AFTER DINNER SPEECH: INFRARED / SUBMILLIMETER ASTRONOMY: ARE WE PREPARED FOR SUCCESS?

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Abstract

Recent advances in infrared detector technology have radically changed the needs of our field. We will need to take these into account as we look to the future.

Key words: detector technology, infrared astronomy

1. Introduction

Some of you may remember the late 1960s television series 'Star Trek' dealing with fanciful voyages in space. When I was Director of the National Air and Space Museum in Washington DC, we decided to do an exhibition on this show to interest children in space ventures and the future of space travel.

One day, I was enthusiastically describing our plans to an acquaintance in management, when he surprised me by asking 'Are you prepared for success?' I said, 'Of course we are looking forward to success.' But that wasn't what he had in mind. He asked, 'If your venture is an absolutely astounding success, are you prepared for the consequences?'

Fortunately our staff had looked ahead: Safety regulations allowed only 200 people at a time in the gallery. We had to determine what to do if we suddenly had several thousand visitors demanding to be let in.

Most of our resources had gone into building the exhibit. So, our staff handled this by inviting a couple of hundred members of local Star Trek clubs to volunteer to help the museum, by working shifts of two or three hours a week. They handed out passes to the thousands of people who lined up outside the museum each morning, admitting fifty visitors to the gallery every fifteen minutes, and then ushered this steady flow of people through the gallery, all day, every day.

The crowds loved the exhibit. And when it finally closed after 11 months, and 900,000 people had seen it, the museum threw a huge party to thank all the volunteers and their families. They had made the exhibit a great success. Without them, we would have been unprepared, and the very same exhibit would have turned into bedlam and a public relations disaster.

It isn't enough to successfully launch a project. You also have to be prepared for the onslaught of its success.

2. Infrared Astronomy

How does this bear on infrared astronomy?

Since its very inception, our field has been preoccupied with obtaining ever more sensitive detectors. In this, we have succeeded beyond all expectations. During the past four decades, detector sensitivity in most wavelength ranges has roughly doubled every two years, so that sensitivities today may be a million times higher than in the 1960s, and close-to-limited by natural backgrounds and fundamental physical constraints. And where we used to be fortunate to have one well-working detector, we now have arrays of millions. As a result, the rate at which we are able to gather data has increased by ten to twelve orders of magnitude. This is the end we always dreamed of reaching. But if we now launch a satellite safely into space, with a great complement of fully working instruments and exquisitely sensitive detectors, are we ready for this success?

It depends!

3. The Rise in Data Rates

Future missions with huge detector arrays, high sensitivities and large dynamic ranges, will generate data at gigabit per second rates. But telemetry capacities have not kept up with these demands and are a hundred to a thousand times slower.

The Midcourse Space Experiment – the MSX mission – launched by the US Air Force in 1996 to survey the Galactic plane at four infrared wavelengths between 6 and 25 μm, recorded data at a rate of 25 Mbps. But power consideration and telemetry downlink time limited the spacecraft's duty cycle to just $\sim 10\,\%$, roughly two to three hours of observations each day (Price et al. 2001) The rest of the time it idled – clearly a mismatch between detector and transmission capacities.

Many other mismatches are arising now, because our detectors have become so powerful. For decades they had been the weakest link. Now they dominate. And this has thrown everything else out of balance. Our task is to cope with the consequences of this success.

MSX had only a few thousand detector elements, and yet it choked on its telemetry. Think how much harder it will be to transmit the flood of data from the millions of

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pixels planned for the Next Generation Space Telescope, NGST.

Data compression is the usually recommended cure. But anyone who has seen the Herculean efforts that Infrared Space Observatory and MSX workers had to go to with interactive procedures to eliminate cosmic ray glitches or memory effects, knows that no reliable data compression scheme is anywhere in sight.

Infrared/optical laser-based telemetry, with orders-of-magnitude higher transmission rates could solve the problem. But these systems are not yet in place, and none of the space agencies seem to be planning their use in astronomy, though both ESA and JPL are looking into adopting the technique for telecommunications systems in space (ESA 2000; Bland-Hawthorn 2000).

Let me go on.

