ASTRONOMY FROM WIDE-FIELD IMAGING

Part One:

WIDE-FIELD SKY SURVEYS AND PATROLS

THE IMPORTANCE OF WIDE-FIELD IMAGING

V.A. LIPOVETSKY
Special Astrophysical Observatory
Russian Academy of Sciences
Nizhnij Arkhys
Karachai-Circessia Republic, Russia, 357147

1. Introduction

The oncoming meeting and the big group of specialists gathered here reminds me of the late sixties, when I started the search for Markarian galaxies at the Byurakan Observatory. We carried out the survey with a 1 m Schmidt telescope (f/2.1). The First Byurakan Survey (FBS) consisted of more than two thousand plates with an exposure time of 30-60 minutes per plate. While guiding the telescope I therefore had plenty of time to think on future survey techniques.

My thoughts concerned improvements of our Survey: get better quality plates, increase the limiting magnitude, speed up the inspection of the plates (we used visual inspection with a lens), and apply special algorithms for plate inspection. Other interesting questions concerned the information that we could extract from our low resolution spectra, how to measure raw redshifts for normal and emission line galaxies, and what research could be done with a velocity resolution of 2000-3000 km/s (no one suspected of large-scale structure in those days).

The FBS took 20 years of hard work to complete, so we could not realize any of our thoughts and dreams of those long nights with the telescope. That is why I am pleased to see the progress made by other astronomers throughout the world. The handful of people doing the survey and other Wide-field Imaging (WFI) work has grown into a large and serious community and created our Working Group (WG). I consider the organizing of this WGWFI as an important step. It is a symbol of the evolution of our science; from individuals into close cooperations. It bears the promise of new possibilities and achievements at the turn of the century.

Generally speaking, WFI is as old as astronomy itself, ancient astronomers used their primitive facilities to compile star catalogues (survey) or to describe planetary movements and the (re)appearance of comets (sky patrol). WFI is also a place where different methods and instruments can coexist peacefully together. The rapid technical progress of the last two decades, ranging from photo emulsion processing to modern observing techniques with large CCDs in scanning mode and pattern recognition in real time, has had considerable impact on WFI.

Several important meetings, related to WFI, have been organized over the last 20 years. Here people discussed new instruments, methods and ideas. These meetings that may be considered as historical milestones are listed below. I apologise if the list does not include many other interesting topics like the Magellanic Clouds and our Galaxy that are related to WFI.

H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging, 3–11.

1964	First Conference on faint blue stars, Strasbourg.
1973	First Conference on role of the Schmidt telescope, Hamburg.
1982	Workshop on Astronomical Measuring Machines, Edinburgh.
1983	IAU Colloquium on the Schmidt telescope, Asiago.
1987	Second Conference on faint blue stars, Tucson.
1988	Workshop 'Optical surveys for QSOs', Tucson.
1989	Workshop 'Digitised Optical Sky Surveys', Geneva.
1991	Second Conference 'Digitised Optical Sky Surveys', Edinburgh.
1993	Present Symposium on WFI astronomy, Potsdam.

This list also includes extragalactic and stellar meetings, not only because of my personal interest, but mainly because of their importance for general methods used in WFI, like the search for QSOs or faint blue stars. The main interest of WFI concentrates on the facilities (general and dedicated telescopes, new detectors), measuring machines and software (processing of data), classification, compression, and archiving of data (maintenance of archive, retrieval of data).

2. Objects and Instruments

All astronomical objects are initially discovered from WFI, which gives a bulk of information for statistics: position, magnitude, colour, etc. Objects discovered from WFI span the full range of celestial bodies, from asteroids to distant quasars:

General problems	Galactic	Extragalactic
surveys of everything	halo and disk	nearby galaxies, MC
position and proper motion	stellar clusters	classification
patrol (SNe, var.)	spiral structure	morphology
study of extended objects	kinematics	red shifts
statistical study of objects	degenerated stars	space distribution
search for Solar system bodies	faint blue stars	clusters of galaxies
atlases and catalogues	peculiar stars: C, WR, ...	quasars and AGN
optical identification	flare stars in clusters	cosmological tests

Technical progress and new ideas have always been the driving forces for wide-field astronomy. The discovery of photography in the middle of the nineteenth century as well as the invention of a new type of telescope by B. Schmidt revolutionized the observations. The most important technical progress for WFI in the twentieth century are:

mid-fifties:	construction of the large Palomar Schmidt telescope and completion of POSS.
mid-sixties:	application of low-dispersion prism for extragalactic work.
early seventies:	introduction of large measuring machines COSMOS, APM; construction of UKST and ESO Schmidt telescopes.
mid-seventies:	IIIa-J plates; application of grisms with large R-C telescopes; ESO and SERC surveys.
late seventies:	beginning of CCD era.

early eighties: multi-object spectrographs.
middle eighties: transit mode observing with CCDs.
nineties: digitizing of old and new atlases (POSS-I, SERC/ESO, POSS-II).

