The Sloan Digital Sky Survey

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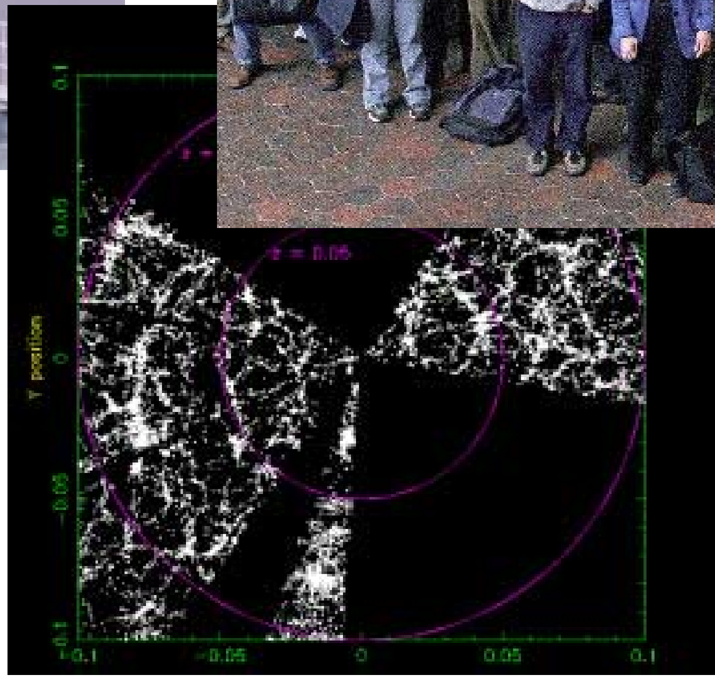
Fermilab

SLOAN DIGITAL SKY SURVEY



Sloan Digital Sky Survey

Goals:

1. Image ¼ of sky in 5 bands
2. Measure parameters of objects on images
3. Obtain redshifts of 1 million galaxies
4. Obtain redshifts of 100,000 quasars

Technique:

1. Construct a 2.5 m telescope with
   CCD array imager, 640-fiber spectrograph
   at Apache Point, New Mexico
2. Operate for 5 years

Science Goals

1. Measure large scale structure of galaxies in a volume of 0.2% of the visible universe

2. Measure large scale distribution of quasars in a volume 25% of the visible universe

3. Measure structure and kinematics of stars in the Milky Way Galaxy

4. Conduct additional leading-edge science projects

Partner Institutions

Fermi National Accelerator Laboratory
Princeton University
University of Chicago
Institute for Advanced Study
Japanese Participation Group
US Naval Observatory
University of Washington
Johns Hopkins University
Max Planck Institute for Astronomy, Heidelberg
Max Planck Institute, Garching
New Mexico State University
Los Alamos National Laboratory
University of Pittsburgh

Funding Agencies

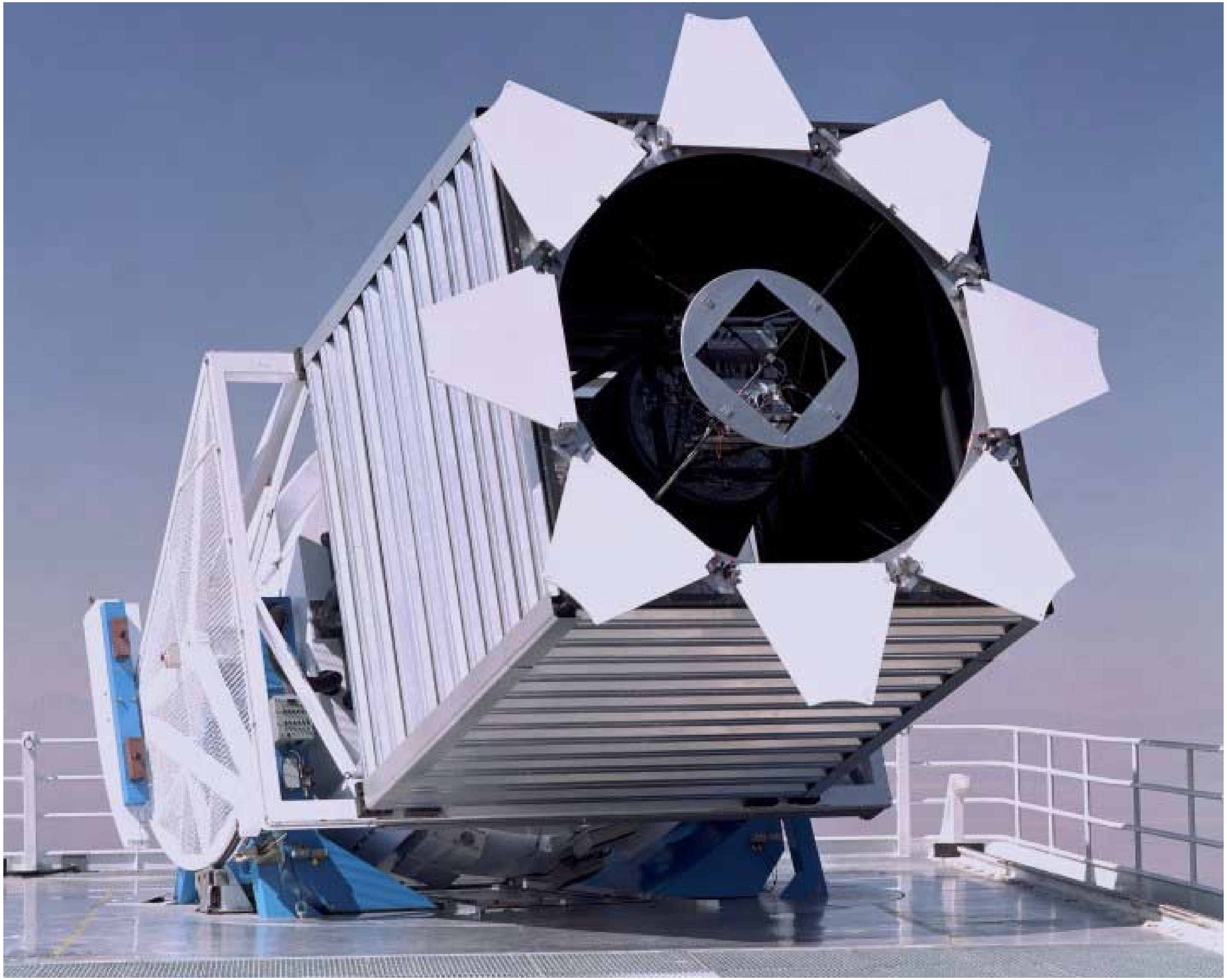
- Alfred P. Sloan Foundation
- Participating Institutions
- NASA
- NSF
- DOE
- Japanese Monbukagakusho
- Max Planck Society

Project Schedule and Cost

- Project Timeline
  - 1988: Project conceived
  - 1990: Construction activities started
  - April 2000: Observing operations began
  - June 2005: Observing phase complete
  - July 2006: Last data release
  - 2005-2007 Extension?
- Project Cost
  - Construction costs: $55M
  - Operations cost: $28M (current forecast)
  - Total project cost: $83M (current forecast)

Apache Point Observatory, New Mexico

2.5-m Telescope

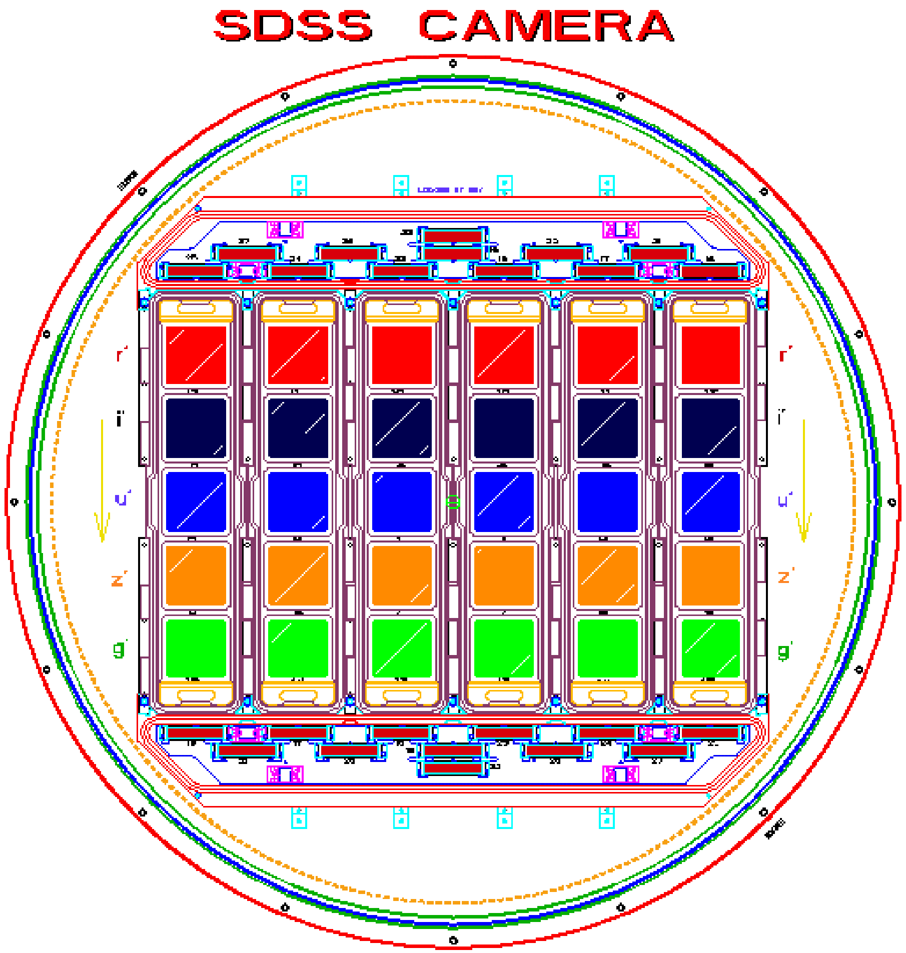


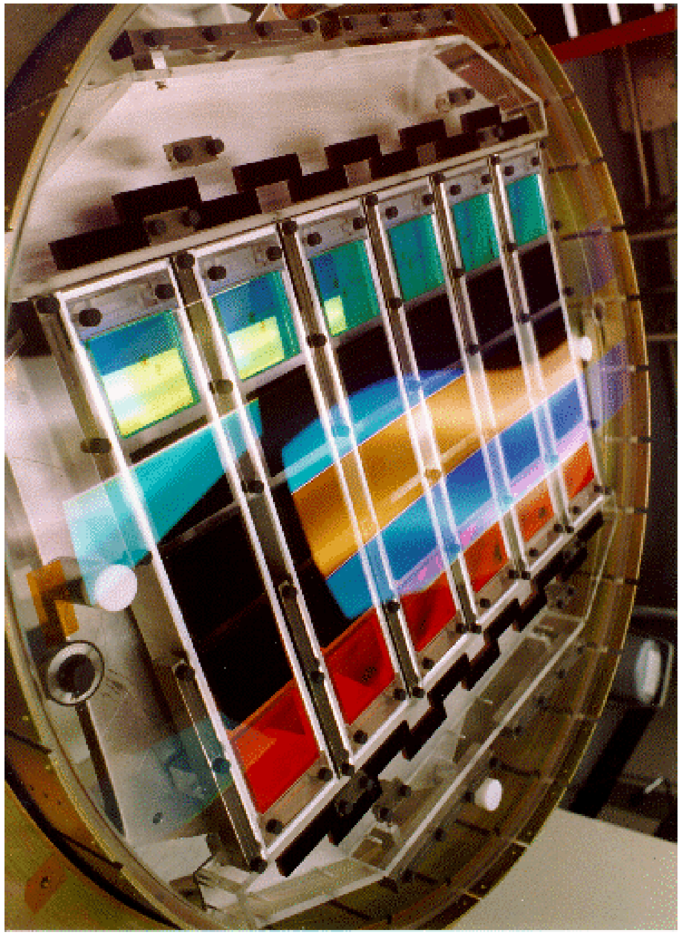
The Mosaic Camera

2.5 degree wide field of view

30 photometric CCDs (each 2048 x 2048 pixels)

6 columns of 5 filters (ugriz)

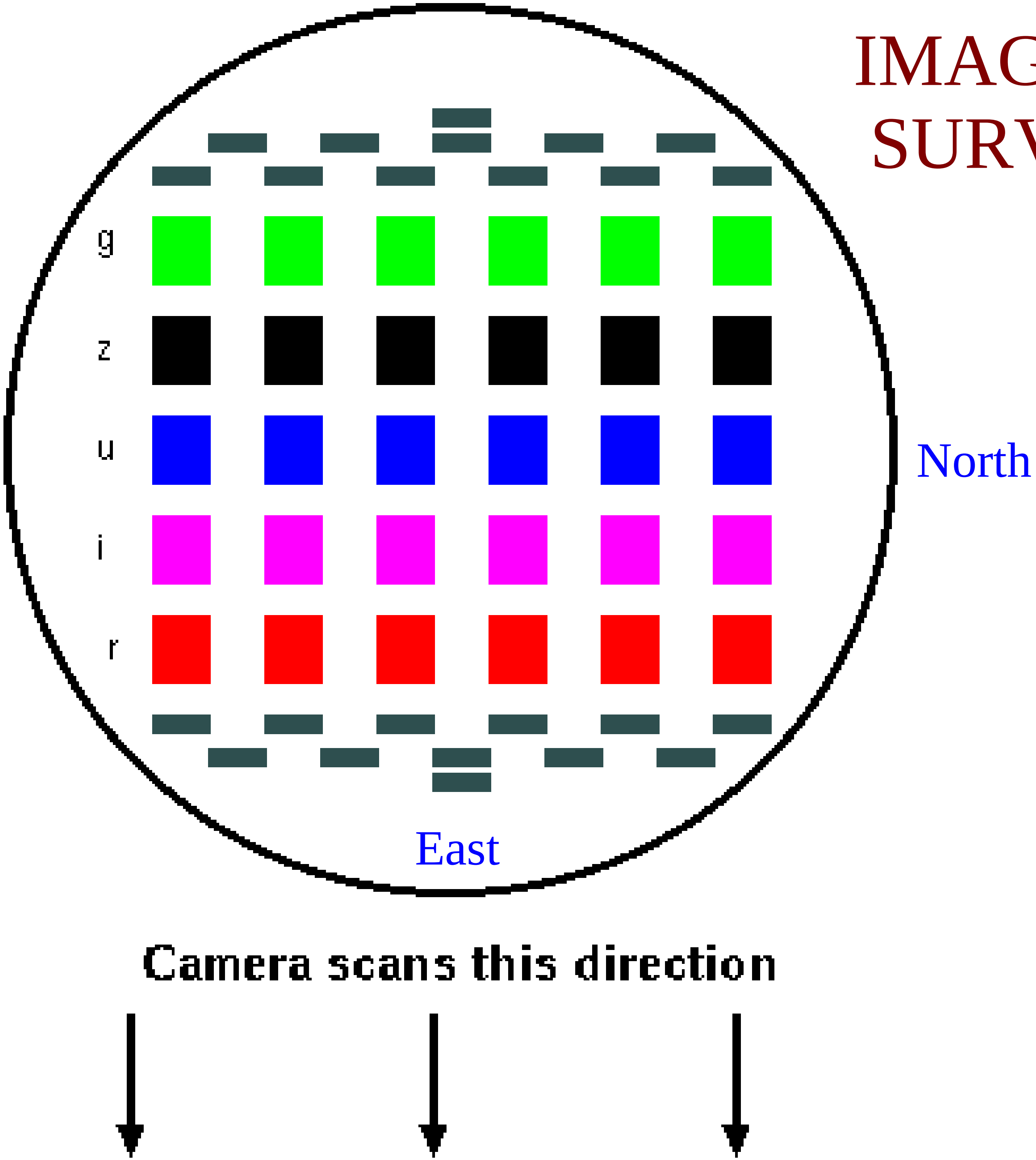




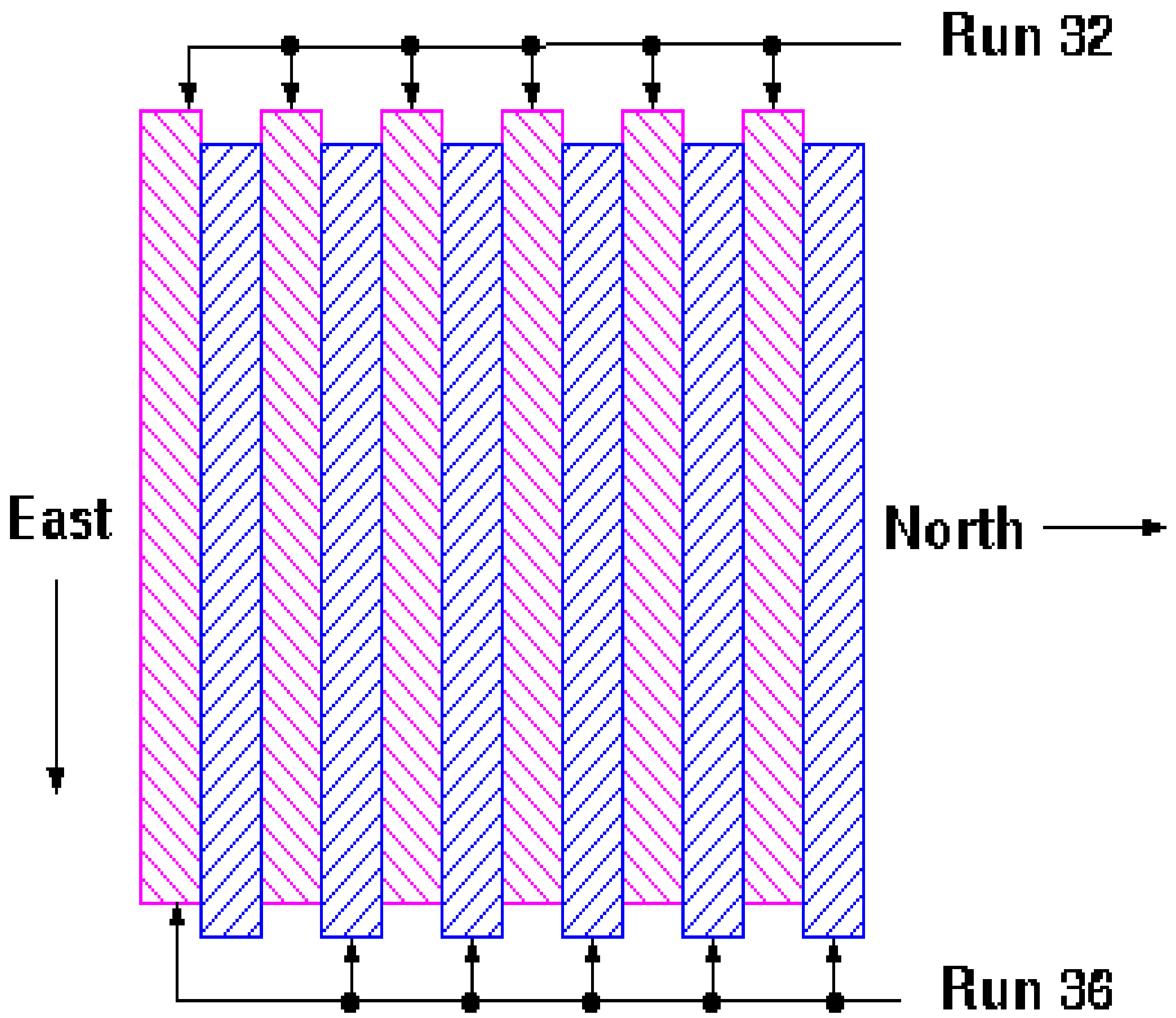
Why “digital”?

