The future of OLIMPO

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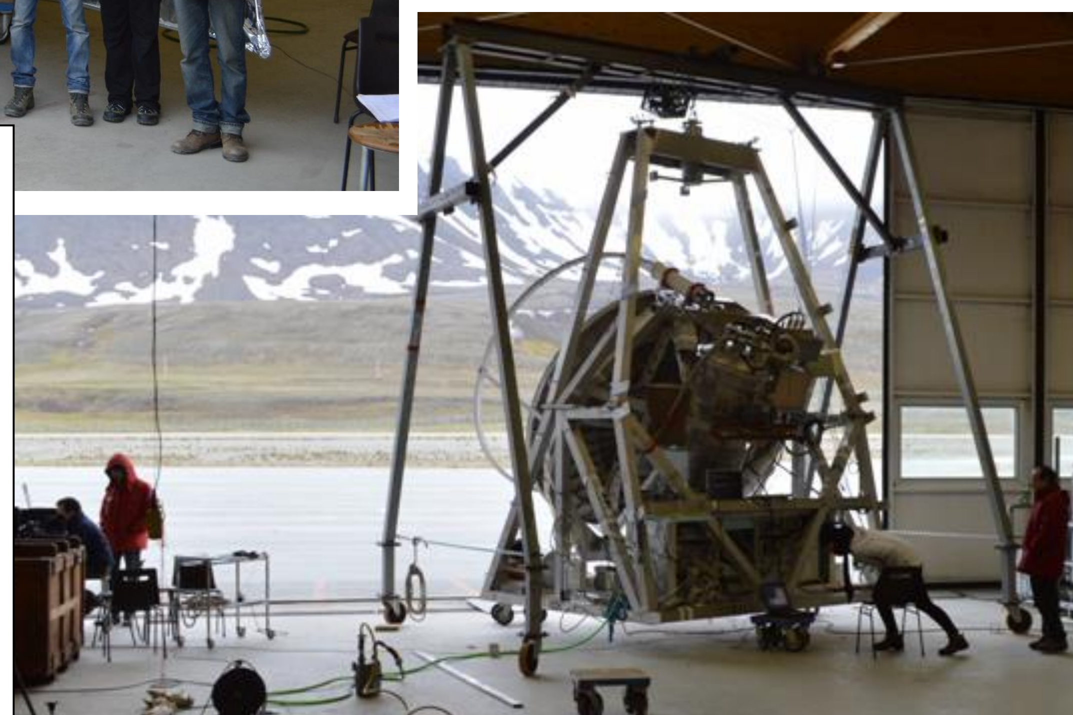
Towards Coordination of the European CMB Programme – Paris APC - 13/Sep/2019

- Long Duration Balloon experiment for mm & sub-mm astronomy > SZ effect
- Operates from the stratosphere - launch from Svalbard
- Cassegrain telescope, 2.6m aperture
- Multifrequency arrays of bolometers
- Low resolution spectrometer



The OLIMPO DFTS: a Differential Fourier Transform Spectrometer

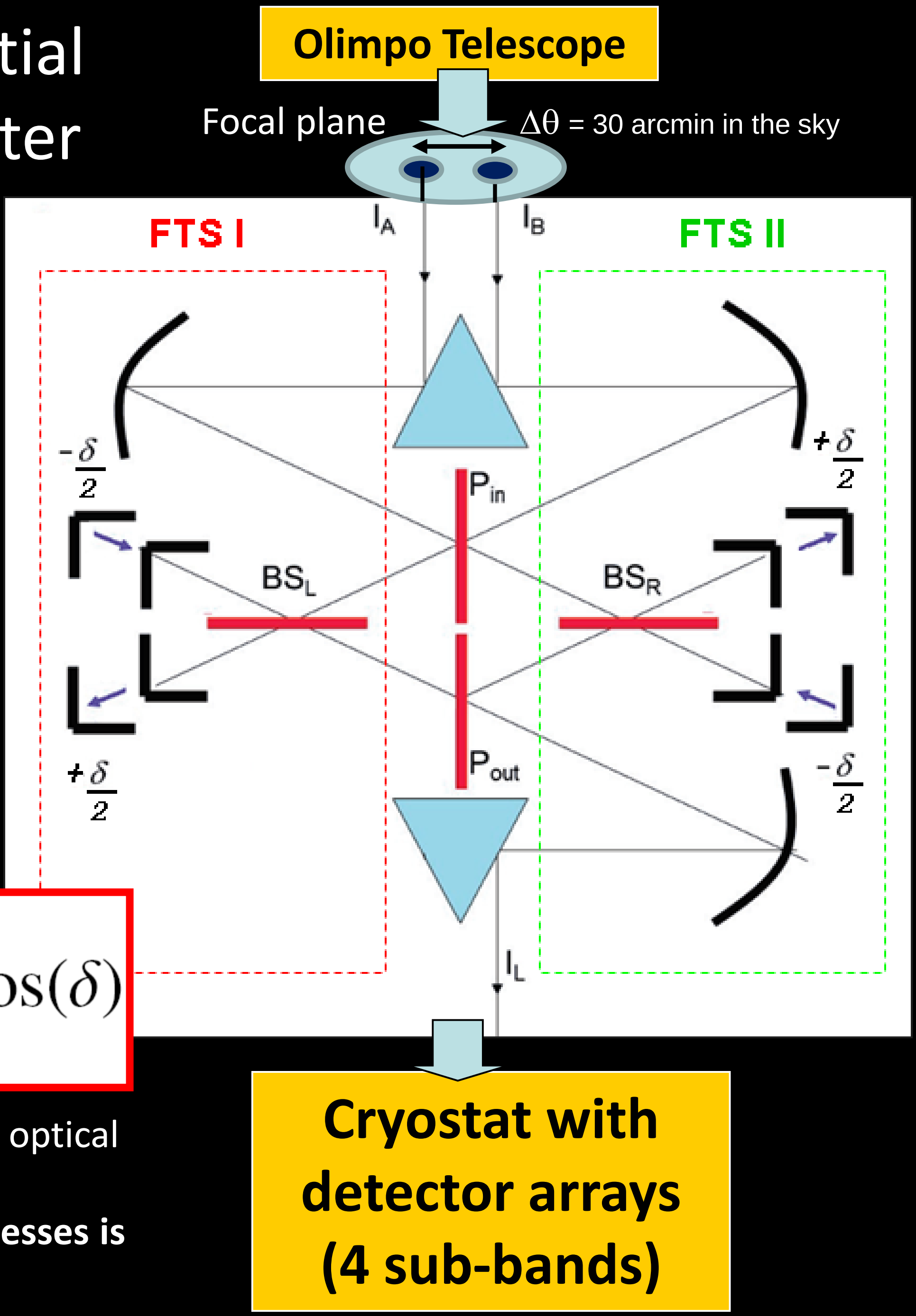
- The instrument is based on a double Martin Puplett Interferomete. Double to avoid the loss of half of the signal.
- A wedge mirror splits the sky image in two halves I_a and I_b, used as input signals for both inputs of the two FTS's.
- In the FTSs the beam to be analyzed is split in two halves, and a variable optical path difference is introduced.

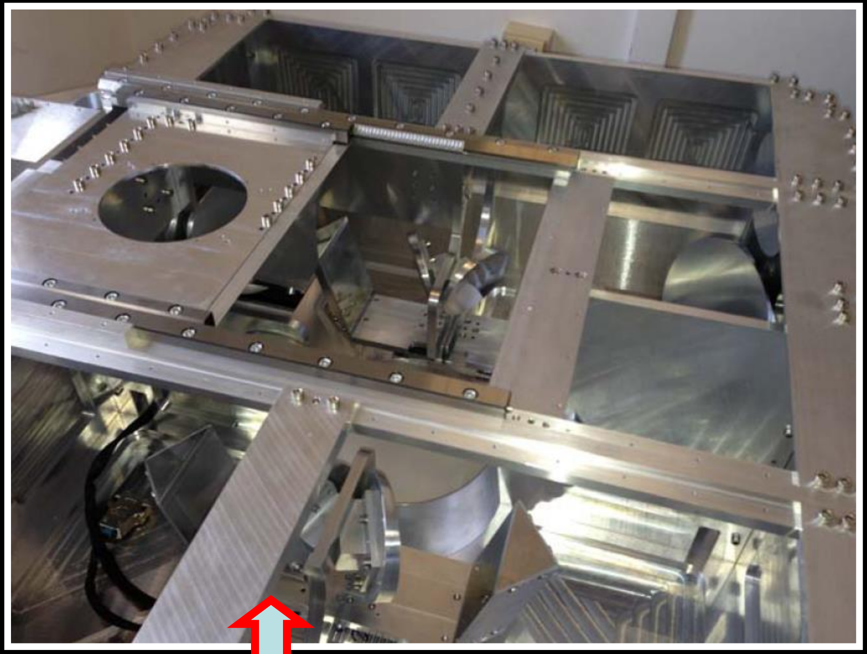
See Schillaci et al. A&A 565, A125, 2014 for a detailed description of the instrument. The output brightness is

$$I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b)\cos(\delta)$$

δ = variable phase shift, introduced by the variable optical path difference.

