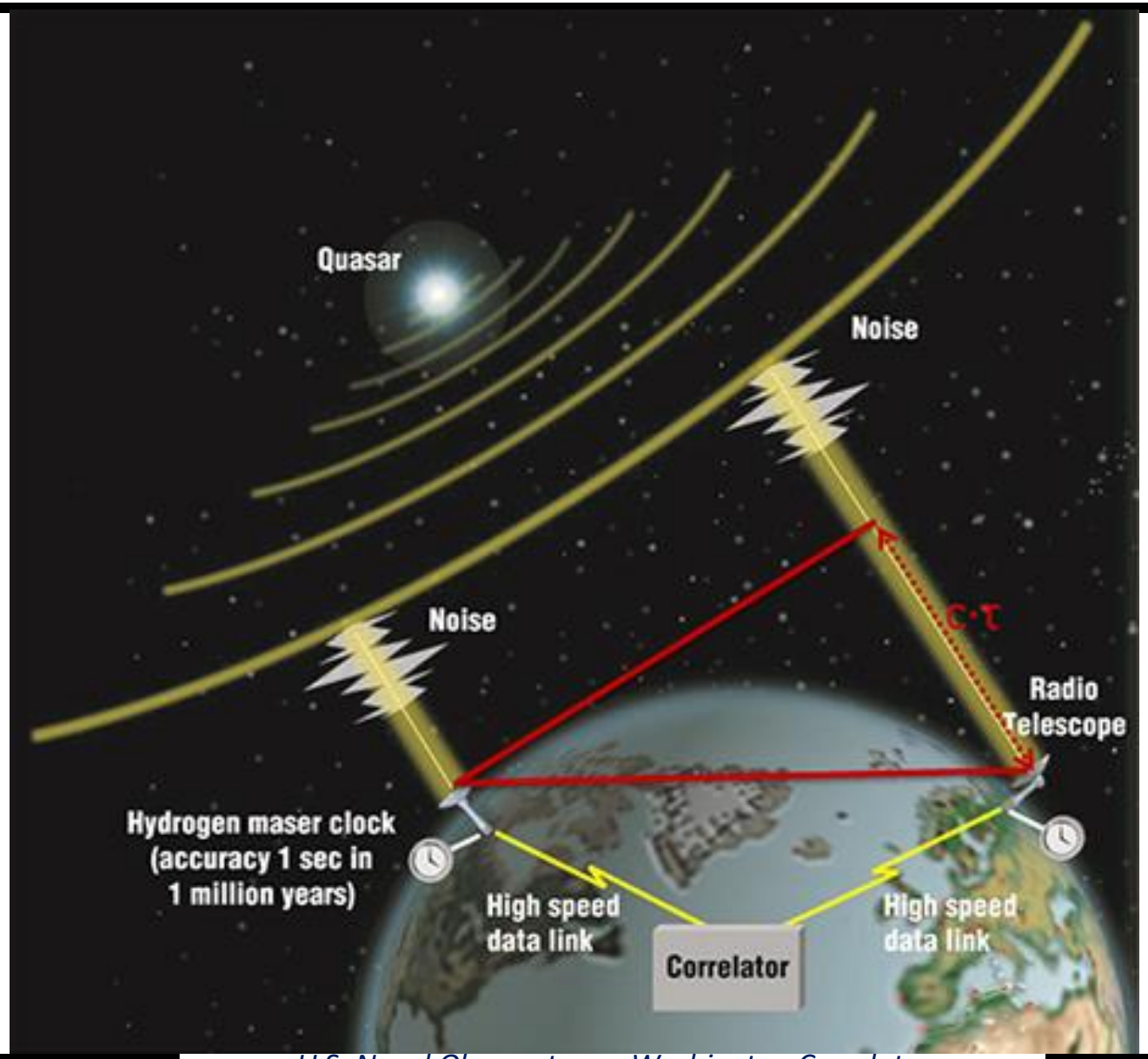
Understanding Correlator Feedback

Sara Hardin & Phillip Haftings
United States Naval Observatory (USNO)
Washington Correlator (WASH)

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.

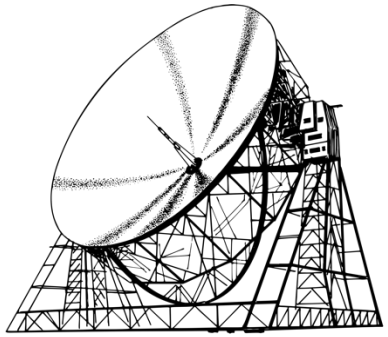
Database
`vgosdb`

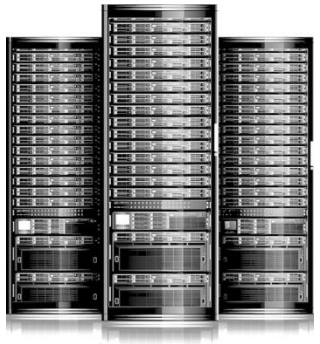
Post-Analysis Users

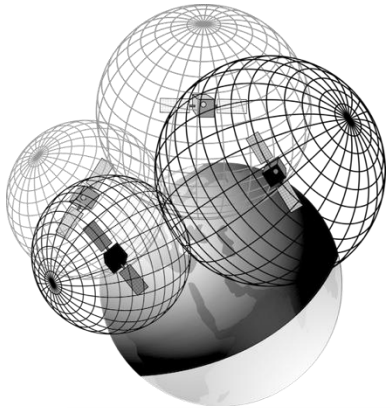
International Earth Rotation and Reference Systems Service (IERS)

Celestial Reference Frame (CRF)

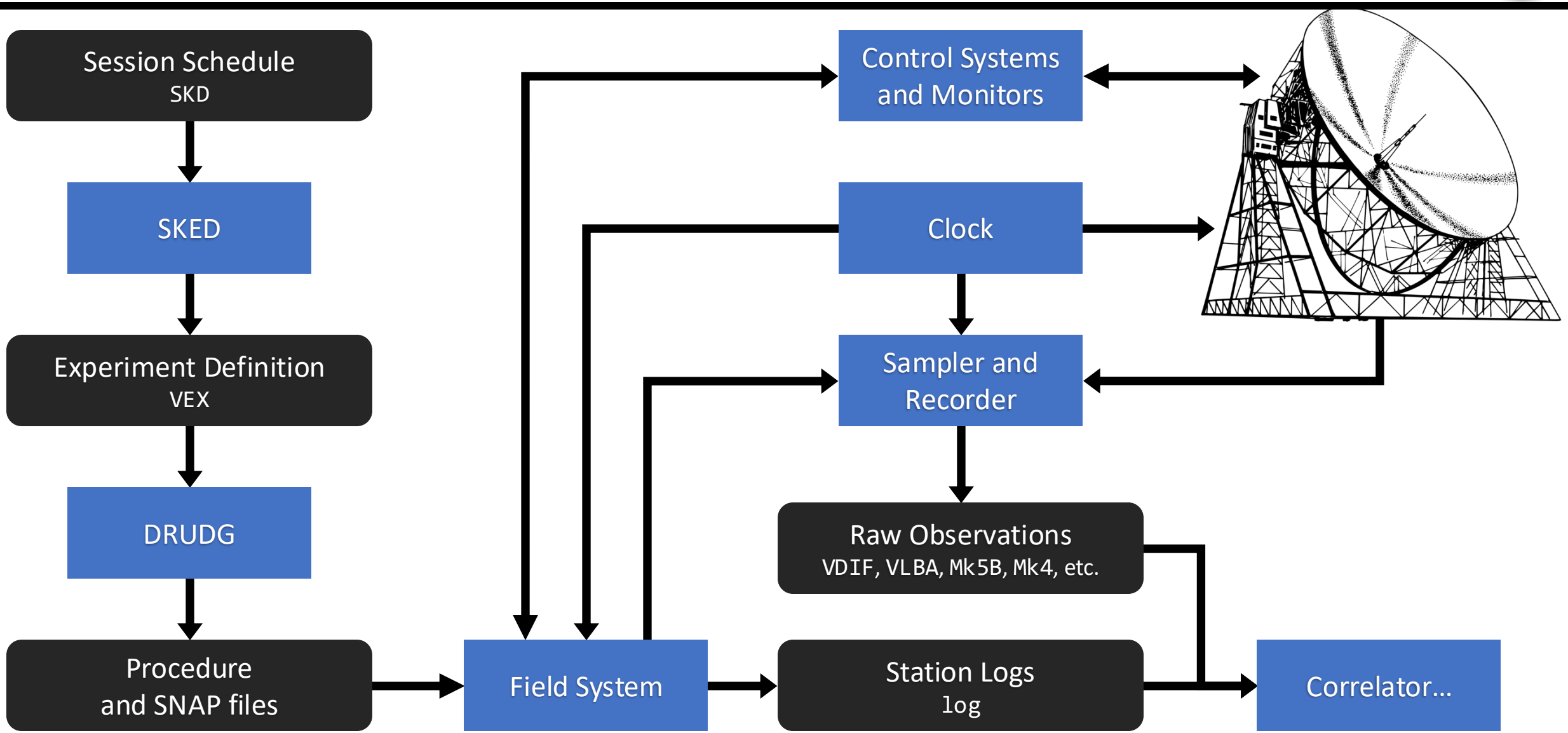
etc.



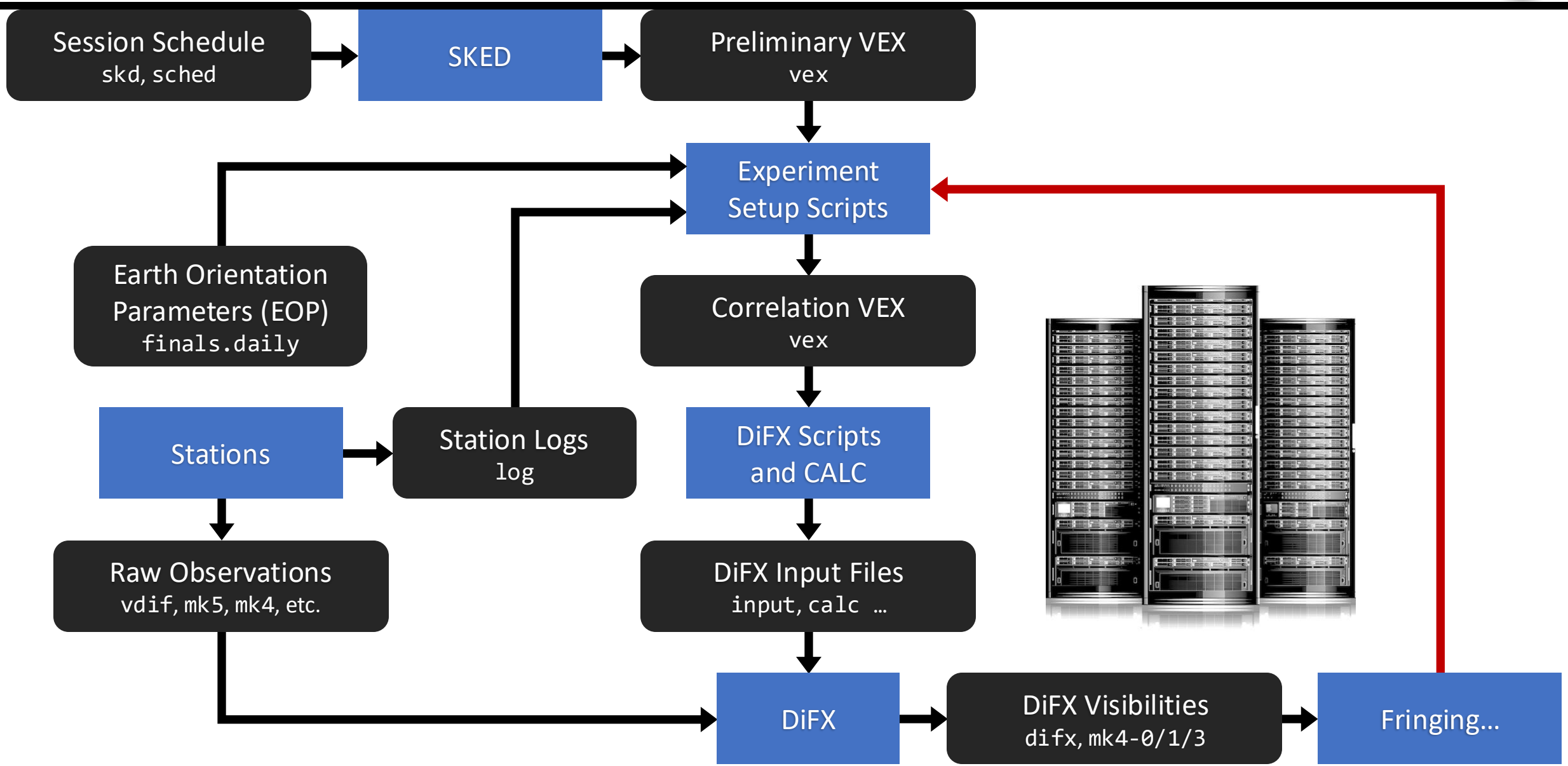




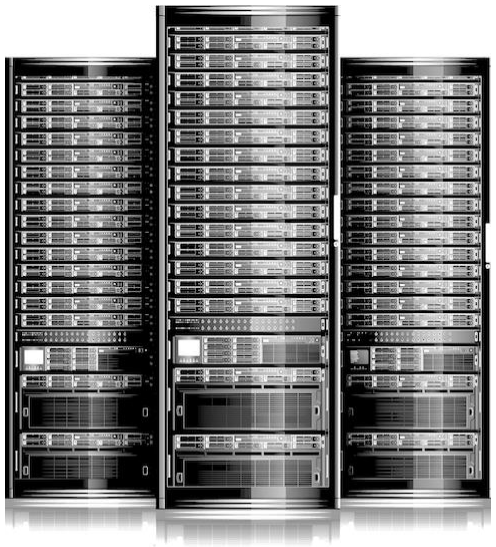
Quick Review: Observation



Quick Review: Correlation



Quick Review: Fringe Fitting



Fringe Setup
`cf`

Phases, Offsets, 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`

Correlator Report
`corr`

Report Script

Station Logs
`log`

Archiving
`vSolve`

VGOS Archive
`vgosdb`

Analysis…

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)

What is fringing?

