# Superconducting Integrated Terahertz Spectrometer for Atmosphere Monitoring and Radio Astronomy

**Valery Koshelets, Pavel Dmitriev, Andrey Ermakov, Lyudmila Filippenko, Andrey Khudchenko, Nickolay Kinev, Oleg Kiselev, Irina Lapitskaya, Alexander Sobolev, Mikhail Torgashin,**

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

**in collaboration with**

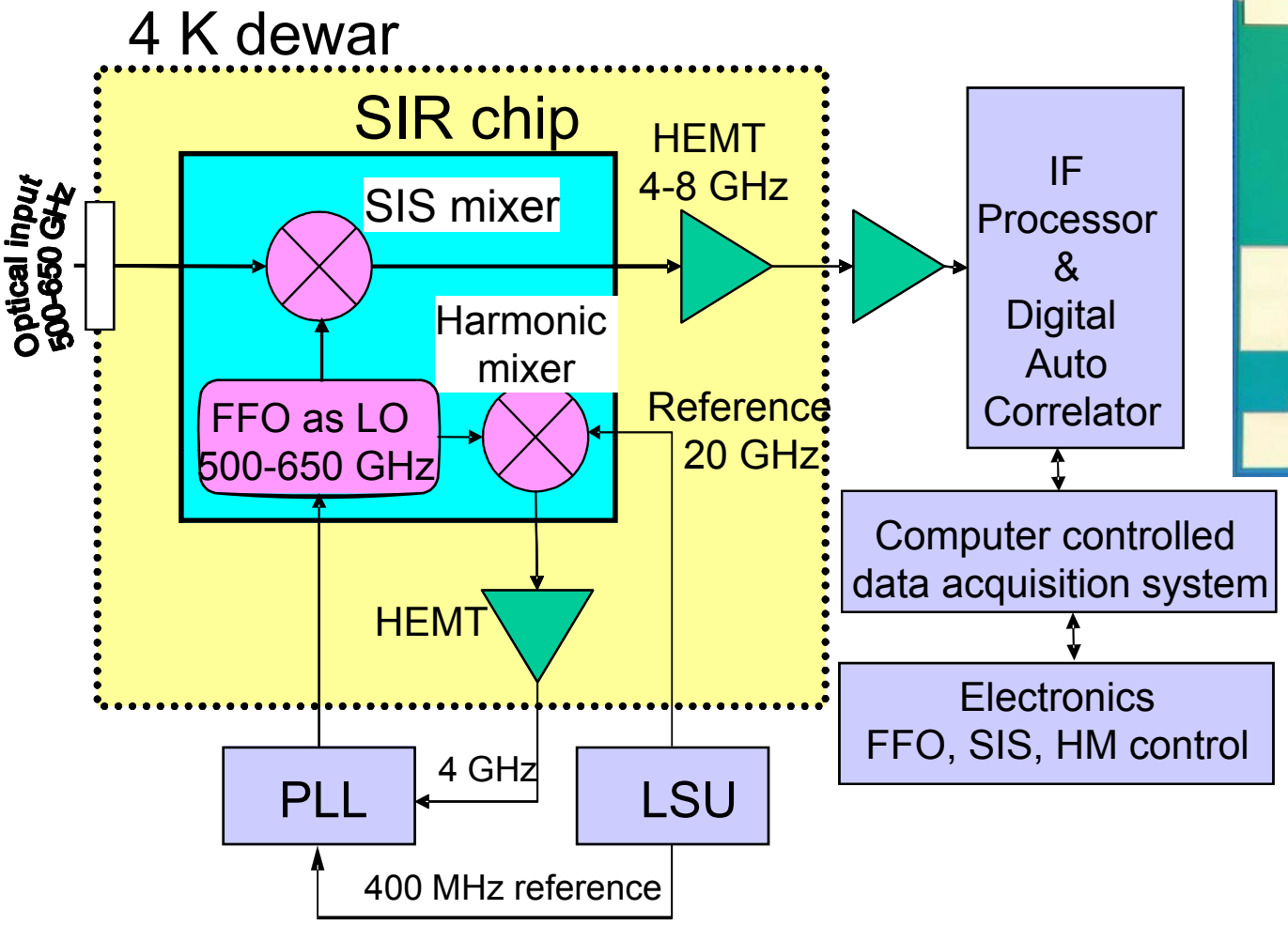
*SRON Netherlands Institute for Space Research, the Netherlands*

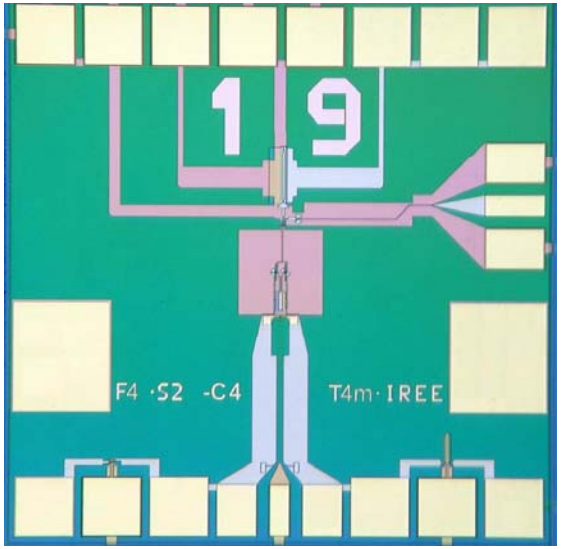
# Superconducting Integrated Terahertz Spectrometer for Atmosphere Monitoring and Radio Astronomy

## Outline

- Superconducting Integrated Receiver (SIR)
- Flux Flow Oscillator (FFO) for the SIR
- TErahertz LImb Sounder (TELIS) project
- TELIS SIR channel: design and performance
- First TELIS flight
- Future SIR applications
- Conclusion

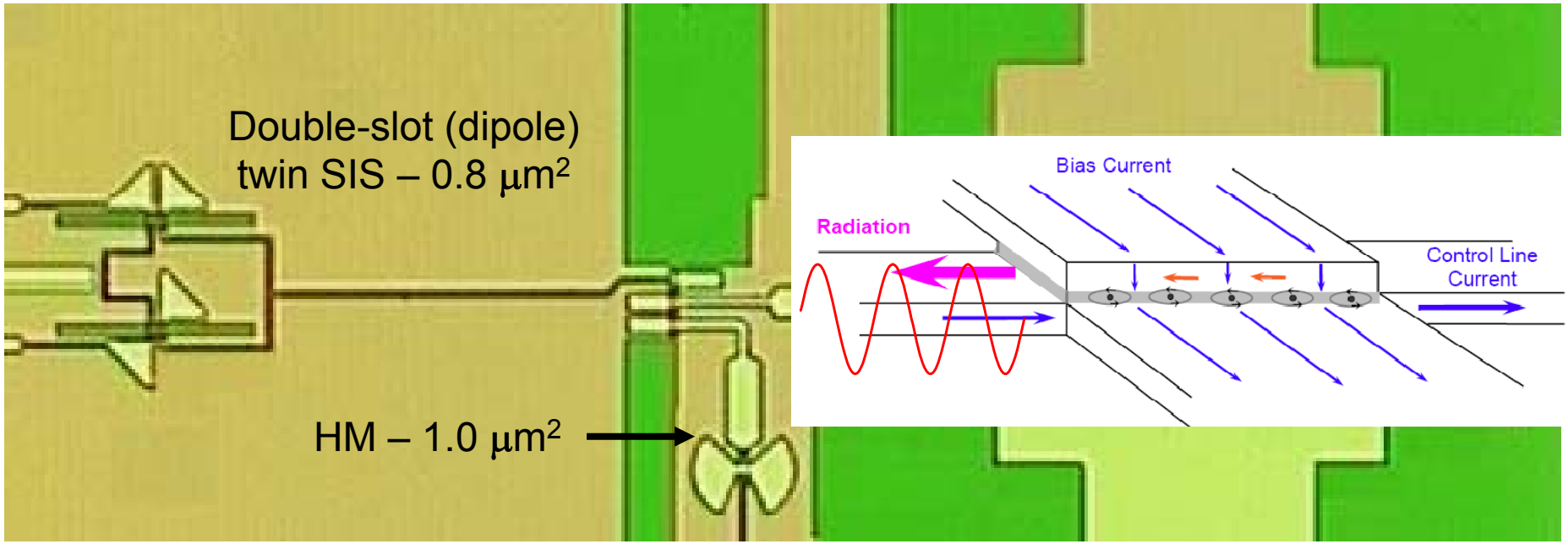
# Superconducting Integrated Receiver (SIR) with phase-locked FFO