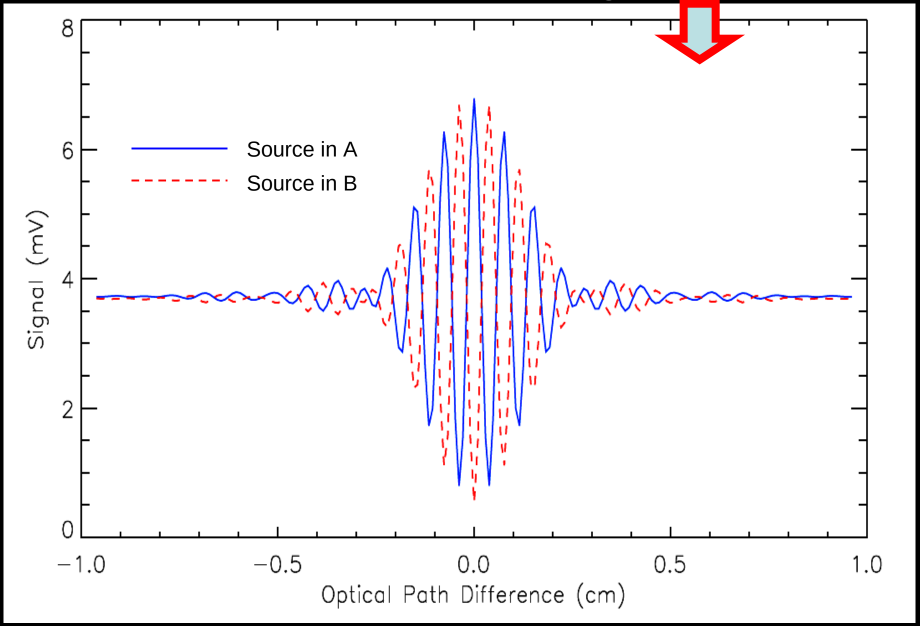
Only the *difference* between the two input brightnesses is modulated by the variable optical path difference.





The real thing….

… and measured interferograms



Literature on OLIMPO & its DFTS

G. D'Alessandro, et al., "*Polarizing beam-splitter rotation in Martin-Puplett interferometers for spectroscopic measurements at millimeter wavelengths*", Infrared Physics & Technology, 85, 92-98 (2017)

G. D'Alessandro, et al., *"Common-mode rejection in Martin–Puplett spectrometers for astronomical observations at millimeter wavelengths"*, Applied Optics, 54, 9269-9276 (2015)

A. Schillaci, et al. *"Efficient Differential Fourier-Transform Spectrometer for precision Sunyaev-Zel'dovich effect measurements"*, Astronomy and Astrophysics 565, A125 (2014)

A. Schillaci, et al., "*On the emissivity of wire-grid polarizers for astronomical observations at mm-wavelengths*", Infrared Physics & Technology, **58**, 64–68 (2013)

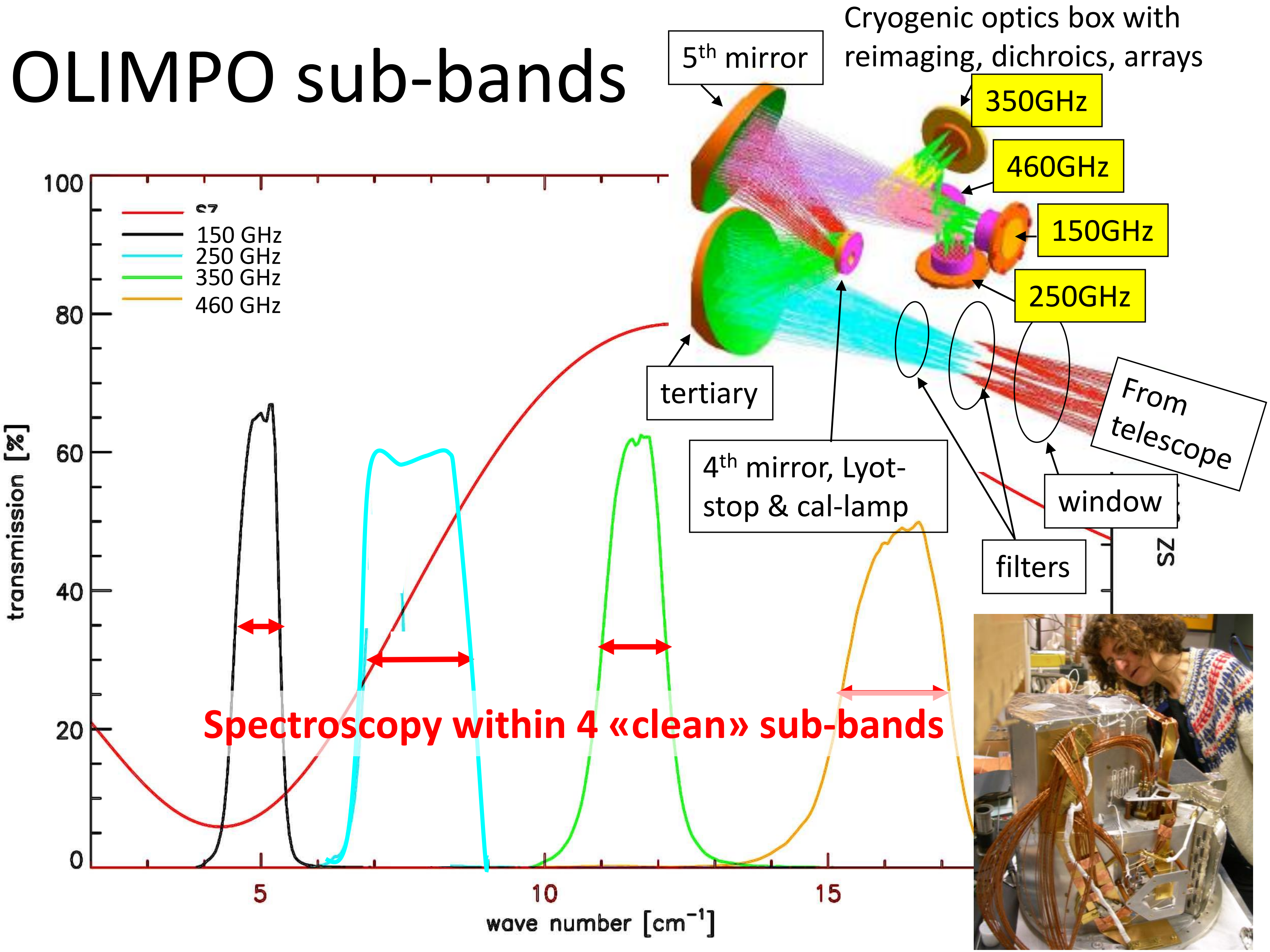
P. de Bernardis, et al., "*Low-resolution spectroscopy of the Sunyaev-Zeldovich effect and estimates of cluster parameters*", Astronomy and Astrophysics, 538, A86 (2012)

A. Schillaci, P. de Bernardis, *"On the effect of tilted roof reflectors in Martin-Puplett spectrometers"*, Infrared Physics & Technology, **55**, 40-44, (2011)

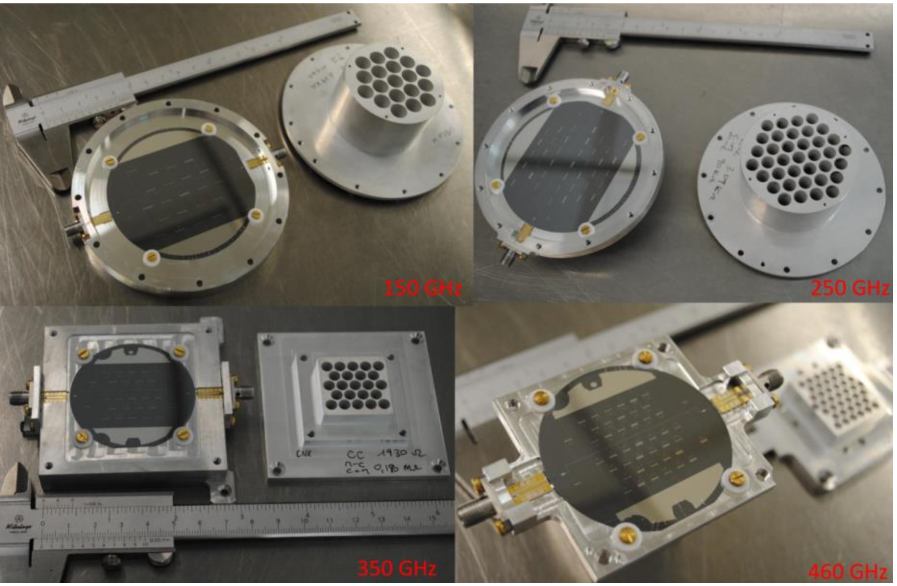
F. Nati, et al. *"The OLIMPO experiment"*, New Astronomy Reviews, **51** (2007) 385-389

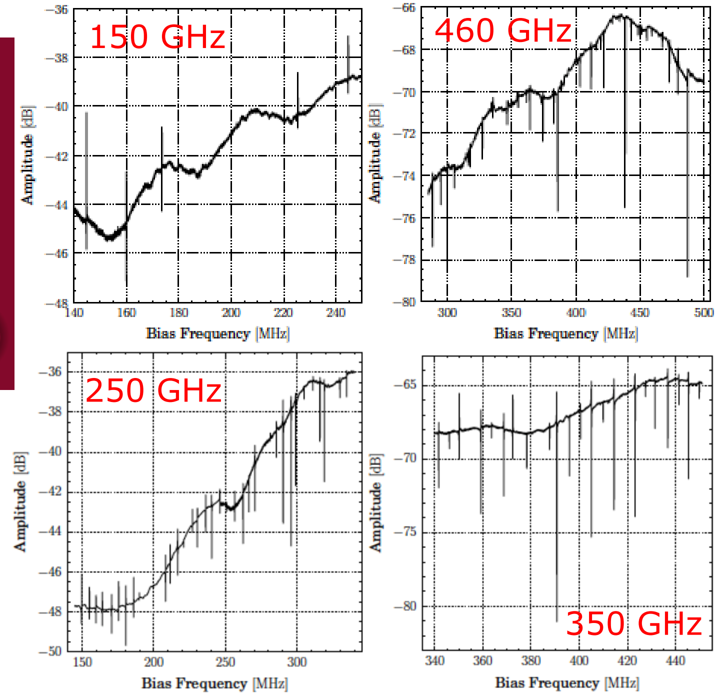
S. Masi, et al., *"OLIMPO: a balloon-borne, arcminute-resolution survey of the sky at mm and sub-mm wavelengths"*, (2003), ESA-SP-530, 557-560.