Basic steps:

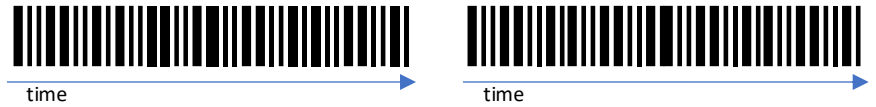
- Correlator outputs visibilities
- Switch to frequency domain
- Combine channels with **group delay**
- Combine baselines with **closure**

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

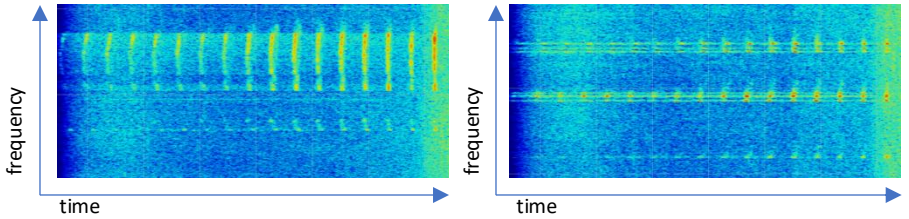


1- or 2-bit voltage readings directly from radio telescope receivers

FFT

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

RF Spectrographs

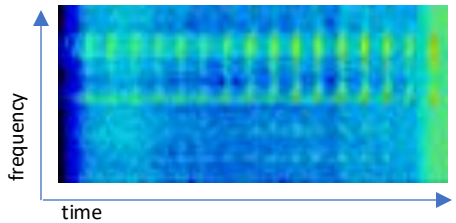


Radio frequency (RF) amplitudes over time

Cross Multiplication

Frequency signals are combined with a simple cross multiplication

RF² Spectrograph



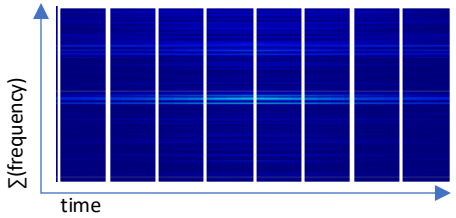
Combined signals (still extremely noisy)

Correlation and Fringing

Integration

Sum over time in chunks to cancel noise with destructive interference

Visibilities

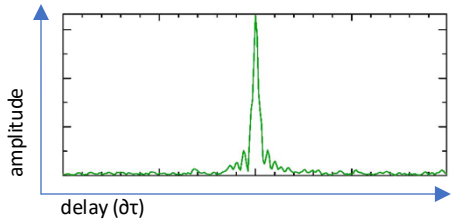


Measure of the contrast of the interference pattern

Fringe Finding

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

Single Band Delay

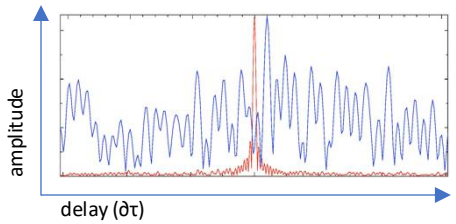


Peaks at the time delay with the greatest common visibility between both telescopes

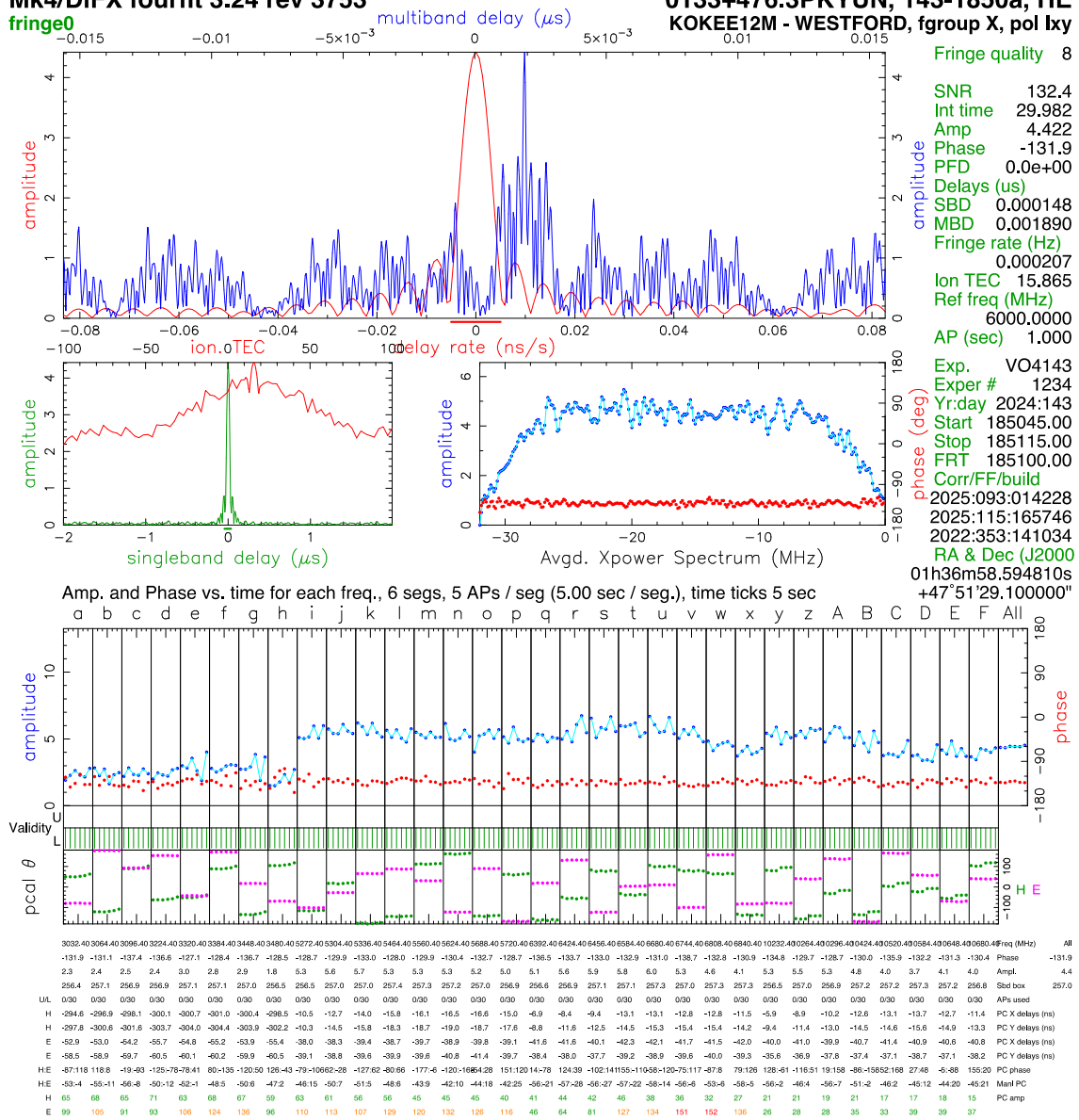
Inverse FFT

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)



Group delay (usec) (SBD)	3.63847865953E+03	Apriori delay (usec)	3.63847676921E+03	Resid mbdelay (usec)	1.89033E-03	+/-	1.3E-06
Sband delay (usec)	3.63847691671E+03	Apriori clock (usec)	2.3785355E+01	Resid sbdelay (usec)	1.47500E-04	+/-	1.3E-04
Phase delay (usec)	3.63847670815E+03	Apriori clockrate (us/s)	1.6771001E-06	Resid phdelay (usec)	-6.10547E-05	+/-	4.0E-07
Delay rate (us/s)	1.04666828097E+00	Apriori rate (us/s)	1.04666824647E+00	Resid rate (us/s)	3.45000E-08	+/-	2.3E-08
Total phase (deg)	89.6	Apriori accel (us/s/s)	-4.43651017344E-05	Resid phase (deg)	-131.9	+/-	3.4

	RMS	Theor.		
			Amplitude	4.422 +/- 0.033
ph/seg (deg)	1.2	1.1	Search (64X1024)	4.420
amp/seg (%)	1.4	1.8	Interp.	0.000
ph/frq (deg)	3.1	2.4	Inc. seg. avg.	4.422
amp/frq (%)	28.4	4.3	Inc. frq. avg.	4.423

Pcal mode: MULTITONE, MULTITONE PC period (AP's) 1, 1 dTEC +/- 0.039
Pcal rate: 0.000E+00, 0.000E+00 (us/s) sb window (us) -2.000 2.00
Bits/sample: 2x2 SampCntNorm: disabled mb window (us) -0.016 0.01
Data rate(MSamp/s): 64 MBpts 1024 Amb 0.031 us dr window (ns/s) -0.005 0.00
Data rate(Mb/s): 8192 nlags: 256 t_cohere infinite ion window (TEC) -100.00 100.

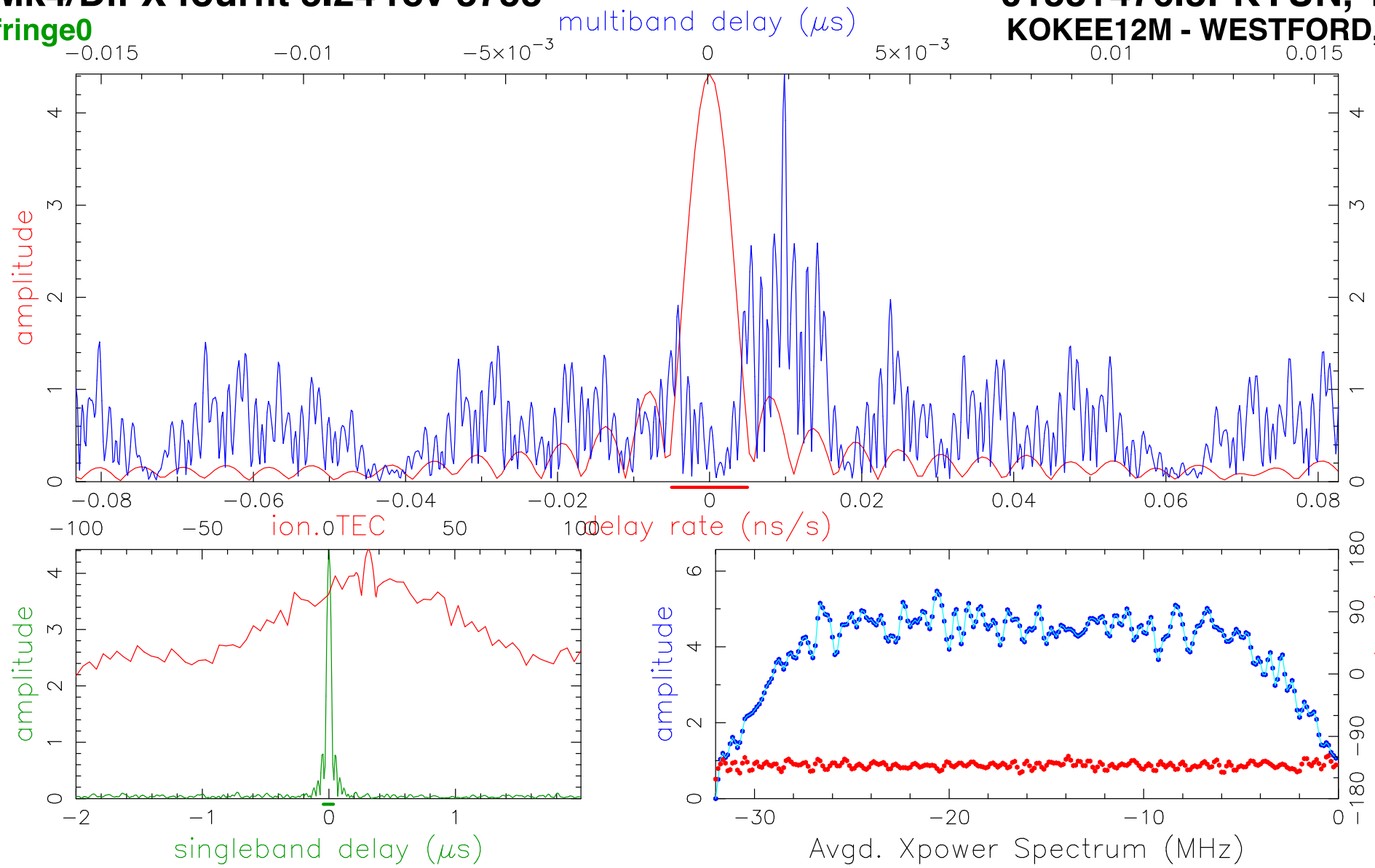
H: az 27.8 el 59.2 pa -140.2 E: az 301.0 el 43.9 pa 70.2 u,v (fr/asec) -624.772 -392.066 simultaneous interpolator

Mk4/DiFX fourfit 3.24 rev 3753

fringe0

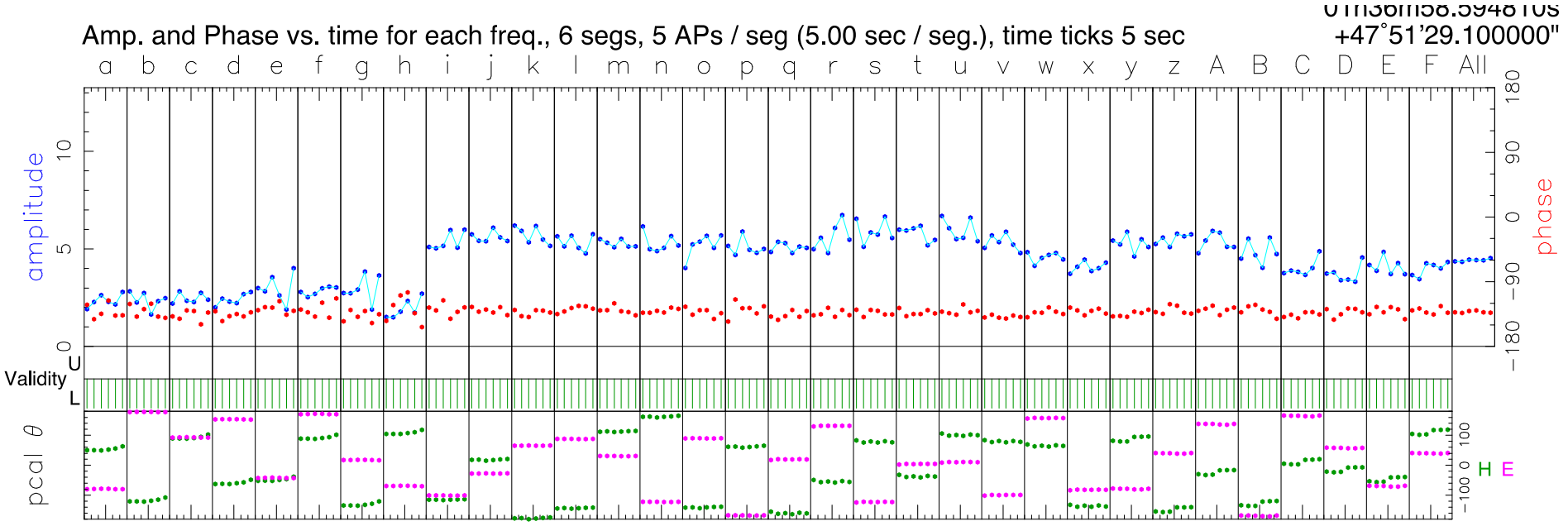
0133+476.3PKYUN, 143-1850a, HE

KOKEE12M - WESTFORD, fgroup X, pol Ixy



Fringe quality 8

SNR	132.4
Int time	29.982
Amp	4.422
Phase	-131.9
PFD	0.0e+00
Delays (us)	
SBD	0.000148
MBD	0.001890
Fringe rate (Hz)	
	0.000207
Ion TEC	15.865
Ref freq (MHz)	
	6000.0000
AP (sec)	1.000
Exp.	VO4143
Exper #	1234
Yr:day	2024:143
Start	185045.00
Stop	185115.00
FRT	185100.00
Corr/FF/build	
	2025:093:014228
	2025:115:165746
	2022:353:141034
RA & Dec (J2000)	
	01h36m58.594810s



	3032.40	3064.40	3096.40	3224.40	3320.40	3384.40	3448.40	3480.40	5272.40	5304.40	5336.40	5464.40	5560.40	5624.40	5688.40	5720.40	6392.40	6424.40	6456.40	6584.40	6680.40	6744.40	6808.40	6840.40	10232.40	10264.40	10296.40	10424.40	10520.40	10584.40	10648.40	10680.40	Freq (MHz)	All
	-131.9	-131.1	-137.4	-136.6	-127.1	-128.4	-136.7	-128.5	-128.7	-129.9	-133.0	-128.0	-129.9	-130.4	-132.7	-128.7	-136.5	-133.7	-133.0	-132.9	-131.0	-138.7	-132.8	-130.9	-134.8	-129.7	-128.7	-130.0	-135.9	-132.2	-131.3	-130.4	Phase	-131.9
	2.3	2.4	2.5	2.4	3.0	2.8	2.9	1.8	5.3	5.6	5.7	5.3	5.3	5.3	5.2	5.0	5.1	5.6	5.9	5.8	6.0	5.3	4.6	4.1	5.3	5.5	5.3	4.8	4.0	3.7	4.1	4.0	Ampl.	4.4
	256.4	257.1	256.9	256.9	257.1	257.1	257.0	256.5	256.5	257.0	257.0	257.4	257.3	257.2	257.0	256.9	256.6	256.9	257.1	257.1	257.3	257.0	257.3	257.3	256.5	257.0	256.9	257.2	257.2	257.3	257.2	256.8	Sbd box	257.0
U/L	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	APs used	
H	-294.6	-296.9	-298.1	-300.1	-300.7	-301.0	-300.4	-298.5	-10.5	-12.7	-14.0	-15.8	-16.1	-16.5	-16.6	-15.0	-6.9	-8.4	-9.4	-13.1	-13.1	-12.8	-12.8	-11.5	-5.9	-8.9	-10.2	-12.6	-13.1	-13.7	-12.7	-11.4	PC X delays (ns)	
H	-297.8	-300.6	-301.6	-303.7	-304.0	-304.4	-303.9	-302.2	-10.3	-14.5	-15.8	-18.3	-18.7	-19.0	-18.7	-17.6	-8.8	-11.6	-12.5	-14.5	-15.3	-15.4	-15.4	-14.2	-9.4	-11.4	-13.0	-14.5	-14.6	-15.6	-14.9	-13.3	PC Y delays (ns)	
E	-52.9	-53.0	-54.2	-55.7	-54.8	-55.2	-53.9	-55.4	-38.0	-38.3	-39.4	-38.7	-39.7	-38.9	-39.8	-39.1	-41.6	-41.6	-40.1	-42.3	-42.1	-41.7	-41.5	-42.0	-40.0	-41.0	-39.9	-40.7	-41.4	-40.9	-40.6	-40.8	PC X delays (ns)	
E	-58.5	-58.9	-59.7	-60.5	-60.1	-60.2	-59.9	-60.5	-39.1	-38.8	-39.6	-39.9	-39.6	-40.8	-41.4	-39.7	-38.4	-38.0	-37.7	-39.2	-38.9	-39.6	-40.0	-39.3	-35.6	-36.9	-37.8	-37.4	-37.1	-38.7	-37.1	-38.2	PC Y delays (ns)	
H:E	-87:118	118:8	-19:-93	-125:-78	-78:41	80:-135	-120:50	126:-43	-79:-106	62:-28	-127:62	-80:66	-177:-6	-120:-168	54:28	151:120	14:-78	124:39	-102:141	155:-110	-58:-120	-75:117	-87:8	79:126	128:-61	-116:51	19:158	-86:-158	52:168	27:48	-5:-88	155:20	PC phase	
H:E	-53:-4	-55:-11	-56:-8	-50:-12	-52:-1	-48:5	-50:6	-47:2	-46:15	-50:7	-51:5	-48:6	-43:9	-42:10	-44:18	-42:25	-56:-21	-57:-28	-56:-27	-57:-22	-58:-14	-56:-6	-53:-6	-58:-5	-56:-2	-46:4	-56:-7	-51:-2	-46:2	-45:12	-44:20	-45:21	Manl PC	
H	65	68	65	71	63	68	67	59	63	61	56	56	45	45	45	40	41	44	42	46	38	36	32	27	21	21	19	21	17	17	18	15	PC amp	
E	99	105	91	93	106	124	136	96	110	113	107	129	120	132	126	116	46	64	81	127	134	151	152	136	26	28	28	35	33	39	39	37		

