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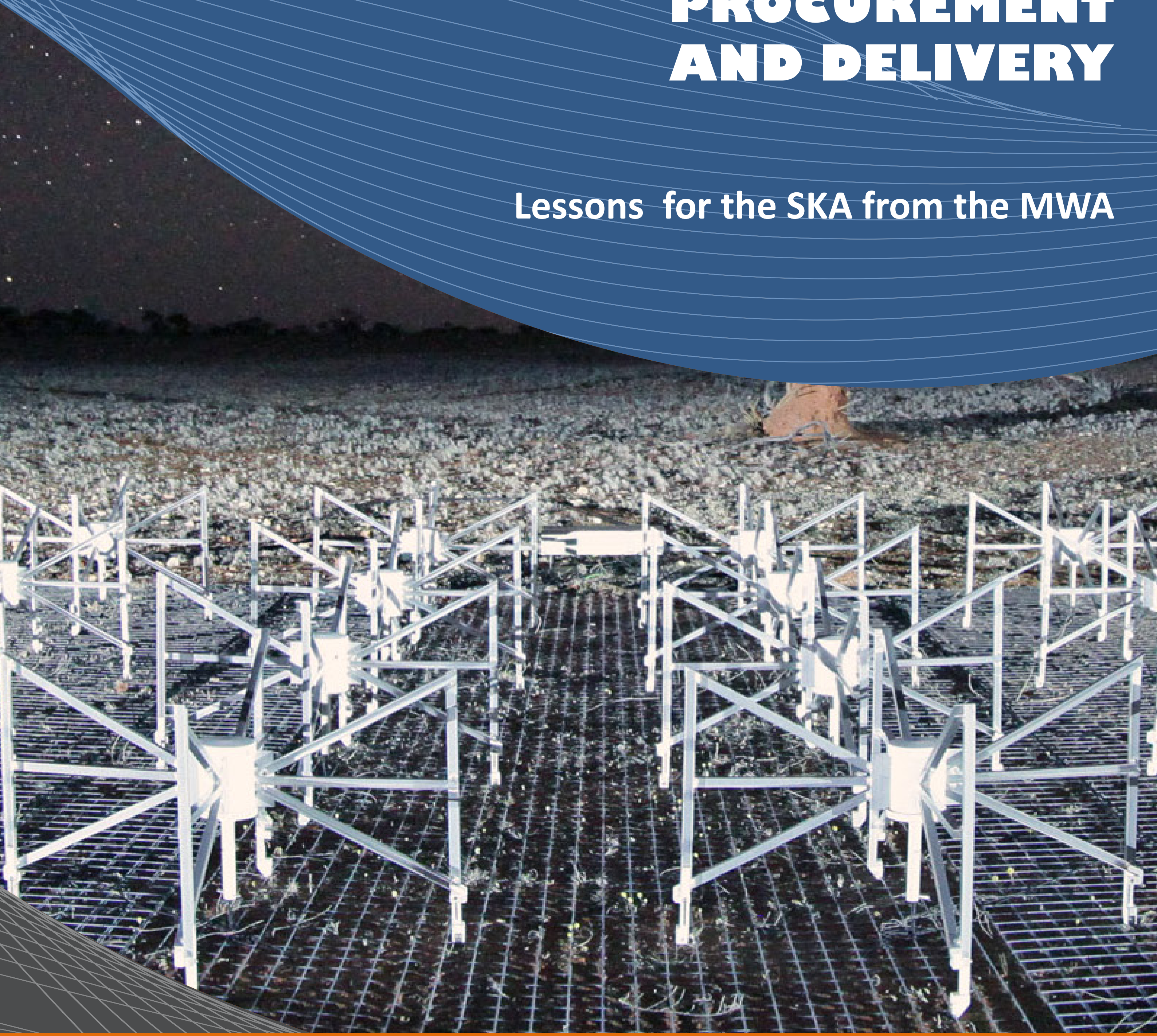
BEING EARLY, FLEXIBLE AND PRESENT IN PROJECT DESIGN, PROCUREMENT AND DELIVERY

Lessons for the SKA from the MWA



BY MWA PROJECT MANAGER - Tom Booler - February 2013

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CRICOS Provider Code 003001J (WA)
02637B (NSW)

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The central high density core of the MWA

INTRODUCTION

In May 2012 Australia was named joint host—with New Zealand and Southern Africa—of the Square Kilometre Array (SKA). The SKA will be the largest, most capable radio telescope ever constructed and will be delivered by a collaboration of more than sixty organisations representing over 20 countries. Originally conceived in the early 1990s, the SKA project is only now reaching the critical mass (in terms of resources and enabling technologies) required to overcome the unprecedented challenges inherent in its design and construction.

Australia is among the vanguard of nations blazing the trail to the SKA. The Murchison Widefield Array (MWA)—a collaboration between 13 institutions in four countries led by Curtin University—is one of just three official SKA precursor instruments. An aperture array operating in the 80-300 MHz range, the MWA is the only official precursor to the low-frequency segment of the SKA (SKA-low) —a segment that will be built in Western Australia. The MWA is located at the Murchison Radio Astronomy Observatory (MRO), Australia's SKA core site.

The MWA has confronted many of the critical challenges that lay ahead of the SKA, albeit on a smaller scale. The successes, failures and lessons learned by the MWA represent a valuable resource to the local and international team that will ultimately be charged with delivering on the promise of the SKA. The purpose of this document is to record and share some of the key lessons from MWA, in order that individuals and organisations that aspire to contribute to the success of the SKA might have the benefit of MWA's experience.

MWA
MURCHISON
WIDEFIELD
ARRAY

Gurlgamarnu

Bottom line up front

The key messages of this document are:

- Infrastructure will be a cost driver of SKA-low and should be considered a discrete sub-system and not just an enabler.
- Infrastructure design and deployment should be addressed early and inform/influence/constrain the design/scale of the instrument—the reverse represents an unacceptable, program level, cost risk.
- Minimise dependencies and serial scheduling, and maximise parallel activity to provide schedule and program flexibility.
- Prototyping and incremental deployment reduce program risk by informing subsequent activities, providing invaluable empirical data and experience, and enhancing program flexibility.
- Clearly articulated and agreed lines of authority and decision making responsibility are crucial to maintaining program progress.
- Understand program level risks and always have a robust, costed ‘Plan B’.
- Concentrate scarce personnel resources proximate to the site so as to ensure that planning and development is informed by the environmental context.
- Be conservative in planning, forecasts and contingency—better to under promise and over deliver than to be judged a failure when measured against optimistic or aspirational targets.
- Local SMEs represent a rich resource. They offer directly relevant and specific insight—particularly with respect to the environment—and have the capacity to add real value.
- Open, collaborative relationships produce positive outcomes and are practical to establish with SMEs.
- Local SMEs are, as a function of their structure and nature, well placed to be more flexible and responsive than larger organisations.

