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A surprise in the updated list of stellar perturbers of long-period comet motion⋆

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ABSTRACT

Context. The second *Gaia* data release (*Gaia* DR2) provided us with the precise five-parameter astrometry for 1.3 billion of sources. As stars passing close to the Solar System are thought to influence the dynamical history of long-period comets, we update and extend the list of stars that could potentially perturb the motion of these comets.
Aims. We announce a publicly available database containing an up-to-date list of stars and stellar systems potentially perturbing the motion of long-period comets. We add new objects and revise previously published lists. Special emphasis is placed on stellar systems. A discussion of mass estimation is included.
Methods. Using the astrometry, preferably from *Gaia* DR2, augmented with data from other sources, we calculate nominal spatial positions and velocities for each star. To filter studied objects on the basis of their nominal minimum heliocentric distances we numerically integrate the motion of stars under the Galactic potential and their mutual interactions.
Results. We announce the updated list of stellar perturbers of cometary motion, including the masses of perturbers along with the publicly available database interface. These data are ready to be used with the observed long-period comets orbits to study an individual influence of a whole sample of perturbers, or specific stars, on a dynamical past or future of a specific comet. New potential perturbers were added; there are 138 more than in the previously published sources.
Conclusions. We demonstrate that a new set of prospective perturbers is an important tool in studies of cometary dynamics. The use of our data changes the results of the past and future cometary motion analysis. We point out a puzzling object in our list, star ALS 9243. The *Gaia* DR2 astrometry suggests a very close encounter of this star with the Sun; however, its astrophysical parameters result in a completely different current distance of ALS 9243 and its high mass.

Key words. astronomical databases: miscellaneous – stars: general

1. Introduction

Continuing a long-standing project to obtain detailed information on the dynamical history of the observed long-period comets (LPCs) we have just finished a major update of the potential stellar perturbers list. This was done on the basis of the most recent stellar data, mainly these published as the *Gaia* Second Data Release (*Gaia* DR2; Gaia Collaboration 2018).

As recently presented in Wysoczańska et al. (2020), due to a great increase in our knowledge of nearby stars, we are able in some particular cases to find stars that can significantly perturb the past (or future) motion of the observed long-period comets. Moreover, in this new list of perturbers there are 138 new objects, and they change the results of dynamical history studies of many LPCs. This research is highly advanced, and a series of detailed papers on the past and future dynamics of LPCs under the influence of nearby stars and the overall Galactic potential is in preparation.

In the present paper we describe in detail the updated version of the list of potential stellar perturbers introduced in the above-mentioned paper. We also announce a simple publicly available database interface to access this list.

It should be noted that our aim is not to determine and study minimum heliocentric distances of passing stars. We use these nominal minimum distances only as a filtering tool while composing the list. For this reason we do not perform any error budget analysis for these values, or for other parameters of the encounters. The uncertainty estimations should be performed individually for each particular star–comet interaction, as done in Wysoczańska et al. (2020), for example. All data necessary to perform such an analysis are included in the announced database.

In Sect. 2 we describe sources used while selecting potentially interesting stars. In Sect. 3 methods applied to single stars and problems concerning estimations of their masses are discussed as perturber mass is crucial in examining mutual interactions between a star and a comet. An in-depth analysis of properties of a single star ALS 9243, a puzzling but potentially strong stellar perturber is presented in Sect. 4. Sections 5 and 6 focus on multiple systems, and the most interesting and troublesome systems are described. In Sect. 7 a brief description of a public database where our results are presented is given. In Sect. 8 we include several examples of how the new list of stellar perturbers might change the results of cometary dynamics studies. We also present the dependence of these results on the assumed mass of ALS 9243. We conclude in Sect. 9 with a short discussion of the main results, issues encountered, and prospect for the future.

⋆ The database described in this paper is available at: https://pad2.astro.amu.edu.pl/stars

2. Compiling the list of perturbers

2.1. Sources

Using modern data on stellar positions and kinematics we decided to check again all stars mentioned in several published papers on stellar encounters with the Solar System for their minimum distances from the Sun. Our initial list of stars consists of the following (the sources partially overlap):

– 156 stars, with the proximity threshold (PT) of 5 pc from García-Sánchez et al. (2001), based on the HIPPARCOS catalogue (ESA 1997);
– 46 stars (PT = 2.5 pc) listed in Dybczyński (2006), based on the ARIHIP catalogue (Wielen et al. 2001);
– 142 stars (PT = 5 pc) analysed in Jiménez-Torres et al. (2011), based on the HIPPARCOS catalogue (ESA 1997);
– 90 stars or stellar systems (PT = 3.5 pc) from Dybczyński & Królikowska (2015), based on the XHIP catalogue (Anderson & Francis 2012);
– 40 stars (PT = 2 pc) from Dybczyński & Berski (2015), based on the HIP2 catalogue (van Leeuwen 2007);
– 42 stars (PT = 2 pc) found by Bailer-Jones (2015a), based on the HIPPARCOS (ESA 1997), HIP2 (van Leeuwen 2007), and *Tycho*-2 (Høg et al. 2000) catalogues;
– 166 stars (PT = 10 pc) listed by Bailer-Jones (2018), based on the *Gaia* DR1 (Gaia Collaboration 2016) and TGAS (Lindegren et al. 2016) catalogues;
– 3379 stars for PT = 10 pc listed in Bailer-Jones et al. (2018a), based on the *Gaia* DR2 catalogue (Gaia Collaboration 2018);
– 3865 potential stellar perturbers (PT = 10 pc) found by us in a subset of *Gaia* DR2 containing over 7 million stars with measured radial velocities;
– 3441 objects (PT = 10 pc) selected from all stars with known radial velocity and parallax found in the SIMBAD database in October 2018 (over 2.2 million stars were checked).

Stars from the last two sources were pre-selected according to the linear motion approximation. Then we concatenated the last three sources, numerically integrated each star under the Galactic potential, obtained its minimum heliocentric distance, and excluded all stars passing farther than 4 pc from the Sun. This refinement (i.e. applying PT = 4 pc) left, in the combined list of the last three sources mentioned above, only 487 stars selected from *Gaia* DR2 and 522 stars selected from the SIMBAD database (these two sets partially overlap). Stars mentioned earlier in at least one of the listed papers, even if new data were adopted and their nominal minimum heliocentric distances increased drastically, were kept for the record. Finally, we obtained a list of 819 unique perturbers with 138 new objects that are identified as potential perturbers for the first time.

2.2. Models and methods

While we use the nominal minimum Sun–star distance only as a filtering tool for completing our list of potential LPCs motion perturbers, it is important to know how we calculate this value. For all stars and stellar systems the final, nominal smallest heliocentric distance is obtained by a numerical integration of equations of motion formulated in a rectangular Galactocentric frame. We use the reference frame transformation parameters and the Galactic position and velocity of the Sun described in Dybczyński & Berski (2015).

The main difference between our approach and the one presented in the above-mentioned paper is that for calculating rectangular coordinates of stars we adopted the distance estimates presented in Bailer-Jones et al. (2018b). The distances obtained this way were collected for 742 single stars and 85 components of multiple systems. For the stars not included in *Gaia* DR2 we relied on Eq. (3) proposed in Bailer-Jones (2015b). As it concerns a model of the Galactic potential, we used the one proposed by Irrgang et al. (2013).

