Testing of current "bolometric" prototypes: GISMO, NIKA & Next Steps

Samuel Leclercq
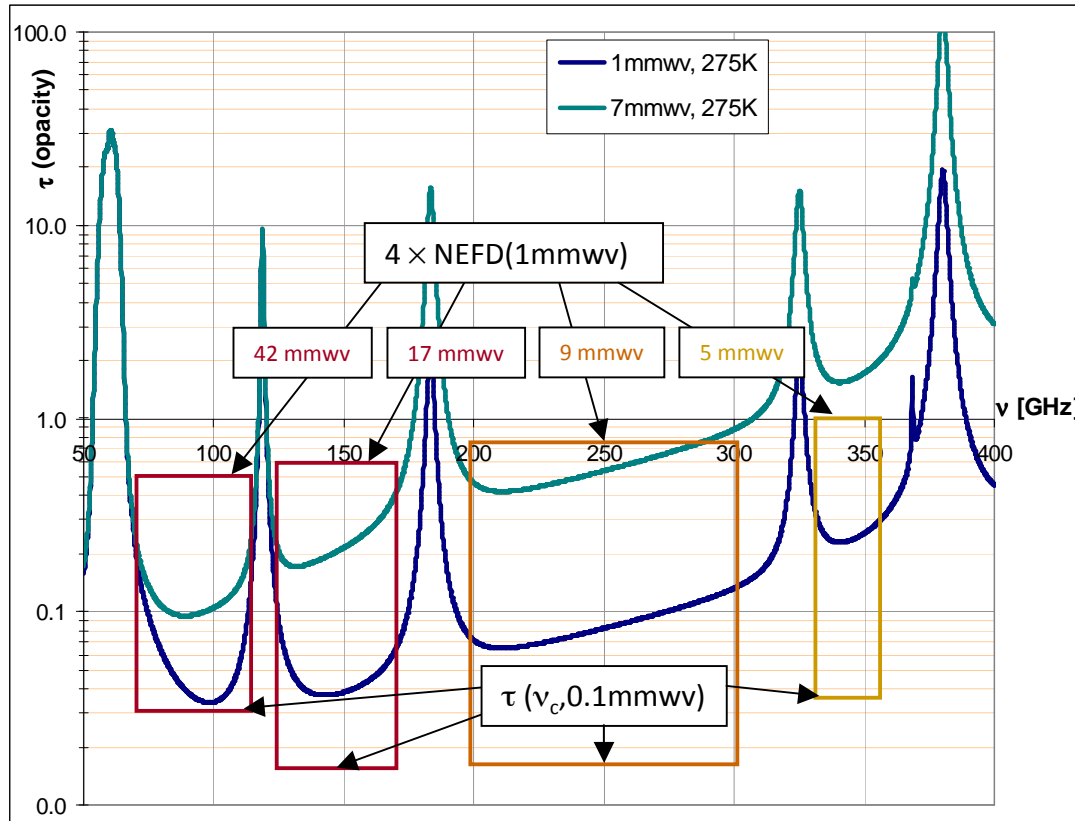
Content

1. Reminders

2. NIKA 1st run at the 30m telescope

3. GISMO 3rd run at the 30m telescope

4. Next Steps

5. Conclusion

1. Reminder

1.1. Bands, pixels, and sensitivities

Atmosphere opacity model for Pico Veleta

(275 K at telescope site, 1 & 7 mm of precipitable water vapor)

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

Main characteristics of the bands available

Band center	Band width max	Airy FWHM (band center)	Number of 0.5Fλ pixels in 7' FOV	"good sky*" NEFD / HPBW
92 GHz **3.25 mm**	45 GHz	22.6"	1100	**4 mJy·s$^{1/2}$**
146 GHz **2.05 mm**	45 GHz	14.5"	2700	**5 mJy·s$^{1/2}$**
250 GHz **1.2 mm**	105 GHz	8.8"	8000	**5 mJy·s$^{1/2}$**
345 GHz **0.87 mm**	25 GHz	6.2"	15000	**30 mJy·s$^{1/2}$**

In the 4 bands "good sky*" $NET_{beam} \sim 0.5$ mK·s$^{1/2}$

* My definition of a "good sky" @ PV:
  1 mm pwv and 60° elevation

MAMBO 2: 117 feedhorns, 3.5' FOV, 250 GHz, ~ **40 mJy·s$^{1/2}$/beam** (OnOff & 4mm pwv). Photon noise limit ~ 8 mJy·s$^{1/2}$

1. Reminder

1.2. GISMO (Nasa GSFC)

- **T**ransition **E**dge **S**ensors

- ν = 150 GHz (λ = 2 mm), $\Delta\nu$ = 22 GHz

- 0.9 Fλ bare-pixels (15"$\times$15" in sky)

- Unpolarized, pixel absorption = 90%

- DC coupled $\Rightarrow$ total power

- 8x16 = 128 pixels

- 1st filled array @ the 30m

- SQUID amplifiers & multiplexers (4$\times$32)

- 260 mK ^{3}He sorption cooler
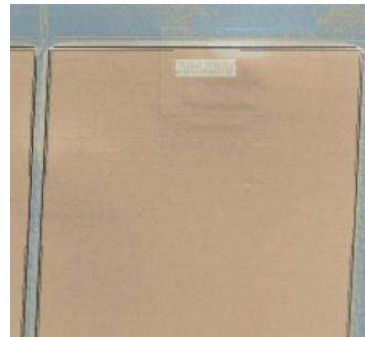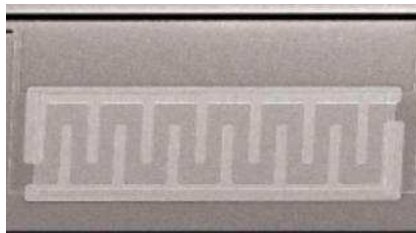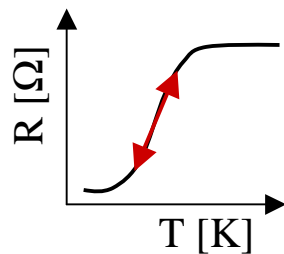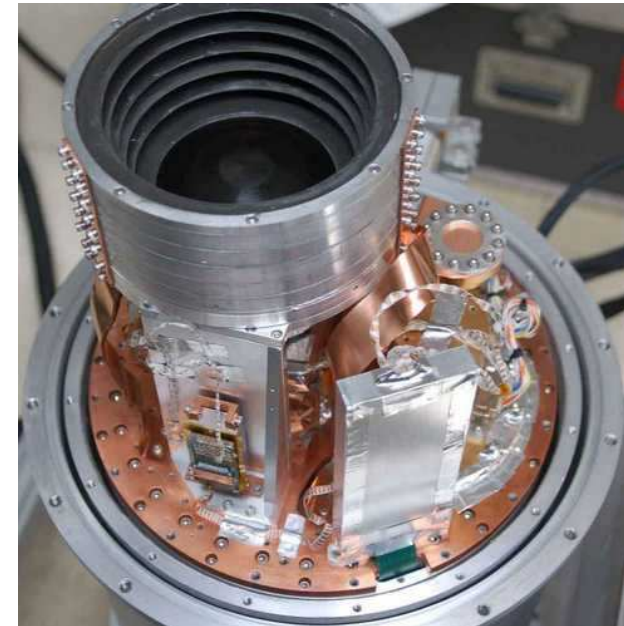
1. Reminder
1.3. GISMO 1st run (11/2007)

Results
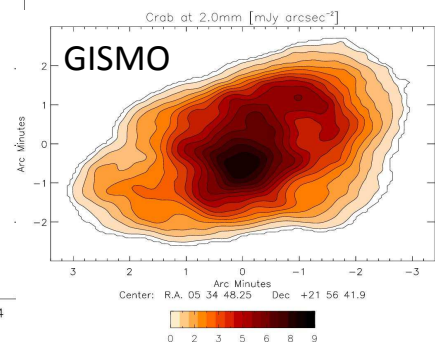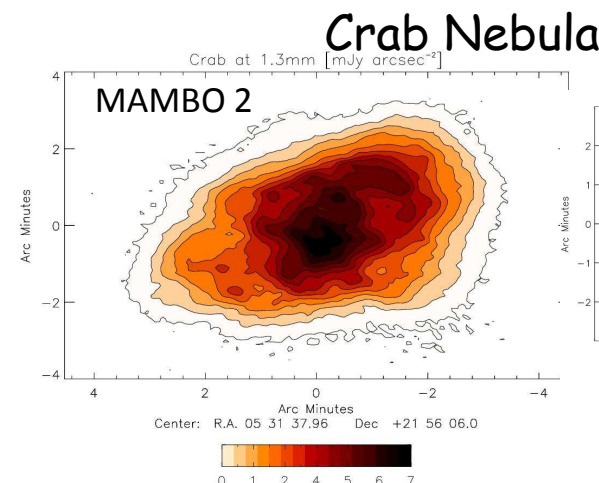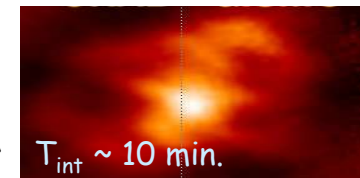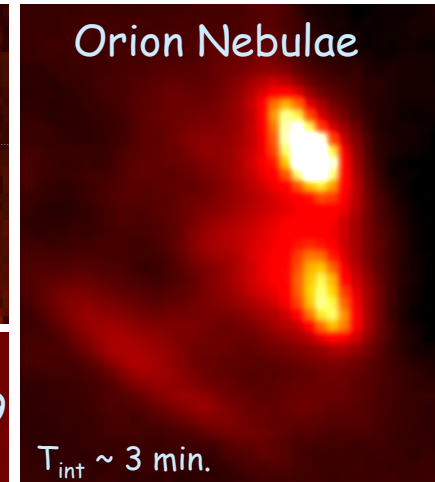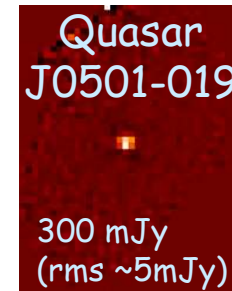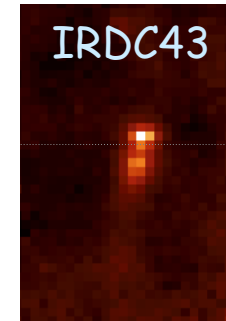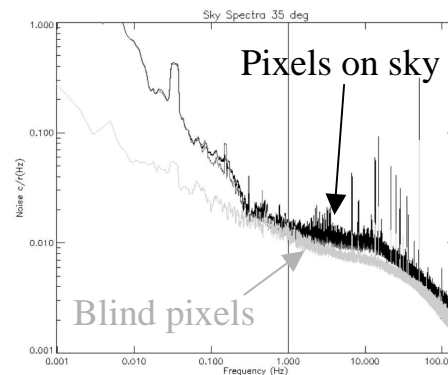
- 1st astronomical source few hours after installation
- Realtime display & interface with telescope OK
- 50% useable pixels
- map NEFD ~ 200 mJy·$s^{1/2}$

$\Rightarrow$ not optimal (see problems)

Article: Staguhn et al, SPIE 2008

Problems

- Broken bias line (25% pixels lost) & 25% weird pixels
- Baffling undersized => warm field stop needed against hot spillover
- Saturation at 35 pW load (150 K sources with 40% ND filter)
- Some EM pickup

Sky Spectra 35 deg

Pixels on sky

Blind pixels

IRDC43

Quasar J0501-019

300 mJy (rms ~5mJy)

Orion Nebulae

T_{int} ~ 3 min.

