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ASTRONOMY AND ASTROPHYSICS

Multi-site continuous spectroscopy

I. Overview of the MUSICOS 1989 campaign organization*

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Abstract. We describe the organization of the multi–site spectroscopic MUSICOS 1989 campaign. This international campaign involved a large number of telescopes distributed around the world. In order to yield a complete time coverage, we had to transport two fiber–fed spectrographs, built at Paris–Meudon Observatory, to remote sites. Three scientific programs were followed during this campaign: 1) search for nonradial pulsations in the Be star 48 Per; 2) search for the signature of "co-rotating interaction regions" in the wind of the pre–main sequence Herbig Ae star AB Aur; 3) Doppler imaging and flare patrol for the RS CVn system HR 1099. The goal of the campaign was to provide a continuous coverage of these three targets in selected spectral lines.

Programs 1 and 3 were successful, in the sense that the resulting duty cycle was over 80% for 48 Per and HR 1099. On the other hand, program 2 was unsuccessful, due to bad weather at most of the sites during the nights devoted to AB Aur.

Although the initial goal of program 2 was not achieved, the observed spectra indicate an unusual activity level for AB Aur, and these results are presented here, while detailed analysis of the results of programs 1 and 3 will be published separately.

Key words: methods: observational – techniques: spectroscopic – stars: activity – stars: emission line, Be – stars: pre-main sequence

1. Introduction

MUSICOS (**MU**lti **SI**te **CO**ntinuous **S**pectroscopy) is a project whose goal is to facilitate multi-site, multi-wavelength observations in stellar spectroscopy. Two workshops were dedicated to this project (Catala & Foing 1988; Catala & Foing 1990), and they showed that this type of observations is definitely needed for many scientific programs, in particular those related to stellar magnetic activity, stellar winds, and stellar oscillations. Most of these programs have similar instrumental needs, namely a world network of spectroscopic facilities providing a resolving power above 30000, on telescopes of the 2m class.

A rapid survey of the existing telescopes of the 2m class and of their available instrumentation leads to the conclusion that: 1) they can provide a good longitude coverage, and 2) many 2m telescopes lack adequate spectroscopic facilities.

The MUSICOS project was born from this conclusion, and a strategy was defined at the end of the first MUSICOS workshop in June 1988:

1. Organize multi-site, multi-wavelength campaigns with the existing instruments, and by using the transportable fiber-fed spectrographs ISIS and ISISbis (belonging to the ISIS

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* Based on observations obtained during the MUSICOS 89 MUlti-SIte COntinuous Spectroscopic campaign from the National Solar Observatory McMath 1.5m, University of Hawaii 2.2m, Canada–France–Hawaii 3.6m, Beijing Observatory Xinglong 2.16m, Crimean Astrophysical Observatory 2.6m Shajn, Observatoire de Haute–Provence 1.52m, and European Southern Observatory CAT 1.4m telescopes

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group of Paris-Meudon Observatory) on some of the 2m telescopes without adequate spectrographs.
2. Define, design and build the prototype of a cheap spectrograph meeting the requirements of the scientific programs needing multi-site observations.
3. Duplicate this spectrograph and install the copies on telescopes of the 2m class around the world.

In December 1989, we organized a world-wide multi-site spectroscopic campaign, following the philosophy of point 1 in the general MUSICOS strategy. The goal of the present paper is to describe the general organization of this campaign. Section 2 describes the three scientific programs that were followed during this campaign; the sites and instruments involved in the campaign, as well as the list of observers, are given in Sect. 3. Section 4 explains the observing strategy followed for each of the three scientific programs. The time coverage achieved on the three targets of the campaign is given in Sect. 5. The data reduction procedures are fully described in Sect. 6. Two of the three programs were successful, and their results will be presented separately. Section 7 shows the results obtained on one of the programs, which was globally unsuccessful due to bad weather conditions, but which nevertheless provided some interesting scientific information. Finally, Sect. 8 gives the conclusion and perspectives for future MUSICOS campaigns.

2. Scientific programs of the MUSICOS 1989 campaign

The basic idea that was followed for the December 1989 campaign was to gather the efforts of several groups of people interested in different scientific programs, all of them needing multisite spectroscopic observations. The December 1989 campaign was a *multi-site multi-program* campaign. There were three scientific programs, which are briefly described in the following. Each of these three programs was coordinated by a Principal Investigator, who was responsible for the scientific choices concerning the target, the observing mode and the observing strategy.

2.1. *Intrinsic variability of Be stars (P.I.: A.M. Hubert)*

The intrinsic photometric variability of Be stars (time scale ≤ 2 days) has been known for several decades. The study of short-term spectroscopic variability of these stars is now undergoing an immense progress, thanks to modern spectrographs and detectors, providing at the same time high spectral resolution, high temporal resolution and high S/N ratio.

About 30 Be stars are known as short-period variables and 40 are suspected as such. There is a peak in their distribution at spectral types B0-B3. The observed spectroscopic variations (limited to a few stars) concern photospheric lines and are of several types: changes in the profile asymmetries and/or "bumps" crossing the line profile, usually from blue to red, and/or intensity variations.

The interpretation of such variations is still controversial: are they due to nonradial pulsations (Rossby waves, spheroidal g-modes,...), to rotational modulation, to phenomena linked to contact binary systems, or to velocity fields at the base of the envelope? The nonradial pulsation interpretation seems to be the most appealing one. In particular, it can explain the existence of multiple periods, observed in some Be stars. On the other hand, the reason why only a few high order modes are excited is not understood, and also nonradial pulsations cannot explain the double waves observed in the light curves.