At first, after completing the preliminary list of 819 objects, we numerically integrated pairs: the Sun with a star or stellar system under the Galactic potential to the past or future depending on the radial velocity sign and recorded the minimum Sun–star distance. After rejecting all perturbers where this distance is greater than 4 pc (this leaves 642 objects), we repeated the calculation as a single numerical integration now having 643 interacting bodies (all perturbers plus the Sun).

It should be noted here that finding the nominal minimum Sun–star distance serves here only as an approximate tool for filtering potential perturbers. These perturbers are intended to be used in dedicated studies of cometary dynamics, where a detailed analysis of the uncertainties should be carefully done taking into account of both stellar and cometary data errors. An example of such an analysis one can found in Wysoczańska et al. (2020). Readers interested just in Sun–star encounters and their uncertainties should consult other papers, for example Dybczyński & Berski (2015) and Bailer-Jones et al. (2018a).

3. Masses of single stars

Single stars were processed in a standard way, described in Sect. 2.2. In the great majority of cases we used the astrometry from *Gaia* DR2 together with the radial velocity from the same catalogue, if available. When a star was absent in this source we used the SIMBAD and VIZIER databases to find the most appropriate data. Having positions, proper motions, distance estimates, and radial velocities, we calculated rectangular components of the spatial position and velocity. Since we were collecting potential perturbers of the motion of long-period comets, we needed one more parameter: the mass of the perturber.

To complete the list of stellar perturbers it was necessary to obtain stellar masses. As *Gaia* DR2 do not provide us with masses of stars, we had to search for them in other sources.

We were unable to find a catalogue or literature source of masses that covered all the stars in question; therefore, our choice was to gather as many different sources of stellar mass estimates as possible, even if these sources overlap for particular stars. This approach facilitated a verification of mass estimates and showed whether there is a compliance between different sources and methods.

In the following we describe specific sources and methods that allowed us to obtain stellar mass estimates with a clear indication of how many masses were collected with each of these methods.

From our list 405 stars have their mass estimates presented in Bailer-Jones et al. (2018a) and 572 masses of single stars can be found in Anders et al. (2019). These two sources contain only masses of stars included in *Gaia* DR2.

We also performed our own estimations. For M dwarfs we used a formula from Benedict et al. (2016), which allows us to estimate masses M as a function of the absolute brightness M_K,

$$M = C_0 + C_1(M_K - x_0) + C_2(M_K - x_0)^2 + C_3(M_K - x_0)^3 \\ + C_4(M_K - x_0)^4, \tag{1}$$

where the polynomial coefficients are $C_0 = 0.2311$, $C_1 = -0.1352$, $C_2 = 0.0400$, $C_3 = 0.0038$, $C_4 = -0.0032$ and the magnitude offset equals $x_0 = 7.5$. We use the K band because it more closely agrees with the model, as stated in Benedict et al. (2016). Using this method we were able to obtain masses for 74 single stars from our list of perturbers.

We estimated the masses of main sequence dwarfs with known effective temperatures utilising the formulas from Eker et al. (2018):

– for ultra low masses in the range $0.179 < M/M_\odot \leq 0.45$

$$\log(L) = 2.028(135)\log(M) - 0.976(070); \qquad (2)$$

– for very low masses in the range $0.45 < M/M_\odot \leq 0.72$

$$\log(L) = 4.572(319)\log(M) - 0.102(076); \qquad (3)$$

– for low masses in the range $0.72 < M/M_\odot \leq 1.05$

$$\log(L) = 5.743(413)\log(M) - 0.007(026); \qquad (4)$$

– for intermediate masses in the range $1.05 < M/M_\odot \leq 2.40$

$$\log(L) = 4.329(087)\log(M) + 0.010(019); \qquad (5)$$

– for high masses in the range $2.40 < M/M_\odot \leq 7$

$$\log(L) = 3.967(143)\log(M) + 0.093(083); \qquad (6)$$

– for very high masses in the range $7 < M/M_\odot \leq 31$

$$\log(L) = 2.865(155)\log(M) + 1.105(176). \qquad (7)$$

For each star its mass was calculated with all of these formulas, and then we checked which validity conditions were met. Thanks to these formulas we managed to obtain 402 stellar masses; we also verified them via the conditions stated in Table 5 from Eker et al. (2018). After the verification we ended up with 310 masses.

The formulas from Eker et al. (2018) have to be used in conjunction with the formulas from Andrae et al. (2018). This allows us to calculate a radius and a luminosity of the star when only an effective temperature is given.

Additionally, utilising the luminosity in J band, 473 masses were obtained from the tables created by Pecaut & Mamajek (2013). Using the same tables 445 masses were gathered based on the luminosity in K_s band, and 495 masses when the luminosity in V band was used. Each time, when possible, it was checked whether the effective temperature matched the calculated mass.

Because *Gaia* DR2 provides us with luminosities in G band it was necessary to convert them into other bands. The following formulas from *Gaia* DR2 documentation Gaia Collaboration (2018) were used:

– to convert into V band

$$G - V = -0.01760 - 0.006860(G_{BP} - G_{RP}) \\ - 0.1732(G_{BP} - G_{RP})^2; \qquad (8)$$

– to convert into J band

$$G - J = -0.01883 + 1.394(G_{BP} - G_{RP}) \\ - 0.07893(G_{BP} - G_{RP})^2; \qquad (9)$$

– to convert into K_s band

$$G - K_s = -0.01885 + 2.092(G_{BP} - G_{RP}) \\ - 0.1345(G_{BP} - G_{RP})^2. \qquad (10)$$

For 702 single stars their mass estimates were directly obtained from Pecaut & Mamajek (2013) tables using only the effective temperature given.

The TESS catalogue (Stassun et al. 2018; Muirhead et al. 2018) was also used as a source of star mass estimates. From TESS1 325 masses were gathered, while in TESS2 there were no masses of the stars in question.

Using all these sources, for most of the stars we obtained several, sometimes different, mass estimates. For the great majority of them (572 from among 783 single stars) we finally decided to use the mass estimates from Anders et al. (2019). For objects missing from this source we decided to take a mean of the gathered values after the most extreme ones and the most flawed ones had been excluded.

Masses of components of multiple systems were obtained in a similar way depending on the data availability. Seventy-six stellar masses of components of multiple systems recognised by *Gaia* DR2 were gathered from Anders et al. (2019). We also used tens of other sources found through the SIMBAD and VIZIER databases. In some cases mass estimates were taken from papers that describe the specific multiple system.

4. A new, puzzling, but potentially strong stellar perturber: ALS 9243

Using the astrometry from the *Gaia* DR2 catalogue and the radial velocity from the SIMBAD database we found that a star ALS 9243, never mentioned in earlier papers in a context of being a cometary motion perturber, 2.5 Myr ago passed as close as 0.25 pc from the Sun. The main surprise, however, was the estimated mass of this star. According to the spectral type O9 – B0 and the luminosity class IV repeated in the literature we should assume its mass to be over 15 solar masses. Such a close passage of such a massive star that took place only 2.5 Myr ago would have had a strong influence on the observed long-period comet orbits and probably on the Solar System as a whole. At first we classified this object as a multiple star due to the information from the SIMBAD database, but later it appeared that its multiplicity has not been confirmed. Although this object can be found in the WDS catalogue (Mason et al. 2001) based on observations done by Aldoretta et al. (2015), there is no indication of a name of the alleged second component and data necessary to calculate its position and velocity.

