Recent Results with NIKA & GISMO at the 30-meter telescope

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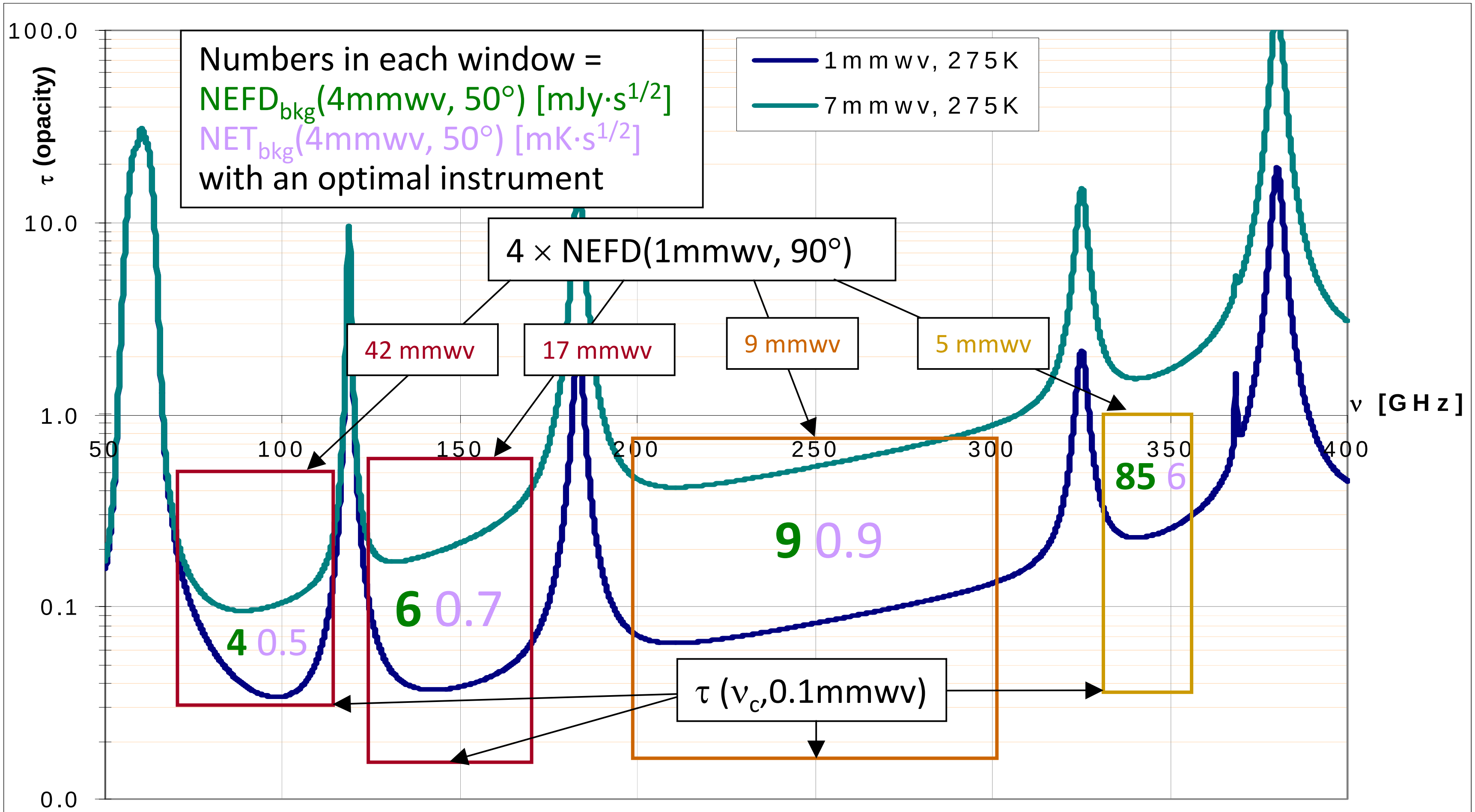
Content

1. Reminders
2. NIKA 2nd run at the 30m telescope
3. GISMO 4th run at the 30m telescope
4. Perspectives

1. Atmosphere opacity & background limited NEFD at Pico Veleta

Simple model (1 pseudo-continuum + 11 H_2O & O_2 lines based on fits to ATM in the 50-400 GHz range)



⇒ 90 & 150 GHz always, 250 GHz often, 350 GHz few weeks/year.

1. Purpose of the continuum prototypes

Test new technologies to replace MAMBO-2 with a better instrument:

Characteristic	MAMBO-2	Future instrument
Bands	1.2 mm	1.2 mm & 2.1 mm
Sensitivity	35 mJy·s$^{1/2}$	5..10 mJy·s$^{1/2}$
FOV (diameter)	4 arcmin	~ 6 arcmin (each band)
Coverage of the FOV	25 % (horns)	> 90 % (filled array)
Polarization	No	Possible

⇒ More pixels: 117 → 2000..8000

⇒ Mapping speed more than ×100 faster* !

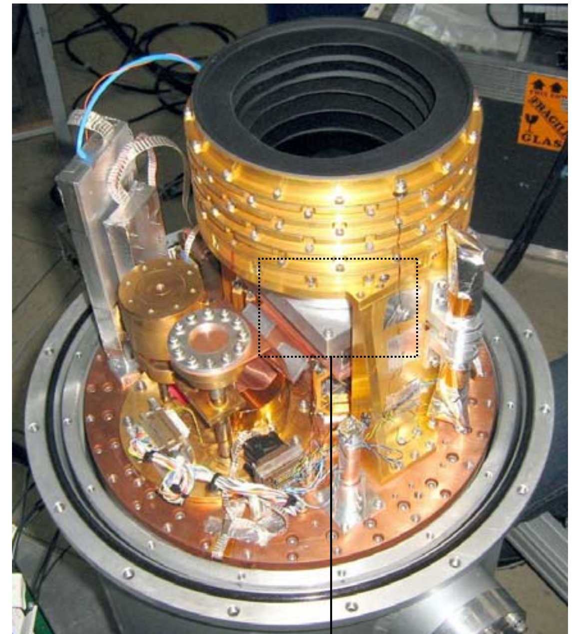
⇒ New observing window at the 30m MRT

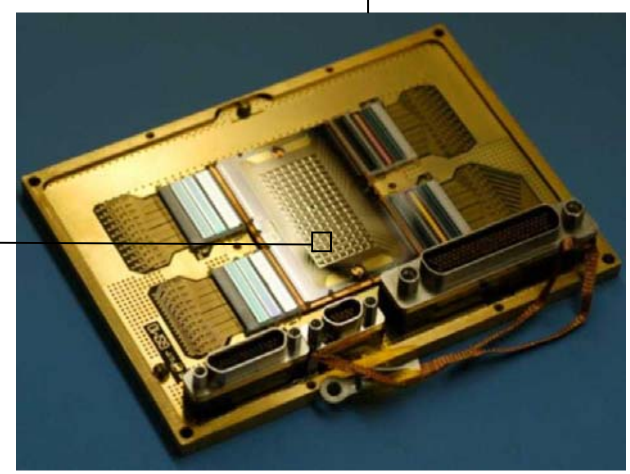
* Mapping time: $t \sim NEFD^2 \cdot (\Omega_{map} / \Omega e_{array})$

$\Rightarrow t_{MAMBO\text{-}2} / t_{5'\times5',0.5F\lambda,filled} = (35^2/(117\cdot(11/60)^2)) / (8^2/6^2) \approx 150$

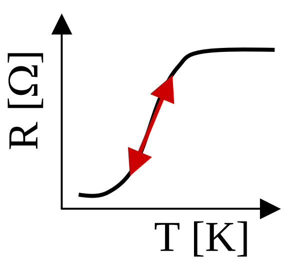
1. GISMO main features

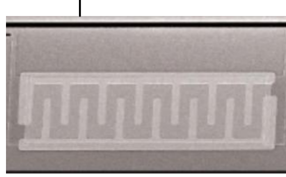
- **T**ransition **E**dge **S**ensors (bolometers)
- ν = 150 GHz (λ = 2 mm), $\Delta\nu$ = 22 GHz
- 0.9 Fλ bare-pixels (15"×15" in sky)
- Unpolarized, pixel absorption = 90% (~20% full optical chain)
- DC coupled $\Rightarrow$ total power
- 8x16 = 128 pixels filled array
- SQUID amplifiers & multiplexers (4×32)
- 260 mK ^{3}He sorption cooler
- Built by GSFC (Nasa), PI: Johannes Staguhn

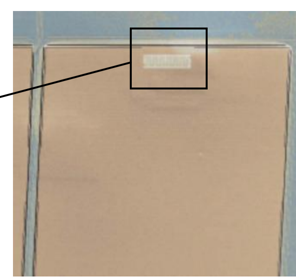




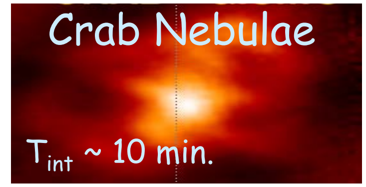
Absorbed photons modify membrane temperature which modify TES resistance

