1 Title: A variability survey of Local Group Galaxies

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1.1 Abstract: (10 lines max)

The primary aim of this survey is to observe 4 Local Group Galaxies 50 times over a 3 year period down to point-source magnitudes of about K= 18.8 and Z= 21.5 (15σ, Vega system) in a single observation. This will enable the detection of all cepheids and AGB Mira variables in those galaxies (and RR Lyrae in Fornax). In addition, the brightest variable main-sequence stars and eclipsing binaries will be detected. This survey will provide a unique database of variable objects. The primary science driver is to understand the pulsational properties of the RR Lyrae, cepheids and AGB variables and to link these to the (spatially resolved) Star Formation History of these galaxies. The secondary science goals include the analysis of other classes of pulsational variables and the selection of detached eclipsing binaries for follow-up studies. Other uses include the analysis of the galaxies' colour-magnitude diagram (the co-added data with reach 5σ limiting magnitudes of about K= 22.1 and Z= 24.6), study of the galactic foreground population, including proper motion studies, and quasar variability.

2 Description of the survey: (Text: 3 pages, Figures: 2 pages)

2.1 Scientific rationale:

In the course of the micro lensing surveys in the 1990's the monitoring of the Galactic Bulge, Small and Large Magellanic Clouds (MCs) has revealed an amazing number and variety of variable stars. A big impact was felt and is being felt in variable star research, like cepheids and RR Lyrae stars, variability in AGB stars and eclipsing binaries (EBs). The sheer number of variables detected allowed for the first time detailed statistical studies of e.g. the period-luminosity relations of fundamental mode and overtone cepheids and Mira variables.

Apart from this aspect, there is also an important connection between pulsation and stellar evolution. As generations of stars evolve with time they change their luminosity and effective temperature, lose mass and enrich the ISM. At the same time they cross various instability strips and become unstable to pulsation. The number of such pulsators and the period distribution reflects therefore the properties of the underlying stellar population. As an example, Figure 1 shows the period distribution of fundamental mode and first overtone cepheids in the LMC and SMC. They are clearly different; what can we learn from that? Metallicity plays a role here, but in one of the earliest MACHO papers Alcock et al. (1999, AJ 117, 920) used the period distribution of cepheids to infer a burst of recent ($\sim 1.1 \;\; 10^8$ yr) star formation in the LMC, and that the main centre of star formation has been propagating along the bar.

As a second example, Figure 2 shows the theoretical fundamental mode period distribution of Miras of various initial masses. On average, larger initial masses result in longer period Miras. These calculations were used by Groenewegen & Blommaert (2005, A&A 443, 143) to explain the observed trend in the Galactic Bulge Mira period distribution at similar longitudes but different latitudes.

The proposed survey is a one for variable objects in general. However, the prime science driver is to link the pulsational properties of the most important classes of variables to the Star Formation History (SFH) and Age Metallicty Relation (AMR) of the target galaxies.

Table 1 contains a summary of the properties of the main classes of variable objects of the survey. Below these classes are introduced briefly and the reasons explained why it is important to conduct the survey in K and Z.

AGB stars

Allmost all stars with initial masses in the range 1-8 M$_\odot$ will pass through the AGB (Asymptotic Giant Branch) phase, which is the last stage of active nuclear burning before they become post-AGB stars, Planetary Nebulae and finally White Dwarfs. The main characteristics of the AGB are (A) the active nucleosynthesis (mainly carbon, nitrogen, s-process elements) which allow an AGB star to make the transition M $\rightarrow$ S $\rightarrow$ C in spectral

Table 1: Properties of principle classes of variables

Class	M_I	M_K	$Ampl_I$	$Ampl_K$	Period (days)	remarks
RR Lyrae	-0.3 to +0.5	-1.1 to 0.0	0.15 - 1.0	0.08 - 0.5	0.4-0.8	
Cepheids	-7.1 to -3.2	-8.2 to -4.0	0.15 - 0.6	0.10 - 0.4	3-60	1
AGB-Miras	-9. (to +20)	-11. to -4.	$\gtrsim$0.45	$\gtrsim$0.2	50-1200	2, 3
Eclipsing Binaries	-5.3 to -2.9	-4.8 to -2.4	–	–	$\lesssim$3.5	4,5

[1]Period range of linear part of fundamental mode PL-relation.
[2]Amplitudes that define Mira type variability. Semi-regular variables have similar periods to Miras but with smaller amplitudes.
[3]In I the brightest magnitude is indicated. Dust obscured Miras can become extremely faint in the optical.
[4]Magnitude range of 50 dEB in the SMC with OB-type companions (Harries et al. 2003, Hilditch et al. 2005).
[5]The bright cutoff in I and K-magnitude is in fact due to the saturation of the OGLE CCDs.

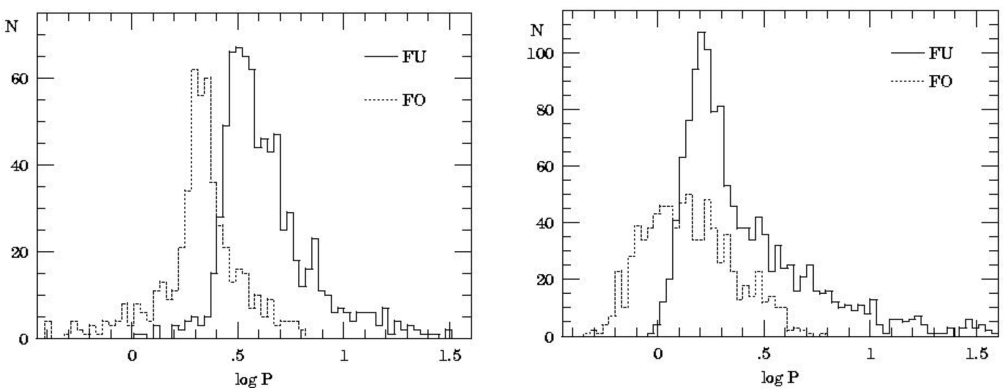

Figure 1: Period distribution of fundamental mode (FU) and first overtone (FO) cepheids in the LMC (left) and SMC (right) based on OGLE data (Udalski et al. 1999, AcA 49, 223 and AcA 49, 437).

type depending on the number of so-called thermal pulses and subsequent dredge-up events, and (B) the very heavy mass loss, induced by stellar pulsation, which results in a huge expanding molecular and dust shell around the star. The combination of nucleosynthesis and heavy mass loss make AGB stars the most important contributor to the enrichment of the ISM in dust and many atomic species.

