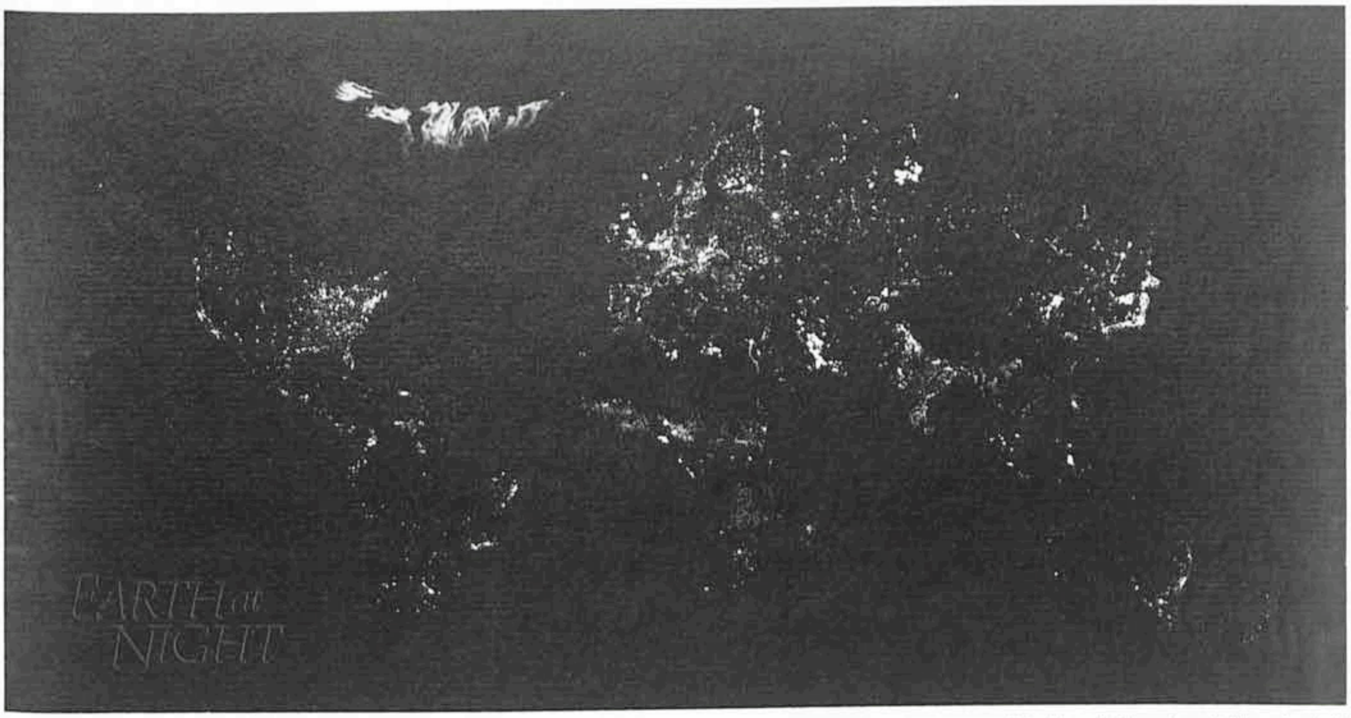

The Earth at night: this photo-composition of many satellite pictures illustrates the different sources of light pollution. In addition to light emission from urban areas, note the agricultural savannah fires in central Africa, natural gas flares from oil fields (Persian Gulf, North Sea . . .) and also the Aurora Borealis in the north. Credits: United States Air Force / DMSP Archives, National Snow and Ice Data Center, NOAA, University of Colorado / W. T. Sullivan, II, University of Washington, Seattle / Kerry Meyer.

radio frequency interference, one could mention the SETI programme, dedicated to the Search for Extraterrestrial Intelligence in the 1–10 GHz band.

The main pollution is created by radars but in urban areas, there are various other less known sources such as defective home appliances or high success gadgets like garage door remote openers. U.S. regulations allow observatories to proceed to inquiries in case of nuisance from such local sources of radio pollution.

A satellite dedicated to the detection of radio frequency interference from space will be operational in 1992 in frequency bands near 300 MHz.

Space Debris

This is an issue which goes far beyond the astronomical community. Any new spacecraft design has to include an anticollision shield. Damages due to collision with objects other than meteoroids may be severe and the pressure for reducing the threat will be stronger and stronger. ESA created in 1986 a working group on space debris and a report will soon be available.

It is estimated that 70 % of debris come from military explosions which have now been banned. More than 7,000 objects larger than 10 cm are tracked by the North American Aerospace Defense Command (NORAD). A catalogue is available to civilians and astronomers from the Naval Space surveillance Center (Dr. S.H. Knowles, Dahlgren, VA, U.S.A).

