Photometric Calibration for WFCAM data

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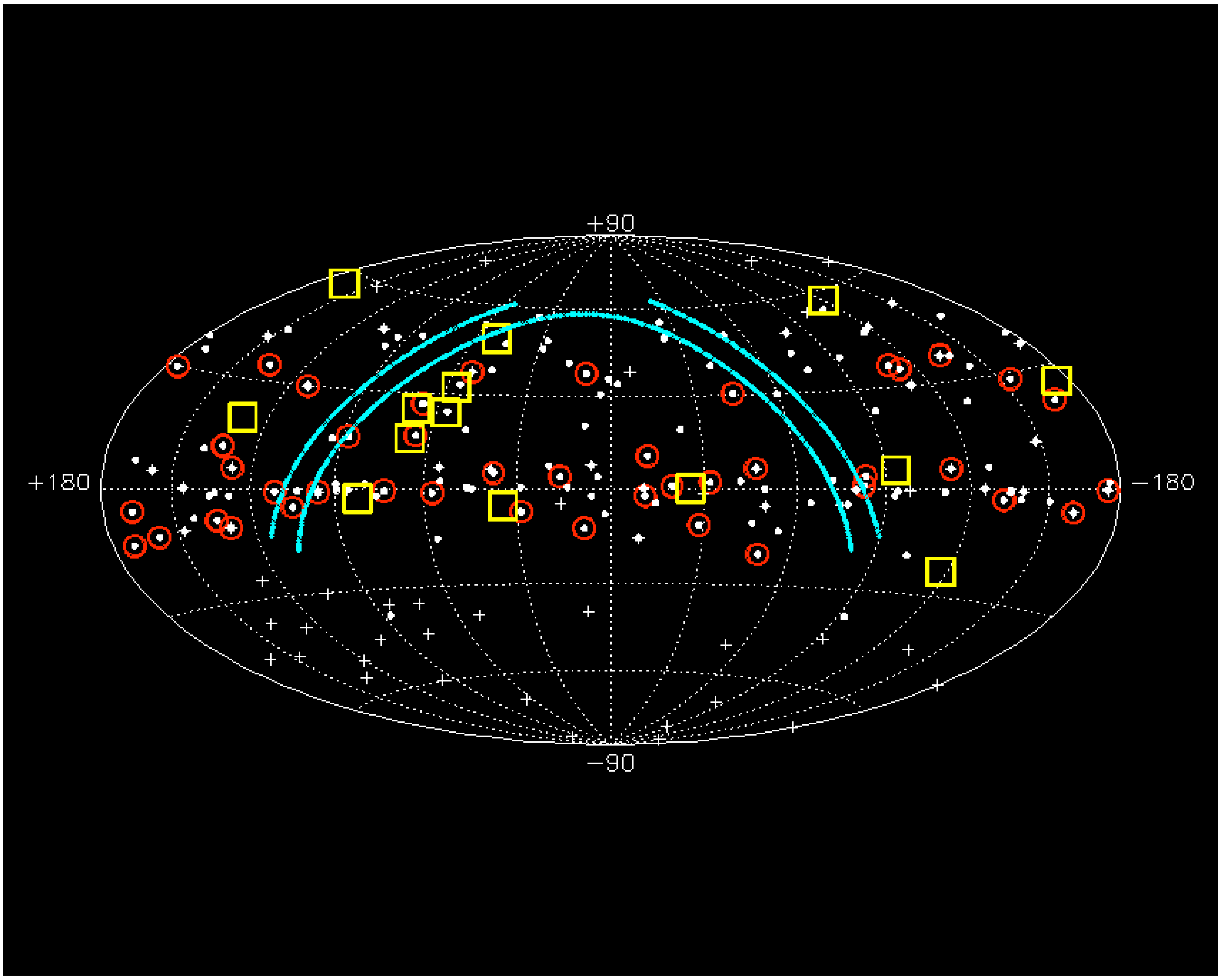

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1 Introduction

1. The purpose of this document is to discuss the photometric calibration of data from the planned UKIRT Wide Field Camera (WFCAM) in the context of the Vista Data Flow System (VDFS). The first draft of this document has been prepared to coincide with the WFCAM observing workshop (held at ROE during 12-13/6/2003).

2. The specific aims of the document are:

3. to describe in detail factors which could affect the photometric calibration of data taken with WFCAM.

4. to suggest techniques for investigating the photometric performance of the instrument and telescope during commissioning.

5. to propose nightly observing strategies which will enable photometry to be measured to the accuracy required by the UKIDSS science programmes.

6. This document does not discuss in any detail post-facto calibration of WFCAM data via overlapping or bootstrapping techniques, although we do raise the issue. It is intended that this document will evolve to incorporate the results of discussion around the issues raised (and omitted!) herein.

2 State of Play

Hambly et al. (2001) have already written a detailed document discussing WFCAM calibration and in particular investigating the need to do preparatory observations with existing instrumentation. The resulting detailed discussion between the authors came to the following conclusions:

1. The majority of the UKIRT Faint Standards (Hawarden et al. 2001) will be observable by WFCAM. Standard fields can therefore be tied to this system. Also some of the Persson et al. (1998) standards have been re-observed with UFTI and put on the same system.

2. Standard fields are preferred to standard stars - more objects beats down the noise and allows for spurious variable objects. They also allow the investigation of spatial systematics in the calibration and include a bigger colour range to enable determination of the colour equations.

3. The spatial systematic detector calibration effects are best modelled (at least initially) by 'meso-stepping' a dense stellar region across the detector. This region need not be a calibrated standard field.

4. There is not much to be gained from using the 2MASS standards – the filter pass bands are quite different (and this difference is variable over time as they include H_20 bands). The JHK filters on WFCAM are part of the MKO filter set –

i.e. they are very similar to the UFTI filters and the sensitivity function will therefore depend only on QE differences between the detectors which look to be small (Casali ****).

