The book ends with a postface, which contains Buick's final reflections.

Overall, this is a useful introduction to the development of the orrery and its historical context. It is intellectually accessible and does not require prior knowledge. However, it would benefit from a more explicit Introduction to outline what the reader can expect and a Conclusion to refer back to points made in the Introduction and draw the story together and to a close. I also think that some of the content could be condensed and redistributed to make the overall narrative stronger. Reference to other recent publications on London's instrument makers would not only help to situate this narrative within wider discussions, but would also help to tighten the content.

## Reference

Buick, T., (2013). *Orrery: A Story of Mechanical Solar Systems, Clocks, and English Nobility*. New York, Springer.

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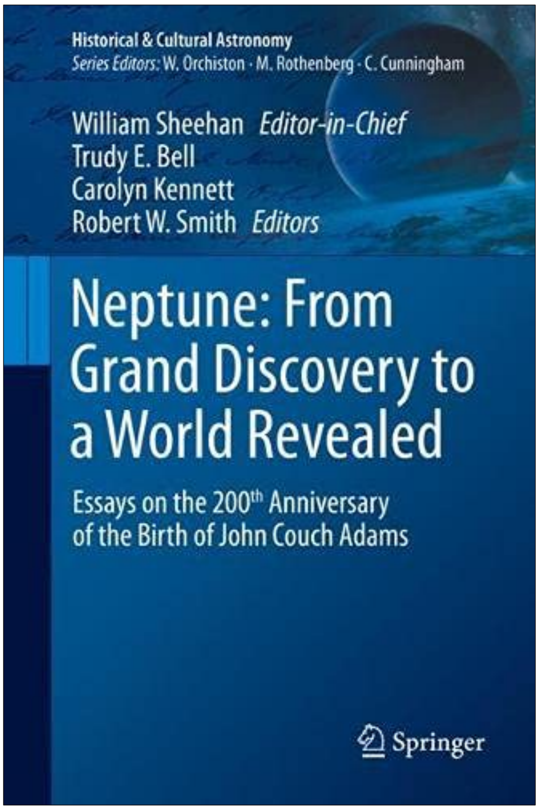
***Neptune: From Grand Discovery to a World Revealed. Essays on the 200th Anniversary of the Birth of John Couch Adams*, edited by William Sheehan, Trudy Bell, Carolyn Kennett and Robert W. Smith. (Cham (Switzerland), Springer, 2021). Pp. xxxi + 403. ISBN 978-3-030-54217-7 (hardback), 160 × 240 mm, US$139.99.**

This volume is a monument to collaborative scholarship on a topic of considerable importance that reaches well beyond its subject, the planet Neptune. Five of the ten chapters are authored or co-authored by the meticulous and indefatigable William Sheehan, two by historian Robert Smith, and the remaining three by Brian Sheen and Carolyn Kennett on John Couch Adams, James Lequeux on Le Verrier, and Davor Krajnović on the German side of the story. Additional contributions as co-authors come from Clifford Cunningham, Kenneth Young, and Richard Baum. Co-editors Trudy Bell and Carolyn Kennett have successfully ensured the volume coheres. All are experts on Neptune's history and have written on aspects of the subject in the past. On the occasion of Adams's 200th birthday in 2019, they now take a new look at Neptune's discovery using both primary records and new secondary research. The result is a triumph of Neptune studies, and in a broader sense a significant contribution to the history of celestial mechanics and to the study of personal, cultural, and institutional roles in science.

The discovery of Neptune has long been one of the great sagas in the history of astronomy, replete with controversy encompassing theory and observation, discovery and credit, personality and social environment. The outlines of the story are well known. On 1 June and 31 August 1846 the Paris astronomer U.J.J. Le Verrier presented papers with his calculations for the elements of a new putative planet and predictions of where it should be found based on residuals in the orbit of Uranus. Not having access to a proper telescope at Paris Observatory, he wrote Johann Gottfried Galle, among others, and on 23 September Galle and his student




Heinrich d'Arrest found the planet within an hour using the 9.6-inch (24-cm) Fraunhofer refractor at Berlin Observatory, pictured on page 206.

That much is certain. But the plot quickly thickens as the British enter the scene: the young Cambridge mathematician John Couch Adams had made a series of unpublished predictions, notably in September and October 1845, almost a year before Le Verrier. The Director of the Cambridge University Observatory, Reverend James Challis, had at first failed to follow up on these predictions of his countryman. He only began to search for the planet beginning in July 1846, and spotted it with the 11.75-inch Northumberland Refractor on 4 and 12 August, but did not realize it was a planet and therefore made no announcement. And according to contemporaneous and later critics British Astronomer Royal George B. Airy—initially skeptical of the chances for success for such a search—dawdled until it was too late, yielding glory for the discovery to the French and Germans.