**SIR microcircuit**

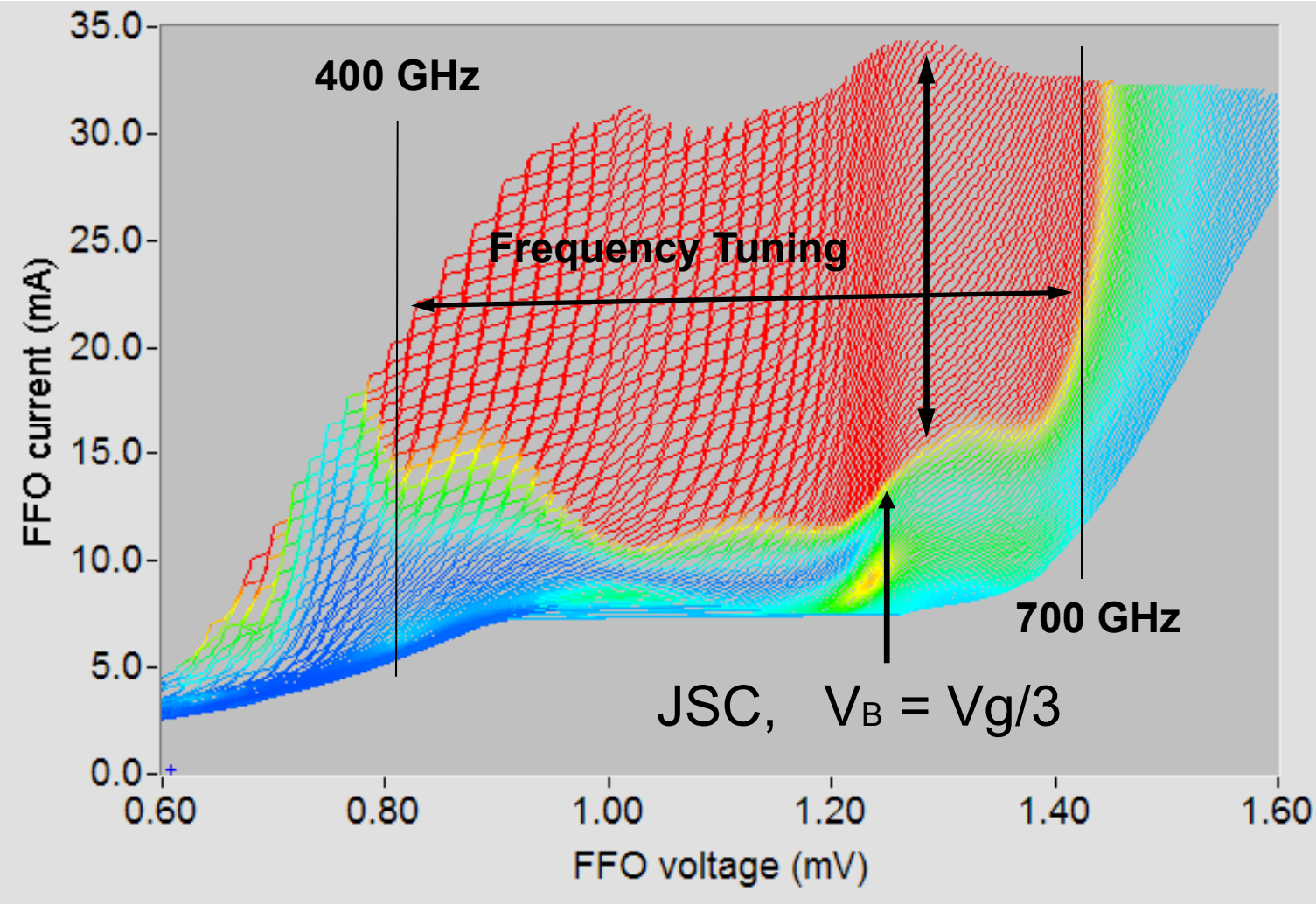
# Internal part of the SIR Microcircuit



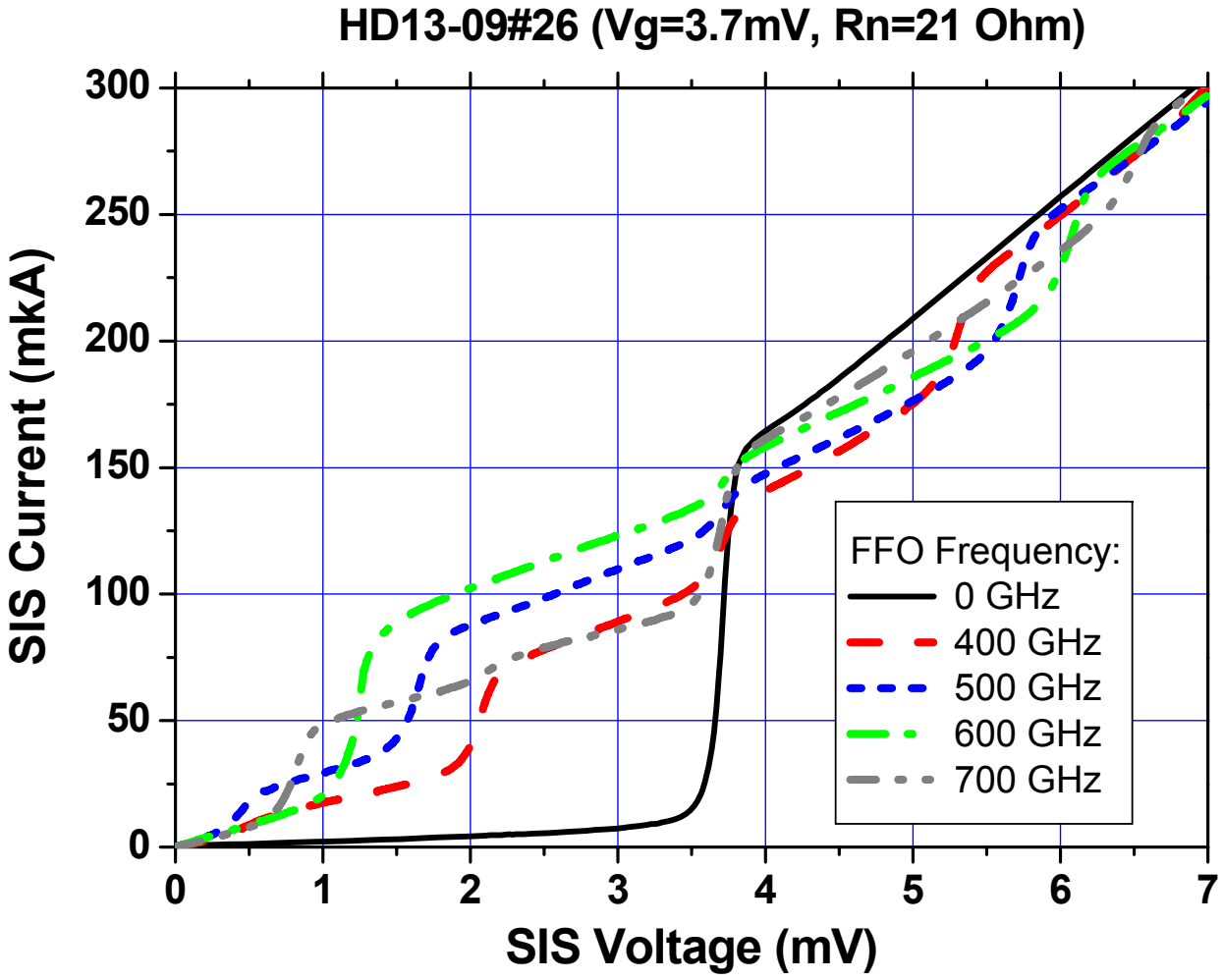

**Nb-AlOx-Nb, Nb-AlN-NbN; Jc = 5 - 10 kA/cm²**

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

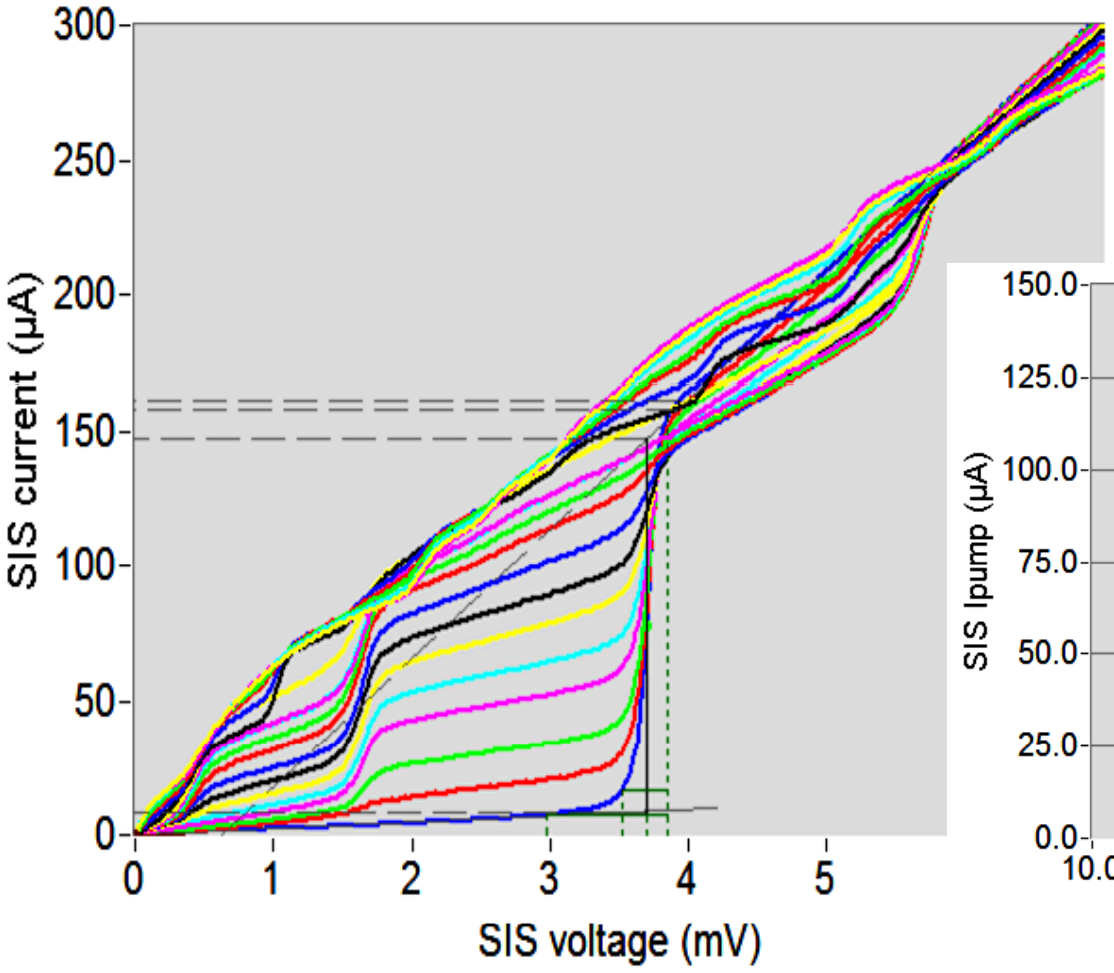
# Nb-AlOx-Nb and Nb-AlN-NbN FFO for SIR

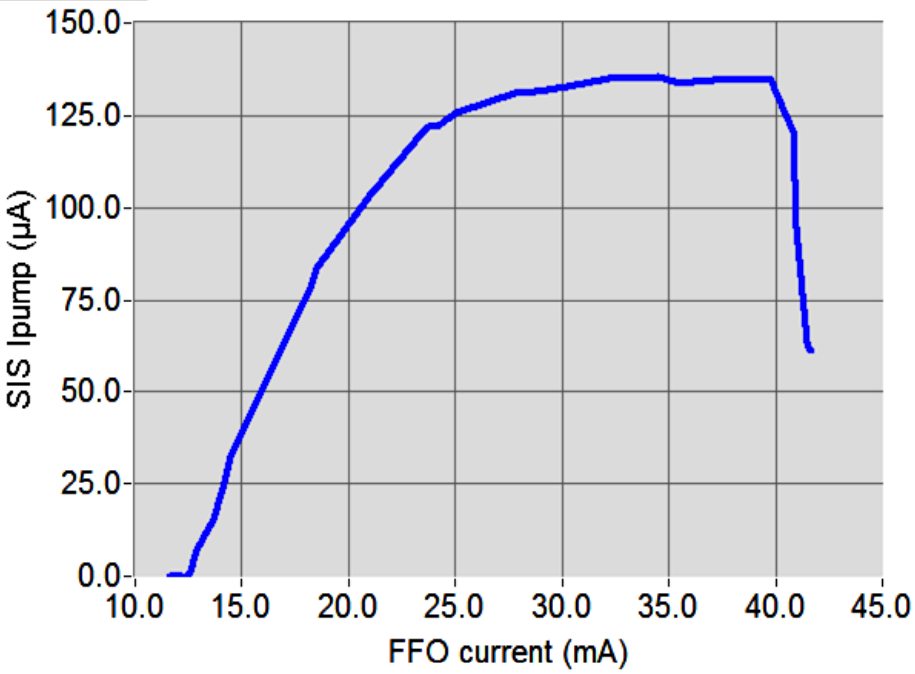


# Nb-AlN-NbN SIS pumped by FFO; FFO frequency tuning

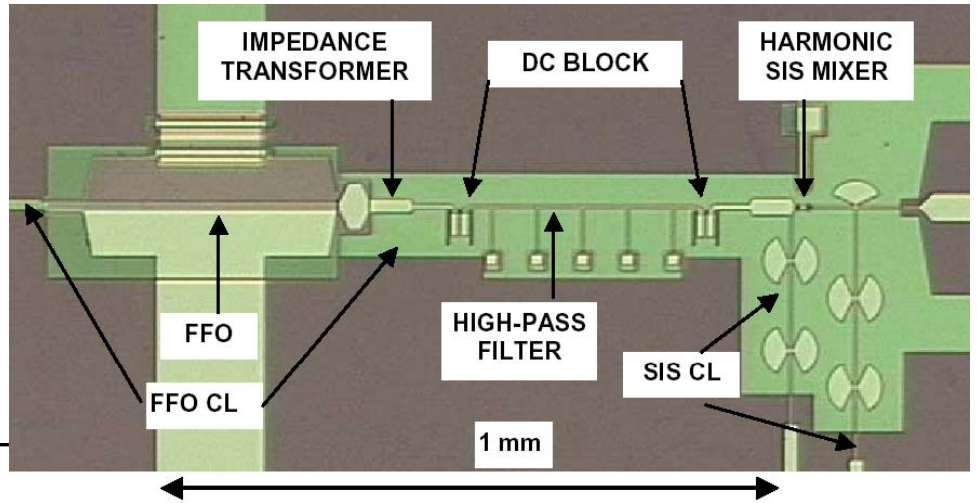


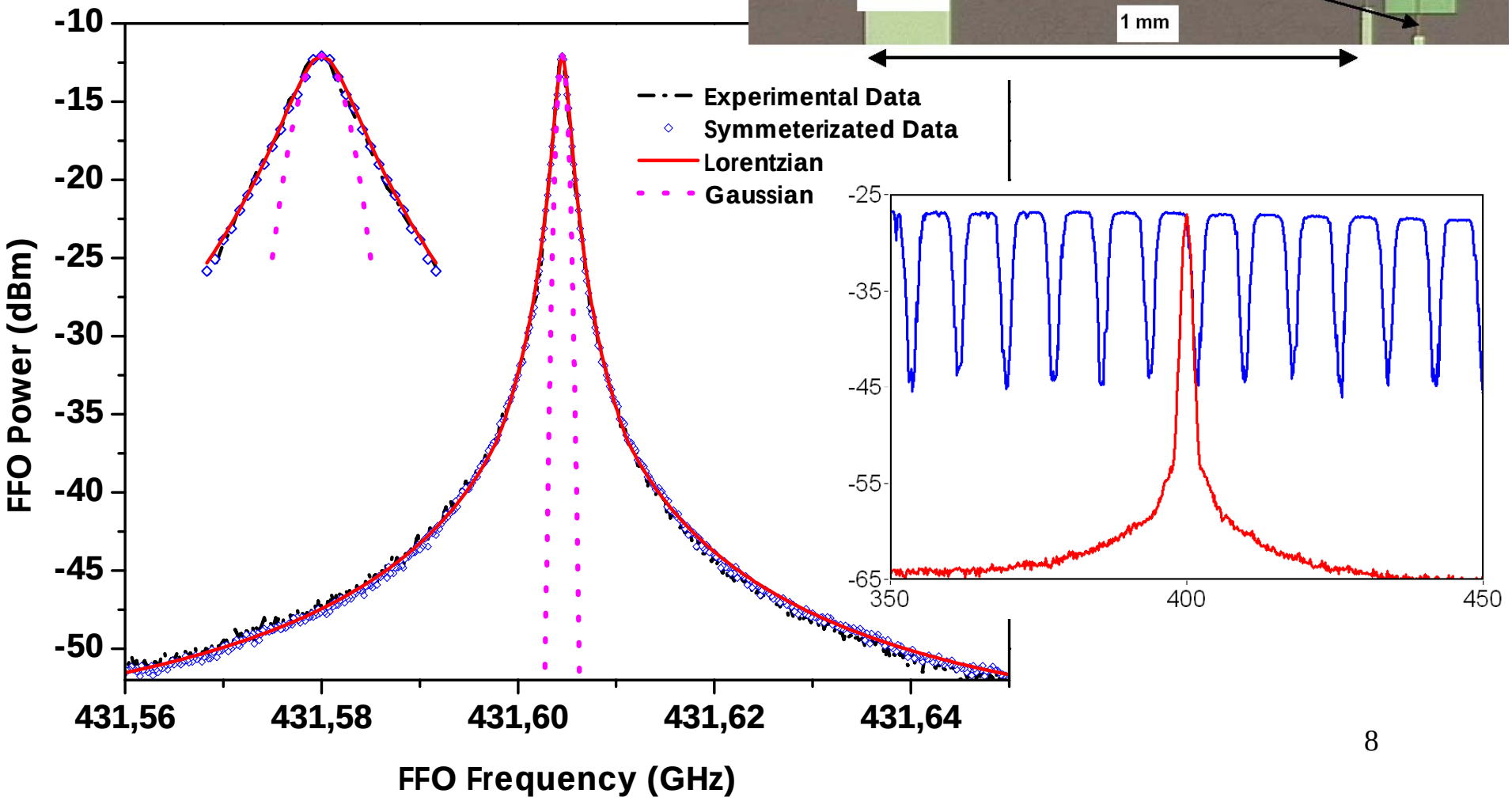
# Nb-AlN-NbN SIS pumped by FFO; FFO power tuning (f = 500 GHz)



