Observing and Data Reduction with MIRC-X

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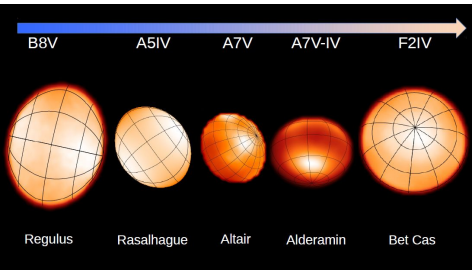
MIRC-X Overview

MIRC-X Overview

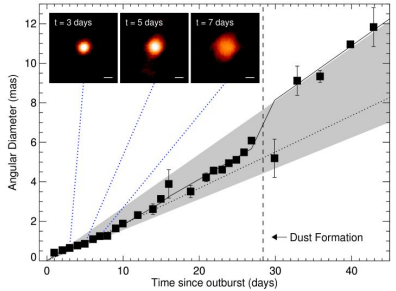
- Combines light from 6 telescopes of CHARA in J/H bands
  - 15 baselines simultaneously, up to 330m
  - Resolution: ~0.5 milli-arcseconds
  - Limitations: Can only observe objects with H < 7.5
- An upgrade of Michigan InfraRed Combiner (MIRC)
  - Monnier et al (2006; 2010)
  - Goals of upgrade: 1) Maximize sensitivity, 2) Extend wavelength coverage to J-band, 3) Enable polarization interferometry
- Observing modes currently offered:
  - H-band PRISM (R~22, 50, or 102)
  - H-band GRISM (R~190)
  - J-band, polarization modes to come
- MIRC-X is explained in detail in upcoming paper by Anugu et al (submitted)

MIRC-X Science Programs

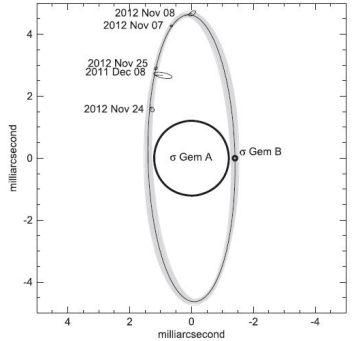
- A wide variety of science interests currently underway with MIRC-X:
  - Stellar diameters
  - Imaging!
    - Rapid rotators, RS CVn, RSG, YSOs, novae
  - Binary stars → orbits, multiplicity surveys, planet searches with precision astrometry
  - Be Stars



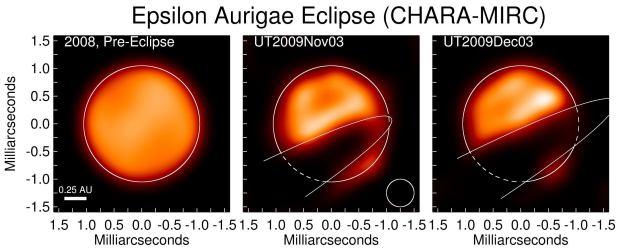
Monnier+2007, Zhao+2009, Che+2011



Schaefer+2016



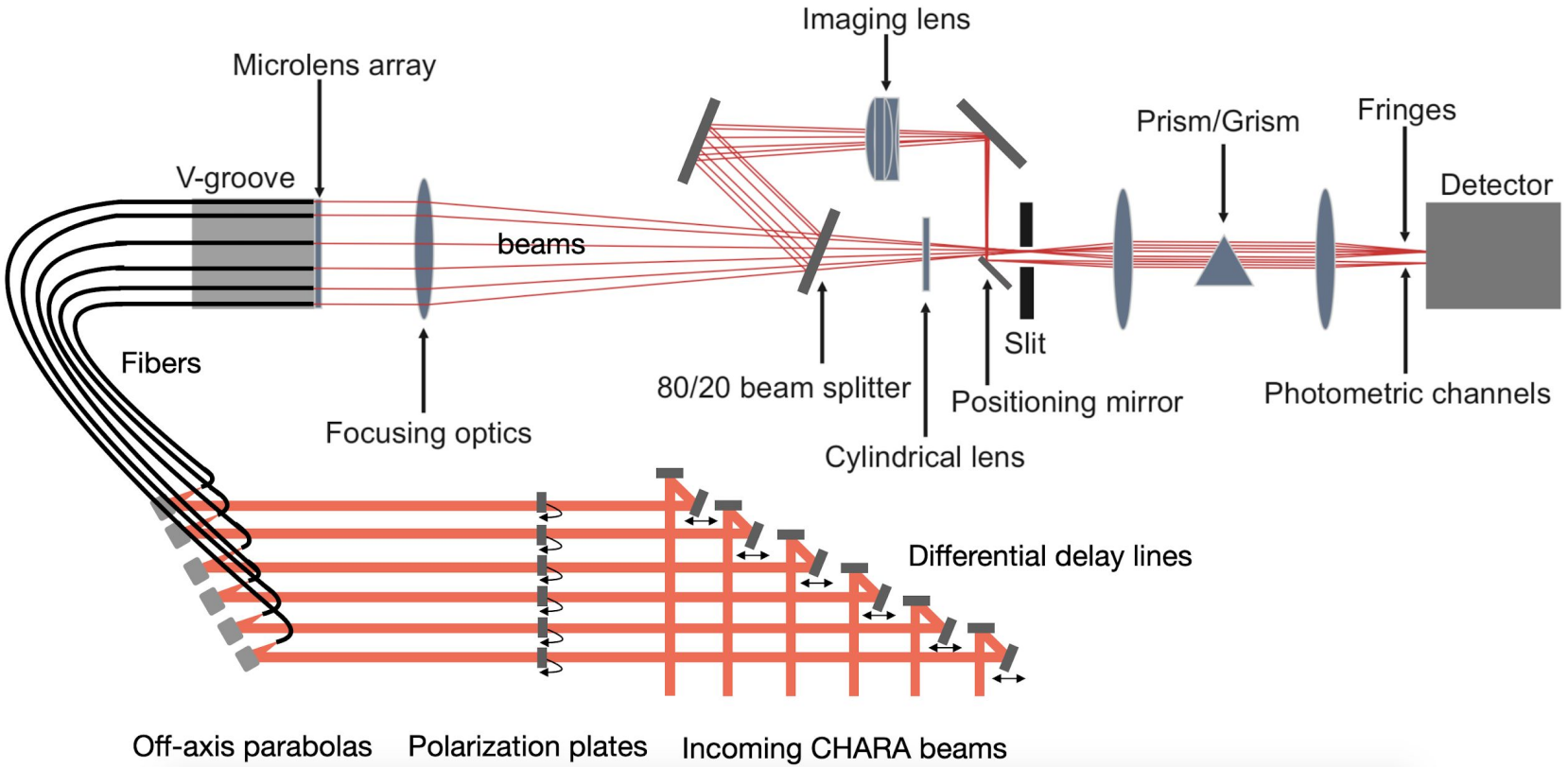
Roettenbacher+15



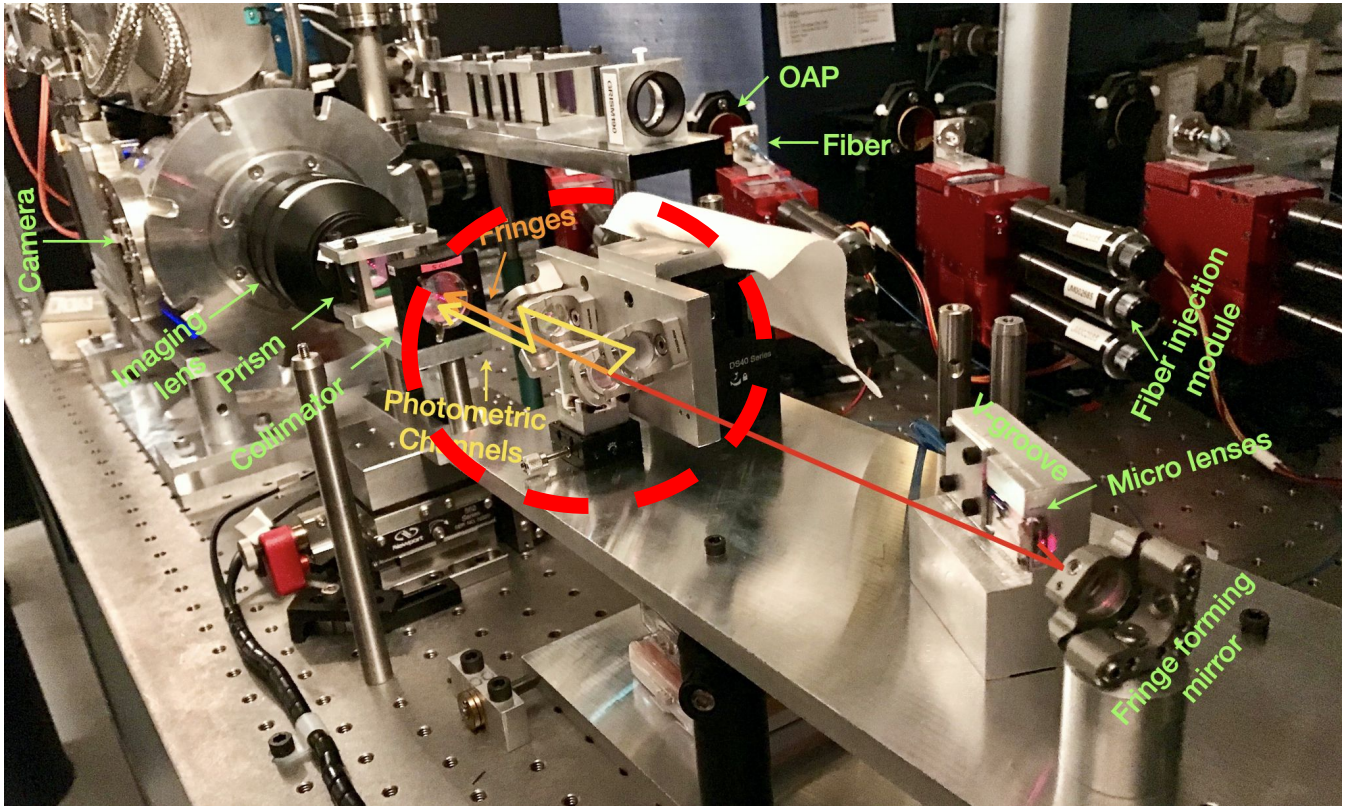
Kloppenborg+2010

MIRC-X Instrument

MIRC-X Instrument



MIRC-X Instrument



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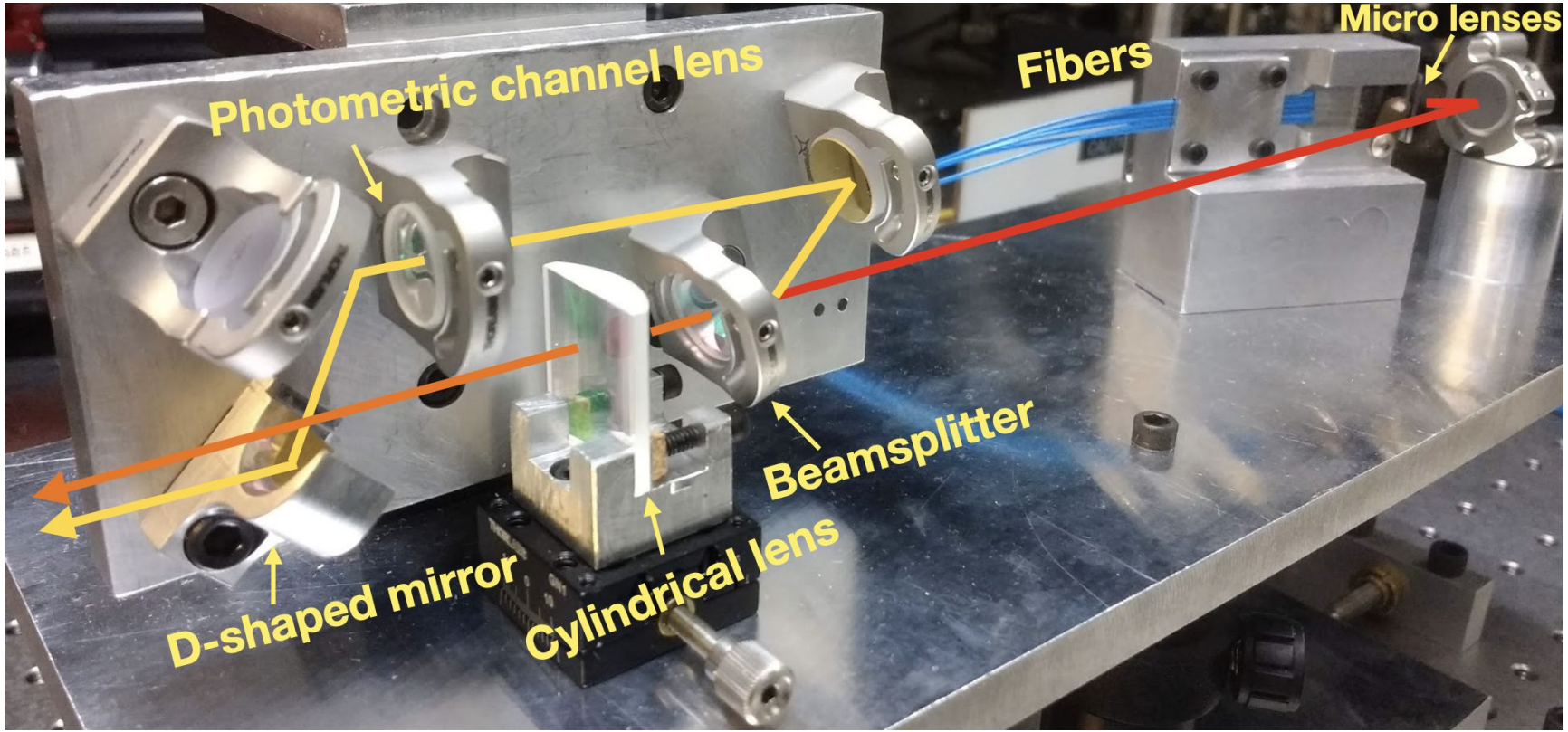


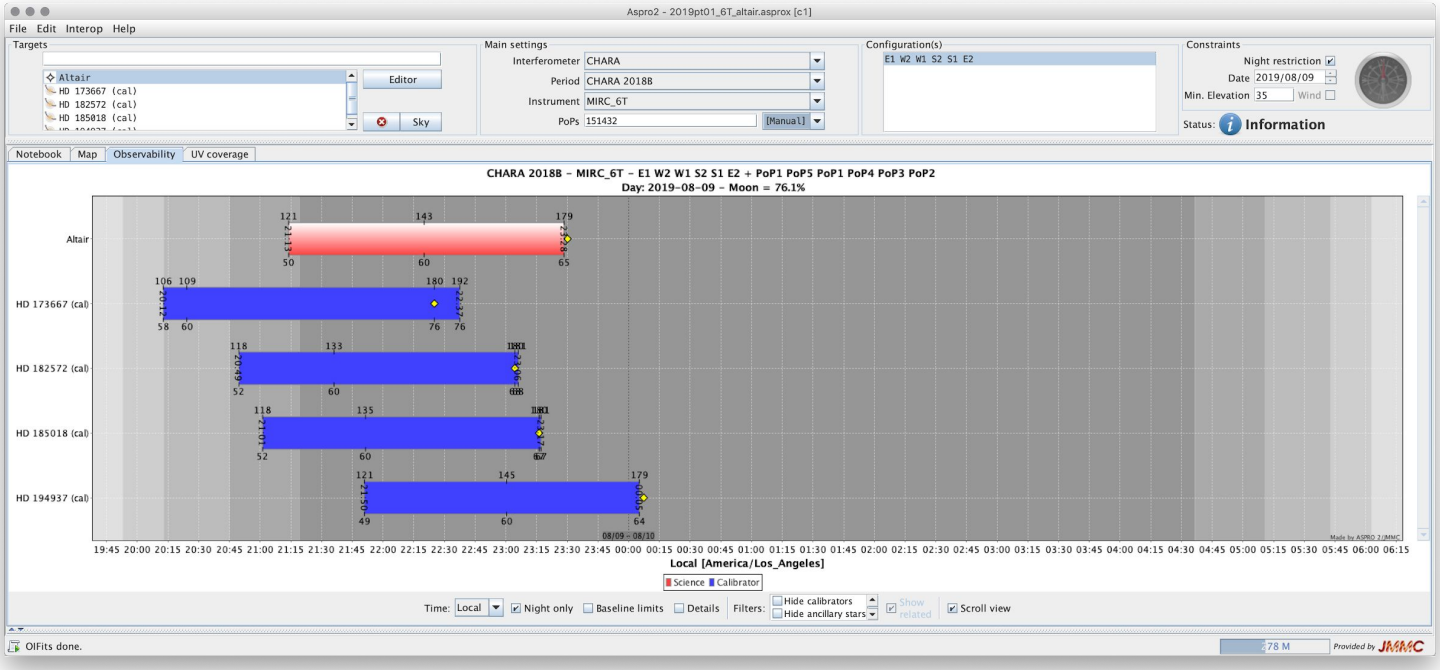
Planning Observations

Planning Observations

- MIRC-X is a slow cadence beam combiner
  - Observations on a single object take 20 minutes at the bare minimum for recording data
- Calibrator selection
  - Make sure your calibrators are ~30 min to an hour before your target is in delay
  - Within the same mag range as your object (exception: very bright targets)
- Typical Observing sequence
  - Cal1-Obj-Cal2
- MIRC-X designated beam order (as of 2018)
  - E1-W2-W1-S2-S1-E2

