The Calar Alto Key Project for Sloan Digital Sky Survey Follow-up Observations (2001–2002)

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1 Introduction and summary

From 2001 to 2002 a Key Project for Sloan Digital Sky Survey (SDSS) follow-up observations was carried out at Calar Alto Observatory, covering four semesters. The purpose of this project was to enable SDSS follow-on studies not possible with the standard SDSS instrumentation or standard SDSS observing modes. The Key Project made use of MPIA guaranteed time, which was made available to the SDSS collaboration as MPIA's in-kind contribution. A total of 138 nights were allocated to the Key Project, corresponding to 19% of the available time at Calar Alto. All observations were carried out in service mode. Approximately 60% of the observations used the 2.2-m telescope, and $\sim 40\%$ the 3.5-m telescope. The most popular instruments were TWIN, CAFOS, and MAGIC. The weather permitted us to obtain data during 41% of the time.

In the framework of the Key Project a wide variety of subprograms were executed, ranging from stellar astronomy to high-redshift quasars. The types of programs included target-of-opportunity observations, regular short programs, and long-term projects. Five refereed papers have resulted so far from the Key Project. In the following sections I will describe the Key Project in more detail (see also Grebel 2001).

2 Background: The Sloan Digital Sky Survey

The Sloan Digital Sky Survey (SDSS) is a large international survey project to map up to one quarter of the sky photometrically and spectroscopically using a dedicated 2.5-m telescope at Apache Point Observatory, USA (York et al. 2000). During its five years of operation (2000 – 2005) the SDSS is expected to measure accurate positions and luminosities of more than 100 million stars and galaxies in five different wavelength ranges (Fukugita et al. 1996; Gunn et al. 1998; Hogg et al. 2001; Smith et al. 2002; and Pier et al. 2003). It will also determine the redshifts of more than a million galaxies and quasars, providing a three-dimensional map of the Universe (Eisenstein et al. 2001; Strauss et al. 2002; Richards et al. 2002). Various universities and research institutes in the United States, Japan, and Germany are participating in this gigantic effort, among them the Max-Planck Institute for Astronomy.

The SDSS carries out a simultaneous optical drift-scan survey in the five filters u, g, r, i, z (see the SDSS Project Book at `http://www.astro.princeton.edu/PBOOK/welcome.htm`). The limiting magnitude of SDSS imaging is $r \sim 22.3$ mag, and SDSS astrometry is accurate to ~ 45 mas (Pier et al. 2003).

The SDSS also obtains medium-resolution (R=2000) spectroscopy for 10^6 galaxies (mainly field galaxies with $r < 17.77$ mag; Strauss et al. 2002) and for a color-selected sample of $\sim 10^5$ quasars (Richards et al. 2002). The SDSS is the largest redshift survey undertaken to date.

The SDSS is unprecedented in its combination of depth, homogeneity, and area coverage. The scientific potential of the SDSS is enormous and addresses a wide variety of astrophysical key questions. The SDSS provides an invaluable database for areas such as local star formation, stellar and galaxy luminosity functions, Galactic structure, low-surface brightness galaxies, galaxy evolution, clusters of galaxies, lensing, quasars, large-scale structure, and cosmology.

The participation in the SDSS provides privileged data access to the member institutions. During the proprietary period SDSS data are pipeline-reduced and calibrated. SDSS data products include image data, photometry and astrometry catalogs, wavelength- and flux-calibrated spectra, and redshifts. The SDSS commissioning data were released to the public in June 2001 (Early Data Release, Stoughton et al. 2002; `http://archive.stsci.edu/sdss/`). It covered ~ 460 square degrees on the sky and 52,896 spectra. The first regular release, Data Release 1 (Abazajian et al. 2003; `http://www.sdss.org/dr1/`) in April 2003 covers 2099 square degrees, including 186,240 spectra. Additional releases are planned on an annual basis.

3 Why a Key Project for SDSS Follow-up Observations?

The SDSS provides a growing, homogeneous database of photometric and spectroscopic data obtained at fixed wavelength ranges with fixed resolution and exposure times. While this database enables a wide range of scientific applications on its own or in combination with other archives, many projects require targeted follow-up observations. Different wavelengths, resolutions, integration times, or repeated observations may be necessary to complement the SDSS data.

The instrumentation at Calar Alto Observatory provides a great opportunity for targeted follow-up observations at wavelength ranges, integration times, etc., not afforded by the SDSS. Furthermore, Calar Alto offers access to other instrumentation and techniques than available through the SDSS. A number of projects were identified within the SDSS collaboration that would greatly benefit from targeted follow-up observations.

