WP 5–6X2

WP TITLE: **CMB calibration and SRT**

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RA1

First Year, t0+6months

Preliminary procedures and strategies to observe and characterize sky calibration sources

1 - 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).

Two additional mirrors (M6, M7) will be added later to have two more foci for Space Science applications.

- **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.

Focal Position F1 (Primary Focus)

- Three servo axes PFP (Primary Focus Positioner): Z axis (focus axis), X axis (parallel to elevation) for receivers translation and swing axis with a rotation 0° - 76°;
- Two Helium lines for cryogenic receivers;
- Maximum loads on servo axes = 1700 Kg;
- Available volume ≈ 6.7 m^3 (2.97 x 1.5 x 1.5 meter (X, Y, Z));
- Receiver supported at frequencies from 0.3 to 22 GHz.

Focal Position F2 (Gregorian Focus)

- Vertex room: of about 200m^3 where receivers and other services and devices are installed;
- Three Helium lines are available. Each line has own compressor in the basement room;
- A Gregorian rotation turret system is accomodating up to seven mono- and multi-feed receivers;
- Available volume ≈ 1.1 m^3 (0.6x0.6x2.9m (X,Y,H));
- Available frequencies: from C band (4 GHz) up to 116 GHz;
- Current status: one receiver installed, K-band, multi-feed 7-beams, cryogenic.

Focal Positions F3 and F4 (BWG Foci)

- BWG room: a mirror (M3) reflects the beam which can be intercepted by either M4 or M5;
- Two Helium lines are available;
- Up to two mono-feed coexisting receivers can be installed, from L band up to 32 GHz;
- Receivers in the BWG foci are parallel to the optical axis.

1.1 – Atmosphere opacity at *SRT*

The 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

From historical time series observations are possible all year round. 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.

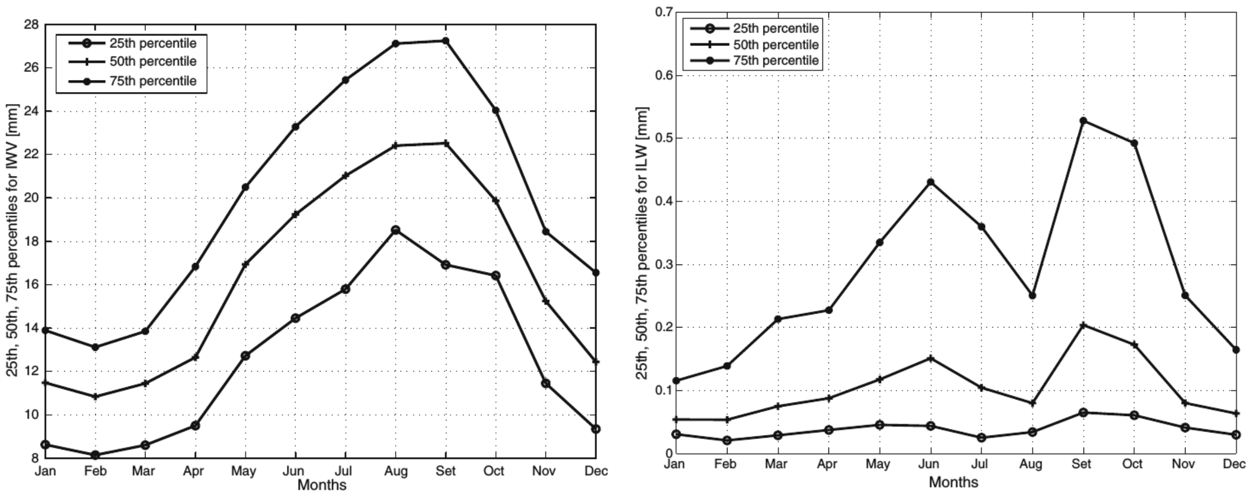

Fig.1.1 Monthly quartile plots for precipitable and integrated water vapour at the SRT site.