It is of utmost importance to discover the ultimate cause of this variability. For this, we need numerous series of high spectral and temporal resolution profiles ($R \geq 20000, t_{exp} \leq 30$ min), with a high S/N ratio ($\geq$300). The high S/N ratios are needed because the variations usually do not exceed 0.5%. The expected periods of these variations range between 1 and 15 hours, imposing short exposure times on one hand, and continuous observations on the other hand.

The target that was chosen for this program is the Be star 48 Per. This star has a spectral type B3V, and a visual magnitude $m_V = 4.1$. It has been proposed as a possible rapid photometric variable by Percy (1987), and has no shell that would affect the photospheric lines. The line chosen was the He I line at 6678 Å.

2.2. *Streams in the winds of Herbig Ae/Be stars (P.I.: C. Catala)*

The Herbig Ae/Be stars are pre-main sequence stars with masses ranging from 2 to 5 $M_\odot$ (Herbig 1960; Strom et al. 1972; Cohen & Kuhi 1979; Finkenzeller & Mundt 1984). Their location in the HR diagram, when compared with theoretical evolutionary tracks (Gilliland 1986), indicates that they are in a radiative phase of their contraction, i.e. that they are not supposed to possess outer convection zones.

However, Praderie et al. (1982) and Catala et al. (1986a) have shown that these stars have stellar winds and extended chromospheres, i.e. dense regions where the temperature reaches values well above the effective temperature. The source of energy responsible for these phenomena is still unknown. Even though no firm proof exists that the chromospheres of the Herbig Ae/Be stars are linked to a magnetic field, the term "activity" has been widely applied to these phenomena in the literature. Another manifestation of this activity consists of the rotational modulation of lines formed in the wind (e.g. the Ca II K line, the Mg II resonance lines,...). This rotational modulation is ascribed to fast and slow streams alternating on the line of sight as the star rotates (Praderie et al. 1986; Catala et al. 1986b). This model, built by analogy with the well known structure of the solar wind (Burlaga 1984), suggests the presence of a magnetic field at the star's surface, which would be responsible for the stream structure of the wind.

If a stellar wind is structured in fast and slow streams, the fast streams "overtake" the slow ones, and pairs of shocks are formed at the interface between the streams (one direct shock and one reverse shock). The region comprised between the shocks is called "corotating interaction region" or "CIR", and has some very interesting characteristics (Mullan 1984):

- its density is higher than that of the surrounding medium (factor 2 in the solar wind).

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- the velocity is intermediate between that of the fast streams and that of the slow streams.
- the CIR's rotate with the star's angular velocity.
- their azimuthal extent is small.

Given these characteristics, the CIR's are expected to give rise to narrow components, either in emission or in absorption, in lines like the Ca II K line or the Ca II IR triplet. These components must be blueshifted, and must appear and disappear rapidly, but their appearance is recurrent and periodic, the period being that of the stellar surface. The observation of such phenomena is very important for our study of the atmospheres of the Herbig Ae/Be stars. On one hand, it would definitely confirm the stream model proposed to explain the observed rotational modulation in the Ca II and Mg II lines, on the other hand it would provide very precise constraints on the structure of the wind and of the stellar surface:

- the equivalent width of the narrow components would allow us to determine the density in their region of formation, and therefore would tell us how far out the shocks are formed, which is a crucial parameter of this kind of model (Catala et al. 1986b).
- the "life-time" of a CIR at each appearance indicates its azimuthal extent, and provides constraints on the geometry of the active regions at the star's surface, responsible for the wind structure.

Because the Herbig stars have rotation periods between 1 and 2 days, multi-site observations are absolutely necessary for this program: a nearly total time coverage is needed to observe the passage of CIR's on the line of sight, because we expect them to be visible only a few hours per rotation cycle.

Bi-site observations of one of these stars, AB Aur (A0V, m_V = 7.2), have shown the rotational modulation of the Ca II K line, the rotation period being 32 hours (Catala et al. 1986b). Moreover, some of the spectra obtained during this bi-site observation show the presence of narrow components in absorption, which could well correspond to the CIR's. However, the time coverage was not sufficient to show the periodicity of their occurence, let alone to derive the constraints mentioned above.

This is why we tried to observe AB Aur in the Ca II K line and the Ca II IR triplet in a multi-site campaign. To conclude as to the existence of CIR's, it was necessary to observe continuously during at least 2 rotation cycles. The period being 32 hours, or 1.33 days, we tried to observe this star for 3×24 hours.

2.3. *Surface structures and flares on RS CVn systems (P.I.: B.H. Foing)*

The binary RS CVn systems are detached synchronized systems, with periods between 1 and 14 days, usually consisting of a K0 IV primary and a G5 V secondary. A review of the properties of such systems can be found in Hall (1976). Their most important characteristic (Hall 1980) is a quasi-sinusoidal distorsion of their light curve. Among the possible explanations, the spot model is the most successful: the variations (except for the eventual eclipse) are ascribed to rotational modulation of a non uniform distribution of photospheric spots. A rotational modulation of the chromospheric emission in the Ca II K line was also discovered for several stars (Vaughan et al. 1981), and IUE observations (Marstad et al. 1982; Rodono et al. 1987) have shown a possible correlation between the maximum of chromospheric and transition region emission and the photometric minimum in the case of II Peg, indicating that the chromospheric plages may be located at proximity of photospheric spots. A further step in the understanding of the activity in these systems consists of obtaining the large scale distribution of active structures at the surface.

