The Nearby Stars

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Abstract

In this paper a short overview is presented about our knowledge of the solar neighborhood, which in this context extents to a distance of 25 parsec from our Sun. The astrometric, photometric, and spectroscopic properties of the stars within this sphere were compiled and critically evaluated at the Astronomisches Rechen-Institut since more than 50 years. At present, we know within this volume almost 4000 stellar objects. Some conclusions to be drawn from such a small sample for our Galaxy will be described in more detail.

1. Introduction

On July 9, 1951 Wilhelm Gliese (1915 - 1993) received from Peter van de Kamp, then professor at Swarthmore College and director of the Sproul observatory in Philadelphia and well known expert for faint nearby stars, the suggestion to work on nearby stars. Wilhelm Gliese then astronomer at the Astronomisches Rechen-Institut in Heidelberg and engaged in the preparation of a new version of the fundamental catalogue FK4 (Fricke, et al. 1963) was eager to enter a new research field aside of the routine astrometric work he had to do. The above date was the starting point of a very successful story which is still continuing: almost every time when a new extrasolar planet or a brown dwarf as a companion of a brighter star is detected this brighter star has an identification number in the Gliese-Catalog (Gliese, 1957, 1969) or its subsequent editions (Gliese and Jahreiß, 1979, 1991).

In the search for nearby stars we can distinguish several time periods. In the very beginning before about 1935 trigonometric parallax work was mainly focused on all bright stars having visual magnitudes $V < 6^m$. This strategy had the consequence that the median parallax for about 5,800 stars compiled in the General Catalog of Trigonometric Stellar Parallaxes (Jenkins, 1952) was only 18 mas (milliarcsec) and herewith not much larger than the mean error of ± 16 mas.

Measuring trigonometric parallaxes from ground was then –and is still– a rather tedious work. Therefore, a preselection is appropriate to obtain promising targets among the rapidly growing number of fainter stars. And indeed, a star having a high proper motion provided such a promising target.

Just to recall, the first proper motions of fixed stars were detected in 1718 by Edmund Halley for Aldebaran, Sirius, and Arcturus. Halley found the positions of these three stars to be half a degree different from those cataloged by Ptolemy, Hipparchus and Timocharis. Halley wrote: “It is scarcely credible that the Ancients could be deceived in so plain a matter, three Observers confirming each other. Again their stars being the most conspicuous in Heaven, are in all probability the nearest to the Earth; and if they have any particular motion of their own, it is most likely to be perceived in them.” And, indeed, all three stars are closer than 20 pc from the Sun, with Sirius – the brightest star on the sky – now the fifth nearest star. Also the first successful trigonometric parallax measurements in the year 1838 by F. W. Bessell for 61 Cygni, T. Henderson for α Centauri, and F.G. W. Struwe for Vega had high proper-motion stars as targets.

Having this in mind, Peter van de Kamp was one of the first astronomer starting trigonometric parallax work on faint high-proper motion stars. Yet, in this time period only a small number of parallaxes could be determined, and in his first Catalog of Nearby Stars (Gliese, 1957) also spectroscopic parallaxes were taken into consideration. The advent of photoelectric photometry in the sixties of the last century allowed also the use of photometric UBV RI parallaxes in the second edition (Gliese, 1969). The search limit was then extended to 22 parsec.

Photometry was much easier to obtain than trigonometric parallaxes and in the following years extensive photometric surveys by Olin Eggen, Ed Weis, and others of the high-proper motion catalogs compiled by Luyten (1979, 1980) or Giclas provided many new nearby stars. Simultaneously, with the commissioning of the 61-inch US Naval astrometric reflector (Strand, et al. 1974), designed to determine trigonometric stellar parallaxes of stars too faint for the reflectors being then in use, a considerable improvement in trigonometric parallax work took place. Therefore, within a rather short time interval almost 300 new nearby stars became known as well as an additional list of 159 nearby candidates (Gliese and Jahreiß, 1979). In 1991 a first digitized version (Gliese and Jahreiß, 1991) was published.

