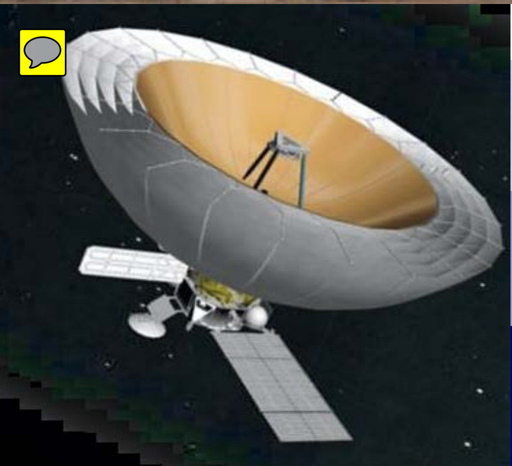


EUCAS 2013, Genova, Italy

Superconducting detectors for Millimetron space mission

A. Baryshev, A. Smirnov, S. Likhachev, V. Koshelets, G. Goltsman, Th. De Graauw, N. Kardashev

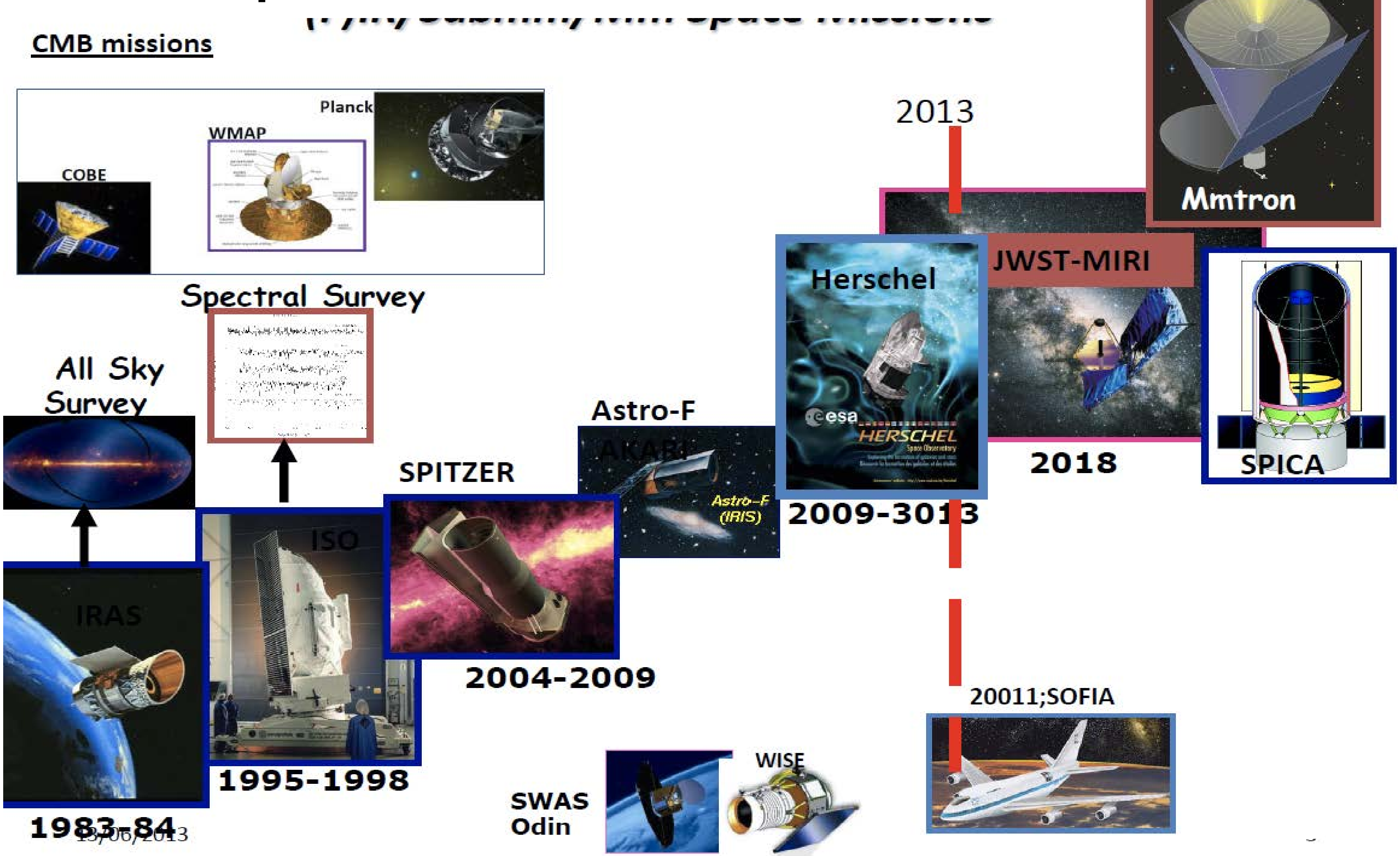
SAPIENZA UNIVERSITÀ DI ROMA

RESHETNEV COMPANY

SRON

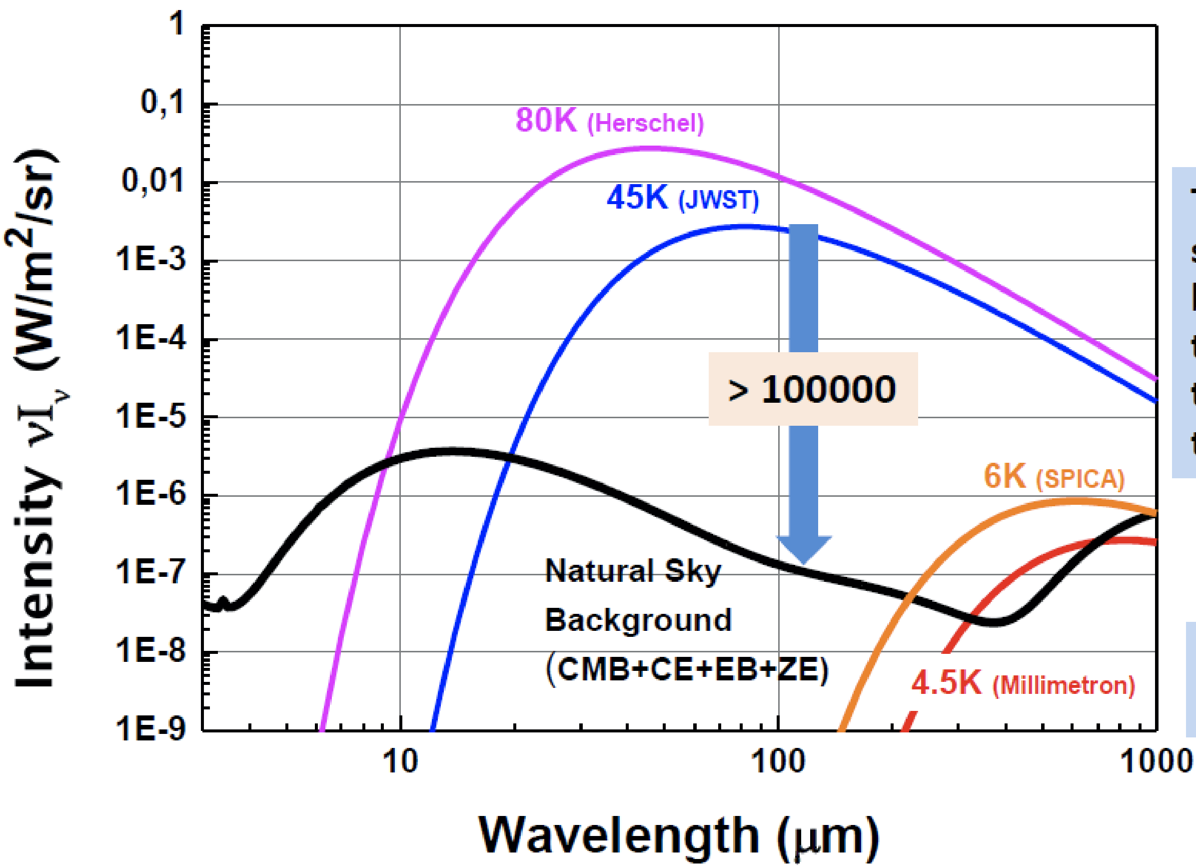
university of groningen

IR Space Missions overview



Scientific requirement for next space missions: low background

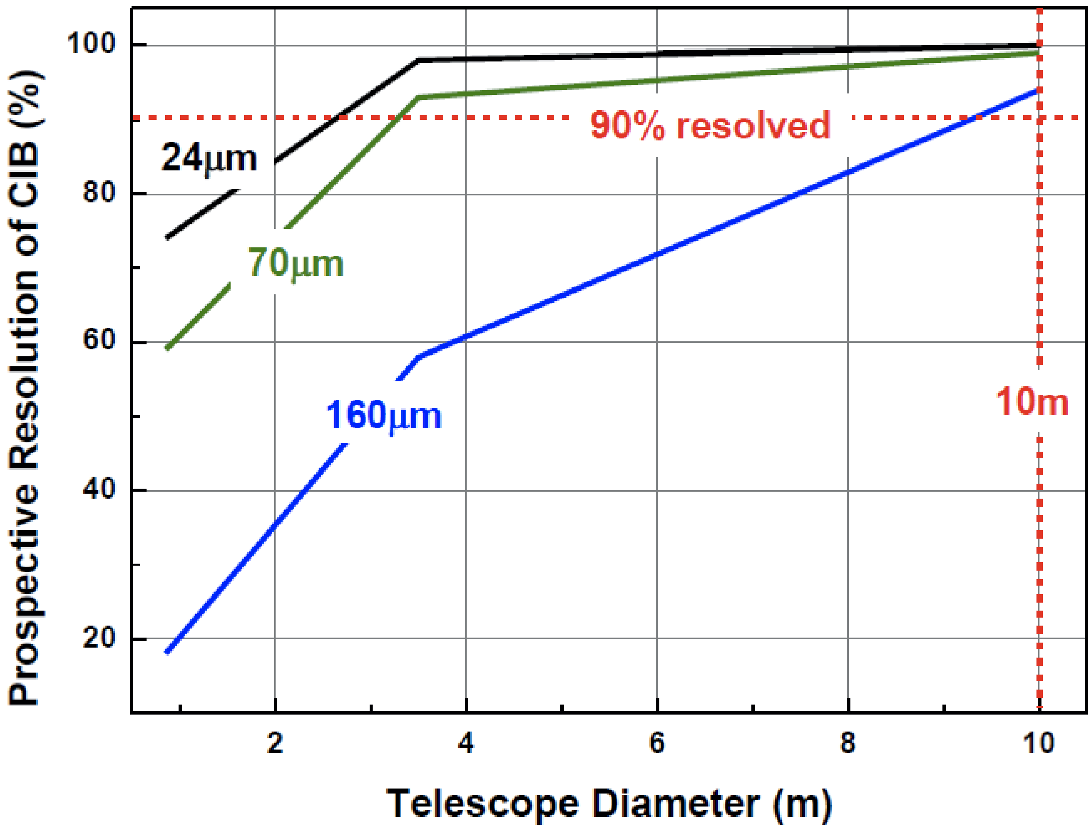
Cold telescope



The intensity of the thermal self-emitted radiation falls below the limit provided by the natural sky background if the telescope is cooled to temperature < 10K

