Improvement of the old reductions of irregular satellites using the first publications of the data

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1. Introduction

The use of long-exposure photographic plates made the discovery of additional natural satellites possible. The first satellite to be discovered in this manner, Phoebe, was found in 1899 by W.H. Pickering. A reliable model of satellite motion must be constructed with high accurate observations and with data spreading over a period as long as possible. Some old literatures have given the positions of the natural satellites and the reference stars for determining its positions. At that time, the catalogue they used did not contain enough stars, so there were not many catalogue stars on the plates. Because of the unsatisfactory precision of the old catalogue at the epoch and the imprecise measurements on the plate, the positions of the reference stars were not very precise. At present, although we have no plates, we can reduce the positions of the natural satellites from the row data provided in these literatures with modern precise astrometric catalogues, such as PPM and UCAC2.

The purpose of this work is to reduce the old observations of Phoebe (Saturn IX), in order to improve its orbit. Figure 1 shows the numbers of the early photographic observations of Phoebe from 1898 to 1996. Most of the positions are in the equatorial coordinate system, but some of them are relative to the Saturn, which can also be used to improve the orbit of Phoebe.

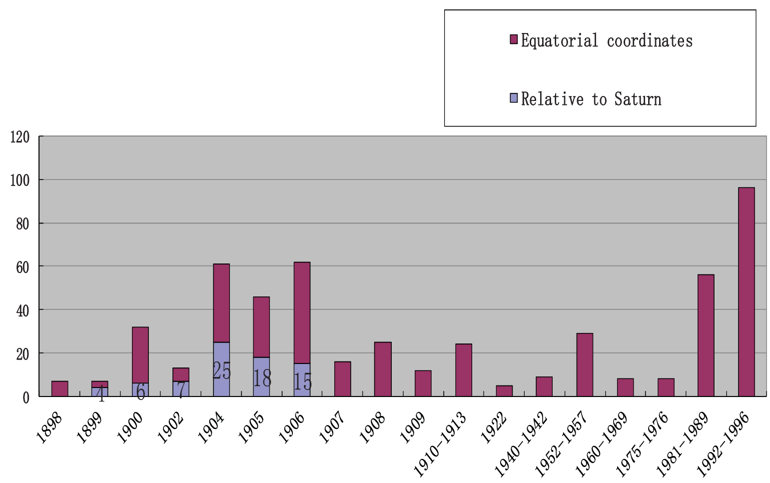

Fig 1 Numbers of the early photographic observations of Phoebe

We take an article (Pickering 1908) as an example to explain how we reduce those early observations.

The first observation of Phoebe and the details of the plates are presented in Pickering (1908). The author has given the detailed information of the plates: the number of the plates, the date of observation, the centers of the plates, and the number of the measurements. Pickering (1908) also mentioned the information of the reference stars including their label numbers in the catalogue, the magnitudes, and the positions. The author used the assumed centres to calculate the computed coordinates of Phoebe. 10 stars were used as reference stars in the first 7 plates. 42 plates were mentioned in the article, which are archived in Harvard Astronomical Plate Collection, however these plates have not been scanned yet. As other satellites of Saturn were also measured, such as Titan, Hyperion, and Iapetus, we can also obtain relative positions between Phoebe and other satellite of Saturn.

2. Data reduction and results

The relationships among the measured coordinates of a star on the plate, the standard coordinates, and the spherical coordinates are the same as what we use now (see). The main improvement of our method is that we use more reference stars with more accurate astrometric positions, to determine the position of the target Phoebe.

There are two cases in the early publications: (1) the positions of the satellite and the reference stars were provided; (2) the potions of the reference stars were not given. If the positions of reference stars were not given explicitly in the old literature, we can first search the stars in the old catalogue which were used at that time. The stars with the distance to the satellite less than 1 degree and the magnitude between 9 and 10 mag are regarded as the reference stars. We should choose at least 6 reference stars. Then the positions of the reference stars and the satellites are transformed to the J2000 mean equatorial coordinate system or the ICRS, using the IAU1976 precession parameters (Lieske 1979).

After that we use the proper motions in the new catalogue to calculate the positions of the stars at the epoch of the old catalogue, and then identify these reference stars in the new catalogue. We regard two stars in two catalogues as the same star if the position distance is smaller than 15 mas and the difference of the magnitude is less than 1 mag. We choose the natural satellite given in the article as the centre of the plate if we don't know the centre. With the positions of the stars and the satellite in the literature (not necessary to transform the reference system), we can calculate the tangent coordinates of the stars. Then we use these coordinates as the measured coordinates on the plate, to determine the center of the plate, the parameters of the plate (4 parameters at least or more if we have more stars), and the standard coordinates of the stars and the satellites.

Finally with the standard coordinates and the positions of the stars in the new catalogue the positions of the satellite can be calculated.

For the example, Fig. 2 shows the positions of the reference stars and Phoebe. The black stars means the 10 reference stars mentioned in the paper (Pickering 1908), the red marks () means the reference stars found using our method by identifying the same star in two catalogues, the two compared catalogues are the CPD catalogue (Cape Photographic Durchmusterung: Gill et al. 1895-1900) which was used at that time and UCAC2 (including U2SUP, which means the UCAC2 Bright Star Supplement) (Urban et al. 2006). The circles means the 7 reduced positions of Phoebe and the green point means the positions of Phoebe in the JPL ephemerid. We can see that the red marks are identical with the black stars, which means that with our method, the real reference stars can be found. Because of the unsatisfactory precision of both the old catalogue and the proper motions of the new catalogue, sometimes it is difficult to identify all the reference stars.