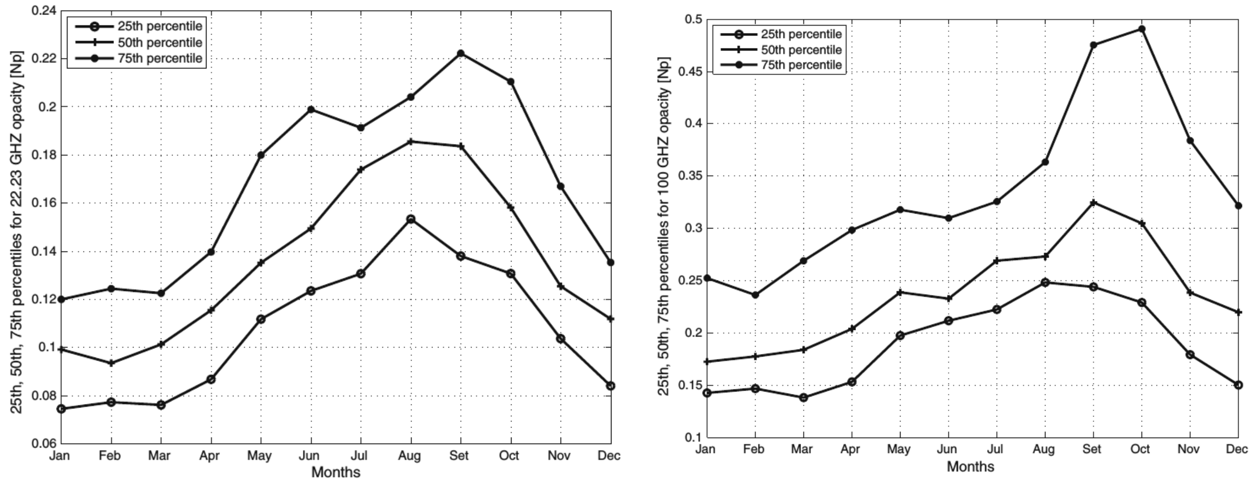

Fig. 1.2 Monthly quartile plots for 22.23 and 100 GHz opacity at the SRT site.

Quantity	Jan	Feb	Mar	Apr	May	Jun
IWV	45	49	43	30	10	5
ILW	54	59	64	59	67	77
τ (0.3)	100	100	100	100	100	100
τ (1.4)	100	100	100	100	100	100
τ (6.7)	100	100	100	100	100	100
τ (10)	100	100	100	100	100	100
τ (15)	100	100	100	100	100	100
τ (18)	100	100	100	100	100	100
τ (22)	94	94	92	86	70	59
τ (22.12)	93	93	90	85	66	56
τ (22.23)	91	91	89	82	63	51
τ (23.69)	97	98	95	90	82	76
τ (23.72)	97	98	95	91	83	77
τ (23.87)	98	98	96	92	85	81
τ (30)	100	100	100	99	96	97
τ (42.82)	83	86	85	78	77	82
τ (43.12)	81	85	83	76	75	80
τ (88.63)	47	48	49	35	17	12
τ (90.66)	46	47	48	34	17	11
τ (100)	34	35	35	25	9	6

Quantity	Jul	Aug	Sept	Oct	Nov	Dec
IWV	4	2	4	5	17	32
ILW	83	79	64	54	51	53
τ (0.3)	100	100	100	100	100	100
τ (1.4)	100	100	100	100	100	100
τ (6.7)	100	100	100	100	100	100
τ (10)	100	100	100	100	100	100
τ (15)	100	100	100	100	100	100
τ (18)	100	100	100	100	100	100
τ (22)	49	38	40	48	74	87
τ (22.12)	45	34	38	46	73	86
τ (22.23)	40	31	36	42	71	84
τ (23.69)	72	61	55	62	83	93
τ (23.72)	73	62	56	62	83	93
τ (23.87)	77	68	60	66	85	94
τ (30)	97	97	91	94	97	99
τ (42.82)	86	81	65	64	72	78
τ (43.12)	84	77	62	61	69	75
τ (88.63)	7	4	5	6	23	33
τ (90.66)	7	4	4	6	22	33
τ (100)	3	2	2	3	12	24

Tab. 1.1 Monthly percentage probability (January-June) of parameter values being below specific threshold values: PWV (= IWV) < 10 mm, ILW = 0 mm (clear sky condition), atmospheric opacity $\tau < 0.15$ Np at various frequencies (GHz).

