Understanding Correlator Feedback

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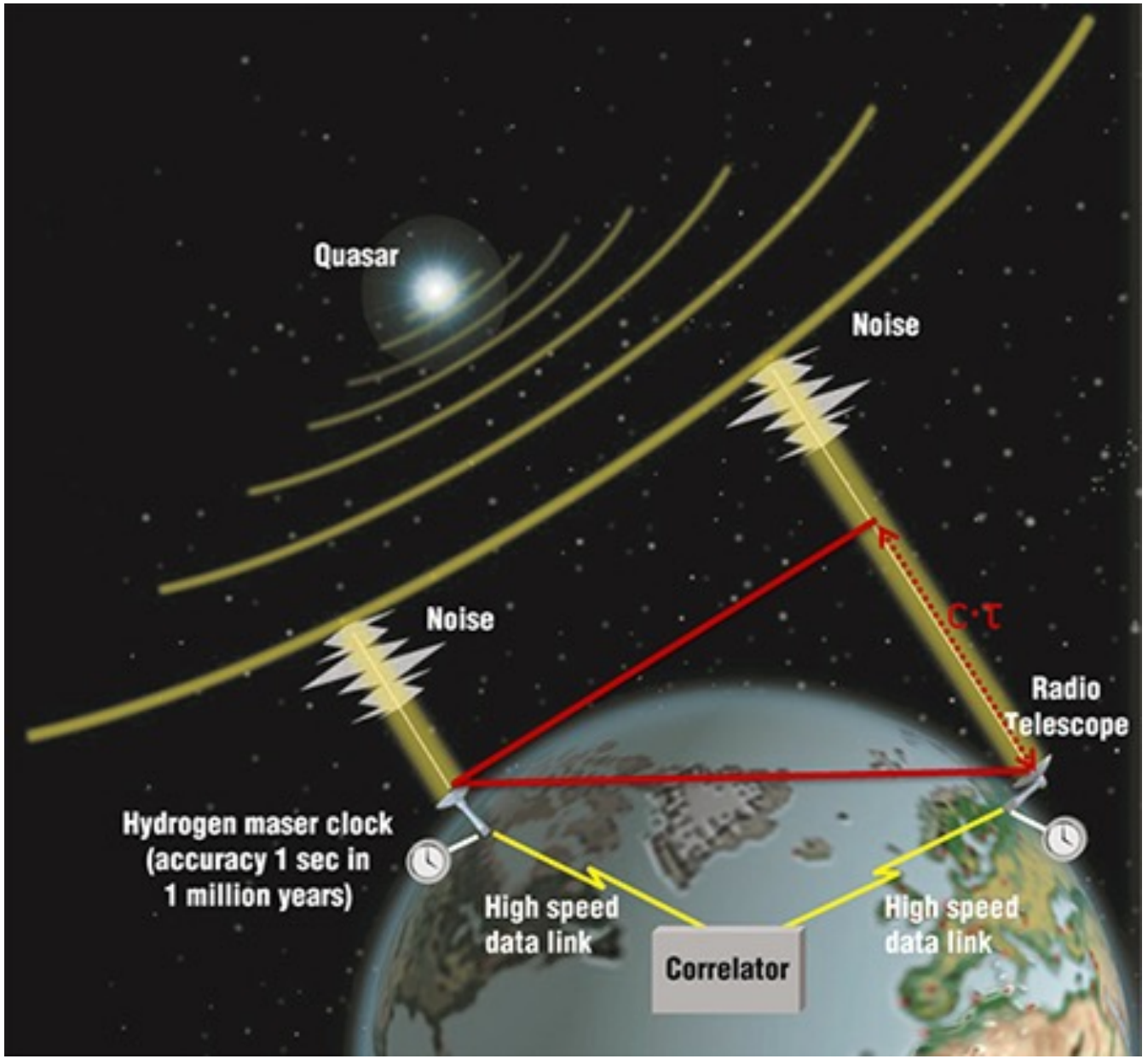
With thanks to:
Alessandra Bertarini – Bonn Correlator (BONN)
David Hall – Washington Correlator (WASH)
Mike Titus – Haystack Correlator (HAYS)

Quick Review: Bird's Eye View



Quick Review: Bird's Eye View

Scheduling
SKED, SCHED, etc.

Session Plan
`skd`, `sched`, `vex`

Observation
DRUDG, etc.

Observations
`log`, `vdif`, etc.

Correlation
`DiFX`, etc.

Visibilities
`DiFX`, `mk4-3`, etc.

Fringing
HOPS, etc.

Fringes
`vgosdb`

Analysis
`vSolve`, `Calc/Solve`, etc.

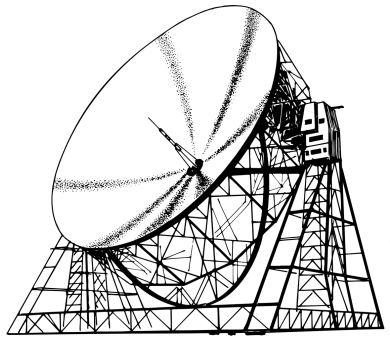
Database
`vgosdb`

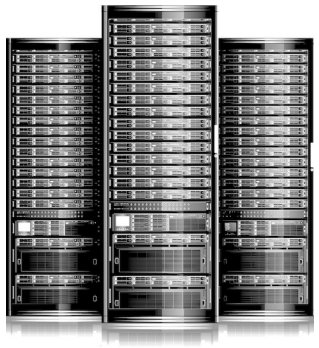
Post-Analysis Users

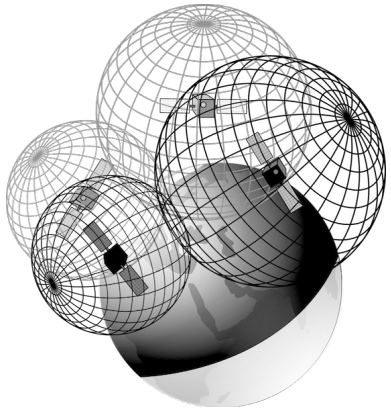
International Earth Rotation and Reference Systems Service (IERS)

Celestial Reference Frame (CRF)

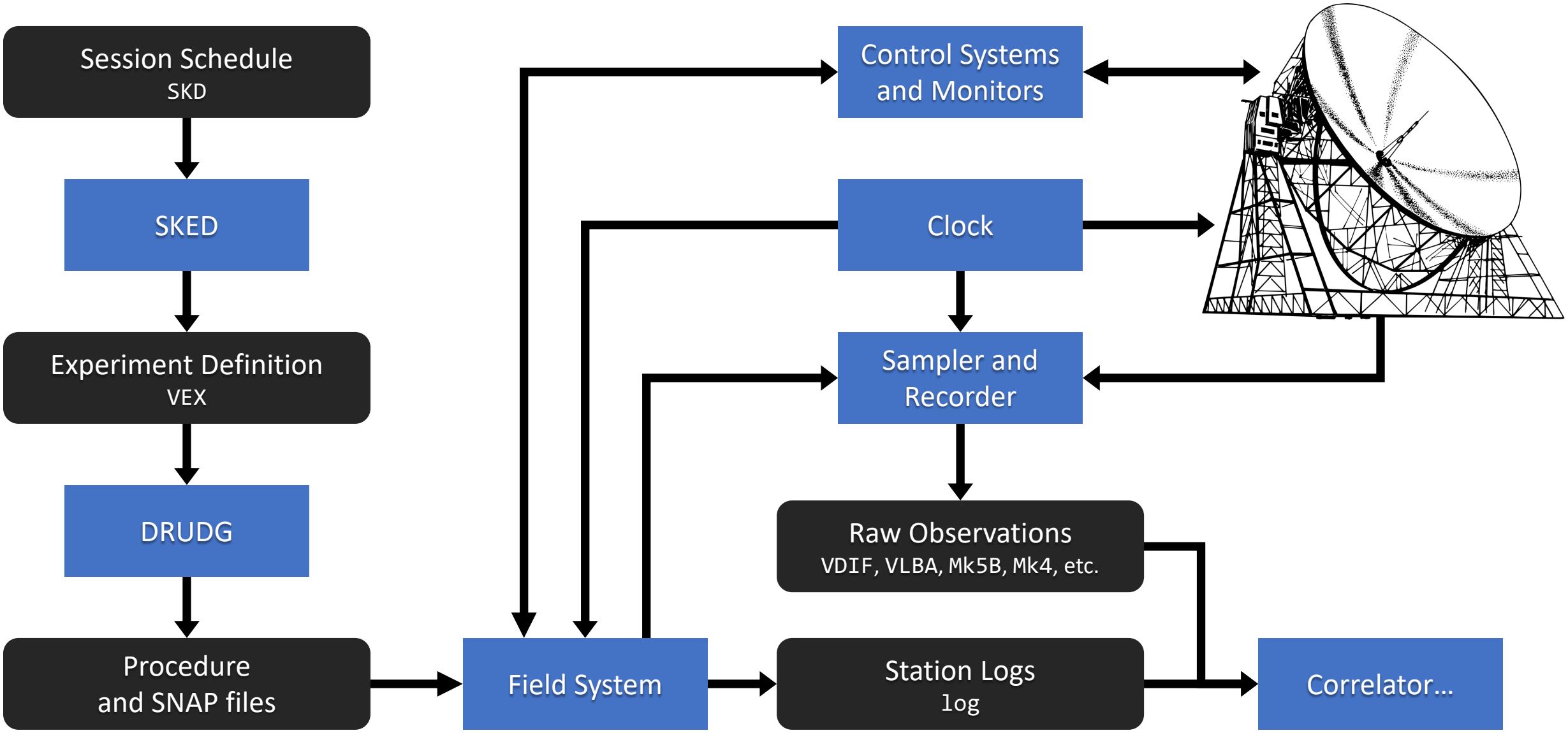
etc.



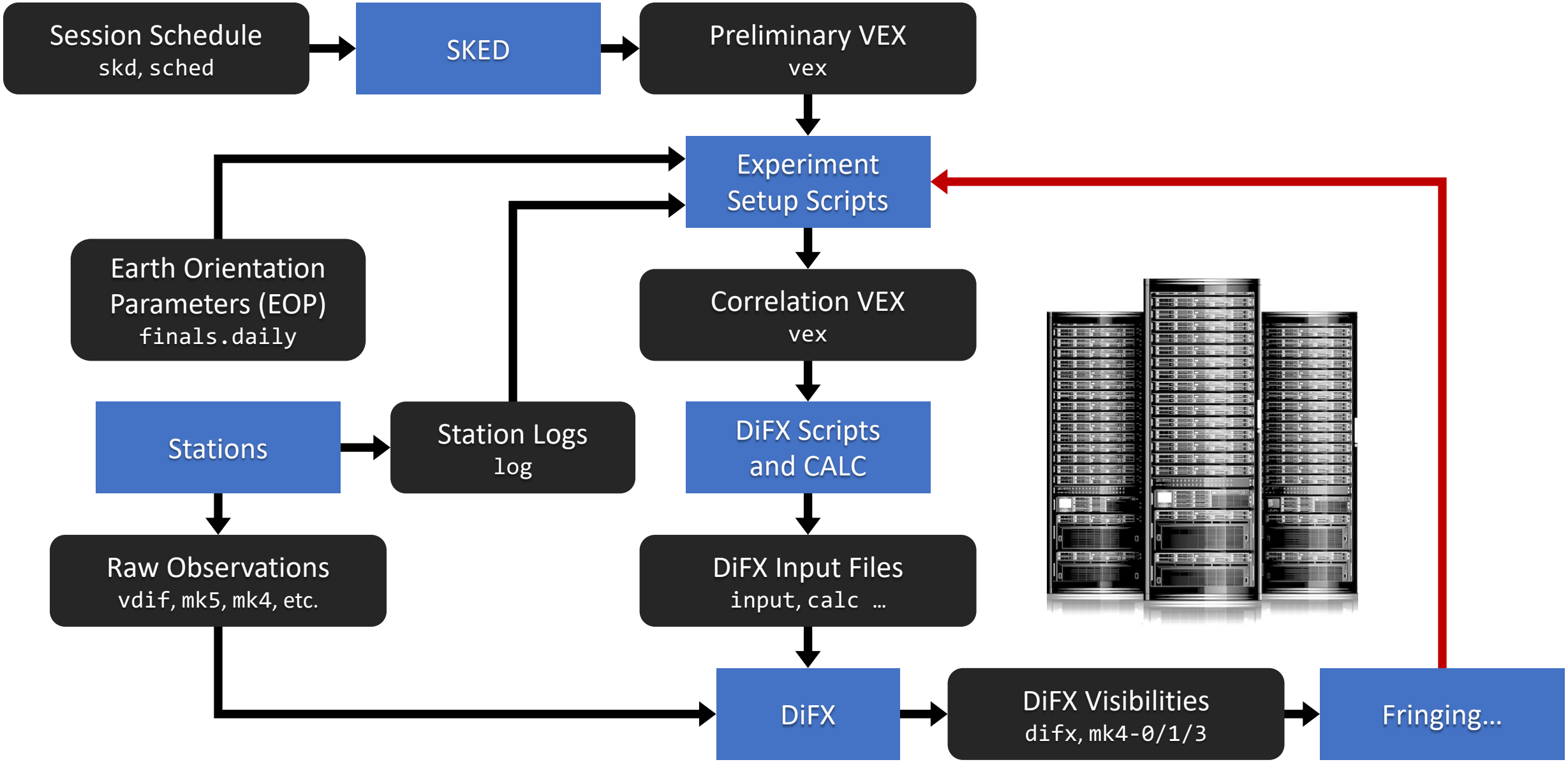




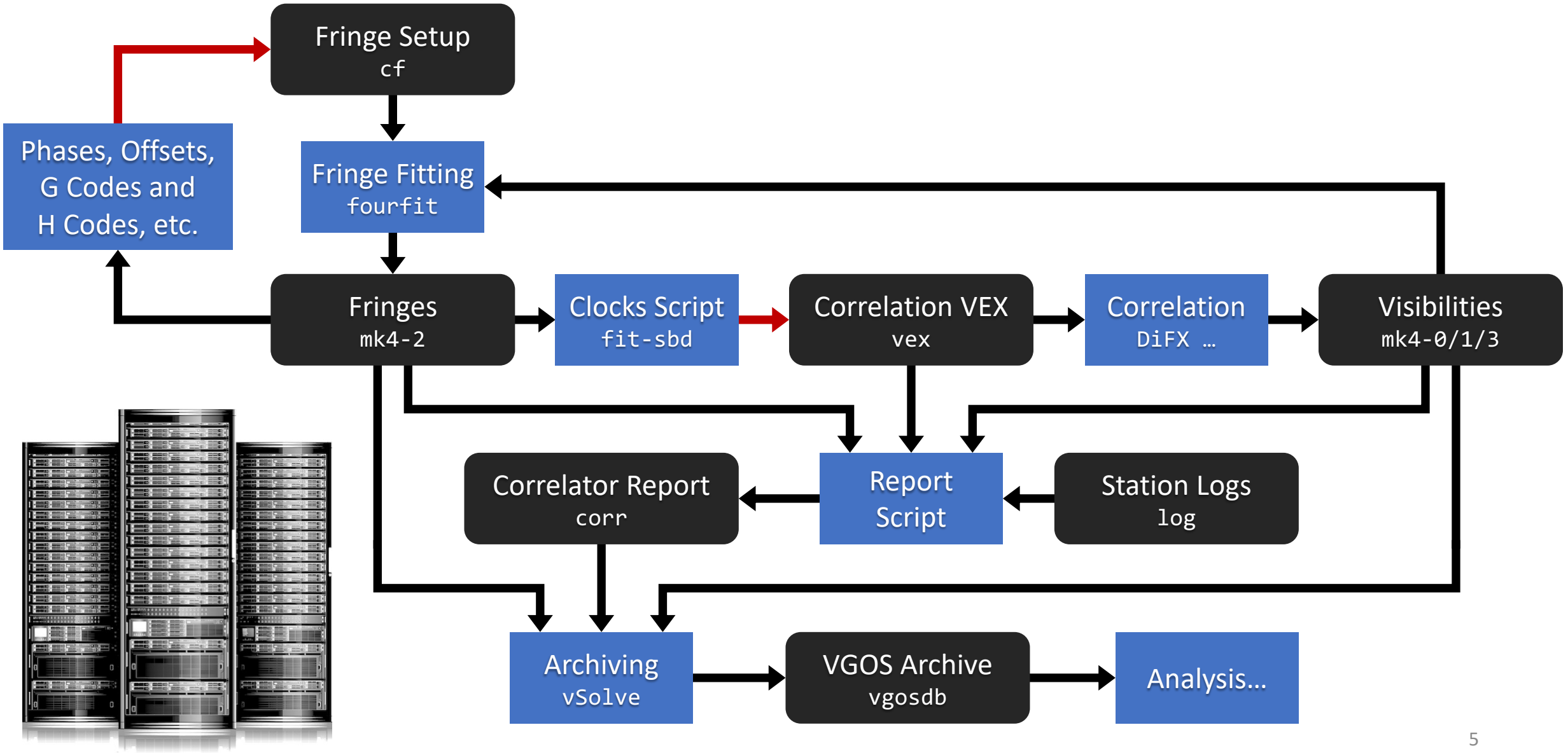
Quick Review: Observation



Quick Review: Correlation



Quick Review: Fringe Fitting



TLDR: What is correlation?

- Need the **time lag** between signals at different sites:
  - **Cross correlate** signals together to overlay them
  - **Fourier transform** from time to frequency domain
  - It's a **virtual interferometer**
  - Inspect **frequency spectra** to estimate time lag
  - Correct for instrumental effects at each antenna

- Order of operations is flexible:
  - **XF** = (X) **Cross correlate**, then (F) **Fourier transform**
  - **FX** = (F) **Fourier transform**, then (X) **cross correlate** (multiply)

TLDR: What is fringing?

Basic steps:

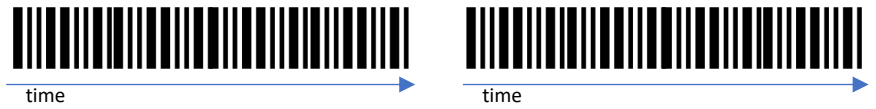
- Correlator outputs visibilities
- Switch to frequency domain
- Combine channels with **group delay**
- Combine baselines with **closure**

HOPS Software does this fringing

- Haystack Observatory Postprocessing System (HOPS) has a program for **Four**ier transform **fit**ting (fringe fitting) VLBI baseline data called **Fourfit**.