T_{int} ~ 10 min.

Crab Nebula

Crab at 1.3mm [mJy arcsec^{-2}]

MAMBO 2

Center: R.A. 05 31 37.96   Dec +21 56 06.0

Crab at 2.0mm [mJy arcsec^{-2}]

GISMO

Center: R.A. 05 34 48.25   Dec +21 56 41.9

1. Reminder
1.4. GISMO 2nd run (10/2008)

Upgrades

- Detector board
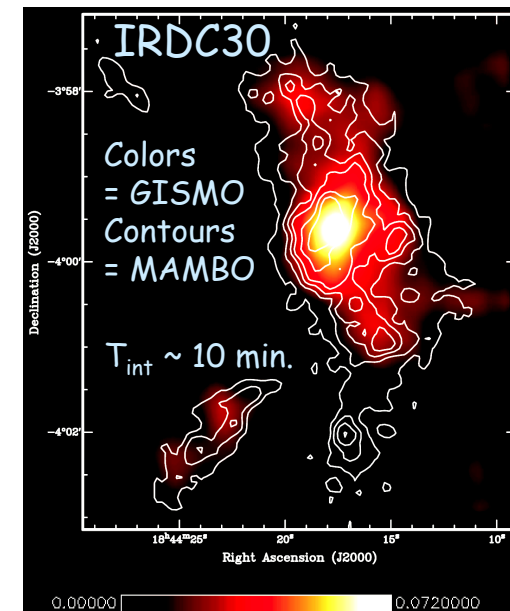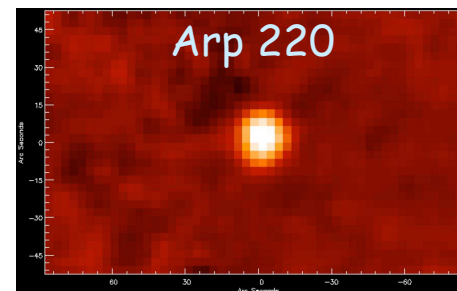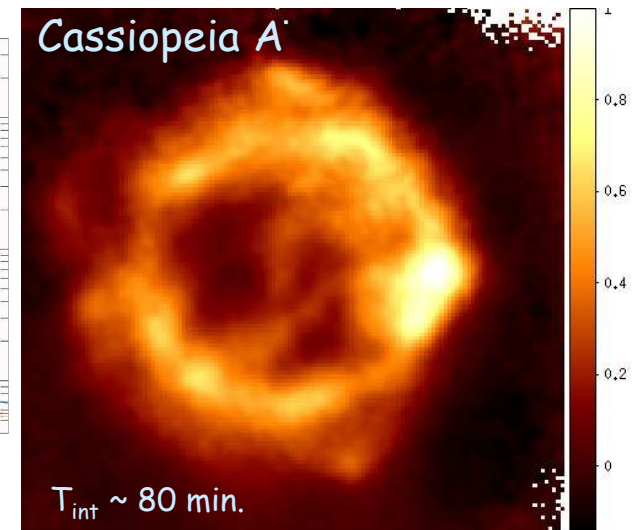- Baffle
- EM shield
- Shutter
- Lissajou (telescope)

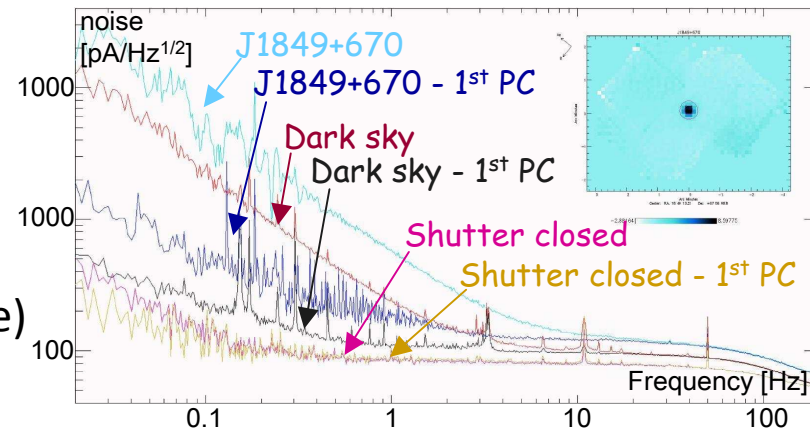noise [pA/Hz$^{1/2}$]

J1849+670
J1849+670 - 1st PC
Dark sky
Dark sky - 1st PC
Shutter closed
Shutter closed - 1st PC

Frequency [Hz]

Results

- 60% useable pixels
- map NEFD ~ 45 mJy·s$^{1/2}$

$\Rightarrow$ better but cloudy weather

Problems

- Short in 1 MUX (25% pixels lost)
- Excess noise (in maps, some pixels not used)
- Anti-vibration table mismatch (shocks)
- Internal calibration LED misaligned

Cassiopeia A

T_{int} ~ 80 min.

Arp 220

IRDC30

Colors = GISMO
Contours = MAMBO

T_{int} ~ 10 min.

0.00000   0.0720000

1. Reminder

1.5. NIKA (CNRS Néel / IRAM / AIG Cardiff / SRON)

- **K**inetic **I**nductance **D**etectors

- ν = 150 GHz (λ = 2 mm), $\Delta\nu$ = 40 GHz

- ~0.5^+ Fλ bare-pixels (~ $9^{+"} \times 9^{+"}$ in sky)

- Total power

- Filled arrays

- Antenna KID

- Lumped Elements KID

- Great multiplexing capacities

- 80 mK ^{3}He-^{4}He dilution fridge

- Telecentric optics, reflective baffle
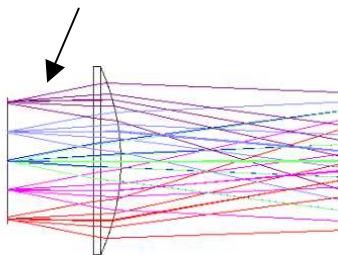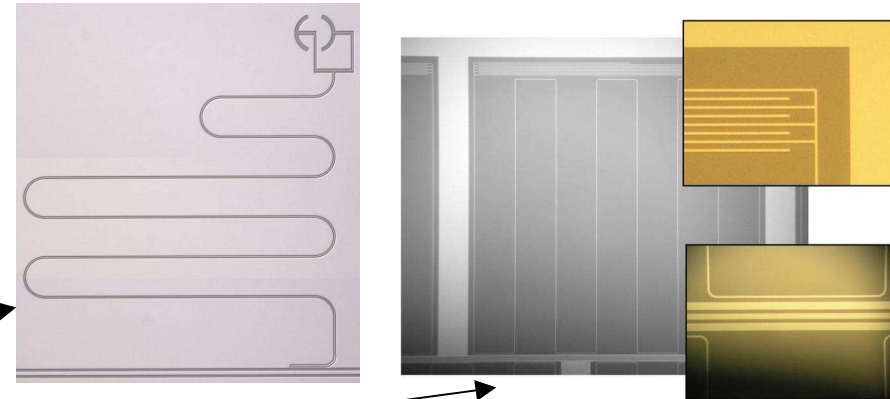
absorbed
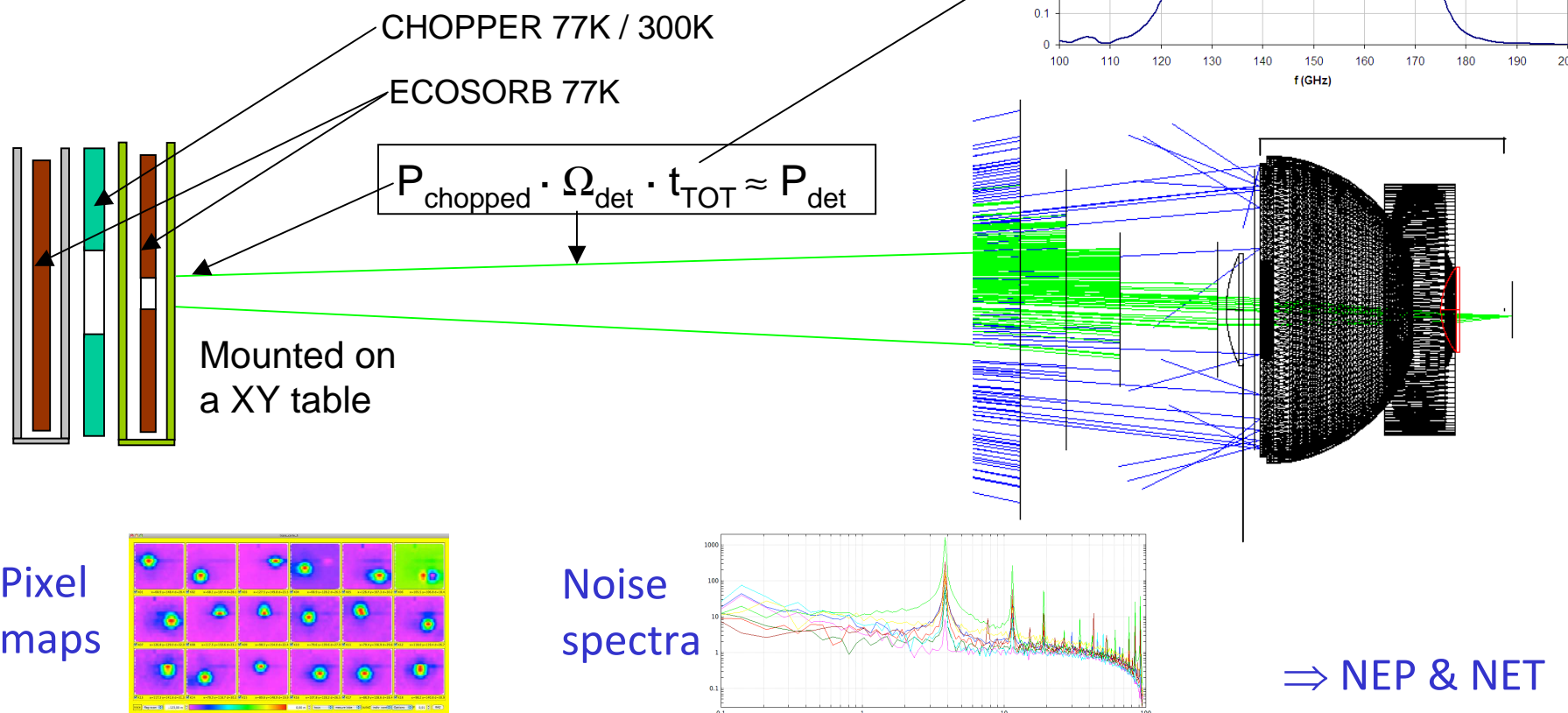photons
modify
resonance

δf F_0

S21 [dB]

F [Ghz]

Attenuation [dB]