5. There is no strong requirement to pre-observe fields with UFTI/UIST – all calibration can and should be done with WFCAM.

The suggested strategy was:

1. Check the spatial performance of the telescope + detector + reduction system, using a dense stellar region - e.g. a globular cluster.

2. Choose suitable calibration fields (spaced at suitable intervals in Right Ascension and covering a range of Declination), possibly centred on the UKIRT faint standards.

3. Observe UKIRT faint standards, and

4. Tie in calibration fields to the UKIRT FS system. Calibration fields should be observed on a minimum of 3 photometric nights (assuming there is already some photometric pedigree).

3 Photometric Calibration of Wide Field NIR Images

The WFCAM wide field of view, large pixels and four detectors add complexity to the issue of photometric calibration. The way in which the instrument will be used, being on the telescope for large blocks of time and running in predominantly a survey mode, mitigates these problems by providing a stable configuration and enabling us to take a long term approach. By defining routine calibration procedures at an early stage we should be able to maximise the accuracy of WFCAM data, and hence the scientific productiveness and legacy of the archive, for the minimum of fuss.

In **Appendix A1**, I briefly outline the photometric problem we are trying to solve. The accuracy to which we can calibrate WFCAM data depends crucially on our observing strategy. Effects which need to be accounted for during commissioning and the lifetime of the project include the following:

- spatial systematics (scattered light/flatfield errors)
- variable pixel spatial scale across the FOV
- extinction colour dependence
- differential extinction across the field
- chip-to-chip gain dependence
- chip-to-chip QE colour effects
- filter colour terms
- extinction time dependence
- geometrical/optical spatial effects (e.g. vignetting, secondary reflectivity function)

To get the most out of the pipeline processing, we need to define observing practices (MSBs) which should be rigorously adhered to by the WFCAM observers.

In addition we need to ensure that time is set aside during commissioning and in every semester to characterise the performance of the instrument and to update the standard star fields.

4 Detailed Discussion of WFCAM Calibration

Following the initial document, I have revisited the WFCAM photometric calibration and highlight some important steps which need to be planned.

4.1 Choice of Primary Standards

In a 5 (1) second exposure the detectors will saturate at magnitudes of J=11.5 (9.8), H=11.5 (9.8), K=11.1 (9.4) (Casali et al. 2003; numbers in brackets are the 1 second saturation limits). Which means that nearly all the UKIRT standard stars (http://www.jach.hawaii.edu/JACpublic/UKIRT/astronomy/calib/fs_izjhklm.dat) are in reach of WFCAM (defocusing can be used for brighter stars, but this should be avoided if possible).

Persistence effects have been measured and appear to be small (2 10^{-4} after 20 seconds, Casali et al. 2003) therefore there should be no problem in observing the UKIRT faint standards, with the caveat that these are preliminary results from only one detector.

4.2 Spatial Calibration

Manfroid, Selman & Jones (2001) discuss the effect of scattered light in ESO WFI sky frames, i.e. by flatfielding a science image with data that contains an additive, spatially-dependent component, one will introduce a systematic calibration error across the field of view. However, the ESO WFI does seem to suffer a much larger effect than is seen in the INT WFC. There are two simple ways to check that the data reduction pipeline does not introduce an error of this nature.

- Observe a star (or star field) at many different positions on the science array during a photometrically stable night.

- Observe a previously calibrated star field which is dense enough to measure the spatial calibration.

In practice, at commissioning, it may be simplest to observe a single star and step it across the array. This will enable a quick (e.g. 64 pointings x 1s to give an 8x8 grid) and accurate check of any spatially dependent systematics. Using a dense star field will improve accuracy but will require a lot more analysis effort. Once a calibrated field is set up, this becomes a quick and simple routine check requiring only one image, providing the field contains enough stars.

4.3 Choice of Secondary Fields

These will become legacy fields for the calibration of WFCAM, VISTA and future IR projects. We consider the following as requirements:

- The field should extend over 14x14 arcminutes for WFCAM. VISTA fields need to be larger, but can be extended with VISTA itself.

- They should span 24 hours in RA, preferably spaced every 2 hours (1 hour?) eventually, maybe every 4 hours initially. Some fields to the North should be defined to enable observations at airmass 1.00, and to simultaneously span a rage of zenith distance.

- Similar fields should be chosen in the South for VISTA.

- The density of sources should be adequate to characterise the position dependent systematics in WFCAM. This is at least 100 stars with K magnitudes no fainter than 18 (otherwise prohibitively long exposures required)

- They should encompass a broad spread in colour so that we can determine colour terms.

Some suggestions for targets are:

1. Near or around existing UKIRT Faint Standards

2. In Open Clusters

3. On the edges of globular clusters

4. Fields selected purely on the basis of number density (e.g. from 2MASS)

Our preference is option [1] and 2MASS star counts[1] indicate that at high galactic latitude there are approximately 300 sources per square degree per magnitude at JHK=17. 2MASS data has been examined to investigate the colour properties of candidate fields. Figure 1 shows objects selected from a 13.65×13.65 arcmin region centred on the blue standard RU149D. This is a good candidate secondary standard field for the following reasons:

- RU149D will not saturate in a typical WFCAM standard exposure (5s) enabling direct calibration for all the other stars in the field.
- The field is reasonably devoid of bright stars – avoiding saturation and persistence issues for the detector (there are 3 stars with H<10 in the 2MASS point source catalogue).
- There are some 700 stars in the 2MASS PSC to J=16
- Stars cover a wide range of colour.

Globular clusters, [3], may have a strong gradient across the field, although the horizontal branch will ensure a good range of colour. The densest regions must be avoided and additional care taken with aperture photometry given the crowding.

