The Sloan Digital Sky Survey: From Asteroids to Cosmology

Conference Summary

Jim Gunn, 18 August 2008

An aside (or 2 or 3):

1987-2008 from concept to completion.

The *CONCEPT* was driven by the need for a REDSHIFT survey
We thought we could sell a redshift survey.

But imaging was a fundamental part of the original `strawman';
some of us, me included, were as enthusiastic or more so about the imaging than the spectroscopy.

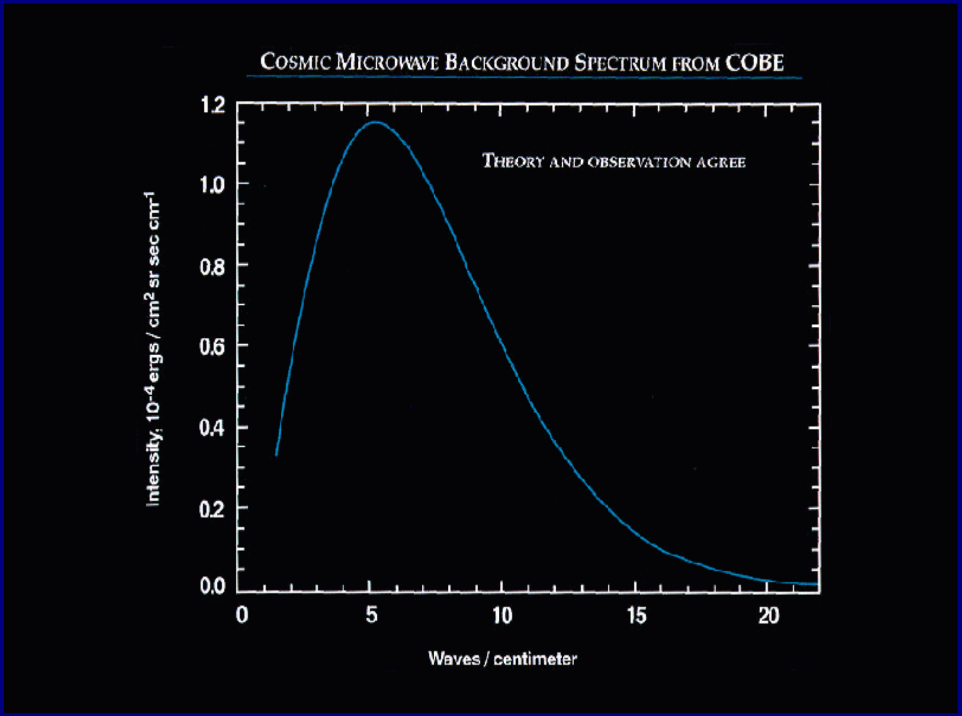
Why?

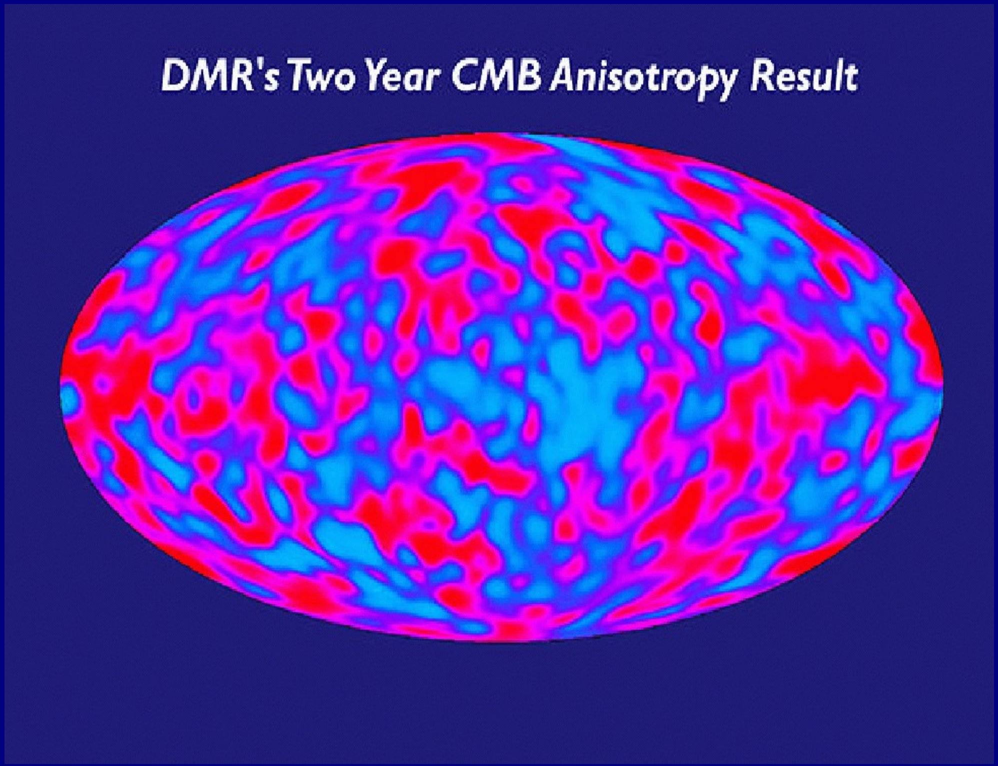
In X-ray, radio, IR—all the `new' astronomical bands, there were quantitative surveys, but NOT in the optical.

