Edwin Hubble and Cepheids: Clinching the Case for Galaxies and Remaking the Andromeda Nebula

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Resumen

El descubrimiento de Edwin Hubble de las estrellas variables cefeidas en la nebulosa de Andrómeda a finales de 1923 y 1924 se considera uno de los grandes descubrimientos de la astronomía del siglo XX. De acuerdo como se cuenta la historia, rápidamente el descubrimiento transformó nuestra galaxia, la Vía Láctea, en una de las innumerables galaxias que existen. En este artículo, sostengo que se deben interpretar los hallazgos de Hubble como una prueba fehaciente de la existencia de las espirales como galaxias, y que incluso el propio Hubble consideró que la detección de novas en 1917 en espirales, era posiblemente más significativa que sus cefeidas.

Palabras clave: *Edwin Hubble, V.M. Slipher,* galaxias, Galaxia de Andrómeda, variables Cepheidas

Abstract

Edwin Hubble's discovery of Cepheid variable stars in the Andromeda Nebula in late 1923 and 1924 is widely regarded as among the great discoveries of twentieth century astronomy. Quickly, so the story goes, the discovery transformed our Milky Way galaxy into one of a myriad of galaxies. I instead argue in this paper that it is better to interpret Hubble's finds as clinching the case for the spirals as galaxies, and that even Hubble himself regarded the detection of novae in spirals in 1917 as arguably more significant than his Cepheids.

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I. Introduction

On the 23rd of November 1924, the *New York Times* newspaper carried a story with the headline: "FINDS SPIRAL NEBULAE ARE STELLAR SYSTEMS. Dr. Hubbell [sic] Confirms View That They Are `Island Universes' Similar to Our Own.'" There followed a short account of how Dr. Hubble of the Carnegie Institution's Mount Wilson Observatory had discovered 36 Cepheid variable stars in two of the great spiral nebulae, the Andromeda Nebula and Messier 33. Then, by applying the relationship between a Cepheid's period and its intrinsic brightness, Hubble had secured distances to the two spiral nebulae of around 1,000,000 light years. Hubble's results had been made possible by Mount Wilson's "great telescopes," the 60-inch and 100-inch reflectors that were powerful enough to resolve "the outer portions of the nebulae into swarms of stars, which may be studied individually and compared with those in our own system (Anonymous, 1924)."

The Carnegie Institution of Washington was one of the leading institutions of American science in 1924, and Mount Wilson was just one of the research establishments made possible by its support. The Mount Wilson Solar Observatory (from the start of its life the Observatory was concerned with much more than studies of the Sun) had been founded in 1904, and the Carnegie Institution was always keen to advertise the findings of the Institution's scientists and the impetus for the *New York Times* story clearly came from the Carnegie.

A standard astronomy text-book story emerged that gave all of the credit to Hubble and the Cepheids, and it is one that press releases and news stories by the Carnegie have continued to underline to the present day. That is, Hubble's Cepheids were the key finds in proving that the spiral nebulae are "in reality distant stellar systems or `island universes'…." But we should note that the *New York Times*story refers to how Hubble's Cepheids had provided "confirmation" of the spiral nebulae as island universes. Further, Hubble himself, as we will see, reckoned that perhaps an even more important discovery in the shift to island universes had come a few years before he located his first Cepheid variable. It is undeniably dramatic to describe how "Overnight, the Milky Way had been demoted [by Hubble's Cepheids]. No longer the universe entire, it was just another among the many spiral galaxies and other nebulae that filled a vastly expanded universe" (Weintraub, 2011, p. 205), or to view the `Astronomy Picture of the Day' with the legend "Edwin Hubble Discovers the Universe"(Astronomy Picture of the Day, 2023), or to read a book entitled *The Day We Found the Universe*(Bartusiak, 2009).However, in this paper I will argue that it accords much better with the available evidence to see Hubble in 1923 and 1924, as I have argued elsewhere, as clinching the case for external galaxies,rather than making a completely unexpected discovery (Smith, 2009).

In this paper I will in part be summarizing and bringing together various points I and other scholars have made in different publications in order to provide a coherent account in a relatively short space of the `remaking' of spiral nebulae into external galaxies in the early twentieth century. I will therefore point to other works that provide fuller accounts of various issues that I can only touch on here.

