Draft version July 30, 2022
Typeset using LaTeX **RNAAS** style in AASTeX631

# The Closest Past Flyby of a Known Star to the Solar System: HD 7977, UCAC4 237-008148 or WISE J072003.20-084651.2?

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## ABSTRACT

It is argued that the closest past flyby of a known star to the solar system was that of Scholz's star (WISE J072003.20-084651.2). Here, we show that the distribution of distances of closest approach of this star has a median value of 0.330 pc with a 90% probability of coming within 0.317–0.345 pc of the Sun; the associated time of perihelion passage is determined to be between 78.6–81.1 kyr ago with 90% confidence, with a most likely value of 79.9 kyr. Using *Gaia* DR3 data and the latest planetary ephemerides, we found that UCAC4 237-008148 (RUWE=0.927) approached even closer with a median perihelion distance of 0.259 pc and a 90% confidence interval of 0.249-to-0.269 pc, 1.158 Myr ago. HD 7977 might have passed 0.15 pc from the Sun 2.77 Myr ago, but it has RUWE=2.015.

*Keywords:* Stellar kinematics, Solar system

## INTRODUCTION

Scholz's star (WISE J072003.20-084651.2) was involved in one of the closest past flybys of a known star to the solar system (Mamajek et al. 2015; Dupuy et al. 2019). Bailer-Jones et al. (2018) used *Gaia* DR2 to identify even closer past stellar encounters with the Sun. *Gaia* DR3 (Gaia Collaboration et al. 2016, 2022) may include new data useful to confirm or reject the reality of such events but, if the Renormalized Unit Weight Error (RUWE) >1.4, the relevant astrometric solution could be problematic and it may produce inaccurate results. The RUWE is the square root of the normalized chi-square of the astrometric fit to the along-scan observation; the normalization is necessary to consider sources with extreme colors or magnitude.[1] Here, we present an updated analysis that uses software developed by Aarseth (2003)[2] to perform $N$-body calculations (de la Fuente Marcos & de la Fuente Marcos 2012) based on *Gaia* DR3 input data and the latest planetary ephemerides (Park et al. 2021)[3] as input, and considering the physical model used in de la Fuente Marcos & de la Fuente Marcos (2022).

## SCHOLZ'S STAR

This binary made of an M-dwarf and a brown dwarf was first noticed by Scholz (2014). Mamajek et al. (2015) found that it may have passed $0.25^{+0.11}_{-0.07}$ pc from the Sun, $70^{+15}_{-10}$ kyr ago. This result was independently confirmed by de la Fuente Marcos & de la Fuente Marcos (2018), finding a perihelion distance of 0.28±0.12 pc (57.8 kau), 73±14 kyr ago (averages and standard deviations); de la Fuente Marcos et al. (2018) found that this flyby may have perturbed the Oort cloud. Dupuy et al. (2019) collected additional data to compute improved values of distance, 68.7±2.0 kau, and time, 80.5±0.7 kyr. For validation purposes, we used the data in Dupuy et al. (2019) —its

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[1] https://gea.esac.esa.int/archive/documentation/GDR2/Gaia_archive/chap_datamodel/sec_dm_main_tables/ssec_dm_ruwe.html
[2] http://www.ast.cam.ac.uk/~sverre/web/pages/nbody.htm
[3] https://ssd.jpl.nasa.gov/?horizons

associated source *Gaia* DR3 3048443305671969152 has no astrometric solution— and updated ephemerides to perform $N$-body simulations as described above. Figure 1, top panels, shows the results of $10^5$ integrations of control orbits of WISE J072003.20-084651.2. The distribution of times is shown in the top-left panel, the mean and standard deviation are 79.9±0.8 kyr; the median value is 79.9 kyr and 78.6–81.1 kyr is the 90% confidence interval. The distribution of perihelion distances in the top-right panel has a mean and standard deviation of 0.330±0.008 pc (68 170±1 750 au, median of 68 148 au) with a 90% probability of coming within 0.317–0.345 pc (<0.351 pc, 99%).

