Second run of NIKA at the 30m telescope

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Reminder 1: Purpose of the continuum prototypes

Test new technologies in view to replace MAMBO-2 with a more powerful instrument:

- Better sensitivity: 35 mJy·√s… → 5..10 mJy·√s
- Better coverage of the focal plane: horns → filled array
- Bigger field of view: 4' → >6' (> ×2 area)
- More bands: 1.2mm → 1.2mm & 2.1mm
- Possibly intrinsic sensitivity to polarization

⇒ More pixels: 117 → 2000..7000

⇒ Mapping speed more than ×100 faster* !

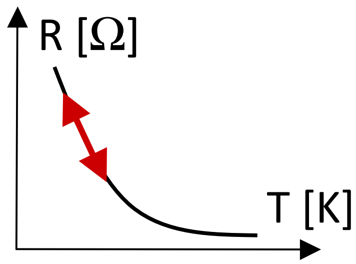
⇒ New observing window, never available until now

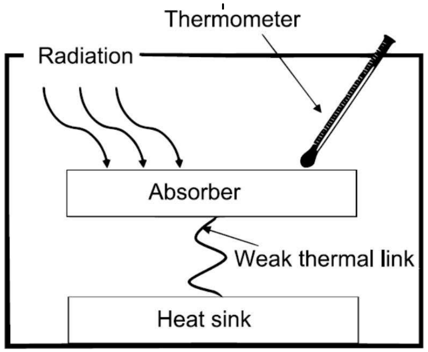
* Mapping time: $t \sim NEFD^2 \cdot (\Omega_{map} / \Omega e_{array})$

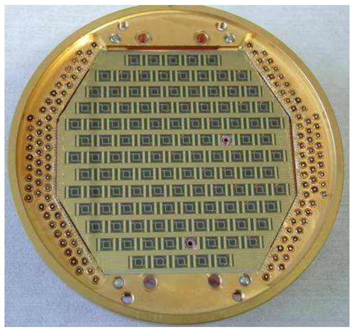
$\Rightarrow t_{MAMBO\text{-}2} / t_{5' \times 5', 0.5F\lambda, filled} = (35^2/(117 \cdot (11/60)^2)) / (8^2/6^2) \approx 150$

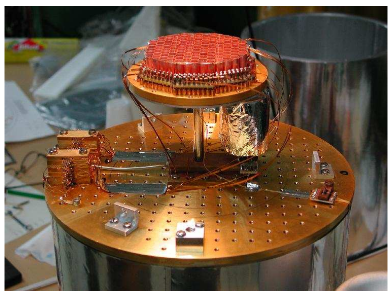
Reminder 1: Continuum detector technologies

MAMBO 2:
semi-conductor bolometers



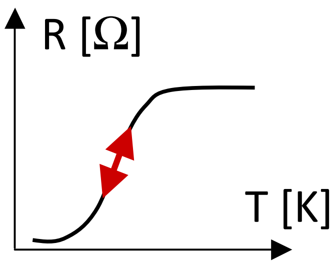


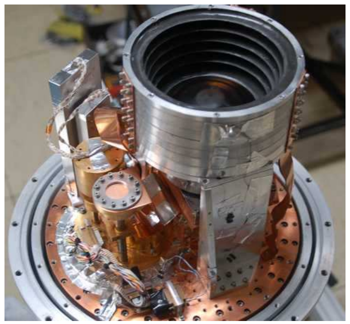




250 GHz
~35 mJy·√s
117 pixels
$\pi/_{4}$ 4'^{2} FOV

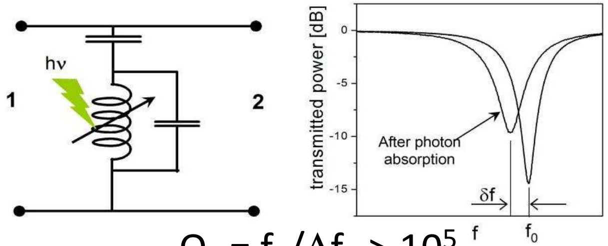
GISMO:
superconducting bolometers



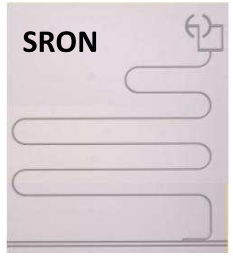


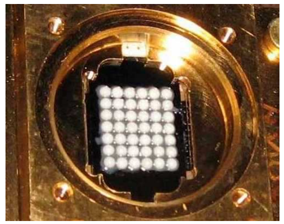
150 GHz
~25 mJy·√s
128 pixels
4'×2' FOV

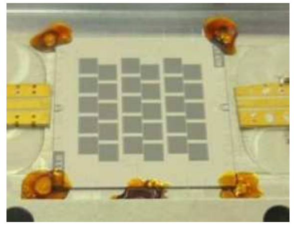
NIKA (1):
kinetic inductance detectors



$Q_L = f_0/\Delta f_0 > 10^5$

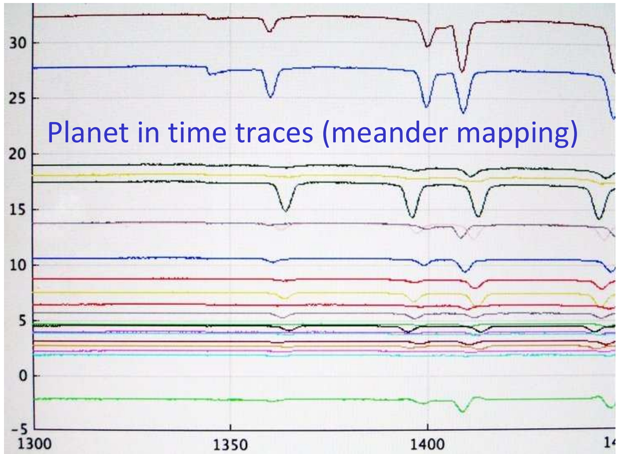


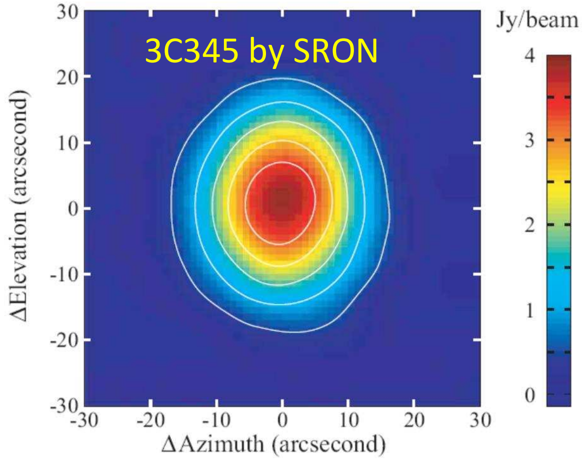




150 GHz
~150 mJy·√s
40 pixels
1'×1' FOV

Reminder 2: NIKA 1 at the 30m MRT (10/2009)





Sensitivity after data processing:

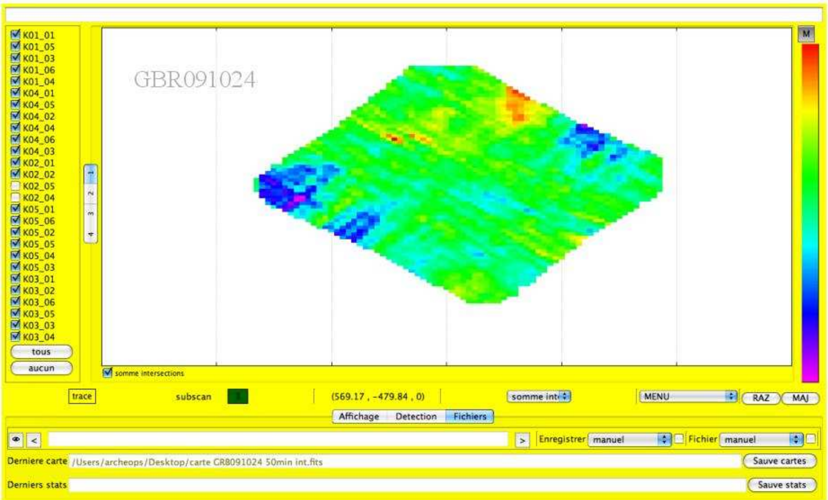
$NEFD_{HPBW}$ = 120 mJy·√s

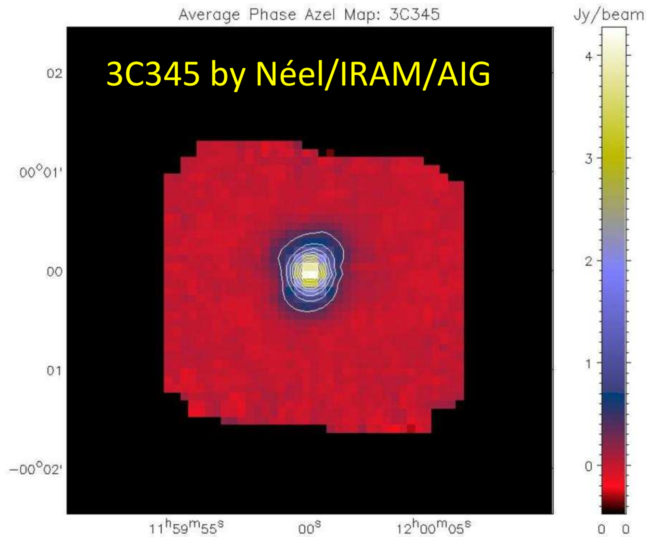
NET_{HPBW} = 15 mK·√s

Background photon noise limit:

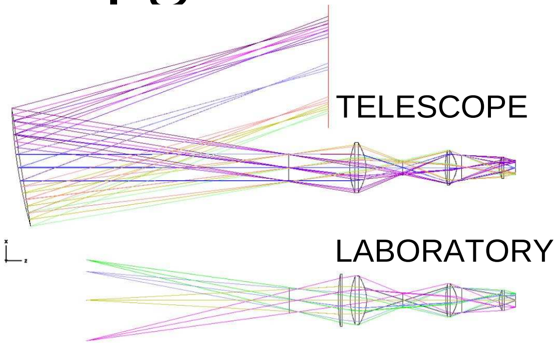
$NEFD_{HPBW}$ ~ 7 mJy·√s

NET_{HPBW} ~ 1 mK·√s





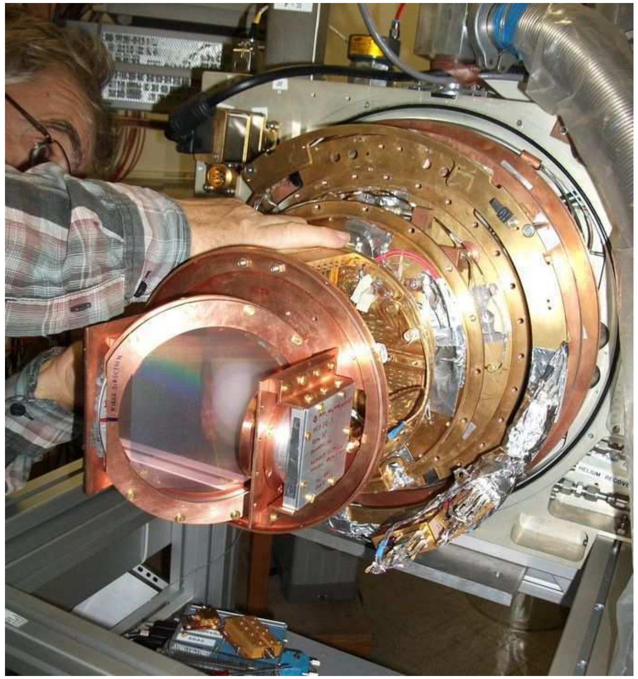
NIKA 2: upgrades & lab tests



Sky simulator: cold black body for optical tests in lab (T adjustable from 50 to 300 K) ~5mm "planet" on X-Y table

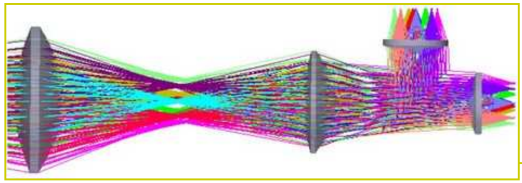
NIKA 2 new elements:

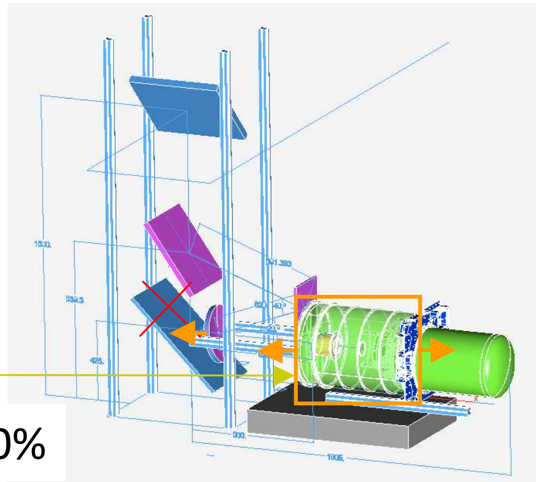
- Optics (biconic mirror, 4 lenses, polarizer, filters)
- Cryostat: longer baffle, 2 array holders
- 2.1 mm: Néel-IRAM 144 pixels, f_0 = 1.5 GHz, Δf_{mux} = 2 MHz
- 1.3 mm: SRON 256 pixels, f_0 = 5 GHz, Δf_{mux} = 4 MHz
- Sensitivity goal: ~×4 better than 1st run
- Electronic: 2 Casper Roach Boards (230 MHz bandwidth), IRAM 1.5 GHz amplifier, Caltech 5 GHz amplifier



NIKA 1 optics and cryostat, and main changes for NIKA 2

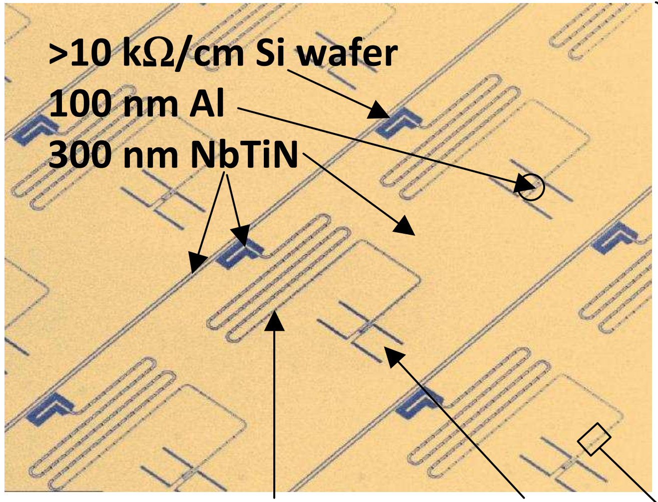
NIKA 2 cryostat optics



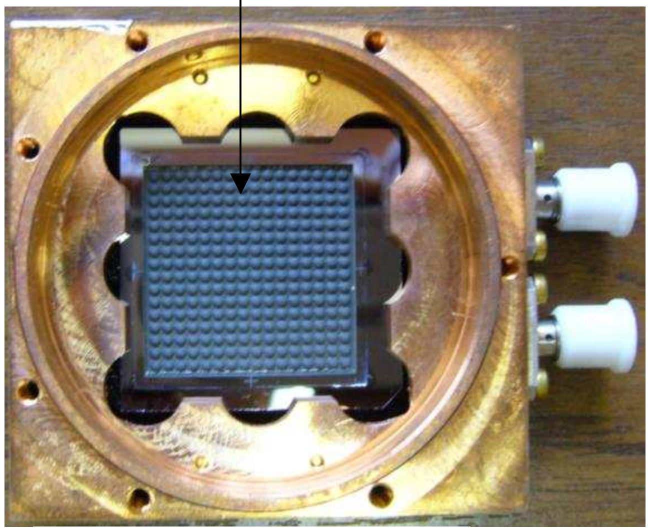


Total optical transmission ≈ 40%

NIKA 2: upgrades & lab tests

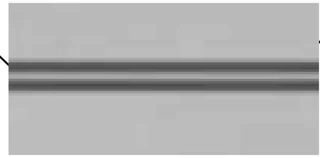


λ/4 waveguide resonator, Twin-slot antenna, 1.6mm Si micro-lenses

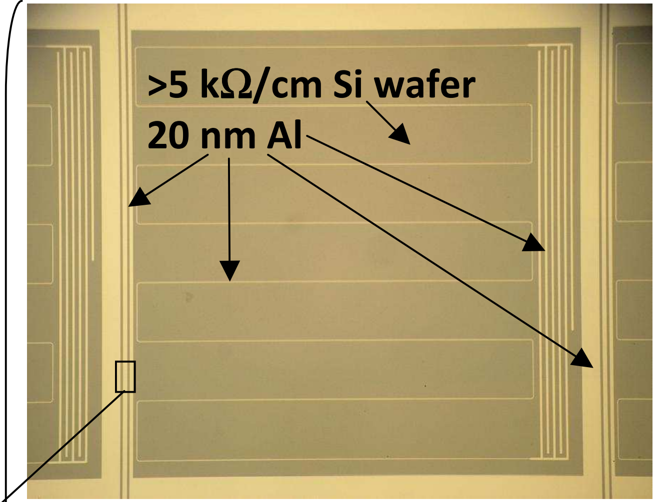


Pixels

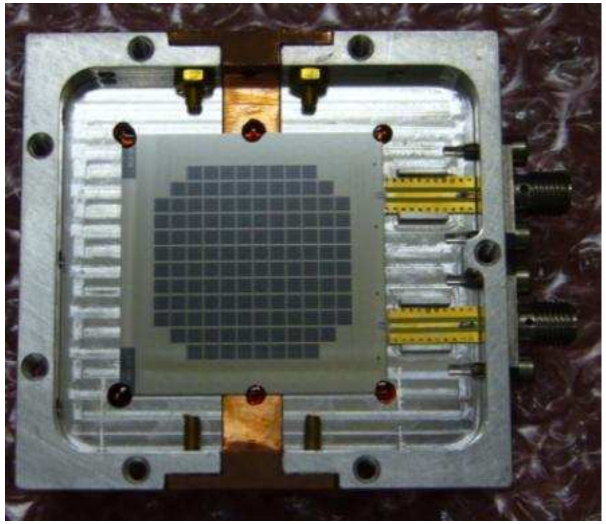
- **1.3 mm band** (220 GHz) SRON pixel size = 1.6mm = 0.8Fλ = 11" FWHM on the sky; 62 used in run → ~1.5' FOV



- **2.0 mm band** (150 GHz) Néel-IRAM: pixel size = 2.25mm = 0.75Fλ = 17" FWHM on the sky; 112 used in run → ~2' FOV