What is currently poorly understood is the exact relation between stellar mass, metallicity, pulsation and mass loss rate. What is important in the current context is that AGB stars pulsate and during their evolution evolve from the smaller amplitude semi-regular pulsators to the large-amplitude Mira variables. This was beautifully demonstrated by Wood et al. (1999, IAU Symp. 191, p. 151) and Wood (2000, PASA 17, 18) and subsequently confirmed by others (e.g. Cioni et al. 2003, A&A 406, 51; Groenewegen 2004, A&A 425, 59). The major result is shown in the right panel of Figure 3. Depending on the amplitude selected, variable AGB stars occupy distinct sequences (labelled ABCD) in a period-K-magnitude diagram. If the largest amplitude variables are selected one retains the classical PL-relation for Mira variables which is known for some time (Feast, Glass, Whitelock, Catchpole, 1989, MNRAS 241, 375). The theoretical interpretation is that Miras are pulsating in the fundamental mode, while stars on sequences B and A are first, second and higher overtone pulsators .

However impressive, the MACHO and OGLE surveys in R and I did not find all variable AGB stars. Known since IRAS times is a population of (mid)-IR bright sources in the MCs that represents the most advanced stages of AGB evolution with the highest luminosities and mass loss rates. This sample was expanded and studied further with ISO and currently a few hundred of such sources are known in the MCs with a few dozen having their pulsation periods being determined by infrared monitoring. The colour-magnitude diagram (CMD) of these sources is shown in Figure 3, indicating that the magnitude range is between -11 and -4 in M_K. The spectral energy distribution and K-band lightcurve of one such star are shown in Figure 4. The main points are that (A) these objects have very long periods (up to 1200 days), (B) they have very red colours and are invisible in I and Z, and hence it is essential to monitor these stars in the infrared, and (C) an IR survey will still find the–on average–bluer variables found by MACHO and OGLE.

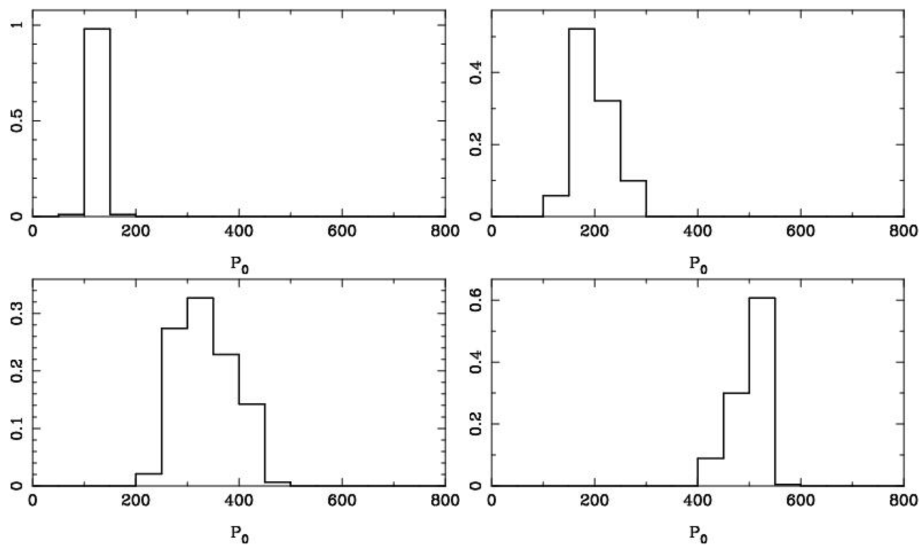

Figure 2: Theoretical period distribution of optically visible AGB-Miras inside the observed instability strip for masses 1.1 (main-sequence lifetime 11 Gyr), 1.5 (2.7 Gyr), 2.0 (1.2 Gyr), and 3.0M$_\odot$ (200 Myr) (left to right, top to bottom). From Groenewegen & Blommaert (2005, A&A 443, 143).

Cepheids

Classical δ Cepheids evolve from stars of masses $\sim$3 to $\sim$11 M$_\odot$ and have periods in the range 1-100 days. They provide the traditional distance scale indicator through the PL-relation. Although this relation is often used in V and/or I it is now well known that the K-band PL-relation holds more promise. Firstly because of the smaller corrections for interstellar absorption, secondly because of the intrinsic smaller scatter in the PL-relation (roughly 1/2 of the scatter in the V-band), and thirdly because of the small (if any) dependence on metallicity. Although there has been quite some debate on the presence (even the sign!) of the metallicity effect on the PL-relation it is generally agreed that any effect should become smaller in the infrared.

Recently it has become clear that the PL-relation is not linear over the entire range in period. The micro-lensing surveys especially discovered many short-period cepheids and it seems that there is a break in the PL-relation around a period of a few days (e.g., Bauer et al. 1999, A&A 348, 175). Therefore the limit in absolute magnitude to which the survey should be sensitive is set at one corresponding to a period $\gtrsim$3 days (Table 1).

Eclipsing Binaries

In particular *detached* eclipsing binaries (dEBs) are among the rare astrophysical systems where stellar mass and radius of the two components can be determined with percent accuracy when accurate light and radial velocity (RV) curves are available (Andersen 1991, A&AR 3, 91). This is classical astrophysics which was put onto another level by the micro-lensing surveys. A few 1000 EBs have been discovered in the MCs (e.g. Wyrzykowski et al. 2003, AcA 53, 1 and 2004, AcA 54, 1).

Some of them have been followed-up with spectroscopy to obtain RV data and perform a combined lightcurve and RV curve analysis to obtain the distance to the LMC and SMC (see e.g., Guinan et al. 1998, ApJ 509, L21; Harries et al. 2003, MNRAS 339, 157; Hilditch et al. 2005, MNRAS 357, 304), even as far as M31 (Ribas et al. 2005 ApJ 635, L37). What makes EBs particularly powerful is that the error in the distance estimate in a single well-observed system (0.06 - 0.10 in distance modulus, see the review by Clausen 2004, NewAR 48, 679) is already comparable to the dispersion in optical and infrared cepheid PL-relation based on hundreds of stars.

Figure 5 shows an example of the type of dEB one would like to use. It has a period of 2.39 days and the radii relative to the orbit are $r/a = 0.25$ and hence the system is well detached. This example–as well as the main target in the present survey–consists of two early-type main-sequence companions as they are bright enough for spectroscopic follow-up. The magnitude range quoted in Table 1 is that of the 50 dEB in the SMC used by Harries et al. and Hilditch et al. to derive an accurate distance to the SMC.

