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New orbits for comets C/1843 J1 (Mauvais) and C/1853 W1 (van Arsdale)

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New orbits for comet C/1843 J1 (Mauvais) and comet C/1853 W1 (van Arsdale) are calculated. Both orbits are hyperbolic, with $e = 1.001145$ and semi-major axis $a = -1412.18$ AU for Mauvais and $e = 1.000700$ and $a = -2919.24$ AU for van Arsdale. Integrating the orbits backwards indicate that both comets were born in the far Oort cloud.

1 Introduction

Although comets Mauvais (C/1843 J1) and van Arsdale (C/1853 W1) do not pertain to a family, cogent reasons exist to study their orbits together. Both are catalogued with parabolic orbits, and I have given reasons for recalculating parabolic orbits in previous publications such as Branham (2007), their perihelion distances are large, beyond the Earth's orbit, and both have a substantial number of observations covering several months. Only 30 % of catalogued orbits have perihelia larger than Mauvais's and 15 % larger than van Arsdale's. They were both observed, moreover, in the mid-19th century and should have comparable precision of the observations, unlike what would happen if we were to look at the observations of a modern comet and one in the Middle Ages. To calculate non-parabolic orbits for both, therefore, seems worthwhile rather than otiose.

2 The Observations

Victor Mauvais discovered his comet on 3 May 1843, which becomes 4 May when corrected for the civil-astronomical difference in days, at the Paris Observatory. Robert van Arsdale discovered the comet that bears his name on 25 Nov. 1853 in Newark, New Jersey. The comet was observed for the first time in Europe on 2 December and, communication time being what it was in 1853, the discovery attributed to Klinkerfues. A literature search, primarily in the ADS data base (http://adswww.harvard.edu/) but also in a few other publications not included in the ADS, yielded a total of 283 observations in right ascension (α) and 281 in declination (δ) made between 4 May and 18 September 1843 for Comet Mauvais and 130 in α and 127 in δ, made between 3 December 1853 and 1 March 1854, for Comet van Arsdale;

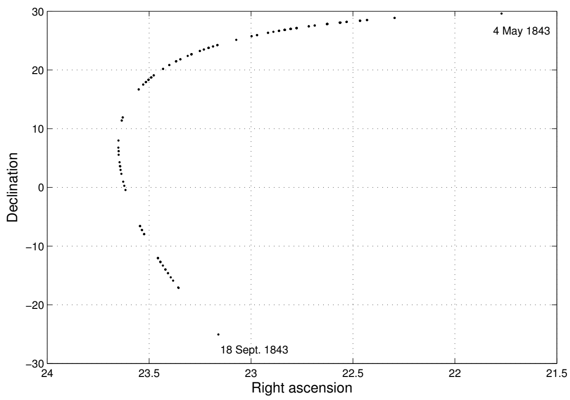

Fig. 1 The observations (Mauvais's comet).

van Arsdale's original observations starting on 25 November 1853 were of insufficient precision for inclusion in the orbit computation. Table A1 summarizes the observations for Comet Mauvais and Table A2 for Comet van Arsdale. Figures 1 and 2 show them in graphical form.

All observations were published as apparent places. The Vienna observations were used in their original, unaveraged form. Processing 19th century observations becomes complicated; see Branham (2011) for details. I should, however, mention a few particularities of the observations. When a reference star is mentioned one should always compare the star in the original catalog with a re-reduction of the star's position, whether mean or apparent, taken from a modern catalog such as the Tycho-2 catalog (Høg et al. 2000), which has far smaller mean errors. When the observation is given as a difference, $\Delta\alpha$ and $\Delta\delta$, from the reference star the difference should be applied, corrected if necessary for differential aberration and refraction, to the recalculated star position. All of the Vienna observations were published as $\Delta\alpha$ and $\Delta\delta$ differences. If only the reference star is mentioned then the differences between the 19th century and the mod-

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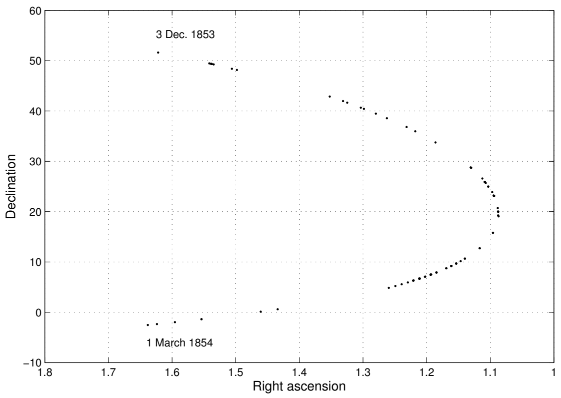

Fig. 2 The observations (van Arsdale's comet).

