The Fortunes and Misfortunes of the Hubble Space Telescope

Gustav A. Tammann,
Professor at the University of Basle,
Director of the Institute of Astronomy,

Lukas Labhardt,
Lecturer at the University of Basle
Institute of Astronomy

The quality of astronomical images is of fundamental importance for research. Observation is however greatly hampered by the constant commotion in the Earth's atmosphere. Astronomers have known for a long time that the only way of overcoming this limitation is to work from space, even in the case of observation in the visible range, for beyond the turbulent atmosphere much fainter light sources can be observed at a far higher resolution (the ability to distinguish between two astronomical objects close to each other).

Despite the very high cost of the instrument itself (some 1.5 billion dollars) astronomers were already proposing, in the immediate post-war years, that an optical telescope be placed in orbit round the Earth. In the 1970s they managed to persuade NASA to put the proposal into practice. The decision by the European Space Agency to take a 15% share in the project opened up fabulous opportunities for Swiss astronomers. In this way Switzerland was indirectly assigned some 1% of observing time. That sounds like hardly anything but is in fact a lot bearing in mind the scale of the undertaking.

The most complex satellite ever built

The specifications for the Hubble space telescope (*HST*) were fairly awe-inspiring. One task was of course to acquire images of faintly luminous stars and galaxies sharper than had ever been seen before. But the spectra of those objects had also to be captured and analysed in order to determine their physical state and chemical characteristics, which explains why the *HST* is the most complex satellite the world has seen to date. The specified fifteen year operational lifetime was again a very demanding technical requirement. Serious difficulties arose too in the area of data transmission. The telescope would have to be remotely controlled and would also have to record considerable volumes of data and send them back to Earth. An institute was set up in Baltimore specially for this purpose and today employs a staff of 300, 15% of whom are Europeans.

The *HST*, with its 2.4 m diameter mirror, was in many ways an outstanding pioneering achievement, incorporating a whole series of technical innovations, but it was ready all the same in 1985 for a launch in 1986. Shortly before the mission was due to begin, the *HST* timetable and indeed NASA's entire programme was however cast into disarray by the Space Shuttle *Challenger* disaster. The telescope did not in the end reach orbit until 1990.

Determining very large distances

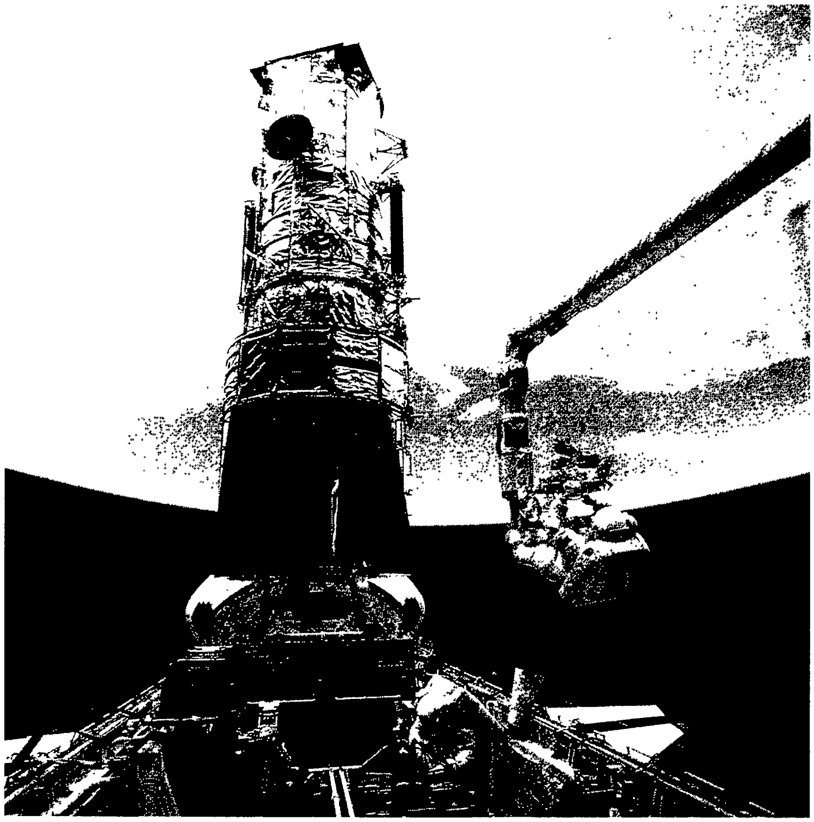
From the very earliest planning stage, we decided to use the space telescope to determine the true luminosity of a near supernova. This would, in our opinion, provide an answer to the problem of determining large distances, for while all objects of this kind are known to have virtually the same luminosity, the absolute values concerned are not known. If the distance and luminosity of a supernova - or better still of several supernovae - could be established independently of one another, the distance from Earth of tens of very remote supernovae could then be deduced. The rate at which the Universe is expanding, or in other words the time that has elapsed since the Big Bang, could then also be determined. It was hoped too that, with the *HST*, supernovae could be observed that are so far away as to allow variations in the rate of expansion over the history of the Universe to be measured. This was then a project worthy of the most expensive telescope ever.