When the key project data acquisition status of the CADIS (Calar Alto Deep Imaging Survey) project ended in 2000, "SDSS follow-up observations" were established as the subsequent observational long-term project at MPIA (PI: E.K. Grebel). By allocating guaranteed amounts of observing time to the SDSS Key Project project throughout several semesters we obtained sufficient flexibility to accommodate target-of-opportunity observations as well as to carry out follow-up observations for large SDSS science projects, thus optimizing the scientific returns of this unique survey.

4 Key Project Operations

The requirement of flexibility and of accommodating a range of different scientific programs distinguishes the SDSS Key Project from other, strongly focused long-term key projects carried out at Calar Alto. A special challenge was to make an intelligent guess of the possible time and instrumentation needs for the SDSS Key Project. We countered this challenge in three ways:

(1) We identified a set of long-term projects of interest to SDSS scientists at MPIA and within the SDSS collaboration as a whole.

(2) We inquired within the collaboration about the anticipated needs considering the available Calar Alto instrumentation, and used ongoing SDSS follow-up projects at other observatories as an additional guide. These two considerations determined our request for a certain number

of nights per instrument and semester.

(3) We re-arranged the distribution telescope and instrumentation allocations for the key project every semester based on changing needs and feedback from the various proposers.

The time allocation process had two stages. First, I wrote a detailed proposal for the Key Project as a whole, explaining the various subprojects planned for the next semester and justifying the amount of the requested time and instrumentation. This proposal also contained a progress report and a long-range plan for the coming semesters. The proposal then went to the Calar Alto TAC. Due to the MPIA guaranteed time nature of the program, it did not undergo the regular TAC process but served primarily to inform the TAC about the forthcoming needs and present status of the Key Project.

The SDSS Key Project also differed from conventional key projects in operating like an observatory on a small scale: In addition to requesting applications for long-term projects well ahead of the next semester, the SDSS collaboration was offered the opportunity to apply for observations during the semester roughly a month before the observations would be due to be carried out. This was done primarily to allow persons in need of rapid follow-up observations to get data, but also in order to give newly emerging projects a head start. Thus after time for the Key Project as a whole had been allocated for a given semester, the SDSS collaboration could submit proposals through a simple, on-line web form developed by Daniel Harbeck at MPIA. The proposals were informally evaluated by the SDSS group at MPIA during our regular meetings. The final responsibility for time allocation and scheduling rested with me as SDSS Key Project PI in Heidelberg.

Planning and overseeing the actual execution of the service observations at Calar Alto Observatory was the task of Calar Alto staff astronomers Francisco Prada during the first three semesters, and Santos Pedraz during the last semester of the key project operations. These two staff members also carried out a number of the service observations themselves and provided support regarding the technical feasibility and implementation. Without the dedicated help of the Calar Alto staff the Key Project would not have been possible.

Service observations were in fact a key element for the SDSS Key Project. Th observing mode ensured very short turn-around times, observations carried out by experts for the various instruments, and flexible scheduling since it became easier to switch between programs depending on their needs of specific time windows or on their requirements regarding weather conditions. Another major advantage of service mode are the significant savings in travel expenses for the proposers.

Thanks are also due to the Calar Alto director, Roland Gredel, who generously allocated unexpended time from technical/engineering runs and Director's Discretionary Time to the Key Project. This enhanced our ability to accommodate target-of-opportunity observations and to compensate for weather losses. Last but certainly not least I would like to thank Hans-Walter Rix, whose continued support as the managing director of MPIA made the Key Project possible.

5 Key Project Statistics

The number of nights per semester and for the project as a whole is given in Table 1. The difference between the number of requested nights and actually allocated nights is due to the additional nights made available to us courtesy Roland Gredel (see above). Averaged over four semesters, we requested 17% of all available nights at the 2.2-m and 3.5-m telescopes and received 19% of the available time.