Correlation and Fringing

Raw Data Streams

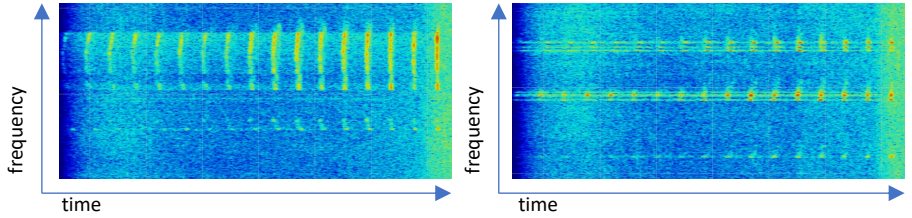


1- or 2-bit voltage readings directly from radio telescope receivers

FFT

Fast Fourier transform (FFT) converts from time to frequency domain

RF Spectrographs

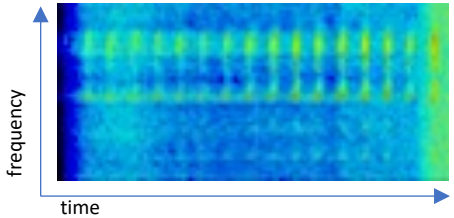


Radio frequency (RF) amplitudes over time

Cross Multiplication

Frequency signals are combined with a simple cross multiplication

RF² Spectrograph



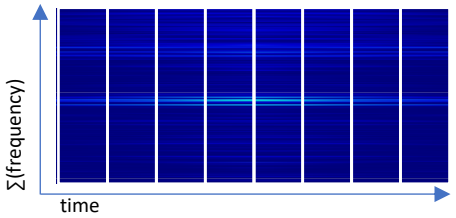
Combined signals (still extremely noisy)

Correlation and Fringing

Integration

Sum over time in chunks to cancel noise with destructive interference

Visibilities

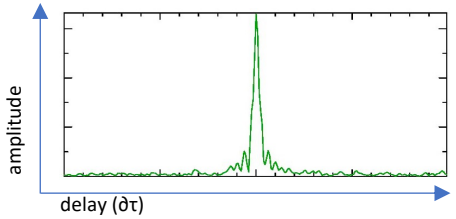


Measure of the contrast of the interference pattern

Fringe Finding

Find slope of visibility vs phase (fringe rate) and correct

Single Band Delay

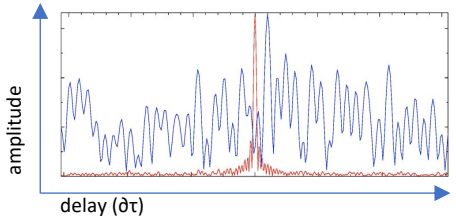


Peaks at the time delay with the greatest common visibility between both telescopes

Inverse FFT

Perform inverse fast Fourier transform from frequency to time domain

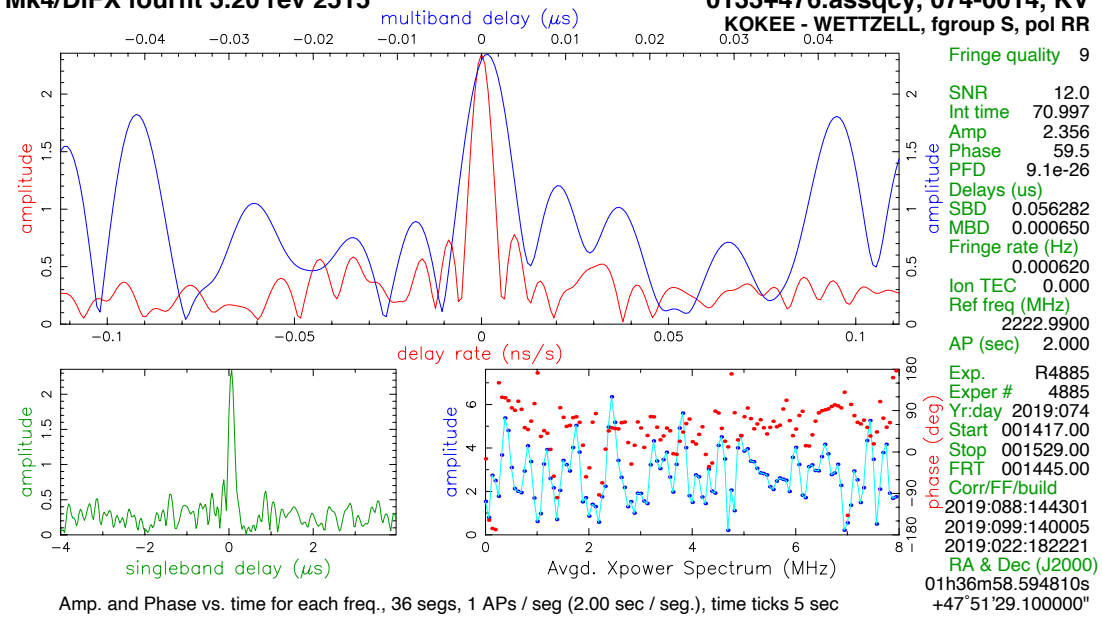
Multiband Delay



Sum of sine waves returned from inverse FFT for each channel (used for closure)

Mk4/DiFX fourfit 3.20 rev 2515

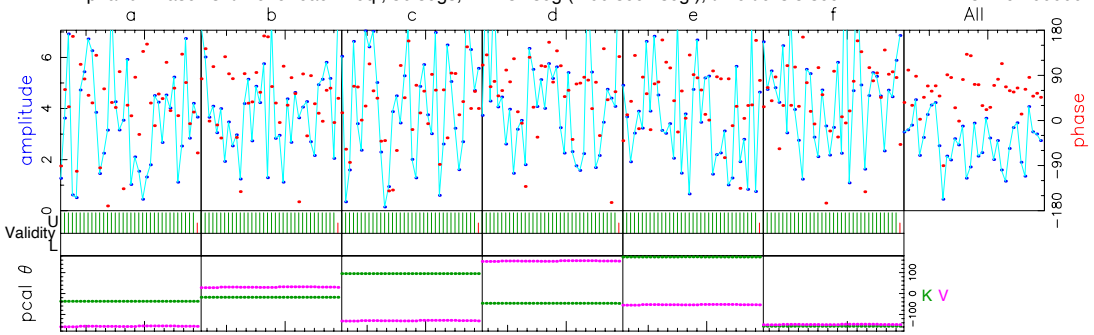
0133+476.assqcy, 074-0014, KV
KOKEE - WETTZELL, fgroup S, pol RR



Fringe quality 9

SNR	12.0
Int time	70.997
Amp	2.356
Phase	59.5
PFD	9.1e-26
Delays (us)	
SBD	0.056282
MBD	0.000650
Fringe rate (Hz)	
	0.000620
Ion TEC	0.000
Ref freq (MHz)	
	2222.9900
AP (sec)	2.000
Exp.	R4885
Exper #	4885
Yr:day	2019:074
Start	001417.00
Stop	001529.00
FRT	001445.00
Corr/FF/build	
	2019:088:144301
	2019:099:140005
	2019:022:182221
RA & Dec (J2000)	
	01h36m58.594810s
	+47°51'29.100000"

Amp. and Phase vs. time for each freq., 36 segs, 1 APs / seg (2.00 sec / seg.), time ticks 5 sec



	2225.99	2245.99	2265.99	2295.99	2345.99	2365.99	Freq (MHz) All
	52.6	59.2	52.0	84.2	42.9	60.4	Phase 59.5
	2.2	2.3	2.3	2.8	2.2	2.6	Ampl. 2.4
	130.3	130.1	131.6	131.0	130.2	131.0	Sbd box 130.8
U/L	36/0	36/0	36/0	36/0	36/0	36/0	APs used
K	-235.1	-228.0	-205.4	-215.8	-213.2	-222.6	PC R delays (ns)
V	18.8	19.9	18.6	19.2	29.1	29.4	PC R delays (ns)
K:V	-37:-157	-18:30	95:-130	-47:155	175:-54	-156:-148	PC phase
K:V	0:0	0:0	0:0	0:0	0:0	0:0	Manl PC
K	34	32	33	32	32	34	PC amp
V	23	22	22	20	22	22	
K	S00UR	S01UR	S02UR	S03UR	S04UR	S05UR	Chan ids
							Tracks
V	S00UR	S01UR	S02UR	S03UR	S04UR	S05UR	Chan ids
							Tracks

Group delay (usec)(model)	1.60781220657E+04	Apriori delay (usec)	1.60781214154E+04	Resid mbdelay (usec)	6.50300E-04	+/-	2.6E-04
Sband delay (usec)	1.60781776974E+04	Apriori clock (usec)	-9.6033335E+00	Resid sbdelay (usec)	5.62820E-02	+/-	5.7E-03
Phase delay (usec)	1.60781214898E+04	Apriori clockrate (us/s)	2.2560000E-07	Resid phdelay (usec)	7.43945E-05	+/-	1.2E-05
Delay rate (us/s)	3.20831533045E-01	Apriori rate (us/s)	3.20831254366E-01	Resid rate (us/s)	2.78679E-07	+/-	2.9E-07
Total phase (deg)	104.6	Apriori accel (us/s/s)	-1.17340437588E-04	Resid phase (deg)	59.5	+/-	9.5

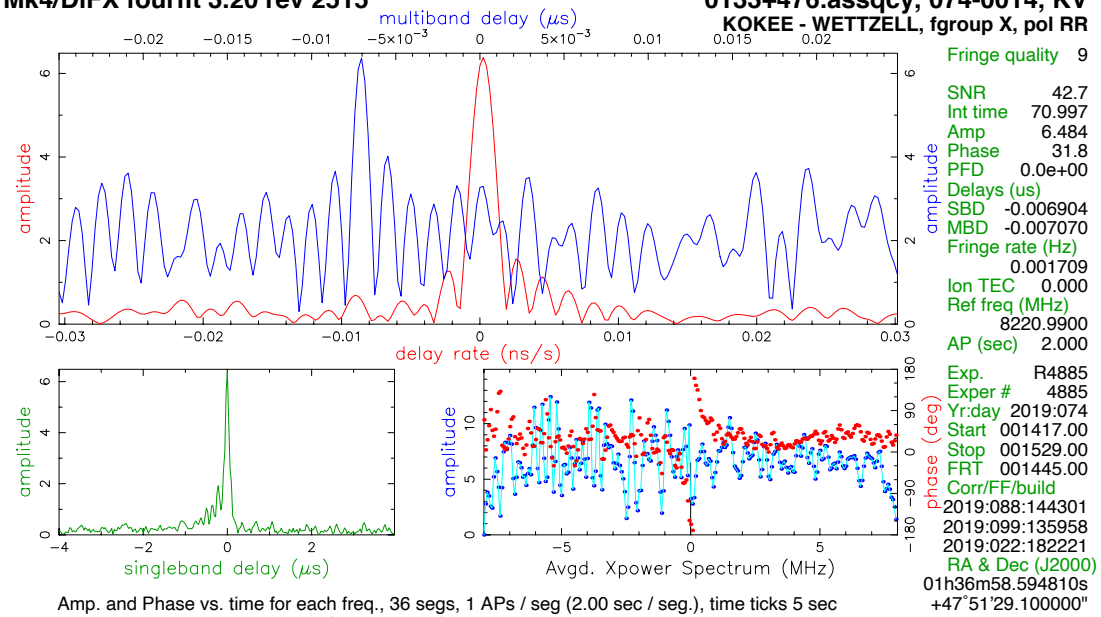
	RMS	Theor.					
ph/seg (deg)	40.2	28.6	Amplitude	2.356 +/- 0.196	Pcal mode: MULTITONE, MULTITONE PC period (AP's) 5, 5		
amp/seg (%)	41.7	49.9	Interp.	0.000	Pcal rate: 0.000E+00, 0.000E+00 (us/s)	sb window (us)	-4.000 4.000
ph/frq (deg)	15.7	11.7	Inc. seg. avg.	2.397	Bits/sample: 1x1 SampCntNorm: disabled	mb window (us)	-0.050 0.050
amp/frq (%)	9.6	20.4	Inc. frq. avg.	2.363	Sample rate(MSamp/s): 16	dr window (ns/s)	-0.112 0.112
					Data rate(Mb/s): 96 nlags: 128 t_cohere infinite	ion window (TEC)	0.00 0.00

K: az 12.5 el 63.3 pa -162.5 V: az 349.4 el 8.1 pa 10.3 u,v (fr/asec) -71.600 -321.748 simultaneous interpolator

Control file: cf_4885 Input file: /isan/data1/correlator/run/r/r4885/Production_Pass/1234/074-0014//KV..assqcy Output file: Suppressed by test mode

Mk4/DiFX fourfit 3.20 rev 2515

0133+476.assqcy, 074-0014, KV
KOKEE - WETTZELL, fgroup X, pol RR



Fringe quality 9

SNR	42.7
Int time	70.997
Amp	6.484
Phase	31.8
PFD	0.0e+00
Delays (us)	
SBD	-0.006904
MBD	-0.007070
Fringe rate (Hz)	
	0.001709
Ion TEC	0.000
Ref freq (MHz)	
	8220.9900
AP (sec)	2.000
Exp.	R4885
Exper #	4885
Yr:day	2019:074
Start	001417.00
Stop	001529.00
FRT	001445.00
Corr/FF/build	
	2019:088:144301
	2019:099:135958
	2019:022:182221
RA & Dec (J2000)	
	01h36m58.594810s
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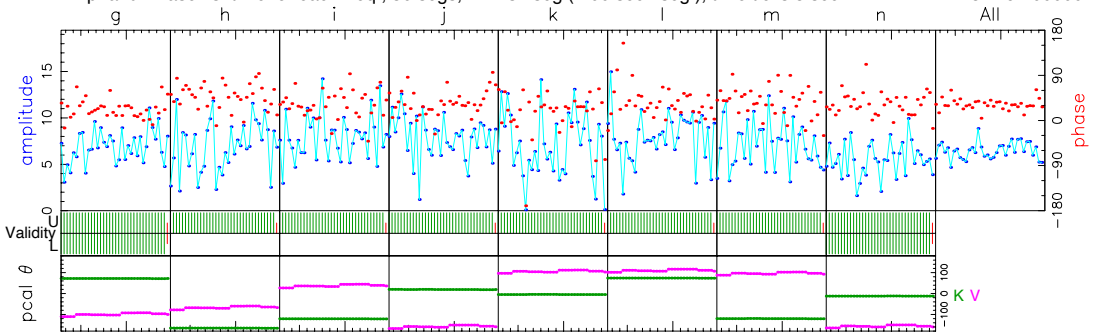
Amp. and Phase vs. time for each freq., 36 segs, 1 APs / seg (2.00 sec / seg.), time ticks 5 sec



	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz) All
	22.2	51.2	32.3	33.9	24.2	33.1	38.5	30.4	Phase 31.8
	6.6	6.4	7.2	7.2	6.5	7.2	6.4	5.2	Ampl. 6.4
	129.1	129.3	128.9	128.9	128.2	128.2	128.2	128.3	Sbd box 128.8
U/L	36/36	36/0	36/0	36/0	36/0	36/0	36/0	36/36	APs used
K	-244.2	-233.9	-229.3	-235.1	-243.1	-250.8	-242.1	-251.4	PC R delays (ns)
V	56.7	57.4	57.8	54.3	75.1	71.7	72.1	68.4	PC R delays (ns)
K:V	72:-100	-165:-67	-121:37	19:-158	-5:105	74:110	-120:96	-12:-157	PC phase
K:V	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	Manl PC
K	23	25	24	23	22	20	14	11	PC amp
V	21	20	23	22	21	23	22	22	
K	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids
									Tracks
V	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids
									Tracks

Group delay (usec)(model)	1.60781143456E+04	Apriori delay (usec)	1.60781214154E+04	Resid mbdelay (usec)	-7.06979E-03	+/-	1.3E-05
Sband delay (usec)	1.60781145114E+04	Apriori clock (usec)	-9.6033335E+00	Resid sbdelay (usec)	-6.90400E-03	+/-	1.2E-03
Phase delay (usec)	1.60781214261E+04	Apriori clockrate (us/s)	2.2560000E-07	Resid phdelay (usec)	1.07599E-05	+/-	6.5E-07
Delay rate (us/s)	3.20831462188E-01	Apriori rate (us/s)	3.20831254366E-01	Resid rate (us/s)	2.07822E-07	+/-	2.2E-08
Total phase (deg)	166.7	Apriori accel (us/s/s)	-1.17340437588E-04	Resid phase (deg)	31.8	+/-	1.9

	RMS	Theor.					
ph/seg (deg)	11.1	8.1	Amplitude	6.484 +/- 0.152	Pcal mode: MULTITONE, MULTITONE PC period (AP's) 5, 5		
amp/seg (%)	13.3	14.1	Interp.	0.000	Pcal rate: 0.000E+00, 0.000E+00 (us/s)	sb window (us)	-4.000 4.000
ph/frq (deg)	9.8	3.8	Inc. seg. avg.	6.432	Bits/sample: 1x1 SampCntNorm: disabled	mb window (us)	-0.025 0.025
amp/frq (%)	9.8	6.6	Inc. frq. avg.	6.430	Sample rate(MSamp/s): 16	dr window (ns/s)	-0.030 0.030
					Data rate(Mb/s): 160 nlags: 128 t_cohere infinite	ion window (TEC)	0.00 0.00

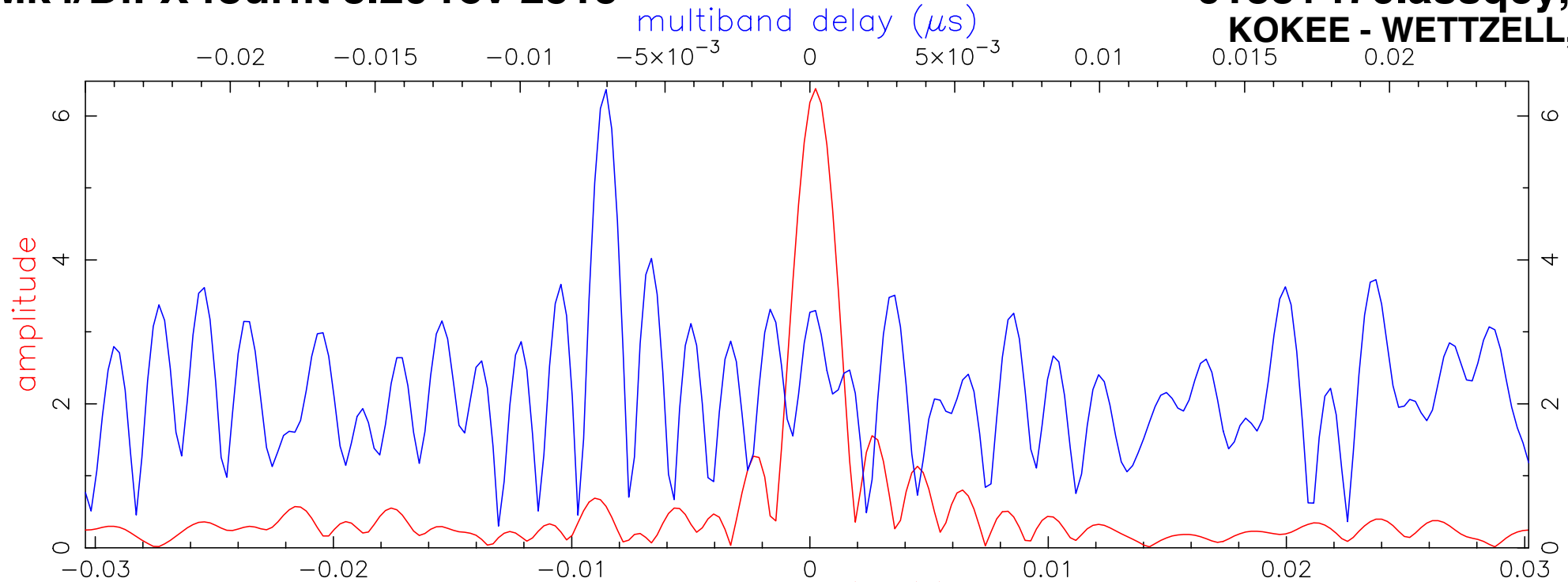
K: az 12.5 el 63.3 pa -162.5 V: az 349.4 el 8.1 pa 10.3 u,v (fr/asec) -264.790 -1189.877 simultaneous interpolator

