MILLIMETRIC SARDINIA RADIO TELESCOPE RECEIVER BASED ON ARRAY OF LUMPED ELEMENTS KIDS


2nd mm Universe @Nika2 28June-2July 2021 Sapienza University in Rome

Photo credits: Sergio Poppi / INAF Cagliari
OVERVIEW:

- Sardinia Radio Telescope
- MISTRAL instrument
  - cryostat
  - optic
  - detectors array
- schedule
- science case
- conclusion
SARDINIA RADIO TELESCOPE

Sardinia radio telescope, SRT Lat. 39.4930N - Long. 9.2451E, is a multipurpose instrument operated in either single dish or Very Long Baseline Interferometer mode.

Manufacturing started in 2003 and completed in August 2012. The technical commissioning phase to validate scientific performances was managed by National Institute for Astrophysics and concluded in 2014.

The Early Science Program observations started in 2016, and regular proposal in 2018.

Navarrini et al. https://openaccess.inaf.it/handle/20.500.12386/28787
SARDINIA RADIO TELESCOPE

Placed at 600m above sea level in Sardinia near Cagliari.

Estimation of sky opacity, based on recorded atmospheric data, forecasts [http://hdl.handle.net/20.500.12386/28787] <0.15 (50th percentile) at 93GHz during the winter nights. The PWV in the same conditions is mainly 8mm.

Green Bank Telescope \( \tau < 0.125 \) (50th percentile) @86GHz, and PWV<9mm (50th percentile) [https://www.gb.nrao.edu/mustang/wx.shtml]

50 years of radiosonde profiles taken at Cagliari airport (30Km far, at sea level) and scaled for SRT site shows PWV<11mm (50th percentile) and opacity <0.2 (50th percentile) at 100GHz. [Nasir et al. Exp Astron 29:207-225(2011)]
The antenna (M1) is fully steerable, 64m in diameter. Composed of 1008 aluminum elements controlled by electromechanical actuators.

M1 and M2 are shaped to minimize spillover and the standing waves between the feed and the subreflector.

An f/0.33 primary focus occurs near the M2 sub-reflector. 7.9m in diameter is composed of 49 aluminum elements. Its position can be changed for focus adjustment.

M1 and M2 are shaped to minimize spillover and the standing waves between the feed and the subreflector.


The gregorian focus, f/2.34 occurs around 20 meters below M2 in the **Gregorian room**.

MISTRAL will be placed in this room by using the gregorian focus of SRT.
Data resume:

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 primary mirror</td>
<td>64m</td>
</tr>
<tr>
<td>M2 sub reflector</td>
<td>7.9m</td>
</tr>
<tr>
<td>Primary focus</td>
<td>f/0.33</td>
</tr>
<tr>
<td>Gregorian focus</td>
<td>f/2.34</td>
</tr>
</tbody>
</table>

Pointing accuracy          2-13 arcsec  
Range in elevation         5-90deg     
Range in Azimuth           180+/−270deg