WHAT IS THE MWA AND WHAT DOES IT HAVE TO DO WITH SKA?

The Murchison Widefield Array (MWA) is a joint project between an international consortium of universities to build and operate a low-frequency aperture array in the frequency range 80-300 MHz. The MWA is a new type of radio telescope. With no moving parts, it utilises prodigious computer power to create wide-field images of the radio sky. All of the telescope's functions, including pointing, are performed by electronic manipulation of the signals received by stationary receiving elements.

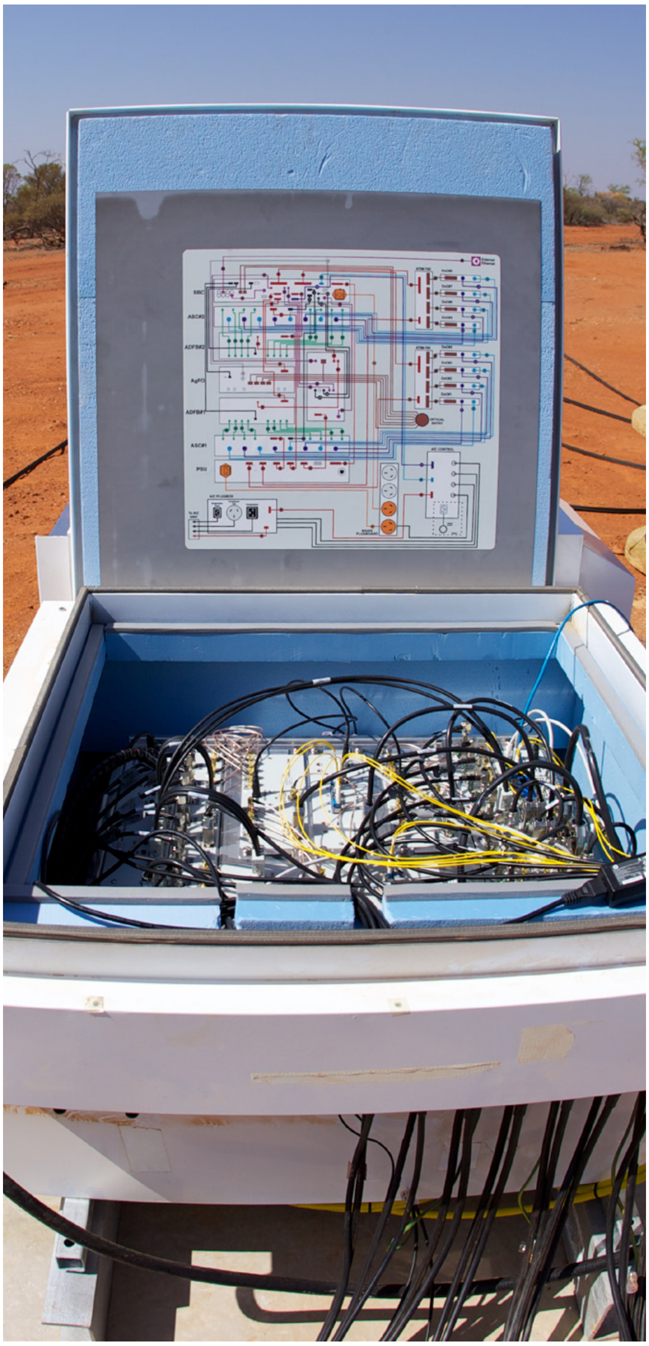
The MWA is located at CSIRO's Murchison Radio Observatory (MRO)—the site that will host the low-frequency element of the Square Kilometre Array (SKA)—situated in the radio-quiet Murchison River Catchment of Western Australia's Mid-West region.

The MWA consists of 2048 dual-polarisation dipole antennas (4096 effective receiving elements) optimised for the 80-300 MHz frequency range, arranged as 128 "tiles"—each a 4x4 array of dipoles—forming a high fidelity imaging array. The majority of the tiles are scattered across a roughly one kilometre core region, forming an array with very high imaging quality, and a field of view of several hundred square degrees at a resolution of several arc-minutes. The remaining tiles are positioned at locations outside the core, yielding baseline distances of up to three kilometres to allow higher angular resolution.

The main scientific goals of the MWA are: to detect neutral atomic hydrogen emission from the cosmological Epoch of Reionisation (EoR); to study the Sun, the heliosphere, the Earth's ionosphere; and to study radio transient phenomena. The MWA is the first so-called large-N array, fully cross-correlating the signals from the 128 tiles of 16 crossed dipoles (each).

The MWA is the only low-frequency SKA-precursor instrument located on an SKA site. It is a fraction of the size of the SKA-low, comprising only 4096 collecting elements dispersed over an area of approximately ten square kilometres. However, the MWA and SKA-low are derived from common theoretical lineage and can be decomposed to the same functional component set.

The construction of the MWA therefore offers valuable insight into the challenges that must be overcome in order to establish the infrastructure needed to support SKA-low.



WHAT DID THE MWA LEARN?

Infrastructure lessons

One of the principle objectives of the MWA is to demonstrate the validity and utility of a software defined instrument. The MWA's receiving elements—its 2048 dipole antennae—are fixed in position. They do not move. The instrument's functions, including 'steering' the beam on the sky, are achieved by electronic manipulation of the signals received by the static receiving elements. This is in contrast to the traditional dish-based arrays, where the dish itself is a mechanical beamformer and requires mechanical steering to point on the sky. This is a fundamental difference between low frequency dipole arrays and dish-based arrays.

One of the benefits of this approach to the design of radio telescopes is that the 'front-end' of the instrument, its collecting elements, can be relatively simple and cheap. This means that the investment of resources can be concentrated further up the signal chain, in the 'back-end' of the data handling and processing systems that enable the scientific exploitation of the signals collected.