Frequency[GHz]
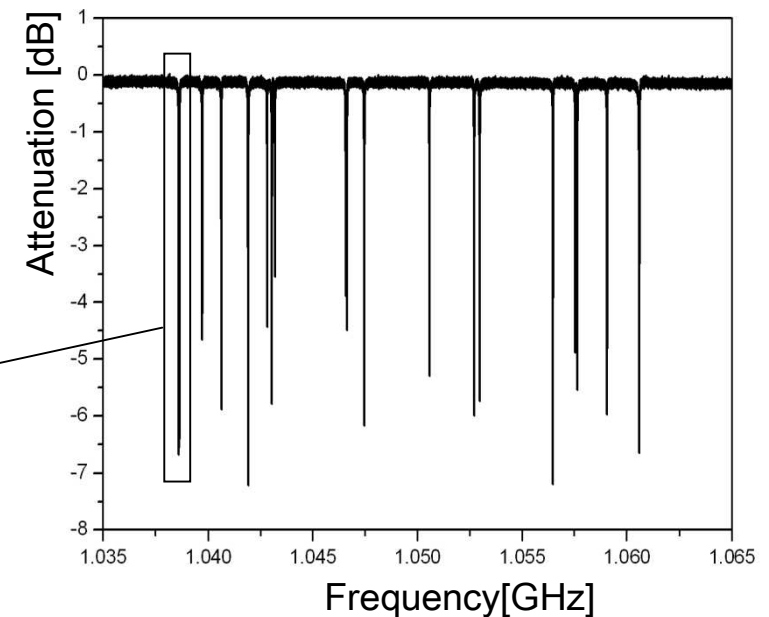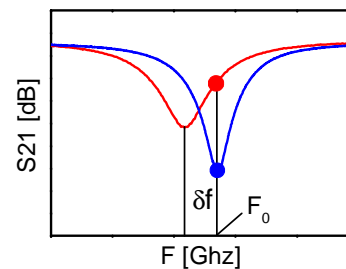
2. NIKA 1st run (10/2009)

1.1. Lab tests

Requirements:
- 32 pixels
- 10^{-16} W/Hz$^{1/2}$ (few mK·s$^{1/2}$)
- 1-20 Hz
- Good illumination and negligible stray light

Transmission Filters

CHOPPER 77K / 300K

ECOSORB 77K

$$P_{chopped} \cdot \Omega_{det} \cdot t_{TOT} \approx P_{det}$$

Mounted on
a XY table

Pixel
maps

Noise
spectra

$\Rightarrow$ NEP & NET

2. NIKA 1ˢᵗ run (10/2009)

1.2. Instrument

- 7×6 = 42 A-KID 0.5Fλ, MPIfR "Bonn" electronic

- 6×5 = 30 LEKID 0.75Fλ, "Bonn" or Néel FPGA

- Polarized, absorption = 30%

- All cryogen fridge (He bottles)

- Detector noise > photon noise

150 K Shield

70 K Shield

4 Filters @ 70 K:
270 Ghz low-pass
2 thermal infra-red
Blockers
Zitex – 300 microns

4K Shield

Ecosorb   240 Ghz low-pass filter

Thermalized SS Coax

Detector Array

NbTi Coax + 10 dB
Attenuator @ 100 mK
(not shown)

20 dB Attenuator +
DC block

4K HEMT Amplifier

Still shield with Metglas
1 K

210 Ghz low-pass Filter

Detector array
behind 127 to 170
Ghz bandpass filter

Baffle
(Ellipsoid mirror)

2. NIKA 1st run (10/2009)

1.3. Installation in the 30m cabin
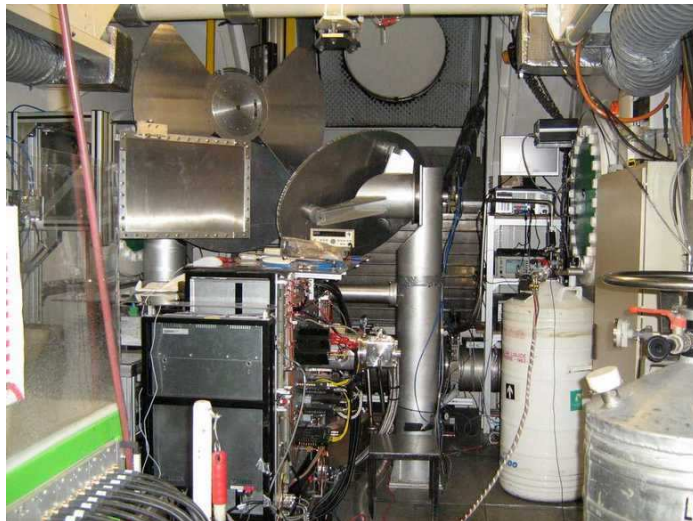
First light
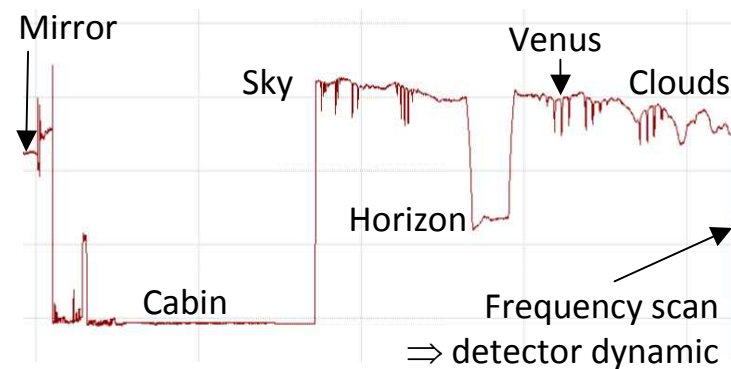
2. NIKA 1st run (10/2009)
1.4. Calibration

<u>Geometry</u>: Detector ↔ Nasmyth ↔ AzEL ↔ RaDec
⇒ Detectors positions recovered @ ~2" level

<u>Sensitivity:</u>

Venus | Mars
angular diameter = 10.7 | 7.5 "
Temperature = 232 | 205 K
HPBW [Pixel*2mm_Airy] ~ 18 | 19 "

Effective T = $232 \cdot (10.7/18)^2 \cdot 50\%$ |
$205 \cdot (7.5/19)^2 \cdot 50\% = 41$ | 16 K

Pixel S/N (planet signal / noise spectra)
~= 500 | $1000 \ Hz^{1/2}$ @ 1Hz

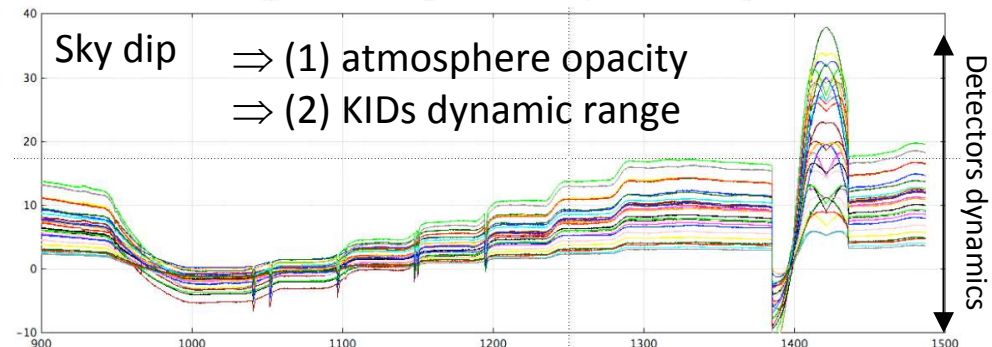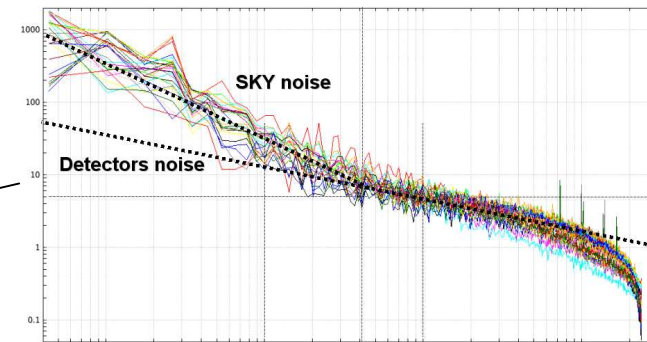Noise Equivalent Temperature
NET_{pix} = T / (S/N) = 81 | $17 \ mK/Hz^{1/2}$ @ 1Hz
NET_{beam} = NET_{pix} = 38 | $10 \ mK/Hz^{1/2}$ @ 1Hz

Optimal background photon noise calcul:
$NET_{beam} < 1 \ mK/Hz^{1/2}$

Beam map — 80% Flux₀, 50% Flux₀

Mars 20 KIDs — Jy/beam

SKY noise, Detectors noise

Sky dip ⇒ (1) atmosphere opacity ⇒ (2) KIDs dynamic range
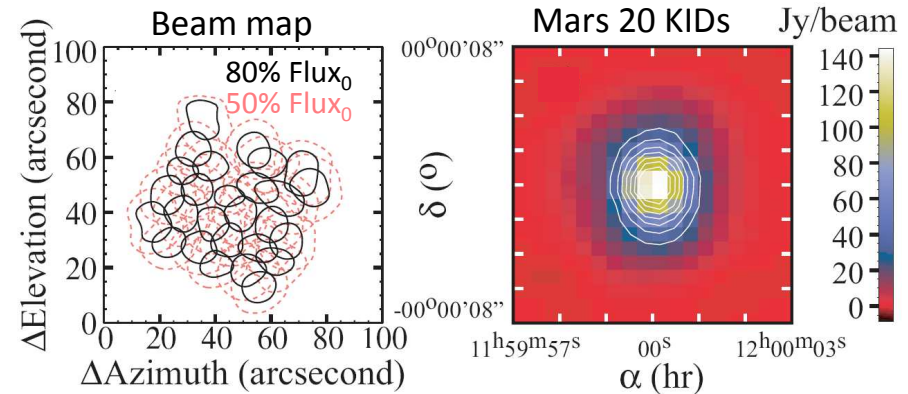
2. NIKA 1st run (10/2009)
1.5. Observations with A-KID (SRON)

The NIKA team in the 30m control room
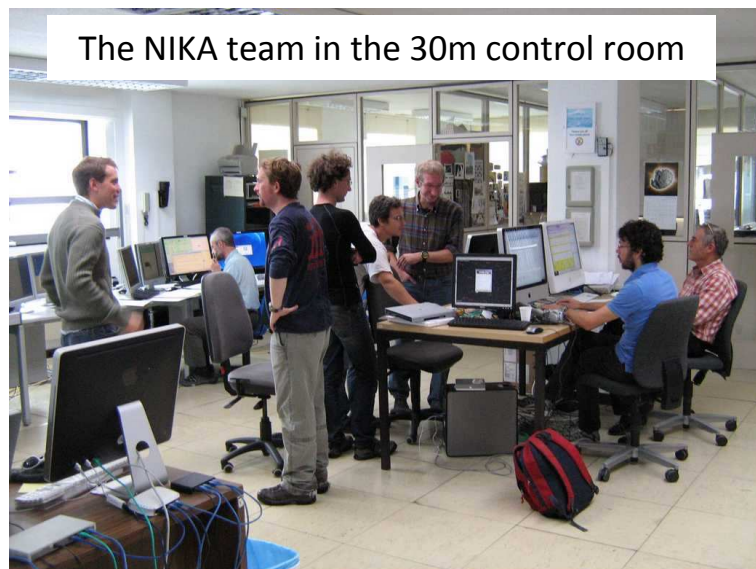
Raster scan on 3C273 (individual pixels & sum)