I have therefore selected a list of around 48 UKIRT Faint Standards spread over 43 fields on which to base the secondary standards. These standards are listed in Appendix A5 which also includes discussion of the criteria for selecting the standard fields. Finding charts, star counts and colour-magnitude diagrams for all these fields can be found at http://www.ast.cam.ac.uk/~sth/wfcam/wfcam_standards/

[1] http://www.ipac.caltech.edu/2mass/releases/second/doc/sec6_7a.html

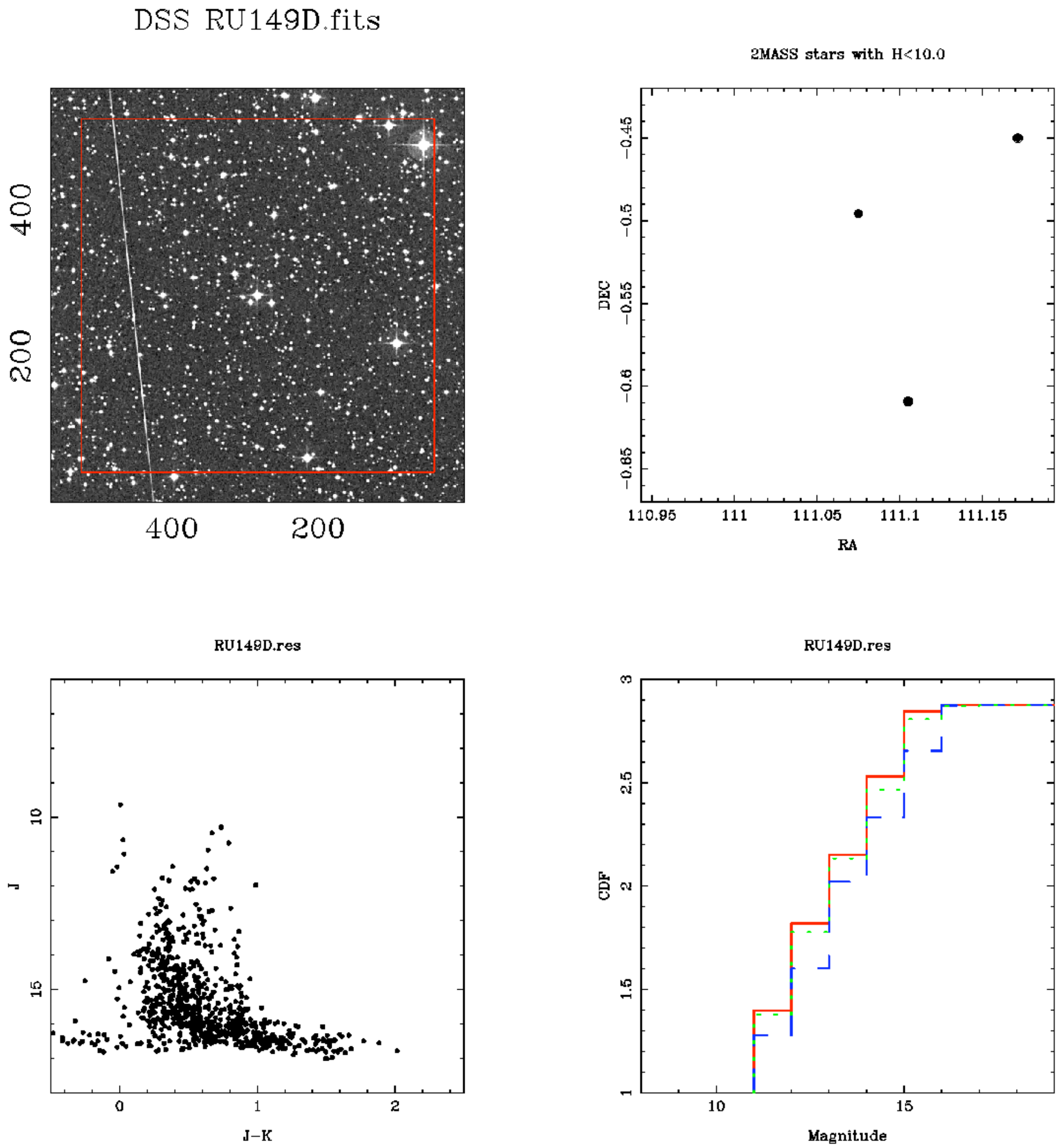

Figure 1. [top left] DSS image centred on RU149D spanning 15x15 arcmins and illustrating the span of one WFCAM chip. [top right] 2MASS stars brighter than H=10 in the field of RU149D on the same detector. [bottom left] colour-magnitude diagram from 2MASS and [bottom right] 2MASS star counts for the same detector.

4.4 Narrow Band Filters

A clear strategy for calibration of the narrow band filters needs to be set in place. Three suggestions are

1. Use spectrophotometric flux standards.
2. Use normal standard fields and bootstrap the filters into the VEGA system.

3. Use a synthetic calibration.

Suggestion (3) seems unreliable. The preferred approach would be to tie the WFCAM standard fields into a system based on spectrophotometric standards if we can find any.

Our level 1 approach would be to bootstrap into the Vega system. By observing a whole range of UKIRT FS in all filters - including the narrow band - we can plot $H2_{instrumental}$-K vs J-K for example. The solution to a fit through the sequence requires that for J-K=0, H2-K must also be zero by definition. Thus we solve for the H2 zero-point and any colour term. Note that WFCAM calibration will use secondary standards where there are typically >100 per chip down to J=16 so we will eventually have very many stars measured in all filters. Figure Figure 4 shows the spread in colours of the selected UKIRT faint standards.

In order to turn the instrumental zeropoints into fluxes, we'd really need to measure some photometric standards at H2.

