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Gemini as Pathfinder for 21st Century Astronomy

> *"We have been going round a workshop in the basement of the building of science. The light is dim, and we stumble sometimes. About us is confusion and mess which there has not been time to sweep away. The workers and their machines are enveloped in murkiness. But I think that something is being shaped here – perhaps something rather big. I do not quite know what it will be when it is completed and polished for the showroom. But we can look at the present designs and the novel tools that are being used in its manufacture; we can contemplate too the little successes which make us hopeful."*
>
> *(A. Eddington 1933)*

Abstract

Synergies between new ground- and space-based observatories are promises for the role of 8- to 10 meter telescopes, with a generous discovery space that still lies ahead in the coming decade. I explore examples of science areas where our largest ground-based telescopes can build up a precious inventory of targets and fields to be probed deeper with the coming Extremely Large Telescopes (ELTs). The operational model of the Gemini telescopes is dominated by queue/service observing. A visiting and interaction model that helps to re-engage astronomers with their "machines" is presented and discussed. I surmise that ELTs may not be the last generation of single aperture ground-based optical-infrared telescopes. The recent history of radio astronomy–going in the direction of un-filled reconfigurable arrays of antennae–points to the increasing importance of interferometry in optical/infrared astronomy. Finally, I share some candid lessons learned from the Gemini partnership that deal with operational issues and governance.

1. Introduction

In late November and early December 1609, Galileo Galilei observed the sky with a small telescope of his own design and fabrication. Its aperture (30-50 millimeters) was tiny. To minimize aberrations, he had sized down the aperture with a diaphragm. Compared to the giant telescopes of today, his apparatus was extremely modest. Still, the discoveries that it enabled were staggering and rocked the 17th century scholarly world. The invention (a rather complex and debated topic) and early use of the telescope had a dramatic effect on the course of astronomy. The subsequent application of the telescope to the whole electromagnetic spectrum is proof of the success and power of this versatile observing tool. Today's telescopes have become giant hi-tech machines run by sophisticated organizations. It is significant that the Gran Telescopio Canarias (GTC) is being dedicated almost exactly four centuries after Galileo stupendous achievement.

In the middle of the coming decade, the infrared James Webb Space Telescope (JWST) will start operating. The Hubble Space Telescope (HST) will likely have been decommissioned. As HST did, JWST will have a huge scientific impact and also influence the way ground-based observatories operate and follow up on their discoveries. Synergies with the radio millimeter Atacama Large Millimeter Array (ALMA) expected to be in full operations in 2012 will be enormous. Large dedicated survey telescopes (Pan-STARRS (Panoramic Survey Telescope & Rapid Response System) 1&2, VISTA (Visible and Infrared Survey Telescope for Astronomy), VST (VLT Survey Telescope) or Subaru Telescope/HyperSuprimeCam) now coming on-line will be very powerful for finding new objects and transients that will require spectroscopic follow up on 8 to 10 meter telescopes.

The Large Synoptic Survey Telescope (LSST, still not funded, and unlikely to be so within a few years) may start operations on Cerro Pachón, Chile around 2018. Because of its mission and capabilities, this powerful survey facility will put huge demands in terms of spectroscopic follow-up. Robust "Point-and-shoot" capabilities will become essential for the next generation of ground-based telescopes. Interestingly, the GTC is located at a meridian that will increase coverage of the diurnal time domain from both hemispheres.

Large gains made by the current 8 to 10 meter aperture telescopes will not be attributable to aperture size but successful active and adaptive optics systems that have demonstrated that the turbulent structure of the atmosphere is amenable to analysis and correction (Mountain 2000; Smith 2009). Also, new developments in spectrograph design (single slit, multi-object, integral field unit, immersed gratings, cryogenic system, detector technology etc.) for all wavelengths have equipped astronomers with enhanced tools that would have been dreams a few decades ago (see, for example, the review of European Southern Observatory (ESO) optical spectrographs by Dekker 2009).

Any Extremely Large Telescope (ELT) with fully-operational instruments will come into full science operation only during the first half of the 2020s. Hence, the current generation of 8 to 10 meter telescopes have a ten-year window of scientific “freeway” ahead with a generous discovery space.

2. Gemini science niches for the ELTs

The Gemini telescopes (Figure 1 and 2) built and commissioned during the 1990s, started science operations in late 2000 (Gemini North) and 2001 (Gemini South). The two 8 meter optical/infrared telescopes are separated by 11,000 kilometers and present some interesting technical, and logistical challenges. They have been under steady operation for about eight years (as of mid-2009) and their lifetimes are likely to overlap with the next generation of 20 to 42 meter behemoth telescopes. What can the role be for telescopes such as Gemini in the preparatory and transitional era for these new machines? Among several possible areas Gemini, and others, can lay the groundwork for ELT exoplanets research, fine-scale spectroscopic mapping of galaxy cores and gamma-ray bursts study as sites of first light objects.

