Optical Surveys of Galaxies: Past, Present, and Future

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(Hosei University)

Recent review:
http://ned.ipac.caltech.edu/level5/March12/Djorgovski/Djorgovski1.html
1. Early Photometric Surveys
2. Early Redshift Surveys
3. Modern Surveys
4. Impacts of Modern Large Surveys
5. Future Surveys
1. Early Photometric Surveys
2. Early Redshift Surveys
3. Modern Surveys
4. Impacts of Modern Large Surveys
5. Future Surveys
As a contribution to the study of the structure of the metagalactic system, we have completed a photometric catalogue, appearing later in annals, of more than a thousand extragalactic objects brighter than the thirteenth magnitude. The primary virtues of the survey are its essential completeness and the fair homogeneity of the magnitudes over the whole sky. The primary virtues of the survey are its essential completeness and the fair homogeneity of the magnitudes over the whole sky.
Compilation of 1249 mostly known ‘Extragalactic Nebulae’

First magnitude-limited catalog based on more or less uniform photographic plates

Not naked eye!

Large efforts to give calibrated magnitudes
A Revised Shapley-Ames Catalog (1981)

Sandage, A. and Tammann, G., Carnegie Institution of Washington

The present catalog is, then, a compilation of available data on **redshifts**, morphological **types**, and **magnitudes** for Shapley-Ames galaxies, using literature sources to summer 1980. *(1246 galaxies)*

Study of the Local Supercluster and Field Luminosity Function

**Redshift distribution**

**Spatial Structure**

**Luminosity Function**


Binggeli et al. 1988, *ARAA*, 26, 509
Shane-Wirtanen (Lick) Count (1954)


Counts of extragalactic nebulae (m<18.4) in 10’x10’ cells over 12h<α<18h, -23° <δ<20°

Plates taken with 20-inch Carnegie Astrograph of the Lick Observatory

New analysis by Seldner et al. 1977, AJ, 82, 249

First analysis of correlation function of galaxy distribution

Totsuji & Kihara 1969, PASJ, 21, 221
Peebles 1973, AJ, 185, 413
World’s Major Schmidt Telescopes

- **Palomar Schmidt** (1949; 122cm)
- **Tautenburg Schmidt** (1960; 134cm)
- **Kiso Schmidt** (1974; 105cm)
- **ESO Schmidt** (1973-98; 100cm)
- **UK Schmidt** (1973; 122cm)
- **LAMOST** (2010; 400cm)
- **Tautenburg Schmidt** (1960; 134cm)
## Major Surveys with Schmidt Telescopes

<table>
<thead>
<tr>
<th>Designation</th>
<th>Survey Area</th>
<th>Emulsion+ Filter</th>
<th># of plates</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSS- I (B)</td>
<td>$-30^\circ &lt; \delta &lt; +90^\circ$</td>
<td>103 a-O+ none</td>
<td>936</td>
<td>1949-56</td>
</tr>
<tr>
<td>POSS- I (R)</td>
<td></td>
<td>103 a-E+ Plexiglass 2444</td>
<td>936</td>
<td></td>
</tr>
<tr>
<td>POSS- II (J)</td>
<td>III a-J+ GG 385</td>
<td></td>
<td>894 (894*)</td>
<td>1987-1999</td>
</tr>
<tr>
<td>POSS- II (R)</td>
<td>$0^\circ &lt; \delta &lt; +90^\circ$</td>
<td>III a-F+ RG 610</td>
<td>894 (891*)</td>
<td></td>
</tr>
<tr>
<td>POSS- II (I)</td>
<td>IV-N+ RG 9</td>
<td></td>
<td>894 (780*)</td>
<td></td>
</tr>
<tr>
<td>USNO (J)</td>
<td>$0^\circ &lt; \delta &lt; +90^\circ$</td>
<td>III a-J</td>
<td>894</td>
<td>1995?-99</td>
</tr>
</tbody>
</table>

