The INT Wide Field Imaging Survey (WFS)

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Abstract

The 2.5m Isaac Newton Telescope (INT) is currently being used to carry out a major multi-colour, multi-epoch wide field CCD based survey over an area of $\sim$100deg^2. The survey parameters have been chosen to maximize scientific return over a wide range of scientific areas and to complement other surveys being carried out elsewhere. Unique aspects of the survey are that it concentrates on regions of sky that are easily accessible from telescopes in both Northern and Southern terrestrial hemispheres and that it the first public survey to use filters similar to that being used by the Sloan Digital Sky Survey. A major aim of the the INT Wide Field Survey programme is to bridge the gap between the all-sky photographic 2 band surveys such as Palomar and UK Schmidt sky surveys and the ultra-deep keyhole survey such as the Hubble Deep Field. Apart for the science that can be derived directly from the optical data, the datasets will provide ideal target lists for multi-object followup with fibre and slit based systems (e.g. GMOS, 2DF, WYYFOS, FMOS) on 4m and 8m class telescopes.

Key words: Surveys, archives, databases

1 Introduction

Astronomy is basically an observational science, and the development and advancement of the subject has relied heavily on surveys of the sky at optical wavelengths to expand our knowledge of the observable Universe. However despite the considerable advances in optical detector technology very little improvement has been made in large scale surveys beyond those available in the 1950's when the Palomar Sky Survey was carried out. A photographic plate taken on a 1.2-m Schmidt telescope is sky limited in about 1 hour but is only 1-2% efficient. Thus our current best wide field optical sky surveys are equivalent to no more than a $\sim$60 second glance at the Universe with modern CCDs using a 1m telescope. In spite of the inherent limitations of photographic plates, they are still used for major scientific programmes. In recent years, this has been primarily due to the availability of online digital atlas images and catalogues based on these photographic material.

In an effort to rectify this apparently dismal situation, and to provide the basic scientific underpinning deep imaging requirements as we enter the 8m era, the 2.5m Isaac Newton Telescope on LaPalma is being used to carry out a series of wide field imaging programmes under the generic title of the INT Wide Field Survey (WFS) project. The WFS project consists of a series of independent survey programmes with distinct aims as we outline below. The WFS project takes into account both surveys like SDSS (Gunn & Weinberg 1995) which is used a 2.5m telescope and has an exposure time of ∼60 seconds, and other CCD based surveys such as those that are being carried out by NOAO [1] and ESO [2] (Nonino et al 1999). The unique elements of the INT survey are

(1) optimal choice of fields so that most are easily visible from telescopes in both hemispheres
(2) inclusion of U band
(3) large area
(4) temporal information
(5) good coverage with deep radio surveys i.e. FIRST, WENSS
(6) wide RA coverage optimized for efficient follow-up
(7) choice of SDSS bandpasses for longevity.

This article briefly describes the Wide Field Survey (WFS) programme. This is a peer reviewed survey programme that aims to provide deep high quality CCD data to the community both quickly and in a convenient form. The survey is deeper than the Sloan Digital Sky Survey, and aims to provide significant targeted areal coverage, typically of fields being observed by facilities at other frequencies e.g. radio, ISO and X-rays.

2 The INT Wide Field Survey

The concept of the WFS originated in 1991 within the context of the science case for a CCD mosaic for the Isaac Newton Telescope. Formal approval for the survey programme began with a proposal to the ING Board in October 1997. The primary goal was to exploit the excellent capabilities of a recently completed CCD based mosaic that effectively filled the unvignetted focal plane of the 2.5m Isaac Newton Telescope (see Figure 1). The immediate aim was

[1] http://www.noao.edu
[2] http://www.eso.org

to carry out a major CCD based multi-colour survey in a timely fashion over a period of 4–5 years and allow instant and easy access to the processed data to facilitate its rapid scientific exploitation

The WFS proposal was approved by the ING Board in October 1997 with a subsequent 'Announcement of Opportunity' closing in March 1998. Conditions of solicitation included that the survey data is available to all UK and NL based observers in near real-time. Raw data is typically available as taken, whilst the pipeline reduced data is available after one month. Subsequently the raw and processed data is available to the rest of the astronomical community after one year. Pipeline processing of the data is the responsibility of the Cambridge Astronomical Survey Unit.

A WFS International Review Panel approved three main programmes in the first year, allocating five–six 'dark/grey' weeks per semester to the WFS. In June 1999 a first year review carried out by PATT and the International Review Panel confirmed the continuation of the first year WFS programmes into 2000.