Personalities and national identities quickly became involved, and even nascent American astronomy. Sears Cook Walker at the newly founded U.S. Naval Observatory (USNO) had read Le Verrier's June 1846 memoir and asked Superintendent Matthew Fontaine Maury's permission to search for the new planet. But, Maury's USNO, like Airy's Greenwich, was overloaded with the routine work of positional astronomy, and the search did not take place. News of the discovery reached the United States on 20 October; the Bonds spotted the new planet the next day with Harvard's 4.5-inch refractor, and Maury himself observed it in the next two days with the USNO's 9.6-inch refractor constructed by Merz and Mahler, successor to Fraunhofer and virtually identical to Galle's discovery instrument. Walker was left to search for prediscovery observations, which he was the first to do successfully, and then to calculate Neptune's orbit. All very useful, but the thought that a new major planet might have been discovered in the United States rankled those who wished to boost science in America (pp. 319–323, and Dick, 2003: 92–95).

The book follows a logical sequence. After a first chapter where Sheehan tackles the preliminaries to the Neptune discovery, including the relevant celestial mechanics, in the second chapter Clifford Cunningham (certainly the world's expert on the history of asteroid discovery), joins Sheehan to analyze Herschel's discovery of Uranus in 1781 and the discovery of the first asteroid, Ceres, by Giuseppe Piazzi and his often unheralded assistant Niccolò Cacciatore at Palermo Observatory on 1 January 1801. A highlight of Chapter 2 is Trudy Bell's table of 23 prediscovery sightings of Uranus from 1690 to 1771: 7 by John Flamsteed, 3 by James Bradley, 1 by Johann Tobias Mayer, and 12 by Pierre Charles Le Monnier, sightings that would help determine the orbit of Uranus and set the stage for predictions of yet another planet.

The next two chapters cover in considerable detail the life and role of John Couch Adams, followed by chapters on the French and German contributions. James Lequeux's chapter is based on his excellent biography of Le Verrier, now translated into English by Bernard Sheehan (Lequeux, 2013). Astronomer Davor Krajnović's 60-page revealing chapter draws on German primary and published sources to contextualize the discovery within the German scientific community, and also, incidentally, demonstrates that astronomers really can write good history.

Chapters 7 and 8 comprise Smith's analysis of the ensuing international controversies, and (with Richard Baum), Lassell's discovery of Neptune's largest satellite Triton that allowed Neptune's mass to be determined, as well as his spurious discovery of Neptune's ring. (Baum died in 2016, but this chapter is based on an earlier joint paper). Neptune indeed does have rings, but Lassell could not have seen them; nonetheless the known named rings of Neptune now immortalize Adams, Le Verrier, Galle – and Lassell, and are an appropriate nod to history, even if Challis and D'Arrest might feel aggrieved were they alive today.

The final chapters round out the book with Sheehan and Young's reassessment of Neptune's orbit, and the events of the last two decades since Voyager 2 visited Neptune. Once again the United States enters the story in both cases, starting with Walker's role in Neptune's orbit calculation and Benjamin Peirce's claim from Harvard that the discovery was a 'happy accident', and ending with NASA's role in the Voyager probes. The details of the happy accident claim are discussed in Chapters 7 and 9; Sheehan and Young conclude that Galle and d'Arrest had indeed been incredibly lucky "… just not so much for the reasons Peirce had thought it …" (page 331). There is considerable overlap among all these chapters, but this turns out to be felicitous, as the story is told and retold from many angles, with contradictory interpretations and descriptions, from both the major players and the historians, Rashomon-like.

The many interesting themes of these chapters are too numerous to analyze in detail. But let us address two examples. The first is the problematic nature of discovery, present throughout the book, but which Robert Smith tackles head on in Chapter 7. He does so not to judge who should get credit, but to illuminate the standards of discovery in the mid-1840s. He finds that much of the controversy was due to very different conceptions of what constituted a new discovery. Thus, Challis believed that his sightings of Neptune in August, a month before the Berlin observations—but without recognizing it as a planet—qualified him to be the discoverer of the new planet. Others did not agree, including most emphatically the Berlin 'discoverers'. Smith logically asks "If … Challis did not discover Neptune on August 4, 1846, then what allows us to claim Herschel discovered Uranus on March 13, 1781 …" since Herschel believed he had discovered a comet, and there were many other pre-discovery sightings of Neptune by Michel Lalande and others stretching back to Galileo in 1612 and 1613 (Kowal and Drake, 1980). Discoveries get made in both the physical and social worlds, Smith argues, and the answers are not always the same.

