АСТРОФИЗИКА

ТОМ 46 МАЙ, 2003 ВЫПУСК 2

УДК: 524.316

INFRARED PROPERTIES OF A SUB-SAMPLE OF LATE - TYPE STARS PROVIDED BY THE FIRST BYURAKAN SPECTRAL SKY SURVEY

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Received 23 October 2002
Accepted 15 November 2002

We present the first results of analysis of infrared properties of the faint M and C type stars found on the FBS plates. By cross - correlating the subsample of FBS late - type stars with infrared catalogues, we have shown that several families of objects can be separated. It provides ways to better characterize the properties of these families, their nature and their typical distances.

Key words: *stars:infrared colours - stars:luminosities:AGB stars*

1. *Introduction.* In this paper we investigate how recent infrared data bases such as 2MASS [1] photometry can help to derive the nature of late-type stars provided by the First Byurakan Spectral Survey (FBS). The latter carried out by Markarian and associates in the years 1965-1980 is a Schmidt telescope objective-prism survey covering more than 17000 sq. degrees of the Northern sky [2]. The plates have a useful field of 4 by 4 degrees, and the prism provides spectra with a dispersion of 1800 Å/mm near 4300 Å (3400-6900 Å spectral range) for objects with a V magnitude brighter than 15 mag. In addition to studies devoted to galaxies [2], other extragalactic objects or blue galactic stars [3], the examination of the prism-objective plates have allowed to identify a large number of cool stars. These are either of M-type (oxygen rich) or C-type (carbon-rich) late-type stars. Neverthless the very low spectral resolution of the plates prevent from determining the luminosity of the finding stars, mainly the M-type ones. However this information is of special interest since these stars generally lie at high Galactic latitudes and therefore belong either to the thick disk or the halo of our Galaxy.

A first list of C-star candidates was analysed in Gigoyan et al. [4]. In particular, the subsequent medium-resolution slit spectroscopic observations have confirmed, generally, the carbon-rich nature of the stars discovered by K.G. (eye-scrutinizing) on the FBS plates.

In the present work our goal is to give the first analysis of the infrared properties of M and C stars found by the FBS survey. More specifically, taking advantage of the recent release of the 2MASS data, we wish to check

if JHK photometry can be used, at least for some individual objects or statistically, to derive information on the nature of the stars of interest. This would be extremely useful for searching cool AGB (Asymptotic Giant Branch) stars, since carrying out slit spectroscopy for a large number of objects is telescope time consuming.

The first question is whether infrared photometry can provide, for the cool stars, a spectral classification such as that estimated from the FBS plates for M-type and C-type stars. A second goal is estimating, at least statistically, the luminosity of these stars in order to find out in which proportion these stars are dwarfs, helium-burning (clump) giants, or even more luminous stars lying on the asymptotic giant branch, possible mass-losing AGB stars. In addition to the 2MASS data, we will also consider data from IRAS [5,6] catalogs, especially well suited to identify late-type stars with dusty envelopes.

2. *The sample and optically derived properties.* In the first approach we have chosen to analyse the M and C stars published by Gigoyan et al. [7,8]. Their lists XI and XII include a total of 145 objects, and constitute a typical sub-sample of the entire cool-star survey of the FBS plates. Among those 145 objects we have ignored objects FBS 0919-031 and FBS 1151-057 (from list XI) because, despite of a careful examination, they could not be identified on the POSS digitized images [9] (http://skyview.gsfc.nasa.gov/). It is worth noting that they are classified M8-9 and are either possible variable objects or very high proper motion dwarfs. The third one, FBS 2217-009 from list XII [8] was also deleted because it is a very bright object previously catalogued by Stephenson [10]. This make the total number of late-type stars to be considered as 142. Fig.1 shows their distribution in galactic coordinates: among them 84

