Report of the eMERLIN review panel

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Executive Summary

eMERLIN will provide the UK with a unique and world-leading capability in widefield, high-resolution radio astronomy until at least the middle of the next decade. It will complement new facilities at other wavelengths providing critical information at centimetre wavelengths required to address many of the most important astronomy questions of the coming decade. As such, eMERLIN will play both an important role in the multi-wavelength approach required to address the high priority science goals of PPARC's astronomy programme over the coming decade. As a key component of the European VLBI network, eMERLIN will also contribute significantly towards maintaining the UK's leading role in European radioastronomy. By maintain/developing skills in radio astronomy engineering, eMERLIN will also further enhance UK's role in the design, construction and operation of next-generation of radio astronomy facilities, particularly the Square Kilometre Array. eMERLIN should be supported at level commensurate with a front-rank international facility. Additional resources required may be supported in part through new investment in SKA development, or via consortia assembled to conduct campaign science programmes on the facility. With modest initial investment, further operating efficiencies may be gained, without significantly increasing the 'whole of life' costs for eMERLIN over currently planned levels.

Background

With the operations support for the MERLIN/VLBI facility due for assessment in 2005, the MERLIN Steering Committee agreed it would be timely to initiate a Visiting Panel review of the current success and, in the eMERLIN era, the future capability of the facility in an international context. In particular the review would be asked to consider the operational and resource requirements necessary to maximize the impact of eMERLIN as it begins routine operation. The input and conclusions from the review would also be used as part of the PPARC Science Committee's own strategic discussions in late 2005. The full Terms of Reference for the review panel are shown at Annex A. The Panel membership is shown at Annex B.

1. The scientific role of eMERLIN

eMERLIN extends the current sensitivity of the MERLIN National Facility by more than an order of magnitude. At centimetre wavelengths, eMERLIN will deliver world-leading capabilities well matched to existing (or proposed) observational capabilities at other wavelengths to which UK astronomers (will) have access. These include the Atacama Large Millimetre Array (ALMA) in the submillimetre domain, the optical/near-infrared ESO and Gemini telescopes, and space facilities such as the James Webb Space Telescope in the mid-infrared. As such, eMERLIN will play both a unique and important role in the multi-wavelength approach required to address the high priority science goals of PPARC's astronomy programme over the coming decade. The

sensitivity gain of eMERLIN will also allow experiments of interest to the PPARC astroparticle physics programme (e.g. dark matter) and the solar system programme (e.g. planet formation).

The panel commends the eMERLIN community on the strength and breadth of the science case which addresses important areas including the formation of galaxies and black holes at high redshift, the formation of stars and planetary systems in our own galaxy, disentangling nuclear activity and star formation in the distant universe and providing a unique window into the study of high energy processes in extreme systems in the local universe. eMERLIN will build on the growing scientific impact on the current MERLIN facility. Since 1999, MERLIN has produced 50-60 refereed papers per year within a mean of 12 citations per paper. This compares favourably to the ISI citation average for astronomical sciences of 7 per paper for the period 1998-2002. MERLIN's oversubscription rate currently runs at just over 2, similar to other comparable radio astronomy facilities including the Australia Telescope Compact Array (ATCA) and the Very Large Array (VLA). This should increase further with the order-of-magnitude improvement in sensitivity enabled by eMERLIN.

The panel concludes that the science case will be sufficient to establish eMERLIN as a highly-productive and world-leading scientific facility until the middle of the next decade. Until at least the middle of the next decade, it will provide unique, deep (5μJy flux limit) wide-field (up to 10arcmin) imaging capabilities at centimetre wavelengths in the 50-1000milliarcsecond (mas) domain. eMERLIN will bridge the important gap in spatial resolution – and the one best matched to proposed facilities at other wavelengths e.g. ALMA and JWST – between the electronic Very Long Baseline Interferometer (EVLBI: resolution 1-10mas) and the Extended VLA (EVLA: resolution 500-5000mas). Beyond this period, the scientific competitiveness of the facility will depend on the progress of other next-generation instruments, including the Square Kilometre Array (SKA) and European VLBI Network (EVN).

The panel was encouraged to note the growth and diversity of the MERLIN user base. The vast majority (78%) of MERLIN principal investigators are now[1] from outside the University of Manchester, with 25% coming from other UK users and 53% from overseas. In total, researchers from over 50 institutes received time on MERLIN last year. This broadening of the demographic must continue if eMERLIN is to achieve its full scientific potential, and may be one of the criteria by which PPARC and Merlin Steering Committee (MSC) measures its impact within the UK programme. The panel was also encouraged to see the current high level of overseas use of eMERLIN.