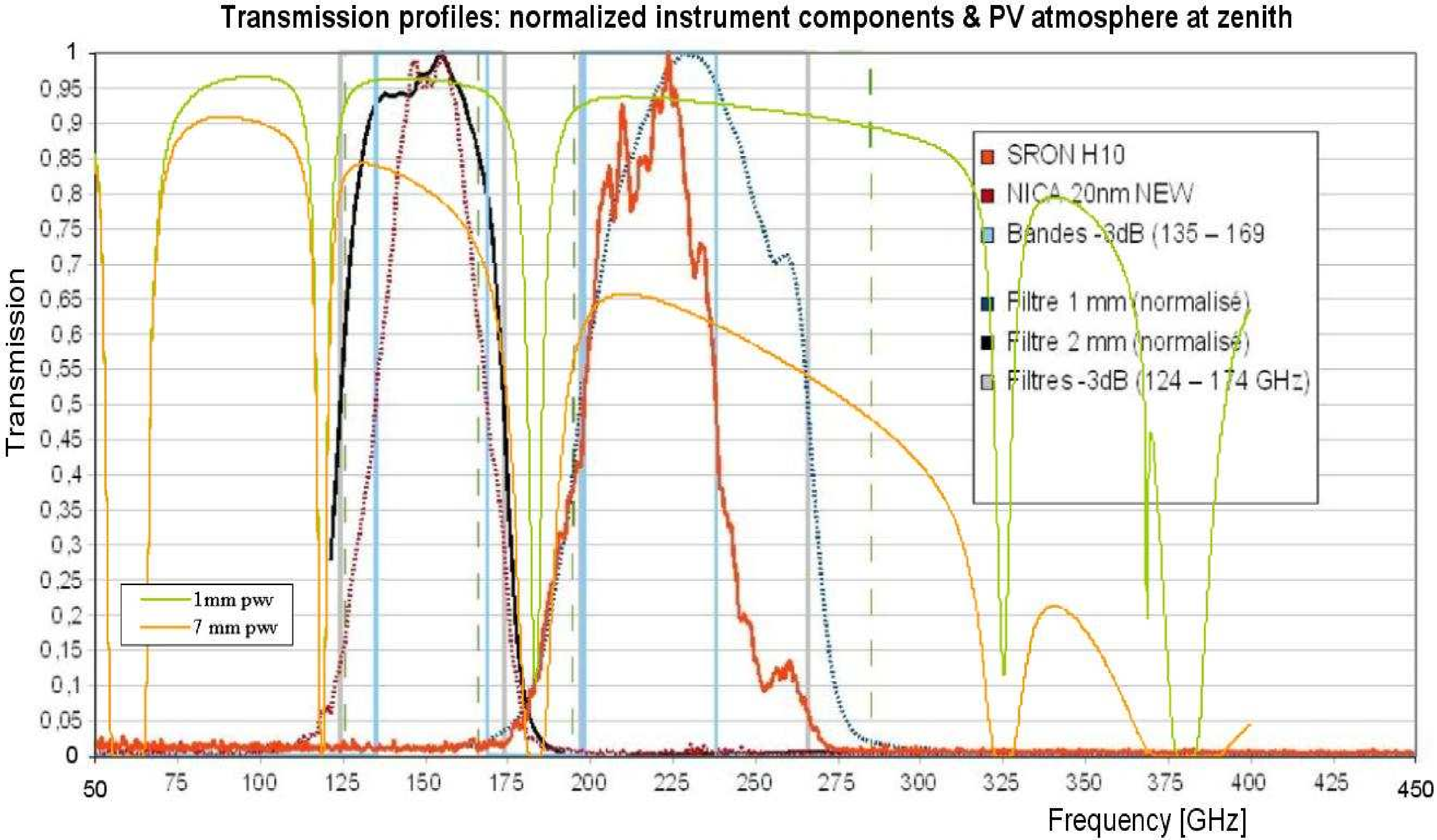


Capacitor + Inductive meander (~ solid absorber) => ~ free space Z



50 mK/Hz$^{1/2}$ (1Hz) ← Sky simulator NET = $S_n(f)/R(T)$ → 6 mK/Hz$^{1/2}$ (1Hz)

NIKA 2: upgrades & lab tests



Bands spectral response obtained with a Martin-Puplett interferometer

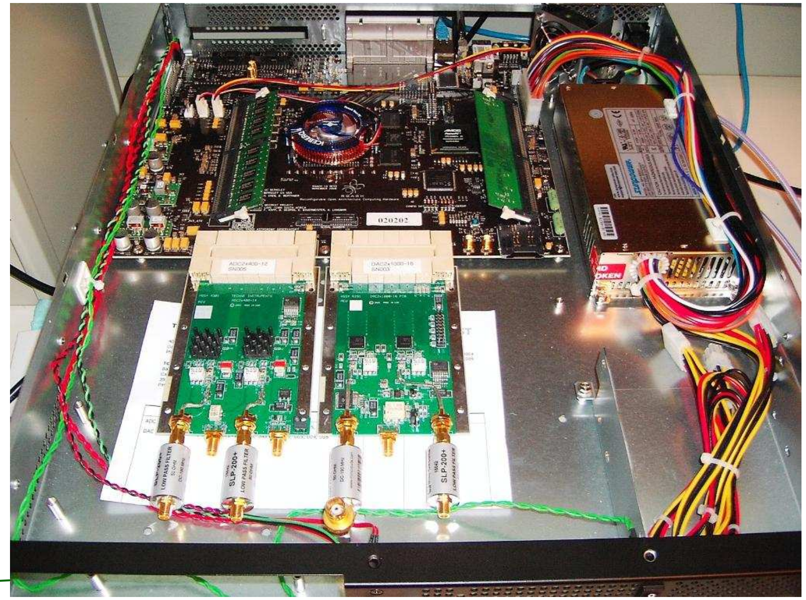
NIKA 2: upgrades & lab tests

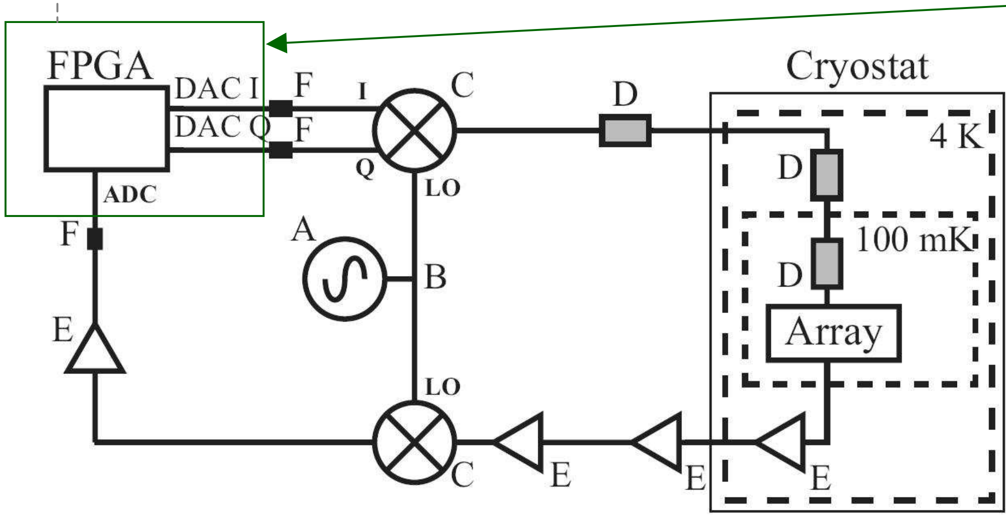
Computer

Electronics

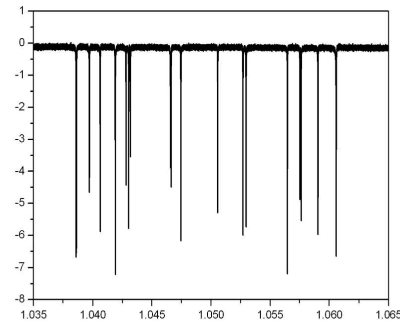
Based on 2 **CASPER ROACH Boards** from the **Open Source project** (development of 128 channels modules for KIDs readout).

- Rubidium clock reference
- 466 MSPS
- 233 MHz readout
- 72 (1mm band) & 112 (2mm band) "lock-in like" tone generator
- each pixel response broadcasted at 22Hz





A) High frequency synthesizer
B) Splitter
C) Mixer
D) Attenuator
E) Amplifier
F) Low pass filter



Frequency multiplexing
1 tone / pixel on a feed line

Individual pixel response = pair of in-phase (I) and quadrature (Q) values.

