Have we missed an interstellar comet four years ago?

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October 31, 2018

ABSTRACT

New orbit for C/2014 W₁₀ PANSTARRS is obtained. High original eccentricity of $e = 1.65$ might suggest an interstellar origin of this comet. The probable reasons for missing this possible important event is discussed and a call for searching potential additional observations in various archives is proposed.

1. Introduction

In the course of a redetermination of orbits of long period comets (hereafter LPCs) we recently attempted to check, whether the assumption of a parabolic orbit for hundreds of comets discovered after 1950 is fully justified in all cases (Królikowska & Dybczyński, in preparation). During this research we found an interesting case of the comet C/2014 W₁₀ PANSTARRS. It was observed during one month only, with a small total number of 17 observations distributed very heterogeneously (November 25–28 and December 22). The data is extremely scarce, however it surprised us that the published orbital solutions for this comet are so different.

The discovery of C/2014 W₁₀ was announced by R. Wainscoat and R. Weryk in a Minor Planet Center CBET 4030 electronic telegram on the 5th of December, 2014. This comet was discovered on the 25th of November 2014 in four w-band CCD exposures taken with the 1.8-m Pan-STARRS1 telescope. During the follow-up observations the recognizable coma of 1-8 arcsec level was reported, as well as the barely visible tail. Full details might be found in the quoted CBET.

Basing on 14 observations taken during three days: November 25, 26 and 28 the preliminary orbit was published in the quoted CBET and the following MPC electronic circular: MPEC 2014-X31, issued on the same day. At MPC they obtained the elliptical, short period orbit with elements presented in the first data column in Table 1.

Such a preliminary orbit (distant, Halley type comet) as well as the low brightness of the object (20.1 – 21.4 mag) probably discouraged other observers and only three additional observations were obtained on December 22, 2014, from iTelescope Observatory, Mayhill, NM, USA, which previously observed this comet on November 28. This poor quality orbit is copied on the quoted CBET and the following MPC electronic circular: MPEC 2014-X31, issued on the same day. At MPC they obtained the elliptical, short period orbit with elements presented in the first data column in Table 1.

First of all we observe, that in all previous solutions a perihelion passage date even A YEAR LATER:

\begin{align*}
\text{perihelion passage date} &= \text{November 25, 2014} \\
\text{perihelion passage date} &= \text{December 22, 2014}
\end{align*}

We may speculate that a small total number of observations and large residuals obtained for the last three observations with respect to the previously published orbit stimulated the staff at MPC (probably as a routine) to replace the previous orbit with the new one, based on all 17 observations but with the eccentricity assumed to be 1.0. This ‘final’ MPC orbit is presented in the second data column in Table 1.

The parabolic orbit is dramatically different from the short period elliptical one previously published. All elements are significantly different but the most striking (at least for us) change is in the perihelion passage date. While in the elliptical solution a comet was observed nine month AFTER the perihelion and goes away, in the parabolic solution it is observed 2.5 month BEFORE perihelion and is approaching.

This poor quality orbit is reprinted in several Internet places, for example at the Seiichi Yoshida’s popular cometary catalog, or on some Halley type comet list. At the JPL Small Body database one might find also a parabolic orbit for C/2014 W₁₀, based on all 17 observations with the mean weighted residual of 0.′24, very similar to the ‘final’ MPC solution (where mean residual is not given). The similarity is so good that one might guess, that this is the same orbit as at MPC, but calculated for a different osculation epoch. Surprisingly there is one strange thing at JPL – they provide uncertainties for all elements INCLUDING ECCENTRICITY. Available is also a full 6×6 covariance matrix there so it seems that they OBTAINED not ASSUMED a parabolic orbit.

It might be worth to mention, that from the set of first 14 observations Japan amateur astronomer Kazuo Kinoshita obtained a completely different but also parabolic orbit, perfectly fitting to this subset of observations. By putting $e = 1.0$ he obtained $q = 6.51927$ only, different angular elements and the perihelion passage date even A YEAR LATER: $T = 2016$ Aug. 17.267 TT with the mean residual of 0.′19.

All the above motivated us to check carefully what orbital information can be obtained from these 17 observations available at MPC.

2. New orbit determination

First of all we observe, that in all previous solutions a perihelion distance is large, what means that nongravitational forces might play a marginal role in the case of this object so we decided to deal with purely gravitational solutions only, which is also a typical approach for such a short observational arc.

