On-board Integrated Submm Spectrometer for Atmosphere Monitoring and Radio Astronomy

(supported by ISTC project 3174)

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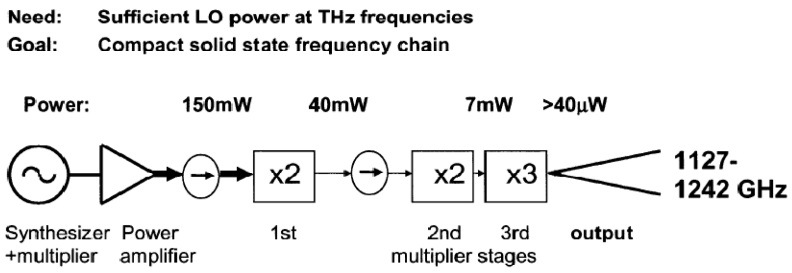
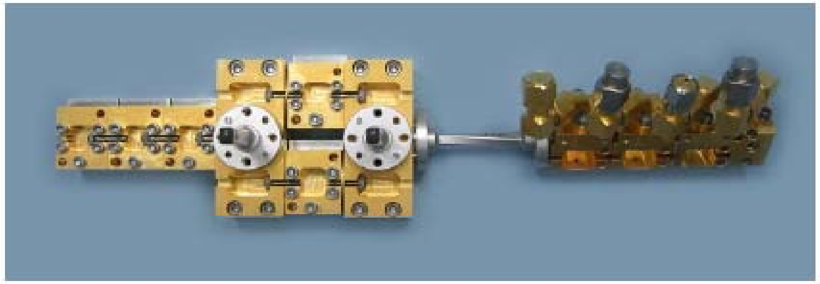
Kotel'nikov Institute of Radio Engineering and Electronics, Moscow, Russia

in collaboration with

SRON Netherlands Institute for Space Research, the Netherlands

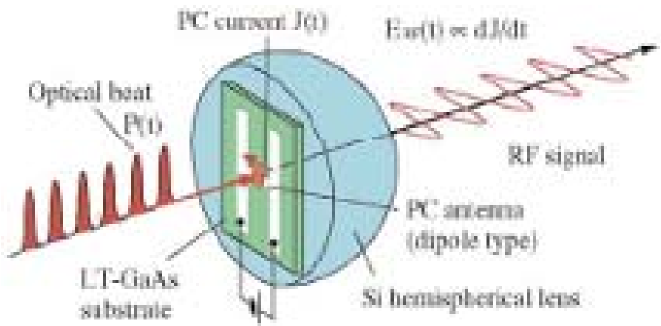
Astronomy sub-mm LO sources:





HIFI multipliers, JPL

Multiplier chains (JPL, RPG, VDI)



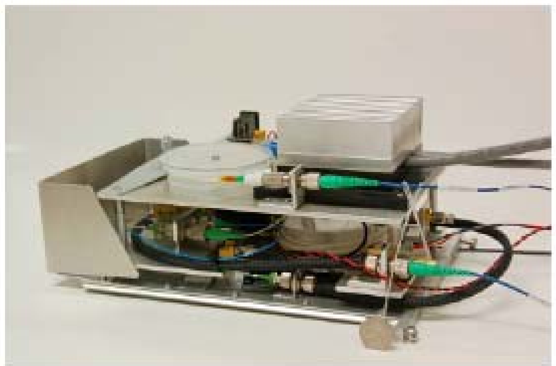


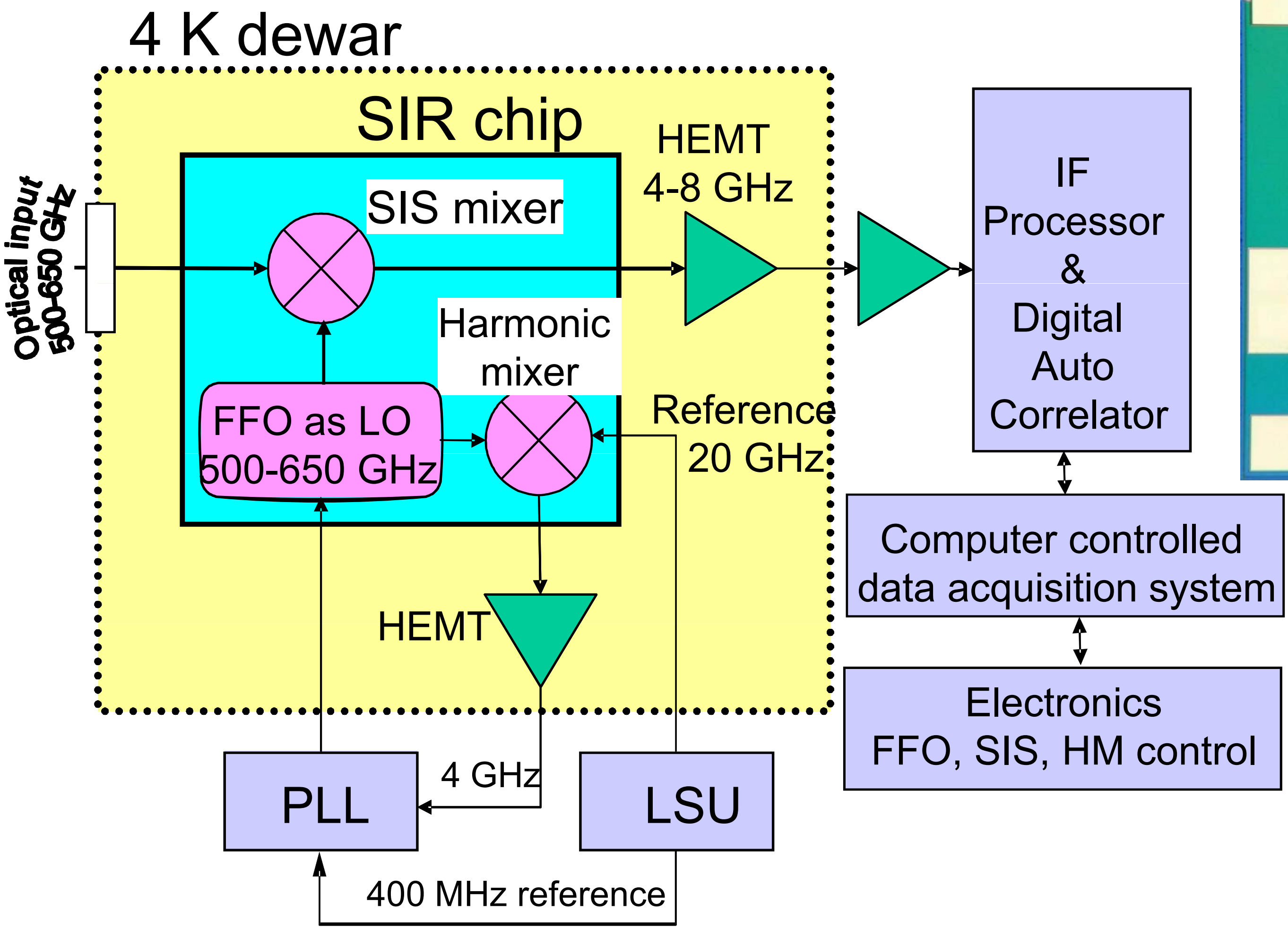
Photo mixers,

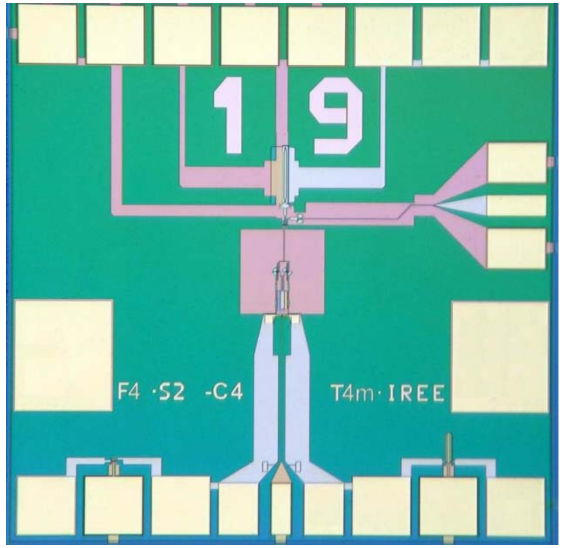
Down

conversion

Harvard Smithsonian; 160-260 GHz

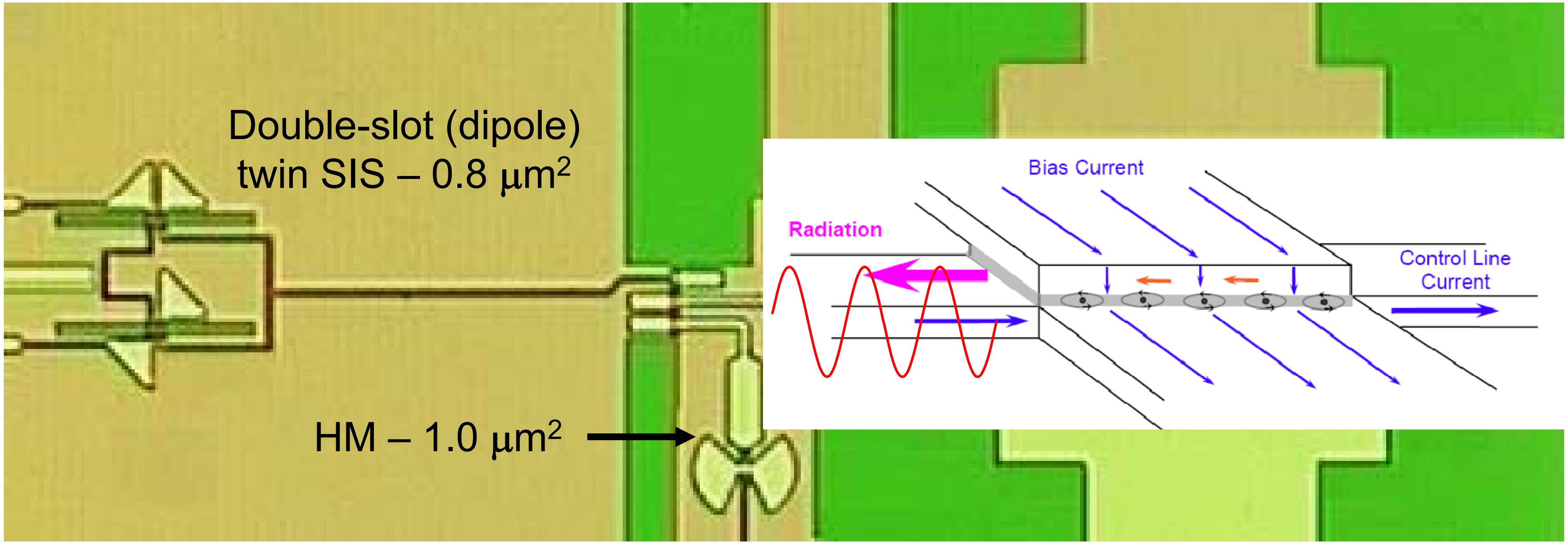
Superconducting Integrated Receiver (SIR) with phase-locked FFO