NIKA 2 at the 30m MRT: October 2010 run plan

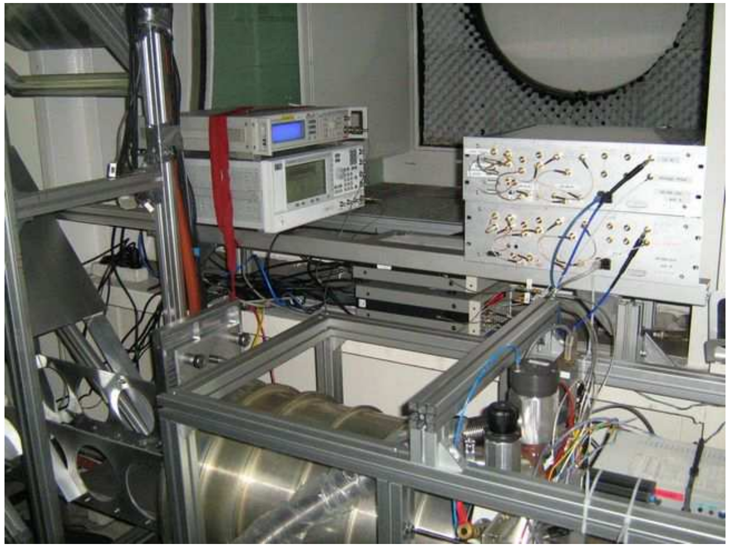
day\hour		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
We	13																			Arrival of truck						
Th	14											Preparation					3-4h: Mount, align, cool down									
Fr	15															1-2h: tests, calibration, pointing										
Sa	16															1-2h: tests, calibration, pointing										
Su	17															1-2h: tests, calibration, pointing										
Mo	18							Observations 6h30 - 20h30																		
Tu	19											Maintenance								Observations 17h30 - 2h30						
We	20																Observations 14h30 - 2h30									
Th	21																Observations 14h30 - 2h30									
Fr	22										Observations 9h00 - 21h00															
Sa	23																				Observations 18h00 - 6h00					
Su	24																Observations 14h30 - 2h30									
Mo	25				Warm up					Dismount			MAMBO-2 re-mount													

LST = 8h

Preparation: mounting, alignment, cooling, cabling & software, detectors tuning, pointing, focus, flux calibration on planets

Observations: selection of 75 sources based on variety and references in literature for comparison; radio sources (IRAM catalog), galactic sources, galaxies, quasars, clusters of galaxies => Fluxes: (≤)100 .. (≥)0.01 Jy

NIKA 2 at the 30m MRT: Installation

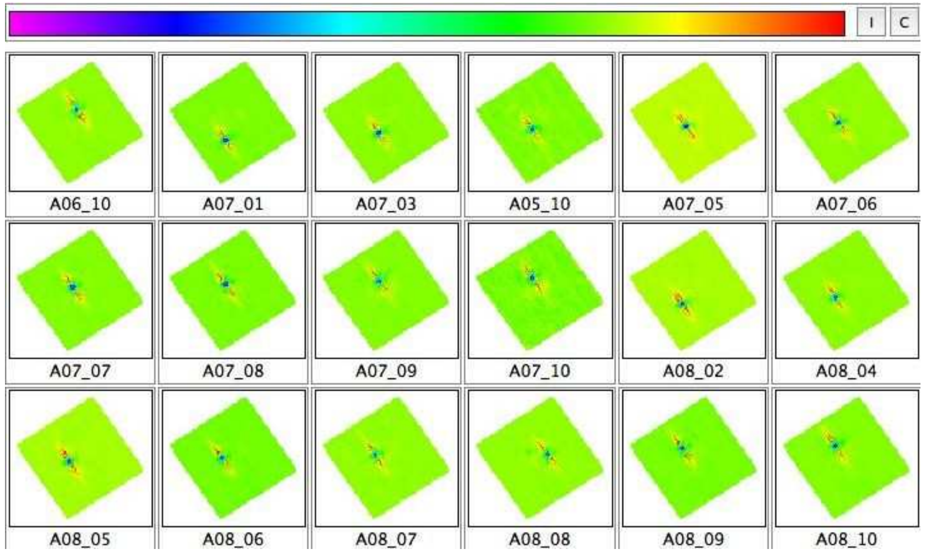





NIKA 2 at the 30m MRT: Preparation phase

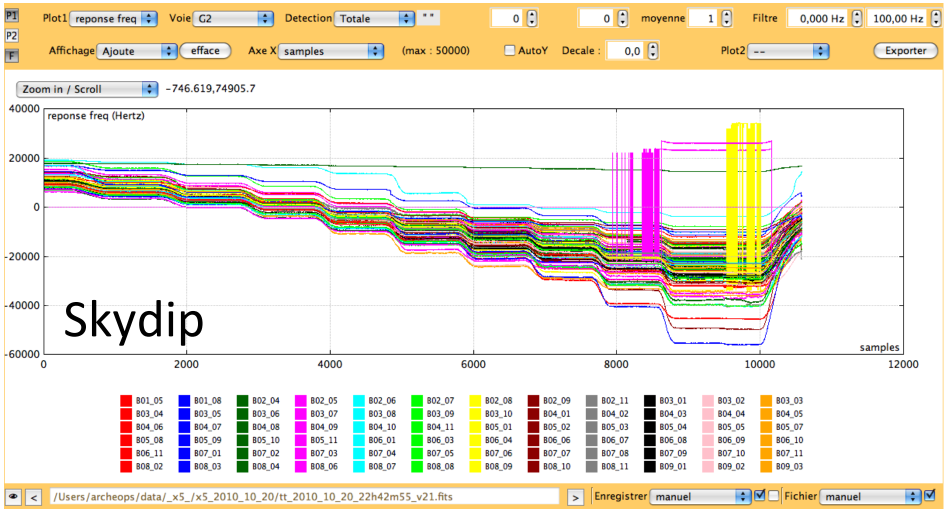
(acquisition soft, merging with telescope data, detector tuning, …)

Control room



Mars maps (pointing, focus, calibration…)

Tuning the resonances



NIKA 2 at the 30m MRT: Preliminary observations

(... calibration)

Mapping **planets**

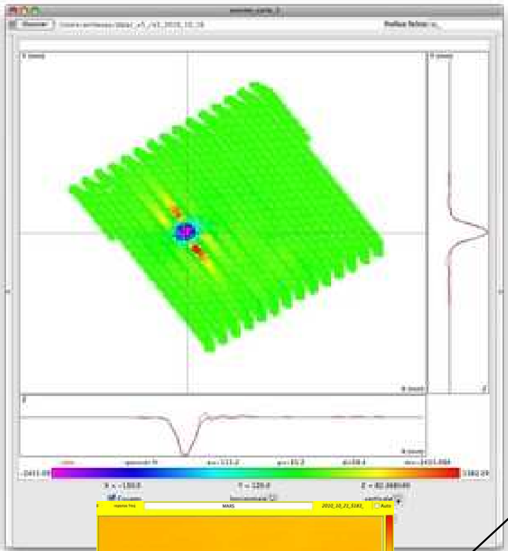
⇒ relative positions of arrays in the sky (pointing)

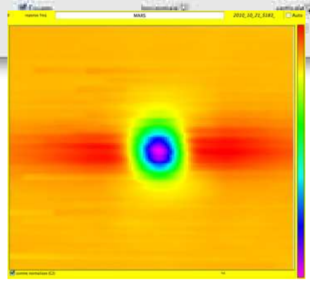
⇒ relative pixel responses (gains)

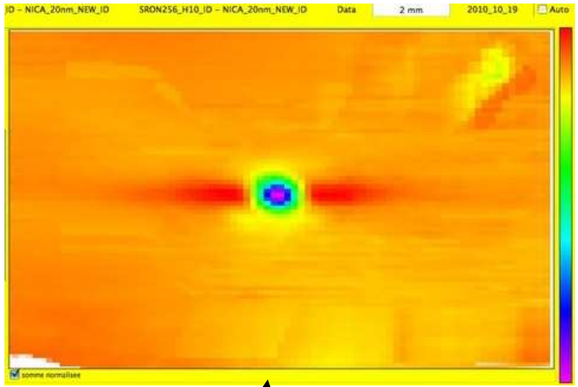
⇒ beam sizes & height vs M2 shifts (focus)

⇒ known signal vs noise (sensitivity)

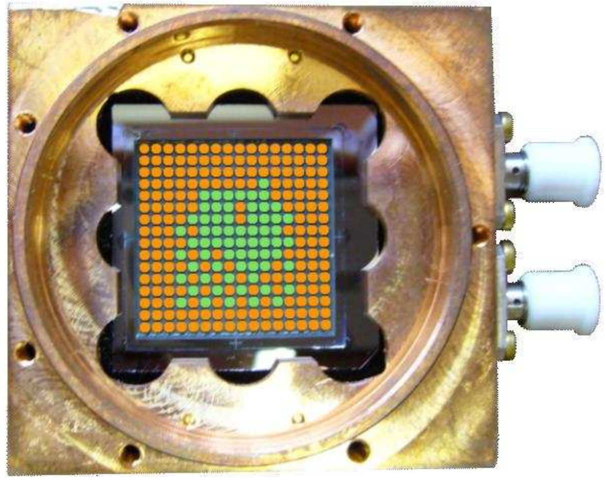
⇒ response to various fluxes (linearity)

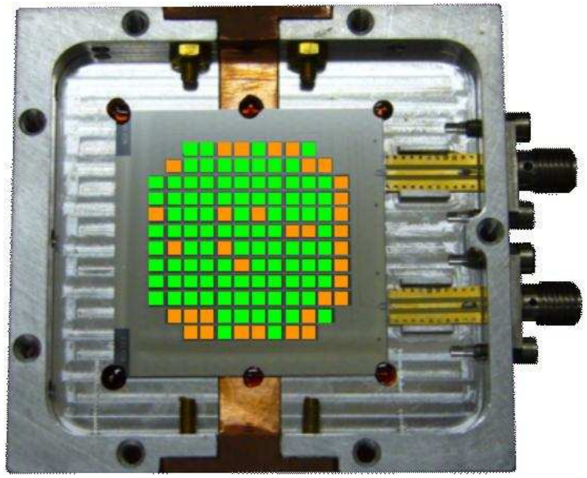






Mars, Neptune, Uranus, Ganymede, Callisto, Io





Pixels of 1mm and 2mm arrays used for the observations (green [orange] = inside [outside] the bandwidth of the tones generators)