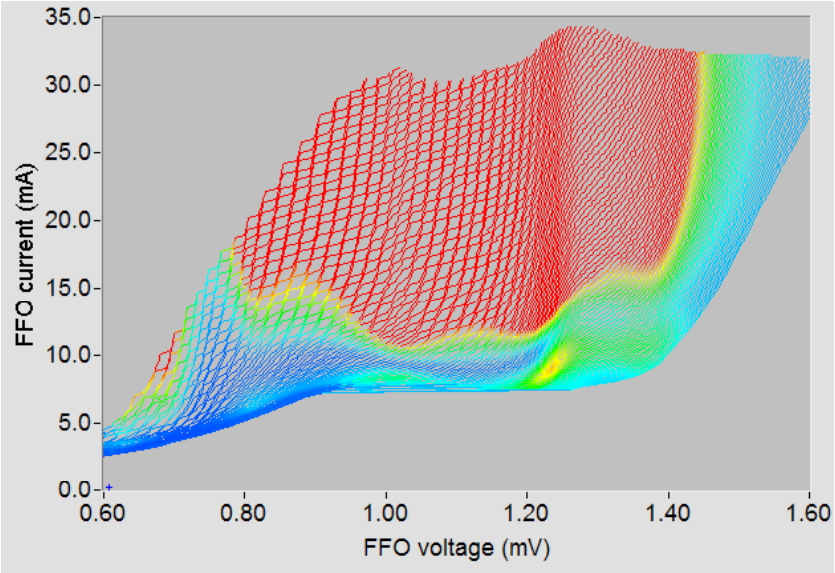



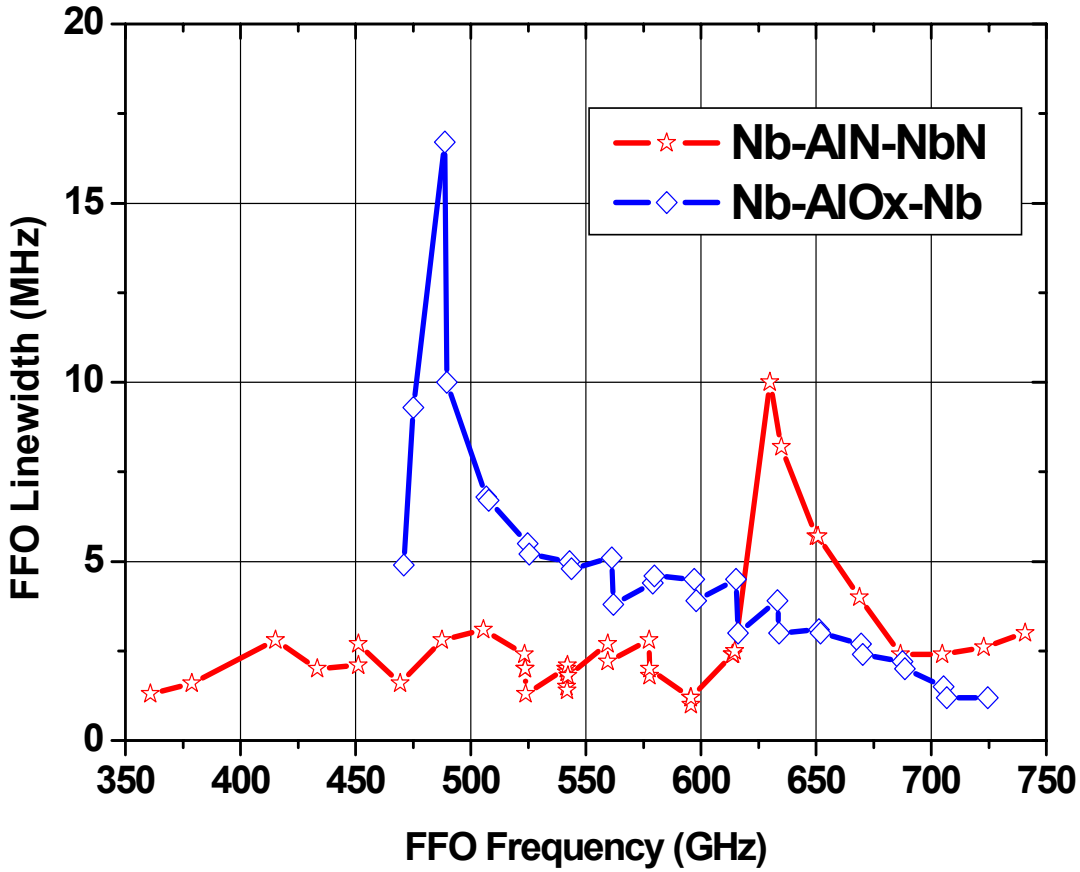
# FFO Spectrum



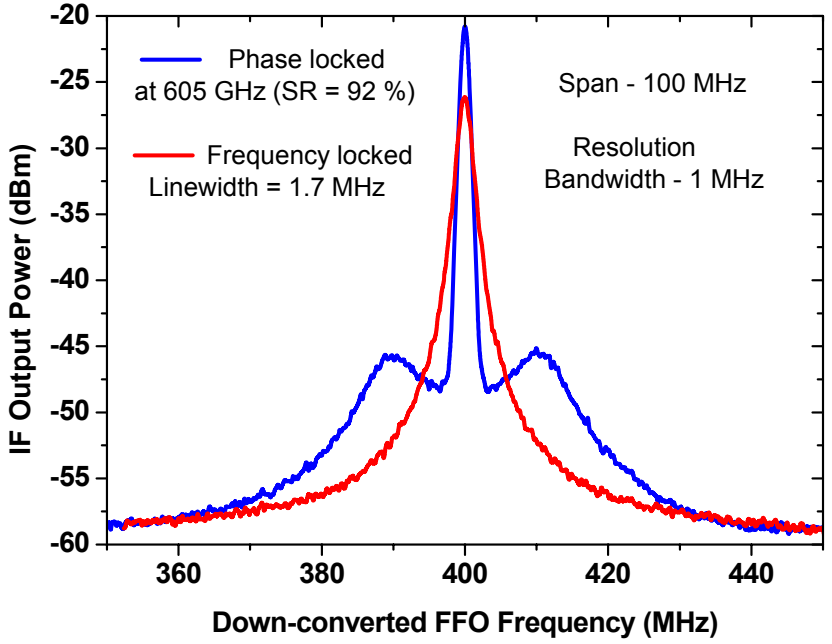



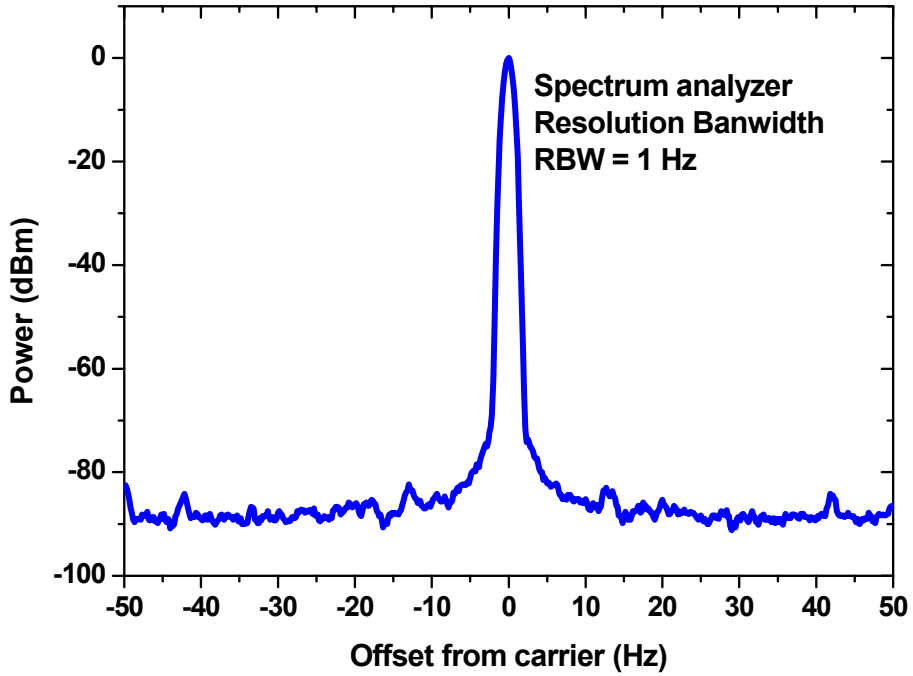
# Frequency dependence of the FFO: Nb-AlOx-Nb and Nb-AlN-NbN circuits



# FL and PL spectra of the FFO :
## frequency 605 GHz; LW = 1.7 MHz; SR = 92 %



# Development of the Integrated Spectrometer for TELIS (TErahertz LImb Sounder)

**Valery Koshelets, Lyudmila Filippenko, Pavel Dmitriev, Andrey Ermakov, Andrey Khudchenko, Nickolay Kinev, Oleg Kiselev, Alexander Sobolev, Mikhail Torgashin,**

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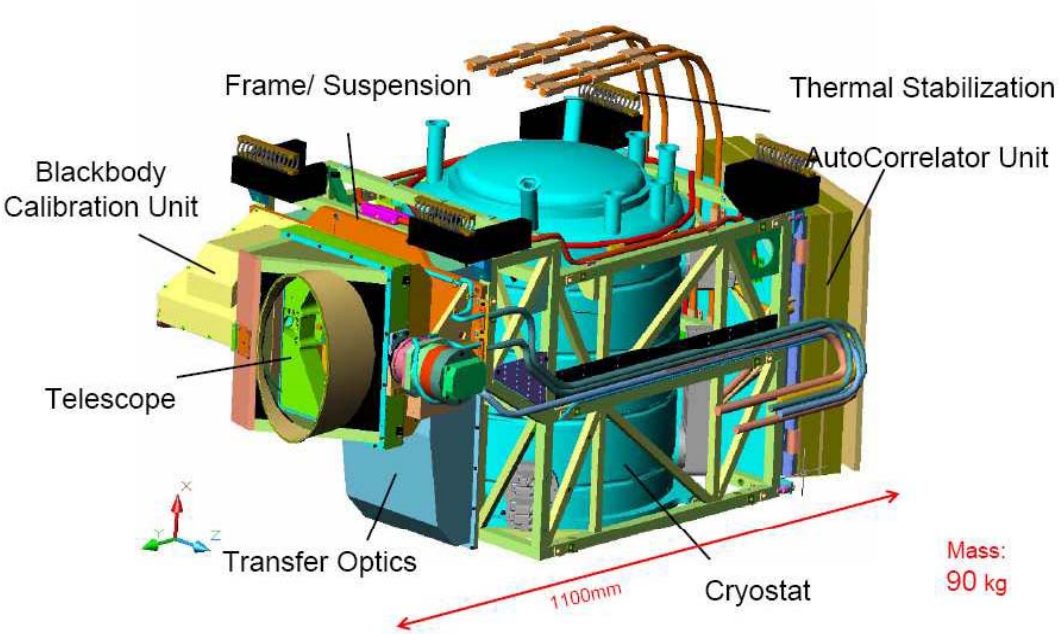
**Pavel Yagoubov, Gert de Lange, Hans Golstein, Leo de Jong, Arno de Lange, Bart van Kuik, Ed de Vries, Johaness Dercksen, Ruud Hoogeveen, Avri Seleg**

