



# Data Reduction Overview: MIRC-X/MYSTIC pipeline, OIFITS data format

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MIRCX+MYSTIC collaboration



# Outline

- Introduction to MIRC-X and MYSTIC
- How observations are executed?
- Data reduction
- Overview of OIFITS



# Useful information

Data reduction manual

<https://www.chara.gsu.edu/tutorials/mirc-data-reduction>

Pipeline (Python 2.7)

[https://gitlab.chara.gsu.edu/lebouquj/mircx\\_pipeline.git](https://gitlab.chara.gsu.edu/lebouquj/mircx_pipeline.git)

Papers

Anugu et al. 2020, Monnier et al. 2018, Setterholm et al. (submitted)

Important

Join slack (mircx.slack.com, ask John)



# Introduction to MIRC-X and MYSTIC

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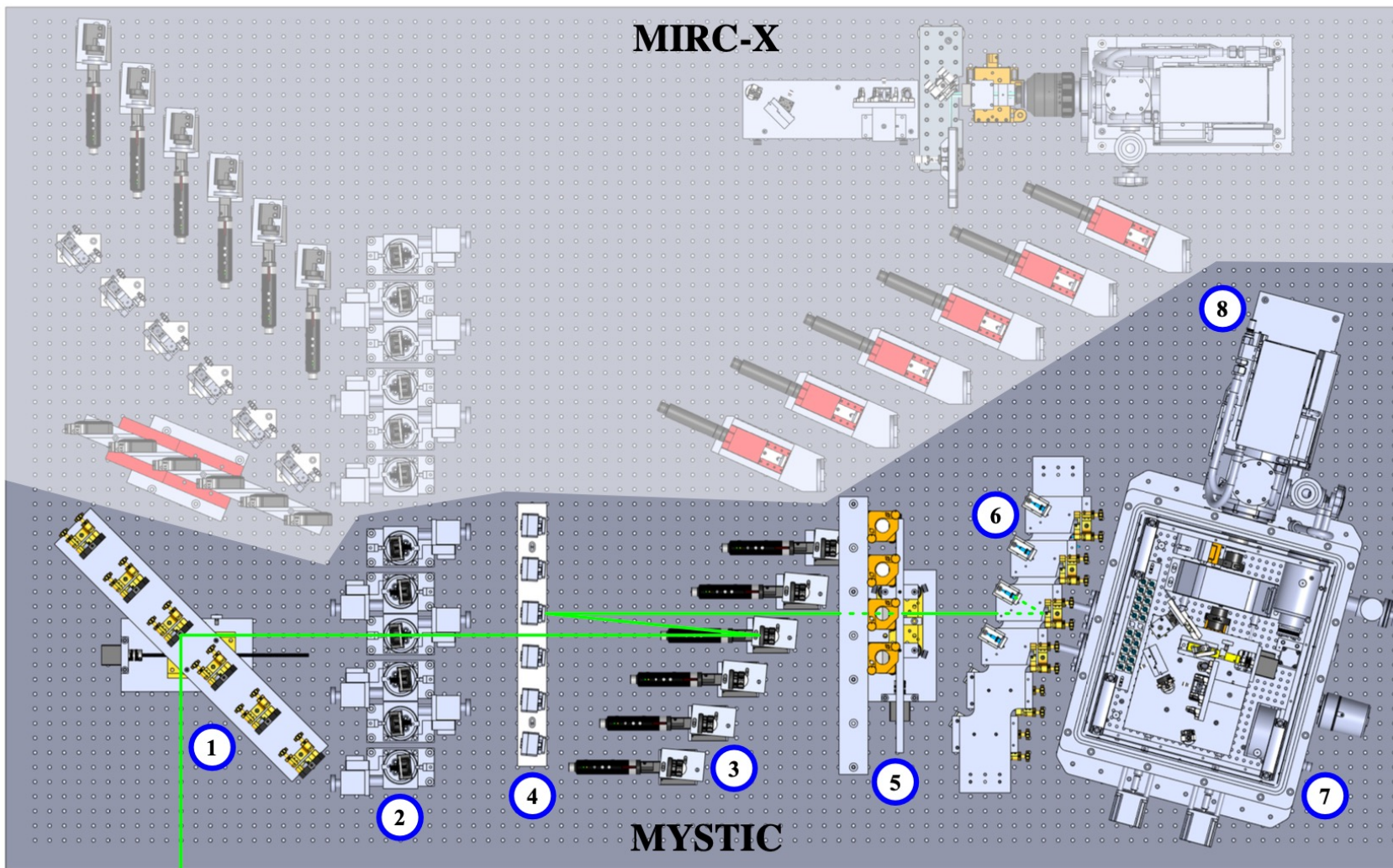
Australian  
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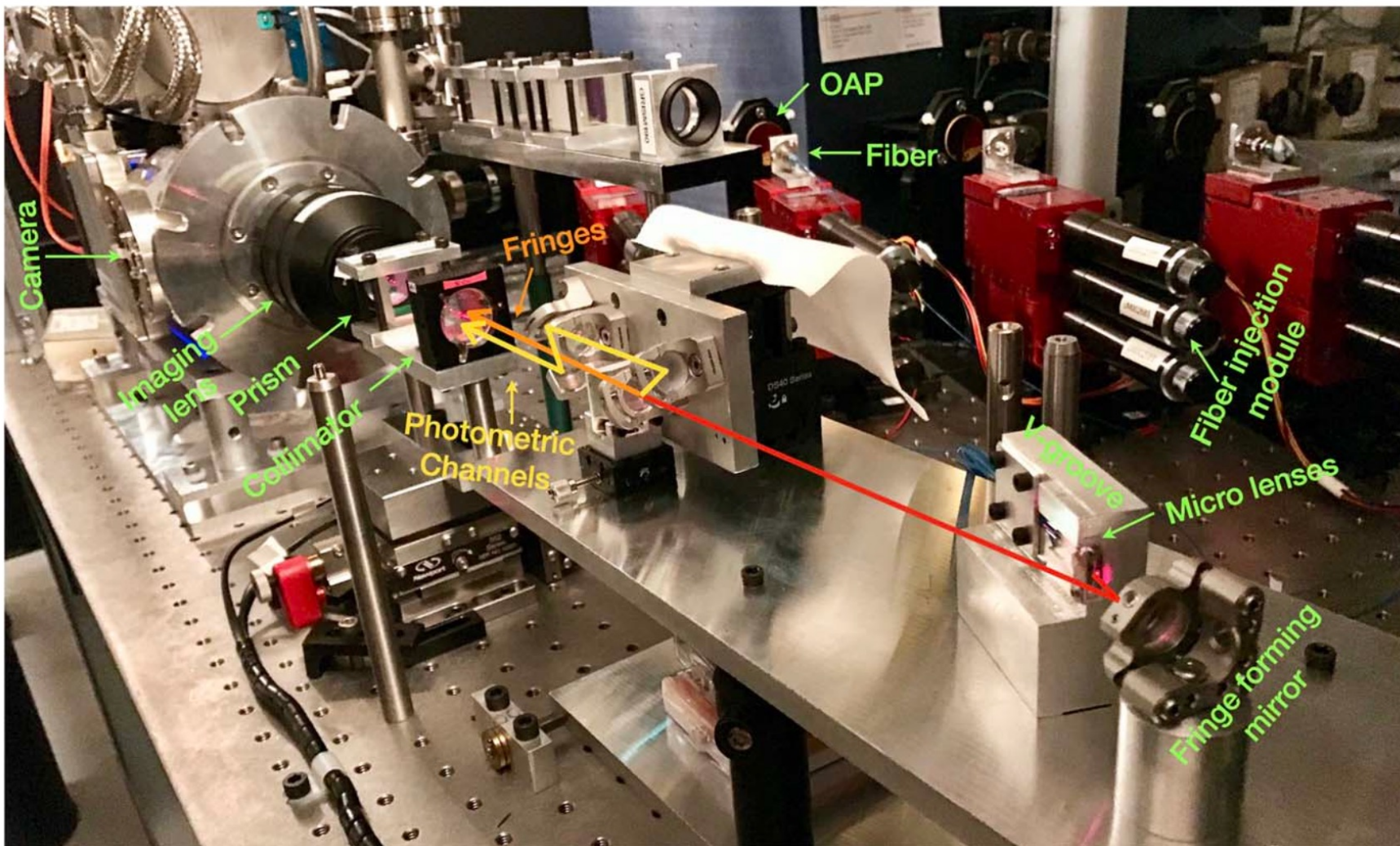
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SANGYO  
UNIVERSITY



# MIRC-X and MYSTIC

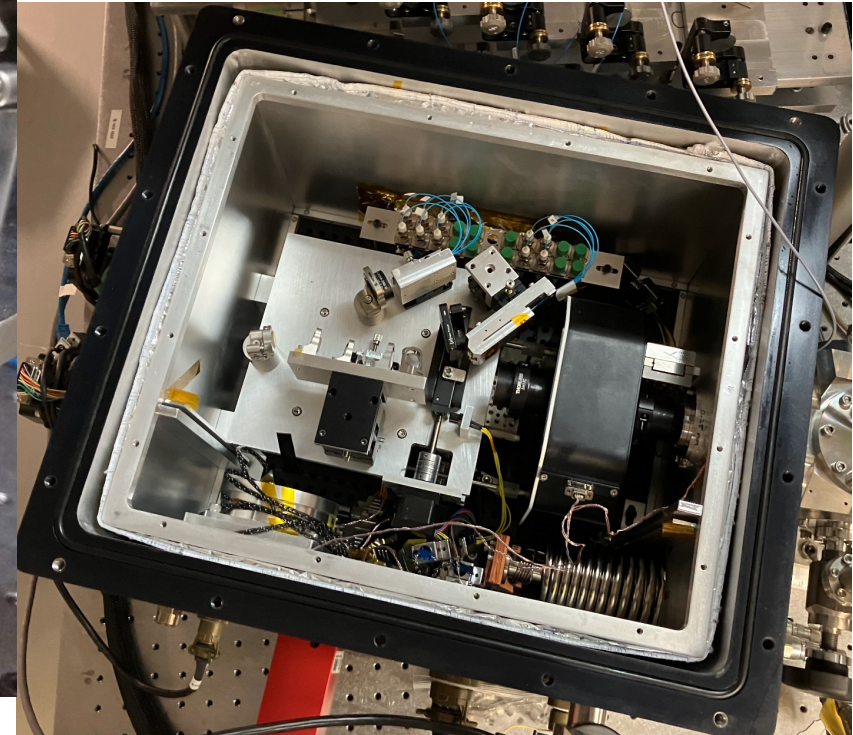
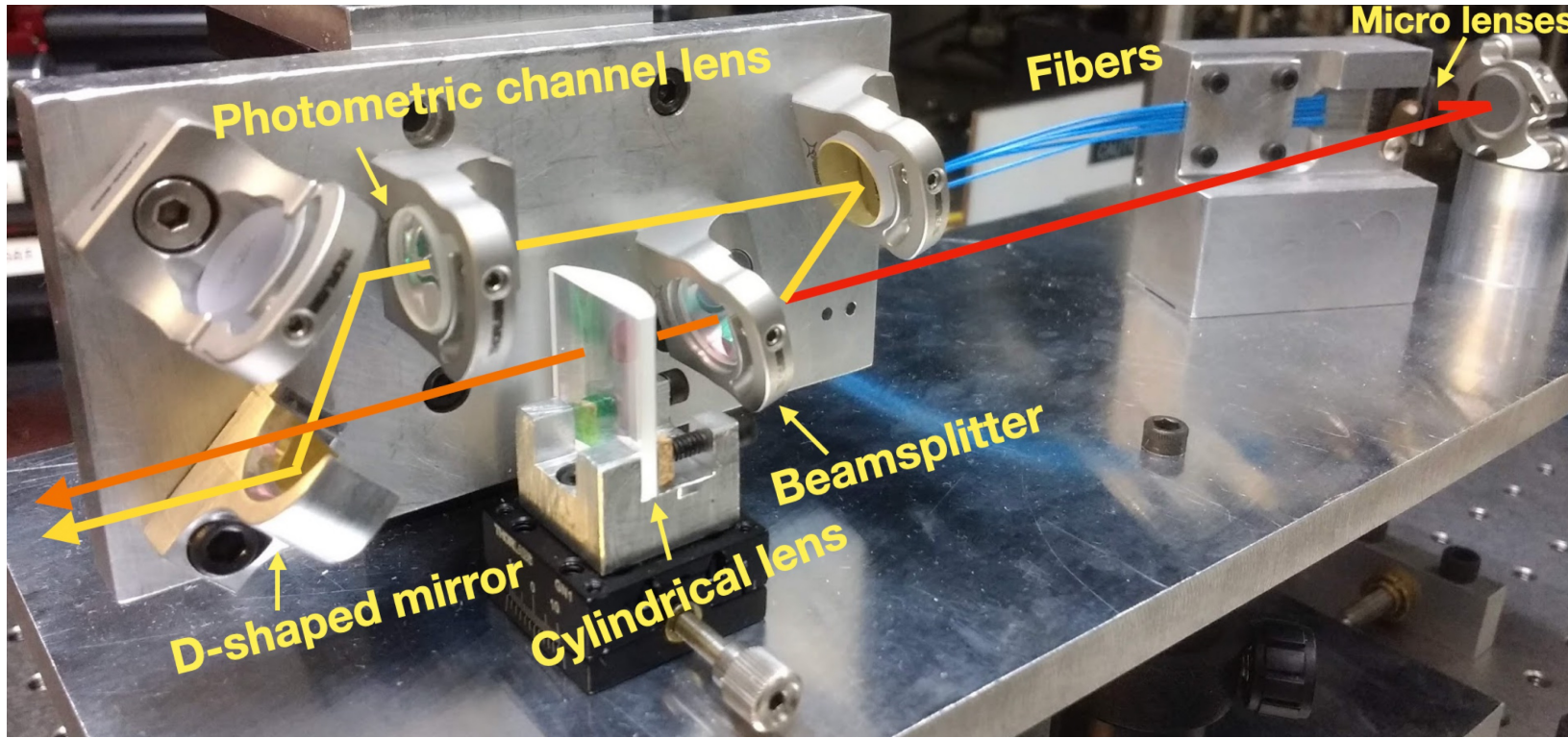