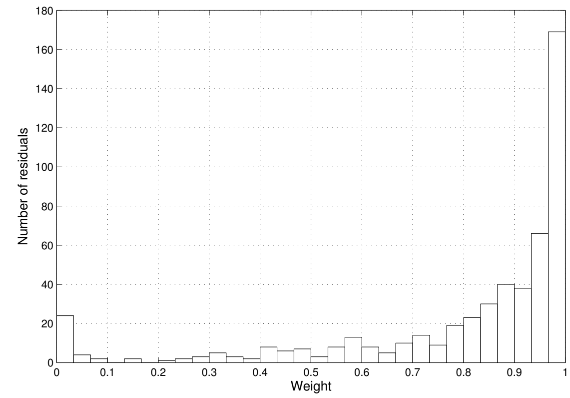

Fig. 3 Welsch weighting for Mauvais's comet.

ern positions should be applied to the α and δ published by the observer.

For comet Mauvais the Kremsmünster observations mention the references stars as α and β Persei, but unfortunately not the catalog from which the positions were taken. These observations had to be used as published. The Greenwich observations for Mauvais present a conundrum. The observations of the comet are published along with observations of stars. But it appears as if those stars are not reference stars because the section is titled "Right ascension and north polar distance of Mauvais' first comet and neighboring stars". Thus, these stars are referred to as "neighboring" rather than "reference" stars. The observations, moreover, mention sidereal time of transit and, for north polar distance measurements, reading of the circle (presumably declination circle) or, for right ascension measurements, the hour circle. One may infer that the observers used the equatorial telescope as a combined transit instrument and vertical circle. No correction, therefore, was applied to these observations.

From previous research with 19th century comets I have found that often a large observed minus computed position $(O - C)$ is not a genuine bad observation. Sometimes an observer wrongly identifies a reference star, transposes numbers, or performs many other correctable errors. For comet Mauvais, however, I could find no easy correction for large $(O - C)$'s, which thus must be considered genuine bad observations. For comet van Arsdale only one observation had to be corrected. Table A3 shows the correction plus some star identifications not given in the original publications.

3 Ephemerides and differential corrections

The rectangular coordinates and velocities of the comet and the Earth were calculated by a program, used in numerous investigations previously, that treats the solar system as an N-body problem and takes the starting coordinates published in the Marsden and Williams catalog (Marsden & Williams 2003). The program is a 12th order Lagrangian predictor-corrector that incorporates general relativity. To obtain coordinates and velocities for the Earth, the moon is carried as a separate body. This means a small step-size, $0^{\mathrm{d}}.25$. To correct the comet's orbit partial derivatives are calculated by Moulton's method (Herget 1968), which integrates the partial derivatives to correct for the osculating rectangular coordinates and velocities epoch. The rectangular coordinates, after interpolation to the moment of observation for the Earth and to the moment of observation antedated by the light time correction to allow for planetary aberration, are then converted to a unit vector that is transformed to a mean or apparent place in α and δ by application of precession, nutation, annual aberration, relativity, and so forth. The final step calculates an observed minus a computed place, $(O - C)$, in α and δ.

Various weighting schemes are possible once one has post-fit residuals from a differential correction. Among modern, robust weightings are the biweight, the Talwar, and the Welsch. Branham (1990, Sect. 5.5) discusses all of these weighting possibilities. Welsch weighting accepts all residuals, but assigns low weight to large residuals, so low as to become less than the machine ϵ for extremely large residuals,

$$\mathrm{wt} = \exp(-r_i/2.985)^2, \quad |r_i| < \infty. \tag{1}$$

The final solution does not depend critically on which weighting has been used.

The first differential correction was calculated by use of the robust L_1 norm. Because the norm is robust it becomes unnecessary to eliminate discordant observations. The residuals from this first correction then supplied the basis for further corrections based on Welsch weighting. For the first iteration I used the MAD (mean absolute deviation), the sum of the absolute values of the residuals divided by the degrees of freedom, for the measure of dispersion. Subsequent iterations employed the mean error of unit weight, $\sigma(1)$. Figures 3 and 4 show the respective Welsch weighting for comet Mauvais and for comet van Arsdale.