4.5 New broadband filters

Y and Z filters. SKL is setting up UKIRT Z-band standards, but this Z seems markedly different to the WFCAM Z filter. We need to define a consistent calibration method to put these filters in the same system as JHK. I propose to use the same technique as was used for the INT WFC z-band, i.e. tie the system into Vega by observing a stars of varying colour, a plot of e.g. Z-J vs J-K should pass through (0,0). This is also the proposed system for the narrow-band filters (above).

Sandy Leggett has now synthesised UKIRT YZ magnitudes for a range of stars with spectra using laboratory measured Y and Z WFCAM filter profiles. She has also estimated colours for a few objects based on their spectral type and VIJHK magnitudes. See Appendix 5 for more details.

4.6 Definition of magnitude system

The WFCAM project needs to decide which magnitude system to work in. Stellar astronomers prefer Vega, while the extragalactic community prefer the AB system (allegedly). I propose to work in Vega and provide transformation coefficients for the AB system. I think we need to avoid releasing two sets of magnitudes, e.g. J_{WFCAM}^{Vega}, J_{WFCAM}^{AB}.

4.7 Science Requirement

The science requirement from UKIDSS is to achieve 2% accurate photometry. See Hambly et al. (2001) for some discussion of what this accuracy means.

5 Commissioning Calibration Plan

We propose to make the following observations **as soon as** the instrument is generating sensible images. In the current (March 2005) schedule, this comprises about one to two nights worth of time intermingled with science verification observations. The planned observations are:

1. Observations of UKIRT FS standards in all filters on all 4 chips. We will select targets from Section 9.4 spanning a range of colours.
   - Aims: chip-to-chip calibration (include. colour terms) and begin secondary standards setup
   - Time taken: 5 mins x 4 chips x 10 standards = 3 hours approx

2. Investigation of spatial systematics (in a range of filters)
   - Aims: to measure any correction required.
   - Time taken: 25 pointings x 10s x 5 filters = 30 mins approx

3. Tie in of pre-selected secondary fields (in all filters)
   - Aims: To set up about 40 standard fields to enable quick and accurate WFCAM calibration
   - Time taken: 5 mins x 20 standards x 2 obs = 3 hours approx
   - Note: This will be repeated 6 monthly to ensure full RA coverage and inititally monthly to set the fields up quickly and help with the identification of variable stars.

4. Observations of spectrophotometric standards (in narrowband filters)
   - Some of the standards in Section 9.4 have spectroscopy

This should be seen as a priority and given precedence as soon as conditions merit the observations.

[2] becomes routine and very quick when secondary standard fields are in place, and could be performed every night as a check on or correction to the standard 2D pipeline reduction. As confidence in the pipeline reduction is established, then the frequency can be reduced, perhaps only making the test every time the instrument is mounted.

5.1 Spatial Systematics: Mesostepping

We assume that the spatial sensitivity of each detector can be approximated by a polynomial surface, i.e. a magnitude offset as a function of (x,y) measured from the centre of the detector, e.g.

$$ZP(x,y) = \sum_{hk} a_{hk} x^h y^k$$

For example, in quadratic form, at positions i and j:

$$ZP(x_i, y_i) = a_{00} + a_{10}x_i + a_{01}y_i + a_{20}x_i^2 + a_{11}x_i y_i + a_{02}y_i^2$$

$$ZP(x_j, y_j) = a_{00} + a_{10}x_j + a_{01}y_j + a_{20}x_j^2 + a_{11}x_j y_j + a_{02}y_j^2$$

The difference in sensitivity/zeropoint between two positions i and j is then:

$$\Delta ZP(x_i,x_j,y_i,y_j) = a_{10}(x_i - x_j) + a_{01}(y_i - y_j) + a_{20}(x_i^2 - x_j^2) + a_{11}(x_i y_i - x_j y_j) + a_{02}(y_i^2 - y_j^2)$$

If we make two observations of the same star at offset positions i (x_i,y_i) and j (x_j,y_j), we sample this function such that the difference in magnitude measured is Δm_{ij} then:

$$\Delta m_{ij} = \Delta ZP(x_i,x_j,y_i,y_j)$$

In the simplest case, observing the same star in a number of different places would allow you to measure the Δm_{ij} as a function of (x_i,y_i) and (x_j,y_j). One could then fit a polynomial using least-squares and solve for the a_{hk}. The multiple observations of multiple stars in a grid across the array ensures we can solve for the polynomial coefficients accurately.

5.1.1 Observations

We propose a 5x5 uniform grid of pointings, stepping the telescope 1/5 of a detector width between each pointing position, e.g.:

1	2	3	4	5
10	9	8	7	6
11	12	13	14	15
20	19	18	17	16
21	22	23	24	25

These observations should only be done in photometric conditions, largely because cloud will give variations in sensitivity on spatial as well as temporal scales. We will measure a region with a high enough stellar density that we are using many stars to solve for the polynomial coefficients. Two offset observations at the end of the sequence can be used to tie all four chips together (i.e. gain correction).

6 Nightly Calibration Plan

1. Observations of standard stars will be made hourly on every WFCAM night (UKIDSS/PATT/UoH) when the dome is open, independent of photometric conditions and seeing.

2. Each standard will be observed in all 5 broadband filters.

3. Observations in additional narrowband filters will be at the discretion of the observer.

4. Observations will be made with a 3-point jitter pattern and no microstepping.

5. Exposure times will be 10.0 seconds NDR mode in the Y and Z filters (to be background limited) and 5.0 seconds CDS MODE in the JHK filters. Narrowband filters ?