**Allocated space for MISTRAL experiment in Gregorian room:**

700MM X 700MM X 2400MM

Table 3. Microwave receivers installed and under construction for the SRT.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L- and P-band coaxial feed</td>
<td>0.305–0.410</td>
<td>F1</td>
<td>1 × 2</td>
<td>0.47–0.59</td>
<td>50–80</td>
<td>Commissioned</td>
</tr>
<tr>
<td></td>
<td>1.3–1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-band mono-feed</td>
<td>5.7–7.7</td>
<td>F3</td>
<td>1 × 2</td>
<td>0.64–0.70</td>
<td>24–28</td>
<td>Commissioned</td>
</tr>
<tr>
<td>K-band multi-feed</td>
<td>18–26</td>
<td>F2</td>
<td>7 × 2</td>
<td>0.60–0.66</td>
<td>40–70</td>
<td>Commissioned</td>
</tr>
<tr>
<td>S-band multi-feed</td>
<td>2.3–4.3</td>
<td>F1</td>
<td>5 × 2</td>
<td>0.76</td>
<td>54</td>
<td>Under construction</td>
</tr>
<tr>
<td>C-band (low) mono-feed</td>
<td>4.2–5.6</td>
<td>F4</td>
<td>1 × 2</td>
<td>0.62–0.70</td>
<td>30–35</td>
<td>Under construction</td>
</tr>
<tr>
<td>X- and Ka-band coaxial feed</td>
<td>8.2–8.6</td>
<td>F1</td>
<td>1 × 1</td>
<td>0.64</td>
<td>120</td>
<td>Under testing</td>
</tr>
<tr>
<td></td>
<td>31.8–32.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q-band multi-feed</td>
<td>33–50</td>
<td>F2</td>
<td>19 × 2</td>
<td>0.45–0.56</td>
<td>45–120</td>
<td>Under construction</td>
</tr>
<tr>
<td>W-band mono-feed</td>
<td>84–116</td>
<td>F2</td>
<td>1 × 1</td>
<td>0.34a</td>
<td>115</td>
<td>Under refurbishment</td>
</tr>
</tbody>
</table>

Note: The S band will have 7 feeds.

- **Q BAND**
- **W BAND** (16 BEAMS POLARIZATION SENSITIVE)
- **W BAND** (408 BEAMS)
- **K/Q/W BANDS** (1 BEAM POLARIZATION)

2019

2020

Note: the S band will have 7 feeds.
The cryostat has been provided by QMC. It is composed of two radiation shields at 40K and 4K cooled down by a pulse tube. Another shield, cooled at 1K by He4 fridge, surrounding the focal plane assembly. The detectors reach 250mK thanks to He6 fridge.
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MISTRAL: CRYOSTAT

Sumitomo RP-182B2S-F100H
1.5W @ 4.2K and 36W @ 48K
- remote valve
- air cooled
- 100m He lines [Coppolecchia et al. @LTD-19th]

Chase Twin GL10 fridge
2XHe3 251mK @20uW
(For focal plane)
He3 332mK @30uW
(For focal plane support)
He4 840mK @150uW
The experiment will change elevation several times during the observations. A magnetic shield surrounds the detectors, fridges, and relevant read-out parts to mitigate the earth's magnetic field effects.

The shield (1mm thick) is made of Cryoperm 10 with $\mu_r > 70000$
MISTRAL: OPTICS DESIGN

R1 = 293MM
K1 = -0.4
R2 = 450MM
K2 = -1.4
N = 3.4 @ 4K

COLD STOP:
125MM CIRCULAR APERTURE COATED WITH ABSORBER MATERIAL (I.E. ECCOSORB AN72)

R1 = 1304MM
K1 = 1.6
R2 = -556MM
K2 = 2.8
N = 3.4 @ 4K

FOV = 4′-> 94.4MM
FOCAL SCALE RATIO = 2.54″/MM

Anti reflection coating will cover each lenses surfaces

Credits: Marco De Petris
MISTRAL: OPTICS DESIGN

MISTRAL FOCUS

H-PSF avg in band
Field 0.0 arcmin
Strehl Ratio = 0.97
FWHM = 4.8mm = 12.2arcsec

Credits: Marco De Petris
MISTRAL: OPTICS DESIGN

MISTRAL FOCUS

H-PSF avg in band
Field 2.0 arcmin
Strehl Ratio = 0.91
FWHM = 5mm = 12.7arcsec
MISTRAL: DETECTORS

LEKID & WORKING PRINCIPLE

- Low temperature, fast, superconductive detectors;
- Cooper pair binding energy: $2\Delta = 3.52k_BT_c$;
- Radiation with $h\nu > 2\Delta$ can break Cooper pairs, producing a change in the population densities, and thus in the kinetic inductance, $L_k$.
- High-$Q$ LC resonators.