4.1. What we know about the star ALS 9243

The star in question was probably first mentioned and named in 1965 during the completion of the Luminous Stars in the Northern Milky Way catalogue (Nassau et al. 1965; Hardorp et al. 1965). The star was designated as LS VI -04 19, which reads: Luminous Stars, volume six, declination zone -04, star number 19. This was an objective prism survey aimed at young stars. They quote OB as the "estimated spectral type". Almost forty years later an all-sky database of OB stars was collected by Reed (2003, 2005) and he assigned a new name to this star: ALS 9243. We use this name throughout the present work.

Later on, this star was also included in large modern catalogues: *Tycho*-2 (as TYC 4809-2410-1; Høg et al. 2000), 2MASS (as J06593022-0448438; Cutri et al. 2003), and finally *Gaia* DR2 (as DR2 3101630187797866112; Gaia Collaboration 2018).

In an elegant paper by Graham (1971) the photometric distance to this star was first estimated, as was its radial velocity.

Table 1. ALS 9243 distance estimates and measurements.

Distance [pc]	Method	Ref
2400	Photometric	Graham (1971)
3300 ± 800	Photometric	Avedisova & Kondratenko (1984)
31 (−21 + ∞)	Trig. parallax	*Tycho*-1 (ESA 1997)
86 (−35 + 83)	Photometric	Ammons et al. (2006)
256	Photometric	Pickles & Depagne (2010)
2900	Photometric	Garmany et al. (2015)
3200	Photometric	Aldoretta et al. (2015)
443	Photometric	Stassun et al. (2018)
94.7 (−3.5 + 3.7)	Trig. parallax	*Gaia* DR2 (Gaia Collaboration 2018)
94.5 (−3.3 + 4.0)	Trig. parallax	(Bailer-Jones et al. 2018b, based on *Gaia* DR2)
93 (−4 + 6.0)	Photo-astrometric	(Anders et al. 2019, based on *Gaia* DR2)

In the last row of his Table I is listed a distance modulus equal to 11.9^m, equivalent to the distance of 2.4 kpc (other distance estimates are presented in Table 1), and $v_r = 49.5$ km s^{-1}. In the same year Crampton (1971) associated the star for the first time with the H II region, and narrowed its spectral classification down to B0 IV. A year later Crampton (1972) published radial velocity measurements of the star in question, again using the objective prism, ranging from 26 to 55 km s^{-1} during a ten-day interval.

A recent paper by Anders et al. (2019) recalculates the distances and astrophysical parameters of a large number of *Gaia* DR2 stars. For ALS 9243 they obtained a distance of about 93 pc and a mass of only 0.65 $M_\odot$. These results strongly depend on *Gaia* DR2 results for this star. However, it should be noted that the most preferred *Gaia* DR2 (Gaia Collaboration 2018) astrometry quality indicator, a re-normalised unit weight error (RUWE)[1] for ALS 9243 equals 6.97 while the upper RUWE limit for "good" astrometric solutions is 1.4[2].

4.2. Atmospheric parameters of ALS 9243

We tried to solve this puzzling inconsistency in ALS 9243 parameters. In January 2020 we requested and were kindly provided with three spectra with the fiber fed echelle spectrograph ESPERO connected to the 2 m telescope in Rozhen National Astronomical Observatory (Bonev et al. (2017)) with resolving power $R \sim 40\,000$ and in the range from 410 to 950 nm. In our analysis presented below (still simplified and approximate), we used only one spectrum observed on 9 January due to its better quality, where the measured signal-to-noise ratio was between 30 and 40.

The atmospheric parameters: an effective temperature $T_{\rm eff}$, a surface gravity $\log g$, and a projected rotational velocity $v \sin i$ were calculated using the iSpec code (Blanco-Cuaresma 2019; Blanco-Cuaresma et al. 2014). The observed spectrum was compared with a grid of fluxes BSTAR2006 (Lanz & Hubeny 2007) created with TLUSTY model atmospheres and SYNSPEC spectra. We used stellar atmosphere models that are metal line-blanketed, non-LTE, plane-parallel, and we examined hydrostatic atmospheres.

At first, the effective temperature and the surface gravity were estimated using the Balmer lines Hα and Hβ. For hot stars
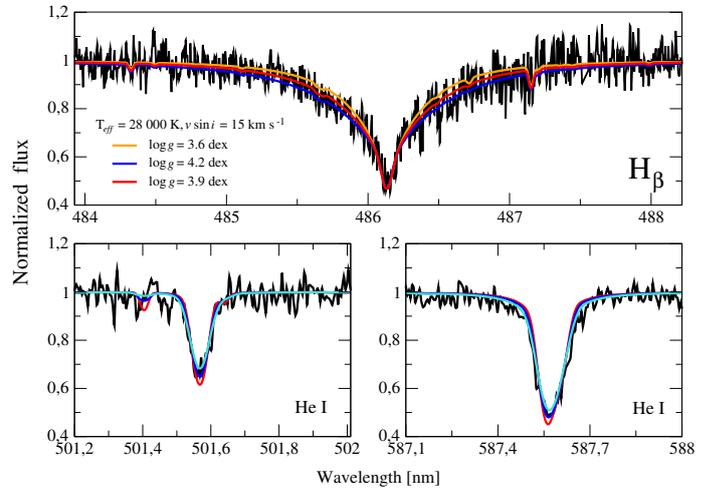

Fig. 1. Comparison of the observed spectrum (black) and synthetic spectra (colours) of the Hβ region and He I lines. For He I lines the different colours correspond to synthetic spectra calculated for various $T_{\rm eff}$, $\log g$, and $v \sin i$ within the error limits (aquamarine: $T_{\rm eff} = 26\,000$ K, $\log g = 3.7$ dex, $v \sin i = 10$ km s^{-1}; blue: $T_{\rm eff} = 28\,000$ K, $\log g = 3.9$ dex, $v \sin i = 15$ km s^{-1}; red: $T_{\rm eff} = 30\,000$ K, $\log g = 4.2$ dex, $v \sin i = 20$ km s^{-1}).

($T_{\rm eff} > 8000$ K) Balmer lines are sensitive to the $\log g$ parameter, thus both $T_{\rm eff}$ and $\log g$ parameters were derived simultaneously. Additionally, we assumed a microturbulence velocity of 2 km s^{-1} and a macroturbulence of 0 km s^{-1}. The metallicity [M/H] value was fixed to 0.0 dex. In our calculation we also used the six neutral and ionised helium lines (He I, He II), which are clearly visible in the ALS 9243 spectrum, such as He II (468.6, 471.4 nm) and He I (501.6, 587.5, 667.8, 706.7 nm). The obtained effective temperature is $28\,000 \pm 2\,000$ K, $\log g = 3.9 \pm 0.3$ and $v\sin i = 15 \pm 5$ km s^{-1}. The comparison of the observed and synthetic spectra within the error limits of Hα and two He lines is shown in Fig. 1.

