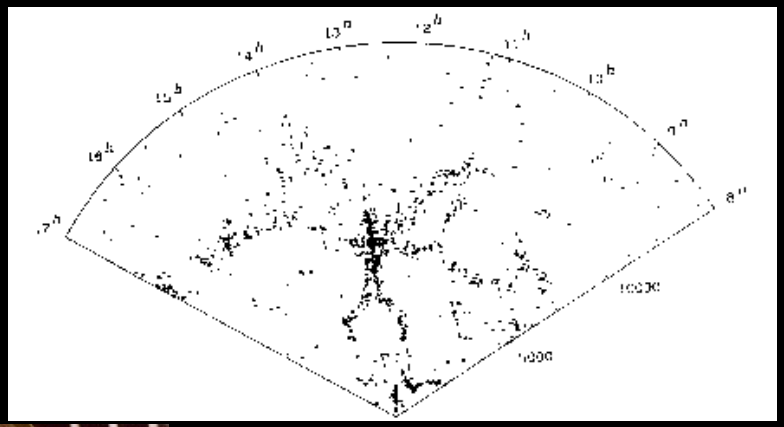
Observational Cosmology at Fermilab:

Sloan Digital Sky Survey
Dark Energy Survey
SNAP

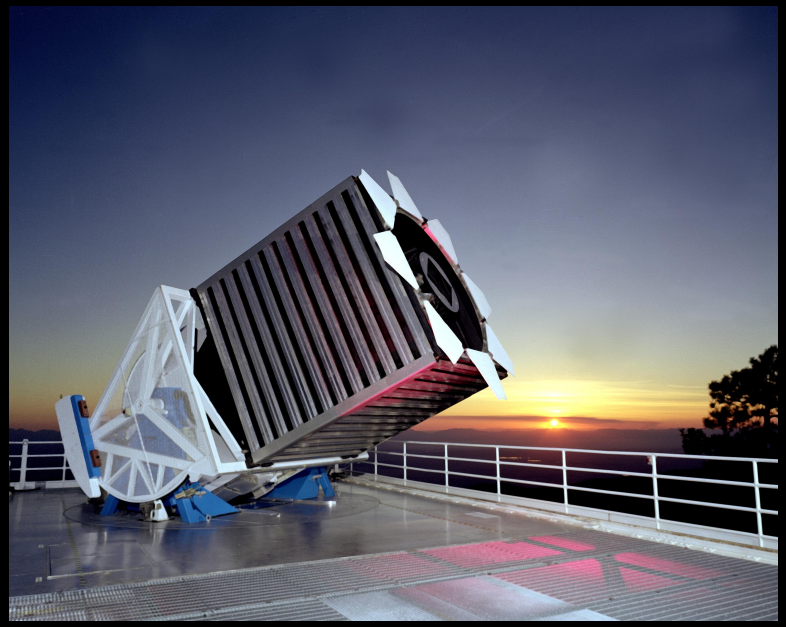
Gajus Miknaitis
Fermilab Users Meeting
May 31, 2006

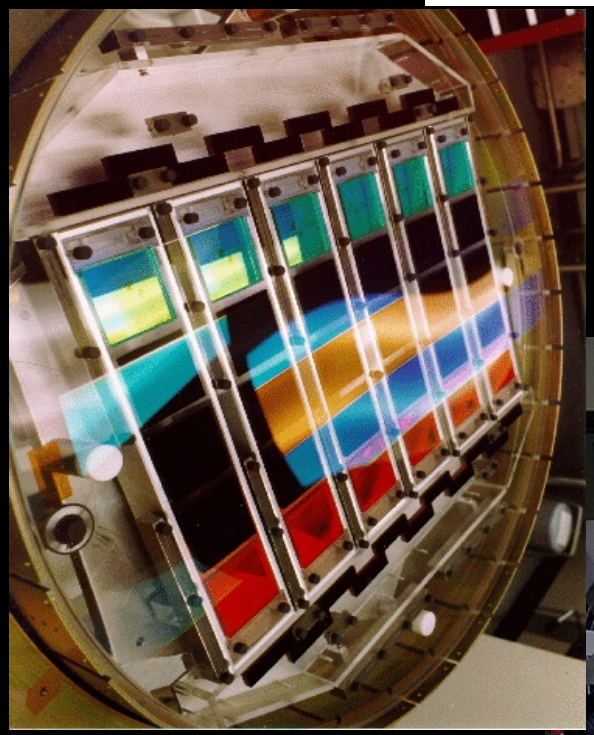
Sloan Digital Sky Survey (SDSS)

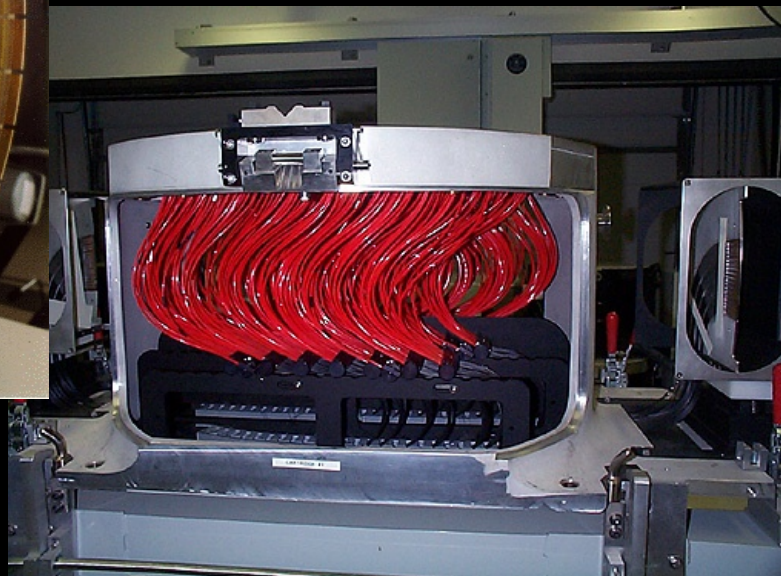
<u>Motivation</u>: study the distribution of matter in the universe by measuring the distribution of galaxies in space (2D + redshift)



CfA Redshift Survey (1986)







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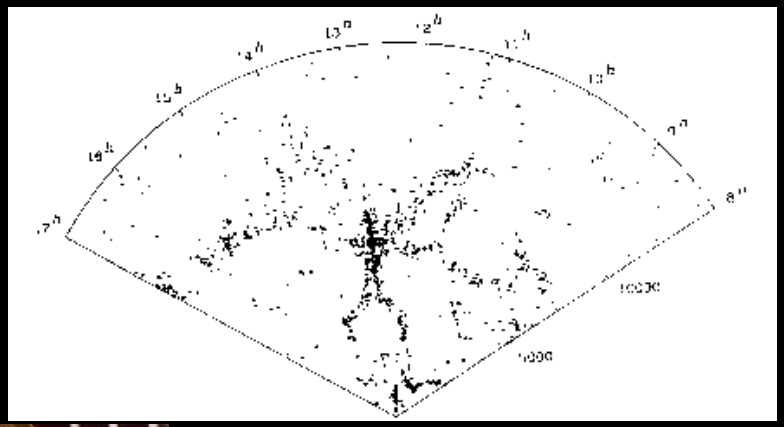

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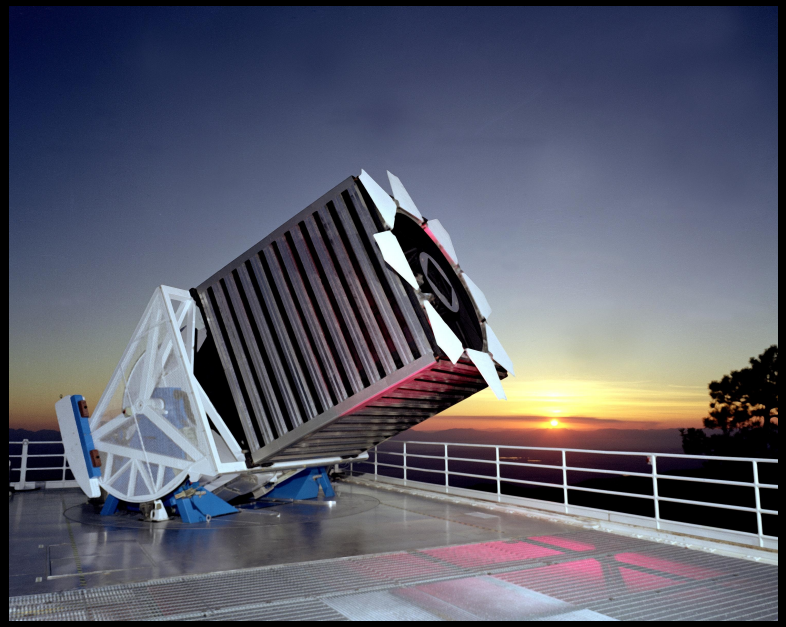
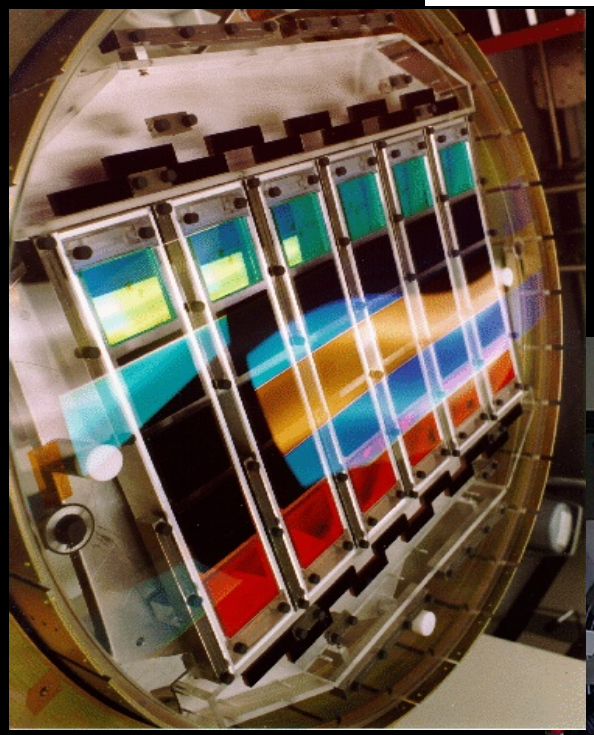
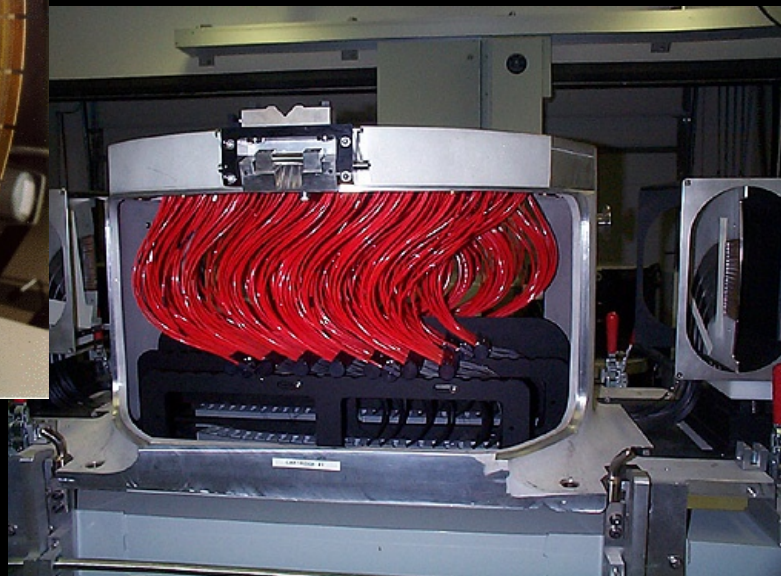




Imaging camera: →
find galaxies, measure their angular positions



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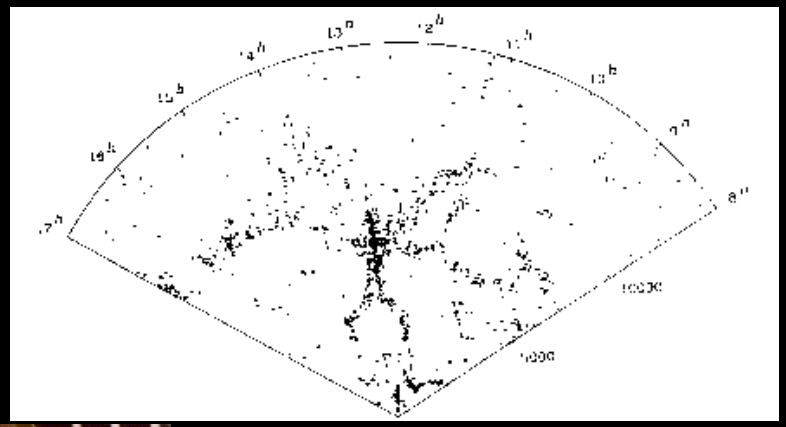

