Journal of Astronomical History and Heritage 5(2):141-153 2002

The 1900-1 opposition of 433 Eros, the solar parallax, and the contribution of Padova Observatory

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Abstract
In 1898 a new asteroid, 433 Eros, was discovered. As the opposition of 1900 October 30, would bring this asteroid very close to Earth, the *Comité International Permanent pour l'Exécution Photographique de La Carte du Ciel* instituted a special temporary Commission with the task of co-ordinating micrometric, heliometric, and photographic observations from different places on Earth, in order to determine the solar parallax. Fifty-one astronomical observatories, including the Italian Observatories of Arcetri, Padova, and Teramo, took part in this project with visual and photographic observations. Antonio Maria Antoniazzi, astronomer at the Padova Observatory, observed the new asteroid from 1900 October to 1901 February. The 122 observations made in Padova from October to December, formed part of the data set used by Arthur Hinks of the Cambridge Observatory, who had the task of reducing all of the observations. In addition to discussing the final outcome of the 1900-1 programme, this paper briefly examines the solar parallax investigations associated with the Eros opposition of 1930-1.

Keywords: *Eros oppositions, solar parallax, Padova observations*

1 INTRODUCTION

On 1898 August 13, Gustav Witt of the Urania Observatory[1] in Berlin (Witt, 1898, 1899b), and independently on the same date, Auguste H P Charlois of the Nice Observatory (Perrotin, 1898), discovered a new asteroid, named 1898 DQ, on their photographic plates. From the moment of this discovery, the *Astronomische Nachrichten* (1898-9) started to publish ephemerides, orbital elements (Berberich, 1898; Millosevich, 1899), magnitude estimates, and other kinds of observations from European observatories. Meanwhile, *The Astronomical Journal* (1898-9) published data mainly from North American observatories.

Witt assigned the new celestial body the masculine name of Eros, in contrast with the tradition of giving feminine names to asteroids. In fact, because of its peculiarly high diurnal motion in RA (100^s), he believed that the new body could not belong to the asteroid group (Witt, 1899a), but Julius Bauschinger, Professor of Theoretical Astronomy in Berlin, claimed that 1898 DQ was an asteroid, arguing that its aphelion was 0.17 AU from the inner asteroid ring and that other asteroids had been found with their perihelion distances internal to the orbit of Mars. He also pointed out that because of the small mass and high eccentricity of its orbit, Mars could not be the absolute inferior limit of the asteroid ring, and it was probable that other asteroids would be found between Eros and Hungaria (Bauschinger, 1899). Eros was the first member of the group of Earth-approaching asteroids to be discovered, and the number 433 was assigned to it.

The Eros opposition of 1900 October 30 would bring the asteroid very close to Earth (minimum distance, December 26), and would provide astronomers with an excellent opportunity to determine the solar parallax. This encouraged the *Comité International Permanent pour l'Exécution Photographique de La Carte du Ciel* (Permanent International Committee for Photographic Execution of Sky-map) to establish a special temporary Commission with the task of co-ordinating observations.

In his opening speech at the meeting of 1900 July 19 – the fifth session of the International Committee – the President, Maurice Loewy, highlighted this extraordinary event with the following words:

> But you will have to examine one of the greatest problems of astronomy, the solution to which, sought for a century and more in many different ways, now seems ripe for serious progress. In fact, the discovery of the planet *Eros* will give the possibility of determining the parallax of the Sun at certain epochs, with a precision until now unattainable. The strong organisation of the observatories associated in the sky-map undertaking, has led many members of the Committee to believe that this work may be done efficaciously by many of those establishments, the geographic location of which is best suited for such a mission. (Réunion ..., 1900:3; translated from French).

The special Commission, presided over by Loewy, consisted of nine members: W H M Christie (RGO), D Gill (Royal Observatory, Cape of Good Hope), E Weiss (Vienna Observatory), C Trépied (Algiers Observatory), H G van de Sande Bakhuyzen (Leiden Observatory), W L Elkin (Harvard Observatory) G Hartwig (Bamberg Observatory), C-L-F André (Lyons Observatory) and P Henry (Paris Observatory). The Commission was charged with the task of preparing resolutions to be submitted to the International Committee and then organizing the associated observations. Work started during the 1900 meeting, and in a short time observational criteria were adopted and six circulars were issued, containing all the necessary instructions on how to correctly perform the observations and data reductions.