Group delay (usec) (SBD)	3.63847865953E+03	Apriori delay (usec)	3.63847676921E+03	Resid mbdelay (usec)	1.89033E-03	+/- 1.3E-06
Sband delay (usec)	3.63847691671E+03	Apriori clock (usec)	2.3785355E+01	Resid sbdelay (usec)	1.47500E-04	+/- 1.3E-04
Phase delay (usec)	3.63847670815E+03	Apriori clockrate (us/s)	1.6771001E-06	Resid phdelay (usec)	-6.10547E-05	+/- 4.0E-07
Delay rate (us/s)	1.04666828097E+00	Apriori rate (us/s)	1.04666824647E+00	Resid rate (us/s)	3.45000E-08	+/- 2.3E-08
Total phase (deg)	89.6	Apriori accel (us/s/s)	-4.43651017344E-05	Resid phase (deg)	-131.9	+/- 3.4

	RMS	Theor.						
			Amplitude	4.422 +/- 0.033	Pcal mode: MULTITONE, MULTITONE PC period (AP's) 1, 1	dTEC +/-	0.039	
ph/seg (deg)	1.2	1.1	Search (64X1024)	4.420	Pcal rate: 0.000E+00, 0.000E+00 (us/s)	sb window (us)	-2.000	2.000
amp/seg (%)	1.4	1.8	Interp.	0.000	Bits/sample: 2x2 SampCntNorm: disabled	mb window (us)	-0.016	0.016
ph/frq (deg)	3.1	2.4	Inc. seg. avg.	4.422	Data rate(MSamp/s): 64 MBpts 1024 Amb 0.031 us	dr window (ns/s)	-0.005	0.005
amp/frq (%)	28.4	4.3	Inc. frq. avg.	4.423	Data rate(Mb/s): 8192 nlags: 256 t_cohere infinite	ion window (TEC)	-100.00	100.00

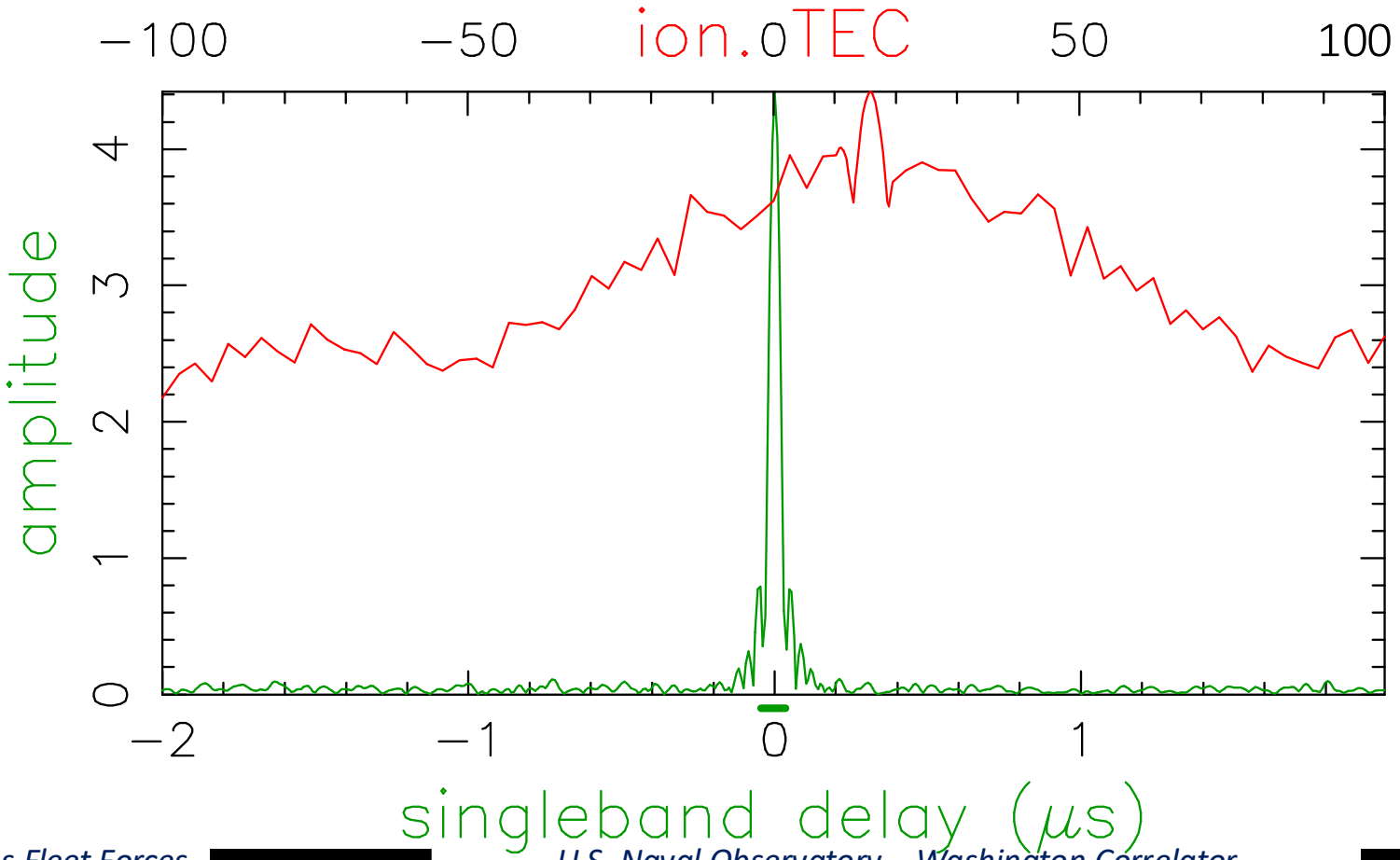
H: az 27.8 el 59.2 pa -140.2 E: az 301.0 el 43.9 pa 70.2 u,v (fr/asec) -624.772 -392.066 simultaneous interpolator

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 ≅ 0 (due to clock pass corrections)

HOPS Fourfit: Single Band Delay (SBD) Cont.

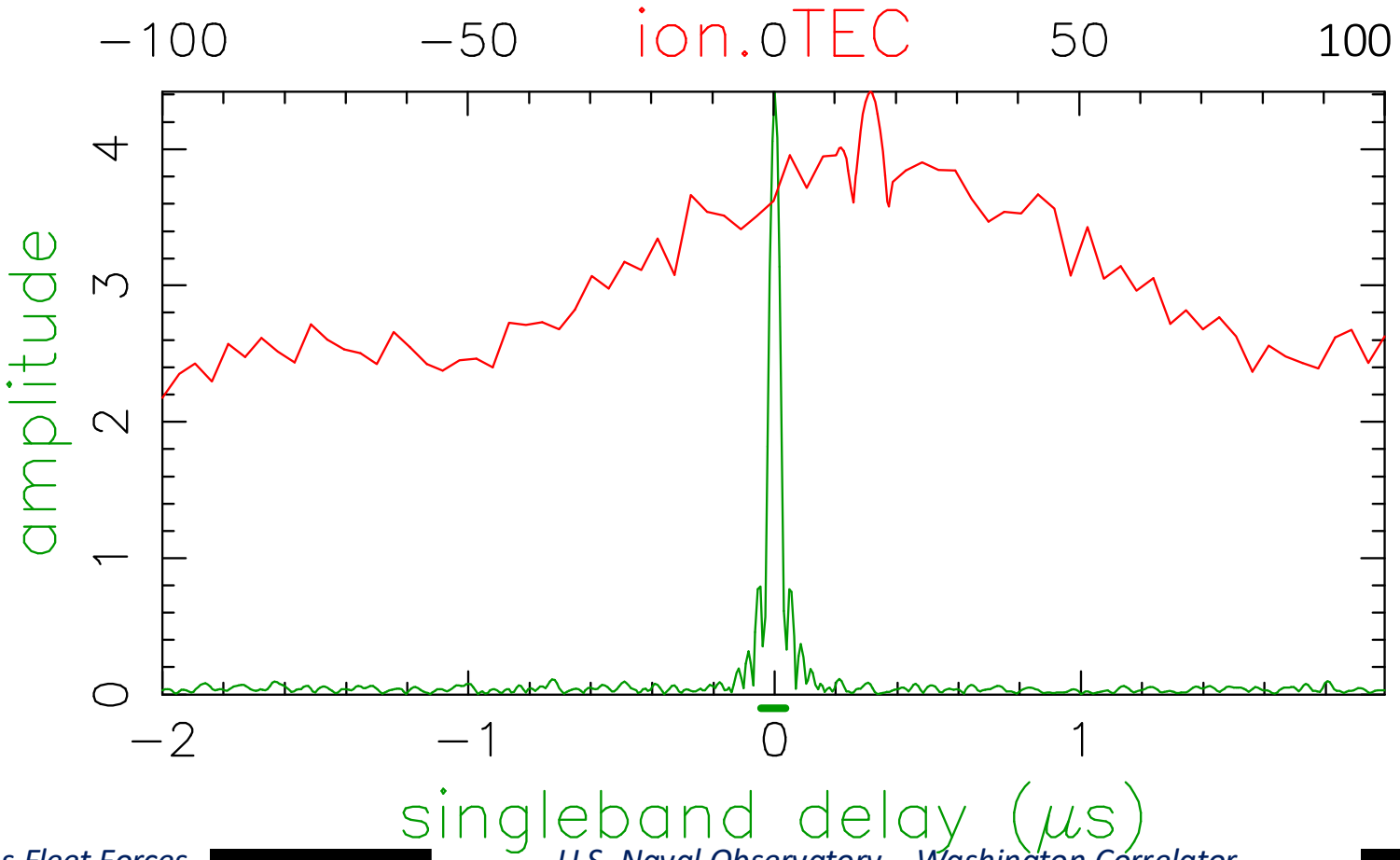
- Clock pass makes apparent **SBD ≤ 20 ns**, and ideally ≤ 10 ns
- Amplitude is typically a few hundred parts per million



Fringe quality	8
SNR	132.4
Int time	29.982
Amp	4.422 × 100ppm
Phase	-131.9
PFD	0.0e+00
Delays (us)	
SBD	0.000148 μs
MBD	0.001890
Fringe rate (Hz)	
	0.000207
Ion TEC	15.865
Ref freq (MHz)	
	6000.0000
AP (sec)	1.000
Exp.	VO4143
Exper #	1234
Yr:day	2024:143
Start	185045.00
Stop	185115.00
FRT	185100.00
Corr/FF/build	
	2025:093:014228
	2025:115:165746
	2022:353:141034
RA & Dec (J2000)	
	h36m58.594810s
	-47°51'29.100000"

HOPS Fourfit: Ionospheric fitting

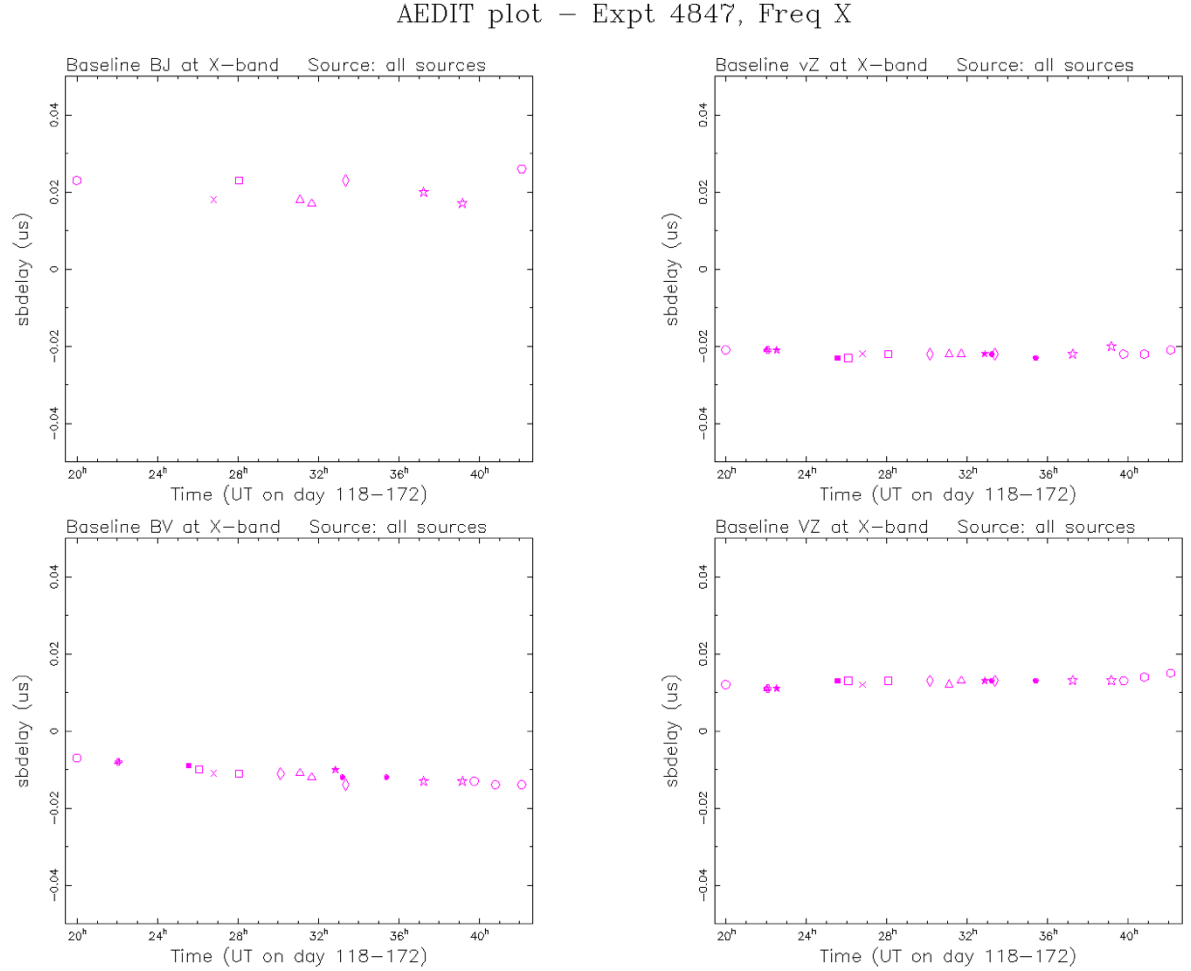
- Ionospheric fit in red
- Should be a single peak (solution)