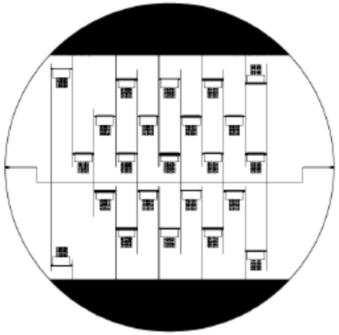
OLIMPO sub-bands

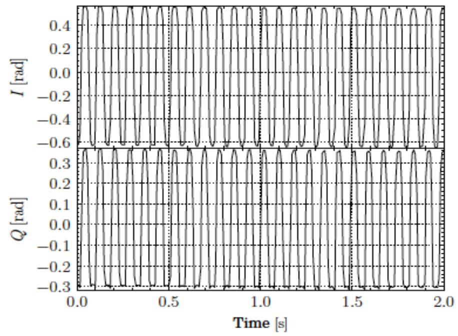


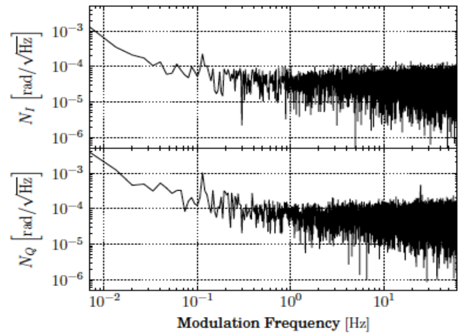
OLIMPO - Kinetic Inductance Detectors







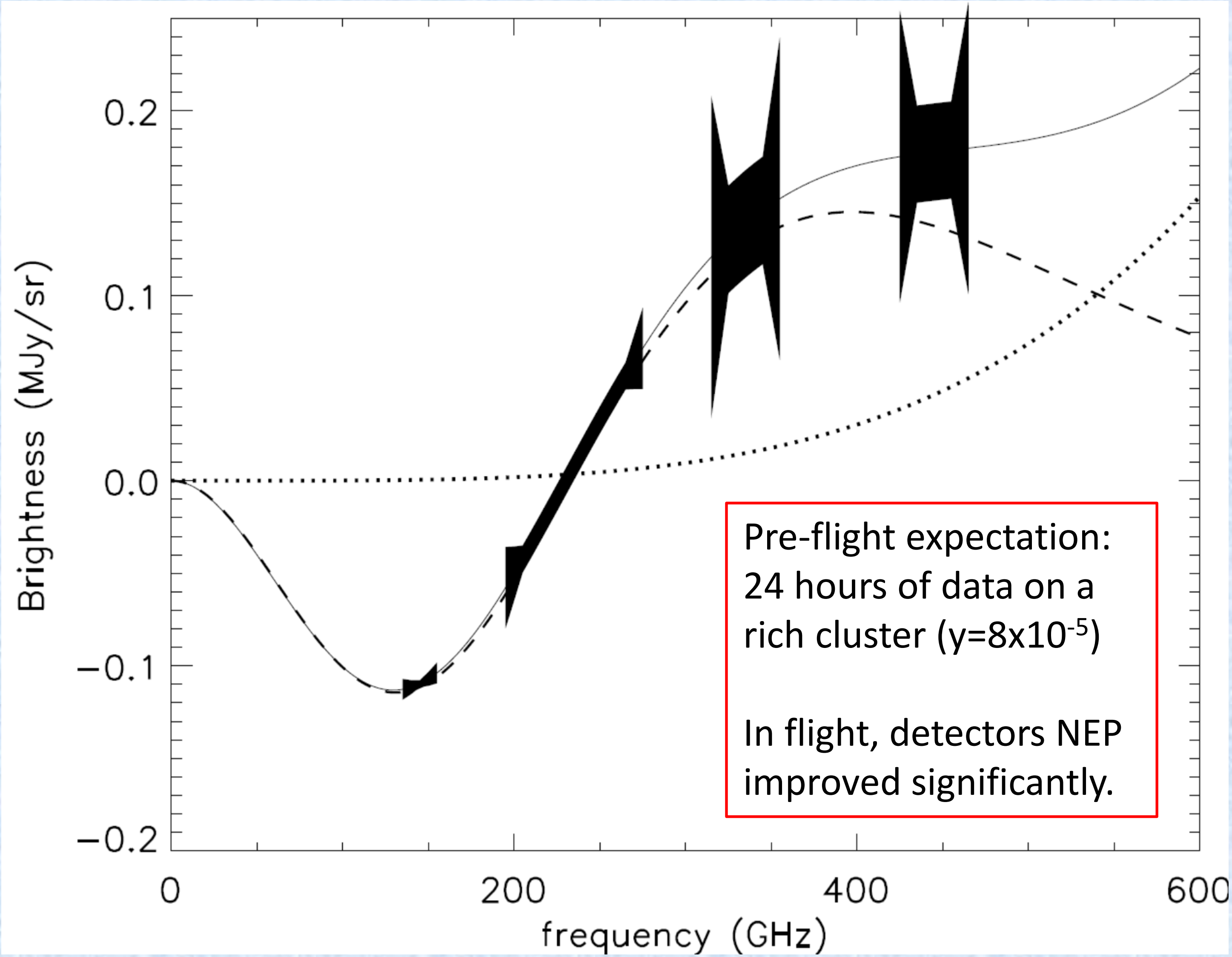




Channel	NET_{RJ} $[mK/\sqrt{Hz}]$
150 GHz	0.180
250 GHz	0.145
350 GHz	0.288
460 GHz	0.433

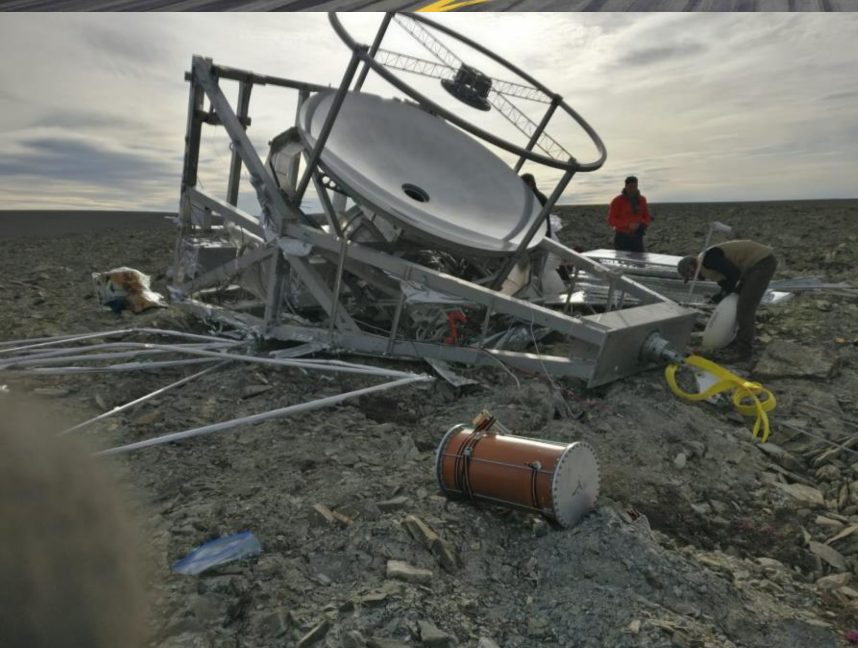
typical NET including radiative load from warm spectrometer

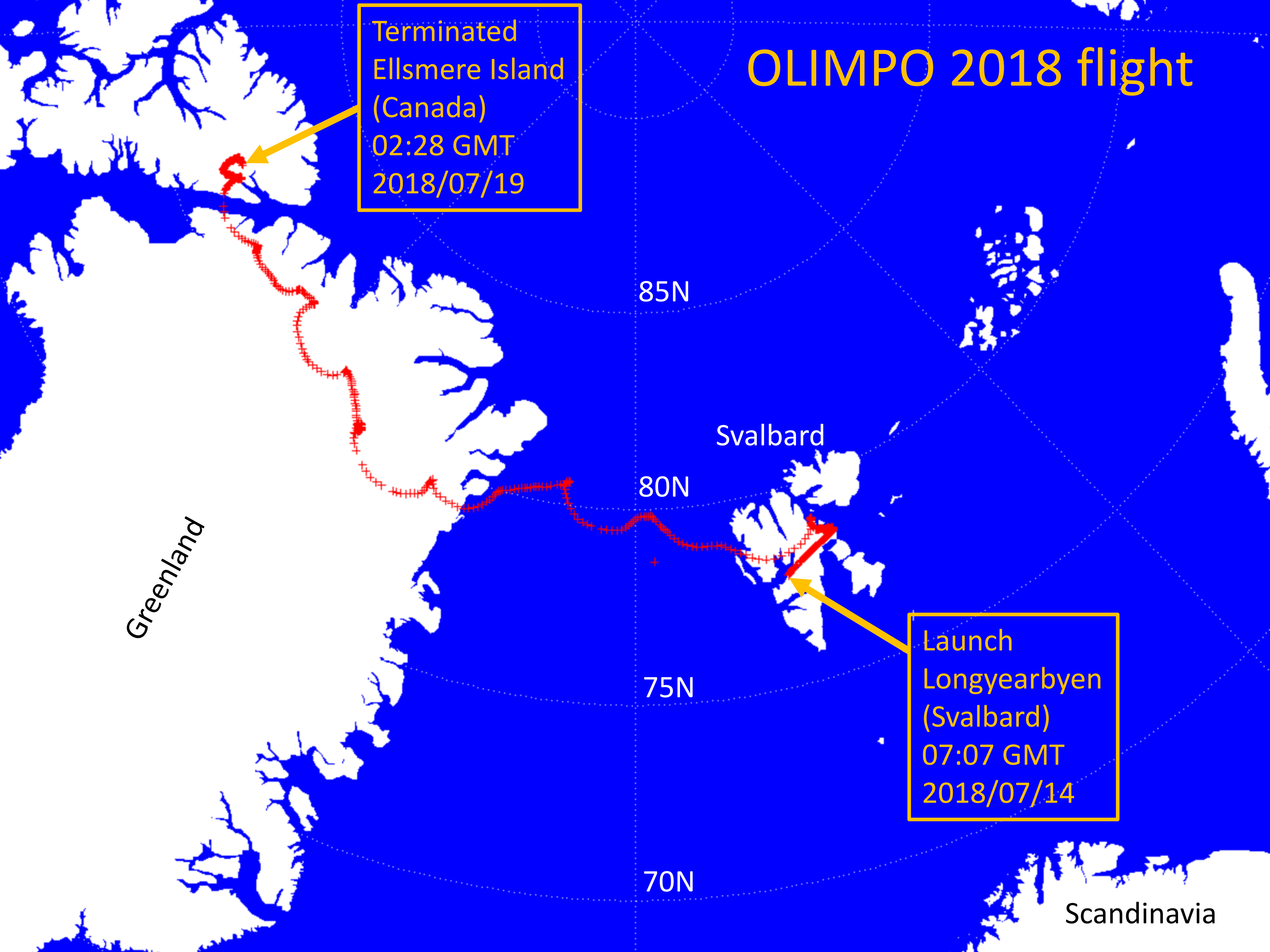
A. Paiella, et al., *Kinetic Inductance Detectors for the OLIMPO experiment: design and pre-flight characterization*, JCAP**01**(2019)039, 2019, astro-ph/1810:00598, Pre-flight calibration of OLIMPO produces the following expectation for the in-flight performance :