*SRON Netherlands Institute for Space Research, the Netherlands*

**Nopporn Suttiwong, Georg Wagner, Manfred Birk (PI)**

*Institute for Remote Sensing Technology, DLR, Germany*

# TELIS (Terahertz Limb Sounder)

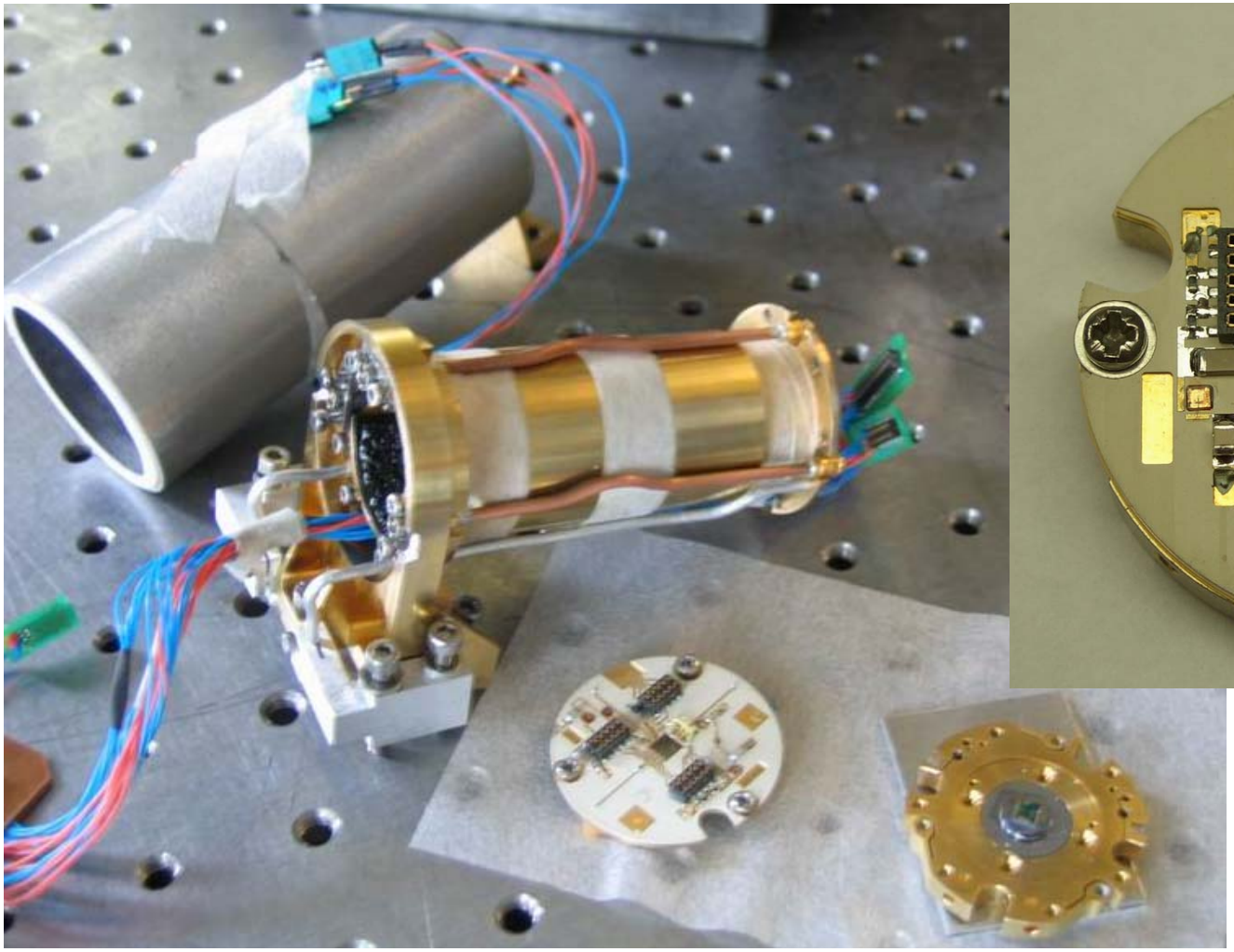


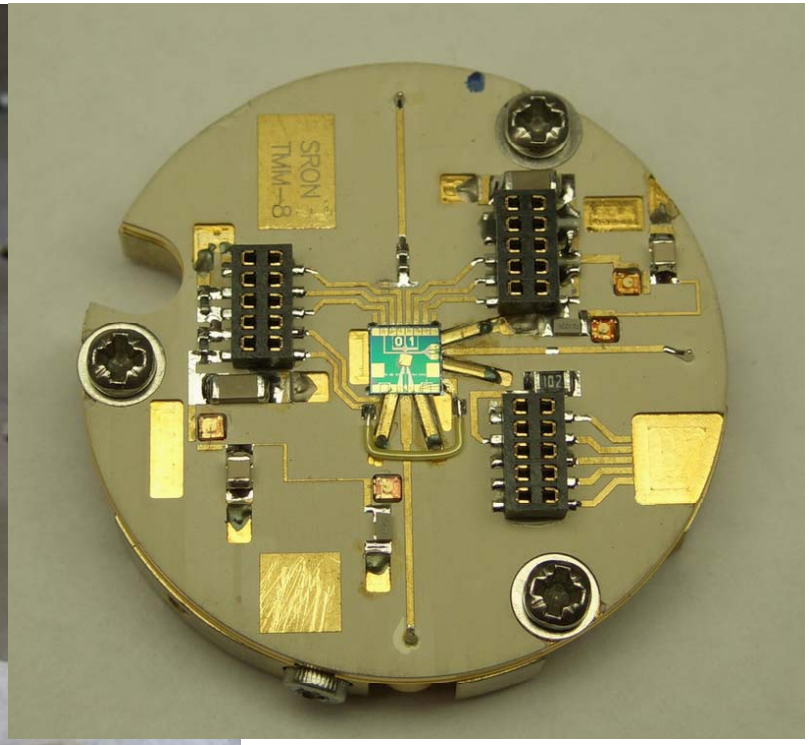

**Balloon-Borne TELIS Instrument**

## TELIS Objectives:

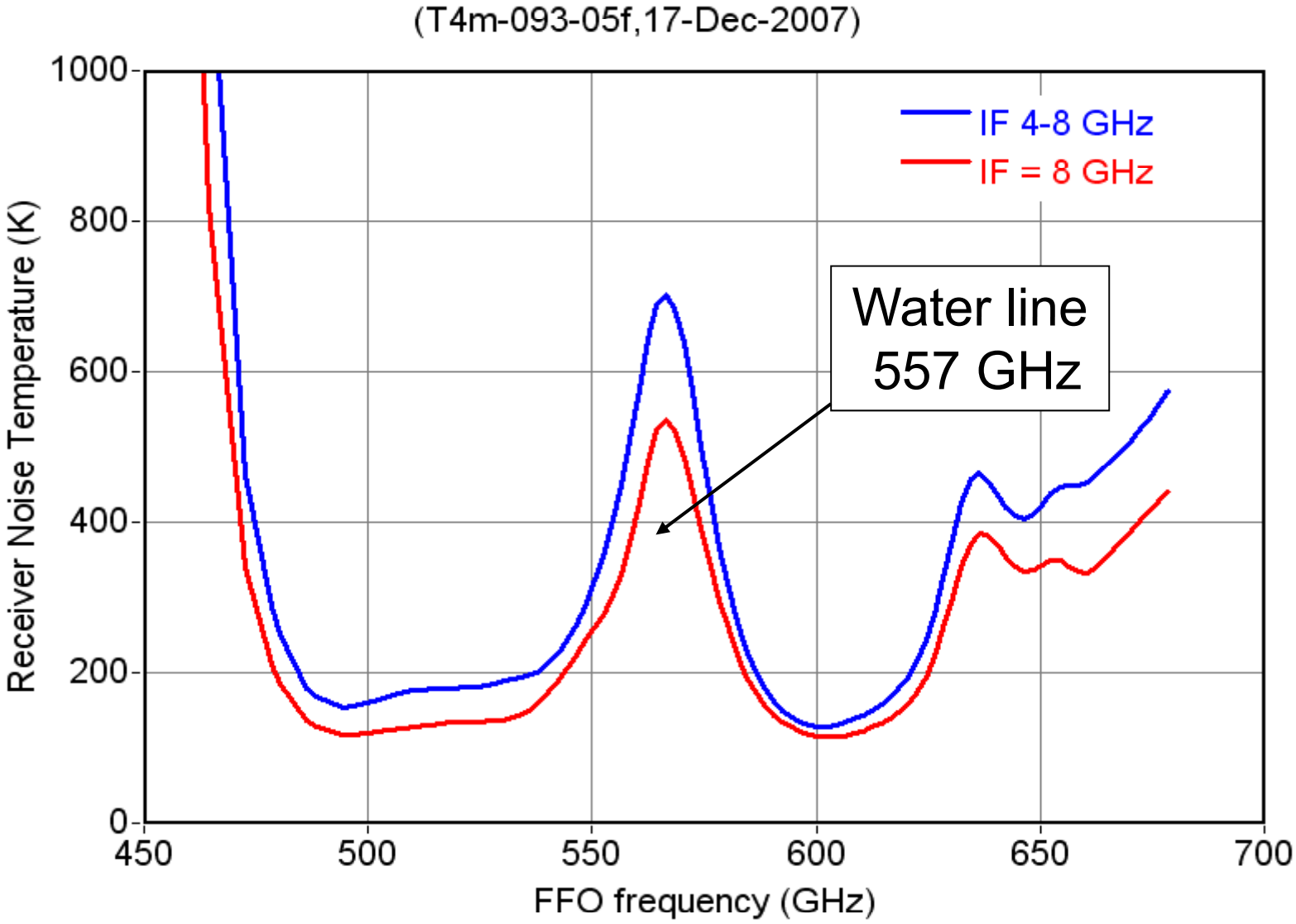
- Measure many species for atmospheric science:
  ClO, BrO, $O_3$, HCl, HOCl, etc;
  - Chemistry, Transport, Climate
- Serve as a test platform for new sensors
- Serve as validation tool for future satellite missions
- Three independent frequency channels, cryogenic heterodyne receivers:
  - 500 GHz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

# SIR Mixer Block with Shields

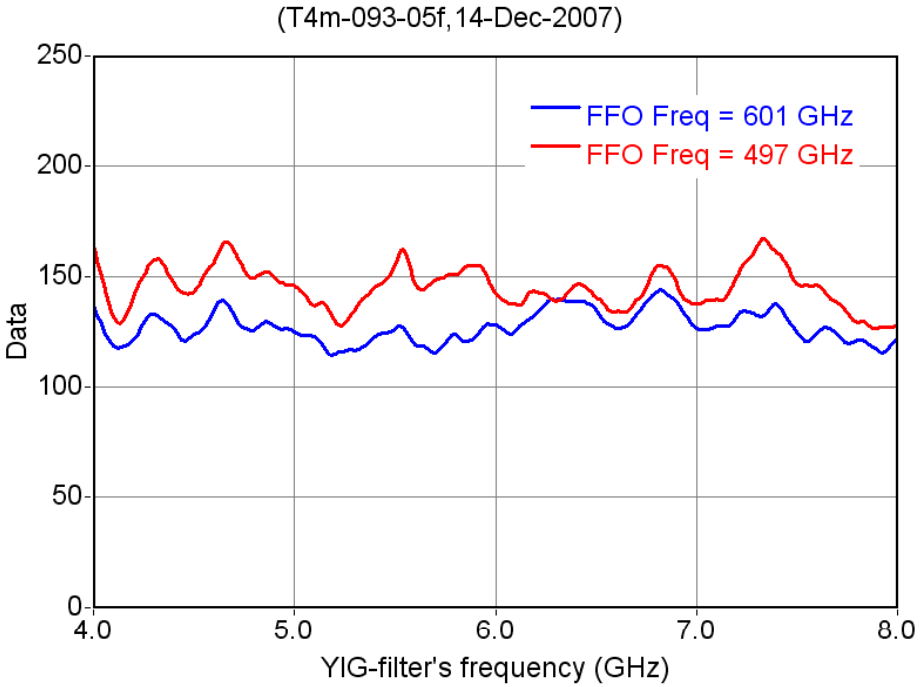


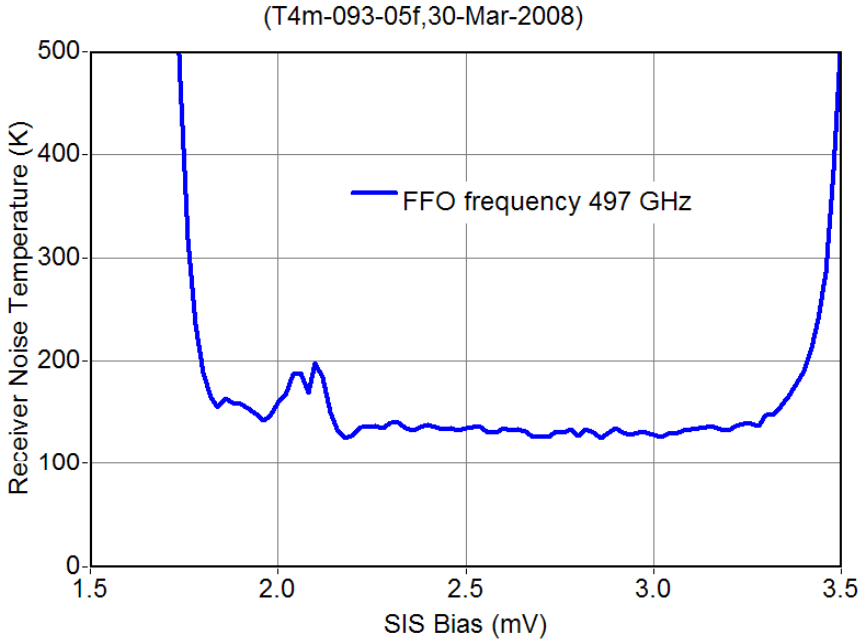


# Noise Temperature of the Flight SIR (DSB)



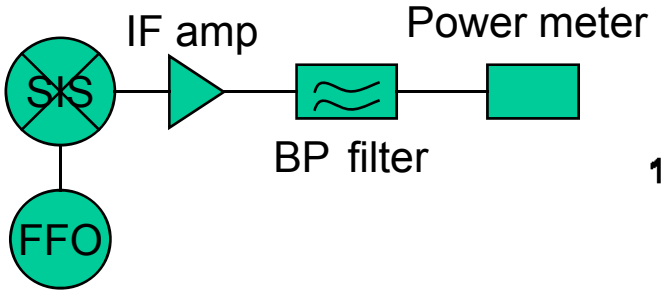
# SIR Noise Temperature on Intermediate Frequency and SIS Bias

