VISTA PUBLIC SURVEY STATUS REPORT
(87th OPC MEETING)

This report has to be returned to the Observing Programmes Office of the European Southern Observatory (opo@eso.org) before October 31, 2010.

PROPOSAL ESO No.:
TITLE: VISTA VARIABLES IN THE VIA LACTEA (VVV)
PRINCIPAL INVESTIGATOR: DANTE MINNITI

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1. Scientific Aims (brief description)

The VVV public near-IR variability survey is scanning the Milky Way bulge and an adjacent section of the mid-plane where star formation activity is high. The survey will take 1929 hours of observations with the 4-metre VISTA telescope during five years (2010 − 2014), covering a billion point sources across an area of 520 sqdeg, including 33 known globular clusters and ~ 350 open clusters. The final product will be a deep IR atlas in five passbands (0.9 − 2.5 μm) and a catalogue of more than a million variable point sources. Unlike single-epoch surveys that, in most cases, only produce 2-D maps, VVV variable star survey will enable construction of 3-D map of the surveyed region using well-understood distance indicators such as RR Lyrae stars, red clump giants, and Cepheids. This survey will yield important information on the ages, reddenings and metallicities of the Galactic stellar populations, and also discover moving objects in the Solar System and beyond. The observations will be combined with data from 2MASS, MACHO, OGLE, EROS, VST, Spitzer, HST, Chandra, INTEGRAL, WISE, Fermi LAT, XMM-Newton and ALMA for a complete understanding of the variable sources in the inner Milky Way, and also background sources such as SNe in distant galaxies, AGNs and QSOs. This public survey will provide data available to the whole community and therefore will enable further studies of the history of the Milky Way, its star cluster evolution, and the population census of the Galactic Bulge and center, as well as the investigations of the star forming regions in the disk. The combined variable star catalogues will have important implications for theoretical investigations of pulsation properties of stars.

2. Detailed progress report with respect to initial estimate from the Survey Management Plan (including preliminary results, whether published or not).

2.1. Progress report

There has been a lot of data acquired by ESO, and a lot of progress has occurred, especially at CASU with the pipeline data processing and at VSA with the archival products, that allowed a variety of tests and early scientific results by the Science Team members. All this activity is only briefly described here, using mostly representative figures with explanatory captions rather than lengthy text, but we would be glad to provide more detailed information if needed. In the figures and text below we try to summarize all aspects of the complex work.

PHASE 2 FOR YEAR 1:

The OBs preparation and submission was a significant work, but it was successful. We submitted a total of 112 Obs for Dry Run (179.B-2002(A)). Unfortunatelly none of these were completed since they were only observable at the very end of that period. For the first year year (first official period) we submitted 2460 Obs (run ID 179.B-2002(B)), designed to cover a total of 196 bulge fields and 152 disk fields, with each field observed in JHKs as first priority, then in the ZY filters, and finally 5 epochs in Ks.

OBSERVATIONS:

The observation statistics as of mid-October 2010 are the following (see Figures 1-3):

Bulge:
JHKs: 176 out of 196 fields completed = **90%** (in all three filters)
YZ: 78 out of 196 = **40%** (in both filters)
VAR: 113 out of 5x196 (980) = **12%** OBs completed

Disk:
JHKs: 152 out of 152 fields completed = **100%** (in all three filters)
YZ : 128 out of 152 = **84%** (in both filters)
VAR: 547 out of 5x 152 (760) = **72%** OBs completed

In total that makes **49 %** of the VISTA OBs planned for this period. We note that at the date of this report the bulge season is nearly over, so this percentage would improve a little bit (but not much) .

Also, the OBs include different number of exposures (depending on the combination of filters). With 10 exposures for each tile (5 filter +5 epochs) the statistics looks a bit better. Out of 3480 planned exposures we have 2056, that is **59%**.

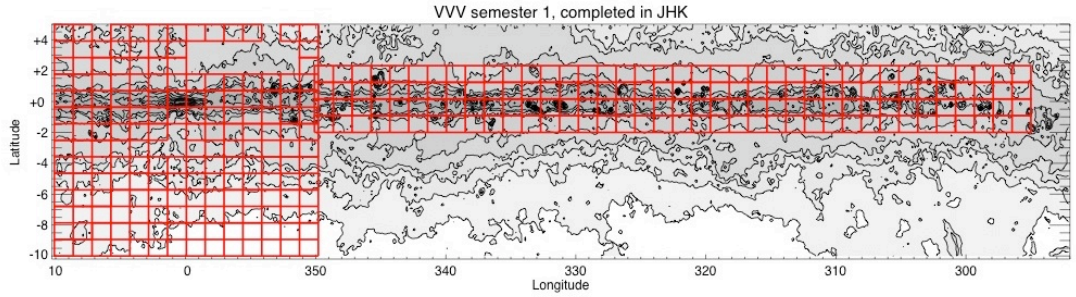

Fig. 1. VVV Survey observations completed in JHKs until Oct 26th, 2010. At this date the bulge season is over, so we do not expect much more progress than that shown in the present report. These OBs were given the highest priority, and the multicolor map of the VVV survey region is almost complete. This is already allowing a variety of interesting applications and also the first science results, as described below.

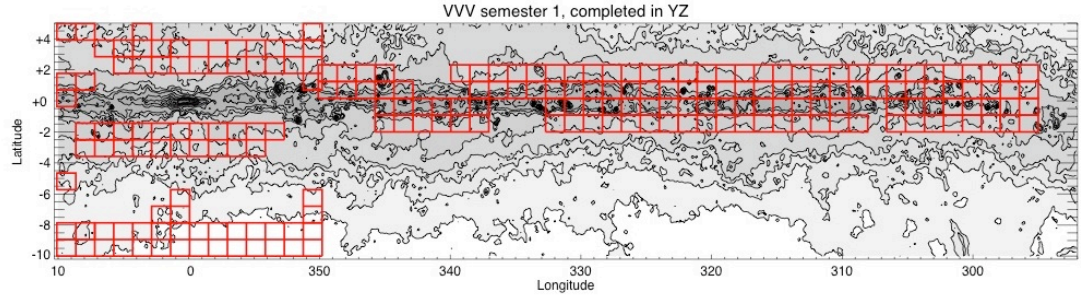

Fig. 2. VVV Survey observations completed in ZY until Oct 26th, 2010. These ZY filter observations were given slightly lower priority that the JHKs maps. However, we obtained significant coverage, specially in the disk region. These filters are essential to complement and interpret the information provided by the JHKs maps: they can lift the degeneracy or ambiguity of the JHKs color-color diagrams and color-magnitude diagram in the presence of large and variable interstellar extinction.