This problematic nature of discovery is widespread, encompassing virtually every aspect of the history of astronomy to the present day and undoubtedly extending to other sciences as well. Dick (2013) discusses this underappreciated subject in detail for 82 classes of astronomical objects, though unfortunately not taking into account the evolution of the idea of discovery. David Wooten's chapter 'Inventing Discovery' in his book *The Invention of Science* (Wooten, 2015) goes some ways towards remedying this omission. In any case readers looking for a definitive answer to who *really* discovered Neptune will be disappointed. Multiple authors in this volume declare that such a judgement is not their goal or role. The anatomy of discovery reveals it to be an extended affair, including phases of pre-discovery, discovery (with sub-phases of detection, interpretation, and understanding), and post-discovery, the latter phase where issues such as credit, reward, and classification are adjudicated. The events surrounding Neptune are prime examples of this anatomy.

A second theme involves inferences and predictions made from the results of celestial mechanics. As Allan Chapman (who writes the Foreword) and others have emphasized, the discovery of Neptune via gravitational perturbations initiated a whole new field of astronomy. One of the persistent questions in the wake of Neptune's discovery has centered around the existence of Planet X, a tenth planet, based on the residuals of Uranus that are found after comparisons of observations with theory, the observed minus computed 'O minus Cs' as we called them during my time at the U.S. Naval Observatory. During the 1980s this was still a viable issue at the Naval Observatory and elsewhere (see Harrington, 1988), and those who made claims about even the possibility of a new planet were sure to catch the attention of the media. But as Sheehan points out in his final chapter, based on work by E. Myles Standish Jr. at the Jet Propulsion Laboratory, by 1993 the putative residuals of both Uranus and Neptune were reduced to zero in the aftermath of the Voyager probes (Standish, 1993; page 363 in the book). Gibson Reaves (1994) soon pointed out that the false residuals were due to errors in both theory and observation, including Lowell's method of smoothing observations. In addition, Voyager 2 observations revised the mass of Neptune downward by 0.5%, a downgrading equal to the mass of Mars, which of course also revised its gravitational effect on Uranus. The quest for a major planet beyond Neptune was revived in 2016 when Batygin and Brown (2016) inferred a large planet based not on Neptune's residuals but on the configuration of a subset of the so-called Kuiper Belt Objects (KBOs). That claim, too, has fallen by the wayside due to errors in earlier KBO surveys. Celestial mechanics giveth, and celestial mechanics taketh away. So does the International Astronomical Union (IAU). Thanks to a vote of the IAU in 2006, Pluto is now classified as a dwarf planet, and a dwarf planet is declared not to be a planet at all, leaving Neptune as the supreme outer guard of the Solar System. Searches for any major planet beyond Neptune would now be for a Planet IX, and seem increasingly unlikely to succeed.

The failure thus far to find Planet IX or X is somewhat compensated by the spectacular findings beyond Neptune, what Pluto New Horizons Principal Investigator Alan Stern likes to call the 'Third Zone' of the Solar System. For we now know that beyond the rocky planets and the gas and ice giants lay the Trans-Neptunian Objects (TNOs), including dwarf planets such as Pluto, Haumea, and Eris, and hundreds of thousands of Kuiper Belt Objects, small rocky and icy bodies with a combined mass perhaps 10% of the Earth, not to mention comets and enigmatic objects such as the interstellar intruder Oumuamua. Together with Pluto, these objects have presented yet another major challenge for classification in astronomy (Dick, 2013; 2019), especially since Eris is believed to be slightly larger and more massive than Pluto. As it now stands, Pluto is simultaneously a dwarf planet, a TNO, and a KBO. If Pluto were a planet, then there would be many other planets, including Eris. Or if Pluto as a dwarf planet was considered a planet (which it officially is not), there would be many planets in the class of dwarf planets. Sheehan's last chapter nicely summarizes the Kuiper Belt, what Europeans like to call the Edgeworth-Kuiper Belt, but that's another story. It also surveys the discovery of the first exoplanets, and describes current theories of the migration of gas giant planets in our Solar System and others over time – all relevant to Neptune.

