The Importance of 4m Class Observatories to Astrophysics in the 2020s

Thematic Area: Ground Based Telescope Facilities

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I. Key Science Goals and Objectives

Retaining community access to 4m class telescopes in the upcoming decade is critically important for a number of applications, including (but not limited to) transient follow-up observations, high-risk/high-reward observations, instrumentation test beds, and student training.

In the era of big glass and the current development of extremely large telescopes, there is no question that telescopes of increasingly large apertures will be required for numerous advancements in observational astronomy and astrophysics. Furthermore, large ground-based surveys such as the Sloan Digital Sky Survey (SDSS) and the Large Synoptic Survey Telescope (LSST) are contributing to a paradigm shift in terms of the mode in which ground-based observational astronomical research is being conducted, with many researchers now using data mining techniques to take advantage of the enormous data volume rather than making single PI-led observations from a telescope. However, ground-based surveys such as the Zwicky Transient Factory (ZTF) and LSST, as well as space missions such as the Transiting Exoplanet Survey Satellite (TESS), will yield numerous discoveries of interesting targets that require follow-up observations in order to be better characterized. It is in this realm of time domain follow-up observations that 4m-class telescopes can play a significant role, provided that their relative ease of access is retained. Examples of such science cases are given in Table 1.

Transient Type	**Discovery Technique**	**Follow-up Data Desired**	**Technology Required**
Optical counterparts to GW sources	LIGO	Photometry, spectroscopy	Optical and IR imaging & spectrographs (Kasliwal et al. 2019)
Interstellar asteroids	Pan-STARRS	Photometry, spectroscopy	Optical and IR imaging & spectrographs
Gamma ray bursts	Swift, Fermi Gamma-ray Space Telescope	Photometry, spectroscopy	Optical and IR imaging & spectrographs (Cuby et al. 2019)
Gamma-ray blazars	IceCube, HAWC, MAGIC, Fermi	Photometry, polarization	Optical and IR Cameras
Supernovae	ZTF, LSST	Photometry, Spectroscopy	Long-slit spectrograph

Free floating planets	Pan-STARRS, microlensing	Photometry, spectroscopy	Optical and IR imaging & spectrographs
Tidal disruption events	Pan-STARRS, ZTF, LSST	Photometry, Spectroscopy	Optical and IR echelle spectrographs

Table 1. Examples of transient phenomena that could be followed up with 4m class telescopes.

Telescopes of this class with capabilities such as remote observing and flexible scheduling will be particularly well-suited for time domain follow-up observations, which often require rapid turnaround from the time of discovery to subsequent characterization.

Additionally, time domain methods provide information for non-transient phenomena that cannot be probed through classical spectroscopy or photometry. Such methods include microlensing, asteroseismology, reverberation mapping, and Doppler tomography. In the case of AGN reverberation mapping, in particular, much of the foundational work (cf., Peterson et al. 2004) was carried out on 1-m class telescopes because of the required time investment. However, this work has focused on the nearest and brightest AGN in the sky, which may not be representative examples of the underlying population, therefore 4-m class telescopes are integral to expanding the parameter space in order to better understand the physics involved in AGN feeding as well as the role of AGN feedback in galaxy evolution.

Ground-based telescopes also serve as an important testing ground for innovative but potentially risky observations. New observational experiments can be developed and tested with 4m-class telescopes, in some cases demonstrating the limitations of this aperture size and hence the need for more advanced capabilities. Time Allocation Committees on the more competitive larger telescopes will be more receptive to proposals for which proof-of-concept observations were conducted. In some cases a high-risk observation on a 4m class telescope will be successful, thus telescopes of this class can be used by astronomers to test out new observing strategies or techniques with potentially a high scientific yield.

In addition to the scientific discoveries that will be enabled by observations with 4m-class telescopes, such telescopes can also be used as instrumentation test beds. For both space-based and ground-based instrumentation, heritage is an important factor in selection. Ground-based telescopes that are accessible for the testing and demonstration of new technologies and instrumentation will play a critical role in the definition of future instrument suites for larger telescopes and satellites.

Finally, 4m-class telescopes can serve as an important resource for training future generations of astronomers. In the era of big data and large astronomical surveys, students may gain new skills in the areas of data mining, but without practical experience at a telescope they may lose sight of the origins and limitations of those data. Students need to understand where their data come from in order to effectively analyze them. The experience of working with instruments and telescopes first-hand, from developing an observing plan to conducting the observations and then analyzing their data, provides students with an end-to-end understanding of what goes into the planning of the data pipelines in the larger surveys. The 4m class telescopes are ideally suited for developing the skills and training for future ground-based astronomers who may not end up using telescopes themselves, instead taking advantage of the large data produced by ground- and space-based surveys.

II. Technical Overview

As listed in Table 1, general instrument properties that are desirable on 4m class telescopes include optical and near-infrared spectroscopy at both low and high resolution as well as imaging. Additional more specialized instrumentation could include technologies such as polarimeters, integral field unit spectrographs, and diffusers for increasing ground-based photometric precisions (Stefansson et al. 2017).

There are a number of different metrics that can be used to assess the value of 4m class telescopes to the modern astronomical community. A commonly used metric for contributions to the endeavor of astronomical research is publications, both the total numbers and their scientific impact as measured by citations (Fig. 1).