Background limited < 300 μm if $T_{tel} \approx 4.5$ K

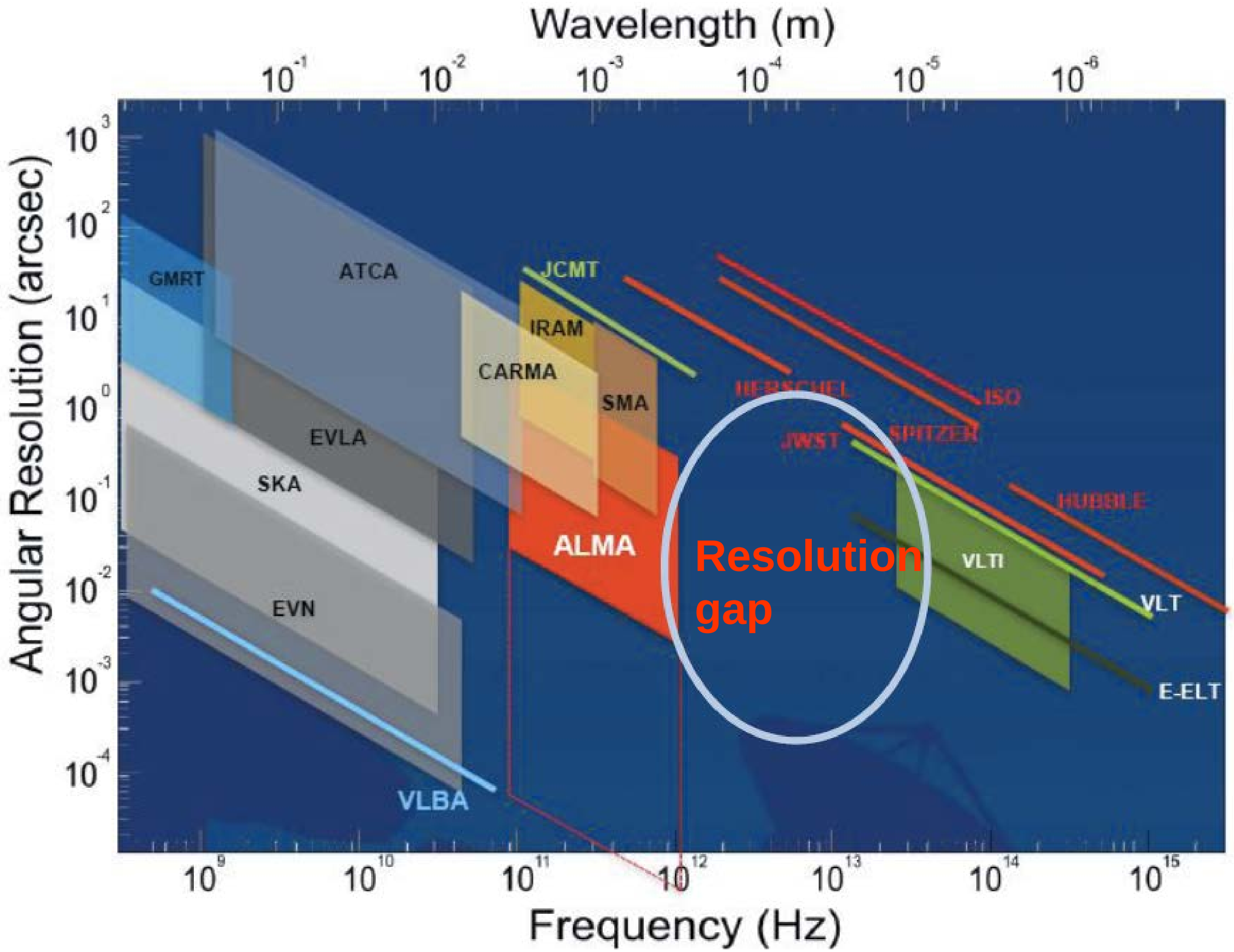
Scientific requirement for next space missions: high spatial resolution



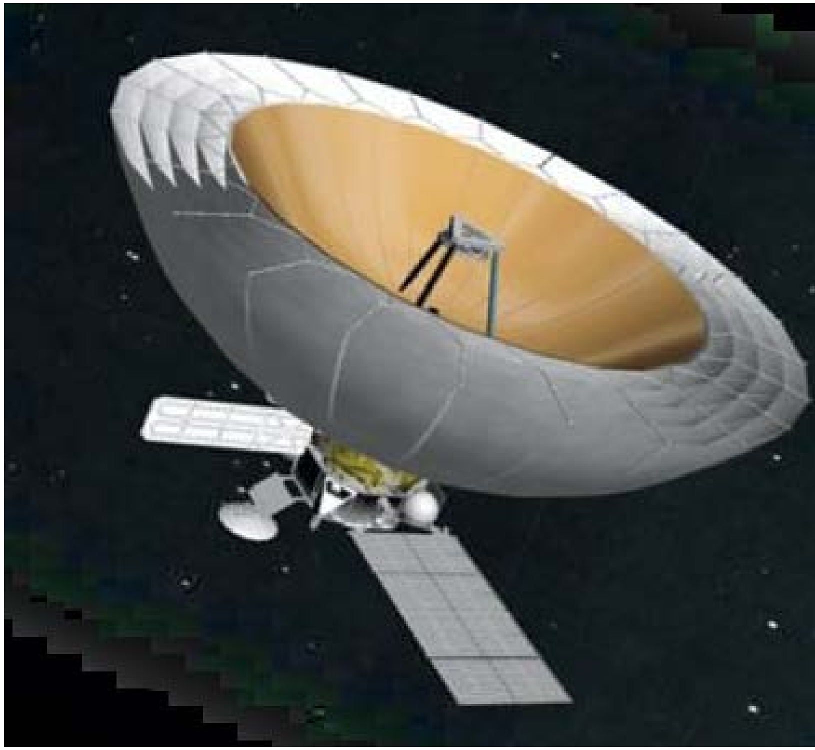
The telescope with a big aperture can resolve more than 90% CIB into individual sources

* Dole, H., Rieke, G. H., Lagache, G., et al., ApJ, 154, 93–96 (Sept. 2004)

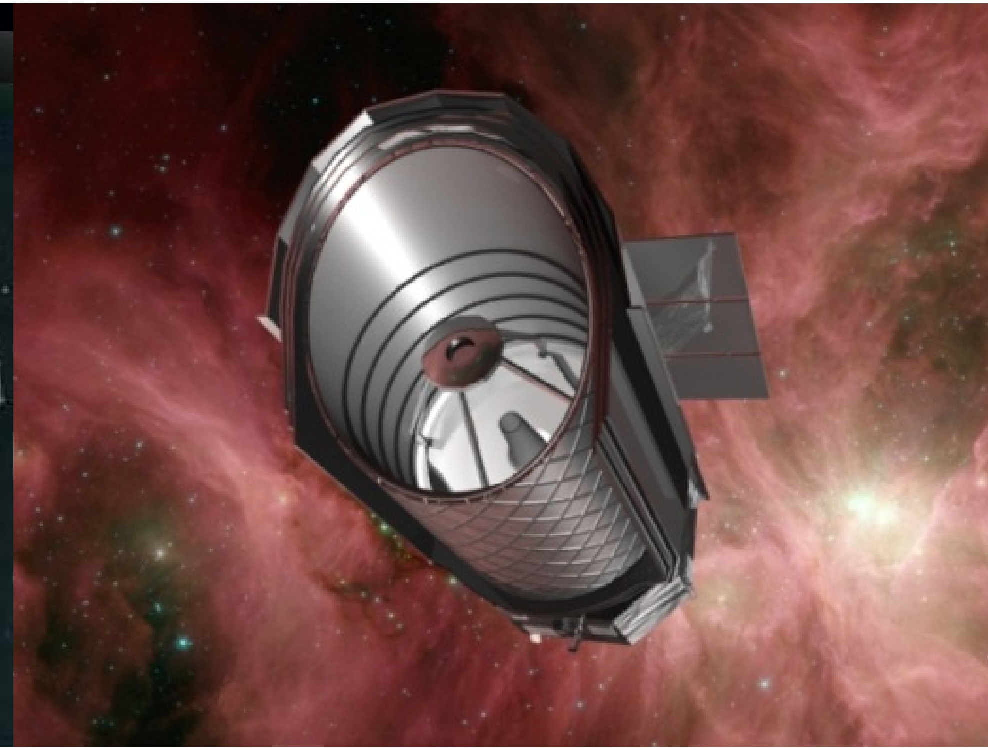
High spatial resolution



Near future space missions: both cold



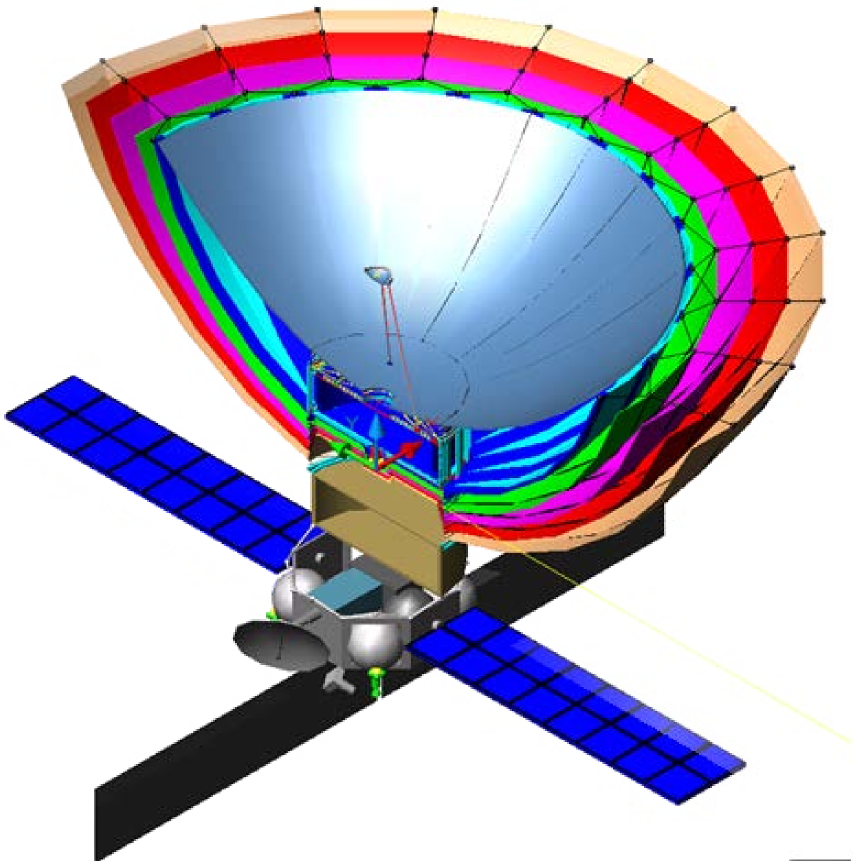
Millimetron/Spectrum-M



SPICA

Both require very sensitive detectors

Millimetron mission overview



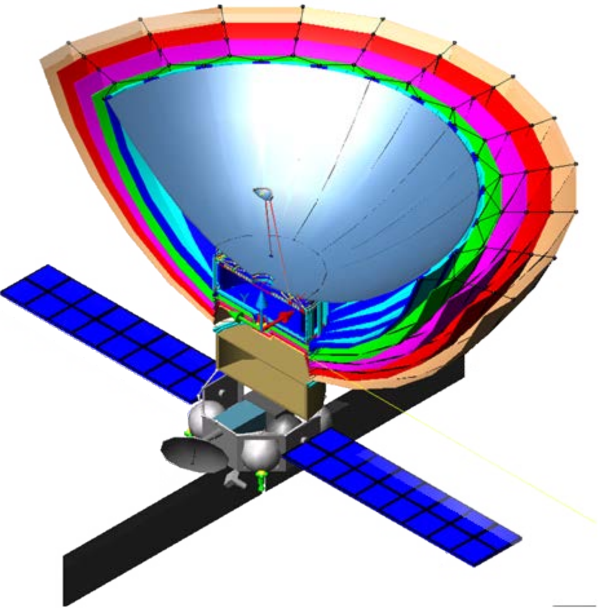
First 10 m class space telescope for - the FIR, submm and mm range
- deployable and adjustable
- mechanically cooled (<10K)with post-cryo life
- L2 orbit - for cosmology and astrophysics

Dual operation modes:
- S-VLBI up to 1 THz
- single dish with observatory-style
- largest array formats flown to-date
- state-of-the-art instrumentation with extensive space technology heritage

Launch date aimed for 2019/2020

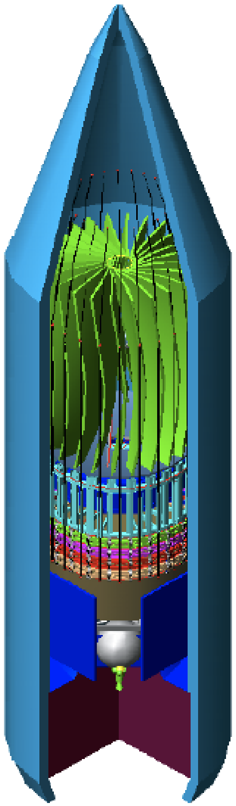
Lifetime: 10 years; at cryo >3 years

Millimetron mission overview, contd.

