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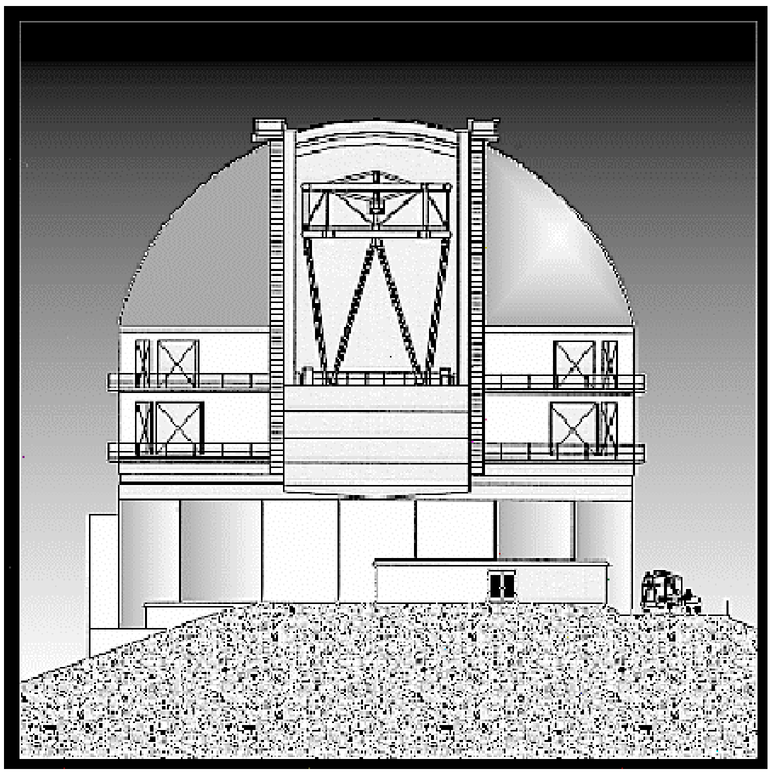
RPT-PS-G0061

New Observing Modes for the Next Century - A Workshop Summary



Workshop held July 6-8, 1995, in Hilo, Hawaii

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"It should be borne in mind that there is nothing more difficult to handle, more doubtful of success, more dangerous to carry through than initiating change. The innovator makes enemies of all those who prospered under the old order, and only lukewarm support is forthcoming from those who would prosper under the new." Niccolo Machiavelli, 1513[1].

Like all good ideas, these 'new' modes of observing are not new.

Almost four centuries ago, Galileo made the first observations ever taken with a telescope. As we move forward in history three hundred years or so and the astronomical technology changes radically to the Palomar 200 inch, we still find Hubble, or at least his night assistant, using this telescope in a way that would be instantly recognizable to Galileo, though the telescope itself would appear to Galileo as a gargantuan machine. Even in 1931 it was recognized that there were limitations with traditional ways of using telescopes; *".. weather and the general seeing conditions didn't always pay attention to the plans of astronomers and the allocation committee. In the brainstorming sessions [in 1931] the astronomers asked if the telescope could be switched from one focus point to another in minutes rather than hours, so the balance of the night could be put to profitable use"*. [An extract from Ronald Florence's book, The Perfect Machine - Building the Palomar Telescope.][2] The same discussion came up again in 1984 when the KECK was started; *"..both the designs and scheduling of large telescopes should be flexible enough to allow quick changeovers to programs that can benefit from good seeing. Adherence to this goal will, I believe necessitates substantial changes in the operating philosophy in use at most observatories"*. [Sandy Faber, "Large Optical Telescopes - New Visions into Space and Time".][3]

Perhaps the most notable feature of these discussions is that they have, to date, *not* changed the operating philosophies of most observatories. Part of the problem, and I am afraid our discussions at this workshop may have fallen into the same trap, is that it is easier to be wonderfully qualitative in our arguments but rarely are we very quantitative I am going to give you a very personal view of how I think this workshop may have shown us some new directions, and perhaps even raised some new concerns, and then pose some of the questions that we as a community have yet to tackle. So why now, near the end of this wonderful millennia of observational astronomy, do we at this workshop now have the cheek to say that our new telescopes are going to have to be used differently? Figure 1, which shows delivered images at the CFHT measured on consecutive nights compared with what we will expect from our new generation of telescope, shows why.

