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Planning of an experiment for VLBI tracking of GNSS satellites

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Overview

A brief introduction on the general motivation of this work

Description of tests and experiments performed until now

Problems and further developments

Four good reasons for tracking GNSS satellites by VLBI

1) **To establish** a direct link of geodetic VLBI to the geocenter

2) **To verify** whether GNSS orbits could be obtained by the VLBI technique, to contribute a direct comparison and combination of spatial positioning techniques

3) **If signals from GNSS satellites** and from radio sources are observed with the same radio telescopes the GNSS observations could be linked directly to the ICRF (International Celestial Reference Frame)

4) **VLBI-determination of independent GNSS** orbits could also impact the GNSS field and lead to improving present models and methods for orbit determination

Main measurement principles for direct observation of a GNSS satellite by VLBI:

1) **VLBI geodetic observations by radio telescope networks** (Preston *et al.*, Science 1972, demonstrated the feasibility of using the method for accurate TACSAT satellite tracking, and for geodesy)
2) **Phase referencing observations respect to the background radio sources**
3) **Use of dedicated emitter directly installed on GNSS satellites sending signal to Earth radio telescopes** Something similar was already proposed about 30 years ago (Counselman and Shapiro, Science 1979)

More details on such methods will be presented at the Workshop *VLBI and GNSS: New Zealand and Australian Perspectives* on Feb. 15, 2010 prior to the SCANZ2010 Conference www.aut.ac.nz/skanz2010

Projects about a multitechnique satellites by JPL and GFZ

GRASP – "Geodetic Reference Antenna in Space"

JPL (*Yoaz Bar-Sever, Bruce Haines,Sien Wu, Frank Lemoine, and Pascal Willis)*: A mission to enhance the Terrestrial Reference Frame

MicroGEM – "Kleinsatellit für GNSS Fernerkundung und Schwerefeldmessungen"

GFZ Potsdam (Jens Wickert *et al.*): Plans for a small LEO satellite that can, among other things, receive GNSS-signals, can be tracked with SLR, and can send artificial VLBI signals.

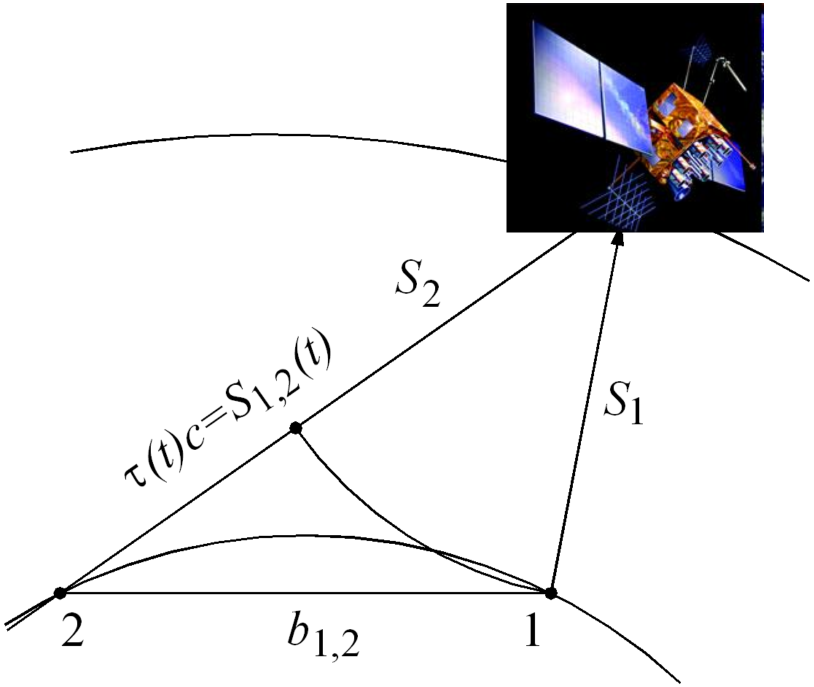
WHY the method: VLBI geodetic observations of a GNSS satellite by radio telescope networks now ?

