Figure 1: *ESO 50-cm telescope with the TV guiding system of FLASH. The total weight of the guiding system is only about 35 kg. It contains the fiber-fed interface, comparison lamps and a conventional SIT low-light-level camera.*

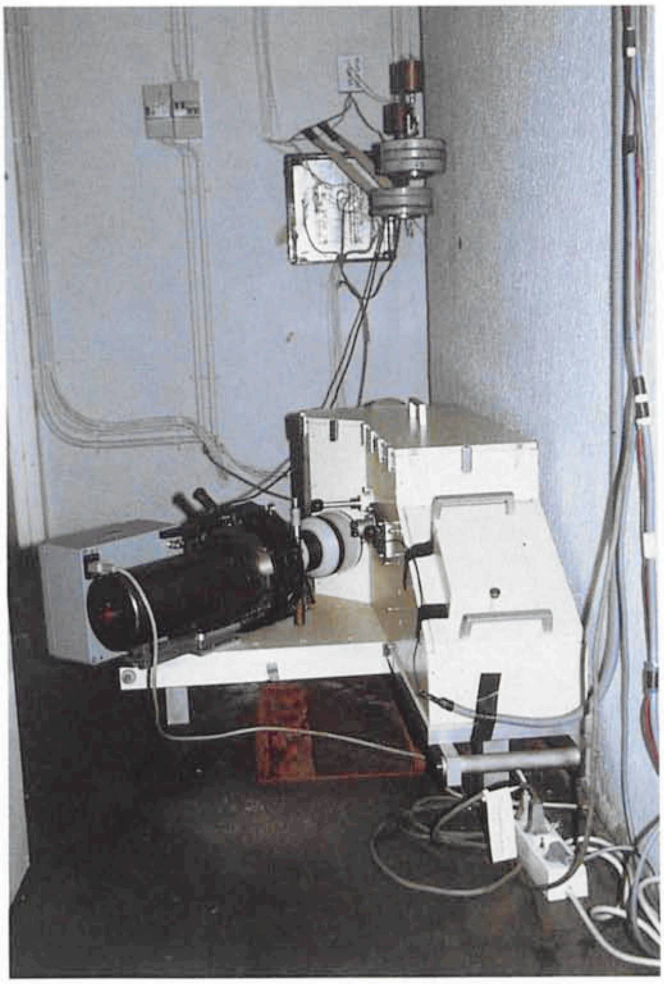

Figure 2: *Our spectrograph with CCD and CCD electronics, in the small cabin at the concrete base of the telescope, the smallest coudé room in the world. In the background some counterweights of the telescope balancing system can be seen.*

plifies the merging of the reduced different echelle orders. One also eliminates flexure problems while housing the instrument in a temperature and humidity controlled room. During observing at the ESO 50-cm telescope the spectrograph was placed in the small cabin at the concrete base of the telescope behind the astronomers office with only two connections to the outside world, one incoming fiber and one outgoing coaxial cable.

With an efficient detector, stars down to a magnitude of 7 are in the reach of the ESO 50-cm telescope. Using an EEV CCD with 1252×770 pixel of 22 μ, we get 2700 Å in one exposure. At standard setup we selected the wavelength range from 4050 to 6780 Å. This setting allows observations of 57 echelle orders simultaneously, with a generous overlap between the orders. With a 100 μ fiber, which corresponds to 2.″75 at the ESO 50-cm telescope, the spectral resolution is about 20,000. During observation, up to 100 CCD frames (including ThAr- and flatfield-spectra) can be stored on the hard disk of the CCD control computer. These frames are transferred to magnetic tapes each morning and later copied to DAT-tapes by ESO.

Luminous Blue Variables

Apart from supernovae at outburst LBVs are the most luminous stars in the Universe ($M \approx -9$ to -11). For more recent reviews see Wolf (1992) and Stahl (1993). The LBVs have recently been recognized as keys in connection with the evolution of massive stars. At quiescence they define an inclined instability strip of OB supergiants (Wolf, 1989) close to the Eddington limit. They are characterized by photometric variations of 1 to 2.5 mag in timescales of years and longer. At maximum brightness they are surrounded by cool ($\approx$ 8000 K), dense ($N \approx 10^{11}$ cm^{-3}) slowly expanding ($v \approx 100$ km s^{-1}) envelopes of typically equivalent spectral type A. In addition to the large outbursts, photometric microvariations of 0.1 to 0.2 mag on timescales of 1 to 2 months or more have been found in all those cases observed in more detail (van Genderen, 1989).