4. Software and Hardware

Hand in hand with the new detector arrays comes a new phenomenon. Software and data handling costs are beginning to match, and could soon exceed, the cost of hardware and launch.

Like ISO, the Space Infrared Telescope Facility, SIRTF, will be launched with only some of the astronomical observing modes fully supported. The escalating software demands of increasingly complex missions have simply not been fully appreciated.

In part the inattention to software has resulted from our own inexperience. As Martin Kessler pointed out on the opening day of our workshop: on ISO we could have saved hardware costs, and presumably devoted more resources to software, if we had not designed the mission for observing modes which were never implemented because the software could not be developed. Other capabilities like polarization measurements became operative only so late in the mission that they were insufficiently utilized and would never have been used at all if ISO operations had not run well beyond the 18-month nominal mission life.

Governmental agencies have also failed to appreciate that software costs need to be matched to the traditional cost drivers – hardware and launch. As a result, funding for software is often far too limited and appropriated too late.

5. Archival Efforts

With the greatly expanded data flow the new detector arrays make possible, we are also beginning to establish complex archives for the benefit of future generations. This too is new territory going well beyond the traditional photographic plates that most astronomers felt they knew how to read and would continue to be able to read for centuries.

Despite a great deal of truly thoughtful work by many groups, we still have not fully solved the problem of conveying to future generations all the peculiarities of the data now in hand. Three hurdles must be overcome, each successively more difficult than the previous. The first is the speed with which data storage technologies become outmoded – typically 3 years, right now. The second is the loss of corporate memory through workers leaving the field. This happens on time scales of ten to twenty years. The third is the evolution of language, characteristically over the course of a century: Thus, we have difficulty reading the works of James Clerk Maxwell today, because his mind set, his technical terms and his mathematical notations were all so different. In effect, he spoke a different language.

If we ask what would be needed from us, three centuries from now, when the next supernova lights up in the large Magellanic Cloud and astronomers want to compare it to the supernova of 1987, we need to know how to prepare our archives so they will stand this test of time. We don't yet know how to do this.

We saw with ISO that interactive data analysis persistently gives substantially better results than even the very best automated pipelines developed with care. But interactive analysis depends on a great deal of personal knowledge and word-of-mouth advice. Corporate memory is a wonderful asset, but we don't know how to transmit it to future generations.

At the Air and Space Museum I gained my first real appreciation of how much we still depend on corporate memory. Pilots were always pestering us to fly the wonderful old aircraft particularly the fighter planes in our collections. We refused to let them, but other aviation museums did not. As a result, year after year, irreplaceable historic airplanes have been lost to posterity. Today's pilots, who fly far more complex machines, think that these old airplanes will be 'a piece of cake'. They fail to realize the peculiarities of the old aircraft, because most of this knowledge used to be passed from pilot to pilot by word of mouth and is not adequately documented in the old hand books of the times. So, unless you know that a Mustang had a tendency to veer to the left on takeoff, you start down the runway and end up crashing into the airfield tower.

We don't want future generations of astronomers to end up crashing because we failed to adequately document peculiarities of archived data.

6. Sociological Changes in the Field

Let me turn to another new mismatch. We astronomers are a competitive lot. We vie with each other to be first to publish new results. Our promotions and stature in the field depend on it.

But we are steadily drifting into big science projects as the manpower required by our space missions escalates. Two weeks ago, SIRTF announced its selection of six legacy projects, huge consortia of scientists funded

Figure 1. Martin arguing in favour of lateral thinking and against the danger of not seeing the forest because of all the trees.

to adhere to strict management rules, production schedules, and an obligation to rapidly deliver processed data to the larger community with an explicit abdication of traditional rights to publish first.

How will this new generation be rewarded? Academic communities do not yet appreciate the intellectual importance of large projects, and we in astronomy risk losing or failing to attract some of the very best people whose universities or observatories will only reward clearly individual achievements rather than team efforts. This is a problem we should energetically tackle. The accelerator physics community has long faced this difficulty and has never successfully solved it.

In summary, a great deal remains to be done, both technically and on a human level, before we are fully prepared for the successes the great advances in detector technology are heaping on us.

7. The Military's Contributions of the Past

Now, you may counter all this by asking, 'What's so new? We've always had problems, and we've inevitably solved them.'

