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6th International Symposium “METROLOGY OF TIME AND SPACE"

ON-BOARD ACTIVE HYDROGEN MASER FOR RADIOASTRON MISSION
(DESIGN AND EXPERIMENTAL RESULTS)

A. Utkin, A. Belyaev, Y. Pavlenko,

“Vremya-CH”, Nizhny Novgorod, Russia

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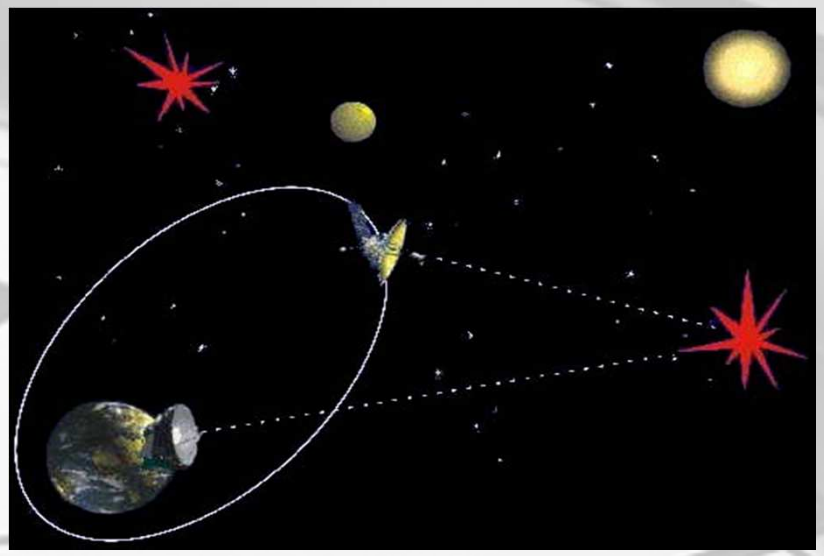
Introduction

The Radioastron is an international space VLBI project led by the Astro Space Center of Lebedev Physical Institute in Moscow, Russia.

Scientific program:

- Galactic nuclei.
- Cosmology effects; redshift dependence of various physical parameters of galactic nuclei; dark matter and dark energy effects.
- Star and planetary systems formation, masers and Megamasers.
- Stellar mass black holes and neutron stars.
- Interstellar and interplanetary media.
- Fundamental astrometry and development of the high precision celestial coordinate frame.
- Development of the high precision model of the Earth's gravitational field.



Parameters of the Orbit:

- Period (variable) 8 - 9 days.
- Apogee between 310,000 and 390,000 km.
- Perigee between 10,000 and 70,000 km.
- Initial inclination 51°.

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General information

- Active on-board hydrogen maser technology (the first in the world active H-maser intended for operation in open space).
- Using space vacuum for pumping the microwave cavity.
- Frequency instability

  2×10^{-13} @ 1 s,

  3×10^{-15} @ 1000 s.
- Increased mechanical durability of the construction
- Additional pressurized volume for electronic packages
- Weight 60 kg, size 460x729 mm (diameter and height)
- Operational lifetime more than 10 years