The technology was becoming available, we NEEDED a big redshift survey, and we NEEDED a quantitative survey to replace the photographic POSS>

Meanwhile.....

***18** years ago COBE was launched, and we knew for certain that the CMB was thermal, and fluctuations were discovered for the first time, which with limited precision appeared to agree with the predictions of inflation.*





We needed badly to have a good, big redshift survey to find out what these fluctuations evolved INTO.

So....

It seemed like a Really Good Idea to mount a large survey or surveys which could build upon the POSS and the CfA redshift surveys.

It should have accurate photometry over a broad a wavelenth range as possible, so modern detectors were necessary

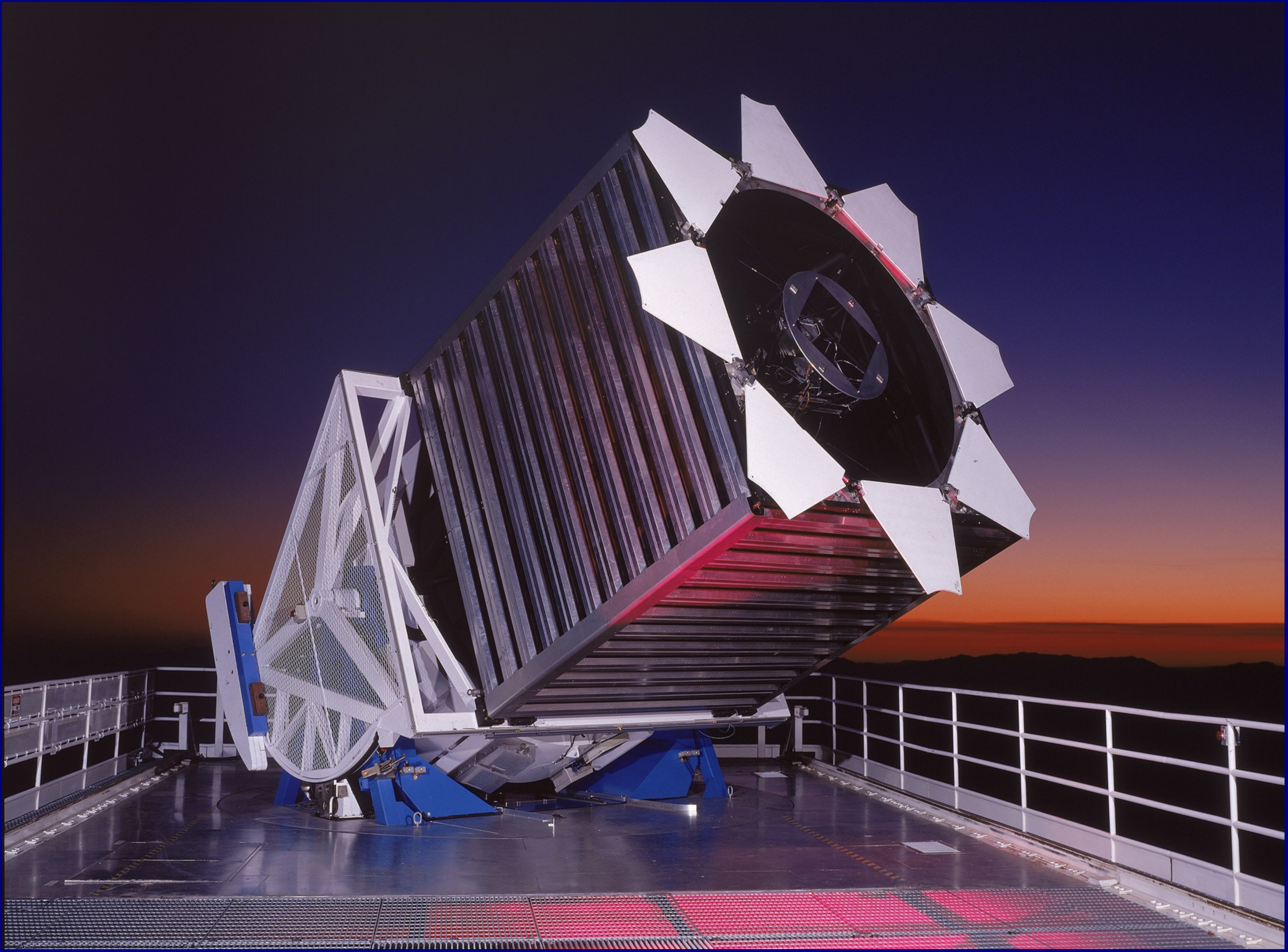
It should obtain spectra over as large a wavelength range as possible, and MUST multiplex in order to get a large number of spectra in a reasonable time.