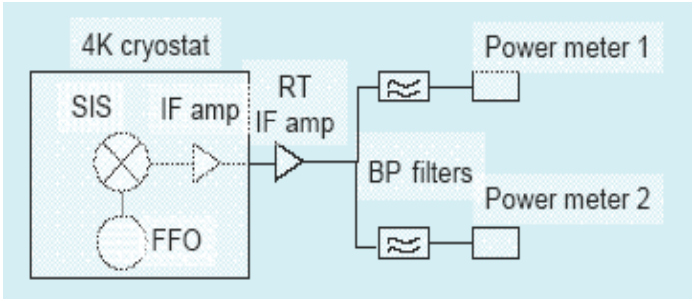


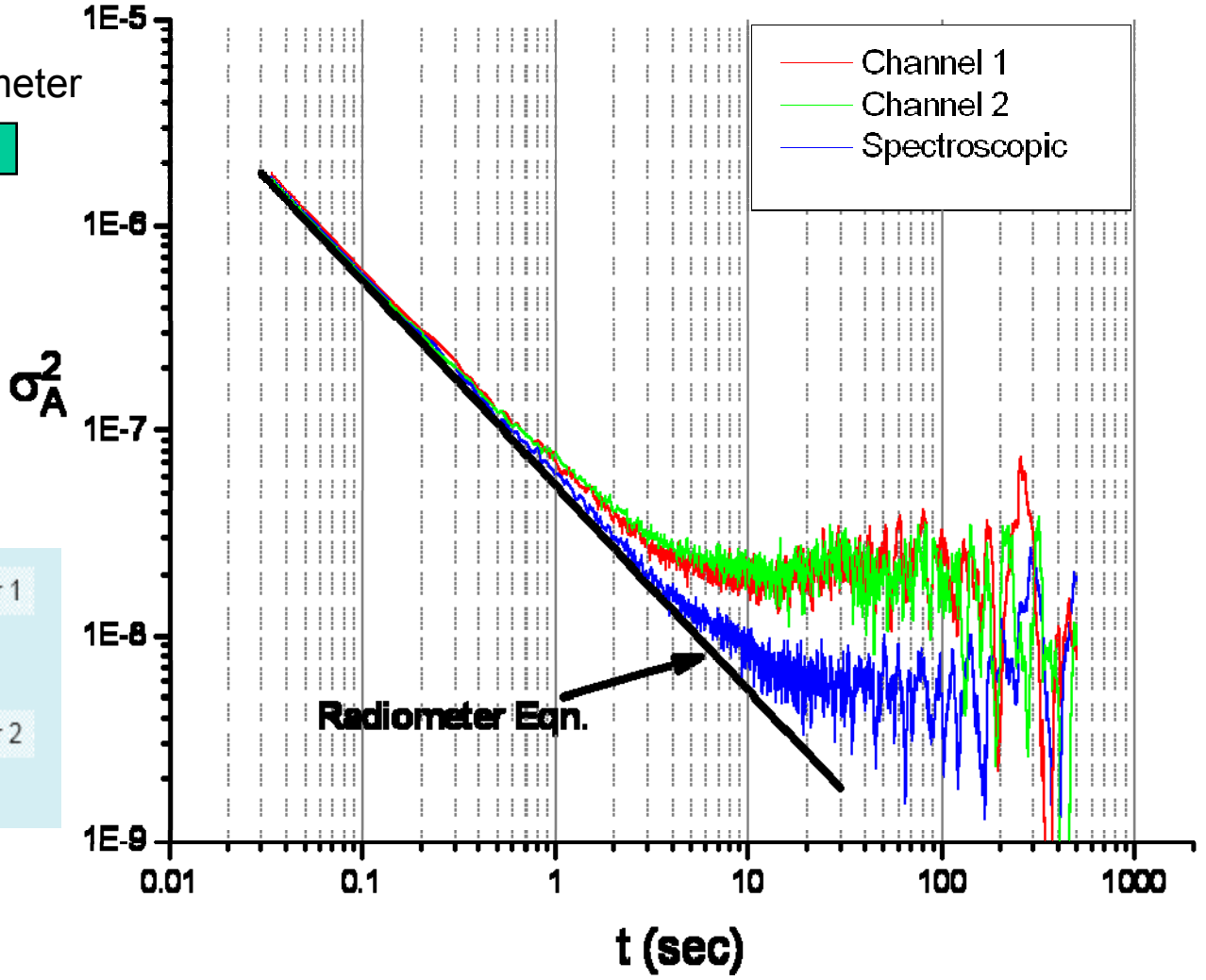



# SIR Stability: Allan variance test

SRON Netherlands Institute for Space Research

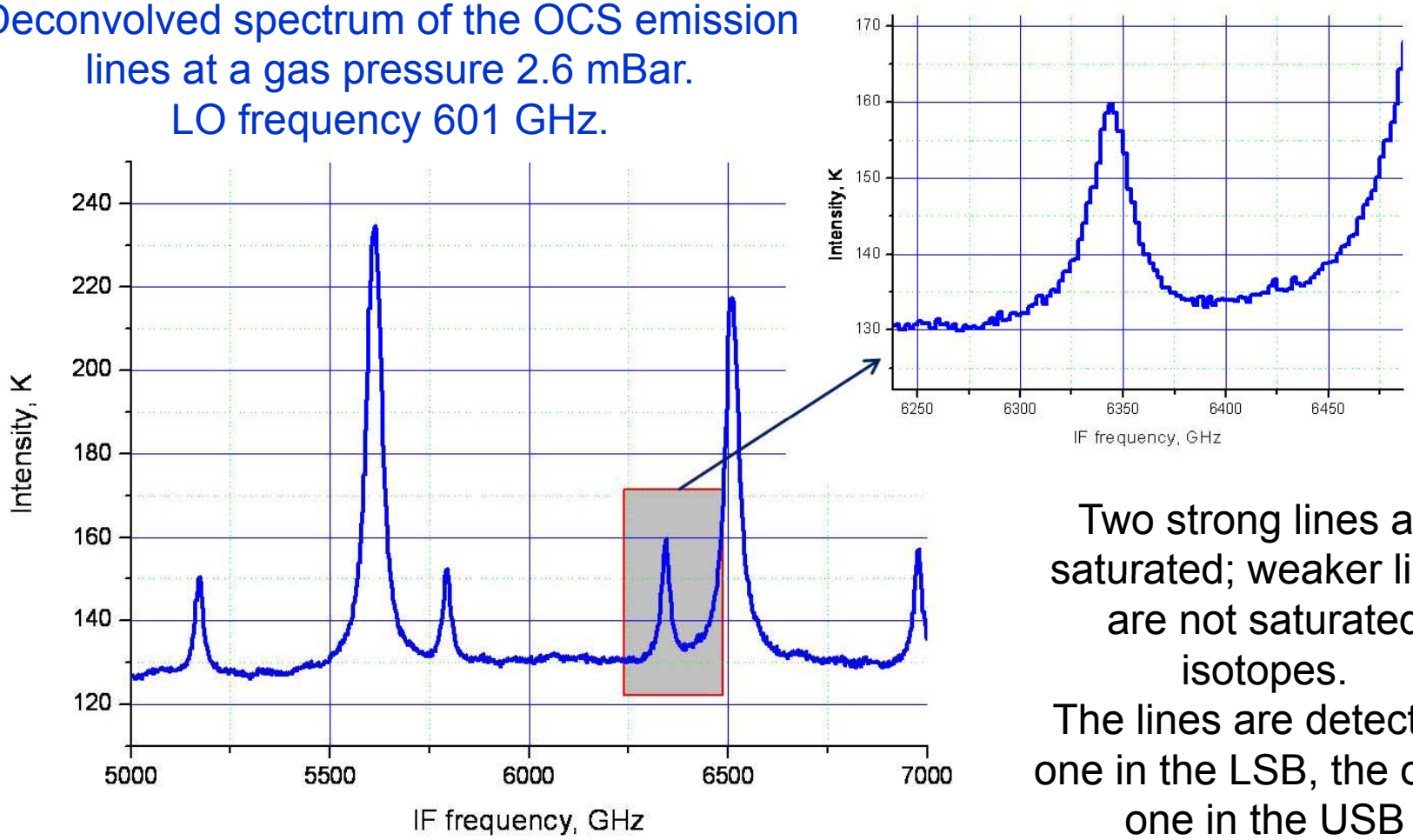


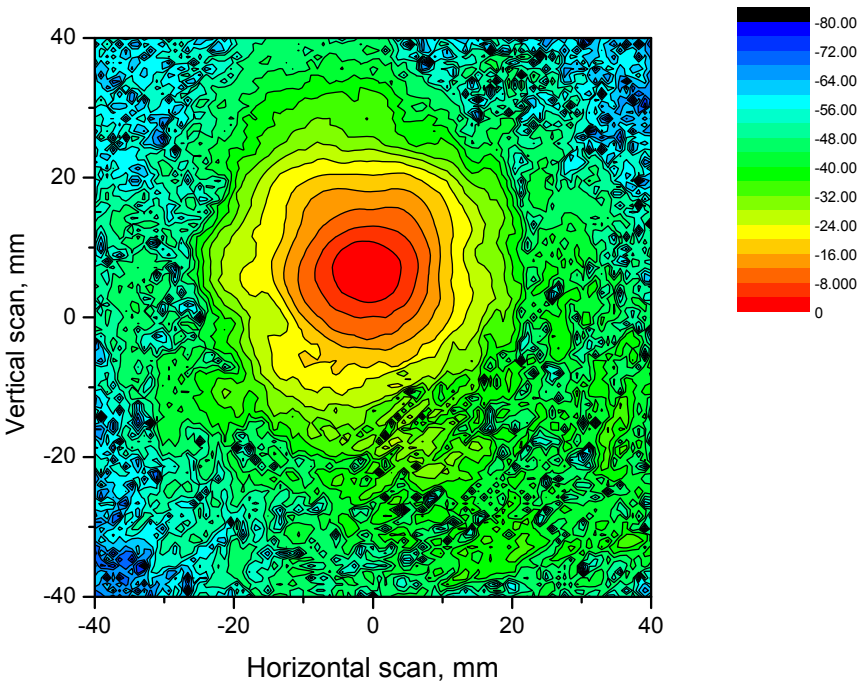
# SIR Spectral Resolution

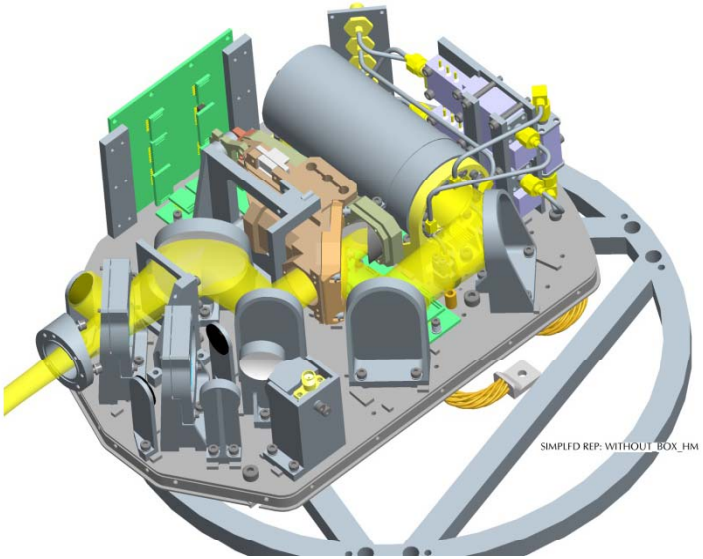
Deconvolved spectrum of the OCS emission lines at a gas pressure 2.6 mBar. LO frequency 601 GHz.