Linking the front-end collecting elements and the back-end processing systems requires a high capacity data network capable of delivering information over long distances with precision (timing distribution and accuracy) and integrity (low network-generated error rates and robust error identification and handling). A power distribution network, deployed in parallel, is required to support the collection and transport of signals—information— throughout the network.

In the SKA-low, as for MWA (Figure 1), the infrastructure cost will likely exceed, by far, the cost of the instrument front-end. Given that the infrastructure represents the principle cost driver of the fielded component of the system, it is appropriate to consider it as a sub-system in its own right and a 'platform' for a flexible instrument.

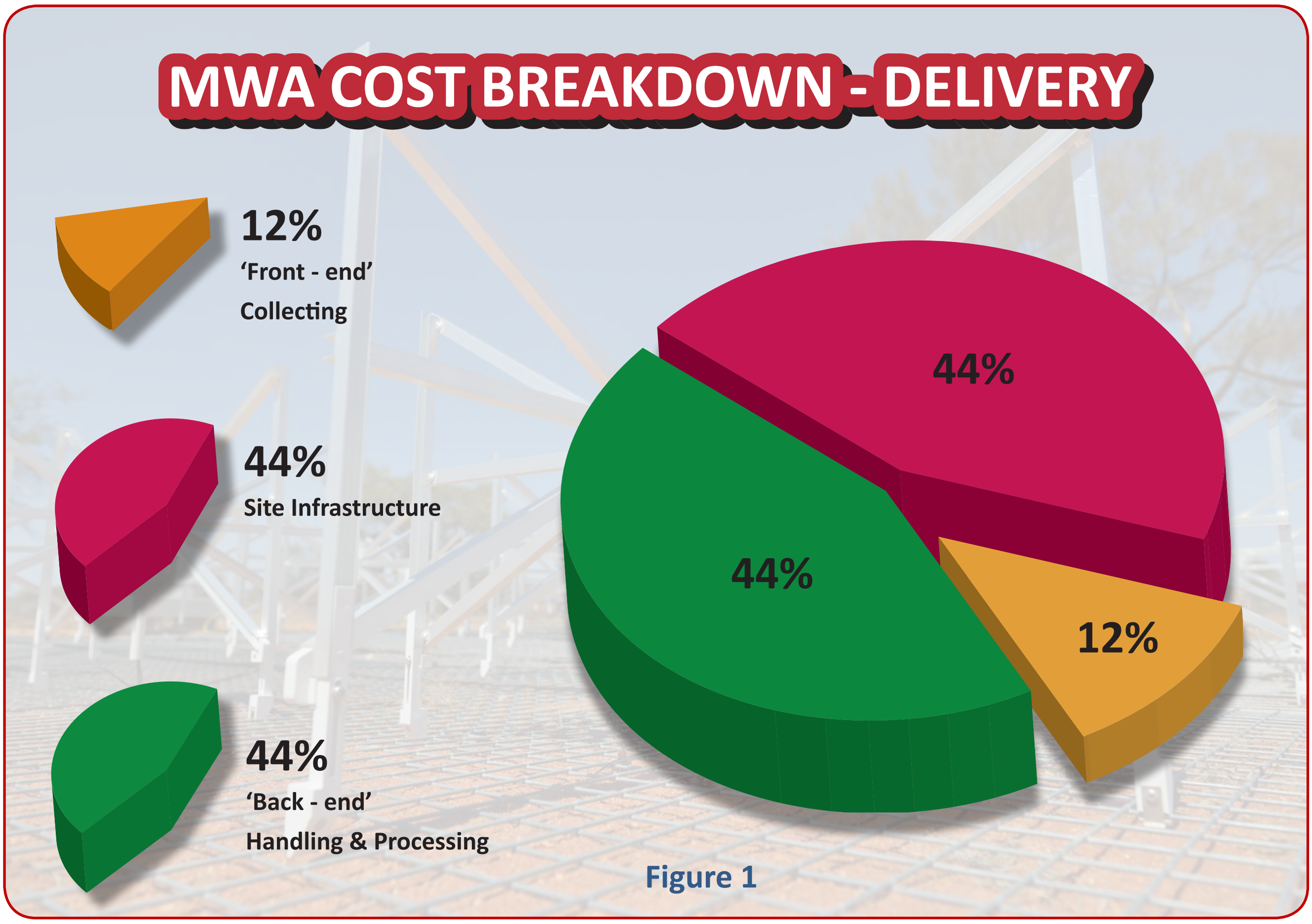


Figure 1

The core of the low-frequency component of the SKA will be constructed on the MRO in the remote Mid-West region of Western Australia. The low-frequency aperture array will comprise millions of collecting elements dispersed over an area of thousands of square kilometres. The signals collected by these elements need to be accurately and reliably transported over long distances to a central processing facility. The scope and complexity of the data and power network infrastructure required to facilitate this is unprecedented in a remote setting such as the MRO.

There are substantial overhead costs associated with construction in remote locations like the MRO. For example, the civil component of the MWA site works program—principally trenching and the laying of electrical and fibre optic cable—cost in the order of $900,000. To complete the same work in Geraldton or its immediate surrounds (for example) would have cost in the order of $200,000 [1]. This disparity reflects the fact that the logistics of supporting operations and a workforce dislocated from support services by several hundred kilometres are expensive. Furthermore, as these costs increase as a function of time, they represent a major source of cost risk. Controlling the cost (including procurement and deployment) of the network and power infrastructure will be critical to delivering SKA efficiently.

The MWA experience provides a compelling cost-based argument for addressing infrastructure requirements early in the SKA preconstruction phase. Through most of the MWA design phase it was a given that the array would comprise 512 tiles. Over time, a great deal of intellectual effort and resources were applied to determining exactly how these 512 tiles should be arrayed on the ground to optimise the instrument's capabilities. It was only after these questions had been settled that the infrastructure required to support the proposed array layout was considered.

