Calibration and Performance of the AKARI Far-Infrared Imaging Fourier Transform Spectrometer

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To be submitted to PASJ

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Available data for calibration

Source	P/D	mode	# of pointings	referenece
Uranus	Point	SED	2 pointing	Moreno's model
Neptune	Point	SED	2 pointing	Moreno's model
Ceres	Point	SED	1 pointing	Muller's model
M82	Point	SED	2 pointing	ISO/LWS
M82	Point	Full	7 pointing	ISO/LWS
GC	Diffuse	Full	5 pointing	ISO/LWS
M20	Diffuse	SED	1 pointing	ISO/LWS
M17	Diffuse	Full	1 pointing	ISO/LWS
Eta-Carinae	Diffuse	Full	6 pointing	ISO/LWS
Internal source	Diffuse	SED	every all pointings	
Aperture Lid	Diffuse			35K BB

Procedure of Data Analysis

Raw data

Time Series Data

- **Periodic time interval sampling with position data of moving mirror**

Glitch

- **Sigma clipping**
- **Bad data interpolation**
- **Without transient correction**

Interferograms

DFT

- **Range : SED +/-0.42cm, Full -2.7cm**
- **Apodization : non or hanning**
- **Phase correction : linear**

cf : Long term time variation ~ 10%

Raw Spectrum

Procedure of Data Analysis

Raw Spectrum

calibration

- **SCF : spectral correction factor**
- **Flat correction : spectral correction factor**
- **Conv2 absolute flux**
- **Defringe**

Final Spectrum

SCF

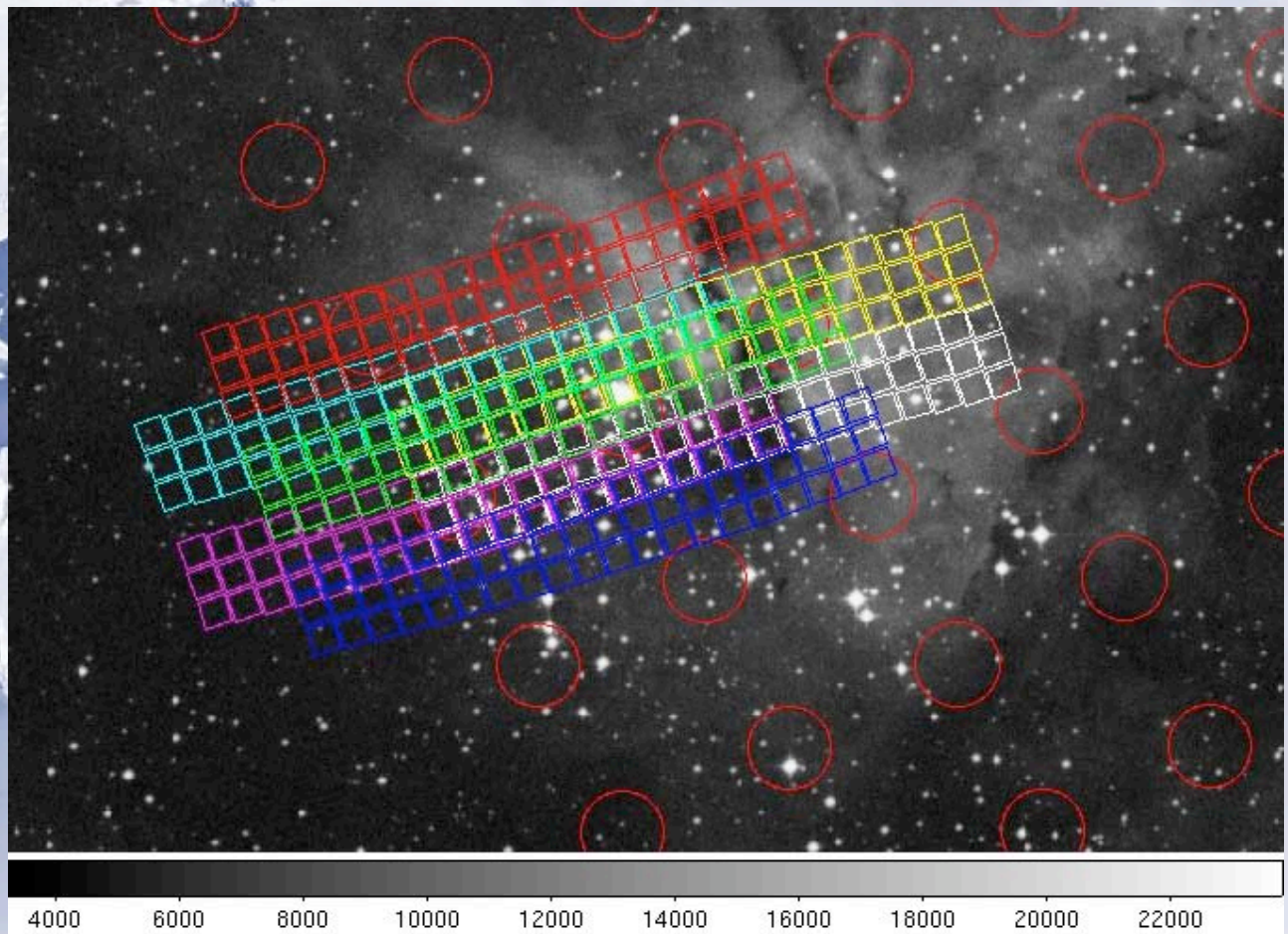
Definition

Object spectra = (raw spectra) * SCF
SCF = (normalized SCF) * flat * absolute_factor

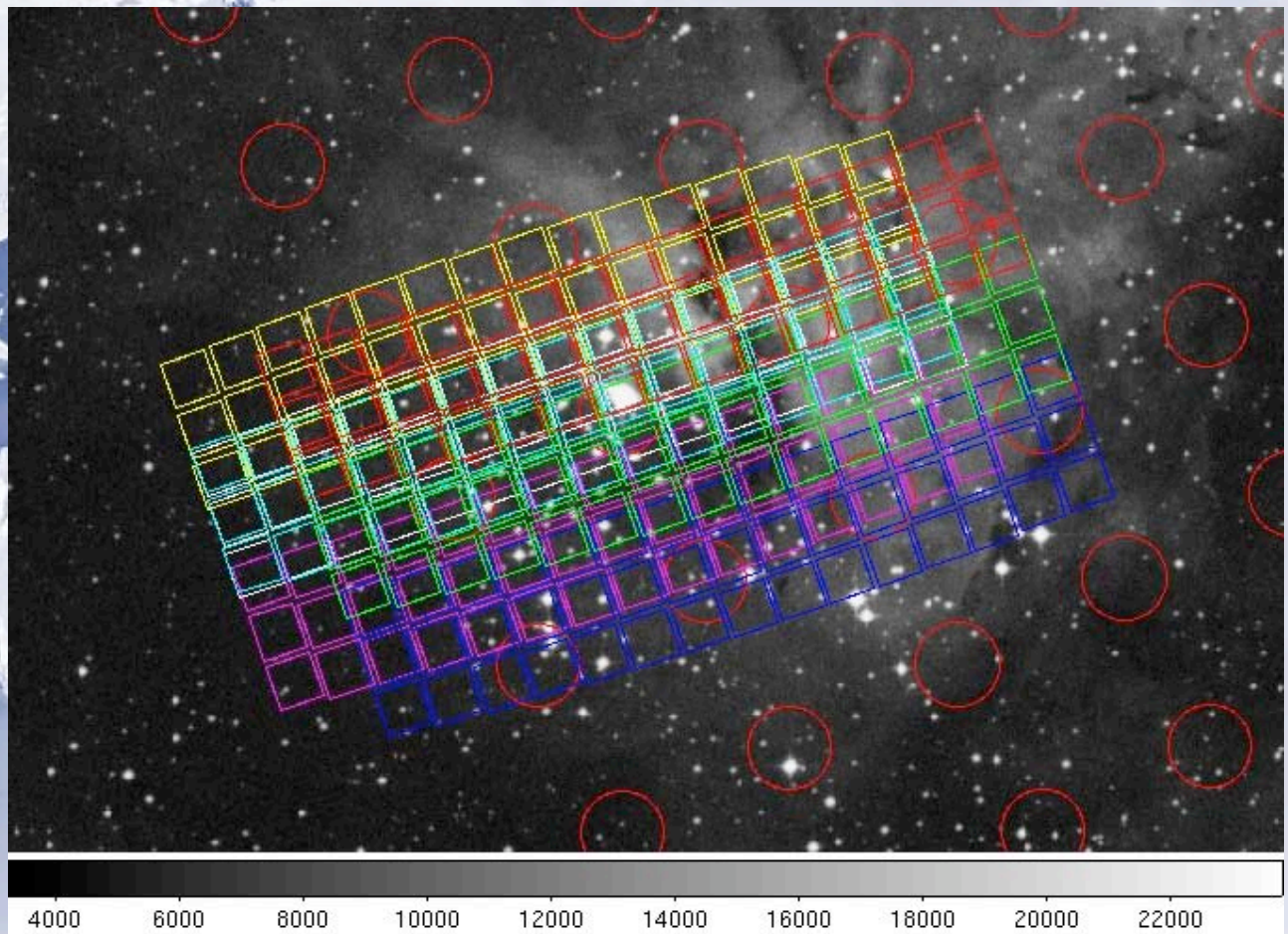
Used data (ISO/LWS)

Carina_{SW/LW},
GC_{SW/LW},
ISMGN_M82_{SW/LW},
M17_{SW/LW},
M20_{SW/LW},
M82_{SW/LW}.

