e-MERLIN

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ABSTRACT

MERLIN is an aperture synthesis array of seven radio telescopes operating at centimetre wavelengths and spread across England with a maximum baseline of 217 km. The network is operated from Jodrell Bank Observatory and includes the 76-m Lovell Telescope. MERLIN pioneered the use of radio links to create a high-resolution network operating in real time, but these links now limit the sensitivity of the instrument. e-MERLIN is a major project to increase the bandwidth and hence the sensitivity of MERLIN by more than an order of magnitude. This increased sensitivity, together with the high resolution provided by the long baselines of MERLIN, will enable a wide range of new astronomical observations from young stars in our own Galaxy to the evolution of galaxies across the Universe.

e-MERLIN will have a bandwidth of 2 GHz in each polarization. Achieving this bandwidth has required the design and construction of new feeds, polarizers, amplifiers and IF electronics. New C-band (4-8 GHz) receivers have already been installed on several telescopes and the first observations of excited OH and methanol emission lines have been made at 6.0 and 6.7 GHz. A key part of the project is an optical fibre network connecting each of the five remote telescopes to Jodrell Bank. This fibre network has been installed and is now being commissioned. A new correlator is being built by DRAO Penticton, following the WIDAR design for the EVLA correlator. In order to increase the flexibility of e-MERLIN, new deployable lenses have been designed to allow rapid switching between frequency bands.

INTRODUCTION

With baselines of up to 217km, MERLIN provides cm-wavelength radio imaging at 10 to 150 mas resolution, spanning the gap between connected arrays such as WSRT and the VLA and VLBI arrays such as the VLBA and EVN. MERLIN has been very productive over the last decade in sub-arcsecond studies of protostars, evolved stars, novae, X-ray binaries, supernovae, starforming galaxies, AGN and gravitational lenses. However, the sensitivity of MERLIN is restricted by the relatively narrow-band microwave links which connect the telescopes to the correlator at Jodrell Bank Observatory. Heroic efforts with long integrations on deep fields such as the HDF-N have produced spectacular results and illustrate the potential science that is possible as the sensitivity is increased. Optical fibre connections between the telescopes and the correlator now offer a way to increase the bandwidth of MERLIN by more than two orders of magnitude and hence provide this much needed sensitivity increase.

The e-MERLIN project, which is tightly focused on this bandwidth upgrade, has been funded by The University of Manchester, the Northwest Development Agency, PPARC, the University of Cambridge and Liverpool John Moores University.

DESIGN GOALS

The e-MERLIN upgrade will increase the instantaneous bandwidth from the current 2 x 15 MHz to 2 x 2 GHz in order to gain sensitivity. In addition to the installation of optical fibres and associated transmission systems, this requires new or modified feeds and receivers, new IF and sampling equipment and a new correlator. New frequency bands are beyond the current scope of the project. However, a major enhancement to the operational flexibility of e-MERLIN will be achieved by converting the three E-Systems telescopes from primary to secondary focus operations at L-band. Any receiver on any of the telescopes (except the Lovell Telescope) will thus be selectable within one minute. The new correlator will support wide-field observations, spectroscopy with <1km/s resolution at L-band, and allow flexible tuning of sub-bands.

Table 1: Summary of e-MERLIN capabilities.

Band	Frequency (GHz)	Current sensitivity (uJy in 12 h)	e-MERLIN sensitivity (uJy in 12h)	e-MERLIN Surface Brightness (K in 12h)	Resolution (mas)
L	1.3 – 1.8	35	4.0	140	140
C	4 – 8	50	1.4	47	40
X (Proposed)	8-12	-	1.6	54	20
K	22-24	400	25	800	8

SCIENCE

This section gives a brief update of some key aspects of the original e-MERLIN science case, available at www.merlin.ac.uk/emerlin.

Gravitational lenses & Cosmology

MERLIN played a key role in the JVAS/CLASS survey [1] and *e*-MERLIN will be the ideal instrument with which to follow up these and other new lens systems to elucidate the mass structure of galaxies. The presence or absence of an 'odd image' is a diagnostic of the central mass distribution of the lensing galaxy. Galaxies are expected to have finite cores and therefore, in the absence of a central massive black hole, the strength of the odd image gives a measure of the true core radius. With very few exceptions [2], odd images have not yet been detected, implying either very small core radii or the presence of a central massive black hole. The sensitivity of e-MERLIN together with its 100-mas resolution will allow a search for odd images to a brightness level much fainter than images made with other instruments.

