A proposal in response to the announcement of opportunity for:
LARGE SCALE IMAGING SURVEYS WITH THE INT WIDE FIELD CAMERA

The INT Wide Angle Survey

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Summary: We propose to carry out the first major fully digital, multi-epoch and multi-waveband wide angle survey over a significant area($\sim$100deg^2) of sky. The survey parameters have been carefully chosen to maximise the scientific impact without compromising the individual science goals. The proposed survey encompasses a wide range of strategic areas of topical and future interest, ranging from the determination of cosmological parameters to searches for Solar System objects. Optimal use of the INT WFC will allow exploration of new areas of parameter space with respect to currently available wide area survey data, including: enhanced dynamic range and photometric precision; significantly wider wavelength coverage; the attainment of lower surface brightness levels; digital astrometric capabilities; and an in depth exploitation of temporal variability signatures. This enhancement over currently achievable survey capabilities will lead to enormous advances on a wide range of astrophysical fronts. Although this proposal is targeted at a series of specific goals, we anticipate that by our judicious selection of survey passbands, exposure times, observing strategy and survey regions, the data will be readily usable for a much wider series of important astronomical applications, thereby maintaining and extending the UK and NL's pre-eminence in wide field survey astronomy.

Table 1: Survey Fields(12)

Field	Coordinates J2000	l,b	size °	bands	multi-epoch	other data†
0000+00	00 00.0 +00 00	98,−60	3x3	ugriz		N,F
0230+00	02 30.0 +00 00	169,−53	3x3	ugriz	gi	N,F,X
0340+00	03 40.0 +00 00	187,−41	3x3	ugriz		N,F
Pleiades	03 47.0 +24 00	167,−23	3x3	ugriz	iz	N
0801+4018	08 01.7 +40 19	180,+30	3x3	ugriz	gi	N,F,W
1040+00	10 40.0 +00 00	249,+49	3x3	ugriz	gi	N,F,2DF,X
HDF-N	12 36.0 +62 00	126,+55	3x3	ugriz		N,W,X
Virgo	12 39.0 +12 27	294,+75	3x3	ugriz		N
NGP/Coma	12 51.4 +27 08	0,+90	3x3	ugriz		N,F
ELAIS-N1	16 10.0 +54 30	84,+45	3x3	ugriz		N,F,W,
NEP	18 00.0 +66 00	96,+30	3x3	ugriz		N,W,X
2240+00	22 40.0 +00 00	69,−49	3x3	ugriz	gi	N,F

Notes to table:
†existing or planned survey material; N:NVSS, F:FIRST, W:WENSS, X:X-ray data(ROSAT or XMM)

Table 2: Science Programs(23)

Science Program	sample size	surface density deg^{-2}	area deg^2	bands	hours†	nights‡	notes
Outer Solar System	20	<1	40	gr	160	33	1
Low mass stars							
Brown Dwarfs(Pleiades)	10	-	9	iz	22	5	2
Young Field BDs	10	-	100	iz	127	27	
Young White Dwarfs(Pleiades)	1	-	9	ugr	22	5	
Proper Motion study (cool white dwarfs)	10	-	20	gi	48	10	3
Galactic Structure	1000000	10000	100	ugriz	367	77	
Stellar Variability							
Pop I(CVs, LMXBs)	20	-	20	ugriz	74	16	
Pop II(RR Lyraes)	100	-	20	gi	77	16	5
Low Surface Brightness Galaxies	100	-	100	gi	160	34	
Extremely Red Galaxies	100	-	100	gi	160	34	
2DF Galaxy Survey	10000	5000	20	ugriz	74	16	
2DF QSO Survey	2000	100	20	ugriz	74	16	
Supernovae (0.15<z<0.25)	20	-	20	gi	94	20	4
Clusters of Galaxies (0.50<z<1.00)							
Evolution	100	5	20	gi	32	7	
Large Scale Structure	500	5	100	gi	160	34	
AGN variability							
	1000	50	20	ugriz	74	16	7
	1000	50	20	gi	77	16	8
Radio Sources							
Large Scale Structure	5000	100	50	ugi	120	25	6
High redshift galaxies	50	-	50	ugi	120	25	6
Radio Loud Quasars	500	10	50	ugi	120	25	6
Optically Selected Quasars							9
(z<2)	15000	150	100	ug	160	34	
(2<z<5)	1000	10	100	ugri	320	67	
(z>5)	>10	<0.5	100	riz	207	43	
Total time for independent programs					2730	569	10
Total time for merged photometric program			100	ugriz	367	77	10
Additional time for temporal and kinematic program					119	25	10

