Bolometers at the 30m telescope: future instruments, GISMO & other prototypes

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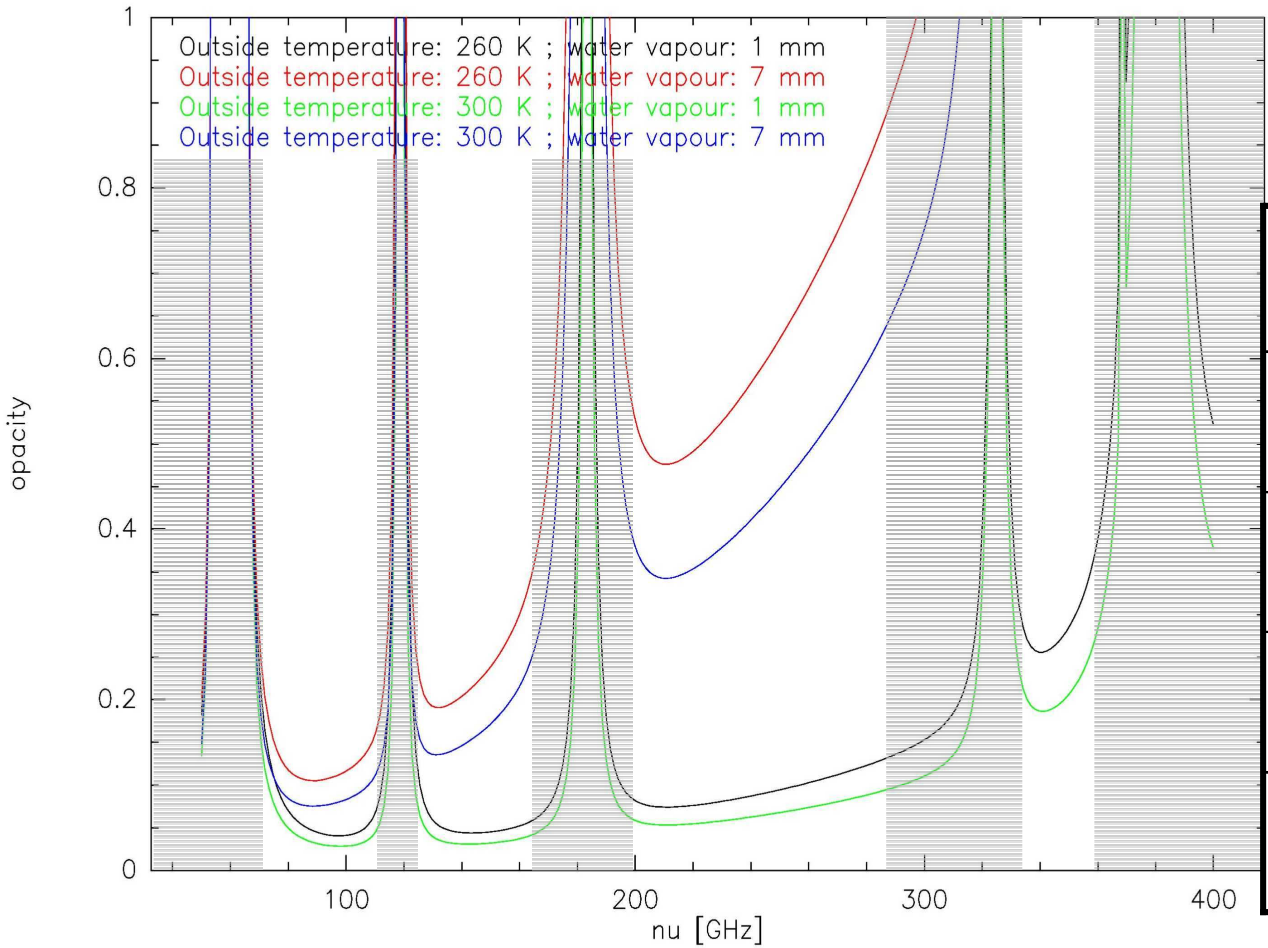
Content

1. Specifications for the future instrument
2. 2007 & 2008 GISMO runs
3. Néel/SRON/Cardiff prototype(s)
4. Conclusion & next steps

1.

Bands available at the 30m

ATM opacity model at Pico Veleta, for winter (260K) and summer (300K) with good weather (1mm of water vapour) and bad weather (7mm)



Bands centre for a maximal width and diffraction pattern size

λ (mm)	ν (GHz)	Δν (GHz)	Airy HPBW
3.2	94	36	22.6"
2.05	146	40	14.5"
1.25	240	90	8.8"
0.87	345	24	6.2"

1. Simulations for an optimal bolometer array

Efficiencies, pixels types and FOV

Aperture efficiency = relative flux losses: $\varepsilon_a = A_e / A$

Beam efficiency = relative power in main beam

Forward efficiency = relative power from $\Omega = 2\pi$

Ruze (Surface RMS) : $\varepsilon_a(\lambda) = \varepsilon_0 \exp(-\Sigma_c(\sigma_{hc} 4\pi R/\lambda)^2)$

Measures 2007 [C.Thum]: ε_0 = ohmic losses * blockage * 13dB taper * alignment * Ruze @ 86GHz = **65 %**

$$\varepsilon_a = \begin{pmatrix} 61 \\ 45 \\ 35 \\ 16 \end{pmatrix} \% \qquad B_{eff} = \begin{pmatrix} 73 \\ 54 \\ 42 \\ 19 \end{pmatrix} \% \qquad F_{eff} = \begin{pmatrix} 92 \\ 90 \\ 86 \\ 75 \end{pmatrix} \%$$

Pixel types	0.5Fλ square bare multimodes pixels in a filled array	2Fλ round 10dB edge monomode feedhorns in a compact array
Global pixel efficiency	$\eta_{extended} < 50\,\%$ $\quad \eta_{point} \sim \varepsilon_a/4$	$\eta_{extended} < 65\,\%$ $\quad \eta_{point} \sim \varepsilon_a$

Number of pixels

for 2 fields of view

FOV = (4.8' 10')

Square grid: $N_b = \begin{pmatrix} 540 & 2400 \\ 1400 & 5700 \\ 3600 & 16000 \\ 7300 & 32000 \end{pmatrix}$

FOV = (4.8' 10')

Hexagonal grid: $N_h = \begin{pmatrix} 40 & 170 \\ 95 & 420 \\ 260 & 1100 \\ 530 & 2300 \end{pmatrix}$

MAMBO 2: 117 pixels (feedhorns), FOV=3.5’

1. Simulations for an optimal bolometer array

Bands: λ = [2mm ; 1mm]

Background sources: atmosphere, ground, telescope, cryostat.

Sensitivities

	0.5Fλ bare multimode, $\eta_{InstNoRuze}$ ~ 45%	2Fλ feedhorn monomode, $\eta_{InstNoRuze}$ ~ 60%
Collected power (1mmwv)	P_{bkgb} = [7 ; 20] pW	P_{bkgh} = [40 ; 110] pW

Benchmark: Jupiter ~10s pW, 1mJy point source ~10s aW

Noise Equivalent Power $[(\mathrm{Shot})^2 + (\mathrm{Bunching})^2]^{1/2}$	NEP_{bkgb} = [50 ; 100] aW/Hz$^{1/2}$	NEP_{bkgh} = [200 ; 400] aW/Hz$^{1/2}$
Optimal pixel if η_{PixAbs}= **90%** :	NEP_{pixb} ~ [20 ; 30] aW/Hz$^{1/2}$	NEP_{pixh} ~ [70 ; 140] aW/Hz$^{1/2}$

	4×0.5Fλ bare, OTF	2Fλ horn, OnOff
Noise Equivalent Temperature (extended sources → F_{eff})	NET = 0.4 mK·s$^{1/2}$	NET = 0.6 mK·s$^{1/2}$
Noise Equivalent Flux Density (point sources → diffraction: $\varepsilon_a < \eta_{diffpix} < B_{eff}$)	NEFD ~ 3 mJy·s$^{1/2}$	NEFD ~ 4 mJy·s$^{1/2}$

MAMBO: NEFD ~ 40 mJy·s$^{1/2}$ (~10x higher than expected to get it background limited).

1. Expectations for the future science grade instrument

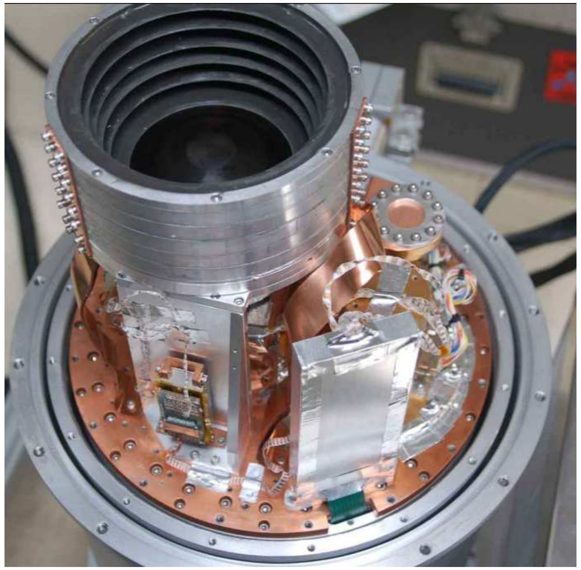
- At least 2 colors (bands / channels)
- Current preferred colors: λ = [1.25 ; 2.05] mm (ν = [146 ; 240] GHz)
- Total efficiency per pixel > 40%
- Background limited instrument : $NEP_{pix} < NEP_{bkg}/3$
- Sensitivity: ~0.4mK·s$^{1/2}$ & ~3mJy·s$^{1/2}$ @ 1mmwv, and stay <1mK·s$^{1/2}$ & <10mJy·s$^{1/2}$ in a large dynamic range (15-150 K_{RJ} background)
- Preference for fully sampling (0.5Fλ) pixels (advantage for mapping)
- Preference for filled array (best to fight anomalous refraction in sky noise)
- Field Of View ≥ 6'
- Preference for multiplexing since FOV>6' ⇒ 100s - 1000s pixels
- Negligible sensitivity to stray-lights
- Cost < 6M€ including (5M€ as dedicated time ⇒ <1M€ cash)

2.