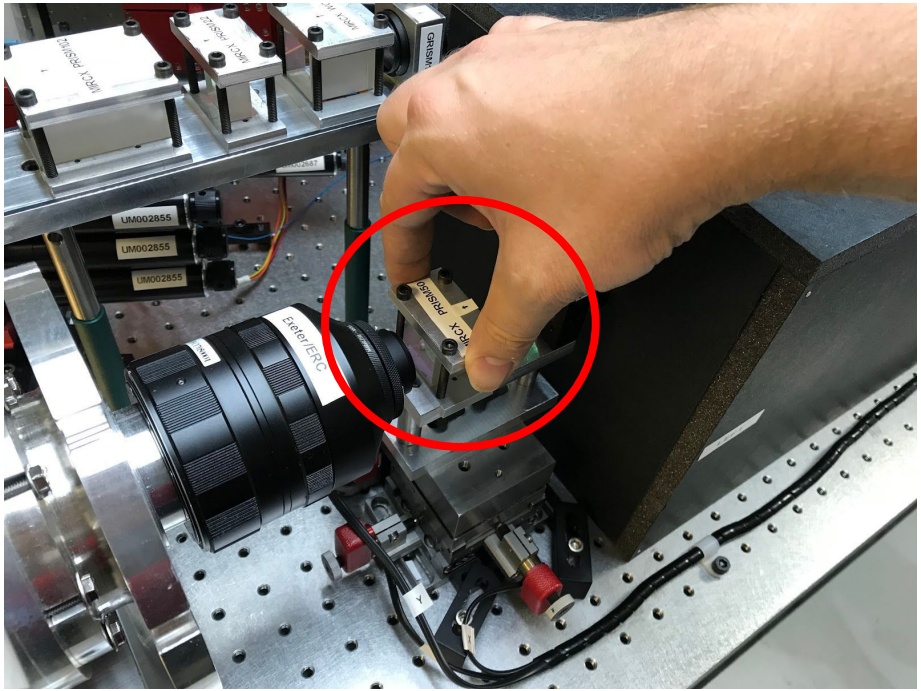
Planning Observations

- Aspro2 & searchcal



Planning Observations

- Various modes for MIRC-X
  - PRISM 50 (default mode)
  - GRISM 190
- Polarization coming soon…
- J-band mode coming soon…
- Future plans with MYSTIC (K-band)



Observing with MIRC-X

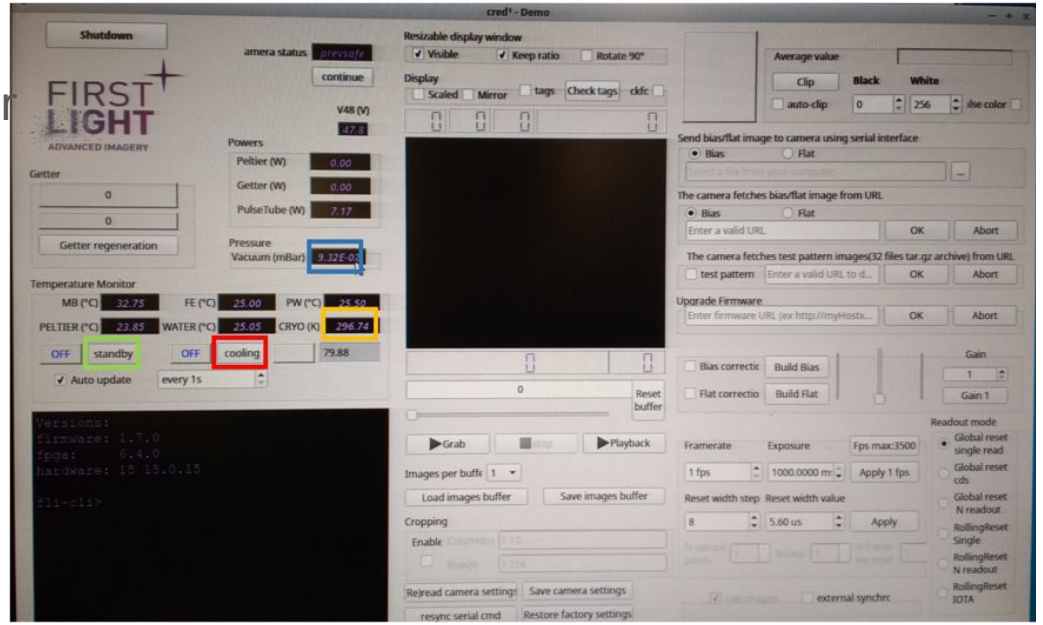
Standard Observing Sequence

1. Acquire star at the telescopes
2. Perform a fiber explorer map to align light into the fibers
3. 10 minutes of DATA, with all shutters open and fringes tracked
4. 1 minute of BACKGROUND with all shutters closed
5. 1 minute of each beam where the shutter of only one of the six beams is open sequentially
6. 3 minutes of FOREGROUND frames where all shutters are open but the optical path is set to a large value to ensure that no fringes are present in the data set

Taken from Anugu et al (submitted)

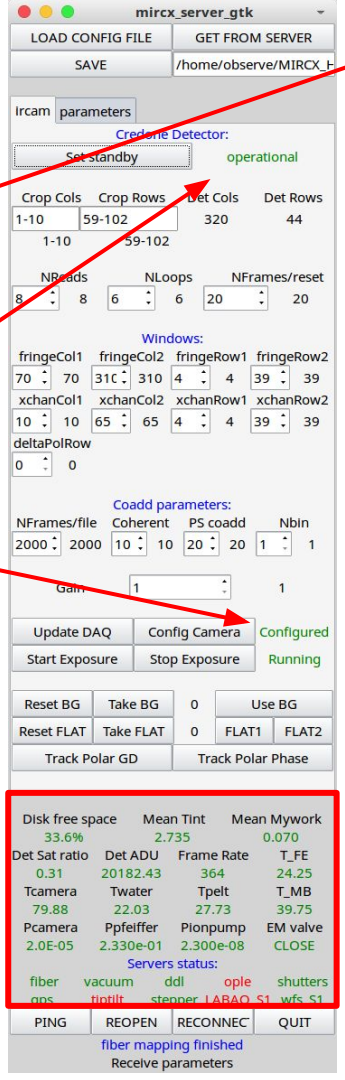
Startup & C-RED-ONE GUI

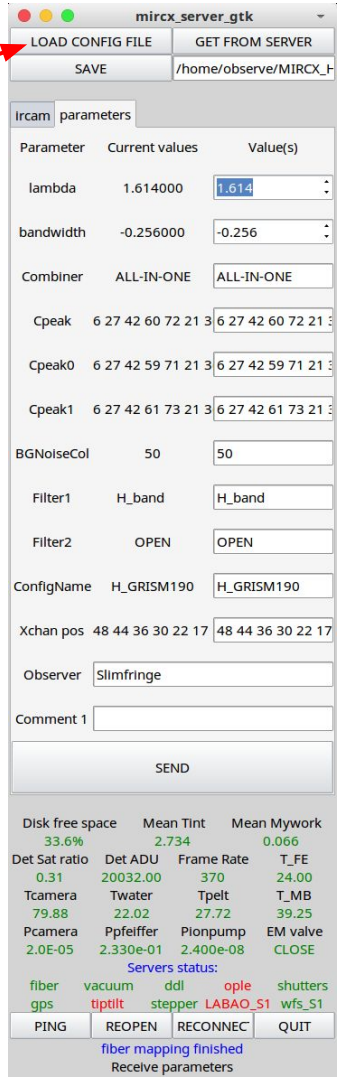
- User manual for MIRC-X observing on CHARA wiki
- Always start servers before opening any GUIs
- C-RED-ONE GUI used to monitor camera but not used throughout the night



MIRC-X server GUI

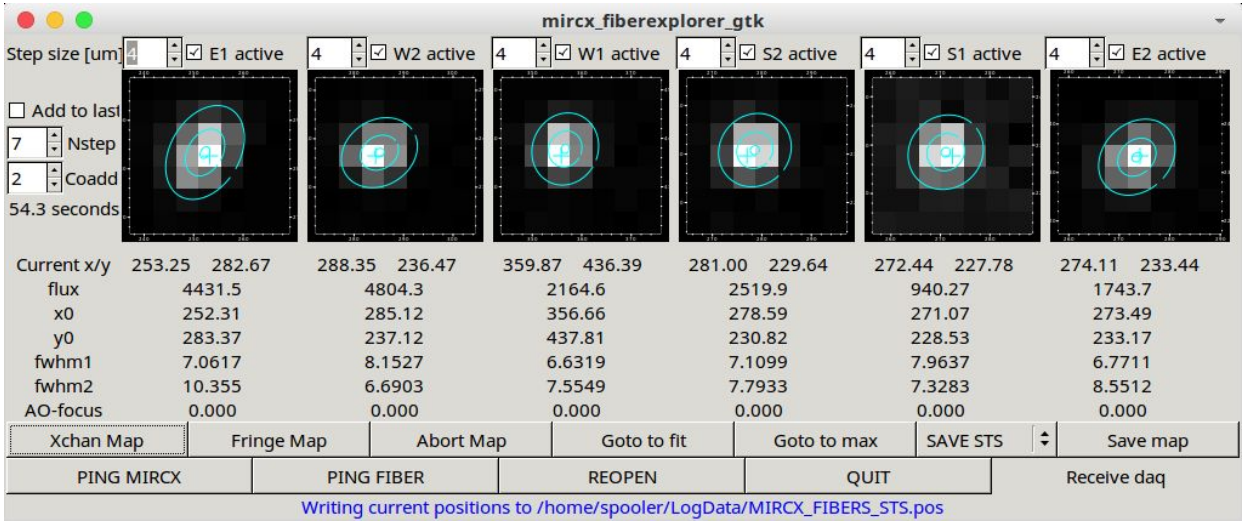
- Load in parameters for mode and send
- Now you can start operations and send your parameters to the camera
- Monitor this GUI throughout the night to make sure settings are fine!





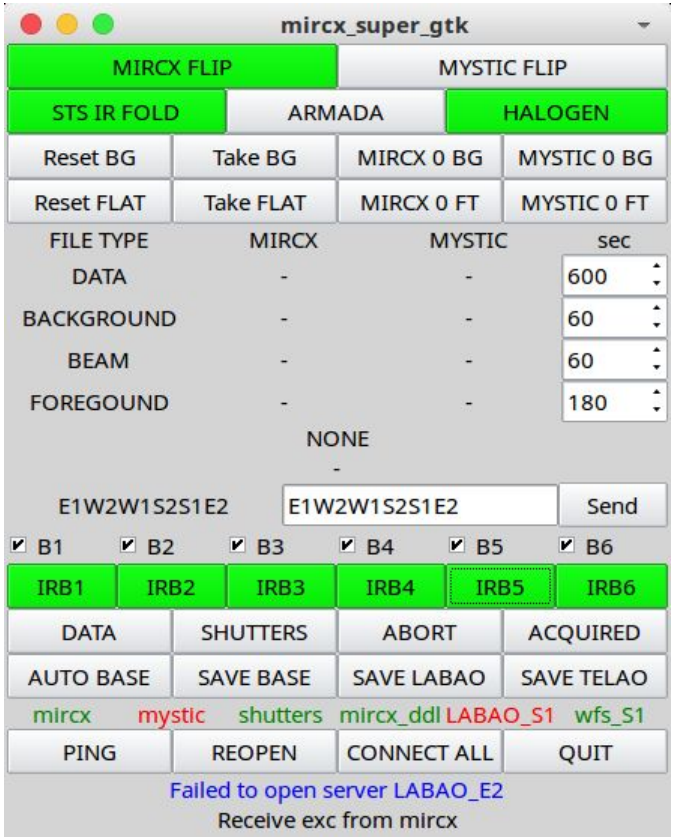
MIRC-X fiber explorer GUI

- Use this to make sure that you are getting light in the fibers
  - Can adjust Step size, Nstep, and Coadd throughout the night
- Good seeing: Beams are compact & produces nice 2D gaussian profiles
- Bad seeing: Light from beams are spread out



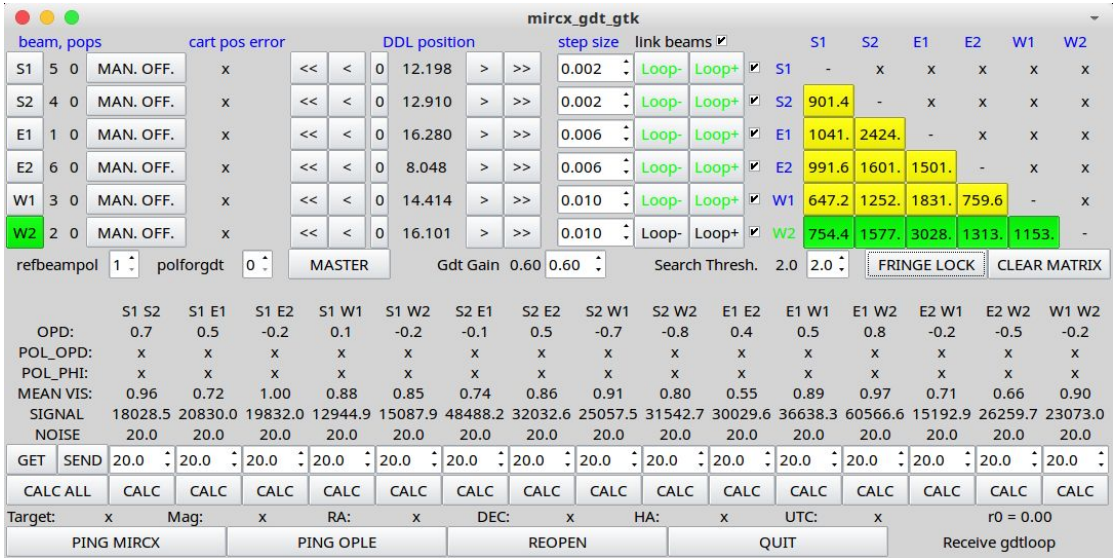
MIRC-X super gtk GUI

- Can reset/take backgrounds
- Can reset/take flats (for bright objects to avoid issues with cross-talk)
- Use this to record data