# MIRC-X



Anugu et al. 2020

# Beam combiner optics



MIRC-X  
Anugu et al. 2020

MYSTIC

Setterholm submitted  
Monnier et al. 2018



# Observations

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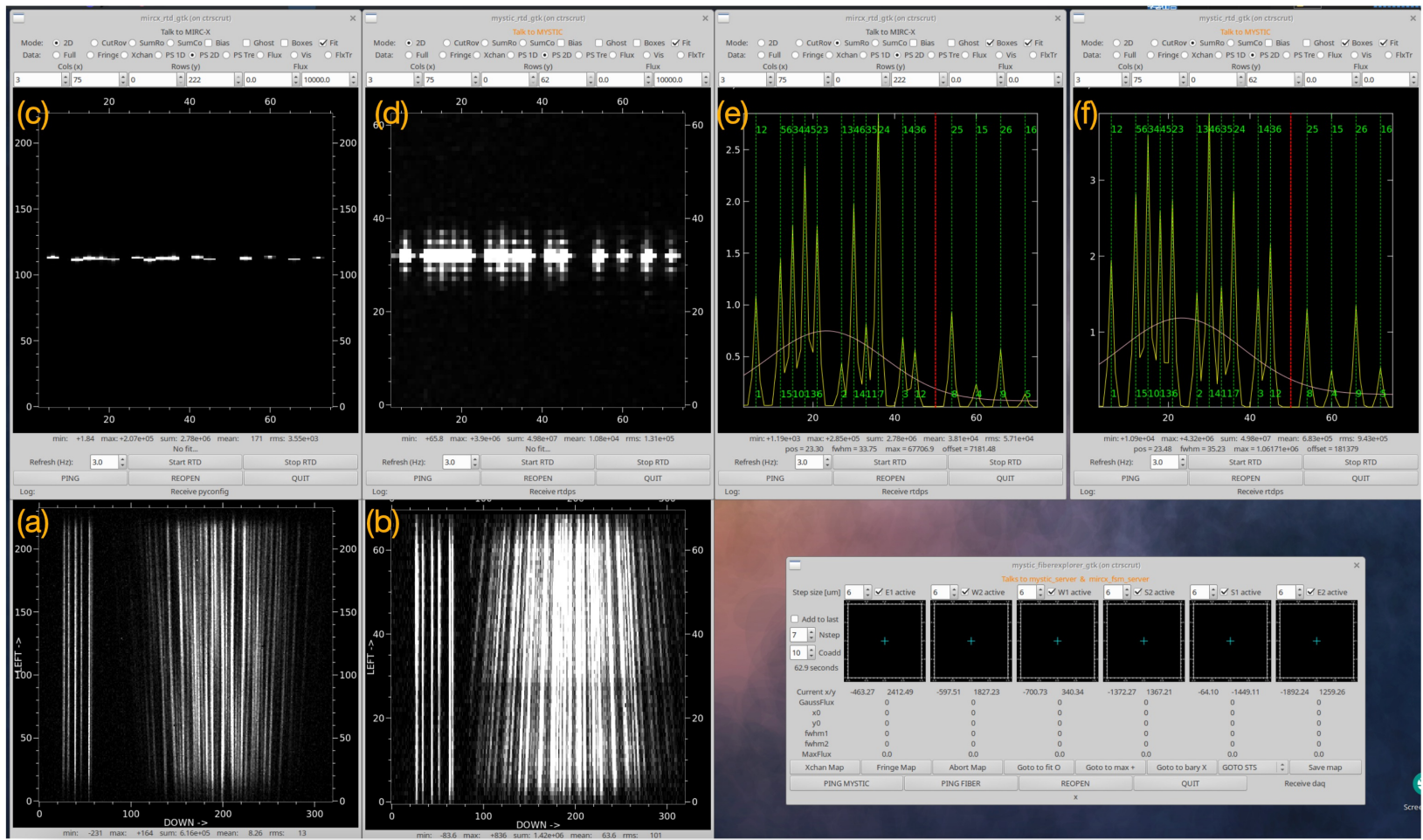


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# Offered observing modes



MIRC-X (R)	MYSTIC (R)
20	20
50	49
102	100
198	278
1170	981
-	1724



# Observations: K=7.2 and H=7.5

The screenshot displays the CHARA control interface with several windows:

- mystic\_rtd.gtk (on ctrscrt):** Shows a 3x3 grid of beam positions for K=7.2. The beams are labeled S1-S2, S2-E2, S1-E2, S2-W1, S1-W1, E2-W1, S2-W2, S1-W2, E2-W2, S1-E1, E1-E2, W1-W2, and E1-W2, E1-W1, S2-E1.
- mircx\_rtd.gtk (on ctrscrt):** Shows a similar 3x3 grid for H=7.5 with labels S1-S2, S2-E2, S1-E2, S2-W1, S1-W1, E2-W1, S2-W2, S1-W2, E2-W2, S1-E1, E1-E2, W1-W2, and E1-W2, E1-W1, S2-E1.
- mystic.gtk (on ctrscrt):** Shows observation parameters for K=7.2. The table below is a simplified version of the data shown in the interface.
- mircx.gtk (on ctrscrt):** Shows observation parameters for H=7.5. The table below is a simplified version of the data shown in the interface.
- mystic.fiberexplorer.gtk (on ctrscrt):** Shows fiber positions and flux data for K=7.2.
- mircx.fiberexplorer.gtk (on ctrscrt):** Shows fiber positions and flux data for H=7.5.

beam	pop	lbc	MAN	FT	6nm	DL offset	step size	S1	S2	E1	E2	W1	W2						
S1	5	2	-0.00	MAN	FT	6nm	<<<< 0	-3.174	>>>	0.010	Loop+	Loop+	S1	-	x	x	x	x	x
S2	4	3	-0.00	MAN	FT	1nm	<<<< 0	-0.788	>>>	0.006	Loop+	Loop+	S2	20.6	-	x	x	x	x
E1	1	1	-0.00	MAN	FT	5nm	<<<< 0	0.984	>>>	0.006	Loop+	Loop+	E1	3.9	8.8	-	x	x	x
E2	2	2	0.00	MAN	FT	-9nm	<<<< 0	-1.426	>>>	0.010	Loop+	Loop+	E2	9.6	6.9	4.4	-	x	x
W1	3	1	0.00	MAN	FT	10nm	<<<< 0	0.928	>>>	0.010	Loop+	Loop+	W1	5.3	7.5	6.0	3.5	-	x
W2	2	5	-0.00	MAN	FT	-1nm	<<<< 0	0.000	>>>	0.010	Loop+	Loop+	W2	3.4	4.2	5.4	2.8	7.6	-

beam	pop	lbc	MAN	FT	6nm	DL position	step size	S1	S2	E1	E2	W1	W2						
S1	5	2	-0.00	MAN	FT	6nm	<<<< 0	-0.009	>>>	0.002	Loop+	Loop+	S1	-	x	x	x	x	x
S2	4	3	-0.00	MAN	FT	1nm	<<<< 0	-0.000	>>>	0.002	Loop+	Loop+	S2	11.4	-	x	x	x	x
E1	1	1	-0.00	MAN	FT	5nm	<<<< 0	-0.001	>>>	0.006	Loop+	Loop+	E1	3.1	3.0	-	x	x	x
E2	2	2	0.00	MAN	FT	-9nm	<<<< 0	-0.005	>>>	0.006	Loop+	Loop+	E2	12.3	12.4	3.3	-	x	x
W1	3	1	0.00	MAN	FT	10nm	<<<< 0	-0.002	>>>	0.010	Loop+	Loop+	W1	3.5	3.6	1.3	2.6	-	x
W2	2	5	-0.00	MAN	FT	-1nm	<<<< 0	0.000	>>>	0.010	Loop+	Loop+	W2	1.6	4.1	2.1	0.9	3.1	-

Current x/y	GaussFlux	x0	y0	fwHM1	fwHM2	MaxFlux
-477.63 2425.46	4606.7	-477.63	2425.5	10.201	12.399	3890.7
-623.91 1826.98	3665.5	-623.91	1827	10.467	12.643	3722.7
-720.32 353.42	6941.9	-720.32	353.42	6.3837	9.9638	3782.9
-1399.37 1368.27	2626.9	-1399.4	1368.3	15.08	8.2561	2516.5
-89.41 -1447.43	3351.1	-89.41	-1447.4	10.722	9.8822	2704.2
-1904.73 1258.77	6386.2	-1904.7	1258.8	10.722	8.4901	5256.8

Current x/y	GaussFlux	x0	y0	fwHM1	fwHM2	MaxFlux
100.28 134.30	840.78	100.28	134.31	12.519	20.672	730.3
282.72 282.60	655.6	282.73	282.6	16.961	10.768	750.6
298.20 276.35	825.06	298.21	276.35	8.893	9.8803	644.8
263.07 319.86	1127.4	263.07	319.87	12.257	7.5189	1145.5
206.41 234.48	598.01	206.41	234.48	13.86	11.644	572.3
220.47 224.82	1262.2	220.47	224.82	8.2406	11.156	969.1



This screenshot shows the CHARA control room interface. The top left panel displays camera settings for 'MIRCK\_X' and 'MIRCK\_Y' cameras, including crop boxes and det rates. The top right panel shows a 'MIRCK\_FIBERexplorer' window with a grid of fiber images and a data table. The middle left panel shows 'Coud parameters' and 'Update DAQ' options. The middle right panel shows a 'MIRCK\_SERVER' window with a table of fiber IDs and their corresponding data. The bottom left panel shows 'Disk free space' and 'Det det rates' information. The bottom right panel shows a 'MIRCK\_SERVER' window with a table of fiber IDs and their corresponding data.

This screenshot shows the CHARA control room interface. The top left panel displays camera settings for 'MIRCK\_X' and 'MIRCK\_Y' cameras, including crop boxes and det rates. The top right panel shows a 'MIRCK\_FIBERexplorer' window with a grid of fiber images and a data table. The middle left panel shows 'Coud parameters' and 'Update DAQ' options. The middle right panel shows a 'MIRCK\_SERVER' window with a table of fiber IDs and their corresponding data. The bottom left panel shows 'Disk free space' and 'Det det rates' information. The bottom right panel shows a 'MIRCK\_SERVER' window with a table of fiber IDs and their corresponding data.

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# What DATA we take?

mircx\_super\_gtk

MIRCX FLIP MYSTIC FLIP

STS IR FOLD ARMADA HALOGEN

Reset BG	Take BG	MIRCX 0 BG	MYSTIC 0 BG
Reset FLAT	Take FLAT	MIRCX 0 FT	MYSTIC 0 FT

FILE TYPE	MIRCX	MYSTIC	sec
DATA	-	-	600
BACKGROUND	-	-	60
BEAM	-	-	60
FOREGROUND	-	-	180

NONE

E1W2W1S2S1E2 E1W2W1S2S1E2 Send

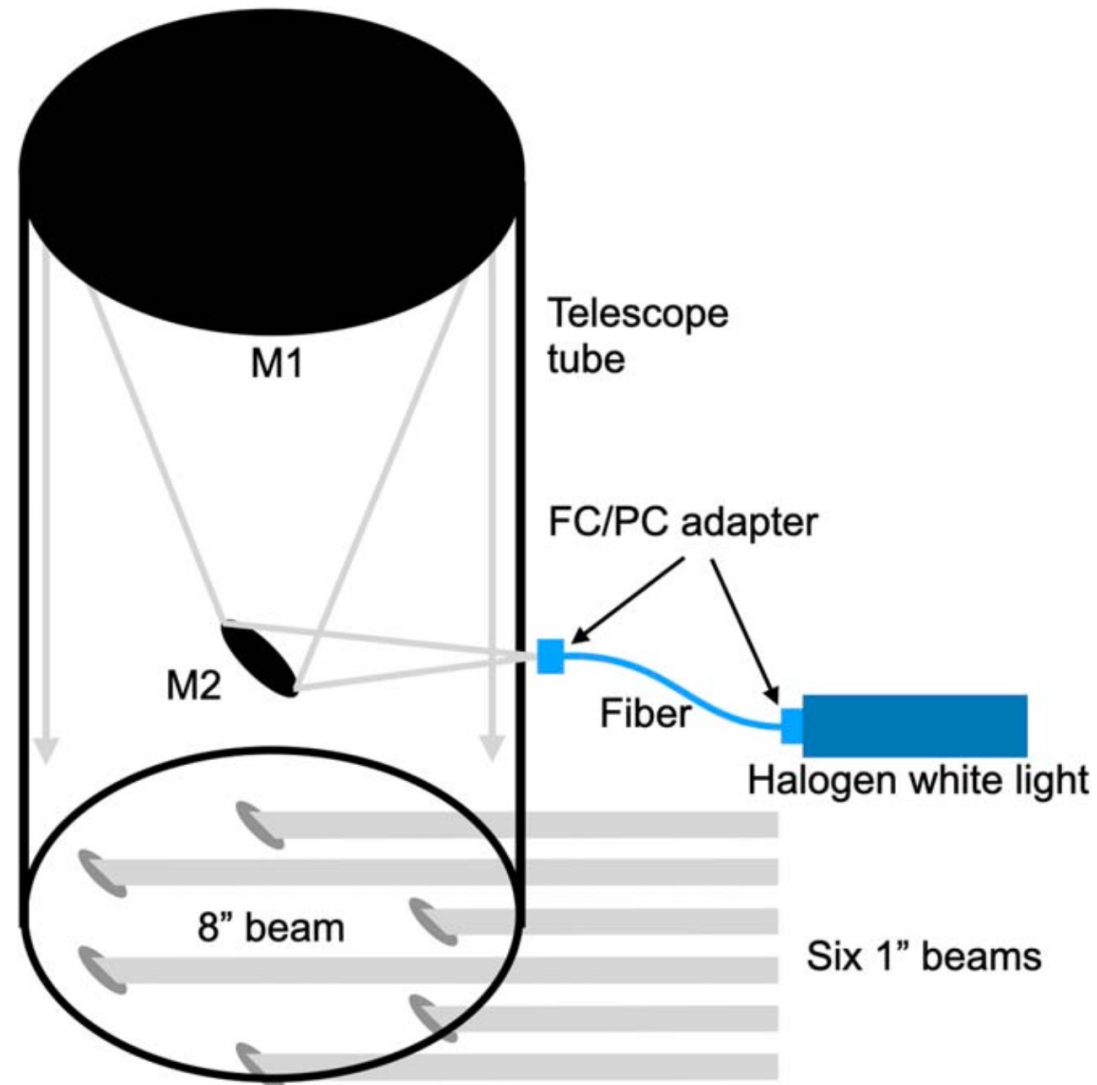
B1  B2  B3  B4  B5  B6

IRB 1 IRB 2 IRB 3 IRB 4 IRB 5 IRB 6

DATA	SHUTTERS	ABORT	ACQUIRED
AUTO BASE	SAVE BASE	SAVE LABAO	SAVE TELAO
mircx	mystic	shutters	mircx_dll LABAO_S1 wfs_S1
PING	REOPEN	CONNECT ALL	QUIT