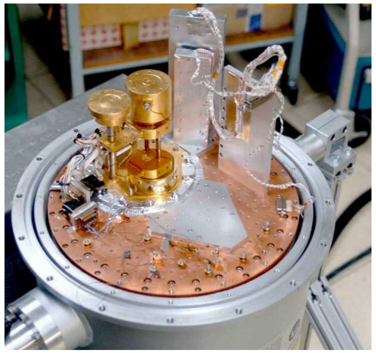
GISMO

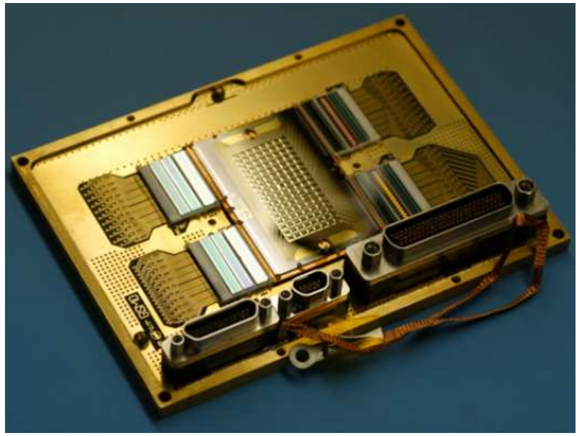
GSFC (J.Staguhn)

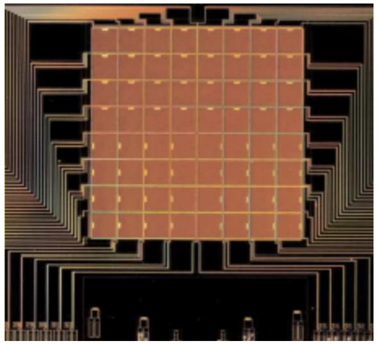
- 8x16 = 128 pixels
- Band: λ=2mm (ideal for high z dusty galaxies)
- 1^{st} filled array (no gap) @ the 30m
- 14"×14" bare-pixels ⇒ 1Fλ, but S/N optimized
- TES detectors (BUG architecture), DC coupled, background limited
- SQUID 4×32 multiplexers & amplifiers (NIST)
- Data recorded in proprietary format after merging with telescope parameters
- 260mK ^{3}He sorption cooler

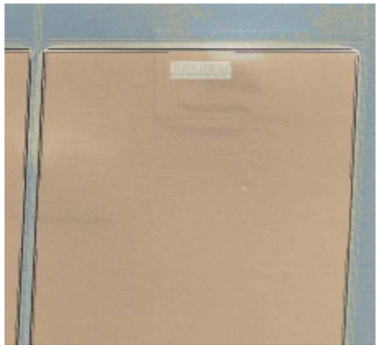


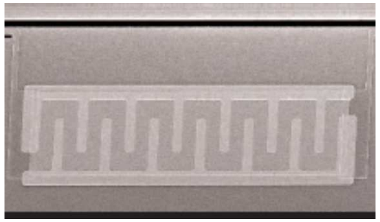
$NEP_{pixG} \sim 40\ aW/Hz^{1/2}$











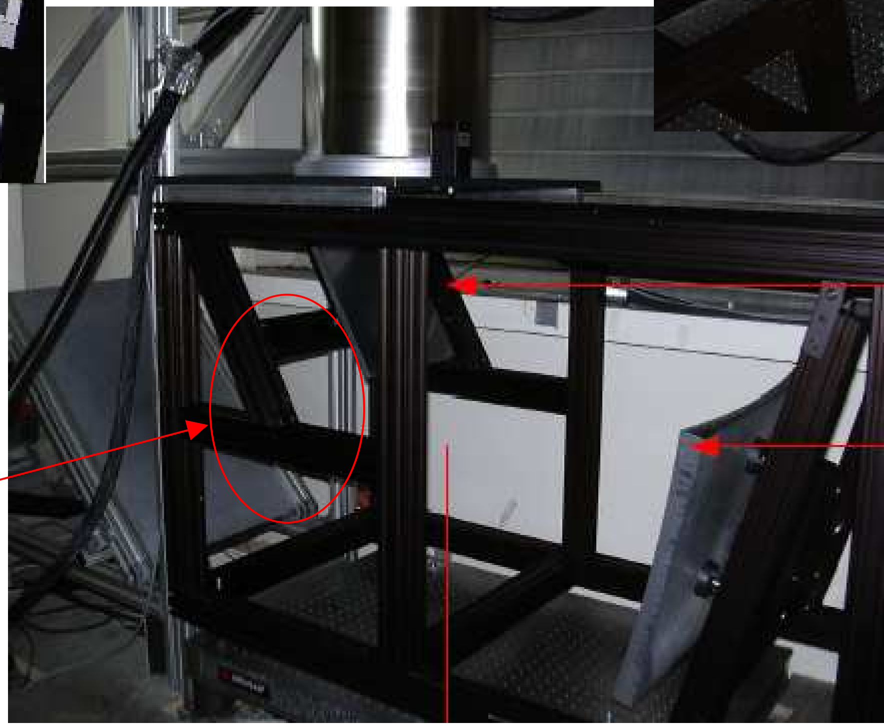
2.

GISMO 1st run (11/2007)

In the 30m receiver cabin

GISMO in front of M3 (elevation>30°)

Electronics



M5

M6

New M8 (Goddard)

New M7 (Goddard)

Telescope focal plane

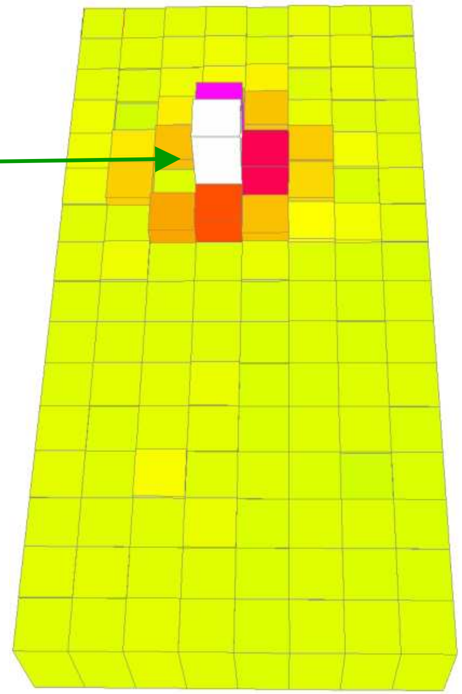
2.

GISMO 1st run (11/2007)

Tests, alignment, 1st light

25% pixels dead (bias line broken), 25% weird, 50% good.

Alignment and focus easy thanks to real time monitoring (hand in beam, liquid N_2 load, Mars).



Problem: apparent bigger FOV than M6 allow ⇒ hot stop on cryostat window ⇒ aperture < 30m (2008 studies showed the problem was due to the baffling).

Interface between GISMO and telescope data, control of pixel bias via SQUIDs feedback, pointing, wobbling: all OK.
Saturate on strong source (>35pW) even with 45% grey filter.

Observations showed no benefit for using the wobbler (OnOff) .

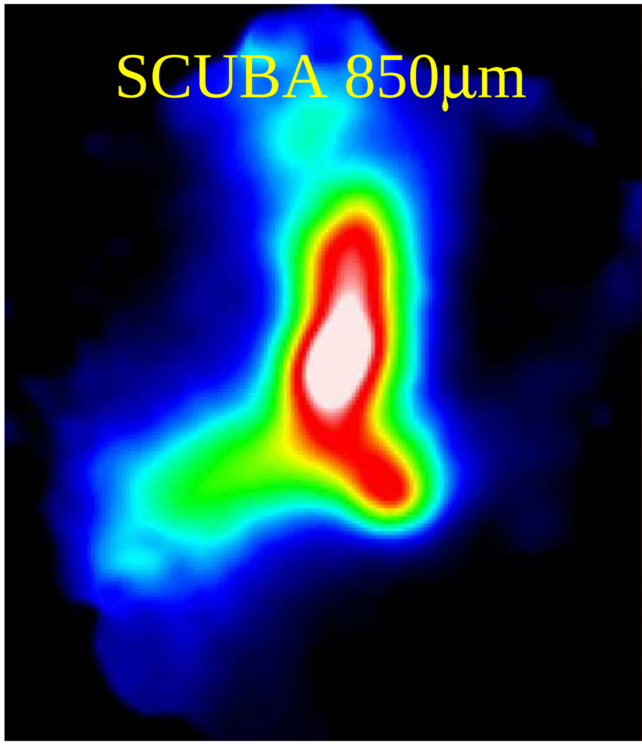
Very good weather (<1mmwv most of the time).