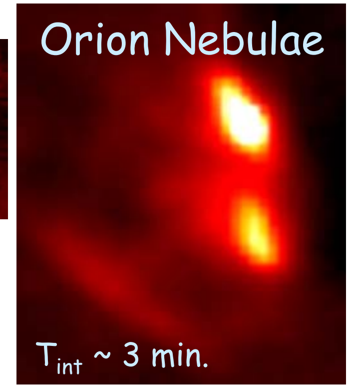






1. GISMO runs 1 to 3





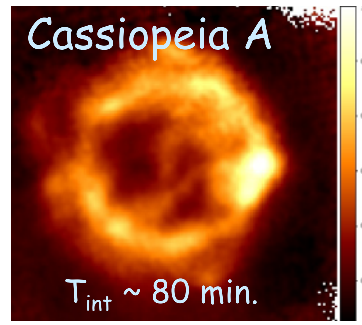
<u>1st run</u> (11/07):

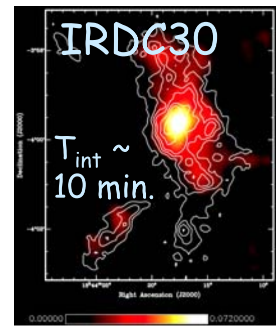
- 50% useable pixels (broken bias line + bad feedbacks)
- Problems: baffling, saturation load, EM pickup

⇒ Map* NEFD ~ 200 mJy·$s^{1/2}$

Articles: Staguhn et al., SPIE 2008 ; Dicker et al., ApJ 2009 ; Arendt et al., ApJ 2011

Upgrades: Detector board, Baffle, EM shield, Shutter, Lissajou





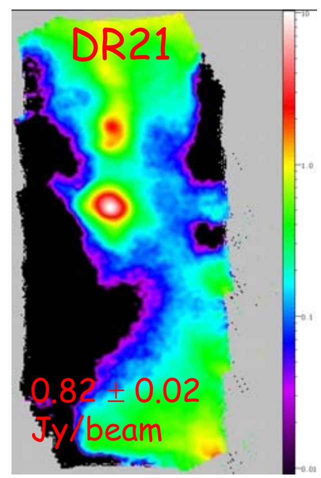
<u>2nd run</u> (10/08):

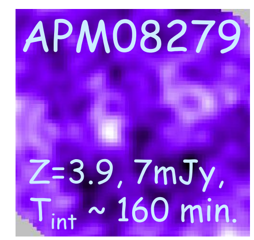
- 60% useable pixels (short in 1 MUX + some bad SQUIDS)
- Problems: noisy pixels, shocks, cloudy weather

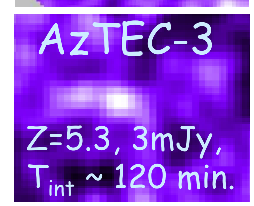
⇒ Map* NEFD ~ 45 mJy·$s^{1/2}$

Articles: Staguhn et al., AIP conf. 2009 ; Arendt et al. in prep.

Upgrades: MUX, ND Filter box, software (control & processing)







<u>3nd run</u> (04/10):

- 90% useable pixels (some bad SQUIDS)
- Problems: stray lights in ND filter box, others (time losses)

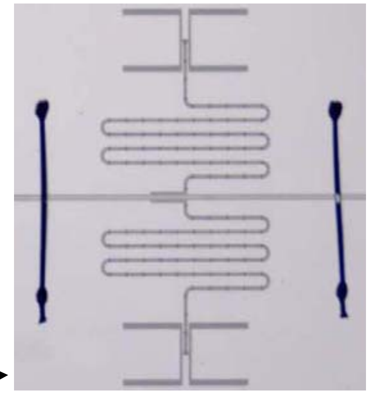
⇒ Map* NEFD ~ 45 mJy·$s^{1/2}$

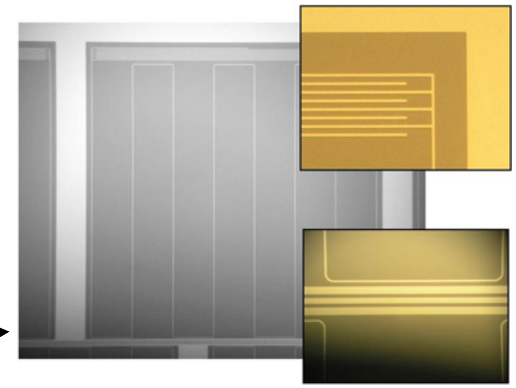
Articles: Dwek et al, ApJ 2011 ; Capak et al, Nature 2011

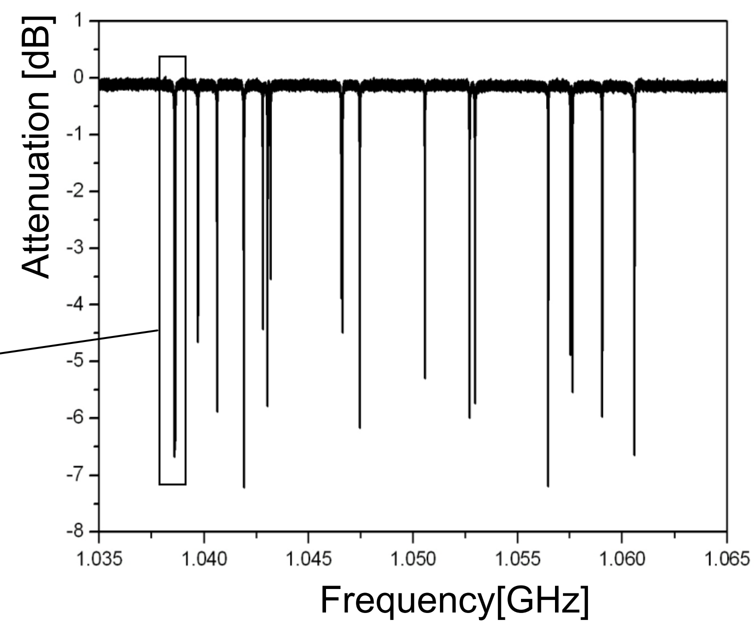
* Time stream NEFD = Map NEFD/√2, background limit ~ 5..10 mJy ·$s^{1/2}$

1. NIKA main features

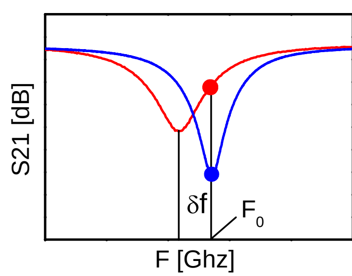
- **K**inetic **I**nductance **D**etectors
- ν = 150 GHz (λ = 2 mm), $\Delta\nu$ = 40 GHz
- ~0.7^{+} Fλ bare-pixels (~ 9^{+}"$\times$$9^{+}$" in sky)
- Total power
- Filled arrays
- Antenna KID
- Lumped Elements KID
- Multiplexing all pixels in one feed line
- 80 mK ^{3}He-^{4}He dilution fridge
- Built by CNRS-Néel / IRAM* / AIG-Cardiff / SRON, PI: Alain Benoit







Absorbed photons modify kinetic inductance, which modify resonance frequency



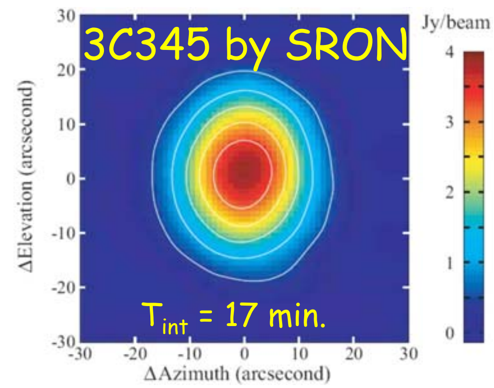
*Markus Rösch PhD. (LEKID)

1. NIKA run 1

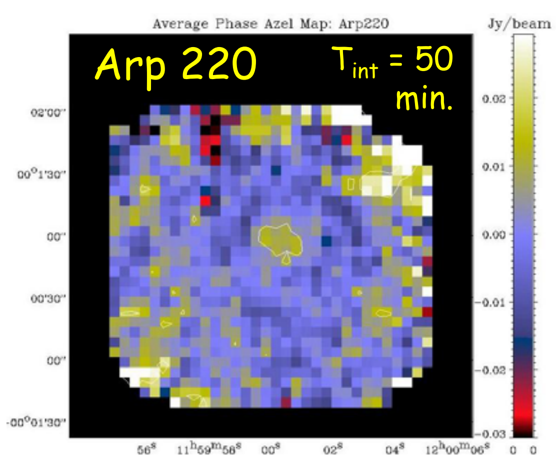
<u>1st run</u> (10/09):