After a solution has been calculated one should check for the randomness of the residuals. A runs test measures how often a variable, distributed about the mean, changes sign from plus to negative or negative to positive, the runs,

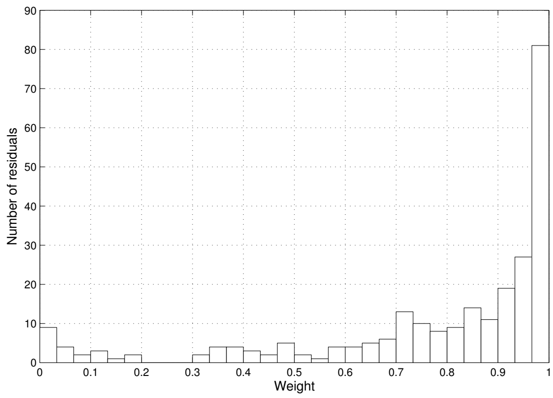

Fig. 4 Welsch weighting for van Arsdale's comet.

which have a mean for n data points of $n/2 + 1$ and a variance of $n(n-2)/4(n-1)$ (Wonnacott & Wonnacott 1972, pp. 409–411). An advantage of the runs test over other tests for randomness resides in its being nonparametric, not assuming normality of the data, although to actually calculate probabilities for the observed runs one does assume approximate normality.

4 The Solutions

Table 1 shows the final solution for the rectangular coordinates, x_0, y_0, z_0, and velocities, $\dot{x}_0$, $\dot{y}_0$, $\dot{z}_0$, along with their mean errors and also the repeated mean error of unit weight $\sigma(1)$ for Mauvais's comet. Table 2 shows van Arsdale's solution. Table 3 gives the correlation matrices for both comets. The highest correlation for Mauvais, –86.1 %, and the highest for van Arsdale, 88.9 %, while high are not excessive, and the respective condition numbers of 466.1 and 205.7 for the data matrices show that the solutions are stable.

Table 4 gives the orbital elements corresponding to the rectangular coordinates of Table 1, and Table 5 the same for Table 2: the time of perihelion passage, T_0; the eccentricity, e; the semi-major axis, a; the perihelion distance, q; the inclination, i;the node, Ω;and the argument of perihelion, ω.

Table 1 Solution for rectangular coordinates and velocities for Mauvais's comet; epoch JD 2394480.5, equinox J2000.

Unknown	Value	Mean Error
x_0 (AU)	1.6604440e+00	5.2538567e–05
y_0 (AU)	–9.0013724e–01	9.5471074e–06
z_0 (AU)	–7.7141703e–02	7.4504707e–06
$\dot{x}_0$ (AU d^{-1})	1.2265172e–02	8.1705379e–07
$\dot{y}_0$ (AU d^{-1})	9.22508150e–03	2.3267985e–07
$\dot{z}_0$ (AU d^{-1})	–8.8179494e–03	2.9534601e–07
$\sigma(1)$	9″.42	

Table 2 Solution for rectangular coordinates and velocities for van Arsdale's comet; epoch JD 2398200.5, equinox J2000.

Unknown	Value	Mean Error
x_0 (AU)	1.0590894e+00	2.2608653e–05
y_0 (AU)	1.2621169e+00	9.8718535e–06
z_0 (AU)	1.2406914e+00	1.7880864e–05
$\dot{x}_0$ (AU d^{-1})	7.7756379e–03	1.0127861e–06
$\dot{y}_0$ (AU d^{-1})	4.8967578e–03	4.0973437e–07
$\dot{z}_0$ (AU d^{-1})	–1.4234013e–02	4.7037817e–07
$\sigma(1)$	5″.04	

Table 3 Correlation matrices for Mauvais's (upper triangular) and van Arsdale's (lower triangular) comets.

1.0000	–0.8606	0.5723	0.2818	0.2837	–0.8173
0.7521	1.0000	–0.5959	–0.0833	–0.2814	0.7919
0.8888	0.6637	1.0000	–0.3686	0.6431	–0.6298
0.0575	–0.0415	0.0670	1.0000	–0.6707	0.0901
-0.0561	–0.3810	–0.0411	0.8230	1.0000	–0.5124
-0.8276	–0.6341	–0.9403	0.0435	0.1196	1.0000

Table 4 Elliptic orbital elements and mean errors for Mauvais's comet, equinox J2000.