3 The INT Wide Field Camera

The INT Wide Field camera (Ives,Tulloch & Churchill 1996) is mounted at the prime focus (f/3) of the 2.5m Isaac Newton telescope on LaPalma, Canary Islands. The camera consists of a close packed mosaic of 4 thinned EEV 2kx4k CCDs. The layout is shown in Figure 1. The CCDs have a pixel size of 13.5microns corresponding to 0.33 "/pixel. The edge to edge limit of the mosaic neglecting the $\sim$1' inter-chip spacing is 34.2'. In normal survey mode we use a step size in RA and Dec of 30' and 20' respectively. This provides $\sim$10% overlap on all edges and means that the partially vignetted chip is overlapped completely to aid photometric calibration.

4 The current WFS Programmes

The main science programmes chosen include a 'wide shallow' programme, a smaller deep area programme, and a programme to address temporal variability. The specific programmes are described briefly below:

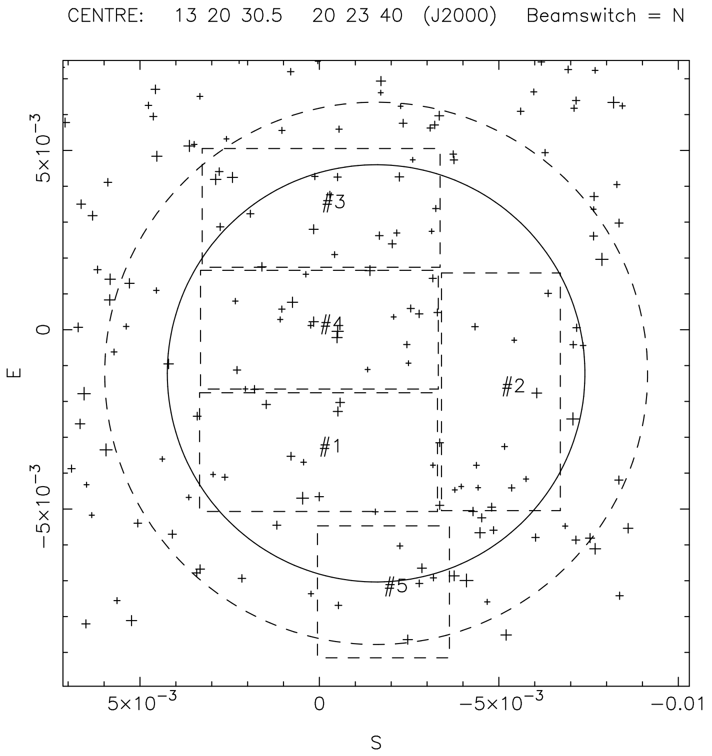

Fig. 1. Layout and normal orientation for the INT Wide Field Camera. The inner solid circle shows the unvignetted central diameter(40arcmin). The dashed circle shows the 50% vignetted region(52arcmin)

Table 1
Nominal photometric limits in 1 arcsec seeing for INT Wide Angle Survey

Waveband	Exposure Time (secs)	5σ detection limit in 1" seeing with PSF profile fitting		1σ Surface Brightness limit per square arcsec	
		(Vega mag)	(AB mag)	(Vega mag)	(AB mag)
u	600	24.3	25.2	26.5	27.4
g	600	25.2	25.1	27.4	27.3
r	600	24.5	24.7	26.7	26.9
i	600	23.7	24.1	25.9	26.3
z	600	21.7	22.6	23.9	24.8

Table 2
Science Themes(n=23)

Science Theme	sample size	surface density deg^{-2}	area deg^2	bands	nights‡
Outer Solar System	20	<1	40	gr	33
Low mass stars					
Brown Dwarfs(Pleiades)	10	-	10	iz	5
Young Field BDs	10	-	100	iz	27
Young White Dwarfs(Pleiades)	1	-	10	ugr	5
Proper Motion study (cool white dwarfs)	10	-	20	gi	10
Galactic Structure	10^6	10^4	100	ugriz	77
Stellar Variability					
Pop I(CVs, LMXBs)	20	-	20	ugriz	16
Pop II(RR Lyraes)	100	-	20	gi	16
Low Surface Brightness Galaxies	100	-	100	gi	34
Extremely Red Galaxies	100	-	100	gi	34
2DF Galaxy Survey	10^4	5000	20	ugriz	16
2DF QSO Survey	2000	100	20	ugriz	16
Supernovae (0.15<z<0.25)	20	-	20	gi	20
Clusters of Galaxies (0.50<z<1.00)					
Evolution	100	5	20	gi	7
Large Scale Structure	500	5	100	gi	34
AGN variability	1000	50	20	gi	16
Radio Sources					
Large Scale Structure	5000	100	50	ugi	25
High redshift galaxies	50	-	50	ugi	25
Radio Loud Quasars	500	10	50	ugi	25
Optically Selected Quasars					
(z<2)	15000	150	100	ug	34
(2<z<5)	1000	10	100	ugri	67
(z>5)	>10	<0.5	100	riz	43
Total time for independent programmes					553
Total time for merged programme			100		102