SIR microcircuit

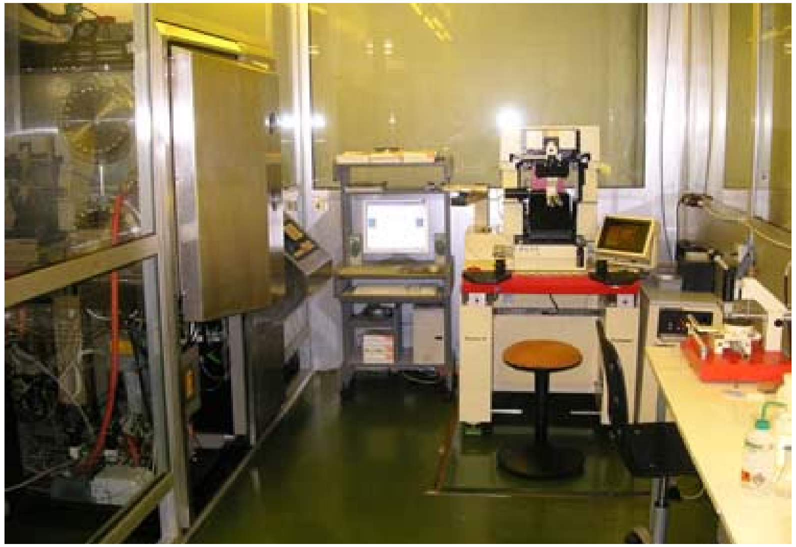
Internal part of the SIR Microcircuit

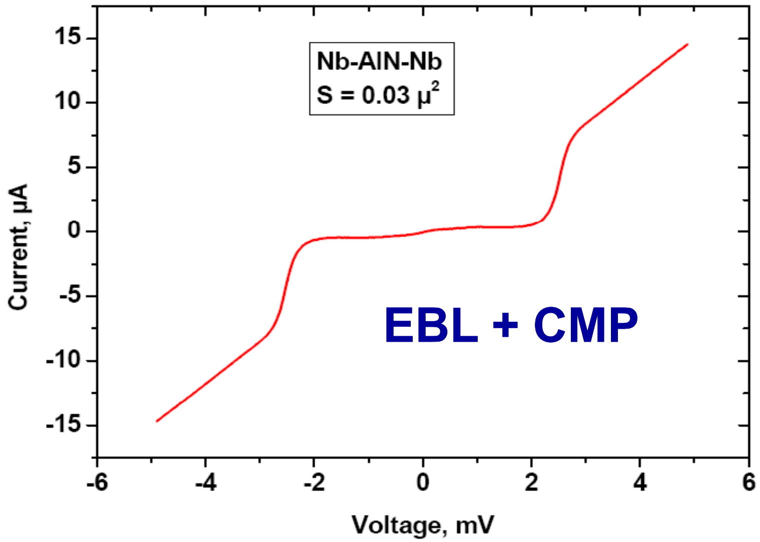


Nb-AlN-NbN; Jc = 5 - 10 kA/cm²

Optionally: SIS – Jc = 8 kA/cm²; FFO + HM = 4 kA/cm²

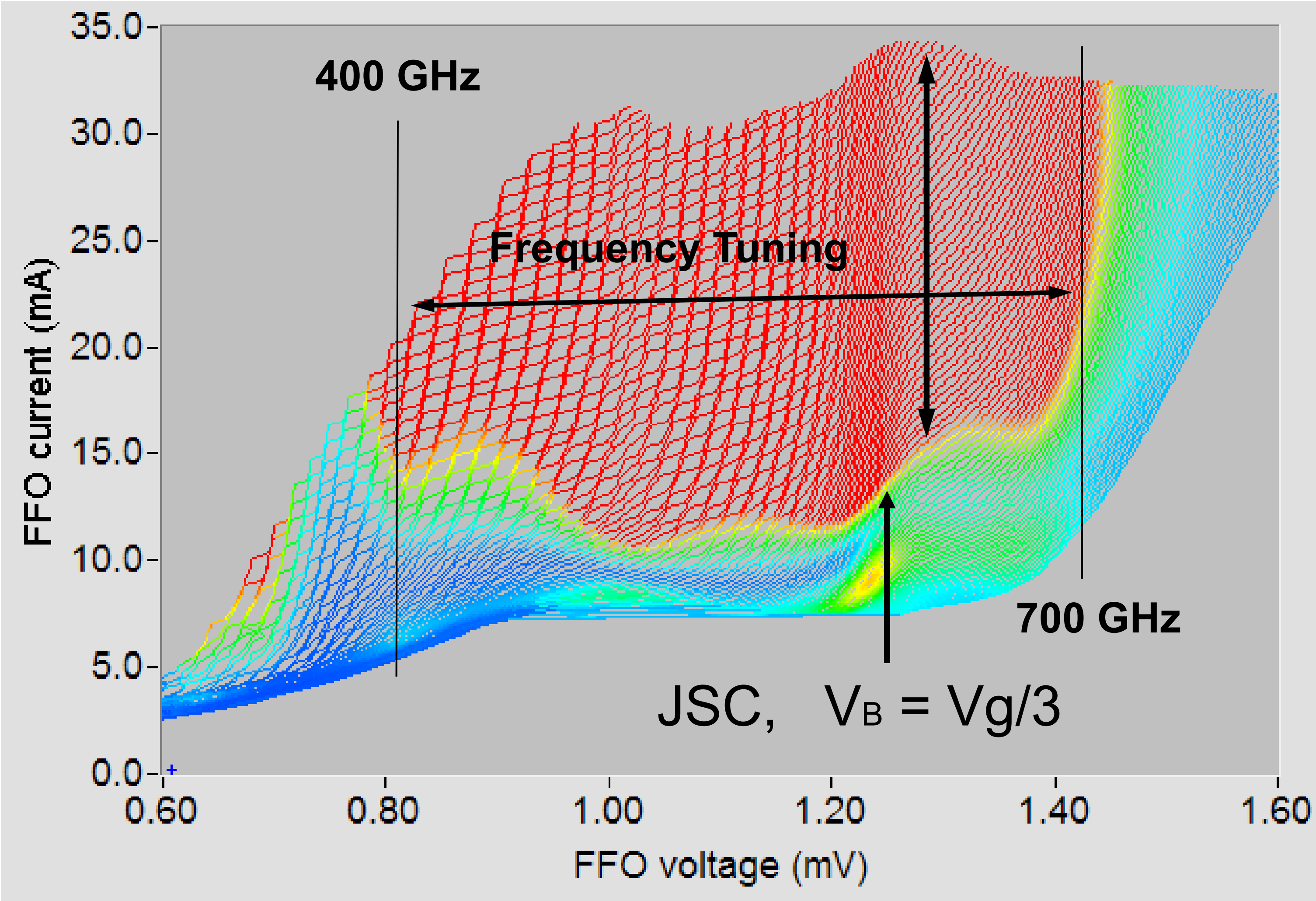
Laboratory of Superconducting Devices for Signal Detection and Processing





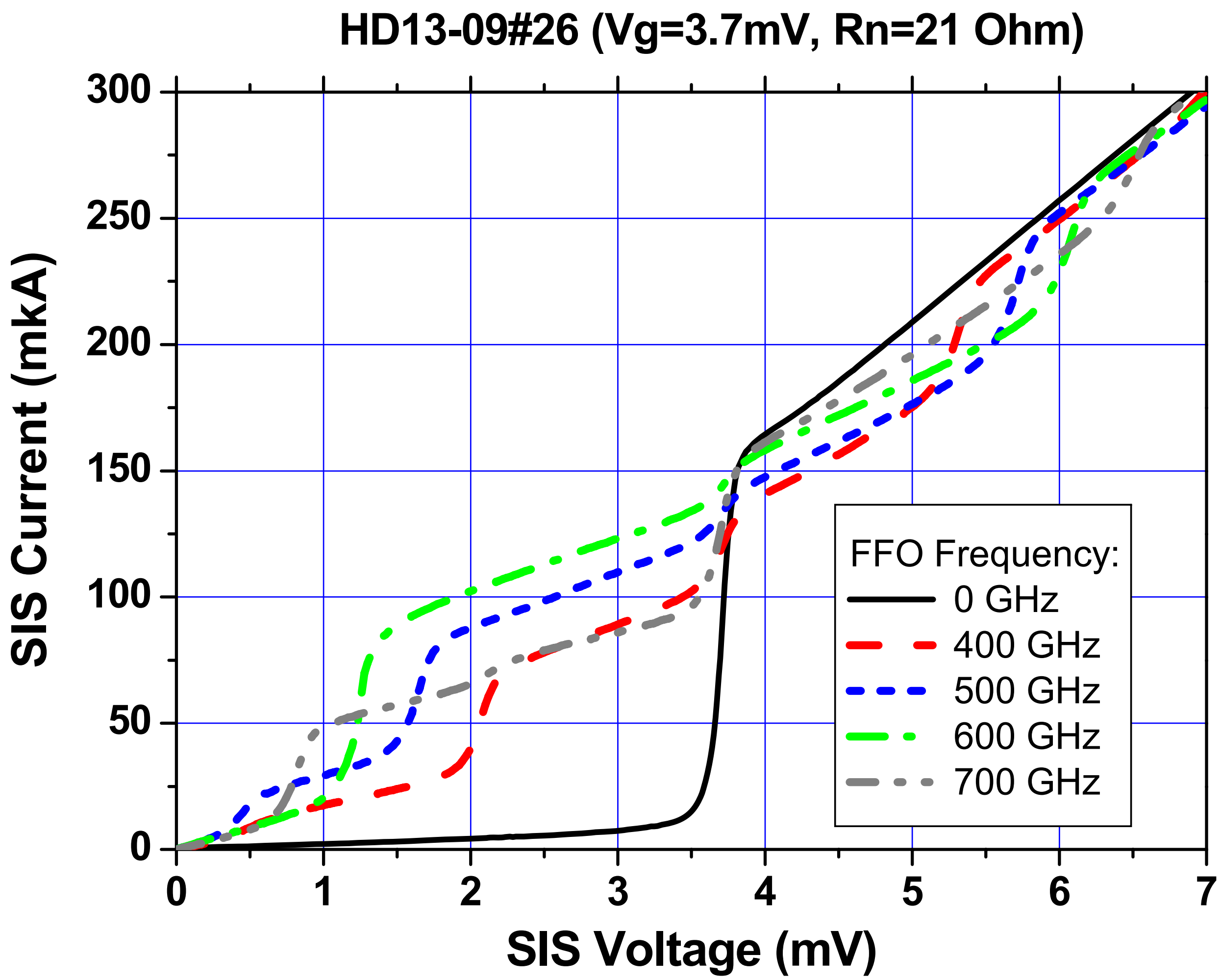
Nb-AlN-NbN
Nb-AlOx-Nb;
J_c = 1 - 100 kA/cm^2
d = 2 – 1 nm
S = 0.1 – 1000 mkm^2