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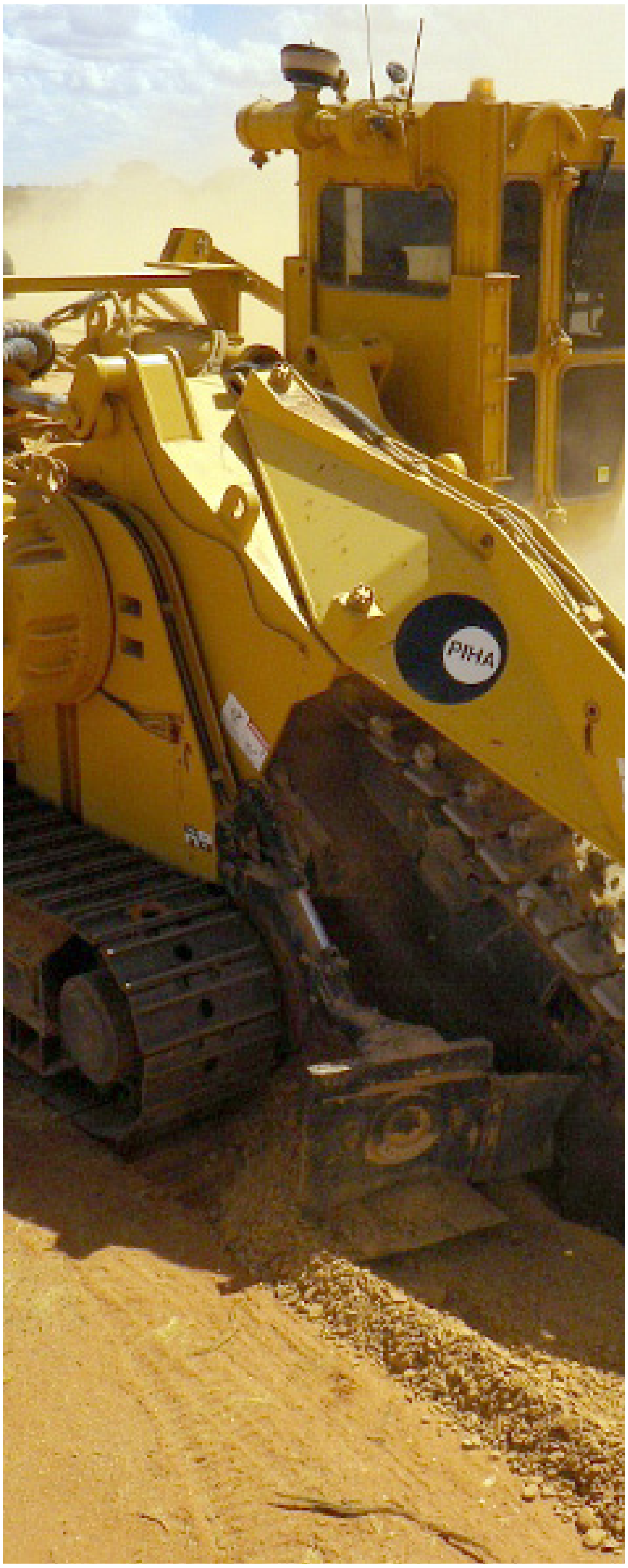
[1] Estimate based on empirical data provided by MWA's infrastructure contractor, GCo Electrical.



The MWA Project Team was proactive in trying to manage the risks inherent in the site infrastructure works. Having had the opportunity to observe and learn from the CSIRO’s (very recent) experience in deploying the infrastructure for the MRO and ASKAP Projects, MWA was well informed as to the challenges associated with the scope of work and the site. As part of this proactive approach to risk awareness and management, the same engineering firm that designed and procured the MRO and ASKAP infrastructure was engaged to design and procure the MWA’s.

When the work package to deliver the MWA site infrastructure required to support 512 tiles was competitively tendered, the prices submitted by prospective contractors were more than double the cost estimates provided by the engineering firm and well in excess of the project budget allocated for the purpose. The Project Team was forced to undertake a de-scoping and cost balancing exercise that resulted in a down-sized infrastructure, capable of supporting up to 200 tiles, with 128 tiles actually deployed—one quarter of the instrument envisioned before its infrastructure had been taken into account.

Infrastructure will be a significant cost driver of SKA-low. The experience of the MWA design and delivery illustrates the difficulties in costing infrastructure on a remote site in a competitive and dynamic market. To defer consideration of infrastructure until after an aspirational instrument has been designed—unconstrained by reality— is folly. From a cost perspective, to constrain the size of the instrument by first establishing the capacity of the infrastructure is a far more prudent approach than attempting to grow the infrastructure to fit the aspirational instrument.

Key Messages

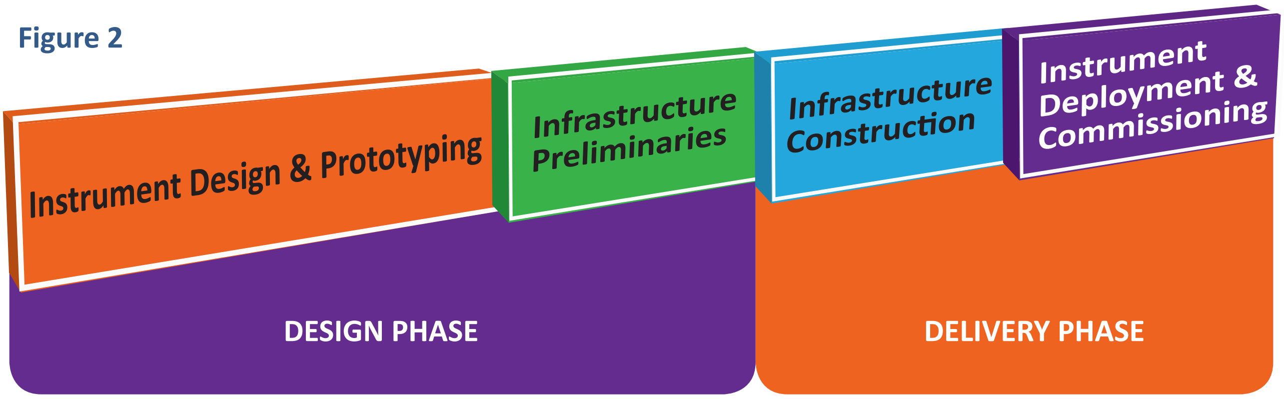
- **Infrastructure will be a cost driver of SKA-low and should be considered a discrete sub-system and not just an enabler.**
- **Infrastructure design and deployment should be addressed early and inform/influence/constrain the design/scale of the instrument—the reverse represents an unacceptable, program-level, cost risk.**

Program lessons

The MWA delivery schedule was a function of a variety of external influences and dependencies. Faced with a non-negotiable, externally imposed deadline the MWA Project Team was forced to adopt a reactive management model—adapting to developments in the project as they presented, in order to maintain momentum and ensure the integrity of the overall program. The structure of the MWA delivery schedule should serve as a cautionary tale to the SKA. Equally, the focus and agility demonstrated by the MWA Management Team is a model of what will be required of those charged with delivering the SKA.

