MULTIOBJECT SPECTROSCOPY WITH EFOSC:

Observation of the Cluster A 370

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1. Introduction

Since the first experiment with Multiple Object Spectroscopy (MOS – see *The Messenger* **41,** September 1985) made on EFOSC, the announced new facility called PUMA 2 has been implemented. This is a small, computer-controlled punching machine with which the observer (on the site and during his own run) can make the aperture masks he or she needs.

The PUMA 2 system was developed by the Toulouse Observatory from a prototype PUMA first used at CFHT in Hawaii (Fort et al. 1986). PUMA 2 was implemented for the first time on the 3.6-m ESO telescope in February 1986 during a technical run in order to check the machine operation on-site and to develop and test the software facilities. Since then several astronomers have used the system. Two of us (B.F. and G.S.) took part in a run in November 1986 to measure velocities in clusters of galaxies. We believe it would be interesting for future users to comment on the way MOS has been used, and to present the performance which can be achieved with EFOSC. This paper should be considered as a run report and will give first results from the data reduction made in Toulouse on the observations of galaxies in the cluster Abell 370, using partially automated software. Results of MOS observations are also presented by D'Odorico and Dekker (1986).

2. Equipment and Procedures

2.1 EFOSC

For a detailed description of EFOSC we refer to the ESO Operating Manual. The detector in use during the November run was the ESO CCD #8, which is a high resolution (15 μm pixel) RCA CCD that we used in 2 × 2 binned mode. The quantum efficiency is about 80 % and the read-out noise 35 electrons rms.

2.2 PUMA 2

The PUMA 2 system is a microprocessor-controlled machine with which holes and slits can be punched in thin (0.15 mm thick) copper sheets called masks or starplates. Two different punch heads (0.3 and 0.5 mm corresponding to 2.1 and 3.6 arcseconds) allow the choice between two hole sizes. It is also possible to punch slits with these widths by punching a series of adjacent, partly overlapping holes. The relative positioning accuracy of the holes is 10 μm, given by stepper motors of the Microcontrole XY tables. The PUMA 2 is linked to the HP 1000 instrument control computer and the file with positions to be punched may be sent directly to the PUMA 2 microprocessor or temporarily stored on disk or cassette.

2.3 Preparing the masks

To prepare a mask one needs an EFOSC image of the field of interest. An inexperienced user should obtain it on a previous night, so he/she can go at ease through the interactive object selection process and the preparation of the mask the day before the observing night. This implies the use of MOS on the second night of an observing run, except when the preceding observer agrees to take the short exposures which are required. In our case Dr. A. Pickles kindly agreed to take an image of A 370 during his run, thus allowing us to make the spectrographic observations during our first night. It was a real chance as it turned out to be the best night of the whole run.

2.3.1 Taking direct pictures of the field

Images of the field are usually taken in white light. 1-minute exposures are sufficient to detect all objects suitable for spectroscopy.

It is important to note that, depending on the grism used and on the desired spectral range, the field image may have to be decentred in order to put the spectra of interesting objects in a suitable place of the CCD. As an example, with the B 300 grism, and if the spectral range 4500–6500 Å is desired, the objects must be chosen between the lines 100 and 300 on the CCD frame (decentring of the field about 30″ south).

2.3.2 Selecting the objects

The selection of the objects is done interactively on an image of the field at the 2-D display in the 3.6-m control room. The batch programme used for this purpose runs within the IHAP data reduction system and requires pointing with the cursors at the targets and at the positions of free sky to be used for comparison. Mistakes in the entering of the cursor positions can be corrected and the programme gives a warning if the spectra overlap. The procedure takes less than half an hour if the number of objects is less than about 10.

