THE MUSICOS NETWORK FOR MULTI-SITE CONTINUOUS SPECTROPHOTOMETRY

B.H. FOING  Institut d’Astrophysique Spatiale (IAS), BP 10, 91371 Verrieres le Buisson, France

C. CATALA, J. BAUDRAND, T. BOEHM  Paris-Meudon Observatory, 92195, Meudon, France

and the MUSICOS team

ABSTRACT  Multi-site networks can be useful for the study of late-type stars and the solar/stellar connection (asteroseismology, stellar rotational modulation, surface structures, Doppler imaging, variable winds, coordinated multi-frequency observations with space satellites...) specially for programs requiring a continuous spectroscopic coverage around the clock during several days. MUSICOS, (for MUlti SIte COntinuous Spectroscopy) is a project for a multisite network of high resolution spectrometers around the world partly dedicated to continuous spectroscopy, under development in France, with European and extra-European collaborators. The stellar activity and asteroseismological goals drive the highest constraints on the spectrometer (high efficiency, high S/N, wavelength range over 500Å, spectral stability). Accordingly, a prototype of the MUSICOS spectrograph has been developed, tested in the laboratory and qualified at the 2m telescope at Pic du Midi. The instrument design and performances (low cost fiber-fed cross-dispersed echelle spectrograph with a resolution 38000 ) are described and the strategy for a multisite network of similar spectrographs is presented. The first MUSICOS campaign dedicated to 3 programmes in december 1989, involved sites and telescopes in Mauna Kea (CFH and 2.2m UH), Kitt Peak McMath, La Silla 1.4m CAT, France 1.5m OHP, Crimea 2.6m Shajn and China 2.16m Xinglong with two fiber-fed spectrographs transported for this campaign at Hawaii and Xinglong. This allowed the Doppler imaging of surface structures and the monitoring of two exceptional white-light flares on HR1099.

Keywords: MUSICOS, multi-wavelength observing

THE NEED FOR MULTI-SITE SPECTROSCOPY

We organised in June 1988 a national workshop in France about the scientific use of multi-site spectroscopy (see Catala and Foing 1988). The workshop was attended by 50 participants, from different fields of solar and stellar physics. The interest for continuous spectroscopy was recognised for various topics for the study of asteroseismology, stellar rotational modulation, surface inhomogeneities, for stellar activity short term phenomena, or Doppler imaging of surface structures. Also the study of wind variability, flare patrol, or eclipse imaging was stressed. Additionally, a joint network of high resolution
spectroscopy and photometry would give a simultaneous support to continuous satellite observations. The need for multi-site continuous coverage (taking as example networks of solar seismology) was especially recognised for the asteroseismology programs e.g. of OB, Be, delta Scu, fast rotating B stars and solar type stars (see Dappen 1988, Catala and Foing 1988).

THE MUSICOS PROJECT

MUSICOS is an international project started in 1988 which aims at developing a multi-site network of high resolution spectrographs. This project has received support from many scientists, from European countries, America and Asia so far. The goal of Musicos is to facilitate multi-site spectroscopic observations, first by setting up an organisation helping the coordination of observations from existing instruments at different sites, then by designing, developing and installing similar spectrometers in well-chosen sites around the world, for which part of the time would be devoted to multi-site observations.

Given the positive impact of the first MUSICOS workshop and the interest shown by several other European teams, we have decided to get started on the practical and technical aspects of the project as soon as 1989. In a first phase, we have been organising multi-site campaigns using resident instruments on various telescopes around the world and a transportable fiber-fed monochromator spectrometer (ISIS, developed at Meudon Observatory and used until 1988 at the 1.93 m telescope at OHP). In a second phase, we continued in 1990-1991 the design and development of an cross echelle fiber-fed spectrometer, and perform tests in the laboratory and at telescope on this prototype to assess the scientific performances of this fiber-fed spectrograph. In a third phase, we shall develop an instrument that can be proposed for duplication to different foreign collaborators. This will allow at long term multi-site campaigns with identical instruments, and to reach the limits in quality, sensitivity and homogeneity of ground based continuous spectroscopy that are set by asteroseismology requirements.

REQUIREMENTS FOR ASTEROSEISMOLOGY AND STELLAR ACTIVITY

Asteroseismology requires high S/N, and the possibility of observing a large number of photospheric lines, together with the specific requirements of a high spectral stability and very accurate velocity calibration. The need for pre-reduction of data at each site, in order to control in real time the instrumental parameters (quality of night, drifts) is also important.