Unknown	Value	Mean Error
T_0	JD 2394327.05739 06.55739 May 1843	$0^{d}.00255$
a (AU)	–1412.18	153.42
e	1.0011446	0.0001246
q (AU)	1.6163135	0.0616023
Ω	147°.726809	0°.0575582
i	31°.572166	0°.0582352
ω	139°.727262	0°.1085916

Table 5 Elliptic orbital elements and mean errors for van Arsale's comet, equinox J2000.

Unknown	Value	Mean Error
T_0	JD 2398222.96939 04.46939 Jan 1854	$0^{d}.01381$
a (AU)	–2919.24	665.46
e	1.0007004	0.0001599
q (AU)	2.0447284	0.0623055
Ω	224°.1988181	0°.0789831
i	97°.6433309	0°.0995998
ω	131°.9797456	0°.1892009

5 Discussion

Having the final orbits we can calculate the randomness of the residuals. Figure 5 gives a histogram of the residuals before use of the Welsch filter for comet Mauvais, but with extreme residuals eliminated by Pierce's criterion (Branham1990, pp. 78–80) and Fig. 6 the final residuals after use of the Welsch filter. Figures 7 and 8 do the same for van Arsdale's comet.

If we consider only nonzero residuals, the runs test for comet Mauvais reveals 248 runs out of an expected 282, a

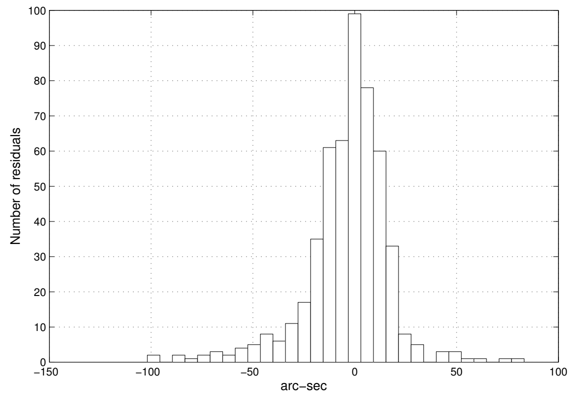

Fig. 5 Histogram of residuals for Mauvais'scomet.

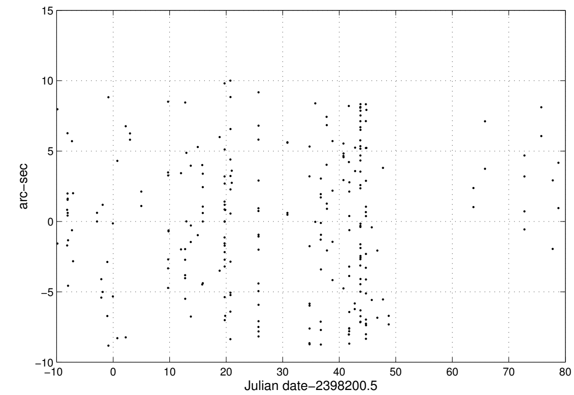

Fig. 8 Residuals after weighting for van Arsdale's comet.

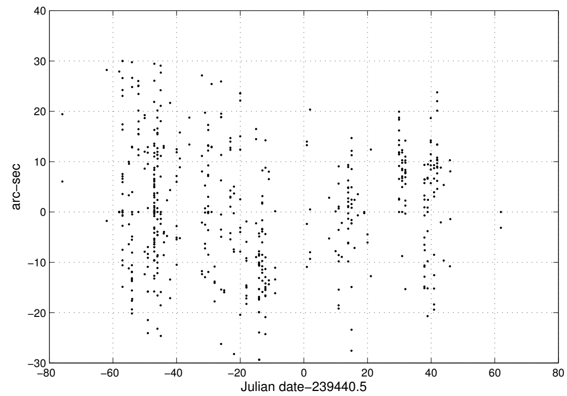

Fig. 6 Residuals after weighting for Mauvais's comet.

