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Contents

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Strategies for Optimizing Scientific Productivity for Future Observatories:

A “Flat World” for Astronomical Research

“...the world needs you to be forever the... generation of strategic optimists, the generation with more dreams than memories, the generation that wakes up each morning and not only imagines that things can be better but also acts on that imagination every day.”
Thomas L. Friedman

Abstract:
During the course of an observatory's life, the strategy adopted for maintaining productivity must change as scientific ideas evolve, technologies change, and other observing facilities evolve. This paper examines the convergence of trends that may lead to a "flat world" for astronomical research and a landscape dominated by factors other than aperture size. These trends include: a data enabled research capability fueled by rapid technology advances which will democratize access to information; shifting telescope economics that focus new investment strategies, and an evolving trend towards larger highly multiplexed research teams that cross institutional lines and national affiliations.

1. Introduction

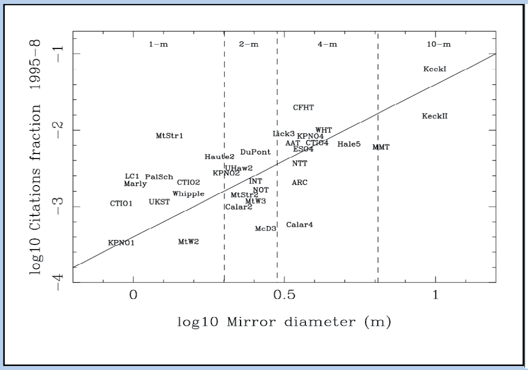
This year we celebrate both the 400th anniversary of Galileo's use of the telescope, and the 150th anniversary of the publication of Darwin's Origin of Species. Two of the most fundamental issues facing astronomers today also involve questions of origins but on an even grander and more profound scale – how did the Universe originate and what conditions are necessary for the origin of life. It is fitting, then, that we welcome the Gran Telescopio Canarias (GTC) in this dual anniversary year as a powerful new tool in what is the ultimate search for Origins.

The commencement of science operations for the GTC offers an exciting opportunity not only for Spanish and European astronomers, but for the world. And it comes at a time when observatories in the 8-10 m class are examining their own strategies for future growth. This paper is intended to examine strategies that have been employed in the past, and consider factors that may influence the future landscape.

Including the GTC, there are now 16 telescopes of aperture 6.5 meters and larger. The over-subscription rate on them is high - typically a factor of 4 or more. One decade from now there may be three extremely large telescopes-the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT), and the European Extremely Large Telescope (E-ELT). The key science questions posed to justify the construction of each of these three ELTs are similar and are also concerned with origins and evolution: the origin of the universe and life within it and the evolution of the universe's structure and content. The ambitious science programs being defined to address these key questions will take up much of the available time on all three telescopes for a number of years.

As the generation of 2 m telescopes gave way to 4 m telescopes and the 4 m telescopes to 8 m telescopes, there has been a recurring debate over how to optimize the science role and productivity of those that were "superseded". Indeed, the recent ASTRONET Strategic Plan has called for reviews of operations modes of existing telescopes in the E-ELT era. Such reviews, carried out both in the US and Europe, will need to make a reasoned judgment about, not only the continuing support of smaller telescopes, but their fundamental scientific role.

Understanding what makes an observatory productive is fundamental to developing such strategies. There are several measures of scientific productivity, although no generally accepted standard. The most common is to examine the publication rates. In a 2000 paper when large telescopes were just coming on line, Benn and Sanchez examined the scientific productivity of a wide range of ground and space-based observatories over the prior decade. They found a correlation between telescope productivity and aperture size (and capital costs). Additionally they found that 1-4 m class telescopes accounted for a significant (~15%) fraction of the top cited papers. They stated that "The strong showing by 1-m and 2-m telescopes in the 1990s augurs well for the continued scientific impact of 4-m telescopes in the era of 8-m telescopes."



HIGH-IMPACT OBSERVATORIES

Rank	Facility	Citations	Participation
1	SDSS	1892	14.3%
2	Swift	1523	11.5%
3	HST	1078	8.2%
4	ESO	813	6.1%
5	Keck	572	4.3%
6	CFHT	521	3.9%
7	Spitzer	469	3.5%
8	Chandra	381	2.9%
9	Boomerang	376	2.8%
10	HESS	297	2.2%

1990's 2000's

Figure 1: Telescope Productivity Patterns Over the Past Two Decades

In a 2009 paper, Madrid and Macchetto carried out another review of the highest impact observatories in the mid 2000s. Although 8-10 m class telescopes clearly made an impact, they found changing patterns of scientific use emerging that have equal importance. Specifically, large public data sets such as from the Sloan Digital Sky Survey (SDSS), the Hubble Deep Field, and other large-scale surveys have had impacts comparable to or greater than high impact niche programs and large aperture telescopes. The clear correlations found by Benn and Sanchez had begun to change. The aim of this paper is to examine several traditional approaches to maintianing the productivity of observatories during their evolution, particularly as larger facilities become operational, and to compare these approaches with the emerging trends underlying Figure 1. The "Flat World" described herein will result from the convergence of technology, economics, and sociology.