GNSS signals share the same optics as the VLBI signals (including gravitational and thermal deformations) therefore a direct comparison of the two techniques and of the different realizations of Terrestrial Reference Systems would become immediately possible.

Phase referencing observations with respect to the background radio sources show differences of the propagation media for the sources at infinity and the near-Earth satellites. Such differences need to be studied in more detail (S. Pogrebenco private communication).

The use of a dedicated emitter on the satellites is also very promising but it can not immediately be checked: a dedicated mission needs to be planned, and before that a direct connection with the GNSS field is necessary.

Measurement principle for VLBI geodetic observations of a satellite by radio telescope networks



G, Seeber 2003

The orbiting satellite is considered as a radio source observed with the VLBI technique

The delay (range difference) is measured like:

$$S_{1,2}(t) = \tau(t)c$$

$$S_{1,2}(t) = \frac{1}{2\pi}\Phi_{1,2}(t)\lambda + N\lambda$$

The main difference with respect to a natural radio source: a satellite is not at infinity but it is a ‘near field source’

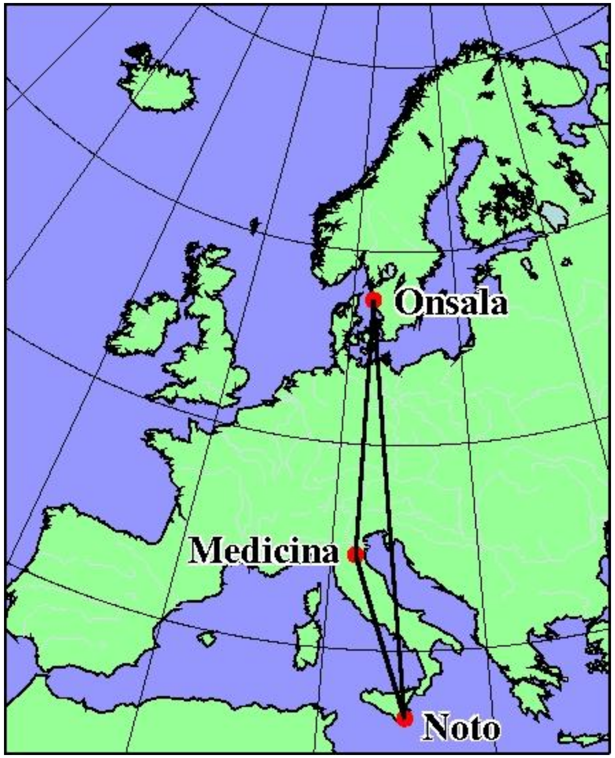
Delay models and correlation

The wave fronts arriving at two antennas can hence not be considered as being a plane wave front. A different geometrical model is required

Delay models to correlate signals from spacecrafts for deep space missions at a finite distance have already been developed and implemented (e.g. Sekido & Fukushima, 2006)

Such delay models require some modification to correlate signals from radio sources at a finite distance orbiting around the Earth

Planning of an initial three-station experiment tracking the same satellite



Among the GNSS constellations it was chosen to track GLONASS satellites because the frequency of emitted signals was observable by all three VLBI station L-band receivers.

VLBI tracking of GLONASS satellites
Main Objectives of the tests and observations

Several attempts were performed during 2009 and 2010:
Feb., Mar., Jul,, Oct. 2009, and 2010, January 20/21

The first goals of these observations were:
- to develop and test the scheduling for different satellites
- to verify satellite tracking at different Az and EL
- to test possible necessary signal attenuation
- to verify correlation detection and, if it works, to process delays and delay rates in the next second step

