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Beyond the planets: early nineteenth-century studies of double stars

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In 1837 the German-born astronomer F. G. W. Struve published his famous catalogue of double stars.[1] For Struve this was the culmination of 12 years' detailed observation of a class of celestial objects lying exclusively beyond the solar system; for historians of astronomy it poses the problem of explaining why the study of double stars became a significant part of astronomical endeavour, as it did, during the 1820s and 1830s. For, although Struve's interest was extreme, it was shared to a lesser extent by several eminent contemporaries, including John Herschel, Friedrich Bessel, Johann Encke, James South and Félix Savary. Their combined efforts represented an important transition in astronomy: for the first time one of the emphases of the subject moved beyond the solar system to the so-called fixed stars. The question of the emergence of interest in double stars is of historical significance, therefore, as it is related to the problem of the origins of 'stellar astronomy'.[2] This essay is thus intended to offer an explanation of astronomers' interest in double stars, and to tackle the related question of whether this transition constituted a major break in the history of astronomy. Furthermore it is proposed that answers to these problems may be found by considering the practice of astronomy dominant during the first half of the nineteenth century. Astronomers in this period were overwhelmingly concerned with a refined form of positional astronomy. The problems they chose to solve were by and large related to the difficulties of the accurate reduction of observational data, and the compilation of reliable tables and star charts, which were then used as a background against which the motions of solar system objects were plotted. By assessing individuals' studies of double stars within this context it can be seen firstly that such studies were no more or less than specific examples of a general case, and secondly that the stars themselves were not usually of intrinsic interest. In general it was the positions of the stars on the

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[1] F. G. W. Struve, *Stellarum duplicium et multiplicium mensurae micrometricae*, St. Petersburg, 1837; a synopsis was published simultaneously in French: *Étoiles doubles. Mésures micrometriques*, St. Petersburg, 1837.

[2] The use of the term 'stellar astronomy' is here meant to include particular studies of the intrinsic properties of celestial objects known by astronomers to lie beyond the solar system. Such studies would be those undertaken to increase astronomers' understanding of the objects themselves and thus exclude work—such as the provision of stellar catalogues—carried out as an aid to solar system studies. See M. E. W. Williams, 'Was there such a thing as stellar astronomy in the eighteenth century?', History of Science Insert, 1983, *21*, 369–85.

celestial sphere which were significant, because astronomers could apply established laws of celestial dynamics to those measurements. As a result astronomers' treatment of double stars is more readily explained as an extension of the associated disciplines of positional astronomy and celestial dynamics than as anything radically new.

The term 'double star' itself requires further explanation at this point. Astronomers in the twentieth century distinguish between 'optical' doubles and 'physical' doubles or 'binary' stars. The former are pairs of stars which appear on the celestial sphere to lie within a certain small angle of each other: the components of such objects are totally independent and are in fact usually at great distances from each other in space. The latter group consists of pairs of stars which actually lie close together and are physically associated in that they are revolving around a common centre of gravity.

'Binary' stars as a celestial category or term was not introduced into the astronomical literature until the first decade of the nineteenth century when William Herschel described their common orbital motion,[3] although double stars were far from being a newly recognised phenomenon at that period. The fact that certain pairs of stars appeared to lie very close together on the celestial sphere and possible ways of exploiting this information were discussed by Galileo;[4] but it was not until the final third of the eighteenth century that anyone paid close attention to the number of double stars visible or tried to draw any conclusions from their presence.[5] However, in 1767, the Reverend John Michell, whose wide natural philosophical interests included astronomy, wrote an astounding and by now famous paper which considered the problem of calculating, or estimating the distances of the stars. Michell's paper was unusual for several reasons but, most significantly, in the course of it he applied probabilistic agruments to the apparent distribution of the stars, coming to the conclusion that[6]

> such double stars, etc., as appear to consist of two or more stars placed very near together, do really consist of stars placed near together.

Several years later his conclusion had to be pointed out to William Herschel when the latter submitted to the Royal Society a paper dealing

[3] W. Herschel, 'Account of the Changes that happened, during the last Twenty-five Years, in the relative Situation of Double-stars; with an Investigation of the Cause to which they are owing', *Phil. Trans.*, 1803, *93*, 339–82; reprinted in J. L. E. Dreyer (ed.), *The collected scientific papers of Sir William Herschel*, 2 vols., London, 1912, *2*, 250–76. Continued in *Phil. Trans.*, 1804, *94*, 353–84, and in Dreyer, *2*, 277–96.

[4] G. Galilei, *Dialogo di Massimi Sistemi del Mondo Tolemeico e Copernico*, Florence, 1632; English translation by S. Drake: *Dialogue concerning the two Chief World Systems*, 2nd edition, Los Angeles, 1967, 382–3.

[5] Contributors following Galileo included James Gregory, David Gregory, John Wallis and Roger Long.