Three types of instruments are widely used for imaging †: prime focus with corrector or the Cassegrain focus of classical telescopes with typical field-of-view (FOV) 0.2-0.3°, Ritchey-Chretien telescopes, fov = 1 - 1.5° and Schmidt telescopes with fov = 4 - 6°. The size of the detector has to be 10 - 35 cm to cover the total field. Among all known optical detectors, image-tubes, TV-cameras, CCDs, and photographic plates, only the latter fully satisfies the astronomers' needs. About a decade ago the term 'wide-field imaging' was a synonym for 'photographic imaging with a Schmidt telescope'.

Astronomers usually observe as many objects as possible for better statistics, whether or not these objects stem from all-sky surveys. The research projects involve often thousands and sometimes hundreds of thousands of objects. When one studies a single object, say M 31 or the LMC, it is important to obtain high resolution pictures. On such an image we want as many pixels as possible or, more precisely, bytes of information. The information content of the images is restricted by seeing and pixel size on the one hand, and the size of telescope image and detector on the other hand. It is the result of the total number of pixels and the dynamic range.

Therefore, we define 'wide-field imaging' as 2D images with $4{,}000^2$ - $10{,}000^2$ pixels. The best Schmidt and Ritchey-Chretien telescopes combined with the largest astronomical plates may even reach image sizes of $40{,}000^2$. IIIa-J plates with 10-15μ resolution have about $25{,}000^2$ pixels, which is 6 times more than the largest CCD mosaic (up to $10{,}000^2$ pixels).

A technological breakthrough is the digitisation of Schmidt plates; in the nineties WFI becomes more and more 'digitizing astronomy', described in detail by Monet (1993). Large CCD mosaics and work stations with upgraded software and algorithms are important as well. This makes it possible to work with samples consisting of hundreds of millions of objects.

POSS-I has been available for about 40 years but only now, in digital form, it and its successor POSS-II become powerful tools. The complex digitizing machine and modern computers changed the total volume of information by many orders of magnitude. Moderate prices make them available for any astronomical organization which would never buy glass copies of POSS-II and a large measuring machine. The crucial question is how to operate with 10^9 stars or 5×10^7 galaxies. Without computers, any statistical work with these amounts of data would take many thousands of human-years (compare with work on Lick counts of faint galaxies by Shane and Wirtanen, or compilation of galaxy clusters by Zwicky and Abell in the 1950s and 60s). There are different strategies to manage digital WF data. One is to store all pixel data (STScI, Lasker 1992) that can be up to a few hundred Gb. Another method is to extract all astronomical objects into a final catalogue, therewith reducing the data volume a thousand times (USNO, Monet 1993). It is of course possible to compromise and store objects in a database and keep pixel images for extended objects (Univ. of Minnesota, Pennington et al. 1992).

† We do not mention the classical astrograph with fov = 6-12°; they have a rather limited possibility for astrophysics because of ill lens input.

3. Why Optical Imaging?

Today astronomers observe the whole spectral range, from radio to γ-ray, in which the optical part is only a tiny piece, although still very important. The main characteristics of the various spectral regions are shown in Table 1. It is evident that optical imaging overtakes the other regions in number of pixels (volume of information). Compared to X-ray or IR it is much cheaper, and optical projects with ground-based telescopes can be considered permanent. It may compete with radio astronomy in cost and simplicity of observing. Lower sensitivity of radio receivers should be compensated by large sizes of antennae.