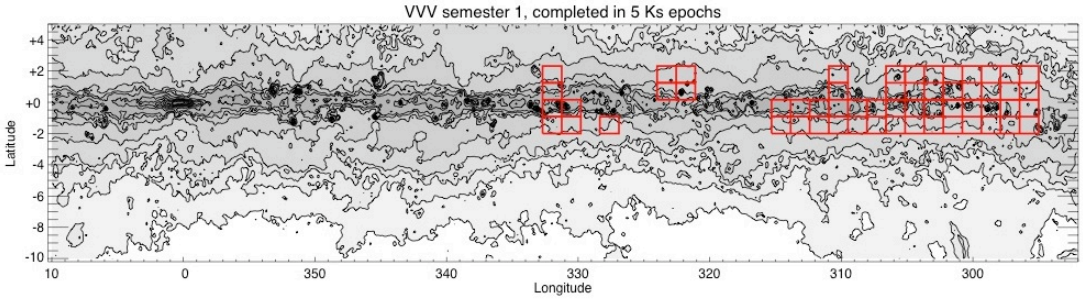

Fig. 3. VVV Survey observations completed in 5 Ks epochs until Oct 26th, 2010. These Ks observations of the first year were intended to test the variability search techniques, and to provide a long term baseline for stellar variability (e.g. microlensing, long term variable sources), as well as for proper motions. We decided to give them lower priority than the multicolor maps, and it is evident that the total coverage is rather poor due to the time lost to telescope intervention and weather.

The two main reasons for the incompleteness were:

1. This year 2010 was a particularly bad year regarding the weather in Northern Chile.
2. There was a VISTA intervention in late April after which the data taken for VVV were faulty (elongated images), which was solved in late June.

We believe that without these two problems, the VVV Year 1 would have been nearly 100% completed. Using an anagram for politeness sake, "this happens". Obviously it is of paramount importance that these observations are carried out next period.

DATA PROCESSING:

This was only what ESO has observed, and not what is available on CASU, which has so far released the reduced data V1.0 until 1st August 2010. The lag in processing the data is reasonable, and we are not worried. The data processing is being carried out without major problems. The worst bottleneck for the VVV Survey team has been the data transfer rate, which has been resolved in different ways with the help of CASU (scheduling bulk transfer at certain dates, or physically delivering the disks).

CAMBRIDGE ASTRONOMICAL SURVEY UNIT

The data processing pipeline at CASU released in May 2010 the version 0.8, which was very reasonable, and in September 2010 the version 1.0, which is very good, and can be publication quality after proper checks are made. The team has worked on the quality control using this v.1.0 data, as detailed below.

VISTA SURVEY ARCHIVE

In addition, the advanced data products at the VSA archival unit are also progressing towards Phase 3. The user interface and schema have undergone several iterations with the survey team in order to better serve the requirements of the survey.

In particular, the VSA "Dailysync" release is also up to date with data up until August. The SQL functionality is working, permitting variability searches when we have enough data. Dealing with the (huge) VVV object catalogues has proved a challenge at the archive end, so a new VVV only ingest database is being set up to expedite catalogue creation.

FUTURE STEPS: PHASE 3 - YR 1 AND PHASE 2 - YR 2:

We are getting ready for Phase 3 for Year 1 (handing the first year's data to ESO).
First there will be a Workshop at ESO Garching on Nov 30, 2010.
The data would be handed to ESO via VSA at the end of March 2011, we foresee no significant delays.

We expect that Phase 2 for Year 2 would be submitted in Feb 2011.
In spite of the large number of OBs that we would have to submit also for this second year, we foresee no delays with this Phase 2. We expect that things would run more

smoothly that YR 1 because now the software is tested and there would be no significant changes.

TEAM MANAGEMENT:

The large team benefited from periodic VVV Science Team Workshops (seven in total), held bimonthly in Santiago (Chile), plus one Workshop at Hertfordshire and another one at Leeds (UK), plus interaction through Twiki pages at vvvsurvey.org. We plan to have an all hands Workshop in Viña del Mar, Chile, on 8-10 Dec 2010, in order to plan the Year 2 observations, the Phase 3, the next stage of Quality Control, and publication of the scientific results.

SCIENCE RESULTS:

Even though it is early to have scientific results, we can highlight a few interesting findings.

Fig. 4. Field of 2'x1.8' centered on the new bulge globular cluster VVV CL001 that we have recently discovered (Astronomy & Astrophysics, submitted Sep 2010).