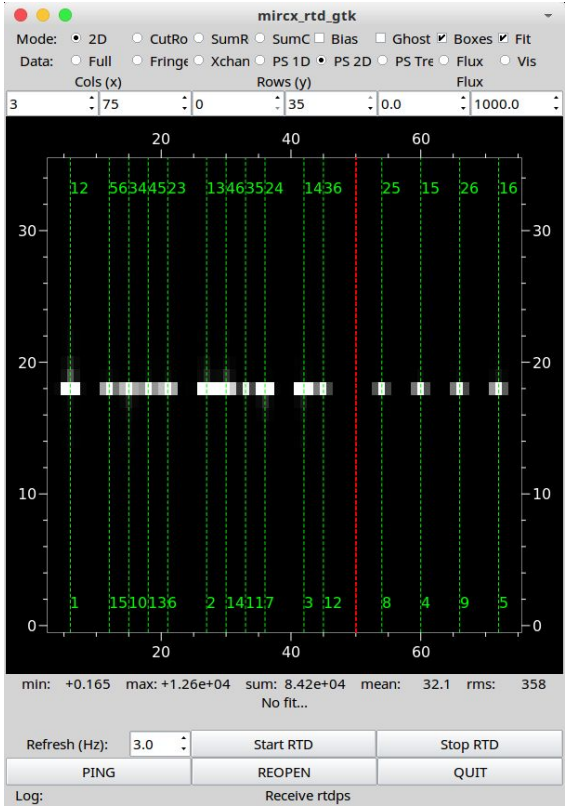
MIRC-X GDT GUI

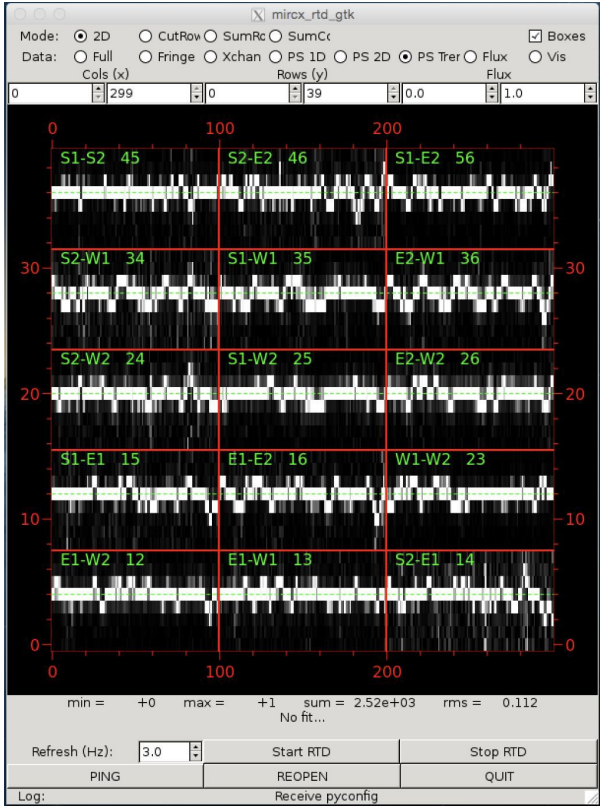
- This GUI lets you control offsets between carts
- When the fringe is found, fringe lights up “yellow”; locking on a fringe will turn the fringes “green”
- You have the option to “track” on a fringe
- You can lock on cross-fringes but ultimately want to lock with ref cart



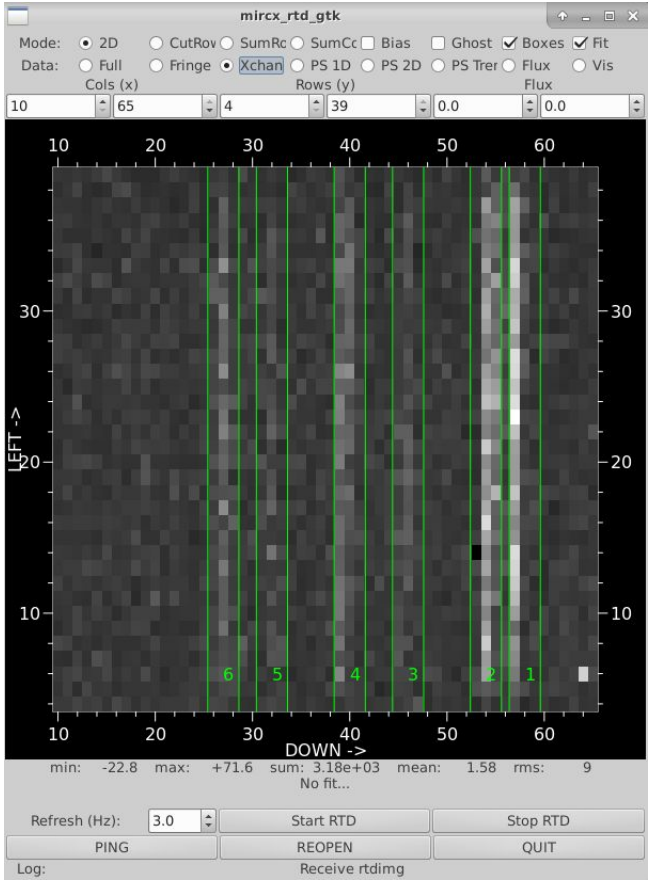
MIRC-X RTD GUI

- Using this GUI allows you to find fringes in “waterfall plot”
- Many different type of plots to help with observations

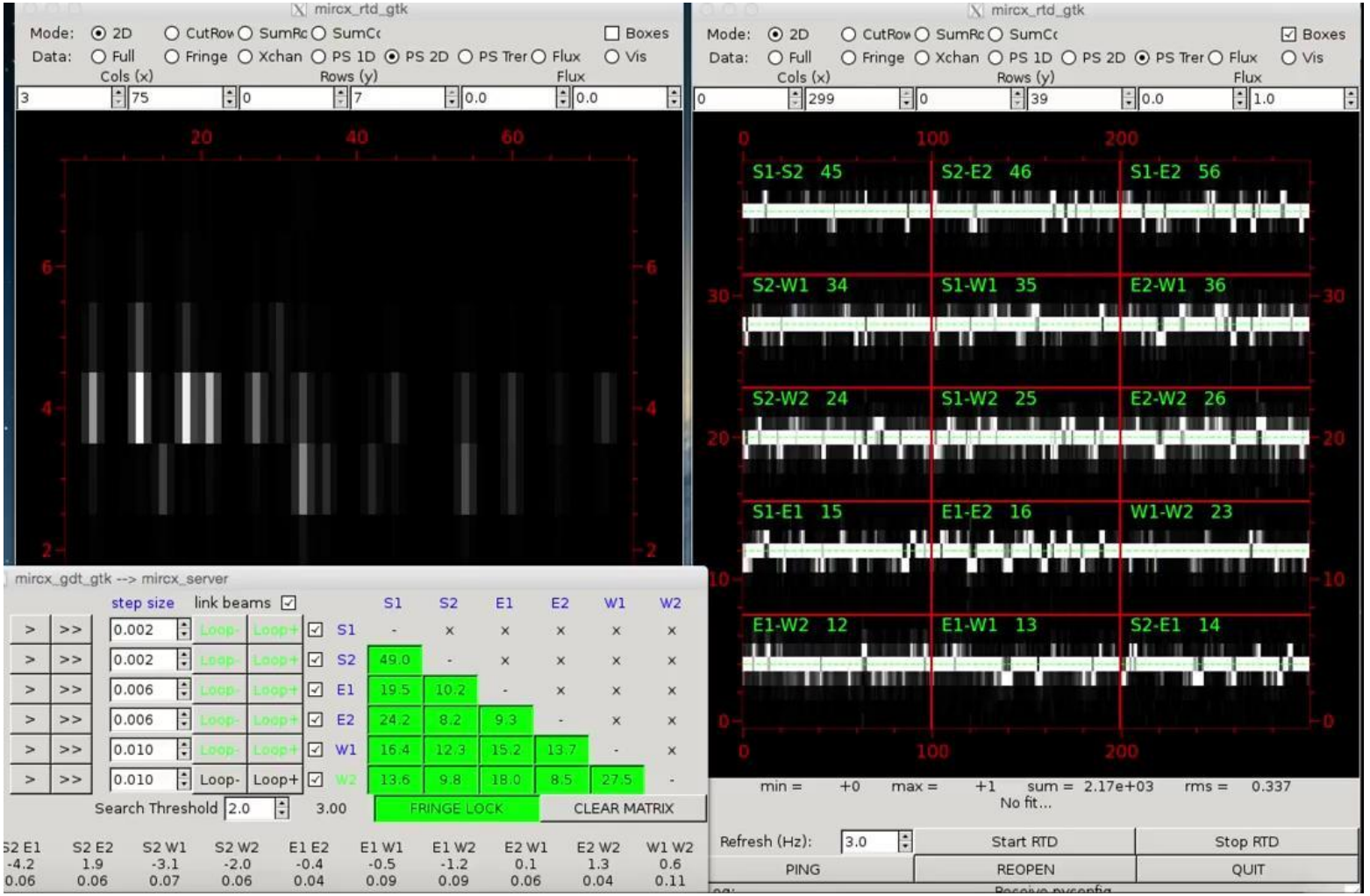




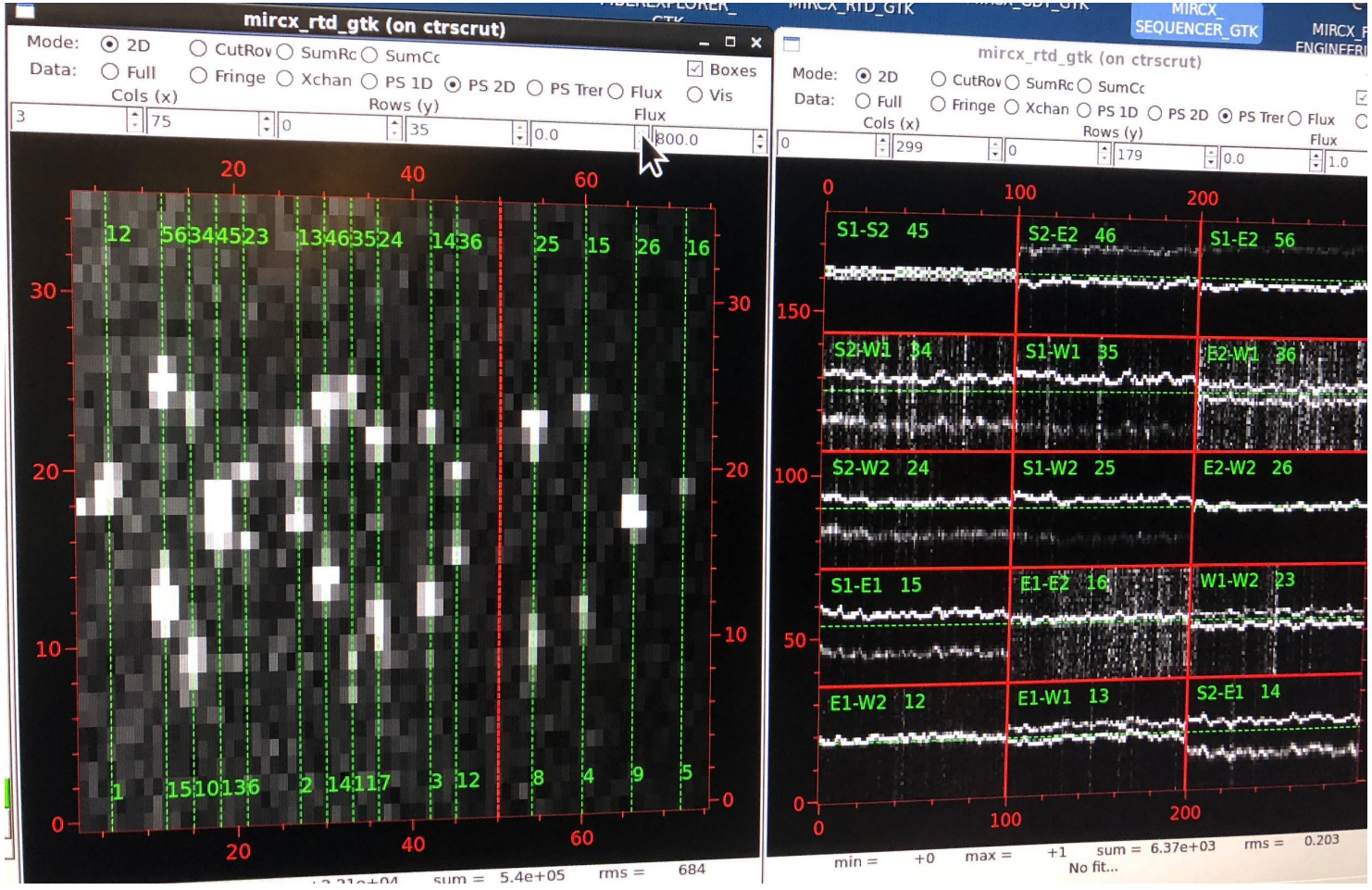
Fiber Mapping → Make sure flux injected into MIRCX



Add a on-sky map here
(maybe move up this slide in
presentation?)


mircx_rtd_gtk
Mode: 2D CutRow SumRc SumCc Boxes
Data: Full Fringe Xchan PS 1D PS 2D PS Trer Flux Vis
Cols (x) Rows (y) Flux
3 75 0 7 0.0 0.0
20 40 60
6 4 2
mircx_rtd_gtk
Mode: 2D CutRow SumRc SumCc Boxes
Data: Full Fringe Xchan PS 1D PS 2D PS Trer Flux Vis
Cols (x) Rows (y) Flux
0 299 0 39 0.0 1.0
0 100 200
S1-S2 45
S2-E2 46
S1-E2 56
S2-W1 34
S1-W1 35
E2-W1 36
S2-W2 24
S1-W2 25
E2-W2 26
S1-E1 15
E1-E2 16
W1-W2 23
E1-W2 12
E1-W1 13
S2-E1 14
30 20 10 0
mircx_gdt_gtk --> mircx_server
step size link beams
S1 S2 E1 E2 W1 W2
0.002 0.002 0.006 0.006 0.010 0.010
Loop- Loop+
49.0
19.5 10.2
24.2 8.2 9.3
16.4 12.3 15.2 13.7
13.6 9.8 18.0 8.5 27.5
Search Threshold 2.0 3.00
FRINGE LOCK
CLEAR MATRIX
S2 E1 S2 E2 S2 W1 S2 W2 E1 E2 E1 W1 E1 W2 E2 W1 E2 W2 W1 W2
-4.2 1.9 -3.1 -2.0 -0.4 -0.5 -1.2 0.1 1.3 0.6
0.06 0.06 0.07 0.06 0.04 0.09 0.09 0.06 0.04 0.11
min = +0 max = +1 sum = 2.17e+03 rms = 0.337
No fit...
Refresh (Hz): 3.0
Start RTD
Stop RTD
PING
REOPEN
QUIT

A binary star in GRISM mode:



Six Telescope Simulator (STS)

- Internal light source for checking MIRCX performance, switching modes, testing
- Used each night before observations
- Installed in May 2019