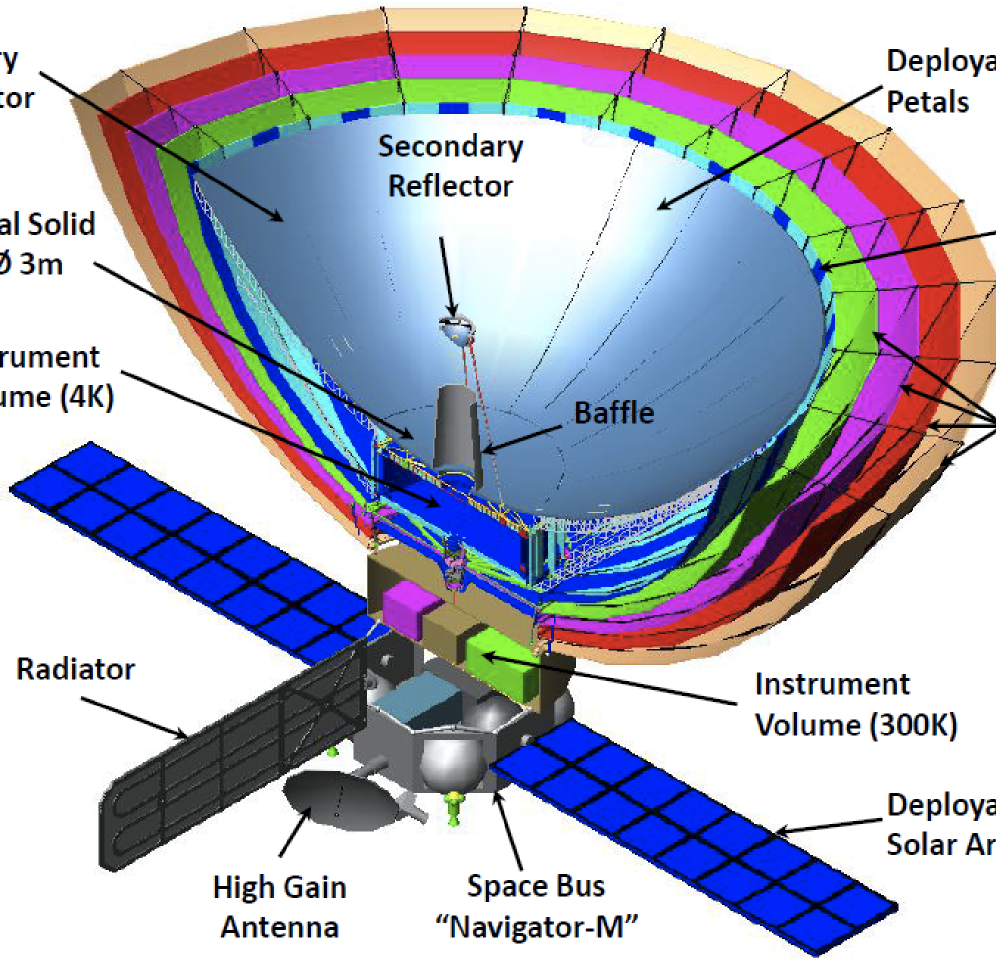


- **Wavelength range: 50 (goal)/150μm – 3mm/17mm(S-VLBI)**
- **Two modes of observation: S-VLBI element and as single-dish telescope**
- **Instruments: Heterodyne and Direct detection (arrays)**
- **Cassegrain system, Primary with aperture Ø10m (≤ 10μm rms) consist of central solid dish Ø3m (≤ 5μm rms) and deployable petals**
- **Cooling: radiation + mechanical coolers**
- **Telescope temperature: < 10K; 4.5 K goal.**
- **Total mass: ≤ 6600 kg**
- **Total electrical power : ≤ 4000 W**
- **Orbit: L2 for the Sun-Earth system**
- **Lifetime: 10 years (3 years with active cooling)**

Millimetron mission concept

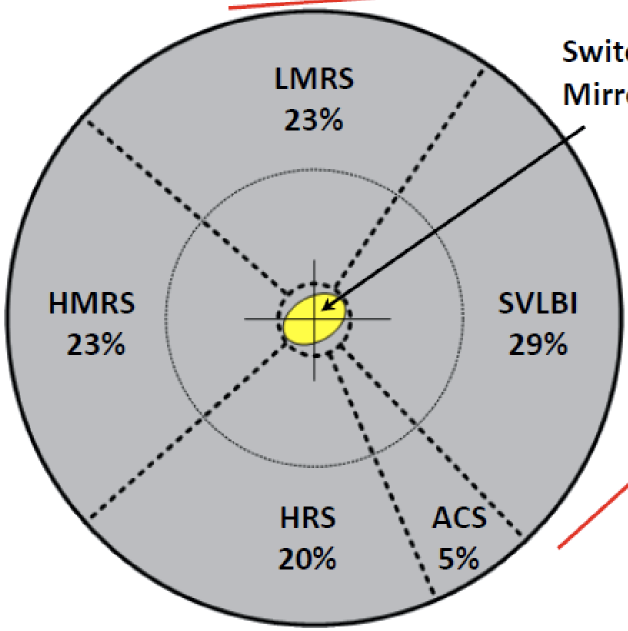


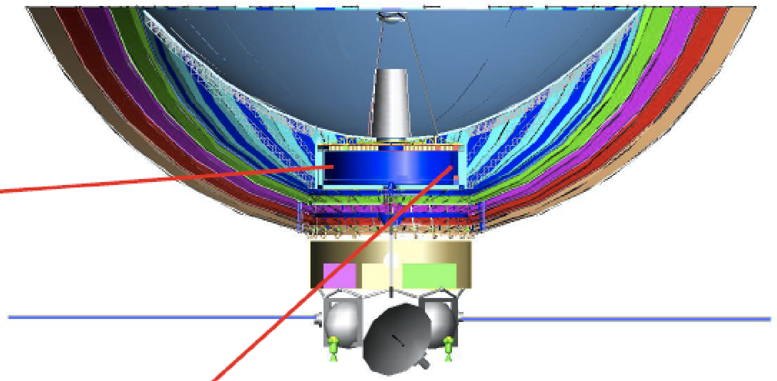
The launch packaging in fairing



Resources available on Millimetron

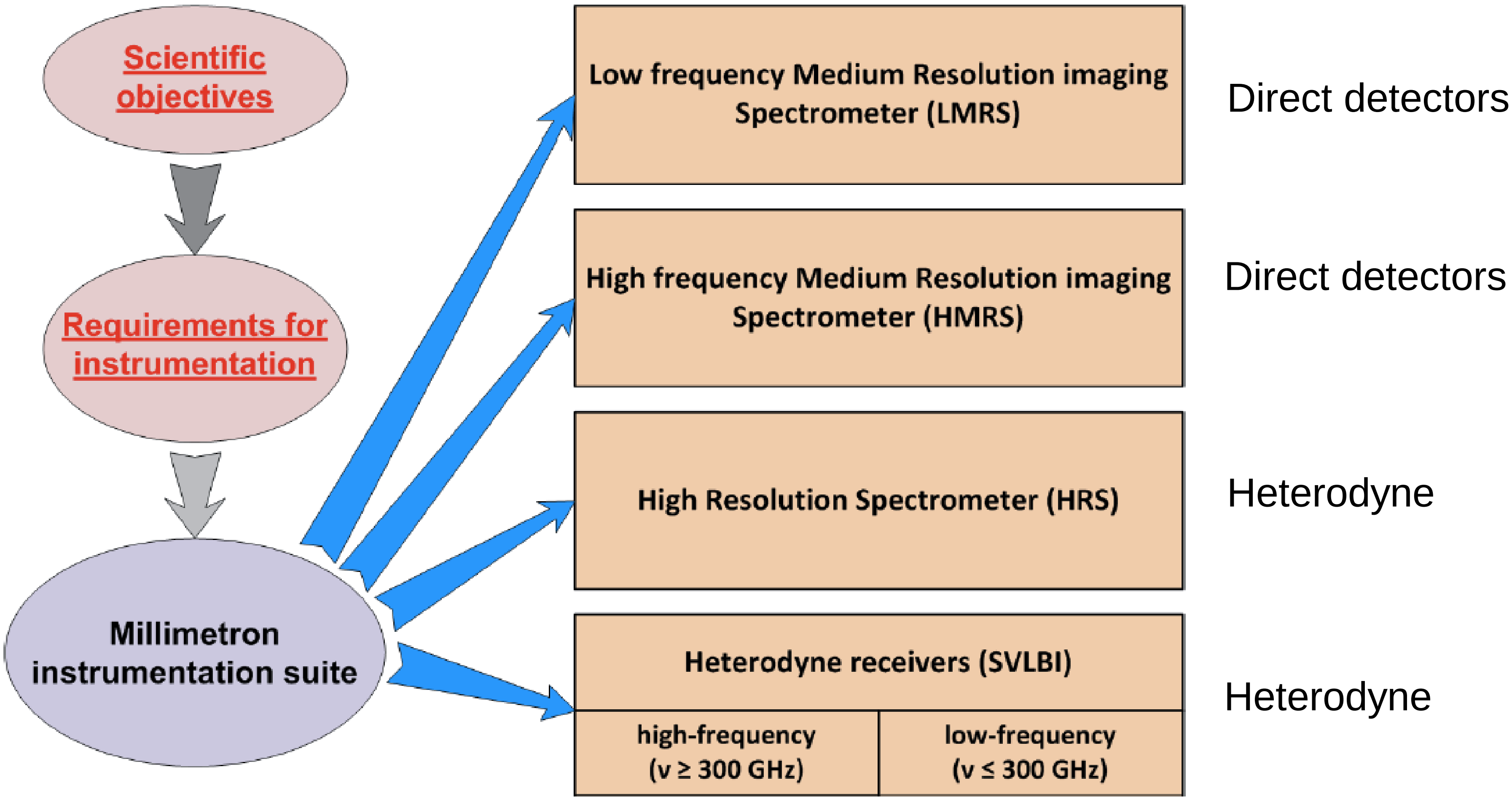
A preliminary sketch of the assembly of instruments in the cryogenic volume





- ✓ Instrument Volume: 2.5   0.8 m (diameter   height)
- ✓ Cold Mass: ≈ 300 kg (with margin)
- ✓ Thermal loads :
  - ≤ 100 mW @ 4.5 K stage
  - ≤ 15 mW @ 1.7 K stage

Millimetron Instrumentation



Detector technology requirements

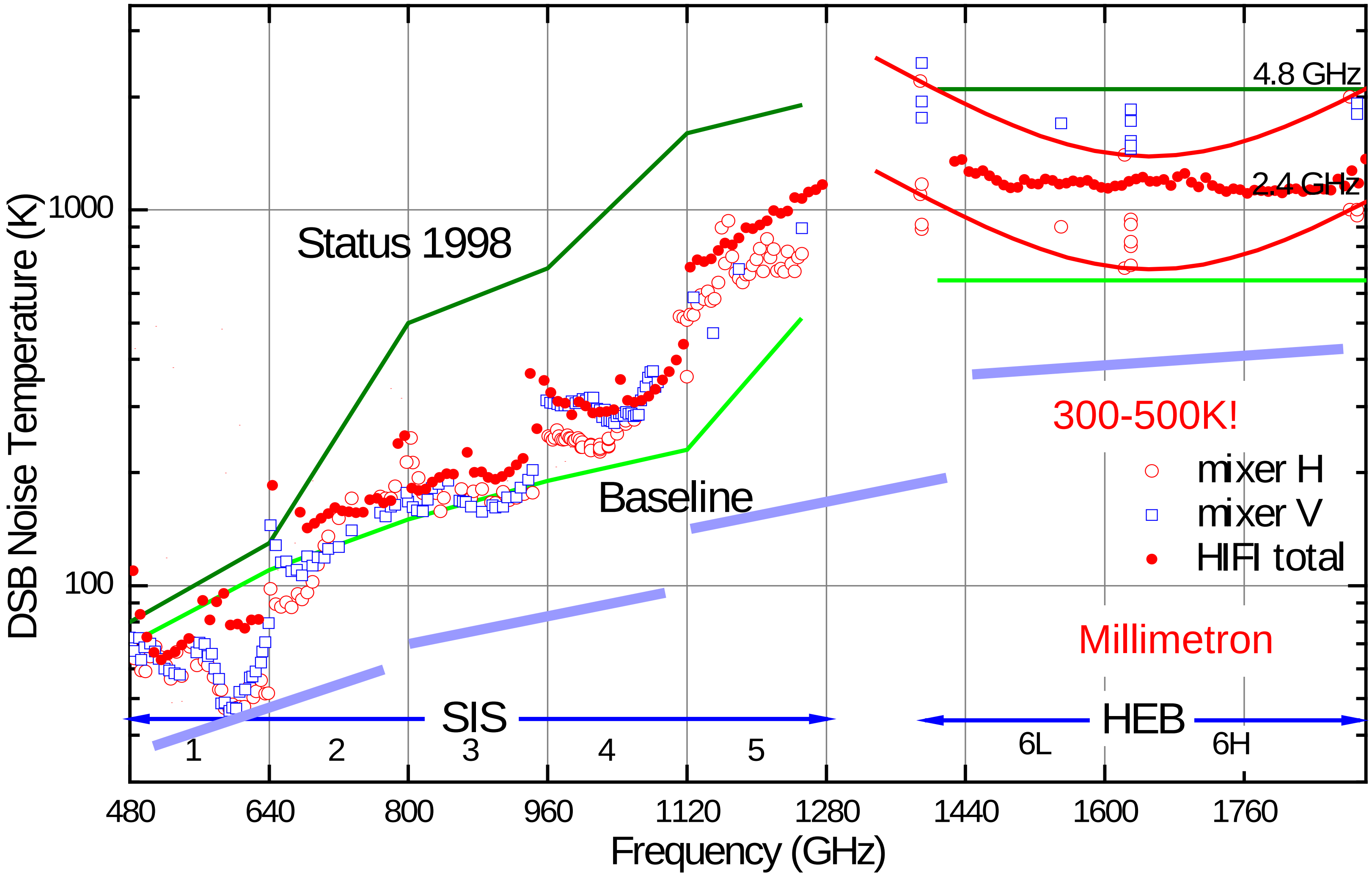
- High Sensitivity
- Low mass
- Low power consumption (also for readout)
- Low power dissipation both ambient and cryogenic level
- Low wire count for many detector pixels
- Vacuum compatibility
- **Low sensitivity for cosmic ray hits**