The number of debris increases constantly because of mutual collision and the critical density could be reached in 50 years if nothing is done. Cleaning the small debris by retrieval is considered as unrealistic nowadays because of the cost. Short term solutions such as propulsion of obsolete satellites to a "disposal" orbit could create a belt of debris around the earth. A third solution is the re-entry through the earth atmosphere for disposal.

As for consequences on astronomy, each photographic plate of the new Palomar sky survey includes an average of five tracks from satellites or debris. The space telescope will see 4 debris of 10^{th} magnitude per hour per degree of field of view and 1,000 debris of 20^{th} magnitude per hour per degree of field of view. A geostationary satellite is seen from ground with mag 14. The space shuttle is mag −3. Solar panels send bright flashes to ground and may interfere with gamma ray burst observations. According to the relative position of the Sun, one square inch of solar cell can be visible with the naked eye. At least one optimistic information to conclude: those problems usually occur only until two hours after sunset and start two hours before sunrise. *M. SARAZIN*

50 Years of RGU Photometry

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1. Introduction

Fifty years have elapsed since W. Becker (1938) proposed to use three-colour photometry for the study of stars which are too faint for spectral classification. He stressed that the choice of the passbands had to be guided by the properties of stellar radiation rather than by the properties of existing instruments. The three passbands were chosen such as to reflect the two basic characteristics of the visible spectral energy distribution of a star: a long-wave colour index (G-R) as a measure of temperature and a short wave colour index (U-G) defined by two well separated passbands measuring the UV-depression caused by line blocking and the Balmer depression.

Since then a multitude of different photometric systems have been established, each serving a different purpose. The UBV system (Johnson and Morgan 1953) as the most similar one to the RGU system has become the most widely known and used because it could be established both photographically and photoelectrically. Although a systematic comparison of the RGU and UBV system has not been undertaken, we refer to Fenkart and Esin-Yilmaz (1985) and the third section for some aspects of this comparison. Due to the lack of red sensitive photocathodes, the RGU system was originally defined as a photographic system (see Table 1, Becker 1946, Becker 1965, Buser 1978). In the past 10 years the photoelectric RGU system has been established (Trefzger et al. 1983) and we want to present here some new results based on photoelectric measurements along with a brief historical outline of the photographic RGU programme.

2. The Photographic RGU System

From ~1940 through ~1960, the first photographic RGU measurements were carried out with the Hamburg, Ann Arbor, Asiago and Cleveland Schmidt telescopes. The interpretation of the data

TABLE 1: *Characteristics of the photographic RGU system.*

	Emulsion	Filter	λ_o	$\Delta\lambda$ (FWHM)
U	Kodak 103aO	UG2 (2 mm)	3593 Å	530 Å
G	Kodak 103aO	GG5 (2 mm)	4658 Å	495 Å
R	Kodak 103aE	RG1 (2 mm)	6407 Å	430 Å

confirmed that progress in the following fields could be expected (Becker and Steinlin 1956):

1. Identification of faint main sequence stars as well as statistical absolute magnitude determinations (photometric parallaxes).
2. Determination of interstellar reddening along the line of sight.
3. Distance determination of galactic clusters.
4. Distinction between late-type main sequence and giant stars.

Among the first objects studied with the RGU system during that period were the open clusters (Becker and Stock 1958) using the still widely applied technique of main sequence fitting (both with a long *and* short wave colour-magnitude diagram) in order to determine distance as well as interstellar reddening. This technique led to an internally consistent distance scale with random errors less than ~15% together with crude relative ages (main sequence turnoff). The distribution of the very young open clusters (Becker 1963) clearly revealed part of a spiral arm pattern in the solar neighbourhood consistent with other optical spiral tracers (e.g. H II regions) and thus proved the power of the method. The basic data of the Basel cluster work is contained in two cluster catalogues (Becker and Fenkart 1971, Fenkart and Binggeli 1979).

In the next phase the more ambitious goal of exploring the distribution of the field stars of our Galaxy was envisaged. In the late 1950's, but especially after 1961, when the first RGU plates with the Palomar Schmidt telescope were taken by U.W. Steinlin, the foundations were laid to the Basel Galactic Structure programme. At that time (and probably still nowadays) most of the information about the structure of the galactic halo (today often called spheroidal component SC) came from the study of globular clusters and RR-Lyrae stars, whose masses may constitute as little as 1% of the total SC. Therefore the investigation of the field SC was a challenging task and led to a *halo survey* consisting of systematic, three-colour photometric investigations of starfields down to limiting magnitudes of 18 m to 19 m. These fields were chosen more or less in the meridional plane passing through the Sun and the galactic centre and, if possible, overlapping with Selected Areas.