2. Strategic Paths for Observatory Development

There is a great deal of well-justified optimism about the enormous contributions that 8-10 m class telescopes can make over the next decade. The advent of adaptive optics (AO) on these telescopes allows them to image objects in the near-IR with a spatial resolution at or close to their diffraction limit and with greatly increased sensitivity. AO also greatly adds to the synergy between these telescopes and space observatories such as the Hubble Space Telescope. Properly equipped, these telescopes can now tackle problems that would have been impossible even a decade ago. These range from studies of close-by objects within our own solar system to high redshift galaxies near the edge of the visible universe. Such enhanced capabilities mean that 8-10 meter telescopes will be much more than handmaidens to the few ELTs to be built; the GTC and its similarly sized companions will remain powerful tools for research and exploration in their own right. A few examples of areas that are prime candidates for such research and exploration by these telescopes are:

• High resolution studies of satellites of the giant planets as well as of asteroids and the larger Kuiper belt objects. This work will add to our knowledge of planetary atmospheres and the formation and early evolution of our Solar System.

• Near-IR AO observations from the ground combined with optical observations from space at the same spatial resolution provides a powerful new tool for studying resolved stellar populations within our own galaxy as well as in other nearby galaxies. Such a greatly expanded wavelength baseline permits detailed comparison with models in order to determine star formation histories.

• Near-IR AO observations are revealing previously hidden details of circumstellar disks and planet formation outside of our solar system.

• Observations of the Galactic Center have been able to closely define the properties of the central black hole and investigate star formation in its vicinity.

• Integral Field Spectrographs operating behind AO systems can now spatially resolve the dynamical structure of galaxies that formed only a few billion years after the big bang. Such knowledge adds greatly to our understanding of galaxy formation, mergers, and accretion in the early universe. As is the case of resolved stellar populations, observations from space in the visible at the same spatial resolution can, when appropriate, provide additional insight to galaxy formation processes.

Despite the exciting science that will be done on 8-10 m class telescopes, it is appropriate to examine their role in the era of 30 m telescopes and advanced space based observatories.

One classic view towards maintaining observatory scientific productivity has been that the scientific role of an observatory transitions from one of discovery (of unknown objects or processes) to one of exploration (of known objects or processes) as it is eclipsed by telescopes of larger aperture classes. Beyond this, observatories have often attempted to optimize their scientific productivity and service to their user in a variety of different ways. The most successful strategies have been the ones that have remained flexible and able to take maximum advantage of new discoveries and new technologies. Many times these strategies have not been the ones originally envisioned.

There have been three approaches, in general, that observatories have adopted as their world view.

• Type I: Full Service a well-resourced observatory seeks to offer a full range of services and acquire a broad range of capabilities, both workhorse and niche, that meet the widest range of needs for its user community.

• Type II: Vertically integrated observatory seeks to optimize its value by establishing a synergy with other major observing facilities, for example a larger aperture class of ground based telescopes, or space missions.

• Type III: Laterally integrated observatory seeks to establish strategic relationships with observatories in its own class and leverage broader participation for its user community.

AURA manages a wide range of observatories and telescopes with successful and unsuccessful experience in all of these strategies.

3. Type I: Full Service

Undoubtedly, a full service observatory will acquire the most dedicated and loyal community that will advocate for its best interests, optimal budget, and play a central role in making it scientifically productive. The Space Telescope Science Institute, established in 1983, was from the outset, a full service observatory that incorporated imaging and spectroscopic capabilities in the UV to the near-IR, robust data archiving, data pipelining, and observer grant support. By most measures, HST is one of the most productive observatories, and one of the most productive science missions NASA has ever undertaken.

With a staff of 400 including nearly 100 astronomers, a $45M/yr operating budget, a $20M/grant program, and over 700 users per year, STScI's role extends far beyond operating HST. STScI and HST have become one of the major sustaining sources of funding and science for the entire US community. STScI/HST users have also emerged as a powerful political force and were instrumental in achieving a series of Shuttle servicing missions for HST including the one just completed.

The U.S. National Optical Astronomy Observatory (NOAO) was originally conceived as a classic full service observatory offering access in the north and south, state of the art telescopes with a diverse suite of instrumentation, data reduction tools, and a large and diverse science staff. NOAO was a major source of instrumentation nationally. By the year 2000, however, it had become clear that the resources would not allow this as a sustainable model. Increasingly, alternative access to state-of-the-art telescopes became available to roughly half of US astronomers. AURA and the community found that a different strategy was needed for NOAO as illustrated in the following.