Fringe quality	8
SNR	132.4
Int time	29.982
Amp	4.422
Phase	-131.9
PFD	0.0e+00
Delays (us)	
SBD	0.000148
MBD	0.001890
Fringe rate (Hz)	
	0.000207
Ion TEC	15.865 TECU
Ref freq (MHz)	
	6000.0000
AP (sec)	1.000
Exp.	VO4143
Exper #	1234
Yr:day	2024:143
Start	185045.00
Stop	185115.00
FRT	185100.00
Corr/FF/build	
	2025:093:014228
	2025:115:165746
	2022:353:141034
RA & Dec (J2000)	
	h36m58.594810s
	47°51'29.100000"

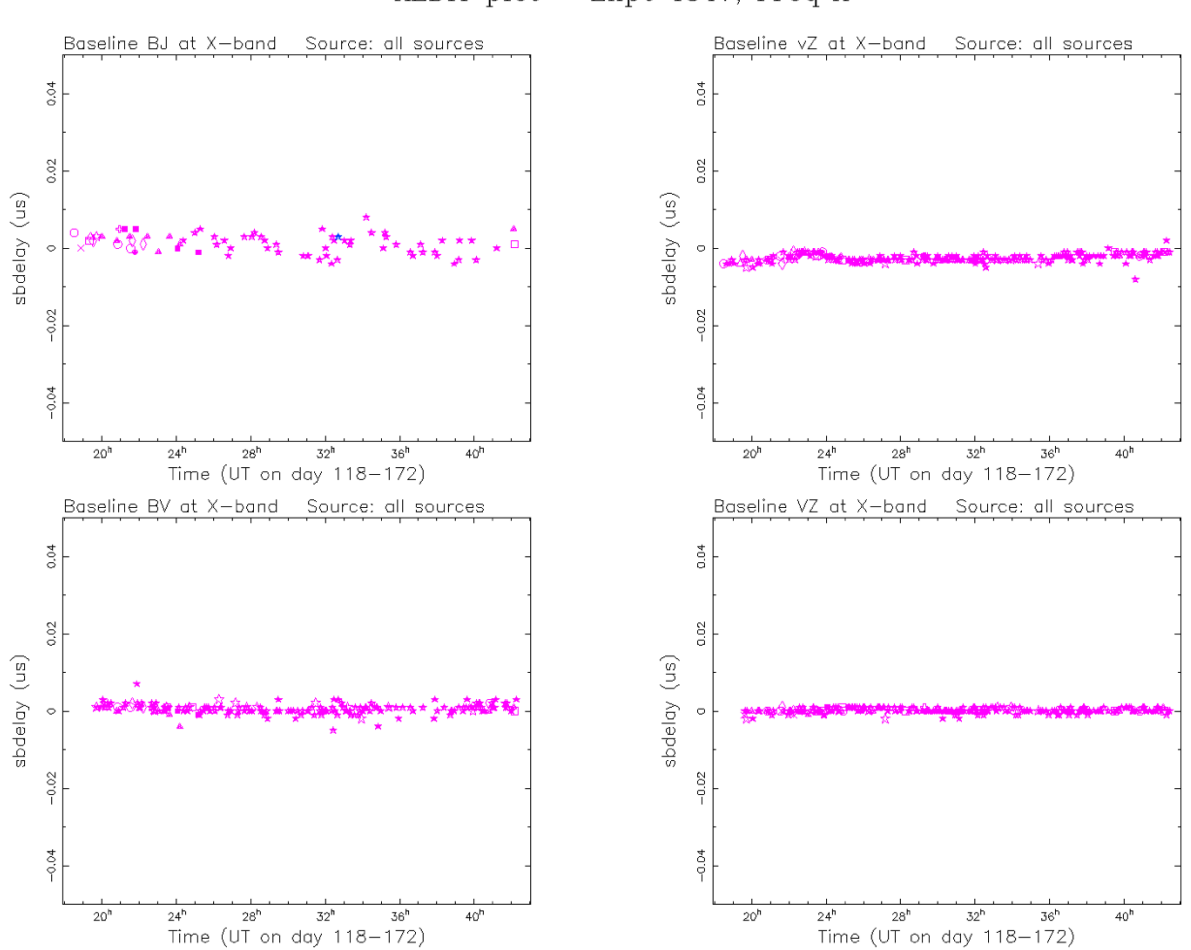
HOPS aedit: Plot View

Clock pass, before offset and rate corrections



HOPS aedit: Plot View

Production pass, after offset and rate corrections



HOPS Fourfit: First Look

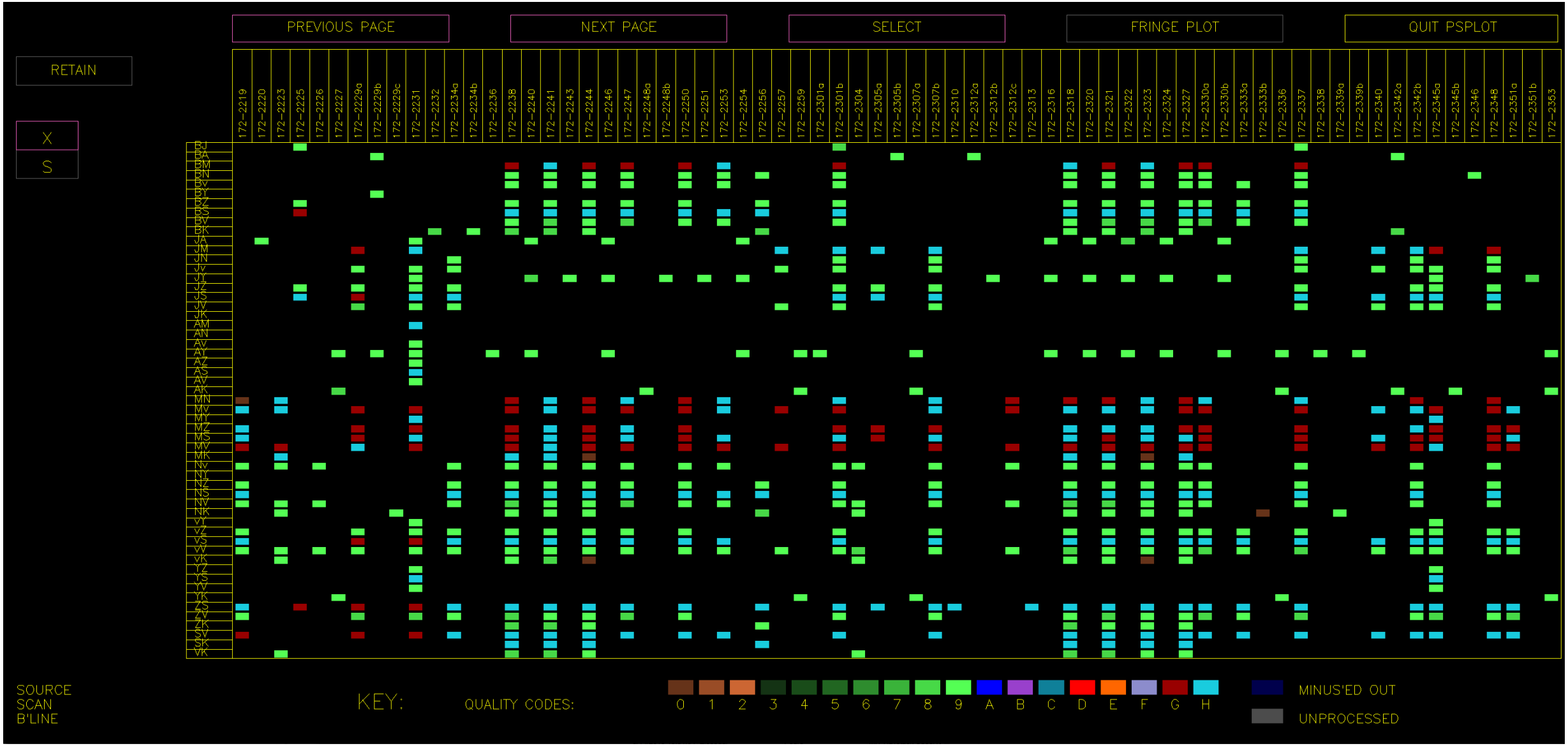
Before Configuration:

- Lots of G Codes (low amp. chan.)
- No H Codes (low amp. pcal)
  - But there could have been!
- 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:X	-	-	-	-	-	-	-	24	-	5	-	-	5	31	76	156	548	127	158	1130
E:X	-	-	-	-	-	-	-	87	-	33	-	1	2	17	67	176	273	185	256	1097
H:X	-	-	-	-	-	-	-	47	-	32	-	-	2	3	20	50	138	237	741	1270
I:X	-	-	-	-	-	-	-	19	-	50	-	-	2	6	21	60	134	199	440	931
K:X	-	-	-	-	-	-	-	12	-	14	-	-	-	3	28	44	98	47	224	470
M:X	-	-	-	-	-	-	-	25	-	46	-	-	2	10	22	68	259	279	449	1160
N:X	-	-	-	-	-	-	-	35	-	34	-	4	39	137	306	310	76	44	110	1095
O:X	-	-	-	-	-	-	-	34	-	39	-	-	-	3	16	25	88	50	229	484
S:X	-	-	-	-	-	-	-	252	-	14	1	1	8	33	82	141	316	81	175	1104
T:X	-	-	-	-	-	-	-	253	-	13	1	2	12	20	84	111	328	153	176	1153
V:X	-	-	-	-	-	-	-	8	-	10	-	-	6	19	72	181	472	106	96	970

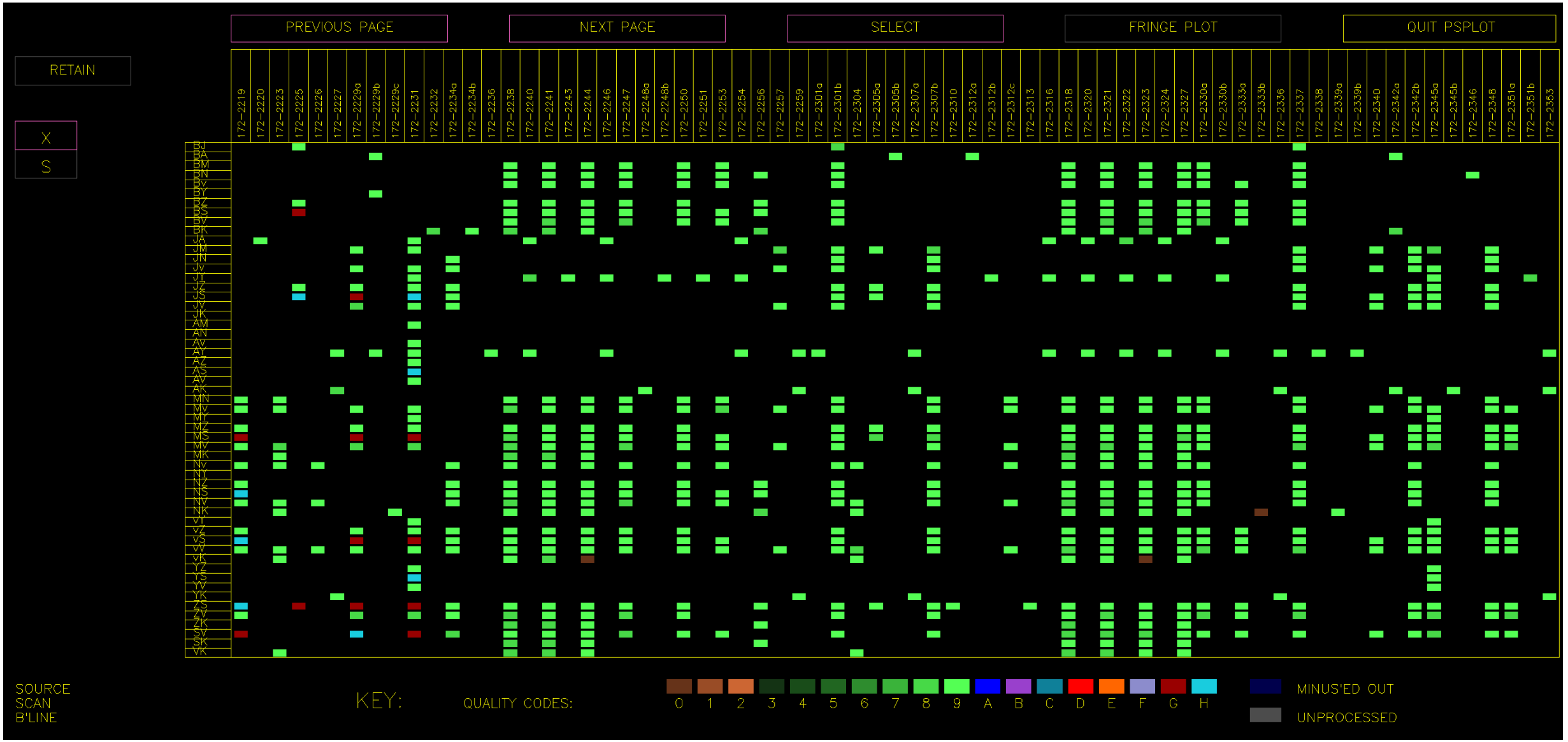
	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
*:X	-	-	-	-	-	-	-	398	-	145	1	4	39	141	397	661	1365	754	1527	5432
:	-	-	-	-	-	-	-	398	-	145	1	4	39	141	397	661	1365	754	1527	5432

HOPS aedit: Summary View



Before cf configuration file.

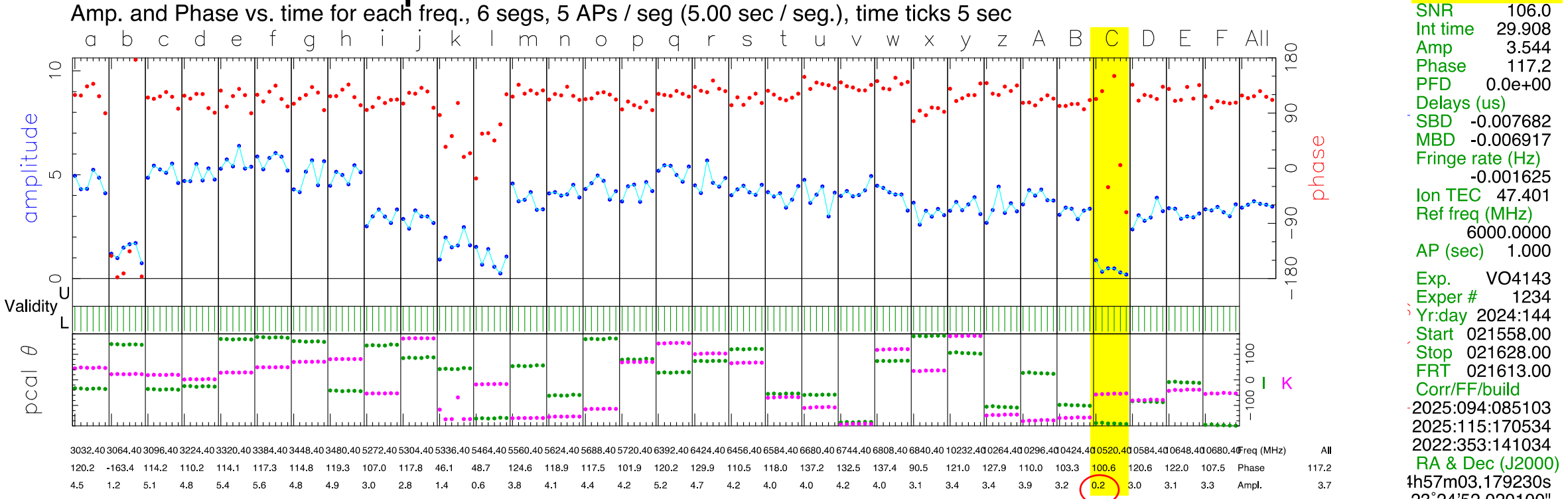
HOPS aedit: Summary View



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: $\boldsymbol{SNR_{chan} < \frac{SNR_{avg}}{10}}$
- Correlator drops channels with excessive G Codes.

