Multi-beam SIS Receiver Development

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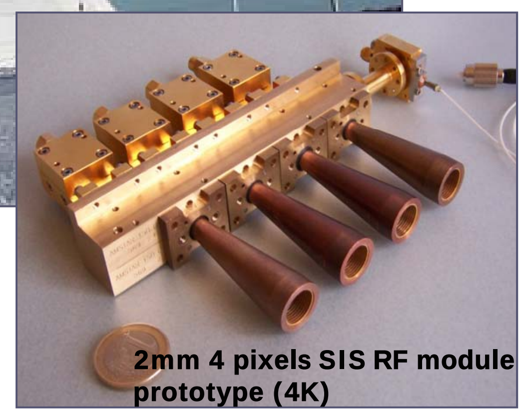
List of Acronyms

- IRAM: Institut de RadioAstronomie Millimetrique
- RF: Radio Frequency
- IF: Intermediate Frequency
- SIS: Supraconducting-Isolator-Supraconducting
- SSB: Single Side Band
- 2SB: Two Side Bands
- LNA: Low Noise Amplifiers
- OMT: Ortho Mode Transducer
- GM-JT: Gifford-Macmahon-Joule-Thomson.
- GM: Gifford-Macmahon
- FOV: Field Of View
- HPBW: Half Power Beam Width
- PTFE: Poly Tetra Fluoro Ethylene
- HDPE: High Density Poly Ethylene

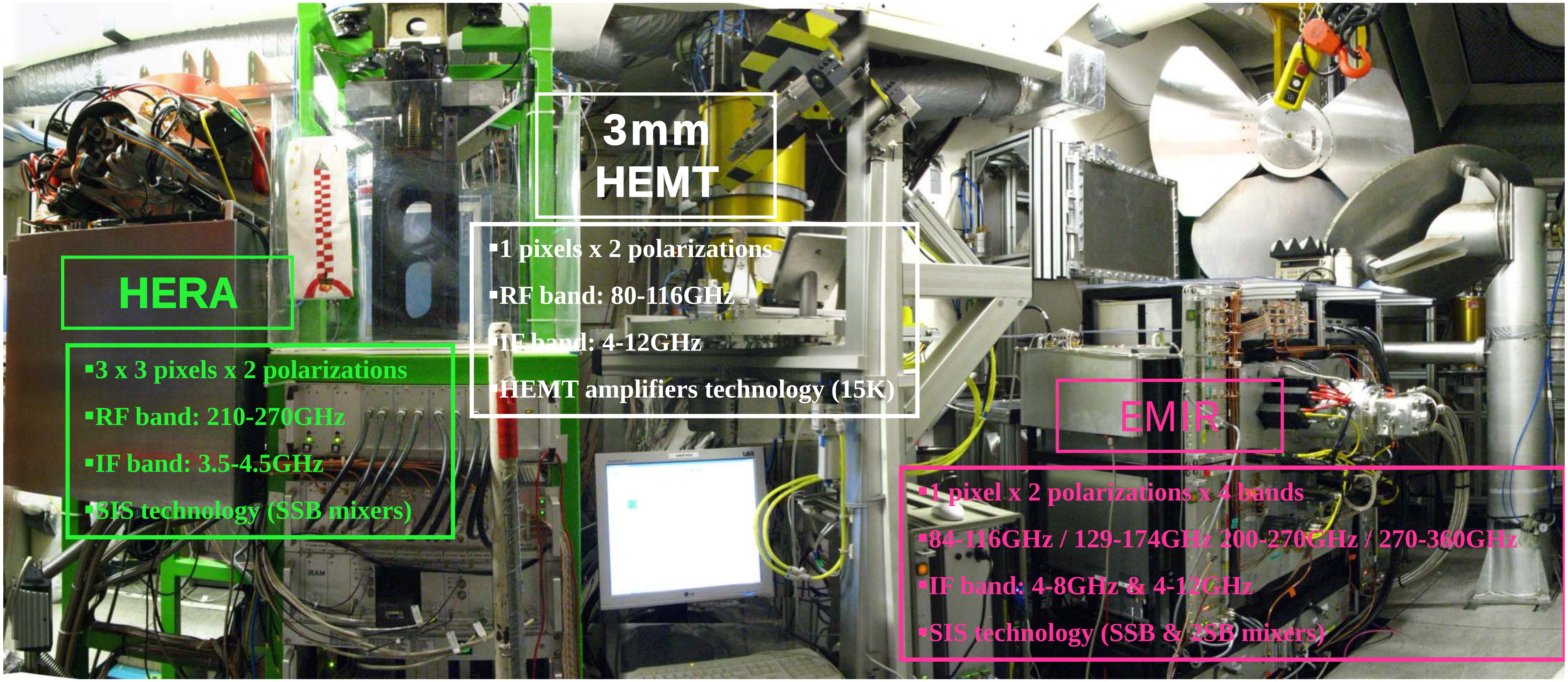
IRAM Pico Veleta Telescope


2mm 4 pixels SIS RF module prototype (4K)

Interest in developing Multi-beam SIS Receivers:

- Increase mapping speed of extended sources
- Improve data quality

Current Heterodyne Instrumentation @ Pico Veleta



GM-JT Daikin cryocooler CG308SC

3 stages: 77K /15K /4K(2.5W)

Coldest T° ~ 4.2 K (unloaded stage)