4. Type II: Vertically Integrated

There are many well documented examples of powerful synergies that have been achieved in the field of astronomy. One of the most prominent of these is the discovery of "dark energy" in which ground-based telescopes such as the Blanco 4 m provided an initial data base for Type I Supernovae which were subsequently measured with great precision by HST. Yet, this stunning achievement was not a part of the strategic vision for either HST or the ground based telescopes that contributed to this discovery. Thus the question is whether such synergies can be predicted with enough reliability to form a long-term basis for a strategic development plan incorporating engineering choices and instrumental development.

In the US, the Gemini project received its start as one of the high priority recommendations of the Decadal Survey carried out by John Bahcall. The decade of the 90s was to be "The Decade of the Infrared" and exploited with a grand strategy that was based on complementary observations from what was then known as the Space Infrared Telescope (now, the Spitzer Observatory), the SOFIA airborne observatory, and an IR optimized Gemini observatory.

The need to provide imaging and spectroscopy in IR atmospheric windows with a low IR background telescope became a major engineering driver for Gemini's telescope structure, mirror coating, and instrumentation. Current Gemini instrumentation envisioned to exploit this scientific phase space included Michelle in the North and T-ReCS in the South, both operating in the mid IR. Yet, many of the synergies that were envisioned have not materialized.

In general, the interests of the ground-based astronomical community have remained strongly rooted in the visible. Michelle and T-ReCS are by no means the most subscribed instruments and the more common follow-up for Spitzer observations are deep optical and near-IR imaging and spectroscopy as well as radio observations. Ground based mid-IR is rarely used for follow-up because of a lack of sensitivity or need for high resolution to resolve bright sources. SOFIA has not yet entered scientific operations and it is unknown whether this will renew interest in Gemini Mid IR capabilities. For Spitzer, productive synergies have been found in other "Great Observatories" .

As another example, in the early 2000s, NOAO telescopes were envisioned to provide the scientific basis for optimizing the use of Gemini for the major part of the US community. Although there was clearly a case to be made for NOAO telescopes as an essential gateway to Gemini and other large aperture telescopes on the horizon, this linkage never emerged as a strong feature of the NOAO landscape, nor of Gemini. For the most part, observing proposals for Gemini are self-contained science cases.

Comparison of Different Recommended Infrared Facilities

Facility	Most Important Attributes
SIRTF	Unequaled sensitivity for imaging and moderate-resolution spectroscopy Broad wavelength coverage from 2 to 700 μm 7.5 (λ/30 μm) arcsecond imaging of faint sources at $\lambda > 30$ μm
Infrared-optimized 8-m telescope	0.7 (λ/30 μm) arcsecond imaging for $\lambda < 30$ μm High-resolution spectroscopy in atmospheric windows For $\lambda < 30$ μm Evolving instrumentation
SOFIA	High-resolution spectroscopy at $\lambda > 30$ μm 2.5 (λ/30 μm) arcsecond imaging at $\lambda > 30$ μm Training of instrumentalists

Figure 2: Original Role for Gemini as envisioned by 1990 US Decadal Survey

Despite some of these known shortfalls in achieving full vertical integration as a sustainable strategy, the potential for achieving synergy with the new generation of space and ground telescopes is compelling. A detailed scientific case for synergy between a thirty meter class telescope and the James Webb Space Telescope was developed by AURA's Giant Segmented Mirror Telescope Science Working Group.

5. Type III: Laterally Integrated

A laterally integrated strategy seeks to optimize scientific productivity by pooling and leveraging observing capabilities across observatories, many times in the same class. This provides a user community with a richer array of observing capabilities. For example, management and integration of the U.S. "system" of telescopes is now the central organizing principle for NOAO. Access to 6-10 m class telescopes is now successfully under way through the NOAO managed Telescope System Instrumentation Program (TSIP).

Within the U.S., as well as other countries, there has also been a re-emergence of interest in small and mid-sized telescopes. Motivated by a desire to better characterize how 1-6 m class telescopes could maximize their scientific productivity as part of a hierarchy of telescopes that could support 8 m and 30 m class telescopes, NOAO undertook a focused study referred to as ReSTAR (Renewing Small Telescopes for Astronomical Research). This can be seen as another effort to better define a vertical integration strategy.

The surprising result of the ReSTAR study, however, was that, in addition to this anticipated support role, these small and mid-sized telescopes retained an important niche in the hierarchy that was not related to larger telescopes, but simply to exploit science that was suited to this class of telescopes (a finding consistent with the Benn and Sanchez paper mentioned earlier). Some examples of this science include:

• Synoptic and time-critical observations of rapidly moving solar system objects such as comets and asteroids.

• In the rapidly growing field of exo-planet studies, these telescopes are well-suited for time domain studies of exo-planets transiting in front of their parent stars and for follow up of microlensing events.

• Studies for Star forming regions and of the inter-stellar medium via wide field imaging in both broad and narrow-band filters.

• Stellar interferometry and astero-seismology for detailed two and three dimensional studies of individual stars.