VLBI tracking of GLONASS satellites Expected Power

GLONASS carriers in L1 band: [1602.56 – 1615.50] MHz

Bandwidth: L1 C/A 1.022 MHz
L1 P 10.220 MHz

Emitted Power EIRP ~ 26 dBW

Earth distance ~19000 Km

Calculated receiving $\mathbf{T}_{\mathbf{(Md\ and\ Nt)}} = 1.5\cdot10^{6}$ K

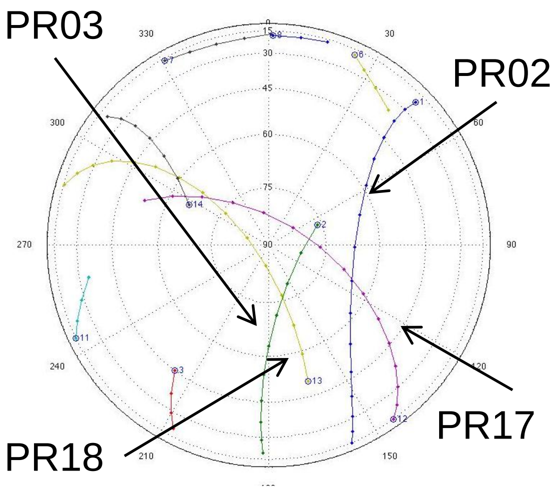
Some tests at 1 MHz and 10 MHz bandwidth using an artificial signal with same power of GNSS satellite.

The receiver could still work in linear area without reaching saturation. At Onsala a 20 dB attenuation has been added to the RF-chain

VLBI tracking of GLONASS satellites

Sky plots of 2010, January 21

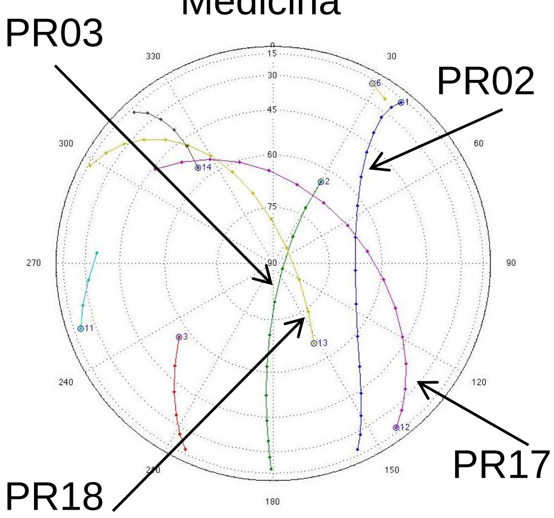
Onsala



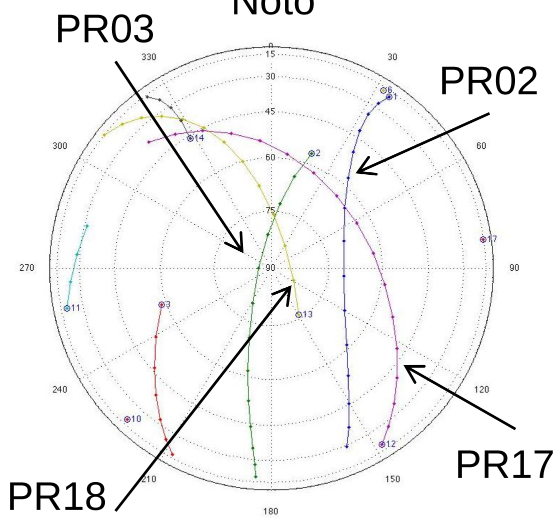
UT	Sat	Freq. [MHz]
08:00-08:55	PR17	f=1604.2500
09:00-09:55	PR02	f=1599.7500
10:00-10:50	PR03	f=1604.8125
10:55-12:00	PR18	f=1600.3125

Simulaneously visible at Onsala, Medicina, and Noto

Medicina



Noto



The telescopes were positioned with 20 s updates to follow the satellites.