(POSS = Palomar Observatory Sky Survey)
<table>
<thead>
<tr>
<th>Designation</th>
<th>Survey Area</th>
<th>Emulsion+ Filter</th>
<th># of plates</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UK Schmidt</strong> (SERC=Science and Engineering Research Council)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SERC(J)</td>
<td>$-90^\circ \leq \delta \leq -20^\circ$</td>
<td>III $a-J + \text{GG 395}$</td>
<td>606</td>
<td>1974-87</td>
</tr>
<tr>
<td>E(J)</td>
<td>$-15^\circ \leq \delta \leq 0^\circ$</td>
<td>III $a-J + \text{GG 395}$</td>
<td>288</td>
<td>1979-90</td>
</tr>
<tr>
<td>E(R)</td>
<td></td>
<td>III $a-F + \text{RG 630}$</td>
<td>288 (272*)</td>
<td>1984-</td>
</tr>
<tr>
<td>SERC(I)</td>
<td>$-90^\circ \leq \delta \leq 0^\circ$</td>
<td>IV-N + RG 715</td>
<td>894 (767*)</td>
<td>1984-</td>
</tr>
<tr>
<td>AAO(R)</td>
<td>$-90^\circ \leq \delta \leq -20^\circ$</td>
<td>III $a-F + \text{OG 590}$</td>
<td>606 (583*)</td>
<td>1989-2000</td>
</tr>
<tr>
<td>H$\alpha$</td>
<td>銀河面</td>
<td>Tech-Pan + H$\alpha$ 659</td>
<td>233 (108*)</td>
<td>1997-</td>
</tr>
<tr>
<td></td>
<td>マゼラン雲</td>
<td>Tech-Pan + H$\alpha$ 659</td>
<td>40 (24*)</td>
<td></td>
</tr>
<tr>
<td><strong>ESO Schmidt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESO(B)</td>
<td>$-90^\circ \leq \delta \leq -20^\circ$</td>
<td>II $a-O + \text{GG 385}$</td>
<td>606</td>
<td>1973-78</td>
</tr>
<tr>
<td>ESO(R)</td>
<td>$-90^\circ \leq \delta \leq -20^\circ$</td>
<td>III $a-F + \text{RG 630}$</td>
<td>606</td>
<td>1973-88</td>
</tr>
</tbody>
</table>

(* as of April 1999)
Eye Inspection of Survey Plates or Printed Charts

Palomar Charts

Scale: 67.1”/mm

6.6°
Major galaxy catalogs made from Schmidt surveys

**Eye Inspection**

- **Morphological Catalogue of Galaxies (MCG):** 4 volumes
  Vorontsov-Velyaminov et al. 1962-68 (Moscow State Univ.)
  ~29,000 galaxies from POSS-I

- **Catalogue of Galaxies and Clusters of Galaxies (CGCG):** 6 volumes
  Zwicky et al. 1961-68 (California Institute of Technology)
  ~28,000 galaxies from POSS-I complete down to $m_z=15.5$ mag and
  ~9700 clusters of galaxies

- **Uppsala General Catalogue of Galaxies (UGC)**
  12,921 galaxies from POSS-I with $\delta>-2.5$ down to 14.5 mag

- **The ESO/Uppsala Survey of ESO(B) Atlas**
  Lauberts 1982 (ESO)
  ~16,000 galaxies from ESO quick B survey with D>1'

**10,000-30,000 galaxies**

**Man-power limit of a single person or a few people**
Catalogue of Galaxies and Clusters of Galaxies (CGCG)

Symbols Used on the Charts

On the charts, the following symbols have been adopted for galaxies of different brightness:

- **:** large open
- *:* medium open
- •: small open
- ☐: large compact
- ◆: medium compact
- ☐: small compact
- ▲: large medium compact
- ▲: medium medium compact
- ▲: small medium compact
- ▲: very small medium compact

The GC Stars, of which only a few have been selected on each plate, are represented on the charts by a cross: †, and the contour lines of the clusters are numbered on the outside according to the following example:

12 = Cluster No. 12 on the chart

Palomar Chart (Virgo Cluster) 6.6 deg
These galaxy catalogs had been an important and indispensable basis of galaxy studies and observational cosmology until recently.

**CGCG (Zwicky et al. 1961-68)**

# of papers whose abstracts include ‘Zwicky catalog’ is about **270** (except IAUC and CBET)

**UGC (Nilson 1973)**

as of Aug. 5, 2012

# of papers whose abstracts include ‘Uppsala catalog’ is about **150** (except IAUC and CBET)

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**Total citation:** 905

**Total citation:** 1584
Digitization of Schmidt Plates (1980s-90s)

Plate Scanning Machines

COSMOS: Co-ordinates, Sizes, Magnitudes, Orientations, Shape

PDS microdensitometer (PDS 2020 GMS)

Automated Photographic Measuring System (APM)

The Minnesota Automated Plate Scanner (APS)
APM Galaxy Survey

~3 million galaxies from UK Schmidt plates down to $b_J=22$ over 7000 square degrees.

The APM Galaxy Survey
Maddox Sutherland Efstathiou & Loveday

http://vo.iucaa.ernet.in/2df/Survey/apm.html

Input catalog of 2dFGRS (2dF Galaxy Redshift Survey)
Reference Catalogue of Bright Galaxies

Morphological type, magnitude, diameter, ....