The measured image sizes bottom-out at about 0.3 arcseconds, not because this is the intrinsic best seeing at the site but because that's the way the CFHT was designed, and this is one of the best telescopes currently on Mauna Kea. Most of the current generation of 4-meter class telescopes were designed this way. Our new large telescopes, Gemini, Subaru, VLT or Keck are all being designed to ensure that the delivered images are in limited by the best atmospheric seeing and diffraction. The result is that the potential dynamic range in image quality that we expect from our new generation of telescopes is going to be far greater than we are used to. When you consider background-limited observations which depend on image size θ where the

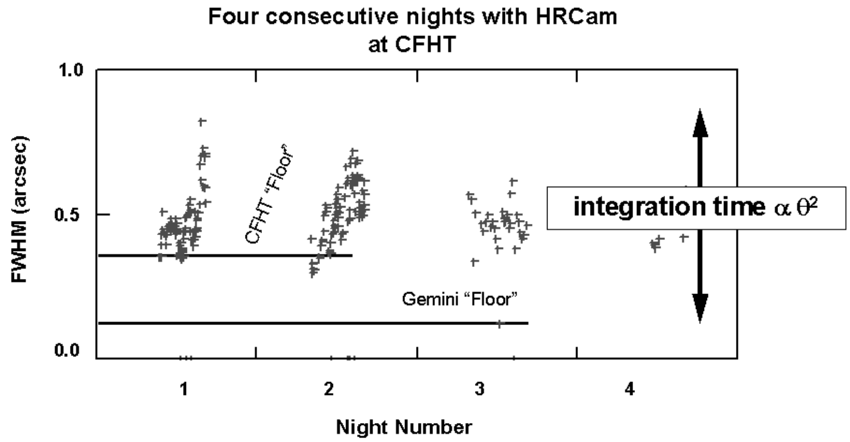


Figure 1. Delivered images at the CFHT from a series of consecutive nights, compared with what we will be expecting from the new generation of large telescopes.

integration time to reach a given signal to noise varies as $1/\theta^2$ -- such as spectroscopy of compact objects -- these variations can have a dramatic effect on observational efficiency. With what I will call classical telescopes, integration times can vary by factors of 3 since the variations in image size range from 0.5 - 0.8 arcseconds With the new telescopes delivering anything from 0.2 to about 0.7 arcsecond images (depending on conditions), we are looking at integration times that could vary by a factor of ten. Now consider the implications of using adaptive optics, which all the big telescope programs are trying to implement. With these systems we will have the potential to deliver almost diffraction-limited 0.1 arcsecond images. However, as the atmospheric seeing varies, caused by changes in r_0 or τ_0, we can now expect anything from 0.07 to 0.7 arcsecond images. To get an infrared spectra of a compact object like a brown dwarf may take one hour or a hundred hours depending on the conditions that night -- so how do you plan a survey when you are subject to such a lottery? The same arguments can be recast for observations in windows that are affected by water vapor such as the 3, 20 or 30 micron windows. Though low emissivity telescopes make observations in these windows faster, our observations are now more sensitive to changes in atmospheric water vapor. The only way to successfully exploit the new generation of telescopes is to find a way to match observations to conditions. However, logic in itself is not necessarily sufficient to change observational habits of the last four hundred years.

Why we will *have* to change

"*... Men [astronomers] are generally incredulous, never really trusting new things unless they have tested them by experience*." - Niccolo Machiavelli, 1513[1]

I think the real reason why we are going to have to change the way we use groundbased telescopes, even ignoring the experience of our radio colleagues, is that optical and infrared astronomy is being profoundly affected by the Hubble Space Telescope. HST has shown us that there are actually new reasons and new ways to do observational astronomy. Figure 2 is an image from HST, provided by Simon Lilly.