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

1. 2nd r separated by 1hour from 1st epoch r 2. z repeated yearly for PM 3. i band repeated a year later 4. g(300s)x3; i(300s)x2 ; repeated annually 5. SN and KB strategy gives logarithmic sampling 6. only half of fields covered by FIRST survey 7. select the QSOs 8. observe fields monthly, 6monthly and annually ie 3 times/year 9. programs are independent 10. approximate breakdown of dark:grey:bright is 50%:30%:20%

Scientific Case [1]

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. We propose to out the first significant multi-colour, multi-epoch CCD based optical survey of an area of $\sim$100deg^2. The science program is summarised in Table 2 where we have listed individual programs that can be directly attempted with the proposed survey, but have not included countless other possible spin-off projects which we anticipate the survey will stimulate. Many science programs can be attempted from the survey material alone whereas others will require extensive follow-up with large telescopes including the next generation of 8-m class telescopes such as Gemini and VLT.

The proposed project takes into account both future surveys like SDSS which has an exposure time 10 times less and other CCD based surveys such as those that are being carried out by NOAO and ESO. The unique elements of our proposed survey are: (i) optimal choice of fields so that most are easily visible from telescopes in both hemispheres; (ii) inclusion of U band; (iii) larger area (iv) temporal information; (iv) good coverage with deep radio surveys ie FIRST, WENSS; (v) wide RA coverage optimised for efficient follow-up; (vi) choice of SDSS bandpasses for longevity.

It is impossible to justify such a wide and rich bonanza of scientitific programs on a single page and we encourage the reader to browse the case for wide field surveys made by:

ESO–http://www.eso.org/research/sci-prog/eis/

SDSS–http://www.astro.princeton.edu/BBOOK/

CFHT– http://cdsweb.u-strasbg.fr:2001/projects/megacam/

NOAO– http://www.noao.edu/scope/supcap_workshop/ and http://www.noao.edu/noao/noaodeep/

Some examples of the scientific goals of our proposed survey are:

• **Galactic Studies** including the Halo and disk WD luminosity function, 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 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.

• **Optical Variability**. By surveying an intermediate Galactic latitude 3x3 degree field once per year in the u,g,r,i,z passbands and two 'single shot' WFC fields (0.25 deg^2), 12hr apart in RA, more regularly, we will obtain multi-epoch data for a wide variety of projects allowing: several thousand quasars to be yearly monitored yielding measures of variability -v- luminosity, redshift, quasar-type etc.; rapid monitoring of a subset at 1% accuracy of $\approx$100 qsos to B$\sim$23, for studies of quasar variability on very short timescales; detection of distant RR-Lyrae variables for studies of the extent of the Halo.