Not complete in any sense

(1) Reference Catalogue of Bright Galaxies (RC1)
G. & A. de Vaucouleurs 1964, University of Texas Press

2599 galaxies

(2) Second Reference Catalogue of Bright Galaxies (RC2)
G. & A. de Vaucouleurs, H.G. Corwin 1976, University of Texas Press

4364 galaxies

(3) Third Reference Catalogue of Bright Galaxies (RC3)
G. de Vaucouleurs et al. 1991, New York: Springer

23,024 galaxies

Exponential increase!
1. Early Photometric Surveys
2. Early Redshift Surveys
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Era of Redshift Surveys (1980’s- 90’s)

First hint of large-scale structure

Importance of completeness!

260 sq. deg

238 galaxies
(m<15.0)

(only) 44 new redshifts toward completeness

CfA Survey

CfA-I (1977-1982)
- m<15.5 mag
- 7031 galaxies
- 2401 galaxies (m<14.5) over 8700 deg^2 (b>40, δ>0)

CfA-II (1984-1995)
- m<15.5 mag
- ~18000 galaxies (m<15.5) over 9700 deg^2

Motivation for wider and deeper surveys

IRASz: IARS Point Source Catalog Redshift Survey
SPS: Supergalactic Plane Survey
SAPM: Stromlo-APM Redshift Survey
SSRS2: Southern Sky Redshift Survey II
CFRS: Canada-France Redshift Survey
ORS: Optical Redshift Survey
LCRS: Las Campanas Redshift Survey
ESP: ESO Slice Project
CNOC2: Canadian Network for Obs.’l Cosmology Field Galaxy Redshift Survey

Geller et al. 1987, IAUS, 124, 301
wide survey $m_B < \sim 16$ mag

CfA-II

1769 galaxies

150 h$^{-1}$ Mpc

~ 1990

~ 2000

wide survey $m_B < \sim 16$ mag

150 h$^{-1}$ Mpc

200 h$^{-1}$ Mpc

finger of God
1. Early Photometric Surveys
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Modern Wide Surveys

Imaging Survey + Spectroscopic (Redshift) Survey

Photometric Catalog

2dF Galaxy Redshift Survey (2dFGRS)

(photographic photometry and) redshifts of 220,000 galaxies

Southern Hemisphere

m_B<~19 mag

m_B<~16 mag

3.9 m

Started in 1997, completed in 2001
Final Data Release - 30 June 2003

APM (photographic) Galaxy Survey was used as the input catalog

Sloan Digital Sky Survey (SDSS)

5-band Photometry: $3.57 \times 10^8$ objects

redshifts: 930,000 galaxies, ~100,000 quasars, and 460,000 stars.

m_B<~16 mag

3.57x10^8 objects

z=0.15

z=0.1

z=0.05

2.5 m

Started in 2000, completed in 2008

Apache Point Observatory (2800m; New Mexico, USA)

Survey Volume

Two 320-channel spectrographs

Survey Volume

z=0.2

800 Mpc

our Galaxy

Imaging survey

5 bands

Quantum Efficiency

Wavelength (Å)

Spectroscopic Survey

Proceeded in parallel

640+ holes

Plug plates

Camera

Fiber cartridge

Our Galaxy Survey Volume

z=0.2

800 Mpc

our Galaxy

Apache Point Observatory (2800m; New Mexico, USA)
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Impacts of a large survey (1)


Galaxies living in higher density regions are redder.

However, the relation between local density and color is different for galaxies of different luminosities.

The relation is more pronounced for faint galaxies than for bright galaxies.
Impacts of a large survey (2)

Large sample ➔
- Small statistical error
- Accurate estimate of intrinsic dispersion

Luminosity (Mass) → Metallicity Relation

53,000 star forming galaxies in the SDSS sample


Impacts of a large survey (3)

<table>
<thead>
<tr>
<th>Absolute magnitude</th>
<th>Sersic index</th>
<th>Surface brightness</th>
<th>Color indices</th>
</tr>
</thead>
</table>

- $M$
- $n$
- $\mu$
- $(u-g)$
- $(g-r)$
- $(r-i)$
- $(i-z)$

Global trend at a glance

Large sample

144,609 galaxies

Impacts of a large survey (4)

**Discoveries!**

<table>
<thead>
<tr>
<th>anticipated</th>
<th>before SDSS</th>
<th>after SDSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>quasars</td>
<td>&lt;~15,000</td>
<td>~&gt;80,000</td>
</tr>
<tr>
<td>High-z (z&gt;5) quasars</td>
<td>None (z_{max}=4.897)</td>
<td>~60 (DR5 catalog) + 13 z&gt;6 quasars</td>
</tr>
<tr>
<td>L and T dwarfs</td>
<td>~20 (mostly from 2MASS, 1999)</td>
<td>71 (new from SDSS, 2006)</td>
</tr>
<tr>
<td>Lensed QSOs</td>
<td></td>
<td>36 (25 new)</td>
</tr>
</tbody>
</table>

**serendipitous**

**Green Peas**
Actively star forming compact dwarf galaxies

**Actively star forming E galaxies**
77,429 quasars (DR5 Catalog).

Known quasars (open circles)
Impacts of a large survey (5)

Detection of Weak Signals!

