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ASTRONOMY AND ASTROPHYSICS

# New astrometric binaries among HIPPARCOS stars

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**Abstract.** A new realization of the International Celestial Reference System (ICRS) is built upon the data of the HIPPARCOS catalogue and astrometric ground-based catalogues of the $20^{th}$ century reduced to the HIPPARCOS system. Non-linear motion of some stars has been detected with this realization of the ICRS. This motion is separated into the proper motion of the barycentre and the revolution of the photocentre around the barycentre. The latter is believed to be induced by fainter components of star-like mass. The periodic motion of the photocentres of the stellar systems HIP 4427 ($\gamma$ Cas), HIP 11072, HIP 45699, HIP 54214 and HIP 116727 is discussed in detail. Related periods and amplitudes are evaluated and proposed for confirmation by other methods. The periodic motion of the photocentre of *Be* star $\gamma$ Cas is of particular interest.

**Key words:** astrometry – reference systems – catalogs – stars: binaries: general – stars: individual: gam Cas

## 1. Introduction

Stellar systems with faint satellites of star-like mass can be discovered and investigated by separating the observed spatial motion of the visible star or photocentre into its revolution around the barycentre and the linear motion of the barycentre. Such stellar systems are known as astrometric binaries. The data usually used for their discovery and investigation are series of star positions published in observational astrometric catalogues at various epochs and referred to a common coordinate system. Such a system, the ICRS, officially adopted by the IAU (1999) is realized at optical wavelengths by the HIPPARCOS catalogue (HIP) (ESA 1997). Therefore this catalogue can be used as the reference for all other catalogues.

Only few astrometric binaries were known before the HIPPARCOS. This mission found 2622 stars with proper motion variable in the course of 3.36 years of the mission. They are listed in the part DMSA/G, acceleration solution, of the HIP catalogue. These objects are suspected astrometric binaries with periods above some 10 years. A few hundred additional stars with considerable discrepancy between HIP and ground-based proper motions are pointed out by many authors (Wielen 1997; Gontcharov & Kornilov 1997). The reason for such a discrepancy is that the HIP proper motion is an 'instantaneous' motion of the photocentre during the mission, whereas the ground-based one is close to the barycentric motion of the stellar system during several decades. Thus, the HIP is not a perfect realization of the ICRS at optical wavelengths. The HIP proper motions should be refined by the data from compiled and observational ground-based catalogues.

This can be done by different methods. The first one is based on the principles of statistical astrometry developed by Wielen (1997) and realized in the FK6 catalogue by Wielen et al. (1999).

Another method is rather obvious (see Wielen et al. 1999, Sect. 3): to combine many ground-based catalogues directly with the HIP. In this paper we consider some results obtained within our realization of this method.

## 2. Method

We considered 4638 stars common to the HIP and FK5/FK5 Extension catalogues. The list of 45 observational ground-based catalogues that we used includes the ones obtained in 1938–1994 by astrometric instruments in La Palma, Washington, Pulkovo, Perth and others. The list is being published by Gontcharov et al. (2000). Some basis of the method is described by Gontcharov & Kornilov (1997).

The procedure was:

1. Mean weighted proper motions were calculated using the proper motions from the well-known catalogues: HIP, GC, N30, FK5 as well as from new compilations: N70E (Kolesnik 1997), CMC9 (Carlsberg Meridian Catalogue # 9 1997), KSV2 (Time Service Catalogue 2) (Gorshkov & Scherbakova 1998).
2. Those calculated mean proper motions together with positions, radial velocities and parallaxes from the HIP were used to calculate the differences $\Delta\alpha$ and $\Delta\delta$ in the sense of 'catalogue minus HIP at the catalogue epoch' for every *single* star in every observational ground-based catalogue.
3. The systematic trend in these differences was approximated by Legendre-Hermite-Fourier functions of $\alpha$ and $\delta$, and then eliminated from the coordinates of *all* stars in the observational ground-based catalogues.