During the past decade our group has observed spectra of the established and newly discovered LBVs of the Galaxy and of the Magellanic Clouds more or less regularly each year at La Silla with CASPEC. The exhibited long-term spectral variations shown by the LBVs have been of vital importance for a better understanding of the outburst phenomenon. They have contributed quite considerably to derive the general picture sketched above. On the other hand, with snap shot observations, typically separated by one year, the detailed hydrodynamic processes cannot be studied.

The Campaign

For a better understanding of the atmospheric motions, systematic spectroscopic monitoring over a time span of months with good resolution in wavelength and time is badly needed. We therefore applied for two contiguous observing runs of two months each at

But what can you do with that sort of astrometry? The prospects are enormous – to name just a few: parallaxes of more distant and/or fainter classes of objects like very low-mass white dwarfs, optical counterparts of neutron stars, and brown dwarf candidates; orbits for close (2–10″) binaries; proper motions of globular clusters, and proper motions within globular clusters; and proper motions for the Galaxy's satellite galaxies.

There are also prospects for CCDs to be extended towards the observation of bright stars – those objects too faint for HIPPARCOS and too bright for current CCD techniques, or those objects too distant for HIPPARCOS. The use of anti-blooming techniques, and the development of CCDs with larger full-well capacities, may allow precise astrometry to be done with the brightest stars. An alternative technique, being explored at the USNO, is to carry out observations with a CCD mosaic, bonded onto a single silicon substrate, in which one of the CCDs is configured as a frame transfer CCD, allowing very short (and unsaturated) exposures of a target star, while the surrounding CCDs acquire deep images of the surrounding stars for use as reference objects.

Conclusion

I've tried to show, in the sections above, some of the interesting results currently being obtained with CCD astrometry, some of the exciting prospects for its future, and how straightforward it is to actually do it. Several programmes at La Silla currently use CCDs for astrometric purposes, both for studies of the solar system and nearby stars, and future programmes are planned to expand on their use for these local studies. Within the next year, I hope to carry out test observations with the NTT, to explore its use for high precision astrometry below the 1-mas barrier in studies of the Galaxy's satellites. It is my hope that the activity in this field will encourage more members of the general community to investigate this "rediscovered" astronomical technique – one which shows such astounding promise for the future.

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High-Resolution Spectroscopy at the ESO 50-cm Telescope: Spectroscopic Monitoring of Galactic Luminous Blue Variables

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Introduction

High-dispersion spectroscopy used to be the domain of big coudé spectrographs attached to large telescopes. At least since the launch of IUE it has become quite obvious that high-resolution spectroscopy can be done with a telescope as small as 45 cm if equipped with an echelle spectrograph. With IUE even extragalactic objects are being investigated. All known Luminous Blue Variables (LBVs) of the Magellanic Clouds, for example, have been repeatedly observed by our group in the high-resolution echelle mode.

For obvious reasons it is also very desirable to use echelle spectrographs connected to small telescopes for ground-based observations. The pressure for observing time is much smaller than for large telescopes and hence long-term programmes have a better chance of being realized if achievable with a small telescope.

Echelle spectrographs, however, are well known to be very sensitive to bending effects. If directly attached to the telescope, e.g. at the Cassegrain focus, the necessary mechanical stability can be reached only at the expense of great weight (e.g. CASPEC of the ESO 3.6-m telescope weighs more than 500 kg). The use of echelle spectrographs for ground-based observations at small telescopes, therefore, used to be very limited. The possibilities for doing this, however, have improved dramatically since the advent of optical fibers for astronomical observations.

With our fiber-linked echelle spectrograph attached to the ESO 50-cm telescope we obtained unprecedented time series of highly resolved spectra of a few galactic LBVs and, as a by-product, of two other hot stars. A short description of the instrumentation and of the campaign and observational results are presented in this report.

Instrumentation

The idea of building a compact, fiber-linked, portable high-resolution echelle spectrograph was conceived in 1984 and looked very promising in filling an instrumentation gap of nearly all smaller telescopes. The spectrograph named FLASH (fiber-linked astronomical spectrograph of Heidelberg) has been designed and constructed at the Landessternwarte Heidelberg (Mandel, 1988) and has subsequently been successfully used for spectroscopic monitoring campaigns at different sites and telescopes.

