

DETAILS OF THE SPATIAL STRUCTURE AND KINEMATICS OF THE CASTOR AND URSA MAJOR STREAMS

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Abstract. A list of the Castor stream members is compiled based on the data from various authors. The membership probabilities for some stars are revised based on the individual apex, multiplicity, observational errors, and peculiarity. The apex of the Castor moving group is determined using the apex diagram method. The parameters of the Castor and Ursa Major streams are compared and the positions of the two streams on the apex diagram are found to differ by 225° , implying that the two groups move in almost opposite directions. Stars of both moving groups are intermixed in space, the Castor stream occupies a smaller volume than the UMa stream and is located inside it. Our results can be useful for understanding the morphology of the Galactic disk in the Sun's vicinity.

Key words: Galaxy: solar neighborhood – open clusters and associations – moving groups: individual: Castor, Ursa Major

1. INTRODUCTION

Our analysis of stellar groups is based on the use of their proper motions, radial velocities, and parallaxes. The accuracy and reliability of these parameters depend on the distance to the stars. To obtain the most reliable results, here we investigate the Castor and Ursa Major (UMa) streams, which are the closest to the Sun and therefore may provide insight into the structure of the Galactic disk in the solar vicinity.

A feature of both streams is that they have many multiple systems, some of which consist of up to six stars! For example, the UMa stream contains a sextuple system, which includes Mizar and Alcor (Mamajek et al. 2010) and, perhaps HD 76644 (Zhuchkov et al. 2006). Moreover, the UMa stream contains three kinematic groups.

To investigate the space motions of the stars, we use the AD-method that we developed earlier. This method consists in searching for regularities in the positions of “individual star apexes”. The individual star apex is the point in the sky indicating the direction of the space velocity of the star if the velocity vector starts from the origin of the equatorial system. The right ascension and declination of this point are denoted as A and D , respectively. This method is good at showing details of motions and can be used to reliably detect the kinematic structure.

The layout of this paper is as follows. We first compile the list of the Castor

stream objects with the membership revised using the AD-method and stars with large errors discarded. We then compute the apex of the Castor stream and compare its parameters with those of the UMa stream. We find the apex positions and the structure of the AD-diagram to differ for the two streams. We also compare the positions of the streams in space and discuss the results.

2. BRIEF DATA DESCRIPTION

We use the results of five studies. Caballero (2010) lists in his Table 1 the candidate objects of the Castor moving group, a total of 70 stars. Anosova & Orlov (1991) identified 10 stars as probable members this group. Agekyan & Orlov (1984) found nine moving groups in the solar vicinity, the space motion of their group V is close that of the Castor group. Barrado and Navascues (1998) used the Hipparcos catalog (ESA 1997, hereafter referred to as HIP) data to identify 16 stars as bona fide members of the Castor stream. Shkolnik et. al. (2012) found six additional candidates from their study of M-type dwarfs.

We use the Caballero (2010) list, the most extensive of the five, as a basis for our compilation. We add to it three stars from Anosova & Orlov (1991), seven stars from Agekyan & Orlov (1984), and six stars from Shkolnik et al. (2012). We thus have a total of 86 stars (all stars identified by Barrado y Navascues (1998) are already included in the list of Caballero (2010)). We adopted the radial velocities for stars of our combined list from the SIMBAD database and the remaining parameters from HIP (for stars included into this catalog). For the six stars from Shkolnik et al. (2012) we adopt all their parameters from that paper. In the next section we describe the preparation of the list of the Castor moving group stars, determine their membership using the AD diagram, and discard stars with large errors, as well as the runaway star. We will publish the list of stars of the Castor moving group stars in the near future.

3. THE CASTOR AD-DIAGRAM

Only 70 stars in our combined list have a complete set of the parameters to determine their individual apexes. We computed these individual apexes and their error ellipses using the technique described by Chupina et al. (2001).

Fig. 1 shows the AD-diagram for the Castor stream. For most of the stars the error ellipses are small. Stars with large error ellipses have HIP numbers 29067, 33451, 60661, 72622, 113263, 116132. We did not use these stars in our apex determination and excluded them from our list of stream members. The large errors of the parameters of these stars distort the inferred apex, and they are located far from the average apex position in the AD-diagram. HIP 60661 is a runaway star (Lopez-Santiago et al. 2010) and its membership in the Castor group is not yet clear.