### UCAC4 237-008148

Bailer-Jones et al. (2018) found that UCAC4 237-008148 (0.82 $M_\odot$) encountered the solar system with a median perihelion distance of 0.232 pc and a 90% confidence interval of (0.199, 0.264) pc; the associated distribution of times has a median value of 1.162 Myr and 1.151–1.173 Myr is the 90% confidence interval. Wysoczańska et al. (2020), Dybczyński & Breiter (2022), Dybczyński & Królikowska (2022) and Dybczyński et al. (2022) found respective values of 0.199±0.006 pc and 1.084±0.004 Myr, from *Gaia* EDR3. The star, *Gaia* DR3 5571232118090082816, has a full data set with RUWE=0.927. Figure 1, middle panels, shows the results of $10^4$ integrations of control orbits of UCAC4 237-008148. The mean and standard deviation of the time of perihelion passage are 1.158±0.006 Myr; the median value is 1.158 Myr and 1.148–1.168 Myr is the 90% confidence interval. The mean perihelion distance and its standard deviation are 0.259±0.006 pc (53 476±1 274 au, median of 53 490 au) with a 90% probability of approaching within 0.249–0.269 pc (<0.274 pc, 99%). These results match well those in Bailer-Jones (2022).

### HD 7977

Bailer-Jones et al. (2018) found that HD 7977 (1.07 $M_\odot$) approached with median perihelion distance of 0.429 pc and a 90% confidence interval of (0.368, 0.494) pc; the associated distribution of times has a median value of 2.788 Myr and 2.731–2.853 Myr as 90% confidence interval. Wysoczańska et al. (2020), Dybczyński & Breiter (2022), Dybczyński & Królikowska (2022) and Dybczyński et al. (2022) found $0.032^{+0.027}_{-0.026}$ pc and $2.471^{+0.026}_{-0.026}$ Myr, from *Gaia* EDR3. *Gaia* DR3 5109116185692390 40 has RUWE=2.015; therefore, it could be a multiple system with unreliable data. In any case, our calculations ($5\times10^2$ integrations, Figure 1, bottom panels) give values of the relevant parameters of 0.15±0.02 pc and 2.77±0.02 Myr; the timing matches that in Bailer-Jones (2022) but our distance is larger.

## DISCUSSION AND CONCLUSIONS

UCAC4 237-008148 flyby seems to be the new *bona fide* closest past encounter of a known star to the solar system. It is believed that such flybys send small bodies hurtling towards the inner solar system (see e.g. Dybczyński & Królikowska 2022) and large-scale impacts on Earth may trigger climate change and other harmful effects (see e.g. Collins et al. 2005). It is therefore intriguing that the passage of UCAC4 237-008148 is somewhat consistent in time with the beginning of the mid-Pleistocene Climate Transition, 1.2–0.55 Myr ago, that witnessed a global extinction episode (see e.g. Hayward et al. 2007). Furthermore, the possible flyby of HD 7977 is well correlated with the Pliocene extinction that occurred ∼2.6 Myr ago (see e.g. Pimiento et al. 2017) and the Eltanin asteroid impact that happened about 2.5 Myr ago (Goff et al. 2012). It is however worth mentioning that correlation does not imply causation, and these could be just coincidences. Besides HD 7977, other flybys in Dybczyński et al. (2022) that may not have occurred involve UCAC4 364-018255 and UCAC4 556-008431 with no solution in *Gaia* DR3.

We thank S. J. Aarseth for providing the code used in this research and A. I. Gómez de Castro for providing access to computing facilities. This work was partially supported by the Spanish 'Agencia Estatal de Investigación (Ministerio de Ciencia e Innovación)' under grant PID2020-116726RB-I00 /AEI/10.13039/501100011033. This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