[6] J. Michell, 'An inquiry into the probable parallax, and magnitude of the fixed stars . . . ', *Phil. Trans.*, 1767, *57*, 234–64, 249. Michell's paper is set into its wider philosophical context in B. Gower, 'Astronomy and probability: Forbes versus Michell on the distribution of the Stars', *Annals of Science*, 1982, *39*, 145–60.

with a similar subject: the use of double stars for the measurement of stellar distances.[7] Herschel's paper not only produced a direct response from the Astronomer Royal, Nevil Maskelyne, who wrote to him pointing out the existence of Michell's paper, it also provoked Michell himself into reiterating his conclusions in print in a paper published by the Royal Society in 1784.[8] But Herschel appears not to have heeded Michell's arguments; it was not until his own paper of 1803, when he coined the term 'binary star' that he publicly accepted their existence. Herschel's reason for acceptance was, moreover, different from Michell's as it derived from the observational evidence he had accumulated which showed that many of the components of doubles had moved with respect to each other, suggesting orbital motion. It was this motion which subsequently, although not immediately, attracted the attention of astronomers, and it was normally to Herschel that astronomers who later showed interest in double stars referred.

Thus any account of early nineteenth century interest in double stars must begin with the work of William Herschel, less because he treated them in the same way as his contemporaries and immediate successors, than because they always referred back to his endeavours. As explained above, Herschel's original interest, like Michell's, was in optical doubles and resulted from his intention to measure annual stellar parallax and hence to calculate stellar distances. In the event he was unable to use his observations of doubles for this purpose;[9] however, during the mid-1780s he produced two extensive catalogues of the objects, both of which were referred to frequently during the early nineteenth century as the first reliable and lengthy lists of doubles.[10] It was not until after the turn of the century that Herschel returned in print to the subject of double stars, but when he did so his reasons were clear and relevant. In 1802 he published his third and final catalogue of nebulae and star clusters, prefaced by his 'Remarks on the Construction of the Heavens'. Central to these remarks was Herschel's list of categories or 'classes' into which he divided all celestial objects. He wrote that,[11]

> in dividing the different parts of which the sidereal heavens are composed into proper classes, I shall have to examine the nature of the various celestial objects that have been hitherto discovered, in order to arrange them in a manner conformable to their construction. This will bring in some extensive

[7] W. Herschel, 'On the parallax of the fixed stars', ibid, 1782, *72*, 82–111; reprinted in Dreyer, *1*, 39–57.

[8] J. Michell, 'On the means of discovering the Distance, Magnitude, &cc of the Fixed Stars . . . ', *Phil. Trans.*, 1784, *74*, 35–57.

[9] Reasons for his failure are discussed in my Ph.D. thesis, 'Attempts to measure annual stellar parallax: Hooke to Bessel', University of London (Imperial College), 1981, Chapter 3.

[10] W. Herschel, 'Catalogue of Double Stars', *Phil. Trans.*, 1782, *72*, 112–63, and ibid., 1785, *75*, 40–649.

[11] Idem., 'Catalogue of 500 new Nebulae, nebulous Stars, planetary Nebulae, and Clusters of Stars; with Remarks on the Construction of the Heavens', ibid., 1802, *92*, 477–528; reprinted in Dreyer, *2*, 199–234, 199.

> considerations, which would be too long for the compass of a single paper; I shall therefore now only give an enumeration of the species that offer themselves already to our view, and leave a particular examination of the separate divisions, for some early future occasions.

The second entry on the list was 'double stars', and in June 1803 and June 1804 papers dealing with this category were read to the Royal Society. They were the natural extension of the research programme set up in the 'Remarks'. Herschel began the 1803 paper by referring to his list, and then explained that he need not dwell on the first class ('insulated stars') because studies of the solar system told astronomers an enormous amount about this class. He subsequently maintained, 'I may therefore immediately go to the second, which treats of binary sidereal systems, or real double stars'.[12] It is clear, therefore, that Herschel intended to work his way through his list; and indeed he continued, after the papers on doubles, to work out his views on the relationships between the other categories.[13] The significant point here is that when Herschel wrote his 1803 and 1804 papers on double stars his main interest in them was how, as one of his classes, they fitted into his overall vision of the sidereal heavens. This does not preclude his having been interested in their observable properties: he had to be able to identify such properties in order to categorise the objects properly. Indeed both papers consist of detailed studies of the relative motions of the two components, together with a discussion of the possible reasons for such motions. Nevertheless, Herschel's main concern in his treatment of doubles was tied in with his larger interest in the construction of the heavens.

As with most of his other work, however, this was *not* how his papers on doubles were perceived or used by other astronomers. In fact no use whatever was made of them for some time; not until 1812 did any astronomer refer to them in print.[14] But it is revealing to investigate what other astronomers made of Herschel's work when, eventually, they did refer to it. The first mention of it came in F. W. Bessel's important 1812 paper considering the particular double star 61 Cygni.[15] Bessel's attention was drawn to this star because it was believed to have a high proper motion relative to the other fixed stars. It was in this paper that Bessel confirmed the existence of such a motion, and it is usually for that reason that the paper on 61 Cygni is remembered. It deserves closer attention than that, however, particularly in an account of the emergence of interest in the

[12] Idem., ref. 5, Dreyer, *2*, 250.

[13] Idem., 'Astronomical Observations relating to the Construction of the Heavens, arranged for the Purpose of a critical Examination, the Result of which appears to throw some new light upon the Organisation of the celestial Bodies', *Phil. Trans.*, 1811, *101*, 269–336; and 'Astronomical Observations relating to the sidereal part of the Heavens, and its connection with the nebulous part: arranged for the purpose of a critical Examination', ibid., 1814, *104*, 248–84. See also Simon Schaffer, 'Herschel in Bedlam: natural history and stellar astronomy', *British Journal for the History of Science*, 1980, *13*, 211–39.