3. Imaging of exoplanetary systems, a pathfinder for exploring outer worlds

Everyday the field of exoplanet imaging research is progressing in ways and with jumps that appeared impossible yesterday. The current trends in discovery will continue to be driven by the massive efforts from space and ground facilities (now including several amateur programs that monitor planetary transits). The techniques of reflex motion and primary/secondary eclipsing by planetary companions will continue to reveal hundreds of planets, from a few Earth masses to that of several Jupiter, from the rocky/watery smaller bodies to giant gaseous, brown-dwarf-like objects and perhaps even stranger objects. However, we now have the means to go beyond these baby-steps with direct imaging of exoplanetary systems.

Figure 1. View of the Gemini North telescope with its 12-Watt solid-state laser beam propagating for laser guide star adaptive optics observations.

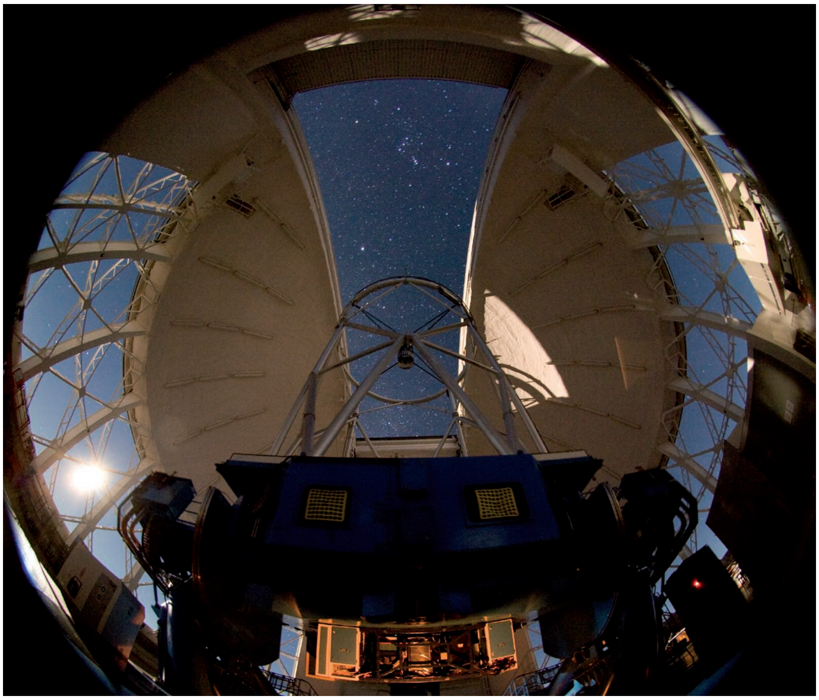

Figure 2. View of the Gemini South dome (from inside) and telescope. The Near-Infrared Coronagraphic Imager (NICI) is the instrument visible attached to the Cassegrain instrument support structure. Three other instruments (not visible) are mounted on the remaining ports.

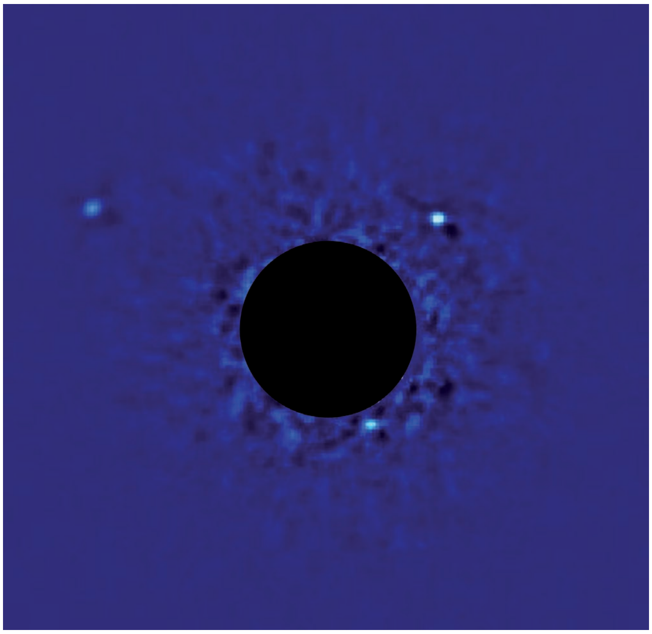

Figure 3. The exoplanetary system of nearby star HR8799 as viewed in K-band by Gemini North NIRI infrared imager. The system was discovered using the adaptive optics system on the Gemini North and W.M. Keck telescopes. (Credit: Marois et al. 2008)

It is up to the current generation of large 8 to 10 meter telescopes equipped with very high contrast adaptive optics imagers and spectrographs to build an "atlas" or inventory of exoplanet systems. These will be probed by imaging to further depths by the ELTs a decade from now. Indeed, systems now on-line at Gemini (NICI), Subaru (CIAO), Keck and VLT (NACO) are capable of building a large inventory of known exoplanetary systems and and leading to a grasp on the nature of extra-solar planets (Figure 3). The Gemini Planet Imager (Macintosh et al. 2006) and ESO/SPHERE (Beuzit et al. 2006, 2008) will take this to the next step by boosting our ability to perform spectroscopy on these systems.

