P1: The solar motion

Purpose

The purpose of this project is to derive the motion (velocity vector) of the Sun with respect to nearby stars. This is done using stars in different colour intervals.

Theory

The velocity of the Sun, $\boldsymbol{v}_s$, relative to a group of n stars is the same as the mean heliocentric velocity of the stars, only with the opposite sign:

$$\boldsymbol{v}_s = -\langle \boldsymbol{v} \rangle = -\frac{1}{n} \sum_{i=1}^{n} \boldsymbol{v}_i \tag{1}$$

where $\boldsymbol{v}_i$ is the heliocentric velocity of the ith star.

The problem is that we do not know the full three-dimensional vector $\boldsymbol{v}_i$ (why not?), only its projection on the tangent plane on the sky. Using data from Hipgal and formulae from the Lecture Notes we can compute for each star the tangential velocity vector $\boldsymbol{v}_{ti}$. This is related to the space velocity by

$$\boldsymbol{v}_{ti} = \boldsymbol{T}_i \boldsymbol{v}_i \tag{2}$$

where $\boldsymbol{T}_i$ is the tangential projection matrix for star i (see Sect. 2.7 in the Lecture Notes). Fortunately, knowing the tangential velocities for a number of stars scattered over the sky is sufficient to compute $\langle \boldsymbol{v} \rangle$. The trick is as follows:

$\boldsymbol{T}_i$ depends only on the position of the star, and is therefore statistically independent of $\boldsymbol{v}_i$ (assuming that the velocity distribution is constant within the volume under study). Taking the average over the stars in the sample therefore gives:

$$\langle \boldsymbol{v}_t \rangle = \langle \boldsymbol{T}\, \boldsymbol{v} \rangle = \langle \boldsymbol{T} \rangle \, \langle \boldsymbol{v} \rangle \tag{3}$$

(where the second equality follows from the statistical independence of $\boldsymbol{T}_i$ and $\boldsymbol{v}_i$). The mean velocity is then obtained as

$$\langle \boldsymbol{v} \rangle = \Big[\langle \boldsymbol{T} \rangle \Big]^{-1} \langle \boldsymbol{v}_t \rangle \tag{4}$$

Note that $\boldsymbol{T}_i$ is a singular matrix for any i, so it is not possible to solve $\boldsymbol{v}_i$ from (2); nevertheless $\langle \boldsymbol{T} \rangle$ turns out to be non-singular if the stars are reasonably scattered over the sky.

Different groups of stars, selected by their colour index $B{-}V$, show different mean velocities. The reason for this will be studied in a later project (P4). For now it will be sufficient to compute $\boldsymbol{v}_s$ for different intervals of colour index and note the overall trends.

Selection of stars

Each student (or group) selects at least two intervals in colour index $B-V$ from the table below. Make sure the whole colour range is covered by the students together. Results are noted in the table. Note that there is room for three determinations per colour interval.

For each selected colour interval, estimate the absolute magnitude of the faintest main sequence stars and hence the maximum distance at which the Hipparcos Catalogue will be reasonably complete (assuming that the catalogue is complete to $V = 8$). Also estimate the maximum age of the main sequence stars in the colour interval.

Use `Hipgal` to extract data for the stars with the selected colours and distances. Include an upper limit on the V magnitude (e.g. 8.0 mag). It is also recommended to put an upper limit on the standard error in parallax (e.g. 1.5 mas) to avoid including questionable data. At least about 200 stars are needed in each group. If necessary, `pmin` can be adjusted to increase the number of stars (roughly, `pmin` should be between 8 and 20 mas).

Calculations

All calculations are made in galactic coordinates, based on data extracted by means of Hipgal. Use MATLAB to compute $\boldsymbol{v}_{ti}$ and $\boldsymbol{T}_i$ for each star in a sample. Then calculate the mean matrices and apply (4). Do not forget to reverse the sign to get $\boldsymbol{v}_s$!

Analysis of results; reporting

Based on the combined results of all students, discuss the trend (versus colour) in each of the three velocity components.

The report should include

- a title page containing the name of the course (ASTM13 Dynamical astronomy), the project title (P1: The solar motion), your name, and a date
- a short description (with motivation) of your selection of stars. Be careful to state all the selection criteria used in Hipgal as well as the resulting number of stars
- the derived components of $\boldsymbol{v}_s$
- a short discussion of the results
- figures (if any) with explanation of axes, symbols, etc
- a complete listing of the MATLAB program used for the calculation

TABLE 1. Summary of derived solar motion as function of colour index $B-V$. Suggested constraints: $V \leq 8.0$ mag, $\sigma_p \leq 1.5$ mas.

$B-V$ [mag]	$p_{\min}$ [mas]	n [–]	v_{s1} [km/s]	v_{s2} [km/s]	v_{s3} [km/s]
< -0.05					
-0.05 to 0.0					
0.0 to 0.1					
0.1 to 0.2					
0.2 to 0.3					
0.3 to 0.4					
0.4 to 0.5					
0.5 to 0.6					
0.6 to 0.7					
0.7 to 0.8					