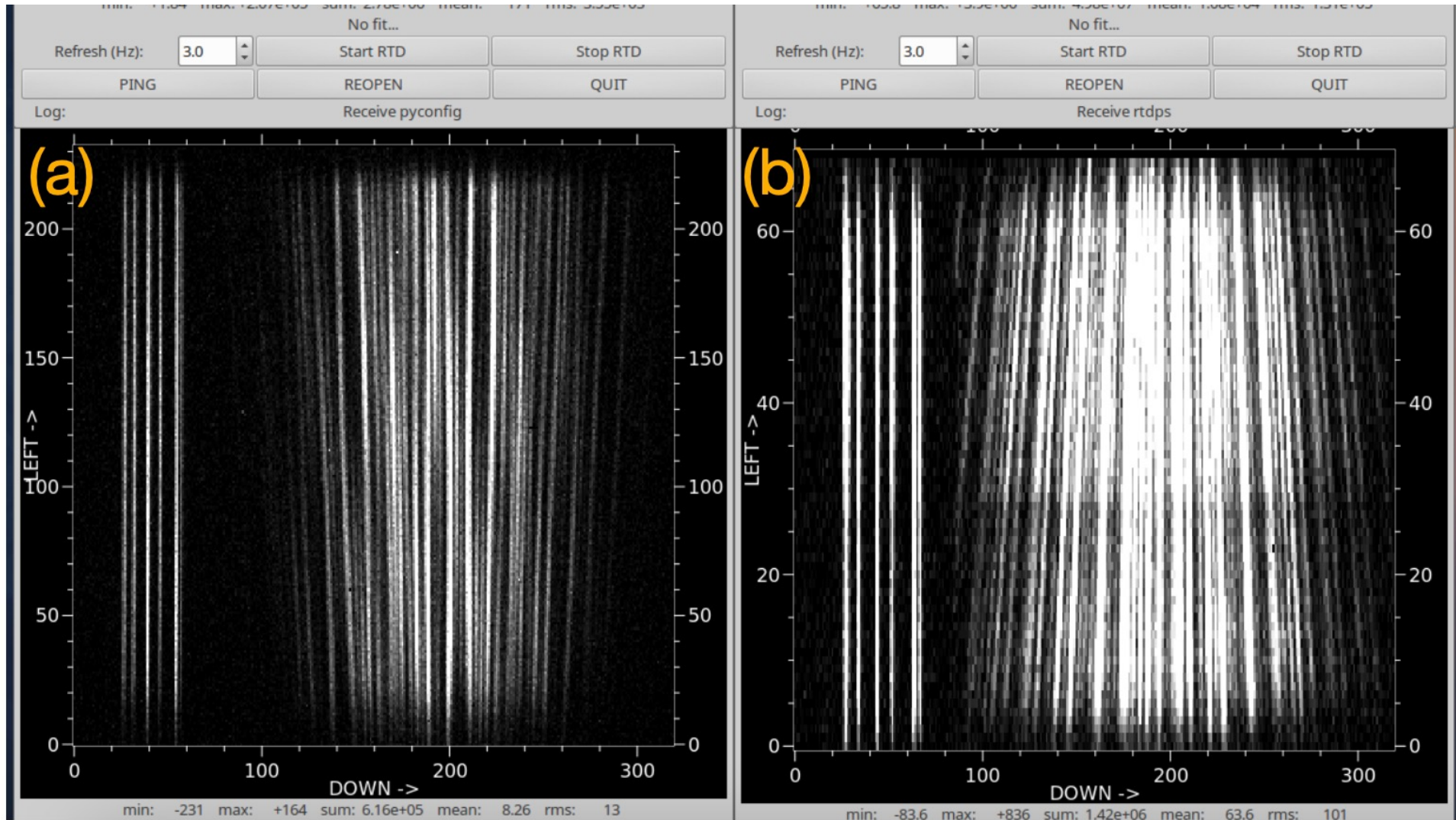
Failed to open server LABAO\_E2  
Receive exc from mircx

# Six Telescope Simulator (STS)





# What the data fits contain





# Data reduction

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## Squared visibilities for the baseline ij

$$V_{ij}^2(\lambda) = \frac{|\langle I_{ij}(\lambda, t) \times I_{ij}(\lambda, t - 1)^* - \beta(\lambda) \rangle|}{2\langle P_i(\lambda, t) \times P_j(\lambda, t) \rangle}$$

ij – tels





# Bispectrum of closing triangle $ijk$

$$C_{ijk}(\lambda) = \langle I_{ij}(\lambda, t) \times I_{jk}(\lambda, t) \times I_{ik}^*(\lambda, t) - \beta_{ijk}(\lambda) \rangle$$



# How to run the pipeline

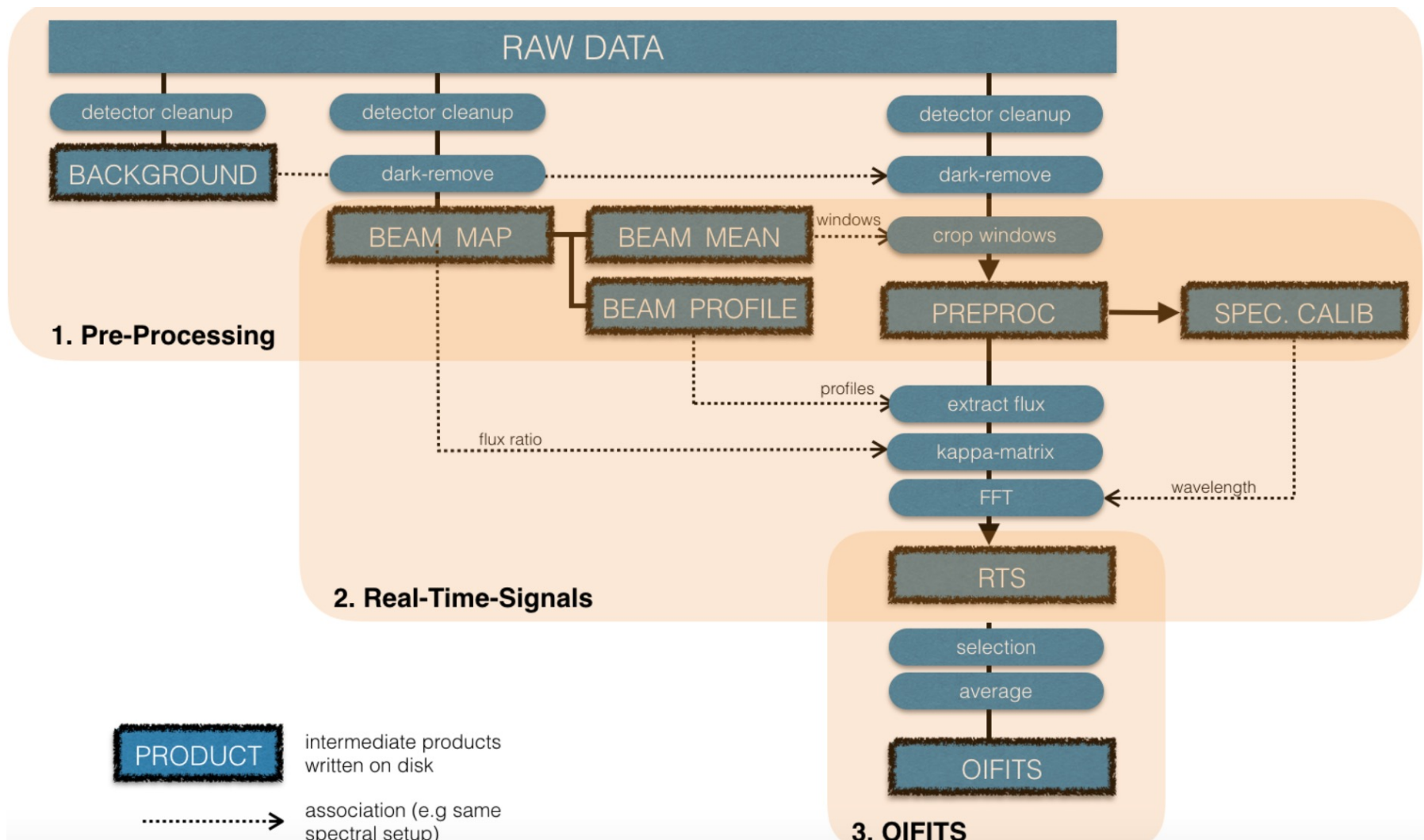
```
cd your_data/  
mircx_reduce.py
```

Creates directories **preproc**, **rts**, **oifits**

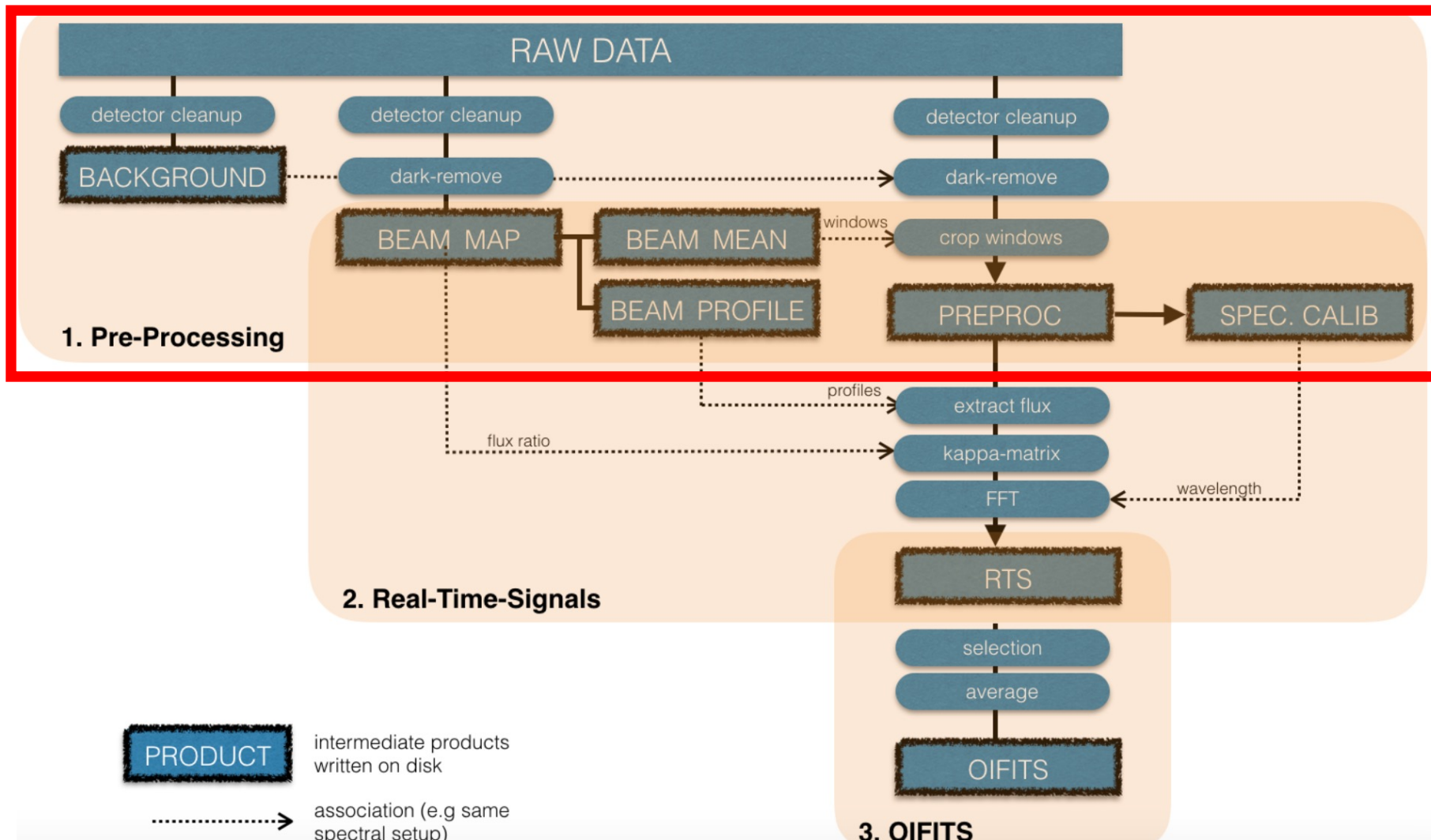
Pipeline divided into 3 steps:

- Pre-processed files (PREPROC)
- Real Time Signal (RTS)
- Raw and calibrated OIFITS

# Schematic diagram of the data reduction



# Preprocessing (preproc)



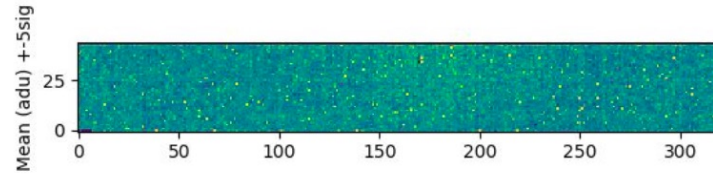


# 1) Pre-Processing Step

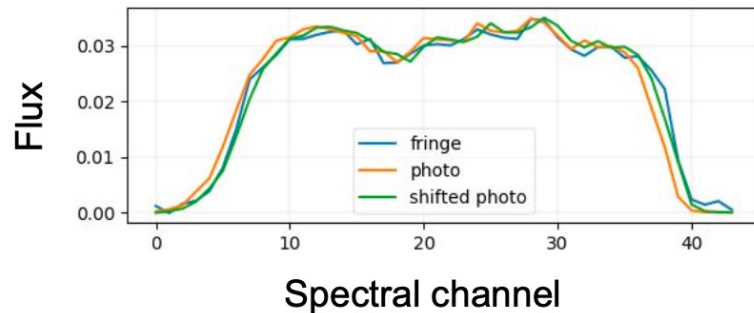
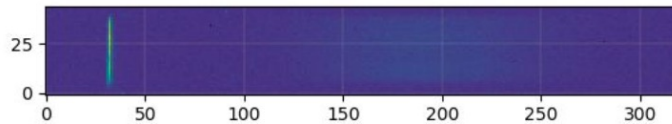
- Associate detector setups; targets / shutters
- Detector cleanup, bad pixel removal
- Creates PREPROC data files, beam maps, spectral calibration

**Background Files:** Either SHUTTER or SKY

G40-L6-R8 59004.4673 HD\_199766

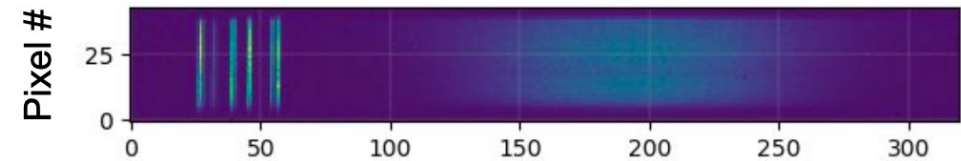
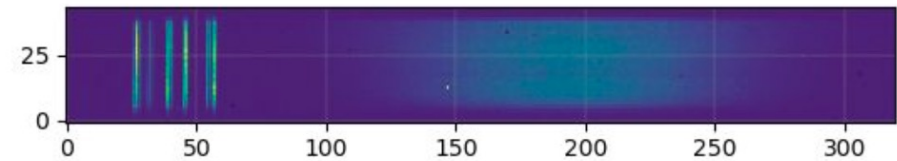
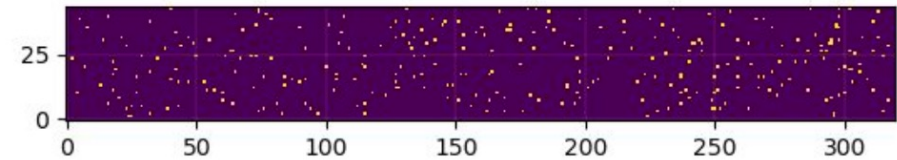


**Create Beam Maps:**



**Create "Cleaned" Data preproc files:**

G40-L6-R8 59004.4606 HD\_199766

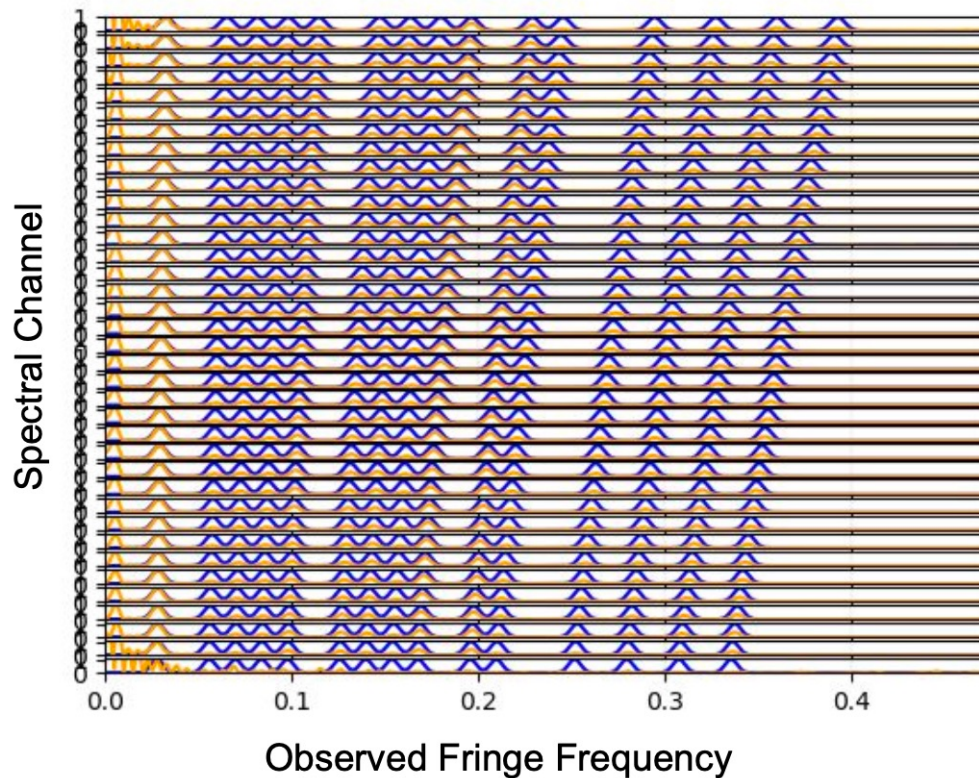


# 1) Pre-Processing Step

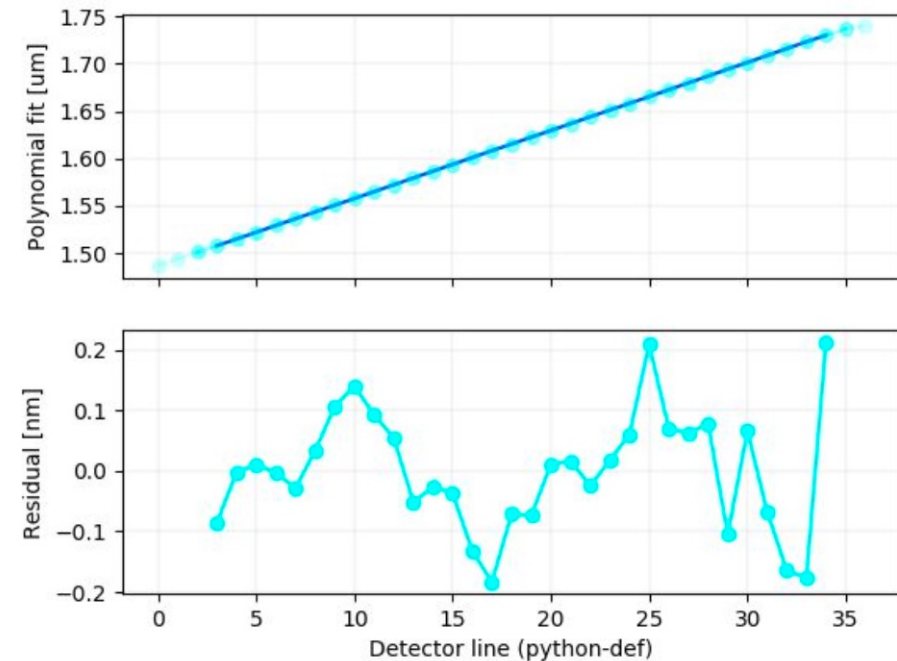
- Associate detector setups; targets / shutters
- Detector cleanup, bad pixel removal
- Creates PREPROC data files, beam maps, spectral calibration

All Fringe Files of Given Setup →  
Spectral Calibration

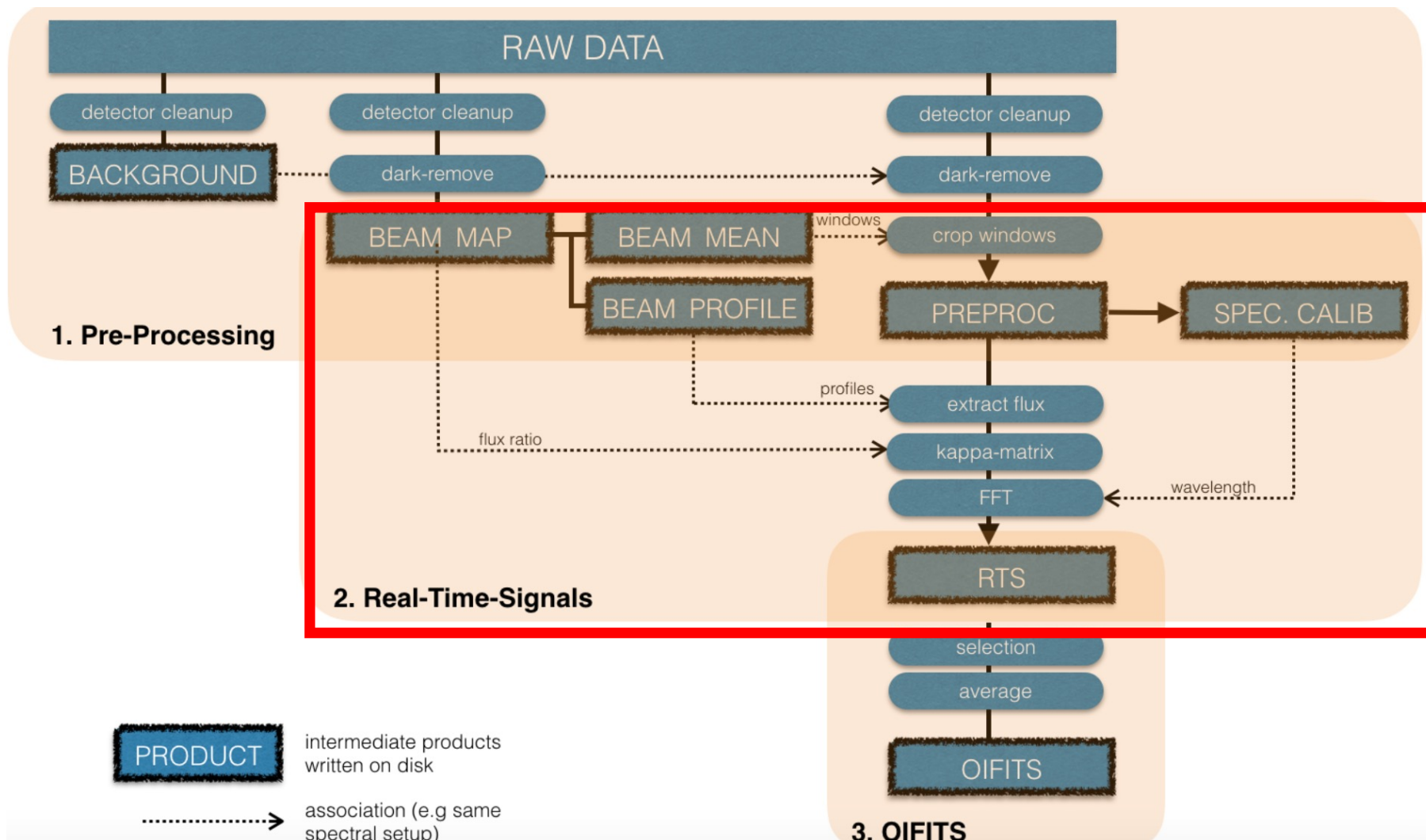
Observed PSD (orange) and scaled template (blue)



Polynomial fit  
(dark blue=poly, cyan=valid channels, light cyan = all channels)



# Real-Time-Signals (RTS)



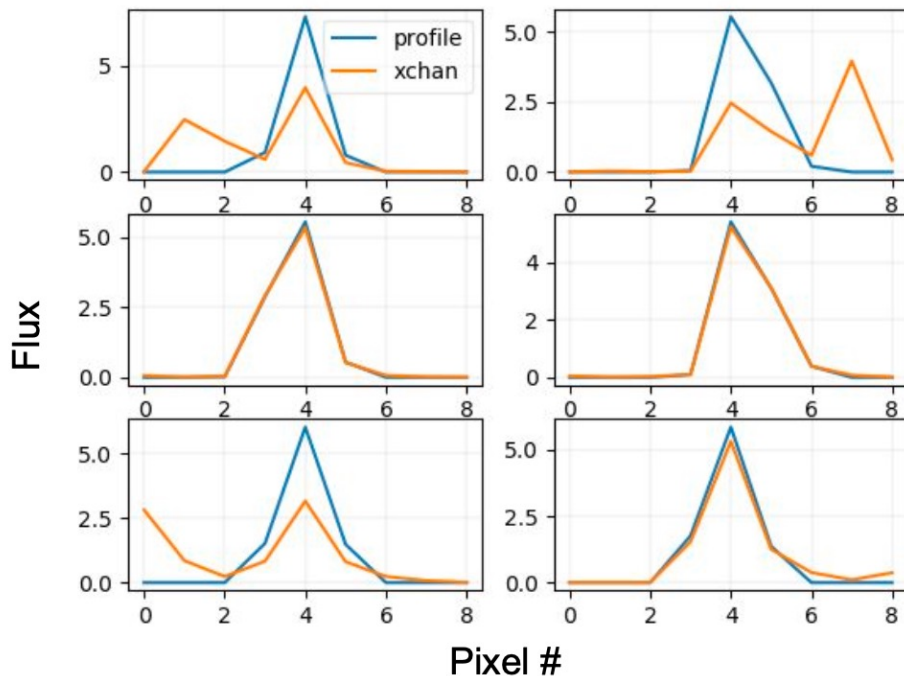


# 2) RTS Step

- Compute real-time photometry
- Fringe power
- Compute bispectrum bias
- Crude vis2