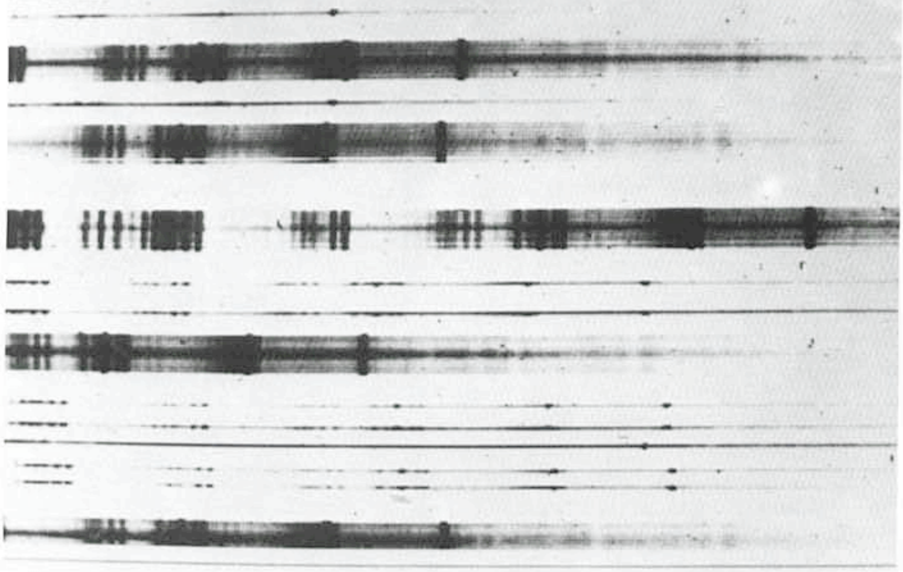

Figure 1: *CCD frame obtained with MOS using the B 300 grism. The mask has 5 slits and 11 holes and contains 12 object spectra. Note the number of radiation events in this 1h 30-minute exposure.*

For survey-type observing programmes which require an optimization of the distribution of objects and sky apertures to optimally fill the CCD, a semi-automatic programme like the one used by the Toulouse group at the CFHT (Fort et al. 1986) is more effective. The objects are automatically detected in the field image, using for example criteria like magnitude, colour or size. The batch procedure then optimizes the selection, given boundary conditions like length of the spectrum, minimum separation between the objects, need of sky reference. ESO is investigating the possibility to implement such a procedure as well but interfacing an existing Fortran programme into IHAP is not straightforward.

2.3.3 Punching the masks

This is a very efficient procedure as 6 masks with a given hole size can be prepared at a time. The size of the holes or slits can be chosen at this step. Holes and slits can be easily mixed on the same mask by punching the same mask twice before dismounting it from the PUMA 2 table. The hole shapes and sizes are very accurate, better than 10 μm. Repeating the punching on the same starplate may remove the burrs that sometimes remain and then give holes a slightly irregular shape.

The machine usually runs quite smoothly except for an occasional punch break. Replacing the punch takes a few minutes and is taken care of by the ESO maintenance staff.

2.3.4 Mounting and aligning the masks

The masks are put in place on EFOSC by the night assistant or by the astronomer after a short instruction. This operation is easy and the masks are maintained in a very accurate and repetitive position.

The observer is assisted in the alignment of the mask on the field by using an IHAP batch procedure that compares an image of the mounted mask (illuminated with a calibration lamp) with an image of the field. Provided the guide probe and telescope coordinates have been carefully noted when taking the direct picture, it takes at most two iterations and about 10 minutes to align the mask on the field with an accuracy as good as 0.25 arcsec rms.

The operation of the instrument rotator has been improved a few months ago. It now sets to an accuracy of $0\overset{\circ}{.}1$. This is sufficient for accurate alignment and makes the rotation of the EFOSC wheel (which is more complex since it also involves a translation of the mask) unnecessary.

2.3.5 Taking the spectra

The procedure is described in the EFOSC Operating Manual and from the experience we obtained during our run we would like only to mention some precautions to be taken to secure accurate results after reduction.

The so-called blue halogen lamp covers very well the range 3500–7500 Å and is normally used for flat-fielding.

It is necessary to take calibration lamp spectra through each mask as the dispersion is not exactly linear and changes with the position in the field, along the columns.

It is useful to keep a short direct image of the mask (with the halogen lamp or the dome lighting) for future automated reduction. It gives also information about the transmission of the different apertures.

All of these calibration exposures can be taken during daytime. However, we preferred to take them directly before or after the science exposure since almost no telescope time is lost and one makes sure that no important calibrations are forgotten. Also, when using this method, data and related calibrations are stored consecutively on the same tape, reducing the chance of errors during data reduction.

As the exposure times are long, we always chose to work at hour angles smaller than 1.5 hour and zenith distance less than 30° in order to minimize the effects of atmospheric refraction.

Figure 1 is an example of a CCD frame obtained in MOS with a mask punched with both slits and holes.