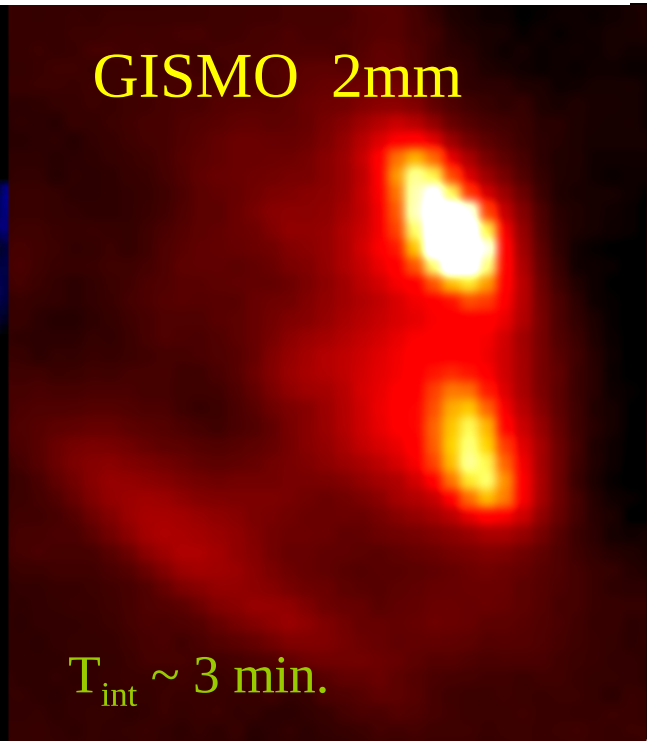
2.

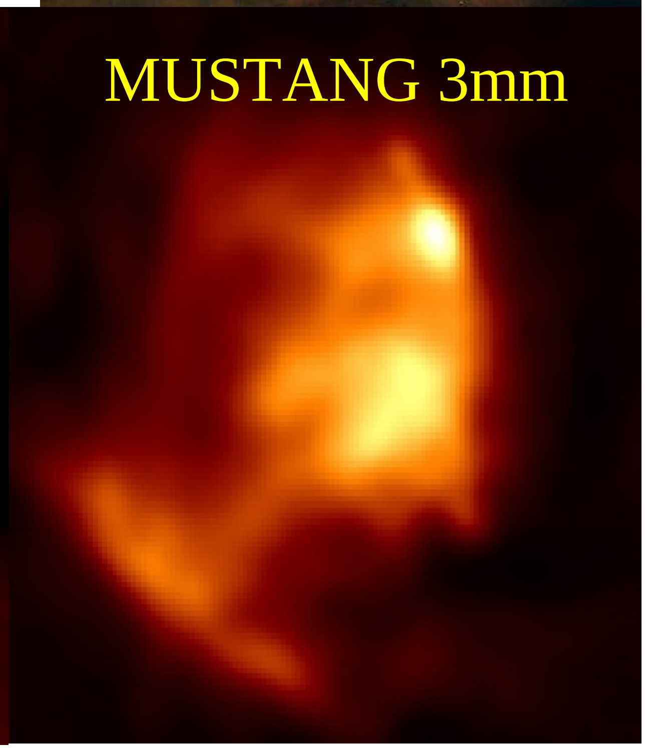
GISMO 1st run (11/2007)

Some astronomical sources

Orion Nebulae



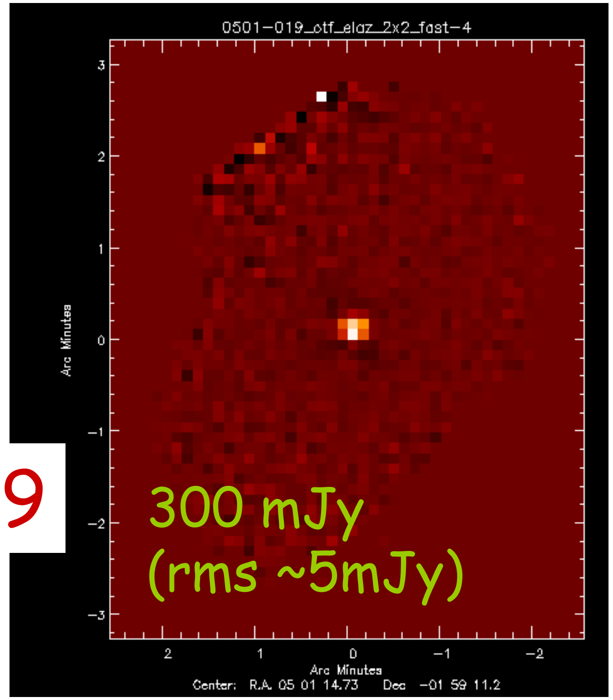




2.

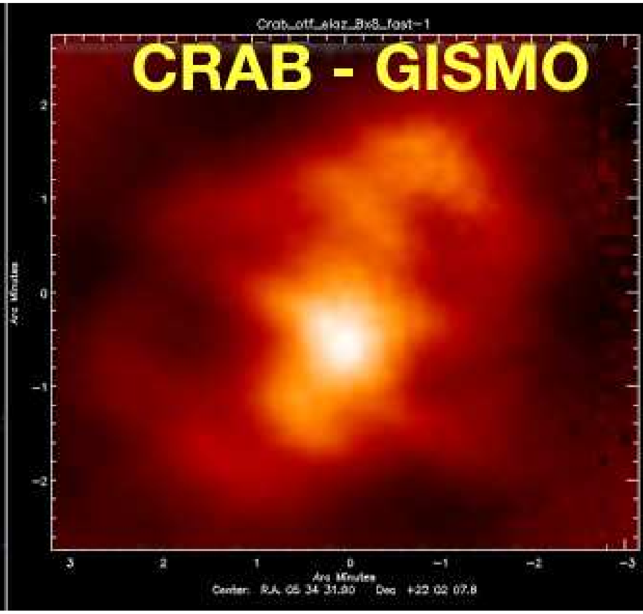
GISMO 1st run (11/2007)