Heterodyne instruments coverage

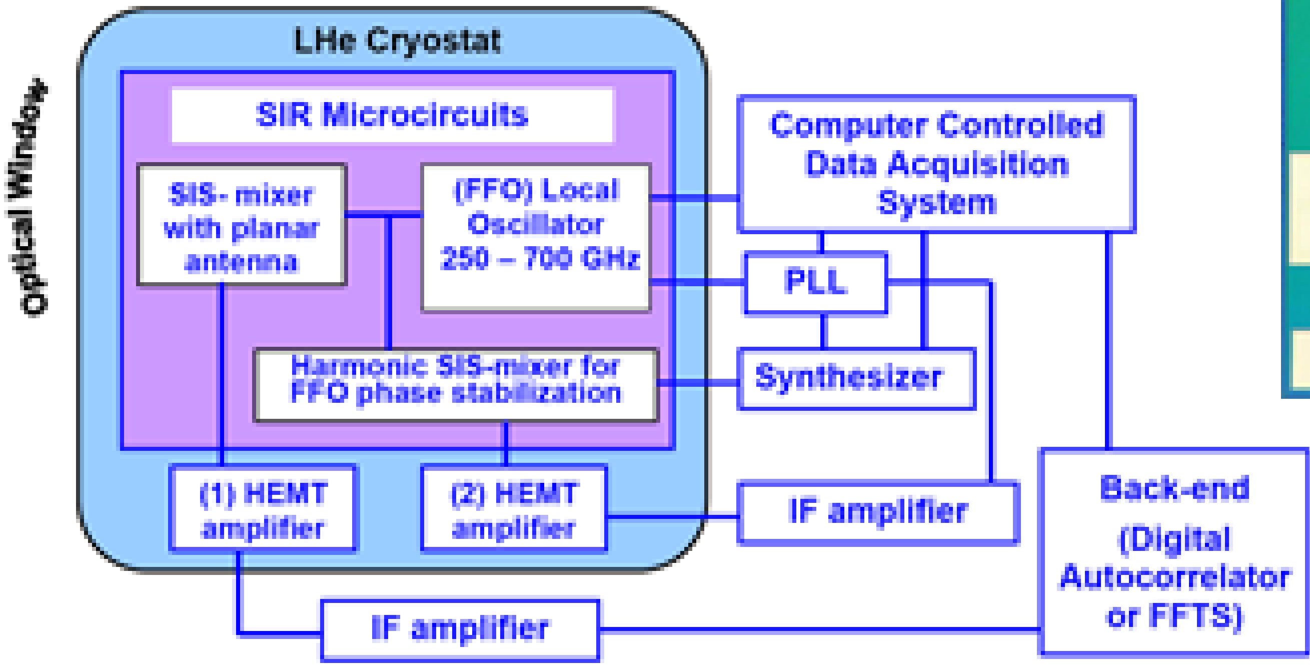
8 GHz IF bandwidth, x 16 in peak configuration

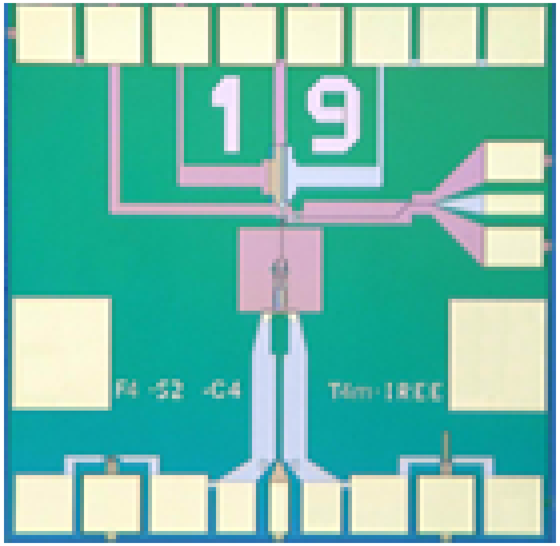
Band	Frequency (GHz/THz)	IFBW (GHz)	Polarization	Array size
1a 1b	275 – 373	4-12 (SIS)	H V	Single pixel
2a 2b	557 – 752	4-12 (SIS)	H V	Triangular (baseline) Hexagonal (goal)
3a 3b	752 – 950	4-12 (SIS)	H V	Hexagonal
4a 4b	0.95 – 1.15 1.15 – 1.40	4-12 (SIS) 1-8 (HEB)	single	Hexagonal
5a 5b	1.40 – 1.80 1.80 – 2.10	1-8 (HEB)	single	Hexagonal
6a 6b	2.45 – 3.00 4.76 – 5.36	1-8 (HEB)	single	Hexagonal

Heterodyne sensitivity



Superconducting Integrated Receiver (SIR) with phase-locked FFO





SIR microcircuit

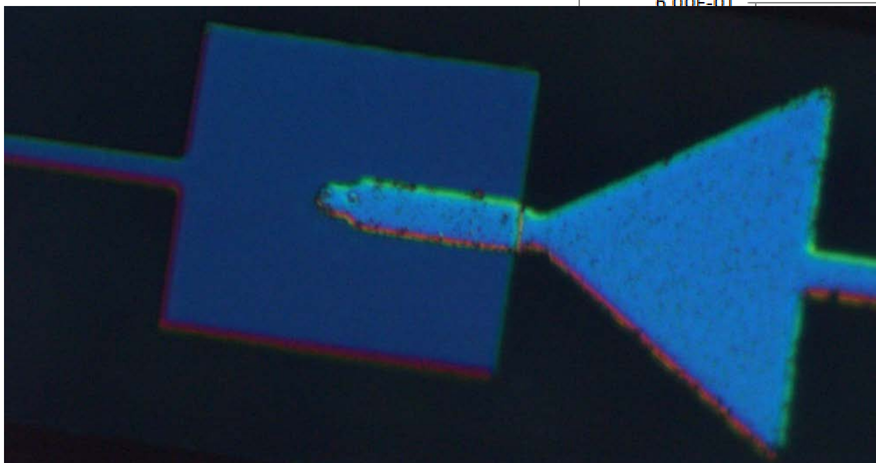
Nb–AlOx–Nb или Nb-AlN-NbN

Current density : Jc = 3 – 8 кA/см^2;

Tunnel barrier thickness : ~ 1 nm;

SIS junction area: ~ 1 μm^2

SIS technology



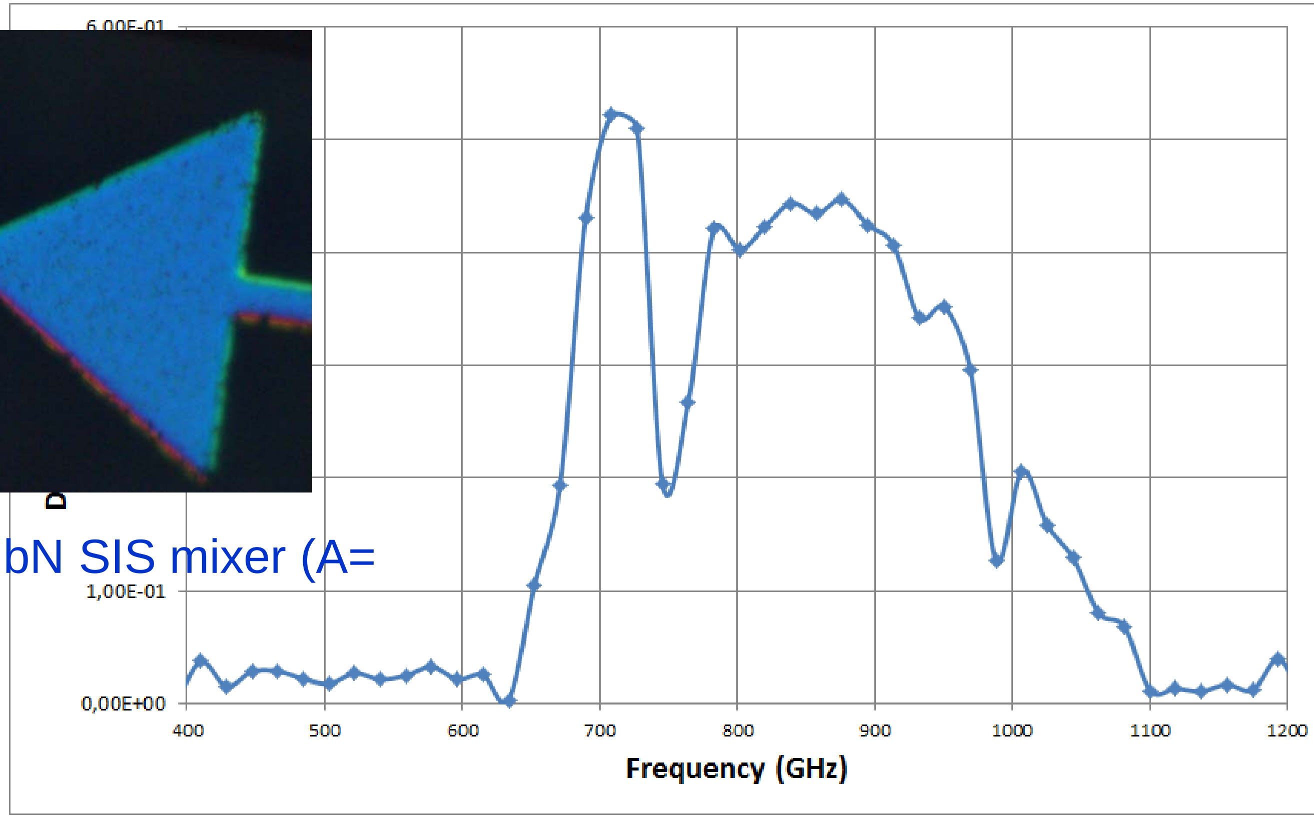
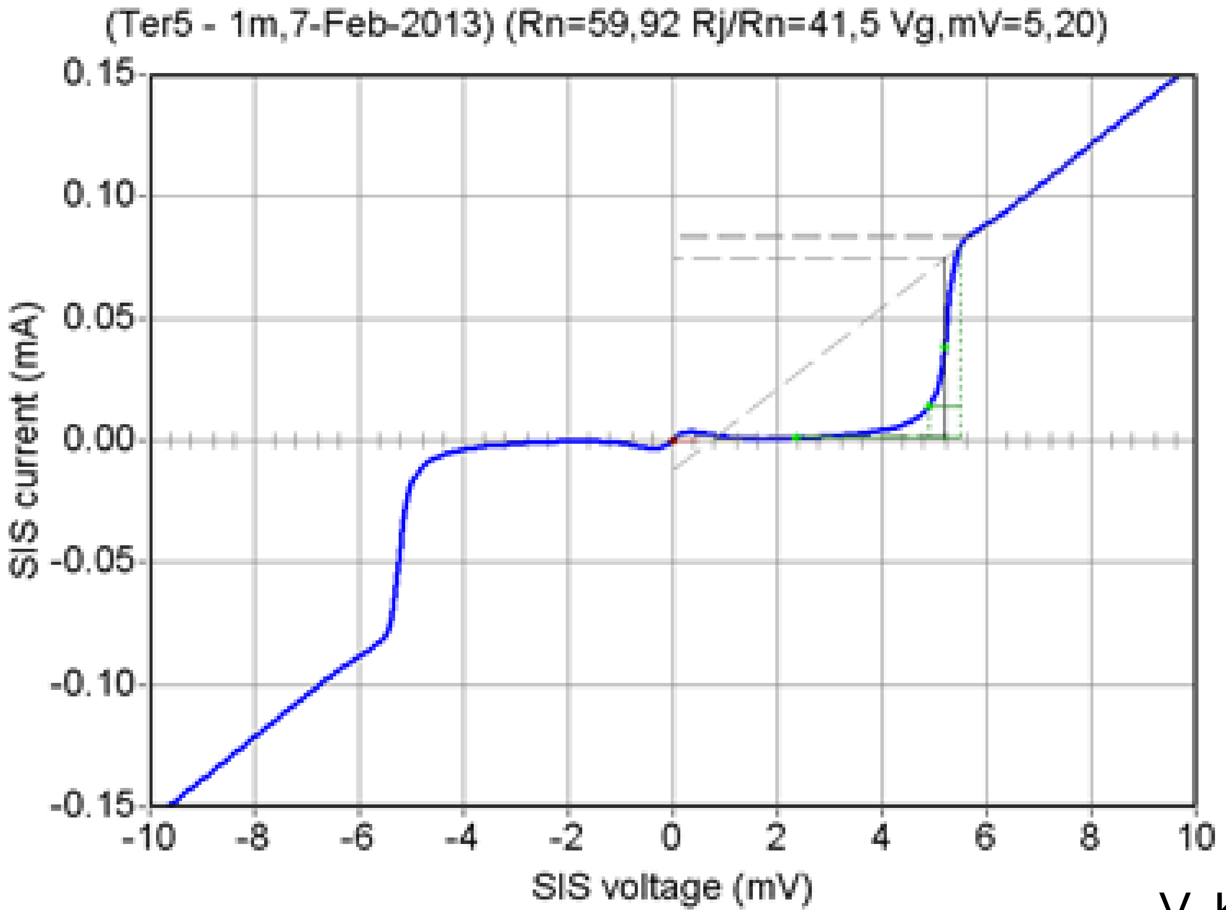