RR Lyrae

RR Lyrae represent the classical population-II distance indicator with periods in the range 0.4 to 1 day. Tra-

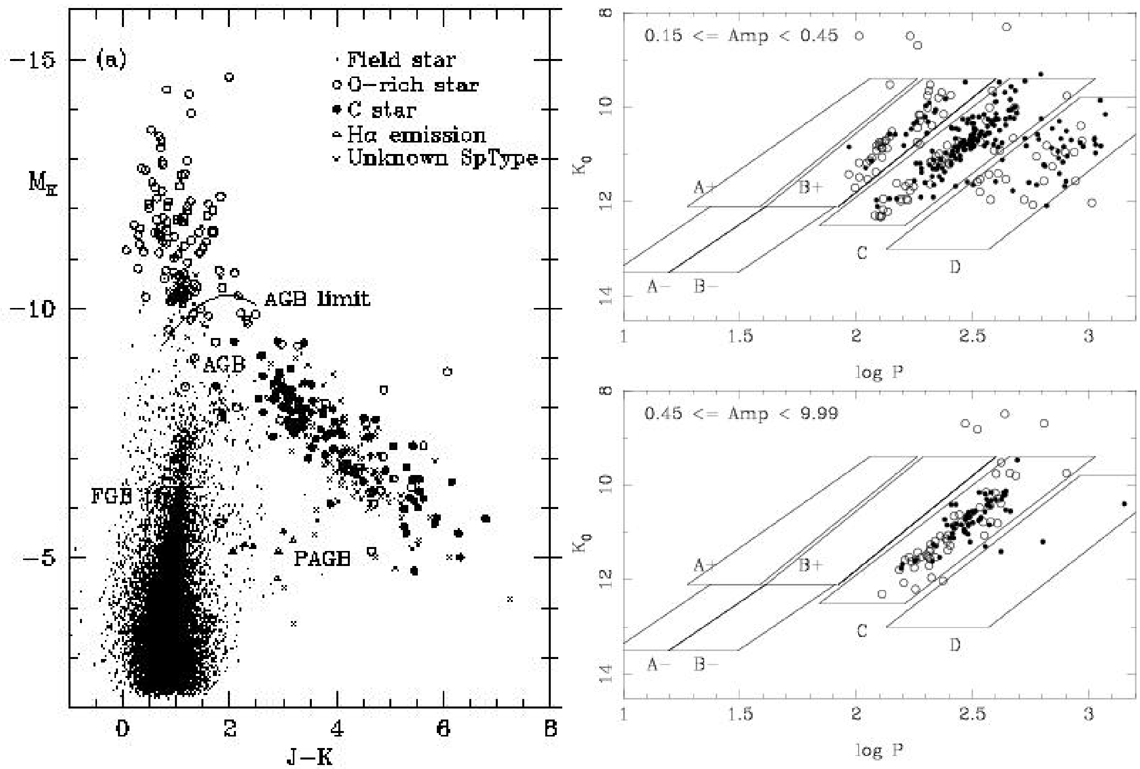

Figure 3: Left: Colour-Magnitude diagram for a sample of known mid-IR sources (IRAS and MSX) in the LMC. Stars above the AGB limit are foreground stars and LMC supergiants. A distance modulus of 18.5 has been assumed (From Zijlstra et al. 2006, in prep.). Right: Single-epoch 2MASS K-band PL-relation for the LMC based on OGLE data. Panels indicate selection on OGLE I-band amplitude. Carbon stars are indicated by filled circles, M- and S-stars by open circles. Boxes related to the "ABCD" sequences are indicated and discussed in the text. From Groenewegen (2004, A&A 425, 595).

ditionally the relation between $M_{\rm V}$ and [Fe/H] is used but this has obvious disadvantages. The interstellar absorption, but also the fact that individual [Fe/H] values are unknown. It has recently been demonstrated both theoretically (Bono et al. 2001, MNRAS 326, 1883; Catalan et al. 2004, ApJS 154, 663) and empirically (Carney et al. 1995, AJ 110, 1674; Longmore et al. 1990, MNRAS 247, 687, Del Principe et al. 2005, AJ 129, 2714) that in the K-band there exists a true period-luminosity relation, $M_{\rm K} = -2.34 \log P - 1.17$ (at $Z=$ 0.0005), with only a small remaining dependence on metallicity.

Blue main-sequence variable stars

The MACHO and OGLE databases also revealed hundreds of blue variable main-sequence stars (Keller et al. 2002, AJ 124, 2039; Mennickent et al. 2002 A&A 393, 887). Both rapid (about 50d) as prolonged (100-500d) eruptive events were observed, and follow-up showed that 91% of spectroscopically observed stars showed Balmer emission, hence they are Be stars. It still remains unclear if the Be phenomenon occurs at a particular evolutionary phase or is caused by a different mechanism, possible connected to metallicity. This will be investigated for the target galaxies.

Kolaczkowski et al. (2004, ASPC 310, 225) discovered 64 β Cephei (periods $\sim$5 hours) and slowly pulsating B stars (SPBs; periods $\sim$2 days) in the LMC from OGLE and MACHO photometry and found them to have significantly longer periods than similar ones in our Galaxy. This discovery in such a low metallicity environment, as well as the recent failure to explain the excitation of an observed mode in the best studied class member ν Eri (Pamyatnykh et al. 2004, MNRAS 350, 1022; Ausseloos et al. 2004, MNRAS 355, 352), clearly pointed

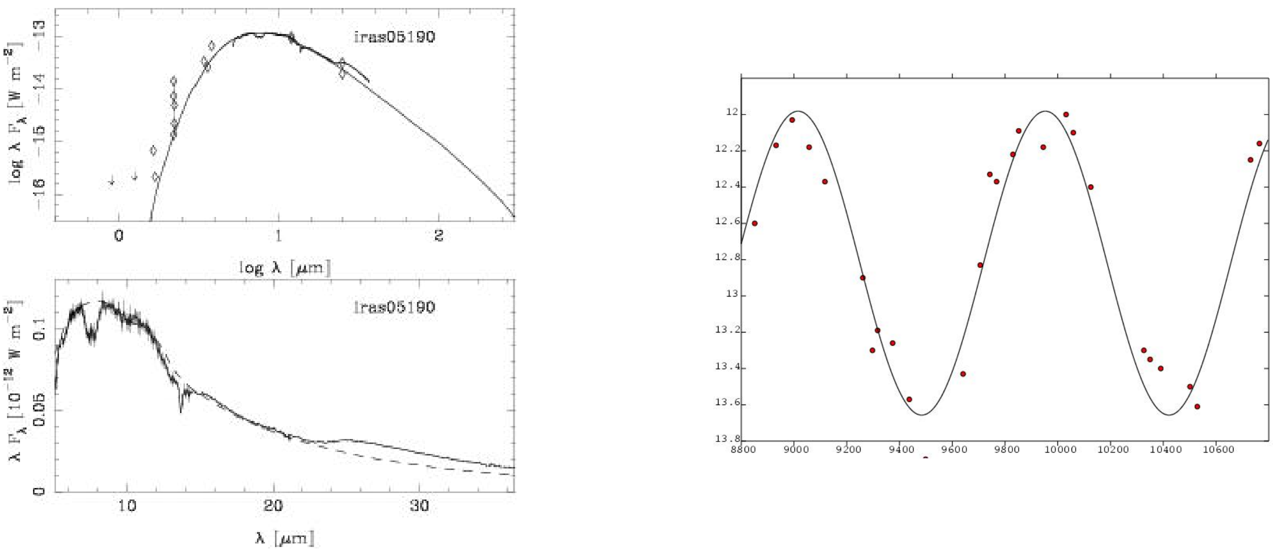

Figure 4: Left: Dust radiative transfer model fit to the spectral energy distribution and Spitzer IRS spectrum (Groenewegen et al. 2006) of the source IRAS 05190-6748 in the LMC, which is a known LPV with a period of 939 days and K-band amplitude of 0.8 mag (Whitelock et al. 2003, MNRAS 342, 86; Right panel). Its mean magnitudes are K= 12.8, $J-K$= 8 and $Z-K$= 16! Derived are a luminosity of 13000 $L_\odot$ and a mass loss rate of 2 × 10^{-5} $M_\odot$ yr^{-1}. The star is a carbon star and the excess near 30 μm is due to the Magnesium-Sulfide dust feature, while molecular absorption by C_2H_2 and HCN is visible near 7.5 and 13.5 micron.

out our lack of knowledge on the excitation mechanism of pulsation modes in, and thus evolutionary models of massive main sequence stars. As the dominant modes of pulsating B stars typically have amplitudes of a few hundredths of a magnitude, the current survey will imply a major step forward by providing a good statistics of the dominant pulsation periods for a large unbiased sample of pulsating B stars outside our own Galaxy.