Later on, in the mid nineties, the discovery of the first extrasolar planet around the G5 dwarf Gliese 882 = 51 Peg (Mayor and Queloz, 1995) and of the first brown dwarf Gliese 229B (Nakajima et al. 1995) gave an enormous impetus to improve and extend the search for the missing faint nearby stars. Only two years later the Hipparcos Catalog (ESA, 1997) provided trigonometric parallaxes of unprecedented accuracy for practically all bright stars. Consequently, the bright portion ($M_V < 9$ mag) of the *Catalog of Nearby Stars* was at once cleaned from problematic distance determinations (Jahreiß and Wielen, 1997). Photoelectric photometry was limited to stars brighter than $V \sim 15^m$, and the determination of spectral types and spectroscopic parallaxes had an even brighter limit of $V \sim 12^m$. But, the definition of MK spectral types for M dwarfs in the infrared portion of the spectrum overcame these constrains, see Jahreiß et al. (2001), and allowed eventually the extension of the search to the faintest stars in Luyten’s high-proper motion catalogs.

This search could be even more intensified at the beginning of the 21st century when the large infrared surveys 2MASS and DENIS came in use, and Willem Luyten's catalogs could be supplemented by new and deeper high-proper motion surveys based on the various *digital sky surveys* (DSS).

A further great step forward will occur with ESA's new astrometric mission GAIA (Perryman, 2005). GAIA will be launched in 2012 to observe within five years one billion stars, complete to $V \sim 20^m$, and providing parallaxes to an accuracy of 20 microarcseconds. GAIA will not only measure distances and proper motions, but also radial velocities and further spectroscopic properties of the stars. Such we may obtain the most accurate 3D-picture of our Galaxy we have ever had.

2. The data

The substantial progress in our knowledge obtained during the past half century is illustrated in Table 1 where the number of stars in the subsequent versions of the Catalog of Nearby Stars are compared for increasing distance intervals from the Sun. The search limit for the first Gliese-Catalog in 1957 was 20 parsec much larger than previous compilation of the nearest stars but still appropriate to the precision of the trigonometric parallax measurements then obtained. In 1969 the search limit was extended to 22 pc, and later on to 25 pc taking into account the progress in measuring trigonometric parallaxes.

Table 1. *The progress of the Catalog of Nearby Stars*

CNS [pc]	1957	1969	1996	2005	number density	number density %
0 - 5	52	54	65	66	.126	100
5 -10	179	207	268	300	.082	65
10 - 20	863	918	1593	2018	.069	55
20 - 25			949	1515	.047	38
0 - 20	1094	1179	1926	2384	.071	56
0 - 25			2875	3899	.060	47

Since 1969, i.e. during the past 40 years, fourteen new objects were detected and confirmed by trigonometric parallaxes to be within the innermost sphere of 5 parsec. Among these the brown dwarf (T1 + T6) binary detected in 2003 as a very wide (separation 402 arcsec) common proper motion companion to the K4 dwarf Gliese 845 = ε Indi by Scholz et al. (2003).

At present we know within 5 pc altogether 68 individual stars in 50 stellar systems: 1 A-, 1 F-, 3 G-, 49 M-dwarfs, furthermore 4 white dwarfs and 4 brown dwarfs. This led to a mean distance of 2.7 pc between the different stellar systems. Yet, as can be seen in Table 2, our nearest neighbors - the triple system α Centauri A+B together with Proxima Centauri - are only 1.3 pc away. The individual components have the properties listed in Table 2. Column 6 gives the luminosity in solar luminosities, and column 7 the mass in solar masses.

Table 2. *Our nearest neighbors Proxima Centauri and α Centauri A and B*

	R [pc]	Spectral type	m_V	M_V	$L/L_\odot$	$M/M_\odot$
Proxima Cen	1.31	M5.5	11.05	15.48	.000 06	0.11
α Centauri A	1.33	G2 V	0.01	4.38	1.51	1.14
α Centauri B	1.33	K2 IV	1.35	5.72	0.44	0.91

In Table 3 similar properties of the two absolute brightest stars in our sample as well as three of the faintest objects are listed. The K giant Aldebaran has a M2 dwarf companion at a separation of about 30”. The fast rotator Regulus has a K1 + M4 dwarf binary at 177 arcsec separation, and may be itself a spectroscopic binary with a white dwarf component of 0.3 solar masses. Gliese 229B - the first brown dwarf - was detected by Nakajima et al. (1995) as companion to the M2 dwarf Gliese 229. These examples are already clear indications that most of the nearby stars appear in binary or multiple systems.

