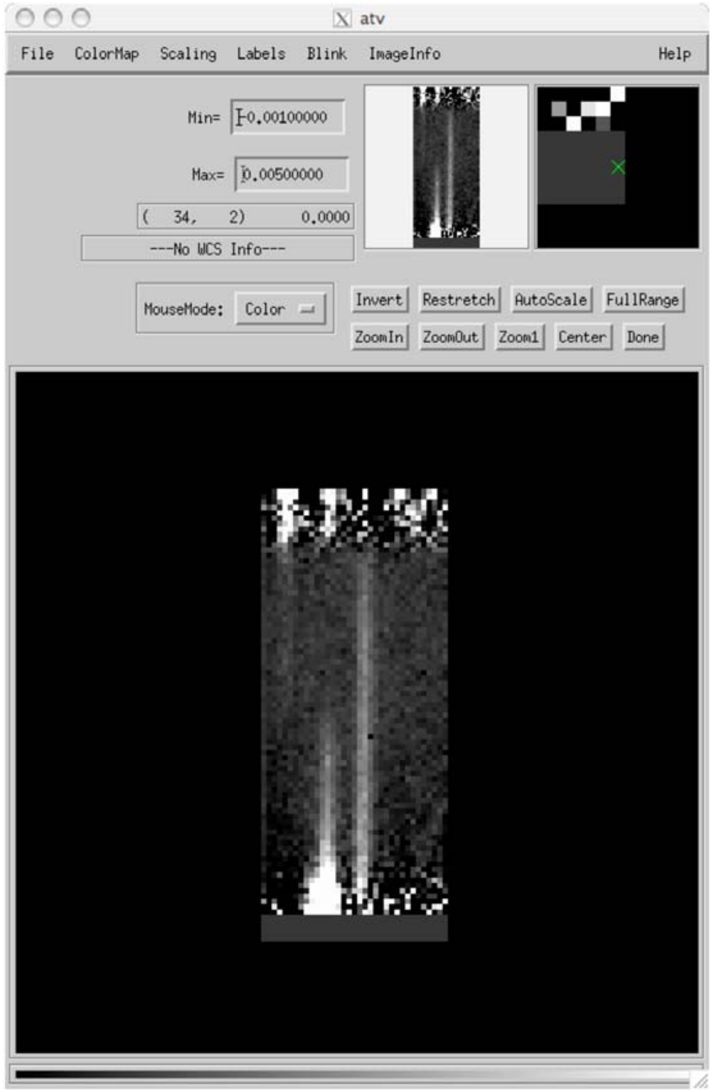
And their overlapping masks

Specimage: _wc vs. _fc

WC=Wavelength Calibrated



FC=Flux Calibrated



Some Featured Calibration Topics

- Cosmic-ray removal
- Measuring relative shift among subframes
- Sky subtraction and source masking
  - Scattered light
- Distortion?
- Determination of wavelength reference position
- Identifying zero-th order light
- Correcting spectral tilt
- Flats in more details
- Spectral resolution
- Treatment of Source Overlapping

Removal of Cosmic Ray Events

- The cosmic ray events will be identified as outliers while combining frames with a clipping-averaging algorithm.
- Exception:
  - NIR refimage
  - MIR-S/L short frames

Measuring Relative Shift among Subframes

- Measurement will be done only in
  - NIR for SPEC (NP/NG)
  - MIR-S for REFIMAG (S9W)
- And then the results are converted for shifting
  - MIR-S/L for SPEC (SG1/2)
  - MIR-L (LG2) for REFIMAG (L18W)
- By using all available bright field stars
  - Regardless of sources specified in the target table.
- Method: cross-correlating whole images
  - among SPEC and REFIMAG subframes
  - among long vs. short subframes

Sky Subtraction and Source Masking

- For the whole images:
  - NIR/SG1: outlier-resistant lower-order fit will be applied.
    - before stacking
  - SG2/LG2: smaller scale local filter will be applied.
    - where sky level is higher, and is more structured.
  - Object-masking feature will be made available in the next release of the toolkit.
- For the extracted images:
  - An average value of the surrounding sky is subtracted.
    - For subtracting any remaining sky.
    - But the sky level is negligibly small for the extracted images.

Correcting Spectral Tilt

- Due to miss-alignment of disperser's insertion angle to the chip Y axis, dispersion direction is slightly tilted from the Y axis.
  - Tilt angle is less than dx=1 pix per dy=50 pix
- The tilt is corrected by simple image transformation
  - Based on the tilt angle information stored in the CAL database.

Distortion?

- (A sort of) Distortion is corrected for
  - wavelength zero-point shift in NP
  - spectral tilt
- Other kind of spectral/image distortion will NOT be corrected.
  - Since the distortion is negligibly small for spectral calibration.
- Note: no distortion will be corrected even on the reference images.
  - To find simple REF/SPEC source position matching.
  - Therefore, output of imaging and spectral calibration toolkits differ from each other.

Determination of Wavelength Reference Position

Wavelength reference-point is set by

1. Source position on the REF image

And is further corrected by considering

2. Satellite jitter
3. Spectral distortion

2: Jitter is measured in NP/NG, and is converted for MIR-S/L, due to brightness of field stars at NIR.

