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A Domeless, Mobile 2-meter Telescope

J. Kingsley[a], P. Strittmatter[a], K. Gonzales[a], T. Connors[a], B. Kingsley[b,c],
B. Jannuzi[a], Y.Yoshii[a,d], T. Minezaki[d]

[a]Steward Observatory, The University of Arizona, Tucson, AZ 85721, USA
[b]Lowell Observatory, Flagstaff, AZ 86001, USA
[c]Northern Arizona University, Flagstaff, AZ 86001, USA
[d]The University of Tokyo, Institute of Astronomy Tokyo 181-0015, Japan

ABSTRACT

There are many astronomical, interferometric and space situational awareness applications for single and multiple 2-meter aperture optical and infrared mobile telescopes that are low cost, can be easily transported and quickly deployed at a variety of sites. A design concept is presented for a trailer-mounted 2-meter telescope with a novel micro-enclosure that allows the telescope to be moved and deployed quickly for observations. The telescope is protected from adverse weather using a weatherproof telescope tube instead of a conventional dome or enclosure. It has Cassegrain, Nasmyth and coudé foci suitable for astronomical, interferometric, space situational awareness, and laser communications applications, and is designed for replication at low cost. An initial implementation is being developed to explore the performance of such a telescope using re-purposed primary and secondary mirrors and other components from the MAGNUM telescope.

1. INTRODUCTION

Interest in mid-sized telescopes that can be quickly produced at low cost to meet the diverse and growing needs of applications in astronomy, interferometry, space situational awareness (SSA), laser communications and education among others is growing rapidly. Some of these applications require multiple such telescopes so that constraining unit cost is a major requirement. At the same time, it has become increasingly difficult and time consuming to obtain long term access to good observing sites while post-use site restoration costs can be considerable for traditional approaches. Mobile telescopes can potentially solve several of these problems at least for some applications and this potential provided the key motivation for this joint Tokyo/Arizona demonstration project.

In this paper, we describe some advantages, specific requirements and possible applications of 2-meter class mobile telescopes, by which we mean systems that are self-protected from adverse weather conditions and mounted on readily movable platforms so that they do not need permanent special purpose enclosures. We do so with specific reference to the so-called MAGNUM II project for which we use repurposed optical components from the MAGNUM telescope. Our purpose is to document the potential benefits and drawbacks of such a system for different applications and suggest some concepts for future mobile/transportable telescopes. The goal is ultimately to enable production of 2-

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meter class mobile/transportable telescopes to serve science and other data driven applications in a timely, cost-effective and minimal-risk manner.

2. POTENTIAL APPLICATIONS /ADVANTAGES OF A MOBILE TELESCOPE

There are many reasons to consider a mobile telescope as opposed to a conventional telescope in a special purpose enclosure on a semi-permanent foundation and with a large dome or equivalent. The main purposes are to be mobile, to lower cost, to minimize environmental impact and thus gain easier site access and to enhance flexibility to address a broader range of science or commercial needs. Each application will have special requirements but many of them can be served by the same basic design approach although the optimum aperture size may not necessarily be 2-meter depending on application.

Applications. We consider here the following potential mobile telescope applications, namely astronomy – including both research and educational - interferometry arrays, SSA and laser communications. Astronomical observations (various forms of photometry at different spectral resolution) are normally carried out with single telescopes with a variety of instruments that may require location at different foci (prime, Cassegrain, Nasmyth, coudé). There has been recent discussion of using telescope arrays for high sensitivity observations in an attempt to gain larger collecting area at lower cost than can be achieved by increasing the aperture of a single telescope. Atmospheric seeing also plays an important role in determining ultimate sensitivity and gains may be possible with a stand-alone telescope (i.e. without enclosure) as well as with seasonal adjustments to specific site location.

For interferometry, whether for astronomical or SSA purposes, arrays of easily movable telescopes are required to sample baselines of a larger aperture system to achieve higher resolution albeit with less light collecting capacity. Interferometric mobile telescopes would require a Nasmyth or coudé focus and transmittal of the light to central location that is collimated and through light tubes or via fiber optics are combined in a center area to form an image in an instrument. The mobile telescopes will have to be very stable to form a good interferometric image but would facilitate the reconfiguration of the array to permit more baselines to be sampled. When not used for interferometry, the array could be used for photometric observations.