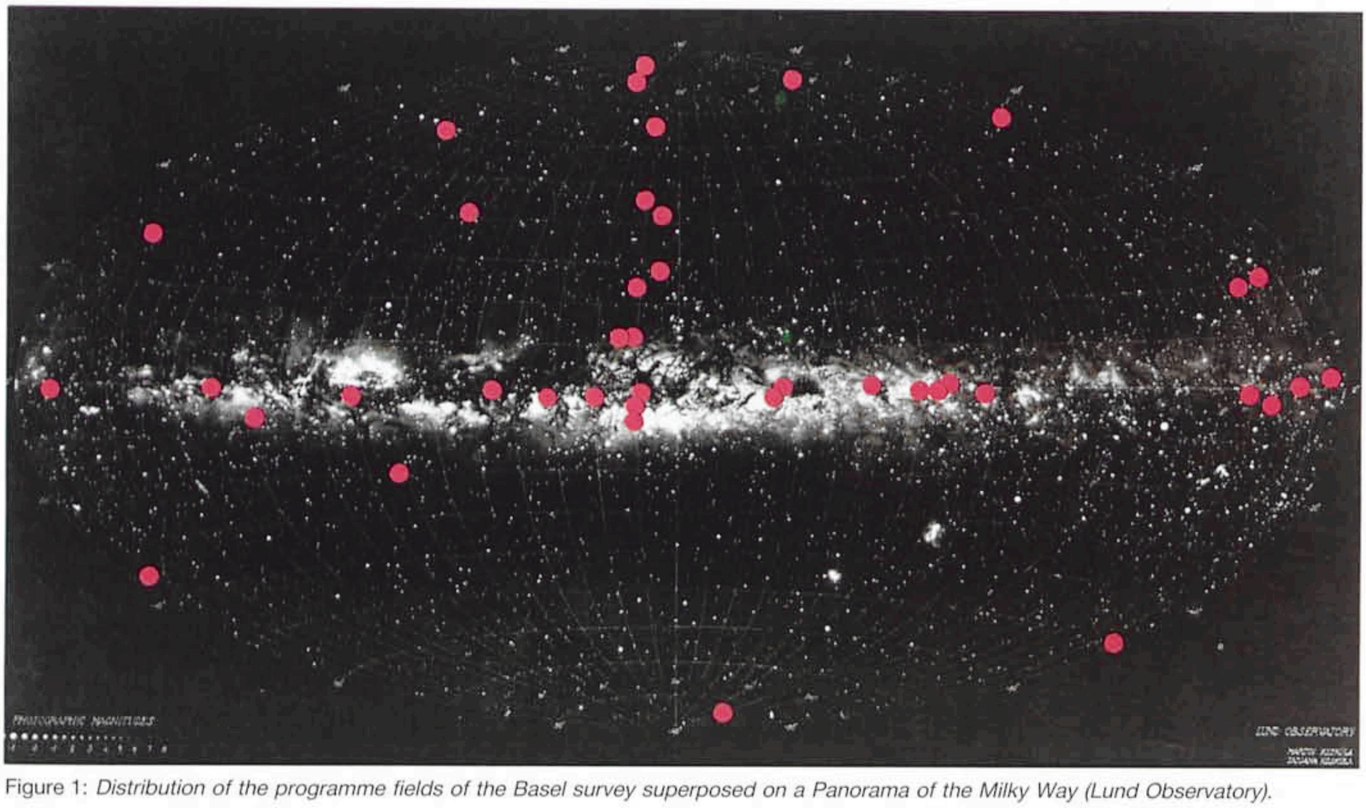

Figure 1: *Distribution of the programme fields of the Basel survey superposed on a Panorama of the Milky Way (Lund Observatory).*

The so far published 10 photometric catalogues (can be distributed on request) contain the RGU data of 16 starfields of the *halo survey* (~30,000 stars) as well as of 33 starfields of the *disk survey* ($|b| < 10°$, ~55,000 stars). The distribution of these fields projected on the sky is shown in Figure 1. The field sizes were chosen in order to give a statistically significant number of stars between 1,500 and 2,000. The typical halo field sizes are between 1 and 3 square degrees whereas the typical disk field sizes are between 0.1 and 0.3 square degrees. For every field the stellar space densities along the line of sight have been determined for those stars which can be photometrically classified using the stellar statistical tools as described by Becker (1965). Furthermore, these data can serve as a powerful preselective tool for sampling specific stellar populations in order to study them spectroscopically or with intermediate-band photometry as will be exemplified next.