Crucial information is provided by the spatial distribution of phenomena linked to the magnetic field. In particular, the Doppler imaging method (Donati 1992, and references therein) consists of using the effect of localized spots on line profiles, combined with Doppler shifts due to the star's rotation, to reconstruct an image of photospheric spots at the stellar surface. The study of the spot signatures at various rotational phases indicates the location of the spots in longitude and latitude.

Methods and scientific goals of the MUSICOS program on HR 1099 were:

- to observe unblended photospheric lines (Ca I and Fe I lines at 6430 and 6439 Å) during the rotation.
- to analyze the data with Doppler imaging reconstruction codes.
- to obtain the spot configuration on HR 1099, and to compare it with that of the Sun and other stars.
- to measure quasi-simultaneously the signature of chromospheric structures in the Ca II H and K lines, and the Hα line, for which a correlation with coronal X-ray emission has been shown.
- to correlate the photospheric active structures (spots) with the chromospheric structures (plages) in terms of spatial extent (are there, like on the Sun, plages not located on top of spots, but surrounding such spots, or appearing as precursors of spots?). These phenomena, observed on the Sun, need to be studied in different stellar conditions (different convection zones, rotation, etc...).
- to obtain the vertical structure in temperature and density in active regions and to derive scaling laws for the energy balance.

These goals can in principle be reached if at least 15 phases are observed continuously during the rotation of these systems (periods between 1 and 3 days for the most interesting objects). Multi-site observations were strongly needed, and 3 complete days were dedicated to this Doppler imaging program. The multi-site aspect brings a considerable gain in the phase coverage for Doppler imaging.

The target chosen for this program was HR 1099, which has a spectral type K1IV-G5V, and a visual magnitude m_V = 5.7. Its rotation period is 2.8 days.

In addition to this Doppler imaging program, we conducted a flare patrol on HR 1099, by monitoring its Ca II K and Hα lines, and its photometry in several bands, almost continuously for three days, with the following goals:

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Table 1. List of sites, telescopes and equipment

site	telescope	spectro	detector	nb of nights
Hawaii	2.2m UH	ISISbis R = 65000	TI 800×800	8
	3.6m CFH	Coudé R = 35000	FORD 516×516	2
Kitt Peak	McMath 1.5m	R = 20000 R = 40000	TI 800×800	9
ESO Chile	1.4m CAT	CES R = 50000	THX CCD	3
	1.0m	CaIIK spectro	Reticon 128	28
France	1.52m OHP	Aurélie R = 23000 R = 40000	linear THX 2048	9
Crimea	2.6m Shajn	Coudé R = 50000	GEC 576×385	9
China	2.16m Xinglong	ISIS R = 40000	THX 576×384	10

Table 2. Observers

site	name	country
Hawaii (UH)	T. Simon	USA
	J. Baudrand	France
	J.G. Cuby	France
Hawaii (CFH)	P. Felenbok	France
	J. Czarny	France
Kitt Peak	J. Neff	USA
	P. Avellar	USA
ESO	S. Char	France
	S. Jankov	France
OHP	A.M. Hubert	France
	H. Hubert	France
	M. Floquet	France
	H. Chatzichristou	France
Crimea	I. Tuominen	Finland
	J. Huovelin	Finland
	P. Petrov	USSR
	A. Shcherbakov	USSR
	I. Savanov	USSR
China	Li Qibin	China
	Huang Lin	China
	Jiang Shiyang	China
	Zhai Disheng	China
	Cao Huilai	China
	C. Catala	France
	J. Guérin	France
	M. Dreux	France
	B.H. Foing	France

- to distinguish flare and transient enhancements from those due to rotational modulation of active structures.
- to study the energy budget, time evolution and dynamics of flares on HR 1099.

3. Sites, instruments and participants to the campaign

The original plan, which was gradually set up starting in the summer of 1988, was to observe the three stars from 6 sites, indicated in Table 1. The original list of observers is given in Table 2. In Hawaii, eight nights on the UH 2.2m telescope were followed by two nights at CFHT.

Two fiber–fed spectrographs were transported to remote sites for this campaign: ISIS was mounted on the 2.16m at Xinglong (China), while ISISbis was installed on the UH 2.2m in Hawaii.

The ISIS spectrograph (Felenbok & Guérin 1988) was linked to the Cassegrain focus of the telescope by a silica fiber, via a Cassegrain adaptor, which also provides TV guiding and calibration lamp control. The mounting of the spectrograph is of Czerny–Turner perpendicular type. The collimator is a parabolic mirror with an aperture of f/3.75, and the camera is an f/5 spherical mirror. Two gratings, mounted on a rotating barrel, can be used: 1) a 600 gr.mm^{-1} grating with 48° blaze, yielding a dispersion of 3 Å.mm^{-1} at Hα, and 2) a 300 gr.mm^{-1} grating with 8° blaze, yielding a dispersion of 16 Å.mm^{-1} at Hα. At the entrance of the spectrograph, the 105 μm optical fiber illuminates a slit, whose width is chosen to give the best compromise between spectral resolution and photon losses on the sides of the slit. With the detector used and a 40 μm entrance slit, the ISIS spectrograph yields a resolving power of about 40000 with the 600 gr.mm^{-1} grating, and 10000 with the 300 gr.mm^{-1} grating.

The ISISbis spectrograph (Cuby et al. 1990) is a table top instrument, fed from the Cassegrain focus with a 110 μm fiber. The main characteristics of this instrument include a Bowen-Walraven image slicer providing 5 slices of 36 μm, a parabolic collimator, a 316 gr.mm^{-1} grating with 63° blaze, and a spherical mirror as camera. Order separation was achieved by narrow band filters. The resolving power of the instrument varies with wavelength, between 55000 and 80000.

