Revista Mexicana de Astronomía y Astrofísica
ISSN: 0185-1101
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Instituto de Astronomía
México

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Revista Mexicana de Astronomía y Astrofísica, vol. 28, junio, 2007, pp. 24- 30
Instituto de Astronomía
Distrito Federal, México

RevMexAA (Serie de Conferencias), **28**, 24–30 (2007)

BREAKING THE COST CURVE IN OBSERVATORY OPERATIONS

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RESUMEN

Los telescopios muy grandes de nueva generación han traído consigo grandes presupuestos operativos. Si estos presupuestos se siguen escalando en proporción a los costos de construcción como ocurrió en el pasado, el encontrar los fondos de operación para los telescopios aún más grandes puede ser un reto mayor que el encontrar los fondos para la construcción. Por eso sugiero que se revisen los modos de operación comúnmente usados en los grandes observatorios de sitios remotos. Con las conexiones de banda ancha, las observaciones pueden llevarse a cabo remotamente desde las instituciones socias, y no se necesita que los observadores viajen a los observatorios. Los telescopios y sus instrumentos pueden ser mantenidos en completa operación por un conjunto de personal relativamente pequeño, si durante la construcción se tiene cuidado en la calidad y facilidad de mantenimiento. Las conexiones de banda ancha permiten un completo monitoreo e información de diagnóstico sobre el rendimiento del telescopio e instrumentos desde las instituciones socias, y ellas pueden ser las responsables para el soporte de alta tecnología del instrumento. El ahorro en costos se consigue con equipo de bajo mantenimiento, poco personal en los observatorios, y la participación directa de las instituciones socias con sus investigadores y personal técnico.

ABSTRACT

The new generation of very large telescopes have brought with them large operations budgets. If these budgets continue to scale in proportion to construction costs as they have in the past, finding the operating funds for even larger telescopes now being planned may be more challenging than funding construction. I suggest that the modes of operation commonly being used at major observatories in remote sites be re-examined. With the availability of high bandwidth connections, observations can be carried out remotely from the partner institutions, and there is no need for observers to travel to the observatories. With careful attention to quality and ease of maintenance during construction, the telescope and its instruments can be kept in full operation by a relatively small local staff. The high bandwidth connection allows full monitoring and diagnostic information on the performance of the telescope and instruments at the partner institutions, and they can be responsible for the high-tech support of the facility. Cost savings are achieved through lower-maintenance equipment, a smaller staff at the observatory, and direct participation of the partner institutions and their scientists and technical staff.

Key Words: **SOCIOLOGY OF ASTRONOMY**

1. INTRODUCTION

Over time the operating costs of a major observatory are greater than the entire cost of its construction. A common rule-of-thumb often used during the construction phase is that it takes 5-10% of the construction cost to operate each year. For existing observatories it is often hard to ascertain and evaluate the operating costs, because what is included in "operations" and how it is calculated can vary considerably from one observatory to another. Nevertheless the "5-10% rule" is widely quoted, and when applied to the very expensive giant telescopes now being contemplated, leads to very high expected operating costs. Also, it is often the case that operating funds are more difficult to obtain than construction costs, and a full cost-model for a new observatory including construction and the first 10-20 years of operation will show a requirement for at least twice the cost of construction alone. Potential funding sources will likely expect to see realistic plans for sources of the entire funds, including operations, before providing any significant partial funding.

It is obvious that breaking the scaling law of operating expenses to ever larger telescopes is highly desirable. Does the "5-10% rule" hold indefinitely? At the very least, what can be done to keep the scaling closer to 5% than to 10%? In §2 I will discuss the common models for operating a modern, large observatory in a remote site. In §3 I will examine

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the various potential cost centers for observatory observations. It is this list that actually varies from observatory to observatory in their "operations" expense accounting, though all things on the list are generally done one way or another everywhere. In §4 and §5 I will discuss ways of both lowering costs and transferring them in ways that could make the source of the operating costs more distributed and more tractable to the partner institutions.

