VGOS-related work at the Onsala Space Observatory

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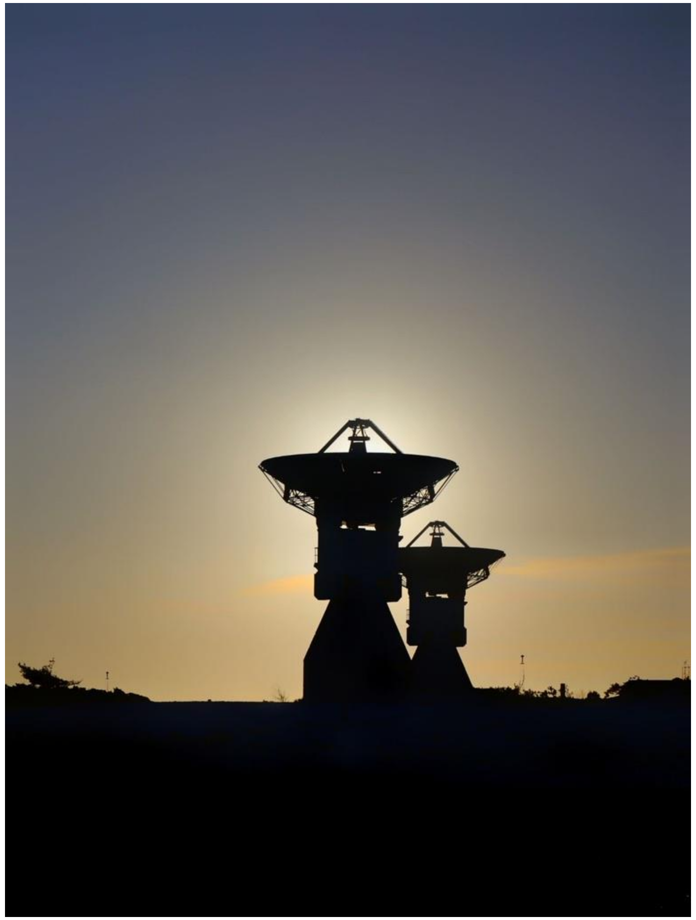
IVTW IX 2024

Outline

1) Testing 16 Gbps recording, 128 channels
2) Holography of the OTT
3) Invar measurements of OTT telescope towers

Onsala Twin Telescopes

- MTM/OHB 13.2 m telescopes
  - Oe: QRFH 3-18 GHz
  - Ow: Eleven-feed 2-14 GHz
- Two FS computers
- Two DBBC3 backends
- Several Flexbuff recorders
- Inaugurated 2017 and operational since 2020



1) Testing 16 Gbps, 128 channel recording

- ”Standard” VGOS observations:
  - Four bands with 8 channels of 32 MHz each, in 2 polarizations,
    - => 64 channels (i.e. 4 x 8 x 2)
  - 8 Gbps per system
  - Using operationally DBBC3 firmware v125

- Test observations in 2024:
  - Using DBBC3 firmware v126
  - Four bands with 16 channels of 32 MHz each, in 2 polarizations
    - => 128 channels (i.e. 4 x 16 x 2)
  - 16 Gbps per system: two jive5ab ports with 8 Gbps each
  - Four shared CPU cores between the two flexbuffs

VGOS operational ”VO”

	Start (MHz)	Stop (MHz)	B (MHz)
Band-A	3000.4	3480.4	480
Band-B	5240.4	5720.4	480
Band-C	6360.4	6840.4	480
Band-D	10200.4	10680.4	480

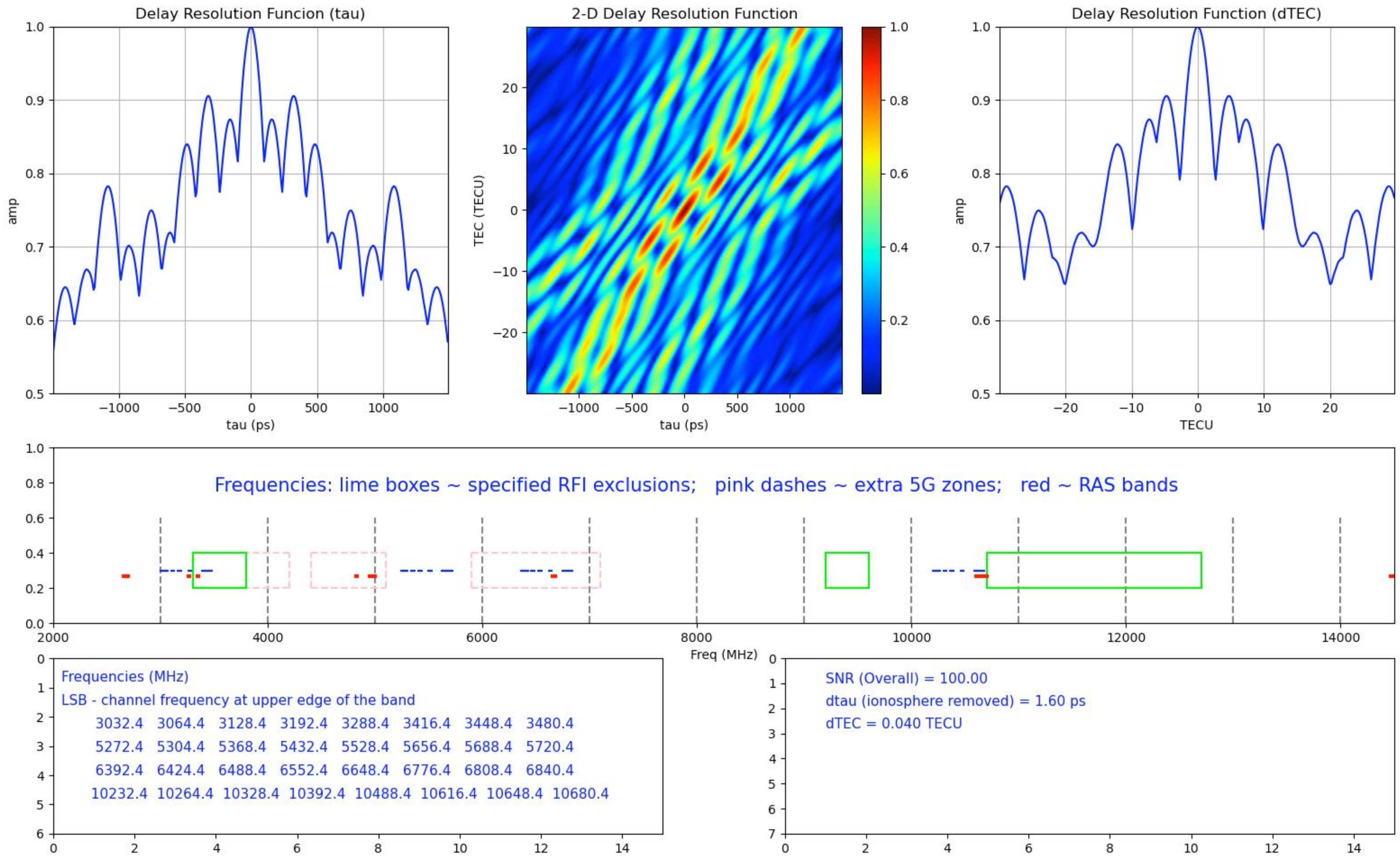
start frequency

stop frequency

each channel 32 MHz wide

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	2		4		6			9				13	14	15	
B	1	2		4		6			9				13	14	15	
C	1	2		4		6			9				13	14	15	
D	1	2		4		6			9				13	14	15	

VO


Delay Resolution Funcion (tau)
amp
tau (ps)
2-D Delay Resolution Function
TEC (TECU)
tau (ps)
Delay Resolution Function (dTEC)
amp
TECU
Frequencies: lime boxes ~ specified RFI exclusions; pink dashes ~ extra 5G zones; red ~ RAS bands
Freq (MHz)
Frequencies (MHz)
LSB - channel frequency at upper edge of the band
3032.4 3064.4 3128.4 3192.4 3288.4 3416.4 3448.4 3480.4
5272.4 5304.4 5368.4 5432.4 5528.4 5656.4 5688.4 5720.4
6392.4 6424.4 6488.4 6552.4 6648.4 6776.4 6808.4 6840.4
10232.4 10264.4 10328.4 10392.4 10488.4 10616.4 10648.4 10680.4
SNR (Overall) = 100.00
dtau (ionosphere removed) = 1.60 ps
dTEC = 0.040 TECU

VGOS ”OSO 128”

	Start (MHz)	Stop (MHz)	B (MHz)
Band-A	3000.4	3768.4	768
Band-B	3992.4	6040.4	2048
Band-C	6648.4	7672.4	1024
Band-D	10424.4	11448.4	1024

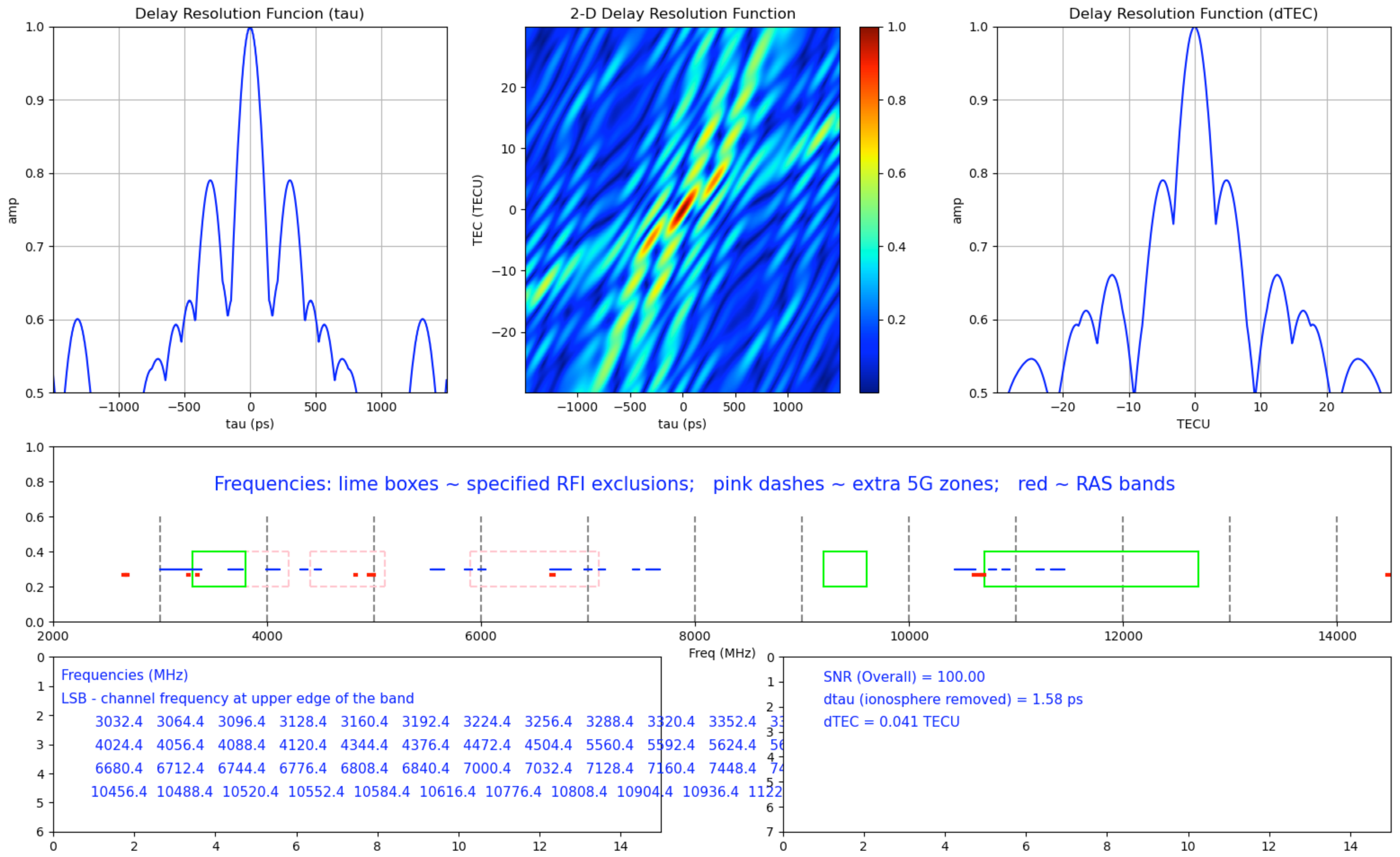
each channel 32 MHz wide

start frequency

stop frequency

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	...	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
A	1	2	3	4	5	6	7	8	9	10	11	12									21	22	23	24																									
B	1	2	3	4							11	12			15	16																		49	50	51	52							59	60			63	64
C	1	2	3	4	5	6					11	12			15	16									25	26			29	30	31	32																	
D	1	2	3	4	5	6					11	12			15	16									25	26			29	30	31	32																	