[14] There were a few references to Herschel's work in the correspondences between certain German astronomers, in particular Gauss and Olbers; see C. F. Gauss, *Werke: Briefwechsel mit H. W. M. Olbers*, edited by C. Schilling, Berlin, 1900, *1*, 188–9, 196–7.

[15] F. W. Bessel. 'Über den Doppelsterne Nro. 61 Cygni', *Monatliche Correspondenz*, 1812, *26*, 148–63.

stars. In it Bessel seems to be concerned exclusively with the universe beyond the solar system. But his interest was not that of William Herschel. Firstly, for Bessel, the convincing evidence that 61 Cygni is a binary could only come from precise observations of stellar positions and thus could not be provided by the type of observation made by Herschel, who observed the appearance of objects rather than their exact positions. According to Bessel's own account he had 'long since' been seeking proof from observations made in the previous century of the existence of real double stars, and the evidence he sought was of a motion against the background of the rest of the sky shared by the two supposed components of the double. It was the fact that both members of 61 Cygni move across the sky with the same speed and in the same direction which fixed Bessel's interest in it as a double star.[16] Furthermore, although Bessel was full of praise for Herschel's 'admirable catalogue' he was unable to use the data contained in it, among his detailed analyses of previous observations of 61 Cygni; the main thrust of his appreciation of Herschel's work was that the latter's observations drew attention to double stars and, more importantly, Herschel always checked and rechecked them.

The necessity for repeated observation was always central to Bessel's work, so it is not surprising that he should emphasise that aspect of Herschel's work. Moreover, given Bessel's approach to the study of astronomy, it is unsurprising that he made no more of Herschel's enterprise. During the 1830s, by which time Bessel's reputation as an astronomer was second to none, he delivered a series of popular lectures on astronomy. Early in the first he explained that 'what astronomy must do, has always clearly been the same: it must impart order to the apparent motions of celestial bodies'.[17] Although this was said 20 years after Bessel's earliest work on 61 Cygni it is evident that even as early as 1812 he felt that his job as an astronomer was to 'impart order' to the masses of data he possessed. In 1812 he was deeply immersed in the reduction of James Bradley's observations (made between 1750 and 1762, but not published until the early nineteenth century), and he was doing precisely that: working out how much of the apparent motions of celestial objects could be attributed to terrestial causes—precession, nutation, atmospheric refraction, aberration and parallax—and how to explain any residual motion. He was, in other words, in the business of refining positional astronomy, a realm of enquiry never pursued by William Herschel.[18]

The most significant point about Bessel's treatment of 61 Cygni is that

[16] Ibid., 149.

[17] Idem., *Populäre Vorlesungen über wissenschatliche Gegenstände*, edited by H. C. Schumacher, Hamburg, 1848, 5: 'Was die Astronomie leisten muss, ist zu allen Zeiten gleich klar gewesen: sie muss Vorschriften ertheilen, nach welchen die Bewegungen der Himmelskörper.'

[18] Bessel's enormous undertaking in the refinement of positional astronomy resulted in the publication of two very influential volumes: *Fundamenta Astronomiae*, Königsberg, 1818; and *Tabulae Regiomontanae*, Königsberg, 1830. See also D. B. Hermann, 'Some aspects of positional astronomy from Bradley to Bessel', *Vistas in astronomy*, 1976, *20*, 183–6.

for the first time he thought in terms of extending the known techniques and expertise of celestial dynamics to the heavens beyond the solar system. Following his conclusions about the star's proper motion, derived from his work in positional astronomy, he was prompted to write that 'this remarkable pair of stars . . . is worthy of the very attentive consideration of astronomers in that it can lead us to interesting conclusions about the realm of the fixed stars.'[19] Furthermore he explained how, 'it would pay us to observe the annual parallax of this pair of stars . . . thus we will be able to calculate from that the sum of their masses.'[20] What more was Bessel in fact doing than extending his expert knowledge of dynamics to the realm of the fixed stars? He clearly believed that the techniques of celestial mechanics developed by astronomers for the treatment of motions within the solar system could be applied to all celestial objects—to stars and planets alike. For Bessel, the essential point to accept was that other systems were like our own, and not a fundamentally different class of object. They could then be analysed using tried and trusted methods. It is here that the difference between Bessel's and Herschel's concerns in astronomy become most apparent: whereas Herschel was interested in categorising and systematising the whole heavens, Bessel wished to investigate particular areas which could be scrutinised precisely, as planets, asteroids and comets were. Bessel's interest in 61 Cygni in particular and double stars in general was that of a mathematical astronomer: eventually he was to subject observations of several binaries to exactly the same sort of analysis as that used for the planets, satellites and the comets of our own system. It was the same mathematical rigour and attention to detail which in 1824 produced his paper on planetary perturbation theory, that 14 years later produced his identification beyond all possible doubt of the parallax of 61 Cygni.[21] His study of double stars must be assessed within this context.