Photo of the Nb/Al-AlN_x/NbN SIS mixer (A= 0.5 μm^2)

V. Koshelets et al

NbN-MgO_x-NbN SIS on the MgO substrate;

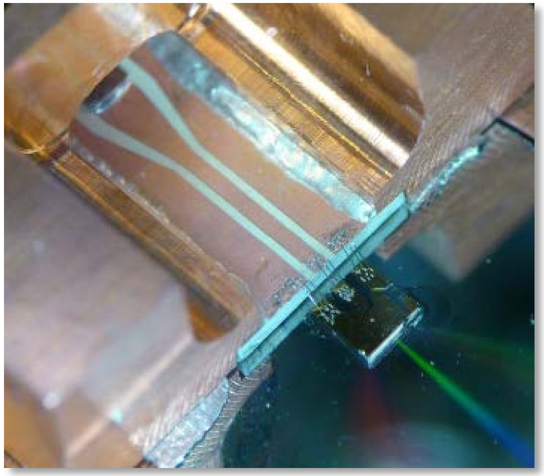
tunnel barrier made by plasma oxidation of the 1.5 nm Mg layer

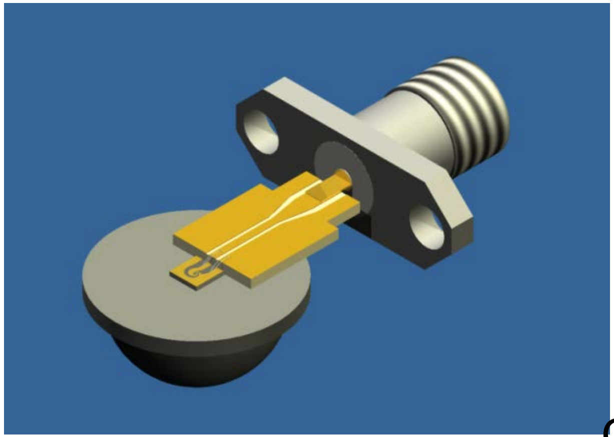


V. Koshelets et al

Hot Electron Bolometer

- NbN 2 x 0.2 μm^2
- Quasi-optical,
- Tight spiral antenna
- Coated Si lens for 4.3 THz



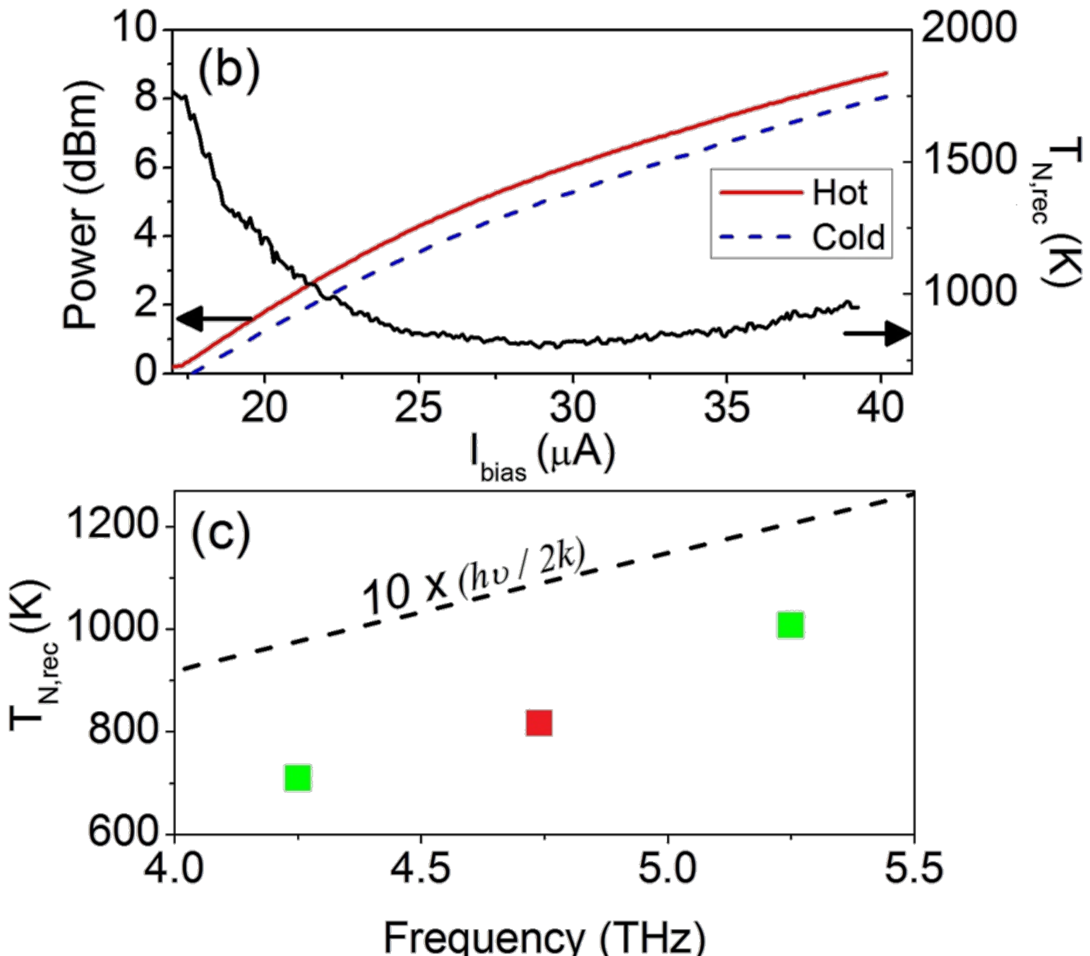


Gao et al

HEB-QCL at 4.7 THz

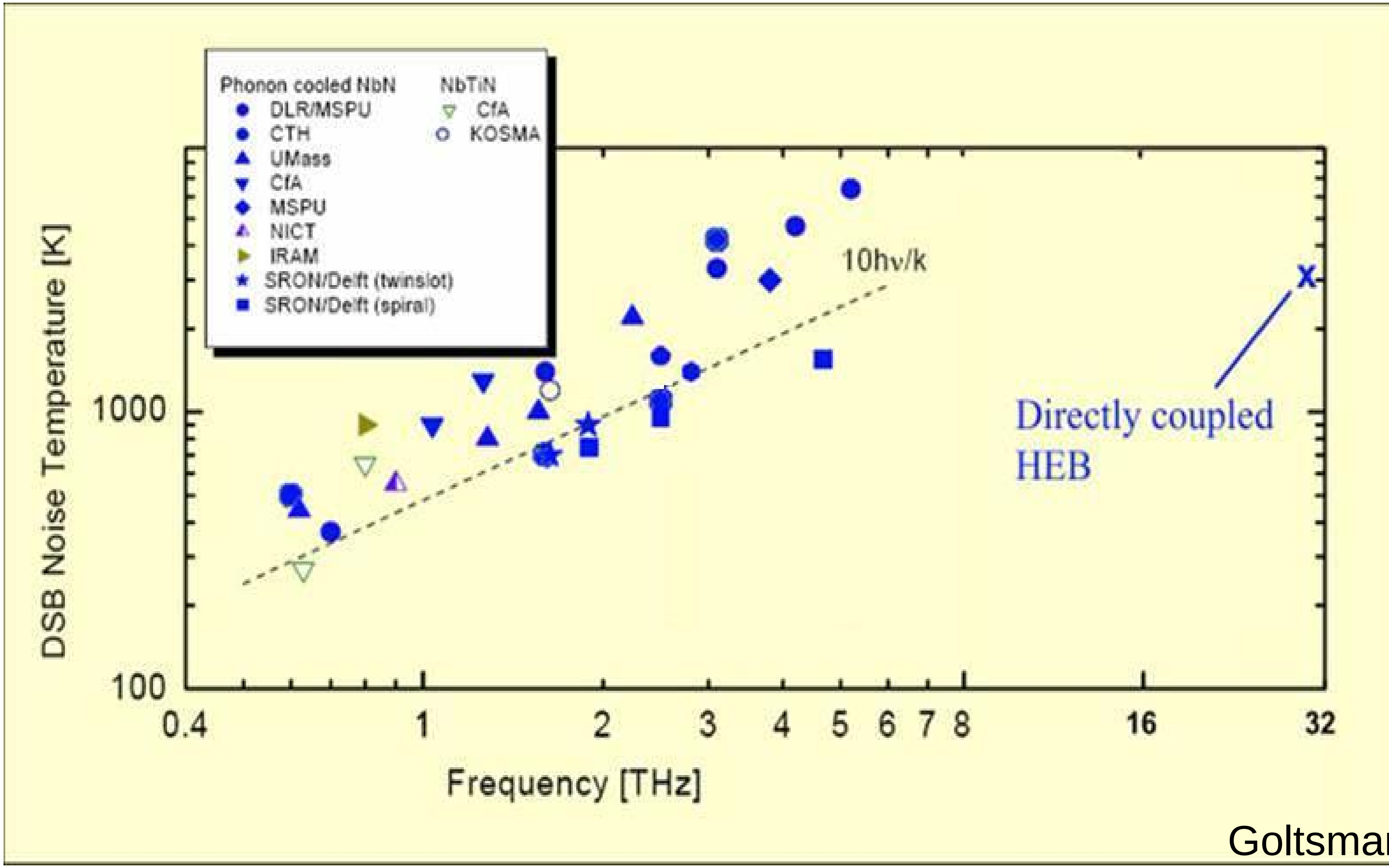
Lab setup for 4.7 THz receiver

- Measured $T_{rec,}$DSB of 815 K with 4.7 THz QCL (3 μm beamsplitter)
- ~ 7 times quantum noise
- Red point: QCL LO
- Green points: FIR gas laser



