# THE CHANGING FACE OF ASTRONOMY

**Lodewijk Woltjer**

Less than a century ago astronomers worked as individuals, today many of us function in groups of ever increasing size studying ever larger samples of planets, stars, galaxies, quasars and other objects. Most of these are faint and their observation requires powerful telescopes. Large samples are needed and therefore also many researchers to deal with the large volume of data. Both demand much funding and so astronomy has become "big science" in the same way as particle physics has done. Why does Society at large provide us with that funding? Two different motivations exist: utilitarian and more philosophical ones.

The former relate to clocks, to imaging instruments over the whole electromagnetic spectrum, to GPS, to Virtual Observatory Technologies for dealing with large data sets, to impact risks, to the influence of the Sun on the Earth's atmosphere and climate, to technologies of Earth observation, to mention just a few items that are "useful". The latter are very different and concern considerations of man's place in the world at large: The heliocentric solar system and the discovery by Galileo of "myriads of stars" (now with planets), the realization that the Universe is very large, very old, evolving with perhaps some kind of beginning and filled with invisible matter, the nature of gravity, the probabilistic nature of physical law, and an understanding of the origin of the elements. If as the philosopher Dilthey (1834-1911) wrote "*Nature is not only the scene of history. The physical processes and the effects that follow form the substrate of all relations, of the action and reaction in the historical world. The physical world thus constitutes the matter for all domains in which the spirit has expressed its purposes, its values and its essence.*", a gross understanding of these matters is a prerequisite of rational thought. Unfortunately recent polls show that in the U.S. 55 % do not accept human evolution and 67 % the Big Bang. The latter is all the more amazing, since one could have expected that belief in a God could go well with a singularity at the origin of the Universe. In the EU and in China the evolution skeptics are less prominent, though still near 30 %. Even with less philosophically charged issues like global warming, one sees the limits of the belief in scientific analysis, especially if it leads to inconvenient consequences. Astronomy could have an important role in education by being particularly accessible through its images. It may also be helpful in augmenting the flow of students into other natural sciences. But with willful obscurantism still as widespread as it seems to be, one has difficulty being too optimistic.

Even though science is universal, decisions of where to place the center of one's efforts in science, and in particular its funding, are not. As the former French minister of science Hubert Curien wrote in 1978 "*The risk of overdependence on the US should, however, not be neglected. One should ensure that the part of our scientific activity that depends on American decisions, taken on the basis of considerations that are not necessarily our own, does not become too preponderant … dependence, independence, interdependence and overdependence, there would be a good subject for an essay and that not only in space.*"
In today's more multipolar world these risks have diminished, as cooperative ventures not only with the U.S., but also with China, India, Japan and Russia have become more common. Nevertheless, for every large project a careful evaluation of the pros and cons of possible collaborations should be made.

Today most West European countries are members of ESO and ESA. With Czechia the first middle European country has joined ESA and ESO. Even though there may be problems to be solved, an extension to Eastern Europe would be beneficial in many ways. After all, in the European Astronomical Society the unity of all Europeans from the Atlantic to the Urals has been realized from the beginning twenty years ago.

## The Large Projects

Progress in science has come about by advances in technology, by adequate funding and by the gradual accumulation of knowledge which allows future studies and instruments to be planned in a rational way. European ground based astronomy will be dominated by four large projects: the VLT and the E-ELT in the optical/near IR (ESO), ALMA, (mm/submm; ESO/Japan/U.S.) and SKA (cm/dm; "world"). E-ELT (42-m) and SKA (Square Kilometer Array) are still in the planning phase, while ALMA is approaching completion.

In space there are miscellaneous missions in the inner solar system. In addition, observatories study X- and gamma rays, the far IR and the cosmic microwave background, and in the near future a census will be made of a billion stars with individual distances and motions. ESA has a major involvement in the NASA JWST project, a powerful near-to-mid-IR telescope to be launched in 2014 by an Ariane V rocket, while its share in HST continues. Two big projects, Exo Mars and a large X-ray observatory, are being planned or discussed in a time frame extending from the end of the current decade or into the next one. Finally, there is a project of uncertain cost and schedule that has sometimes been discussed under the name of Darwin: a nulling interferometer to image and spectroscopically analyze earth-like planets and their atmospheres around nearby stars. If any astronomical project could create popular enthusiasm in Europe, it would be this. From the preceding summary it appears that Europe is engaged in a coherent, well balanced program in space and on the ground.

## The VLT

Until the VLT came along, undisputed leadership in ground based optical telescopes was with the U.S. The same was the case in detectors, sometimes reinforced through U.S. export laws. Change came through the remarkable willingness of some of the European countries to provide some 300 M€ for the initial project, followed by funding for interferometry and additional instrumentation. The initial motivation for the VLT was to build the biggest collecting area for the "available" money and locate it in a place with a low turbulence, dry atmosphere. First discussions started in 1977; the project was approved in 1987 and completed essentially on budget in 2000 with the erection of the fourth 8-m telescope. In the meantime interferometry has been fully integrated into the VLT with four mobile 1.8-m telescopes added to the four 8-m ones, yielding milliarcsecond angular resolution.