2 – Receivers at SRT

High frequency receivers are located in the secondary focus whereas low frequency in the primary focus. In the following figures and tables the list of receiver already available and under development.

Receivers in operation		
Receiver ID	Frequency coverage [GHz]	
	Min	Max
SRT P/L	0,305	0,410
	1,3	1,8
SRT Chigh	5,7	7,7
SRT K	18,0	26,5
SRT X/Ka	8,2	8,6
	31,85	32,25

Receivers under development / under evaluation		
Receiver ID	Frequency coverage [GHz]	
	Min	Max
SRT S	3	4,5
SRT Clow	4,2	5,6
SRT Q	33	50
SRT W (ex-IRAM)	84	116

Table 2.1 – Frequency coverage: (left) receivers in operation, (right) receivers under development.

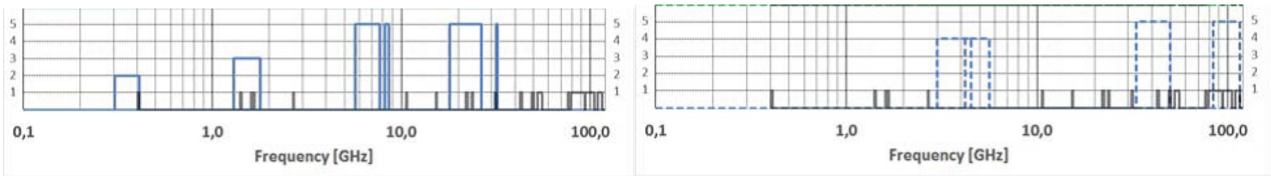

Figure 2.1 – (left) receivers in operation and (right) under development.

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
Two different parameters are generally used:

- SEFD (Jy), which is the ratio between the system temperature (K) and the antenna gain (Kelvin/Jansky). These two parameters describe the performance of the receiver and the characteristics of the antenna. SEFD does not include the instantaneous bandwidth of the receiver.
- Theoretical sensitivity, which is 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.

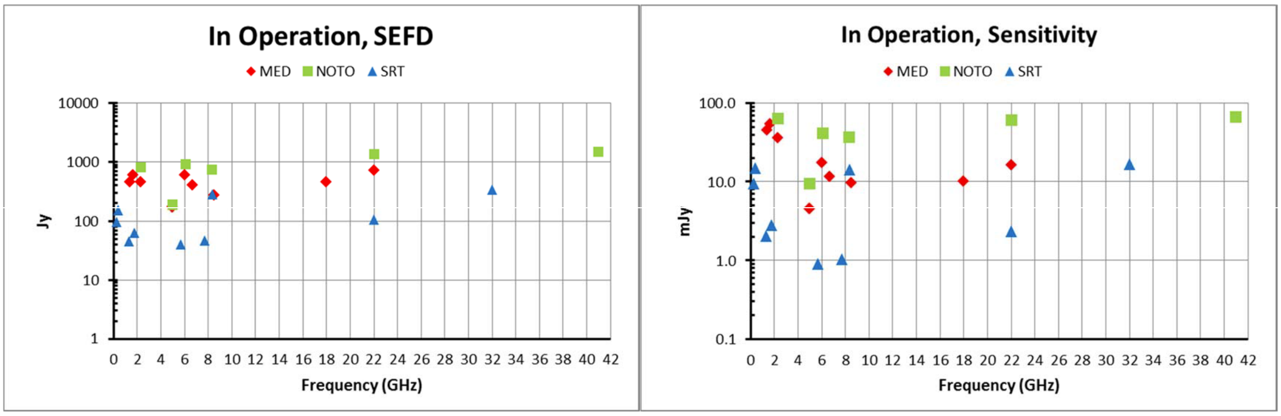

Fig. 2.2 – System Equivalent Flux Density (left) and sensitivity (right) for receivers in operation