Notes to table:
†assumes an effective area of 0.25deg^2; nominal exposures of 600s in (ugri); 300s in z; overheads per exposure of 120secs, unless stated otherwise.
‡assumes an average night of 8hrs and overall observing efficiency of 60% allowing for weather, standards

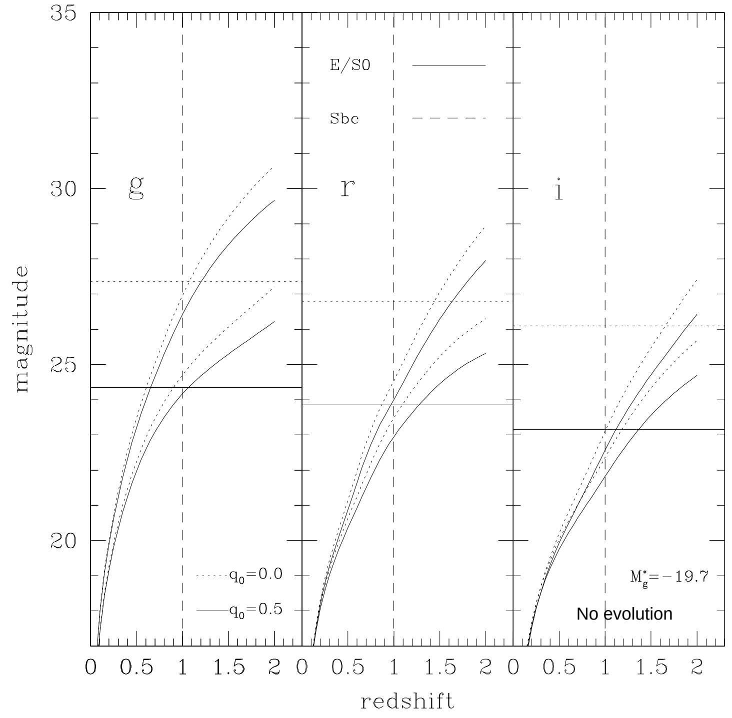

Fig. 2. Observed magnitude versus redshift for L* unevolving galaxy spectral energy distributions. The horizontal lines indicate the magnitude limits(5-σ in a 2 arcsec diameter aperture) and the surface brightness limits for the proposed INT observations. The vertical line is drawn at z=1. The upper curves are for an Elliptical galaxy SED and the lower pair are for a starforming Spiral galaxy SED.

4.1 The INT Wide Angle Survey (WAS): co-PI's, McMahon, Irwin, Walton

This is the largest programme approved and includes sub-projects ranging from determination of cosmological parameters (e.g. via SN Type Ia studies) to searches for solar system objects. The underlying philosophy of the WAS survey is encompassed in Table 2 where we the time requirements of over 20 topical scientific programmes. If all these programmes were carried out under the normal PI's based time allocation procedures the total on-sky time required is almost 600nights. However, if the programmes are combined they can be executed in around 100nights. By merging the requirements of the various programmes we end up with a highly efficient observing strategy. An important aspect of the reduced time requirements is that the projects will also be executed quickly.

The limiting magnitudes and wavebands being used are summarized in Table 1. Figure 4 shows how these limits transform onto the observational plane

Table 3
Nominal Major Survey Regions for INT Wide Angle Survey

Field	Coordinates J2000	l,b	size† °	bands‡	multi-epoch
NGC Equatorial Strip	10 < α <15	b>+30	75x0.5	ugriz	g/r
SGC Equatorial Strip	22 < α <03	b<−30	75x0.5	ugriz	g/r
WFSJ0220−05	02 20.0 −05 00	169,−53	3x3	ugriz	g/r
WFSJ0354+00(SA95)	03 54.0 +00 00	187,−41	3x3	ugriz	
Pleiades	03 47.0 +24 00	167,−23	3x3	iz	z
WFSJ0801+40	08 01.7 +40 19	180,+30	3x3	ugriz	
Virgo	12 39.0 +12 27	294,+75	3x3	ugriz	
WFSJ1610+54	16 10.0 +54 30	84,+45	3x3	ugriz	
WFSJ2240+00(SA114)	22 40.0 +00 00	69,−49	3x3	ugriz	g/r