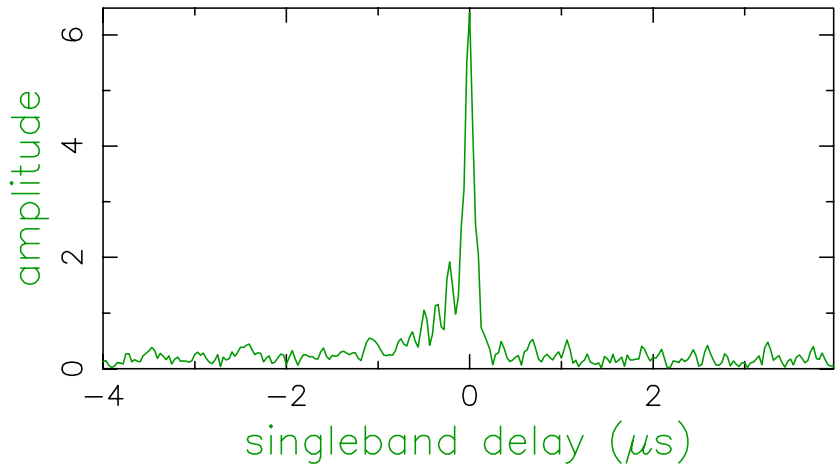
Control file: cf_4885 Input file: /isan/data1/correlator/run/r/r4885/Production_Pass/1234/074-0014//KV..assqcy Output file: Suppressed by test mode

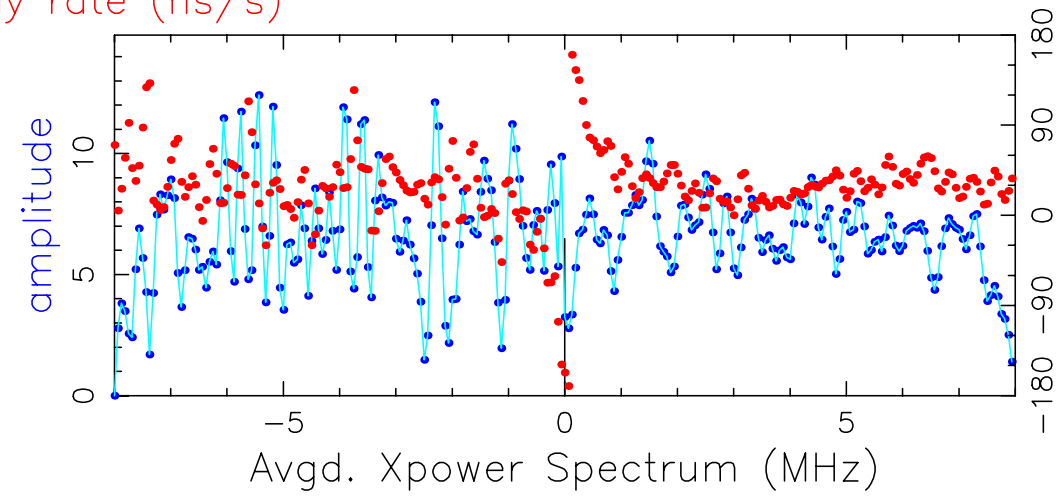
Mk4/DiFX fourfit 3.20 rev 2515

0133+476.assqcy, 074-0014, KV

KOKEE - WETTZELL, fgroup X, pol RR







Fringe quality 9

SNR	42.7
Int time	70.997
Amp	6.484
Phase	31.8
PFD	0.0e+00
Delays (us)	
SBD	-0.006904
MBD	-0.007070
Fringe rate (Hz)	0.001709
Ion TEC	0.000
Ref freq (MHz)	8220.9900
AP (sec)	2.000
Exp.	R4885
Exper #	4885
Yr:day	2019:074
Start	001417.00
Stop	001529.00
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Corr/FF/build	2019:088:144301
	2019:099:135958
	2019:022:182221
RA & Dec (J2000)	01h36m58.594810s
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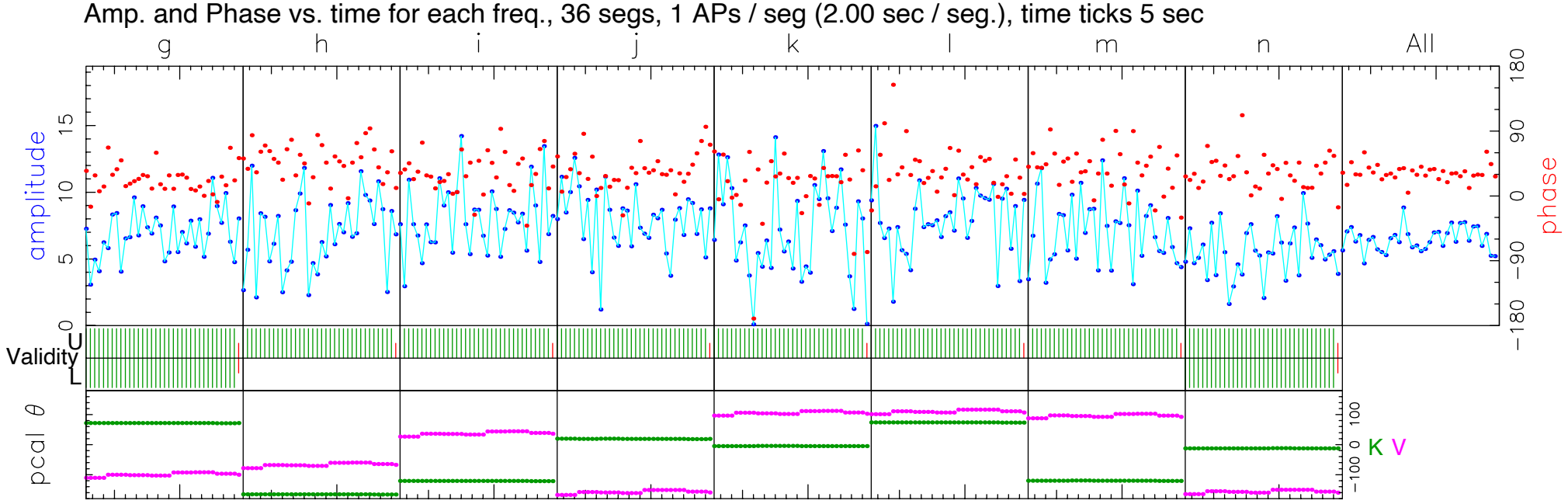

	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz)	All
	22.2	51.2	32.3	33.9	24.2	33.1	38.5	30.4	Phase	31.8
	6.6	6.4	7.2	7.2	6.5	7.2	6.4	5.2	Ampl.	6.4
	129.1	129.3	128.9	128.9	128.2	128.2	128.2	128.3	Sbd box	128.8
U/L	36/36	36/0	36/0	36/0	36/0	36/0	36/0	36/36	APs used	
K	-244.2	-233.9	-229.3	-235.1	-243.1	-250.8	-242.1	-251.4	PC R delays (ns)	
V	56.7	57.4	57.8	54.3	75.1	71.7	72.1	68.4	PC R delays (ns)	
K:V	72:-100	-165:-67	-121:37	19:-158	-5:105	74:110	-120:96	-12:-157	PC phase	
K:V	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	Manl PC	
K	23	25	24	23	22	20	14	11	PC amp	
V	21	20	23	22	21	23	22	22		
K	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids Tracks	
V	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids Tracks	

Group delay (usec)(model)	1.60781143456E+04	Apriori delay (usec)	1.60781214154E+04	Resid mbdelay (usec)	-7.06979E-03	+/- 1.3E-05
Sband delay (usec)	1.60781145114E+04	Apriori clock (usec)	-9.6033335E+00	Resid sbdelay (usec)	-6.90400E-03	+/- 1.2E-03
Phase delay (usec)	1.60781214261E+04	Apriori clockrate (us/s)	2.2560000E-07	Resid phdelay (usec)	1.07599E-05	+/- 6.5E-07
Delay rate (us/s)	3.20831462188E-01	Apriori rate (us/s)	3.20831254366E-01	Resid rate (us/s)	2.07822E-07	+/- 2.2E-08
Total phase (deg)	166.7	Apriori accel (us/s/s)	-1.17340437588E-04	Resid phase (deg)	31.8	+/- 1.9

	RMS	Theor.						
			Amplitude	6.484 +/- 0.152	Pcal mode: MULTITONE, MULTITONE PC period (AP's) 5, 5			
ph/seg (deg)	11.1	8.1	Search (128X256)	6.221	Pcal rate: 0.000E+00, 0.000E+00 (us/s)		sb window (us)	-4.000 4.000
amp/seg (%)	13.3	14.1	Interp.	0.000	Bits/sample: 1x1	SampCntNorm: disabled	mb window (us)	-0.025 0.025
ph/frq (deg)	9.8	3.8	Inc. seg. avg.	6.432	Sample rate(MSamp/s): 16		dr window (ns/s)	-0.030 0.030
amp/frq (%)	9.8	6.6	Inc. frq. avg.	6.430	Data rate(Mb/s): 160	nlags: 128 t_cohere infinite	ion window (TEC)	0.00 0.00

K: az 12.5 el 63.3 pa -162.5 V: az 349.4 el 8.1 pa 10.3 u,v (fr/asec) -264.790 -1189.877 simultaneous interpolator

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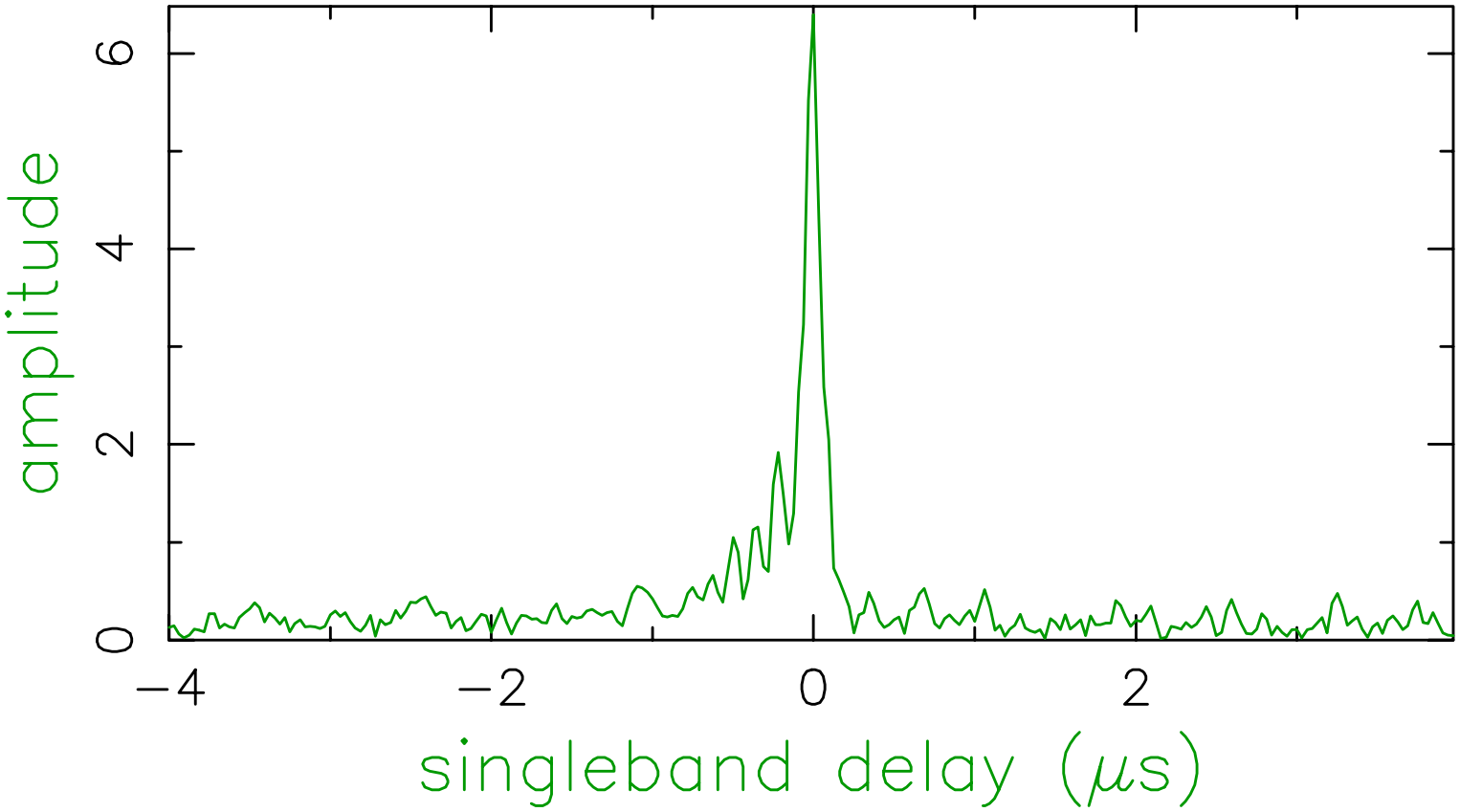
HOPS Fourfit: Single Band Delay (SBD)

- **Clock pass**:
  - relatively few observations
  - measure SBD and SBD rate
  - add SBD correction to **clock offset(s)** and **clock rate(s)**
- Update a priori clock offsets
- **Production Pass**:
  - all observations
  - apparent SBD $\cong 0$ (due to clock pass corrections)

HOPS Fourfit: Single Band Delay (SBD) Cont.

- Clock pass makes apparent **SBD ≤ 20 ns**, and ideally ≤ 10 ns
- Amplitude is typically a few hundred parts per million

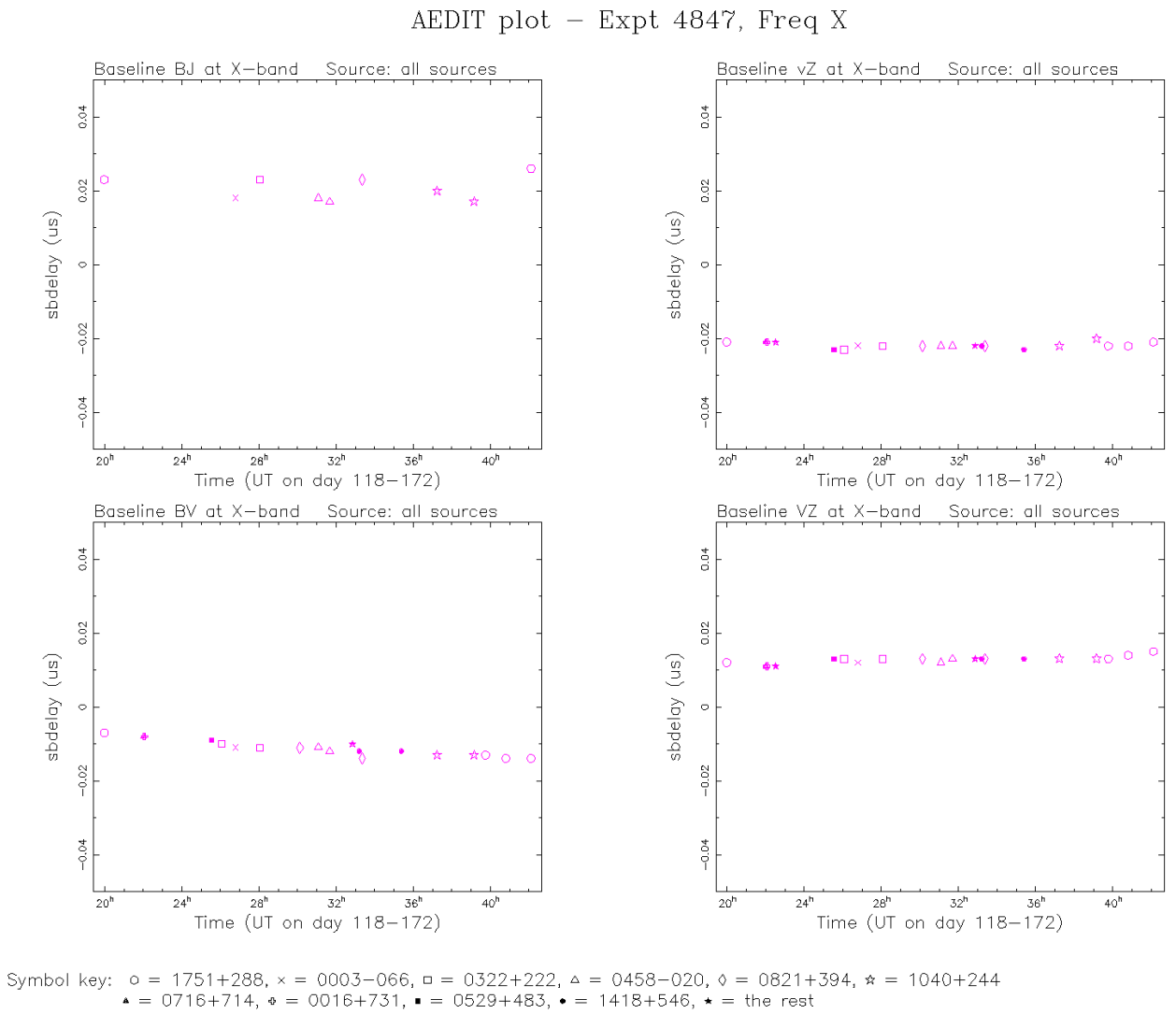


Fringe quality 9

SNR 42.7
Int time 70.997
Amp 6.484 × 100ppm
Phase 31.8
PFD 0.0e+00
Delays (us)
SBD -0.006904 μs
MBD -0.007070
Fringe rate (Hz)
0.001709
Ion TEC 0.000
Ref freq (MHz)
8220.9900
AP (sec) 2.000