To date, the eMERLIN team has performed exceptionally well against the original development milestones of the project. Nevertheless, the eMERLIN Project Management Committee should continue to monitor the project closely, particularly the major outstanding risk; the eMERLIN correlator. Further major upgrades, including any provision of X-band capability and the upgrade of the Defford telescope surface should be considered and evaluated at a later date, when all outstanding risks associated with the project as currently defined have been addressed.

If the project can be kept on track, eMERLIN will be commissioned 2-3 years ahead of the EVLA. This will provide eMERLIN with a major strategic advantage over ELVA, particularly in the early scientific exploitation of the 500-1500mas resolution domain. For example, early deep-field L-band observations with eMERLIN may solve the key question of the relative contributions of AGN and starburst emission to the faint radio population, thereby allowing UK-

[1] From semester 02A to date.

led teams to drive the agenda for subsequent observations with EVLA. The panel recommends that the MSC continue to ensure that the eMERLIN telescope maintains its advantages over the EVLA by focussing on the core elements of the eMERLIN project.

As part of the overall strategy of increasing its user base, the panel recommends that the MSC ask the eMERLIN Director to investigate the establishment of broadly based science consortia to propose and carry out some of the major eMERLIN survey programs. These consortia should be established in the near future, conducting any preparatory work required in order to realise the full scientific potential of eMERLIN as early as practical in its operational phase. The division between large consortia-driven programs and individual targeted programs may be left to the eMERLIN time assignment committee (TAC) to decide on the basis of scientific merit. TACs, guided by PATT have a good history of balancing the needs of large and smaller programmes on UK facilities and of monitoring the performance of consortia running multi-semester programmes[2]. The panel also recommends that the MSC may wish to develop an indicative 'year in the life of eMERLIN'; a potentially powerful tool in illuminating the nature, diversity and impact of the science programs which will be possible with the eMERLIN facility. A 'year in the life of eMERLIN' may also help clarify future operational models (see below) and their resource requirements.

The panel considers that an early science demonstration program with the prototype correlator in mid-2006 will play an important role in increasing the profile of eMERLIN. The panel recommends that the MSC develop such a program with the eMERLIN Director as soon as possible, with the aim of making the full dataset and quality-assured data products from this early programme available to the community before the full system is commissioned in 2007/08.

2 Strategic Context

The panel notes that investment in the development and build phase of the eMERLIN programme has undoubtedly contributed to the position where the UK is well placed in the early development of the SKA. MERLIN/eMERLIN is the UK's only national cm-wavelength radio astronomy facility and will undoubtedly continue to act as a catalyst for ongoing UK scientific/engineering engagement in the international SKA program. eMERLIN development is particularly relevant for the SKA in the area of data transport over optical fibres and the management of a geographically-distributed network. The impact of MERLIN/eMERLIN on the UK's role in the SKA is already evident; the MERLIN Director is currently chair of the International SKA Steering Committee, the UK has played a influential role in the development of the EU FP7 SKA design study (SKADS) proposal, and the 2PAD Focal Plane Array program, led by the University of Manchester, is likely to play a central role in the reference design likely to be adopted by the international SKA program in early 2006.

As outlined below, a major risk factor in the future operation of eMERLIN is the limited skill-base permitted by proposed funding levels. The panel notes that any broad national investment in UK SKA development activities may also assist the eMERLIN Director in maintaining the range of skills (through the pool of people available) and establishing a more distributed and efficient support network for the National Facility.

[2] Such programmes include the 2dF galaxy and QSO redshift surveys on the Anglo-Australian Telescope, the SCUBA survey programme on the JCMT and the wide-field imaging surveys on the INT.

The panel notes that the development of an 'intelligent' sensor network capable of automated fault-identification, self-diagnosis and repair is essential for the SKA; any investment in this area for the SKA would be strongly aligned with eMERLIN operations. Indeed eMERLIN may be seen as the test-bed for this technology, which has potential benefits to the SKA and beyond. A nationally coordinated approach to SKA technology development, potentially facilitated by the MERLIN/eMERLIN project staff, would also help strengthen the UK's technology position within the international SKA project, and the panel commends the MERLIN Director's proactive approach. The panel recommends that the MSC continue to encourage the MERLIN Director to facilitate an open dialogue between potential University, institutional and industrial partners aimed at establishing a UK technology grouping (virtual or otherwise) associated with cm-wavelength radio astronomy developments. The panel noted the strong synergies between the eMERLIN program and the European VLBI network (EVN). eMERLIN will add significant science capability to the EVN, providing important coverage in the u-v plane and affording a factor of 10-30 larger bandwidth than the EVN, The panel strongly recommends to the MSC that eMERLIN should operate in tandem with the EVN when the EVN is scheduled at an eMERLIN frequency. Once eMERLIN is commissioned, funds should also be sought to provide full cross-correlation of the eMERLIN and EVN antennas.