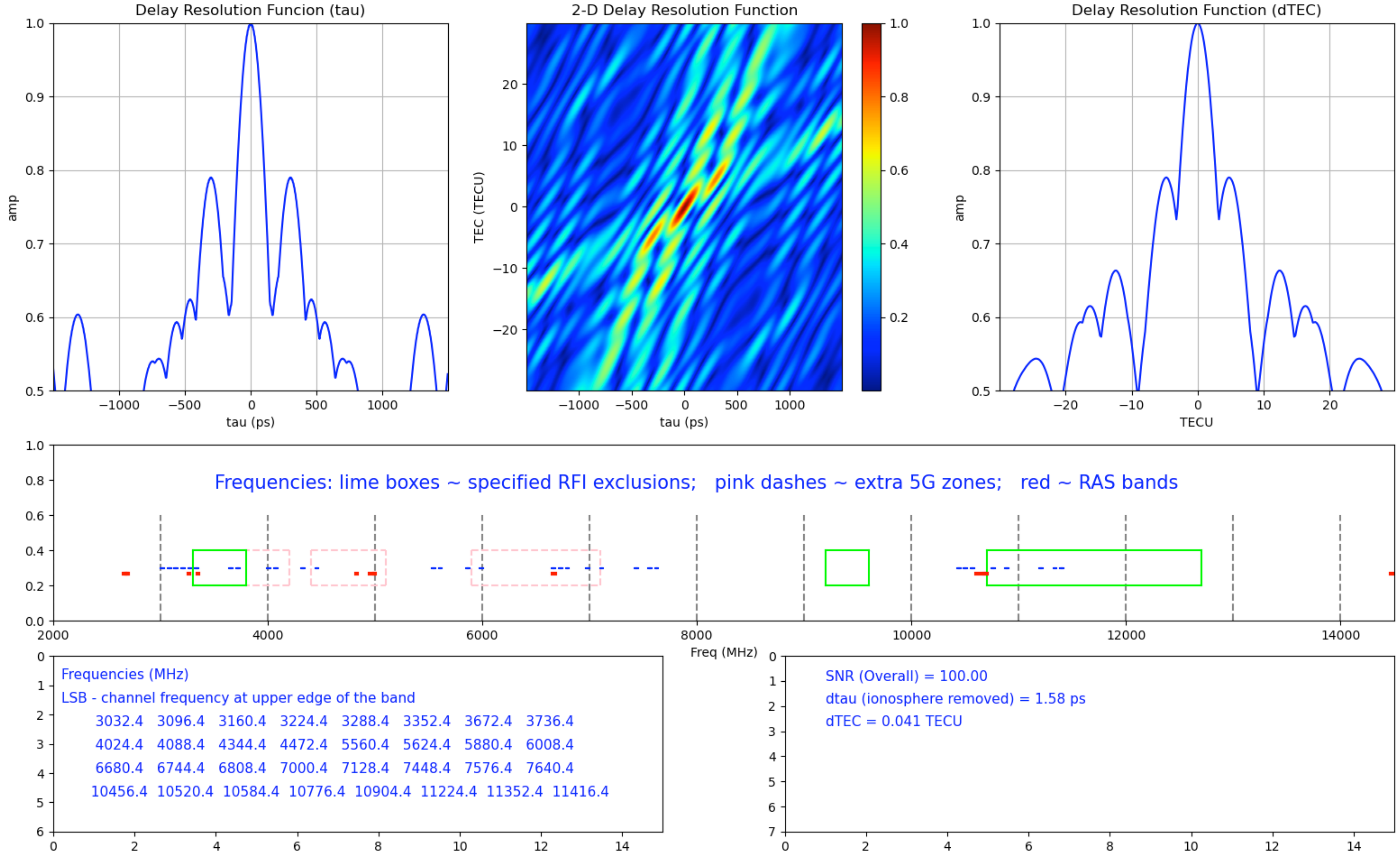
OSO 128


Delay Resolution Funcion (tau)
amp
tau (ps)
2-D Delay Resolution Function
TEC (TECU)
tau (ps)
Delay Resolution Function (dTEC)
amp
TECU
Frequencies: lime boxes ~ specified RFI exclusions; pink dashes ~ extra 5G zones; red ~ RAS bands
Freq (MHz)
Frequencies (MHz)
LSB - channel frequency at upper edge of the band
3032.4 3064.4 3096.4 3128.4 3160.4 3192.4 3224.4 3256.4 3288.4 3320.4 3352.4
4024.4 4056.4 4088.4 4120.4 4344.4 4376.4 4472.4 4504.4 5560.4 5592.4 5624.4
6680.4 6712.4 6744.4 6776.4 6808.4 6840.4 7000.4 7032.4 7128.4 7160.4 7448.4
10456.4 10488.4 10520.4 10552.4 10584.4 10616.4 10776.4 10808.4 10904.4 10936.4
SNR (Overall) = 100.00
dtau (ionosphere removed) = 1.58 ps
dTEC = 0.041 TECU

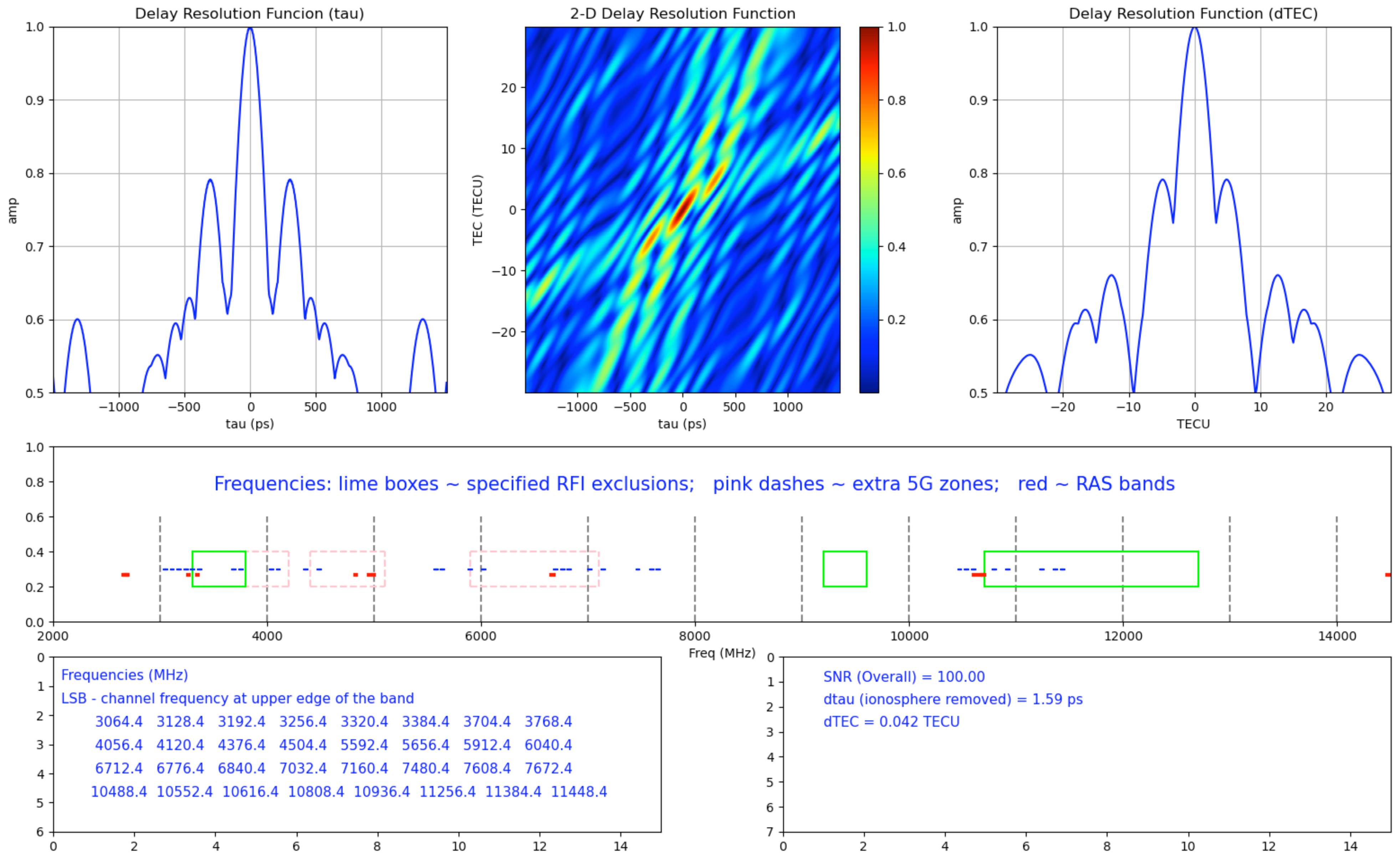
VGOS ”OSO 128: 64 odd / 64 even”

odd	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	…	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
A	1		3		5		7		9		11										21		23																										
B	1		3								11				15																			49		51								59				63	
C	1		3		5						11				15										25				29		31																		
D	1		3		5						11				15										25				29		31																		
even	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	…	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
A		2		4		6		8		10		12										22		24																									
B		2		4								12				16																			50		52								60				64
C		2		4		6						12				16										26				30		32																	
D		2		4		6						12				16										26				30		32																	

OSO 128,
64 odd



OSO 128,
64 even



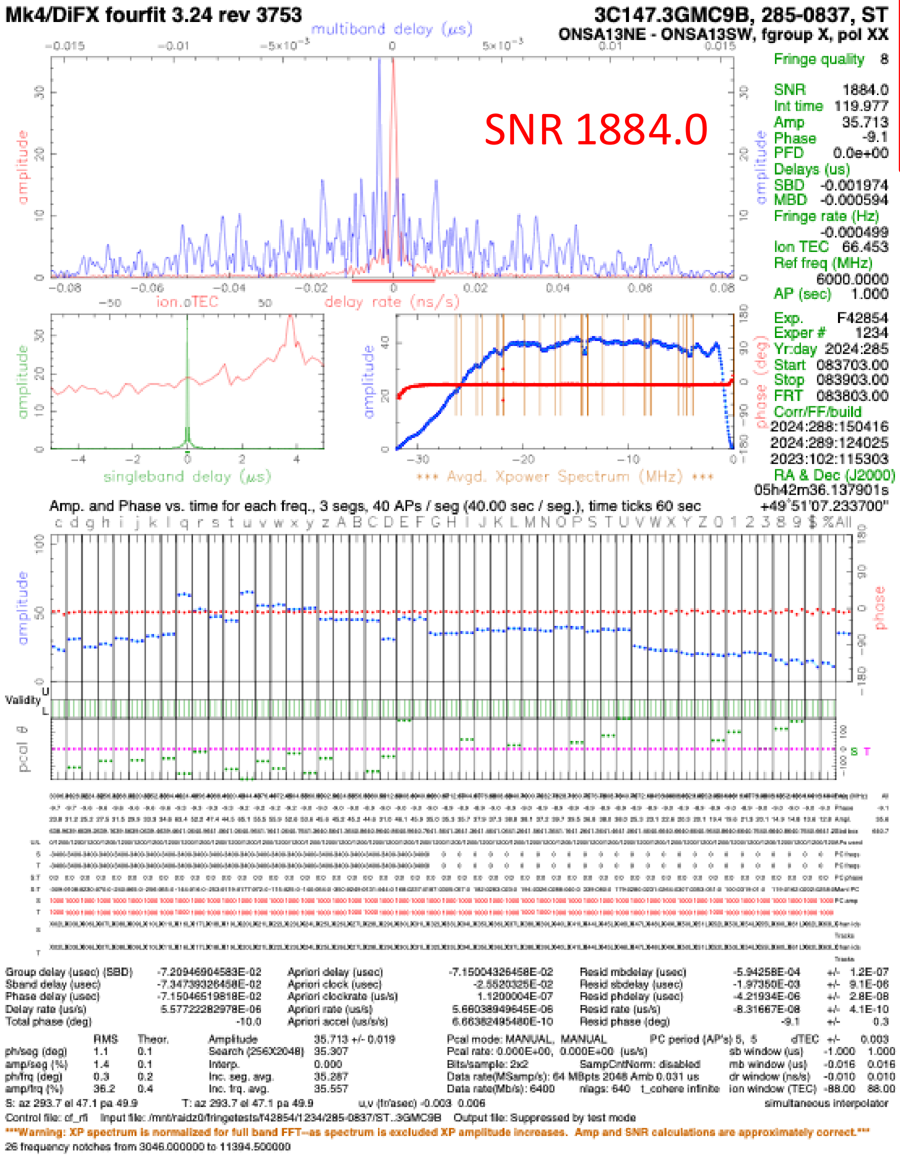
Observation and experience

- Observation of radio source 3C147 for 120 s
- Successful 128 channel per station recording (i.e. 16 Gbps)
  - No data loss
- Successful 128 channel DiFX correlation