Table 1. WFI in different ranges

Parameter	Optical	Radio	X-Ray	NIR	FIR
ground-based	+++	+++	---	+ ?	-- ?
cosmic	+++	+++	+++	+++	+++
size, pxl	≤ 20,000	≤1,000	100-500	≤ 1,000	100-500
sensitivity	very high	medium	very high	low	medium
spectral range	0.3-1.0 μ	mm - m	full range	few bands	full range
inform. limits	no	no	yes	no	yes
weather impact	strong	weak	no	very strong	no
total area	tens sq. m	unlimited	few sq.m	tens sq.m	few sq. m
duration	unlimited	unlimited	few years	unlimited	few years
cost	low	low	very high	medium	very high

3.1 ADVANTAGES AND WEAKNESS OF OPTICAL WFI

The main advantage of optical WFI is the fact that in this range many objects radiate. In fact, all objects with a temperature in the range 1,000 - 100,000 K may be observed at optical wavelengths. Fortunately many spectral lines arising in this temperature range provides us with basic knowledge on physical conditions in stars and galaxies. Below some more advantages of optical WFI are listed:

1) optical WFI is the oldest and the most traditional method in astronomy, it deals with cheap and simple detectors — photographic plates and even the human eye — and the most powerful computer — the human brain;
2) simple processing of data and cheap and simple storage of data (plates);
3) until recently the only way to receive main physical information: distance, temperature, mass, chemical composition (nowadays also using HI and CO at radio wavelengths!);
4) very high resolution: up to 10^9 pixels (Kodak 4415 film, large size), the largest CCD mosaic has 10^8 pixels (compare with best resolution in other regions: several 10^6 pixels);
5) high quantum efficiency (nowadays Q = 90 - 99% for the best CCD).

In spite of the many attractive features, there are also serious weak points in the optical range which restrict or disable some kind of observation. Some of these weaknesses can be partly overcome, like low sensitivity of photographic plates with replacement by CCD. Others are basic and demand observing in space or the employment of other ranges. These are the following:

1) strong dependence on the site and the weather conditions — seeing, humidity, sky brightness;
2) many biases and selection effects, caused by the narrow wavelength range. This causes some problem for cosmological studies, e.g. spectral lines may be out of the optical range due to large redshifts††;
3) it may be difficult or even impossible to observe certain types of objects like pulsars, γ-bursters, radio galaxies, masers. Objects with very low temperature (compact region of star-formation) or very high temperature (e.g. H 1504+65 with T_e = 160,000 K). These can only be observed in the IR or X-ray regime;
4) the most abundant elements in the Universe — HI and HeI — are not observable in this range.

3.2 OPTICAL SURVEYS

Present day observers have many tools available to start a new survey project. For example, when searching for primeval galaxies, the possibilities are numerous: multi band observations of large areas using UKST or ESO Schmidt, employing the VLA in the shifted 21 cm HI line, observing narrow lines with dedicated Fabri-Pérot interferometer, reprocessing IRAS or ROSAT data, or one can even try to invent something new.

According to their geometry, surveys may be divided into four types: wide-angle (all-sky), slice survey, pencil beam survey, multi-pencil beam survey. The success of a new survey program depends on chosen strategy, relevant instrument and facility.

As shown by many authors, the type of instrument and detector to be used depends on the expected density of objects and their magnitudes. For example, Schmidt telescopes (ST) may be used when the object density is a few per square degree or less. To study objects with a density of several tens per square degree a RC type telescope will be more productive, whereas with a density of hundreds or thousands objects the multi-slit techniques may be extremely fruitful. The productivity of a survey can be written as a mathematical function of the total area and limiting magnitude. This function can be used to compare different surveys. Following Terebizh (1985) we introduce 'capacity' (or power) of a survey as follows:

$$\theta = \frac{\Omega}{4\pi} \times 10^{0.6(m_{\rm lim}-15)}$$

The normalizing factor $10^{-0.6\times15}/\pi$ is chosen to get $\theta = 1$ for an all-sky survey down to a limiting magnitude of 15^m. This is a reasonable limit to accomplish a survey in a large area by a small group in 10-15 years.

The capacity enables us to estimate the expected volume of work. Furthermore, it opens the possibility to choose between several methods and strategies when planning future projects. As an example we compiled in Table 2 some completed, ongoing and future projects related to the search for QSOs and faint galaxies. Figure 1 shows the area covered versus the limiting magnitude for these surveys. Note that practically all modern QSO surveys lie close to $\theta = 1$,

†† Radio and X-ray surveys may produce more homogeneous QSO and AGN samples but with other properties!

and a few ongoing projects like the Case survey and the Hamburg Quasar Survey are substantially above this line (we hope they will be finished).