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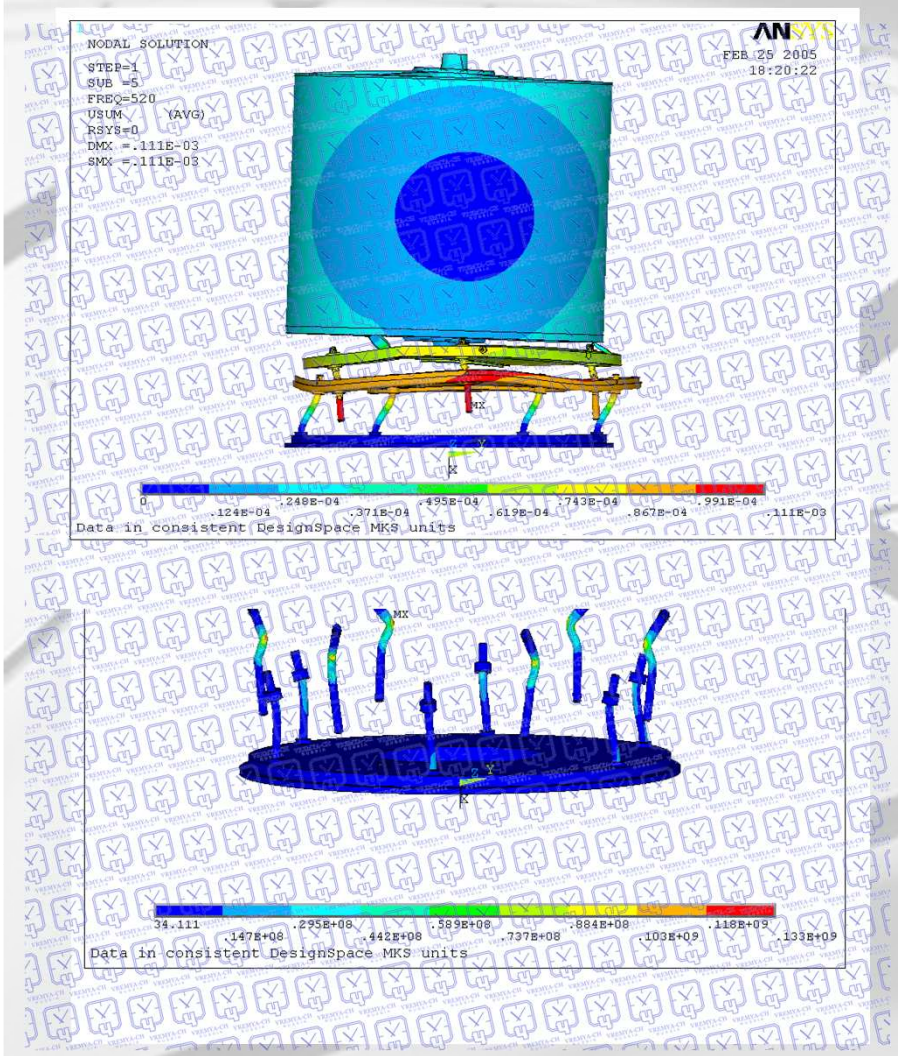
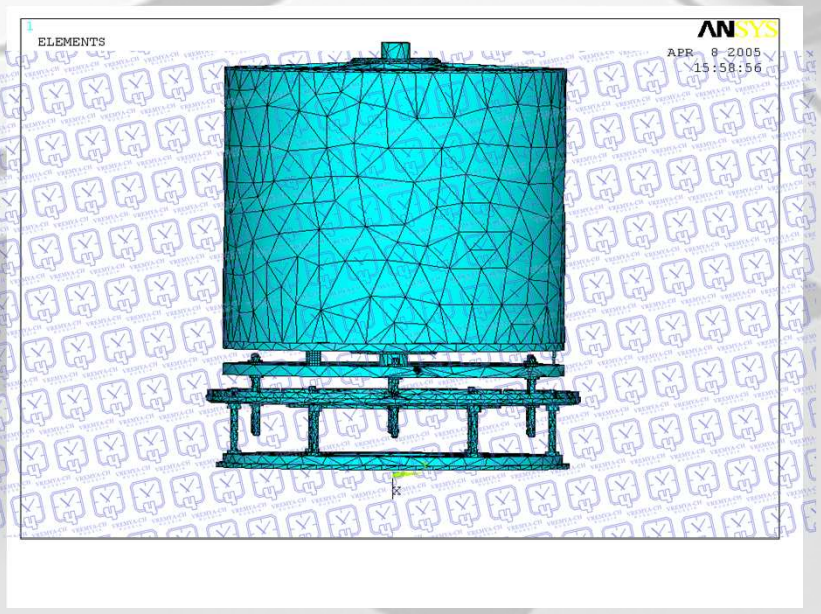
Mathematical modeling