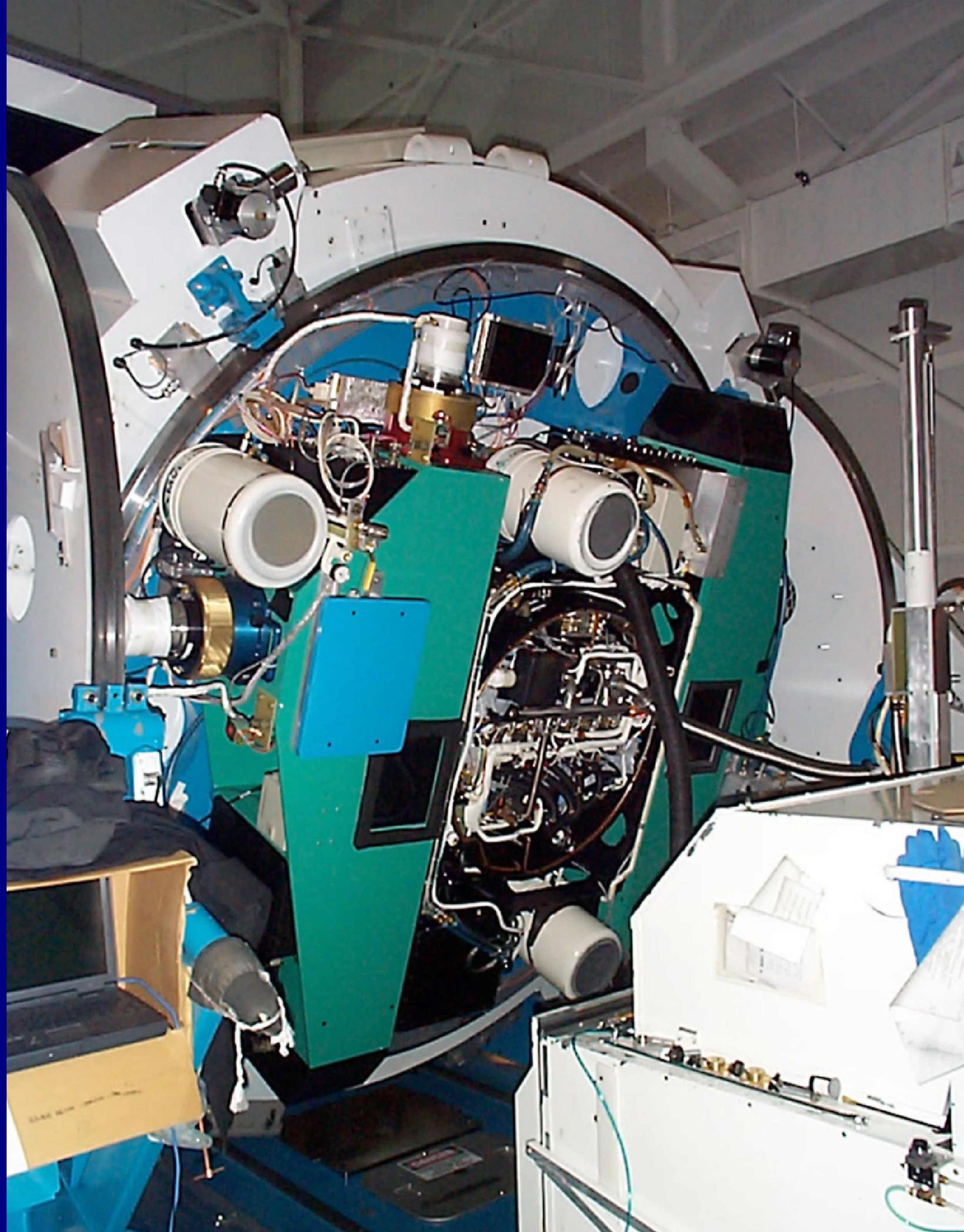
1 million galaxies x 1 hour exposure is 1 million hours