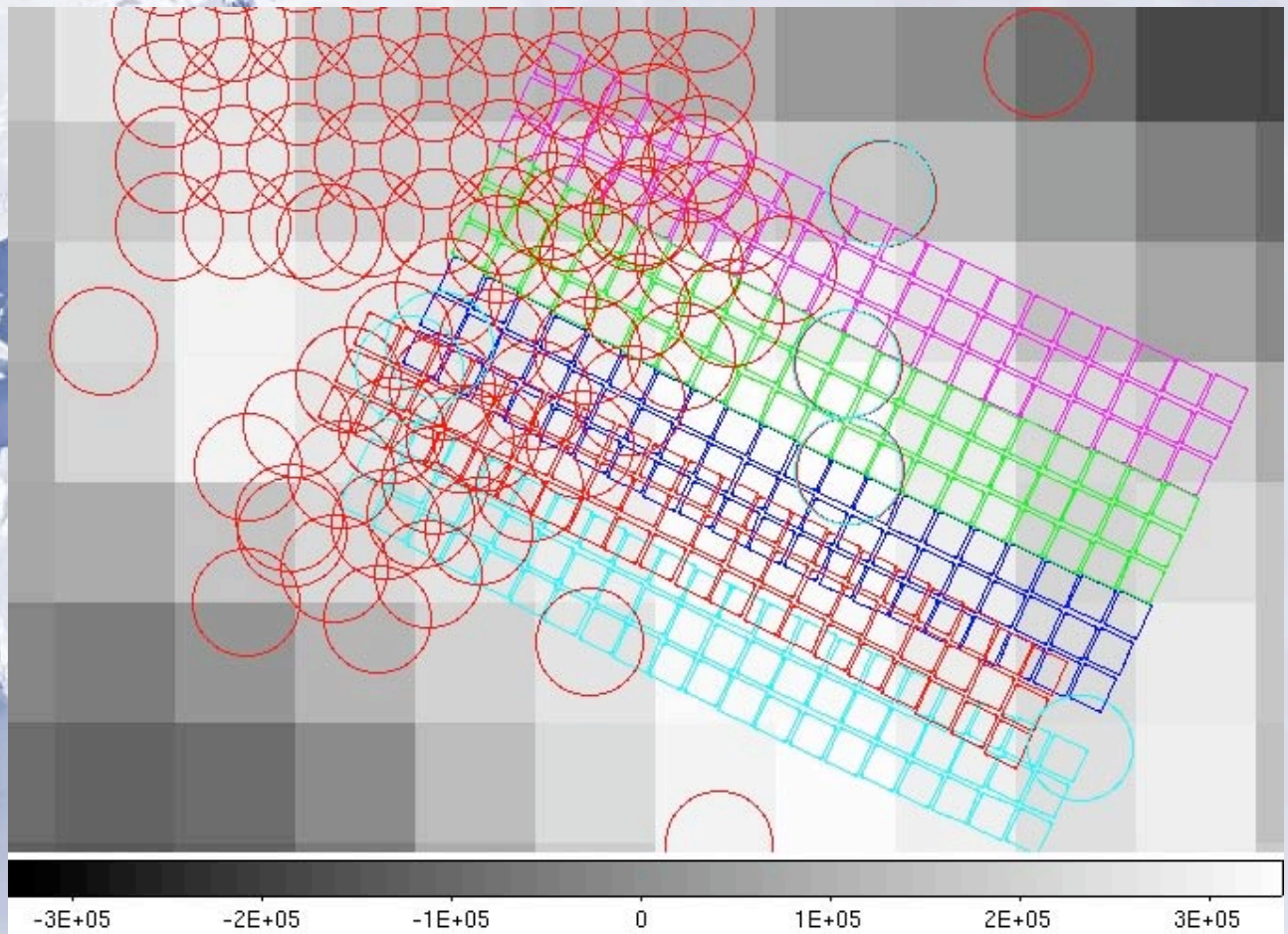
Carina_SW



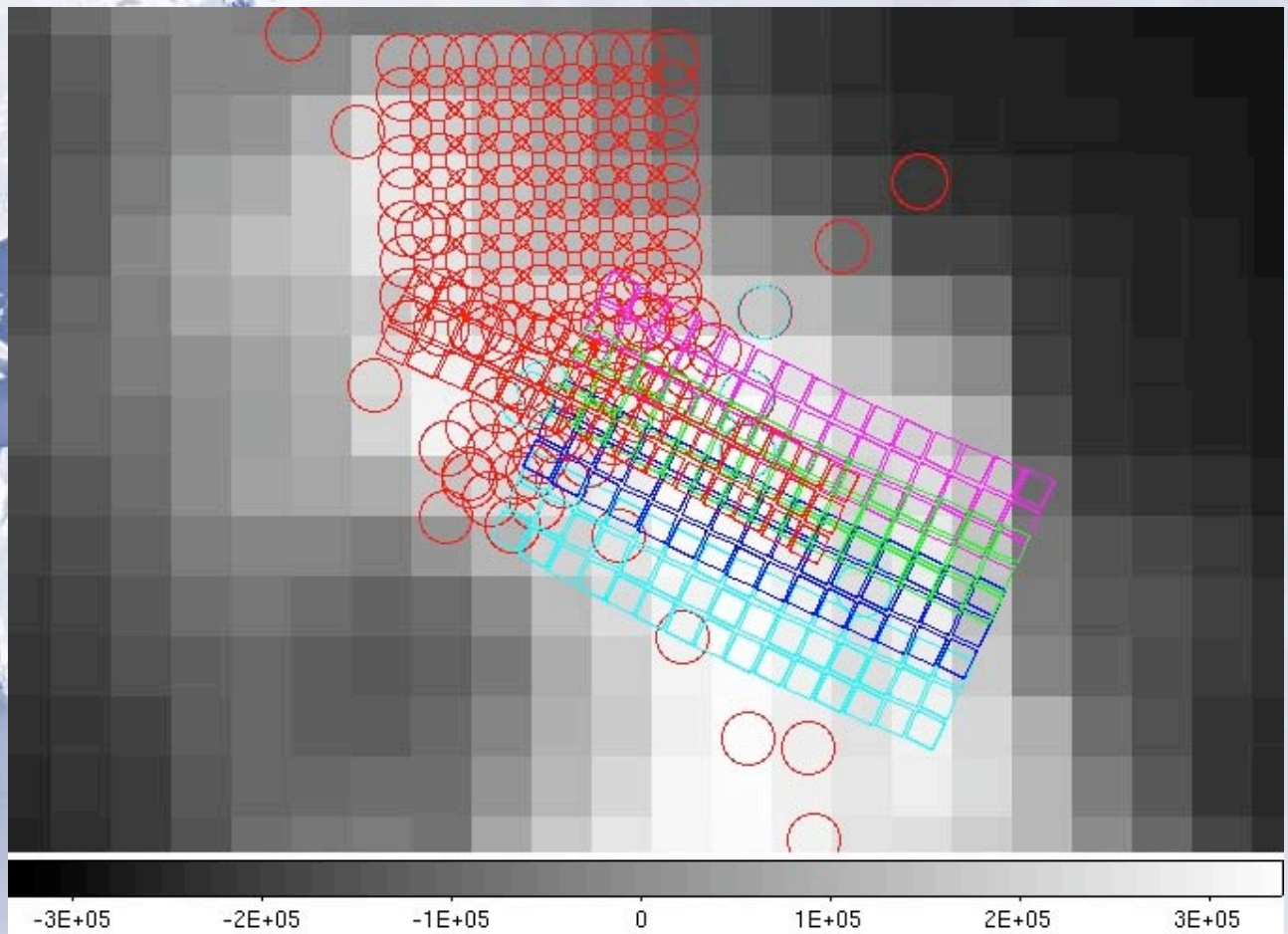
Carina_LW



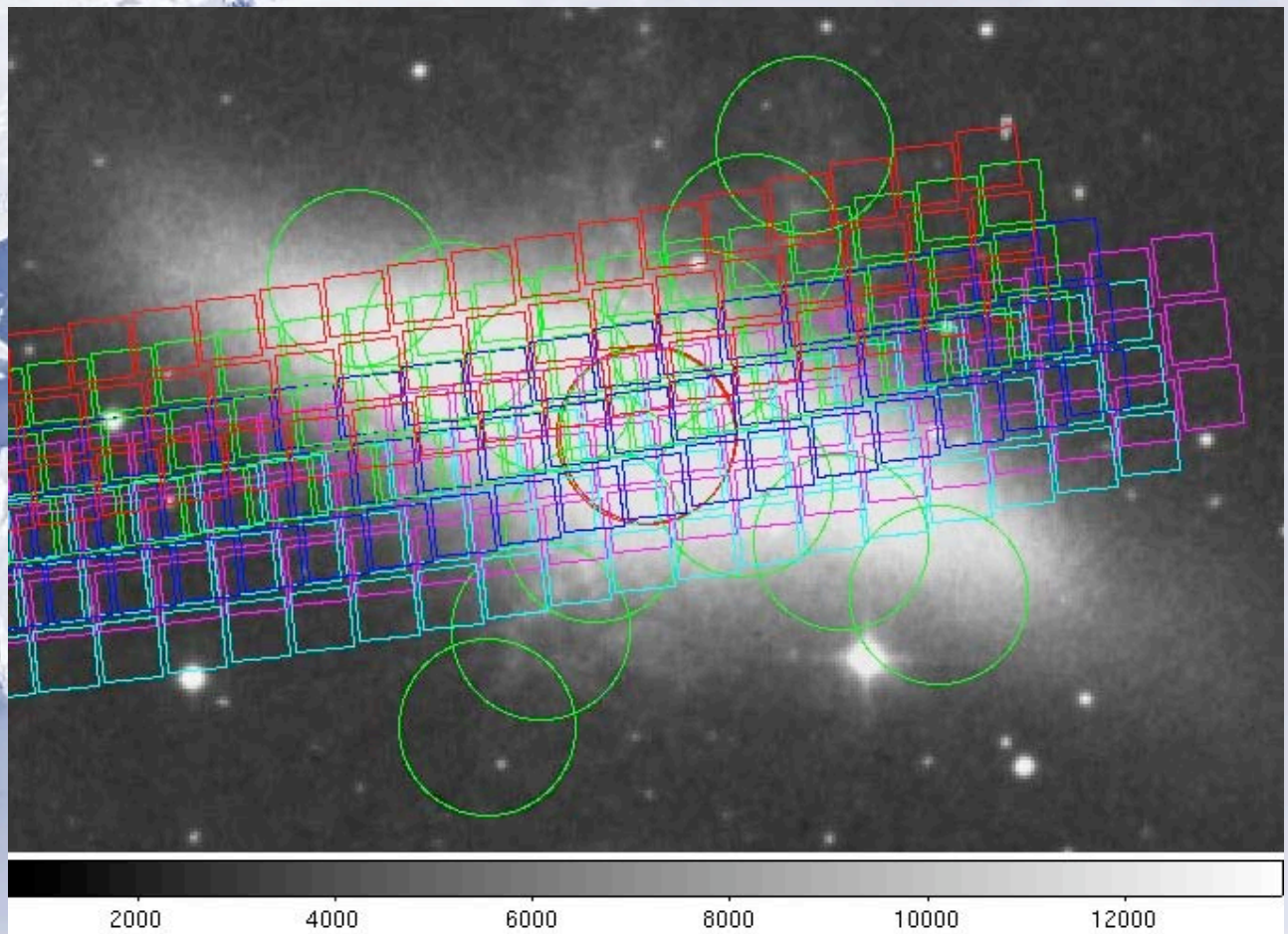
GC_SW



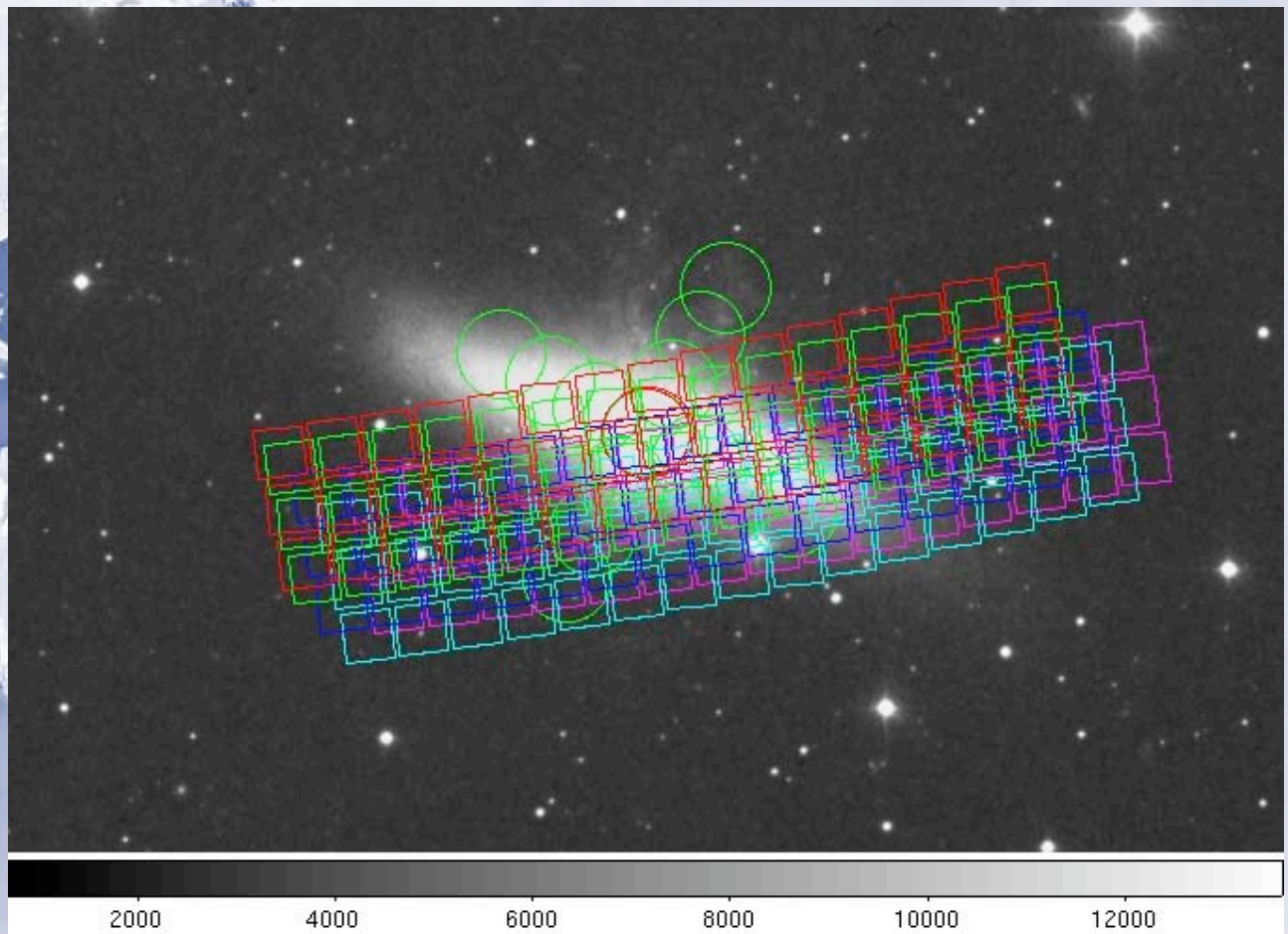
GC_LW



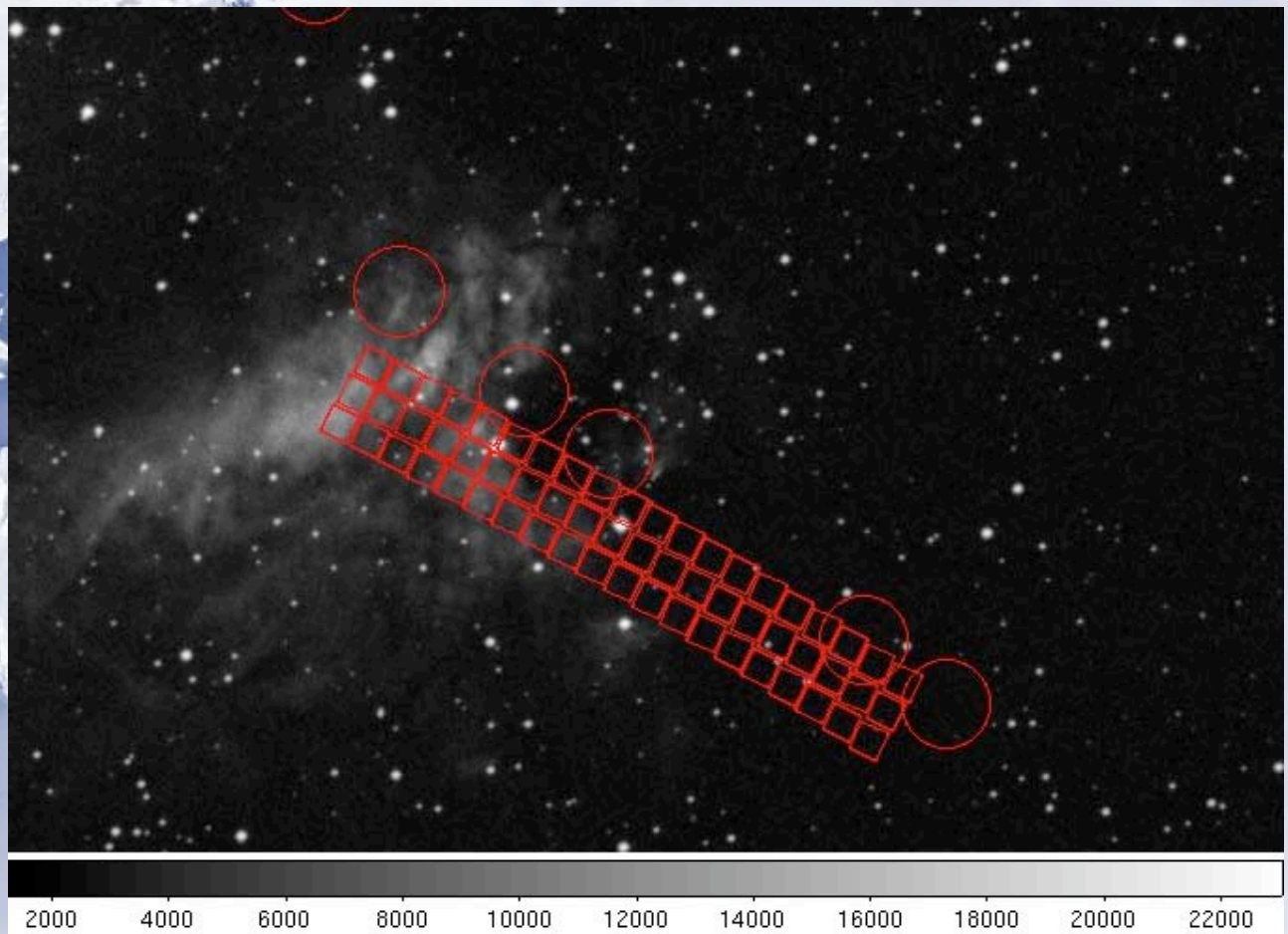
M82_SW



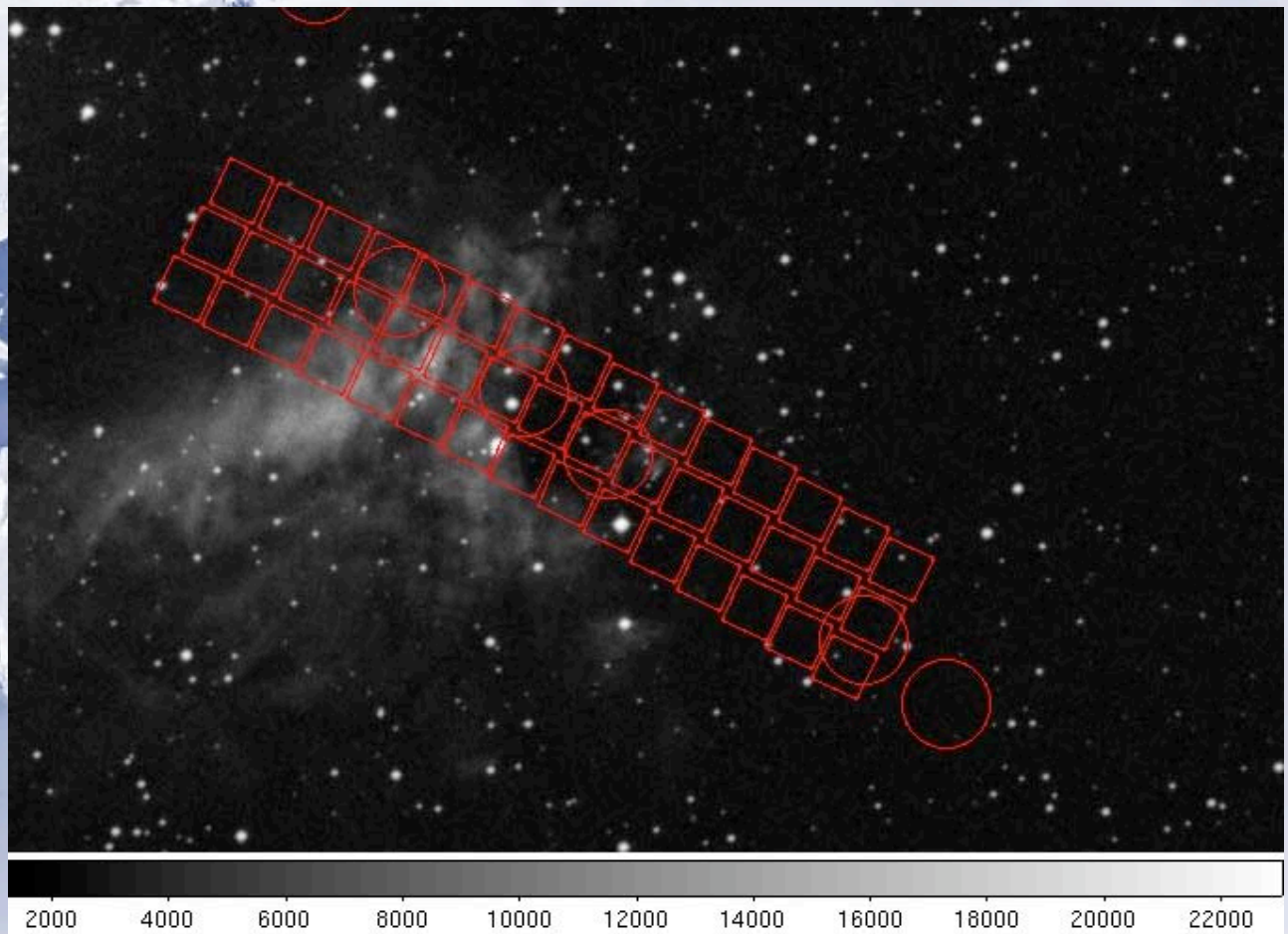
M82_LW



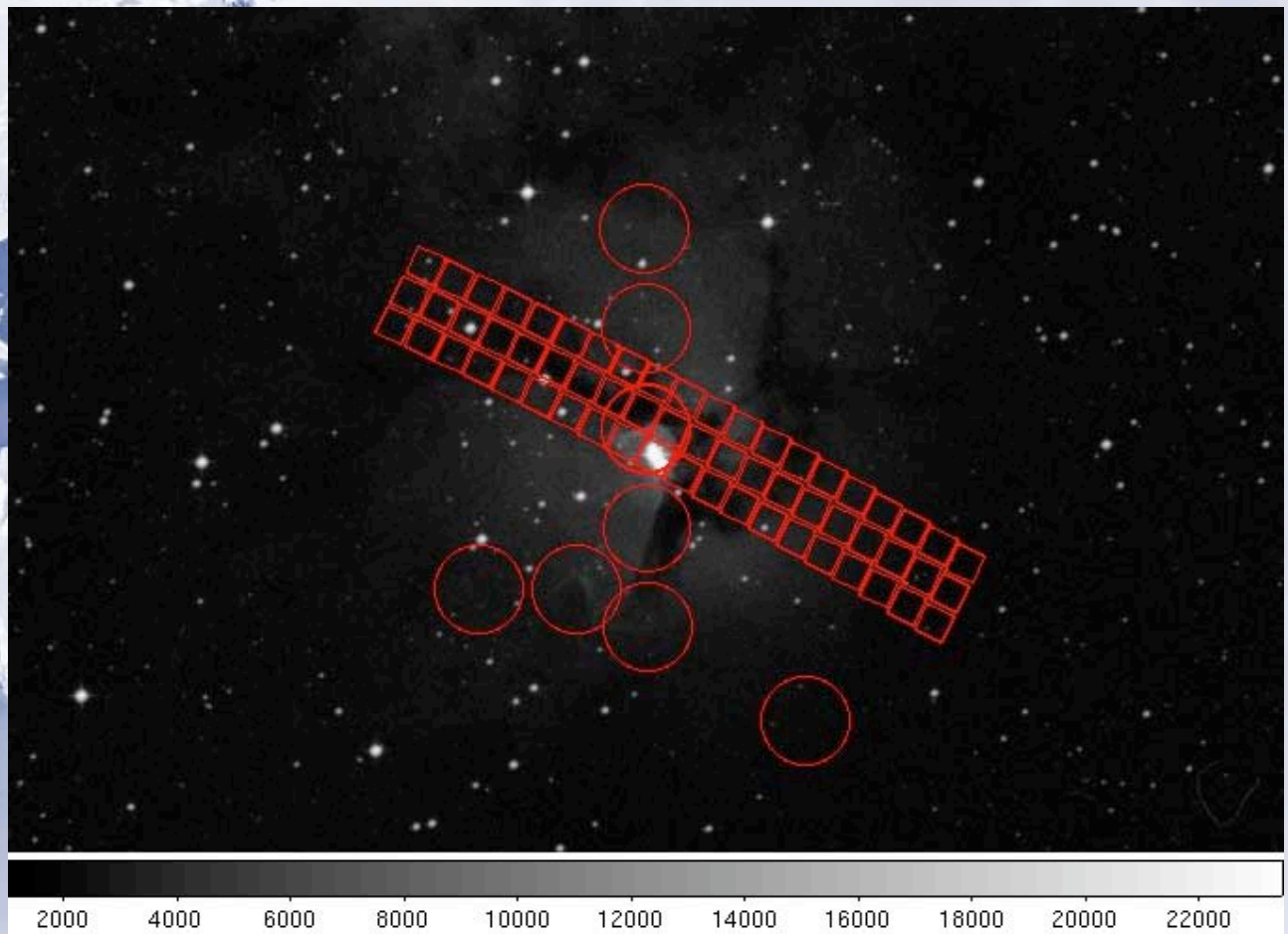
M17_SW


2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000

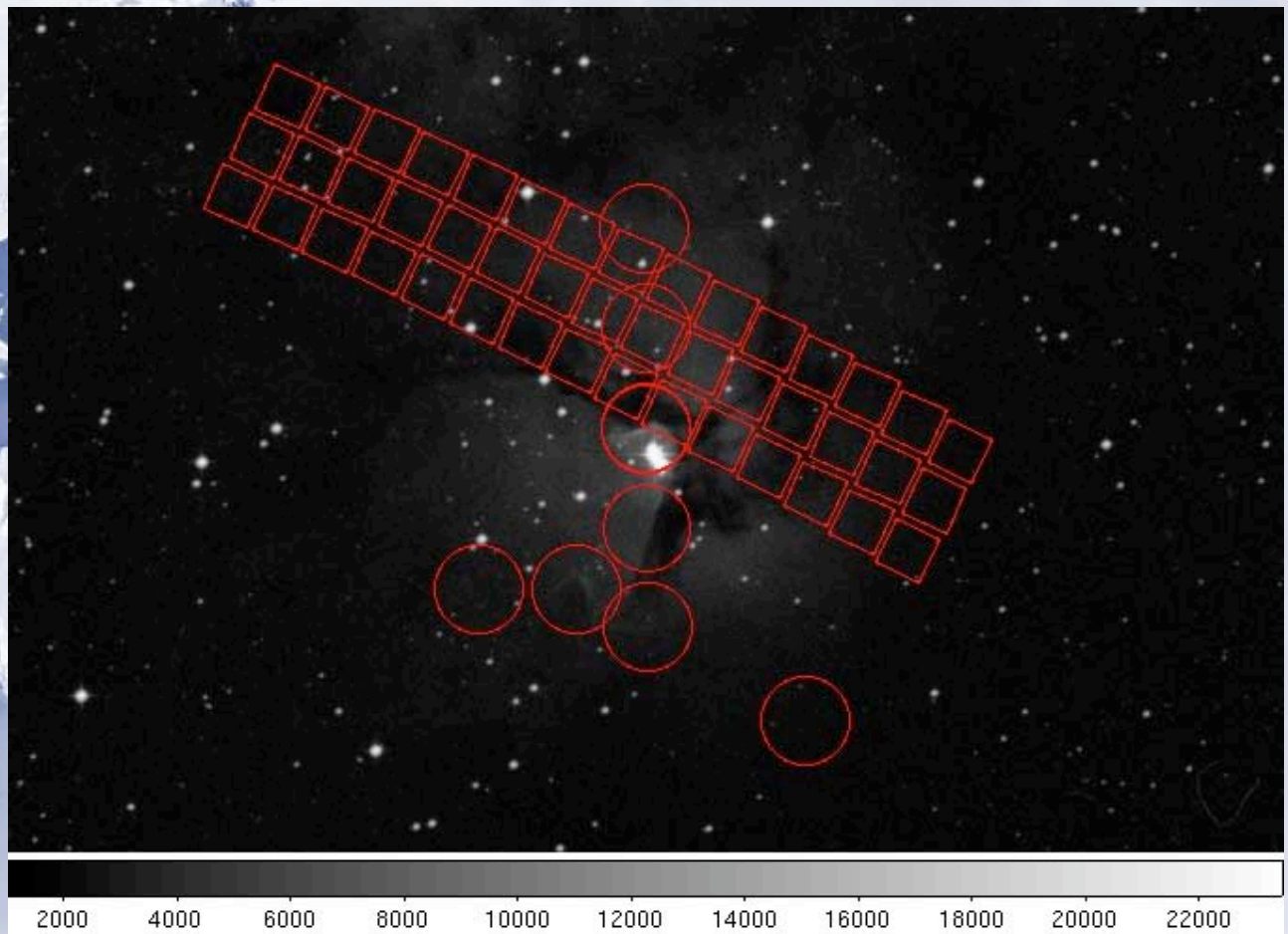
M17_LW


2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000

M20_SW

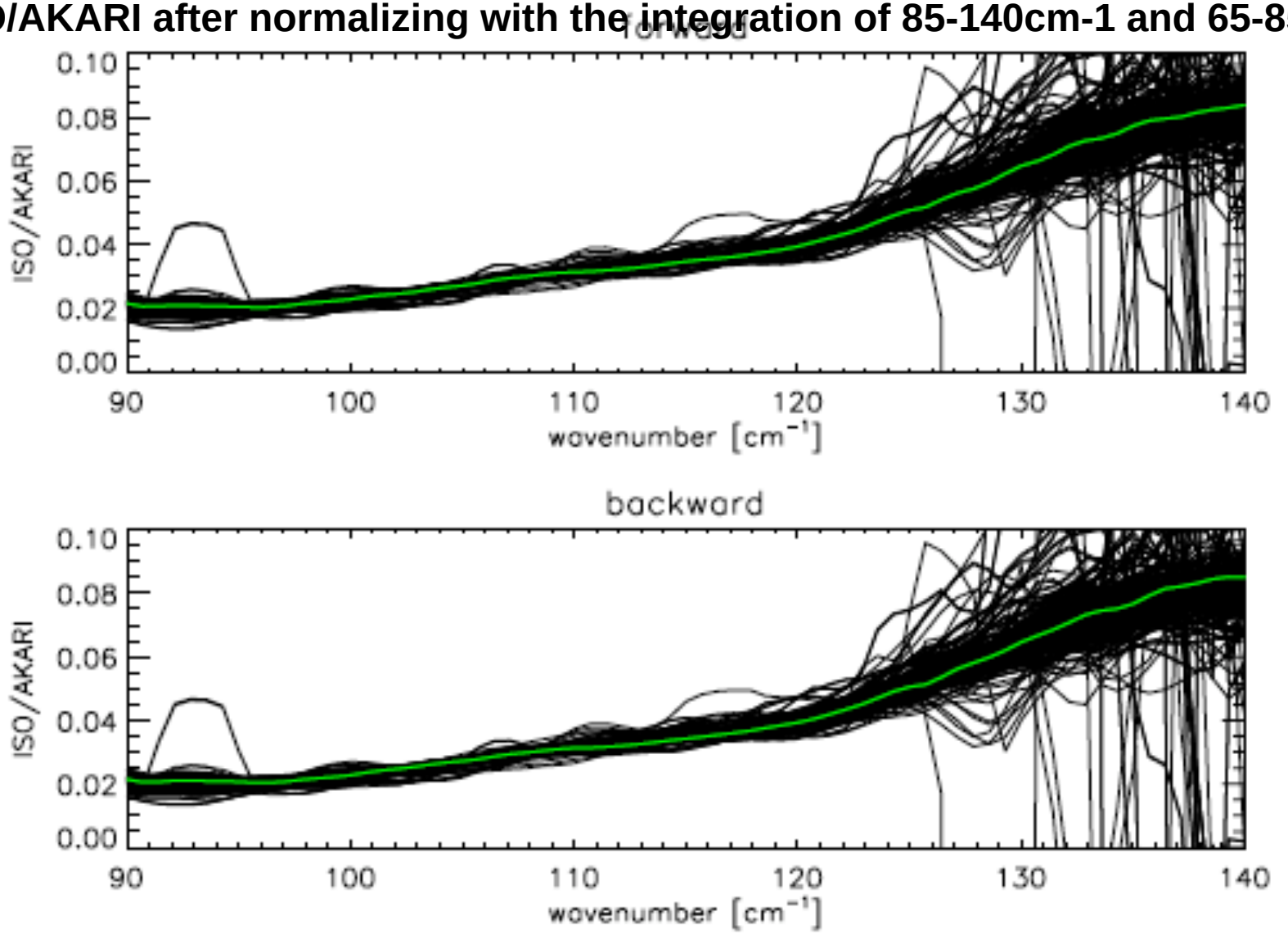

2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000

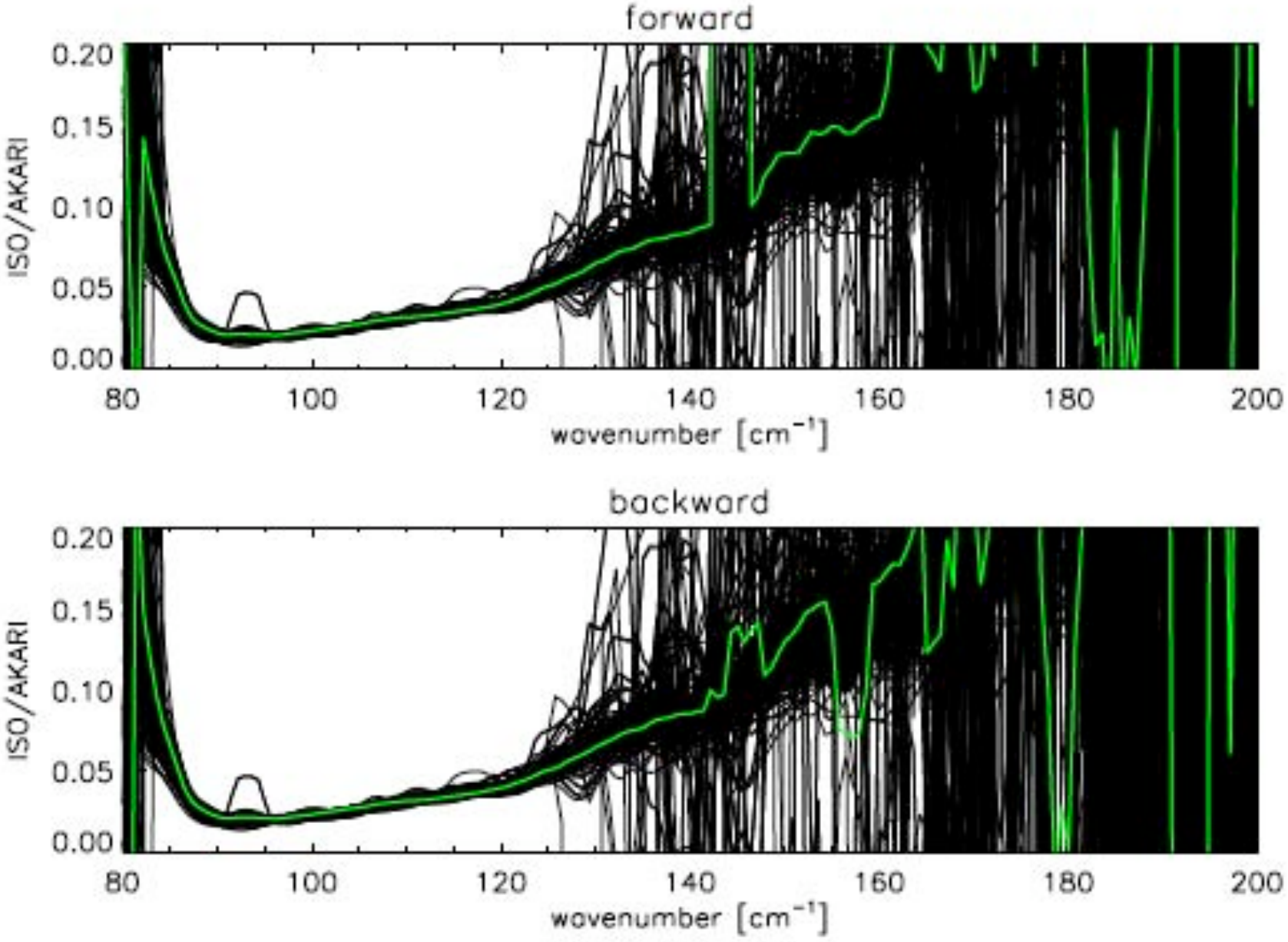
M20_LW

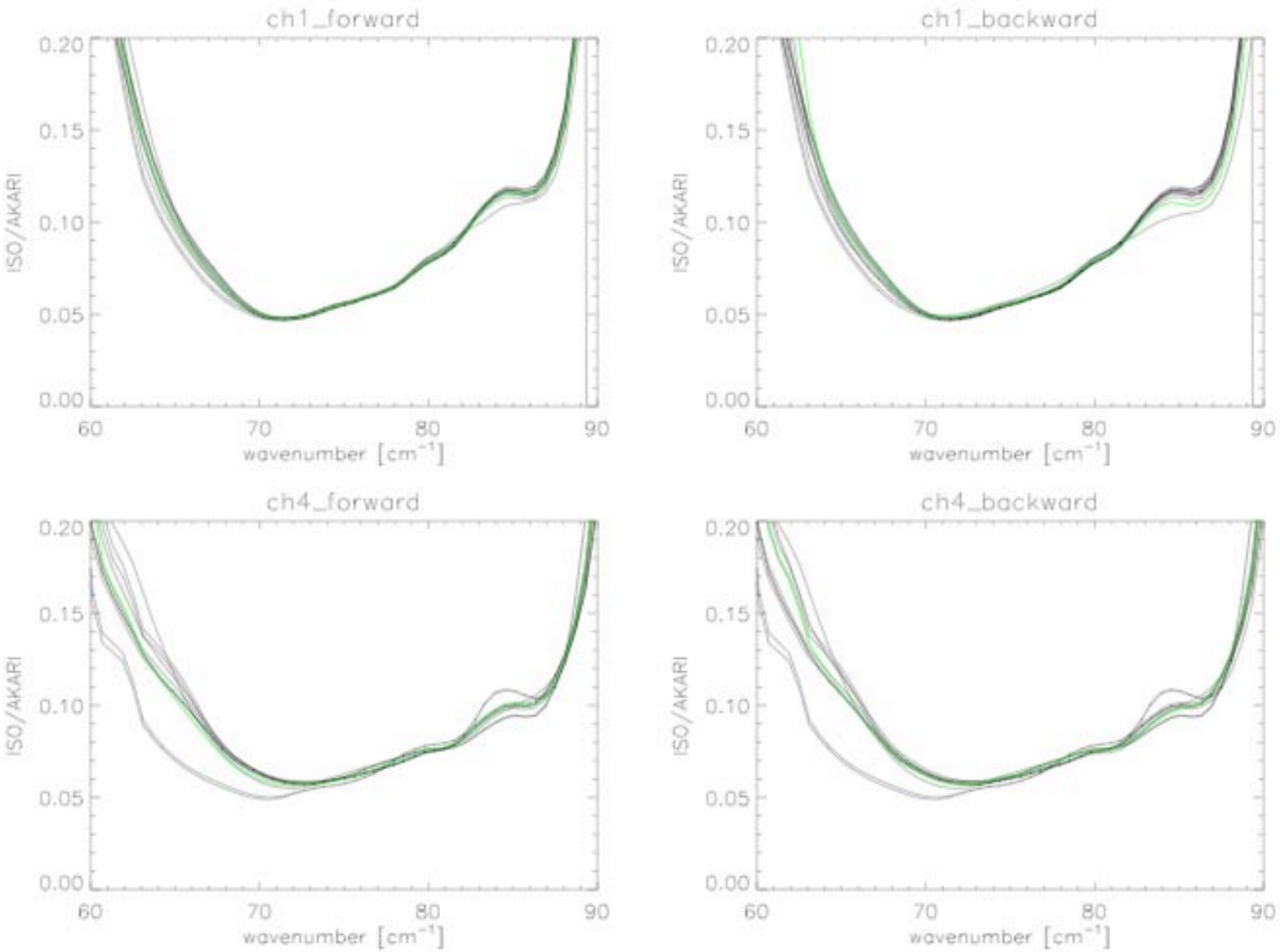

2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000

Derive normalized SCF

ISO/AKARI after normalizing with the integration of 85-140cm-1 and 65-85cm-1




forward
ISO/AKARI
0.20
0.15
0.10
0.05
0.00
80
100
120
140
160
180
200
wavenumber [cm⁻¹]
backward
ISO/AKARI
0.20
0.15
0.10
0.05
0.00
80
100
120
140
160
180
200
wavenumber [cm⁻¹]



We use the common normalized SCF for all the pixels of SW and different normalized SCF for each pixel of LW.

Correlation of normalized SCF between AKARI and ISO

Description:

- Each channel has two panels.

  First panel

  : the integration over 65-85cm-1 of ISO/AKARI (i.e. normalization factor used above) vs. that of ISO spectra. This shows the dependence of the in-band flux against the source brightness.

  black = forward scan,

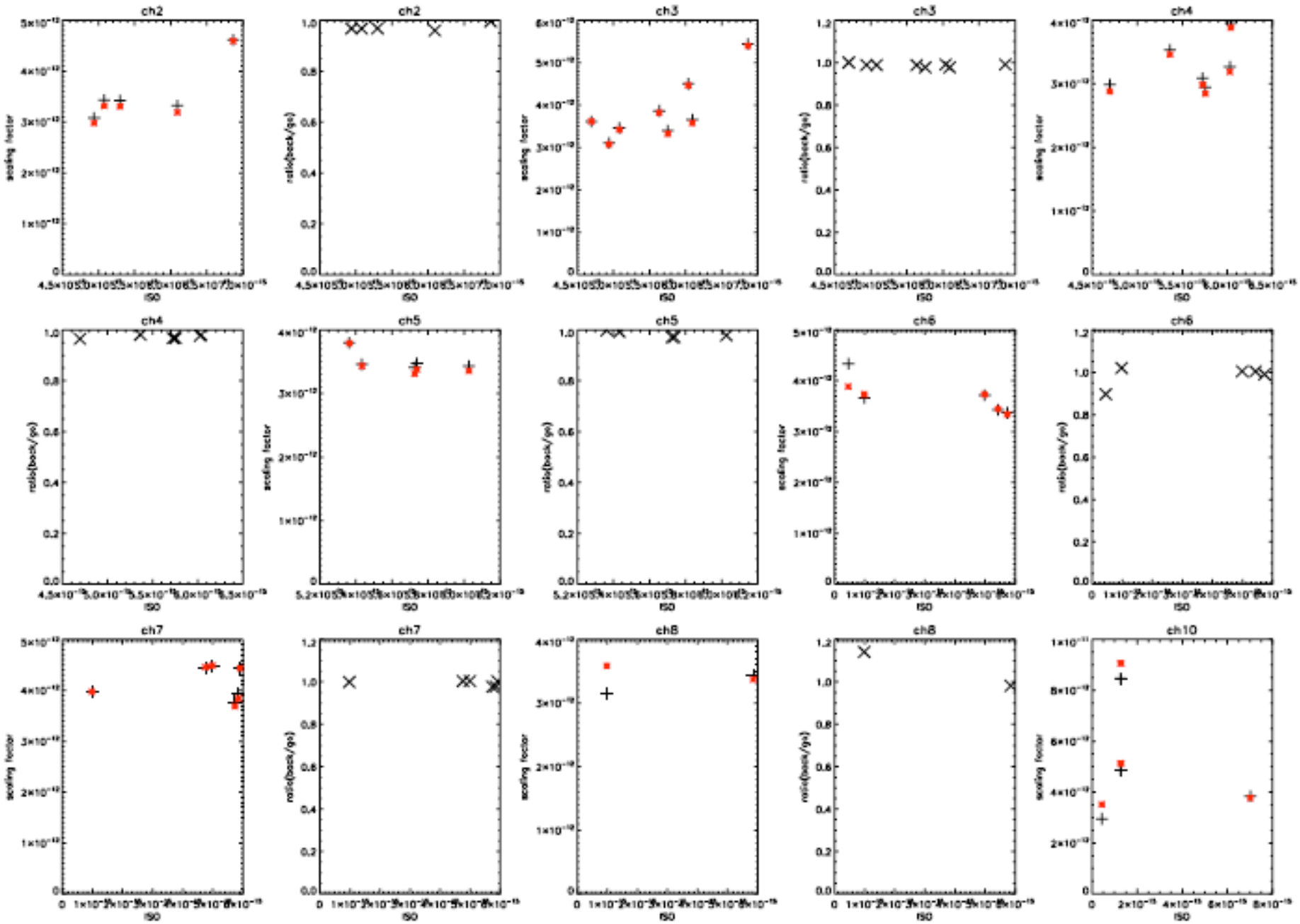
  red = reverse scan

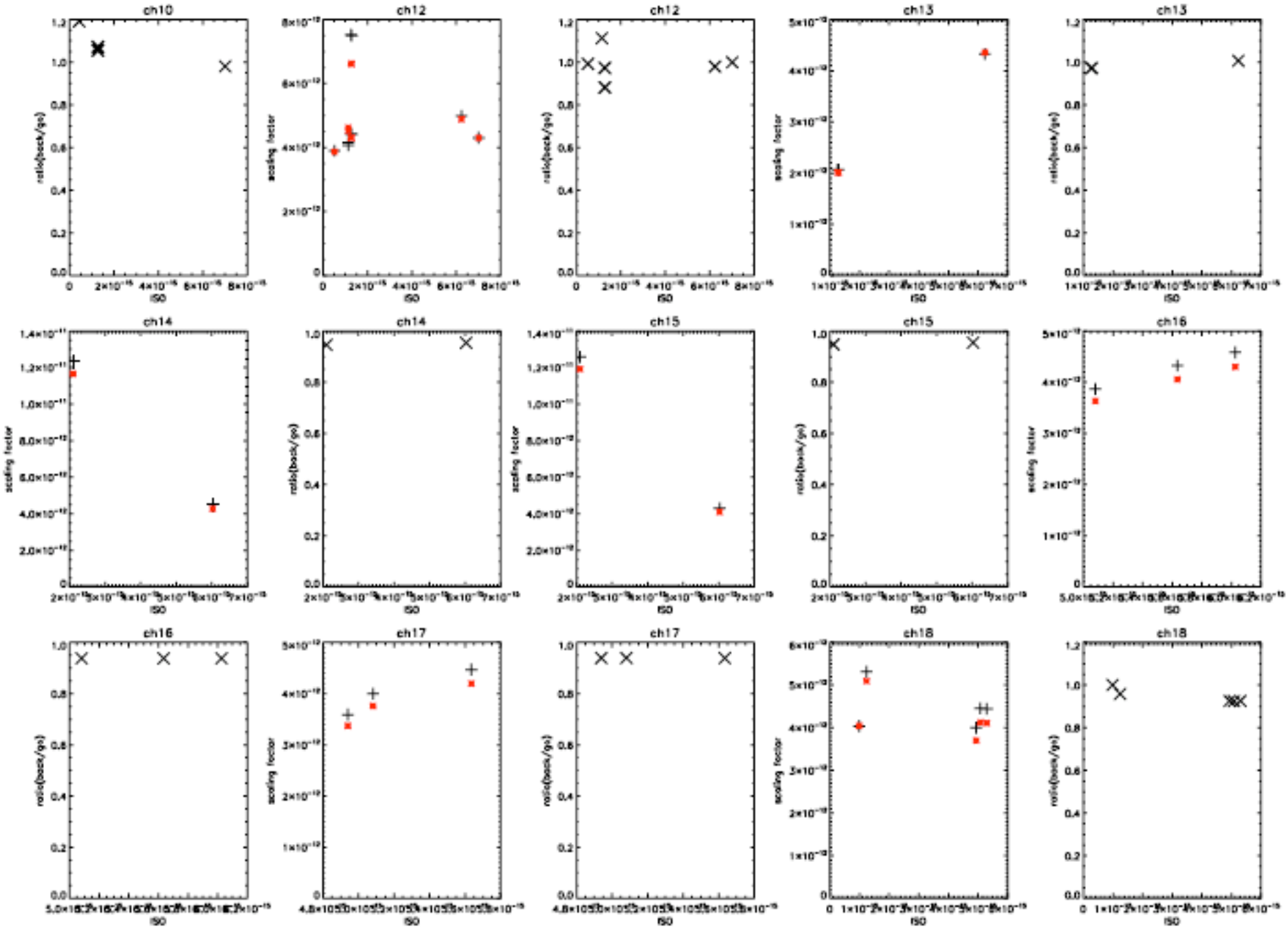
  Second panel

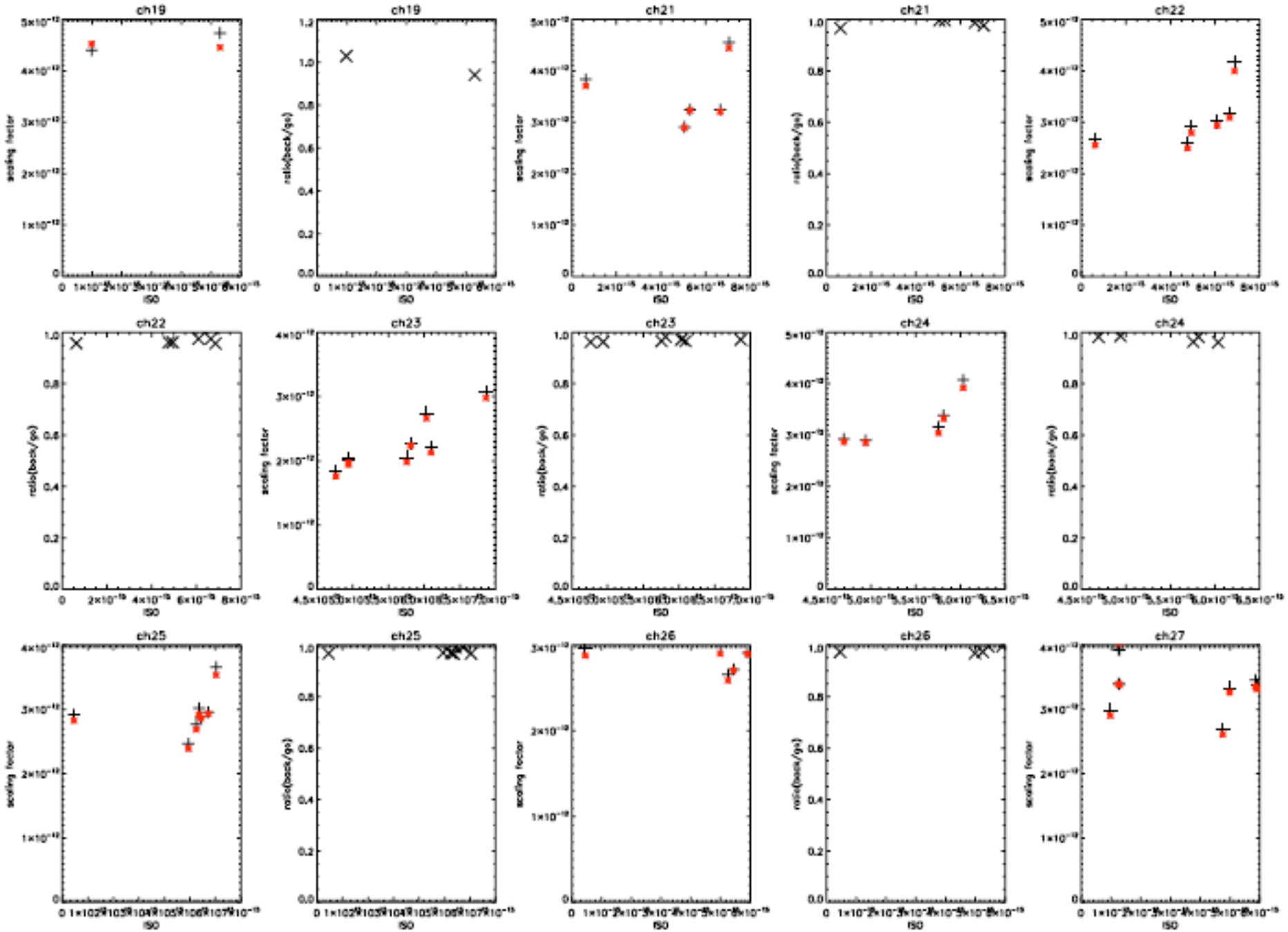
  : ratio of reverse scan / forward scan of the first panel.

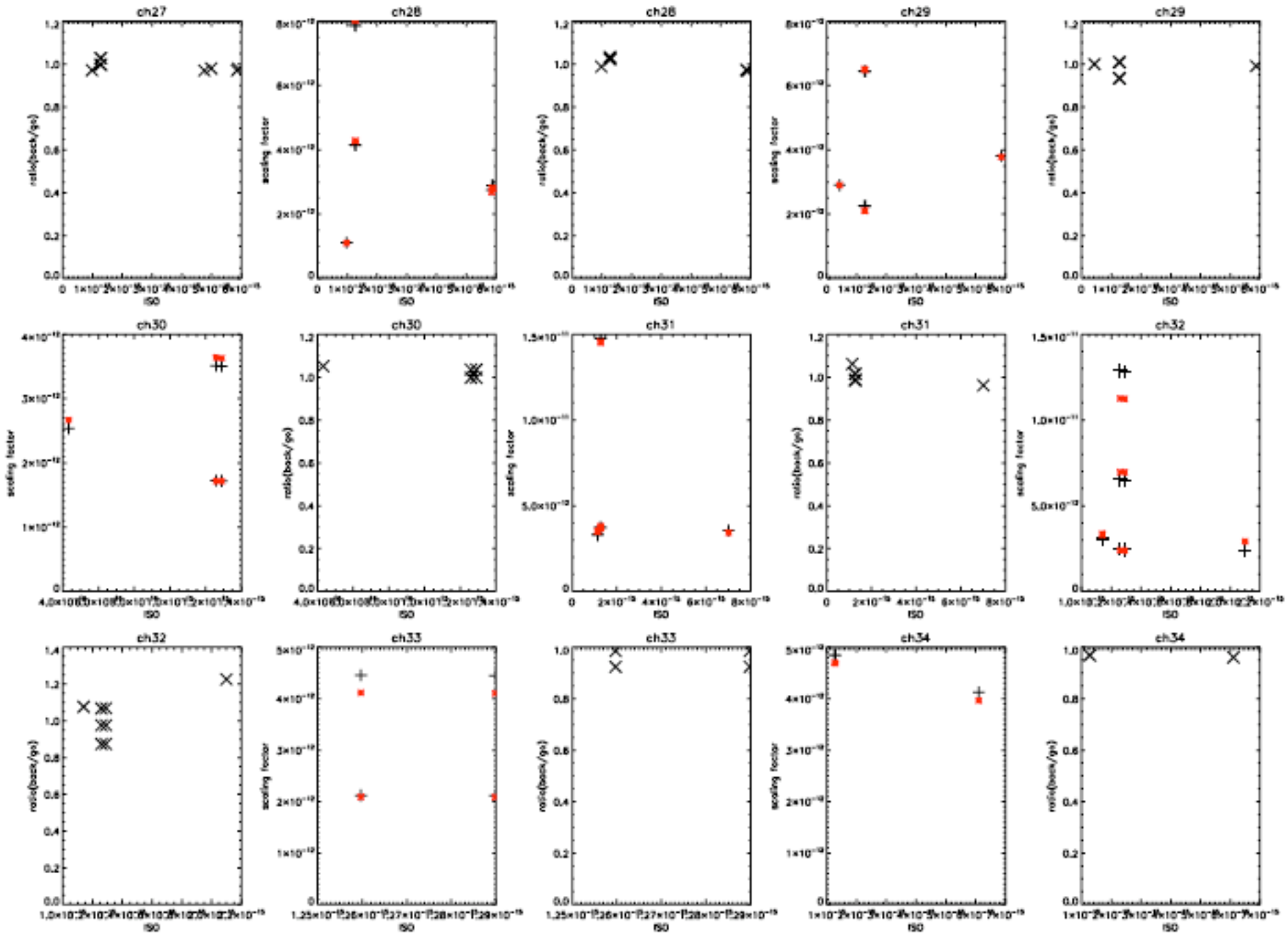
Remarks:

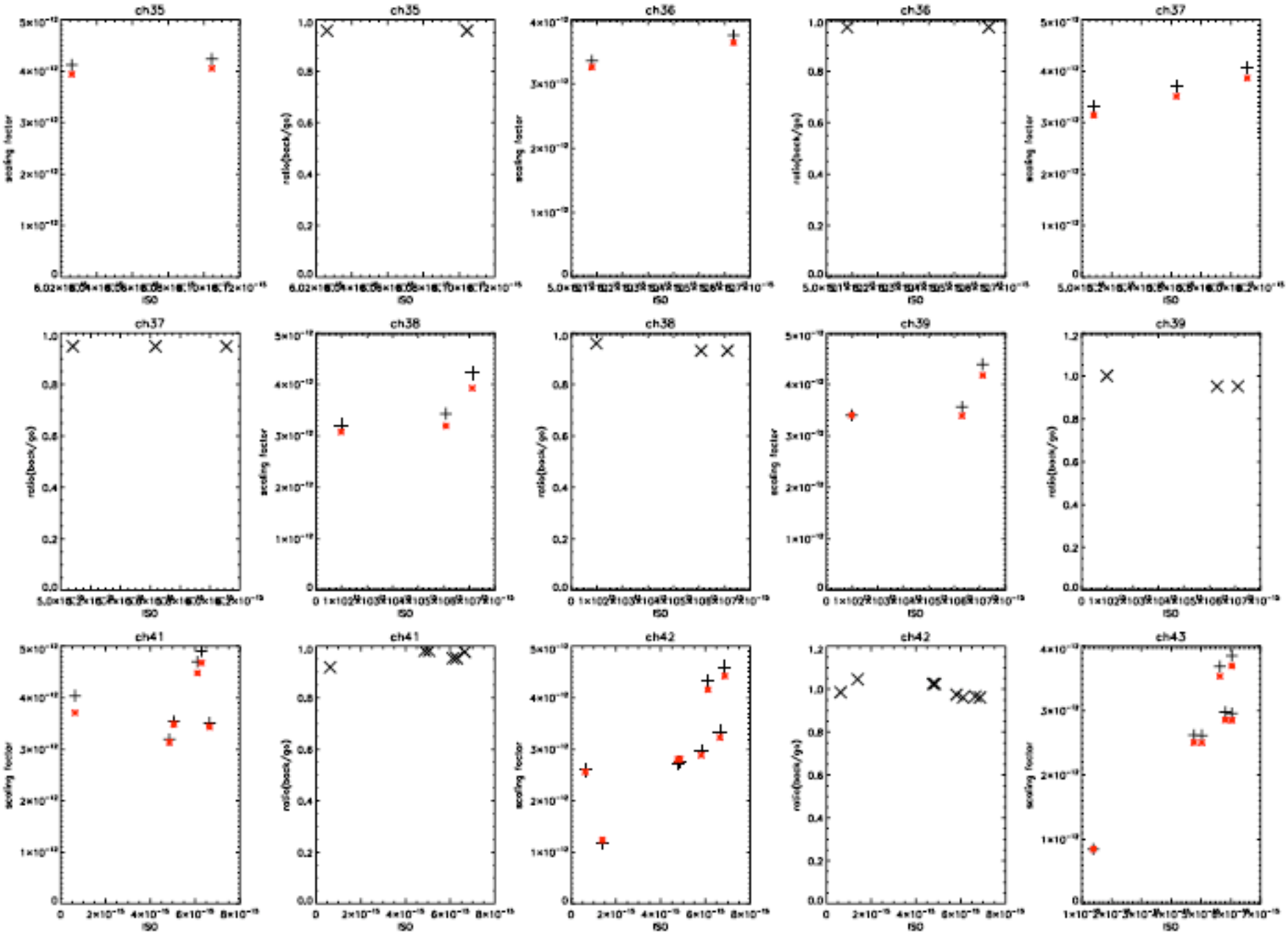
- Overall good correlation …!?
- Number of marks represent target number of multi pointings both AKARI and ISO.