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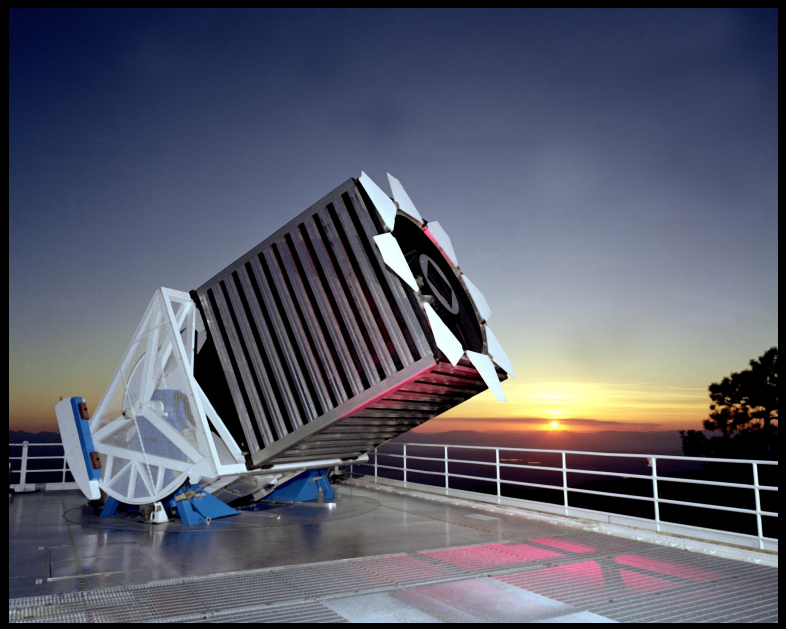
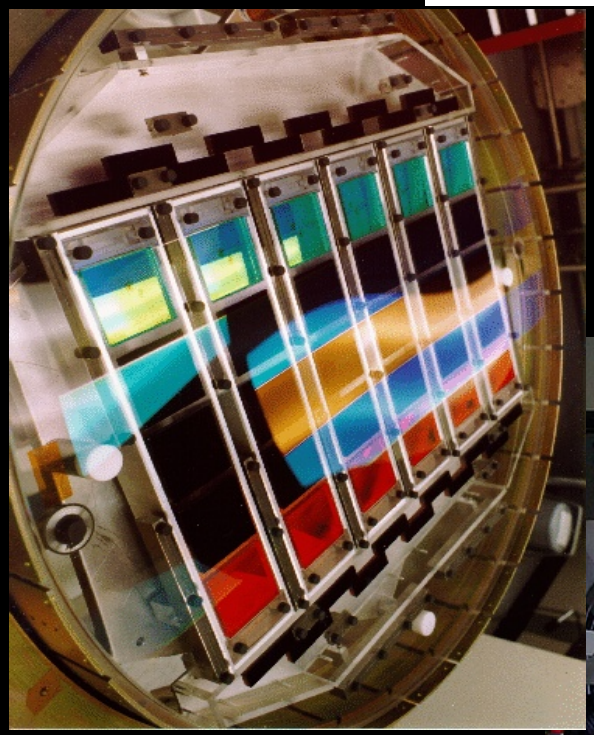
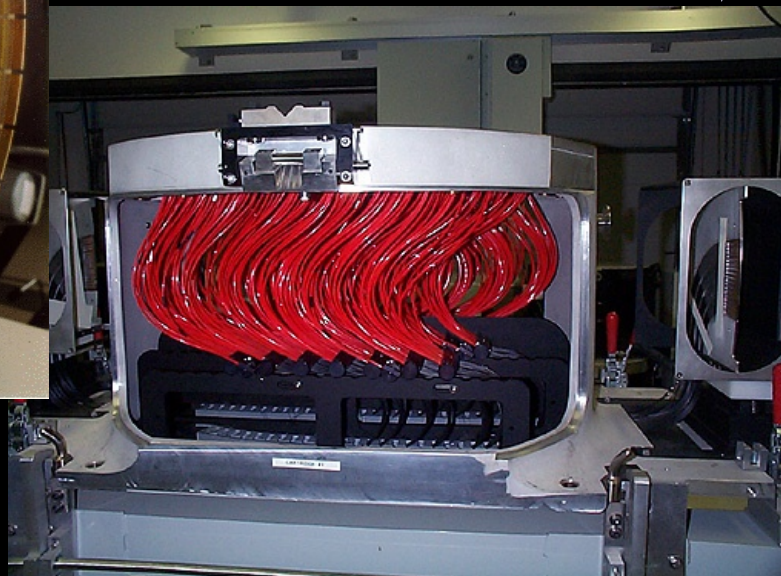




Multi-object spectrograph:
measure galaxy redshifts
distance ≈ redshift



Imaging camera:
find galaxies, measure their angular positions

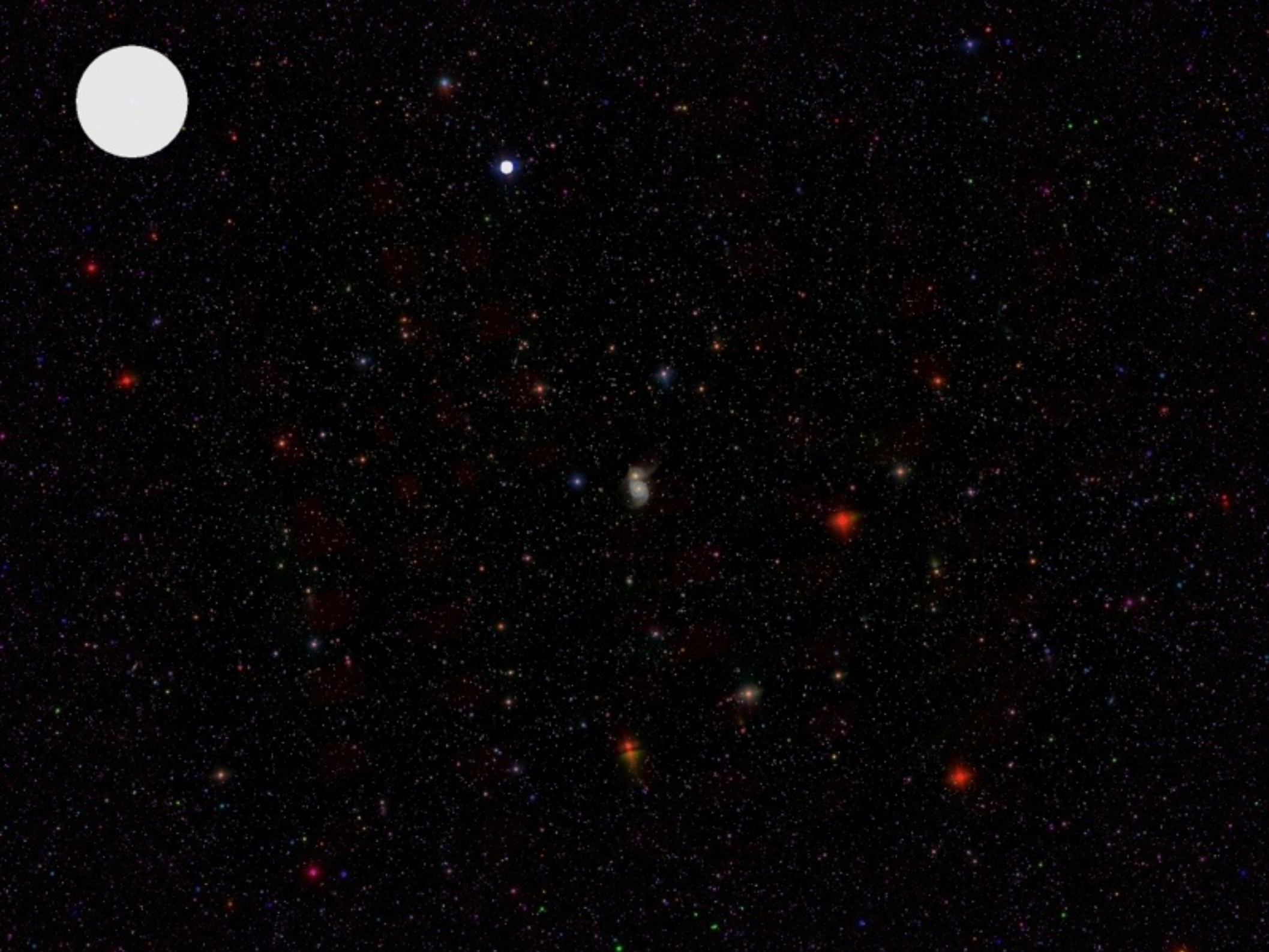
SDSS data set

After ~5 years of operation, SDSS has:

- imaged more than 8,000 square degrees of the sky in five bandpasses

- detected nearly 200 million celestial objects

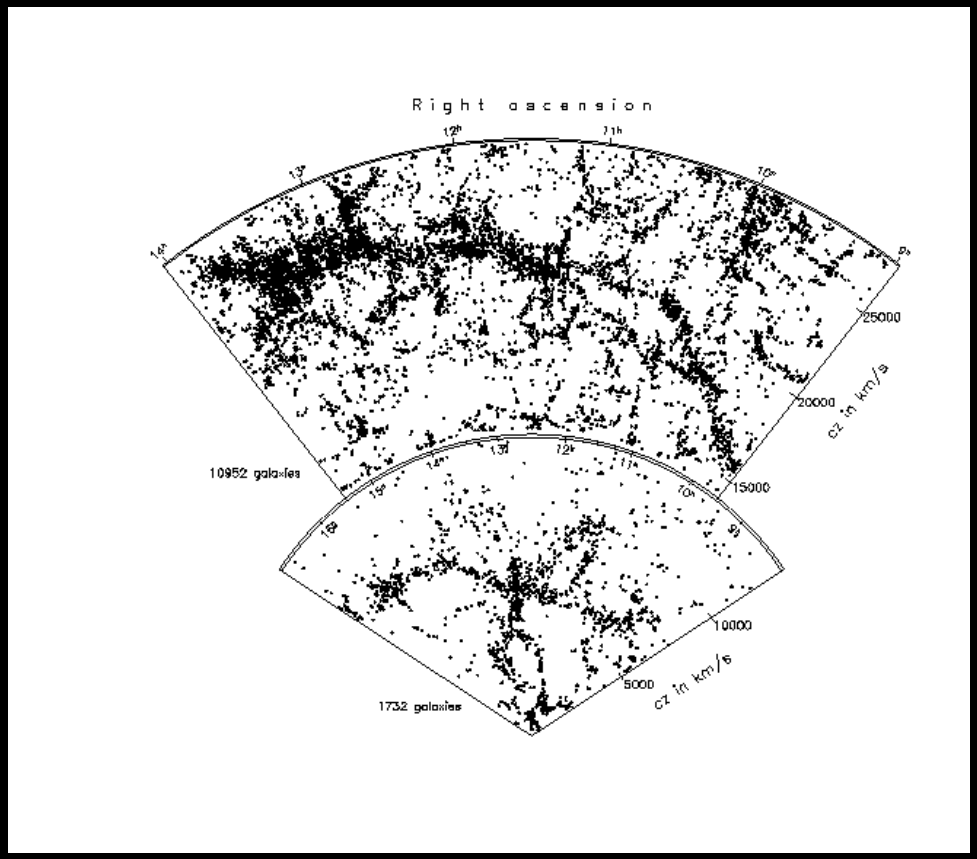
- measured spectra of more than 675,000 galaxies, 90,000 quasars, and 185,000 stars