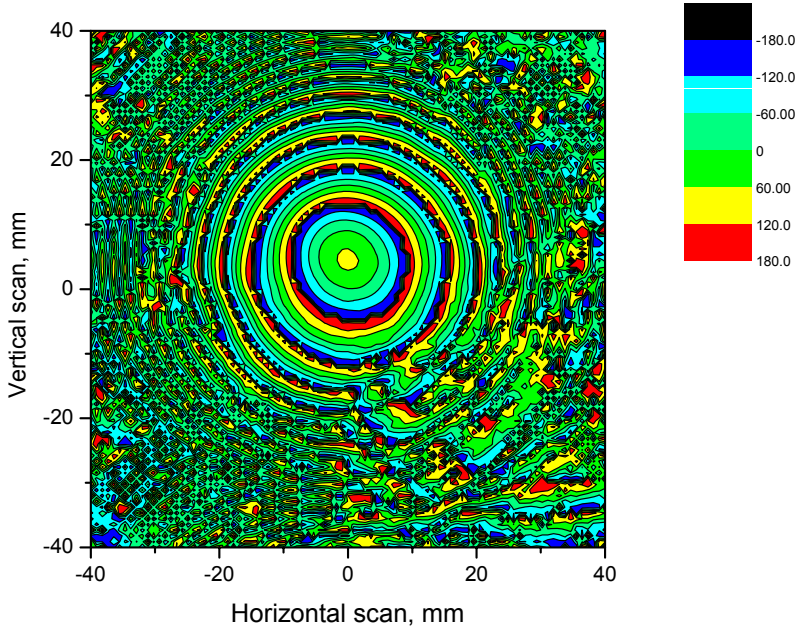

Two strong lines are saturated; weaker lines are not saturated isotopes.
The lines are detected, one in the LSB, the other one in the USB

# Amplitude and phase APB of the SIR with cold optics



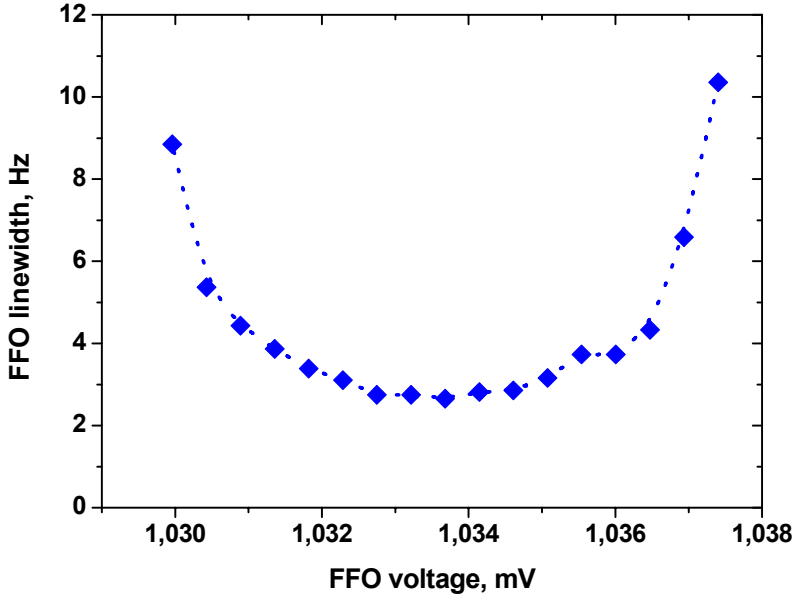

**Amplitude**

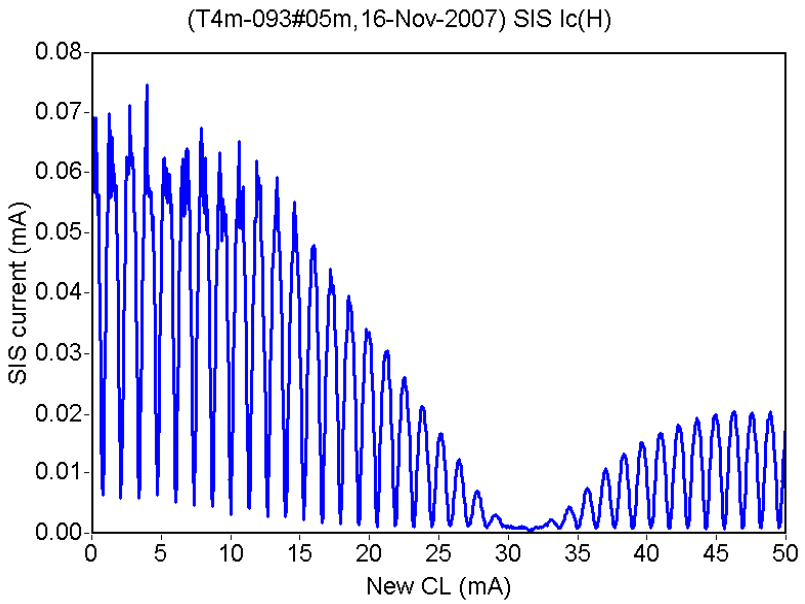


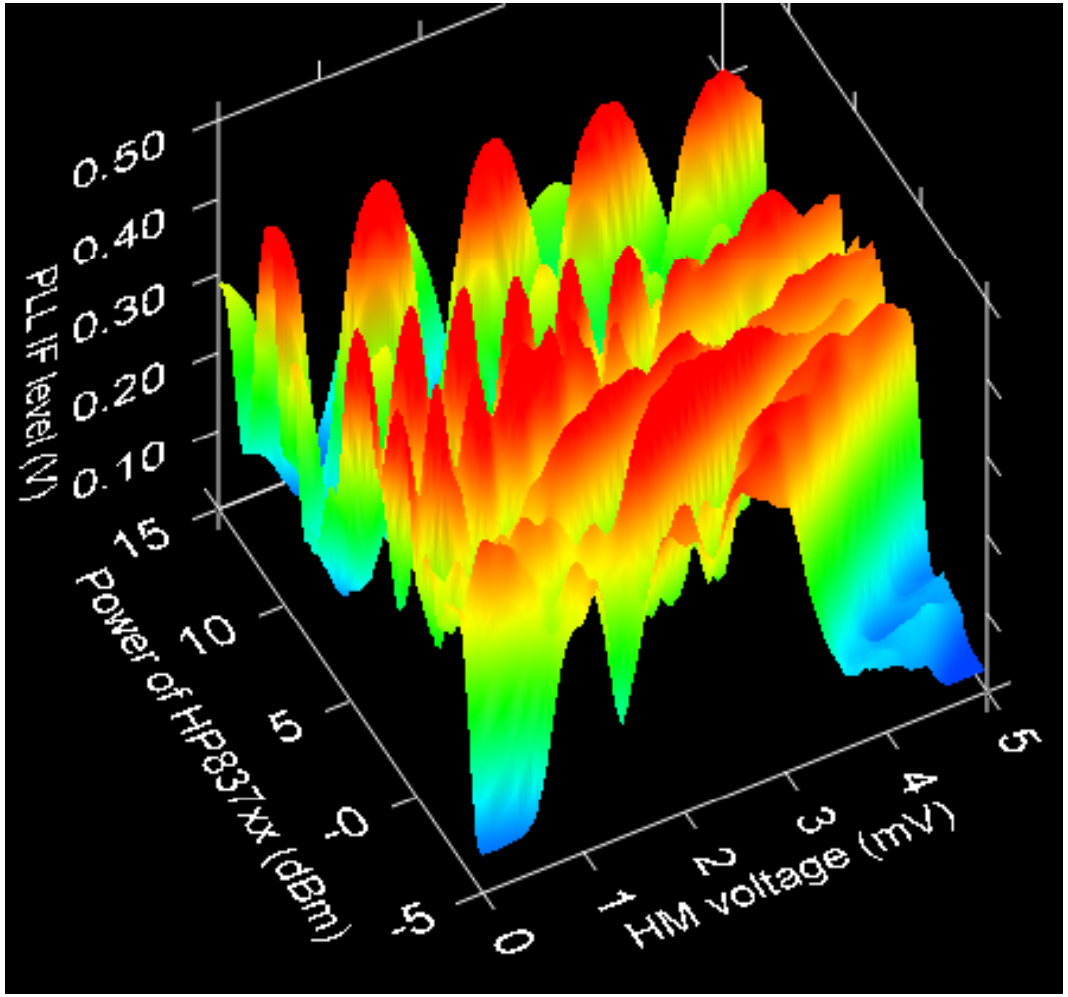

**Phase**

# SIR for TELIS – remote operation

FFO frequency of about 500 GHz



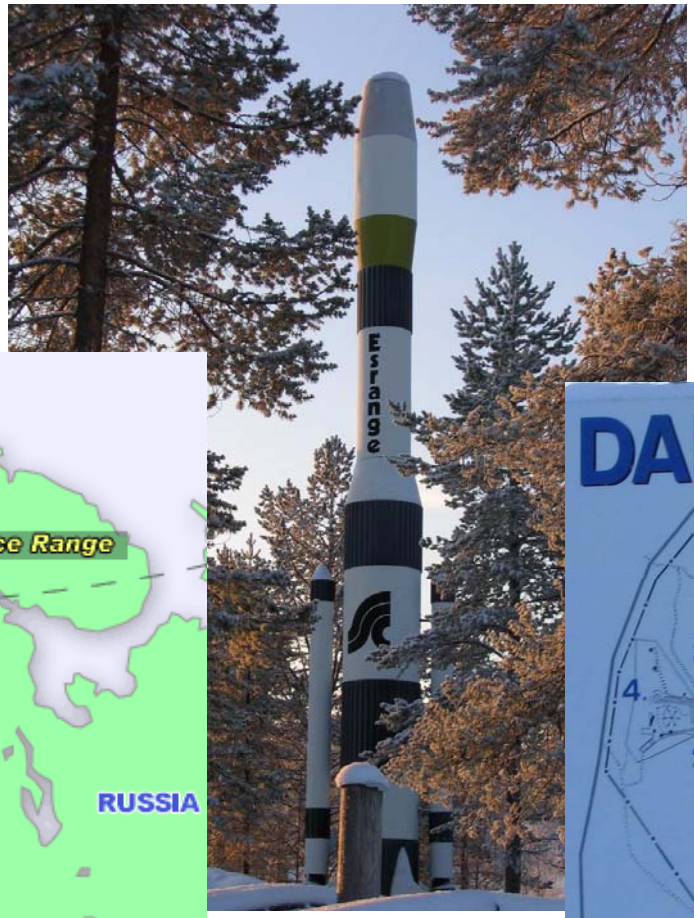



# TELIS-SIR Main Parameters

**(parameters determined by digital correlator are in parentheses)**

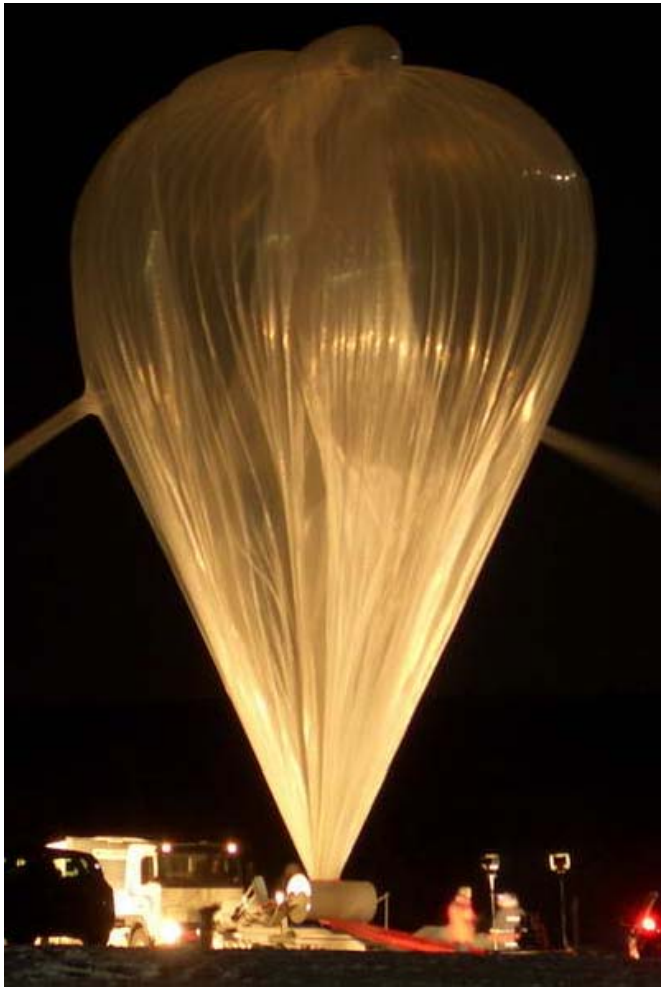
| | |
|---|---|
| **Input frequency range, GHz** | **500 – 650 ГГц** |
| **Minimum noise temperature in the range (DSB), K** | **120 К** |
| **Output IF range, GHz** | **4-8 (5-7) ГГц** |
| **Spectral resolution, MHz** | **< 1 (2) МГц** |
| **LO frequency net, MHz** | **< 300 МГц** |
| **Dissipated power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

# Esrange Space Center , Kiruna, Sweden, 67.5°N, 21.1°E; March 2009




Swedish Space Corporation


# TELIS (Terahertz Limb Sounder)



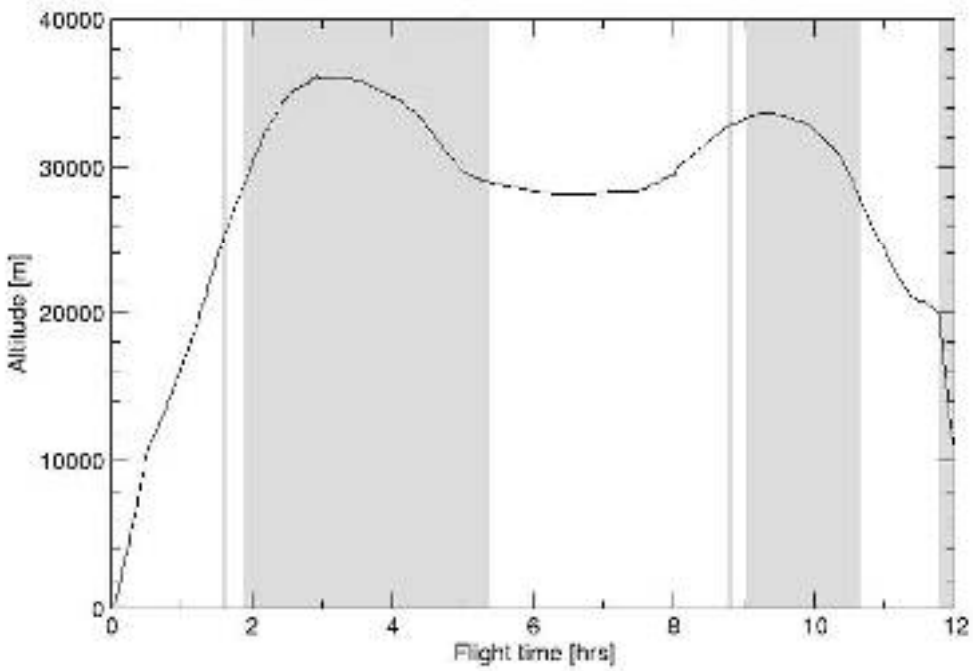
TELIS-MIPAS at Esrange, Sweden; March 2009