Table 1. Number of nights in the Key Project

Semester	Nights requested	Nights allocated
Spring 2001	44	48
Fall 2001	23	28
Spring 2002	40	47
Fall 2002	15	15
All	122	138

The SDSS Key Project used only the two largest telescopes at Calar Alto Observatory, i.e., the 2.2m and the 3.5m telescopes. With 59% of all allocated nights, the 2.2-m telescope was our main work horse. The distribution of nights by instrument is shown in Table 2. Column 2 of this table gives the number of total nights allocated per instrument, column 3 the fraction the of nights allocated for this instrument, column 4 the number of nights during which data were actually taken, and column 5 the fraction of nights during which data were taken. Table 2 shows that the TWIN longslit spectrograph at the 3.6-m telescope and the imager and spectrograph CAFOS at the 2.2-m telescope were the two most popular instruments, followed by the infrared imager MAGIC at the 2.2-m. The last two columns of this table indicate amount of time during which observations were possible (the remainder was lost or unusable due to bad weather.

Table 2. Number of allocated and usable nights per instrument

Telescope	Instrument	Allocated # of nights	Fraction of total	# of nights observed	Fraction of allocated nights
2.2-m	MAGIC	31	22%	12.8	41%
	CAFOS	47	34%	21.4	46%
	BUSCA	4	3%	0.4	10%
3.5-m	TWIN	48	35%	17.3	36%
	MOSCA	5	4%	3.8	76%
	Omega Prime	3	2%	0.3	10%
	Total	138	100%	56	41%

Expressed in terms of time of the year, December was by far the worst month weatherwise, while the summer period (roughly speaking, May to October) was the best. I have to emphasize that our "random sampling" of anything between one night to more than one week per month does not permit us to derive reliable weather statistics for Calar Alto as a whole. Consider, for instance, a month in which two nights were allocated to the Key Project: If these two nights were lost while the remainder of the month was excellent, this month be listed with a misleading 0% fraction, and vice versa.

Next we consider the distribution of the number of nights by science area (Table 3). Extragalactic studies were clearly the favorite subject area. For example, the three long-term projects carried out at MPIA concentrated on quasars and galaxies and were allocated 45% of the total available time. For the distribution of nights by program, please see Table 4.

Table 3. Fraction of nights by subject area

Subject area	Fraction of nights
QSOs	25%
Galaxies	38%
Stellar popul. / Gal. structure	17%
Stars	20%

Table 4. SDSS Key Project subprogram statistics

Subject area	Fraction of nights				
PI	Short title	Instrument	Total # nights	# of nights observed	Completion fraction
Quasars					
Pentericci	JHK colors of QSOs	MAGIC	18.5	8	43%
Zheng	JHK colors of QSOs	MAGIC	10.0	3	30%
Johnston	Lensed QSOs	CAFOS	9.0	0	0%
Hall	Bright QSO candidates	CAFOS	5.5	3	55%
Bowen	QSO absorption lines	TWIN	2.0	0	0%
Galaxies					
Rix	Rotation curves and T-F	TWIN	30.0	12.3	41%
Kniazev	LSBs	CAFOS	10.0	2.3	23%
	LSBs	TWIN	3.0	0.5	17%
Prada	Bright galaxy redshifts	CAFOS	7.5	3.3	45%
Tucker	Compact groups	CAFOS	2.5	1.4	57%
Stellar populations / Galactic structure					
Odenkirchen	Palomar 5's tidal tails	TWIN	9.6	2.3	24%
	Red giants in Draco	MOSCA	5.0	3.8	76%
Harbeck	Calibrating globulars	CAFOS	6.3	3.3	52%
Helmi	Identifying halo giants	CAFOS	3.0	2.1	70%
Stars					
McGehee	T Tauri stars	CAFOS	6.5	2.5	38%
	T Tauri stars	TWIN	5.3	2.2	42%
	Draco giant mol. cloud	Ω Prime	3.0	0.3	10%
	Draco giant mol. cloud	MAGIC	2.5	1.8	72%
Hennessey	RR Lyrae lightcurves	CAFOS	5.9	3.5	59%
	RR Lyrae lightcurves	BUSCA	4.0	0.4	10%

Note that the sum of the nights listed in Table 4 exceeds the total number of nights quoted earlier since some of the programs were only to be executed if certain conditions (such as seeing below a certain value) were met. Also, I would like to emphasize that terms like "usable nights" or "completion fraction" only refer to whether data were taken. Whether the obtained data are useful for the corresponding subprogram is a different question that has to await the reduction and analysis of the date. For instance, a program to measure lightcurves needs good sampling; if this program was completed only partially it may not be possible to derive reliable periods.

6 SDSS Key Project subprograms and first results

In this Section we will briefly present a few of the SDSS Key Project subprograms.