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4. The proper motions were recalculated using the series of corrected ground-based positions. These proper motions were then used for the next iterations (steps 2–4) until the obtained improvements were insignificant.

The accuracy of the ground-based catalogues and transformation procedure was tested by intercomparison of catalogues with close epochs as well as by comparison with the HIP. The mean dispersion of the residuals in the sense 'catalogue minus HIP at the catalogue epoch' is less than 0.2 arcsec for all refined catalogues.

After three iterations we can consider the refined observational catalogues as being referred to the ICRS. The obtained proper motions together with positions, parallaxes and radial velocities from the HIP can be considered as a new optical realization of the ICRS (very close to the HIP for the epoch 1991.25). It will be published elsewhere as the Proper Motions of Fundamental Stars catalogue (PMFS). The linear motion of these 4638 stars (i.e. classic proper motion) is derived with a precision of about 0.5 milliarcseconds per year (hereafter mas/year) for probable single stars and 1–2 mas/year for known or suspected non-single ones. For a few hundred stars (in fact, stellar systems) with significant non-linear motion of the photocentre in the PMFS a separation of the motion into the photocentre revolution around the barycentre and the linear motion of the barycentre was possible.

Our refined star positions at various epochs allow us to detect and investigate periodic non-linear motion with amplitude of more than 0.15 arcsec and periods from 10 to 100 years. There are some 60 known systems with such parameters of orbital motion. Some of them were used as a test of reliability of our results: good agreement with known orbits was found.

## 3. Results

All results for non-linearly moving stars will be published elsewhere as the Astrometric Binary Catalogue. The results for 5 astrometric binaries are discussed here in detail. Some of the stars are known as visual, spectroscopic or astrometric double or triple systems. But no periodic motion of components or photocentre has ever been observed. Since the amplitudes and periods of the motion are now estimated astrometrically we recognize the stars as new astrometric binaries.

The barycentric linear motion of these stellar systems and its precision in mas/year taken from the PMFS are listed in Table 1 together with the proper motions from the FK5, HIP and long-term prediction proper motions (so called LTP mode) from the FK6(I) (Wielen et al. 1999). As expected, in most cases the PMFS barycentric linear motion is closer to the 'long-term' FK5 and FK6 proper motions than to the 'instantaneous' one from the HIP.

Figs. 1 – 5 show the variations with time of the right ascension (Fig. 1a etc.) and declination differences (Fig. 1b etc.) in mas between the individual catalogue positions and the PMFS. The mean linear motion (i.e. barycentric motion) has been subtracted to show more clearly some non-linear component of the motion. Every dot with error bar is the result from one ground-based catalogue. The HIP position is at epoch 1991.25 and has practically zero difference. The curves are drawn for visualizing the coordinate variations.

**Table 1.** The proper motions of the astrometric binaries

| HIP number | | PMFS | FK5 | FK6 | HIP |
|---|---|---|---|---|---|
| 4427 | $\mu_{\alpha*}$ | $+23.7 \pm 0.4$ | $+26.0$ | | $+25.7$ |
| | $\mu_\delta$ | $+0.3 \pm 0.6$ | $-5.3$ | | $-3.8$ |
| 11072 | $\mu_{\alpha*}$ | $+196.4 \pm 0.8$ | $+200.2$ | | $+197.3$ |
| | $\mu_\delta$ | $-60.1 \pm 1.7$ | $-62.3$ | | $-4.4$ |
| 45699 | $\mu_{\alpha*}$ | $-124.6 \pm 0.4$ | $-124.2$ | $-124.0$ | $-133.5$ |
| | $\mu_\delta$ | $-127.5 \pm 0.7$ | $-127.3$ | $-126.4$ | $-134.2$ |
| 54214 | $\mu_{\alpha*}$ | $+12.7 \pm 0.4$ | $+12.8$ | $+14.3$ | $+25.8$ |
| | $\mu_\delta$ | $-78.9 \pm 0.7$ | $-79.0$ | $-76.7$ | $-71.4$ |
| 116727 | $\mu_{\alpha*}$ | $-74.5 \pm 0.7$ | $-67.4$ | | $-48.9$ |
| | $\mu_\delta$ | $+142.4 \pm 1.7$ | $+150.9$ | | $+127.2$ |