2 THE WORK OF THE COMMISSION

The special Commission decided that parallax determinations of Eros would be carried out by means of micrometric, heliometric, and photographic observations, by co-operation between European and North American observatories, and between observatories in the Northern and Southern Hemispheres. Observations were to be performed with the widest convenient hour angle, to obtain the maximum value of parallactic displacement. However, the asteroid had to be observed at zenith angles of ≤70° in order to reduce refraction effects. Observational continuity was to guarantee determination of the asteroid's motion with the greatest precision and directly, day by day: this fact was essential in determining accurately the parallax of Eros. The Commission also established the need to take a series of photographic plates covering the whole region of the sky where Eros was situated in order to determine the positions of suitable comparison stars with extreme precision, and this task was particularly entrusted to those observatories which were already involved in the Carte du Ciel project (*Circulaires* 1-2, 1900:103-112).

Observatories which participated in the project from the beginning were: Algiers, Athens, Bamberg, Bordeaux, Cambridge (England), Cape of Good Hope, Catania, Cordoba, Edinburgh, Greenwich, Harvard, Heidelberg, Leiden, Leipzig, Lyons, Marseilles, Minneapolis, Mount-Hamilton, Nice, Paris, Potsdam, Collegio Romano, San Fernando, Strasbourg, Tacubaya, Toulouse, Upsalla, Vienna, Vienna, Washington, and Williams Bay (*Circulaire* 1, 1900:108). These were soon joined by observatories in Berlin, Besançon, Brussels, Charlottesville, Christiania (= Oslo), Denver, Dublin, Evanston, Florence, Helsingfors, Koenigsberg, Lisbon, Madison, Northfield, Oxford, Padova, Palermo, Poulkovo, Thachent, and Teramo (*Circulaire* 5, 1900: 126). According to *Circulaire* 1 (1900:108),

> The initial challenge for each Observatory contributing to this common work ... [is to] decide what part it will carry out. We kindly request Observatories to inform the President of the Executive Commission, as soon as possible, about their precise intentions, so that the necessary arrangements can be made to complete the general plan ... (translated from French).

In *Circulaire* 3, dated 1900 August 17, the Commission provided all the observatories with a table of the daily period of visibility of Eros; a second table of the equatorial coordinates of its orbital points, spaced at approximately one degree intervals; and ephemerides of Eros up to 1901 January 7, calculated by E Millosevich (1900) of the Collegio Romano. Later ephemerides, up to March 8, were published in *Circulaire* 5, dated 1900 October 10. *Circulaire* 4 listed 307 comparison stars whose positions would have to be determined with extreme precision, and a further 352 stars were added in *Circulaire* 5. Lastly, in *Circulaire* 6, which was actually issued on 1900 December 4 while the Eros observations were in progress, the Commission provided the apparent positions of the 77 fundamental stars and the 4 polar stars in Newcomb's Catalogue (Newcomb, 1898), that could be used in the reduction of the meridian observations of Eros.

Between 1901 and 1907, when *Circulaire* 12 was printed, the Commission published observations and results from the various observatories. *Circulaire* 10 (1903) contained visual observations from Arcetri, Besançon, Charlottsville, Cordoba, Edinburg, Heidelberg, and photographic observations from Bordeaux and Paris, while in the Supplements Loewy provided tables to facilitate the transformation from rectangular to equatorial coordinates on the photographic plates. *Circulaire* 11 (1904) listed visual observations from Marseille, Padova, and Paris; photographic observations from Alger, Northfield, Catania, San Fernando, Paris, Toulouse, and Bamberg (heliometric observations); and the star catalogue prepared by Tucker of Mount Hamilton. *Circulaire* 12 (1907) provided visual observations from Teramo, Paris, Poulkovo, Christiania, and Nice, and photographic observations from Helsingfors, Greenwich, Cambridge, Oxford, Poulkovo, Upsalla, and Minneapolis. The newest and best ephemerides, computed with the vast quantities of data collected; the most recent positions of comparison stars; and all the equations useful for data reduction, concerning measurement errors, effects of atmospheric refraction, etc., were also published.

3 THE PHOTOGRAPHIC OBSERVATIONS

The Eros campaign was strictly linked to the Astrographic Catalogue (*Carte du Ciel*) because of the positions of the reference and comparison stars, both for visual and photographic observations of the asteroid. The precision of the stellar positions would impact on Eros's coordinates and, in consequence, the value of the solar parallax.

Newcomb (1900) favoured photography as the best method of observing the asteroid during this important campaign. He was convinced of this because of the precise positions of celestial bodies that were attainable on photographic plates, and because suitable photographic telescopes were in use at various observatories that were favourably located in relation to the Eros observations. However, there was a problem concerning the faint photographic magnitude of Eros and its rapid motion, so Hinks (1900) suggested that observers should track the asteroid and let the stars trail in guiding telescope. The next step was the reduction of the photographic plates, where many exposures of Eros were present, and the accuracy of the measures partly depended upon the plate-measuring machines (Hinks, 1901a, 1901b, 1901c, 1901d, 1904c, 1904d).