The long-term Key Project subprogram that received the highest allocation of nights was the Hα rotation curve program led by Hans-Walter Rix. This program aims at constraining the scatter in the Tully-Fisher relation by obtaining long-slit spectra of late-type galaxies, and at determining their individual mass profiles. (Since the SDSS spectrograph is a fibre spectrograph, it does not yield rotation curves.) Approximately 100 SDSS-selected galaxies in the range of 0.1 $L^\star$ to 3 $L^\star$ and 5,000 km s^{-1} to 15,000 km s^{-1} were successfully observed and are currently being analyzed.

The long-term subprogram with the second-largest allocation of nights was led by Laura Pentericci at MPIA. The goal of this program was to measure the near-infrared properties and the continuum shapes of high-redshift quasars ($3.6 < z < 5$) in the SDSS through JHK$'$ photometry. These data were used to study the quasars' rest-frame spectral energy distributions longward of the Lyman α line and their evolution with redshift. This program was successfully concluded, and a paper has been submitted (Pentericci et al. 2003).

The third long-term subprogram at MPIA, led by Alexei Kniazev, consists of detailed follow-up studies to explore the properties of low-surface-brightness (LSB) galaxies in the SDSS. In particular, redshifts of LSBs too faint to be spectrometered by the SDSS are being obtained in order to explore the faint end of the galaxy luminosity function for a volume-limited sample of LSBs. In addition to Calar Alto observations, data are also being taken at ESO, Chile. Owing to the large number of galaxies, the program was not yet completed when the Key Project ended and now continues at Calar Alto and at ESO as a regular program. The first paper resulting from the LSB project was recently submitted (Kniazev et al. 2003).

The research led by Amina Helmi (MPA) may serve as illustration for a regular, one-semester program within the Key Project. The program sought spectroscopic confirmation of metal-poor red giant candidates identified photometrically in the SDSS for Galactic structure studies. The program was completed, and the results are published in Helmi et al. (2003).

The confirmation of very high-redshift quasar candidates, led by Xiaohui Fan (Princeton University and University of Arizona) is an example of a successful target-of-opportunity program. (Note than target-of-opportunity programs are not listed in Table 4.) Calar Alto was used to obtain infrared colors for one of the new quasar candidates (to exclude confusion with L and T dwarfs), and to confirm the redshift of another quasar, which turned out to be the highest-redshift quasar known to date. The results of these studies, which combine data from many different observatories, are published (Fan et al. 2001, 2003).

Hence at present five papers based in part on data obtained in the framework of the Calar Alto SDSS Key Project have appeared in the refereed literature or are currently being refereed. For more detail on the SDSS projects at MPIA, please see Grebel (2001).

7 Experiences and outlook

A number of time-allocation methods were tried out during the SDSS Key Project. We started by trying to accommodate every observing request, maximizing flexibility through monthly allocations. When the bi-annual review showed that in this mode weather losses simply took too heavy a toll, preventing many programs from obtaining sufficient data, we gradually moved to prioritized allocations for the long-term programs with buffers for short programs and target-of-opportunity observations. In the last semester of Key Project operations, no more calls for proposals were sent out; instead the primary effort went into ensuring a successful completion of the long-term programs. So despite its comparatively small community and small scale, our Key Project went along a similar path as taken by regular Calar Alto and ESO time allocations.

The advantages of a guaranteed-time Key Project became obvious during its execution: Users were able to depend on the reliability and continuity of guaranteed-time observations and turn-around times were fast. The Key Project allowed us to carry out a few experimental projects that might not have been possible in the regular TAC process; they permitted the execution of very small and short quick-look projects, and of very large projects requiring substantial amounts of observing time. Service mode proved vital for the successful execution of this Key Project.

While the initial planning foresaw a Key Project that would run for five years, i.e., for the entire duration of the SDSS, we ended it after two years. There were several reasons for this decision: Several of the PhD student and postdoc projects were nearing completion, leading to a decreased demand owing also to the limited duration of the temporary appointments that characterize these positions. The emphasis of our follow-up observations began to shift to larger telescopes. Two of the three long-term projects had been successfully completed. We felt that the one remaining longterm project (LSB galaxies) would do equally well when applying for time competitively, which has since proven to be correct. Also, there was an increasing demand for other key projects at MPIA. A new, separate key project (non-SDSS-related) was being initiated by the adaptive optics group at MPIA, and additional key projects using the new wide-field imaging instrumentation at Calar Alto were being planned. All in all, we had reached a well-suited point in time to terminate our Key Project. We look forward to the continued publication of the results of the various subprojects.

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