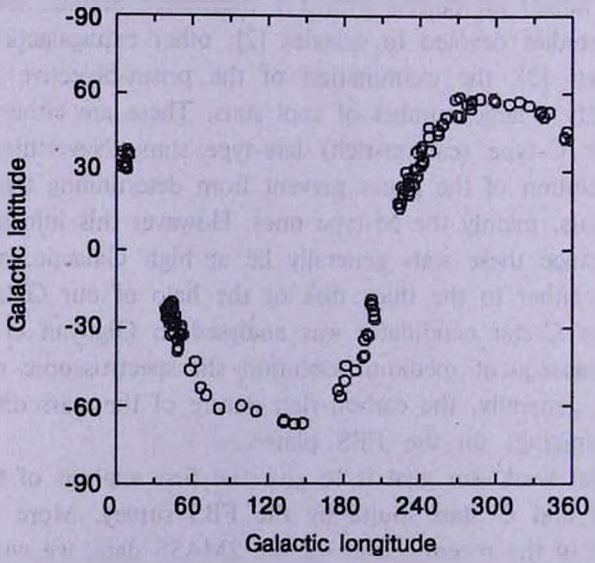

Fig.1. Galactic coordinates (l,b) of the FBS late-type stars [7,8].

(59%) are at $|b| > 30°$ and 108 (76%) at $|b| > 25°$.

For each object R and B magnitudes were retrieved from the USNOC-A2.0 catalog [11]. This allows us to plot the R magnitudes versus the $B-R$ colour index (Fig.2). Fig.2 shows that the most of stars have R in the range 10 to 15, and $B-R$ between 1 and 3.5. However since the USNOC photometry is not very reliable (~0.4 mag. accuracy), the $B-R$ index has to be considered with some caution.

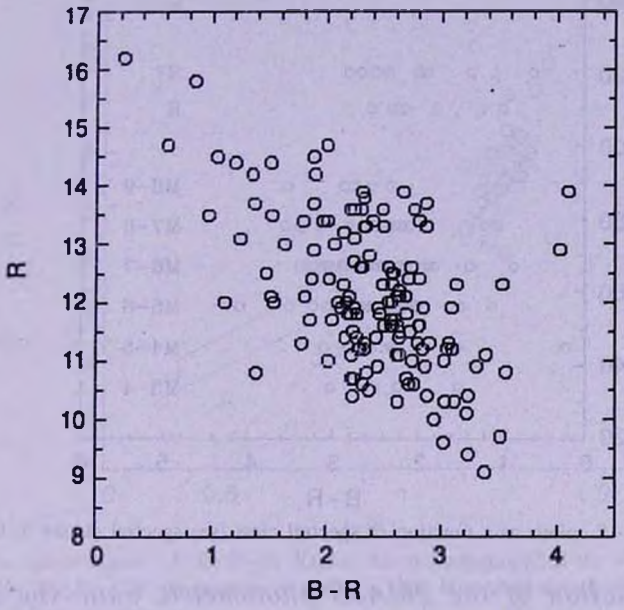

Fig.2. Colour-magnitude ($B-R$, R) diagram for the FBS [7,8] late-type stars.

For each late-type star found on FBS plates, a spectral classification was assigned by K.G.: it could be either from the M-type (ranked M3-4, M4-5, M5-6, M6-7, M7-8, or M8-9), or from the R-type (R or R?), or C-type (C or C?). In Fig.3 we have plotted the spectral subclass as a function of $B-R$. We arbitrarily coded M3-4 as 134, M4-5 as 145, etc., M8-9 as 189, R as 210, R? as 220, C as 240 and C? as 250. It can be seen that there is no clear separation between the natural groups when one considers the $B-R$ colour index. This may be due to the following grounds:

a) relatively poor accuracy of USNOC B and R magnitudes leading to a $B-R$ index not accurate enough,

b) stars with high carbon abundance may also be warm (early R-type) in contrast with cool evolved AGB C-stars which are intrinsically very red ($B-R > 3.0$),

c) some warm objects at low Galactic latitudes may be affected by reddening making the $B-R$ index redder.

In summary, according to the spectral classes derived from objective-prism plates, USNOC photometry does not provide any clear indication on the nature of the late-type candidates identified on the FBS plates. In particular, it is not clear whether the bulk of M stars contains a majority of dwarfs, giants, or cool AGB stars.