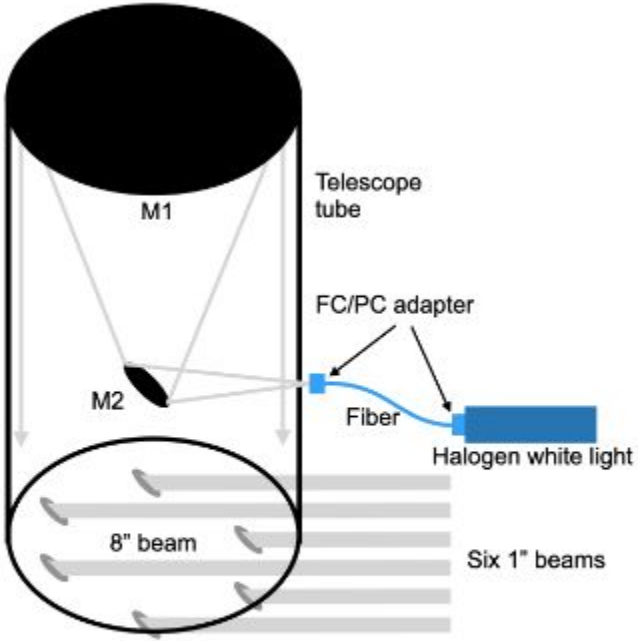
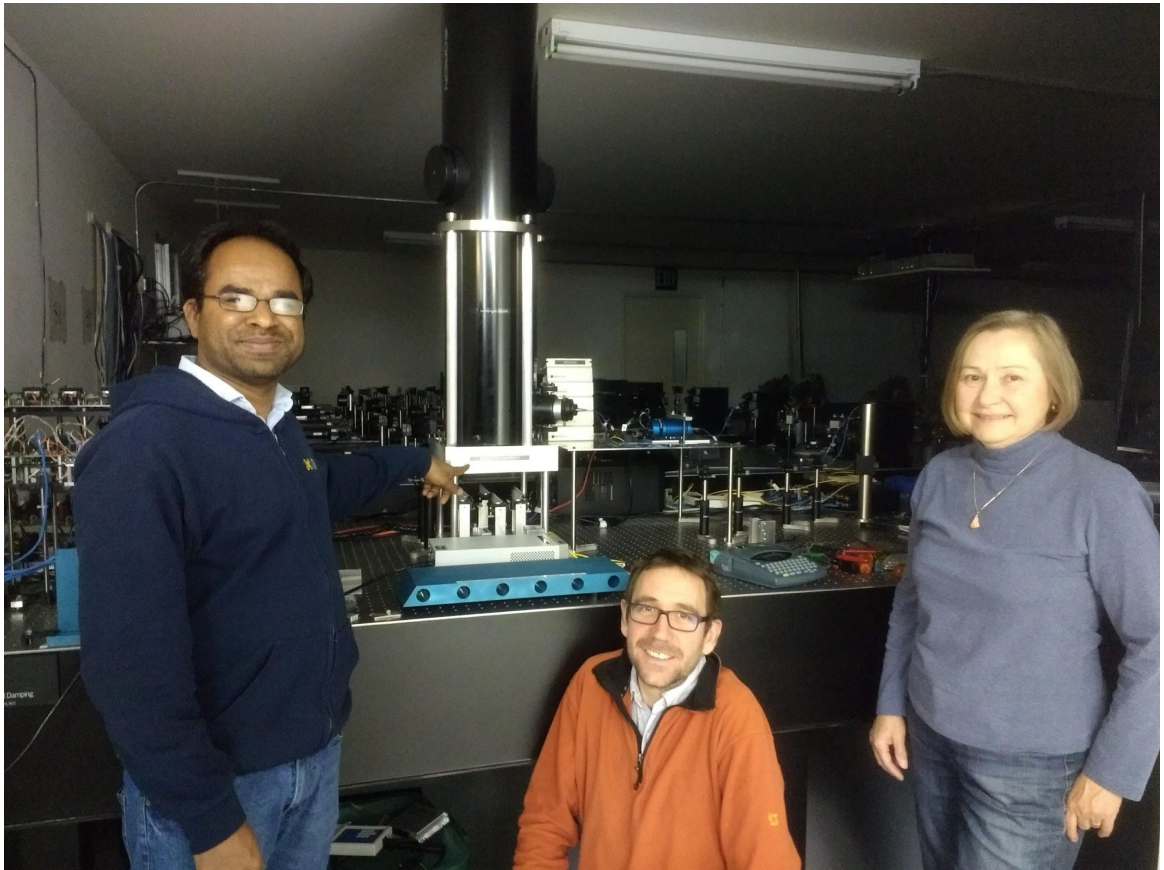
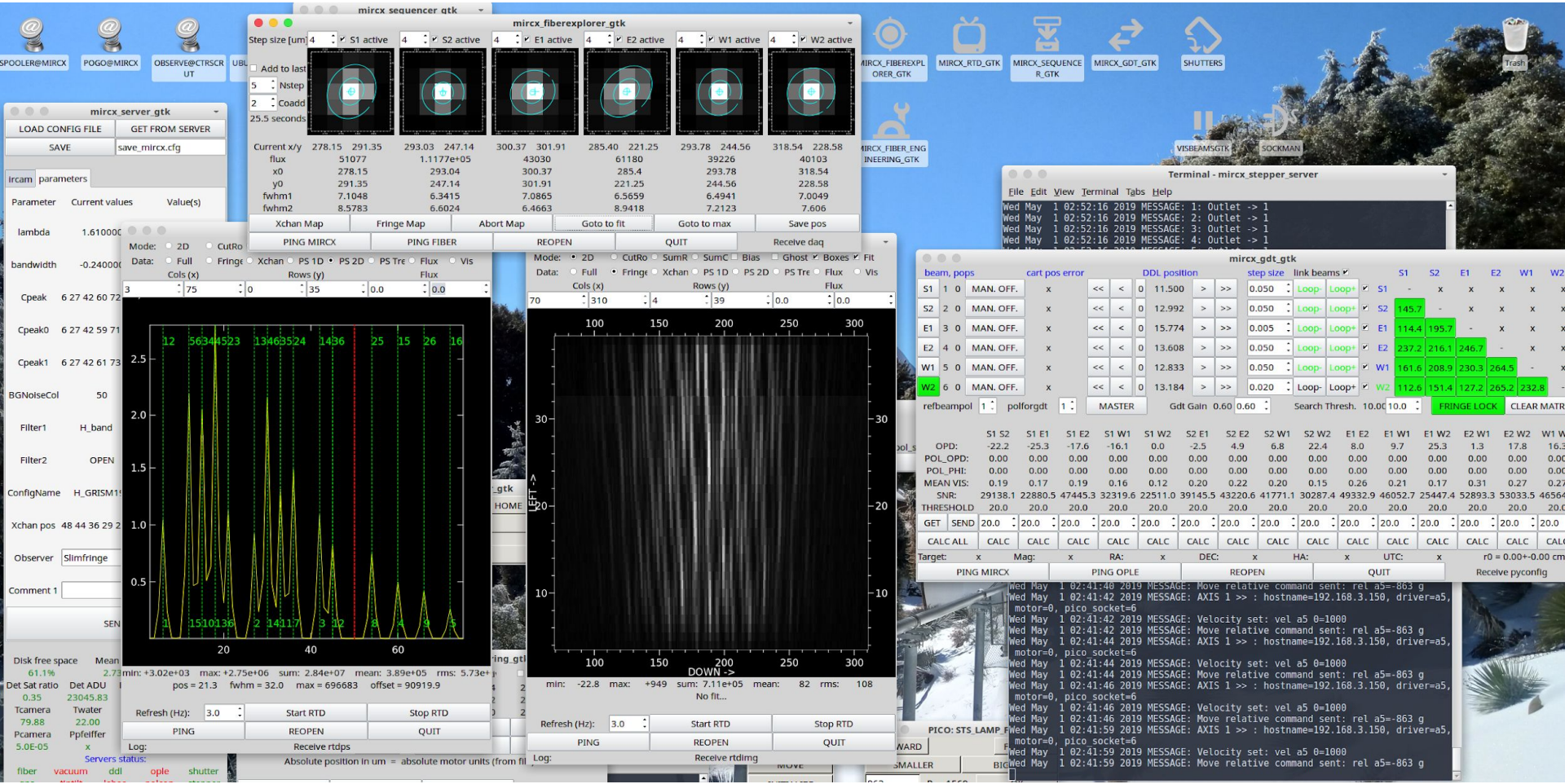


Figure 9. Layout of the six telescope simulator (STS, not to scale). Six coherent beams are extracted from an 8-inch collimated beam created by a Classical Dobsonian telescope acting in reverse. The telescope eyepiece is fed by a single-mode fiber, which is injected light from a halogen lamp.



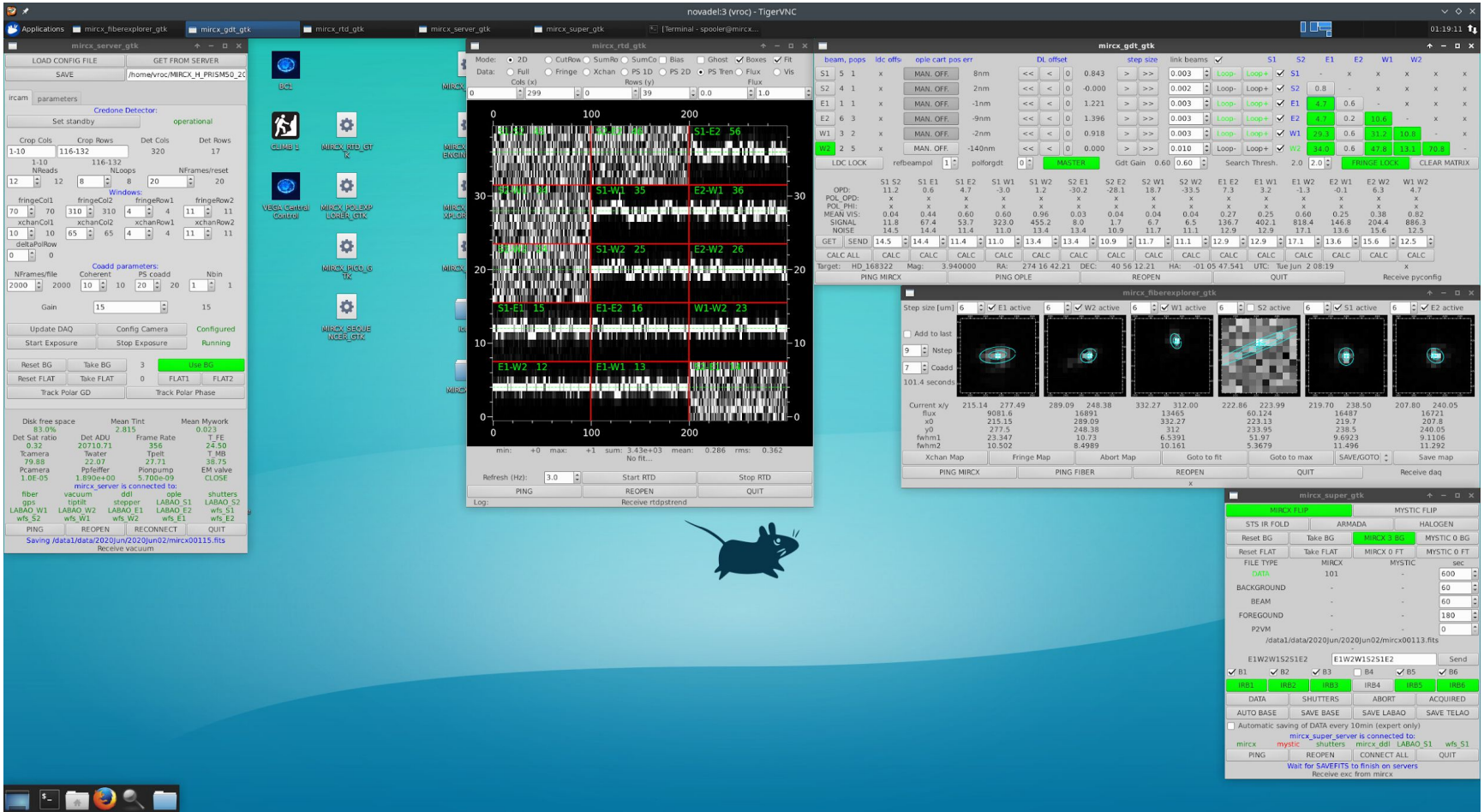
Anugu et al (submitted)

Six Telescope Simulator (STS)



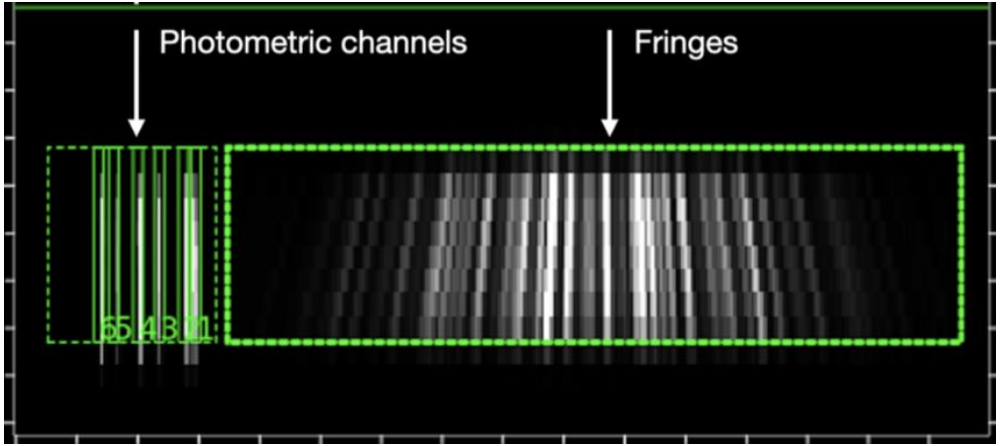
Remote Observing

- VNC connection through machine in Atlanta
- Most MIRC-X runs are done remotely now



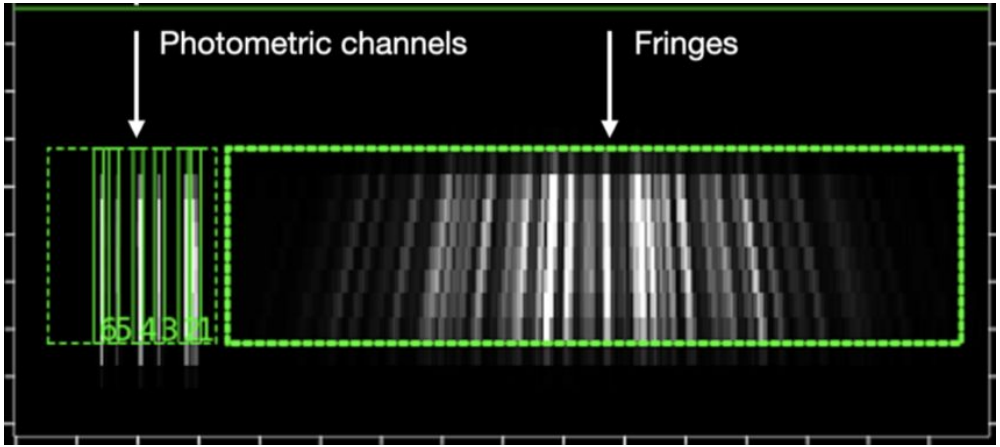
MIRC-X Data Reduction

What we measure at the detector:



(stored in FITS files)

What we measure at the detector:



(stored in FITS files)

Data Pipeline

Interferometric Observables for Imaging / Modeling:

15 baselines

- Squared Visibilities
- “Differential” Phase

20 triangles

- Closure Phase

(OIFITS files)

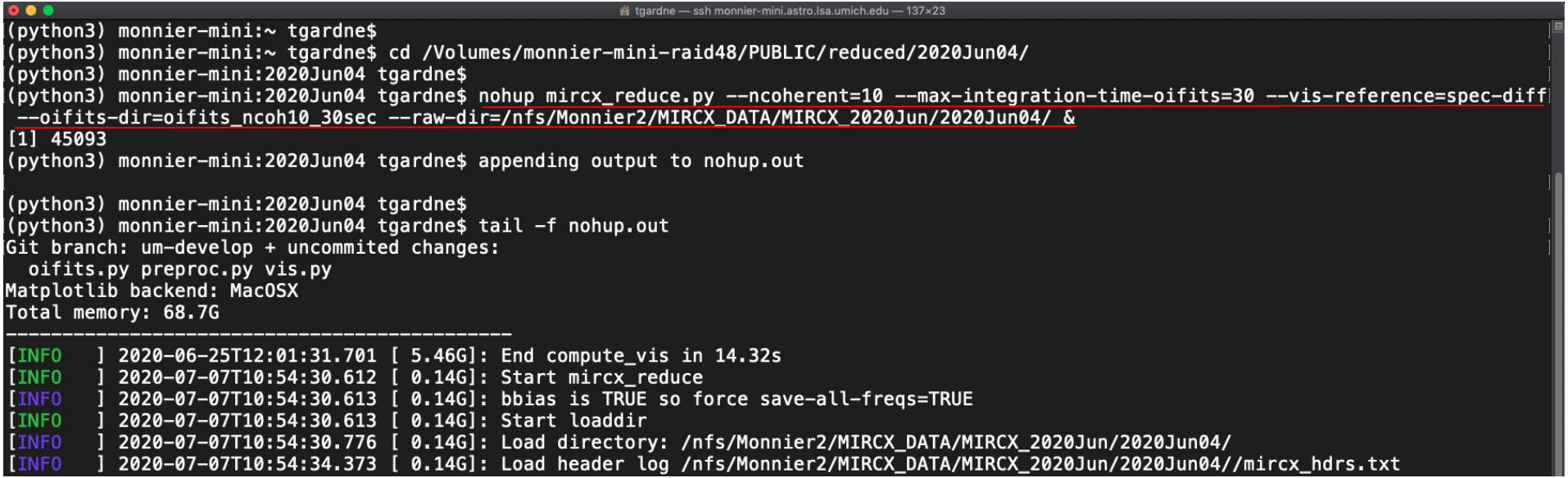
MIRC-X Data Reduction Pipeline - Overview