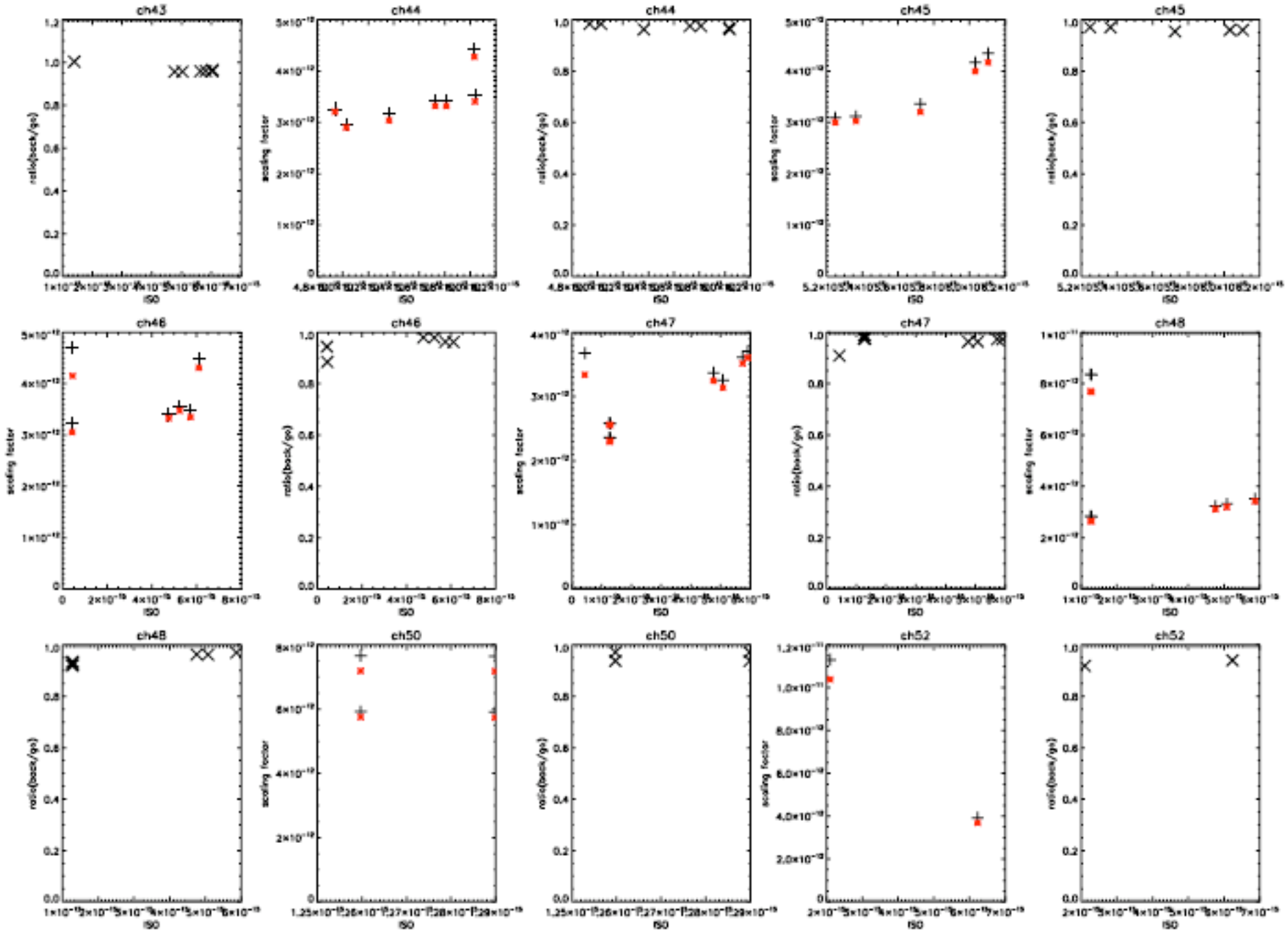

ch2
ch2
ch3
ch3
ch4
ch4
ch5
ch5
ch6
ch6
ch7
ch7
ch8
ch8
ch10
scaling factor
ratio(back/gs)
ISO

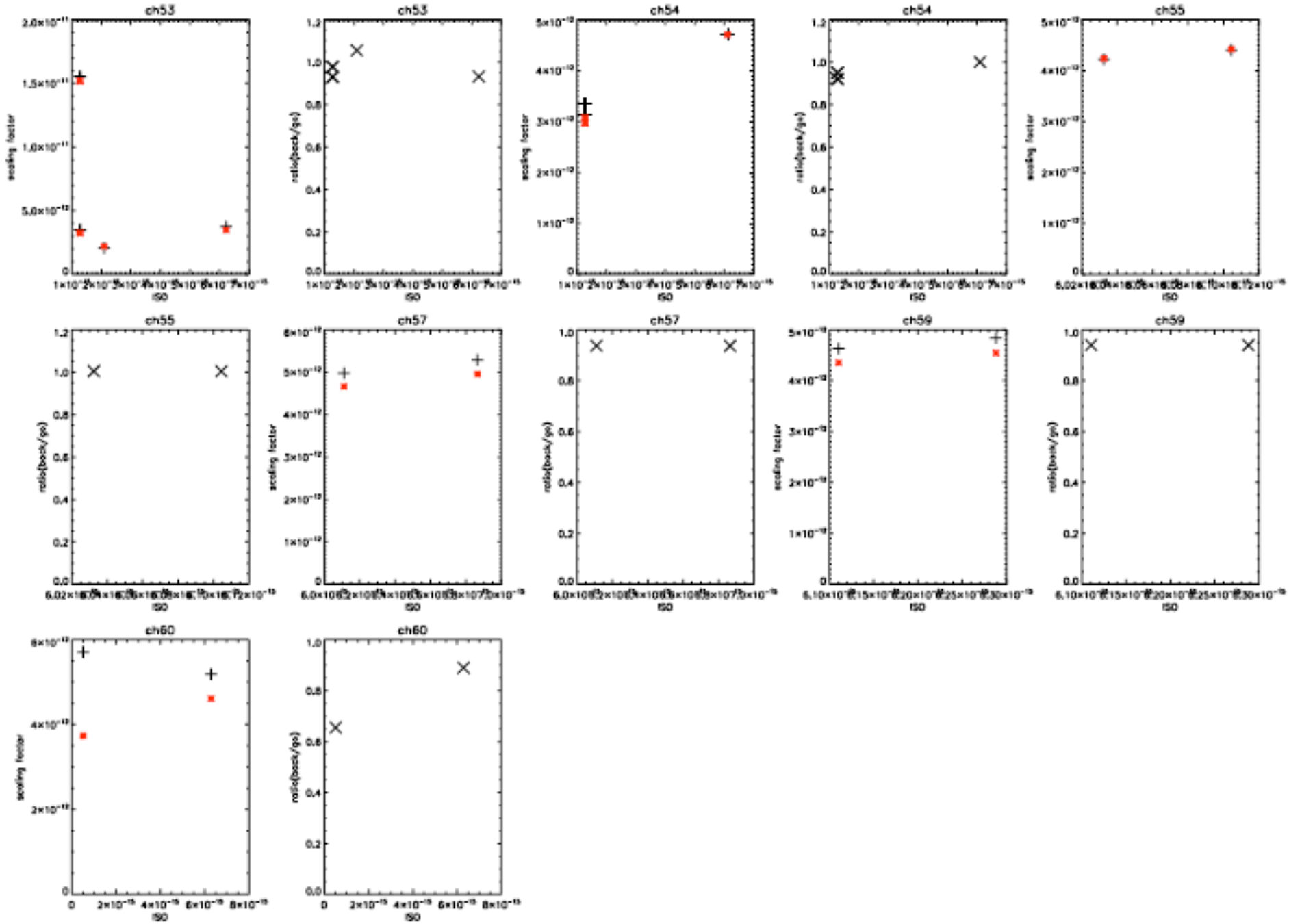

ch10
ch12
ch12
ch13
ch13
ch14
ch14
ch15
ch15
ch16
ch16
ch17
ch17
ch18
ch18
ratio(back/gs)
scaling factor
iso

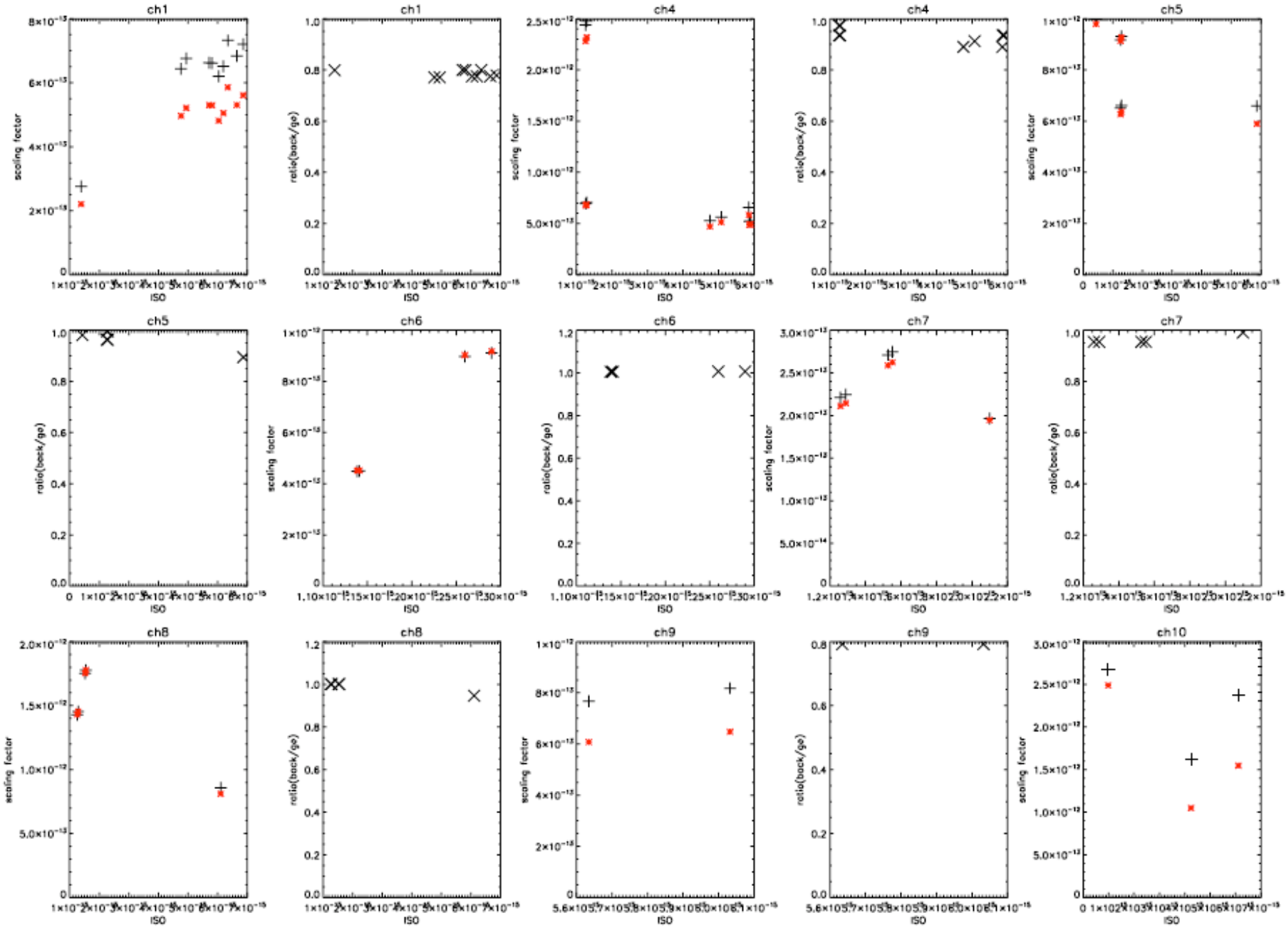

ch19
ch19
ch21
ch21
ch22
ch22
ch23
ch23
ch24
ch24
ch25
ch25
ch26
ch26
ch27
scaling factor
ratio(back/gs)
ISO

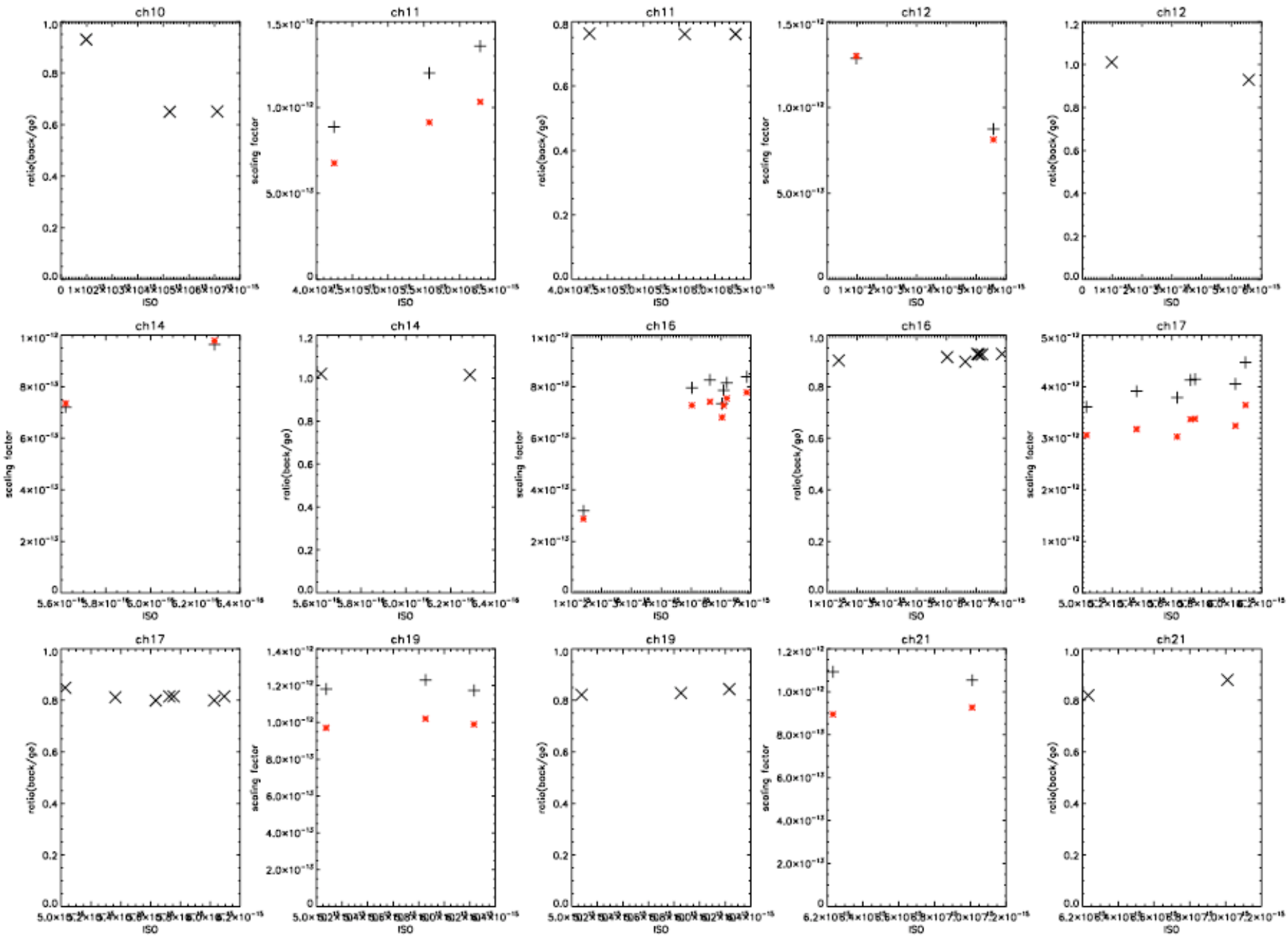

ch27
ch28
ch28
ch29
ch29
ch30
ch30
ch31
ch31
ch32
ch32
ch33
ch33
ch34
ch34
ratio(back/gs)
scaling factor
iso

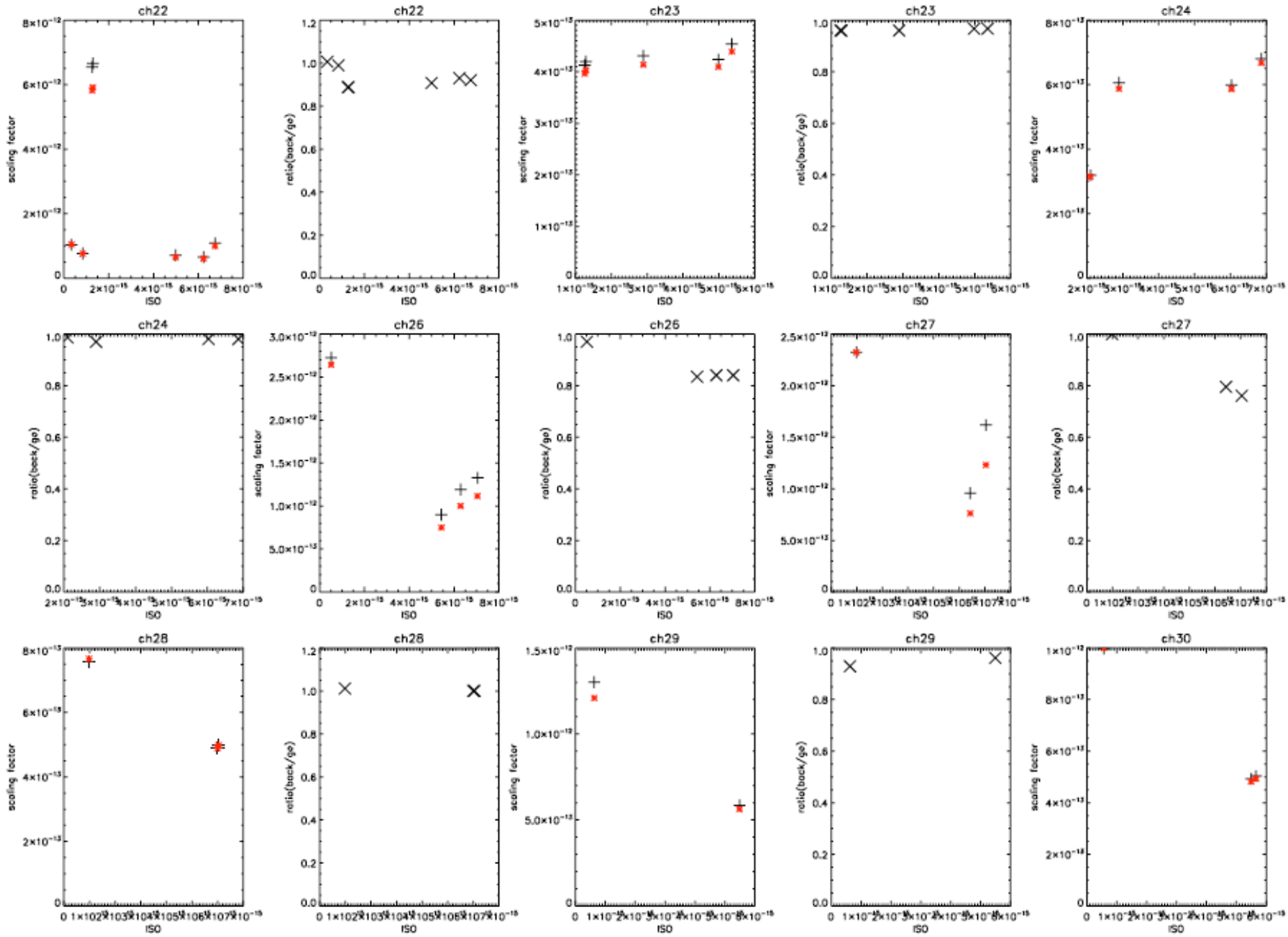

ch35
ch35
ch36
ch36
ch37
ch37
ch38
ch38
ch39
ch39
ch41
ch41
ch42
ch42
ch43
scaling factor
ratio(back/gs)
iso

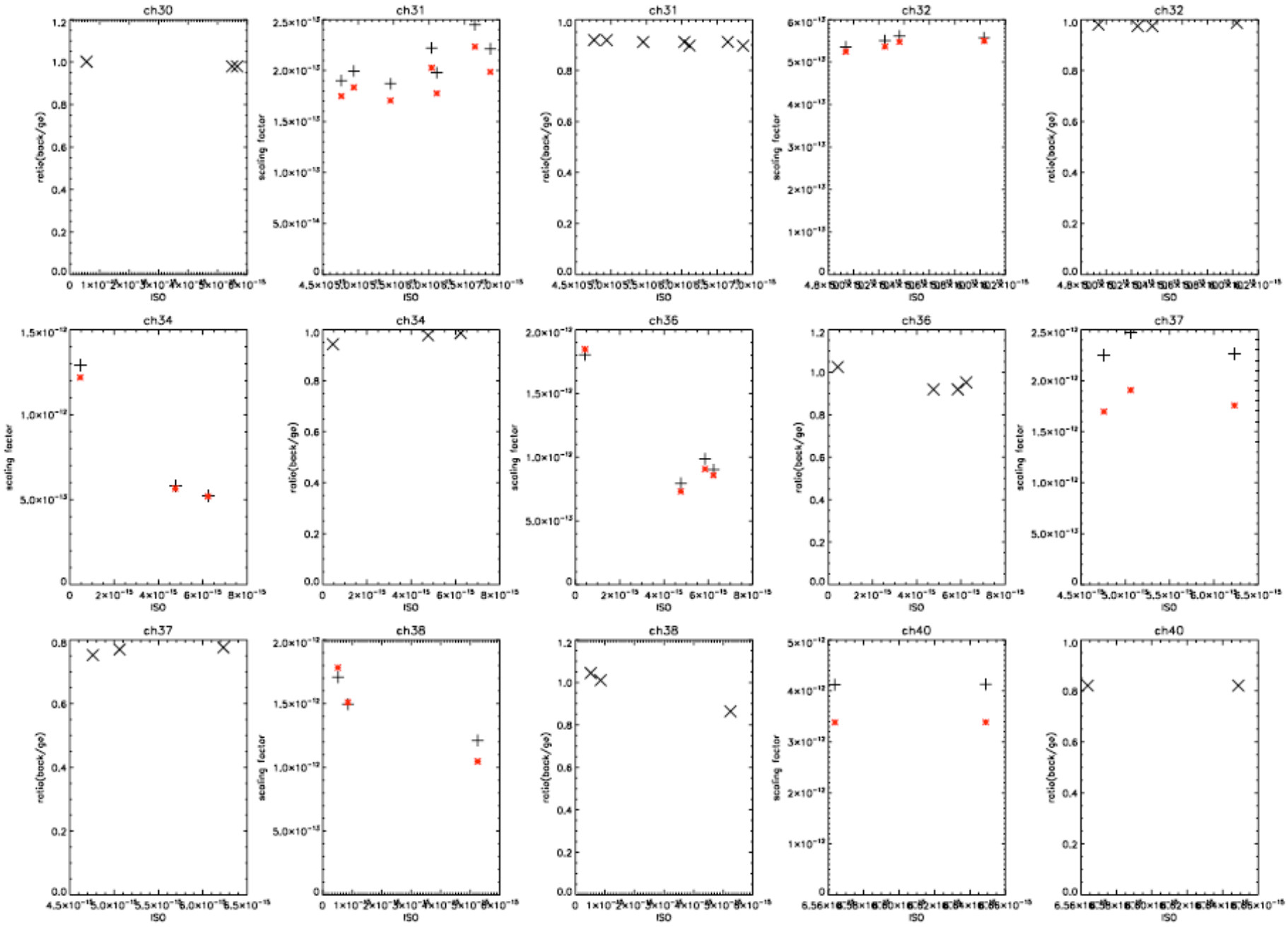

ch43
ch44
ch44
ch45
ch45
ch46
ch46
ch47
ch47
ch48
ch48
ch50
ch50
ch52
ch52
ratio(back/gs)
scaling factor
iso

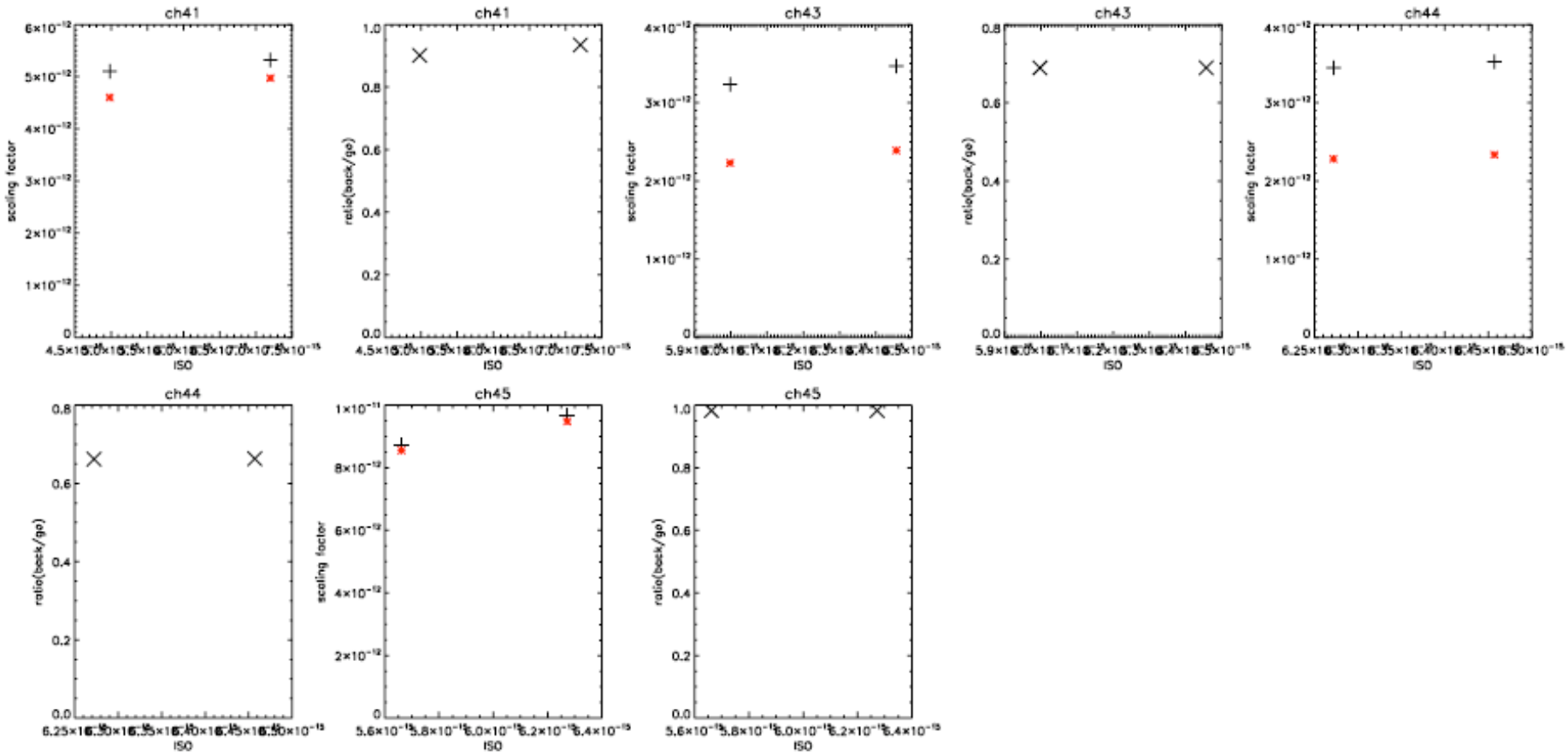

ch53
ch53
ch54
ch54
ch55
ch55
ch57
ch57
ch59
ch59
ch60
ch60
scaling factor
ratio(back/go)
iso


ch1
ch1
ch4
ch4
ch5
ch5
ch6
ch6
ch7
ch7
ch8
ch8
ch9
ch9
ch10
scaling factor
ratio(back/go)
ISO


ch10
ch11
ch11
ch12
ch12
ch14
ch14
ch16
ch16
ch17
ch17
ch19
ch19
ch21
ch21
ratio(back/go)
scaling factor
ISO


ch22
ch22
ch23
ch23
ch24
ch24
ch26
ch26
ch27
ch27
ch28
ch28
ch29
ch29
ch30
scaling factor
ratio(back/ge)
ISO

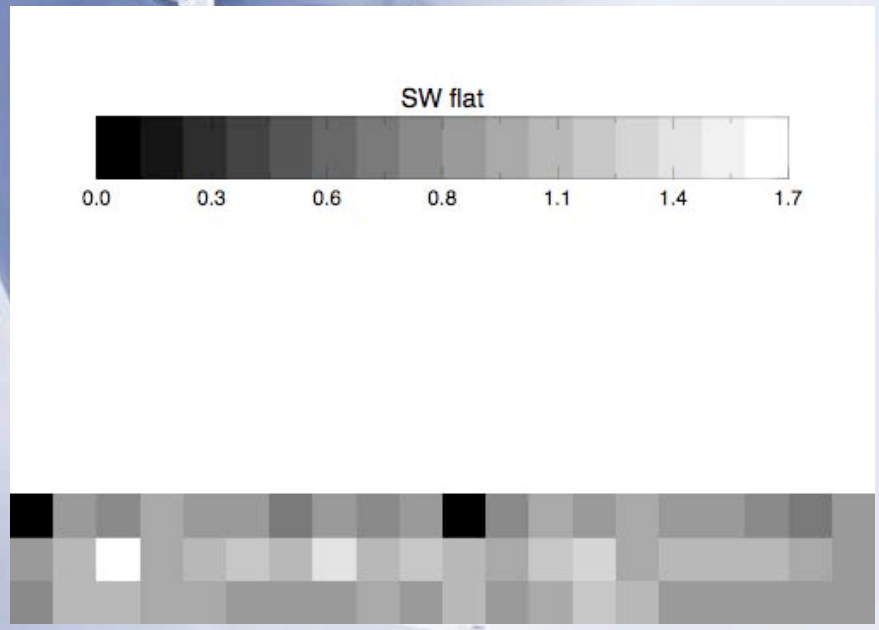

ch30
ch31
ch31
ch32
ch32
ch34
ch34
ch36
ch36
ch37
ch37
ch38
ch38
ch40
ch40
ratio(back/ge)
scaling factor
ISO

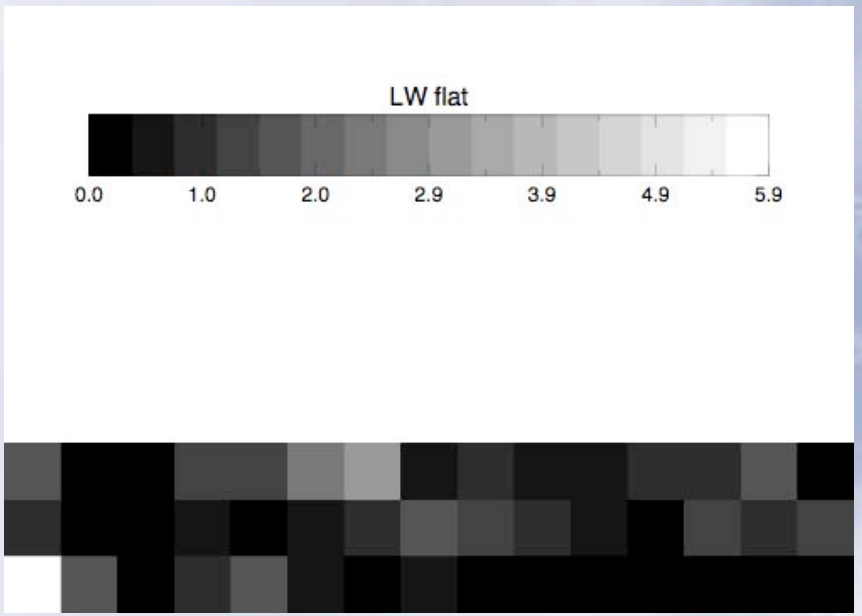

ch41
scaling factor
ISO
ch41
ratio(back/ge)
ISO
ch43
scaling factor
ISO
ch43
ratio(back/ge)
ISO
ch44
scaling factor
ISO
ch44
ratio(back/ge)
ISO
ch45
scaling factor
ISO
ch45
ratio(back/ge)
ISO