The MWA Project was conducted as a serialised sequence of discrete activities as described in Figure 2.

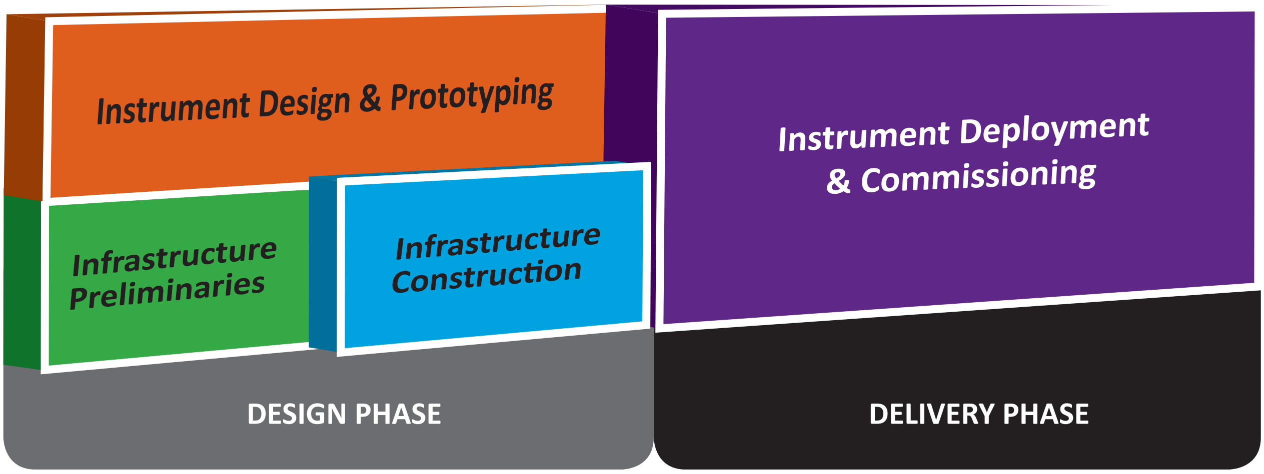
Figure 2



In this serialised model, finalisation of the instrument design was a pre-condition for the start of the other activities that needed to occur. With a finite timeline for completing the project, the longer the instrument design takes, the less time is available to complete the remaining project activities. The infrastructure required to support the MWA instrument was not considered in detail until late in the design phase. The Project Team's focus on the development of the instrument, to the exclusion of site related considerations resulted in a delivery program where the many complex processes involved in delivering the site infrastructure were compressed and sub-optimal.

The parallelisation of phases, where feasible and appropriate, is an effective way of building flexibility into a project schedule. Had work commenced on infrastructure activities in parallel with the instrument design process, as described in Figure 3, the MWA schedule would have included far more flexibility to accommodate the risks and leverage the opportunities inherent in the design and construction of the site infrastructure.

Figure 3



Substantial program benefits were realised when the MWA schedule did utilise parallel activities. The establishment and operation of a prototype array in parallel with the later stages of instrument design and development yielded dividends across a range of program elements. The prototype array—consisting of components that were, functionally, relatively mature but not production ready or environmentally packaged—allowed the functional design of the instrument to be validated before the project committed to large scale component production. System, sub-system and component performance was able to be tested and characterised in context—in the field and under the environmental conditions in which the instrument must operate.

Operating and maintaining the prototype array also provided invaluable experience for the personnel charged with commissioning, operating and maintaining the final instrument. The project engineering staff established a robust understanding of the practical considerations of assembling and maintaining the instrument in the field. The project scientific staff gained experience in handling, processing and understanding the data collected by the instrument. The analogue of this process in the SKA sphere is the pre-construction program, which will deploy successive low frequency verification systems to the MRO in parallel with (and as part of) the final SKA-low design phase. Maximising this parallelisation throughout pre-construction, in particular with respect to advancing the site infrastructure, will be advantageous.

The collective experience the MWA Project Team gained through operating the prototype array proved critical to maintaining the project schedule through the compressed delivery phase that resulted from the predominantly serial program. Planning for the instrument deployment and commissioning activities was well informed by the experience of constructing and operating the prototype. As a result, the instrument deployment and commissioning were focussed and efficient.

Large and complex projects like the SKA cannot be completed without taking some intermediate steps on the way to the ultimate goal. SKA-low will transition through a number of verification systems (prototypes) as the design of the instrument matures on the path to full-scale production and deployment. Many of the lessons from MWA prototyping, delivery, operations and maintenance activities are directly applicable to SKA-low verification systems and can help to ensure that they are as efficient and informative as possible.

In a concrete and practical sense, the excess infrastructure capacity available on the MWA site represents a valuable, low-overhead test bed for early, and small-scale SKA-low prototypes. With power provided in the field and a complete signal path from the site to Perth (and beyond), SKA-low prototypes can be fielded rapidly and regularly at a fraction of the cost of establishing prototypes at a greenfield site. Less tangible but no less important is the experience of the MWA team in deploying, operating and maintaining an aperture array on the MRO.

Key Messages

- Minimise dependencies and serial scheduling, and maximise parallel activity to provide schedule and program flexibility.
- Prototyping and incremental deployment reduce program risk by informing subsequent activities; provide invaluable empirical data and experience; and enhance program flexibility.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Organisational lessons

The valuable experience and the lessons that MWA has to offer are hard won. The Project made fundamental mistakes, and faced and overcame numerous crises before realising its objectives. In responding to these challenges the MWA evolved a number of organisational characteristics that fostered project momentum— a prerequisite for project success. The international SKA Organisation must ensure that the structures and processes that it establishes to develop and deliver the SKA allow and encourage these traits to flourish.

Broad, complex stakeholder networks are common in large projects. The MWA is a formal collaboration between 13 institutions, has a membership that spans more than 20 institutions, has numerous industry partners, and receives funding through a variety of mechanisms in several countries. With such a diversity of stakeholders a range of perspectives and opinions must be weighed in considering issues and making decisions. In projects, where time (schedule) and money (budget) are finite, the time taken for project stakeholders to reach consensus represents a significant, program-level, risk.

