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Future stellar flybys of the Voyager and Pioneer spacecraft

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Following their encounters with the outer planets in the 1970s and 1980s, Pioneers 10 and 11 and Voyagers 1 and 2 are now on escape trajectories out of the solar system. Although they will cease to operate long before encountering any stars (the Pioneers already have), it is nonetheless interesting to ask which stars they will pass closest to in the next few million years. We answer this here using the accurate 3D positions and 3D velocities of 7.2 million stars in the second Gaia data release (GDR2, Gaia Collaboration 2018), supplemented with radial velocities for 222 000 additional stars obtained from Simbad[1].

We adopt the same method we used for tracing the possible origin (and future encounters) of the interstellar object 'Oumuamua (Bailer-Jones et al. 2018a). We determine the asymptotic trajectories of the four spacecraft by starting from their ephemerides from JPL's Horizons system[2], propagating them numerically to the year 2900, and then extrapolating to the asymptote. Using a linear motion approximation we then identify those stars which approach within 15 pc of each spacecraft ($\sim$ 4500 stars in each case). Finally, we integrate the orbits of these stars and the spacecraft through a Galactic potential and identify close encounters. Statistics of the encounter time, separation, and velocity are obtained by resampling the covariance of the stellar data and integrating the orbits of the resulting samples. The uncertainties on the asymptotic spacecraft trajectories are negligible compared to those of the stars, and are therefore neglected.

The most interesting encounters we find are listed in Table 1. Proxima Centauri (Gaia DR2 5853498713160606720) is the first flyby in three cases, because that star is currently the nearest neighbour to the Sun (at 1.3 pc). We have not considered its acceleration due to Alpha Centauri in this work. The accompanying data tables list around ten encounters closer than 1 pc per spacecraft, but some of these are unreliable (and are not in Table 1) due to implausibly large radial velocities and/or possibly poor astrometric solutions. Very bright stars like Sirius and Alpha Centauri are not in GDR2 so are not in this study.

Voyager 1's closest flyby, TYC 3135-52-1 (Gaia DR2 2051984436005124480), lies above the main sequence in the colour-magnitude diagram, suggesting it may be a binary, in which case its astrometry may be unreliable. Gaia DR2 2091429484365218432 and HD 28343 (Gaia DR2 145421309108301184) are the second and third closest encounters respectively. Gl 445 (Gaia DR2 1129149723913123456) is the earliest encounter within 1 pc.

Ross 248 (Gaia DR2 1926461164913660160) is the closest encounter for Voyager 2. The second closest is with Gaia DR2 4370380741264455296, even though that star is currently 160 pc away. Its fourth closest encounter will be with h^1 Sgr (Gaia DR2 6767920580693895808), an intrinsically bright and blue delta Scuti-type star.

HIP 117795 (Gaia DR2 2011565220332867584) is the closest encounter to Pioneer 10. Although its GDR2 radial velocity of -285.87 ± 0.41 km/s is suspiciously large, especially when considering its modest tangential velocity of just 11 km/s, Simbad lists an independent and consistent radial velocity measurement of -285.9 ± 0.2 km/s. Bailer-Jones et al. (2018b) found that this star will pass 1.05 pc from the Sun 100 to 200 years later. HD 152311 (Gaia DR2 4127420626087054976) is a binary, so its astrometry is possibly incorrect. This leaves HD 52456 (Gaia DR2 3153772873178431744) as the next closest encounter. Ross 248 is the earliest encounter, and Pioneer 10 has its closest approach to Proxima Centauri at essentially the same time.

Pioneer's 11 closest flyby is with TYC 992-192-1 (Gaia DR2 4490721567368465408). Its next closest is with Gaia DR2 454473057495679385. Gl 445 appears again here, as the fourth closest encounter. It is interesting that in 1.2 myr,

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[1] http://simbad.u-strasbg.fr/
[2] https://ssd.jpl.nasa.gov/horizons.cgi