Table 3. *The two absolute brightest and three of the faintest stars known within 25 pc*

name	R [pc]	Spectral type	M_V	M_K	$M/M_\odot$
Aldebaran	20.4	K5 III	–0.64	–4.53	~2.5
Regulus	24.3	B8 IV	–0.53	–0.82	3.4
Gliese 229B	5.8	T7 V	~26.0	15.61	~0.04
Gliese 570D	5.9	T8 V		16.40	~0.04
2M0415-09	5.7	T8 V		16.64	~0.04

The color-magnitude diagrams in Figure 1 and 2 give an overview what types of stars are populating the closer solar neighborhood. Thanks to the Hipparcos parallaxes the bright part of the V vs. B-V diagram in Figure 1 shows the true distribution for $M_V < 8^m$. The three brightest stars are indicated by their popular names.

Apart from Regulus, a B8 type subgiant, no further OB stars are within 25 pc. The upper part in the red is populated by 37 K giants headed by Aldebaran and Arcturus.

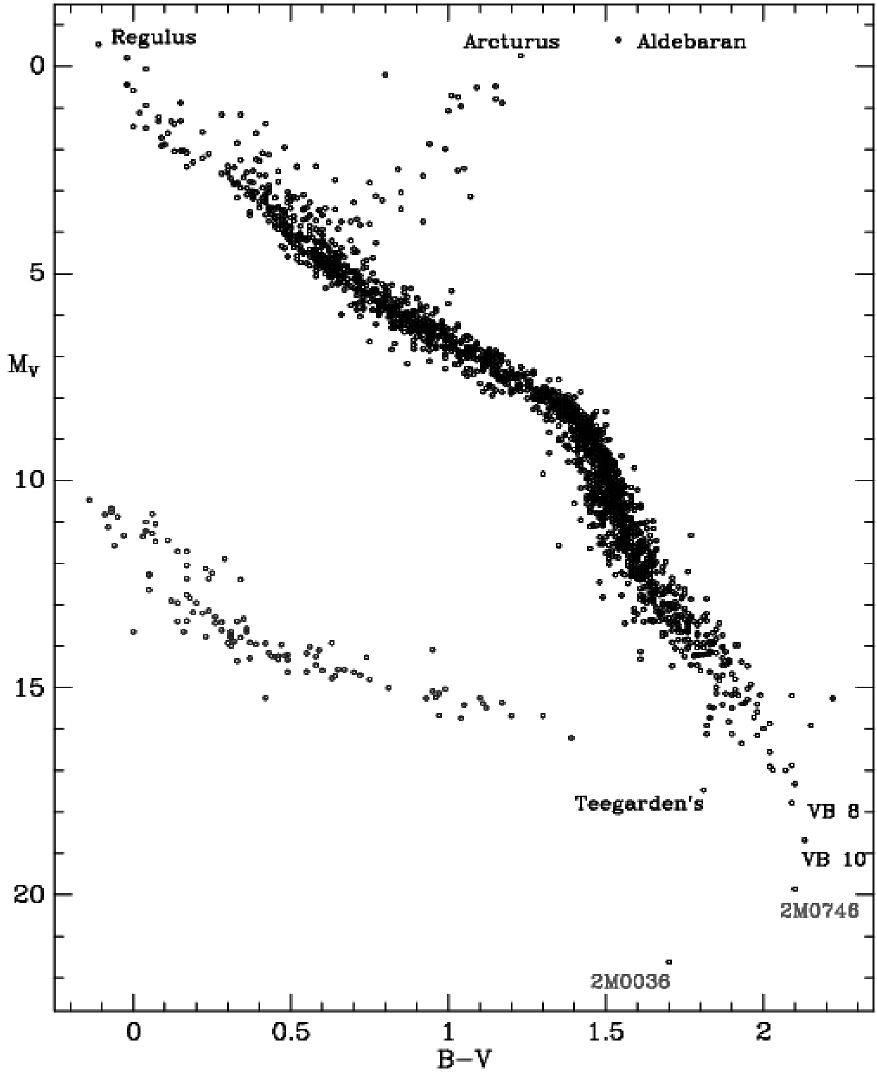

Figure 1. *The color-magnitude diagram shows 2000 stars within 25 pc having trigonometric parallax errors smaller than 15 per cent and reliable visual magnitudes. For $M_V < 9^m$ the true distribution can be seen, whereas for the fainter dwarf stars the increasing incompleteness of the catalog becomes dominant.*