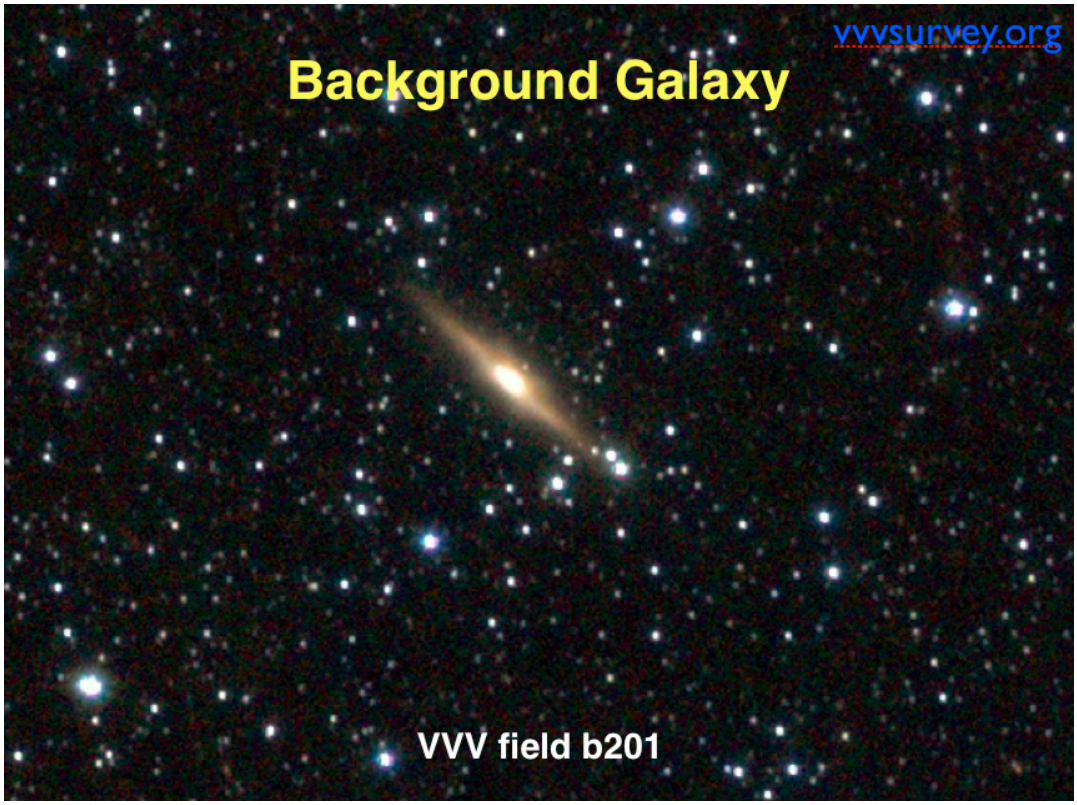

Fig. 5. Portion of field b201 showing a large galaxy, illustrating the image depth and quality. In fact, we see hundreds of galaxies, indicating that the VVV Survey can pirce through the whole Milky Way disk and beyond.

VARIABILITY:

Even though this was not expected as a major activity of Year 1, a very important part of our Public Survey is variability. Therefore, we did a few tests using the Science Verification data, finding known RR Lyrae from the MACHO and OGLE surveys (e.g. Figure 6).

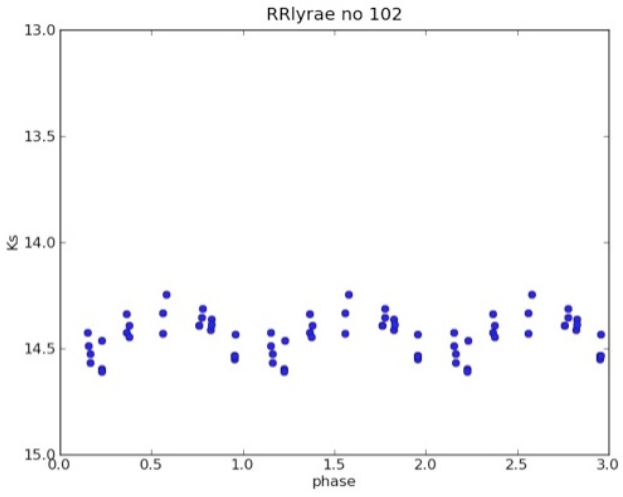

Fig. 6. Phased Ks light curve of a known RR Lyrae from OGLE (one of the 86 plots from the thesis of undergraduate student J. C. Beamin).

These tests were successful, because we recovered the variables, and could even phase them with their corresponding periods (and in some cases found period changes). We are now searching for new variables, and waiting for more epochs to be observed. Year 2 would be more dedicated to these kinds of tests before the main variability campaigns during Years 3 and 4.

LIGHT CURVE TEMPLATES:

There is a lack of high quality light curves in the IR to use as templates for our survey. Therefore we have started the task of building these light curves with different telescopes, an example of a light curve obtained with REM during semester 2010A is shown below.

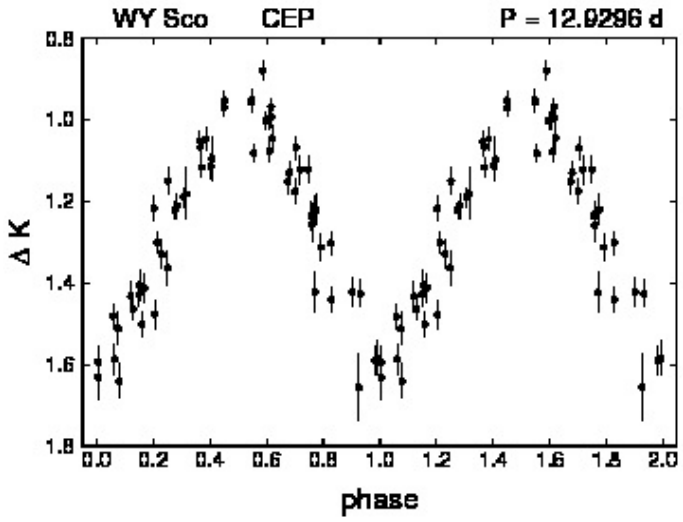

Fig. 7. REM light curve of WY Sco, a Cepheid star observed during semester 2010A. The period has been determined using the PDM method, and is consistent with the one derived on the basis of optical data alone and reported in the GCVS (i.e., P = 12.9191 d).

We are also following up saturated VVV massive stars in the H-band in order to complement the coverage of star forming region.

2.2. Publications

Even though the definitive data for our survey are not ready, we have prepared a few publications that would be useful for the community in order to show the quality of the survey data and to encourage the use of the VVV Survey. These publications highlight some early early scientific results:

- D. Minniti, P. W. Lucas, J. P. Emerson, R. K. Saito, M. Hempel, P. Pietrukowicz, A. V. Ahumada, M. V. Alonso, J. Alonso-García, J. I. Arias, R. M. Bandyopadhyay, R. H. Barbá, L. R. Bedin, E. Bica, J. Borissova, L. Bronfman, M. Catelan, J. J. Clariá, N. Cross, R. de Grijs, I. Dékány, J. E. Drew, C. Fariña, C. Feinstein, E. Fernández Lajús, R. C. Gamen, D. Geisler, W. Gieren, B. Goldman, O. González, G. Gunthardt, S.