In 1903, a dispute arose between Hinks, Loewy, and Dyson about the collection and publication of data from the various participating observatories and methods used in the reduction of the photographic plates, and a number of papers using the generic title 'Eros and the solar parallax' appeared in *The Observatory*. Hinks (1903) began by complaining about the increasing size of Circulars. He also criticized the fact that each observatory had derived 'individual means' from its own observations, thereby preventing the derivation of a conclusive and definitive mean, and he suggested that the accumulated material might have been handed over to an individual who was expert in working up observational data. In particular, he deplored the procedure adopted by the Committee for the determination of the position of Eros on the photographic plates and in consequence its parallax (i.e. the method of transforming the measured rectangular coordinates into differences in RA and Dec), whilst keeping in mind the missing of faint comparison stars and the very imprecise positions of the reference stars published by the Paris and Bordeaux Observatories.

Loewy (1903) refuted all of Hinks's criticisms: he explained that many comparison stars were missing because data from many observatories had not arrived when the last circular was published; that Paris and Bordeaux observations from the period November 7 to 15 were insufficient because of bad weather; that equatorial coordinates of the reference stars were used successfully for more general scientific purposes, not just for calculating the solar parallax; that individual astronomers were thoroughly competent to effectively reduce their own observations; and finally that data were published as early as possible so that Hinks could use them in his own investigation of the solar parallax.

Hinks (1904a) responded by referring to the differences between the "French and English schools" when it came to photographic methods, and the fact that the photographs had to be used to derive relative places and not absolute ones.

Dyson (1904) from the RGO then entered the dispute. He totally supported Loewy's methodology and derivation of RA and Dec. from the photographic plates, and believed that each observatory should be responsible for the reduction its own measurements.

Once again Hinks (1904b) wrote a short reply in order to emphasize the different opinion between Dyson and himself.

Hinks (1903:343) was also involved in a controversy regarding the measures made with the great equatorials of Washington, Lick, and Yerkes, concluded that "... nearly one half the results ... are useless ..." Tucker (1903), from the Lick Observatory, was quick to respond. He explained the observational methods and their associated errors, provided a list of the mean differences in RA and Dec. derived from observations of 351 different reference stars observed at the Lick Observatory and the U.S. Naval Observatory, and concluded by stating: "It is my purpose to give some attention to the discussion of the list places published in the Circulars of the International Conference." (Tucker, 1903:461).

The Eros campaign continued in spite of this dispute, and it is therefore a little ironic that the processing of all of the photographic and visual observations published in the Circulars and provided by the various participating observatories ended up being undertaken by the University Observatory in Cambridge (UK), under the patronage of the Royal Astronomical Society, and entrusted to none other than Arthur Hinks (see Hinks, 1906, 1907, 1909a, 1909b, 1910). After reducing all of the photographic, heliometric, and micrometric observations made by the participating observatories around the world, Hinks presented his final results to the Paris Academy in 1909. This very large data set produced parallax values of $\pi = 8''.807 \pm 0''.0028$ based on the photographic observations and $\pi = 8''.806 \pm 0''.004$ based on all of the micrometric measures (Solar parallax, 1911). For this work, Hinks was awarded a prize by the *Fondation Leconte*, and the Gold Medal of the Royal Astronomical Society. In his presentation address, the President of the RAS began with these words: "The Gold Medal of the Society has been awarded by the Council to Mr. Arthur Robert Hinks for his Determination of the Solar Parallax from Observations of Eros. It is my privilege to lay before you the grounds of this award." (Address ..., 1912).

4 THE PADOVA OBSERVATORY OBSERVATIONS

4.1 The Micrometric Observations

Antonio Maria Antoniazzi[2] (Figure 1), Assistant at the Padova Observatory, was entrusted to make micrometric observations with the 187-mm f/16 Merz Refractor, the largest telescope at the Observatory (Figures 2 and 3).[3]

For micrometric observations, the Commission (*Circulaire* 2: 110) recommended measuring RA and Dec. with the micrometer, as asteroid and comparison star were contemporaneously visible in the telescope field, so that their differences in RA and Dec. could be measured directly. Instead Antoniazzi decided to employ the transits method, which he thought was more suitable for the small Padova refractor. This method consisted of recording by means of a chronograph and along the same hour circle, the difference in times of transit of the asteroid and the comparison star across the wires of the micrometer, and of measuring the difference in Dec. keeping the telescope fixed. Although this method had a larger number of instrumental errors than that proposed by the Commission (e.g. instability of the telescope, stationary conditions, micrometer orientation, etc.) and was affected by the 'equation of magnitude' (the time difference between the observations) when the comparison star and the asteroid were not of the same magnitude, it did have the great advantage of using the same comparison stars both in the evening and in the morning – something which was impossible with the Commission's method, because of the rapid motion of Eros in RA.