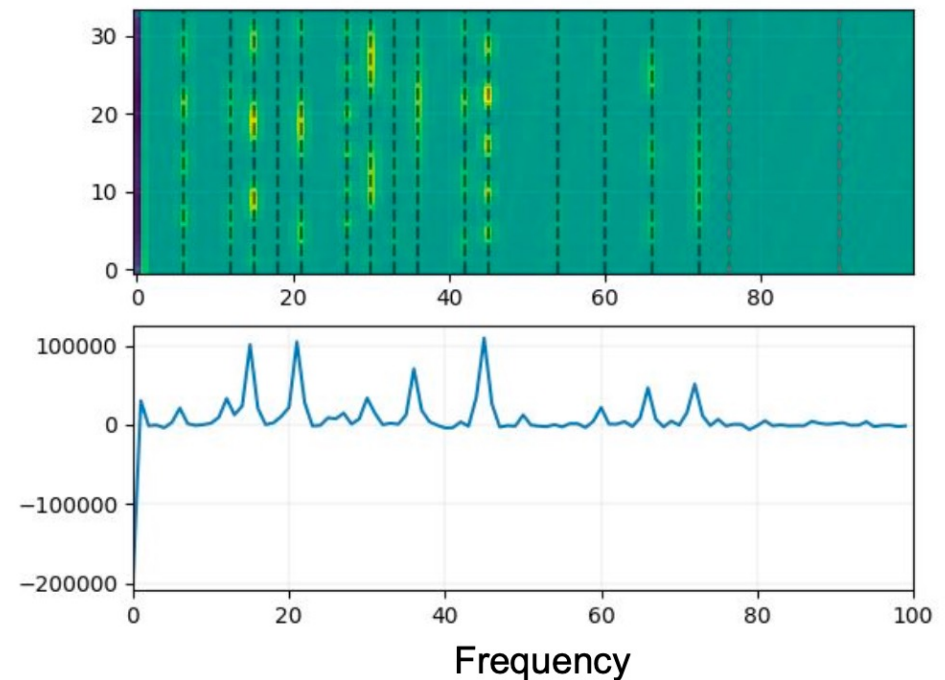
## Beam Profiles, Photometry:

G40-L6-R8 59004.4606 HD\_199766



## Fringes:

G40-L6-R8 59004.4606 HD\_199766



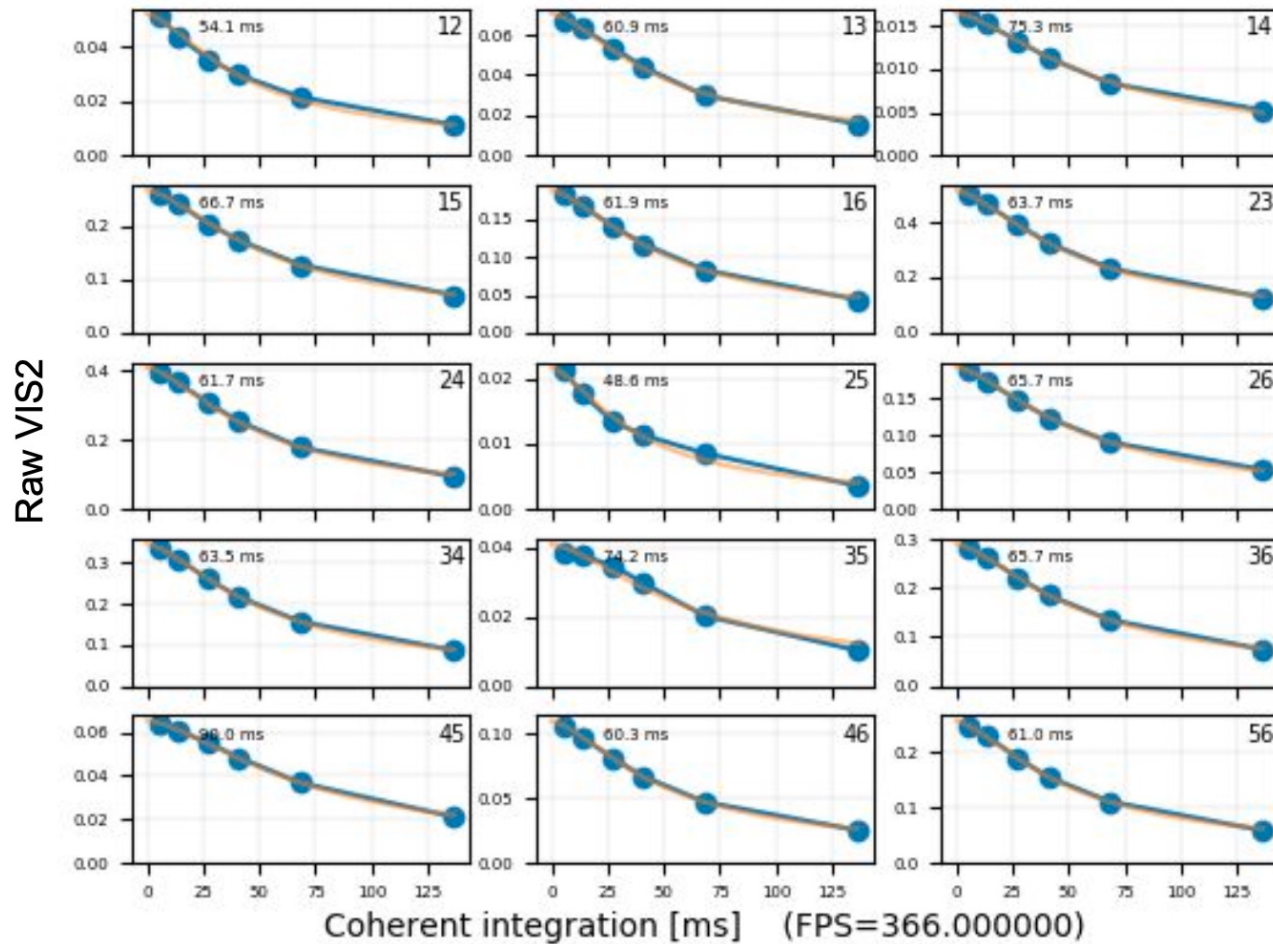




# 2) RTS Step

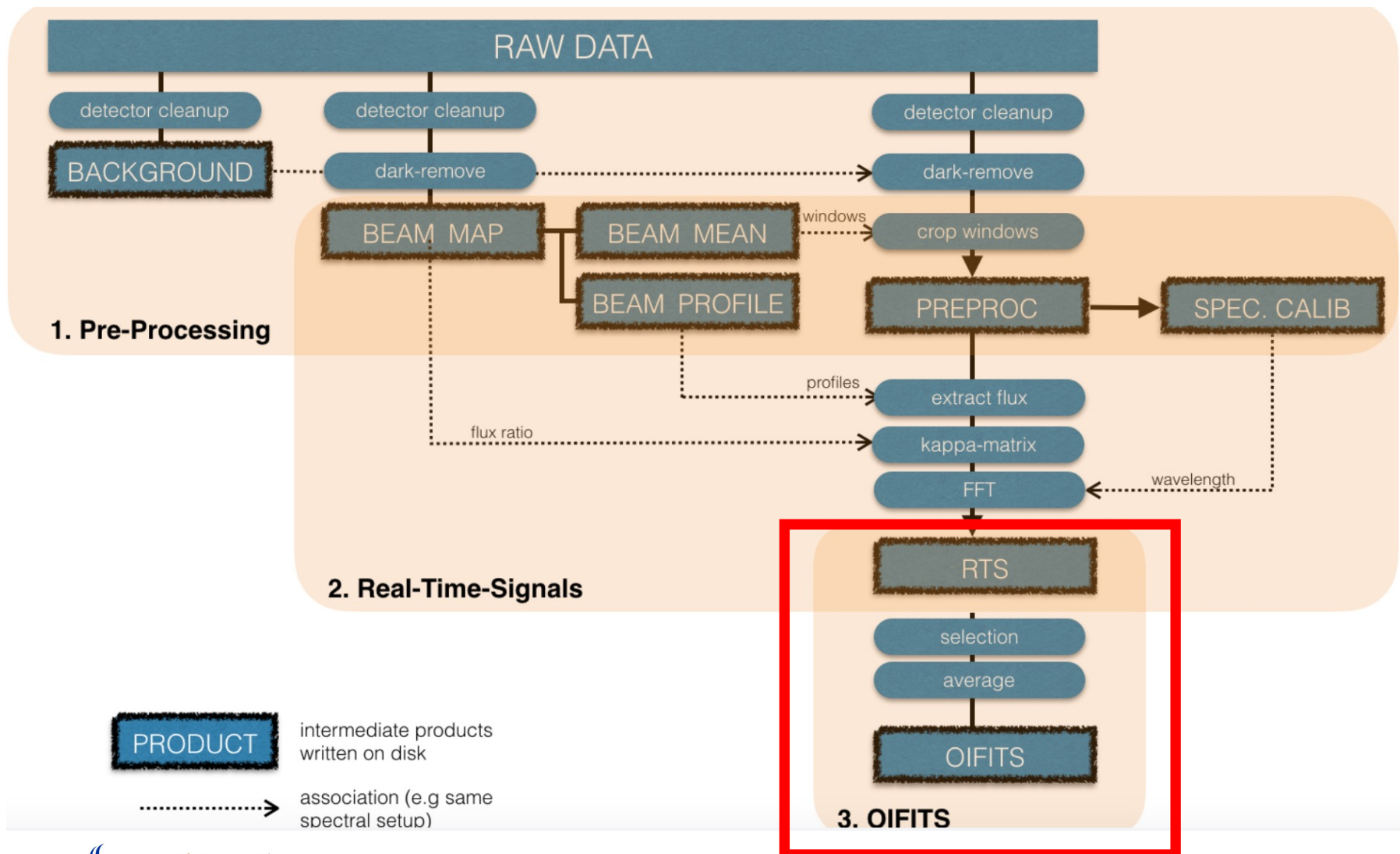
- Compute real-time photometry
- Fringe power
- Compute bispectrum bias
- Crude vis2