At the lower end of the main sequence ($M_V > 8^m$) we find the M dwarfs. Some interesting objects were designed by name. Teegarden's star, a M6.5 dwarf of relatively bright $V = 15.40^m$ is at a distance of 3.8 pc. It was detected only very recently by the Near Earth Asteroid Tracking (NEAT) project (Teegarden et al. 2003) due to its very high proper motion of 5.05 arcsec/year. At present, only nine objects are known with higher proper motions. The two faintest objects detected in the 2MASS Survey (Skrutskie et al. 2006) are brown dwarfs with rather poor optical photometry. Most of the presently known brown dwarfs could be detected in infrared surveys, and are much fainter in optical wavelengths. Therefore, it is more appropriate to present the bottom of the main sequence in a color magnitude diagram (see Figure 2) defined by the infrared colors provided from the 2MASS survey.

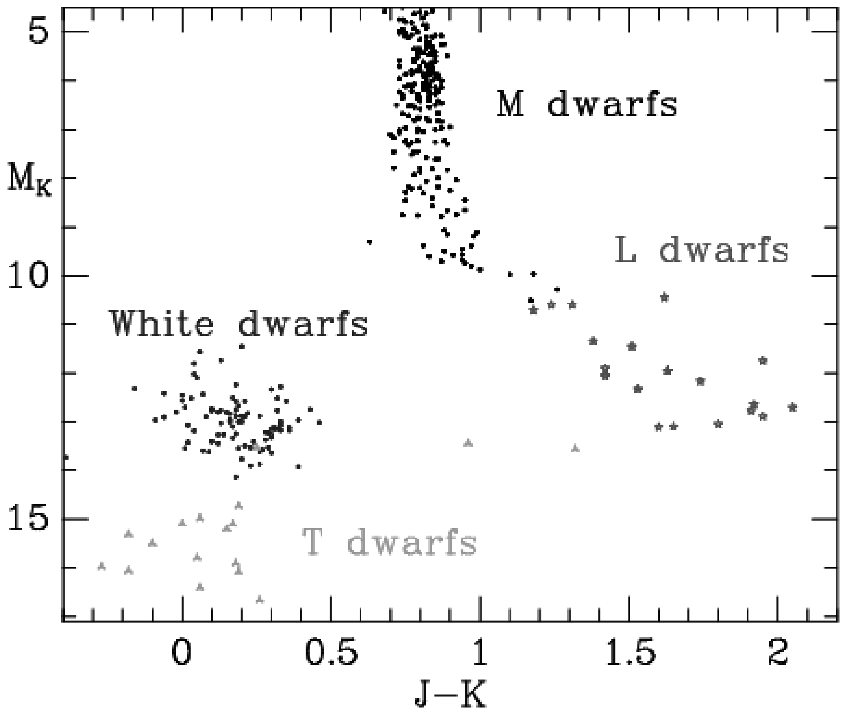

Figure 2. *The color magnitude diagram of the nearby stars in 2MASS infrared magnitudes shows the bottom of the main sequence: M dwarf stars, white dwarfs, and the brown dwarfs of type L and T. Theoretically predicted since several decades the first specimen - Gliese 229B - was only detected in 1995.*

