galaxy is confused with a distant background elliptical galaxy. The easiest way of distinction would be the measurement of the radial velocities of the relevant target objects. However, the nature of the found objects is much better established, and they are quite probably genuine globular clusters of NGC 3109: Their colours are moderately red, and we think they are normal halo objects of this galaxy. This is supported by their distant position from the main disk of NGC 3109.

Unfortunately the other cluster candidates of NGC 3109 could not be observed during this observing run. But the remainder of the observing time was used to observe some other nearby galaxies. A very interesting galaxy turned out to be the probably outlying member of the Sculptor group of galaxies A0142-43. In its halo two objects were observed which resemble those of the found globulars in NGC 3109, and may be even a bit larger in their absolute dimensions. Again, their position relative to the parent galaxy and their colours indicate typical halo objects. A huge H II region in the main body of A0142-43 shows that star-forming processes took place quite recently in it.

If there are populous clusters of very young age associated with it they are veiled by this bright gas complex. It should be noted that the estimated absolute luminosity of A0142-43 is 1.5 magnitudes fainter than that of the Small Magellanic Cloud.

We can conclude that our observations tend to confirm the complex situation among the galaxies and their cluster systems. Although it may be useful to detect new cluster systems, the relevant information of their role among the evolution of galaxies can certainly much better be found in detailed kinematical studies.

# Chromospheric Modelling in Late-type Dwarfs 2. CES Observations of Active and Quiescent Stars

*B. H. Foing, ESO*
*J. Beckman, Instituto de Astrofísica de Canarias*
*L. Crivellari, Osservatorio Astronomico di Trieste*
*D. Galleguillos, Universidad de La Serena and Max-Planck-Institut für Radioastronomie, Bonn*

## 1. Introduction

For many years it has been accepted that a stellar atmosphere cannot be considered as a closed thermodynamic system isolated by notional adiabatic walls, and without exchange of matter with the surrounding interstellar medium. A detailed exchange of ideas, developed earlier by Pecker, Praderie and Thomas (1973, *Astron. and Astrophys.*, **29**, 283) can be found in Thomas' monograph "Stellar Atmospheric Structural Patterns" (1983, NASA SP – 471).

Twenty years of UV observations from space have given us clear evidence that stars in every part of the HR diagram are losing mass, and that their external layers are heated by non-radiative energy fluxes up to coronal temperatures of several millions of Kelvins. These major departures from conditions of equilibrium make the modelling of a stellar atmosphere a more difficult task. In fact, the computation of detailed models for the solar and stellar atmospheres is even more difficult than the corresponding problem for photospheres. As discussed in the first article (*The Messenger*, **38**, p. 24), chromospheric models must take into account not only the severe departures from LTE and radiative equilibrium, but also the increased importance of magnetic fields in controlling the energy transport, as well as the linked horizontal inhomogeneities in density and temperature. The most valuable observations available for constraining model chromospheres are high resolution spectra of the lines of the most abundant elements, especially Hα, the H and K lines of Ca II, the infrared triplet of Ca II, and the h and k lines of Mg II.

In this paper we shall describe the observations that we have obtained for a sample of active and quiescent late-type dwarfs as an input for chromospheric modelling. We describe briefly the background of the program originating in IUE observations of Mg II lines, and the objectives of our complementary observations of chromospheric lines at ESO. From the spectra obtained with the Coudé Echelle Spectrograph (CES) we have derived preliminary spectroscopic indicators of activity. We show how this empirical approach can provide a guideline for the next phase of our program: quantitative line modelling from which should emerge the temperature structure, the energy balance, and the structure of the heterogeneity of late-type chromospheres.

## 2. IUE Observations of MgII Lines, and the Background to the Program

During the past six years we have been observing a representative sequence of late-type (late F and G) dwarfs using the high resolution spectrograph of IUE to obtain high quality profiles of the h and k lines. As described in article I, an almost serendipitous consequence of the failure of the stars to show reasonable variability has been a set of averaged profiles of very high quality, with spectral resolution of $1.8 \times 10^4$, high enough to resolve the Doppler self-absorbed parts of the core, and signal to noise ratio of 30 even in the hl and kl minima, good enough for model fitting. Thanks to the powerful IUEARM set of data reduction programs we have been able to identify and remove the interstellar Mg II, leaving line shapes which reflect intrinsic chromospheric and photospheric processes. In addition, absolute fluxes in Mg II have been obtained for comparison with theoretical predictions.