II. Solar Systems in the Making?

The debates over the existence of external galaxies in the late nineteenth and early twentieth century centered on the nature of the spiral nebulae. William Parsons, the third Earl of Rosse, identified the first `spiral nebula'in 1845 by employing his giant 72-inch reflecting telescope, the Leviathan of Parsonstown. Some tens of other nebulae were judged in the next few decades to be spirals, and a few astronomers speculated that that our own Milky Way system too might exhibit a spiral pattern (Alexander, 1852).

The use of photography by astronomers in the late nineteenth century was widely regarded as having helped establish that spiral nebulae are relatively nearby objects, and certainly not distant systems of stars. Perhaps the most spectacular single image of a spiral in this period was secured by the amateur astronomer Isaac Robert. He employed his 20-inch reflecting telescope to photograph the Andromeda Nebula. When the photograph was exhibited at the Royal Astronomical Society in 1888, there were cries of "the Nebular Hypothesis made visible..." Roberts explained that those who accepted the nebular hypothesis—which argued that the stars and their systems of planets had formed out of swirling clouds of dust and gas--"will be tempted to appeal to the constitution of this nebula for confirmation, if not for demonstration, of the hypothesis" (Roberts, 1888, p. 65).Others agreed. For the leading astrophysicist William Huggins, "Roberts' photograph] reveals for the first time to the eye of man its true nature. A solar system in the course of evolution from a nebulous mass! It might be a diagram to illustrate the Nebular hypothesis!.... I never expected to see such a thing" (Huggins, 1888).

At the start of the twentieth century, for the overwhelming majority of astronomers, our Milky Way system is the only such star system visible in even the most powerful telescopes. Perhaps external galaxies did exist, but there was no convincing evidence they had been sighted. A small number of astronomers disagreed, but their opinions carried little weight with their colleagues. At the same time, it was, following the researches of James E. Keeler at the Lick Observatory in California, very widely agreed that there are vast numbers of spiral nebulae. Keeler estimated that around 120,000 nebulae were within reach of the Lick Observatory's 36-inch Crossley telescope, the vast majority of them spiral nebulae (Keeler, 1900, and Osterbrock, 1984).

Here it is worth pointing out that Keeler's researches marked an important moment in the development of astrophysics in the years around 1900. They "denoted the start of the very rapid rise to dominance of American astronomers in observational studies of the nebulae. As in the case of Keeler, the pivotal changes came through the efforts of individual astronomers who had mastered the craft of observing with big telescopes in combination with state-of-the-art photographic plates and spectrographs at good observing sites. Early twentieth-century astronomy was not a republic of science and relatively few astronomers had access to such formidable instrumental means, even in the U.S. (Smith, 2008, p. 100)."

A few astronomers investigated the spectra of the spirals. E.A. Fath, for his Ph.D. at Lick examined the spectra of seven spiral nebulae. He concluded in 1909 that their spectra are the product of light from star clusters, but Fath conceded that he needed accurate distances to the spirals to arrive at firm conclusions (Fath, 1909). At the same time as Fath was pursuing his researches, similar efforts were being made by V.M. Slipher at the Lowell Observatory in Arizona, but he had arrived at the spirals via the planet Mars.

One of the keenest students of the solar system in the late nineteenth century and early twentieth century was Percival Lowell. Lowell was not a professional scientist but rather one of the last `Independent Gentlemen of Science.' As such he employed his personal wealth to support his own solar system researches, as well as the operations of the Lowell Observatory he founded in 1894 in Flagstaff, Arizona, in the southwest of the United States. By the early twentieth century, Lowell had become infamous for his investigations of Mars, the surface of which he believed was crisscrossed by fine, straight lines. He explained these lines as evidence of vegetation running alongside canals engineered by Martians to carry water from the planet's poles to arid regions. While some astronomers agreed with Lowell's interpretation of Mars, many did not. But Lowell was interested in more than Mars, and he wanted to secure wide-ranging information on the solar system and its history. To this end, in 1906 he asked a member of the staff of the Lowell Observatory, V.M. Slipher, to attempt spectroscopic observations of spiral nebulae. Such observations, Lowell believed, would provide information on the history of the solar system. While astrophysicists had examined in detail the spectra of planetary nebulae and the brighter stars, they had not paid much attention to the spectra of the spiral nebulae. Slipher, concerned about the faintness of the spirals, was not hopeful that his observations would be successful.