- In the resonator, the change in $L_k$, produces a change in the resonant frequency $\nu_r$, and in the quality factor $Q$.
- They can be sensed by measuring the change in the amplitude and phase of the bias signal, transmitted past the resonator through the feedline.

- High values of $Q$ allow to multiplex thousands of KIDs, with different $\nu_r$, all coupled to the same feedline.

Credits: Alessandro Paiella
MISTRAL: DETECTORS

HFSS ABSORBER DESIGN RESULTS

Optimisation Results:
- superconductor in Ti-Al bilayer 10 + 30 nm thick ($T_c = 945$ mK); [Catalano et al. A&A 580 A15 2015]
- Silicon substrate 235 μm;
- Front-illuminated 3rd order Hilbert crude absorber with backshort

![Diagram of absorber design results](image-url)
3mm X 3mm absorbers arranged on a equilateral triangle, with a side 4.2mm.
3mm X 3mm absorbers arranged on a equilateral triangle, with a side 4.2mm.

Credits: Alessandro Paiella
MISTRAL: DETECTORS
PIXEL ARRANGEMENT

3mm X 3mm absorbers arranged on a equilateral triangle, with a side 4.2mm.

Credits: Alessandro Paiella
MISTRAL: DETECTORS

Wband_GP1: 3\textquotesingle\, 5 pixel + feedline

Wband_GP2: 3\textquotesingle\, 31 pixel + feedline

MISTRAL_GP1: 4\textquotesingle\, 31 pixel + feedline

Prototype storyline

Credits: Alessandro Paiella, Giorgio Pettinari
MISTRAL: DETECTORS

- **Wband_GP1**: 3'', 5 pixel + feedline
- **Wband_GP2**: 3'', 31 pixel + feedline
- **MISTRAL_GP1**: 4'', 31 pixel + feedline

**Key Tests:**
- Electrical tests
- Electrical responsivity measurement
- Noise Equivalent Power as a temperature function
- Sensitivity to the magnetic field

*One order magnitude less of site background (considering unstable atmosphere)*

- Electrical tests
- Electrical responsivity measurement
- Noise Equivalent Power as a temperature function
- Sensitivity to the magnetic field

**Table:**

<table>
<thead>
<tr>
<th>Operation Temperature</th>
<th>150 mK</th>
<th>250 mK</th>
<th>300 mK</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFP dark [\mu W/\sqrt{Hz}] Avg.</td>
<td>41.5</td>
<td>280</td>
<td>520</td>
</tr>
<tr>
<td>Best</td>
<td>17.0</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>Worst</td>
<td>73.0</td>
<td>500</td>
<td>900</td>
</tr>
</tbody>
</table>

**Graph:**

- Phase Noise \[\mu W/\sqrt{Hz}\] vs. Frequency [Hz] for a temperature of 250 mK.
MISTRAL: DETECTORS

HOLDER DETAILS

- **4'' wafer**
  - Silicon
  - 235um thick

- **SubMiniature version A connector out**
- **SubMiniature version A connector in**
- **band-pass filter**
- **PELCO SEMClip™**
  - beryllium-copper alloy
  - 0.25mm thick

- **launcher connected, through superconducting (aluminium) bonds, to the wafer**

Credits: Alessandro Coppolecchia
MISTRAL: READ OUT

Roach2: FPGA system based, provided by Arizona State University, successfully used for OLIMPO
SCHEDULE

- **DESIGN**: August 2020
- **FABRICATION**: March 2021
- **INTEGRATION AND CALIBRATION**: December 2021
- **INSTALLATION @SRT**: January 2022
- **TOWARDS FIRST LIGHT**: March 2022

**TODAY**: March 2020
W-BAND HIGH ANGULAR RESOLUTION (SOON AT SRT)

**Galaxies**
- Spectral energy distribution
- AGN and radio galaxies
- Spiral galaxies continuum observation
- Mm-wave detection of circumstellar discs