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

Altitude: 40 km (max); Duration: 12 hours

# Flight trajectory (predicted)


## Flight profile (actual)



# 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 ($\Delta T$ = 0.3 K !!) |
| 4 | 507.28 | ClO |
| 5 | 515.25 | $O_2$ /pointing /pressure |
| 6 | 519.25 | BrO ($\Delta T$ = 0.3 K !!) |
| 7 | 607.78 | $O_3$ isotopes |
| 8 | 619.1 | HCl (HOCl, ClO) |

# Spectra measured at limb-sounding

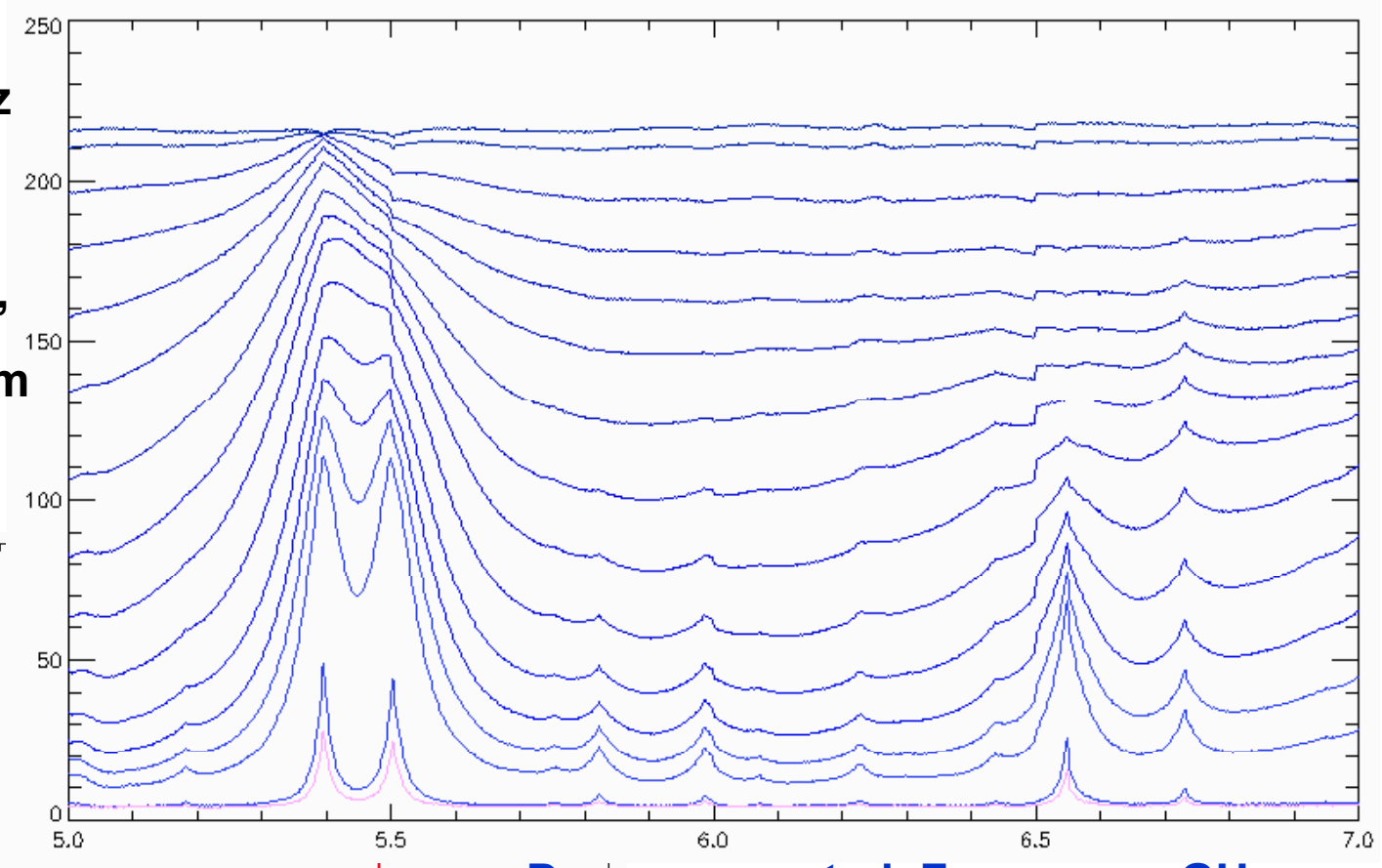
**FFO Freq = 495 GHz**

**Orbit – 30 km;**

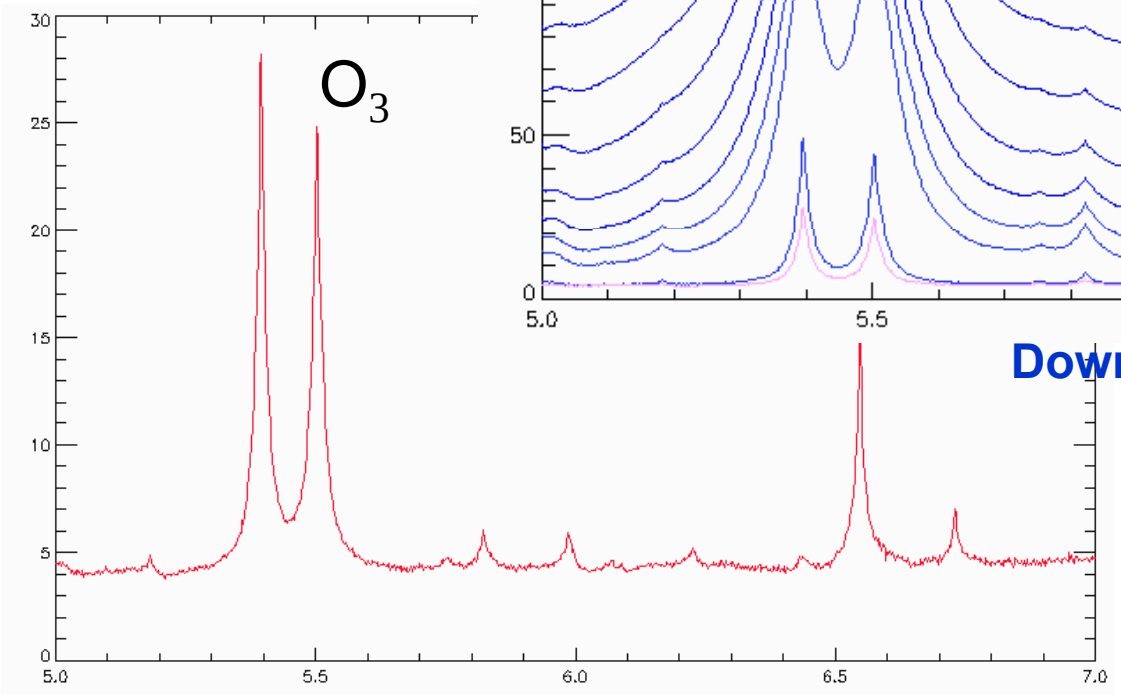
**Increment – 1.5 km,**

**Tangent: 10.5 – 30 km**

**45 degrees up**

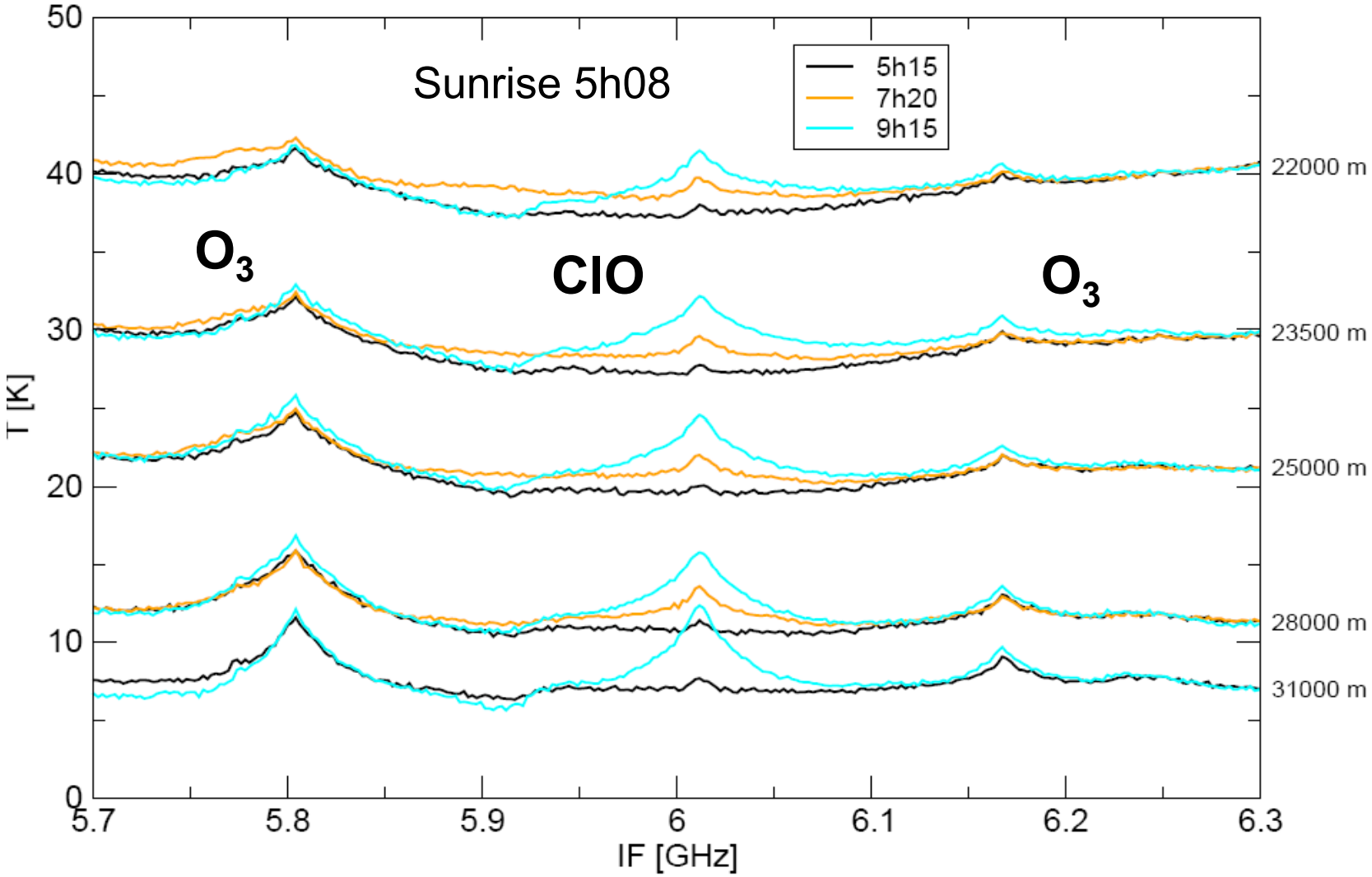



**Down-converted Frequency, GHz**




**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;

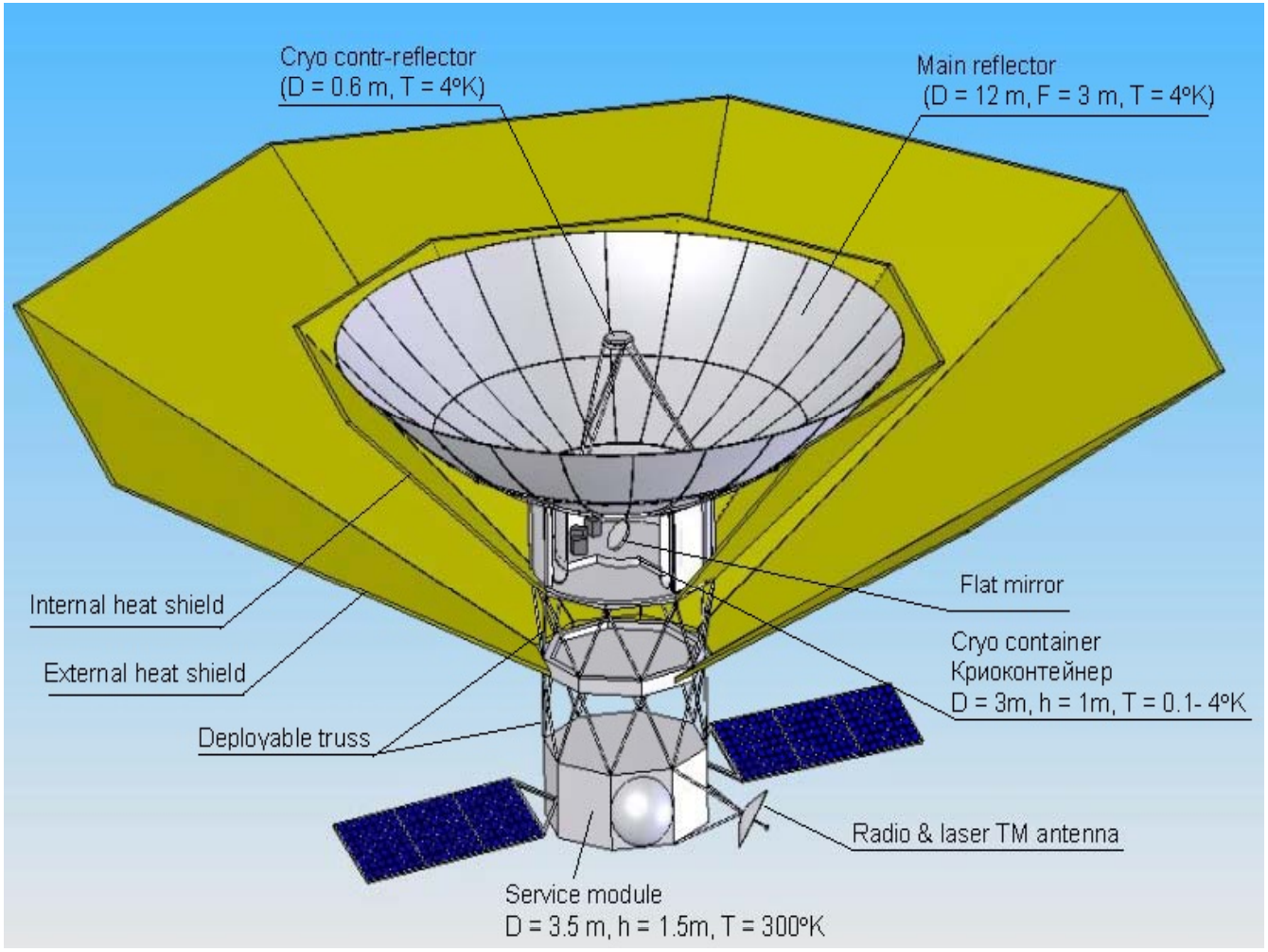
compressor – 42 kg;
power consumption
- 1.2 kW

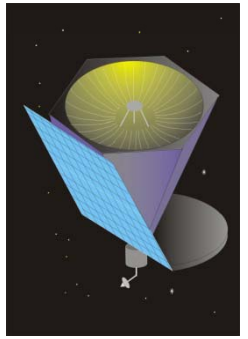
# ESPRIT – Exploratory Submm Space Radio-Interferometric Telescope

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**

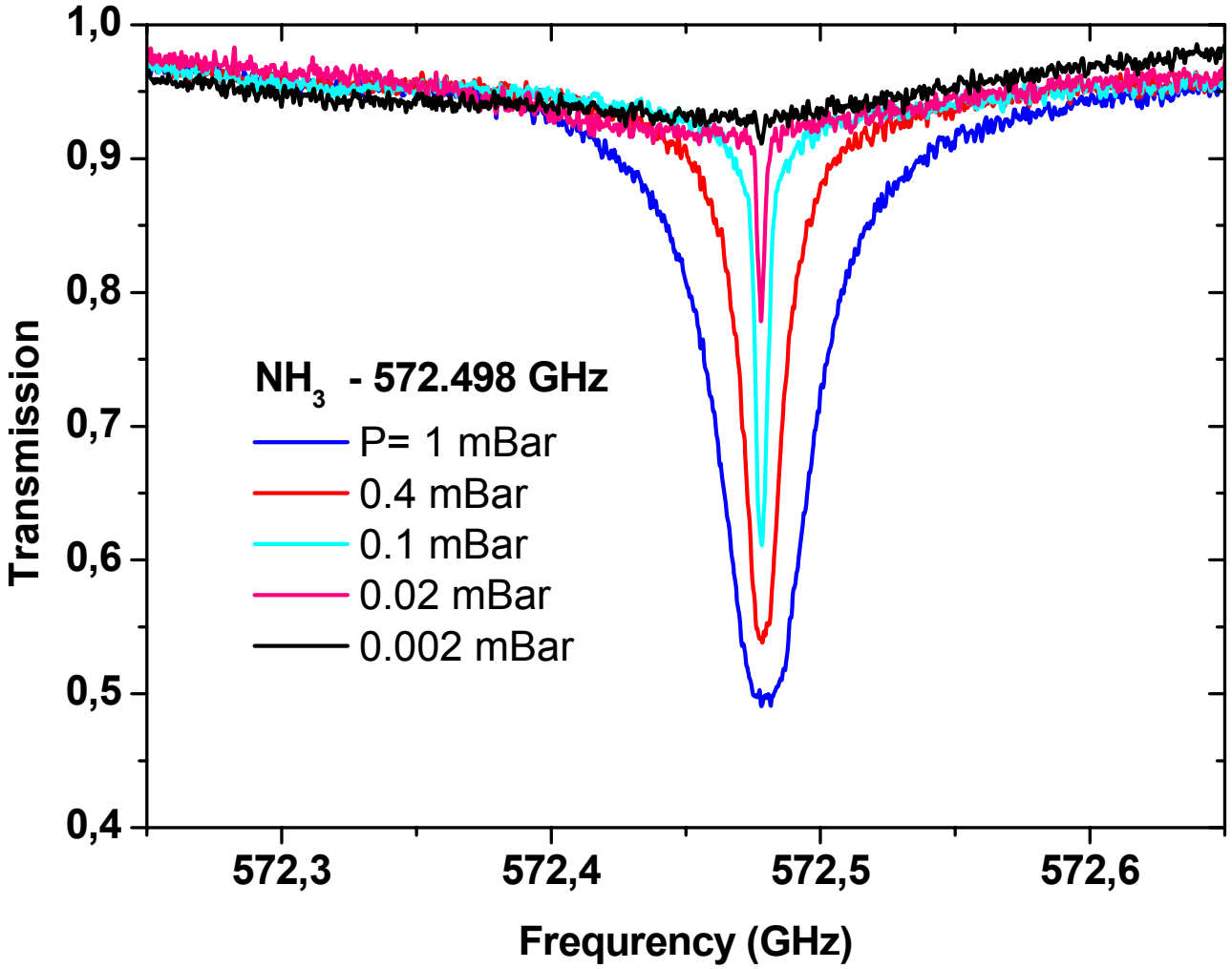
# Medical applications

## Non-invasive medical diagnostics based on analysis of exhaled air

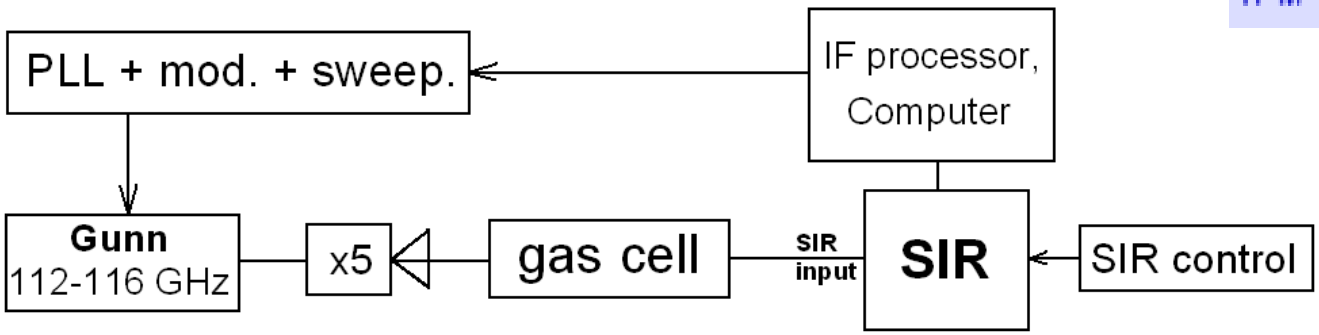