- Problems:
  - difx2mk4 seems currently to have internal restrictions, => no useful phase information for more than 64 channels
  - also difx2fits cannot handle more than 64 channels
  - some channels are heavily affected by local RFI @ OSO

Analysis approach

- Focus on 64 channels only
  a) Correlating all 128 x/y-pol channels, then fringe-fitting only x-pol and y-pol
  b) Correlating separately 64 x-pol and 64 y-pol channels, and fringe-fitting separately
  - Deselect same RFI-affected channels in fringe-fitting
- Fourfit fringe-fitting with several options, with manual phase-cal:
  - 50 (out of 64) x-pol or y-pol channels
  - 25 (out of 32) odd x-pol or y-pol channels
  - 25 (out of 32) even y-pol or y-pol channels
  - 24 (out of 32) x-pol or y-pol channels in band a/b
  - 30 (out of 32) x-pol or y-pol channels in band b/c
  - 26 (out of 32) x-pol or y-pol channels in band c/d



Left:

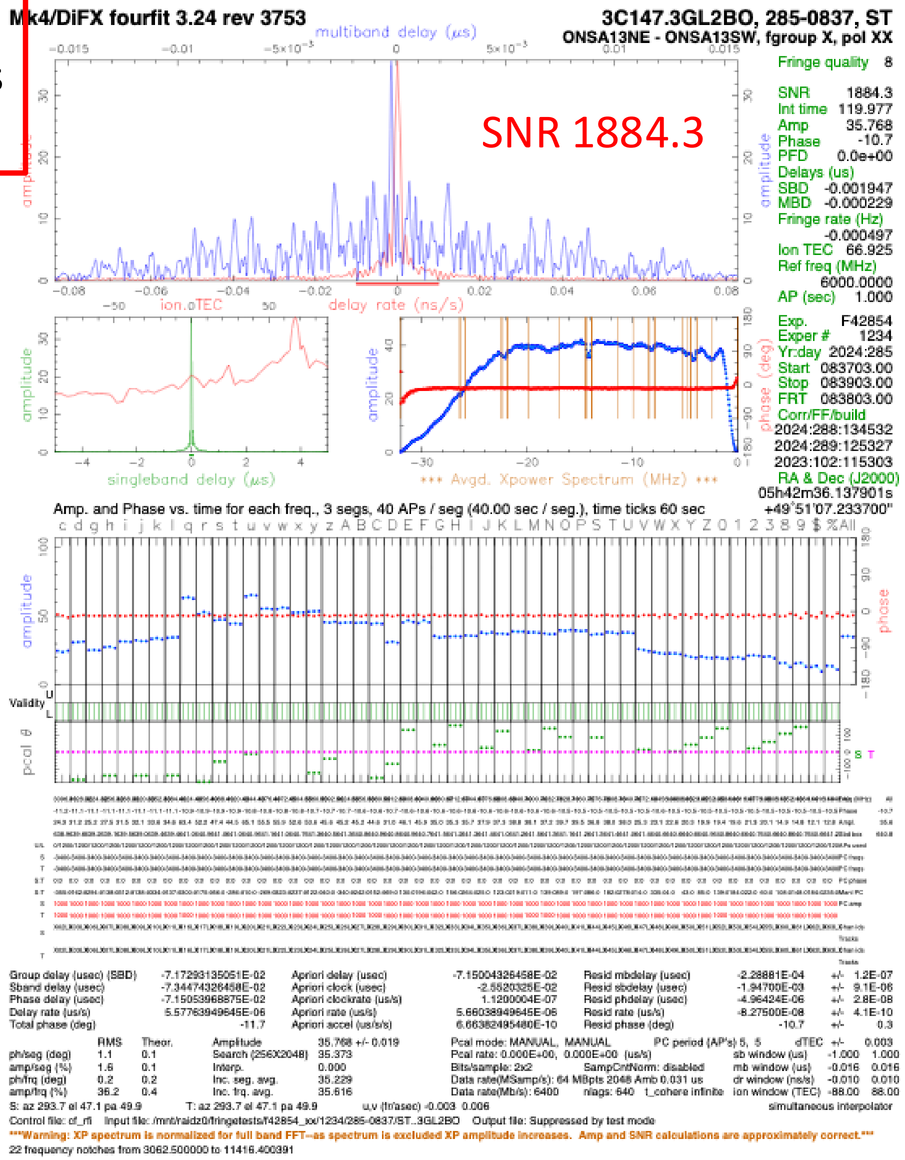
Correlating 128 x-/y-pol channels

Fringe-fitting 50 x-pol

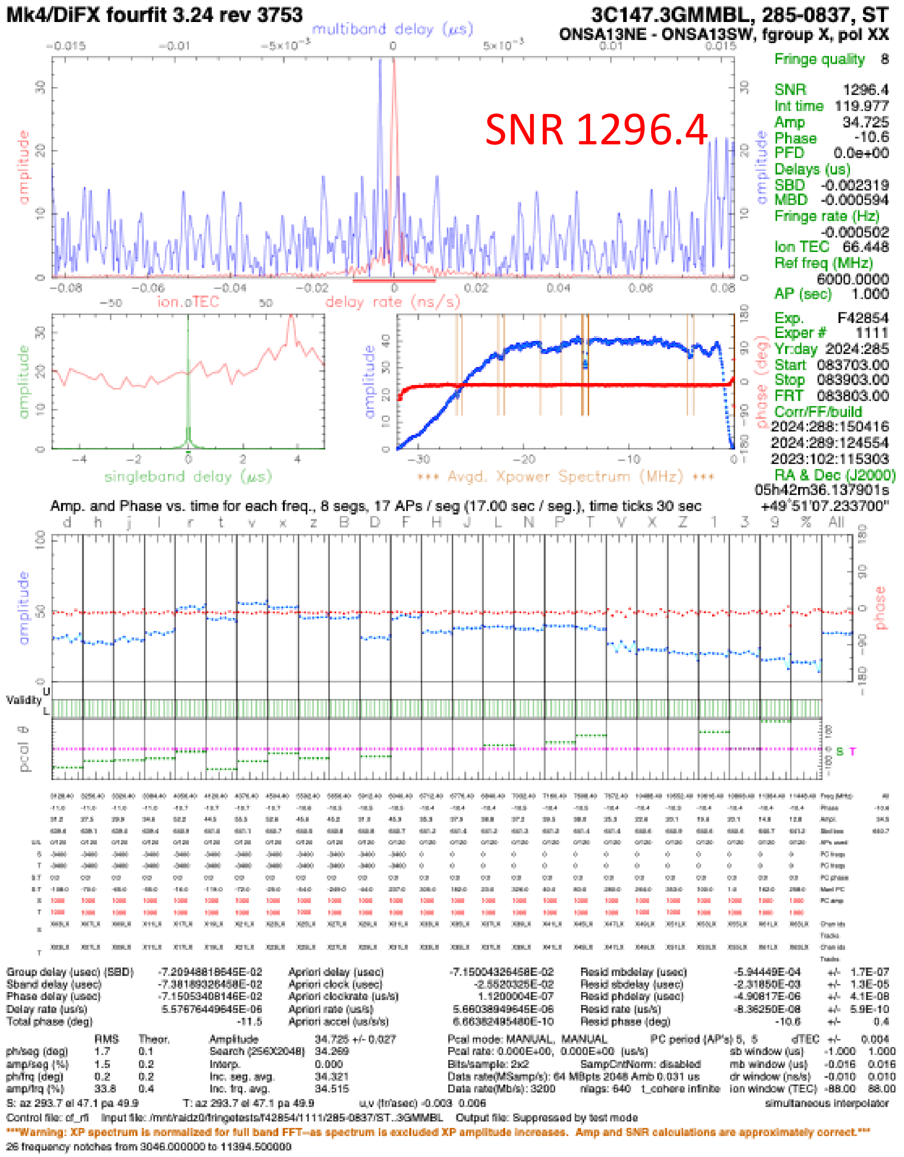
Right:

Correlating 64 x-pol channels

Fringe-fitting 50 x-pol

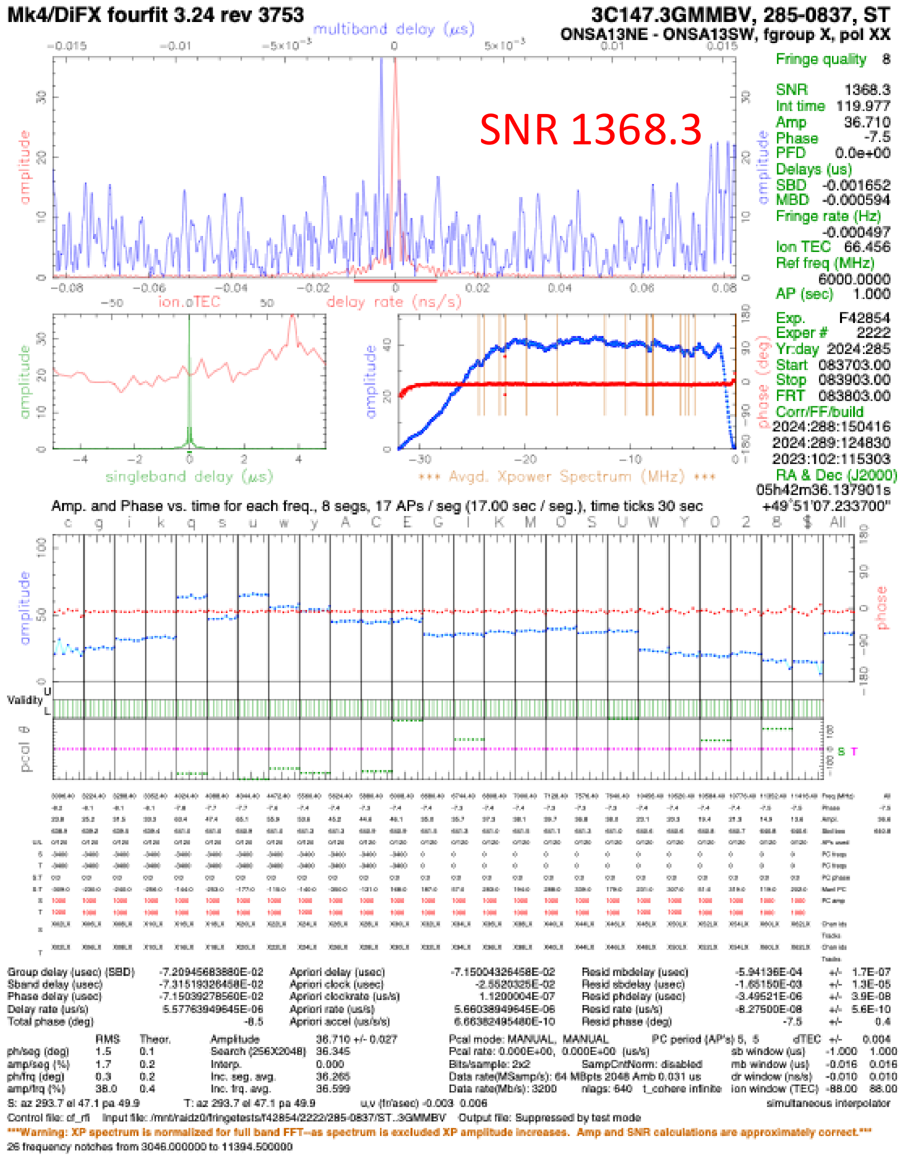


Similar plots and behaviour for y-pol



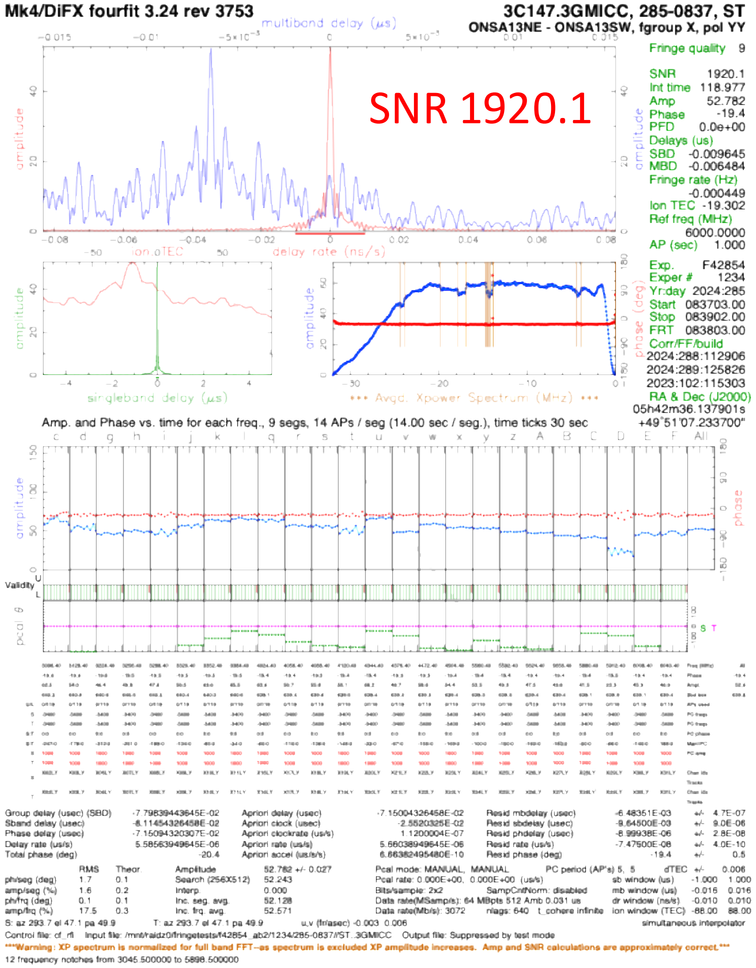
Left:
Correlating 64 x-pol channels
Fringe-fitting 25 odd x-pol