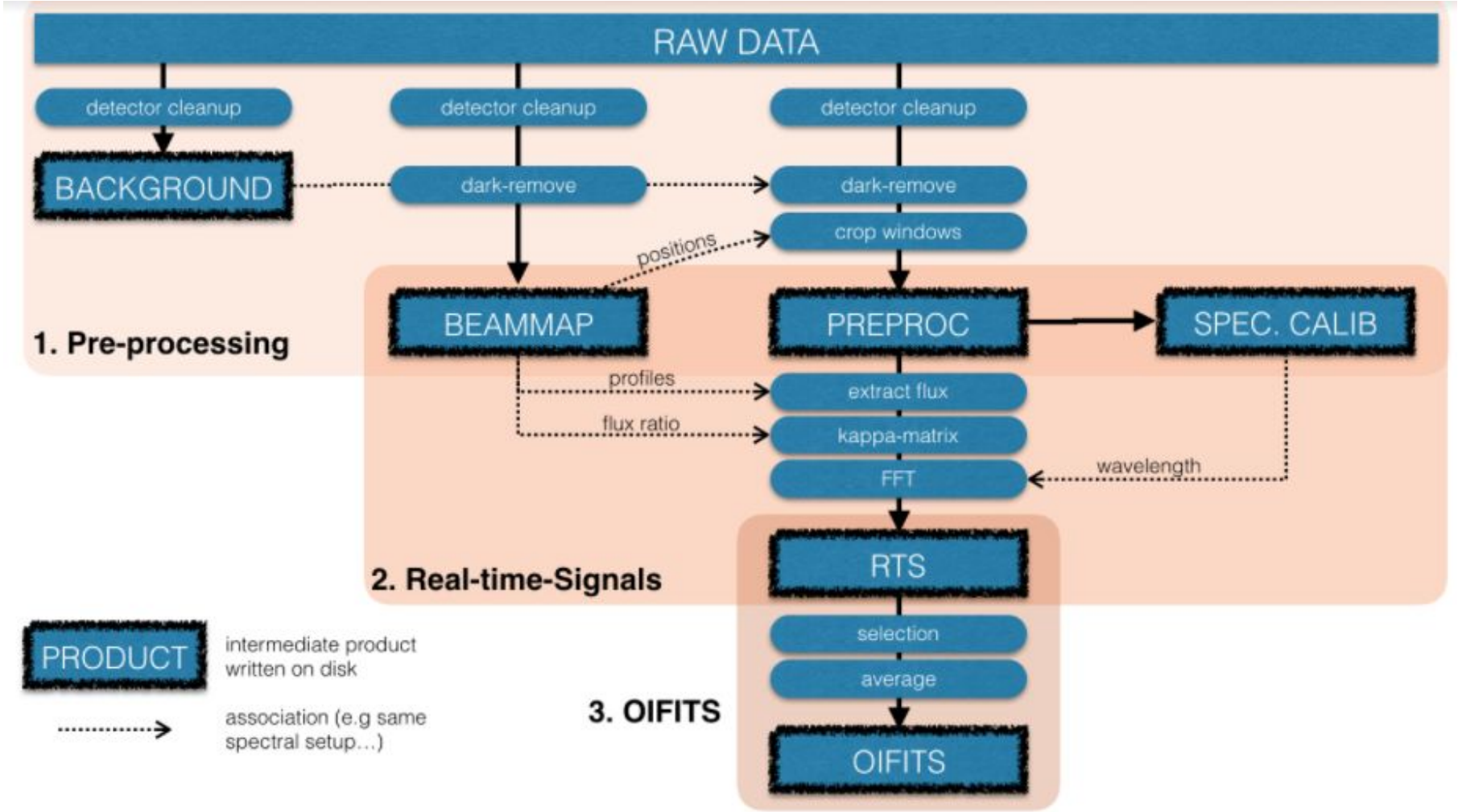
- Raw FITS files of night → Calibrated OIFITS files for imaging/modeling
- Written by Jean-Baptiste Le Bouquin
  - Python 3.7
  - Maintained on git repository: https://gitlab.chara.gsu.edu/lebouquj/mircx_pipeline
- Pipeline divided into 3 steps:
  - Pre-processed files (PREPROC)
  - Real Time Signal (RTS)
  - Raw and calibrated OIFITS

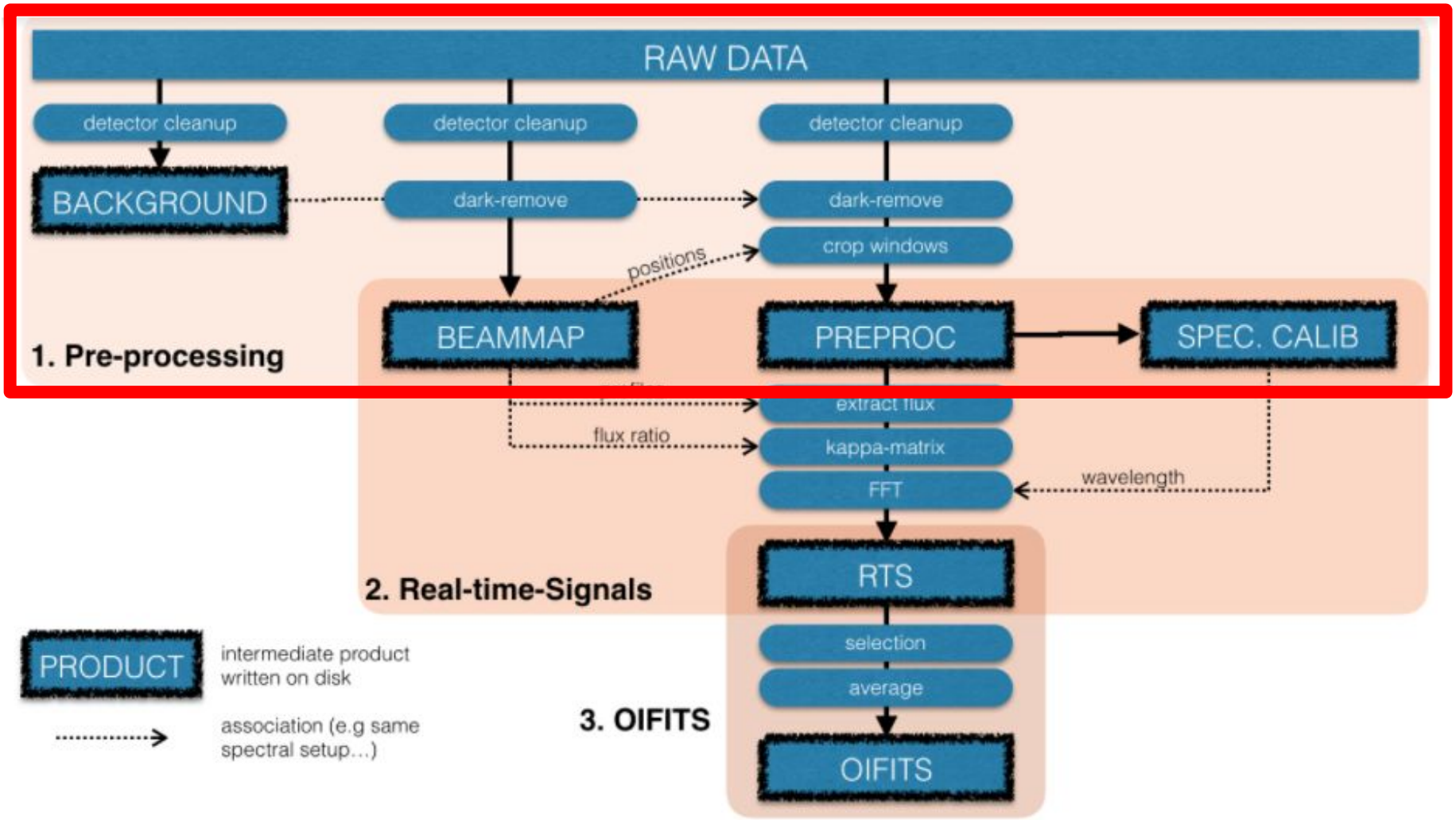
- *MIRC-X and its data reduction pipeline are detailed in an upcoming paper*
  - *Anugu et al, 2020 (submitted)*

How to Run the MIRC-X Pipeline

- Run via command line in terminal, designed to be automated
- Many different user input options / modes




RAW DATA
detector cleanup
detector cleanup
detector cleanup
BACKGROUND
dark-remove
dark-remove
crop windows
positions
BEAMMAP
PREPROC
SPEC. CALIB
1. Pre-processing
profiles
flux ratio
extract flux
kappa-matrix
FFT
wavelength
2. Real-time-Signals
RTS
selection
average
3. OIFITS
OIFITS
PRODUCT
intermediate product written on disk
association (e.g same spectral setup…)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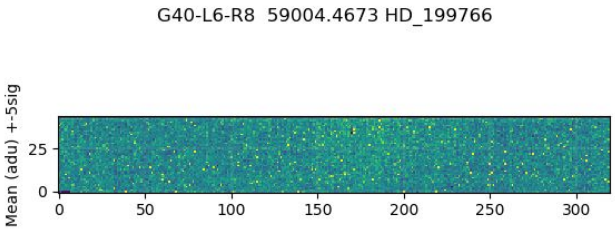
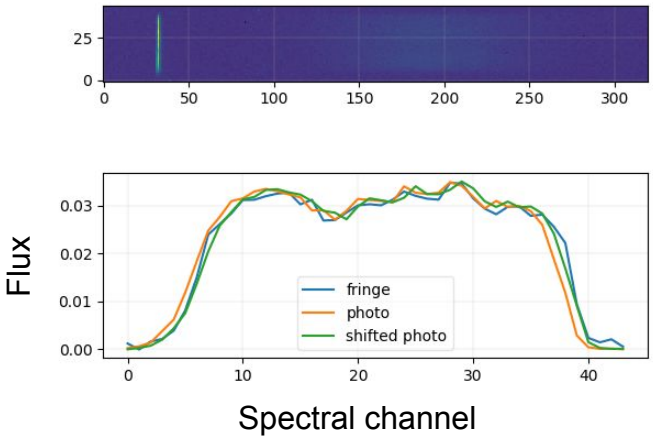
1) Pre-Processing Step

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

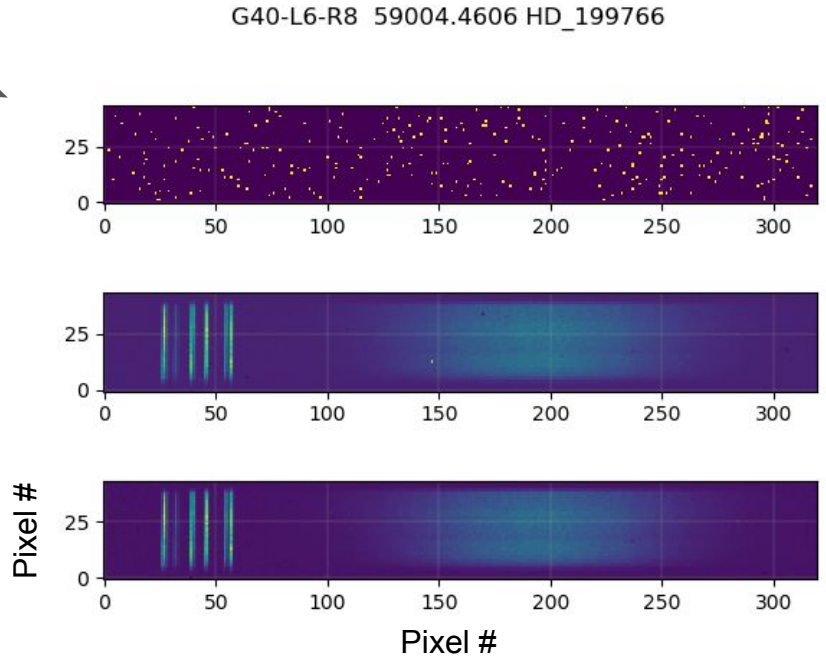
Background Files:



Create Beam Maps:



Create "Cleaned" Data preproc files:



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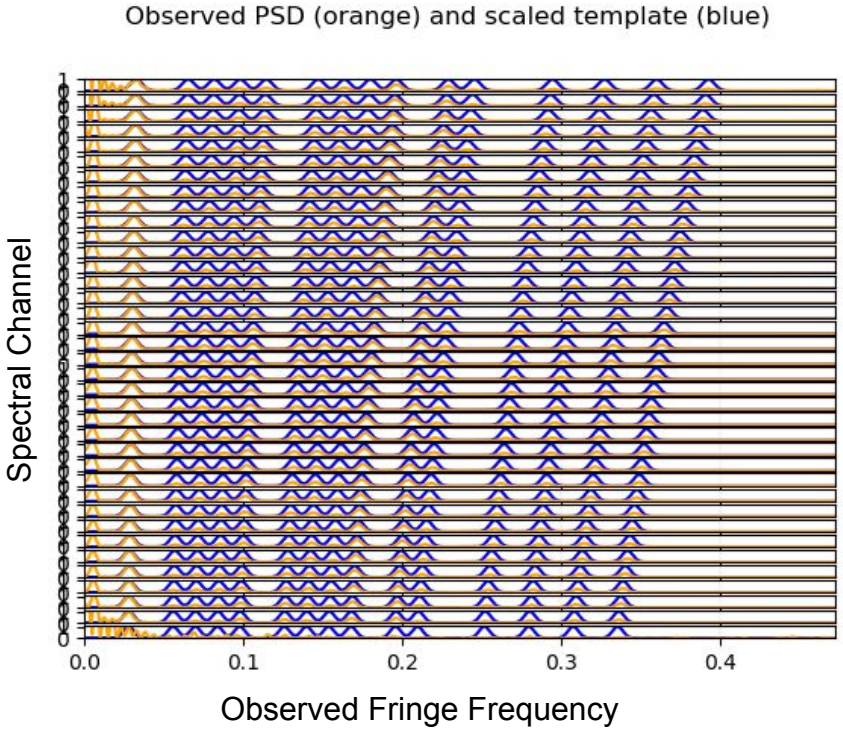
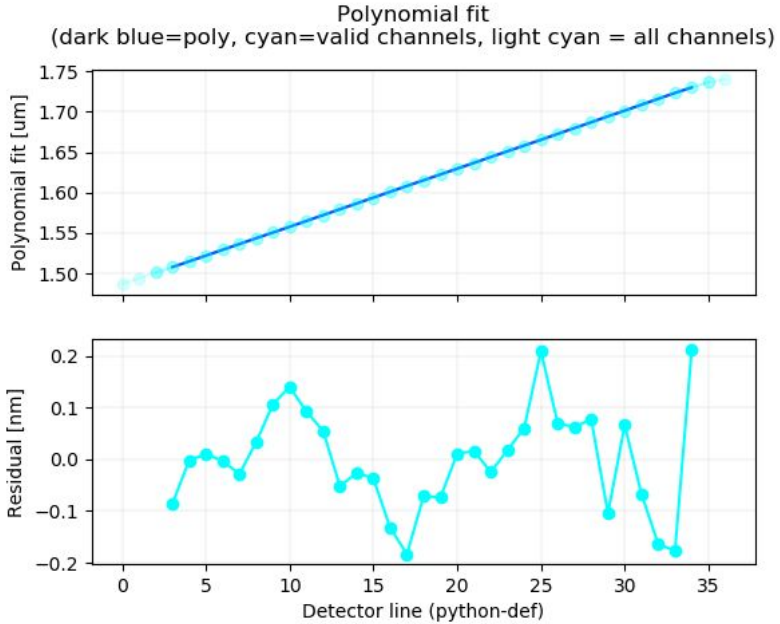
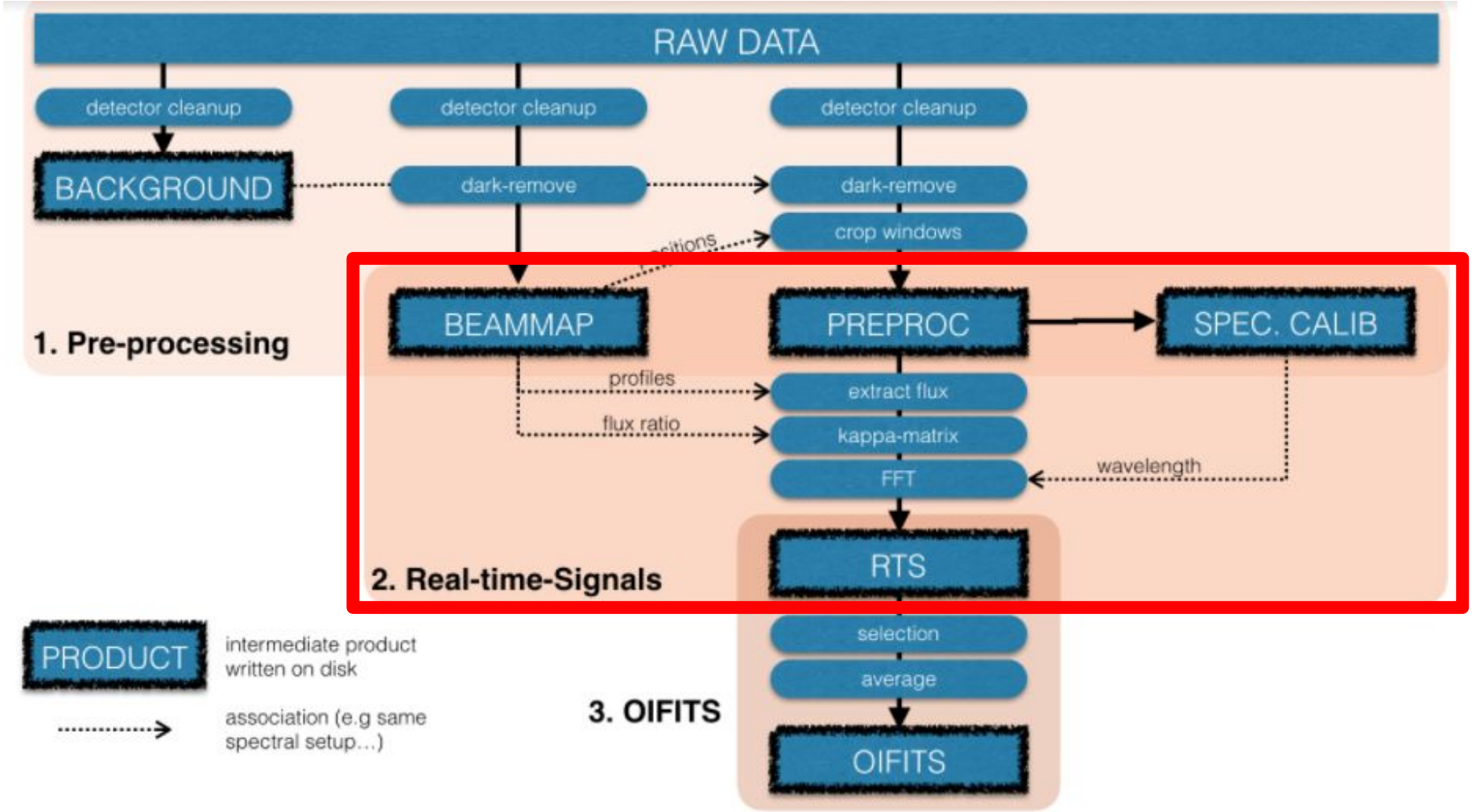
All Fringe Files of Given Setup →
Spectral Calibration