Nb-AlOx-Nb and Nb-AlN-NbN FFO for SIR

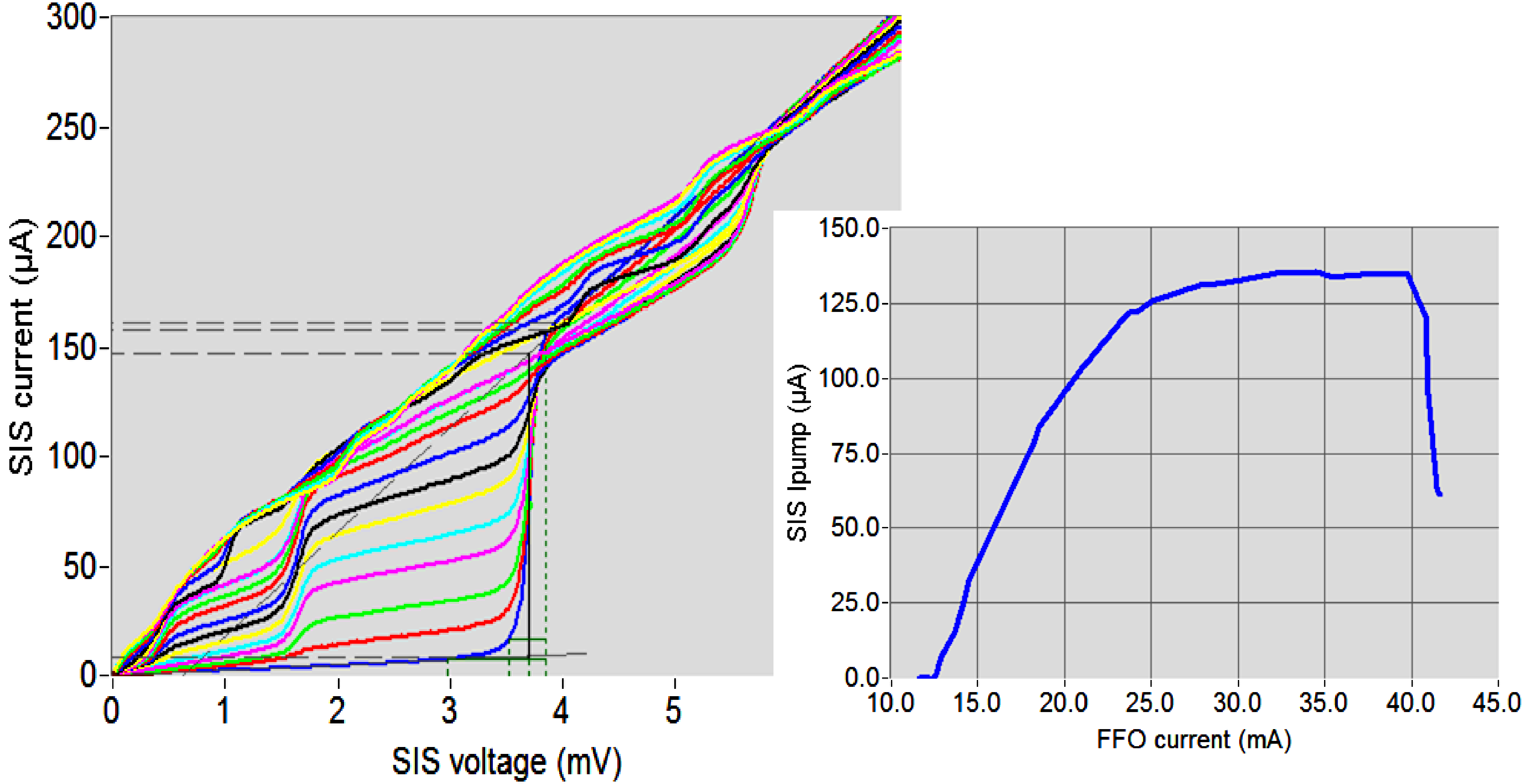


V.P. Koshelets, et al, Phys. Rev. B, vol. **56**, pp 5572-5577, (1997)

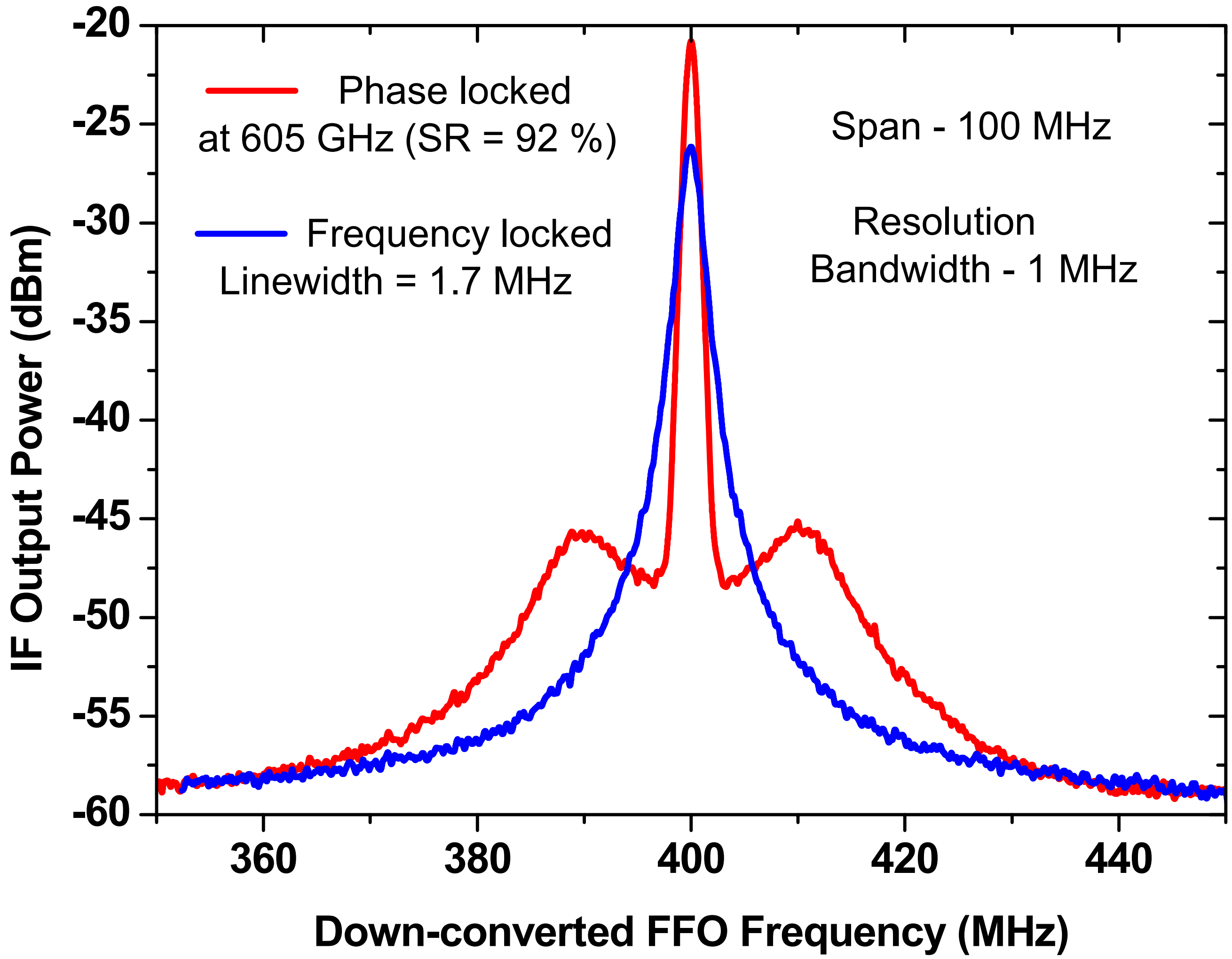
Nb-AlN-NbN SIS pumped by FFO; FFO frequency tuning



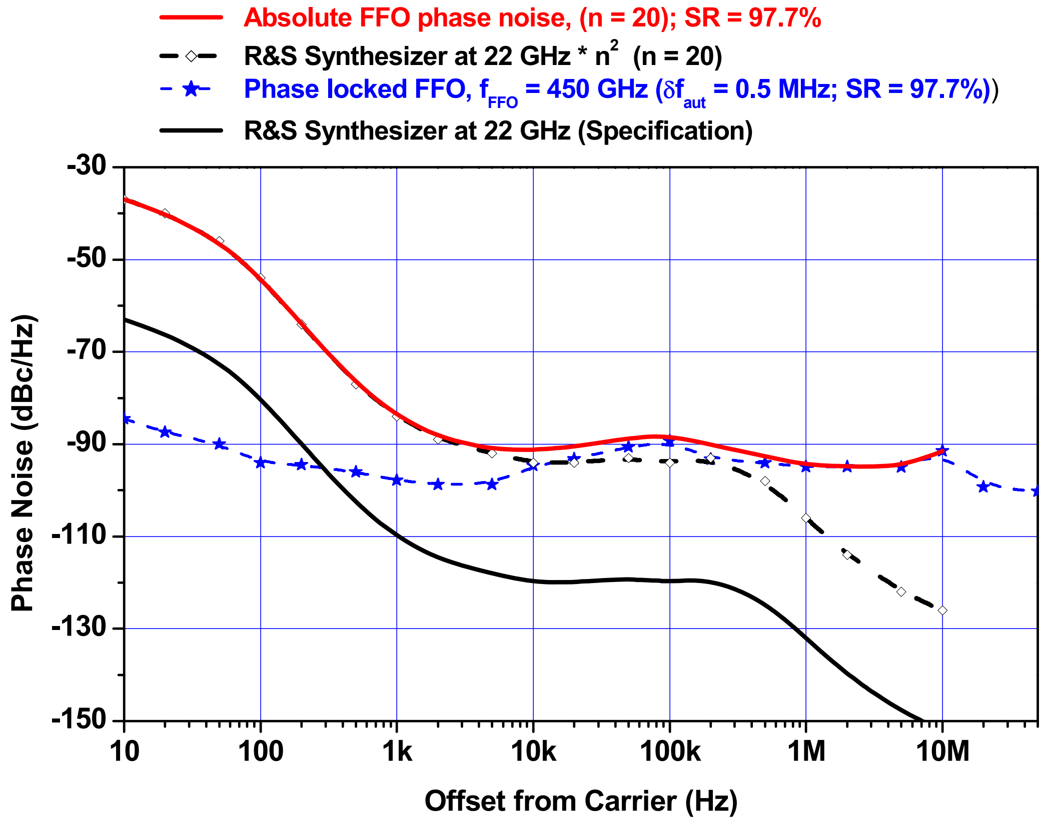
Nb-AlN-NbN SIS pumped by FFO; FFO power tuning (f = 500 GHz)

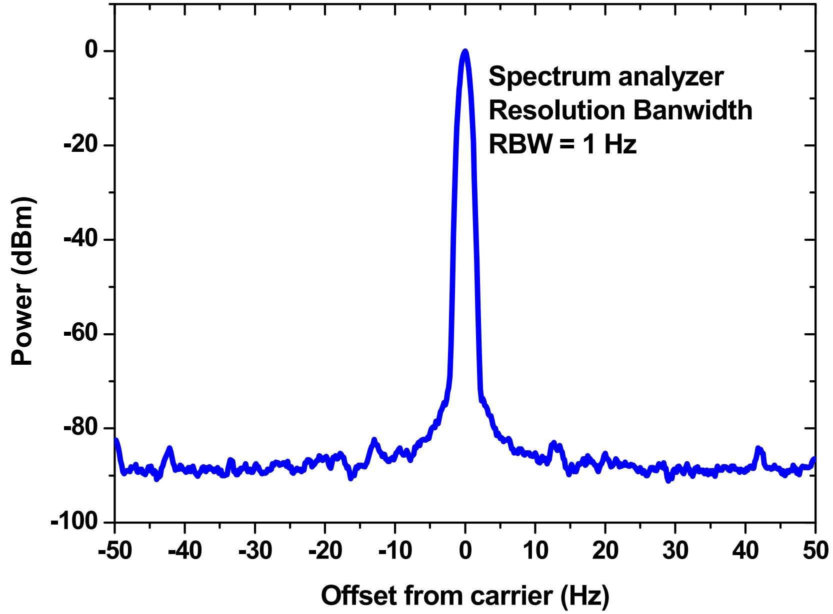


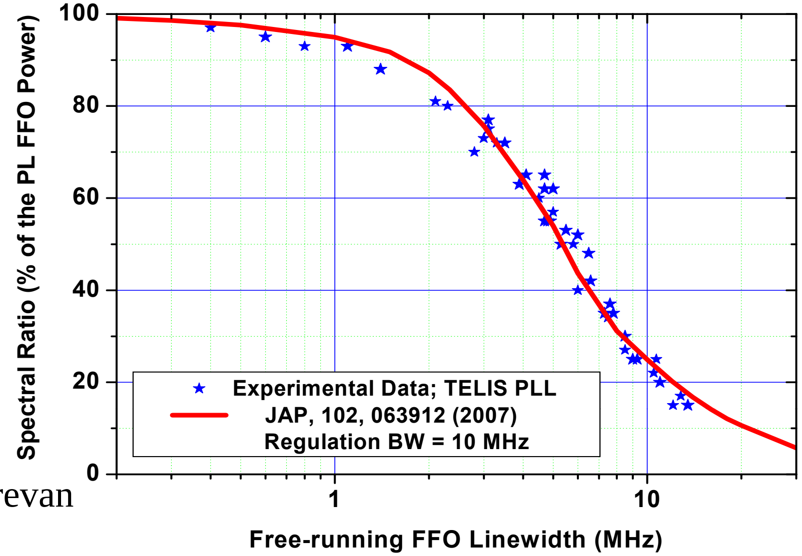
FL and PL spectra of the Nb-AlN-NbN FFO : frequency 605 GHz; LW = 1.7 MHz; SR = 92 %