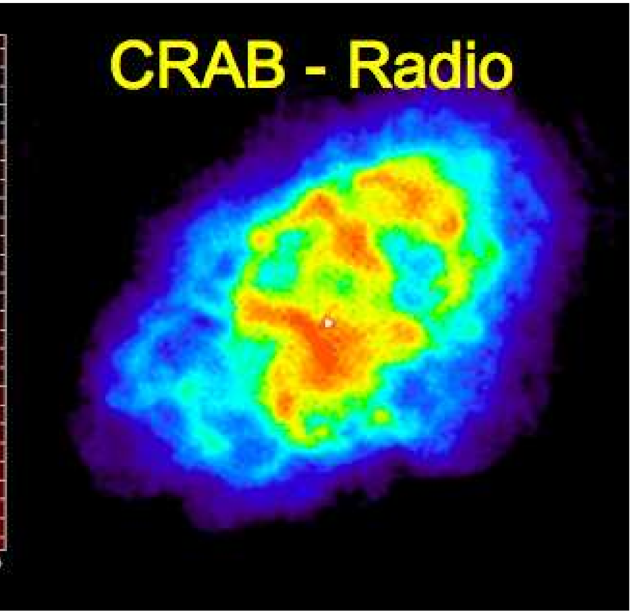
Some astronomical sources



Quasar J0501-019

Crab Nebulae

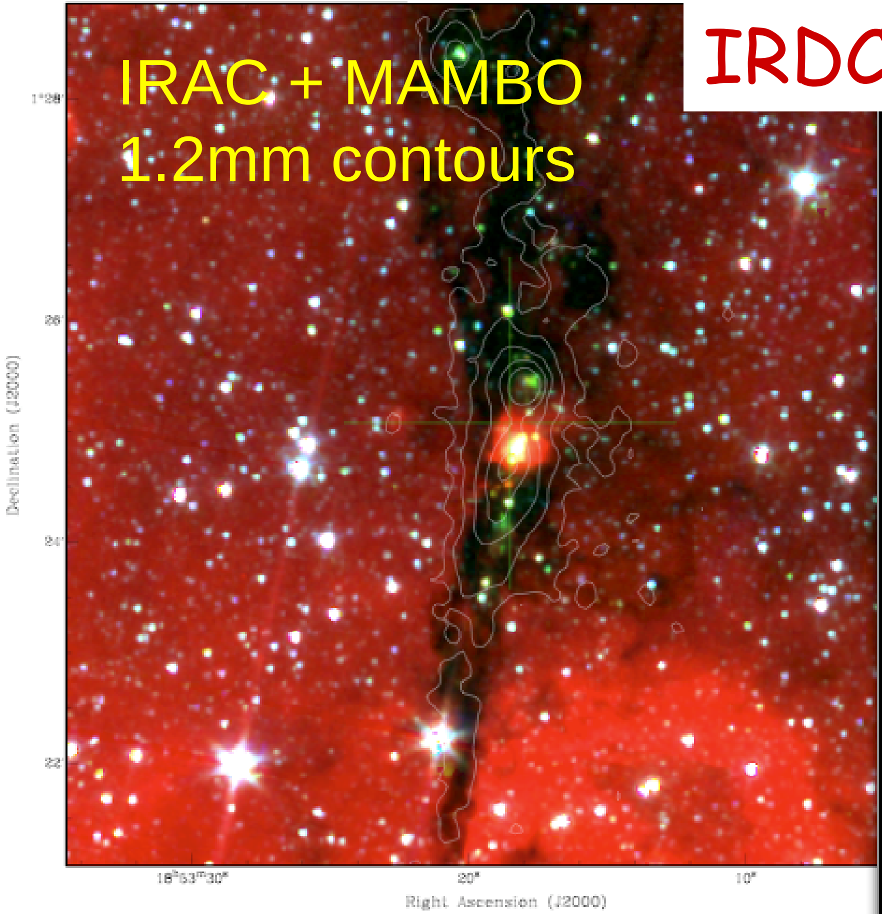


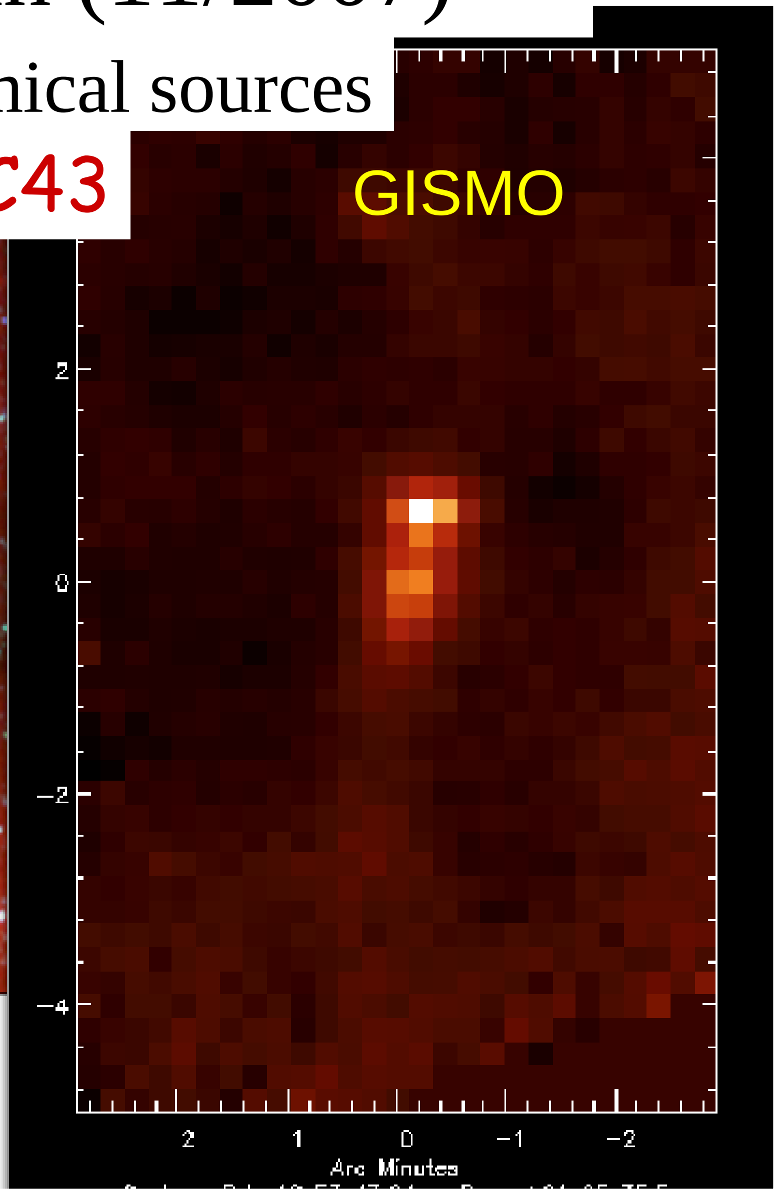


GISMO 1st run (11/2007)

Some astronomical sources

IRDC43





2.

GISMO 1st run (11/2007)

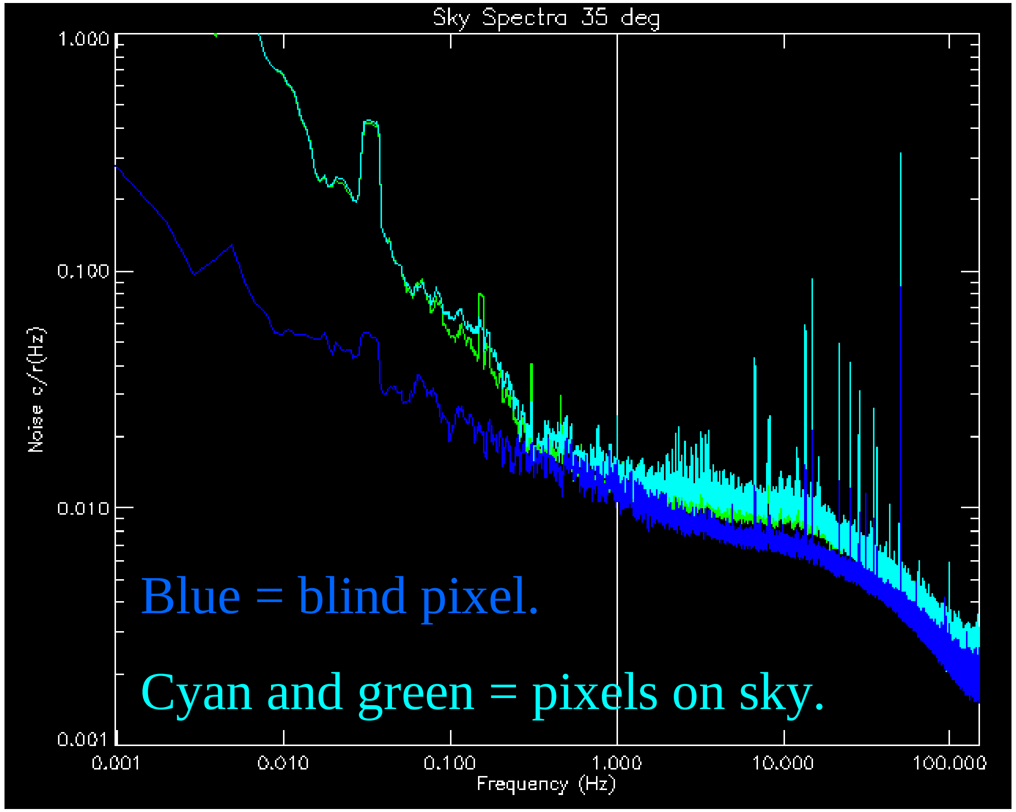
Observations outcome

Sensitivity observed: rms ~ 15 mJy after 10 min ⇒ ~ 100 mJy in 1 sec

Corrections:
- 50% of bad pixels
- Additional aperture stop
- "high" background (sky and mirrors)

Estimated system NEFD~15mJy·$s^{1/2}$
- Observed weak sources
- Skydips
- ~20% background from optics

(8 mirrors = 16K, good sky = 40K)

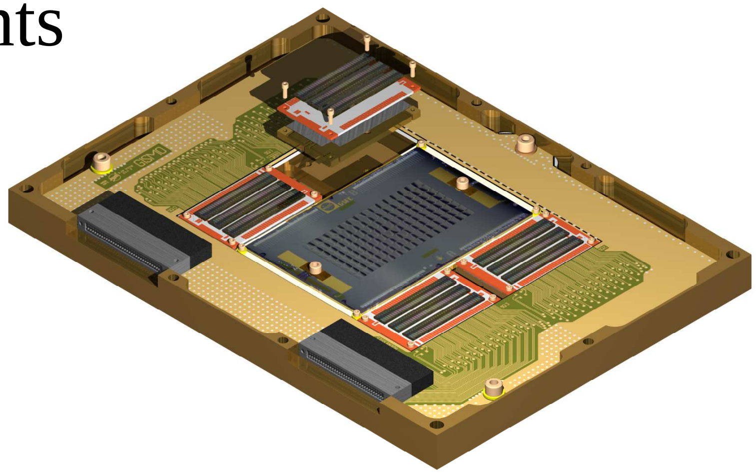


Major issues: hot spillover / warm optics / bad pixels / electromagnetic pickup / MUX shielding / grey filter / observing modes (all OTF) / data handling & reduction

2.

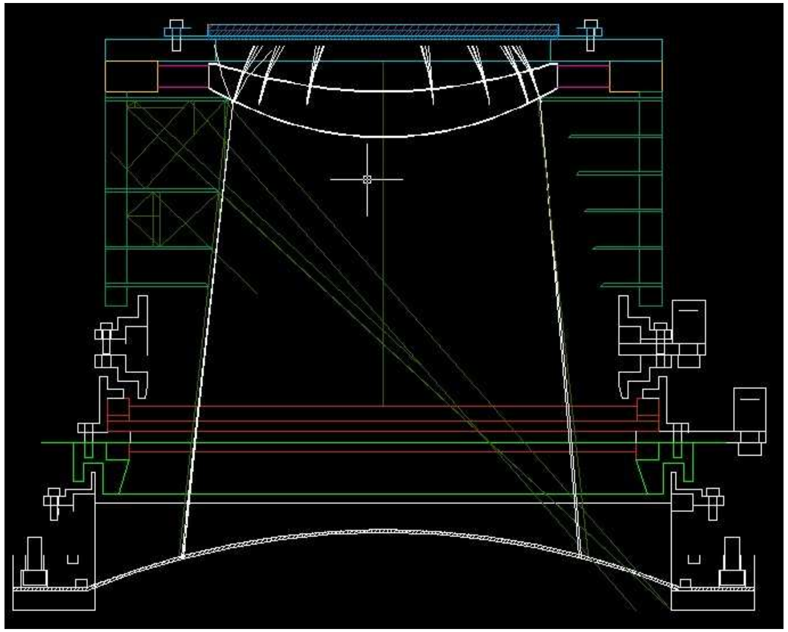
GISMO 2nd run (10/2008)

Improvements



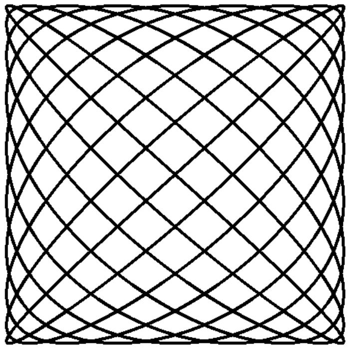
Detector:

- New detector circuit and readout boards (new biasing lines, more robust)
- Better magnetic shielding of SQUIDs
- New cold baffles
- Shutter (no neutral density filter)
- Battery opto isolated
- Software (SQUID tuning & data)



Telescope:

- Lissajou observing mode
- PAKO routines for GISMO



2.