3D ANSYS mechanical construction simulation model
128555 nodes, 62497 elements



Field of maximal accelerations. Blow along axis Y with amplitude 40 g

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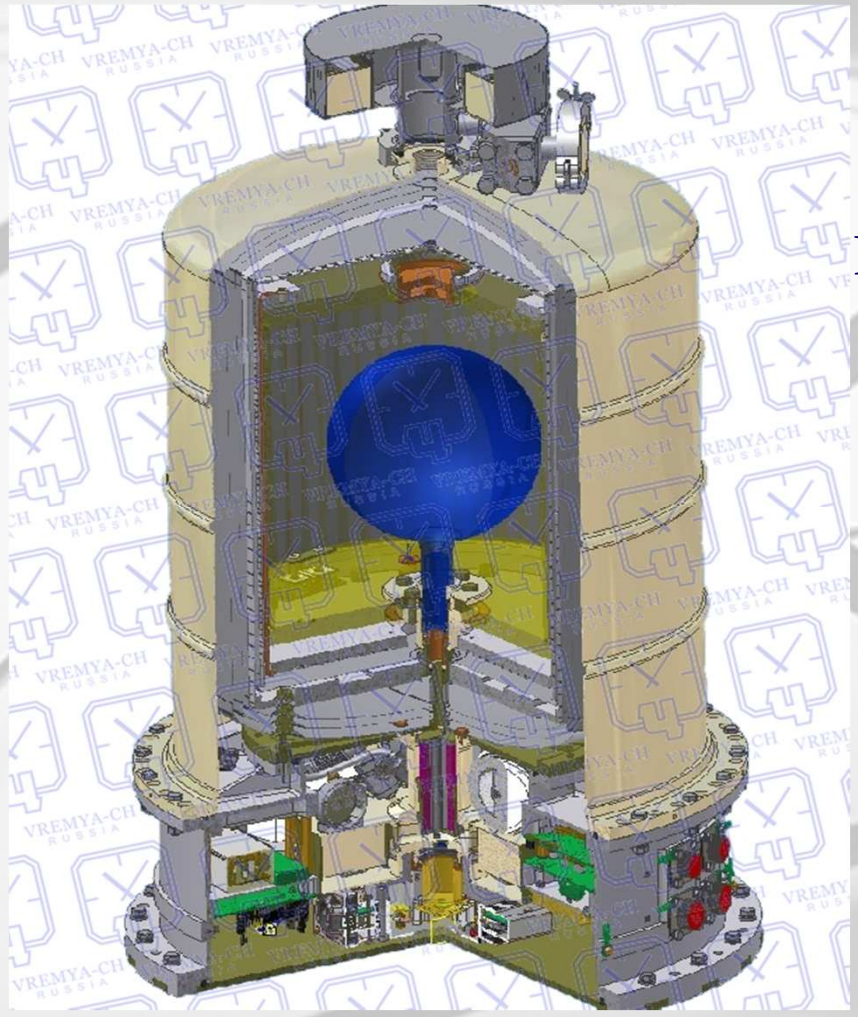
Design features



General view of the on-board hydrogen maser

Physical package with additional pump (on the top). Electronic package with additional pressurized volume filled with dry nitrogen placed on thermostabilized plate. Needed temperature accuracy – not more than ±1 ºC in any point of working temperature range from 25 to 35ºC.

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Physical package design features

- Considerable increase of mechanical durability of the construction.
- Using of space vacuum for pumping the microwave cavity.
- Additional pressurized volume, filled with dry nitrogen.
- Development of a new atomic beam forming system with improved parameters.
  - ✓ Increased capacity of the hydrogen source is 45 l·bar.
  - ✓ Pumping elements produced from titan-vanadium alloy. Capacity 50 l·bar.
  - ✓ Reinforced construction of the ion pump.
  - ✓ Reinforced construction of the discharge bulb.
  - ✓ Reinforced construction of the purifier.

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Theoretical investigation of cavity parameters

Temperature coefficients for different materials and temperature accuracy for instability $1 \cdot 10^{-15}$

Cavity material	α_T	$\Delta f_{cav} / 1°C$	Accuracy of maintenance of a cavity temperature for instability $1 \cdot 10^{-15}$
Polycrystalline glass	$\pm 3 \cdot 10^{-7} K^{-1}$	426 Hz	$1.23 \cdot 10^{-4} °C$
Aluminum	$22 \cdot 10^{-6} K^{-1}$	31250 Hz	$1.68 \cdot 10^{-6} °C$
Quartz	$+5 \cdot 10^{-7} K^{-1}$	710 Hz	$7.4 \cdot 10^{-5} °C$
Carbon fiber	$+5 \cdot 10^{-7} K^{-1}$	710 Hz	$7.4 \cdot 10^{-5} °C$

Polycrystalline glass cylinder with a multilayered carbon fiber covering was designed and realized.

