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Optical Surveys of Galaxies: Past, Present, and Future

Sadanori Okamura

Department of Advanced Sciences, Faculty of Science and Engineering, Hosei University,
3-7-2 Kajino-cho, Koganei city, Tokyo, 184-8584 Japan
email: sadanori.okamura@hosei.ac.jp

Abstract. A brief history is given of wide area optical surveys of galaxies and resulting catalogs, starting from the Shapley-Ames Catalog through POSS and CfA surveys to modern surveys. Scientific impacts of large surveys are described in terms of the complete sample, large homogeneous samples, and new discoveries. Upcoming and future ambitious surveys are also mentioned. A recent review of surveys in various wavelength regions is given by Djorgovski *et al.* (2012).

Keywords. surveys, catalogs, galaxies

1. Early Photometric Surveys and Resulting Catalogs

Shapley-Ames catalog (SA) (Shapley & Ames 1932) is the first magnitude-limited catalog of galaxies based on more or less uniform photographic plates instead of the naked-eye observation. Three essential factors of the survey, i.e., completeness, homogeneity, and wide sky coverage, were explicitly mentioned for the first time in the SA. Another important early survey was the number count of about 210,000 faint galaxies carried out at Lick observatory by Shane & Wirtanen (1954),which led to the first secure measurement of two-point correlation function of galaxy distribution in the form of $\xi(r) \propto r^{-1.8}$ (Totsuji & Kihara 1969; see also Peebles 2012).

Eye-inspection of wide-field photographic plates produced from sky surveys with large Schmidt telescopes led to large galaxy catalogs. Among others, Catalogue of Galaxies and Clusters of Galaxies (CGCG) by Zwicky *et al.* (1961-68) and Uppsala General Catalogue of Galaxies (UGC) by Nilson (1973) are noted. CGCG and UGC had been the major data sources of observational cosmology until recently because of their reasonable completeness. Entries of all the manually produced catalogs in these days are less than $\sim 30,000$, which may reflect the man-power limit.

Three issues of the Reference Catalogues (RC) by de Vaucouleurs and colleagues were the state-of-the-art compilations of galaxy data including 2599 (RC1, 1964), 4364 (RC2, 1976), and 23024 (RC3, 1991) galaxies. Digitization of Schmidt plates by dedicated scanning machines were intensively carried out in 1980s-90s, resulting in far larger catalogs such as APM Catalog which contains 2 million galaxies (Maddox *et al.* 1990).

2. Redshift Surveys and Modern Surveys

Inspired by the pioneering work by Gregory & Thompson (1978), many redshift surveys were carried out in 1980s-90s. CfA-I ($m \leqslant 14.5$) and CfA-II ($m \leqslant 15.5$), representative early wide surveys which used CGCG and UGC as input catalogs, led to the discovery of the large scale structure of the universe (e.g., de Lapparent *et al.* 1986). The CfA survey motivated many wider and/or deeper redshift surveys (e.g., Kontizas 1997).

Modern wide spectroscopic surveys went down to $m \sim 19$ mag, more than three magnitudes deeper than those before 2000. New photometric catalogs deeper than CGCG were necessary as the input catalog for these surveys. APM catalog was used in 2dfGRS which measured redshifts of 220,000 galaxies (Colless *et al.* 2001). In the Sloan Digital Sky Survey (SDSS) which measured redshifts of more than a million galaxies, photometric survey to produce the input catalog and spectroscopic survey based on the input catalog were carried out in parallel using the same 2.5-m telescope (York *et al.* 2000).

3. Impacts of Large Surveys

Large surveys which collected an unprecedentedly large amount of data of unprecedentedly high quality (in terms of accuracy and homogeneity) always made a large impact on astronomy, by allowing us to construct a complete samle free from biases and a statistically large homogheneous sample, and often leading us to new discoveries.

SA and its successor, A Revised Shapley-Ames Catalog by Sandage and Tammann (1981) became the basis of the studies of the structure of the Local Supercluster (Yahil *et al.* 1980) and luminosity function of field galaxies (Binggeli *et al.* 1988). SDSS turned data-poor studies of galaxy properties into precision science. Large high-quality samples from SDSS enabled the detection of extremely weak signals which had been buried in the noise in previous data (*e.g.,* Eisenstein *et al.* 2005). The Next Generation Virgo Survey (Ferrarese 2012) will surpass the Las Campanas Survey 30 years ago (Binggeli *et al.* 1985) by 8 mag. in the integrated magnitude and 3 mag. in the surface brightness.

4. Upcoming and Future Surveys

Astronomy is changing from a data-starving science to a data-rich science. There are a wealth of existing and upcoming digital surveys in optical and near-infrared (see Sec. 4.1 of Djorgovski *et al.* 2012). The Large Synoptic Sky Survey (LSST) is a very ambitious future survey using a dedicated 8-m telescope in Chile, which will produce data of 100 Petabyte scale. Another survey with 8-m Subaru Telescope (HSC Survey; Takada 2010) is about to start in 2013.

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