GISMO 2nd run (10/2008)

Tests, alignment, 1st light

>80% pixels working, but a ground loop cause a crosstalk from the SQUIDs of one column to others ⇒ shutdown 25% pixels.

Good detector noise spectra with dewar window closed, much better than 1st run in receiver cabin.

Interface GISMO-telescope, pixels control, observing modes: all OK.

Internal calibration source not usable due to LED misalignment.

Worst weather than 1st run (very cloudy).

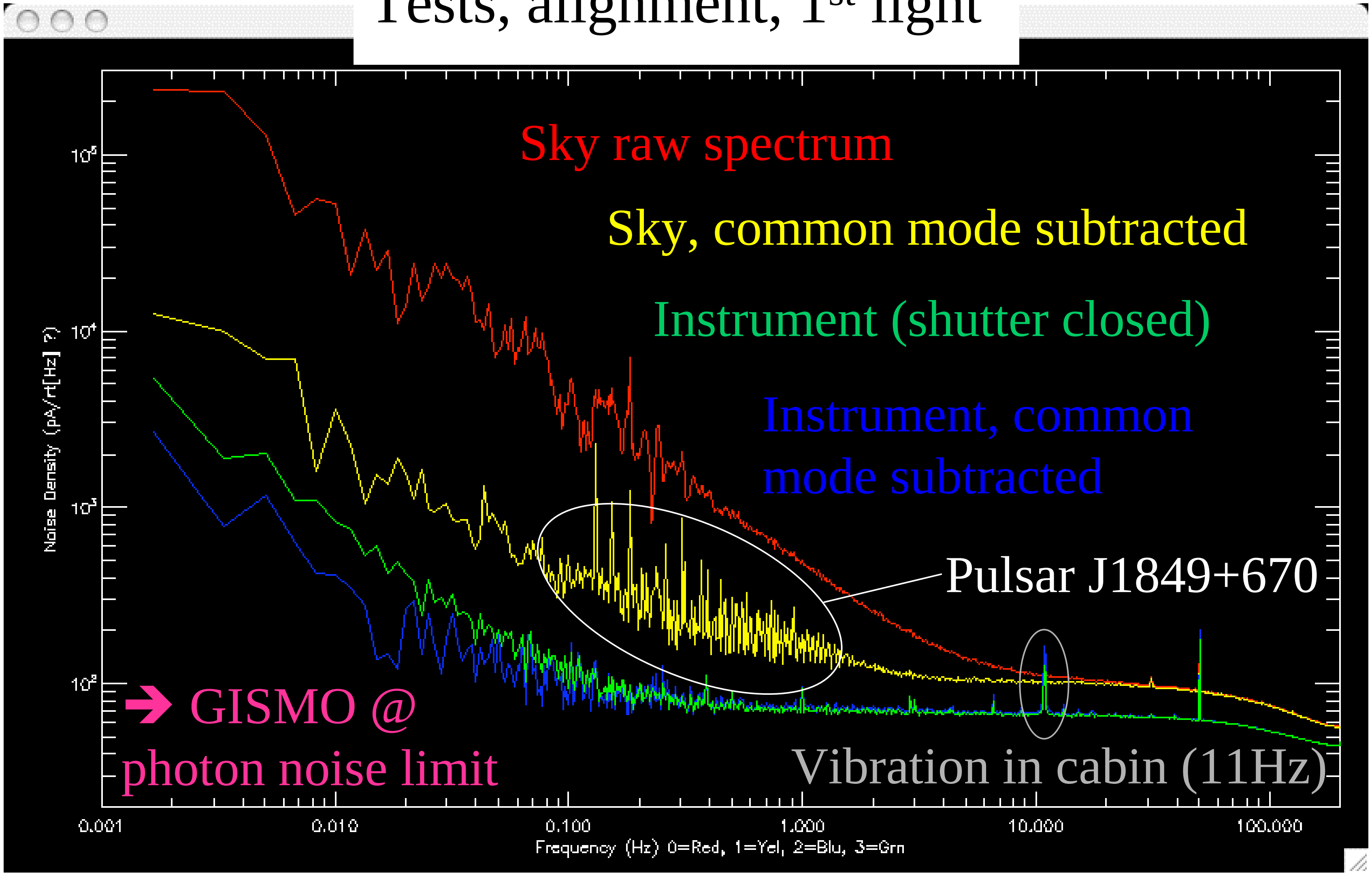
1st order data reduction software OK.

Sweep telescope ⇒ pickup of earth magnetic field ⇒ much lower than sky photon noise (and than 1st run) ⇒ good SQUIDs shield.

2.

GISMO 2nd run (10/2008)

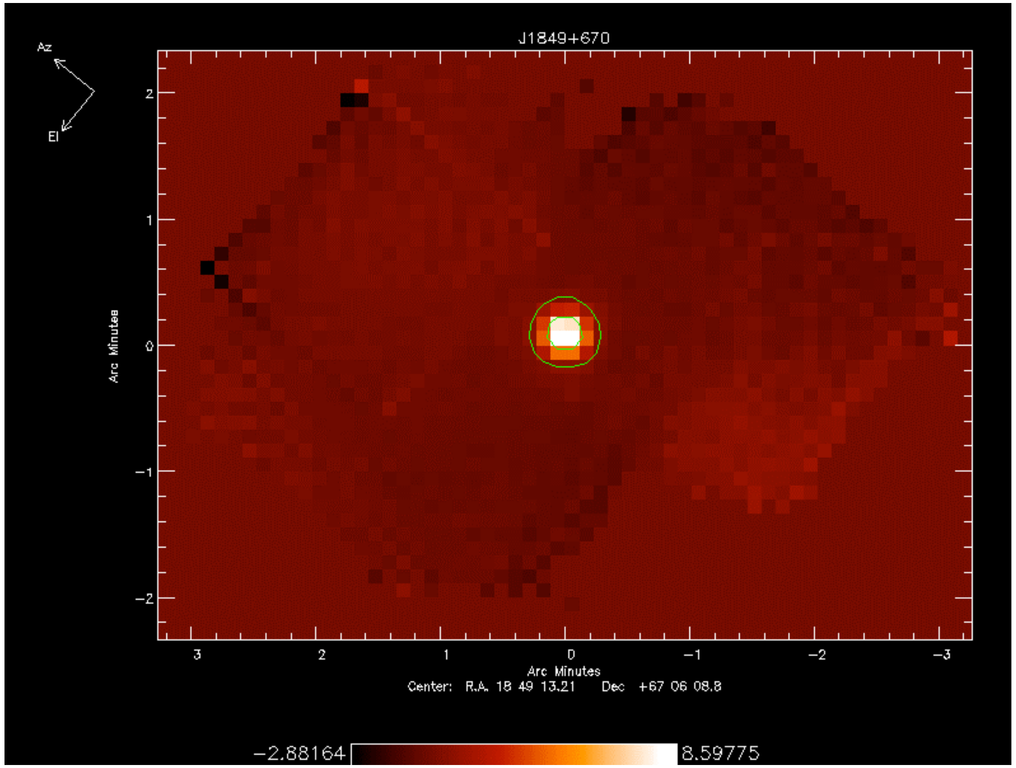
Tests, alignment, 1st light



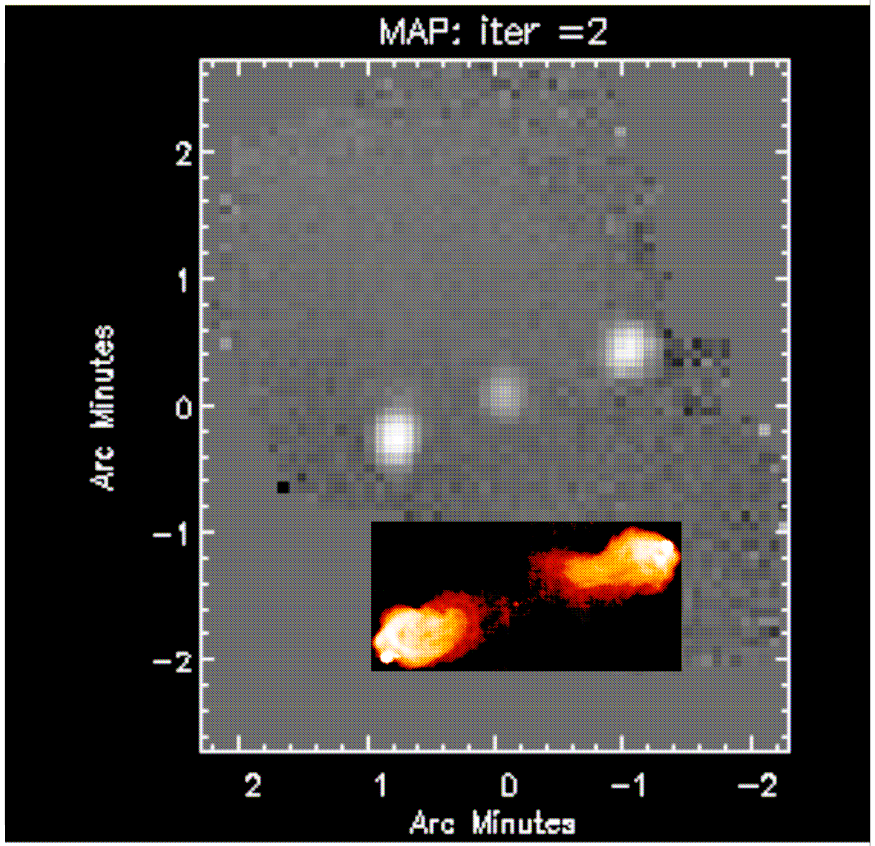
GISMO 2nd run (10/2008)

