PROJECT: Studi di Cosmologia		WP 5-6X2
WP TITLE: **CMB calibration and SRT** **CONTRACTOR**: **Università di Milano Bicocca** **START EVENT**: KO **END EVENT**: RF **WP MANAGER**: **Massimo Gervasi**		**Sheet**: 1 **of** 1 **Issue Ref**: 1 **Issue Date**:01/09/2016

1. RATIONAL OF THE PROJECT

Aim of the project are: 1) a detailed survey of sky calibration sources for CMB polarization experiments, procedures and strategy of observation with CMB experiments and with SRT; 2) a study of the accuracy achievable in the calibration of CMB polarization signals using sky sources, through the observation of few representative sky sources with SRT.

Among the deliverables of the project are:

- A recommendation of the procedures and strategies to observe sky calibration sources by CMB polarization experiments and by SRT for supporting them;
- A list of the most representative sky sources to be used as calibration signal in CMB experiments and their most relevant features;
- An estimation of the accuracy achievable in the calibration of the CMB signal using sky sources.

2. RESULTS EXPECTED AFTER SIX MONTHS FROM THE KO-MEETING

The main target after six months is the definition of preliminary procedures and strategies to observe and characterize sky calibration sources. In particular, the definition of the systems available at SRT and the most suitable configuration for observing polarized calibration targets.

3. RESULTS OBTAINED AFTER SIX MONTH FROM THE KO-MEETING

Definition of the capabilities of SRT and its exploitation for calibration source observations

- SRT offers the capability to observe sky sources with a resolution of ~ arcmin up to relatively high frequency bands.
- Atmospheric opacity limits the observation at highest frequency bands (~100 GHz) to the winter season (from January to April), but there is no limitation for lower frequencies.
- Among the receivers installed at SRT, the most suitable for observations of polarized sources is the K-band (18.0-26.5 GHz). It is a multi-feed receiver operated at the Gregorian focus. It is the highest frequency large-bandwidth receiver already available. In the future more receivers will be installed, among them the Q-band (33-50 GHz) and W-band (84-116 GHz) can be used.
- Two back-ends could be selected for the observations: a total power with a bandwidth up to 2 GHz; a spectro-polarimetric system with 1024 channels and a bandwidth up to 2.3 GHz.
- Observations of polarized calibration targets can be scheduled starting from 2019, when operations at SRT are expected to resume after the planned shutdown and commissioning phases.
- A survey of point-like sources was carried on during the Early Science Program, from February to August 2016. The possibility to use a small fraction of these data, identifying some possible polarized calibration sources, is currently under investigation.
- A complete survey of the northern sky is planned to start as soon as SRT operations will resume. Also This survey, could be used for the purpose of this WP. The feasibility of that will be investigated.

In the following sections a description of the telescope and its main features are reported. For more details see: M. Beltran, et al. (National Institute for Astrophysics); "*Receivers for Radio Astronomy: current status and future developments at the Italian radio telescopes*"; Revision v5.3; 2017.

Sardinia Radio Telescope: main features

Optical configuration

- **Primary Mirror Dish** (D): 64 m shaped profile with an active surface (1008 panels and 1116 actuators).
- **Secondary Mirror Dish** (d): 7.9 m (concave – shaped profile).
- **Tertiary Mirror Dishes** (ellipsoid): M3 (size: 3.9 – 3.7 m), M4 (3.1 – 2.9 m) and M5 (3.0 –2.8 m).
- **Prime focus**: Focal Length (F1) = 21.0234 m; Focal ratio (F1/D) = 0.33.
- **Gregorian focus**: Focal length (F2) = 149.87 m; Focal ratio (F2/D) = 2.34.
- **Beam Wave Guide foci** (F3 and F4): M3 + M4 Focal length (F3) = 83.91m; Focal ratio (F3/D) = 1.37; M3 + M5 Focal length (F4) = 179.87m; Focal ratio (F4/D) = 2.81.

Total surface accuracy (**RSS**): 305 μm. Antenna efficiency is quite constant vs. elevation, due to the primary mirror active surface system compensating for gravitational deformations.

Aperture Efficiency (theoretical maximum, i. e. not including surface effects ≈ 60%)

- 52% @ λ = 5 cm (measured);
- 56% @ λ = 1.3 cm (measured);
- 43% @ λ = 0.7 cm (expected with 305 micron).

Pointing Accuracy: On both axes, azimuth and elevation, 0.002 degrees RMS (7.2 arcsec). No calibration is required during standard antenna operations.