J. L. Kloosterman et al., Appl. Phys. Lett. 102, 011123 (2013)

Sensitivity overview



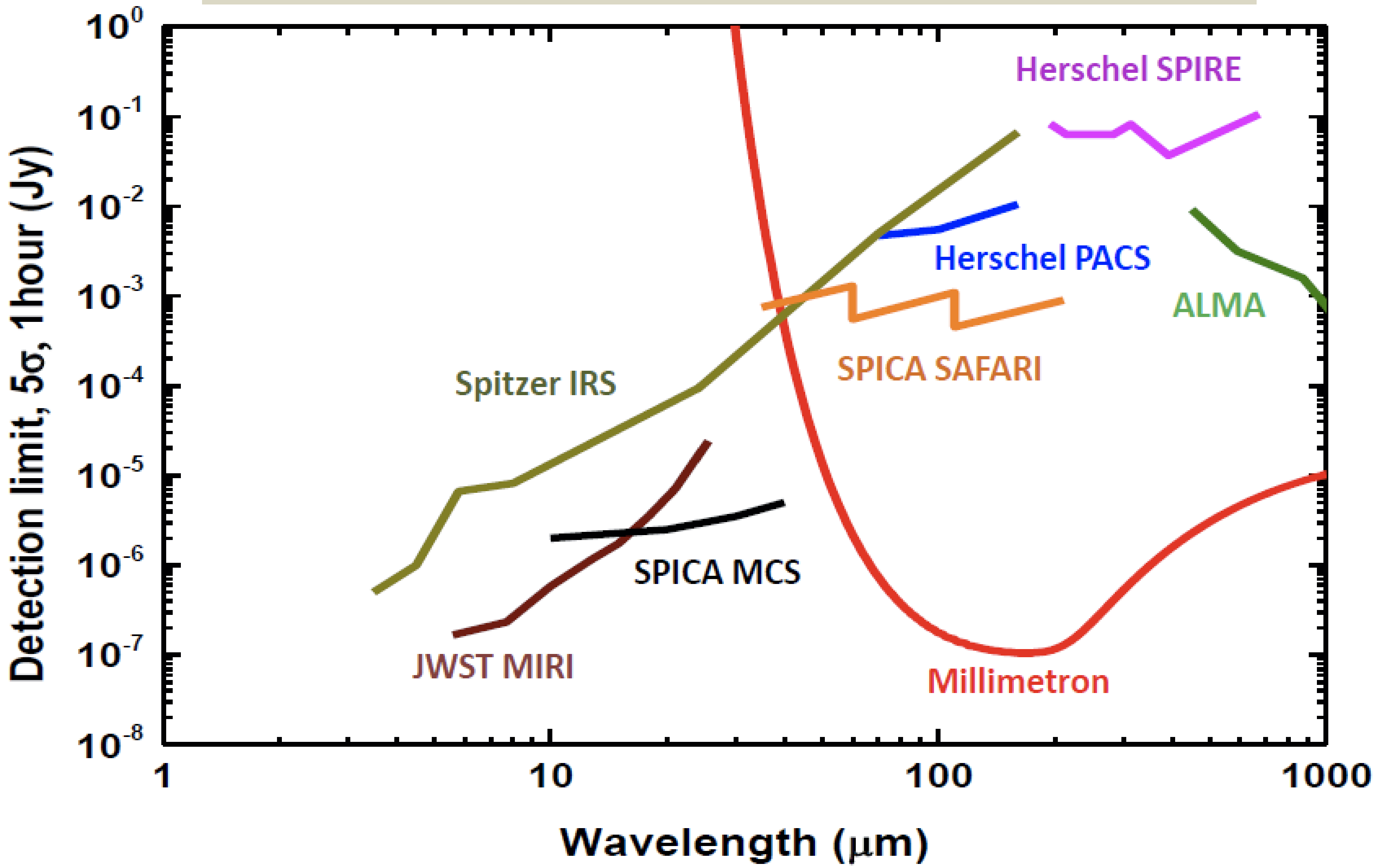
Goltsman et al

Direct detectors

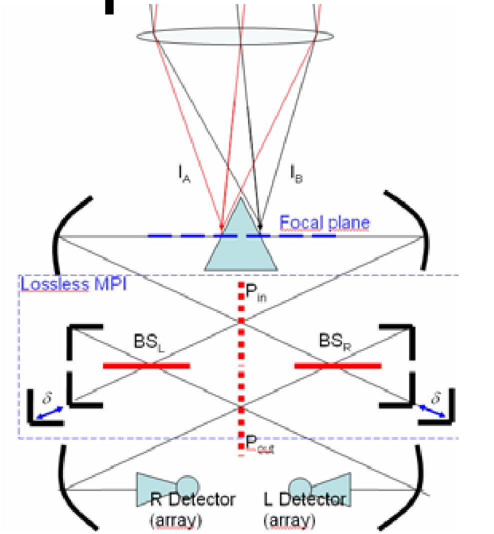
- Microwave Kinetic Inductors
- Cold Electron Bolometers CEB
- Transition edge sensors

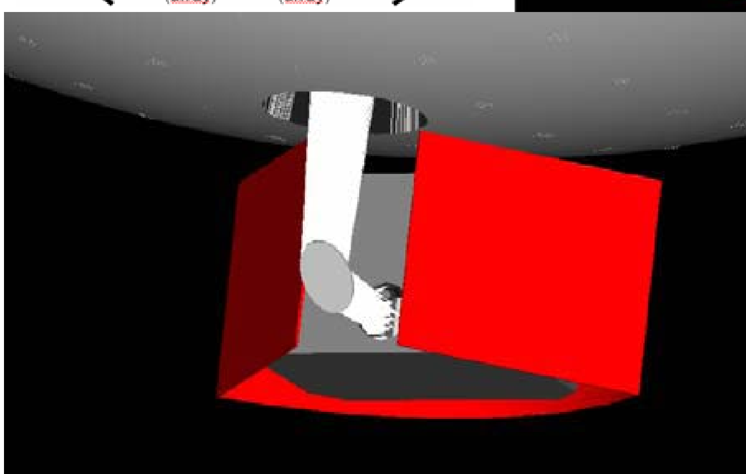
- NEP <1E-19 Goal 1E-21, for grating spectrometer

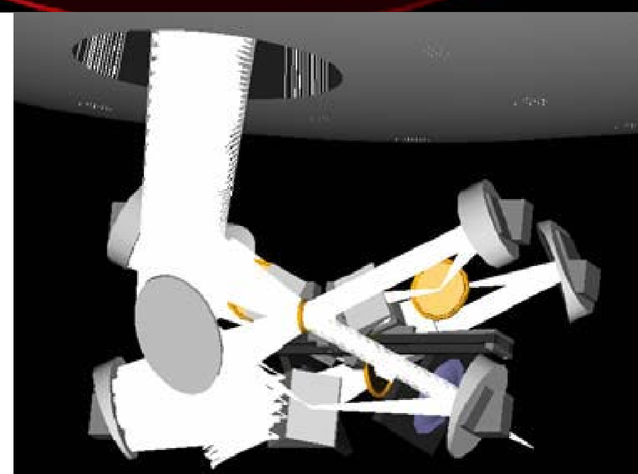
Spectroscopic sensitivity, grating



Medium resolution low frequency spectrometer layout

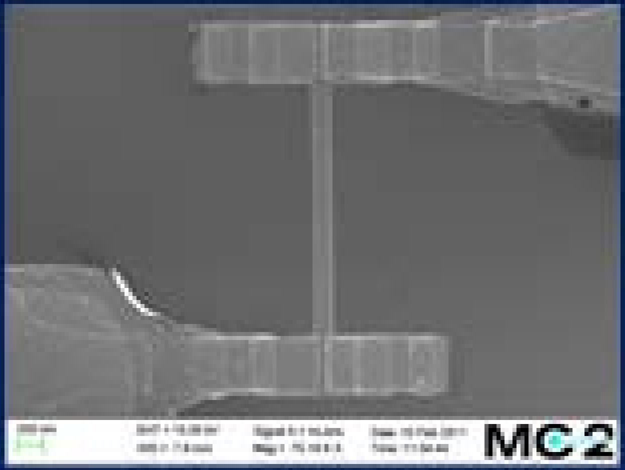


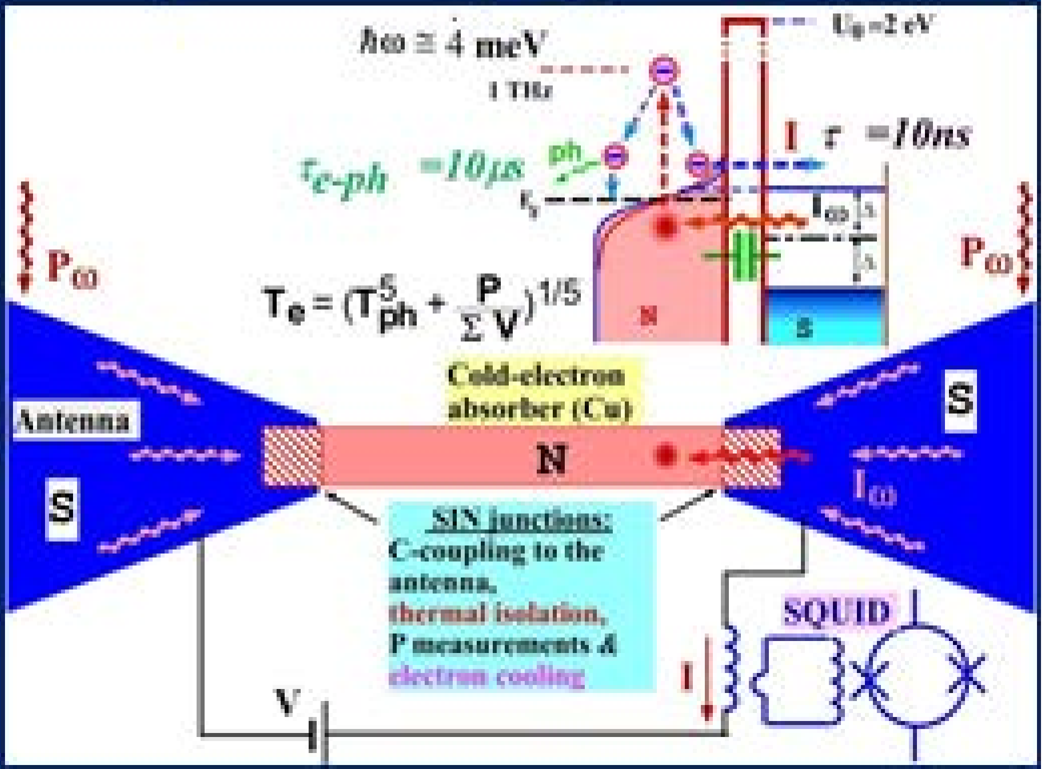




P. De Bernardis et al

Cold-Electron Bolometer (CEB) with Capacitive Coupling to the Antenna





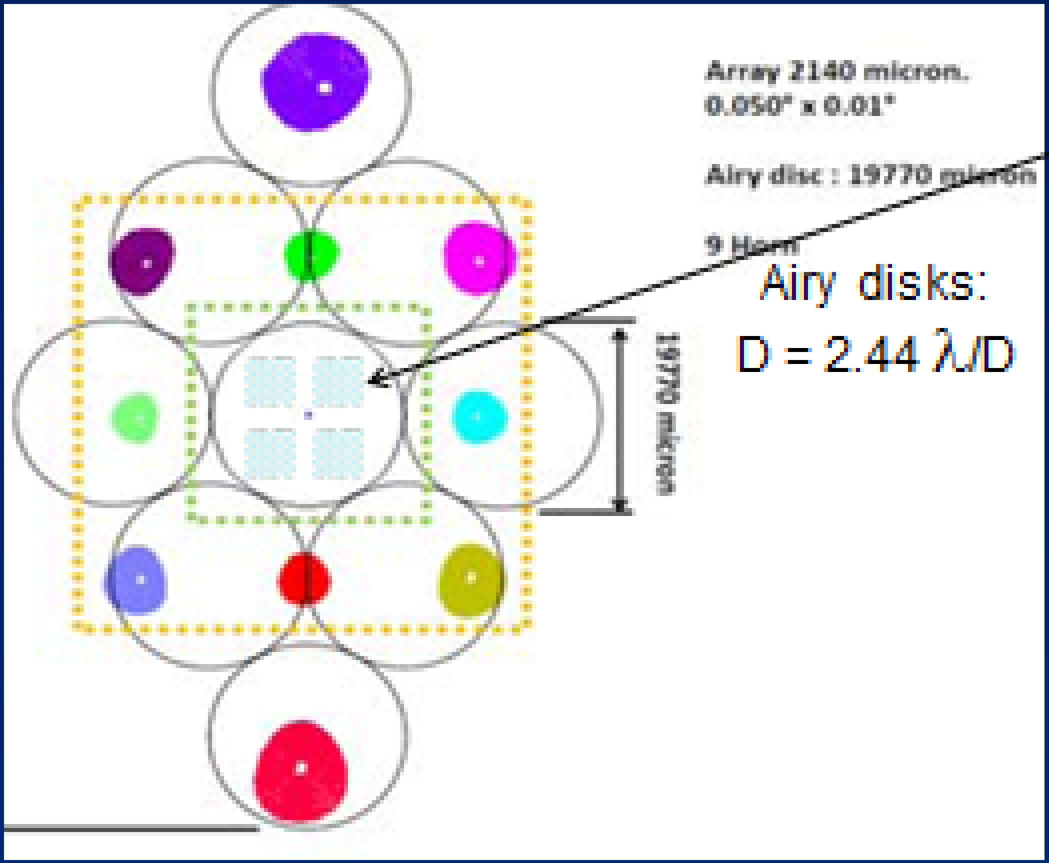
Main features of the CEB:

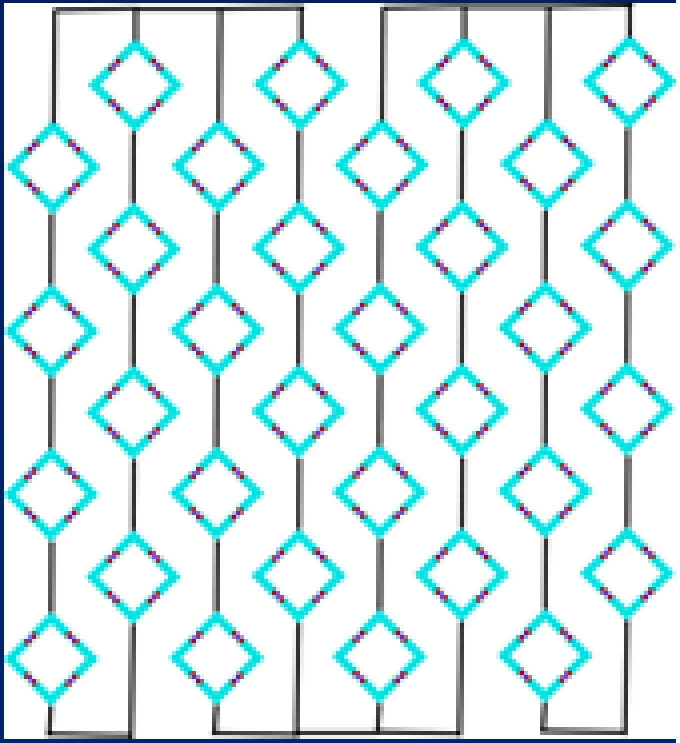
1. High sensitivity due to electron cooling effect:

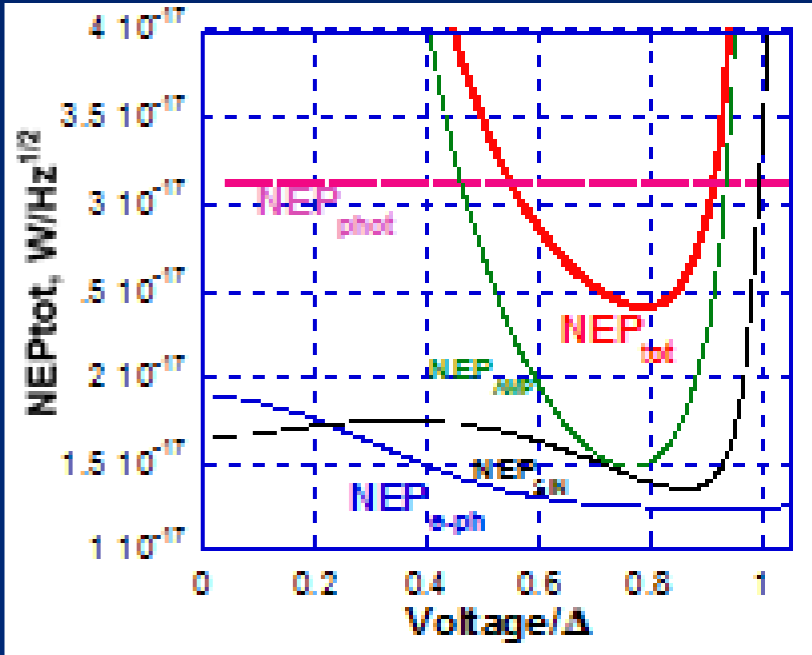
NEPceb<NEPph for any optical power load (from 80pW for LSPE to 0.02 fW for SPICA)

2. High dynamic range due to direct electron cooling
3. Insensitivity to Cosmic Rays (CR)
4. Very easy to fabricate in arrays on planar substrate

4 CEB Arrays with Dual-Polarized Antennae in each Airy disk



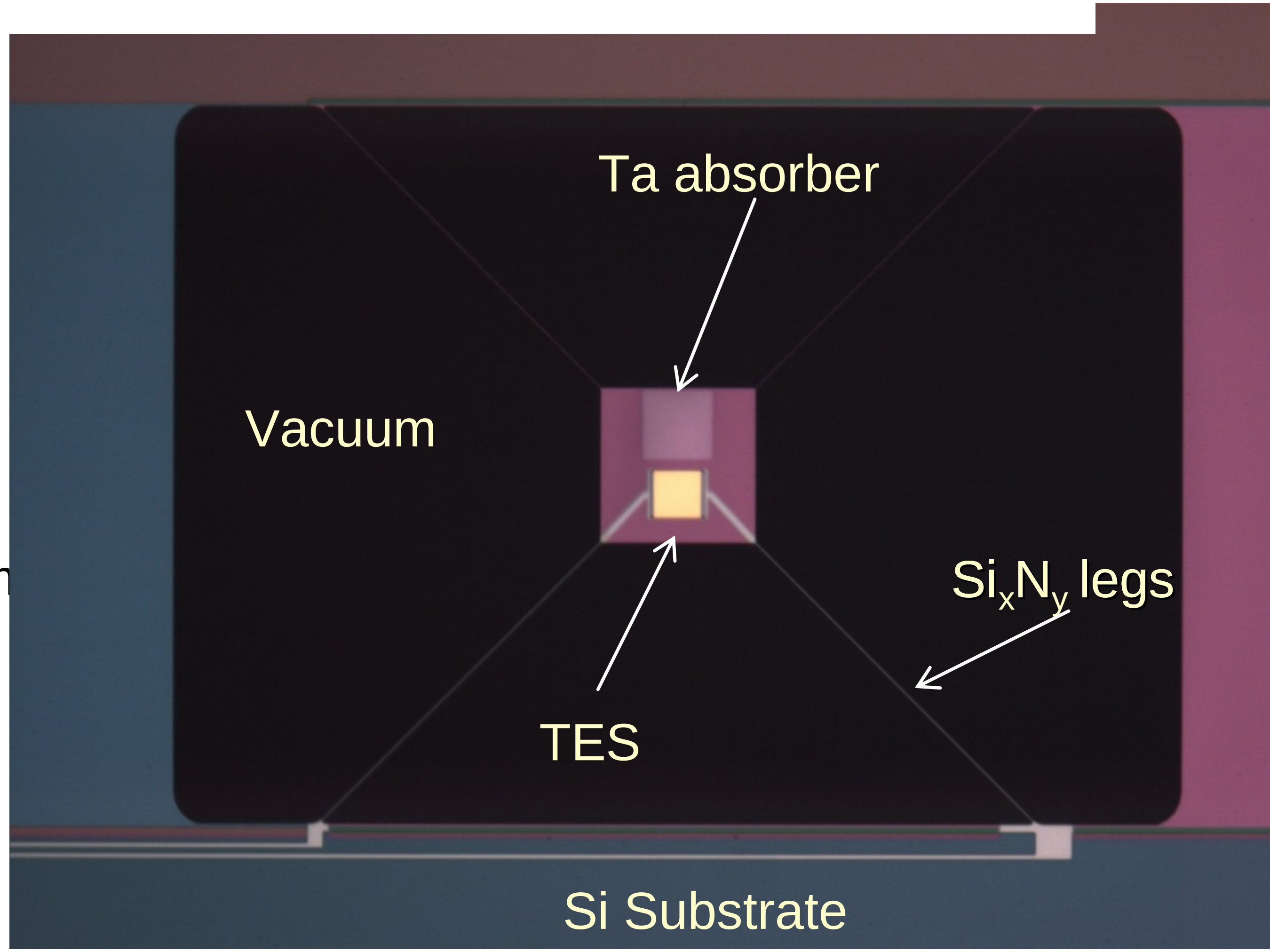




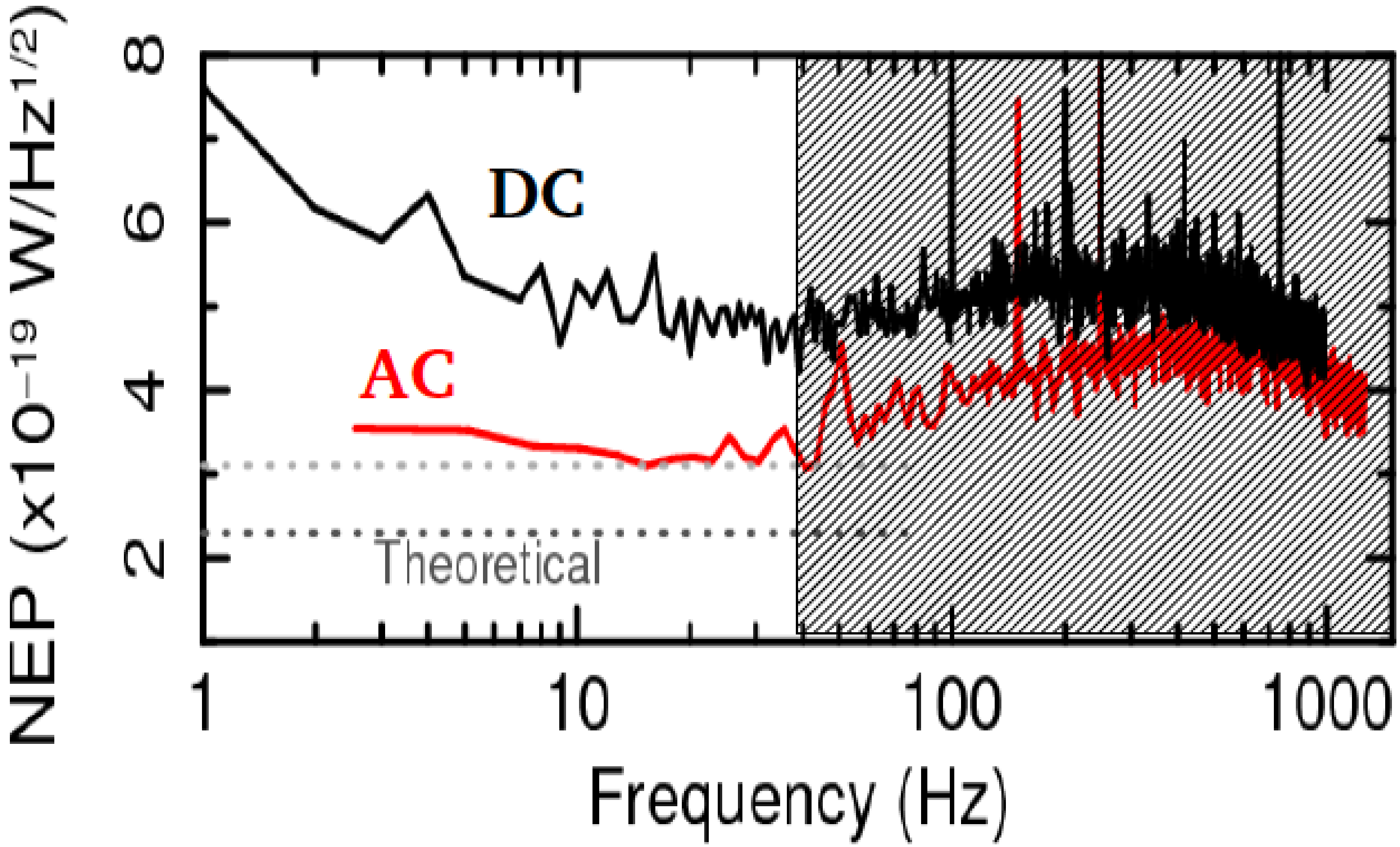
Transition edge sensors, SPICA SAFARI

TES: Ti/Au 50x50 μm^2
thickness SiN
island/legs=500nm
G = 0.27 pW/K @100m
Tc=80.0 mK