Right:
Correlating 64 x-pol channels
Fringe-fitting 25 even x-pol

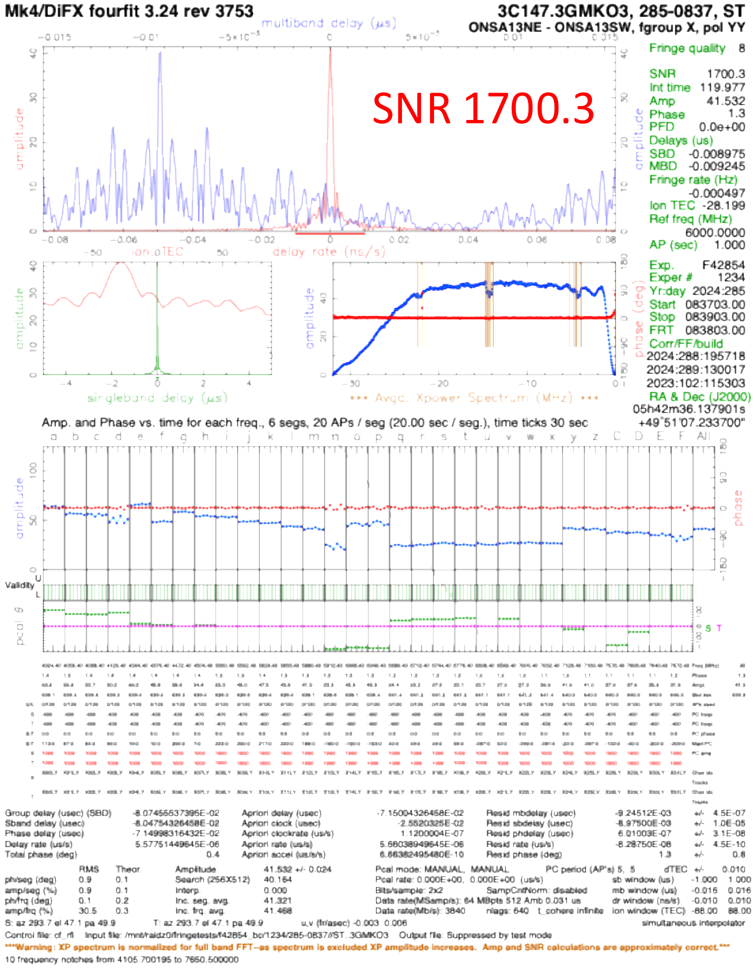


Similar plots and behaviour for y-pol

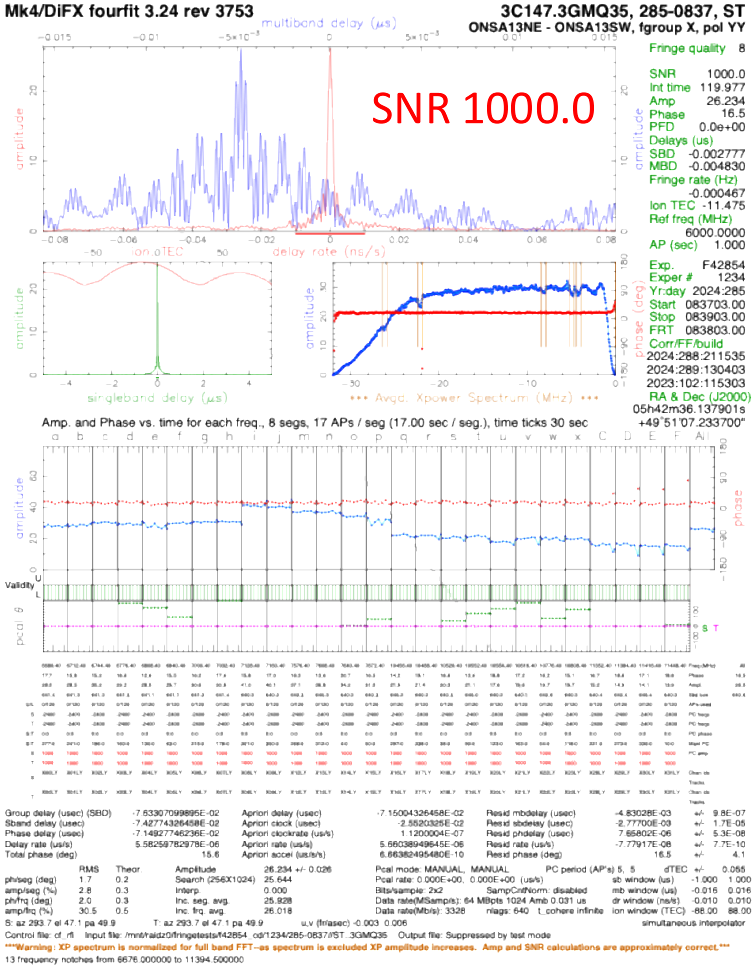
Correlating 64 y-pol channels
Fringe-fitting 24 y-pol a/b



Correlating 64 y-pol channels
Fringe-fitting 30 y-pol b/c



Correlating 64 y–pol channels
Fringe-fitting 26 y-pol c/d



Similar plots and behaviour for x-pol

Summary

type	channels	x-pol			y-pol		
		SNR	phase	delay	SNR	phase	delay
128 corr	50 (64)	1884	350.0	−72.095 ns	2027	356.0	−76.950 ns
64 corr	50 (64)	1884	348.3	−71.729 ns	2030	356.0	−76.905 ns
64 corr	25 odd (32)	1296	351.5	−72.095 ns	1395	355.0	−76.950 ns
64 corr	25 even (32)	1368	348.5	−72.095 ns	1472	357.1	−76.951 ns
64 corr	a/b, 24 (32)	1608	357.8	−77.149 ns	1920	339.6	−77.984 ns
64 corr	b/c, 30 (32)	1789	356.0	−70.634 ns	1700	0.4	−80.746 ns
64 corr	c/d, 26 (32)	1081	352.2	−69.951 ns	1000	15.6	−76.331 ns

Some differences

Agreement within 1 ps

Different parts of the spectrum

Preliminary conclusions

- Successful observation with 16 Gbps (128 channels)
- DifX correlation seems to work with 128 channels
- Restrictions in difx2mk4 and difx2fits complicate further analysis
  - Phase information gets partially lost when using > 64 channels
- Correlating 128 vs 64 gives slightly different results
  - Seems not to be related to fourfit
  - Potentially another difx2mk4 issue?
- Odd/even channel analysis gives results within 1ps

2) Holography

- Using geostationary satellite EUTELSAT-16
  - @ OSO: AZ 175, EL 24
  - Frequency 11 GHz and bandwidth 1 MHz
  - Feeding RF-signal from OTT to a dedicated FPGA
- Stop-and-go control with the VLBI FS
  - ONSA13NE “staring at” EUTELSAT-16
  - ONSA13SW “scanning” with 107 positions in AZ and 108 in EL
- Real-time correlation with FPGA, post-processing with inverse FFT
  - Derive aperture illumination
  - Derive aperture phase

Flowchart

Preparation:
- Use TLE-files to prepare .snp-files:
- ONSA13NE => ”staring” at EUTELSAT-16
- ONSA13SW => scanning 38 x 38 HPBW

VLBI-FS operation:
- Positioning on grid of 107 x 108 points
- 10 s on each position
- Takes about 19 h

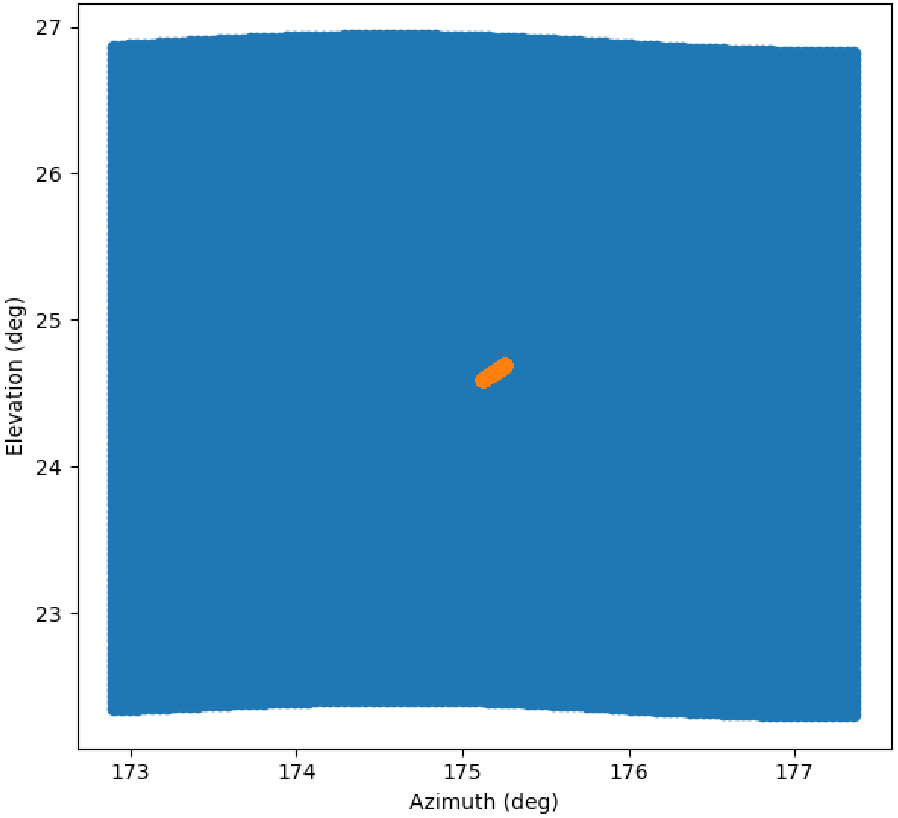
RF-signal processing:
- Tapping RF-signals (x- / y-pol) @ 10.9-11.9 GHz
- Down-conversion to 30 MHz – 1 GHz

FPGA-processing:
- Sampling IF-signals in 1 MHz chunks
- Real-time correlation
- Data storage in hdf5 files