G40-L6-R8 59004.4606 HD\_199766



→ Gives an idea of how many frames to coherently average for OIFITS step

# Uncalibrated OIFITS (OIFITS)

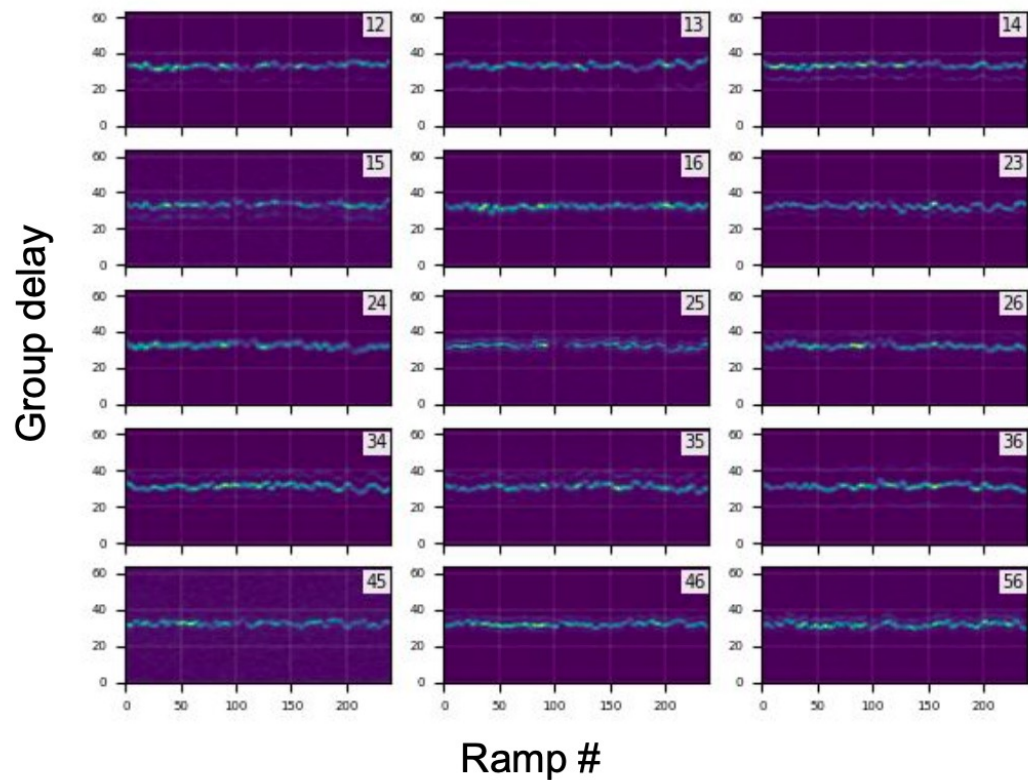




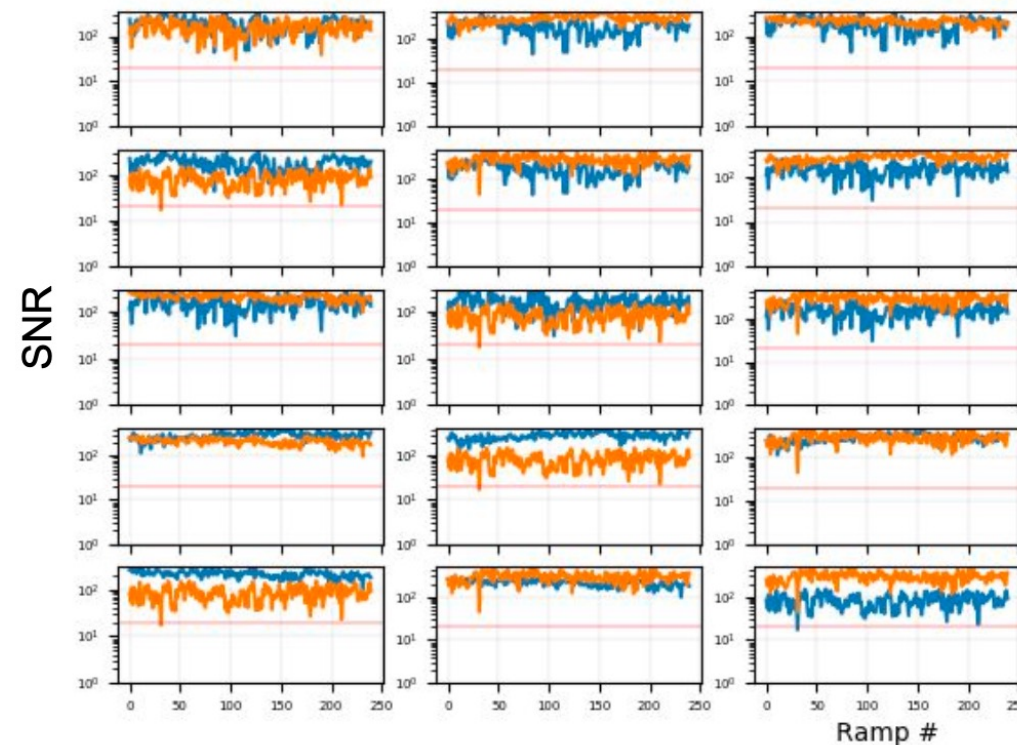
# 3) OIFITS Step

- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

G40-L6-R8 59004.4606 HD\_199766 NCOHER=10



Flux in fringe  
G40-L6-R8 59004.4606 HD\_199766 NCOHER=10

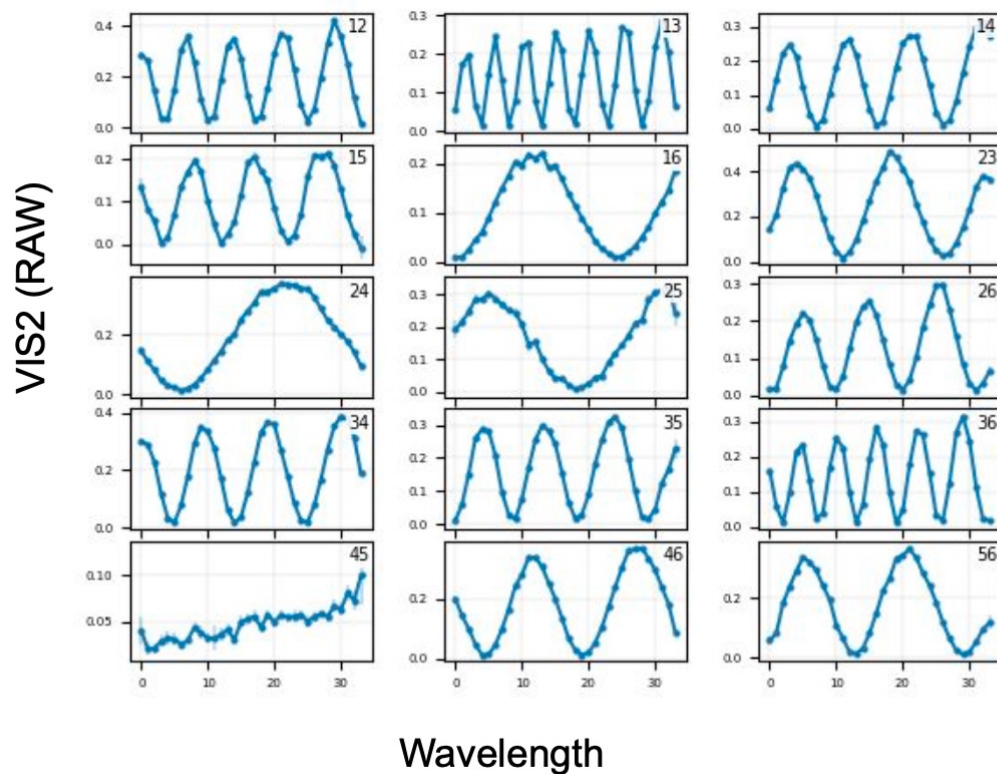




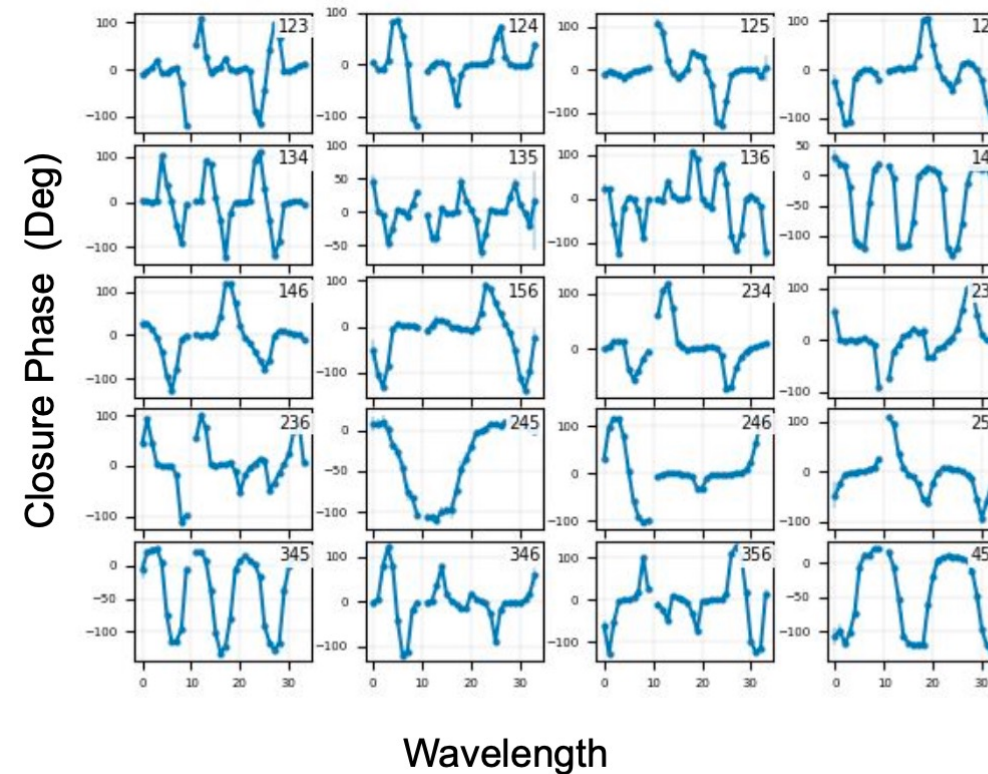
# 3) OIFITS Step

- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

G40-L6-R8 59004.4606 HD\_199766 NCOHER=10



G40-L6-R8 59004.4606 HD\_199766 NCOHER=10



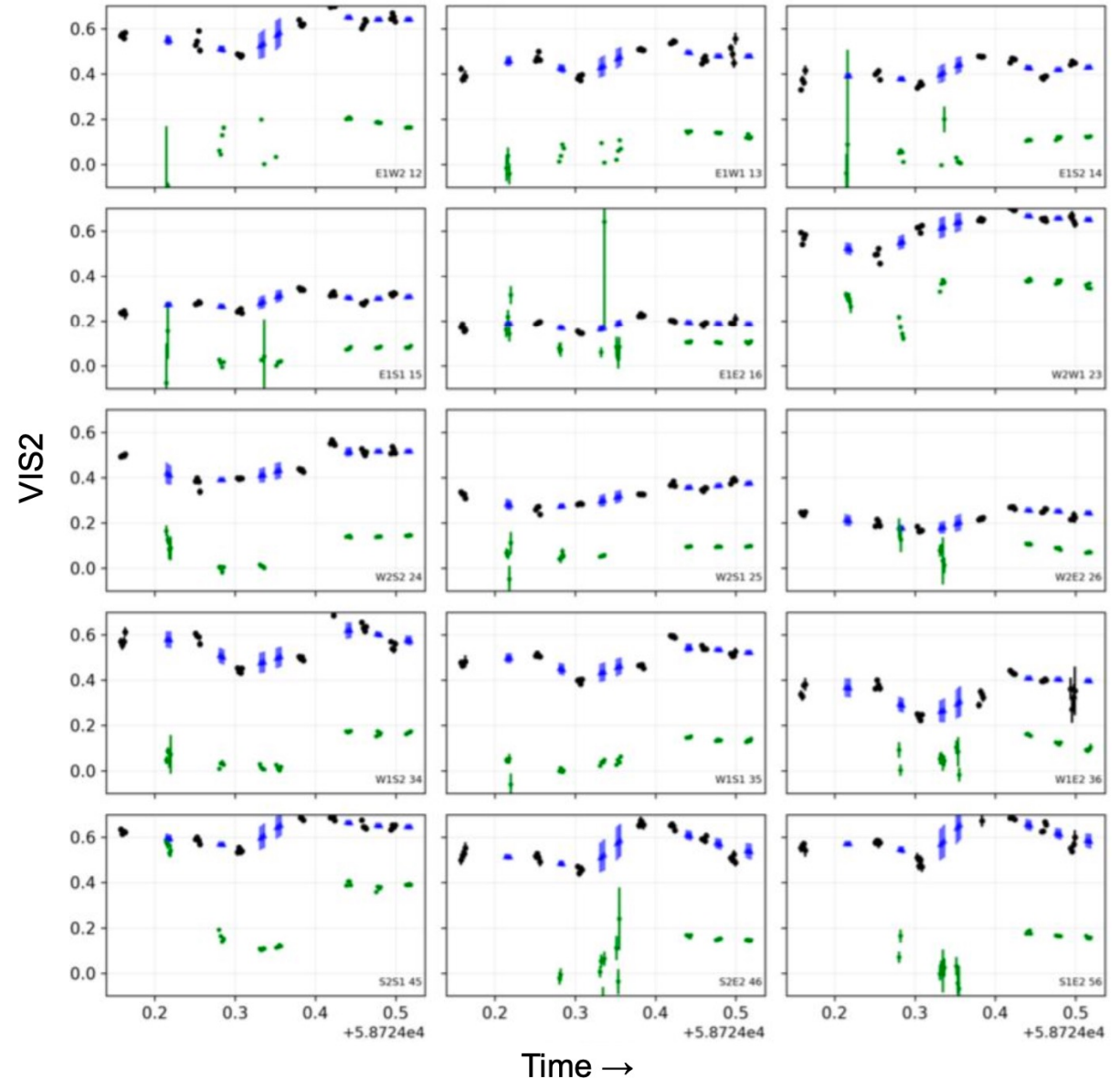


# Calibration

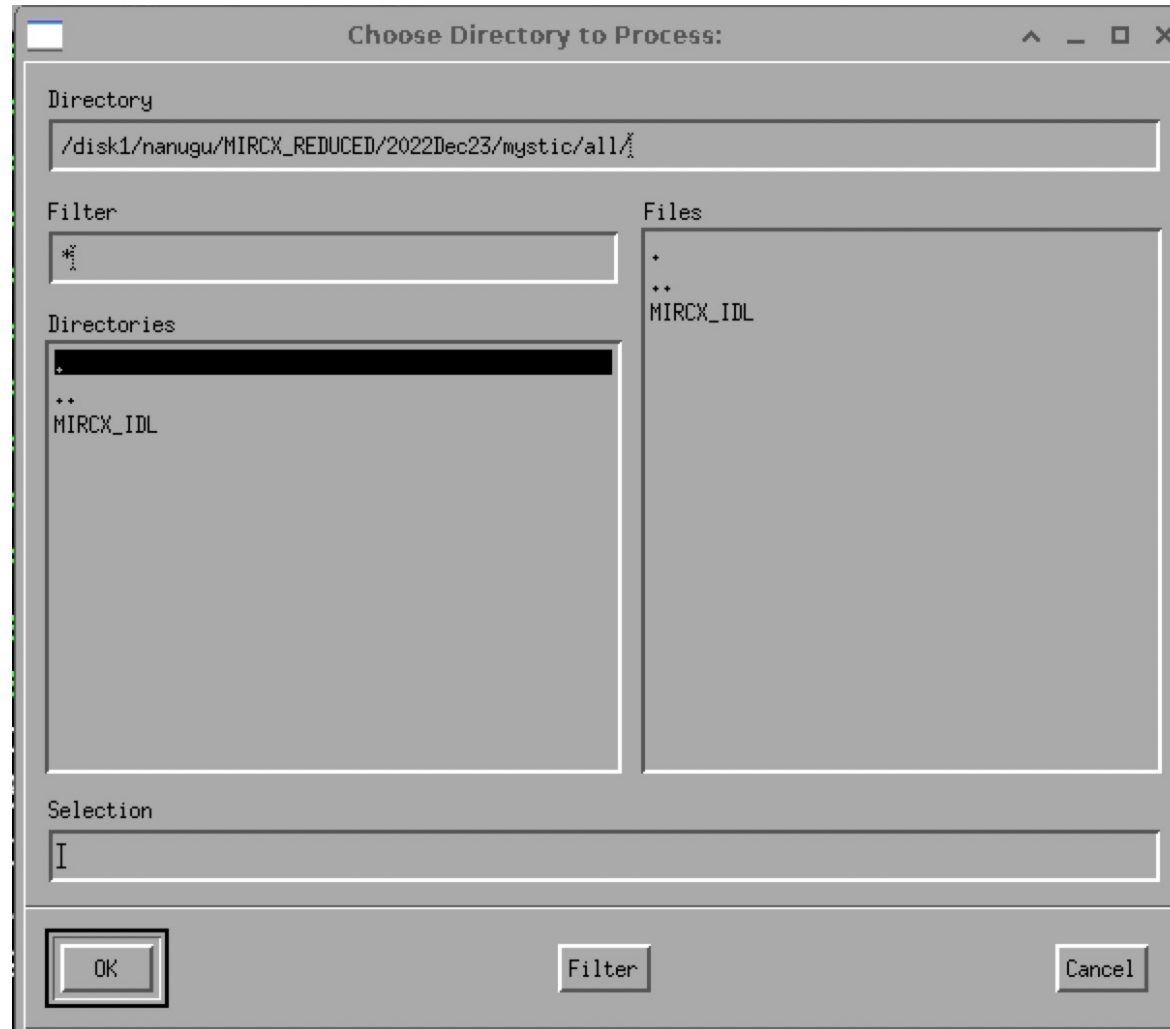
1. `mircx_calibrate.py` (python)
2. `mircx_cal.script` (IDL)

