# Sloan Digital Sky Survey

# 2003 ANNUAL REPORT

## 26 November 2003

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## 1. Introduction

This Annual Report for the Sloan Digital Sky Survey covers the interval 1 October 2002 through 30 September 2003 for activities, and calendar year 2003 for the financial reporting, as with previous reports.

The report is organized in a way that roughly follows the data stream: we describe the data collected at Apache Point Observatory, the data-processing operation, the data-distribution operation, and the scientific results announced during this interval. We further report on undergraduate and graduate student projects based on the SDSS data archives, as well as other ways we have communicated our results, listing publications in an Appendix. Finally, we present financial performance for 2003 and planning for 2004.

We have enough experience that we can base observing performance in a given period not with a model, but with an average of past performance. In this sense, 2003 was a very good year for imaging because of excellent weather in the second quarter, enabling us to catch up with the baseline plan for imaging in the North Galactic Cap. The total number of spectroscopic plates acquired in 2003 was similar to the number acquired in 2002. Our rate of obtaining data is limited by atmospheric conditions at the observatory, as opposed to procedures that are within our control. This is a strong statement supporting the excellence of the observing systems.

At the beginning of the reporting period the pipelines were in a state of change, but by the end of the reporting period the pipelines (and the rest of the data-processing system) had become far more stable. As a result, we are now current in processing the entire archive with a common version of the reduction code, the first time this has been achieved.

We reached a milestone in 2003 with the first public data release, DR1. The investment made in developing the data-access interfaces and in the documentation for DR1 will carry forward to DR2, and much of the work to prepare DR2 was undertaken in the reporting period.

The scientific productivity of the SDSS Collaboration has increased significantly with respect to past years, as measured by submitted publications to refereed journals. This pattern is as expected, since the Collaboration has now had access to a significant fraction of the ultimate survey data volume. Three of the highlights described in the following are the power-spectrum derived from more than 200,000 galaxy redshifts, the detection of the integrated Sachs-Wolfe effect (in combination with the WMAP data), and the discovery of the gravitational lens with the most extreme known angular splitting.

John Peoples retired as SDSS Director on July 1, being replaced by Richard Kron. Michael Strauss was elected SDSS Scientific Spokesperson, replacing Richard Kron on October 1 2003. Bill Boroski and Jim Gunn continued in their positions of Project Manager and Project Scientist, respectively.

The financial performance in 2003 was according to the budget. The financial plan for 2004 applies available resources to operate the survey in much the same way as in 2003.

## 2. Observing Statistics for 2003

We have imaged 76% of the baseline area for the Northern Survey and 99% of the baseline area for the Southern Survey. All of these data have been processed and calibrated and meet survey quality requirements. As shown in Figure 2.1, we have accumulated a total of 5,824 square degrees of imaging data for the Northern Survey. (Throughout we consistently use "unique" square degrees as opposed to "footprint" square degrees. The former units do not account for overlap between the stripes, but have the advantage that they scale with observing time, which is the commodity that we can forecast.) During the period from October 2002 through September 2003, we obtained 2,405 square degrees of new Northern Survey imaging data, or 158% of the baseline goal of 1,521 square degrees for this period. Favorable weather conditions, system availability, and operational efficiency all contributed significantly to our imaging progress.

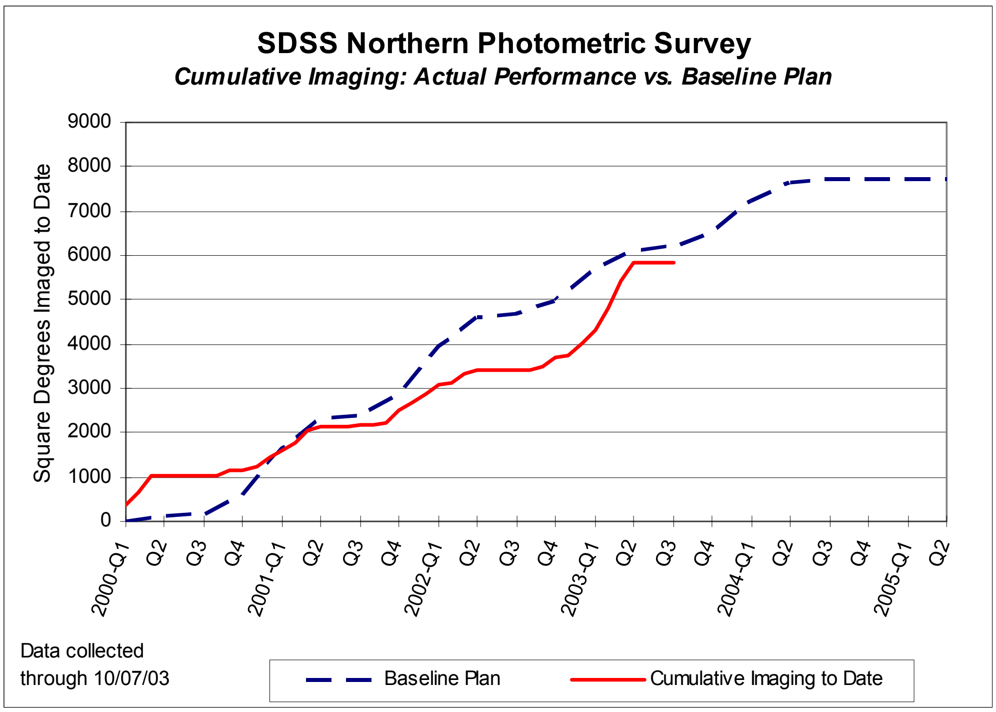


Figure 2.1. SDSS Northern Survey

The Southern Survey consists of three separate, non-overlapping, 2.5-degree wide stripes in the southern galactic hemisphere and was declared complete at the end of 2001. With the Southern Survey complete, efforts in 2003 focused on obtaining repeat imaging data of the Southern Equatorial Stripe. For the period October 2002 through September 2003, we obtained 1,032 square degrees of new imaging data, which is 75% of the baseline goal of 1,378 square degrees for the same period. The cumulative area of imaging data obtained on the Southern Equatorial Stripe through September 2003 is shown in Figure 2.2.

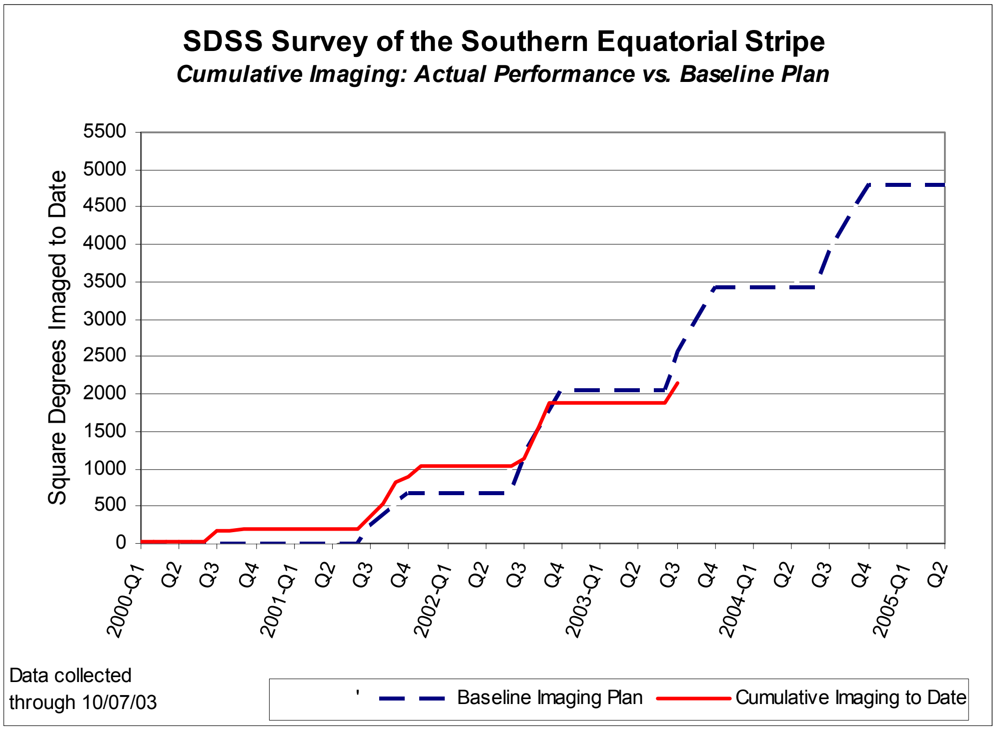


Figure 2.2. SDSS Survey of the Southern Equatorial Stripe

We also made steady progress on the spectroscopic surveys during 2003. Through the end of September 2003, our baseline goal was to have observed 818 plates on the Northern Galactic Cap, whereas in fact we had observed 679. The 156 standard plates on the Southern Survey stripes have effectively completed that survey. We have also observed 183 special-targetting plates on the celestial equator in the Fall sky, of which 113 were obtained in this reporting period. Since each plate yields 640 spectra, by now we have obtained slightly more than 651,500 spectra that meet survey requirements. Approximately 598,000 have both been classified with high confidence and have a high confidence redshift. The classifications of these spectra are shown in Table 2.1. The table does not include those spectra that were classified with lower confidence or the spectra that were dedicated to a special purpose, such as sky background.

Table 2.1. Classification of High Confidence Spectra

| | Stars | Galaxies | Luminous Red Galaxies | QSOs | High-Z QSOs |
|---|---|---|---|---|---|
| Northern and Southern Surveys | 53,496 | 322,680 | 81,298 | 52,581 | 3,524 |
| Survey of Southern Equatorial Stripe | 32,468 | 34,284 | 9,016 | 8,089 | 629 |
| Total | 85,964 | 356,964 | 90,314 | 60,670 | 4,153 |

As of October 1, 2003, we are behind the cumulative Northern Survey spectroscopic baseline goal by 139 plates. Table 2.2 shows the number of plates observed per quarter and cumulative performance against the baseline goal for the Northern Survey. We were behind the baseline goal at the end of September 2002 and fell further behind in 2002-Q4 and 2003-Q1 due to poor weather. We gained some of this back in 2003-Q2 when the weather improved. However, better weather conditions also allowed us to allocate more observing time to imaging, which took time away from the spectroscopic program. Allocating time in this manner is consistent with our longstanding policy of imaging whenever conditions are suitable, since obtaining imaging data continues to be our highest priority.

Table 2.2. Progress in the Northern Spectroscopic Survey

| Period | Plates Observed | Baseline Goal in Period | Cumulative Difference *(Plates Observed minus Baseline)* |
|---|---|---|---|
| As of Sep 30, 2002 | 435 | 492 | -57 |
| Oct-Dec | 19 | 66 | -47 |
| Jan-Mar | 93 | 156 | -63 |
| Apr-Jun | 125 | 93 | +32 |
| Jul-Sep | 7 | 11 | -4 |
| Total | 679 | 818 | -139 |

The baseline plan assumed that imaging would end in the third quarter of 2004 and that we would devote all observing time in the final year to the spectroscopic survey. However, we now plan to image whenever conditions permit through the end of the survey, in order to image as much of the Northern Galactic Cap as possible. The result is that less time will be available for spectroscopy; therefore, we will fall substantially short of the baseline goal for the Northern Survey. We can use the past two years of operating experience to forecast the total number of plates we will likely observe by the end of June 2005. Table 2.3 shows the total number of plates observed in each of the past two years and forecasts the number of plates we are likely to observe in the remaining 21 months of the survey.

Table 2.3. Forecast for the Northern Spectroscopic Survey

| Period | Plates Actually Observed | Forecast | Cumulative Total | Baseline Goal |
|---|---|---|---|---|
| Through Sep 2001 | 206 | | 206 | 206 |
| Oct 2001 – Sep 2002 | 229 | | 435 | 492 |
| Oct 2002 – Sep 2003 | 244 | | 679 | 819 |
| Oct 2003 – Sep 2004 | | 240 | 919 | 1146 |
| Oct 2004 – Jun 2005 | | 240 | 1159 | 1540 |

Since we have observed 156 plates in the Southern Survey compared to the baseline goal of 148 plates, the spectroscopic aspect of the Southern Survey is considered complete. In anticipation of this event, and in accordance with the SDSS Principles of Operation (PoO), we issued a call for proposals to the SDSS collaboration in January 2002, approved 17 proposals, and merged them into one coherent observing program. The process was more fully described in the 2002 Annual Report. During the period October 2002 through September 2003, we observed a total of 113 special program plates.

Progress in all areas over the past year can be attributed in large part to operational efficiency and system availability. Over the past twelve months:

- Imaging efficiency averaged 85%; the baseline efficiency goal is 86%. Observing software and procedural changes made in 2002 significantly improved imaging efficiency and are now fully integrated into the observing program.

- Spectroscopic efficiency averaged 57%; the baseline efficiency goal is 64%. We fall short of the stated spectroscopic efficiency goal for two reasons. First, the baseline did not include 3 minutes per plate for CCD readout time. Second, the baseline did not include 6 minutes per plate for a smear exposure which is taken for spectrophotometric calibration. If these 9 minutes are added to the baseline plan, then the adjusted spectroscopic efficiency goal is 57%, which is exactly what we averaged over the past twelve months.

- System uptime averaged 96%; the baseline goal is 90%. Although we regularly exceed the baseline goal, we continually seek to improve system reliability to ensure that all systems are fully functional whenever the weather is suitable for observing.

We have noted in previous reports that weather has consistently been our biggest impediment to survey progress. Although we still experienced a wide variation in weather conditions from month to month, there were five observing runs during the past year in which the amount of time the weather was suitable for observing actually exceeded our baseline expectation. Notably, weather exceeded baseline expectations during the months of January, February, May, late-June, and September. System uptime during these months averaged 94%, which allowed us to take full advantage of favorable weather conditions and make substantial progress toward survey goals.

## 3. Performance of Observing Systems

### 3.1 Observing Systems

Observing Systems includes the equipment and systems used at Apache Point Observatory to acquire survey data. This includes the SDSS 2.5m telescope, Photometric Telescope (PT), imaging camera and spectrographs, ancillary support systems, and observing software.

As mentioned earlier, aggregate system uptime averaged 96% for the year, well above the baseline goal of 90%. Figure 3.1 shows system uptime since we started measuring system performance in August 2001. There were three months during the past year in which system availability was significantly below average. The first, and most serious, occurred in February and was related to the installation of new shutters in the spectrographs. As a result of misaligned sensors, LED light leaks, and bent connector pins, system availability dropped to 87%, its lowest level since we started measuring uptime. The second occurred in the June/July observing run and was related to spectrograph power supply problems. The third occurred in September and was related to drive bearing problems. Details of these problems, as well as other highlights from the past year, are discussed below.

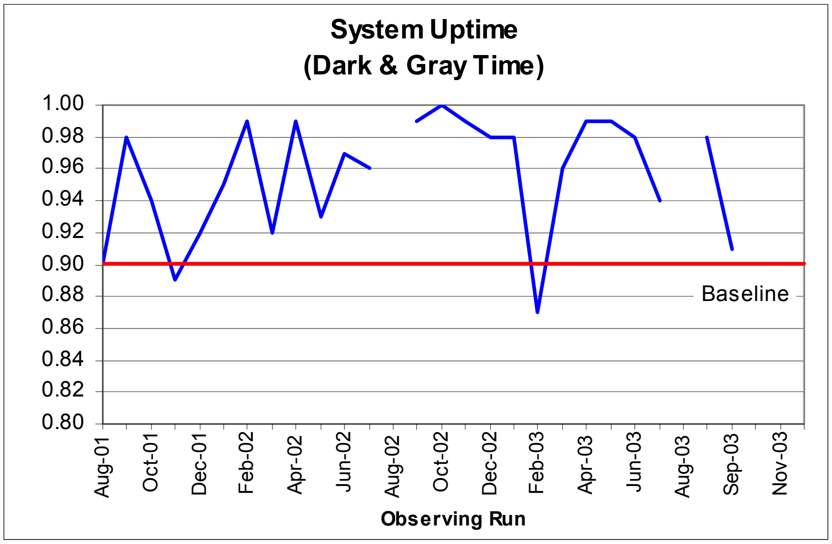


Figure 3.1. System uptime when conditions were suitable for imaging or spectroscopic observing.