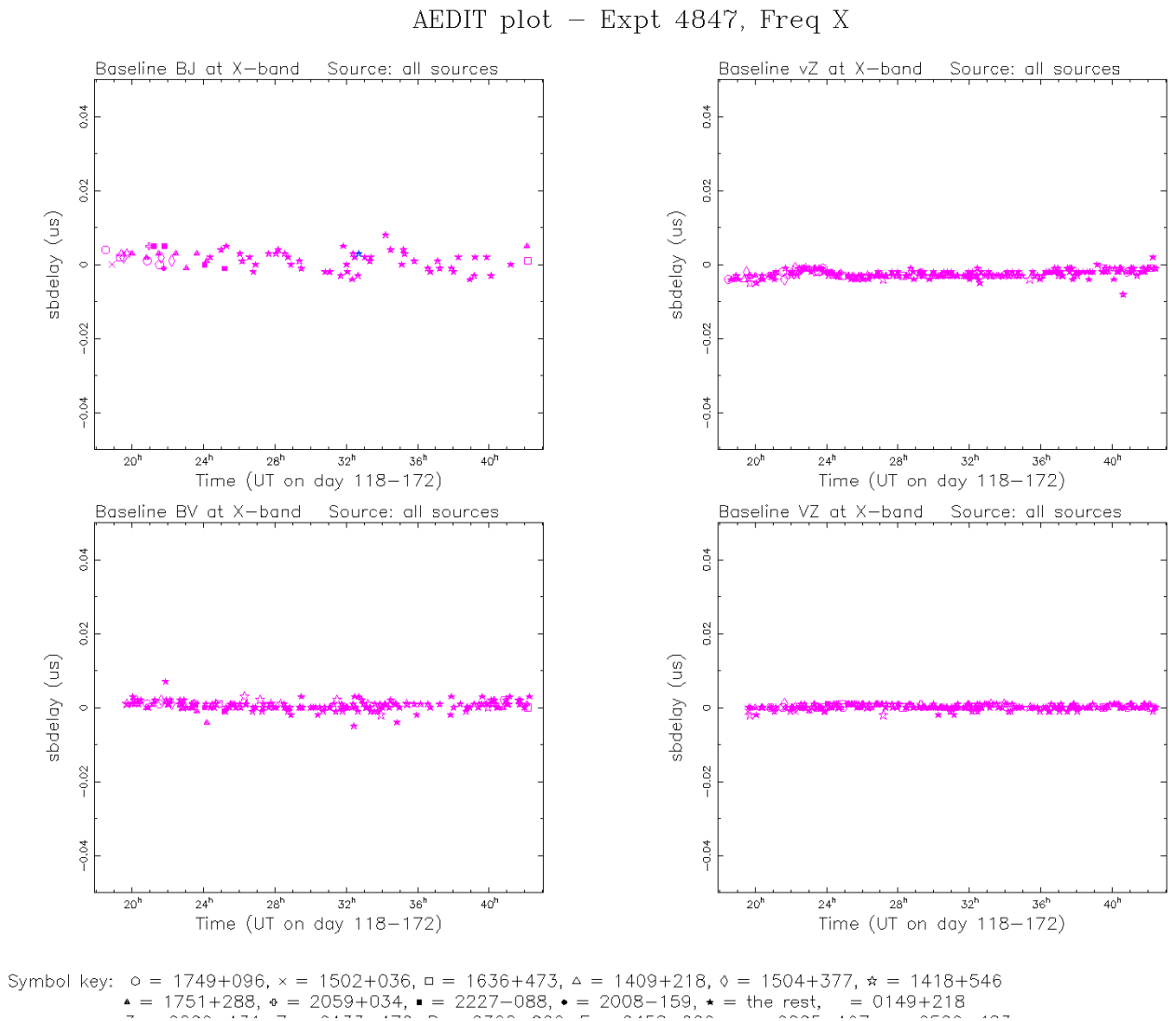
Exp. R4885
Exper # 4885
Yr:day 2019:074
Start 001417.00
Stop 001529.00
FRT 001445.00
Corr/FF/build
2019:088:144301
2019:099:135958
2019:022:182221
RA & Dec (J2000)
01h36m58.594810s
+47°51'29.100000"

HOPS aedit: Plot View



Clock pass, before offset and rate corrections

HOPS aedit: Plot View



Production pass, after offset and rate corrections

HOPS Fourfit: First Look

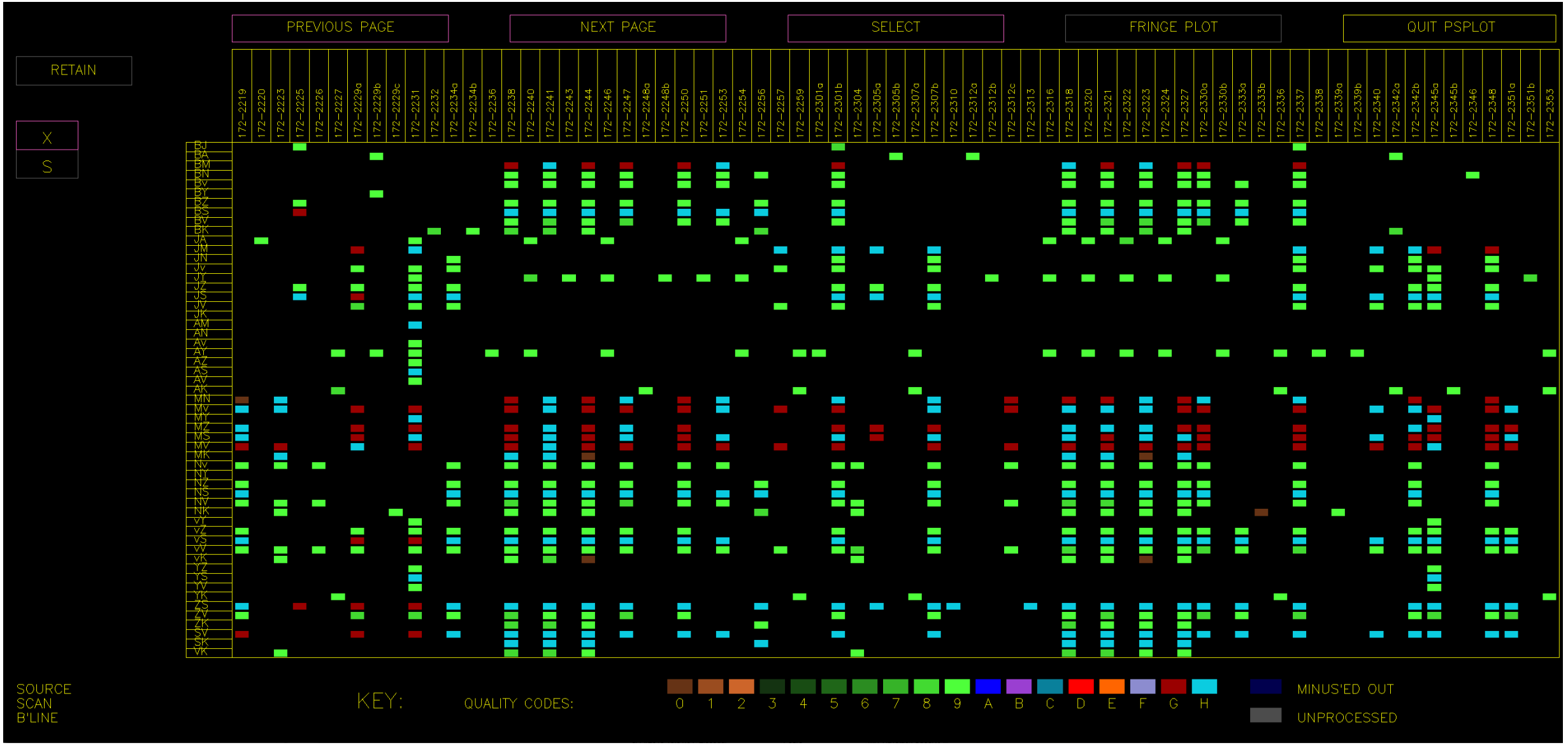
Before Configuration:

- Lots of G Codes (low amp. chan.)
- Lots of H Codes (low amp. phase)
- Some 0 Codes (no fringe detected)
- Other quality codes are spread out.

	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
A:S	-	-	-	-	-	-	18	25	22	-	-	-	-	-	-	1	36	668	770
A:X	-	-	-	-	-	-	8	**77**	8	-	-	-	-	-	-	3	61	613	770
B:S	-	-	-	-	-	-	**263**	32	-	-	-	-	-	-	1	17	204	1029	1546
B:X	-	-	-	-	-	-	92	**294**	4	-	-	-	-	1	1	9	101	1044	1546
J:S	-	-	-	-	-	-	**124**	44	31	-	-	-	-	-	1	7	85	725	1017
J:X	-	-	-	-	-	-	49	**196**	18	-	-	-	-	-	-	3	69	682	1017
K:S	-	-	-	-	-	-	68	53	19	-	-	-	-	-	-	7	62	745	954
K:X	-	-	-	-	-	-	16	**160**	26	-	-	-	-	-	1	15	154	582	954
M:S	-	-	-	-	-	-	**1406**	**319**	11	-	-	-	-	-	-	-	-	-	1736
M:X	-	-	-	-	-	-	**914**	**791**	31	-	-	-	-	-	-	-	-	-	1736
N:S	-	-	-	-	-	-	**234**	64	16	-	-	-	-	1	1	52	255	1011	1634
N:X	-	-	-	-	-	-	105	**335**	8	-	-	-	-	3	1	12	107	1063	1634
S:S	-	-	-	-	-	-	**413**	71	41	-	-	-	-	1	1	56	307	891	1781
S:X	-	-	-	-	-	-	177	**1585**	19	-	-	-	-	-	-	-	-	-	1781
V:S	-	-	-	-	-	-	**360**	37	13	-	-	-	-	-	2	13	123	1283	1831
V:X	-	-	-	-	-	-	**206**	**337**	7	-	-	-	-	2	3	32	321	923	1831
v:S	-	-	-	-	-	-	**340**	66	22	-	-	-	-	-	2	11	172	1254	1867
v:X	-	-	-	-	-	-	160	**395**	12	-	-	-	-	3	1	21	150	1125	1867
Y:S	-	-	-	-	-	-	19	21	21	-	-	-	-	-	-	4	94	557	716
Y:X	-	-	-	-	-	-	11	66	3	-	-	-	-	1	1	-	41	593	716
Z:S	-	-	-	-	-	-	**537**	170	30	-	-	-	-	-	4	90	326	595	1752
Z:X	-	-	-	-	-	-	160	**354**	4	-	-	-	-	2	2	11	130	1089	1752

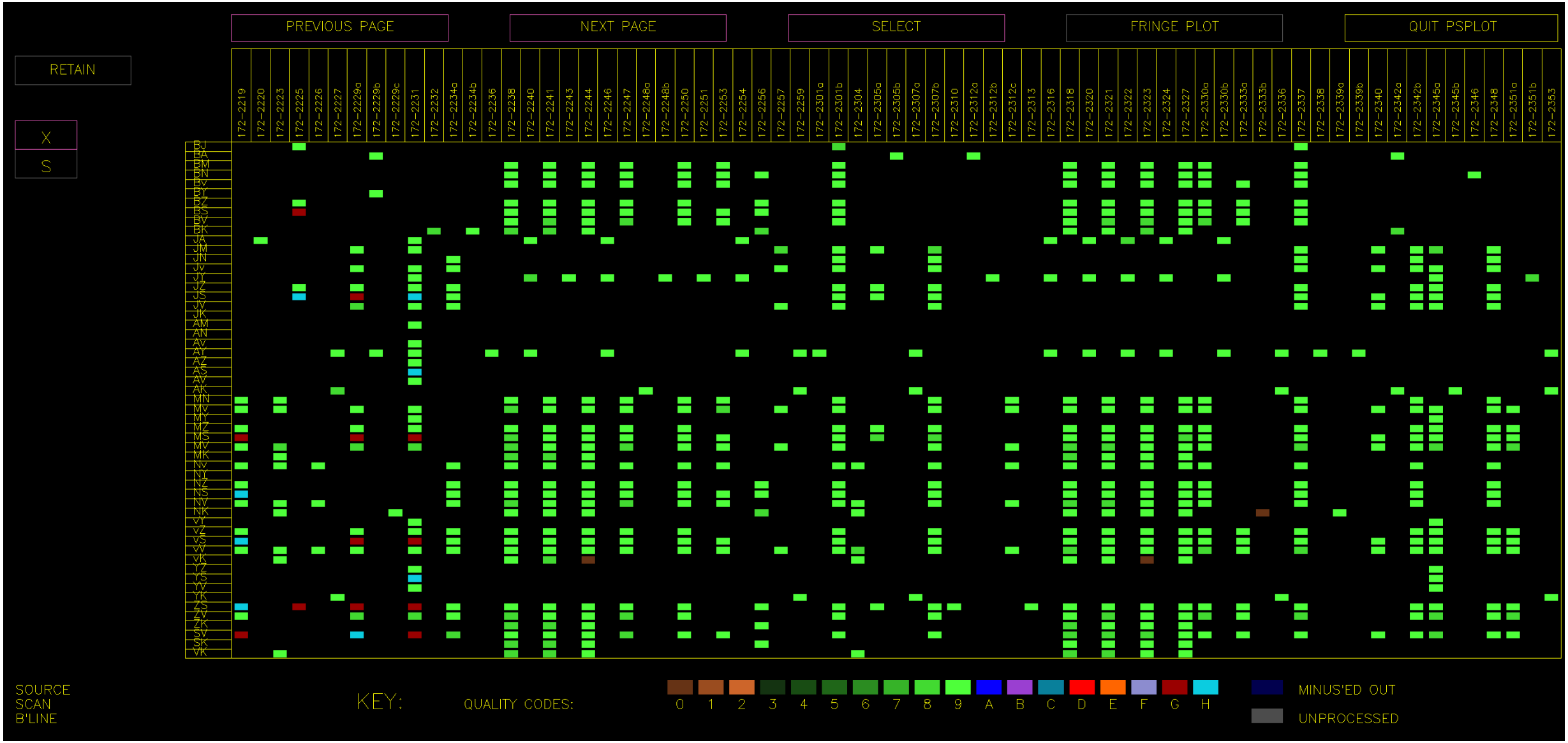
	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
*:S	-	-	-	-	-	-	**1891**	451	113	-	-	-	-	1	6	129	832	4379	7802
*:X	-	-	-	-	-	-	**949**	**2295**	70	-	-	-	-	6	5	53	567	3857	7802
:	-	-	-	-	-	-	**2840**	**2746**	183	-	-	-	-	7	11	182	1399	8236	15604

HOPS aedit: Summary View



Before cf configuration file.

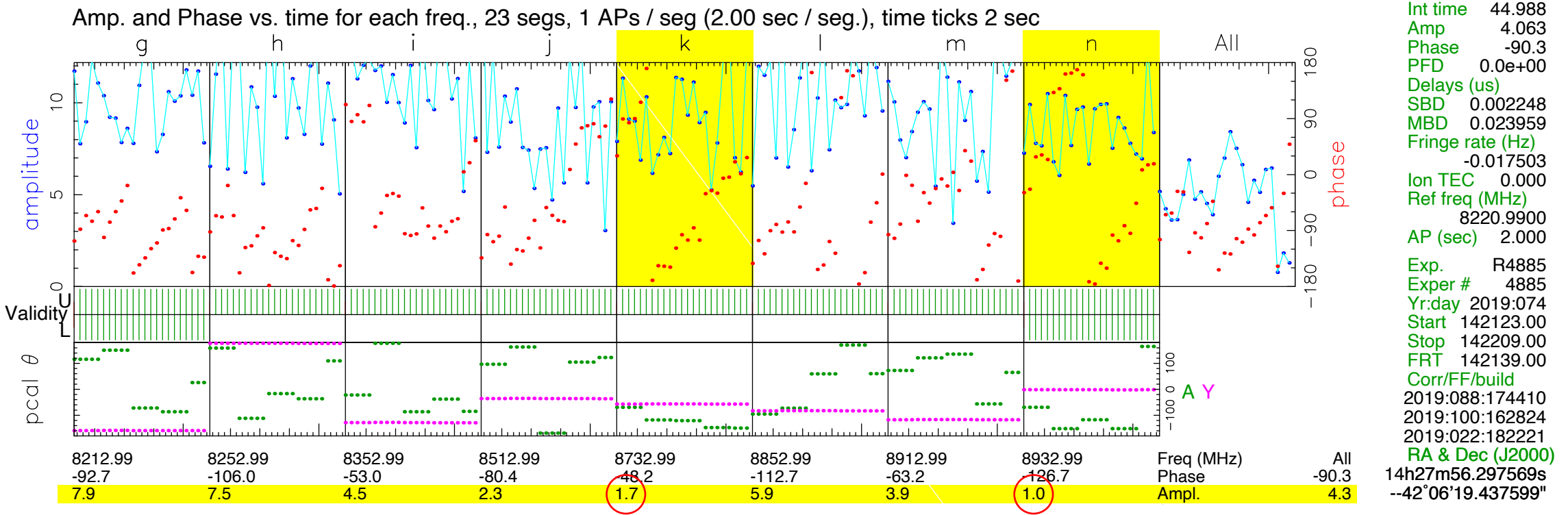
HOPS aedit: Summary View



After cf configuration file.