Flat

$$= \frac{I\,(\textit{internal calibration source in orbit}) * I\,(\textit{aperture lid before launch})}{I\,(\textit{internal calibration source before launch})}$$

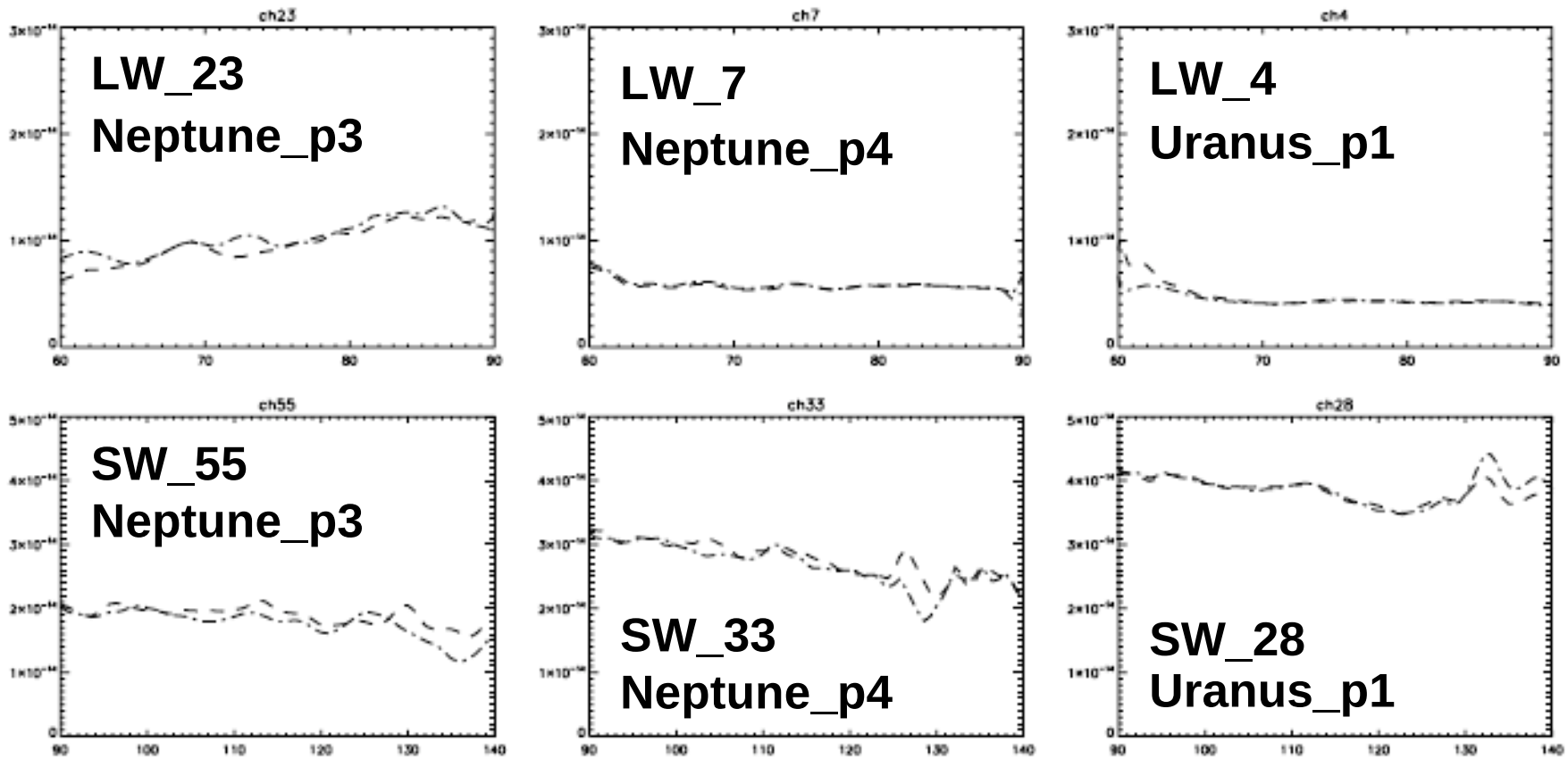
where $I()$ means the integration of the spectrum over effective wavenumber range





Absolute flux conversion factor

$$= \frac{(\textit{planet model})}{(\textit{raw spectra} * \textit{normalized SCF} * \textit{flat})}$$



Comparison between Neptune p3 and p4

(cf_akari_iso_spectrum)

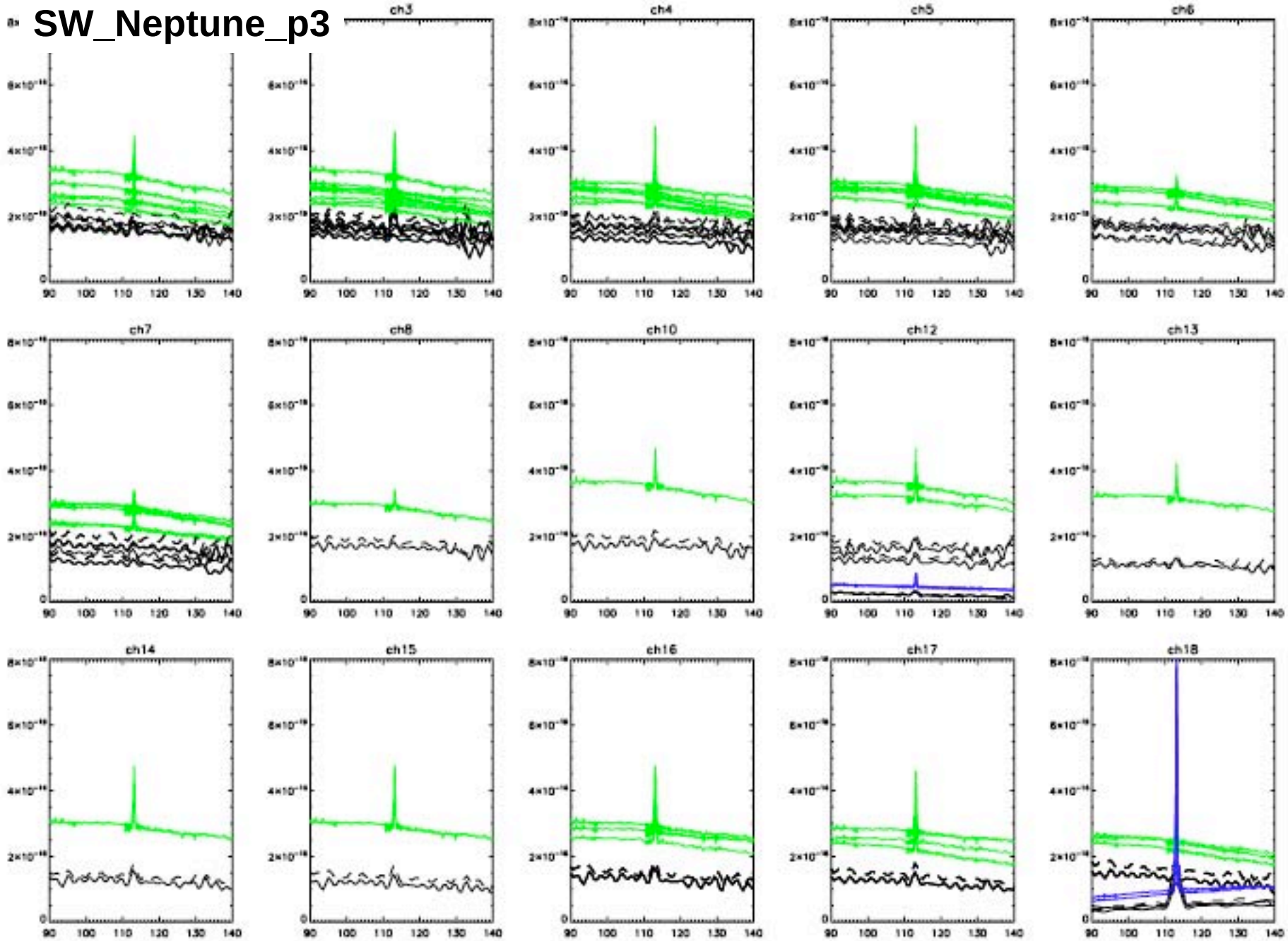
Description:

- **black = AKARI spectra using the absolute flux conversion factor from Neptune_p3 or p4**
- **green, blue = ISO/LWS spectra**
  Only GC(green), M17(green) and M20(blue) spectra are plotted.

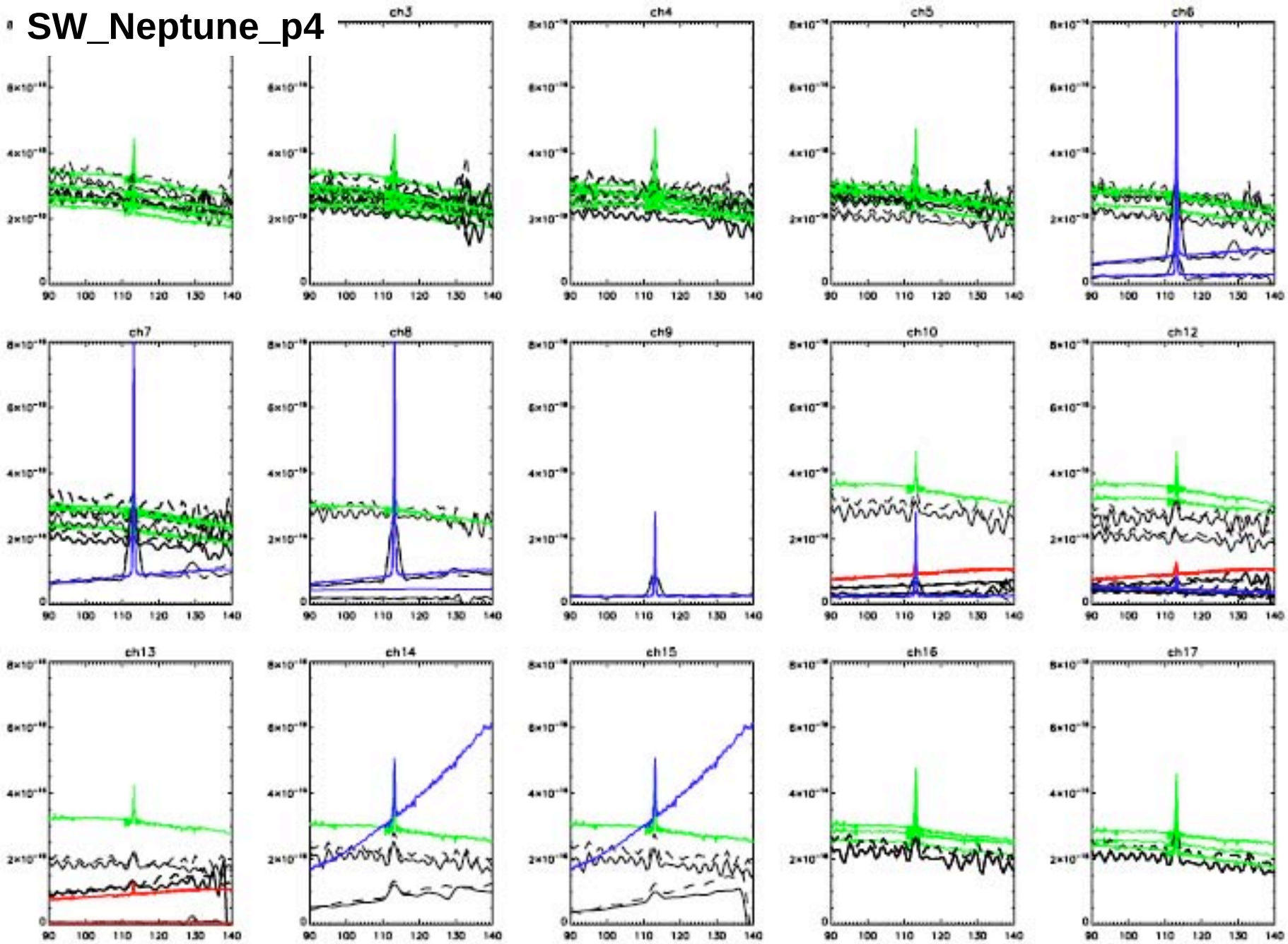
Remarks :

These figures indicate that the absolute flux conversion factor from Neptune_p4 is better than that from Neptune_p3.

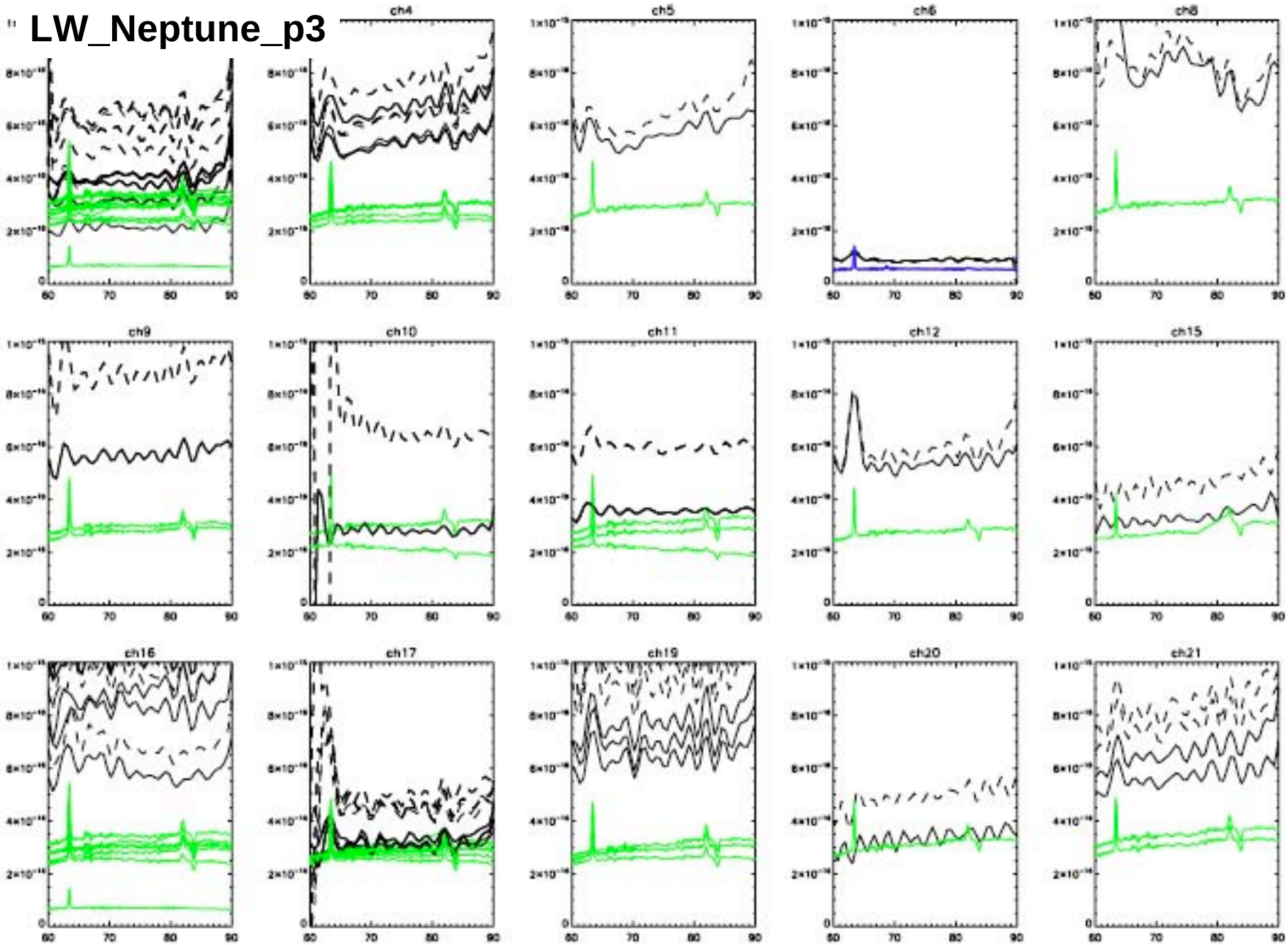
SW_Neptune_p3



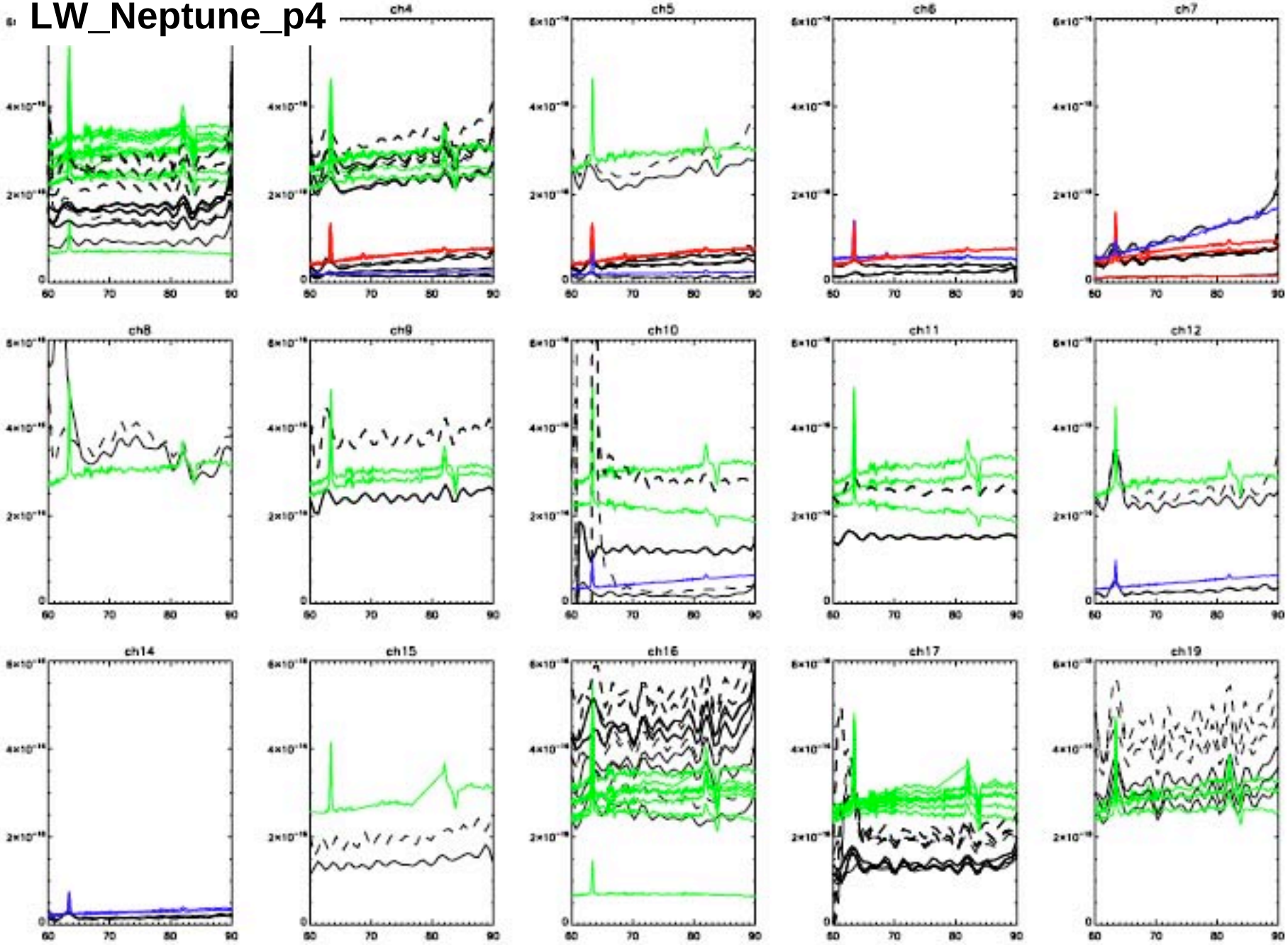
- **SW_Neptune_p4**



LW_Neptune_p3



LW_Neptune_p4



Comparison between AKARI and ISO spectrum

Description:

black = calibrated AKARI data.

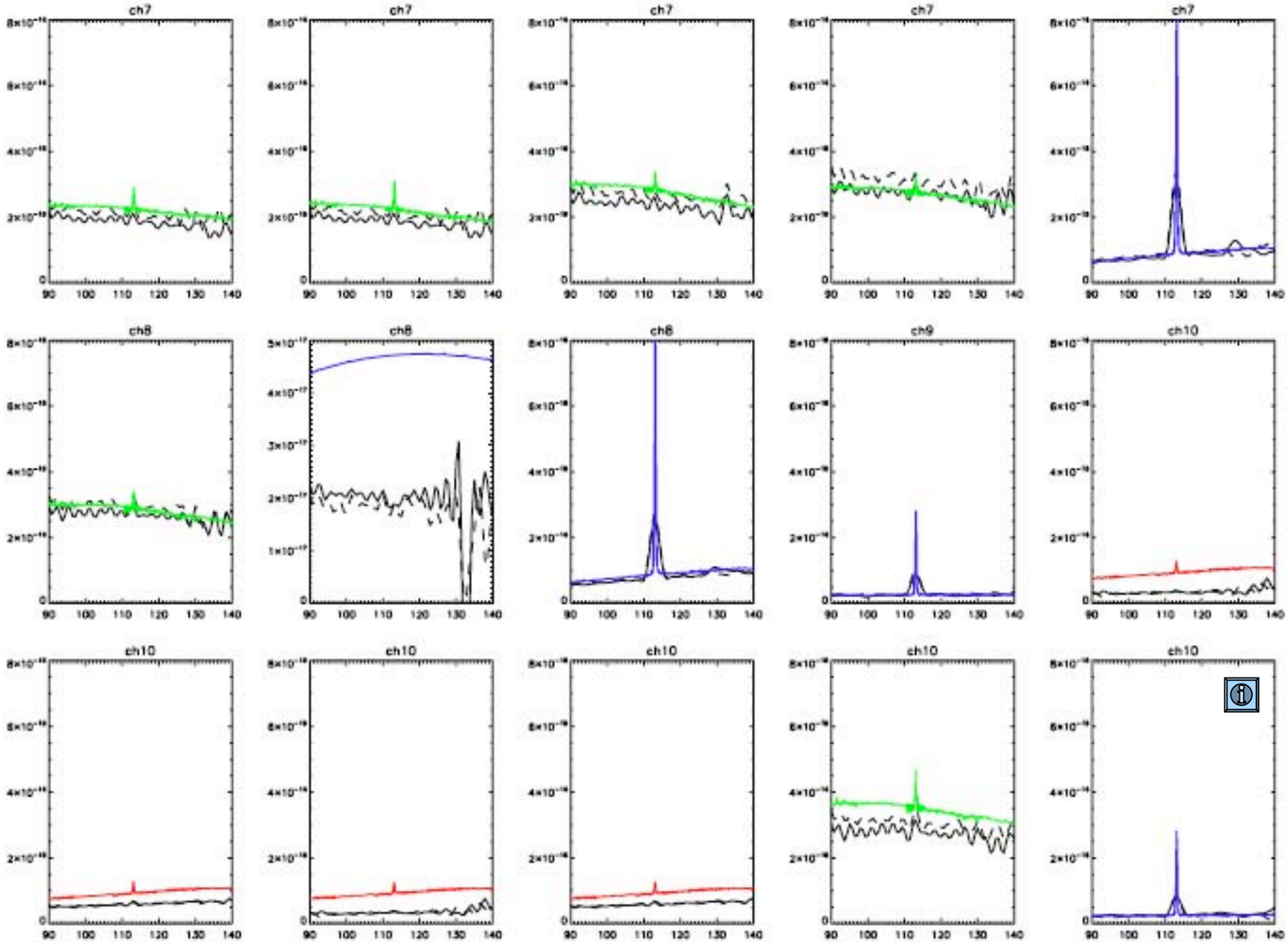
color : ISO/LWS or planet model data

green = M17 and GC,

blue = M20, Carina, and Uranus,

red = M82 and Neptune)

SW sample


ch7
ch7
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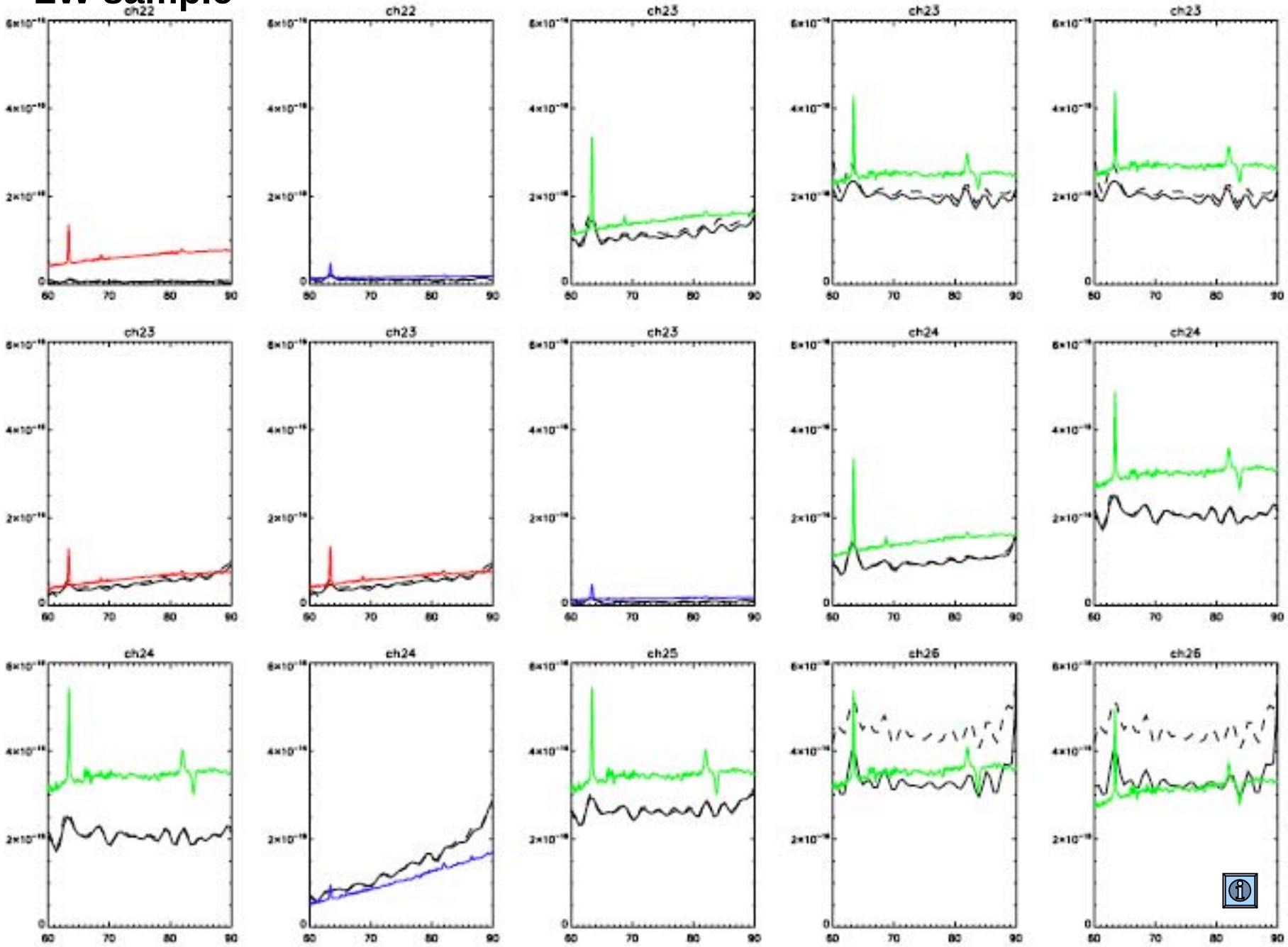
ch10
ch10

LW sample


ch22
ch22
ch23
ch23
ch23
ch23
ch23
ch23
ch24
ch24
ch24
ch24
ch25
ch26
ch26

Uncertainty of absolute flux conversion factor

Figures:

ceres_LW/SW

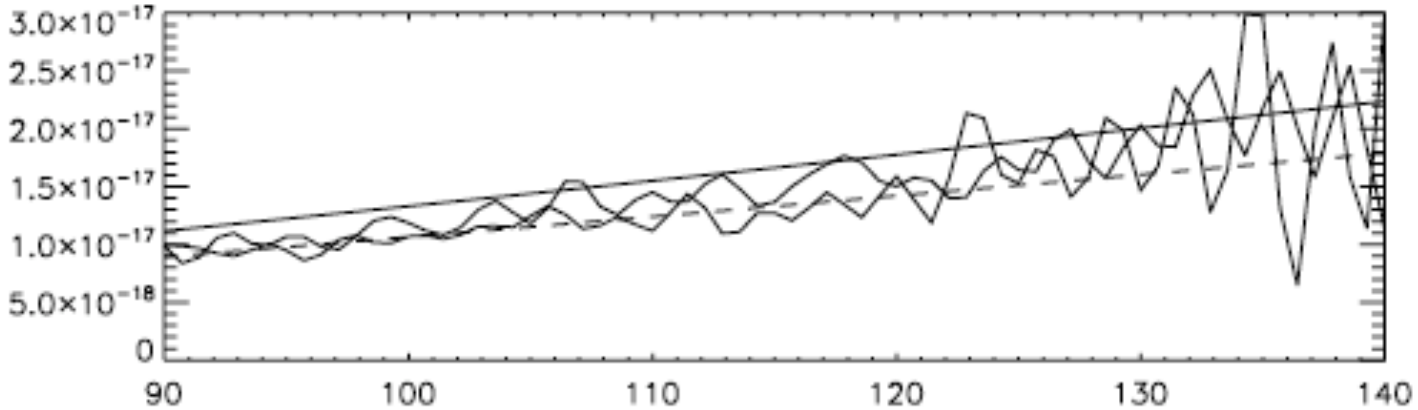
Description:

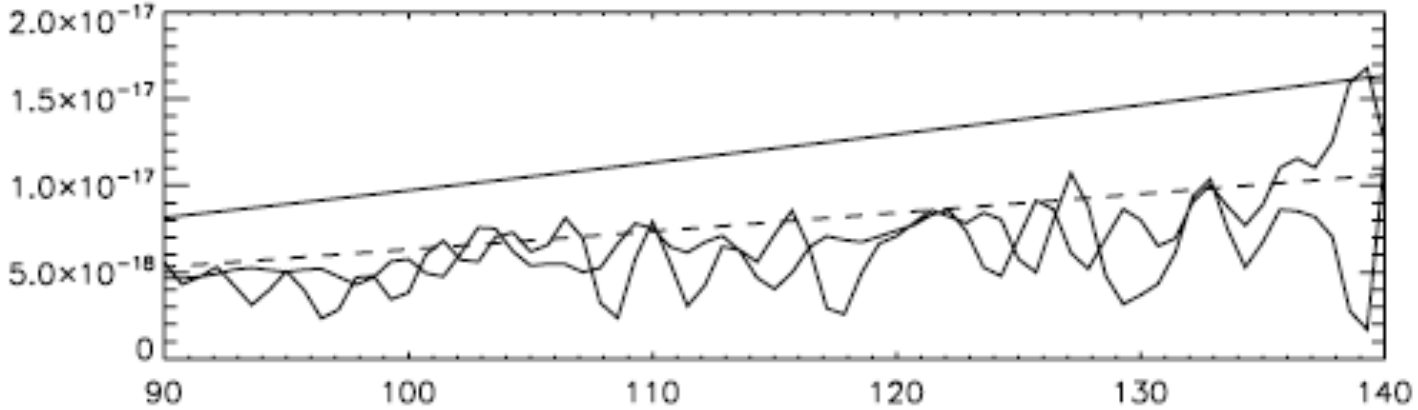
Solid line : Calibrated Ceres spectra of AKARI and model spectra
Dashed line : Scaled model spectra to fit the observed spectra

Results :

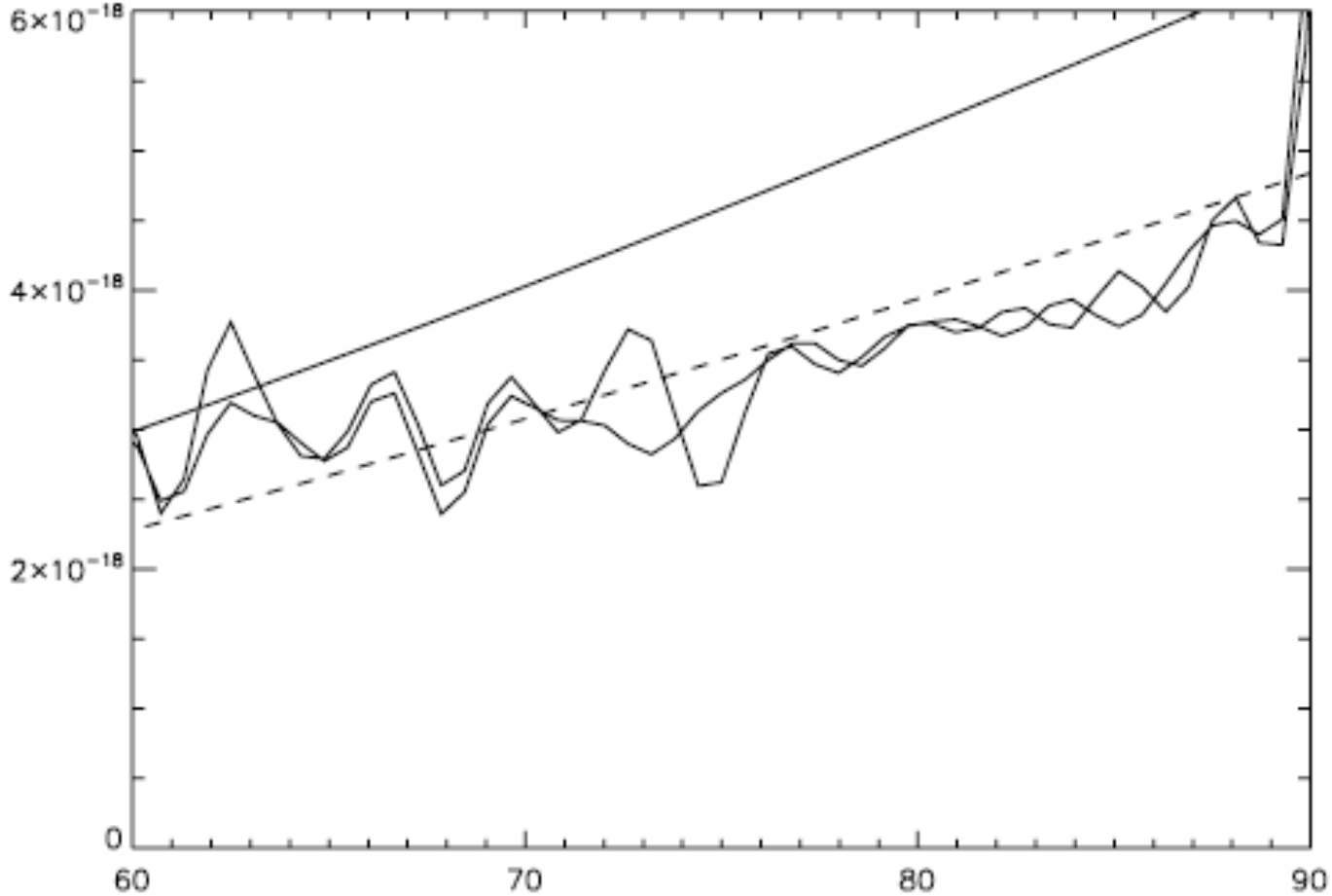
We estimate the uncertainty of absolute flux conversion factor as <u>35%</u> and <u>25%</u> for SW and LW, respectively.
(dashed line / solid line)