- Previous surveys use photographic plates (e.g. Palomar sky survey POSS)
  - cheapest large-area detector for visible photons
  - plate scanner needed to digitise
- But CCD is current state of the art for astronomy
  - more linear, more sensitive, easier calibrated
  - digital data processing and archiving
  - “data mining” across multiple astronomical databases

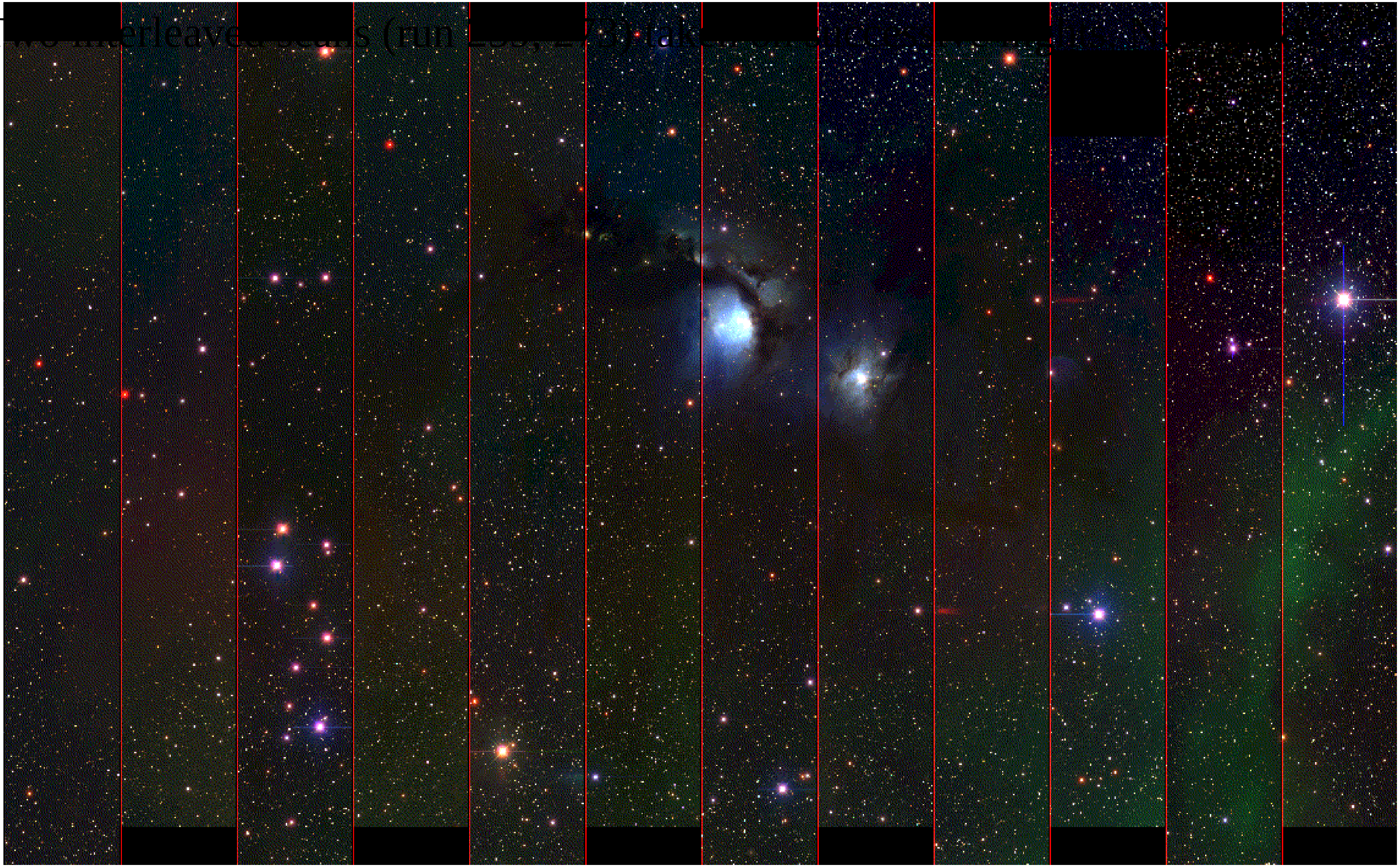
IMAGING SURVEY



2 interleaved ***scans*** cover the full 2.5 deg width of a ***stripe***



Two interleaved scans (run [illegible]) tak[illegible]



Color coding: *g* *r* *i* (3 images taken in succession over 8 minutes)

FNAL in SDSS

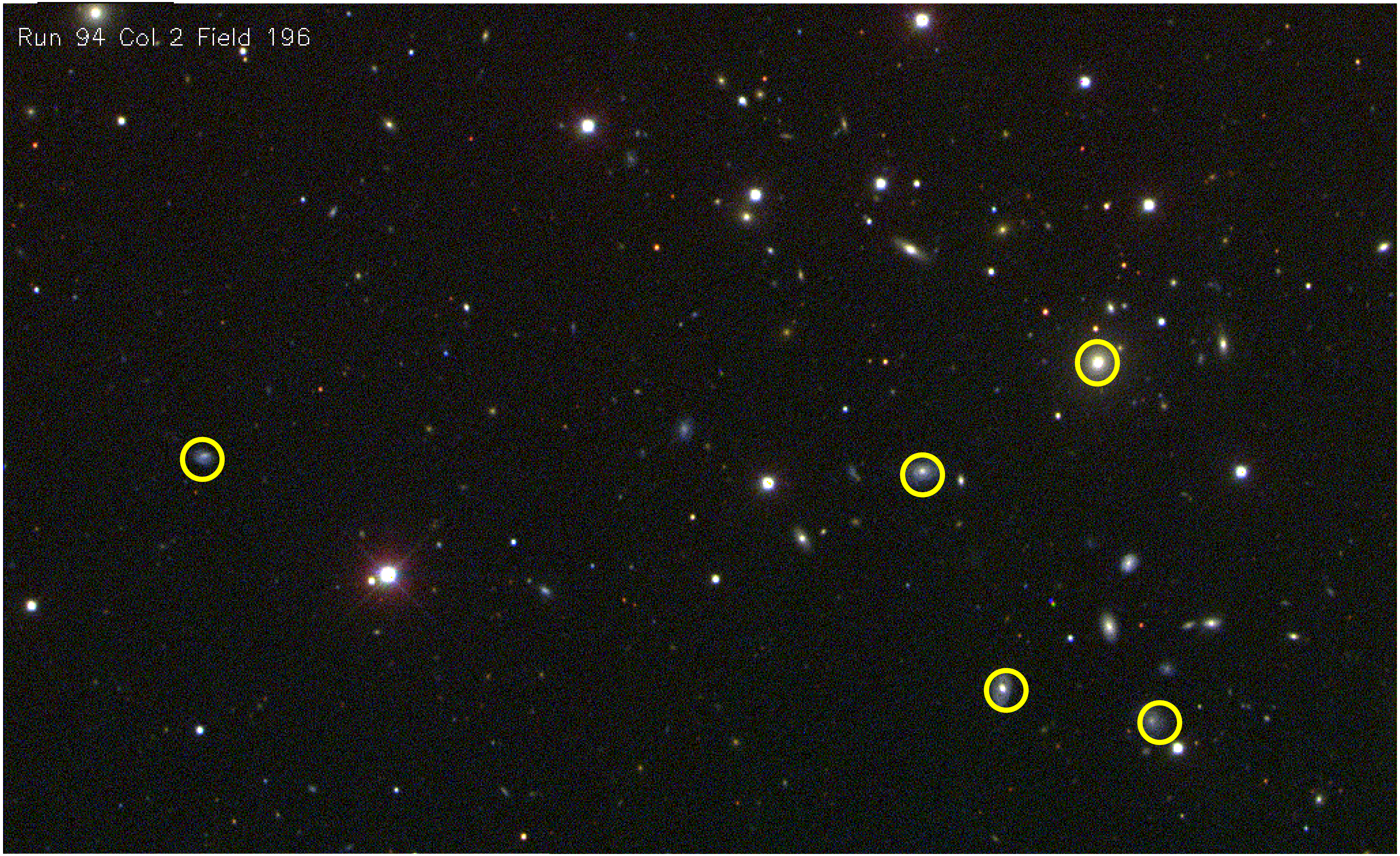
Role:

- Data acquisition
- Data processing
- Survey Planning
- Data distribution
- Support telescope and instrument systems

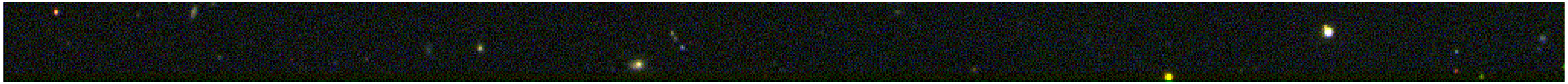
Science:

- Galaxy angular correlation functions (Dodelson)
- Weak lensing (Annis)
- Galaxy clusters (Annis, Kent, Tucker)
- Milky Way halo structure (Yanny, Kent)
- Galaxy evolution (Lin)
- QSO luminosity function (Stoughton)
- Near Earth Asteroids (Kent)

Of 103 refereed papers, 17 have current or former FNAL scientist or student supervised by FNAL as lead author



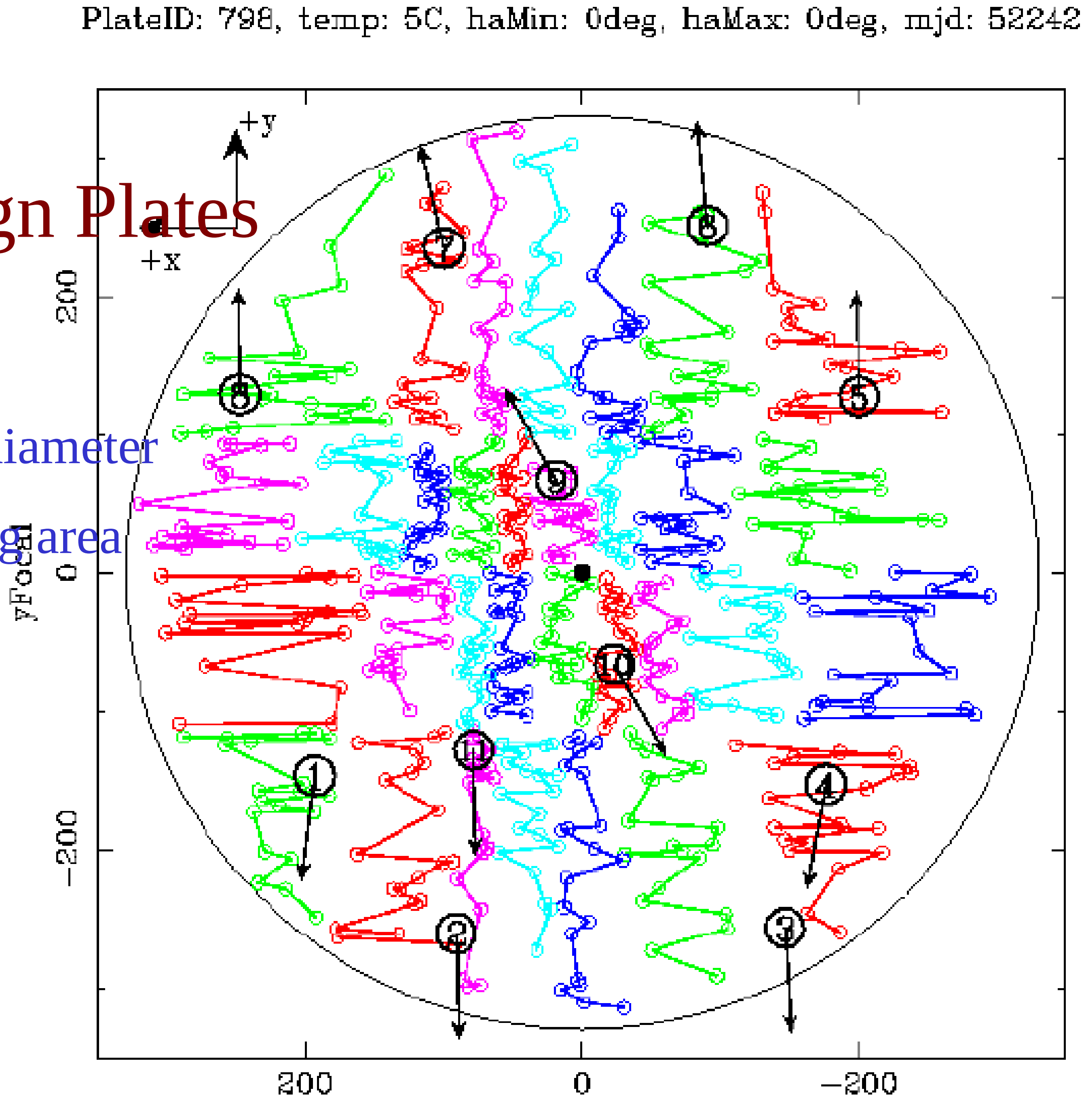
Identify Galaxies, Quasars for spectroscopy



Design Plates

3 deg diameter

7 sq deg area



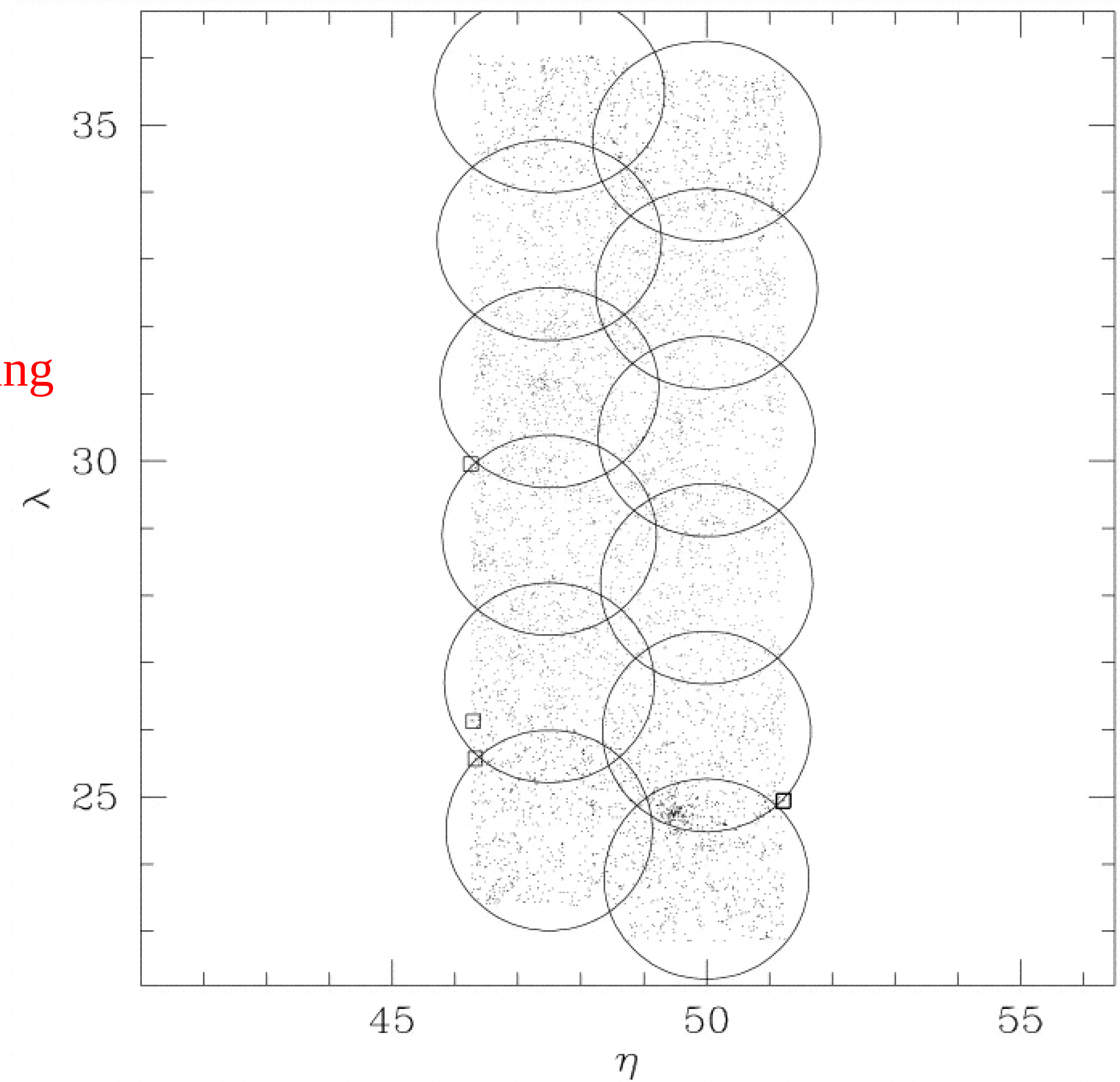
Tiling

Survey tile centers and target assignments to tiles are optimized

Sampling Rates:

