Some matters relating to the documentary evidence of the discovery of Neptune. Disputes and controversies

Norma Foster BSc

normafoster16@hotmail.com

The discovery of the planet Neptune was regarded as one of the greatest discoveries of the nineteenth century. Its existence was first detected, not by eye or with telescope, but by the mathematical analysis of the orbit of the planet Uranus. The perturbations of Uranus were under investigation by John Couch Adams (1819-1892) in Cambridge, and Urban Le Verrier (1811-1877) in Paris. Both these astronomers believed that the irregularities in the motion of Uranus could only be attributed to the action of an unknown planet of the Solar System. However, the circumstances of the discovery have once again become a matter of dispute and contention by some recent historians. My aim is to review the essential facts and the interpretation placed on them and to examine the conspiracy theories that have arisen from an examination of the documentary evidence. These conspiracy theories have detracted from Adams, the true merit of his early researches and his place in the history of the discovery. There has also been speculative allegations made of the character of Adams based on selected documentary evidence, which I believe is not necessarily a true representation of the facts. In presenting a fair portrayal of Adams's researches, I have reconstructed his 1845 October solution in a way that has not been done before.

Adams was a young Cambridge mathematician who had gained recognition for his mathematical talent by his great success in college examinations. Le Verrier was an established astronomer who was renowned for his scientific analysis of planetary motion. For all his natural talent, Adams was in character modest and unassuming. He arrived at the final results of his investigation of the theory of Uranus in the Autumn of 1845, but he did not publish his results immediately, but placed them in the hands of the two leading astronomers of the country; James Challis (1803-1882), director of the University Observatory, Cambridge and George Biddell Airy (1801-1892), Astronomer Royal and director of the Royal Observatory, Greenwich. In doing this he hoped for a British discovery.

This was in contrast to Le Verrier who published his research in the pages of *Comptes Rendus de l'Académie des Sciences* the proceedings of the Academy of Science in Paris, France. Le Verrier concluded in his next memoir (Nov. 1845) that the perturbations of Uranus could not be attributed to the action of the known planets. On 1 June 1846, Le Verrier published his second memoir in which he predicted the place of the unknown planet at true longitude 325 degrees for the epoch beginning of 1847 and that an error of 10 degrees was not probable. Following on at 31 August 1846, Le Verrier published his third memoir that predicted the mass, elements of orbit, and position of the unknown planet. These results reached British observatories on 29 September 1846. Meanwhile, Le Verrier sent his results to the Berlin Observatory requesting a search for the planet. Here, the planet was discovered on 23 September 1846 by astronomer Johann Gottfried Galle (1812-1910) and his assistant Heinrich Louis D'Arrest (1822-1875). Le Verrier was immediately credited with the discovery of the new planet. As Adams's research was unknown to French Astronomers, they disputed that English Astronomers should be attributed with any part of the discovery. It was not until Adams's papers were published as a supplement to the *Nautical Almanac* in December 1846 that any recognition was given to Adams. It is well documented that Adams called in at Greenwich to see Airy on his way down to Cornwall, but Airy was away in France. Adams returned to the Greenwich Observatory, a month later on 21 October 1846, but Airy was not at home. Consequently Adams left his paper of results and a message to say he would return in an hour. On his return, he was informed that Airy

was at dinner and was not to be disturbed. Adams was left with no alternative but to return to Cambridge without seeing the Astronomer Royal. It was a great disappointment to him that the search for the planet was not taken up by British astronomers at that time.

The controversy surrounding the discovery of the new planet, the result of the two independent lines of research, one published in a scientific journal and the other not, meant there was an urgent need for Airy, Challis, and Adams to give an account of the circumstances leading up to the discovery of the new planet. Three papers were read at an important meeting of the Royal Astronomical Society (RAS) on 13 November 1846.

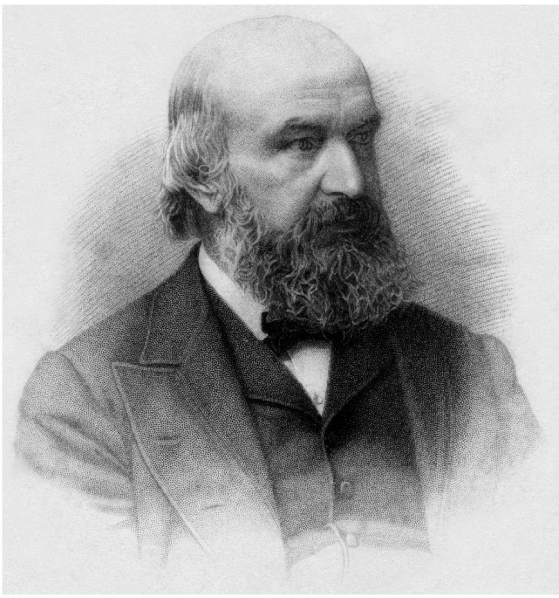


Fig.1 John Couch Adams (engraved by G.J. Stodart from a photograph by J.E. Mayall)
Nature (14 November) 1886
Courtesy of Institute of Astronomy, Cambridge

Airy gave his account of the circumstances relating to the discovery of the new planet in his report to the RAS that was read in full at the society's meeting in November 1846 and published in its Memoirs in 1847. Airy believed he was in a good position to write his report as 'though partaking of the general movement of the age he had not directly contributed either to the theoretical or to the observing part of the discovery'. Airy included in his report two important papers by Adams; the first the paper of results that was left for him by Adams at the Royal Observatory in October 1845, and the second, the letter he received from Adams on 2 September 1846 describing the final results of his two investigations based on his hypotheses of average distance.

Airy recorded in his report of the important paper that he said was communicated to him by Adams in October 1845. This paper contained the final results and orbital elements of Adams's early solution predicting the planet's place for 1 October 1845. Airy recorded:

> On one of the last days of October 1845, Mr Adams called at the Royal Observatory, Greenwich, in my absence, and left the following important paper:-
>
> No 11 J C Adams, Esq. to G B Airy.
>
> According to my calculations, the observed irregularities in the motion of *Uranus* may be accounted for by supposing the existence of an exterior planet, the mass and elements of orbit are as follows:-

Mean distance (assumed nearly in accordance with Bode's Law)	38.4
Mean Sidereal motion in 365.25 days	1° 30' 9"
Mean longitude, 1st October 1845	323° 34'
Longitude of perihelion	315° 55'
Eccentricity	0.1610
Mass (that of the Sun being unity)	0.0001656.[1]

Fig.2 George Biddell Airy, Astronomer Royal
By J. K. Maguire, by G. Ransome of Ipswich, 1852
Courtesy of the Science Museum, London

This solution by Adams predicted the planet's place at mean longitude 323 degrees 34 minutes for the epoch

1 October 1845. Airy recorded this was the solution that Adams left for him at the observatory in October 1845.

Airy also expressed his delight on receiving Le Verrier's June memoir of 1846 that predicted the planet's place at 325 degrees for the epoch January 1847:

> I cannot sufficiently express the feeling of delight and satisfaction which I received from it. The place which it assigned to the disturbing planet was the same, 'to one degree', as that given by Mr Adams's calculations, which I had perused seven months earlier. To this time I had considered that there was still room for doubt of the accuracy of Mr Adams's investigations; for I think that the results of algebraic and numerical computations, so long and so complicated as those of an inverse problem of perturbations, are liable to many risks of error in the details of the process. But now I felt no doubt of the accuracy of both calculations as applied to the perturbation of longitude.[2]

This assertion by Airy that the predictions made by the two astronomers were 'within one degree' was later to be disputed by historians on re-examining the documentary evidence. Since the prediction by Adams of 323 degrees 34 minutes was not within one degree of the prediction of 325 degrees by Le Verrier. This report by Airy was also the first claim of co-prediction made by British astronomers after the discovery.

An abstract of the paper by Professor Challis was also read by Sheepshanks, society secretary, at the historic meeting on 13 November 1846. Challis recorded that he received from Adams in September 1845 a solution of geocentric longitude of the new planet for the epoch 30 September 1845.

Challis recorded:

> In September (1845) Adams placed in my hands a paper containing the numerical values of the mean longitude at a given epoch, with the elements of orbit, mass and geocentric longitude, September 30, of the supposed disturbing planet, which he called in anticipation 'The New Planet', evidently showing the conviction in his mind of the reality of its existence. Towards the end of the next month, a communication of results, slightly different, were made to the Astronomer Royal, with the addition of what was more important, viz. a list of the residual errors of mean longitude for a period extending from 1680-1840, after taking into account the disturbing effect of the new planet.[3]

This solution by Adams predicted the mass, elements of orbit, elements of orbit, geocentric longitude and mean longitude of the disturbing planet for the epoch

Fig.3 James Challis Plumian Professor, c.1866
Photograph portrait by Maull & Co., London.
Courtesy of Institute of Astronomy, Cambridge

end of September 1845. The original paper by Adams is recorded as item 32, in Challis Observatory file/D3.

