# Technology Transfer at ESO

Martin Cullum (ESO)

**Technology Transfer has become an important theme for the European Commission as a means of promoting innovation and competitiveness within European industry. It is also an area where organisations like ESO, that are engaged in developing highly advanced research facilities, can and do make significant contributions. This article discussed some of the processes involved in Technology Transfer and provides several examples of technological innovations developed by ESO in-house and through its procurement activities.**

Broadly defined, Technology Transfer concerns the transfer of knowledge and innovations from laboratories and research institutes to industry, or the use of ideas and developments from one field in others that were not originally intended.

At its meeting in Lisbon in 2000, the European Council set the objective of transforming the EU into the "most competitive and dynamic knowledge-based economy in the world" by 2010. To achieve this very challenging goal, a number of measures were planned, including revision of the framework for state aid for R&D, stimulating mobility of researchers between academia and industry, encouraging Public-Private Partnerships (PPPs), support for R&D innovations with Small and Medium-sized Enterprises (SMEs) as well as optimising the mechanisms for Technology Transfer within Europe.

Technology Transfer is also being actively promoted by the European Competitiveness Council that comprises ministers of research, education and industry or economy, as an essential element of improving European competitiveness.

Although Europe has traditionally been rather good at technological innovation, it has often lagged behind its main industrial competitors in exploiting innovations commercially. There are many reasons for this, but one important aspect is the relatively large contribution made to the overall economy in Europe by SMEs. Even before the recent enlargement of the European Union, 65 % of the EU GDP was generated by SMEs, and this figure is even larger now. This compares to only 45 % in the USA, for example. In general, larger enterprises have their own research departments and development laboratories, and the research carried out is largely, although by no means entirely, oriented towards specific products and fields that the company exploits commercially. This is often referred to as the "closed" model for technological innovation.

But even in the USA, SMEs invest three to six times more in R&D than their European counterparts who have traditionally relied more on "open" collaborations with external academic and research organisations. This can have certain advantages in that the accessible areas of research are very broad but experience has shown that the transfer of innovations from academia to industry is not a very efficient process. Not infrequently, promising open collaborations fail due to problems relating to the protection of Intellectual Property Rights that do not exist with in-house developments.

Apart from targeted research collaborations, there are other processes that can lead to Technology Transfer and ones in which scientific research organisations like ESO make significant contributions. Many European organisations, including ESA, EMBL, CERN, ESRF as well as national organisations such as the Max-Planck-Gesellschaft have adopted Technology Transfer as a core activity, and proactively search for market applications for their technological developments. In some cases this even extends to promoting start-up companies through venture capital funds.

## Why is Technology Transfer important for ESO?

More than ever before, the governments of ESO's Member States are looking not only at the scientific return but also at the industrial return they get from their contributions to ESO and the indirect benefits to their economies and to society as a whole. In these days of strained national budgets, the pursuit of scientific knowledge alone is not always sufficient to justify the investment into ever more ambitious and expensive projects.

Although ESO has no official mandate or funds to invest in Technology Transfer activities, it is a clear goal in the charter of EIROforum[1] of which ESO is a member. Through the very nature of its activities, ESO makes a significant contribution to Technology Transfer within the Member States. To help quantify this contribution and to highlight the process at ESO, a survey of ESO Technology was carried out in 2004 and the results presented to the ESO Council in December 2004. The results are accessible from the main ESO web page under *Projects & Developments* and provide a compendium of technologies that have been developed or promoted by ESO over the last 15 years or so. Most of the examples are associated with the VLT development period.

## Processes of transferring technology at ESO

The transfer of ESO developed or promoted technologies to industry can take several forms.

1. Novel technologies that have been developed by ESO or pushed beyond customary limits, or novel combinations of technologies that have been developed by ESO and made available for industrial exploitation.
2. Technologies that have been developed or extended in collaboration with industry through ESO development contracts.
3. Technologies that have been developed or extended by industry through the execution of an ESO procurement contract.
4. ESO developments that have been used for other similar projects elsewhere.
5. ESO patents.

## Examples of Technology Transfer at ESO

The following paragraphs give a few examples of such technologies to illustrate the processes just described.

[1] EIROforum is a collaboration between seven European intergovernmental scientific research organisations that are responsible for infrastructures and laboratories (CERN, EFDA, EMBL, ESA, ESO, ESRF and ILL).

## In-house developed technologies

### *Active Optics*

The ESO New Technology Telescope (NTT) was the first optical telescope with actively controlled optics. The main driver behind this development was to break the classical cost-diameter law for large telescopes but, even at first light, the NTT demonstrated image quality almost never seen previously on ground-based telescopes. Since the NTT, essentially all large optical telescopes worldwide use active optical control.