3. An Example of MOS Observations: Galaxies in the Cluster A 370

3.1 The astrophysical programme

Very little is known about the dynamic evolution of clusters of galaxies and the evolution of the galaxies in clusters. Multi-object spectroscopy is an ideal tool to investigate these problems. For example, the normal evolution models for galaxies (Bruzual 1981, Guiderdoni 1986) do not explain the excess of blue

Figure 2: *Image of A 370 cluster of galaxies taken with a B filter on EFOSC (20-minute exposure). The elongation of the images is due to the reproduction process from the TV screen.*

Table 1: *Spectra obtained during the observing run at the 3.6-m with EFOSC in MOS mode (1–4 November 1986)*

Cluster	Number of apertures	Number of objects	exposure time
A 2444	28 holes	14 objects	1h
A 551	26 holes	13 objects	40 mn + 45 mn
A 370	25 holes	13 objects	1h 30 mn + 1h 30 mn
	11 holes + 5 slits	12 objects	1h 30 mn
	16 holes + 4 slits	13 objects	1h 30 mn
	21 holes + 3 slits	14 objects	1h 30 mn

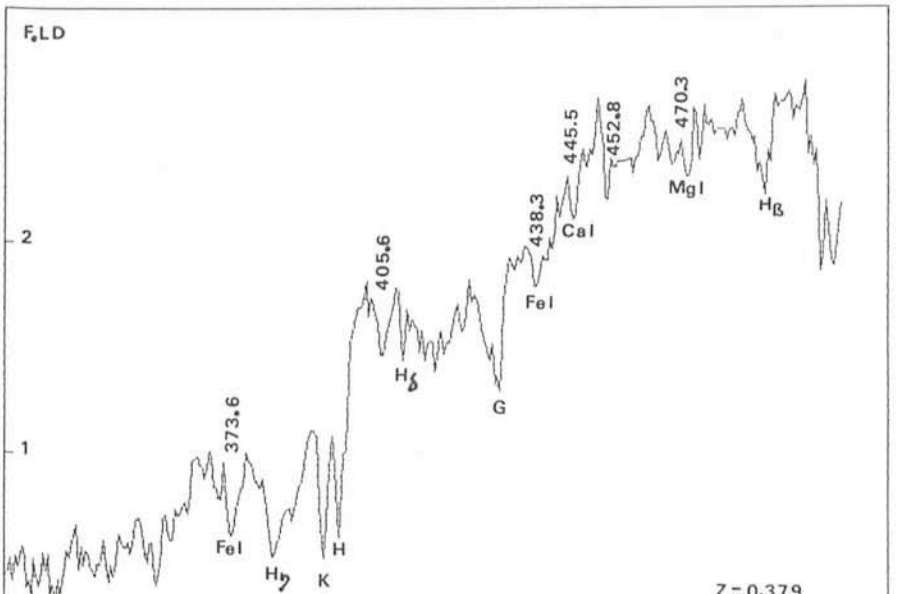

Figure 3: *Spectrum of the brightest galaxy of the cluster A 370 (No. 20, cD type) with a redshift of z = 0.379.*

