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A GAIA Revised Oort Cloud Encounter with Gliese 710

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Abstract: The encounter between Gliese 710 and the solar system is re-examined in light of the newly published parallax and proper motion measurements within the GAIA data 1 release. The up-dated astrometric parameters are found to be significantly different from those implicated by the earlier Hipparcos Catalog and the revised encounter will see GL 710 pass some 5 times closer to the Sun than previously indicated. The closest encounter distance is now found to be 0.064 ± 0.020 pc at a time 1.36 ± 0.12 million years from the present. There is now a 100% certainty that GL 710 will pass through the outer boundary of the Oort cloud, and it will possibly pass as close as 5200 AU to the Sun, indicating the potential for non-negligible gravitational perturbations of those cometary nuclei located close to the inner boundary of the Oort cloud. The revised encounter conditions indicate that a relatively strong cometary shower is likely within the inner solar system, although how this will modify the terrestrial impact probability remains unclear. We find that GL 710 might be expected to capture and accrete several thousands of cometary nuclei as it moves through the Oort cloud, and such impacts can be expected to drive anomalous flare activity. We additionally find that GL 710 will quite likely trigger sublimation-driven outgassing from cometary nuclei situated within a few astronomical units of its path across the Oort cloud.

Keywords: Gliese 710, GAIA Data 1 Release, Flare Activity, Oort Cloud, Cometary Impacts

1. Introduction

The GAIA data release 1 on 14 September 2016 [1, 2] affords a new opportunity to revise and re-examine astronomical calibrations and phenomenon that depend critically on accurate parallax and proper motion determinations. Here we re-examine the future close encounter condition of the star GL 710 (HIP 89825; HD 168442) with our solar system. Gliese 710 has long been highlighted as a star that will approach and even penetrate the outer-boundary of the Oort cloud [3, 4, 5]. This latter boundary, located at a heliocentric distance of some 100,000 AU, represents the erstwhile edge of the solar system and is populated by a vast number of cometary nuclei. It is the outcome of the gravitational perturbations that Gliese 710 will impose upon Oort cloud cometary nuclei that has drawn most attention in the literature [3, 4, 5, 6]. Indeed, it is entirely possibility that the close encounter of GL 710 will result in an enhanced influx of long-period comets to the inner solar system and thereby heighten planetary impact probabilities [6, 7]. The latter situation, of course, is of some considerable interest to Earth inhabitants, and while the outcome of events associated with GL 710 are of no immediate concern, similar such encounters, with other stars, will have taken place in the past, and cometary impacts have left observable signatures of devastation within the historical climate and species extinction records [7, 8, 9].

The typical encounter time $T_{\rm enc}$ between the Sun and another star having a space velocity V_S, at a closest approach distance $d_{\min}$ is

$$T_{enc} = \frac{1}{\pi d_{\min}^2 N^* V_S} \tag{1}$$

where N^* is the number density of star systems per unit volume of space. In the solar neighborhood N^* = 0.09 systems/pc^3 and taking a characteristic space velocity of 20 km/s, the typical close encounter time at $d_{\min}$ = 100,000 AU (the edge of the Oort cloud) is $T_{enc} \approx 7.5 \times 10^5$ years. Clearly, the solar system has undergone many thousands of encounters similar to that expected of GL 710, and no existential threat is apparent [10]. This being said, the greater the penetration depth of a passing star into the Oort cloud, so the greater will the likelihood be of producing a distinct enhancement of long period comets moving into the inner solar system.

