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2009 : July 2009 - Author Commentaries : Donald Schneider

AUTHOR COMMENTARIES - 2009

July 2009

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Donald Schneider

Science Watch® Newsletter Interview

For centuries astronomers have used survey techniques to compile catalogs and inventories of celestial objects. The greatest observers in antiquity, Hipparchus and Ptolemy, produced the first catalogs. In the eighteenth century Messier compiled a list of 110 nebulae, which William Herschel expanded to several thousand, discovering Uranus serendipitously in the process. In 1887 astronomers met in Paris to agree on a global collaboration, the Carte du Ciel, which would map millions of stars and galaxies. The project continued for decades, producing weighty catalogs, but little of astrophysical or cosmological significance; the mere acquisition of data could not unlock the secrets of the universe. In the 1950s the famous Palomar Sky Survey demonstrated the superiority of photographic deep surveys, following which the remarkable growth of space astronomy and observational cosmology was propelled by surveys across the entire electromagnetic spectrum.

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In the past decade, a dedicated 2.5-meter telescope at Apache Point Observatory, New Mexico, has transformed our knowledge of the inventory of the universe by producing the Sloan Digital Sky Survey (SDSS). The SDSS is one of the most ambitious and influential surveys in the history of astronomy. It has obtained deep, multicolor images covering more than a quarter of the sky, and created three-dimensional maps containing over a million galaxies and approximately 100,000 quasars. There is great interest in what the SDSS data reveal about the state of the universe during the first billion years after the Big Bang.

One member of the large SDSS team, Donald Schneider of Pennsylvania State University, has recently distinguished himself in the Thomson Reuters database.

Schneider currently ranks at #2 among the most-cited authors in the Thomson Reuter's *Essential Science Indicators*SM Space Science category, based on papers published and cited over the last decade. He was also featured earlier this year in the annual *Science Watch* roundup of authors with multiple Hot Papers published over the last two years (March/April 2009 issue).

> *"By some measures, the scientific impact of the SDSS over the past decade is comparable to or exceeds that of the Hubble Space Telescope,"* says Donald Schneider of Pennsylvania State University.

Schneider received a bachelor's degree in physics and mathematics from the University of Nebraska in 1976. He received a doctoral degree in astronomy from the California Institute of Technology in 1982 and was a research fellow there from 1982 to 1985. From 1985 to 1994, he was a member of the Institute for Advanced Study in Princeton, New Jersey. He joined the faculty at Penn State in 1994 as an associate professor of astronomy and astrophysics, was promoted to professor in 1999, and named Distinguished Professor in 2008.

From his Penn State office in University Park, Schneider spoke to Science Watch Physics correspondent Simon Mitton.

SW: What attracted you to research on high-redshift quasars?

In the late 1970s I was a graduate student at Caltech, where my thesis adviser was James Gunn. He was one of the designers of the first Wide-Field and Planetary Camera for the Hubble Space Telescope, which involved the use of charge-coupled devices (CCDs), which back then were novel. In my doctoral research I used prototype CCDs to obtain images of clusters of galaxies, to determine if the most luminous galaxies could be used as cosmological probes. CCDs were ideal for that research. I finished that project in the early 1980s.

The potential of this new CCD technology fascinated Maarten Schmidt, who in 1963 had first correctly interpreted the spectrum of the quasar 3C273 and determined its redshift (z=0.158). I was familiar with the data-processing requirements of CCD surveys because at that time we had to write our own software packages from first principles. I had the good fortune to be hired by Schmidt as a postdoc, and over the next fifteen years Jim, Maarten, and I performed a number of surveys for high-redshift quasars—that is, with redshift larger than four—in which Maarten was particularly interested.

SW: How did you make those surveys?

We used a scanning technique in which the telescope is a transit instrument, detecting objects as the rotation of the Earth sweeps them across the field of view of the CCD. This approach allows the spectra of a large number of objects to be obtained in a single night. I suspect the success of this technique stimulated Jim Gunn to propose the much bolder Sloan Digital Sky Survey. The SDSS camera, which Jim designed, is operated in scan mode.