• Synoptic imaging and spectroscopic studies of variable stars and stellar clusters.

• Synoptic photometric and spectroscopic observations of extra-galactic compact objects to study the physics of accretion disks.

• Wide field surveys for medium to high redshift galaxies to study large scale structure in the Universe (Big-BOSS, Dark Energy Survey, etc.

At present, NOAO is pursuing several paths to optimize the suite of small to intermediate class telescopes in the US. The next logical step will be to engage the international community to examine the possible benefits of federating small and intermediate class telescopes on a larger scale.

Another example of an emerging lateral integration is the time exchange program the Gemini Observatory is pursuing with the Subaru Telescope and with Keck. Both of these agreements involve the exchange of classical nights on Gemini with classical nights on Keck and on Subaru. The instruments involved are those that are unique to the specific telescopes and would not otherwise be available to their respective communities, all of whom benefit.

6. Strategies for the Future: A "Flat World" for Astronomical Research

Thomas Friedman, in his book The World is Flat, has described the decline of traditional economic institutions and the emergence of a level playing field global economy. The economies of the past dominated by nations, and later by corporations, then multi-national corporations, have given way to one dominated by individuals armed with information and information technology. This was enabled by the convergence of technology, social factors, and political events, the net result of which was the creation of a global, web-enabled playing field that allows for multiple forms of collaboration and the sharing of knowledge and work. More importantly this could be done in real time, without regard to geography, distance, or even language.

It is now commonly recognized that every new technology creates new opportunities to conduct the basic activities of management and organization. Traditional management activities that have relied on hierarchical organizations (i.e. someone being in charge) such as

• Accumulating and allocating resources

• Coordinating and controlling activities

• Motivating and aligning efforts

are increasingly being redefined and overtaken by technological innovations. A flat world is a world without hierarchy but not a world without shape. Leaders

- – Aided human eye
    - • Large information content, low recording rate
- – Photographic Plate
    - • Large information content (1 MB/cm2, ~3 GB/plate)
    - • Moderate recording rate (QE ~2-4%)
    - • Analysis and distribution limited
- – 2-d photon counting arrays (4kx4k)
    - • Large information content (30 – 300 MB)
    - • High recording rate (high QE)
    - • Analysis can be automated
    - • Distribution widespread (tape, CD, internet)
- – 3-d energy resolving arrays
    - • Enormous information content & data rates
    - • 12k x 12k x 100(l) x 2 Bytes: 100 GB

Figure 3: Evolution in Information Technology

in all fields, including science, will be successful only if they can perceive this shape and capitalize on it.

This has a strong parallel in the field of astronomy. Despite the successes and failures of the three world views characterized above, these are all linear strategies based on a static landscape, a landscape that is now changing. There is now a convergence of technology, economics, and sociology that is creating a new (level) playing field which is no longer dominated by institutional status nor aperture size alone.

The observatory today is a hierarchical ecosystem involving a complex array of technical and sociological factors that go far beyond glass collecting area. The vision of the Director and scientific staff, form of organizational governance, culture of its user base, structure and practices of the Time Allocation Committee, choices of operating modes, etc., all dramatically affect the approach to doing research and resulting output of an observatory.

The past has been dominated by a structure in which observatories have cultivated user communities expected to not only exploit technical and scientific advantages, but to advocate and remain loyal. The reward for the astronomer was the receipt of data. Astronomers fortunate enough to gain access to cutting edge facilities and acquire these data prospered; this hierarchical world was accepted. The observatory played a central role with the largest telescopes providing the most valuable data.

Figure 1 suggests a dramatically changing landscape for the role of observatories in the future. A level playing field for science productivity has begun to emerge that is independent of the size of the telescope, or the hierarchical status of the astronomer. This landscape has begun to "flatten" for several reasons including:

• Information: the ability to produce, transmit and use astronomical data,

• Economics: a dramatic shift in the economics of telescopes vis-à-vis their instruments, and,

• Sociology: an emergence of large scientific teams versus lone astronomers.

7. Information

The increasing ability to collect, transmit, and understand large volumes of information has caused a paradigm shift from one in which the focus of investment was the telescope itself, to one in which a highly multiplexed instrument has become the focus of investment, with the telescope being a minor partner. Technology for producing data has progressed at an astonishing rate from photographic plates to two dimensional photon counting arrays, to three dimensional energy resolving arrays. From figure 4, the relative increase in mega-pixels used in astronomical observations has increased substantially faster than the growth in glass collecting area. This has focused the need to establish workable public archives and effective tools for accessing and using this increasingly massive amount of information.

The Virtual Astronomical Observatory in the US and the International Virtual Observatory are intended to provide an array of such tools. As shown in table 1, within the US alone known archives account for over 500TB with a growth rate of nearly 250TB/yr. The onset of future observatories such as ALMA will add considerably to this. The Large Synoptic Survey Telescope (LSST) will generate 30 TB per night over ten years of operations.