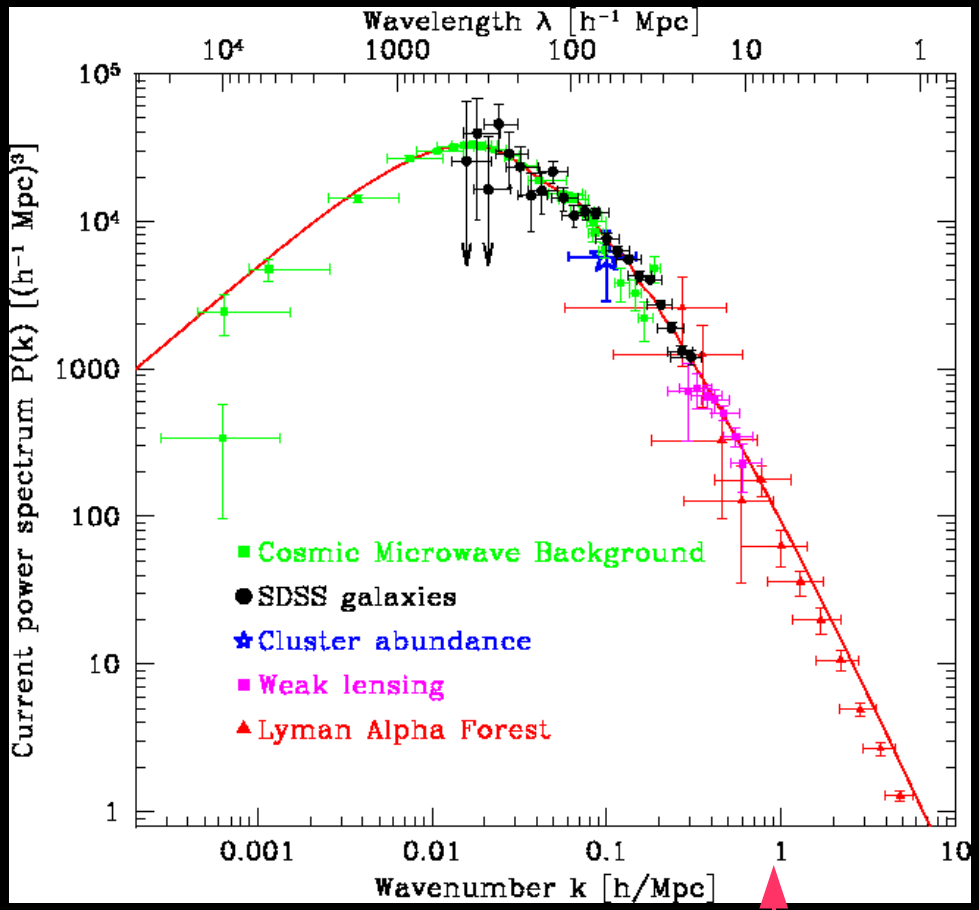
data: Sloan Digital Sky Survey
and the Bright Star Catalog

visualization: David W. Hogg (NYU)
with help from Blanton, Finkbeiner,
Padmanabhan, Schlegel, Wherry

SDSS & Large Scale Structure

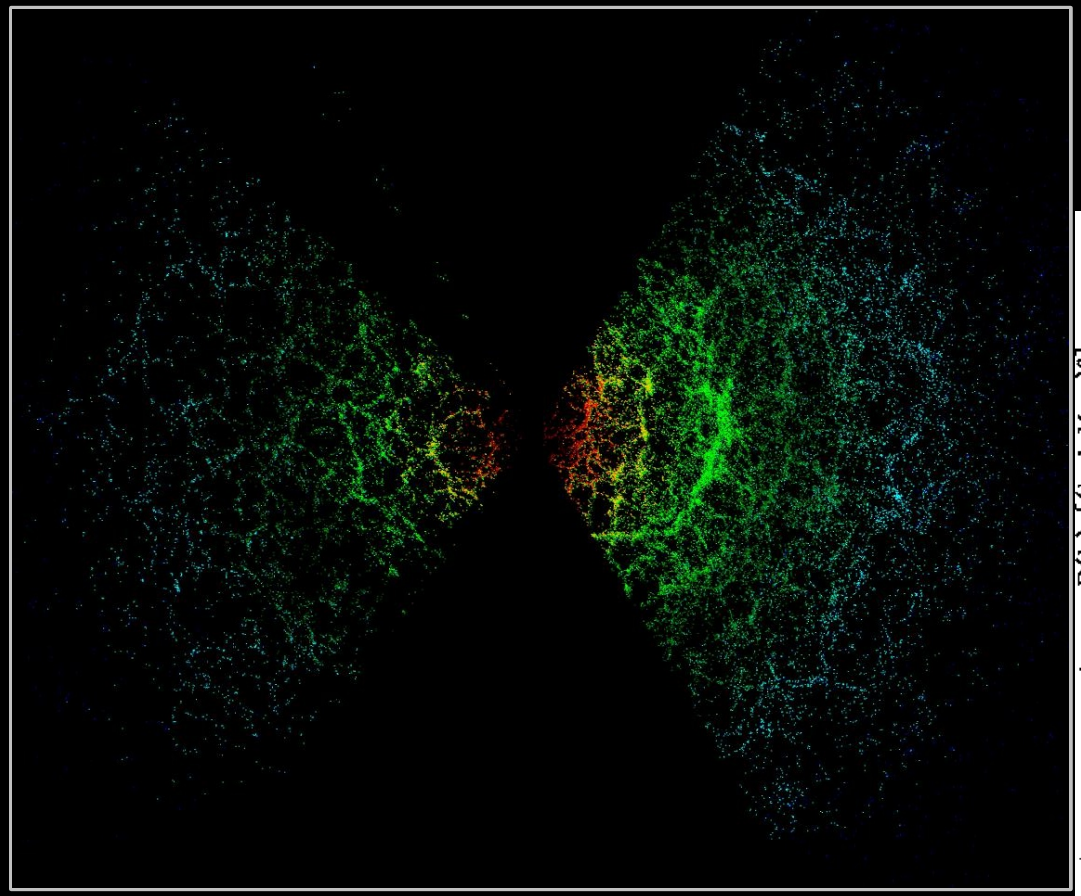


power spectrum of matter

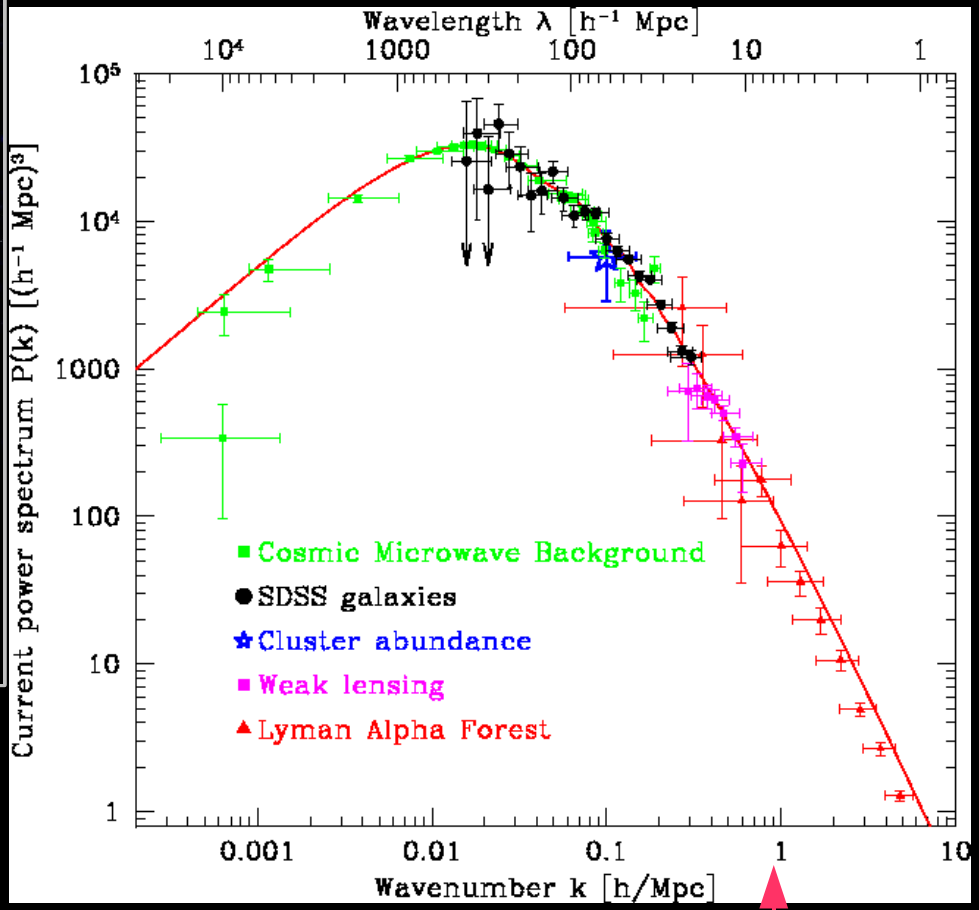


1 megaparsec

SDSS & Large Scale Structure



power spectrum of matter



1 megaparsec

Scientific impact of the SDSS

- As of May 30, 2006, **1080** refereed, published papers mention SDSS, “Sloan Survey” or make use of SDSS data
- Over 31,000 citations of these papers in the literature.
- 22 SDSS papers with more than 200 citations

Some science highlights

- State-of-the-art Large Scale Structure measurements
  - 3D power spectrum of matter
  - detection of baryonic acoustic oscillations
- Catalog of 10^5 quasars out to $z \approx 7$
- Reionization of the universe at $z=7$ (Gunn-Peterson effect)
- Catalog of 10^6 galaxy clusters to $z=0.5$
- Tidal tails and stellar streams in our galaxy
- Discovery of many rare low-mass dwarf stars
- etc, etc!

SDSS II: The Sequel

SDSS I: april 2000 - june 2005
completed

SDSS II: july 2005 - july 2008

SDSS collaboration

~150 scientists from

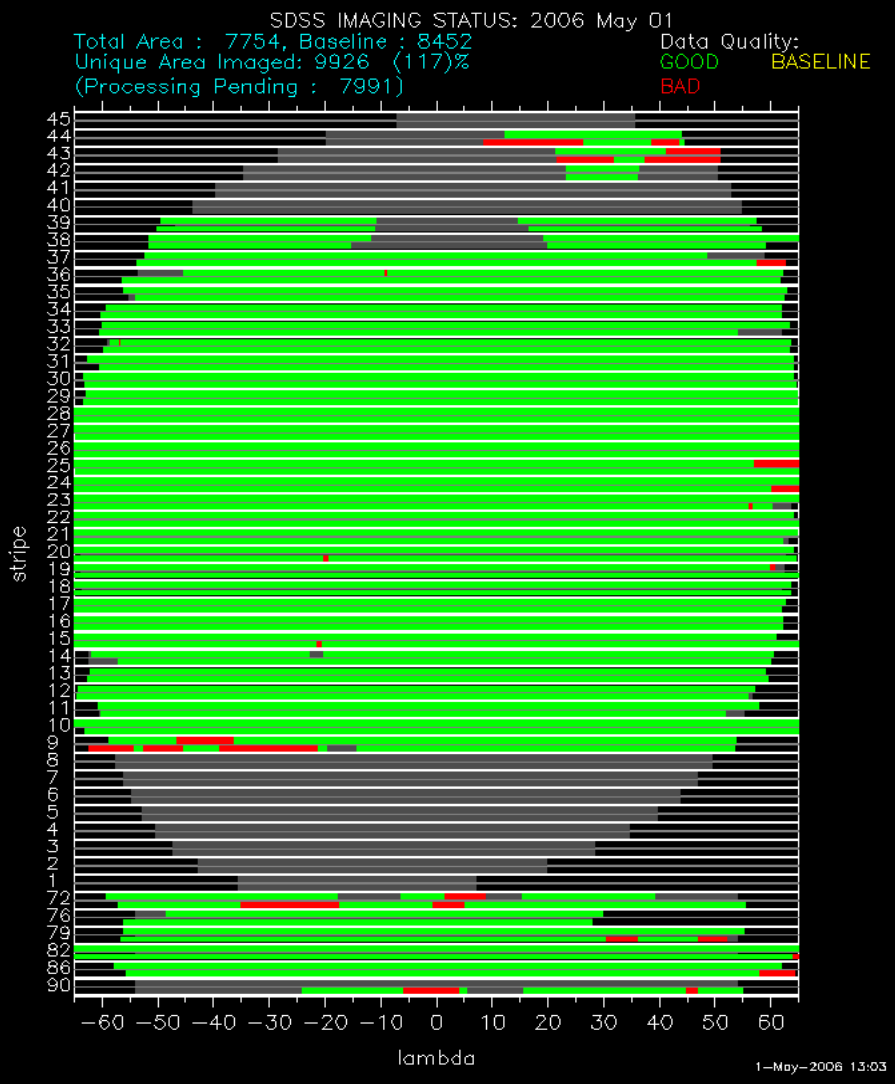
Am. Museum Nat. History
Astrophysical Inst. Potsdam
U. Basel
Cambridge U.
Case Western Reserve
U. Chicago
Drexel U.
Fermilab
Institute for Adv. Studies
Japanese Participation Grp
Johns Hopkins U.
JINA
Kavli Institute for Particle Astrophysics
Korean Scientist Group
LAMOST (China)
Los Alamos Nat. Lab
Max Planck Inst. Astron.
Max Planck Inst. Astrophy.
New Mexico State U.
Ohio State U.
U. Pittsburgh
U. Portsmouth
Princeton U.
US Naval Obs.
U. Washington