3: Distortion exists only in NP, and is corrected based on distortion table in the CAL database.

Identifying Zero-th Order Light

- Location of the zero-th order light is calculated from object positions on the reference images.
- The toolkit creates region marks showing locations of the zero-th order light images.
- By comparing actual zero-th order light image location with the predicted location, one may find wavelength offset for further correcting wavelength reference position.

- No subtracting the zero-th order image will be made.

Spectral Resolution

- Spectral resolution changes from object to object, if they are not point sources.
  - The spectroscopic resolution of the slit-less spectroscopy mode is determined by the size of the object.
  - Deconvolution of the spectra may introduce unexpected uncertainties, and thus not implemented in the toolkit.
  - Users should compare the observed spectra with the image size on the reference image to interpret the spectra properly.

(NO) Treatment of Source Overlapping

- When two or more objects are close to each other on the reference images, one spectral image could overlap on another one.
- The toolkit outputs mask images/region files to show overlapping.
  - If overlapping happens, a part of the spectral information will be lost since the software cannot separate overlapping spectral images to restore the original information.

Flat Fielding on Spec. Images

- Calibration of wavelength-dependent flat and spectral response is very important.
- However, it is not simple in slit-less spectroscopy mode.
  - The object itself defines the aperture of the spectra, and its location before actually performing the observation is unknown.
  - One pixel of the chip detects both background and object light.
    - The background light is a sum of all light within the spectral coverage of the dispersing elements.
    - Only a fraction of the light whose wavelength is determined by location of the object is detected on the pixel.
  - We need a cube of flat images (i.e., 3D information of the flat response over X, Y, and lambda axes) to fully calibrate the slit-less spectroscopy images.
  - But it will not be possible to obtain such a cube.
    - Due to lack of any good calibrators both on sky and in the laboratory.

[Flat Equation]

- We assume the following simple approximation of the spectral-flat response.

Flat response =		
	Sky flat	**(position-dependent and wavelength-independent)**
	X Object flat	**(position-dependent and wavelength-dependent)**
and		
Object flat =		
	Object flat 1	**(position-dependent and weak wavelength-dependent)**
	X Object flat 2	**(only wavelength-dependent)**
or		
	Object flat 1	**(position-dependent and weak wavelength-dependent)**
	X spectral response	**(only wavelength-dependent)**

  - We checked validity of this flat calibration process during the PV phase.
    - By examining spectra of the same spectroscopic standard stars observed at different location on the chip.
    - So far no big troubles have been reported.

Flat Fielding - part 1 - [Sky flat]

- Sky flat will be made by combining many actually observed frames.
- The spectroscopy images will be divided by this background flat.
  - Then, images of object spectra, over flat background light, will be obtained.

Flat Fielding - part 2 - [Color Correction/ Spectral Response Calibration]

- Color correction images (2D) is made for each extracted spectroscopy image…
  - Given a pixel, by interpolating two imaging superflats taken with different broad-band filters, along wavelength direction, for wavelength of the pixel.
- Then, the spectral response curve is used to find the flux of the spectra.
  - The response curve is location-independent (1D table of spectral response vs. wavelength).

Comments on Individual CAL Items

- Superdark
  - Adopt superdark images for imaging pipeline.
- Spectroscopy superflats
  - Combined and normalized images of large number of 'serendipitous sky' images.
    - Right now, only one flat is available per disperser, I.e., no temporal change is considered.
  - For slit flats, spectral normalization was also made.
- Imaging superflats for color correction
  - Adopt superflat images for imaging pipeline.

Continued.

- Sensitivity Calibration
  - Flux standard star observations have been made.
  - Sensitivity monitor has been made, but no temporal sensitivity change is found.
- Wavelength Calibration
  - Emission-line objects were observed for calibrating the wavelength.
    - WR stars and compact PNe for slit-less area
    - Extended PNs for slit.
  - No grism/prism insertion trouble was found.
    - Spectral tilt is fixed.

Problems/Difficulties One Need to Know in Reducing the Data

- Satellite jittering correction:
  - Sometimes it is difficult to automatically measure relative shifts with cross-correlation method.
  - Sometimes it is also difficult to find wavelength reference point in NP/NG.
- Array anomalies correction:
  - Similar kinds of anomaly seen in imaging data will be also seen in spectroscopy data.
  - Right now they are only partially corrected in empirical ways.

Cont.

- Background un-uniformity
  - Scattered light of the Earth shine makes it very difficult to subtract background in SG2/LG2, limiting final S/N of the spectra.
- Temporal change of flat pattern:
  - Time dependent flat response is known to exist.
  - The “soramame” feature seen in MIR-S images are also seen in SG1/2.

Cont.

- Hot pixels on MIR-L:
  - Larger number of hot pixels can be seen in LG2.
  - They often limit final S/N of spectra.
- Flat-fielding the NG slit spectra:
  - Due to faintness of the sky, flat-fielding might worsen the S/N of the spectra.
- Source confusion on NIR:
  - This has been known before launch.
  - But you may have surprised to see how serious the problem is.

Q/A Session

- Any questions?
- Any suggestions?
- Any complaints?