The original document is headed in Challis handwriting:

Received in September 1845
My dear Sir

The Elements of the New Planet I make to be as follows:-

Mean Dist. 38.4

Mean Long. at end of Sept.r 321°30'

Long Per.n 321°30'

Ecc.y = 0.1428

Mass = 0.000173 Sun's mass = 1

Geoc. Long. at end of Sept.r = 320° 30'

d.m's about 1' per day . (daily motions)

I remain, my dear Sir,
Yours very truly
J C Adams.[4]

This result by Adams predicted the geocentric longitude of the New Planet at 320° 30' for the epoch end of September 1845 and was based on Adams's

original hypothesis of average distance at twice that of Uranus. Challis acknowledged that he received this geocentric solution from Adams in September 1845 and that Adams communicated some different results to Airy the following month. Unfortunately, Challis does not say in what way these results differed from his. Challis recorded that his solution was of importance to the practical astronomer.

Adams presented his paper to the Royal Astronomical Society in November 1846; an abstract of which was read at the meeting of the society. His paper was published in the memoirs of the Royal Astronomical Society in May 1847. Adams confined his report to his analysis of theory of the perturbations of Uranus based on the supposition of an external disturbing planet. His aim, was to determine the mass, orbit and position of the disturbing body beyond Uranus to account for the deviations in the planet's path. Adams recorded in paragraph 4 of his memoir:

> My attention was first directed to this subject several years since by reading Mr Airy's valuable report on the recent progress of Astronomy (This was Airy's report on the state of Astronomy to the British Association in 1832).
>
> I find among my papers the following memorandum dated July 3 1841: 'Formed a design at the beginning of this week, of investigating as soon as possible after taking my degree, the irregularities in the motion of Uranus, which are yet unaccounted for; in order to find whether they may be attributed to the action of an undiscovered planet beyond it, and, if possible, thence to determine the elements of its orbit, i.e. approximately, that would lead to its discovery'.
>
> Accordingly in 1843, I attempted a first solution of the theory of Uranus assuming the orbit to be a circle with a radius equal to twice the mean distance of Uranus from the sun. The results showed a good general agreement between theory and observation and I applied to Airy, through Challis, for the observations of some years in which the agreement appeared less satisfactory. The Astronomer Royal, in the kindest possible manner, sent me in February 1844 the results of all the Greenwich Observations of Uranus.

Adams then recorded:

> After obtaining several solutions differing little from each other, by gradually taking into account more and more terms of the series expressing the perturbations, I communicated to Professor Challis, in September 1845, the final values which I obtained for the mass, heliocentric longitude, and elements of the orbit of the assumed planet. The same results, 'slightly corrected', I communicated in the following month to the Astronomer Royal.[5]

Adams continued his report with a detailed description of the calculations and method of procedure he used in obtaining his results. These calculations extended over some twenty pages in his report. He then recorded in paragraph 31 of his memoir:

> Hence the values of the mass and elements of orbit of the disturbing planet, resulting from the first hypothesis as to the mean distance, are the following:

	a/a' = 0.5
Mean Long. Of the Planet, October 6, 1846	*325° 7'*
Longitude of the Perihelion	315° 57'
Eccentricity of the Orbit	0.16103
Mass (that of the Sun being 1)	

He added, 'These are the results which I communicated to the Astronomer Royal in October, 1845'.[6]

This statement of results by Adams is the final results of his original investigation based on his assumption of average distance at twice the distance of Uranus. This solution predicted the mean longitude of the new planet 325° 7' for the epoch 6 October 1846. Adams recorded that these were the final results that he communicated to Airy in October 1845. There is no uncertainty here.

However, this does not tally with Airy's report that the paper he received was Adams's solution predicting the planet's place at mean longitude 323° 34' for the epoch 1 October 1845. So there is a discrepancy in these two official reports; Adams saying one thing and Airy another, regarding the final results that Adams communicated to Airy in October 1845. So how can this discrepancy have occurred? Airy must have had his reasons for writing his report as he did; having obtained permission from both Challis and Adams to publish any of the correspondence on the topic at his own discretion.

According to Adams, he obtained two solutions of mean longitude in the autumn of 1845, the first he communicated to Challis in September 1845, and a second, 'slightly corrected' solution to Airy in October 1845. The important task is then to determine from the documentary evidence which two solutions was Adams was referring to and what was the 'slight correction' he made to his former solution. Unfortunately, Adams was not explicit as to the nature of the 'slight correction' he made.

Until now, the steps taken by historians have been to compare the geocentric solution Challis recorded

that he received from Adams in September 1845, with the solution of mean longitude recorded by Airy that he claimed was communicated to him by Adams in October 1845. However, on comparing the mass and orbital elements of these two solutions, the values are not the same. The values of the mass are 0.000173 and 0.0001656. The values of the longitude of perihelion are 320° 30' and 315° 55'. The eccentricity of orbit is 0.1428 and 0.1610. So the two solutions are not the same. The claim by Adams, that the solution that he communicated to Airy in October was a 'slightly corrected' version of the solution he delivered to Challis in September 1845, does not appear to be supported by the examination of the documentary evidence. So what has gone wrong?

The reason is that the wrong two solutions have been compared by historians. The two solutions that should be compared are Adams's solution of mean longitude of 323° 34' for the epoch 1 October 1845 recorded by Airy, and the solution of mean longitude 325° 7' for epoch 6 October 1846 recorded by Adams. When these solutions are compared their results are similar. The value of the mass is 0.0001656 for both; the longitude of perihelion is 315° 55' in the first and 315° 57' in the second solution; with the eccentricity 0.1610 and 0.16103 respectively. The only difference in the solutions is that Adams's prediction of mean longitude 323° 34' for the epoch 1 October 1845 in the solution recorded by Airy, has been 'slightly corrected' to the prediction of mean longitude 325° 7' for the epoch 6 October 1846 in the solution recorded by Adams. So it can be surmised that the second solution is a 'slightly corrected' version of the former.

It would appear from an examination of these two solutions that the 'slight correction' that Adams made to his final results in the autumn of 1845 was the update of his final results from the epoch 1 October 1845 to the epoch 6 October 1846. Presumably, Adams updated his final results to the following epoch when the planet would next be in a good position for observation. This means, that the paper recorded by Airy in his memoir to the Royal Astronomical Society, is actually the former solution that Adams communicated to Challis in September 1845, and not the solution that Adams left for him at the Observatory in October 1845. Since, Adams categorically says the final results he communicated to Airy in October 1845 was prediction of mean longitude 325° 7' for the epoch 6 October 1846.

I would therefore conclude that Airy made a mistake in reporting Adams's paper and this error has been overlooked by historians until this present time of writing. I believe the misreporting of Adams's papers by Airy has far reaching consequences on determining the true facts of the discovery, and the importance of Adams's early researches. In most part, the reconstruction of Adams's 1845 October solution has been taken entirely from Airy's report and Adams's version of events has been largely ignored or undervalued.

Taking Adams as authority, the final results that he communicated to Airy in October 1845 was his solution that predicted the planet's place at 325° 7' for the epoch 6 October 1846. This prediction is 'within one degree' of the prediction of 325 degrees made by Le Verrier in June 1846; a fact that has been strongly disputed in recent accounts of the discovery.

Challis confirmed the heliocentric nature of the solutions that Adams obtained in the autumn of 1845 in his letter to the Athenaeum on 17 October 1846 – just three weeks after the discovery of the new planet:

> 'Circumstances of the discovery of the New Planet' In September, 1845, Mr Adams communicated to me values which he had obtained for the heliocentric longitude, eccentricity of orbit, longitude of perihelion, and mass of the assumed exterior planet, – deduced entirely from un-accounted – for perturbations of Uranus. The same results, somewhat corrected, he communicated in October, to the Astronomer Royal. M Le Verrier, in an investigation which was published in June of 1846, assigned very nearly the same heliocentric longitude for the probable position of the planet as Mr Adams had arrived at, but gave no results respecting its mass and the form of its orbit.[7]

Here, Challis acknowledged that he received from Adams a solution of mean longitude in the September of 1845, and that a similar solution was communicated to Airy in October. Unfortunately, Challis does not say how the solution given to Airy differed from the solution he received. The subsequent literature on Neptune may have been very different if he had. However, Challis also concluded in his report to the Observatory Syndicate and University Senate in December 1846: 'The earliest evidence of the complete solution of the inverse problem of perturbations is to be dated from October 1845'.[8] Presumably, this was the date at which Adams arrived at the final results of his original investigation that he communicated to the Astronomer Royal in October.