The various ways of breaking the cost curve of operations presented here contain no fundamentally new ideas. In fact, many aspects of what I discuss were common many years ago. But the combination of these various modes and philosophies in new ways results in a proposed mode of operations that does differ from what is presently being used or proposed for future observatories.

2. COMMON OPERATIONAL MODELS FOR EXISTING LARGE OBSERVATORIES

2.1. *Organization*

By necessity large observatories have come about through the partnership of two or more institutions. Only the highest quality sites have been selected for the largest telescopes, and they are generally situated in remote locations far from any of the partner institutions. This has led to the creation of a large local staff at the remote location, typically including a Director, scientists (support and research), engineers, technicians, physical plant personnel, business office staff, and more. There is often a headquarters facility (HQ) at low elevation that provides space for the majority of the people plus a dedicated mountain crew. In addition, there is sometimes another main HQ back near the partner institutions (e.g., the ESO HQ in Garching), and there can even be multiple smaller "HQs" distributed among the partners, especially if they are multi-national.

In addition to operations, some development activity usually goes on at the observatory HQ. This can include the development of such things as new telescope guiders, advances in telescope control and software, advances in adaptive optics systems, and upgrades to existing instruments. Generally no major new facility instruments are developed at the observatory HQ, as this effort is usually done at the partner institutions.

The combination of development work and scientists on the staff usually implies significantly more work is taking place at the observatory site than that required simply to operate the telescopes and instruments and maintain them in top operating condition. Also, the effort that is expended on maintaining and repairing the telescope and instruments, with its associated resource demands, can vary considerably, but is likely to draw on a significant part of the budget.

2.2. *Operations*

To use a telescope at the remote facility, it has been common practice for the observers to travel to the observatory site and observe from the mountain top. More recently, especially at the Keck Observatory, observers still travel to the remote observatory, but observe from the low-altitude HQ rather than from the mountain top. This is particularly advantageous when the telescope is located at high elevation, such as the summit of Mauna Kea, with its environmental challenges for the observers. By traveling to the telescope HQ, however, the observer is able to take advantage of local expert help in setting up and operating the equipment. Thus, in addition to a telescope operator, a support scientist or the equivalent is often on duty, as well as additional technical support people available on-call if problems develop. For complex instruments such as adaptive optics systems, additional support people may be required to be present throughout observing. Even when the observer is at the low elevation HQ, the telescope operator is generally located at the telescope; this is not essential, though. The existence of observers traveling to the remote site requires personnel concerned with logistics and some planning for lodging.

Two further variations of traditional observing are in use. Full remote observing is increasingly used at Keck and other observatories, during which the observer remains at or near the partner institution but still is in control of the observing by the use of a high bandwidth connection. With an excellent connection and a well-designed interface, observers report little difference between observing at the HQ or mountain top near the telescope and observing from their partner institution. The second variation of traditional observing is service observing. For this, the time is assigned to a particular program, but the observing is carried out by local observatory staff following instructions previously supplied by the scientist whose time it is. This can be efficient for routine, survey-type programs, or for a program that requires a very short (e.g., hour or two) straightforward observation.

At the opposite extreme from the traditional mode of observing is queue observing, during which the scientist for whom the data is being obtained has no direct interaction with the telescope, operator, or local staff while the observation is being made. The observing schedule for the night can be derived from a complex mix of different programs that have been assigned different priorities, and depending on the observing conditions, that program in the mix with the highest priority for the conditions at that time will be carried out. This has the obvious benefit that maximum advantage can be taken of the observing conditions at any one time, and high priority programs will very likely be carried out. In traditional mode observing, a highly-rated program may simply be clouded out on its assigned nights and not get done. Queue observing has the disadvantage that no on-line evaluation of results is generally done, with no opportunity to follow up on unexpected results or cut short on uninteresting results. Also, the scientist has no direct knowledge of exactly what transpired when the data were obtained. To some extent this can be mitigated by allowing the observer to eavesdrop while his or her data are being obtained. Queue observing can also require additional personnel to make the observations, assess conditions, maintain multiple instruments in readiness, set up the queue, etc. The full extra expense can be considerable.