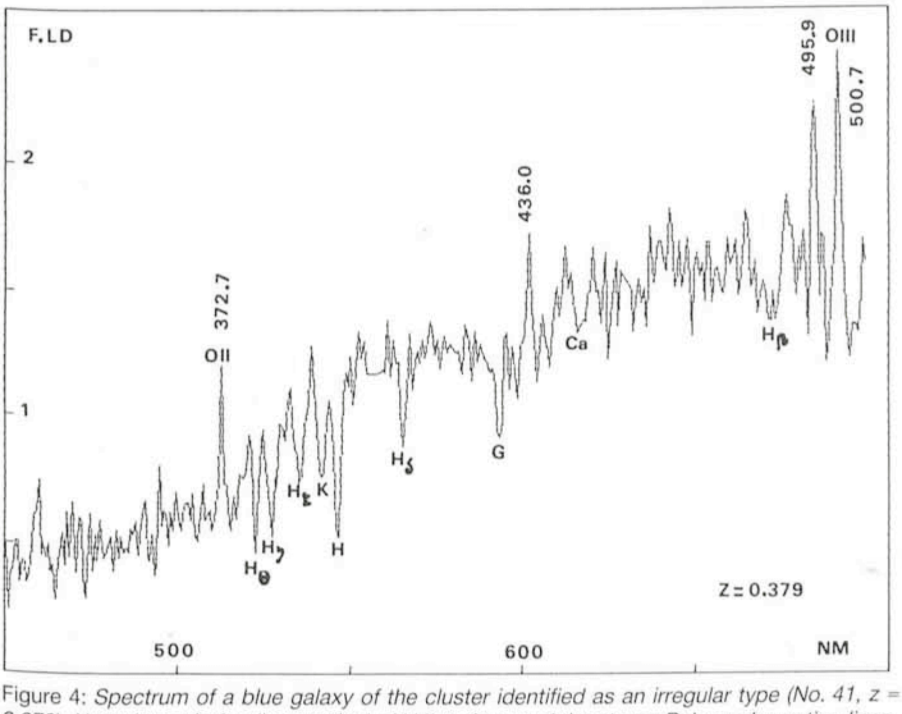

Figure 4: *Spectrum of a blue galaxy of the cluster identified as an irregular type (No. 41, z = 0.379). Note the emission lines typical of H II regions and the strong Balmer absorption lines.*

objects found in clusters with z ⩾ 0.2 (Butcher-Oemler effect, hereafter referred to as B.O.). This effect raises a lot of questions on the physical processes involved, the time scales, the initial conditions and their role in evolution. It is clear that it is necessary to accumulate spectrographic observations on clusters of varying richness, shape and redshift.

For the ESO run, we chose A 370, a very rich cluster at z = 0.374 (Fig. 2), as the first priority target. Some preliminary low dispersion observations at CFHT (Mellier et al., 1987) have shown a very unexpected high content of spirals which had to be confirmed at higher resolution.

3.2 Observational results

Of the 3 nights given for our run only 2 nights were useable for the MOS mode because of bad weather conditions. 79 spectra were obtained with a mean of 13 per mask. Two other clusters were studied besides A 370 and the observations are summarized in Table 1.

No problems arose during the observations but we feel that if it is to be efficiently exploited, this type of observation demands two observers, especially if most of the programme is devoted to MOS spectroscopy and they are not familiar with MOS or EFOSC.

3.3 Data reduction

All the spectra were reduced in 6 full weeks, using the software developed in Toulouse for the PUMA 1 system on the CFHT (see Soucail et al., 1987 for a full description). Changes needed for the ESO images were minimal and no particular problem arose in the reduction process. The only remark concerns a rather large number of radiation events on the CCD (ESO #8 has a frequency of 5.2 events/minute/cm^2). Twin exposures on the same field are useful to identify and correct them. The reduction software has been developed on a VAX computer in Toulouse, and it could be integrated in MIDAS, the ESO reduction package which runs on the same computer. It includes some interesting features related to the special format of the data, like the different positions of the apertures on the CCD and the faintness of the objects.

4. The Results

4.1 Performance

Despite the poor weather conditions, the limiting magnitudes are quite good: in one hour's exposure, with the B 300 grism, we obtained spectra of B = 22, V = 21.2, R = 20.7 galaxies at a signal-