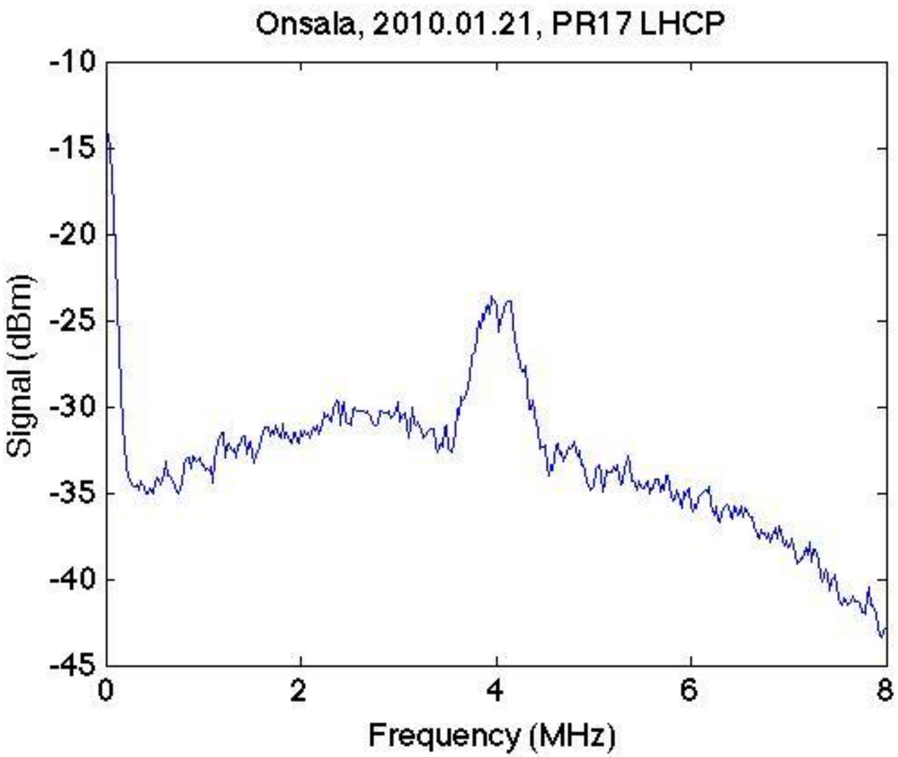
VLBI tracking of GLONASS satellites
Observational set-up arrangements

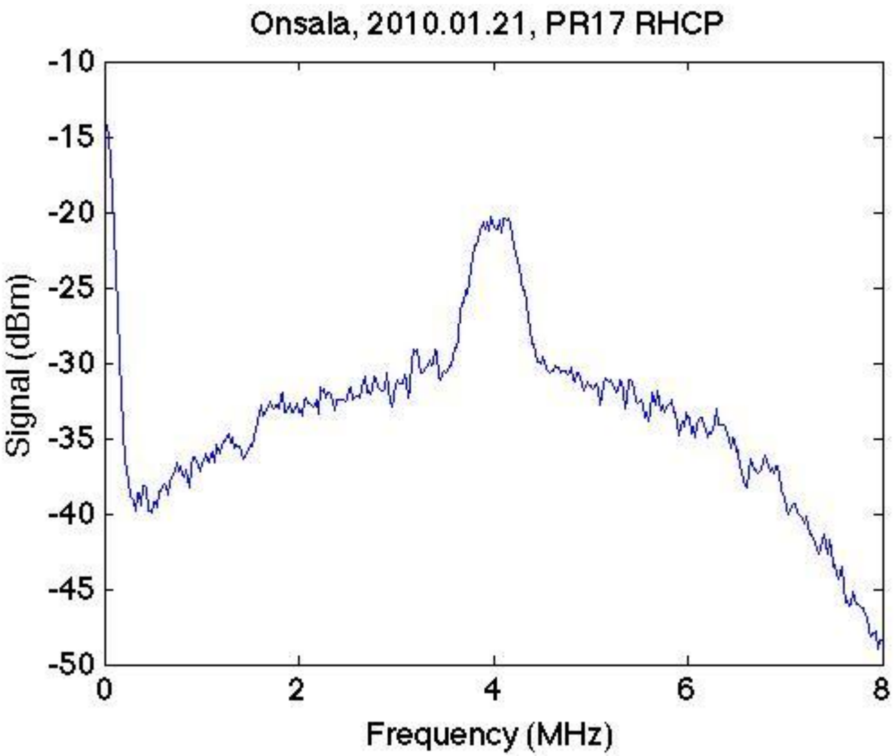
Observations were performed using the standard Mark4 VLBI data acquisition rack, for Onsala and Medicina, VLBA for Noto