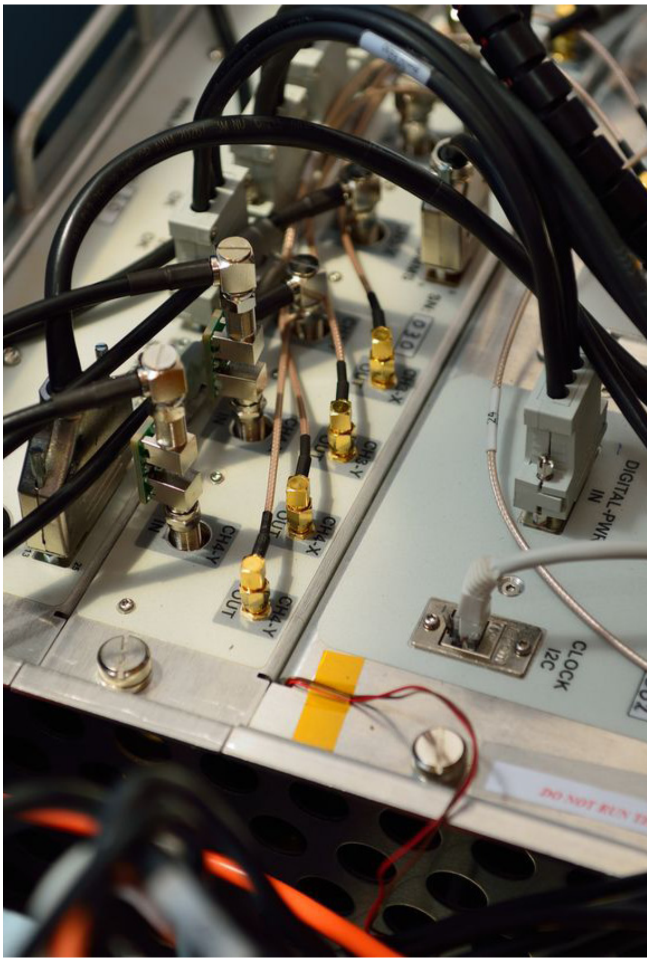
Confronted with a compressed delivery phase, as a result of the serialised program described in Figure 2, the MWA had to be agile and efficient in considering and resolving issues. This was achieved by a number of means:

The MWA is governed by a representative board. The representative board model constrains and simplifies the process of establishing internal consensus and supports efficient issue resolution and decision making.

In order to leverage the efficiency offered by the representative board model the Executive Management took a proactive approach to informing the Board. Significant resources were invested in understanding the MWA's program-level risks and developing contingency[2] strategies. The Board was engaged in the ongoing process of risk and contingency planning. This ensured that the Board was postured to quickly orient to the facts of emerging issues, consider the relative merits of the various courses of action available, decide on the most appropriate course of action, and provide direction.

A critical enabler of good and timely decision-making is an appreciation of the dynamic relationships between project inputs—time and resources[3], and outputs—capability[4]. This appreciation is key to understanding the scope and implications of the trade-offs implicit in any course of action considered in the context of the decision making process. By measuring and articulating program level risk in terms of trade-offs, the MWA was able to quickly assess its options in a crisis and take action to mitigate consequences or seize opportunities.

[2] 'Contingency' refers to any measures taken to mitigate potential risks or manage risks realised—not just budget contingency.
[3] 'Resources' refers to all categories of input including financial, personnel, intellectual, consumables etc
[4] 'Capability' is defined and measured by a variety of qualitative and quantitative metrics including form, fit, function, quality, safety, efficiency, performance etc



The decision making efficiency engendered by these measures saw the MWA delivery schedule preserved in spite of several considerable obstacles.

In July 2011, with austerity measures taking their toll on science funding in the United States, the National Science Foundation (NSF)[5] declined a proposal to fund the delivery phase of the 512-tile MWA. Having identified this as a key program risk, the MWA had prepared and costed a contingency plan—to proceed with the deployment of infrastructure capable of supporting the full 512-tile instrument, and restricting the initial instrument to 128-tiles. When the NSF decision came, the MWA put a compelling argument to Astronomy Australia Limited (AAL)[6] and was given approval to proceed with the contingency plan. Proactive management of risk and efficient decision making prevented this significant development in the project from having any impact on the overall project delivery schedule.

Being well prepared to enact its contingency plan, the MWA Project Team conducted a competitive tender for the deployment of the site infrastructure (power and data networks) required to support the 512-tile instrument soon after the NSF decision. When the responses to the request for tender were received, the costs submitted were more than double the cost estimate[7] for the site infrastructure. The MWA Board was kept apprised throughout the rapidly evolving infrastructure design and costing exercise—conducted within the context of a live tender—that ensued. With a robust understanding of the trade-off space involved and supported by prospective contractors willing to collaborate to identify a compromise between affordability and capability, a way forward was quickly identified—site infrastructure to support up to 256-tiles with a 128-tile instrument deployed initially. Having been informed throughout, the MWA Board was able to endorse the outcome without imposing any delay to the project delivery schedule.

These examples bear out the benefits of having an organisation structured to facilitate good and timely decisions in the teeth of a crisis. However, the MWA also offers examples where the same traits can be applied to reap the opportunities that are often implicit in adversity.

When the MWA was to be 512-tiles there were technical constraints that dictated that the task of correlating the vast amounts of data taken be performed by a ‘hardware correlator’—an assembly of built-to-purpose circuit boards networked together. As bespoke, highly optimised systems, hardware correlators are expensive and risk laden. As such, the MWA correlator was being tracked as a program level risk and alternative implementations were being investigated and scoped on an ongoing basis in the lead up to the NSF decision. Reducing the instrument’s size to 128-tiles as part of the contingency plan triggered in the wake of the NSF’s determination afforded the opportunity to re-examine the implementation of the MWA correlator.

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[5] US funding agency and principal source of MWA funding from Project inception in 2006 through 2010.

[6] AAL is a not-for-profit company that advocates on behalf of the Australian Astronomy community, and allocates and distributes funding provided for Astronomy by the Australian Government.

[7] Cost estimate provided by the engineering firm engaged to design and procure the infrastructure.