A crucial step towards realising a practical active optics telescope was the development of the so-called Shack-Hartmann wavefront sensor at ESO. It combines a compact optical device following an idea originally proposed by Roland Shack at the University of Arizona in 1970 with CCD detectors that started to be used for astronomy in the early 1980's. This device allows the optical alignment and shape of the main optics of the telescope to be measured and corrected in real-time. A key component of the wavefront sensor is the lenslet array which contains 400 lenslets, each 0.5 or 1.0 mm across depending on the application. ESO worked together with the Paul-Scherrer-Institut in Switzerland to develop the master and Jobin-Yvon France to manufacture the final copies of these arrays.

A number of commercial products based on Shack-Hartmann wavefront sensors have since been commercialised, for example devices for optical testing by Imagine Optic in France, for eye surgery by Zeiss in Germany and for optical alignment and testing by Spot Optics in Italy. Shack-Hartmann wavefront sensors are widely used in adaptive optics systems which correct aberrations caused by atmospheric turbulence – a technology that was also pioneered by ESO.

## ESO technology development contracts

### *Volume Phase Holographic Gratings*

Since Volume Phase Holographic Gratings (VPHGs) were first proposed for astronomy in 1998, they have had major impact on astronomical spectroscopy.

Figure 1: Diagram showing the principle of Active Optics. The Wavefront Sensor detects telescope aberrations and misalignments and corrects the shape of the main mirror and position of the secondary mirror to provide real-time correction.

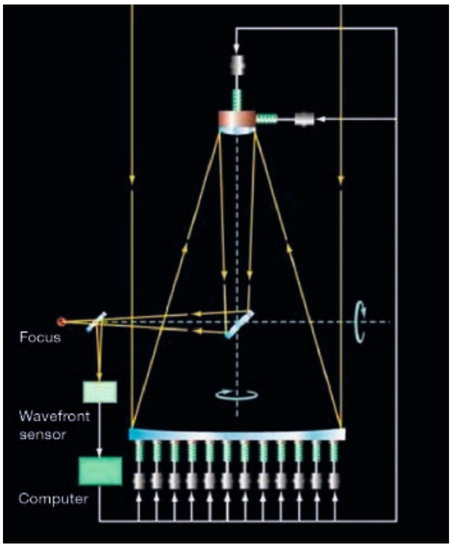
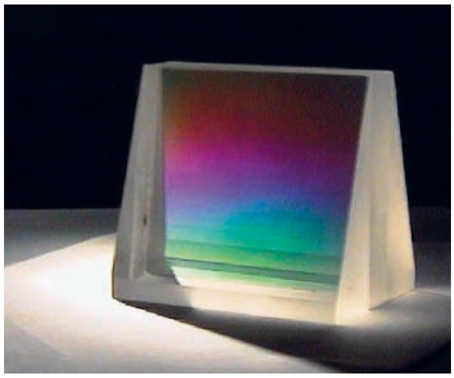



Figure 2: Example of a Volume Phase Holographic Grating sandwiched between two prisms to allow linear transmission.



The light passing through a VPHG, instead of being diffracted by a surface relief pattern as in a classical diffraction grating, undergoes Bragg refraction as it passes through a thin transparent layer in which the refractive index is modulated. This provides a very high optical efficiency together with low sensitivity to polarisation and reduced scattering.

The original VPHGs were produced for Raman Spectroscopy and these were small and not ideally suited for astronomy. A facility to manufacture large Volume Phase Holographic Gratings was set up at the Centre Spatial de Liège. ESO led a consortium of 5 astronomical institutions that allowed 10 prototype gratings to be manufactured up to 30 cm in size. The Centre Spatial de Liège has since created a spin-off company that is the leading European supplier of VPH gratings and currently the world's largest facility for the manufacture of these products.

### *Strip tape encoders*

Important components of any large telescope are the high accuracy angular position encoders needed for axis control. When ESO originally approached the world's leading manufacturer of high-precision strip tape encoders, Heidenhain in Germany, they could not guarantee that the stringent technical requirements for the VLT encoders could be met. Moreover, the tape mounting technique used at the time required a complex mechanical system to ensure that the tension in the tape was always constant and uniform. ESO placed a development contract with Heidenhain to produce an internally mounted tape encoder and provided them with a full-sized bearing for tests. The results of this development were so conclusive – in terms of both improved accuracy and simplified mechanics – that this subsequently became the standard way of mounting high-precision strip encoders.

## Technology developed through procurement contracts

### *8-m mirrors – blanks and polishing*

One of the main technological hurdles to be overcome for the VLT project was the manufacture of the 8-m blanks for the primary mirrors. Mirrors of this size had never been manufactured before and several approaches were investigated by ESO. A contract was eventually placed with Schott in Germany for the supply of the blanks. This necessitated the creation of new manufacturing facilities and the development of the production processes for glass-ceramics to completely new dimensions. The successful completion of the VLT contract put Schott in a leading position to bid for future projects requiring large optics.