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

[1] see http://www.ast.cam.ac.uk/~rgm/int_ao for further details

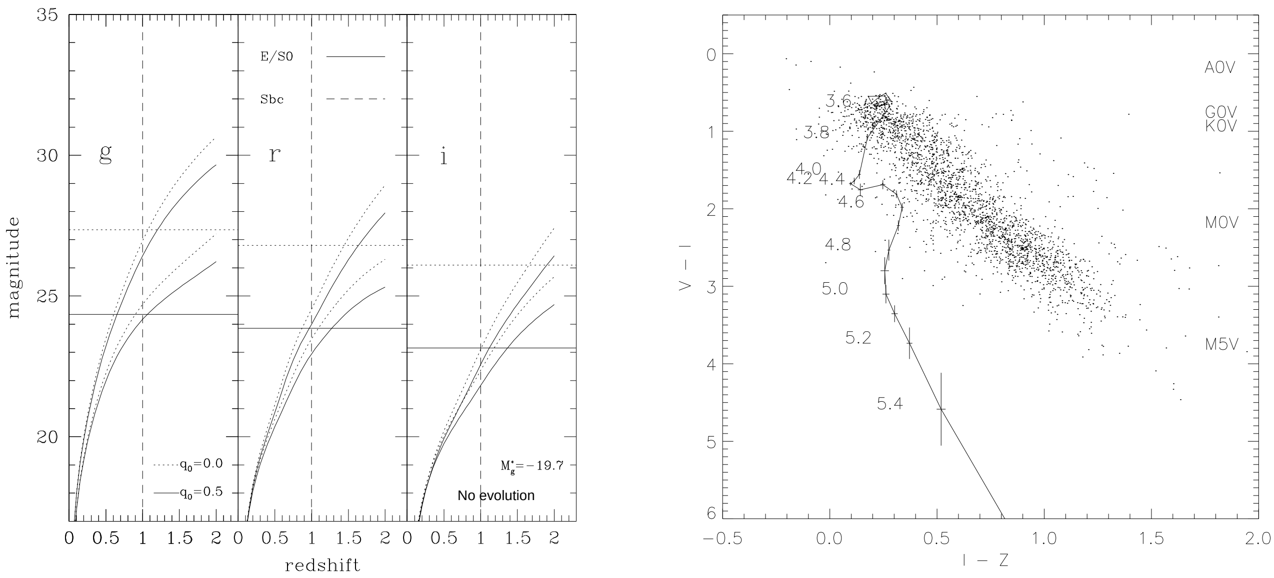

Figure 1: (a) Observed magnitude versus redshift for L* unevolving galaxy spectral energy distributions. The horizontal lines indicate the magnitude limits(5-σ in a 2 arcsec diameter aperture) and the surface brightess limits for the proposed INT observations. The vertical line is drawn at z=1. (b) Expected V-I, I-Z, colours for a 'typical' high redshift quasar superposed on the observed stellar locus based on WHT data obtained with the NAOJ MCCD. The solid line shows how the theoretical locus of the colours of higher redshift quasars change with redshift. Note the paucity of z>5 quasar candidates in this 1deg^2 region centred on SA57