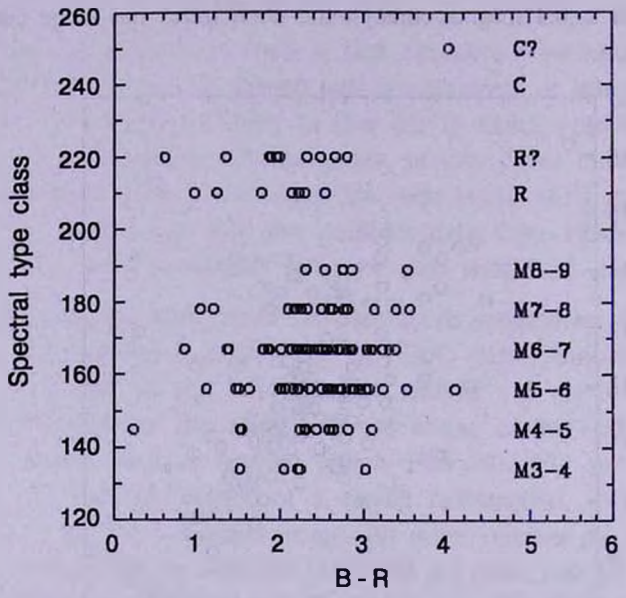

Fig.3. The $B-R$ colour as a function of spectral class (see spectral classes in text).

3. *Exploitation of the 2MASS photometric data.* Our sample was cross-correlated to the 2MASS 2nd incremental data release [1]. We found 68 objects with JHK photometry. This corresponds to about 48% of the considered sample, and is in good agreement with the present spatial coverage of the 2MASS Catalog (50% of the sky). Since most of our objects have $R<15$ and $R-K>0$, we expect $K<15$ for them (see Fig.2): hence JHK photometry will be available for most of objects of interest when the data of the complete 2MASS survey will be released.

J, H or K magnitudes are in the range of about 6-15 and accuracies in the region of 0.1 mag. or much better. This near-infrared photometry led to the determination of color indices such as $J-K$ or $R-K$. Fig.4 shows that the $J-K$ index separates the sample objects remarqably well in three families, namely $J-K\sim0.5$, $J-K\sim0.8$ and $J-K>1.1$ median indices (note that there are only 2 stars with $J-K\sim0.5$ and this blue family has to be confirmed). This separation is also seen in $R-K$ despite the fact that the R magnitude is less accurate. In Fig.4, we have also indicated the locus of the dwarf stars of spectral types K0 to M7 obtained by cross-identifying all $K-M$ dwarfs belonging to the SIMBAD [9] database (http://simbad.u-strasbg.fr/) with the

2MASS database. This points out that relatively few dwarfs are present among the late - type stars found by the FBS survey [7,8].

The family at $J-K=0.85$ is probably mostly populated by giants. In order to check this trend, we have crossed the sample of stars (mostly R-type giants and a few C-rich dwarfs) detected in the Hamburg/ESO objective-prism

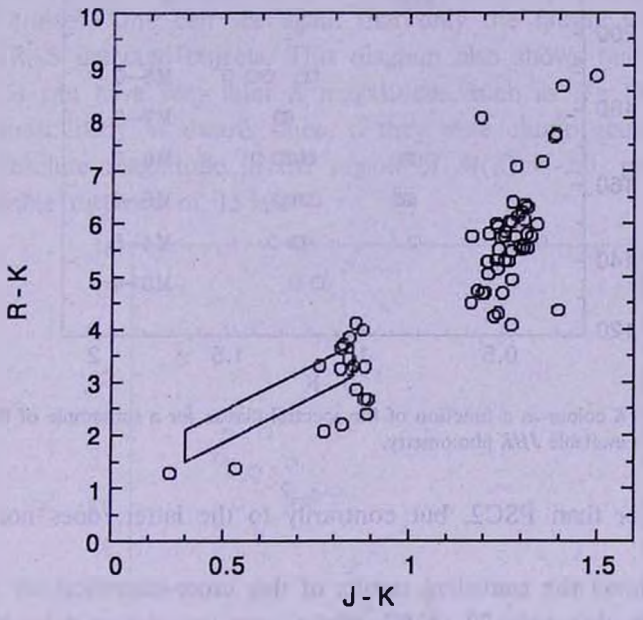

Fig.4. The colour-colour ($J-K$, $R-K$) diagram for the subsample of the FBS [7,8] late-type stars, for which 2MASS JHK photometry is available. The known M-dwarfs are located inside 2 parallel inclined lines on diagram.

survey of Christlieb et al. [12] with 2MASS. This survey covers about 6400 deg^2 in the South Galactic pole at a limiting magnitude of $V=16.5$ while the selection criteria are based on CN and C_2 blue-green features (< 5200 Å). It is found that most of them have $J-K$ indices in the range 0.6 - 0.9, which are typical for giants (and some dwarfs) at high Galactic latitudes.