SW: So, together you significantly increased the number of high-redshift quasars?

Yes we did. Several times a year the three of us would travel to the 5-meter telescope on Palomar, where we would scan strips of the sky. We would then examine the data, trying to spot potential quasar candidates, and then return to Palomar and use high-quality spectroscopy to identify high-redshift quasars.

SW: Would you describe the SDSS, and explain how it led to great progress in extragalactic research?

SDSS was conceived by Jim Gunn, who has led the project throughout its existence. Jim and the University of Chicago's Richard Kron and Donald York were the key people in the initial phase of the SDSS; it has been a great privilege for me to work with them. The scanning we'd done at Palomar suggested that much more could be achieved with a more capable CCD camera.

We started scanning in 1984 with one CCD, then Jim developed an instrument called the Four-Shooter for the Palomar 5-meter: it had four highly sensitive CCDs, and our quasar survey, after several years of effort, covered 1.5% of the sky. Jim soon envisaged a camera with 30 large CCDs that could image enormous areas of sky. SDSS was designed to investigate extragalactic problems, so the survey area avoided the galactic plane. In the end the SDSS covered one quarter of the sky.

The SDSS's great steps forward were obtaining digital, multicolor images of a large area of the sky to brightness levels that were significantly deeper than any previous survey with similar sky coverage (for example, the Palomar Sky Survey), and high-quality spectra of more than one million galaxies and quasars. The CCD camera was designed to take images using five different filters from the ultraviolet to the near infrared.

SW: What was your role?

I was asked in 1990 to be the chairman of the quasar working group; this was my primary contribution to the survey. At that time the number of catalogued quasars was only a few thousand, so the SDSS proposed far more than an order of magnitude increase in the quasar count. Furthermore, the quality of the spectra we obtained was far superior to most of the previously published quasar spectra. In 2002 I also became the SDSS Scientific Publication Coordinator.

SW: So, how many objects, and their spectra, can SDSS grab on a clear night?

There are many amazing aspects of the Sloan survey. The camera is a marvel. The telescope's optics are extraordinary: the focal plane has a diameter of 2.5 degrees, which is five times the apparent diameter of the Moon.

The survey technique is firstly to do imaging, from which we identify targets for spectroscopic investigation. Next we make an aluminum plate about a meter in diameter that represents the 2.5-degree focal plane view of the sky, and drill tiny holes exactly where the target objects (quasars, galaxies, even stars) are going to appear on the focal plane. Optical fibers are then attached to the holes; the spectrographs can record 640 simultaneously. The fiber optics feed two double spectrographs that obtain spectra covering the wavelength range between 380 nm and 920 nm.

Exposures are typically an hour in length, and SDSS has approximately 2,000 fields to view. On a really productive night the survey completes several thousand spectra of extragalactic objects. The Survey Coordinator, Steve Kent of the University of Chicago, did a masterful job of orchestrating the interplay of the imaging and spectroscopic observations to allow the data to be efficiently collected.

Highly Cited Papers by Donald P. Schneider and Colleagues, Published Since 2000

(Ranked by total citations)

Rank	Papers	Cites
1	D.G. York, *et al.*, "The Sloan Digital Sky Survey: Technical summary," *Astronom. J.*, 120(3): 1579-87, 2000.	1,905
2	C. Stoughton, *et al.*, "Sloan Digital Sky Survey: Early data release," *Astronom. J.*, 123(1): 485-548, 2002.	976
3	M. Tegmark, *et al.*, "Cosmological parameters from SDSS and WMAP," *Phys. Rev. D*, 69(10): no. 103501, 2004.	801
4	D.J. Eisenstein, *et al.*, "Detection of the baryon acoustic peak in the large-scale correlation function of SDSS luminous red galaxies," *Astrophys. J.*, 633(2): 560-74, 2005.	611
5	M. Tegmark, *et al.*, "The three-dimensional power spectrum of galaxies from the Sloan Digital Sky Survey," *Astrophys. J.*, 606(2): 702-40, 2004.	534

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I have to relate that when I gave my first talk on performing this quasar survey, at an astronomy meeting in 1991, initially the audience just laughed—they did not believe we could do it!