To evaluate the uncertainties of all determined parameters we took into account the difference in values calculated separately from the lines. The obtained uncertainties are mainly caused by low signal-to-noise ratio and continuum normalisation process of the echelle spectra during which it is difficult to recover the original line profiles. The estimated atmospheric parameters for ALS 9243 object should be verified in the future from a spectrum of a better quality, with a signal-to-noise ratio of at least 100.

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[1] See: Lindegren, L. 2018, Considerations for the Use of DR2 Astrometry, Tech. rep., available at http://www.rssd.esa.int/doc_fetch.php?id=3757412
[2] See *Gaia* Data Release 2 Documentation (release 1.2), Sect. 14.1.2

Table 2. ALS 9243 spectral classifications.

T_{eff} [K]	Spectrum	Luminosity class	M_V	Ref
–	OB	–	–	Nassau et al. (1965)
–	–	–	-3.4^m	Graham (1971)
–	B0	IV	–	Crampton (1971)
–	O9.5	V	-2.29^m	Georgelin et al. (1973)
–	B0.5	V	–	Mayer & Macák (1973)
–	O9.5	V	–	Moffat et al. (1979)
6608	–	–	–	Ammons et al. (2006)
–	F5	V	–	Pickles & Depagne (2010)
–	–	–	-3.6^m	Garmany et al. (2015)
–	O9.7	IV	–	Aldoretta et al. (2015)
7773	–	V	–	Stassun et al. (2018)
6185	–	V	–	Gaia Collaboration (2018)
5461	–	–	–	Anders et al. (2019)

Our temperature measurement is in good agreement with most of the previous spectral type determinations (Table 2). The obtained temperature and $\log g$ correlate with B0 spectral type and subgiant luminosity class IV. According to Straižys (1992) tables this corresponds to a mass of $\sim 22\,M_\odot$.

4.3. Call for observations

The trigonometric distance obtained by *Gaia* DR2 seems to be highly inconsistent with the luminosity and the visual magnitude of such a massive star. The star should be much farther away. On the other hand, the $J - H$ colour index of the star suggests a lower temperature of about 6800 K; fluxes in J and H band were taken from Cutri et al. (2003) and the respective values of 9.692 and 9.553 were adopted. All of these contradictory results could be explained for example by the extremely high extinction. In the line of sight we have a molecular cloud SH2-287. However, the cloud might be in the star background or closer to us, and the distance of the SH2-287 is estimated to be 2.1 kpc (Neckel & Staude 1992). The striking discrepancy between the trigonometric and photometric results should be explained with future observations.

We would like to encourage observers to make an effort to clarify this situation by taking high quality positional and spectro-photometric observations of ALS 9243. Our preliminary attempt revealed that it is a difficult object as it is not so bright and it is visible in the background of (or surrounded by) a H II nebula. The most striking controversy is the distance: 0.1, or over 2 kpc. In addition, its mass estimate varies from 0.5 to over $20\,M_\odot$.

For now, in the absence of a clear explanation of the discrepancies found in the literature, we decided to keep this star in our list, to use the *Gaia* DR2 astrometry, and to adopt a compromise mass of $2\,M_\odot$.

5. Multiples

Almost all previously published lists of stars passing through the close solar neighbourhood (García-Sánchez et al. 2001; Dybczyński 2006; Jiménez-Torres et al. 2011; Dybczyński & Berski 2015; Bailer-Jones 2015a, 2018; Bailer-Jones et al. 2018a) contain only objects considered to be single stars, even if they are in reality parts of multiple systems. Treating com-

ponents of multiple systems as single stars often leads to misleading conclusions. While a particular component of a multiple system seems to encounter the Sun at a very small distance, the centre of mass of this multiple can even move in another direction.

Because stellar systems are statistically more massive than single stars, and can therefore act as more significant perturbers, in our work we tried to analyse as many cases of multiplicity as possible. Each star from our list was checked to determine whether it is a component of a system. Identification of multiple systems was done via the SIMBAD database, and this explains why our search for multiples was generally limited to stars mentioned in earlier papers. New potential perturbers found only thanks to the *Gaia* cannot be checked for multiplicity; to the best of our knowledge no studies have been published identifying all cases (or even a significant part) of multiple systems in *Gaia* DR2.

While the SIMBAD database facilitated our work on this subject, we had to check each case carefully by an extended research. Some stars identified in SIMBAD as components of multiple systems are, in fact, single stars, having for example completely different parallaxes. Their alleged multiplicity can, for example, remain from the time where they were observed close to other stars and thought to be dynamically bound to them. On the other hand, although some stars are definitely parts of multiple systems, due to the data incompleteness we sometimes had to treat the whole system as a single star.

It is important to note that the most reliable centre of mass kinematic parameters can be obtained only when the five-parameter astrometry and the radial velocity are given for all components for the same epoch, which is nearly never the case. For most of the multiple systems we calculated their centre of mass parameters with data available in *Gaia* DR2 or with data available in the SIMBAD database. Specific systems were described in dedicated papers in only four cases, and we relied on the data found therein.

In Sect. 6 we describe several interesting cases of stellar systems. These systems were either thoroughly examined by us and for the first time classified as multiple stellar perturbers (even though some individual components of these systems were previously suggested as stellar perturbers) or, by considering their multiplicity, we ruled them out from the list of potential stellar perturbers. Where possible, a comparison with the results found in papers listed in Sect. 2 is given.

Table 3. Algol system centre of mass parameters.

Parameter	Value	Unit
Parallax	34.7 ± 0.6	mas
Primary mass	3.70	$M_\odot$
Secondary mas	0.79	$M_\odot$
Tertiary mass	1.51 ± 0.02	$M_\odot$
Right ascension proper motion	2.70 ± 0.07	mas yr^{-1}
Declination proper motion	-0.80 ± 0.09	mas yr^{-1}
Radial velocity	2.1	km s^{-1}
Right ascension	$3^{\mathrm{h}}08^{\mathrm{m}}10\overset{\mathrm{s}}{.}13241 \pm 0.7$	mas
Declination	$40°57'20\overset{''}{.}3353 \pm 0.6$	mas

6. Multiples: special cases

6.1. Algol

Algol, also known as β Persei, is a very bright hierarchical system. It consists of a close binary stellar system with a more distant tertiary component. Algol's components were not separated in the SIMBAD database. In the past it was treated as a single star and was classified as a stellar perturber by many authors: García-Sánchez et al. (2001), Dybczyński (2006), Jiménez-Torres et al. (2011), and Dybczyński & Królikowska (2015). Despite a rather distant passage near the Sun (over 3 pc) this perturber is rather important in near-parabolic comet motion studies due to its large systemic mass and a very small systemic velocity relative to the Sun.

In the *Gaia* DR2 catalogue one of the components of this system has its right ascension and declination measured, but there are no parallax, proper motion, and radial velocity data, and more importantly there are no clues to which component was observed.

Taking this into account, we decided to rely on data found in another source. Based on observations focused on Algol and UX Arietis, Peterson et al. (2011) published a parallax, a declination, a right ascension, both proper motion components, and a radial velocity of the centre of mass of this triple system. We adopted these values, which are listed in Table 3.