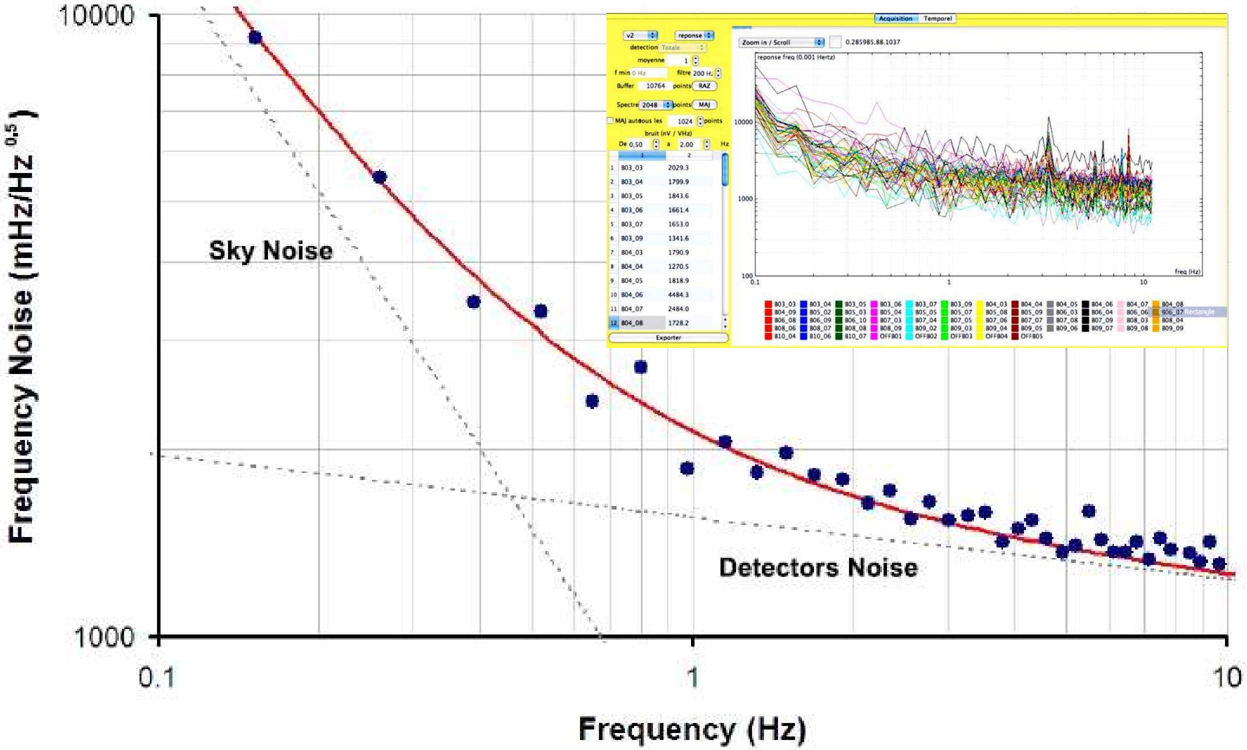
NIKA 2 at the 30m MRT: Preliminary observations

(... calibration)

Average « raw » S/N on Mars:

$T = 210K$
$\theta = 4.1''$
$F/T = 2k(\pi \cdot \theta^2/4)/\lambda^2$
$NET = T/(S/N)$
$NEFD = F/(S/N)$

	2mm	1.3mm
Signal :	2-4 kHz	10 kHz
Noise :	2 $Hz/Hz^{0.5}$	16-20 $Hz/Hz^{0.5}$
Mars flux :	40Jy	107Jy
S/N	≈ 1000 $Hz^{0.5}$	≈ 500 $Hz^{0.5}$
NEFD (1Hz)	≈ 30 $mJy/Hz^{0.5}$	≈ 150 $mJy/Hz^{0.5}$
NEP (1Hz)	≈ 0.23 $fW/Hz^{0.5}$	≈ 3 $fW/Hz^{0.5}$

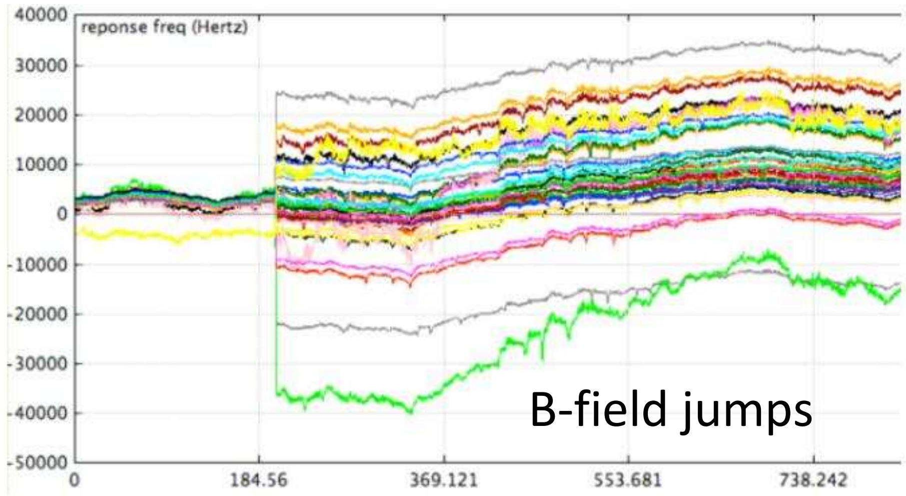


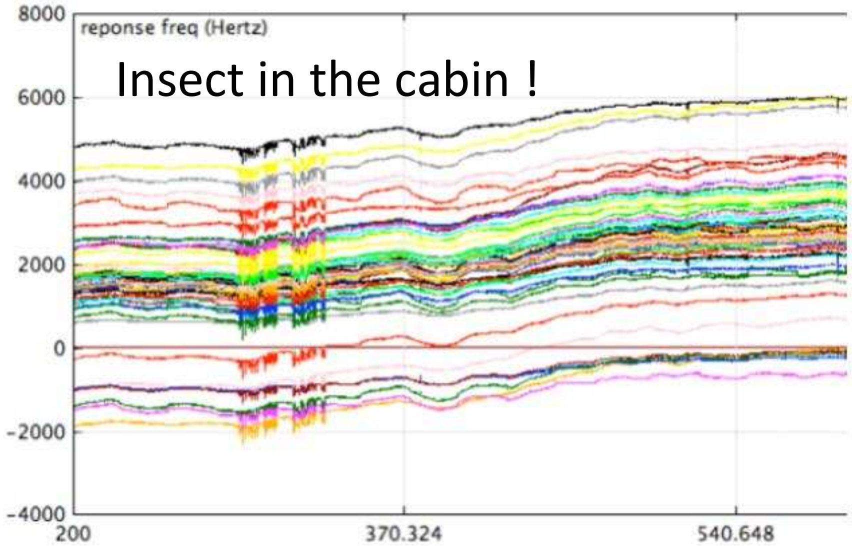
NEP (1Hz) ≈ estimated by sky simulator !

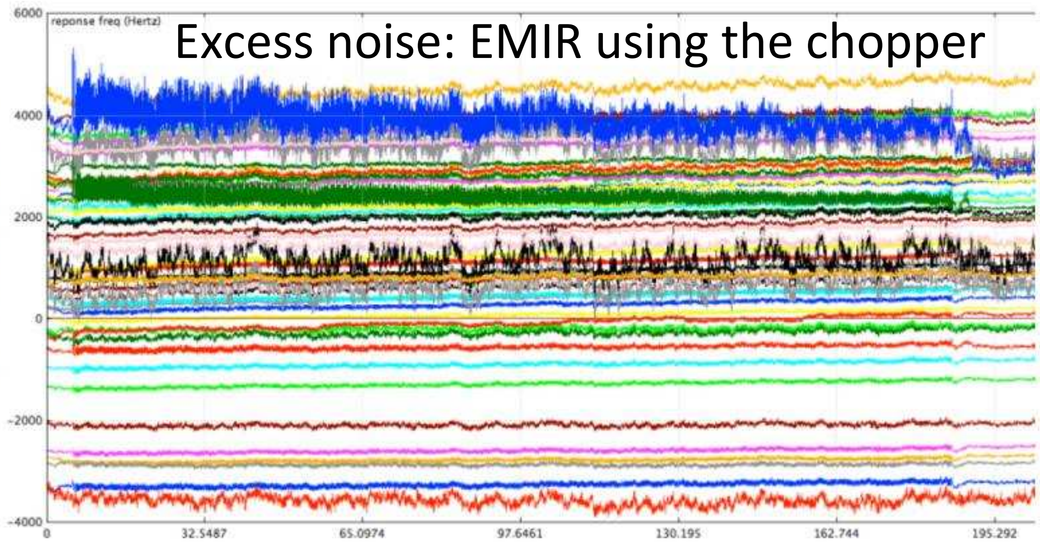
Flat and stable noise spectra

⇒ Sensitivity still dominated by pixel, but much lower than 1st run AND large bandwidth

