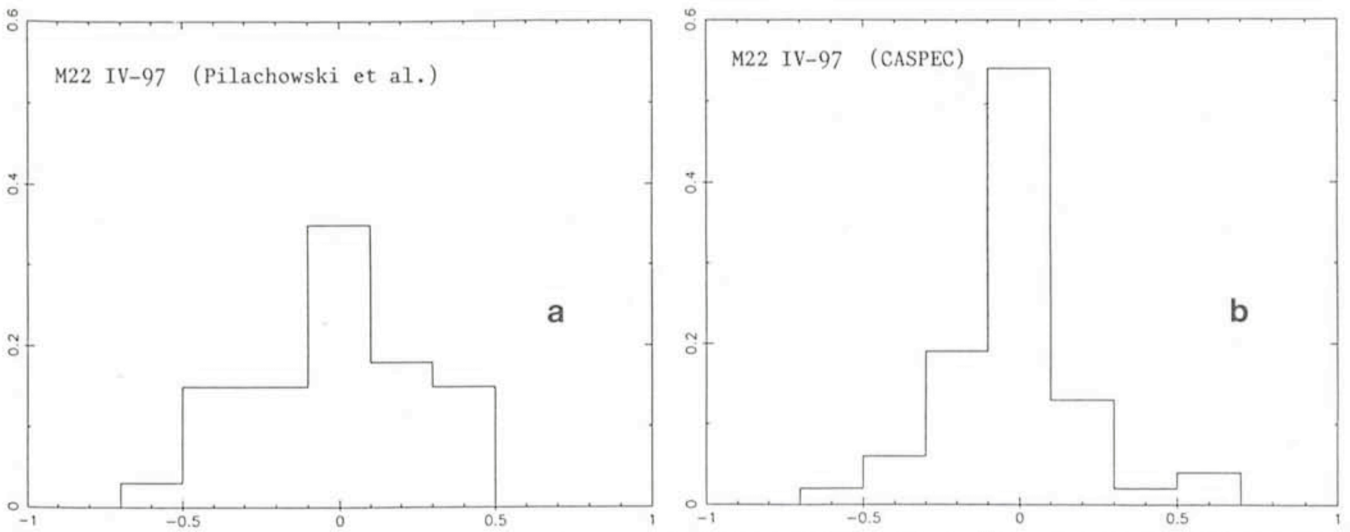

Fig. 5: *Histogram of the dispersion of Fe I measurements of the star M22 IV97: (a) at Kitt Peak (Pilachowski et al. 1982); (b) at ESO (CASPEC).*

emission in these globular cluster stars and in the active star HD 184711 (Spite et al. 1981; Gratton et al. 1984).

In addition, we recently obtained some other excellent spectra of stars in ω Cen, NGC 6582, and in the Magellanic Clouds (field stars and globular cluster stars). All these spectra are now under reduction and seem very promising.

We are very grateful to Dr. D'Odorico for advising us about the optimal use of CASPEC and CCD for our program.

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High Resolution Monitoring of the Emission Lines in SS 433

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Introduction to SS 433

During the last few years the star 433 of the Stephenson Sanduleak catalogue of emission-line objects has become one of the most intensively observed sources in the Galaxy. It is believed to be an X-ray binary whose compact component is either a neutron star or a black hole. Attention was drawn to SS 433 in 1978 by Clark and Murdin (1978), who pointed out that independently discovered X-ray and radio sources were probably associated with SS 433. The object is situated at the center of a supernova remnant detected at radio wavelength (W 50) and showing Wolf-Rayet like winds.