It would seem from Challis's report to the Royal Astronomical Society in November 1846, that he restricted his description of Adams's researches to his solutions relating to the search for the planet. As no biography of Adams was written during his life time it has been the role of the historians to interpret the

importance of Adams's early researches from the existing documentary evidence on the subject.

W. M. Smart also gave his interpretation of Adams's early researches in his biography of Adams at the centenary of the Neptune discovery in 1946. Smart recorded, 'It was the results of this investigation – to which we refer to as Hypothesis I that formed the short statement which he left for Airy's information on his abortive visit to the Royal Observatory on 1845 October 21'.[9] Smart also recorded that the solution given to Airy on October 1845 was an improvement on that given to Challis a month earlier as a few more terms in the disturbing function were included. In view of my research, I believe Smart is only partially correct in the interpretation of the documentary evidence. The difference between the solution given to Challis and the solution given to Airy was not the effect of adding more terms to the disturbing function, but the update of his final results of his original hypothesis from the epoch 1 October 1845 to the epoch 6 October 1846. I believe Smart further fudges the issue when he says:

> The results of the two solutions are exhibited in Table I (the first as given to Airy in 1845 October with the exception that to exhibit the comparison between the two hypotheses (I and II) the mean longitude of the unknown planet is brought up to 1846 October 6, the date for which it was calculated in Hypothesis II.

TABLE 1

	Hypothesis I	Hypothesis II
	a' = 2a	a' = 1.942 a
Mean Log., 1846 Oct 6	325° 07'	323° 02' [10]

Smart is correct in saying that the solution in Hypothesis I is the solution that Adams communicated to Airy in October 1845, but I believe he is not correct in saying 'with the exception that to exhibit the comparison between the two hypotheses the mean longitude of the unknown planet is brought up to 1846'. The solution given to Airy in October 1845 was his 'slightly corrected' solution that predicted the planet's place at mean longitude 325° for the epoch 6 October 1846.

Sir H. S. Jones, in his publication, *John Couch Adams and the discovery of Neptune*, neatly sidesteps the issue by not distinguishing between the two solutions obtained by Adams in the autumn of 1845 by saying:

> By September 1845, he (Adams) had completed the solution of the problem, and gave to Challis a paper with the elements of orbit of the planet, as well as its mass, and its position for 1 October 1845. The position indicated by Adams was actually within 2° of the position of Neptune at that time. A careful search in the vicinity of the position would have led to the discovery of Neptune.[11]

True, Adams's prediction of 323° 34' for the epoch 1 October 1845 was 1° 26' away from the prediction made by Le Verrier of 325°.

The American scientist and historian, M. Grosser, in his publication *The Discovery of Neptune* (1962, 1979) also used as authority the reports by Challis and Airy to the Royal Astronomical Society (*Monthly Notices of the RAS*, 1847), to reconstruct the solutions obtained by Adams in the autumn of 1845. Grosser recorded:

> Before starting for Greenwich, Adams wrote out a summary of his results, which he left with Challis. Included in the summary was a significant addition to the elements of the hypothetical planet; its geocentric longitude on September 30 1845.[12]
>
> However, from the original manuscripts by Adams it is revealed that the solution of geocentric longitude recorded by Challis was obtained at an earlier date in September, possibly 18 September 1845. Challis recorded this solution was of great importance to the practical astronomer.

Grosser also surmised taking Airy as authority:

> The paper that Adams left at the Royal Observatory was a concise summary of his solution to the problem of Uranus. [13] Grosser noted that the solution recorded by Airy was of mean longitude 323 degrees 34 minutes for the epoch 1 October 1845; with the word 'new missing in Airy's version of the paper – as by then the new planet had been discovered.

Grosser concluded, 'This was the situation at the end of 1845. In England, John Couch Adams had solved the problem and submitted the result to George Airy, who had pigeon-holed it at Greenwich and (intentionally or not) rebuffed its author.'[14]

However, I think it unlikely that Airy did pigeonhole Adams's paper in the Observatory files as Grosser described. Given Airy's passion for method and order, he would not have filed a document that he believed of doubtful value. It is more probable that Airy discarded Adams's paper, when he did not hear back from him after asking the radius vector question. Airy would have then been obliged to make use of the paper communicated to Challis instead. Grosser also recorded, 'On September 2 1846, unaware that Airy was in Germany, Adams wrote to him at Greenwich, enclosing his sixth corrected solution to the problem of Uranus'.[15] Evidently, Grosser had consulted Samson's

Catalogue of Adams's original manuscripts on the Perturbation of Uranus that listed as his sixth solution the final results of Adams's second investigation based on his assumption of average distance at 1/30 part less than before.

The historian Dennis Rawlins also made what I believe to be, a wrong diagnosis of Adams's papers in his publication, 'The Neptune Conspiracy: British Astronomy's Post-Discovery Discovery', *The International Journal of Scientific History* (*DIO*), 2 (1992) and in his subsequent paper 'The British-Neptune Disaster File Recovered…', *DIO,* 9 (June 1999). In his 'Speculative Reconstruction' of Adams's actual 1845 October solution, Rawlins compared the elements of orbit of the geocentric solution recorded by Challis with the elements of orbit of the solution of mean longitude recorded by Airy. Rawlins found what he called 'a huge difference' in the elements of orbit of these two solutions. He recorded that the eccentricity of orbit of 0.14 in the geocentric solution recorded by Challis was very different from the eccentricity of orbit of 0.16 in the solution recorded by Airy. He then asserted, 'It is inexcusable that Adams called a shift from 0.14 to 0.16 merely 'slight' and falsely referred to the 0.14 solution as his 'final' solution (of a series of such 'differing from each other') as he plainly did.'[16] Rawlins also asserted that no popular account had ever mentioned this 14% shift in value. He then made the allegation that it was because his results were flawed that Adams tried to suppress them and that is why they were not published. The author concluded in section I8: 'A Cohering Hypothesis' (p 140), 'I propose that Adams's timidity after his long-suppressed math blunder is the core of the Neptune scandal – a secret hidden all these years by [1] Adams's and Airy's peculiar behaviour and excuses, and now [2] the disappearance of so many original records'.[17]

Rawlins also made the allegation that the 1845 October paper was never actually submitted by Adams to Airy until November 1846, only in time for the Royal Astronomical Society reports. Apparently, the author W. Sheehan wrote to Rawlins congratulating him on his success on solving the Neptune scandal on receiving the latest copy of his publication.[18]

This apparent breakthrough by Rawlins on the merit of Adams's papers may have made sensational writing but lacks authenticity. There is no evidence to show that the results obtained by Adams were flawed. It was Rawlins that made the error by comparing the wrong solutions. I have shown that the two solutions that are similar are the two solutions of mean longitude, the solution recorded by Airy and the statement of results recorded by Adams. It can be deduced that the latter solution is a 'slightly corrected' version of the former. The only difference in the solutions is that the final prediction of 323°34' for the epoch 1 October 1845 has been updated to the prediction of mean longitude 325° 7' to the epoch 6 October 1846 for the second solution. I believe that Adams may have made this update to his prediction of the planet's place while he was a month in Cornwall, before his return visit to see Airy at Greenwich in October 1845.

The Missing Neptune Papers

It is remarkable that the important Neptune papers went missing from the Royal Greenwich Observatory Archives, for a period of some forty years, from 1958-98. The missing Neptune files were found in Chile at the flat of Olin Eggen, a former assistant astronomer at Greenwich, after his death in 1998. The Neptune files were returned to the RGO archives by Adam Perkins in August 1999. It is interesting that the original paper by Adams predicting the mean longitude of the new planet at 323° 34' for the epoch 1 October 1845 was inserted out of sequence at the front of the Neptune file. The original paper by Adams is headed; '1845 October' in another hand than Adams.[19] I believe this to be in Airy's hand. On closer inspection the pages of this solution have been folded into eighths.