A special Ca II K spectrometer, developped by the Institut d'Astrophysique de Paris and the Institut d'Astrophysique Spatiale, was transported to the European Southern Observatory site in La Silla, and installed on the 1m telescope for 28 nights (Char 1992; Char et al. 1993).

The other spectrographs used during the campaign were part of the standard equipment provided at the sites involved, and their full description can be found in the corresponding user's manuals.

Figure 1 shows the distribution of the sites on the Earth, as filled circles. From this figure, it can be easily seen that the distribution provides a good longitude coverage, with some redundancy east of Hawaii and west of Crimea.

An additional photometric campaign on the Be target 48 Per was also organized for the same dates, by Drs. M. Alvarez, J.P. Sareyan, and J. Chauville (Alvarez et al. 1990). The organization

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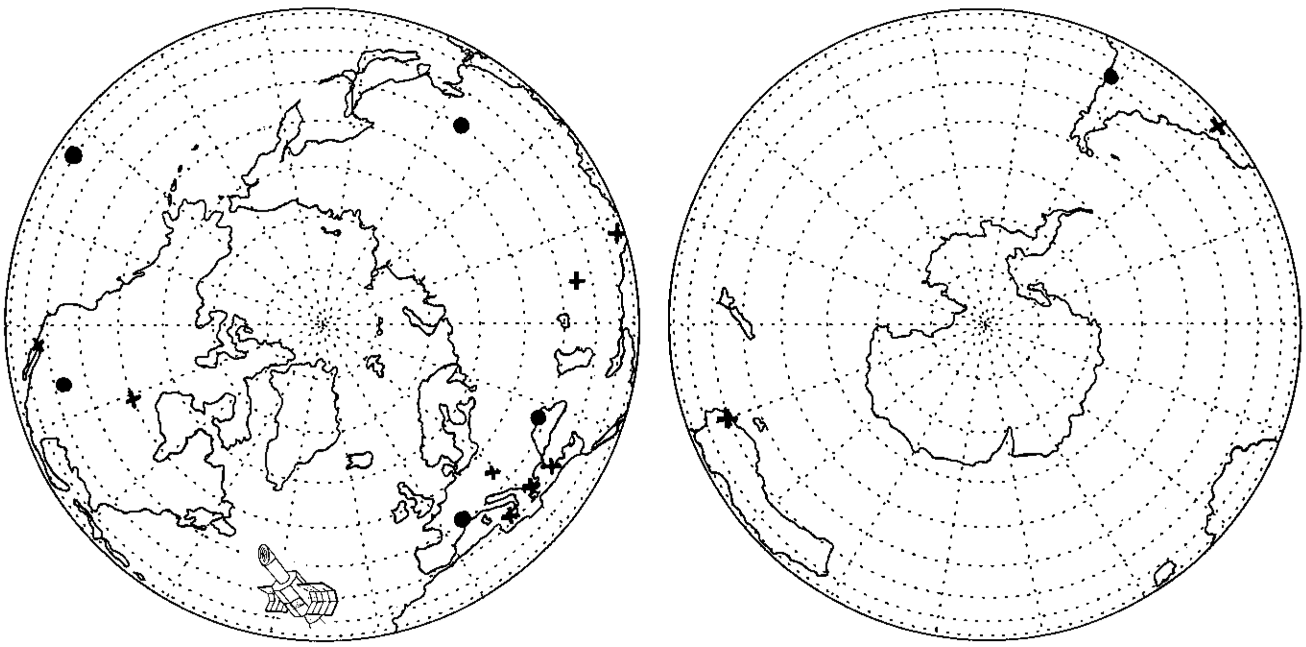

Fig. 1. The distribution on the Earth of the sites involved in the campaign. Filled circles indicate the sites involved in the original plan, "+" symbols represent photometric and "additional" sites

and results of this photometric campaign will be presented in a separate paper.

In October 1989 (2 months before the campaign), we published an IAU Circular (IAU Circular No 4877) announcing the campaign and inviting astronomers from the whole world to participate. As a result, up to 17 telescopes were pointed to the three targets during the campaign, including IUE. The distribution of the additional sites on the Earth is shown in Fig. 1 as "+" symbols, and the list of these "additional" sites and observers is given in Table 3. This table lists both the participants to the photometric monitoring of 48 Per organized by Drs. Alvarez and Sareyan and those who announced their intention to observe one or several of the three targets during the campaign.

4. Observing strategy

Because constant communication between all participants was totally impossible, the observing strategy was very clearly defined before the campaign. This way, a good compromise could be found for each instrument between the requirements of the scientific programs and the instrumental limitations. For each program, three priorities were defined among the desired characteristics of the spectra. These priorities are given in Table 4. The rule was to try to fulfil the three desiderata. If not possible, the third priority was to be released in the allowed limits. If the goal was still not reached, the second priority had to be released, and so on.