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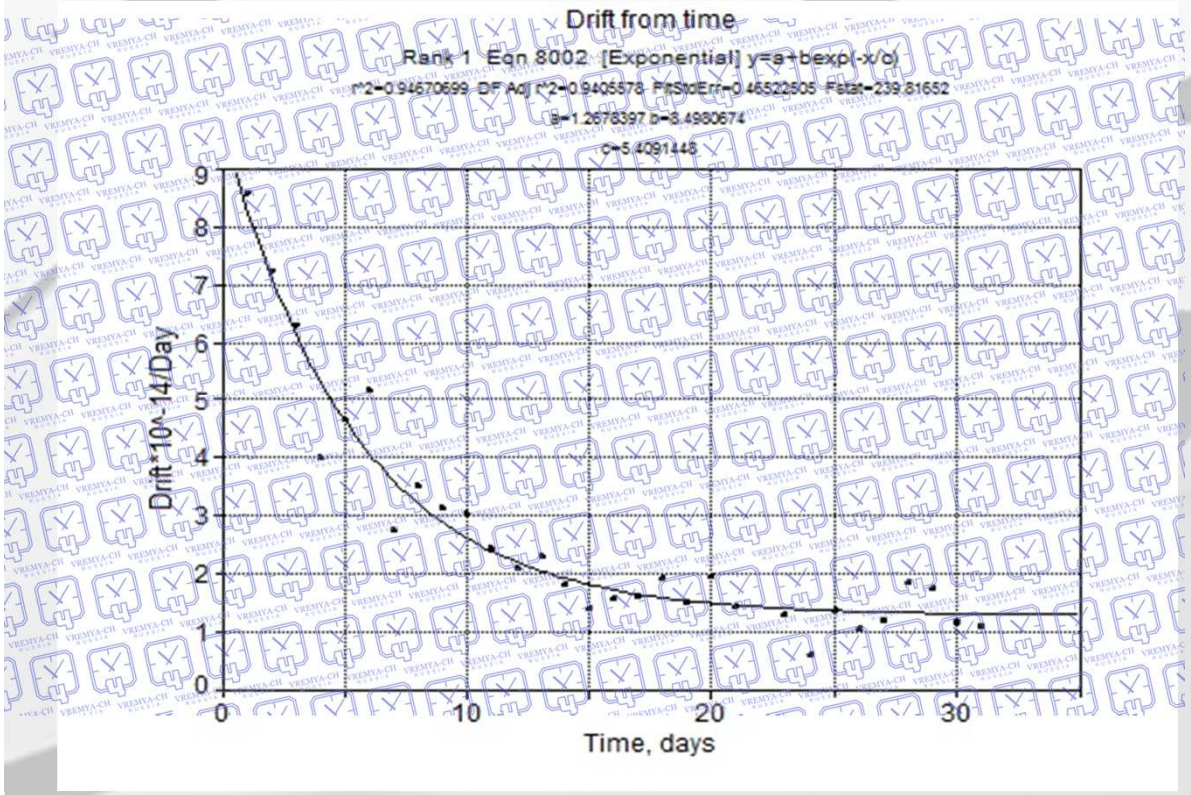
Polycrystalline glass cylinder with a multilayered carbon fiber covering

Cavity temperature coefficient of frequency : $Temp.coeff\,(cavity) = -48\,{}^{Hz}\!/_{1^\circ C}$

Correspond to: $\alpha_T\,(cavity) = -3.38 \cdot 10^{-8}\,K^{-1}$



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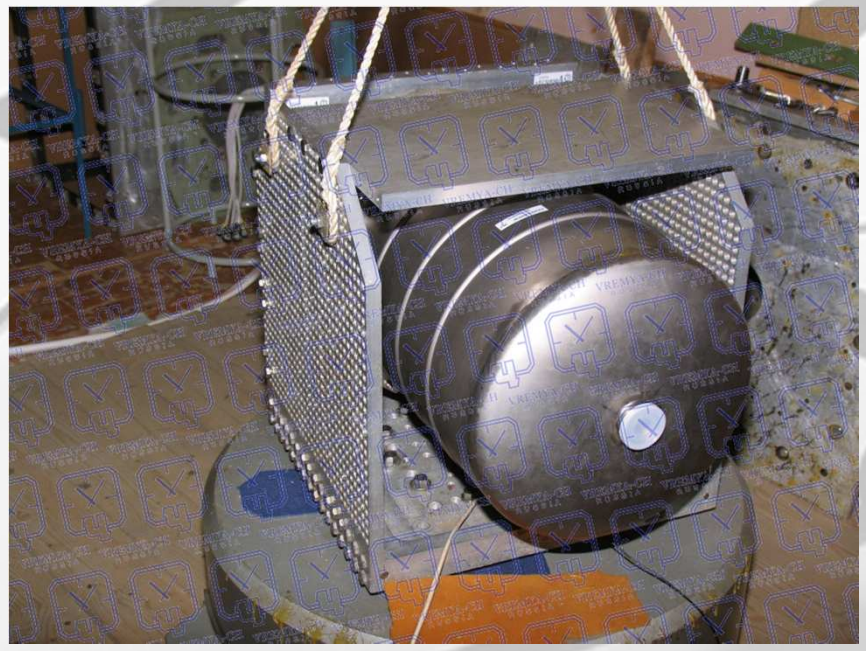
Mechanical and shock testing