Table 2. Capacity θ of different surveys

Name	Area Ω	m_{compl}	θ	Instrum	Authors
CGCG	20000.	15.7	1.27	ST	Zwicky et al. 1961-68
FBS	17000.	15.7	1.09	ST	Markarian et al. 1987
BQS	10714.	16.1	1.04	ST	Schmidt, Green 1973-83
SBS	1000.	17.5	0.77	ST	Stepanian et al. 1993
UM	830.	18.0	1.27	ST	McAlpine et al. 1981
LBQS	454.	18.4	1.23	ST	Hewitt et al. 1993
APMMC	45.7	20.0	1.11	ST	Warren et al. 1991
CTI	43.7	20.0	1.06	trans	McGraw et al. 1988
CFHT	9.4	20.5	0.46	RC	Crampton et al. 1989
PFUEI	7.8	20.5	0.38	trans	Schmidt et al. 1986
AAT	4.2	20.9	0.35	RC	Boyle et al. 1988
MZZ	0.69	22.0	0.27	RC	Marano et al. 1988
KOKR	0.29	22.6	0.26	RC	Koo, Kron 1988
CHFT/PUMA	0.07	23.1	0.12	multisl	Schade 1991
BAS	500.	21.0	48.0	ST	Chen, 1993 -"-
HQS	17000.	17.5	13.0	ST	Hagen et al. 1993 -"-
CASE	8000.	17.5	6.13	ST	Pesch et al. 1991 -"-
SGP Z surv	40.5	19.4	0.48	multisl	Vettolani et al. 1993 -"-
POSS-I	29000.	20.5	1100.	ST	atlas
POSS-II	21000.	22.5	16000.	ST	-"-
Sloan DSS	10000.	23.0	15000.	RC	project (digitized sky)
LITE	100.	24.0	610.	RC	-"- (multi-color)
BAC	500.	21.0	48.	ST	-"- (17 narrow bands)

Notes: **trans** — transit mode; **multisl** — multislit mode.

The early work by E. Hubble should also be mentioned here. His pioneer study on faint galaxies counts in 1283 fields shows a very high capacity, although today Hubble's survey of 300 square degrees would require only 8 plates (!) with the 48″ Palomar Schmidt telescope (Minkovski 1984). Nevertheless the very high capacity θ = 7 is evidence of an excellent job.

Very promising are some future projects like LITE (Vigroux 1993) or BAC surveys (Chen 1993). The most impressive results are digitised atlases like POSS-I, POSS-II or the Sloan Deep Sky Survey project. Because their capacity is a few thousand, these projects can never be carried out using present day instruments, even not by all astronomers together. But new generation of dedicated telescopes with large CCD mosaics will change our observations completely. Optimistic estimations show that soon we will be able to 'digitise' the whole sky within one year (Monet 1993).

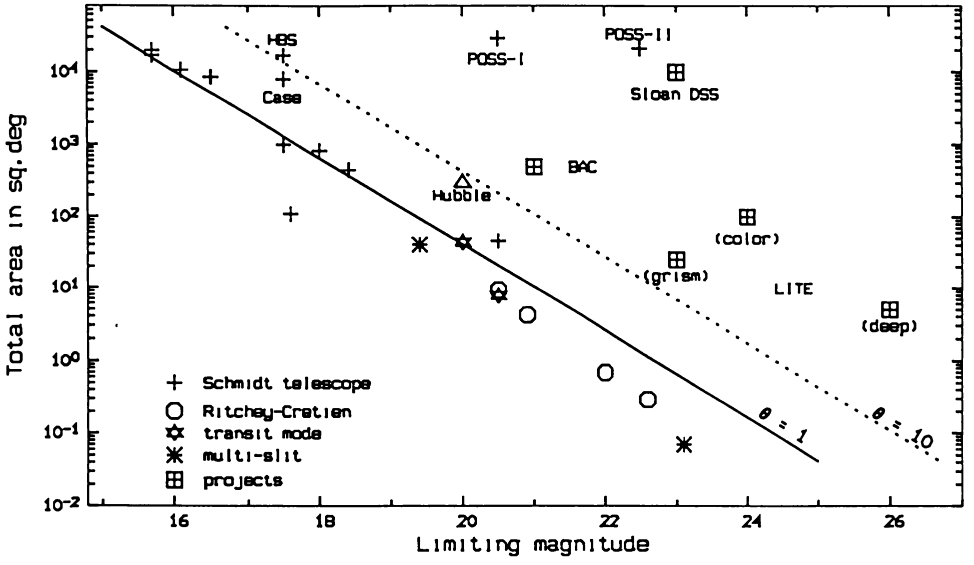

Figure 1. Comparative capacity of θ of the surveys; triangle denotes survey by E. Hubble.