The schedule of the observations was also carefully defined before the campaign. The first three nights of the campaign were devoted to the Be star 48 Per. The observing schedule consisted of obtaining continuous series of spectra of the He I 6678 A line,

Table 3. "Additional" observers

site	name	country	mode[1]
San Pedro Martir	M. Alvarez J.P. Sareyan J. Chauville	Mexico France France	P
Tashkent	A. Aslanov	USSR	P
Mt Tamborine	A. Page	Australia	P
Manitoba Univ.	C. Brown	Canada	P
Cabrillo College	R. Nolthenius	USA	P
Thessaloniki Obs.	L. Mavridis	Greece	P
Izmir Observatory	C. Ibanoglu V. Keskin C. Akan	Turkey	P
ESO	G. Cutispoto	Italy	P
Xinglong	Huang Lin Zihe Guo Jinxin Hao Jiang Shiyang Zhai Disheng	China	P
Lick Observatory	S. Vogt	USA	S
Minas Gerais	R. de la Reza	Brasil	S
Wien Observatory	J. Hron H. Maitzen	Austria	S
Vainu Bappu Obs.	K. Ghosh	India	S
La Nave Obs.	S. Catalano M. Rodono	Italy	S
IUE	T. Ayres	USA	UV S

[1] *P: photometry S:spectroscopy*

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Table 4. The observing strategy: definition of the priorities

program	priority 1	priority 2	priority 3
Intrinsic variability of the Be star 48 Per	$S/N > 300$	t_{exp} = 20 min maximum allowed= 40 min	highest possible R minimum allowed= 20000
Streams in the wind of AB Aur	$t_{exp} \leq 2$ hrs	R = 30000 minimum allowed= 10000	$S/N > 100$ minimum allowed= 30
Doppler Imaging of HR 1099	$S/N > 200$	t_{exp} = 30 min maximum allowed= 1 hr	highest possible R minimum allowed= 30000
Flare patrol of HR 1099	R = 30000	t_{exp} = 15 min maximum allowed= 30 min	highest possible S/N minimum allowed= 50

interrupted every other hour by a calibration sequence involving readouts, flat-field exposures, and wavelength calibration exposures. A comparison star, γ Peg, was also observed once from each site.

The next three nights were spent on the pre-main sequence Herbig Ae star AB Aur. The goal was to observe continuously the Ca II K line (Ca II IR triplet in China and Crimea), with a calibration sequence at the beginning and the end of each night.

The last three nights of the campaign were devoted to the RS CVn system HR 1099. The observing schedule was shared between the Doppler imaging program and the flare patrol. The details of the observing procedure for this program are given in Foing et al. (1993).

5. Time coverage

Figure 2 shows the time coverage obtained for the three programs of this campaign. Only the observations corresponding to the core program are indicated in this figure. We note that the coverage of the Be star 48 Per was excellent, with a duty cycle of nearly 86%, and that on the RS CVn system HR 1099 was quite good (duty cycle $\sim$ 80%). Only the program on the pre–main sequence star AB Aur was unsuccessful, due to the bad duty cycle obtained for this star ($\sim$ 45%).

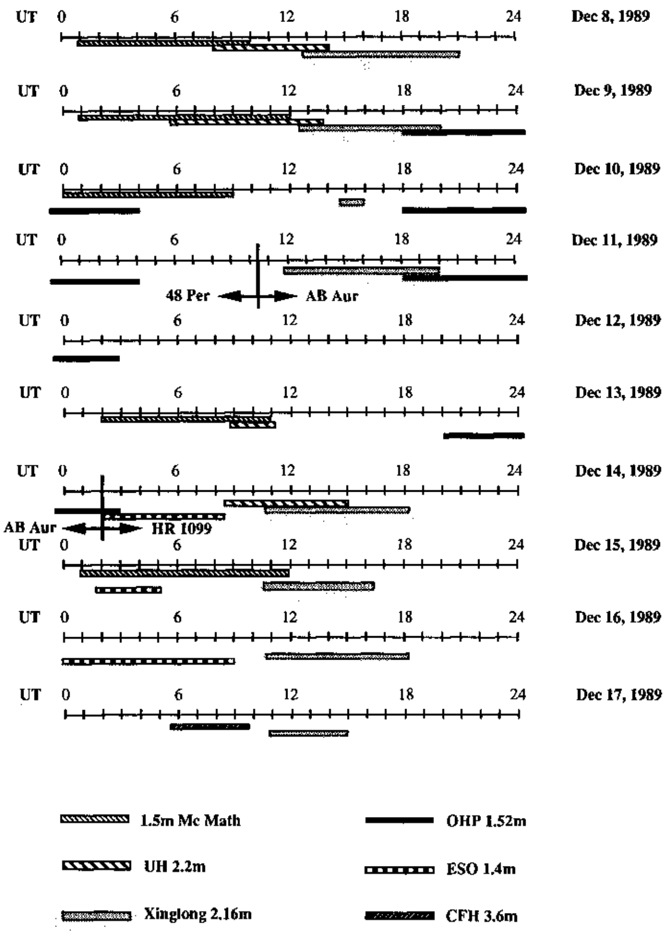

Fig. 2. The effective time coverage obtained during the MUSICOS 1989 campaign

6. Data reduction

The reduction of the campaign data was performed under the responsibility of the three P.I.'s (Drs. A.M. Hubert, C. Catala and B.H. Foing). This data reduction was performed mainly on the VAX-8600 of Paris-Meudon Observatory, using the eVe software developed at Paris-Meudon Observatory. In addition, the IHAP reduction package was used at ESTEC for reducing the ESO data, and for the very final steps of the processing for program 3 (Doppler imaging and flare patrol on the RS CVn system HR 1099). In the following, we describe the reduction procedure that was applied to the spectroscopic data from Kitt Peak, Hawaii UH 2.2m, Hawaii CFHT, Xinglong (China), and OHP (France). In the description that follows, we assume that the dispersion is along the direction of CCD columns. This is actually the case for the data originating from Kitt Peak, Hawaii UH 2.2m and Hawaii CFHT. The spectra recorded in Xinglong are along the row direction, and a transposition of the spectra was performed. The OHP data are monodimensional.