Broadband random vibration in a range 20 – 2000 Hz with vibroacceleration up to 10 g

Shocks with amplitude up to 40 g



Variation of cavity frequency not more than 3 kHz with total varactor tuning range 24 kHz.

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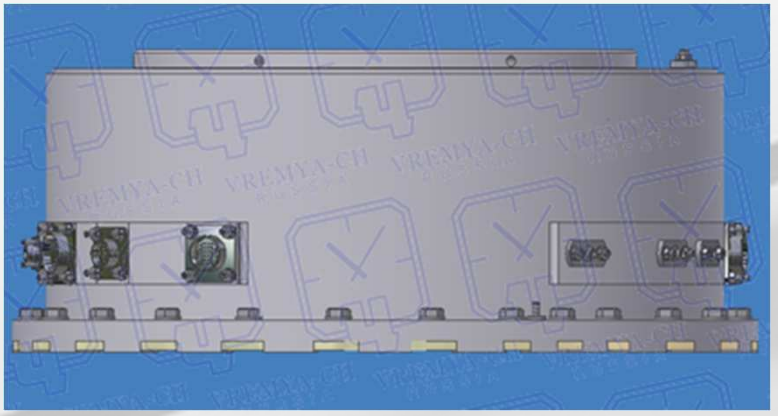
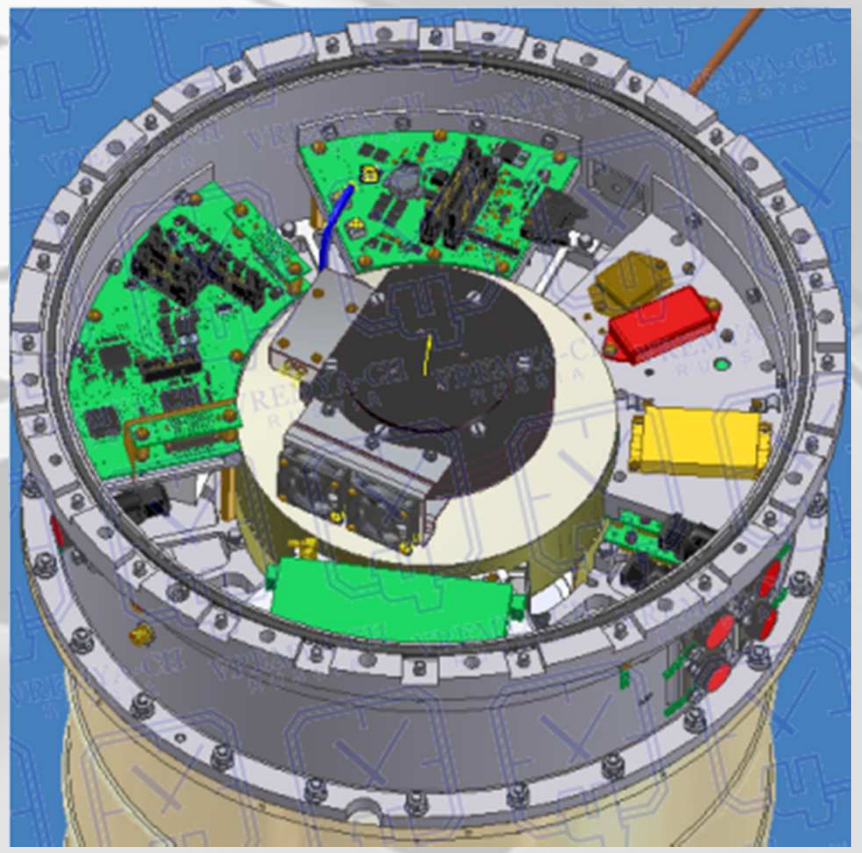
Additional pressurized volume for electronic part and discharge bulb

- Provide stable discharge starting.
- Sufficient heat-removing from discharge bulb and High Frequency Oscillator.
- Sufficient heat-removing from all electronic elements.