1 http://www.cbet.astro.wisc.edu/cbet/004000/CBET004030.txt (subscription needed)
2 https://physics.ucf.edu/~yfernandez/cometlist.html
3 http://www.aerith.net/cometcatalog/2014W10/2014W10.html
4 https://physics.ucf.edu/~yfernandez/cometlist.html
5 http://jcometobs.web.fc2.com/cmt/k14w10.htm
Table 1. Publicly available C/2014 W₁₀ orbits from various sources. Angular elements with respect to the ecliptic of J2000. Only for the orbit given at JPL, we were able to reproduce also the uncertainties of orbital elements.

| Orbit calculator         | MPC prelim. | MPC final | JPL         | Kinoshita       | Patrick Rocher |
|--------------------------|-------------|-----------|-------------|-----------------|----------------|
| number of observations   | 14          | 17        | 17          | 14              | 17             |
| mean residual            | n.a.        | n.a.      | 0°24        | 0°19            | 0°21           |
| perihelion passage [TT]  | 2015 Feb. 9 246 | 2014 Feb. 6 757 | 2014 Feb. 07 6 ± 979 days | 2016 Aug. 17 267 | 2013 Aug. 29 115 |
| perihelion [AU]           | 7.4247577   | 7.9952199 | 8.0 ± 0.75  | 6.51927        | 7.7604333      |
| semimajor axis [AU]       | 0.6039453   | 1.0       | 1.0 ± 0.87  | 1.0             | 1.223709       |
| inclination [deg]         | 72.97258    | 85.11344  | 85.13 ± 12 | 76.637         | 87.760905      |
| longitude of the ascending node [deg] | 40.86266 | 43.68179  | 43.68 ± 2.8 | 41.695         | 44.289828      |
| argument of perihelion [deg] | 19.01185 | 356.23188 | 356.3 ± 64 | 61.067         | 344.592321     |
| orbital period [yrs]      | 81.2        | –         | –           | –              | –              |
| epoch of osculation [TT]  | 2015 Feb. 9 0 | 2014 Feb. 6 0 | 2014 Dec. 1 0 | n.a.           | 2015 Feb. 9 2 |

Our first unresolved puzzle is how to obtain a Halley type orbit from the first 14 observations. Instead, from these three-day arc we obtained a hyperbolic osculating orbit (solution A0, see the first column of Table 2, which is highly incompatible (especially from the point of view of the eccentricity) with that obtained at MPC. The additional argument that the preliminary MPC orbit might be significantly wrong is that additional three observations made on December 22 drastically diverge by over two arc minutes. On the contrary they are considerably closer to our solution A0, on a level of 20 arcsec.

Our next solution, named A2 and based on all 17 observations is presented in the second column of Table 2. This orbit fits very well to all observations, residua are presented in the first column of Table 2. Since all these values are pretty small we did not introduce any weighing.

Can this solution be improved further? We decided to check whether ‘catalogue debiasing’ according to the procedure described by [Farnocchia et al. (2015)] change the orbital solution essentially. According to our previous experiences these corrections, based on averaged catalogue biases and approximating unknown proper motions are of little use in cometary astrometry, mainly due to intrinsic errors of measuring diffuse object positions, usually significantly greater than these corrections. However in this case, where all residua are so small (one may say: asteroidal) we decided to apply them, obtaining another solution, named D2.

We were really surprised obtaining an osculating eccentricity even more hyperbolic, see the last column of Table 2. Since the mean residual is slightly decreased, orbital element uncertainties on the same level or smaller and all particular residua are pretty small we decided to announce our solution D2 as the definitive one. That solution, on a level of 20 arcsec, is dispersed we mention that VCs reached a distance of 250 au. All planetary perturbations as well as relativistic corrections were applied. Finally we changed a reference frame to the barycentric one.

3. Possible dynamical past of C/2014 W₁₀

At first we would like to stress that due to large uncertainties of the osculating (and therefore also the original) orbit parameters nothing can be said about the dynamical past of this comet for sure. However, according to very small obtained residua and large perihelion distance (which makes significant nongravitational effects improbable) we describe here the probable past dynamics of this object. Our main purpose is to show that similar cases should be treated in future with greater care by more reliable preliminary orbit determination and alerting observers about the importance of the object to initiate more follow-up observations.