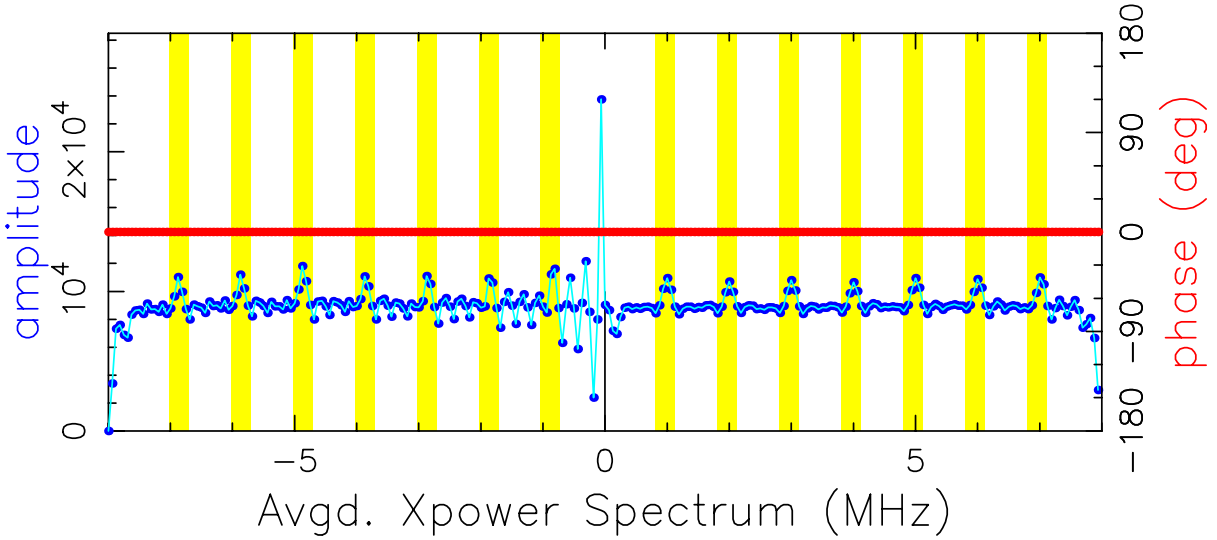
HOPS Fourfit: Weak Channels

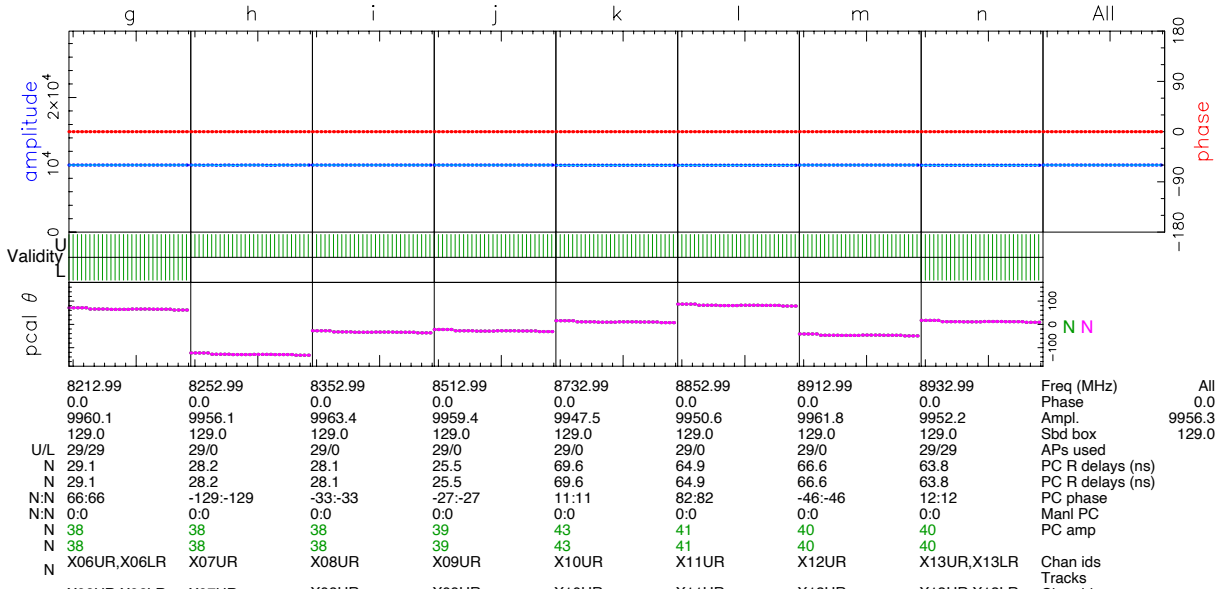
- Radio frequency interference (RFI), and/or signal chain problems can cause low signal to noise (SNR) in one or more channel(s).
- **G Code** error (weak channel) happens when: $\boldsymbol{SNR_{chan} < \frac{SNR_{avg}}{2}}$
- Correlator drops channels with excessive G Codes.



HOPS Fourfit: Phase Calibration (pcal)

- Injected phase calibration (pcal) tones cause regularly spaced spikes in the apparent power spectrum of autocorrelations.
- Spacing is usually 1 MHz for S/X-band observations.
- Weak tones can be missed.
- Narrow RFI at pcal frequencies may cause spurious detection.
- DiFX extracts all pcal tones, so a few missing tones can be ignored, (e.g. due to RFI).



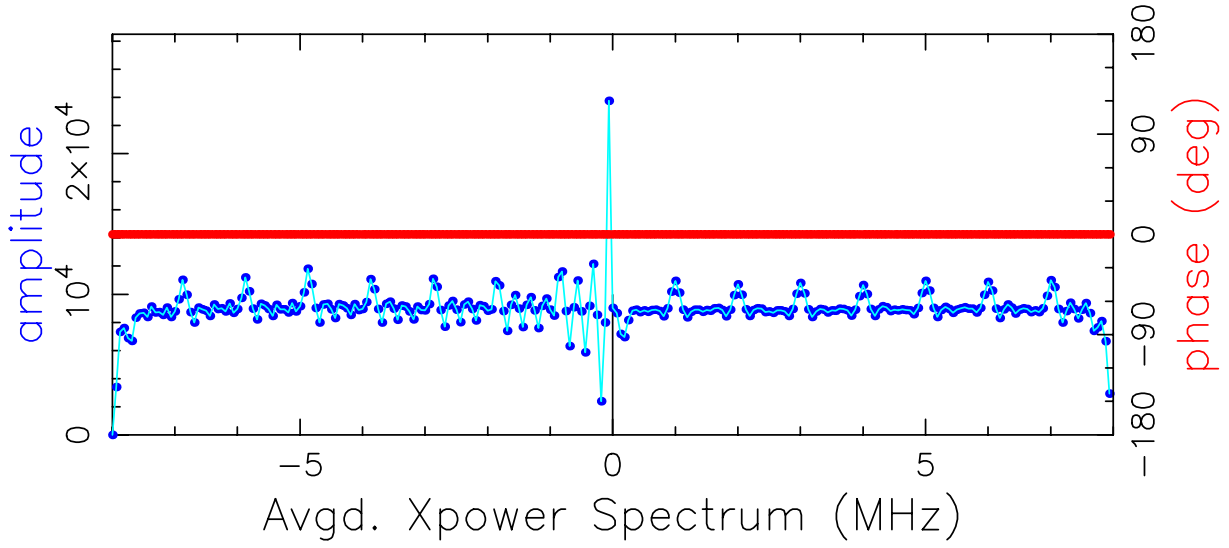


	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz) All
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Phase 0.0
	9960.1	9956.1	9963.4	9959.4	9947.5	9950.6	9961.8	9952.2	Ampl. 9956.3
	129.0	129.0	129.0	129.0	129.0	129.0	129.0	129.0	Sbd box 129.0
U/L	29/29	29/0	29/0	29/0	29/0	29/0	29/0	29/29	APs used
N	29.1	28.2	28.1	25.5	69.6	64.9	66.6	63.8	PC R delays (ns)
N	29.1	28.2	28.1	25.5	69.6	64.9	66.6	63.8	PC R delays (ns)
N:N	66:66	-129:-129	-33:-33	-27:-27	11:11	82:82	-46:-46	12:12	PC phase
N:N	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	Manl PC
N	38	38	38	39	43	41	40	40	PC amp
N	38	38	38	39	43	41	40	40	
N	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids Tracks

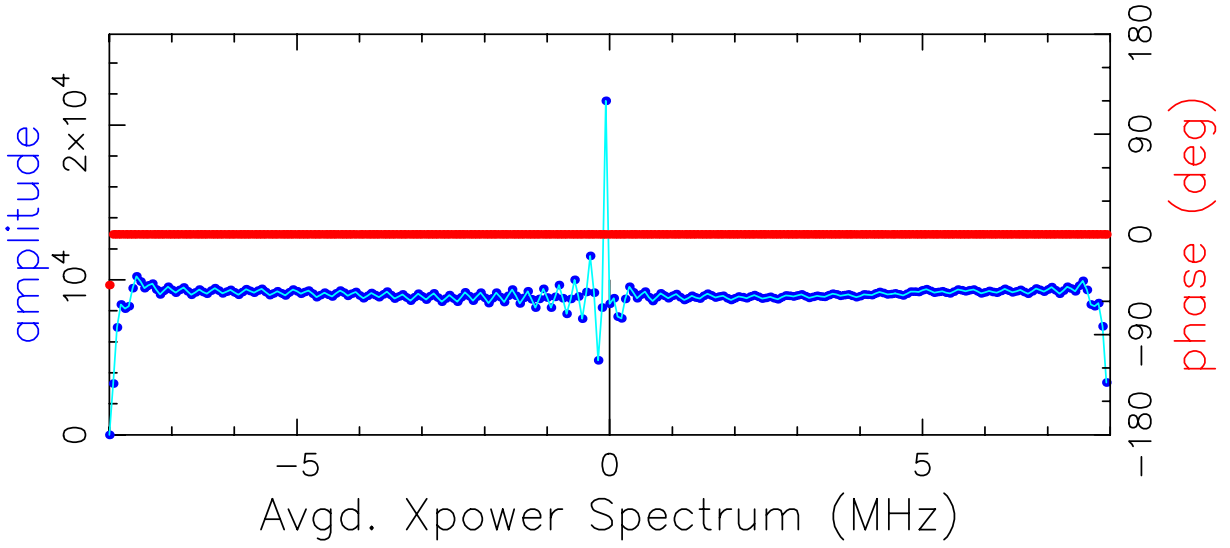
HOPS Fourfit: Phase Calibration (pcal) Cont.

- Here are two example power spectra from autocorrelations with and without good phase calibration tone injection.

sufficient
phase calibration tones

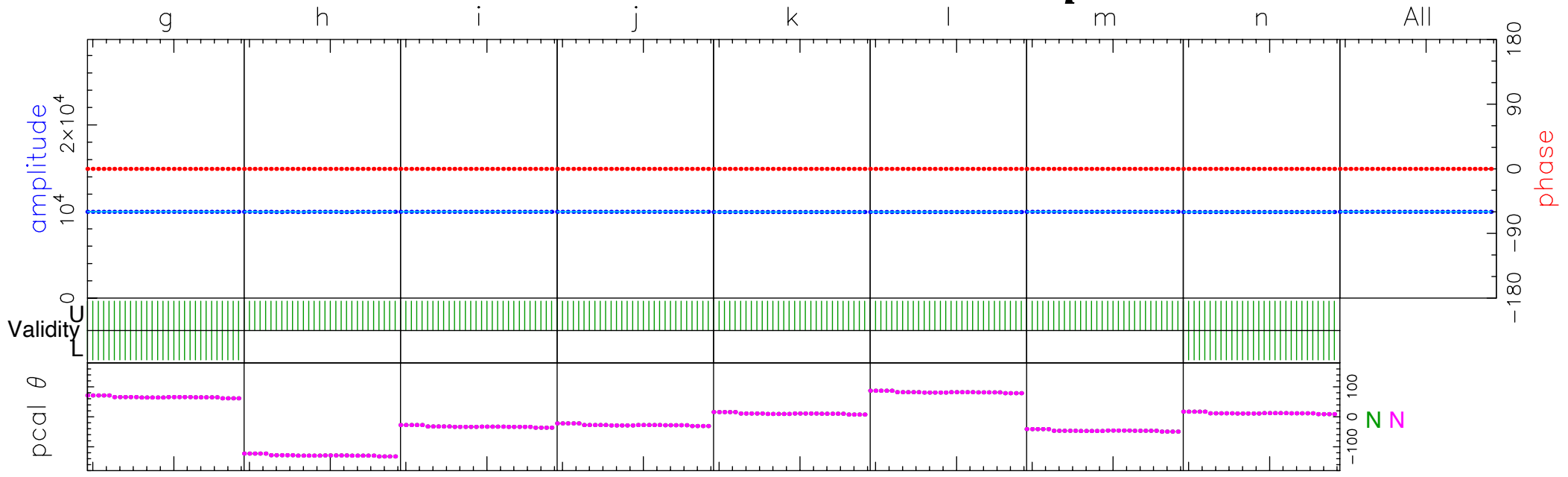


no detectable
phase calibration tones



HOPS Fourfit: Phase Calibration (pcal) Cont.

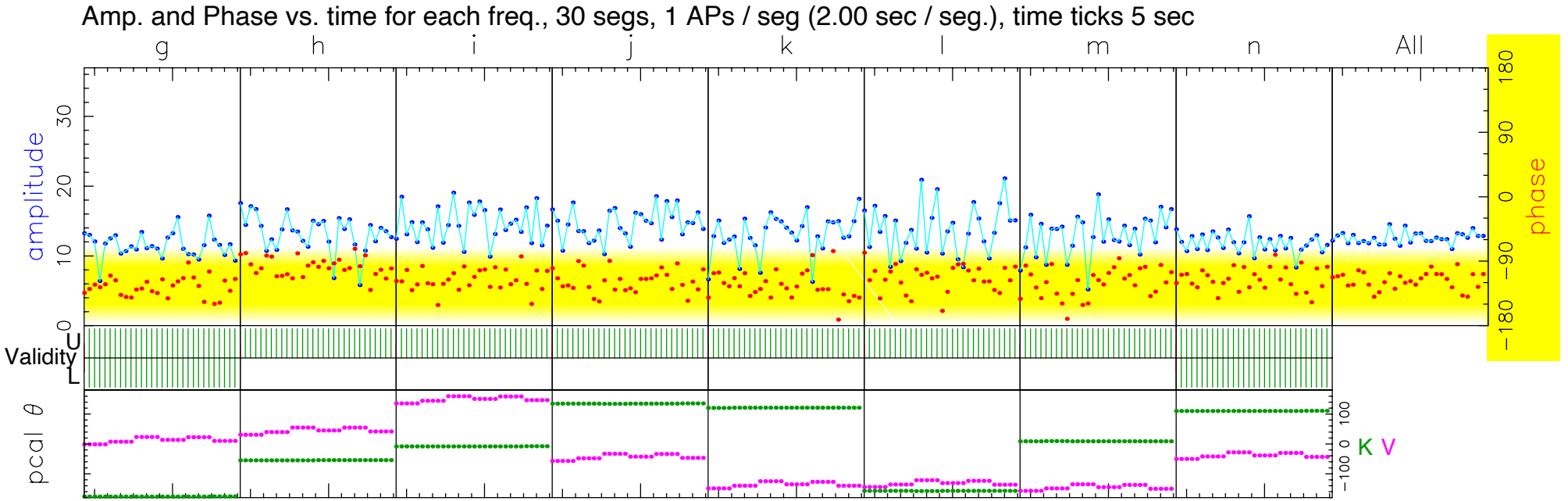
- Phase calibration (PC) amplitude corresponds to pcal SNR.
- **H Code** error (no pcal) happens when: $\boldsymbol{Amp_{pcal} < 500ppm}$



	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz)	All
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Phase	0.0
	9960.1	9956.1	9963.4	9959.4	9947.5	9950.6	9961.8	9952.2	Ampl.	9956.3
	129.0	129.0	129.0	129.0	129.0	129.0	129.0	129.0	Sbd box	129.0
U/L	29/29	29/0	29/0	29/0	29/0	29/0	29/0	29/29	APs used	
N	29.1	28.2	28.1	25.5	69.6	64.9	66.6	63.8	PC R delays (ns)	
N	29.1	28.2	28.1	25.5	69.6	64.9	66.6	63.8	PC R delays (ns)	
N:N	66:66	-129:-129	-33:-33	-27:-27	11:11	82:82	-46:-46	12:12	PC phase	
N:N	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	Manl PC	
N	38	38	38	39	43	41	40	40	PC amp	
N	38	38	38	39	43	41	40	40		
N	X06UR,X06LR	X07UR	X08UR	X09UR	X10UR	X11UR	X12UR	X13UR,X13LR	Chan ids Tracks	

HOPS Fourfit: Phase Calibration (pcal) Cont.

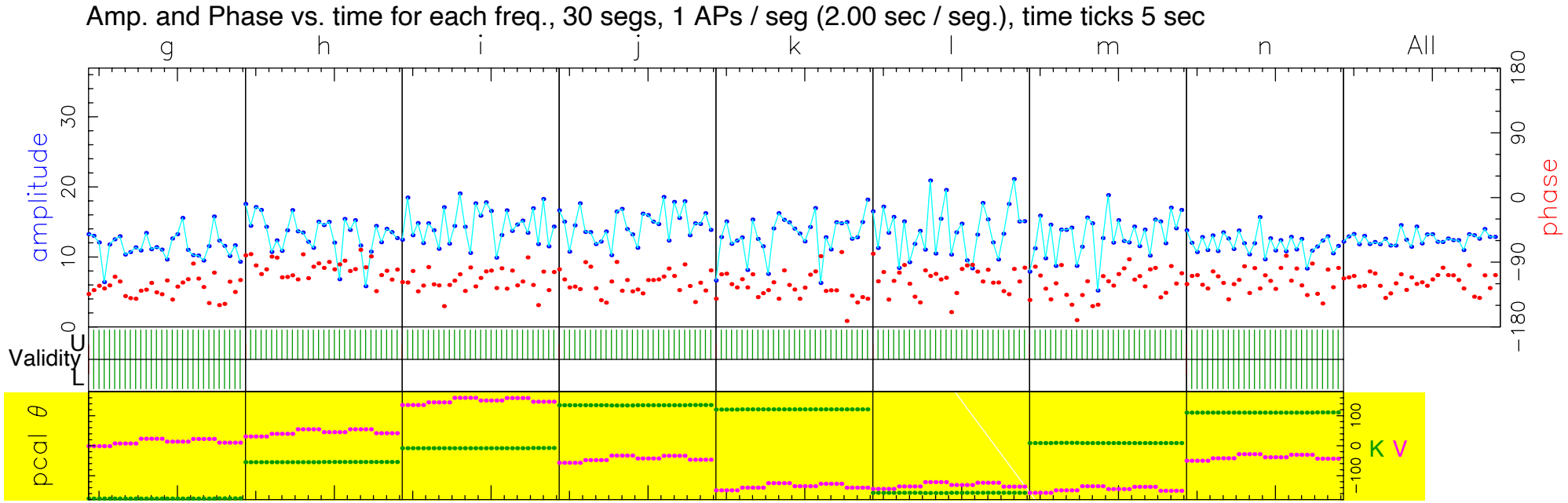
- After fringe fitting and phase calibration, the phases should appear normally distributed around a single mean value.



	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz)	All
	-125.7	-98.1	-115.5	-117.7	-123.7	-113.8	-118.3	-114.7	Phase	-116.6
	11.2	12.9	14.1	14.1	12.4	13.3	12.3	11.4	Ampl.	12.4
	129.3	129.3	129.4	129.3	128.7	128.2	128.7	128.6	Sbd box	129.0
U/L	30/30	30/0	30/0	30/0	30/0	30/0	30/0	30/30	APs used	
K	-243.3	-234.0	-229.6	-235.3	-242.0	-249.9	-241.4	-252.8	PC R delays (ns)	
V	56.7	57.4	57.8	54.3	75.2	71.8	72.3	68.7	PC R delays (ns)	
K:V	-176:12	-54:44	-8:150	135:-43	121:-136	-157:-132	9:-146	110:-39	PC phase	

HOPS Fourfit: Phase Calibration (pcal) Cont.

- Measured pcal phase should be relatively flat within each channel.
- Slopes or curves in the pcal phase within a channel can indicate a drifting or unstable phase calibration.