6. The array must be flushed after each filter change.

7. Darks will be measured during the calibration sequence.

8. The MSB must be kept to <6 minutes, thus the overhead is no longer than 10%. (Substitute actual elapsed time calculation here)

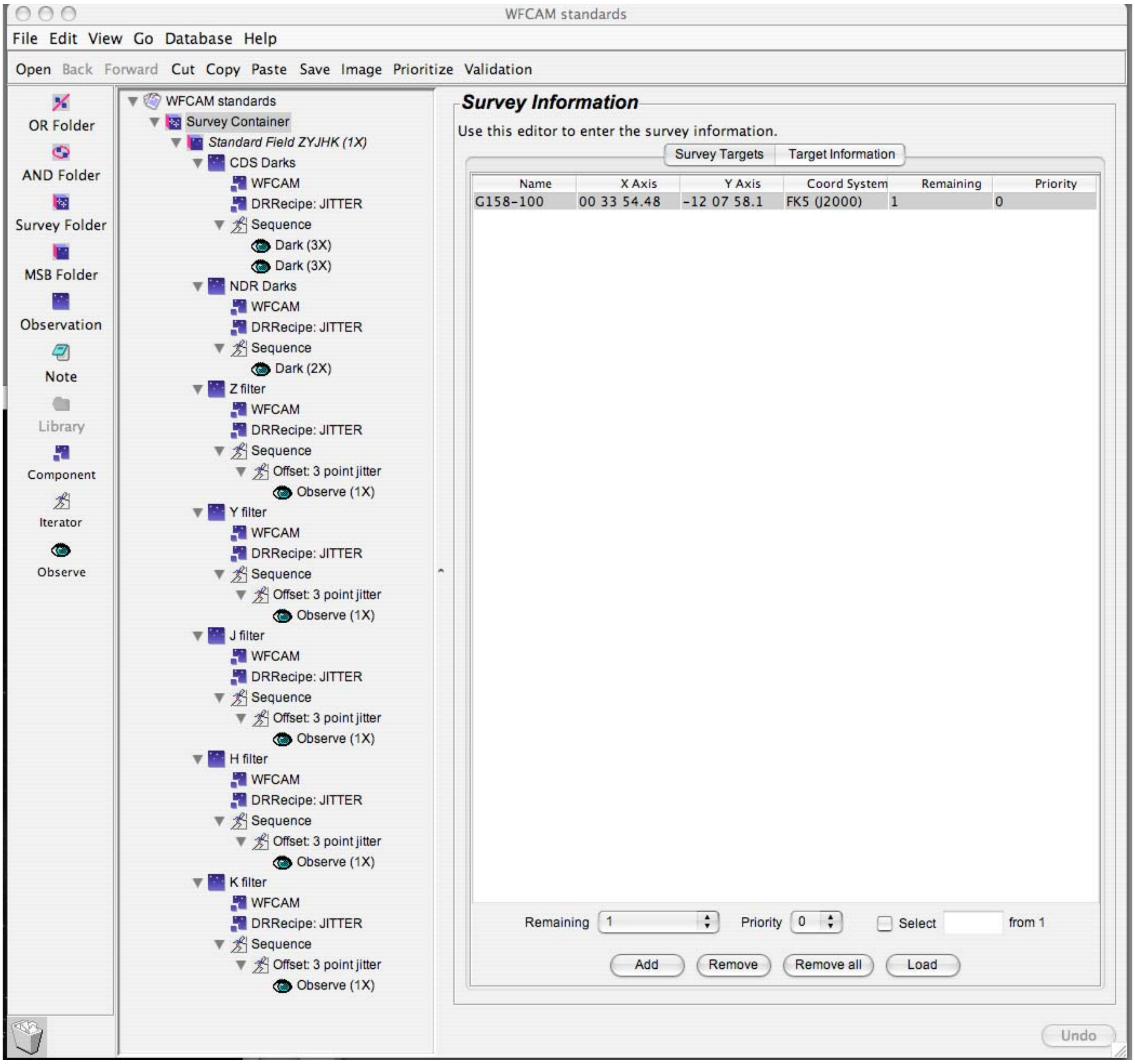

Figure 2: AN example MSB created using the UKIRT OT

7 Proposed Secondary Standard Fields

I've started with the Persson et al. (1998, AJ, 116, 2475) and UKIRT FS (Hawarden et al. 2001 Mon.Not.R.astr.Soc. 325, 563, Leggett et al. 2003 Mon.Not.R.astr.Soc. in press and http://www.jach.hawaii.edu/JACpublic/UKIRT/astronomy/) lists of primary standard stars. I am attempting to define secondary standard fields which have a primary standard at their centre to enable direct calibration (for one detector at least). The Persson standards are actually a little bright so everything that follows is based on the UKIRT Faint Standards (which actually include a few of the Persson stars).

7.1.1 Standard Field Selection

The UKIRT Faint Standards comprise 114 fields - which is rather more than we need. I want to refine this to more like 2-3 per hour in RA, of which the majority should be equatorial, with a scattering further to the north so that they pass almost overhead (UKIRT latitude is +19.82 degrees).

7.1.2 Selection Criteria

Further selection criteria are:

- Primary standard must not saturate WFCAM in minimum exposure (about 1 second).
- Would be nice if primary standard did not saturate WFCAM in a typical standard exposure (5 seconds).
- Want the field to be reasonably rich, at least >100 stars per detector
- Want the primary (and secondary) standards to cover a wide range of colours.
- Don't want anything hideously bright to fall on the array.

7.1.3 WFCAM saturation

I have set very approximate and conservative saturation limits from CASU derived zero-points (see http://www.ast.cam.ac.uk/vdfs/reports/commissioning/) - objects brighter than these limits have been cut from the candidate standards list. These are listed below:

	1 ADU/s	SAT(1s)	SAT(5s)
Y	22.8	10.55	12.35
J	23.1	10.85	12.65
H	23.4	11.15	12.95
K	22.6	10.35	12.15

Assumptions: 30,000 counts in 1 second, where 40% of counts fall within central 0.4 arcsecond radius circle, and all off this flux ends up on one pixel.