3. The stellar luminosity function

Our Sun is about 8 kiloparsec away from the galactic center and is located about 15 pc above the galactic plane. Compared to the dimension of our galaxy the volume occupied by our nearby star sample is extremely small. We can assume that within this tiny volume the stars are homogeneously distributed. Therefore, the deficit of absolutely faint nearby stars must be due to the incompleteness of our sampling. More detailed information about this incompleteness can be obtained in analyzing the cumulative distribution of our star sample for different absolute magnitudes. In an log(parallax) versus log(number of stars) diagram the cumulative distribution of a volume complete sample is expected to increase with slope –3. The result is shown in Figure 4. Here the straight border lines have slope –3, and the upper curve, the cumulative distribution of all stars, shows such a slope only to a distance of about 6 pc. For the stars with larger distances the slope becomes flatter. In other words, incompleteness starts at about 6 pc and is caused by the absolutely faint stars. This is demonstrated by the middle curve showing the distribution of all CNS4 stars with $M_V > 8^m$. Whereas, the distribution of the absolutely bright stars with $M_V < 8^m$, which is represented by the lower curve, follows slope –3 till the limiting distance of 25 pc, i.e. the bright nearby stars are statistically complete.

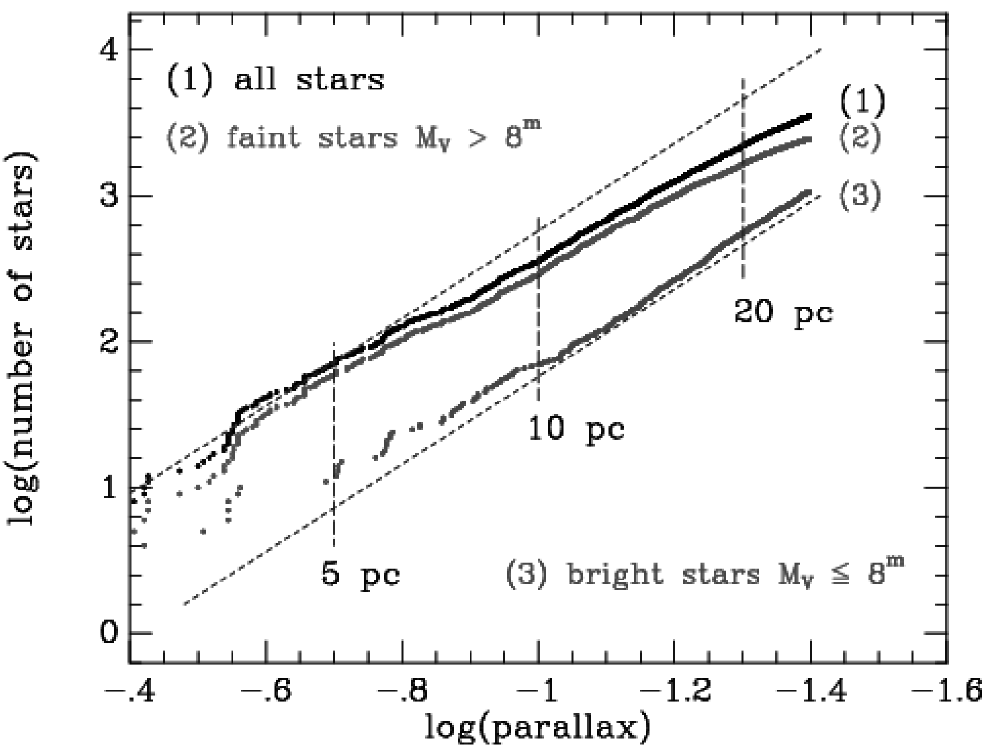

Figure 4. *The cumulative values of log(N) vs. log(parallax) for all CNS4 stars (upper curve), for the absolutely fainter stars (middle curve), and for the brighter stars (lower curve). The dashed straight lines have slopes of –3, characterizing a statistically volume complete sample. Obviously the catalog is complete for the bright stars (3), whereas the incompleteness for the whole catalog (1) is governed by the absolutely fainter stars (2) and begins immediately beyond 5 pc.*

A detailed investigation allows us to determine complete subsamples defined by distance and also declination zones on the sky. For example, Luyten's catalogs of high-proper motion stars are reaching fainter objects for the portion of the sky covered by the Palomar Survey with a limiting magnitude of $m_{pg} \sim 21^m$. Under the reasonable assumption that the faint stars in our search volume near the galactic plane are homogeneously distributed, it is possible to construct the luminosity function representing the true distribution of the nearby stars.