The likely outcome of a close encounter between a star and a comet located within the Oort cloud, can be gauged according to the tangential impulse velocity δV, where

$$\delta V = 2G\left(\frac{M_S}{V_S}\right)\left(\frac{1}{d_S}\right) \quad (2)$$

where G is the universal gravitational constant, d_S is the impact parameter corresponding to the closest approach distance between the star and a specific comet, and M_S is the mass of the perturbing star. The change in the perihelion distance δq resulting from such a velocity impulse, when the comet is at aphelion, will then be

$$\delta q = Q(1-e)\frac{\delta V}{V_{aph}} \quad (3)$$

where $Q = a(1 + e)$ is the comet's aphelion distance, a is the semi-major axis of the comet's orbit, e is the orbital eccentricity and V_{aph} is the comet's velocity at aphelion. The velocity at aphelion is

$$V_{aph}^2 = \frac{GM_{sun}}{a}\frac{(1-e)}{(1+e)} \quad (4)$$

For $Q = 5\times10^4$ AU, $e = 0.9$, the aphelion velocity is of order $V_{aph} \approx 0.04$ km/s. Gliese 710 is a K7 spectral type, luminosity class V star [11] and accordingly it has a canonical mass of $M_S = 0.67\ M_\odot$ and a radius of $R_S = 0.36\ R_\odot$ [12]. The measured radial velocity for Gliese 710 is $V_R = -18.3$ km/s [13] and its space velocity is $V_S = 13.80$ km/s (based upon the GAIA astrometry data – as discussed in section 2 below). In order for a star like Gliese 710 to produce a non-negligible velocity perturbation of say $\delta V / V_{aph} = 0.1$ on our Oort cloud *test* comet with $V_{aph} \approx 0.04$ km/s, the impact parameter will need to be smaller than $d_s \approx 20{,}454$ AU, corresponding to $d_{min} \approx 7.05 \times 10^5$ AU (≈ 0.34 pc). Equation (3) further indicates that such an encounter will result in a characteristic perihelion distance change of $\delta q = 500$ AU. Clube and Napier [14] and Hills [15] argue that an episode of cometary bombardment will ensue if perturbations produce $\delta q > 100$ AU. Accordingly we take as a minimum condition for Gliese 710 to produce a cometary shower a close encounter distance smaller than 0.34 pc of the Sun.

2. GAIA Revision of Closest Approach

Table 1 is a compilation of astrometric data for Gliese 710. Row 3 of Table 1 indicates a dramatic reappraisal of the proper motion parameters for GL 710 within the GAIA data 1 release [1], and it also reveals a dramatic reappraisal of the star's closest approach distance d_{min}. Indeed, the closest approach distance is now placed well within the inner Oort cloud region, and at a distance where significant perturbations of cometary nuclei will likely take place.

Table 1. *Astrometric data for Gliese 710 as provided by the Hipparcos archive database (row 2), the SIMBAD database [11] and [16] (row 3), and the GAIA data 1 release [1] (row 4). Column 2 indicates the parallax in milliseconds of arc; columns 3 and 4 provide the proper motion components in milliseconds of arc per year. Columns 5 and 6 indicate the deduced space velocity and closest approach distance.*

System	π (mas)	μ_{RA} (mas/yr)	μ_δ (mas/yr)	V_S (km/s)	d_{min} (pc /AU)
Hipparcos	51.81 ± 1.43	1.74 ± 1.40	2.06 ± 1.06	13.80	0.345 / 71,161
Hipparcos-rev	51.12 ± 1.63	1.15 ± 1.66	1.99 ± 1.22	13.80	0.302 / 62,292
GAIA	52.3543 ± 0.2663	-0.4677 ± 0.1304	-0.1759 (8) ± 0.0895(6)	13.80	0.063 / 12,995

Using the GAIA data 1 release (Table 1) parameters as our guide we have performed a Monte Carlo study of possible closest approach distances for GL 710. We evaluate d_{min} and the time from the present to reaching the minimum distance T_{min} by generating 2500 combinations of the encounter parameters (specifically the parallax and proper motion values) adjusted with a random multiplier, between -1, and 1, of the allocated uncertainty. Table 2 and figure 1 provide a summary of our results.