By mid-1912, he had adapted his spectrograph so that instead of a Voigtlander f/14.2 camera lens, he was instead using an f/2.5 spectrograph camera lens. Slipher judged this change meant his spectrograph was now about 200 times faster than the three-prism instrument that he had initially employed and that clear spectra of spirals were now within reach.

Armed with his more effective spectrograph attached to the 24-inch refracting telescope of the Lowell Observatory, Slipher captured four superior quality plates of the Andromeda Nebula in the second half of 1912. Not only could Slipher detect absorption lines in the spectra, but he was also able to measure the Nebula's radial velocity by the shifts of the spectral lines. He thereby arrived at the remarkable result that the Andromeda Nebula was racing towards the Earth at around 300 kms per second (interpreting the shifts in the positions of the spectral lines as Doppler shifts). In 1912, no other astronomical object was known to move faster. Slipher announced his findings in a short paper in 1913 (Slipher, 1913). For Slipher at this time, "the Andromeda Nebula and similar spiral nebulae might consist of a central star enveloped and beclouded by fragmentary and disintegrated matter which shines by light supplied by the central sun. This conception is in keeping with spectrograms of the Andromeda Nebula made here and with Bohlin's value for its parallax [of 19 light years] (Slipher,1912, p. 55). Slipher, in line with the 1888 photograph of the Andromeda Nebula, interpreted it as a solar system-scale object.

After this success, Slipher pressed on with his researches, but the work advanced slowly. He found that to obtain useful plates of the spectra of the spirals required long exposures, often over several nights. By 1914 he had nevertheless collected radial velocities for fifteen spirals, most of which exhibited redshifts and so were presumably receding from the Earth. At this time, he still thought that a spiral shone by the light reflected by material that surrounded a central sun.[1]

Slipher's results, however, suggested a different interpretation to a few other astronomers. The now famous Danish astronomer Ejnar Hertzsprungarguedto Slipher in 1914 that the speeds of the spirals were so great that they could not be part of the Milky Way system. They had to be galaxiesoutside of our own stellar system.

Astronomers were thoroughly familiar with calculations of the solar motion, that is, the motion of the Sun with respect to the system of stars. Starting in 1915, a few astronomers began to calculate the motion of our stellar system with respect to the system of spiral nebulae, and in so doing took the spirals to be distant star systems. Slipher himself performed this calculation in 1917. He also announced that he now supported the island universe theory, that is, the theory' in which the universe contains a myriad of island universes or galaxies in modern terminology. It "has for a long time been suggested," Slipher noted, "that the spiral nebulae are stellar systems seen at great distances. This is the so-called island universe theory, which regards our stellar system and the Milky Way as a great spiral nebula which we see from within. This theory, it seems to me, gains favor in the present observations" (Slipher, 1917, p. 9).

In late 1916, the director of the Lick Observatory, W.W. Campbell, had delivered a lecture to the American Association for the Advancement of Science on "The Nebulae." In so doing, he represented what I have elsewhere called the `Lick School,' in which its members took a generally

1 On Slipher's spectrographic investigations see also Smith (2013) and Smith (1994).

skeptical attitude to newer developments in astrophysics together with support for the spirals as external galaxies. Along with other evidence that he drew on in his 1916 lecture, Campbell employed the radial velocities of the spirals and their spectra to argue that it was likely that the spirals are star systemsseparate from out Milky Way Galaxy (Campbell, 1917).

By 1917, then, there was significantly more support for the idea of the spirals as external galaxies than there had been a decade earlier. And 1917 saw astronomers acquire important new evidence to support this positon.

III. Novae in Spirals

The American astronomer H.D. Curtis was another member of the `Lick School.' After first training in Greek and Latin, he became a Professor of Latin and Greek at Napa College in California. While there he came across a small telescope and became fascinated by astronomy. This led to a career change, and he secured his Ph.D. in astronomy from the University of Virginia in 1902and then joined the Lick Observatory. There he became adept in the use of the Observatory's 36-inch Crossley reflector. With its aid, in 1917 Curtis found three objects that he suspected were dim novae in two spiral nebulae.