2 channels (VCs) of 8 MHz bandwidth
(upper, 1 RHCP, 1 LHCP)

Formatted data were recorded with Mark5A
Scan length = 10 sec
Phasecal = on
Calibrator = Cygnus A (1 min observation)

The signal spectrum in the VC at Onsala for PR17 LHCP and RHCP



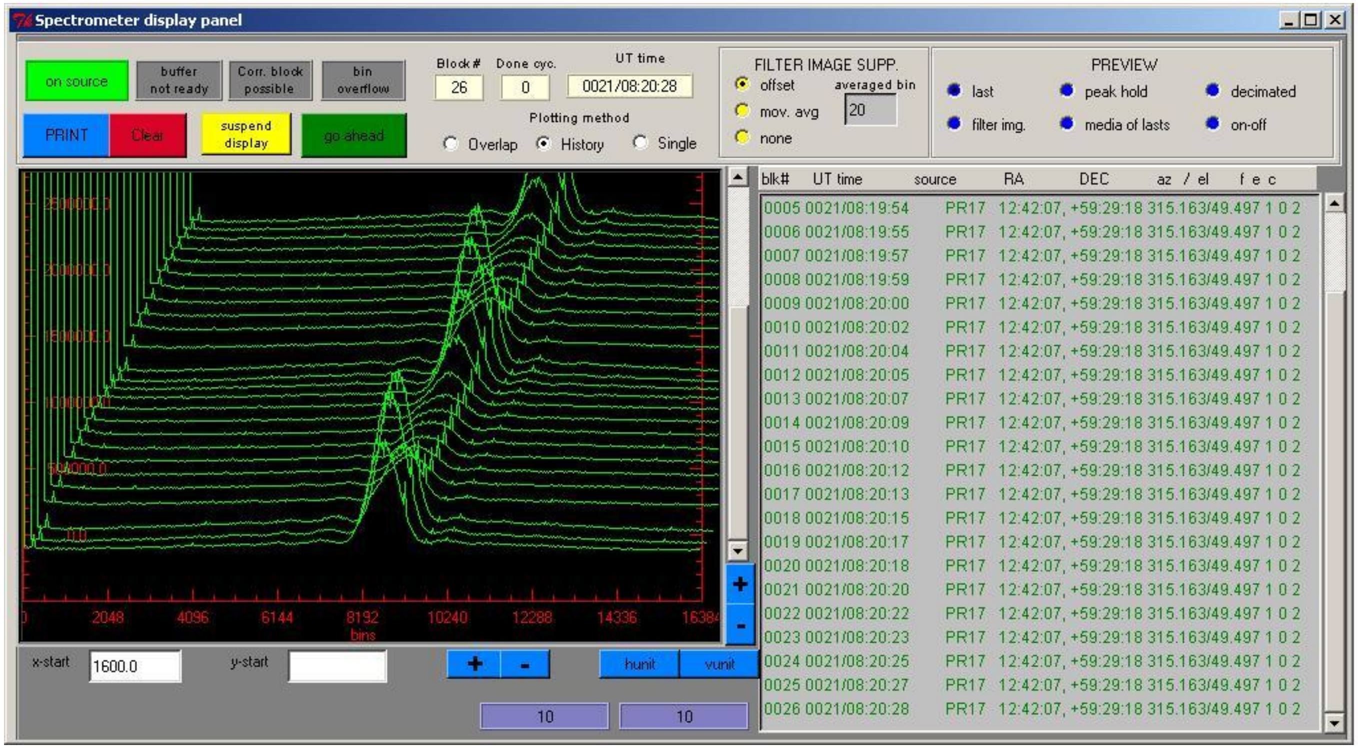


VLBI tracking of GLONASS satellites
Preliminary results:

Spectra on satellites PR17 in Medicina:

Power signal fluctuating carrier = 1604.2 (MHz), UT 08:20

Az = 321° .686, El = 52° .766

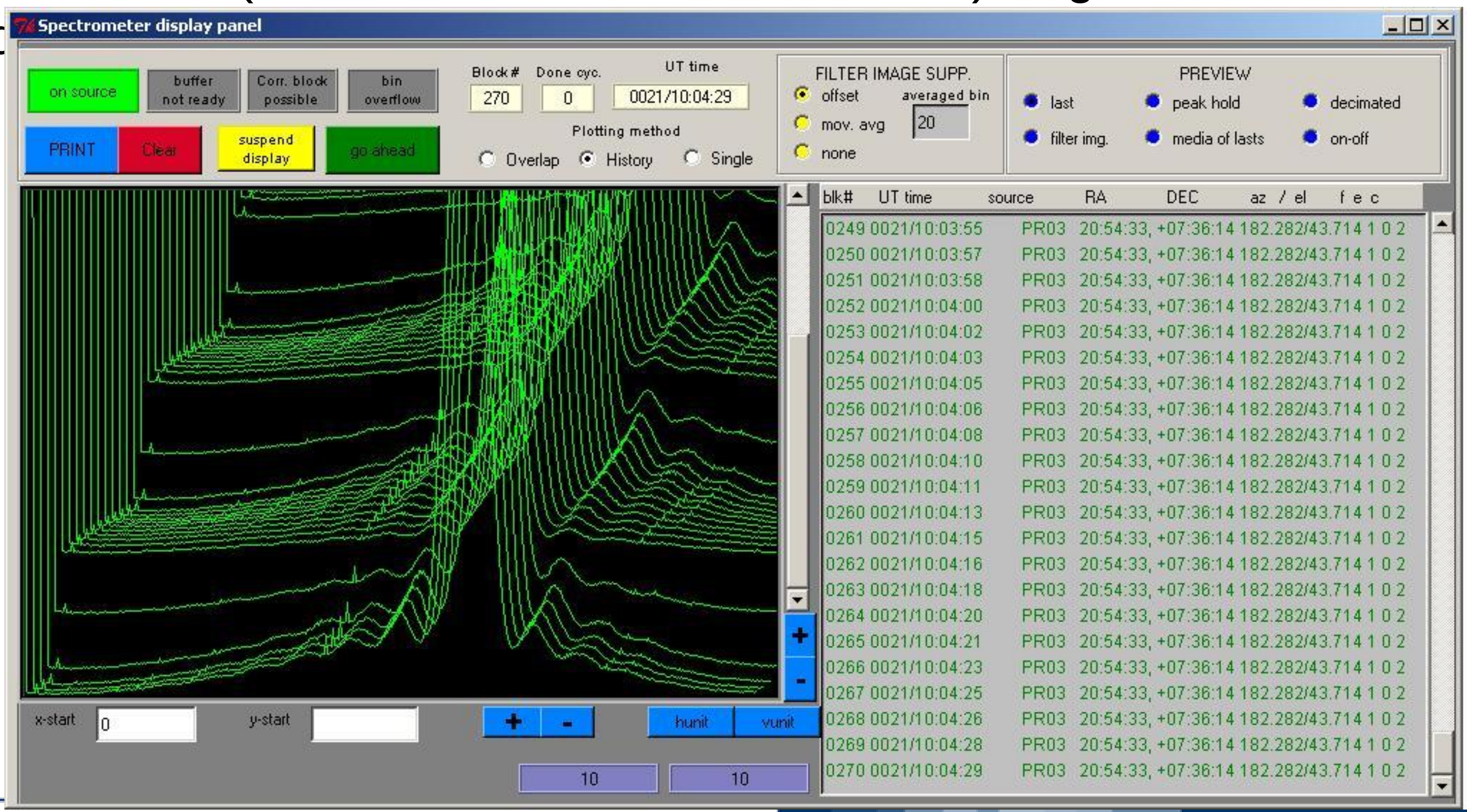


VLBI tracking of GLONASS satellites

Preliminary results:

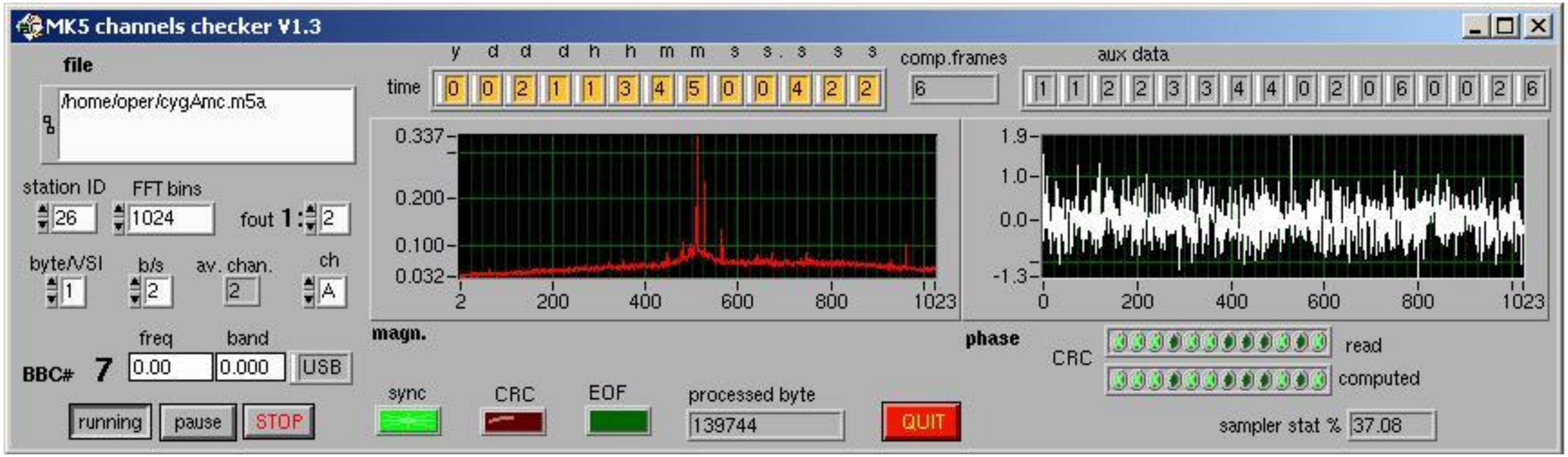
Spectra on satellite Cosmos 2447 (PR03)
carrier = 1604.8 (MHz), UT=10:05

Large signal fluctuations for Medicina Az = 182° .505, EL= 46° .248) and Onsala (Az =182° .314, EL = 31° .321). High attenuation was rec



VLBI tracking of GLONASS satellites
Calibrator Observation

At the end of the satellite observations an observation on Calibrator Cygnus A was performed for 1 min at 13:45 UT



Noto: **reduced attenuation by 19 dB /16 dB (RHCP / LHCP)**

Medicina: reduced attenuation by 29 dB /10 dB (RHCP / LHCP)

Onsala: reduced attenuation by 27 dB / 5 dB (RHCP / LHCP)

Conclusions

GNSS satellites can be tracked with VLBI telescopes some aspects/setup need to be refined: more observations needed to understand some anomalies

Tracking could be simplified by implementing the SatTrack-module in the next official FS-version

Attempts to correlate the recorded data from Jan. 21 are ongoing

Acknowledgments:

We want to thank the staff at the three observatories that supported the experiments and many colleagues for discussions and comparisons.