The Hipparcos-rev dataset implicates a nominal closest approach distance of 0.302 pc (62,292 AU) for GL 710 (from Table 1), with the range between the maximum and minimum encounter distances being $18{,}688 < d_{min}$ (AU) $< 133{,}041$. Using the Hipparcos-rev parameters there is a 94 percent probability that GL 710 will cross the Oort cloud boundary ($d_{min} < 100{,}000$ AU); there being a 23% probability that d_{min} will fall inside 50,000 AU and a 1% probability that d_{min} will be smaller than 20,000 AU. With the new GAIA data 1 release parameters these probabilities are profoundly changed and Gliese 710 will now, with a 100% certainty, not only cross the outer Oort cloud boundary but will enter deeply into its interior with $5{,}218.5 < d_{min}$ (AU) $< 22{,}586.0$. The revised encounter conditions now indicate a 26% probability that d_{min} will be smaller than 10,000 AU; a 10% probability that d_{min} will be smaller than 8,000 AU, and a 2% probability that d_{min} will be smaller than 6,500 AU.

Table 2. *Statistics relating to possible GL 710 encounters (GAIA data). The minimum and maximum values are based upon extreme combinations of allowed uncertainty terms. The final row provides the average expected encounter condition.*

	d_{min} (pc)	T_{min} x10^3 years
Minimum	0.0253	1178.3
Maximum	0.1098	1590.4
Average	0.064 ± 0.020	1362.5 ± 115.1

