Concluding Remarks

Bruce Bohannan

Kitt Peak National Observatory, P.O. Box 26732, Tucson, Arizona 85726 U.S.A. [1]

Abstract

This workshop brought proposed directions in instrumentation for the Isaac Newton Group together with scientific and technical needs of the ING astronomical community. A personal summary of the critical issues, questions, and approaches raised at this workshop includes the mission of the ING, the role of $<$4-m aperture telescopes today, the importance of continuous renewal, the power of AO, and the data glut.

Key words: observatory operations

1 Introduction

As I thought back over the past three days of many excellent and creative ideas to see if a theme had emerged, a movie popped into my mind. The documentary *Fast, Cheap & Out of Control* looks at four diverse professionals—lion tamer, robot builder, researcher of naked mole rats, and topiary gardener—to find that they have much in common. They are all dedicated, creative, fearless, outrageous, and live to leave a legacy. It offers lessons in leadership, project management, and risk management, combined with tales of crisis. As astronomers and instrument makers we can identify with such themes.

A maxim repeated often during the workshop was that new instruments provoke new ways of looking at the universe, and thus new scientific discoveries. This maxim says less about telescope aperture than it does about newness. In the era of 8 to 10-m telescopes the key to success in operating 4-m class facilities is to do things faster and cheaper than the 8-meters, yet at the same time

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enabling world-class science. We have to develop instrumentation in a shorter time so as to respond to evolving technology and new scientific challenges.

What about "out of control?" "Out of control" does not imply a run-away situation; just not in direct control, "do this, do that, don't do that!." The style of observing that we have long cherished—the astronomer at the telescope taking data all night long—may not be the only observing mode of the future. Remote and robotic observation may be cost-effective alternatives.

2 The Mission of the ING and Future Research Directions

The fundamental mission of the Isaac Newton Group is common to all research observatories. Is it to manage telescopes and instruments? To provide observing time to those who submit observing proposals? To collect photons? To complete scientific programmes? To take observations that lead to papers in scientific journals? Yes and no! The mission is more than any of these combined. The fundamental mission is to enable scientific discoveries.

Future discoveries in astronomy will build upon the remarkable advances of the past in ways that are more than adding decimal points. The challenge of the first decades of the 21st century will be to answer detailed questions about the amount and nature of the matter in the universe and to understand the physical processes that have shaped the evolution of the universe. While this begins with understanding the Big Bang itself and includes the possibility of an energy that is accelerating the expansion of the universe, all aspects of astronomy will be involved, including even those objects called stars.

The starting point in shaping an observatory's future is to assess the nature of future astronomical research, to ask what broad topics are likely to be pursued, with increasingly fuzzy predictions over decades. For the ING, what matters most are critical science issues from the UK-Dutch-Spanish perspective.

3 Do Less than 8-m Aperture Telescopes Still Matter Today?

While the largest aperture telescopes have always been a major source of scientific breakthroughs, advances in instrumentation—both new and significant improvements to existing ones—and adequate allocation of observing time are the most critical factors for most scientific discoveries. The current generation of 4-m telescopes will serve two future roles: to provide critical surveys to feed the 8-meters with selected objects and to carry out world-class research themselves (some may argue with this ordering). In addition, because 4-m apertures are no longer a scarce resource, science opportunities not possible in the past—e.g. those involving large numbers of objects or critical time sampling—can now to scheduled.

Because 4-m telescopes are well matched to 8-m spectroscopic limits, wide-field imaging and multi-object spectroscopy at 4-m apertures will be critical to the success of 8-m programmes. For example, to explore the change with time of the universe's geometry, one would identify galaxies and quasars at intermediate and high redshifts, with actual measurement of redshifts requiring 8-m aperture. To quantify large scale structure requires the discovery of supernovae on a 4-m with photometric and spectroscopic follow-up on an 8-m.

More than just feeding larger apertures, the second vital role for 4-m facilities is world-class science problems that can be solved at this aperture alone. An advantage of existing 4-m facilities over the new 8-meters is that the 4-meters are generally well equipped with instruments that cover the full capability range. Innovative instrumentation that draws upon this strength can lead to new discoveries, despite a smaller aperture. In addition, as Charles & Mason (2000, this issue) reminded us, ground-based 4-meters provide critical support of space science (see "Supporting space science projects" these proceedings).