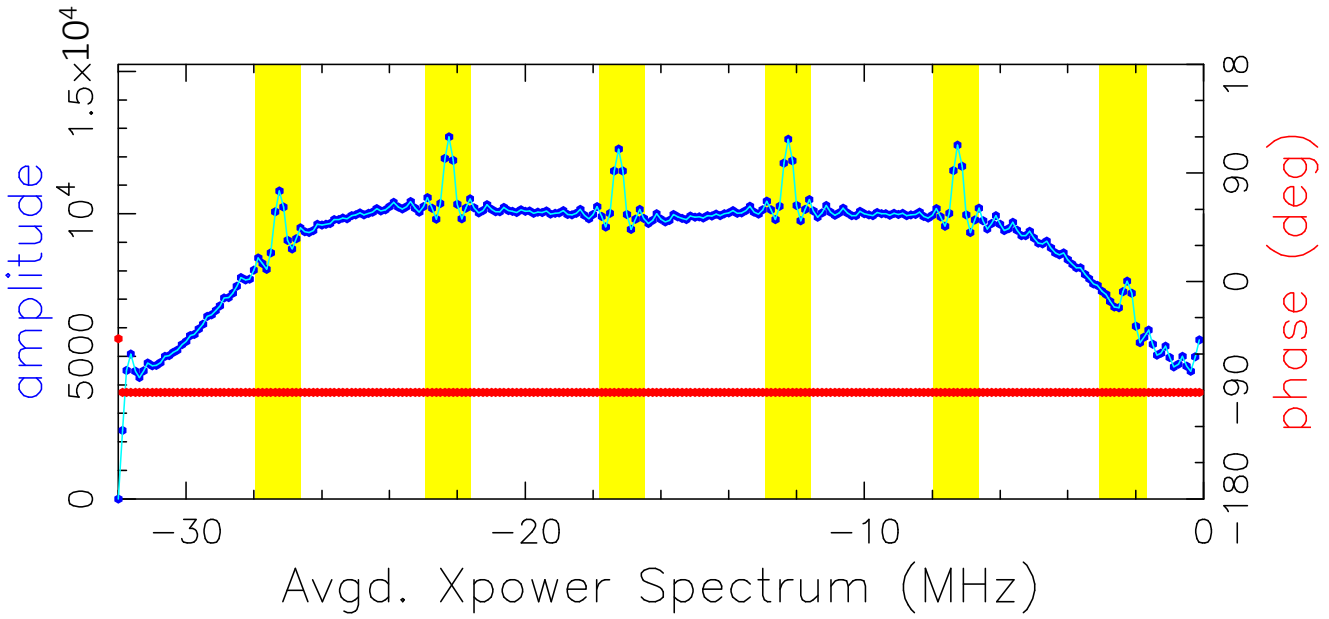


Fringe quality 6
Error code G
SNR 106.0
Int time 29.908
Amp 3.544
Phase 117.2
PFD 0.0e+00
Delays (us)
SBD -0.007682
MBD -0.006917
Fringe rate (Hz)
-0.001625
Ion TEC 47.401
Ref freq (MHz)
6000.0000
AP (sec) 1.000

Exp. VO4143
Exper # 1234
Yr:day 2024:144
Start 021558.00
Stop 021628.00
FRT 021613.00
Corr/FF/build
2025:094:085103
2025:115:170534
2022:353:141034
RA & Dec (J2000)
1h57m03.179230s

HOPS Fourfit: Phase Calibration (pcal)

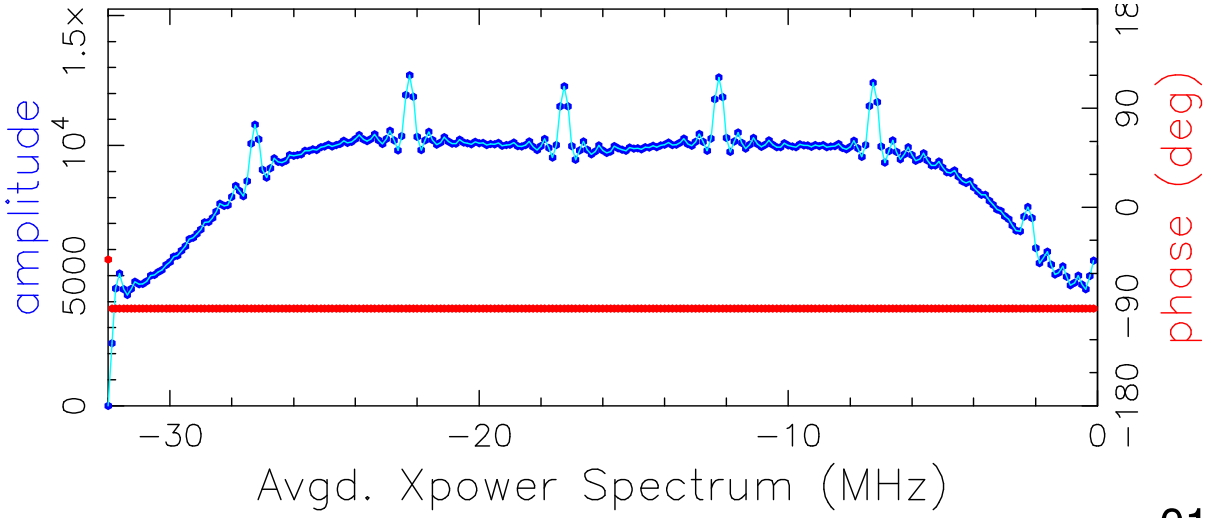
- Injected phase calibration (pcal) tones cause regularly spaced spikes in the apparent power spectrum of autocorrelations.
- Spacing is either 5 or 10 MHz for VGOS observations.
- Weak tones can be missed.
- Narrow RFI at pcal frequencies may cause spurious detection.
- DiFX extracts all pcal tones, so a few missing tones can be ignored, (e.g. due to RFI).



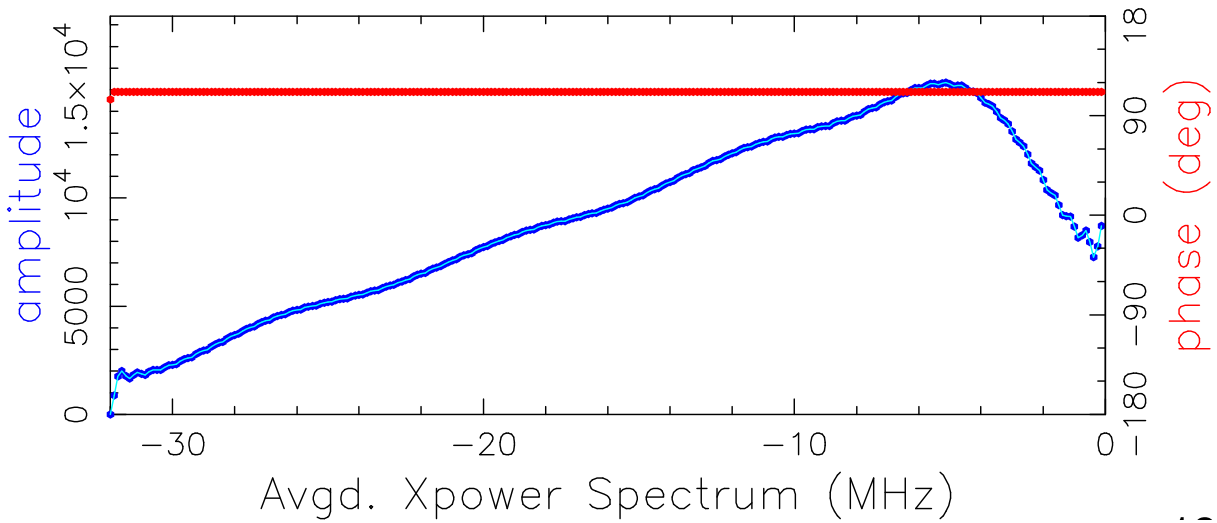
HOPS Fourfit: Phase Calibration (pcal) Cont.

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

sufficient
phase calibration tones

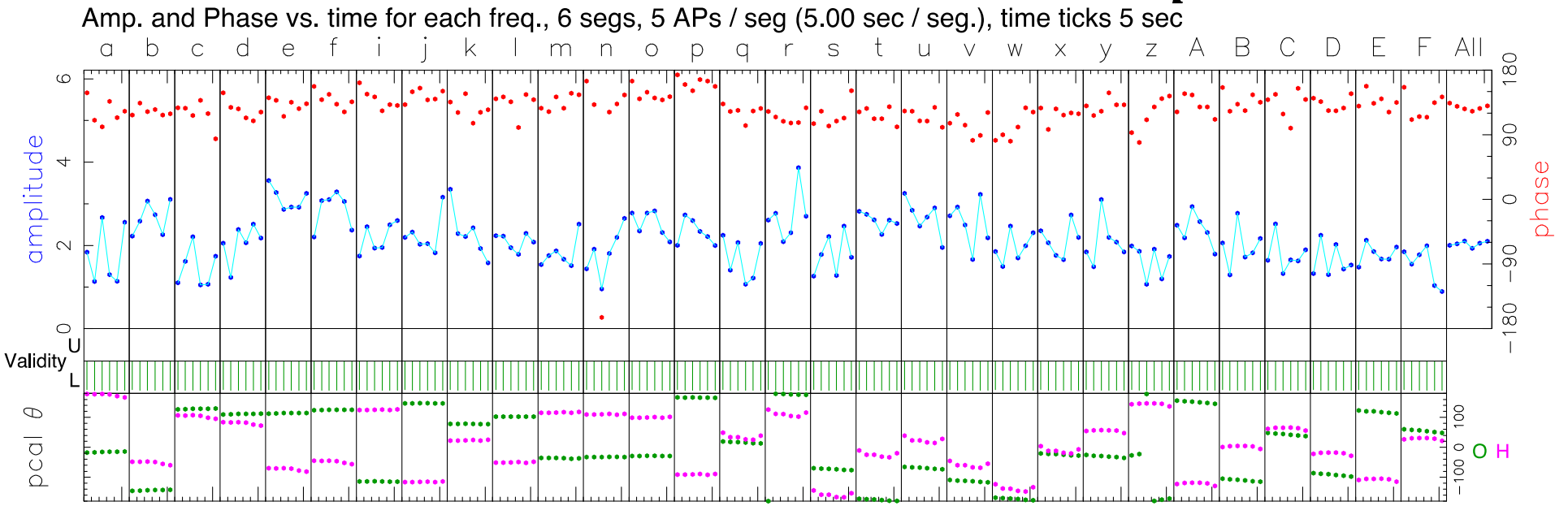


no detectable
phase calibration tones



HOPS Fourfit: Phase Calibration (pcal) Cont.

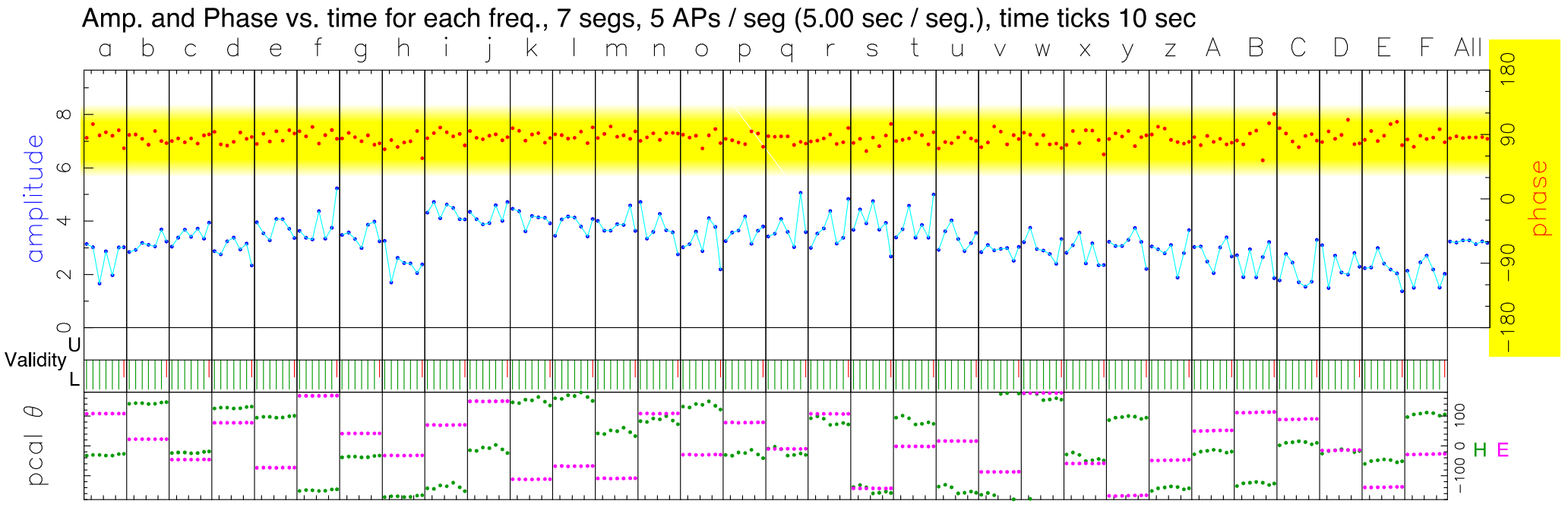
- Phase calibration (PC) amplitude corresponds to pcal SNR.
- **H Code** error (no pcal) happens when: $\boldsymbol{Amp_{pcal} < 100ppm}$



	3032.40	3064.40	3096.40	3224.40	3320.40	3384.40	5272.40	5304.40	5336.40	5464.40	5560.40	5624.40	5688.40	5720.40	6392.40	6424.40	6456.40	6584.40	6680.40	6744.40	6808.40	6840.40	10232.40	10264.40	10296.40	10424.40	10520.40	10584.40	10648.40	10680.40	Freq (MHz)	All
	120.9	122.6	116.6	123.3	132.0	137.8	138.5	144.8	126.3	135.2	136.0	142.9	146.4	161.6	123.8	114.2	116.9	117.5	116.7	103.8	100.7	118.0	130.2	114.4	131.6	136.5	134.6	132.8	137.1	127.1	Phase	128.2
	1.7	2.6	1.4	2.0	3.1	2.8	2.2	2.2	2.2	2.0	1.8	1.7	2.5	2.3	1.7	2.7	1.7	2.6	2.6	2.5	1.9	2.1	2.1	1.5	2.3	1.9	1.7	1.6	1.8	1.4	Ampl.	2.1
	256.5	255.6	255.3	255.8	255.8	255.4	256.1	255.9	255.3	255.5	255.6	255.6	255.2	255.3	257.0	255.2	256.1	254.9	254.9	255.2	255.7	255.5	255.9	255.8	255.0	255.2	255.4	254.9	255.1	254.9	Sbd box	255.5
U/L	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	APs used	
O	77.7	71.5	72.2	72.3	70.2	73.7	72.4	69.7	71.5	71.5	69.8	69.8	70.5	70.3	43.7	54.0	44.7	49.1	51.4	50.8	46.3	51.9	28.2	28.9	28.9	29.8	30.0	27.1	27.1	30.3	PC X delays (ns)	
O	72.3	74.9	77.3	69.9	71.3	73.1	70.8	70.5	72.3	70.0	72.3	69.9	70.9	69.7	42.2	49.4	46.2	49.3	47.9	48.6	41.3	50.4	29.5	23.3	30.1	30.2	31.6	29.4	28.2	29.7	PC Y delays (ns)	
H	-294.7	-296.9	-298.0	-300.1	-300.7	-301.0	-10.4	-13.0	-14.1	-15.8	-16.1	-16.7	-16.6	-14.9	-7.2	-8.4	-9.5	-12.9	-13.2	-12.9	-12.8	-11.4	-6.1	-8.8	-10.2	-12.7	-13.3	-13.6	-12.5	-11.1	PC X delays (ns)	
H	-297.8	-300.6	-301.6	-303.7	-304.0	-304.4	-10.4	-14.6	-15.8	-18.3	-18.6	-19.2	-18.8	-17.6	-8.6	-11.7	-12.4	-14.9	-15.4	-15.3	-15.4	-14.3	-9.4	-11.4	-13.0	-14.4	-14.6	-15.7	-15.0	-13.5	PC Y delays (ns)	
O:H	172:-179	21:-14	-99:169	134:-105	50:180	10:-109	-86:-91	167:43	75:-168	87:156	-95:-16	-100:-4	-92:3	85:179	127:119	-73:-156	37:-60	-81:99	10:167	-38:96	-122:26	25:161	-98:-66	152:15	140:121	-144:-113	47:-47	159:-127	15:151	-47:-72	PC phase	
O:H	169:-4	162:-6	165:-4	163:-1	170:0	171:4	183:5	181:0	194:0	168:0	184:6	175:7	153:7	163:9	171:-6	165:-6	158:-6	146:-5	143:-6	135:-5	148:-2	143:-4	198:-9	184:2	135:-7	148:0	196:3	210:5	199:5	196:6	Manl PC	
O	100	99	105	65	95	108	57	48	51	59	27	48	50	49	38	43	34	24	19	22	16	16	6	1	5	24	16	15	9	6	PC amp	
H	56	59	56	60	53	58	53	51	45	48	40	43	41	36	33	36	34	38	33	35	32	25	15	15	13	14	12	13	13	11		

HOPS Fourfit: Phase Calibration (pcal) Cont.