These predictions are of two types. One concerns the way in which energy is deposited within the chromosphere: whether by acoustic or magneto-acoustic input. This we can examine through a comparison of line profiles with model atmospheres. The second is the relation between age, rotation rate and chromospheric activity, first quantified by Wilson (*Ap. J.*, 1980: **226**, 379) and subsequently explored observationally by Vaughan and his co-workers. Activity indicators can be derived from spectra, calibrated in a coherent manner, and studied for variations in effective temperature, rotation rate and age. In a second step the line profiles can be modelled in detail. An intrinsic weakness of any chromospheric model based on

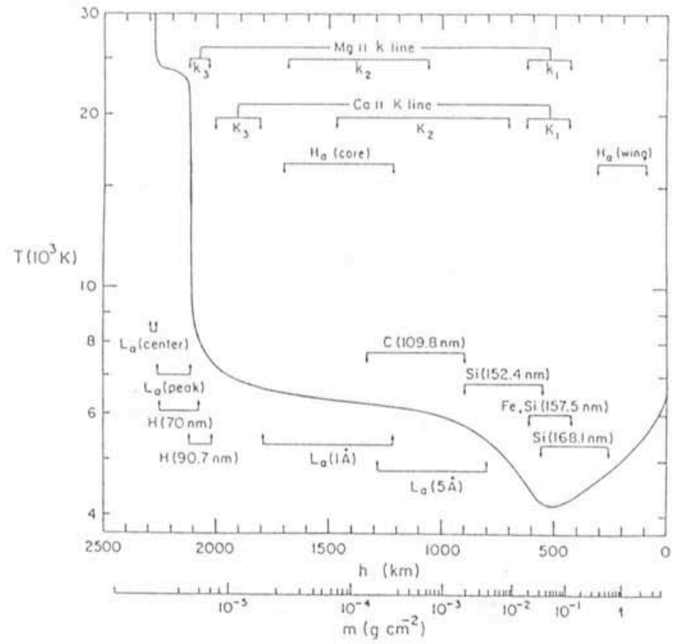



Figure 1: *On the average quiet-Sun temperature distribution derived by Vernazza, Avrett and Loeser (1981)* Ap. J. Suppl. **45,** *635, the estimated depths where the various spectral features originate are indicated for the Mg II, Ca II and Hα lines.*

fitting a single emission line is its non-uniqueness. This is one important reason to use the group of lines referred to in the introduction, where profiles are formed in different, but thoroughly overlapping layers of the chromosphere. In Figure 1 we indicate the mean formation layers of the core and the wings of those lines for the Sun, i.e. for the quiet Sun temperature distribution derived from the EUV continuum, Lyα and other observations by Vernazza, Avrett and Loeser (*Ap. J. Suppl.* 1981: **45,** 635)

## 3. Objectives of our Chromospheric Modelling Programs

Clearly the most striking difference between the chromospherically active and chromospherically quiescent stars as far as our data are concerned is the fact that the Mg II emission cores do not exhibit major quantitative differences, whereas the Ca II cores are strikingly different, with the active stars showing much more emission.

In one sense the reasons for these chromospheric differences are fairly clear, as we know that the active regions of the type observed on the Sun (where the chromospheric plages show up strongly in Ca H and K) are likely to be the cause of the H and K enhancements in active stars. Solar plage activity corresponds to magnetic activity and hence strong stellar Ca H and K corresponds to stars with greater average surface magnetic activity. One result of this activity is to channel more energy into the chromosphere, possibly via MHD waves, and a major manifestation of the activity is the enhanced presence of magnetically controlled jets, or spicules, which are concentrated along the boundaries of the supergranules in the solar chromosphere (spicules have diameters in the $10^3$ km range, and the supergranules in the $10^4-10^5$ km range), and which appear with greater surface density in the plages. Put simply, the quiescent resonance line emission cores exhibit the interspicular chromosphere, and the active cores exhibit the spicular component, although this is an oversimplification.