A. Paiella, et al., *Kinetic Inductance Detectors for the OLIMPO experiment: design and pre-flight characterization*, JCAP**01**(2019)039, 2019

July 14th, 2018




OLIMPO 2018 flight
Terminated
Ellsmere Island
(Canada)
02:28 GMT
2018/07/19
85N
80N
75N
70N
Svalbard
Greenland
Launch
Longyearbyen
(Svalbard)
07:07 GMT
2018/07/14
Scandinavia

Kinetic Inductance Detectors : in-flight performance

Calibration lamp signals (10 mK optical stimulator) as in-flight calibration transfer

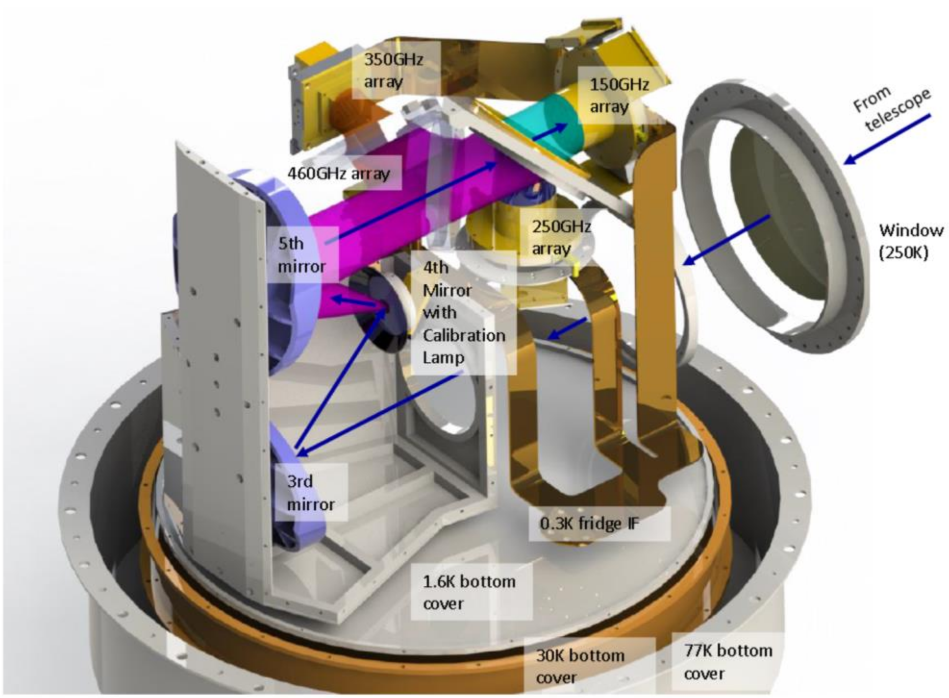
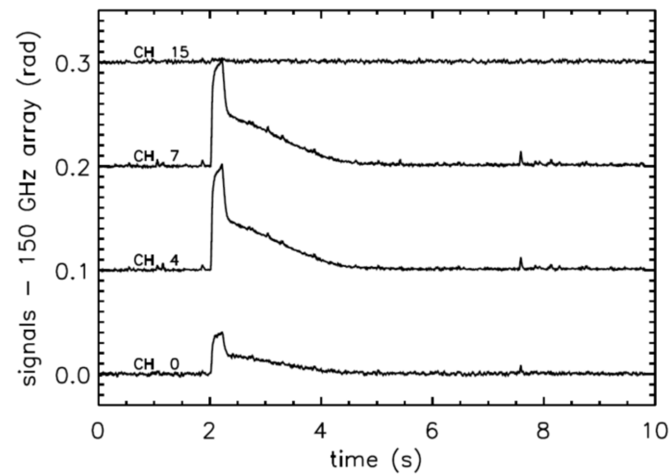
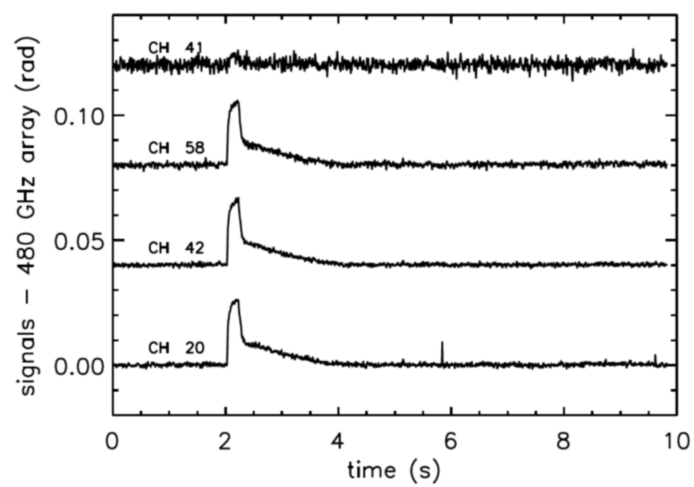


Figure 4. Sketch of the OLIMPO cryogenic reimaging optics (3rd mirror, 4th mirror, 5th mirror, dichroics and detector arrays). The cryogenic liquid tanks and many parts of the outer shell and shields have been hidden to show the optical system. The calibration lamp is located in the center of the 4th mirror, which is the Lyot stop of the optical system, and close to the *foci* of the 3rd and 5th mirrors. The beam from the calibration lamp, illuminating the four detector arrays is also shown. The path of the chief ray coming from the telescope and reaching the 150 GHz array is indicated by the blue arrows. For scale, the diameter of the 1.6 K L^4He tank is 45 cm.





See Masi et al. *Kinetic Inductance Detectors for the OLIMPO experiment: in--flight operation and performance* JCAP 1907 (2019) arXiv:1902.08993

Kinetic Inductance Detectors : in-flight performance

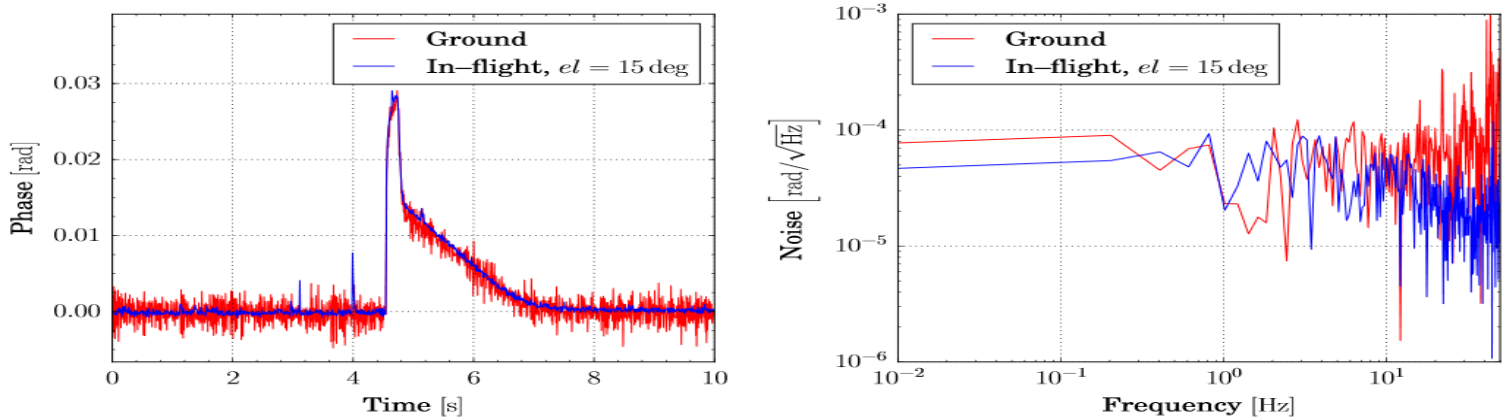


Figure 7. *Left panel*: comparison between the calibration lamp signals at ground (red line) and in-flight (blue line). The flight data have been renormalized to produce the same calibration lamp signal amplitude as the data taken on the ground. The improvement of the signal to noise ratio in flight is evident. *Right panel*: comparison between the noise spectra at ground (red line) and in-flight (blue line). Both panels refer to pixel 7 of the 150 GHz array.

Channel [GHz]	f [Hz]	N_g/N_f	average $\mathrm{NET_{RJ}}$ [$\mu\mathrm{K}\sqrt{\mathrm{s}}$]	
			ground	in-flight
150	10	2	182	91
250	17	8	250	31
350	23	3.5	247	71
460	31	4.5	329	73

Table 3. Array-averages of the ratio between the noise at ground (N_g) and in-flight (N_f), and noise equivalent temperature (in the Rayleigh-Jeans approximation, referred to the cryostat window, at the signal frequencies f expected during the scans of the DFTS mirrors. In both cases the instrument was in photometer configuration. In-flight, the telescope was observing the sky at 15° elevation. The uncertainty on the NET estimates is of the order of 15% for the ground NET and 20% for the in-flight NET.