Our equipment, comprising the spectrograph, a TV guiding system, mechanical interfaces, a computer system with a magnetic tape, monitors and power supplies with a total weight of about 600 kg fits into eight medium-size containers. Two well-trained people are able to install and adjust the system in less than half a day.

In practice, our spectrograph works much like CASPEC with only two significant differences; the rectangular spectrograph slit is replaced by a round fiber with 100 μ core diameter and the spectrograph is not mechanically connected with the telescope. The light scrambling property of the fiber results in a homogeneous illumination of the echelle grating independent of guiding errors and seeing variations which also simthe ESO 50-cm telescope in periods 50 and 51 to observe the established galactic LBVs η Car, AG Car and HD 160529 with FLASH. The length of the period was motivated by the timescales mentioned above for photometric microvariations for which in the case of HD 160529 semi-periods of 57 and 101 days have been quoted in the literature (Sterken, 1977 and Sterken et al., 1991). Note that the typically expected dynamical timescales of the extended atmospheres of LBVs of a few hundred solar radii during outburst are also of this order. ESO generously allocated the requested observing time from February through May 1993. Only 15 nights could not be used due to bad weather. The campaign has thus certainly contributed to improved statistics of useful nights in 1993 at this telescope, which is normally used for photometry only.

Figure 3: *Control room at astronomers office with CCD-, computer- and TV-guiding-monitor, personal computer, and magnetic tape. With this equipment we are completely independent, using only the naked telescope at each observation site.*

Fortunately, ESO has provided travel expenses for six observers so that the heavy burden of securing more than one thousand scientific frames could be distributed upon the shoulders of several members of the Wolf pack. At the end of his run of typically three weeks duration, each observer sent the DAT tapes to the Landessternwarte Heidelberg-Königstuhl, where the gathered data were feverishly reduced. It should be noted that the efficient handling of the huge amount of spectroscopic data was only possible due to the already existing far-reaching automatization of the reduction procedure which is a modified version of the ESO-MIDAS echelle reduction package running at the UNIX workstations of the Landessternwarte (cf. Stahl et al., 1993a).