It was to develop this aspect that we set up a small working group chaired by Allan Sandage, the great American astronomer. Other members of the group included Abhijit Saha of India, highly versed in image processing and photometry, and the Italians Duccio Macchetto and Nino Panagia, who knew the space telescope inside out. The photometry of faint stars having a long tradition at the University of Basle, the present authors very naturally joined the group; the fact that the programme also embraced Cepheids and supernovae – at the instigation of Swiss astrophysicist Fritz Zwicky, whose memory is still alive in all our minds – gave us yet more reason for doing so. This small group had two striking features. The first was its international make-up, admittedly nothing unusual in astronomy. The second was the remarkable team spirit that evolved over time. Cooperation among the members was thus a model of its kind.

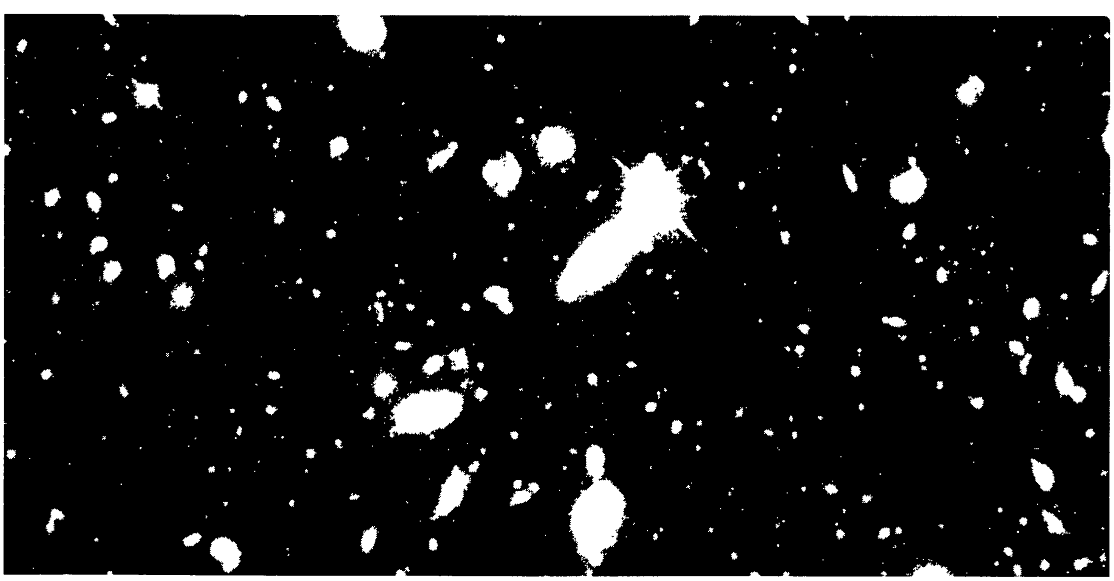
A sure-fire success but...

When the space telescope was launched we submitted our observation requests. Putting these together had been no easy matter. Just what would this new instrument offer? The scientists called upon to assess the relevance of our project would inevitably be inundated with other proposals – would we succeed in winning them over?

Our submission was framed as follows: it was a recognised fact that the Cepheids are the best distance indicators in the Milky Way and other galaxies, but with terrestrial telescopes Cepheids could be observed up to a distance of ten million light-years at most. However, no Type Ia supernova had been observed in such "close" proximity in the last hundred years. Hence our basic argument: galaxy IC 4182 – in which extraordinary observations had been taken of a supernova in 1937 – would be ideal for the job of calibrating the luminosity of supernovae. While it was too remote to be observed from the ground it was so near that success could be guaranteed.