Phase Noise of the PL FFO







Development of the Integrated Spectrometer for TELIS

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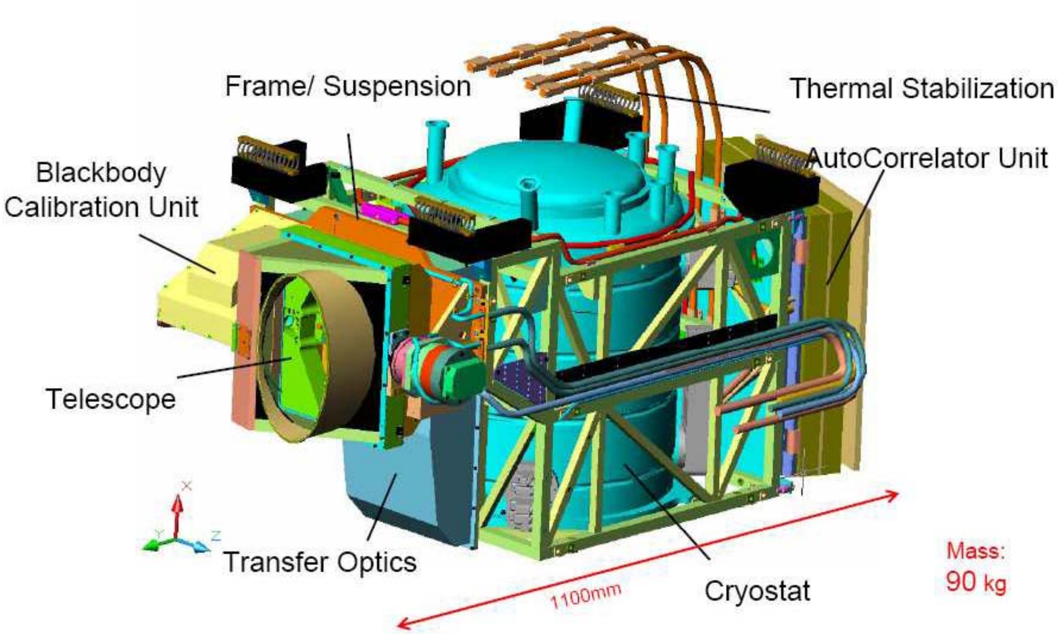
TELIS (Terahertz Limb Sounder)

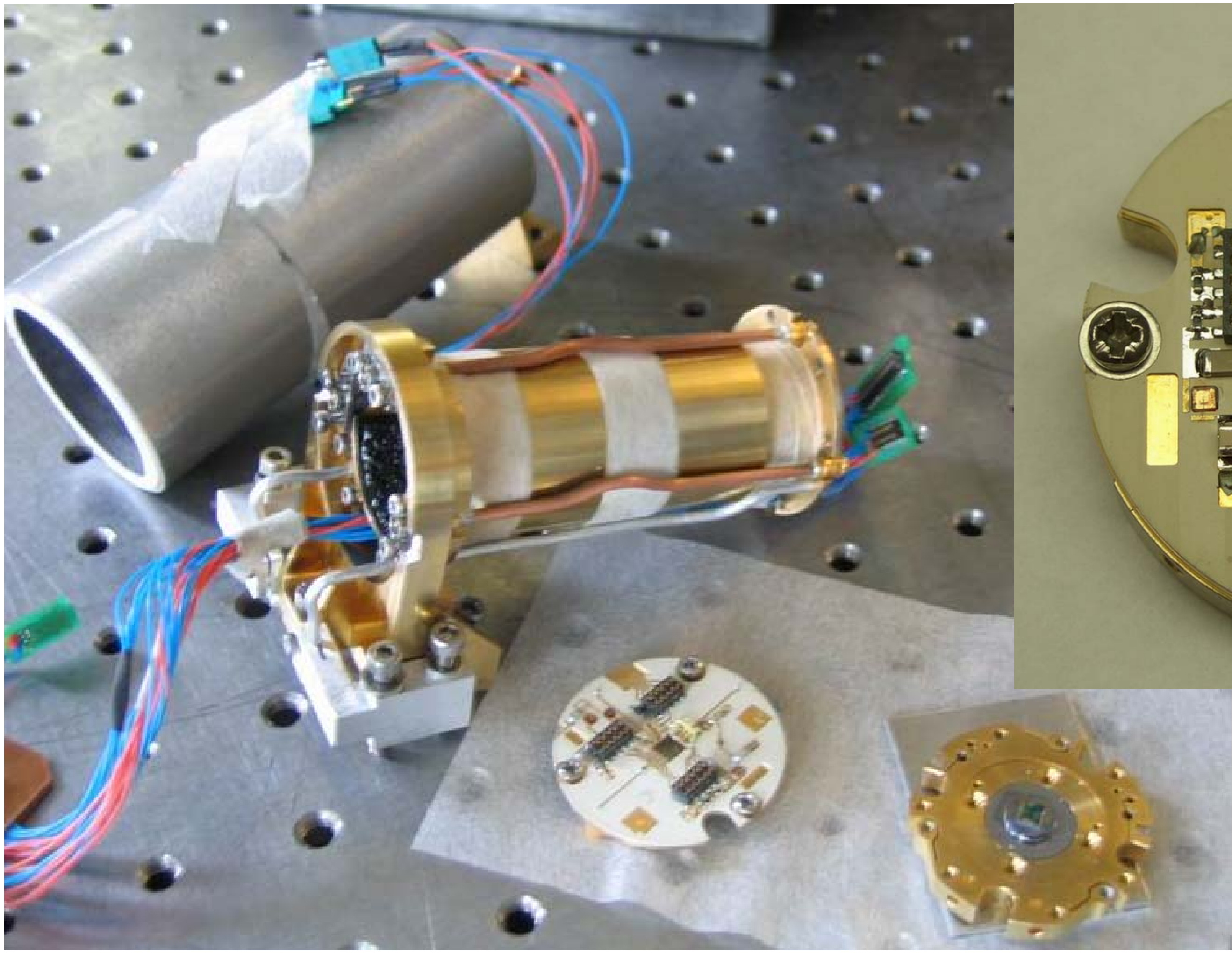


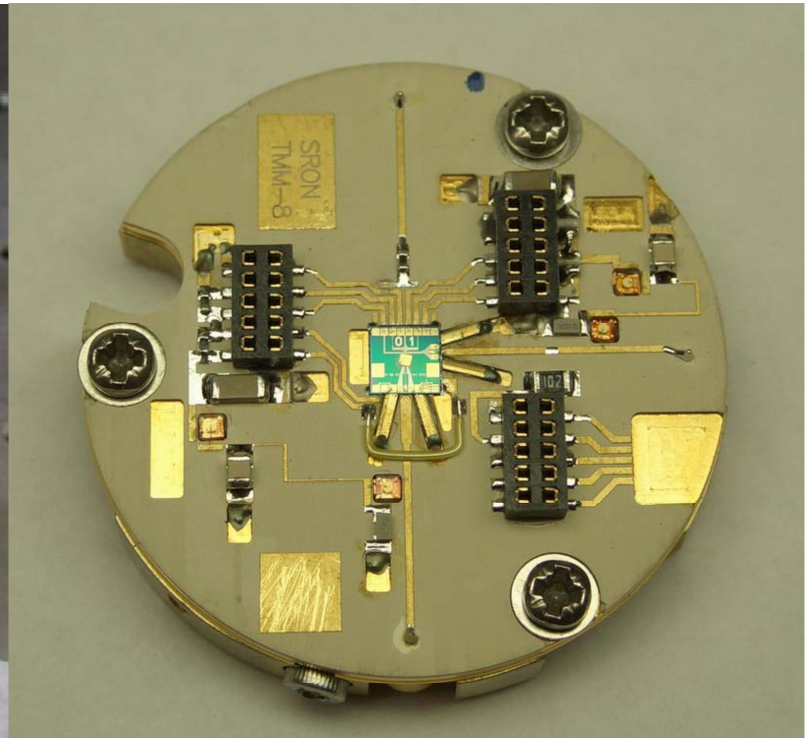
TELIS Instruments

TELIS Objectives:

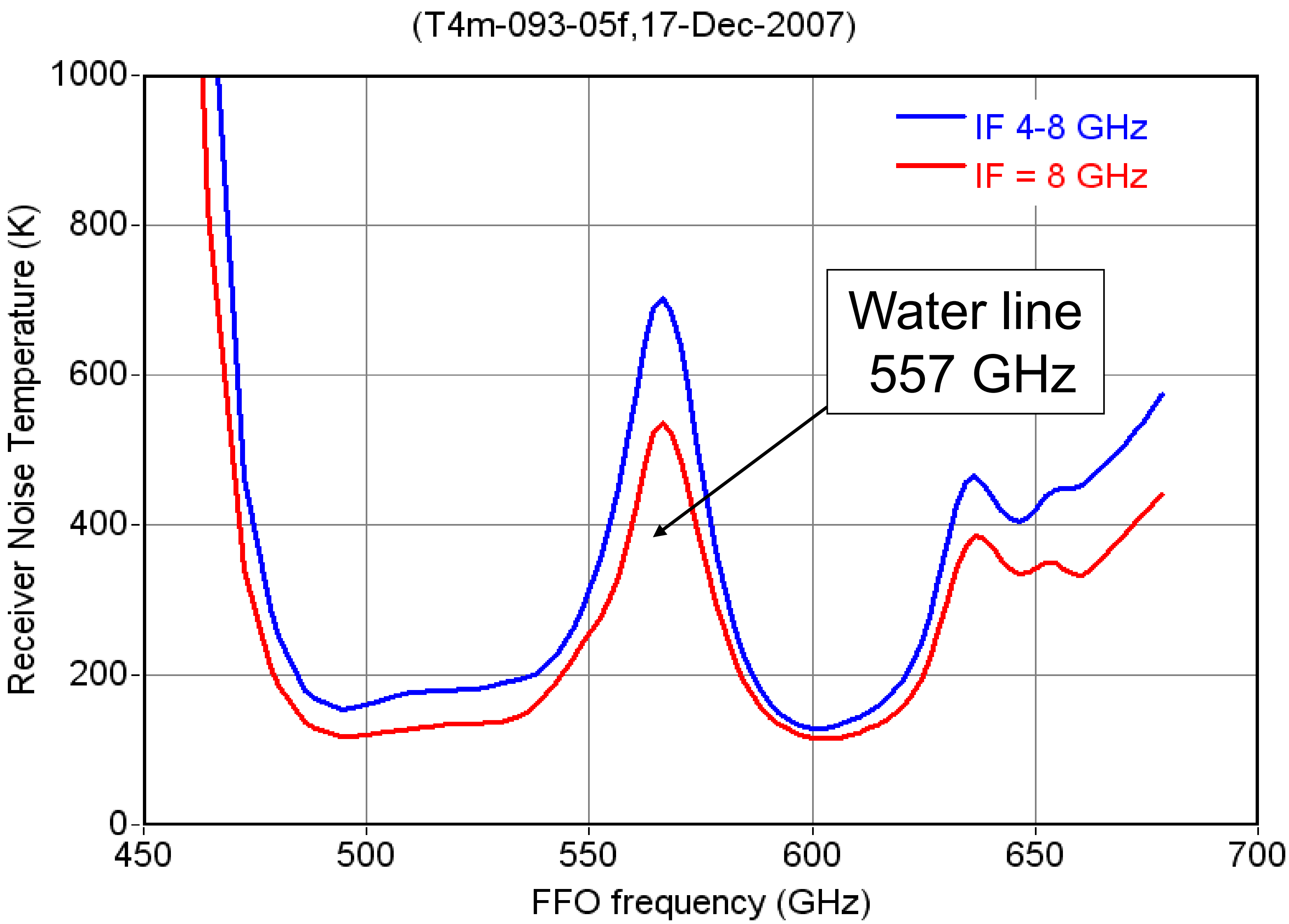
- Measure many species for atmospheric science: ClO, BrO, O_3, HCl, HOCl, etc;
  - Chemistry, Transport, Climate
- Serve as a test platform for new sensors
- Serve as validation tool for future satellite missions
- Three independent frequency channels, cryogenic heterodyne receivers:
  - 500 GHz by RAL
  - **500-650 GHz by SRON-IREE**
  - 1.8 THz by DLR (PI)