For all the systems there is an interrelation between the variations of $\alpha$ and $\delta$ so that an elliptical orbit can be determined describing the motion. Moreover, all parameters of the systems are consistent with the constraining formula: $\sum M = a^3/(\pi^3 \cdot P^2)$, where $a$ – semi-major axis in mas, $\pi$ – parallax in mas, $P$ – orbital period in years, $\sum M$ – sum of masses of components in solar mass. The latter, being a function of absolute magnitudes, was roughly evaluated from the HIP data.

### 3.1. HIP 4427 ($\gamma$ Cas)

The results are shown in Fig. 1. The most probable period is $\geq$60 years, the amplitude of the photocentre motion is about 150 mas. We can estimate a parallax of 6.5 mas and a semi-major axis of $\geq$300 mas (46 AU). All these data are consistent with the known sum of masses of $26 M_\odot$. The proposed parallax is slightly higher than the one in the HIP, 5.3 mas, but it is still consistent with the HIPPARCOS intermediate data.

About a hundred recent publications relate to $\gamma$ Cas, a widely investigated *Be* star with a tilted circumstellar disk. It is a known double system (components *A* and *B*) with a supposed third component *a* close to *A*. The masses of 3 components *A*, *a* and *B* were evaluated by Tokovinin (1997): 17.80, 8.33 and 1.20 $M_\odot$. Our results may reflect the orbital motion of the photocentre of the pair *Aa*. It may help to confirm the existence of the component *a*.

### 3.2. HIP 11072

This star is known from the HIP (see part DMSA/G in Vol.1 of the HIP catalogue) as an astrometric binary with acceleration solution. There is some disagreement between the known spectral type – G2V and the absolute magnitude from the HIP – 3.6$^m$. The secondary may have contributed to the magnitude determined by HIPPARCOS.