SW


3.0×10⁻¹⁷
2.5×10⁻¹⁷
2.0×10⁻¹⁷
1.5×10⁻¹⁷
1.0×10⁻¹⁷
5.0×10⁻¹⁸
0
90
100
110
120
130
140


2.0×10⁻¹⁷
1.5×10⁻¹⁷
1.0×10⁻¹⁷
5.0×10⁻¹⁸
0
90
100
110
120
130
140

LW



Defringe

Procedure:

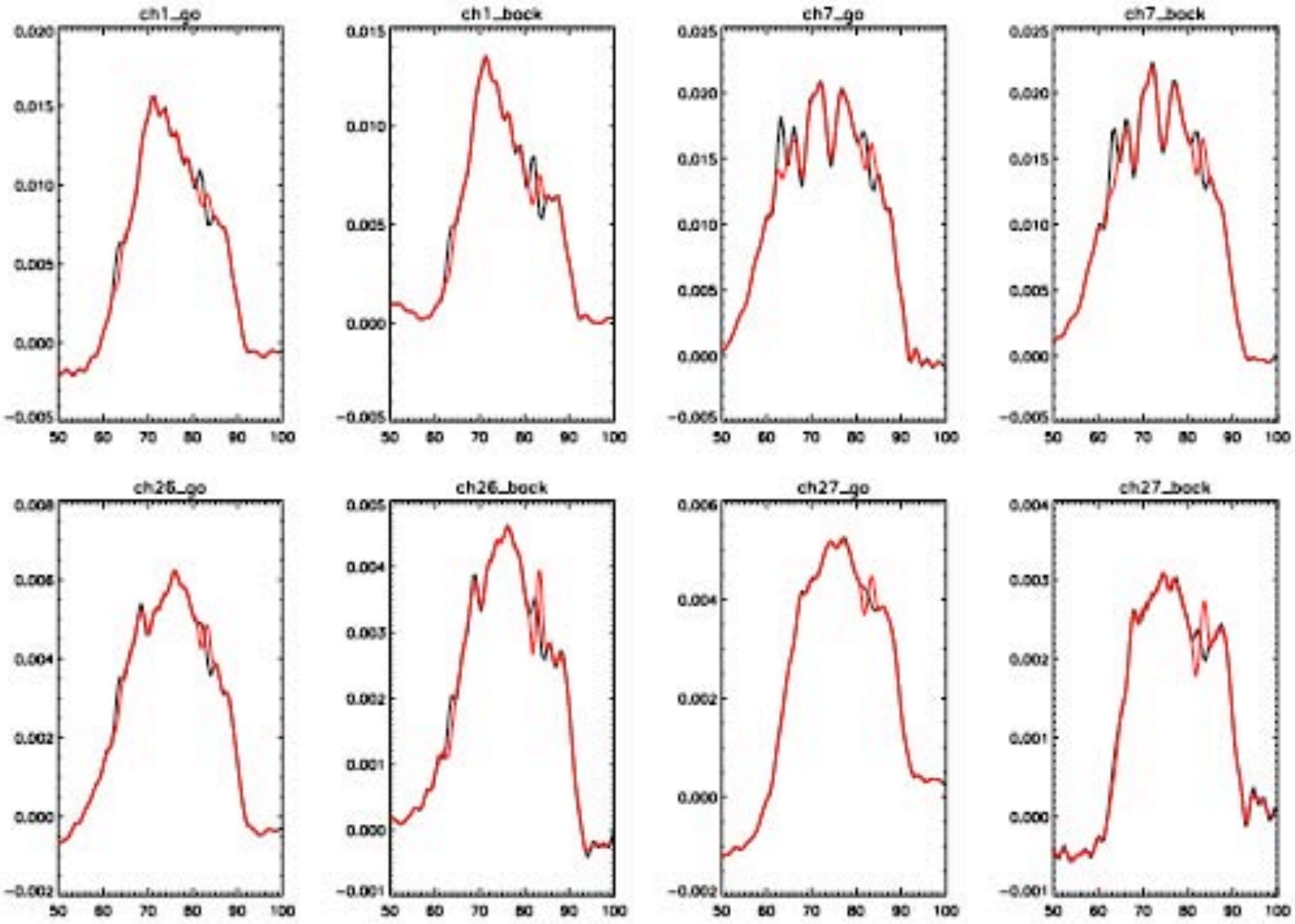
- Mask around lines
- Smooth full-resolution spectrum in the range of FSR (= continuum spectrum which derived by SED mode)
- Make template (masked spectrum - smoothed spectrum)
- Average template spectrum every channel & go/back
- Fitting with Airy function locally (on line)

Description:

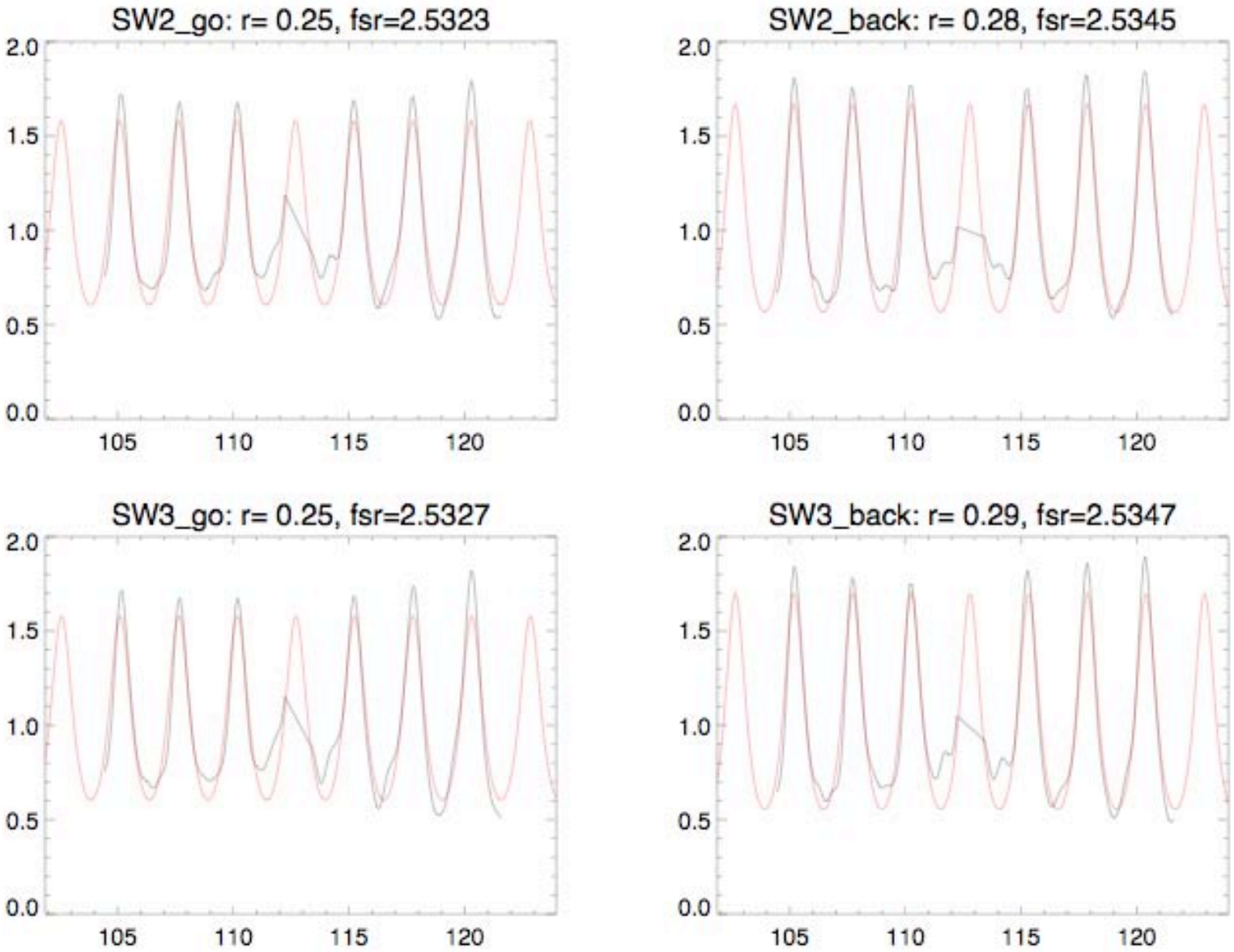
- The smoothed spectrum is same profile to low resolution spectrum (SED mode).
- These figures show the fit with Airy function with free parameters of free spectral range and reflectivity.

black = fringe template using GC spectra
red = fitted Airy function

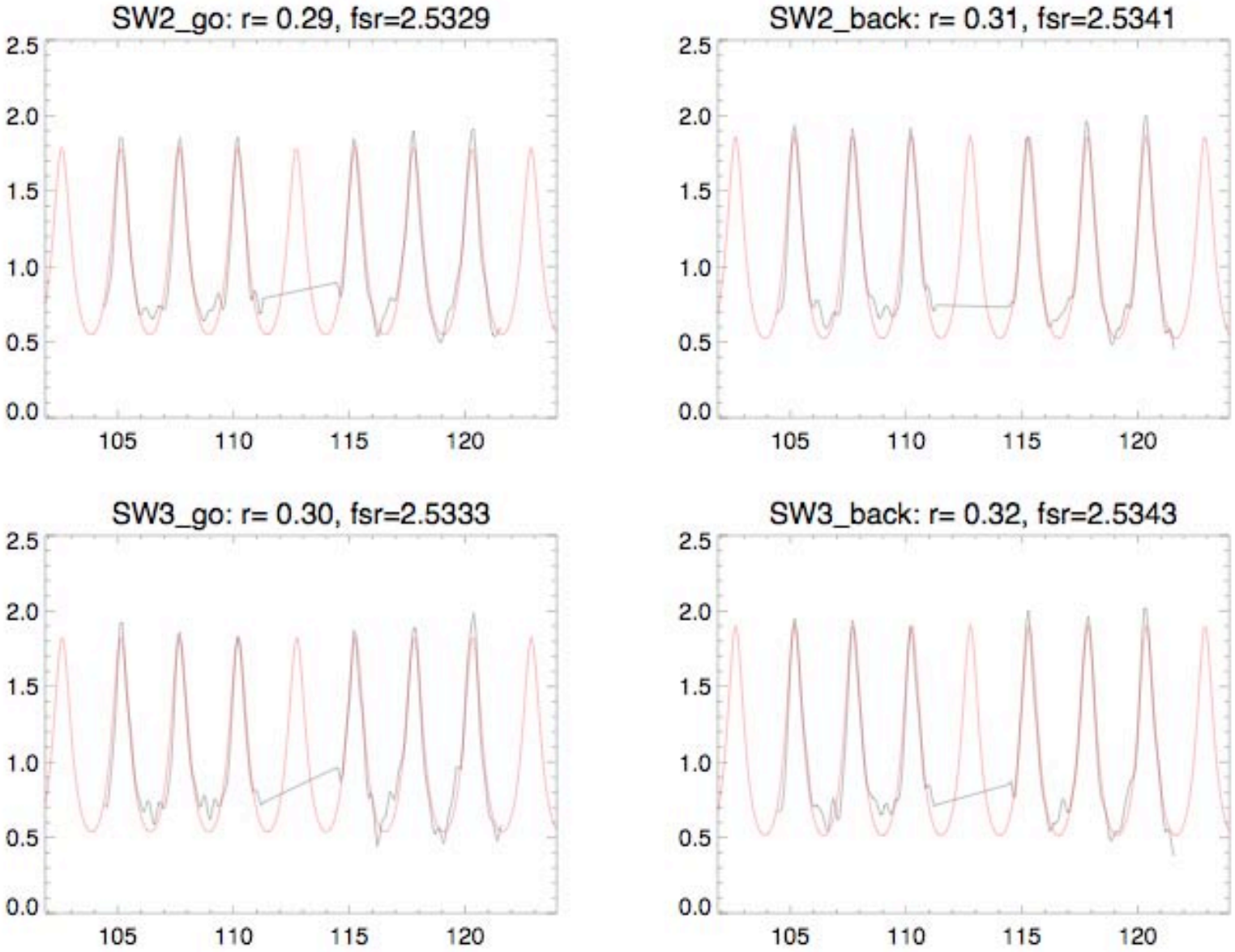
red = full-resolution spectra smoothed on spectrum base.
black = spectra from interferogram of SED
(oneside of SED range [-0.42, 0])



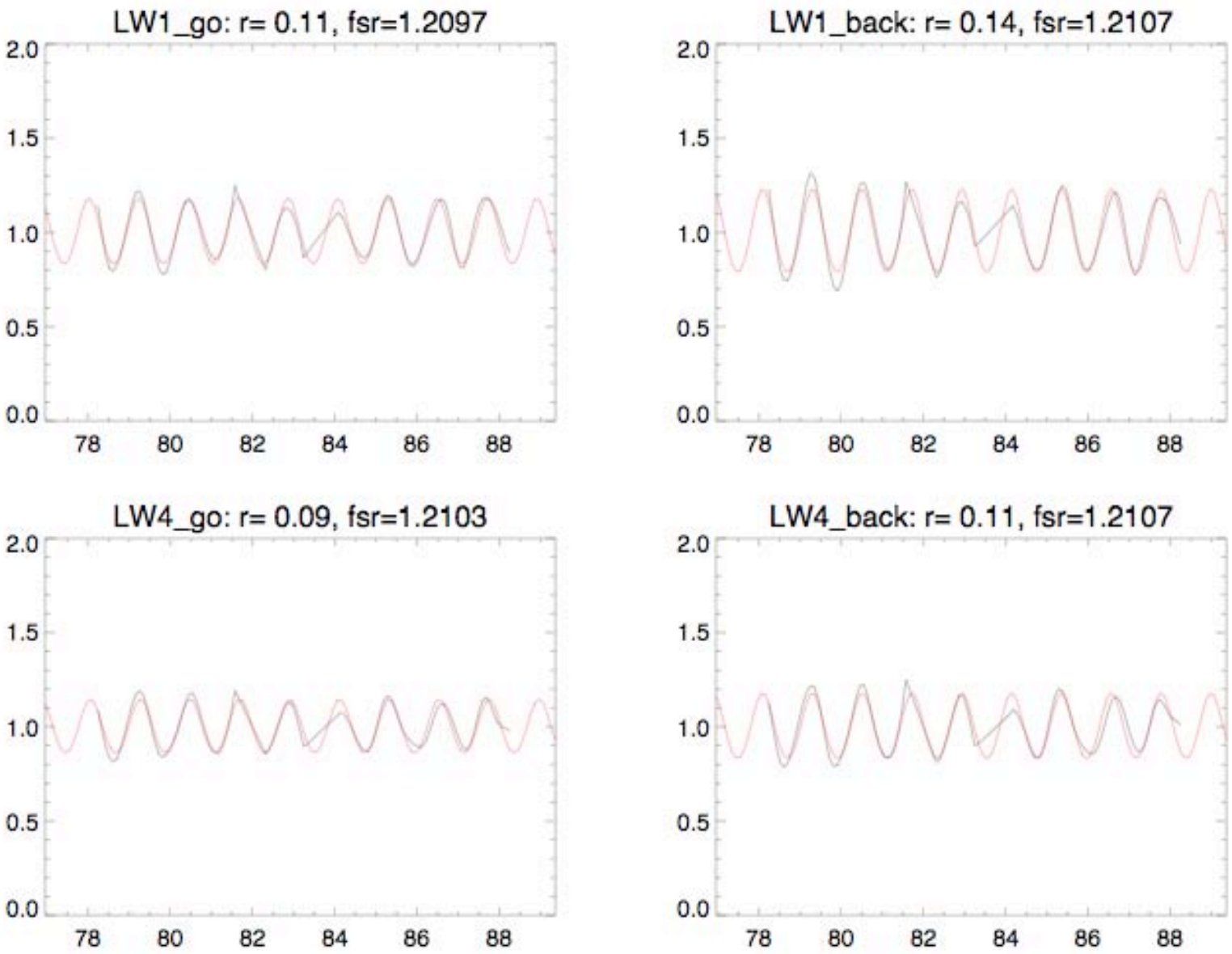
Fringe fit around [OIII]88um with 'hanning' apodization



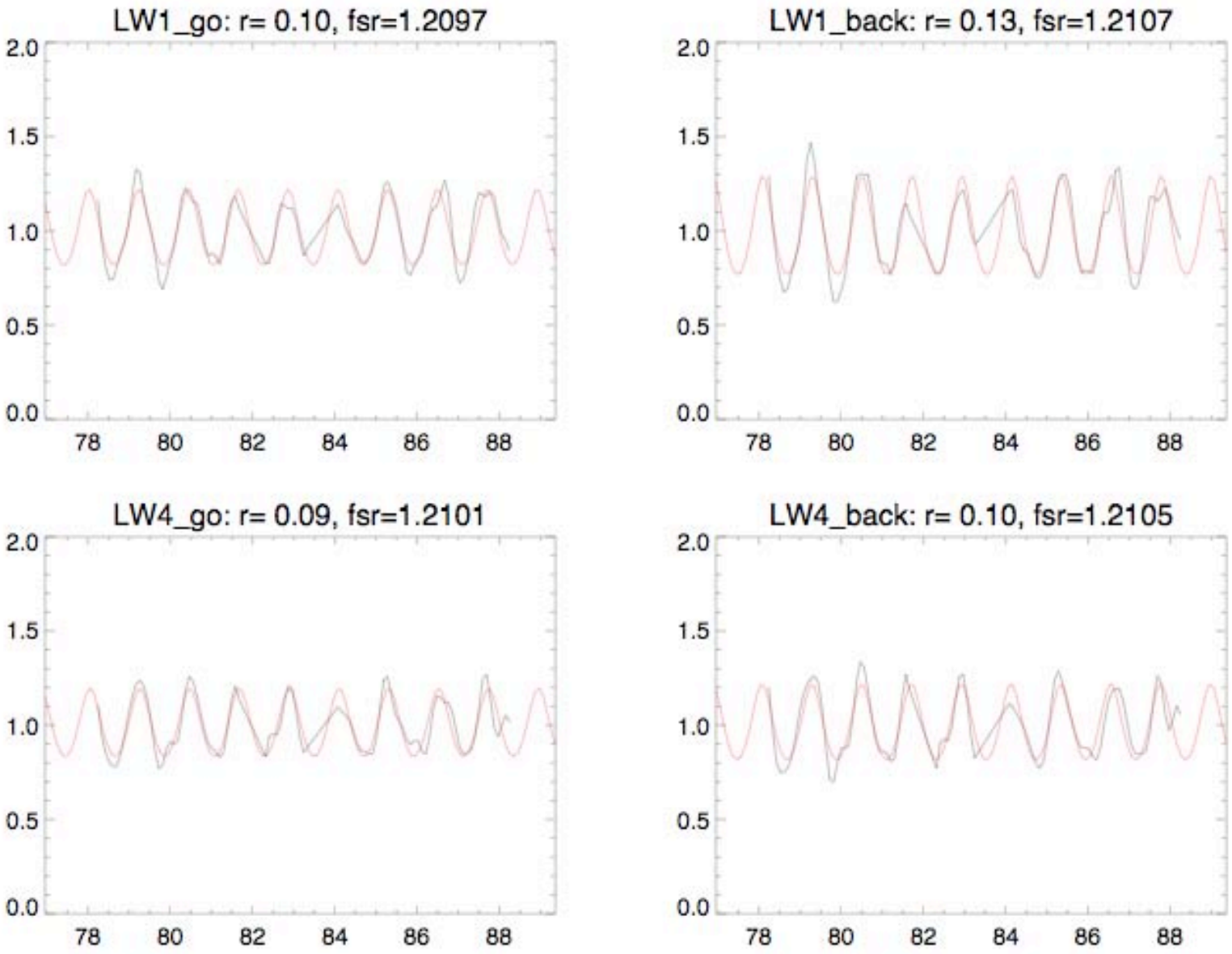
Fringe fit around [OIII]88um without apodization

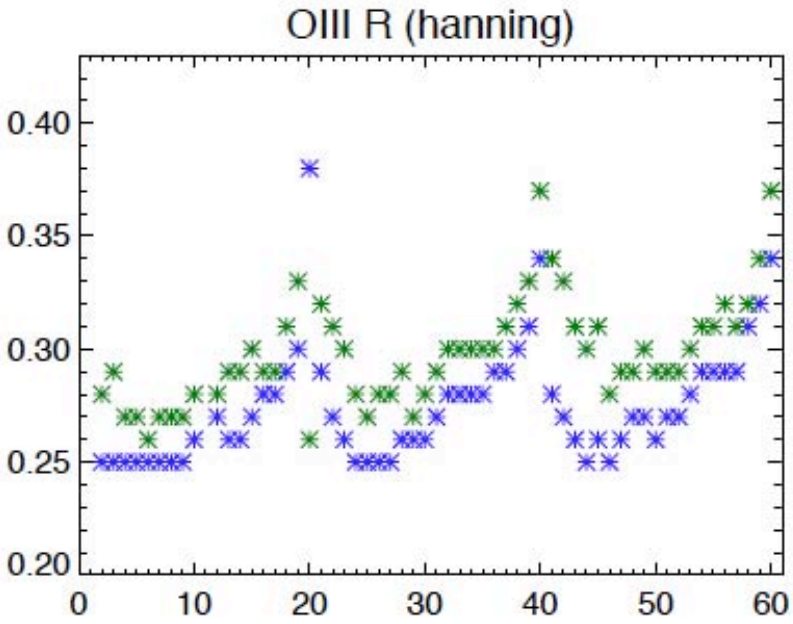


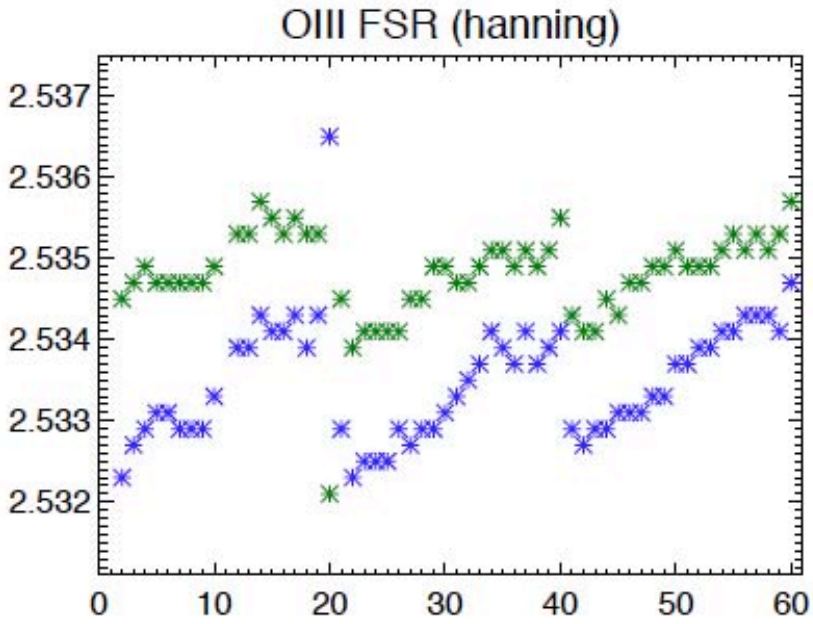
Fringe fit around [NII]122um with 'hanning' apodization

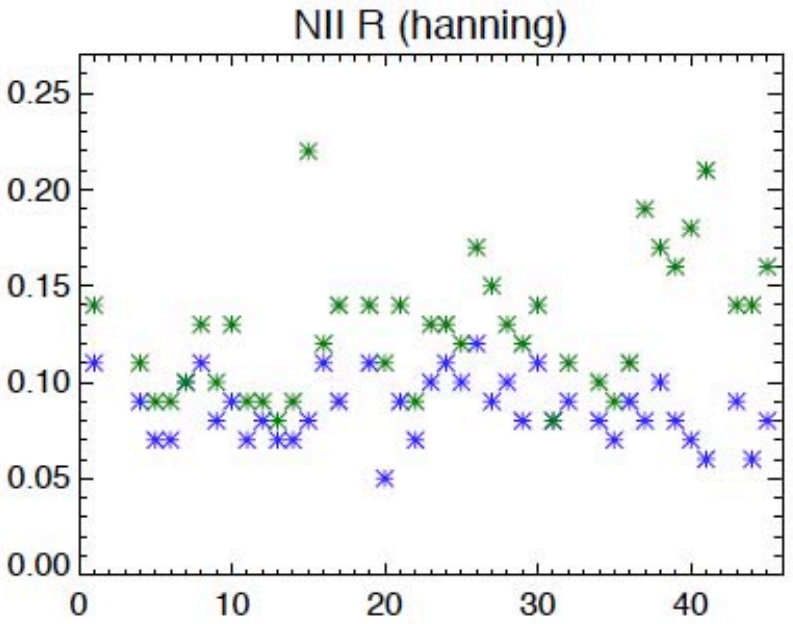


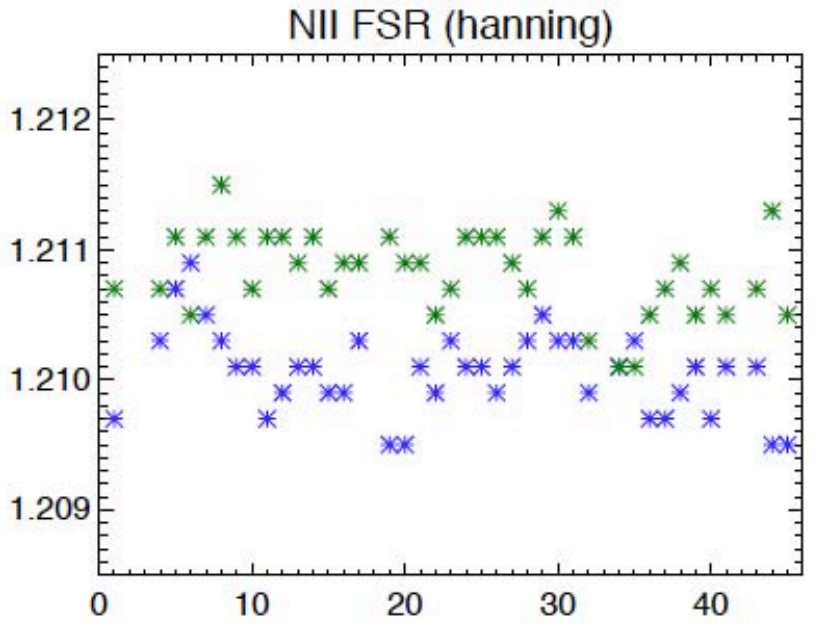
fringe fit around [NII]122um without apodization