In Table 4 the resulting luminosity function of the nearby stars is given for visual absolute magnitudes. For each magnitude bin (column 1) $\Delta M_V = M_V \pm 0.5^m$ the function $\Phi(M_V)$ in column 2 gives the number of stars within a sphere of radius 20 pc. The errors given in column 3 are Poisson errors. Column 4 lists the

Table 4. *The luminosity function (number of stars within 20 pc³)*

M_V	$\Phi(M_V)$	ε_Φ	$\Phi(M_V)$ main seq.	$L/L_\odot$	$M/M_\odot$
–1	1	1	.5	213	5.4
0	4	2	2	85	3.5
1	11	3	8	34	2.6
2	16	3	14	13	1.8
3	41	5	36	5	1.5
4	57	6	53	2	1.2
5	98	7	98	0.8	1.0
6	100	7	100	0.34	0.9
7	98	7	98	0.134	0.75
8	112	9	112	0.054	0.66
9	140	14	140	0.021	0.58
10	235	50	235	0.0085	0.51
11	299	57	277	0.0034	0.37
12	427	191	427	0.0013	0.25
13	512	209	427	0.0005	0.17
14	341	171	256	0.00021	0.14
15	597	226	597	0.00008	0.12
16	427	191	427	0.00003	0.10
17	341	171	341	0.00001	0.09

luminosity function for the main sequence stars only, i.e. red giants above and white dwarfs below the main sequence (see Figure 1) were eliminated. Finally, column 5 and 6 give the visual luminosity in units of the solar luminosity and the mass for a corresponding main sequence stars in solar masses, respectively.

The resulting luminosity function proves that by far the most frequent number of stars in the solar neighborhood are M dwarfs with absolute visual magnitudes in the range $M_V \sim 13^m - 15^m$. These stars are five times more common than solar type stars, to recall the Sun's $M_V = 4.83^m$. Yet, as can be seen in column 5 and 6, the luminosity of such a M dwarf is less than 1/2000 of the solar luminosity, and its mass is smaller than 1/7 of the solar mass. On the other side, the maximum of the total luminosity, with more than 700 $L_\odot$, comes from the few A dwarfs and K giants near $M_V = 0^m - 1^m$.

The transition from red to brown dwarfs, i.e. objects with and without hydrogen-burning nuclear fusion has in color or spectral type no exact limit. It occurs near spectral type M7 around $M_V = 17^m$. Initially as many brown dwarfs were expected as red dwarfs. Now, recent investigations (Cruz et al. 2007) estimate about 1,000 brown dwarfs within 25 pc, i.e. almost six times less than ordinary M dwarfs.

Table 5. *Estimated number of nearby stars within 25 pc according to spectral types*

A	F	G	K	M0…6.5	M7…9.5	L	T	K	White
dwarf stars					brown dwarfs			giants	dwarfs
40	140	260	570	5700	320	250	460	37	320

Table 5 gives the number of stars to be expected within 25 pc for different spectral types. The first five columns give the number of ordinary main sequence stars, columns 6 to 8 the number of brown dwarf stars. Columns 9 and 10 list the number of K giants and white dwarf stars, respectively. From Table 3 we derive the local stellar mass density to $0.04\ M_\odot/pc^3$. The local density of the interstellar matter is $\sim 0.05\ M_\odot/pc^3$. Since the dynamically determined local mass density is estimated to $0.102 \pm 0.010\ M_\odot/pc^3$ (Holmberg and Flynn, 2000) the formerly often discussed *missing mass* is obviously smaller than 10 per cent. Summing up the luminosities in Table 4 the mass to luminosity relation results in M/L = 0.8.