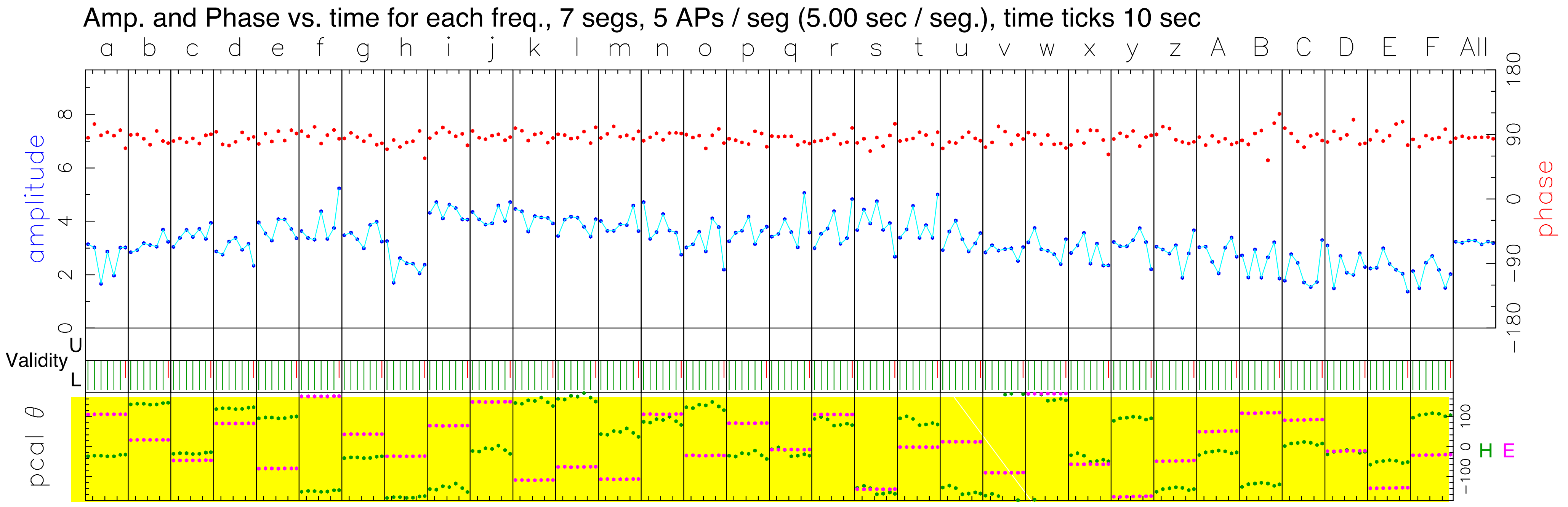
- After fringe fitting and phase calibration, the phases should appear normally distributed around a single mean value.



	3032.40	3064.40	3096.40	3224.40	3320.40	3384.40	3448.40	3480.40	5272.40	5304.40	5336.40	5464.40	5560.40	5624.40	5688.40	5720.40	6392.40	6424.40	6456.40	6584.40	6680.40	6744.40	6808.40	6840.40	10232.40	10264.40	10296.40	10424.40	10520.40	10584.40	10648.40	10680.40	Freq (MHz)	All
	91.0	84.8	83.1	83.4	87.0	89.6	84.0	76.5	89.8	87.3	89.2	88.0	89.4	87.3	86.8	82.9	83.4	84.3	81.2	85.4	81.5	84.9	82.8	85.0	85.9	87.4	81.0	87.1	86.1	86.1	91.1	84.6	Phase	85.7
	2.6	3.1	3.5	3.0	3.7	3.7	3.5	2.4	4.3	4.2	4.1	3.8	3.9	3.8	3.3	3.6	3.8	3.6	3.9	3.8	3.3	2.9	3.0	2.8	3.2	2.8	2.8	2.4	2.1	2.3	2.2	2.1	Ampl.	3.2
	256.0	256.3	256.8	256.8	257.0	256.9	257.0	256.8	256.7	257.0	257.0	257.2	257.3	257.3	257.2	257.0	256.5	257.0	257.0	257.2	257.2	257.1	257.4	257.1	256.8	257.2	257.0	257.3	257.7	257.1	257.5	257.1	Sbd box	257.0
U/L	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	APs used	
H	-294.7	-297.0	-298.2	-300.3	-300.8	-301.1	-300.5	-298.6	-10.5	-12.8	-14.1	-15.7	-16.1	-16.5	-16.6	-15.1	-7.1	-8.4	-9.4	-13.2	-13.2	-12.9	-12.8	-11.4	-5.9	-8.9	-10.2	-12.8	-13.3	-13.6	-12.7	-11.4	PC X delays (ns)	
H	-297.9	-300.7	-301.7	-303.8	-304.1	-304.5	-304.0	-302.3	-10.3	-14.6	-15.9	-18.3	-18.7	-19.2	-18.7	-17.9	-8.8	-11.7	-12.5	-14.7	-15.3	-15.4	-15.5	-14.3	-9.4	-11.5	-13.0	-14.4	-14.6	-15.6	-15.0	-13.4	PC Y delays (ns)	
E	-52.9	-53.0	-54.2	-55.7	-54.9	-55.3	-53.9	-55.3	-38.1	-38.2	-39.4	-38.8	-39.7	-38.9	-39.8	-39.1	-41.6	-41.6	-40.1	-42.4	-42.1	-41.8	-41.4	-42.0	-40.0	-41.3	-39.9	-40.5	-41.4	-41.0	-40.9	-41.0	PC X delays (ns)	
E	-58.5	-58.8	-59.7	-60.5	-60.2	-60.3	-59.9	-60.4	-39.1	-38.7	-39.6	-39.9	-39.6	-40.9	-41.5	-39.7	-38.3	-38.1	-37.8	-39.2	-38.9	-39.7	-40.0	-39.3	-36.2	-36.9	-37.6	-37.7	-37.1	-38.7	-37.2	-38.1	PC Y delays (ns)	
H:E	17:118	-137:9	87:-92	-15:-77	35:43	-165:-13	3:52	-115:-41	53:-89	-166:-11	5:79	55:84	-40:12	17:-149	85:47	-71:139	111:-64	-138:54	-3:157	-104:-95	44:-104	29:133	17:24	-176:142	18:-32	135:78	-90:-175	168:-129	-52:-164	-76:77	-106:-59	54:48	PC phase	
H:E	-53:-4	-55:-11	-56:-8	-50:-12	-52:-1	-48:5	-50:6	-47:2	-46:15	-50:7	-51:5	-48:6	-43:9	-42:10	-44:18	-42:25	-56:-21	-57:-28	-56:-27	-57:-22	-58:-14	-56:-6	-53:-6	-58:-5	-56:-2	-46:4	-56:-7	-51:-2	-46:2	-45:12	-44:20	-45:21	Manl PC	

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.



	3032.40	3064.40	3096.40	3224.40	3320.40	3384.40	3448.40	3480.40	5272.40	5304.40	5336.40	5464.40	5560.40	5624.40	5688.40	5720.40
	91.0	84.8	83.1	83.4	87.0	89.6	84.0	76.5	89.8	87.3	89.2	88.0	89.4	87.3	86.8	82.9
	2.6	3.1	3.5	3.0	3.7	3.7	3.5	2.4	4.3	4.2	4.1	3.8	3.9	3.8	3.3	3.6
	256.0	256.3	256.8	256.8	257.0	256.9	257.0	256.8	256.7	257.0	257.0	257.2	257.3	257.3	257.2	257.0
U/L	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33
H	-294.7	-297.0	-298.2	-300.3	-300.8	-301.1	-300.5	-298.6	-10.5	-12.8	-14.1	-15.7	-16.1	-16.5	-16.6	-15.1
H	-297.9	-300.7	-301.7	-303.8	-304.1	-304.5	-304.0	-302.3	-10.3	-14.6	-15.9	-18.3	-18.7	-19.2	-18.7	-17.9
E	-52.9	-53.0	-54.2	-55.7	-54.9	-55.3	-53.9	-55.3	-38.1	-38.2	-39.4	-38.8	-39.7	-38.9	-39.8	-39.1
E	-58.5	-58.8	-59.7	-60.5	-60.2	-60.3	-59.9	-60.4	-39.1	-38.7	-39.6	-39.9	-39.6	-40.9	-41.5	-39.7

	6392.40	6424.40	6456.40	6584.40	6680.40	6744.40	6808.40	6840.40	10232.40	10264.40	10296.40	10424.40	10520.40	10584.40	10648.40	10680.40	Freq (MHz)	All
	83.4	84.3	81.2	85.4	81.5	84.9	82.8	85.0	85.9	87.4	81.0	87.1	86.1	86.1	91.1	84.6	Phase	85.7
	3.8	3.6	3.9	3.8	3.3	2.9	3.0	2.8	3.2	2.8	2.8	2.4	2.1	2.3	2.2	2.1	Ampl.	3.2
	256.5	257.0	257.0	257.2	257.2	257.1	257.4	257.1	256.8	257.2	257.0	257.3	257.7	257.1	257.5	257.1	Sbd box	257.0
U/L	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	0/33	APs used	
H	-7.1	-8.4	-9.4	-13.2	-13.2	-12.9	-12.8	-11.4	-5.9	-8.9	-10.2	-12.8	-13.3	-13.6	-12.7	-11.4	PC X delays (ns)	
H	-8.8	-11.7	-12.5	-14.7	-15.3	-15.4	-15.5	-14.3	-9.4	-11.5	-13.0	-14.4	-14.6	-15.6	-15.0	-13.4	PC Y delays (ns)	
E	-41.6	-41.6	-40.1	-42.4	-42.1	-41.8	-41.4	-42.0	-40.0	-41.3	-39.9	-40.5	-41.4	-41.0	-40.9	-41.0	PC X delays (ns)	
E	-38.8	-38.1	-37.8	-39.2	-38.9	-39.7	-40.0	-39.3	-36.2	-36.9	-37.6	-37.7	-37.1	-38.7	-37.2	-38.1	PC Y delays (ns)	

HOPS Fourfit: Final Look

After Configuration:

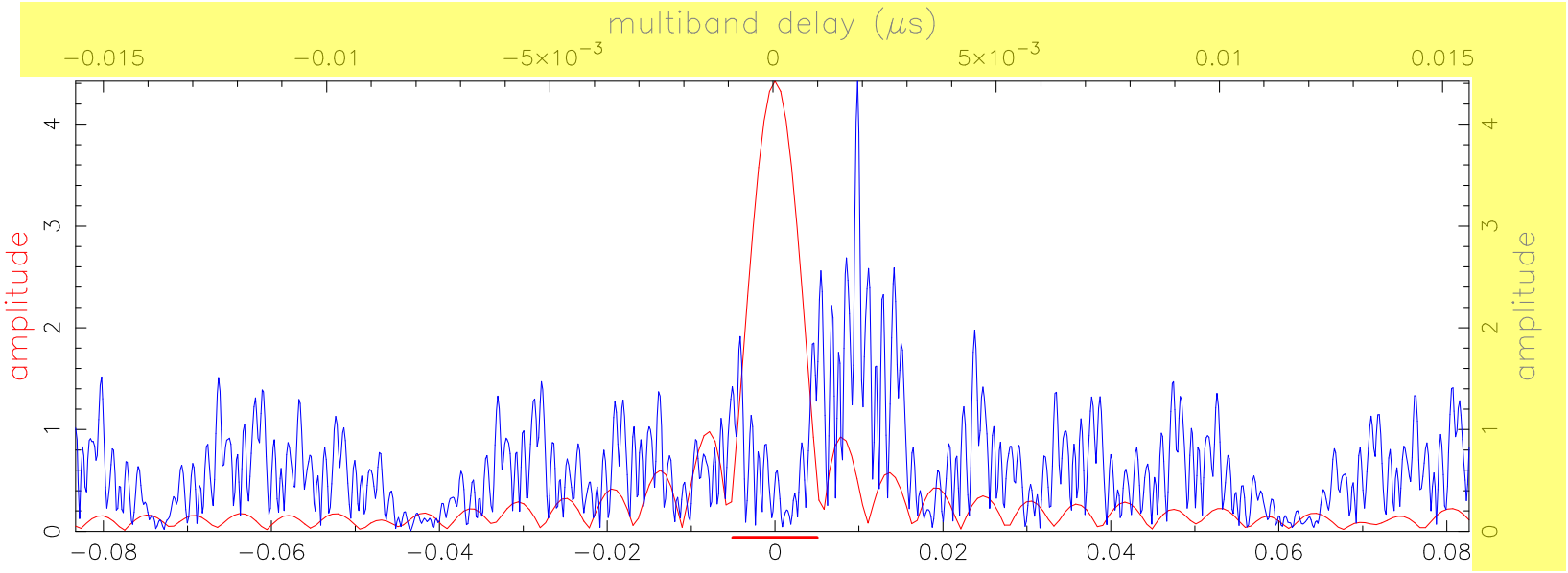
- Fewer G and H Codes
  - Sometimes a few new ones after pseudo-Stokes I
- Fewer 0 Codes
- More 7—9 Codes
- Goal:
  ≥ 90% 7—9 Codes

	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
A:X	-	-	-	-	-	-	-	3	-	-	-	-	-	-	2	17	136	792	180	1130
E:X	-	-	-	-	-	-	-	13	-	-	-	-	-	-	4	16	177	867	20	1097
H:X	-	-	-	-	-	-	-	20	1	-	-	1	-	2	45	80	198	559	364	1270
I:X	-	-	-	-	-	-	-	17	1	-	-	-	-	1	23	51	123	477	238	931
K:X	-	-	-	-	-	-	-	44	-	-	-	1	1	1	34	90	197	53	49	470
M:X	-	-	-	-	-	-	-	16	-	-	-	-	1	1	17	28	112	689	296	1160
N:X	-	-	-	-	-	-	-	2	-	-	-	-	-	-	17	56	412	425	183	1095
O:X	-	-	-	-	-	-	-	9	2	-	-	-	-	1	20	45	122	126	159	484
S:X	-	-	-	-	-	-	-	90	-	-	2	5	17	36	81	23	135	633	82	1104
T:X	-	-	-	-	-	-	-	93	-	-	2	5	17	36	85	23	141	610	141	1153
V:X	-	-	-	-	-	-	-	5	-	-	-	-	-	-	4	19	111	763	68	970

	A	B	C	D	E	F	G	H	0	1	2	3	4	5	6	7	8	9	*
*:X	-	-	-	-	-	-	-	156	2	-	2	6	18	39	166	224	932	2997	890	5432
:	-	-	-	-	-	-	-	156	2	-	2	6	18	39	166	224	932	2997	890	5432