When comparing the morphology of the two-colour diagrams in different regions of the Galaxy, several important features can be noted, which reflect the sampling of photometrically distinct populations. As an example, Figure 2 shows the two-colour diagrams of SA 57 (pointing to the galactic northpole) and of a field in the galactic anticentre. Four groups of stars, which are marked with different symbols and which are described in the caption, can statistically be identified by the photometry. So far, the RGU data have been used to select complete samples of F and G type dwarfs and subdwarfs at the galactic north and southpole regions for more detailed studies with intermediate band photometry (Pel et al. 1988, Spaenhauer and del Rio 1989). Special interest deserves the fact that the mean loci of the late-type giant stars show a large variation (Fig. 2b). This led to the distinction between "left" and "right side" giants (relative to the main sequence) and was qualitatively interpreted as a metallicity effect (Becker 1979, see also the next section). Up to now only a small part of the RGU data contained in the catalogues has been exploited in the context of "Galaxy modelling" (Buser and Kaeser 1985, Bahcall et al. 1985, Fenkart 1989). The main reason preventing to extract the full information, especially the one contained in the U magnitudes because of their metallicity dependence, was the lack of a sound physical calibration of the RGU colours in terms of T_{eff}, log g and [Fe/H]. Two basic approaches exist to achieve this goal, both of which have been undertaken during the past 10 years at Basel observatory. On the one hand, one has to define the photoelectric RGU system with a set of standard stars as well as a grid of programme stars with known physical parameters. On the other hand, one can use synthetic photometry in conjunction with spectral scans or theoretical model atmospheres provided the system is well defined. Both approaches should ideally go together controlling each other and giving additional information. For instance, because model atmospheres can be constructed as a function of continuously varying physical parameters, synthetic photometry will fill the gaps in the dis-

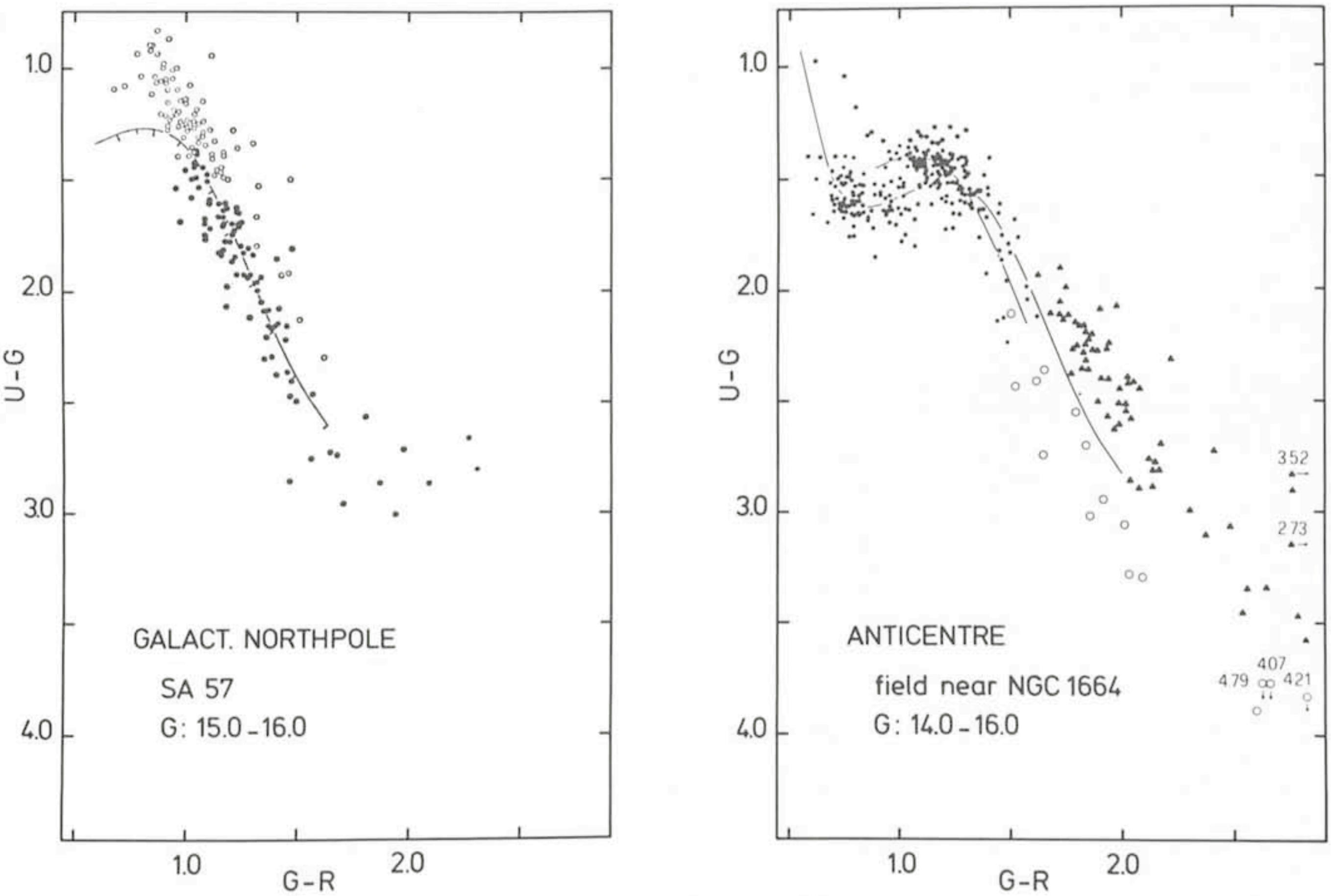

Figure 2 a: *RGU two-colour diagram of stars in the galactic northpole region SA 57 (Fenkart 1967). Only stars in the apparent magnitude range 15 m < G < 16 m are shown. Two groups of stars can be statistically identified: main sequence stars of population I (●) and main sequence stars of population II with large UV excesses (o).*