There were no substantial upgrades to the 2.5m Telescope or associated hardware systems in 2003. Minor improvements included modifications to the telescope counterweights and the installation of new flat-field lamps for the imaging camera. Bronze nuts were installed on the telescope counterweight drive assembly to replace plastic units prone to failure. New flat-field lamps were fabricated and installed to better verify the calibration of the imaging camera. In addition, effort went into finishing up the instrument change interlock system, which is designed to increase equipment protection during instrument change operations. Work during the past year included finishing interlock system code modifications, developing a graphical interface to display the status of the instrument change interlocks, and testing and commissioning the system, some of which is on-going.

We experienced several telescope drive bearing failures in the latter part of the year. In separate incidents, a small drive bearing failed on the instrument rotator drive assembly and a large bearing failed in the drive reduction unit on one of the three windbaffle azimuth drive motors. The cause of the rotator bearing failure is still not certain; the failed bearing was replaced with a unit from the spares pool. Failure of the windbaffle drive reducer bearing was caused by an improperly machined housing that allowed excessive force to be applied to the bearing. Over several years of operation, the excessive force led to premature bearing failure. The repair was made by shimming the existing housing and installing a new bearing from the spares pool. The remaining two windbaffle azimuth drive assemblies were inspected and found to have proper bearing clearances. Although we do not anticipate a recurrence of this problem, we have nonetheless ordered a full set of replacement bearings for all three drive motors. In addition to the two bearing failures, one of the telescope altitude drive bearings began showing signs of excessive wear to the extent that it caused telescope drive oscillations. Because of the bearing housing design, special tooling was fabricated to remove and replace the bearing. We intend to inspect all remaining drive bearings to identify and replace as necessary those showing any signs of unusual wear or loss of lubrication. It is worth mentioning that the WIYN 3.5m telescope at Kitt Peak was manufactured by the same telescope vendor and is currently experiencing similar drive bearing problems. The SDSS engineering team and the WIYN telescope engineer have been in contact and are sharing information on failure mode analysis and possible courses of corrective action.

We experienced secondary mirror oscillations late in the Spring observing season that became noticeably worse when we commenced observing operations after the summer shutdown. We determined the problem to be in the controller board for the piezo actuators that are used to fine-tune the position of the secondary mirror. We replaced the faulty wire-wrap board with a newly designed printed circuit board. The new board was fabricated, stuffed, tested and installed in September. We have not had secondary mirror oscillations since the new board was installed.

Photometric Telescope operations were greatly improved with the installation of a new filterwheel controller. The existing controller occasionally failed to properly increment to the next filter in the calibration sequence, which led to filterwheel runaways. The problem became progressively worse during the year, until a redesigned controller was fabricated and installed along with new control code. The new system works exceptionally well. We have not experienced a single runaway since the new controller was installed.

The imaging camera performed well throughout the year, with no potential imaging time lost to camera problems. Summer maintenance work included improvements to the liquid nitrogen fill system and improved grounding of the imaging camera to the telescope. No work was required inside the imaging camera this year, which marks the first summer maintenance period in which we did not have to open up the imaging camera for maintenance or repair. The spectrographs also performed well throughout the year, although we experienced a number of small ancillary system problems, some of which resulted in lost observing time. In November, the observers reported guider focus problems that the engineering team traced to variations in guide fiber alignment that exceeded acceptable limits. Inspection and shimming corrected the problem. In December, the observers found it necessary to re-collimate the spectrographs in the middle of an observing night, which cost roughly 2.5 hours of observing time. We expect that improved procedures will preclude this from happening again. In late-January, new spectrograph shutters were installed to eliminate cold weather problems encountered with the original shutter design. Unfortunately, a number of problems during shutter installation caused a significant loss of observing time. First, a clevis was installed incorrectly, which subsequently knocked a shutter position sensor out of alignment. Second, tape that blocked light from an LED on the position sensor came loose, causing a light leak within the spectrograph. Third, several pins on a connector bent and shorted together during re-assembly, which caused a loss of communication with one of the spectrograph cameras. Unfortunately, these events happened in series, took several days to troubleshoot and resolve, and reduced system availability to 87% during the February observing run. In June, we experienced power supply and microprocessor failures that were promptly replaced with new units from the spares pool.

During the course of the year, we implemented a program to monitor, record, and repair damaged optical fibers in the cartridges used for spectroscopy. It was noted that many of the stainless steel ferrules on the ends of the optical fibers were pulling away from the plastic sheathing surrounding the fibers. As separation of the ferrule from the sheathing at this location could lead to broken fibers, a special tool was developed to install splints that reinforce the fiber-to-ferrule connection. We are currently splinting approximately 2-3 fibers per month. To date, we now have splints on 447 fibers, or 8% of the 5,760 fibers installed in the nine spectroscopic cartridges. With regard to broken fibers, there are a total of 16 broken fibers in the nine cartridges.

The software programs used to operate the telescopes and instruments and acquire data remain under version control and have been quite stable over the past year. Beyond minor bug fixes, software changes included modifying MOP to accommodate the new PT filterwheel controller previously described, developing improved guiding code for the spectrograph guider, modifying the Telescope Performance Monitor (TPM) to improve data logging and the TPM alarm system, and developing software tools to assist with the implementation of on-the-mountain QA on spectroscopic data. The MOP changes are complete and the new code is fully functional. Spectroscopic guider code changes were proposed to enhance operations efficiency, but further testing and debugging of the modified code is required. Many TPM code changes have been made, tested, and implemented. Additional changes are being made as new bugs are identified through system testing. Finally, on-the-mountain QA tools are being used by the Observers to verify the quality of spectro data shortly after acquisition.

We completed the installation and commissioning of a new Cloud Camera in 2002-Q4 and placed it into full operation in early 2003. The Cloud Camera is used by the Observers to detect the presence of cloud cover at APO. Cloud Camera outputs are also used by on-the-mountain reduction software to assess the level of photometric conditions during imaging runs. The new Cloud Camera was designed and built to replace an existing unit that was becoming ever-more difficult to maintain due to component obsolescence and insufficient software documentation.

The Differential Image Motion Monitor (DIMM) is now mounted on an outward corner of the 2.5-m telescope pier, a location that allows it to precisely measure the seeing conditions under which the 2.5-m telescope is collecting data. Work included hardware installation, control software development, integration, and testing. We are currently in the final stages of commissioning.

As in past years, the PT primary mirror was aluminized at Sunspot during the summer shutdown. This year, we modified the aluminizing fixture for the PT mirror to improve how the mirror is handled during transport and held in place during aluminizing. The 2.5m primary mirror was aluminized at Kitt Peak at the end of September. To improve the efficiency of the 2.5m mirror removal/installation process, new mirror stands were designed and fabricated. We elected not to re-aluminize the 2.5m telescope secondary mirror this year based on the acceptable condition of the existing coating.

Plug plate production and preparation operations ran smoothly throughout the year. From October 2002 through September 2003, we drilled a total of 490 new plates, 215 of which are special plates for the southern survey area. As we acquire more imaging data over time, we intend to build some float into the plate production schedule to reduce our exposure to potential milling machine failures. We have also designed and are in the process of fabricating a new plug plate drilling fixture that will improve drilling operation efficiency and reduce exposure risk. Although the UW shop has done a very good job with plate production and we have not had any serious delivery or schedule problems, we recognize the vulnerability of operating with only a single source for plug plates. To remedy this, we plan to use the existing fixture to qualify a back-up drilling vendor, once the new fixture is in service in the UW shop. Having a qualified second vendor will significantly improve the robustness of the plug plate production operation and reduce the risk associated with a single supply source.

### 3.2 Observatory Support and Infrastructure

SDSS operations at APO continued running smoothly during the year. The SDSS Observers succeeded in making incremental improvements in operational efficiency to the point were we now routinely meet or exceed baseline throughput model predictions, weather permitting. Also, improved operational procedures and better data-checking software was employed for better on-site data quality monitoring. The new thermal infra-red cloud camera went into routine use, and substantial work on the seeing monitor replacement was accomplished. The Observers also provided testing and check-out support of all engineering systems as needed, and they routinely operated and monitored the semi-robotic Photometric Telescope.

All site infrastructure support, such as the provision of liquid nitrogen, staff and visitor on-site housing and office space, etc., was furnished as needed. Housing accommodations were provided at the observatory for visiting scientists, engineers, and other technical staff supporting SDSS operations. In addition, on-site housing was provided to the SDSS Observers when they were on shift.

Early in the year, the eighth full-time observer was hired and the site staffing levels remained stable throughout the year. The Observers provided important non-observing support to the SDSS, e.g., participation in engineering and operations planning telecons, helping to generate the monthly science plan, calling for and planning the shake-up/down activities, and testing the various hardware and software systems after repairs and/or upgrades have been implemented. Also, time-domain and Galactic-plane observations were tested for feasibility, using telescope time that was otherwise unusable for the main survey observing.

The site hosted a joint SDSS Advisory Council and ARC Board of Governors meeting in June. During these meetings, the APO Operations Building was dedicated in the memory of Donald R. Baldwin, who was the ARC Secretary/Treasurer from 1984 until his death this year.

Under a federal cost-sharing grant, APO was selected as the site for a pilot project to undertake tree thinning and ground-fuels clearing in the down-slope up-wind direction around the observatory. A contractor treated roughly eight acres of observatory grounds during the winter months, and completed the project before the fire season started. In spite of continuing drought, the Sacramento Mountains were spared from suffering a major forest fire this year.

For the upcoming year, in addition to supporting standard SDSS observing operations, we will continue to improve operating efficiency, improve the adequacy of our spare parts inventory and engineering documentation, and support planning activities for the post-Survey era.

## 4. Status of the Pipelines

This past year has seen a convergence in the pipelines used to analyze the SDSS data. The pipelines had been evolving as scientific analyses were carried out and ever more subtle problems uncovered. The outputs of the pipelines have thus gotten ever more reliable and robust. In the last year, we implemented what we expect are the last major rounds of modifications to the software.

### 4.1 The Photometric Pipeline

As the First Data Release (DR1) was being prepared for public distribution, we discovered a major error in the way that the galaxy model fits were being carried out to images in the SDSS. Each object image is fit to a model of both an exponential (appropriate for spiral disks) and de Vaucouleurs (appropriate for ellipticals) profile of arbitrary inclination, properly convolved with the point-spread function (PSF); the results include a galaxy type, scale size, orientation and axis ratio, and total magnitude. Fixing this bug, and testing it completely, occurred in the last quarter of 2002 and the first quarter of 2003. We have shown with extensive testing on real data and simulations that the model total magnitudes are now unbiased relative to PSF magnitudes for stars, and unbiased relative to Petrosian magnitudes for galaxies. Thus for much astronomical work, the model magnitude is a good proxy for "total" magnitude for all types of objects. Our star-galaxy separation is based on the difference between model and PSF magnitudes for objects; the division between stars and galaxies has gotten substantially sharper with the code fix in place.

A series of related improvements to the code has also helped the behavior of the deblender in the case of bright nearby galaxies with substructure. We require that the deblender automatically handle the case of two overlapping galaxies at 21st magnitude, and also a face-on 14th magnitude flocculent spiral galaxy at low Galactic latitude. Extensive examination of images of NGC galaxies has shown that the fraction of cases in which bright galaxies are shredded by the deblender is now 1% or less.

This latest version of the photometric pipeline is termed V5_4; it has been run on all available image data, and these data have been made available to the collaboration. This is the first time that we have had all our data uniformly reduced and all made available. The First Data Release in April 2003 consisted of V5_3 reductions, without the fixes described above; DR2 will consist exclusively of V5_4 reductions.

### 4.2 Testing the Quality of the Photometric Data

Given that the SDSS collaboration itself has written now well over 200 papers based on these data, and that there are probably of order 100 papers written by the general astronomical community based on public SDSS data, it is fair to say that the data have been very extensively tested scientifically. It is through this process that many of the problems that have led to improvements in the pipelines have been found. It is worth mentioning a few specific tests, however. We have developed an extensive series of "Quality Assurance Tools", which carry out a variety of internal checks of the quality of the imaging data. For example, the QA tools look for changes in the locus of stars in color-color space as a function of position in the sky; consistency in the photometry of stars in the overlap between adjacent scanlines; and consistency in various measures of the brightness of galaxies and stars. These QA tools are run routinely as part of the data processing "factory," and the results are examined to check both the quality of the data and to show up any problems in the pipelines or the processing. All the V5_4 reductions have passed with flying colors.

Rigorous tests have been carried out by two groups within the SDSS of the uniformity of the galaxy sample by looking for non-physical substructure in the sample correlated with survey stripe geometry, foreground reddening, seeing, and so on. These tests have concluded that our data are consistent with the survey goals of 0.02 mag photometric calibration errors in the rms sense. Still, photometric calibration is something that requires constant vigilance, and continued cross-checks are in progress.

### 4.3 The Spectroscopic Pipelines

Spectrophotometry (i.e., the absolute flux calibration of the spectral data) had been realized to be a genuinely difficult problem in the SDSS, and we phrased the requirements for it on a 'best-effort' basis. However, the quality of our spectra has reinforced the desirability to calibrate them as well as possible, and an extensive effort over the last year has given rise to substantial improvements in the spectrophotometry. Even the version distributed in the DR1 has been good enough to carry out a detailed analysis of variability of quasars between the imaging and spectroscopic data. The recent improvements (due to refinements in the modeling of the spectrophotometric calibration stars taken on each plate, an improved treatment of Galactic reddening, and various algorithmic improvements) have led to a scatter between photometric colors measured from the images and from the spectra as small as 5%; this accuracy is unprecedented for large spectroscopic data sets. This accuracy has allowed SDSS scientists to look for subtle effects in, for example, the internal reddening and stellar populations in galaxies, and the relationship between temperature and chemistry of various populations of stars.

There have been recent refinements in the radial velocity standards for the 1d pipeline (which classifies spectra and determines redshifts): systematic errors in stellar velocities at the level of 20 km/s have largely been removed. We have been able to show through a variety of lines of argument that one of our pipelines gives consistent radial velocities at the < 10 km/s level brighter than r ~ 18.

We compared the redshifts from two independent pipelines (spectro1d and specBS) for all 186,240 spectra in DR1. We found that 1% of the spectra were of too low quality to allow a redshift to be determined, and of the other 99% of the spectra, the two pipelines agreed for all but 1%. Eyeball examination of the discrepancies allowed us to determine the right answer in most of these cases; thus we could confidently say that the redshift error rate for the DR1 spectra was a few tenths of a percent or lower. That performance is again unprecedented for large spectroscopic datasets, and is substantially better than our requirements.

## 5. Data Processing and Distribution

### 5.1 Data Processing Operations

The data processing "factory" at Fermilab runs the pipelines on the data arriving from Apache Point Observatory, creating directories of files according to imaging run number and spectroscopic plate number. These files and directories are then available to the Collaboration for testing and for scientific analysis. Another output of the factory is the drilling files for the spectroscopic plates that are fabricated at the University of Washington.

The capacity (speed and disk space) of the factory needs to be high enough to enable reprocessing of older data while new data are being acquired and processed. The factory needs to provide internal checks on the integrity of the files. The factory also needs to facilitate scientific validation, for example by spinning files from more than one version of the reduction pipelines. In 2003, all of these aspects were developed and made more efficient. An example of an improvement in efficiency relates to dealing with multiple detections of the same object, a process called resolving. This step now requires far less human intervention. The median turnaround time to process new data was a few days, including applying the calibrations. Since the beginning of the survey, the factory has been consistently processing the data in time to meet the monthly drilling schedule, a notable achievement.

Work went into improving the documentation of the imaging pipeline Quality Assurance (QA) tools, improving the imaging QA outputs, developing and documenting procedures to declare a given run acceptable, and determining how to effectively document QA test results.

Data processing operations during 2003 featured the introduction of a new version of the photometric pipeline which fixes a bug as described elsewhere. Production processing using this new version of the photometric pipeline, Photo v5_4, began near the beginning of Q3 after a period of intense testing. The new processing also takes advantage of improved flat fields. Procedures for the automated production of flat fields are continuing to be developed. Data processing operations are now current in the sense that all new data are being processed as tapes arrive at Fermilab, and all older data have been reprocessed. This is another significant achievement, especially considering the extraordinary volume of new imaging data acquired in Q2.

Relatively small upgrades to the spectroscopic pipelines were also implemented. They include correcting a unit problem in the 2d header file, improving the calculation of Lick indices (galaxy absorption line measurements) and their errors, and changing the galaxy spectral class for which galaxy velocity dispersions are calculated (necessitated by an earlier change in the PCA spectral eigentemplates used to classify galaxies). Considerable effort has been invested in manual checking of the outputs on a plate-by-plate basis. Quality procedures were established and quality tests performed on the spectro data, following the previous reworking of the spectro requirements.