Space situational awareness applications are similar to those of astronomy but have the specific need to track objects in a non-traditional manner with specific performance requirements. In the case of geostationary orbits (GEO) only minimal tracking is required. The more challenging case for the mobile telescope is the low earth object (LEO) that has extremely fast motion tracking requirements. An object can easily go horizon to horizon in less than a minute of time. Other tracking requirements in this application can be flying objects such as missiles, planes, balloons, rockets and other objects.

A more recent application is laser communication to a satellite in space or to other objects, even ground based. This will need to have the ability to track GEO, LEO and other possible non-conventional sources. This type of system will require a Nasmyth or coudé focus so the laser and instrumentation can be fixed on the mobile telescope trailer and access the sky through the telescope. This is a rapidly growing field due to the expansion of communication from the ground to satellites in space and back. Having a mobile telescope stations is advantageous in the development of these systems and for future operational systems, including in military applications.

Advantages of the Mobile Telescope

A major potential advantage of the stand alone, mobile telescope is that it obviates the need for a special purpose, rotating building to protect the instrument from the elements and permit observations. Such enclosures have customarily represented a large fraction of the cost of astronomical telescopes even though they serve no astronomical purpose and may contribute significantly to image blurring or seeing. Significant progress in reducing the cost of the enclosure relative to the rest of the system has been made over the last century by steadily reducing the focal ratio of the primary mirror and hence focal length of the mirror. This was made possible by advances in mirror polishing and testing technology so that modern telescopes now have primaries with focal ratios close to f/1. Indeed, the Giant Magellan Telescope (GMT) has a segmented f/0.7 primary mirror although some of the impact on enclosure size has been offset by the need for a Gregorian secondary to accommodate adaptive optics requirements. Having reached geometrical structures corresponding to f/1 configurations, there is clearly little further scope for building cost reduction along this path. Eliminating the need for a building altogether is, however, a possibility and can be explored starting with mid-sized telescopes as proposed here. As noted below, the principal question to be addressed is whether such telescopes can be adequately protected from the elements and perform at least as well as the traditional systems.

A second advantage of the mobile telescope approach is that it clearly has less environmental impact and reduces the cost of site restoration after the project lifetime. This should help reduce environmental concerns and thereby render the task of obtaining permission to proceed with telescope projects less demanding. In fact, many projects, and not only large ones, have incurred substantial delays and suffered major cost increases while awaiting approval of long term access – and have resulted in corresponding losses in scientific or other valuable output. Obtaining site access will be much easier if the project makes no permanent changes to the site and, as the 2-meter scale, has a low visual profile of the telescopes.

A third advantage, especially for arrays but even for single telescopes as long as there are multiple customers, is that they can be built in a production facility where optimum cost and schedule processes can be arranged in or near cities where resources are abundant. The telescopes can then be tested in this facility where problems can easily and most economically be solved. Once accepted at the production facility, the telescope can easily be moved to a convenient site that is good enough to demonstrate performance for final acceptance; this can also be accomplished quickly and at low cost with a mobile telescope. It can then be moved again to the site of operations, or in some applications, from site to site as needed for the application in question.

In the event of a forest fire or other catastrophe the telescope could be rapidly moved from one site to another or put into low cost storage. A telescope could be moved to a simple service structure or to the production site to undergo major maintenance, upgrades or to be reconfigured for a different application. This would greatly reduce the time, cost, and expensive travel time to a mountain top and difficulties of working in a remote location.

3. SPECIFIC REQUIREMENTS

A mobile telescope should have specific needs and requirements to ensure the full system is functional and compatible with all the key requirements of an operational telescope. The telescope should be mounted on a trailer that can be towed with a suitably sized truck and positioned on a site reasonable for mobility. The trailer will need to be stabilized so the telescope systems can be transported with the minimal amount of work and disassembly. The mobile telescope system should have to be protected from the weather and be safe and secure. The utilities should have to be provided on site or part of the mobile system. In addition to the above requirements the telescope will have to retain good optical seeing and good optical pointing in various operational weather conditions.