2 b: *RGU two-colour diagram of stars in the galactic anticentre region (Becker and Fang 1973). Only stars in the apparent magnitude range 14^m < G < 16^m are shown. Three groups of stars can be statistically identified: main sequence stars of population I (●) which are split into two groups because of a steplike increase of interstellar reddening caused by a nearby cloud; giant stars of population I (o, "left-side" giants) and giant stars of population II (▲, "right-side" giants).*

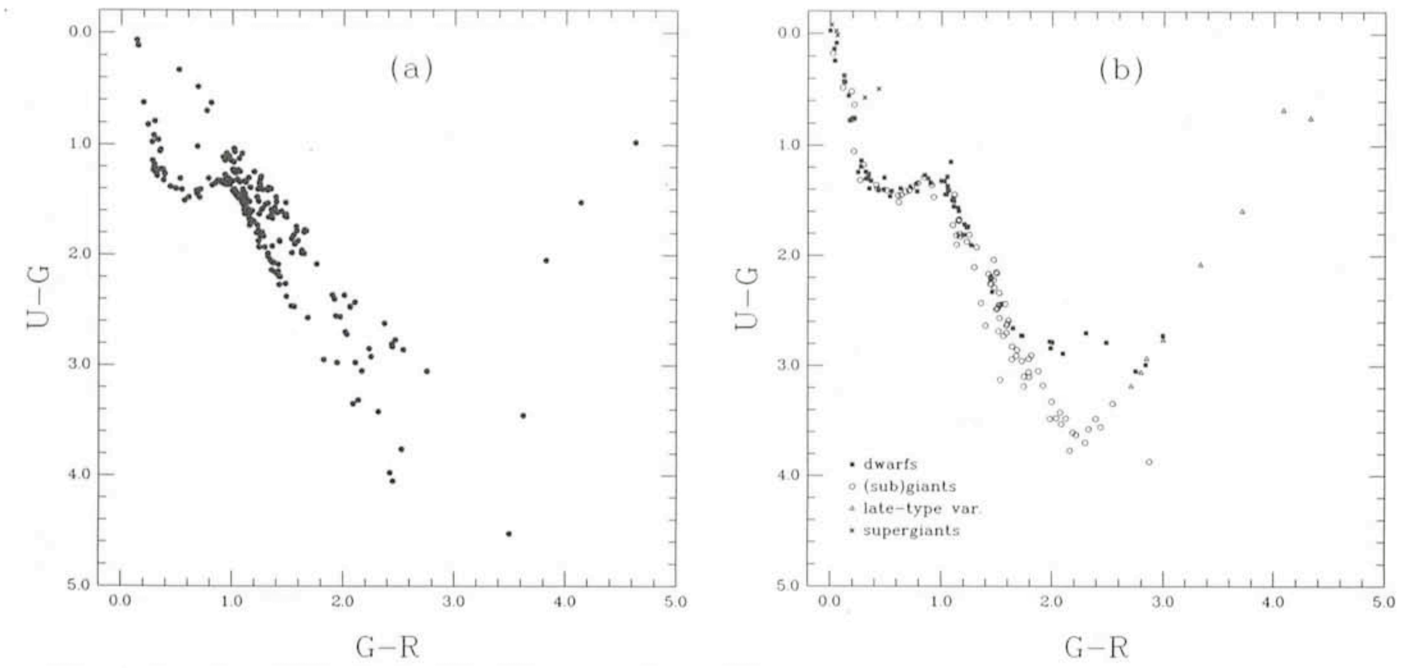

Figure 3: *The two-colour diagram for the photoelectric RGU system: a) compilation of 275 well-observed stars covering a broad range in both colours. The sample comprises stars covering a large metallicity range and they are not corrected for reddening; b) measurements resulting from synthetic-filter photometry of the spectrophotometric data by Gunn and Stryker (1983). Due to the chemical homogeneity of the sample, the dereddened stars show very little scatter for a given luminosity class. Different luminosity classes are marked by different symbols.*

crete grid of photoelectrically observed stars. Furthermore, the internal consistency of a photometric system or catalogue essentially depends on the proper transformations between the standard system and the instrumental systems, a problem that can be tackled by synthetic photometry. For a discussion of the use of synthetic photometry concerning the photographic RGU system, we refer to Buser (1979) and the references therein.