It was in 1979 through a study of its optical spectrum by Bruce Margon that SS 433 entered the astronomical hall of fame. The spectrum is dominated by Hα emission lines although He I, He II and C III/N III are also present, as well as stellar and IS absorption lines. The remarkable discovery was that the Hα lines were split in three components. Two of them oscillate with opposite phase over a huge radial velocity range (–30,000 to +50,000 km/s) with a 164-day period. Shortly after Margon's discovery, Andy Fabian and Martin Rees suggested that these moving "satellite" lines arise in two oppositely directed jets and the kinematic "precessing jet" model developed in detail by Abell and Margon has had remarkable success in explaining observations of SS 433. Precession of the (v = 0.26 c) jets was invoked to explain the 164-day period (see e.g., Margon, 1984). Beautiful confirmation of this precessing jet model was provided by radio measurements by several groups which showed that SS 433 is resolved on various scales from less than 3 milliarcseconds up to 2 arcseconds, is jet-like and has a changing corkscrew structure which varies in good agreement with predictions of the model

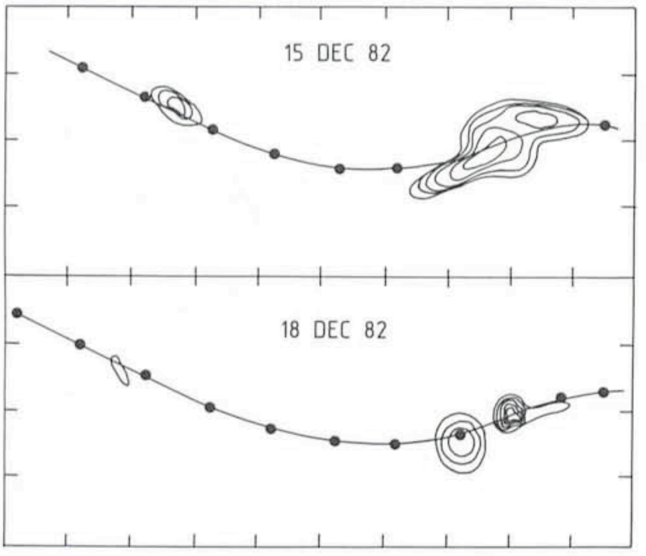

Fig. 1: *Contour maps of SS 433 showing the evolution of the structure in time; the solid lines represent the expected trajectories of blobs on the kinematic model (Schilizzi et al. 1984).*

derived from optical spectroscopy (see fig. 1). The radio measurements provided one more in a chain of tantalyzing similarities between nonthermal radio emission in stars and active galaxies.

Gravitational accretion and radiation pressure are often invoked to explain the acceleration of particles in the stellar jets; the confinement of the beams is believed to result from the presence of a magnetic field or from the rotation of the system. Independently of detailed models, there is considerable evidence that SS 433 is an X-ray binary whose compact component is either a neutron star or a black hole. The optical radiation obviously originates both from a central source (accretion disk and illuminated companion), and also from rapidly moving regions which are in interaction with the ISM and responsible for the Doppler-shifted recombination lines; the companion star is likely to be dominated by the accretion disk.

The Purpose of the High Spectral Resolution

One of the most intriguing questions regarding SS 433 concerns the exact relationship between the relativistic plasma responsible for the synchrotron radio emission and the ionized gas which emits the optical lines. In the case of extragalactic jets, several cases of morphological associations have been found between radio-continuum and optical-line knots implying that as a jet propagates through the ambient medium it can interact vigorously with its environment. Could the satellite emission lines in SS 433 be produced by similar processes?

In an effort to relate the changing details in the Hα profile to the moving blobs in the radio jet, we have used the CASPEC echelle spectrograph on the 3.6 m telescope to monitor the spectrum of SS 433 simultaneously with VLBI measurements of the radio structure being carried out by a group which includes Richard Schilizzi (Dwingeloo), Renee Vermeulen and Vincent Icke (Leiden), Richard Spencer (Jodrell Bank), Richard Porcas and Istvan Fejes (Bonn) and John Romney (NRAO). During this campaign which lasted two weeks, Paul Murdin also obtained a set of medium resolution optical spectra using the 2.5 m Newton telescope at La Palma, and X-ray observations with the Exosat satellite were obtained.