After Bessel's early interest in 61 Cygni it was again a number of years before double stars emerged as objects worthy of the attention of astronomers. However, during the 1820s and particularly by the early 1830s it was standard practice at a number of important observatories in Europe to produce catalogues of doubles. The emergence of the study of double stars during this period is associated in particular with the work of F. G. W. Struve in Dorpat, and with that of William Herschel's son John, carried out in collaboration with the astronomer James South. How or why

[19] Bessel, ref. 15, 149–50: 'Dieses merkwürdige Sternenpaar . . . ist der sehr aufmerksamen Betrachtung der Astronomen würdig, indem es uns zu interessanten Folgerungen über das Fixsternen-Gebäude fürhen kann'.

[20] Ibid., 161: 'Gelingt es uns, die jährliche Parallaxe dieses Sternenpaars zu beobachten . . . so würden wir daraus die summe ihrer Massen berechnen können.'

[21] Idem., 'Untersuchungen des Theils des planetarischen Störungen, welche aus der Bewegung des Sonne entsteht', *Abhandlungen der Berliner Akademie der Wissenschaften (Mathematische Classe) 1824*, Berlin, 1824, 1–31; and 'Bestimmung der Entfernung des 61 des Sterns des Schwans', *Astronomische Nachrichten*, 1839, *16*, 65–85.

their interests were aroused has hitherto largely been unexplored by historians, although Pannekoek suggests tentatively that,[22]

> double star astronomy became the first field of application for the refined nineteenth century instruments, with their higher standards of accuracy. It began with F.G.W. Struve . . . who in 1819 had already measured doubles, in 1824 introduced the new 9″ refractor, the biggest Fraunhofer instrument to double star work.

It is certainly true that Struve began his 12 year search for and close measurements of double stars as soon as the new Fraunhofer refractor had been erected at Dorpat and suitably tested. It is also true that the type of project Struve envisaged required the best possible instruments. But that is not the complete story. As Pannekoek points out, Struve's interest in double stars antedated considerably his acquisition of the Fraunhofer refractor. In fact Struve's work on these objects began well before 1819; his earliest publication on the subject appeared in 1817,[23] and according to a later account of his, written in 1837, his interest dated back to his arrival at the Dorpat observatory in 1813. On finding an 8-foot transit instrument there he claimed,[24]

> So my first concern was to set up the large instrument in the meridian, and when observing the transits of several double stars I was surprised to be able to resolve them into their components, although, according to Herschel, these stars were among the most difficult to separate. This circumstance revealed the perfection of the instrument, and fortified me in the resolution I had already made to select double stars as the subject of my research. As far as I knew, no astronomer was working on these stars at that time; I had hopes therefore of obtaining important results from comparing my new observations with those made by Sir William Herschel about 1780 and 1800.

As already mentioned, Struve's first publication on doubles appeared in 1817, and before the arrival of the Fraunhofer refractor he published at least five letters or papers on the subject and four catalogues of doubles. In addition he devoted sections of the first three volumes of observations made at Dorpat specifically to accounts of his latest observations of doubles.[25] There can be no doubt, therefore, that Struve made the study of double stars one of his main concerns early in his career.

In order to understand why he might have done this, we must again

[22] A. Pannekoek, *A History of Astronomy*, London, 1961, 430.

[23] F. G. W. Struve, 'Auszug aus einem Briefe des Hrn. Prof. Struve an den Director der Sternwarte Seeberg', *Zeitschrift für Astronomie und verandte Wiss*, 1817, *4*, 462–73.

[24] Idem., *Mesures micrometriques*, ref. 1, 13–14: 'Mon premier soin fut donc d'établir le grand instrument dans le méridien, et en observant le passage de plusieurs étoiles doubles, je fus surpris d'en reconnaitre les satellites, quoique, suivant les données de Herschel, ces étoiles appartinssent aux plus difficile à séparer. Cette circonstance me décela toute la perfection de l'instrument, et me fortifia dans la résolution que j'avais prise anterieurement de choisir les étoiles doubles pour objet de mes recherches. Aucun astronome, à ma connaissance, ne s'occupait alors de ces étoiles; j'avais donc l'espérance de parvenir à des résultats importants par la comparaison de mes nouvelles observations avec celles qu'avait enterprises Sir William Herschel vers les années 1780 et 1800.'

[25] All Struve's publications are usefully listed at the end of Z. K. Novokshanova, *Vasily Yakovlevich Struve*, Moscow, 1964, 249–71.

consider briefly the nature of astronomical practice during the early years of the nineteenth century. The main areas of debate between astronomers were over the accuracy of the various catalogues produced at different observatories. Astronomers continually addressed the problems of data reduction and strove to prove that their own methods of reduction were not only adequate but the best available. There was no consensus however; the values of constants used varied from observatory to observatory as did the reliability of the instruments and of the observers. Closely tied in with these problems was the positive attempt, particularly by Continental astronomers, to ensure that any solutions offered were mathematically rigorous. It was the period of experimentation with statistical methods of analysis, following Gauss's vitally important work on the method of least squares,[26] and the huge contribution of Laplace to probability theory and to error theory.[27] Gauss's work was particularly relevant to the computation of the orbits of celestial objects: a subject already crucial for cometary theory, and the importance of which increased even further following the discovery between 1801 and 1807 of the first four minor planets. In order that astronomers could plot the positions of these objects as accurately as possible they needed very good catalogues of stellar coordinates; this need exposed clearly the problems of data reduction. Gauss's work pointed the way to a solution, and it was Bessel who applied Gauss's method for the first time to large numbers of astronomical observations. The mathematics involved was complex but despite this, in fact probably because of it, astronomers, especially in the German states, were determined that this type of analysis was essential to provide acceptable stellar positions.