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Testing in a space environment modeling chamber

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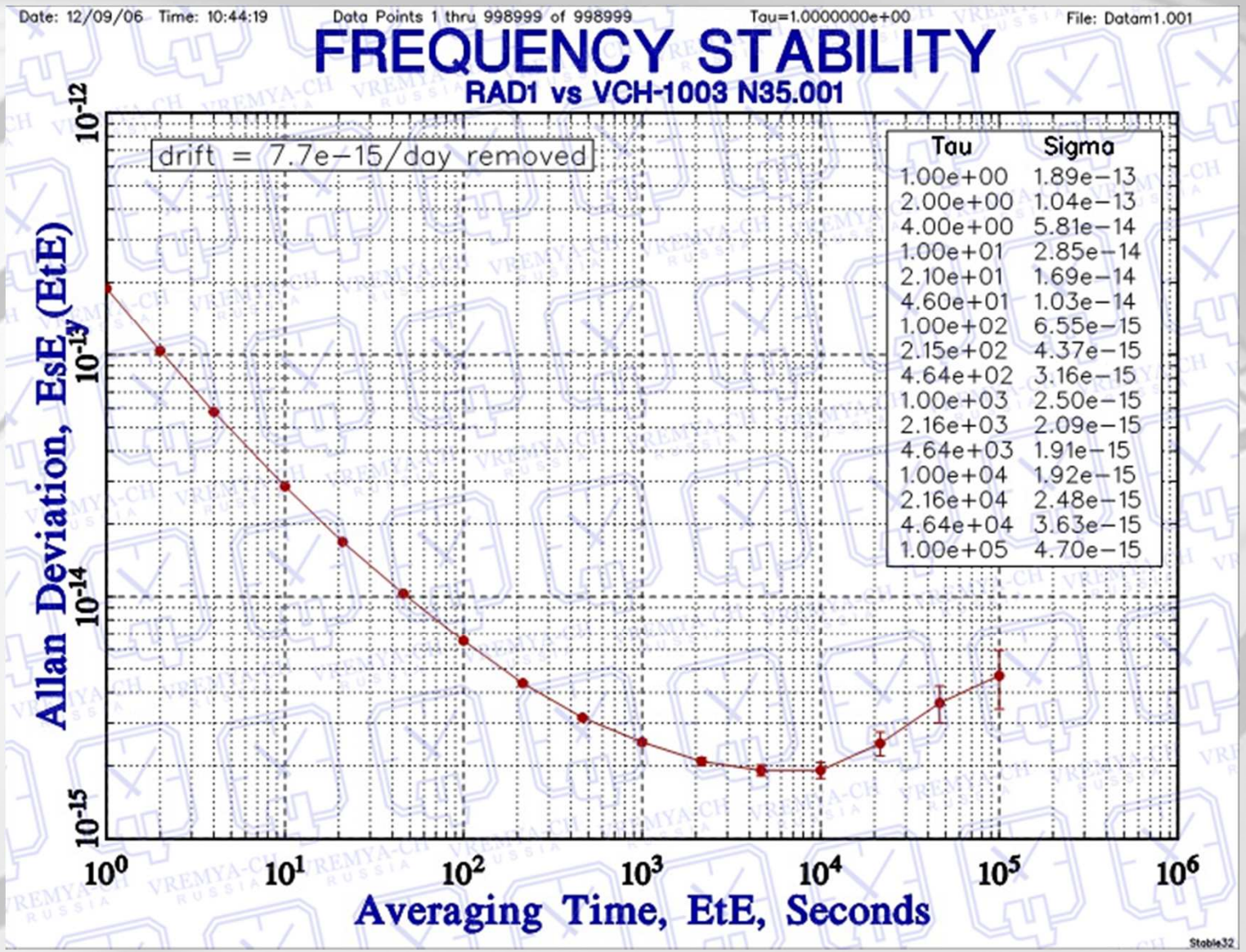
Frequency stability