NIKA 2 at the 30m MRT: Example of problems



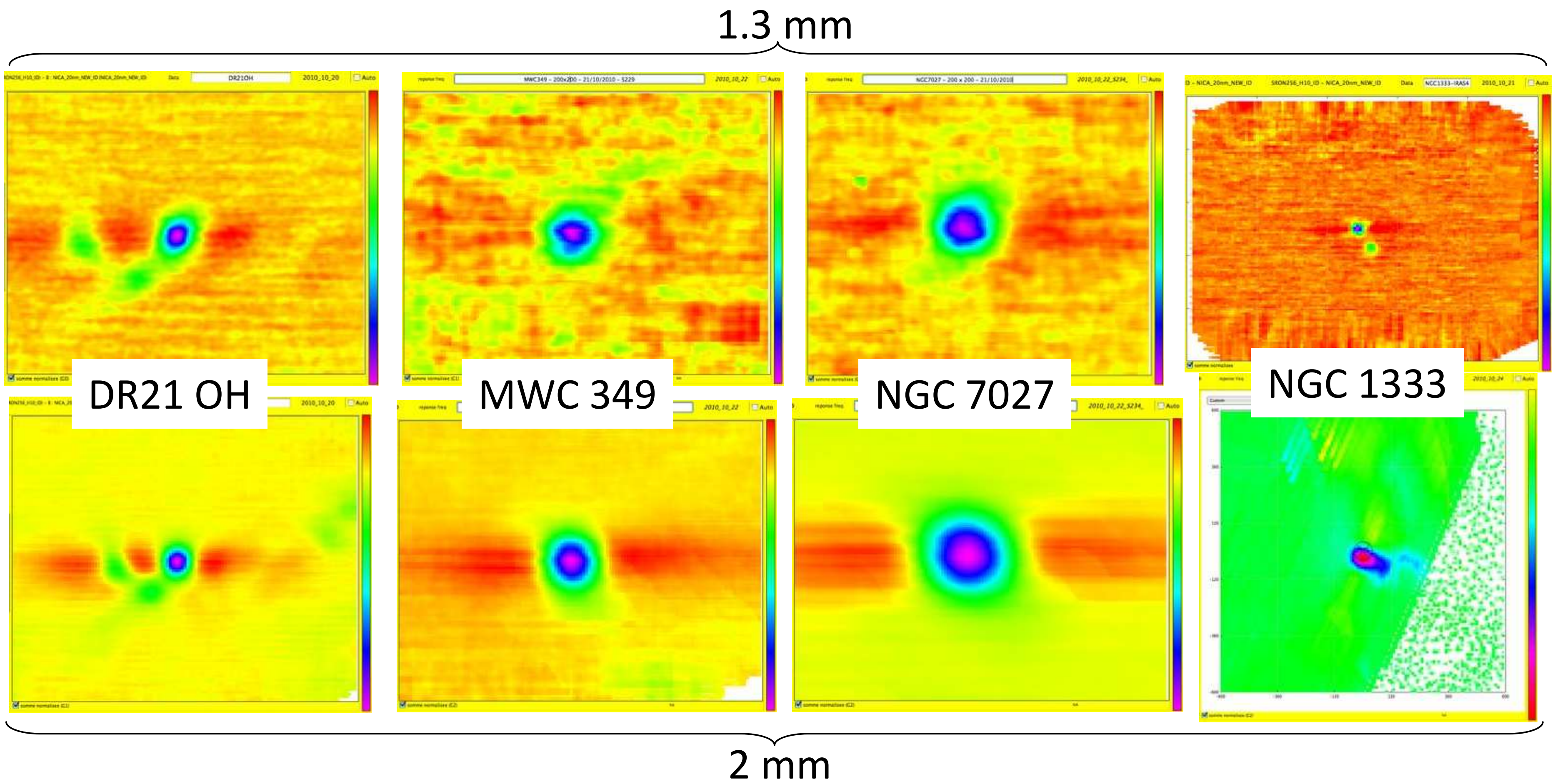




NIKA 2 at the 30m MRT: Observations

Radio sources, galaxies, clusters of galaxies, quasars

Example of Quick-Look sum maps with causal filter obtained with the 2 arrays

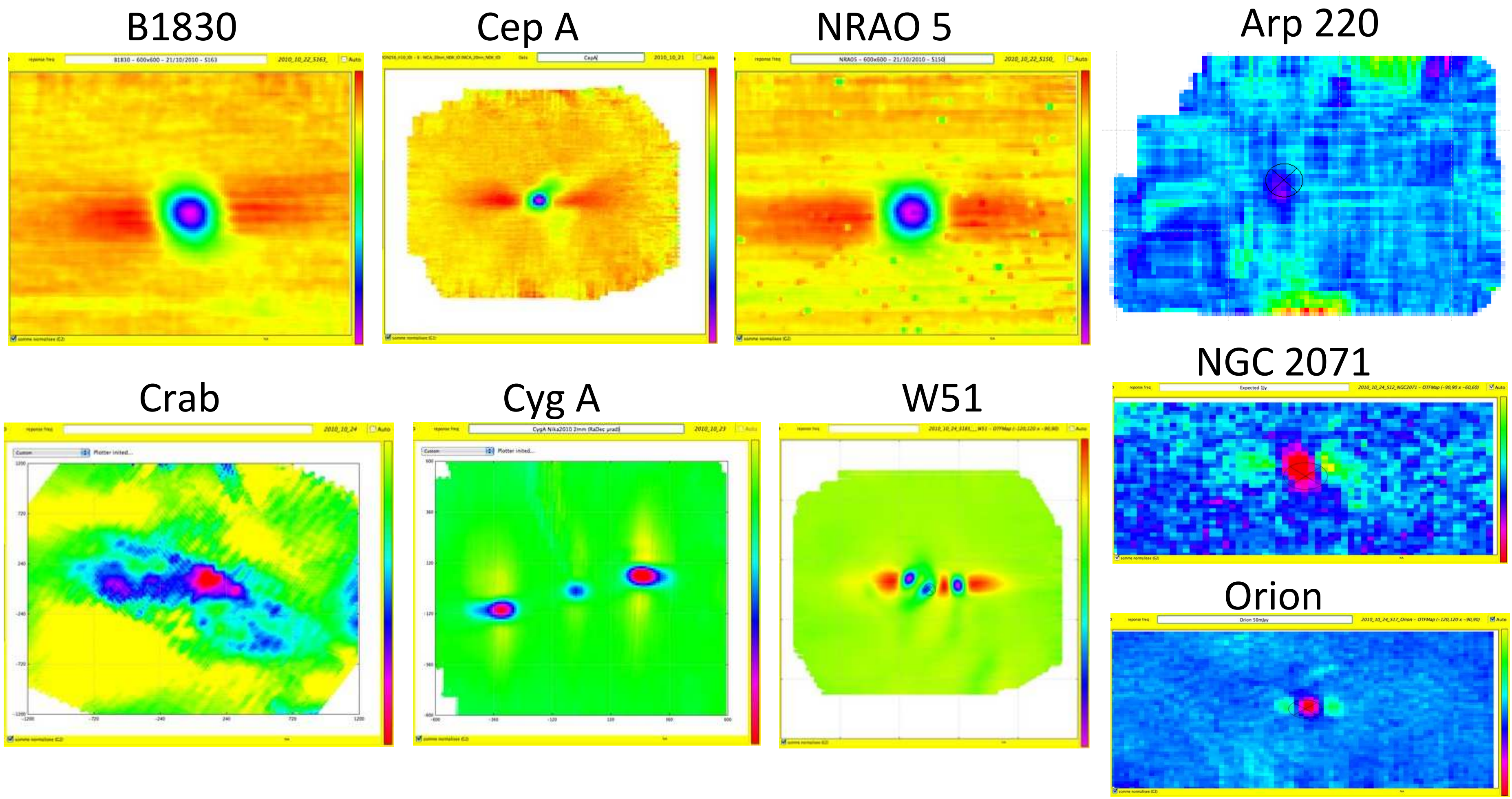


>1 Jy sources (DR21OH, MWC349, NGC7027...) in real time,
few 100 mJy (NGC 1333...) seen quickly

NIKA 2 at the 30m MRT: Observations

Radio sources, galaxies, clusters of galaxies, quasars

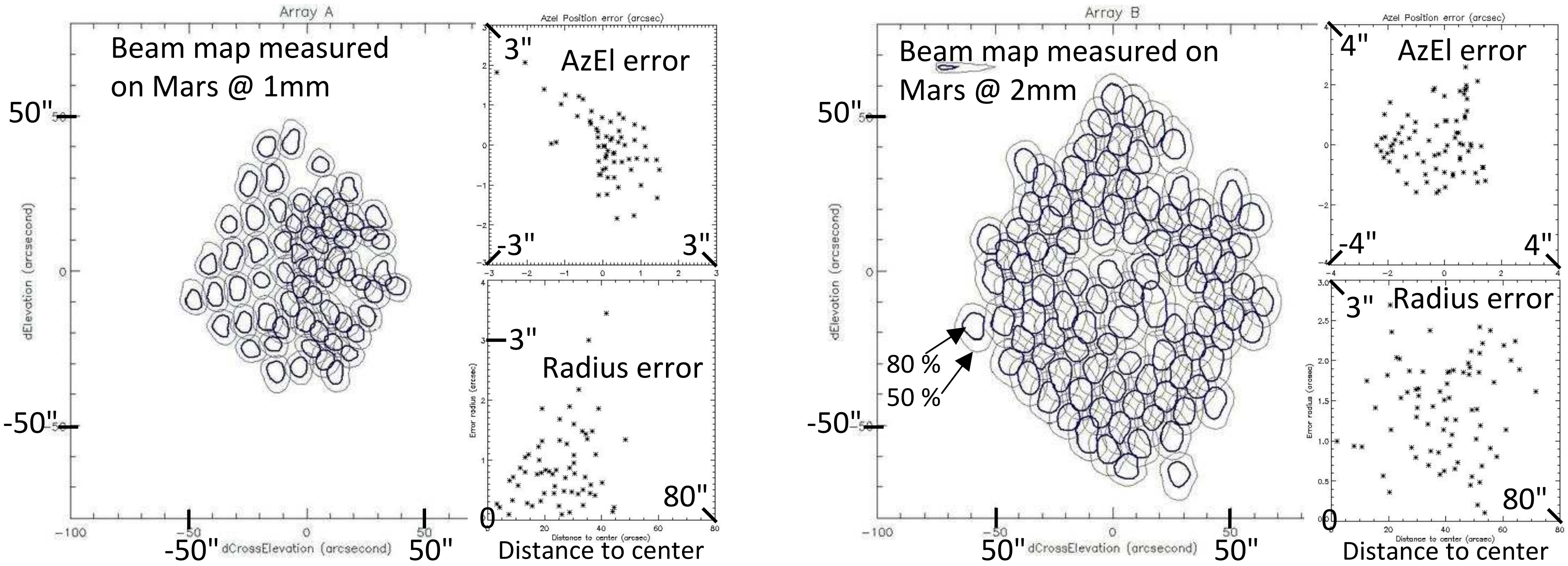
Example of Quick-Look sum maps with causal filter obtained with the 2 mm array