SDSS II: components

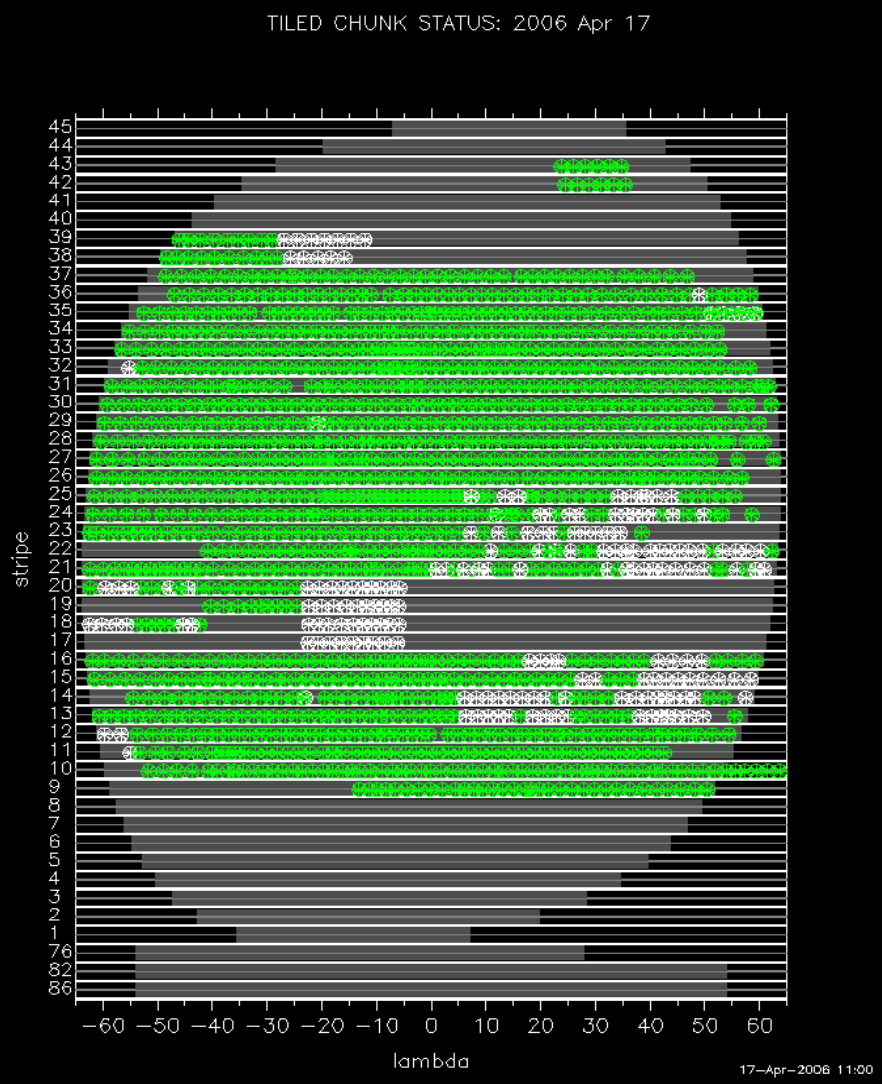
1. **SDSS "legacy"**: complete the original imaging and spectroscopy survey
2. **SEGUE**: study the (dark matter) halo of the Milky Way
3. **Supernovae**: survey to discover ~200 SNe to probe the expansion history of the universe (dark energy)

1. SDSS “legacy”

Imaging is complete
(gap filled)

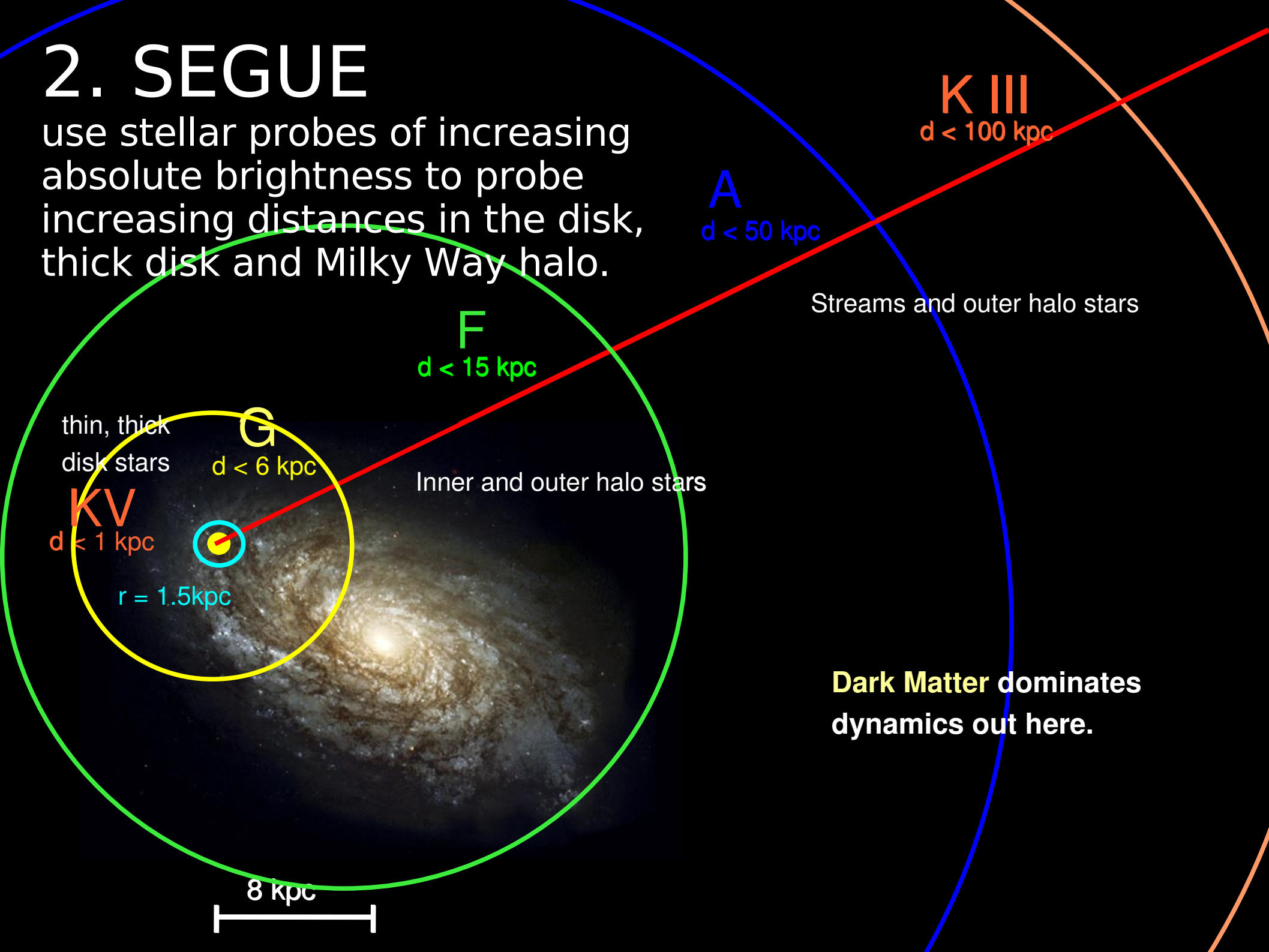


Spectroscopy on track
(two years left)



2. SEGUE

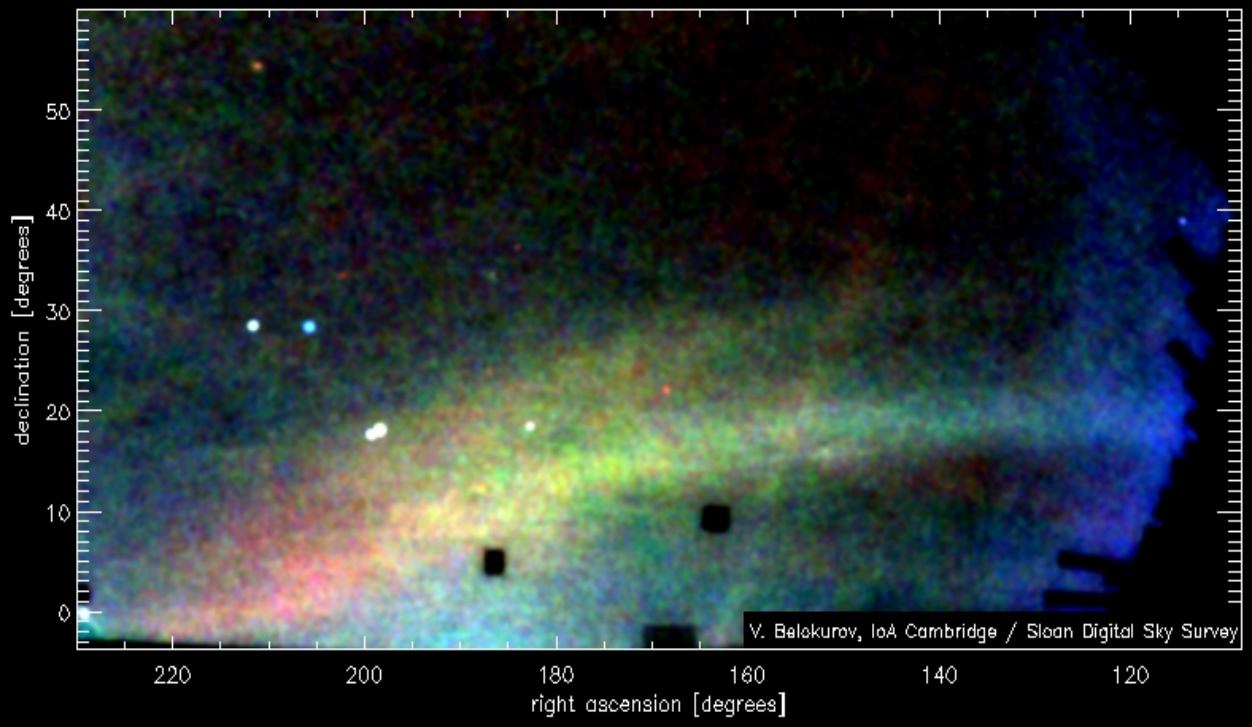
use stellar probes of increasing absolute brightness to probe increasing distances in the disk, thick disk and Milky Way halo.



Dark Matter dominates dynamics out here.