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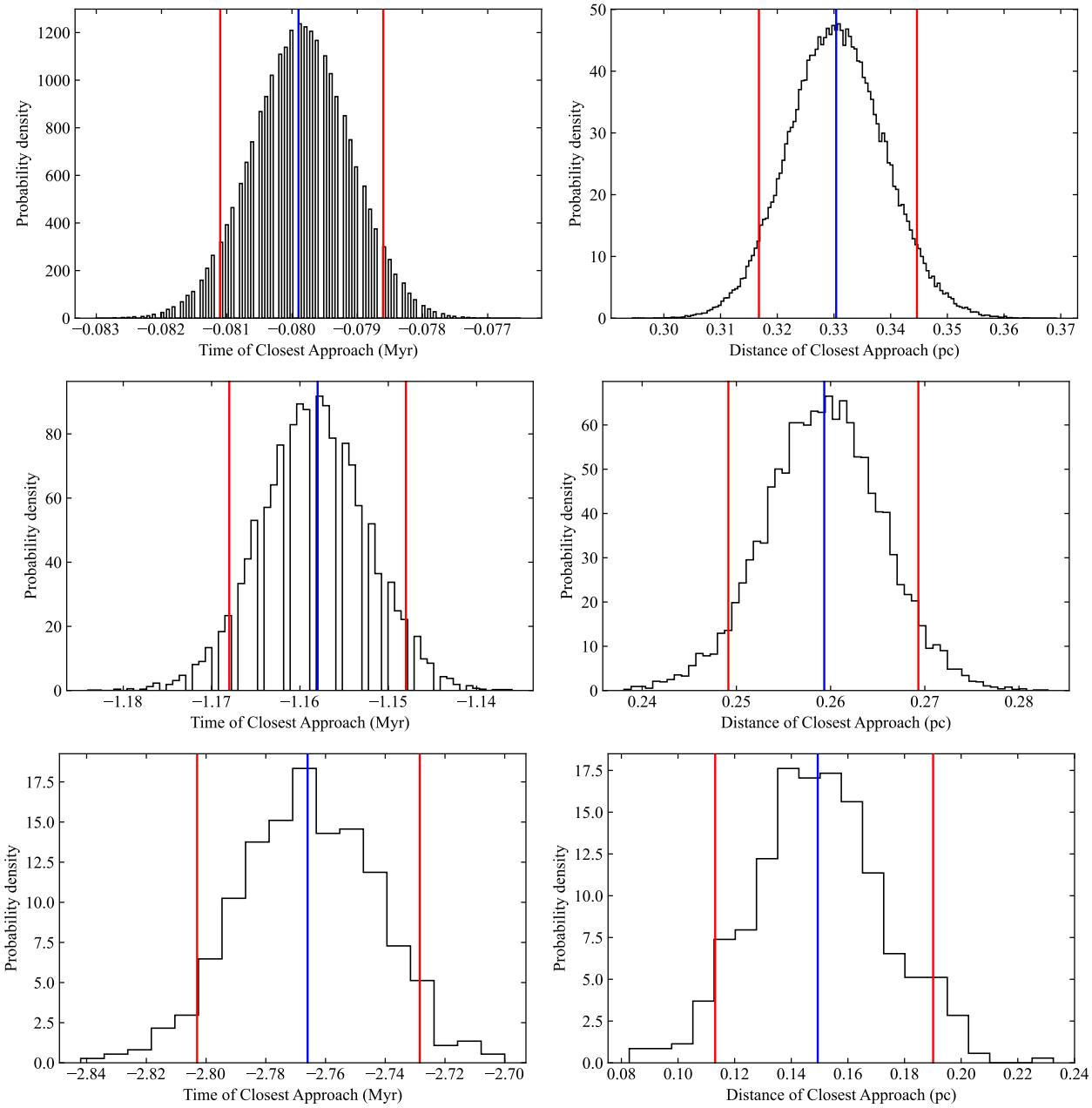


**Figure 1.** Top panels: Past perihelion passage of WISE J072003.20-084651.2 as estimated from input data from Dupuy et al. (2019) and the $N$-body simulations discussed in the text. The results for UCAC4 237-008148 and HD 7977 are shown in the middle and bottom panels, respectively. The distributions of times of perihelion passage are shown in the left panels and perihelion distances in the right panels. The blue vertical lines mark the median values, the red ones show the 5th and 95th percentiles. Histograms have been produced using the Matplotlib library (Hunter 2007) with sets of bins computed using Numpy (Harris et al. 2020) by applying Freedman and Diaconis' rule and using counts to form a probability density such as the area under the histogram will sum to one.


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