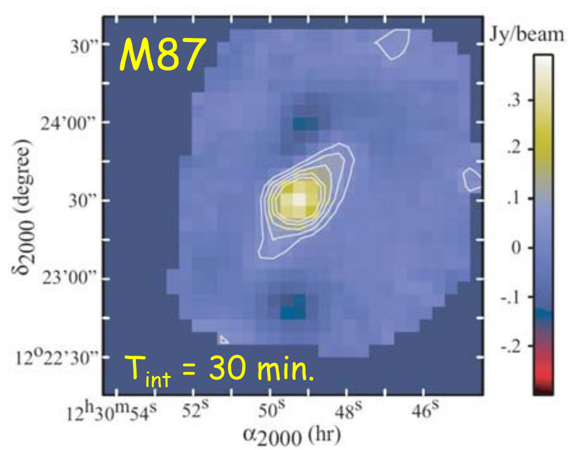
- 42 A-KID array (SRON), then 32 LEKID array (Néel/IRAM/AIG-Cardiff)
- Polarized pixels, absorption ~60% (~30% full optical chain)
- >90% useable pixels (some frequency shifts due to flux trapping)
- Problems: EM pickup, non-optimal pixel architecture

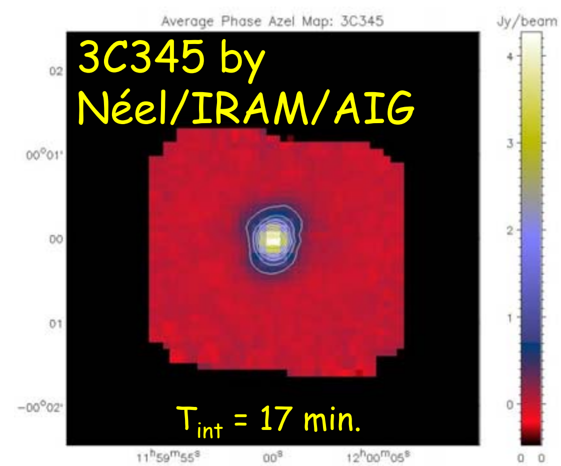
⇒ Map* NEFD ~ 120 mJy·$s^{1/2}$



Article: Monfardini et al, A&A 2010



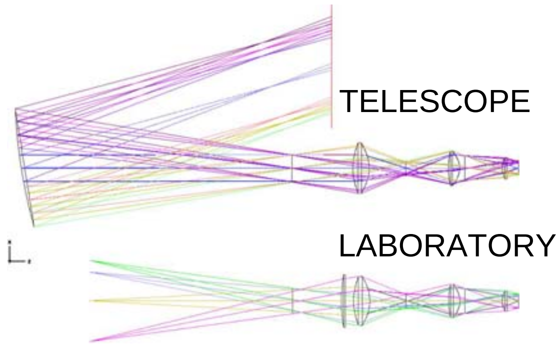




* Background limit ~ 5..10 mJy ·$s^{1/2}$

2. NIKA 2nd run: 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



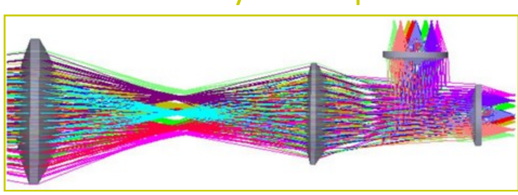
New NIKA elements:

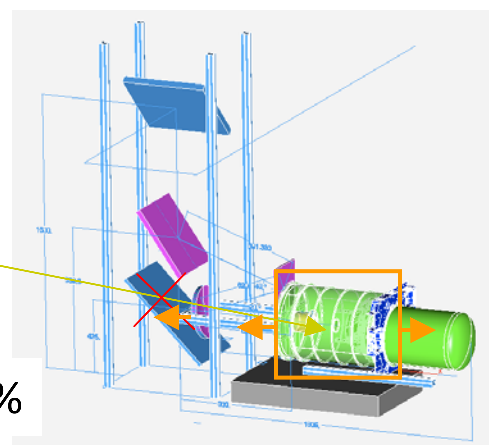
- Optics (biconic mirror, 4 lenses, polarizer, filters)
- Cryostat: longer baffle, 2 array holders
- 2.1 mm: Néel-IRAM 144 pixels, f_0 = 1.5 GHz, Δf_{mux} = 2 MHz
- 1.3 mm: SRON 256 pixels, f_0 = 5 GHz, Δf_{mux} = 4 MHz
- Electronic: 2 Casper Roach Boards (230 MHz bandwidth), IRAM 1.5 GHz amplifier,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

$\Rightarrow$ Sensitivity goal: ~$\times$4 better than 1st run

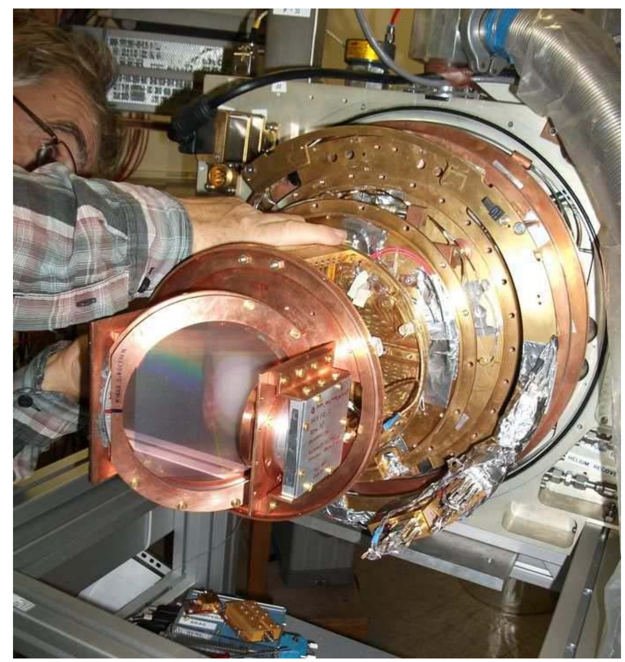
NIKA 1 optics and cryostat, and main changes for NIKA 2

NIKA 2 cryostat optics

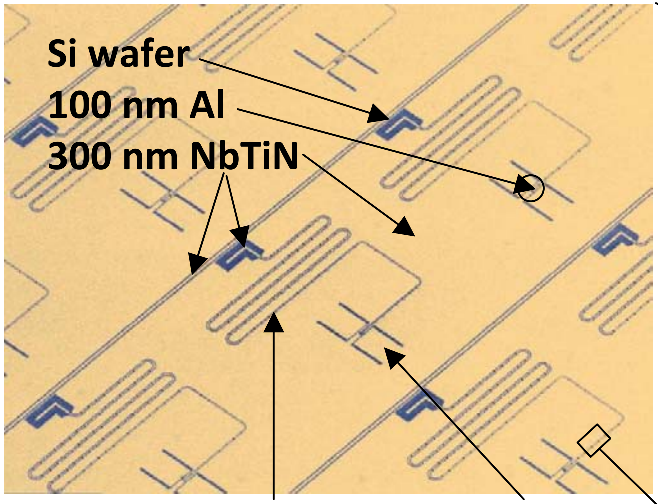




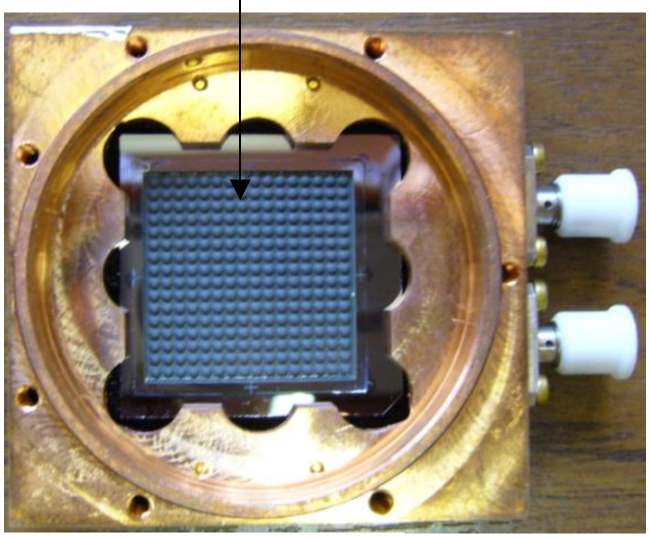
Total optical transmission $\approx$ 40%