Some observatories use a mix of both queue and traditional observing. In addition, there is a considerable range in how observatories treat the level of on-call support, observer assistance, and other observing related issues.

3. WHAT DOES IT REALLY COST TO OPERATE AN OBSERVATORY?

It can be amusing to hear representatives of different observatories discussing how much it costs to operate their observatories. A says that his observatory cost X dollars a year to operate, while B says that her observatory costs Y dollars a year in operations cost. They are comparable facilities, yet X is four times Y. B says "how can you spend so much more than us to do the same thing? You must be wasting a lot of money!" At least two things can seriously affect the meaningfulness of the comparison: (1) are they really doing the same things, and (2) are they including the same costs in the cost of operations? In my experience it is generally the case that comparisons of how much it costs to operate observatories are very suspect, because what is required for operation and what is included in the operations budgets of observatories vary tremendously from observatory to observatory. Moreover, in my experience, it is common for observatory directors not to fully understand the budget of their own observatories in the sense of what is included in it and what is left out. In addition, some observatories get a considerable amount of effort and resources "free". It never shows up in their budget. Other observatories pay for just about everything. National observatories are usually operated and costed differently from "private observatories."

Operations can include many components, some of which are obvious. All observatories must have some management and business operation. Is any of this in fact subsidized by the partner institutions? All observatories have a budget to maintain and operate the general facility, telescope, and instruments. This budget also includes some level of repair. But what about large items? What happens if a major repair needs to be done? Does this come out of the budget, or are extra funds sought elsewhere? For example, the Keck Observatory maintains a large reserve for items like this. A recent repair to the dome shutter partially depleted the reserve. This was restored from the operations budget. Do other observatories do this? How much assistance is given observers? This varies considerably among the observatories, depending on their style and mission. Is data reduction software provided for all instruments? Who pays for it? How much development is done with observatory funds? Are all new guiders, CCD controllers, software systems, AO components, etc., part of the budget, or do the funds for this come from elsewhere? Is this work all done by observatory staff, or might some of it be done by scientists and staff at the partner institutions, who provide some or all their services free of charge? What about facility instruments and their upgrades? Are they fully-costed in the operations budget? Does that cost include PIs who may have faculty or other appointments at some institution and thus not have their salary charged to the operations budget? Is full overhead charged for all non-observatory personnel working on observatory projects, or do other institutions subsidize part of the costs? Does the local staff do research, which of course would represent an additional burden on the operations budget? Is there an archive? If so, how sophisticated is it, and how is it paid for? How extensive is public outreach? How is it paid for? Is there a fund-raising campaign? How is that paid for?

The above paragraph gives an idea of how complex an observatory budget can be. It is clear that comparing observatory budgets is a difficult exercise because of the variety of ways the various components are handled and included or not included in the budget. However, if the goal is to reduce the operating cost of an observatory, one must be as clear and comprehensive as to what goes into it as possible.

4. REDUCING AND MANAGING THE COST OF OBSERVATORY OPERATIONS

There are several components to consider as part of cost reductions for operations. One is the basic cost of operating the observatory itself. What is necessary so that nightly observing can proceed in an efficient, effective way, and how far can the cost of this be minimized without negatively affecting the scientific effectiveness of the observatory beyond an acceptable level? What strategies can be used to cut costs of the scientific operation of the telescope? A second goal is to minimize the cost of maintenance and repair of the telescope and its instruments. Operations costs can be lowered through quality control. A third goal is to minimize duplication of expertise at multiple locations to the maximum extent possible. A fourth goal is maximizing access to operations funding in all forms. As I said at the beginning, raising the funds for operations is often a major challenge. By carrying out various aspects of the observatory's work at the partner institutions, this challenge can be met in ways that could be more acceptable to the partners' sponsoring institutions and allow the transfer of significant amounts of costs to those institutions in support of their own goals.

4.1. *A Minimalist Approach to Operations at the Observatory*

A major operations expense of nearly all observatories with telescopes in very remote locations is the very large staff needed to support nighttime operations, telescope and instrument maintenance and repair, upgrades, development programs, and visiting observers. The latter can itself require a sizable subgroup.