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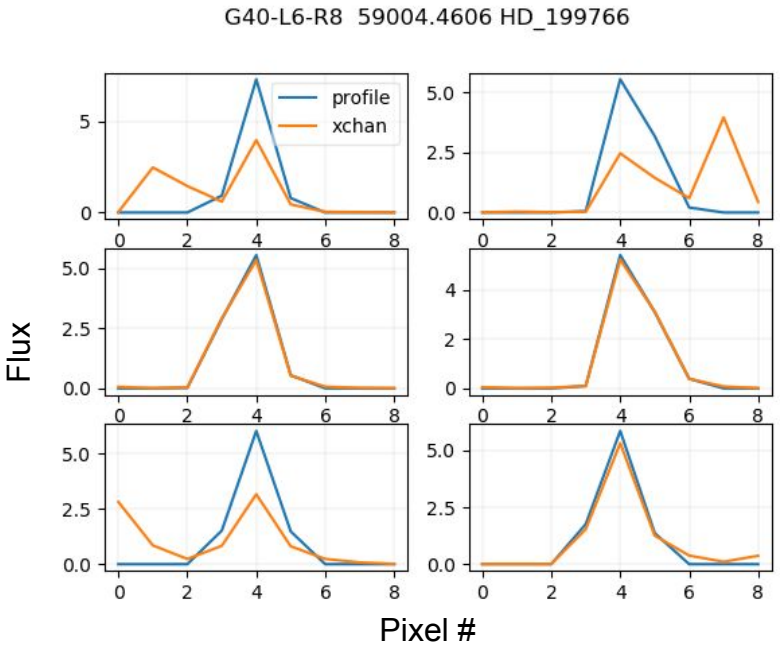
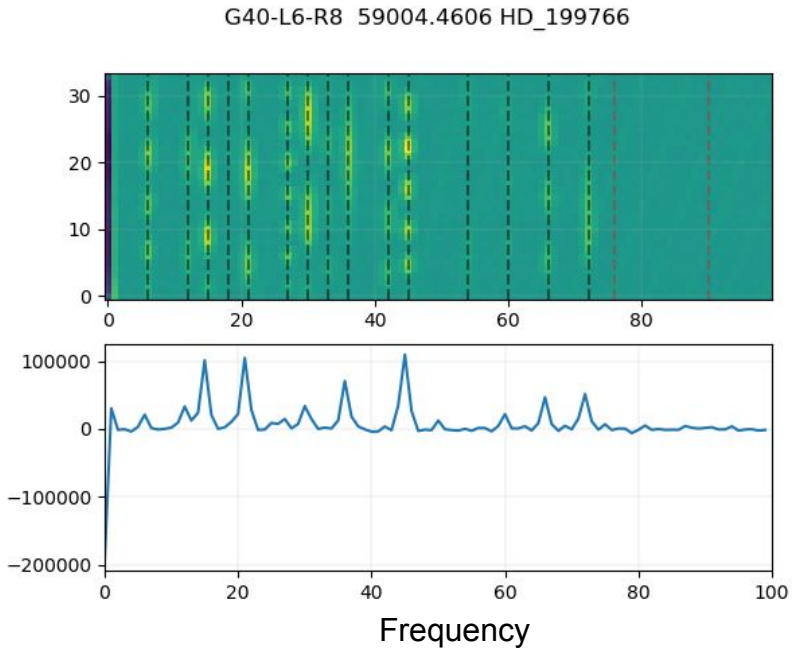
2) RTS Step

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

Beam Profiles, Photometry:



Fringes:



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- Compute real-time photometry
- Fringe power
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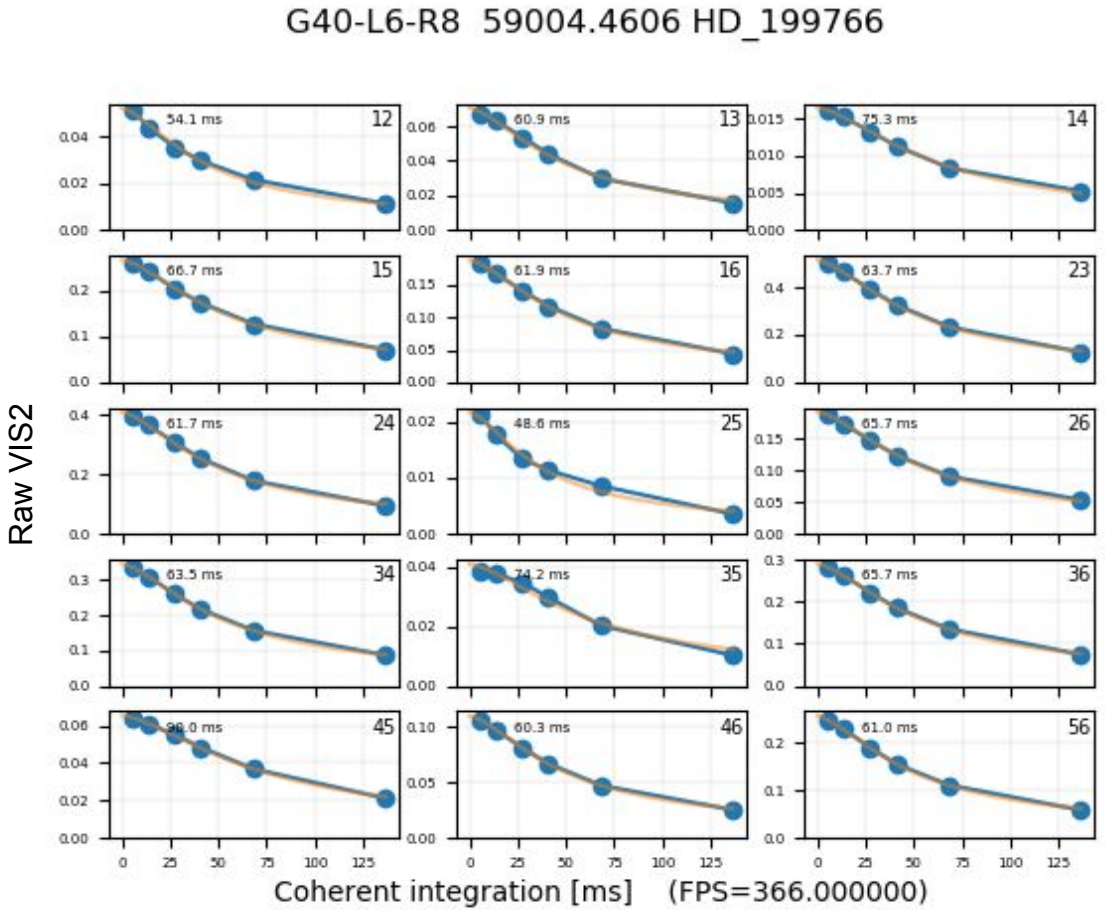
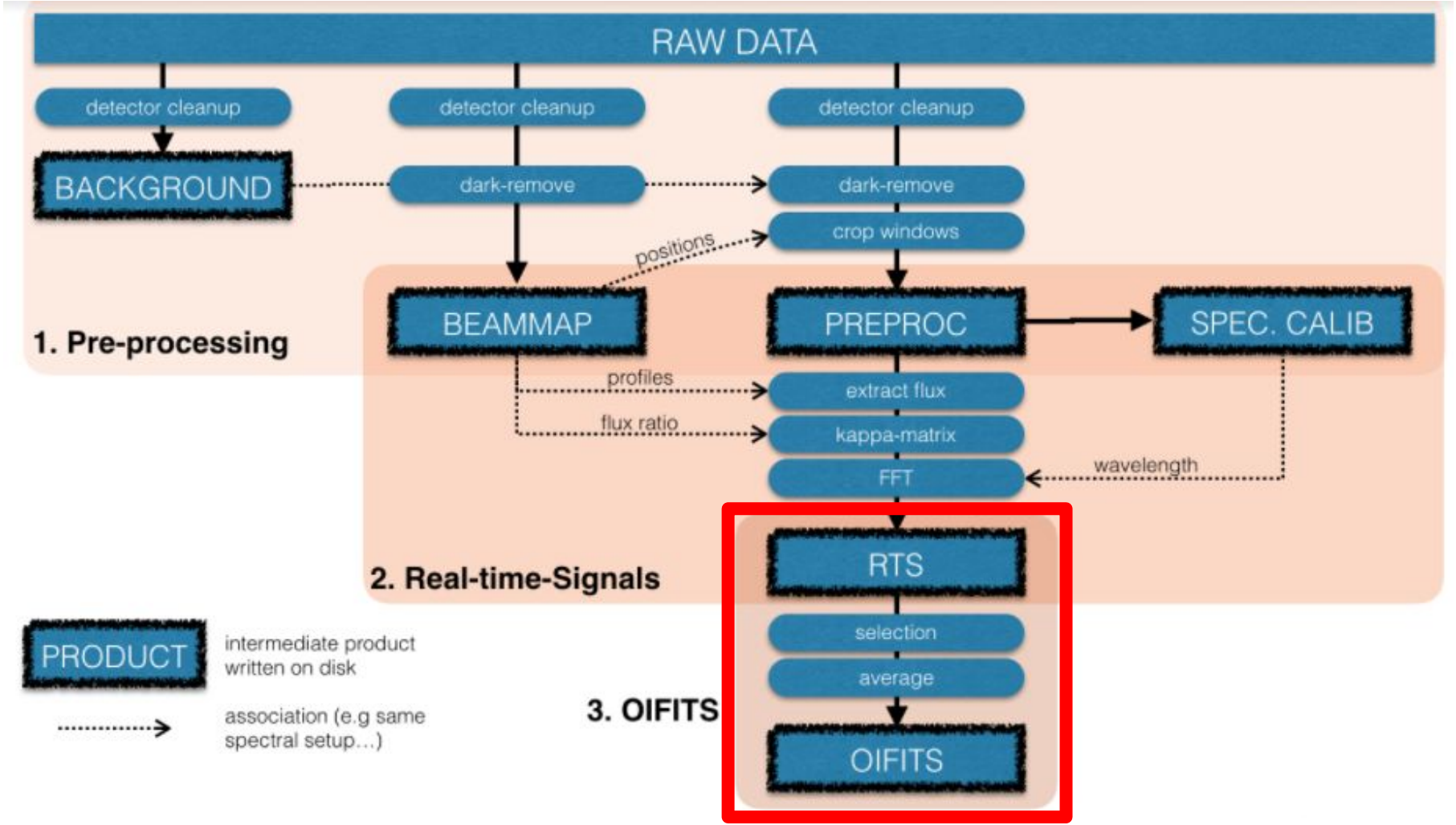


Gives an idea of how many frames to coherently average for OIFITS step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3. OIFITS
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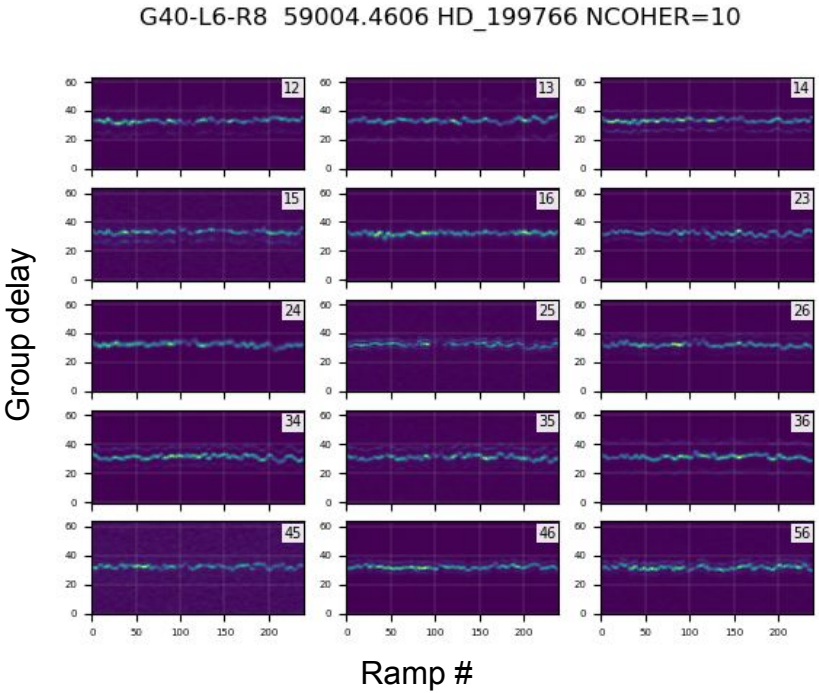
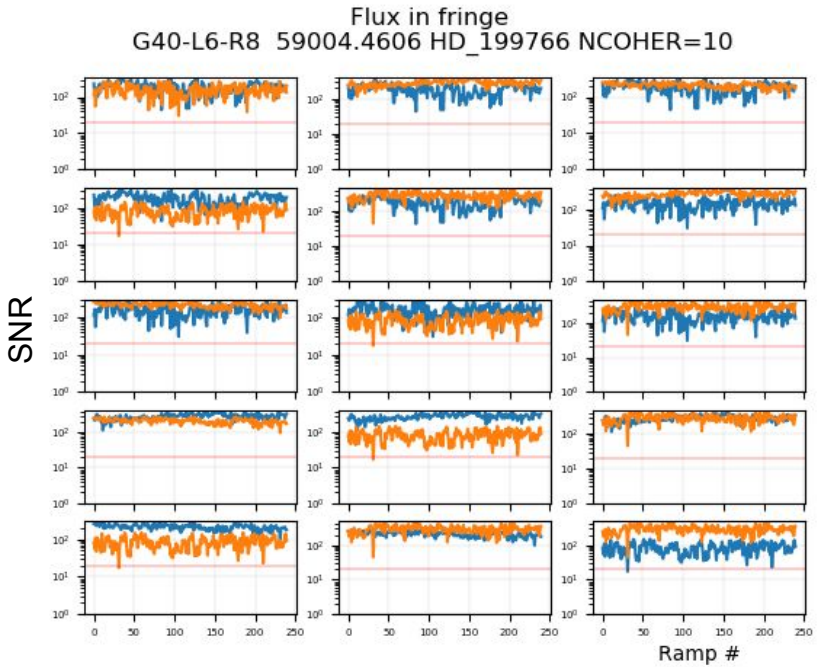
intermediate product written on disk
association (e.g same spectral setup…)