Quasars

Using MACHO data Geha et al. (2003, AJ 125, 1) presented 47 spectroscopically confirmed (out of 260 candidates observed) variable QSO in the MCs over an area of 17.5 sq.deg. Similar results from OGLE data were obtained by Eyer (2002, AcA 52, 241), presenting 130 QSO candidates over 7 sq.deg in the MCs in the magnitude range $(V-I) < 0.9$, $17.5 < I < 20.5$, which were partially followed-up and confirmed by Dobrzycki et al. (2003, AJ 125, 1330 & 2005, A&A 442, 495). Sumi et al. (2005, MNRAS 356, 331) present 97 candidates in the direction of the Bulge over 11 sq.deg. The variations in I are of a few tenths of a magnitude.

Based on these results one may expect of order 60 QSO per “tile” down to the proposed survey limit of $Z \approx 21.5$.

2.2 Immediate objective:

2.2.1 Primary objective

The immediate objective is to observe a few Local Group Galaxies 50 times over a 3 year period and to make a unique catalog of variable objects. The prime targets are RR Lyrae, cepheids, AGB Mira variables (including the dust obscured ones) and the brightest eclipsing binaries. The survey will also find variable main-sequence stars, foreground objects and quasars.

From the pulsation properties listed in Table 1 as well as the detailed simulations described in Sect. 4 regarding time sampling and S/N constraints to recover periods, the following requirements follow: duration of the survey 3-years, 50 observations with non-uniform time sampling, S/N in a single observation of 15 at the Z-magnitude limit of the faintest RR Lyrae and cepheids, and S/N of 12 at the K-magnitude limit of the faintest Miras.

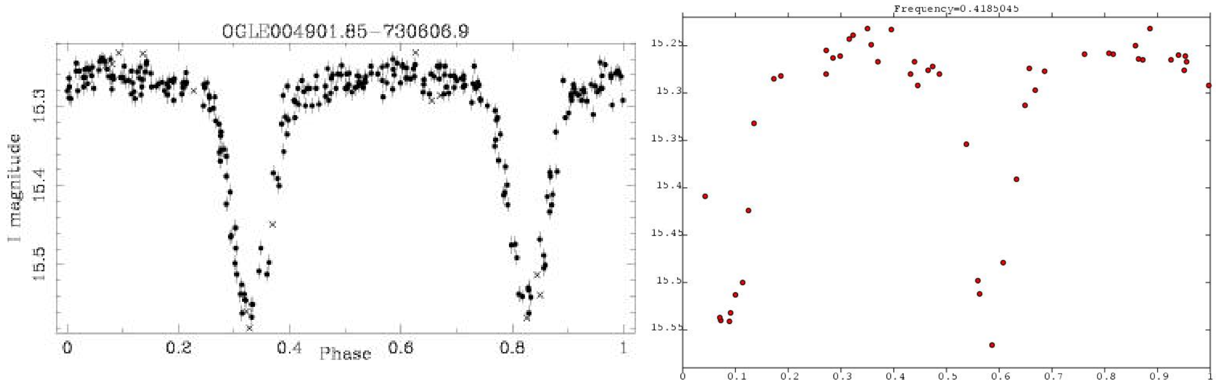

Figure 5: Left: Original OGLE data of a typical detached EB we want to find in our survey, with a period of 2.39 days and relative radii r/a= 0.25 (from Harries et al. 2003). Right: simulated lightcurve of the same EB in our survey (with 50 observations, see Sect. 4). The period is recovered to within 0.1%.

An essential requirement is a SFH such that these types of variables are present. The review by Dolphin et al. (astro-ph/0506430) is used as a guidance and this requirement leaves us mainly with Irregular galaxies which show a complex SFH and eliminates almost all dwarf spheroidal galaxies of our Galaxy as they are predominantly old (e.g. sculptor, carina), and do not have an intermediate and young population.

The galaxies that are finally selected are Fornax, NGC 6822, IC 1613 and WLM, and some properties of these galaxies are listed in Table 2, while the SFHs are illustrated in Figure 6. WLM and NGC 6822 appear to have similar SFH and one of the science goals would be to investigate if this is confirmed by the properties of the variable stars in these galaxies; IC 1613 has a more pronounced 2-3 Gyr old population while Fornax has had a decreasing SFR over the last 5 Gyr. Intermediate age carbon stars are known in all these galaxies (listed in Table 2).

In Fornax, we aim to identify all RR Lyrae, cepheid, AGB stars and short-period EBs.

For the other 3 galaxies we aim to (A) identify the $P \gtrsim$3d cepheids in Z and use the derived periods to phase the data in K in order to obtain accurate amplitudes and mean magnitudes in K, (B) identify most of the AGB stars, (C) use existing data (see Sect. 3) on RR Lyrae to phase the Z and K band data in order to obtain accurate amplitudes and mean-magnitudes, and (D) identify the short-period EBs.

The K-band period luminosity relation, and period distributions, will be constructed for RR Lyrae, cepheids and Miras. At this point, the scientific verification includes a series of obvious steps: 1) Intercomparison of such observables (and comparison with those derived for the MCs and Bulge) in order to detect statistical differences to be later associated with the different metal content and SFHs of these galaxies; 2) Evaluation of these classes of variables as distance indicators, using mainly the K-band period luminosity relation, and taking into account other distance indicators available for these galaxies like the I-band RGB-tip; 3) Comparison of the period distributions with the outcome of population synthesis models which, assuming a certain SFH and AMR, predict these quantities; the SFH and AMR can be initially taken from other authors and then be refined in order to fit the data. The spatial variation of the SFH can also be investigated in this way.

In order to estimate the number of stars and variables to be detected in the survey the TRILEGAL population synthesis code (http://trilegal.ster.kuleuven.be) is used (Girardi et al. 2005, A&A 436, 895), which allows to produce simulated CMDs of the Galactic foreground and a stellar system with a certain SFH and AMR at a fixed distance. Simulations are performed in the UKIDSS photometric system. The absolute number of stars generated is tuned so as to produce the observed integrated $M_{\rm V}$ and $M_{\rm B}$ (from Mateo 1998, ARA&A 36, 435) of the system.