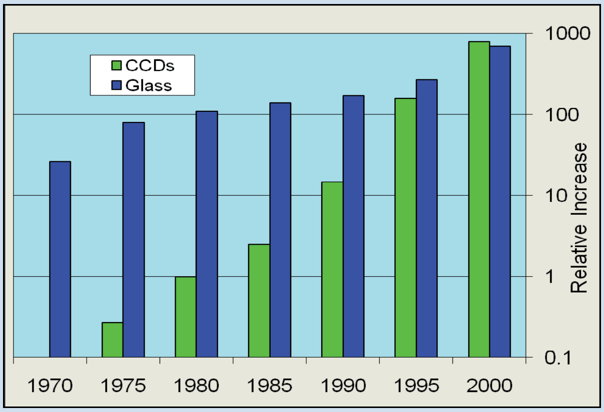


Figure 4: Relative increase in cumulative Glass and Megapixels for all telescopes

Public data bases from surveys have enabled research by astronomers from all institutions, at every stage of their careers. It is no longer necessary for a small institution to be marginalized as a minor partner in a big project. The Sloan Digital Sky Survey accounts for nearly 2,500 publications thus far. Of these, nearly 2/3rds are authored by astronomers not part of the SDSS consortium. As seen in figure 5, Hubble Space Telescope accounts for about 700 publications per year, half of which are from archival data. To date, there are nearly 1,400 publications using Hubble Deep Field data.

This trend also addresses a major need in the US and other countries to ensure that investments in research have the broadest possible impact and achieve social goals that are perceived to be part of the contract between the science community and public funding institutions.

US Archives	2010 Holdings (TB)	GROWTH RATE (TB/yr)
Space Telescope Science Institute	113	65
Goddard (HEASARC)	70	12
Chandra Science Center	14	1.5
Spitzer Science Center	26	6
NASA/IPAC (IRSA)	50	50
NASA/IPAC (NED)	5	0.2
SAO Astrophysics Data Sys	10	0.5
TOTAL SPACE	288	135.2
NOAO	47	10
NRAO	70	50
GEMINI	7	0.9
KECK	4	1.5
SMA	4	0.6
Arecibo	40	55
Sloan Digital Sky Survey	88	--
TOTAL GROUND	260	118

Table 1: U.S. Data Holdings and Growth Rates

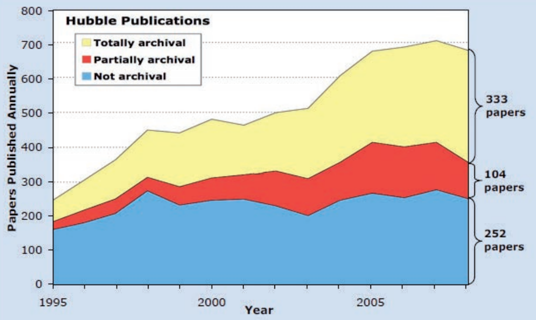


Figure 5: HST Publication Statistics

Large utilitarian, well-constructed, and well calibrated data sets in accessible archives such as has been the example of the Great Observatories, and future dedicated survey telescopes such as the Large Synoptic Survey Telescope have vastly diminished the value of raw data, the currency of the past on which the present hierarchical structure is based. An expectation is rapidly growing that astronomical data should be considered a public good and freely and immediately provided to all. This surely will democratize the future sociology of astronomy. The former paradigm in which an observatory depended on a community of strong advocates and users that identified with the telescope and guided its scientific development may give way to new culture.

NOAO, the US national observatory, is also in the process of making a transition from its traditional role to serve a broad segment of investigators to one that will utilize its venerable Blanco telescope to conduct a Dark Energy Survey to use over 500 nights over a 5 year period. Under consideration also is to use the Mayall 4 meter telescope to undertake the BigBOSS survey of a similar magnitude. It is significant that these projects are strongly influenced by the interests of the US Department of Energy and the high energy physics culture.

For Gemini, the present time allocation system is currently divided among six partners, two hosts, and the Gemini staff making it exceedingly difficult to allocate large blocks of time that would support surveys of the type that could enhance its productivity.

8. Economics

It is significant to note that for the highest impact entry in Figure 1, SDSS, the 2.5 m telescope itself was a minor partner in its success. The creators of Sloan focused their attention at the outset on the camera and the mass of data it would produce. While the telescope itself cost about $6 million, the imaging camera and spectrograph was in excess of $7.5 million. In annual operating cost for operating the telescope and managing the data was over $5 million per year, well in excess of the "standard" 10% of capital costs.

This reversal of traditional observatory economics poses great difficulties in the context of the present funding system which has been strongly focused on financing and building the telescope itself rather than building instruments and the collecting and processing of large data sets. The Wide Field Multi Object Spectrometer (WF-MOS) which was under consideration by the Gemini Observatory would have cost as much as a Gemini telescope itself. Unfortunately the extent of this shifting landscape was appreciated only too late and the effort was cancelled.