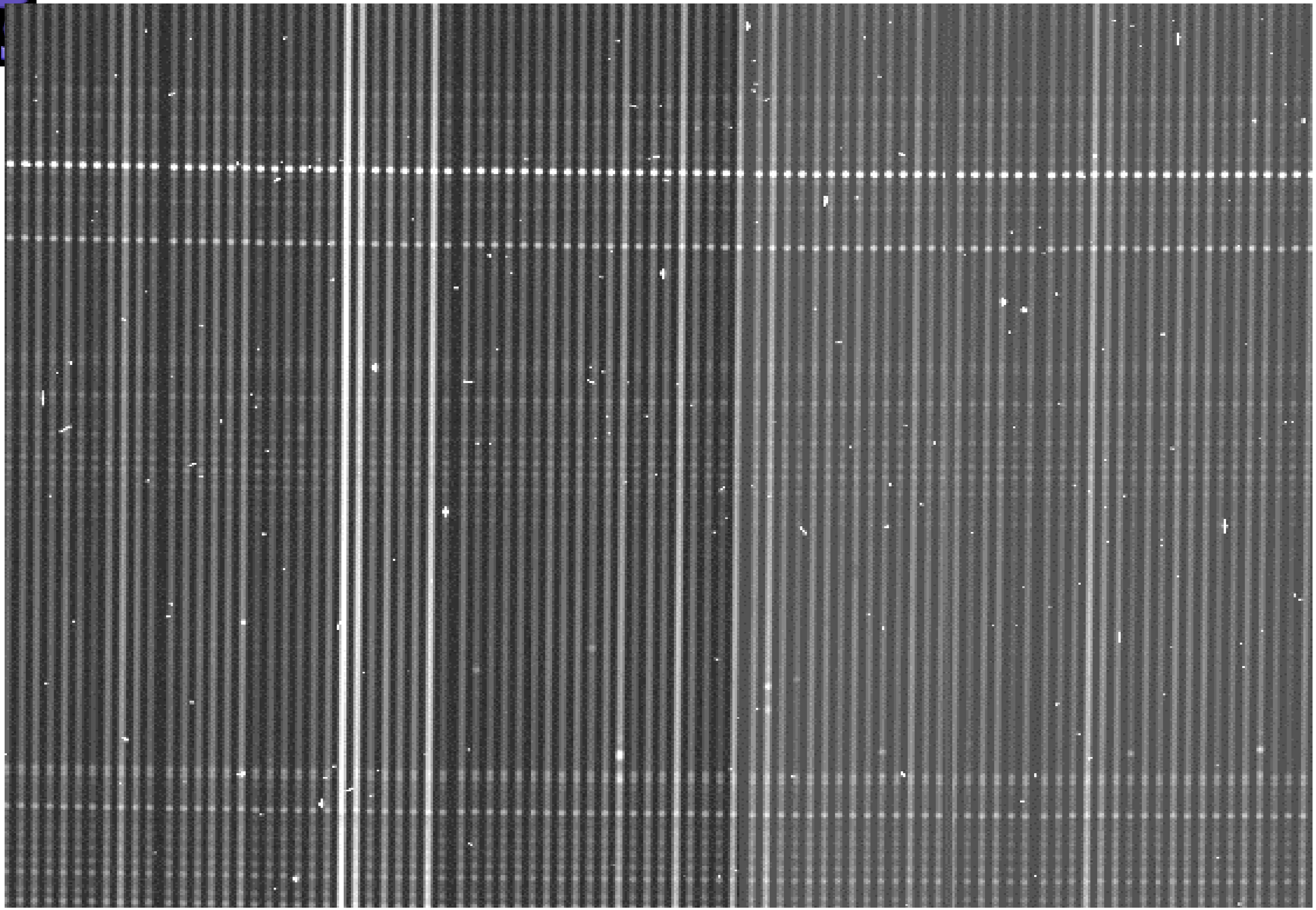
>92% all targets

>99% non-colliding



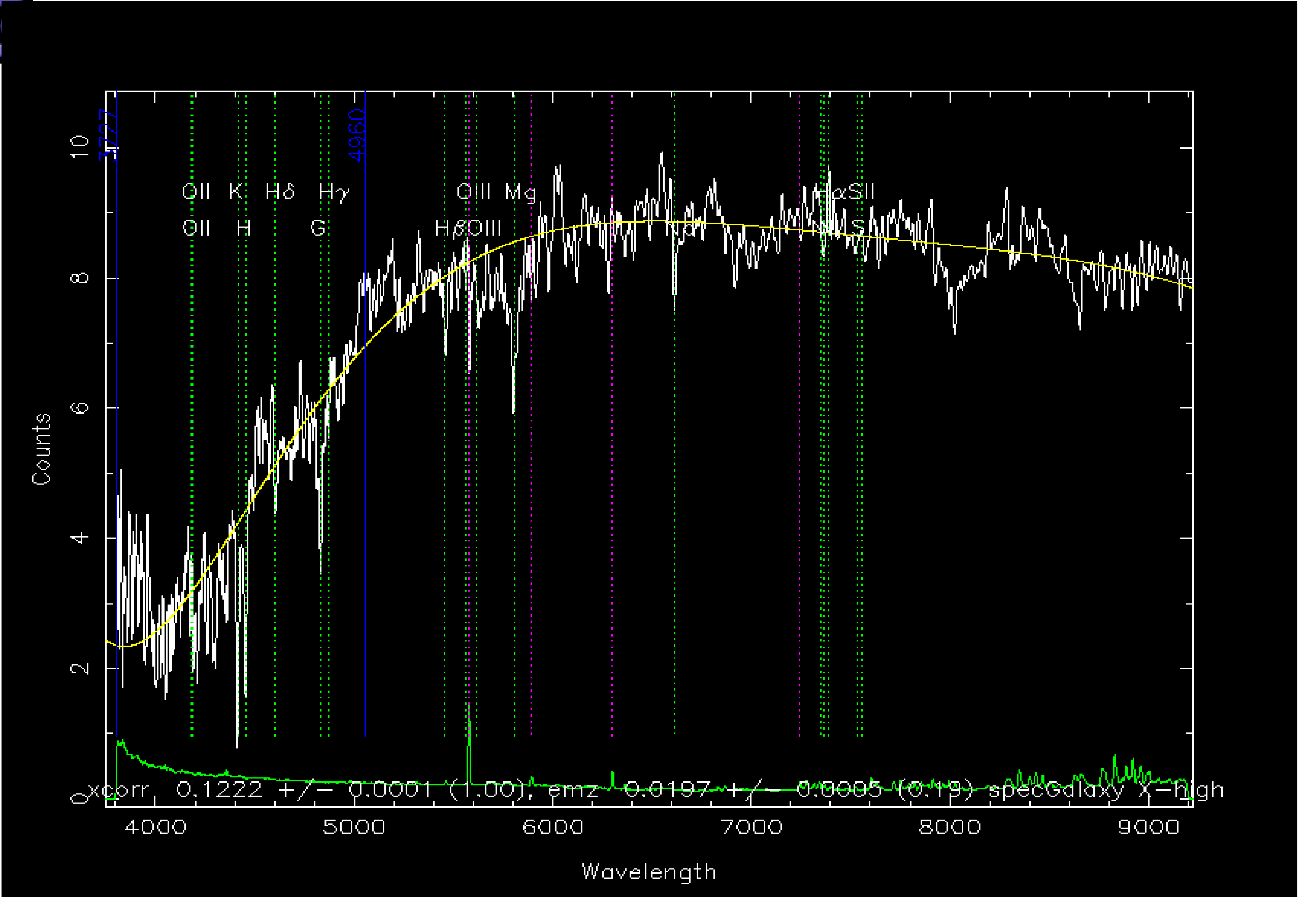
Plugging the fibers

Spectroscopy

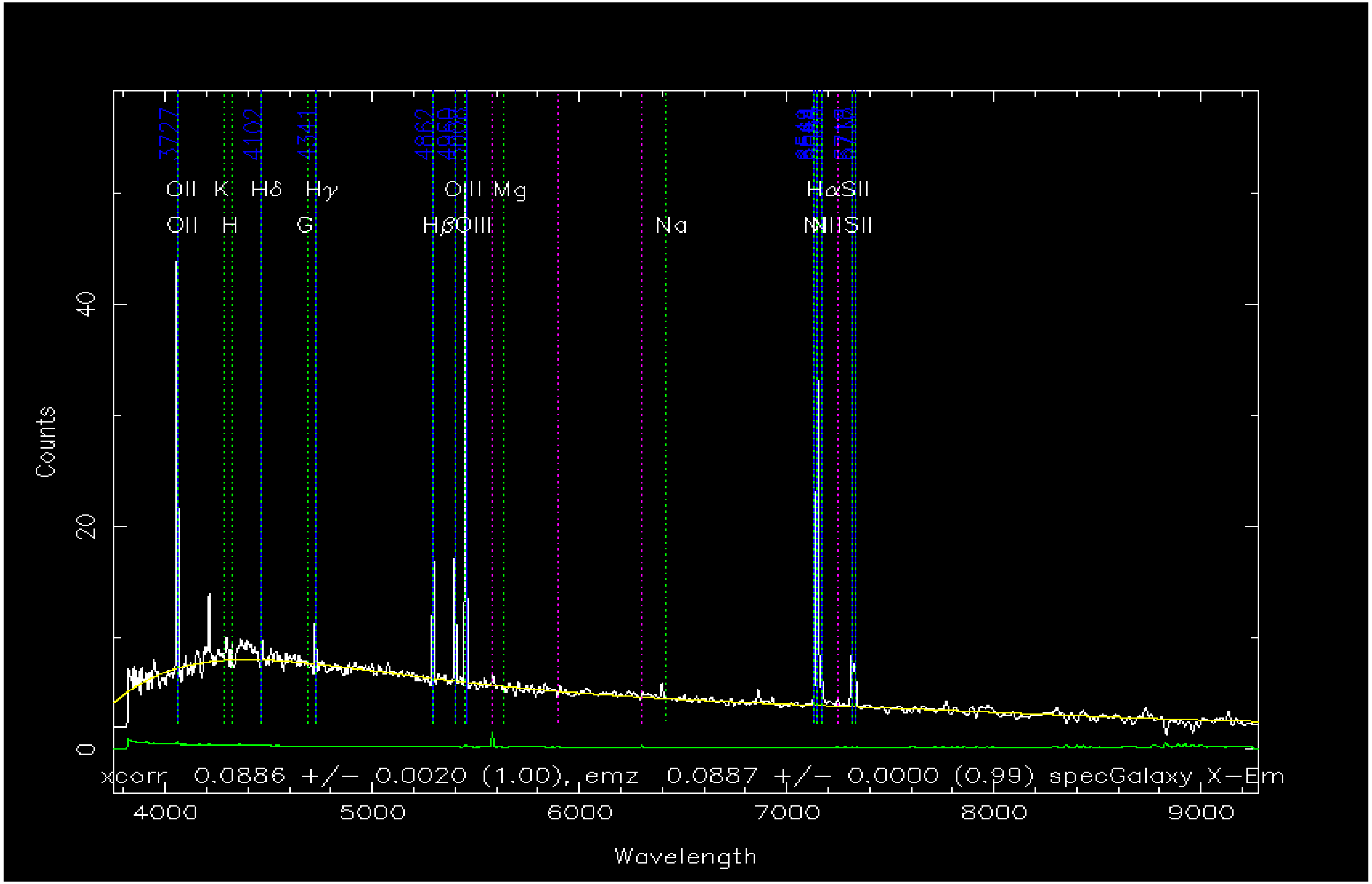


Wavelength

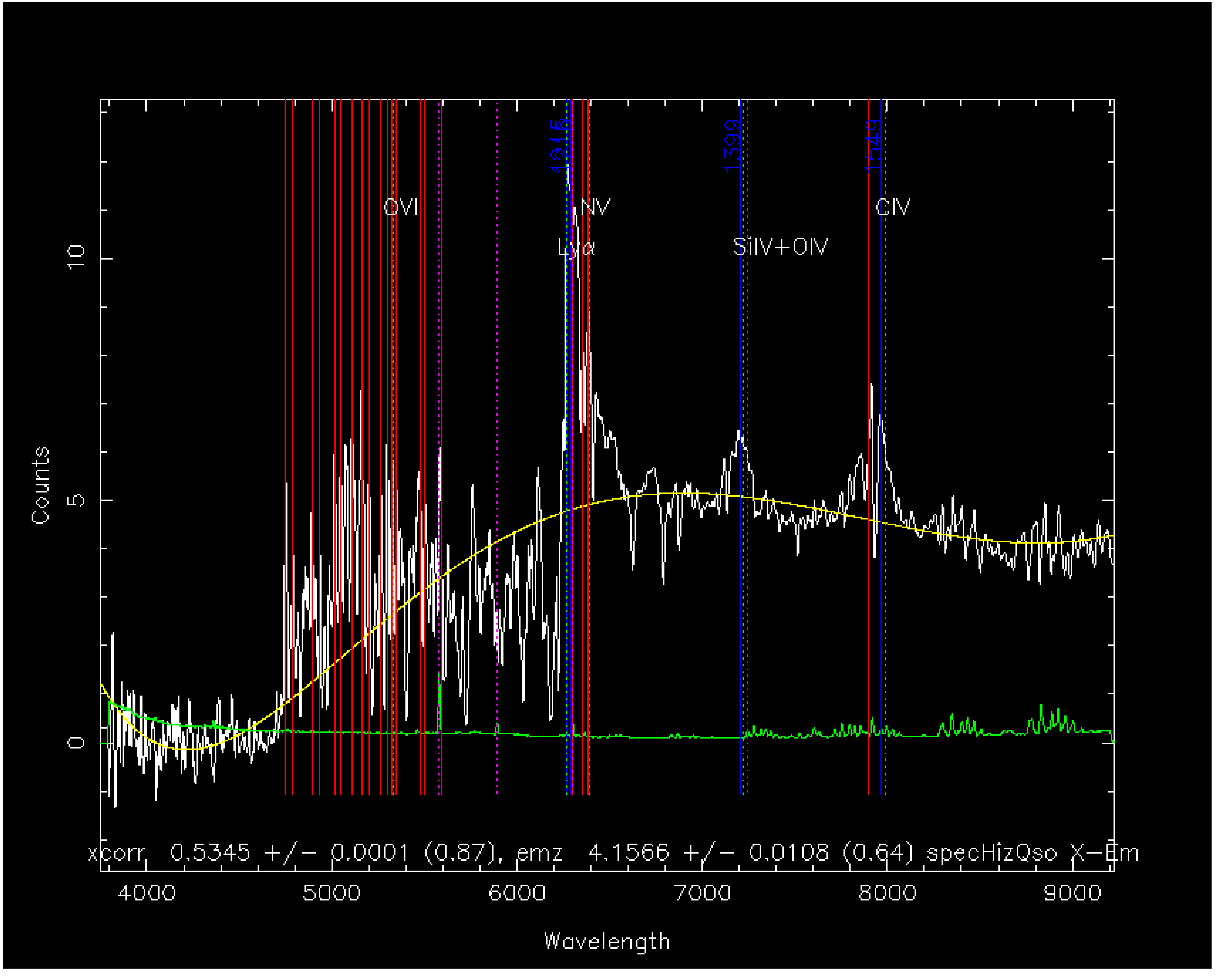
Spectra of 100 objects out of 640 Total



Elliptical galaxy spectrum z=0.12

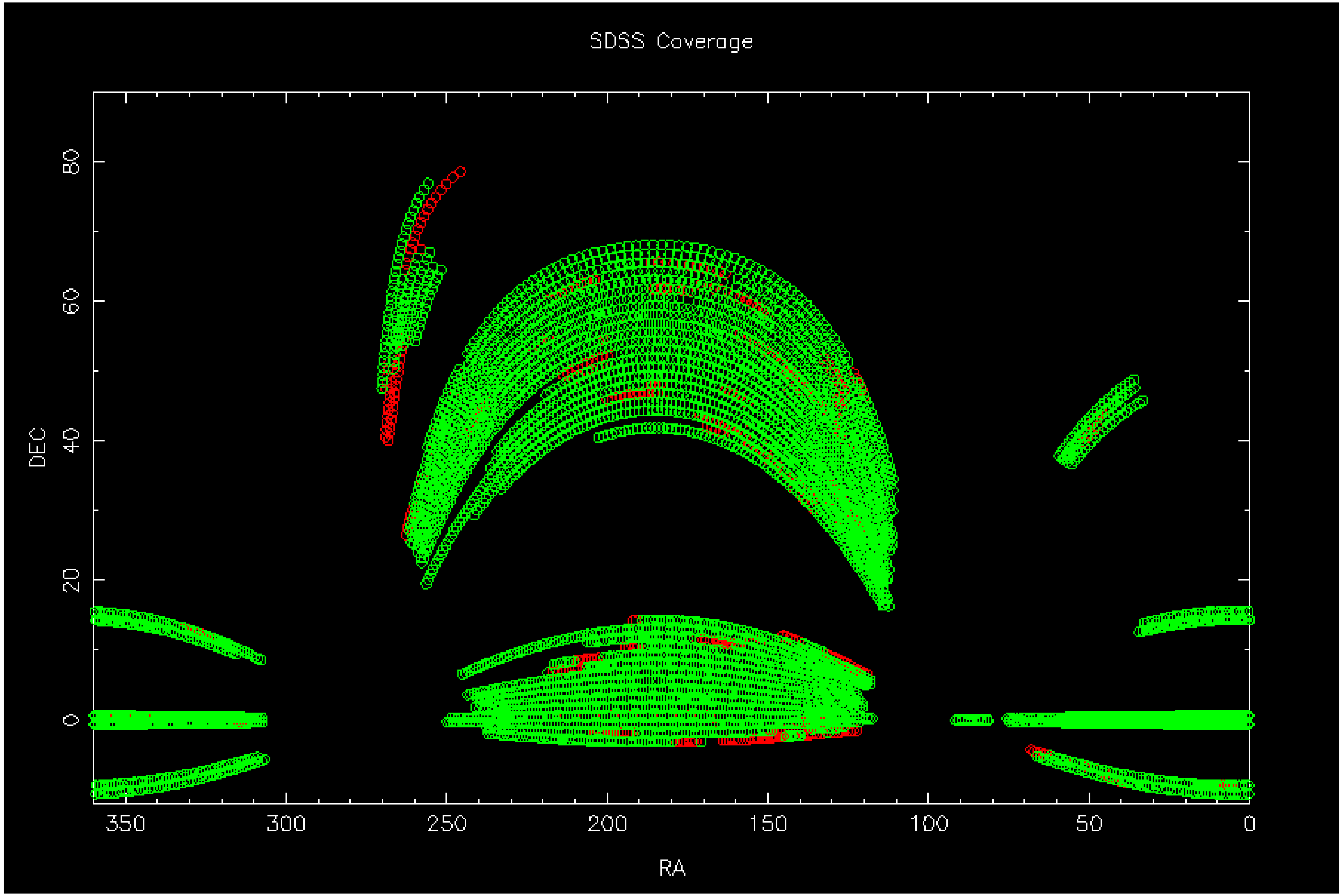


Spiral galaxy spectrum z=0.089



Quasar spectrum z=4.16

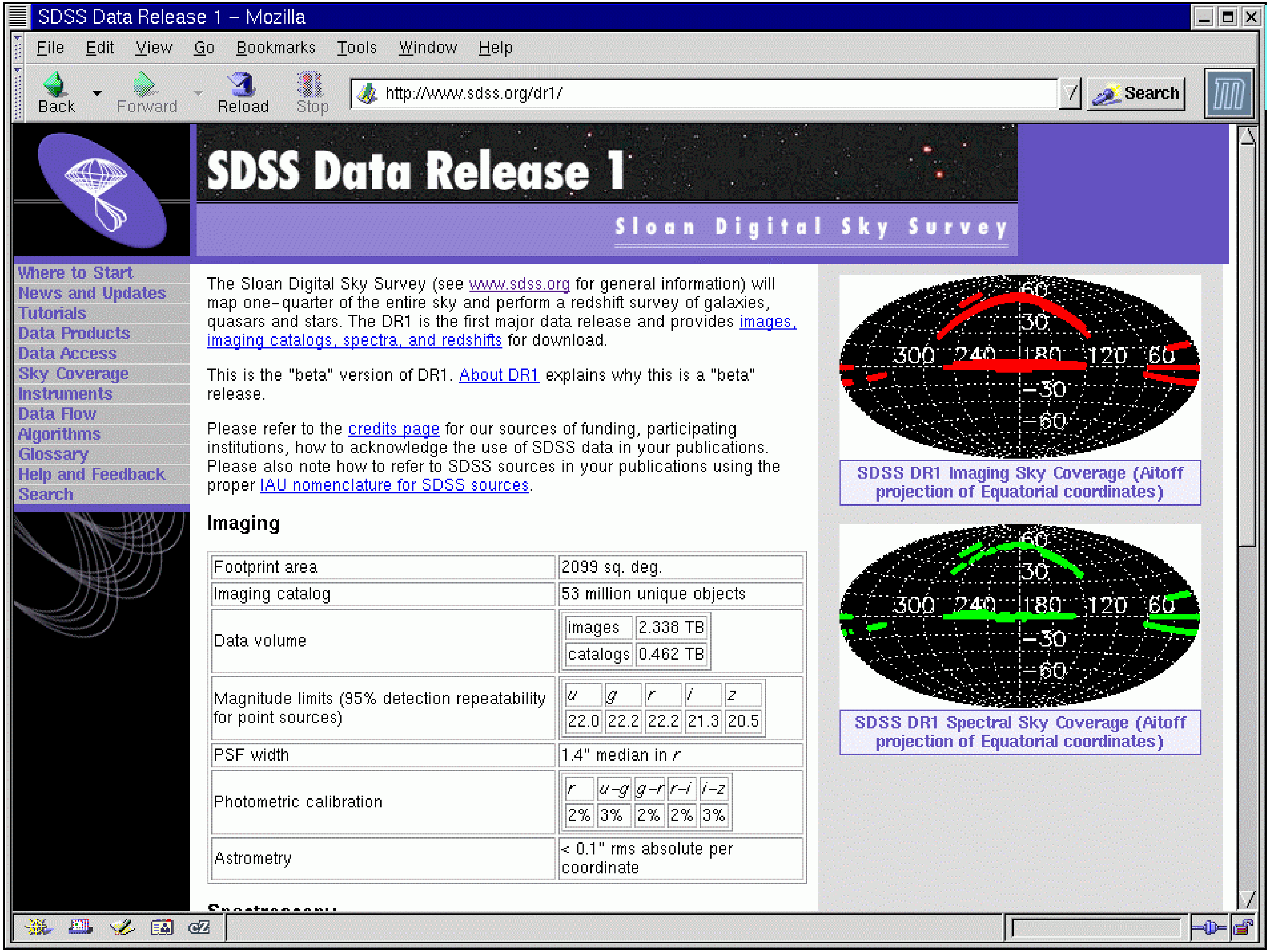
Current Sky Coverage (equatorial coordinates)



Access & Distribution of SDSS Data

- I. Early Data Release (EDR)
  - June 2001
  - Commissioning data + first survey quality data
  - 460 sq deg. + 24,000 spectra

- II. Data Release 1 (DR1ß)
  - April 2003
  - 2099 sq. deg. + 150,000 spectra
  - 3 Terabytes total



SDSS Data Release 1 – Mozilla

File Edit View Go Bookmarks Tools Window Help

Back Forward Reload Stop http://www.sdss.org/dr1/ Search

SDSS Data Release 1

Sloan Digital Sky Survey

- Where to Start
- News and Updates
- Tutorials
- Data Products
- Data Access
- Sky Coverage
- Instruments
- Data Flow
- Algorithms
- Glossary
- Help and Feedback
- Search

The Sloan Digital Sky Survey (see www.sdss.org for general information) will map one-quarter of the entire sky and perform a redshift survey of galaxies, quasars and stars. The DR1 is the first major data release and provides images, imaging catalogs, spectra, and redshifts for download.