The concentration of points in the central part of Fig. 1 is not the core of the stream, nor the scattered periphery should be viewed as its corona. The scatter of points is due to the presence of multiple stars whose velocities are distorted by the orbital motion. Here we do not analyze the features that are apparent in the diagram, such as, e.g., nonuniform density distribution and different orientations and sizes of the axes of the error ellipses.

We determine the Castor apex by averaging the individual apex values by applying an iterative 3σ clipping: we first compute the mean apex averaged over

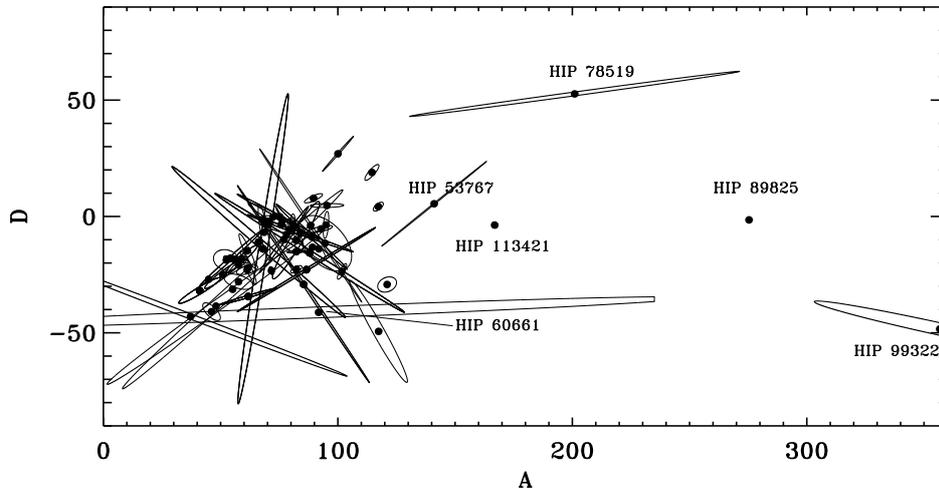


Fig. 1. The AD-diagram with the error ellipses for the Castor stream. The stars with large errors ellipses are marked by their HIP numbers.

all stars, then discard the stars lying beyond 3σ and repeat the procedure. After four iterations we find $A = 79.33^\circ$, $D = -15.06^\circ$ based on the data for 65 stars, which are assigned the highest membership probability in our list. The apex position is shown in Fig. 2 and we discuss it in Section 5.

4. COMPARISON OF THE AD-DIAGRAMS FOR THE CASTOR AND UMA STREAMS

To compare the kinematics of the two streams, we plot in Fig. 2 the AD diagram including the data for both the Castor and UMa moving groups, adopting the data for the latter from our earlier paper (Chupina et al. 2001). In this AD diagram the UMa stream is represented by single stars exclusively. As already noted, this stream includes three groups, which are marked in Fig. 2.

Why is the dispersion of points for the Castor stream so large? This is because this stream contains many multiple systems whose individual apex positions may be incorrect. The angular distance between the UMa and Castor apexes in Fig. 2 is about 225° , implying that the two streams move in opposite directions in space.

5. STREAMS IN SPACE

Fig. 3 shows the distribution of stars projected onto the Galactic plane in the Cartesian coordinate system with the origin at the Sun. The X-axis points toward the Galactic center; the Y-axis, in the direction of Galactic rotation, and the Z-axis (not shown here), toward the North Galactic Pole. As far as the Z-coordinate is concerned, the streams studied are located practically in the Galactic midplane at distances of 10.6 pc and 2.4 pc for UMa and Castor, respectively.

The entire Castor stream is located inside the central part of UMa. It has the ellipse-like outlines with the semi-major axis located almost along the diagonal of the XY-box. The two streams have almost equal space velocities: 20.1 km s^{-1} for UMa and 20.3 km s^{-1} for Castor.