Any chromospheric model must take into account this inhomogeneity, although it is possible that even two stream models will prove insufficient. At all events, the ability to obtain the highest quality profiles, with a spectral resolution sufficiently high that a resolved element is significantly finer than the sharpest core features, is allowing us to make progress in the following areas:

(a) To measure true chromospheric radiative losses as a function of $T_{eff}$ and rotational velocity, making comparisons between acitve and quiescent stars.

(b) To assess the run of microturbulent velocity with depth in the chromosphere.

(c) To compute numerically departures from hydrostatic equilibrium, by using measured line core asymmetries to assess the velocity fields.

(d) To attempt detailed models in which all the parameters of a chromosphere can be derived, using the modern analytical tool of partial redistribution theory, and taking both horizontal inhomogeneity and velocity fields into account.

In addition to high resolution CES spectra on which the empirical side of a modelling program is now being based, it is important to have three other types of information at our disposal: (a) absolute spectrophotometry at modest resolution, in order to calibrate fluxes; (b) near infrared photometry in the classical I, J, H, K bands in order to derive the major radiative loss contribution made by $H^-$ in these cooler stars, and (c) if practicable, direct measurements of rotational modulation of (eg. H and K) line cores because this is the only accurate way to infer rotational velocities of slowly radiating stars (v sin i $\leq$2 km s).

## 4. The Use of ESO Facilities

There is no doubt that the CES spectrograph, fed either by the CAT or of course by the 3.6 m telescope, is the leading coudé facility at present available. In our recent runs, aimed at acquiring the line profile data whose purpose is outlined above, we have obtained at Hα, for 3rd magnitude stars, signal-to-noise ratios of 300 in the continuum, with spectral resolution $10^5$, in exposures of the order of 1 hour with the CAT. When one considers that the free spectral range of between 30 Å and 70 Å is adequate to take in even the broadest photospheric absorption and that the reticon offers a dynamic range capable of measuring the H1 and K1 intensity minima at the same time as the H2 and K2 maxima, there is no further need to emphasize the value of this facility for chromospheric modelling observations. We have now sampled 13 quiescent and 12 active stars, taking in all of the chromospheric diagnostics mentioned, plus the $^6$Li/$^7$Li doublet at λ 6707 Å for most of them. They cover a range of spectral classes from F8 to K5 down to limiting magnitude $m_v = 5$. At this magnitude one is beginning to touch, with the CAT and the present instrumental configuration, effective dark count limitations on the signal-to-noise ratio required to sample the H1 and 1k minima.

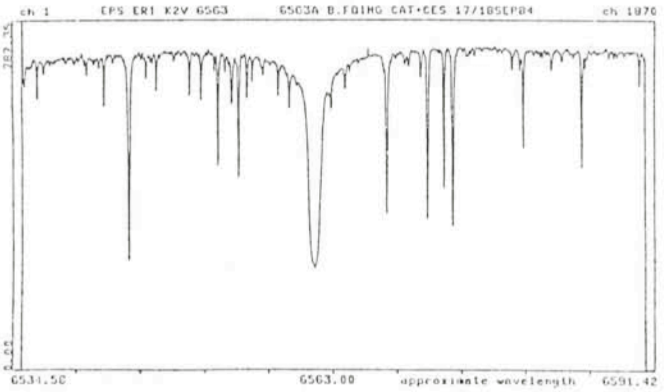
In addition to the CES, ESO offers the near-infrared standard photometer needed to compute the $H^-$ radiative loss measurements with those of the two other major contributors, viz. the Mg II and Ca II resonance doublets. Further the use of the 1.5 m telescope with Boller and Chivens spectrograph for making absolute flux determinations provides another key link in the chain of observational inferences needed for useful chromospheric modelling. In fact, only the UV spectra (Mg II and Lyα) and the direct measurement of rotational velocity via H and K modulation are lacking at present in order to complete the battery of facilities required to attack this problem. While it will never be possible to do away with IUE or ST, it would indeed be possible to envisage a rotational modulation spectrometer attached to an ESO telescope of the 1.5 m class.