7.1.4 Reduced List

After manually sorting the 114 UKIRT FS stars based on the above criteria, I'm left with a shortlist of 48 standards, spread over some 43 fields (I've manually added back in a few brighter ones for which we have estimated/synthetic YZ magnitudes – see table below). The figure below shows the distribution of these fields in an equatorial hammer-aitoff projection diagram (0 hours RA is at the centre of the plot). Dots are the UKIRT FS stars (+ = Persson). Red circles are the selected fields.

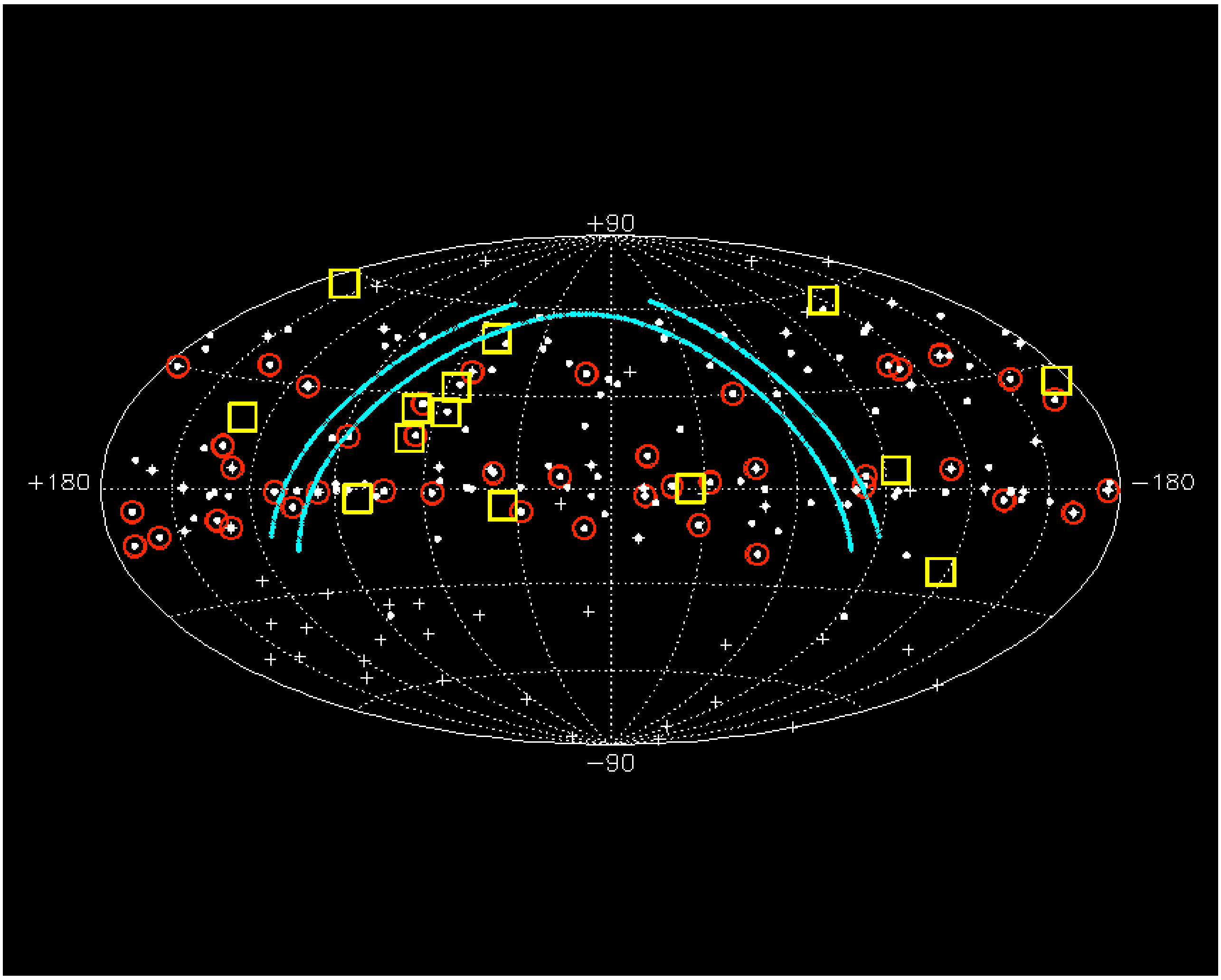

Figure 3 A Hammer-Aitoff projection in equatorial coordinates (0 degrees at the centre) illustrating the distribution of the selected secondary standard fields (○) across the sky. UKIDSS target fields (from GCS, UDS, DXS) are shown as □. The GPS is shown as ≈. Standards from the Persson and UKIRT FS catalogues are + and • respectively. **Update figure to include extra few standards near high DEC DXS fields and low dec GCS field.**

In addition, the following figure shows that the colour distribution of the selected standards is representative of the FS sample as a whole, and importantly I've kept the reddest and bluest stars (postscript version).