	8212.99	8252.99	8352.99	8512.99	8732.99	8852.99	8912.99	8932.99	Freq (MHz)	All
	-125.7	-98.1	-115.5	-117.7	-123.7	-113.8	-118.3	-114.7	Phase	-116.6
	11.2	12.9	14.1	14.1	12.4	13.3	12.3	11.4	Ampl.	12.4
	129.3	129.3	129.4	129.3	128.7	128.2	128.7	128.6	Sbd box	129.0
U/L	30/30	30/0	30/0	30/0	30/0	30/0	30/0	30/30	APs used	
K	-243.3	-234.0	-229.6	-235.3	-242.0	-249.9	-241.4	-252.8	PC R delays (ns)	
V	56.7	57.4	57.8	54.3	75.2	71.8	72.3	68.7	PC R delays (ns)	
K:V	-176:12	-54:44	-8:150	135:-43	121:-136	-157:-132	9:-146	110:-39	PC phase	

HOPS Fourfit: Final Look

After Configuration:

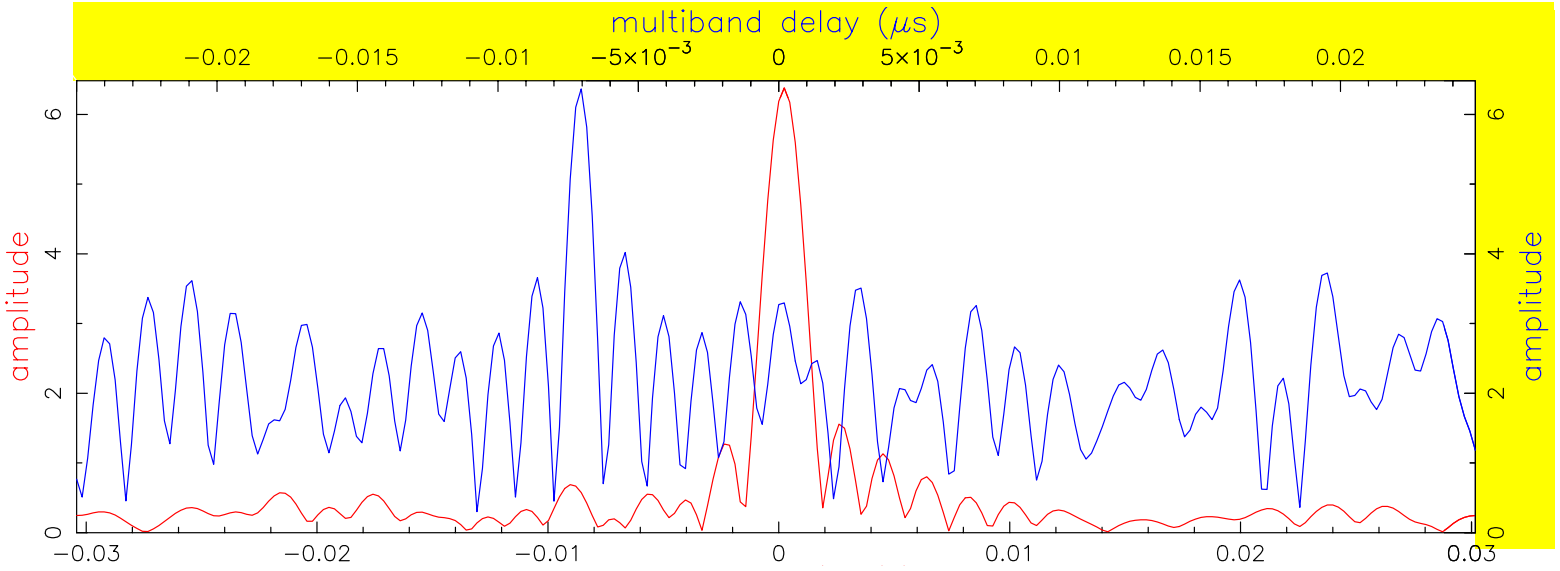
- Fewer G and H Codes
- Fewer 0 Codes
- More 7—9 Codes.
- Goal:
  ≥ 90% 7—9 Codes

	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
A:S	-	-	-	-	-	-	-	2	21	-	-	-	-	-	-	-	34	713	770
A:X	-	-	-	-	-	-	-	3	5	-	-	-	-	-	-	9	85	668	770
B:S	-	-	-	-	-	-	31	10	-	-	-	-	-	-	-	11	216	1278	1546
B:X	-	-	-	-	-	-	7	3	2	-	-	-	-	2	3	20	156	1353	1546
J:S	-	-	-	-	-	-	2	2	29	-	-	-	-	-	1	4	53	926	1017
J:X	-	-	-	-	-	-	1	5	11	-	-	-	-	-	3	10	117	870	1017
K:S	-	-	-	-	-	-	5	6	18	-	-	-	-	-	-	3	57	865	954
K:X	-	-	-	-	-	-	4	2	16	-	-	-	-	-	2	26	190	714	954
M:S	-	-	-	-	-	-	24	7	8	-	-	-	-	-	2	19	166	1510	1736
M:X	-	-	-	-	-	-	7	3	5	-	-	-	-	13	22	65	432	1189	1736
N:S	-	-	-	-	-	-	17	8	15	-	1	-	-	1	1	23	306	1262	1634
N:X	-	-	-	-	-	-	3	5	4	-	-	-	-	7	4	25	162	1424	1634
S:S	-	-	-	-	-	-	43	-	36	-	1	-	-	1	-	33	298	1369	1781
S:X	-	-	-	-	-	-	39	29	19	-	-	-	-	3	9	80	440	1162	1781
V:S	-	-	-	-	-	-	21	6	13	-	-	-	-	-	2	6	109	1674	1831
V:X	-	-	-	-	-	-	8	2	7	-	-	-	-	7	9	60	578	1160	1831
v:S	-	-	-	-	-	-	26	9	22	-	-	-	-	-	2	7	170	1631	1867
v:X	-	-	-	-	-	-	5	5	12	-	-	-	-	8	12	50	308	1467	1867
Y:S	-	-	-	-	-	-	1	2	21	-	-	-	-	-	-	2	101	589	716
Y:X	-	-	-	-	-	-	-	4	3	-	-	-	-	1	1	4	61	642	716
Z:S	-	-	-	-	-	-	52	34	27	-	-	-	-	-	4	34	306	1295	1752
Z:X	-	-	-	-	-	-	8	3	4	-	-	-	-	3	5	21	221	1487	1752

	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
*:S	-	-	-	-	-	-	111	43	105	-	1	-	-	1	6	71	908	6556	7802
*:X	-	-	-	-	-	-	41	32	44	-	-	-	-	22	35	185	1375	6068	7802
:	-	-	-	-	-	-	152	75	149	-	1	-	-	23	41	256	2283	12624	15604

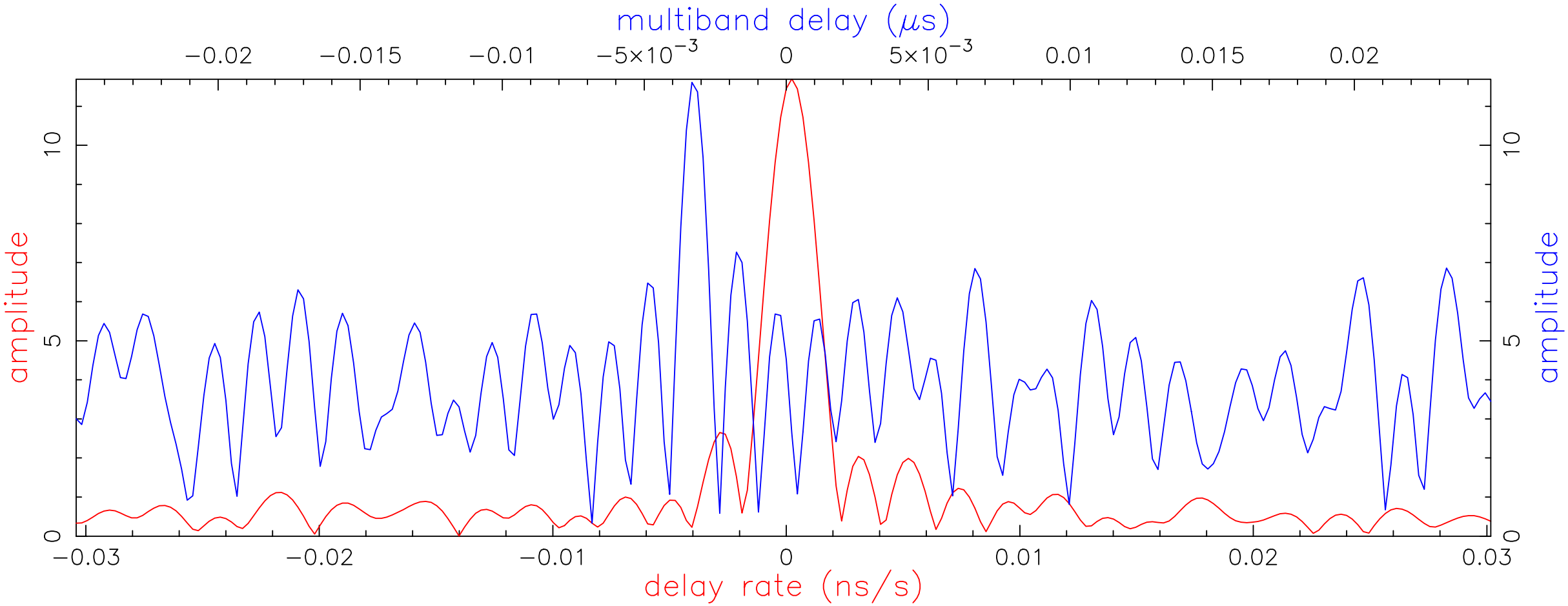
HOPS Fourfit: Multiband Delay

- Each channel only gives a single mean frequency:
  We must combine channels to cover the whole band.
- Fourier transforming phase differences between each channel yields a representative sine wave.
- Different spacings produce different sine waves (some redundant).
- The sum of these sine waves is the **multiband delay function**.



HOPS Fourfit: Multiband Delay Cont.

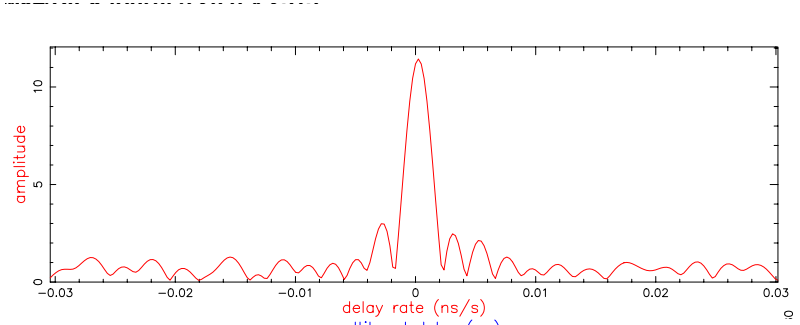
- Removing channels removes spacings and causes ambiguities.



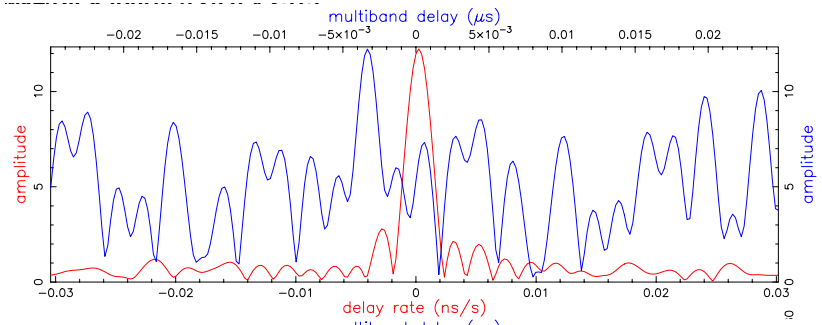
8 channels, 28 spacings

HOPS Fourfit: Multiband Delay Cont.

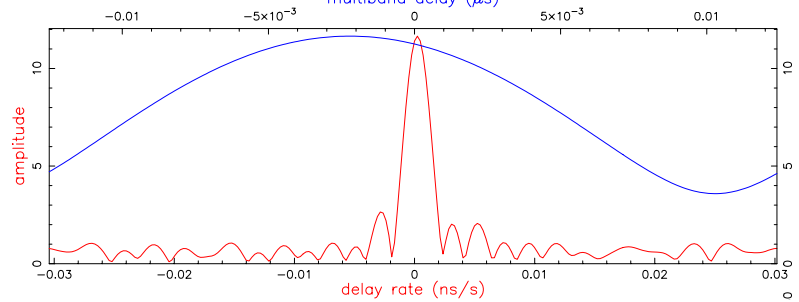
1 channel
0 spacings



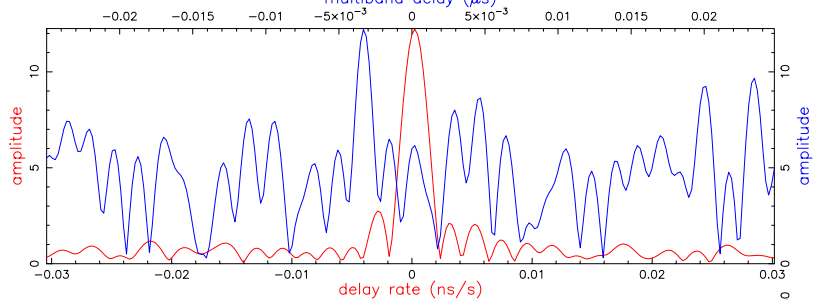
5 channels
10 spacings



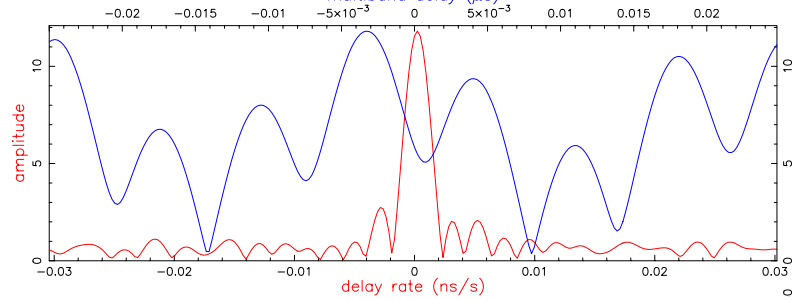
2 channels
1 spacing



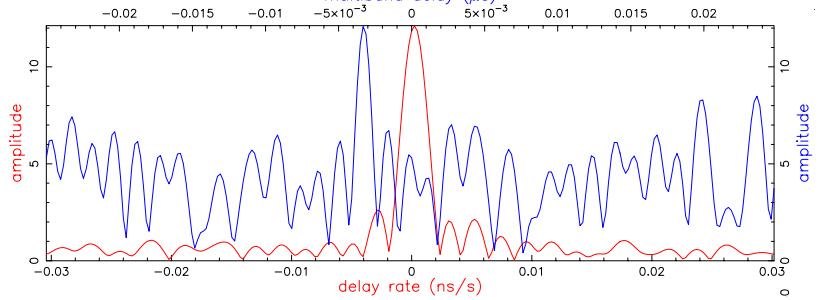
6 channels
15 spacings



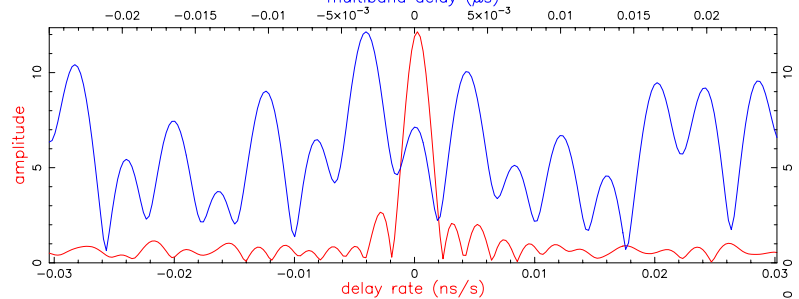
3 channels
3 spacings



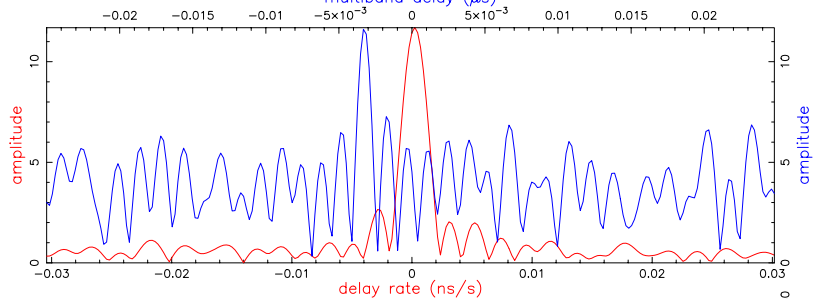
7 channels
21 spacings



4 channels
6 spacings

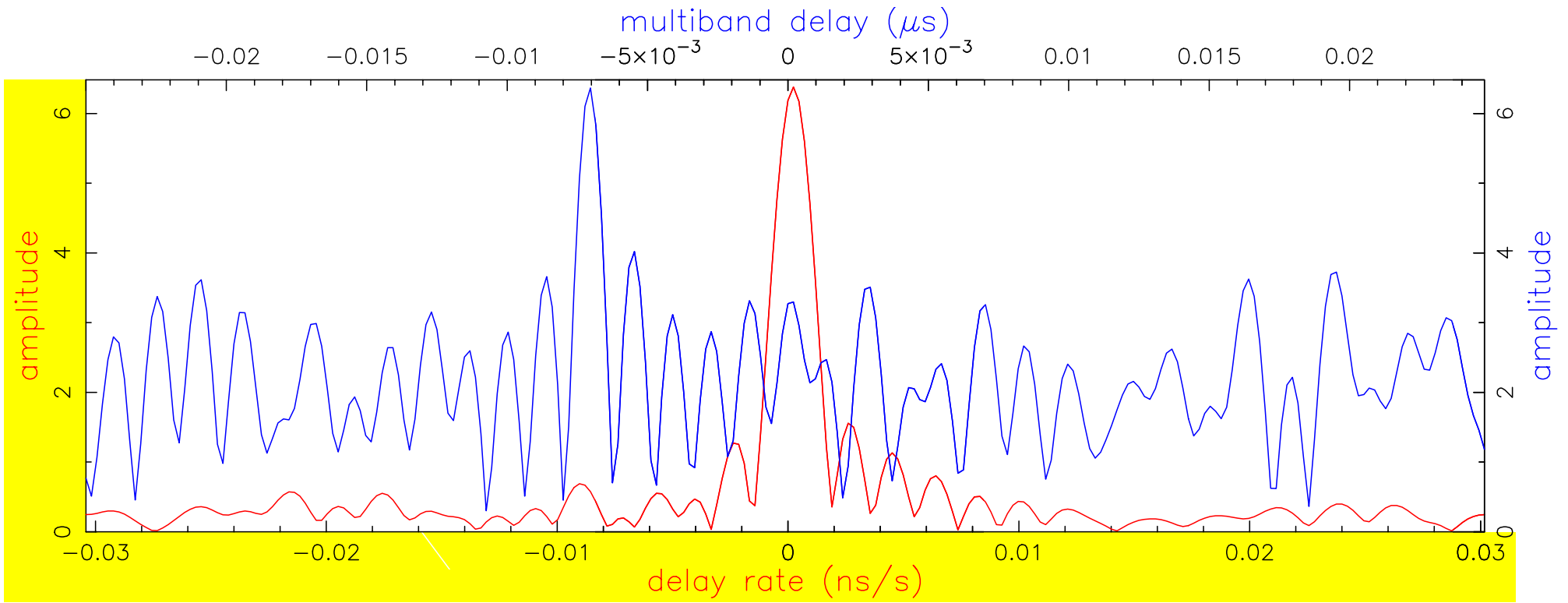


8 channels
28 spacings



HOPS Fourfit: Fringe Rate and Delay Rate

- Fringe Rate (FR): Phase Slope vs Time
- Delay Rate (DR): Phase Slope vs Frequency