The author, Tom Standage, in his work, *The Neptune File* (2000) gave an interesting account of Adams's papers and the recovery of the missing Neptune file. Under the section, 'The young detective' he says:

> One day in late September 1845, he finally arrived at a solution: – a set of numbers that represented the corrections to the orbit of Uranus and the orbital characteristics of the unseen planet. Adams calculated the planet relative to the Sun on 1 October 1845 to be 326.5 degrees, placing it in the constellation of Aquarius, near the border with the neighbouring constellation of Capricornus.[20]

However, Standage does not say on what this evidence this result was based. He also recalled Adams's historic visit to Greenwich in October 1845 to see Airy:

> Before setting out he wrote out a brief summary of his results – According to my calculations, the observed irregularities in the motion of Uranus may be accounted for by supposing the existence of an exterior planet, the mass, and orbit of which are as follows, he then noted and appended the details of the new planet.[21]

Standage remarked that this description of Adams's paper was taken in accordance with Airy's report of

Adams's paper to the Royal Astronomical Society (1847), read to the Society in November 1846. The author surmised on page 133:

> With his passion for order, Airy bound all these letters, along with Adams's original note predicting the new planet's position, a sheaf of newspaper clippings, and all other documents relating to the matter into a scrapbook. He labelled it: 'Papers relating to the Discovery, Observations, and Elements of Neptune' and filed it away in the archives of the Royal Observatory.[22]

Evidently, Standage did not have any reason to doubt Airy's version of events, that the paper Adams communicated to Airy in October 1845, was his solution that predicted the mean longitude of the planet at 323° 34' for the epoch October 1 1845. However, my interpretation of the documentary evidence is that the paper recorded by Airy in his memoir was actually the final results that Adams communicated to Challis in October 1845, and not the paper that he communicated to Airy. It is well known that Adams did not want to enter into the controversy over the discovery of the new planet. He was aware that his researches had not been published and therefore he could make no claim for priority of discovery. But I believe that it is Adams's own report to the Royal Astronomical Society that holds the key to the Neptune affair. Adams categorically says that the final results that he communicated to Airy in October 1845, was his prediction of 325° 7' for the epoch 6 October 1846.

A further analysis of Adams's solutions was also made by Professor Sampson in his memoir to the Royal Astronomical Society, *A Description of Adams's manuscripts on the Perturbation of Uranus* in December 1901. The original manuscripts by Adams were presented to Professor Sampson by his widow, Mrs Eliza Adams, some nine years after Adams's death. From these original manuscripts he identified six solutions obtained by Adams.

The first solution obtained by Adams was his trial solution in September 1843. This solution was based on the assumption that the orbit of the disturbing planet was a circle with eccentricity zero. This solution predicted the mean longitude of the planet at 304° for the epoch 24 September 1843.

The second solution by Adams in 1844 was obtained by taking into account the eccentricity of orbit of Uranus and the astronomical data supplied by Airy. This solution determined the mean longitude of the planet at 253° 28' for the epoch at the opposition of Uranus 3 May 1810. The third set of solutions by Adams was obtained in April and May 1845 by taking into account more and more terms of the series representing the perturbations. Sampson recorded that the close agreement of these solutions inspired in Adams a great confidence in his results. The forth solution obtained by Adams was his geocentric solution dated for 18 September 1845. This solution predicted the geocentric longitude of the planet at 320° 30' for the epoch 30 September 1845. The fifth solution was obtained by Adams in October 1845. Sampson noted this solution predicted the mean longitude of the planet at 323° 34' for the epoch 1 October 1845, as recorded by Airy. The sixth solution was obtained by Adams in August/September 1846. This solution was the final results of his second investigation based on his hypothesis of average distance at 1/30 part less than before. This solution predicted the mean longitude of the planet at 323° 2' for the epoch 6 October 1846 and was communicated to Airy by Adams in his letter on 2 September 1846.

However, I would add that there is another solution that should be added to Sampson's list; that would occupy a position between solution five and solution 6 on Sampson's list. This is the solution by Adams that he obtained in October 1845 that predicted the planet's place at mean longitude 325° 7' minutes for the epoch 6 October 1846. This was the final results of his original hypothesis that Adams communicated to Airy in October 1845. Unfortunately, this solution by Adams seems to be missing from Airy's Neptune file.

Adams's original manuscripts contains all his working of his solutions obtained during the period from 1843-1846 and the steps in the procedure he used to obtain his final results. Each of Adams's solutions were determined from the value of Θ, the difference between the mean longitude of Uranus and the disturbing planet, as determined from the equations of condition. Sampson noted in his description of Adams's various solutions, in his RAS memoir (1901) section E, the value of Θ corresponding to the final results of his original hypothesis was Θ = -51° 30'.5. From this value Adams determined the mean longitude of the disturbing planet for the epoch 3 May 1810. The sidereal motion of the planet was then calculated from the epoch 1810 to the epoch in question and the mean longitude of the planet determined for that epoch. Sampson recorded of Adams's papers, 'Θ = -51° 30'.5 as in the Memoir paragraph 30, is found on page 5, eccentricity and apse, (longitude of perihelion) on page 6, mass on page 7 as in his Memoir paragraph 31'.[23] Sampson also noted on page 167 of his work, 'These are the results of the communication to Airy in October 1845, of which there is a facsimile in Vol. I, of Adams's Scientific Papers, following page liv'.[24] Here, Sampson assumed as all other scholars of Neptune

have done, that the solution communicated to Airy was the solution by Adams that predicted the planet's place at 323° 34' for the epoch 1 October 1845.

Similarly, Sampson identified the working of Adams's second investigation based on his second hypothesis of average distance, from Adams's manuscripts. The final results of this solution were communicated to Airy by Adams on 2 September 1846. Sampson recorded, 'We come to the solution of the second hypothesis, which was communicated to Airy on 1846, September 2'. Sampson noted on page 168 that, 'the successive approximations to the equations of condition for the second investigation are found in section EVII page 13 and EVIII page 6, and the final values on page 9 with Θ = -46° 54' 50'.[25] of his original manuscripts. These values corresponded with those given by Adams in his memoir in paragraphs 47 and 48.

Finally, Sampson noted that Adams tested the outcome of his theory with comparison of differences in mean longitude of Uranus as deduced from theory and from observations of Uranus for the years 1843, 1844 and 1845. Sampson noted the small errors in the results provided an indication of the exactness of his theory.

Sampson described the progress he made in cataloguing Adam's original manuscripts in his letter to Mrs Adams on 14 January 1904. Sampson was a pupil of Adams when he was an undergraduate at Cambridge. Sampson was now professor of Physics at Durham University and wrote:

> With this I am sending you a copy of the RAS memoir of my description of the Neptune Papers. In the introductory remarks I tried my best to get to the bottom of the conditions that determined the success of the predictions – but I found this very difficult to do. However, I did what I could. I have not given many words to the eulogy that is so cheap a careful study of the work is to me a more sincere tribute. But the most interesting part is the facsimile reproduction at the end. It is well done don't you think? On the bottom, p 10, you have the finish of all the determination of Neptune for the date September 1843.[26]

In his description of Adams's original manuscripts, Sampson paid particular attention to Adams's early 1843 solution that was preserved in great measure in his original papers. The W.16 Source volume that formed the basis of Sampson's description of Adams's Manuscripts on the Perturbations of Uranus is held at St John's College Special Collections Library, Cambridge. The source volume, 'Manuscripts of the Perturbations of Uranus – J. C. Adams' was arranged

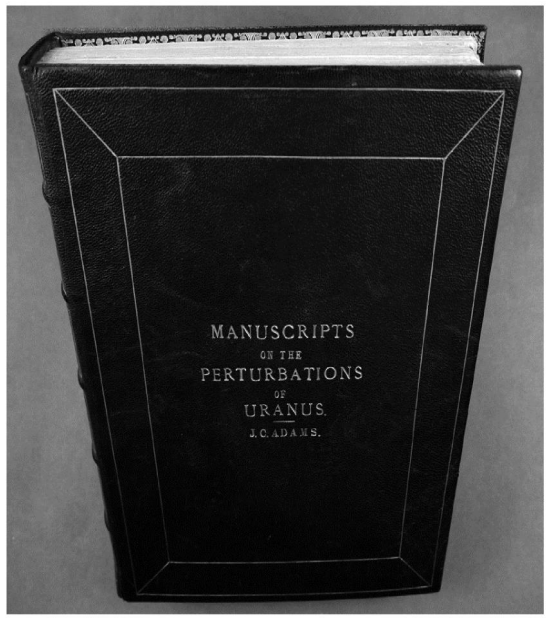


Fig.4 Volume W.16 (1901)
By permission of the Master and Fellows of St John's College, Cambridge