Angular Resolution ≈ 32 arcsec (λ/1cm)

Atmosphere opacity at *SRT*

SRT is equipped with an atmosphere monitoring system (ASM) that provides all the fundamental atmospheric parameters required for observation and the calibration, such as Tsys, opacity, PWV, ILW, and brightness temperature. The ASM is based essentially on a historical data archive (radio soundings time series, 1950-2016), on real time measurements (microwave radiometer, GPS, weather gauges), and on forecast data (time span = 48 h). The goals of the ASM are: (*i*) to characterize the atmospheric site parameters; (*ii)* to give a support to observations in real-time; and (*iii)* to forecast the weather conditions.

The results for K-band

Precipitable water vapor during winter months ranges, on average, between 8 and 15 mm, respectively, for 25% and 75% of the percentile. The median opacity at 22.23 GHz is 0.10 Np in winter and 0.16 Np in summer.

The results for high frequencies

Observations at higher frequencies may be performed usefully during winter time; the median opacity at 100 GHz is usually below or equal to 0.2 Np in the period that ranges from January to April.

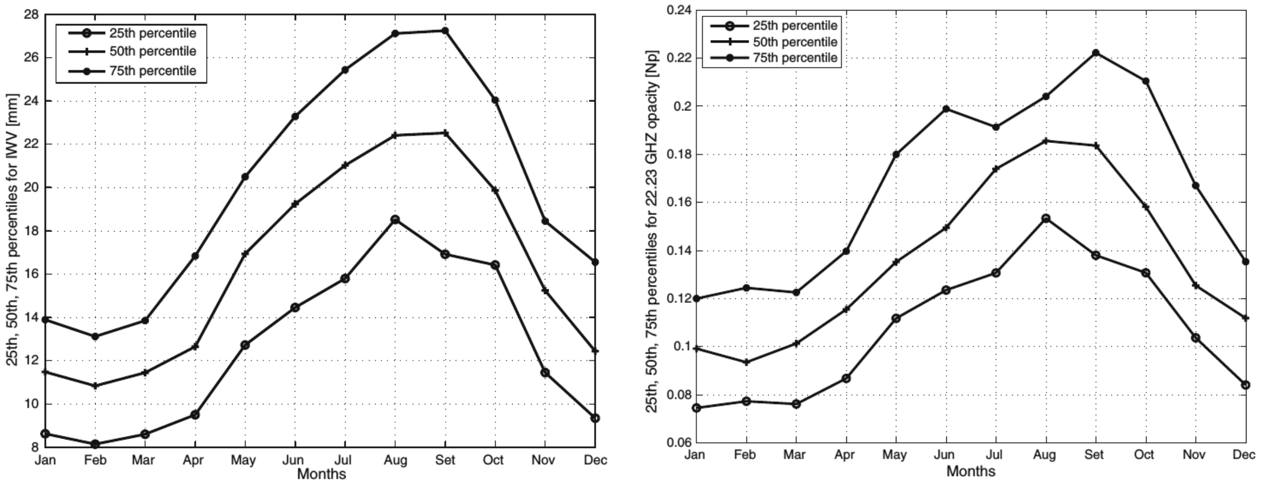

Fig.1 Left: Monthly quartile plots for precipitable water vapour at the SRT site. Right: Monthly quartile plots for 22.23 GHz opacity at the SRT site.

Receivers at *SRT*

High frequency receivers are located in the secondary focus whereas low frequency in the primary focus. In table 1 the list of receivers already available, together with some measured feature, and under development.

Table 1 – Receivers in operation or under development at SRT.

Receiver band	P	L	C-high	K	X	Ka	S	C-low	Q	W
ν_{min} (GHz)	0.305	1.3	5.7	18.0	8.2	31.85	3	4.2	33	84
ν_{max} (GHz)	0.410	1.8	7.7	26.5	8.6	32.25	4.5	5.6	50	116
Feed number	1	1	1	7	1	1	7	1	19	1
Angular resolution	56.2’	12.6’	2.8’	50”						
T-sys (K)			33	70-90						
Status	available	available	available	available	available	available	Under development	Under development	Under development	Under development

Polarization properties

Almost all receivers have dual circular polarization (LCP and RCP) outputs. This configuration is recommended for single-dish polarimetric observations. In fact, with respect to linear polarization ones, circular polarization receivers allow a more accurate determination of the Q and U Stokes parameters.

Performance of the receiving system

The theoretical sensitivity is defined as the 1-sigma RMS noise (Jy) detectable by the instrument back-end with the nominal instantaneous bandwidth in 1 second of integration time.

This parameter has to be taken as a lower limit to the actual sensitivity because of: *(i)* the presence of RFI reducing the available instantaneous bandwidth; *(ii)* receiver performances typically worse than theoretical ones; *(iii)* the confusion limit reducing the sensitivity actually reachable in a given frequency band.