The natural measure of the quantity of imaging data is square degrees. One square degree corresponds to about one Gby of raw or reduced imaging data (pixels). The cumulative number of square degrees acquired as of October 1 2003 is 13,348 ("gross"), and of these, 5044 were acquired in 2003. However, this is only part of the story, since we have undertaken multiple reprocessing of the data. The cumulative number of reprocessed square degrees is 32,188, of which 8503 were reprocessed in 2003. The factory reprocessed some imaging data several times to support the development and testing of Photo v5_4 and to verify the quality of new flat fields generated to improve photometric calibration accuracy.

Of the total of 1188 plates obtained up to October 2003, all scientifically valid plates have been reprocessed with the current spectroscopic pipelines. Of these plates, 387 were newly acquired in 2003. About the same number of spectroscopic plates were designed during this past year, and the drilling files sent to the shop at the University of Washington on schedule.

We commissioned seven new machines (sdssdp30 through sdssdp36) to replace sdssdp2 and sdssdp3. This replacement was necessitated by the performance of PSP for very long runs. We also physically moved all data processing computers from Wilson Hall to Feynman Computing Center, where they are all on an uninterruptible power supply.

The factory now has a total disk storage capacity of 43 Tbytes, of which 34 Tbytes is currently used.

To ensure data availability, an extensive effort was undertaken to back up all of the data for Data Release 1 onto the Enstore tape robot at Fermilab. The robot is used extensively by the factory to back up other critical survey data as well.

## 5.2 Data Distribution Operations

### 5.2.1. Development of Data Distribution Systems

The main focus of work in 2003 was the creation and distribution of the first data release, DR1, and the definition and creation of the second data release, DR2. Two principal interfaces provide the collaboration and public with access to the SDSS data: the Data Archive Server (DAS) and the Catalog Archive Server (CAS). Through a web interface, the DAS provides access to pixel data (spectra, atlas images, raw frames, corrected frames, binned frames), as well as color images and plots in the form of flat files. The CAS is a Structured Query Language (SQL) database of objects, loaded from the DAS files, that enables the construction of catalogs of various classes of astronomical objects.

DR1-DAS was made available to the Collaboration in November 2002 in preliminary form. DR1-CAS with a test load was made available to the Collaboration in January 2003 and in final form in April 2003. DR1-DAS was made available to the public in April 2003, and DR1-CAS was made available to the public in June 2003. The target date for public release of DR1 had been January; the slip was partly due to the recognition and evaluation of the bug in the model-magnitude computations in photo v5_3 and earlier versions, as detailed elsewhere, plus longer-than-expected development times for the interfaces, and the time needed to complete the documentation. We wrote a formal paper that describes DR1 (Abazajian et al. 2003 AJ 126, 2081).

DR1 contains two versions of the imaging data: Target and Best. The Best version contains images and photometric catalogs with the highest quality data at the time of the data release. For DR1, the Best imaging data were processed with photo v5_3. The Target version contains those imaging data at the time the target selection algorithm was run for that part of the sky. Target data were processed with the version of photo current at the time the target selection algorithm was run.

Originally we considered the possibility of replacing the Best imaging data in the initial DR1 release (what we had called the beta release) with data reprocessed with photo v5_4. Now, the DR1 release is considered final and all imaging data reprocessed with photo v5_4 will be released as part of DR2.

### 5.2.2 Data Archive Server

The DAS tools include a web interface to provide access to the DR1 binary FITS files, a finding chart maker, and an interim DAS-SQL interface. The finding chart maker produces a JPEG image, optionally with spectro and imaging objects superimposed, and a corresponding FITS image file in a selected band. The interim DAS-SQL interface provides easy access to the Target and Best versions of the imaging data and to the spectroscopic data for DR1. It was developed to expedite the release of DR1: it is “interim” in the sense that much of the DAS-SQL interface functionality is now present in the CAS. Early testing of the interim DAS-SQL interface proved useful in verifying that all of the input files were on disk and correctly named, and in generating the coverage charts for DR1.

In parallel with work on the DAS interfaces, we finished the Data Release 1 web site, completed extensive web-based documentation to support the DR1, implemented a help desk at Fermilab to support the public’s use of the data (we receive and respond to roughly three requests for help per week), and ran extensive stress tests on the DAS system to verify performance under heavy loads.

Many terabytes of data have been transferred from the DAS by users accessing the rsync server in 2003. Usage statistics are available at http://das.sdss.org/data/dp7.a/crw/rsync_usage/

In Q3, the DAS was loaded with reprocessed imaging and spectro reductions (photo v5_4 and spectro rerun 23) in preparation for DR2. Specific activities included loading the data, verifying its integrity, updating documentation, and making the DR2-DAS available to the collaboration.

### 5.2.3. Catalog Archive Server

The CAS includes many tools for loading and validating the data prior to release, including file converters to convert FITS files into the comma-separated value (CSV) file format required for the SQL Server load; "loaders" to load the CSV files into a temporary database; and "validators" to verify that the data in the temporary database is loaded correctly and that data values are within defined parameters. The CAS operation also includes a "publish" step which merges new data from the temporary database into a production database. A functional version of the tools for loading imaging and spectra data was completed at the end of 2002 and a test suite consisting of several imaging runs, with corresponding spectra, was loaded into a prototype database for evaluation.

In preparation for moving the CAS loading process to Fermilab, we developed a system plan for the computing hardware needed to load and serve SDSS data to the Collaboration and to the public. As of the end of 2002, all of the hardware required for the CAS cluster at Fermilab had been received and was later installed.

The loading process detects and flags corrupt data. We identified 40 corrupt fpAtlas files out of a total of 150,000 files; and the corrupt files were successfully recovered and restored. While this is a very small fraction, it did create time-consuming difficulties for the developers. We have been nonetheless encouraged by the ability of the CAS loading and validation process to provide a strong additional check of the integrity and completeness of the data.

CAS schema and data model changes were made to coincide with the change from Photo 5_3 to Photo 5_4, and the CAS comma-separated value generators were updated to reflect these data model changes. Several test loads were made using Photo 5_3 outputs formatted to reflect the Photo 5_4 data model, which allowed testing of the loading process prior to the availability of actual Photo 5_4 data. Enhancements were also made to the sdssQA tool, one of the interfaces to the data contained in the CAS. In addition to addressing bugs, enhancements included redesigning the object browser and output preview interfaces, overhauling the output format handling, and incorporating and testing new sample queries. The sdssQA plotting tool was also finished and tested. Significant effort also went into improving CAS performance and query response times and developing extensive documentation to support the CAS.

In coordination with the public release of the DR1-CAS in June, we updated the SDSS DR1 web pages and created the documentation required to support the CAS release. Usage statistics on the DR1-CAS can be found at http://skyserver.sdss.org/log/en/traffic/:

Once the DR1-CAS was made available to the collaboration, the production CAS loading process was transferred from the development environment at Johns Hopkins University to the production environment at Fermilab. Activities included solving several computer hardware and software configuration and security issues, installing the necessary operating system and applications software, installing and testing comma-separated value file generation scripts, generating CSV files from binary data files, loading the files into a CAS SQL Server database, verifying data load integrity, and developing adequate process documentation. Integrating the CAS loading operation into an automated production environment is largely complete.

By the end of the reporting period we had completed the CAS system documentation and commenced data loading in preparation for DR2 (that is, photo v5_4 reductions).

The SkyServer is a version of the CAS with multiple languages (English, Japanese, and German) that integrates educational material with the access tools. While these elements have not been directly supported by the SDSS, the SkyServer is nevertheless an important public face of the SDSS by virtue of its accessibility. There have been a number of months with over a million hits on the SkyServer, an extraordinary accomplishment for an astronomy education site.

All of the machines at Fermilab that support data distribution (Collaboration, public, and SkyServer) were moved from Wilson Hall to Feynman Computing Center, where they are on an uninterruptible power supply.

## 6. Scientific Results from the SDSS in 2003

In the last year, the SDSS Collaboration has posted 85 papers planned for refereed publications to its internal publications website. The Astrophysics Data System web site lists 166 refereed papers in this same time interval that make reference to the survey in their abstract. Still another index, is the number of papers based on publicly available SDSS data, most of which are authored by astronomers outside the SDSS Collaboration. The accounting of these papers in Appendix A shows 31 papers in this category. We note that the rate of these papers was significantly higher at the end of the reporting period. Here we briefly summarize some of the principal scientific results of the past year, which range from dramatically new types of white dwarf stars, to newly discovered gravitational lenses, to substructure in the Galactic halo.

### 6.1 Large-Scale Structure

The measurement of the large-scale distribution of galaxies was the defining science goal of the SDSS, and the SDSS is now reaching its potential; at its half-way point, it is by far the largest single redshift survey of galaxies (and quasars as well), with 447,000 galaxy redshifts. The clustering of galaxies on the largest scales is often quantified in terms of the power spectrum; this has been determined using over 200,000 galaxies with redshifts by two independent groups within the SDSS, led by Max Tegmark and Adrian Pope, respectively. The technical difficulties are not trivial, due to the complications of peculiar velocities systematically distorting the peculiar velocity maps, the effects of the survey geometry, and the fact that galaxies of different luminosities cluster differently. The results probe the clustering of galaxies to scales beyond 300 Megaparsecs (Mpc). The level of clustering is in beautiful quantitative agreement with direct extrapolation of the fluctuations seen in the Cosmic Microwave Background 400,000 years after the Big Bang, confirming the basic cosmological model.

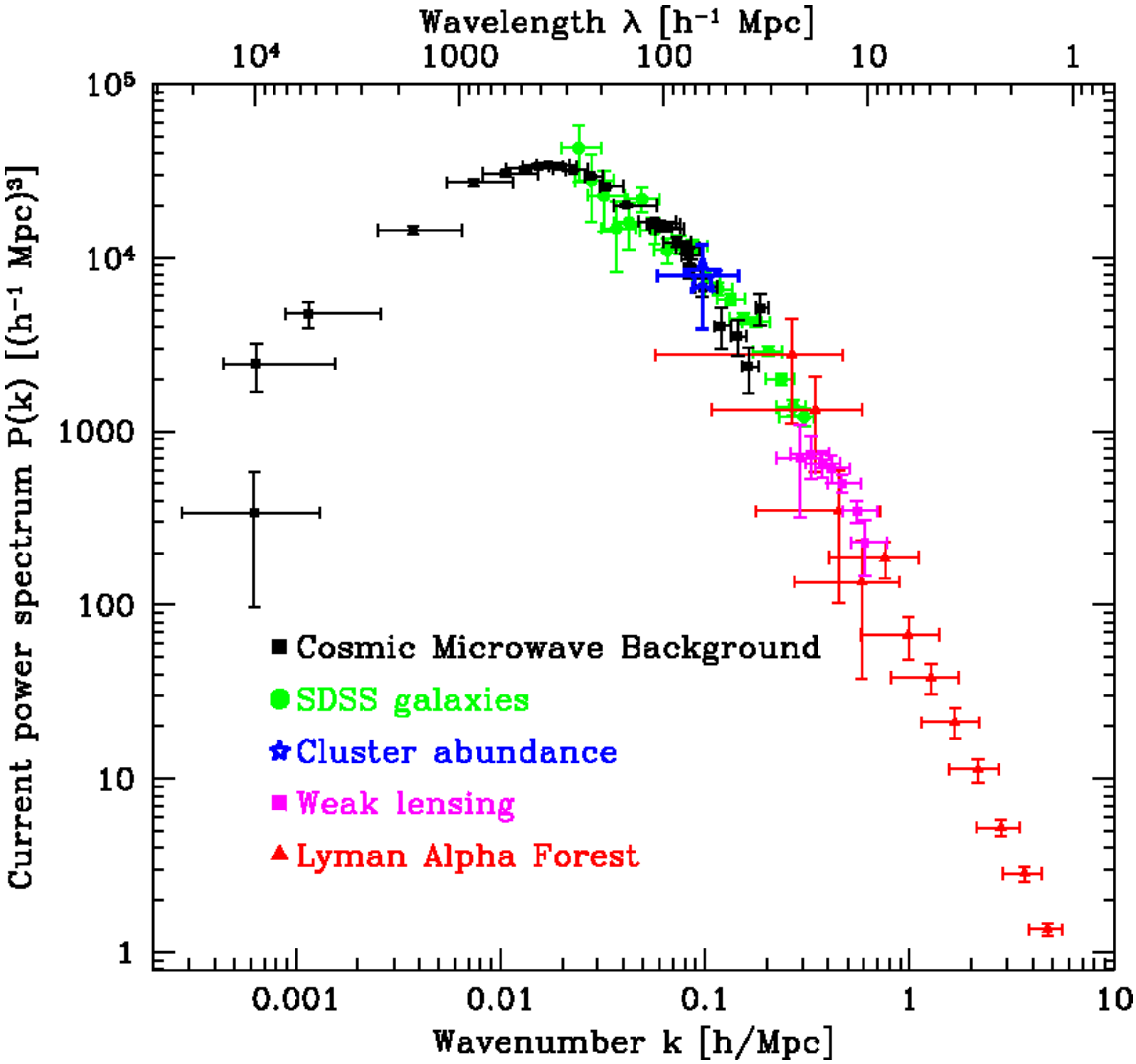


Figure 1. The power spectrum of galaxy clustering (SDSS galaxies) plotted with four other independent measures, spanning four decades in spatial frequency, and demonstrating remarkable consistency. These data provide fundamental constraints on cosmological models.

One of the ingredients of this cosmological model is a substantial contribution of "dark energy," which is invoked to explain the observed acceleration of the universe's expansion. Another way to constrain the effects of dark energy is to look for the integrated Sachs-Wolfe (ISW) Effect, whereby photons from the CMB gain energy falling into, and then lose energy climbing out of, the gravitational wells of collapsing large structures. Two groups, one led by Ryan Scranton, and the other led by Enrique Gaztanaga using public SDSS data, have cross-correlated the SDSS galaxy counts with the maps of the CMB from the WMAP satellite; they detect a positive correlation on large scales (albeit at a statistical significance of 3 sigma or so). This result shows that Omega_m is substantially less than unity. When combined with the constraint on curvature from measurements of fluctuations in the cosmic microwave background radiation, the detection of the ISW correlation provides new evidence for the existence of dark energy.

Another way to measure cosmological parameters is via the number density of clusters of galaxies, which is sensitive to the normalization of the power spectrum, and the density of matter Omega_m. Neta Bahcall, Feng Dong, and Jim Annis have led a group of researchers in SDSS to put together a large sample of clusters of galaxies from the SDSS; they have used the statistics of the sample to derive some of the tightest constraints yet on the normalization of the power spectrum, in good agreement with the analysis of the power spectrum determined from other approaches.

Galaxy clustering on small scales also conveys cosmological information. Astronomers have long been impressed by the almost perfect power-law nature of the small-scale correlation function. A team led by Idit Zehavi has carried out the most precise measurement to date of the correlation function, and has found definitive evidence for deviations from the power law on scales of 1-3 Mpc. These deviations are beautifully explained in a model in which the galaxy clustering has two sources: the clustering of dark matter halos on relatively large scales, and the varying number of baryonic galaxies within each halo. Further work along these lines should give new insights on the relative distribution of galaxies and dark matter, and how galaxies form in dark-matter potential wells.

### 6.2 Galaxy Properties

With detailed and accurate morphological, spectroscopic, photometric, and redshift information for hundreds of thousands of galaxies, subtle effects can be discerned. Michael Blanton and David Hogg have explored the relationship between galaxy properties and their large-scale environment, examining correlations between galaxy color, luminosity, and number of neighboring galaxies within 8 Mpc. They confirmed the well-known result that the most luminous red galaxies are found in very dense regions, but found that low-luminosity red galaxies are also preferentially in clusters. Thus clusters have an over-abundance of dwarf galaxies relative to the field. They also found that the well-known relationship between color and luminosity among red galaxies is independent of the local environment. These results will need to be accounted for in any successful galaxy formation model.

A spiral galaxy seen edge-on gives a view of the halo of the galaxy, and allows direct measurement of the thickness of the disk. The halo light is tremendously faint, and is therefore poorly characterized in galaxies. Stefano Zibetti has led a team that has stacked the SDSS images of over 1000 galaxies; they find evidence for very red stellar halos, implying old ages and/or substantial metal enrichment. These results support the idea that halos were assembled via early merging of satellite galaxies (a conclusion which jibes with SDSS results from our own Milky Way; see below).