In view of these values, the Algol system, with its total mass equal to $6.0\,M_\odot$, is the most massive perturber in our list. We use the proximity threshold of 4 pc when constructing our list of perturbers to keep the Algol system included. Using the input values presented in Table 3 we obtained a minimum distance of 3.78 pc during the closest approach to the Sun, which took place 13.06 Myr ago with the relative velocity of only 2.17 km s^{-1}. The last two values mentioned make Algol's encounter the oldest and slowest of all the perturbers in our list. It is worth mentioning that the data from Peterson et al. (2011) significantly changed these parameters. The previously used values, derived on the basis of Lestrade et al. (1999) or the HIPPARCOS catalogue, read as follows: the minimum distance of ~3 pc, the closest approach at 6–7 Myr ago with the relative velocity of 4 km s^{-1}.

6.2. ρ Orionis

ρ Orionis is a spectroscopic binary classified as stellar perturber by Dybczyński & Królikowska (2015). It was then treated as a single star as its components are not listed separately in XHIP (Anderson & Francis 2012), which was the only source of the 6D stellar data used by the authors.

Thanks to *Gaia* DR2 we were able to update the data concerning this system. Both of its components were identified by us

in the *Gaia* DR2 catalogue as *Gaia* DR2 3235349837026718976 and *Gaia* DR2 3235349940105933568 objects. The second does not have the radial velocity measured in *Gaia* DR2, so we adopted the value from Malaroda et al. (2006). We used masses from Tokovinin (2018) where it is suggested that ρ Orionis is a triple system, but due to lack of any positional information about the third component we decided to assume that it is a binary system.

New data allowed us to calculate the centre of mass parameters and the new parameters of the approach. While in Dybczyński & Królikowska (2015) the minimum distance from the Sun was equal to 3.23 pc, now it is over 17 pc. The encounter happened 2.60 Myr ago at the relative velocity of 46.14 km s^{-1}.

As can be seen, an improvement in the quality of the data and the confirmation of the binary character of the object in question cancelled the importance of ρ Orionis as a stellar perturber of cometary motion.

6.3. Ross 614

Ross 614 was first discovered as a single star by Ross (1927). Then Reuyl (1936) detected the second component of this very low mass system which consists of red dwarfs. Later it was the subject of extensive studies, the most recent ones conducted by Ségransan et al. (2000), Gatewood et al. (2003), and Kervella et al. (2019).

Only one component of Ross 614 can be found in the *Gaia* DR2 catalogue, where it is identified as *Gaia* DR2 3117120863523946368, but it does not have its radial velocity measured. For the second component, even in the SIMBAD database, the data are incomplete.

Although the above-mentioned papers examine the nature of this stellar system in depth, the data found therein are not sufficient for our purpose. For this reason, our decision was to take the masses of both components from Anders et al. (2019), but to use the astrometry done only for Ross 614A. Incomplete data from *Gaia* DR2 were augmented with radial velocity from Gontcharov (2006).

With these values adopted our calculations show that this system encountered the Sun 0.09 Myr ago at a distance of 3.25 pc. The relative velocity at the time of approach was 27.18 km s^{-1}.

In comparison with the results obtained in the past, the minimum heliocentric distance of Ross 614 increased. In the XHIP catalogue Anderson & Francis (2012), and also in Dybczyński & Królikowska (2015), it was equal to 3.03 pc. In order to obtain more reliable parameters of the approach new astrometry for the second component (Ross 614B) is needed.

6.4. α Canis Majoris

α Canis Majoris, also known as Sirius, is a visual binary containing Sirius A, which is the brightest star in the sky, and Sirius B, the nearest white dwarf. There was a long-lasting discussion whether there is a third body in that system because of irregularities in the orbits of Sirius A and B. This possibility was ruled out by extensive studies (see e.g. Bond et al. 2017).

Sirius was classified as a stellar perturber by García-Sánchez et al. (2001), Dybczyński (2006), Jiménez-Torres et al. (2011), and Dybczyński & Królikowska (2015), but in none of these papers was multiplicity considered.

In *Gaia* DR2 only one component is included as *Gaia* DR2 2947050466531873024, but it does not have radial velocity measured and there is also no radial velocity in the SIMBAD

Table 4. α Canis Majoris centre of mass parameters (position and proper motions for 1950.0 epoch in the FK4 frame).

Parameter	Value	Unit
Parallax	0.3777 ± 0.0031	mas
Primary mass	2.063 ± 0.023	$M_\odot$
Secondary mass	1.018 ± 0.011	$M_\odot$
Right ascension proper motion	-0.0379	$^s\,yr^{-1}$
Declination proper motion	-1.211	$''\,yr^{-1}$
Radial velocity	-7.6	$km\,s^{-1}$
Right ascension	$6^h42^m56\overset{s}{.}73$	
Declination	$-16°38'46\overset{''}{.}4$	

Table 5. Heliocentric coordinates and space velocity components of α Centauri AB and Proxima in the Galactic frame.

Parameter (unit)	αCen	Proxima
X (pc)	0.95845 ± 0.00078	0.90223 ± 0.00043
Y (pc)	-0.93402 ± 0.00076	0.93599 ± 0.00045
Z (pc)	-0.01601 ± 0.00001	-0.04386 ± 0.00002
XV ($km\,s^{-1}$)	-29.291 ± 0.026	-29.390 ± 0.027
YV ($km\,s^{-1}$)	1.710 ± 0.020	1.883 ± 0.018
ZV ($km\,s^{-1}$)	13.589 ± 0.013	13.777 ± 0.009
Mass ($M_\odot$)	2.0429 ± 0.0072	0.1221 ± 0.0022

database. For that reason because we were unable to calculate centre of mass parameters, we decided to use the values found in Gatewood & Gatewood (1978) augmented with new measurements of masses from Bond et al. (2017). The values adopted here are listed in Table 4, where positions and proper motions are given in relation to 1950.0 epoch in FK4 frame. They were recalculated to be consistent with other data.

From these data we obtained parameters of the encounter with the Sun which will happen at 2.41 pc in 0.06 Myr. This result is generally in agreement with minimum heliocentric distances obtained earlier. The relative velocity at the time of the approach will be equal to $18.49\,km\,s^{-1}$ which makes it a relatively slow passage. The α Canis Majoris system is one of the most massive objects on our perturber list.

6.5. γ Leonis

The WDS catalogue (Mason et al. 2001) identifies four components of γ Leonis system. We conducted in-depth investigation to verify whether these components belong to the system.

While two of them (WDS J10200+1950A and WDS J10200+1950B) have exactly the same parallax of 25.96 mas, the third (WDS J10200+1950Ca,Cb) has a parallax of 201.3683 mas, and the fourth (WDS J10200+1950D) is measured to be 1.4566 mas. All these values were taken from the SIMBAD database. As can be seen, only the first two components actually create a binary system. In the light of the available data, two later components were treated by us as single stars that happen to be visually close to the system.