Stacking of 683 clusters of galaxies at 0.2<z<0.3


Detection of diffuse intracluster light

Detection of the Baryon Acoustic Peak

46,748 luminous red galaxies in 0.72 h⁻³ Gpc over 3816 deg² at 0.16 <z< 0.47

Impacts of a large survey (6): Virgo Cluster
Las Campanas Survey: VCC (Virgo Cluster Catalog)

Binggeli et al. 1984, AJ, 89, 64 ;
1987, AJ, 94, 251

Study of dwarf galaxies beyond the Local Group

Virgo Cluster Catalog: VCC
2096 galaxies down to B~18 mag


Virgo dwarf galaxies

2.5m du Pont Tel.
+ 50-cm pg. plates

67 plates (1.5 deg FoV)

15 degrees
right ascension

20 degrees
deciliation

1277 certain members

574 possible members

245 background galaxies
Next Generation Virgo Cluster Survey (NGVS)


CFHT/MegaPrime, 
~140 nights (2009-2012) 
104 deg^2 

five SDSS bands 
(point source) 
\( u^* = 25.9 \) AB mag 
\( g' = 25.7 \) AB mag 
\( r' = 25.2 \) AB mag 
\( i' = 24.9 \) AB mag 
\( z' = 24.6 \) AB mag 

\[
\begin{align*}
\mu_B &= 7 - 11 - 15 - 19 - 23 \\
M_B &= -8 \text{ mag.} \\
\langle \mu_B \rangle_e &= 24 \\
\end{align*}
\]

average surface brightness 

absolute magnitude \( M_B \) (mag)

VCC limit 
Palomar Chart limit (1960s)

NGVS limit (1985)

NGVS limit (2012)

Virgo dwarf 
LG dwarf at Virgo distance 

Limit of giant early-type galaxies
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Major Existing, **Upcoming**, and **Future** Surveys

SXDS: The Subaru/XMM-Newton Deep Survey
COSMOS: Cosmic Evolution Survey
CFHTLS: Canada-France-Hawaii Telescope Legacy Survey
NDWFS: The NOAO Deep Wide-Field Survey
BCS: Blanco Cosmology Survey
Stripe82: SDSS Legacy Survey Stripe82
RCS2: Red Sequence Cluster Survey 2
**VST-ATLAS**: VLT Survey Telescope (2.6m tel)
PS1/PS2: Pan-STARRS 1&2 Telescopes
KIDS: Kilo degree Survey (VST)
**HSC**: Hyper Suprime-Cam Survey
**DES**: Dark Energy Survey (DECam+Blanco 4m)
**Skymapper**: Skymapper Southern Sky Survey
**Euclid**: Euclid Satellite
**LSST**: Large Synoptic Survey Telescope

Black: Existing
Magenta: Upcoming
+ Red
Blue: Future
Major Existing, Upcoming, and Future Surveys

HSC=Hyper Suprime-Cam on Subaru Telescope

(Credit: M.Takada, HSC survey team)
Hyper Suprime-Cam (HSC) on Subaru Telescope

Japan/Princeton/Taiwan Collaboration with Mitsubishi/Canon/Hamamatsu

Suprime-Cam

Hyper Suprime-Cam

116 2Kx4K CCDs

Comparison of Field of View

HST/ACS

Suprime-Cam

HSC

LSST: 9.6 sq. deg

1.77 sq. deg

840 mm φ

1.7 m

0.05 deg

0.5 deg

1.5 deg

0.5 deg
Major Existing, **Upcoming**, and **Future** Surveys

Data Amount and Data Rate

- 30 TB/night (10 years)
- 0.5 TB/night
- 0.2 TB/night

HSC Survey will explore new frontier in survey parameter space

Coming soon (2013-)

Stay tuned!!

(Credit: M. Takada, HSC survey team)
Summary

- Essential factors of galaxy surveys
  Completeness, Homogeneity, Wide sky coverage

- Innovative surveys/catalogs opened frontiers
  SA/RSA catalog, Lick Count, POSS, CGCG, UGC, ...SDSS

- Impacts of large surveys
  complete sample, small statistical error/weak signal
detection, discoveries (anticipated, serendipitous), ...
Next Generation Virgo Survey (NGVS)

- Upcoming and future surveys
  data amount: 300TB-100PB,
data rate: (0.5TB-10TB)/night