SW: A couple of the highly cited SDSS papers are on quasar spectra. Why is the survey particularly valuable for studying high-redshift objects?

My primary interest in the SDSS was its tremendous potential to identify high-redshift quasars. When the SDSS was first proposed, there were only about a dozen known objects with redshifts larger than four. Luminous quasars are particularly interesting as they are thought to be fuelled by supermassive black holes—those with a billion or more solar masses. When we detect high-redshift quasars, we are viewing them when the universe is less than a billion years old. What mechanism allows such massive objects to be assembled so quickly?

High-redshift quasars are rare and faint, so, to find them, large areas of sky needed to be scanned at high sensitivity. You also need to be aware that when you attempt to detect high-redshift quasars, very little of their radiation appears in the optical band; one must move to near-infrared wavelengths to study these objects. The SDSS possessed all three properties to find high-redshift quasars: coverage of large area of sky, ability to detect faint objects, and imaging and spectroscopic observations that reached to wavelengths longer than 900 nm. Our expectations in this area were exceeded: the SDSS had first light in May 1998, and before the end of the year the SDSS team, led by Xiaohui Fan, now at the University of Arizona, and Michael Strauss, of Princeton University, had identified the most distant luminous quasar (a redshift in excess of five).

SW: The most highly cited paper from SDSS is the technical summary, with Don York as the lead author. [Note: see adjoining table, paper #1.] The paper describes the data products and serves as an introduction to extensive technical online documentation. That paper was followed by the #2 paper in the table, on the early data release. What was the significance of these papers?

Paper #1 is the primer for the survey. It contains a description of the survey goals, the instrumentation, and the observing strategy—it is a must-read for anyone interested in the possibility of using SDSS data. The early data-release paper, 108 pages in length, describes the first public release of the SDSS data (in 2001) and contains a detailed description of the survey: e.g., definition of the survey coordinate system; construction of the object catalogs; photometric and spectroscopic calibration; details of the spectrograms; how to access the data, etc. The processing of the imaging data was particularly challenging; this was overseen by Robert Lupton of Princeton University. The exciting part—or the thrilling or scary part, you might say—was this: how to create a structure that has hundreds of gigabytes of data, and make it publicly available in a manner that would be efficient from the point of view of users.

In 2001, Internet capacities were far from what they are today. We had to anticipate the questions people would be asking of the data. Even though the early release was only a tiny fraction of what we have now, there was considerable concern in the team about the effectiveness of the data-access mechanisms. The evidence suggests that we were, in fact, very successful. If you examine the numbers of papers that are based upon SDSS data, I believe you will find that authors who are *not* members of the SDSS team are in the majority. Furthermore, studies of scientific impact have shown that SDSS has had an enormous influence: by some measures it is comparable to or exceeds that of the Hubble Space Telescope over the past decade.

SW: Four of SDSS's top-ten most-cited papers, including #2 in the table, describe the public release of the data. Observational astronomers usually like to interpret their data before releasing it publicly.

The SDSS team provides a public data release once per year. The final SDSS-II release occurred in the fall of 2008. With each release we publish documentation describing the data as well as any changes in the processing software, calibration, etc., that are relevant for interpreting the information. SDSS team members do have proprietary access to the fully calibrated data for a few months before it is released to the public, but the success of the survey would have been considerably reduced if the data had not been released by the community.

SW: The third-most highly cited paper, which is on the cosmological parameters, has more than 800 citations. How is the SDSS used as a cosmological probe?

Measurement of fundamental cosmological parameters was one of the driving forces in the creation of the SDSS. To address many aspects of this problem, one must assemble very large, extremely well-calibrated databases—exactly what SDSS was designed to create. With the positional (location on the sky) and redshift (distance from Earth) measurements you know where all these objects are in three-dimensional space; the SDSS allows us to view the locations of galaxies and quasars on the largest scales. The structures we observe act as constraints on cosmological models.