The separation of the FBS sample in three families is also interesting to be considered in Fig.5, where the spectral class derived from FBS plates is plotted against $J-K$. One can see especially that all R-type (or R?) belongs to the group at $J-K\sim 0.8$, and that most of the objects from the M-class have $J-K>1.2$. The family having $J-K>1.2$ is most likely populated by early-type or late-type AGB stars, and this trend is further confirmed by far-infrared data discussed below.

4. *Exploitation of the IRAS PSC2 and FSC catalogs.* Our late-type star FBS [7,8] sample was cross-correlated with the IRAS Point Source Catalog (PSC2) [5]. When a source was found to have no counterpart in the PSC2, this one was searched in the Faint Source Catalog (FSC) [6],

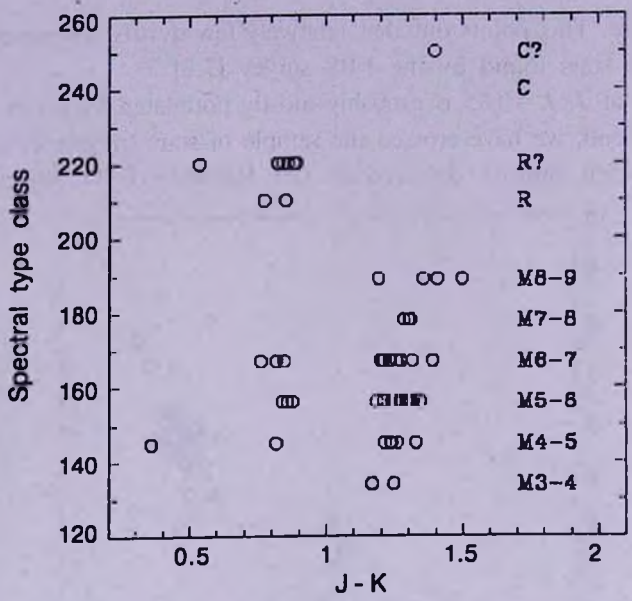

Fig.5. The $J-K$ colour as a function of the spectral classes for a subsample of the FBS [7,8] late-type stars with available JHK photometry.

which is deeper than PSC2, but contrarily to the latter, does not cover all the sky.

Table 1 shows the statistical results of this cross-identification procedure. It can be seen that only 72 (50%) of the stars was detected by IRAS. The only criteria we lay down is a true detection at 12μm, that is at least a flux quality of 2 or 3. The IRAS fluxes are between 0.1 and 7 Jy.

Thanks to the full sky coverage of IRAS, one can come to the conclusion that the undetected objects have a flux below ~0.1 - 0.2 Jy, the 12μm IRAS detection limit. Examination of the R magnitudes shows that those undetec-

Table 1

THE SAMPLE OBJECTS FROM THE LATE-TYPE STAR FBS SURVEY DETECTED BY IRAS

	Total	M3-4	M4-5	M5-6	M6-7	M7-8	M8-9	R and C
Number	142	5	14	35	45	19	8	18
Seen by IRAS	72	3	7	21	23	13	5	0

ted objects are not fainter in R than the other ones. They are simply too warm to be seen by IRAS.

It is worth noting that there is roughly the same proportion of IRAS detected objects with M-type whatever their subclass (50-60%). Another point which

is very clear is that none of the R or C type objects are detected by IRAS. This supports the fact that R-classified objects are giants, with no dust.

5. *Luminosities and distances.* Finally, we have plotted in a K, $R-K$ diagram (Fig.6) all of our sample objects with 2MASS JHK photometry. Those which were jointly detected by IRAS are pointed out with encircled crosses. One can see again that only the family with $R-K>4.5$ contains IRAS detected objects. This diagram also shows that warm objects ($R-K\sim1.5$) can have very faint K magnitudes, such as $K=13$ to 15. These stars are most likely M dwarfs since, if they were clump giants, they would have an absolute magnitude in the region of $M(K)=-2.0$, putting them at an improbable distance of 15 kpc.