SIR Mixer Block with Shields

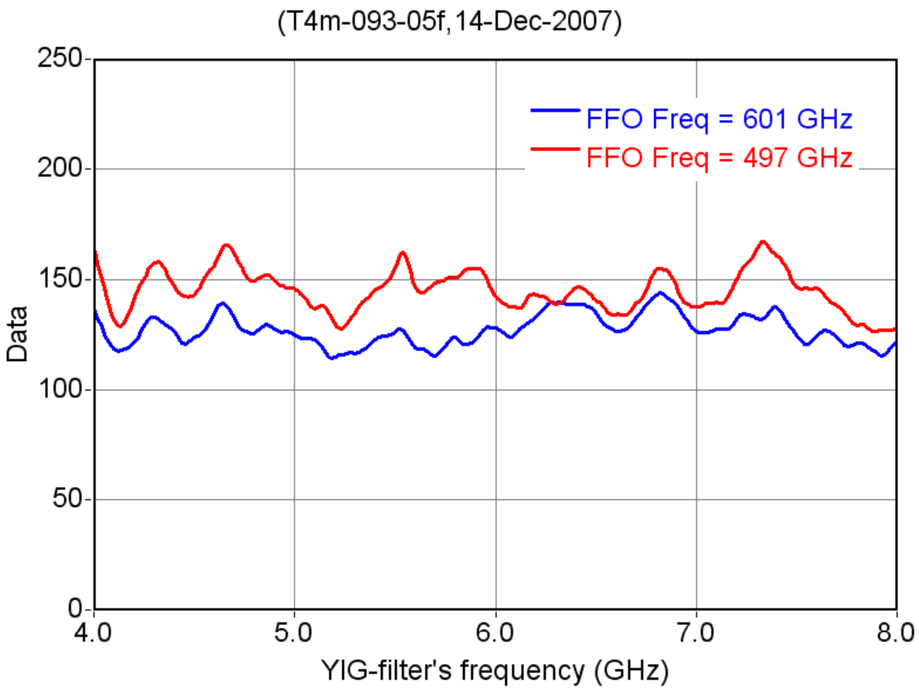


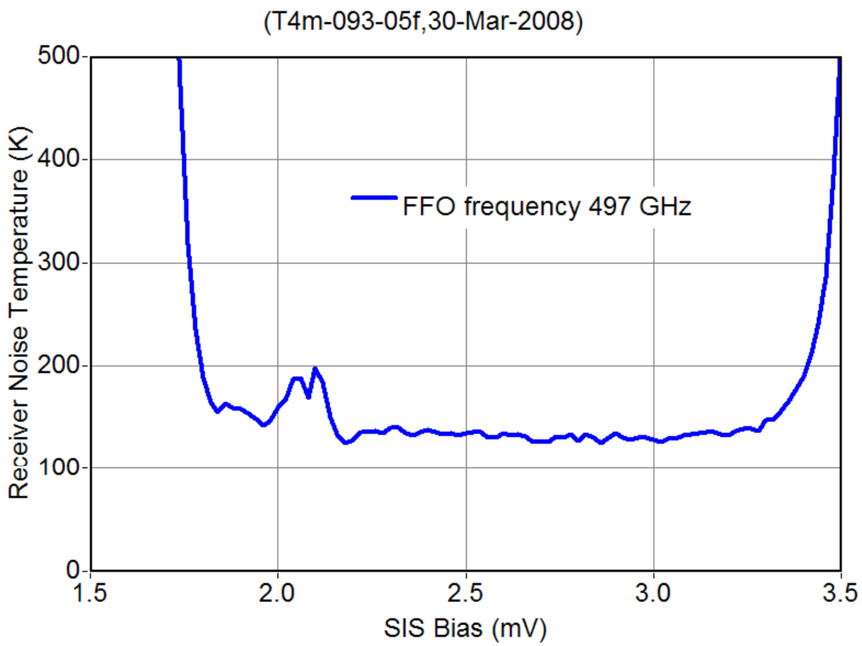


Noise Temperature of the Flight SIR (DSB)

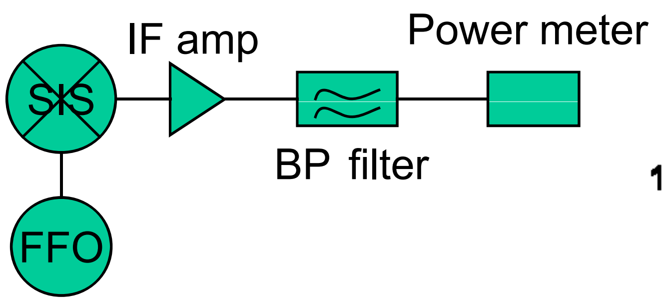


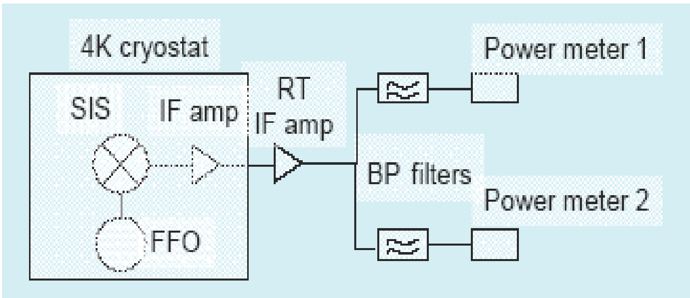
SIR Noise Temperature
on Intermediate Frequency and SIS Bias