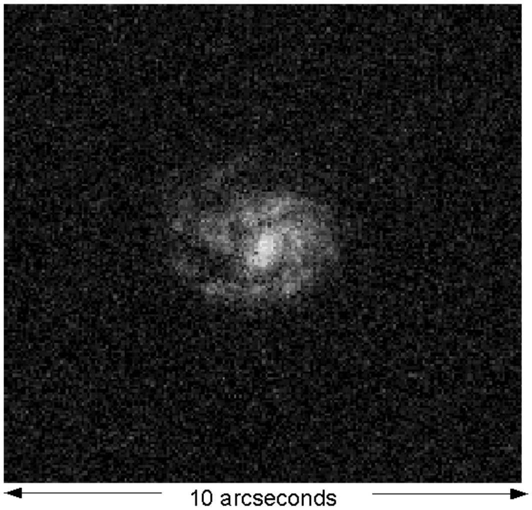


Figure 2. HST image of M101 "look alike" at z=0.6, courtesy of S. Lilly[4]

This is the galaxy taken in true color. The reddened bulge is clearly visible as are the HII regions in the spiral arms. This galaxy is at redshift 0.6 and is only 3 arcseconds across. We are seeing halfway back in time and there is structured information right down at the 0.1 arcsecond scale. From the ground we can actually begin to enter this new regime revealed by HST with our far larger 8 - 10m telescopes, assuming we get good seeing.

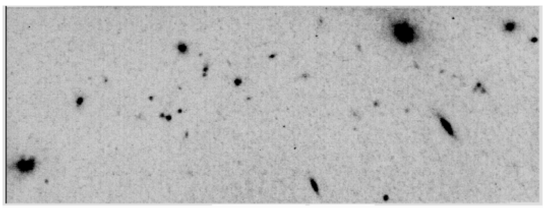
The HST has to be used in a very different way than most groundbased astronomers are used to. There has to be extensive pre-planning, pre-sequencing (worse still, your observational intentions are made public on the World Wide Web) and the observations are taken remotely by a HST support crew. It is "self evident" that the advantage groundbased astronomers have is better, closer control of their telescope; however, I doubt that is really the case. Contrast and compare the two pictures in Figure 3.

Figure 3. Astronomers in the HST control room (left) as compared to astronomers in the UKIRT control room (right). (courtesy of STScI and Steven Beard, respectively).

On the left is a picture of the HST control room during the comet encounter with Jupiter, and on the right is the groundbased control room at UKIRT during an equally busy experiment. Both sets of observers are in air-conditioned control rooms, and both groups are actually looking at their telescope and experiments through a series of computer screens. This is the way we all "see" telescopes today. Add to this what we have heard today from all the people who have been talking about remote observing, and it is apparent that the control room on the right does not have to be on Mauna Kea or Cerro Pachon, it can be in Hilo, La Serena, Baltimore or Cambridge; in fact, it can be anywhere there is a data line. Bruce Gillespie, Andreas Wallander, and Bob Hansen have all told us this remote approach to observational astronomy works well. The telescopes are efficient and the astronomy is well done.

The concept of *"an Observatory as a factory (we deliver)"* *Dietrich Baade, New Observing Modes for the Next Century Hilo, Hawaii, 5-8 July 1995*

Let's have another look at what we can do with HST and compare it with a groundbased observation. Figure 4a is a possible HST 'discovery' of a nascent galaxy cluster at redshift two "observed" by Alan Dressler[5]. The image in Figure 4b is what you see from the ground in 1.2 arcseconds seeing at 1.6µm -- it's an observation of mine from UKIRT.