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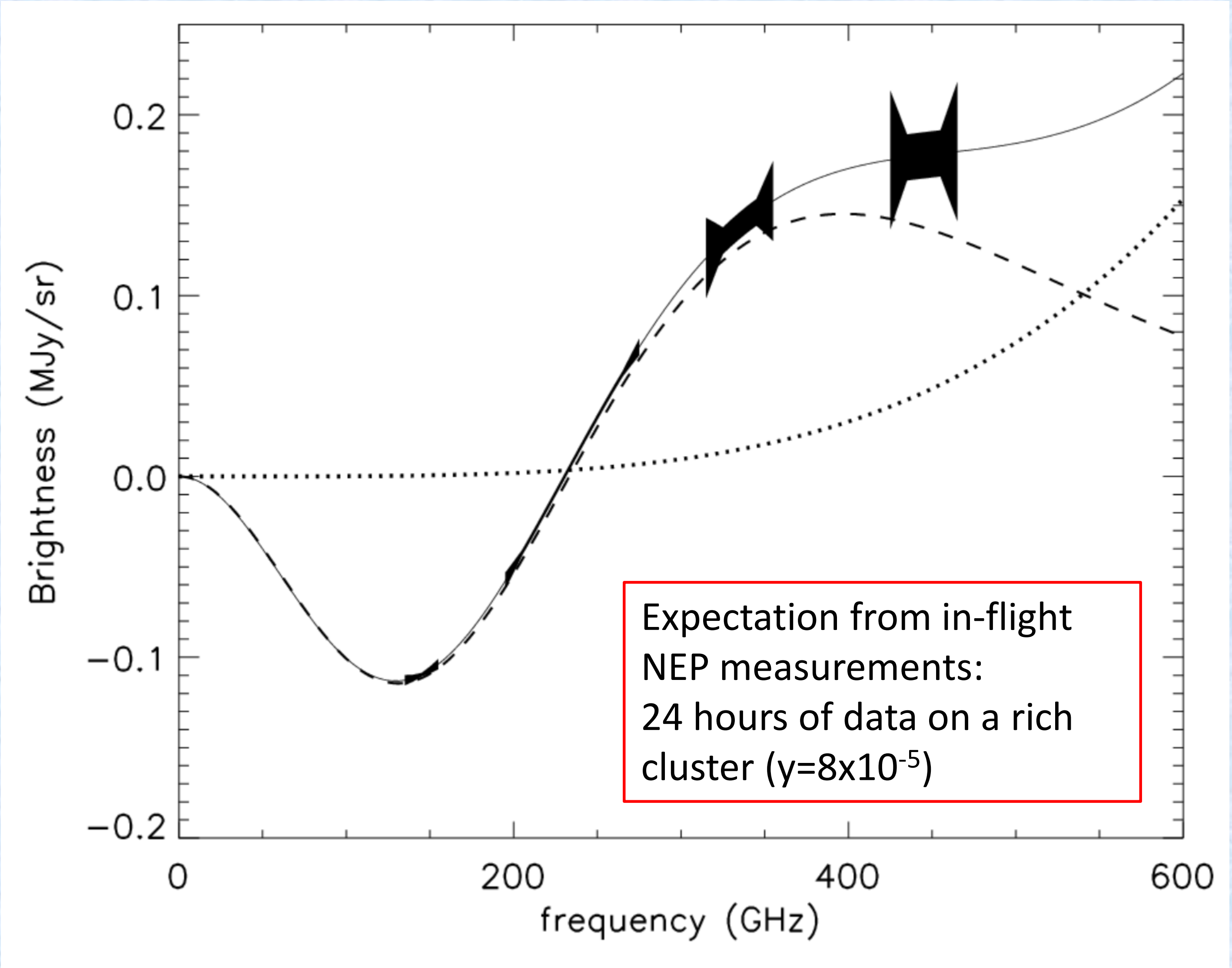
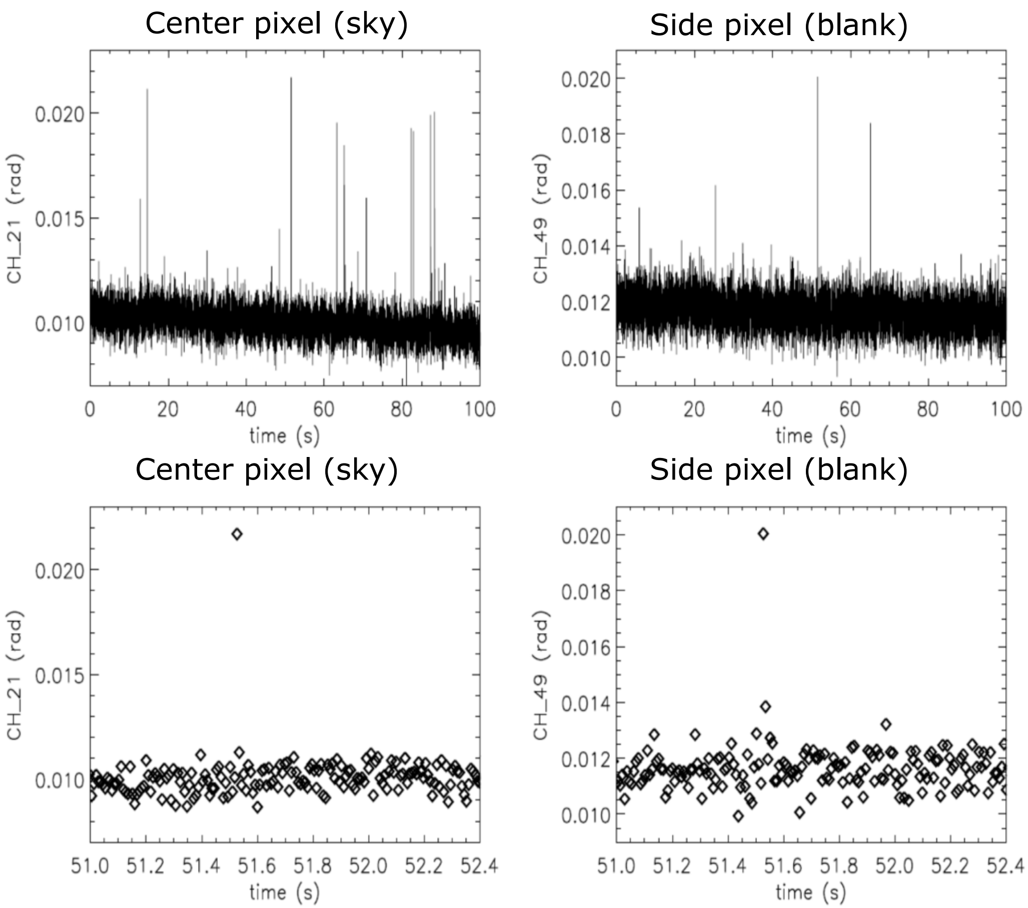
See Masi et al. *Kinetic Inductance Detectors for the OLIMPO experiment: in--flight operation and performance* JCAP 1907 (2019) arXiv:1902.08993


0.2
0.1
0.0
−0.1
−0.2
Brightness (MJy/sr)
0
200
400
600
frequency (GHz)
Expectation from in-flight
NEP measurements:
24 hours of data on a rich
cluster (y=8x10-5)

Kinetic Inductance Detectors : in-flight performance

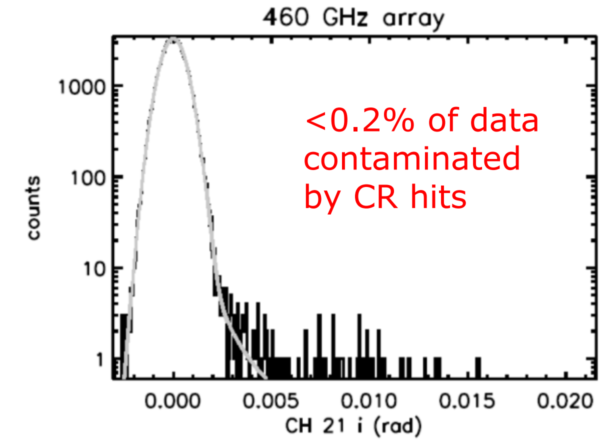
Response of KIDs to cosmic rays in the stratospheric environment – first test ever