For the hundred of thousands of simulated stars it is then verified if they are within the (theoretical) instability strips of the RR Lyrae (Marconi et al. 2003, ApJ, 596, 299; Di Criscienzo et al. 2004, ApJ, 612, 1092),

Table 2: Target list

Galaxy	RA (h m)	DEC (° ′)	b (°)	Diameter[(a)] (′)	A_V	N_C [(b)]	Distance Modulus	Visibility[(c)] (days)
WLM	00 02	-15 27	-73	26	0.12	149	24.9	120 + 80 = 200
IC 1613	01 05	+02 08	-61	34	0.08	195	24.4	99 + 90 = 189
Fornax	02 39	-34 31	-66	100	0.07	>104	20.7	90 + 128 = 218
NGC 6822	19 44	-14 48	-18	42	0.78	904	23.6	180 + 27 = 207

[a] Based on the major axis tidal radius (Mateo 1998) and extent of AGB carbon star population.
[b] Number of known AGB Carbon stars (summarised in Groenewegen astro-ph/0407282).
[c] Visibility is defined as the number of days in the odd and even ESO periods when the source is for more than 2 hours at airmass less than 2.

cepheids (Bono et al. 2000, ApJ, 529, 293; Marconi et al. 2004, A&A, 417, 1101) and Miras (Groenewegen & de Jong 1994, A&A 288, 782) and if so periods are calculated from the respective pulsation equations. With this procedure the number of variables has been predicted.

Summed over all 4 target galaxies we expect to monitor $\sim 10^6$ stars and find $\sim$350 cepheids, $\sim$600 Miras, of order 10 short-period dEBs, and $\sim$2000 RR Lyrae in Fornax.

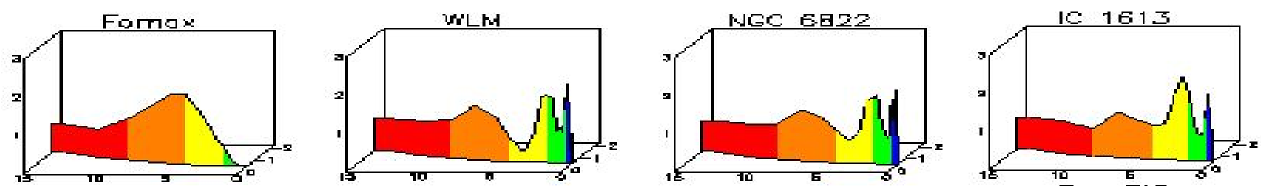

Figure 6: Star Formation Histories and age-metallicity relation of the 4 target galaxies (Dolphin et al. astro-ph/0506430). The youngest population is coded in blue, the oldest in red.

2.2.2 Secondary objective

- Variability studies of the main-sequence population in the 4 galaxies, the field and quasars.
- Co-addition of all data to produce deep CMDs (about K= 22.1 and Z= 24.6, 5σ). This will allow a further constraint on the SFH via population synthesis models.
- Identification of high-proper motion objects.

Sumi et al. (2004, MNRAS 348, 1439) from 4-year of OGLE Bulge data using 260-510 images taken with 0.42″ pixels in 1.3″ median seeing condition were able to derive a complete sample of proper motions down to 7 mas/yr at a 10σ level. Our survey will have a shorter baseline in time and 5-10 times fewer images, but will be taken under better seeing conditions and with smaller pixels. Its not unreasonable to expect that our survey will be able to detect proper motions as small as 20 mas/yr for the brighter stars (corresponding to a transverse velocity of 100 km/s at 1 kpc).

- Study of the foreground population, in particular WDs which represent the fossils of the Galactic SF, and low mass stars, which provide information on the IMF. Information on both classes of stars can constrain the ingredients of the TRILEGAL population synthesis code.

For example, in the 1.0 × 1.5 sq.deg. field towards IC 1613 there are predicted to be 950 stars with absolute K-magnitudes corresponding to L1 to T7 dwarfs, and 50 cool H-rich WDs with $T_{\rm eff}$ below 10 000 K, brighter than the 5σ limit of K= 22.1. 700 of the cool dwarfs and all of the WD are within 1 kpc and are likely to be identified by their proper motion.

If the data from the proposed survey is combined with other multi-colour data (e.g. VST, see Sect. 3) then these interesting populations can also be identified from colour-colour diagrams.

3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those? (1 page max)

The propsed survey is unique when viewed overall in terms of targets, the K-band filter choice and time sampling. Only VISTA has the capabilities in terms of field-of-view, IR filters, and sensitivity to perform a survey of Local Group galaxies in any immediate future.

The OGLE and MACHO project are still continuing (OGLE-III and Super-MACHO) but continue to target only the Magellanic Clouds and the Galactic Bulge region using optical filters.

The Australian *Stromlo Southern Sky Survey* on the 1.35m *SkyMapper* will observe the entire southern sky in $v + ugriz$. It will take only 6 epochs however and will only reach z= 20.0 in a single observation.

The Pan-STARRS (the Panoramic Survey Telescope & Rapid Response System) operates in the Northern sky and will also operate in the optical only. It is also unclear when this system would be operational as for the moment they are in the process of completing a prototype telescope.

The only K-band survey-like work in Local Group galaxies we are aware off is using the JHK SIRIUS camera (7.7′ FoV with 0.45″ pixels) on the 1.4m IRSF in South-Africa. The situation is sketchy but our understanding is that Fornax will be monitored using 36 seperate pointings, with the central pointings covered 12 times [the outer ones only 6 times] over 800 days, down to $K \lesssim$17. This means that not the entire galaxy will be covered, that they will be sensitive to discovery of the brightest AGB stars only, and that period determination will only be possible for the largest amplitude variables.

Patricia: any comments ?

Many ground-based optical datasets exist on the 4 targets. What is important in the current context is that these galaxies will be observed in a uniform way in *OmegaCam* GTO on the VST in a program by Held et al. Proposed are observations in $UBVi$ down to V= 24.5 mag. This suggests limiting magnitudes comparable to ours in the co-added data, and this means that colour-colour diagrams can be constructed to aid in classifying and selecting interesting classes of objects.

The *HST* archive was checked but only relatively few WFPC2 pointings exist.

Variable stars have previously been identified in the 4 target galaxies. 116 cepheids have been identified using V and I imaging in NGC 6822 (Pietrzynski et al. 2004, AJ 128, 2815) and similarly 135 cepheids are now known in IC 1613 (Udalski et al. 2001, AcA 51, 22). These observations covered only the central part of the galaxy however and only a minority have been reobserved in the IR (Pietrzynski et al. astro-ph/0601309).