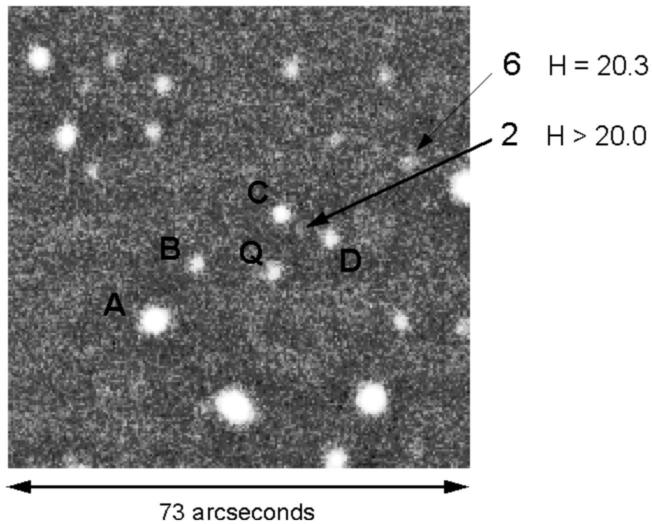


Figure 4a (l) and 4b (r). HST and UKIRT images of a possible nascent cluster.

I did not make this observation at all; I sent in an e-mail file and two weeks later the UKIRT service program sent me back this deep H-band image and, as you can see, these objects are actually quite faint. The problem with this observation is that at the time the observation was taken, the seeing was 1.2 arcseconds. As a result, I did not get deep enough to detect many cluster members. I needed 0.4 - 0.5 arcsecond seeing which can occur relatively frequently at 2.2 microns on UKIRT. So this observation has gone back in the UKIRT service queue and is waiting to be repeated. I am still waiting because as Suzie Ramsay Howatt has pointed out in her talk on the UKIRT service program, there are only a few nights per semester where these observations actually get done, so it may take several semesters for a given program to "win" the weather lottery. Suzie also showed that the success rate for these types of programs is completely independent of the scientific merit. In reality, whatever queued observation that matches current conditions is the observation done. To get ahead of the game, as Todd Boroson has shown in his simulations, the successful matching of conditions to observations requires that a substantial fraction of the time be allocated to this type of service or queue observing. As we have heard in the last few days, the test beds for these approaches are going to be the WIYN and JCMT telescopes.

This brings me to serendipity which seemed to cause greatest concern during our discussions in the last few days. Figure 5 is from recent paper by Hanson & Conti[6] and it contains a discovery. It shows a stellar infrared spectral sequence of a sample of embedded stars in M17. On the left is what you might expect inside the middle of a star formation region, hot blue O/B stars. On the right, are the spectra of rather cooler stars. As you go up the sequence it is apparent the CO features go from absorption (expected) to emission (unexpected). These latter stars represent a new class of objects and are likely to be young stars surrounded by disks, similar to those seen by Odel with the HST in the Orion Molecular Cloud. This is a serendipitous discovery. In our new

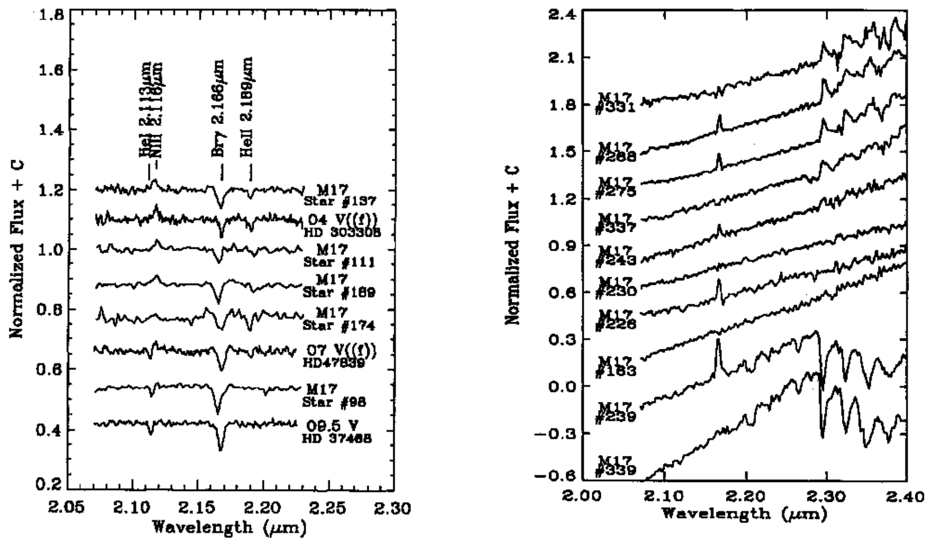


Figure 5. Infrared stellar sequence from stars in M17 (Hanson & Conti, 1995)

queue-based world, each one of these spectra could be taken on different nights and put together on the computer to produce this result. The astronomer would still have discovered this new class of objects.