The panel notes that the eMERLIN correlator is a next-generation version of the present EVN correlator, again providing the UK with important expertise in the implementation of this digital technology relevant to the SKA.

3 The eMERLIN Operational model

3.1 Staff profile

Current MERLIN operations are only sustainable at present staff levels (25.75FTE) with access to the broader skill base (6.25FTE) enabled by the eMERLIN build and development. At this level of resourcing, a quarter of MERLIN's work-force is identified as 'single-point' failures. Down time due to technical failures is also high (15%) and is directly attributable to the current resourcing levels. Having considered the current skills base available, the proposed operational environment and the facility reliability statistics, the Panel strongly recommends to the MSC that a level of 32 FTE as outlined in the eMERLIN's future planning document is the minimum required to provide both the necessary staff numbers and full range of skills to operate the eMERLIN facility. The panel notes that the area in which eMERLIN will suffer the greatest skill gaps is digital system engineering.

An enhanced level of staffing is not only needed to mitigate the risk of any a significant blow out in the level of technical downtime caused by lack of skills, but more importantly, to ensure an appropriate occupational health and safety environment for staff. Under the current MERLIN operational procedures, it is also likely that the EU's Working Time Directive would be violated unless staffing levels are raised to 32 FTE. The panel notes with great concern that many University personnel may be currently violating such directives in support of MERLIN operations, but that it is, as yet, untracked since these personnel do not log their effort. The panel urges the MSC to consider the introduction of effort logging for all staff involved in MERLIN operations as soon as possible. This will enable the eMERLIN Director to monitor and track, and if necessary, take remedial action on this issue.

There are significant operational overheads in MERLIN/eMERLIN from the geographically distributed nature of the antennas. The panel notes that the MERLIN Director has already

expended considerable effort to identify opportunities for a distributed support model, with mixed success to date. The panel endorses the approach that the MERLIN Director to continue to seek opportunities to support antennas via local expertise, wherever possible. This would not only yield greater operational efficiencies, but mitigate safety risks caused by travelling.

The panel notes that the MERLIN Director will achieve some staff saving in administration through the move to offices located in Manchester and further cross-support from the University. The panel also notes that the projected level of support from the University of Manchester for the eMERLIN program (approximately 15 FTE largely for Lovell Telescope support) is already significant and unlikely to be increased further.

The panel also notes that the current staffing level for eMERLIN is 30-50% below that of other comparable radio astronomy National and International Facilities (ATNF, VLA, IRAM) even when the University of Manchester staff dedicated to Lovell telescope operations are included. Against this international benchmark even a modest increase to 32 FTE delivers a very lean support structure.

The panel acknowledge that this additional staff effort represents a significant increase (£360k p.a.) in the operational support for eMERLIN over current MERLIN levels. Elevated levels of investment in SKA developments in the coming years may help reduce this figure by sharing skilled staff with eMERLIN. This is particularly likely in the area of high-speed digital electronics. Indeed, in the same way the eMERLIN investment has helped deliver the minimum required skill-base for MERLIN operations over the past five years, so may SKA investment help provide that skill base for eMERLIN over the coming decade. Given the tendency for day-to-day operational requirements to take precedence over longer-term development work, such a model would only be practical if the boundary between eMERLIN operations and SKA development could be clearly delineated and managed. The success of the current eMERLIN development program existing concurrently with MERLIN operations provides adequate demonstration that such a model is workable in practice.

Furthermore, the panel note that 32FTE minimum staff level falls below the optimum level to fully realise the scientific potential of eMERLIN. The panel recommends to the MSC that further staff resources (3-4 FTE) are invested in the areas of user support and data analysis/archiving. This may be achieved by direct investment in additional facility staff, or possibly through in-kind provision of staff effort from the consortia established to facilitate major survey programs as suggested above. The latter approach has the advantage that any additional resources are specifically targeted to delivering the science of key programs. In the past, science consortia have successfully developed and distributed sophisticated data-handling tools and data management systems, based on their own exploitation of their survey data. This has provided improved facilities for the entire community, as well as supported the timely release of well-analysed datasets[3].