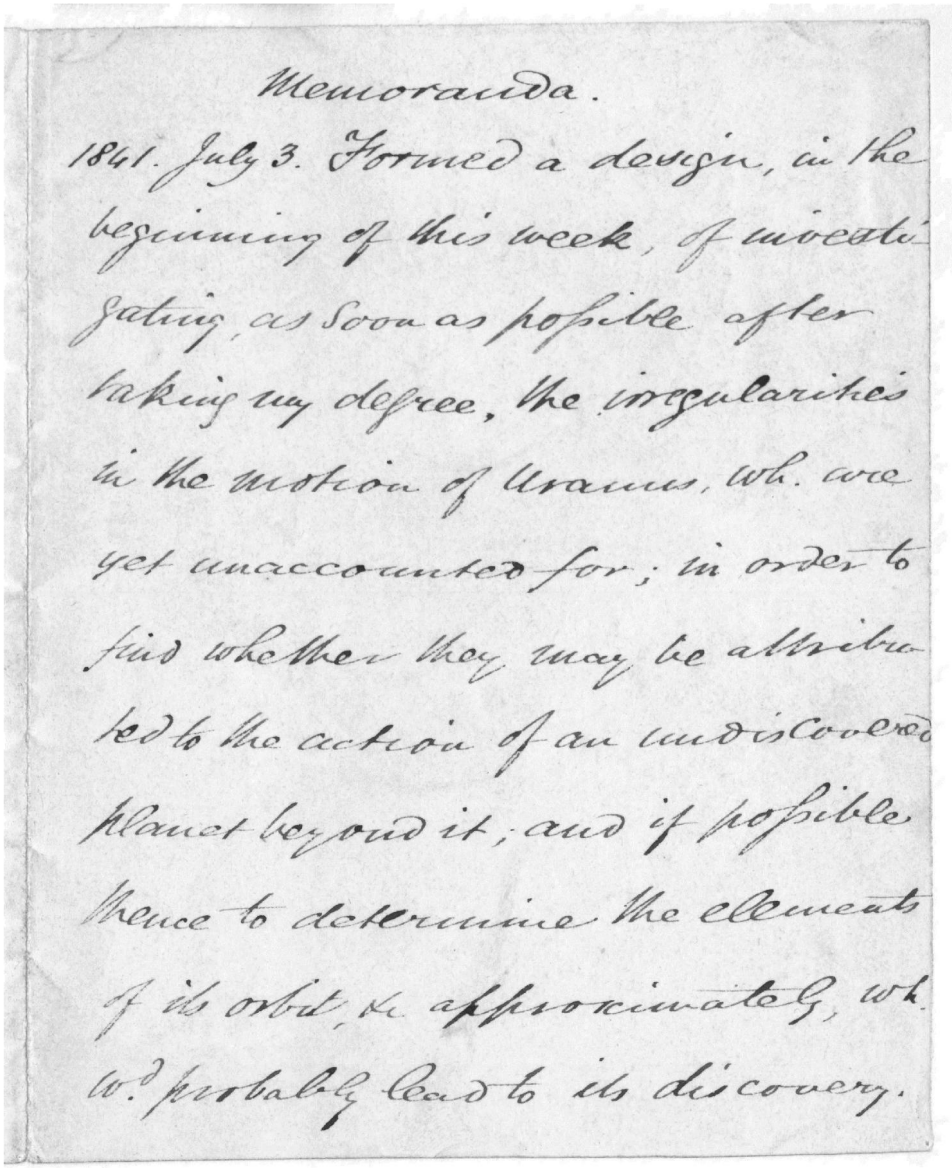
and described by R. A. Sampson after receiving the manuscripts from Adams's widow, Mrs Eliza Adams in 1901.[27] The contents include the original memoranda by J. C. Adams on 3 July 1841 in which he resolved to solve the perturbations of Uranus on the hypothesis of an external planet of the Solar System. The source manuscripts that are of particular importance are the original papers in sections E-IV5, E-IV6, and E-IV7 and E-VIII6 of the volume. The first three manuscripts record the working by Adams of the final results of his original investigation carried out in the Autumn of 1845, based on his value of Θ = -51°30'.5 corresponding to paragraph 30 of his memoir, that predicted the mass, and elements of orbit of the planet. The manuscript E-VIII6 shows the working of the final results of Adams' second investigation based on the reduction of average distance by 1/30 part of his original hypothesis, with Θ = -46° 54' 50, that relates to paragraphs 47 and 48 of his memoir.[28]

The Working of Adams's Final Results and the Slight Correction he made to his final Results

Using the notation; ε as the mean longitude of Uranus, $\acute{\varepsilon}$ as the mean longitude of the planet, and θ as the difference between the mean longitude of Uranus and the disturbing planet; the quantities are connected by the equation $\acute{\varepsilon} = \varepsilon - \theta$. As ε the mean longitude of Uranus is known from observation, then knowing θ, $\acute{\varepsilon}$, the mean longitude of the planet can be determined.

With θ = -51° 30' determined by Adams from the equations of condition, and the mean longitude of Uranus at the epoch 1810.328 (3 May 1810) = 217° 55', then the mean longitude of the planet at the epoch 1810.328 (3 May 1810) = 269° 25'. Adams recorded the sidereal motion of the planet in 36 synodic periods of Uranus to be 55° 12' (I checked this using the numbers 1.0121 x 1.515 x 36 = 55° 12') Precession = 30'. The mean longitude of the planet for the epoch 1846.762 (6 October 1846) works out to be 269° 25' + 55° 12' + 30' = 325° 7'. This is the important result that Adams obtained in October 1845 and communicated to airy

The same procedure as above can be used to rework the previous solution of mean longitude 323° 34' for the epoch 1 October 1845. Using θ = -51° 30' as before, the mean longitude of the planet at the epoch 3 May 1810 = 217° 55' + 51° 30' = 269° 25'. Reworking the calculation for the epoch of 1 October 1845 requires calculating the sidereal motion of the planet in the interval between the epoch 1810 and 1845 that is in 35 years. The synodic period of Uranus is 1.0121 from astronomical tables and the sidereal motion of the planet in one year = 1.515 (from Adams's result of 1° 30' 9" in 1 year). The sidereal motion of the planet in 35 synodic periods of Uranus


Memoranda.

1841. July 3. Formed a design, in the beginning of this week, of investigating, as soon as possible after taking my degree, the irregularities in the motion of Uranus, wh. are yet unaccounted for; in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and if possible thence to determine the elements of its orbit, &c approximately, wh. wd probably lead to its discovery.

Fig.5 Memoranda by J.C. Adams 3 July 1841
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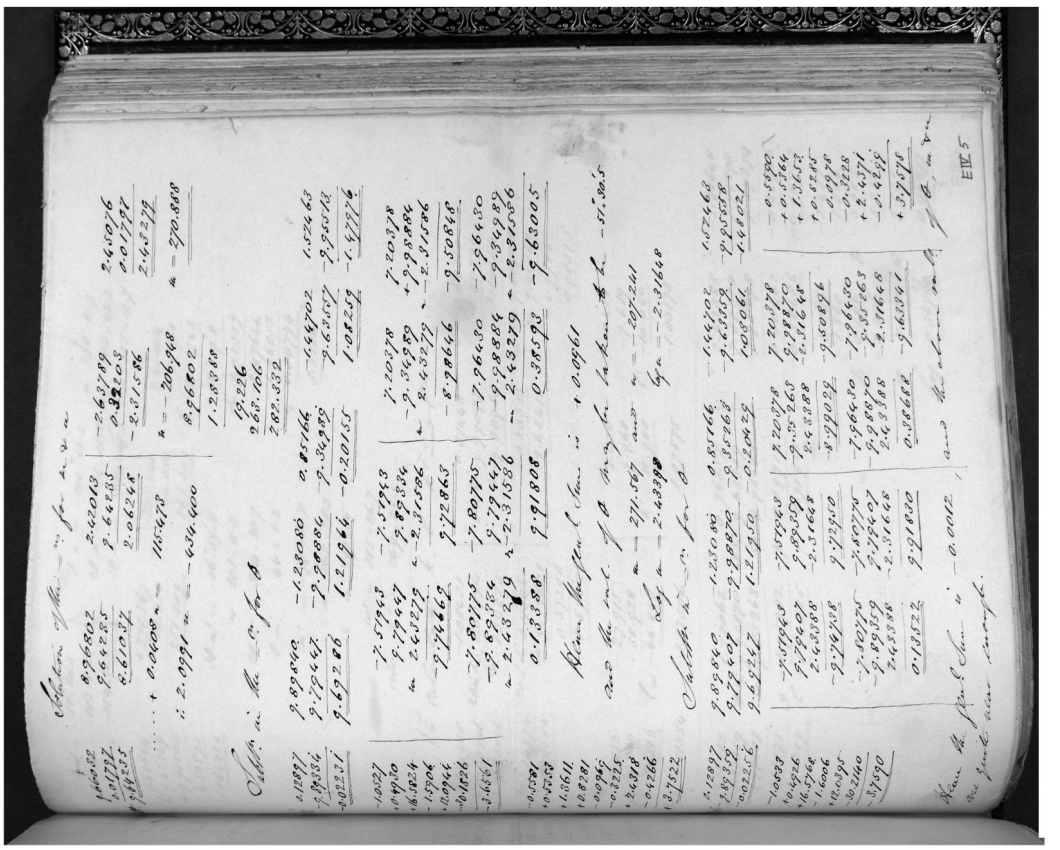