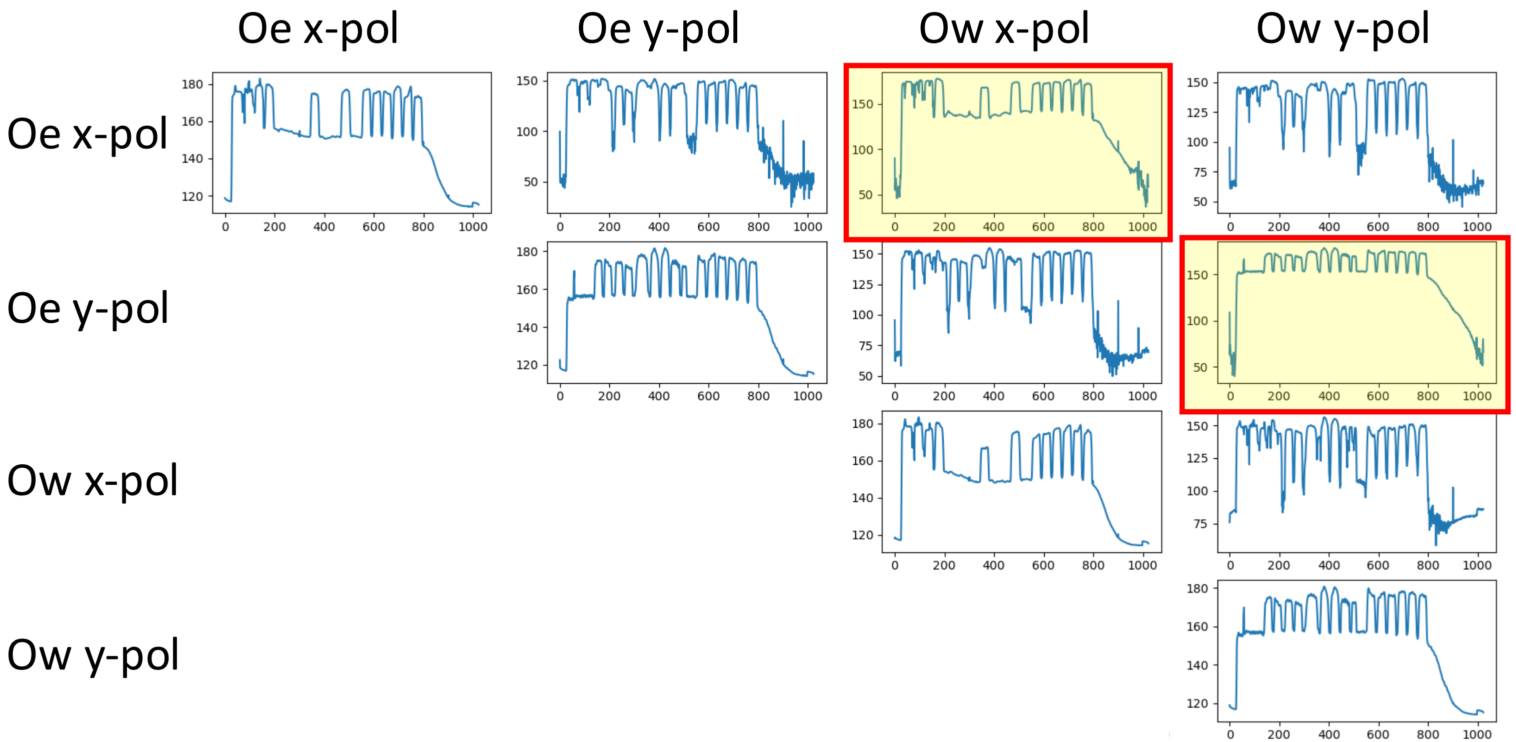
Post-processing:
- Using 1 MHz channel @ 11 GHz
- Averaging to 10 s grid points
- Inverse FFT to get aperture amplitude & phase

Observation and correlation

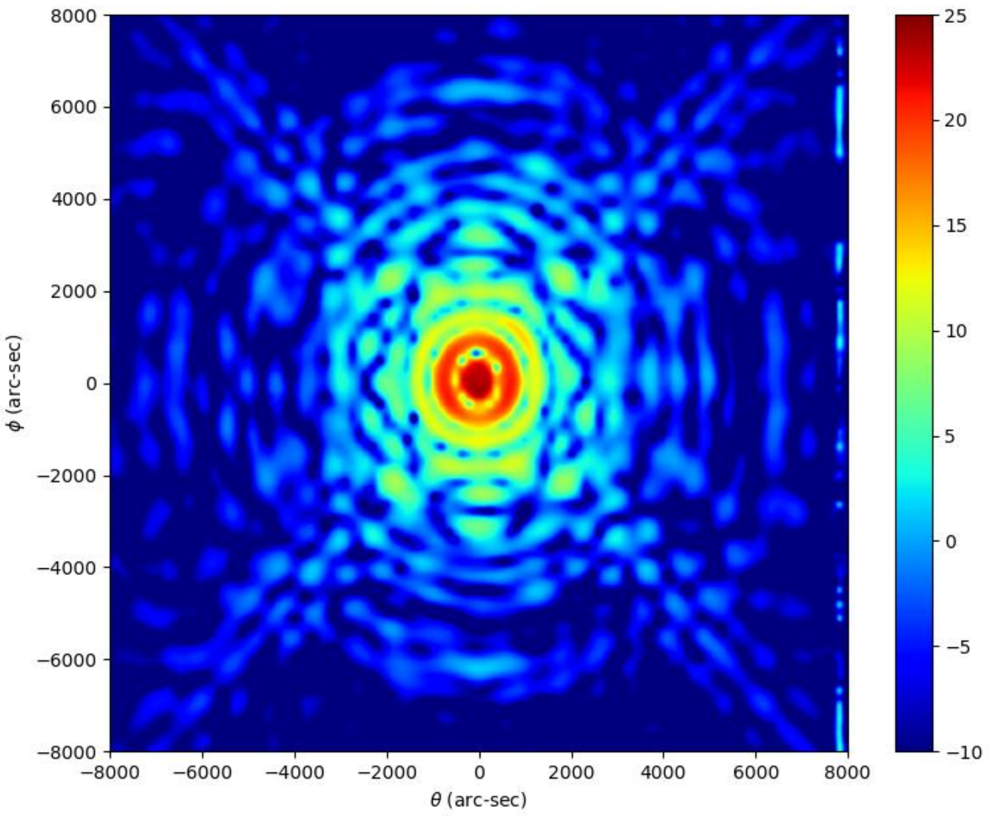
grid 107 x 108 points



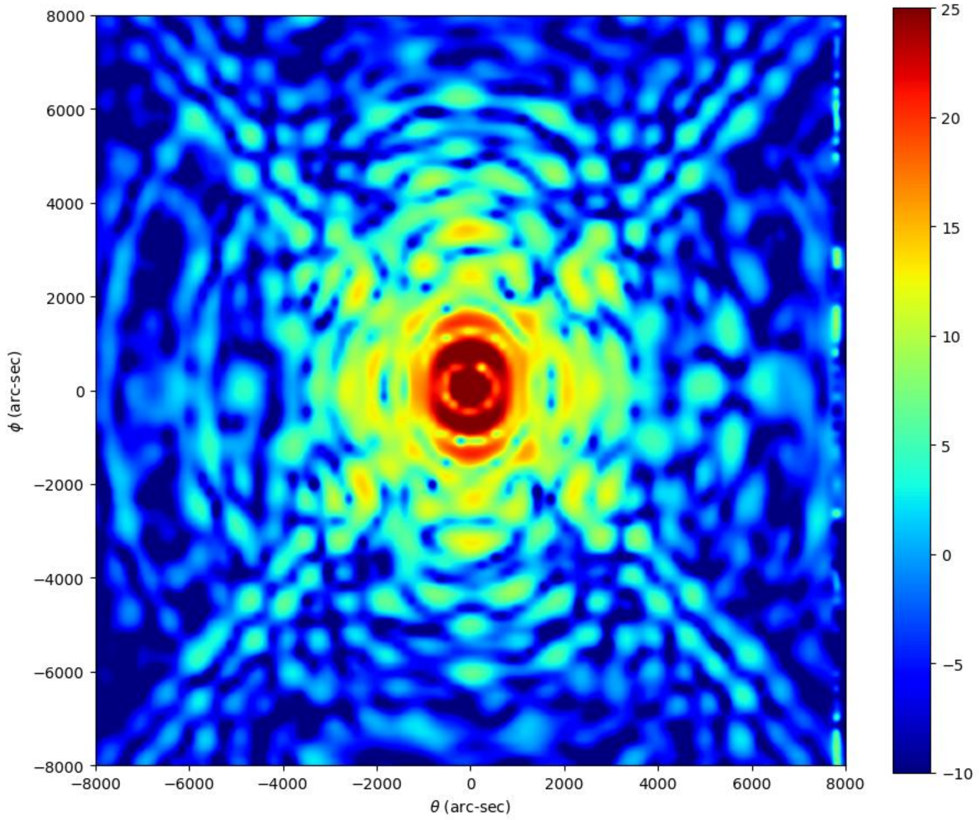
38 x 38 HPBW



ONSA13SW beam maps (dB)

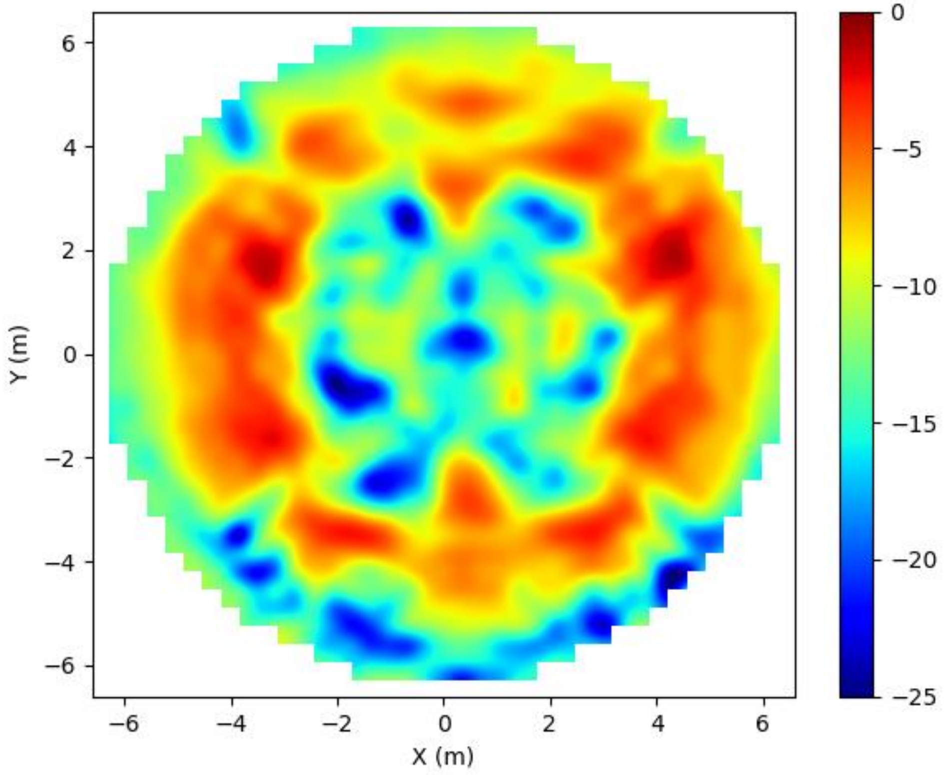


x-pol

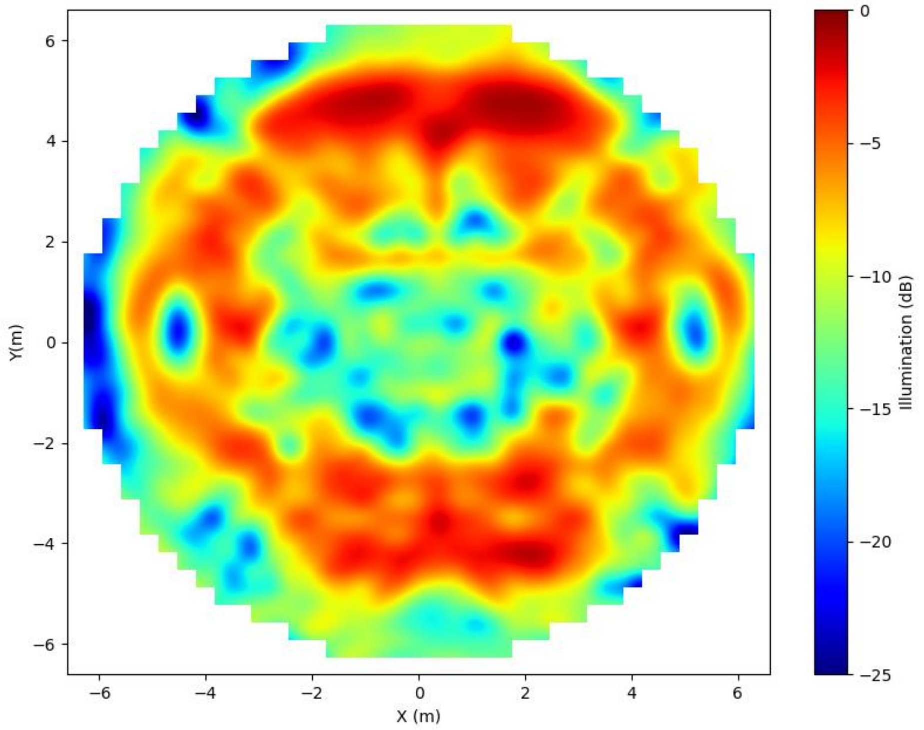


y-pol

ONSA13SW aperture amplitude (dB)