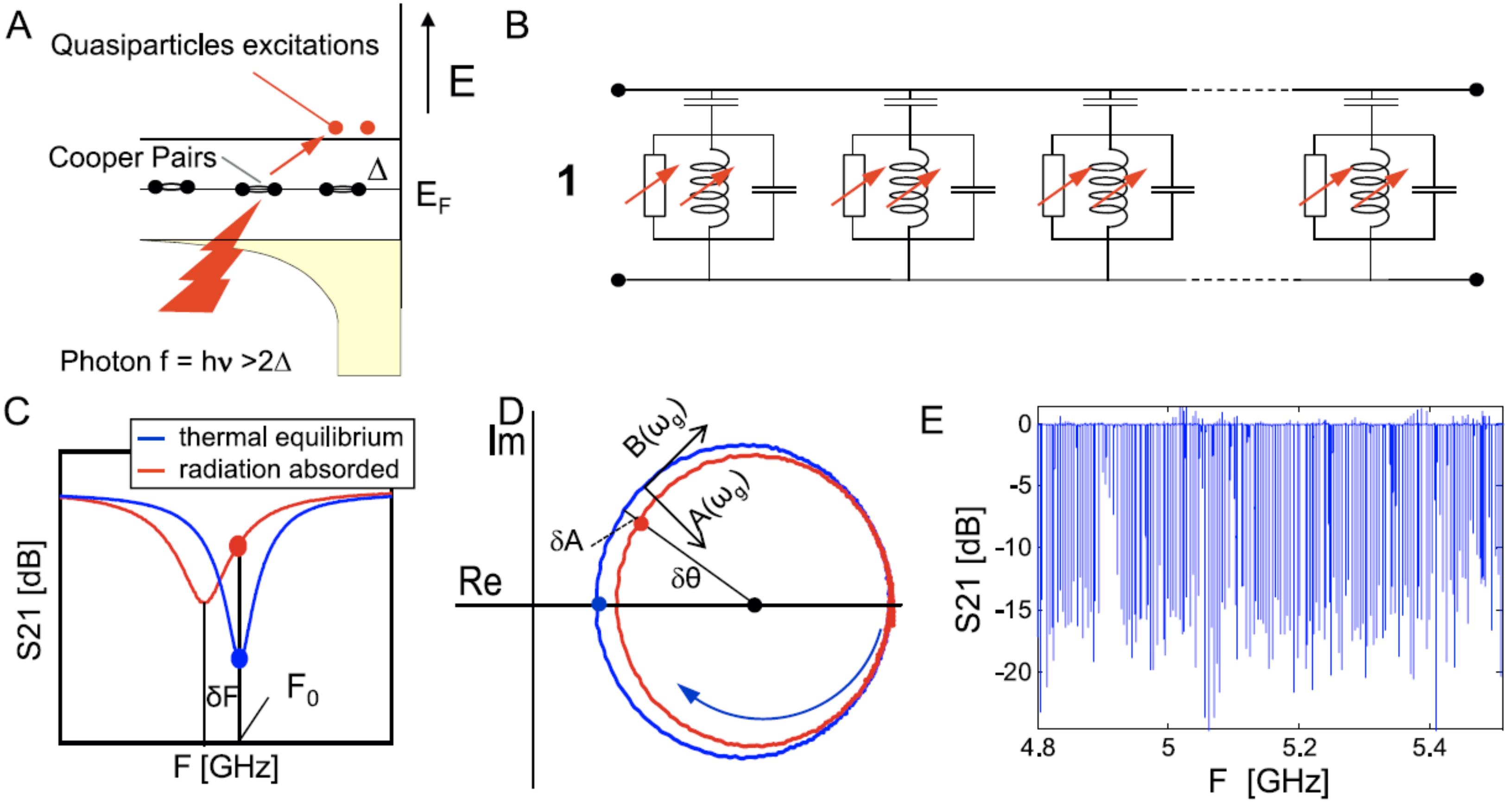
Gao, et al



Measured sensitivity (50mK)

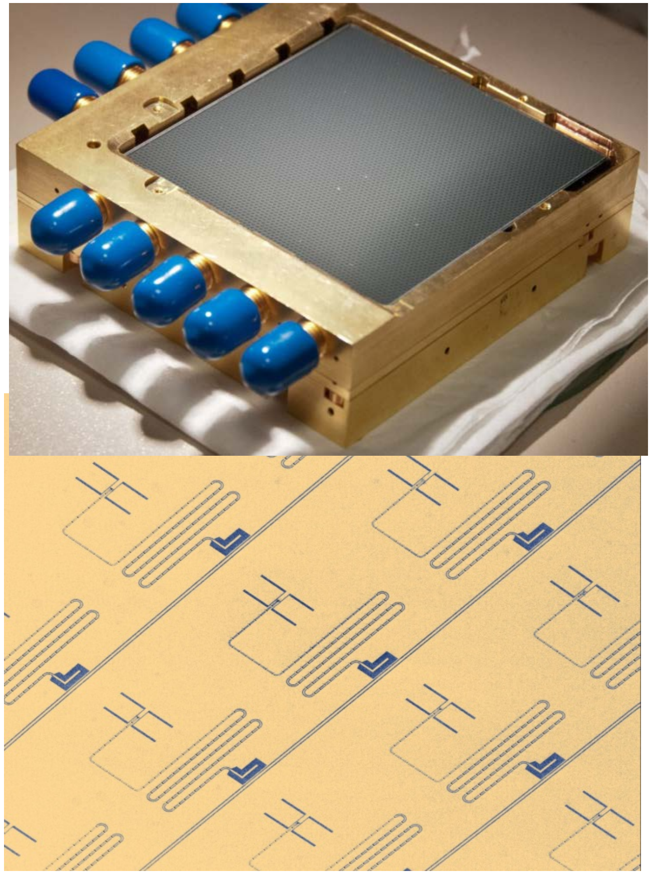


Microwave Kinetic Inductance detectors



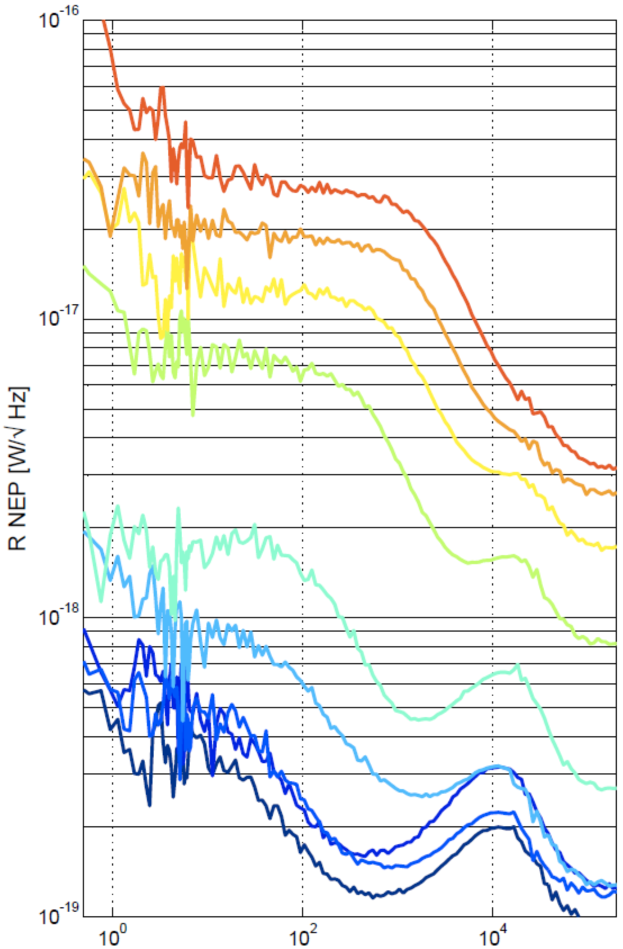
Baselmans et al

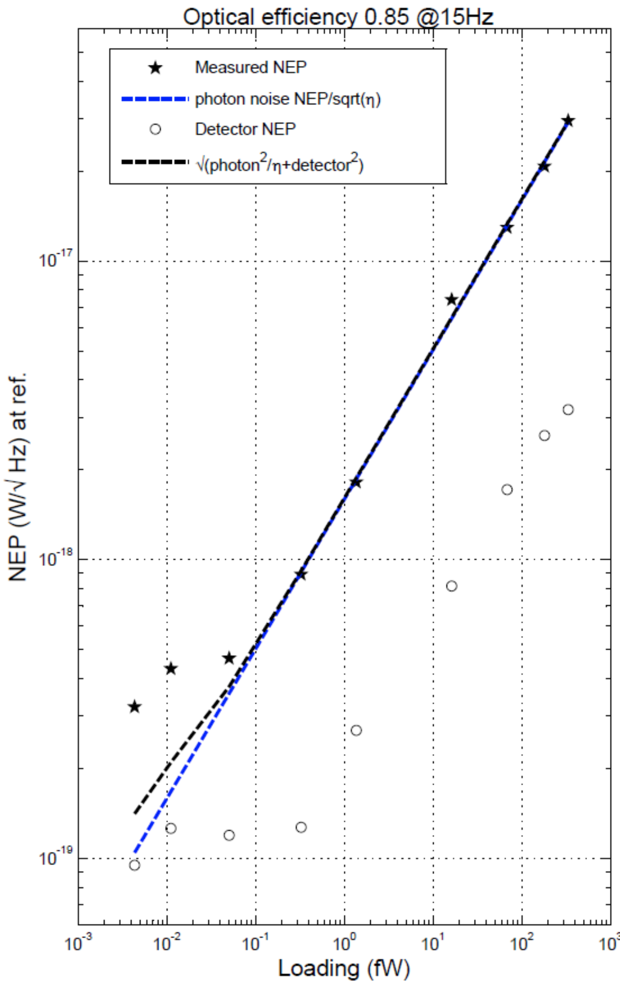
Ground based camera



25000 pixels, NEP 1E-18 demonstrated <1THz

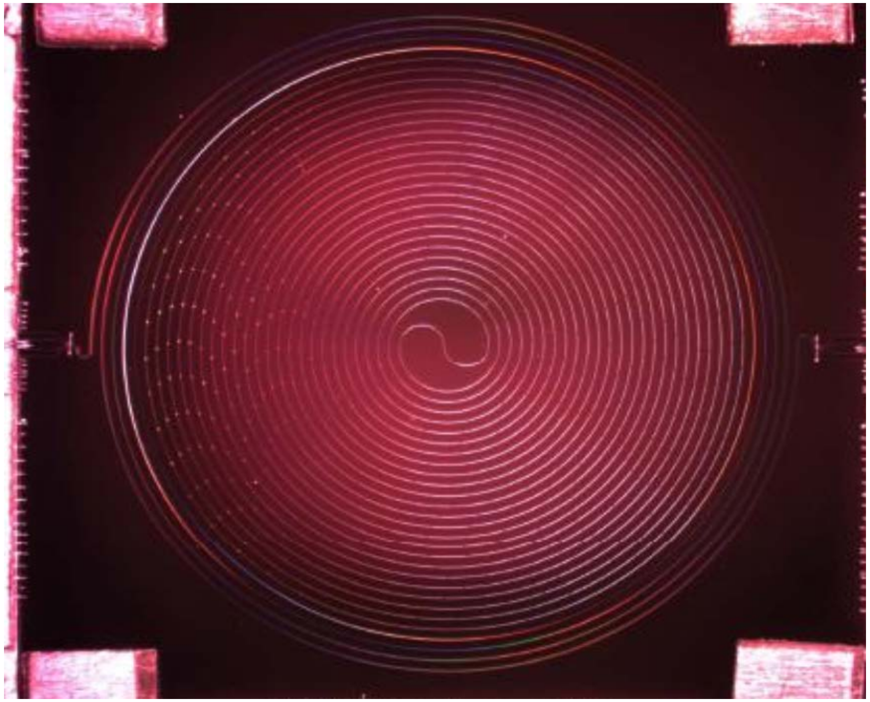
NEP 1E-19 >1THz

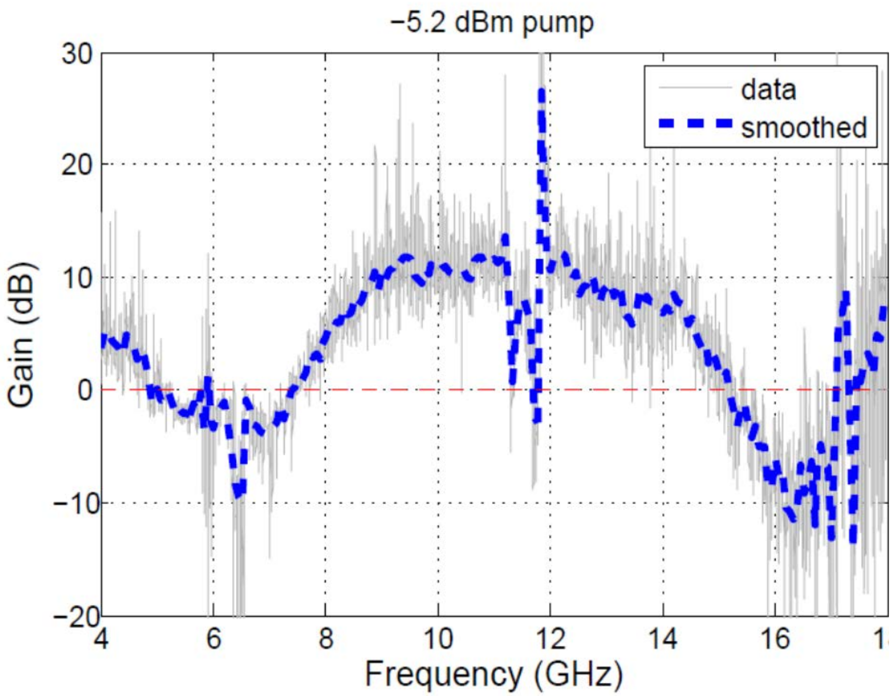




Baselmans et al

Parametric Amplifier Development





P. Day, J Zamuidzinas et al