We decided to calculate the centre of mass parameters for γ^1 Leonis and γ^2 Leonis. None of the components is in the *Gaia* DR2 catalogue, so all the data were taken from the SIMBAD database. γ^1 Leonis has its mass ($1.41\,M_\odot$) estimated in Niedzielski et al. (2016). For γ^2 Leonis we have to adopt a crude mass estimate of $1.50\,M_\odot$ based on spectral type. For this system we calculated the minimum heliocentric distance as 33.32 pc, which will occur in 0.26 Myr at a relative velocity equal to $73.06\,km\,s^{-1}$. These values ruled γ Leonis out from our final list of stellar perturbers.

WDS J10200+1950Ca,Cb is treated as a single star and as such it is included in the RECONS[3] list of the 100 nearest star systems. It is also included in the *Gaia* DR2 catalogue as *Gaia* DR2 625453654702751872 where it does not have the radial velocity measured. We augmented data from *Gaia* DR2 with a radial velocity from the SIMBAD database and a mass of $0.467\,M_\odot$ from the TESS1 catalogue. Our results show that this

star encountered the Sun 0.21 Myr ago at the minimum distance of 3.41 pc and the relative velocity of $17.14\,km\,s^{-1}$.

For WDS J10200+1950D, also identified as *Gaia* DR2 625453856566097024, data from *Gaia* DR2 were used and the mass value of $1.04\,M_\odot$ from Deka-Szymankiewicz et al. (2018) was adopted. The minimum distance of 638.01 pc was obtained, and we can state that this star is definitely not a stellar perturber of long-period comet motion.

These examples show that when considering multiple systems, we cannot even rely on data found in databases of multiple systems and a careful investigation of each alleged component is necessary.

6.6. α Centauri

The α Centauri system, with its three components, is the nearest stellar system to the Sun. It comprises α Cen A, a solar-like star; α Cen B, which is a cooler dwarf; and Proxima, a cool red dwarf, recently recognised to be a host of the nearest exoplanet, Proxima Centauri b.

All of its components were classified as stellar perturbers in García-Sánchez et al. (2001), Dybczyński (2006), Jiménez-Torres et al. (2011), Dybczyński & Królikowska (2015), and Bailer-Jones (2015a). Only in Dybczyński & Królikowska (2015), however, was α Centauri treated as a multiple system, and centre of mass parameters were calculated to obtain the minimum heliocentric distance. Since α Cen A and α Cen B are not included in the *Gaia* DR2 catalogue, and Proxima does not have its radial velocity measured in *Gaia* DR2, we based our calculation on the heliocentric coordinates given in the Galactic frame found in Kervella et al. (2017), summarised in Table 5.

From these values we obtained the centre of mass parameters for the system and the parameters of the closest approach to the Sun, which will happen in 0.03 Myr at the distance of 0.97 pc and with the relative velocity of $32.35\,km\,s^{-1}$. This result is generally in agreement with the values previously published for components of α Centauri.

6.7. HD 239960

HD 239960, also known as Kruger 60, is a visual binary comprising two M spectral type stars and it is supposed to be a host of a planetary system (see e.g. Bonavita et al. 2016). This stellar system was earlier identified as a stellar perturber, but its multiplicity has never been taken into account.

Recently both components of Kruger 60 were observed by *Gaia*, and new astrometry is available in the *Gaia* DR2 catalogue. The components of the system are designated *Gaia* DR2 2007876324466455424 and *Gaia* DR2 2007876324472098432. For both of them the radial velocity is missing in this source.

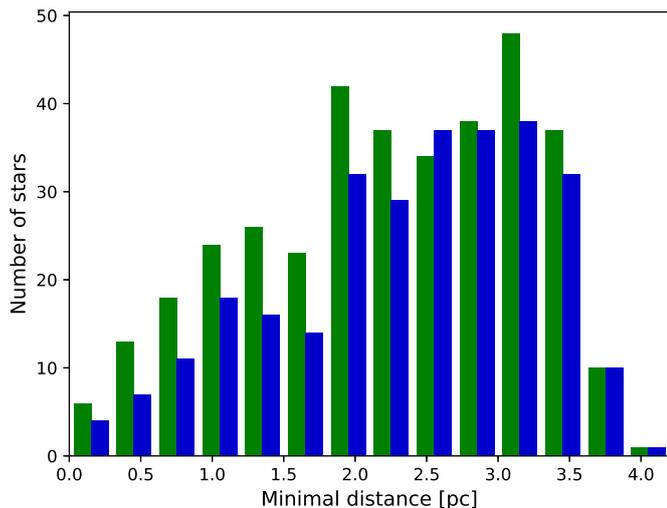---

[3] http://www.recons.org/

Fig. 2. Histogram of minimum heliocentric distances. Distances were divided into two subsets. The green bars correspond to the encounters from the past, the blue bars depict the minimum distances of approaches that will occur in the future. A total of 642 stars with minimum distances of less than 4.0 pc were considered.

Values from the *Gaia* DR2 catalogue can be augmented with radial velocities found in the SIMBAD database and other sources. The SIMBAD database contain values from the General Catalogue of Stellar Radial Velocities (Wilson (1953)), $-24.0\,\mathrm{km\,s^{-1}}$ for HD 239960A and $-28.0\,\mathrm{km\,s^{-1}}$ for HD 239960B, the error on the radial velocity is in both cases estimated to be $5\,\mathrm{km\,s^{-1}}$. There is no indication on epochs of observation when these values were measured. In the literature it is possible to find values of radial velocities of these stars ranging from -36.0 to $-16\,\mathrm{km\,s^{-1}}$, but often without any information on which component was observed.

Because the orbital period of Kurger 60 is estimated to be only 44.6 years (Bonavita et al. 2016) we tried to use positions, proper motions, and radial velocities referring to the same epoch. As it was impossible at first, we decided to use the available data and calculate position and velocity of the centre of mass. Positions, proper motions, and parallaxes from *Gaia* DR2 were used in conjunction with radial velocities from Wilson (1953) and masses found in Bonavita et al. (2016).

While working on the list of stellar perturbers described herein a second interstellar comet 2I/Brisov was discovered. We were involved in a study on its origin, and Kruger 60 seemed to be a good candidate (for details see Dybczyński et al. 2019). An in-depth investigation on data available for this stellar system showed us that they are insufficient to obtain reliable results. Thanks to Fabo Feng (priv. comm.) we have been given an access to the new, unpublished right ascension, declination, parallax, proper motions, and the radial velocity of the centre of mass of Kruger 60 which were calculated using the PEXO package (Feng et al. 2019) based on data from HIPPARCOS (van Leeuwen 2007), the WDS catalogue (Mason et al. 2001), and the recent LCES HIRES/Keck survey (Butler et al. 2017).

These data were further used to obtain parameters of the approach to the Sun. Kruger 60 is a future perturber. It will reach its minimum heliocentric distance of 1.81 pc in 0.09 Myr with a relative velocity equal to $38.03\,\mathrm{km\,s^{-1}}$. This is a slightly smaller distance than presented in the recent paper by Bailer-Jones (2015a) where Kruger 60 was classified as a close approaching star, but its multiplicity was not considered.