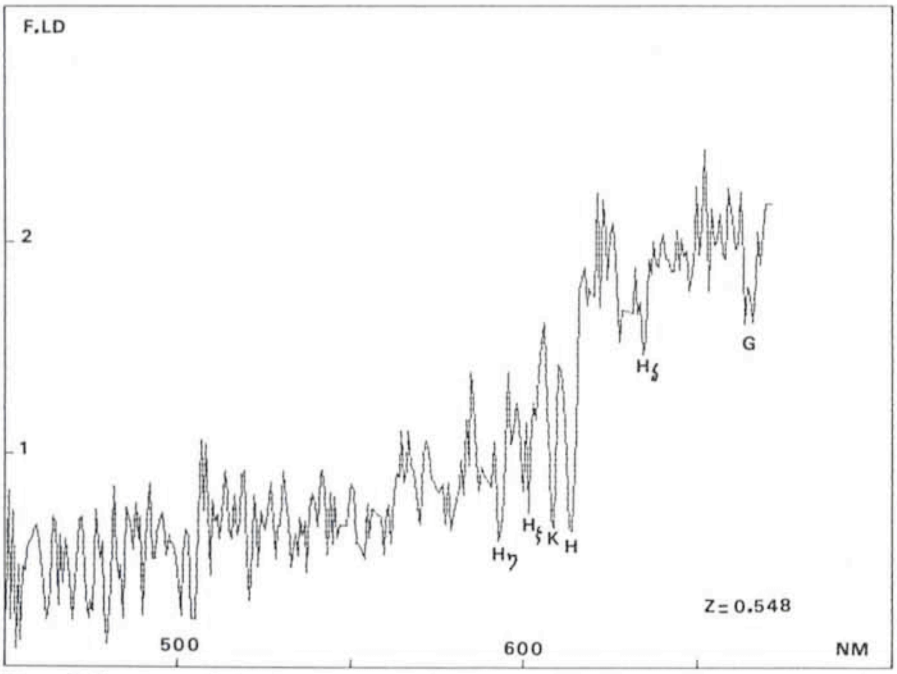

Figure 5: *Spectrum of a background galaxy found in the field of the cluster (No. 14, z = 0.548).*

to-noise ratio on the continuum of 10. These performances are about 0.7 magnitude fainter than the ones obtained at CFHT with a focal reducer that has not been specially designed for this kind of experiment. It is possible to go even fainter by co-adding several exposures which has the additional advantage of better removal of radiation events. Examples of spectra of galaxies in the field of A 370 are given in Figures 3 to 5.

4.2 Astrophysical results

From a run at CFHT in 1985 and the last run at ESO, we have 90 spectra in the field of A 370, which represents an unusually large number for such a redshift (z = 0.374, see Fig. 6). About 55 spectra are from cluster members and they give a velocity dispersion of 1300 (+ 230, – 150) km/sec and a M/L ratio of 130 (with the virial approximation), very similar to those measured on closer clusters. A complete study of A 370 will be given in a forthcoming paper (Mellier et al., 1987) but we summarize here the most significant results.

A 370 is a very rich cluster (richness similar to Coma), X-ray emitting, and shows a large population of blue B.O. objects. The proportion of 21 % given by the photometry (Butcher and Oemler, 1983) has been reduced to about 11 % from our spectrographic measurements, because of a better evaluation of the contamination by foreground objects but the B.O. effect is now well confirmed by the spectroscopic measurements.

The B.O. objects are more precisely spirals or Magellanic galaxies but no active nuclei are present. By comparing these observational results with star population synthesis models with the same resolution (Guiderdoni and Rocca-Volmerange, 1987) one obtains a good galaxy type distribution. The result is an unexpectedly high rate of spiral galaxies (50 % as compared with 5 % in Coma) at a time 2/3 H_0^{-1}.

Both more observations and theoretical investigations have to be made to explain why at about the same redshift, clusters showing about the same overall properties seem to have so different galaxy contents. Could the pressure effect of the dense intergalactic gas in the centre of rich clusters be a possible answer?

5. Conclusion and Future Developments

As a conclusion we shall say that now the MOS mode on EFOSC in its present status is certainly one of the most efficient systems used on 4-metre class telescopes. It is clear from our experience that the performance in terms of limiting magnitude is quite good.

Further improvements could be made soon in the object selection procedure by allowing a mixed (manual and automatic) procedure for selecting the targets. With a more flexible and user-friendly procedure, the possibility of mask preparation and observation in the same night could be implemented.

An important question is the choice between holes and slits. The trade-off is the number of objects per mask compared to the sky subtraction accuracy which depends on the crowdedness of