3C345

MWC349

Warm-up NIKA and change array
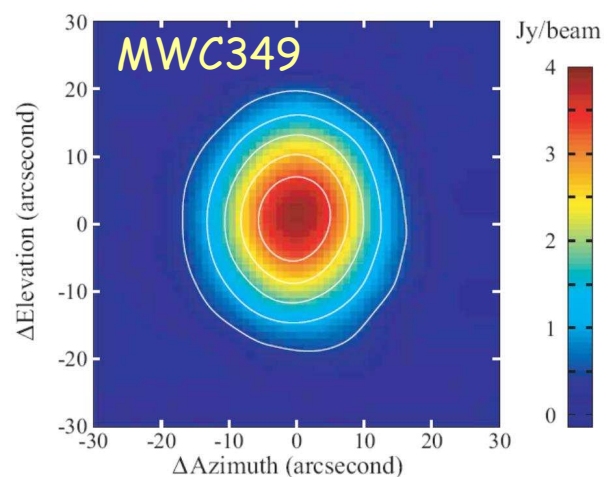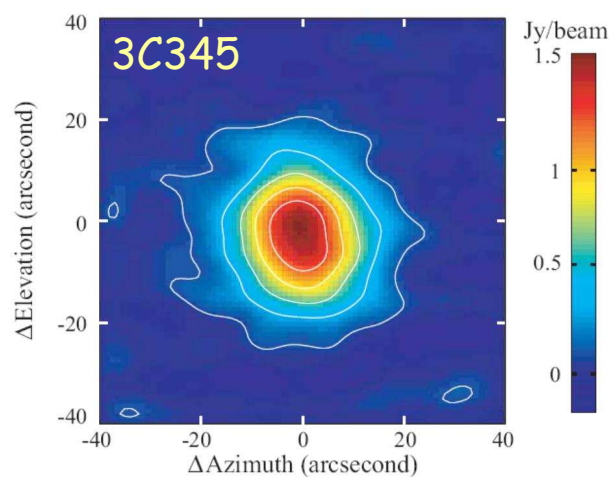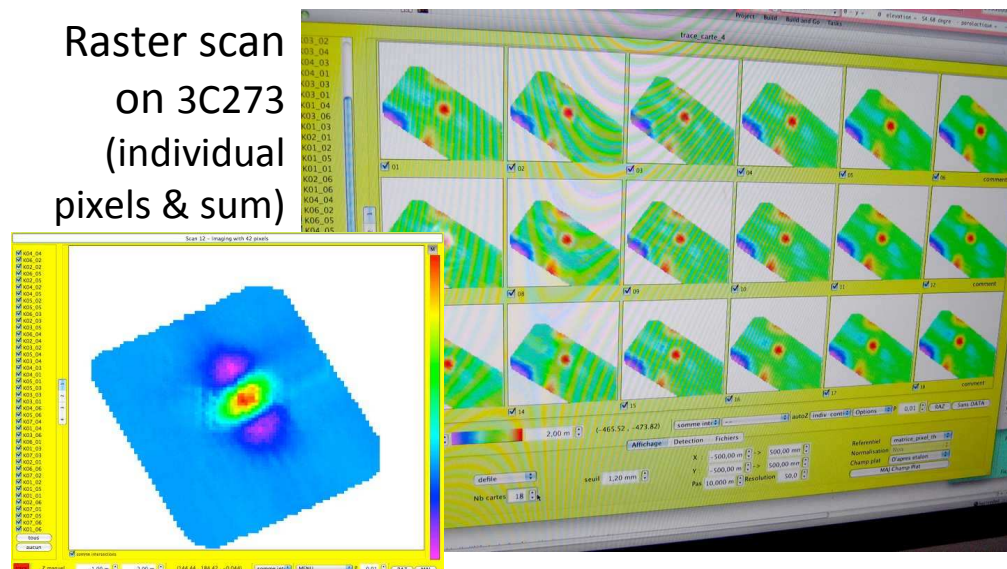
2. NIKA 1st run (10/2009)
1.6. Observations with LEKID (Néel/IRAM)

Average Phase Azel Map: B1418+546
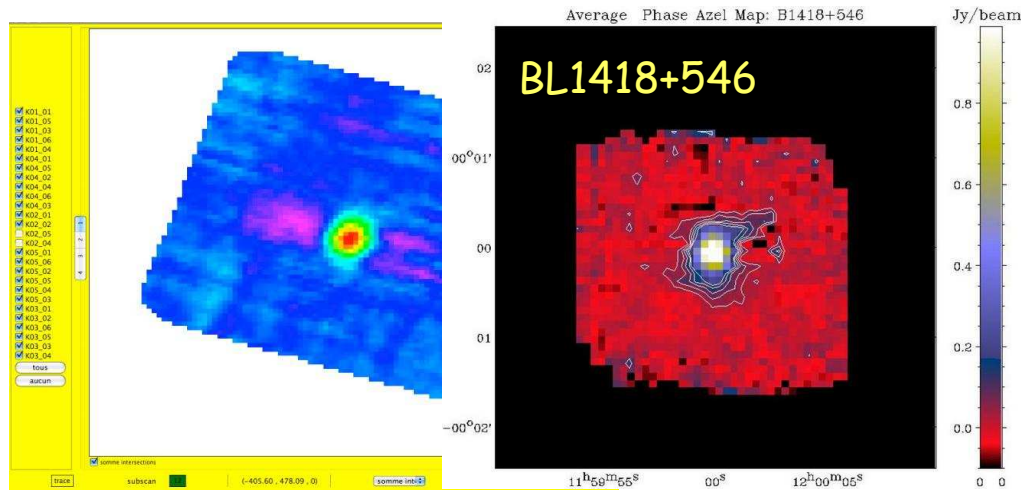
BL1418+546

Source	Scan (")	t_{int} (s)	F_{mes} (Jy)
3C345	69-73	210 x 5	4.35 ± 0.01
B1418+546	75-82	210 x 8	1.17 ± 0.01
MWC349	94-96	210 x 3	1.47 ± 0.03
B1800+440	98-99	210 x 2	0.09 ± 0.01
3C273	66-67	110 x 2	14.78 ± 0.04
Arp220	125-166	110 x 32	0.007 ± 0.003

Average Phase Azel Map: Arp220

Arp 220

M87
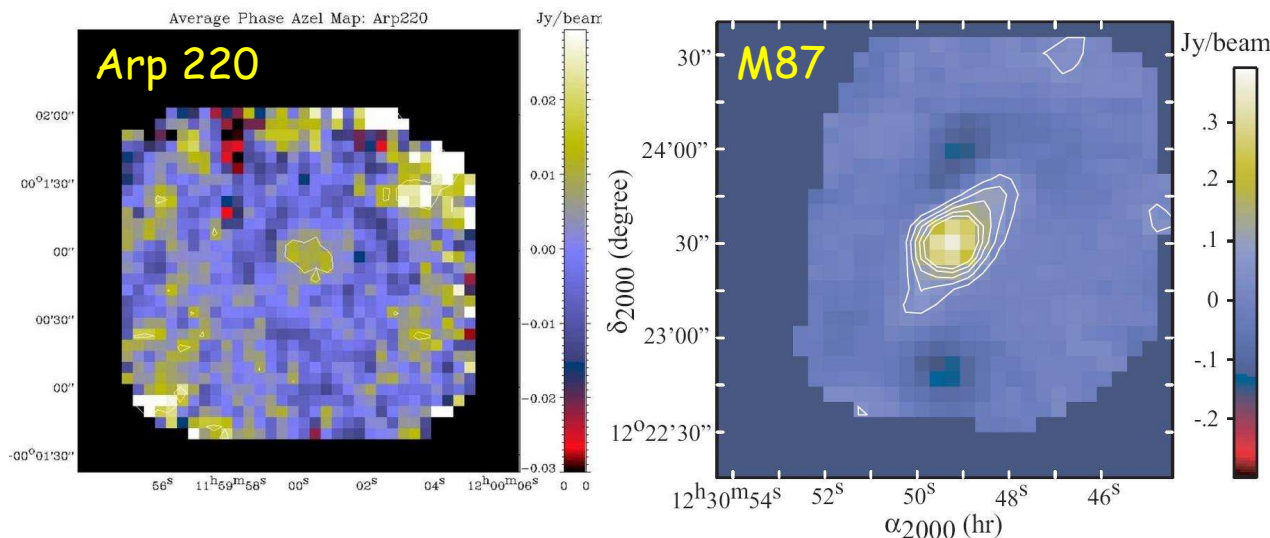
Working pixels	25 LEKIDs
rms in 1 scan	37 mJy after 210 s
NEFD$_{beam}$	240 mJy·s$^{1/2}$
rms in 1 map 90"x90"	2.9 mJy after 44x110 s
NET$_{beam}$	46 mK·s$^{1/2}$

2. NIKA 1st run (10/2009)
1.7. Outcome of the run

- Unpacking to 1st astronomical light in only 4 days.

- ~<10% bad pixels.

- Alignment and focus quick and easy.

- Only relatively strong sources observed.

- Noise & Sensitivity dominated by detector $\Rightarrow$ ~20× from optimal background.

- Successful run: 1st time ever that KID see astronomical sources.

- Run useful to learn interfacing the instrument with the telescope.

- Several improvements already in progress to reach expected sensitivities.

Article: Monfardini et al submitted to A&A: http://arxiv.org/abs/1004.2209

3. GISMO 3rd run (04/2010)

3.1. Instrument

- Same cryostat as 1st and 2nd runs

- Same 16×8 = 128 TES 0.9Fλ bolometers as 2nd run

- New SQUID MUX package

- New 4K motorized Neutral Density Filters

- New internal calibration LED

- New external shutter control

- New control software (calibration, observations, I-V, sky dip, ...)

- New data reduction software: CRUSH-2

- New GISMO documentation (control & data reduction)

4K NDF box

4K Si lens

mounted in 30m workshop

77K filter and can

4K filter and can

4K baffle
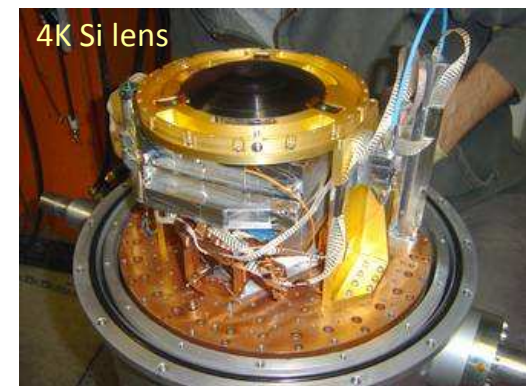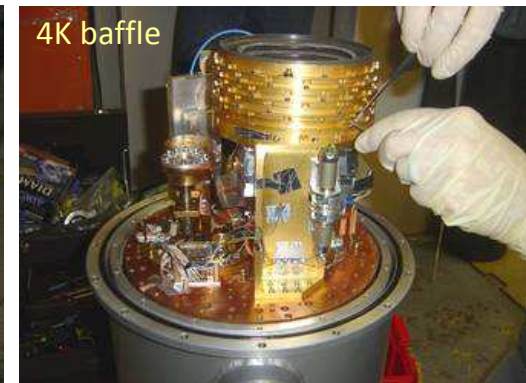
3. GISMO 3rd run (04/2010)
3.2. Installation in the 30m cabin