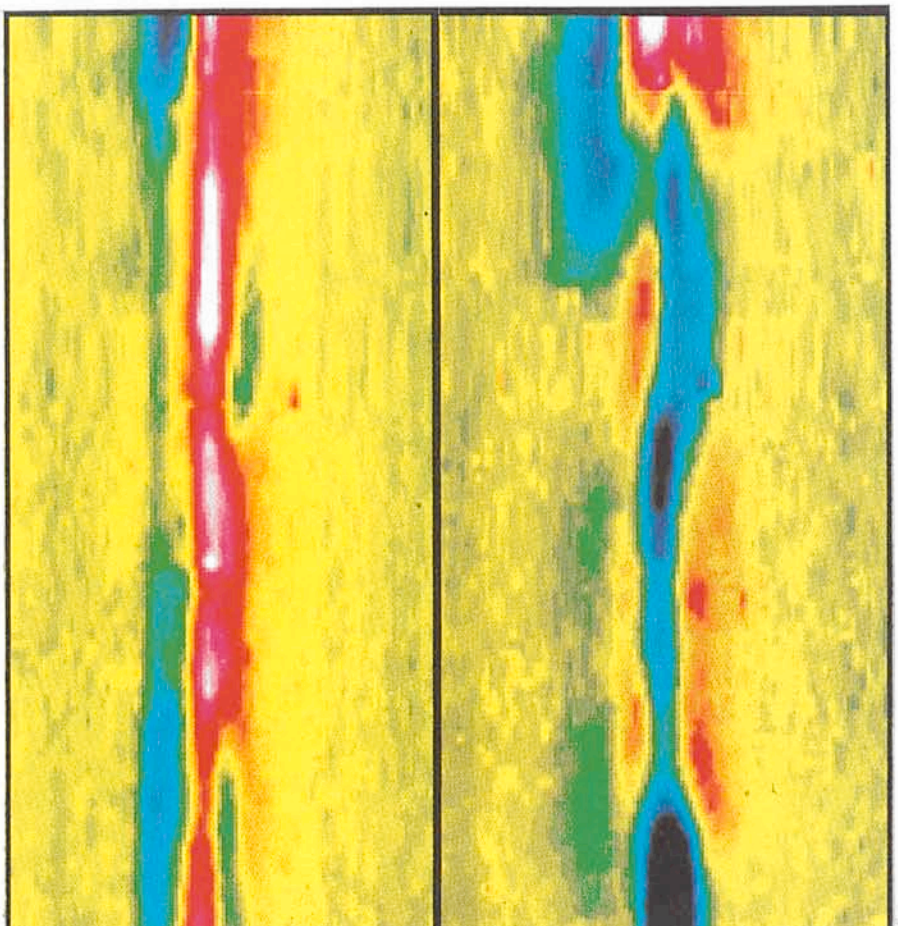

Figure 4: *Line profiles and profile variations of Si II 6347 (left) and He I 6678 (right) of AG Car. Look up table: black, blue (absorption) – green, yellow (continuum) – red, white (emission). The lines are centred to the systemic velocity (+ 20 km s^{-1}) of AG Car. The complete width of the abscissa is from –300 to +300 km s^{-1} for both lines. The ordinate gives the time from JD2449023 (bottom) to JD2449139 (top).*

Results

A quick inspection of the incoming data has readily shown the considerable line profile variations of the target stars. This is demonstrated in Figure 4 by He I 6678 (right) and Si II 6347 (left) of AG Car which had a visual magnitude of about 7 during the campaign. A spectrum with a S/N ratio of about 100 in the red spectral range was obtained in about two hours exposure time. In the time span JD2449023 to JD2449139 we could observe AG Car in 91 nights. Figure 4 exhibits the variations of the colour coded intensity distributions of the lines. The lines are centred at the system velocity (+20 km s^{-1}) of AG Car. The total width of the abscissa is 600 km s^{-1} for both lines. The ordinate gives the time interval increasing from bottom to top. The increasing intensity is coded from black, blue (absorption) to green, yellow (continuum), and to red, white (emission). Spline fits through the intensity at each wavelength and resampling in equidistant time steps were used to interpolate for those few nights of not spectroscopic quality and to account for not completely equal time intervals from night to night.

As shown by the Figure, in the beginning He I 6678 showed a strong absorption line at virtually systemic veloci-

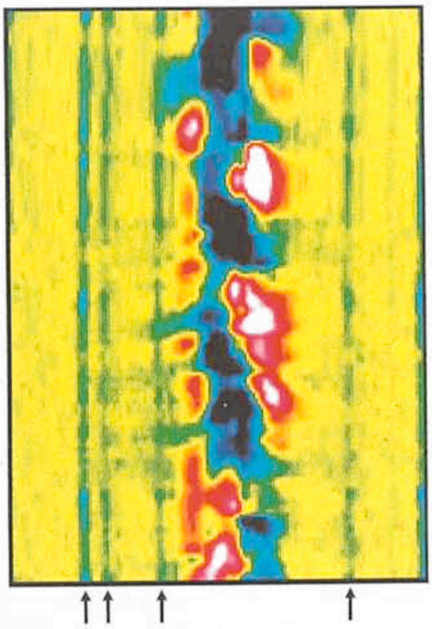

Figure 5: *The dramatic Hα-profile variations of β Ori. Centre of the abscissa is the laboratory wavelength of Hα; the complete width is from –410 to +410 km s^{-1}. Look up table as for Figure 4. The ordinate extends from JD2449023 to JD2449128 (bottom to top). Note the smooth curvature of the terrestric lines (indicated by arrows) due to the reduction of the spectra to heliocentric velocities, which also demonstrates the accuracy of the radial-velocity measurements.*

ty. A few days later an additional faint absorption at a velocity of about 120 km s^{-1} and slightly later a redshifted emission became discernible. This type of profile was followed by an inverse P Cygni-type profile after the third month of our campaign. Finally, during the last month, quite drastic changes occurred from an inverse P Cygni-type profile via a double absorption to a pronounced P Cygni-type profile.

The corresponding profile variations of Si II 6347 are less pronounced. A P Cygni-type profile is prevailing with an expansion velocity of about 100 km s^{-1} which agrees with the wind velocity previously derived for AG Car by Wolf and Stahl (1982). But the intensities both of the emission and absorption components vary quite considerably. Occasional substructures in the emission component are also discernible.