Until now little data were available on the emission line profiles of SS 433 with resolutions of better than a few

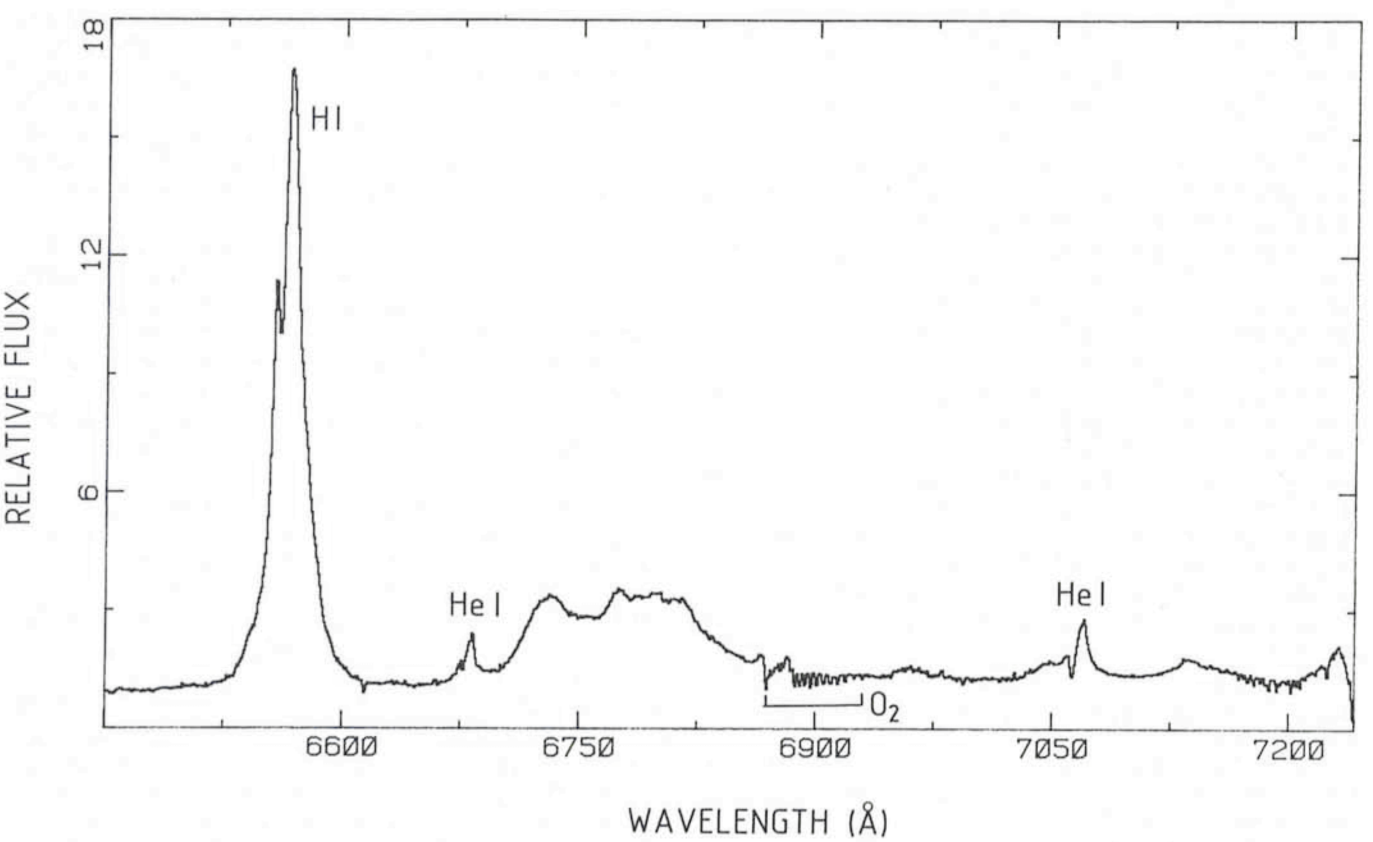

Fig. 2: *SS 433 shows a composite spectrum of steady emission lines and Doppler-shifted lines known as "moving lines". This spectrum has been obtained with CASPEC at the ESO 3.6 m, in a 40 mn exposure. The emissions observed here are HI (6563 Å), HeI (6678 and 7065 Å) and their broad shifted counterparts. In addition, possible P-Cygni profiles are observed in the steady HeI lines.*