4. Velocities

For most of the nearby stars radial velocities are available. This allows the computation of their space velocity components: U in the direction of the galactic center, V in the direction of galactic rotation, and W in the direction of the north galactic pole. Our Sun has the following velocity components

$$(U, V, W) = (8.3 \pm 1.3, 7.8 \pm 3.3, 8.0 \pm 1.4) \text{ km/s}$$

with respect to the *local standard of rest* characterising the velocity centre, with that the stars in the solar neighbourhood are rotating around the galactic centre. This value already shows, that our present picture of the solar neighbourhood is only a snapshot. Due to the *velocity dispersion* shown in Figure 6 as a function of age the content of the 25 pc sphere remains not constant in time: we meet in our neighbourhood stars coming from very distinct locations of our Milky Way.

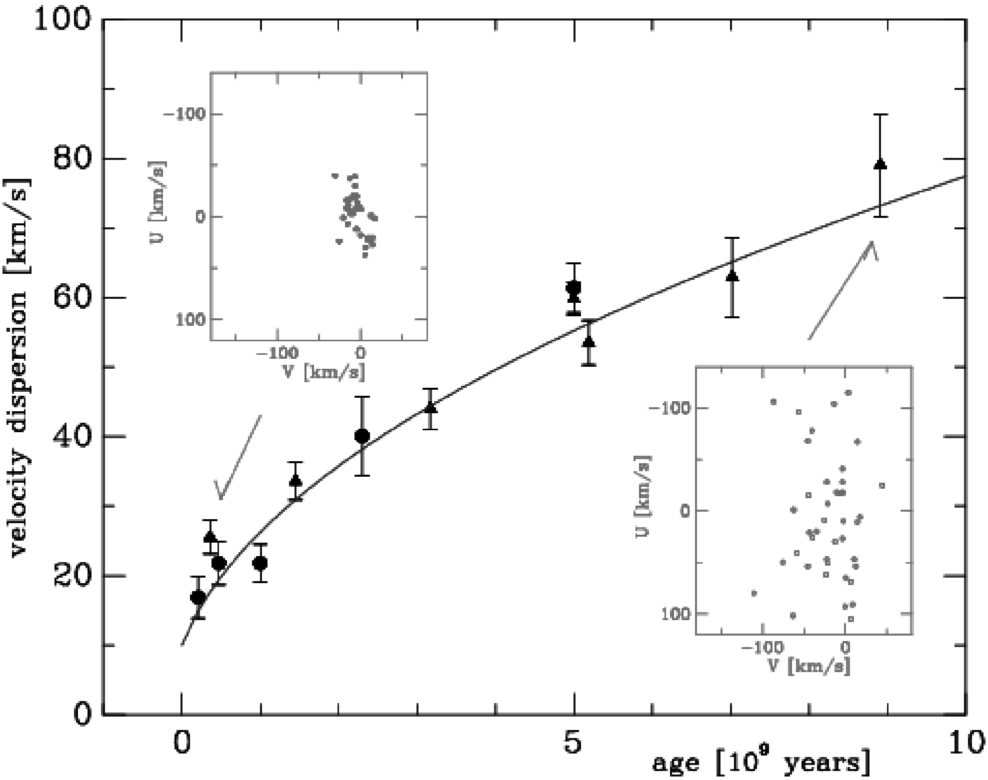

Figure 5. *The increase of the velocity dispersion with increasing age of the stars. The inner panels illustrate the increasing velocity distribution for a young and old subsample within the galactic plane. Such an increase can be best explained by a diffusion process of the stellar orbits (Wielen, 1977).*

We may ask are there stars coming closer to our Sun than our present nearest neighbour Proxima Centauri. Figure 5 contains all such stars coming closer than 2 parsec within the past or future 80,000 years. We see the more interesting events occur in the near future. Barnard's star, a M4 dwarf with the largest known proper motion (10.4 arcsec/year) will have its closest encounter in 10,000 years. But, it cannot outrun Proxima Centauri, whose closest approach will take place in 30,000 years. Only between 32,000 and 50,000 years the α Centauri triple system will be superseded by Ross 248 and Gliese 445. Since several decades it is speculated that the extinction of the dinosaurs 65 million years ago was due to a Nemesis star. It should have entered the Oort cloud, whose outer limit is at about 0.5 parsec, and triggered a cometary shower into the inner solar system with several comets striking our Earth.

