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

<table>
<thead>
<tr>
<th>Name</th>
<th>Array</th>
<th>FOV (arcmin²)</th>
<th>Pix scale (arcsec/pix)</th>
<th>ID</th>
<th>Type</th>
<th>$\Delta \lambda$ (μm)</th>
<th>$\lambda/d\lambda$</th>
<th>Spec. Length</th>
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<tbody>
<tr>
<td>NIR</td>
<td>InSb</td>
<td>9.5' X10.0'</td>
<td>1.46”</td>
<td>NP</td>
<td>prism</td>
<td>1.8–5.5</td>
<td>22@3.5μm</td>
<td>81 pix</td>
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<tr>
<td></td>
<td>512 X412</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIR-S</td>
<td>Si:As</td>
<td>9.1' X10.0'</td>
<td>2.34”</td>
<td>SG1</td>
<td>grism</td>
<td>5.3–8.3</td>
<td>47@6.6μm</td>
<td>85</td>
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<tr>
<td></td>
<td>256 X256</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>MIR-L</td>
<td>Si:As</td>
<td>10.3' X10.2'</td>
<td>2.51” x2.39”</td>
<td>LG1</td>
<td>grism</td>
<td>11</td>
<td>19@14.4μm</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>256 x256</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LG2</td>
<td>grism</td>
<td>17.7–25.0</td>
<td>27@20.2μm</td>
<td>79</td>
</tr>
</tbody>
</table>
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
  – *We need to find source locations on the reference image.*
  – 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

direct image  spectral image

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.list F132903_N.fits F132906_M.fits F132913_N.fits F132918_M.fits F132923_N.fits NP.lst SG2.lst
DARK_NIR.list F132904_M.fits F132909_N.fits F132914_M.fits F132919_N.fits L10W.lst OLD/
F132900_M.fits F132905_N.fits F132910_M.fits F132915_N.fits F132920_M.fits LG2.lst README.5124003.1
F132901_N.fits F132906_M.fits F132911_N.fits F132916_M.fits F132921_N.fits N3.lst S9W.lst
F132902_M.fits F132907_N.fits F132912_M.fits F132917_N.fits F132922_M.fits NG.lst SG1.lst
```

---

**Spec Image X4**

**Spec Image X4v**

**Ref Image X1**
AOT04a Raw Data (MIR-S/L)

MIR-L

MIR-S

SG1/2

LG2

wavelength

maneuver
Darks
(AOT04a)

Pre-dark

Post-dark

Super-dark
Calibration Data in ‘/CALIBDIR’

```
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

Ridge due to zero-th order light

Fade near Y=0

Fade near Y=Ymax

NP

NG

SG1

SG2

LG2
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

IRC SPECTROSCOPY SYSTEM THROUGHPUT

System Throughput

Wavelength (μm)
Sensitivity
(per AOT04, long, 1sigma)
Example 1: The Planetary Nebula
Example 2: The Infrared-Luminous Galaxy

• Intentionally removed. Sorry.
Calibrating the Data
A single IRC_SPECRED works on both slit-less and slit 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 than 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.

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
AOT4 input data

$(X_i, Y_i)$

$(X_s, Y_s)$

Pixel ADU

ADU'

Wave. calib. pos./$\lambda$-dependent flat

for obj. A

Wave. calib. pos./$\lambda$-dependent flat

for obj. B

Sens. response corr. (pos. independent)

Source overlapping? Is aperture size OK?

Dark sub. Flat for sky Sky sub.

Ref. imag

Spec.

Cut along disp.

Source extraction

Pixel

ADU

ADU'

$\lambda$

Jy

One-dim. cut

Source overlapping? Is aperture size OK?
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.
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
Multiple pointing data not covered by the IRC_SPECRED
AOT4 input data

- Source detection
  - \((X_i, Y_i)\)
- \((X_s, Y_s)\)

- Coord. trans.

- Dark sub.
  - Flat for sky
- Sky sub.