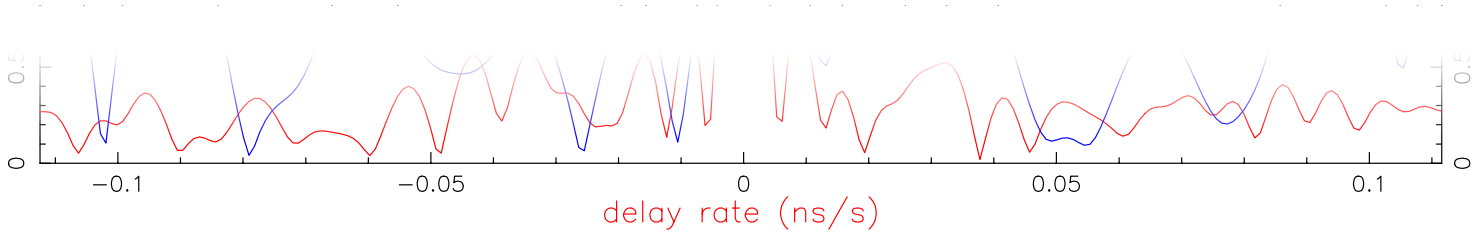
Fringe quality 9

SNR 42.7
Int time 70.997
Amp 6.484 × 100ppm
Phase 31.8
PFD 0.0e+00
Delays (us)
SBD -0.006904
MBD -0.007070
Fringe rate (Hz)
0.001709
Ion TEC 0.000
Ref freq (MHz)
8220.9900
AP (sec) 2.000

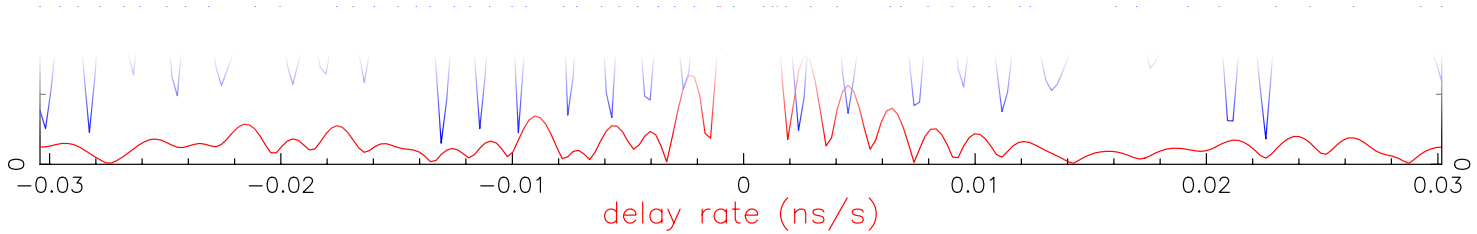
Exp. R4885
Exper # 4885
Yr:day 2019:074
Start 001417.00
Stop 001529.00
FRT 001445.00
Corr/FF/build
2019:088:144301
2019:099:135958
2019:022:182221
RA & Dec (J2000)
01h36m58.594810s
+47°51'29.100000"

HOPS Fourfit: Fringe Rate and Delay Rate Cont.

- Delay Rate (DR) window = $\frac{1}{2 \cdot AP \cdot \nu}$
  - $AP =$ accumulation period
  - $\nu =$ reference frequency
- The DR plot axes are confined by the DR window:



- S (1 sec AP, 2.22 GHz): DRW = 2.25×10^{-10}



- X (1 sec AP, 8.22 GHz): DRW = 6.08×10^{-11}

Fringe quality 9

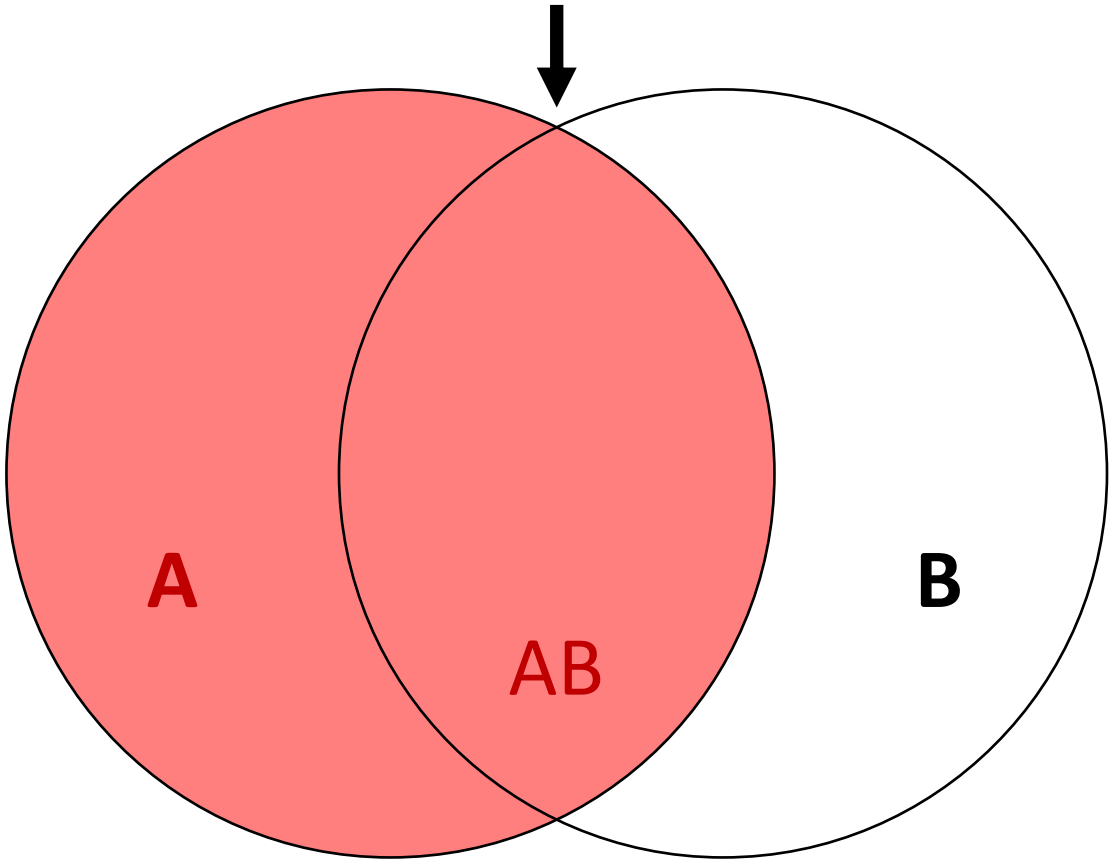
SNR 42.7
Int time 70.997
Amp 6.484 × 100ppm
Phase 31.8
PFD 0.0e+00
Delays (us)
SBD -0.006904
MBD -0.007070
Fringe rate (Hz)
0.001709
Ion TEC 0.000
Ref freq (MHz)
8220.9900
AP (sec) 2.000

Exp. R4885
Exper # 4885
Yr:day 2019:074
Start 001417.00
Stop 001529.00
FRT 001445.00
Corr/FF/build
2019:088:144301
2019:099:135958
2019:022:182221
RA & Dec (J2000)
01h36m58.594810s
+47°51'29.100000"

The Baseline Problem:

We only see 2-station **baselines** and 3-station **closures**.

We can't tell which station
has a problem with only one baseline
(we need to use other information).



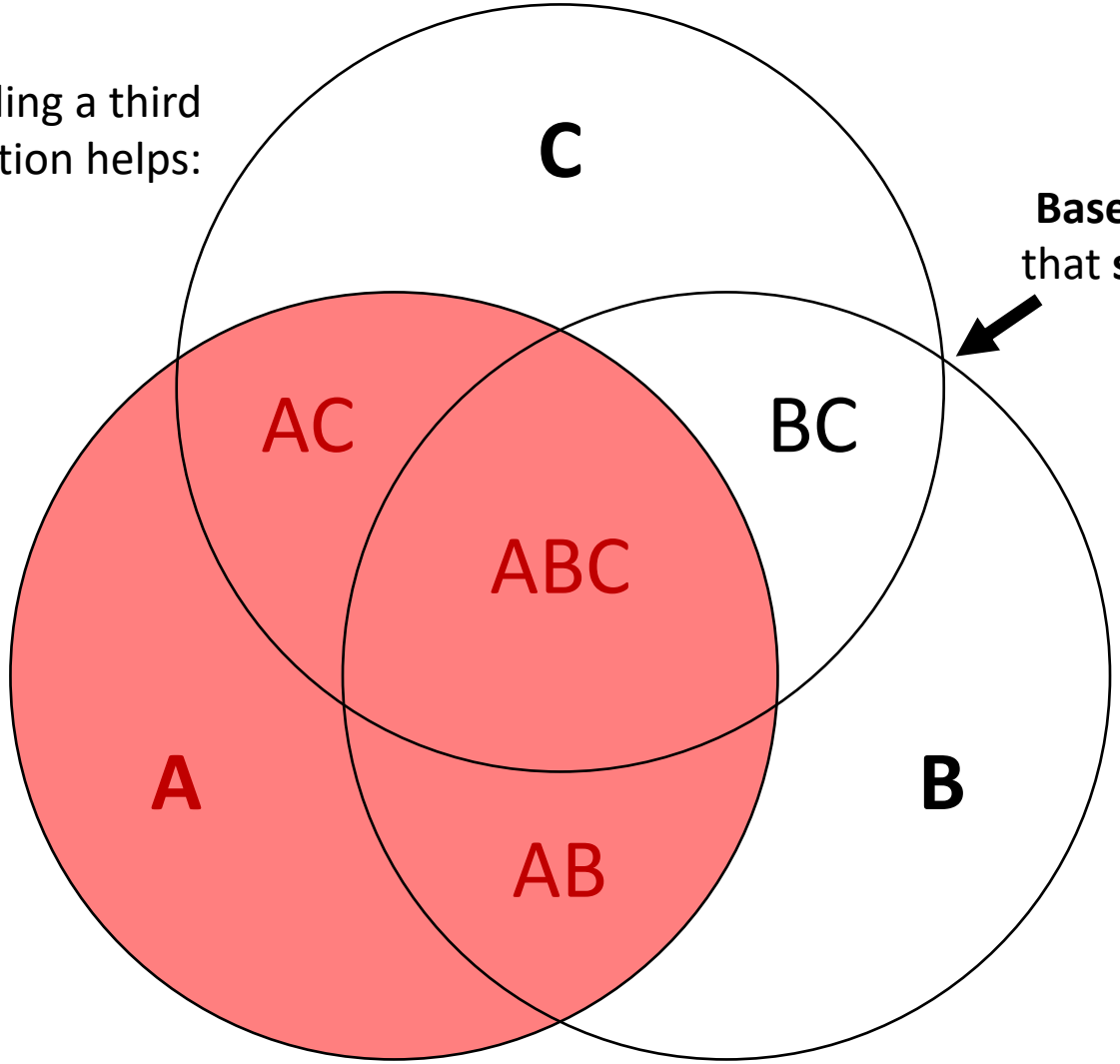
Correlator Report:

```
+CORRELATOR_NOTES
Aa-Bb: Removed channel(s) from
       fringe fitting: SR1U
```

The Baseline Problem:

We only see 2-station **baselines** and 3-station **closures**.

Adding a third station helps:

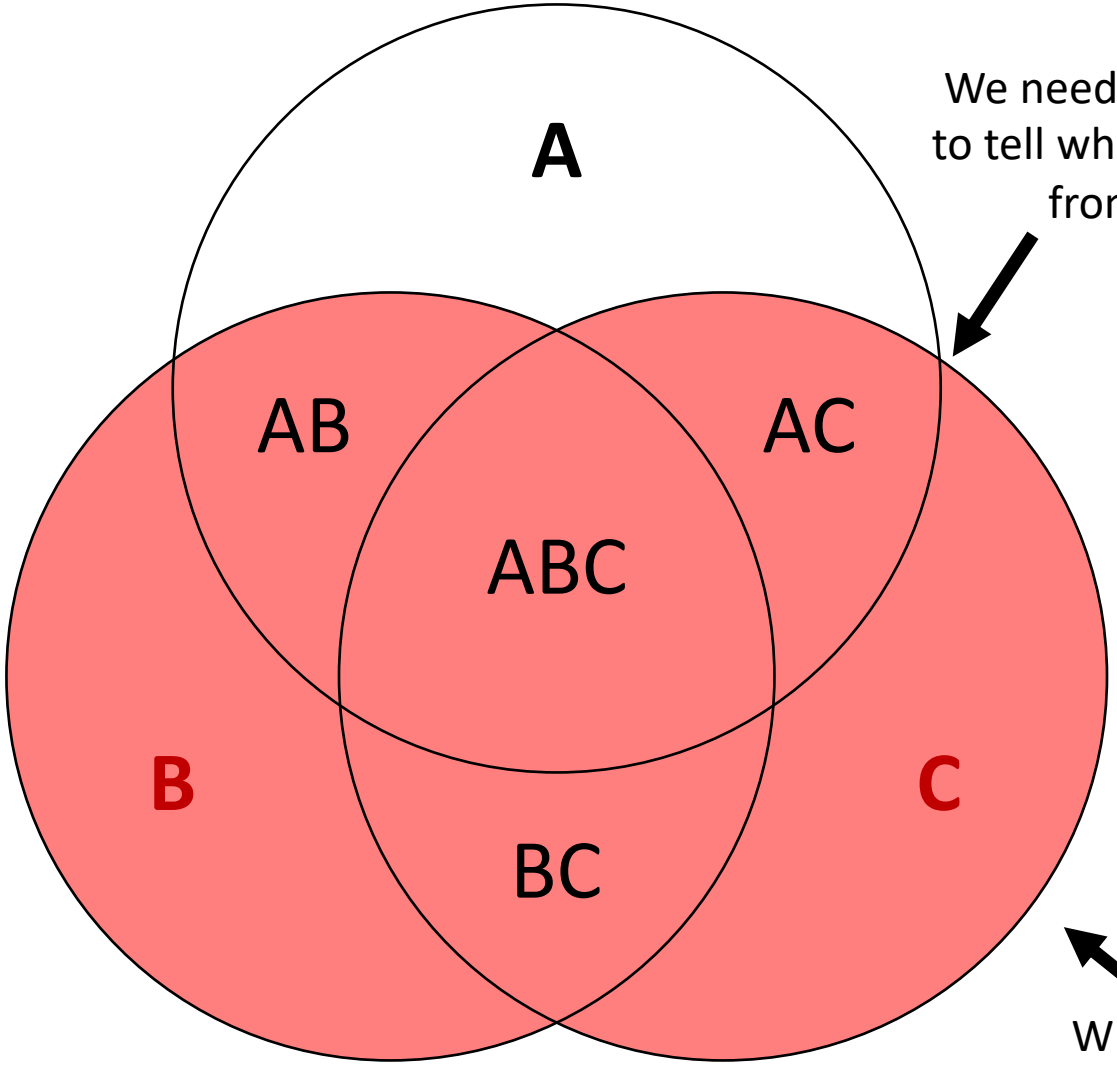


Baseline BC is okay, so we conclude that **station B** and **station C** are okay.

```
+NOTES

station  note
------------------------------------------------------
Aa-Bb    Removed channel from fringe fitting: S03UR

* station  2-char station ID, baseline,
           closure set, or - for general notes
* note     correlator notes and feedback
```

The Baseline Problem:

We only see 2-station **baselines** and 3-station **closures**.



We need at least **one okay baseline** to tell which stations have a problem from baseline data alone.

```
+NOTES

station   note
------------------------------------------------------
Aa-Bb-Cc  Removed channel from fringe fitting: S03UR

* station  2-char station ID, baseline,
           closure set, or - for general notes
* note     correlator notes and feedback
```

What if two stations have the problem?

The Current Washington Correlator

- Transfer
  - 2.5 Gbps eTransfer
  - Mark5 and Mark6* systems
- Hardware
  - 6.45 TFLOPS (1,792 CPU cores)
  - 4.17 PB storage (2.04 PB ingest + 2.13 PB internal)
- Software
  - DiFX, HOPS, nuSolve, SKED, Python3

* Mark6 systems still expected soon at time of writing

TLDR: What can go wrong?

Slow Data Shipping

Effects:

- **preliminary database** followed by **re-release**
  - data aren't used for EOPs (Earth orientation parameters)
- **station dropped** from session
  - **data are lost** (too late to justify disk space)

Solutions:

- ship data ASAP
- always send the **tracking number** to the correlator.
- carefully fill out **customs** declarations / paper work
- use a reputable carrier

TLDR: What can go wrong?

Large Clock Jump

Effects:

- correlator searches for new clock offset
  - 0 sec ± 100 µs, and ± 1 sec ± 32 µs
  - very time consuming (man hours and CPU time)
- clock may not be found
  - **data are lost** (no fringes found)

Solutions:

- always upload log file (with GPS)
- inform correlator of likely jumps
  - put jump and jump size in the **ivs-ops mailing list** start or stop message
- **do not unplug** or reseat cables in the signal chain
  - 1 nm cable shift ≅ 1 nm observed position shift

TLDR: What can go wrong?

Wrong Schedule Used

Effects:

- data are lost
  (out of network)
- split-release w/
  different subnets
  - very occasional
    (special circumstances)
  - smaller subnet usually
    ignored after analysis

Solutions:

- check for schedule changes as close to start time as possible
- check **all three** IVS archives:
  - https://cddis.nasa.gov/archive/vlbi/ivsdata/aux
  - https://ivs.bkg.bund.de/data_dir/vlbi/ivsdata/aux
  - ftp://ivsopar.obspm.fr/vlbi/ivsdata/aux
- FTP timestamps may be wrong!
  - download SKD and compare SCHEDULE_CREATE_DATE

TLDR: What can go wrong?

Bad Channel / Frequency Setup

Effects:

- correlator searches for channel / frequency setup
  - try other known configurations first
  - searching for unknown configuration is very costly *(rarely done)*
- data are often lost

Solutions:

- double-check signal chain and IF/recorder setup before session
- report incorrect channel / freq. setup in SKD or VEX files to IVS
- If something goes wrong:
  - explain *exactly* how channels and frequencies are set up in ivs-ops start or stop message

TLDR: What else can stations do?

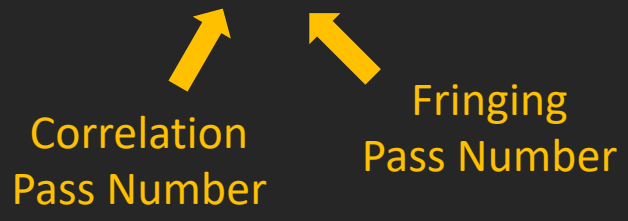
- Double check:
  - **pointing** control
  - **phase cal** injection
  - field system **time sync** (NTP)
  - **channel/frequency** setup
  - **cable cal** and **weather** monitor
- List **missed / problem scans** in **ivs-ops** mailing list stop message.
  - Try to list **why** scans were missed too.
  - The correlator may forward your message in the station notes.