It was in this environment that Struve found himself when he arrived at Dorpat. Like his contemporaries he had to address himself to the problems of precision in positional astronomy. His early publications other than those on double stars covered topics well within mainstream astronomy. Among other things he wrote about lunar occultations, the minor planet Vesta, and about comets. In each of his papers he was careful to point out that his observations and reduction had been carried out with the utmost precision: he was clearly eager to establish himself at the forefront of astronomical research, sharing many of the aims of the established German astronomical community.[28] He was keen to prove his ability as an expert observer and manipulator of data, and from the passage quoted above he clearly perceived that his best means of doing this

[26] C. F. Gauss, *Theoria motus corporum coelestium*, Hamburg, 1809. For a historical appraisal of Gauss's work on the method of least squares see L. Tilling, 'The interpretation of observational errors in the eighteenth and nineteenth centuries', Ph.D. thesis, University of London (Imperial College), 1973, Chapter 6.

[27] P. S. M. de Laplace, 'Sur l'application du calcul des probabilités à la philosophie naturelle', *Connaissance des Temps pour 1818*, Paris, 1815, 361–77.

[28] The most important and active astronomers working in the German states at this time were Olbers, Bessel, Gauss, von Lindenau (until 1817), Bode, Schumacher and von Zach.

was to turn his attention to an area of enquiry which had previously been little studied: that of double stars. Thus, if we consider Struve's early interest in these objects in the light of the major trends in astronomy during the 1810s, it is possible to extend Pannekoek's remarks on the early studies of doubles. As well as being a field for the application of refined instruments, it was one for the application of the refined practice of astronomy as a whole, and it was fully exploited by Struve. Once he had decided to devote much of his time to the observation of doubles he would naturally have used the best instruments at his disposal. He certainly persisted with his chosen research programme. In 1826 he received an honorary medal from the Astronomical Society of London for his work on doubles; the following year he published his first catalogue based on observations made with the Fraunhofer refractor, and after that he devoted his time to the major survey which culminated in the important 1837 catalogue.[29] We must consider next how his work was received and how it fitted in with similar studies undertaken in Britain by John Herschel and James South.

It was in Britain that the greatest interest in and reaction to Struve's work took place, not surprisingly since it was in London that South and Herschel were beginning their searches for double stars, and nothing of a similar nature appeared to be happening anywhere else in Europe at the time. However, it was in Edinburgh rather than in London that most of Struve's work was reported at regular intervals, from 1823 onwards.[30] His observations were usually reported without editorial comment, but one entry in 1824 was introduced with the words,[31]

> the greatest degree of interest which is now attached to the accurate observation of the colour, magnitude, and relative position of double stars, gives a particular value to the observations of Mr. Struve.

Unfortunately, precisely who showed this 'greatest degree of interest' was not disclosed. But it was in 1824 that South and Herschel published their combined catalogue of doubles. The authors made it clear that they knew of Struve's work, writing,[32]

> the comparison of his observations of such of our stars as have been measured by him with our own, will not be found the least interesting part of the paper. So far as it goes, the coincidence of our results, with very few exceptions, are

[29] F. G. W. Struve, 'A comparison of observations made on double stars. Letter to John Herschel', *Memoirs of the Astronomical Society of London*, 1826, *2*, 443–55; idem., *Catalogus novus stellarum duplicium et multiplicium*, Dorpat, 1827.

[30] Idem., 'Observations on double stars', *Edinburgh Philosophical Journal*, 1823, *9*, 334–41; and ibid., 1824, *10*, 102–9, 331–8; idem., 'Observations on double stars', *Edinburgh Journal of Science*, 1824, *1*, 137–9.

[31] *Edinburgh Philosophical Journal*, 1824, *10*, 331.

[32] J. F. W. Herschel and J. South, 'Observations of the apparent distances and positions of 380 double and triple stars . . . ', *Phil. Trans.*, 1824, *114*, iii, 1–412. ('Distance' here means the angular separation of the components; 'position' the orientation with respect to the meridian of an imaginary line joining them.)

> striking, and afford the most satisfactory ground for reliance on the methods employed by both.

They did, however, point out that they and Struve had started their surveys independently and in ignorance of one another. Furthermore, they referred to similar, and again independent, work being carried out by Professor Amici (a mathematics teacher at Modena, famous for his remarkable work on the optical systems of microscopes), but they had been unable to obtain many of his results.[33] Given that the independence of these endeavours was stressed it is important next to establish the origins of the interest of South and John Herschel.