3.1 Trailer

The trailer used for the mobile telescope could vary widely from a custom large semi type heavy weight trailer to a modest trailer that could be towed behind a heavy-duty pickup truck. The goal is a low-cost and effective solution. For a 2-meter mobile telescope it could be a 30,000 pounds gross vehicle weight trailer with a 5th wheel trailer connection. This would be best for traveling to a site for delivery and other on-site moves that do not occur very often. For an interferometer, the choice might be to have the telescope mounted on a track, treads or high maneuverable four or more-wheel system that could be put on a large trailer for transport to the site. The construction industry does this for large heavy equipment like excavators and man lifts. The mobile telescope is designed to be removed from the trailer for permanent mounting if desired or could be located on a foundation with the intent to be moved around a site with multiple foundations by a transporter similar to the Very Large Array (VLA) [1] or Atacama Large Millimeter Array (ALMA) transporters [2].

The trailer used for transport needs to ride smoothly and minimize harmful vibrations and shocks that could damage the telescope performance. The best solution is an air ride 5th wheel trailer that has dual axles and four wheels with all wheel braking capability. There should be consideration whether foam filled tires or other alternatives as necessary. The truck towing the trailer will also have an air ride suspension along with an air ride 5th wheel interface. These can all be commercially available products and systems. The elevation axis will be free to move and connected to the trailer through an air suspension system at the optical tube where the secondary mirror connects. This will reduce the loading on this long structure during transport. The telescope should be designed for transport with minimal restrictions. A 2-meter telescope will fit within a standard size of 8’ wide and 13’-6” height and gross trailer weight loading of <30,000 pounds. By remaining within these parameters, a standard heavy-duty trailer can be towed with a heavy-duty pickup truck rated for this capacity loading. Several heavy-duty pickups and trailers in these sizes are commercially available at competitive pricing. Under these conditions the mobile telescope system can be move nearly any time without special restrictions, permits or added costs.

3.2 Telescope Structure

The telescope structure is to be designed to have greater than 10 Hz lowest resonant frequency mode. In addition, the telescope will be evaluated for seismic loading for the sites where it will be possibly and likely located. In most cases the seismic loading is greater than the typical transport loading on a trailer system as described above.

There are many sensitive items in a mobile telescope that will require special considerations such as: primary mirror, secondary mirror, fold mirrors, correctors, and instruments. Most other equipment can be rated or designed to meet the transport requirements. If all the above items are to be removed packed and shipped separately, then it defeats the purpose of a mobile telescope being quick and low cost to move. The instrument(s) could easily be removed for a more protected transport if required. The rest of the equipment will have to be robust enough to meet seismic requirements and therefore will meet transport requirements. The primary and secondary mirrors can have an elastomeric circumferential band around mirror constraining the primary mirror to the telescope cell in addition to the support system being limited in travel for transport. In more challenging cases the elastomeric seal can be filled with a fluid and reservoir to provide additional cushioning and dampening reducing the stress on mirrors. Special considerations and systems will need to be implemented for systems based on counterweight mechanisms. This will require dampened actuators with limited range of motion in a fixed position in elevation.

3.3 Weather Protection

To have a well performing mobile telescope, the telescope and optical system must be environmentally protected but also the optical seeing and pointing must be preserved in the process. Most modern telescopes are designed to be in dome and have open truss structures between the primary mirror and secondary mirror to minimize the thermal effects contributing to seeing. It is not uncommon to have seeing effect from the dome and related structures that are often mitigated by preconditioning the temperature in the dome for night time observations. Structures that are operable for venting the dome are also used at night to minimize the dome seeing effects. The mobile telescope has an enclosed tube that is designed to have a low thermal time constant. This is achieved by having a structure that is light, thin and has a large surface area. In addition, it can circulate air over these surfaces to further drive the system to thermal equilibrium in a short time. The air in and around the primary and secondary mirrors is also circulated to keep the glass temperature uniform and as close to ambient temperature as possible.

The pointing of a mobile telescope in wind will be challenging since it lacks the protection from a dome. Many telescopes lack the servo and control power to effectively reject the wind influences. This is best achieved by having a very high-resolution encoder, powerful drive motors and a modern computer control system in conjunction with a rigid telescope structure. The ALMA telescopes are an example of this performance. These ALMA telescopes have a 12-m diameter aperture that is exposed to the wind and the control system can point in these conditions to <1 arc-sec in 20 m/s wind. This pointing in wind should be achievable at a 2-meter aperture since it has a much lower wind cross section than a 12-meter telescope and lower drag coefficient. Pointing can also be influenced by thermal changes to the structure but they are generally mitigated by the wind normalizing the telescope temperature. A stable base for a mobile telescope is essential for wind pointing and is one of the reasons four support out riggers have been implemented. If needed in addition there are commercial systems where screws can be hydraulically screwed into the ground to anchor the outrigger pads for added support. These long screws are inserted into the ground by a hydraulic actuated system and then the outrigger pads can be connected to the screws to form a solid base. In extreme situations these are used to anchor large structures in soft soils and sand.