Notes: † The actual areal coverage per field is determined by the observing time available, observing schedule and observing conditions. ‡ The actual filters may be different e.g. KPNO B or Harris V etc.

for extragalactic studies. The main survey region are listed in Table 3. A number of smaller regions are also being surveyed as determined by calibration requirements and the observing schedule. In addition, we are adding bands to other programmes so that we can increase the areal coverage of multi-colour data at low cost. These fields are listed in Table 4.

The WAS programme is the umbrella programme for the WFS project and leads the coordination efforts with the other programmes on, for instance, field, filter selection, to maximize scientific return of the WFS project. All programmes remain autonomous during this procedure so that the peer reviewed science goals are protected.

Some of the science goals of the WAS are outlined below:

• **Galactic Studies** including both halo and disk white dwarf luminosity function which are relevant to both DM models and to independent calibrations of the Hubble time; stellar density distributions towards the NGP, to improve extant K_z determinations of the local DM; stellar counts towards the anticentre and other widely spaced directions, to determine the stellar warp and refine models of Galactic structure

• **Clusters of Galaxies** the aim is to determine the space density and cluster-cluster correlation function over the range 0.5<z<1.0. Galaxy clusters are the largest gravitationally-bound structures in the Universe, and the study of their abundance and evolutionary history with look-back-time places strong

Table 4
Supplemental survey fields from WAS and the other WFS programmes

Field	Coordinates J2000	l,b	size °	bands‡	multi-epoch	notes
WFSJ0015+35	03 05 −09 35	115,−27	1.5x1.5	ugriz		Dalton
M31	00 43 +41 17	121, −22	2@0.5x0.5			
WFSJ0230+15	02 30 −15 30	155,+42	1.0x1.0	ugriz	v,i	van Paradijs
WFSJ0305−09	03 05 −09 35	190,−54	0.5x0.5	ugriz		
WFSJ0750+20	07 50 +20 30	200,+22	1.0x1.0		v,i	van Paradijs
WFSJ0912+41	09 12 +41 00	181,+43	1.0x1.0	ugriz		Dalton
WFSJ1251+27	12 51 +27 07	0,+90	1.5x1.5	ugriz	v,i	van Paradijs
WFSJ1610+00	16 10 +00 40	12,+36	0.5x0.5			SDSS sampler
WFSJ1624+26	16 24 +26 34	45,+43	1.0x1.0		v,i	van Paradijs
WFSJ1635+46	16 35 +46 30	72,+42	1.0x1.0	ugriz		Dalton
WFSJ1637+41	16 37 +41 16	65,+42	1.0x1.0	ugriz		
WFSJ1720+27	17 20 +27 00	50,+31	1.0x1.0	ugriz	v,i	van Paradijs
WFSJ2000+54	20 00 +54 57	89, +13	0.5x0.5	ugriz		
WFSJ2056−04	20 56 −04 37	44, −27	1.0x1.0	ugriz		
WFSJ2345+27	23 45 +27 30	105,−33	1.0x1.0	ugriz	v,i	van Paradijs

Notes: The exposure times per band vary between these fields, see the WFS WWW page[3] for further details. Also, in some fields the WAS programme summarizehas added wavebands to those obtained by the original PIs. ‡ The actual filters may be different e.g. KPNO B or Harris V etc.

constraints on cosmological parameters and the primordial power spectrum that gave rise to the observed large scale structure.

• **Radio Sources & Radio Galaxies**. Deep optical identification of radio sources allows: accurate counts of different types of host along mJy tracks in the P-z plane, studies of radio source luminosity evolution; multi-band investigation of giant-E standard candles; the largest known sample of low-luminosity RGs with good photometry; large-scale structure from photometric redshifts and cell counts in redshift slices; accurate optical positions of FIRST sources for WYFFOS/2DF followup.

• **Intermediate redshift Type 1a Supernovae**. Whilst dramatic progress has been made in the determination of the fundamental cosmological parameters (Ω, Λ) in the last two years, the analysis is now limited by systematic errors. Identifying ∼20 Type 1a Supernovae in the critical range $0.1<z<0.4$

will allow a detailed treatment of these systematic errors.