2. NIKA 2nd run: Upgrades & lab tests

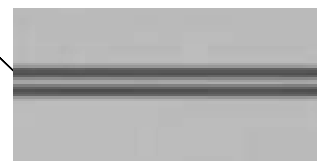


$\lambda/4$ waveguide resonator, Twin-slot antenna, 1.6mm Si micro-lenses

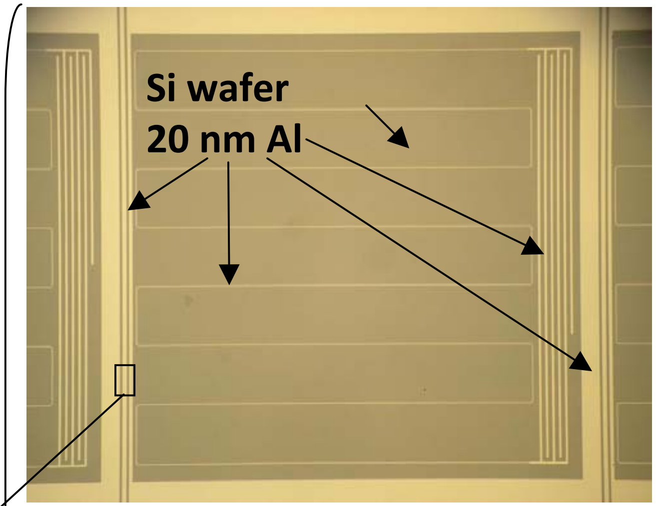


Pixels

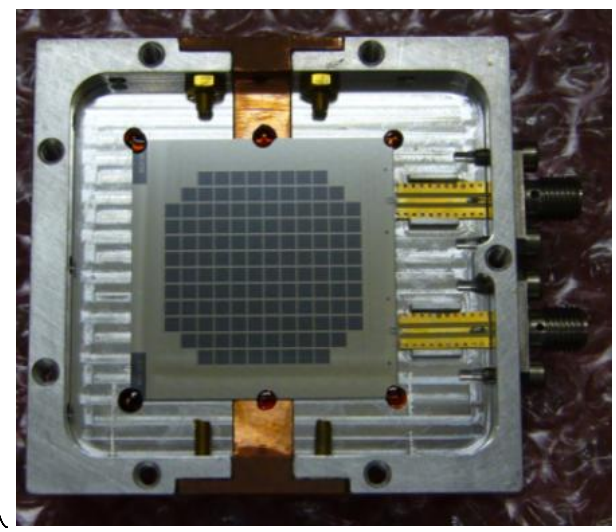
- **1.3 mm band** (220 GHz) SRON pixel size = 1.6mm = 0.8Fλ = 11" FWHM on the sky; 62 used in run → ~1.5’ FOV



- **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

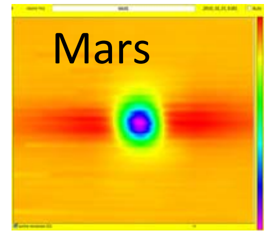


50 mK/Hz$^{1/2}$ (1Hz) ← NET with sky simulator (NET$_{bkg}$=1mK/Hz$^{1/2}$) → 6 mK/Hz$^{1/2}$ (1Hz)

2. NIKA 2nd run: Calibration on sky at the the 30m

Mapping **planets**

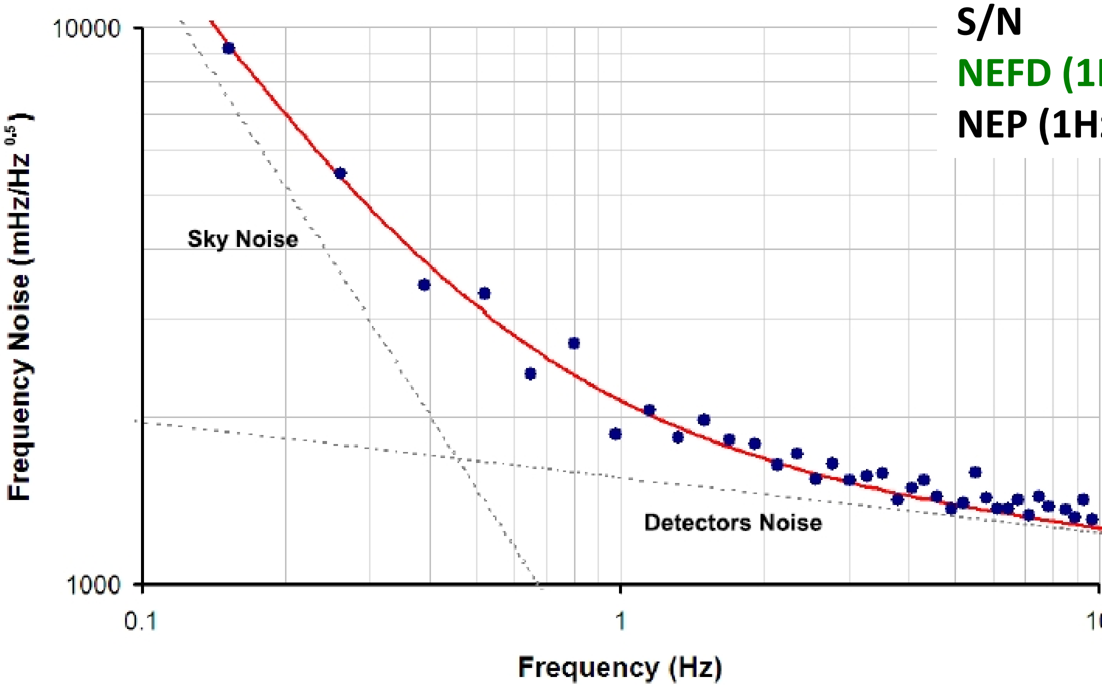
⇒ relative positions of arrays in the sky (pointing)
⇒ relative pixel responses (gains)
⇒ beam sizes & height vs M2 shifts (focus)
⇒ known signal vs noise (sensitivity)
⇒ response to various fluxes (linearity)



Average « raw » S/N on Mars:

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

NEP (1Hz) ≈ estimated by sky simulator !



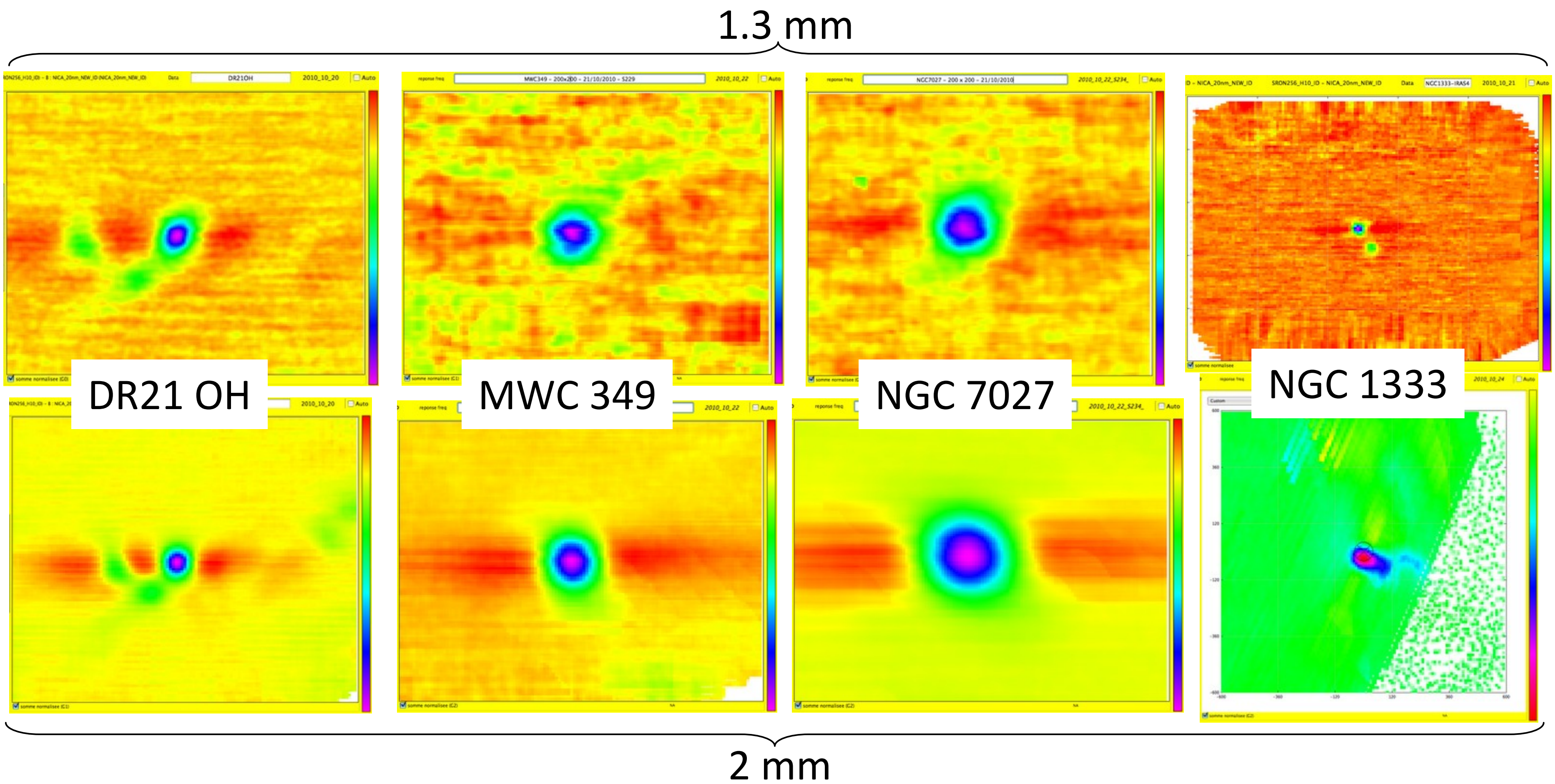
Flat and stable noise spectra

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

2. NIKA 2nd run: Quick-Look to some sources

Radio sources, galaxies, clusters of galaxies, quasars

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

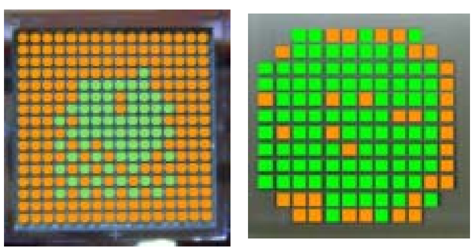


>1 Jy sources (DR21OH, MWC349, NGC7027...) in real time,
few 100 mJy (NGC 1333...) seen quickly