On this occasion, Antoniazzi used the original filar micrometer (Figure 4) of the telescope, which had been adopted by its previous owner, Baron Dembowski, for the measurement of double stars. However, the micrometer was partially modified: the five hour wires were substituted and two parallel wires replaced the single movable one (so that the Dec. measurements were executed by setting the planet between these two wires, instead of bisecting it with only one wire). In addition, Antoniazzi accurately re-measured the pitch of the micrometer screw, obtaining results consistent with the earlier measurements of both Dembowski and also Antonio Abetti (when he was an astronomer at the Observatory).

Antoniazzi's observations commenced on 1900 October 23 and continued until 1901 February 13. A complete observation lasted on average half an hour and consisted of ten 'pointings' with the telescope fixed. For each 'pointing', Antoniazzi recorded the transit times across the five hour wires of both Eros and the chosen comparison star and he also made one or two Dec. measurements. The whole procedure was then repeated both east and west, for each available comparison star, and thus Antoniazzi determined the differences in RA and Dec. between Eros and the comparison star (see Figure 5). In order to minimize the 'equation of magnitude', he took care to select comparison stars of $m_v = 8.5–9$, comparable to the magnitude of Eros at the time. Over a period of four months, Antoniazzi performed 180 micrometric observations, employing 113 different comparison stars, all chosen from the *Astronomische Gesellschaft Catalogue.* He then published his derived geocentric co-ordinates of Eros in *Circulaire* 11 (1904:25-35), and compared them with Millosevich's (1902) ephemerides.

Figure 1. Portrait of Antonio Maria Antoniazzi (1872-1926).

4.2 Data Reduction and Parallax Determination

As is well known, the starting-point for trigonometric determination of the solar parallax is the definition of the equatorial horizontal parallax, π, which is the angle, in seconds of arc, subtended by the equatorial radius of Earth, r, at the Sun's mean distance, d. Thus, the mean Earth-Sun distance, d, also known as the astronomical unit, is given by the formula

$$d = r / \sin \pi$$

However, numerous complex calculations must be performed in order to reduce the observations and derive the solar parallax. As a solution, the method of the transit of Venus gives the difference between the parallaxes of the Sun and Venus, but the opposition of Eros has the advantage that the angle of parallax is larger and thus more easily measurable, and in addition the asteroid appears as a stellar object in the telescope field, so that the position errors are smaller. In both cases, the calculations are laborious, but the latter case avoids the errors of the former due to poor precision in determining the contact times, and the difficulty of using observers located at different observing stations, the geographical coordinates of which have to be very accurately determined.