Gurovich, N. C. Hambly, M. J. Irwin, V. D. Ivanov, A. Jordán, E. Kerins, K. Kinemuchi, R. Kurtev, M. López-Corredoira, T. Maccarone, N. Masetti, D. Merlo, M. Messineo, I. F. Mirabel, L. Monaco, L. Morelli, N. Padilla, M. C. Parisi, G. Pignata, M. Rejkuba, A. Roman-Lopes, S. E. Sale, M. R. Schreiber, A. C. Schröder, M. Smith, L. Sodré Jr., M. Soto, M. Tamura, C. Tappert, M. A. Thompson, I. Toledo, M. Zoccali, "VISTA Variables in the Via Lactea (VVV): The public ESO near-IR variability survey of the Milky Way", 2010, **New Astronomy**, 15, 433 (arXiv:0912.1056)

- R. Saito, M. Hempel, J. Alonso-García, I. Toledo, J. Borissova, O. González, J. C. Beamin, D. Minniti, P. Lucas, J. Emerson, A. Ahumada, S. Aigrain, M. V. Alonso, E. de Amôres, R. Angeloni, J. Arias, R. Bandyopadhyay, R. Barbá, B. Barbuy, G. Baume, L. Bedin, E. Bica, L. Bronfman, G. Carraro, M. Catelan, J. J. Clariá, C. Contreras, N. Cross, C. Davis, R. de Grijs, I. Dékány, J. Drew, C. Fariña, C. Feinstein, E. Fernández Lajús, S. Folkes, R. Gamen, D. Geisler, W. Gieren, B. Goldman, A. Gosling, G. Gunthardt, S. Gurovich, N. Hambly, M. Hanson, M. Hoare, M. Irwin, V. Ivanov, A. Jordán, E. Kerins, K. Kinemuchi, R. Kurtev, A. Longmore, M. López-Corredoira, T. Maccarone, E. Martín, N. Masetti, R. Mennickent, D. Merlo, M. Messineo, F. Mirabel, L. Monaco, C. Moni Bidin, L. Morelli, N. Padilla, T. Palma, M. C. Parisi, Q. Parker, D. Pavani, P. Pietrukowicz, G. Pietrzynski, G. Pignata, M. Rejkuba, A. Rojas, A. Roman-Lopes, M. T. Ruiz, S. Sale, I. Saviane, M. Schreiber, A. Schröder, S. Sharma, M. Smith, L. Sodré Jr., M. Soto, A. Stephens, M. Tamura, C. Tappert, M. Thompson, E. Valenti, L. Vanzi, W. Weidmann, M. Zoccali; "VISTA Variables in the Via Lactea: current status and first results", 2010, **The Messenger**, 141, 24

- Minniti, D., Hempel, M., et al., "A Low-Mass Globular Cluster Next to UKS1 in the Direction of the Galactic Bulge", 2010, submitted to Astronomy & Astrophysics

Conference proceedings:

- P.W. Lucas, and D. Samuel, "Billions of stars: the near infrared view of the Plane with UKIDSS and VISTA", in Highlights of Astronomy, 2010, vol.15, (Cambridge Univ. Press), in press

- Borissova, J., Kurtev, J., Bonatto, Ch. et al., "VVV search for new star clusters towards the starforming regions in our galaxy. First results", in JENAM 2010, Symposium S5 on "Star Clusters in the Era of Large Surveys", 2010, (Springer-Verlag), in press

- R. Kurtev, J. Borissova, Ch. Bonatto, F. Penaloza, V. Ivanov, E. Artigau, S. Folkes, D. Geisler, D. Minniti, P. Lucas, and S. Sale, "VVV study of the young Milky Way star clusters: Mercer 35, 69 and 70", in JENAM2010, Symposium S5 on "Star Clusters in the Era of Large Surveys", 2010, (Springer-Verlag), in press

- Hempel, M.; Minniti, D.; Saito, R.; Pietrukowicz, P.; Lucas, P. W., et al., "VISTA variable survey in the Milky Way", in Stellar Populations – Planning for the Next Decade, Proceedings of the International Astronomical Union, 2010, IAU Symp. 262, p. 287-290

- R. Saito, D. Minniti, P.Lucas, et al., "Vista Variables in the Via Láctea (VVV): Um Survey Público de Variabilidade para a Via Láctea no Infravermelho Próximo", Proceedings of the XXXV Annual Meeting of the Brazilian Astronomical Society, 2010, p. 29

- M. Rejkuba, "The ESO Public Survey VISTA Variables in the Via Lactea", at SuperVOSS, July 2009, http://kino.as.arizona.edu/~supervoss/index.html

We have also developed the VVV Survey Team web page at: http://vvvsurvey.org This is important for work in the Wiki environment and keep the large team informed and coordinated.

We consider that it is very important that there are also 4 undergraduate thesis completed, and a couple of PhD Theses in progress:

- **Daniel Salinas**, "Photometric investigation of selected open clusters in the VVV area", Thesis of Licenciatura, Univ. of Valparaíso, 2010.
- **Carlos Corco**, "ASAS on VVV", Thesis of Licenciatura, Univ. of La Serena, in progress.
- **Alejandra Rojas**, "Identificación de fuentes de alta energía hacia el disco interior de la Vía Láctea usando el Survey VVV", Thesis of Licenciatura, Univ. Católica, July 2010.
- **Juan Carlos Beamin**, "RR Lyrae variable stars in the VVV Survey as distance indicators, as tracers of the Milky way internal structure", Thesis of Licenciatura, Univ. Católica, July 2010.
- **Paulo Ayala**, "Búsqueda de objetos con gran movimiento propio hacia el centro galáctico", Thesis of Licenciatura, Univ. Católica, July 2010.
- **Oscar González**, "Unfolding the Galactic Bulge", PhD thesis, IMPRS Germany, in progress.
- **Francesco Mauro**, "VVV pipeline and cluster photometry", PhD thesis, Univ. of Concepción, in progress.

Finally, regarding outreach, which is an integral part of the Survey, we have made color tiles in jpg available in the web, and done many activities (talks for general public, interviews for the media, posters, pictures, etc.), and have a couple of press releases in preparation.