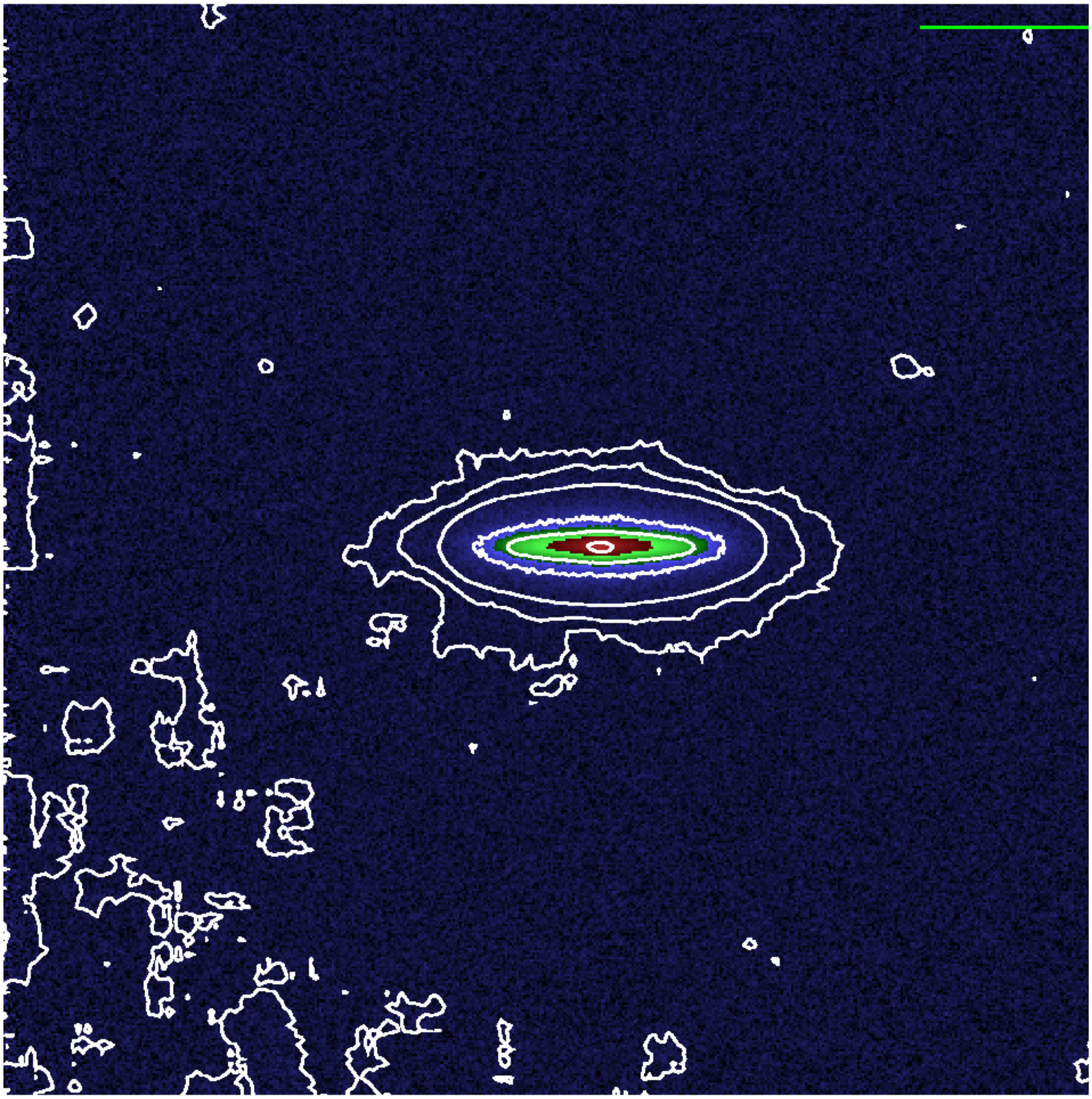

Figure 2. SDSS g-band stacked image of edge-on galaxies after scaling each individual image to a common angular scale length, showing light attributable to the stellar halo.

SDSS astronomers have written a number of papers on the luminosity function of galaxies. But for many purposes, the quantity that one wants to look at is not the distribution of luminosities but the distribution of masses. Given the presence of dark matter, and the fact that different stellar populations have very different mass-to-light ratios, the relationship between luminosity and mass is not always straightforward. However, the SDSS spectra of elliptical galaxies are of high enough quality that velocity dispersions can be determined, which is a measure of the depth of the potential well of the galaxies in their halo. Teams led by Ravi Sheth and Vandana Desai have measured the distribution function for these velocity dispersions in the SDSS sample; this function can be compared directly with the predictions from large numerical cosmological simulations. In related work, Nikhil Padmanabhan and Uros Seljak have explored the relationship between the mass of stars in elliptical galaxies determined from their luminosities and stellar populations, and the dynamical masses inferred from their sizes and velocity dispersions. They have found that the dynamical masses tend to be larger, as one expects due to the presence of dark matter; further modelling allows one to constrain the quantity of low-luminosity stars in these galaxies, as these stars contribute substantially to the stellar masses of galaxies.

Galaxy spectra often have strong emission lines due to gas excited by ultraviolet photons from hot stars. Measurement of the strengths of these lines allows determination of the metallicity of the galaxy. Christy Tremonti has studied the relationship between the metallicity of SDSS galaxies and their stellar masses, using a sample of 23,000 galaxies. At masses below 10 billion solar masses, galaxies show a linear trend with metallicity; the higher the mass, the higher the metallicity. However, above 10 billion solar masses, the trend flattens, and all galaxies have roughly the same metallicity. This is exactly as predicted in models (now almost 20 years old) in which low-mass galaxies lose their metals in winds from supernovae, while such winds do not have enough kinetic energy to escape the potential wells of high-mass galaxies.

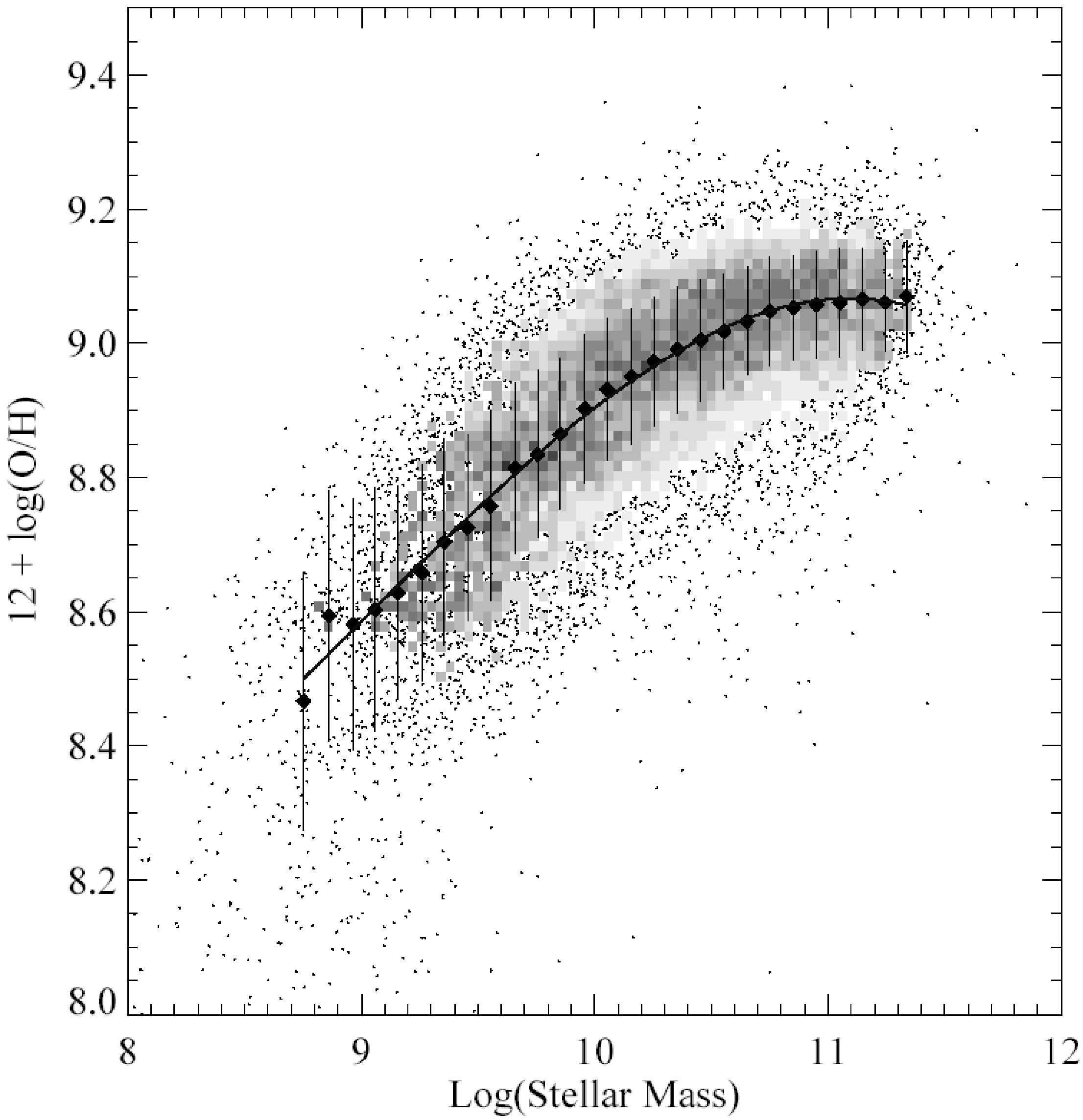


Figure 3. The dependence of the oxygen abundance relative to hydrogen versus the mass in stars, as inferred from modeling the stellar population as constrained by the spectrum of each galaxy.

In addition to gas, dust, stars, and dark matter, galaxies often (and perhaps always) host supermassive black holes in their centers; these black holes manifest themselves with strong high-ionization emission lines. Guinevere Kauffmann and Tim Heckman led a team to study the nature of galaxies which show evidence of such nuclear activity. They found that nuclear activity is often found in galaxies with evidence of young stellar populations, and that activity tended to be strongest in (relatively rare) massive blue galaxies. In related work, Lei Hao has measured the distribution of the luminosity of such active nuclei, and has shown that the population of active nuclei blends smoothly into the distribution of their much brighter but certainly physically related cousins, the quasars.

### 6.3 Quasars

The SDSS has continued to dominate the discovery of high-redshift quasars; the 11 most distant quasars currently known are SDSS discoveries, and SDSS has discovered over 80% of the more than 50 quasars known with redshifts > 4.9. Substantial telescope time is being devoted to these objects around the world. Rick White and Bob Becker observed each of the two highest redshift quasars (at redshifts 6.3 and 6.4, respectively) for over ten hours on the Keck telescope, to obtain extremely high quality spectra, yielding the best results to date on the presence of the Gunn-Peterson effect.

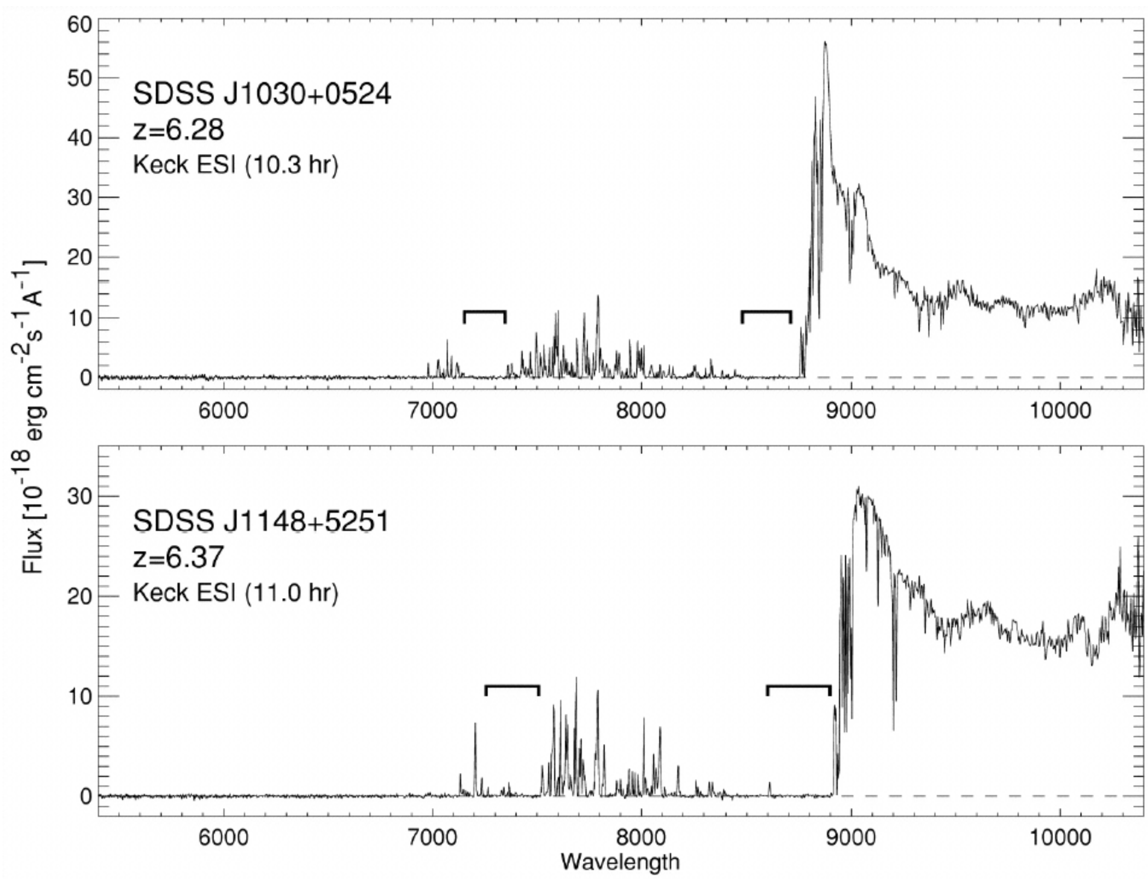


Figure 4. Long-exposure Keck telescope spectra of the SDSS quasars with the highest known redshifts. The wavelength regions of each spectrum indicated by the bars show zero (or essentially zero) flux. This absorption of the quasar light is interpreted as due to Lyman alpha (right bars) and Lyman beta (left bars) from neutral hydrogen in the diffuse intergalactic medium. These data place strong constraints on the ionization fraction in the intergalactic medium at these epochs.

Fabian Walter and Frank Bertoldi spent many tens of hours observing the redshift 6.4 quasar with the Very Large Array and the Pic de Bure radio interferometer. They detected several rotational emission lines of the CO molecule, allowing the direct inference of ten billion solar masses of molecular gas in the interstellar medium of the host galaxy of the quasar. This work is yielding new insights on the interaction between the host galaxies of quasars and their central engines, a relationship that is expected to have been very different in the early universe than it is today.

Where there is molecular gas, there is dust; the fact that quasars are hosted by galaxies suggests that some of them should show evidence for dust reddening. Gordon Richards and Pat Hall are exploring the colors of quasars in the SDSS, and indeed find strong evidence for a population of quasars substantially reddened by dust. However, the dust reddening must at some level be tied to the properties of the central engine itself: there are as yet poorly understood correlations between the amount of dust, the shapes of emission lines, and the presence of broad-absorption-line troughs due to relativistic outflows from the central engines.

Quasars vary in brightness on time scales of weeks to years, a sign that their active regions are very small. Each quasar in the SDSS is observed at least twice: once when its image is taken, and a second time when its spectrum is taken. Brian Wilhite and Dan Vanden Berk have quantified the degree of variability between these two epochs, and have found strong relationships between the degree and timescale of variability, and the luminosity of quasars. There is no strong evidence for any dependence on redshift; a variety of SDSS analyses have shown that the properties of individual quasars are essentially independent of cosmological epoch, once one takes account of the variation with luminosity.