Fig.6a Perturbations of Uranus, E-IV5 obtained in the Autumn of 1845.
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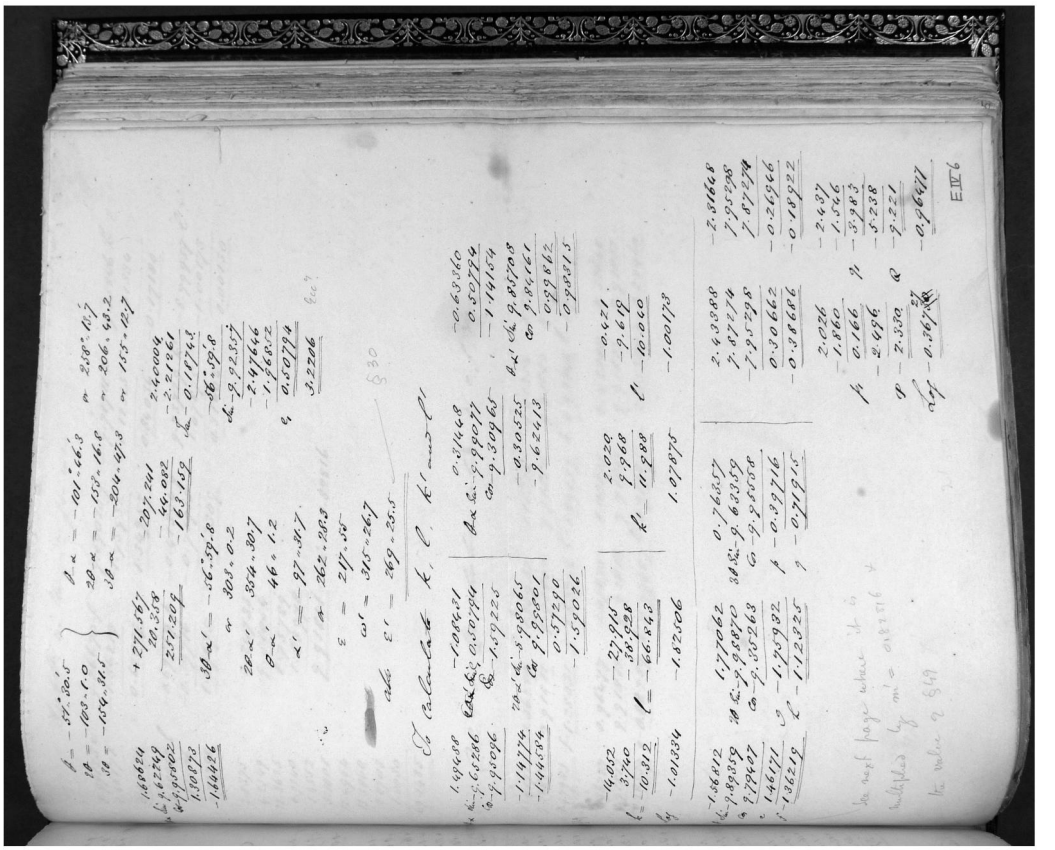

Fig.6b Perturbations of Uranus, E-IV6 obtained in the Autumn of 1845.
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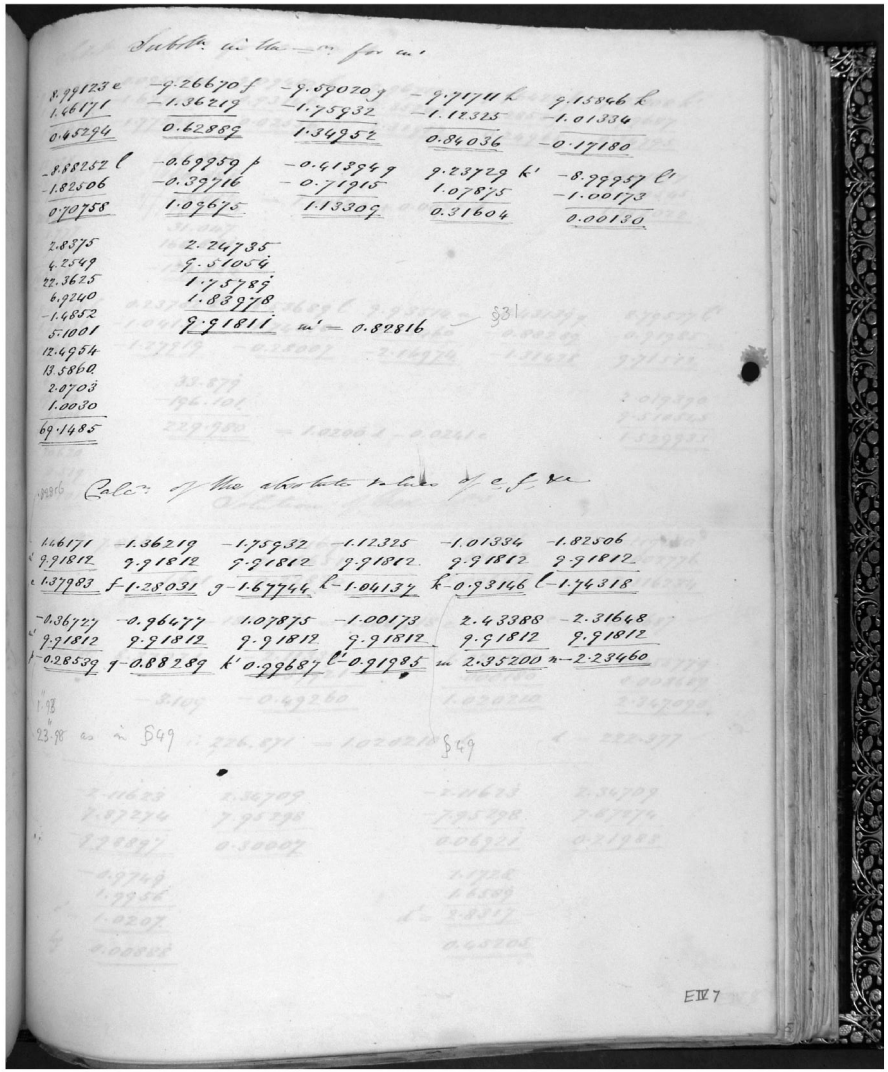

Fig.6c Perturbations of Uranus, E-IV7 obtained in the Autumn of 1845.
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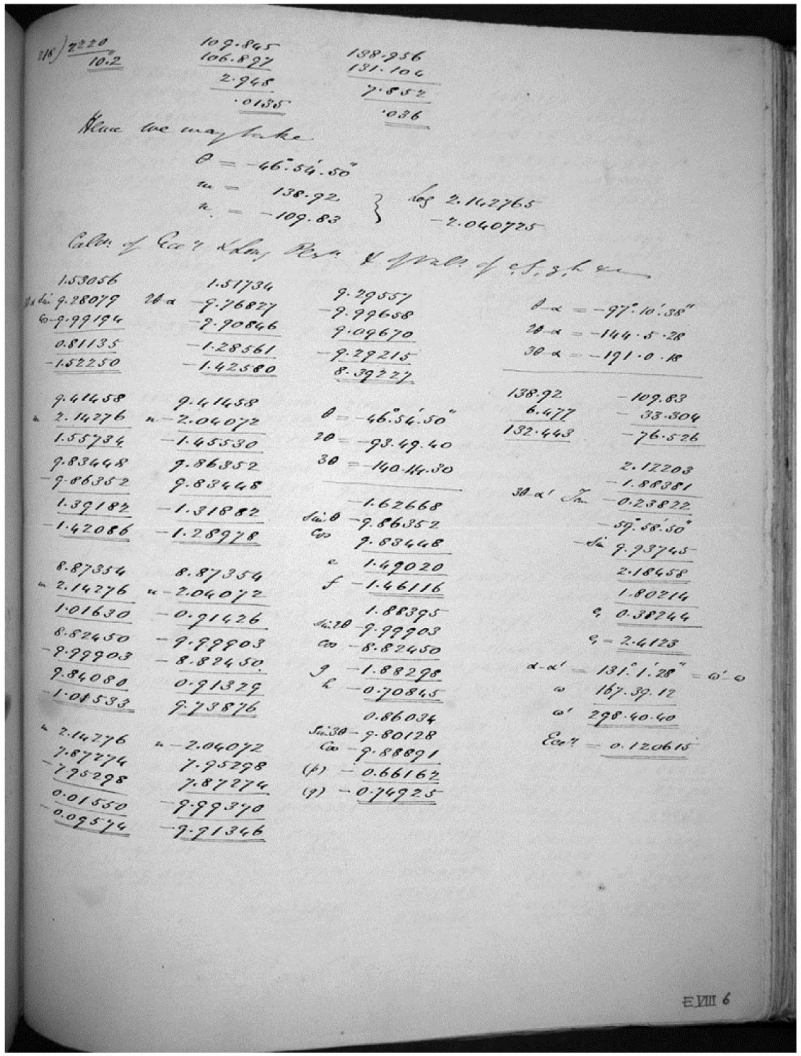