A new era of characterizing the physical, chemical and biological states of exoplanets has already begun. While many parameters will require JWST, ALMA and ELT capabilities, the current 8 to 10 meter-class telescopes, equipped with adequate instrumentation are capable of searching for key but simple bio-signatures or biomarkers (such as H_2O, O_2 or O_3 and the "spectral edge" of vegetation that indicates plant cover) in well-identified exoplanetary bodies. Both direct spectroscopy of the planetary objects, or their transit observations, allow planetary structures and atmospheric studies, e.g. from high precision light curves and transit spectroscopy (e.g. Redfield et al. 2008).

In summary, the current generation of large 8- to 10-meter telescopes can play a key role in building an inventory of exoplanet systems to be probed deeper with the ELTs.

4. Mapping the cores of galaxies and meshing IFU datacubes

The study of the centers of galaxies has become an important step in understanding their merger histories and the growth of massive objects in their cores. Measurement of reliable stellar kinematics of the center of galaxies is important in generating maps of mean stellar velocity, velocity dispersion and higher order moments of the line-of-sight velocity distributions. It is important to make these maps at different scales and mesh them together. It is also essential that the highest spatial resolution be obtained in regions where the velocity fields change rapidly on a small scale, i.e. at the core of the galaxies. For example, Figure 4 shows the kinematics at the center of the galaxy NGC 7332 as extracted from datacubes produced by the SAURON (Spectrographic Areal Unit for Research on Optical Nebulae) integral field unit (IFU) spectrograph on the 4-meter William Herschel Telescope and by the 8 meter Gemini Multi-object Spectrograph (GMOS) IFU. The top left image was taken from the SAURON velocity map from Emsellem et al. (2004). The top right image is the GMOS 5”x7” 0.2”/spaxel close-up of the inner part of that galaxy showing a level of detail in the velocity map that SAURON’s 0.9” spaxels could not see (Maier et al. 2009). The bottom right is a close-up of the SAURON map scaled up to the size of the GMOS field (Falcon-Barroso et al. 2004) which shows how much more detail can be seen with smaller pixels or finer resolution provided by the GMOS-IFU. Still larger scale and lower resolution mapping remain essential to fit the different scales properly.

The point of this comparison (Figure 4) is to show that very unexpected things can be seen at different resolutions. For instance, in this case, the SAURON team was relatively sure that there would be a kinematically decoupled core (KDC), as the “S” in the zero velocity line is usually a good indicator that in higher spatial resolution the subcomponent can be

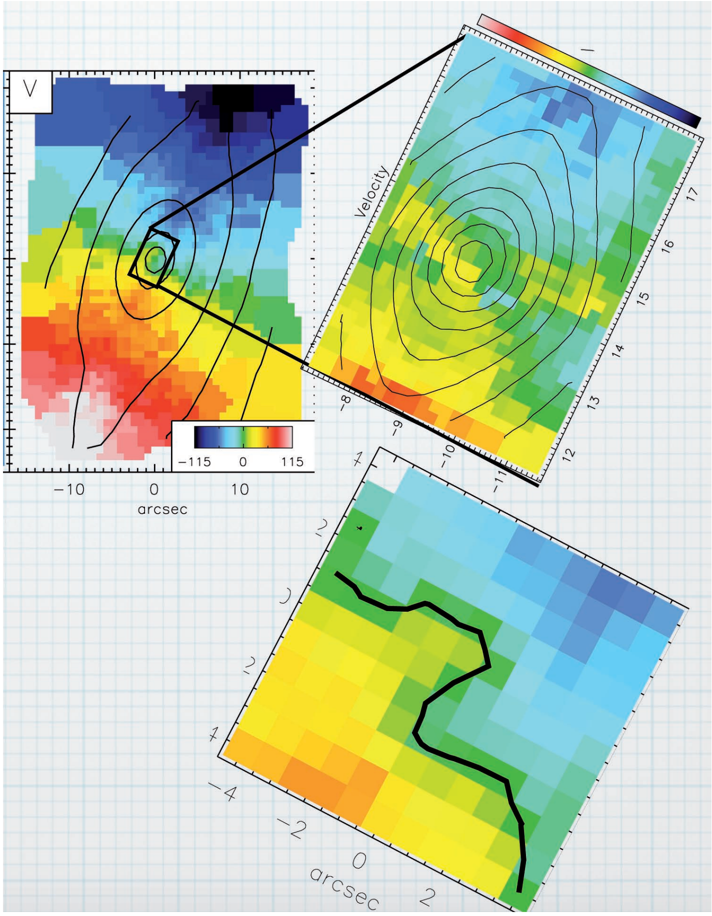

Figure 4. Comparison of the line-of-sight velocity fields of the central regions of the SO galaxy NGC 7332 as measured by integral field unit spectrographs on the William Herschel Telescope (WHT, left) and Gemini North (right) from Maier (2008).

resolved. In this case, this galaxy had undergone a minor merger so recently that the subcomponent has not had enough time to settle into a regularly rotating KDC. This is backed up by the age of the stellar populations and by calculating the dynamical time in the center. Probably what we are seeing here is a KDC in the making. This very centralized tri-axial structure is most likely temporary (as this is a very fast rotating S0 galaxy with very low velocity dispersion) and after one dynamical time will look more like a more smoothly rotating subcomponent.