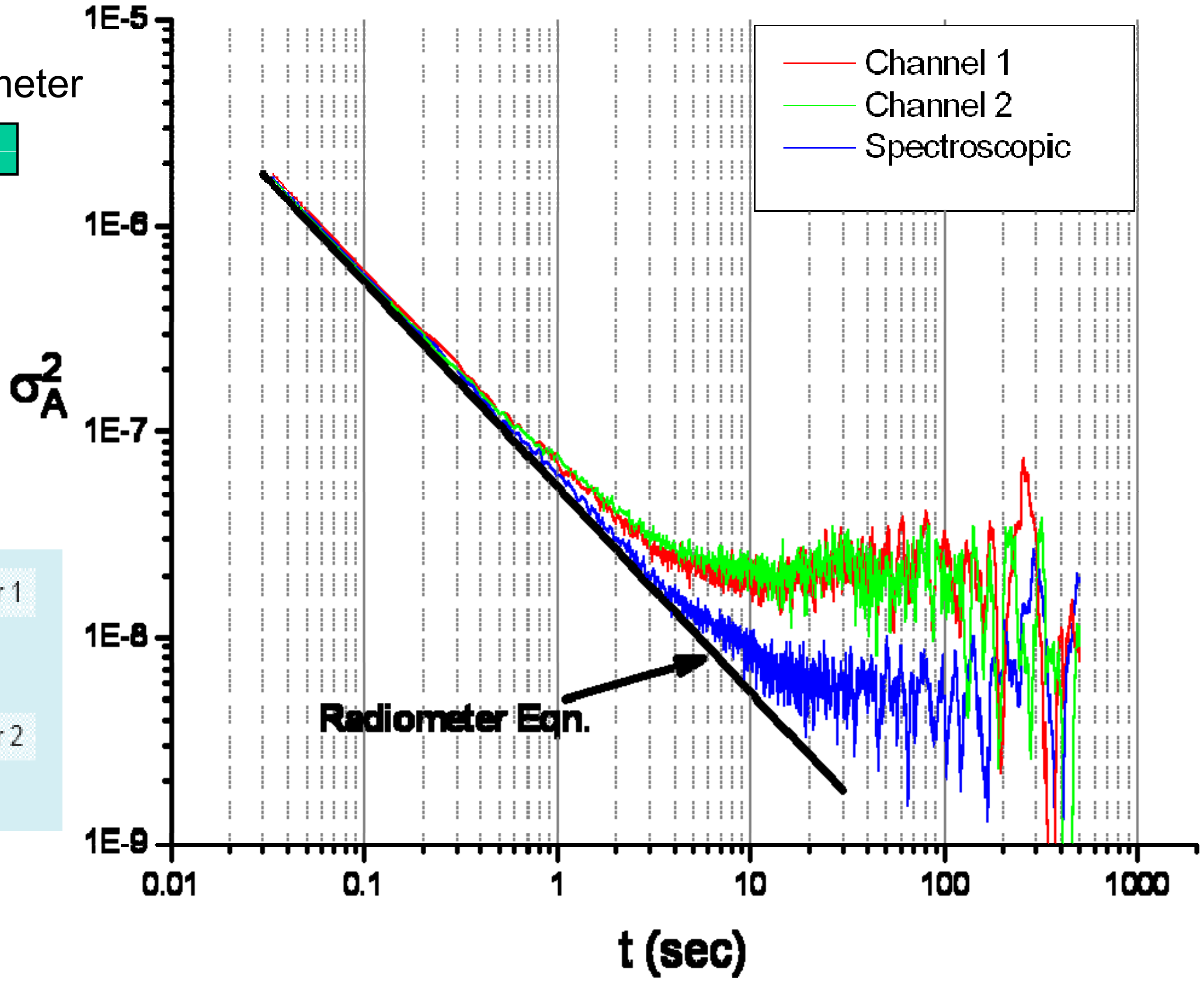




SIR Stability: Allan variance test

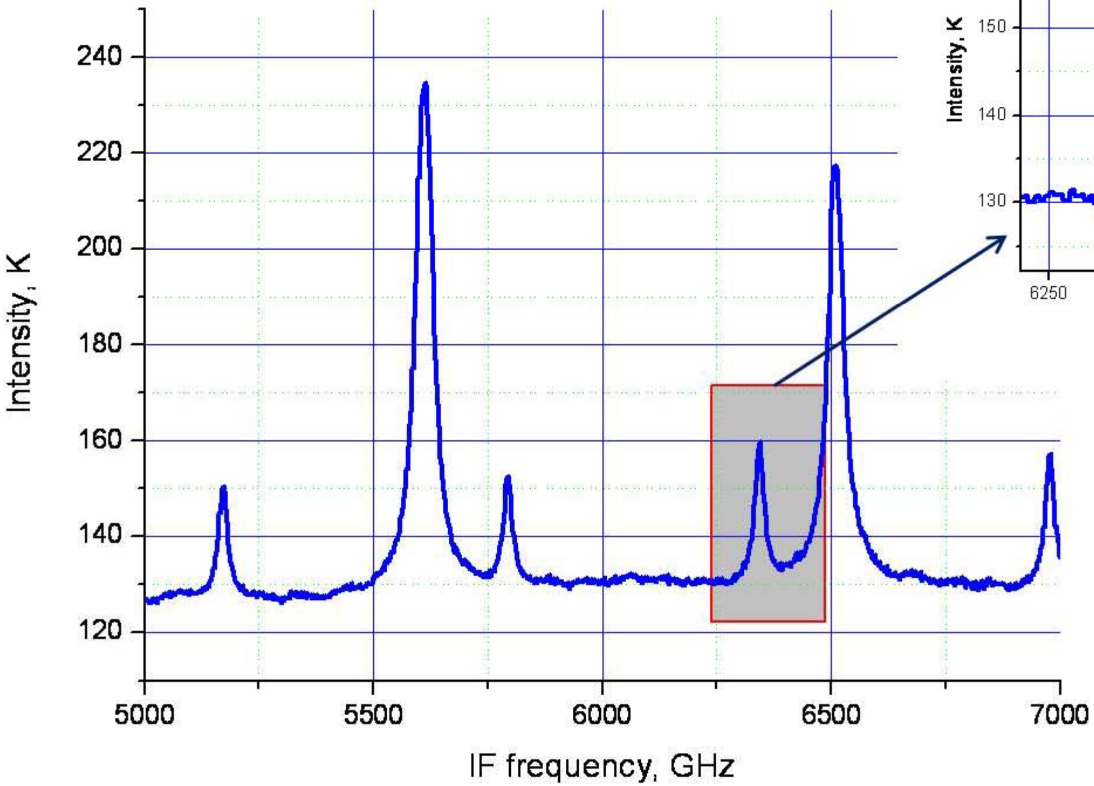


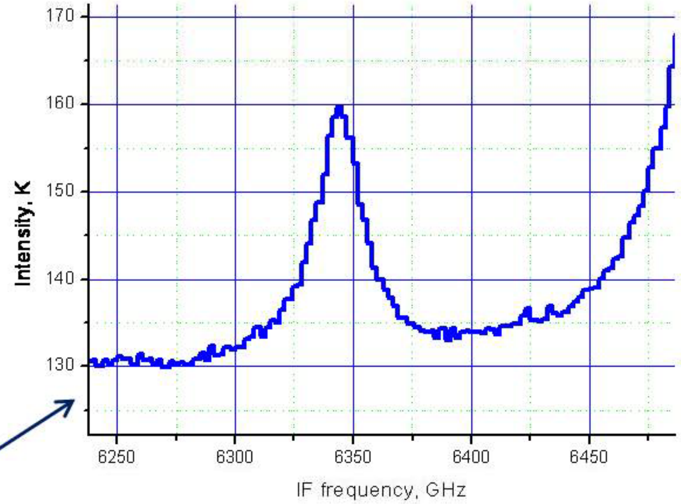




SIR Spectral Resolution

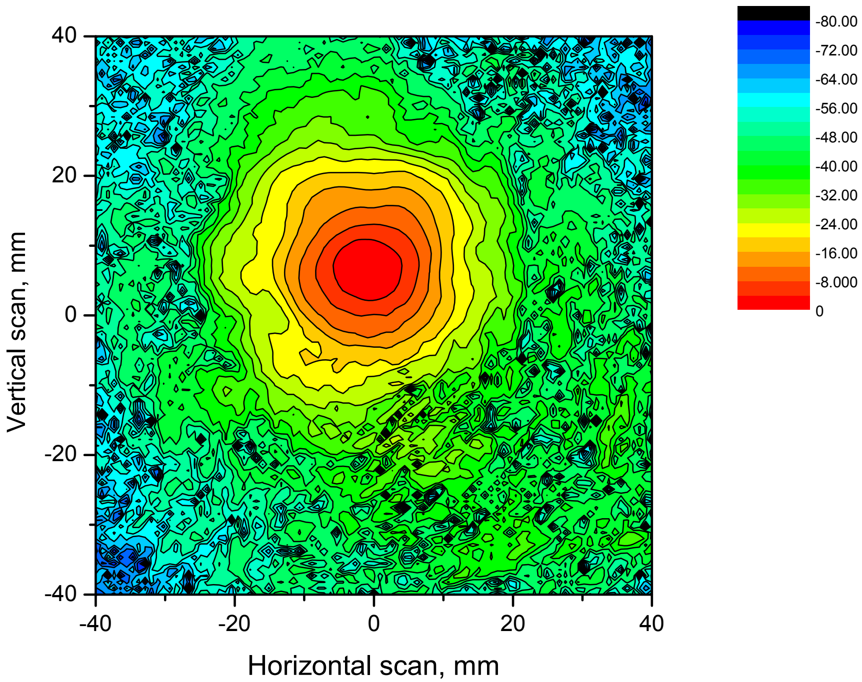
Deconvolved spectrum of the OCS emission lines at a gas pressure 2.6 mBar.
LO frequency 601 GHz.



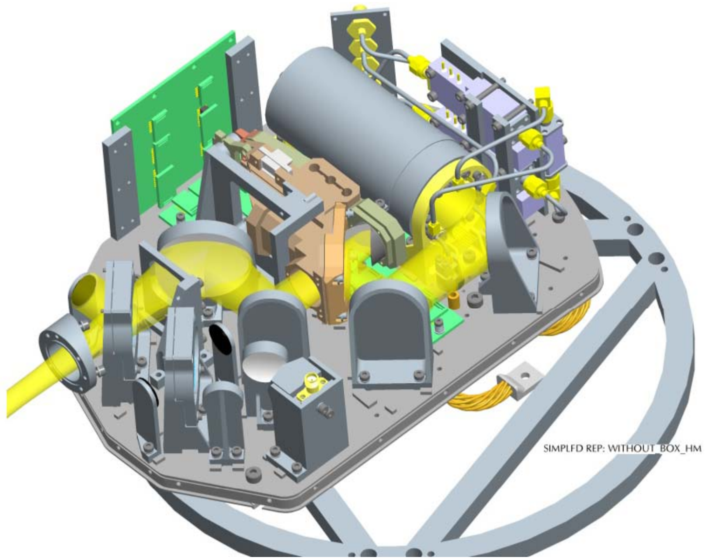


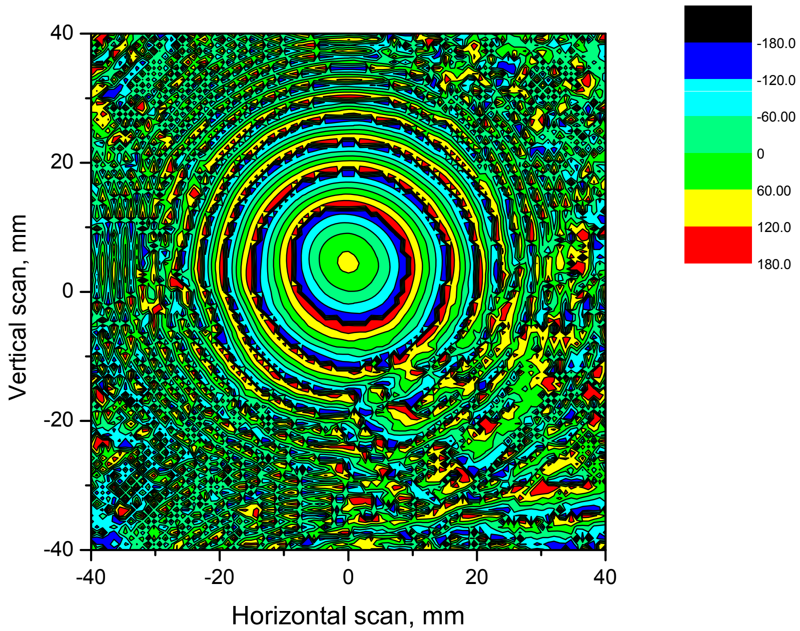
Two strong lines are saturated; weaker lines are not saturated isotopes.
The lines are detected, one in the LSB, the other one in the USB

Amplitude and phase APB of the SIR with cold optics



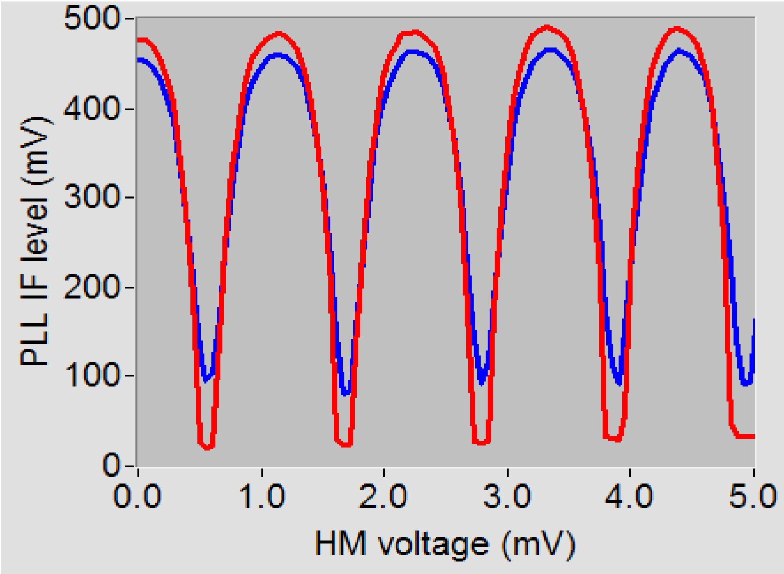
Amplitude

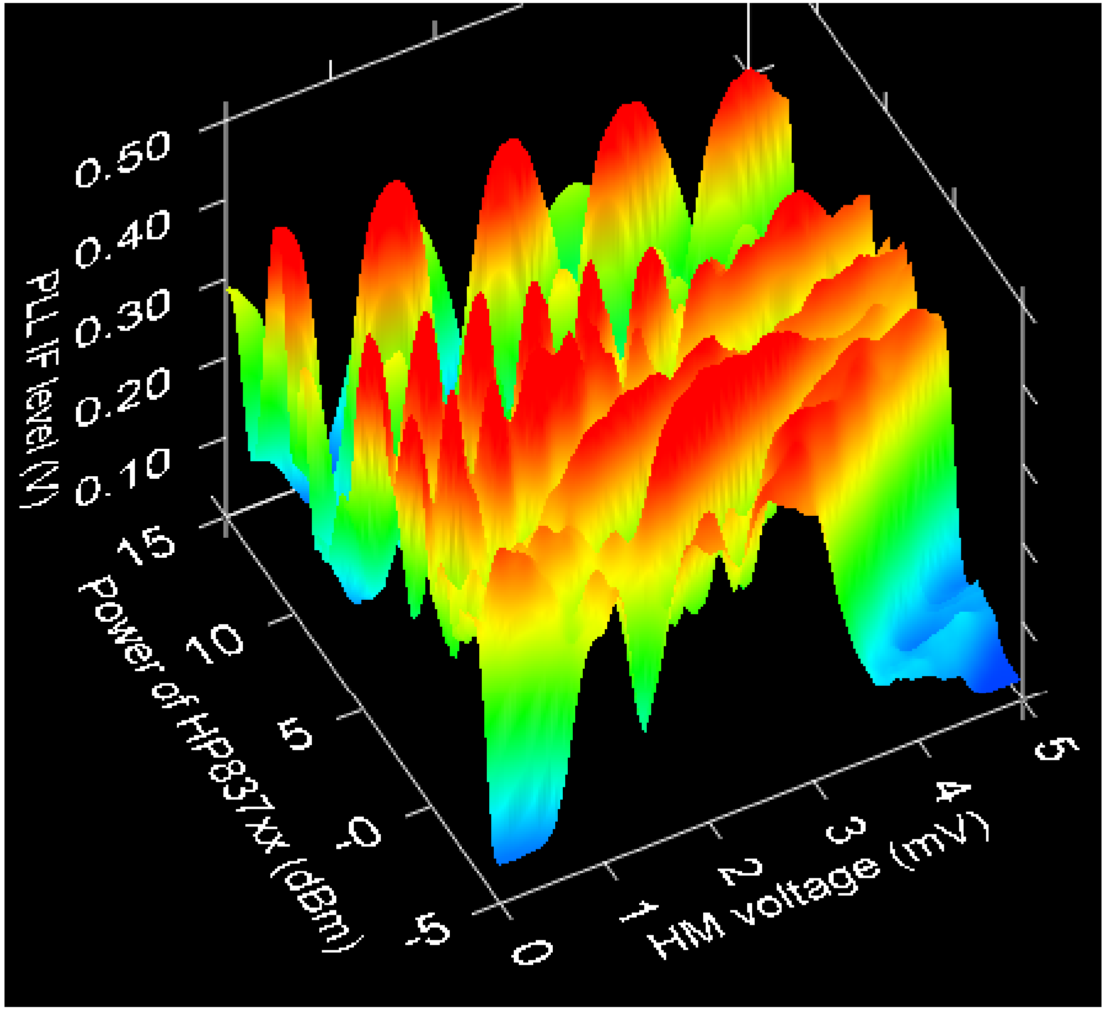


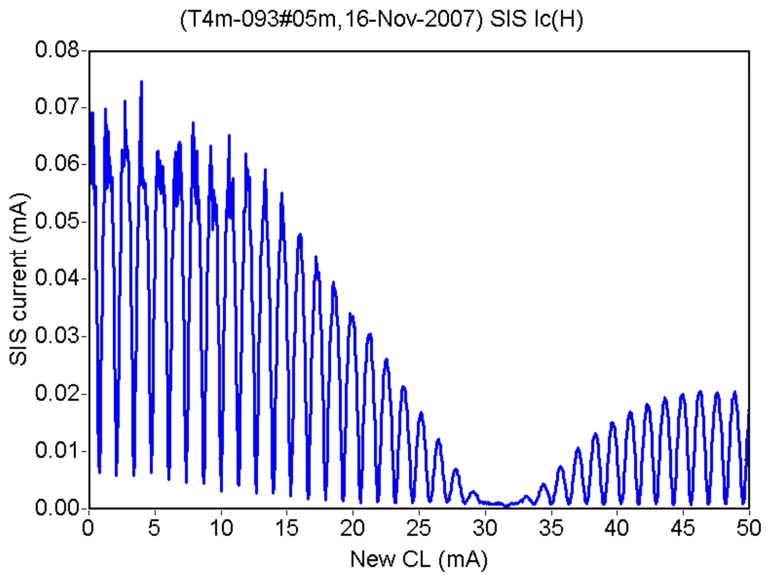


Phase

SIR for TELIS – remote operation







TELIS-SIR Main Parameters

(parameters determined by digital correlator are in parentheses)