How can we help you?

- We'll notify you of…
  - Missing or problematic data
  - Clock issues (such as 1 second offsets)
- Correlator report!
  - Provides feedback on overall and individual performance (clock/pcal/RFI, etc.)
  - Lets IVS know when a session has been correlated and ready for analysis
  - Read it please, or we will be sad ☹

Correlator Report

```
%CORRELATOR_REPORT_FORMAT 3

+HEADER

SESSION      R41083
VGOSDB       20221229-r41083
START        2022-363-1830
END          2022-364-1830
CORRELATOR   WACO
ANALYST      Mike Dutka
VERSION      1-1
```



Correlator Report

Strong fringes
No fringe found
Weak fringes and errors
Not observed

```
+SUMMARY

qcode       total  correlated
-----------------------------
5-9        68.01%      80.13%
0          15.85%      18.67%
1-4,A-H,N  16.14%       1.20%
removed     0.00%       0.00%

* qcode       quality codes, error codes, or status
* total       percent of total scans
* correlated  percent of correlated scans
```

Correlator Report

+STATIONS

station	name	mk4
Bd	BADARY	B
Ht	HART15M	J
Is	ISHIOKA	I
Kk	KOKEE	K
Ns	NYALE13S	b
Ny	NYALES20	N
Wn	WETTZ13N	U
Wz	WETTZELL	v
Ys	YEBES40M	C

* station 2-char station ID
* name 3- to 8-char station name
* mk4 1-char HOPS station code

Correlator Report

Could be poor or missing phase cal, RFI, …

Could be RFI, warm receiver, …

Could be pointing problem, cryo issue, wrong schedule, …

```
+NOTES

station  note
--------------------------------------------------------
Bd       Did not observe

Kk       Applied manual phase calibration
Kk       Removed channel from fringe fitting: S04UR

Ny       No fringes

Wn       Did not observe

Ys       Removed channel from fringe fitting: S03UR

* station  2-char station ID, baseline, closure set, or - for general notes
* note     correlator notes and feedback
```

Correlator Report

Epoch is both the origin of the offsets, and the starting time for each clock break

Note that there are two or more clocks at different epochs for clock breaks

+CLOCK

st	epoch	used-offset	used-rate	raw-offset	raw-rate	comment
Ht	2022-363-1830	9.619	-5.580000e-14	6.667979	-2.010234e-13	
Is	2022-363-1830	0.370	-1.570000e-13	0.148675	2.491744e-14	
Kk	2022-363-1830	7.903	-2.545000e-13	7.346932	-5.665280e-14	
Ns	2022-363-1830	23.987	6.884000e-13	8.110163	8.358000e-13	
Ny	2022-363-1830	-63.386	1.259000e-12	-65.667153	1.259166e-12	
Ny	2022-363-1830	0.000	1.259000e-12	-65.667153	1.259166e-12	clock-break
Wz	2022-363-1830	-4.385	-1.070000e-13	-6.541582	-1.070275e-13	
Ys	2022-363-1830	53.621	1.257000e-12	55.416536	1.391239e-12	

* st 2-char station ID
* epoch time coordinate of offsets and clock model segment start time
* used-offset (usec) station clock minus offset used in correlation at epoch
* used-rate drift rate of station clock minus offset used in correlation
* raw-offset (usec) station clock minus reference clock offset at epoch
* raw-rate drift rate of station clock minus reference clock offset
* comment clock-break, reference station, or other notes

Correlator Report

Note:
HOPS channel names
usually have this format:

+CHANNELS

channel id	frequency
S00UR a	2225.99
S01UR b	2245.99
S02UR c	2265.99
S03UR d	2295.99
S04UR e	2345.99
S05UR f	2365.99
X06LR g-	8212.99
X06UR g+	8212.99
X07UR h	8252.99
X08UR I	8352.99
X09UR j	8512.99
X10UR k	8732.99
X11UR l	8852.99
X12UR m	8912.99
X13LR n-	8932.99
X13UR n+	8932.99

* channel HOPS channel name
* id short name with sideband indicator
* frequency (MHz) sky frequency

Correlator Report

```
+DROP CHANNELS

Ys S03UR
Kk S04UR

+MANUAL PCAL

Kk
```

Station ID → Ys

Channel(s) → S03UR

Station ID → Kk

Correlator Report

QCODES gives a more granular view of the SUMMARY

+QCODES

```
bl:band    0 1 2 3 4 5  6   7   8    9  G  H    N - total
-------------------------------------------------------------
JI:S      11 0 0 0 0 0  0   2   2   84  0  0    0 0    99
JI:X      16 0 0 0 0 0  0   0   7   75  0  1    0 0    99
Jb:S      16 0 0 0 0 0  0   7   6   44  0  0    0 0    73
Jb:X       8 0 0 0 0 0  0   0   7   55  0  3    0 0    73
JN:S      42 0 0 0 0 0  0   0   0    0  0  0   45 0    87
JN:X      42 0 0 0 0 0  0   0   0    0  0  0   45 0    87
Jv:S       9 0 0 0 1 0  1   6  15  172  2  0    0 0   206
Jv:X       4 0 0 0 0 0  1   5  22  173  0  1    0 0   206
JC:S       8 0 0 0 0 0  1   0   9  194  2  0    0 0   214
JC:X       3 0 0 0 0 0  0   2  14  194  0  1    0 0   214
IK:S      21 0 0 0 0 0  1  21 105  182  0  0    0 0   330
IK:X       6 0 0 0 0 0  1   9  56  258  0  0    0 0   330
…
vC:S       0 0 0 0 0 0  2  17  71  240  0  0    0 0   330
vC:X       0 0 0 0 0 2  1   2  48  277  0  0    0 0   330
total   1186 0 0 0 1 7 18 171 866 4028 18 57 1132 0  7484

* bl:band  baseline and frequency band name
* 0        no fringe detected
* 1-9      fringe detected, higher value means better quality
* B        fourfit interpolation error
* D        no data in one or more frequency channels
* E        fringe found at edge of SBD, MBD, or rate window
* F        fork problem in processing
* G        channel amplitude diverges too far from mean amplitude
* H        low phase-cal amplitude in one or more channels
* N        correlation or fringing failed
* -        correlation not attempted
* total    column and row totals
```

Correlator Report

Low SNR ratio means that the antenna's effective SEFD was lower than scheduling expected

SNR ratio near 1.0 means that antenna and scheduling are working as intended

High SNR ratio means that the antenna's effective SEFD was higher than scheduling expected

+SNR_RATIOS

bl	S	n_S	X	n_X
JI	0.824748	88	0.698808	83
Jb	0.632045	57	0.575418	65
Jv	0.806562	197	0.655074	202
JC	0.868830	206	0.395182	211
IK	0.537841	309	0.717275	324
Ib	0.751313	186	0.721237	203
Iv	0.806576	189	0.966395	191
IC	0.850378	151	0.603681	152
Kb	0.535537	126	0.687464	163
KN	-	0	0.332825	1
Kv	0.482250	146	0.883386	161
KC	0.573646	110	0.612876	121
bv	0.761767	208	0.878315	217
bC	0.783280	205	0.512325	223
Nv	0.770276	3	-	0
NC	0.337093	2	-	0
vC	1.035180	330	0.815098	330

* bl baseline
* [A-Z] ratio for this band name
* n_[A-Z] number of scans in average for this band name

Correlator Report

These sections list the software and some settings used for correlation, fringing, and VGOSDB packaging

```
+CORRELATION

SOFTWARE DiFX
VERSION 2.5.4
ALGORITHM FX
NCHAN 256
FFTSPECRES 0.03125 MHz
SPECRES 0.125 MHz
TINT 2.0 sec

+FRINGING

SOFTWARE HOPS
VERSION 3.23-3383

+VGOSDB

SOFTWARE nuSolve
VERSION 0.8.1
```

Correlator Report

Configuration file used for correlation

For DiFX, this will be the V2D file

```
+CORRELATION_CONFIG_FILE

vex = r41083.vex
maxGap = 180000.0
maxLength = 360000.0
singleScan = true
startSeries = 1
antennas = HT, IS, KK, NS, NY, WZ, YS

SETUP normalSetup {
FFTSpecRes = 0.03125
specRes = 0.125
tInt = 2
}

RULE scansubset {
setup = normalSetup
}

ANTENNA HT {
phaseCalInt = 1
toneSelection = all
filelist = filelist
}
ANTENNA IS {
phaseCalInt = 5
toneSelection = all
filelist = filelist
}
…
```

Correlator Report

Configuration file used for fringing

For HOPS, this will be the CF file

```
+FRINGING CONFIG FILE

sb_win -256.0 256.0
mb_win -256.0 256.0
dr_win -0.030 0.030
pc_mode multitone
pc_period 5

if f_group S  ref_freq 2225.99
if f_group X  ref_freq 8212.99

if station K and f_group S  pc_tonemask abcdef    16  16  16  16  16  16
if station K and f_group X  pc_tonemask ghijklmn 148 132 132 132 132 132 132 132

if station J  lsb_offset   0.0
if station I  lsb_offset   0.0
if station K  lsb_offset  70.0
if station N  lsb_offset   0.0
if station b  lsb_offset   0.0
if station v  lsb_offset   0.0
if station C  lsb_offset -20.0

if station C and f_group S  freqs a b c e f
if station K and f_group S  freqs a b c d f

if station K  pc_mode manual
if station K and f_group S  pc_phases abcdef   20.79209  9.12735 90.70320 70.06696 135.72812 10.49509
if station K and f_group X  pc_phases ghijklmn 95.14771 38.72751 62.34361 30.12612  71.47699 93.45794  3.82575 78.31685

if station C and f_group S  pc_phases abcef    8.7 -11.2  0.1 0.0  2.5
if station C and f_group X  pc_phases ghijklmn 0.3  -1.6 -0.6 3.2 12.2 -8.5 -11.1 6.1

…
```

Correlator Report

General setup for all stations

Phase cal tone mask

Lower side band offests

Dropped channels

Manual phase cal

Phase alignment

```
+FRINGING CONFIG FILE

sb_win -256.0 256.0
mb_win -256.0 256.0
dr_win -0.030 0.030
pc_mode multitone
pc_period 5

if f_group S  ref_freq 2225.99
if f_group X  ref_freq 8212.99

if station K and f_group S  pc_tonemask abcdef    16  16  16  16  16  16
if station K and f_group X  pc_tonemask ghijklmn 148 132 132 132 132 132 132 132

if station J  lsb_offset   0.0
if station I  lsb_offset   0.0
if station K  lsb_offset  70.0
if station N  lsb_offset   0.0
if station b  lsb_offset   0.0
if station v  lsb_offset   0.0
if station C  lsb_offset -20.0

if station C and f_group S  freqs a b c e f
if station K and f_group S  freqs a b c d f

if station K  pc_mode manual
if station K and f_group S  pc_phases abcdef   20.79209  9.12735 90.70320 70.06696 135.72812 10.49509
if station K and f_group X  pc_phases ghijklmn 95.14771 38.72751 62.34361 30.12612  71.47699 93.45794  3.82575 78.31685

if station C and f_group S  pc_phases abcef    8.7 -11.2  0.1 0.0  2.5
if station C and f_group X  pc_phases ghijklmn 0.3  -1.6 -0.6 3.2 12.2 -8.5 -11.1 6.1

…
```

Correlator Report

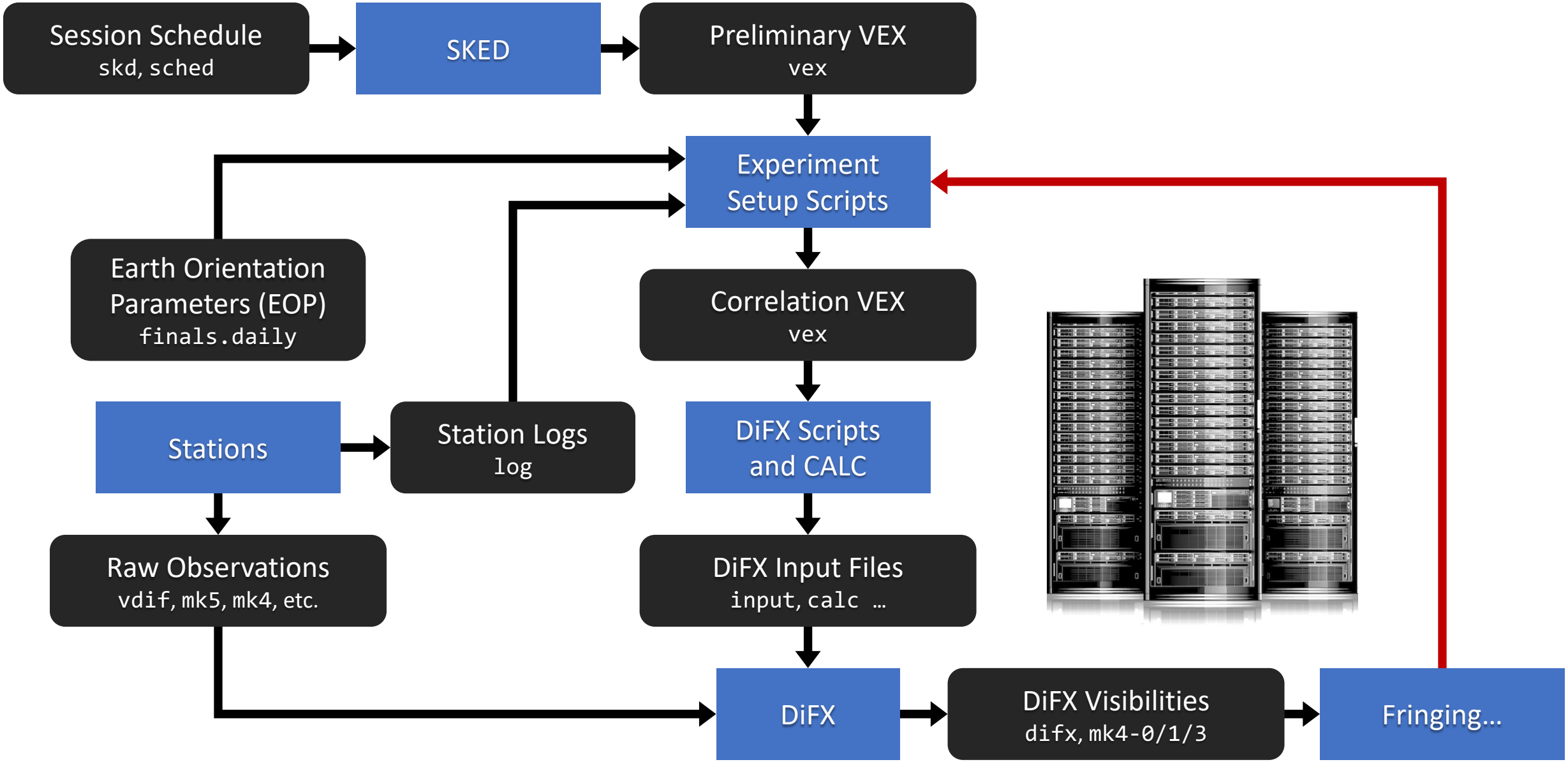
RF “notches”
to cut out shared RFI
for co-located antennas

Each notch consists of a start and end frequency in MHz

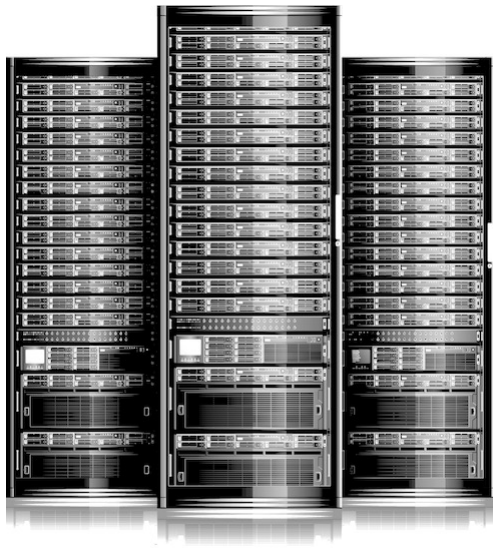
```
+FRINGING CONFIG FILE

…

if baseline bN

  notches

    2225.74 2226.24  2226.74 2227.24  2227.74 2228.24  2228.74 2229.24
    2229.74 2230.24  2230.74 2231.24  2231.74 2232.24  2232.74 2233.24
    2245.74 2246.24  2246.74 2247.24  2247.74 2248.24  2248.74 2249.24
    2249.74 2250.24  2250.74 2251.24  2251.74 2252.24  2252.74 2253.24
    2265.74 2266.24  2266.74 2267.24  2267.74 2268.24  2268.74 2269.24
    2269.74 2270.24  2270.74 2271.24  2271.74 2272.24  2272.74 2273.24
    2295.74 2296.24  2296.74 2297.24  2297.74 2298.24  2298.74 2299.24
    2299.74 2300.24  2300.74 2301.24  2301.74 2302.24  2302.74 2303.24
    2345.74 2346.24  2346.74 2347.24  2347.74 2348.24  2348.74 2349.24
    2349.74 2350.24  2350.74 2351.24  2351.74 2352.24  2352.74 2353.24
    2365.74 2366.24  2366.74 2367.24  2367.74 2368.24  2368.74 2369.24
    2369.74 2370.24  2370.74 2371.24  2371.74 2372.24  2372.74 2373.24

    8204.74 8205.24  8205.74 8206.24  8206.74 8207.24  8207.74 8208.24
    8208.74 8209.24  8209.74 8210.24  8210.74 8211.24  8211.74 8212.24
    8212.74 8213.24  8213.74 8214.24  8214.74 8215.24  8215.74 8216.24
    8216.74 8217.24  8217.74 8218.24  8218.74 8219.24  8219.74 8220.24
    8252.74 8253.24  8253.74 8254.24  8254.74 8255.24  8255.74 8256.24
    8256.74 8257.24  8257.74 8258.24  8258.74 8259.24  8259.74 8260.24
    8352.74 8353.24  8353.74 8354.24  8354.74 8355.24  8355.74 8356.24
    8356.74 8357.24  8357.74 8358.24  8358.74 8359.24  8359.74 8360.24
    8512.74 8513.24  8513.74 8514.24  8514.74 8515.24  8515.74 8516.24
    8516.74 8517.24  8517.74 8518.24  8518.74 8519.24  8519.74 8520.24
    8732.74 8733.24  8733.74 8734.24  8734.74 8735.24  8735.74 8736.24
    8736.74 8737.24  8737.74 8738.24  8738.74 8739.24  8739.74 8740.24
    …
```

End

Quick Review: Correlation



Quick Review: Fringe Fitting



Fringe Setup
cf

G Codes and
H Codes, etc.

Fringe Fitting
fourfit

Fringes
mk4-2

Clocks Script
fit-sbd

Correlation VEX
vex

Correlation
DiFX …

Visibilities
mk4-0/1/3

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Report
Script

Station Logs
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vgosdb

Analysis…