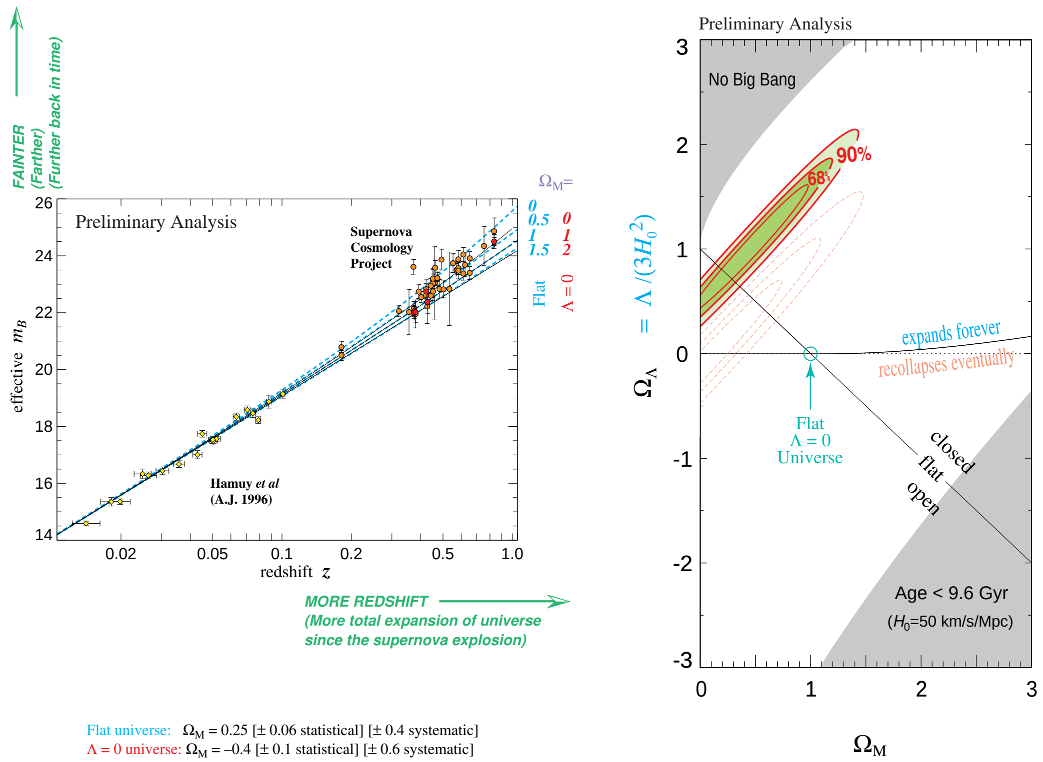

Figure 2: (a) Hubble diagram based on 40 z>0.35 and ~20 lower redshift Type 1a SN from our work. (b) Preliminary analysis showing a tentative detection of a non-zero cosmological constant. The dotted error ellipse is our estimate of the systematic errors.

Technical description

Field Locations

The UK's Wide Field Astronomy Panel carried out a recent community survey on the need for wide field optical imaging. The survey showed a strong requirement for access to digital wide field imaging data at both optical and NIR wavelengths. A few years prior to this a PATT INT CCD Working Group had consulted the community and identified several regions of sky of particular interest including:

- Coma and Virgo clusters
- fields near the North Galactic Pole (for Apr - May)
- fields near the South Galactic Pole (for Oct - Nov)
- equatorial survey strips

In addition we have selected survey fields to have low IRAS cirrus emission, low N(HI), the availability of radio data from FIRST, deep VLA fields and deep ROSAT survey regions, and at least one field close to the Ecliptic allowing a search for faint Solar System objects over a range of Ecliptic latitudes.

Planned Depth & Sensitivity

All telescopes have a natural survey time constrained by slewing, aquisition and readout overheads (two minutes) and by a tradeoff between area coverage and depth. For a 2.5-m telescope on a good site (median seeing of less than 1 arcsec) the natural survey timescale is typically 10-15 min per field to simultaneously maximise time on sky, area covered and volume surveyed. All exposures are sky-noise limited, therefore to go 1 magnitude deeper than this natural limit requires 6x the exposure time and would only be justified if $dN(m)/dm > 6$ at the survey limit. With these generic constraints the INT WFC produces the following survey detection limits in dark sky, using PSF profile fitting in typical seeing of 1.0 arcsec (for 0.7 arcsec seeing add 0.4 mag; 1.5 arcsec seeing subtract 0.4 mag).

Table 3: Survey Detection Limits in 1 arcsec seeing

Waveband	5σ limit (mag)	1σ SB limit (mag/sq arcsec)	5σ Esposure Time (seconds)
U	24.3	26.5	600
G	25.2	27.4	600
R	24.5	26.7	600
I	23.7	25.9	600
Z	21.7	23.9	300

The survey limits will allow detection of: brightest cluster member galaxies out to redshifts beyond z=1; Galactic Halo stellar tracers such as HB/RR Lyrae stars out to 300 kpc; cool white dwarfs to 1 kpc; distant supernovae to z=0.4; Solar System objects beyond 50AU; and probe the visible edge(z<6) of the Universe down to absolute luminosities M_I = -23.

Supernova Search and optical variability strategy

An important element of our program is a multi-epoch and multi-wavelength (gi) monitoring campaign. The SN search will use bimonthly targetting of selected regions to catch SN of the rise, while two 'single shot' WFC fields 12hr apart will be as observed nightly as often as possible – perhaps centred on microlensing targets such as Clover Leaf and Einstein Cross or regions in Coma/Virgo. This will lead to unprecedented measurements of quasar variablity on short timescales; proper motions for large numbers of objects; and multicolour deep stacked images of the selected regions.