3.4 Mobile Telescope Utilities

Electrical power is needed to operate the telescope and is envisioned on most established site as a utility. A cable with a connector can be used for temporary connection to site electrical power in a similar manner as used by large recreation vehicles. In the event electrical power is unavailable onsite an electrical generator or solar/battery power system would be used. The telescope will have a small uninterruptible power supply used to transition from small power outages and to provide power for a systematic shutdown. It will also be used to provide minimal telemetry from the system during a shutdown mode and support a wake up mode some number of hours later so the system can be restored without a human visiting the site in most cases.

Communications will need to be provided between the mobile telescope and the remote-control stations. A robust system is required for remote operations and two independent separate systems are highly desirable. In most cases an established site has internet connectivity that can be used by running an Ethernet cable to the mobile telescope or via local secure Wi-Fi connections. Other alternatives are possible such as cellular, cable, point-to-point, and satellite systems. By having two systems of communication, a much higher level of reliability can be sustained in keeping the telescope operational on the sky. The mobile telescope being remote controlled requires electrical power and active internet communications to remain operational on the sky for observing. In the event there is a power outage or multiple power interruptions over a short period or there is a loss of internet communications the telescope will go into a shutdown mode. This is where the telescope will be put into stow position with the stow pins engaged and aperture shutter closed. The control system will then go into a minimal telemetry mode of reporting power status and weather status. If the systems regain all the critical resources, then it can be commanded to resume observing. The system may also be put into the stow mode if weather condition warrants a shutdown or there is a system fault, or it is commanded by remote control station. There will be multiple independent systems doing these checks. In addition, there will be at least two sun tracker programs and a sun sensor to ensure the telescope avoids the solar illumination of the primary mirror where there is a possibility that it could damage the telescope due to highly concentrated heat. There will also need to be a monitoring system to keep the inside temperature of the tube within acceptable tolerance and if near the tolerance limit then filtered ambient air will circulate through the tube.

4. THE MAGNUM II CONCEPT

4.1 Overview

The MAGNUM II concept is a mobile telescope that is trailer mounted and remotely controlled for observing as shown in figure 1. Optical systems are protected by having an enclosure telescope structure with a sunshade at the end. The telescope will be capable of serving many applications. The initial configuration will be with an optical and infrared camera at Cassegrain focus.