The emission lines in quasars are often said to come from the “broad-line region,” whose geometry relative to the central black hole is poorly understood. Occasionally, however, a quasar gives a direct hint as to the distribution of gas in the central region: a small fraction of quasars shows emission lines with two broad lines, which are interpreted as due to relativistic Doppler effects from a rotating Keplerian disk. Two dozen such cases were known before SDSS, but Iskra Strateva has discovered over 100 double-lined active galactic nuclei (AGN) in the SDSS sample, and has fit disk models to their observed profiles. Over half these objects have profiles that can only be fit by assuming that the disk shows asymmetry. The model fits yield (among other things) the inner and outer radii of the disks, which are crucial parameters for understanding the accretion into the central black hole. If the outer parts of disks become gravitationally unstable and fragment into stars, a possible signature would be an upper limit to the outer disk radius.

In a dramatic confirmation of one of General Relativity's most remarkable predictions, quasars are occasionally seen "split" into multiple images by the gravitational lensing effect of foreground galaxies and clusters. Naohisa Inada and Masamune Oguri have found the most extreme example of this to date: a redshift 1.7 quasar split into four images by a massive foreground cluster of galaxies. The maximum splitting between the four images is over 14 arc seconds, more than twice the value of the previous record-holder. Given the detailed information one can gain about the quasar itself and the lensing cluster of galaxies, this object promises to be a Rosetta Stone for probing cluster potentials and the intergalactic medium on small scales.

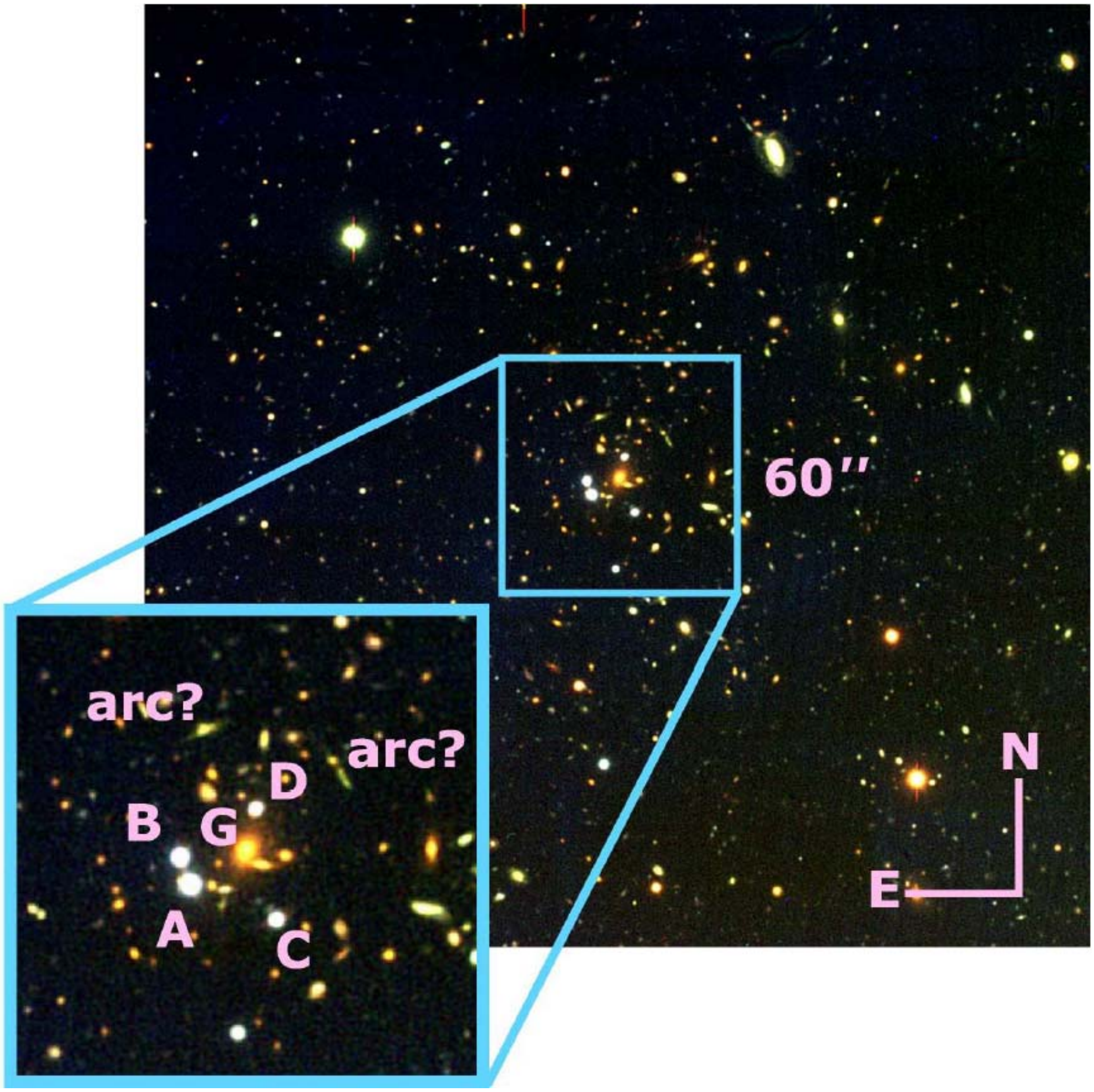


Figure 5 A Subaru telescope image of the quadruple gravitational lens discovered with the SDSS telescope. The four images of the quasar are labelled A, B, C, and D. A rich cluster of galaxies is evident, centered in the field. The dominant central galaxy of the cluster, which contributes to the overall lensing by the cluster, is labelled G. Besides the separate images of the quasar, background galaxies may also be lensed by the cluster, appearing as possible arcs.

Gravitational lensing has also been invoked to explain some of the properties of the highest-redshift quasars: the higher the redshift, the greater the a priori probability that a given quasar is gravitationally lensed. If such an object is indeed lensed, its true luminosity is smaller than otherwise inferred, and therefore the mass of its central black hole is correspondingly smaller. Finding smaller masses would be welcome, as it is a puzzle how such massive black holes (several billion solar masses) could have formed only 800 million years after the Big Bang. Michael Strauss and colleagues have used the Hubble Space Telescope to take images of four of the highest redshift quasars known; none of the four shows any evidence for gravitational lensing. Thus inferences of large black hole masses at early epochs need to be taken seriously.

## 6.4 Stars and Galactic Structure

The SDSS continues to shed light on the smallest and coolest stars, the brown dwarfs. In two related studies of infrared spectra led by David Golimowski and Jill Knapp, it is shown that objects in the current sample can be as light as 10 Jupiter masses and as cool as 500 degrees Kelvin - cooler than the surface of Venus! It is also found that many of the mysterious systematics of the spectra of these objects require that the surfaces are covered with clouds, whose existence and heights are very sensitive to temperature.

The SDSS has since the beginning discovered large numbers of another kind of fascinating small (though not light) stars: the white dwarfs, collapsed remnants of normal stellar evolution for stars originally of less than about 6-8 solar masses. These objects typically have masses half that of the Sun, but are so dense that they are the size of the Earth. A catalog of some 2500 of these objects from the SDSS sample for DR1 has been prepared by Scot Kleinman and collaborators, almost doubling the number known. Included in this sample are large numbers of strange objects with strong magnetic fields and bizarre composition anomalies, including many entirely new classes. For the much more numerous normal ones, the temperatures and surface gravities (which for these stars determine the mass) have been determined and are included in the catalog, which will be a important resource for research in this field.

Many of these white dwarf stars are carbon-rich, a phenomenon perhaps connected with the properties of the stars which are their progenitors. Cool carbon-rich stars (called simply “carbon stars”) are seen in many parts of the temperature-luminosity diagram. These are generally thought to be the result of nuclear helium burning to carbon, which is transported to the surface of the star by convection, or perhaps dumped onto the surface of a close binary companion. The SDSS has, by virtue of the quite strange colors of carbon stars, discovered large numbers of these objects. An investigation led by Ronald Downes has shown that many of these objects are probably unevolved dwarf stars which could not have made the carbon seen in their own interiors, and thus have probably been contaminated by the explosion or eruption of some former companion. Jill Knapp, Josh Schroeder and collaborators have found hotter examples, stars of about the temperature of the Sun, which have carbon molecules in their atmospheres. At the temperatures of these stars, all carbon molecules should be broken up into carbon atoms unless there is a truly enormous overabundance of carbon, the origin of which is still quite mysterious. The velocities of these hot carbon stars suggest that they belong to the old stellar halo of the galaxy, not to the spiral disk containing the Sun and other relatively young objects.

Work done with SDSS samples in the last few years and continuing this year indicate strongly that the halo is not the simple structure it was thought to be, but has been built up over billions of years by collisions and disruption of smaller galaxies with the Milky Way. Work by Brian Yanny, Heidi Newberg and collaborators has demonstrated the existence of a ring of stars very close to the plane of the Galaxy which is probably the tidal debris of such a collision. This stream is similar to the well-known one associated with the disruption of the Sagittarius dwarf galaxy, the nature of which was illuminated by SDSS workers near the beginning of the project.

Globular star clusters in the halo may also be pulled apart by Galactic tides. The cluster Palomar 5, which Connie Rockosi and Michael Odenkirchen and coworkers discovered was being so disrupted, has now been shown to have debris tails extending some ten degrees from the cluster. The total mass in the tails is in fact larger than that still remaining in the cluster, indicating that the disruption is almost complete.

The motions of stars in the halo give important clues not only about the formation of the halo but the mass of the Galaxy. In two independent studies, Edwin Sirko and collaborators and Tim Beers and collaborators have studied the motions of stars in the halo, and confirmed that the halo is hardly rotating at all, and that the Sun's orbital velocity about the center of the Galaxy is approximately what entirely independent estimates have given. Such large-scale radial velocity surveys enable the kinematic field to be especially well characterized at large galactocentric distances.

The study of the halo would benefit greatly if bright stars which can be seen to large distances could be used in the analyses. Bright red giant stars exist in the halo, but their colors are so similar to those of more numerous nearby red dwarfs that they are difficult to distinguish based on photometry. Amina Helmi and colleagues have shown, however, that the SDSS photometry is indeed good enough to distinguish the two kinds of stars well enough that one can make samples which are useful. This technique will be tested this year; if it works as well as it promises, the study of the halo can be extended to several hundred kiloparsecs, giving powerful constraints on the distribution of stars and dark matter in the halo of the Galaxy.

### 6.5 The Solar System

The wide sky coverage, faint limit, and multicolor capability of the survey has enabled heretofore impossible studies of the asteroid population in the solar system, elucidating the origin, orbital properties and distribution in space and size of the myriad asteroid families. Now with a substantial sample of objects observed at least twice, a team led by Gyula Szabo has detected significant color variations with time among the small bodies in the asteroid population. Brightness variations have been known for a long time, associated with the rotation of these irregularly-shaped objects, but the new work suggests that not only are the shapes irregular but that there are likely to be substantial variations of composition across the surface as well. The effect has been seen before in a few large asteroids, but it is somewhat surprising for bodies so small, and the more so since there is no strong correlation of the size of the effect with the size of the body over the studied range of 1-10 km in diameter. The most likely cause of the effect is a combination of space "weathering" by particle bombardment, which causes darkening and reddening of the surface; and collisions, which break up the surface and expose fresh material and perhaps deposit material from one of the objects onto the other.

## 7. Outreach and Communication

### 7.1 Graduate and Undergraduate Education

In 2003, 44 students were working on PhD theses with SDSS data. Brice Menard, Christy Tremonti and Beth Willman finished within the reporting period. The PhD dissertations initiated in 2003 included the following, where the student's name is followed by the advisor's name.

Spectroscopic Gravitational Lens Constraints on Galaxy Mass Distributions (Adam S. Bolton, Scott Burles)

Probing Galaxy-Mass Higher-Order Correlation Functions with Weak Lensing (David Johnston, Joshua Frieman)

Studies of X-ray Selected Stars from RASS/SDSS (Marcel Agueros, Scott Anderson)

The Nature of Flat Galaxies (Stefan Kautsch, Eva K. Grebel)

Bulge/Disk Decompositions of SDSS galaxies (Lidia Tasca, Houjun Mo and Simon White)

Double-Peaked Broad Emission Lines and the Geometry of Accretion in Active Galactic Nuclei (Iskra Strateva, Michael Strauss)

Cross Correlation of Weak Lensing with the WMAP (Chris Hirata, Uros Seljak)

Halo Probability Distribution from Weak Lensing (Rachel Mandelbaum, Uros Seljak)

The DR1 and its interfaces have made it especially easy for students to undertake research projects, and we have seen a dramatic increase in the number of them. Besides the thesis projects outlined above, an additional 35 graduate students worked on SDSS-related projects, as follows:

Princeton University:
- Ed Sirko: Dynamics of the Galactic Halo
- Will Serber: Quasar-galaxy correlations
- Mario Juric: Redshift distortions; Density profile of MW thin and thick disks
- Nick Bond: Kinematics of MW thin and thick disks
- Simon DeDeo: Photometric selection of quasars
- Matt Collinge: BL Lacs in the SDSS
- Niayesh Afshordi: The ISW effect
- Janice Hester: Clusters and filaments in the large-scale distribution of galaxies.
- Latham Boyle: The small-scale velocity dispersion of galaxies
- Gyula Szabo: Color variations of asteroids.

University of Arizona:
- Richard Cool: Evolution of early-type galaxies
- Linhua Jiang: IR spectroscopy of z > 6 quasars

Carnegie Mellon University:
- Gauri Kulkarni: 3-point function of SDSS galaxy data.

Ohio State University:
- Rik Williams: Narrow-line Seyfert 1 Galaxies in the SDSS
- Misty Bentz: Unusual quasars and Lyman-break Galaxies in the SDSS

University of Hawaii:
- Norbert Purger: Efficient searching of the SDSS photometric catalog (master thesis)

University of Chicago:
- Sarah Hansen: RR Lyr stars within the contours of 21cm high velocity clouds.
- Jonathan Mitchell: Elliptical galaxy velocity function and strong lensing statistics

Johns Hopkins University:
- Marci Hendrickson: Spectroscopic follow-up of candidate brown dwarfs
- Kathryn Daniel: Comparing the E+A incidence in SDSS with GOODS galaxies at z = 1
- Tim Reichard: The Structure and Morphology of AGN Hosts in SDSS

Japan:
- Masayuki Tanaka: Correlation study of the properties of galaxies in the SDSS: the effect of local and the global environment (masters thesis)

University of Washington:
- Oliver Fraser: CVs in SDSS
- Sean Raymond: CVs in SDSS, WD-M dwarf pairs
- John Bochanski: CVs in SDSS
- Kevin Covey: Luminosity function of low mass stars in SDSS/2MASS
- Lucianne Walkowicz: CVs in SDSS
- Antonino Miceli: Extreme cyclotron CVs
- Gregory Stinson: X-ray AGN in SDSS

Rensselaer Polytechnic Institute:
- Chongshan Zhao: Determination of 3-D distribution of Galactic dust
- Joathan Purnell: Find streams with Maximum Likelihood techniques

New Mexico State University:
- Brandon Lawton: Structural parameters of spiral galaxies

New York University:
- Morad Masjedi: galaxy environment dependences

University of Pennsylvania:
- Reiko Nakajima: 2-d angular correlation functions and photometric calibration
- Yongzhong Xu: cross-correlating galaxies and foregrounds

In addition to graduate students, 48 undergraduates also worked on SDSS-related projects during the reporting period. At least ten of these were senior theses, and at least eleven resulted in refereed papers.

Princeton University:
- Daniel Grin: Statistics of Lyman Limit systems
- Josh Younger: Subdwarf K and M stars; refinement of quasar photometric redshifts
- Maggie Kirkland: SED's of reddened quasars.
- Phil Hopkins: RR Lyrae spectra, curvature in quasar spectra and reddening
- Martin Niederst-Ostholt: A quasar with narrow Ly alpha emission
- Madhuri Kaul: Search for high proper motion stars
- Charles Steinhardt: The variability of the fine-structure constant alpha
- Joshua Schroeder: SDSS clusters; Carbon stars in the SDSS (senior thesis)
- Vernesa Smolcic: The properties of galaxies in redshifted Stroemgren photometric system (senior thesis)
- Branimir Sesar: Photometric recalibration of POSS catalogs using SDSS (senior thesis)
- Domjan Svilkovic: Variable Faint Optical Sources Discovered by Comparing POSS and SDSS Catalogs (senior thesis)
- Marko Gacesa: The Bruzual & Charlot Galaxy Models in redshifted Stroemgren photometric system (senior thesis)
- Rob Siverd: Radio and optical properties of sources detected by SDSS and modern radio surveys

University of Arizona:
- Chit Linn: star formation and galaxy pairs
- Jason Young: IR photometry of high-z quasar and brown dwarf candidates

Carnegie Mellon University:
- Eric Hilton: Selecting bent-double radio sources for southern plates.
- Kate Land - Matching DR1 to XMM to find distant clusters.