A bright nova had flared in the Andromeda Nebula in 1885 (the `nova' would later be classedas a supernova), and astronomers widely judged it as proving that the Nebula could not be an external star system. In 1890, the well-known astronomy writer Agnes Clerke invited her readers to consider if "... the Andromeda Nebula were a universe apart of the same real extent as the Galaxy, it should be situated, in order to reduce it to its present apparent dimensions, at a minimum distance of twenty-five galactic diameters. And a galactic diameter being estimated by the same authority at thirteen thousand light-years, it follows that, on the supposition in question, light would require 325,000 years to reach us from the nebula. The star then which suddenly shone out in the midst of it in August 1885 should have been at 564 times the distance inferred from its effective brightness. In real light it should have been equivalent to 318,000 stars like Regulus, or to nearly fifty million such suns as our own!" (Clerke, 1890 p. 368). How could a single star possibly reach such an extraordinary brightness? This result, in the opinion of Clerke and many others, was a reduction to absurdity that ruled out the Andromeda Nebula as an external galaxy. A decade later, astronomers detected another nova, Z Centauri (it too would now be classed as a supernova), in a spiral, NGC 5253, but it was found when it was declining in brightnessand did not prompt the intense interest of the Andromeda Nebula's 1885 nova.

In 1917, however, astronomers' interest in novae in spirals was sparked by Curtis's findings and a nova detected by the Mount Wilson astronomer and telescope designer and builder, George Ritchey. Ritchey, a highly skilled observer, was taking photographic plates of various spirals when in July 1917 he found a nova in the spiral NGC 6946. By that date, Curtis had already found his three novae, two in the spiral NGC 4321 and one in NGC 4527. Astronomers at the Lick Observatory and the Mount Wilson Observatory now went on the hunt among their collections of photographic plates for novae in spiral nebulae. More novae were soon identified. This evidence allowed Curtis to estimate the magnitudes near maximum light of these novae in spirals. By using the novae, he was now able to calculate the distances to the spirals by means of two mutually independent methods. But whichever method he used, the distances he estimated for the spirals that contained novae put them far outside our own stellar system. Here, in Curtis's view, was compelling evidence for the island universe theory (Hoskin, 1976).

Also in 1917, at Mount Wilson, the astronomer Harlow Shapley also used the spiral novae to estimate distances to the spirals. In a few years, Shapley would participate in the famous `Great Debate' of 1920, when he and Curtis debated `The Scale of the Universe.' Here Shapley had opposed the island universe theory. But in 1917, he *supported* the theory. As a result of the novae found in the Andromeda Nebula, Shapley calculated that the Nebula was about one million light years away, and so close to the answer Hubble would arrive at in 1924 (Shapley, 1917, p. 216).

There had been a major shift in astronomical thinking by late 1917 in fact. The theory's active supporters now "included such prominent astronomers as Eddington, Jeans, Campbell, Shapley, Curtis, Slipher, Hertzsprung, Crommelin, and the brilliant Willem de Sitter. There were many who wished to suspend judgement, but the only spirited and persistent public criticism came from [the British astronomer]J.H. Reynolds. He, however, was almost a lone figure trying to stem a rising tide of astronomical opinion (Smith, 1982, p. 44)."

IV. Van Maanen's Measurements

The debate on the status of the spirals at this period also involved the measurements of the motions of spiral nebulae by the Mount Wilson astronomer Adriaan van Maanen. These were widely accepted by astronomers to be the only strong pieces of evidence against the island universe interpretation of the spirals between about 1920, when van Mannen's results started to clash with theidea of island universes, and 1925, when astronomers generally decided the internal motions observed by van Maanen were spurious. Why, then, were these measurements significant in the island universe debate?

Van Maanen's approach consisted of comparing photographs of a spiral taken some years apart and checking for motions in the intervening period. Heanalyzed the motions of several spirals, and his results were consistent in indicating motions outward from the center and along the spiral arms of the nebulae. At the Great Debate in 1920, Shapley used van Maanen's measurements to argue against the spirals as island universes. A couple of years earlier, Shapley had advanced his theory of the `Big Galaxy,' that is, he contended our Milky Way Galaxy is 300,000 light years across, and so much larger than other astronomers allowed. If the spiral nebulae were indeed galaxies and about the same diameter as our own Galaxy, then the sizes of the motions measured by van Maanen indicated speeds greater than the velocity of light. For Shapley, this was an obviously impossible result, and so for him it was a reduction to absurdity. Shapley therefore argued the spirals could not be galaxies comparable in size to ourown Milky Way Galaxy (Smith,1982, pp. 105-11).