Some astronomical sources

Pulsar J1849+670



Cygnus A

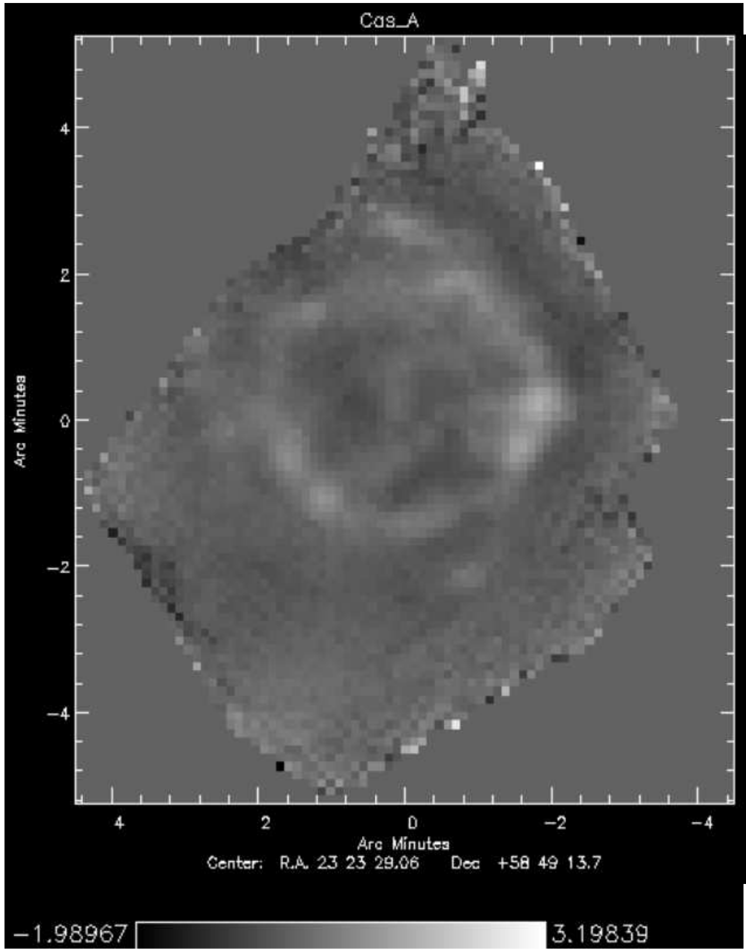


grey: GISMO 2mm, color insert: VLA 21cm

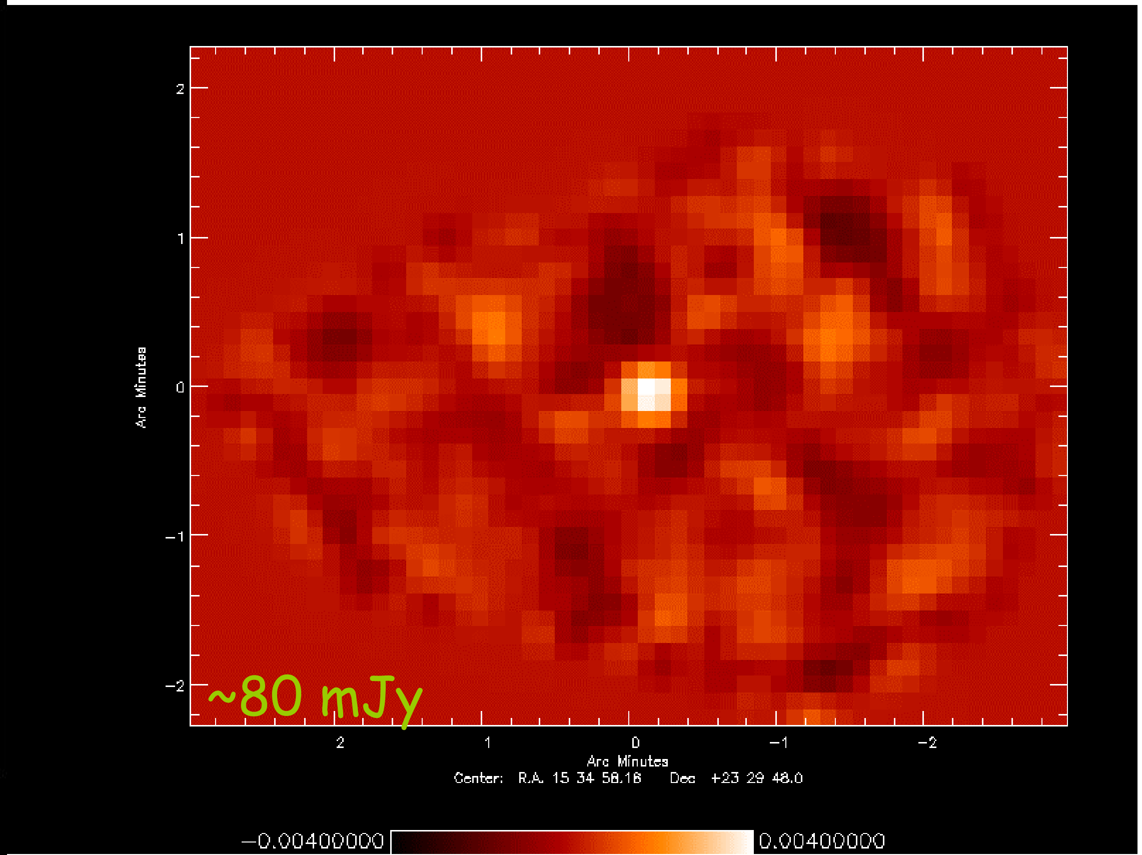
GISMO 2nd run (10/2008)