Input frequency range, GHz	500 – 650 ГГц
Minimum noise temperature in the range (DSB), K	120 К
Output IF range, GHz	4-8 (5-7) ГГц
Spectral resolution, MHz	< 300 МГц
LO frequency net, MHz	< 1 (2) МГц
Dissipated power at 4.2 K stage, mW	< 30 мВт
Operation temperature, K	< 4.5 К

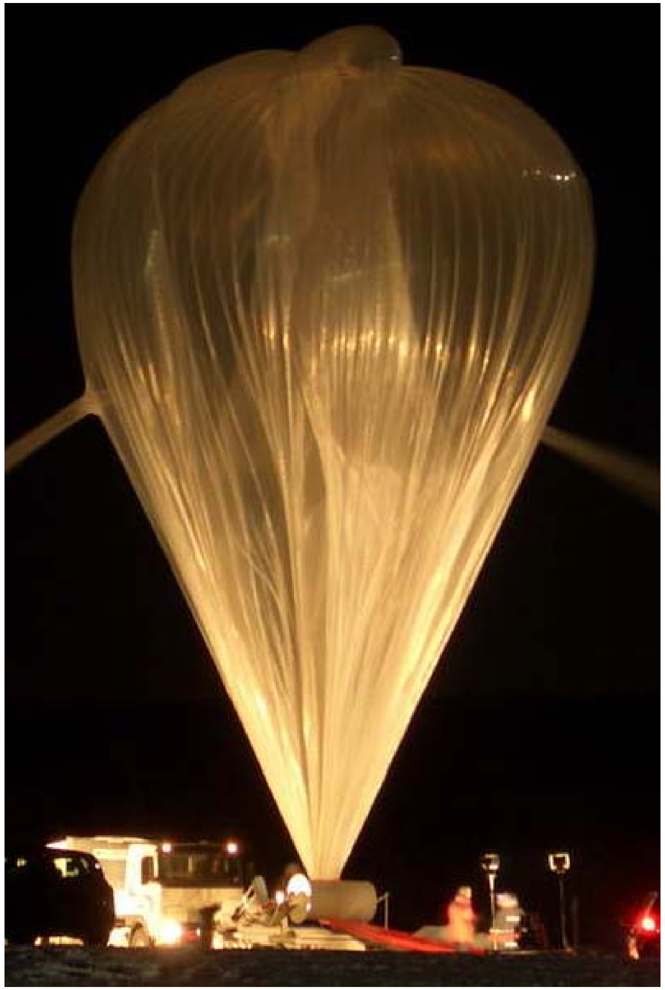
Esrange Space Center , Kiruna, Sweden, 67.5^{o}N, 21.1^{o}E; March 2009

Swedish Space Corporation

TELIS (Terahertz Limb Sounder)

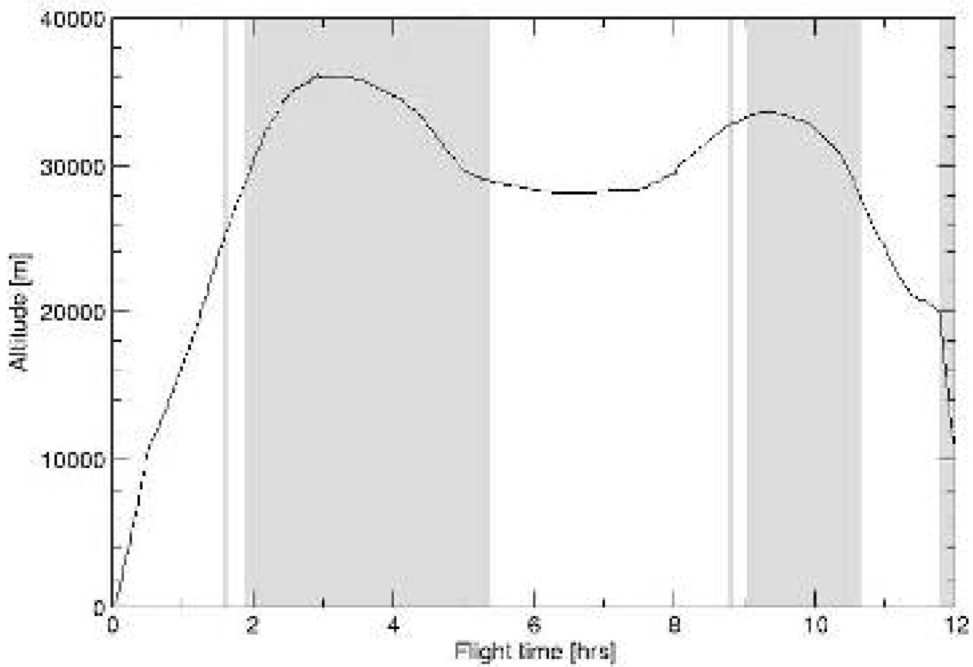
TELIS-MIPAS at Esrange, Sweden; March 2009

Balloon size: 400 000 m3; Payload weight: 1 200 kg



Flight trajectory (predicted)

Flight profile (actual)



26-28 May, 2009

Frequencies and substances selected for the first TELIS flight

##	FFO Frequency, GHz	Substances (High priority)
1	495.04	H_2-^{18}O
2	496.88	HDO
3	505.6	BrO (ΔT = 0.3 K !!)
4	507.28	ClO
5	515.25	O_2 /pointing /pressure
6	519.25	BrO (ΔT = 0.3 K !!)
7	607.78	O_3 isotopes
8	619.1	HCl (HOCl, ClO)

Spectra measured at limb-sounding

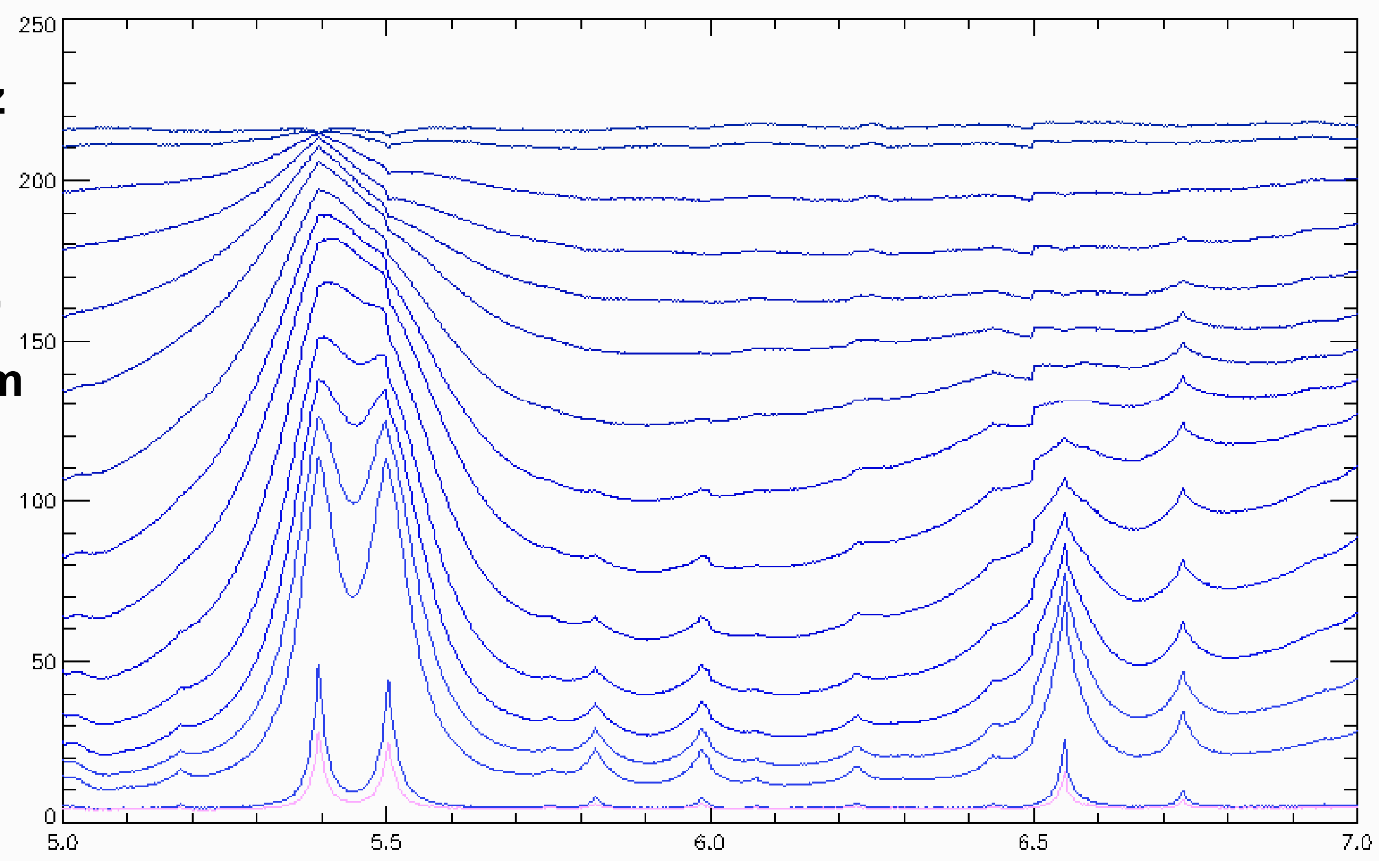
FFO Freq = 495 GHz

Orbit – 30 km;