This is the "beta" version of DR1. About DR1 explains why this is a "beta" release.

Please refer to the credits page for our sources of funding, participating institutions, how to acknowledge the use of SDSS data in your publications. Please also note how to refer to SDSS sources in your publications using the proper IAU nomenclature for SDSS sources.

Imaging

Footprint area	2099 sq. deg.
Imaging catalog	53 million unique objects
Data volume	images 2.338 TB; catalogs 0.462 TB
Magnitude limits (95% detection repeatability for point sources)	*u* 22.0, *g* 22.2, *r* 22.2, *i* 21.3, *z* 20.5
PSF width	1.4" median in *r*
Photometric calibration	*r* 2%, *u–g* 3%, *g–r* 2%, *r–i* 2%, *i–z* 3%
Astrometry	< 0.1" rms absolute per coordinate

Spectroscopy

SDSS DR1 Imaging Sky Coverage (Aitoff projection of Equatorial coordinates)

SDSS DR1 Spectral Sky Coverage (Aitoff projection of Equatorial coordinates)

http://www.sdss.org/dr1/

SDSS Data Products

Object catalog	500 GB
parameters of >10^8 objects	
Redshift Catalog	1 GB
parameters of 10^6 objects	
Atlas Images	1500 GB
5 color cutouts of >10^8 objects	
Spectra	60 GB
in a one-dimensional form	
Derived Catalogs	20 GB
clusters	
QSO absorption lines	
4x4 Pixel All-Sky Map	60 GB
heavily compressed	
Corrected Frames	15 TB

All raw data (40TB) saved at Fermilab

SCIENCE WITH SDSS

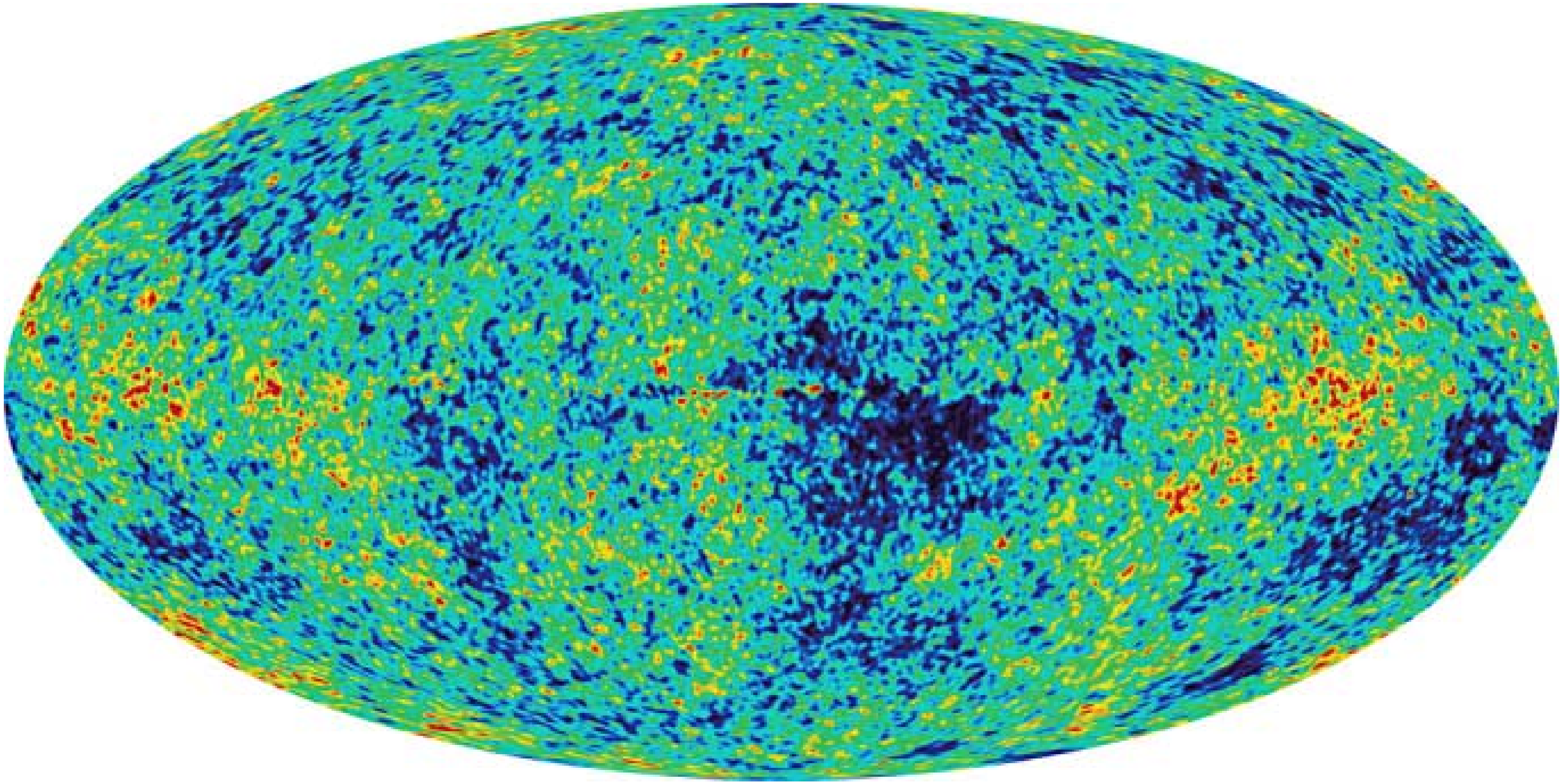
Astrophysics/Particle Physics Connection

Large scale structure today arose in universe from processes occuring above $T=10^{27}$ K ($E=10^{14}$ Gev).

Large Scale Structure

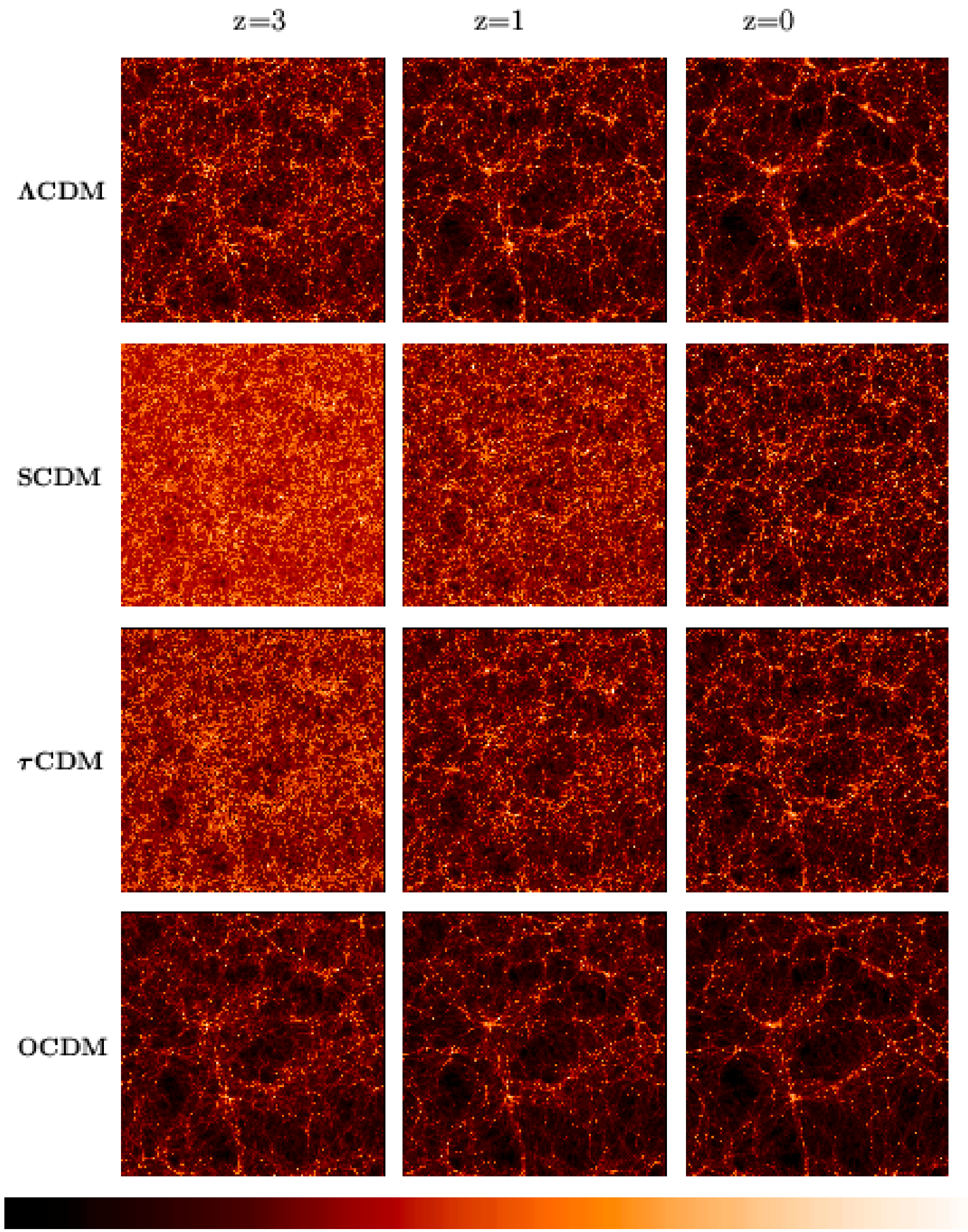
(Tegmark, Blanton, Pope, Zehavi, …)

Cosmic microwave background (CMB) fluctuations measured by WMAP



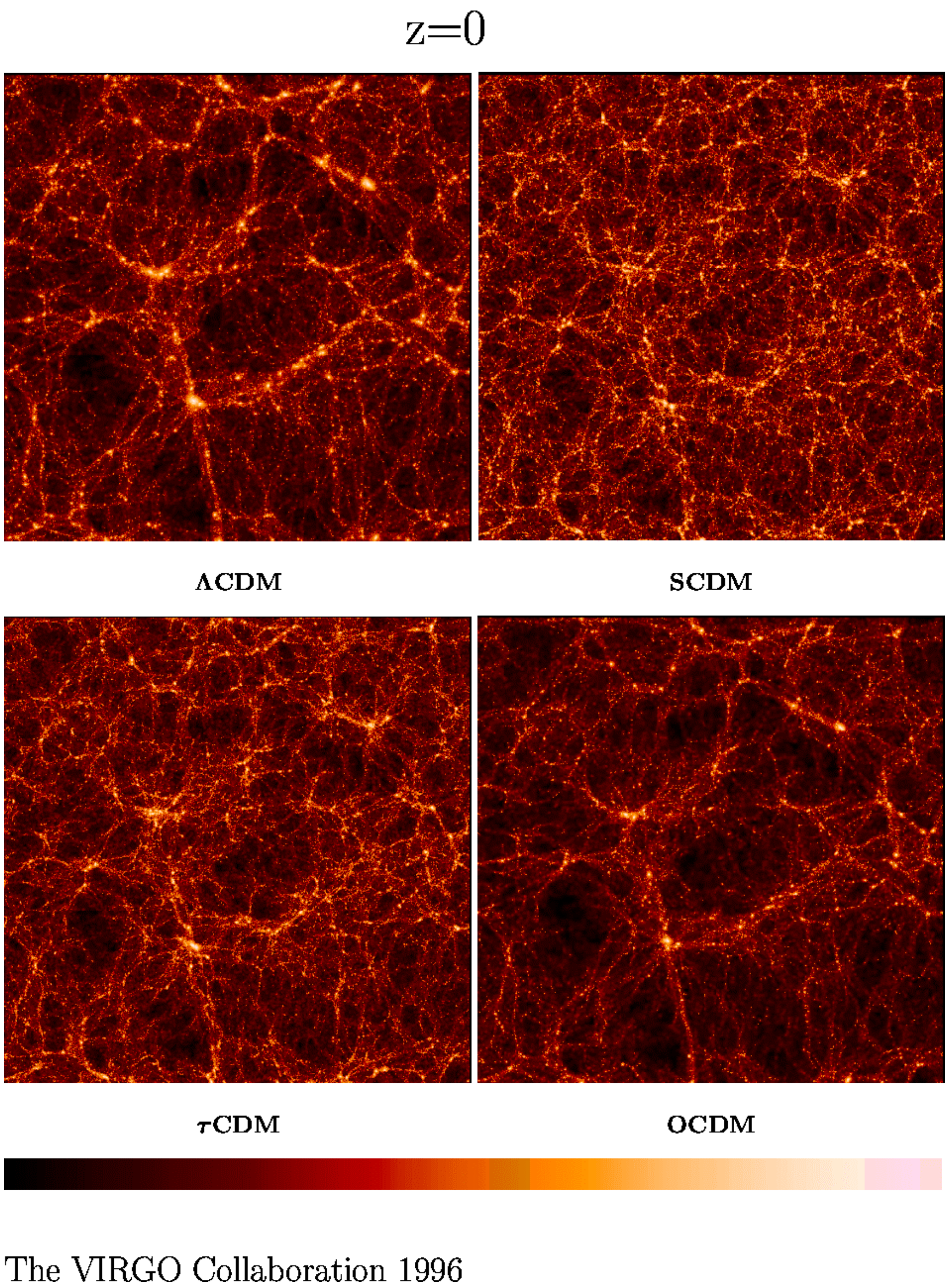
Evolution of large scale structure with redshift in a variety of N-body simulations

The clustering of galaxies observed today evolved from the initial quantum fluctuations in the early universe.

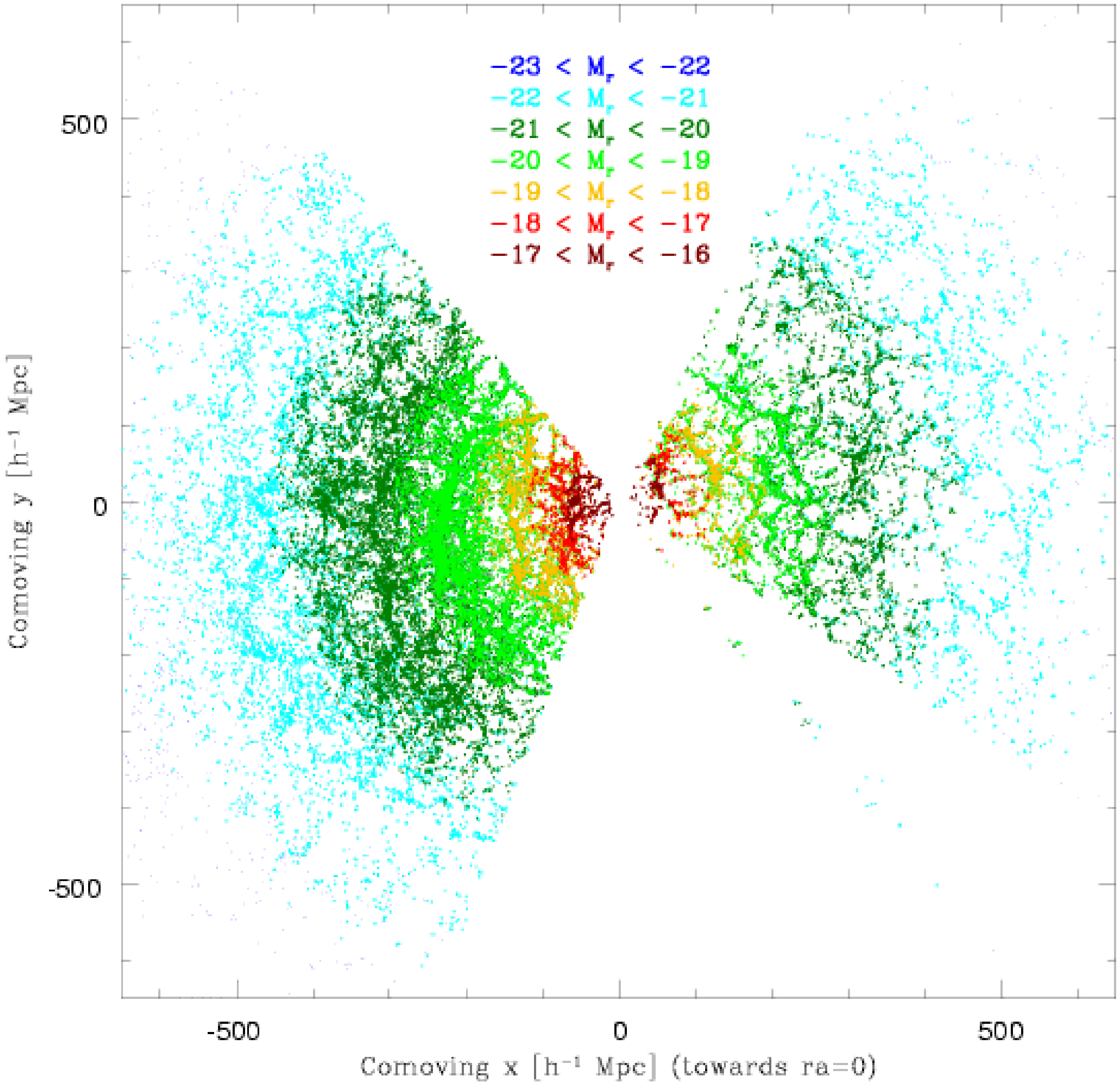


The VIRGO Collaboration 1996

Present-day distribution of large scale structure in a variety of N-body simulations



Sample: 205,443 galaxies 2417 sq deg mean redshift z = 0.1



Shown: 66976 galaxies within 5° of equatorial plane, color coded by absolute magnitude

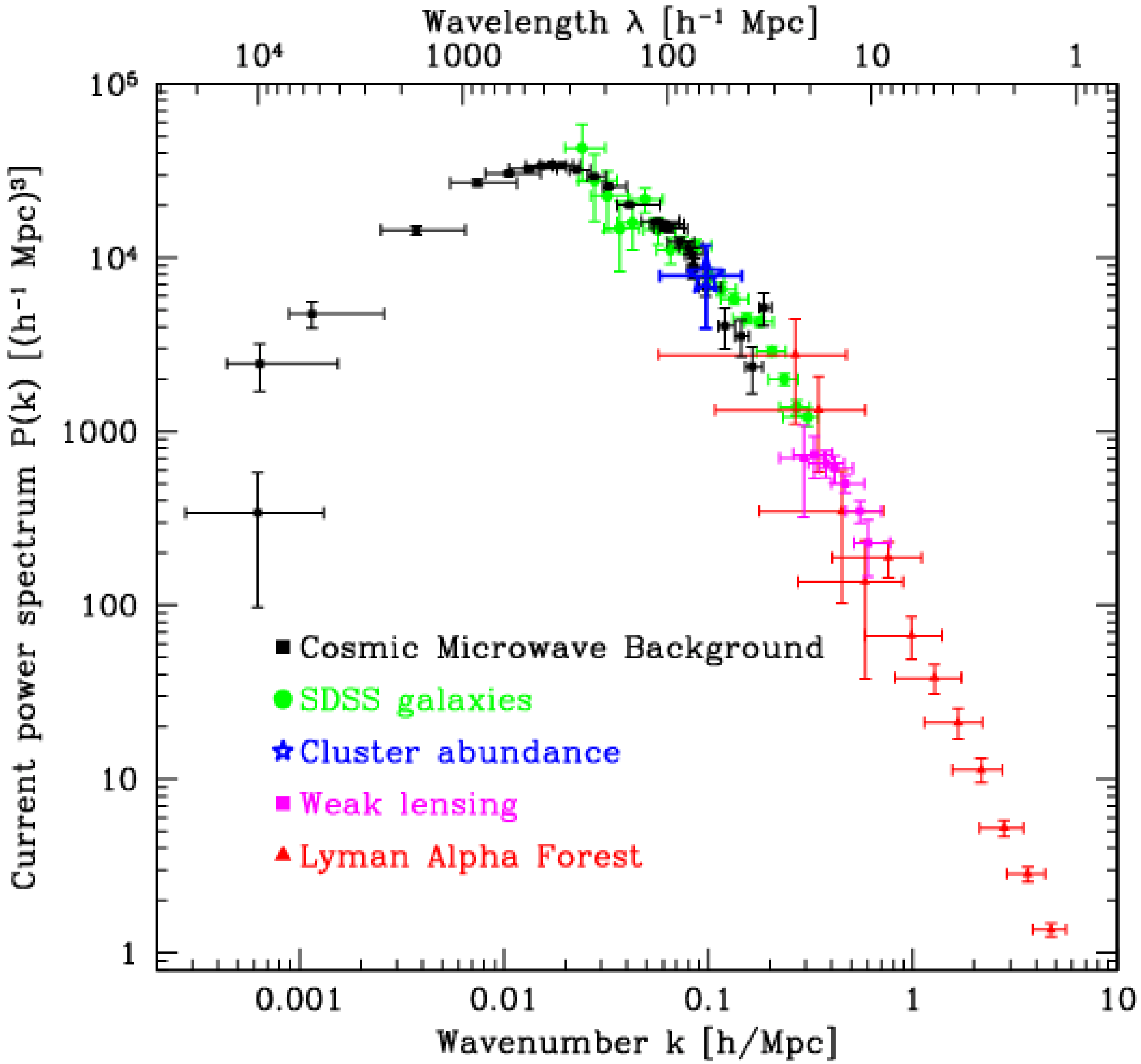
Tegmark et al. 2003

The Galaxy Power Spectrum P(k)