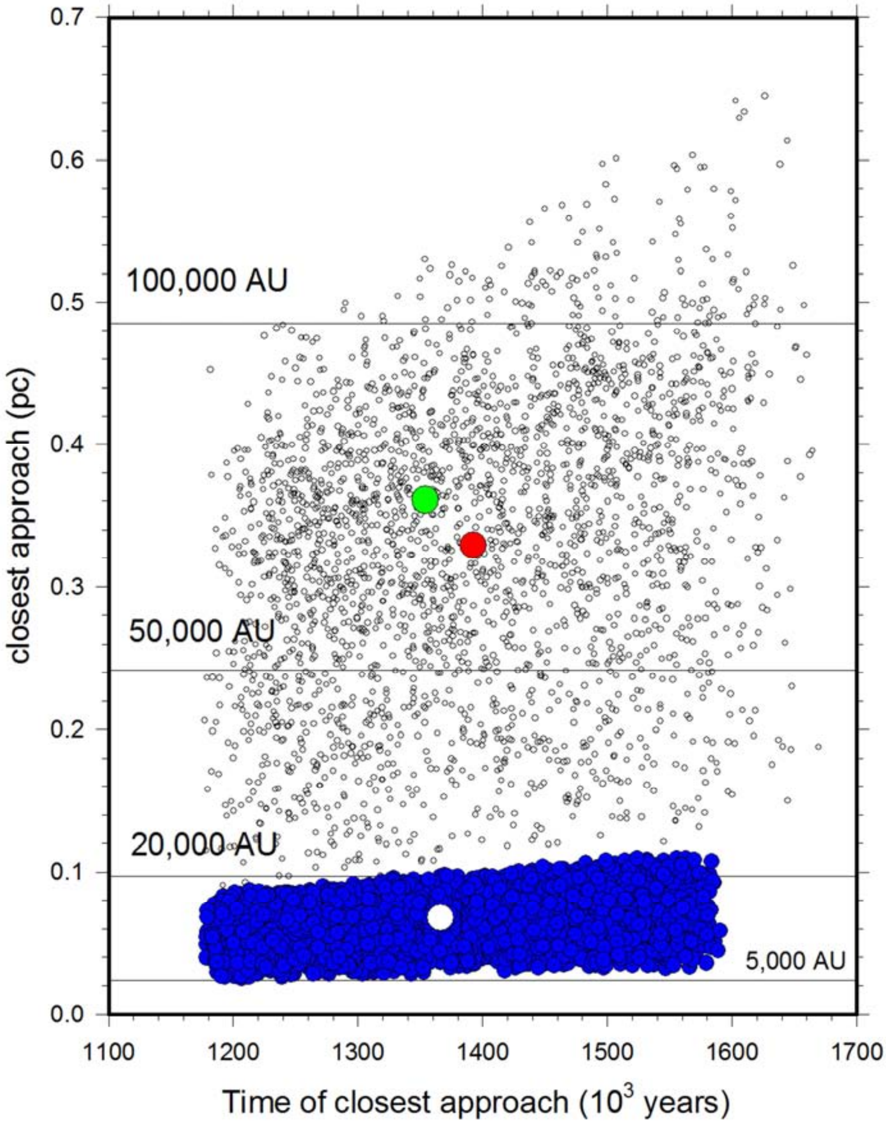

Figure 1. *The realization of 2500 encounters for Gliese 710 with randomly sampled combinations of allowed uncertainty in the radial velocity, parallax and proper motion. The white disk indicates the average closest approach distance and closest approach encounter time for the GAIA data 1 release (from Table 2). The same simulation has been run using the Hipparcos-rev data [11, 16], and these data points are shown as small circular dots. The green disk indicates the average closest approach distance (0.36 pc) and closest approach encounter time (1.358x10*^{6} *yr) for the Hipparcos data. The red disk indicates the average closest approach distance (0.33 pc) and closest approach encounter time (1.394x10*^{6} *yr) for the Hipparcos-rev data.*

3. Encounter Effects

While the various properties of the Oort cloud are all inferred from computer simulations [see e.g., 15, 17, 18, 19] there is general agreement that the most populated region is located at about 3,000 AU from the Sun (the inner edge: R_{in}), and that the total mass of cometary nuclei between R_{in} and the outer boundary at R_{out} = 10^5 AU is of order 10 Earth masses. In the extreme close encounter condition (Table 2) $d_S = d_{min} - 3000 \approx 2200$ AU, and from equation (2) we have: $\delta V / V_{aph} \approx 0.23$ and $\delta q \approx 70$ AU, for Q = 3000 AU and e = 0.9, which is a significant perturbation effect. For the nominal d_{min} value (see Table 2), however, we have $d_S \sim 10^4$ AU and $\delta V / V_{aph} \approx 0.05$, with $\delta q \approx 15$ AU, for Q = 3000 AU and e = 0.9. While a strong perturbation is not implicated for those comets located in the most densely populated region of the inner Oort cloud, a dramatic scattering of comets located towards the outer Oort cloud boundary is indicated during the GL 710 encounter.

The path length of Gliese 710 through the Oort cloud is $L_{OC} = 2\sqrt{R_{out}^2 - d_{\min}^2}$, and the Oort cloud crossing time will be $T_{enc} = L_{OC} / V_S$. For d_{min} = 0.064 pc = 13,200 AU, the Oort cloud crossing time will be about 68,000 years. During this time interval GL 710 will not only gravitationally scatter cometary nuclei it will also begin to directly accrete them. The gravitational capture radius is given by $b = R_S\sqrt{1+(V_{esc}/V_S)^2}$, and with the escape velocity for GL 710 being V_{esc} = 842 km/s (according to canonical mass and radius values [12]), we find b = 0.1 AU. The cross-section area for accreting cometary nuclei will be $\sigma = \pi b^2 = 0.033$ AU^2. The number density $n(r)$ of cometary nuclei at radius $r \geq R_{in}$ = 3000 AU, within the Oort cloud is given by Howe and Rafikov [20] as a power law with

$$n(r) = 500\left(\frac{3000}{r}\right)^{3.5} \text{ cometary nuclei / AU}^3 \qquad (5)$$

In equation (5) it is assumed that the typical cometary nucleus has a diameter of 1-km, and that the mass of the Oort cloud is 10 Earth masses. The number of cometary nuclei directly accreted, N_{acc}, by GL 710, as it moves through the Oort cloud is readily determined from equation (5) for different closest approach distances, and sample results are presented in table 3.