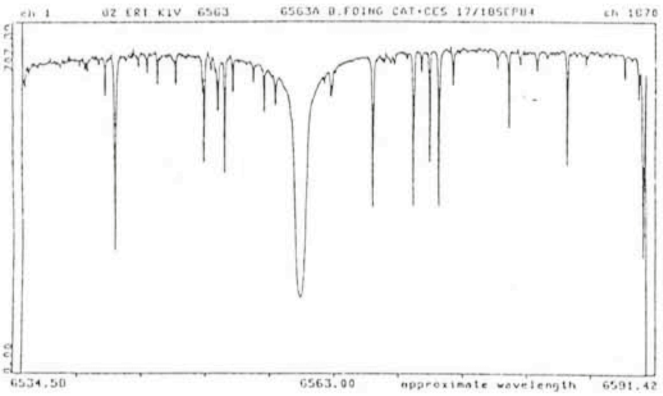
Even now, the less accurate approach to rotational velocities via line asymmetries can be used on CES spectra. In sum, ESO is certainly currently the best observatory in the world from which to mount a concerted campaign on chromospheric activity of solar-like stars.

## 5. Comparison of Observed Chromospheres Inferred from CES Spectra

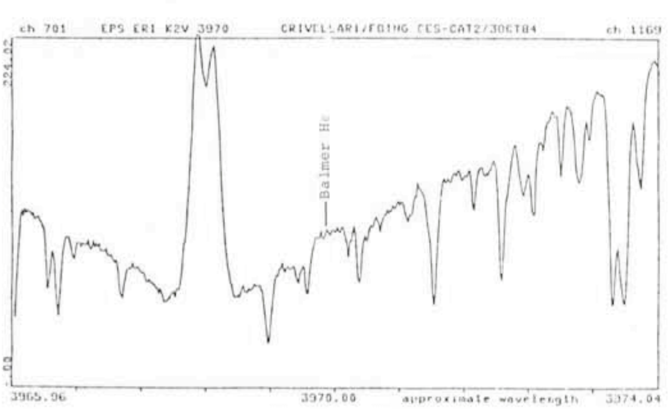
As examples of the comparison of chromospheric lines from pairs of stars with similar spectral type but with different bands of activity we show, in Figure 2a and 2b, CES spectra of the cores of the Ca II H lines in ε Eri and α Cen B. The K1 V star α Cen B shows a central reversal which is in fact quite clear when contrasted with the underlying photospheric background. However, α Cen B can be considered as a quiescent star compared to the K2 star ε Eri, for which the very strong central emission indicates a much higher degree of activity. Note also the asymmetry between the H2 violet and red peaks, as well as the appearance of the Balmer line Hα in emission for ε Eri. The Ca II core of ε Eri looks similar to the cores of these lines emitted from a plage region on the Sun. We can use the other chromospheric lines in addition to the classical K or H indexes, to study the differential effect of the acitivity.

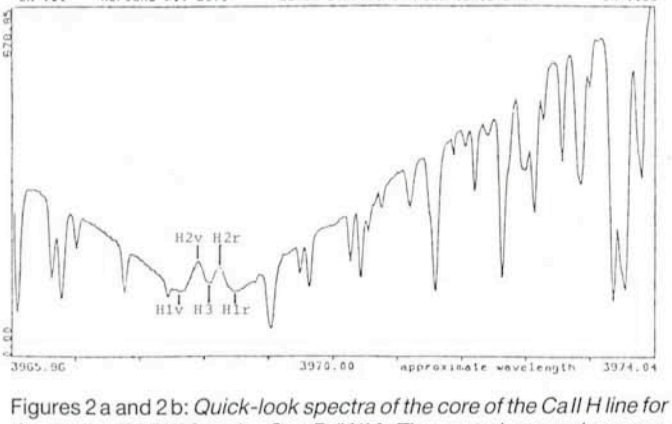
Figures 3a and 3b show spectra of Hα for the two K2V stars ε Eri end $O^2$ Eri. The wings of the Hα profiles are undistinguishable for the two stars, which confirms that they have the same effective temperature. However, the intensity at the center of the core of the active star ε Eri is 40% more than for the quiescent $O^2$ Eri. The difference in the equivalent width between the two profiles represents the energy excess contribution in Hα due to the activity. Note here the slight asymmetry in the core of Hα for ε Eri.