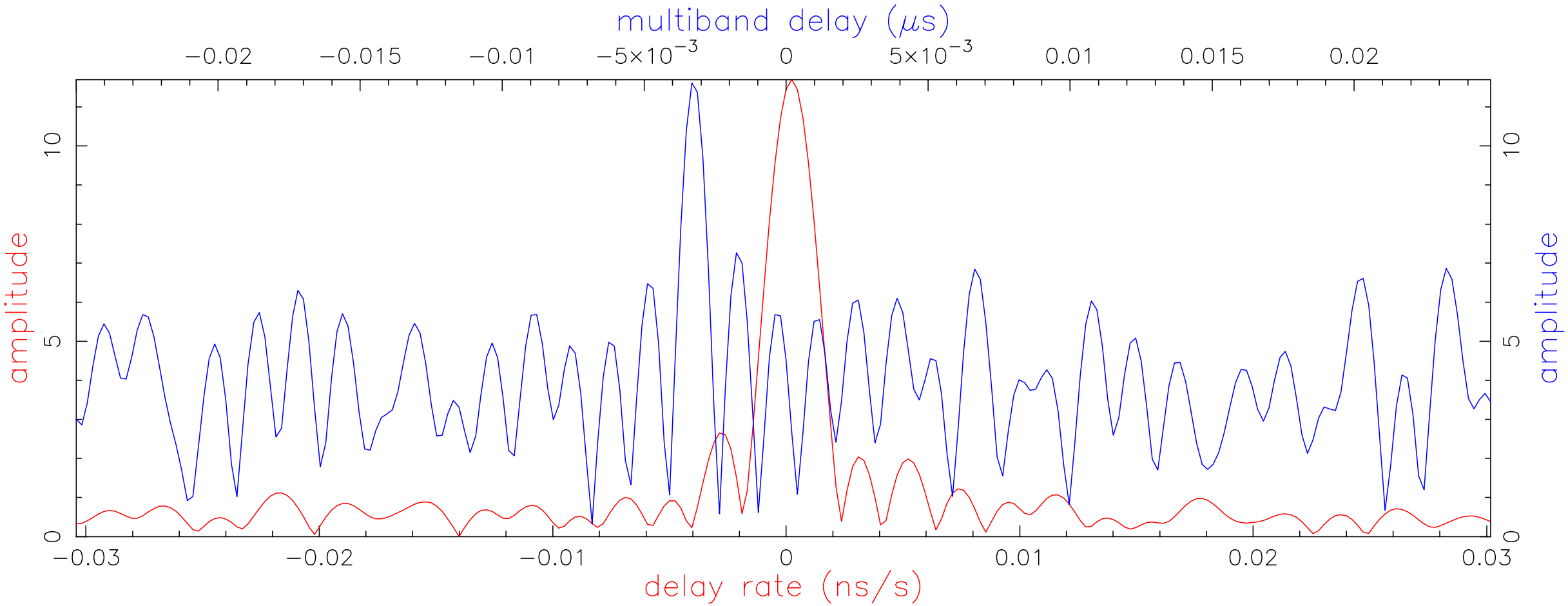
HOPS Fourfit: Multiband Delay

- Each channel only gives a single mean frequency:
  We must combine channels to cover the whole range of frequencies.
- 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.

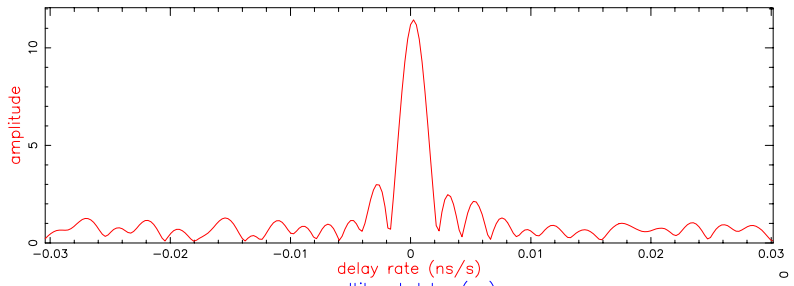
- Removing channels removes spacings and causes ambiguities.



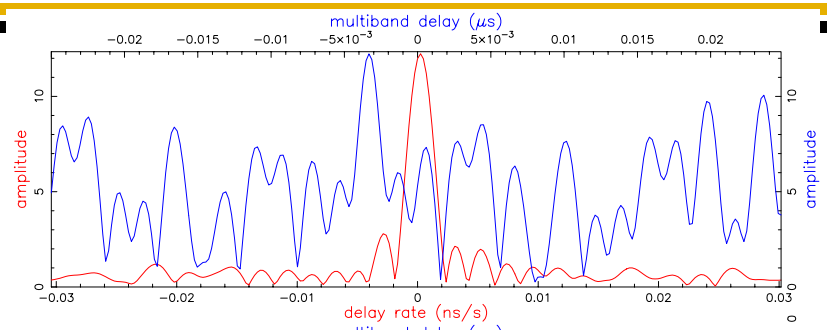
8 channels, 28 spacings

HOPS Fourfit: Multiband Delay Cont.

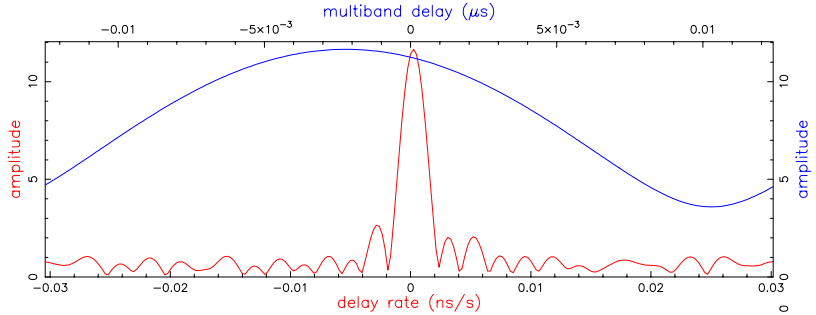
1 channel
0 spacings



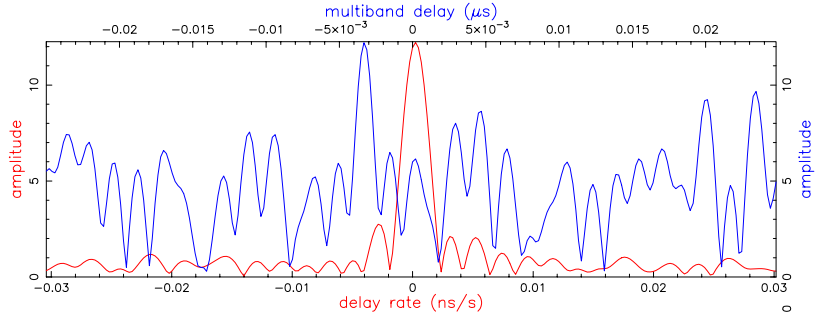
5 channels
10 spacings



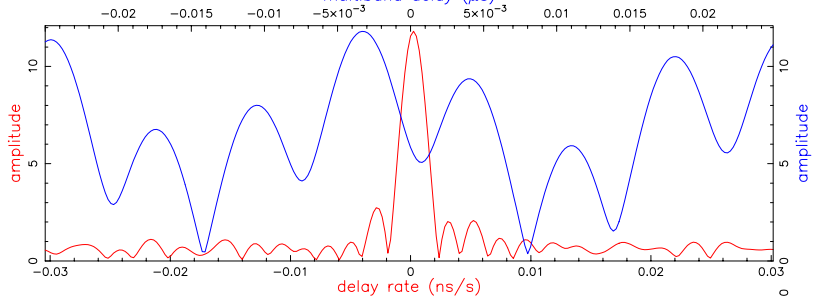
2 channels
1 spacing



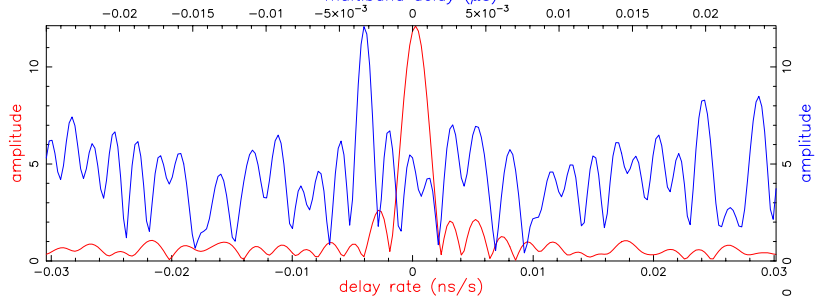
6 channels
15 spacings



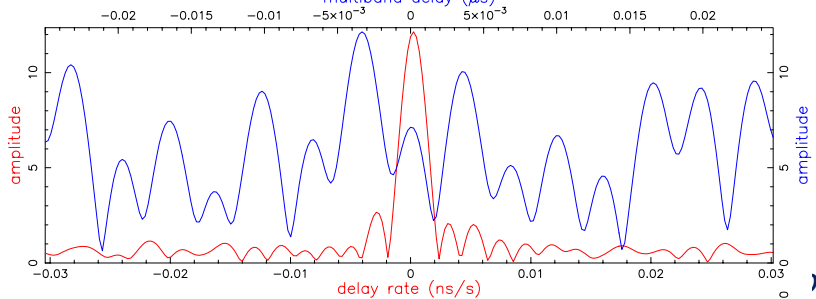
3 channels
3 spacings



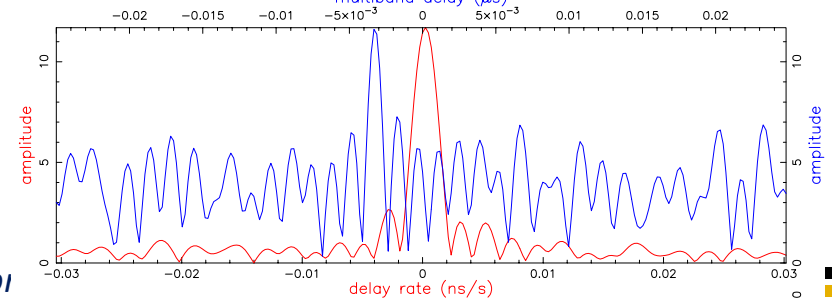
7 channels
21 spacings



4 channels
6 spacings

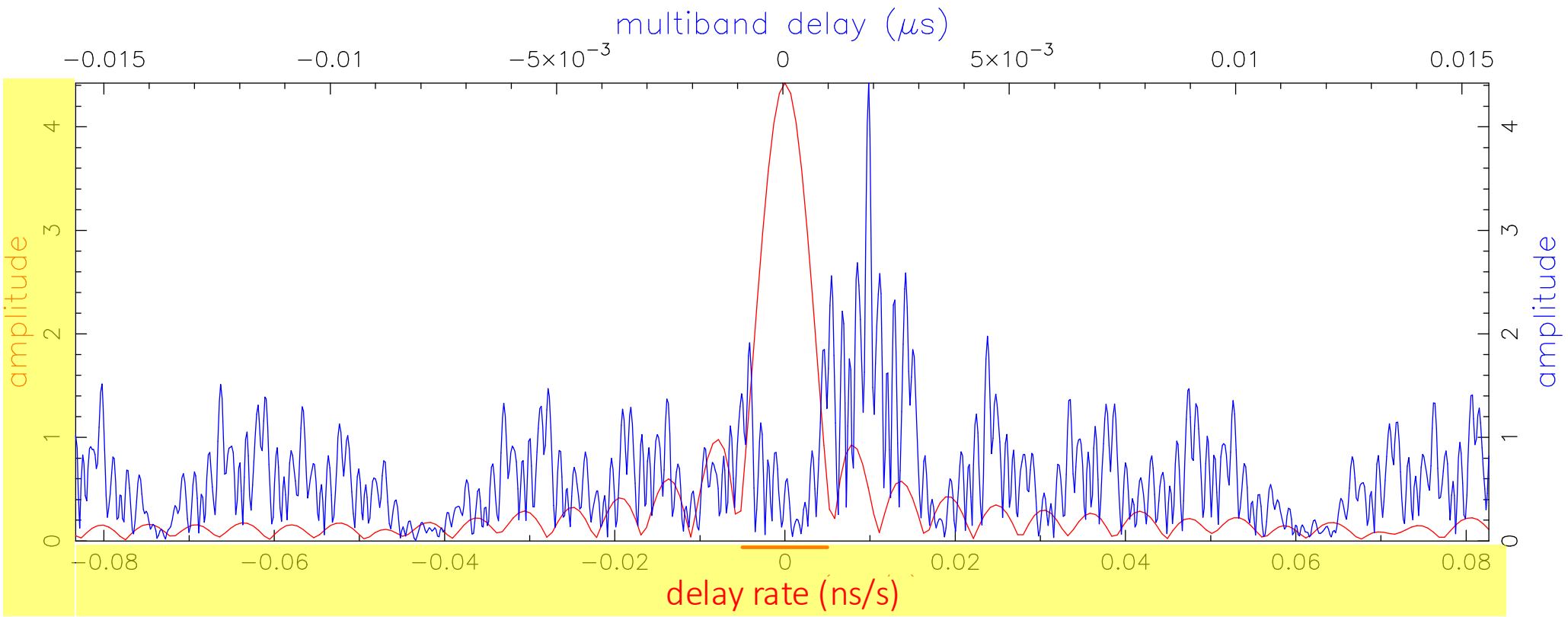


8 channels
28 spacings



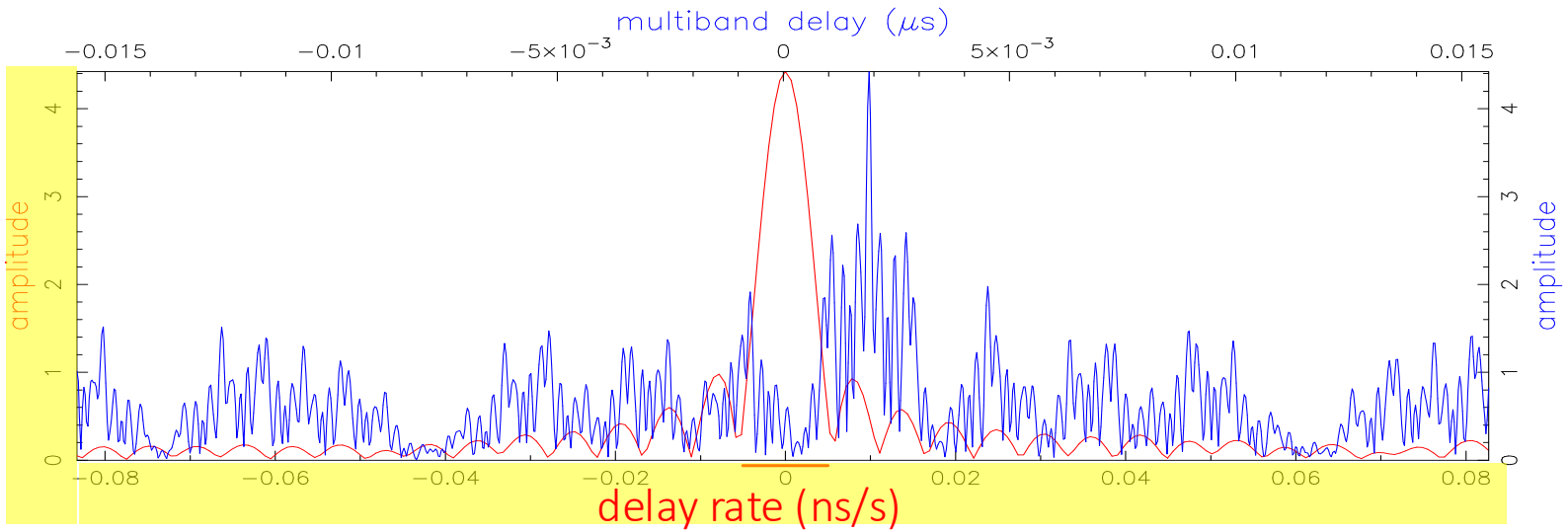
HOPS Fourfit: Fringe Rate and Delay Rate

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



HOPS Fourfit: Fringe Rate and Delay Rate Cont.