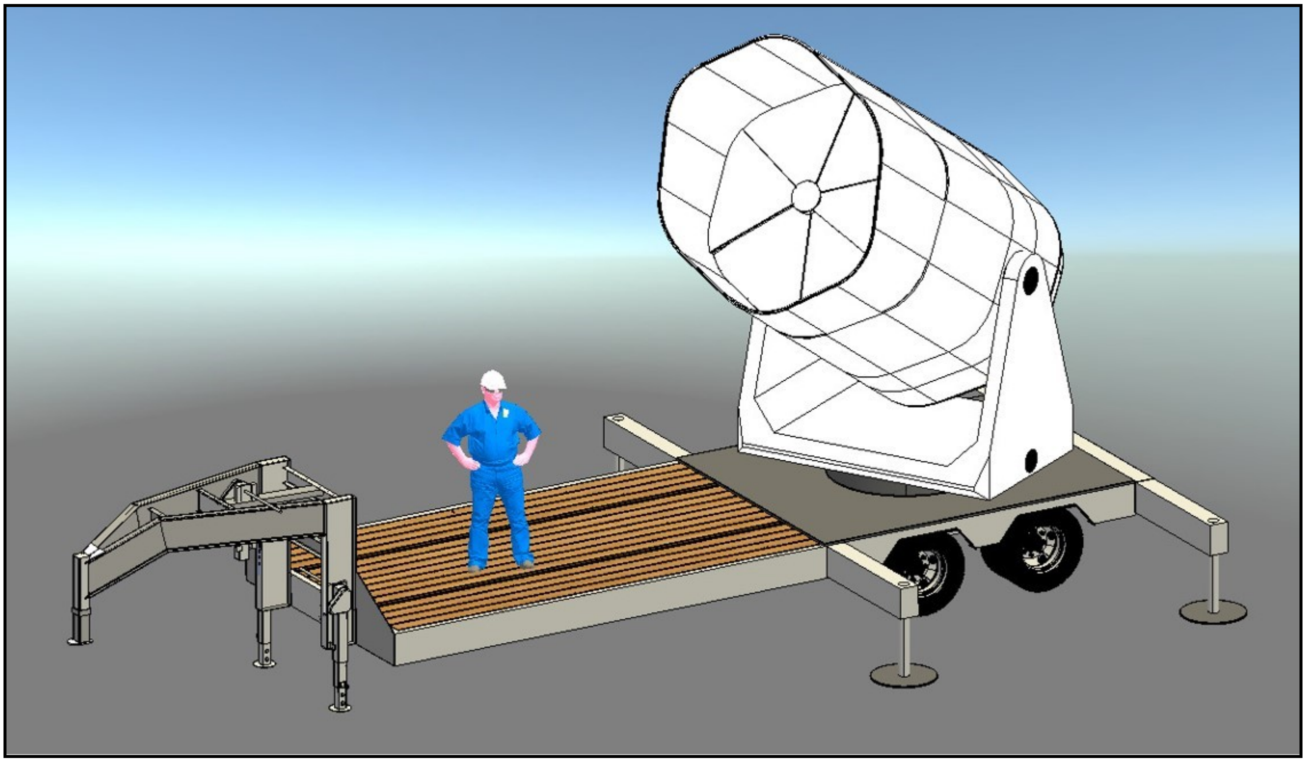

Figure 1. MAGNUM II trailer mounted telescope concept.

The telescope optics and coatings are protected by having an enclosed telescope structure with a sunshade at the end. The end of the optical tube would have multiple petals, actuated shutter system that is fail safe to protect the optics. This system is designed based on a combination of standing seam roof and seals like what is used in an automotive trunk. The design also relies on water being shed off surfaces by gravity, in troughs and gutters that prevent water and debris reaching the optics. The optics not only need to be protected from the water but also from sun and at times wind with debris. This also applies for condensation, snow, and ice.

The telescope tube is designed as a hexagonal tube structure with large radius outside edges. The top point of the hexagon is oriented "up" to the elevation axis and the hexagon flat sides interface with the elevation bearings. It has a sunshade that extends out past the secondary mirror that provides protection from stray light, sun, and weather. The shutter is enclosed in the sunshade and not blocking the clear aperture during observing. The telescope stow position is just below horizon in elevation and pointing in the direction of the prevailing wind. Therefore, rain and snow will run off the telescope tube and sunshade while avoiding collecting on the structure as much as possible. For rain or snow to get into the end of the sunshade it would have to be blown in and then it would still be protected by the shutter with seals. This system will be called a micro-enclosure.

The MAGNUM II telescope concept as shown in figure 1 will use the optics, primary mirror support system, instrument rotator and instruments of its predecessor. A new altitude-azimuth mount and drive systems will be implemented as a mobile telescope but could be removed from the trailer and installed on a permanent site. The telescope will be built in Tucson, Arizona and tested. Then it will be move to Mt. Lemmon or another observing site to repeat the testing and start observing.

4.2 Telescope Mount

The MAGNUM II telescope will have an altitude-azimuth mount that will fit on a standard 8' wide 5th wheel trailer that is 29' with a maximum overall height of 13'-6". A turntable bearing will be used in azimuth for stiffness and to have a low profile on the trailer. The elevation bearings will be spherical roller bearings. By using direct drive motors and high resolution on axis encoders (>24 bits) a modern servo system will best be able to achieve excellent pointing in the operating environmental conditions. The standard operational range of the telescope in azimuth is +/-270° and in elevation down to horizon and up to zenith. The telescope mount will have one stow pin in azimuth and two in elevation. Two energy absorbing snubbers will be used in elevation to limit the range of motion. A braking system will be on both axes for emergency shutdown and to firmly hold the telescope in a fixed position during servicing. There will be pancake slip rings in both axes for power, communications, and some control lines. There will be cable wraps for cryogenic lines. Mounts will be provided on the yoke arms for two Nasmyth instrument boxes. There will be an 8" inch diameter coudé port from the elevation axis and then through the yoke, exiting the azimuth axis.