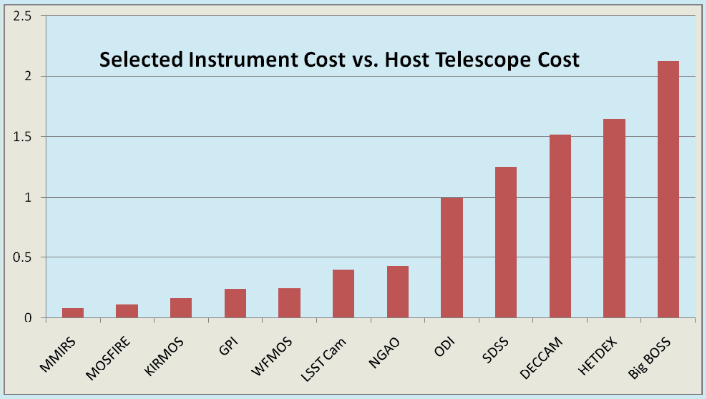


Figure 6: Selected Instrument vs. Telescope Cost Ratios

Figure 6 illustrates some instruments and their relationship to their host telescopes. These consist of instruments beyond the resources of the host observatories and funded through the Telescope System Instrumentation Program, some recent Gemini instruments, and present and future instruments, some of which are on older NOAO telescopes. Those on the right hand portion clearly redefine traditional telescope economics (see end notes for instrument descriptions).

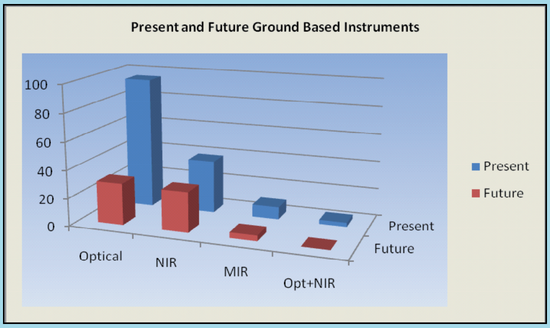


Figure 7. Survey of Planned Instruments

There are many factors that can account for this shift in the economics of astronomical instruments. Figure 7 is the result of a 2005 survey conducted by Simons et al. which shows the increasing trend towards number of planned NIR instruments out of the traditional optical regime. The most important reason is related to the science drivers for future discovery.

	Optical	Infrared
Current	$400,000	$3,750,000
Future	$6,600,000	$5,000,000

Table 2. Current and Future Median Instrument Costs (From Simons, et al)

First, fundamental cosmological questions require the discovery and study with imaging and spectroscopy of large numbers of very distant objects. One of the key science cases for larger telescopes is based on observations of objects whose spectrum is shifted into the near-IR. Second, observations of dust obscured regions, such as the center of the galaxy, regions of star formation, and extra-solar planetary systems, also require infrared observations at the highest spatial resolutions that will be supplied by AO systems. Equally important are multiplexed detectors that are only available from industry. Given that the market for these detectors does not extend far beyond the astronomical community, their cost remains high, as does the cost of AO systems and related laser hardware.

Another major science driver is the increasing emphasis on ultra wide-field surveys which need Giga pixel CCD mosaic focal planes in the visible. Comparable large infrared focal planes are currently beyond the resources of most astronomers, but would drive this economic trend even more strongly. Table 2 shows the current and anticipated costs for optical and infrared instruments for all telescopes from the Simons et al survey. Clearly, the costs of optical instruments with large multiplexed arrays are anticipated to increase by more than an order of magnitude. Infrared instruments are already costly and will continue to be so due to the limited market for array suppliers.

The transition from building instruments for 4 m telescopes to building instruments for 8 m telescopes was a difficult one in the US community. The old management paradigm which depended on the talents of one or a limited number of instrumentalists, most times located at universities, is giving way to one based on sometimes dispersed teams involving many institutions. For detectors, the core of the discovery potential for an instrument, astronomers are becoming increasingly dependent on commercial industrial suppliers which are rooted in the aerospace culture. Thus the interface between these two cultures must necessarily adapt to the aerospace standard.

The cost of the management approach is now significant, but proving itself necessary as the instruments increase in size and complexity. There is not yet experience in going from 8 m class instruments to 30 m class instruments, however the TMT and GMT projects within the US are concerned with fielding a usable class of first light instruments that can provide an initial science potential, with consideration of second generation instruments to truly take advantage of the larger apertures.

The era of 30 m class telescopes and James Webb Space Telescope will strongly affect the economics of astrophysical research and the public perceptions of its costs and benefits.