3. The Photoelectric RGU System: Steps Towards the Physical Calibration

The photoelectric RGU system is defined by a combination of a photomultiplier with an S-20 cathode and three broad-band interference filters for the pass-bands R, G and U (Trefzger et al. 1983) matching closely the photographic system. Observations of northern standard stars were carried out using the 1-m telescope at the Gornergrat Observatory in Southern Valais, Switzerland, during several observing runs between 1980 and 1983. The observations on La Silla were carried out using the 1-m telescope and the ESO 50-cm telescope during 5 observing runs between 1984 and 1987.

The goal of these observations is the study of the photometric properties of stellar samples with well-known physical parameters, e.g. effective temperature, gravity, absolute magnitude, metallicity and reddening. The following samples were chosen for this purpose:

- Main sequence stars of different effective temperatures, both field stars and members of open clusters, in order to determine the position of the main sequence in the two-colour diagram and to establish a calibration in terms of absolute magnitude.
- Stars of different luminosities, especially cool stars, for luminosity calibration of field stars.
- Dwarfs and giants in a large metallicity range with the aim of calibrating their UV excesses as a function of metal abundance, thus providing the empirical basis for a statistical study of the chemical structure of the galactic halo (Trefzger 1981).

Figure 3a shows the two-colour diagram of a compilation of our stellar samples. The S-shaped lower envelope in the left part of the diagram indicates the main sequence for unreddened stars. Those stars lying above the main sequence are either affected by interstellar extinction and/or metal deficiency (see below). In order to determine the shape of the two-colour diagram for normal (solar abundance) stars, we derived colours from observed stellar energy distributions by digitally simulating the photoelectric RGU system. The library of stellar spectrophotometric data published by Gunn and Stryker (1983, hereafter GS) provides a large sample of various normal stellar types and represents a valuable tool for the calibration of photometric systems (cf. Labhardt and Buser 1985, Labhardt 1988). The GS fluxes were dereddened employing the interstellar reddening law as given by Seaton (1979) and Howarth (1983). Furthermore, the corrective function recently published by Rufener and Nicolet (1988) was adopted. Synthetic colour indices were obtained by numerically multiplying the relative response functions of the photoelectric RGU system with the intrinsic energy distributions of the stars in the GS library. The resulting two-colour diagram is shown in Figure 3b for different luminosity classes. It will be used as a guide for the proper interpretation of an observed two-colour diagram like the one shown in Figure 3a. The detailed comparison of the observed and calculated two-colour diagrams is subject to further investigation and will be published elsewhere.

In the following we want to discuss some results obtained from photoelectric observations of dwarf and giant stars belonging to different stellar populations of our Galaxy. Figure 4 shows the two-colour diagrams of Hyades dwarf stars with spectral types between A1 and K2 for the UBV and RGU systems. Also indicated are measurements of 46 mostly metal-poor dwarf stars, selected from the comprehensive catalogue of Cayrel et al. (1985) of stars with known parameters T_{eff}, log g and [Fe/H]. Their metallicities vary in the range $-3.5 < [Fe/H] < +0.6$; their temperatures are between 6260 K and 4800 K and their gravities are around log g = 4.3. We used the UBV colours published in the catalogue mentioned above to compare

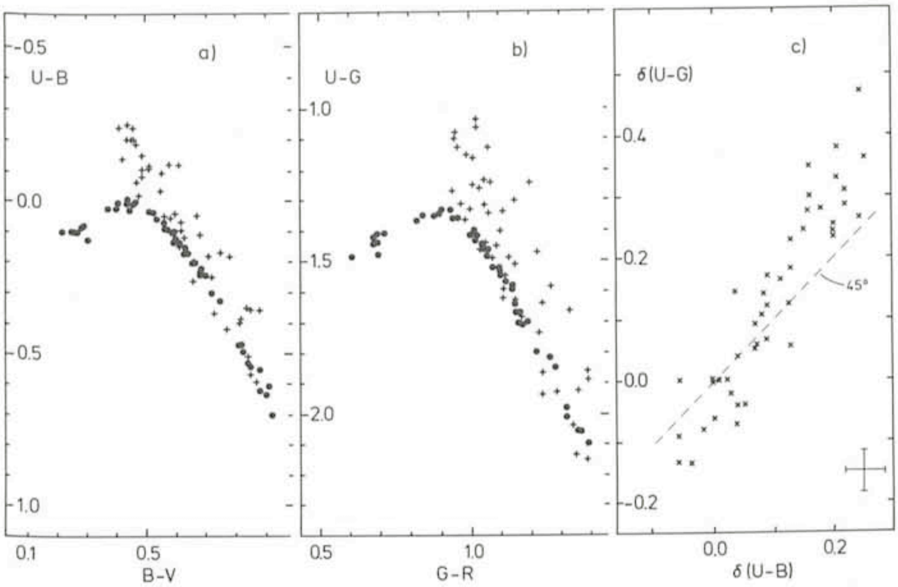

Figure 4: *The two-colour diagrams of the Hyades main sequence (●) and metal-poor dwarfs (+) are shown for the UBV system (Fig. 4a) and for the RGU system (Fig. 4b). Figure 4c compares the UV excesses as measured in the two photometric systems (UV excess = vertical distance of a particular star above the Hyades main sequence).*