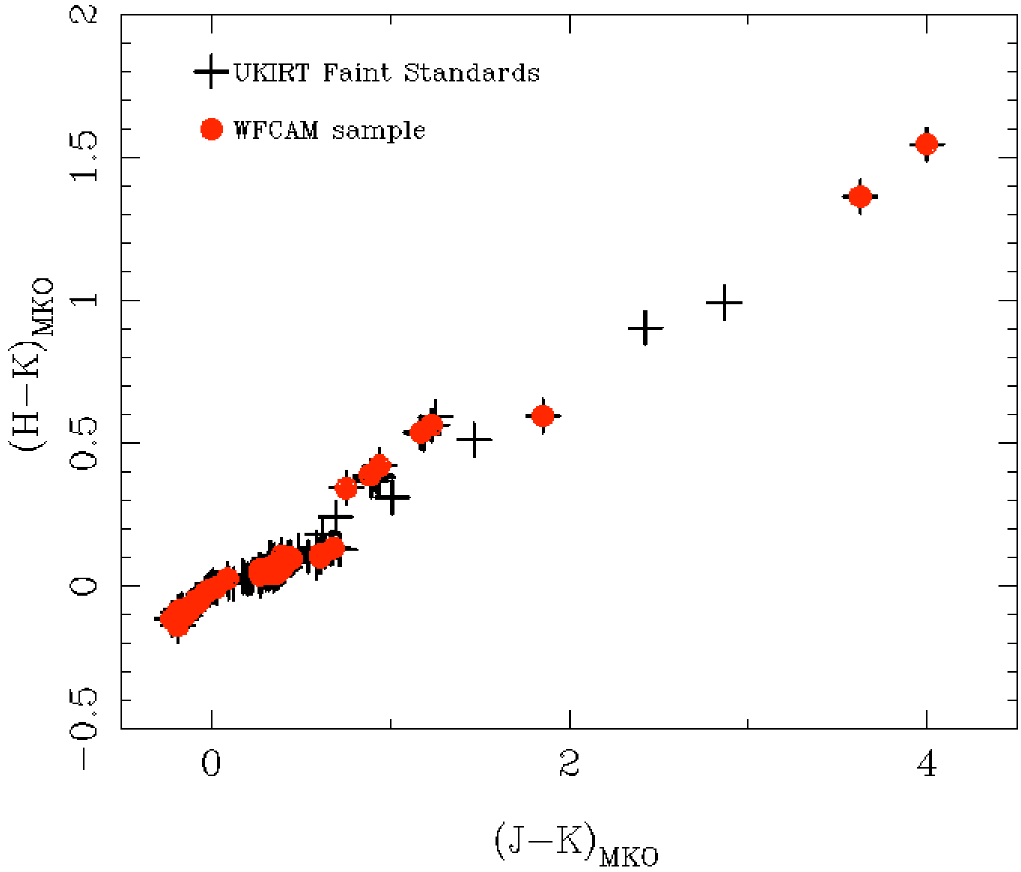

Figure 4 The colours of the WFCAM subsample compared to the complete UKIRT Faint Standard list

The rest of this page gives the list itself, plus for each field I've made a figure incorporating:

- A DSS image to give a feel for the crowding of the region
- A colour magnitude diagram from the 2MASS Point Source Catalogue
- The 2MASS Point Source Catalogue source counts

which can be found at http://www.ast.cam.ac.uk/~sth/wfcam/wfcam_standards/.

8 References

- Hambly, Harwaden, Adamson, Casali, Warren, Leggett, 2001, http://www.ukidss.org/technical/technical.html (section 6), *Photometric calibration for WFCAM data.*
- Casali, 2003, WFCAM Performance *and Summary of Characteristics*.
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- Manfroid, Selman, Jones, 2001, ESO Messenger (June), p.16, *Achieving 1% photometric accuracy with the ESO Wide Field Imager*.
- Nikolaev et al., 2000, AJ, 120, 3340, *A global photometric analysis of 2MASS calibration data*.
- Persson, Murphy, Krzeminski, Roth, Reike, 1998, AJ, 116, 2475, *A new system of faint near-infrared standard stars*.

9 Appendices

9.1 Definition of the problem

At any time (*t*), on any night (*n*), for any star (*i*), in any waveband (*b*),

$m^{cal}_{ib} = m^{inst}_{ibtn} + ZP_{btn} - k_{btn} (X - 1)$,

where *ZP* is the Zero Point (i.e. the magnitude at airmass unity which gives 1 count/second at the detector), m^{cal} is the calibrated magnitude, m^{inst} is the measured instrumental magnitude *(-2.5 x log10[counts/sec]*), *k* is the extinction coefficient and *X* is the airmass of the observation. This assumes that second order extinction term and colour dependency of *k* are both negligible.

Typically, the Zero Point of the instrument + telescope system should be stable throughout the night. Long term decreases in the sensitivity of the instrument, and hence a decreasing *ZP*, could be caused by e.g. the accumulation of dust on the primary mirror.

The 2MASS project found extinction varied seasonally. They allowed the *ZP* to vary through the night, but fixed the extinction. One could reasonably allow the extinction to vary through the night, given that the dominant contributors are H_20 and CO. The *ZP* then becomes a measure of the system throughput and can be easily monitored with the pipeline summit using the 2MASS catalogue.

9.2 The 2MASS standard fields

The updated 2MASS standards table contains 32 standard fields. These are 16 equatorial fields, uniformly distributed in RA, and 8 each of North and South polar fields, in the range Dec=+/-30 to 60, i.e. fine for UKIRT and VISTA. More than 2000 standards are spread between these 32 fields, i.e. something like 100 stars per field. Field areas are around 1 degree x 8.5 minutes, i.e. width is 60% of a WFCAM field of view. Standards typically have few hundred up to 1500 hundred scans, RMS errors at the bright end are at the few percent level.

The filter profiles between 2MASS and MKO are significantly different, e.g. the 2MASS J filter contains significant water vapour lines. Hambly et al. (2001) suggest that these differences lead to huge uncertainties in the *ABSOLUTE* calibration of the photometry. They propose re-observing 2MASS fields in MKO filters – or defining new glob cluster field. WFCAM can then be used to extrapolate fields to larger range of RA, DEC.

Overall these fields do not seem to be useful - they are smaller then the FOV of the instrument. In their favour they do have a small photometric legacy, although the error on any measurement of an individual star is large. Additionally the transforms from a low, wet site to a high, dry site will compromise photometric accuracy. We probably would do better selecting our own fields.

9.3 Remaining Questions

- What is the minimum number of measurements (fewest overheads on survey time) that are needed to achieve the Science Requirement accuracy?