Data analysis and results

Pixels characteristics & pointing

- 62 at 1mm + 98 at 2mm = 172 valid pixels / 224 electronics outputs (52 double, blind, bad, off resonance, undefined)
- FWHM: 12.5" at 1mm, 16" at 2mm (focus from QL, not redone yet...)
- Pointing accuracy: array optical axis < 1", pixel < 2", source to source ~1-2"
- Simple method: offset, rotation, scaling on EMIR pointing model
- Source Az/El offset corrections done offline from nearest planet/quasar data



Data analysis and results

Calibration

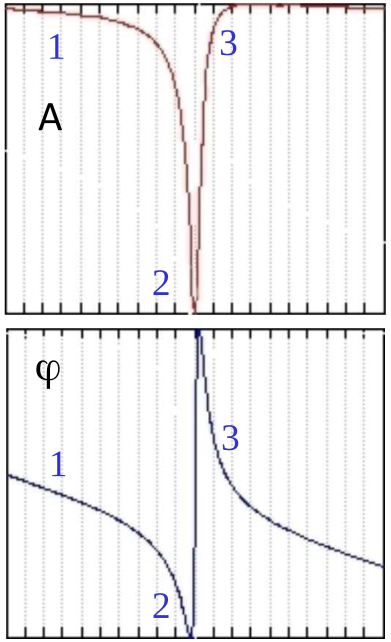
- Only using Response in Frequency signal (better than run1)
- Assumed to be linear with power
- From I and Q, get complex phase on calibration circle, then translate to equivalent frequency shift, as measured during KID tuning

Traditional transmission amplitude:

$A^2 = I^2 + Q^2$

and phase:

$\varphi = \text{atan}(Q/I)$



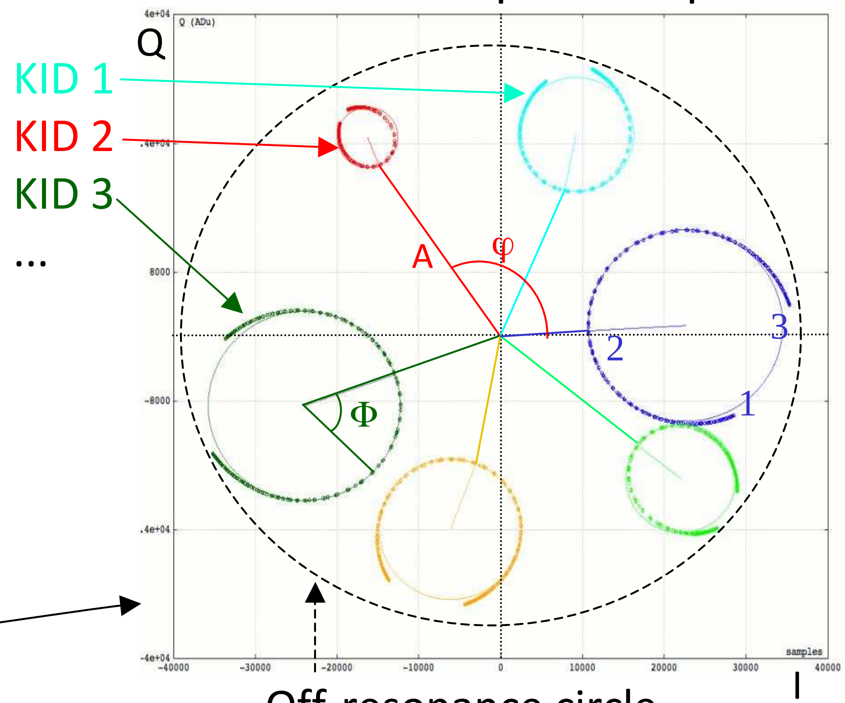
Equivalent frequency shift:

$\Phi = \text{atan}(Q-Q_c/I-I_c) - \Phi_0$

$\sim \delta f_0 \sim (f_0^3/n_s)\delta P_i$

f_0 = resonance frequency,
n_s = Cooper pair density,
P_i = incident power

Resonance loops in I-Q plane



Off-resonance circle

Data analysis and results

Photometry (current status, work in progress)

- 10% reproducibility within a planet (same planet observed at different days)
- Neptune (19.5", 7.4Jy) from Uranus (54.8", 20.7Jy) calibration: (16.9", 7.0Jy) = 15% precision
- MWC349 using Mars one day and Uranus another day: fluxes are off the official values (2.01 and 1.49 Jy) by 12% and 30%, but they are stable
- Atmosphere opacity correction: use τ(225GHz), a ν^2 law, and elevation
- To be done: intercalibration(flat-field), Skydips, OnOff (wobbler) data

Map-Making

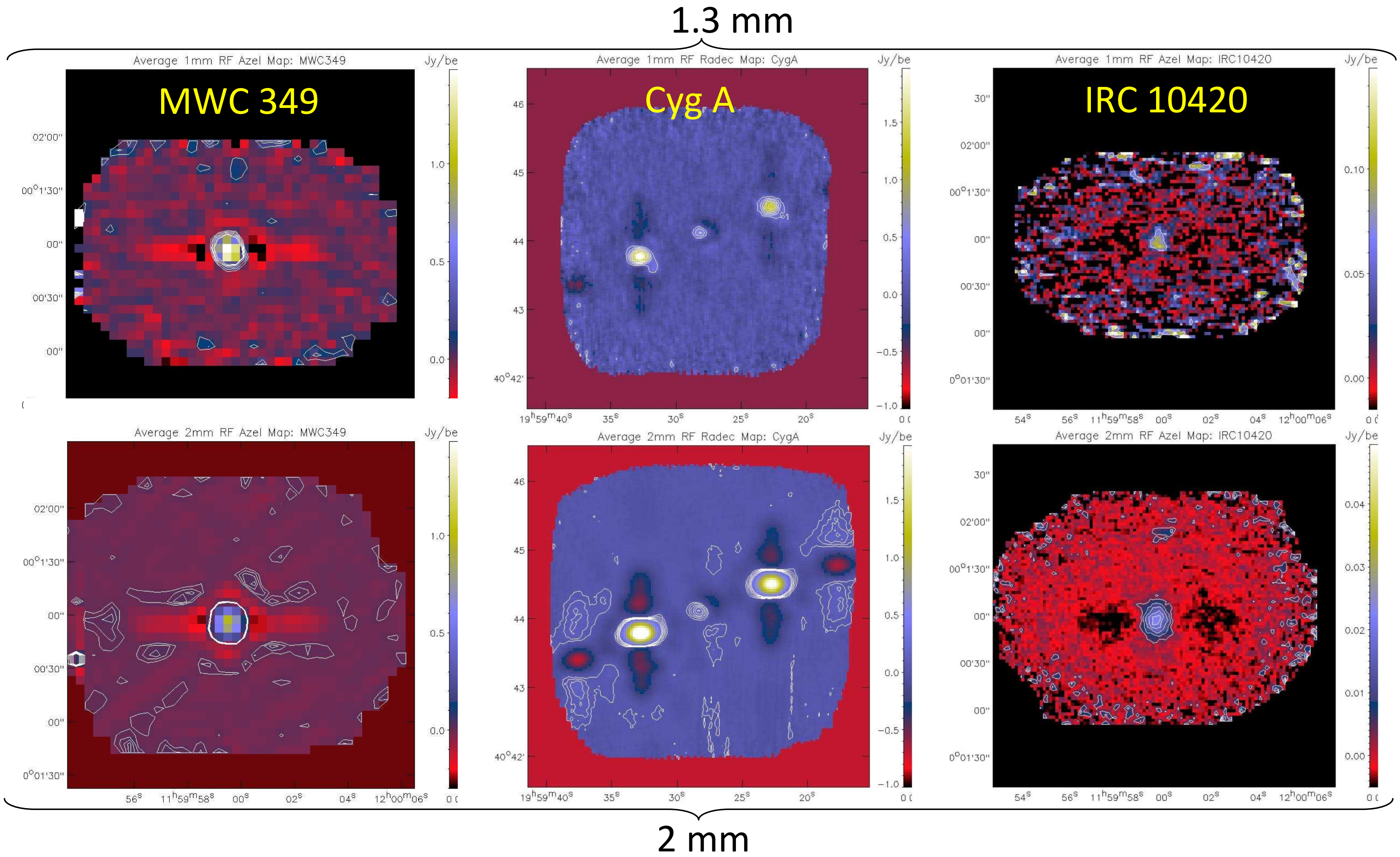
- 1 map per kid per scan produced with interpolation to the 4 nearest grid points
- Pointing: use on-the-fly center coordinates and beam map offsets
- Noise evaluated at detector map level by histogram fitting. Pixel correlation corrected