HDV10 cryostat

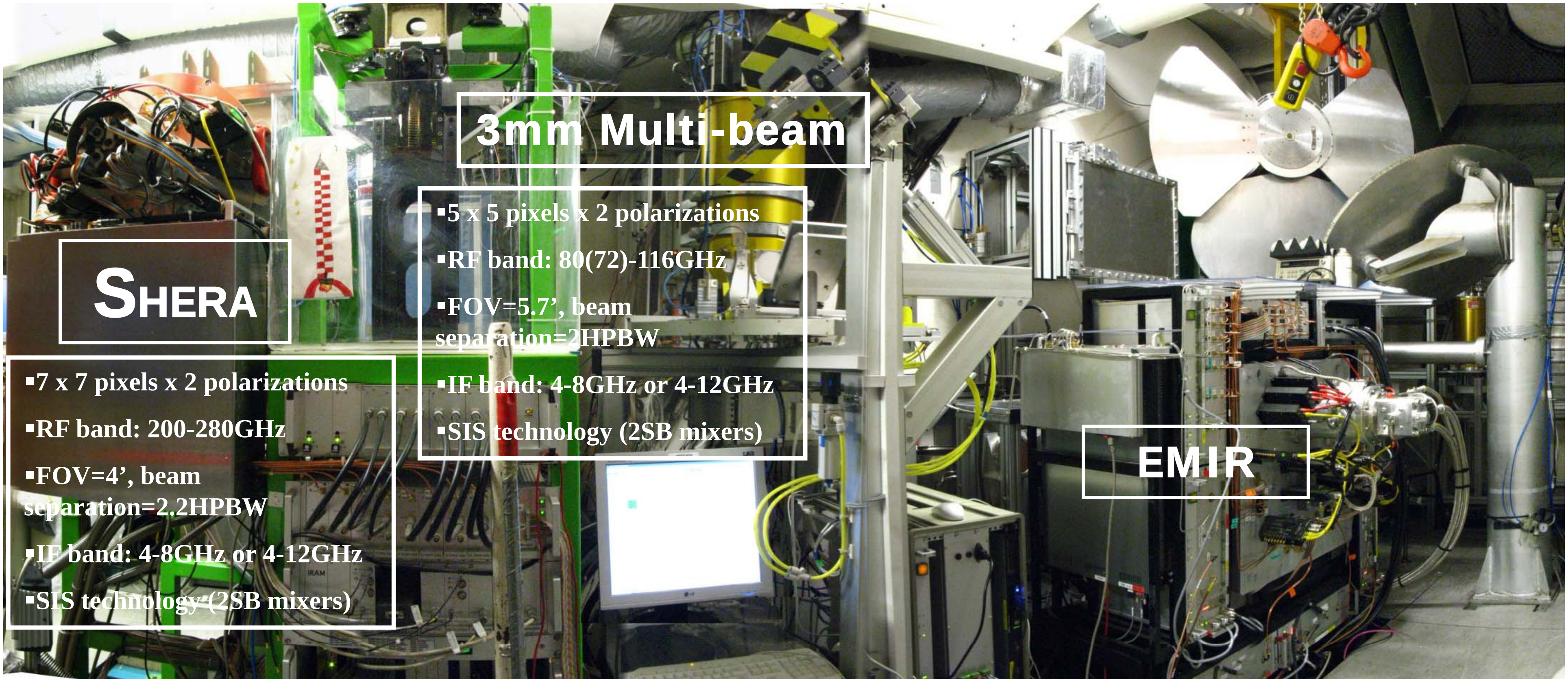
2 stages: 77K/ 15K

GM Sumitomo cryocooler RDK-3ST

3 stages: 77K /15K /4K(1W)

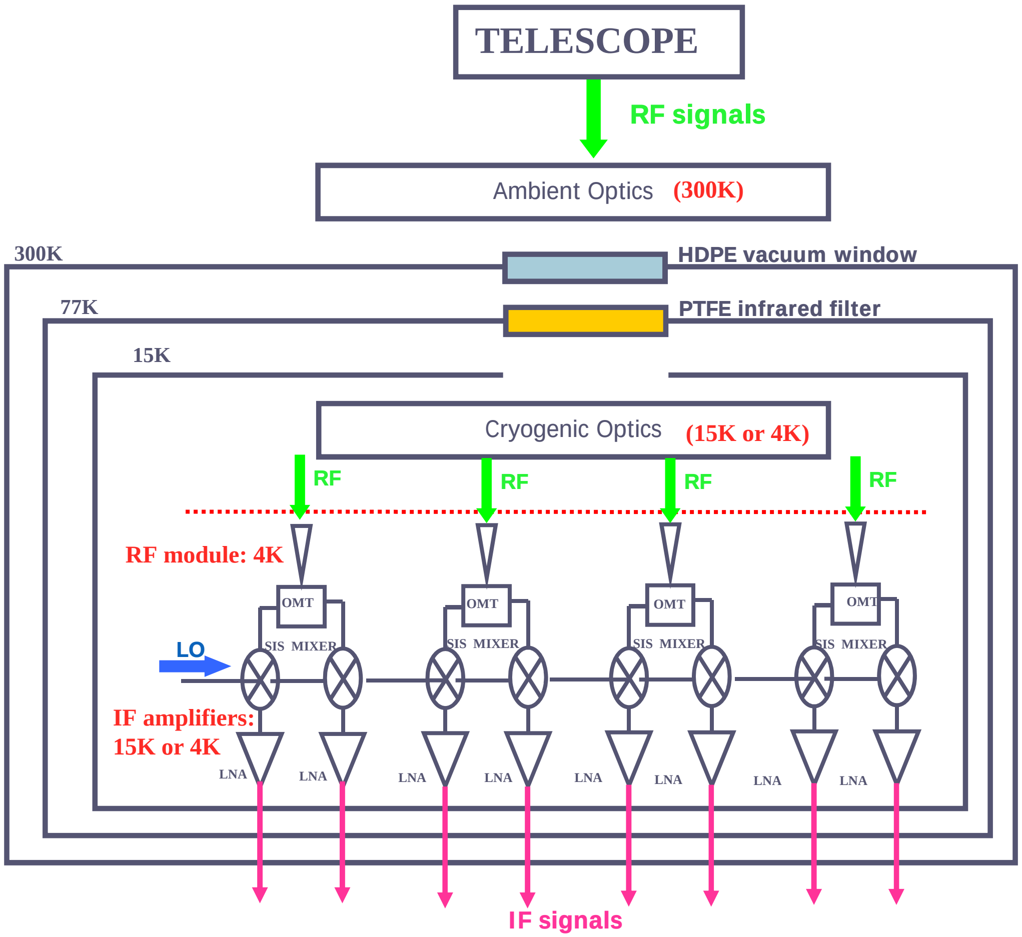
Coldest T° ~ 3 K (unloaded stage)