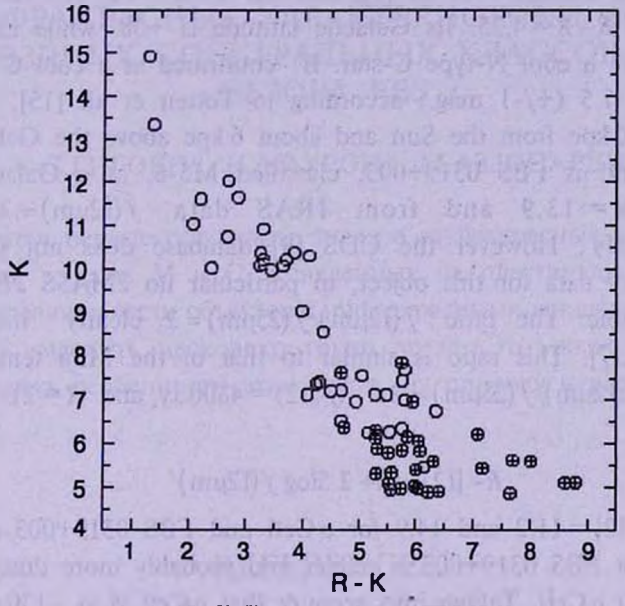

Fig.6. The colour-magnitude ($R-K$, K) diagram for the FBS [7,8] late-type stars with available 2MASS photometry. IRAS detected stars are noted with an encircled crosses.

On the contrary, the group around $J-K\sim0.8$ and $R-K\sim3.0$ contains giants most likely. All R-type stars found in the FBS belong to this family, and are too bright in R, statistically, to be dwarfs. With $K\sim11$ and $M(K)=-2$ [13], they are at a distance of about 4 kpc from the Sun. Since they have Galactic latitudes $|b|$ in the range 40-70°, their distances to the Galactic plane are a few kpc, making them typical objects of the thick disk population.

The group at $R-K>4.5$ (and $J-K>1.2$, see Fig.4) are mainly early or late AGB stars, with very often dust infrared emission. A very rough estimate of their distances can be obtained by taking K absolute magnitudes typical of the Mira-stars, namely in the range $-8.0<M(K)<-6.5$ (see Feast et al. [14]).

Adopting $M(K) = -7.0$ and a mean apparent magnitude $K = 6.0$, one obtains a typical heliocentric distance of 4 kpc again. A plot of $|b|$ versus $R-K$ shows that most of the stars with $R-K < 6.5$ have an absolute Galactic latitude between 20 and 60°, while the coolest ones with $R-K > 6.5$ all have $|b|$ between 20 and 30°. Therefore their hight above the Galactic plane are again 1 to 4 kpc, probing the thick disk. It is interesting to note that there is no faint and cool ($K > 8.0$ with $R-K > 4.5$) object, in agreement with the scarce cool intermediate age AGB stars lying in the halo.

Finally, there are two very interesting $B-R$ very red objects, with $B-R > 4.0$: The first, FBS 1008-066, was independantly discovered by the Hamburg/ESO carbon star survey by Christlieb et al. [12]. Although not detected by IRAS, it is classified C? in [7], and has $B-R = 4.0$, $R = 12.9$, $K = 8.59$, $J-K = 1.398$, $R-K = 4.35$. Its Galactic latitude is +38° while its colors are consistent with a cool N-type C-star. If confirmed as a cool C star, hence with $M(K) = -7.5$ (+/-1 mag.) according to Totten et al. [15], its distance is at about 10 kpc from the Sun and about 6 kpc above the Galactic plane.

The second is FBS 0319+003, classified M5-6, at a Galactic latitude $b = -44°$, $R = 13.9$ and from IRAS data $f(12\mu m) = 2.6$Jy, and $f(25\mu m) = 1.3$Jy. However the CDS [9] database does not provide any complementary data for this object, in particular no 2MASS *JHK* photometry is available. The ratio $f(12\mu m)/f(25\mu m) = 2$ clearly indicates dust emission [16,17]. This ratio is similar to that of the Mira template *o* Ceti which has $f(12\mu m)/f(25\mu m) = 2.2$ ($f(12) = 4800$ Jy and $R = 2$). Computing the quantity

$$R-[12] = R + 2.5 \log f(12\mu m) \qquad (1)$$

we find $R-[12] = 11.2$ and 14.9 for *o* Ceti and FBS 0319+003 respectively, indicating that FBS 0319+003 is redder and probably more dusty and more luminous than *o* Ceti. Taking into account that *o* Ceti is at ~130 pc [18], the heliocentric distance of FBS 0319+003 would be, with a very large uncertainty, between 5.5 kpc(scaling on 12μm fluxes) and 30 kpc(scaling on the *R* magnitude). Those two objects give evidence that cool stars selected from the FBS survey deserve further investigations.