- The power spectrum P(k) measures the strength of clustering on different scales (wavenumber k)
- Essentially the square of the Fourier transform of the galaxy density distribution
- Want as large and as 3D a survey as possible to minimize survey window function effects and maximize ability to measure power spectrum on the largest scales
- Shape and amplitude of P(k) constrains structure formation and evolution models and cosmology

SDSS P(k) fit: O_m = 0.291 ± 0.023   L* galaxy s_8 = 0.93 ± 0.02

Power Spectrum



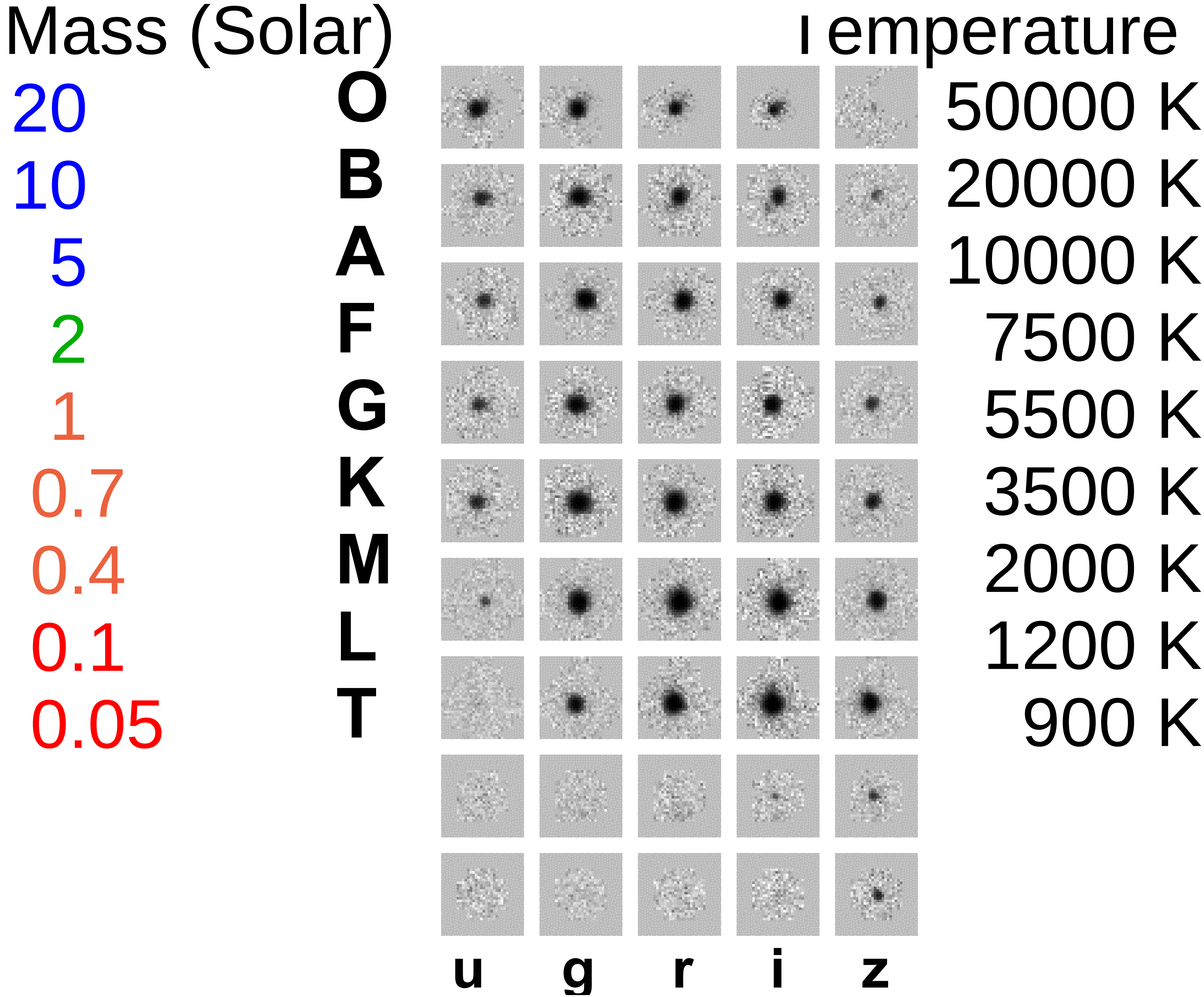
Wavenumber

fixed: h = 0.72,
baryon fraction
O_b/O_m = 0.17,
spectral index n_s=1

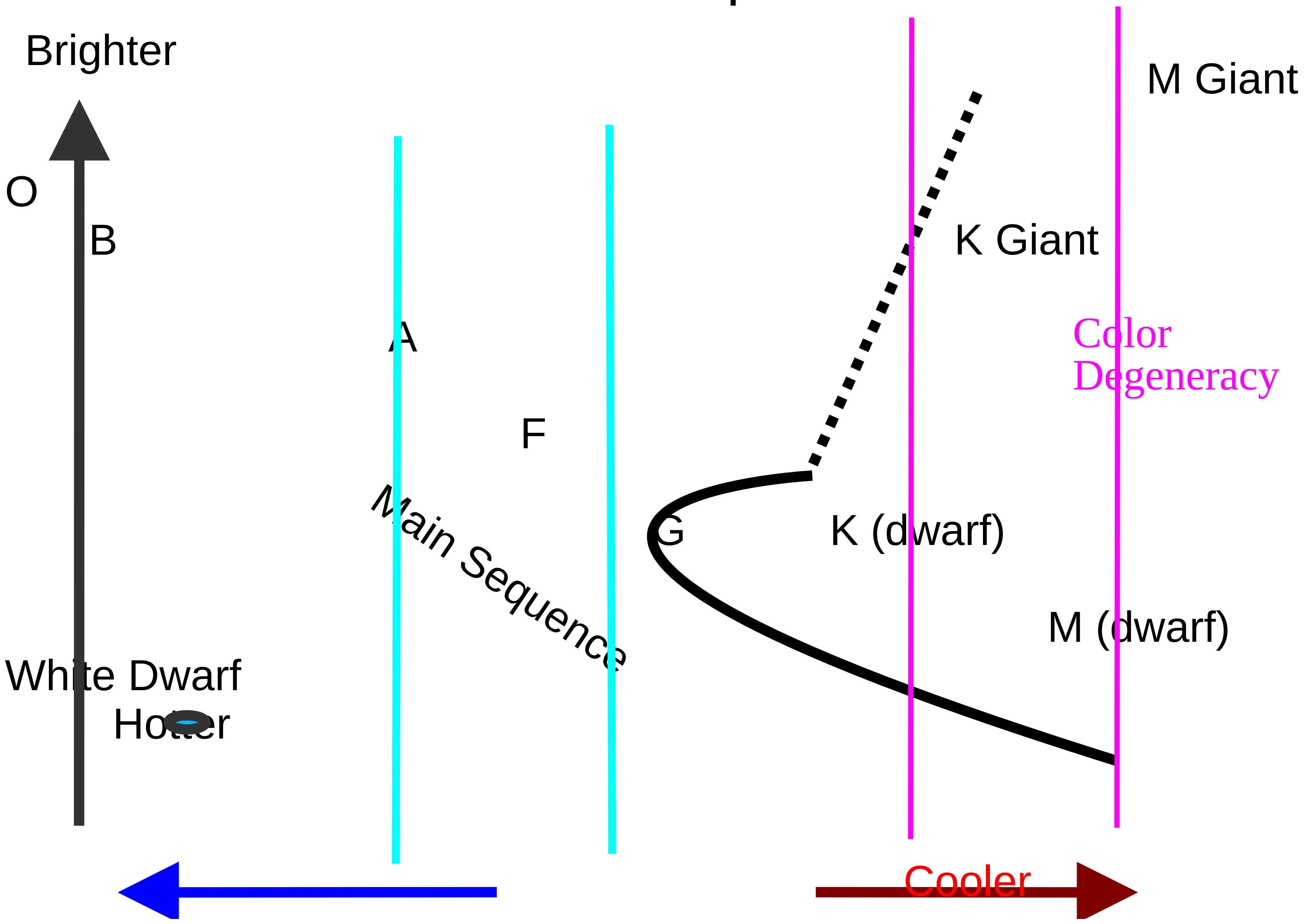
Tegmark et al. 2003

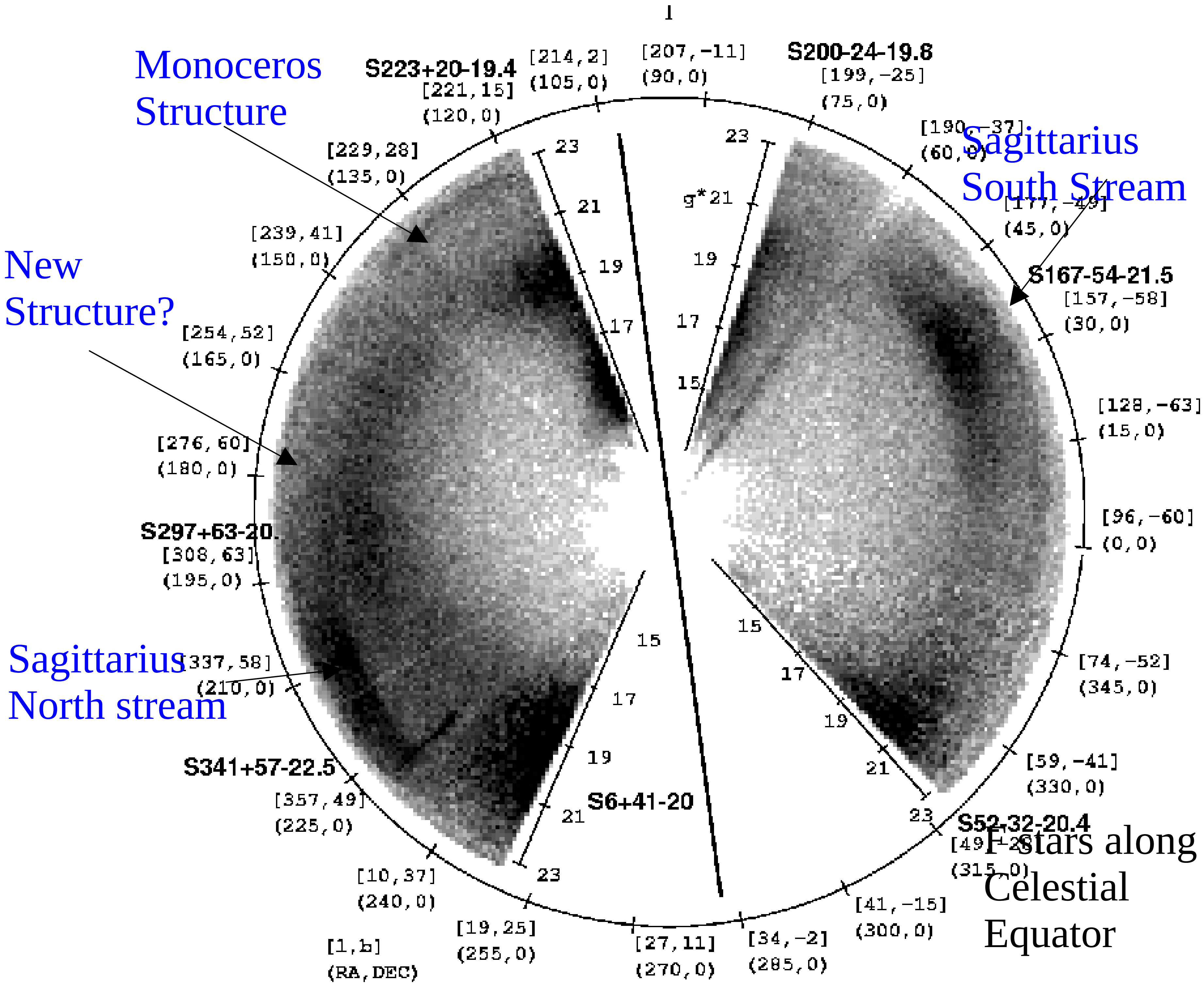
Galactic Structure

(Yanny, Newberg, …)


Mass (Solar)
20
10
5
2
1
0.7
0.4
0.1
0.05
O
B
A
F
G
K
M
L
T
Temperature
50000 K
20000 K
10000 K
7500 K
5500 K
3500 K
2000 K
1200 K
900 K
u
g
r
i
z

The Stellar Sequence





Monoceros Structure
New Structure?
Sagittarius South Stream
Sagittarius North stream
F-stars along Celestial Equator
S223+20-19.4
S200-24-19.8
S167-54-21.5
S297+63-20.
S341+57-22.5
S6+41-20
S52-32-20.4
[1,b]
(RA,DEC)
[207,-11]
(90,0)
[214,2]
(105,0)
[221,15]
(120,0)
[229,28]
(135,0)
[239,41]
(150,0)
[254,52]
(165,0)
[276,60]
(180,0)
[308,63]
(195,0)
[337,58]
(210,0)
[357,49]
(225,0)
[10,37]
(240,0)
[19,25]
(255,0)
[27,11]
(270,0)
[34,-2]
(285,0)
[41,-15]
(300,0)
(315,0)
[59,-41]
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[96,-60]
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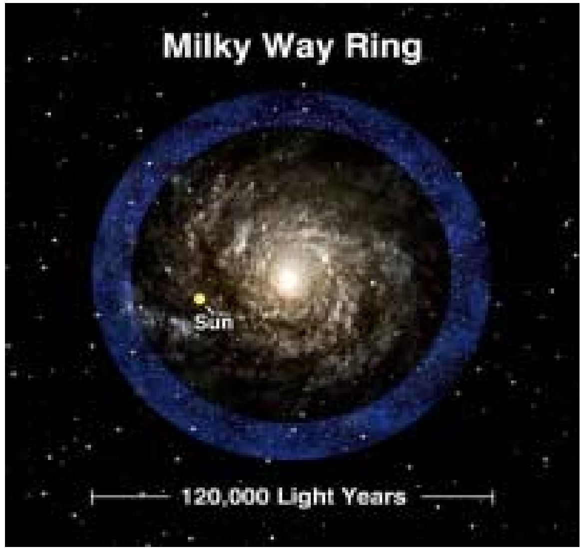
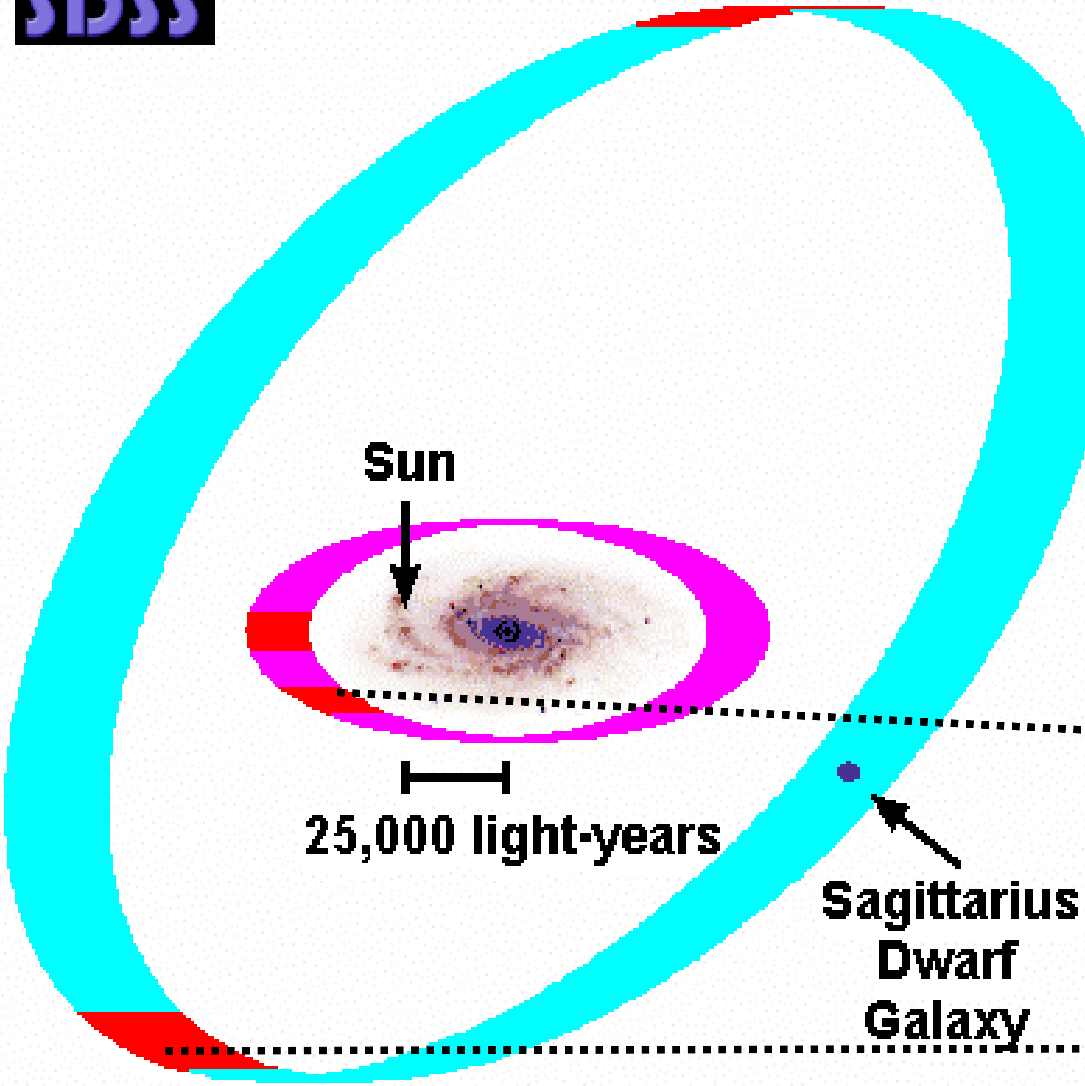
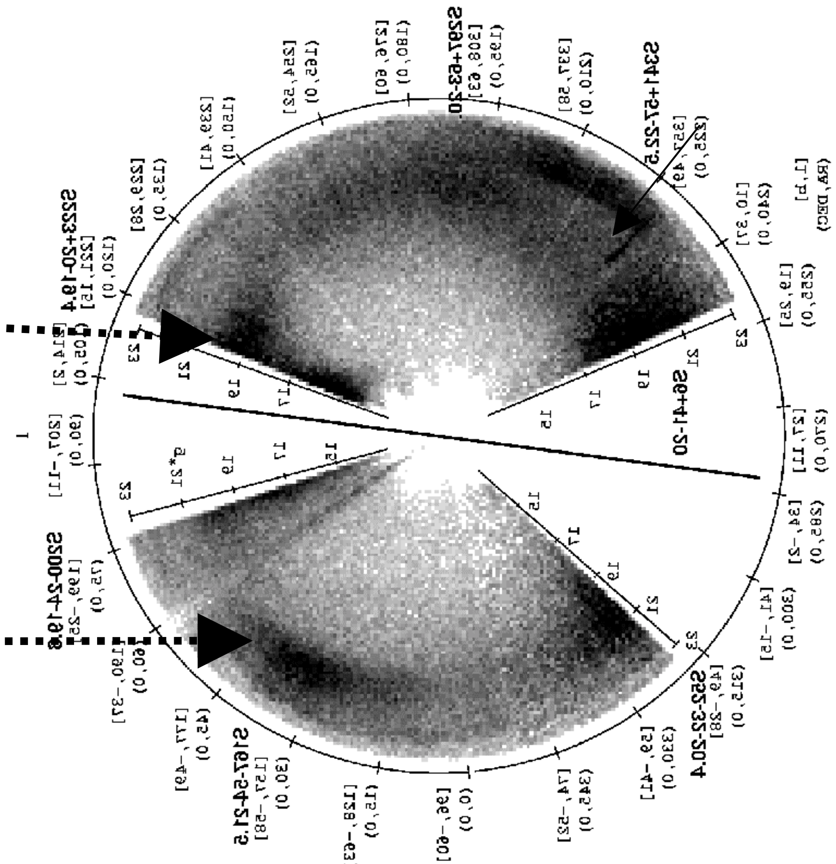
[128,-63]
(15,0)
[157,-58]
(30,0)
(45,0)
(60,0)
[199,-25]
(75,0)
g*21