Poor seeing backup project

Whenever the seeing is >1.5" we shall bin the CCDs (2x2) to 0.6 arc second pixels take 150second exposures and carry out a shallower wider angle search for SN. The data can also be used for LSB galaxy searches.

Data analysis plan

Observing strategy and local data processing
We propose to observe, initally over four semesters, each selected region to within 0.4 magnitudes or better of the limits specified in Table 3. This will require seeing conditions better than 1.5 arcsec During conditions poorer than this we would revert to the backup project. In the bright parts of any grey nights allocated we would image in the Z and I-bands. The remaining broad-band imaging would need to be carried out during dark time. This proposal would be ideally suited for 'queue' observing, and therefore could be scheduled at the 'grey' ends of 'dark' queue periods. In semester 98B *et ibid* we request 20 nights to be allocated to this project, to be split into 3-4 periods of 5-7 nights preferably excluding December,January & June,July (Galactic Plane overhead). An inital allocation of 12 weeks spread over 4 semesters would enable the equivalent of ≈100 square degrees of sky to be covered in multiple passbands. We anticipate that most of the data acquisition will be carried out in 'queue' service mode using semi-automated observing techniques developed during the 4 night AO allocation in April. Observing will be divided between local ING collaborators and co-I's. From semster 98B the JKT could be operated remotely from the INT control room, and hence contemporaneous photometric calibration data could also be aquired. Maintainence of flat field libraries and the archive data tower at the ING would involve the named ING personnel who would also provide general on-island support. The on-island activities will be co-ordinated by Walton.

Data processing and quality control
We are committed to maximising the scientific return from this project by involving the rest of the community as much as possible. We will therefore use pipeline processing techniques to ensure that the data obtained is available to the community in the most timely manner possible. Raw data will automatically be archived on the ING CD tower (350 Gbytes). Initial pipeline pre-processing will be performed to bias-correct and for preliminary flat-fielding of the data, this being written to CD-ROM for inclusion in the archive and hence immediate general access to the user community. Copies of the pre-processed data will be made nightly and sent to the Cambridge Data Centre. Staff there with expertise from the APM and archiving/data handling (Irwin, Lewis, Bunclark & others) will be responsible for further processing.

Astrometric calibration will be via the on-line public APM photographic sky catalogues and incorporated in both the digital maps via FITS header extensions and in any object catalogues. Photometric calibration frames will be obtained at intervals throughout each photometric night of the survey from the INT or JKT, backed up by JKT service data for non-photometric nights. Quality control will be assured by a rigorous and mainly automatic data handling system making use of the extensive improvements provided by the new INT DAS. Data from the CAMC will be used to give an indication of the grey extinction values for each night. Data from the WFC autoguider would be automatically logged and processed to track changes in image quality and relative transparency through the night and the science data will be used to monitor overall sky levels for each exposure.

A photometrically and astrometrically calibrated product will be made generally available from the ING and the Cambridge Data Centre including catalogues of all objects plus associated parameters.

Analysis and interpretation
McMahon will be the overall science coordinator ensuring the relevant data flows to the following topic teams: Galactic structure – Gilmore, Kuijken, Smartt, DeZeeuw; Clusters of galaxies – Cotter, Bremer, Carter, Abraham, Saunders; Radio IDs FIRST, NVSS, WENSS – Benn, Bremer, Miley, Rottgering; IRAS FSC & ISO IDs – Rowan-Robinson, Miley, Oliver; Supernovae – Walton, McMahon, Ellis, Tanvir, Hook, Carter; Brown dwarfs & cool white dwarfs – Jameson, Hambly; AGN variability – Hawkins, Lawrence; Proper motions – Hambly, Irwin; Galaxies – Phillipps, Davies, Abraham, Maddox, Bridges; Outer Solar System – Fitzsimmons, Irwin; High redshift quasars – McMahon, Irwin; Dim Halo Globular clusters & Dark Matter – Pollaco.