Whether I choose this result, or Hubble's redshift distance scale, or a 12 year search for planets (Walker et al 1995)[7], I do not believe discoveries are made at the telescope, riding the weather variations like a cowboy riding a bucking bronco. Usually discoveries emerge after long nights at a terminal trying to reconcile an awkward data set with preconceived models.

Astronomy in the 21st Century?

The workshop has already shown us some disturbing glimpses of what the future might have to offer us. John Galaspy's plot of measured observing efficiency against consecutive nights during a run on the CFHT is the first of these. With the increasing complexity of instruments on the CFHT, it is taking observers, who perhaps visit the telescope no more than once a year, at least one night to begin observing efficiently, after which their measured efficiency grows monotonically throughout the run.

So what is it going to be like with the new generation of telescopes? Firstly, they will be controlled with an array of wavefront sensors and control loops. Gone are the days when we would rely on clever levers, steel and even Finite Element Analysis to keep our large optics aligned. We are going to have to use a series of guide stars and then the image quality is going to depend on how bright those stars are, how far they are from your object and how you choose the servo bandwidths, which in turn will depend on wind direction and how you set the enclosure. Finally the images may also depend on how you set the temperature of the enclosure and mirror several hours earlier. Throw into this an

Figure 6. Is this a model for 21st Century groundbased astronomy?

adaptive optics system, perhaps even a laser beacon, and suddenly it becomes apparent only the most prepared and experienced observers will be able to fully exploit these telescopes "on the fly".

Now, I thought when I came to this workshop that the most untractable problem facing queue observing was how to schedule such complex sequences and then efficiently re-schedule them when conditions change. I was surprised to learned that computer aided dynamic scheduling appears a "solved problem." Mark Johnston's talk on the HST scheduling software SPIKE was particularly illuminating -- especially his proposed variant where several 'agents' continually run schedules each based on a single change in conditions (see the front cover of these proceedings). CFHT and VLT are already experimenting with SPIKE. It appears we will soon have the ability to efficiently match observations to conditions.

The next exciting step is to predict what conditions are likely to be ahead of time. The one group of people that we didn't have represented here were meteorologists. However, Mark Sarazin is not doing too badly. Using extensive meteorological data he showed us how he can now apparently "nowcast" good seeing with a 70%-80% probability at Paranal. In addition, Doug Simons (Simons, 1995)[8] has demonstrated a correlation between GOES 7 satellite weather maps and the CSO tau water meter on Mauna Kea, making it likely that we can predict the water vapor at least 24 hours ahead (see Figure 7). So perhaps within a few years, it may not be uncommon for astronomers to know what seeing or water vapor column to expect *before* they get to the telescope. Let's look a little further over the precipice to the next century.