We are seeing a renaissance of surveys and 4-m telescopes are the perfect tool. For non-limiting observations, the collecting area times the area on the sky is a good performance metric as it is proportional to the number of objects to be discovered or studied. Based on this metric, a 4-m has equal or better performance than the 8-meters with their limited field-of-view. In general, the 8-meters have one-half the field-of-view of most 4-meters, which just offsets the 2 times aperture gain to yield equal performance per exposure. Moreover, for a top 4-m equipped with a wide-field imager (e.g. 35 arc min FOV) or a multi-object spectrometer (50 arc min FOV), the advantage for non-limiting observations over the 5.5 arc min field of Gemini becomes even greater. Most critically, wide-field IR surveys are required as 2MASS simply doesn't go deep enough to feed the monster.

The study of stars themselves is not lost in answering big questions about the universe. Such hot topics as supernovae, gamma ray bursters, and the chemical element enrichment of the universe require a profound understanding of stellar physics. Indeed, star formation is a poorly understood process. In particular, we don't know much about the initial mass function—is there a universal one? does the IMF vary with chemical composition?—or about the role of binary stars. Much critically remains to be understood about stars and 4-m class telescopes will play a key role in such discoveries.

4 Instruments: New, Renewal and Retirement

In contrast to the current 4-meters, which were designed as work-horse telescopes, the 8-10-m facilities are narrowly focused with limited instrumentation. Instrument development on 4-m telescopes has a distinct cost and time advantage. The fundamental questions raised at this workshop about instruments included: What instrumentation is needed to address the science issues? What new instruments should be built? When to upgrade an instrument? How to decide when to retire an instrument?

The importance of a strategic plan cannot be stressed too much. Only by looking at the likely science questions for the future can an observatory assess what new instruments to consider. While we heard a variety of scientific opportunities, this workshop did not have the mandate to explore the future of astronomical research and of possible technological advances.

Words of advice from our discussions are tough ones. The instrumentation plan—new instruments, upgrades, retirements—is derived from the strategic science plan. From the instrumentation plan, make a list of instruments in priority order—rank new instruments highly—and draw a line where you can afford to operate at a given level of performance and reliability. In order to bring new instruments on-line in a timely fashion, old instruments may have to be retired; too many instruments leads to operational complexity.

Another way to say that new instruments enable new science is that "proposals follow instruments." Our experience at NOAO is that new instruments have a very high demand—often with 5:1 or more over-subscription ratios—and then tail off, reaching a steady-state demand of $\sim$2:1 after some five years.

Continuous renewal is the best way to keep an instrument competitive. For example, most of the "greatest hits" over the first four decades of Kitt Peak National Observatory (see the special supplement to Nature 395, no. 3701, 1 October 1998) used one of the first instruments commissioned on the Mayall 4-m telescope, the R-C Spectrograph. This venerable instrument is still highly requested on the Mayall, second only to the brand-new 8K square Mosaic CCD imager. Why? Because it has been continually upgraded with advanced technology that enabled new scientific programmes.

Where significant performance gains can be made at relatively low cost—based on science drivers, not technological gee-whiz—an instrument should continue to mine *world-class* science and then be retired when requests fall off. While it is true that it *could* continue to do *good* science, in times of scarce resources, no other option exists but to throw it into the caldera as the observatory can no longer afford to do everything. To decide when to retire an instrument, a trigger threshold for demand—e.g. if requested $<$ N nights, then this instrument is no longer productive and becomes too expensive to operate—would be a good quantitative point to start the decision. R. Bower ("The LDSS Future", 2000, these proceedings) presented an excellent model of how science should be the driver of the critical choices of which instrument to continue.

A few ING-specific comments on instruments emerged in my notes: NAOMI is clearly the top priority and should proceed expeditiously. Multi-object spectroscopy appears to be a high priority, but a plan is needed for implementation. Two faint-object spectrometers are not cost-effective; low-cost improvements should be made to enhance the margin of the one chosen.

If the UK is to continue to be a major player in instrument development, both in space and on the ground, a major observatory must be available for testing. Where else but the ING would the performance of superconducting junction detectors be determined (Peacock et al. 1998). R. Sharples ("Recent developments in Spectroscopy", 2000, these proceedings) told us of the importance of the ING to development work in fibers and IFUs.