## 4) Calibration

- True source visibility is corrupted by system losses
- Compute 'transfer function' with calibrator stars to account for this
- Use calibrators to calibrate visibilities / phases of science targets



# IDL mircx\_cal.script



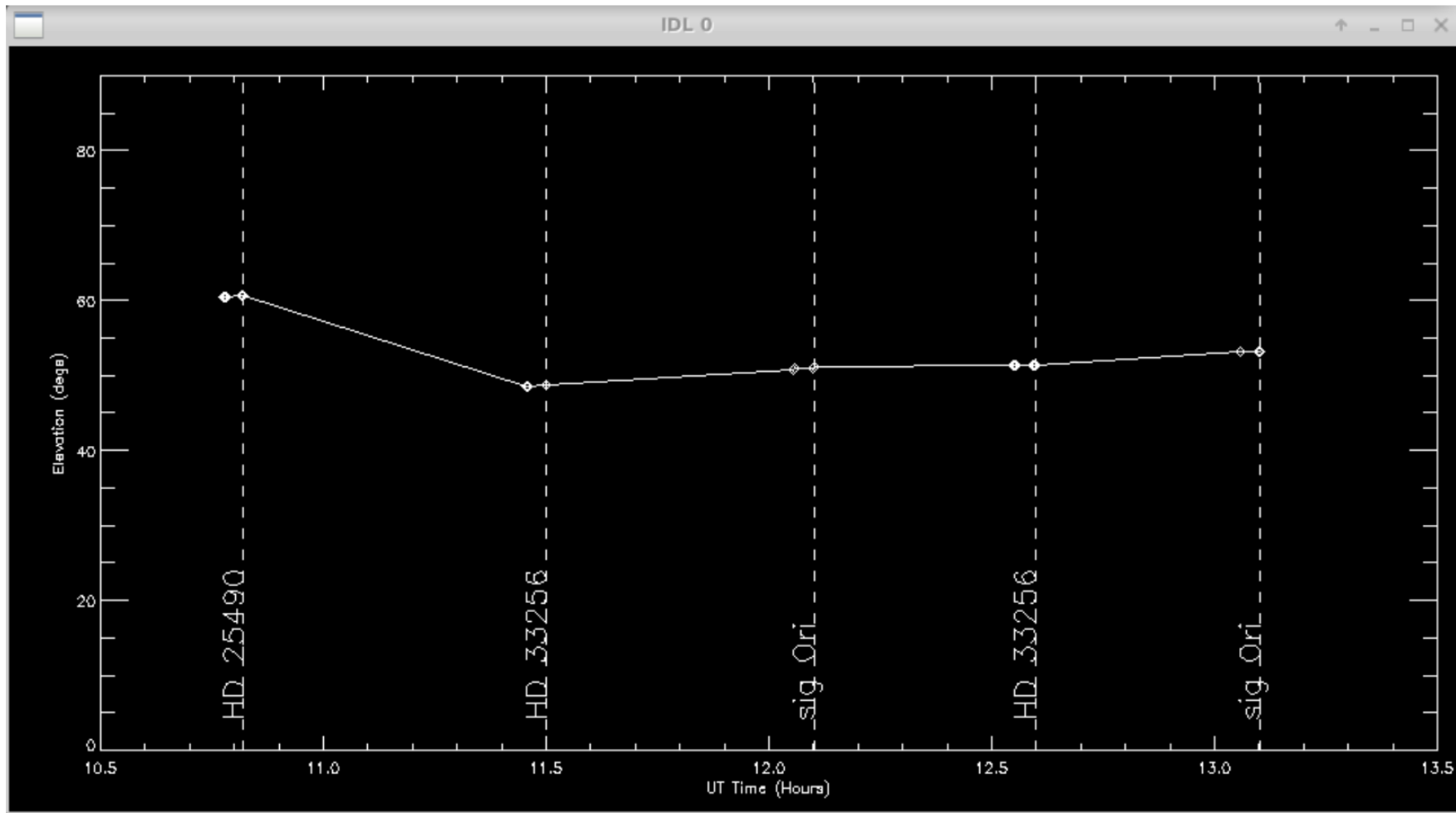
## mircx\_cal.script

```
6 Loading name: HD_52961 OLD NAME: HD_52961
7 Loading name: HD_52961 OLD NAME: HD_52961
8 Loading name: HD_52961 OLD NAME: HD_52961
9 Loading name: HD_52961 OLD NAME: HD_52961
0 Loading name: HD_52961 OLD NAME: HD_52961
1 Loading name: HD_52961 OLD NAME: HD_52961
2 Loading name: HD_52961 OLD NAME: HD_52961
3 Loading name: HD_52961 OLD NAME: HD_52961
4 Loading name: HD_52961 OLD NAME: HD_52961
5 Loading name: HD_52961 OLD NAME: HD_52961
6 Loading name: HD_52961 OLD NAME: HD_52961
7 Loading name: HD_52961 OLD NAME: HD_52961
8 Loading name: HD_52961 OLD NAME: HD_52961
9 Loading name: HD_90251 OLD NAME: HD_90251
0 Loading name: HD_90251 OLD NAME: HD_90251
1 Loading name: HD_90251 OLD NAME: HD_90251
```



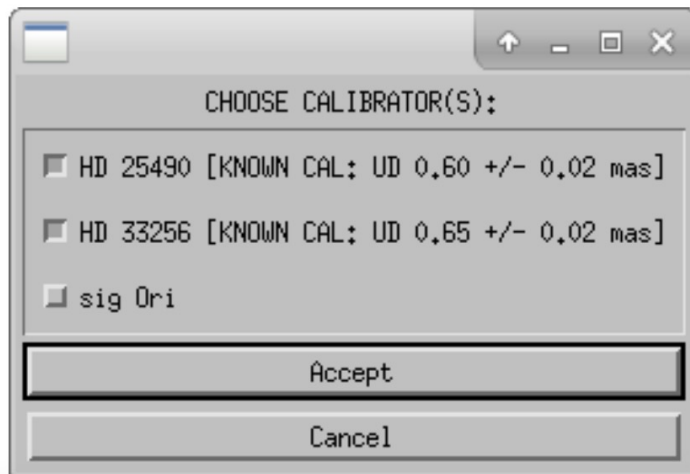
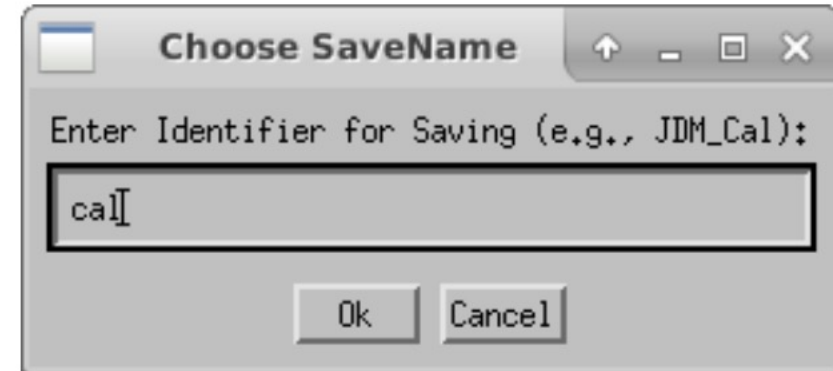
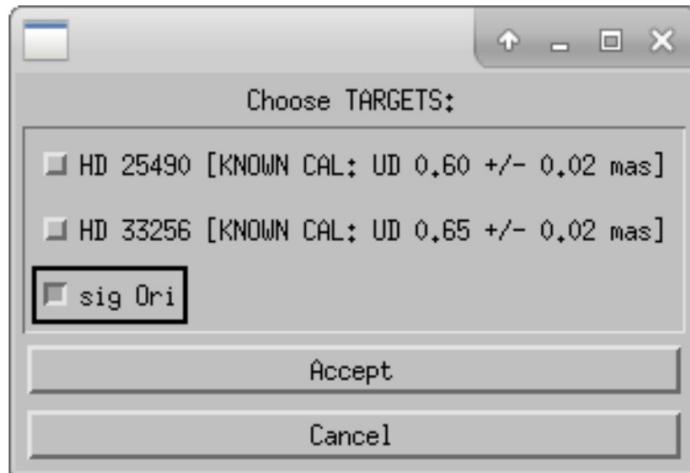