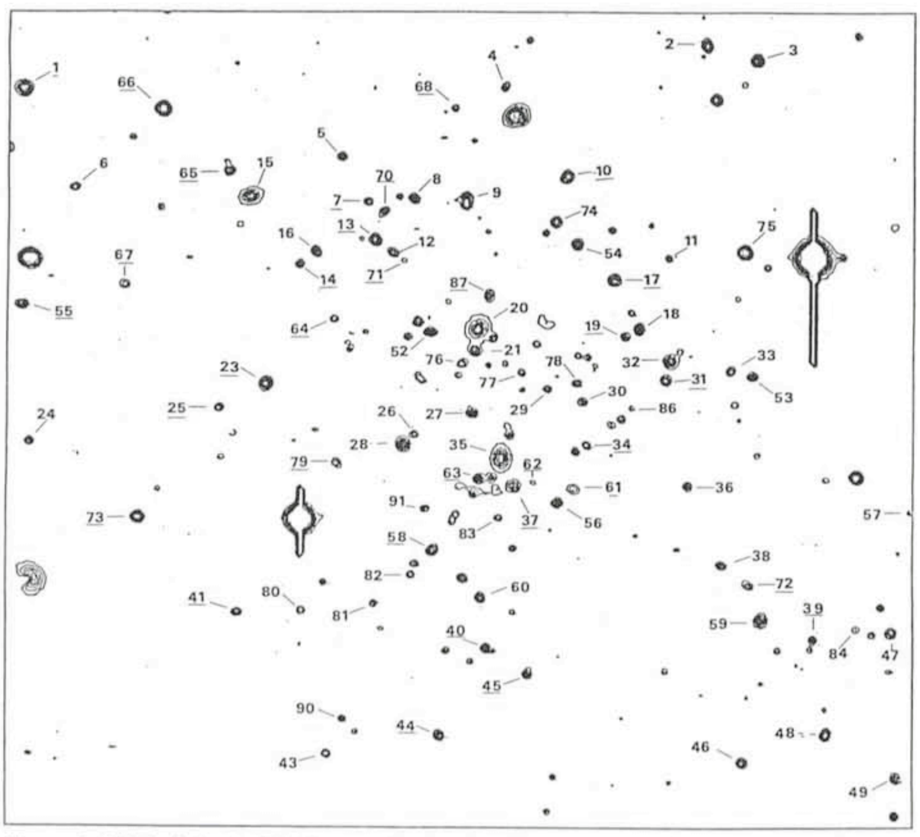
Figure 6: *Field of the A 370 cluster with the identification of all the objects from which a spectrum has been obtained at ESO or at CFHT with the PUMA system. The underlined numbers correspond to objects of which the spectra were obtained at ESO in November 1986.*

As an example, slits do not seem very well fitted for programmes where a lot of spectra in a rather crowded field are needed. The advantage of slits is certainly a better sky subtraction in the case of very faint objects. In the case of bad seeing, slits are also more efficient. More accurate extraction algoriths such as e.g. the one proposed by Hornes (1986) could also be used on slit spectra. These might yield a considerable improvement in the S/N ratios and in the limiting magnitudes. An efficient future EFOSC/MOS facility should allow both round holed and rectangular slits to be used in a flexible way, depending on the astrophysical project. It should be possible to interactively adapt the aperture sizes to the prevailing seeing.

Work is now being carried out at ESO and Toulouse Observatory to investigate other mechanisms for the making of the mask, such as laser cutting and the punching of precise rectangular slits.

On the data reduction side, further work is necessary to develop optimized software in order to cope with the large amount of data generated by this powerful observing technique.

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NOTE ADDED IN PROOF

In a recent note in *NATURE* (Vol. 325, 572), B. Paczynski discusses the "discovery" of a giant luminous arc in the core of the cluster A370, as announced in January 1987 at the 169th Meeting of the AAS. It should be pointed out that this object was already identified in a poster paper which was presented at IAU Symposium No. 124 in Peking in August 1986. A further discussion may be found in a recent paper by Soucail et al. (*Astronomy & Astrophysics,* 172, L14; January 1987). More observations of this interesting structure were obtained in October 1986 with EFOSC.

Nuevos meteoritos encontrados en Imilac

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(Traducido del ingles por C. EULER, ESO)

Desde tiempos prehistóricos han sido coleccionadas piedras que caen del cielo. Hasta hace poco eran la única fuente para hacer estudios de laboratorio de la materia extragaláctica, e incluso en nuestra era espacial, siguen siendo una valiosa fuente de investigación de la temprana historia del sistema solar.

Se estima que como término medio cada kilómetro cuadrado de la superficie terrestre es golpeada cada millón de años por un meteorito con un peso superior a 500 gramos. La mayoria se pierden en los océanos o caen en regiones con escasa población. Como resultado, los museos en el mundo reciben anualmente tan sólo alrededor de 6 meteoritos cuya caída fuera atestiguada. Otros llegan por hallazgos casuales que en la mayoría de los casos son meteoritos que han caído en tiempos prehistóricos.