3) OIFITS Step

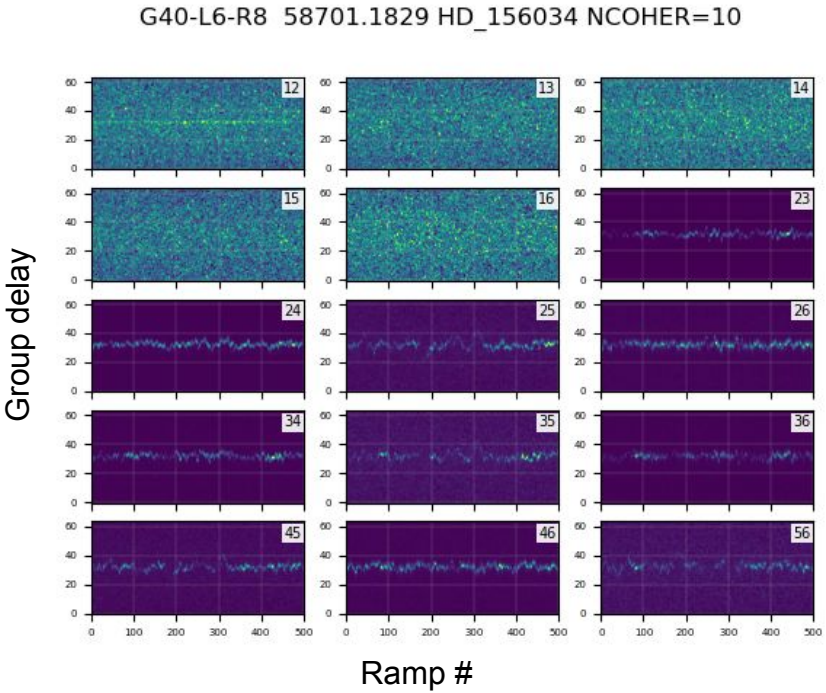
- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

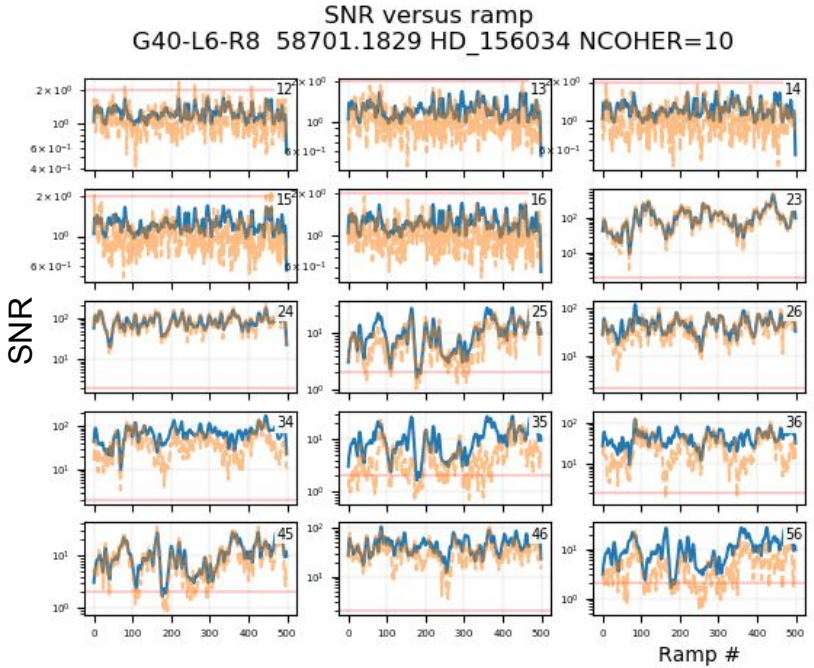




3) OIFITS Step

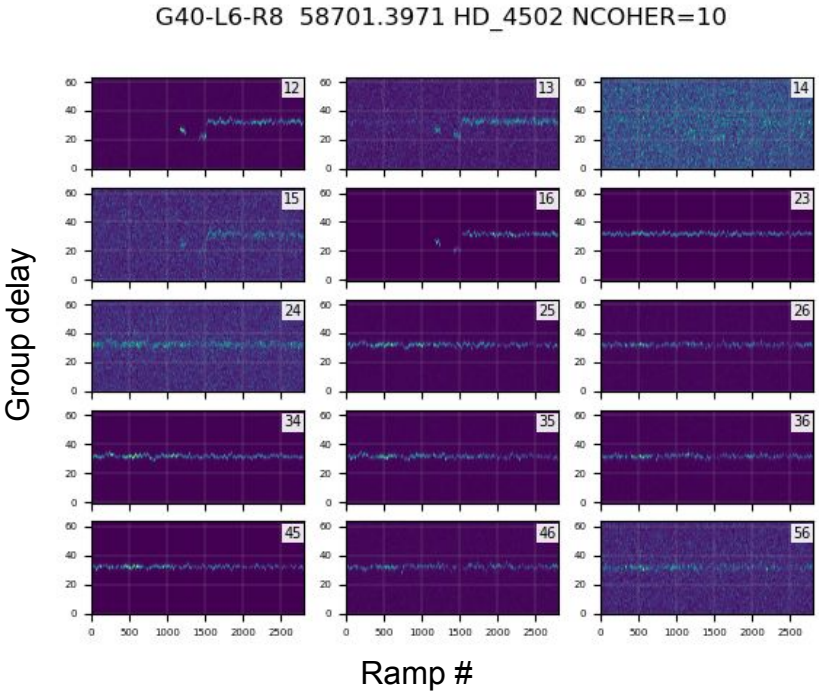
- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

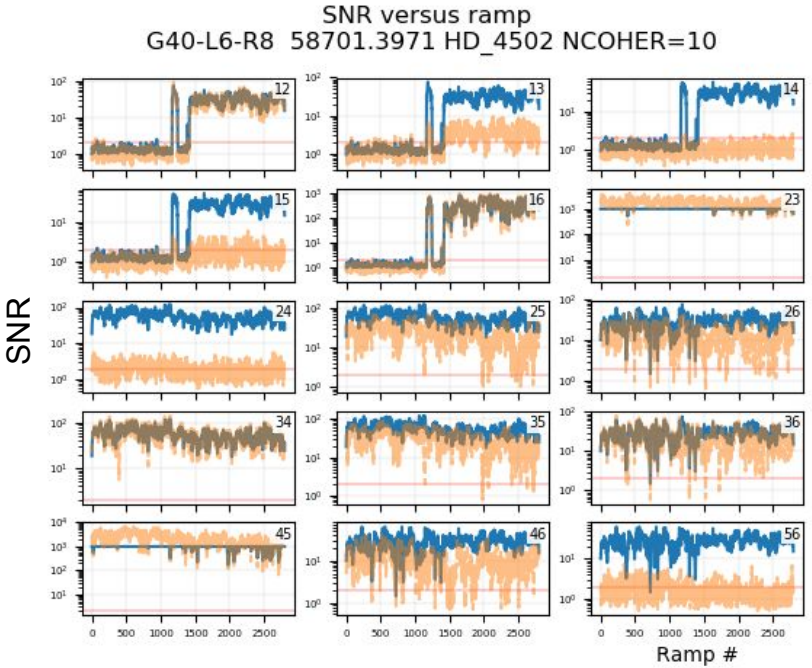




3) OIFITS Step

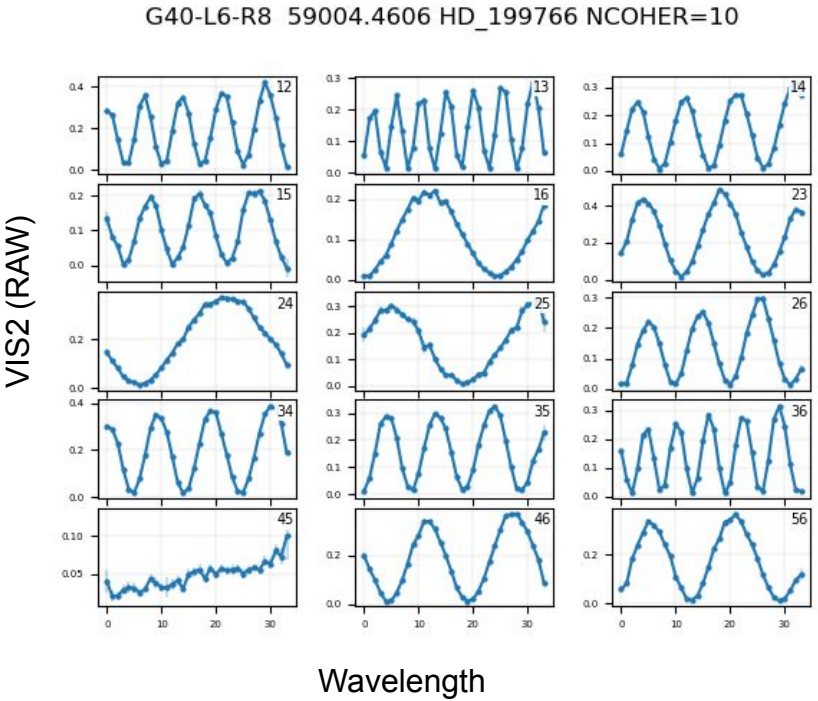
- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

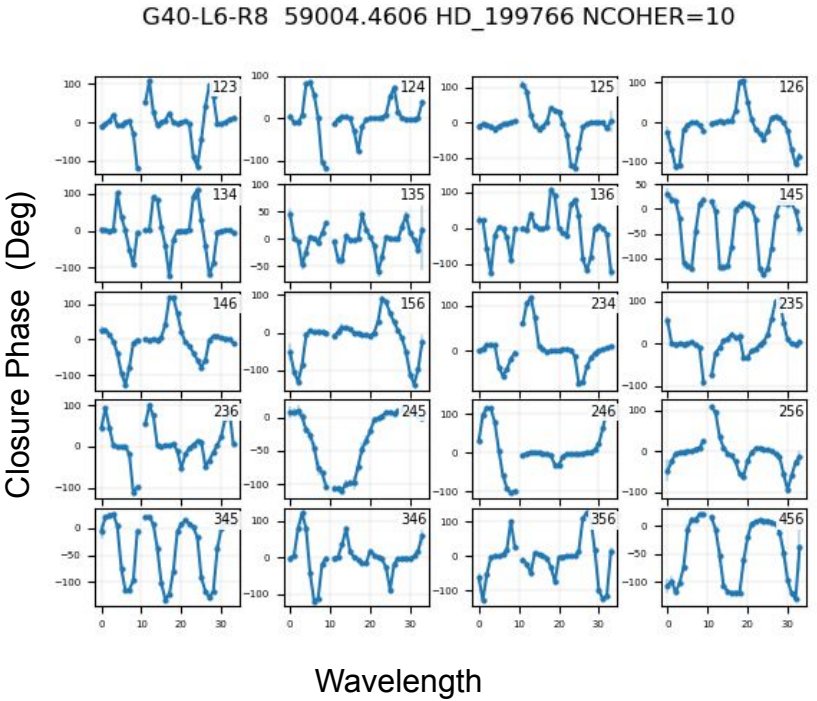




3) OIFITS Step

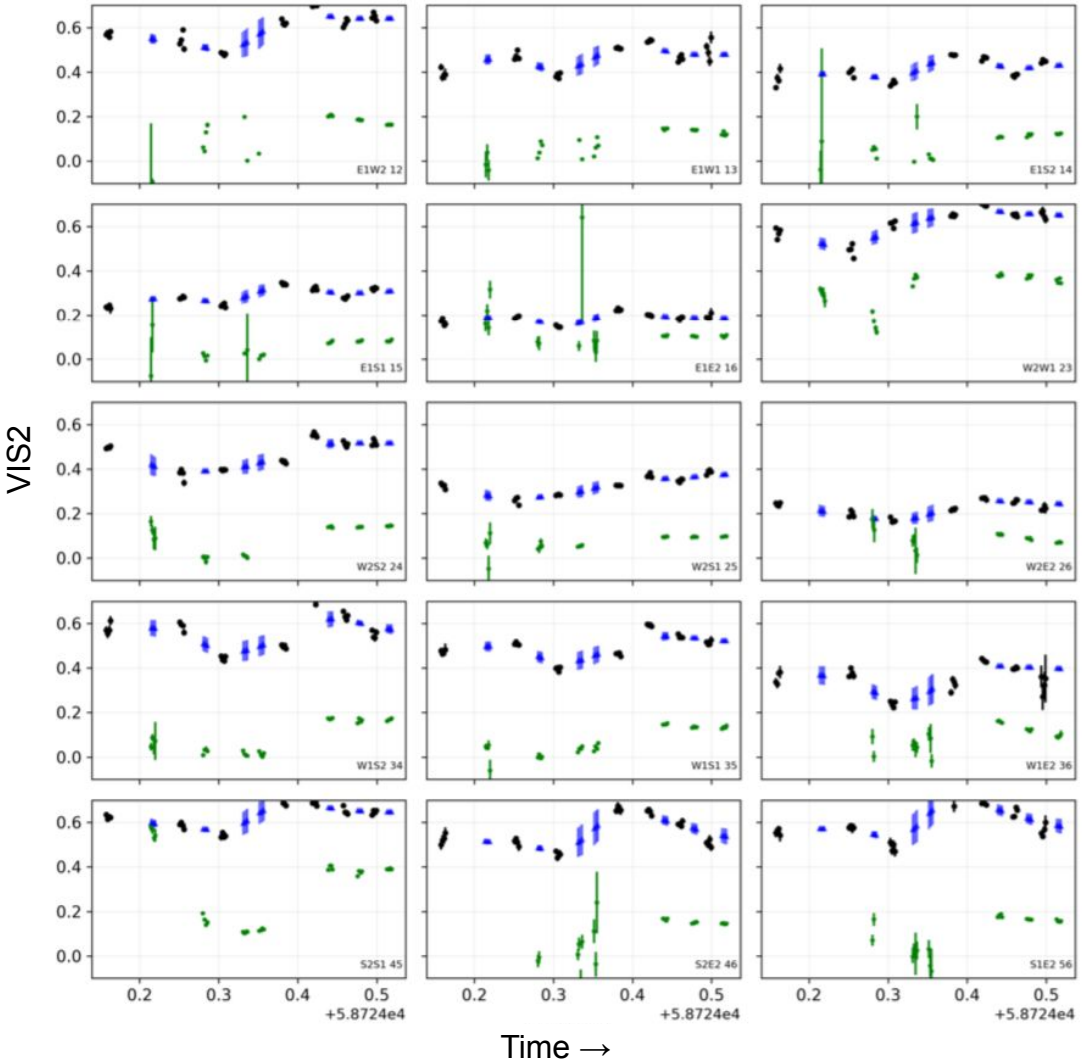
- Further selection criteria for cleaning
- Computation of raw visibilities, differential phase, closure phase