Some astronomical sources

Cassiopeia A



Arp 220

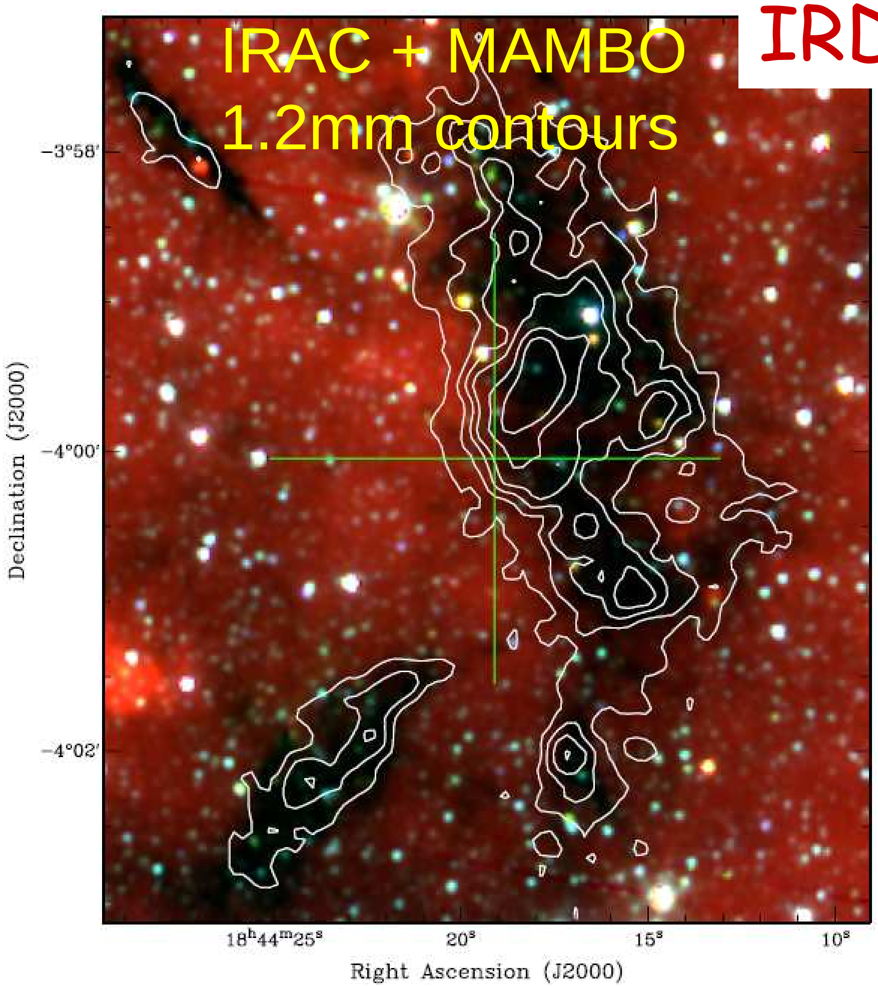


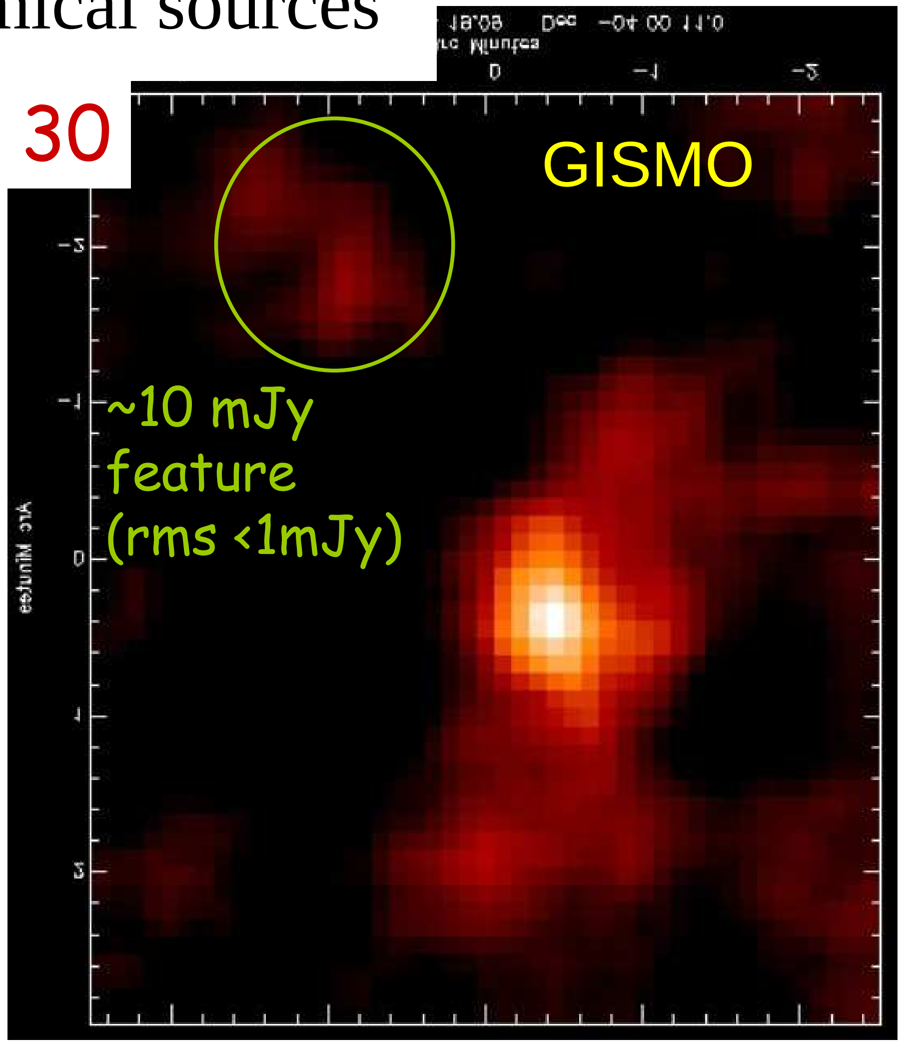
2.

GISMO 2nd run (10/2008)

Some astronomical sources

IRDC 30





2.

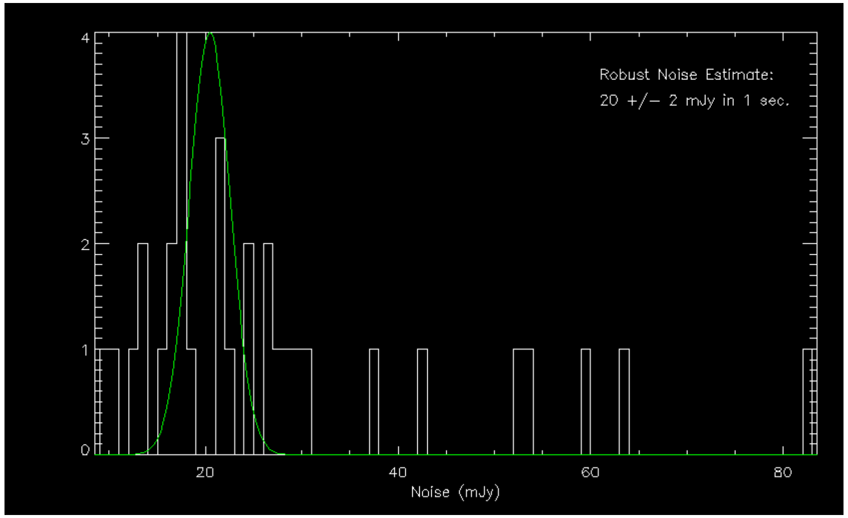
GISMO 2nd run (10/2008)

Observations outcome

NEFD~20mJy·s$^{1/2}$ from pixel time streams ~ close to background photon noise (bad weather).
But maps show ×5 higher noise ⇒ problem with pixel gain in data reduction ?

Main improvements of run 2 vs run 1:

- Decrease in pickup noise & hot load on detector.
- Pixel yield significantly improved.
- Stray beam eliminated.
- One ground reference for the instrument.
- Enhanced tunability of SQUIDs and detectors.
- Mapping efficiency using Lissajous scan pattern.



The results from run 2 include:

- High-quality image of Cygnus A, an image of Mon R2 IRS 2.
- High redshift sources (APM08279+5255, SDSS J1148+5251, PKS 2322+1944,…).
- Cold dust content of Arp220, NGC 660, NGC 1068 and NGC 891
- Map of Orion molecular cloud including OMC-2, and OMC-4, and IRDC30.
- Numerous quasars and stars as system characterization.

Issues: noise in maps (in progress) / SQUIDs crosstalk (fixed) / calibration LED (fixed)

3.

Other bolometer prototypes for the 30m

History & collaborators

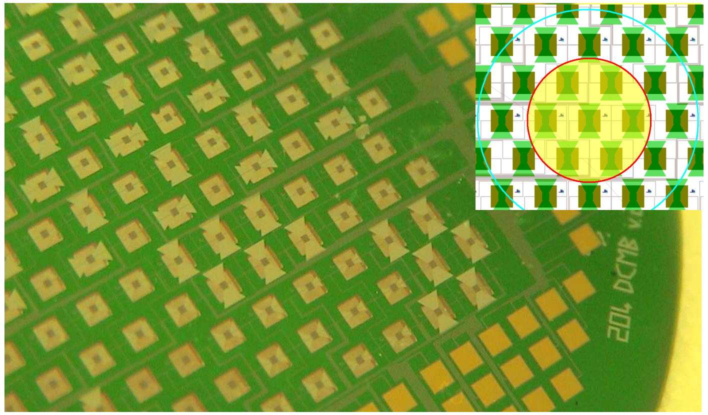
- 2 years ago we sent a call for letter of interest about new bolometers for the 30m.
- 6 labs answered positively: GSFC, Néel, CEA, Cardiff, MPIfR, SRON ⇒ different technologies: TES, Semi Conductors, KIDs ; filled arrays, feedhorns.
- 10/2008 Bolo technical meeting (Sky noise, Stray lights, …) ⇒ triggered collaboration Néel (NbSi, Cryostat) + SRON (KIDs, FFT cards) + Cardiff (KIDs, filters), GSFC continues with GISMO (TES), CEA and MPIfR have adaptation projects (PACS-ArTéMiS and LABOCA) but currently inactive.
- Ph.D. student (M. Roesch) @ IRAM started KIDs studies with Néel.

3.

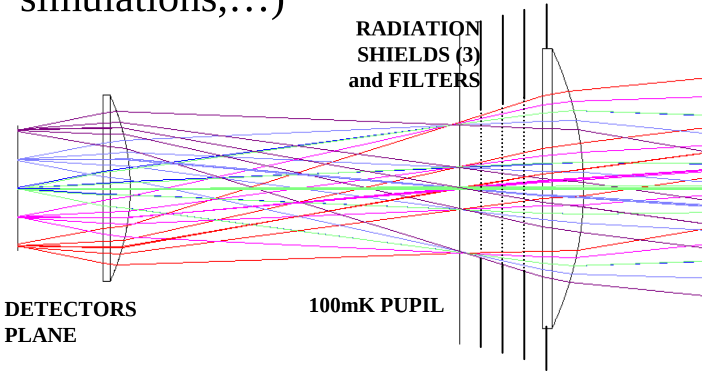
Other prototypes

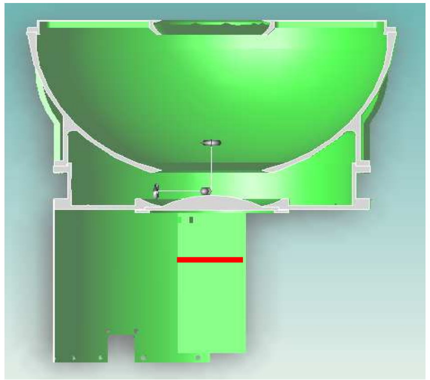
Néel/DCMB (A.Benoit)

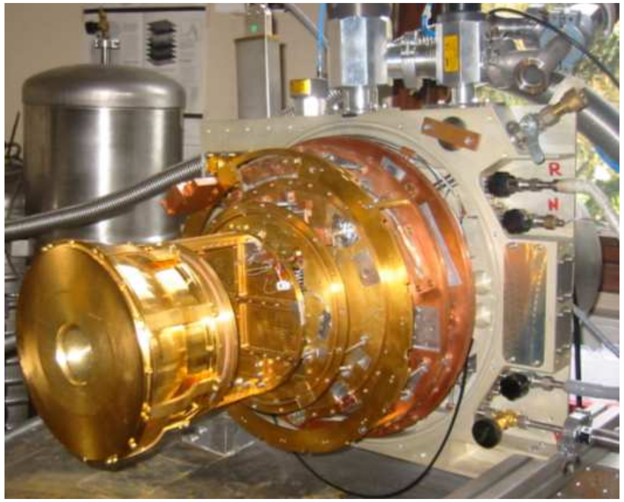
- Nb_xSi_{1-x} high impedance
- 204 microbolometers
- Antenna-coupled
- Diffraction limited (ν = 220GHz)
- 2x2mm^2 pixels, λ = 1.5, 2, 3 mm
- Time domain multiplexing (QPC-HEMTs)
- 120K JFETs amplifiers
- Telecentric system (high Strehl ratio), HDPE lenses
- 100mK ^{3}He-^{4}He dilution fridge optimize dynamic
- Horizontal cryostat with cold baffle
- Other works in DCMB (TESs, SQUIDs, Hot e-, KIDs, simulations,…)



Tests: good homogeneity, thermal & electrical responses, BUT η_{pix} < 5% !







3.