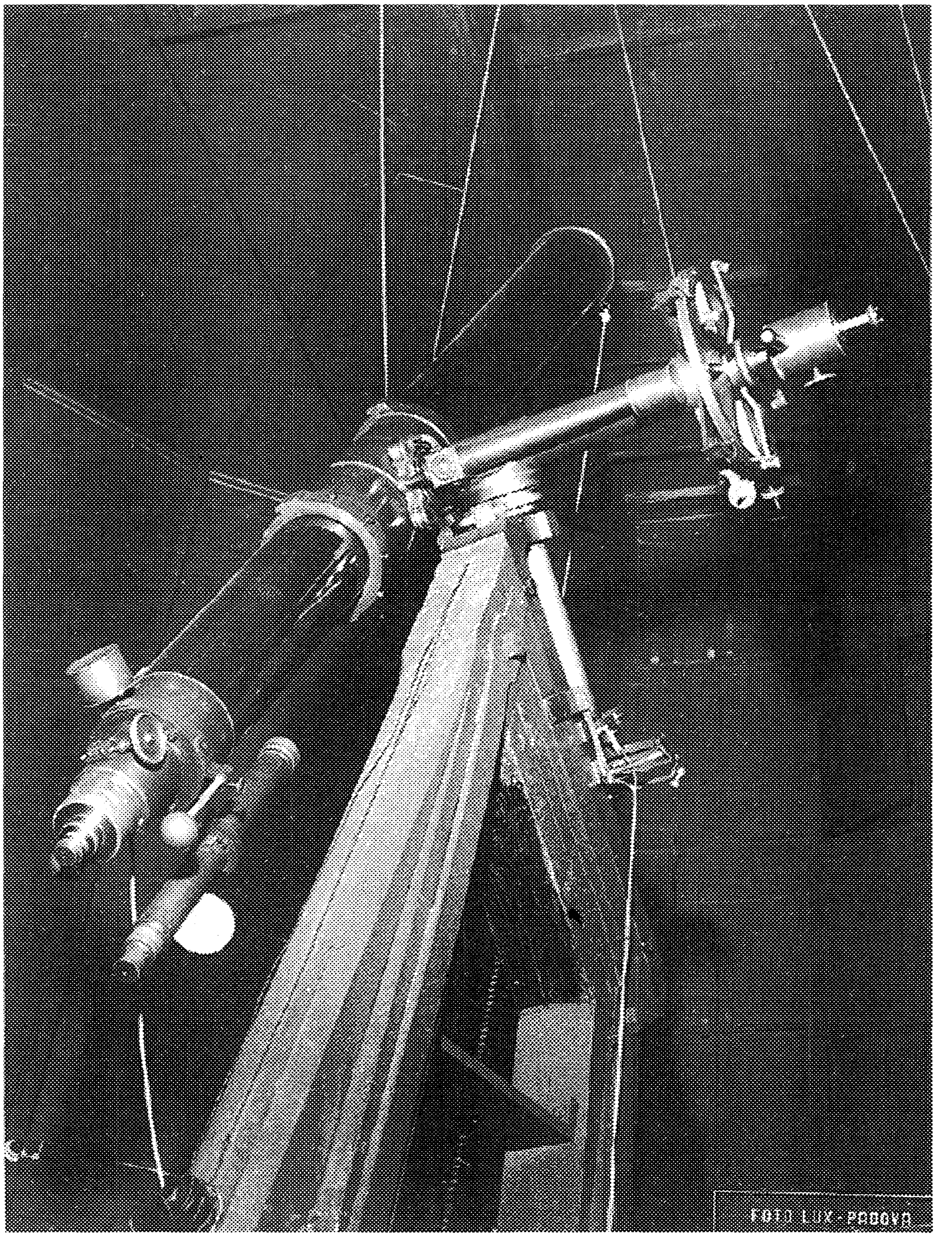


Figure 2 The 187-mm Merz refractor of Padova used for the Eros observations (Photograph: Astronomical Observatory of Padova, Historical Archives).

In Antoniazzi's procedure, the correction to be derived concerns the standard solar parallax adopted for the calculations, and this depends on the diurnal parallax of the asteroid, the unknown correction of its ephemeris, and the mean deviation of the hour wires from the direction of the declination circle, in short, three unknowns for each equation. For instance, the comparison of the observed RA and that calculated of the ephemeris, gives the difference $(O-C)_\alpha$. If α is the true RA, it will be $O_\alpha = \alpha + \Delta O_\alpha$ and $C_\alpha = \alpha + \Delta C_\alpha$, so that $(O-C)_\alpha = \Delta O_\alpha - \Delta C_\alpha$. Of the systematic errors of the observed values, only two are considered: one from calculation of the diurnal parallax by adopting the standard value of solar parallax, which must in turn be corrected, and the other regarding the above-mentioned orientation of the hour wires. The general form of the equation is:

$$(O-C)^s_\alpha = -\frac{\rho}{15\Delta}\cdot\frac{\cos\varphi\cdot\sin\tau}{\cos\delta}d\pi'' - \frac{(\delta_\circ-\delta_*)''}{15}\cdot\frac{\tan\omega}{\cos\delta}+\frac{x''}{15\cos\delta}$$

where $x'' = -15\Delta C_\alpha \cos\delta$, and is the correction for the ephemeris in seconds of arc.

Figure 3. The high medieval tower transformed into the Padova Astronomical Observatory from 1767 to 1777. On the left is circular brick dome constructed in 1882 to house the Merz refractor (Photograph taken in 1929: Astronomical Observatory of Padova, Historical Archives).

Thus, because the difference between observed and calculated RA is equal to the difference between their respective errors, an equation of three unknowns, as mentioned above, is found. Antoniazzi (1911:318) concluded: "It will be possible to determine the three