the UBV system with the results obtained in the RGU system. In both photometric systems these stars show substantial UV excesses relative to the (somewhat metal-rich) Hyades. This is in qualitative agreement with the properties of halo stars as observed in the photographic survey.

However, the UV excesses δ (U-G) measured in the RGU system are considerably larger than the δ (U-B) values of the UBV system. Figure 4c displays a star-by-star comparison of the corresponding UV excesses as measured in the two photometric systems relative to the Hyades main sequence. The slope of the linear relationship is 1.52 showing clearly the higher sensitivity of the RGU system to separate metal-poor stars from metal-rich ones. The stars with the highest UV excesses are expected to be those with the lowest metallicities, because weakening the lines predominantly enhances the stellar flux in the U band. This is confirmed by the spectroscopically determined [Fe/H] values. It is interesting to note that those stars in our sample that are still more metal-rich than the Hyades are located below the Hyades main sequence, showing negative UV excesses. Again, this effect is more pronounced in the RGU system than in the UBV system.

The variation of δ (U-G) as a function of [Fe/H] depends on stellar temperature and therefore on (G-R); the lines of different metallicities and temperatures in Figure 4b can be drawn on the basis of our empirical data in combination with theoretical colours calculated from model atmospheres (Buser 1979). This work is still in progress. It will eventually provide a statistical method to estimate metallicities of large samples of halo stars based entirely on three-colour photometry thus allowing a physical interpretation of the large data base of the Basel halo and disk survey.

As mentioned already in the preceding section, giant stars sampled from fields in different parts of the galactic disk and bulge show systematic displacements in the two-colour diagram. It was suspected some time ago (Becker 1979, Spaenhauer and Thévenin 1985) that this could be related to variations of the mean metallicity within the galactic disk and inner halo. In order to study the properties of metal-poor giants in the RGU system, we observed a sample of stars from the list of extremely metal-poor giants published by Bond (1980). Their metallicities were determined from Strömgren photometry and are in the range between $-2.7 < [Fe/H] < -1.5$. In Figure 5 we compare the positions of these metal-deficient giants with the location of the giants of the old disk cluster M 67 (Tammann 1963). The large displacement of the metal-poor giants towards the upper right is obvious and is related to the same kind of UV excess in these weak-line stars as is observed in halo dwarfs as well. This strongly supports the conjecture that metallicity differences between giants in different parts of the Galaxy show up in the two-colour diagram; after proper calibration this gives us the possibility to map the metallicity gradient within the galactic disk, see e.g. Neese and Yoss (1988), as well as within the inner halo.

Measuring very cool stars is a quite difficult task because the U-band signal always remains low due to the small amount of stellar flux in the blue part of the spectrum. However, there is a strong interest in learning more about the RGU colours of the reddest stars: a good fraction of the photographically recorded field stars are red and in order to understand their contribution to the local galactic structure we would like to distinguish between late-type dwarf and giant stars. By observing a representative sample of both M-type dwarfs and giants, all of which are MK standard stars, we are in the process of tackling these problems. The reduction of the relevant measurements necessitates a safe extrapolation of our transformation equations, as the colour range of our standard stars does not yet include very red stars. For this purpose, the GS library was used to establish the relations between the photoelectric RGU colours and MK spectral classification. For a large part of the diagram given in Figure 6 the relations are monotonically increasing and are almost identical for dwarf and giant stars. It is interesting to note the large range covered in (U-G) by the stars of the MK spectral classes K and M, and the ambiguity of the relation in the right-most part of Figure 6a. Nevertheless, these relations turn out to be defined well enough in order to calibrate the intrinsic colours of late-type stars.