3. Quality Control and Advanced Data Products. The advanced data product submission plan should be described here. In addition the PI should comment on Quality Control on the acquired data. In particular, do the acquired data meet the survey requirements including image quality, target limiting flux, sky subtraction filters?

QUALITY CONTROL AND ADVANCED DATA PRODUCTS:

We summarize in the following Figures some of the results of Quality Control, in which we checked image defects, telescope problems, seeing, zero points, magnitude limits, ellipticities, airmass, etc.

Visual Quality Control was performed in two steps. Initially this was done by the Southern team using the JPEG images of the individual pawprints supplied by CASU before August 2010. Then, visual Quality control of VVV tiles is underway by members of the European team using the FITS images supplied by CASU version 1.0. The JPEG images are not adequate for this (even in the VSA at ROE) because they look too small when displaying whole tiles (or too big when zoomed in). This intense activity is continuing, and we are still identifying images that need to be reprocessed or reacquired. We have produced a handy pdf document illustrating common defects in the images, that will be linked to our web page.

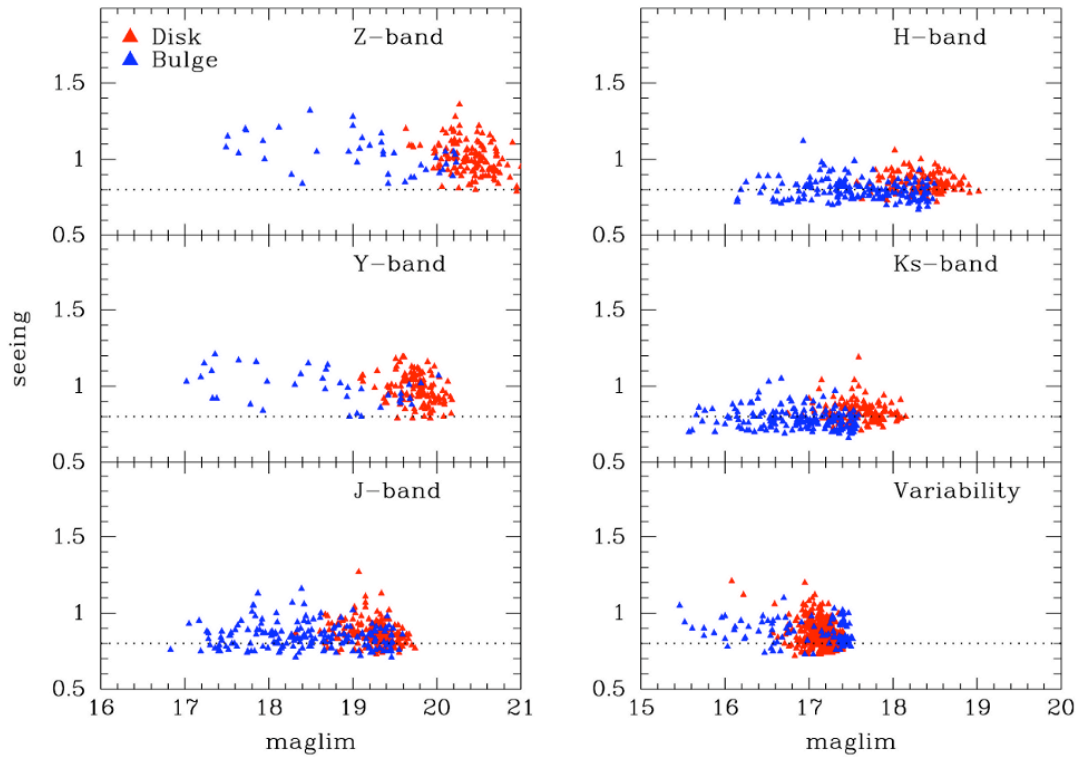

Fig. 8. Seeing vs magnitude limit for different disk and bulge fields. The brighter limiting magnitude and larger scatter for bulge fields are due to crowding. We have different plots like these (that are not shown for the sake of space), exploring the dependences of various image parameters, that we have also used to identify problems and defective images.

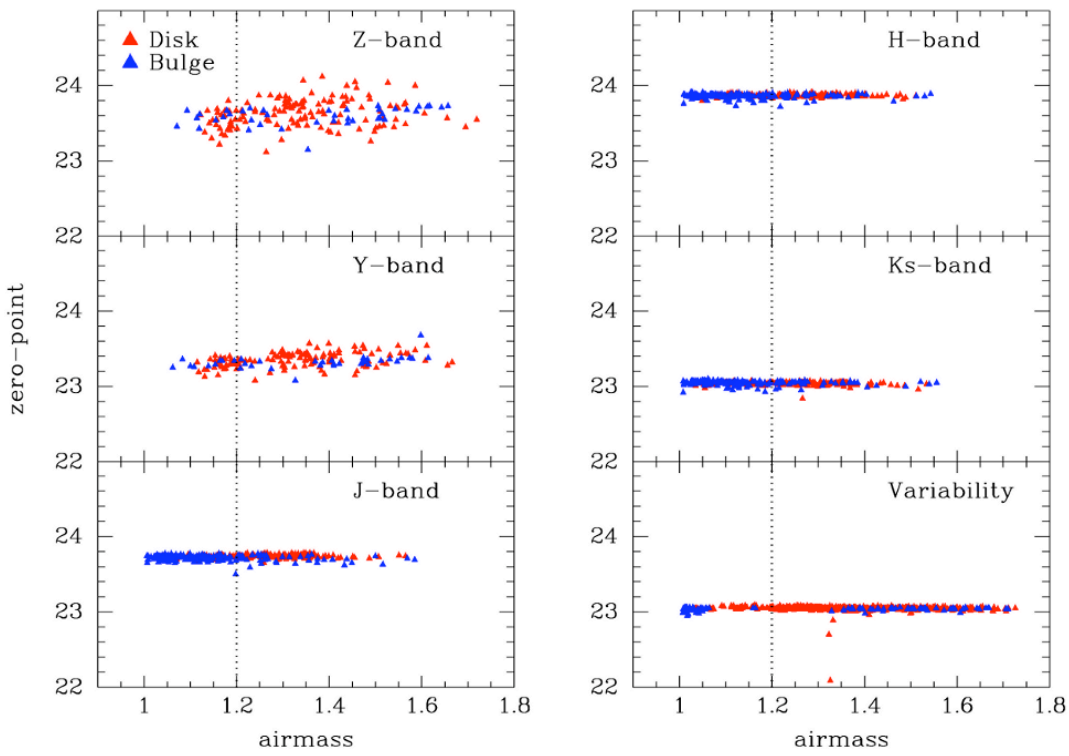

Fig. 9. Photometric zero-point vs. airmass for different disk and bulge fields. There are no significant biases, and the larger scatter seen for the ZY-bands is expected.