I suggest that a major observatory with a large telescope in a remote site should be designed from the outset with the idea that the principle activity of its local staff will be the support of nighttime observing. This staff will include telescope operators, instrument technicians, AO support staff, mechanical, electrical, and software engineers and technicians as deemed necessary for operations, and those that maintain the physical plant. There will be no scientists, support or otherwise, at the observatory. There will be no need for any kind of observer support at the observatory, because observers will never be present at the observatory except when they are required to participate in the commissioning of an instrument or major new system.

The entire observatory — telescope, instruments, everything possible — will be designed from the beginning with remote observing, remote operation, and remote monitoring in mind. It should be possible to monitor virtually every aspect of telescope and instrument performance in real time from a location or locations at the partner institutions. All observations can be carried out from the partner institutions in real time with the observer "present" when traditional observations are being carried out. The telescope itself can even be operated remotely, though it could also be run locally at the observatory. The Keck Observatory is already being used very effectively in this mode, with the telescope operator on the mountain top and the observer at his or her own institution connected by high-bandwidth video and data connections.

No major repairs or upgrades of the telescopes or instruments are expected to be done by the observatory staff, as they are primarily an operations staff; of course minor repairs will be made by them. However, since direct and high-bandwidth communication will be continually available to the partner institutions, highly expert and knowledgeable assistance is always available at the partner institutions. There is no need to duplicate this kind of personnel at the observatory. All facility instruments and development work — advances in guiders, detectors, telescope software packages, AO systems, etc. — will be done at the partner institutions or places they choose. None of it will be done at the observatory. In short, the staff and infrastructure of the observatory will be designed to be that minimum required for the effective nighttime operations of telescope and nothing more. There will probably still have to be some minimal central HQ at the observatory for overall management and coordination, business functions, hirings, etc., but it needn't be large. For all of this to work, there must be tight coupling between the activities of the remote observatory and the partner institutions, most likely through strong and responsible science and technical oversight groups formed by the partner institutions. This is as it should be, because after all it is their observatory.

4.2. *Cost Savings Through Quality Control*

Higher reliability of equipment can lead to lower operating costs, though a willingness to put up with some level of lost observing time can also save money. In general, the resource load of maintenance and repairs depends on the reliability of the equipment and the ease of servicing and repair. Higher quality equipment and simple servicing and repair can significantly reduce this resource load. This is extremely important in the area of software. Quality control of software delivered to observatories often leaves a great deal to be desired and results in a heavy load of maintenance and repair on the observatory staff. Software problems are often the major contributor to inefficient observing and lost time. Software problems are often the most vexing, as the documentation can be out-of-date or incomplete, and the overall system, including that associated with the instruments, can be so complicated that no one locally understands it very well.

In my experience, most mechanical failures either require minor fixes, a part replacement, or are so major as to be beyond the local staff. Electronics problems can have a greater range in the intermediate level, but they too often require expertise beyond that available at the observatory. In fact, the inability of the local staff to recognize soon enough that they should seek outside help can be a significant problem for observatories.

I suggest that, from the very beginning of a telescope project until its completion, quality control be given an extremely high priority. Extra investments made during the design, development, construction, and commissioning phases of the observatory to ensure the highest quality and reliability of all components and systems is well worth the investment. You will pay then, or you will pay later during operations, when funds will likely be harder to come by. Reviews must be held regularly, conducted rigorously, and passed with high marks throughout the project. This holds for software as well.