The MWA technical team quickly concluded that a ‘hybrid-software correlator’, with tried and tested software at its core and making use of in-hand and off-the-shelf hardware, would provide greater utility, could be implemented cheaper and with less risk. Having been kept up to date with the progress of the MWA hardware correlator and the parallel investigation of alternatives, the MWA Board were well informed when it came time to make a decision. The Board directed the implementation of the hybrid-software correlator and work commenced immediately. Through a comprehensive understanding of the trade-off space and by enabling timely decision making, the MWA was able to turn the withdrawal of the NSF to its advantage (in one respect if not on balance) by reducing the risk associated with a key instrument sub-system.

The agile management and decision making that allowed the MWA to maintain its delivery schedule in spite of numerous significant challenges was underpinned by the efforts of a small core team based at Curtin University. The MWA’s few dedicated, full-time personnel resources[8] were co-located at Curtin. Each member of the core team was given a clear mandate to provide coordination and stewardship of an element of the delivery Project. This required the core team to liaise with contributors and direct effort across the collaboration. Having the core team collocated was essential to maintaining project wide awareness and coordination—with a paucity of resources it is vital to prevent redundant or duplicated effort. The concentration of the full-time personnel resources and allocation of responsibility ensured that the finite level-of-effort available across the Project was applied as efficiently as possible.

The location of the core team was also a critical factor in the successful delivery of the MWA. With a compressed deployment and commissioning program, and little to no scope for post-deployment design revisions, it was vital that the design of the instrument be appropriate to the intended environment. Having the core team located close (in relative terms) to the MRO site allowed them to develop a thorough appreciation of the environment that could be fed into the design cycle. The benefits (described above) of operating and maintaining the 32-tile prototype array—a task performed primarily by the Curtin based team—are testament to the value of proximity.

It is naïve to think that at the outset of any large and complex undertaking—let alone one of the scope and scale of the SKA— that every contingency can be anticipated. It is folly

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[8] Through the delivery phase the MWA Project consisted of four full-time personnel and a raft of fractional in-kind contributions from across the collaboration.

to make grand promises and engender over optimistic expectations when determining factors—including the dreaded “unknown unknowns”—are outside of the Project’s control. Early in a Project’s design, forecasts should tend to the conservative and reflect only milestones and timelines in which there is a very high level of internal confidence. This will ensure that progress is measured and assessed in the appropriate context—positive progress and responsiveness remains the focus rather than missed (optimistically derived) milestones and/or slipping schedules. Over time, as the Project matures, appreciation of its risk profile and vulnerabilities will improve. It may then be appropriate to sharpen forecasts.

Having acknowledged that there will be a lot of things that are unanticipated and/or not able to be controlled by the project, it is important to make sure that appropriate contingency is set aside to deal with them as and when they arise. There is a strong temptation to risk manage contingency in an effort to stretch limited resources to deliver as much as possible. The danger inherent in this approach is that a substantial risk—that cannot be accommodated by the level of contingency carried—is realised. The Project will be forced to make drastic compromises or risk failing. Better to set about a more modest scope with ample contingency and have the option of reallocating released contingency, than to be forced to accept late changes and capability sacrifices.

Key Messages

- **Clearly articulated and agreed lines of authority and decision making responsibility are crucial to maintaining program progress.**
- **Understand program level risks and always have a robust, costed ‘Plan B’.**
- **Concentrate scarce personnel resources proximate to the site so as to ensure that planning and development is informed by the environmental context.**
- **Be conservative in planning, forecasts and contingency—better to under promise and over deliver than to be judged a failure when measured against optimistic targets.**

Industry lessons

Realising the goals of the SKA will require unprecedented developments in a variety of technology areas. However, a variety of the enabling and supporting tasks and technologies required by the SKA are already well understood and applied, albeit to different applications and ends. The SKA must leverage the knowledge and capabilities resident in industry to the greatest extent possible, and concentrate its finite resources on those unique and unprecedented problems that set the SKA apart from any previous undertaking.

Recognising the limitations of its own competencies, experience and capacity the MWA Project Team turned to industry to help realise the objectives. A number of MWA components and sub-systems were designed and manufactured by small-to-medium enterprises in the US and Australia; the site infrastructure design was completed by an engineering consultancy; and the site infrastructure was delivered (procured, deployed, constructed and commissioned) by a Geraldton based electrical contractor.

The challenge for industry, in terms of its involvement in any novel undertaking such as the MWA or SKA, is to add value rather than just tick boxes. All of the contractors and industry partners engaged with the MWA contributed to its successful completion. However, while all performed their roles with professional competence, some added real value and were instrumental in ensuring the successful outcome.

GCo Electrical (formerly Geraldton Electrical Co) is a Geraldton based electrical contractor. GCo was awarded the MWA site infrastructure contract following a competitive tender process conducted at the end of CY2011. The MWA's experience with GCo highlighted a number of benefits of local SME engagement and participation.

GCo was awarded the MWA site works contract in large part because they demonstrated a collaborative approach and willingness to add value through the course of a complicated tender process that saw the original scope of work substantially amended. As a smaller company—the other tenderers were large companies with national and international footprints—the relatively small MWA[9] contract represented more of a prize to GCo than it did to the larger tenderers. As such, GCo was more motivated and willing to be flexible and work with MWA to scope and design a mutually beneficial outcome.

GCo's flexibility, responsiveness and agility—critical enablers of the successful deployment of the MWA site infrastructure and instrument—are possible because they are (comparatively) small and local.

GCo's size allowed the MWA management team the opportunity to establish strong, open relationships with GCo personnel at all levels (executive, management and delivery). This had the effect of establishing, within GCo, an organisation wide appreciation of what MWA was, it's intent and priorities, and the constraints and challenges that it entailed. This awareness laid the foundation for agile, flexible and proactive management of issues as they emerged throughout the planning and delivery of the site infrastructure.

GCo's general experience working in the Gascoyne region of WA—where the MRO is located— was invaluable to MWA. An open dialogue about the cost drivers and risks associated with working on a remote site generally and the MRO specifically lead to a robust, common understanding of the Project's risk profile. As a result, MWA was able to ensure that it established and maintained an appropriate contingency profile throughout the Project.

The return on the time and effort invested in establishing a strong, collaborative relationship; and the benefits of having a flexible, local partner are underscored when project risks are realised.

The plant required to perform the cable trenching around the MWA site (Figure 4) is extremely effective, but maintenance intensive and prone to damage and breakdown. The machine is highly specialised and extremely expensive, and thus rare. As a consequence there are substantial timelines associated with remediation or repairs that cannot be conducted by the crew on site. MWA experienced three such incidents through the course of its trenching program. Each of these incidents involved more than five days plant down time—delays that MWA could ill afford given its highly serialised and compressed schedule.