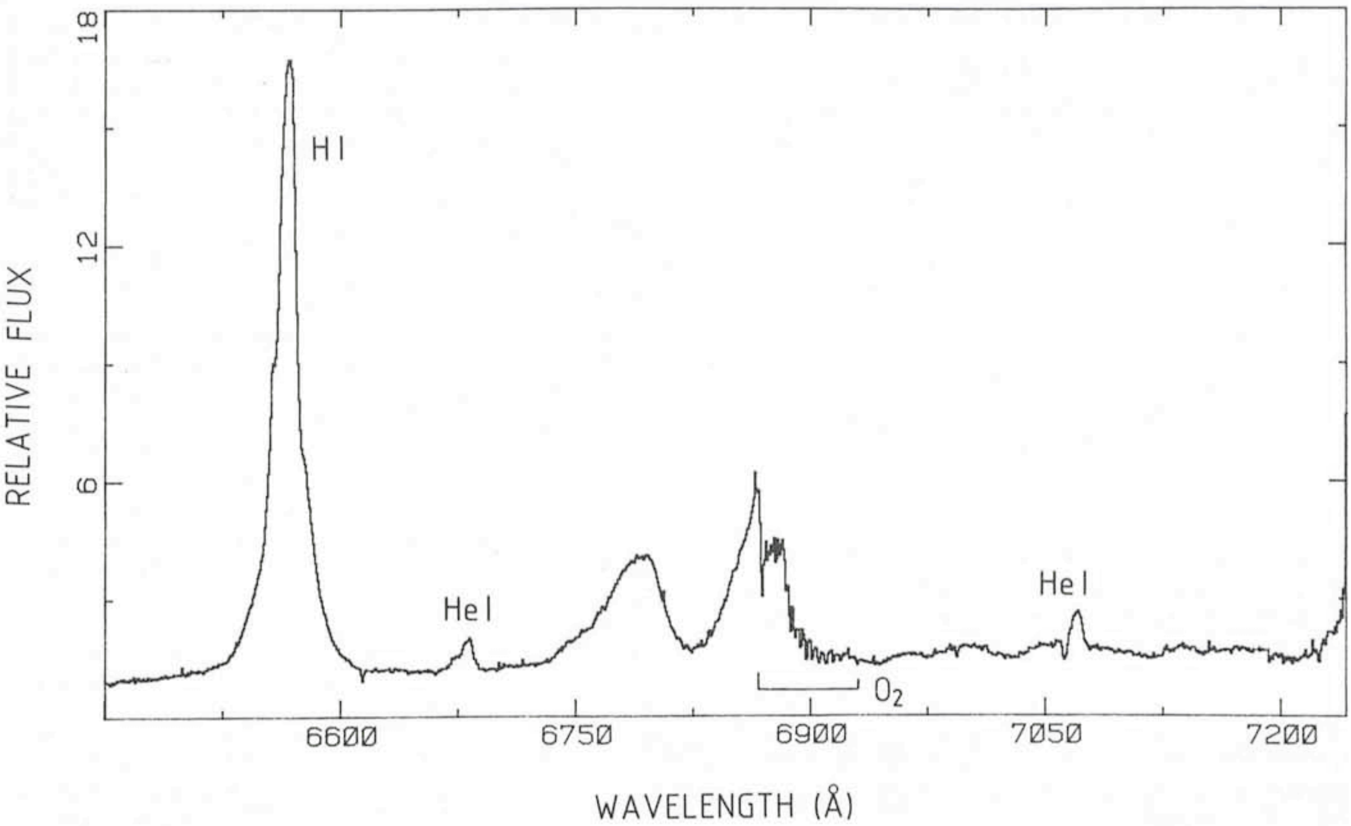

Fig. 3: *An example of unexpected emission regarding the precession period; the two features at 6790 and 6860 Å cannot easily be explained by the standard kinematic model.*

angstrom. It was our hope that observations of the lines at high spectral resolution coupled with the radio maps would give a unique tool for probing possible interactions.