7. Online database for stellar perturbers

After collecting all the necessary data, we prepared a simple database containing all the data with their uncertainties and sources. We also included heliocentric rectangular position and velocity components in the Galactic frame together with the adopted mass estimates of all 819 considered perturbers. The whole set of these objects was numerically integrated back and forth in time taking into account all their mutual interactions and including the Galactic overall potential, as described in Dybczyński & Berski (2015). Our results reveal that 713 of our perturbers encountered or will encounter the Sun within a distance of less than 10 pc, and 642 were or will be closer than 4.0 pc. We finally accepted this later proximity threshold as the one defining the potential perturber, just to keep the Algol system in our list. This system is important because of its high mass of 6 $M_\odot$ and extremely low relative velocity of $2\,\mathrm{km\,s^{-1}}$. Finally, we keep the data for all 819 objects in our database, but we name only 642 of them as "potential perturbers" of the near-parabolic comet motion. It is worth mentioning that the final list includes 138 new objects for the first time qualified as potential stellar perturbers of long-period comet motion.

The distribution of the nominal minimum distances between these stars and the Sun is presented in Fig. 2. The number of the past perturbers is slightly greater than the number of the future ones, due to a disproportion of data from the SIMBAD database (where there are many more objects with positive radial velocity). This disproportion can also be noticed in the data from the *Gaia* mission, see for example the results in Bailer-Jones et al. (2018a) when the sample is limited to stars with minimum heliocentric distance smaller than 4 pc.

Our list seems to be complete (in the sense of covering all objects with available data) up to 2.5–3 pc. There are several reasons for a smaller number of objects with greater nominal encounter distance in our list. These include several initial sources with small proximity threshold and a deficiency of the closest and/or high proper motion stars in *Gaia* DR2. As stated before, we adopted PT = 4 pc for our list to keep the Algol system included, but from the point of view of the LPCs perturbations only much closer encounters are important.

The obtained nominal minimum distances from the Sun are also included in the database for all objects. We will use the objects with a small minimum heliocentric distance in the long-period comet dynamical studies. All the remaining objects are placed in our database for the record since they were mentioned in earlier papers. Some of them might return to the list of potential perturbers when new data is gathered. As a consequence, we can trace how the importance of a specific object changes due to the improvement of data quality.

In Fig. 3 we also present three-parameter statistics of stellar close passages near the Sun which includes the most important nominal parameters from the point of view of the star–comet interaction: minimum distances, relative velocities, and masses of the perturbers. To increase the readability of this plot we restrict ourselves to stars passing the Sun with a relative velocity lower than $200\,\mathrm{km\,s^{-1}}$. The purpose of this figure is only to graphically illustrate the content of our database, i.e. nominal parameters of potential perturbers. Readers interested in a detailed distribution of stars approaching the Sun and in the completeness of our current knowledge in this field should consult the extensive study by Bailer-Jones (2018).

Our database is publicly available[4] with a simple interface to access the data and their uncertainties, and the sources. Various
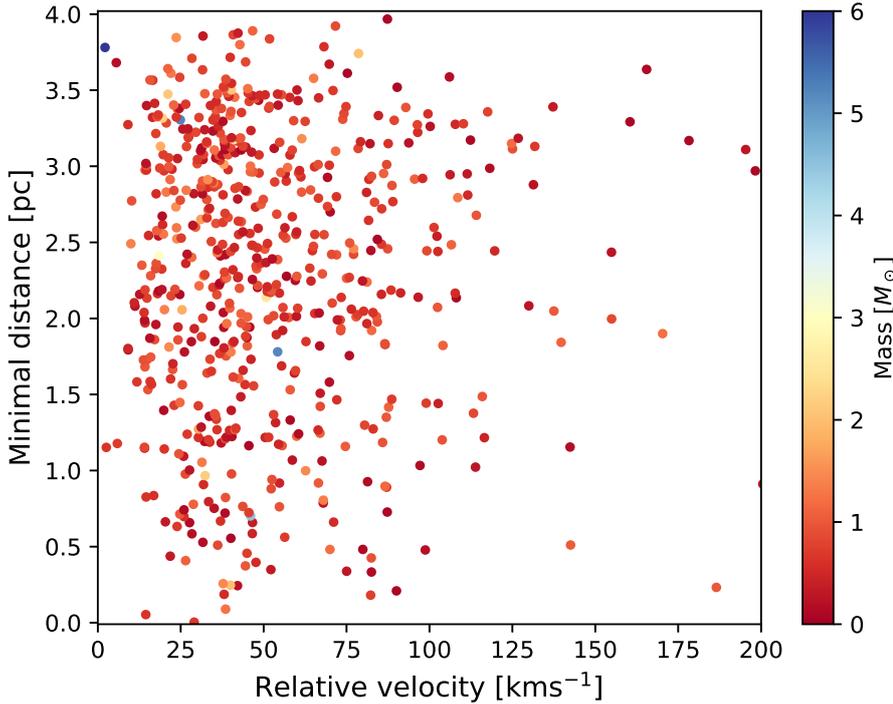
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[4] https://pad2.astro.amu.edu.pl/stars

Fig. 3. Nominal relative velocities, minimum heliocentric distances, and masses of objects included in our list. A total of 613 stars were plotted (see text for details).

lists and statistics are also available, and crucial results are made available for download.

8. Usefulness and importance of the new list of stellar perturbers

As already stated, the aim of collecting the list of stars and stellar systems announced in this paper is to provide a tool for studying past and future motion of long-period comets outside the planetary zone. We carefully selected all potential stellar perturbers of the LPC motion based on the contemporary sources of stellar data, mainly the *Gaia* DR2 catalogue (Gaia Collaboration 2018). The *Gaia* mission results are revolutionary in this respect; for example, before this mission we had no more than 130,000 stellar parallaxes at our disposal, most of them from the Hipparcos catalogue (van Leeuwen 2007). Now we can use over 1.3 billion parallaxes (see e.g. Bailer-Jones et al. 2018b) in our search for potential LPCs motion perturbers.

The last paper that described the past and future motion of LPCs under simultaneous Galactic and stellar perturbations (Królikowska & Dybczyński 2017) used a list of 90 potential stellar perturbers selected on the basis of data from the XHIP catalogue (Anderson & Francis 2012) which was a compilation of the Hipparcos mission results augmented with radial velocities available at that time. In that paper Królikowska & Dybczyński (2017) studied 100 LPCs with large osculating perihelion distances and found no strong stellar perturbation effects.

Now we offer the updated list of 642 potential perturbers. Some of them can perturb cometary motion in a spectacular way (see Wysoczańska et al. 2020), but the effect of the newly obtained list of perturbers on motion of many more comets is also noticeable and very important. A paper describing this in great detail is in preparation; here we only show selected results for four comets to serve as an example. In Table 6 we present previous perihelion distances (one orbital period to the past) for C/1993 F1, C/1997 BA6, C/1999 N4, and C/2006 E1, obtained using three different dynamical models. The starting perihelion

distances of the original orbits are presented in the first row. The next three rows consists of previous perihelion distance values obtained without stellar perturbations, with an old dynamical model used in Królikowska & Dybczyński (2017) and using the list of stellar perturbers announced in this paper, respectively. These values are presented here as three deciles (10%, 50%, 90%) since the distribution of clones used for the uncertainty estimation is far from being Gaussian. For studying the uncertainties, as an alternative, one can apply the method proposed by Feng & Bailer-Jones (2015).