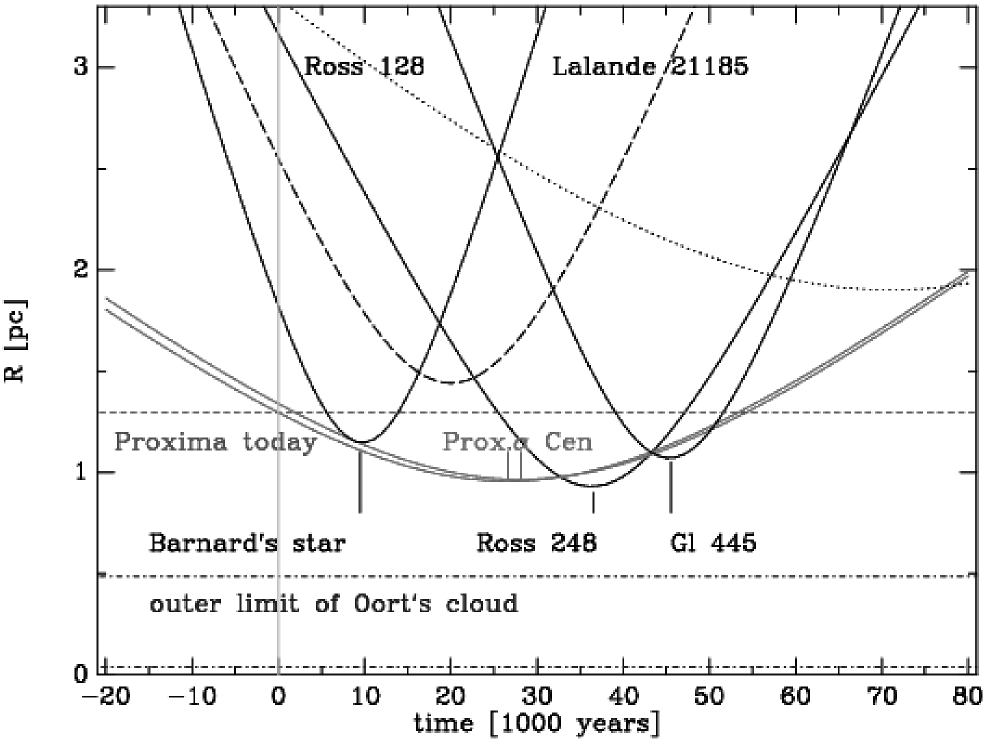

Figure 6. *Closest approach of known stars within 100 000 years. None of these stars is entering the Oort cloud whose outer limit is at about 0.5 parsec.*

We may ask, can we find such a Nemesis star in our catalog. The stars in Figure 6 remain too far away from the Oort cloud. Even expanding the search to the full Hipparcos catalog,, only one candidate remains: the K7 dwarf Gliese 710. This 0.65 solar mass star was detected in a spectroscopic survey more than sixty years ago. Already its discoverer A.N. Vyssotsky (1948) was aware of a possible close approach to the Sun due to its negative radial velocity and almost zero proper motion. Using the best available data its closest encounter with the Sun will be 0.25 ± 0.13 parsec, and it will occur in 1.36 ± 0.04 million years from now.

5. Conclusion

Within the past 60 years the compilation and critical evaluation of subsequent versions of the Catalog of Nearby Stars or in short Gliese Catalog provided valuable information not only about our immediate solar neighbourhood but also far beyond. Only here with the best data by hand it was possible to study in more detail the distribution and kinematic properties of the faint stars constituting the most numerous stellar species in the Milky Way. Only in recent years the Hipparcos satellite and the various digital sky surveys in combination with infrared surveys like 2MASS or DENIS, and not to forget the Sloan Digital Sky Survey (SDSS) offered the opportunity to study these stars in more distant regions. But, the fundamental properties remain more or less unchanged, and we may expect most curiously the results of the GAIA mission.

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