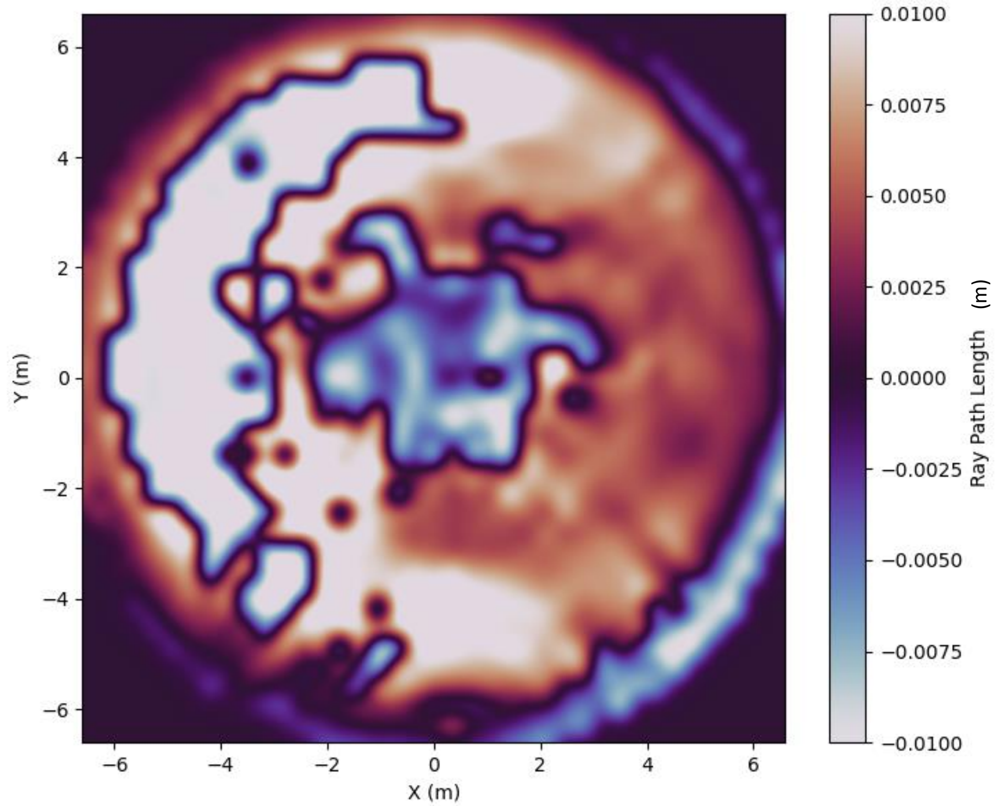


x-pol



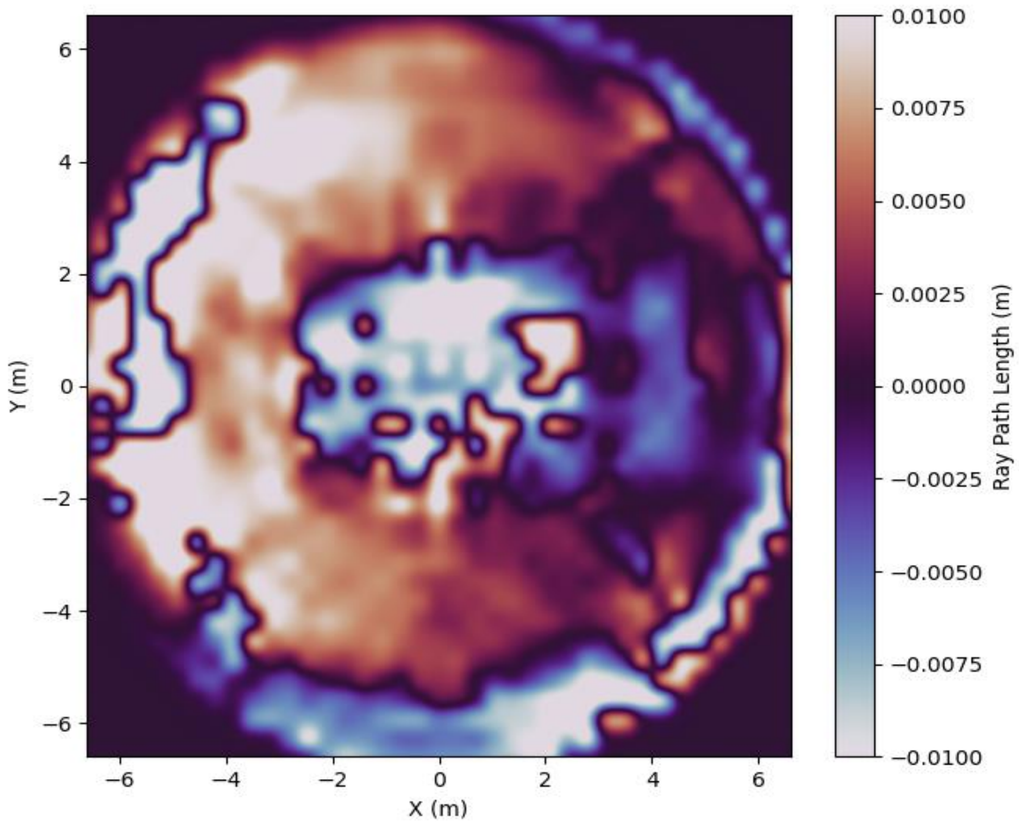
y-pol

ONSA13SW ray path length (m)



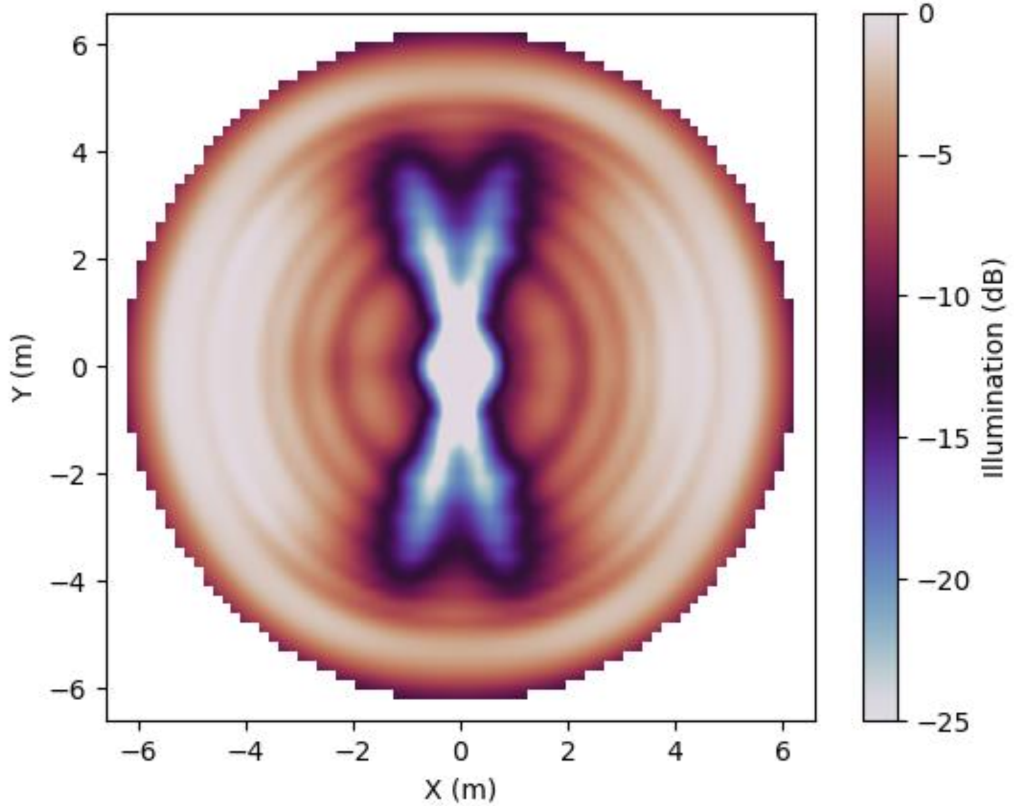
x-pol

RMS: ± 3 mm

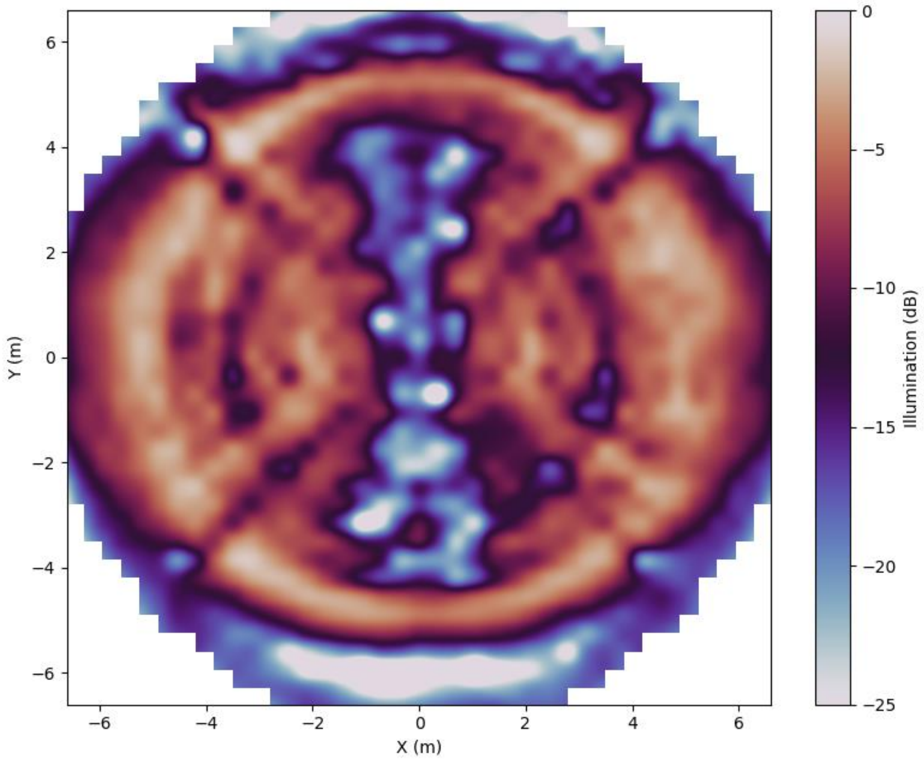


y-pol

Previous results for ONSA13NE (QRFH)