In Królikowska & Dybczyński (2017) a comet is classified as dynamically old if its previous perihelion distance is below 10 au. Instead, it is called dynamically new if the previous perihelion distance appears to be greater than 20 au. As can be seen, the use of the new list of stellar perturbers reversed this classification for three of the presented comets. Such a change is noticed in a large fraction of almost 300 studied LPCs and will be described in a future paper (Dybczyński & Królikowska, in prep.).

But there is one important problem with the list of stellar perturbers announced in this paper, namely ALS 9243. As described in detail in Sect. 4, there is a fundamental inconsistency in the data available for this star: its distance obtained with the *Gaia* mission strongly disagrees with its previously published spectral type and luminosity class. This controversy may lead to two solutions:

– The distance based on *Gaia* DR2 is completely wrong, the star is much farther away (over 2 kpc) and this completely rules out this star as a potential perturbers.

– The astrometric results presented in *Gaia* DR2 are approximately correct, which makes this star an important perturber since its nominal minimum distance from the Sun is as small as 0.25 pc and the approach occurred over 2 Myr ago, so almost all the observed LPCs can be affected by it. But, to be able to calculate this effect, we need the mass of this star.

The most often quoted spectral type and luminosity class of ALS 9243 is O9 IV (see Table 2), which results in a mass of 18.5 solar masses. Since these astrophysical parameters are in

Table 6. Examples of the LPC dynamical history results obtained with different models.

	C/1993 F1			C/1997 BA6			C/1999 N4			C/2006 E1		
$q_{original}$	5.89950 ± 0.00007			3.440371 ± 0.000006			5.504739 ± 0.000006			6.03608 ± 0.00001		
q_{prev} (Galaxy only)	7.33	8.16	9.76	15.90	19.54	24.74	6.36	6.44	6.54	22.78	31.80	48.86
q_{prev} old model	7.12	7.92	9.44	16.89	20.67	26.08	6.33	6.41	6.50	21.55	29.96	46.00
q_{prev} new model	46.27	58.31	68.13	3.10	3.92	7.36	72.07	74.29	75.87	21.91	25.69	52.01

Notes. Shown are the perihelion distance values for four representative comets: of the original orbit (first row); at a previous perihelion, but calculated without stellar perturbations (second row); at a previous perihelion, as obtained in Królikowska & Dybczyński (2017; third row), and at a previous perihelion, but obtained with the new list of perturbers (fourth row). In the last three rows a previous perihelion distance is presented in the form of three deciles, 10%, 50%, and 90%.

Table 7. Influence of the assumed ALS 9243 mass on the previous perihelion distance of the same comets as presented in Table 6.

	C/1993 F1	C/1997 BA6	C/1999 N4	C/2006 E1
O:	5.8995	3.4404	5.5139	6.0361
18.5	58.0720	1486.4459	73.7724	2513.8460
10.0	58.0730	361.4909	73.7736	656.4899
5.0	58.0735	60.0877	73.7743	137.7216
2.0	58.0738	3.7164	73.7747	22.0914
1.0	58.0740	5.5040	73.7748	15.6289
0.0	58.0741	17.6174	73.7749	25.1433
G:	8.1556	19.6341	6.4411	31.8632

Notes. The first row, labelled "O", presents the starting perihelion distance of the original orbit. The last row, labelled "G", presents the previous perihelion distance when all stellar perturbations were omitted. In the remaining rows the first column shows the assumed mass of ALS 9243 expressed in solar masses.

contradiction with the *Gaia* DR2 astrometry, and such a close passage of a hot and massive star 2 Myr ago seems improbable, we have to make a trade-off. For now, waiting for new data, we decided to use the *Gaia* DR2 astrometry, but we assume the mass of ALS 9243 to be equal to 2.0 solar masses.

The correct mass value of ALS 9243 might be crucial for the LPCs dynamical history studies, as we show in Table 7. Here we used nominal orbits of the same comets as shown in Table 6; however, we calculate their previous perihelion distance assuming different masses for ALS 9243. In the first row, labelled "O", the starting value of the perihelion distance is shown. In the next six rows the previous perihelion distances of these four comets are presented, calculated using the assumed mass of ALS 9243 shown in the first column. For the sake of additional comparison, in the last row, labelled "G", we present the previous perihelion distance obtained without stellar perturbations at all, only as a result of the galactic perturbations.

One can easily observe that comets C/1993 F1 and C/1999 N4 are practically not affected by ALS 9243 at all. However, the remaining two comets are clearly affected by this star, and their previous perihelion distance depends on its assumed mass.

9. Conclusions and prospects

Due to a great increase in our knowledge of the Galactic neighbourhood of the Sun we were able to correct and update the list of potential stellar perturbers of long-period comet motion. The initial list of analysed objects included 751 single stars and 69

stellar systems. After analysing all cases we ended up with 781 single stars and 38 multiple systems. Among them 642 objects appeared to have their nominal minimum heliocentric distance smaller than 4 pc, and therefore are classified by us as potential perturbers of LPC motion.

Our updated list consists of two groups: new stars or stellar systems found by us in a manner described in Sect. 2, and stars that were previously classified as stellar perturbers in the earlier papers mentioned in Sect. 2. Objects from the latter group were thoroughly examined to determine whether new or more accurate data are available. Thanks to the improvement in the quality of data we were able to verify the importance of each perturber, to see how it changes due to new measurements, and more importantly to check whether the star in question is a component of a multiple system. In some cases taking the multiplicity into account resulted in removing the perturber from the list; in other cases this approach just changed the expected value of the minimum heliocentric distance, and therefore the potential influence of this particular perturber on LPC motion.

The examples presented in Sect. 6 show the importance of taking the multiplicity into account, and many drawbacks of still incomplete data which sometimes limited and hindered us from calculating the centre of mass parameters based on data concerning all known components of the considered system. The main issues are the lack of radial velocities measurements and masses (which is also applicable to single stars), different epochs of measurements of the positions and proper motions of components of the systems (which can lead to unrealistic results), and incomplete data on the multiplicity of systems, especially those with stars observed by *Gaia* mission for the first time. These issues may be addressed with the future *Gaia* data releases.

While gathering the data necessary to calculate the nominal minimum heliocentric distances of the stars, we came across a star designated ALS 9243. Based on available measurements (from the *Gaia* DR2 catalogue augmented with radial velocity from the SIMBAD database), we determined that this star visited the vicinity of the Sun 2.5 Myr ago at a distance equal to 0.25 pc. This object has never been mentioned as a stellar perturber, and before the *Gaia* mission its distance was often estimated to be more than 1 kpc. Because of the discrepancies in mass estimates, we decided to check the atmospheric parameters of the star in question. Our results indicates that this star seems to be very massive, even up to 22 $M_{\odot}$, which is inconsistent with its distance presented in *Gaia* DR2. We hope, in the very near future, that we will be given an opportunity to obtain consistent data and verify the significance of this perturber. Before the clarification of this puzzling case, we decided to use *Gaia* DR2 astrometry and adopt 2.0 $M_{\odot}$ as the mass of ALS 9243 in our database.

All of our data (with sources) and our results are gathered in a small publicly available database of potential perturbers. This might be a useful tool in future dynamical studies of near-parabolic comets dynamics.

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