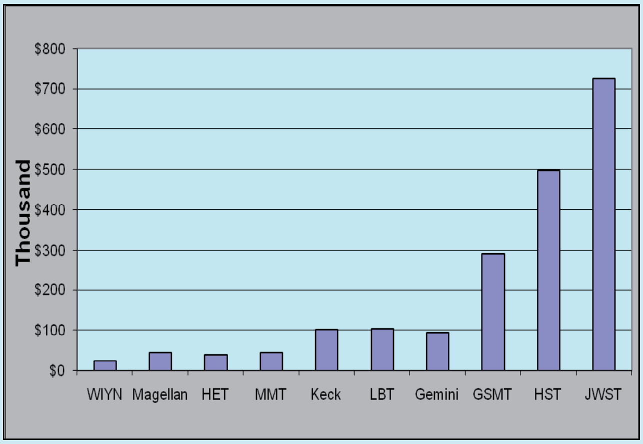


Figure 8: Opportunity Cost per "Night" for Selected Telescopes

Figure 8 compares the cost of current 6-10 m class observatories in the US with the "nightly" cost of operating the Hubble Space Telescope at present and the James Webb Space Telescope in the middle of this decade. Also included is the anticipated cost of operating the 30 m class Giant Segmented Mirror

Telescopes under consideration. Clearly, there is a reasonable gradation given the relative scientific contributions these are expected to make. However these costs are large and there is a need to ensure that the 6-10 m class telescopes are optimized in their use.

In the US, the community is undertaking Astro2010, its decadal survey. One initiative under discussion is a “National Treasure Program” for the next generation of 8 m class instruments. Recognizing the high cost of the new generation of instruments, this initiative seeks to place the highest leverage instruments on the most compatible and useful telescope, whether this is a public telescope or one operated by an independent or private entity. Public access would be granted on a competitive basis.

9. Sociology

In addition to information and economics, an equally important trend is taking place with the rapidly growing prevalence of “teams” in astronomical research. Unlike Friedman’s flat world in which the information empowered individual emerges as the evolutionary end state, the astronomical world began with the individual and is evolving in the opposite direction. Not only are the investigator teams growing larger, they cross observatory lines and rely more and more on facilities across the electromagnetic spectrum and from space and ground. This can be quantified by looking at how many authors have contributed to the 100 most cited astronomical papers each year. Figure 9 shows that over a six year period the total number of authors for the top 100 papers has doubled, going from an average of 10 per paper in 2001 to 20 per paper in 2006. Figure 10 shows that such large team publications have large impacts in terms of citation rates. This same analysis also suggests a dramatic increase in the number of highly cited publications based on data from multiple facilities. The astronomy community itself is undergoing a lateral integration that crosses the boundaries of observatories, institutions, and countries.

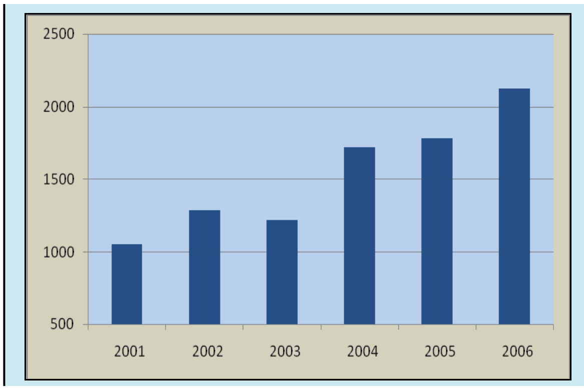
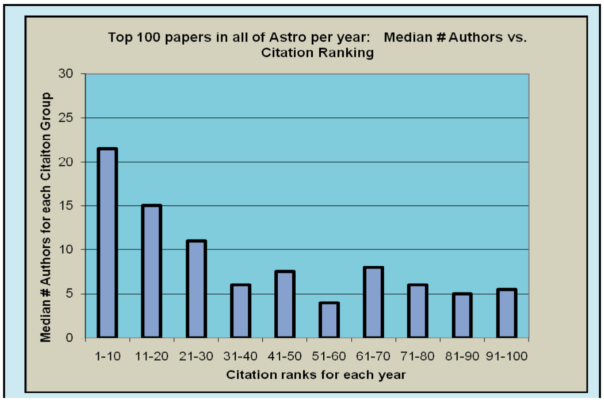


Figure 9: Author Count for top 100 papers.
Figure 10: Citacion Rates vs. Author Count.



10. New Directions

The convergence of these three factors—a data enabled research capability fueled by rapid technology advances, shifting telescope economics that focus new investment strategies, and an evolving trend towards larger highly multiplexed research teams—will flatten the world of astronomy. With regard to observatories, these factors could also lead to a stronger integration of observing capabilities across all present telescope classes and eventually for 30-40 m class telescopes. In order to achieve a full exploration potential, complementary instruments, time trading between observatories and a more facile way of forming collaborative teams will be needed.

While there will still be a need for efficient and rapid follow up with capable instruments, a more important role could be fulfilled. Rather than becoming just a support telescope for JWST and ELTs, the GTC could become a powerful element of a broader array of 8-10 m telescopes that can offer the collective community capabilities not otherwise available.