Table 3. *Number of cometary nuclei swept-up by GL 710 as it moves through the Oort cloud. Column 1 indicates the closest approach distance; columns 2 and 3 indicate the path length and the Oort cloud crossing time. Column 4 indicates the total number of cometary nuclei that Gliese 710 will potentially accrete during its crossing of the Oort cloud. The last row indicates the encounter parameters based upon the Hipparcos-rev [11, 16] data.*

d_{min} (pc / AU)	L_{OC} x10^4 AU	T_{enc} x 10^4 yr	N_{acc}
0.025 / 5218.5	19.97	6.86	10,828
0.063 / 12,995	19.83	6.81	1920
0.110 / 22,648	19.48	6.69	520
0.302 / 62,292	15.66	5.37	37

The number of cometary nuclei accreted by Gliese 710, as it moves through the Oort cloud, will depend sensitively upon just how close it approaches the inner boundary at R_{in} = 3000 AU. For the nominal encounter, the possible number of comets accreted will be of order several thousand, with the average interval between encounters being ~35 years. The actual encounter rate will likely be considerably smaller than 35 years, however, since most of the cometary nuclei will be swept up when GL 710 is at its closest approach location. The observable outcome of a cometary nucleus impacting a stellar atmosphere has been discussed by Andrews [21], Beech [22] and Brown *et al.* [23], where it is argued (by all authors) that such impacts will result in air-burst-like detonations with energies comparable to that of stellar flare-phenomena: $E_{imp} \sim ½\, m\, V^2 \sim 10^{23}$ Joules (taking the impact velocity to be $V \sim V_{esc}$ and $m = 2.6\text{x}10^{11}$ kg – based upon a 1 km diameter comet of bulk density 500 kg/m^3). Gliese 710 is tagged as being a possible variable star [11] but there is no record of past flare activity.

In addition to showing impact induced flare activity, there is the added potential for GL 710 to undergo intrinsic superflare activity. Such flares can release as much as 10^{29} Joules of energy depending upon the star's rotation rate. Candelaresi *et al.,* [24] find that superflare energy varies as the inverse square root of the Rossby number Ro = P_{rot} / t_{conv}, where P_{rot} is the rotation period and t_{conv} is the convective turnover time. The rotation period of GL 710 is not known, but its rotation velocity has been measured, giving $V_{rot} \sin i$ = 6.42 ± 0.78 km/s [11]. Adopting a characteristic radius of 0.36 $R_\odot$ [12] for GL 710, we obtain a rotation period P_{rot} ~ 3 days. Characteristic convective turnover times within main sequence stars have been calculated by Landin *et al.*, [25] and we adopt from their study a value of $t_{conv} \approx 94$ days. These characteristic values indicate Ro^{-1} ~ 30 for GL 710 and from Candelaresi *et al.,* [24] we find that superflares with energies up to ~ 10^{28} Joules might be realized. If this energy is emitted over a characteristic flare-time of ten seconds, then the luminosity of GL 710, for those ten seconds, will effectively increase by a factor of ten. What is not presently known, however, is the expected occurrence frequency of such superflares – only future observations of GL 710 will reveal such data. If GL 710 chances to undergo a superflare event during its passage through the Oort cloud then thermal alteration of cometary nuclei can be expected. Indeed, we consider the potential heating of cometary nuclei by GL 710 next.

The equilibrium temperature T_C of a cometary nucleus at an offset distance D from a star of luminosity L_S will be

$$T_C = 278\left[\left(\frac{L_S}{D^2}\right)\frac{(1-A)}{\varepsilon}\right]^{1/4} \qquad (6)$$