For some other astronomers like Curtis, van Mannen's observations were not credible. Curtis had attempted to measure the motions of spirals himself and so had experience of this line of study. He decided that van Maanen's motions could not "exist at all in the quantities he gives (Curtis, 1924)." Van Maanen, however, had a reputation as a skilled observer and he was an established astronomer at arguably the world's leading observatory. Some other astronomers therefore found it harder than Curtis to reject van Maanen's observations out of hand.

For astronomers concerned with the nature of the spiral nebulae, what, then, to do? One obvious approach was to obtain more photographic plates of the spirals and to search for more novaeand to use them as distance indicators. The more novae that could be found and their brightnesses measured, the better it would be for calculating the distances to the spirals. Curtis's own researches on the spiral nebulae had ended when he moved from the Lick Observatory to the Allegheny Observatory in 1921 to become its director. After he left, no one at Lick was much interested in photographing spiral nebulae with the Observatory's largest telescope, the 36-inch Crossley reflector. The field now was open for Edwin Hubble at the Mount Wilson Observatory.

Hubble had been invited to join the Mount Wilson staff in 1917 as he was completing a Ph.D. thesis at the Yerkes Observatory near Chicago on "Photographic Investigations of Faint Nebulae." After service in the United States Army (the U.S.had entered World War I in 1917), Hubble took up his position at Mount Wilson in 1919. That was the year that the 100-inch Hooker Telescope, the most powerful telescope in the world, went into operation, thereby providing Hubble with enormous aid in his studies of nebulae.[2]

Even as a graduate student completing his Ph.D. thesis at Yerkes, Hubble, influenced in particular by the high radial velocities of the spirals, had inclined towards the island universe theory. In 1922, he had also estimated the distance to the spiral M33 by comparing the brightnesses of four stars in an emission nebula in M33 with similar stars in an emission nebula in our Galaxy, and his answer was about 100,000 light years (Smith, 1982, p. 12). In the same year, 1922, Hubble discussing what astronomers then generally regardedas a spiral, the giant elliptical galaxy M87, reckoned that the star-like objects clustering around the nebula were best viewed as stars until they could be definitely shown not to be stars.The followingyear, Hubble commented on the report of a nova in M87 (regarded as the time as a giant spiral) and noted it had appeared on two plates taken with the 100-inch reflector at Mount Wilson. He pointed out that there is "a very marked tendency for exceedingly faint stars to cluster about the outskirts of the nebula…A possible analogy may be found in Messier 31, the great spiral in *Andromeda,* which has bright amorphous nebulosity about the nucleus but breaks up in the outer regions of thespiral arms into condensations which on plates made with the 100-inch reflector cannot be distinguished from star images" (Hubble, 1923, p. 263)

2 On Hubble, see, among others, Christianson (1995) and Hetherington (1996).

By 1923, then, Hubble regarded the outer regions of at least some spirals as composed of stars, or at least the images recorded were indistinguishable from star images.

Figure 1. Astronomy Picture of the Day for 6 October 2023.
Hubble's `discovery' plate for the first Cepheid in the Andromeda Nebula (courtesy of the Carnegie Institution for Science).

By this time, Hubble had embarked on a program to find novae in spiral nebulae. As a result of this program, in October 1923, Hubble recorded an object that he initially reckoned to be a nova. By February 1924, he had changed his mind. He had drawn a light curve for the `nova' and found it exhibited the characteristics of the behavior of a Cepheid variable star. Hubblewrote to Shapley, who by then had moved to the Harvard College Observatory, that "You will be interested to hear that I have found a Cepheid variable in the Andromeda nebula (M31)." Hubble explained that in the last five months he had "netted nine novae and two variables... The two variables were found last week...." In Hubble's opinion, the light curve of the first variable he had identified very clearly showed the characteristics of a Cepheid (Hubble, 1924).