Future Heterodyne Instrumentation @ Pico Veleta

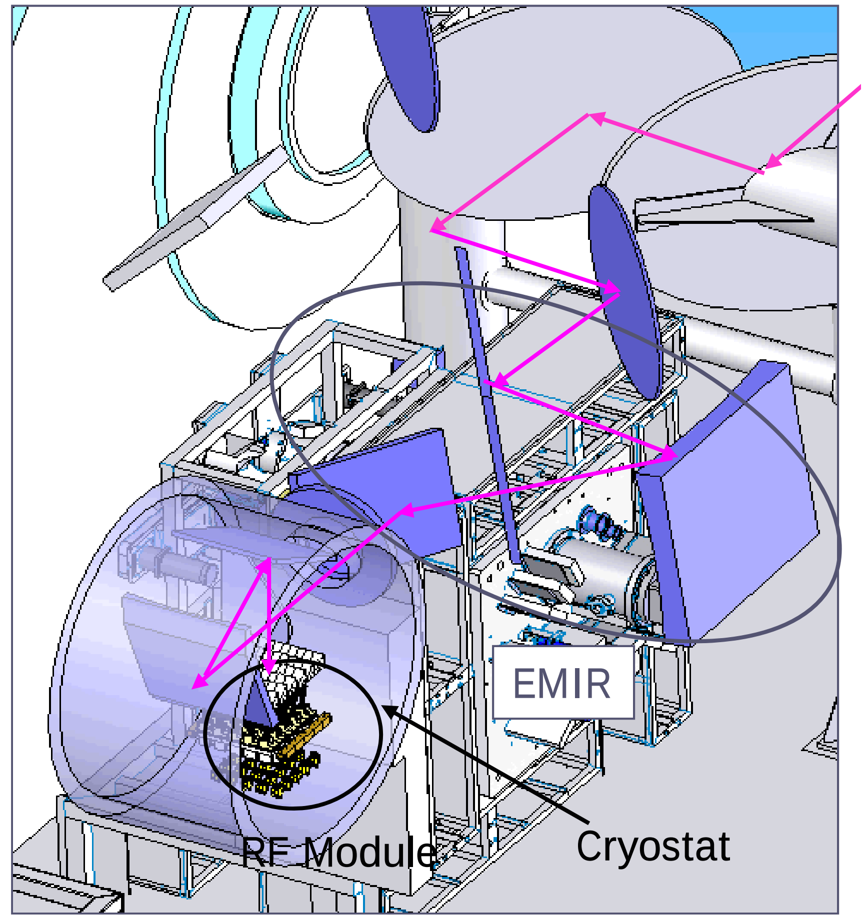


Multi-beam SIS Receiver Overview

Synoptic of a 4-pixel array



3D view of the future 3mm multi-beam



Requirements and Critical Design Items

Main requirements:

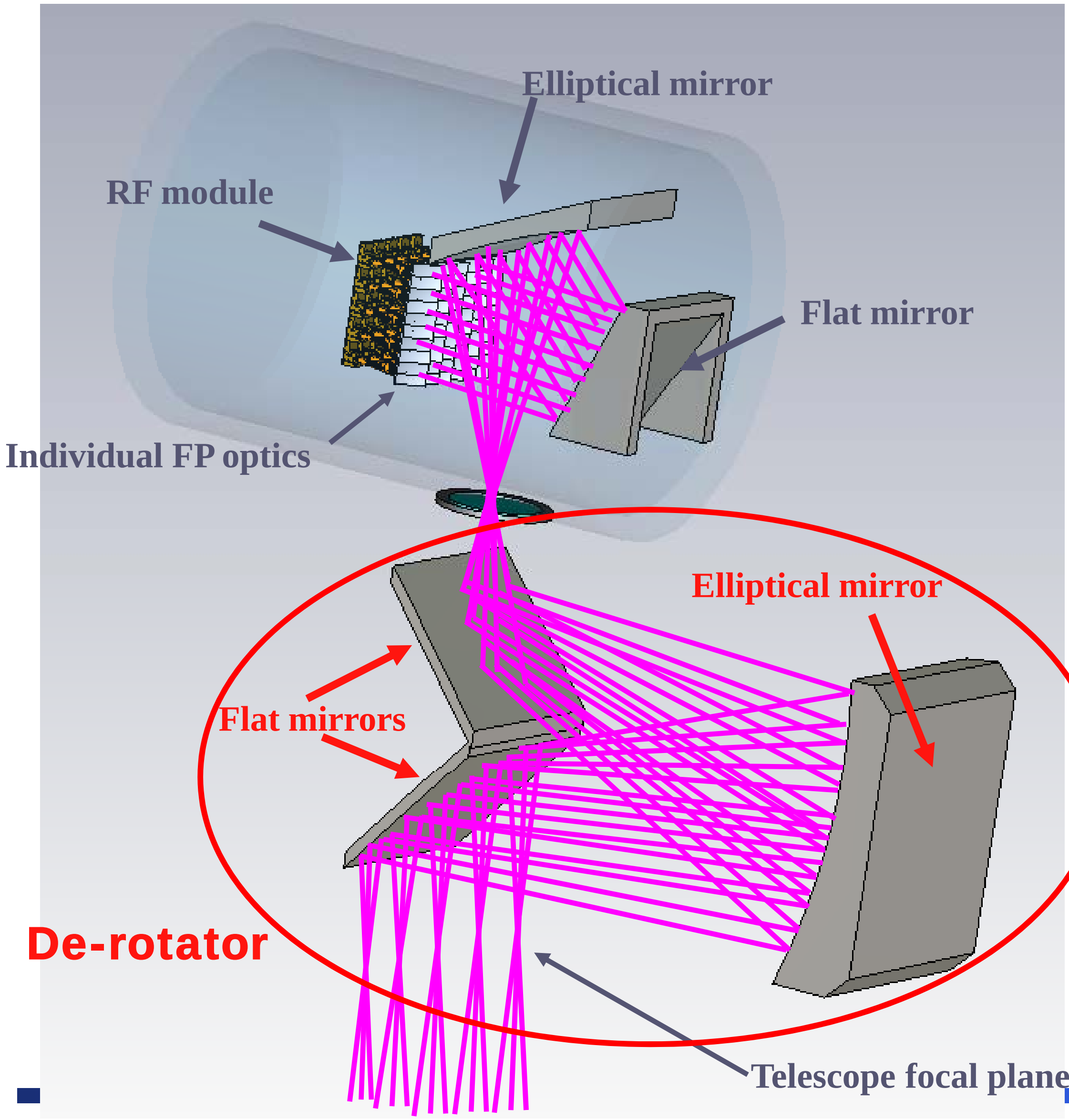
- Compact size
- Easy to be repaired or upgraded
- State of the art performances (noise, stability, optics)

↓

Some critical points in the receiver design:

- Optics design → receiver size, cryostat size, receivers performances...
- RF module design →cryostat size, receiver performances, repairing procedure
- Cryogenic aspects →cryostat size, receiver performances, repairing procedure

Optics Design Overview of the 3mm Multibeam



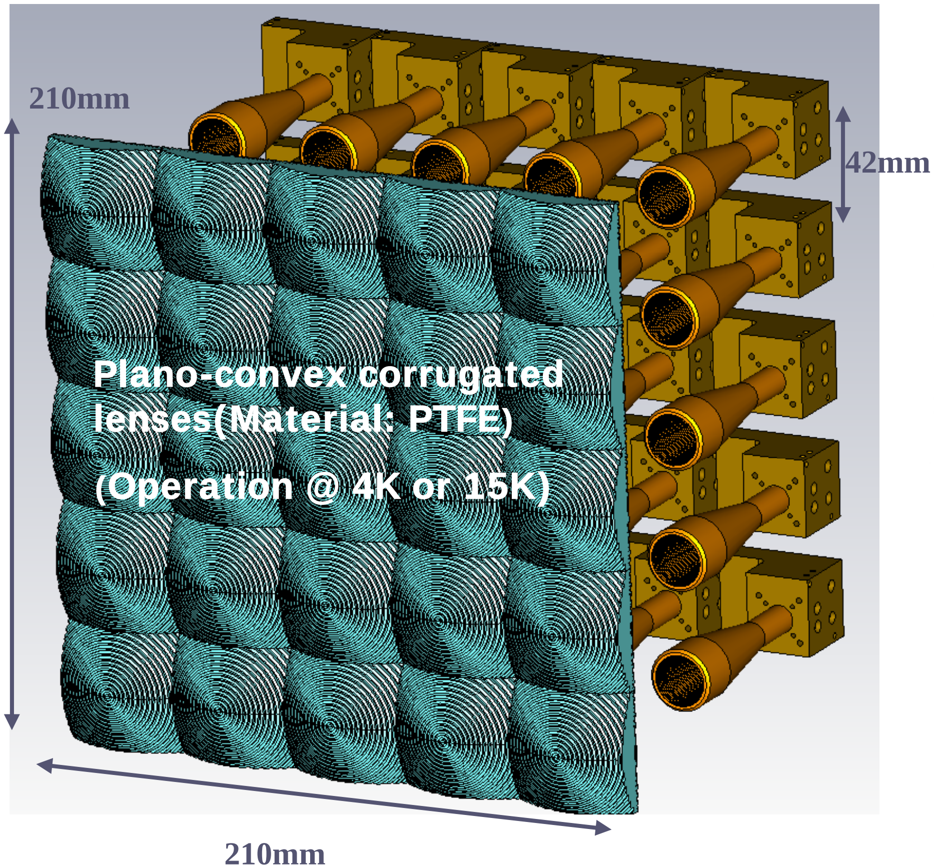
- Frequency independent sub reflector illumination (taper = -12dB)
- Transform 2HPBW (=68.5mm in FP) spacing on the sky into 42mm between feeds
- Limited thermal radiation due to 300K window and IR filter