where L_S is in solar units, D is in AU, A is the albedo and ε is the emissivity. The luminosity of GL 710 is taken to be that of a typical K7 star, with $L_S = 0.15\ L_\odot$ [12], and cometary appropriate values for A and ε are 0.04 and 0.75 respectively. The temperature at distance D(AU) from GL 710 will accordingly be $T_C = 184 / D^2$. Water-ice sublimation will commence once the temperature is greater than ~ 150 K, and accordingly any cometary nucleus situated within 1.1 AU of the path of CL 710 could begin to show some form of coma and/or tail development. Under the brief conditions that might apply during a superflare event the water ice sublimation distance will increases to ~ 2 AU. The nominal water-ice sublimation radius of 1.1 AU is nearly 11 times larger than that of the accretion radius of GL 710 and a significant number of cometary nuclei will accordingly undergo some degree of thermal processing. Sublimation of the more volatile ices such as N_2, CO and CH_4 will commence at much lower temperatures than that for water ice, and cometary outgassing activity might well be evident over a large volume of space surrounding GL 710 as it moves through the Oort cloud. Indeed, CO ice will begin to sublimate once the temperature exceeds 25 K, and this will occur for distances up to 3 AU of GL 710. Since encounters similar to that expected for GL 710 will have taken place many times in the solar system's past, this latter result underscores the notion that not all long-period cometary nuclei are going to be pristine in the sense of their never having undergone thermal alteration prior to their first perihelion passage [26].

4. Discussion

Canadian astronomer David Levy has famously remarked that, "comets are like cats: they have tails and they do what they want". The encounter conditions between GL 710 and the solar system's Oort cloud, and its observational consequences, in spite of the new astrometric data from the GAIA spacecraft instrumentation, are largely a matter of informed speculation. While we are confident in the correctness of the revised encounter conditions, the expected closest encounter distance and the time of closest approach, as well as the actual effects of GL 710 upon Oort cloud cometary nuclei remains unclear. This latter condition is mostly a reflection of our poor knowledge, at the present time, of the Oort cloud itself. Numerical models indicate a complex, dynamical structure for the Oort cloud, but we are still woefully ignorant of the actual number density of cometary nuclei, and its variation with heliocentric distance, at the present epoch - this uncertainty will, no doubt, be removed through future numerical simulations and observational efforts. For the present, however, it would appear that GL 710 will likely induce some form of distinct comet shower, and accordingly the planet impact probability will be raised somewhat above its present level. Steel [27] argues that the terrestrial planet impact probability, per perihelion passage, is of order $3 \pm 1 \times 10^{-9}$ for long period comets arriving from the Oort cloud. While it is not presently possible to determine how many additional cometary nuclei might be perturbed from the Oort cloud into the inner solar system by GL 710, the numbers are highly unlikely to dramatically change the terrestrial planet impact probability above that found at the present time. This being said, even a slight increase in the impact probability is cause for concern since the typical impact velocity of a long period comet from the Oort cloud will be of order 55 km/s [27]. The impact energy associated with a 1-km diameter cometary impactor will accordingly be a substantial 4×10^{20} Joules (10^{14} kilograms of TNT equivalent energy). The outcomes of such low-probability, high-consequence impacts, even if they are potentially set in the distant future, are assuredly worthy of continued study at the present epoch [28].

5. Conclusions

The recent GAIA date 1 release [1] provides an opportunity to reassess the future encounter and closeness of approach distance conditions between Gliese 710 and the solar system. The newly revised parallax and proper motion data, along with the much reduced uncertainties in these terms, allows us to draw the conclusion that not only will Gliese 710 definitely cross the outer boundary of the Oort cloud, but that it will likely approach as close as 13,000 AU (0.064 ± 0.020 pc) to the Sun. The time of closest encounter is set some 1.36 ± 0.12 million years from the present. It now seems highly likely that Gliese 710 will directly accrete cometary nuclei as it passes through the inner regions of the Oort cloud, potentially leading to anomalous flare-like activity, and that it will induce a distinct epoch of heightened long-period comet influx into the inner solar system. Additionally, we find that the encounter will likely result in the thermal processing of numerous Oort cloud cometary nuclei.

References

[1] See, http://sci.esa.int/gaia/58210-gaia-data-release-1/.

[2] The Gaia collaboration, 2016. The Gaia mission. *Astron. Astrophys*. Manuscript aa29272-16.

[3] Garcia-Sanchez, J., *et al*. 1999. Stellar encounters with the Oort cloud based on Hipparcos data. *Astron. J*. 117, 1042-1055.