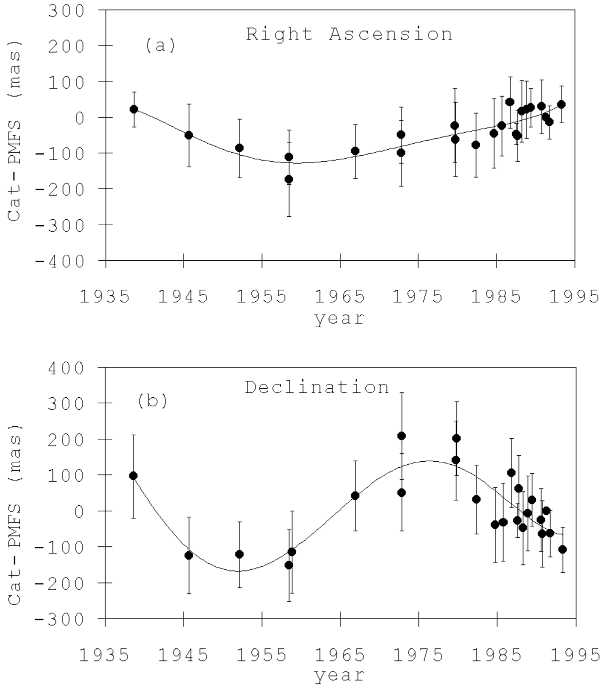


**Fig. 1a and b.** HIP 4427 non-linear motion: **a** right ascension, **b** declination

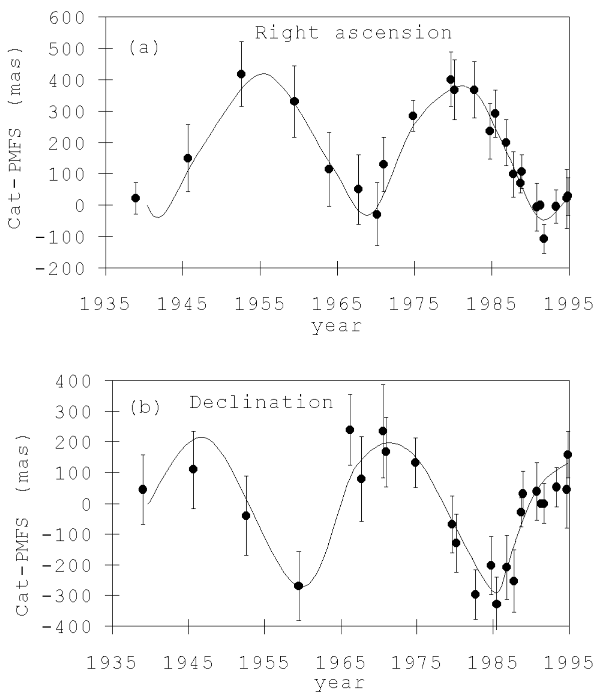


**Fig. 2a and b.** HIP 11072 non-linear motion: **a** right ascension, **b** declination

The results are shown in Fig. 2. The most probable period is about 25 years, the amplitude of the photocentre motion is about 250 mas. We can estimate a semi-major axis of about 500 mas and a mass sum of $2M_\odot$ which would be consistent with the known parallax of 46 mas.

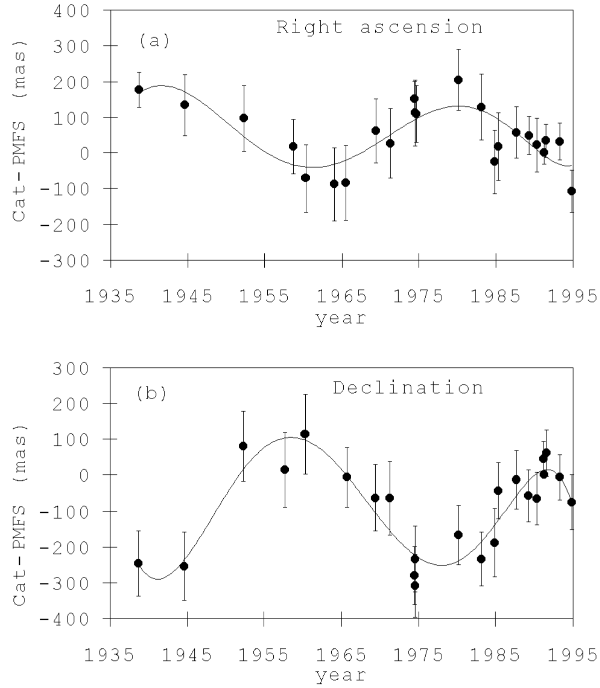


**Fig. 3a and b.** HIP 45699 non-linear motion: **a** right ascension, **b** declination

### *3.3. HIP 45699*

The results are shown in Fig. 3. The most probable period is about 35 years, the amplitude of the photocentre motion is about 170 mas. We can estimate a semi-major axis of about 350 mas and a sum of masses of $2M_\odot$ which would be consistent with the known parallax of 26 mas. This star has been marked in the FK6 as a highly probable astrometric binary.

### *3.4. HIP 54214*

The results are shown in Fig. 4. The most probable period is about 30 years, the amplitude of the photocentre motion is about 200 mas. The most reasonable relation between the semi-major axis – 300 mas, parallax – 18 mas (instead of 16 mas in HIP) and sum of masses – $5M_\odot$ suggests that the hidden secondary is more massive than the primary. This star has been marked in the FK6 as a highly probable astrometric binary.

### *3.5. HIP 116727 ($\gamma$ Cep)*

This is a known spectroscopic triple system with periods of 2.5 and >30 years as found by Walker et al. (1992). This star is also known from the HIP (see part DMSA/G in Vol.1 of the HIP catalogue) as an astrometric binary with acceleration solution. There is some disagreement between the known spectral type – K1IV and the absolute magnitude from the HIP – $2.5^m$. The secondary and tertiary have probably contributed to the magnitude determined by HIPPARCOS.