The same approach must also be used for the development of instruments. Typically instrument problems lead to more lost observing time than telescope problems. Moreover, instrument maintenance and repair generally requires high-level people, who will be limited at the observatory in the model proposed here. The instruments must be thoroughly reviewed at all stages, and no instrument should be shipped to the observatory without passing a thorough, extensive pre-ship review that demonstrates that it is 100% complete, reliable, and ready for scientific observations. That is essential for the minimalist approach for observatory operations to work. To simplify matters, instruments should be standardized as much as possible. The telescope interface should be completely specified and rigorously enforced, the software should be professionally written and documented following observatory standards, and hardware should be standardized as much as possible. There should be standardized user interfaces. Manuals and simulators are essential and should be provided before the instrument is shipped. Pipeline and full data reduction packages are very important. The telescope should be designed so that instrument changes require minimal reconfiguration. Less staff would be required, and fewer mistakes would be made. Obviously, telescope scheduling should be done to minimize demands on staff for instrument changes.

5. THE ROLE OF THE PARTNERS IN OBSERVATORY OPERATIONS

The operations model discussed here transfers major aspects of observatory operations to the partner institutions, as the observatory itself is almost entirely devoted to the scientific operation of the telescope. In fact, this model is quite similar to the mode of operation of the two major private California observatories: Lick and Palomar. In both cases, the responsibility of the mountain staff is almost entirely limited to the support of scientific operations. All instrument development, upgrades to existing instruments, development and upgrade of new auxiliary equipment and systems, and major repairs are carried out under the direct supervision, control, and typically with the resources of the observatory faculty, staff, and facilities located at the operating institutions. With telescopes and instruments that operate reliably, trips to the observatory by staff located at the institutions can be kept to a minimum. Furthermore, with excellent communication links between the observatory and the institutions, the high-level technical personnel and scientists located at the institutions can be directly involved as needed in trouble shooting and repair of observatory equipment. There is no need to maintain a high-level staff at the observatory itself.

At the institutions discussed above, many of the research scientists who use the telescopes are directly involved in the management, operation, and advancement of the observatory. A tight connection between scientists and the equipment they use for their research, in astronomy as well as other fields, has repeatedly been demonstrated as the optimal way to do science. Furthermore, by having the observatories under the direct control of the sponsoring institutions, it is possible to incorporate and stimulate other activities that are part of the institutions' mission. In the case of Lick and Palomar, and many other observatories, the sponsoring agencies are educational institutions. Having the observatory's true headquarters located at these institutions opens up the possibility for extensive student and postdoctoral fellow interaction and education. This is especially important in the area of instrumentation. It is extremely important for the health of astronomy that there be places where the next generation of instrumentation experts are trained, and this can occur naturally at these educational institutions. In addition, the opportunity exists for considerable savings in the operations budget insofar as many of the scientists and faculty deeply involved in observatory matters have their salaries paid by the institutions as part of their appointment. In fact, many opportunities exist for cost-sharing and resource contributions by the sponsoring institutions. These forms of support for observatory operations are likely to be far more palatable to the institutions than simply writing a check and sending it off to some distant observatory HQ.

Since observers would normally not travel to the observatory to carry out their observations, provisions would have to be made at the partner institutions for remote observing locations. This is quite straightforward. There already exist dedicated remote observing facilities at the UC campuses in Santa Cruz, Los Angeles, and San Diego plus one at Caltech, that allow observers to carry out their Keck Observatory observations with little difference compared to what they would have experienced if they had traveled to Hawaii. Direct support and assistance to observers while they are observing will have to be provided, but there are likely to be multiple solutions for this. I envision that the responsibility for overall monitoring, support to the observatory staff, and major repairs for the facility instruments will remain with the institution and team that built it. With instruments that provide detailed monitoring information about their performance, it would be possible for performance issues to be recognized early-on by groups charged with monitoring performance, and instruments could be maintained at peak operating levels. Some operations funding would be provided to these groups and this would be a very cost-effective way to retain expert, dedicated involvement. It would also be an additional incentive for the partners to invest in the long-term stability of their technical groups.

Matters such as queue and service observing would also be overseen and organized either by one or more of the partners or perhaps by an HQ located at one of the partner institutions. Generally, all faculty at the partner institutions and many others who only need to work part-time on observatory matters would have all or much of their salary paid for by the partner institution, reducing the "standing army" problem. It is unlikely that a major headquarters is needed for the observatory at or near the partner institutions. More likely, a small headquarters will be located at one of the partner institutions to provide some centralized general oversight, management, and business function for the observatory, but even this could be partly distributed among the partners.