University of Chicago:
- Yusar Alsayyad: Checking a catalogue of absorption lines in SDSS QSO spectra
- Abhishek Kumar: Web page displaying SDSS quasar absorption line systems
- Britt Lundgren: Statistics of QSO absorption line systems from SDSS (senior thesis)
- Tristan Smith: Search for QSO absorption line systems for measuring deuterium abundance (senior thesis)
- Natale Sharnidze: Checking SDSS QSO absorption line catalogs
- Matthew Woods: A database for the SDSS QSO absorption lines
- Eric Johnson: strong lensing, catalog of voids
- Nada Petrovic: Black hole-line width correlations in QSOs

University of Hawaii:
Laszlo Dobos: Spectrum web service for the Virtual Observatory

Johns Hopkins University:
Christina Williams: Spectroscopic follow-up of candidate brown dwarfs

University of Washington:
James Frith: CV's in SDSS
Brandon Lawton: CV's in SDSS
Ethan Owens: CV's in SDSS
Michael Wolfe: CV's in SDSS, Study of an SW Sex star

Rensselaer Polytechnic Institute:
Miranda Nordhaus: Physical Parameters of Stars with SDSS filters
Nate Cole: Distribution of stars in Sagittarius Dwarf Tidal Stream
Kristopher Dawsey: Finding streams with Maximum Likelihood techniques
Warren Hayashi: Finding streams with Maximum Likelihood techniques
Fred Liu: Finding streams with Maximum Likelihood techniques

Japan:
Kenji Mitsuhashi: Visualization of maps of SDSS galaxies (senior thesis)

Penn State University:
Tim Reichard: BAL Quasars in the SDSS Early Data Release (senior thesis)
Jonathan Trump: Identical quasars in the SDSS; DR1 BALs (senior thesis)

University of Illinois:
Amy Bender: The Environments of low Redshift Quasars
Thomas Spinka: Machine Learning Approaches to Photometric Quasar Selection

University of Wyoming:
Justin Stute: u'g'r'i'z' Standard Stars
Katie Cantrell: Open Clusters in u'g'r'i'z' Filters

Fermilab:
Cristin Rider: Open Clusters in the u'g'r'i'z' system

University of Pittsburgh:
Ross Burton: Identification of Post-Starburst Quasars in the SDSS DR1
Nicolas Allen: Spectroscopic inspection of SDSS quasar sample

New York University:
Alejandro Quintero: galaxy merger rates and environment dependences
Nicholas Wherry: scaling three-color images for by-eye analyses

## 7.2 Collaboration Meetings

The SDSS Collaboration met in Flagstaff, AZ in April, and again at the beginning of October 2003 at Fermilab (Batavia, IL). These meetings draw typically 70 - 90 scientists (including graduate and undergraduate students) from across the SDSS participating institutions and some external scientists. Initially the meetings provided an opportunity to discuss technical issues such as calibration, but more recently they have emphasized reports on ongoing research with the data. The meetings also provide an effective opportunity for the Working Groups to organize projects, and for collaborative work to be identified and initiated.

In July 2003, SDSS scientists led by Gordon Richards and Patrick Hall organized an international scientific conference entitled "AGN Physics with the SDSS." This was a meeting to discuss the scientific potential of SDSS data to tackle major questions in the study of the physics of active galactic nuclei, and brought together over 100 researchers both from within and outside the SDSS collaboration. This conference was sponsored in part with generous grants from the NSF and the Sloan Foundation. The SDSS dataset is widely seen in the AGN community as setting a new standard in optical studies of AGN. It was particularly heartening to see that large numbers of AGN researchers from outside the SDSS collaboration are using public SDSS data to carry out ground-breaking research. The majority of the contributions to the 450-page conference proceedings are from non-SDSS scientists.

## 7.3 American Astronomical Society Meetings

The SDSS routinely maintains an exhibit booth at AAS meetings and organizes Special Sessions on recent results. Often there is an associated press release or press conference. In 2003 we organized two Special Sessions, the first at the Seattle AAS meeting and the second at the Nashville AAS meeting. The papers are listed below.

January 2003 Seattle
Stars and Galactic Structure in the Sloan Digital Sky Survey

65.01 The Metallicities of SDSS Stars in the Halo and Thick Disk of the Galaxy -- Implications for Galaxy Formation
T.C. Beers (Michigan State University)
65.02 Halo Structure and Ghostly Streams
H. J. Newberg (Rensselaer Polytechnic Institute)
65.03 Mining the Galaxy: White Dwarfs in the SDSS
S. J. Kleinman (Apache Pt. Observatory)
65.04 The SDSS Brown Dwarf Survey
G. R. Knapp (Princeton University)
65.05 The Scale Height of the Thick Disk
C. M. Rockosi (University of Washington)
65.06 Triumph of the Dwarfs: Faint Carbon Stars in the SDSS
B. Margon (STScI)

May 2003 Nashville
Galaxy Clusters in the Sloan Digital Sky Survey

51.01 Galaxy Properties as a Function of Environment
C.J. Miller, R.C. Nichol, P.L. Gomez, M. Bernardi (CMU), A.M. Hopkins, A.J. Connolly (Pitt), SDSS Collaboration
51.02 The Stellar Mass, Metallicity, and AGN content of SDSS Galaxies as a Function of Local Environment
C. A. Tremonti (JHU / Steward Observatory), T. M. Heckman (JHU), G. Kauffmann, S. Charlot, J.. Brinchmann, S. White (MPA), M. Seibert (JHU)
51.03 The overdensities of galaxy environments as a function of luminosity and color
D. W. Hogg (NYU), SDSS Collaboration
51.04 Early-Type Galaxies and their environment: constraints on models of galaxy formation
M. Bernardi (Carnegie Mellon University), SDSS Collaboration
51.05 Galaxy Biasing and Mass-to-light Ratios from Weak Lensing in the SDSS
E.S. Sheldon (Center for Cosmological Physics, U. of Chicago), J. Frieman, D. Johnston (University of Chicago), T. Mckay (University of Michigan), SDSS Collaboration
51.06 Properties of Void Galaxies in the SDSS
M. S. Vogeley, R. R. Rojas, F. Hoyle (Drexel University)

## 7.4 Outreach at Apache Point Observatory

Daytime guided tours of the SDSS facilities were provided to 21 school and special-interest groups this past year; these tours were coordinated with the outreach program at the National Solar Observatory, where the groups were given tours of both NSO and APO on the same day. Also, several groups of students from various ARC institutions visited the site and were given detailed tours of the SDSS equipment as well as opportunities to watch observing.

As in the past, the general public was offered self-guided daytime tours of APO, and more than 10,000 site information brochures were distributed at various tourist locations in the area. The "SDSS Progress" web page at the site was updated with technical and informational photos and text. The Site Director (Kurt Anderson) and Records Specialist (Gretchen Van Doren) attended two Southwest Consortium of Observatories for Public Education (SCOPE) meetings, and the Site Director is the PI on an IDEAS outreach proposal submitted to NASA. Also, the 7th annual Observatory Site Managers meeting, which was held at Lick Observatory, was organized and chaired by the APO Site Operations Manager (Bruce Gillespie).

The APO exhibit at the Sunspot Astronomy & Visitors Center was given a major renovation, including samples of SDSS plug plates, filters, and CCDs. We hosted a film crew from the Korean National Television service. Also, NMSU completed the 30-minute video about the SDSS, which was begun last year; NMSU Public Television plans to air it both locally and nationally in the coming year. In addition, about 100 copies of the short APO video produced last year were distributed to various destinations, as were over 10,000 SDSS/SCOPE posters.

Two Alamogordo high-school students from the "gifted" program began a mentorship program at APO in the fall semester of 2003. They are working with two members of the site technical staff and are providing help on various site and SDSS data and networking projects. If this program proves beneficial to both the students and the site, we plan to continue the program in the future and hope to involve students from other schools in the area.

APO sent staff and exhibits to the National Astronomy Day event in Albuquerque, and the Southern New Mexico State Fair in Las Cruces. Several of the APO staff are active members of the Alamogordo Amateur Astronomy Club, and scientific presentations were given by the SDSS Observers at various workshops.

### 7.5 Public Information Officer

Gary S. Ruderman, a Chicago freelance writer, acts as Public Information Officer for the SDSS. In the last year, Ruderman has distributed more than a dozen press releases (see listings at www.sdss.org) in support of the SDSS consortium members, resulting in news coverage in more than 100 news outlets here and abroad. He has presented the SDSS story to the Chicago-area IEEE membership; represented the SDSS at an open house for Congressional staffers; and represented the SDSS at a symposium on Ground-based Astronomy sponsored by the National Science Foundation.

### 7.6 Web Sites and Outreach

The SDSS web site http://www.sdss.org continues to be developed to provide the principal public entry to the SDSS. This site contains links to the data distributions and to the SkyServer. The SkyServer web site, http://skyserver.sdss.org, makes all released SDSS data available to the general public. The SkyServer was loaded with DR1 data on October 5 2003, and the success of this development will be documented in next year's report.

The educational resources on SkyServer are being continually augmented. Those who have contributed in the past year include Jordan Raddick (Johns Hopkins University), Robert Sparks (the Prairie School, Racine, WI), Barbara Estevez, (North Lake Park Elementary School, Orlando, FL), and Cristobal Lara (Barcelona, Spain). The educational material and approach has been presented at a variety of conferences, including the January and May 2003 AAS meetings, the American Association of Physics Teachers, various amateur astronomer groups, The Seventh Inter-American Conference on Physics Education in Havana, Cuba, and several briefings at the National Science Foundation (on the future of the Hands-On Universe program, as well as the Ground-Based Astronomy Symposium held on October 7 and 8, 2003).

Between January 1, 2003 and October 4, 2003, when SkyServer was hosting EDR data, the SkyServer web site received more than 4.3 million page views, for an average of about 430,000 per month. This is more than double the 2002 figure of 160,000 page views per month.

In addition, SkyServer has begun to partner with other EPO groups. We have received a development grant from NSF's Computer and Information Science and Engineering Directorate (Strategic Technologies for the Internet program) to work with two other projects. One is Hands-On Universe (HOU), which makes a network of small telescopes and image processing software available to high school students. The other is the Collaboratory of Northwestern

University, which provides a suite of easy-to-use online communication tools to students and teachers. We plan to offer a site that allows students spread around the world to analyze SDSS data and perform follow-up observations with HOU telescopes, while using Collaboratory resources to communicate with one another and with scientist mentors.

## 8. Financial Performance: 2003 Budgets and Costs

The operating budget, which the Advisory Council approved in November 2002, for the year 2003, consisted of $1,800K of in-kind contributions from Fermilab, US Naval Observatory (USNO), Los Alamos National Laboratory (LANL), and the Japan Participation Group (JPG); and $3,400K for ARC funded expenses. The sources of funds for the 2003 budget are shown in Table 8.1.

Table 8.1. Sources of Funds for the 2003 Budget ($K)

| Sources of Funding | Cash | In-Kind | Total |
|---|---|---|---|
| A. P. Sloan Foundation | 2,000 | | 2,000 |
| National Science Foundation | 885 | | 885 |
| Japan Participation Group | 175 | | 175 |
| Prior year funds | 340 | | 340 |
| Fermilab | | 1,500 | 1,500 |
| Los Alamos National Laboratory | | 156 | 156 |
| United States Naval Observatory | | 124 | 124 |
| Japan Participation Group | | 20 | 20 |
| Total | 3,400 | 1,800 | 5,200 |

The initial ARC-funded cash budget of $3,400K included $201K for management reserve. A review of our cost performance through September 2003 predicts that expenses for 2003 will be $2,995K. Since this is below the approved budget, we reduced the management reserve to $50K and have allocated $151K of the unused funds from the 2003 budget to the management reserve for 2004 and beyond. Table 8.2 shows the forecast cost performance by project area for ARC-funded cash expenses in 2003. The forecast is based on actual expenses through September, and estimated expenses for the period October through December.

Table 8.2. Summary of ARC-Funded Cash Expenses for 2003, by Project Area ($K)

| Category | 2003 Budget | Actual Expenses* |
|---|---|---|
| Survey Management | 245 | 298 |
| Collaboration Affairs | 16 | 7 |
| Observing Systems | 769 | 647 |
| Data Processing and Distribution | 533 | 552 |
| Observatory Support | 1,447 | 1,442 |
| ARC – Corporate Expenses | 189 | 49 |
| Sub-total | 3,199 | 2,995 |
| Management Reserve | 201 | 50 |
| Total | 3,400 | 3,045 |

*Includes actual expenses through Q3 and predicted expenses for Q4.

The cost increase in Survey Management reflects support for the new Director and support for time domain tests conducted to explore possible new uses of the SDSS hardware beyond mid 2005. The costs for these needs were not included in the 2003 budget when it was prepared in November 2002. The budget for Observing Systems appears under spent because funds held in the ARC Corporate Account for unanticipated hardware needs and additional technical support were not required during the year. The cost increase in Data Processing and Distribution is due to the purchase of computing hardware to support data distribution and increased salary costs due to promotions and higher than anticipated cost-of-living adjustments. Expenditures for Observatory Support are right on track with the budget for the year. The budget for ARC-Corporate Expenses appears under spent, again because funds set aside for unanticipated needs were not required. After the books for 2003 are closed, we will place any remaining unspent management reserve funds in the management reserve for 2004 and beyond.

Table 8.3 compares the budgeted and actual in-kind contributions in 2003 by institution and Table 8.4 shows the distribution of in-kind contributions by project area. The estimated value of the in-kind contributions in 2003 is $1,636K. In-kind contributions were $164K below the 2003 budget for the following reasons: The level of in-kind support provided by Fermilab to support the observing systems at APO was less than forecast because the amount of actual support required for existing systems was less than we estimated. The level of in-kind support for data processing was also less than anticipated because the priority Fermilab placed on its collider program and other projects reduced the availability of some people. The level of in-kind support provided by the JPG was less than forecast in the 2003 budget because no effort was required on the part of the JPG group to support the imaging camera. These reductions were partially offset by a slight increase in the in-kind contributions made by LANL. LANL provided engineering support to expand and maintain the capability of the telescope performance monitor, and astronomer support for the testing effort associated with data distribution operations. The USNO group provided the project with the agreed-upon level of effort.

Table 8.3. Budget and Costs for the 2003 In-kind Contributions, by Institution ($K)

| Institution | Budget | Actual In-kind Contribution* |
|---|---|---|
| Fermilab | 1,500 | 1,281 |
| Los Alamos National Laboratory | 156 | 226 |
| United States Naval Observatory | 124 | 129 |
| Japan Participation Group | 20 | 0 |
| Total | 1,800 | 1,636 |

* Includes actual expenses through Q3 and predicted expenses for Q4.

Table 8.4. Summary of In-kind Contributions, by Project Area ($K)

| Category | Budget | Actual In-kind Contribution* |
|---|---|---|
| Survey Management | 216 | 158 |
| Observing Systems | 562 | 537 |
| Data Processing and Distribution | 1,022 | 941 |
| Total | 1,800 | 1,636 |

* Includes actual expenses through Q3 and predicted expenses for Q4.

The costs reported for 2003 are preliminary, since this report was prepared prior to the end of the calendar year. The preliminary costs are based on actual expenses through Q3 and a revised forecast of Q4 expenses made by the participating institutions. As actual costs incurred by some institutions through December will not be reported until the end of the first quarter of 2004, we will amend this report with the final cost accounting at that time. Details on the use of funds obtained from the Sloan Foundation and the National Science Foundation are provided in Appendix B.

## 9. Financial Planning

### 9.1. 2004 Budget

On November 24, 2003, a budget of $5,206K for the year 2004 will be presented to the ARC Board of Governors for approval. The proposed 2004 budget is fully funded. It consists of $3,400K in cash provided by ARC, including a management reserve of $152K, and in-kind support from the MOU Partners with an estimated value of $1,806K. The sources of funds for the 2004 budget are shown in Table 9.1.