At a good site, there are ~1000 dark, clear hours per year

No overhead, 1000 years.

A few hundred fibers, a few years even with overhead.





But we did some more things.

Some scientific things.
Some organizational things
Some `technical' things
Perhaps, some guidance for the future.

SDSS has touched almost all the fields of astrophysics, and have heard about most of them here

LSS – not only from the distribution of ordinary galaxies, but LRGs, QSOs, lines in the Lyman-alpha forest, and the distribution of the dark matter from lensing. AND the quantitative description of the very different spatial distributions of galaxies of different types and luminosities.

`galaxies' don't trace ANYTHING; one has to be exquisitely careful.

The BAO co-discovery with 2dF, and the cosmic distance scale.

With WMAP, the emergence of precision cosmology and the concordance model.

Beautiful summaries from Simon White, Dan Eisenstein, Ofer Lahav. Hints at a crack in the concordance model from Will Percival, but preliminary yet; stay tuned. (DR7? BOSS ?) Will reminds us that z-space distortions are as powerful as lensing to measure structure growth (but require spectra. More later.)

*Twist on the L * M/L technique to get Wm from Jeremy Tinker (a grandchild) (The HOD had not been invented, so we could not promise or forsee any of the quite wonderful and diverse results from it, such as the spatial distribution of galaxies with quite simple assumptions from Andrey Kravtsov.*

ISW (we did not promise) from Bob Nichol—3 independent approaches, solid detection.

Martin Haenelt : the Lyman-alpha forest is a powerful tool for looking at P(k) for large k; consistency problems earlier with it may be resolved by doing the physics better. Probably best way to get at neutrino masses IF the (g)astrophysics can be understood.

Galaxies:

SDSS is not JUST a redshift survey and imaging survey—it is a SPECTROPHOTOMETRIC survey; the spectra are superb and well calibrated, as is the surface photometry in the images. David Schlegel always reminds me that the excellence of the spectra was a well-kept secret worth keeping—we could have gotten the REDSHIFTS in much less time.

One of the primary purposes of the SDSS (at least in my mind) was to establish the properties of the galaxies in the universe at the present with precision, so that we would know what the (much smaller) samples of high-redshift objects from large telescopes might evolve INTO.

SDSS discovered the red/blue bimodality of galaxy properties. Central theme of galaxy evolution presently, situation reviewed by Sandy Faber. The effects of environment (fraction but not properties) from Mike Blanton.

Quasar lenses from composite spectra and the mass distribution in elliptical galaxies from Adam Bolton (we SURE did not promise this one). Ellipticals have r^{-2} density distributions to large radii.

Galaxies, cont:

Dust is a major problem with understanding the intrinsic properties of galaxies from photometry and spectroscopy. David Schiminovich reminded us that with panchromatic data we might be able to begin to understand what is going on (We have to, I think.)

Evolution (or not) on the red sequence is a central problem, not well understood (are we asking too much of population synthesis models?) The situation was reviewed by David Wake.