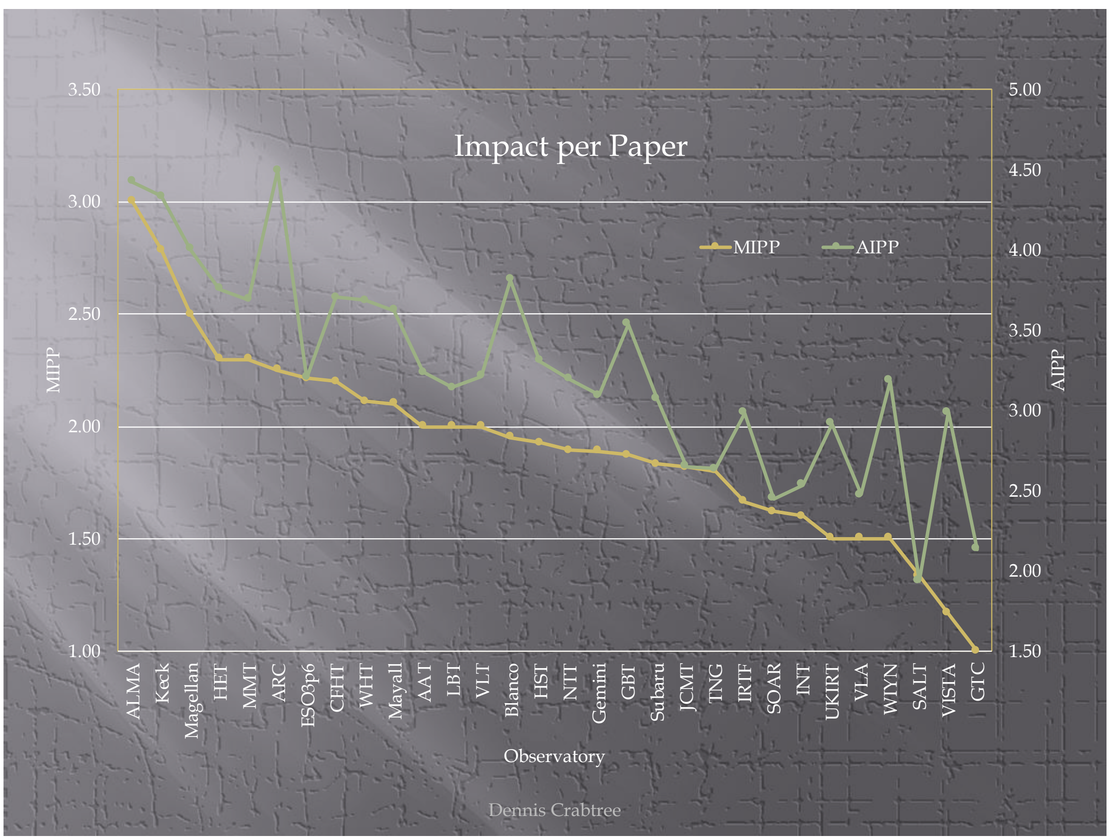

Figure 1. Impact per paper for a number of different telescopes from 2012-2016 (Crabtree 2019). Impact per paper is defined as the ratio of the number of citations that paper has received to the citation count for the median AJ paper of the same year. MIPP = median impact per paper; AIPP = average impact per paper.

However, there is also the impact on human resource development (number of students trained, impact on student and faculty recruitment) as well as less tangible effects (e.g. the ability to leverage 4m class telescope access to gain additional resources such as grants or observing time on more competitive telescopes).

There is no single formula for the successful operation of 4m class telescopes. However, it is clear that in order to remain competitive, attributes such as remote observing, flexible scheduling, and state-of-the-art instrumentation are paramount.

III. Technology Drivers

Capitalizing on the capabilities of 4m class telescopes does not strictly require any new technology development; however, there are technological innovations that will make these telescopes more productive and important in the coming decade. These technologies center around remote or automated observing, automated fiber placement, automated optimization of real-time scheduling, and automated data reduction and calibration. Many of these technologies are already in development at some of the current 4m facilities, such as the fiber-positioning technology ongoing for the DESI program (Baltay et al. 2019) at the Kitt Peak 4-m, the many telescopes with remote observing and queue observing modes, and the robotic telescopes around the world. However, these are far from optimal or ubiquitous, and support for developments in these areas will be critical to making the most of our 4m telescope resources.

The timeline for maturation of these technologies should be in keeping with the development of large time-domain surveys, as we are seeing with the instrumentation of DESI and SDSS-V (Kollmeier et al. 2017), as well as robotic follow-up of GRBs (e.g., Martone et al. 2019), and the development of Astropy (Astropy Collaboration et al. 2018), which should mature to include spectroscopic reductions in the coming decade. However, support for these efforts will be required if they are to keep up with the demands of the planned surveys of the 2020s.

IV. Organization, Partnerships, Current Status, and Schedule

Four-meter class telescopes in the US have several different operational models that include privately owned observatories, publicly owned facilities, or public-private partnerships. Most are overseen by a Board of Directors or a management oversight committee of some sort, and user input is frequently solicited from Users Committees. The 4m class telescopes described herein are already operational. Some have been continuously operated for more than a half-century (e.g. the 3.0 m Shane Telescope at Lick Observatory) whereas others were added to the national telescope landscape within the last quarter century.

The operational lifetime of telescopes of this class is not well defined. In some cases, telescopes that had been operated in a classical observing mode have been repurposed for specific surveys (e.g. the Mayall 4-m at Kitt Peak). In other cases 4m-class telescopes have added new instrumentation capabilities in order to remain competitive. The timescale for the development and implementation of new instrumentation is typically of order 2-5 years, and requires substantial capital investment and advanced planning to take advantage of anticipated desired modes of observing.

V. Cost Estimates

Annual operating budgets for 4m class telescopes are in the few $M range. The source of these operating costs varies depending on the operations model, and can include member contributions, federal funds if the telescope is part of a national portfolio of ground-based observing assets, and private contributions. Funding for operations costs remains a major challenge in the era of tightening university budgets and shifting priorities at the national observatory level. In order to maintain access to these facilities by the astronomical community, stable funding for these observatories should be retained.

VI. References

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