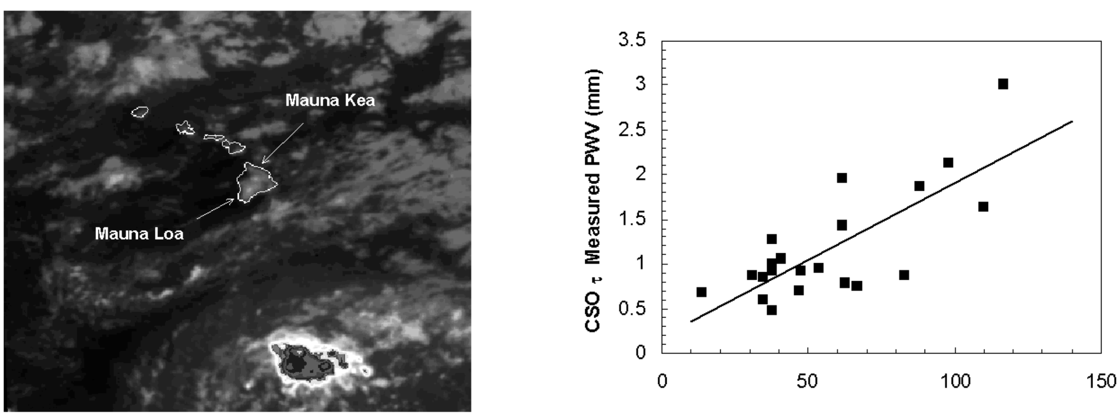


Figure 7. GOES 7 satellite weather map of Hawaii (left) and the correlation with the CSO tau water meter on Mauna Kea (right). (Simons 1995)[8]

The contrast between today's approach and tomorrow's astronomy struck me most profoundly when I listened to the series of talks started by Jack Baldwin. Jack talked of the plan to allocate almost 100% of the time on the CTIO 0.9m to service photometry. An *exception would be made* for those experiments where good accuracy is required and the expertise of the observer is key. This was followed by the talks of Greg Henry and Mark Drummond who showed that you can do accurate photometry fully automatically. Their system delivers hundreds of stars measured to milli-magnitude quality automatically across the sky. If the clouds come in, the system is so efficient you just throw that part of the night away and do it all again the next night by simply pushing the repeat button.

Listening to these talks I realized that we astronomers read about the technological revolution all around us and we blithely assume this revolution will not apply to us. In particle physics the people who scanned bubble chamber photographs have gone - they've been replaced by computers. Hopefully, in the next century there will be a lot less lawyers, and a tax consultant will be an expert system you load onto your home computer. It appears that by the next century photometrists will also be gone. So what other "astronomer skills" can be computerized?

The logic of what we have heard in the last few days leads us to a vision of a telescope that looks rather similar to a particle accelerator, HST, or VLA, in fact, in Dietrich Baade's words, a "factory" of scientific data. However, to ensure that we have not been led astray in this debate, we astronomers do need to examine why we do astronomy and I believe ask and provide answers to two key questions. The first of these is, how do we measure scientific success?

"Defining scientific success is a bit like life, you can see how to do it by looking back, but unfortunately you have to live it forwards." Mike Edmunds, *New Observing Modes for the Next Century, Hilo, Hawaii, 5-8 July 1995.*

Right at the beginning of this workshop, we had a very interesting talk from Mike Edmunds who described the way the UK allocates telescope time. The allocation committees always find there are three classes of proposals, the superb proposals, the scientifically or technically unfeasible proposals and then a whole swath of proposals in between which occupy most of their time. Mike posed the very reasonable question, "what would happen to the scientific quality of the field if allocation committees simply used lottery to determine if these middle range proposals were given an allocation." I think what Todd Boroson showed us, with his simulations contrasting classical and queue scheduling, is that all proposals face a lottery. His simulation of queue scheduling gave the following results:

1. Proposals which have been allocated a higher scientific grade actually get completed at the expense of more average proposals.

2. Observations do use more of the available observational "parameter space," such as best seeing and driest conditions. This means from the ground we may actually be moving into new areas of astronomy. For example, we will be able to combine HST spatial resolution with the collecting areas of 8 - 10 m telescopes.

3. Queue scheduling appears to give astronomers greater access to the telescopes as more individual observations actually get done.

This is not a direct answer to the question, but if as Thomas Kuhn concluded in *The structure of Scientific Revolutions*[9], "*the unit of scientific achievement is the solved problem,*" certainly giving astronomers greater access to unique observational parameter space should allow more problems to be tackled. Whether these problems get solved will still depend, even in our queue-based world, on the ingenuity of the astronomer.

So finally, we have to ask one more question before we embark on changing the whole culture of groundbased optical and infrared astronomy – who are our customers?