Star-formation at High Redshift

Using MERLIN and the VLA at 1.4 GHz to cover a 10 arcminute field around the Hubble Deep Field North, Muxlow et al [3] have detected 92 radio sources above a conservative threshold of 40 uJy at a resolution of 0.2 to 0.5 arcsec. The majority, which are associated with relatively bright galaxies in the redshift range 0.3 to 1.3, have been shown to be starburst systems with steep spectra. However, the X-ray emission which has been detected by Chandra from a substantial fraction of these sources appears to show the hardened characteristics of obscured AGN. e-MERLIN at 5 GHz could have the resolution and sensitivity to distinguish between the extended starburst emission and that from an associated, but obscured AGN. If so, it will have a major impact on the understanding of the relationship between starformation and active nuclei in these young galaxies.

The latest ACS GOODS (N) field overlies most of the MERLIN+VLA 10 arcminute field. A statistical investigation of the ~13,000 galaxies in the overlap region has shown that even at I=26 the majority of galaxies will be detectable at levels of 4 uJy. Thus a deep e-MERLIN+EVLA integration at 1.5 GHz should detect at least 2000 objects in a single pointing.

Nearby Starbursts

MERLIN has detected and resolved over 50 young SNR in M82 [4]. The youngest SNR is ~40 years old and VLBI observations have revealed an expansion velocity of ~10,000 kms^{-1}. The high sensitivity of e-MERLIN will enable the direct measurement of the expansion velocities and decelerations for a large number of the SNRs in M82. e-MERLIN will also be able to image SNRs in more distant starburst galaxies from which a full statistical study of SNRs in such objects can be completed. This should lead to a detailed calibration of the relationship between the overall radio properties and the starformation rate in these galaxies.

Stellar evolution in the Galaxy

Young high mass stars emit thermally at radio wavelengths even before they begin to ionise the surrounding ISM to form ultra-compact H II regions. Low mass YSOs are known to produce highly collimated jets, probably driven by magneto-hydrodynamic forces. However, although very collimated jets from high-mass YSOs are rare, they can usually be detected at cm wavelengths on MERLIN scales. At present it is unclear whether the dichotomy between jets and equatorial winds, and by implication magnetic and radiative driving mechanisms, is a function of evolutionary stage, mass, or initial conditions. Radio continuum mapping of large samples of YSOs with e-MERLIN and the EVLA should reveal which of these geometries is common.

IMPLEMENTATION

Receivers and Feeds

The new C-band system required the construction of new feeds, polarizers and amplifiers to work over a 4-8 GHz band. In fact, four new feed designs were required for the various telescopes which make up MERLIN. Left and right circular polarizations are extracted using a quadridge orthomode transducer (OMT) and a 90-degree hybrid coupler. The OMT has been designed at JBO and was a significant challenge in terms of its broad-band performance and the precision engineering required. The hybrid coupler, which uses high temperature superconducting materials, has been designed in conjunction with the Emerging Device Technology group at the University of Birmingham. The low noise amplifiers (LNAs), which use InP technology, have been adapted from a MPIfR design. A noise temperature of ~5K across most of the 4 – 8 GHz band has been achieved. A new cryostat has been designed and constructed to house the OMT, LNAs and coupler. Three of these new C-band systems were completed and installed last year and have been used to produce the first MERLIN images of interstellar methanol and excited OH emission at 40 milliarcsecond resolution. The remaining receivers will be installed this year.

The L-band receiver suite for e-MERLIN, which covers 1.3 – 1.7 GHz, required only minor modification although, in order to allow a rapid change between the C- and L-band receivers, a new lens, horn and lens mechanism has been designed for the three E-systems telescopes. The lens itself is a 1.7m diameter, 350-kg piece of polyethylene, cast and machined in sections. It can be swung into place and located at the millimetre level by a screw-driven carriage. All three lens mechanisms have now been installed and new lenses will be installed and commissioned later this year. New superconducting front-end filters will allow a single contiguous 400 MHz band and the new LNAs will reduce the overall system noise to ~30K.