→4W on 77K stage

→80mW on 15K stage

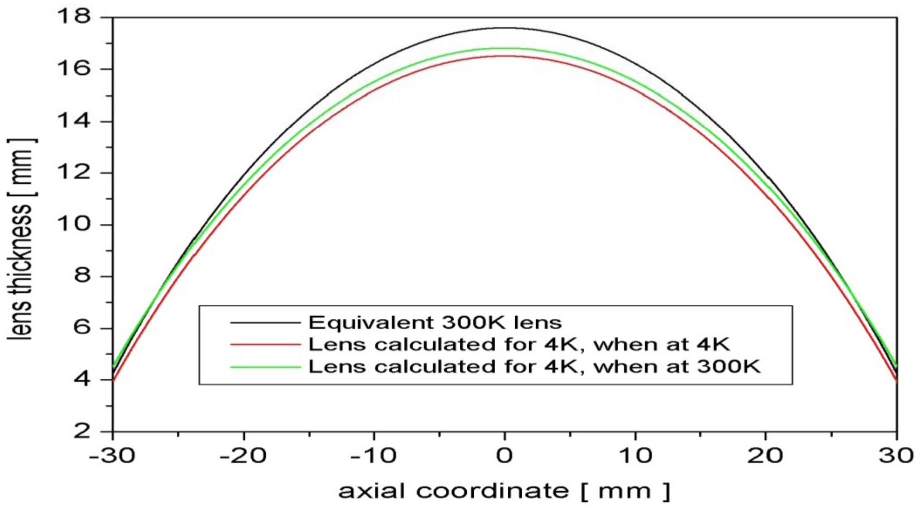
- Optimal beam coupling between telescope and horn apertures
- K-mirror for image rotation

3mm MB: Individual Cryogenic Optics Design Option A: Refractive Optics



Lens design @ 4K:

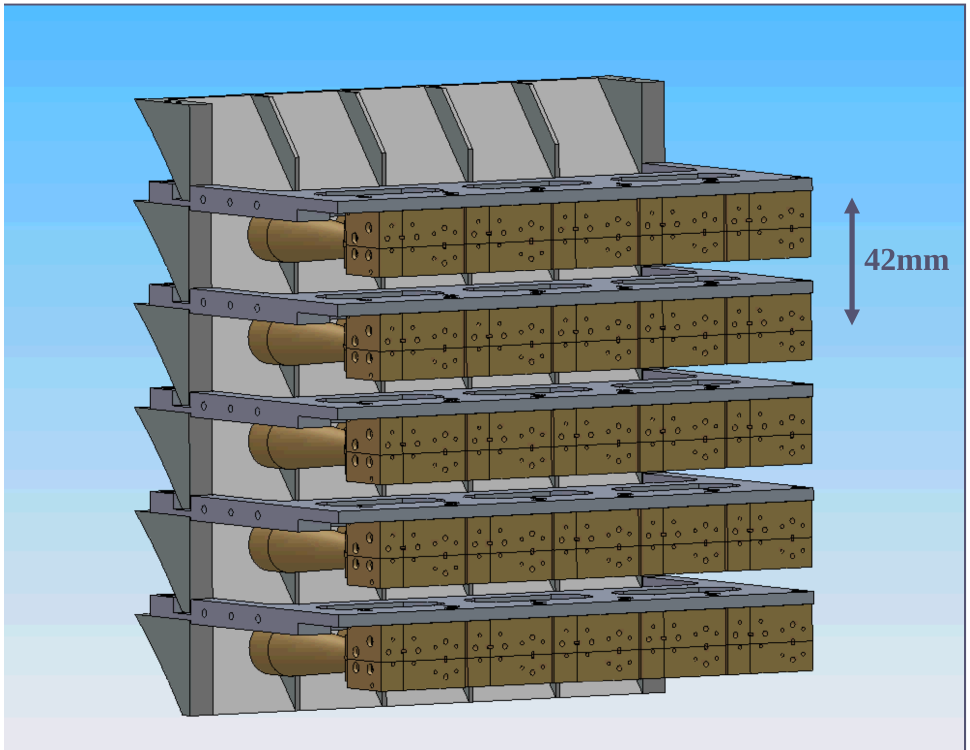
- Permittivity: ε_r = 2.07 (300K) → 2.16 (4K)
- Linear thermal contraction: 1.6% to 2.1%

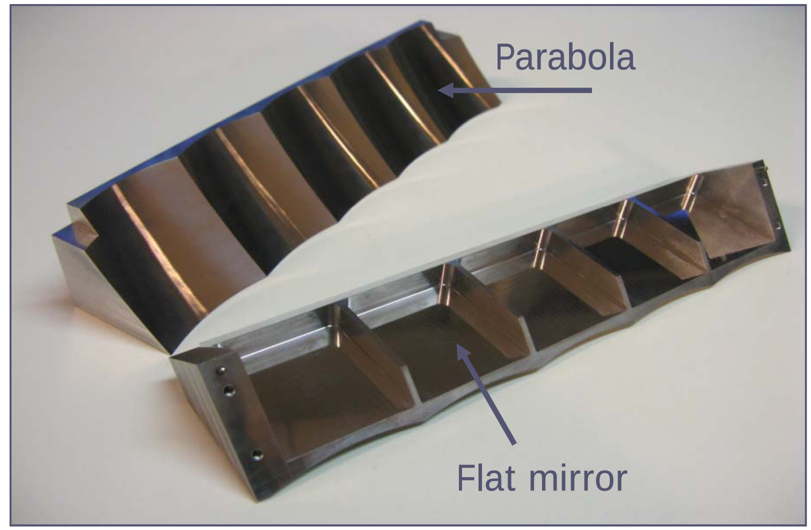


Effects of lenses absorption losses on receiver noise temperature:

→ ~ + 5K (@ 300K window output) if Trec = 50K (@ horn output)