Several further observational facts about SS 433 remain difficult to explain using the standard model, among them sudden fluctuations and disappearances of the moving lines, the great number of harmonics of the precession period and the energy necessary to power the beams. With the hope of investigating some of these questions we decided to carry out high spectral resolution monitoring of SS 433.

Thanks to the high through-put of the telescope/spectrograph/detector combination (around 6 percent efficiency), we were able to obtain, using integration of the order of 40 minutes, high S/N spectra of SS 433 over a range of 1000 Å, with a resolution of 0.65 Å.

We used CASPEC together with the 31.6 l/mm grating. Since SS 433 is faint (magnitude 14.2 .5 in V), we applied electronic binning of the CCD in order to reduce the effect of the read-out noise. Eleven spectra were obtained between May 19 and June 3. They have been reduced with the echelle reduction package in the MIDAS data analysing system running on the VAX 780 at ESO-Garching. The accuracy of the wavelength calibration was found to be better than .07 Å, when checked on the He-Ar lines of the comparison lamp spectrum.

Preliminary Results from the CASPEC Data

Figures 2 and 3 show two of the reduced spectra. The data have still to be fully analysed, but some preliminary findings are summarized below.

On the basis of the precession period, we expected to find three Hα components; a zero velocity one (in fact red-shifted by 100 to 300 km/s depending on the phase of the orbit), a red component varying between 6950 Å and 6700 Å and a blue component varying between 6600 Å and 6900 Å.

(i) It is clear that the moving lines are generally resolved and that they show complex structures which one might interpret as a result of a clumpiness of the beams, implying that different velocity clouds show up simultaneously in the line of sight. As a consequence of observations made on one night where two spectra were obtained with a time separation of only 2 hours, we were able to observe that these structures evolve extremely rapidly.

(ii) The zero velocity Hα component shows a complex and variable profile. In particular, a feature is observed on the blue wing and its variations seem to be related neither to the precession period, nor to the orbital one; this would support the interpretation that the double Hα profile is a variable self-absorption although a more complete investigation will be necessary to reject the hypothesis of a blue-shifted emission. Moreover, variable P-Cygni profiles seem to be present in the He I steady emission lines.

(iii) In addition to the predicted Hα satellite lines, strong unidentified emission lines are seen in two of our spectra, fading out in less than three days (cf. fig. 3).

(iv) To explain the position of the satellite lines within the framework of the standard kinematic model we needed to apply a phase shift of about .02 (3 days) to our observations. Although this shift is contained within the observed scatter of the fitted precession period, the complexity of the spectra makes it very difficult to find a symmetric evolution of the line around 11,000 km/s, as suggested by the kinematic model, and our data are therefore not sufficient to properly constrain the ephemeris (cf. fig. 2). If we accept this phase shift as being real, we can explain the deviation from the model by keeping in mind the great number of harmonics found in the velocity curve, which produce a scatter of up to 100 Å in the line centers. This scatter should be correlated between the two shifted lines.

It is clear that, by combining our data with those obtained in La Palma at about the same time, we will be able to reach a more complete understanding of these phenomena.

What Can We Expect from the Comparison of Optical and VLBI Data?

The VLBI observations are at present being reduced and should be available within a few months. Comparison of the two data sets will then be attempted. If moving features in the optical spectrum appear to be correlated with changing blobs in the radio jet, the origin of the Hα emission will be determined; this would provide a new possibility for mapping of the ionized gas structures, since until now imaging in the optical range has not shown any extended features around SS 433. In addition, detailed kinematic mapping of the propagation of the SS 433 jet could be envisaged with the Space Telescope, if the data correlation proves positive.