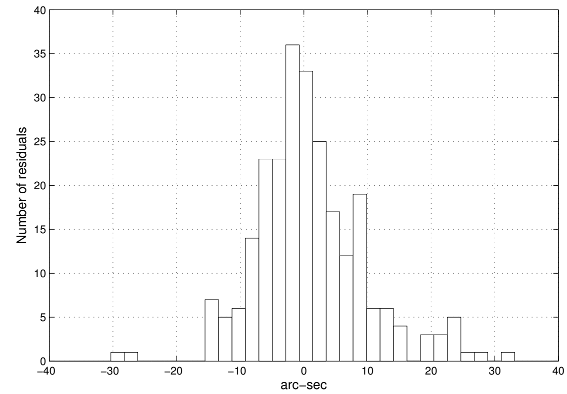

Fig. 7 Histogram of residuals for Mauvais's comet.

decided deficiency of runs with almost 0 % chance of being random. This must be explained because further differential corrections do not change the orbit. One's first inclination might be to attribute the lack of randomness to the observations that could not be referred to the Tycho-2 reference system. If we look at only the 268 Vienna observations there are 105 runs out an expected 124 for the nonzero residuals, a 2.0 % chance of being random. $\sigma(1)$ also falls to $8''.45$. Although use of residuals reduced to a common system improves somewhat the situation, it still does not explain the overall deficiency of runs.

One's second inclination might be to suspect a deviation from pure Keplerian motion caused by outgassing. Given the perihelion distance significant outgassing seems unlikely, but should be demonstrated rather than assumed. To investigate the possibility I used Eq. (5) of Branham (2012) to model a radial component of a non-gravitational force. The final residuals, however, also showed only 248 runs. Thus, non-gravitational forces are not the explanation.

There also seem to be no systematic trends associated with α or δ. If the time span of 137.82 days is divided into 6 hour time intervals, spectral analysis of the residuals in α reveals no periodicity: all noise is white noise. The same is true for the residuals in δ. There remains, therefore, scant possibility of a $\Delta\alpha_\alpha$ clock error for the α residuals or a $\Delta\delta_\delta$ circle error for the δ residuals.

The answer to the conundrum appears to be that the prefiltered residuals are far from normal: coefficient of skewness of –0.68, 0 for a normal distribution, even though there are more positive than negative residuals, 261 versus 253; kurtosis of 7.53, 3 for a normal distribution; and a Q factor of 0.21, 2.11 for the normal. We therefore have a distribution that is far more leptokurtic than the normal and with lighter tails. Although the runs test is nonparametric, is does assume *approximate* normality to calculate means and variances.

These arguments also pertain to comet van Arsdale, where because of the perihelion distance outgassing is even more improbable than with comet Mauvais. The comet exhibits 110 runs out of an expected 129 with an almost equal number of positive and negative residuals, 128 and 129. The skewness, nevertheless, is 0.25; this time the distribution is platykurtic, kurtosis of 0.86, but still light-tailed, Q factor of 0.32. Again, the distribution is far from normal.

An orbit has been calculated for Mauvais's comet, and that orbit is hyperbolic. The comet will never return to the solar system and represents no NEO threat in the future. But what about the past? Could the comet have originated outside of the solar system? To test this possibility I integrated the orbit backwards with heliocentric coordinates to JD –47990369.5 (24 September –136106). At a distance of ≈ 18 AU the orbit definitely changes from high eccentricity ellipse, $a = 881106$ AU, to hyperbola, $a = -285930$ AU. At the extreme limit of the integration the heliocentric distance becomes $r = 9719$ AU, $a = 5025$ AU, $e = 0.998995$, and velocity close to zero, ≈ 0.08 km s^{-1}. These values remain far from definitive because of the nonrandomness of the residuals and accumulated round-off error, even with use of the compensated sum to perform the integrations (Higham 1996, pp. 92–97). It thus seems as if the comet was born in the far Oort cloud and acquired energy as it approached the inner solar system until the orbit became hyperbolic.

The same conclusion pertains to van Arsdale's comet as well. The orbit is hyperbolic, and the comet will never return. Integrating the orbit backwards to JD –5009269.5 (27 December –18428), perhaps less of overkill than that employed with Mauvais's comet, shows a high eccentricity ellipse, $e = 0.99887$, at a heliocentric distance of $r = 3507$ AU and $a = 2854$ AU, and low velocity, ≈ 0.44 km s^{-1}. The orbit changes from ellipse to hyperbola at a distance of ≈ 7.7 AU. It thus appears as if this comet was also born in the far Oort cloud.