Baldacci et al. (2005, A&A 431, 1189) obtained lightcurves for 262 variables in NGC 6822, including some RR Lyrae, in a single FORS FoV. Similarly Dolphin et al. (2001 ApJ 550, 554) discovered 13 RR Lyrae in a single WFPC2 field in the halo of IC 1613.

Regarding Fornax the most complete work on variable stars is still that of Bersier & Wood (2002 AJ 123, 840), who discovered 500 RR Lyrae, 17 anomalous cepheids, 6 type-II cepheids and 85 candidate [due to the short overall time span of their observations] long period variables using V, R imaging. Their survey covered only 0.5 sq.deg or a minor part of the galaxy.

Few observations have been performed in the case of WLM; a few cepheids are known from the work of Sandage & Carlson (1985 AJ 90, 1464).

In summary, our proposed observations are unique and will be definitive in the search for all AGB Mira stars and short-period detached EBs in all 4 galaxies. The survey will complement existing data on cepheids in NGC 6822 and IC 1613, but will be unique in the extent of the IR observations. For WLM and Fornax the proposed survey will give the first complete survey for cepheids, and for RR Lyrae in Fornax.

In addition, all 4 galaxies are targets in a *ASTRO-F* Mission Program by Nakada et al. and will also be observed in mapping mode with IRAC and MIPS onboard *Spitzer* (although Fornax only partly). The sensitivities are similar and such that at shorter wavelength all stars with $L \gtrsim$1000 $L_\odot$ will be detected while in the mid-IR all AGB stars with mass loss $\gtrsim 10^{-6}$ $M_\odot$ yr^{-1} should be detected.

4 Observing strategy: (1 page max)

The basic observing strategy for each galaxy will be to combine in a standard way the "pawprints" obtained after 3×2 steps in X and Y-direction in a single "tile" of 1.0×1.5 degree^2 of sky which is essentially uniformly covered. Fornax will be covered by 3 tiles, the other galaxies by a single "tile".

An important part of the observing strategy deals with the time sampling and time duration. The overall duration of the survey of 3 years is driven by the science requirement to detect the Mira population on the AGB, the large majority of which have periods less than 1000 days (although there are some rare exceptions known in the direction of the Galactic Bulge with periods of 1500 days). The 3-year duration ensures that essentially all AGB stars are followed over at least one pulsation period.

The problem of the optimum time-sampling in the case of a limited number of observations was investigated by Madore & Freedman (2005, ApJ 630, 1054) in the context of the *Hubble* Key program on extra-galactic cepheids. They showed that periods can be recovered with minimum problems of aliasing when the observing times are distributed according to a powerlaw $\sim t^{-\alpha}$.

Extensive simulations have been carried out in order to estimate the number of observations, N, α and the signal-to-noise required. Analysed were the typical lightcurve of an RR Lyrae with a period of 0.65 days (and amplitude of 0.15 mag), a cepheid of 3 days (and amplitude of 0.15 mag), an LPV of 300 days (and amplitude 0.2 mag), and the proto-typical detached EB with an orbital period of 2.39 days (see Figure 5). A Gaussian photometric error on each datapoint is included. The simulations are for a typical target galaxy (Table 2) observable 200 days per year. The simulated lightcurves have been analysed with a combination of Fourier analysis (the *fasper* routine from the Numerical Recipes-suite) and Phase Dispersion Minimization (PDM, see Stellingwerf, 1978, ApJ 224, 953) as has been used successfully in datamining the OGLE database (Groenewegen, 2004, A&A 425, 595; Groenewegen, 2005, A&A 439, 559 Groenewegen & Blommaert, 2005, A&A 443, 143).

The number of observations is set by the science requirement to detect detached EBs potentially suitable for follow-up radial velocity studies to obtain accurate radius, mass and distance estimates. To identify such EBs there basically have to be sufficient observations in the eclipses to 'trigger' the periodicity of the signal. For the typical EB under consideration the simulations indicate that with 50 observations the period-finding algorithms have a 99% chance of finding a significant frequency at the correct value. For an EB with a similar r/a but a period of 3.5 days this drops to about 50%. This rises to 99% again at this orbital period for a slightly less detached system with $r/a \approx 0.3$.

The required signal-to-noise is set by the requirement to recover the period of the intended targets with the smallest (Z-band) amplitudes. Simulations for an amplitude of 0.15 mag for both the 0.65 day RR Lyrae and the 3.0 day cepheid indicate that a magnitude error of 0.07 (S/N= 15) is required to do so. For the AGB star with the slightly higher amplitude this is S/N= 12.

Figure 7 indicates the influence of the time-sampling on the Fourier spectrum for the cepheid with P= 3 days and amplitude 0.15 mag (with 50 observations over 3 years with 200 days of observability per year). While for $\alpha = -0.0$ (uniform time sampling) there are many aliases, this is greatly reduced for $\alpha = -0.4$ and -0.5.

As an example, with 50 observations over 3 years with 200 days of observability per year for $\alpha = -0.4$ the times of observations would be t= (0, 1, 4, 7, 11, 16, 21, 26, 32, 39, 46, 53, 61, 69, 77, 86, 95, 105, 115, 125, 136, 147, 159, 170, 182, 195), (373, 386, 399, 413, 426, 441, 455, 470, 485, 501, 516, 532, 548), (930, 947, 964, 982, 999, 1017, 1035, 1054, 1072, 1091, 1111) days. It is important to stress that for the scheduling these are "weak" constraints in ESO terminology. Also, the observations do not have to be executed in that particular order, so that the observing times can be spread more or less evenly over the 3-year period.

Finally a word on the requested observing conditions. No constraint on moon illumination is set. On the other hand good seeing conditions are required in order not to run into confusion problems.

The number of sources expected is based on the TRILEGAL population synthesis code as described in Sect. 2.2.1 and is divided by the area listed in Table 2. Taking into account that the surface density in the central parts of the galaxies may be higher by an estimated factor of 3, and using a confusion limit defined as 1 source per

20 seeing disks (e.g. Dole et al. 2004, ApJS 154, 93), it is determined that the seeing must be $\lesssim 0.8''$ not to be confusion limited in Z in a single exposure, and in K in the co-added data.