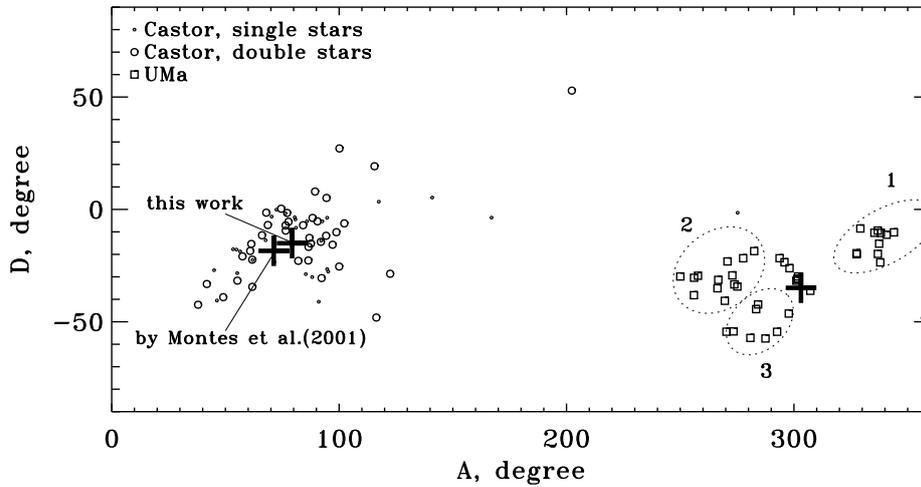


Fig. 2. The AD-diagram for the Castor (open circles) and UMa (open squares) streams. The big crosses indicate the stream apex positions.

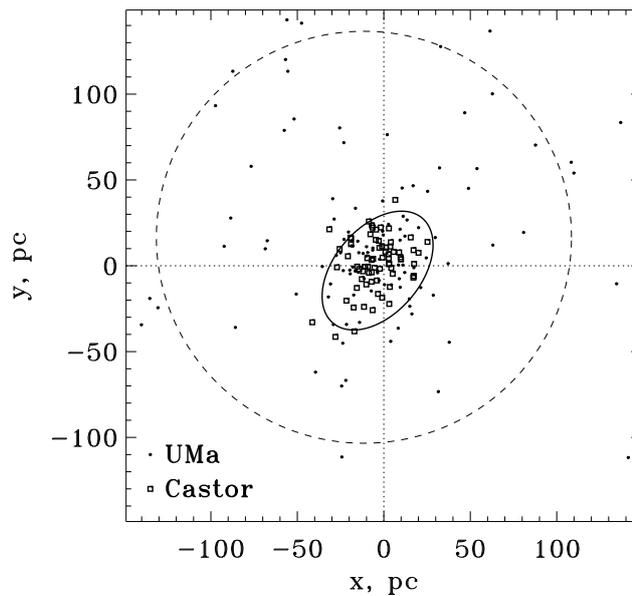


Fig. 3. Distribution of stars of the Castor and UMa streams projected onto the XY plane (Galactic plane). The Castor and UMa stream stars are shown as squares and solid dots, respectively. The areas occupied by the UMa and Castor's streams are outlined by the dashed and solid lines, respectively.

We estimated the above space velocities from the available data on radial velocities, parallaxes, and proper motions. These space velocities can be useful for understanding the physical nature of the streams studied.

Table 1. Comparison of the Castor apex position determinations.

Author	A , degrees	D , degrees
This work	79.33	-15.06
Montes et al. (2001)	71.25	-18.44

6. DISCUSSION AND CONCLUSIONS

Stars of two streams closest to the Sun are considered in phase space. These streams are the interesting phenomenon in the Galaxy disk. The Castor and UMa moving groups interpenetrate each other in space and they are moving in opposite directions.

Can the Castor stream be viewed as a kinematic groups within the UMa stream? Their space velocities differ very much, by more than 40 km s^{-1} . Obviously, these star systems are not gravitationally bound and will diverge. These groups must originate from different parts of the disk. The UMa stream and the whole Sirius supercluster move in the direction of the antiapex of most of the Galactic clusters, whereas the position of the Castor stream in the velocity space is close to that of the clusters.

Structures like the UMa and Castor streams are not uncommon. There are systems of clusters in phase space, e.g., the group of clusters in the Orion Sword (Bouy et al. 2014). In the same area, Group 189 was discovered, which can belong to the corona of NGC 1977. Famaey et al. (2008) detected four structures which correspond to the Hercules's flow, Pleiades, Hyades, and Sirius groups.

We determined the position of the Castor stream apex. Our results slightly differ from the apex position determined by Montes et al. (2001) (see Table 1). The difference may be due to the fact that the above study was based on the data for late-type stars only. Individual apexes in the AD-diagram deviate strongly from the average value with the scatter equal to $\sigma_A = 18.92^\circ$ and $\sigma_D = 14.43^\circ$. We inferred this Castor apex estimate taking into account both these large scatter values and parameter errors.

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