6 Conclusions

New orbits for comets Mauvais and van Arsdale have been calculated by use of least squares and the Welsch filter for residuals. The final residuals are not really random, but this is most likely caused by the non-normality of the residuals. The final orbits are hyperbolas and thus neither of these comets represents an NEO threat. They appear to have been born in the far Oort cloud as high eccentricity ellipses converted to hyperbolas as both comets approached the inner solar system.

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A Summary of the Observations and Errors and Missing Information in the Observations

Table A1 Observations of comet C/1843 J1 (Mauvais).

Observatory	Obsns. in α	Obsns. in δ	Reference[1]
Kremnsmünster, Austria	11	11	AN, 1843, No. 21, pp. 39–40
Vienna, Austria	134	134	Annal Wien, 1849, Vol. 33, pp. 17–27
Greenwich, England	57	55	Green. Obs., 1845, Vol. 5, pp. 64–78
Paris France	7	7	AN, 1843, No. 20, pp. 24–25 AN, 1843, Vol. 21, pp. 39–40
Hamburg, Germany	54	54	AN, 1844, No. 21, pp. 12–13 MN, 1843, Vol. 6, p. 10
Königsberg, Germany	20	20	AN, 1846, No. 24, pp. 385–386
Total	283	281	

[1] AN: Astronomische Nachrichten; MN: Monthly Notices RAS.

Table A2 Observations of comet C/1853 W1 (van Arsdale).

Observatory	Obsns. in α	Obsns. in δ	Reference[1]
Kremnsmünster, Austria	4	4	AN, 1854,, No. 908, pp. 321–322
Vienna, Austria	55	52	Annal Wien, 1855, Vol. 4, pp. 78–82
Olmütz, Czech Republic	2	2	AN, 1854, Vol. 38, No. 902, pp. 213–214
Berlin, Germany	11	11	AN, 1854, No. 38, pp. 15–16 AN, 1854, No. 38, pp. 73–74 AN, 1854, No. 38, pp. 269–270
Bonn, Germany	29	29	AN, 1854, No. 38, pp. 49–50 AN, 1854, No. 38, pp. 341–342
Göttingen, Germany	6	6	AN, 1854, No. 38, pp. 93–94 MN, 1854, No. 38, pp. 409–410
Hamburg, Germany	4	4	AN, 1854, No. 38, pp. 11–12 AN, 1854, No. 38, pp. 61–62
Cambridge, Mass. USA	5	5	AJ, 1854, Vol. 3, pp. 159–160
Padua, Italy	2	2	AN, 1854, No. 38, pp. 165–166
Rome, Italy	5	5	AN, 1854, No. 38, pp. 191–192
Leiden, Netherlands	7	7	AN, 1854, No. 38, pp. 30–40 AN, 1854, No. 38, pp. 331–332
Total	130	127	

[1] AJ: Astronomical Journal; AN: Astronomische Nachrichten; MN: Monthly Notices RAS.

Table A3 Errors and missing information for van Arsdale's comet.

Observatory	Reference[1]	Date or Ref. Star No.	Error or Missing Data
Berlin, Germany	AN, 38, 73–74	d	Tycho-2 747 01864 1
Hamburg, Germany	AN, 38, 11–12	22 Dec	Tycho-2 753 01415 1 Tycho-2 753 00482 1
Hamburg, Germany	AN, 38, 61–62	25 Dec	Tycho-2 750 00983 1 Tycho-2 750 02342 1
Hamburg, Germany	AN, 38, 61–62	28 Dec	Tycho-2 748 01864 1 Tycho-2 747 01524 1 Tycho-2 747 00043 1
Padua, Italy	AN, 38, 165/166	18 Jan	Tycho-2 0617 00415 1
Rome, Italy	AN, 38, 191/192	a	Tycho-2 613 00964 1
Rome, Italy	AN, 38, 191/192	K	Tycho-2 027 00801 1
Cambridge, USA	AJ, 3, 159	b	Tycho-2 303 01307 1
Cambridge, USA	AJ, 3, 159	24 Dec	Change sign of $\Delta\delta$
Cambridge, USA	AJ, 3, 159	c	Tycho-2 750 01618 1

[1] AJ: Astronomical Journal; AN: Astronomische Nachrichten.