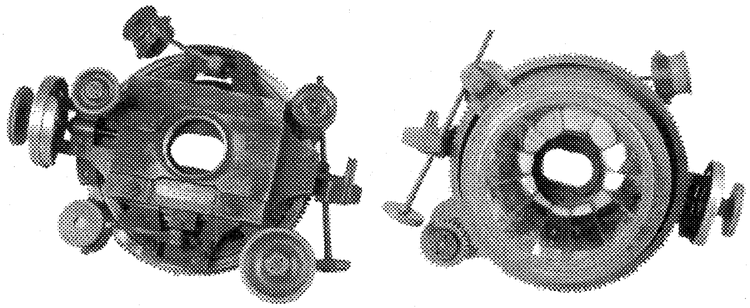
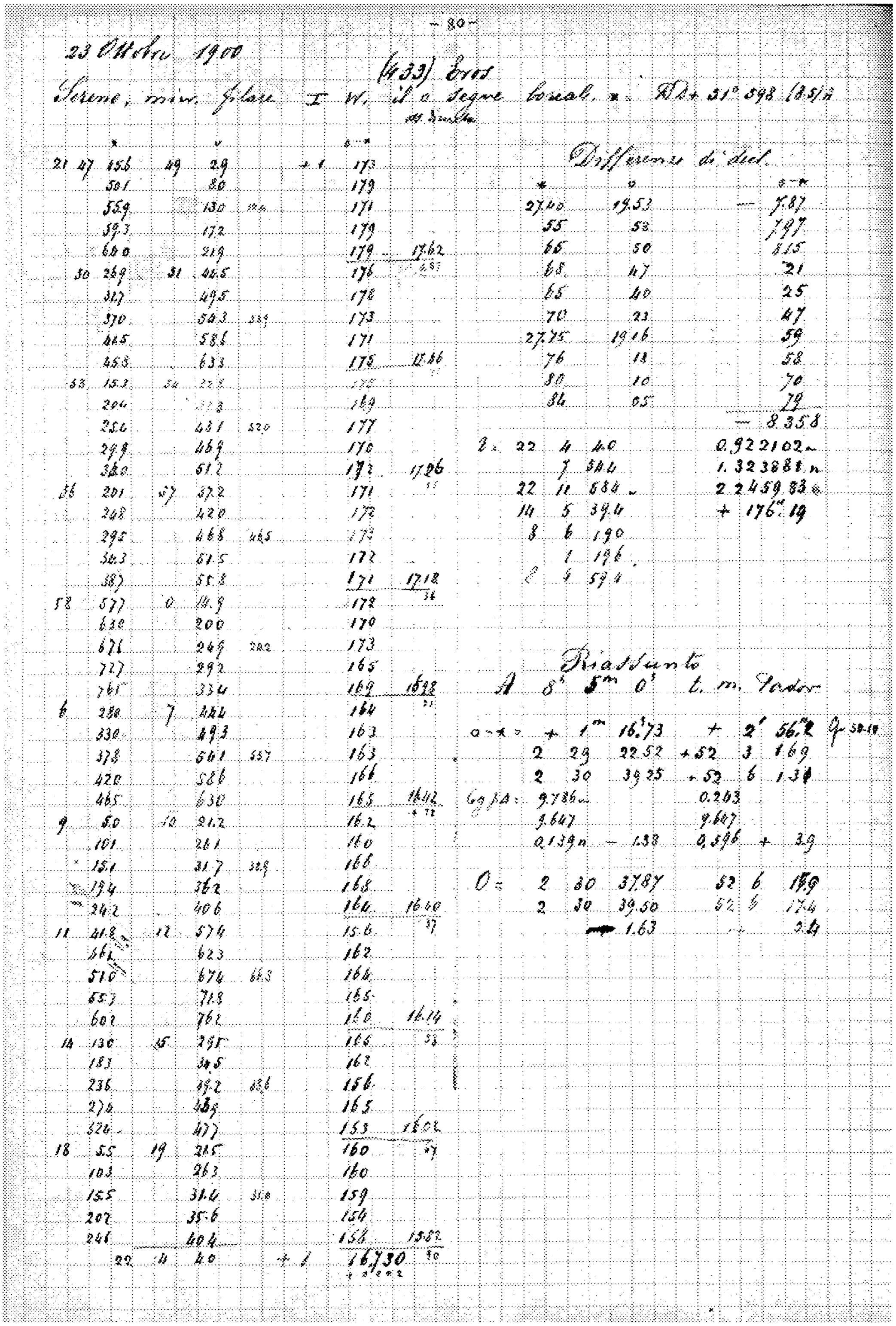


Figure 4. The filar micrometer used for the Eros observations. Shown on the right is the reflecting mirror system used to obliquely illuminate the thin spider wires with red light (Museo *La Specola*, Astronomical Observatory of Padova).

unknowns by combining equations relative to time intervals in which the three unknowns may be considered constant, or to combine equations relative to time intervals in which one or more unknowns have different values, provided that the number of unknowns will correspondingly increase." The solution of this system of equations gives $d\pi$, the correction to be added to the adopted value of solar parallax.



– 80 –

23 Ottobre 1900

(433) Eros

Differenze di decl.

Riassunto

Figure 5. The Observations Register showing the first page of micrometric measures of Eros made by Antoniazzi (Register of observations: Astronomical Observatory of Padova, Historical Archives).