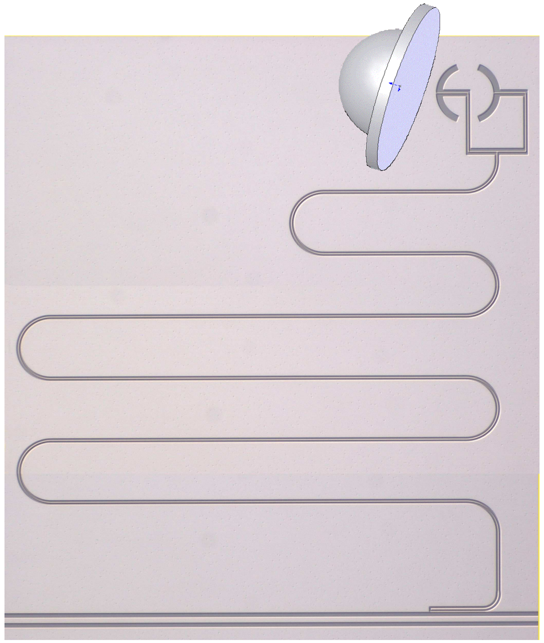
Other prototypes

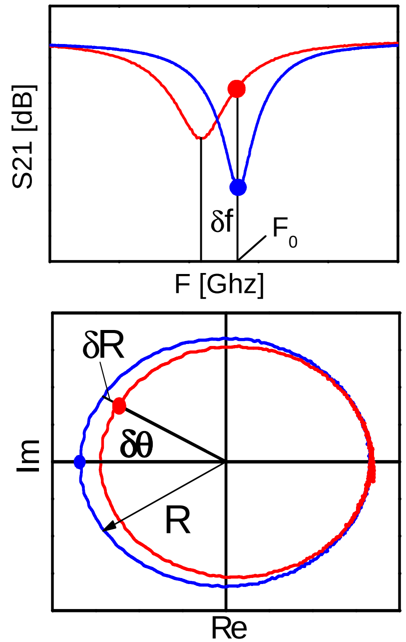
SRON (A.Baryshev) / Cardiff (Ph.Mauskopf)

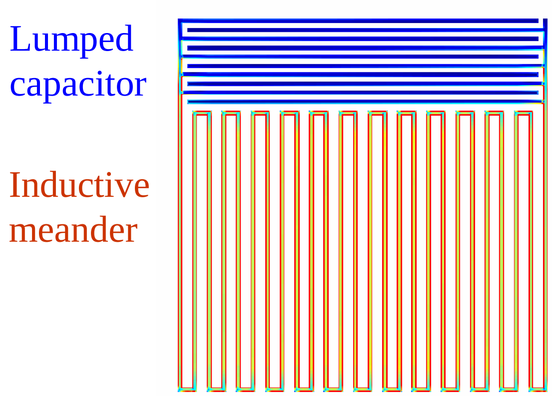
- KIDs (SPICA-SAFARI)
- Need micro lenses array
- Very low dark lab NEPs

- TES (SCUBA2, CLOVER)
- LEKIDs
- Filters
- Lenses coating, polarizer, FTS, modeling

KIDs: photons break Cooper pairs, create quasiparticles, change kinetic inductance
⇒ system resonance (A, f, Φ) ; simple manufacture & kilo-pixels multiplexing





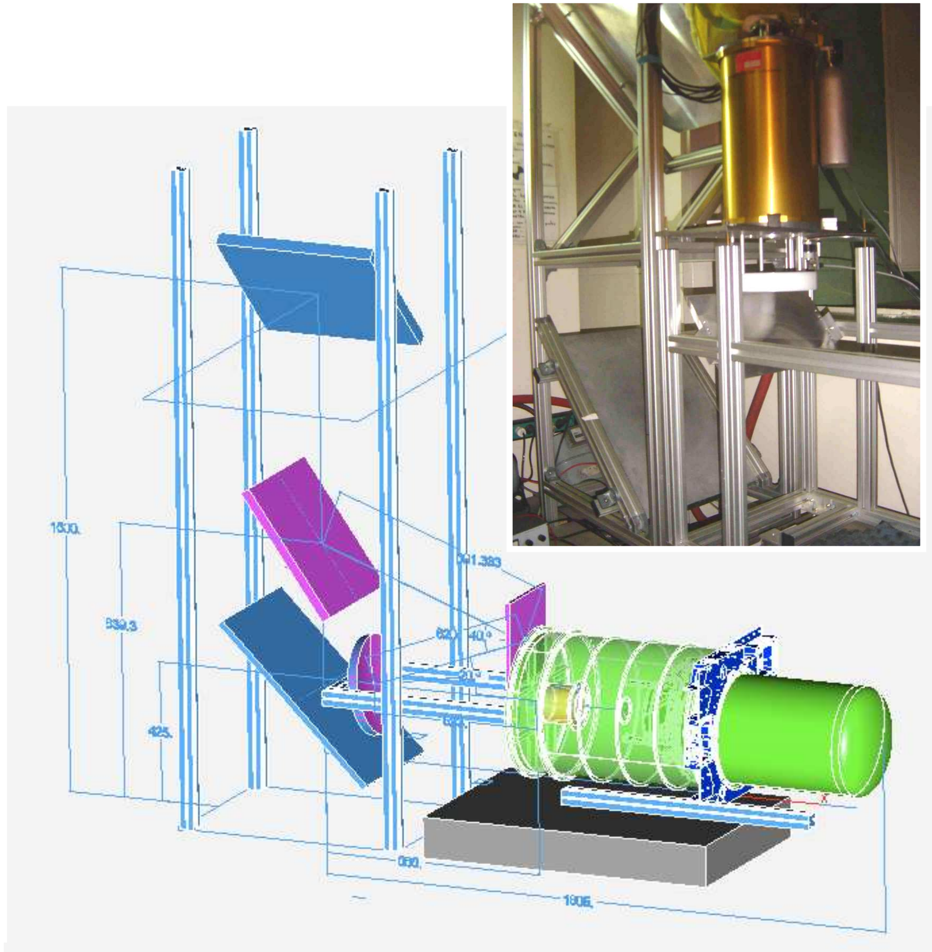


3.

Other prototypes

NIKA (Néel IRAM KIDs Array) or DCMB

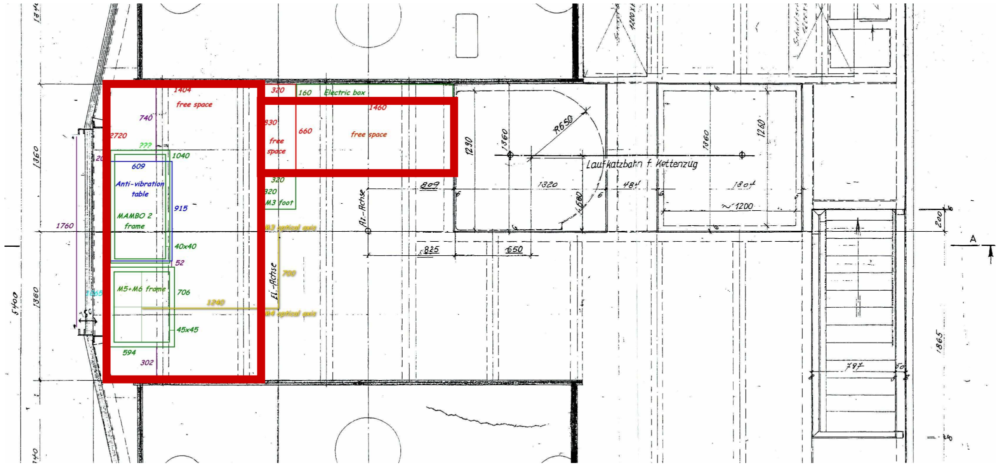
- [Néel + SRON + Cardiff + Roma La Sapienza + MPIfR + IRAM]
- Collaboration started after October 2008 bolometer meeting at IRAM.
- Goal: 2mm band prototype at the 30m telescope in 2009.
- KIDs (All collaborators) or NbSi (DCMB).
- MPIfR FFTS or Berkeley CASPER boards.
- Néel optical cryostat.
- Filters (Cardiff / Néel).
- HDPE lenses and 3 mirrors (Néel + IRAM).
- Interfacing with telescope position data (Néel + IRAM).



Other prototypes

Requirements to test a prototype at the 30m

- Array with at least 32 pixels fully characterized with lab tests.
- Sensitivity for useful tests and first light science: $\eta_{pix} \geq 0.5$ & $NEP_{inst1F\lambda} < 10^{-16} W/Hz^{1/2}$
  $\Rightarrow$ good weather: NET~0.5mK·s$^{1/2}$, NEFD~8mJy·s$^{1/2}$, $t_{10mJy@3\sigma}$ ~ few seconds.
- Preliminary frequency range of optimization is 1-20 Hz, noise spectra will be taken.
- Optical measurements: valuable illumination of the telescope and no stray-light.
- Instrument control & mapping software OK to avoid down time during telescope tests.
- The prototype components must fit in the available space in the receiver cabin.



Objective: observation of ~10mK / ~100mJy sources in few seconds...

4.

Conclusion & next steps

- Compared to MAMBO2 the future science grade instrument will have to show a significant improvement in imaging capacities (sensitivity, FOV, number of pixels)
- A number of labs answered our call for this project
- 2 prototypes: GISMO and NIKA
- 2 GISMO runs showed encouraging results
- NIKA is in preparation

- GISMO improvements, instruments switching bench, data processing (SHARC2 → MOPSIC)
- Néel 6 arcmin FOV instrument project (max possible on 4 inches wafer)
- IRAM 7+10 arcmin optics: 2 steps, 3 solutions for motorization studied (Excel/Zemax, motors contractor F.Hidalgo, cinematics A.Perigouard, 3D modeling F.Copé)

4.

Conclusion & next steps