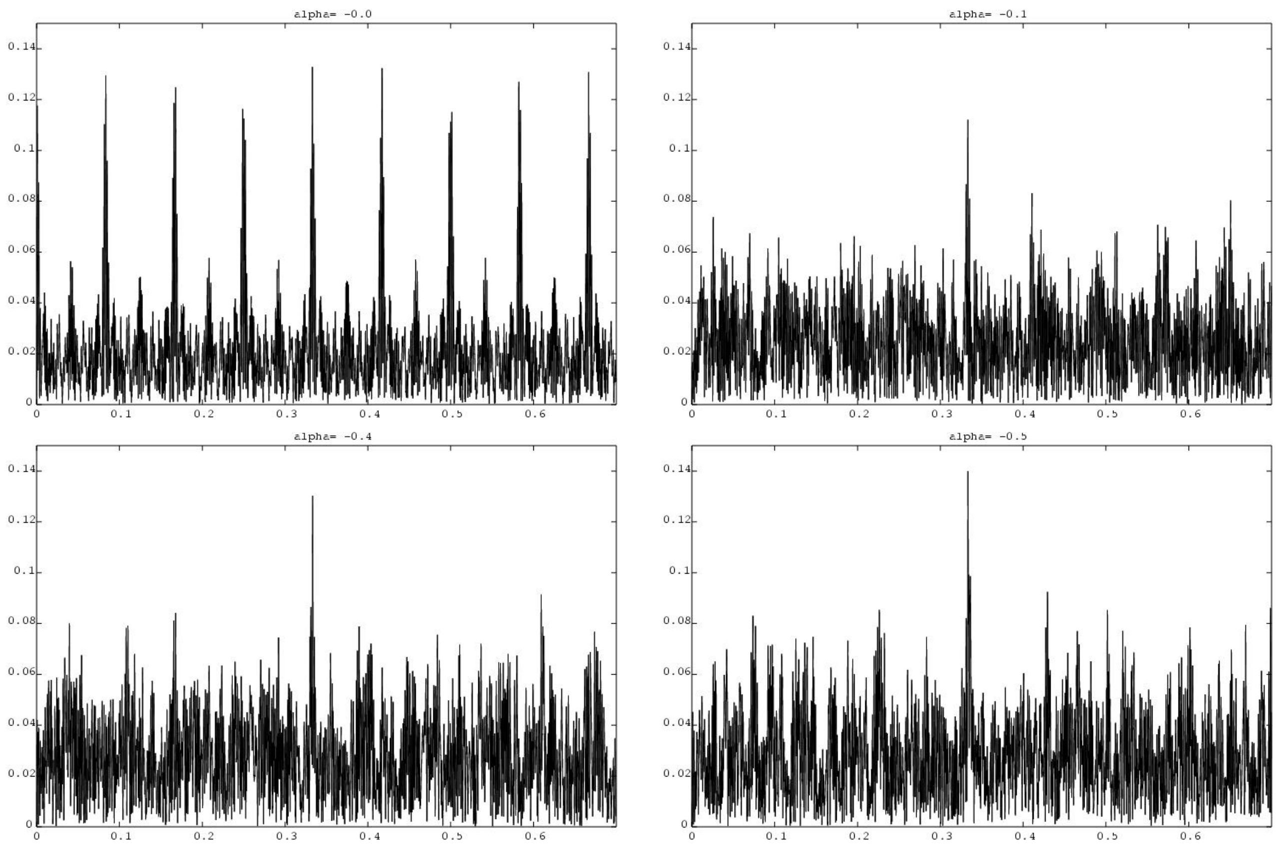

Figure 7: Fourier spectra of a variable with a 3 day period and 0.15 mag pulsation amplitude and 0.07 mag random Gaussian photometric error added for 50 observations over 3 years with observability of 200 days per year, for different time sampling from perfectly uniform (α= 0) to increasingly non-uniform.

5 Estimated observing time:

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P79	101	0,1,2,19h	no restriction	<0.8	clear
P80	71	0,1,2,19h	no restriction	<0.8	clear
P81	101	0,1,2,19h	no restriction	<0.8	clear
P82	71	0,1,2,19h	no restriction	<0.8	clear
P83	101	0,1,2,19h	no restriction	<0.8	clear
P84	71	0,1,2,19h	no restriction	<0.8	clear

5.1 Time justification: (1 page max)

The VISTA ETC was first used to derive a single source exposure time needed to achieve a certain signal-to-noise, and then the "Observing Strategy"-mode of the ETC was used to finalise the settings. Default settings of airmass= 1.2, seeing= $0.8''$, $2''$ aperture photometry and a Blackbody spectrum of 3000 K were used throughout.

Table 3: Observational set-up[1]

Galaxy	Filter	DIT (s)	NDIT	NEXP	micro-step	depth (Vega mag)	time per tile (s)	remarks	time per galaxy (h)
Fornax	Z	1	1	1	1×1		286	shallow	
	Z	25	1	1	2×2	21.4 at S/N=15	2662	deep	
	K	2	4	1	1×1	16.8 at S/N=16	466	shallow & deep	
									3 × 47.4
WLM	Z	1	1	1	1×1		286	shallow	
	Z	40	1	1	2×2	21.7 at S/N=15	3742	deep	
	K	1	1	1	1×1		286	shallow	
	K	10	3	2	2×2	19.0 at S/N=12	5974	deep	
									142.9
NGC 6822	Z	1	1	1	1×1		286	shallow	
	Z	6	1	1	2×2	20.5 at S/N=15	1294	deep	
	K	1	1	1	1×1		286	shallow	
	K	10	3	2	2×2	19.0 at S/N=12	5974	deep	
									108.9
IC 1613	Z	1	1	1	1×1		286	shallow	
	Z	20	1	1	2×2	21.3 at S/N=15	2302	deep	
	K	1	1	1	1×1		286	shallow	
	K	10	3	2	2×2	19.0 at S/N=12	5974	deep	
									122.9
TOTAL									516.9

[1]NJITTER is always 3, and NPAW is always 6.

Parameters are the on-chop exposure time (DIT), the number of co-adds (NDIT), which are repeated NEXP times. The micro-step pattern can be specified (1×1 or 2×2), as well as a jitter pattern (NJITTER). The number of pointings (Npaw) is fixed to 6.

The proposed settings and integration times per tile per observation and for the total program are listed in Table 3.

Given the very large dynamic range of the the sources we require a shallow and a normal setting, except for the K-band observations in Fornax were one setting will suffice. With the shortest possible DIT of 1 sec the saturation limit[1] is $K = 9.7$ and $Z = 10.8$.

The 2MASS catalog was searched within 30 arcmin radius of the central position of the galaxies and the number of sources brighter than $K = 9.7$ is very small (13-19) for WLM, Fornax and IC 1613, and 88 for NGC 6822.

Then, with NDIT= 1, NEXP= 1, 1×1 micro-stepping and NJITTER= 3, the real time spent is 286s in K and Z for the shallow observations. With this setting a S/N= 15 is achieved at $K = 15.8$ and $Z = 18.2$.

For the regular observations it is proposed to use 2×2 micro-stepping and NJITTER= 3 and vary DIT to obtain the desired S/N.

The need to use of 2 suits of integration times will lead to the beneficial situation that for a limited magnitude range ($K \approx 12$ - 16, and $Z \approx 14.5$ - 18) there will be 100 independent observations.