We report here other details described by Antoniazzi, in order to show how accurate his calculations were:

> Because of the long duration of each observation, I thought that in reductions related to this time interval, I should have to take into account the second variation of the parallax; therefore, differences $\alpha_0 - \alpha_*$, $\delta_0 - \delta_*$ [asteroid minus star] derived from each comparison were corrected for the difference between the corresponding parallax and that corresponding to the mean of the times. These differences were also reduced to the mean time of observations by means of the asteroid's motion derived from the ephemerides. Then, the two means were calculated, and their probable errors extracted by the deviation of the single values from them; so, through the errors, I thought to be able to give a summary indication *a posteriori* of the general conditions in which observations had been made, as they might have affect the precision of the results. (Antoniazzi, 1911:314).

The latter values were then corrected for differential refraction and for the error relative to the position of the instrumental pole. Antoniazzi (1904) made a preliminary calculation of the solar parallax before sending his data to Paris, deriving a value of $\pi = 8''.84 \pm 0''.03$. But he suspected that the error in micrometer orientation would have a sensible influence on this determination, which could be best evaluated by using more precise positions of comparison stars.

Of the 131 observations made in Padova between 1900 October and December, 122 formed part of the data utilized by Hinks. According to the method of transits, the mean value was $\pi = 8''.839 \pm 0''.015$, corresponding to 8″.91 for the Padova observations (Hinks, 1910). Antoniazzi realized that the wrong parallax value, calculated from his observations, was perhaps due to the relatively-inaccurate positions of the comparison stars he had adopted. For this reason, he asked Hinks for data from his *Standard Photographic Catalogue*, and he then repeated his computations, including also his observations of 1901 January and February. This analysis produced a solar parallax of $\pi = 8''.795 \pm 0''.023$ (Antoniazzi, 1911), which is remarkably close to the modern value of $\pi = 8''.794148 \pm 0''.000007$ adopted by the IAU, especially given the unfavourable conditions under which he made the observations: a small telescope located just a few metres above ground level, close to a river, with a damp atmosphere lit by newly-introduced electric street-lamps. Antoniazzi's result is also within the error limits of $\pi = 8''.806 \pm 0''.004$, which is the figure that Hinks derived from all micrometric measures.

5 DISCUSSION AND CONCLUDING REMARKS

Eros continued to be in the limelight for solar parallax measurements, and during the opposition of 1930-1 was at a closer distance to Earth than it had been at any time since 1900. In 1925 and in subsequent years, the discoverer of Eros, Gustav Witt (1925, 1930) calculated ephemerides for the up-coming opposition, and in 1931 he published advice for visual micrometric observers (see Witt and Kopff, 1931).

The International Astronomical Union played an important role in these activities. During the 1925 General Assembly Commission 34 (Solar Parallax) was created (Fowler, 1926), and in 1927 a special grant of £50 was given to the President of the Commission, the Astronomer Royal, Frank Dyson. In his report at the General Assembly of 1928, Dyson recommended that improved photographic observations be made (Stratton, 1929), but with his election to the Presidency of the IAU Harold Spencer Jones took over as President of Commission 34.

In 1930, Jones published guidelines for the photographic observations in *Astronomische Nachrichten*, *The Astronomical Journal*, and *Monthly Notices of the Royal Astronomical Society* (Jones, 1930a, 1930b, 1930c, 1930d), and at the same time he wrote to the Presidents of the various National Committees affiliated with the IAU asking for their co-operation in this important project. He stressed that it was essential that observatories widely distributed in both latitude and longitude took part to the campaign, making micrometric and photographic observations.

Emilio Bianchi, Director of the Observatory of Milan and President of the Italian Committee, made inquiries among Italian observatories, and six of them (Trieste, Padova, Milan, Florence, Catania, and Teramo) agreed to participate; Antoniazzi's micrometric observations of 1900-1 were taken as a guide (Bianchi, 1930). Giovanni Silva, Director of the Observatory of Padova, trained the young astronomer Ettore Martin (1934) on how to observe

Eros with the 187-mm Merz Refractor, the very same instrument that had been used by Antoniazzi during the opposition of 1900. Most other Italian observatory also conducted micrometric observations (see Gennaro, 1937; Righini, 1937), but Catania decided to rely on photography (Taffara, 1936, 1937).

Because of Eros's brightness, Jones favoured photography, with multiple exposures on the same plate rather than individual long trailed images. This method, although not previously used, "... proved to be an unqualified success and is undoubtedly the best method for the photographic observation of a fast moving object giving a stellar image." (Jones, 1955:16).