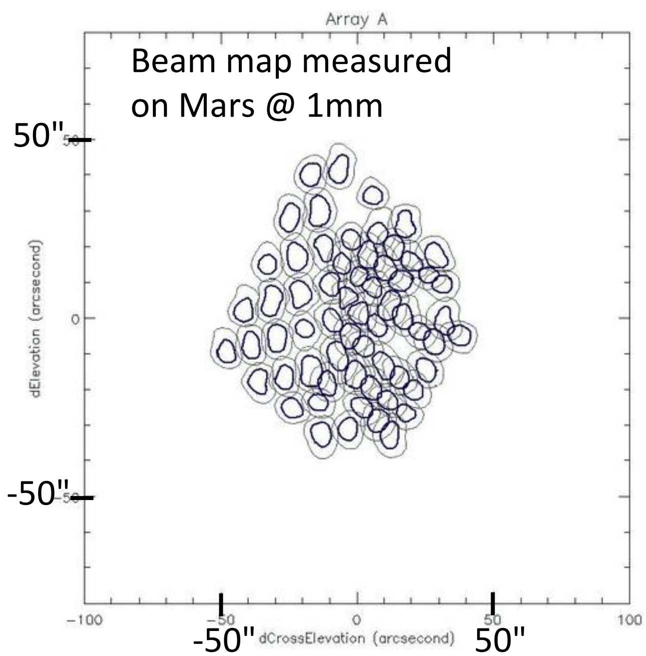
2. NIKA 2nd run: Data analysis and results

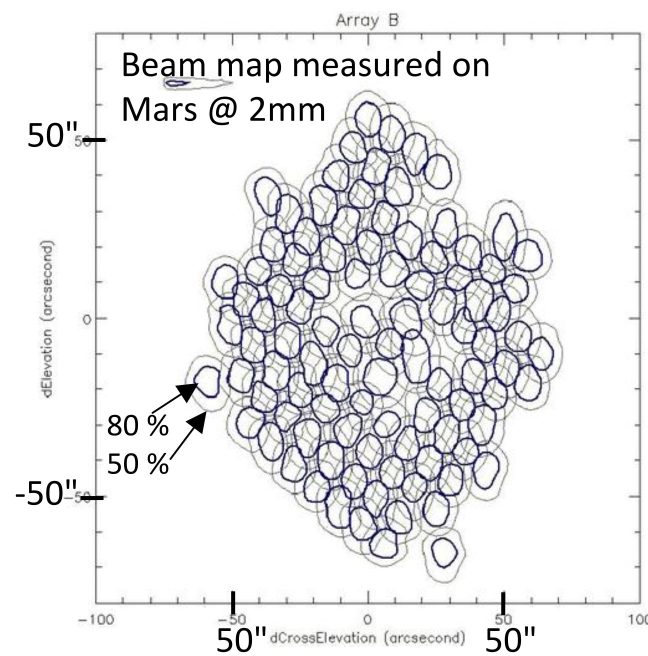
Pixels characteristics & pointing

- 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...)
- Simple pointing method: offset, rotation, scaling on EMIR pointing model
- Pointing accuracy: array optical axis < 1”, pixel < 2”, source to source ~1-2”
- Source Az/El offset corrections done offline from nearest planet/quasar data



Valid pixels on the 1mm and 2mm arrays: green = inside the bandwidth of the tones generators, orange = outside)





2. NIKA 2nd run: 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

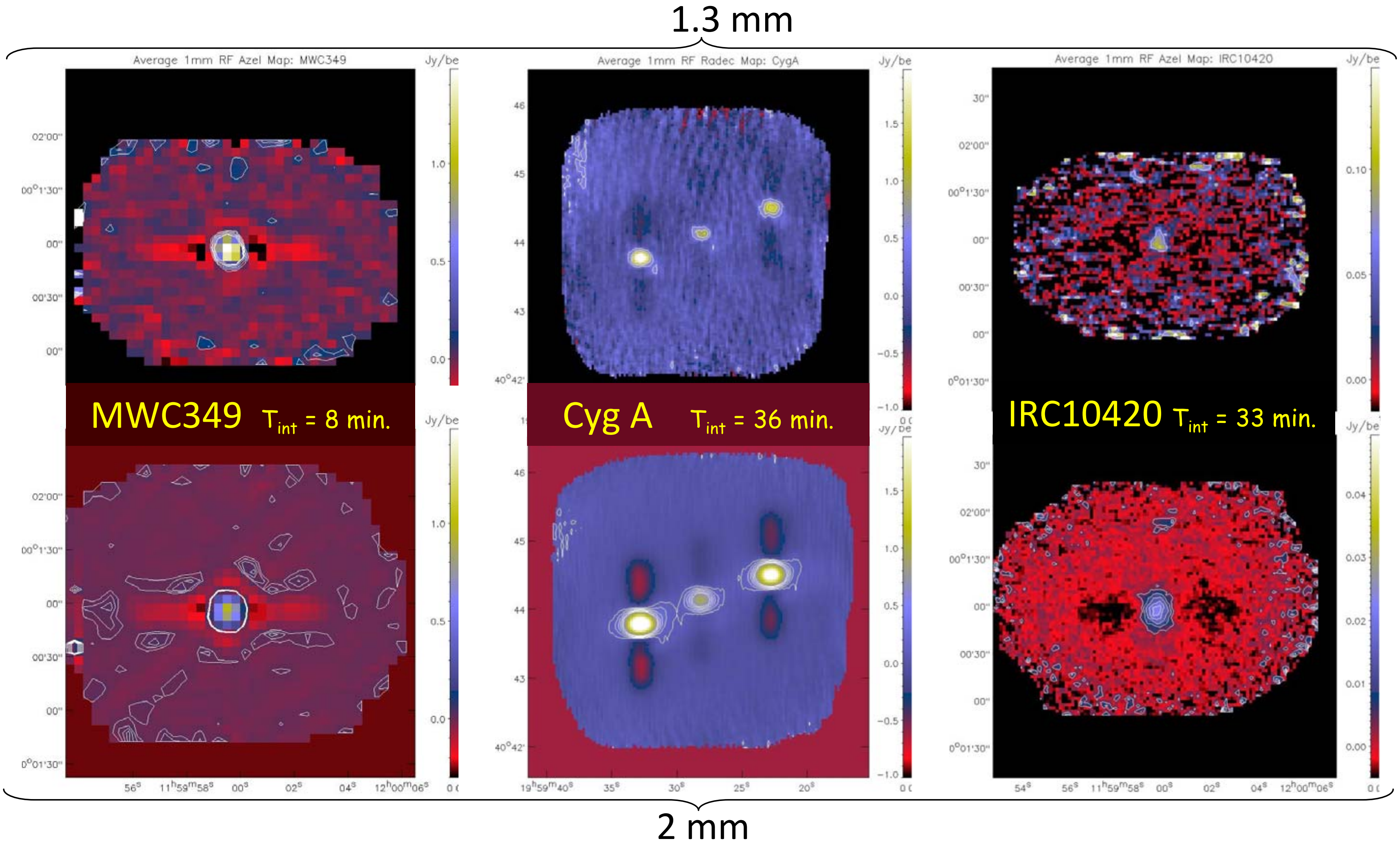
- 1 map per kid per scan produced with interpolation to the 4 nearest grid points
- Pointing: use on-the-fly center coordinates and beam map offsets
- Noise evaluated at detector map level by histogram fitting. Pixel correlation corrected

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)

2. NIKA 2nd run: Some processed images

Radio sources, galaxies, clusters of galaxies, quasars



2. NIKA 2nd run: 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, better than 30% accuracy on absolute photometry

Sensitivity: conservative **NEFD** (data reduction still in progress)

= **450 mJy·s$^{1/2}$ @ 1mm** → >10x MAMBO-2 (OK for a 1st time)

= **37 mJy·s$^{1/2}$ @ 2mm** (NET = 6 mK·s$^{1/2}$) → ~3x better than 1st run ! Still ~4x to gain to reach the background limit