Table 9.1. Sources of Funds for the 2004 Budget ($K)

| Sources of Funding | Cash | In-Kind | Total |
|---|---|---|---|
| A. P. Sloan Foundation | 1,000 | | 1,000 |
| National Science Foundation | 844 | | 844 |
| Japan Participation Group | 84 | | 84 |
| Prior year funds and interest earnings | 728 | | 728 |
| New member funds | 744 | | 744 |
| Fermilab | | 1,451 | 1,451 |
| Los Alamos National Laboratory | | 222 | 222 |
| United States Naval Observatory | | 133 | 133 |
| Total | 3,400 | 1,806 | 5,206 |

The funds from the A.P. Sloan Foundation are from a commitment to award ARC $10,000K for the observation phase of the Five-Year Baseline Survey. The initial award was made in December 1999 and to date the A.P. Sloan Foundation has awarded ARC $9,000K for the Five-Year Baseline Survey. We anticipate that they will provide ARC with the remaining $1,000K of the award at the end of the calendar year, pending a satisfactory review of our progress on the survey. ARC anticipates receiving $844K from the National Science Foundation in 2004, as shown in Table 9.1. This will be the fourth allocation from a multiyear grant of $4,000K that ARC received in August of 2001. The amount of NSF funds that ARC will receive in 2004 and beyond is subject to fulfilling the terms of the grant. The funds from the Japan Participation Group represent their commitment to purchase $84K in supplies. The funds will be primarily used to finance finished plug plates. Prior year funds represent unspent funds from prior year allocations that have been carried forward. New member funds represent prior cash payments made by institutions to join the SDSS collaboration as Affiliate Members. 2004 marks the first year in which the new partner fund is being drawn down to support survey operations.

With regard to in-kind contributions, Fermilab will continue to provide support for Observing Systems, data processing and distribution, and survey management. Los Alamos will provide support for the maintenance of the observers' software and testing the output of the data processing pipelines. The U.S. Naval Observatory will provide support for the maintenance of the astrometric pipeline and the operational database.

Table 9.2 shows the allocation of the 2004 cash funds by project area. Table 9.3 shows the distribution of anticipated in-kind contributions by project area. Both tables compare the 2004 budget to actual 2003 expenditures in each category.

Table 9.2. Allocation of 2004 Cash Funds, by Project Area ($K)

| Category | 2003 Actual Expenses* | Proposed 2004 Cash Budget |
|---|---|---|
| Survey Management | 298 | 294 |
| Collaboration Affairs | 7 | 16 |
| Observing Systems | 647 | 647 |
| Data Processing and Distribution | 552 | 593 |
| Observatory Support | 1,442 | 1,522 |
| ARC – Corporate Expenses | 49 | 176 |
| Sub-total | 2,995 | 3,248 |
| Undistributed Contingency | 50 | 152 |
| Total | 3,045 | 3,400 |

*Includes actual expenses through Q3 and predicted expenses for Q4.

Table 9.3. Distribution of 2004 In-kind Contributions, by Project Area ($K)

| Category | Actual 2003 In-kind Contribution* | Anticipated 2004 In-kind Contribution |
|---|---|---|
| Survey Management | 158 | 191 |
| Observing Systems | 537 | 541 |
| Data Processing and Distribution | 941 | 1,074 |
| Total | 1,636 | 1,806 |

*Includes actual expenses through Q3 and predicted expenses for Q4.

## 9.2. Financial Planning: Funding Requirements

Table 9.4 shows the current cost estimate for the five-year observing phase of the Survey, and the cost of operations for 2004 through the end of the Survey. The cash portion of the 5-year budget is $17,560K. Existing cash and in-kind commitments will provide sufficient funds to complete the survey.

Table 9.4. Cost to Complete the 5-year Survey, by Project Area ($K)

| Category | Cost to Complete* | Total 5-year Cost Forecast |
|---|---|---|
| Survey Management | 830 | 2,578 |
| Collaboration Affairs | 37 | 78 |
| Observing Systems | 1,735 | 7,721 |
| Data Processing and Distribution | 2,373 | 8,653 |
| Observatory Support | 2,,423 | 7,482 |
| ARC – Corporate Expenses | 291 | 761 |
| Sub-total | 7,690 | 27,274 |
| Management Reserve | 450 | 450 |
| Total | 8,140 | 27,724 |

* For the period January 1, 2004 to November 30, 2005 (includes close-out costs)

The cost estimate to finish the Survey includes costs for a modest project closeout plan, which provides support for an orderly shutdown of SDSS operations over a five-month period beginning in July 2005. Shutdown activities include decommissioning systems to leave them in a safe state, completing final documentation, writing final summary reports. They also include processing any unprocessed data and transferring the SDSS Archive to a long-term steward. The closeout plan was revised in 2003 to increase the duration of the closeout period from three to five months, to provide sufficient time to properly complete shutdown activities. The estimated cost of the closeout is $485K, of which $322K is cash and the remainder is an in-kind contribution from Fermilab.

## 10. Outlook

In 2004, we expect to continue operations as we have done in 2003. As the area in the North Galactic Cap fills in, the options for observing the remaining parts of this footprint will become progressively more restricted. The nature of any "end game" effects in observing strategy will start to become apparent in 2005, when we will be better able to evaluate the impact on observing efficiency. If the future weather is similar to the past average weather, and if there are no other unforeseen problems, then we expect to have a single filled volume in the North Galactic Cap mapped in the imaging survey by the end of the five-year survey (30 June 2005). However, the spectroscopic survey will have covered two areas with a gap between them.

In the South Galactic Cap, we have been pursuing a rather different strategy. The imaging has concentrated on repeated scans of the equator, and the spectroscopic time has been used mostly for extending the target-selection criteria in various ways as a test of the effect of boundaries in parameter space that we have necessarily imposed in the Northern survey. In the Fall of 2004, we may change the scientific objectives to include new observations to map the stellar halo of the Milky Way (structure, kinematics, and chemical abundances). These objectives are motivated partly by our recent success at discovering structure in the Milky Way halo, and partly on the developing astrophysical field that aims to account for the structures of galaxies according to detailed gas-dynamical models in the context of Cold Dark Matter hierarchical clustering. That is, in a sense we can use the SDSS facilities to study cosmology by observing relatively local stars. Since these observations would represent a change to the original Survey goals (referring only to the part of the year when unobserved regions in the North Galactic Cap are not available), a process will be developed to achieve consensus within the Collaboration and with our sponsors.

A related issue concerns the status of the project after the end of the funding period. As mentioned in the 2002 Annual Report, a Futures Committee was formed to explore the scientific merit, practicality, and level of institutional interest in continued operations. This Committee finished its charge in 2003 with a report to the SDSS Advisory Council. The conclusions were that 1) the SDSS systems will continue to be highly competitive in our niche well beyond 2005; 2) a number of scientific programs were identified that address important current problems in astronomy; 3) these programs mesh with the interests of a broad range of the current SDSS participating institutions. Accordingly, the Advisory Council instructed the Survey management to develop proposals to seek additional funding for operations beyond 30 June 2005. This process was started in 2003 and will conclude in 2004.

The second public data release, DR2, will occur a few months later than stated in our release plan; this delay provides essential time for validation of the release by the Collaboration. The same release plan calls for DR3 to be publicly available in October of 2004, and it is our intent to meet this goal.

We have requested a Special Session at the summer American Astronomical Society meeting (Denver, CO) on the topic "SDSS and Multi-Wavelength Astronomy." If approved, this session will explore such topics as galaxy spectral energy distributions by matching with 2MASS and GALEX data, and the radio properties of starburst galaxies.

# APPENDIX A - 2003 Publications

The Luminosity Function of Void Galaxies in the Sloan Digital Sky Survey
ApJ submitted - Fiona Hoyle, et al.

The H$\alpha$ Luminosity Function of Morphologically Classified Galaxies in the Sloan Digital Sky Survey
AJ submitted - Osamu Nakamura, et al.

A Snapshot Survey for Gravitational Lenses Among z>=4.0 Quasars: I. The z>5.7 Sample
AJ submitted - Gordon Richards, et al.

Detection of Intergalactic HeII Absorption at Redshift 3.5
ApJL submitted - W. Zheng, et al.

Blue Horizontal Branch Stars Selected from the Sloan Digital Sky Survey: II Kinematics of the Galactic Halo
AJ submitted - Edwin Sirko, et al.

Blue Horizontal Branch Stars Selected from the Sloan Digital Sky Survey: I Sample Selection and Structure in the Galactic Halo
AJ submitted - Edwin Sirko, et al.

Halos around edge-on disk galaxies in the SDSS
MNRAS accepted - Stefano Zibetti, et al.

Discovery of the Largest Separation Lensed Quasar from the Sloan Digital Sky Survey
Nature submitted - Naohisa Inada, et al.

SDSSJ115517.35+634622.0: A Newly Discovered Gravitationally Lensed Quasar
AJ submitted - Bart Pindor, et al.

Detection of the Integrated Sachs-Wolfe Effect
Phys Rev Lett submitted - Ryan Scranton, et al.

Sagittarius Tidal Debris 90 kpc from the Galactic Center
ApJL 596:191 (2003) - Heidi Newberg, et al.

The Ensemble Photometric Variability of ~25000 Quasars in the Sloan Digital Sky Survey
ApJ submitted -Daniel E. Vanden Berk, et al.

Photometric Properties of Void Galaxies in the Sloan Digital Sky Survey
AJ submitted - Randall R. Rojas, et al.

Quantifying the Bimodal Color-Magnitude Distribution of Galaxies

ApJ submitted - Ivan K. Baldry, et al.

VLT + UVES Spectroscopy of the Low-Ionization Intrinsic Absorber in SDSS J001130.56+005550.7
A&A submitted - Damien Hutsemekers, et al.

The extended tails of Palomar 5: A ten degree arc of globular cluster tidal debris
AJ accepted - Michael Odenkirchen, et al.

The Sloan Digital Sky Survey Quasar Catalog II. Data Release 1
AJ submitted - D.P. Schneider, et al.

SDSS J0903+5028: A New Gravitational Lens
ApJ submitted - David E. Johnston, et al.

Stellar and Dynamical Masses of Ellipticals in the Sloan Digital Sky Survey
New Astronomy submitted - Nikhil Padmanabhan, et al.

Star formation rate indicators in the Sloan Digital Sky Survey
ApJ submitted - Andrew Hopkins, et al.

The dependence on environment of the color--magnitude relation of galaxies
ApJL submitted - David Hogg, et al.

Candidate Type II Quasars from the Sloan Digital Sky Survey: I. Selection and Optical Properties of a Sample at $0.3<Z<0.83$
AJ accepted - Nadia L. Zakamska, et al.

Galaxy Types in the Sloan Digital Sky Survey Using Supervised Artificial Neural Networks
MNRAS submitted - Nick Ball, et al.

Double-Peaked Low-Ionization Emission Lines in Active Galactic Nuclei
AJ submitted - Iskra V. Strateva, et al.

SDSS White Dwarfs with Spectra Showing Atomic Oxygen and/or Carbon Lines
AJ submitted - Jim Liebert, et al.

Selection and photometric properties of K+A galaxies
ApJ submitted - Alejandro Quintero, et al.

Continuum and Emission Line Properties of Broad Absorption Line Quasars
AJ submitted – Timothy Reichard, et al.

The 3D Power Spectrum of Galaxies from Early SDSS Data
ApJ submitted - Max Tegmark et al.

Discovery of Eight New Extremely Metal-Poor Galaxies in the Sloan Digital Sky Survey
ApJL submitted - Alexei Kniazev, et al.

Magnetic White Dwarfs from the SDSS. The First Data Release
ApJ submitted - Gary Schmidt, et al.

Minkowski Functionals of SDSS galaxies I: Analysis of Excursion Sets
PASJ submitted - Chiaki Hikage, et al.

The Host Galaxies of AGN
MNRAS submitted - G. Kauffmann, et al.

A Large, Uniform Sample of X-ray Emitting AGN: Selection Approach and an Initial Catalog from the ROSAT All-Sky and Sloan Digital Sky Surveys
AJ submitted - S.F. Anderson, et al.

A Merged Catalog of Clusters of Galaxies from Early SDSS Data: BH1
ApJ submitted - Neta A. Bahcall, et al.

Distributions of Galaxy Spectral Types in the Sloan Digital Sky Survey
AJ submitted - Ching-Wa Yip, et al.

Investigating the SDSS Cataclysmic Variable SDSS J132723.39+652854.29
PASP submitted - Michael Wolfe, et al.

Cataclysmic Variables from SDSS II. The Second Year
AJ submitted - Paula Szkody, et al.

An Initial Survey of White Dwarfs in the Sloan Digital Sky Survey
AJ submitted - Hugh Harris, et al.

The Environment of Passive Spiral Galaxies in the SDSS
PSAJ submitted - Tomotsugu Goto et al.

On Departures From a Power Law in the Galaxy Correlation Function
ApJ submitted - Idit Zehavi, et al.

The near-IR properties and continuum shape of high redshift quasars from the Sloan Digital Sky Survey
A&A submitted - Laura Pentericci, et al.

VLT+UVES Spectroscopy of the CaII LoBAL Quasar SDSS 0300+0048
ApJ submitted - Pat Hall et al.

The size distribution of galaxies in the Sloan Digital Sky Survey
MNRAS accepted - Shiyin Shen, et al.

Observing the dark matter density profile around isolated galaxies
ApJ submitted - Francisco Prada et al.

Angular Clustering with Photometric Redshifts in the Sloan Digital Sky Survey
ApJ submitted - Tamas Budavari, et al.

The velocity function of early-type galaxies
ApJ submitted - Ravi K. Sheth, et al.

A Low Latitude Halo Stream around the Milky Way
ApJ submitted - Brian Yanny et al.

A Survey of z>5.7 Quasars in the Sloan Digital Sky Survey II: Discovery of Three Additional Quasars at z>6
AJ accepted - Xiaohui Fan et al.

The Overdensities of Galaxy Environments as a Function of Luminosity and Color
ApJL accepted - David W. Hogg et al.

A Catalog of Broad Absorption Line Quasars from the Sloan Digital Sky Survey Early Data Release
AJ accepted - Timothy A. Reichard et al.

Red and Reddened Quasars in the Sloan Digital Sky Survey
AJ submitted - Gordon T. Richards et al.

Determining the Lensing Fraction of SDSS Quasars: Methods and Results from the EDR
AJ accepted - Bart Pindor et al

Luminosity Function of Morphologically Classified Galaxies in the SDSS Survey
AJ accepted - O. Nakamura et al.

The Galaxy Luminosity Function and Luminosity Density at Redshift z=0.1
ApJ submitted - Michael R. Blanton, et al.

The Sloan Digital Sky Survey: The Cosmic Spectrum and Star-Formation History
ApJ accepted - Karl Glazebrook, et al.

Hdelta-Selected Galaxies in the Sloan Digital Sky Survey I: The Catalog
PASJ submitted - Tomotsugu Goto, et al.

SDSS catalog of stars in the Draco dwarf spheroidal galaxy
ApJS accepted - Heather A. Rave et al

**Based on Public Data**

Strong Emission Line HII Galaxies in the Sloan Digital Sky Survey. I. Catalog of DR1 Objects with Oxygen Abundances from Te Measurements
ApJS submitted - Alexei Y. Kniazev

Galaxy Ecology: Groups and low-density environments in the SDSS and 2dFGRS
MNRAS submitted - Michael Balog, et al.

The Selection of RR Lyrae Stars Using Single-epoch Data
AJ submitted - Zeljko Ivezic, et al.

Detection of the ISW and SZ Effects from the CMB-Galaxy Correlation
ApJL submitted – Pablo Fosalba, et al.

The Rest-Frame Optical Luminoisity Density, Color, and Stellar Mass Density of the Universe from z=0 to z=3
ApJ submitted – Gregory Rudnick, et al.

Dust Emission from the Most Distant Quasars
A&A accepted – Frank Bertoldi, et al.

Combining WMAP and SDSS Quasar Data on Reionization Constrains Cosmological Parameters and the Star Formation Efficiency
ApJ accepted - Weihsueh Chiu, et al.

Color Variability of Asteroids in SDSS Moving Object Catalog
MNRAS submitted - Gy.M. Szab, et al.

Multiepoch Sky Surveys and the Lifetime of Quasars
ApJL 597:109 (2002) – Paul Martini, et al.

Evolution of the Galaxy Luminosity Function at z < 0.3
MNRAS accepted - Jon Loveday, et al.

A Survey of Open Clusters in the u'g'r'i'z' Filter System: I. Results for NGC~2548 (M48)
AJ submitted - Cristin J. Rider, et al.