[1]defined here as when the central pixel is at half of actual saturation.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function/Expertise	Affiliation	Country
M. Groenewegen	PI	University of Leuven	B
C. Aerts	Main-sequence variables	University of Leuven	B
G. Bono	Cepheids/RR Lyrae/theory	INAF-Osservatorio Astronomico di Roma	ITA
M.-R. Cioni	AGB stars	ROE	UK
J. Debosscher	Lightcurve classification	University of Leuven	B
L. Eyer	QSO/Datamining techniques	Geneva Observatory	CH
L. Girardi	Population synthesis	University of Padua	ITA
L. Le Guillou	DIA	University of Leuven	B
P. Marigo	AGB stars	University of Padua	ITA
M. Salaris	Population synthesis	Liverpool John Moores Univ.	UK
P. Whitelock	AGB stars	SAAO	S-Africa

6.2 Detailed responsibilities of the team:

The survey team is relatively small but includes scientist with all the experience and expertise needed to exploit the survey data.

The main centre is **Leuven (Groenewegen/Aerts/Le Guillou/Debosscher)** which has a longstanding tradition in asteroseismology and variable star research in general. Groenewegen, as PI, will interact with the VDFS team and supervise the quality assessment of the dataproducts. He has data mined the OGLE database, and has published on all main types of large-amplitude variable stars (AGB stars, RR Lyrae, cepheids and EBs). He also has experience with survey pipelines as former member of the ESO Imaging Survey (EIS) team. He will interact with the other co-I's. Aerts is president of IAU commission 27 variable stars, and an expert in asteroseismology. She has interpreted numerous datasets of small-amplitude pulsating stars, from surveys, from dedicated ground-based campaigns and from the WIRE and MOST space missions. She is co-I of the CoRoT space mission responsible for the interpretation of the data of B-type stars. As part of the Belgian CoRoT involvement, Debosscher is doing his Ph.D. on supervised and unsupervised classification of the lightcurves of the exoplanet field data of CoRoT. In addition, members of our institute were involved in various GAIA Working Groups, and in the recently formed Coordination Units, in particular CU7 on Variability. Geneva and Leuven will be the main centres for issues related to period search, simple model fitting and lightcurve classification and follow-up observations for interpretation of the most interesting stars. Before joining the team in Leuven, Le Guillou was part of the EROS microlensing survey team and has extensive experience in Difference Image Analysis. When this Public Survey is awarded time we will seeks funds for one Ph.D. or postdoc to become involved with the VDFS team to develop and implement the tasks that are particularly important for this project, namely detection of proper motion, period determination and lightcurve classification and analysis.

The computer facilities at the Institute for Astronomy are ample. Every employee has his/her own Linux workstation and for central computing purposes there is a cluster of 22 PC Dell PowerEdge 750 & 1850 machines (1-4 GB RAM) and 12 TB disk storage.

Geneva (Eyer).

Padua (Girardi/Marigo).

Liverpool (Salaris).

Rome (Bono).

Edinburgh (Cioni).

Capetown (Whitelock).

6.3 Data reduction plan:

We intend to use the VISTA Data Flow System (VDFS) ****

Astrometrically and photometrically calibratated images, and source catalogs.****

Ingestion into database ***

The multi-epoch source catalogs will be combined to give for each source the time sequence of magnitudes. On this the variability analysis will be performed using Fourier analysis and PDM to find the period, and subsequent non-linear lightcurve fitting, as already in place.

In a second phase, the Difference Image Analysis technique will be implemented to derive a final catalog of variable sources. ****

proper motion ****

6.4 Expected data products:

- For each galaxy, for both Z and K filter there will be 2×50 (for the shallow and regular exposures) instrumentally corrected images with a corresponding weight image, all on the same astrometric reference frame, and with appropriate FITS headers.
- For each such image there will be a source catalog with pixel coordinates, R.A. and Dec, photometry and photometric error, a star-galaxy separation classifier.
- For each galaxy, for both Z and K filter there will be an image of all corresponding data co-added, with a corresponding source catalog.
- A catalog of variable sources will be produced from analysis of the PSF photometry.

  The variability analysis, lightcurce classification and period determination will be done using various techniques, from Fourier analysis and PDM as is already in place, to supervised and unsupervised classification methods which are currently being developed in Leuven as part of preparation of the COROT mission.
- In a further step, Difference Image Analysis (a.k.a Image Subtraction) (Alard, 2000, A&AS 144, 363; Wozniak, 2000, AcA 50, 421) will be implemented. Based on the experience with OGLE data this should reduce the photometric error by a factor 2-3, or, in other words, to reach a similar photometric error at a magnitude which is 0.7 mag fainter.

  Laurent LeG: any comments ?

  With this, a second and final catalog of variable sources will be produced.
- A catalog of large proper motion objects will be produced.

6.5 General schedule of the project:

T0 = start of the survey.

T0 + 1 year = sufficient data to test the period finding, lightcurve classification and lightcurve fitting steps in the processing pipeline.

T0 + 2 years = sufficient data to test the proper motion analysis step in the processing pipeline.

T0 + 3 years = end of nominal survey.

T0 + 3.5 years = publication of a variable star catalog based on PSF photometry.

T0 + 4 years = publication of the final variable star catalog based on DIA, and a catalog of large proper motion objects.

7 Envisaged follow-up: (1 page max)

- Eclipsing binaries.

  One of the aims of the survey is to find detached EBs suitable for distance determinations. The ephemeris will be determined from analysis of the Z and K-band lightcurves with the FOTEL code (Hadrava 2004, Publications of the Astronomical Institute of Academy of Sciences 92, 1), with which we have experience.

  With this information in hand any follow-up observations can be planned in detail, e.g. to obtain the radial velocities at quadrature, or to improve the lightcurve in the eclipses.

  The expected magnitudes are in the range $Z=$ 15-18 (Fornax) to 18-$\sim$21 (other galaxies).

  Typical follow-up with the 1000 l/mm grating with FORS will take 60 minutes for a $Z=$ 19.8 mag. source. With the PFIS on SALT one would be able to reach even fainter targets. Almost all dEBs are therefore bright enough for spectroscopic follow-up.

  With the RV curve in hand the parameters of the system can be determined (mass and radius of the two components, distance, and the orbital parameters). Mass, radius and effective temperature (from the spectra) can be compared to evolutionary tracks.

- Spectra of the QSO candidates, in order to determine redshift.

  Typical follow-up with a 300 l/mm grating with FORS will take 20 minutes for a $Z=$ 20 mag source.

- Spectra of the main-sequence variables.

  As for the dEBs, typical follow-up with a 1000 l/mm grating is possbile with 8-10m telescopes for sources with $Z \lesssim$21.

- Spectra of L and T-dwarf candidates for spectrral classification.

  As for the dEBs, typical follow-up with a 1000 l/mm grating is possbile with 8-10m telescopes for sources with $Z \lesssim$21.

- mid-IR spectroscopy of AGB stars to study the properties of the dust.

  For example, the infrared carbon star shown in Figure 4 has an estimated flux density in the 10 micron region of 40 mJy at the distance of Fornax and 1 mJy at the distance of WLM. This is well within the range of MIRI on JWST (1h, 10σ sensitivity of 1.6 mJy at a spectral resolution of 2000), and a MIDIR instrument on a 40m ELT (1h, 10σ sensitivity of 0.15 mJy at a spectral resolution of 300).

8 Other remarks, if any: (1 page max)