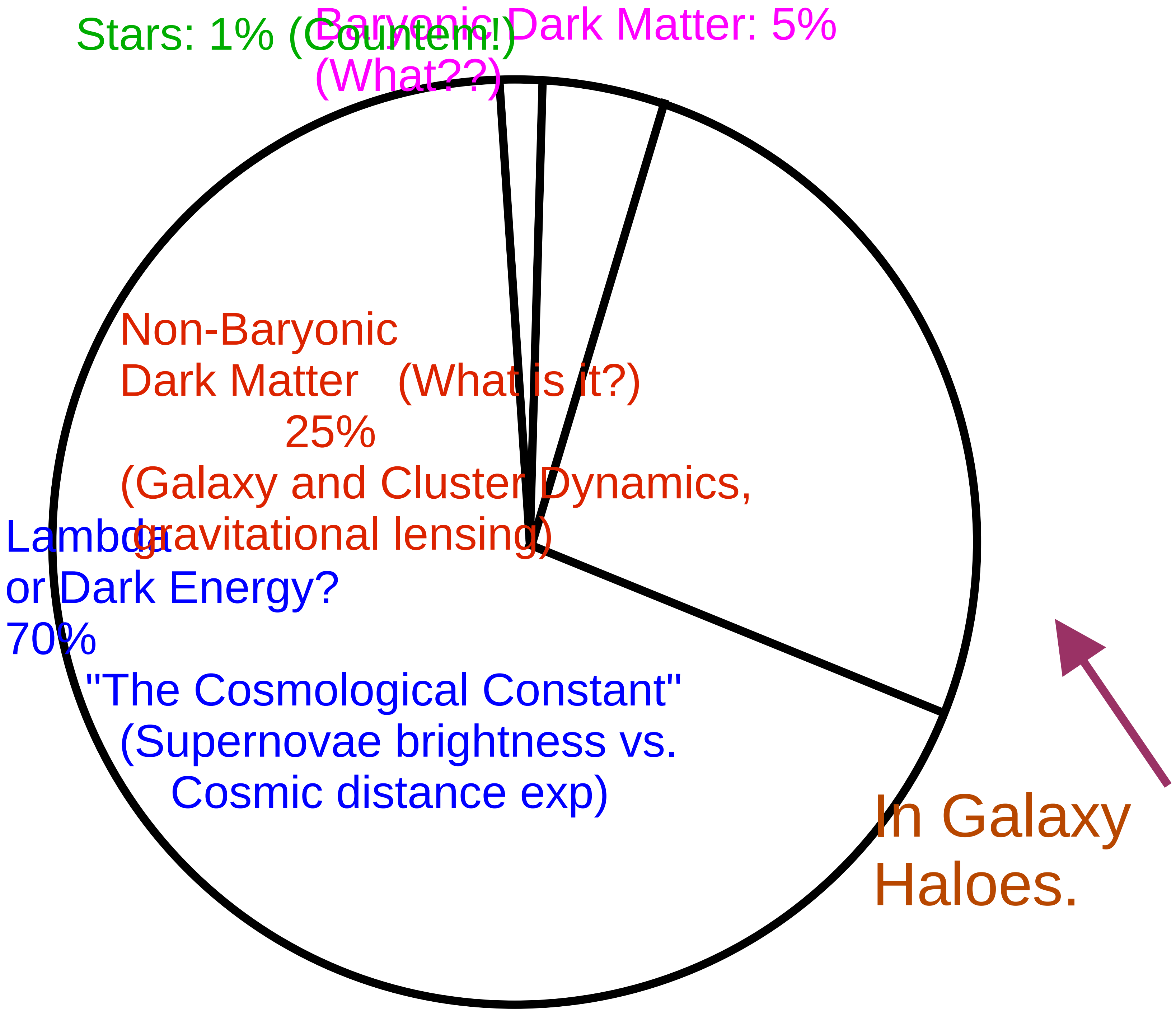
Rings around the Galaxy

(Yanny & Newberg)





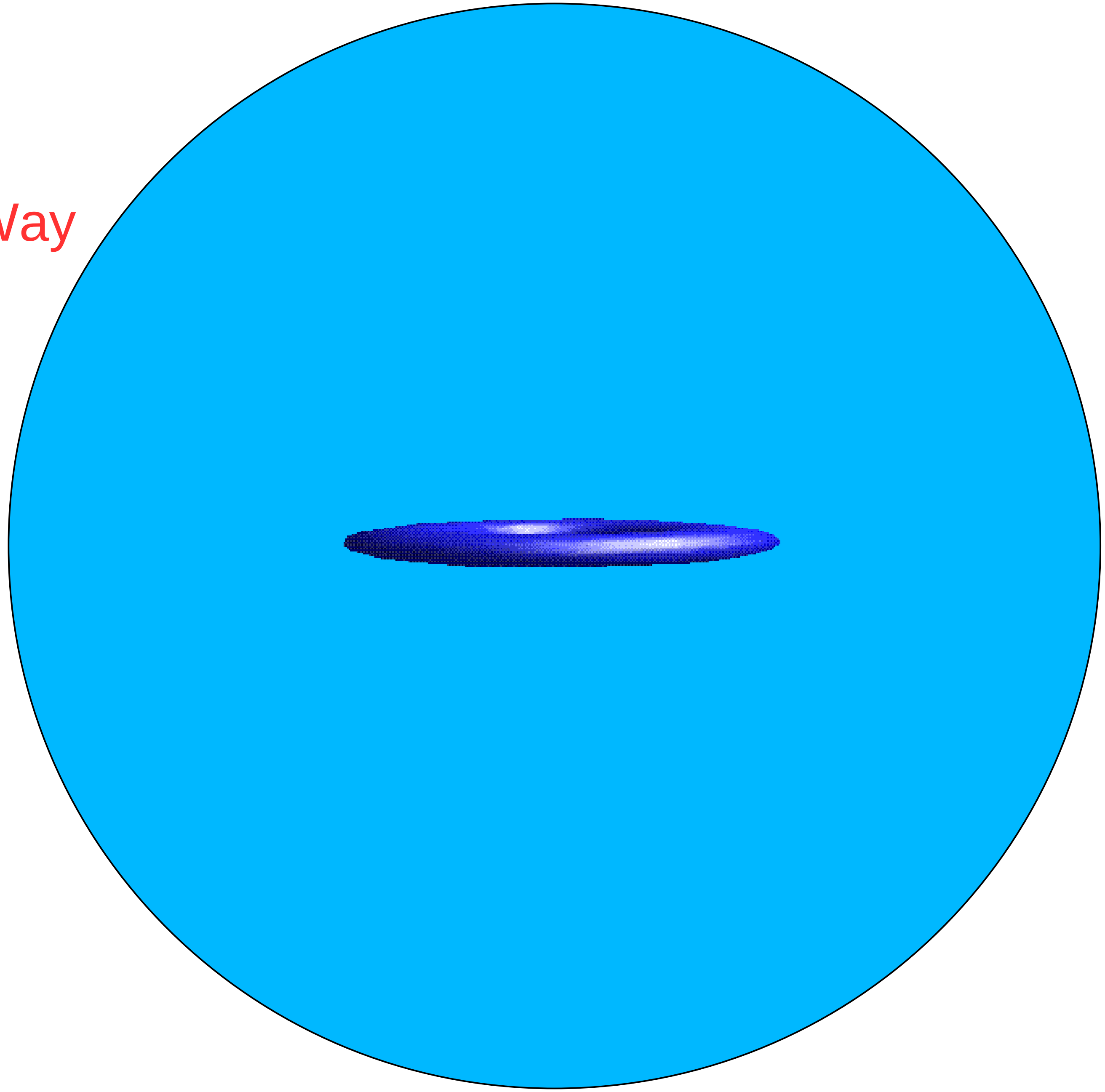




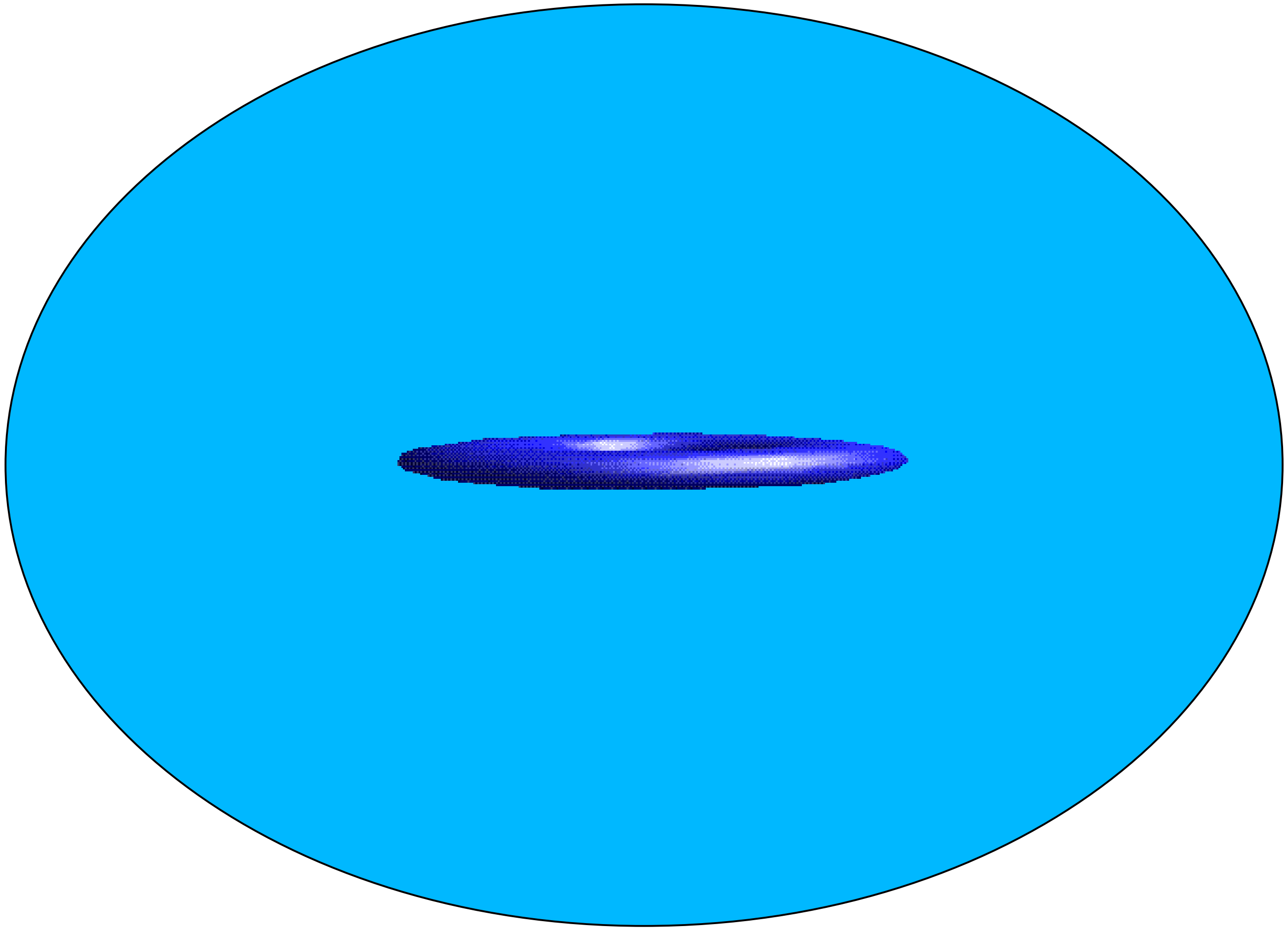
Forms of
Matter-Energy in the Universe (the pie chart).

Spherical halo: q=1.0

A Disk Galaxy
like the Milky Way
and its dark
matter
halo.

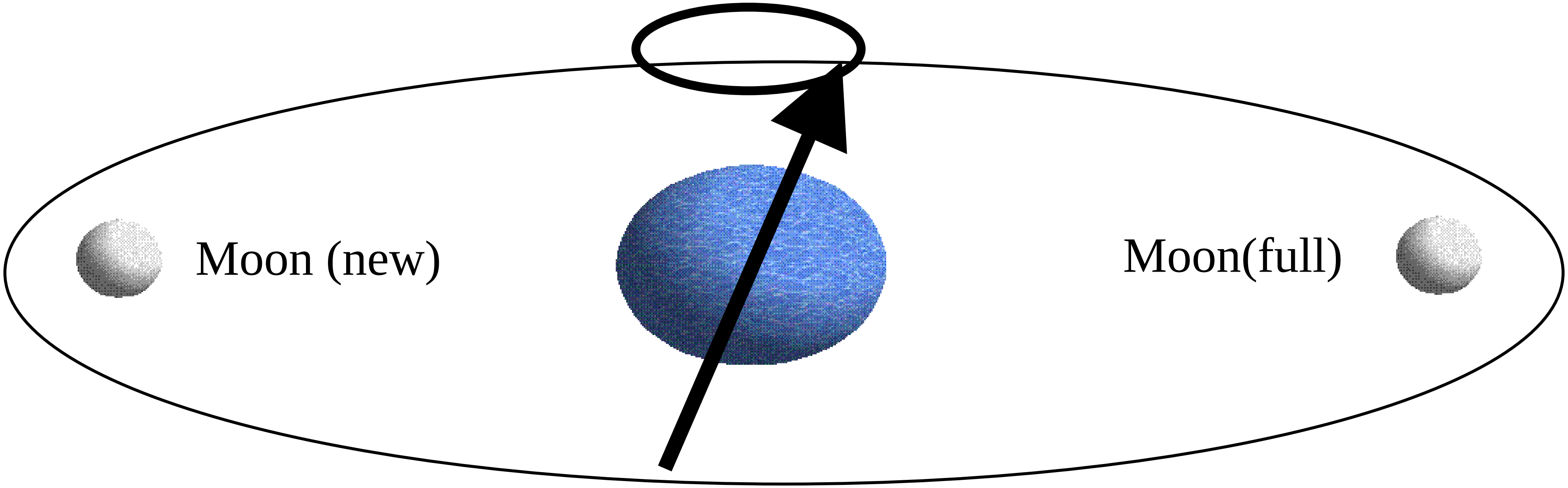


Flattened halo: q=0.75

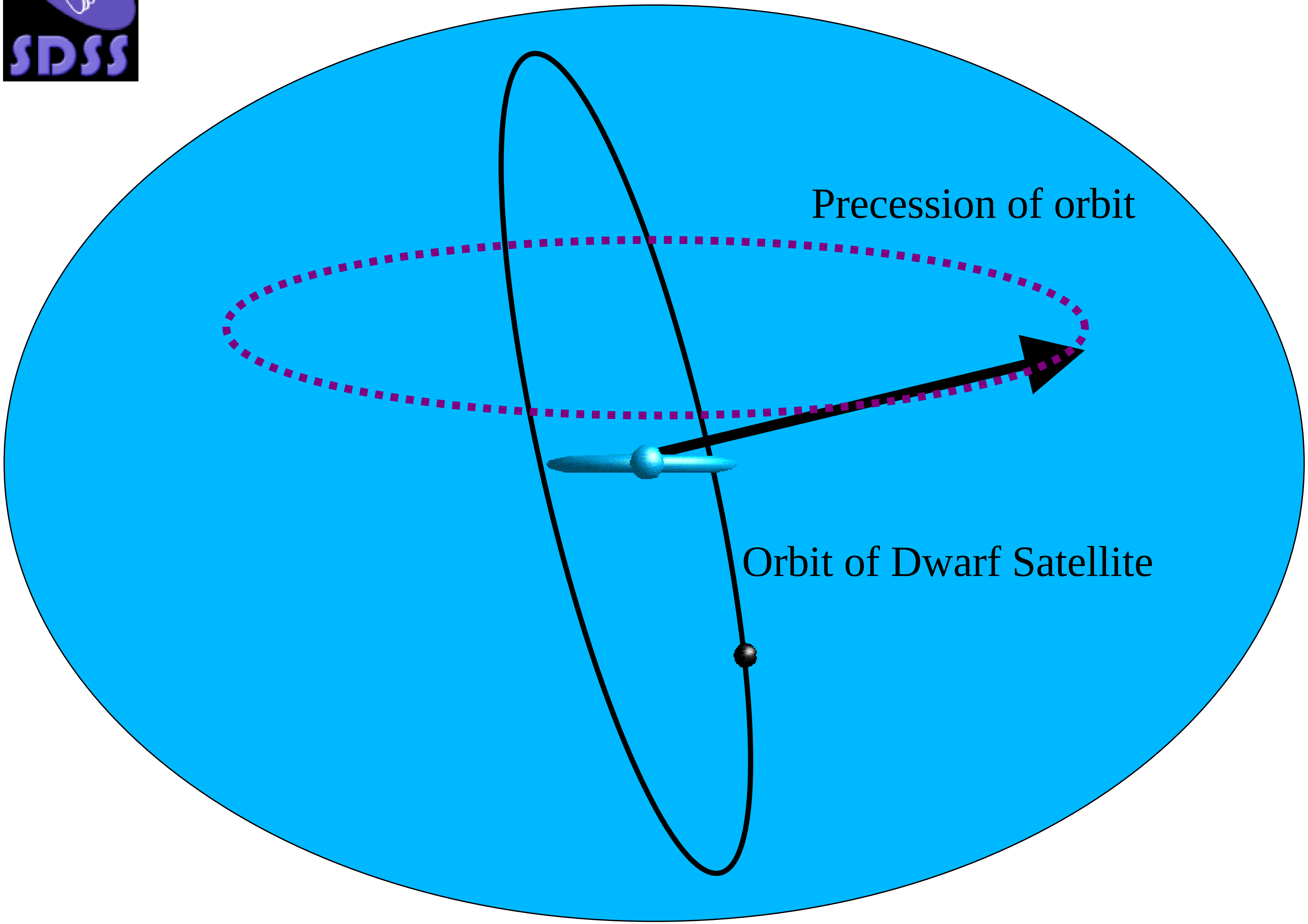


Vega Polaris

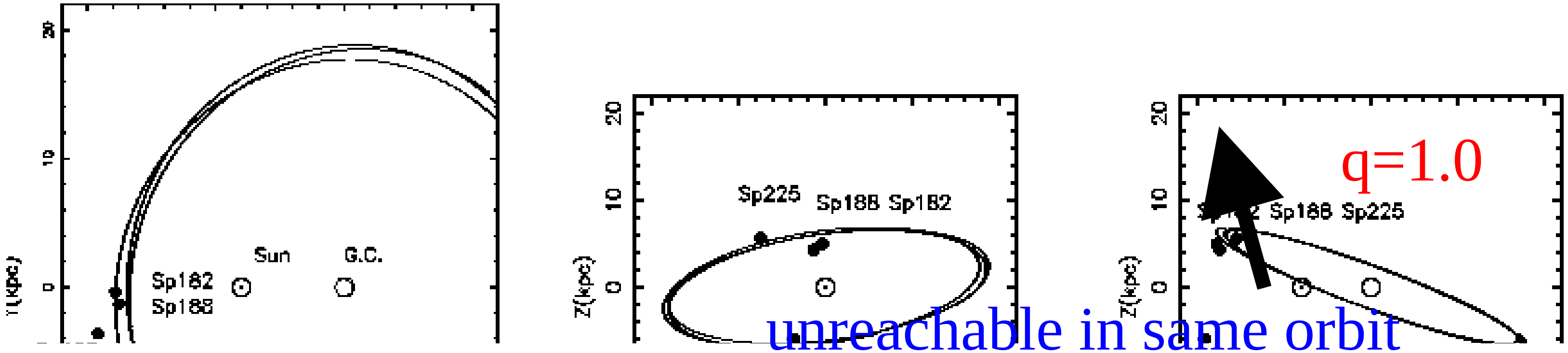
Earth-moon dynamic system is a ’flattened potential’
The result is precession of the Earth’s Axis (North Star changes) with period = 26,000 years