Since our spectrograms cover a large wavelength range, a number of strategic lines formed in different layers can be scrutinized and can be used to probe the time- and depth-dependent velocity fields in the atmospheres of LBVs. The results clearly demonstrate that the campaign has provided a wealth of information, a very good basis for a deeper understanding of the physics of the winds of LBVs and for modelling the hydrodynamic processes connected with the LBV phenomenon.

In addition to the galactic LBVs, we observed the B9Ia supergiant β Ori and the O7V star Θ^1 Ori C. β Ori was always exposed for five minutes at the beginning of each night to check the setup of the equipment and to control the focus of the telescope. In 86 nights (JD2449023-JD2449127) spectra were secured. Quite interestingly, dramatic Hα-profile variations ranging from inverse to normal P Cygni-type profiles via double emission to pure absorption were observed (see Figure 5; look up table like for AG Car). The change from normal to inverse P Cygni-type profiles and vice versa sometimes occurs within a few nights.

Hα emission in B supergiants is often interpreted in terms of steady-state mass loss. The rapid variability of the surface phenomena concluded from the Hα variations of β Ori, however, indicates that a steady-state approach to describe these extended atmospheres and their winds is at least not a complete one. Allowance has to be made for time-dependent hydrodynamic processes.

In addition, it is well known that fiber-fed spectrographs with their light scrambling properties allow for particularly precise radial-velocity measurements. Therefore, the set of data of β Ori represents an invaluable treasure for oscillation analyses and theoretical investigations of pulsational motions. Such a homogeneous set of data over such a long time period and broad spectral range has never been obtained before with modern detectors for any of the hot supergiants.

Again it is evident that for realistic wind models of even "normal" supergiants the impact of long-term spectroscopic monitoring programmes is quite essential.

Our attention has been drawn to Θ^1 Ori C by Manfred Pakull. This famous O7V star of the Trapezium of the Orion nebula is known to be spectroscopically peculiar and variable. Occasional inverse P Cygni-type profiles of the He II 4686 line had been observed and reported in the literature (Conti, 1972). Therefore, we put this star into the list of our targets. In the period JD2449023 to

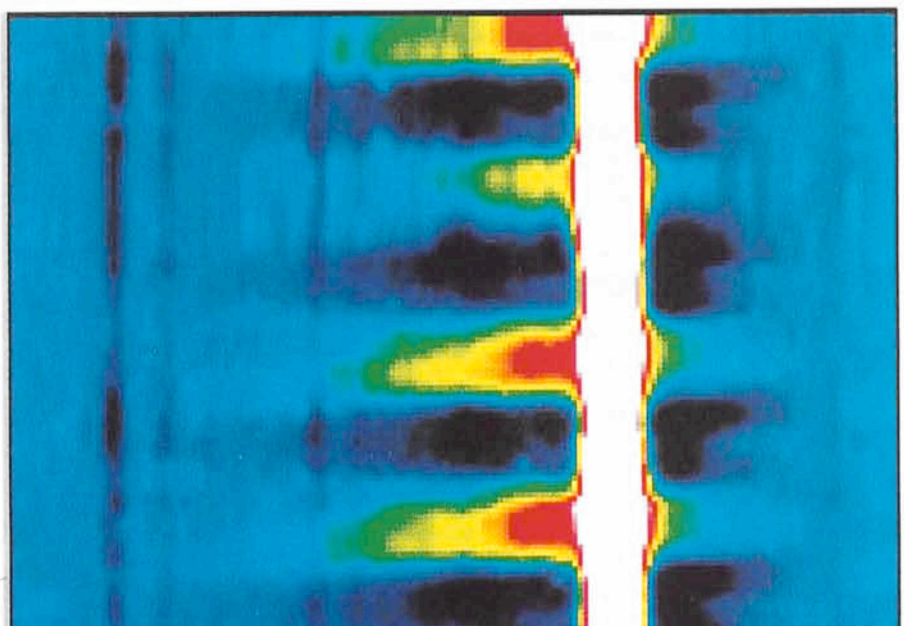

Figure 6: *The spectacularly regular Hα-profile variations with a period of 15.43 ± 0.03 days of Θ^1 Ori C. Look up table: black (absorption – blue (continuum) – green, yellow, red, white (emission). The spectrum extends from the nebular emission (white), to –600 km s^{-1} to the left and to +300 km s^{-1} to the right. The time span on the ordinate is JD2449023 to JD2449112. The curvature of the terrestric lines is again evident.*