Fig.7 Perturbations of Uranus, E-VIII6 obtained in Aug./Sept. 1846.
By permission of the Master and Fellows of St John's College, Cambridge

is then 1.0121 x 1.515 x 35 = 53°, 66 = 53° 40'. Using the sidereal motion as 53° 40' and the precession 30', the mean longitude of the planet for the epoch 1 October 1845 is 269° 25' + 53° 40' + 30' = 323° 35'. This value corresponds very closely with the prediction of mean longitude 323° 34' for the epoch 1 October 1845, as determined by Adams and in the paper recorded by Airy.

Thus I have shown mathematically, that the 'slight correction' that Adams made to his former solution was the update of his final results from the epoch 1 October 1845 to the epoch 6 October 1846. No other scholar of Neptune has made this deduction from Adams's papers.

My reconstruction of the actual paper that Adams communicated to Airy in October 1845, would be the statement of results recorded by Adams in his memoir, predicting the mass and elements of orbit and mean longitude of the planet at 325° 7' for the epoch 6 October 1846; together with a list of the residual errors in mean longitude of Uranus obtained from observation and theory for the years 1780-1840, after taking into account the disturbing influence of the planet as in his previous solution calculated for the epoch 1 October 1845. The paper then would include the residual errors in longitude for the ancient observations of Uranus for the years 1690-1771, and his reservation of the residual error found from Flamsteed's observation of 1690 as in his previous solution.

The loss of the British discovery

The new planet was not detected by Challis until 1 Oct. 1846, after the discovery by Galle and D'Arrest at Berlin, using the Bremiker Hora XXI star map, just available at the Berlin Observatory, but not then on general release. The loss of the discovery was keenly felt by British astronomers who attributed the loss of the discovery to Airy's poor treatment of Adams and the delay in the search for the planet. Other allegations have also been made to account for the loss.

The historian Robert Smith, in his paper, 'The Cambridge Network in action: The Discovery of Neptune', *ISIS*, 80 (3), Sept. 1989, attributed the loss of the British discovery to the 'Cambridge Network', a body of men at Cambridge that strove to promote the progress of science in Cambridge. He asserted, 'The place of the Cambridge Network in the British scientific community was central to understanding the events surrounding the discovery'. Smith also alleged, 'The secrecy surrounding the discovery by Airy, Challis and Adams appears to have been an attempt to make a Cambridge 'snuggery' affair of it, for Challis and the Northumberland equatorial'.[29] He also alleged that the Cambridge astronomers strove to keep the discovery their own.

Other allegations have been made from the interpretation of the documentary evidence. The claim of co-prediction by Adams was 'an essential illusion', and not supported by documentary evidence. Historians have alleged that the British astronomers evoked the concept of a 'within one degree' myth in order to steal the discovery from the French. They also allege from the examination of the documentary evidence that there was a great deal of uncertainty in Adams's solutions, that he lacked confidence in his results, and this was the reason for the non-publication of his work.

The author Dennis Rawlins, in his paper 'The Neptune Conspiracy, British Astronomy's Post-Discovery Discovery', *DIO* (1992) strongly contended any British claim in the discovery of the planet Neptune. Rawlins asserted in his introductory page:

> Detailed evidence is presented indicating, that throughout 1846 Summer, Cambridge University astronomers conspired to capture Neptune by keeping *Cantab* Adams's work unpublished while they exploited the provocative secret that 2 men's math had independently pointed to the same celestial position for Uranus's unknown perturber. It is concluded that Le Verrier ought to be recognized as the planet's sole discoverer.[30]

Rawlins also asserted:

> Adams is widely held to be the true predictor of Neptune's position and is honoured for this achievement by a memorial in Westminster Abbey near Isaac Newton's tomb. However, Adams role in the discovery was actually nil and his behaviour has always been inexplicably murky.[31]

Rawlins also maintained, that even though Adams's 1845 prediction was accurate enough to effect the planet's discovery, there was not sufficient confidence by British astronomers in the results. The key person lacking the necessary confidence was Adams himself, partly due to his own astronomical inexperience, and partly due to the fact he had not yet in 1845 tested his theoretical calculations. Rawlins also blamed the loss of the British discovery on what he calls 'Adams's waiting game'. Adams waited until November 13, 1846 to release his hypothetical elements to the public.[32]

Further allegations have been made of the conduct of the British astronomers by Nicholas Kollerstrom in his publication: 'Neptune's Discovery and the British Case for Co-Prediction' (2001) based the reports by Airy, and Challis. Kollerstrom asserts:

> Within two months of the discovery, Challis, Airy and James Glaisher, three of Britain's top astronomers, had publicly committed themselves to the radically unsound view that Adams's and Le Verrier's predictions agreed 'within one degree'. Nothing has more skewed the debate than this claim: they differ by about 4 degrees.[33]

Kollerstrom then made the following controversial statement, 'The "within one degree" concept was a vital part of the myth built up by Adams's prediction and had the advantage that persons retelling the story did not have to bother about the confusing astronomical details'.[34] I would dispute these allegations. The prediction made by Adams of mean longitude 325° degrees 7' for the epoch 6 October 1846, is 'within one degree' of the prediction made by Le Verrier of 325°. There was no bogus claim by British astronomers. There was no 'essential illusion'. There was no conspiracy by British astronomers in an attempt to steal the discovery from the French. The loss of the British discovery was simply an unfortunate chain of events that delayed the publication of Adams results and the search for the planet.

Kollerstrom also used the speculative result by Adams of 315° 20' in his letter to Airy on 15 October 1846 and his prediction of 336° from the July ephemeris based on the Wartmann Star as an indication of further disparity in his results. Kollerstrom asserted, 'That even though Adams later amended this result (315°) "Adams" preferred solutions swung over a twenty degree range from July to September of 1846 – no wonder Challis was unsure where to point his telescope'.[35]

The American/British authors, W Sheehan, N. Kollerstrom, and C. Waff, in their article, 'The Case of the Pilfered Planet?: Did the British steal Neptune', *Scientific American*, (November 22, 2004) also disparage Adams's results on the basis of their deductions. They describe Adams's solutions as simply a 'sorcerer's trick' conjured up from theory to match the numbers. They maintain Adams had no more confidence in his results than Airy did and was given far more credit for the discovery than he deserved. The authors say in their concluding paragraph, 'The Brits Stole Neptune':

> From our view of the original documents, we have concluded that Adams's British contemporaries gave him more credit than was due to him, even though he had performed some remarkable calculations. Adams utterly failed to communicate his results forcefully to his colleagues and to the world. We can affirm that Adams does not deserve equal credit with Le Verrier for the discovery of Neptune. That credit belongs only to the person who succeeded both in predicting the planet's place and in convincing astronomers to search for it. This achievement was Le Verrier's alone.[36]

The authors W. Sheehan, and S. Thurber also gave an account of the circumstances of the discovery of Neptune in their paper 'John Couch Adams's Asperger Syndrome and the British non-discovery of Neptune', *Notes and Records of the Royal Society*, (July 2007). These authors assert that although Airy and Challis were blamed for the loss of the British discovery, the blame should really go to Adams, for not publishing his work and not communicating his researches forcibly to the world. According to Sheehan and Thurber, 'With Challis and especially Airy traditionally cast in the role of villains' in the story of the discovery and 'Adams has been portrayed as a wronged innocent', they argue that this is a gross simplification of the events'. They maintain:

> Adams emerges as a rather complex and even paradoxical individual, whose intellectual astuteness was offset by equal measures of social-skills deficiencies, a tendency to procrastinate and tinker even when the situation called for action and an almost pathological difficulty in writing prose narrative, a near fatal combination that made him seem drift, indecisive and mute at the very moments when conviction and clear indications of what his investigations had uncovered were needed.[37]

These authors suggest the most likely explanation is that Adams probably had Asperger Syndrome, or Autistic Spectrum Disorder (ASD), which they claim to be a common condition among mathematicians and physicists at the highest levels of achievement and which severely hampered the ability to navigate the social world of Victorian science. The authors list the core symptoms as, 'difficulties in social relationships and communication skills, strong narrow interests, and repetitive behaviours'. They add, 'individuals at various levels on the autism dimension will evince these core symptoms with varying degrees of severity'.[38]

However, much of what I have read of Adams would not support this point of view and there is little to suggest that he had Asperger syndrome. In character, Adams was shy and modest, but that is not to say that he was indecisive and unable to negotiate the social complexities of the social and scientific society in which he lived.