Each of these incidents could have had significant cost and schedule implications for MWA had it not been for GCo's flexibility and responsiveness. The GCo crew on the ground were quick to assess the situation and provide courses of action to be considered by the MWA/GCo hierarchy. They were proactive in shuffling their own work program—bringing forward tasks that were not dependent on the plant or its progress and deferring tasks that were. Their management team were able exercise their local network to bring additional resources to bear to offset the loss of the plant or facilitate other tasks. Where re-programming was not possible or appropriate GCo were able and, infinitely more importantly, willing to completely demobilise from site with just hours' notice—negating the substantial marching army costs that would otherwise accrue with an idle labour force on site.

Figure 4

Key Messages

- **Local SMEs represent a rich resource. They offer directly relevant, specific insight—particularly with respect to the environment—and have the capacity to add real value.**
- **Open, collaborative relationships produce positive outcomes and are practical to establish with SMEs.**
- **Local SMEs are, as a function of their structure and nature, well placed to be more flexible and responsive than larger organisations.**

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[9] At ~AUD2.5m the MWA site works contract was small when compared to the large infrastructure projects that are typical in the northwest of WA—mining infrastructure projects, or even the MRO/ASKAP infrastructure.

ACKNOWLEDGEMENTS

The MWA project development partners are:

- Australia National University
- Commonwealth Scientific Industrial Research Organisation (CSIRO)
- Curtin University (MWA Lead Organisation)
- Harvard University / Smithsonian Centre for Astrophysics
- Massachusetts Institute of Technology / Haystack Observatory
- Massachusetts Institute of Technology / Kavli Institute
- Melbourne University
- Raman Research Institute
- Swinburne University of Technology
- University of Sydney
- University of Tasmania
- University of Western Australia
- Victoria University of Wellington

The MWA makes use of CSIRO's Murchison Radio-astronomy Observatory.

We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site.

Support for the MWA comes from the U.S. National Science Foundation (grants AST-0457585, PHY-0835713, CAREER-0847753, and AST-0908884), the Australian Research Council (LIEF grants LE0775621 and LE0882938), the U.S. Air Force Office of Scientific Research (grant FA9550-0510247), and the Centre for All-sky Astrophysics (an Australian Research Council Centre of Excellence funded by grant CE110001020).

Support is also provided by the Smithsonian Astrophysical Observatory, the MIT School of Science, the Raman Research Institute, the Australian National University, and the Victoria University of Wellington (via grant MED-E1799 from the New Zealand Ministry of Economic Development and an IBM Shared University Research Grant). The Australian Federal government provides additional support via the National Collaborative Research Infrastructure Strategy, Education Investment Fund, and the Australia India Strategic Research Fund, and Astronomy Australia Limited, under contract to Curtin University.

We acknowledge the iVEC Petabyte Data Store, the Initiative in Innovative Computing and the CUDA Center for Excellence sponsored by NVIDIA at Harvard University, and the International Centre for Radio Astronomy Research (ICRAR), a Joint Venture of Curtin University and The University of Western Australia, funded by the Western Australian State government.

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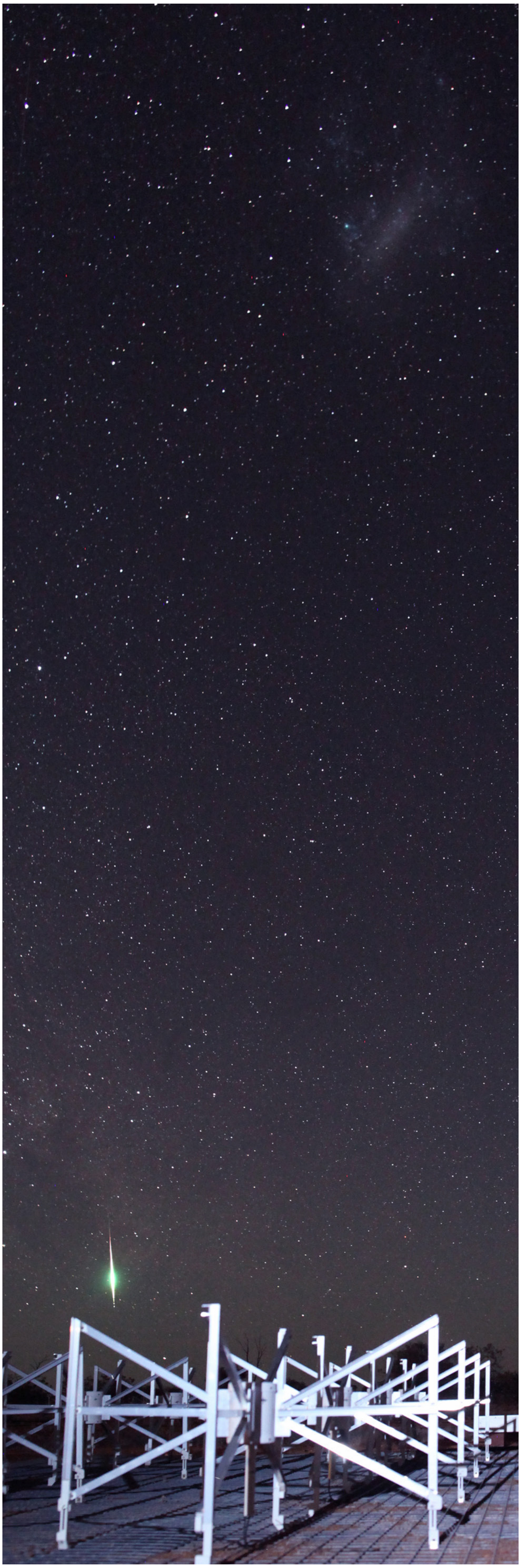
About the Author:

Tom Booler, a Senior Project Manager with client side and client facing experience in the government and private sectors, has been the MWA Project Manager since early 2011. With over 12 years' experience in capability development and delivery, Tom has been involved in all phases of the project and asset lifecycles in a variety of complex and dynamic environments. Tom is an advocate of a practical approach to project management—preferring a selective and tailored application of project management's suite of sub-disciplines, tools and techniques to a prescriptive one. Tom hopes to contribute constructively to the SKA by continuing his involvement in the MWA, and by supporting Curtin's participation in a number of SKA pre-construction work packages.



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