5. GRBs at z > 7: signposts for proto-galaxies

Locations of distant Gamma Ray Bursts (GRBs) are fields to be blind-imaged in the near-future with JWST and ELTs. Very high redshift GRBs are the smokestacks of intense massive star factories. With the observation of the first GRB at $z = 8.3$ (Tanvir et al. 2009), we are now probing the re-ionization era (Figure 5). Before the ELT era opens, another way to apply "gain" to the problem of detecting objects at the extreme margins of sensitivity for 8 to 10 meter class telescopes will be to use gravitational lensing to amplify the light from catastrophic events occurring all the way back to z~20. Once detected, we will need to perform low-resolution spectroscopy to characterize the physics of these enigmatic objects. Gemini's near infrared multi-object spectrograph FLAMINGOS-2 will be equipped with a special tunable Fabry-Perot system (F2T2). Combined with Multi-Conjugate Adaptive Optics (MCAO) it will be a totally unique capability well into the next decade and could be the only system capable of detecting/characterizing these objects from the ground. Basic measurements may be only redshift, element abundances of oxygen and elementary dynamical/kinematical properties of proto-galaxies. Still, this will be a crucial step to break effectively through the $z = 7$ "wall" while waiting for ELTs.

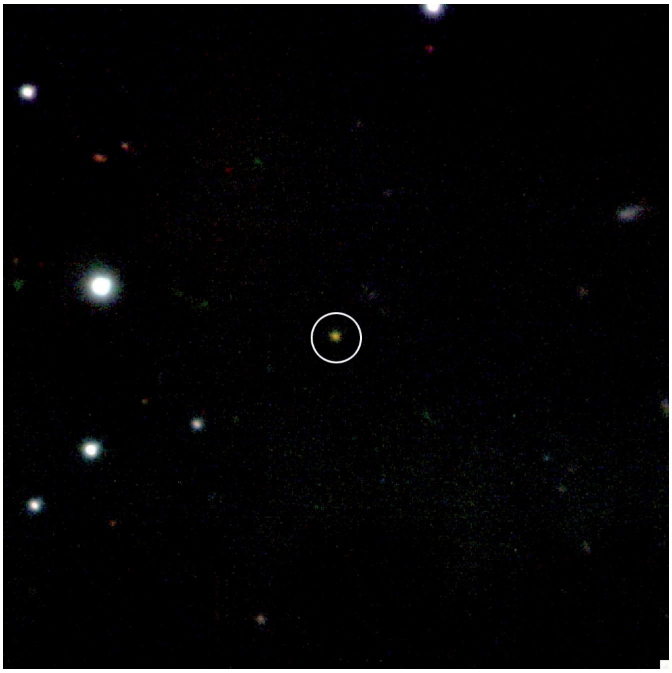

Figure 5. Near infrared image of GRB 090423 from NIRI on Gemini North. The host object is at z = 8.3 based on photo/spectro determination from Gemini, UKRIT and VLT measurements (Tanvir et al. 2009).

6. "Queue" observing and re-engaging astronomers with their science machines

The original Gemini operating model was 50% "queue" (or service observing) and 50% "classical" (i.e. observer scheduled for a fixed block of time and dates), because the Gemini Board assumed that 50% queue would not actually be used. However, the demand for queue proved to be overwhelming. Gemini's current operational model of 90% queue 10% classical (determined by demand) is rather unique, but not exclusive, amongst 8 to 10 meter telescopes. The transition to 90/10 was therefore dramatic.

Gemini has conclusively shown that the multi-instrument queue model delivers completed science programs in the conditions required, for the highest ranked science programs. Nevertheless, queue or service observing on this scale is still rather new to the ground-based community and it is just now being learned. Hobby-Eberly Telescope (HET), South African Large Telescope (SALT) and VLT also have an observing model dominated by queue and new telescopes like the GTC are adopting a similar model.

Gemini's queue model enables science to be performed that simply could not be accomplished with a classically scheduled model. One example is the follow up spectroscopy of supernova candidates of the now completed Supernova Legacy Survey (SNLS) (Astier et al. 2006). The goal of SNLS was to produce a definitive sample of distant type-Ia supernovae to distinguish between the different theories of dark energy. Gemini provided spectra for 230 objects (500 hours over five years) of the 400 spectroscopically confirmed supernovae. This program utilized approximately nine hours of Gemini telescope time per month over five years. If this program were classically scheduled on one night per month, it would have had a 25% chance of obtaining the required conditions. Our regular and continuous monitoring of the large-scale cloud system on Saturn's moon, Titan, is another good example of the benefits of a queue observing model (Schaller et al. 2009).