Figures 3a and 3b: *Spectra of the Hα line for the two K2V stars ε Eri and $O^2$ Eri. The wings of the Hα line are undistinguishable between the two stars, but the core intensity of the active ε Eri is 40% more than for the quiescent $O^2$ Eri, showing the chromospheric emission due to the activity.*



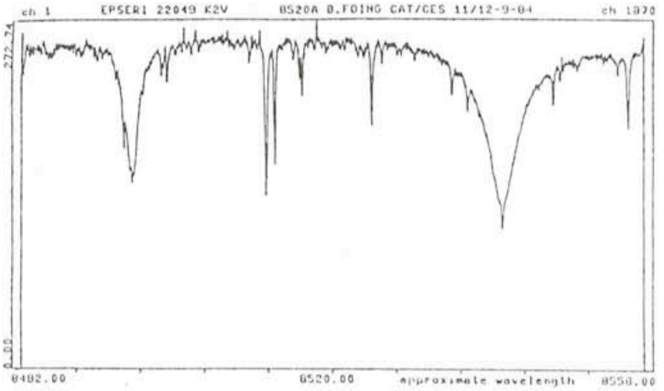



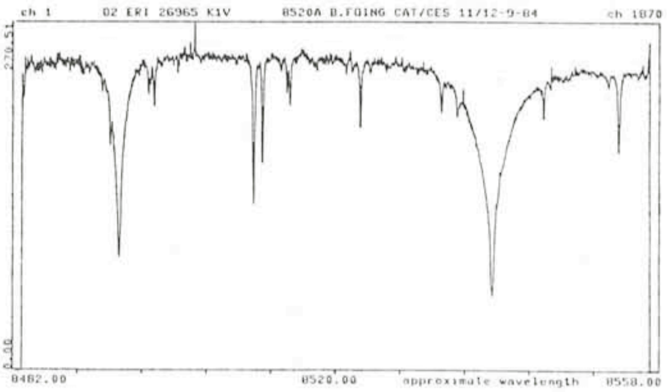

Figures 2a and 2b: *Quick-look spectra of the core of the Ca II H line for the stars ε Eri (K2V) and α Cen B (K1V). The central reversal appears clearly by contrast with the underlying photospheric background, even for the quiescent star α Cen B. The very active ε Eri shows a central emission very similar to that emitted from the solar "plages".*

For the same two stars, Figures 4a and 4b show spectra of two of the Ca infrared triplet lines. Here again we can see clearly that the absorption lines are filled in by a chromospheric emission component; the intensities at the centers of the two lines are twice as strong in ε Eri as in $O^2$ Eri. In order to use these observations as measurements of flux excesses we must proceed via absolute flux calibrations, a consideration which clearly applies to all our measurements. Once again in these triplet lines there is asymmetry in the core emission, and also clear evidence not only of emission, but of a sharp central self absorption. It is interesting to note that we have found in the more active stars changes in the central intensity and in the asymmetry of the chromospheric lines. These changes could be related to rotational modulation of the chromospheric emission due to plage transit over the visible surface. In these cases we have to ensure that a complete set of spectral lines, either simultaneous observations or observations at the same rotational phase, are taken, if we intend to produce consistent models of active chromospheres.

## 6. Activity Indicators

In section 5 we illustrated some spectral signatures of the activity observable via the CES in different lines. Here, in Figure 5, we have plotted a group of activity indicators. Namely the core intensity in the line of Hα and of the "triplet" lines at




Figures 4a and 4b: *Spectra of two lines of the Ca infrared triplet at 8498 and 8542 Å, for ε Eri and O² Eri. Again, for the active ε Eri, the Ca II absorption lines are partially filled by a chromospheric emission core.*

λ 8490 and λ 8542. These intensities are presented in units of flux in the nearby continuum. Although still somewhat crude, these indicators are able to give us some useful immediate information about stellar activity. The most notable feature of Figure 5 is the wide dispersion of activity with spectral type, which is certainly consistent with the existence of another parameter controlling the activity. This is probably the rotation rate, as suggested by Vaughan et al. (*Ap. J.*, **250,** 276, 1981). We have included our sample of quiescent stars in Figure 5 to provide a baseline from which activity can be measured and by way of contrast have also included indicators for two RS CVn binaries, which are known to show very high levels of activity.

These rough activity indicators can be refined to represent by calibration true chromospheric losses in the corresponding lines. They are useable as guidelines to describe the variety of chromospheres of our star sample, and will be employed in plots against effective temperature and rotation period. Subsequently we will, however, need to make detailed models, deriving the temperature structure and energy balance with height, which are necessary to analyze the processes which in fact heat the chromosphere.