When it came to reducing the observations, Jones found the photographic observations were more accurate and more numerous than the micrometric measures, and so he decided to use only photographic data in deriving a value for the solar parallax. Data came from 2847 photographic plates taken with 30 different telescopes at the following observatories (18 in the Northen Hemisphere and 6 in the Southern Hemisphere): Pulkovo, Bergedorf, Radcliffe (Oxford), Greenwich, Leipzig, Uccle, Prague, Dearborn, Van Vleck, Allegheny, Washington, Leander McCormick, Catania, Lick, Algiers, San Fernando, Tokyo, Zô-Sé, Union, Yale (Johannesburg), Cape of Good Hope, La Plata, and Melbourne. The data reductions were concluded during the Second World War, and Jones (1941) arrived at a solar parallax of $\pi = 8''.790 \pm 0''.001$ (although subsequent investigations by Atkinson (1982) were to show that he had underestimated the probable error). At the 1943 Annual General Meeting of the Royal Astronomical Society he was awarded the Gold Medal for this result (Chapman, 1943), but a complete and detailed discussion of the data from all the participating observatories was only published in 1955 (Jones, 1955).

The value of the solar parallax determined from Eros observations of 1930-1 was not definitive (e.g. see Hughes, 2001), and a new value for the astronomical unit (A.U. = 149,597,870 km) derived from primary astronomical constants (Duncombe *et al.*, 1977) was adopted by the IAU in 1976, from which a calculated solar parallax of $\pi = 8''.794148$ is given. Astronomical constants are continuously the subject of attention and revision, and the most recent determination of π was based on radiometric observations of the inner planets and was in agreement with the IAU value of 1976 (see Pitjeva, 2001).

As regards the Eros campaigns, two final points deserve to be mentioned. Firstly, between the oppositions of 1900 and 1930 astronomical photography became an indispensable tool in positional astronomy, as plate reduction techniques were continually refined. Secondly, a phenomenon not mentioned above is the variability in brightness of Eros. This feature was observed in 1901 (Parkhust, 1901; *Report* ..., 1902) and also during the 1930-1 opposition, and many astronomers carried out magnitude estimates and derived light-curves. The hypothesis that Eros could be a complex system consisting of two or more bodies was suggested in order to explain the variability. If this was so, then Eros was hardly a suitable body for the derivation of an improved value of the solar parallax. As Jones (1940:422) later pointed out: "If these conclusions are confirmed, the extensive programme of observations made at the opposition of 1931 and the heavy labour of their reduction, as well as the considerable, though less extensive, programme of 1901, have been made in vain." However, Jones (ibid.) believed that the light curve of Eros was due to the irregular shape of the asteroid, and that this body therefore was a suitable target for solar parallax determinations. History has proved him right, for images obtained by the spacecraft NEAR-Shoemaker recently showed Eros to be an irregularly-shaped asteroid with approximated dimensions of 34 × 13 × 13 km (e.g. see Veverka, *et al.*, 2001).

6 NOTES

1. The Urania Observatory was a public observatory of the Urania Society, founded in Berlin on 1888 March 8, on the initiative of Wilhelm Foerster, Director of the Royal Observatory of Berlin. The founding principle of the Urania Society was "Verbreitung der freude an der naturerkenntniss" (To spread pleasure in knowledge of nature), and for this aim a journal, *Himmel und Erde* (*Sky and Earth*), was also founded. The telescope used by Witt in discovering Eros was a 12 Parisian inches (*c.* 35-cm) refractor.
2. Antonio Maria Antoniazzi (*b.* Collalto di Refrontolo [Treviso], 1872 April 1; *d.* Padova, 1926 November 30) received a degree in mathematics from the University of Padova in 1893, and became Assistant to Giuseppe Lorenzoni, Director of the Astronomical

Observatory, in 1894. He taught theoretical geodesy from 1908. In 1913, Lorenzoni retired, and Antoniazzi was appointed Professor of Astronomy at the University of Padova and Director of the Observatory. During his appointment, he petitioned in vain for funds to improve the old astronomical instrumentation. However, the political situation in that time was critical and, when the First World War broke out, the high tower of the Observatory was commandeered by the army for the purpose of sighting enemy aircraft, since the city of Padova was only a short distance from the theatre of war, and Supreme Headquarters were located in it. Antoniazzi's scientific activity was devoted to classical astronomy – in particular, to calculations of planetary and cometary orbits, which he published in *Astronomische Nachrichten* – and to geodesy. He also published papers in *Atti dell'Istituto Veneto di Scienze Lettere ed Arti.*

3. This instrument had been purchased in 1881 by Lorenzoni (1881) from the heirs of Baron Ercole Dembowski, an astronomer from Milan who was famous for his double star work. In order to house the refractor, Lorenzoni had a dome built for it at Padova Observatory in 1882.
4. The 'equation of magnitude' mentioned by Antoniazzi, depends on the error in recording the exact instant at which two objects of different magnitude, such as an asteroid and a comparison star, are crossing the micrometer wire.

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