What are the main factors that contributed to making the VLT project successful?

(1) The early development of the 3.5-m New Technology Telescope which tested a number of technologies later used in the VLT telescopes, in particular the active optics pioneered by Ray Wilson who will discuss that subject later in the present JENAM. Other innovations included direct drives for moving the telescope and a compact, rotating, well ventilated building. These factors contributed to a cost reduction of a factor of three compared to the 3.6-m telescope at La Silla. The fact that the NTT was built well within its approved budget gave confidence that the VLT budget was entirely realistic.

(2) The flexibility of having four large telescopes each with different, but complementary quasi-permanent instruments and with a perfect systems integration, which in the future will also allow a smooth integration of the nearby 42-m E-ELT. In the past the need to change instruments had frequently led at the 3.6-m telescope to numerous breakdowns.

(3) The participation of numerous institutes, scientists and engineers in the development of instruments, which created a strong feeling of a European community and ensured that technology became an equal partner in that

community. In parallel the interaction with the space engineers led to a much more rigorous approach towards technology in the astronomical institutes with respect to quality control, respecting deadlines and budgets, etc. As a result also a high efficiency quasi-industrial management structure was developed for the operational phase of the VLT.

(4) The interferometric option which was from the beginning pushed by Pierre Léna and which just now has reached the state where the four large telescopes may be coupled simultaneously to produce images with resolutions of a milliarcsecond in the near IR. For many years all over the world interferometry had led a somewhat marginal existence, but now the excellent engineering of the four large telescopes, the four 1.8-m mobile ones and the delicate combining optics has created a situation where many programs become possible. From just measuring stellar diameters we have now advanced to obtaining high-resolution images of the inner regions of AGN. Several decades of excellent interferometric work may be anticipated.

(5) The choice of the superior site of Paranal as the location of the project. Though this added significantly to the cost, it has proven to be well worth it both for the quality of the atmosphere and for the total amount of observing time. In fact, no place in the world appears to have such a low cloudiness as the Paranal area. The nearby Cerro Armazones was found to be equivalent, though somewhat windier, and at the time less accessible. It gives confidence that some 25 years later those two mountains remained at the top in a new survey of possible sites. There are some indications that climate change begins to affect the Pacific, though not necessarily for the worse at Paranal/Armazones. While the quality of the atmospheric turbulence in Antarctica seems to be superior (especially at dome A), the sky coverage would be limited and the access difficult and extremely expensive. So it could only be considered for certain niche projects with relatively small telescopes, but not for projects like the VLT or E-ELT.

## The Future

Are we going to build ever-larger telescopes? Plans for the next generation of radio, optical, infrared and X-ray telescopes are in advanced stages or on the way to realization with price tags in the range of 1-5 billion Euros well above those for the previous generation. Will there be the interest and the capacity in Society to continue providing such – or even larger – sums? For a long time in the European, and even more in the American, mindset there has remained a brilliant future on the horizon with vistas of scientific discovery, technological development and economic growth. Characteristic was the influential 1945 report by Vannevar Bush to the U.S. President "Science: The Endless Frontier". But will scientific development really be endless? An early warning sign may have been the fate of the big particle collider in the U.S., abandoned after several billion dollars had been spent. And at NASA the JWST originally budgeted at less than 1,000 MUS$ has now reached the 5,000 MUS$, while having been reduced somewhat in diameter. Of course, the result was that a number of other projects could not be executed. Hence the title of a recent article in *Nature*: "The telescope that ate astronomy". At ESO the 100-m OWL planned in 2000 was wisely downsized to 42 m without much change in budget. So, prudence is called for not to overreach and lose one's credibility.

But even apart from issues of affordability, the question may be asked if every next step in our instruments will be equally productive? Will the future developments have as large an impact on our image of the world as those of an earlier generation? We may doubt it. The beginning of quantum mechanics was so exciting because it fundamentally changed not just a specialized part of physics but also much of science, including chemistry, astronomy and biology. Similar situations in the future seem rather unlikely. As science becomes more and more narrowly specialized, it may remain very interesting to its practitioners but a disconnect to Society at large seems possible. In that case the way is open to many forms of obscurantism. Education may be helpful in this respect, and it is perhaps there that astronomy has special opportunities.

How Society at large views science has a major influence on the rewards of a scientific career. If the view is positive, the brighter minds are inclined to favor such a career. If not, they will study other subjects. But is not an ageing society likely to be much less inclined to worry about science – except perhaps for antiaging pharmaceuticals? So while I see a bright future for astronomy in the next half-century or even somewhat beyond that, I believe that thereafter we may well look back to a past golden age, irremediably lost. If so, it might be well if we would plan for a less favorable situation. Of course one may argue about the precise time scale on which future events will unfold. However, it seems difficult to avoid the suspicion that science may not be an infinite frontier after all.