Star streams as probes of Dark Matter!

density of F stars in a patch on the sky, color-coded by their brightness



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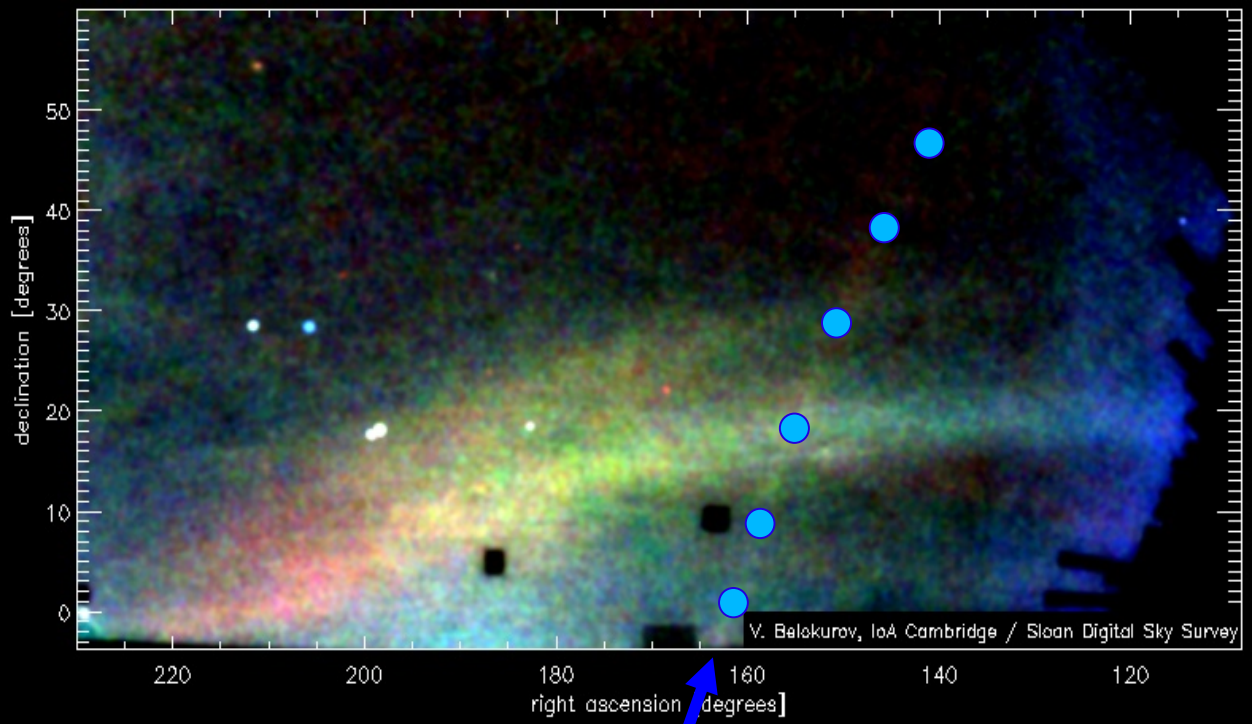

Newly discovered 'orphan stream'!

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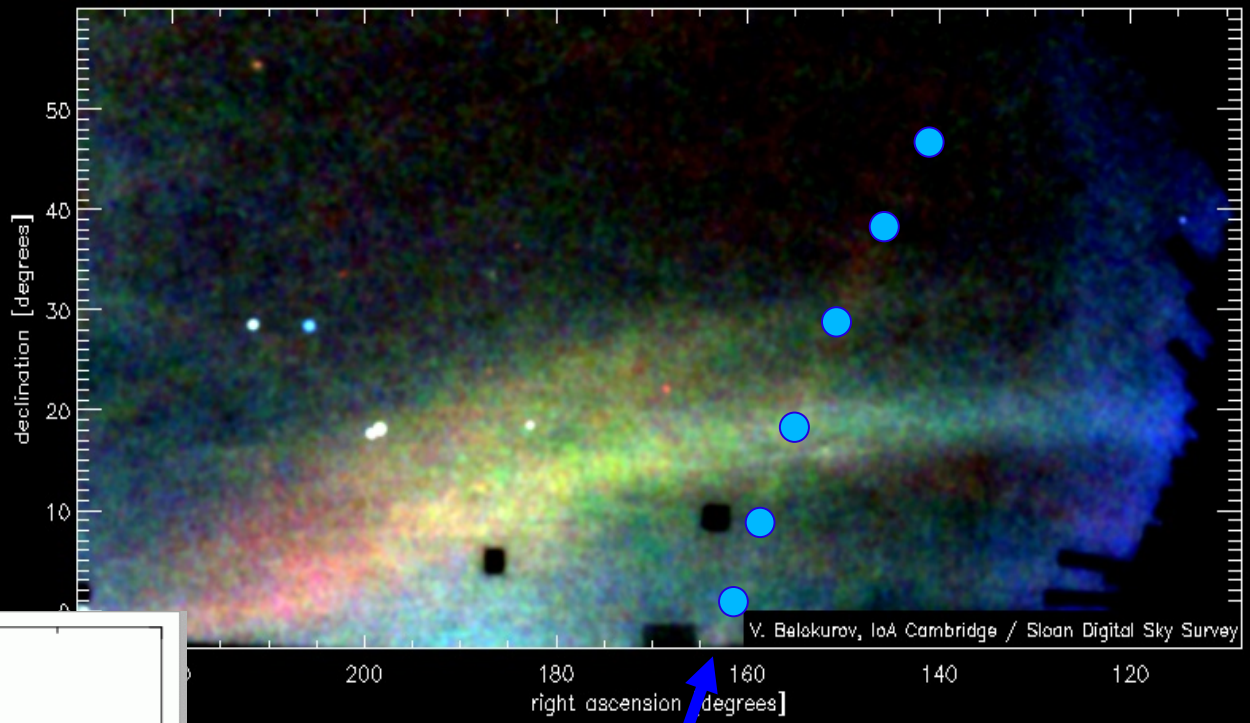
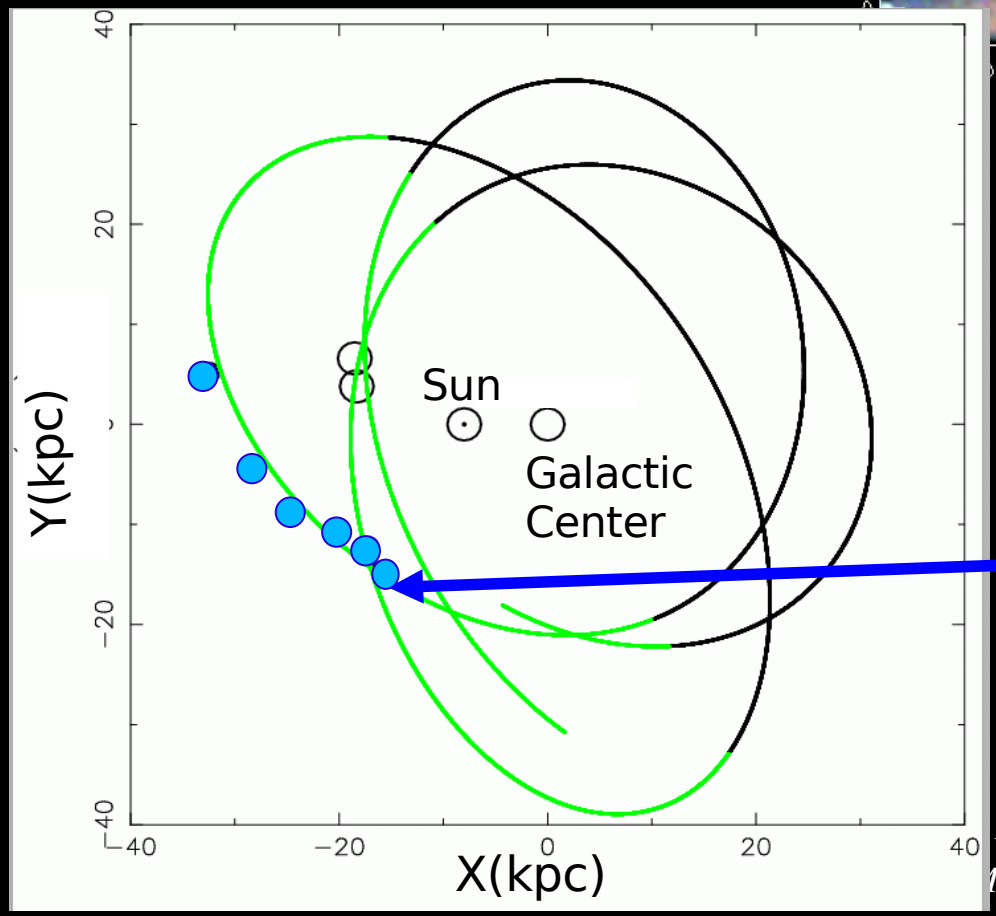




Newly discovered 'orphan stream'!

Fitting the orbit of this stream in 3-D can constrain the shape of the Dark Matter Halo surrounding our Milky Way Galaxy.

Fit is consistent with a spherical halo

Miknaitis

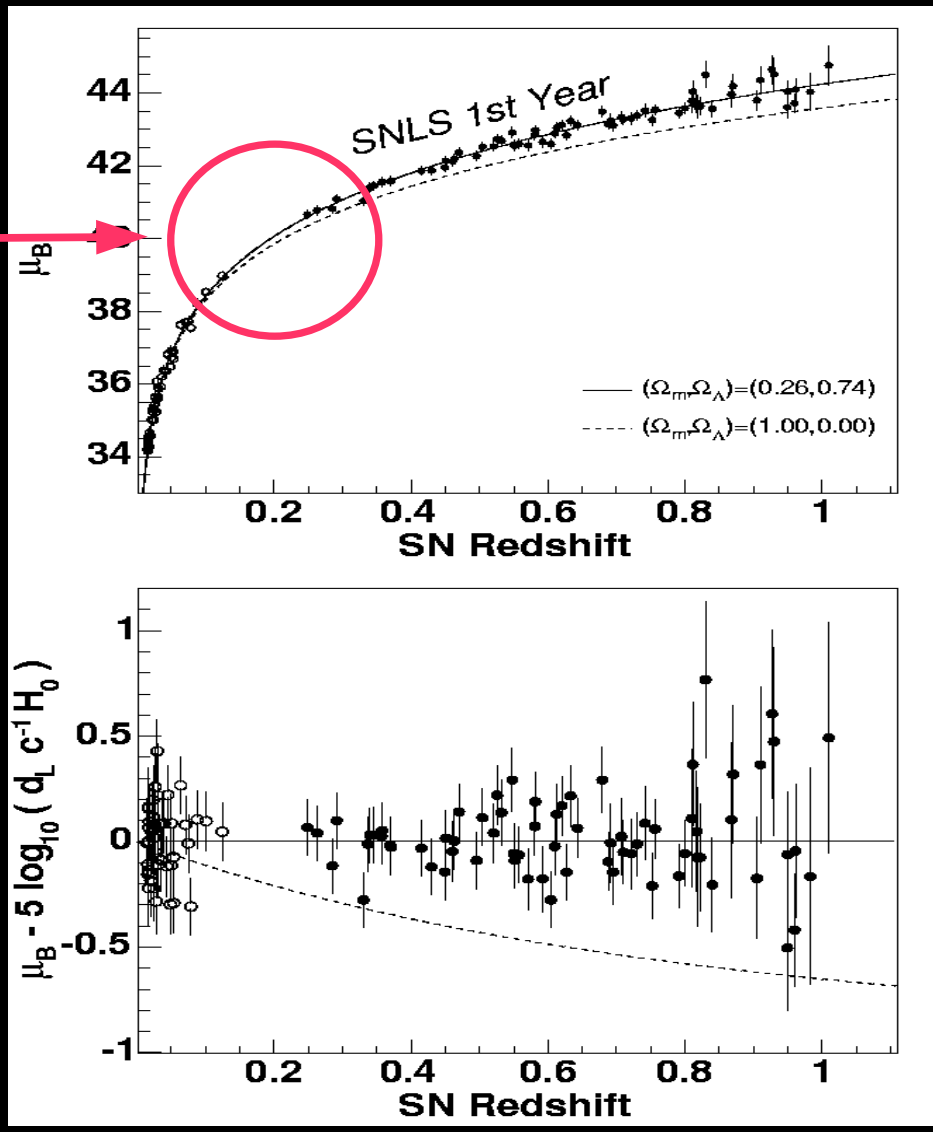
Meeting, May 31, 2006

3. Supernovae & Dark Energy

- Type Ia supernovae are standard(izable) candles.
- By measuring their brightness and cosmological redshift, we can trace the expansion rate & thus infer the make-up of the universe as a function of time.
- Initial SN experiments found surprisingly that the universe appears to be **speeding up**, fueled by gravitationally repulsive "**dark energy**".