# Lists the targets Elevatin vs time





# Choose your targets and calibrators

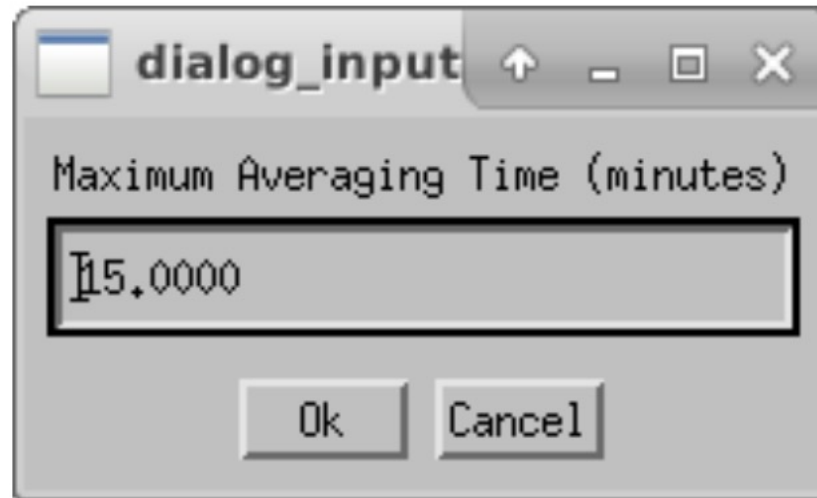


It automatically picks  
Calibrator UD sizes from  
catalogs

But you can insert if you have  
better calibrator sizes

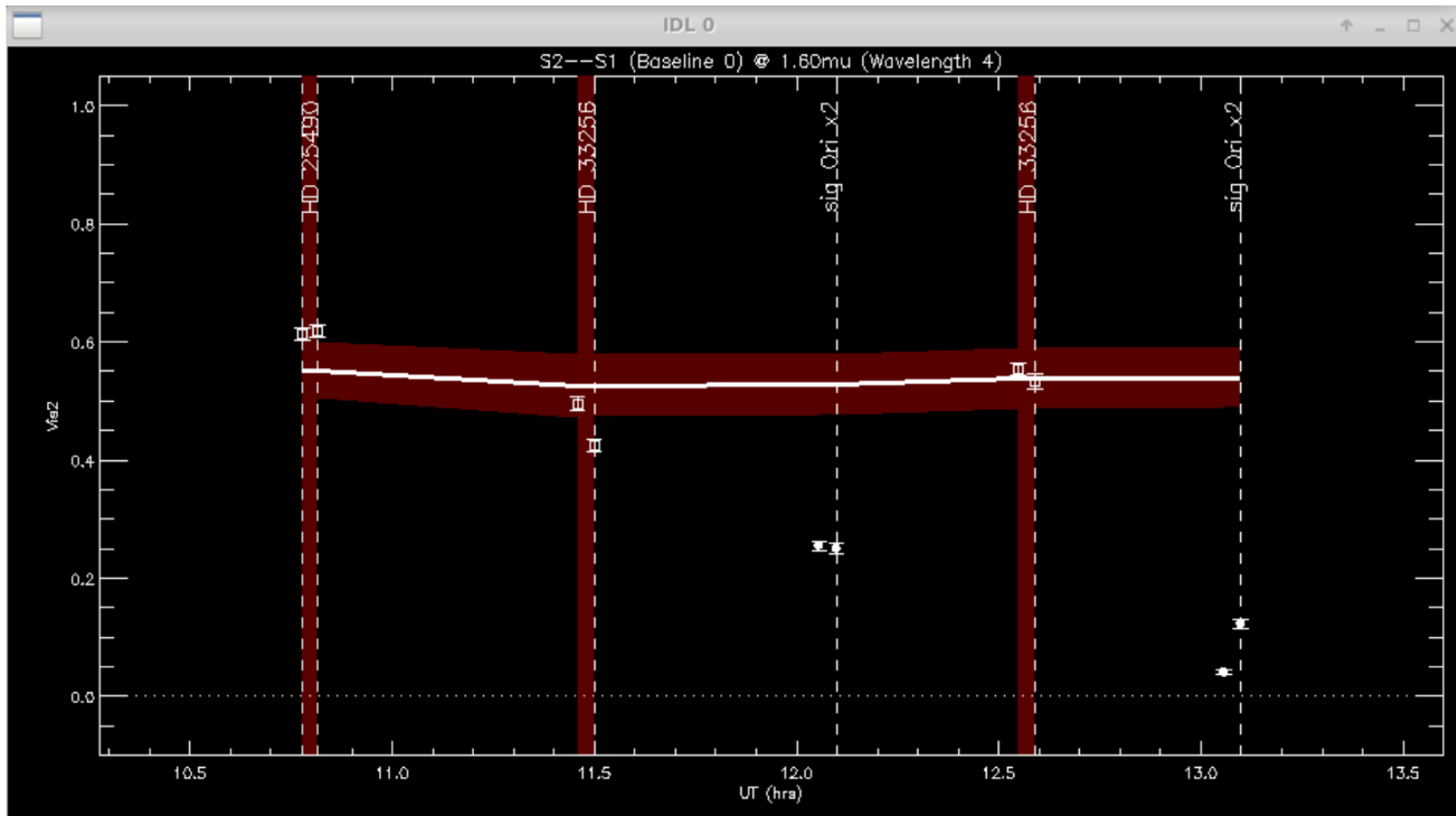


# Averaging of data





# We can filter the data



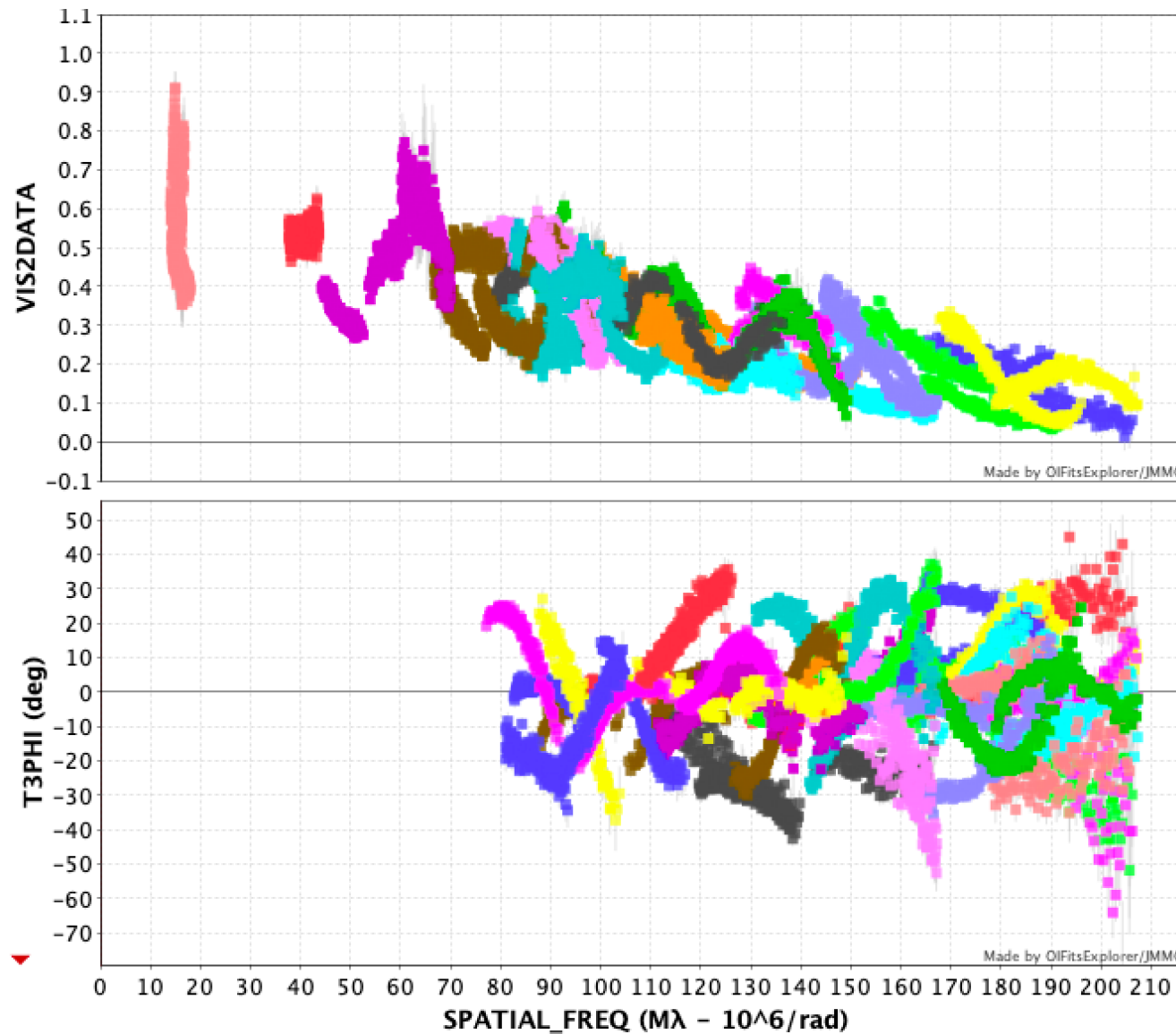
Pros:

Powerful to filter the data

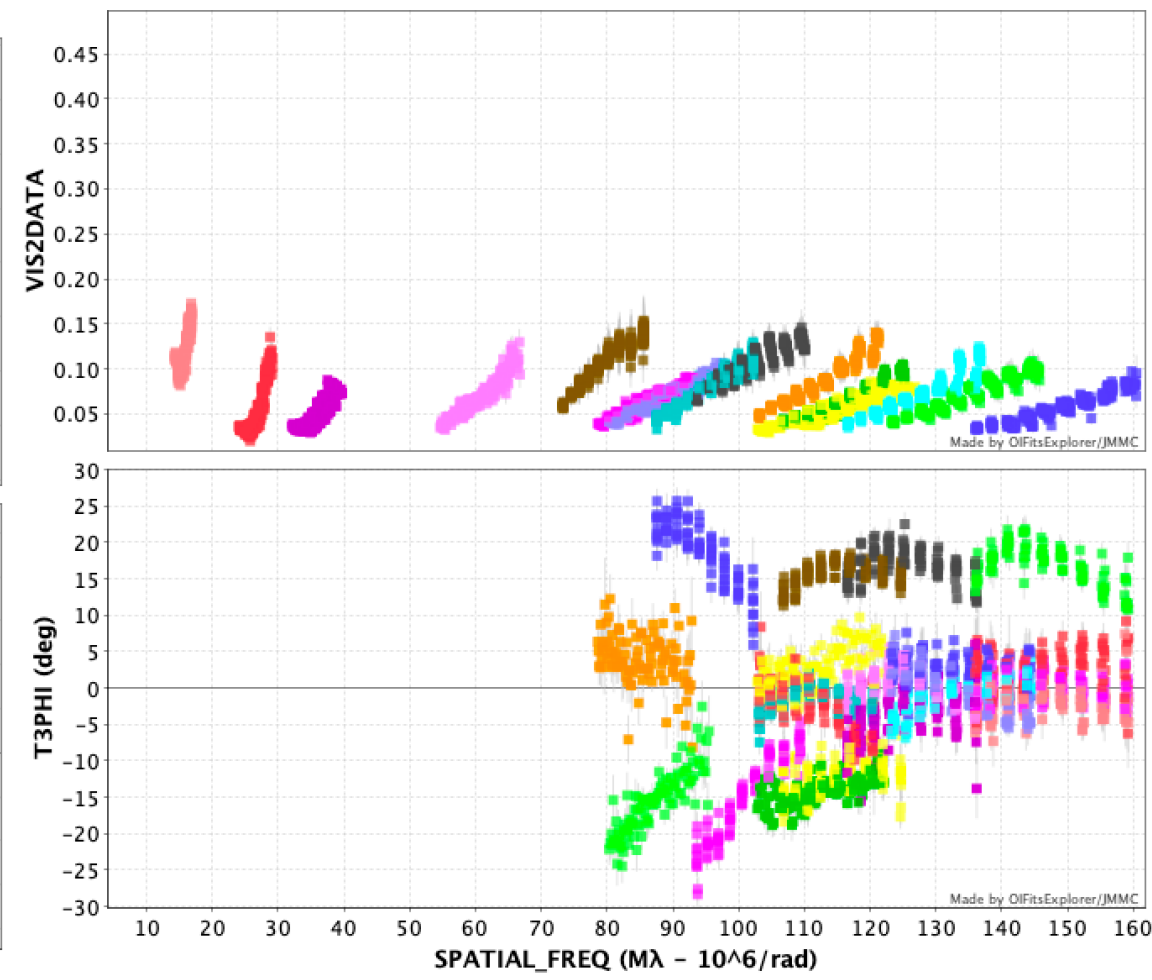
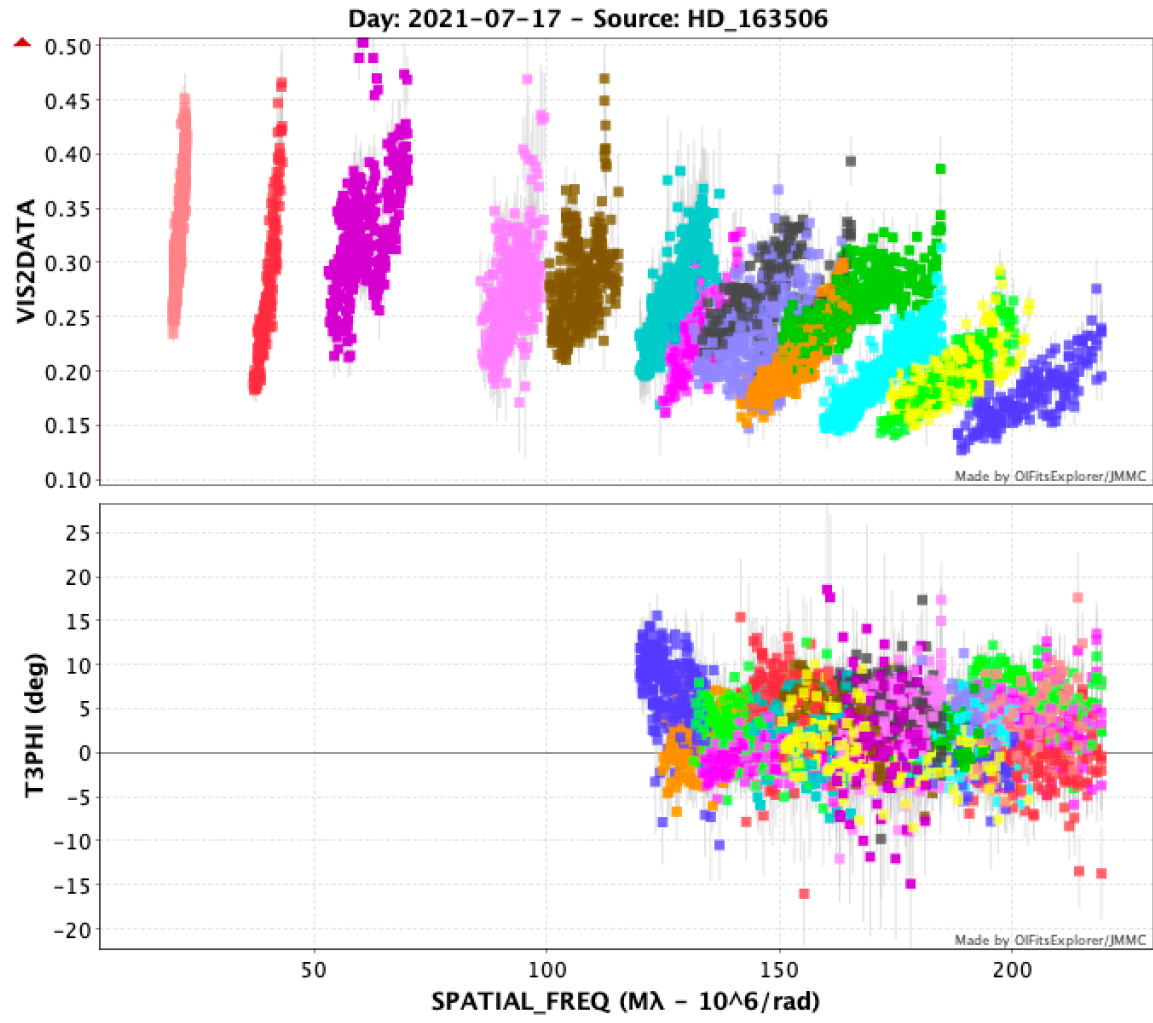
Cons:

Not repetitive as you cannot describe your filtering in the paper

# Calibrated OIFITS



# Calibrated OIFITS





# OIFITS format

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EXETER

Select FITS file extension - mircx03577\_oifits\_viscal.fits

Extension	Header	Type	Size	#1	#2	#3	#4	#5
PRIMARY	...	IMAGE	1 x 1	load				
1 OI_WAVELENGTH	...	BINARY TABLE	2 x 34	EFF_WAVE	EFF_BAND			
2 OI_TARGET	...	BINARY TABLE	17 x 1	TARGET_ID	TARGET	RAEPO	DECEPO	EQUINOX
3 OI_ARRAY	...	BINARY TABLE	7 x 6	TEL_NAME	STA_NAME	STA_INDEX	DIAMETER	STXYZ
4 OI_FLUX	...	BINARY TABLE	8 x 6	TARGET_ID	TIME	MJD	INT_TIME	FLUXDATA
5 OI_VIS2	...	BINARY TABLE	10 x 15	TARGET_ID	TIME	MJD	INT_TIME	VIS2DATA
6 OI_VIS	...	BINARY TABLE	12 x 15	TARGET_ID	TIME	MJD	INT_TIME	VISPHI
7 OI_T3	...	BINARY TABLE	14 x 20	TARGET_ID	TIME	MJD	INT_TIME	T3PHI

Exit      Read All