SDSS provides the definitive fundamental plane for early-types. Genevieve Graves provides a dissection of the residuals, and we begin to understand things in terms of age, metallicity, and (maybe) baryon/DM ratio. Stay tuned.

Galaxy morphology (`real' morphology, as distinct from colors) has only recently received much attention, but now from thousands of people in the GZoo (Steve Bamford) and from a clever piece of code Changbom Park), and provides yet more for us to understand about galaxy properties. The importance is not yet completely clear.

Galaxies, cont:

How do black holes grow? Guinevere Kauffmann presented evidence that the growth is very tightly tied to the star formation rate, and demonstrates the same downsizing as seen in galaxy SF activity.

Very little of this incredibly rich field was anticipated, partly because the subjects were not well developed or did not exist when the survey was conceived, partly because the data are better than anyone anticipated, and partly because no one had considered the power of the sheer volume of data.

Quasars (cf Guinevere):

The luminosity function (Scott Croom, Gordon Richards)
Downsizing again. Big black holes producing powerful AGN do most of their growth at early times, but the inferred halo masses are constant at a few 10, solar masses. Type II objects exist at all luminosities, but are relatively less common at high luminosity.

From clustering (Nick Ross) : More evidence that at a given epoch, most BH in active galaxies have approximately constant halo masses and hence probably BH mass; clustering amplitude is relatively insensitive to luminosity. So Eddington ratio or, less likely) efficiency determines luminosity. Some evidence (Francesco Shankar) from continuity equation arguments that efficiency was higher in the past.

Naohisa Inada reviewed the long-term and excellent work by him and his collaborators on strong QSO lenses, which has produced 32 new lenses, two multiple-image cluster-scale ones; one of these shows the host galaxy clearly.

Quasars (cont)

Varsha Kulkarni reported on work on the metallicity of absorbers using zinc absorption. DLAs are metal-weak; weaker (subDLA) have high metallicity, some supersolar. Big metal-rich galaxies are running out of gas? (Yes, but quantitatively?)

Ryan Hickox told us about multiwavelength studies of AGN from the AGES survey. Downsizing again. Radio AGN in LRGs, Xray in green galaxies, IR in blue cloud galaxies, increasing Eddington ratio—again most active objects with halo masses of ~ few x 1012 solar masses.

Most striking thing from these talks was convergence on a constant halo mass for quasar activity, and strong suggestion of downsizing and decreasing Eddington ratio to explain luminosity function.

The Galaxy:

It is now generally agreed that the Galaxy as other galaxies have grown by accretion of smaller systems. Kathryn Johnston presented a set of diagnostics to determine the history , mass range, and orbital properties of the accreted objects by comparing with simulations. Heidi Newberg and Kevin Schlaufman presented techniques for and results of searches for structure in SDSS/SEGUE spectroscopic data, and Mario Juric described purely photometric techniques which also allow detailed mean structural parameters to be determined, including metallicity. Heather Morrison discussed the Monoceros structure and suggested that it could well be the result of a nearly planar accretion of a moderately massive satellite. geometry??? disturbance (?) of existing warp/flare ??

Gerry Gilmore discussed the structure of very small satellite galaxies as contrasted with star clusters, and suggested that there is a zone between 30 and 100 pc in size in which neither exist except for objects with only transient existence; all `real' galaxies having dark halos are > 100 pc in size.

The Galaxy(Cont):

The nature of the high-velocity HI clouds has been a mystery for many years, especially as regards their role in supplying the disk with fresh primordial gas to fuel star formation. Bart Wakker told us about distance measurements using SDSS BHB stars, complete and analyzed for 15 fields, 95 stars. It appears that the nearby large HVCs supply a few tenths of a solar mass per year of low-Z gas, and adding smaller ones may make the necessary ~1 solar mass/yr needed to maintain the SFR. (But the MW is dying—how much do we need NOW??)

Stars:

Pierre Bergeron showed us beautiful results on white dwarfs from the large SDSS sample. Luminosity function to high accuracy. Problems with model atmosphere energy distributions from insufficiently accurate Stark effect calculations MAY have large effects on DA SEDs and calibration. Stay tuned.

Tim Beers reviewed the stellar zoo as seen by SDSS, along with oddities such as magnetic pulsating white dwarfs.