Rapid Targets of Opportunity (ToO) programs do routinely take advantage of the Gemini queue and quick data access from the Gemini Science Archive (GSA). PIs have been known to submit follow-up triggers based on preliminary data analysis within the same night and to issue an IAU circular within hours of the observation. The quality of Gemini's networking and videoconference infrastructure, and the 15-minute average access to data in the GSA, make fast, remote data fetching a capability within the queue that is unique to Gemini.

The NICI exoplanet search campaign at Gemini South is conducted in a block-scheduling mode within the queue. The NICI campaign, which requires clear sky and very good image quality, is the top priority in the queue when these conditions are met during the "NICI blocks." Campaign target selection is a complicated real-time process. From their offices at the University of Hawaii, team members access their data within minutes from the GSA in Victoria, Canada, and provide feedback to the observers on Cerro Pachón (and/or La Serena) in Chile via a live video link.

For the period 2011-2015, Gemini will take the queue model to the next level of efficiency and effectiveness, while simultaneously addressing many of the concerns raised by the science user community. Gemini has the following main goals for science operations that could provide clues to more efficient science operations and data delivery for the future ELTs. We will try to (1); deliver all requested data for all scheduled queue programs, (2); deliver optimal signal-to-noise (or maximum exposure time) on all science targets, and (3); complete a quality assessment pipeline that runs at each telescope and which facilitates the previous goal.

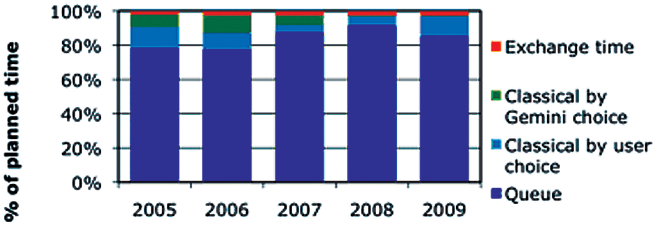

Figure 6. Statistics of queue and classical time on both Gemini telescopes over the last semesters 2005 to 2009.

In the past several Gemini proposal rounds, less than 10% of the total time requested was for classical time (Figure 6). From Gemini's perspective, the market demand is clear. However, our operational model which is dominated by service/queue observing has the disadvantage of isolating the users from the facility. This is not a good thing because of the desire to keep a synergy of innovation between the users and the observatory, and the need to train the future generation of observational astronomers. A close relationship and interaction between users and the observatory's staff needs to be developed in a different and more imaginative way.

First, the queue/service system at Gemini is very versatile and allows for last minute changes (e.g. targets or filters to be approved by Gemini management, normally with a very quick response time). Exchanges between Gemini staff and PIs can be simply triggered by "notes" in the Observing Tool requesting that we call or notify the PI (or co-I) at the time of the observations or when data are ready by an e-mail message. We also are implementing a system of fast notification of data availability. Unfortunately, not all our users are aware of this flexibility of the queue and responsiveness of the observatory. For example, we have discovered that several PIs are unaware of our "repeat" observing guarantee, if they realize that the data they have received were not obtained under the requirements they put in their proposal. While we had foreseen about 7% "repeat" of observations, we repeat only between 2-3%.

A survey of Gemini users from 2006 and 2007 showed overwhelming support for Gemini's queue operations model. Of 246 respondents, 81% expressed a preference to dedicate 75% or more of the available telescope time to queue observing, over traditional visiting observer, or "classical" observing.

Only 2% of the respondents indicated a preference for 100% classical observing, compared to 17% in favor of 100% queue-scheduled observing.

Nevertheless, many users are interested in visiting the observatory and participating in the observing process. The Gemini operations model affords this possibility in two ways: through the traditional "classical" observing mode and by welcoming queue PIs to visit the observatory while their programs are in the queue.

One of the most productive ways for Gemini users to participate in data collection is as a visiting queue observer. Gemini makes every effort, within the constraints of priority and weather conditions, to schedule the visitors program while they are at the telescope. There is no guarantee that the PI will see their program executed, but this system has been very popular and successful. This approach is particularly useful for students who come for two-three weeks and participate fully in observatory life. This offers the student much more training than they would receive by accompanying their supervisor for a two-night run on the telescope (that may be clouded out!).

"The days leading up to my time at the summit were ominous. Just a few days before, a large snowstorm hit the top of Mauna Kea. In addition, cirrus clouds had been plaguing observations the whole week prior. However, as the night of my visit approached, the weather changed and there were four photometric nights out of five. Time at the telescope was the most exciting of the visit. On a given night we would take up to six different types of observations: Coronagraphic imaging of exoplanets, Near Infrared (NIR) Integral Field Unit (IFU) observations of compact galaxies, multi-object spectroscopy. Being exposed to such a diversity of observations, I gained a deep appreciation for the difficulty of running such a wide array of instruments. However, the high point of my visit was being present when the last of my 2008B data, NIR observations of four gravitational lenses, were observed."