The results are shown in Fig. 5. The most probable period is about 45 years, the amplitude of the photocentre motion is

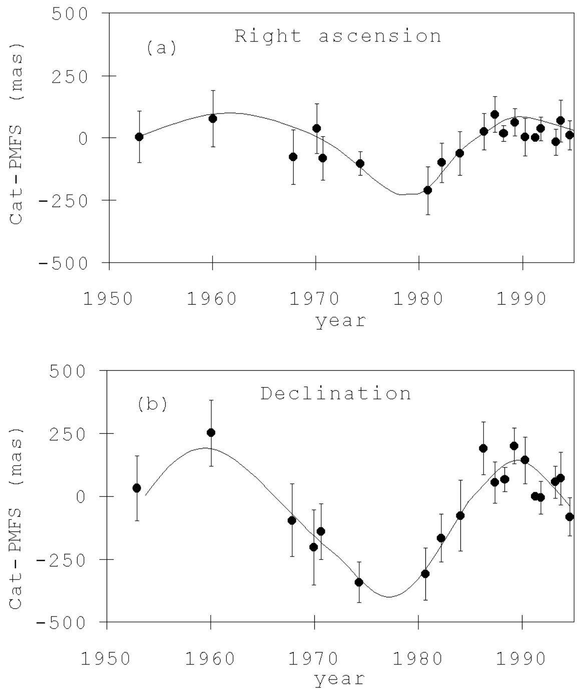


**Fig. 4a and b.** HIP 54214 non-linear motion: **a** right ascension, **b** declination

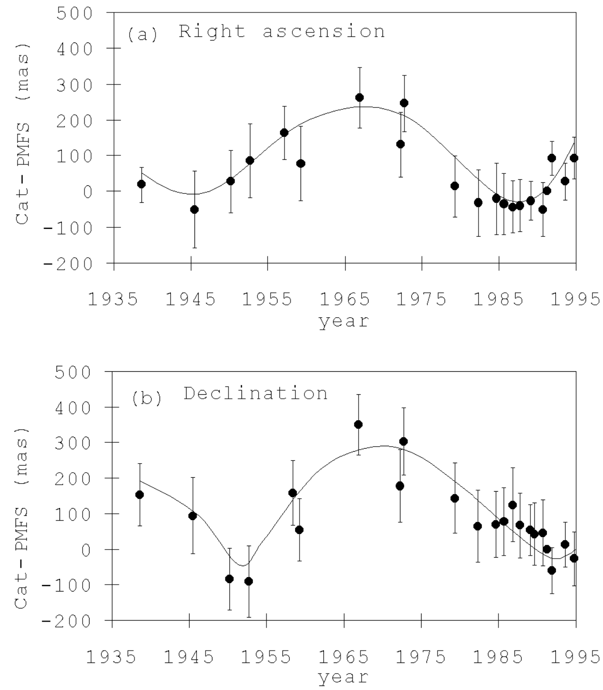


**Fig. 5a and b.** HIP 116727 non-linear motion: **a** right ascension, **b** declination

about 150 mas. We can estimate a semi-major axis of about 1300 mas and a sum of masses of $3M_\odot$ which would be consistent with the known parallax of 73 mas. This non-linear motion of the photocentre may be associated with a known spectroscopic component.

## 4. Conclusions

Information from past astrometric ground-based catalogues was combined directly with the HIPPARCOS data to investigate non-linear star motions. Periods and amplitudes of the orbital motion of the photocentre of 5 stellar systems were evaluated for the first time. These amplitudes are near to the precision of the results and confirmation by other methods is therefore needed.

The results presented here can be interpreted as evidence for faint massive bodies in those stellar systems. The existence of such bodies should be further confirmed by interferometers or large telescopes.

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