## 7. Conclusion

Observations of quiescent and active stars to date have resulted in clear analogs to the activity phenomena observed on the Sun: active regions, photospheric spots, chromospheric plages, coronal structures. Leading directly from the work originally carried out for the Sun by Lemaire et al. and by Vernazza, Avrett and Loeser, our observations can provide strong constraints on models of stellar chromospheres. In a third paper of this series for the *Messenger* we shall present an analysis of subsurface structures linked with activity mecha-

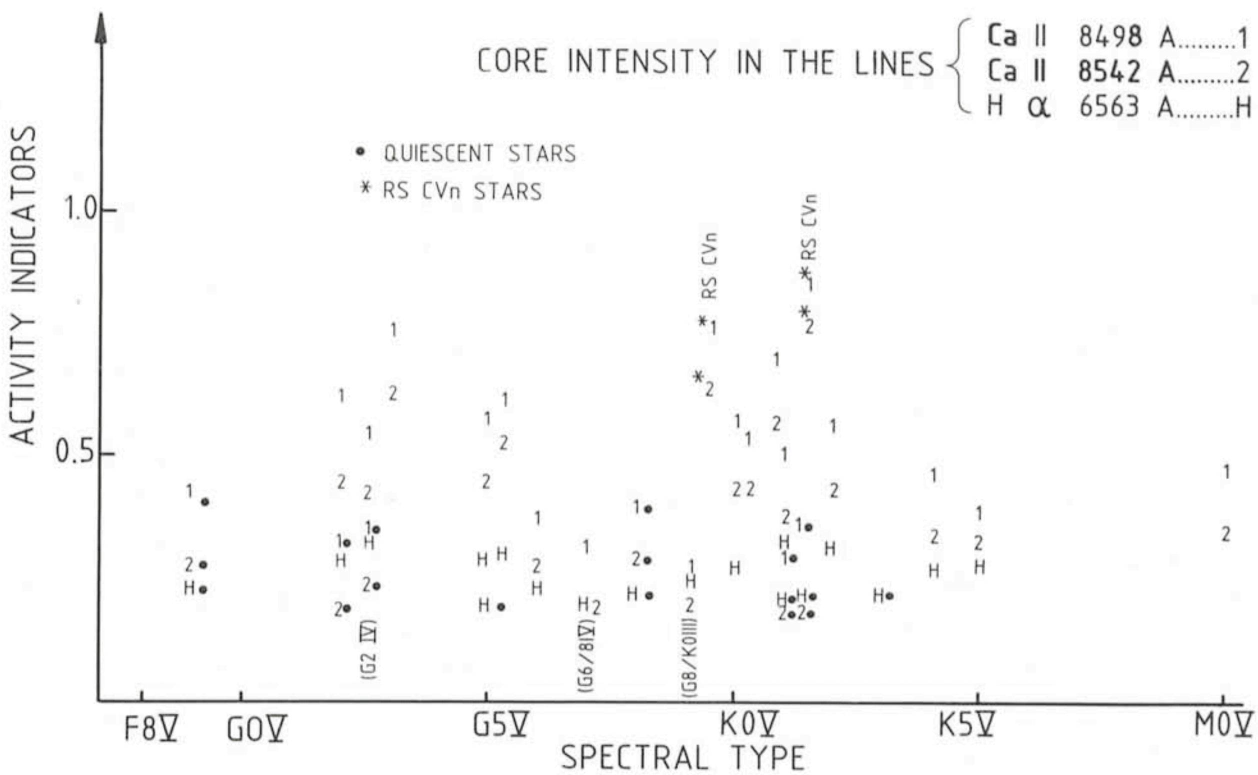



Figure 5: *Variation of some activity indicators as the core intensity of Hα (marked H) and of 8498 Å and 8542 Å lines of the Ca II infrared triplet (marked 1 and 2) for our sample of late type dwarfs. The continuous underlying envelope for our sample suggests a quiescent reference for the study of the activity.*

nisms (magnetic fields and energy sources), gleaned from evidence of spectral line changes during the rotational modulation. We want to understand how the chromospheric structure and magnetic heterogeneities behave according to the major stellar parameters, viz. mass, age, composition and rotation rate, and the present observations will provide us with a key to understanding both chromospheric heating mechanisms, and the dynamo mechanism in late-type stars.