For example, the cosmic microwave background, which in a sense is a snapshot of the universe when it was only a few hundred thousand years old, acts as a very important constraint on the geometry and the basic parameters of the universe. The density perturbations in the microwave background have characteristic length scale (often called baryonic acoustic oscillations), which should be imprinted in the large-scale distribution of matter. By deterFor Sloan Digital Sky Survey, Acclaim Across the Universe this characteristic length at different redshifts, one has a direct measurement of the expansion of the universe, which is one of the fundamental constraints that any cosmological model must satisfy.

SW: Paper #5 in the table is on the three-dimensional power spectrum of galaxies. How does SDSS data help us understand the structure of the universe?

The fundamental SDSS observational quantity is a three-dimensional map of galaxies and quasars, along with their luminosities. We only have one universe, and since astronomy is a passive science, with no possibility of repeat experiments, we must use this snapshot to infer the properties that produced the observed configuration. The time scales for the formation of stars and galaxies are very long, so we do not observe changes in individual objects, but because of the finite speed of light we are able to obtain views of the universe at different times, which provides additional information to constrain theoretical models. The intellectual challenge is to determine the values the cosmological parameters must have to give rise to the structures as we see them today.

SW: Is the SDSS still in progress?

The original survey ran through to 2005; most of the originally proposed imaging and spectroscopy had been completed at that time. For three years starting in 2005 we had the second phase, SDSS-II, which consisted of three projects: 1) the Legacy Survey, which completion of the imaging and spectroscopy of the original survey; 2) a study of the Milky Way galaxy by obtaining new imaging data, often near the Galactic plane, and the spectra of tens of thousands of stars; and, 3) the SDSS supernova survey, which used repeated sweeps of a 300-square degree region of the SDSS supernovae at redshifts up to approximately 0.4.

The third phase of SDSS began in the summer of 2008. SDSS-III, guided by Director Daniel Eisenstein of the University of Arizona, and Project Scientist David Weinberg of Ohio State, consists of four distinct projects, and for the first time uses the SDSS telescope at all lunar phases: 1) an extension of the Milky Way structure survey, which will end in July 2009; 2) a precision radial velocity survey, using an instrument developed by Jian Ge of the University of Florida, to monitor approximately 11,000 stars with the goal of detecting exoplanets; 3) a survey, based upon the SDSS-I and SDSS-II imaging, that will obtain spectra of. approximately 106 galaxies and 105 quasars with the expectation of measuring baryonic acoustic oscillations at redshifts of 0.8 and 2.5; and 4) a Milky Way survey using a high-resolution, infrared spectrograph to acquire spectra of 100,000 stars to examine the chemical history of the galaxy.

SW: SDSS continues to be incredibly productive.

Yes, and we have high hopes for increased capabilities. This summer the spectrographs will be upgraded to improve their sensitivity and they will also be able to obtain 1,000 spectra simultaneously in preparation for starting the baryonic acoustic oscillation project in late 2009. I believe the next five years will be exciting ones for the SDSS!

SW: Finally, what for you has been the most satisfying aspect of SDSS?

Surveys provide the crucial, irreproducible archives that are needed to understand the universe, and they often address questions that had not even been conceived when the survey was completed. I truly believe the SDSS observations will be used for centuries, which is deeply satisfying. As I mentioned, surveys almost always produce discoveries that were not anticipated. In the case of the SDSS, our original proposal only mentioned stars briefly.

If you now examine the list of highly cited SDSS papers you'll find several important works on stars in our galaxy (which inspired the SDSS-II Milky Way project). The SDSS has greatly improved out understanding of stellar streams, which are produced by tidal stripping of dwarf galaxies that venture too close to the Milky Way. The SDSS has also discovered a number of new dwarf companions to our galaxy. The SDSS was not designed to address these questions about the Milky Way and its neighborhood, so much credit must be given to the astronomers who mined the data in an innovative way.

KEYWORDS: DONALD P. SCHNEIDER, DON SCHNEIDER, PENNSYLVANIA STATE UNIVERSITY, PENN STATE, SLOAN DIGITAL SKY SURVEY, SDSS, ASTRONOMY, QUASARS, SUPERNOVAE.

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