4.3 Micro-enclosure

The micro-enclosure concept is designed to remove the requirement of a dome and related infrastructure. The micro-enclosure is an enclosed optical tube with a shudder at the end and a sunshade. This system is designed to protect the optics from weather and other environmental hazards. The optical tube is designed to be light weight, and rigid with a large surface area. The goal for this structure is to have a very low thermal time constant. Air will be circulated for preconditioning to thermally equilibrate the system before observing.

The design is to have water flow off the structure using gravity in a way that there is natural flow minimizing pooling. The open aperture at the end is protected by two sets of three pedal lids that are fail safe as shown in figure 2. The lids will require power to open and to remain open. If commanded to or power is lost the aperture pedals will close automatically. The lids are not flat panels but are tapered shapes with folded edges that overlap. They work in a manner similar to a car trunk lid with overlapping channels that drain and soft rubber seal. In addition, the optical tube when in stow mode or during power loss will slowly tip down to below horizon. This position is very protected due to the sunshade, telescope pointing below horizon and telescope wind socking (pointing away from the wind).

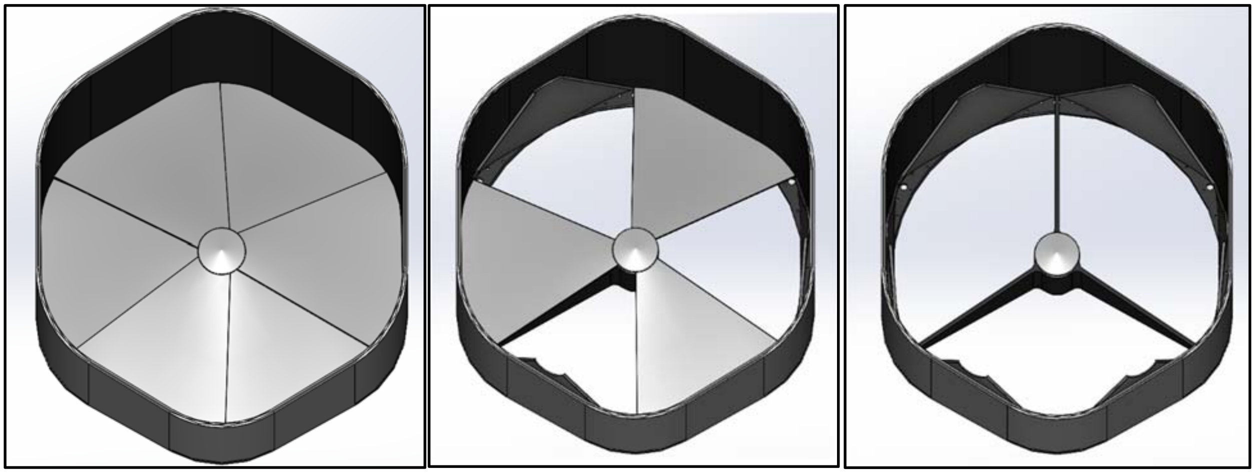

Figure 2. The sunshade with shutter closed, partially open and fully open.

4.4 Modular Design

The telescope will have an overall modular design that will allow it to adapt to various applications. The elevation tipping structure is designed to have five substantial parts. The first is the hub structures that connects to the yoke structure via elevation bearings and drive system. Connecting to the hub is the second part the primary mirror cell and behind it is the third part the instrument cap. On the front side of the hub is the fourth part the optical tube and fifth part the sunshade. The sunshade has the secondary mirror spider and mounting ring. If a different mirror with a longer or shorter focal length is used the telescope cell can be changed and possible the optical tube with the rest of the telescope remains the same. If the telescope is converted to a prime focus system, then the sunshade and possibly the optical tube is replaced. In addition, the telescope drive system can be easily upgraded for faster motion and tracking if required by adding motor segments to increase power.

4.5 Utilities and Communications

This MAGNUM II telescope is to be configured for onsite electrical power and communications. The telescope will be planned to be operated remotely with queued observing to minimize the operations costs.