3. GISMO 3rd run (04/2010)
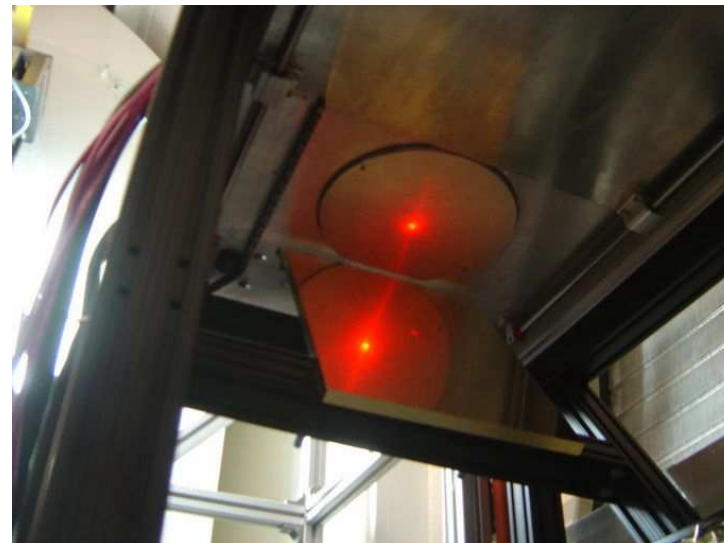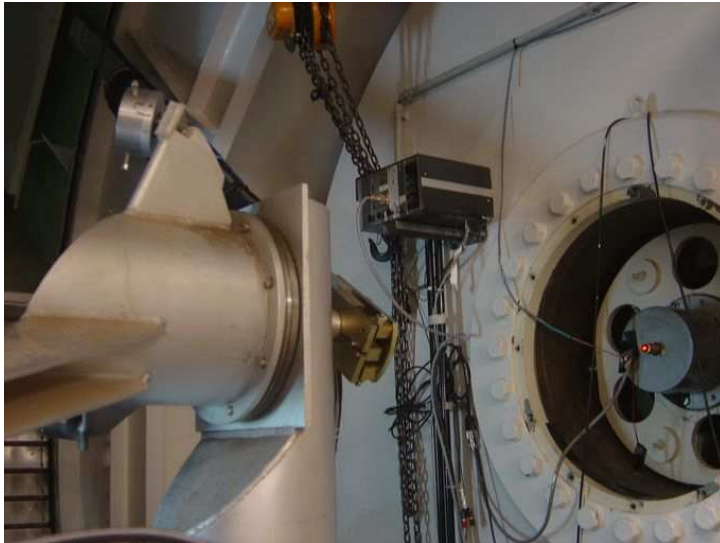## 3.3. Calibration & problems

- Wiggles in I-V curves $\Rightarrow$ CPU overheating
- Closed shutter tests OK (bias, IV, LED, noise spectra...)
- 90% pixels working
- Temperature jump after installation in cabin $\Rightarrow$ wait
- Saturation with open shutter: alignment ? optics broken ?
... stray light in NDF box ! $\Rightarrow$ use old spacer
- Abnormal noise in 3 MUX lines $\Rightarrow$ Battery box
- Non uniform illumination $\Rightarrow$ iterative alignment
- Observations & calibrations: pixel map, sky dip,
calibration sources, pointing model...
- Snow, soft transfer tube, power failure, telescope data...
$\Rightarrow$ time loss
- Some slots of good weather, system better than ever...

I-V curves

hyperbolic = superconducting   linear = normal

N-S transition = optimum

Beam map
(curvature
due to fast
optics M7 &
Si lens)
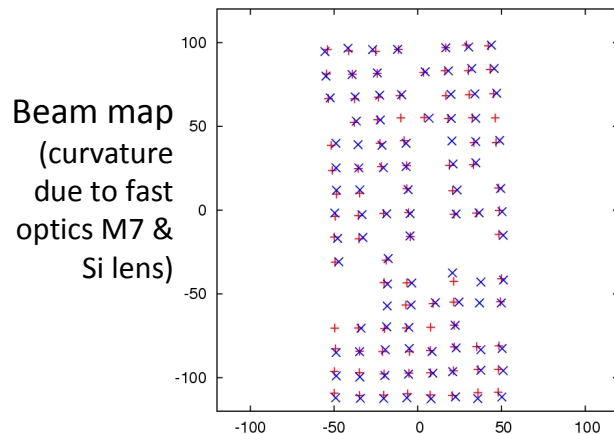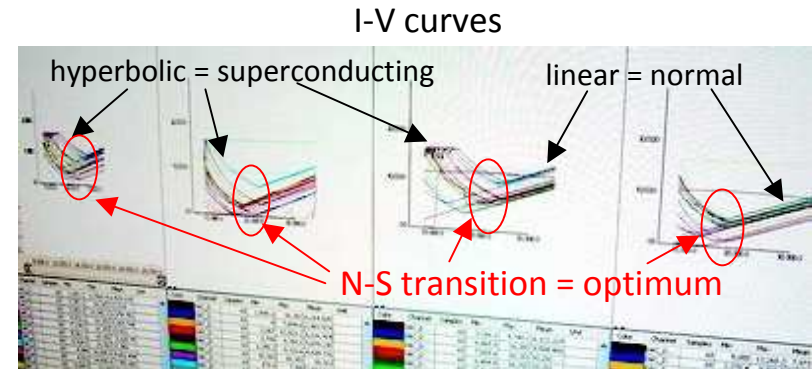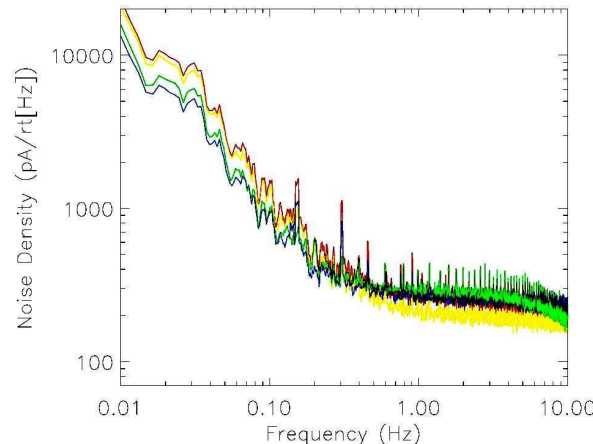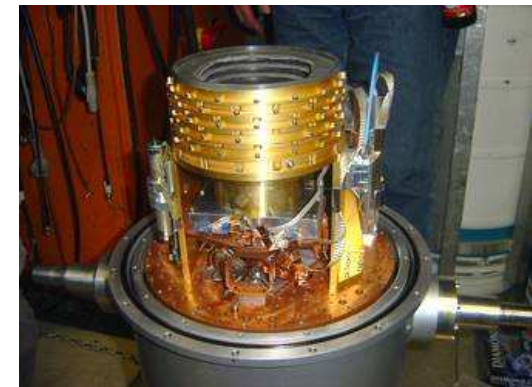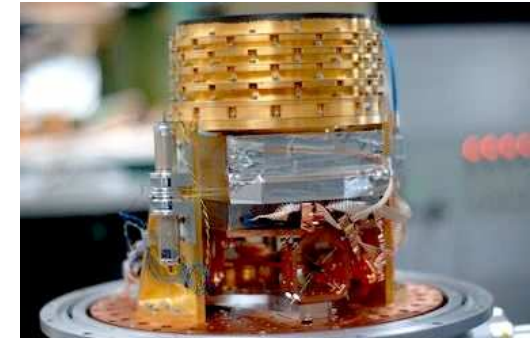
3. GISMO 3ʳᵈ run (04/2010)
3.4. Observations

DR21 (0.82 ± 0.02 Jy/beam)

M82

GM Aur

M87

IC342

←The GISMO team in the 30m control room
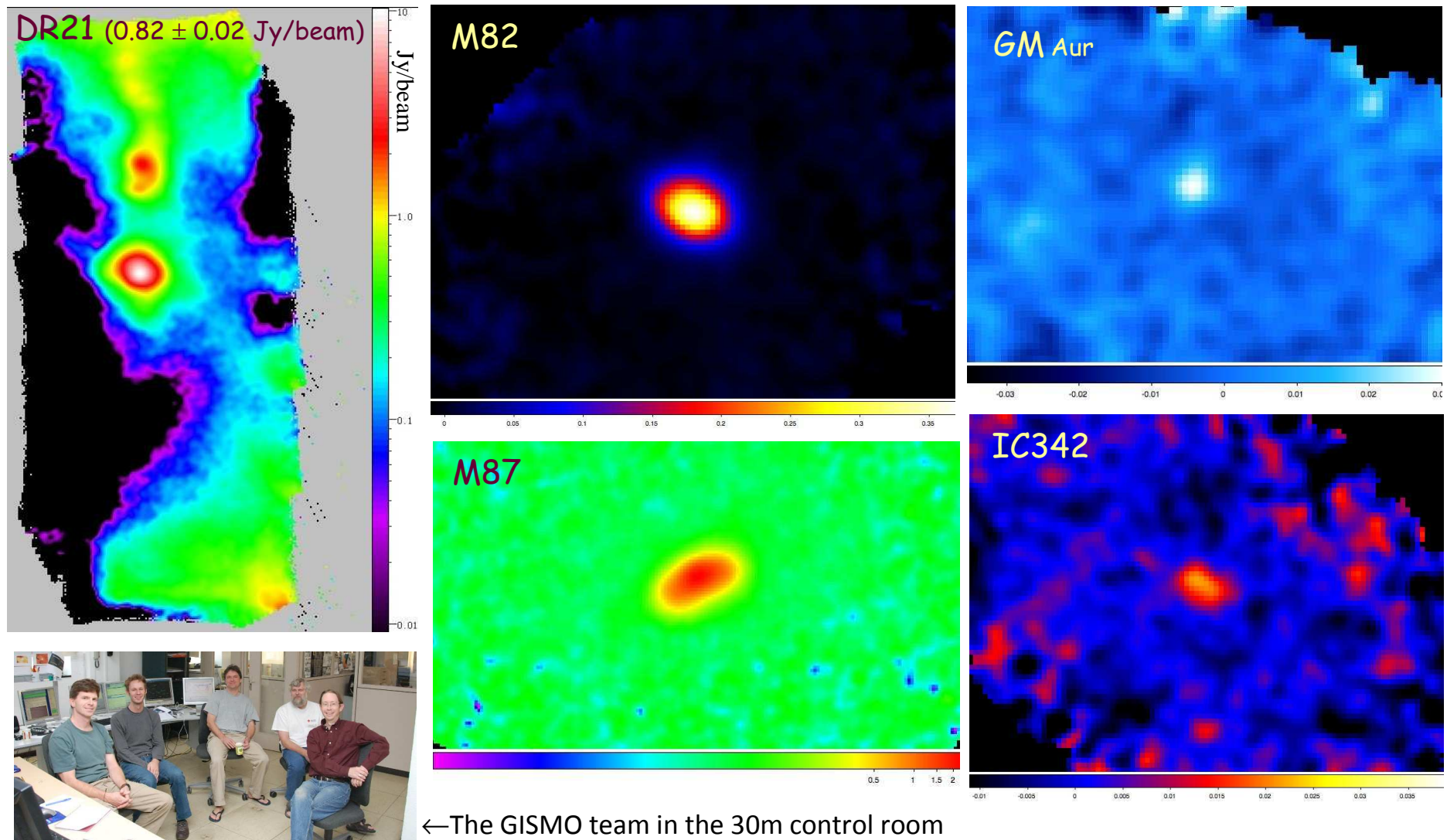
3. GISMO 3rd run (04/2010)

3.5. Outcome of the run

- Goal: astronomical run (proposals from the GISMO team & IRAM astronomers).
- Preparation of instrument, workshop tests, and installation fast and smooth.
- 90% pixel working.
- Instrument control easy when there's no technical problem.

- Astronomy goal could not be fulfill due to time loss caused by unexpected technical and operational problems (stray lights, alignment, weather...).
- Need improve pre-run (optical tests) and in-run (alignment) procedures.

- Once working, the system performances looked netter than ever.
- Stable gains, fast pointing.
- Some nice astronomical images, data reduction in progress.
- Once the technical issues fixed (NDF box mainly), instrument could be available for astronomers community.

4. Next Steps

4.1. NIKA

Sky simulator: box with absorber @ 40K for optical test in lab $\Rightarrow$ get one at IRAM ?