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6.1. Background subtraction

6.1.1. 2D images: data from Kitt Peak, Hawaii UH 2.2m, Hawaii CFHT and Xinglong

For data obtained with a 2D detector, we subtracted a 2D representation of the background, both for stellar spectra and flat-field spectra, in three steps:

1. build the column-average of 10 columns on the left and on the right of the spectrum, far enough from it that no significant contribution from scattered stellar or flat-field light is expected,
2. smooth strongly the two resulting 1D strings, in order to eliminate the contribution of spikes,
3. for each row and each column of the stellar or flat-field spectrum, interpolate between the left and the right smoothed string, and subtract from the spectrum.

6.1.2. 1D images: OHP

For data obtained with a 1D detector, we used the following procedure:

1. use one (or the average of several) dark exposure(s) with the same exposure time as the stellar spectrum (use "bias" exposures for flat-fields),
2. smooth it strongly, in order to eliminate the contribution of spikes,
3. subtract the result of this smoothing from the spectrum.

6.2. Slice extraction and averaging

This step was taken only on 2D images and is very much site dependent, since the image slicers used in the various sites had different characteristics, and the CCD binning parameters were also chosen (or imposed) differently from site to site. For each series of data, the columns containing the stellar spectra, the flat-fields or the comparison lamp spectra were averaged, in a way depending on the site (see below). The output of this step is a 1D spectrum. We give below some details about this procedure. The terms "super-column" and "super-pixel" apply to the geometry of the detector after on-chip binning.

6.2.1. Kitt Peak

The detector was a TI 800 × 800 (15 μ) CCD, read-out with 4-pixel binning in the direction perpendicular to the dispersion. The spectrograph includes an image slicer, giving 5 adjacent slices, for a total width of 5 super-pixels.

The 5 adjacent "super-columns" were simply averaged.

6.2.2. Hawaii UH 2.2m

The detector was of the same type as at Kitt Peak, but read-out with 2-pixel binning in the direction perpendicular to the dispersion. The image slicer of the ISISbis yields 5 non-adjacent slices, for a total width of 36 super-pixels.

First, the columns in each of the 5 slices were averaged, then the 5 slices were averaged.

6.2.3. Hawaii CFHT

The detector was a Ford 516 × 516 (20 μ) CCD, with 13-pixel binning in the direction perpendicular to the dispersion. The CFHT Coudé spectrograph includes an image slicer, which yields 4 adjacent slices, and the total width of the spectra is 3 super-pixels.

The 3 adjacent "super-columns" were simply averaged.

6.2.4. Xinglong 2.16m

Two detectors were used: 1) a Thomson 384 × 576 (23μ) CCD, coated for sensitivity in the blue, and with 9-pixel binning in the direction perpendicular to the dispersion, for the observations of the Ca II K line; and 2) a CCD with a similar chip, non coated, and with no binning for all the other observations. No image slicer was included in the ISIS spectrograph, and in both cases, the total width of the spectra is 9 pixels.

For spectra with no binning, the 9 adjacent pixels were simply averaged. For spectra with 9-pixel binning, the width of the spectra is just the size of a super-pixel, and no averaging was performed.

6.3. Flat-field division

The 1D stellar spectra (output of step 6.2 for 2D images or output of step 6.1 for 1D images) were then divided by the 1D flat-field spectra. This procedure (slice extraction and averaging before flat-field division) is justified if the flat-field spectra fall at the same CCD location as the stellar spectra. We checked for each instrument that the eventual differences between the positions and heights of the stellar and flat–field spectra did not introduce any detectable error in the reduced data. The ISIS spectrograph, operated at Xinglong, showed a slow drift of the spectra in the direction perpendicular to the dispersion. This drift can be attributed to strong temperature changes during the nights, causing some flexion of the axis supporting the gratings. This drift was noticed during a test night before the campaign. We reacted by systematically recording flat–field and wavelength calibration exposures before and after each stellar spectrum. Thus, in spite of the drift, the flat–field and wavelength calibration spectra illuminate exactly the same pixels as the stellar spectra.

6.4. Wavelength calibration

Comparison spectra for wavelength calibration were produced by Th/Ar, Th/Ne, or Fe/Ar lamps. The wavelength calibration was performed after slice extraction and averaging, i.e. no correction for line inclination was attempted. We checked that in all cases, line inclination resulted in negligible loss of resolution. The wavelength calibration introduces a slight resampling of the spectra.

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Table 5. Quality of the data obtained on AB Aur. The listed S/N ratios are per resolved element. A description of the spectrographs is given in Sect. 3.

telescope	R	nb of spectra	t_{exp} (min)	$< S/N >$
2.2m UH	65000	3	90	130
McMath	19000	10	60	300
1.52m OHP	39000	17	60	160
2.16m Xinglong	9000	2 (Ca II K)	120	40
		3 (Ca II IR)	120	300