Ross Fadely (Rutgers University)

The user will often participate in the observations for their program, working side by side with Gemini staff, and learns more about Gemini operations in the process. The observatory benefits from the interaction as it would with a classical visitor, but retains the flexibility to make the most efficient use of the telescope time.

In semester 2008B the massive star Eta Carinae underwent a unique eruption event. This program required several epochs of observations over the semester, a program that could only have been done in queue mode. One of the Co-Investigators visited Gemini South over a 2+ week period, and participated closely in several observations, both from the summit and the base facility in La Serena, Chile.

Therefore, Gemini has developed a system in consultation with its users that allows the observational astronomers to remain fully "attached" to the telescopes and participate in different ways in the observing process and the use of the battery of complex instruments. The observatory and the staff have to remain "reachable" which is very important to ensure cross-fertilization in developing new approaches and ideas for observing strategies and future instruments.

7. Will E-ELTs be the last machines?

No!

Credible concepts of single aperture 50 meter telescopes and an array of 16 x 8 meter fully adaptive telescopes have been explored for several years now (e.g. Mountain 1997). ESO's plan to build a 100 meter optical/infrared telescope, OWL, the OverWhelmingly Large telescope indicates that ELTs are just one more step toward even larger single, full-aperture, telescopes in the foreseeable future. The November 2005 OWL review judged the project feasible, but it identified some technical risks. The review panel "recommended that the project proceed to Phase B, but that a smaller size be considered to mitigate the risks and to contain the budget" (Gilmozzi 2009). Hence the question is whether OWL will be the last machine. The currently planned Giant Magellan Telescope (GMT), Thirty Meter Telescope (TMT) or E-ELT are not the final machines on the drawing board.

Quantum efficiencies of detectors are close to one, and therefore increases in sensitivity on the ground can only be obtained by larger aperture with good adaptive optics capability at this point (Spectroscopy is still waiting for a huge gain with efficient energy detectors that not only detect photons but measure their energy).

Could more information be acquired through means other than telescope size? Clearly if one is after spatial resolution, interferometry (especially with aperture synthesis) is the way to go. Optical interferometers for astronomy have generally been considered marginal players but this situation is changing rapidly. Several optical/infrared interferometers are operational and are providing forefront astrophysical results, such as direct measurements of the size and shape of nearby stars (see review by ten Brummelaar et al. 2009). The current success of the ESO VLT Interferometer (VLTI) that currently emulates a ~100 meter telescope as a new facility on Paranal is bringing aperture synthesis into the toolbox of the "main street" astronomer (Figure 7 and 8).

An even larger Very Large Inteferometer Array (VLIA) of steerable 8 meter telescopes would have the ability to probe structure at infrared wavelengths down to the milli-arcsecond scale. However, the real performance of VLIA will depend on the ability to concentrate a significant fraction of the flux collected by the equivalent

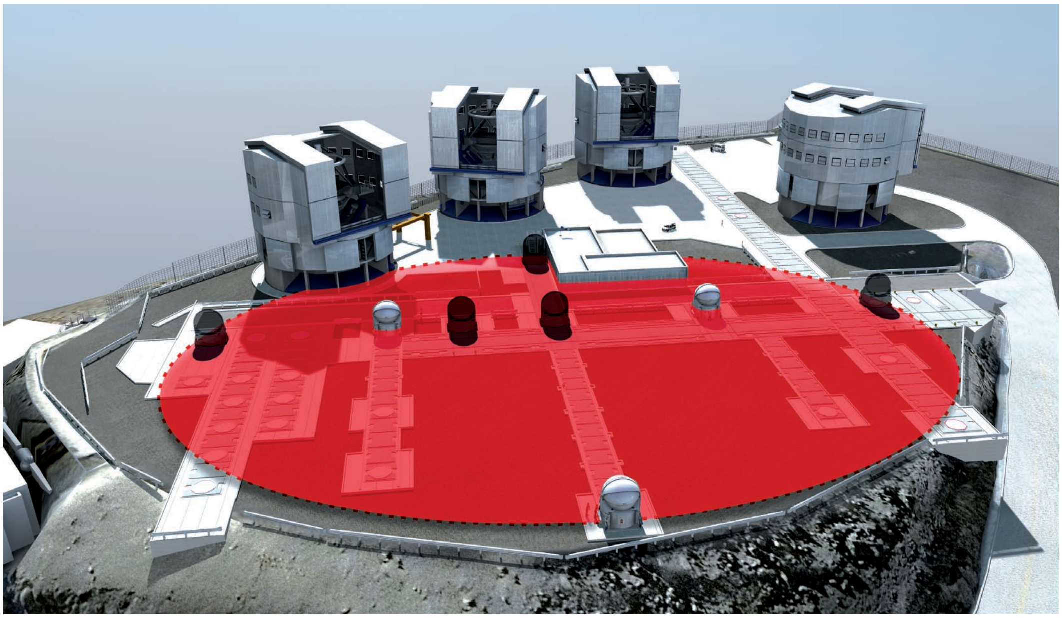

Figure 7. Virtual full aperture ~100 meter telescope as emulated by the VLTI currently in science operation at Cerro Paranal, Chile. (ESO)