6. *Conclusions*. By cross-correlating a typical subsample of 142 FBS-selected late-type stars with infrared catalogs (2MASS and IRAS), we have shown that various groups can be separated, providing ways to better characterize the properties of these families, namely their nature and their heliocentric distances. In the near future we plan to extend this kind of study to the entire sample of late-type stars found on the FBS objective-prism plates, taking into consideration the forthcoming 2MASS data availability throughout the whole sky.

Acknowledgement. K.S.G. is grateful to the CNRS for making possible his visit to Observatoire de Marseille.

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ИНФРАКРАСНЫЕ ХАРАКТЕРИСТИКИ ЗВЕЗД ПОЗДНИХ СПЕКТРАЛЬНЫХ КЛАССОВ ИЗ ОБЗОРА FBS

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Приводятся первые результаты анализа инфракрасных характеристик слабых звезд классов M и C, выявленных на пластинках обзора FBS. Кросс - корреляция части объектов с инфракрасными каталогами показала, что можно выделить несколько групп звезд. Это позволяет хорошо характеризовать особенности этих групп, их природу и расстояния.

REFERENCES

1. *D.J.Schegel, D.P.Finkbeiner, M.Davis*, Astrophys. J., **500**, 525, 1998. (The IPAC extinction Web calculator is www.ipac.caltech.edu/forms/calculator.html).
2. *B.E.Markarian, V.A.Lipovetsky, J.A.Stepanian et al.*, Communications Of The Special Astrophys. Observ., **62**, 5, 1989.
3. *H.V.Abrahamyan, A.M.Mickaelian*, Astrofizika, **39**, 315, 1996.
4. *K.S.Gigoyan, N/Mauron, M.Azzopardi et al.*, Astron. Astrophys., **371**, 560, 2001.
5. IRAS Point Source Catalog. On The Optical Disk. (Sel. Astron. Catalogs), Supplied by NASA, vol. 2, 1991.
6. IRAS Faint Source Catalog. $|b| > 10^{\circ}$. On The Optical Disk. (Sel. Astron. Catalogs), Supplied by NASA, vol. 2, 1989.
7. *K.S.Gigoyan, H.V.Abrahamyan, M.Azzopardi, D.Russeil*, Astrofizika, **44**, 111, 2001.

8. *K.S.Gigoyan, H.V.Abrahamyan, M.Azzopardi, D.Russeil*, Astrofizika, **44**, 405, 2001.
9. *H.Andernach, R.J.Hanisch, F.Murtagh*, RSO Preprint №1033, 1994.
10. *C.B.Stephenson*, Astron. J., **90**, 784, 1985.
11. *D.Monet, B.Canzain, C.Dahn et al.*, The PMM USNOC-A2.0 Catalog, U.S.Naval Observatory and Univ. Space Research Assotiation, 1998.
12. *N.Christlieb, P.J.Green, L.Wisotzki et al.*, Astron. Astrophys., **375**, 366, 2001.
13. *G.Knapp, D.Pourbaix, A.Jorissen*, Astron. Astrophys., **371**, 222, 2001.
14. *M.Feast, P.Whitelock, J.Menzies*, Mon. Notic. Roy. Astron. Soc., **329**, pL7, 2002.
15. *E.J.Totten, M.J.Irwin, P.A.Whitelock*, Mon. Notic. Roy. Astron. Soc., **314**, 600, 2000.
16. *V.E.C.J. van der Veen, H.J.Habing*, Astron. Astrophys., **194**, 125, 1988.
17. *K.V.K.Lyengar, D.J.MacConnell*, Astron. Astrophys. Suppl. Ser., **133**, 201, 1998.
18. *G.R.Knapp, K.Young, E.Lee, A.Jorissen*, Astrophys. J. Suppl. Ser., **117**, 209, 1998.