The major premise that underlies what I am proposing here is that the model that has worked for private observatories like Lick and Palomar, where the observatories are located at most a few hours away by car from their institutions, can be made to work when the observatory is many thousands of kilometers away. Adding to the challenge in this case is the fact that these observatories house very large, complex telescopes with extremely sophisticated instruments. Nevertheless, I believe that it can work in some form, if this mode of operation is planned for from the beginning. As I said above, it depends on the construction of high-quality, highly reliable instruments and telescopes and high bandwidth connections to the observatory. My experience suggests that these are all achievable with acceptable costs if proper management and planning during design, construction, and operation are used. Clearly a somewhat larger observatory staff will be needed for a large observatory at a remote site than is needed for nearby locations such as Lick and Palomar, but it need not be vastly greater. The cost-savings compared to present-day large observatories with local staffs of well over a 100 should be considerable.

6. CONCLUDING REMARKS

The observatory operations model proposed here is fundamentally a return to the approach that was used for decades to very successfully operate private observatories. The goal is to translate this proven approach into the context of a very large, modern observatory at a location very distant from its multiple partners. Cost savings are achieved by building a telescope and its instruments so that they are highly reliable and easily maintainable and therefore only requiring a small staff at the remote observatory whose primary job is to support nighttime operations. The telescope and its instruments will also be capable of being monitored and evaluated in detail from the partner institutions, so that informed, high-level support can be provided to the observatory staff as needed. The remote site does not require a large high-tech staff or any scientists.

The partner institutions would be deeply involved and fully engaged, as they should be, in the management and operation of the observatory, yielding economies and opportunities for cost-sharing not available with the typical large-observatory operations approach being used now. Many of the scientists involved will have their salaries paid by their home institutions. Opportunities for involvement and training of students and postdoctoral fellows would be created. The term "operations funding" can be opened to re-definition. It need not mean that a check is sent from some place to the observatory headquarters, but such support can be provided by a partner institution investing in "itself" and providing in-kind contributions that are consistent with the mission of the partner. There is opportunity for considerable creativity in this regard.

It could be the case that one or more partners, especially if they have a relatively minor share of the observatory, would prefer not to participate directly in the management and technical operation of the observatory in a major way. They would rather have their operations activities be very minimal and their scientists be primarily users of the facility. This of course could be accommodated. The extreme of this is for the partners not to adopt the model presented here, but to turn over all technical and managerial operations of the observatory to an entity expressly created for this, though of course they would retain ultimate responsibility for the scientific direction and fiscal resources of the observatory. This approach decreases the deep involvement of the partners in the operation of the observatory, with all the associated opportunities that come with this discussed above. In many ways this is similar to the Keck Observatory approach, though the founding partners still remain fully engaged in the creation of facility instrumentation. However, for Keck, the large observatory operating organization is located in Hawaii, far from the founding partners, and opportunities for direct involvement in observatory technology by the partners, other than in facility instrumentation, have been limited. Some steps are now being taken to increase partner involvement in the development projects at the observatory.

In the case where all or the majority of the partners are countries, and thus the observatory is effect a "national observatory," the model proposed here would need to be modified if individual institutions are to be involved directly in operations. I have been a long-time advocate of private-public partnerships, having more than decade ago proposed what is now the NSF Telescope System Instrumentation Program (TSIP), whereby national access to "private" facilities is obtained in exchange for NSF support for major instrumentation. For the United States I believe private institutions could and should play a significant role in national facilities. As much integration of teaching and research as possible is good for the future health of the field. Perhaps a good model is provided by the U.S. radio observatories — with national access, and operated by private institutions with NSF funds.

I believe the operations approach proposed here would limit the cost scaling-curve that has been used to estimate operating expenses for large observatories. I am sure that many people will find the model discussed here problematic, but I think it should be given serious consideration. The operations costs for the next generation of very large telescopes that are presently being discussed are so large that those figures alone may be the greatest impediments to building the telescopes.