Flattened Potential



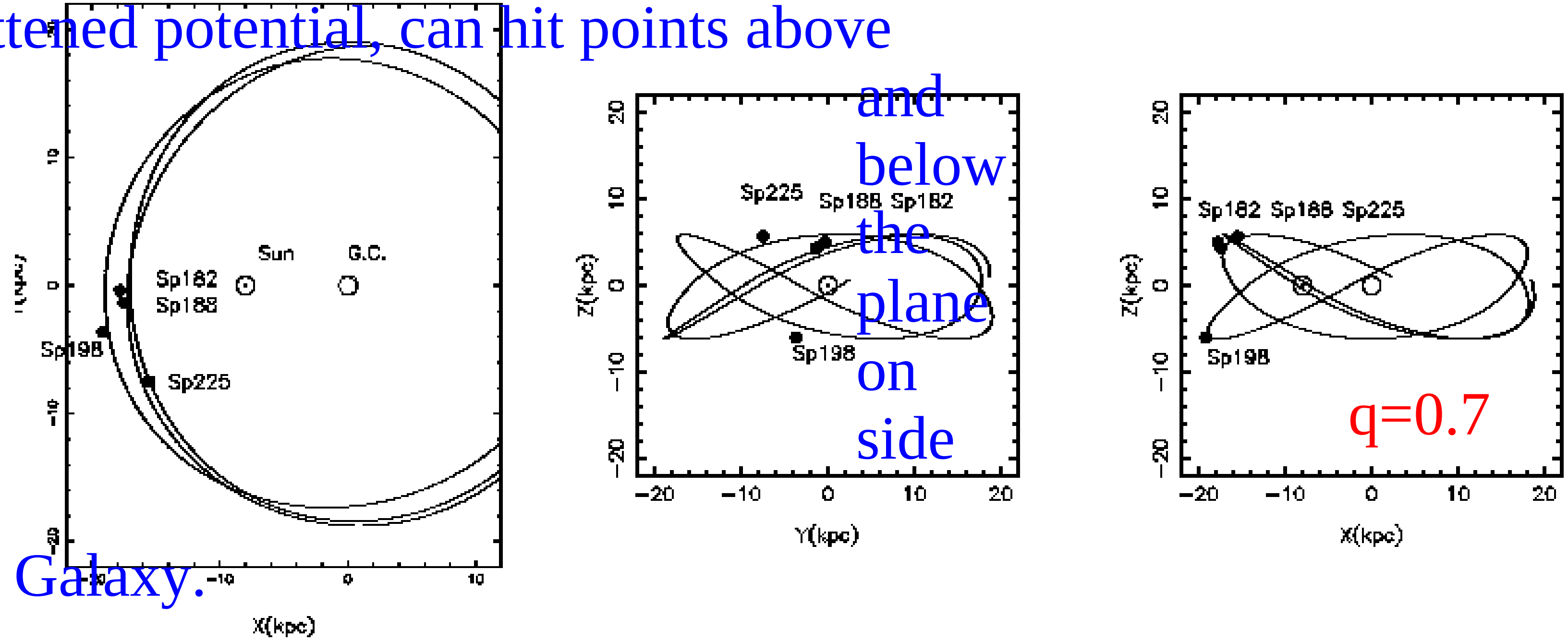
No precession in Spherical potential



q=1.0

unreachable in same orbit

In flattened potential, can hit points above and below the plane on side of the Galaxy.



q=0.7

Summary

z=6.28 Quasar (r, i, z)

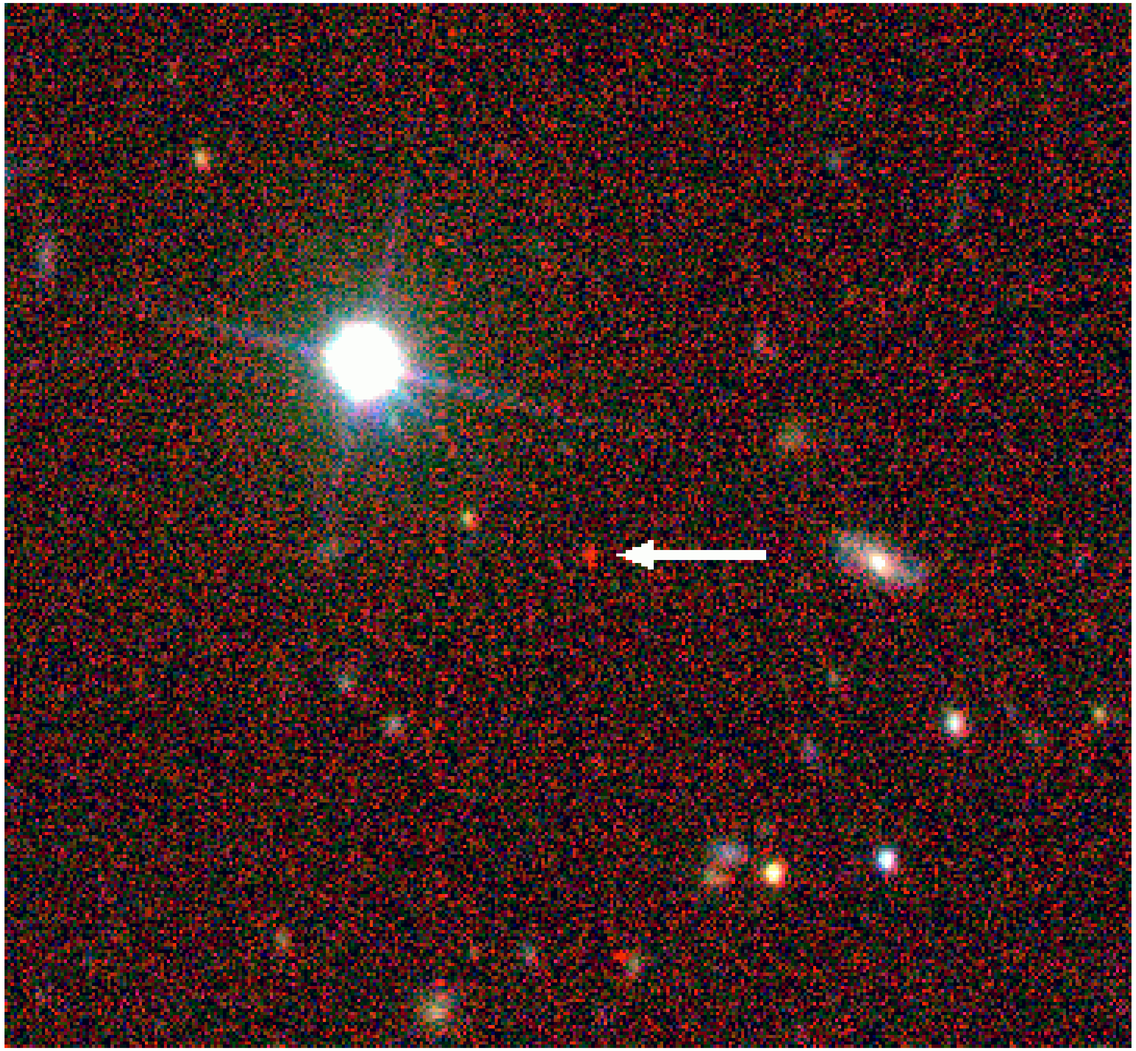
- SDSS status: 67% complete imaging, 46% spectroscopy (May 2003)

- Public Data Release 1 (beta) now available
  - http://www.sdss.org/dr1

- Science
  - Today discussed large-scale structure, power spectrum, galactic structure
  - Many other topics, e.g. quasars, lensing, rare stars, GRB counterparts, asteroids, …
  - http://www.sdss.org/publications

Rare Stars

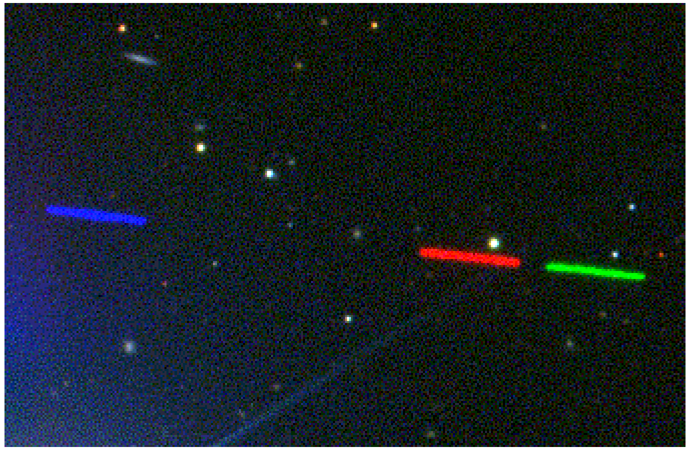
(Strauss, Knapp, Harris, ...)



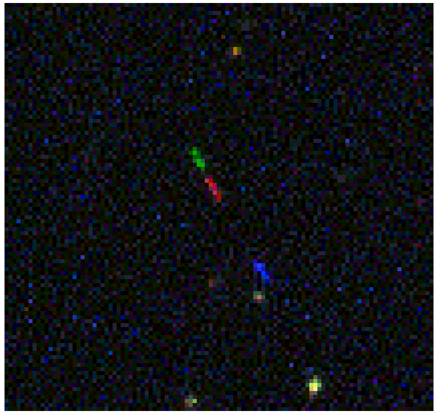
Near Earth Objects in SDSS

Steve Kent, Tom Quinn, Gil Holder, Mark Schaffer,
Alex Szalay, Jim Gray

Coding: g' r' i'



Run 1140
Camcol 4
Field 122



Run 2138
Camcol 2
Field 52

Sloan Digital Sky Survey (E885)

Outline

I. Description of SDSS survey

II. Science projects with the SDSS

III. To the future: a Virtual Observatory

Goal:

Conduct fundamental research in cosmology, particularly formation & evolution of galaxies and large scale structure

Approach:

Digital map of ¼ of sky in 5 bands

Spectra of 1 million galaxies,

100,000 quasars

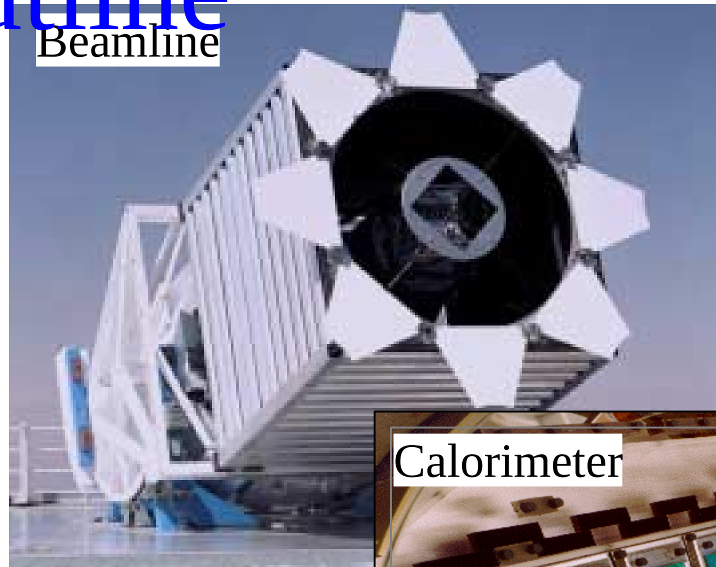
Resources:

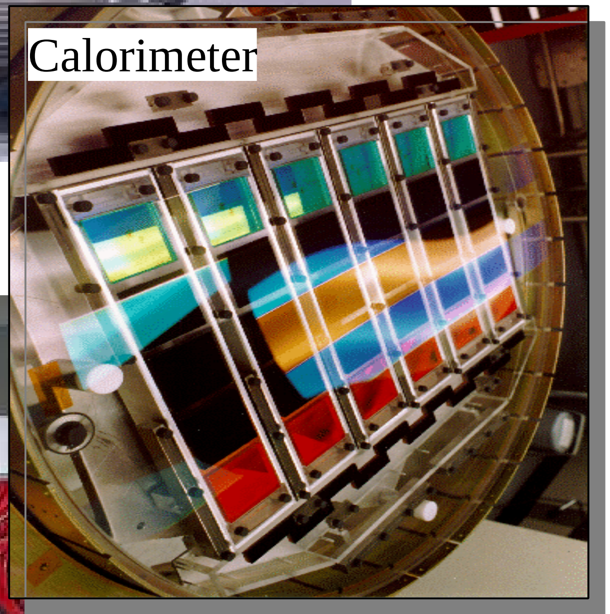
2.5 m telescope in New Mexico

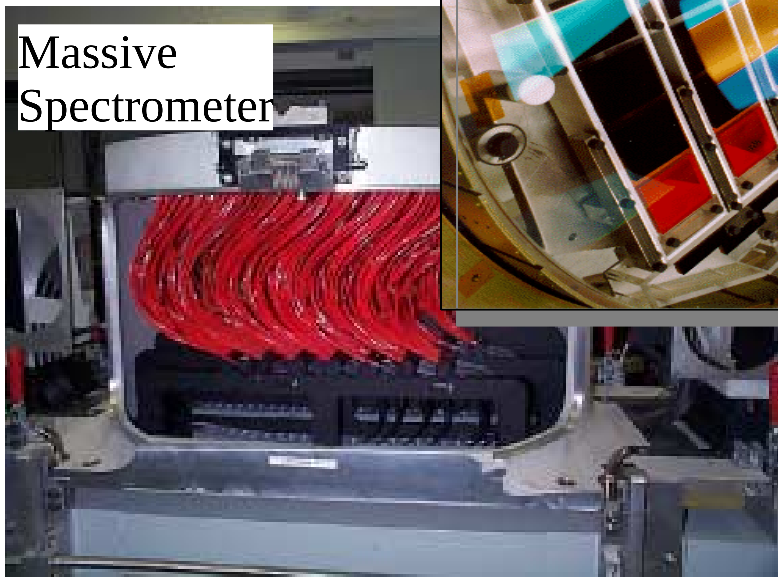
Large CCD camera

640 fiber spectrograph

13 partner institutions

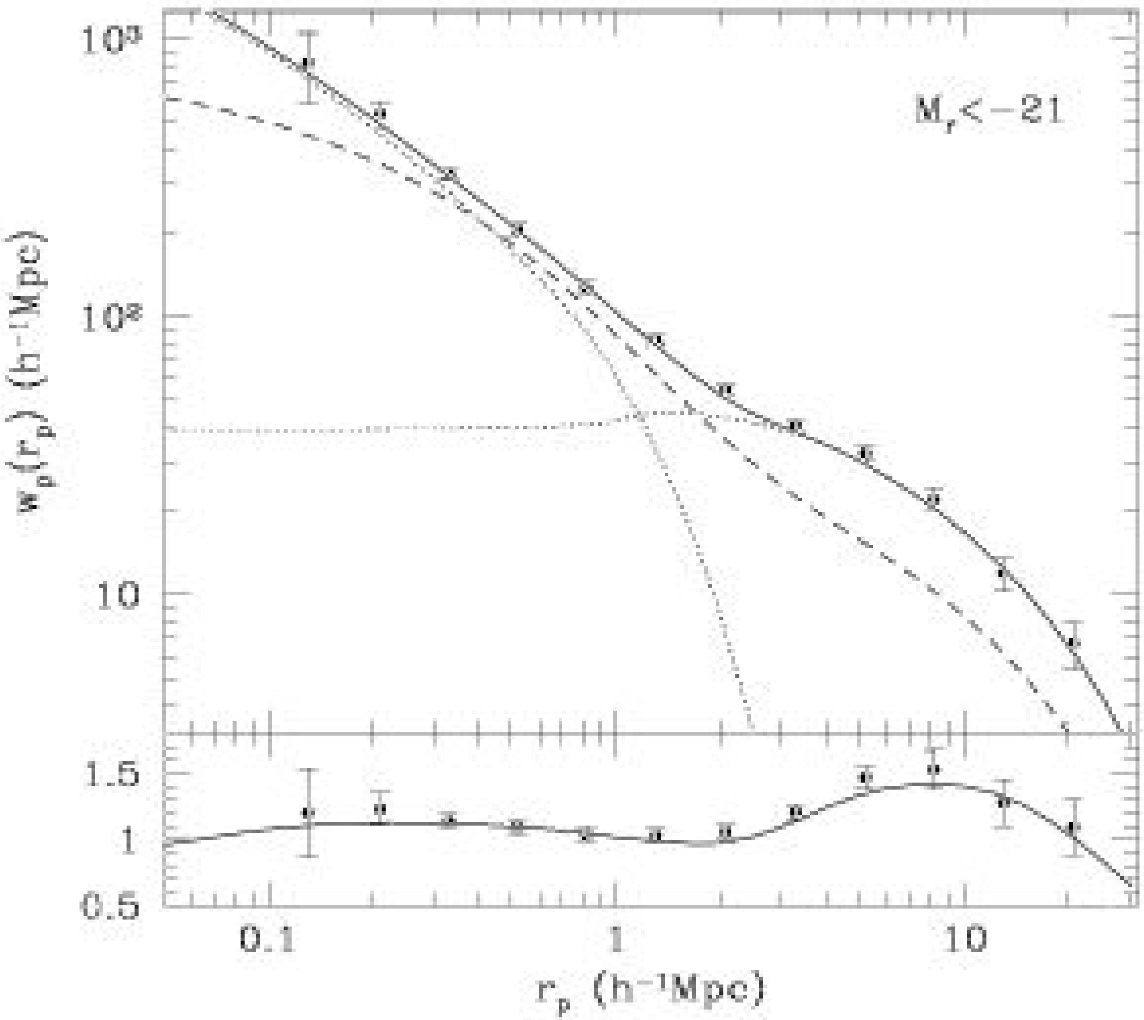






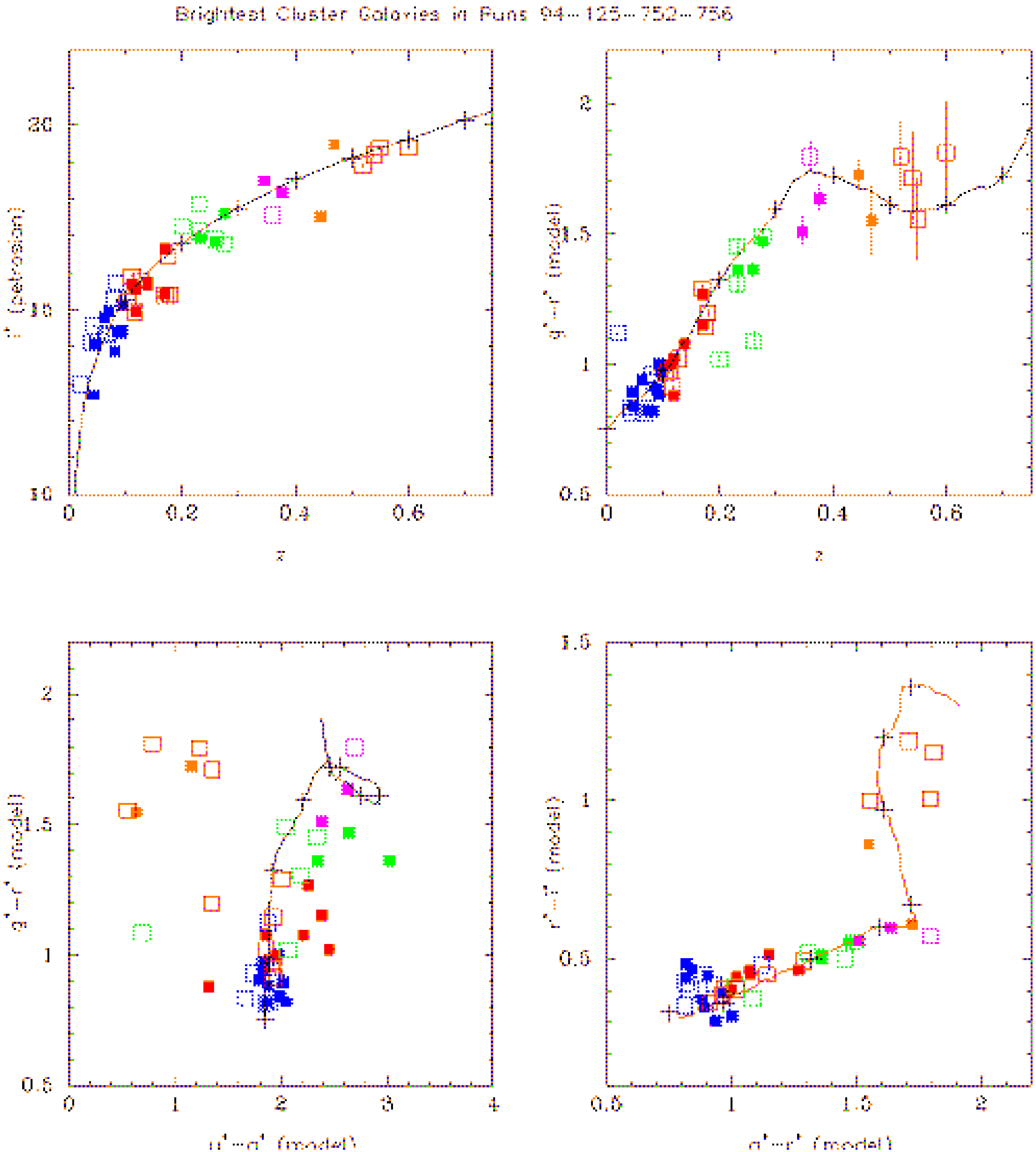
Spatial 2-point Correlation Function

(Zehavi et al. 2003)



Points: SDSS data

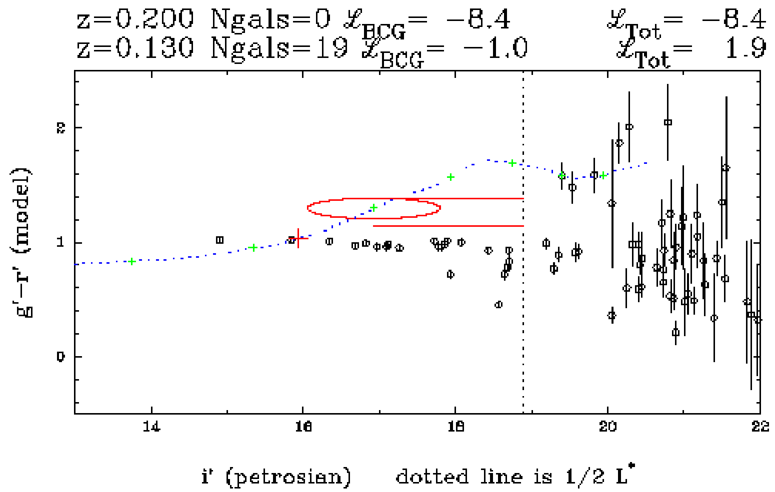
Lines: Best fitting “halo occupation distribution: model maxBcg Algorithm



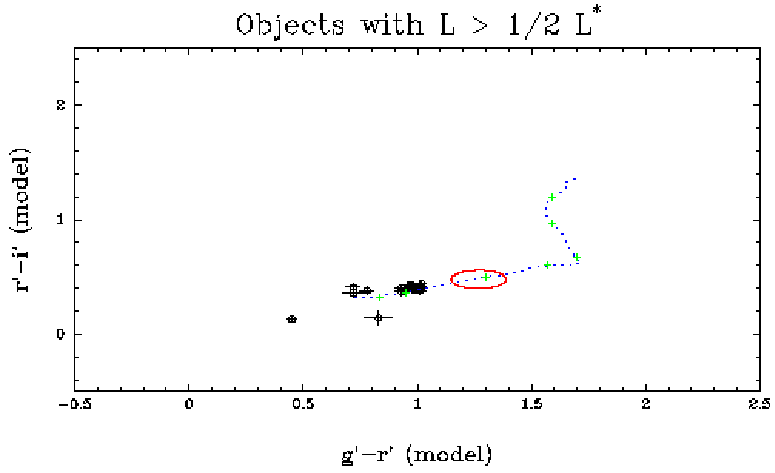
The maxBcg Algorithm (Annis et al.)

- Animation of process for a single galaxy

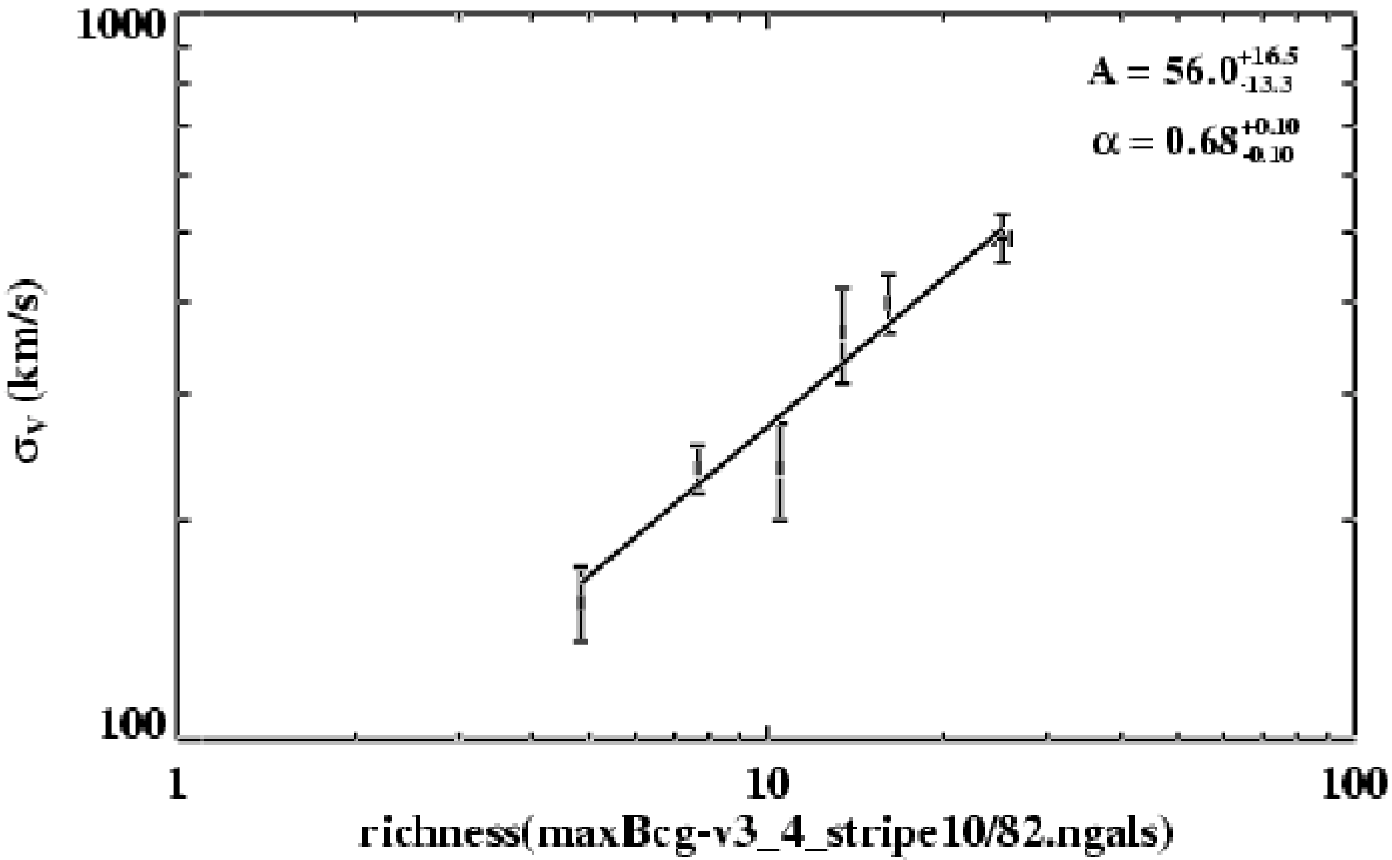
- Perform step for all galaxies
- Build a 3-d map
- Locate maxima

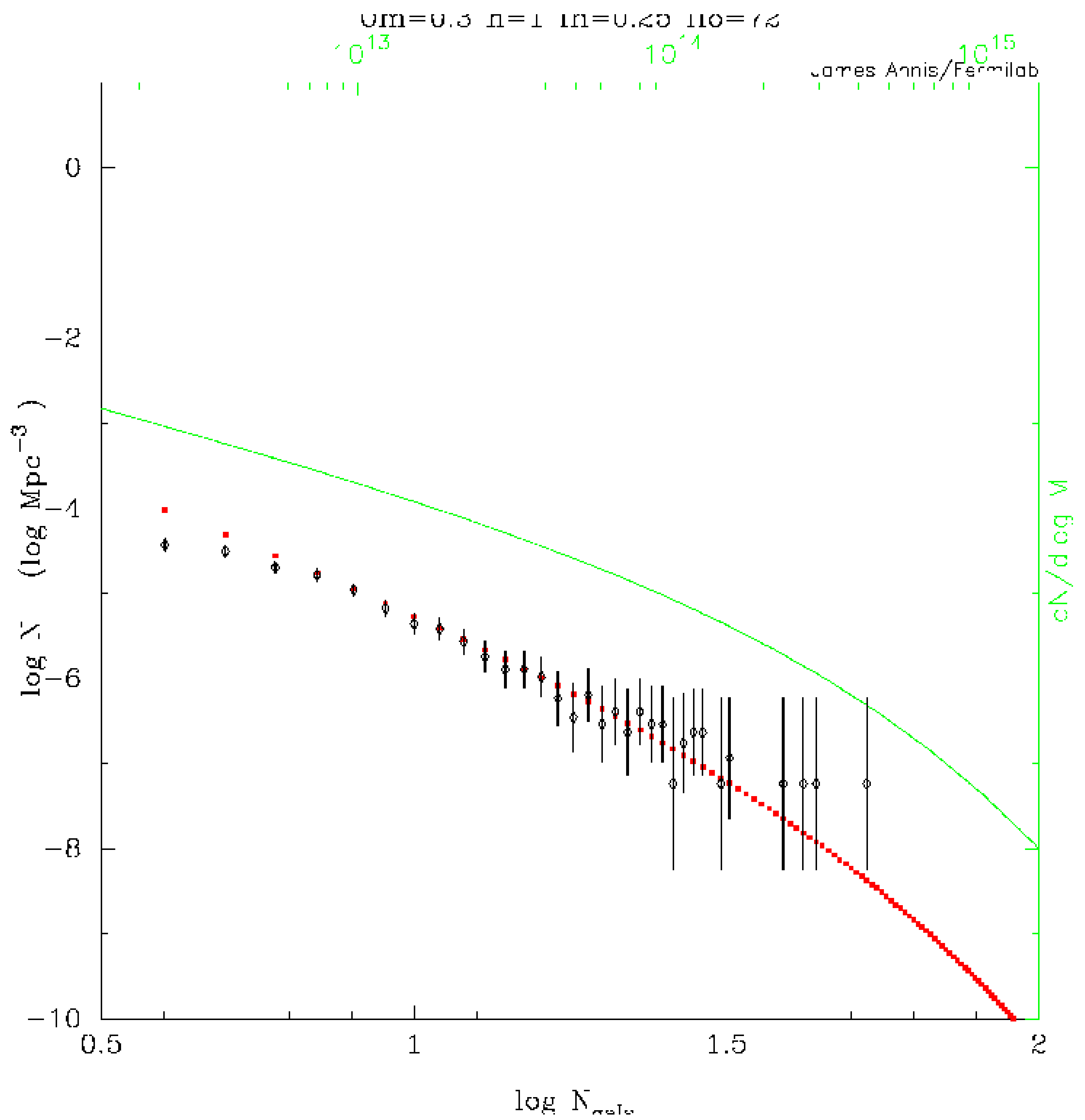


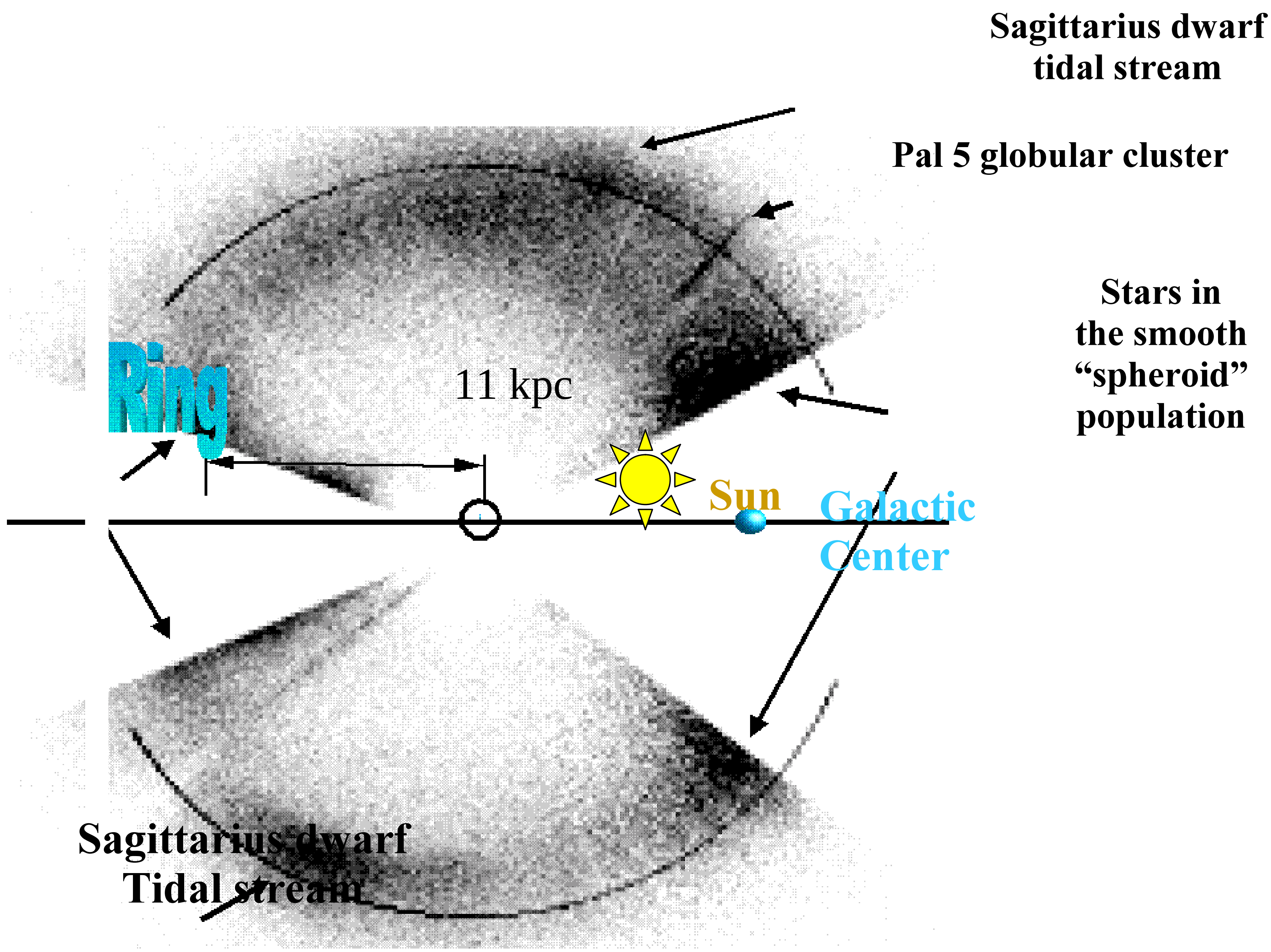
- Strengths
  - Works to high z
  - Very good photo-z
- Weaknesses
  - Strong assumptions built in



maxBcg Calibration from weak lensing




Om=0.3 n=1 m=0.25 ho=72
10^13
10^14
10^15
James Annis/Fermilab
0
−2
−4
−6
−8
−10
log N (log Mpc^-3)
dN/d og M
0.5
1
1.5
2
log N_gals



Sagittarius dwarf
tidal stream
Pal 5 globular cluster
Stars in
the smooth
“spheroid”
population
Ring
11 kpc
Sun
Galactic
Center
Sagittarius dwarf
Tidal stream

Conclusions

1. One sixth of a ring of stars which might encircle the Milky Way has been detected in the Sloan Digital Sky Survey. The ring is 18 kpc from the Galactic Center.
2. The stars are rotating at about 1/2 the disk velocity at the solar position.
3. We detect 2 x 10^7 M_8 in stars, and project that there could be 5 x 10^8 M_8 in stars in the whole ring (comparable to the SMC).
4. The kinematics of the stars are inconsistent with halo/thick disk populations of stars, with velocity dispersion 27 km/s.
5. The distribution (scale height above and below the plane) is inconsistent with thin disk/spiral arm populations.
6. The ring may be a galaxy companion to the Milky Way which was tidally disrupted into a ring.

Conclusions:

The fact that the F stars from the tidal tails of the Sgr dwarf are spread over such a large area 'perpendicular' to their orbit, suggests precession in a flattened potential, $q = 0.75$.

There is possibly another tidal stream orbiting like a ring at $d = 20$ kpc from the Galactic center at inclination < 20 degrees which may also yield interesting information on the potential of the Milky Way's halo.

At least one stream has been seen around M31 and there are polar ring galaxies which can also yield interesting facts about the implied shape of the dark matter surrounding apparently all the light.

Components of the Milky Way:

Bulge -- at center of Galaxy, metal rich stars, flattened (peanut-shape)
Thin Disk -- h = 0.3 kpc, l = 3.5 kpc metal rich stars (incl. Sun)
Thick Disk -- h = 0.6 kpc, l =2.5 kpc, medium old metal poor stars
'Spheroid' -- flattened c/a = 0.8, old metal poor stars
Metal Weak Thick Disk? Existence unclear, h = 2kpc, l = 8 kpc
and
Streams: Sagittarius, Monoceros?, others, metal poor generally

Gas, Dust, White Dwarfs, Neutron stars, (Quark stars??), Black Holes, all small in mass compared to DARK MATTER of unknown nature.

Separation of components
is both Kinematics (rotating or not, flattened or not)
and in Stellar Populations (metalicity of stars).

Clues to Distribution of DARK MATTER from stream orbit tracers.