5 The Power of Adaptive Optics

La Palma appears to be an excellent adaptive optics site, because of its low turbulent layer. ING should continue the progress made to date in developing AO technology (see C. Benn, 2000, these proceedings). Further gains in observing efficiency and in sky coverage require upgrading natural guide-star systems to laser guide-stars. J. Knapen (in "Adaptive optics imaging", 2000, these proceedings) argues that laser guide stars are very necessary to enable AO to do effective research. The Herschel telescope, and other 4-meters, have AO performance advantages over 8-m apertures by allowing narrower slits for higher spatial and spectral resolution with lower contribution from the background. This advantage is particularly significant for multi-slit and IFU applications.

6 GranTeCan and LAST

If the status quo continues, a death spiral of closures will result. First the JKT. Then the INT. Then the question will come, "Is the WHT alone a *national observatory*?" If the answer is "no," the door to La Palma will close in five years or so. The answer instead is to take bold steps to build new facilities that extend existing strengths.

By 2001, the number of 8-m telescopes will be greater than those of 4-m aperture. For example, the CFHT is considering upgrading their facility by placing an 8-m in their existing dome. Since sites on Mauna Kea are unique, upgrading a 4-m to an eight would be a revolutionary step to preserve the advantages of the Canada, France, and Hawaii partnership.

The Gran Telescopio Canaries (J. Espinosa, 2000, these proceedings) and LAST (The La Palma Spectroscopic Telescope) are two bold opportunities for the ING on La Palma. [*Eds. note: LAST was presented by N. Walton at these proceedings*[2] *as a suggested future large telescope project for La Palma. This was in the context of the Joint Infrastructure Fund opportunity. LAST would have been a clone of the Hobby Ebberly Telescope*[3]]

A related investment in SALT would preserve the important, long-term special relationship with South African astronomy and would provide access to the southern sky. An ING with an observing system consisting of the WHT, a significant fraction of the GTC, a major share of LAST, and a share in SALT would provide an impressive astronomical research system for UK and Dutch astronomers.

7 Data, Data, Data and More Data

Astronomers have more data available to them today than most know what to do with. With the increasing complexity of instrumentation and the limited opportunities observers have to use instruments, reduction and analysis tools are the keys to getting observations published. Indeed, data acquisition, reduction, and analysis should be part of the instrument design and deployment.

An 8K square CCD camera produces 138-Mbytes of data with each click of the shutter. Over a three night run on an efficient 4-m telescope, the astronomer will take home an average of 360 object and calibration images, totaling some 50-Gbytes of data. The experience at NOAO is that reduction of Mosaic observations is a cpu-limited task. Even the most experienced astronomer with the fastest computer will take three to four days of hard work to reduce one night of observing. And, as we all know, that may only be the first go-around.

Large format detectors *require* carefully thought-out protocols for data calibration. To maximize productivity, pipeline reduction processing should be used for all but the most demanding of programmes. In addition, mechanisms should be available to assess data quality. Then, if pipeline processing yields

[2] overheads available at http://zwolle.ing-slo.iac.es/IWG/LAST/shef-apr99.ps.gz
[3] http://www.as.utexas.edu/mcdonald/het/het.html

satisfactory results, the astronomer does not have to do it by "hand" (see discussion by Dhillon & Marsh, 2000, on the ULTRACAM data handling requirements, these proceedings).

The model offered for pipeline processing of the ING Wide Field Survey images (M. Irwin, 2000, these proceedings) based on IRAF routines, is a model for all observations obtained in a standardized fashion. Indeed, standard configurations should be offered to observers to the extent possible. In these cases all of the correct steps have been determined, "gotchas" identified, and the necessary calibrations defined. In the case of the ING WFS, the intent is to automate the process down to astrometry, photometry, and the production of object catalogues.

Photographic plates, while of low quantum efficiency, have a long productive lifetime because of their easy storage and access. On the other hand, decades of electronic detector observations have been lost because they are not readily available beyond the original astronomer. The product of an observatory must not end at the publication of the observation. Systems must be put in place for data archiving, data distribution, and data mining, for future access multiplies the original investment of telescope time.

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