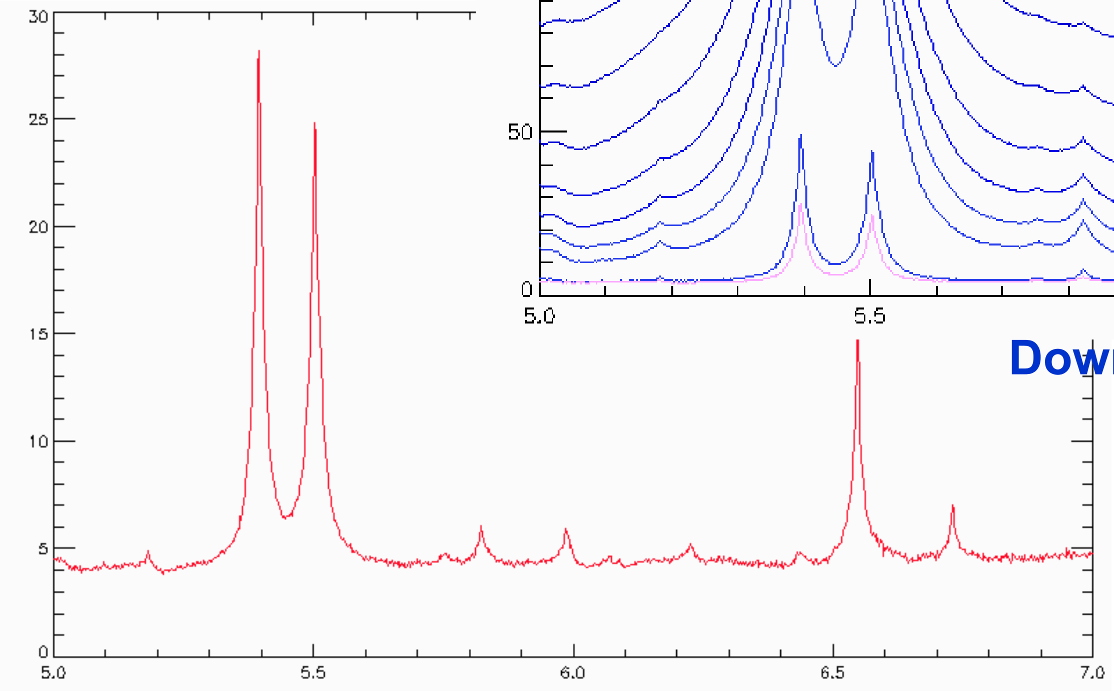
Increment – 1.5 km,

Tangent: 10.5 – 30 km

45 degrees up

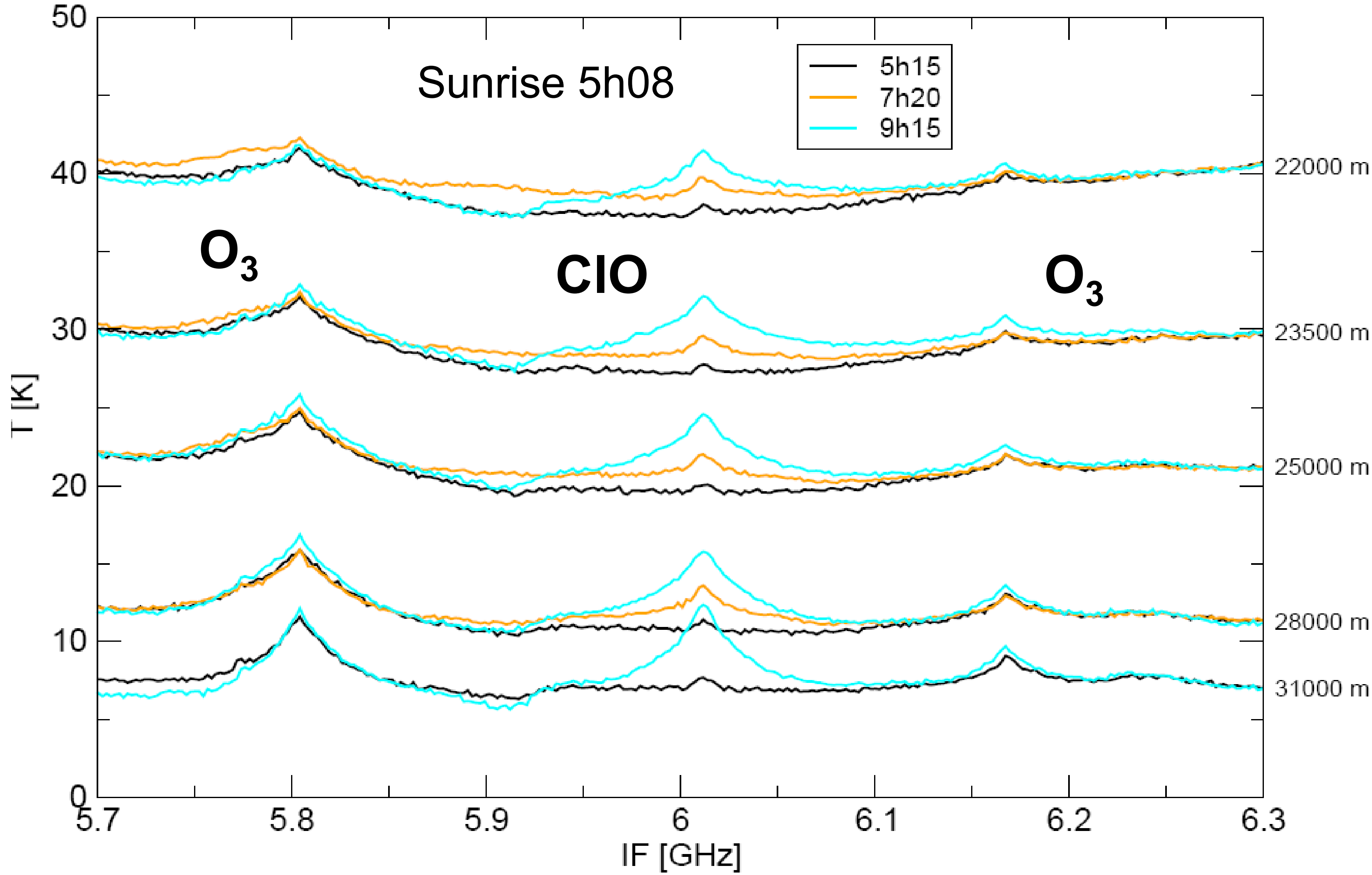


Down-converted Frequency, GHz



Down-converted Frequency, GHz

ClO line over time (FFO = 495 GHz)



Back to the Earth…

30-cm POrtable Submillimeter Telescope (POST)

Purple Mountain Observatory; Nanjing.

Site: Delingha of Qinghai province *(altitude ~3200 m)*

Frequency - 345 GHz
Tr (DSB) < 100 K
Spectral resolution < 1 MHz

2-stage GM type;
cooling capacity
– 0.1 W;

compressor – 42 kg;
power consumption
- 1.2 kW

Arizona Radio Observatory (ARO) Submillimeter Telescope (SMT)

Main reflector: paraboloid D=10 m; F/D=0.35. Subreflector: d=0.69 m;

SIS-345: The MPIfR 345 GHz dual-channel receiver; Tr(DSB) < 125 K

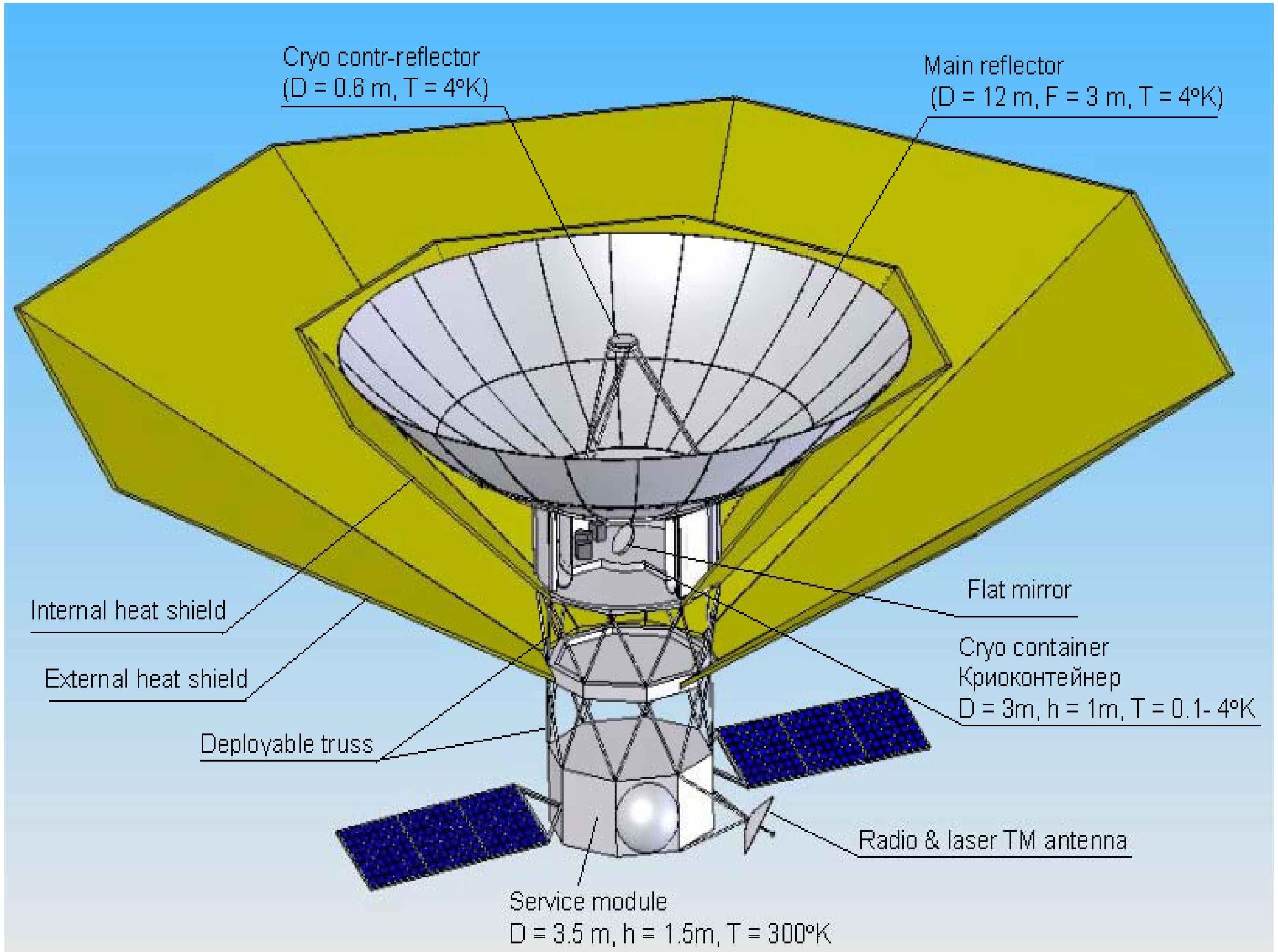
SIS-490: The SORAL 490 GHz single-channel receiver - January 1998. T(DSB) =110-150 K across its 425 to 500 GHz tuning range.

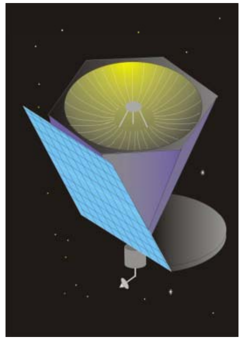
ESPRIT – Exploratory Submm Space Radio-Interferometric Telescope

The six elements of ESPRIT in an Ariane 5

- Telescope sizes ~ 3.5 meter ; off-axis
- Number of elements N = 6 (15 baselines)
- Projected baselines 200 - 1000 meter
- Frequencies:
  Spots in the range 0.5 – 6 THz
- Front Ends - (0.5 – 1.5 THz):
  SIS mixers, multiplier LO /
  SIR = FFO + SIS + HM
  (1.5 – 6 THz) HEB mixers, QCL as LO
- System temperature < 1000 K
- IF bandwidth > 4 GHz (goal 8 GHz)

"Millimetron" – Russian Space Agency (> 2017)
12 m cryogenic mirror; λ = 0,01- 20 mm.





Ground-space interferometer

Conclusion

- Concept of the Phase-locked SIR is developed and tested.
- Nb-AlN-NbN FFOs and SIRs have been successfully implemented.
- 3-rd generation of the SIR with PL FFO for TELIS has been developed showing a possibility to achieve TELIS requirements:
  Frequency range 500 – 650 GHz; Noise Temperature < 150 K;
  IF bandwidth 4 - 8 GHz; Spectral resolution better 1 MHz;
  Beam Pattern - FWHM = 3 deg, with sidelobes < - 17 dB.
- Procedure for remote optimization of the PL SIR operation has been developed and experimentally proven.
- First TELIS flight has been completed in March 2009 (Kiruna, Sweden).
- Future space and ground-base missions are under consideration.
- SIR Technology is mature for future space missions.