It is clear that James South's observations of doubles began at least as early as 1820, because in May of that year he read a paper on the subject to the newly formed Astronomical Society of London. In the introduction to the paper he lamented the lack of attention given to 'this curious subject of enquiry'; 'indeed', wrote South, 'to the venerable President of this Society it is, that astronomy is principally indebted for all she knows, relative to the interesting phenomenon present.'[34] It must be remembered that these remarks were made at one of the first meetings of the new society which had had to choose William Herschel as a compromise candidate for its first president. Following the controversy surrounding the selection of the society's first president it was no doubt expedient to be pleased with the chosen person.[35] In fact, South's paper sheds little light on the early history of the study of double stars. More emerges from the introduction to the 1824 catalogue, in which the authors wrote of William Herschel's work that,[36]

> It was to be naturally expected that, owing to the imperfection of the micrometers with which many of the earlier measures, especially those of 1779 and 1780, were performed, and the novelty of the subject, many errors would have crept in; and that a verification of the facts, by farther observation, would at all events be highly desirable. Accordingly in the year 1816, a second re-examination of the measures was entered on by his son.

Apparently, South had had similar ideas and, as he possessed instruments 'particularly adapted to the purpose', it was he who suggested to Herschel a joint programme of observations, which began in March 1821.

Both South and Herschel appear therefore to have turned their attention to the observation of doubles in order to update the earlier surveys by William Herschel. It is significant, however, that the catalogue published in 1824 was *not* a mere repetition of those compiled in 1803 and

[33] Amici's work on doubles was known in Britain only via the accounts of it published by von Zach in his periodical *Correspondence Astronomique*, published in Genoa.

[34] J. South, 'Observations on the best mode of examining the double or compound stars', *Memoirs of the Astronomical Society of London*, 1822, *1*, 109–14, 109. Paper read 5 May 1820.

[35] For an account of the selection of William Herschel see J. L. E. Dreyer (ed.), *The history of the Royal Astronomical Society*, London, 1923, Chapter 1.

[36] Herschel and South, ref. 32, 1.

1804. The later observations were set out in order of increasing right ascension—as were observations in standard stellar catalogues—not within the categories defined by William Herschel, based on the separation of the components of the double. Secondly, the 1824 paper was entitled 'Observations of the apparent distances and positions of 380 double and triple stars', and those were the parameters emphasised throughout the long paper. In other words, this was closer to positional astronomy than to anything in which William Herschel was involved. Finally, the fact that it was South's 'peculiarly well adapted' instrument that was used is significant. For if the purpose was to repeat and update William Herschel's programme, who better suited or placed to do this than John Herschel at his father's observatory in Slough? What was it about South's telescope that made it more suitable, particularly since we know that John had every faith in the 20-foot telescope at Slough, producing as he did a series of six catalogues of double stars during the late 1820s and early '30s?

A possible explanation of South's actions is that he wished his work to be associated with the name of William Herschel because it would thereby be lent authority. No matter how misunderstood William Herschel's enterprise might have been or how it may have been reinterpreted, he was by the mid-1810s very much the grand old man of astronomy. In November 1825, nearly two years after the combined catalogue and over three years after the death of William Herschel, South alone produced a second detailed analysis of his observations of doubles.[37] South's introduction was again eulogistic in its praise for the endeavours of the older Herschel, but the format of the catalogue was even further removed from Herschel's original work. South in fact explained that his own methods were better suited for his fellow astronomers.

From South's introduction also, we can trace one way in which interest in double stars began to spread: South emphasised that he had been greatly encouraged by Laplace, Humboldt and Arago. At about the same time references to Struve's catalogues and papers began to appear fairly frequently in the correspondences between Bessel, Olbers, Gauss and Schumacher, showing that they too were taking notice.[38] In Königsberg Bessel, swayed by the interest of Struve, South and John Herschel, returned to the serious contemplation of double stars and to an analysis of their motions. In the volume of his observations for 1825 he included a list of doubles; furthermore, we know from the 1830 account of his Fraunhofer

[37] J. South, 'Observations of the apparent distances and positions of 458 double and triple stars, made in the years 1823, 1824 and 1825 . . . ', *Phil. Trans.*, 1826, *116*, 1–391. He was unable to collaborate with John Herschel for the second catalogue as much of the work was carried out in Paris.

[38] See under 'Doppelsterne' in the indexes of the following volumes of correspondence: Gauss-Olbers, edited by C. Schilling, in C. F. Gauss, *Werke: Briefwechsel mit H. W. M. Olbers*, Berlin 1900; Gauss-Bessel, edited by R. Englemann, in idem., *Werke: Briefwechsel mit F. W. Bessel*, Leipzig, 1880; Gauss-Schumacher, edited by C. A. F. Peters, in idem., *Werke: Briefwechsel mit H. C. Schumacher*, St. Petersburg, 1860–3. See also *Briefwechsel zwischen Olbers und Bessel*, edited by A. Erman, Leipzig, 1852, *2*, 311–2, 316–23.

heliometer that he used this instrument extensively for the measurement of doubles.[39] It is possible that his decision to order a heliometer, rather than any other instrument, was influenced by his wish to measure the distance of doubles with increased accuracy. By 1833 Bessel was ready to publish a detailed comparison of Struve's, John Herschel's and his own observations, together with a discussion of particular stars, among them 61 Cygni.[40]

By the time Bessel published his papers on the orbits of double stars it had been established beyond reasonable doubt that Newton's inverse square law was applicable to stellar systems other than our own. To show that this was so astronomers had had to face a dual problem: on the one hand a mathematical one of how the motions of the two objects could be described on paper, and on the other the practical difficulty of gathering sufficient, accurate observations. It was in fact a problem of positional astronomy, analogous to the problem of the calculation of cometary orbits, or the paths of the asteroids: astronomers were working out the orbital elements (the parameters which describe fully the paths of the components in space). The problem was tackled during the late 1820s by at least three astronomers: John Herschel, Félix Savary at the Collège de France, and Gauss's exceptionally able pupil Johann Encke working in Berlin.