NIKA 2nd run:

- September / October
- New cryostat: longer baffle, 2 arrays
- λ = 2 & 1 mm
- Separation by dichroic or polarizer
- ~ 100 pixel for each array
- Sensitivity $\times$ 5 compared to 1st run
- New electronic: Casper Roach Boards
- New filters

NIKA 2:

- 2 bands
- 6' FOV
- > kilo-pixels
- Background limited
- Cryogen free

M6a6am

M5a6am

Pupil

Array 6 arc minutes

M7a6am
(in cold baffle)
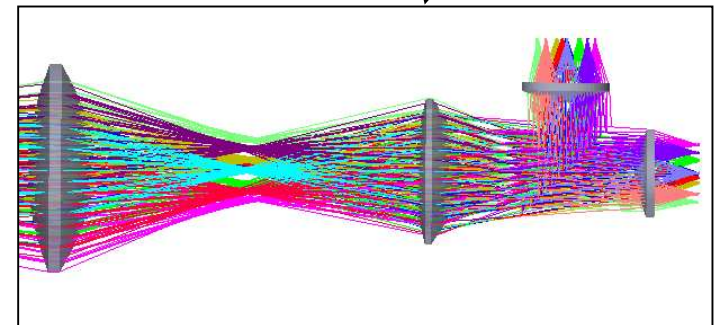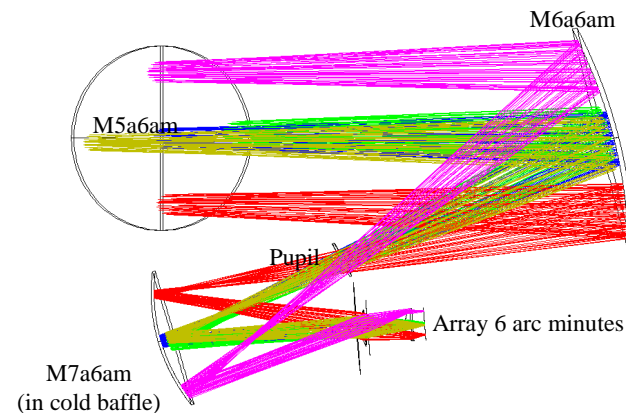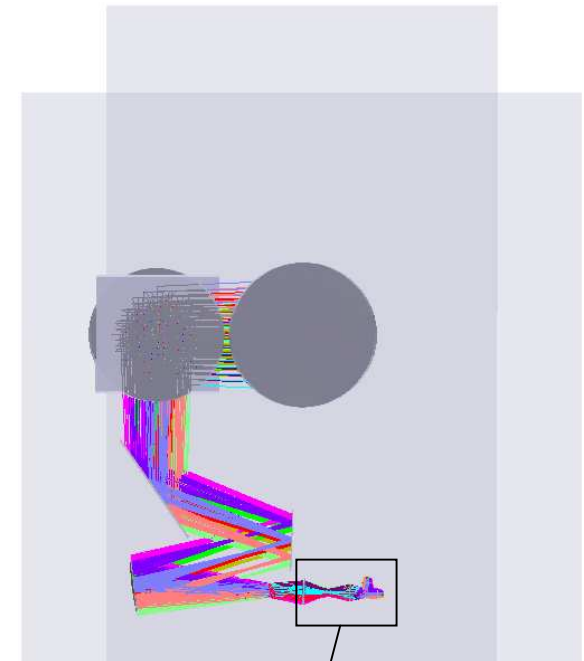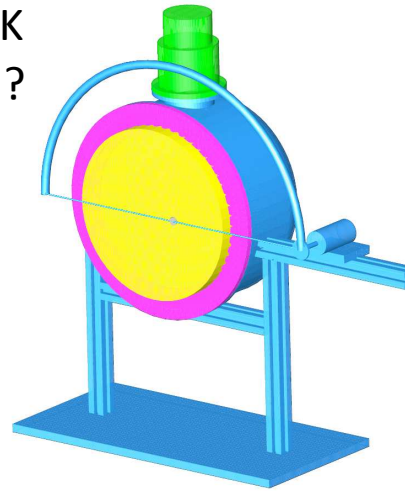
4. Next Steps

4.2. GISMO

Final upgrades:

• Neutral Density Filters box (black paint)

• Power supply

• Find better alignment & operation procedures ?

• Updates control & data software; documentation ?

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

GISMO 2:

• 2 bands (arrays ~ off-the-shelves)

• > 6' FOV

• > kilo-pixels

• Background limited

VIEW FROM THE ROOF TOWARD THE GROUND, ELEVATION AT 0 DEGREE

WALL M4 SIDE

M5_GISMO M5_&_M6_MAMBO

M4

VERTEX CABIN

MAMBO_DETECTORS

M3

ELEVATION AXIS CAPS

M7_MAMBO

GISMO_DETECTORS

M6_GISMO

M7_GISMO

WALL M3 SIDE
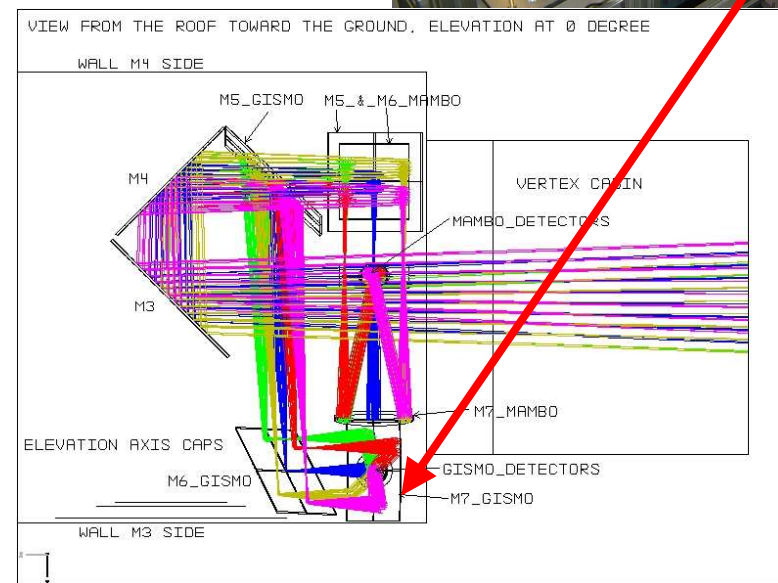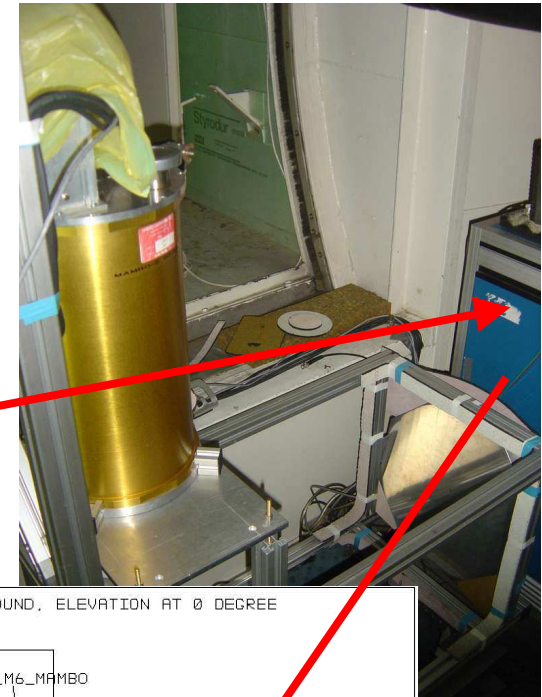
4. Next Steps
4.3. Call for proposal

Reachable with a little modification of the 30m telescope receiver cabin optics:

Band **center**	Maximal **Bandwidth**	0.5Fλ **pixels** in **7' FOV**	best **NEFD$_{beam}$**
92 GHz $\Leftrightarrow$ 3.25 mm	45 GHz	1100	4 mJy·s$^{1/2}$
146 GHz $\Leftrightarrow$ 2.05 mm	45 GHz	2700	5 mJy·s$^{1/2}$
250 GHz $\Leftrightarrow$ 1.20 mm	105 GHz	8000	5 mJy·s$^{1/2}$
345 GHz $\Leftrightarrow$ 0.87 mm	25 GHz	15000	30 mJy·s$^{1/2}$

$\Rightarrow$ Current whished instrument: 3 bands in 3 filled arrays covering 7' FOV with ~15000 pixels (full 2 & 1.2 mm, third .87 mm), background limited (NET$_{beam}$~ 0.5 mK·s$^{1/2}$), large dynamic (~15-150 K$_{RJ}$ background), negligible stray-light, polarization option, cryogen free cryostat.

- Preliminary budget: ~1.7 M€ for non-detector hardware (cryostat, optics, ...) +
  ~2.6 M€ for a TES system (GISMO style) OR ~1.2 M€ for a KID system (NIKA style)
- Availability for astronomer ~2014

Possible compromise: 6' FOV, 2 & 1.2 mm bands only $\Rightarrow$ ~7000 pixels

Conclusion

Néel, AIG Cardiff, SRON, GSFC, CEA, MPIfR answered our 2007 call for proposal

GISMO
➢ Fast conception using the NASA-GSFC TES BUG program & the NIST SQUID MUX development for SCUBA-2 + GISMO specific developments.
➢ 3 runs (11/2007, 10/2008, 04/2010) showing promising results and proving the technology is mostly ready for 100s pixel instrument.

NIKA
➢ Fast conception using a cryostat built in the DCMB frameworks & partners KID and Frequency Division Multiplexing developments + NIKA specific developments (M.Roesch talk).
➢ 1 run (10/2009) showing the world première astronomical images with KID, promising results though sensitivity improvement are required for a science grade instrument.

GIMSO and NIKA are continuously improving with only a limited financial involvement by IRAM. They both need to prove their capacity to scale to kilopixel arrays.
Preparation for the science grade instrument continues: cabin optics, collaboration with GISMO & NIKA teams, call for proposal (competition still opened to any group).