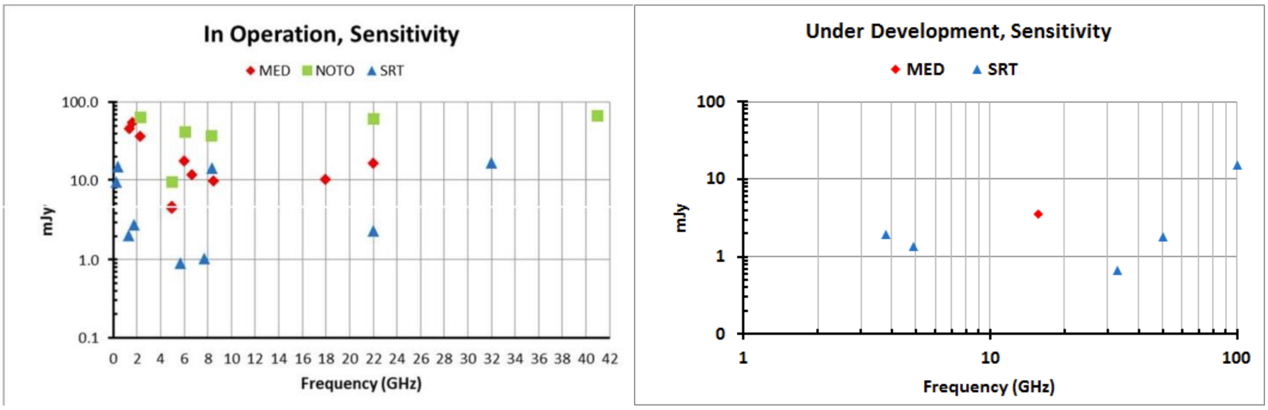

Fig. 2 – System sensitivity for receivers in operation (left) and for receivers under development (right).

Back-ends

Total Power

The total power detector is based on a voltage to frequency converter and a counter implemented in an FPGA chip.

Features: continuum, selectable attenuator, four selectable IF filters, fast switching of calibration diode.

- **Number of inputs** Up to seven dual polarization or 14 single polarization;
- **IF bandwidth** 300 MHz, 730 MHz, 1250 MHz, 2000 MHz;
- **Integration time** 1-1000 ms;
- **Remote interface** Ethernet / TCP.

This back-end has mild to severe issues in the presence of RFI.

SARDARA

The system is based on ROACH2 boards provided by the CASPER Consortium. The boards are equipped with Virtex6 FPGA chips. Boards are supplemented by two ADC that work with 8 bits at up to 5GS/s.

Features: Full Stokes spectrometer, large bandwidth, high frequency and time resolution.

- **Number of inputs** 1 pair of IF signals, i.e. the output of a full polarization receiver;
- **IF bandwidth** 500-2300 MHz;
- **Integration time** Up to 0.5 ms;
- **Spectral channels** 1024 or 16384;
- **Spectral resolution** About 90 KHz;
- **Remote interface** Ethernet / TCP.

The large bandwidth, the high time resolution, and the good spectral resolution make this backend a general-purpose device to be employed in many science cases: continuum; polarimetry; spectro-polarimetry; and wide- as well as narrow-band and multi windows spectroscopy. Currently one Roach chain is implemented, allowing exploitation of only one full polarization feed (2 IFs). Back-end development to support at least 14 simultaneous IFs, each with a bandwidth of 2.1 GHz, is foreseen in the near future. This further implementation will allow the full exploitation of the multi-feed K-band receiver installed at the SRT.

Status of SRT and observation plan

- The telescope is in its early stages of scientific use. The commissioning terminated in 2015 and a 6-month Early Science Program has been run from February to August 2016.
- The telescope has now entered a shutdown phase that will last till the end of 2018 for two major works: migration of control room and equipment room to the new buildings; and repair of the active surface actuators.

The operations of the Early Science Program were run from temporary control and equipment rooms and the final new buildings for regular operations were recently completed; they comprise offices, control room, and equipment/shielded room. The work to procure and set up all equipment to gear them up is in progress and the migration will take place during 2017. The second work consists in the repair of the active surface actuators that went through an unexpected and rapid corrosion phenomenon. The repair work is expected to end by September 2017.

- A commissioning period will follow, in order to test and calibrate the new surface as well as to test all the observation operations from the new control and equipment rooms. This commissioning activity is expected to last until the end of 2018.
- Full SRT operations are expected to resume in 2019.
- Observations of calibration sources can be scheduled after SRT is again in operation.

4. PEOPLE INVOLVED

Massimo Gervasi (WP manager) and Mario Zannoni (Università di Milano Bicocca); Maurizio Tomasi and Davide Maino (Università di Milano); Carlo Burigana and Sara Ricciardi (INAF-IASF Bologna); Francesco Piacentini and Elia Battistelli (Università Sapienza, Roma); Andrea Zacchei (INAF-OATS Trieste); Carlo Baccigalupi and Nicoletta Krachmalnicoff (SISSA Trieste); Marcella Massardi (INAF-IRA Bologna); Ettore Carretti (INAF-OAC Cagliari).