For solar-type oscillations, the velocity signal is much reduced (of the order of 15 cm/s per stronger solar mode). An observing continuity better than 60% in order to decrease the effect of parasite sidelobes and aliasing in the power spectrum, and to increase the signal to noise and resolution on the oscillation modes was requested, which argues for multi-site network. Classical slit spectrographs using one or a few lines are not stable and efficient enough. Resonance cell techniques have a good stability but can apply only to 0 or 1st magnitude stars with 4m class telescopes, which are oversubscribed and make difficult a continuous observing from several sites. For having access to fainter
stars from later-type closest stars or from other classes in the H-R diagram, the multi-line concept may be relevant in the future. For seismology velocity measurements, the MUSICOS spectrometer at 30000 resolution only with a 2m telescope would give on a 3 magnitude star a S/N of 100 in 1 mn, which coupled to the measurement of 400 lines relatively free of blending available on the spectral domain in the cross echelle mode would in principle allow to reach an oscillation detection of 3m/s per mn exposure, and thus a noise of 5cm/s for a continuous 72 hours observation.

Stellar activity requires also the observation of different lines simultaneously, for instance: photospheric lines to be used for magnetic measurements; different unblended lines for Doppler imaging of spots; chromospheric lines such as the Ca II H and K or infrared triplet allow to probe different chromospheric heights; in particular the H alpha line is a very sensitive indicator of extended active structures; Balmer lines give very important temperature, density and dynamic diagnostics for flare studies; both H Balmer line and strong resonance lines such as Na or Ca II can probe circumstellar absorbing material transiting over the disk; also high excitation lines such as He I allow to follow more energetic phenomena or variations of EUV or X radiation.

TECHNICAL DESIGN OF MUSICOS INSTRUMENT

From the scientific requirements after the MUSICOS workshop it was realised that a large range of scientific programmes require a spectral resolution 10000, 30000, and 80000. The main requirements for stellar activity studies and asteroseismology is the availability of large spectral domain in order to measure a number of photospheric lines in solar-type stars, and the stringent constraint for spectral stability down to the 10m/s range. The spectrograph can be fed by an optical fiber (Felenbok, 1988) which makes the instrument transportable and adaptable on another telescope.

The design of the instrument included the following specifications: a spectral resolution of 30000 minimum, a spectral domain 3900-8700 A that can be covered in two successive exposures (blue and red), an efficiency allowing a S/N better than 200 in 1 hour for a star of 6th magnitude with a 2m telescope and an astronomical CCD; a Thomson CCD 1024x1024 (19 μ pixel) proposed as a detector; a fiber feeding; the possibility to acquire 2 spectra simultaneously. A prototype of the MUSICOS spectrograph has been developed (Baudrand and Boehm, 1992). The selected fiber POLYMICRO FHA has a core of 50 μ, which corresponds to 2 arcsecs for an entrance aperture f/2.5. Its chromatic transmission is near 90 percent for a large domain in the visible and in the red, and remains better than 70 percent at 3900 A. Thus, an image slicer is not anymore necessary. Light is directed towards a 400 mm focal length collimator, and then on an echelle grating, a Milton Roy replica (31.6 gr/mm and 63.5 degrees blaze angle). The cross dispersion is given by two SCHOTT rectangle prism working in double pass at deviation minimum, covering the dispersion requirements of the two wavelength regions, 380-540 nm and 540-880 nm. The passage from blue to red needs 4 independent mechanical drives, motorized and simultaneously commanded, requiring less than 3 minutes for the change and yielding a positioning precision within 1 pixel. The whole is articulated around a CANON objective (from the market). A slight tilt of the grating, and a
lateral mirror allow a comfortable mounting of the detector cryostat. This set up has the advantage of being very compact, luminous and inexpensive. We estimate that this spectrograph could be duplicated with a moderate budget of 40,000 US Doll. and within a short month delay. Laboratory results indicated 17 throughput efficiency spectral resolution equivalent to 38000, a spectral coverage in two exposures from 380-880 nm complete until 700 nm using the Thomson 1024 x 1024 CCD, and a minimum separation between adjacent orders of 360 micron. An automatic procedure (MUSBIC) to reduce MUSICOS Echelle spectra was adapted from the ECHFIC programme developed by M. Spite. The extraction of the curved orders and auxiliary spectra (flatfield, Thorium), and wavelength calibration are described in Baudrand and Boehm, 1992. The output can be converted into standard data formats.

THE MUSICOS DECEMBER 1989 OBSERVING CAMPAIGN

For this first MUSICOS campaign at the end of 1989, three programs were chosen among those which really require multi-site spectroscopic observations:

1) Short-period spectroscopic variations in Be stars
2) Corotating stream structures in the winds of PMS Herbig Ae stars
3) Doppler Imaging and flare monitoring of RSCVn-type active stars

Initially, the sites, telescopes and observers to be involved in this campaign, were the following: Mauna Kea 2.2m UH, 3.6m CFHT, Kitt Peak McMath, La Silla 1.4m CAT, France 1.5m OHP, Crimea 2.6m Shajn, China 2.16m Xinglong.