I believe that what is new today is that there is a second novel factor at play. Our past successes have largely been the results not of our own efforts, but that of others'. And this is beginning to change.

Let me try to convince you.

Throughout the Cold War, the US Air Force was building heat-seeking missiles to intercept fast approaching enemy rockets. The problem was that the missiles would have to distinguish the faint glow of an enemy rocket from an infrared background star or galaxy. And nobody knew what that might be.

A series of increasingly sophisticated projects was undertaken to map the heavens. This reached a climax in 1996 and '97 with the impressive MSX survey.

If we ask, first, what these efforts might have cost, and, second, how they have benefitted astronomy, an article by John A. Jamieson can serve as a guide (Jamieson 1995).

For more than four decades, Jamieson was deeply immersed in the military's infrared programs. In tracing advances from the 1940s to the Vietnam war he concludes that the development of detectors that approached the fundamental limits of detectivity, could be manufactured reproducibly, and formed into large arrays, were – together with powerful, small, light computers – the foundations of infrared technology for ballistic missile defense. They gave rise to a revolution in 'non-nuclear, hit-to-kill ballistic missiles' which began in the 1970s.

A further boost came from President Ronald Reagan's 1983 Strategic Defense Initiative – SDI – to, as the president put it, 'Intercept and destroy strategic missiles before they reached our own soil or that of our allies.'

Jamieson estimates that costs for the SDI program from 1985 to 1992, amounted to 'Only about $3.4 billion per year for seven years. The infrared related portions amounted to less than $7.5 billion.'

To put these funding levels in perspective, I estimate that the joint expenditures of all civil scientific agencies world-wide on infrared astronomy from space, over the entire history of the field, is likely to have been of the order of half of these $7.5 billion that the US military spent solely between 1985 and 1992.

So, what did infrared astronomy gain from all this?

Jamieson lists a series of SDI initiatives, a few of which I'll mention here:

1. Measures to radiation-harden detectors against gamma radiation from nuclear debris. The development of 'blocked impurity band' (BIB) detectors were part of this effort. (Here, it's worth noting that ISO showed us how much astronomy can gain from such detectors for reducing noise spikes from naturally occurring cosmic rays beyond Earth's radiation belts.)

2. Hybrid arrays of detectors bonded through indium bumps to electron readout chips to produce complete multiplexed sensing chips.

3. A broad range of materials testing to produce better detectors.

4. Increased sizes of detector arrays.

5. New polishing techniques to produce very low scatter optical surfaces, particularly for beryllium optics.

6. Production of light-weight optics and development of economical computer-controlled polishing, figuring and testing.

7. Development of silicon carbide optics.

8. Development of mechanical cryocoolers for long-term space missions.

Does any of this sound familiar?

8. Military Munificence

MSX, of course, was a purely military mission, though its impact on Galactic astronomy will be fundamental.

On ISO the infrared camera, constructed primarily in France, had a detector array especially devised for the mission by the French defense establishment. The short wavelength spectrometer built mainly in the Netherlands incorporated previously classified infrared detectors provided through the efforts of co-investigator Stephan Price at the US Air Force.

SIRTF, of course, will have vastly greater sensitivity than ISO and incomparably larger detector arrays — all military hand-me-down devices.

Our ground-based colleagues have similarly benefitted from adaptive optics, long shrouded in military secrecy, but now installed on all the most powerful optical telescopes.

The influence of the military on advances in our field are quite evident.

An obverse of this munificence is also clear. Where the military has had no apparent interests, as in the far-infrared and the submillimeter range, we have had to develop instrumentation on our own, and progress has been far slower. We are only just starting work in the submillimeter range, while mid-infrared astronomy, of interest to the military all along, has been flourishing for decades. Much of what we are planning for the future, particularly work in the submillimeter range and long-baseline infrared interferometry in space, is likely not to interest the military. So, if we have to spend our own funds, how do we best go forward?

9. The Future

One thing not to do is to ask for clearly unaffordable projects. We've tried that!

Many among us still remember LDR, the Large Deployable Reflector for submillimeter astronomy, proposed a couple of decades ago for launch into space. Roger Bonnet reminded us of it in his opening speech the other day.