3mm MB: Individual Cryogenic Optics
Design Option B: Fully Reflective Optics

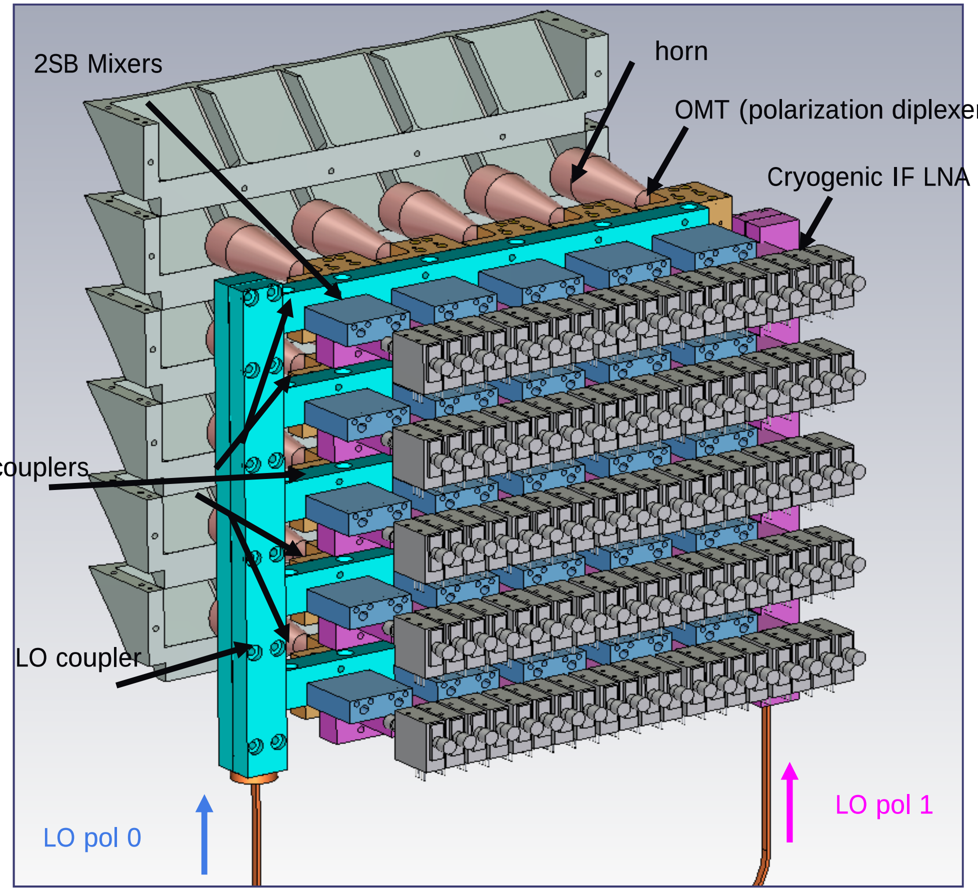




→ No absorption loss & reflection loss

→ Negligible thermal contraction

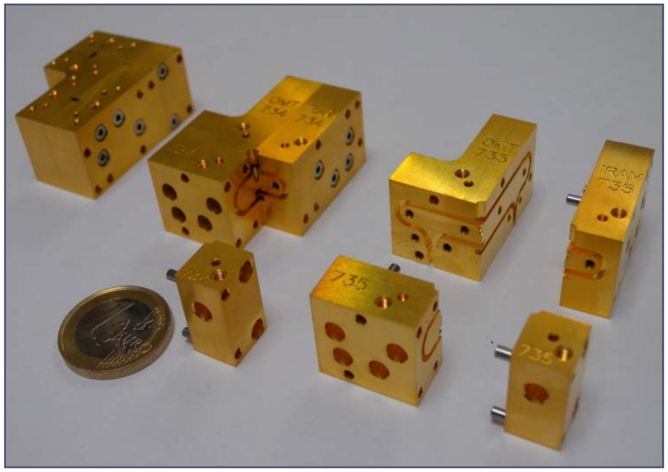
3mm MB: Cryogenic RF Module



Thermal Issues:

- Manufacturing materials of cryogenic waveguide components :

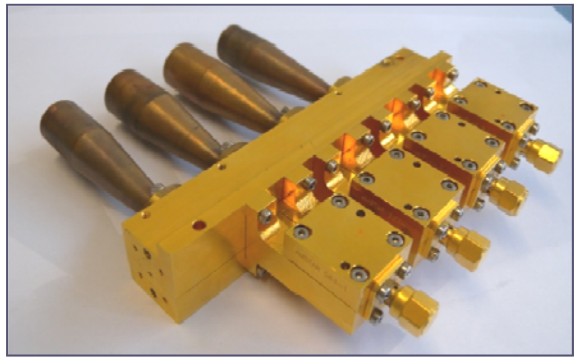
Polarization diplexer (gold plated brass)