4. Nearest Future of Optical WFI

In this section we will mention several directions in which future WFI may evolve. It should be borne in mind that the list is biased to the author's own opinion.

CCD or Plates? The technical progress is always much faster than we can expect. Many astronomers think fine-grain plates will be useful for at least the next 5 years but not longer than the next 10, although this prospect may change considerably when Kodak changes its policy. In the near future an observer will work with a new generation of large mosaic chips, consisting of 8-60 chips, like the NOAO system with $8{,}000^2$ pixels, the 12,000 x 10,000 mosaic for the Sloan Digitised Sky Survey, the Kiso Schmidt system ($8{,}000^2$), and the Subaru JNLT 8-m telescope ($10{,}000^2$)

Measuring Machine. There has been a rapid increase in measuring machines, only two (COSMOS and APM) in seventies and more than 10 today (MAMA, machine at STScI, PMM at USNO Flagstaff, etc.). Because of the huge amounts of data produced by the machines (up to many hundred CD-ROMs), data compression and pattern recognition (source extraction and classification) now becomes a serious problem. Modern algorithms (H-transform, wavelet transform, Baruch et al. 1992; Richter 1993) allow a 30 - 300 fold compression of the data without substantial losses. Another problem, and probably more serious, arises when astronomers start to analyze future catalogues with 10^7 - 10^9 galaxies or stars. Even nowadays, nobody wants to deal with a printed version of the Guide Star Catalog, which contains 10 - 100 times less objects.

Scanning Technique. The application of the Time Delay and Integration (TDI) scanning technique is similar to radio techniques, although much faster because of the large amount of channels (1024 - 2048). The spatial resolution of the technique is high: 0.3″ - 0.6″. The scanning mode gives high degree of homogeneity and zero losses for readout time, which is pretty large for big CCDs. This technique was successfully applied to the quasars survey at large redshifts (4-Shooter surveys with 200″ telescope, Schmidt et al. 1986, 1989) or to monitor the variability of quasars with dedicated CCD Transit Instrument (CTI, McGraw et al. 1986, 1991). It has been used for many years to search for new asteroids at Steward Observatory with different scanning modes (Space watch 0.9 m telescope, Gehrels 1991). At the University of British Columbia a very promising project is under development with a liquid mirror telescope (LMT). Scanning is the only suitable mode for observing with the very simple and cheap 2.7 m telescope (Gibson & Hickson 1992).

Large CCDs + Narrow Band Imaging. The modern CCDs have such a high efficiency that we can observe in narrow bands. ($\delta\lambda/\lambda$ = 0.05 - 0.07) with a high limiting magnitude and a minimal loss of light. It has all the advantages of low resolution spectroscopy. We may expect good results when searching for faint objects by means of this method. When studying crowded fields (Magellanic Clouds, very faint galaxies, globular clusters), narrow-band imaging gives better results than grism or multi-fibre spectrographs, which are hampered by the high surface density. The narrow-band technique was applied to study faint Hα galaxies (0.9 m telescope, 6 bands with $\delta\lambda$ = 80Å, Boroson et al. 1993). Another good example is the search for extremely faint primeval galaxies with a dedicated Fabry-Pérot (5 m telescope, $\delta\lambda$ = 20 - 25Å, limiting magnitude $m_B \approx 23^m$, Djorgovsky 1992; Thomson et al. 1993). There are several projects under development for special multi-colour surveys in large ranges like the Beijing-Arizona Color Sky Survey (17 narrow bands, 3200 - 9000 Å, Chen 1993) or the above mentioned LMT (Gibson & Hickson 1992) with 40 (!) bands from 85 - 150 Å, in an area Ω = 20 square degrees. There are several other surveys in regions of special interest like the survey of C stars in the Magellanic Clouds or search for WR stars in nearby galaxies (Lequeux & Azzopardi 1991).

Multi-object Spectroscopy (MOS). Although this is not exactly in the field of the present meeting, it is very close to it. New generations of MOS like the 400 fibres AAT MOS will enable us to yield as many as 10,000 QSOs in 17 (!) good nights (Boyle 1992). Today there are several large programs to get redshifts of faint galaxies (UKST, ESO, AAT, etc.).

Acknowledgements

In conclusion I wanted to express my best thanks to the Organizing Committee for financial support to visit this meeting and R. Assendorp and H. Tiersch for their help in preparing the report.