The book is primarily centered around the celestial mechanics theme, and one shortcoming for me is that little is said about the physical nature of Neptune, the "World Revealed" of the title, aside from a few pages in Sheehan's final chapter in the context of the 1989 Voyager 2 Grand Tour, still the only spacecraft to visit Neptune. Much remains unknown about the internal structure of Uranus and Neptune, but enough is inferred that astronomers now classify both as ice giants rather than gas giants. How and why Uranus and Neptune became classified as ice giants are among the many fascinating questions about their physical nature. Indeed, although the separation of the rocky inner planets from the giant outer planets dates back to the nineteenth century, the concept of *gas* giants only became commonplace at mid-twentieth century, size being much easier to determine than structure and composition. (The term "gas giants" was apparently first used by the science fiction writer James Blish in the 1952 version of his story "Solar Plexus"). Ice giants did not emerge as a new class of planet until the Voyager 2 spacecraft observations of 1986 and 1989 allowed close study of their structure and constituents (Dick, 2013; 2019). Ice giants are currently defined as planets whose outer constituents are made of elements heavier than hydrogen and helium—probably water, ammonia, and methane—and whose dense cores may dominate the gaseous component. The ice giants are also distinguished by their smaller masses, 14.5 and 17 Earth masses for Uranus and Neptune respectively, compared to 318 and 95 Earth masses for Jupiter and Saturn. The class derives its name because water, ammonia, and methane are considered 'ices' in the conditions under which they exist on Uranus and Neptune.

These are important issues but understandably they lie beyond the scope of the current volume, much as they would have fascinated the nineteenth century discoverers. Readers can turn elsewhere for the ongoing history of our knowledge of the physical nature of the outer planets. Springer's Historical & Cultural Astronomy series has once again published an important, well-produced, well-illustrated, and undeniably expensive volume. While the is not space here to do justice to its many themes, suffice to say this is a landmark volume in Neptune studies whose value goes well beyond the history of that singular planet.

### References


Batygin, K., and Brown, M.E., 2016. Evidence for a distant outer planet in the Solar System. *Astronomical Journal*, 151 (2), 1–12.

Dick, S.J., 2003. *Sky and Ocean Joined: The U.S. Naval Observatory, 1830–2000.* Cambridge, Cambridge University Press.

Dick, S.J., 2013. *Discovery and Classification in Astronomy: Controversy and Consensus.* Cambridge, Cambridge University Press.

Dick, S.J., 2019. *Classifying the Cosmos: How We Can Make Sense of the Celestial Landscape.* New York, Springer.

Harrington, R.S., 1988. The location of Planet X. *Astronomical Journal*, 96(4), 1476–1478.

Kowal, C.T., and Drake, S., 1980. Galileo's observations of Neptune. *Nature*, 287, 311–313.

Lequeux, J., 2013. *Le Verrier, Magnificent and Detestable Astronomer*. New York, Springer.

Reaves. G., 1994. The search for Planet X. In Putnam, W.L. et al. (eds.), *The Explorers of Mars Hill: A Century of History at Lowell Observatory*. Kennebunkport, Lowell Observatory. Pp. 172–188.

Standish, E.M., 1993. Planet X – no dynamical evidence in the optical observations. *Astronomical Journal*, 105 (5), 2000–2006.

Wooten, D., 2015. *The Invention of Science: A New History of the Scientific Revolution*. London, Penguin Random House.



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**_Einstein Was Right: The Science and History of Gravitational Waves_, edited by Jed Z. Buchwald. (Princeton, Princeton University, 2020). Pp. xi + 235. ISBN 978-0-691-19454-7 (hardback), 155 × 240 mm, US$35.**

If measured by its observational lifespan, gravitational wave astronomy is only six years old, the first gravity waves having been detected in 2015. That was a year before the putative centenary celebrations were planned in 2016, to mark Albert Einstein's first prediction of the existence of such waves in 1916. That the publisher wanted this to be a true centenary event is evident from the dust jacket, which appears to invoke a space-time fluctuation in its claim that Einstein predicted gravity waves in 1915, not 1916.

Jürgen Renn (Max Planck Institute for the History of Science, Berlin) pops the proverbial party balloon that was floated to celebrate the 100th anniversary of gravity waves when he writes

> ... it makes little sense to claim that the recent observations of gravitational waves due to the collision of black holes or neutron stars confirm Einstein's predictions from 1916 or 1918. (page 104).

Edited by Jed Buchwald (Professor of History at the California Institute of Technology) this is a celebratory (if not a centenary) book of high calibre. With ten authors, including Buchwald, this is not the usual hard-nosed physics effort. The book delves deeply into historical, sociological and philosophical areas, making it a fertile ground for historians of astronomy.

An overview chapter is offered by 2017 Nobel laureate Kip Thorne, who I first met at