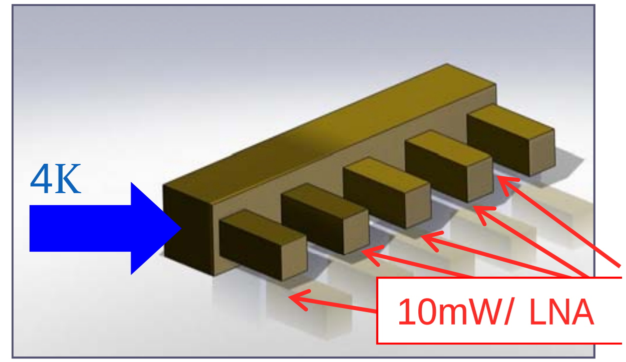


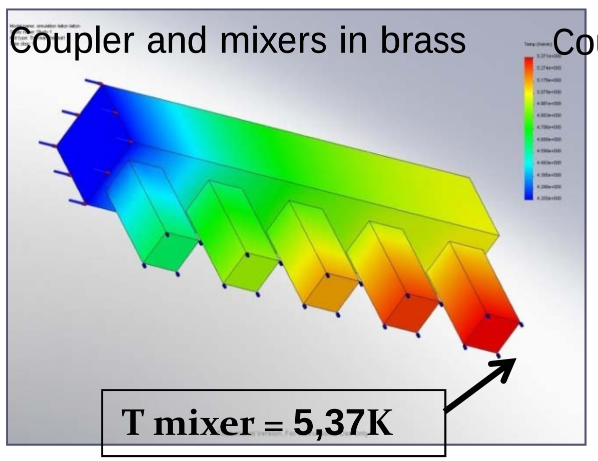
- Physical temperature of active components (mixers, LNA...)
- Dismouting/ repair procedure: cryogenic IF cables & connectors

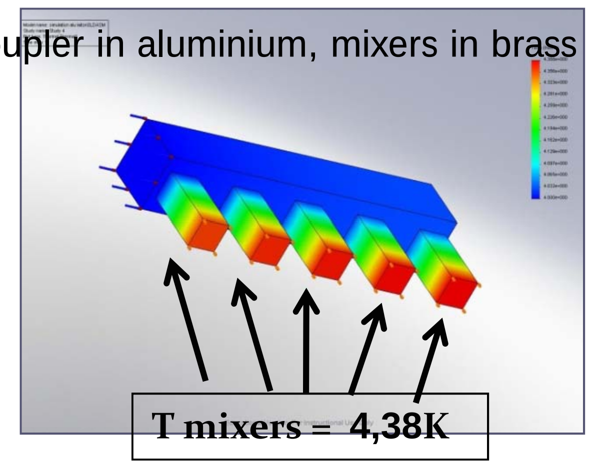
Cryogenic Waveguide Components: Materials Analysis

Thermal simulations







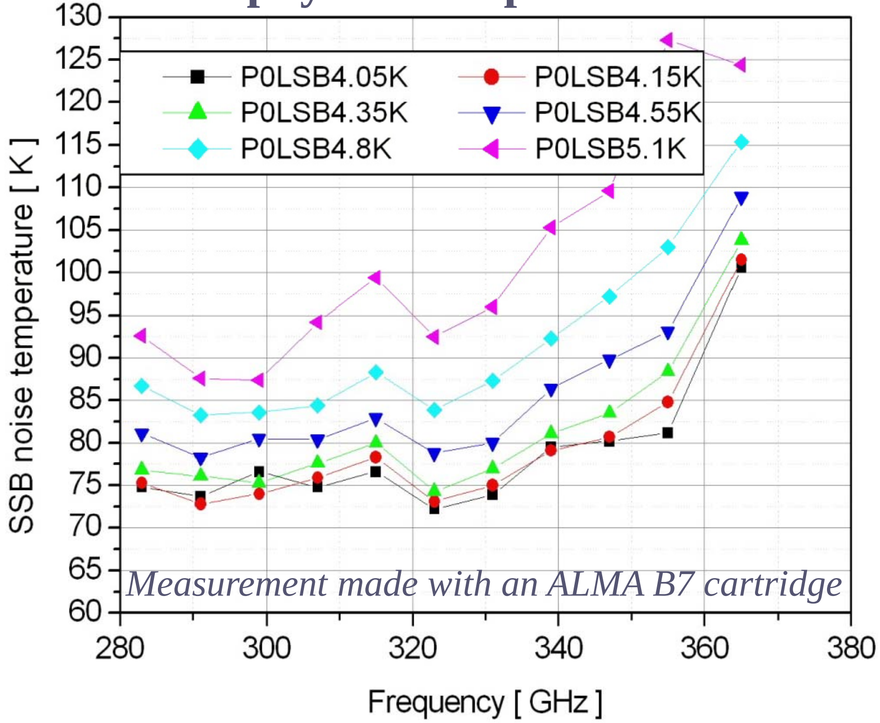


Material requirements:

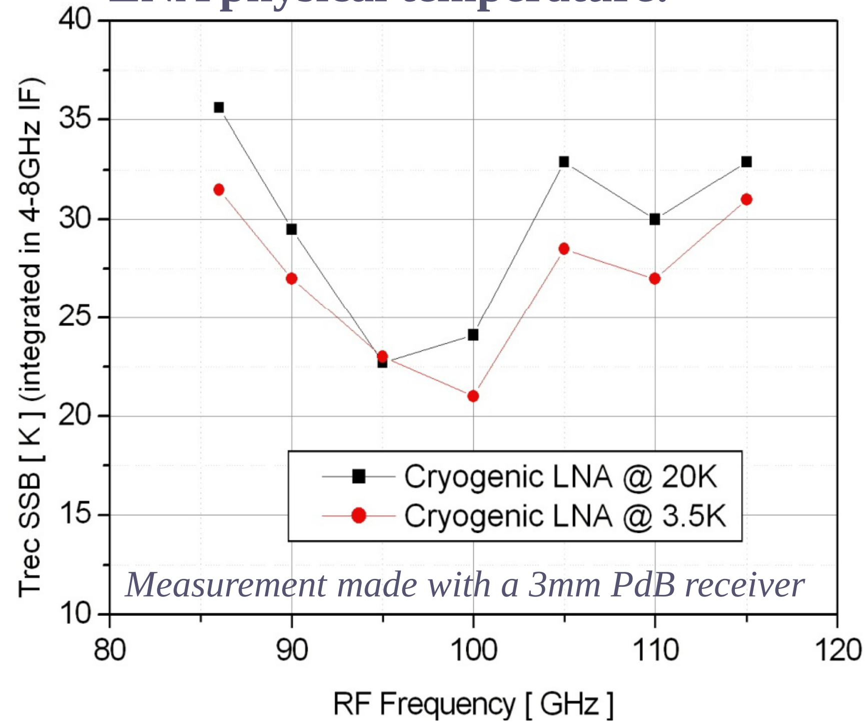
- Low mass volume
- High electrical conductivity
- High thermal conductivity
- Accurate machining

