Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Introducing the MeerKAT Telescope: Studies of masers and their environment

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Abstract. The 64-dish MeerKAT telescope was inaugurated in 2018 and has been conducting regular science operations since then. In the meantime, new observation modes have been under development. Spectral line modes are available, as well as L-, UHF- and S-band receivers. MeerKAT's excellent sensitivity over a wide range of angular scales makes it an excellent choice for studies of HII regions, supernova remnants and planetary nebulae. In addition, an OH megamaser has been detected at $z > 0.5$ for the first time.

Keywords. masers; radio lines: general; radio lines: ISM; radio continuum: general; techniques: interferometric

1. Introduction

The MeerKAT (Karoo Array Telescope) is a precursor to the Square Kilometer Array (SKA) consisting of 64 offset Gregorian dishes with a diameter of 13.5 m. It is located in the Northern Cape, South Africa, in a radio-quiet environment.

The initial science programme consists of 8 Large Survey Projects (LSPs), taking up approximately 67% of allocated observing time in the first $\sim$ five years, as well as yearly open calls for proposals and Director's Discretionary Time (DDT). A wide range of science interests can be addressed with MeerKAT, including star formation, galaxy evolution, transients and pulsar timing (Jonas et al. 2016; Camilo et al. 2018).

Discoveries of note to the maser community include a luminous mainline megamaser at $z > 0.5$ in J033046.20-275518 (Glowacki et al. 2022, and this volume) and satellite lines at $z = 0.89$ towards PKS 1830-211 (Combes et al. 2021). These are just the first results of the LSPs LADUMA (Blythe et al. 2016) and MALS (Gupta et al. 2016) and many more detections from these surveys and other projects are anticipated.

2. Key specifications

More details and updates on the telescope status can be found through `https://www.sarao.ac.za/science/` on the MeerKAT link.

2.1. *Receivers*

The antennas are equipped with dual linearly polarised receivers covering the UHF, L and S bands. Table 1 gives the key parameters of the telescope. The mean system-equivalent flux density (SEFD) is 550 Jy in UHF band, 425 Jy in L-band and 365 Jy in S-band. Sensitivity calculators can be found at `https://apps.sarao.ac.za/calculators`.

2.2. *Correlator modes*

Table 2 lists the available correlator channelisation modes. At the moment, narrow-band modes are only available for L-band. Please note that only the NE107M zoom mode,

Table 1. Key MeerKAT specifications. Note that for S-band the correlator can only process 875 MHz at a time, in one of 5 pre-defined sub-bands. The effective frequency range is narrower than the full digitized range.

Number of Antennas	64
Dish diameter	13.5 m
Minimum baseline	29 m
Maximum baseline	7700 m
UHF frequency range	580 - 1015 MHz [544 to 1088 MHz digitised]
L-band frequency range	900 - 1670 MHz [856 to 1712 MHz digitised]
S-band frequency range	1750 - 3500 MHz

Table 2. Correlator channelisation modes. Note that the filter roll-off for both narrowband modes is 13.5 MHz, thus 27 MHz of the band is not usable. The narrowband modes always run concurrently with the wideband coarse mode.

Mode	**Channels**	**L-band channel width (kHz)**	**UHF channel width (kHz)**	**S-band channel width (kHz)**
Wideband coarse (4K)	4096	208.984	132.812	213.623
Wideband fine (32K)	32768	26.123	16.602	26.703
Narrowband (NE107M)	32768	3.3	n/a	n/a
Narrowband (NE54M)	32768	1.633	n/a	n/a

with a usable bandwidth of $\sim$ 80 MHz has sufficient bandwidth to observe the 1612 MHz OH line simultaneously with the mainlines at 1665 and 1667 MHz. This mode gives a velocity resolution of $\sim$ 0.6 km/s at 1665 MHz. The recently commissioned NE54M mode, which has a usable bandwidth of $\sim$ 27 MHz, has a velocity resolution of $\sim$ 0.3 km/s. The full band (4096 channel) continuum data is recorded simultaneously with narrowband.

2.3. *Array layout*

The MeerKAT array layout is optimised for observations of low-surface-brightness objects with a 'core heavy' configuration consisting of a dense inner component containing 70% of the dishes. The outer component contains 30% of the dishes distributed in a 2D Gaussian uv-distribution, with a dispersion of 2500 m and the longest baseline of 7.7 km. This layout provides roughly uniform sensitivity for angular scales ranging from $8''$ to $80''$ (at L-band). The best spatial resolution that can be achieved at these frequencies is $\sim 4''$ (depending on declination), with $\sim$ 50% loss in sensitivity.

2.4. *Polarimetry*

The receivers have two orthogonal linear feeds. All polarisation products (XX, XY, YX, YY) are always recorded. While good results can be achieved over a limited field of view and frequency range (Cotton et al. 2020), calibration methods for widefield, wideband polarimetry are still under development (Sekhar et al. 2022) and potential users are advised to check the MeerKAT documentation† for updates. A fundamental issue due to the design of the receivers affects the polarisation leakage response across the field of view as a function of position in the primary beam as well as frequency (De Villiers 2023). This effect is much worse in the upper half of each receiver band, and it is advised to limit polarisation measurements strictly to the beam centre at frequencies above 1500 MHz in L-band. This means that detailed studies of maser polarisation and measurements of Zeeman splitting in OH masers are likely not feasible at this time unless the target is on boresight.

† `https://skaafrica.atlassian.net/wiki/spaces/ESDKB/pages/1481572357/The+MeerKAT+primary+beam`

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3. Potential applications

MeerKAT's sensitivity to a wide range of angular scales make it ideal to study diffuse extended structures such as supernova remnants, star forming regions and planetary nebulae. The MeerKAT 1.28 GHz Galactic Centre mosaic (Heywood et al. 2022) is a spectacular example of MeerKAT's imaging capabilities. This is a public legacy data release, and both images and the original visibilities are available to download‡. This dataset provides an opportunity to probe the radio environment of masers seen in this region. A legacy survey of the Galactic Plane covering $250^{\circ} < l < 60^{\circ}$, $|b| < 1.5$ deg (Goedhart et al. in prep) has also been conducted, and visibilities are available from the MeerKAT archive§.

While the MeerKAT correlator does not offer very high spectral resolution, the telescope sensitivity makes searches for new masers quite viable, with e.g. a naturally weighted noise of 5.8 mJy/beam in a single channel achieved in a 5 minute integration in the NE107M correlator mode or 8.3 mJy/beam in the narrower NE54M mode. MeerKAT can also observe Targets of Opportunity, either through regular proposals with well-defined triggering criteria, or through DDT proposals, providing an opportunity for multiwavelength follow-up of maser flares or accretion bursts as seen in Bayandina et al. (2022), for example.

4. Conclusion

The newly commissioned narrow band modes of MeerKAT offer a new opportunity to observe OH masers down to a velocity resolution of 0.3 km/s while the ability to simultaneously record wideband continuum data enables high dynamic range imaging of the maser environment.

MeerKAT's high sensitivity and UHF band receivers enable the detection of OH megamasers to unprecedentedly high redshifts.

5. Acknowledgements

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‡ https://doi.org/10.48479/fyst-hj47
§ https://apps.sarao.ac.za/katpaws/archive-search