References

Baruch, J.E.E., Crolla, A.J. and Boyle, R.D., 1992. In 'Digitised Optical Sky Surveys', eds. H.T. MacGillivray and E.B. Thomson, Kluwer Academic Publishers, Dordrecht, p. 153.

Boyle, B.J., Shanks, T. and Peterson, B.A., 1988. *Mon. Not. R. astron. Soc.*, **235**, 935.

Boyle, B.J., 1991. In 'Space Distribution of Quasars', A.S.P. Conference 21, ed. D. Crawford, p.389.

Boroson, T.A., Salzer, J.J. and Trotter, A., 1993. *Astrophys. J.*, **412**, 524.

Crampton, D., Cowley, A.P. and Hartwick, F.D.A., 1989. *Astrophys. J.*, **345**, 59.

Djorgovsky, S., 1992. In 'Cosmology and Large-Scale Structure in the Universe', A.S.P. Conference 24, ed. R.R. de Carvalho, p. 73.

Gehrels, H., 1991. *Space Sci. Rev.*, **58**, 347.

Gibson, B.K. and Hickson, 1991. In 'Space Distribution of Quasars', A.S.P. Conference 21, ed. D. Crawford, p. 83.

Hagen, H.J., Engels, D., Groote, D. and Reimers, D., 1993. These proceedings.

Hewitt, P.C., Foltz, C.B. and Chaffee, F.H., 1993. *Astrophys. J.*, **404**, L43.

Koo, D.C. and Kron, R.G., 1988. *Astrophys. J.*, **325**, 92.

Lasker, B., 1992. In 'Digitised Optical Sky Surveys', eds. H.T. MacGillivray and E.B. Thomson, Kluwer Academic Publishers, Dordrecht, p. 87.

Lequeux, J. and Azzopardi, M., 1991. In 'Wolf-Rayet stars and interrelations with other massive stars in galaxies', eds. K.A. van der Hucht and B. Hidait, Kluwer Academic Publishers, Dordrecht, p. 619.

Marano, B., Zamorani, G. and Zitelli, V., 1988. *Mon. Not. R. astron. Soc.*, **232**, 111.

Markarian, B.E., Lipovetsky, V.A. and Stepanian, J.A., 1987. In 'Observational Evidence of Active Galaxies', eds. E.Ye. Khachikian et al. IAU Symp. 124, Reidel.

MacAlpine, B.M. and Williams, G.A., 1981. *Astrophys. J. Suppl. Ser.*, **45**, 113.

McGraw, G.T., Cawson, M.G.M., Kirkpatrick, J.D. and Haemerle, V., 1988. In 'Proceedings of a Workshop on Optical Survey for Quasars', A.S.P. Conference 2, eds. P.S. Osmer, A.C. Porter, R.F. Green and C.B. Foltz, p. 163.

Minkovski, R., 1972. In 'Conference on the Role of Schmidt Telescope in Astronomy', ed. U. Haug, Hamburg, p. 5.

Monet, D., 1993. These proceedings.

Pennington, R.L., Humphreys, R.M., Odewahn, S.C., Zumach, W.A. and Stockwell, E.G., 1992. In 'Digitised Optical Sky Surveys', eds. H.T. MacGillivray and E.B. Thomson, Kluwer Academic Publishers, p. 77.

Pesch, P., Sanduleak, N. and Stephenson, C.B., 1991. *Astrophys. J. Suppl. Ser.*, **76**, 1043.

Richter, G., 1993. These proceedings.

Schade, D., 1991. *Astron. J.*, **102**, 869.

Schmidt, M., Schneider, D.P. and Gunn, J.E., 1986. *Astrophys. J.*, **306**, 411.

Schmidt, M. and Green, R., 1983. *Astrophys. J.*, **269**, 352.

Stepanian, J.A., Lipovetsky, V.A. and Erastova, L.K., 1993. In preparation.

Terebizh, V.Yu., 1986. *Contribution of Special Astrophys. Obs.*, **50**, 79.

Thomson, D.J., Djorgovsky, S. and Trauger, J., 1992. In 'Cosmology and Large-Scale Structure in the Universe', A.S.P. Conference 24, ed. R.R. de Carvalho, p. 147.

Vettolani, G. et al., 1993. These proceedings.

Vigroux, L., 1993. These proceedings.

Warren, S.J., Hewitt, P.C. and Osmer, P.S., 1991. *Astrophys. J. Suppl. Ser.*, **76**, 23.