Extra slides
Reminder - Project

Goal   Replace MAMBO 2 with a more powerful "bolometric" instrument

Steps   Specifications, letter of interest, prototypes

Tests, technology validation, call for proposal

Final instrument, optics, delivery

Specification

- At least **2 colors** (bands / channels)

- **Background limited** ($NET_{beam} \sim 0.5 mK \cdot s^{1/2}$ & $NEFD_{beam} \sim 5 mJy \cdot s^{1/2}$ @ 30m 4 windows)

- **Large dynamic** range (15-150 K_{RJ} background)

- Nyquist sampling pixels ($0.5F\lambda$, best for mapping)

- Filled array (best against anomalous refraction)

- **Field Of View $\geq$ 6'**

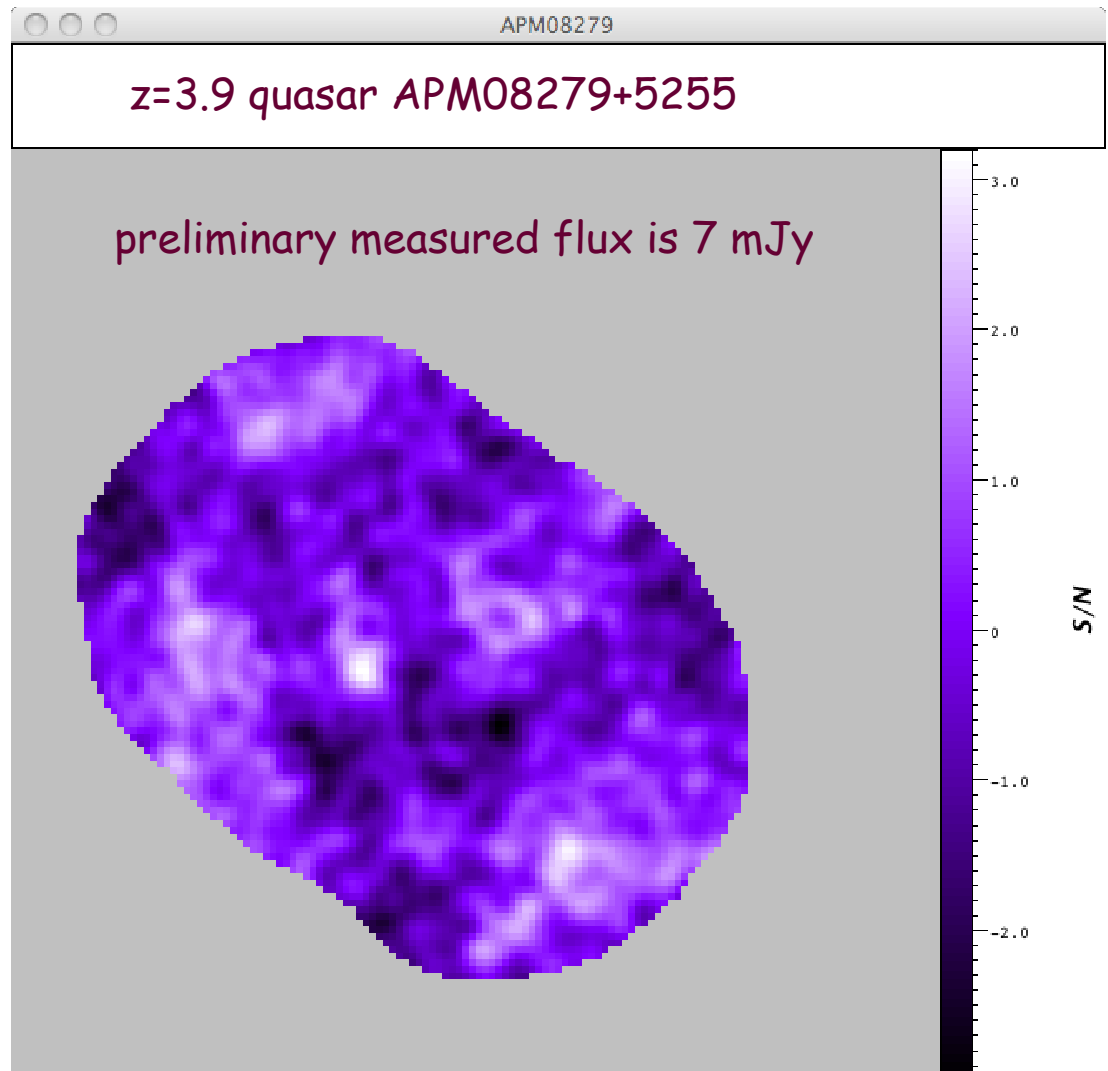- **Negligible sensitivity to stray-lights**

- Cost < 6M€

Extra slides
GISMO 3rd run (04/2010) - Observations

Latest observation processed (May 10), realized with mediocre weather

Nearby quasar J0753 observed between the scans that are summed up here

z=3.9 quasar APM08279+5255

preliminary measured flux is 7 mJy
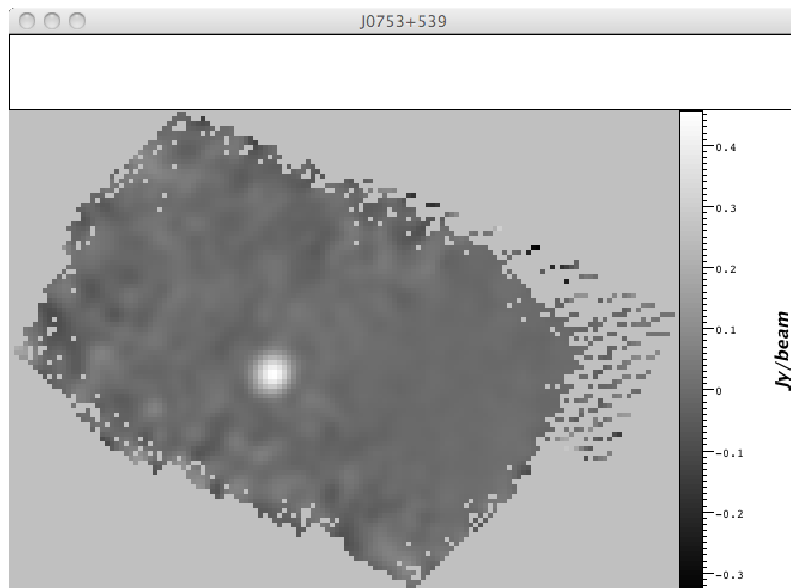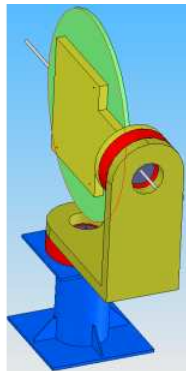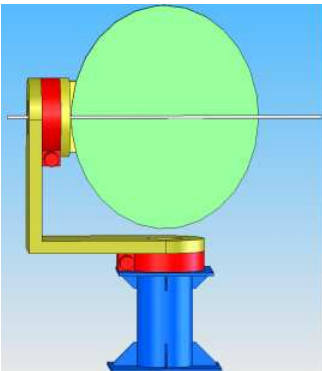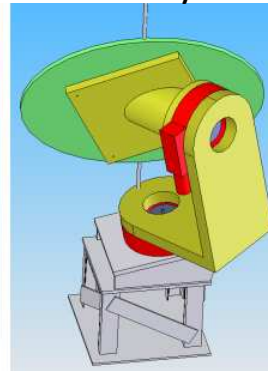
Extra slides
Next Steps - Increase 30m FOV

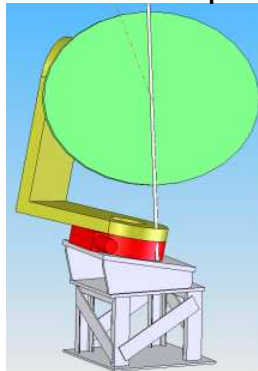**Reorganization of the 30m optics refurbishment project:**
- New M3 leg and motorization (2010 or 2011 ?).
- New M3 and motorized M4 (Nasmyth 7.4' FOV, 2012 ?)
$\Rightarrow$ move everything in the cabin + new mirrors after M4.
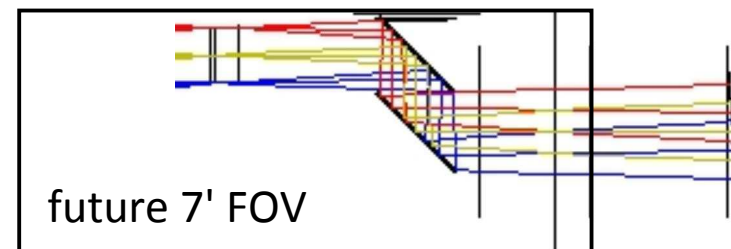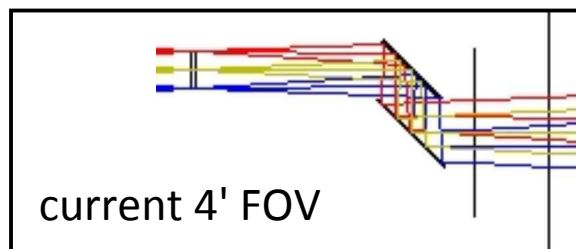- Possibly new fixed M4b (10' FOV, in many years ?).
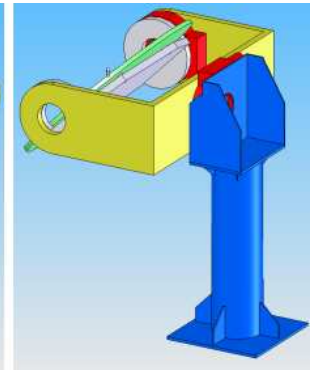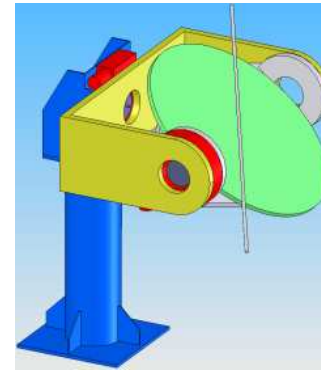
S1: "one-armed alt-azimuthal"   S2: "tilted pseudo-Nasmyth"   S3: "horizontal alt-azimuthal"
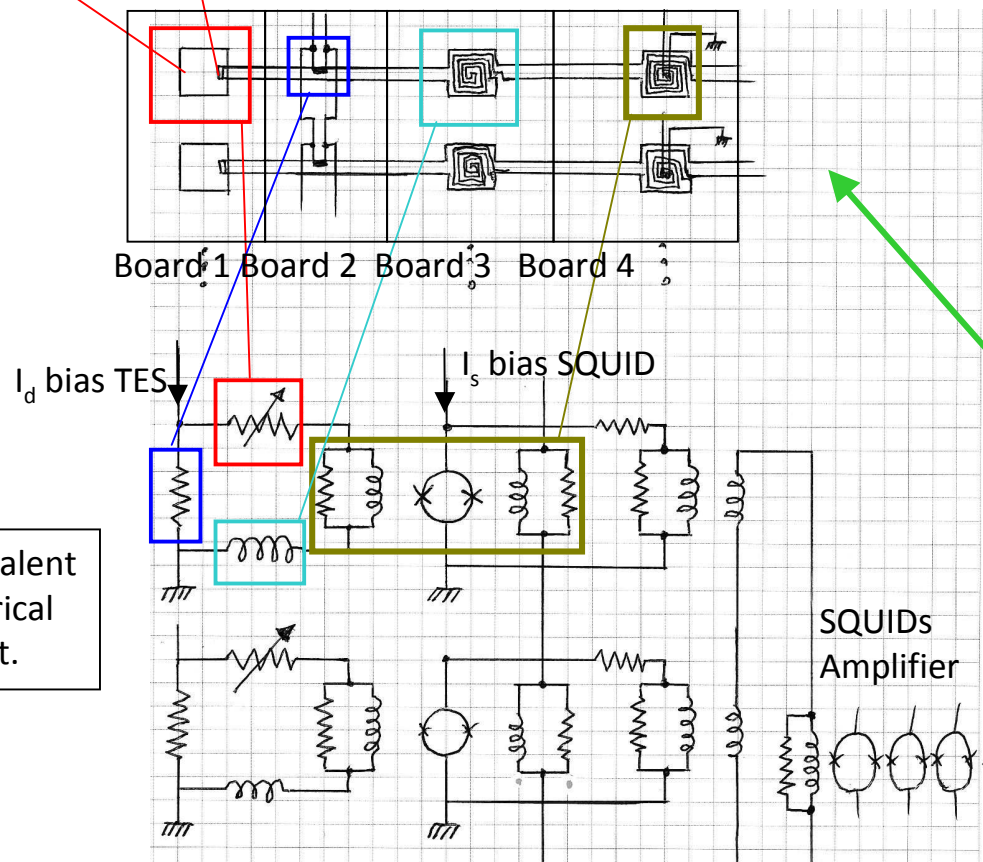