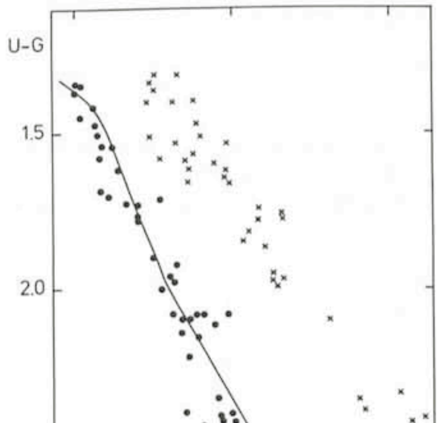

Figure 5: *Two-colour diagram of metal-deficient giants selected from the list of Bond (1980) marked by crosses. The dots indicate the location of giants of M 67 in the photographic RGU system. The line shows the position of the main sequence K stars.*

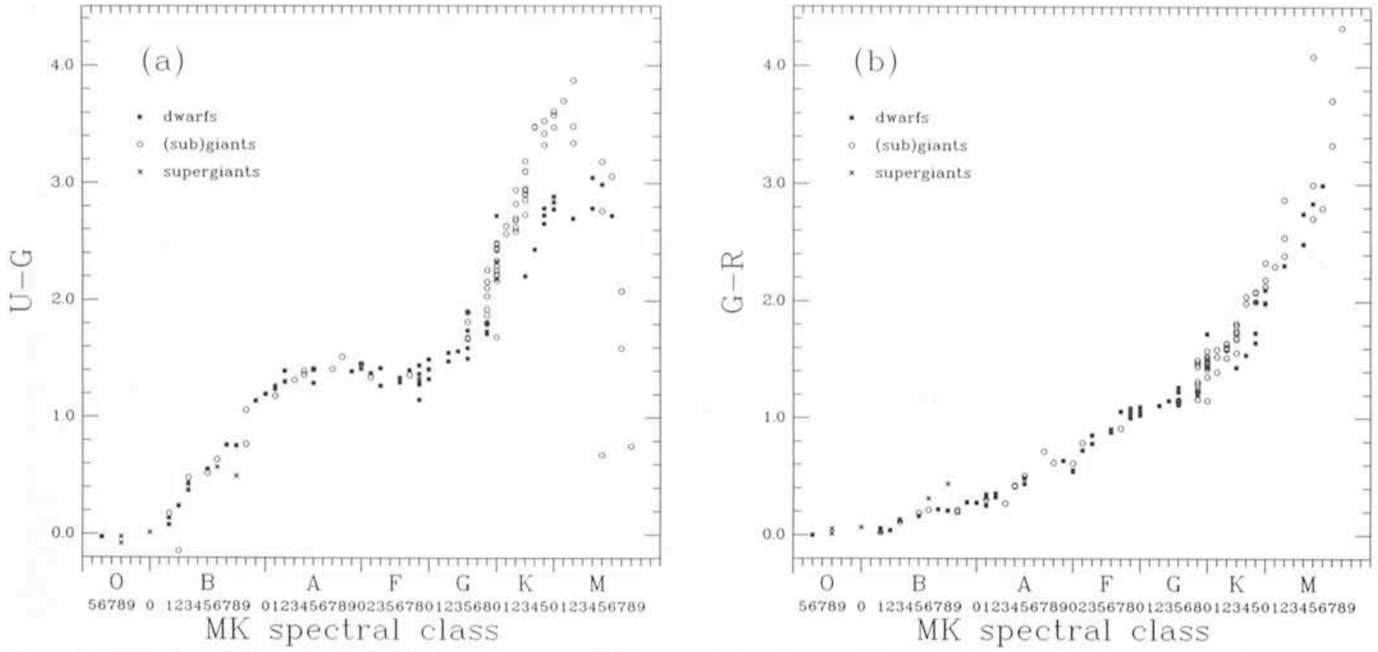

Figure 6: *Calibration of photoelectric RGU colours in terms of MK spectral classification. These relations are based on synthetic photometry of the GS library and MK spectral classes obtained from the Centre de Données Stellaires (Strasbourg).*

4. Conclusions

The photographic RGU system was proposed 50 years ago by W. Becker as a tool for the study of galactic structure and has been the foundation of the Basel RGU survey. The establishment of the photoelectric RGU system was naturally required in order to extract the full information contained in the photographic RGU database. The photoelectric measurements described in the preceding section along with the use of synthetic photometry will provide the essential physical calibration needed for Galaxy modelling as well as for the purpose of preselecting specific stellar samples. With respect to Galaxy modelling we expect that the inclusion of ultraviolet data will put essential constraints on the chemical structure of the principal galactic components (halo, bulge, thick disk and disk). The majority of the stars appearing in the photographic survey belong to the colour domain covered by the photoelectric observations: dwarf and giant stars ranging from spectral type O through K and covering the metallicity range from extreme population II to extreme population I. The extension of the photoelectric system to the very cool (M-type) stars is under way. Furthermore, CCD RGU observations have been carried out on La Silla in order to make faint objects accessible for RGU study.

Acknowledgements

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NOTE: Photographer Gudrun Ewaldt also participated in the making of the centrefold image of the ESO Headquarters in *Messenger* No. 53 (September 1988).