3. SDSS II Supernovae

- SDSS well-suited to finding SNe at *moderate redshifts* that are difficult for other experiments
- Build up **large (~200)** sample of well-observed supernovae to study dark energy and better understand the supernova population
- Study *systematics* which are increasingly important with larger samples



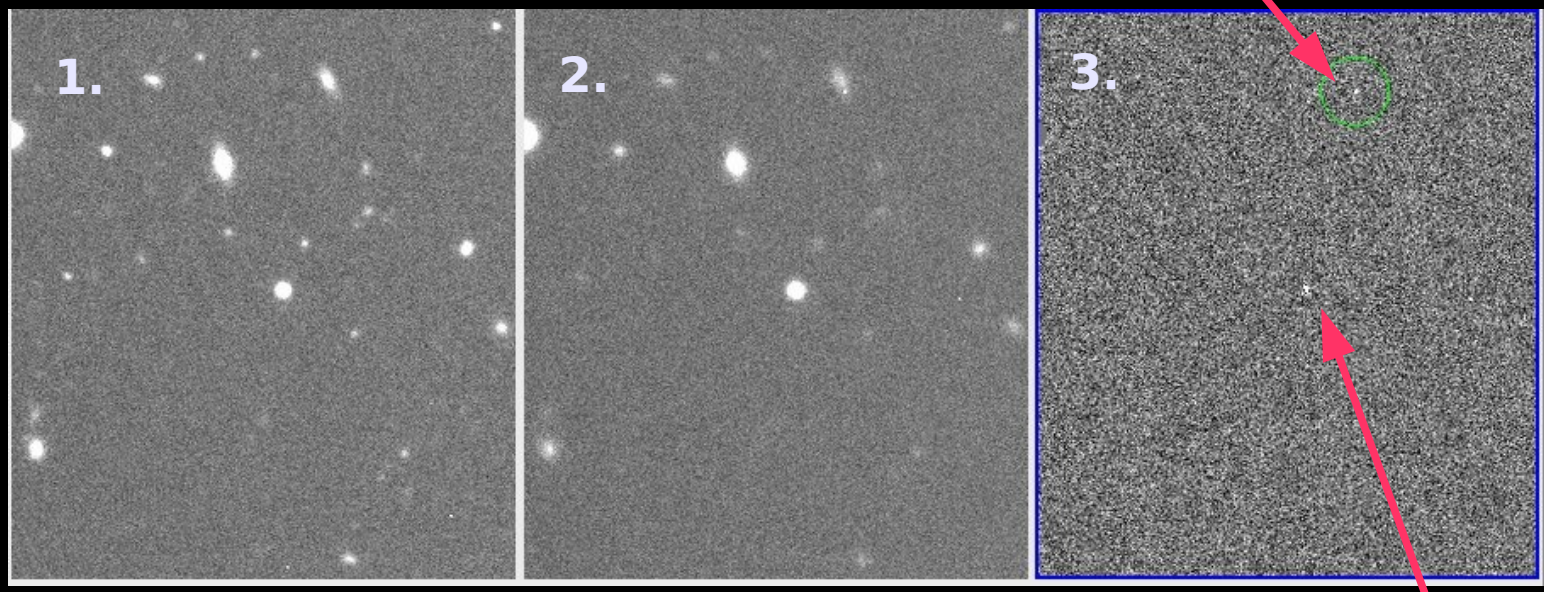
Astier '06

Finding and measuring supernovae

1. Take an image

2. Take another image later

3. Subtract the two



supernova

subtraction artifact

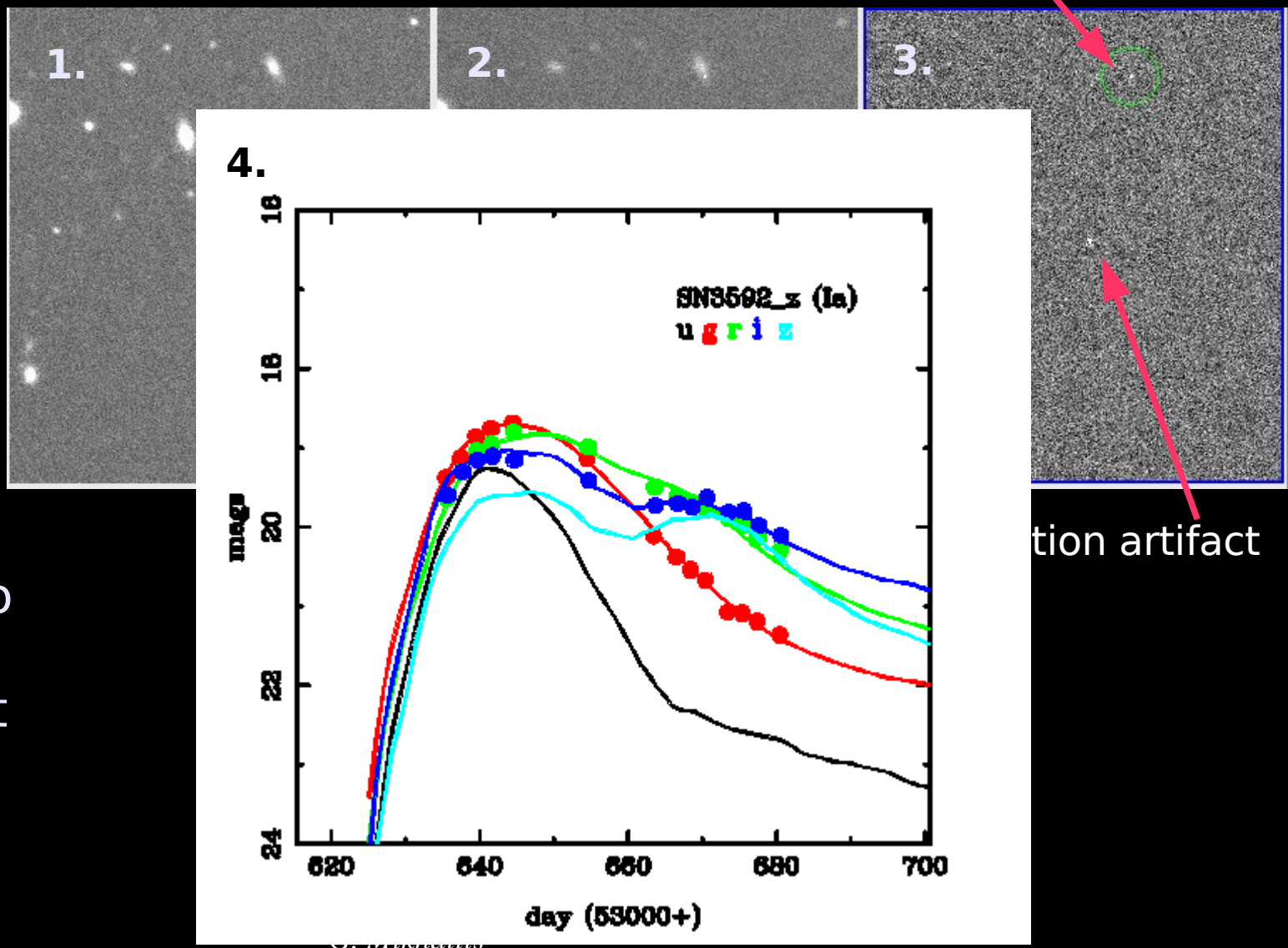
Finding and measuring supernovae

1. Take an image

2. Take another image later

3. Subtract the two

4. Continue taking images to measure supernova “light curve”

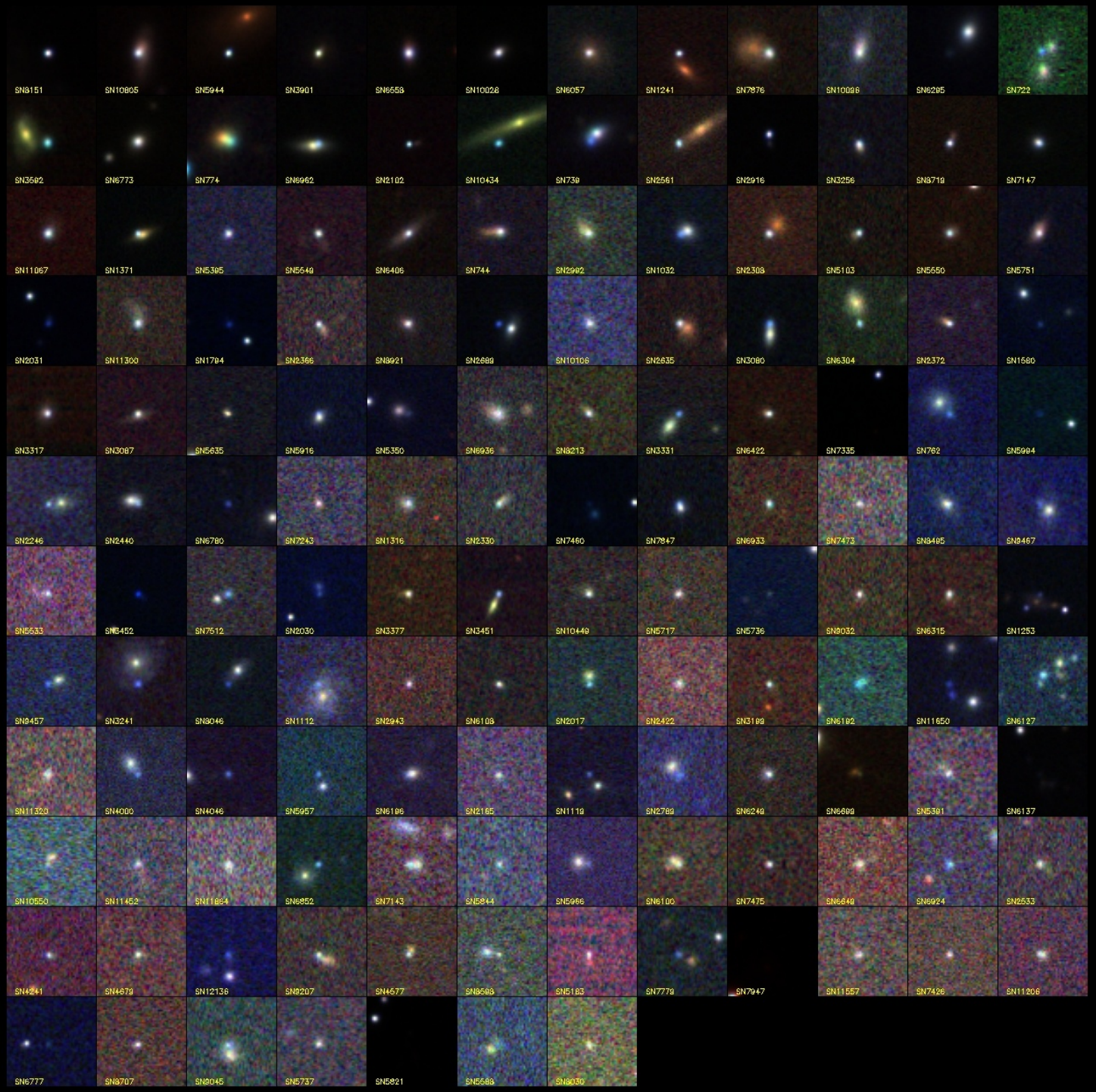


SDSS II first year supernova yield:

139 spectroscopically confirmed Type Ia Supernovae from the Fall 2005 Season

Analysis is underway

2 more years to go!



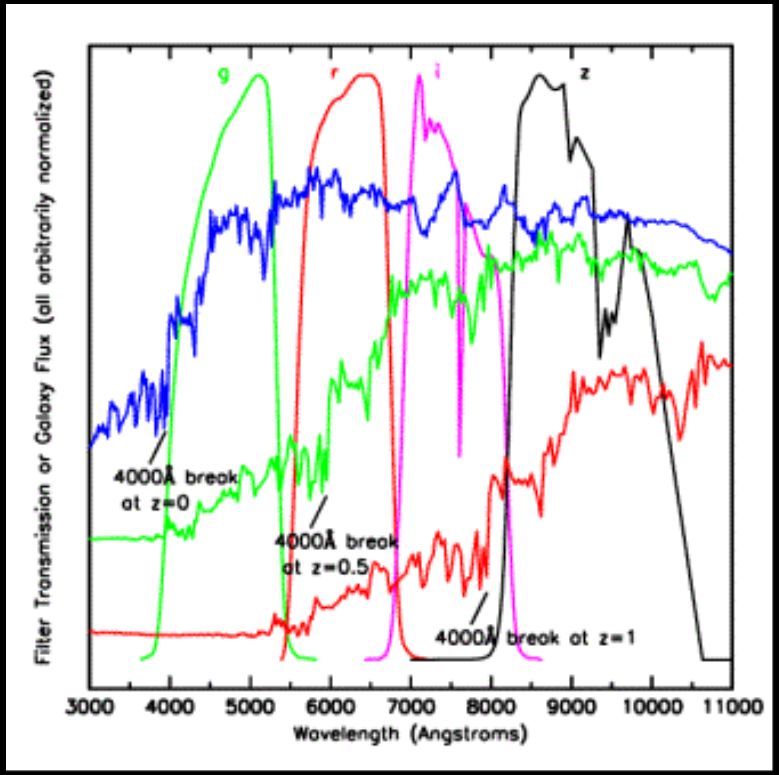
Future projects

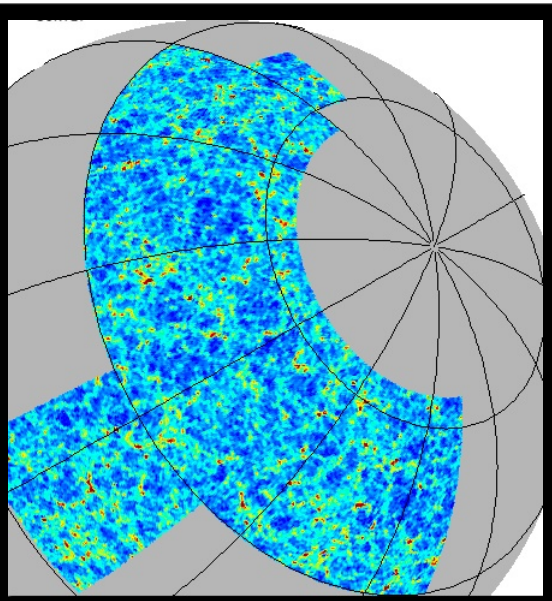
1. **Dark Energy Survey**
first light: 2009