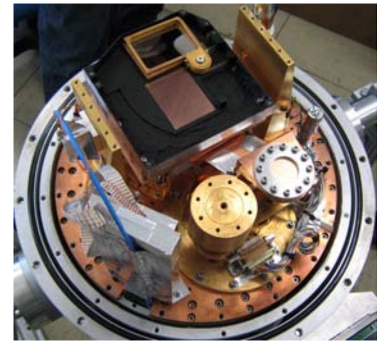
➔ Successful run: lot of progress done since 1st run (one year before), only minor problems at the telescope, sky simulator validated, improvements foreseen

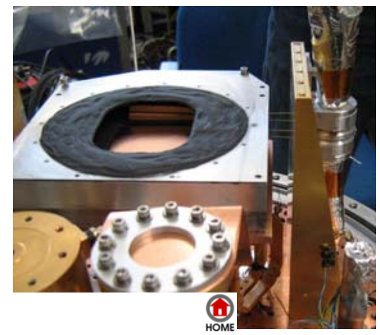
Article: Monfardini et al, ApJ 2011

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

3. GISMO 4th run: Upgrades

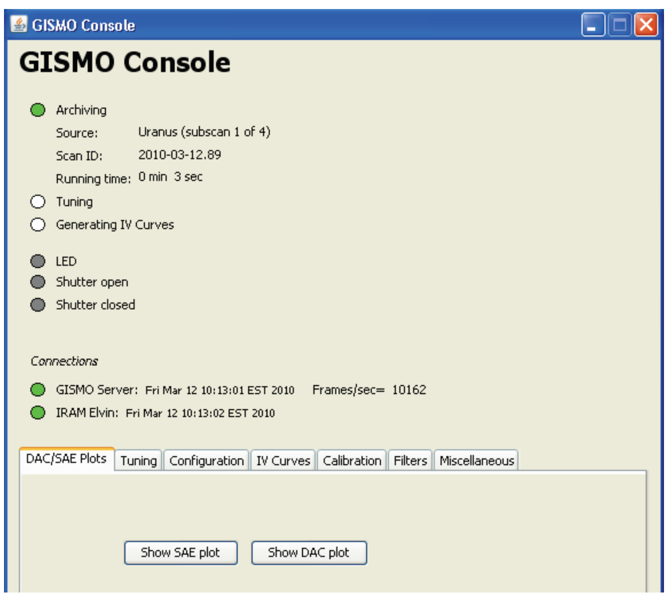


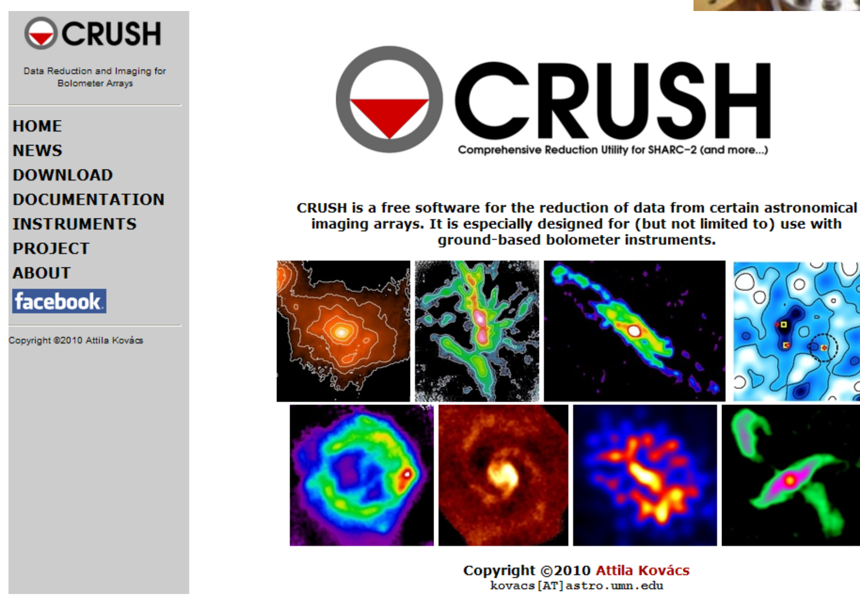


Upgraded GISMO elements:

- 2 motorized neutral density filters (NDF) with 65% and 40% transmissions respectively (compensate the restrained dynamic range of GISMO in case of poor weather conditions)
- One additional low-pass filter (total of 7 filters)
- New mm/THz/IR black-paints on the NDF box and baffles (suppression of residual stray lights)
- SQUID tuning algorithm
- Updated versions of the GISMO control software & CRUSH

$\Rightarrow$ Sensitivity goal: ~×2 better than 2nd & 3rd runs



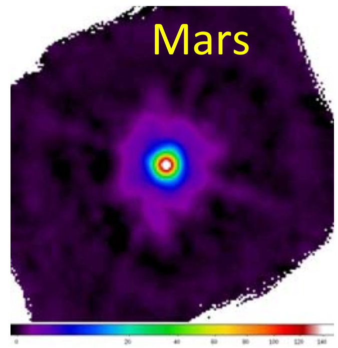


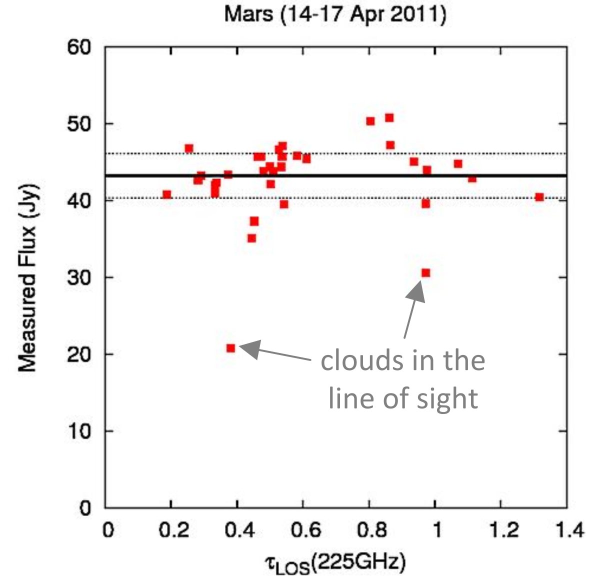
3. GISMO 4th run: Calibration on sky

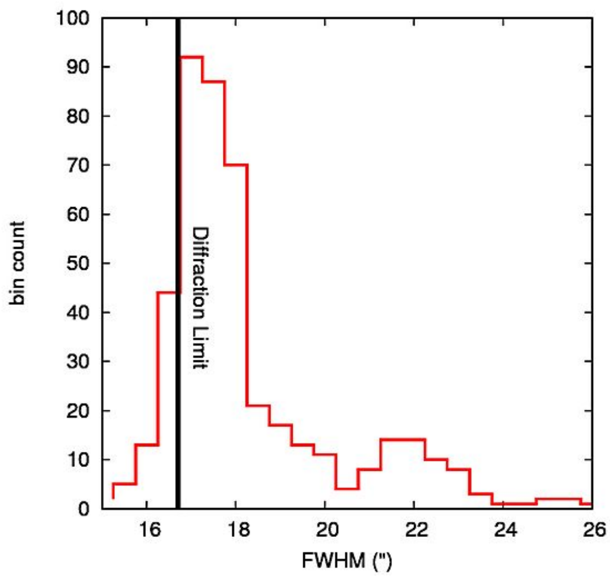
Mapping **planets**

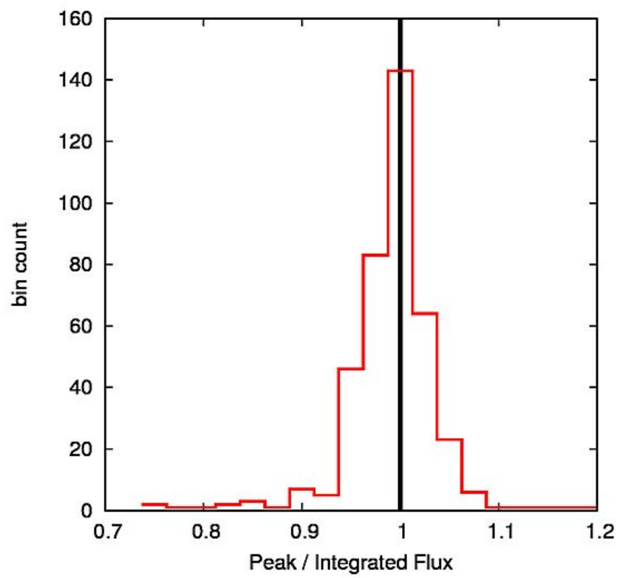
⇒ relative positions of arrays in the sky (pointing)
⇒ relative pixel responses (gains)
⇒ beam sizes & height vs M2 shifts (focus)
⇒ known signal vs noise (sensitivity)
⇒ response to various fluxes (linearity)