The size of the VLT primary mirrors also required a major jump in the state of the art in optical polishing. Indeed, the French firm REOSC (now part of the SAGEM group), who received the ESO contract to polish the four 8-m mirrors, had to build a completely new factory outside Paris for their manufacture.

Not only was the size of these mirrors unprecedented, but also the required image quality set new benchmarks. Indeed, testing the mirrors proved almost as challenging as polishing them. ESO engineers worked closely with the manufacturer to produce a method of specification that not only fulfilled the high technical demands of the VLT project and could be verified at the factory, but also made optimum use of the VLT's Active Optics system for correcting large spatial frequency errors.

The manufacturing and testing facilities developed by REOSC for the VLT were subsequently used to polish the two 8-m mirrors for the US/UK Gemini telescope, as well as for smaller optics for other advanced projects.

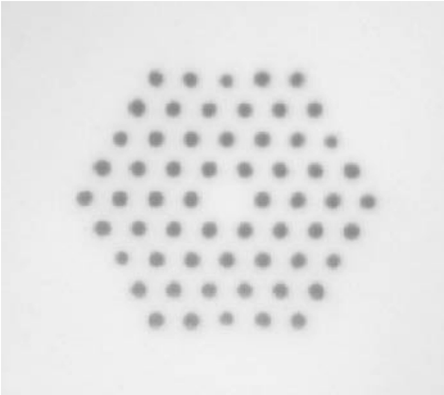
*Photonic crystal fibres*

Another technology promoted by ESO is the use of mono-mode optical fibres to transmit high power (≈ 10 Watt) visible laser beams. These are a key element of ESO's Laser Guide Star Facility and are used to transmit the light from the laser laboratory to the launch telescope located at the very top of the VLT. Compared to previous mirror transmission systems, fibre-optic transmission allows a significant reduction in the cost, complexity and maintenance.

However, a fundamental limitation in using classical mono-mode fibres is due to Stimulated Brillouin Scattering (SBS), a non-linearity which severely limits the laser power that can be transmitted through the fibre. Photonic Crystal fibres – "holey fibres" – were first demonstrated in the laboratory by researchers at Bath University in 1996. These offer an ingenious way of overcoming the problem of SBS by allowing an increase in the effective core diameter of the fibre but without losing the single mode transmission characteristics. This significantly reduces the power density inside the fibre and hence the effects of SBS.

Working initially with Crystal Fibre A/S in Denmark, ESO promoted the development of fibres with characteristics suitable for the LGSF wavelength of 598 nm and with good optical transmission

Figure 2: Section through a photonic crystal optical fibre showing the hexagonal pattern of holes that run axially through the fibre.



to demonstrate the feasibility of this technology with high laser powers. Since then, production fibres have been manufactured by Crystal Fibres and also Mitsubishi which meet ESO's requirements.

ESO's developments have been followed with great interest by other laser guide star projects as well as industry because of the wider commercial implications, for example in the telecommunications industry and the medical field. As a next step, ESO is currently working on the application of hollow-core photonic crystal fibres to the LGSF, which are now becoming available.

*Direct drive systems for telescopes*

Brushless torque motors offer a number of advantages over conventional telescope drive systems, including the elimination of the classical gear train (and hence mechanical simplicity) together with exceptionally good performance. Nevertheless, they had never before been used in large telescopes and nothing of the sizes required for the VLT existed in standard catalogues.

ESO commissioned a study to be carried out by the Swiss firm ETEL, and the results of this confirmed the suitability of the concept. In the VLT, direct drives from ETEL were used in the twelve Adapter/Rotators, and another specialist firm, PHASE in Italy, was contracted to design and manufacture the drives for the four Unit Telescopes, including the 10-m-diameter azimuth drives. Since the VLT, both these firms have expanded into this market and are now among the world market leaders in this field. PHASE, for example, has recently manufactured the drives for the 10-m Gran Telescopio Canarias on La Palma.

ESO technologies used in other projects

*Optical design*

ESO has a unique experience in the field of optical design, covering the wavelength range from UV to far infrared. Although an optical design made for one instrument is not readily useable for another, some ESO designs have been copied manyfold for use at other observatories.

The ESO Faint Object Spectrograph and Camera – EFOSC – was originally developed at ESO for the 3.6-m telescope on La Silla. It pioneered the use of new optical glasses for astronomical instrumentation to produce a very efficient transmissive optical train. Since that time, some 15 copies of this design have been manufactured and put into service at other observatories around the world. Similarly, the design of UVES – the UV and Visual Echelle Spectrograph developed by ESO for the VLT has been reproduced at least 10 times for application elsewhere.