- Source extraction

- Cut along disp.

- Sens. response corr.
  - (pos. independent)

- One-dim. cut

- ADU
  - Pixel for obj. A
- \(\lambda\)

- ADU'
  - Wave. calib. pos. \(\lambda\)-dependent flat for obj. A

- Jy
  - \(\lambda\)

- ADU
  - Pixel for obj. B
- \(\lambda\)

- ADU'
  - Wave. calib. pos. \(\lambda\)-dependent flat for obj. B

- Jy
  - \(\lambda\)

- Source overlapping?
  - Is aperture size OK?
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 increment 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)  
  \( = \text{count(ADU,lambda)}/\text{response(lambda)} \)
- 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.lst DARK_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

```
/home/ohyama/hd1/cova/IRC/PV/SPEC/FLUX/5124003.1/irc_specred_out

ohyama@cava3: ls
5124003.1.N3.NG.refimage_bg.fits
5124003.1.N3.NG.refimage_bg_indiv.fits
5124003.1.N3.NG.refimage_mask.fits
5124003.1.N3.NG.residual_refimage_bg.fits
5124003.1.N3.NG.residual_specimage_bg.fits
5124003.1.N3.NG.source_table.tbl
5124003.1.N3.NG.specimage_bg.fits
5124003.1.N3.NG.specimage_bg_indiv.fits
5124003.1.N3.NG.specimage_bg_mask.fits
5124003.1.N3.NG.specimage_bg_reg
5124003.1.N3.NG.specimage_check.fits
5124003.1.N3.NG.specimage_indiv.fits
5124003.1.N3.NG.specimage_indiv_reg
5124003.1.N3.NG.specimage_reg
5124003.1.N3.NP.log
5124003.1.N3.NP.refimage_bg.fits
5124003.1.N3.NP.refimage_bg_indiv.fits
5124003.1.N3.NP.refimage_mask.fits
5124003.1.N3.NP.residual_refimage_bg.fits
5124003.1.N3.NP.residual_specimage_bg.fits
5124003.1.N3.NP.specimage_bg.fits
5124003.1.N3.NP.specimage_bg_indiv.fits
5124003.1.N3.NP.specimage_bg_mask.fits
5124003.1.N3.NP.specimage_bg_reg
5124003.1.N3.NP.specimage_check.fits
5124003.1.N3.NP.specimage_indiv.fits
5124003.1.N3.NP.specimage_indiv_reg
5124003.1.N3.NP.specimage_reg
5124003.1.S9M_SG1.log
5124003.1.S9M_SG1.refimage_bg.fits
5124003.1.S9M_SG1.refimage_bg_indiv.fits
5124003.1.S9M_SG1.refimage_mask.fits
5124003.1.S9M_SG1.residual_refimage_bg.fits
5124003.1.S9M_SG1.residual_specimage_bg.fits
5124003.1.S9M_SG1.source_table.tbl
5124003.1.S9M_SG1.specimage_bg.fits
5124003.1.S9M_SG1.specimage_bg_indiv.fits
5124003.1.S9M_SG1.specimage_bg_mask.fits
5124003.1.S9M_SG1.specimage_bg_reg
5124003.1.S9M_SG1.specimage_check.fits
5124003.1.S9M_SG1.specimage_indiv.fits
5124003.1.S9M_SG1.specimage_indiv_reg
5124003.1.S9M_SG1.specimage_reg
5124003.1.S9M_SG1_target_table.tbl
NG_SHIFT_X.dat
NG_SHIFT_Y.dat
NP.BLUE.png
NP_SHIFT_X.dat
NP_SHIFT_Y.dat
tmp/
```
Review of FITS Outputs

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

\[
\text{Flat response} = \text{Sky flat} \times \text{Object flat} \quad \text{and} \quad \text{Object flat} = \text{Object flat}_1 \times \text{Object flat}_2
\]

– 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.
• **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?