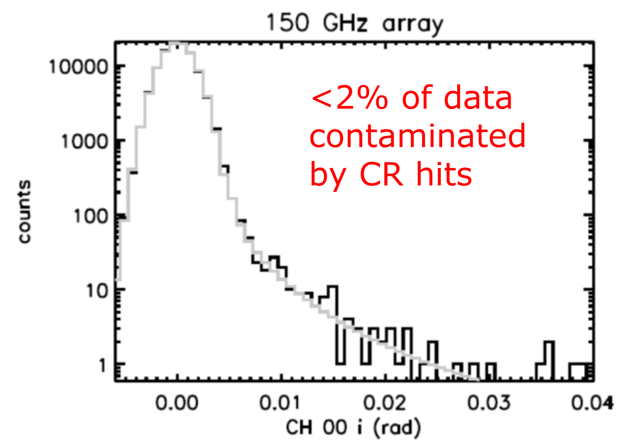
Time ordered data



460 GHz array

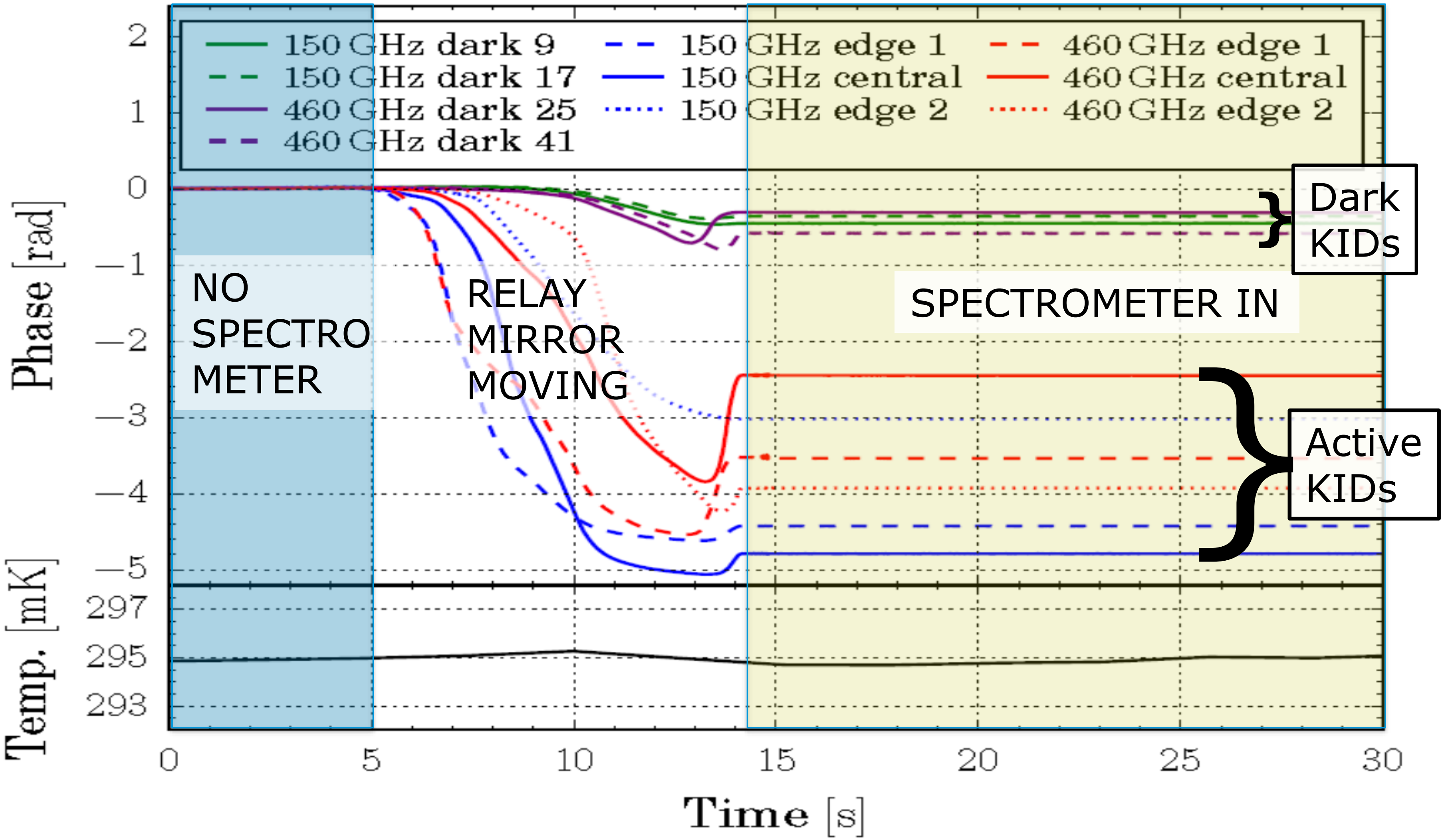
Histograms





See Masi et al. *Kinetic Inductance Detectors for the OLIMPO experiment: in--flight operation and performance* JCAP 1907 (2019) arXiv:1902.08993

OLIMPO DFTS: preliminary performance



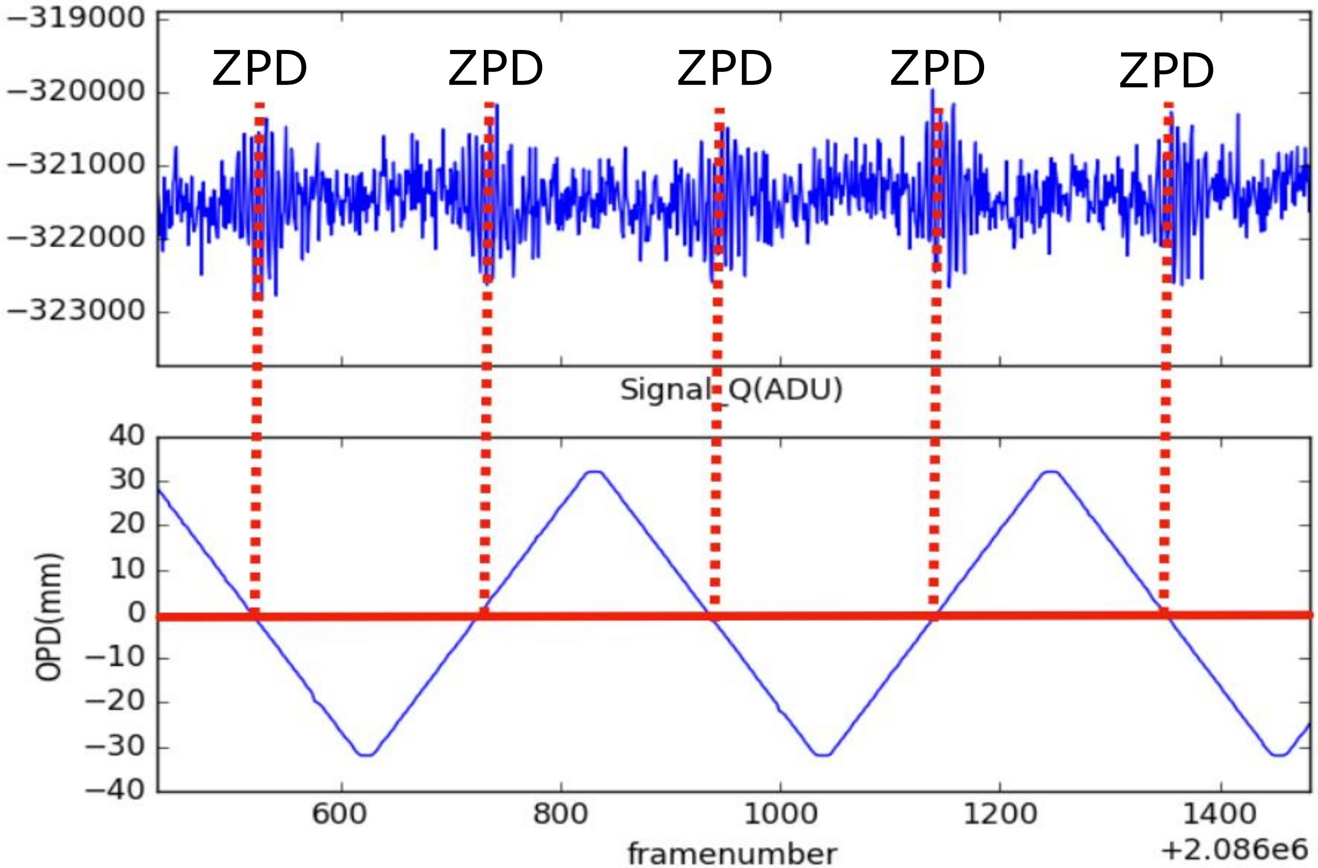
See Masi et al. *Kinetic Inductance Detectors for the OLIMPO experiment: in--flight operation and performance* JCAP 1907 (2019) arXiv:1902.08993

OLIMPO DFTS: preliminary performance

In-flight A-B balance test : pointing blank sky, 150 GHz band

Interferograms barely larger than detector noise (180 uK/sqrt(Hz)) in raw data

Optical path difference:

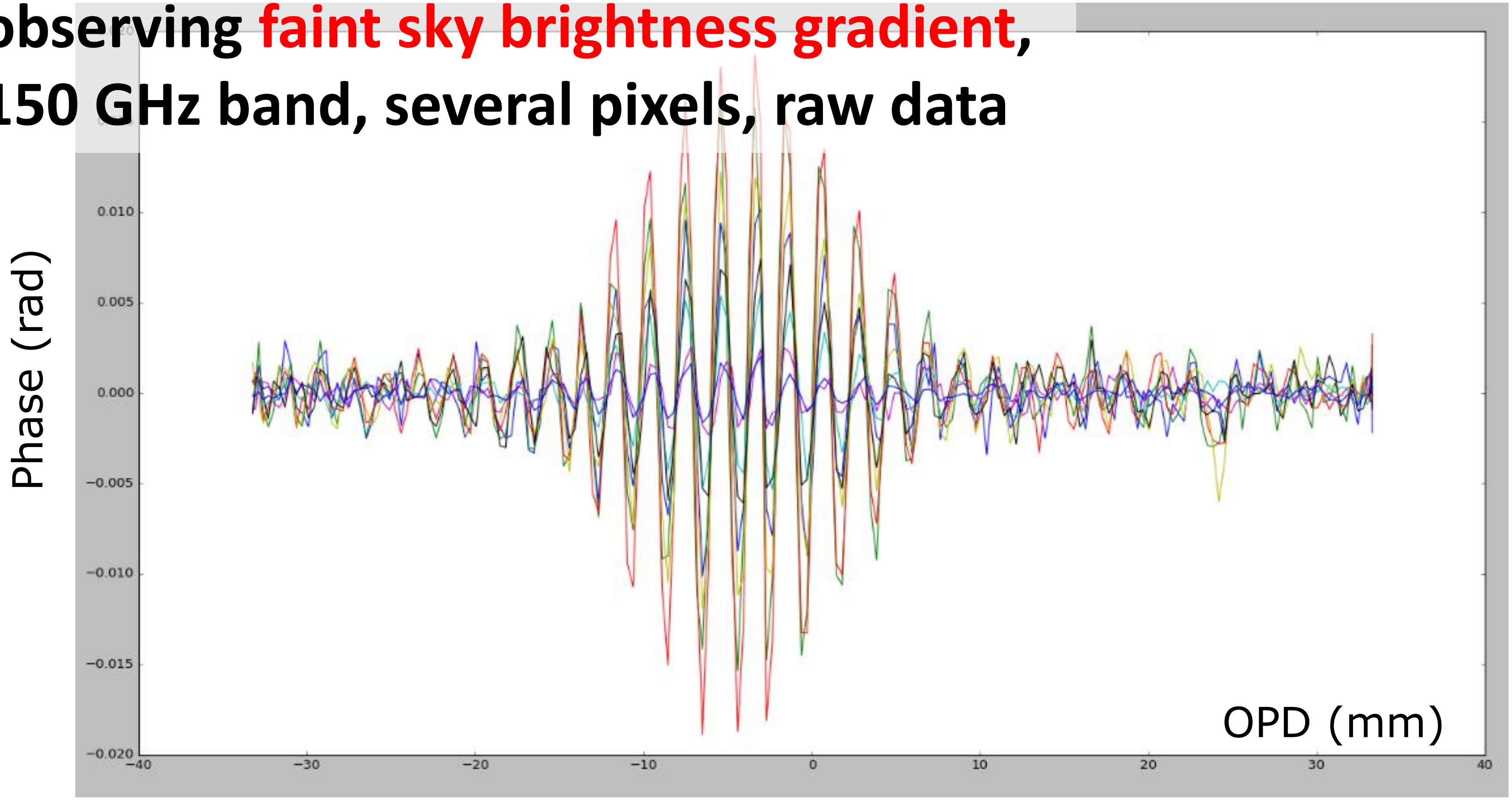


(125 fps)

Preliminary. Analysis: G. D'Alessandro

OLIMPO DFTS: preliminary performance

In-flight A-B signal test :
observing faint sky brightness gradient,
150 GHz band, several pixels, raw data



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In-flight A-B signal test :
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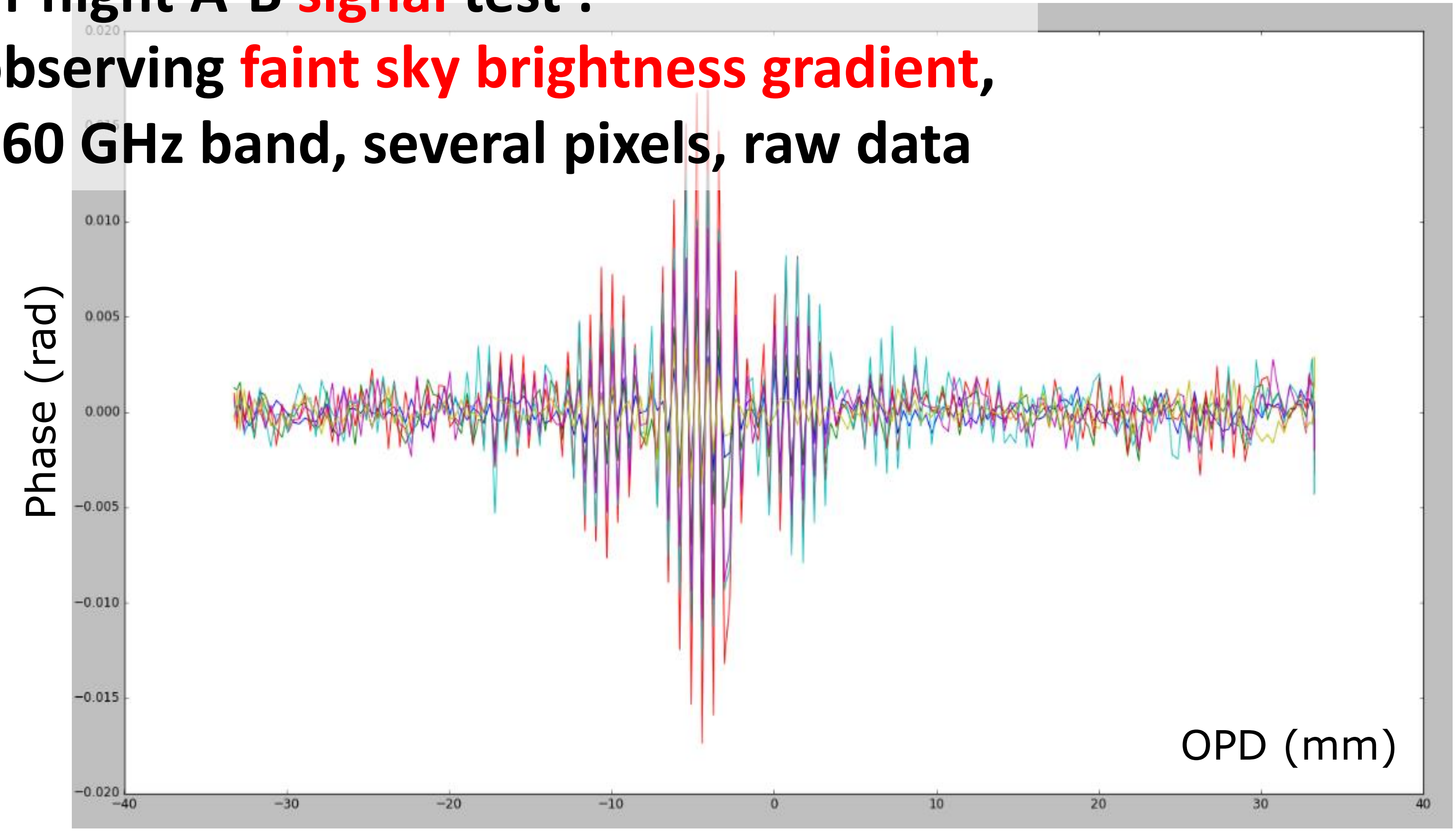


Preliminary. Analysis: G. D'Alessandro

OLIMPO DFTS: preliminary performance

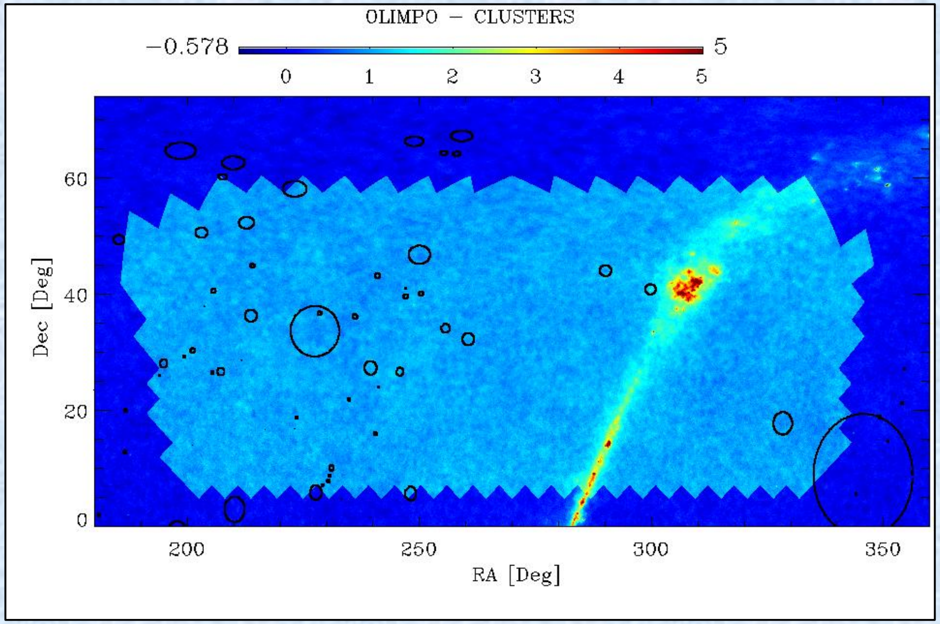
- Very preliminary analysis, much more to come, not ready to make quantitative statements
  - DFTS implementation (@room temperature) basically working:
    - Detectors withstand well the background change when interferometer inserted
    - Mirrors moving smoothly
    - Mirror position accurately monitored
    - Instrument well balanced
    - Data analysis under way
- This has been a test-flight. More data in a forthcoming science flight.

The Future of OLIMPO:
Photon-noise-limited DFTS

	Balloon (45° elevation)				Space	
	Current OLIMPO		Cryo spectrometer		Satellite	
Band Center (GHz)	**Background 240K spectrometer & telescope (pW)**	**NEP 240K spectrometer & telescope (W/sqrt(Hz))**	**Background 2K spectrometer 240K telescope (pW)**	**NEP 2K spectrometer 240K telescope (W/sqrt(Hz))**	**Background 2K spectrometer & 40K telescope (pW)**	**NEP 2K spectrometer & 40K telescope (W/sqrt(Hz))**
150	8	1.1×10^{-16}	2.6	6.5×10^{-17}	0.5	2.9×10^{-17}
250	50	2.6×10^{-16}	14	1.3×10^{-16}	1.1	3.9×10^{-17}
350	15	1.6×10^{-16}	5	9.0×10^{-17}	2.1	1.6×10^{-17}
460	33	2.4×10^{-16}	12	1.5×10^{-16}	0.4	2.7×10^{-17}

- Current OLIMPO (240K spectrometer) basically optimized, for warm telescope
- 2K spectrometer would gain a factor 2-ish in NEP
  –> we plan to re-fly OLIMPO as it is and get science data (see below).
- Satellite version with cold interferometer and 40K telescope can gain a factor 5-10 in NEP (plus gain from larger telescope area) -> Millimetron