To obtain original orbit parameters of C/2014 W₁₀ along with their uncertainties we performed a procedure similar to that performed in our other papers, see for example [Królikowska & Dybczyński (2017)]. In short, we added 5000 virtual comets (VCs) to the nominal orbit obtained in solutions A2 and D2 and followed numerically their motion backwards to a heliocentric distance of 250 au. All planetary perturbations as well as relativistic corrections were applied. Finally we changed a reference frame to the barycentric one.

Elements of the nominal original orbits of C/2014 W₁₀ PANSTARRS obtained from our solutions A2 and D2 are presented in Table 2. We do not list their large uncertainties (as useless) because it appeared that we are dealing with an extremely scattered VCs cloud. Instead, to illustrate how this swarm of VCs is dispersed we mention that VCs reached a distance of 250 au from the Sun in a wide range of nearly 400 years. This shows us how fundamentally this VCs-cloud differs from all the others we have studied so far. Therefore Table 2 only gives orbital elements for nominal solutions (without uncertainties). The original VCs swarm is also much more dispersed than the osculating cloud of VCs and it contains orbits with the original eccentricities in the range from ~0.96 to more than 2.0.
moving towards the sun with a velocity of \(9.29\ \text{km s}^{-1}\) of this comet. According to our nominal solution D2, comet we studied the past evolution of the obtained nominal orbit

Just to illustrate the possible interstellar origin of C/2014 W\(_{10}\) we passed close enough to perturb C/2014 W\(_{10}\) to direct it towards the sun from an Oort cloud orbit. The orbital evolution of this comet during last 0.75 Myrs is presented in Fig. 1. Thin lines show the evolution without stellar perturbations while the thick ones show the results of the full dynamical model. One can observe rather weak perturbation from the star GJ 279 (HD 60532). This star passed approximately 0.75 pc from this comet 0.4 Myr ago at a relative velocity of 62 km s\(^{-1}\) with respect to the comet on its nominal orbit.

During the past 1.2 million years C/2014 W\(_{10}\) travelled \(\sim 10\) pc, finally approaching our sun in 2014. Using the nominal original orbit we have checked 3865 stars that can approach the sun closer than 10 pc selected by Baier-Jones et al. (2018) from the Gaia DR2 catalogue (Gaia Collaboration et al. 2018) and additionally 3440 nearby stars (some overlap of course) from the SIMBAD database (Wenger et al. 2000). None of these stars passed close enough to perturb C/2014 W\(_{10}\) motion significantly or to direct it towards the sun from an Oort cloud orbit. The orbital evolution of this comet during last 0.75 Myrs is presented in Fig. 1. Thin lines show the evolution without stellar perturbations while the thick ones show the results of the full dynamical model. One can observe rather weak perturbation from the star GJ 279 (HD 60532). This star passed approximately 0.75 pc from this comet 0.4 Myr ago at a relative velocity of 62 km s\(^{-1}\) with respect to the comet on its nominal orbit.

Please note that this past evolution of C/2014 W\(_{10}\) PANSTARRS is based on a extremely uncertain original orbit. On the other hand this orbit fits well (as well as all other VCs

### Table 2. Osculating orbits of C/2014 W\(_{10}\) calculated in this paper. Angular elements with respect to the ecliptic of J2000.

| Solution code | A0 | A2 | D2 |
|---------------|----|----|----|
| number of observations | 14 | 17 | 17 |
| mean residual | 0′′19 | 0′′29 | 0′′24 |
| perihelion passage date [TT] | 2016 Jul. 15.6 ± 211 days | 2013 Jul. 3.8 ± 102 days | 2013 May 16.2 ± 42 days |
| perihelion distance [AU] | 4.40 ± 2.26 | 7.575 ± 0.43 | 7.279 ± 0.40 |
| eccentricity | 1.400 ± 0.585 | 1.376 ± 0.379 | 1.653 ± 0.409 |
| inclination [deg] | 64.86 ± 18.8 | 89.14 ± 3.3 | 91.33 ± 3.0 |
| longitude of the ascending node [deg] | 38.74 ± 5.0 | 44.61 ± 0.8 | 45.11 ± 0.7 |
| argument of perihelion [deg] | 84.81 ± 19.4 | 339.41 ± 10.7 | 333.18 ± 7.4 |
| osculating heliocentric 1/a [AU\(^{-1}\)] | -0.0907 ± 0.2349 | -0.0497 ± 0.0607 | -0.0897 ± 0.0744 |
| epoch of osculation [TT] | 2015 Feb. 9.0 | 2014 Feb. 6.0 | 2014 Dec. 1.0 |