After the general announcement sent by J. Butler through the Multi wavelength IAU Working group, and also the IAU circular for our multi-site continuous spectroscopy campaign from 8 to 17 december 1989 (MUSICOS 89 campaign), we received a large observing support (ground based spectroscopic or photometric, or satellite observations) and finally 17 telescopes, including IUE, were pointed towards our targets. In addition to resident spectrographs at OHP, Crimea, CFH, ESO, Lick, Mc Math, we used the two existing versions of the ISIS fiber-fed spectrograph in mono-order mode (one of them used until 1988 at OHP), and specially transported for the MUSICOS campaign the 2.2m University of Hawaii telescope and on the 2.16m newly installed telescope at the Chinese XingLong station.

The first results from the MUSICOS 89 campaign have been presented in the 2nd MUSICOS workshop (Catala and Foing, Eds, 1990). On the RS CVn-type HR 1099, this includes a complete phase coverage allowing a Doppler imaging of photospheric spots. Quasi-simultaneously, we observed modulation of CaII K profile due to chromospheric plage regions. At least two exceptional white-light flares were detected photometrically and by their remarkable spectral signatures in H alpha. The 14 December flare starting at 13:00 UT was followed from China and Catania, and the 15 December flare starting at 2:00 UT was followed from ESO, Hawaii, China and Catania (Foing et al, 1990). We estimated the energy budget for these two events, the first of this importance detected on HR 1099. The interpretation of a filament ejection occurring over a magnetic arcade and the magnetic energy budget are discussed in Foing et al (1991). These
observations bring a new light and a puzzle about energy transport mechanisms in stellar flares.

MUSICOS PROJECT ORGANIZATION AND COLLABORATIONS

There is in France a MUSICOS project group composed of C. Catala (Meudon) and B.H.Foing (ESA/IAS) as Principal Investigators, J. Baudrand (Meudon) is the instrument project manager. A group of Co-investigators and associated scientists is involved in the project. Also contacts were established with European groups in Italy (in Trieste and Catania), in Scandinavia (in Upssala, Helsinki, and Aarhus), in Spain, in United Kingdom (at Armagh). Associate countries such as US (in Hawaii, in Boulder, Goddard, and with the SYNOP group), in USSR (in Crimea) and in China (at Beijing Astronomical observatory) wish to participate to the multi-site project. The MUSICOS project will be open to any input and collaboration during the development phase, and through the observing proposals to the community during the operational phase. The philosophy of the MUSICOS project is to associate the groups interested also on the scientific return, and this is the reason why we start already collaborative campaigns to learn how making, reducing, analysing the results from multisite data. Asteroseismology will require continuous coverage and a good control on the stability and the quality of the measurements. Also, some programs require special observational strategy and might be interleaved with other programs or require service observing.

MUSICOS PLANNING AND PERSPECTIVES

Since 1982, with our collaborators, we have participated to Multi-Site Multi-Wavelength Observing campaign, giving the collaboration framework for operations and scientific analysis. At the end of 1989, we organised an observing campaigns including transport of ISIS and ISIS-bis instruments in complementary sites (Xing Long, Hawaii). In January-Mars 1990, we worked on the preliminary reduction and analysis of the results from this campaign. A MUSICOS workshop organised at Meudon on 27-30 March allowed presentation of these results, further discussion and future organisation and realisation of the MUSICOS project (see Catala and Foing 1990). 1989-1990 was devoted also to the design and development of the spectrograph.

At the end of 1991, instrument tests and qualification of the MUSICOS prototype spectrograph took place at Pic du Midi Observatory, with the B. Lyot 2 m telescope. Spectra were recorded with a Pic du Midi CCD detector. The instrument speed resolving power, wavelength stability and scattered light were determined (Baudrand and Boehm, 1992). The MUSICOS spectrograph will be operated routinely on the 2 m B. Lyot telescope and will also be transported to remote sites for future multi-site MUSICOS campaigns, such as the one planned for December 1992. This campaign would include sites in Hawaii, ESO, OHP, Pic du Midi, Canarias, Crimea, Kitt Peak, AAT, China etc. 1991 has seen the final development of the MUSICOS spectrometer model to be duplicated by the participant countries. In 1992-1993, we plan the duplication and installation in remote sites (such as Hawaii, Xinglong, Canarias), and the start of the
full network operations. When the network is operational, a Multi-Site Guest Observer program will be offered to the community.

Multi-site multi-frequency campaigns in coordination with satellite continuous observations will be also a driver for the MUSICOS operations. A multi-site spectrophotometric network will complement several space missions such as EVRIS on Soviet Mars 94 probe, PRISMA currently under study at ESA for asteroseismology, or Hubble Space Telescope, ROSAT, and future UV and X-ray observatories for stellar activity or microvariability programmes. Also, moon-based astronomy (either from the future lunar base or its precursor missions) will provide very favourable viewing conditions for photometric asteroseismology and multi-frequency stellar activity studies, that can be complemented by global networks.

REFERENCES