John Bochanski reviewed his work on the lower main sequence, and showed that the mass function is well-represented by a log-normal distribution with a peak at about 0.3 solar masses; the mass function in the Galaxy is substantially flatter than Salpeter for masses < ~0.7 solar masses (and maybe a bit above??)

David Lai told us about ESI observations of elemental abundances in [Fe/H] < -2 stars at R~30 kpc. r—process `normal', but common carbon anomalies [C/Fe] > 1 in ~ 30% of objects.

Juna Kollmeier reviewed the fast stars ejected from the GC, fast, and argued that one should look for fast metal-rich lower-mass objects.

Solar System:

Zeljko Ivezic and Alex Parker outlined the remarkable work on a completely unpromised product of SDSS—the asteroids (~500,000 of them)

Half a million objects, color families coincident with dynamical families. Families reflect both composition and strength (Carbonaceous vs Silicates) and age/weathering

Major result: Fewer small objects, so probability of human survival until LSST has first light is significantly enhanced.

2006 SQ 372, 600au-- Oort cloud or Neptune ejectee??

Supernovae:

Wendy Freedman and Mark Sullivan discussed the Carnegie and CFHT Legacy SN surveys, Josh Freeman the SDSS survey.

One can do cosmology with supernovae (else the concordance model would have been pretty slow in coming), BUT the watchword now, all agree, is understanding the systematics in

dust
evolution
(spectro)photometric calibration
k corrections
malmquist
progenitor properties and environment
host properties
modeling techniques
color

Ryan Foley and Wendy agree that redder is bedder; maybe something very funny is going on in the UV.... but can the blue be far behind? (opacity ??)

More Supernovae:

Foley sneaks in some theory—some understanding of metallicity effects on Nickel 56 production, and effects of line blanketing in UV. Stay tuned.

Local SNIa rate from SDSS: ~ 3e-5Mpc^{-3}. Expected? What are progenitors?

Peter Garnavich: Other weird things found in SDSS Ia survey:

helium dwarf nova: double degererate Ia progenitor ??
lens double qso at 2.4 dt=short
deflagration type I (2)
ISM interaction (2)

for `normal' Ias:

rise and fall scaling different
hosts: metals correlate with Hubble residual (scary?)

Systematics, Systematics, systematics.....

The Future:

Many new surveys on the books, including incredibly ambitious ones (is LSST as large a step beyond the state-of-the-art as SDSS???) Striking that most of them are imaging-only surveys.

Won't discuss, but will say something about legacy of SDSS; `lessons learned'

1. Do it right. (Better, cheaper, probably faster in the end)

2. Do NOT do single-purpose surveys. Once a survey instrument is in place, marginal benefit/cost ratio to do more science is very high.

3. The goal of the software should be always to extract all of the information there is in the data (cf point 1). Think about the loss if we had only done photometry (it was actually suggested) to the limit of the main sample. Incredibly useful for diagostics, homogeneity.

4. Fund the software adequately.

The Future:

5. The benefit of the imaging/spectroscopy synergy in SDSS cannot be overemphasized. Photo-zs are not zs. (Some of the imaging surveys should use MANY filters?)

Laughter at a z=1 SDSS, but it is eminently feasible with an 8-meter class wide-field dedicated spectroscopic telescope over a comoving volume as large or larger than SDSS, either with its own imaging or in conjuction with, eg, LSST

WE REALLY NEED A BIG SPECTROSCOPIC SURVEY (LAMOST 2??-- but NOT in China)

Needs near IR capability, so can see old populations (stellar mass) in moderate-redshift galaxies. WFMOS will NOT do this. Probably need cheaper IR arrays.

6. Do NOT underestimate the calibration task. Photometry is really hard. Astrometry is really hard.

The Future:

7. It really IS possible for hundreds of people at tens of institutions to work together in a non-cat-herded manner (few if any constraints on subjects or projects) to produce excellent science.

The Future:

It even appears to be fun as well as useful. SDSS is the most highly cited project in astrophysics over the last few years, and in citations or papers per project dollar is offscale.

Thre are a lot of new projects.
There are a lot of US.
We know how to do this.

It appears to be fun:
SDSS has children (graduates?) doing even SDSS-III

> *The director, project scientist, one project head began as postdocs in SDSS. One project head as UNDERGRADUATE in SDSS.*

So it is possible to launch careers within big surveys—there was some reasonable doubt.