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



Fringe quality 8

SNR 132.4
Int time 29.982
Amp 4.422 × 100ppm
Phase -131.9
PFD 0.0e+00
Delays (us)
SBD 0.000148
MBD 0.001890
Fringe rate (Hz)
0.000207
Ion TEC 15.865
Ref freq (MHz)
6000.0000
AP (sec) 1.000

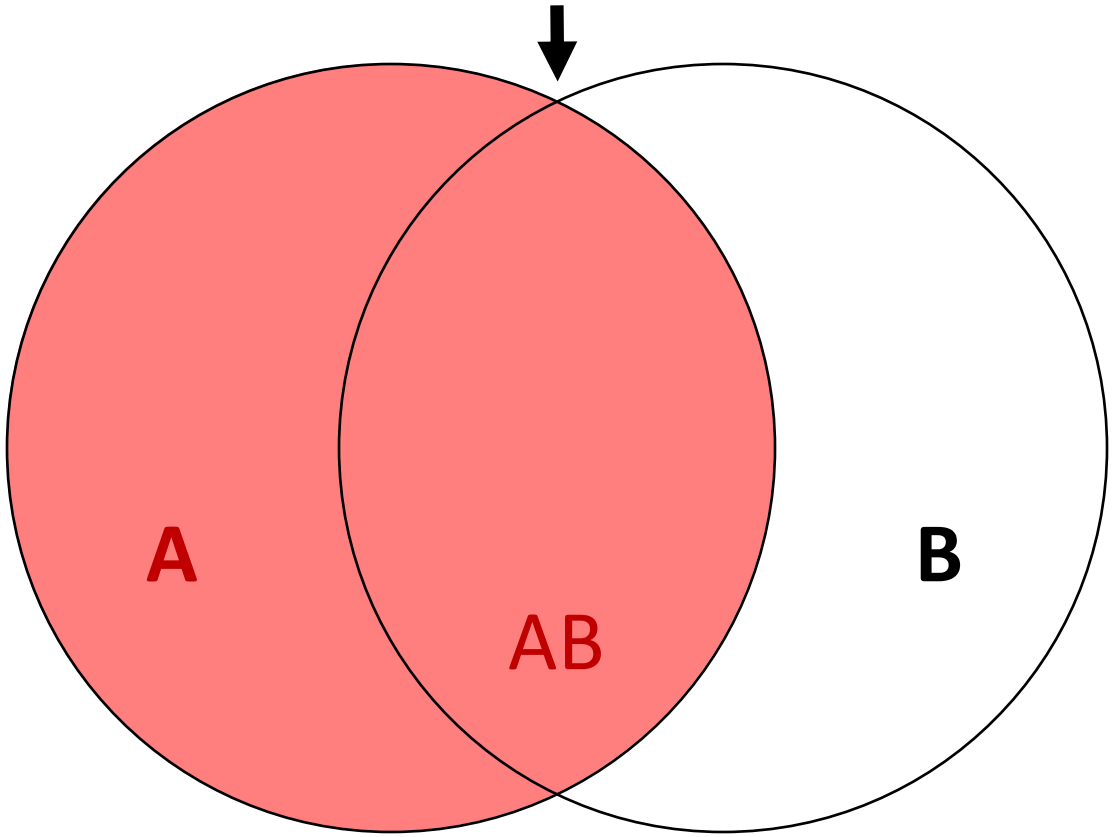
Exp. VO4143
Exper # 1234
Yr:day 2024:143
Start 185045.00
Stop 185115.00
FRT 185100.00
Corr/FF/build
2025:093:014228
2025:115:165746
2022:353:141034
RA & Dec (J2000)
h36m58.594810s
47°51'29.100000"

- Lowest frequency (1 sec AP, 3.03 GHz): DRW = 1.65×10^{-10} ns/s

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).



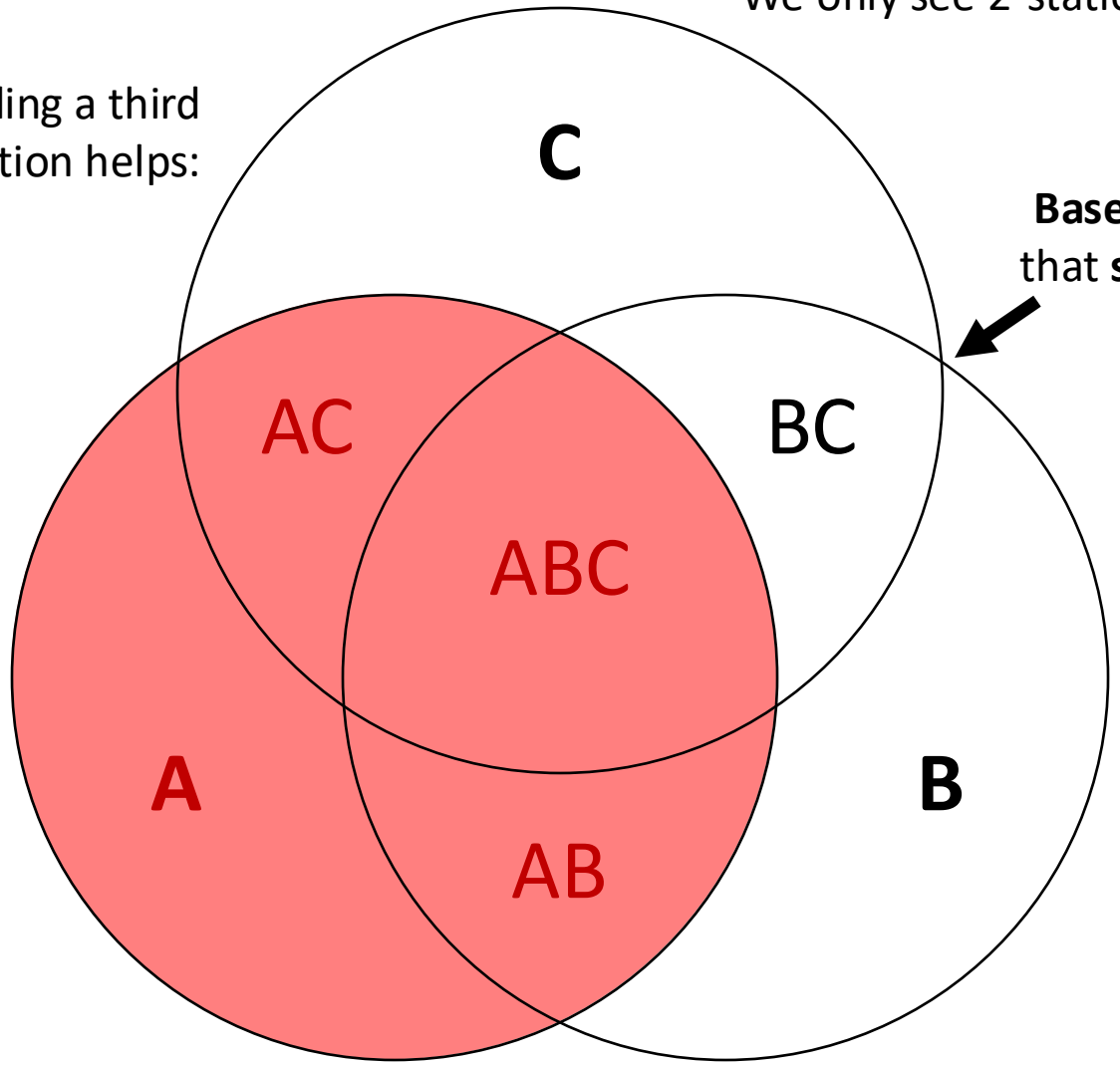
Correlator Report:

```
+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:

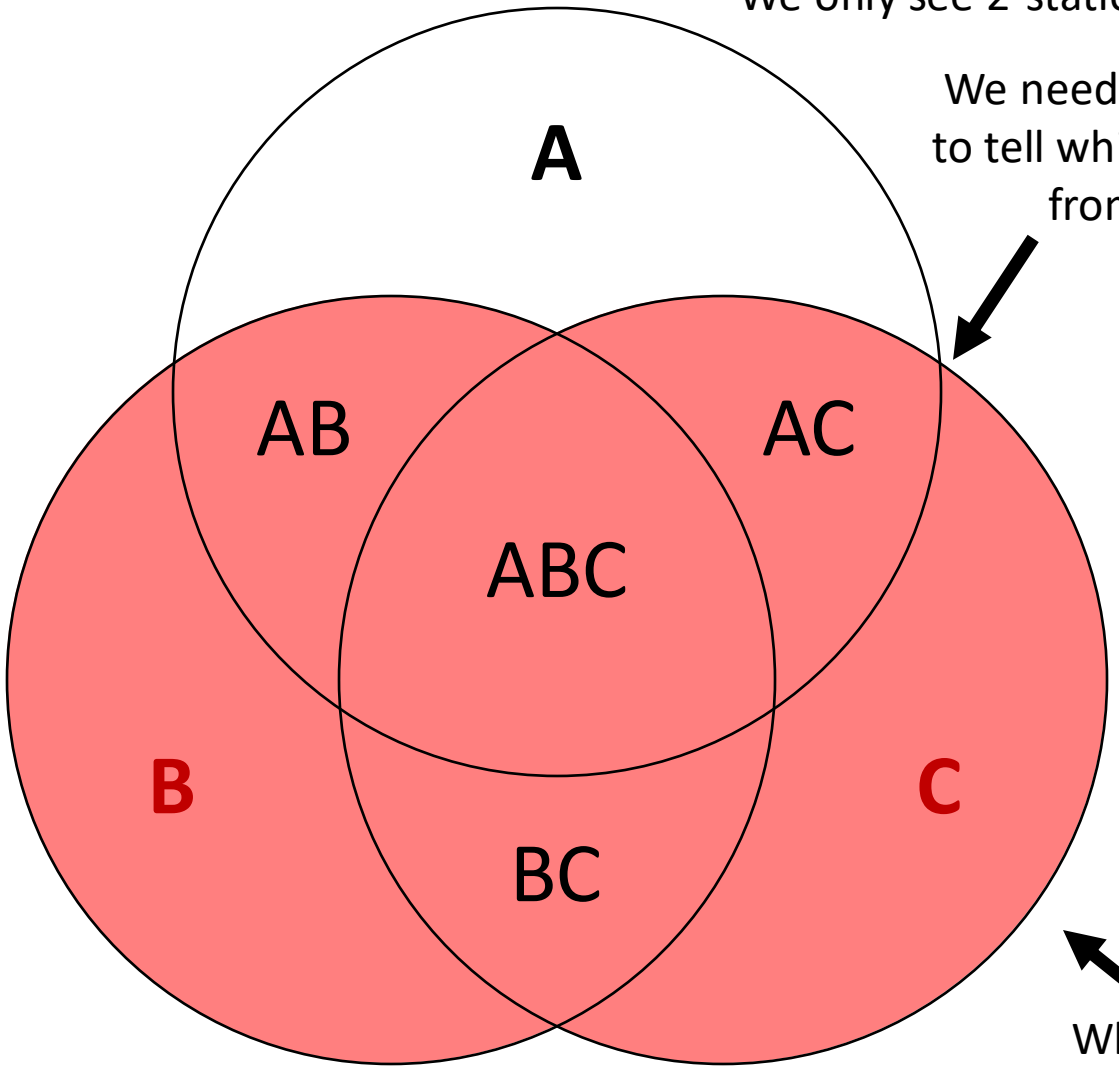


Baseline BC is okay, so we conclude that **station B** and **station C** are okay.

```
+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
  - 9 Gbps eTransfer
  - Mark5 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, VieSched++, Python3

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
```

Correlation Pass Number

Fringing Pass Number

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

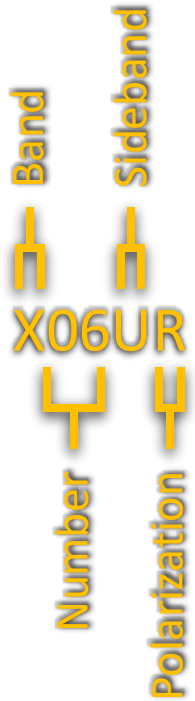
+CLOCK

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	2022-364-0540	-60.020	2.059000e-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

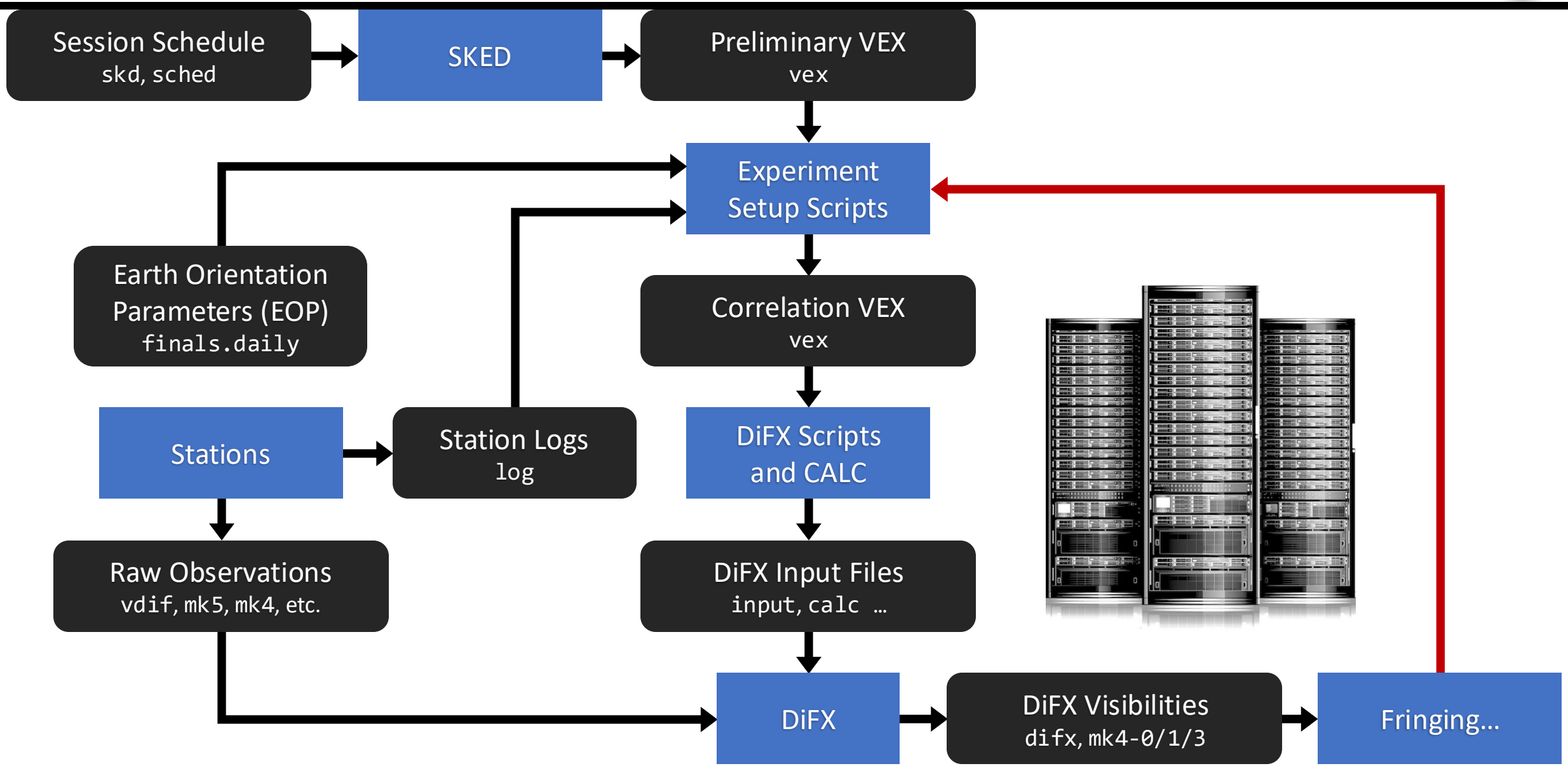
RF "notches"
to cut out shared RFI
for co-located antennas

Each notch consists of a start and end frequency in MHz

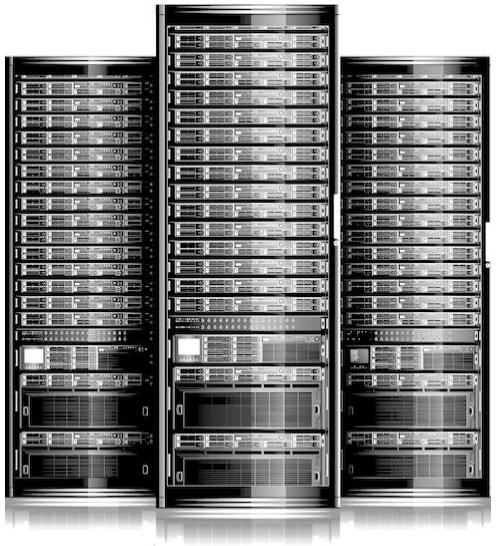
```
+FRINGING_CONFIG_FILE

…

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
    …
```

Thank you!

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

Correlator Report
corr

Report
Script

Station Logs
log

Archiving
vSolve

VGOS Archive
vgosdb

Analysis…