Apart from these specific examples, ESO has had a significant impact, through optical design proposals and design reviews, on the optical design of a very large number of instrumental developments in the ESO Member States and beyond over the last 25 years.

*Computer systems and software*

Ever since the first "mini-computers" were introduced at La Silla in the early 1970's, ESO has been pioneering the use of computers for real-time control of telescopes and interactive data-reduction methods. This led initially to the development of the IHAP data-reduction package for spectroscopic observations and, in the 1980's, the more versatile MIDAS system which has been used by several hundred institutions worldwide.

More recently, ESO has developed a software bundle known as SCISOFT which is a unified collection of the major software packages for astronomical data analysis currently in use today (including IRAF/STSDAS, MIDAS and IDL) as well as many other utilities. The SCISOFT CD-ROM is distributed to over 400 institutions worldwide per year.

A fundamental part of the VLT concept are the Telescope Control Software and Data Flow Systems that allowed, for the first time in a ground-based observatory, the complete end-to-end observing cycle to be condensed into a single homogeneous automated process. This process starts with the preparation of the observing programme, and continues through programme selection, observation simulation, automatic or semi-automatic execution of the observations at the telescope (with or without the presence of the astronomer at the telescope), quality control, data archiving and finally the return of the calibrated data to the observer. Although at the outset it was not easy for many traditional astronomers to accept this revolutionary concept, it has become a standard that has since been emulated by most of the world's major observatories. In recognition of this work, ESO was recently presented with the prestigious 21st Century Achievement Award from the Computerworld Honours Program for the Data Flow System as reported in the June 2005 issue of the ESO Messenger.

### ESO patents

In the past ESO has generally preferred to openly publish ideas rather than to seek patent protection, but in areas where there could exist worldwide commercial application, for example in the communications industry, patent protection has been obtained to allow better regulation of eventual usage through licensing and partnership agreements with industry or other institutes. For example, an ESO patent has been granted for developments related to narrow-band high-power fibre lasers, and a second patent has recently been filed for a high-power fibre laser and amplifier.

### Knock-on benefits due to ESO's industrial procurements

There are also secondary industrial benefits to firms that receive ESO procurement contracts. A study carried out by CERN in 2003[2] amongst firms receiving CERN contracts for technology intensive projects (accounting for about half of all CERN procurement contracts) concluded that: 38 % of all respondents developed new products as a direct result of the original contract; 13 % started new R&D teams; 14 % started a new business unit; 17 % opened a new market; 42 % increased their international exposure; 44 % indicated technological learning; and 36 % indicated market learning.

Without the CERN contract, 52 % of all respondents would have had poorer sales; 21 % would have had lower employment growth; 41 % would have had poorer technological performance; and 26 % would have had poorer performance in valuation growth.

These data collected by CERN are impressive and present additional arguments for maintaining government support for the Organisation. Although no similar study has been carried out at ESO, the similarities between the two Organisations would lead one to expect that comparable benefits would also accrue to ESO suppliers as well.

## Socio-economic benefits of ESO Technology Programmes

The fact that ESO actively pursues projects at the cutting edge of technology and maintains a pool of engineering expertise that is probably unique in the world in the field of ground-based astronomy, also brings socio-economic benefits to the ESO Member States which can also help enhance the economic competitiveness of European industry as a whole.

Through its Student, Fellowship and Associate Programmes, ESO has contributed to the training of a considerable number of young scientists and engineers over the years. After spending some time at ESO engaged in forefront research or developing highly advanced astronomical facilities, these people leave the Organisation, taking with them their accumulated professional experience. This benefits not only their future careers, but also stimulates the research in their home institutions and helps to improve the competitiveness of Europe's industries. In 2004, for example, ESO employed over 100 Students, Fellows and Associates under these programmes.

Similarly, many ESO engineering staff members eventually leave the Organisation to return to industry to work on other high-tech projects, taking with them their professional expertise acquired in the course of their work at ESO.

Additionally, ESO has organised, either alone or with other institutions, many seminars, workshops and summer schools on diverse scientific topics as well as on technical aspects such as adaptive optics and optics. These events also help to develop the scientific and technical competencies within industry and scientific institutions in the Member States.

Less easy to quantify but also valuable are the personal links established during a period of employment at ESO. Even many years later, these personal links can provide a useful channel for information on ESO technologies and programmes and professional advice. The European Commission has long since recognised the importance of mobility amongst young researchers and engineers for enhancing European competitiveness, and has established several programmes to facilitate this.

As can be appreciated from this article, the process of Technology Transfer is many-faceted. It is a process in which, over the years, ESO has made significant contributions, both in encouraging innovation in industries within the Member States as well as improving commercial competitiveness.

[2] "Technology Transfer and Technological Learning through CERN's procurement activity", CERN2003-005, 11 Sept 2003, Education and Technology Transfer Division