The WAS also incorporates two independent distinct science programmes in the summer semesters centred on Virgo and the North Galactic Pole. In fact, in the proposal submission procedure many co-I's of the WAS programme submitted discrete proposals.

- **A multicolour survey of the Virgo Cluster: PI, Davies** This aims to obtain the galaxy luminosity function (LF) of the Virgo cluster as a function of colour and position in the cluster.
- **The Millennium Galaxy Catalogue (MGC): PI, Driver** The MGC will provide a complete and local galaxy catalogue. This survey is being carried out in the B band and lies in a region of sky covered by the 2DF redshift survey.

4.2 A Deep UBVRI Imaging Survey with the WFC: PI, Dalton

This programme is carrying out deep imaging of four contiguous regions of 10 deg^2 to a limiting magnitude of B=26 and I=24.5. It will enable the study of the evolution of galaxy clustering as a function of colour at faint magnitudes and provide a catalogue of rich galaxy clusters at intermediate red shifts.

4.3 Faint Sky Variability Survey (FSVS): PI, van Paradijs

This programme is searching an area of $\sim$10 deg^2, studying photometric and astrometric variability on scales of one hour to a year to a magnitude of V=25. Example areas of investigation include: the evolution of specific galactic populations (e.g. CV's, RR Lyraes, halo AGB stars, brown & white dwarfs, Kuiper belt objects, sdB stars), the structure of the galactic halo, statistics of optical transients related to γ-ray bursts, and deep proper motion studies.

5 Choice of survey regions and photometric bands

In order to maximise the scientific value of the WFS data the WAS survey is concentrating on fields that are equatorial and hence follow-up can be carried out from telescopes on both hemispheres. This mere consideration doubles the scientific return of the survey. We also deliberately centred some of the fields on Landolt photometric calibration fields ie SA95 and SA114.

The choice of photometric wavebands was relatively straightforward. We decided to use bands similar to the SDSS bands (Fukugita et al, 1996). Note our u and z bands are not identical to the SDSS bands. See the WFS WWW pages for further details. The choice of the SDSS bands means that the INT surveys will be directly comparable with work carried out as part of the SDSS. Interestingly, the SDSS g band is very close to the UKST B_J band. However, manufacturing delays have meant that we had to start the survey using the standard INT filter set.

6 Survey Coverage to Date

Survey data is being obtained on a monthly basis and thus a summary of the data obtained will soon be out of date. A complete summary of observations obtained is kept on-line at The situation at the end of May 1999 was that $\sim$60 deg^2 had been observed in the first ten months of the survey.

7 Data Products

The data products currently available for access include:

- Observing logs built from the FITS headers
- A SYBASE WWW user interface to access the raw and processed data
- Library bias frames, flat-field frames, defringing frames and non-linearity corrections
- Colour equations for all filters
- Processed 2D image maps, with a full record of processing steps in the FITS headers
- Astrometric calibration, with the World Coordinate System in the FITS headers
- Photometric calibration — zero points and extinction

In the coming months the data products provided will be expanded after some quality control to include:

- Object catalogues, generated using APM based routines (Irwin, 1985) and SExtractor (Bertin & Arnouts 1996).

8 Further Information

Further information about the INT Wide Field Imaging Survey can be obtained at the Isaac Newton Groups WWW page [4]. In addition, the Wide Angle Survey has as a WWW page [5]. Further details of the pipeline processing are contained in a paper by Irwin and Lewis (these proceedings).

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References

[1] Bertin, E., & Arnouts,S. 1996, A&A Supp, 117, 393.
[2] Fukugita, M., Ichikawa, T., Gunn, J. E., Doi, M., Shimasaku, K., & Schneider, D. P. 1996, AJ, 111, 1748.
[3] Gunn,J.E. Weinberg, D.H., 1995, Wide-Field Spectroscopy and the Distant Universe, proceedings of the 35th Herstmonceaux workshop.
[4] Irwin, M.J., 1985, MNRAS, 210, 979.
[5] Irwin, M.J., Lewis, J.R., these proceedings.
[6] Ives, D.J., Tulloch, S., Churchill, J.,1996, SPIE, 2654, 266.
[7] Nonino, M. et al. 1999, A&A Supp., 137, 51.

[4] http://www.ing.iac.es/Astronomy/science/wfs/index.html
[5] http://www.ast.cam.ac.uk/~wfcsur