The near-future of OLIMPO



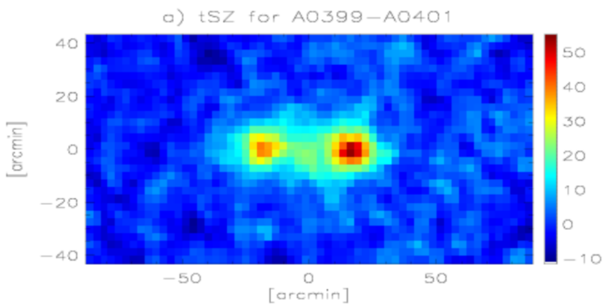
ind	ID	RA	Dec	TIME	frac	NAME
0	1	212.83	52.2	18000	1	3C295CLUSTER
1	40	194.95	27.98	3600	0	ABELL1656
2	43	203.13	50.51	3600	1	ABELL1758
3	44	205.48	26.37	3600	1	ABELL1775
4	45	207.25	26.59	3600	1	ABELL1795
5	48	216.72	16.68	18000	1	ABELL1913
6	49	223.18	16.75	11360.88	1.27	ABELL1983
7	50	223.63	18.63	18000	1	ABELL1991
8	51	223.21	58.05	5640.53	1.28	ABELL1995
9	53	227.56	33.53	18000	1	ABELL2034
10	54	229.19	7	3600	1	ABELL2052
11	55	230.76	8.64	3600	1	ABELL2063
12	56	234.95	21.77	3600	1	ABELL2107
13	57	236.25	36.06	18000	1	ABELL2124
14	58	239.57	27.23	3600	1	ABELL2142
15	59	240.57	15.9	3600	1	ABELL2147
16	61	247.04	40.91	18000	1	ABELL2197
17	62	247.15	39.52	3600	1	ABELL2199
18	63	248.19	5.58	3600	1	ABELL2204
19	65	250.09	46.69	3600	1	ABELL2219
20	66	255.68	34.05	7230	1.49	ABELL2244
21	69	260.62	32.15	18000	1	ABELL2261
22	70	290.19	43.96	3600	1	ABELL2319
23	71	328.39	17.67	3600	1	ABELL2390
24	98	241.24	23.92	13045.75	1.1	AWM4
25	100	299.87	40.73	18000	1	CYGNUSA
26	101	201.2	30.19	18000	1	GHO1322+3027
27	102	241.11	43.08	18000	1	GHO1602+4312
28	107	230.46	7.71	3600	1	MKW03S
29	120	228.61	36.61	18000	1	MS1512.4+3647
30	121	245.9	26.56	13147.05	1.1	MS1621.5+2640
31	128	201.15	13.93	18000	0	NGC5129GROUP
32	134	199.34	29.19	18000	1	RDCSJ1317+2911
33	143	231.17	9.96	18000	1	RXJ1524.6+0957
34	150	211.73	28.57	18000	1	WARPJ1406.9+2834
35	151	213.8	36.2	18000	1	WARPJ1415.1+3612
36	161	194.02	25.95	18000	0	[VMF98]128
37	162	203.74	37.84	18000	1	[VMF98]139
38	163	205.71	40.47	18000	1	[VMF98]148
39	164	214.12	44.78	18000	1	[VMF98]158
40	165	250.47	40.03	18000	1	[VMF98]184

- In a circumpolar summer long duration flight (>200h) we plan to observe 40 selected clusters and to perform a blind deep integration on a clean sky region
- We have optimized the observation plan distributing the integration time among the different targets according to their brightness and diurnal elevation.

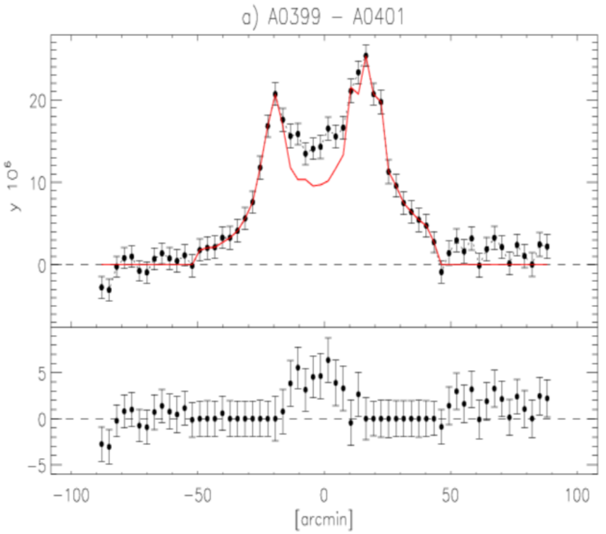
ASI is evaluating options for the next flight opportunity

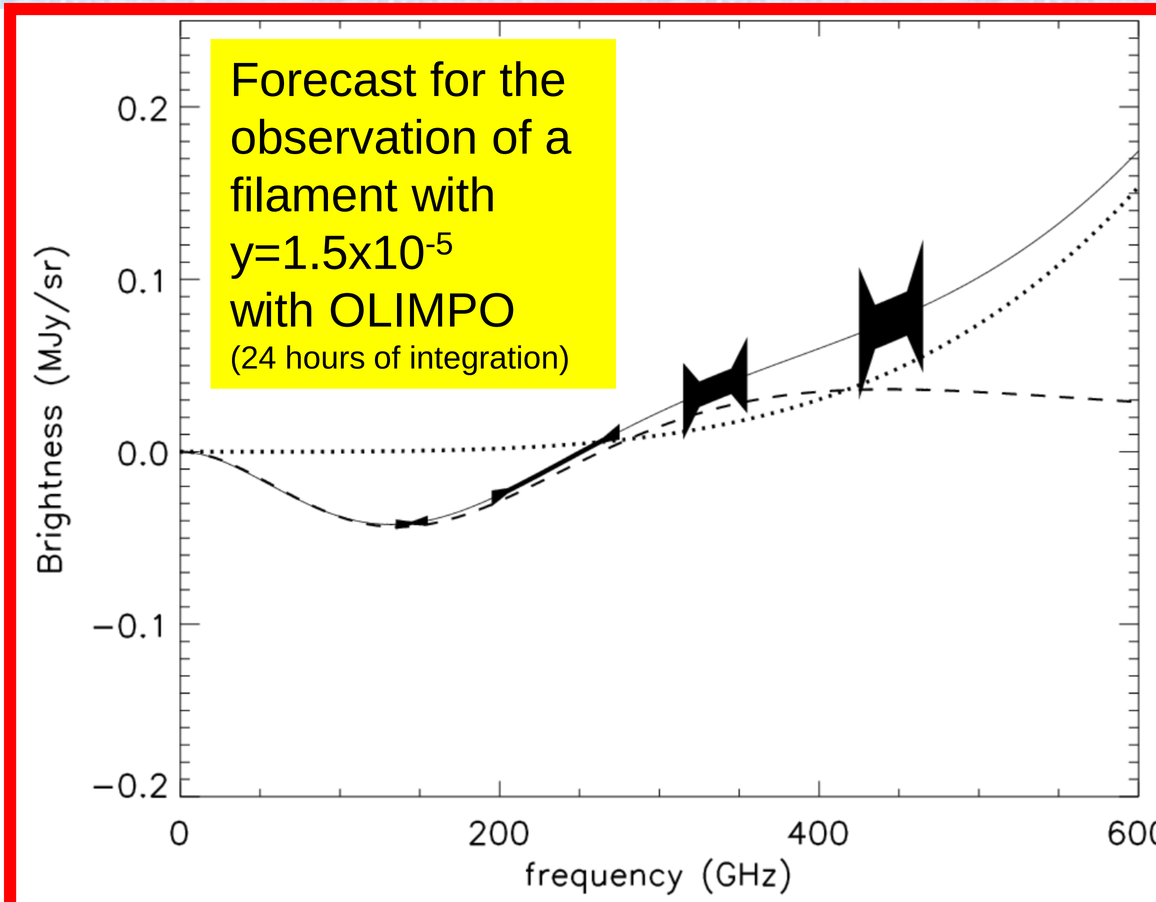
The near-future of OLIMPO

- OLIMPO will also attempt to measure *filaments* between clusters
- Important for synergic study with forthcoming X-ray surveys, like Athena

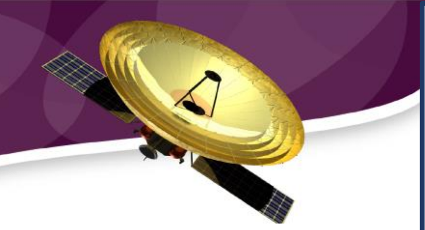


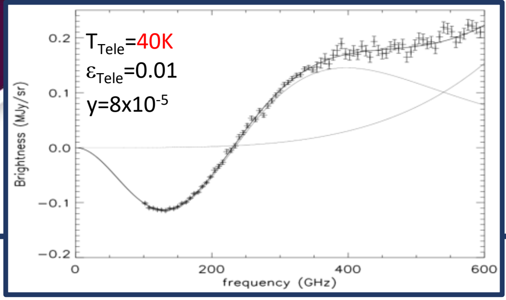
Planck coll. , A&A, 550 (2013) A134





ASI is evaluating options for the next flight opportunity





The far future of OLIMPO: A differential Fourier-Transform Spectrometer **(DFTS)** for Millimetron : 0.1-1 THz

DFTS SCIENCE:

- Spectral distortions of the CMB
  - Spectral dependance of CMB anisotropy
    - important for calibration of anisotropy measurements, and powerful check for foreground residuals
    - detect small effects due to frequency-dependent scattering of CMB photons
  - SZ in clusters and other sources
    - Separation of components
    - Physical properties of the gas (thermal SZ)
    - Non thermal properties (relativistic SZ)
    - Survey 100000+ clusters up to z=3.5
    - Scaling relations
    - SZ in giant radiogalaxies lobes
- Survey of high-z galaxies with the C+ line
  - 10000+ galaxies in 100 hours
  - Beat confusion using spectroscopy
  - Get accurate high-z luminosity function
  - Select evolutionary models
  - Other fine structure lines and metallicity
- AGN survey (cover transition from synchrotron to dust)
- Galactic & planetary science (a lot…)
- …

DFTS IMPLEMENTATION:

- OLIMPO is an excellent pathfinder for a DFTS instrument in space
- The balance test performed with OLIMPO was an expecially severe test (room T interferometer and spectrometer) and was successfull
- Phase-A study (ASI + Kayser IT) for a cryogenic DFTS for Millimetron completed, using 1/4 of the focal plane area and available cryogenic volume