### Table 3. Osculating orbits of C/2014 W\(_{10}\) calculated in this paper. Angular elements with respect to the ecliptic of J2000.

| Date | Observatory | A2 solution residuals | D2 solution residuals |
|------|-------------|----------------------|----------------------|
| 2014 11 25.25361 | F51 | -0′′38 | +0′′05 |
| 2014 11 25.26554 | F51 | -0′′39 | +0′′32 |
| 2014 11 25.27744 | F51 | -0′′07 | -0′′11 |
| 2014 11 25.28933 | F51 | +0′′10 | -0′′03 |
| 2014 11 26.215967 | S68 | +0′′42 | +0′′12 |
| 2014 11 26.217927 | S68 | +0′′40 | +0′′12 |
| 2014 11 26.219888 | S68 | +0′′34 | +0′′10 |
| 2014 11 28.22691 | H01 | +0′′10 | -0′′00 |
| 2014 11 28.271113 | H01 | +0′′24 | +0′′00 |
| 2014 11 28.220180 | H01 | +0′′22 | +0′′06 |
| 2014 11 28.210921 | H01 | +0′′19 | -0′′23 |
| 2014 11 28.25174 | H06 | -0′′24 | -0′′14 |
| 2014 11 28.25565 | H06 | -0′′21 | -0′′22 |
| 2014 11 28.25955 | H06 | -0′′11 | -0′′22 |
| 2014 12 22.08098 | H06 | +0′′32 | +0′′16 |
| 2014 12 22.08407 | H06 | -0′′13 | +0′′12 |
| 2014 12 22.08716 | H06 | -0′′19 | -0′′22 |

### Table 4. Original barycentric orbits of C/2014 W\(_{10}\). Angular elements with respect to the ecliptic of J2000.

| Corresponding osculating solution code | A2 | D2 |
|--------------------------------------|----|----|
| perihelion passage date [TT] | 2013 Jul 4.7 | 2013 May 15.7 |
| perihelion distance [AU] | 7.579 | 7.276 |
| eccentricity | 1.367 | 1.650 |
| inclination [deg] | 89.11 | 91.35 |
| longitude of the ascending node [deg] | 44.57 | 45.08 |
| argument of perihelion [deg] | 339.53 | 333.15 |
| epoch of osculation [TT] | 1863 Jan. 29.0 | 1894 Aug. 14.0 |
| original barycentric 1/a [AU\(^{-1}\)] | -0.0485 | -0.0893 |

### 3.1. Nominal original orbit past evolution

Just to illustrate the possible interstellar origin of C/2014 W\(_{10}\) we studied the past evolution of the obtained nominal orbit of this comet. According to our nominal solution D2, comet C/2014 W\(_{10}\) reached a heliocentric distance of 250 au in 1894, moving towards the sun with a velocity of 9.29 km s\(^{-1}\) from a direction \(\alpha = 14^h03^m\) and \(\delta = -43^\circ35'\). This direction is almost exactly at right angle to the solar apex at \(\alpha = 18.5^\circ\) and \(\delta = +30^\circ\).

During the past 1.2 million years C/2014 W\(_{10}\) travelled \(\sim 10\) pc, finally approaching our sun in 2014. Using the nominal original orbit we have checked 3865 stars that can approach the sun closer than 10 pc selected by Baier-Jones et al. (2018) from the Gaia DR2 catalogue (Gaia Collaboration et al. 2018) and additionally 3440 nearby stars (some overlap of course) from the SIMBAD database (Wenger et al. 2000). None of these stars passed close enough to perturb C/2014 W\(_{10}\) motion significantly or to direct it towards the sun from an Oort cloud orbit. The orbital evolution of this comet during last 0.75 Myrs is presented in Fig. 1. Thin lines show the evolution without stellar perturbations while the thick ones show the results of the full dynamical model. One can observe rather weak perturbation from the star GJ 279 (HD 60532). This star passed approximately 0.75 pc from this comet 0.4 Myr ago at a relative velocity of 62 km s\(^{-1}\) with respect to the comet on its nominal orbit.

Please note that this past evolution of C/2014 W\(_{10}\) PANSTARRS is based on a extremely uncertain original orbit. On the other hand this orbit fits well (as well as all other VCs
orbits) to our limited but precise observational data, so, cannot be ruled out.

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