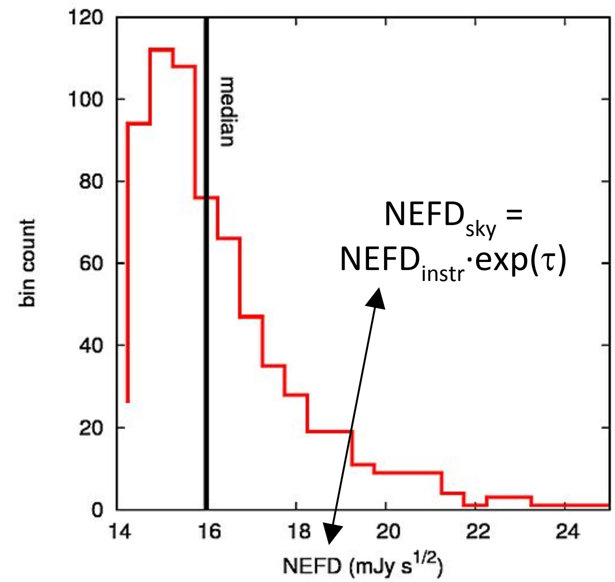
S/N analysis: **NEFD (1Hz)** ≈ 16 mJy·s$^{1/2}$ per beam







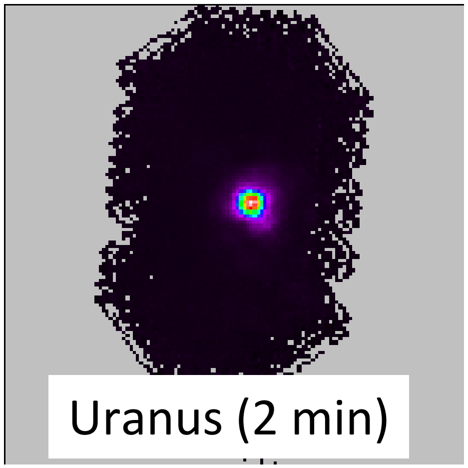


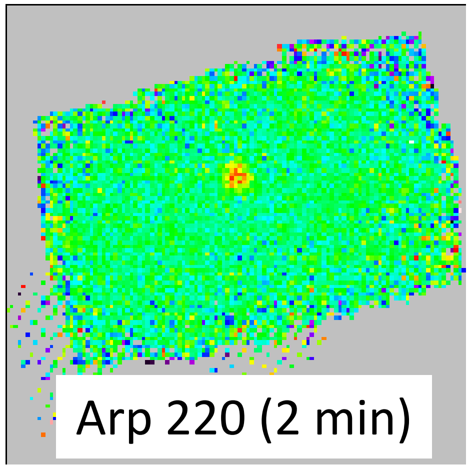


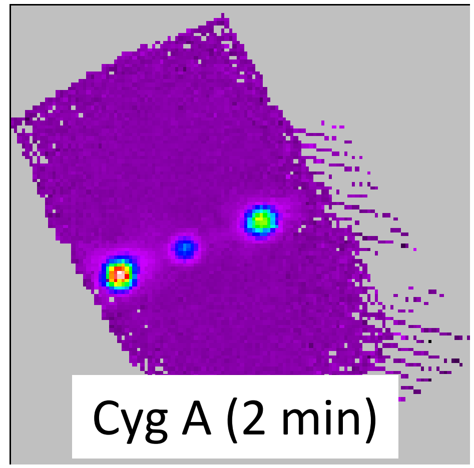
3. GISMO 4th run: Quick-Look to some sources

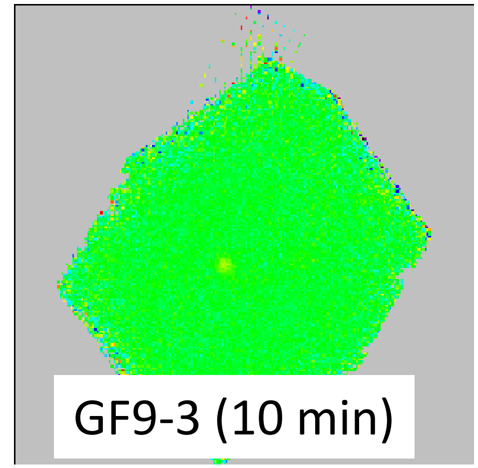
Radio sources, galaxies, clusters of galaxies, quasars

Example of Quick-Look maps automatically posted on a log page after each scan









Remark 1: these individual scan images are "almost raw" (generated with CRUSH basic filter) and serve as real-time quick look control of the good behavior of the observations; the quality and information obtained with processed images are significantly better.

Remark 2: pointings on nearby strong point sources were done between each scan, focus several times a day (particularly at dawn and sunset), beam maps and gains and flux calibrations several times a week.

3. GISMO 4th run: Data analysis & preliminary results

Pixels characteristics & pointing

- 107 = valid pixels (all TESs OK, some dead SQUIDs in the MUX given by NIST)
- FWHM: ~17” (fluctuations depending on the time of the day & night)
- Simple pointing method*: offset, rotation, scaling on EMIR pointing model
- Pointing accuracy (current status): < 3” rms whole array
- Source Az/El offset corrections done offline from pointing references

* We did pointing cessions to implement a GISMO model to the telescope NCS, but this attempt failed due to problems understanding/matching GISMO and NCS coordinate parameters (solvable, need to be worked out)

Photometry (current status, work in progress)

- 7% rms blind calibration up to tau(225 GHz) ~ 1
- Calibration factor itself well determined to ~1.2% rms
- 0.1 rms on the radiometer values = 4% calibration noise @ 2mm

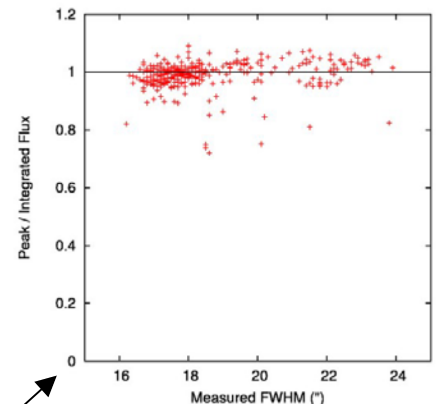
⇒ Skydips seem unnecessary (time consuming vs longer datasets)

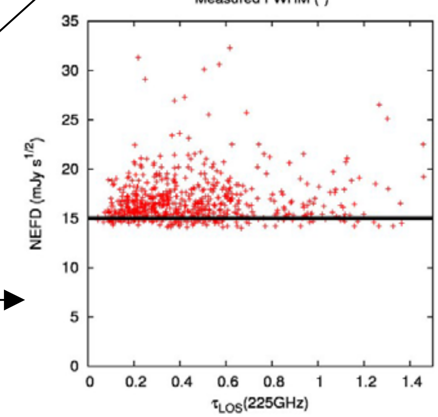
- Flat distribution of the the main peak relative flux vs beam size

⇒ same calibration factor for extended and point sources

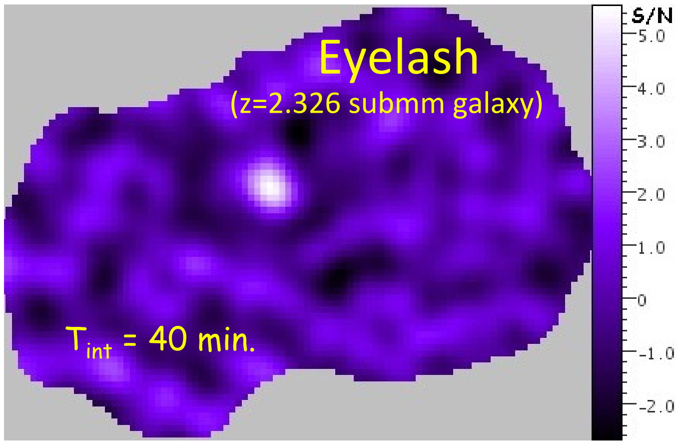
- NEFD ~ 15-17 mJy·$s^{1/2}$ in all weather (τ)

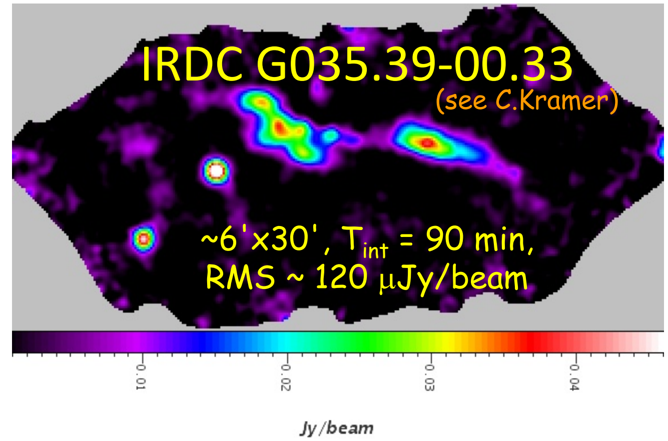
⇒ background noise limit has to be ~5 mJy ·$s^{1/2}$