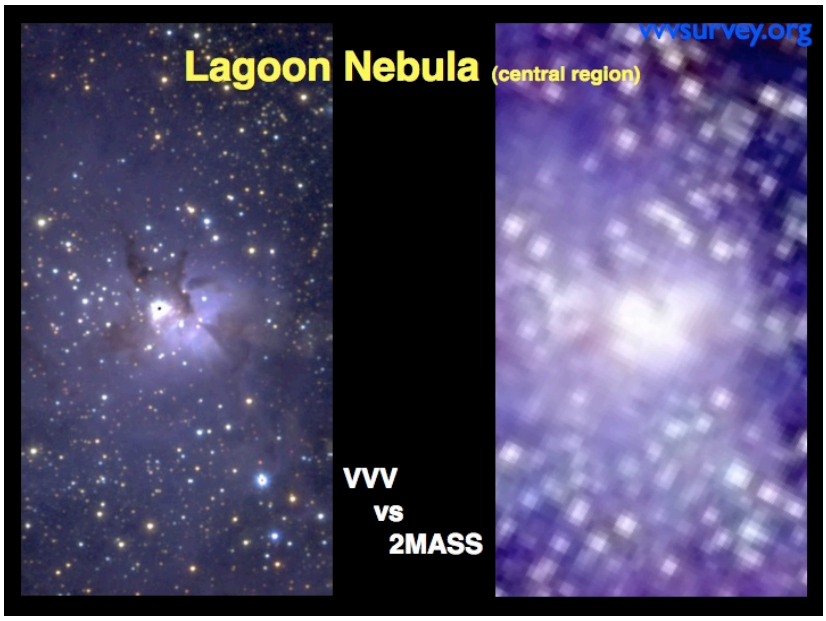

Fig. 10. Central region of the Lagoon nebula from VVV (left) and 2MASS (right), illustrating the substantial improvement in photometric depth and spatial resolution. The VVV Survey data allows the study of the stellar populations even in regions of complicated interstellar background like this one.

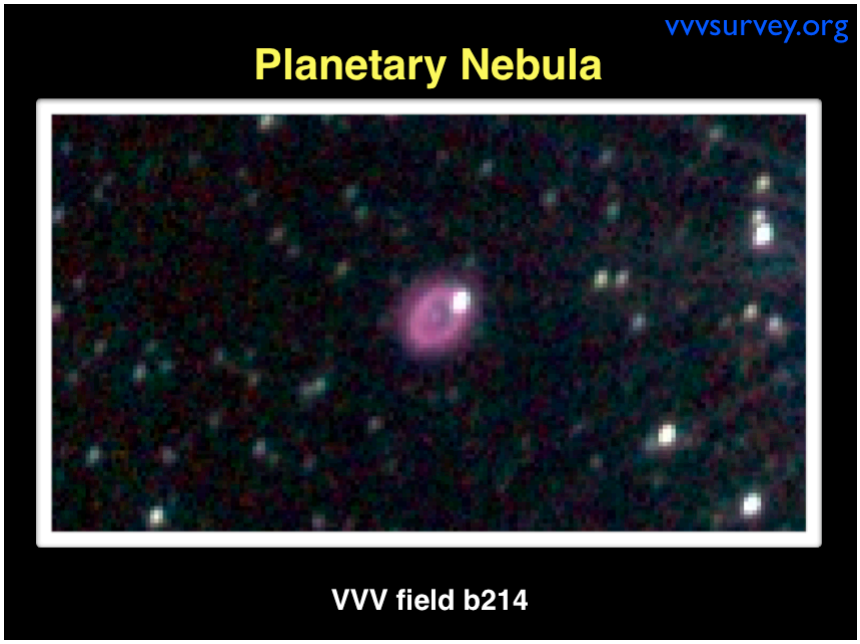

Fig. 11. Zoomed portion of field b214 centered on a planetary nebula. This figure shows an example of elongated stellar images, of the kind that are checked by our quality control.

PHOTOMETRY:

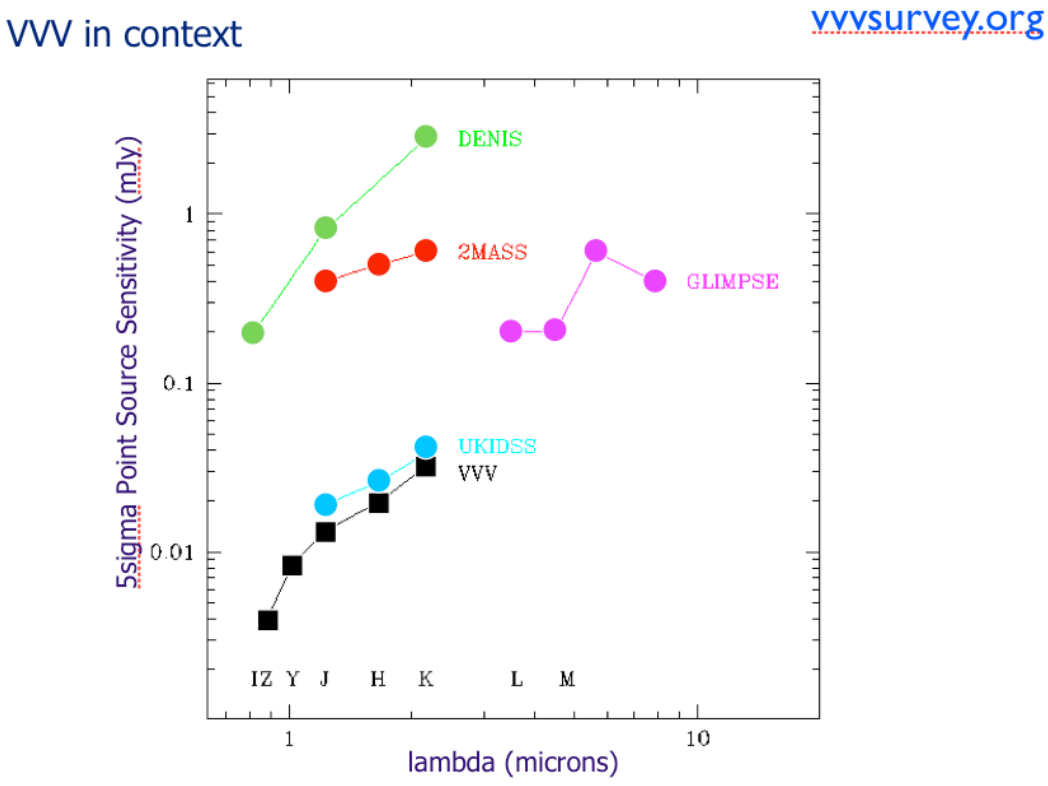

Fig. 12. Limiting magnitudes vs wavelength of different near-IR surveys.

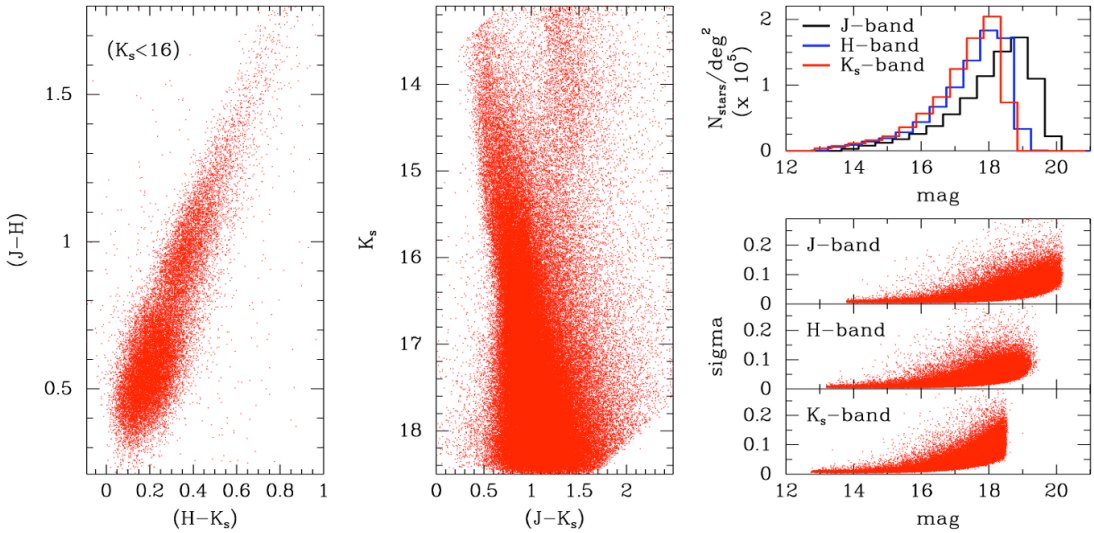

Fig. 13. VVV color-color and color-magnitude diagrams for a representative disk field (leftmost panels), along with the number density as function of magnitude (top right), and the photometric errors (bottom right) for the JHKs filters.

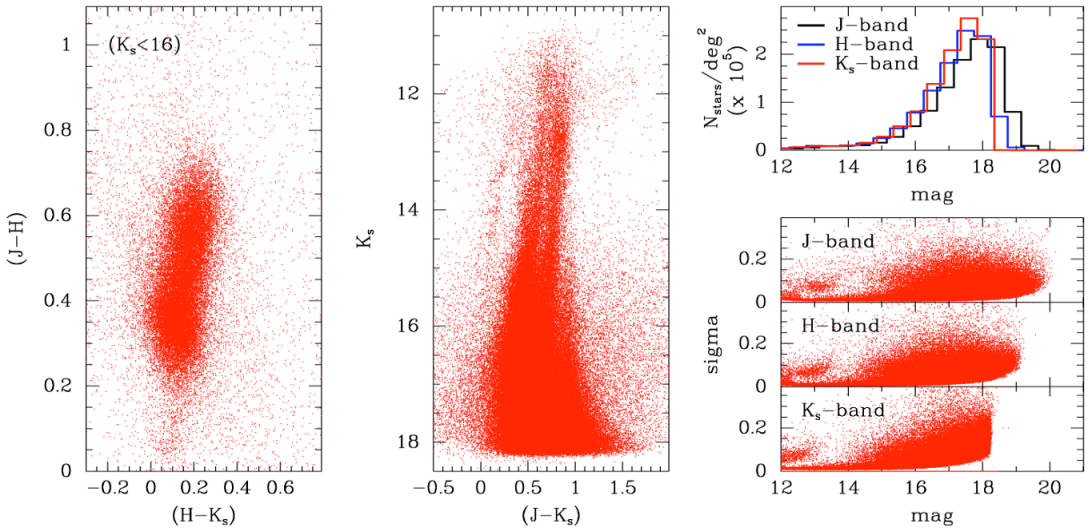

Fig. 14. VVV color-color and color-magnitude diagrams for a representative bulge globular cluster field (leftmost panels), along with the number density as function of magnitude (top right), and the photometric errors (bottom right) for the JHKs filters.