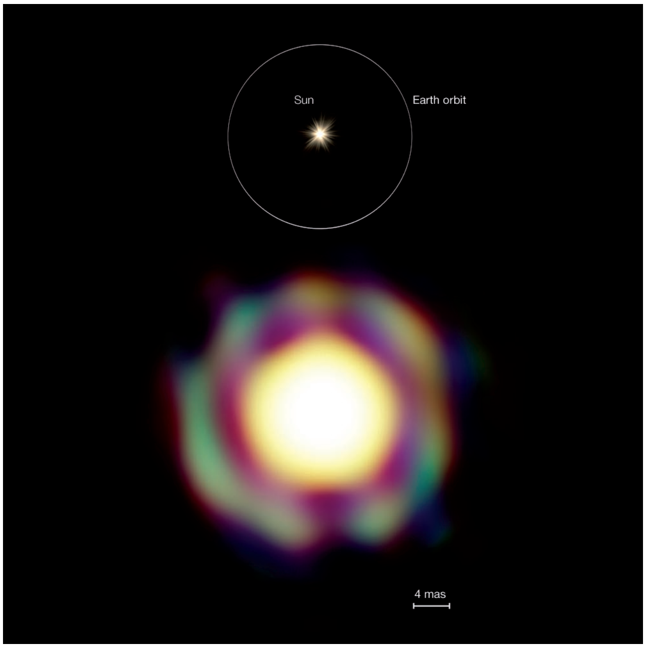

Figure 8. ESO VLTI image of the Mira-like star T Leporis with a comparison of the size of the orbit of the Earth around the Sun. Note the 4 milli-arcsecond scale. (ESO/ J-B. Le Bouquin et al.)

of a 32 meter telescope into milli-arcsec apertures while maintaining a scientifically interesting imaging field of view (Mountain 1997). Let us remember the issue is not only to increase collecting power with aperture but also decrease sky background. On this last front, a smaller telescope in space (e.g. at L2) with 10^3 -10^5 reduction in background is a very efficient approach, although still costly and risky. For the same cost of around $1B (US), a smaller size facility in space may be a serious competitor.

A quick look at the recent history of radio telescopes provides some perspective. The Office of Naval Research 600-foot radio dish at Sugar Grove initiated and canceled in the 1962 may have been the last attempt to build an enormous large single-aperture fully steerable antenna. Today the 100 meter Robert C. Byrd Green Bank Telescope is the largest fully steerable radio telescope. After the 305 meter Arecibo reflecting fixed dish and the Chinese Five-hundred-meter Aperture Spherical Telescope (FAST), radio astronomers have the ambition of the Square Kilometer Array (SKA). Large unfilled apertures is definitely the future direction. ALMA is an interesting reference point: considering the scale and complexity of the project, the size of the partnership needed to make it happen, one may ask: “Is ALMA the last mm/sub-mm facility?” Certainly this is true for some time. However, there is no indication that optical/infrared astronomers show less appetite or imagination than their radio colleagues for aperture growth or creative designs.

Non-scientific or technological considerations will drive the move, or not, to bigger apertures: cost effectiveness of ground versus space and societal threshold, institutional and national economic barriers. Indeed, we see the current ability of national funding organizations challenged by on-going projects. They may balk at providing sufficient money to built a facility for fundamental research where knowledge acquisition and prestige are the key drivers, and spin-offs are relatively minor. One important limiting factor is the cost not only to build but to also operate these extreme systems.

As pointed out by many (e.g. Roy and Mountain 2006), the globalization of astronomy is also strongly driven by external forces. Funding agencies are looking for strong national and international partnerships and prefer collaboration to competition. They also favor a strategic approach that avoids duplication of efforts, encourages the merging of the best ideas and technologies, rewards the mitigation of risks, and optimizes investments in esoteric research areas that are out of the mainstream. The European agencies, leveraging off their collective and coordinated investment through ESO, are managing to fund their current operations at a highly competitive level. This unified approach has yet to be endorsed by the US and Asian communities.

It will be extraordinary to see a significant fraction of the proposed facilities built, outside of very well coordinated international partnerships (Roy and Mountain 2006). As a project’s size grows, so does its visibility. Hence the growing importance of accountability to funding agencies for programs that utilize space telescopes and billion-dollar-scale ground-based facilities has changed the dynamics of doing astronomy on a large scale.

8. Reflections on partnership and lessons learned from Gemini

The latter remarks raise the issue and challenges of partnerships. Exemplary, and most successful, the unification of all European ground-based astronomy under ESO has brought with it a highly focused investment in key technical talent and technology.

In the New World, the development of our national institutions sometimes has had difficulty keeping pace with new funding directions and international opportunities that push astronomy toward even more ambitious partnerships. An unfavorable economic environment and emphasis of stimulus packages toward non-traditional scientific areas may be taking their toll. The current funding context in the light of global financial crisis looks challenging. However, it should encourage the re-deployment of existing partnerships and the creation of new partnerships. Since most European and American countries have saturated the market, many look at Asia as the potential for new consortium initiatives.