[4] Garcia-Sanchez, J., *et al*. 2001. Stellar encounters with the solar system. *Astron. Astrophys*. 379, 634-659.

[5] Bailer-Jones, C. 2015. *Astron. Astrophys*. 575, article A35.

[6] Bobylev, V. V. 2010. Searching for stars closely encountering with the solar system. *Astron. Letters*. 36 (3), 220-226.

[7] Napier, W. 2006. Evidence for cometary bombardment episodes. *Mon. Not. Roy. Astron. Soc*. 366, 977-982.

[8] Schaller, M., Fung, M., Wright, J., Katz, M., and Kent, D. Impact ejecta at the Paleocene-Eocene boundary. *Science*, 354, 225-229.

[9] Farley, K., Montanari, A., Shoemaker, E., and Shoemaker, C. 1998. Geochemical evidence for a comet shower in the late Eocene. *Science*, 280, 1250-1253.

[10] Beech, M. 2008. *Rejuvenating the Sun and Avoiding Other Global Catastrophes*. Springer, New York.

[11] SIMBAD astronomical database: http://simbad.u-strasbg.fr/simbad/.

[12] Lang, K. R. 1992. *Astrophysical Data*. Springer-Verlag, New York. pp. 132-145.

[13] Gontcharov, G. 2006. Pulkovo Compilation of radial velocities of 35,495 Hipparcos stars in a common system. *Astron. Astrophys. Trans*. 25, 145-148.

[14] Clube, S., Napier, W. 1984. Comet capture from molecular clouds: a dynamical constraint on star and planet formation. *Mon. Not. Roy. Astron. Soc*. 208, 575-588.

[15] Hills, J. 1981. Comet showers and the steady-state in-fall of comets from the Oort Cloud. *Astron. J*. 86, 1730-1740.

[16] van Leewen, F. 2007. Validation of the new Hipparcos reduction. *Astron. Astrophys*. 474, 653-664.

[17] Duncan, M., Quinn, T., and Tremaine, S. 1987. The formation and extent of the solar system comet cloud. *Astron. J*. 94, 1330-1338.

[18] Weissman, P. R. 1990. The Oort cloud. *Nature*, 344, 825-830.

[19] Dones, L., Weissman, P., Levison, H., and Duncan, M. 2004. Oort cloud formation and dynamics. In *Star Formation in the Interstellar Medium: in honour of David Hollenbach, Chris McKee and Frank Shu*. ASP Conference Series, volume 323.

[20] Howe, A., and Rafikov, R. 2014. Probing Oort cloud and local interstellar medium properties via dust produced in cometary collisions. *Ap. J.* 781, article 52.

[21] Andrews, A. 1991. Investigation of micro-flaring and secular quasi-periodic variations in dMe flare stars. *Astron. Astrophys*. 245, 219-231.

[22] Beech, M. 2011. Exploring alpha-Centauri: from planets, to a cometary cloud, and impact flares on Proxima. *The Observatory*, 131, 212-224.

[23] Brown, J., Carlson, R., and Toner, M. 2015. Destruction and observational signatures of sun-impacting comets. *Ap. J.* 807, article 165.

[24] Candelaresi, S., Hillier, A., Maehara, H., Brandenburg, A., and Shibata, K. 2014. Superflare occurrence and energies on G, K and M type stars. *Ap. J*. 792, article 67.

[25] Landin, N., Mendes, L., and Vaz, L. 2010. Theoretical values of convective turnover times and Rossby numbers for solar-like, pre-main sequence stars. *Astron. Astrophys*. 510, article 46.

[26] Stern, A., and Shull, J. 1988. The influence of supernovae and passing stars on comets in the Oort cloud. *Nature*, 332, 407-411.

[27] Steel, D. 1993. Collisions in the solar system – V. Terrestrial impact probabilities for parabolic comets. *Mon. Not. Roy. Astron. Soc*. 264, 813-817.

[28] Bostrom, N., and Ćirković, M. 2008. *Global Catastrophic Risks*. Oxford University press.