Table 1. Notable flybys. For each spacecraft the first and closest encounters are shown in the first and second lines respectively. "Asymptote" is the barycentric ICRF direction (degrees) and velocity (km/s) of the spacecraft as it leaves the solar system. (For comparison, stars typically encounter the Sun at a relative velocity of 45 km/s.) $t_{\rm enc}$, $d_{\rm enc}$, $v_{\rm enc}$ are the time from now, star–spacecraft separation, and relative velocity, respectively, of the encounters. "med" is the median of the distribution over the samples, with uncertainties represented by the 5th and 95th percentiles of the distributions. $d_{\rm cur}$ is the current distance to the star from Bailer-Jones et al. (2018c). SpT is the spectral type (from Simbad if available; those marked "late K" have been estimated from the absolute magnitude and colour). The list of all encounters out to $d_{\rm enc}^{\rm med} < 2$ pc (which also includes more data) is available from http://www.mpia.de/homes/calj/voyager_gdr2.html.

Spacecraft &	Star	$t_{\rm enc}$[kyr]			$d_{\rm enc}$[pc]			$v_{\rm enc}^{\rm med}$	$d_{\rm cur}$	SpT
asymptote	name or GDR2 source ID	med	5%	95%	med	5%	95%	[km/s]	[pc]	
Voyager 1	Proxima Centauri	16.7	16.5	16.9	1.072	1.061	1.083	43.2	1.3	M5.5V
$\alpha = 262.8760$	TYC 3135-52-1	302.7	299.5	306.1	0.296	0.289	0.302	46.5	14.4	M3V
$\delta = 12.3199$	2091429484365218432	3405.3	3224.4	3595.7	0.392	0.229	0.540	45.9	159.5	late KV
$v = 16.6048$	HD 28343	487.5	483.2	492.3	0.400	0.395	0.407	22.5	11.2	M0.5V
	Gl 445	44.0	44.0	44.1	0.575	0.574	0.576	116.0	5.3	M4.0V
Voyager 2	Proxima Centauri	20.3	20.2	20.3	0.878	0.867	0.890	46.3	1.3	M5.5V
$\alpha = 316.2717$	Ross 248	42.0	41.9	42.2	0.529	0.528	0.531	72.3	3.2	M5.0V
$\delta = -67.5491$	4370380741264455296	2245.6	2168.4	2334.7	0.558	0.319	0.843	69.9	160.5	late KV
$v = 14.8550$	$\rm h^1$ Sgr	1965.4	1810.8	2141.0	0.708	0.480	0.941	40.9	82.2	A1mA2-F0
Pioneer 10	Ross 248	33.8	33.7	33.8	1.041	1.039	1.044	86.3	3.2	M5.0V
$\alpha = 83.4169$	HIP 117795	90.0	89.7	90.3	0.231	0.230	0.232	290.7	26.8	K8
$\delta = 26.2171$	HD 52456	1250.5	1238.4	1262.4	0.434	0.403	0.464	22.0	28.2	K2V
$v = 11.3149$	Proxima Centauri	34.1	33.6	34.4	1.013	0.990	1.033	23.4	1.3	M5.5V
Pioneer 11	Proxima Centauri	18.3	18.1	18.5	1.040	1.027	1.052	41.8	1.3	M5.5V
$\alpha = 291.8277$	TYC 992-192-1	928.3	920.0	937.4	0.245	0.200	0.292	33.6	31.9	late KV
$\delta = -9.2212$	4544730574956793856	2568.1	2504.2	2640.7	0.439	0.257	0.653	47.2	123.9	late KV
$v = 10.4439$	Gl 445	46.5	46.4	46.6	0.586	0.585	0.588	109.9	5.3	M4.0V
	δ Scuti	1163.4	1110.5	1216.1	0.782	0.641	0.942	51.3	61.0	F2II-III

Pioneer 11 will pass 0.8 pc from the star δ Scuti (Gaia DR2 4155413814250528128), the prototype of the eponymous variability class.

Statistically, the spacecraft will encounter stars within a given distance at approximately the same rate as the Sun does, which Bailer-Jones et al. (2018b) inferred to be one star every 50 kyr within 1 pc (this is an extrapolation and predicts many more stars than found here, because most stars do not have the required data in GDR2). This rate scales quadratically with encounter distance.

Future data releases from Gaia and other surveys that provide radial velocities for more (especially fainter) stars could reveal specific, closer flybys.

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