current 4' FOV

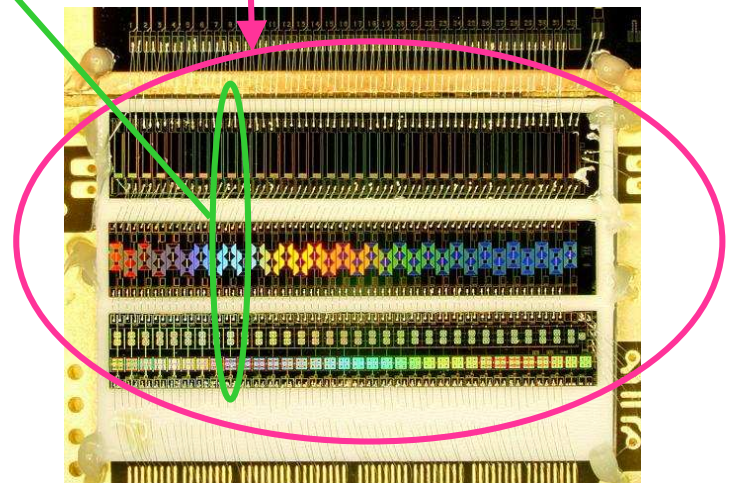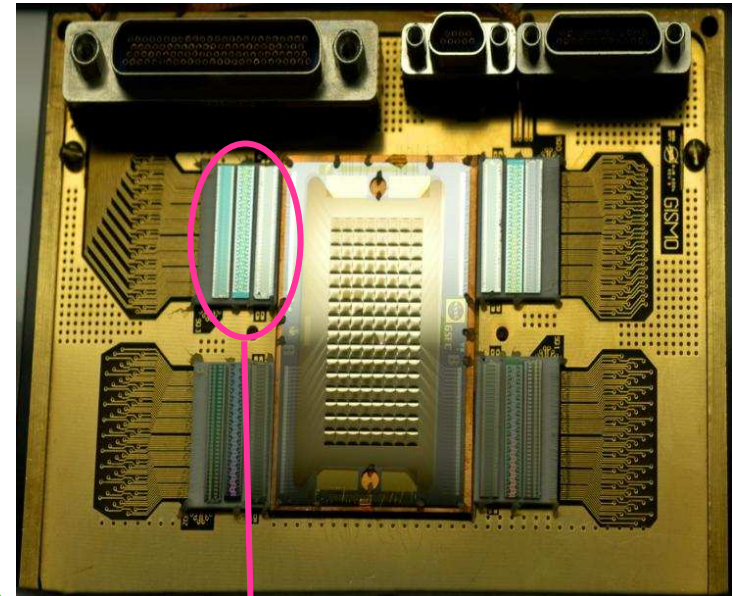future 7' FOV

Extra slides
GISMO backend

Physical aspect of 2 pixels cold backend on a multiplexed line.

Absorber & TES   Bias resistor   Integrator (Nyquist coil)   **Multiplexer switch SQUID and its coils**

Board 1 Board 2 Board 3 Board 4

I_d bias TES I_s bias SQUID
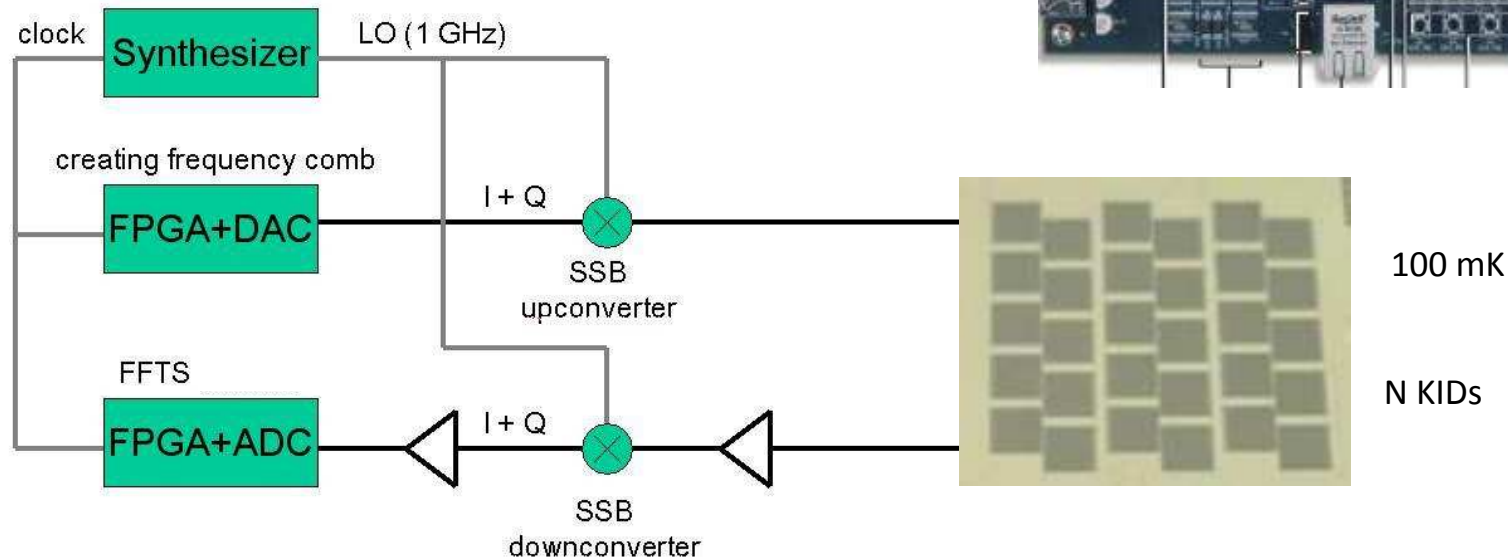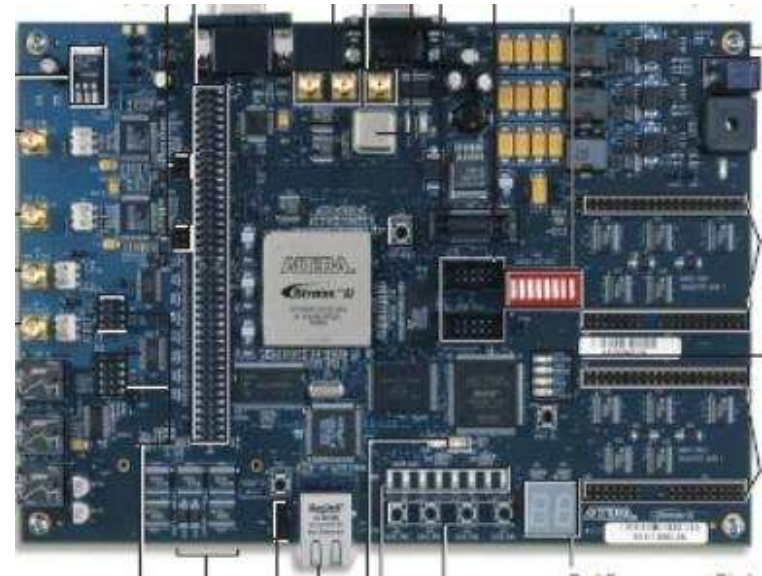
Equivalent electrical circuit.

SQUIDs Amplifier

Extra slides
NIKA backend

- **Neel FPGA board** up to 32 channels.
- A similar (but 400MHz and bigger FPGA) **custom board** is under development at **LPSC Grenoble**, should work up to ~ 128 channels.

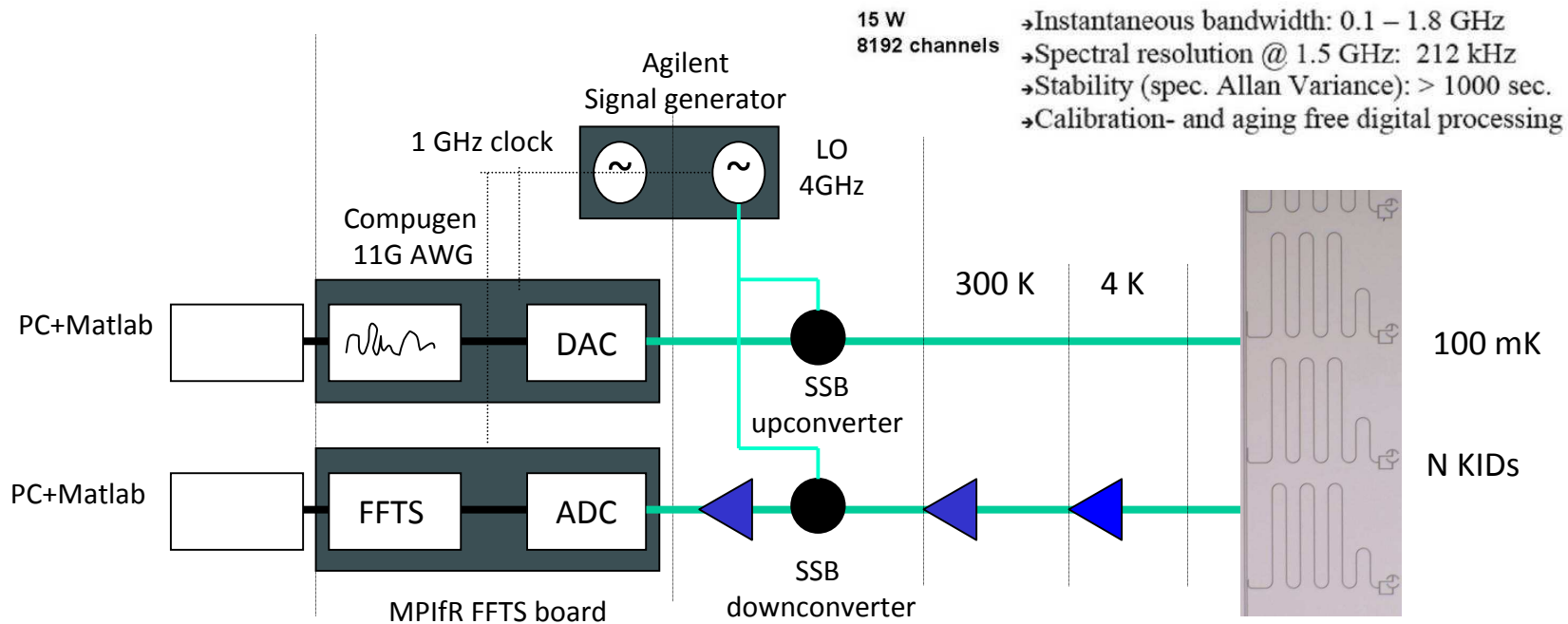**ALTERA evaluation board (STRATIX-II): 2 ADC 12-bit 125 MSPS + 2 DAC 14-bit 160MSPS**

100 mK

N KIDs

Extra slides
NIKA backend

- **Bonn MPIfR FFTS board** + new DAC board. ~128 channels already feasible. Could go up to ~400.

IF input (0 - 3 GHz)

ADC

FPGA Signal processing

5 Volt

Data

15 W
8192 channels

→ Instantaneous bandwidth: 0.1 – 1.8 GHz
→ Spectral resolution @ 1.5 GHz: 212 kHz
→ Stability (spec. Allan Variance): > 1000 sec.
→ Calibration- and aging free digital processing

Agilent Signal generator

1 GHz clock

LO 4GHz

Compugen 11G AWG

PC+Matlab

DAC

SSB upconverter

300 K   4 K

100 mK

PC+Matlab

FFTS   ADC

SSB downconverter

N KIDs

MPIfR FFTS board

Extra slides
NIKA backend

- IRAM paid a participation entry to the Mazin **Open Source project** for developing a 128 channels module, the **CASPER Roach Board**. Néel is working on the 2 boards we got, developing 2 different strategies ("I-Q lock-in" ~90 pixels, FFT in PC ~128 pixels)