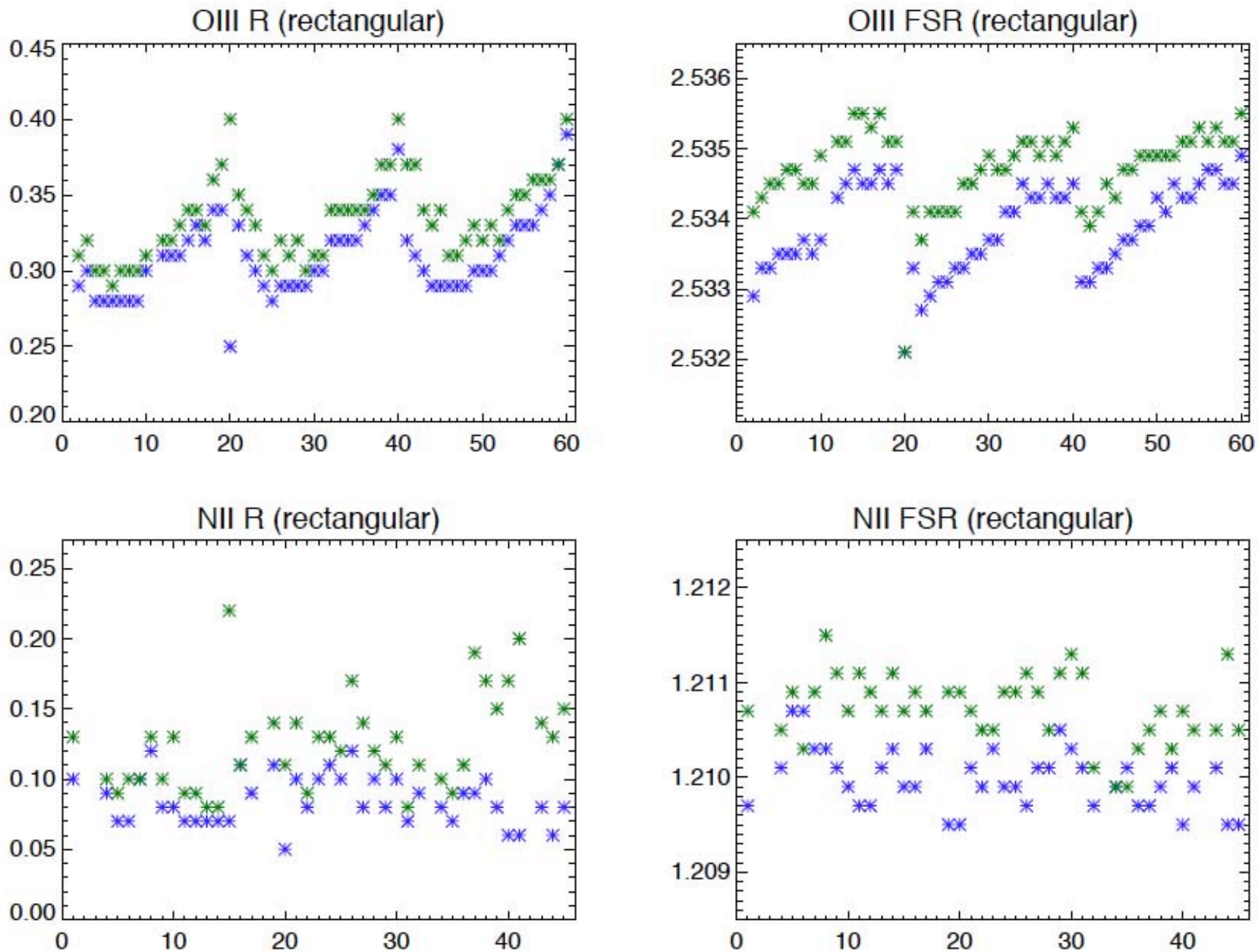


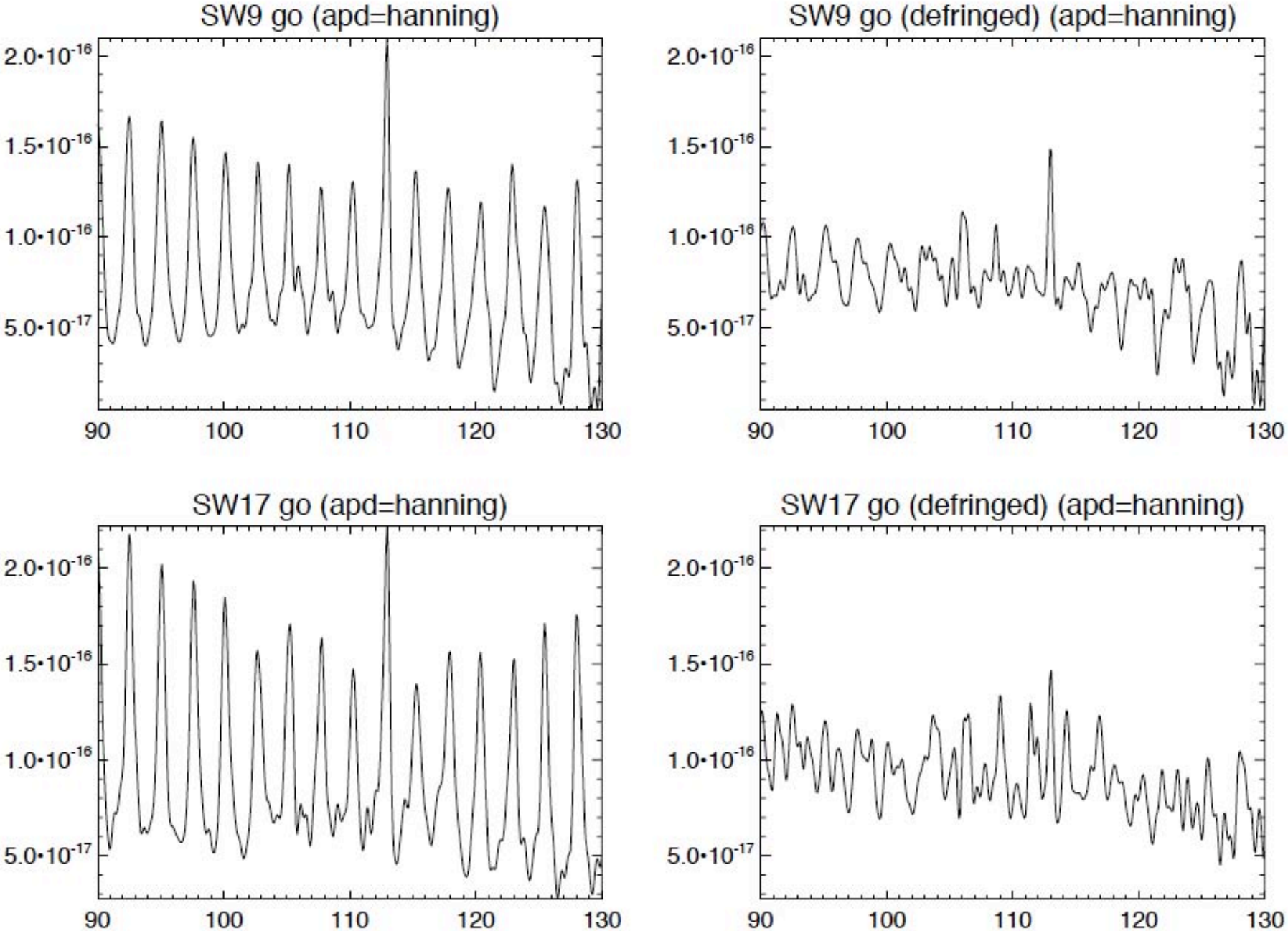

OIII R (hanning)
0.40
0.35
0.30
0.25
0.20
0
10
20
30
40
50
60

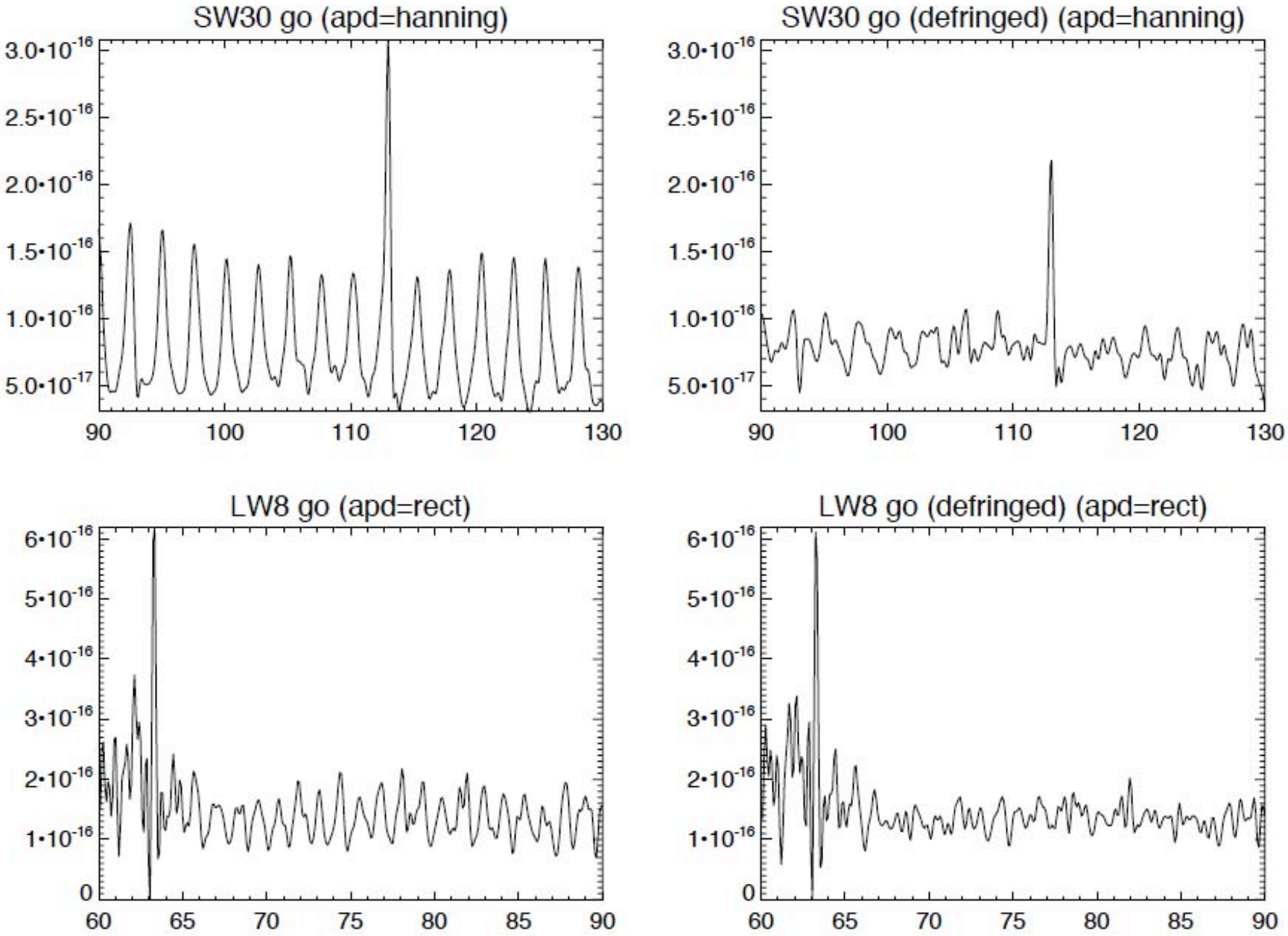

OIII FSR (hanning)
2.537
2.536
2.535
2.534
2.533
2.532
0
10
20
30
40
50
60

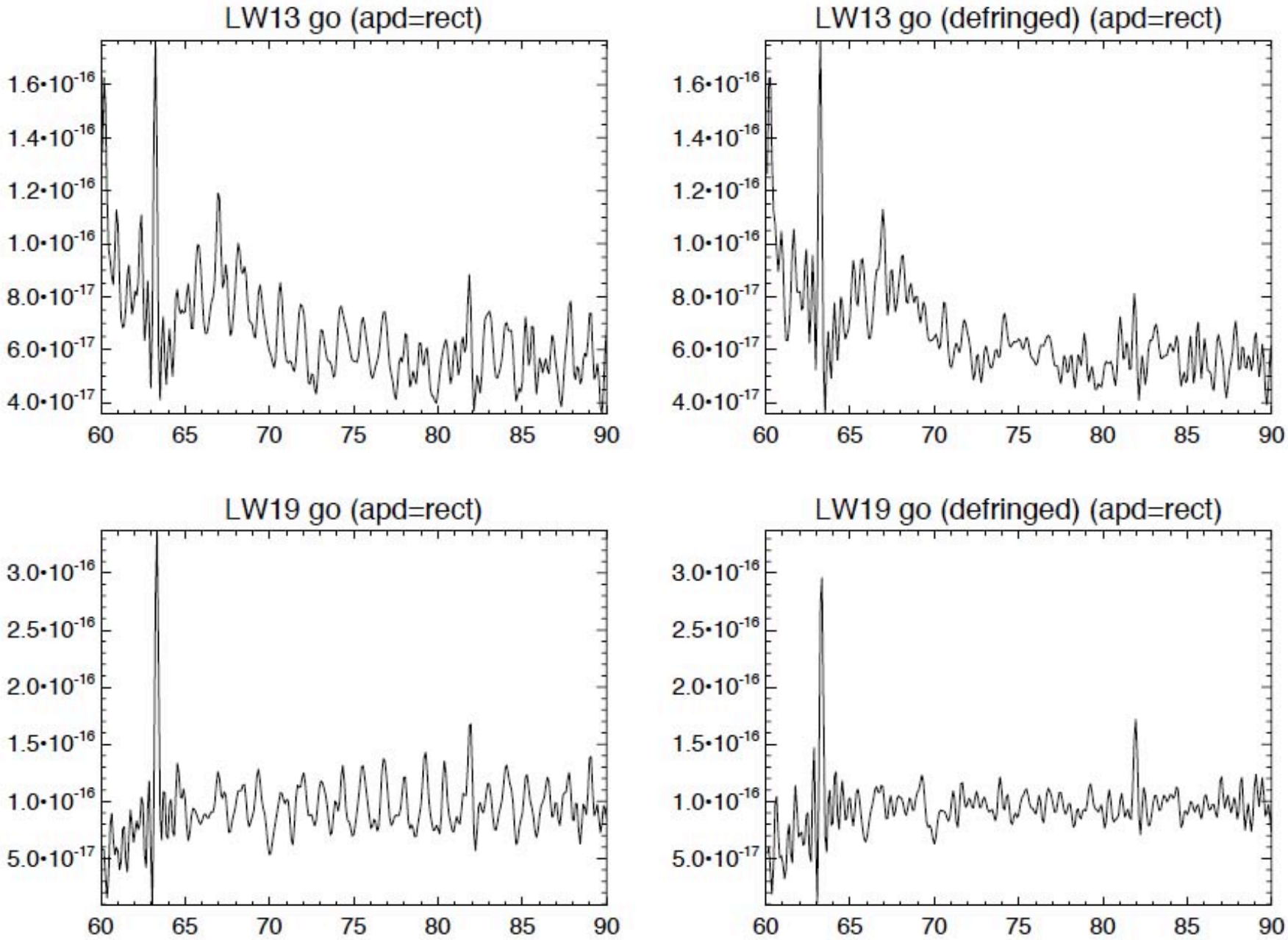

NII R (hanning)
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40


NII FSR (hanning)
1.212
1.211
1.210
1.209
0
10
20
30
40


OIII R (rectangular)
0.45
0.40
0.35
0.30
0.25
0.20
0
10
20
30
40
50
60
OIII FSR (rectangular)
2.536
2.535
2.534
2.533
2.532
0
10
20
30
40
50
60
NII R (rectangular)
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
NII FSR (rectangular)
1.212
1.211
1.210
1.209
0
10
20
30
40


SW9 go (apd=hanning)
SW9 go (defringed) (apd=hanning)
SW17 go (apd=hanning)
SW17 go (defringed) (apd=hanning)
2.0•10-16
1.5•10-16
1.0•10-16
5.0•10-17
90
100
110
120
130

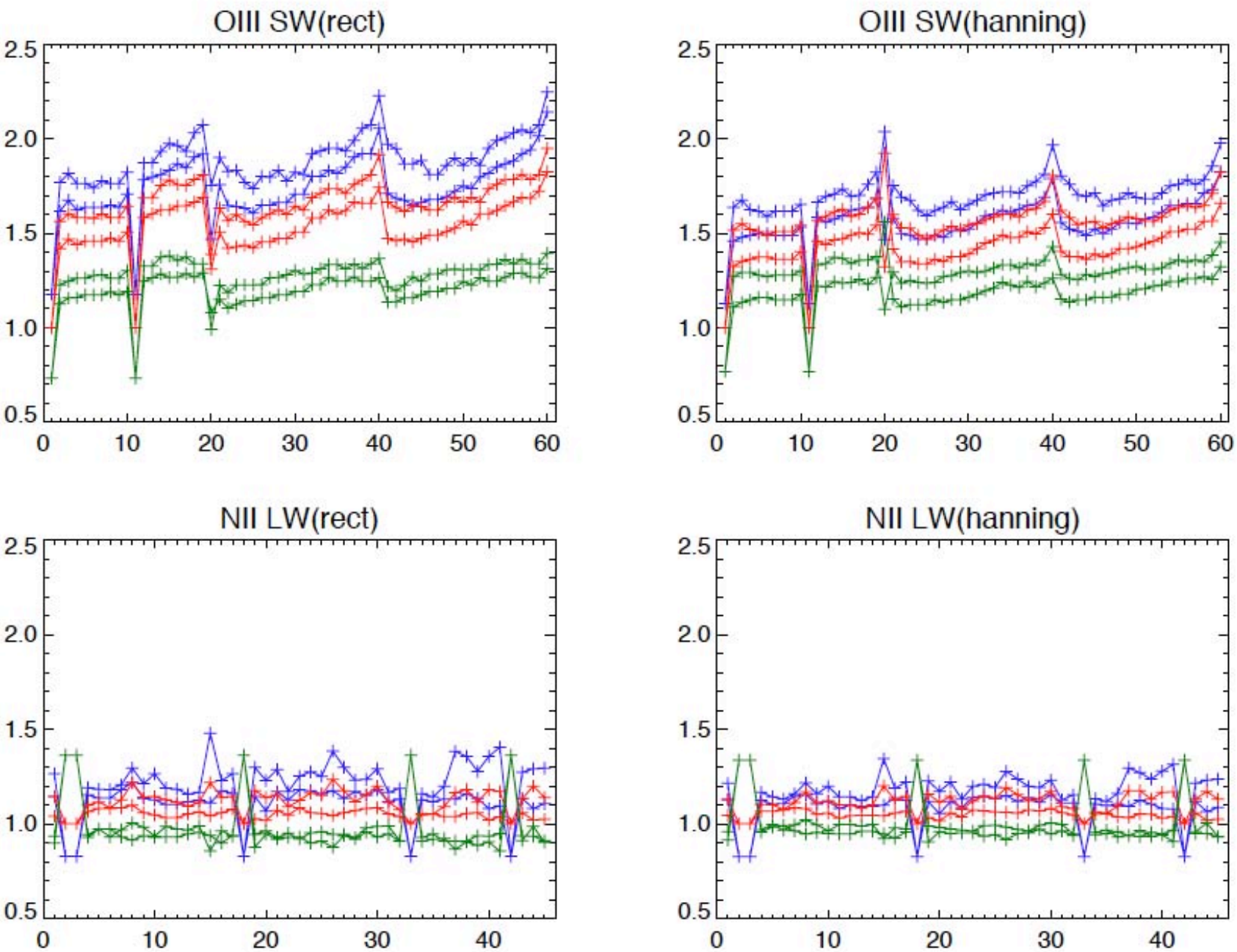

SW30 go (apd=hanning)
SW30 go (defringed) (apd=hanning)
LW8 go (apd=rect)
LW8 go (defringed) (apd=rect)
3.0•10-16
2.5•10-16
2.0•10-16
1.5•10-16
1.0•10-16
5.0•10-17
6•10-16
5•10-16
4•10-16
3•10-16
2•10-16
1•10-16
0
90
100
110
120
130
60
65
70
75
80
85
90


LW13 go (apd=rect)
LW13 go (defringed) (apd=rect)
LW19 go (apd=rect)
LW19 go (defringed) (apd=rect)
1.6•10-16
1.4•10-16
1.2•10-16
1.0•10-16
8.0•10-17
6.0•10-17
4.0•10-17
3.0•10-16
2.5•10-16
2.0•10-16
1.5•10-16
1.0•10-16
5.0•10-17
60
65
70
75
80
85
90

Line position

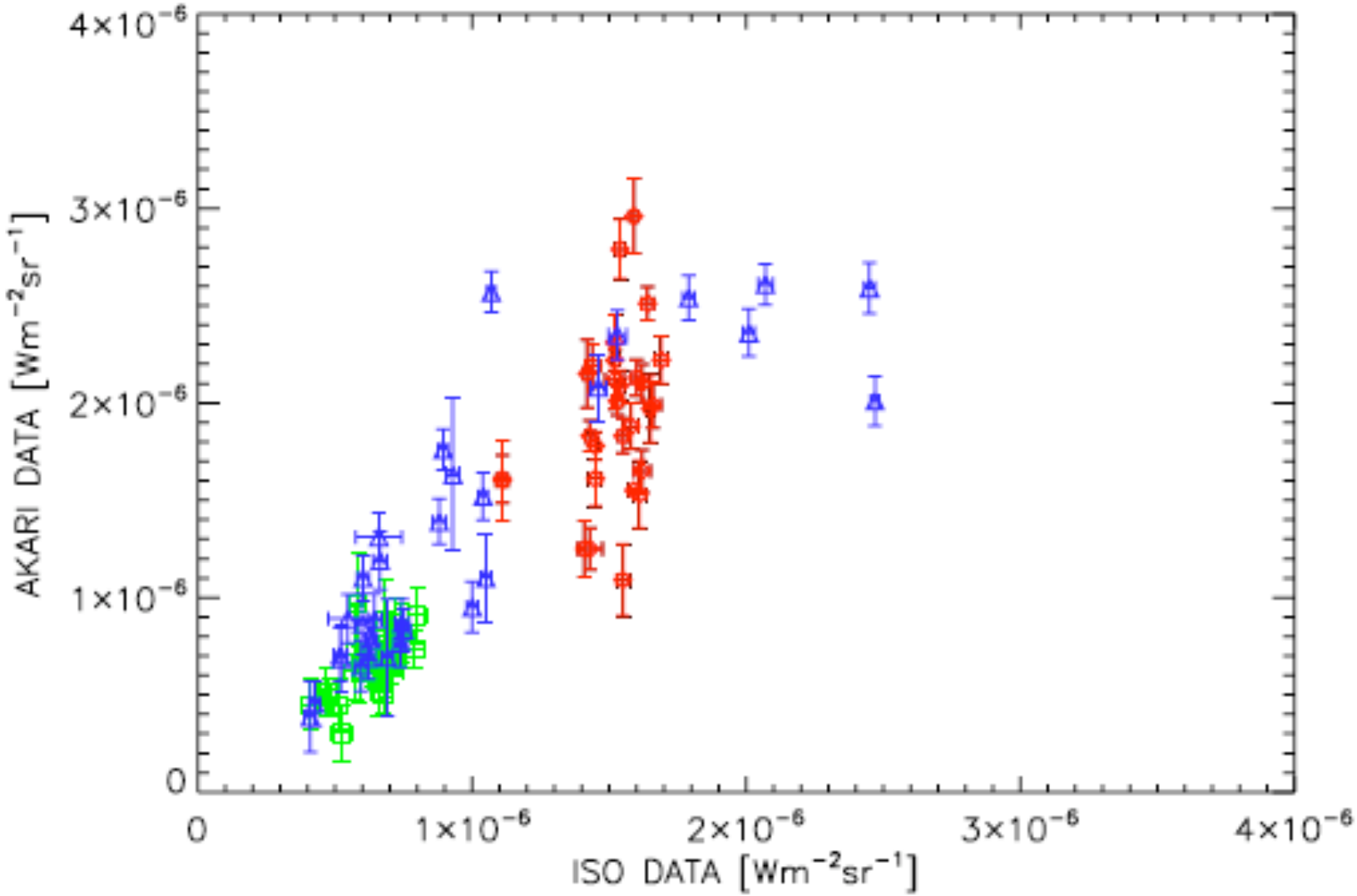
Description:

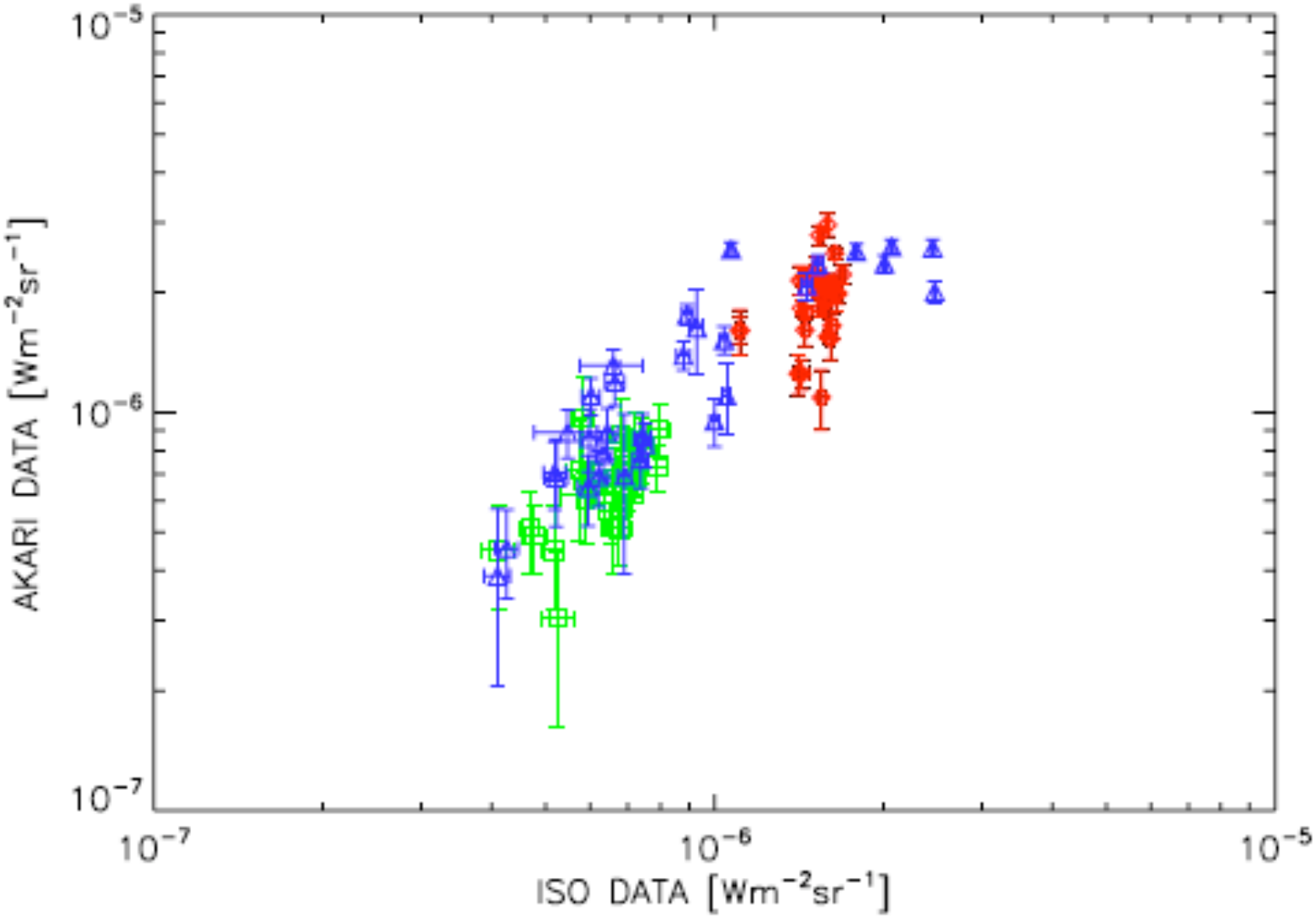
- Correction factor at the wavenumber of [OIII] and [NII] lines in the defringe process.
- Two lines in each color represent forward and reverse scan.
- Three color shows different wavenumber covering the line center of almost all the data.


OIII SW(rect)
OIII SW(hanning)
NII LW(rect)
NII LW(hanning)
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
60

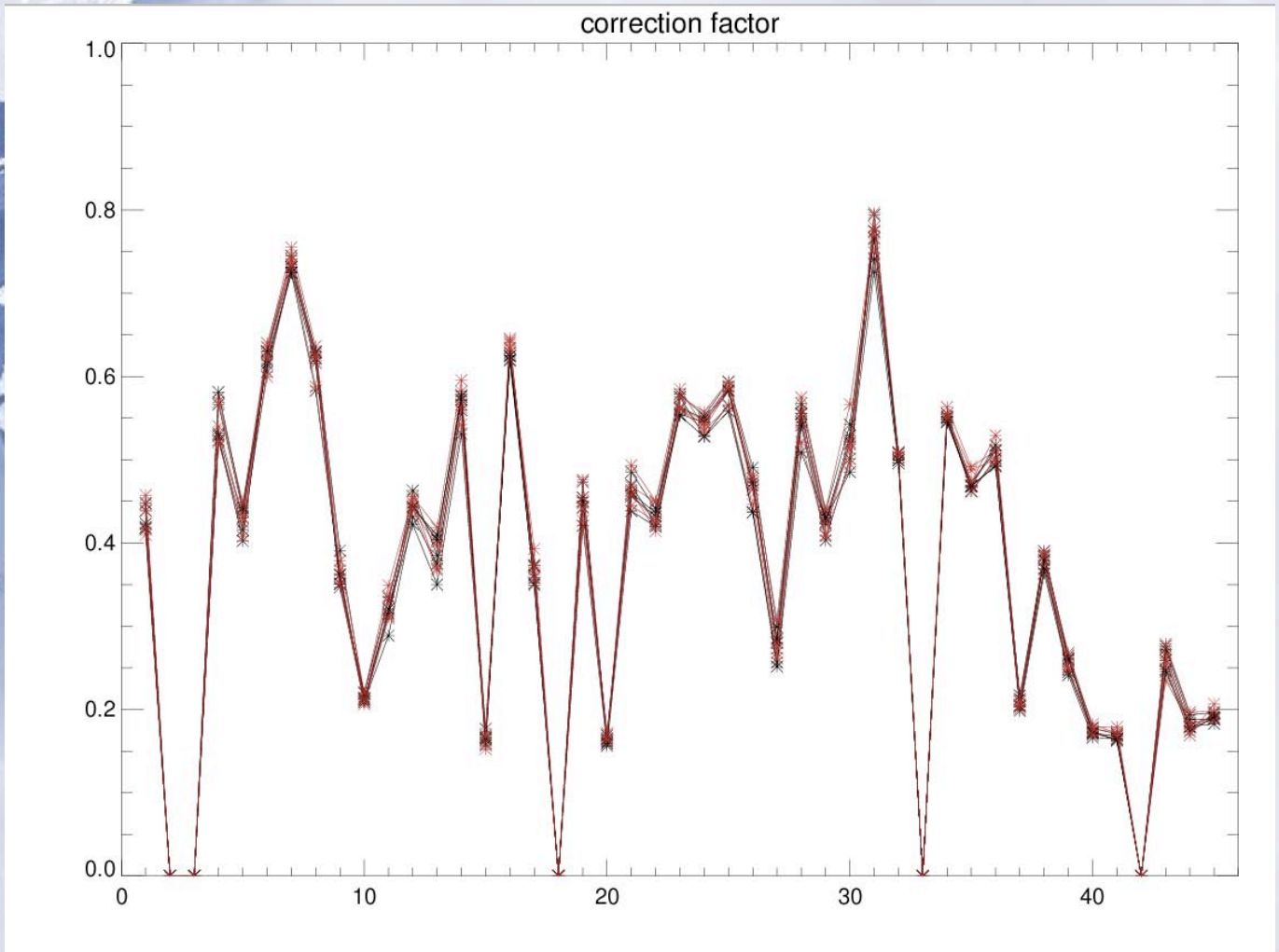
AKARI line flux vs. ISO line flux in GC.

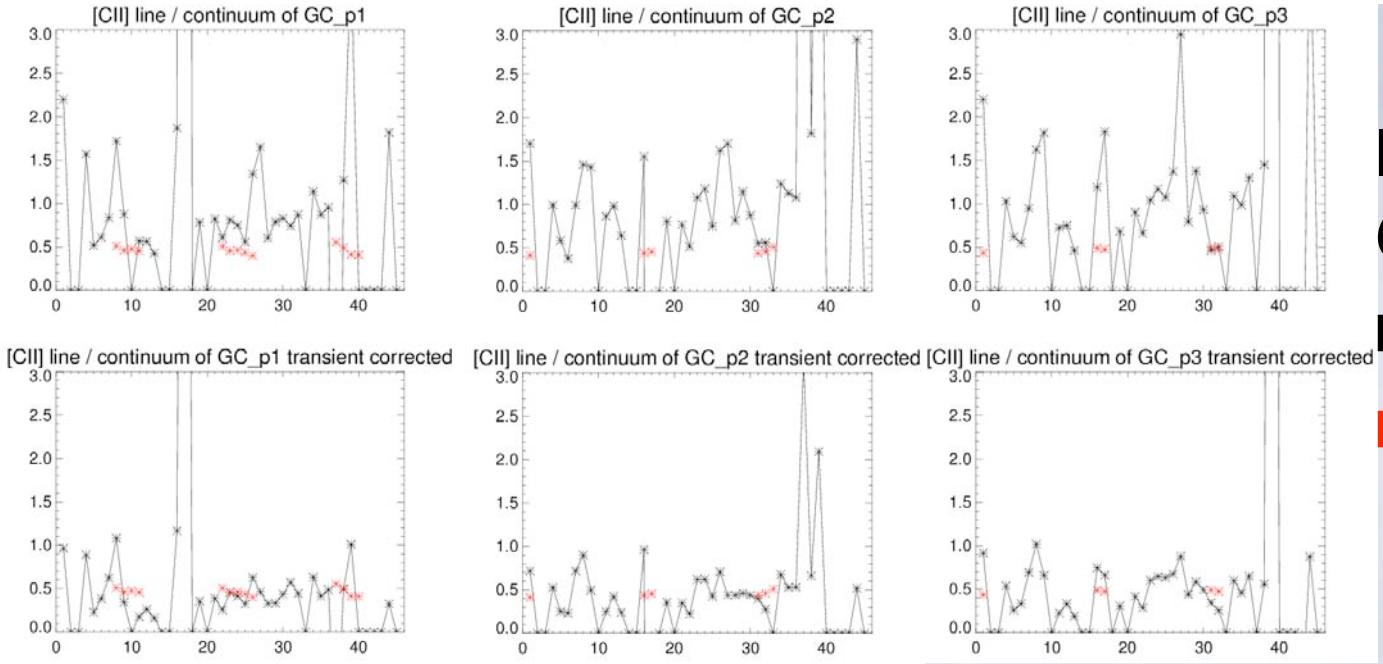
red = [CII]158um
green = [NII]122um
blue = [OIII]88um




10^{-5}
10^{-6}
10^{-7}
AKARI DATA [$Wm^{-2}sr^{-1}$]
10^{-7}
10^{-6}
10^{-5}
ISO DATA [$Wm^{-2}sr^{-1}$]

”transient correction factor” from GC data with the same procedure as Jean-Paul-san did

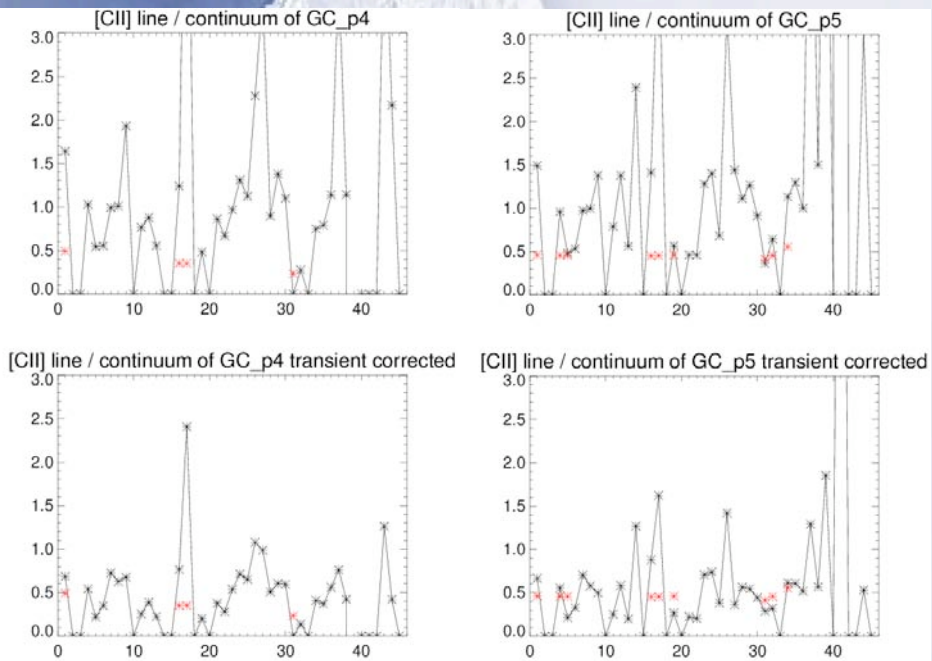




line/continuum @GC

Black : AKARI

Red : ISO/LWS

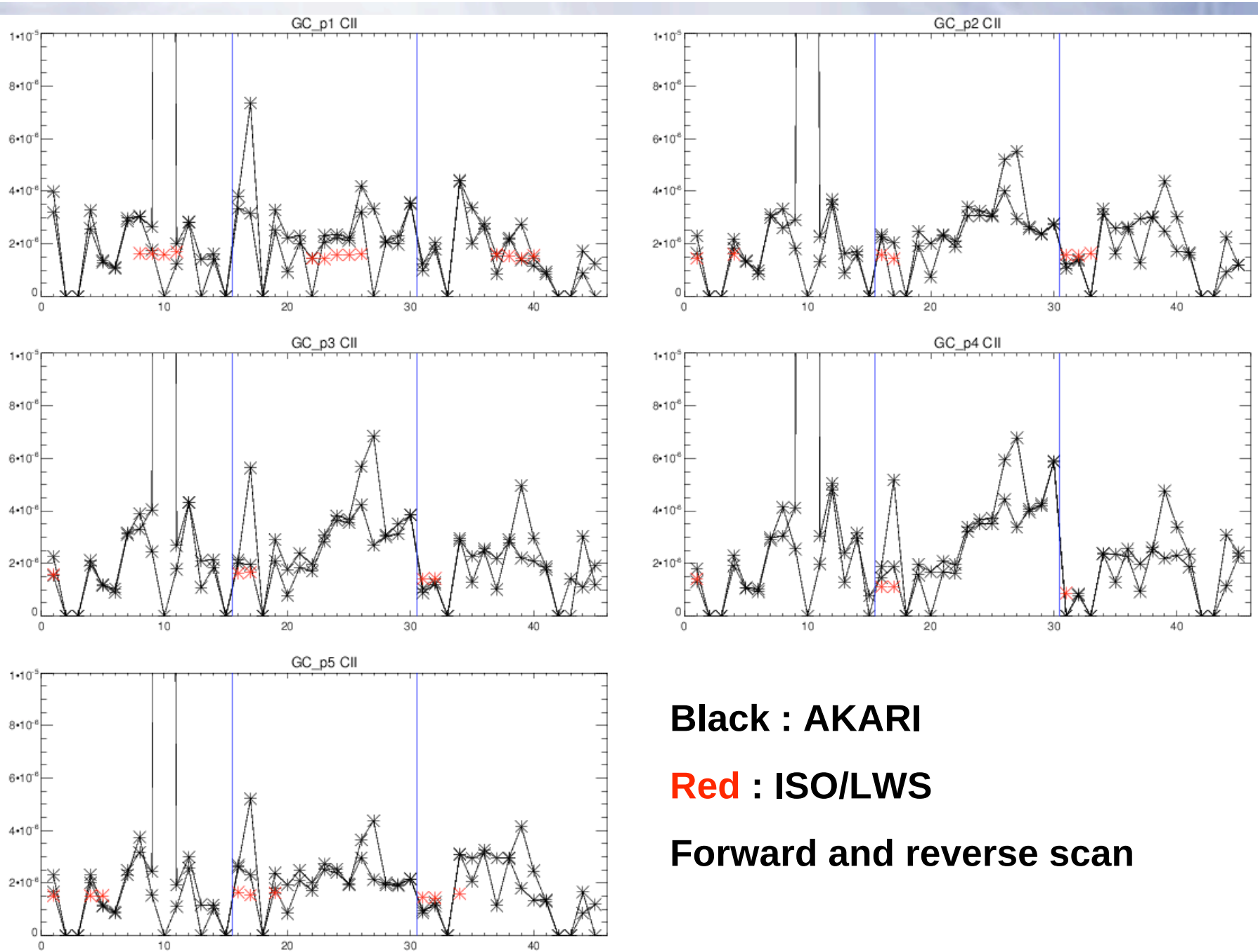


Upper panel of each pointed observation shows line/continuum and lower panel shows line/continuum multiplied by transient correction factor.