3.2 Direct costs

The panel notes that the proposed direct (i.e. non-staff) operational costs of eMERLIN also exceed the current MERLIN operating costs by £300k p.a. The bulk of this is due to new fibre

[3] The 2dF galaxy and QSO redshift survey consortia provided at least 5DSY in the development of their publicly-available archives and interrogation/analysis tools following data release.

maintenance costs (£225k p.a.). The panel recommends to the MSC that the maintenance costs be found to sustain eMERLIN. The panel notes that progress has been made to achieve savings in areas recommended by the Wade review (e.g. more reliable electronic systems and receivers, the introduction of new disk-based VLBI systems). Two further areas of potential savings identified during the Wade review of 2001 have not yet been implemented. First, savings due to the removal of the microwave link systems. This may be possible by implementing the L-band link over fibre (LBLoF), saving on site rental for the microwave links. The net saving from this would amount to £1M over the proposed 10-year lifetime of the eMERLIN facility, for a proposed initial capital outlay of £100k. Moreover, it would mitigate against the high-probability risk of a significant increase in rental costs over the period of eMERLIN operations. The panel recommends to the MSC that the LBLoF program should proceed to concept design phase as soon as practicable, without impacting on the delivery dates of the initial eMERLIN system. Second, the painting of the telescopes with a modern paint system prior to commissioning would remove the need to paint again during eMERLIN's proposed 10-year lifetime (current costs £10k p.a. and the loss of 1 month/yr observing time). The panel recommends to the MSC that eMERLIN should investigate the feasibility and cost of painting the antennas with a modern paint system. With both these savings in place, the non-staff operational costs would reduce to £810k p.a.

The panel considers the current level of downtime, three months per year, to be not only uncompetitive with comparable facilities, but also to be incompatible with eMERLIN's proposed aim to be a world-leading facility. With the enhanced staff complement and any savings made in the painting schedule, the panel request that the MSC, with the Director, develop an operational plan which has, as a goal, a total stand-down period of no more than six weeks per year. Over a ten year scientific lifetime of this facility, this would return a net gain (or potential saving) of 1.5 years, or an opportunity cost of approximately £4.5M over the currently proposed ten-year operational lifetime of eMERLIN. By reducing the downtime, the total lifetime required to complete the eMERLIN science program is reduced so that the 'whole of life' cost for eMERLIN remains constant. The panel therefore recommends to the MSC an enhanced investment model to expedite the delivery science results, while also affording the opportunity for eMERLIN operational resources to be reprioritised on the 2016/17 timescale to SKA pathfinder operations. The Panel recommends that the operational plan for eMERLIN should include a significantly higher level of access to the Lovell Telescope. That level of access should be determined by the scientific needs identified by the eMERLIN TAC, but the improved abilities of the LT at C band suggest that PPARC should plan for a significantly (greater than 50%) higher usage of the LT than in previous years. The Panel acknowledges that any increased access charges negotiated between PPARC and the University of Manchester may erode (at the 10% level) some of the savings identified above.

Annex A

Terms of Reference for the PPARC Review of future *e*-MERLIN/VLBI operations and the future direction of the National Facility

The MERLIN Steering Committee wishes to set up a Visiting Panel to review the operations of the *e*-MERLIN/VLBI National Facility and to provide recommendations on how best to maximise the scientific return and impact of the facility as routine operations with *e*-MERLIN begin and as the technical capability of VLBI increases.

The Visiting Panel should consider the current and future capability of the facility within the context of other radio astronomy developments worldwide, in particular the Square Kilometre Array (SKA), and the UK community's ambitious plans to play a leading role in this project.

The Visiting Panel is asked to:

1. Assess the role of the facility into the next decade and the likely impact of *e*-MERLIN and VLBI science alongside its international competitors.

2 Consider the operational and funding framework required to ensure maximum scientific return from the *e*-MERLIN project.

3 Comment on options for *e*-MERLIN under alternate financial scenarios to those proposed above.

With respect to points 1-3 above, the Panel should:

i Make recommendations on the level of support (including the funding regime, staff effort and access to the Lovell Telescope), required to deliver the scientific objectives;

ii. Consider options for maximising early science impact with *e*-MERLIN;

iii Assess whether the current and proposed levels of support from PPARC for National Facility operations will allow the National Facility to provide a leadership role, at both the UK and International level, in the planning and development of the SKA project.

4. The Visiting Panel will report and make recommendations to the MERLIN Steering Committee, to guide PPARC in its strategic planning. The final report should be submitted to the MERLIN Steering Committee and the Director MERLIN by 31 July 2005.

5. The Visiting Panel shall comprise a Chair and up to four members, including at least one international representative. PPARC will provide administrative support as required, but it is expected that that the Panel will be responsible for drafting its own report.

Annex B

Review Panel membership:

Professor Brian Boyle – (Chair, Director ATNF, Australia)
Professor Mark Birkinshaw (Bristol, UK)
Dr Mark Reid (CfA Harvard, USA)
Professor Steve Rawlings (Oxford, UK)
Professor Rene Vermeulen (ASTRON, NL)