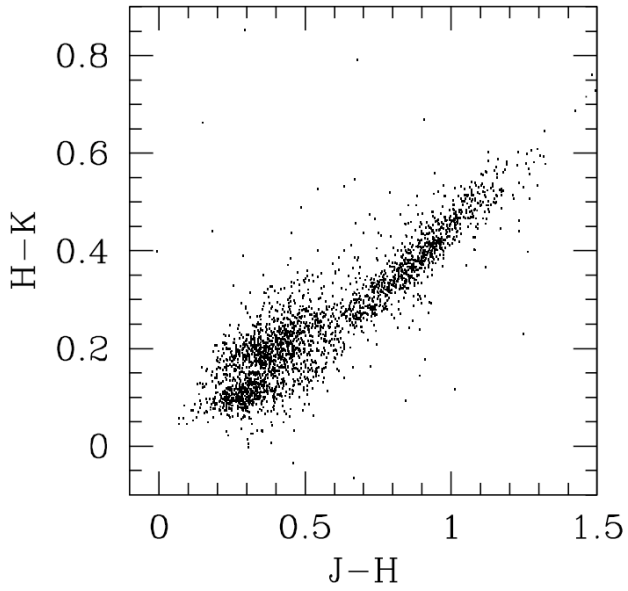

Fig. 15. Color-color diagram for stars with Ks<16.5 in a portion of field d003, illustrating that the high photometric quality allows to discriminate different stellar sequences: RG (top right), MS (top left), and young MS (bottom left). This would enable studies of stellar populations and galactic structure in the bulge and disk fields observed by our VVV Survey.

PHOTOMETRIC CALIBRATIONS:

The following figure illustrates the calibration of a typical field against 2MASS.

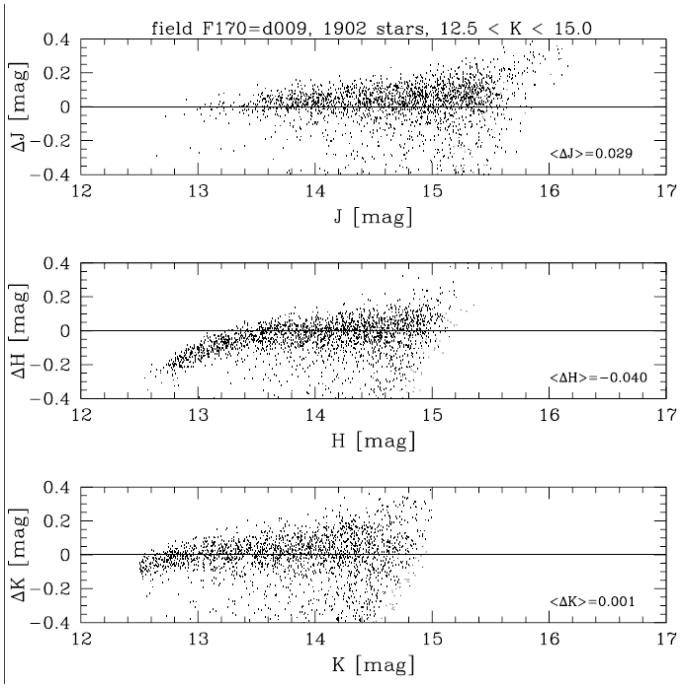

Fig. 16. Photometric differences of a typical portion of a field (d170) with 2MASS. Note the limited magnitude range for which this comparison is possible.

We are finding differences of out to 0.1 mag in some of the disk and bulge fields, which are not surprising. We note that eventually in these regions the VVV would be better calibrated and more homogeneous than 2MASS, because "*The 2MASS Survey has no Level 1 Specifications in the Galactic Plane with regard to completeness, reliability, and photometric accuracy*". Presently we are investigating the calibration as function of crowding in the bulge and disk fields.

In addition to have calibrated the data with respect to 2MASS, we plan to apply for telescope time in Chile to obtain a few additional calibration fields. The difficulty that we foresee here is mostly due to the brightness of the ZY standard stars, which cannot be observed with 4m class telescopes. If no adequate solution can be found, we would bootstrap the ZY calibration from the JHKs calibration of 2MASS plus the VI calibration of OGLE in the bulge and disk fields.

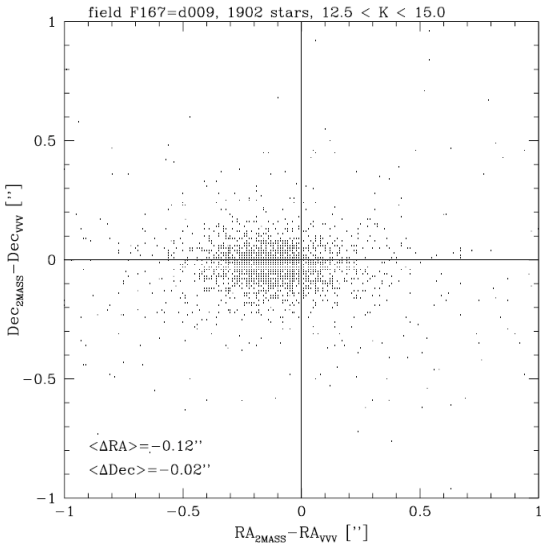

Fig. 17. Astrometric differences of a portion of a typical field (d167) with respect to 2MASS.

To summarize this section, the data production is progressing well, and we see no significant delays with respect to our Survey Management Plan. However, we understand that the details of the submission of the data products to ESO would be decided at the upcoming Workshop on Nov 30th, 2010 in Garching.

4. Are any changes proposed with respect to the Survey Management Plan in P87 (e.g., in strategy, targets, exposure time and/or other settings)? If yes, please provide a clear and detailed justification.

Everything has worked well, and we do not expect significant strategy changes with respect to the SMP. However, our Year 1 data is incomplete as explained. Therefore, most of the effort would be directed to catch up with this. For that we have to work closely in collaboration with ESO, and the strategy would be fine tuned and decided at the Phase 3 meeting on Nov 30th in Garching, where the advanced data product submission plan is to be decided also.

5. Observing Plan for Period 87.

Specify which part of the Survey Management Plan (SMP) the survey will focus on in P87 in the 1st column. If changes are foreseen in P87, please specify details of the observing strategy in the table and provide a full justification in Section 4 above.

SMP Period	Field name/ mean RA	Filter	Time (h)	Seeing	Moon	Transparency	Comments / strategy (e.g., no. of epochs)
P87	Bulge/ 17:00-19:00h	Ks	217	0.8	any	clear	20 epochs in Ks
P87	Disk/ 12:00-17:00h	Ks	75	0.8	any	clear	10 epochs in Ks

Note to the table: there are still observations pending from YEAR 1.