Particular attention will be paid to the following points:

- Does the bending of the radio jets affect the velocities of the moving lines?
- Is there any relation between the production of blobs and the equivalent width of the zero velocity Hα line?
- How is the spectacular appearance and disappearance of emission lines manifested in the radio data?

There are other X-ray stars which are known or suspected to present similarities with SS 433 and with the grander but more distant phenomena seen in AGNs (e.g., Sco X-1, Cir X-1, Cyg X-3, Her X-1 . . .), but none of them has revealed in such an open manner its intense private life. If SS 433 decided to cooperate with us last summer, important new information about the nature of X-ray binaries and even about jets in AGNs may result. It's now up to SS 433!

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T Tauri Stars Through the Looking-Glass

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The Red Queen shook her head. "You may call it 'nonsense' if you like," she said, "but I've heard nonsense, compared with which that would be as sensible as a dictionary!"

Preface

The CASPEC on the 3.6 m telescope is a very powerful new instrument for high dispersion spectroscopy. We have used it (in conjunction with an IDS) to obtain almost all the optical information possible on a number of T Tauri stars, namely calibrated resolved full spectral coverage. The analysis of such a large amount of information will take quite some time; the purpose of this contribution is primarily to acquaint other users with some of both the joys and pitfalls of this instrument which we feel are worthwhile to publicize. We also describe a little of the science in our particular project.

Chapter I

"It seems very pretty," she said [. . .], "but it's rather hard to understand!" (You see, she didn't like to confess, even to herself, that she couldn't make it out at all.)

T Tauri stars are young stellar objects with emission line spectra and complex atmospheres. Found in the upper right of the Hertzsprung-Russel diagram, they have effective temperatures from 3,000 to 6,000 K, and are estimated to be between 10^5 and 10^7 years old. Numerous observations in all parts of the electromagnetic spectrum indicate differences in activity levels of up to three orders of magnitude, together with temporal variations ranging from the beginning of astronomical data taking down to a few minutes. Due to their generally complex nature and the difficulties in obtaining a fully useful set of observational material, relatively little attention has been paid so far to self-consistent physical modeling of these stars. We have made an observational effort to provide new material which will allow the use of "classical" diagnostic tools to obtain detailed structures for most of the stellar atmosphere.

Guided by the rule that physical processes are most easily analyzed in their least complex manifestation, we have chosen seven low to intermediately active T Tauri stars (rather than exotic objects) from the spectral catalogue of Appenzeller et al. (1983). For further references on the stars, see also the original list of Schwartz (1977). The target objects span from G2 to M0 in spectral type, and from 5.8 to 0.5 in $L_\odot$ (see table). We have three pairs consisting of objects which are almost identical in most parameters, except for activity level. Together with a carefully chosen set of standard stars we are in a position to perform a differential activity analysis from the main sequence into the pre-main sequence domain by extrapolating proven diagnostic methods to slightly "perturbed" objects.

Chapter II

"I should see [. . .] far better," said Alice to herself, "if I could get to the top of that hill."

The full astrophysical potential for modeling of PMS stellar activity can only be realized if based on resolved flux calibrated, and high S/N spectra obtained for many diagnostics at the same time. With most instruments, the simultaneous demands of extreme spectral resolution and accurate spectrophotometry mutually exclude each other since the slit size affects both quantities in opposite ways. Thus, we used two different spectrographs concurrently: The ESO echelle spectrograph with CCD (CASPEC) at the 3.6 m and the IDS at the 1.5 m telescope. With a slit size of 3″ × 3″ at the former and 8″ × 8″ at the latter instrument we achieved resolutions of about 12,000 and 500–1,000, respectively. (The IDS grating was used in both first and second order.) The spectrophotometric observations had to be done strictly concurrently, since T