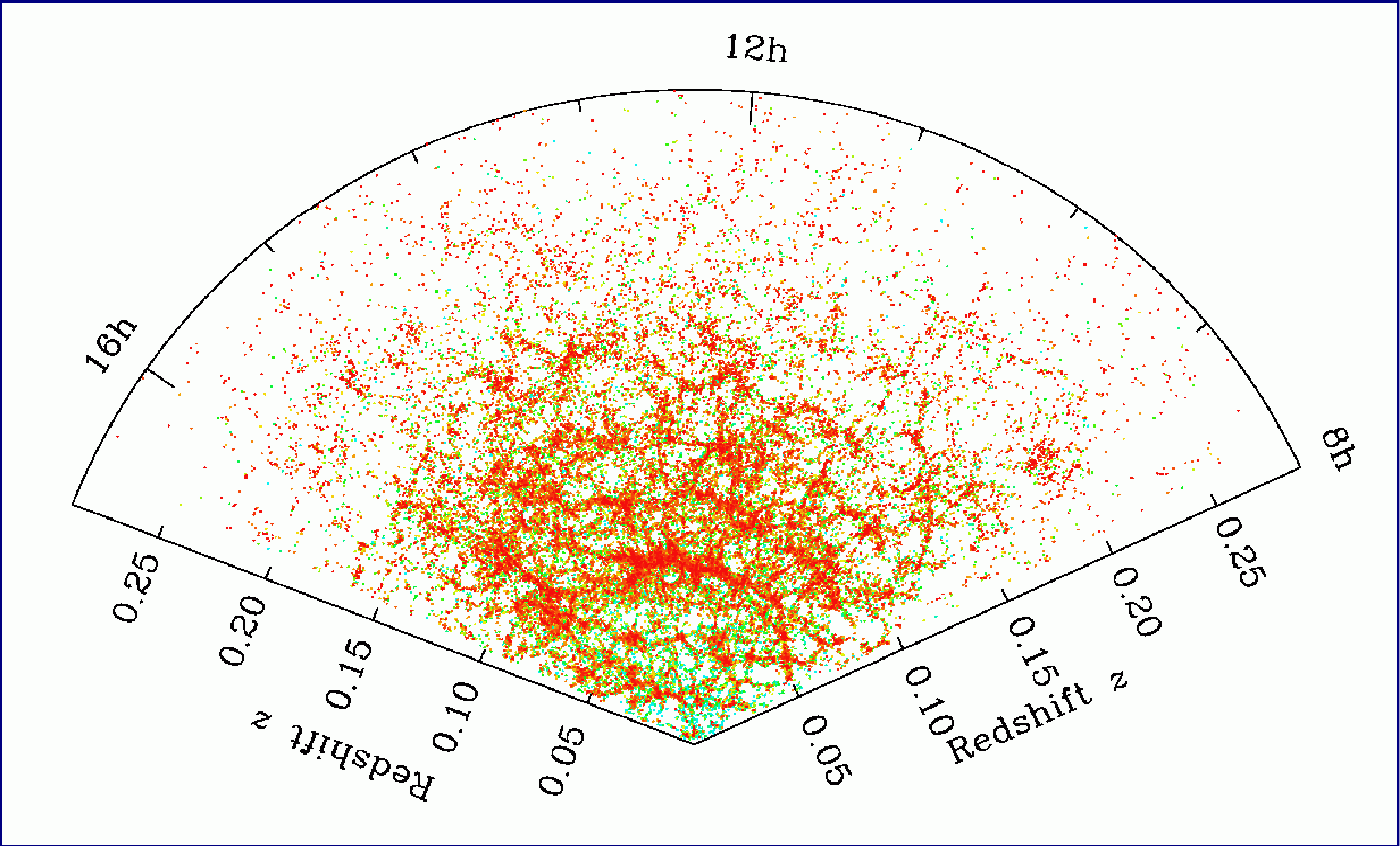
I have at least 4 academic grandchildren making presentations at this meeting, so doing survey science survives in the family.
=> People must like it.

The Future:

There is much to do, in SDSS I-II-III (especially -III)
Do it, and then move on.

Surveys are a new way to do science, and at least for the forseeable future, a good one.

So let's just do it.



Blanton, NYU, a few days ago