"Groundbased Astronomy is a bit like the US 'fee for service' health care system. The Providers are completely de-coupled from the Recipients , and costs are sky rocketing.." Jim Crocker, *New Observing Modes for the Next Century, Hilo, Hawaii, 5-8 July 1995*

I think Jim Crocker gave quite a good answer. Basically government agencies give us money to build large telescopes and then we go on and use them exactly as we like. Let's not forget, we have got a lot of money from our agencies. The latest big projects, KECK, VLT, SUBARU and Gemini have already cost about one and a half billion dollars to build. HST took another two billion dollars. We are getting very generous support but the world is changing. Our telescopes and observatories are being pressured to operate in cheaper ways. We are being asked to close down telescopes. As in the health care business, governments or agencies are asking for some quantitative return on their investments. We have to satisfy the people who give us the money but this also requires that the people who are using the system, the health care system or telescope, are also happy. I think in this contracting environment we're going to have to face the fact that we're going to have more debates on "scientific return" verses cost. The classical way to look at the cost benefits trades has been in table like this below.

Uniqueness	<------------------>	Versatility
Peak Performance	<------------------->	General Performance
Queue + Service Observers	<------------------->	On-site visiting Observers
Best Conditions	<------------------->	Average Conditions
Efficiency of Science	<------- ? -------->	Cost of Operations

The traditional view has always been, that as pressure is put on operating budgets, the tendency is to move the emphasis of an observatory to the right of this table, i.e away from queue or service observing to more traditional observing models. This workshop has shown us this may be the wrong approach. We have seen that dedicated robotic telescopes can do photometry as well as an experienced observer. We have heard a multitude of talks describing software tools that can help automate the business of doing observational astronomy. We have had glimpses of a future when we will be able to predict the quality of a night and adjust our (increasingly limited) resources accordingly. Towards the end of this workshop, one of the most significant talks was from Carol Christian. She is having to automate her UV Space Observatory to save it. She is having to do what lots of companies are doing, throw the people away and replace them by computers to get the costs down. What she told us was that though more planning would now have to be put into using the telescope, and some observing modes may be constrained, it was likely that the science undertaken may be a little different but fundamentally the scientific effectiveness of her telescope would be unaffected. For our new groundbased telescopes, if we take on board new techniques to build an observing system that is automatically reconfigurable to deal with changing weather, we can use the same technology to be adaptable to faults. Suddenly, we may not need two shifts of day crew available to rush up to the mountain to get the observer 'back on line' to complete the scheduled observation. By being fluid and adaptable with observing priorities, relying on automated procedures and stable instrument complements, focusing on getting data rather than providing observing time, we may need less "firefighting."

Carol may have already shown us where the future might lie for us all. And it may be true that astronomy becomes more like particle physics, space science or even radio astronomy. However, this does not belittle the science; our particle physics and radio colleagues still seem a pretty motivated group. If we are to continue to make progress from the ground in optical/IR astronomy, our next Optical/IR 'telescope' may have to be an even larger jump in the direction of dedicated facility, rather than a telescope for individuals (an evolution that has already overtaken our radio colleagues). Table 1 shows an arbitrary view of what the next observatory might be.

Table 1. Possible evolution of the groundbased Optical/IR observatory into the 21st Century

Facility	Baseline (m)	Collecting Area (m^2)
• Gemini, Subaru	8	50
• CHARA Array	354	5.5
• Keck 1 & 2 +	165	157 + 11
• VLTI +	200	201 + 20
• **Very Large Imaging Array**	**1000**	**400 (=22.5m dia. telescope)**

- 14 x 16m fully adaptive telescopes delivering 0.01" - 0.001" images at 2.2microns

If the next observatory is a very large imaging array, I would challenge any of you to use this device by going up there and orienting each telescope and making the interferometer run. It is also going to be difficult to convince funding agencies that running such a complex facility in our traditional way is either cost effective or scientifically productive. From the perspective of an observational astronomer, astronomy may become less fun, but surely as a scientist the big returns from access to a facility like a VLIA may be worth a change in culture.

Jim Crocker summed up our groundbased communities feelings quite well. *"It's always far easier to carry on doing what we've been doing"*. My view is summed up in the following quote from Norton Juster's The Phantom Tollbooth[10]: *"The Mathemagician nodded knowingly and stroked his chin several times. 'You'll find,' he remarked gently, ' that the only thing you can do easily is be wrong and that's hardly worth the effort.'"*

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