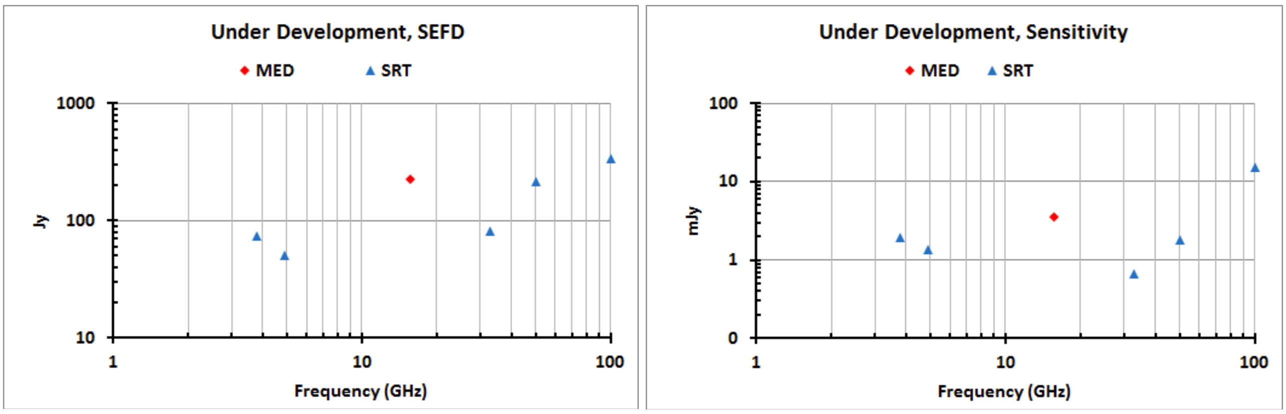

Fig. 2.3 – System Equivalent Flux Density (left) and sensitivity (right) for receivers under development

2.1 - Status of the receivers

The K-band receiver shows a bad reliability in some cryogenic Low Noise Amplifiers, recurrently repaired. Unfortunately, no spares are available so the intervention needs to dismount the component and wait for its recovery. This problem was waiting for a second release of LNAs, never put under production; this should have also solved an unexpected higher noise in the upper part of the band (25.5 to 26.5 GHz).

A major upgrade under consideration is to enlarge the instantaneous bandwidth in the K-band receivers up to the whole band available (8 GHz). This will be done providing sub-bands 1 GHz wide by using new down conversion boards.

2.2 - Back-ends

2.2.1 - 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.

Fast-switch

The fast-switch of the front-end calibration diode is a technique that permits gain variations in the receiving chain to be tracked. This allows the achievement of better data quality by improving the calibration. In order to support this feature, a back-end must be able to generate the pulse train to turn on and off the diode and to adequately treat the samples.

2.2.2 - 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. Currently SARDARA does not support fast calibration diode switching.

3 – 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 – Summary: capabilities of SRT and its exploitation for calibration source observations

SRT, with its optics configurations, offers the capability to observe sky sources with a resolution of ~ arcmin and with 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 can be scheduled starting from 2019, when operations at SRT are expected to resume after the planned shutdown and commissioning phases.
Among the polarized calibration targets for SRT we can include:

- Tau A (Crab Nebula)
- Cygnus A
- 3C274 (Virgo A)
- Cassiopea A

5 – References

1. M. Beltran, P. Bolli, M. Burgay, C. Contavalle, P. Marongiu, A. Orfei, T. Pisanu, C. Stanghellini, G. Zacchiroli, A. Zanichelli; National Institute for Astrophysics; “Receivers for Radio Astronomy: current status and future developments at the Italian radio telescopes”; Revision v5.3; 2017.