4.6 Safety and Security

A remote telescope requires special safety measures since qualified people are not around to supervise or monitor the telescopes in a traditional manner. The site will have a fence around it to keep unauthorized people out and away from the telescope motion. There will be an alarm bell that rings well before telescope motion to warn people in the area. Cameras will monitor the site and a weather station will be there to monitor for adverse weather conditions. Several systems will be in place to engage an emergency shutdown if warranted and to protect personnel if present.

4.7 Summary of key features of MAGNUM II

Listed below are the top-level general specifications that are for MAGNUM 2. The telescopes can be customized with options and features such as: instruments, AO system, fast motion tracking, expanded ranges of motion, self-contained electrical power, communications alternatives, maintenance, servicing and security options. There are also specific options for the ability to use the systems for laser communications.

- Optical and infrared observations at Cassegrain focus
- Remote operation with queue observing capabilities
- Mobile telescope with full protection from the weather and sun
- Telescope mount altitude-azimuth with azimuth ball bearing and direct drive with high resolution encoders and spherical roller elevation bearings.
- 2-meter diameter primary mirror
- Designed to adapt to various instrument focus locations: prime, Cassegrain, both Nasmyth ports and coudé with mounting locations on outside of yoke arms and on the trailer.
- The Nasmyth and coudé port to be designed in for an aperture of 8” in diameter.
- Operational azimuth axis range +/- 270°
- Operational elevation axis ranges of 0° to 90° minimal
- Non-sidereal tracking:
  - Maximum angular velocity:
    - >1°/s in elevation
    - >1.5°/s in azimuth
  - Maximum angular acceleration:
    - >3°/s^2 in elevation
    - >6°/s^2 in azimuth
- Site median seeing <0.85”
- All sky pointing <1.2” RMS
- Sidereal tracking of astronomical objects <0.07” RMS (no wind influence)
- Offset pointing from a bright setup star for faint targets: 0.08” if within 20’ of setup star
- Observatory altitude up to 5,600 m (18,373’)
- Operating temperature range -24°C to 38°C
- Survival temperature range -35°C to 50°C
- Operations with wind up to 17 m/s in various directions
- Survival wind is 50 m/s or site-specific environmental requirements
- Humidity <95% non-condensing
- Rain, snow and ice accumulation
- Seismic specification is 0.8g in addition to gravity in all directions or per site specific requirements
- Electrical power: Electrical compatibility as required and to match site voltage and frequency.
- Communications requirements of 1GB/s Ethernet.

The above specifications form a core set of requirements for a flexible configured mobile telescope that can be transported and deployed world-wide for the common application described in section 2. It can also be reconfigured for various applications and missions at a low cost.

5. FUTURE CONCEPTS

The MAGNUM II telescope is envisioned as being the first of several mobile telescopes that can be implemented at low capital and operations costs, based on existing unused optics or a new generation of very low cost optics [3]. Several of the original 1.8-m MMT mirrors are available to be configured into a telescope as described. They most logically could be used for surveys with a prime focus instrument or configured for other purposes as a general telescope.

A new generation of thin meniscus mirrors is starting to be produced at very low-cost options for specific science and are likely to evolve to being a practical solution for telescopes in this class size in the near term. These thin meniscus mirror can potentially be made in various apertures from 2-meters to 7-meter [4]. The MAGNUM II telescope is planned to be the first of a series of mobile telescopes that can be expanded in aperture up to about 3.5-m. Multiple part telescopes that are larger than this size will fit into a category of transportable telescopes. This means they can be easily assembled and tested at the production facility and then transported in several large modular pieces to a site to be erected on a foundation in a manner they could be economically moved in the future to a new site or relocated on to different locations on a site by a specialized transported to various foundations as in an interferometer. The telescope would be designed in a similar manner to the 2-meter but scaled as large modular sections able to be easily and economically reconfigured. This path should provide the foundation for low cost interferometric mobile/transportable telescopes and for larger aperture systems.

6. SITES

There are many potential sites in the world for 2-meter and greater size telescopes. Nearly all of them will require significant site approval based on the impact of the telescope to the site and surrounding communities. The mobile telescope provides and minimal impact in many ways. First it is mobile and can be installed and removed quickly. Second it has a minimal site impact since no permanent excavation or structure will be needed. Third is the visual exposure is minimal for a telescope of the 2-meter size compared to one with a building and dome structure that can be easily more than three times the volume and two times the height. The availability of sites and approval processes become advantageous due to the extremely low site impact and ability to move the telescope easily.