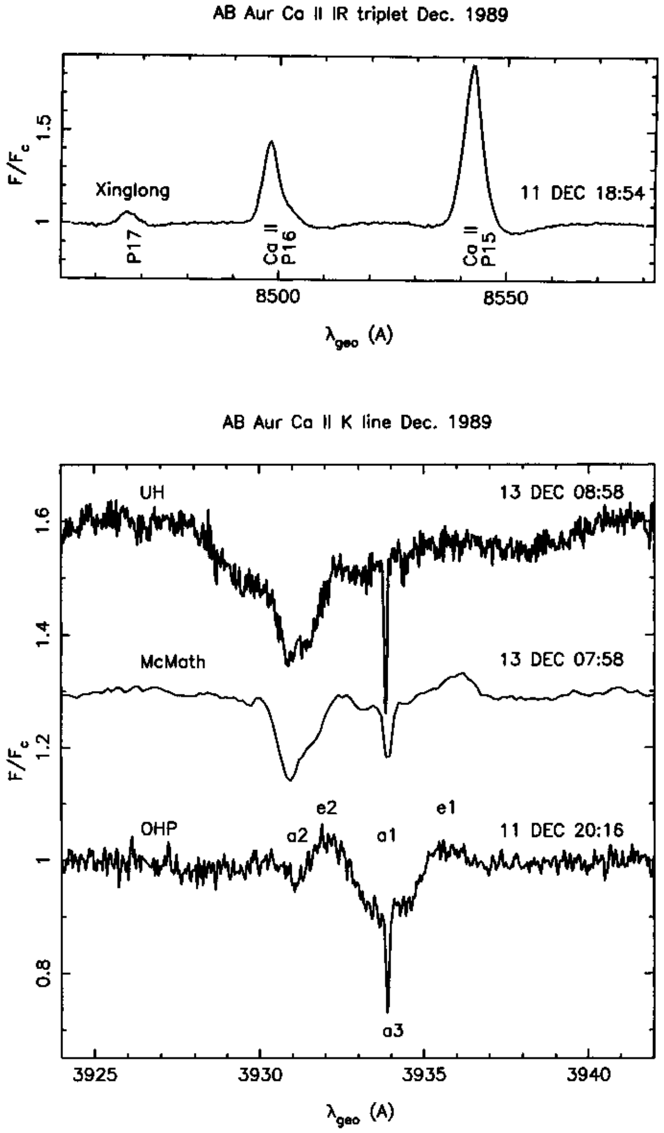

Fig. 3. Examples of Ca II K and Ca II IR triplet profiles of AB Aur obtained on some of the sites involved in the campaign. The components discussed in the text are indicated on the OHP spectrum

7. The Ca II K line and IR triplet lines of AB Aur

As mentioned above, program 2, the continuous monitoring of the Ca II lines of the Herbig Ae star AB Aur, was unsuccessful, due to bad weather conditions on most of the sites involved in the campaign. Only a few spectra were recorded during the three nights devoted to this target. The profiles of the Ca II lines and their variations that we observed during the MUSICOS 1989 campaign are peculiar enough to be presented here. In particular, the Ca II K spectra recorded during the campaign indicate a level of emission that we had never seen before in this star. Therefore, these data can be quite useful for studying the long term evolution of the activity of AB Aur.

7.1. Typical quality of the spectra

Table 5 gives the mean characteristics of the spectra of AB Aur recorded during the campaign.

The main reasons for the poor quality of the Ca II K spectra obtained in Xinglong were the large angle from the blaze at 3933 Å, the low quantum efficiency of the CCD at this wavelength ($< 20\%$), and its rather high read-out noise (40 e^-).

Figure 3 shows a typical Ca II K spectrum for each site involved in the observation of AB Aur, and one Ca II IR triplet spectrum obtained at Xinglong.

7.2. Short-term variations of the Ca II K line

During the monitoring of AB Aur, the Ca II K line shows a level of variability that it had never shown before. Let us describe briefly the various characteristics of this variability.

We first note the remarkable presence of an emission component appearing blueward of the line, a feature that we had never seen before in this star, and which is probably the sign of a very high activity level. On Fig. 3, we have marked the different components that we will discuss in the following: component a1, which is a variable broad absorption component more or less at rest wavelength; component a2, another broad absorption component displaced to the blue, with a mean displacement of about 200 kms^{-1}; component e1, an emission component redward of the line; component e2, another emission component located between the two absorption components; and finally component a3, which is a very narrow absorption component, not variable, presumably of IS origin.

Component a1 is the most variable part of the profile. Its centroid first moves blueward at the beginning of the run, until it reaches a bluemost position 30 kms^{-1} from its original position; another bluemost position seems to be reached at the end of the UH series of Dec. 13, i.e. 36 hrs later. This behavior can in principle be compatible with a rotational modulation with a period of the order of 36 hrs, but the data collected during the campaign do not provide a sufficient time coverage to ascertain this hypothesis.

Component a2 is also very variable in our set of data. It is quite weak at the beginning of the OHP observations on Dec. 11, then increases for about 4 hrs, then decreases again in the next 4 hrs until it disappears completely at the end of the OHP

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series. Twenty-four hours later, at the beginning of the Kitt Peak series on Dec. 13, component a2 is much stronger, and shows a tendency to decrease in intensity while slightly moving to the red near the end of the series. This decrease and motion to the red is also visible on the more resolved three spectra obtained at UH, simultaneously with the end of the Kitt Peak series. Although the 2 Ca II K spectra obtained in Xinglong are of poor quality, component a2 can be seen on the first one, and has almost disappeared on the second one. Three hours later, at OHP, component a2 appears extremely weak, then gradually increases in intensity until the end of the observing run. The behavior of component a2 appears much more complex than that of component a1, and it is not obvious to see if its variations are linked to rotational modulation, especially because of the poor time coverage of our data. Such a component is reminiscent of the blueshifted absorption components already observed for this star (Catala et al. 1986b). Its life-time is longer than 9 hrs (duration of the coverage on Dec. 13), i.e. 1/4 of the star's rotation period. Therefore, it cannot correspond to a CIR, which should have much shorter-lived signatures. A study of the origin of component a2 would require a better time coverage.