Scientific drivers for this exploration role are as likely to be derived from rich databases such as the LSST as any extremely large telescope, and will be carried out by groups of astronomers from many different institutions. It is crucial to remove barriers that might affect the competiveness of new observatories in this new landscape.

In this future landscape, astronomers will not be impeded nor advantaged by the present institutional structures, but will exploit the available phase space for optimizing their research capabilities. The astronomer of the future may well envision a research program that includes an observing program on Keck (through NOAO's TSIP program), object monitoring by a global network of 2 meter telescopes (through the ReSTAR program), observing programs on VLT and GTC (through research team colleagues), a queue scheduled target of opportunity on Gemini, access to JWST and HST archives, and access to a vast LSST real-time database. Focusing a broad range of observing tools on a single problem will define this landscape. None of this requires that such an astronomer be part of an institutional partnership, nor even that the astronomer be at some top-ranked institution, simply that the astronomer be creative.

Such a shift will surely affect the loyalties and political support expected of user communities towards their observatories, and the strategies that astronomers will use in justifying funding from governments and private funding sources. The very concept of judging the productivity of "an" observatory and comparing its ranking with others will be moot in this highly integrated environment.

Within this environment, the GTC has an opportunity to define its future and that of its user community. Who are its user community and what will they want? What linkages will they want with other observatories, user communities, and elements of the new landscape? The "flat world" scenario offers opportunities and challenges as never before.

11. INSTRUMENTS

MMIRS—The MMT and Magellan Infrared Spectrograph is a wide-field near-IR imager and multi-object spectrograph built by SAO, based on the FLAMINGOS and FLAMINGOS 2

MOSFIRE—Keck Multi Object Spectrometer for Infrared Exploration will provide NIR multi-object spectroscopy over a field of view of 6.1' x 6.1', one atmospheric band at a time: Y(0.97-1.12μm), J(1.15-1.35μm), H (1.46-1.81μm), or K(1.93-2.45μm).

KIRMOS—Keck Infrared Multi Object Spectrograph, intended to provide an 11.4 x 11.4 arcminute FOV for imaging and approximately a 4 x 11.4 arcminute FOV for multi-object spectroscopy (R ~ 4000) with a multiplex of 100 to 150 objects.

GPI—Gemini Planet Imager, will provide diffraction limited images between 0.9 and 2.4 microns. The system will be able to see objects ten million times fainter than their parent star at separations of 0.2-1 arcsecond in a 1-2 hour exposure. The science instrument will provide spectroscopy of any object observed.

WFMOS—Gemini Wide Field Fiber Multi Object Spectrograph, intended to be installed on Subaru, would provide Gemini/Subaru with the capability of simultaneously obtaining moderate to high-resolution (R=1,000-40,000) spectra of ~4500 targets in a field of view of 1.5 degrees in diameter.

LSST CAM—The LSST camera will be a large-aperture, wide-field optical (0.3-1 μm) imager designed to provide a 3.5° field of view with better than 0.2 arcsecond sampling. The image surface is flat with a diameter of approximately 64cm. The detector format will be a mosaic of 16 Mpixel silicon detectors providing a total of approximately 3.2 Gpixels.

NGAO—Keck Next Generation Adaptive Optics system will incorporate multiple laser guidestar tomography to increase the corrected field of view and remove the cone effect inherent to single laser guide star systems. The improvement will permit higher Strehl correction in the near-infrared and diffraction-limited correction down to R band.

ODI—One Degree Imager on the Wisconsin Indiana Yale NOAO 4 m telescope on Kitt Peak. The focal plane of the optical imager will be sampled with 0.1" pixels, or 1 Gigapixel in total. The sharpness of images will be actively improved by correcting images for tip/tilt image motion during the integration corrections will be done over the entire field of view, using an Orthogonal Transfer Array CCD.

SDSS—Sloan Digital Sky Survey camera and spectrograph. The camera includes 30 CCDs arranged five to a column. Each CCD is made up of more than four million pixels.

DECCAM—Dark Energy Camera on the NOAO Blanco 4 m telescope, a 3 sq. deg. mosaic camera consisting of a large mosaic CCD focal plane, a five element optical corrector, five filters (g,r,i,z,Y)

HETDEX—An upgrade of the Hobby Eberly Telescope in order to measure Dark Energy. The project has three parts: upgrade of the HET to have a 22 ' diameter field-of-view, deployment of the VIRUS integral field spectrograph, and completion of a wide field survey to constrain the evolution of dark energy.

BIG BOSS-- The BigBOSS experiment is a proposed ground-based dark energy experiment on the NOAO Blanco 4 m telescope to study baryon acoustic oscillations and the growth of structure with an all sky galaxy redshift survey. A 4000-fiber R=5000 spectrograph covering a 3-degree diameter field will measure BAO and redshift space distortions in the distribution of galaxies and hydrogen gas spanning redshifts from $0.2 < z < 3.5$.