Savary produced the first detailed mathematical description of the apparent paths, as viewed from the Earth, followed by two stars moving solely as a result of their mutual gravitational attraction.[41] His treatment of the problem began with the assumption that the motions he wished to describe were deducible directly from the general principles of mechanics. From this precondition he worked out how the two stars ought to appear to move. His first paper was strictly mathematical; it was only in a supplement that he discussed particular observations, and then merely as an example of the theory. In fact for the star he selected (ξ Ursae Majoris) theory and observation did not match exactly, but Savary clearly felt this would be ironed out before many years had passed. He wrote that,[42]

> In a few years it will be easy to re-determine them with a fairly high degree of certainty, and it seems we are already justified in supposing that it will be possible, be it by observation or by calculation, to determine the relative

[39] F. W. Bessel, *Königsberger Beobachtungen*, *10*, Königsberg, 1825; idem., 'Vorläufige Nachtricht von einem auf der Königsberger Sternwarte befindlichen grossen Heliometer', *Astronomische Nachrichten*, 1830, *8*, 397–408, translated into English by R. Main in his paper, 'On the present state of our knowledge of the parallax of the fixed stars', *Memoirs of the Royal Astronomical Society*, 1842, *12*, 1–60, 49–57.

[40] F. W. Bessel, 'Verleichung der gegenseitigen Stellungen von 37 Doppelsternen, welche sowohl in Königsberger beobachtet sind', *Astronomische Nachtrichten*, 1833, *10*, 388–98; idem., 'Beobachtungen der gegenseitigen Stellungen von 38 Doppelsternen', *Abhandlungen Berliner Akademie der Wissenschaften: Mathematike Classe*, 1833, 41.

[41] F. Savary, 'Sur la Détermination des orbites qui décrivent autour de leur centre de gravité deux étoiles tres rapprochées l'une à l'autre', *Connaissance des Temps pour 1830*, Paris, 1827, 56–69.

[42] Idem., 'Addition à la Note sur le Mouvement des Étoiles doubles', ibid., 163–71, 169: 'Dans un petit nombre d'années, il sera facile de les modifier avec une probabilité assez grande, et il semble déjà permis de croire que l'on parviendra à déterminer, soit par l'observation, soit par le calcul, les positions relatives de l'étoile mobile, pour une époque quelconque, dans les limites d'erreur qui n'excèderont par un degré.'

positions of the moving component, at any epoch, within limits of error not exceeding one degree.

Thus Savary believed he was setting out a possible method for determining the orbital elements of doubles which could and should be refined by further observation, and subsequent modification of the theory. Such an approach was very much in line with the contemporary attitude to the evaluation of astronomical constants, which even in the late 1820s were still being continuously recalculated in the light of new observations.

In 1830 Encke published his technical account of how to calculate the orbital elements of double stars, his being full of specific examples.[43] It was a very obvious topic of research for Encke. Taught by Gauss, he was completely familiar with the method of least squares and had spent some time refining Gauss's particular method. He was famous among his fellow-astronomers for his treatment of the observations of the comet now known as Encke's comet, and his paper on the motion of double stars bore all the hallmarks of his earlier work on comets.[44] The mathematics describing the orbits was carefully derived; the observations were numerous and selected from the most highly regarded observers of the day; and the reduction of the observations was meticulous. Encke himself drew the comparison between his work on double star orbits and his earlier studies of cometary paths: clearly he was extending the expertise he had acquired in studying the solar system to another area in need of similar treatment.

While on the Continent Savary, Encke, Bessel and Struve continued their respective studies, in Britain John Herschel also maintained his interest in doubles. Between 1824 and his departure in 1833 for the Cape of Good Hope, he produced an extensive catalogue of doubles observed with the 20-foot telescope at Slough.[45] In addition, in 1831 he published a separate catalogue of micrometrical measurements of over 360 doubles made with a 7-foot achromatic telescope.[46] There was a significant difference between the large catalogue and the two papers dealing with micrometrical measurements. The latter project was the continuation of Herschel's joint work with James South, whereas the former may be seen as the actual review of William Herschel's study that South claimed he had undertaken earlier. When John Herschel came to consider the motions and possible orbits of double stars the catalogue he used was, of necessity, the shorter one compiled using the 7-foot telescope: he needed *accurate*

[43] J. F. Encke, 'Über die Berechnung der Bahnen der Doppelsterne', *Berliner astronomisches Jahrbuch für 1832*, Berlin, 1830, 253–304.

[44] Encke's dissertation on comets is contained in numbers *210* and *211* of the *Astronomisches Nachrichten* and was translated into English by G. B. Airy, *Translation of Encke's dissertation . . .*, Cambridge, 1832.