Desde el punto de vista mineralógico pueden ser divididos en tres clases: piedras, hierros y hierros pétreos. Los meteoritos que caen son en su gran parte pétreos, mientras que aquellos que se encuentran tienen un alto porcentaje de hierro. Esto se debe a que los meteoritos pétreos tienen una erosión más rápida y son menos visibles. Geográficamente las caídas de meteoritos están muy relacionadas con la densidad de la población, la mayor parte descubiertos en Europa y Norteamérica.

La mayoría de los meteoritos se encuentran por casualidad. La búsqueda activa en general requiere demasiado tiempo para ser de interés. Sin embargo, los glaciares de la Antártica han demostrado ser un "buen terreno de caza".

Meteoritos de Imilac

Otras áreas donde se han hecho muchos hallazgos son algunas de las regiones desérticas del mundo, como el lado occidental de Australia, las estepas de Norteamérica, y el Desierto de Atacama en Chile. En este último las precipitaciones anuales son menores que en cualquier otra parte del mundo, menos de 5 mm, lo que obviamente ayuda a la preservación de los meteoritos. Como resultado, uno de los meteoritos atacameños, encontrado en el Tamarugal, tiene una edad terrestre de 2.700.000 años, conocida como la más antigua.

Muchos meteoritos chilenos pertenecen al tipo "Pallásito"* y provienen muy probablemente de una sola caída. Llevan el nombre de las localidades esparcidas geográficamente en un área de 100 por 100 km. En muy pocos casos, sin embargo, se pudo indicar con precisión el lugar del hallazgo y hasta muy reciente se creyó que los meteoritos habían sido encontrados dentro de un área de 100 por 500 m cerca del pequeño Salar de Imilac, que se encuentra aproximadamente a 170 km de Antofagasta. En este lugar existe una excavación similar a un cráter con un diámetro de 8 metros. Este puede haber sido cavado por indios en busca de la imaginada veta de hierro. Varias excavaciones en colinas adyacentes muestran lugares donde en el pasado se han coleccionado meteoritos. Aun la parte superior del suelo contiene muchos pequeños fragmentos de hierro que pesan típicamente I gramo.

Los meteoritos de Imilac han llegado a muchos museos y colecciones particulares en todo el mundo. El ejemplar más grande conocido, de 198 kg, se encuentra en el Museo Británico. Otro fragmento, originalmente de 95 kg, está en Copiapo. El monto total del material encontrado, plausiblemente de origen de Imilac, se calcula en 500 kg.

Los principales hallazgos

Después de varias expediciones se pensó que todos los grandes meteoritos habían sido coleccionados. Sin embargo, podemos informar sobre el reciente descubrimiento de tres meteoritos más, totalizando 59 kg. El hallazgo fue hecho por uno de los autores (F.G.), geólogo. (Nota del editor: F.G. es el esposo de una de las secretarias de la ESO en Santiago, Mariam G., a través de quien los científicos de La Silla fueron informados del descubrimiento). Mientras buscaba agua para una empresa minera supo de la caída en Imilac. Un poblador de la zona le informó de que algunos meteoritos habían sido encontrados algunos kilómetros al sur-oeste del "cráter". Dedicándose a la búsqueda pudo encontrar otros tres con un peso de 5, 19 y 35 kg, respectivamente.

La Universidad del Norte en Antofagasta examinó los fragmentos de 5 y 35 kg y los clasificó como "Pallásitos". Por razones de peso especifico creemos que también el hierro de 19 kg pertenece a ese grupo. Ya que en todo el mundo se han descrito tan solo 33 hallazgos "Pallásitos" (y dos caídos), es un fuerte indicio que los nuevos ejemplares son parte de la conocida caída de Imilac.

* Los meteoritos se pueden dividir en tres clases: piedras, hierros y hierros pétreos. Un sub-grupo de este último es bastante especial: una mezcla de hierro y niquel forma una estructura de tipo esponjoso. Cristales olivinos, con un diámetro de 1 a 10 mm rellenan los orificios, lo que da una relación de volumen metal/olivina de aproximadamente 1 : 1. El primer meteorito de esta índole fue encontrado en 1771/72 por el explorador alemán Peter Simon Pallas en sus viajes a través de Rusia oriental. Meteoritos del tipo "Pallásito" son muy escasos: tan solo menos que un porciento de todas las caídas y 3.5 porcientos de todos los hallazgos pertenecen a este grupo.