- human exhalation contains up to 600 volatile compounds
- some of them can be used as **markers of diseases**

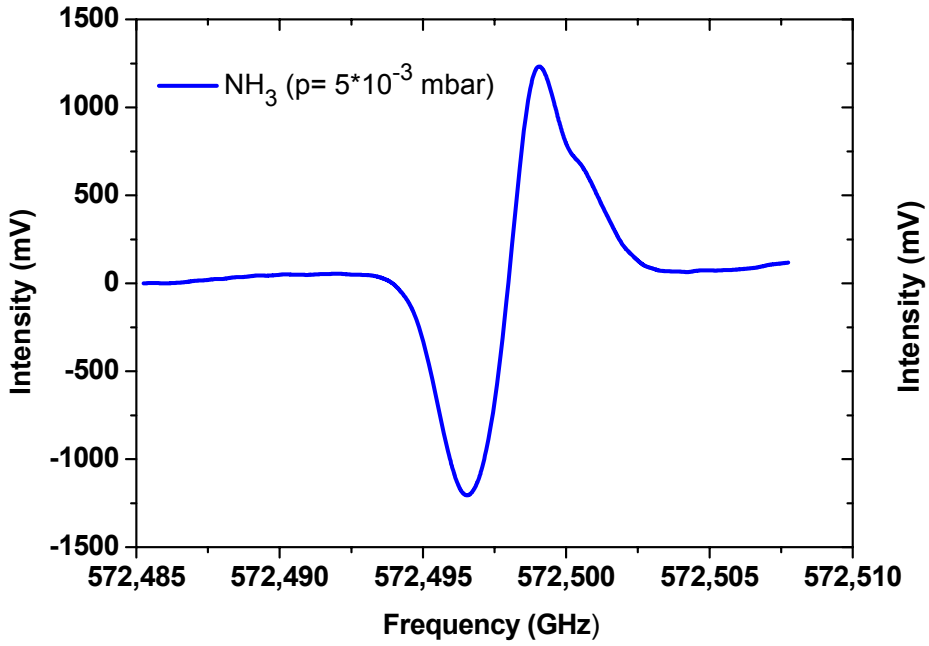
| | |
|---|---|
| **CO** | Blood disease, asthma, oxidative stress |
| **NO** | Diseases of respiratory tract, oncology |
| **$NH_3$** | Diseases of gastro-enteric tract, liver, kidney |
| **$CH_4$** | Malabsorption of hydrocarbons |
| **$CS_2$** | Markers of coronary arteries diseases, schizophrenia |
| **$H_2O_2$** | Radiation injury, asthma |

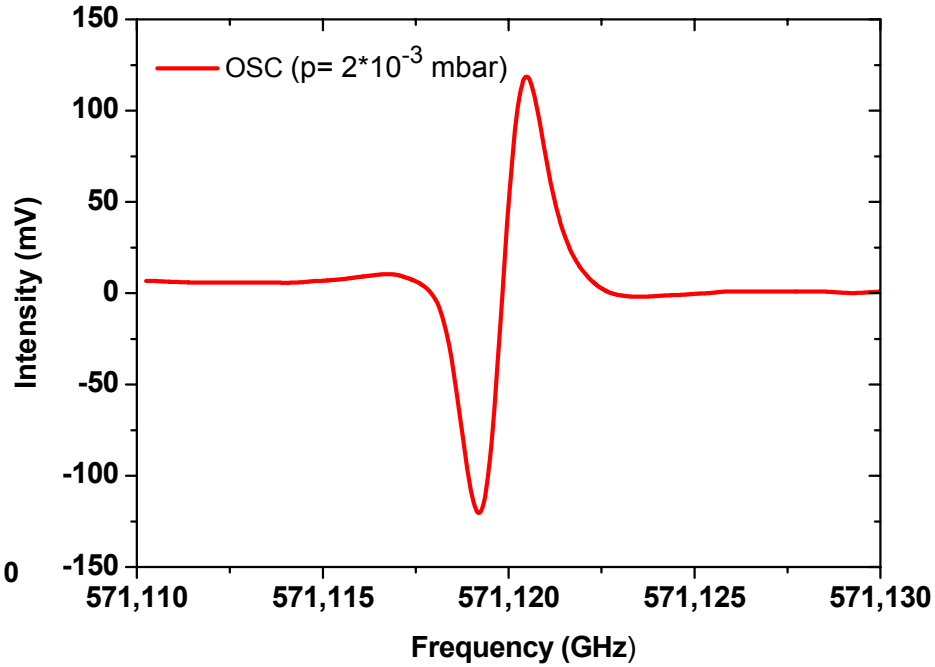
# Gas Spectra Detection by FFTS



# Gas Spectra Detection - 2



# Conclusion

- Concept of the Phase-locked SIR is developed and proven.
- Nb-AlN-NbN FFOs and SIRs have been successfully implemented.
- New generation of the SIR with PL FFO for TELIS has been developed showing a possibility to achieve all 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 SIR operation has been developed and experimentally proven.
- TELIS flight has been completed in March 2009 (Kiruna, Sweden).
- Future space and ground-base missions are under consideration.
- SIR Technology is mature enough for both future space missions and non-invasive medical diagnostic.