Though many studies were undertaken, and many workshops organized, LDR was never built. With its 10 to 30 meter aperture, depending on who was talking, and its demanding technology, it was clearly unaffordable. Two decades later we are happy to be building the 3.5 meter Far Infrared and Submillimetre Telescope, FIRST, instead – a more modest but still a major step forward for submillimeter astronomy.

Several large projects now recommended by the decadal survey that has just been conducted in the United States, and intended for launch in the next ten to twenty years, seem to me to be similarly beyond financial reach unless significantly descoped. The Next Generation Space Telescope, NGST, the Terrestrial Planet Finder, TPF, and the Space Interferometer Mission, SIM, all are enormously ambitious projects. The detector technology required for success is at hand, but much of the infrastructure – high speed telemetry networks to match the data rates of vast detector arrays, station keeping to carry out interferometry, deployment in space of large precision structures, and cryocoolers that will reliably work in space for a decade or longer, still need to be developed and will be costly. Moreover, all three ventures constitute such radical advances, that we are likely to skip a number of useful intermediate steps that could be affordable and could take us forward faster.

10. A Strategy to Move Forward

Where we can no longer count on the military's hand-me-downs, our best bet is to take somewhat smaller, but more assured steps. We need only remember that those in favor of SIRTF in the 1980s, thought that the more modest advances planned with ISO would be useless. That this was untrue was quite clear once the many achievements of ISO became apparent.

In addition, however, we need to adopt an end-to-end approach that rebalances all of the needed infrastructure to catch up to the great successes in detector technologies. This will mean matching telemetry capabilities to detector performance, and software efforts to hardware, mission operations, and archiving. We need to optimize our gathering of data and our ability to transmit the information obtained to future generations. With the cost of missions running in the billions of dollars, what we do today should not ever have to be repeated. So we will have to do it carefully and get it right. Future missions should be able to go truly beyond what we have done rather than finishing tasks we left unattended.

By seeking advances in the infrastructure on which better detectors are dependent, I believe we may ultimately find ourselves fully prepared for success with powerful new missions that society can actually afford.

11. Summary

Preparedness for success really means no more than looking beyond immediate preoccupations – in infrared work a fixation on larger, more sensitive detector arrays or complex optical systems with large numbers of operating modes – to seek an equitable match between all the components on which a successful mission depends. The best detectors and most sophisticated optical systems are of little use if we cannot transmit the gathered data to ground as fast as the spacecraft gathers it, or if the expected mission life is too short to fully utilize, characterize and calibrate each planned observing mode and still leave plenty of time for the actual observing programs. Otherwise, we are just launching expensive hardware into space and not adequately using it. Nor is it useful to spend our budgets on hardware and then skimp on the costs of data processing and archiving. If we did, we'd just be building stuff whose output will lie idle – of little use to astronomy.

As we begin to fully appreciate the proportions of the revolution that the new detector technologies have wrought, I believe that astronomers will take a new look at all the matching advances in various infrastructures that we will need to have in place to rebalance our capabilities.

Our plans and budgets for hardware, software, data transmission, mission operations, data processing, and archiving, will have to be laid out end-to-end, so that these capabilities are matched to each other evenly, right from the start, and with no element wastefully superior to the others. Added to these technological factors, we will need to find ways of attracting the very best people to the field to make sure that the data returned by our missions are put to the most incisive astronomical use.

This is our challenge now. If we can master this kind of technical and social end-to-end planning, there will be few surprises, and we will be prepared as well as possible to deal with any and every future success.

References

Bland-Hawthorn, J. 2000, Personal communication, December 5

ESA ARTES 5 - Global Information Infrastructure - New Systems Architectures *http://telecom.esa.int/artes/artes5/fileincludes/services/fulldescriptions.cfm?mi_cd=GI*

Jamieson, J. A. 1995. 'Ballistic Missile Defense and Infrared Technology – The Influence of Infrared Technology Upon the Russian Revolution and the Soviet Empire', Proc. IRIS (Infrared Instrumentation Society) 40, No.1, 13

Price, S.D. et al. 2001, 'MSX Survey of the Galactic Plane', AJ 121, 2819