[45] The catalogue was published in stages in the pages of the *Memoirs of the Royal Astronomical Society*: 1826, *2*, 459–97; 1829, *3*, 47–63, 177–213; 1831, *4*, 331–96; 1833, *6*, 1–73; 1836, *9*, 193–204.

[46] J. F. W. Herschel, 'Micrometrical measurements of 364 Double stars with a 7-foot Equatorial Achromatic telescope, taken at Slough, in the years 1828, 1829 and 1830', ibid., 1832, *5*, 13–92.

measurements to work out orbital elements.[47] It thus seems that Herschel's interest in double stars was two-fold. On the one hand he saw himself revising his father's studies, and his interest in this aspect can, as S. F. Cannon suggests, 'always be explained away as "filial" piety'.[48] However, no such explanation can be invoked for John's interest in the detailed motions of binary stars. For that we must remember that he was a first class mathematician and that, by the late 1820s, he was a well known and highly respected member of the astronomical community. His work on the orbits of binaries was, like that of Savary and Encke, carried out as an exercise in positional astronomy, and it brought him to the same conclusions as his Continental colleagues: that the law governing the motion of binaries was the inverse square law.[49]

By 1833, therefore, the applicability beyond the solar system of Newton's law was clearly established. This did not mark the end of interest in double stars, however: far from it. Herschel made a detailed survey of them while at the Cape, and on the Continent the study of binaries continued to play an important part in the work of Bessel and Struve among others.[50] The types of investigations which were carried out are encompassed within Struve's splendid publication, his *Mensurae micrometricae*. The magnitude and importance of the undertaking for Struve are reflected in the size and scope of the book. It was not merely another catalogue of doubles: it was a complete study of all aspects of such stars. He dealt in turn with stellar magnitudes, colours, definitions of doubles in terms of their angular separation, their motions—orbital and proper—and their use in the detection of stellar parallax. He gave a detailed description of the telescope and micrometer used, and of how he used them, comparing his own observations with those of several contemporaries. His treatment was indeed comprehensive.

It is clear, therefore, that the study of double stars formed a significant part of astronomical practice during the 1820s and '30s, and it is now possible to expand upon the reasons already suggested for this. An explanation in terms of the instruments available is, on its own, insufficient, although the significance of the instruments cannot be ignored. Equally, the role of William Herschel must be evaluated, but cannot on its own explain why certain astronomers paid as much attention to double stars as they did. His work was probably the direct cause of John Herschel's

[47] Idem., 'On the investigation of the orbits of revolving double stars; being a supplement to a paper entitled "Micrometrical measurements of 364 Double stars &c"', ibid., 171–222.

[48] S. F. Cannon, *Science in Culture*, New York, 1978, 81.

[49] Herschel's solution differed from those of Encke and Savary in that he made use of graphical representations of the relative motions of the stellar components, arguing that the accuracy of his data was more fairly reflected geometrically than analytically.

[50] A number of other characters showed interest also, including Mädler, who studied the orbits of binaries, Dawes, an English astronomer who ran a private observatory in Ormskirk and made many observations of doubles, Dunlop, who compiled a catalogue of doubles visible from his observatory in New South Wales, and von Zach who published a number of letters about doubles in his *Correspondence astronomique*.

long-term surveys, and appears to have influenced Struve to quite an extent. James South used William Herschel's name to legitimise his own project but, certainly by 1825, was engaged in something completely different from Herschel's original enterprise. Finally on the Continent, although Herschel's interest in double stars was known and referred to, its most important aspect was perceived to be the observational data.

Beyond this, Cannon has suggested that 'the interest of some astronomers in not merely locating double stars but also in measuring their rotations accurately to show that these are explicable by dynamical laws' might be the result of 'Humboldtian influence'. However, she qualified this by writing that 'one who speculates about influences in astronomy in this period without knowing where to place Bessel is a rash person indeed.'[51] Certainly there is an important clue here, although it is not only Bessel's role which is crucial. He was a central figure within a group of astronomers working on the Continent, and especially in Germany through the early decades of the nineteenth century, whose main aim was to refine, both mathematically and observationally, the whole practice of astronomy. They were all very much involved in the problems of precision in positional astronomy and were all convinced that between them they could make the subject more mathematically rigorous than ever before. In 1821 Olbers wrote glowingly to Bessel, 'you . . . and . . . Gauss are bringing about an explicit revolution, and making a veritable epoch in observational astronomy', referring to his colleagues' application of mathematics to astronomical observations, especially in the formulation of celestial orbits.[52]

By 1830 attempts to perfect positional astronomy dominated the work at major observatories, and the techniques being derived were applicable equally to observations of the solar system and of the stars. Studies of the orbits of binary stars fitted in naturally: in order to study them successfully astronomers needed good instruments to provide the data, mathematical techniques for reducing them, and a thorough understanding of celestial dynamics to interpret the results. All of these were the standard tools of those engaged in positional astronomy during the 1820s and '30s, and it is within the context of that tradition that early studies of double stars are most easily understood.

[51] Cannon, ref. 48, 80–1.

[52] Letter from Olbers to Bessel, 21 October 1821, printed in Olbers-Bessel correspondence, ref. 38, *2*, 212: 'Sie, lieber Bessel, und unser Gauss, machen eine förmliche Revolution, und eine wirkliche Epoche in der beobachtenden Astronomie.'