- What do we do about extinction? Do we know how MKO extinction behaves seasonally, or over the course of a night, in the infrared? Do we need to use the science arrays? For example the autoguider is monitoring in the V-band; it seems unlikely that we will be able to bootstrap the V extinction into JHK.

- Can we improve on the calibration by tying together groups of nights (how many) or should each night stand alone? What about a global solution a la 2MASS (see Nikolaev et al. 2000)?

- What other information will be available to us apart from WFCAM measurements (e.g. 2MASS measures, autoguider transmission, skyprobe, CSO Tau) and how can we make use of it?

- How do we tie in observations taken during non-photometric conditions? Observations taken in patchy cirrus will not be trivial to calibrate (since cloud structure could be smaller than the FOV.

9.4 List of Standards

FS	Name	RA	DEC	J	H	K	Nchp	YZ
1	G158-100	00 33 54.48	-12 07 58.1	13.414	13.063	12.968	84	
103	p241-g	00 36 29.60	+37 42 54.3	12.328	11.833	11.722	270	
3	F11	01 04 21.63	+04 13 36.0	12.653	12.739	12.833	104	
5	F16	01 54 34.65	-06 46 00.4	12.369	12.336	12.342	75	est
6	F22	02 30 16.64	+05 15 51.1	13.265	13.311	13.383	119	est
10	GD50	03 48 50.20	-00 58 31.2	14.780	14.830	14.969	102	est
x	P247-U	03 32 03.00	+37 20 40.0	11.901	11.614	11.507	505	
114	Hy214	04 19 41.72	+16 45 22.4	14.379	13.860	13.438	207	
116	b216-b7	04 23 50.18	+26 40 07.7	12.777	11.517	10.922	224	
11	SA96-83	04 52 58.92	-00 14 41.6	11.332	11.267	11.241	170	est
12	GD71	05 52 27.66	+15 53 14.3	13.720	13.818	13.910	966	
x	S842-E	06 22 43.70	-00 36 30.0	11.650	11.324	11.224	800	syn
121	s772-g	06 59 46.82	-04 54 33.2	11.984	11.436	11.302	1136	syn
14	Rubin149	07 24 14.40	-00 33 04.1	14.124	14.145	14.206	689	
x	RU149D	07 24 15.36	-00 32 47.9	11.435	11.445	11.469	689	syn
x	P309-U	07 30 34.50	+29 51 12.0	11.816	11.492	11.445	250	syn
x	P545-C	08 29 25.10	+05 56 08.0	11.823	11.588	11.549	219	syn
x	S705-D	08 36 12.50	-10 13 39.0	12.315	12.102	12.045	370	syn
15	M67-I-48	08 51 05.81	+11 43 46.9	12.723	12.415	12.353	408	

16	M67-IV-8	08	51	15.01	+11	49	21.2	12.986	12.694	12.643	502	
17	M67-IV-27	08	51	19.31	+11	52	10.4	12.656	12.345	12.270	508	
123	p486-r	08	51	11.88	+11	45	21.5	10.141	10.157	10.206	456	est
124	lhs254	08	54	12.60	-08	05	03.0	11.482	11.072	10.728	245	syn
125	p259-c	09	03	20.60	+34	21	03.9	10.764	10.432	10.362	110	syn
19	G162-66	10	33	42.75	-11	41	38.3	13.645	13.698	13.784	130	
20	G163-50	11	07	59.93	-05	09	26.1	13.424	13.453	13.506	121	est
129	lhs2397a	11	21	48.95	-13	13	07.9	11.815	11.182	10.645	112	
21	GD140	11	37	05.15	+29	47	58.4	13.020	13.064	13.168	66	syn
132	s860-d	12	21	39.36	-00	07	13.3	12.157	11.875	11.835	81	
33	GD153	12	57	02.30	+22	01	52.8	14.083	14.165	14.270	46	
x	S791-C	13	17	29.60	-05	32	37.0	11.592	11.274	11.231	119	
23	M3-193	13	41	43.57	+28	29	49.5	13.001	12.494	12.393	537	
x	P272-D	14	58	33.10	+37	08	33.0	11.587	11.262	11.202	84	
x	T868-110639	15	10	17.00	-02	41	05.0	12.537	11.868	11.306	156	
138	p275-a	16	28	06.72	+34	58	48.3	10.380	10.377	10.391	144	est
27	M13-A14	16	40	41.56	+36	21	12.4	13.482	13.196	13.130	222	
137	p565-c	16	26	42.72	+05	52	20.3	12.141	11.893	11.843	243	
35	fs35	18	27	13.52	+04	03	09.4	12.167	11.830	11.729	2071	
143	Ser-EC68	18	29	53.79	+01	13	29.9	16.534	14.271	12.908	1206	
144	Ser-EC84	18	29	56.90	+01	12	47.1	15.016	12.563	11.017	1212	
34	EG141	20	42	34.73	-20	04	34.8	12.888	12.927	13.013	262	est
x	P576-F	20	52	47.30	+06	40	05	12.207	11.928	11.867	406	
151	p340-h	21	04	14.75	+30	30	21.2	12.205	11.938	11.870	1057	
29	G93-48	21	52	25.36	+02	23	20.7	13.203	13.248	13.323	181	est
x	BRI2202	22	05	36.00	-11	04	27.0	11.588	11.088	10.700	128	
30	SA114-750	22	41	44.72	+01	12	36.5	11.936	11.972	12.021	138	est
31	GD246	23	12	21.60	+10	47	04.1	13.828	13.935	14.050	115	
32	F108	23	16	12.37	-01	50	34.6	13.563	13.649	13.730	118	

NB: Sandy Leggett has combined synthetic spectra with the WFCAM filter profiles to produce expected YZ magnitudes for a selection of stars (labeled syn). She has also produced estimated YZ mags for a sample of stars with spectral types and VIJHK magnitudes (labeled est).