**Medium**
- Dense core in giant molecular clouds
- Non thermal jet/hot spot

**Synchrotron**
- More and more, by correlating with other experiment

**S-Z effect**
- ICM Thermodynamics, mass profile
- Shocks, cold fronts
- Filament, Cosmic web
- Point sources
W-BAND HIGH ANGULAR RESOLUTION
(SOON AT SRT)

Observing with the Italian radio telescopes

Welcome to the Italian radio telescopes users' page
Here you can access all of the resources needed to achieve successful single-dish and extra-EVN interferometric observations

Contact us

Regular call is closed. Next deadline will be in October 2021.
Proposals for ToOs and DDT can be submitted anytime.
The offered instrumentation is listed here.
CONCLUSION:

• The Sardinia Radio Telescope (SRT) is a multipurpose observatory designed to measure a wide range of radio wavelengths: from 300MHz to 116GHz

• At SRT, the sky opacity in winter is $<0.15$ (50th percentile) at 93GHz

• MISTRAL will be coupled with SRT with a re-imaging optical system. The minimum spatial resolution (FWHM) is 12.2arcsec

• The 408 LEKIDs array has been optimised for best 90GHz absorption and for the background at SRT.

• MISTRAL scientific commissioning will start on January 2022
backup slides
Estimation of sky opacity, based on recorded atmospheric data, forecasts 

<0.15 (50th percentile) at 93GHz during the winter nights. The PWV in the same conditions is mainly 8mm.

Green Bank Telescope \( \tau < 0.125 \) (50th percentile) @86GHz, and PWV<9mm (50th percentile) [https://www.gb.nrao.edu/mustang/wx.shtml]
MISTRAL: DETECTORS

KID DESIGN & ELECTRICAL PARAMETERS

- Multiplexing factor $\propto Q_i > 50000$
- Dynamics $\propto \frac{Q_c}{Q_c + Q_i}$ ($Q_c \sim 20000$)
- Responsivity $\propto Q \sim 15000$

Credits: Alessandro Paiella
KID DESIGN & ELECTRICAL PARAMETERS

- Multiplexing factor $\propto Q_i > 50000$
- Dynamics $\propto \frac{Q_c}{Q_c + Q_i}$ $(Q_c \sim 20000)$
- Responsivity $\propto Q \sim 15000$
MISTRAL: DETECTORS

PRELIMINARY TESTS

<table>
<thead>
<tr>
<th>Operation Temperature</th>
<th>150 mK</th>
<th>250 mK</th>
<th>300 mK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NEP&lt;sub&gt;dark&lt;/sub&gt;</strong></td>
<td>Avg. 41.5</td>
<td>280</td>
<td>520</td>
</tr>
<tr>
<td>Best</td>
<td>17.0</td>
<td>110</td>
<td>180</td>
</tr>
<tr>
<td>Worst</td>
<td>73.0</td>
<td>500</td>
<td>1060</td>
</tr>
</tbody>
</table>

\[
\text{NEP}_{\text{ph,bkg}} = 5000 \text{ aW}/\sqrt{\text{Hz}}
\]


Credits: Alessandro Paiella
NEP_{ph,bkg} = 5000 \text{ aW/}\sqrt{\text{Hz}}
MISTRAL: DETECTORS

KID MAGNETIC FIELD SENSITIVITY

Credits: Alessandro Paiella
MISTRAL: MAGNETIC SHIELD

The simulations were performed with the strongest component of the geomagnetic field aligned with the cryostat optical axis.

Assumptions:
- $\mu_r = 70000$
- no aluminum holder around the detector
- no magnetic tape around the gaps

Credits: Fabio Columbro
MISTRAL: MAGNETIC SHIELD

The simulations were performed with the strongest component of the geomagnetic field aligned with the cryostat optical axis.

Assumptions:
- $\mu_r = 70000$
- no magnetic tape around the gaps

ATTENUATION FACTORS:
- RADIAL COMP. ~ 500
- OPTICAL AXIS COMP. ~ 3