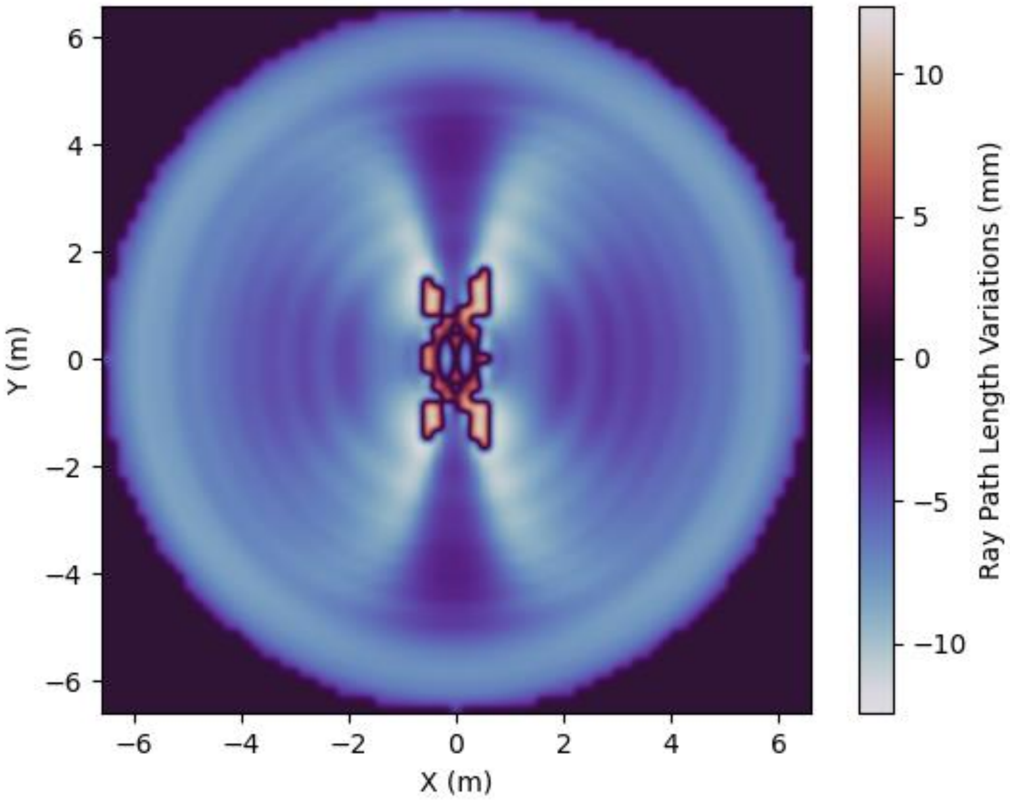


Simulated x-pol

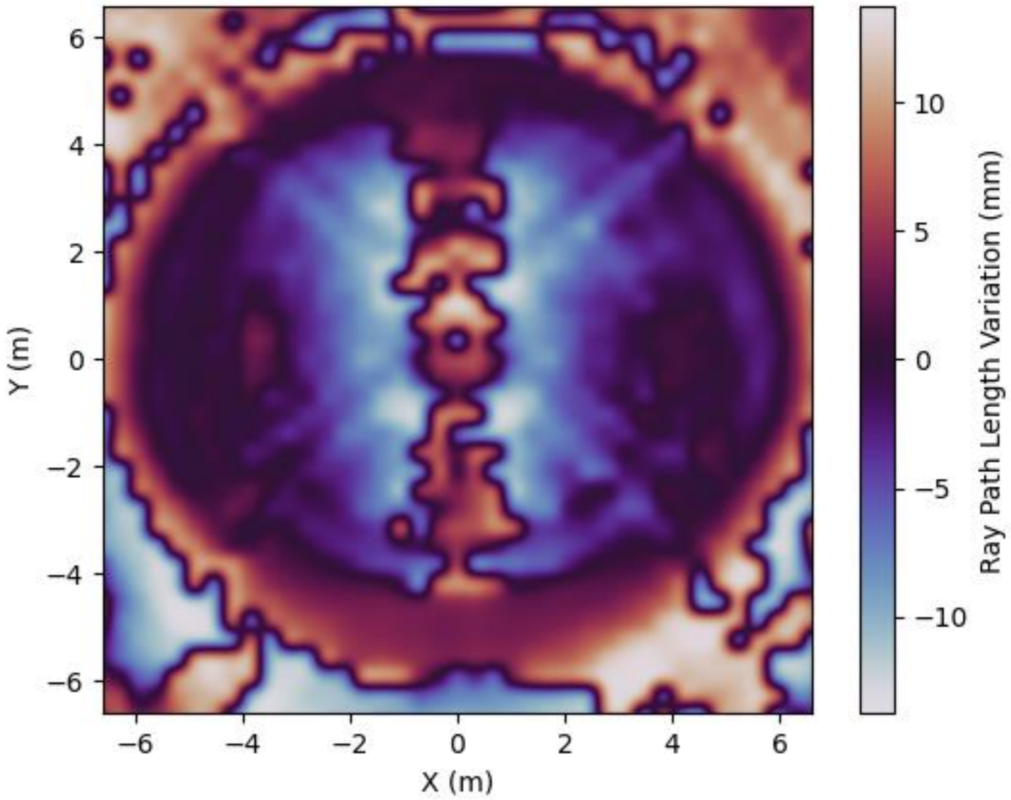


Observed x-pol

Previous results for ONSA13NE (QRFH)



Simulated x-pol



Observed x-pol

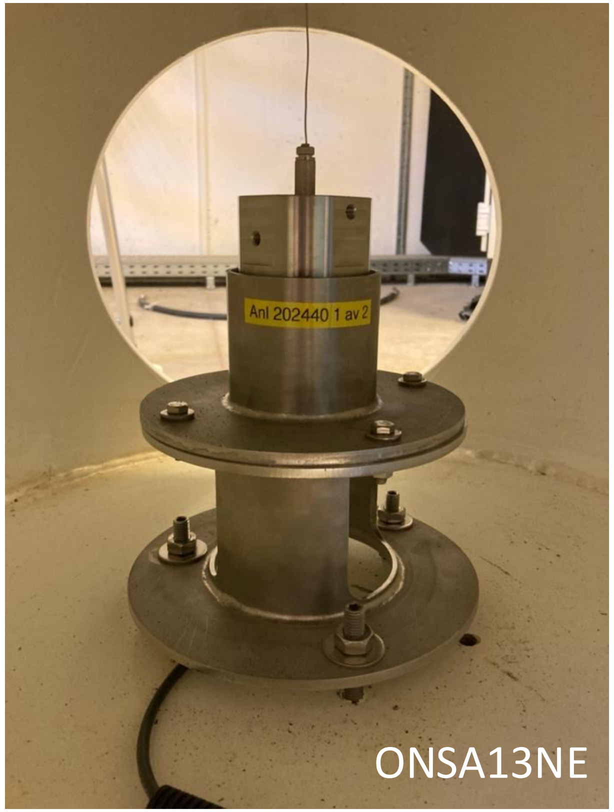
Preliminary conclusions

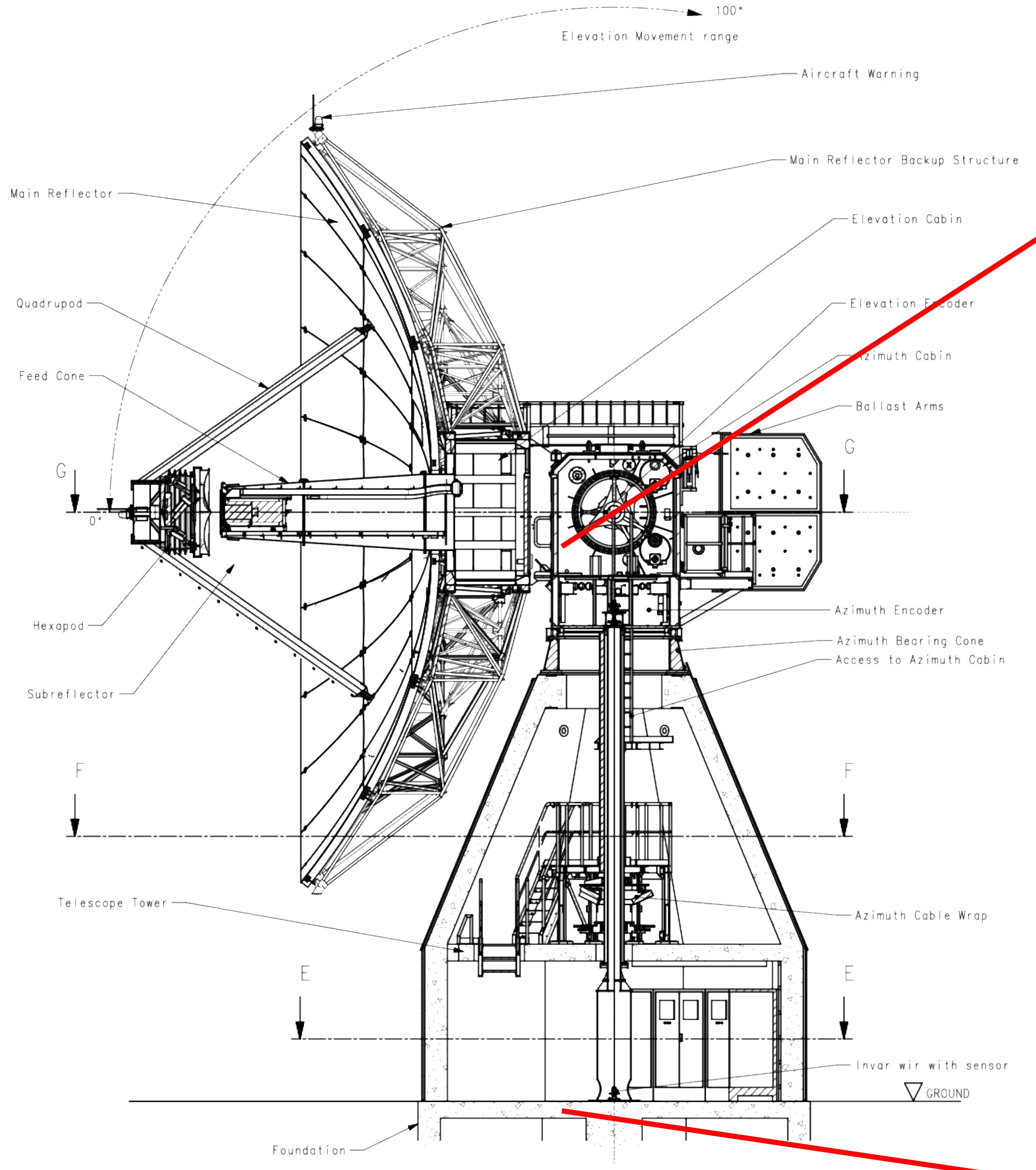
- Successful holography with ONSA13SW and ONSA13NE
  - Results agree reasonably with simulations
  - Phase is impacted by instrumental and environmental effects
    - Surface roughness, deformation, subreflector deformation, atmosphere, oscillator problems, satellite position errors
  - Observations take rather (too) long

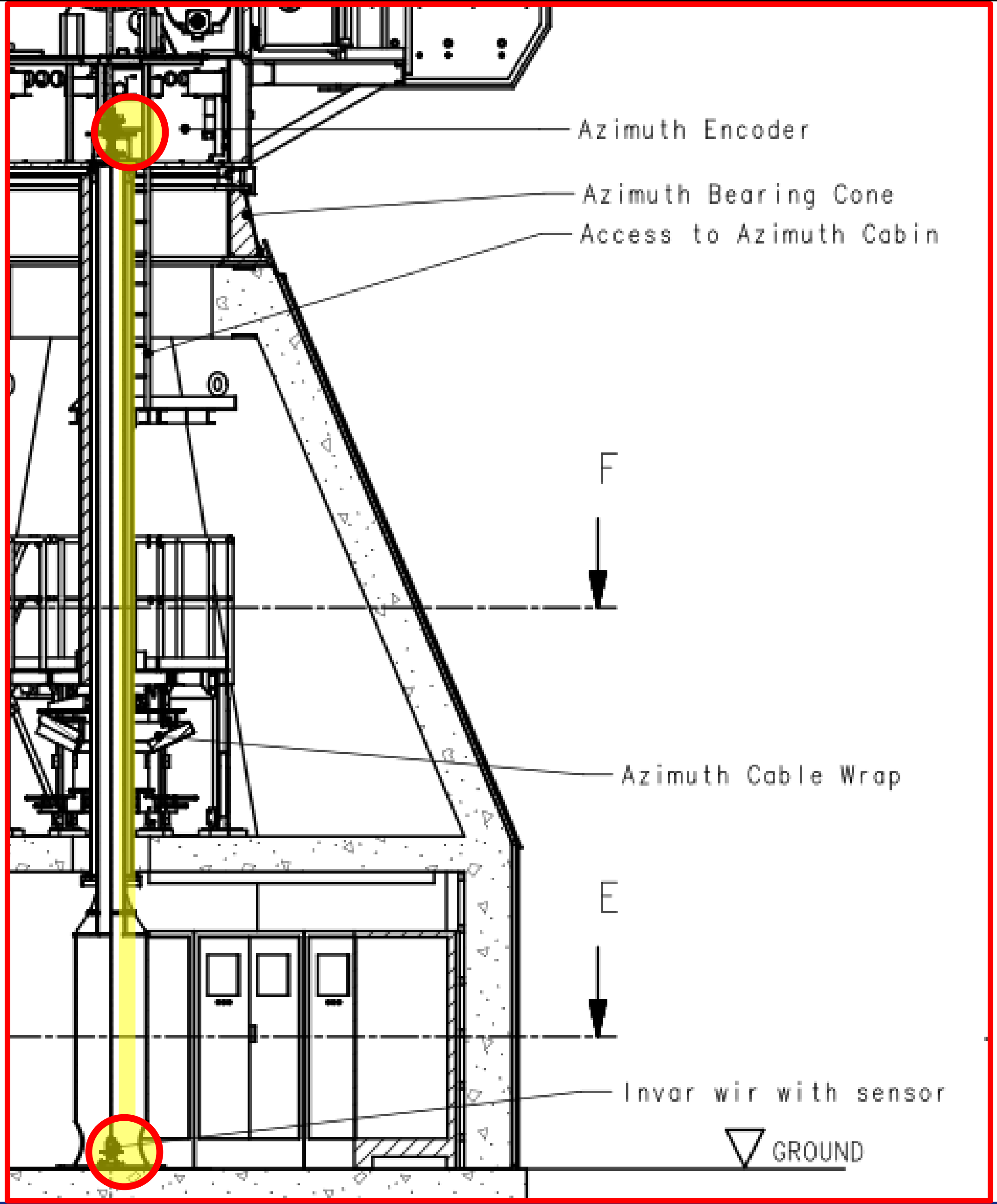
- Plans for improvement:
  - Using same oscillator reference for down-conversion and ADC
  - Characterizing phase stability
  - Reducing observation time
  - Test with natural radio source

3) Invar measurements

- Two invar measurement systems
- Installed December 2023
- Invar wire hanging in the middle of telescope tower
- Weight with magnet to keep the wire straight
- Sensor measuring the distance to the magnet ~25 mm
- Data with 1 s sampling