There are still deviations between LWS and FIS-FTS with the factor of 2-3.

line flux @GC and other regions

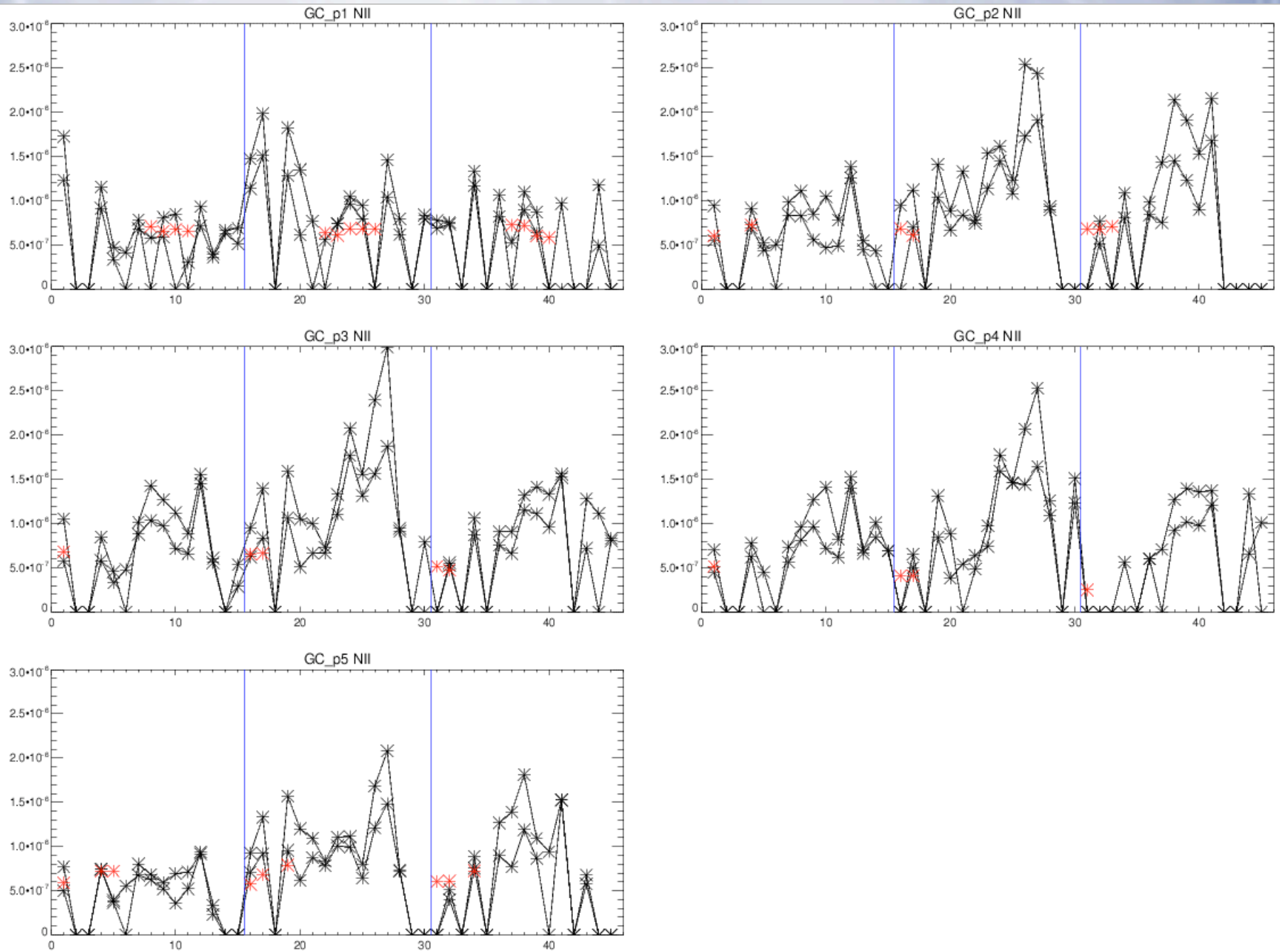
- **After applying the relative and absolute calibration, we fit lines.**
- **For [CII], we use spectra without apodization, without fringe removal. We fit the line with sinc function.**
- **For [NII], we use spectra without apodization, with fringe removal. We fit the line with sinc function.**
- **For [OIII], we use spectra with apodization of hanning, with fringe removal. We fit the line with Gaussian.**
- **Errorbars represent the deviation of forward and reverse scan.**



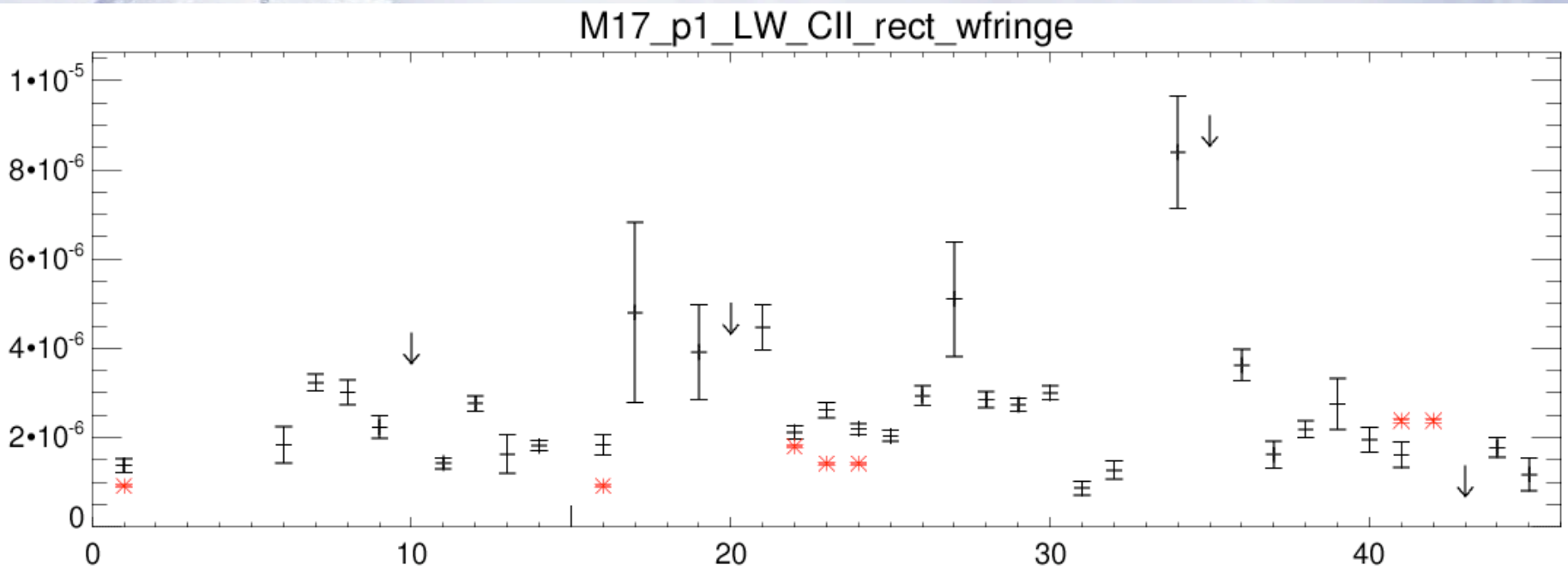
Black : AKARI

Red : ISO/LWS

Forward and reverse scan


GC_p1 NII
GC_p2 NII
GC_p3 NII
GC_p4 NII
GC_p5 NII
3.0•10⁻⁶
2.5•10⁻⁶
2.0•10⁻⁶
1.5•10⁻⁶
1.0•10⁻⁶
5.0•10⁻⁷
0
0
10
20
30
40

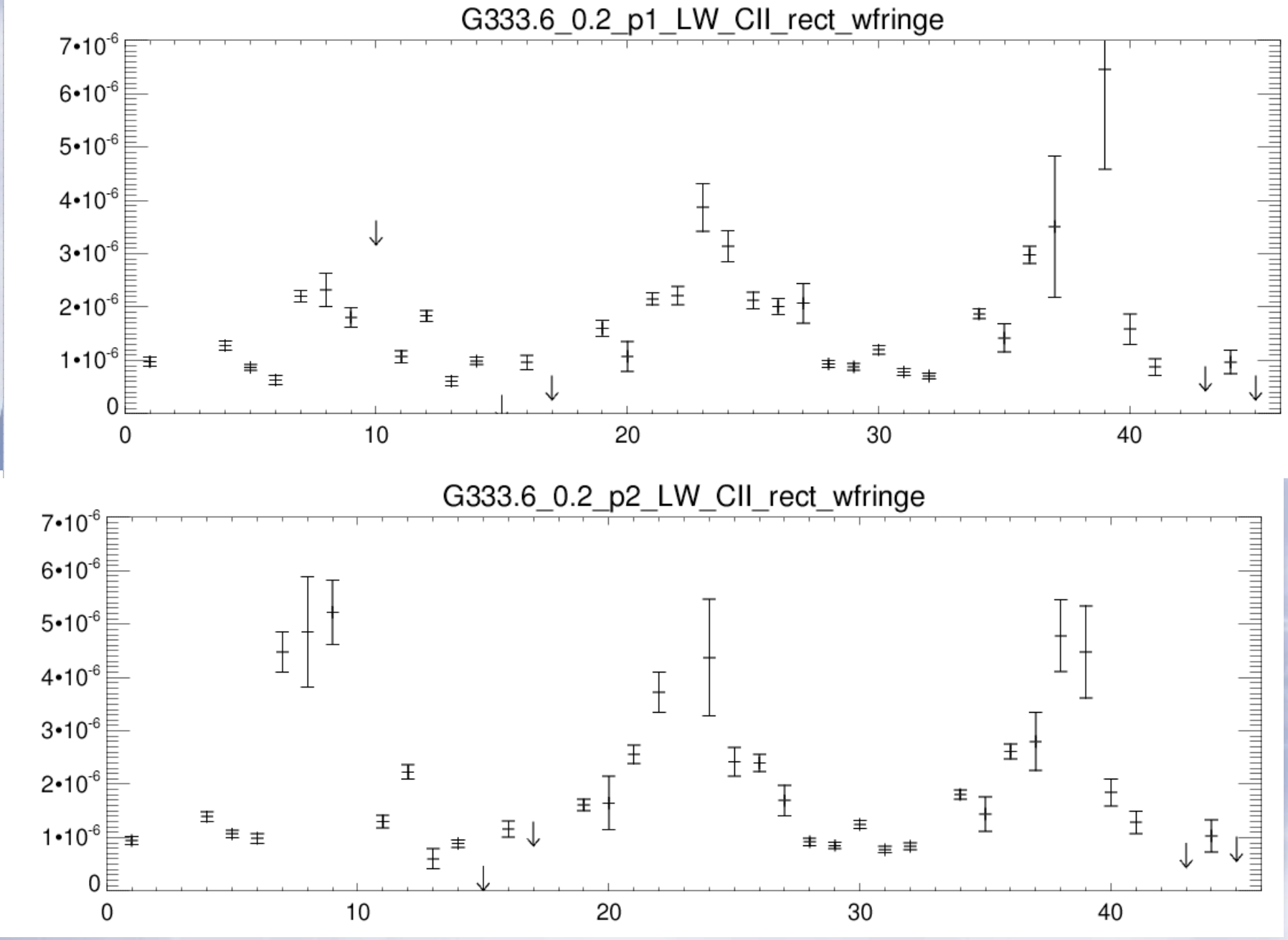
M17



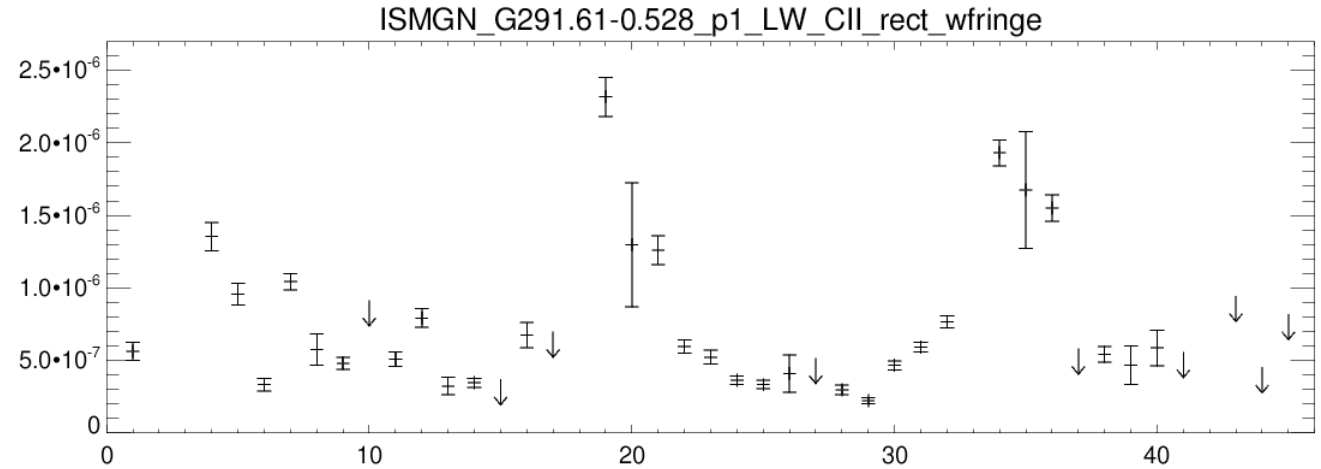
Black : AKARI

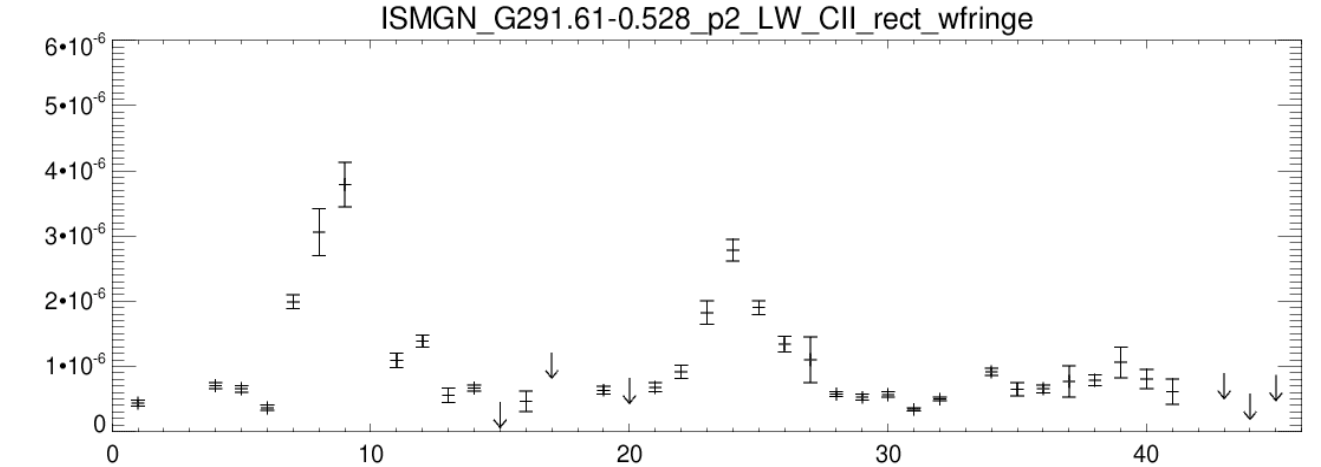
Red : ISO/LWS

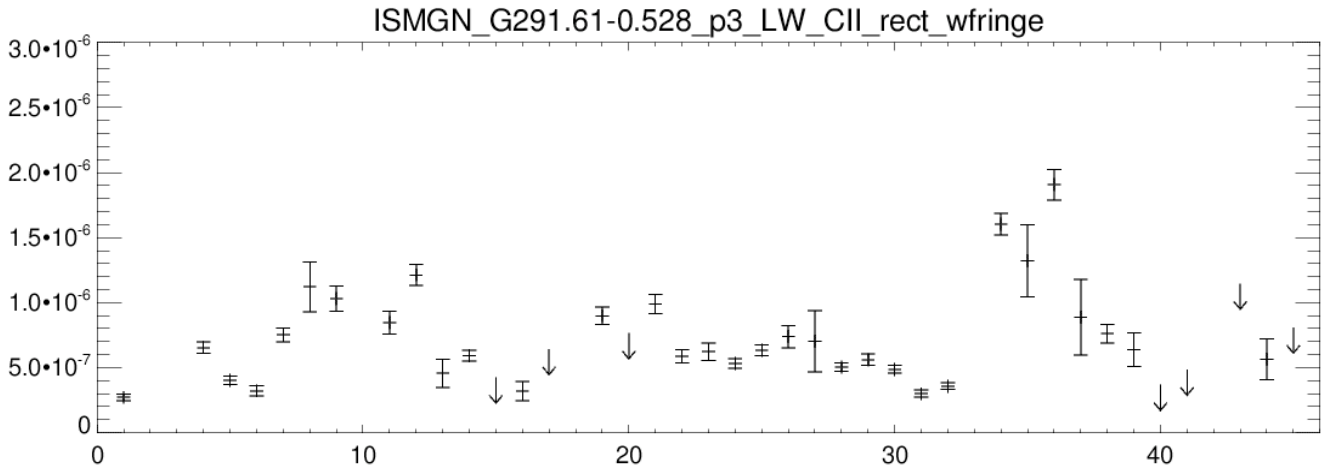
Similar pattern with GC data.



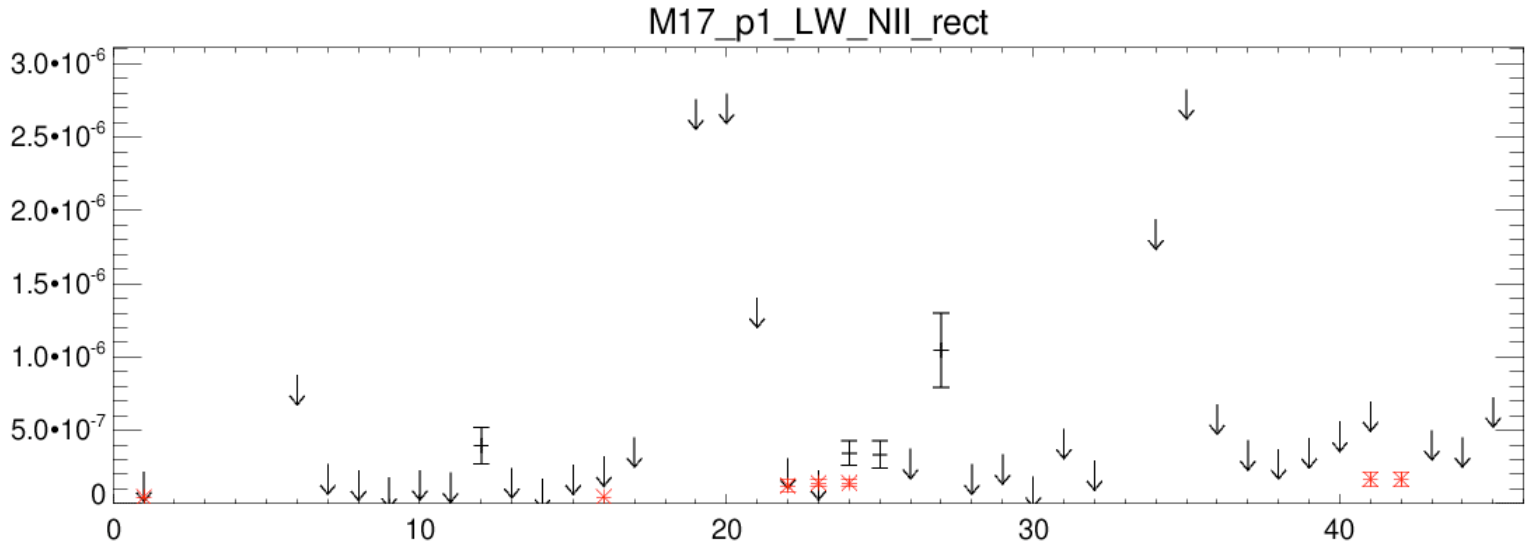
Without ISO/LWS. Also similar pattern with GC.


ISMGN_G291.61-0.528_p1_LW_CII_rect_wfringe
2.5•10-6
2.0•10-6
1.5•10-6
1.0•10-6
5.0•10-7
0
0
10
20
30
40

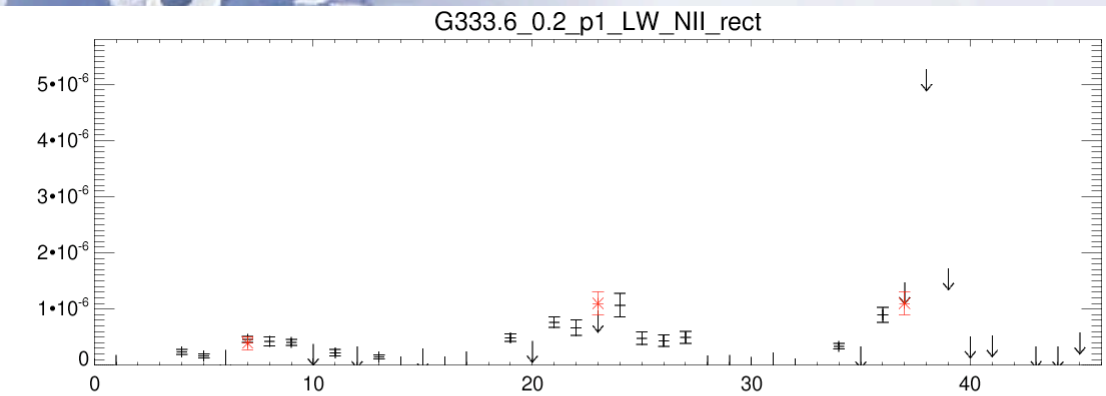

ISMGN_G291.61-0.528_p2_LW_CII_rect_wfringe
6•10-6
5•10-6
4•10-6
3•10-6
2•10-6
1•10-6
0
0
10
20
30
40


ISMGN_G291.61-0.528_p3_LW_CII_rect_wfringe
3.0•10-6
2.5•10-6
2.0•10-6
1.5•10-6
1.0•10-6
5.0•10-7
0
0
10
20
30
40

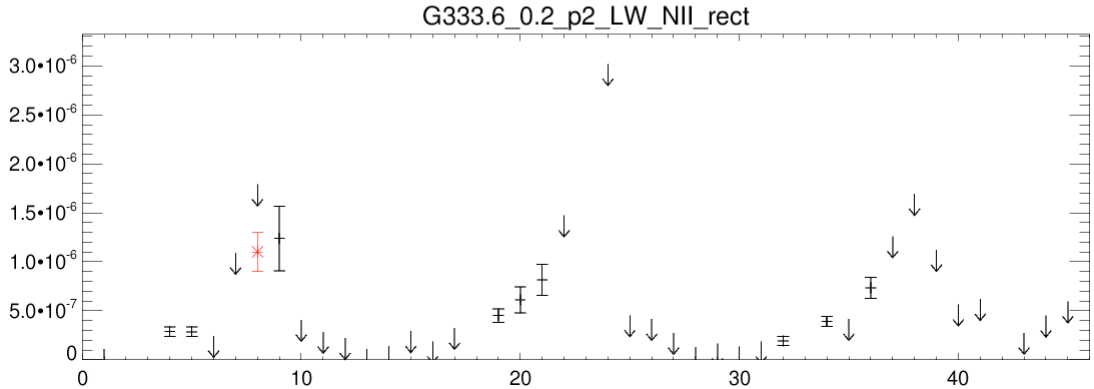
NGC3603



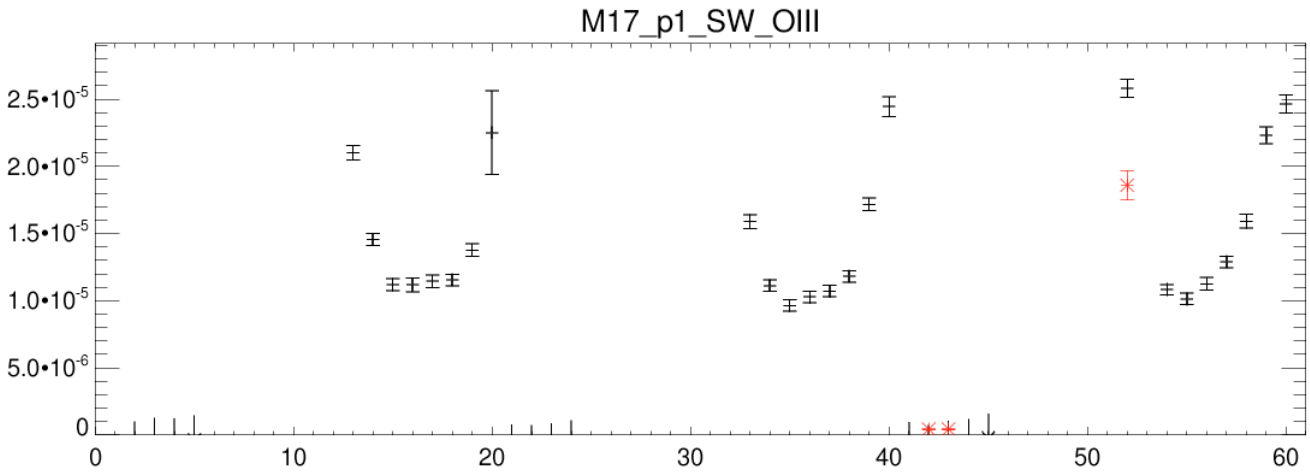
Red : ISO

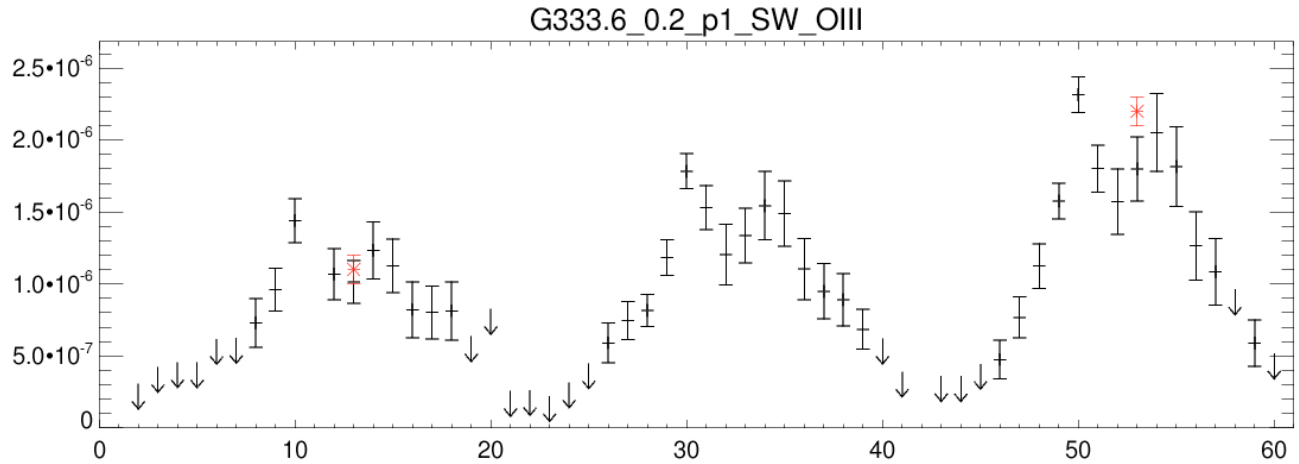


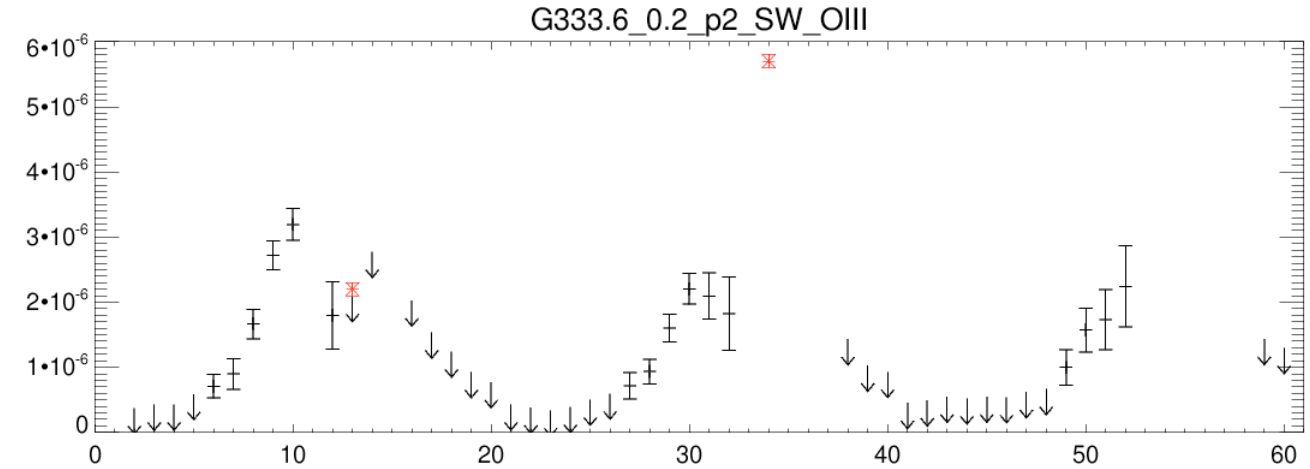
[NII]



Red : KAO







Red : ISO

[OIII]