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Conclusion

Parameter	Requirements	Measurement
Output signal frequency	5 MHz 15 MHz	5 MHz 15 MHz
Frequency instability (Allan variance) 1 s 10 s 100 s 1000s 1 day (Frequency drift removed)	 3×10^{-13} 3×10^{-14} 7×10^{-15} 3×10^{-15} 5×10^{-15}	 1.89×10^{-13} 2.85×10^{-14} 6.55×10^{-15} 2.5×10^{-15} 4.5×10^{-15}
Thermal sensitivity (1/°C)	5×10^{-15}	4.7×10^{-15}
Magnetic sensitivity (1/Gauss)	2×10^{-14}	1.9×10^{-14}
Sensitivity to the power voltage (1/V)	2×10^{-14}	5×10^{-15}
Power consumption in working condition	60 W	52 W
Mass	60 kg	57 kg
Lifetime	10 years	Expecting more then 10 years

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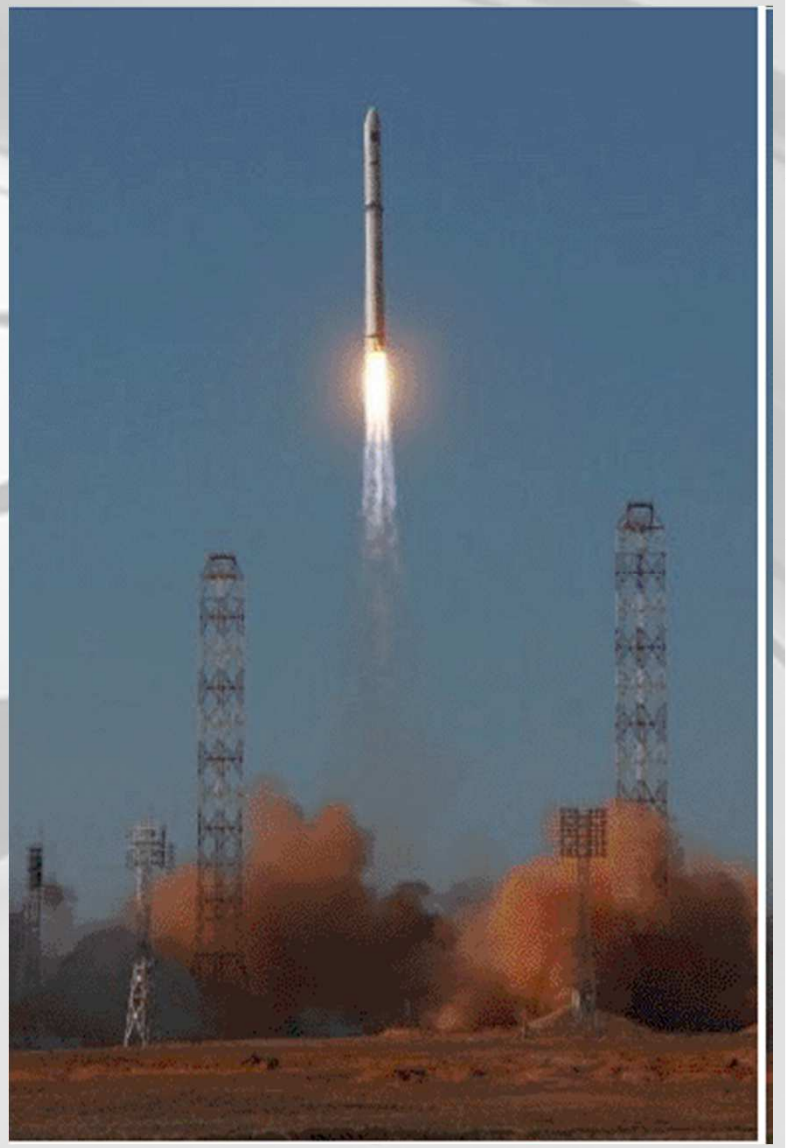
Current situation



18 July 2011 6:31 – Start of Radioastron mission

The first in the world active H-maser launched to open space

Information about Radioastron project:
http://www.asc.rssi.ru/radioastron/

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Thank you for your attention!