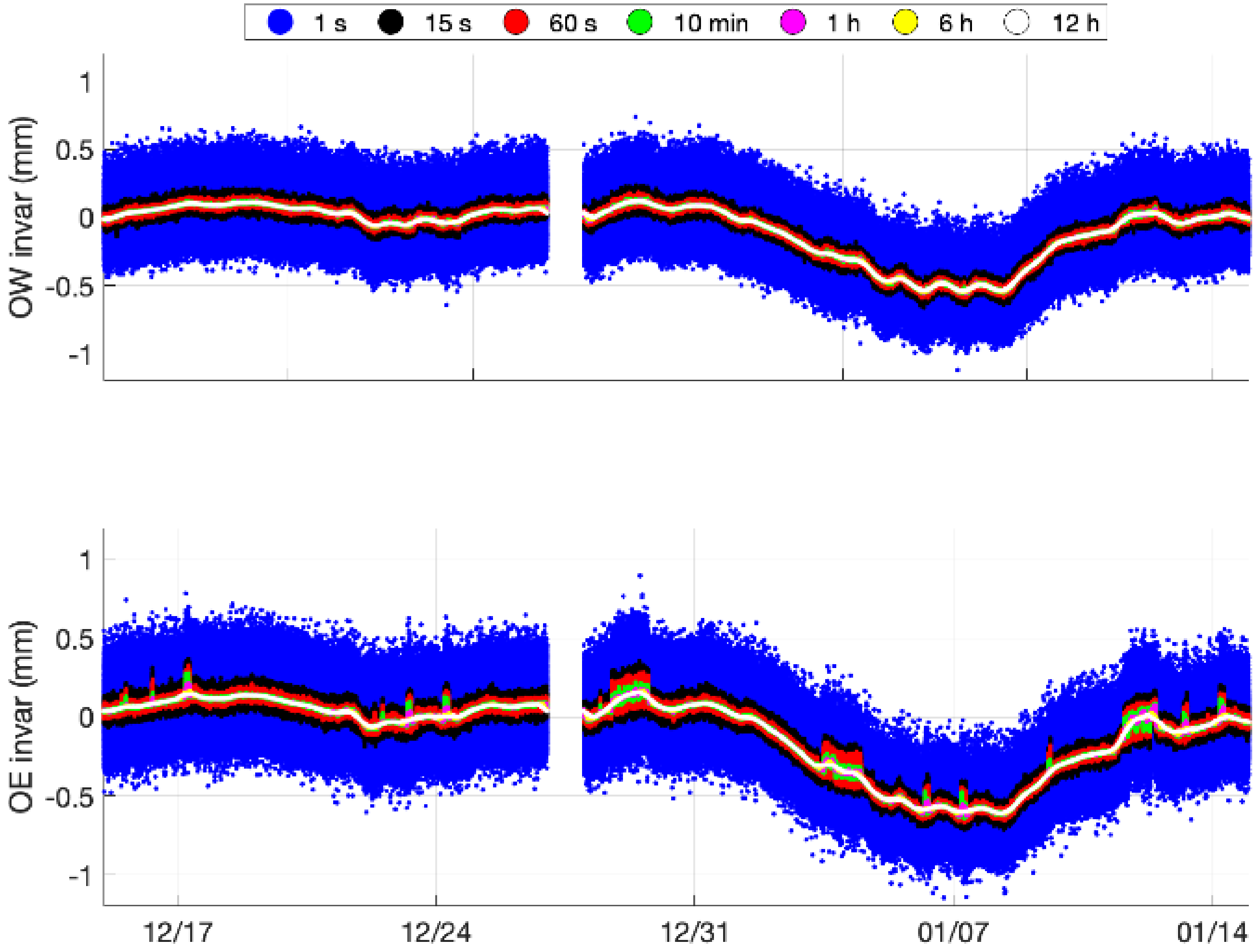



100°
Elevation Movement range
Aircraft Warning
Main Reflector Backup Structure
Main Reflector
Elevation Cabin
Quadrupod
Elevation Encoder
Feed Cone
Azimuth Cabin
Ballast Arms
G
G
0°
Azimuth Encoder
Hexapod
Azimuth Bearing Cone
Access to Azimuth Cabin
Subreflector
F
F
Telescope Tower
Azimuth Cable Wrap
E
E
Invar wir with sensor
GROUND
Foundation


Azimuth Encoder
Azimuth Bearing Cone
Access to Azimuth Cabin
F
Azimuth Cable Wrap
E
Invar wir with sensor
GROUND

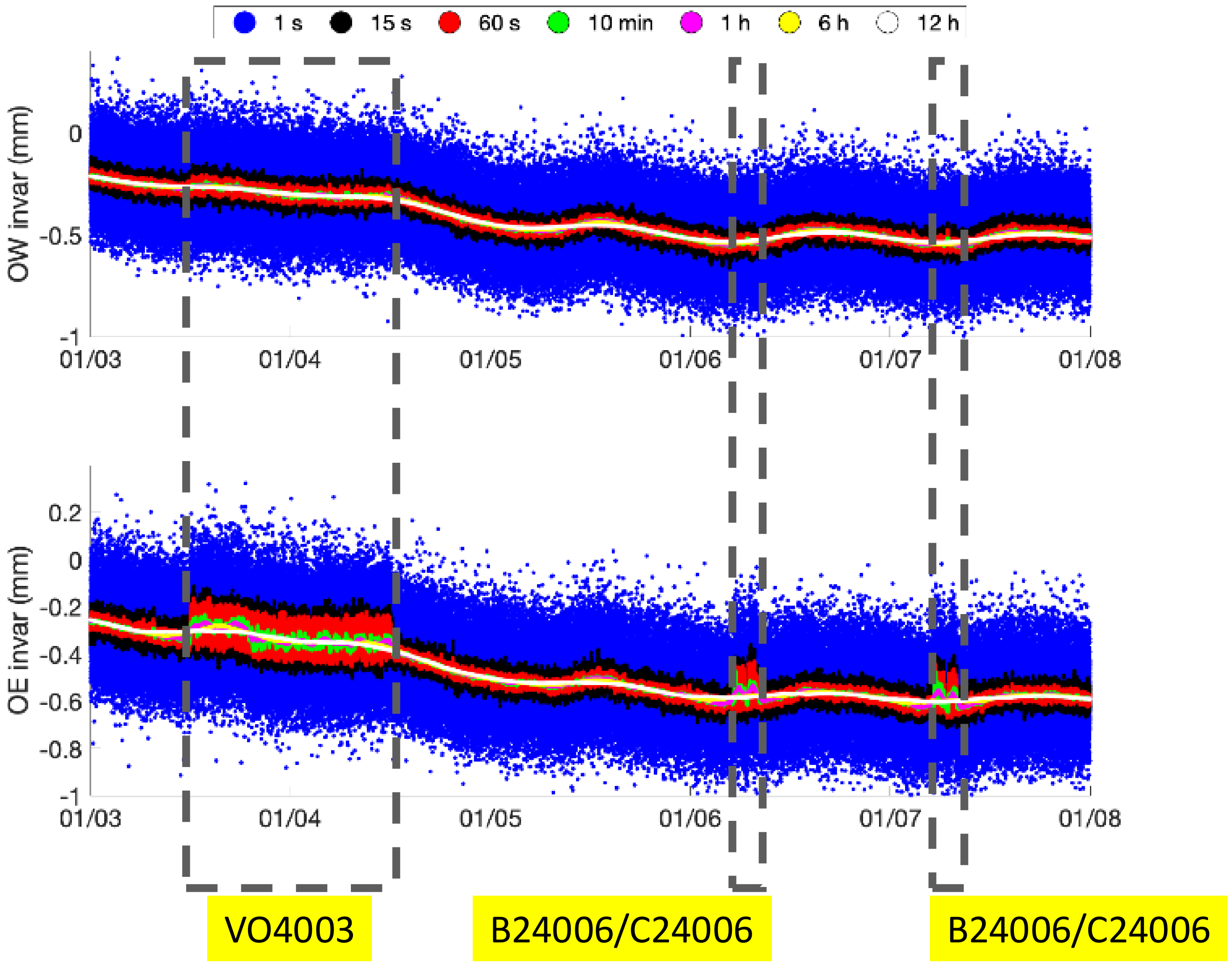
One month of invar measurements

- General: rather large variations ± 0.5 mm from second to second
- Smoothing necessary
- OW shows more ”smooth” invar measurements
- OE clearly affected by telescope operations



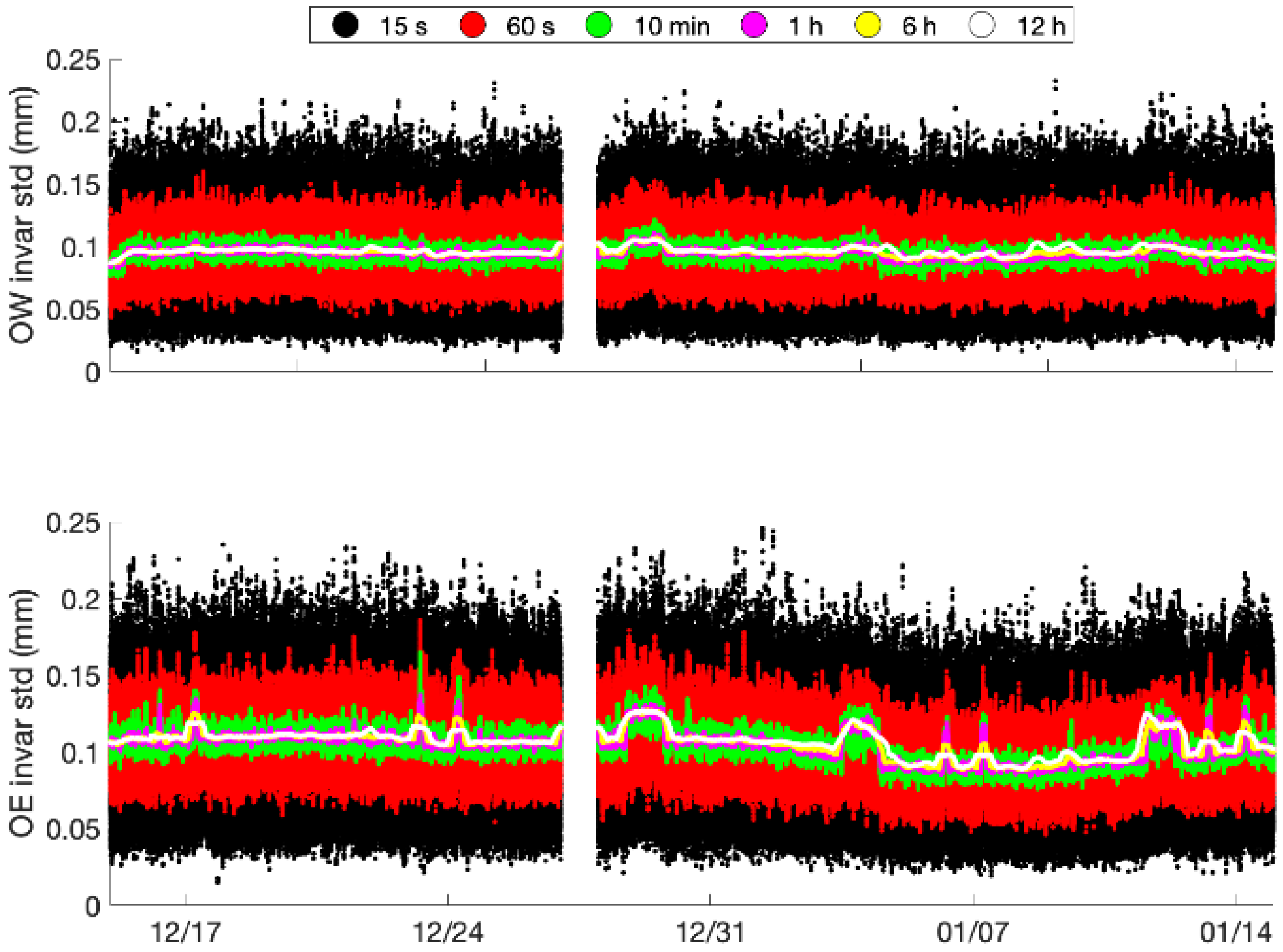
Zooming in to five days

- Both OE and OW were observing during these days
  - VO4003
  - B24006 & C24006
  - B24007 & C24007
- OE invar measurements more affected than OW



Standard deviations

- General: noise on the level of 0.2 mm
- Smoothing necessary
- Telescope operation clearly visible
- OE has more scatter than OW



Preliminary conclusions

- Invar measurement systems have been installed on the OTT
- Measurements are rather noisy
  - Smoothing necessary to derive data that maybe useful for post-processing
- Telescope movement during operations affects the data
  - OE more affected than OW
- More investigations necessary to identify reason


Questions?