Constraining Compact Dark Matter with Quasar Equivalent Widths from the Sloan Digital Sky Survey Early Data Release
ApJ submitted - Craig Wiegert, et al.

The Environment of AGNs in the Sloan Digital Sky Survey
ApJ 597:142 (2003) - Chris Miller, et al.

Morphological Classification of Galaxies by Shapelet Decomposition in the Sloan Digital Sky Survey
AJ submitted - Brandon C. Kelly, et al.

The Richness-Dependent Cluster Correlation Function: Early SDSS Data
ApJL submitted - Neta A. Bahcall, et al

HDS Galaxies in the SDSS II: Merger/Interaction Origin of E+A Galaxies
PASJ submitted - Tomo Goto, et al.

The Cluster Galaxy Circular Velocity Function
MNRAS submitted - Vandana Desai, et al.

Measurements of Cosmic Damped Ly-a Gas Metalicities at Redshifts z=0.9-2.0 from SDSS Spectra
ApJL submitted - Daniel B. Nestor, et al.

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MNRAS submitted – A. Doroshkevich, et al.

Multicolor Photometry of the Galaxies in Abell 2255 by the BATC and SDSS Surveys
ApJS accepted – Qirong Yuan, et al.

Long Term Variability of SDSS Quasars
AJ accepted – Wim de Vries, et al.

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## APPENDIX B. Use of Funds from the A.P. Sloan Foundation & the National Science Foundation in 2003.

The funds from the A.P. Sloan Foundation, NSF, and other sources were expended in 2003 on the project areas shown in Table B1.

Table B1. Summary of Sloan, NSF, and Other Funded Expenditures on 2003 Costs (Accrual Basis, $K)

| Category | A.P. Sloan Funds | NSF Funds | Other Funds | Total |
|---|---|---|---|---|
| Survey Management | 250 | 50 | 0 | 300 |
| Collaboration Affairs | 7 | 0 | 0 | 7 |
| Observing Systems | 304 | 171 | 157 | 632 |
| Data Processing and Distribution | 332 | 219 | 0 | 551 |
| Observatory Support (APO/NMSU) | 979 | 445 | 17 | 1,441 |
| ARC Corporate Expenses | 114 | 0 | 0 | 114 |
| Total Expenditures | 1,986 | 885 | 174 | 3,045 |

The expenditures in Table B1 are for payments made by ARC prior to January 1, 2003. All of the NSF funds awarded to ARC in 2003 were fully committed by the end of calendar year 2003. Details of the payments from the A.P. Sloan Foundation, NSF, and other cash accounts between January 1, 2003 and December 31, 2003 are shown in Table B2. Each line lists the funds paid to a particular institution for the specific scope of work defined in the annual agreements between each institution and ARC. Each agreement has a specific SSP number and provides an initial budget for that SSP. During the year, the Project Manager and the Business Manager track the costs incurred by each SSP. They review all new commitments with the appropriate budget officer from each institution. All commitments in excess of $3,000 require the approval of the Director and the ARC Business Manager. Any changes in the personnel supported by ARC require a revision to the Agreement.

Some of the items deserve a few comments. The costs incurred by Fermilab for SSP48 are for travel in support of survey management responsibilities. Costs incurred by Fermilab on SSP42 include the salaries of two technicians in permanent residence near APO; the procurement of parts and materials, including spares, for the 2.5-m telescope and all other hardware systems in Observing Systems except the DAQ system; and travel expenses incurred by Fermilab employees stationed at APO. Costs incurred by Fermilab on SSP40 include the salary costs for one individual who maintains the SDSS website and data distribution hardware, and who is participating in the preparation of databases for Data Release 2. Costs incurred by Fermilab on SSP61 include the salary costs for an individual responsible for maintaining the observers programs at APO and for assisting in time tracking and efficiency performance analysis, and the travel costs for this individual to travel between Fermilab and APO. Reimbursement of all Fermilab costs is made from the A.P. Sloan Foundation account, as shown in Table B.2.

Table B2. Details of Sloan, NSF, and Other Funded Expenditures in CY2003
(Accrual Basis, $K)

| SSP No. | Description | Sloan Funds | NSF Funds | Other Funds | Total |
|---|---|---|---|---|---|
| **Survey Management** | | | | | |
| SSP21 | ARC Secretary/Treasurer | 11 | 0 | 0 | 11 |
| SSP34 | ARC Business Manager | 55 | 0 | 0 | 55 |
| SSP46 | PU Office of the Project Scientist | 24 | 50 | 0 | 74 |
| SSP48 | FNAL Support for Survey Management | 25 | 0 | 0 | 25 |
| SSP65 | UC Project Spokesperson (2001-03) | 7 | 0 | 0 | 7 |
| SSP66 | SDSS Extension White Paper | 40 | 0 | 0 | 40 |
| SSP67 | UC Support for Survey Management | 44 | 0 | 0 | 44 |
| SSP91a | ARC Support for Public Affairs | 10 | 0 | 0 | 10 |
| SSP91b | ARC Support for SDSS Spokesperson | 4 | 0 | 0 | 4 |
| SSP91i | ARC Support for Public Information Officer | 30 | 0 | 0 | 30 |
| | Sub-total | 250 | 50 | 0 | 300 |
| **Collaboration Affairs** | | | | | |
| SSP91c | ARC Support for Collaboration Affairs | 7 | 0 | 0 | 7 |
| | Sub-total | 7 | 0 | 0 | 7 |
| **Observing Systems** | | | | | |
| SSP42 | FNAL Observing Systems Support | 150 | 0 | 0 | 150 |
| SSP61 | FNAL Observing Programs and DA Support | 31 | 0 | 0 | 31 |
| SSP31 | UW Observing Systems Support | 0 | 161 | 133 | 294 |
| SSP32 | PU Observing Systems Support | 55 | 0 | 0 | 55 |
| SSP36 | JHU Observing Systems Support | 8 | 0 | 0 | 8 |
| SSP33 | UC Observing Systems Support | 34 | 0 | 0 | 34 |
| SSP91d | ARC Observing Systems Support | 26 | 10 | 24 | 60 |
| | Sub-total | 304 | 171 | 157 | 632 |
| **Data Processing and Distribution** | | | | | |
| SSP40 | FNAL Software and Data Processing Support | 113 | 0 | 0 | 113 |
| SSP38 | PU Software and Data Processing Support | 181 | 0 | 0 | 181 |
| SSP39 | UC Software and Data Processing Support | 38 | 0 | 0 | 38 |
| SSP37 | JHU Data Archive Development and Support | 0 | 219 | 0 | 219 |
| | Sub-total | 332 | 219 | 0 | 551 |
| **Observatory Support** | | | | | |
| SSP35 | NMSU Site Support | 979 | 445 | 17 | 1,441 |
| | Sub-total | 979 | 445 | 17 | 1,441 |
| **ARC Corporate Support** | | | | | |
| SSP91e | ARC Corporate Support | 55 | 0 | 0 | 55 |
| SSP91f | ARC Additional Scientific Support | 0 | 0 | 0 | 0 |
| SSP91h | ARC Observers' Research Support | 9 | 0 | 0 | 9 |
| SSP91r | Management Reserve | 50 | 0 | 0 | 50 |
| | Sub-total | 114 | 0 | 0 | 114 |
| | TOTAL CASH EXPEDITURES | 1,986 | 885 | 174 | 3,045 |

Table B3. Details of Sloan, NSF, and Other Funded Corporate Expenditures in CY2003
(Accrual Basis, $)

| Code | Description | A.P. Sloan | NSF | Other | Total |
|---|---|---|---|---|---|
| 91A | ADD'L INTERNET CONNECTION | 200 | 0 | 0 | 200 |
| 91A | AAS EXHIBIT BOOTH, NASHVILLE TENN. | 1,970 | 0 | 0 | 1,970 |
| 91A | BROCHERS AND BANNER | 3,370 | 0 | 0 | 3,370 |
| 91A | NOV/DEC ESTIMATE | 4,000 | 0 | 0 | 4,000 |
| SSP91A | ARC Support for Public Affairs | 9,540 | 0 | 0 | 9,540 |
| | | | | | |
| 91B | NSF/SDSS MTG IN VIRGINIA | 85 | 0 | 0 | 85 |
| 91B | NSF/SDSS MTG IN VIRGINIA | 323 | 0 | 0 | 323 |
| 91B | MANAGEMENT COMM MTG TRAVEL | 170 | 0 | 0 | 170 |
| 91B | NOV BALANCE & DEC ESTIMATE | 3,500 | 0 | 0 | 3,500 |
| SSP91B | ARC Spokesperson Support | 4,078 | 0 | 0 | 4,078 |
| | | | | | |
| 91C | TRAVEL REIMB (WG CO-CHAIR) | 856 | 0 | 0 | 856 |
| 91C | HEIDI NEWBERG TRAVEL (WG CO-CHAIR) | 1,004 | 0 | 0 | 1,004 |
| 91C | TRAVEL REIMB (AAS MTG) | 1,500 | 0 | 0 | 1,500 |
| 91C | TRAVEL REIMB (NSF MTG SUPPORT) | 693 | 0 | 0 | 693 |
| 91C | TRAVEL REIMB (WG CO-CHAIR) | 264 | 0 | 0 | 264 |
| 91C | PAGE CHARGE (ABAZAHAN) | 706 | 0 | 0 | 706 |
| 91C | COLLABORATION MTG SPEAKER | 685 | 0 | 0 | 685 |
| 91C | WG CO-CHAIR TRAVEL TO FNAL | 660 | 0 | 0 | 660 |
| 91C | NOV/DEC ESTIMATE | 500 | 0 | 0 | 500 |
| SSP91C | ARC Support for Collaboration Affairs | 6,867 | 0 | 0 | 6,867 |
| | | | | | |
| 91D | TRAVEL REIMBURSMENT (DIMM) | 231 | 0 | 0 | 231 |
| 91D | TRAVEL REIMBURSMENT (DIMM) | 784 | 0 | 0 | 784 |
| 91D | SDSS ENCL STAIRS (SSP31) | 6,060 | 0 | 0 | 6,060 |
| 91D | DIMM MODIFICATIONS (SSP32) | 2,757 | 0 | 0 | 2,757 |
| 91D | DIMM TRAVEL REIMBURSEMENT | 79 | 0 | 0 | 79 |
| 91D | RE-ALUM 2.5M PRIMARY DEPOSIT | 5,000 | 0 | 0 | 5,000 |
| 91D | ARC INVOICE #4 | 0 | 0 | 24,175 | 24,175 |
| 91D | REFUND RE-ALUM 2.5M PRIMARY DEPOSIT | (5,000) | 0 | 0 | (5,000) |
| 91D | RE-ALUM 2.5M PRIMARY DEPOSIT | 0 | 10,000 | 0 | 10,000 |
| 91D | NOV/DEC ESTIMATE | 16,000 | 0 | 0 | 16,000 |
| SSP91D | ARC Observing Systems Support | 25,910 | 10,000 | 24,175 | 60,085 |

## Table B3. Details of Sloan, NSF, and Other Funded Corporate Expenditures in CY2003 - Continued (Accrual Basis, $)

| Code | Description | A.P. Sloan | NSF | Other | Total |
|---|---|---|---|---|---|
| 91E | REPLENISH PETTY CASH DEC-02 | 1,856 | 0 | 0 | 1,856 |
| 91E | INSURANCE RENEWAL > 1/04 | 898 | 0 | 0 | 898 |
| 91E | TRAVEL ASSISTANCE FUND | 10,000 | 0 | 0 | 10,000 |
| 91E | REPLENISH PETTY CASH JAN-03 | 512 | 0 | 0 | 512 |
| 91E | SERVICE CHARGE FOR LOST JHU CHECK | 30 | 0 | 0 | 30 |
| 91E | TRAILER RENTAL 2003 Q2 | 444 | 0 | 0 | 444 |
| 91E | COMM DIR & OFF INSUR > 3/04 | 6,480 | 0 | 0 | 6,480 |
| 91E | REIMB P.CASH + $2K MTG ADVANCE | 2,220 | 0 | 0 | 2,220 |
| 91E | STOP ON LOST JHU CHECK | 29 | 0 | 0 | 29 |
| 91E | TRANSFER TO NSF #3 | 29 | 0 | 0 | 29 |
| 91E | REPLENISH PETTY CASH MAY-03 | 37 | 0 | 0 | 37 |
| 91E | SERVICE CHARGE | 2 | 0 | 0 | 2 |
| 91E | REIMB MTG FOOD | 54 | 0 | 0 | 54 |
| 91E | REIMB TRAVEL | 1,050 | 0 | 0 | 1,050 |
| 91E | REPLENISH PETTY CASH JUN-03 | 381 | 0 | 0 | 381 |
| 91E | AC MGT EXPENSES | 1,756 | 0 | 0 | 1,756 |
| 91E | 2002 AUDIT | 6,169 | 0 | 0 | 6,169 |
| 91E | TRAILER RENTAL 2003 Q3 | 444 | 0 | 0 | 444 |
| 91E | REPLENISH PETTY CASH JUN-03 | 1,828 | 0 | 0 | 1,828 |
| 91E | TRAILER RENTAL 2003 Q4 | 444 | 0 | 0 | 444 |
| 91E | SDSS AC DINNER | 611 | 0 | 0 | 611 |
| 91E | REPLENISH PETTY CASH JUL/AUG-03 | 282 | 0 | 0 | 282 |
| 91E | REPLENISH PETTY CASH SEP-03 | 564 | 0 | 0 | 564 |
| 91E | AC MGT EXPENSES | 4,358 | 0 | 0 | 4,358 |
| 91E | STORAGE IN ALAMO 2003Q3 & 2004Q1 | 2,515 | 0 | 0 | 2,515 |
| 91E | STORAGE IN ALAMO 2002Q3 & 2003Q2 | 5,029 | 0 | 0 | 5,029 |
| 91E | INV #P5GN583, COMPUTER BATTERY | 207 | 0 | 0 | 207 |
| 91E | NOV BALANCE & DEC ESTIMATE | 7,000 | 0 | 0 | 7,000 |
| SSP91E | ARC Corporate Support | 55,230 | 0 | 0 | 55,230 |
| 91H | TRAVEL REIMBURSMENT (AAS MTG) | 1,943 | 0 | 0 | 1,943 |
| 91H | REIMB TRAVEL (FLAGSTAFF MTG) | 336 | 0 | 0 | 336 |
| 91H | REIMB TRAVEL (AUSTIN, TX MTG) | 1,140 | 0 | 0 | 1,140 |
| 91H | REIMB TRAVEL | 342 | 0 | 0 | 342 |
| 91H | REIMB TRAVEL (PRINCETON) | 1,343 | 0 | 0 | 1,343 |
| 91H | REIMB TRAVEL (PRINCETON) | 908 | 0 | 0 | 908 |
| 91H | NOV/DEC ESTIMATE | 3,000 | 0 | 0 | 3,000 |
| SSP91H | SDSS Observers Fund | 9,012 | 0 | 0 | 9,012 |
| 91I | SDSS PIO EXPENSES JAN-03 | 5,995 | 0 | 0 | 5,995 |
| 91I | SDSS PIO EXPENSES FEB-03 | 1,236 | 0 | 0 | 1,236 |
| 91I | SDSS PIO EXPENSES MAR-03 | 1,474 | 0 | 0 | 1,474 |
| 91I | SDSS PIO EXPENSES APR-03 | 2,479 | 0 | 0 | 2,479 |
| 91I | SDSS PIO EXPENSES MAY-03 | 4,949 | 0 | 0 | 4,949 |
| 91I | SDSS PIO EXPENSES JUN-03 | 2,137 | 0 | 0 | 2,137 |
| 91I | SDSS PIO EXPENSES JUL-03 | 1,619 | 0 | 0 | 1,619 |
| 91I | SDSS PIO EXPENSES AUG-03 | 903 | 0 | 0 | 903 |
| 91I | SDSS PIO EXPENSES SEP-03 | 1,121 | 0 | 0 | 1,121 |
| 91I | SDSS PIO EXPENSES OCT-03 | 3,178 | 0 | 0 | 3,178 |
| 91I | NOV/ DEC ESTIMATE | 5,000 | 0 | 0 | 5,000 |
| SSP91I | SDSS Public Information Officer | 30,090 | 0 | 0 | 30,090 |
| | TOTAL | 140,726 | 10,000 | 24,175 | 174,901 |