Filtering

- Necessary to remove the zero level
- Bandpass for sky noise decorrelation is 10-110 arcsec
- Only strong sources are masked (no bias for the detection of weak sources)

Data analysis and results

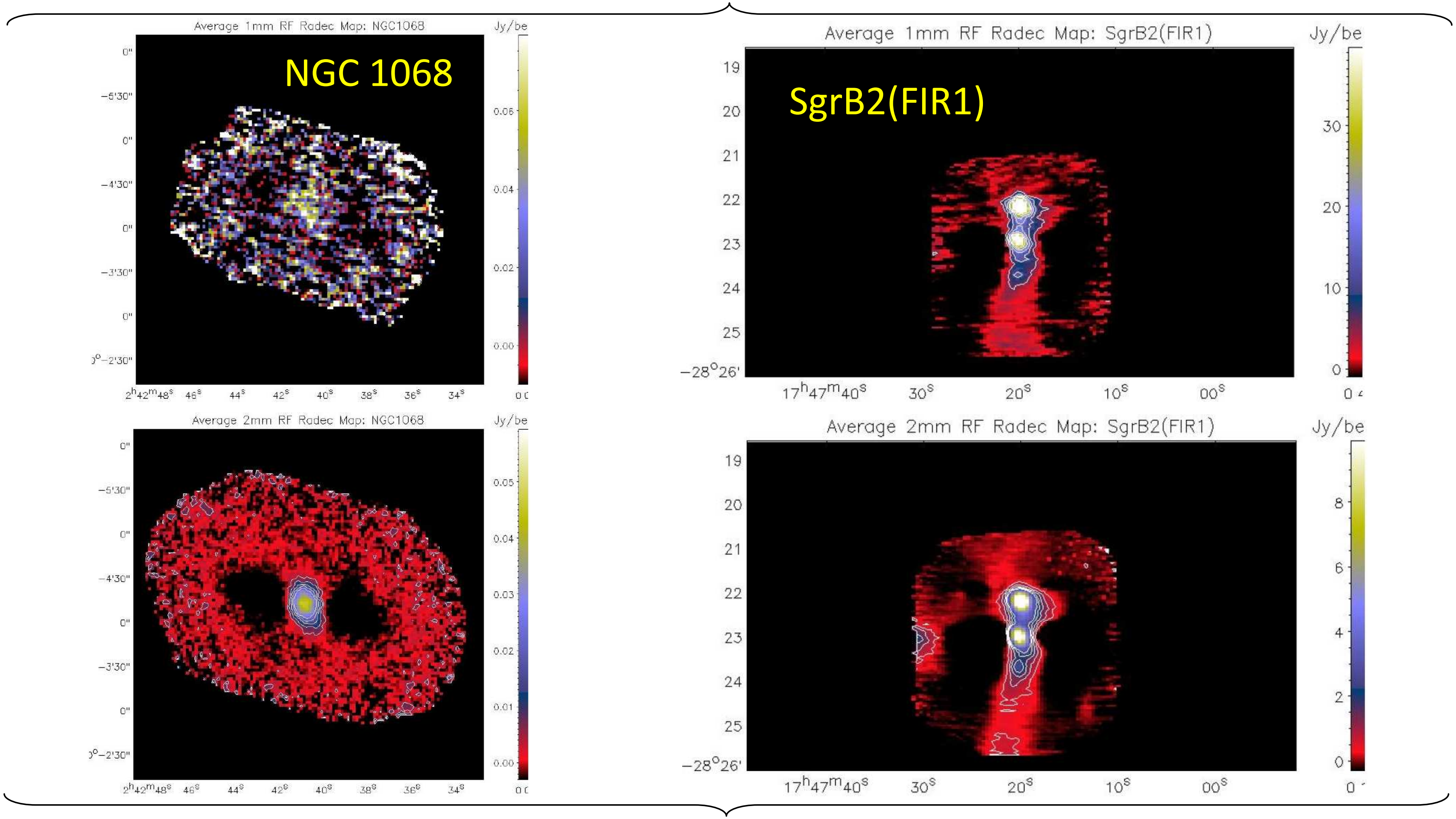
Radio sources, galaxies, clusters of galaxies, quasars



Data analysis and results

Radio sources, galaxies, clusters of galaxies, quasars

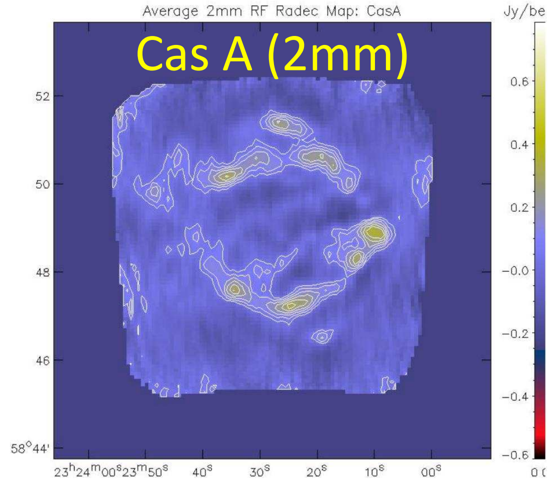
1.3 mm

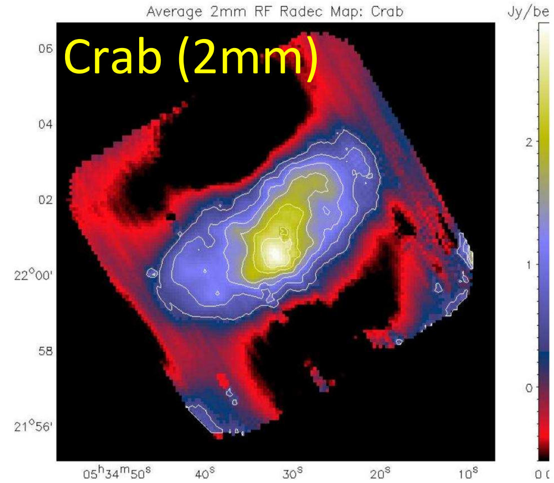


2 mm

Data analysis and results

Source	Integration time [s]	Flux measured (1mm , 2mm) [mJy]	NEFD measured (1mm , 2mm) [mJy·s $^{1/2}$]
Strong sources (no sky decorrelation)			
Neptune	1087	17000 , 7000	2400, 4200
SgrB2(FIR1)	900	76000 , 17700	
MWC 349	495	1700 , 1000	1100 , 1100
IRC 10420	2410	94 , 21	530 , 120
Weak sources (sky decorrelation)			
IRC 10420	2410	94 ± 12 , 21 ± 1	371 , 45
Cyg A	2200	269 ± 34 , 87 ± 22	
NGC 1068	1260	142 ± 25 , 66 ± 3	
PSS 2322	1950	2 ± 12 , 1.1 ± 0.6	330 , 29





⇒ Strong sources: NEFD dominated by source noise (photometric reproducibility)

⇒ Weak sources: conservative NEFDs (mJy·√s): 370 @ 1mm, 40 @ 2mm

⇒ NET ≈ 4 mK·√s

Perspectives

Data analysis:

- Reduce all scans homogeneously (v2 in progress, v3 in January)
- Improve on photometric accuracy (sky noise flat field, IQ circle calibration, next runs: modulate the frequency carrier)
- Improve on sky noise decorrelation (detector choice, map vs sky noise timeline)

Hardware for next run:

- Cryostat → Stronger magnetic field shielding. Pulse Tube Cooler ?
- Filters → from NIKA 2010
- Splitter → Dichroic ?
- Detectors 2mm → Same as NIKA2010 (best Al LEKID tested in laboratory reaches the target sensitivity !) ; dual-polar if dichroic
- Detectors 1mm → Antenna or LEKID (best sensitivity and number of pixels)
- Pixels → 224 per array over a 400 MHz band (see electronics). AR coating ?
- Electronics → «NIKEL» from LPSC (> 256 channels, > 400 MHz band) ? (ROACH is backup if LPSC not ready). 1 kHz frequency modulation for better photometry. Automatic frequency lock on resonances.

Conclusion

- Unpacking to 1st astronomical light in only 24 hours ! (4 days for 1st run)
- ~<10% bad pixels, number of pixels limited by readout electronics
- Alignment and focus extremely quick and easy (M6 attached to cryostat)
- Control software improved since 1st run, real time quick look analysis very convenient
- Strong to moderately weak (few mJy) sources observed
- Non optimal sky calibration, but satisfactory for this "engineering run" with few arc seconds pointing accuracy and better than 30% accuracy on absolute photometry

Sensitivity: conservative NEFD (data reduction still in progress)

= 370 for the 1mm array → ~10x worse than MAMBO, but OK for a 1st time

= 40 $mJy \cdot s^{1/2}$ for the 2mm array → >3x better than 1st run ! Still ~4x to gain to reach the background limit

➔ Successful run: lot of progress done since 1st run (one year before), only minor problems at the telescope, sky simulator validated, improvements foreseen

1st time that

- KIDs achieve such a high sensitivity on a telescope (almost = state-of-art APEX SZ TES)
- so many KIDs are successfully installed on a telescope
- so many detectors observe the sky at the 30m MRT
- a dual band multi-pixel continuum instrument is used at the 30m