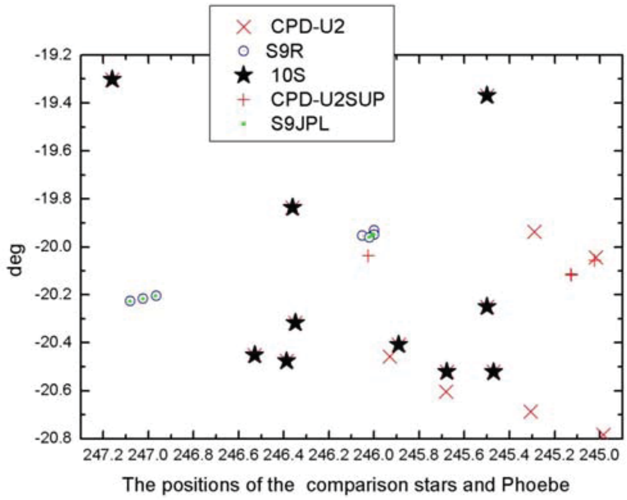

Fig 2: The black stars means the 10 reference stars mentioned in the paper (Pickering 1908), the red marks() means the reference stars found using our method to identify the same star in two catalogue, the two compared catalogues are the CPD(Cape Photographic Durchmusterung: Gill et al. 1895-1900) catalogue which was used at that time and UCAC2, including U2SUP, which means the UCAC2 Bright Star Supplement (Urban et al. 2006). The circles means the 7 reduced positions of Phoebe and the green point means the positions of Phoebe in the JPL ephemerid.

Table1: O-C in the right ascension and declination of Phoebe position

DATE	1875-J2000 (S,")		PPM (S,")		UCAC2 (S,")	
1898 8 17.011	0.225	-63.89	0.0833	-62.1092	0.1093	-62.7261
1898 8 17.096	-0.014	-3.47	-0.1485	-1.6152	-0.1216	-2.2422
1898 8 18.039	10.366	-3.14	10.2496	-1.5398	10.2743	-2.1497
1898 8 19.050	0.164	2.4	0.0402	4.2009	0.066	3.5746
1898 9 16.031	-0.553	1.1	-0.2818	-1.0073	-0.3	-1.4116
1898 9 17.028	-0.183	0.53	0.1101	-1.8303	0.0894	-2.2191
1898 9 18.028	-0.09	-8.66	0.2248	-11.2834	0.2016	-11.6552

We also used the PPM catalogue to identify these reference stars. Table 1 and table 2 are some comparisons of the observed positions of Phoebe and the JPL ephemerid positions in different cases. Table 1 shows the resulting O-C of the positions of Phoebe in right ascension and declination. First column is the date of observation; the second column are the results derived from the position of Phoebe given in the Pickering (1908) by only changing the reference system from epoch 1875 to J2000; the third column are the results of using PPM as the new catalogue to recalculate the positions of 10 mentioned reference stars in Pickering (1908); the last column are the similar results as in column 3, but using the UCAC2 catalogue. This table shows that the result is better when using new catalogue. On the other hand, the results derived from the PPM catalogue are better than those using UCAC2.

Table 2 shows the comparison of results using different parameters to choose the reference stars with the UCAC2 catalogue. The second column is the same as the last column of the table 1. Here “with stars” means we reduce the position of Phoebe with the 10 reference stars mentioned.

Suppose that we don’t know the positions of reference stars, we search the stars in distance with 1 degree around the Phoebe. We consider the distance of the two stars in UCAC2 and CPD catalogues less than 10mas and the difference of the magnitude less than 1 mag as the same star. As a result, we can find 10 reference stars. This is the case “I”. If we choose the same radius around Phoebe and the same magnitude difference, but different distance of the cross identification (15 mas), we can Find 16 stars. This is called case “II” in Table 2.

Table 2: O-C of phoebe position with different methods for choosing reference stars

DATE	With stars (S,")		I (S,")		II (S,")	
1898 8 17.011	0.1093	-62.7261	0.2529	-63.4158	0.2146	-61.951
1898 8 17.096	-0.1216	-2.2422	0.0206	-3.0097	-0.0194	-1.5121
1898 8 18.039	10.2743	-2.1497	10.4008	-2.9381	10.3669	-1.362
1898 8 19.050	0.066	3.5746	0.2018	2.7517	0.1632	4.3009
1898 9 16.031	-0.3	-1.4116	-0.4502	-3.2781	-0.3911	-0.0281
1898 9 17.028	0.0894	-2.2191	-0.078	-4.1321	-0.0126	-0.7867
1898 9 18.028	0.2016	-11.6552	0.0167	-13.6046	0.0887	-10.1674

From Table 2, we can see that the differences are not significant; however the results are better in case “II”. We will try to find more reference stars by choosing suitable parameters in the following study.

3. Conclusions

In this study, we have shown that

(1) some ancient photographic observations are useful to improve the orbit;

(2) if the reference stars were not mentioned in the old literatures, we can still find the reference stars to improve the positions of the natural satellites;

(3) it is necessary to choose a catalogue with high precision in proper motions and positions of stars.