Component e1 already appeared in spectra obtained during previous observing runs. It had been tentatively interpreted as the "normal" red emission component of a P Cygni profile, due to spherical expansion in a stellar wind. In the present set of data, we find that component e1 is variable, although much less than the other components already discussed. The analysis of the equivalent width of component e1 as a function of time reveals a global increase during the observing run, with some shorter-term variations. If we believe that component e1 is the normal red emission of a P Cygni profile, then it must be sensitive primarily to the average density in the wind and to the extension of the emission region, both being function of the mass loss rate. Our data are therefore compatible with a global increase in the mass loss rate during the campaign, the shorter-term variations being perhaps due to rotating inhomogeneities.

Finally, component e2 is probably the most exciting feature exhibited by the Ca II K line of AB Aur during our observing campaign. During the first night at OHP, component e2 sticks above the continuum level on at least two spectra (corresponding to a duration of 2 hrs). This behavior is repeated on 4 spectra obtained at Kitt Peak the next day, with a duration of 3 hrs. Because its level is above that of the continuum, component e2 is a real emission, and not a simple "lack" of absorption between components a1 and a2. We see two maxima in the intensity of this component, separated by approximately 32 hrs, which is close enough to the expected rotation period of the stellar photosphere. A scenario worth examining in future work includes a jet originating from the stellar surface and co–rotating with it, with a temperature in excess of the surrounding wind.

Another possible interpretation of both components e1 and e2 would involve a rotating envelope around the star, possibly a disk; component e1 would correspond to the part of the envelope receding from the observer, and component e2 to the approaching part. In this interpretation, both components should be symmetrical with respect to line center, which is more or less the case in our observations. The rotating envelope would need to have an inhomogeneous angular structure, in order to explain the variability of both components. Their variations should in principle be correlated with a time lag of half a rotation period, since any structure present in the approaching part of the envelope must appear in the receding part half a period later. Our data are not sufficient to search for such a correlation. In all cases, a reliable interpretation would require a better time coverage, as well as a detailed calculation of the formation of the Ca II K line in a chromosphere around an A0 star, in order to understand in which conditions a blueshifted emission component can be produced.

7.3. *Short-term variations of the Ca II IR triplet*

A few spectra of the Ca II IR triplet were recorded at Xinglong just before the first series of Ca II K spectra obtained at OHP. On these spectra, two lines of the triplet are visible: 8498 and 8542 Å. The two lines are in emission and show a gradual decrease in intensity during 8 hours. However, the coverage of these lines is not sufficient to conclude as to a possible correlation between these variations and those in the Ca II K line.

7.4. *Signatures of the CIR's*

As indicated above there is little hope, given the time coverage obtained during this observation, to demonstrate the presence of CIR's. A close examination of the spectra indeed does not show any sign of narrow components in the Ca II K line or in the Ca II IR triplet lines, except for an interstellar component at rest wavelength, already noticed in previous spectra.

What conclusion can we draw from this non-detection? The effective rotation phase coverage is about 65%. However, the quality of the Ca II K spectra obtained in Xinglong is probably not sufficient to conclude to the absence or the presence of narrow components in the Ca II K line. If we except them from the series, the phase coverage is only about 50%. The probability that we have "missed" a CIR, if they exist, is then of the order of 50%, which is rather large. Therefore, we must consider that the results obtained during the campaign are inconclusive, and that we must reconduct this type of observations with more success in the future.

7.5. *Unusual activity level?*

In December 1989, AB Aur seems much more active than we had ever seen it until 1988. The usual behavior of the Ca II K line had always been a rather smooth and periodic variation of the line, reminiscent of what we see in the present set of data for component a1. This time we see, in addition to this usual behavior, 2 additional components (a2 and e2), which are variable on the same time scale. Component e2 in particular is a blue-shifted emission component which sticks above the continuum at least twice in the course of our observing run, which confirms its chromospheric interpretation. We note that the Ca II K line of AB Aur, observed at CFHT in September

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1989 by C. Catala and J.G. Cuby, shows the same type of profile as in December 1989. The duration of this very active phase for this star is therefore longer than 3 months.

8. Conclusion

This campaign was the very first one organized in the framework of the MUSICOS project. In spite of the difficulties encountered during the operations the overall campaign was a success. The time coverage for the spectroscopic monitoring of 48 Per was above 85%, and that of HR 1099 was of about 80%. Only the program on the PMS star AB Aur was not successful, because most of the sites involved were experiencing some bad weather conditions during the three days devoted to the observation of this star.

The analysis of the huge amount of data collected on programs 1 (48 Per) and 3 (HR 1099) is still continuing. Results concerning the two exceptional flares we observed on HR 1099 are published (Foing et al. 1993). The construction of a photospheric image of HR 1099 from the data obtained during the campaign, as well as the analysis of the short–term variations observed in the spectra of 48 Per, are in progress.

This overall very positive result is an excellent motivation to continue our effort for the development of a world spectroscopic network. The future MUSICOS campaigns should involve the MUSICOS spectrograph, developed at Paris-Meudon Observatory (Baudrand & Böhm 1992). This instrument is a fiber–fed, cross–dispersed spectrograph, with a resolving power of 38000, and allowing to record the whole visible spectrum (380–880 nm) in two exposures. The long–term goal of the MUSICOS project would be to have this new instrument duplicated and installed on various telescopes of the 2m class, well–distributed in longitude around the world.

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