More recently, the historian Dr Roger Hutchins, in his work *British University Observatories 1772-1939* (2008), gave what he intended to be an historical perspective of the discovery of Neptune. Hutchins also

based his review extensively on Airy's report (1847). Hutchins records that Le Verrier's mean position of 325° of longitude at the beginning of 1847 was very similar to the position of mean longitude of 323° 34' position for 1 October 1845 which Adams had communicated in a note to Airy, 7 months earlier.[39] Here Hutchins glosses over the apparent discrepancy in the predictions by saying 'very similar'. In fact that the two predictions quoted above are not within one degree. Hutchins then explains that Leverrier's and Adams's results and their sequence are well published and it is possible to seek a historical perspective. In September 1845, when Adams had completed his fourth calculation (later known as Hypothesis I) Challis wrote to Airy on 22 September a letter to introduce Adams. Then quoting Adams 'I left a note for him, containing a short statement of the results at which I had arrived'.[40]

Hutchins concluded this solution was the orbital elements and Adams's prediction of mean longitude 323 degrees 34 minutes for 1 October 1845. Hutchins does not distinguish between the solution communicated to Challis and the solution that Adams left for Airy at the observatory a month later. So I would conclude that this is not a true perspective of Adams's papers as the 'slightly corrected' solution obtained by Adams predicting the planet's place at 325° 7' for the epoch 6 October 1846 is not identified by Hutchins.

On the loss of the British discovery Hutchins concluded, 'There is no documentary evidence of a conspiracy of any sort, no written hint of "if we do this we might gain that". Nor was there any document speaking explicitly of an international race for discovery'. Hutchins surmised, 'Rather than a conspiracy their collegial interests fostered a muddle'.[41] Hutchins attributed the muddle in the discovery to a defect in Adams's character claiming that Adams could not adapt to the social and scientific society of the nineteen century at Cambridge. Hutchins asserted:

> He frequently lost things, failed to keep appointments, and clearly was unable to see the big picture of the Neptune incident. He seems to have been unable to discern what others might think, for instance that his failure to reply to Airy's enquiry would close the correspondence with a man whose advice and support he would again need.[42]

Hutchins concluded that the loss of the British discovery was the result of a human muddle in which Adams's unusual personality was a key factor. The lack of the three astronomers, Airy, Challis and Adams to decide a course of action might in part explain why nobody notified the press of Adams's work. He also asserted that in hindsight his personality was such that neither Airy nor anybody else could have mentored him as critics later suggested should have happened. Hutchins also expressed the view he shared with William Sheehan, '…that Airy did Adams a considerable service by establishing his prior calculation and crediting him simply to one-degree in the official report, a narrative that Adams himself would never have produced'.[43] It was the view of these scholars, there was no justification in a claim of discovery by Adams. That honour should go to Le Verrier alone. However, Adams recorded the close coincidence of Le Verrier's results with his own in his memoir to the Royal Astronomical Society. In June of the present year he followed up in his investigation by a memoir in which he attributed the residual differences to the action of another planet and found a longitude for the new planet agreeing very nearly with the result which I had obtained on the same hypothesis.[44]

Conclusion

While I can see how the discrepancy in the official reports has caused confusion on examining the history of the discovery of Neptune, I do not see why it is necessary to carry out a character assassination of Adams as some recent historians have done to account for the loss of the discovery. I believe there was no conspiracy by the British Astronomers to cover the loss, but an unfortunate chain of events that led to the planet not being detected at Cambridge until after the discovery by Galle and D'Arrest at Berlin. I would conclude there is documentary evidence in the Observatory files to show that Adams is, and always was, the first theoretical discoverer of the planet's place

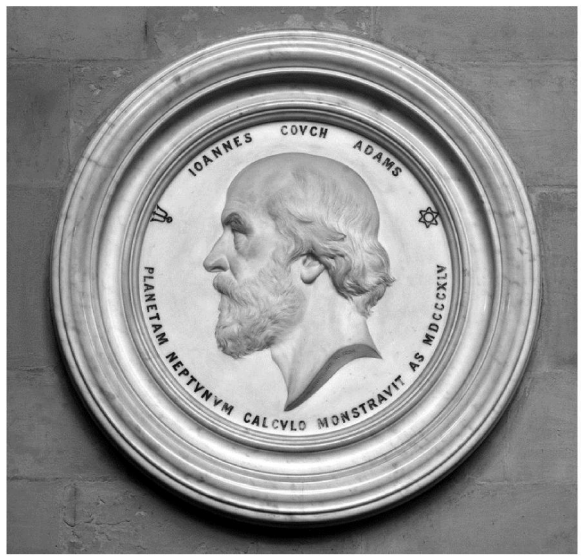

Fig.8 Abbey memorial plaque to Adams 1895
Copyright of Dean and chapter of Westminster

Fig.9 Print of Urban Jean Joseph Le Verrier
Turner, H. H., *Astronomical Discovery*
(London, 1904), Pl.3, p.60
Courtesy of the Royal Astronomical Society

though not so lucky as to claim the full merit of priority of discovery. A view held by the eminent astronomer W. Struve formerly of the Pulkovo Observatory at St Petersburg, as inferred from a letter from Challis to Struve on 10 March 1847.[45]

The verdict of history is that the merit of discovery goes to both astronomers Le Verrier and Adams. There was no question of rivalry between the two men. Adams considered himself to be a friend of Le Verrier's and not a rival. After Le Verrier's death in 1877, Adams was sent a photograph of Le Verrier's statue outside the Paris observatory by his family to 'Adams as a friend'. This is a fitting tribute to the friendship of these two eminent men of science.

Acknowledgements
I owe the conclusion of my research on the scientific achievements of this great astronomer to the following, who have given me support and encouragement throughout the process of accessing the original documents and manuscripts relating to this topic. Former librarians, Malcolm Pratt and Jonathan Harrison, for access to the manuscripts of John Couch Adams held at the Special Collections Library of St John's College, Cambridge and to Kathryn Mckee, for her invaluable help in evaluating the source documents. Adam Perkins, custodian of the Royal Greenwich Observatory archives at the Cambridge University Library, for providing access to the important missing Neptune file, and Jacqueline Cox for her help with the referencing of the Cambridge Observatory archives. David Dewhirst, former librarian at the Institute of Astronomy Cambridge, for his introduction to Adams' academic life and background to his astronomical papers. Mark Hurn, the departmental librarian at the Cambridge Institute of Astronomy, for his special interest in this topic. Mary Chibnall and Jennifer Higham, at the Royal Astronomical Society, Burlington House, London, for their help with accessing the scientific papers of Airy, Challis and Adams held in the memoirs of the society. Malcolm Wright, committee member of the Friends of Lawrence House Museum, Launceston for access to Adams' manuscripts held in the museum. The late family of John Couch Adams, Dr Queenie Muriel Adams and Ethel Roseveare, great nieces, for providing insight into his family. My own family and friends for their support and encouragement. Judith Markland for her invaluable help in preparation for this article. Kevin Johnson for his advice and expertise in providing the format and help with images.

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The Author

Norma Foster is a retired teacher of Physics and Mathematics now living in Gloucestershire. She has a keen interest in the history of Science and Astronomy. The author is married, with three children and six grandchildren and has a connection with the astronomer John Couch Adams through a family link on her mother's side.