Cryogenic Design: Optimal Operating Temperatures of SIS Mixers and LNA

Receiver noise performances vs. SIS mixer physical temperature:



Receiver noise performances vs. LNA physical temperature:

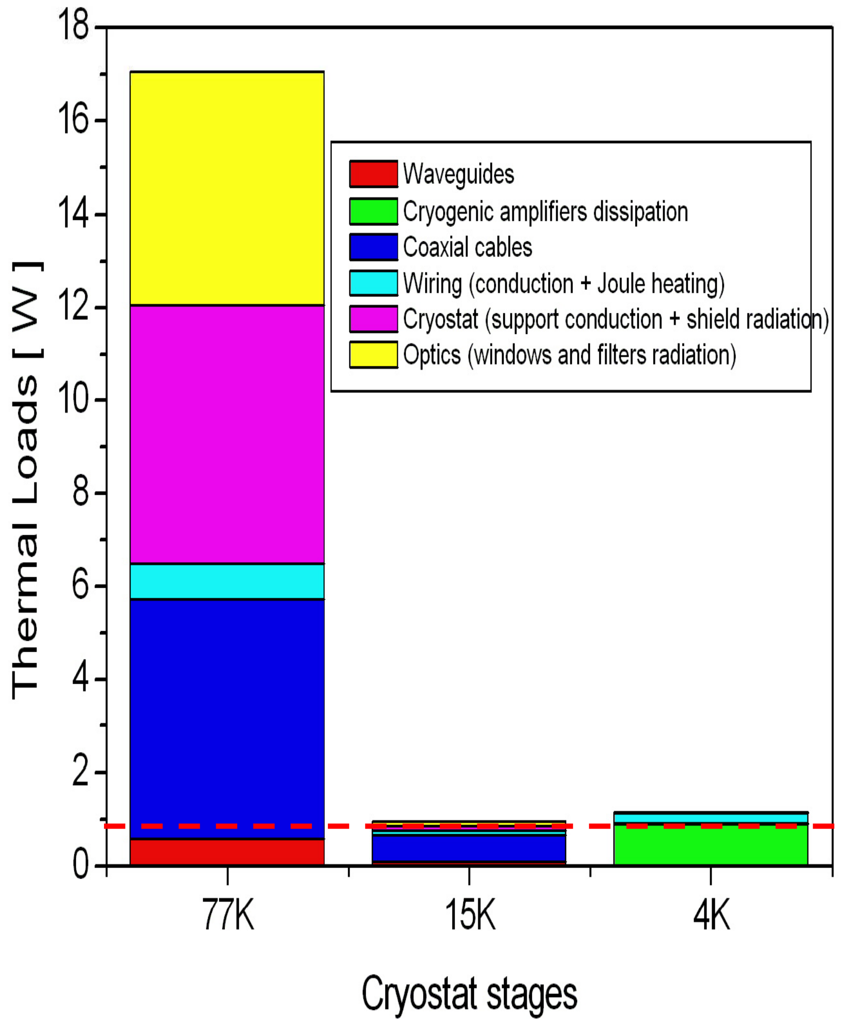


→In the HERA cryostat (GM-JT DAIKIN cryoccoler), mixers physical temperatures ~ 4.7K

→In the EMIR cryostat (GM SUMITOMO cryocooler), mixers physical temperatures ~ 4K

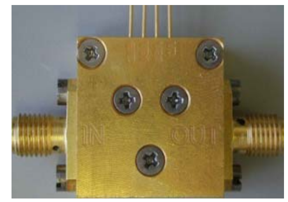
Cryogenic Design: Thermal Budget of the 3mm Multi-beam

(50 pixels, 2SB = 100 IF outputs are considered)



GM RDK-3ST Sumitomo cryocooler maximal capacity on 4K stage

- Main contribution on 4K stage: LNA (9mW/ ampli)



CALTECH 4-12GHz amplifier

- IF transport: SS/CuBe semi-rigid cables (5W(77K)/560mW(15K)/20mW(4K))
  (Other solutions are also considered for IF transport for mechanical reasons):

Flexible cryogenic cable from HIGHTEC

- Wires: MG, ϕ=0.2mm, n~1000 (worse case number for electronic bias of LNA and mixers)

Cryogenic Machine ?

<u>Cryocooler requirements to optimize receiver performances:</u>

- Available power on 4K stage >1.2 W (+ safety margin)
- Temperature on the ***loaded*** 4K stage < 4.2K
- Stability: minimize temperature fluctuations of LNA !

<u>Solutions?</u>

→Use 2 cryocoolers ? (Cost, complexity, space required ...)

→Reduce power consumption of cryogenic LNA

→Not to operate LNA or SIS mixers at the optimal temperature

<u>Requirements for cryostat:</u>

- Low weight → aluminum
- Shape optimized to minimize receiver size and maximize ease of access to cryogenic components for repair or upgrade

RDK-3ST Sumitomo cryocooler