Many of the technologies required for new facilities (adaptive optics, large optics manufacturing, large detectors, high speed computers) will require substantial and coordinated investments to bear fruit. Contrary to previous decades, many of these technology investments (particularly those required for adaptive optics and large format infrared detectors) will not be provided "for free" by the U.S. Department of Energy, the Department of Defense or NASA. Ground-based astronomy is very much on its own this time around, and hence needs to pool resources.

As existing partnerships evolve and new partnerships and consortia develop, the lessons from Gemini, which operates under a different model from ESO, may be useful to consider. Examples of this new approach are the current exchange of observing time between Subaru, Keck and Gemini or Keck and Gemini joining forces to get two solid-state lasers through a single contract. The exchange of nights represents, at the moment, only a few nights per semester, but this trade will likely increase in the near future as it fulfills the demand of our users for multi-telescope access. This also addresses the issue of unnecessary instrument duplication by providing a path for a more coordinated and integrated environment for future instrument development.

Asymmetric partnerships. The Gemini Observatory has six contributing partners, a host institution in Hawaii (University of Hawaii Institute for Astronomy) and the host country Chile (CONICYT). The hosts have 10% of the telescope observing time. Currently Gemini Staff obtain 10% of the Gemini telescope time. Once these allocations are removed from the top, the members have the following observing time allocations: United States 50.1%, UK 23.8%, Canada 15%, Australia 6.2%, Brazil 2.5% and Argentina 2.4% in proportion to their contributions to the annual operating budget. The decimal numbers of these percentages have interesting histories in themselves. The partnership is highly asymmetric and this is reflected in the representation on the Board of Directors, the participation in instrument building, and the overall influence of each 'shareholder' in the decision making process. Asymmetry is not an issue, but having partners with too small a share is questionable. Or if a large partner runs into financial difficulty, the impact is huge.

Distributed model of support. Gemini partner agencies introduced right at the beginning of the observatory's history a system of distributed support where National Gemini Offices (NGOs) handle the telescope observing time proposal process, provide first-line support to the users and act as the intermediary between the various national communities and the observatory. After some early challenges the model has evolved enough to fulfill its core mission. ALMA has adopted a similar approach with its "arclets" system. The distributed model is drastically different from the centralized model of ESO and HST support. The advantage for a multi-time zone consortium like Gemini is a closer and faster interaction between users and observatory support staff. The inconvenience is the risk of the users getting different levels and qualities of service; quality and depth of support depend on the strength of their NGO, its funding level and quality of its staff. Thus, the observatory cannot guarantee an equal, or uniform level of quality of support to its users.

Multi-TACs. Gemini has a single centralized archive center, the Gemini Science Archive (GSA) at the Canadian Astronomical Data Center (CADC) at Herzberg Institute of Astrophysics (HIA), Victoria, Canada. However, it has nine time allocation committees (NTACs): six for the contributing partners, two for the hosts and one for the Gemini staff time. Each partner or institution manages its Time Allocation Committee (TAC) that selects and ranks its proposals. The proposals are then merged through an algorithm that ensures a fair treatment between partners. The merged list is then submitted to the International TAC or ITAC, made up of representatives of each NTAC. ITAC does the final ranked list after reviewing duplication and conflicts of proposals (science or targets) and makes a recommendation to the Gemini Director, who has full authority on the scheduling of recommended programs. The advantage of this system is that each Gemini partner owns and controls its TAC process and each country/institution has their own strategic approach, depending on their access to other 8 to 10 meter-class telescopes or instruments or science priorities. The largest inconvenience is that a multi-TAC is an impediment to large programs that require significant allocation of time in a given, or over several, semesters. Although astronomers can put in a joint proposal requesting time from more than one partner, this is very demanding in terms of multiple reviews and increases "multiple jeopardy".

Governance issues. The Gemini Observatory is under a 20 year International Agreement coming to an end on 31st December 2012. Despite a very heavy penalty for early withdrawal, the partnership has had to face the on-going threat of defaults (i.e. if a partner does not pay its annual dues) or early withdrawal (e.g. the UK announcement (and subsequent reversal) of its plan to pull out in November 2007, and now again in July 2009). This has transformed a strong partnership predicated on mutual trust into a confederation of loosely aligned interests. This has pulled future development programs in odd directions, as some partners may only provide funding for instruments deemed interesting by their specific community, with the risk of sub-critical funding overall.

This text is my sole responsibility. However several colleagues have contributed to many of the ideas presented in this paper. I am grateful to several members of the Gemini Observatory staff, members of the Gemini user community and other colleagues. I am particularly indebted to Doug Simons, Wayne van Citters, William S. Smith, Nancy Levenson, Dennis Crabtree, Inger Jørgensen, Peter Michaud, Bernadette Rodgers, Millicent Maier, Julian Christou, Joe Jensen, Matt Mountain, Phil Puxley, Thijs de Graauw, and Gustavo Arriagada.

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