JD2449112 we exposed Θ^1 Ori C in 89 nights. The typical exposure time was one hour. As evidenced by Figure 6, the spectrum of Θ^1 Ori C is distinguished by extremely regular variations of Hα, the period being 15.43 ± 0.03 days (see Stahl et al. 1993b). In the Figure, the nebular emission (white) is shifted so that a range of –600 to +300 km s^{-1} around Hα is displayed. Continuum is blue. Blue-shifted stellar emission and absorption alternate very regularly with virtually no difference from cycle to cycle. The apparent deviation during the fifth period is caused by worse sampling due to bad weather. Note that the discernible substructure in the black stripes is due to a second maximum of (redshifted) emission. This same strict periodicity was also found for He II 4686 and other different lines. Θ^1 Ori C is a good example to show the importance of having long time series with regular sampling and good resolution in time. Based on previous snap shot observations, the inverse P Cygni-type emission of He II 4686 "occurred on an irregular fashion" and was therefore ascribed to accretion rather than to something strictly connected to the rotation of Θ^1 Ori C. The strict periodicity now established does, however, favour such a connection and makes Θ^1 Ori C the first convincing candidate of an O star oblique rotator.

Conclusion

The results presented demonstrate the considerable impact of long-term high-resolution spectroscopic monitoring programmes at small telescopes on variable star research.

The ESO 50-cm telescope, our fiber-linked echelle spectrograph and the excellent meteorological conditions of the Atacama desert – a perfect match for investigating the long-term spectroscopic behaviour of bright stars.

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Probing the Kinematics in the Core of the Globular Cluster M15 with EMMI at the NTT

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1. M15: a Prototype Collapsed-Core Cluster?

There is now a global theoretical understanding of the long-term dynamical evolution of globular clusters. Different kinds of theoretical approaches predict the collapse of the cluster core, which can then be halted or even reversed by a core heating due to stellar encounters involving binary stars. A cluster could suffer a succession of collapsing and expanding phases: the so-called gravothermal oscillations (for recent reviews see the proceedings of the workshop *Structure and dynamics of globular clusters,* Djorgovski and Meylan eds. 1993).

From an observational point of view, however, the situation is much less clear (see e.g. Meylan 1993). A major difficulty in finding a signature of core collapse in a globular cluster is that the observable structural changes may occur only in a very small central area, where accurate measurements of surface brightnesses and velocity dispersions are greatly complicated by the small number of bright stars dominating the integrated light. In the case of the high-concentration globular cluster M15, considered for a long time as a prototype of the collapsed-core star clusters, the observational difficulties are particularly important.

The current determinations of the surface-brightness profile of M15 do not allow us to discriminate between pre- and post-core collapse models, nor to exclude the presence of a central massive black hole. Although the central luminosity cusp in M15 has now been clearly resolved into several bright stars (see Figures 1 and 2), even the most recent studies from HST data cannot unambiguously determine whether the surface-brightness radial profile flattens off interior to a radius of about 2″ or continues to rise at subarcsecond radii (see Lauer et al. 1991 and Yanny et al. 1993). The central velocity dispersion profile in M15 is also poorly known. Accurate central velocity dispersions are difficult to obtain from radial velocities of individual stars because of crowding and the small number of bright stars. An alternative is to use integrated-light spectra to derive velocity dispersions by measuring the line broadening that arises from the random motions of the stars. In this way, Peterson et al. (1989) obtained velocity dispersion values $8.4 \le \sigma_p \le 30.0$ km s^{-1} over different small (~ 1″) areas of integration in the central few arcseconds of M15. They retain as their best estimate a central velocity dispersion of 25 km s^{-1}, a value difficult to reconcile with any existing model, and possibly indicative of the presence of a central black hole. More recently, we derived a velocity dispersion of 14 km s^{-1} from an integrated light spectrum obtained over a central area of integration of 6″×6″ (Meylan et al. 1991, Dubath et al. 1993, 1994). Because of our larger sampling area, we probably would have missed any central velocity dispersion cusp over an area of ~1″. However, recent numerical simulations (Zaggia et al. 1992a, b, and Dubath et al. 1993, 1994) pointed out that the velocity dispersions derived over such small central areas in M15 are affected by large statistical errors because of the dominance of too small a number of bright stars. These errors can explain the large variation of velocity-dispersion estimates obtained at different locations in the core of M15.

In order to test the existence of a central velocity dispersion cusp in the