2. **SNAP**
first light:~2015

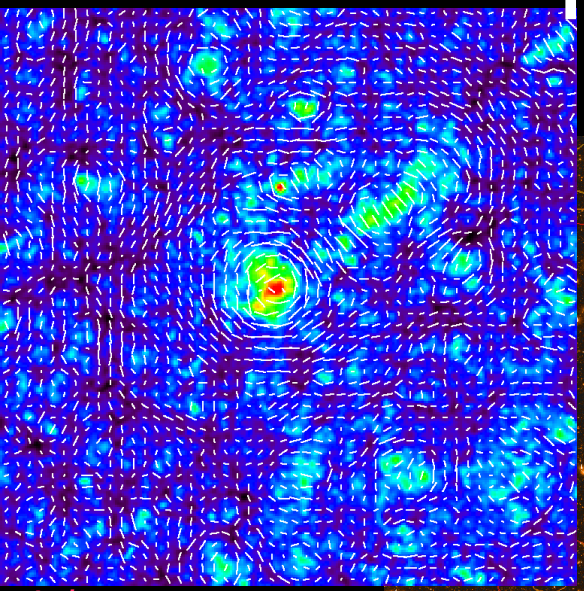
Dark Energy Survey

- What is Dark Energy?
  - Cosmological constant?
  - Scalar field?
  - Modification to gravity?
- Carry out a "photometric" redshift survey to study Dark Energy with **4 complementary techniques**
- Observe **5000 deg²** in 4 broadbands, in Southern hemisphere to overlap with CMB observations by South Pole Telescope
- Requires a new 62 CCD camera (much larger than any current instrument)

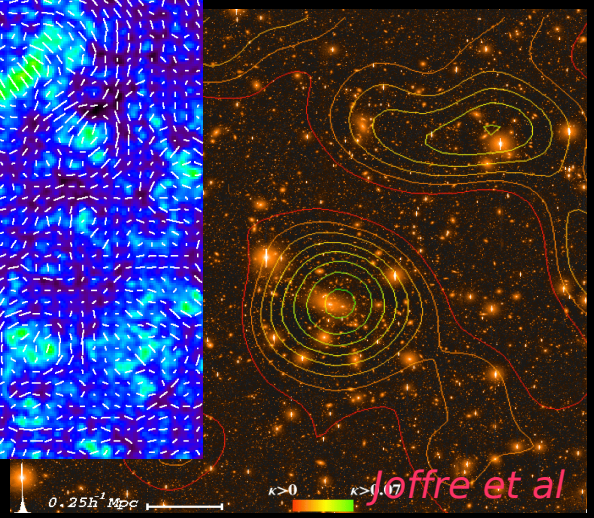




Four probes of Dark Energy

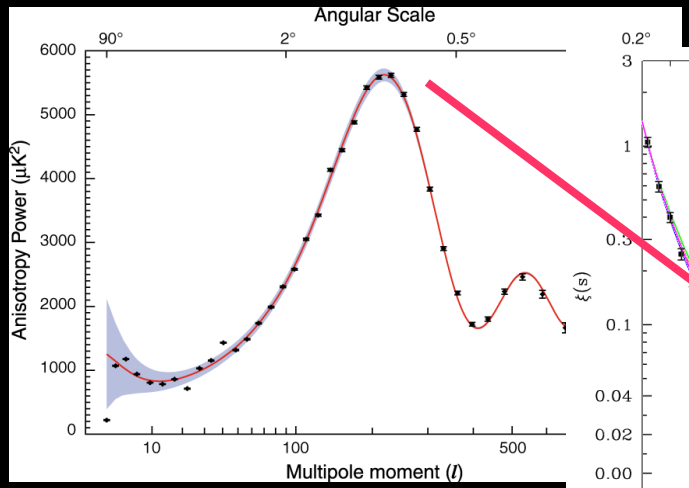


Jain

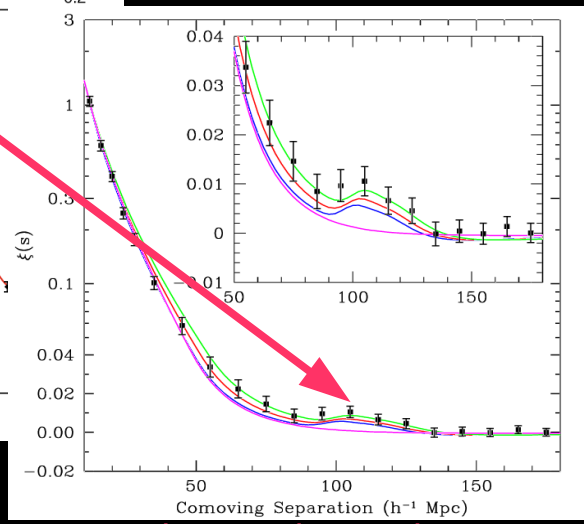


Joffre et al

1. Weak gravitational lensing

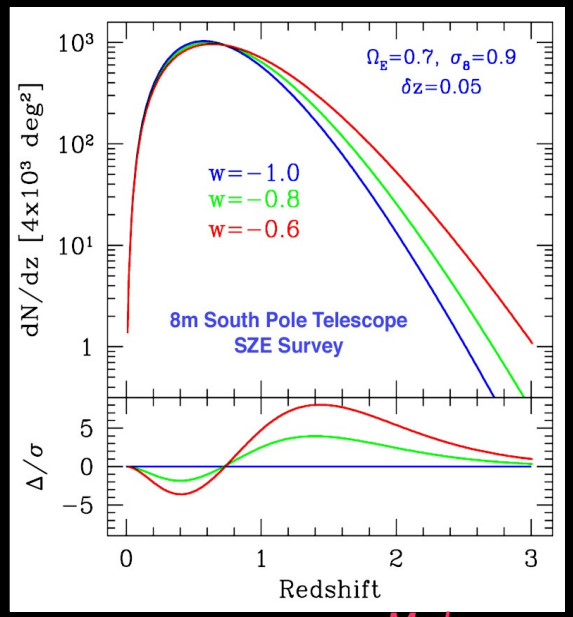


WMAP team



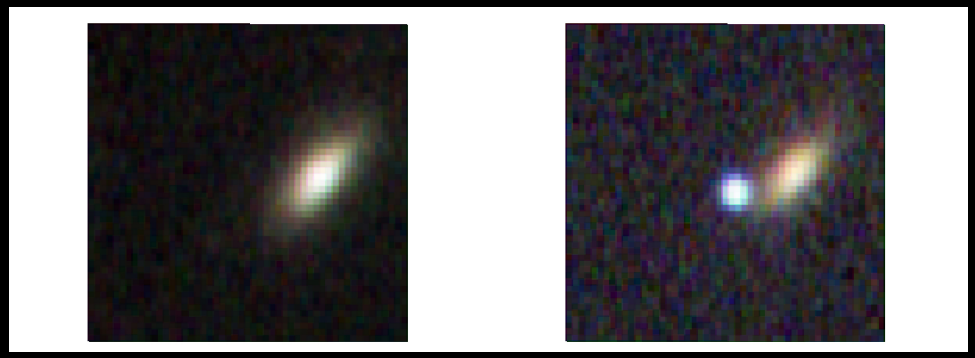
Eisenstein et al

2. Baryonic Acoustic Oscillations



Mohr

3. Cluster counts



4. Supernovae

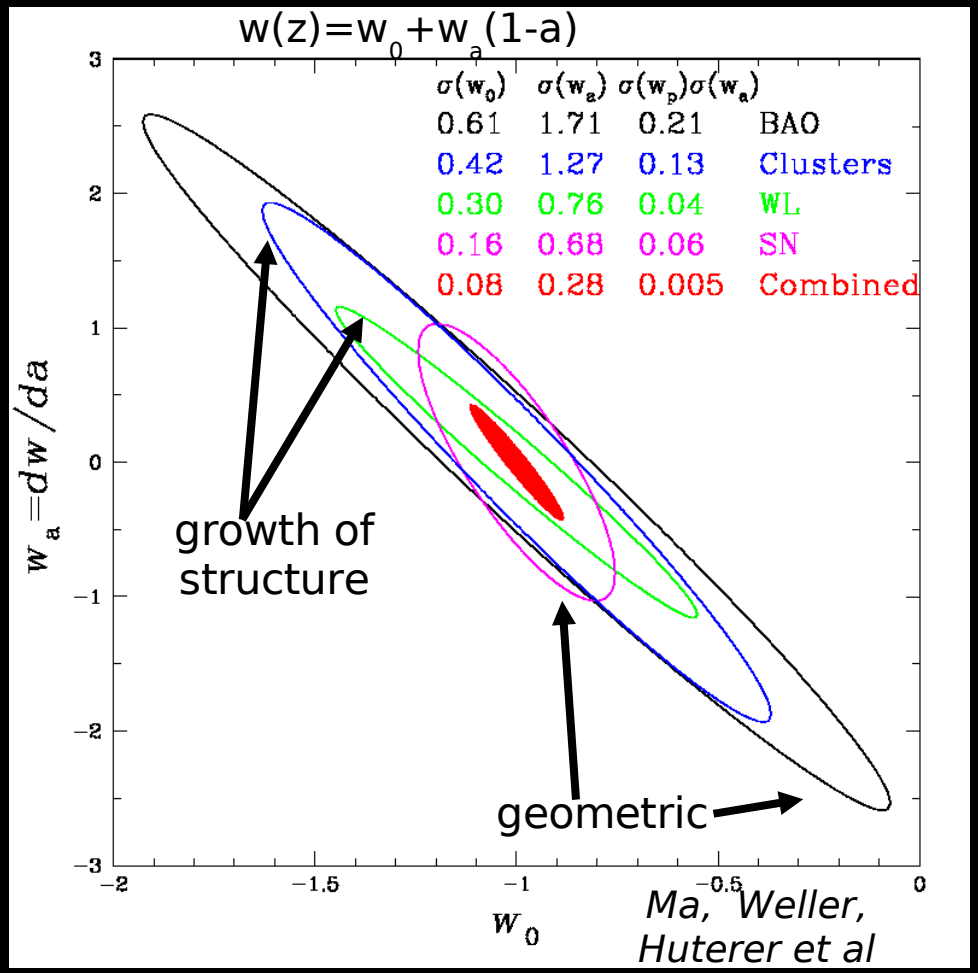
Measuring Dark Energy with DES

By the numbers:

- 300 million galaxies (WL, BAO)
- 10,000 clusters
- 2,000 supernovae

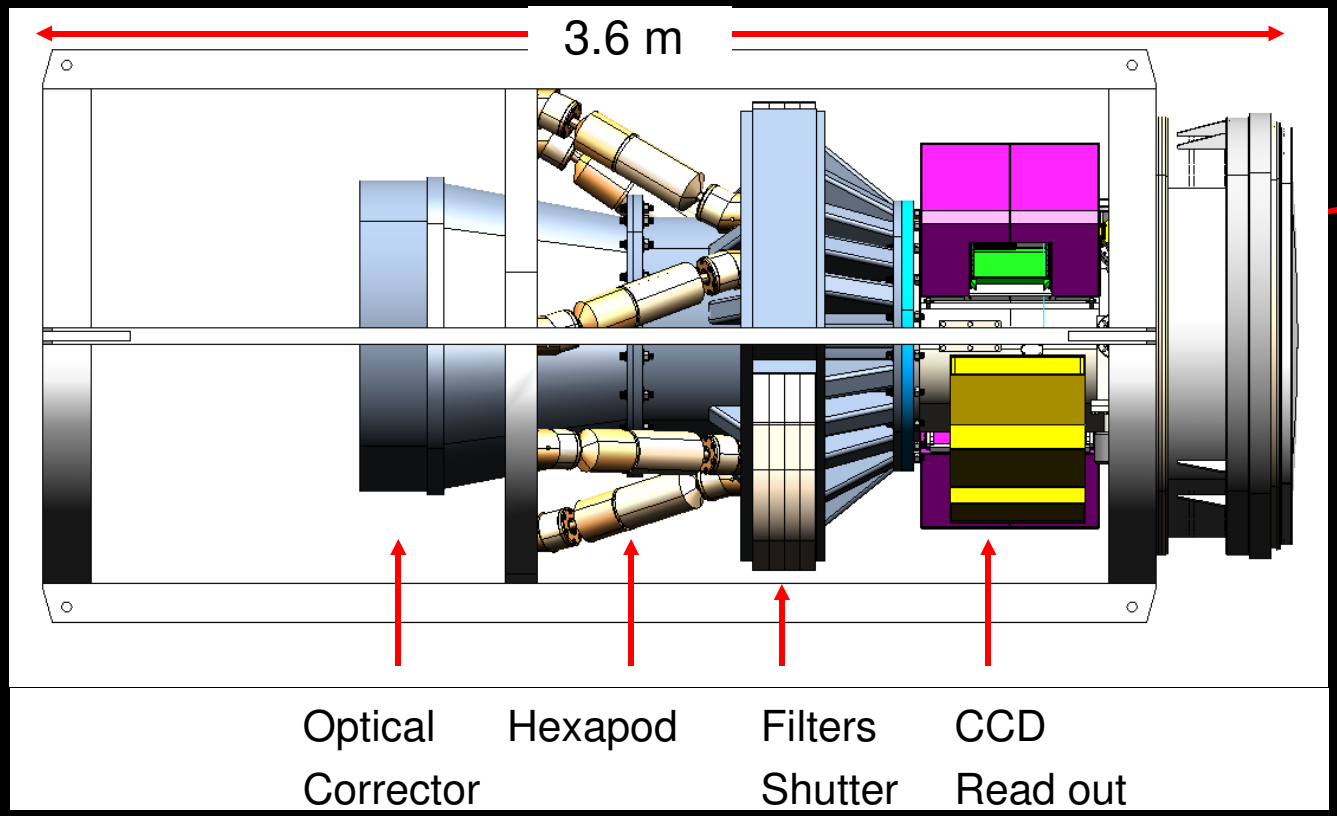
Complementary probes:

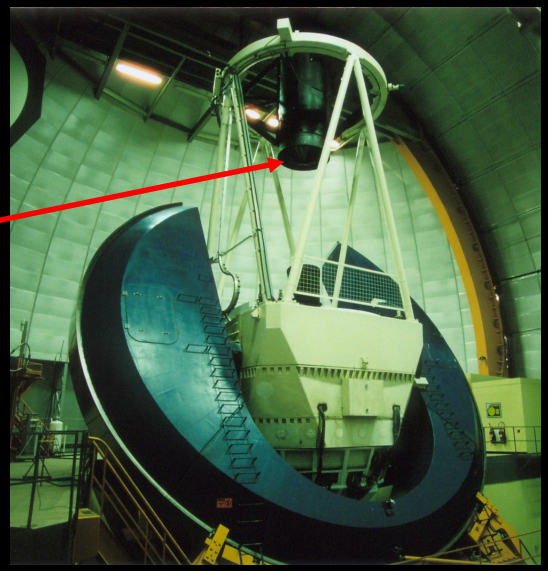
- sensitivity to cosmological parameters
- systematic errors
- measures of physics
  - geometric probes
  - growth of structure



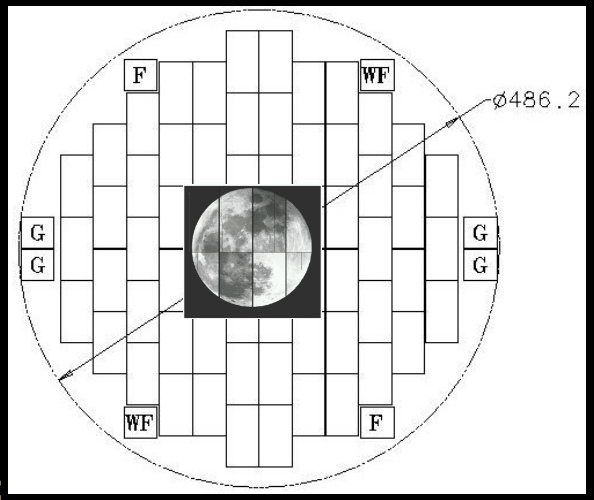
predicted DES constraints on the equation of state of dark energy, *w*, and its evolution

The Dark Energy Camera





CTIO Blanco 4m telescope, operated by NOAO for the NSF



- Full depletion CCDs
- Very large focal plane
- Readout: 17s readout time, 10 e- noise
- 0.6mx0.6m glass filters: g,r,i,z
- 5 element optical corrector

Focal plane:
62 2k x 4k Image CCDs (*520 Mpixels*)
8 2k x 2k Guide, focus, alignment CCDs

The DES Collaboration

Fermilab: J. Annis, H. T. Diehl, S. Dodelson, J. Estrada, B. Flaugher, J. Frieman, S. Kent, H. Lin, K. W. Merritt, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester

University of Illinois at Urbana-Champaign: C. Beldica, R. Brunner, I. Karliner, J. Mohr, R. Plante, P. Ricker, M. Selen, J. Thaler

University of Chicago: J. Carlstrom, S. Dodelson, J. Frieman, M. Gladders, W. Hu, S. Kent, E. Sheldon, R. Wechsler

Lawrence Berkeley National Lab: G. Aldering, N. Roe, C. Bebek, M. Levi, S. Perlmutter

NOAO/CTIO: T. Abbott, C. Miller, C. Smith, N. Suntzeff, A. Walker

Institut d'Estudis Espacials de Catalunya: F. Castander, P. Fosalba, E. Gaztañaga, J. Miralda-Escude

Institut de Fisica d'Altes Energies: E. Fernández, M. Martínez

University College London: O. Lahav, P. Doel, M. Barlow, S. Bridle, D. Brooks, S. Viti, S. Worswick, J. Weller

University of Cambridge: G. Efstathiou, R. McMahon, W. Sutherland

University of Edinburgh: J. Peacock

University of Portsmouth: R. Nichol

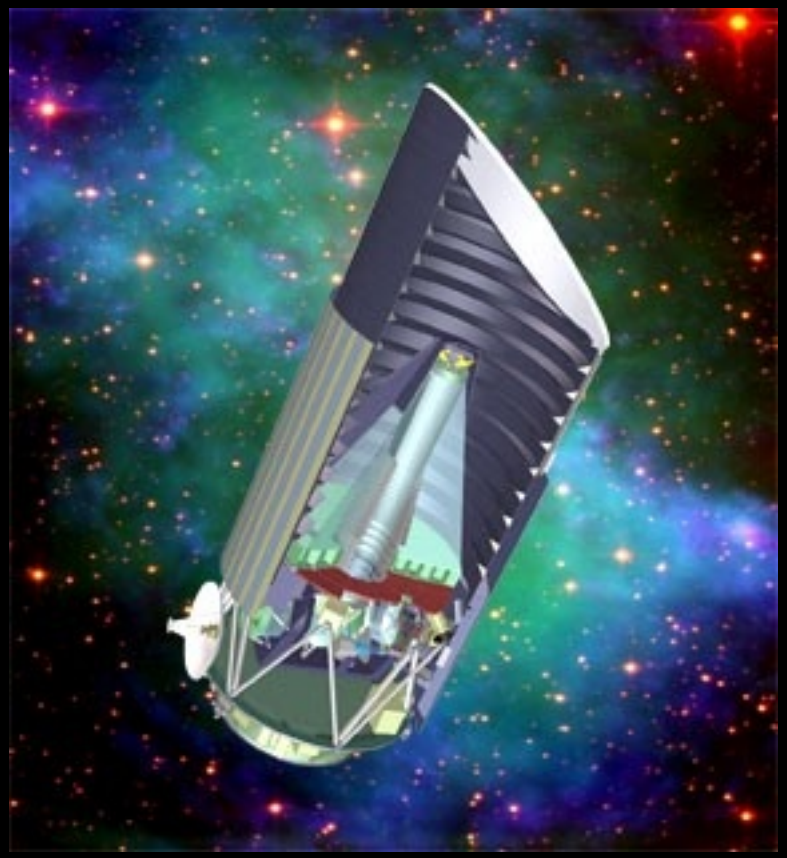
University of Michigan: R. Bernstein, B. Bigelow, M. Campbell, A. Evrard, D. Gerdes, T. McKay, M. Schubnell, G. Tarle, M. Tecchio

Ciemat Madrid: C. Mana, M. Molla, E. Sanchez UAM Madrid: J. Garcia-Bellido

SNAP: Supernova Acceleration Probe

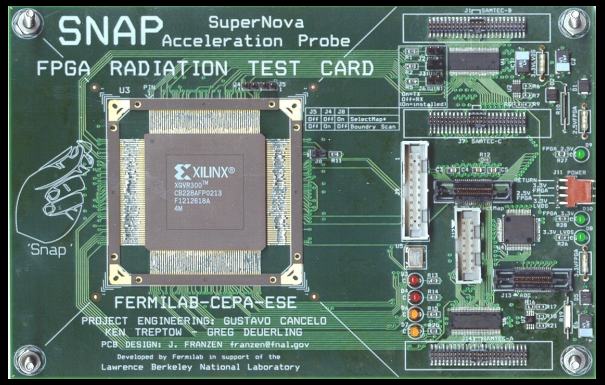
LBNL, UC Berkeley, CalTech, FNAL, Indiana U, IN2P3/INSU (France), JPL, LAM (France), U Michigan, U Penn, U Stockholm, STScI, Yale

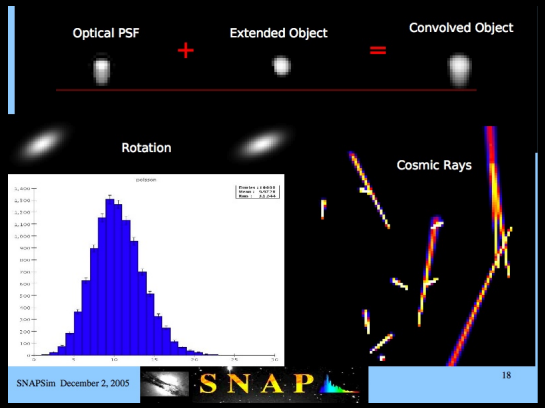
- High precision cosmology from dedicated space-based telescope
  - measurements of ~3000 supernovae to z=1.7
  - weak lensing
- 9 filters, spanning 0.3-1.7 um
- Spectrograph + Imager containing CCD and IR detectors for a total of ~600 million pixels

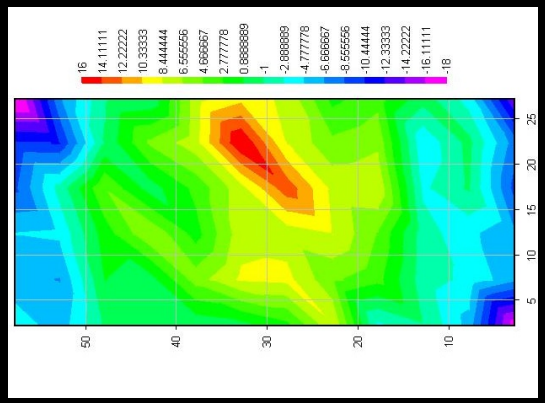


SNAP at Fermilab

- **Electronics**
  - Fermilab regulator IC (ASIC)
    - signal processing for IR chips, template/voltage control
  - Mass memory
    - flash for storage, FPGA for control, radiation damage testing
- **Simulations**
  - Pixel-level image simulations
- **Calibration**
  - Establish/observe SNAP photometric standard stars
- **CCD testing & packaging**
- **Cosmic Ray Shield**
- **Photo-z for Weak Lensing**







Summary

Fermilab is engaged in a variety of exciting observational astrophysics and cosmology projects

SDSS is the world leader in studies of large scale structure of the universe (and many other fields of astronomy)

SDSS-II will enhance our understanding of two of the today's greatest mysteries in cosmology:
Dark Matter and **Dark Energy**

In the future, DES and SNAP will provide precise constraints on the nature of Dark Energy