Astronaut Story Musgrave at the end of the robotic arm operated by Claude Nicollier in the course of maintenance work on the Hubble Space Telescope in December 1993



Galaxies more than ten billion light-years away

Awaiting the decision by the panel of judges was a nerve-racking time, but in the end it came – our proposal had been turned down! The project had its merits, we were told, but was not high-powered enough to warrant *HST* observation time. Our proposal had thus been assigned second-level priority: interesting enough but too simple.

When the impossible happens

Where had we gone wrong? We did not have the impression that the large number of non-American candidates had counted against us. Nor had we any reason to think that some kind of personal rivalry had brought us down. As far as we could make out we had simply made too much of the project's feasibility. How should we respond? Having a second try, this time taking a supernova in a more remote galaxy simply in order to make the task more difficult, didn't make a lot of sense.

Then the impossible happened. The first images delivered by the *HST* were a disaster! They were better than the images of objects observed from the Earth but nothing like as sharp as expected. What was going on? Apparently the primary mirror, itself a hundred million dollar item, suffered from a manufacturing defect. Conclusion: all the complex programmes given priority status were no longer feasible; only the "simple" projects still stood a chance. And so we were advised that our proposal was to be accepted and processed.

From that point on, everything went like clockwork. Within the year we had established the distance of IC 4182 and in the second year we were also able to determine the distance of NGC 5253, which had just produced two supernovae. The three supernovae that had now been calibrated proved to be very luminous, which meant that the remote supernovae – whose apparent brightness is all we can establish – had to be very distant indeed, almost twice as far away as many had believed hitherto.

A technical miracle

We were also witness to a technical miracle at this time. The fine structure of the fuzzy stellar images provided all the information needed to reconstitute what had gone wrong when the mirror was being polished. During manufacture, the mirror's characteristics had been regularly compared with the specified values, but when the optical control equipment used for this purpose had first been set up an error had occurred in the reflection of light; no-one had picked this up and the result had been a 1.3 mm setting error. This in turn had led to a deviation of up to 0.002 mm in the mirror surface profile compared to the required shape. This tiny deviation was what was causing the problem.

Once the optical defect had been fully understood in every detail it became possible to calculate ancillary optics capable of providing the necessary correction. After a great deal of discussion the decision was taken to go ahead with the job of building the ancillary optics and fitting them to the *HST* despite the high costs involved. This was however an operation easier to plan than to carry out. A second Space Shuttle would have to capture the telescope on orbit, following which the ancillary optics would have to be fitted in the weightless environment, an extraordinarily complex operation!

In December 1993 a crew of seven, including Swiss astronaut Claude Nicollier of the European Space Agency, carried the job through to a successful conclusion. Everything went as planned and all of a sudden *Hubble* started to deliver outstandingly sharp images. For NASA the operation washed away the shame of the ill-polished mirror – and it was a success too for ESA, which had supplied new solar panels of exceptionally high quality.

Immeasurable advances

The *HST* has since come to be acknowledged by astronomers as one of the most important observing instruments. Many key questions, some going back a long way, have been answered, in whole or in part. A substantial number of surprising discoveries have been made, though it is still too early to judge the extent of the contribution which the space telescope has made, and will make, to astronomy and our understanding of the Universe.

With the orbital repair work completed, the *HST* offered a wealth of new opportunities, and not just for others. We ourselves could now observe Cepheids in galaxies six times more remote and make out supernovae that had previously been beyond our scope. Thanks to the experience built up during the first phase and the results of our data analysis – an enormously demanding task – our subsequent observation requests proved successful in the face of increasingly severe competition. We have in the meantime added four more supernovae to the earlier three – and the programme doesn't end there.

No need to give up the Big Bang

Before the space telescope began its work scales of distance varied by up to a factor of 2, depending on the author. With the help of the *HST*, calculations accurate to within about 10% are now possible. There is a better understanding too of the age of the Universe since the Big Bang. There had sometimes been fears that the oldest datable objects, the globular clusters, might in fact predate the beginning of the expansion phase. This logical impossibility would have called for the development of a completely new theory of the Universe. But thanks to data supplied by the space telescope, the start of the expansion phase, as previously determined, is now known to be fully in accordance with the age of the globular clusters. It would seem therefore that we are beginning to understand the timescale within which the birth of the Universe is located.

Looking back, we sometimes have the impression that we would never have gained access to the *HST* had it not been for those early troubles. At all events, the initial setback gave us the opportunity we needed, but we can perhaps take credit for having seized it. We would add in this connection that without the uninterrupted financial support of the Swiss National Science Research Fund this research project would never have come about; we offer the Fund our sincere thanks.