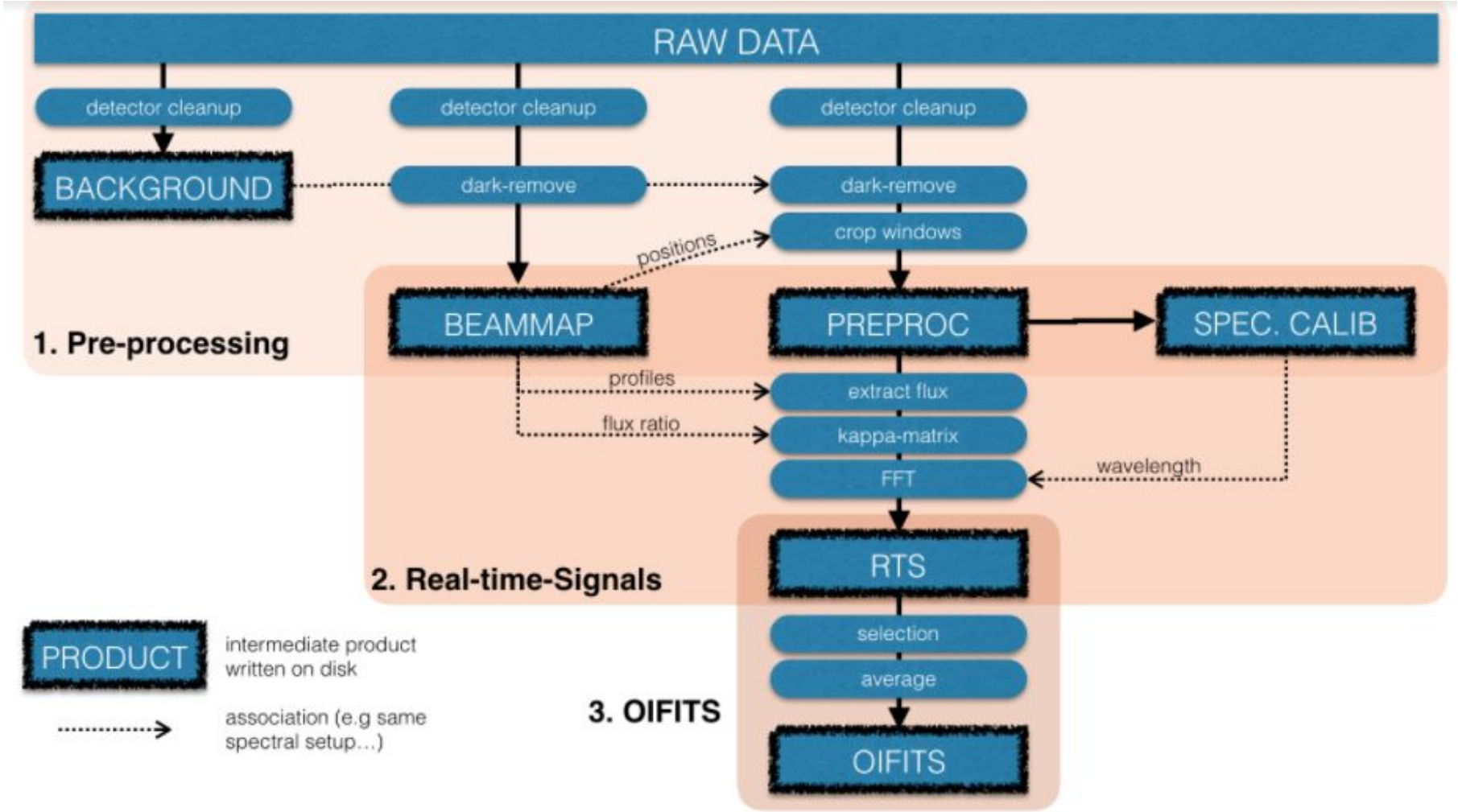




4) Calibration

- 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

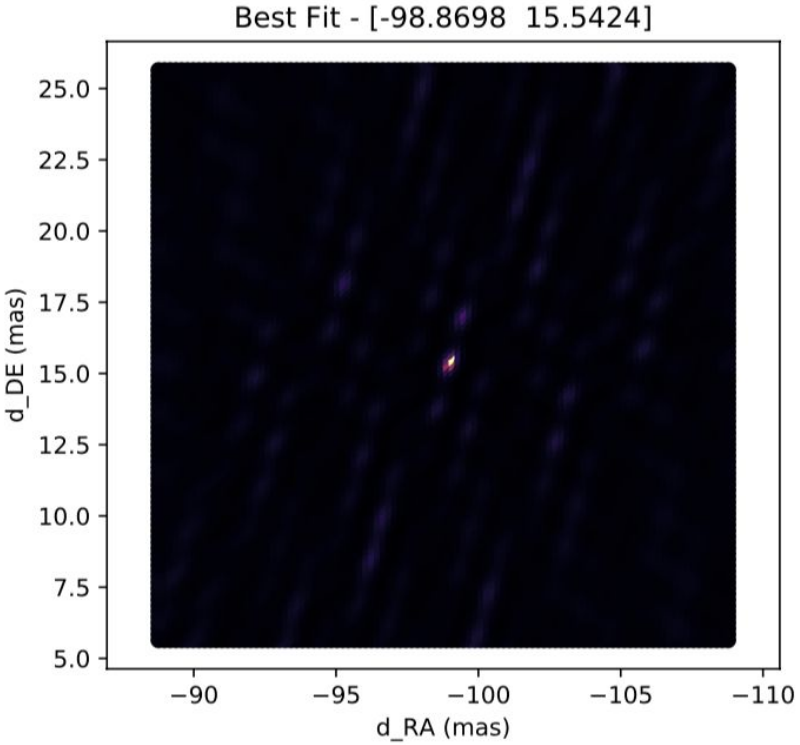


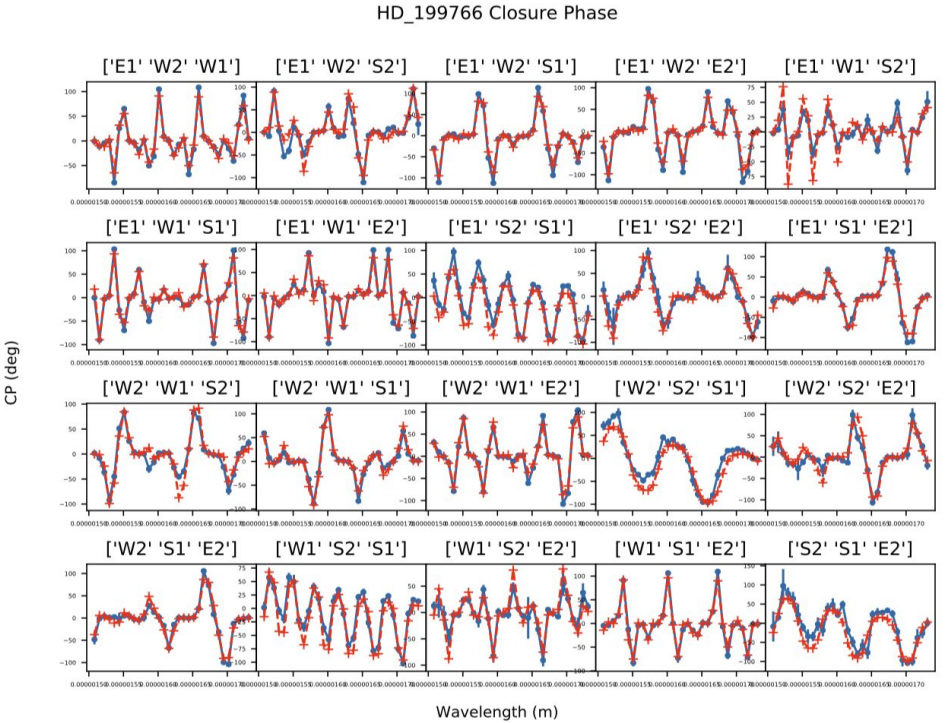

RAW DATA
detector cleanup
detector cleanup
detector cleanup
BACKGROUND
dark-remove
dark-remove
crop windows
positions
BEAMMAP
PREPROC
SPEC. CALIB
1. Pre-processing
profiles
flux ratio
extract flux
kappa-matrix
FFT
wavelength
2. Real-time-Signals
RTS
selection
average
3. OIFITS
OIFITS
PRODUCT
intermediate product written on disk
association (e.g same spectral setup…)

Imaging, model fitting, etc!

- Calibrated OIFITS files compatible with many publicly available softwares
- e.g. CANDID, squeeze, macim, MiRA, bsmem, LITpro, ….

Example → position of a binary companion:



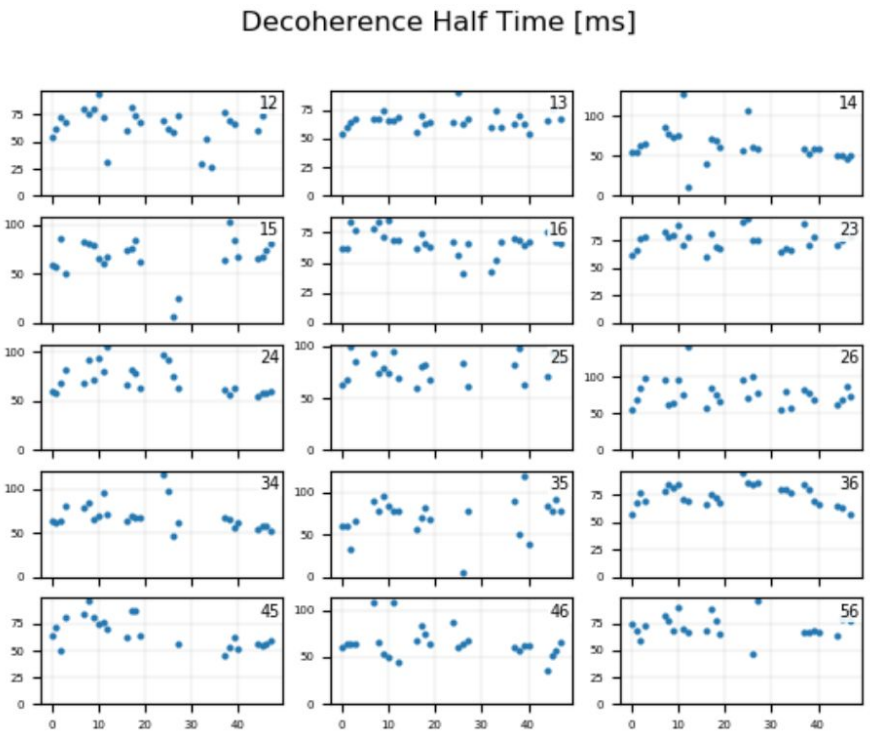


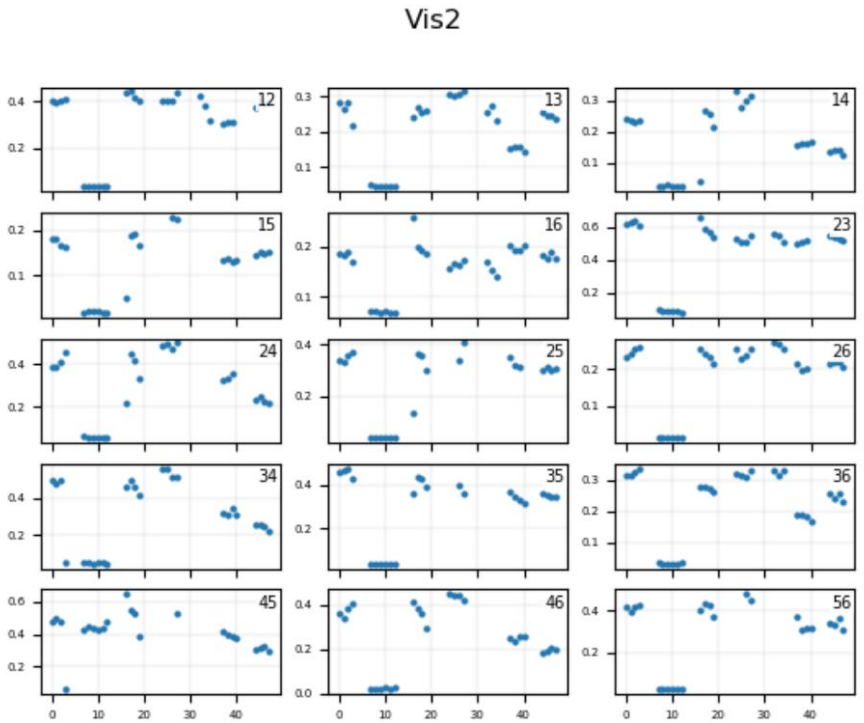
End of Night → Archiving data and MIRC-X Pipeline Wrapper

- Archive script saves 2 copies of compressed FITS data files of night
- Pipeline wrapper written by Claire Davies as a first ‘quicklook’ at data quality
  - Runs preproc, rts, oifits steps
  - Identifies calibrators
  - Fits binary models to check for bad calibrator stars
  - Shows fiber maps for night → beam quality

- Group receives emailed summary reports → Useful for multi-night runs!

Summary reports - Seeing / VIS2 of night

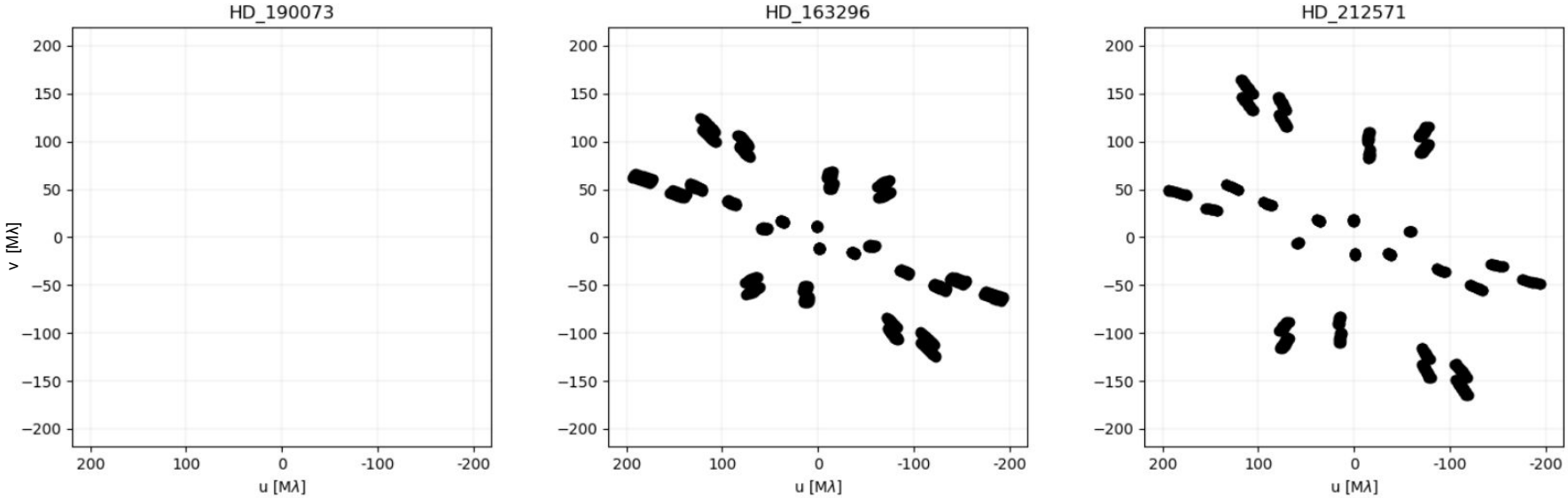




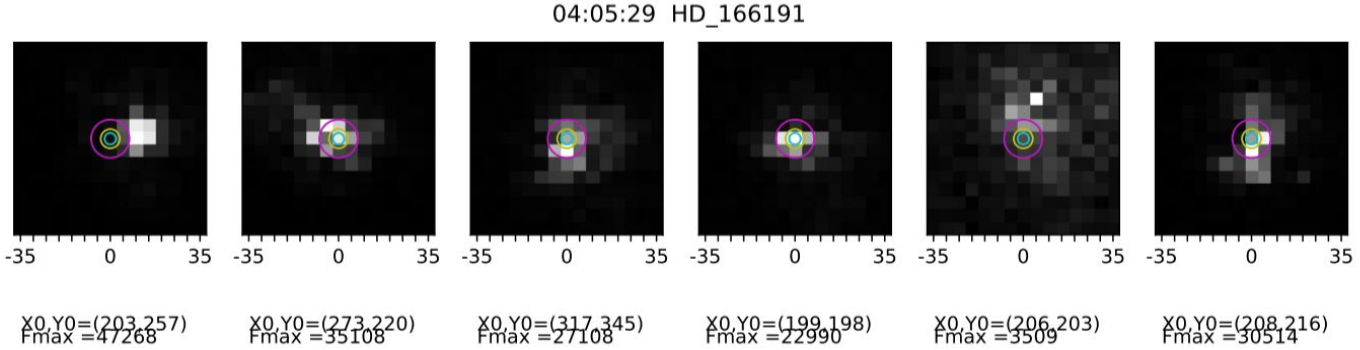
Time →

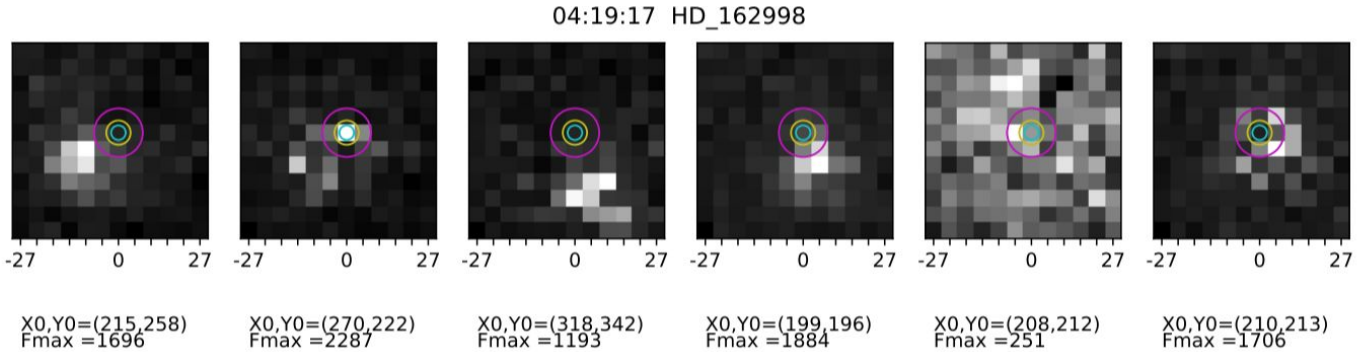
Summary reports - Identify targets / cals

Full night uv-coverage for SCI target(s)



Summary reports - Fiber maps of night





MIRC-X: a highly-sensitive six telescope interferometric imager at the CHARA Array

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Credone detector upgrade - 2017June

Optics upgrade - 2018Sep