The LNAs in the K-band receivers will also be replaced, possibly using MMICs designed as part of the EC-funded Faraday project. These will reduce the K-band system temperature by 30-50%.

IF and Digital Electronics

The e-MERLIN IF system has a common X-band IF (8.0-12.5 GHz). Subsequent downconversion from this to 2-4 GHz or 0.5-1 GHz for the 4Gs/s and 1 Gs/s samplers uses a second LO generated from the existing MERLIN synthesizers, which are very stable and return to the same phase after frequency switching. IF and LO switches provide the option of either observing two polarizations with the same 2 GHz band or one polarization with two adjacent 2 GHz bands.

The pulsed timing system, which operates at 1486 MHz over the microwave data transmission routes to lock the LOs and synchronise the clocks at each telescope to within a few picoseconds, will be retained initially. Methods of phase transfer over long distance optical fibre spans are being investigated.

There will be two pairs of samplers at each telescope: one pair at 1 Gs/s with at least 8 bits for observations with a bandwidth of 500 MHz or less and one pair at 4 Gs/s with at least 3 bits for full-bandwidth observations. The analogue IF system is now being prototyped in the lab and will be tested on a local telescope over the next year. The design for the sampler electronics is almost complete and a prototype board should be ready for test later this year.

Optical Fibre Connections

The data transmission network is the key to the sensitivity increase of e-MERLIN and the most costly part of the project. Since the telescopes are in rural locations, away from the fibre backbones which connect the main centres of population, over 80km of new fibre installation has been required. After an open commercial procurement, a solution was selected with a single contractor responsible for all the new fibre installation (Fujitsu Telecommunications UK). Dark fibres have been leased from three of the major UK data networks for a 15-year period in order to complete the connection from each telescope to Jodrell Bank Observatory. The installation of the new fibre sections used a combination of mole ploughing, where a 40-mm duct was ploughed directly into the verge; horizontal directional drilling, where a steerable drill was used to install typically 100-m lengths of 63-mm duct; and traditional trenching. The horizontal drilling was used to minimize environmental disruption and to tunnel under major and minor roads, rivers and canals. The routes mostly follow minor roads for typically 5 -30 km to reach the existing trunk fibres, which follow major road or rail routes. Installation of the new fibre began last June and was completed on schedule in April this year.

Optical amplification equipment has been installed at various co-location sites (Peterborough, Nottingham, Birmingham, Crewe) in the e-MERLIN optical fibre network and the links are now being commissioned. Almost all of the links have now been tested at 10 Gb/s and are well within the expected performance in terms of loss and dispersion.

The optical transmitter and receiver boards have been designed by colleagues at NRAO in a collaborative venture for the optical tramsmission systems for ALMA, EVLA and e-MERLIN. These will be incorporated into the first fully digital fibre links bringing data back to Jodrell Bank for the ‘first light’ tests next year.

Correlator

The correlator for e-MERLIN is being built by DRAO, Penticton (Canada) using the same WIDAR architecture as the much larger correlator being built by the same group for the EVLA. FIR filters split the 2 GHz input band into 16 x 128-MHz sub-bands each of which is separately correlated and integrated before being seamlessly stitched together. Correlation is carried out with 4-bit samples using correlator chips with 2048 complex lags, giving 0.25 MHz frequency resolution for each of the four polarization combinations. For e-MERLIN, 16 baseline boards, each usually allocated for the correlation of one sub-band for 8 x 8 telescopes will be used. DRAO are currently working towards having all components ready for integration of the first prototype correlator in Penticton in October this year. A 4-station prototype at Jodrell Bank is expected in Summer 2006 for ‘first fringes’.

Conclusion

The upgrade of MERLIN to e-MERLIN is progressing well and we are currently working towards achieving ‘first fringes’ with a new prototype correlator in Summer 2006. This requires the installation of a new IF system, 1 GHz sampler boards and the optical transmission system at two or more of the local telescopes. The longer distance links, requiring the regeneration system at Birmingham, should be fully commissioned towards the end of 2006 allowing wide-band commissioning observations with 4 telescopes including the longest baselines. The full correlator is expected in late 2007, by which time all the IF and 4 GHz sampler installation will be complete. Routine observations in all bands with all telescopes at up to 2 GHz bandwidth should be taking place in mid-2008.

References

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