A short list of potential candidate sites that we have explore are shown in table 1.

#	Site(s)	Location	Approximate Elevation of Site
1	Mt. Lemmon	Mt. Lemmon, Arizona, USA	~9,157'
2	Mt. Bigelow	Mt. Bigelow, Arizona, USA	~8,230'
3	Kitt Peak	Kitt Peak, Arizona, USA	~6,886'
4	Northern Arizona	Multiple sites	`7,000'
5	Southern New Mexico	Multiple sites	~9,186'
6	Colorado	Pikes Peak, Colorado, USA	~14,114'

Table 1. Potential sites for a 2-meter mobile telescope.

7. MAGNUM Telescope Heritage

An initial implementation of the telescope is being made using repurposed primary and secondary mirrors from the Japanese MAGNUM telescope. The MAGNUM Telescope was named for the purpose of the telescope to do Multicolor Active Galactic Nuclei Monitoring (MAGNUM) [5], [6]. A brief history is that it was built at the Haleakara Observatory on Maui Island, Hawaii, USA. The telescope was operated performing active science from 2000 to 2008. Then it was disassembled and transported to Japan to be stored. In 2015 it was shipped to the University of Arizona, Steward Observatory to be located on Mt. Lemmon. This paper has been substantially driven by the MAGNUM telescope and the challenges of moving it and relocating it on Mt. Lemmon and to be repurposed for broader scientific research.

8. CONCLUSIONS

The MAGNUM II telescope plan is to demonstrate these concepts and technologies as a path finder for low cost access to telescopes in the aperture range of 2-meter and greater. Once demonstrated, more telescopes will be produced due to the low cost and quick access to the sky. It will logically lead to larger apertures and other concepts and technologies in the aperture range up to 7-m. These low-cost solutions will be attractive for many applications.

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REFERENCES

[1] VLA Transporter website for more information:
www.vla.nrao.edu/genpub/work/transporter.shtml

[2] ALMA transporter website for more information: www.almaobservatory.org/en/about-alma-at-first-glance/how-almaworks/technologies/transporters/

[3] J. Roger P. Angel, Daniel Apei, Ryker Eads, Daniel J. Eisenstein, Michael Hart, Daewook Kim, Jeffrey S. Kingsley, "Narrow field, low cost optical telescopes using small spherical meniscus mirrors", Proc. SPIE 11445-295, Astronomical Telescopes + Instrumentation (2020).

[4] J. S. Kingsley, R. Angel, W, Davison, D. Neff, J. Teran, B. Assenmacher, K. Peyton, H. M. Martin, C, Oh, D. Kim, E. Pearce, M. Rascon, T. Connors, D. Alfred, B.T. Jannuzi, D. Zaritsky, E. Christensen, J. Males, P. Hinz, R. Seaman, K. Gonzales and D. Adriaanse, "An inexpensive turnkey 6.5-m observatory with customizing options", Proc. SPIE. 10700, *Ground-based and Airborne Telescopes VII* (2018).

[5] Yukiyasu Kobayashi, Yuzuru Yoshii, Takeo Minezaki, Keigo Enya, Tsutomu Aoki, Massahiro Suganuma, Hiroyuki Tomita, Mamoru Doi, Kentaro Motohara, Bruce A. Peterson, Craig H. Smith, John K. Little, Ben Greene, "Automated observatory for multicolor active galactic nuclei monitoring (MAGNUM)", Proc. SPIE 4837, Large Ground-based Telescopes, (4 February 2003): https:doi.org/10.1117/12.458003

[6] Yukiyasu Kobayashi, Yuzuru Yoshii, Bruce A. Peterson, Takeo Minezaki, Keigo Eny
A, Masahiro, Masahiro Suganuma, Tomoyasu Yamamuro, "Multicolor imaging photometer for the MAGNUM project", Proc. SPIE 3354, Infrared Astronomical Instrumentation, (21 August 1988).

[7] J. Roger P. Angel, Daniel Apei, Ryker Eads, Daniel J. Eisenstein, Michael Hart, Daewook Kim, Jeffrey S. Kingsley, "Narrow field, low cost optical telescopes using small spherical meniscus mirrors", Proc. SPIE 11445-295, Astronomical Telescopes + Instrumentation (2020).