Red : KAO

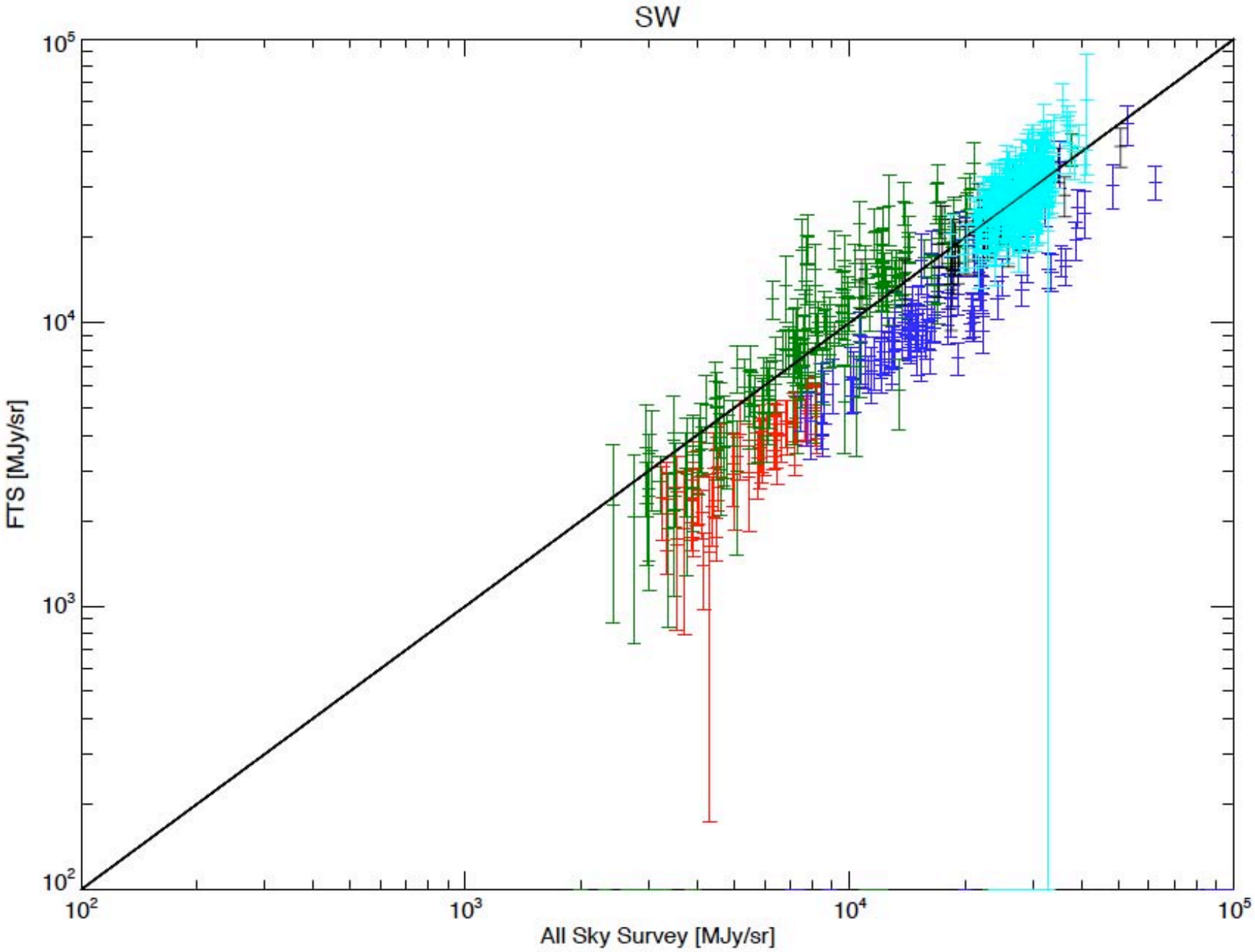
Appendix

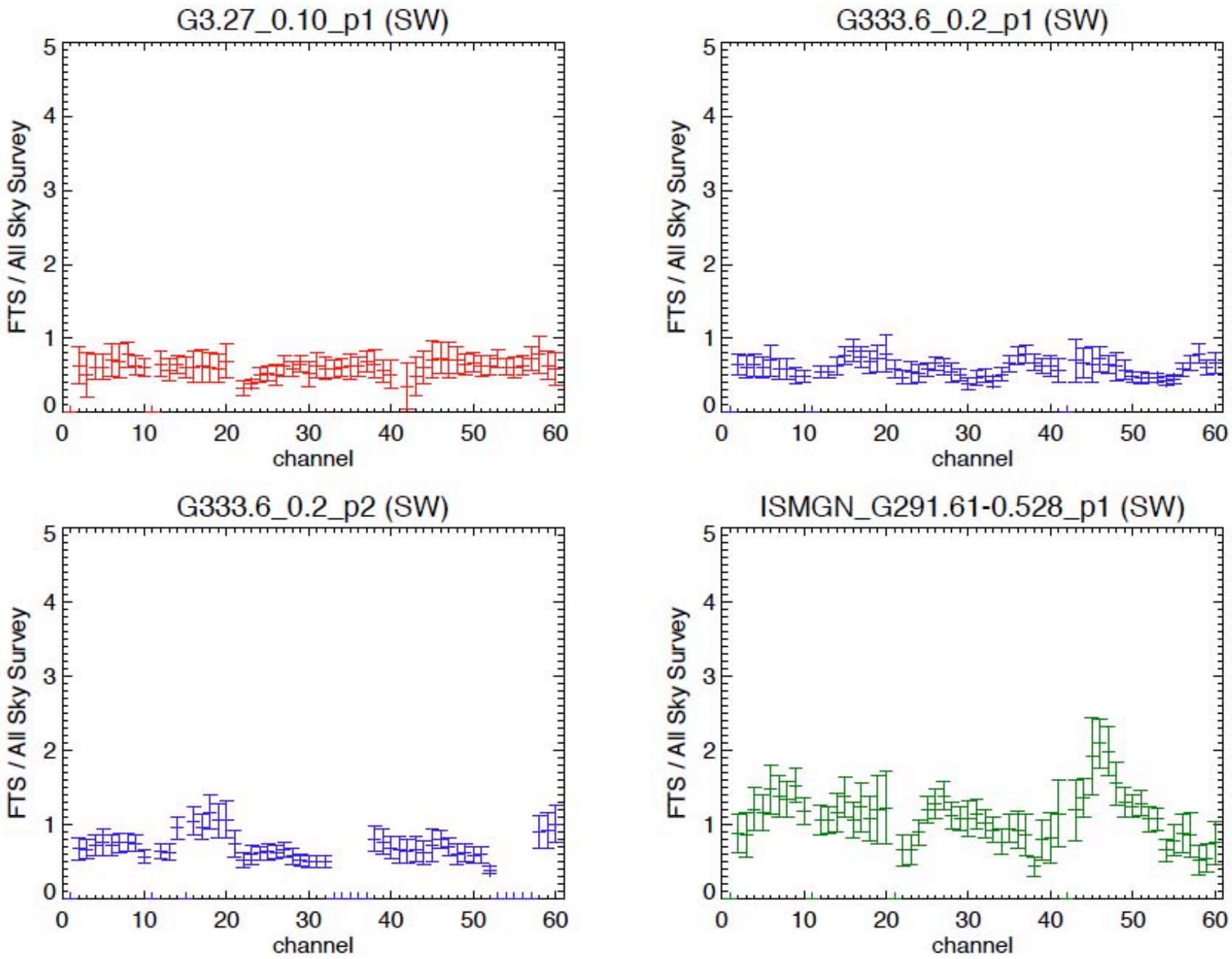
1. Comparison FTS and All sky survey

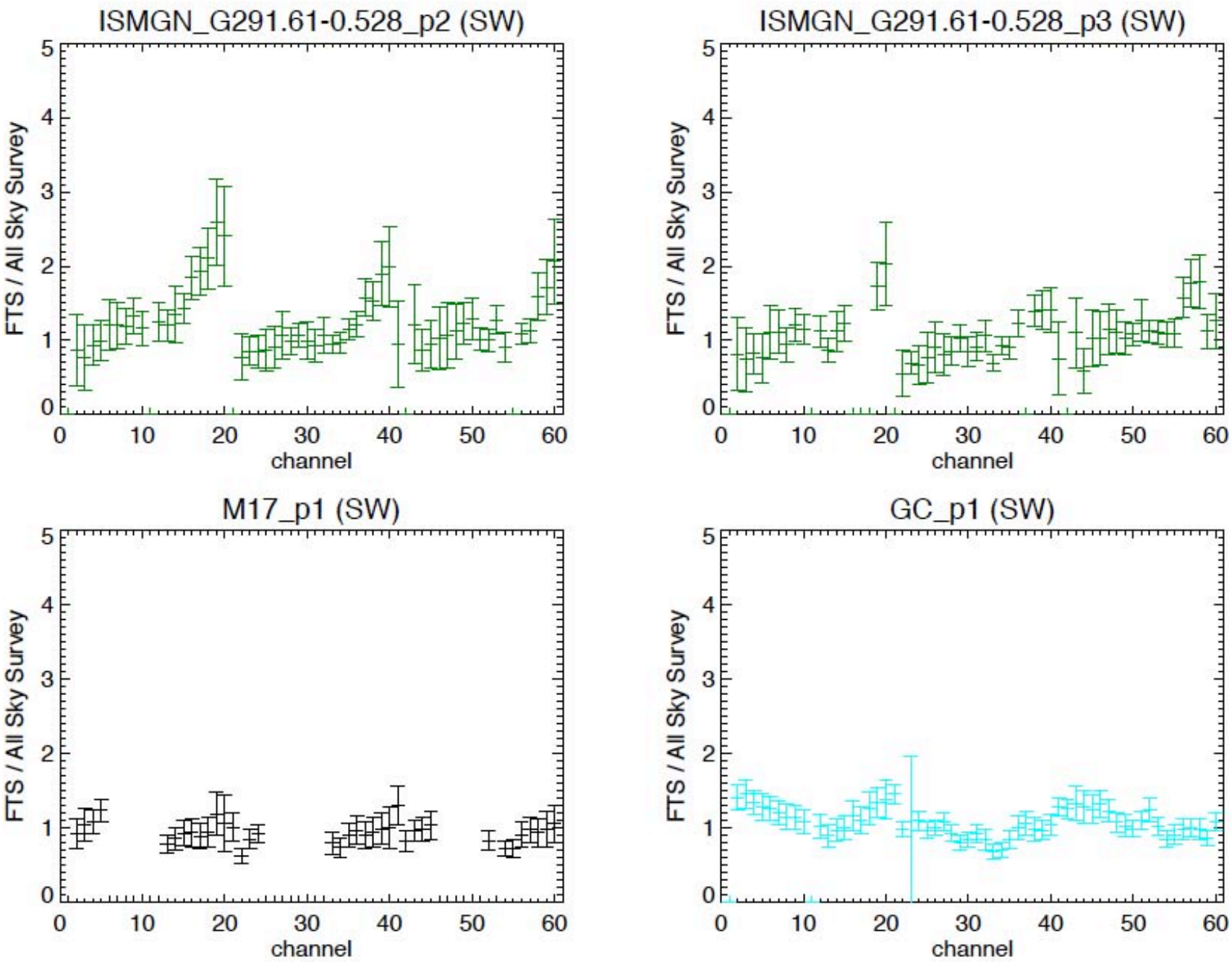
Description:

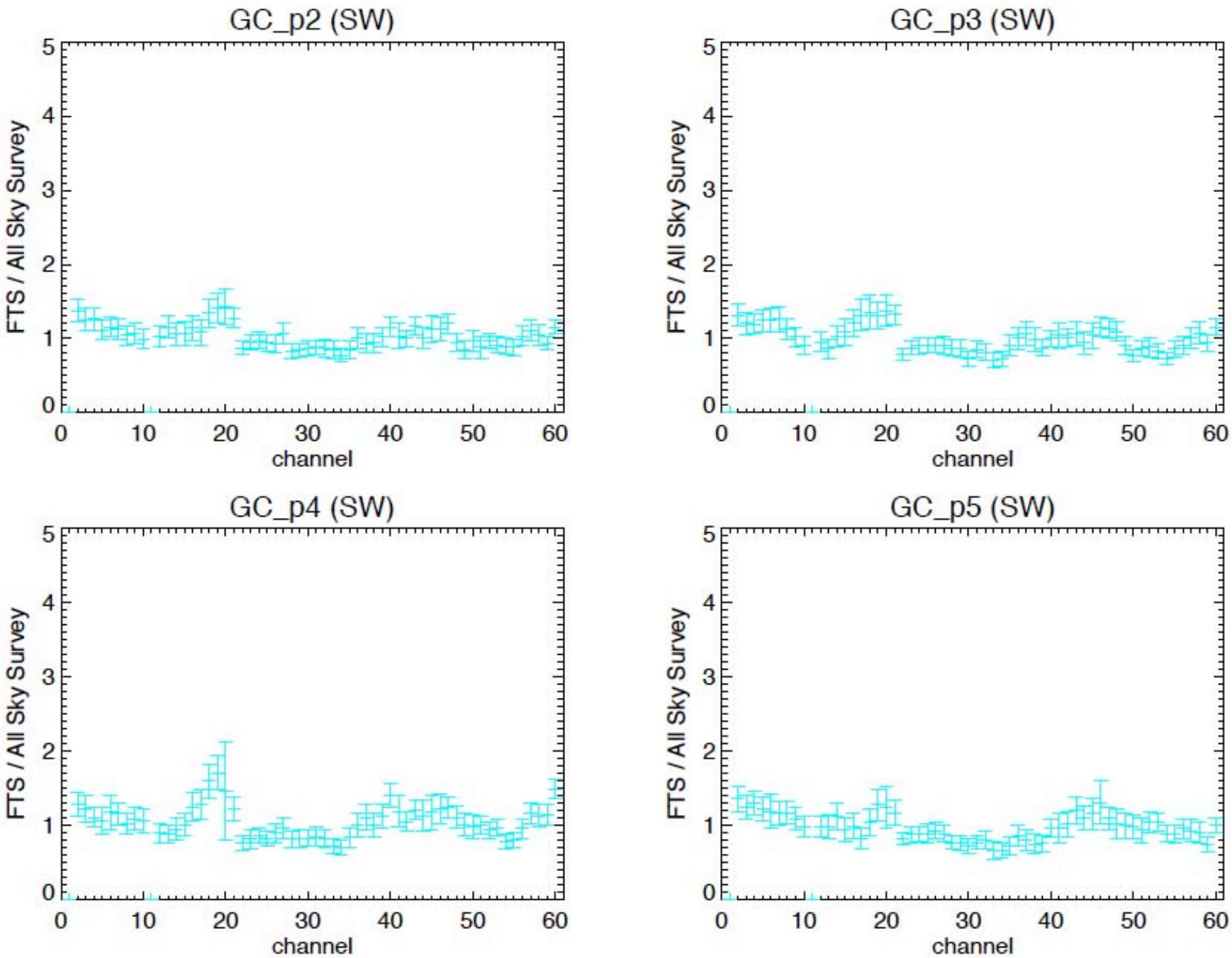
- **Flux at 90um (SW) and 140um (LW) by FIS-FTS vs. FIS All Sky Survey (WIDE-S and WIDE-L).**

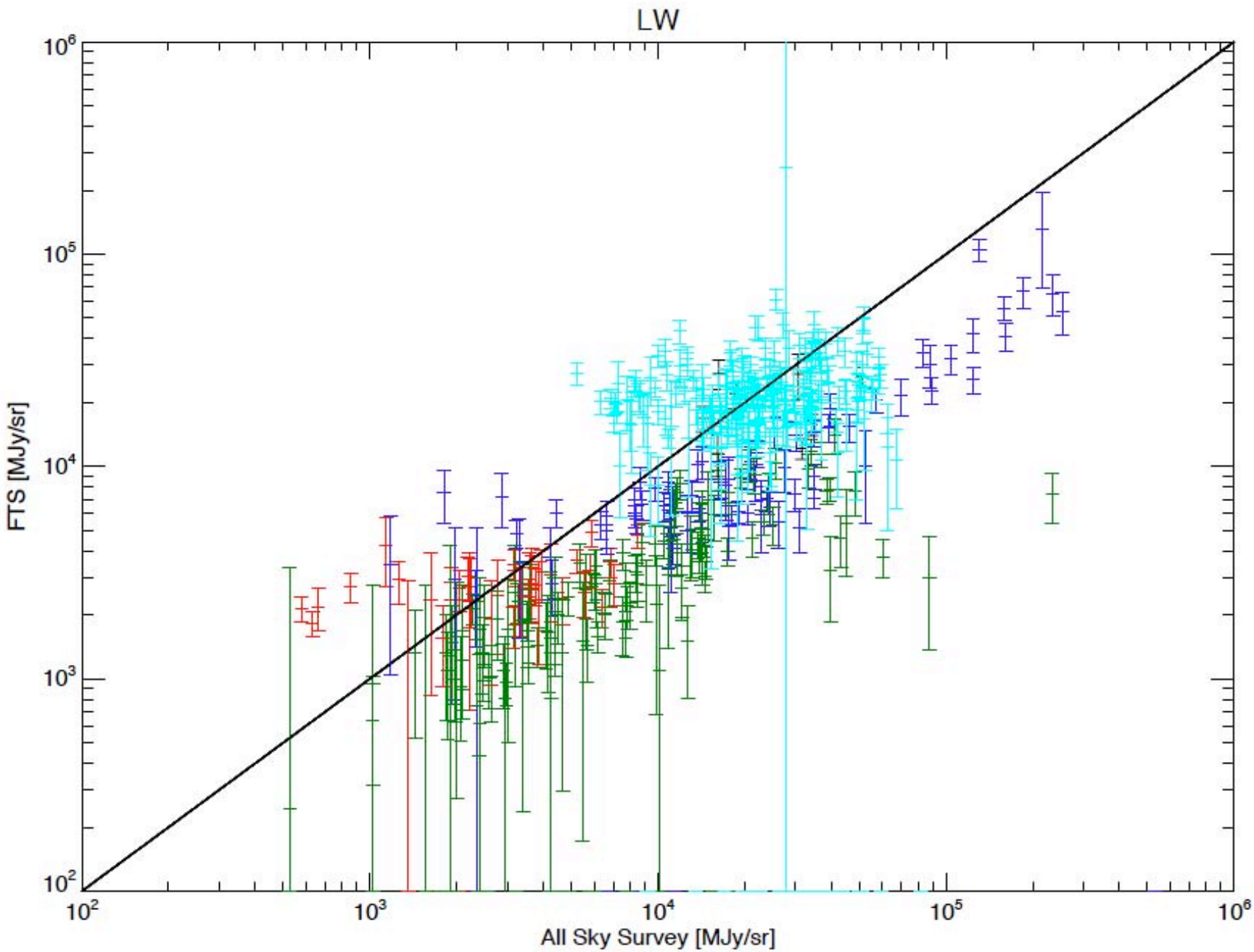
The color correction is not taken into account for all sky survey data.

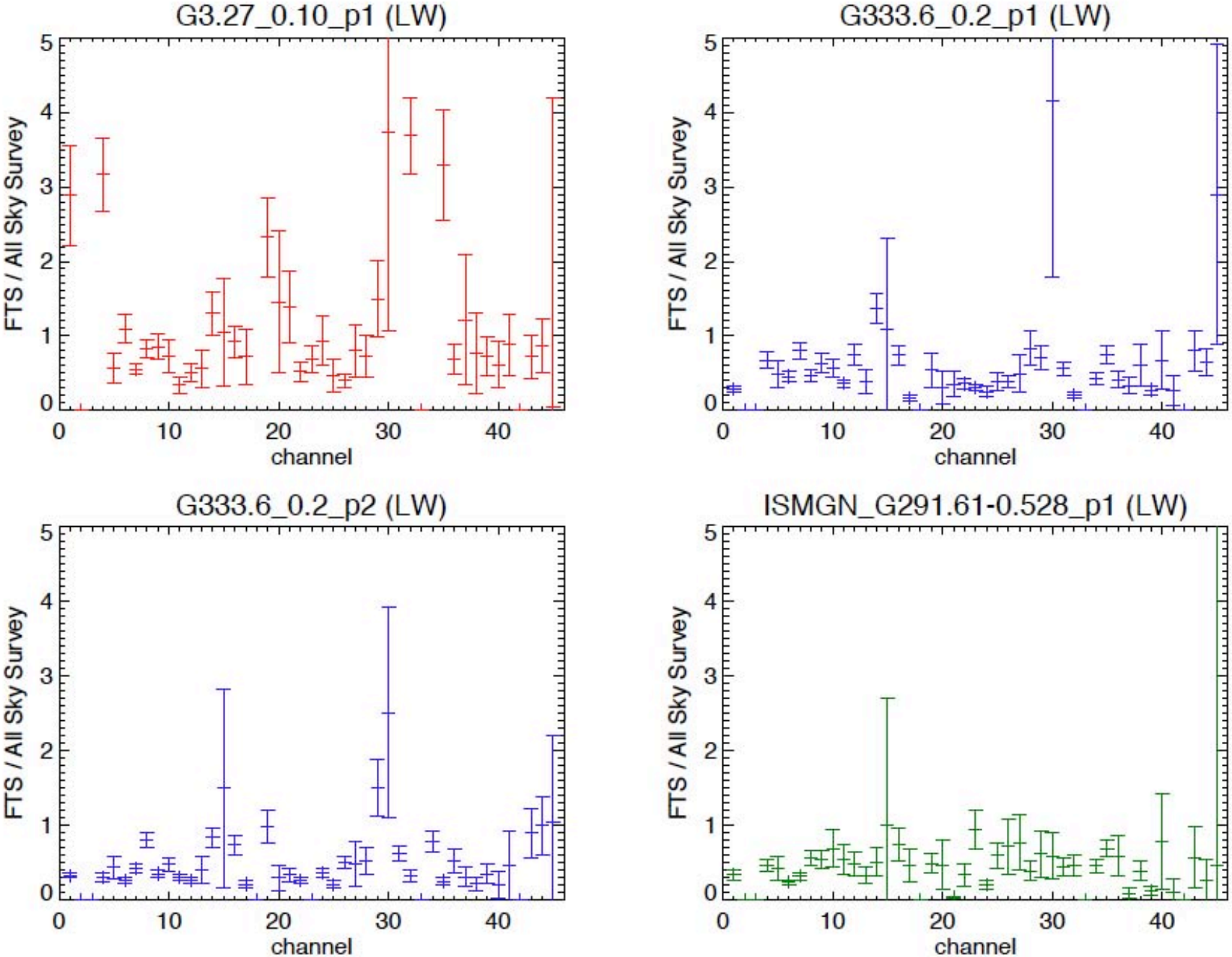

SW
FTS [MJy/sr]
All Sky Survey [MJy/sr]
10^2
10^3
10^4
10^5

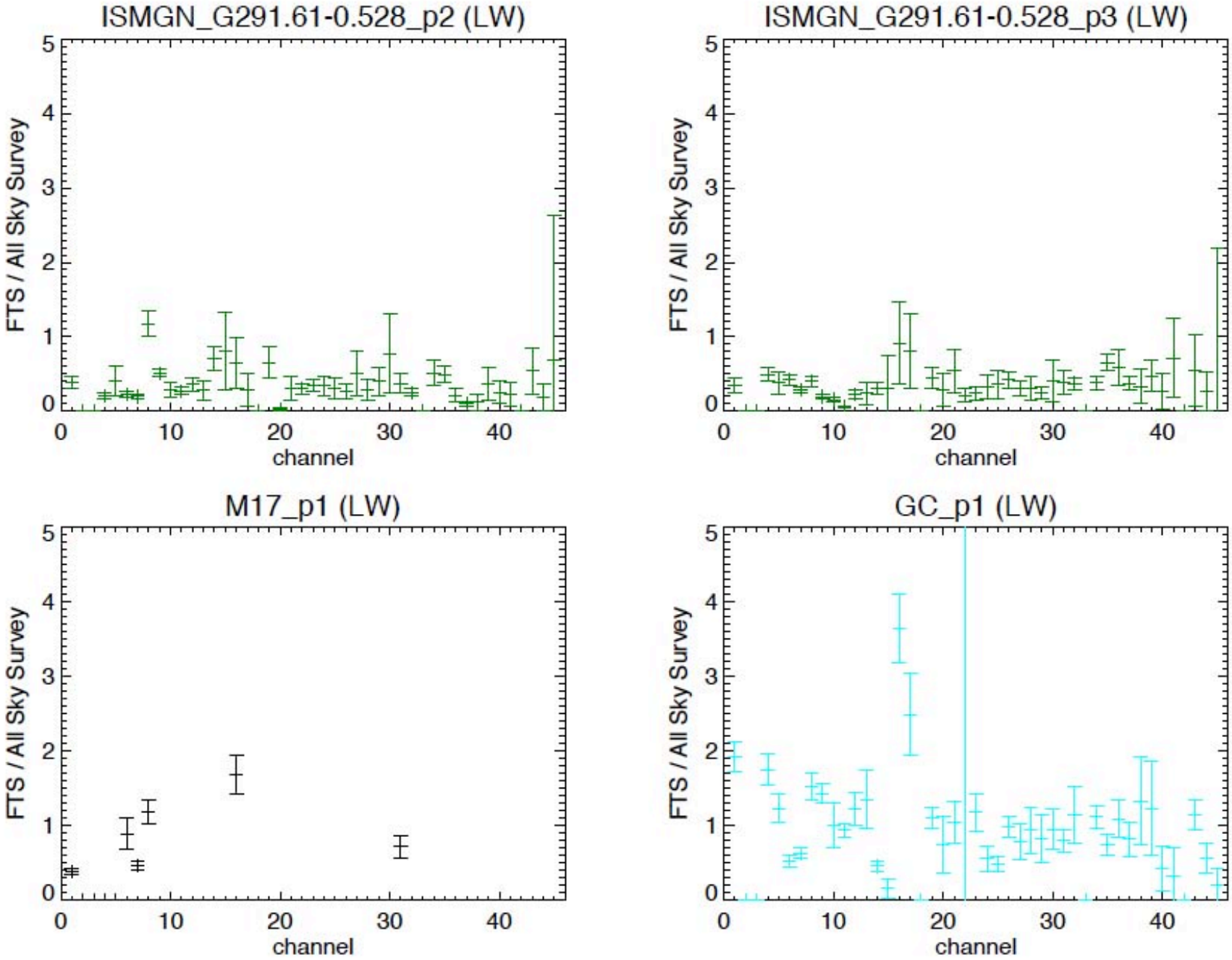

G3.27_0.10_p1 (SW)
G333.6_0.2_p1 (SW)
G333.6_0.2_p2 (SW)
ISMGN_G291.61-0.528_p1 (SW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
0
10
20
30
40
50
60

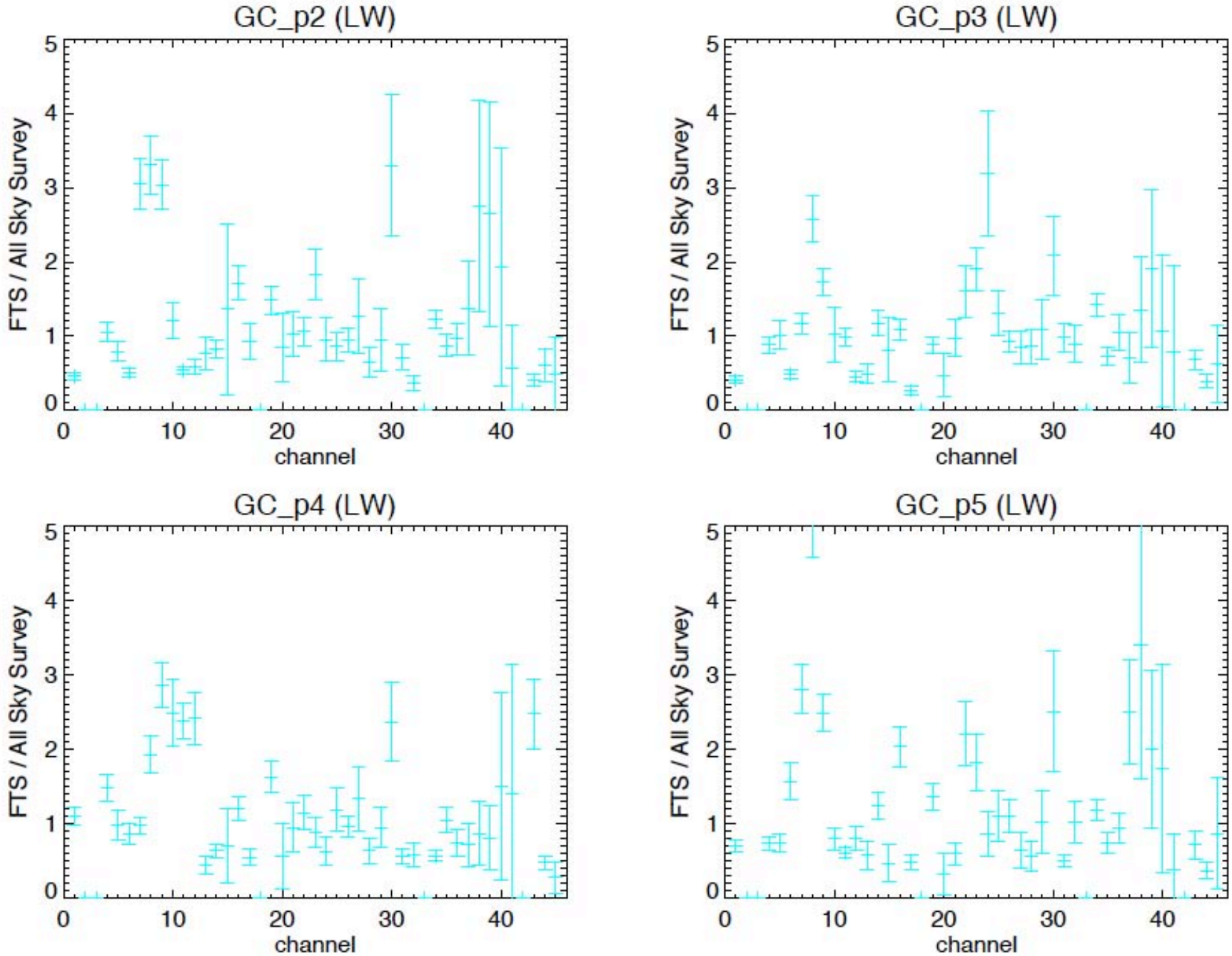

ISMGN_G291.61-0.528_p2 (SW)
ISMGN_G291.61-0.528_p3 (SW)
M17_p1 (SW)
GC_p1 (SW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
0
10
20
30
40
50
60


GC_p2 (SW)
GC_p3 (SW)
GC_p4 (SW)
GC_p5 (SW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
0
10
20
30
40
50
60


LW
FTS [MJy/sr]
All Sky Survey [MJy/sr]
10^2
10^3
10^4
10^5
10^6


G3.27_0.10_p1 (LW)
G333.6_0.2_p1 (LW)
G333.6_0.2_p2 (LW)
ISMGN_G291.61-0.528_p1 (LW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
10
20
30
40


ISMGN_G291.61-0.528_p2 (LW)
ISMGN_G291.61-0.528_p3 (LW)
M17_p1 (LW)
GC_p1 (LW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
0
10
20
30
40

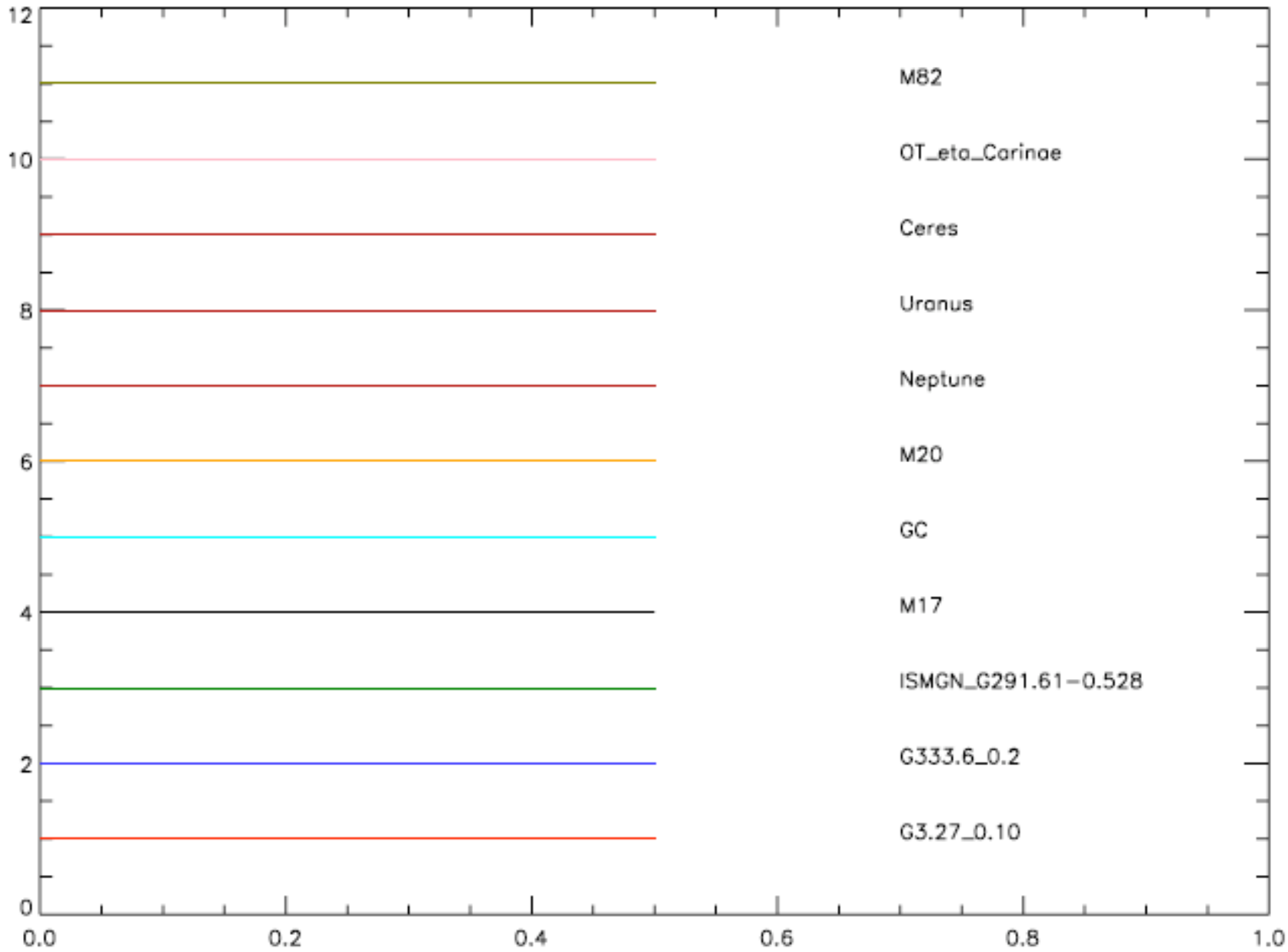

GC_p2 (LW)
GC_p3 (LW)
GC_p4 (LW)
GC_p5 (LW)
FTS / All Sky Survey
channel
0
1
2
3
4
5
0
10
20
30
40

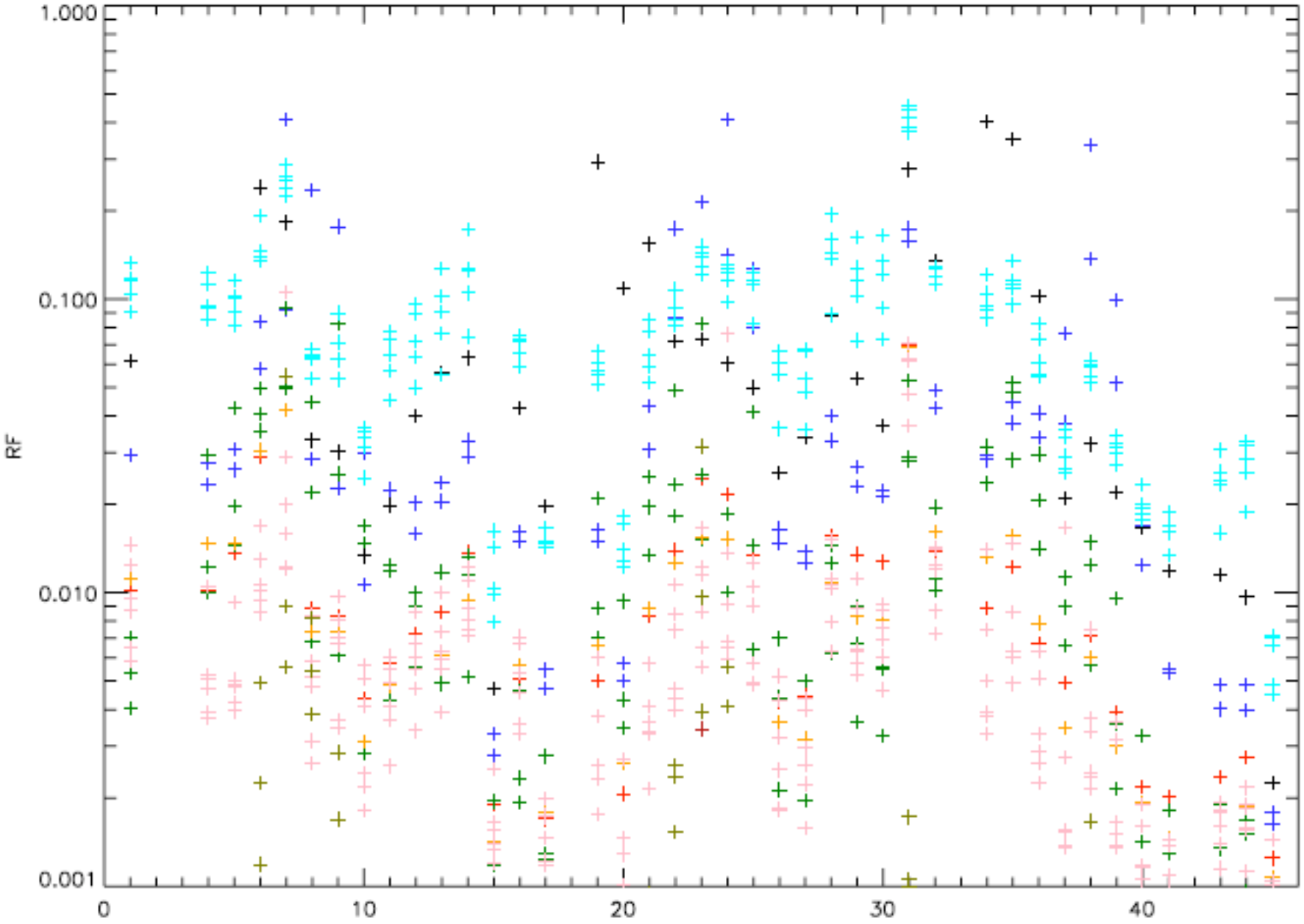
Range of input (estimated) power

Description:

- **For almost all the observations, we estimate the power of "RF band" (55-91cm-1).**

You can see that input power has the range from 1 to 2 order.


12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
M82
OT_eta_Carinae
Ceres
Uranus
Neptune
M20
GC
M17
ISMGN_G291.61−0.528
G333.6_0.2
G3.27_0.10


1.000
0.100
0.010
0.001
RF
0
10
20
30
40