# The Increasing Importance of Statistical Methods in Astronomy

*A. Heck, Observatoire Astronomique, Strasbourg, France*
*F. Murtagh*, The Space Telescope European Coordinating Facility, European Southern Observatory*
*D. Ponz, European Southern Observatory*

You may ask:
"What can a hard headed statistician offer to a starry eyed astronomer?"
The answer is:
"Plenty."

Narlikar (1982)

## Generalities

In the past, astronomers did everything individually, from the conception of a project to the collection of data and their analysis. As the instrumentation became more complex, teams had to be set up and they progressively included people (astronomers or otherwise) specialized in technology. Today it is practically impossible to run a project at the forefront of astronomical research without the help of these technologists.

In a similar way, one can already see that, at the other end of the chain, teams will have to include also people specialized in methodology to work on the collected data. And we are not thinking here only of image processing (which is a natural consequence of sophisticated technology), but mainly of a methodology applicable to already well-reduced data. This is actually the only way to face the challenge put to us by the accumulation of data.

Compared to the past, we are indeed collecting now a huge amount of data (see e.g. Jaschek, 1978), and the rate will speed up in the next decades. Just think that the Space Telescope will send down, over an estimated lifetime of 15 years, the equivalent of $14 \times 10^{12}$ bytes of information, which means a daily average of $4 \times 10^{9}$ bytes! But even if we exclude this special case of ST, we have now at our disposal more and more instruments which are collecting observations faster and faster. And these data are more and more diversified. The rate of data accumulation is higher than the rate of increase of the people able to work on them.

Thus, we will have to work on bigger samples if we want to take advantage and fully use the information contained in all these data, globally and individually. We might well live at the end of the period when a significant number of astronomers are spending their lives investigating a couple of pet objects. If not, what would be the use of collecting so many data?

One way to work efficiently on large samples is to apply, and if necessary to develop, an adequate statistical methodology. If Nature Is consistent, the results obtained by applying the tools developed by the mathematicians and the statisticians should not be in contradiction with those obtained by physical analyses.

However, do not let us say what we did not say: the statistical methodology is not intended to replace the physical analysis. It is complementary and it can be efficiently used to run a rough preliminary investigation, to sort out ideas, to put a new ("objective" or "independent") light on a problem or to point out sides or aspects which would not come out in a classical approach. A physical analysis will have anyway to refine and interpret the results and take care of all the details.

Probably the most important statistical methods, for astronomical problems, are the multivariate methods such as Principal Components Analysis (PCA) and Cluster Analysis. The former allows the fundamental properties to be chosen for a possibly large number of observational parameters. This is clearly an important task, since the apparent complexity of a problem will necessarily grow with improvement in observational techniques.

The problem of clustering is that of the automatic classification of data. Clustering methods can also be employed to pick out anomalous or peculiar objects. These techniques all work at will in a multidimensional parametric space, while graphically, and also classically in statistics, it is difficult to get results from more than two dimensions. These statistical methods are often considered as descriptive rather than inferential and, since astronomy is fundamentally a descriptive science, they would appear to be ideally suited for problems in this field.

In the same way that instrumentation should not be employed without respecting its conditions of use, algorithms should not be applied as black boxes by non-specialists without paying attention to their applicability constraints and their result limitations. Forgetting this golden rule is the best way to contribute to the bad reputation of statistics while ruining from the start any attempt at elaborating relevant conclusions.

Maybe somewhat paradoxically, astronomers have not been among the quickest to realize the potentialities of the "modern" statistical methodology. One of us (AH) became interested in 1974–75 and produced among the first papers in the field. But the idea was in the air and applications started to multiply. He therefore suggested the holding of a first meeting on "Statistical methods in astronomy". It took place in September 1983 at Strasbourg Observatory with the European Space Agency as co-sponsor (the proceedings were published as ESA SP-201).

This was the first opportunity to bring together astronomers using various statistical techniques on different astronomical objects and to review the status of the methodology, not only among astronomers, but also with invited statisticians. The

* Affiliated to the Astrophysics Division, Space Science Department, European Space Agency.