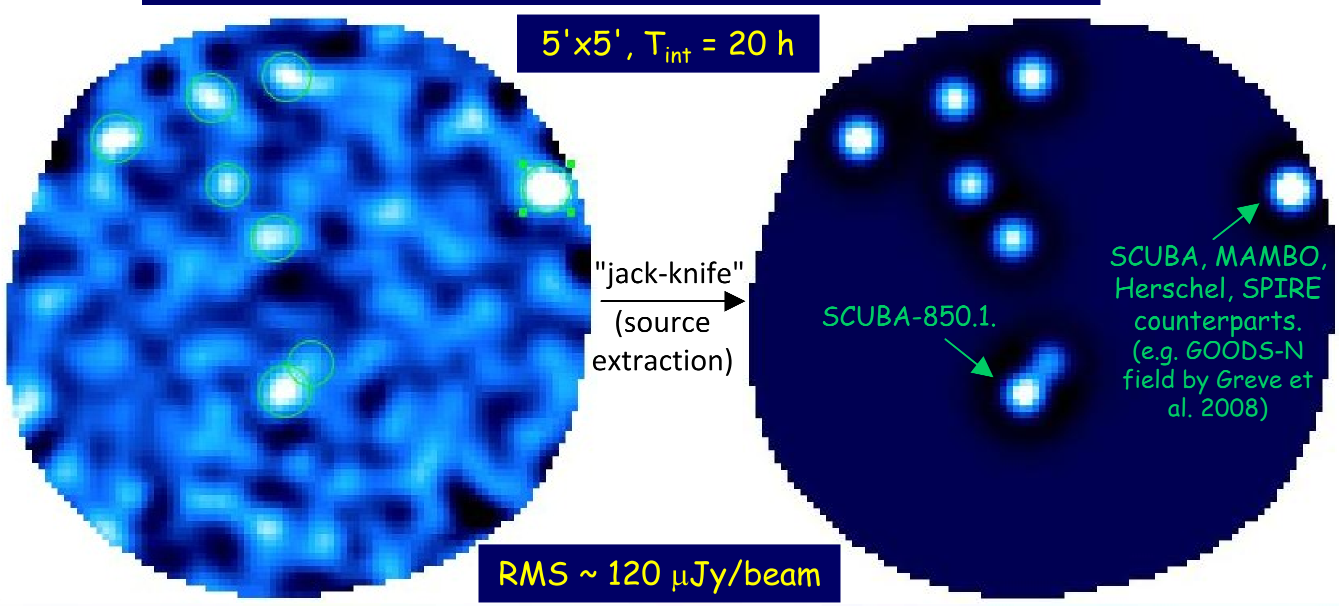
3. GISMO 4th run: Some processed images

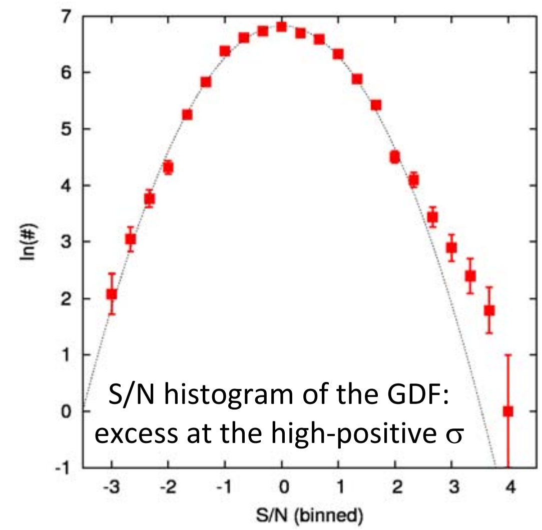


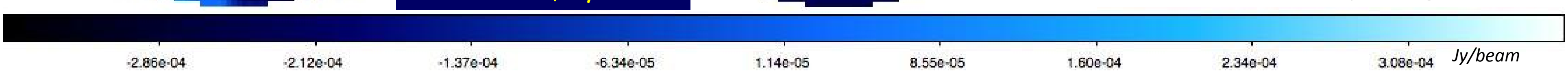


GDF (GISMO Deep Field in HDF / GOODS-N)

5'x5', T_{int} = 20 h







"GDF images are for IRAM internally and the SAC only" J.Staguhn

3. GISMO 4th run: Conclusion

- ~ 30 hours needed from closing cryostat in workshop to 1st astronomical light (quite fast)
- ~<10% bad pixels, number of pixels limited by bad SQUIDs (all TES OK)
- Alignment and focus faster than previous runs (~ 5 hours, but doable in less than 2h)
- User friendly control software & real time quick look analysis very convenient
- Strong to very weak (< 0.2 mJy) sources observed
- Sky calibration looks good with accuracy <10% on absolute photometry

Sensitivity: conservative **NEFD** (data reduction still in progress)

= **17 mJy·s$^{1/2}$!** Still ~3x to gain to reach the background limit

➔ Successful run: lot of progress done compared to previous runs, except for an excess spill-over on M7 no problem with the instrument, the background limit seems reachable

1st time that

- A bolometer instrument achieve such a high sensitivity at the 30m telescope
- So many TESs are successfully installed at the 30m MRT
- A map as deep as the GDF is obtained at the 30m ?

4. Perspectives: NIKA

Data analysis:

- Reduce all scans homogeneously (v3 in progress)
- 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) or ROACH board if LPSC not ready, 1 kHz frequency modulation for better photometry, automatic frequency lock on resonances

4. Perspectives: GISMO

Data analysis:

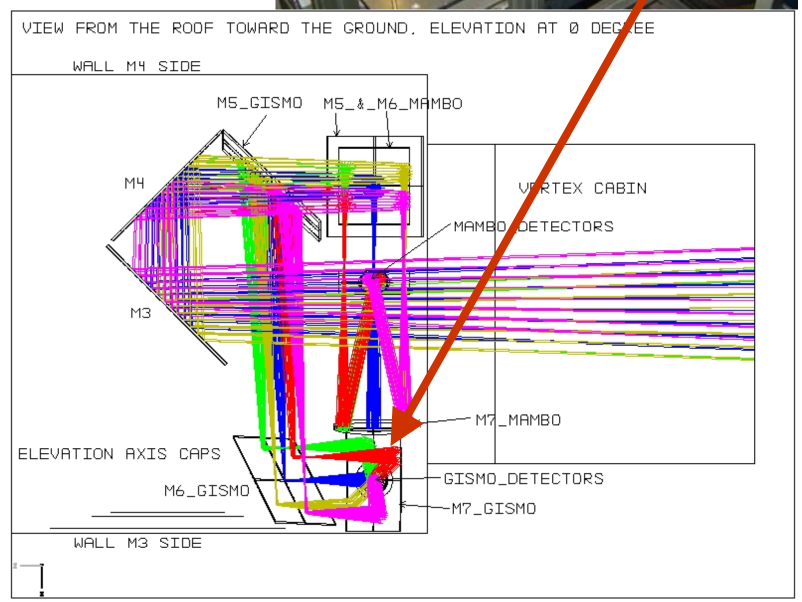
- Reduce all scans homogeneously (in progress)
- Data available to IRAM astronomer whose project have been observed

Ready to be proposed to the community:

- Only updates foreseen: larger M7 and cold snout to reduce stray lights
- Instrument and software in final state
- Sensitivity < 10 mJy·$s^{1/2}$ seems reacheable
- User friendly & documented
- **However**: issues of GISMO pointing model in NCS and limitation to 28° elevation must be solved

Dedicated position in receiver cabin ?

- One proposition with a MAMBO-GISMO switch
- Need 2 flat mirrors, easily movable
- Need a new anti-vibration table ?
- Need to move MAMBO 2 backend



4. Perspectives and conclusion: Beyond the prototypes

GIMSO and NIKA showed impressive sensitivity improvements. The goal of a background limited instrument seems reachable, the scaling to kilopixel arrays still needs to be proven. The preparation for the science grade instrument continues: Optics (GISMO-2, NIKA-x, cabin), Detectors (LEKIDs), GISMO and NIKA teams works, call for tender imminent.

- **2 colors** (bands / channels): λ = [2.05 ; 1.25] mm (ν = [240 ; 146] GHz)
- **Background limited** ($NEP_{inst} \sim$ [18 ; 38] aW/Hz$^{1/2}$; $NET_{beam} \sim$ 0.5 mK·s$^{1/2}$ & $NEFD_{beam} \sim$ 5 mJy·s$^{1/2}$ for both bands under good sky conditions in 1-100 Hz frequency domain)
- **Large dynamic** range (20-200 K_{RJ} background) $\Rightarrow$ $\Delta T/(NET/2) = 10^6\ s^{-1/2}$
- Nyquist sampling pixels (0.5Fλ, best for mapping)
- Filled array (best against anomalous refraction)
- **Field Of View = 6.5'** maximum $\Rightarrow \sim$ 2000 + 6000 pixels
- **Negligible sensitivity to stray-lights**
- Mapping speed improvement expected > 150
- **Cost = 1M€ cash + 1M€ dedicated time** from IRAM
- Delivery to community: 2014
- (polarization option)

END