Hubble was hard at work chasing more Cepheids and his success in this hunt led to the report in the *New York Times* in November 1924 that we discussed earlier. By late December 1924, in a paper for a meeting of the American Astronomical Society, Hubble had found 12 Cepheids in the Andromeda Nebula and 22 in M33 for which periods and photographic magnitudes had been determined. Hubble had told Shapley in February 1924 that he had calculated the distance to the Andromeda Nebula from the first Cepheid to be over 300,000 parsecs (978,000 light years) and in his American Astronomical Society report he gave the distance to M33 as 285,000 parsecs (930,000 light years) (Hubble, 1925).Here, clearly, were distances to the largest, and so presumably nearest, spirals that put them far outside of our own Galaxy, even if an astronomer regarded Shapley's estimate for the diameter of the Galaxy (300,000 light years) as reasonably accurate, and at this point relatively few astronomers did with many judging the Galaxy to be a lot smaller than Shapley's estimate. With a smaller Galaxy, the cases for the Andromeda Nebula and M33 as galaxies were even stronger.

We should also note that Hubble was not the first to find a variable star in a spiral. J.C. Duncan at Mount Wilson had detected three in M33 in 1920, and Max Wolf at Heidelberg in 1922 found another. But neither Duncan nor Wolf had identified their variables as Cepheids, despite Duncan using 17 photographic plates to track the brightness changes of his variables (Smith, 1982, p. 122).

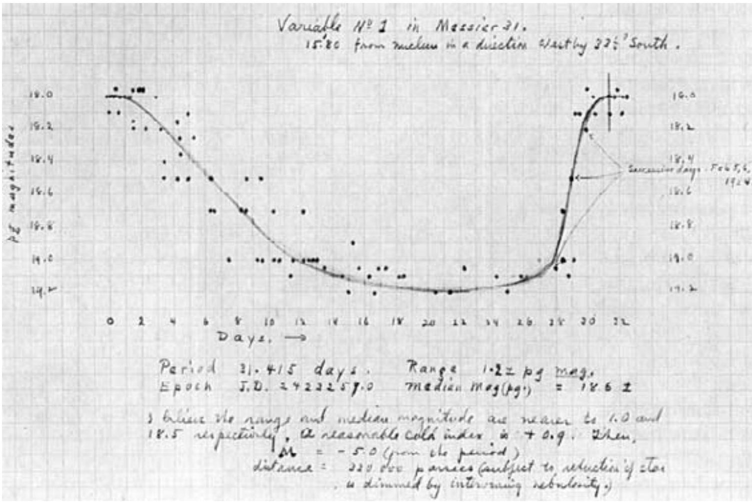

Figure 2. The light curve Hubble drew for the first Cepheid he found in the Andromeda Nebula (Courtesy of the Carnegie Institution for Science).

As Hubble found more Cepheids in more spirals and other astronomers corroborated his finds, astronomers swung behind the island universe theory. Van Maanen's results on the internal motions in spiral nebulae were the only pieces of noteworthy evidence against the spirals as external galaxies, but the testimony of the novae and the Cepheids carried far more weight for astronomers so that van Maanen's measurements were no longer taken seriously.

V. Conclusions

What, then, are we to make of Hubble and the Cepheids in the Andromeda Nebula? First, our journey from 1888 to the mid-1920s to examine the story of the spiral nebulae has often involved the Andromeda Nebula. As has frequently been the case in astronomy, discovery also meant transformation as we saw how the Andromeda Nebula was transformed from a solar system in the making into an external galaxy.

Second, it underlines the point that the notion of discovery in astronomy often involves a complex process that cannot be collapsed down to a single event at a particular point in space and at a particular time, and that discoveries often have a history in which their meaning and interpretation are not be stable over time, a point of course made some decades ago by Thomas Kuhn (Kuhn, 1962).[3] However, the approach often taken in astronomy textbooks and by contemporary science writers is to simplify and strip down discovery stories so that a single individual is identified as the discoverer, and the discoveries are tied to a single `Eureka Moment' of insight. This process has served to present Edwin Hubble and the Cepheids as the most significant moment in the acceptance of the island universe theory. The demands of `telling a powerful story,' however, have triumphed over historical accuracy.

Hubble himself argued that the novae found on photographic plates in 1917 were crucial. As Michael Hoskin pointed out some years ago (Hoskin, 1976, p. 48), in his *The Realm of the Nebulae,* Hubble suggested in 1936 that even when compared to his find of Cepheids in 1924 or the first measurement of the radial velocity of a spiral in 1912, the novae were "perhaps the most significant" because the discovery of "novae on photographic plates initiated the study of stars involved in nebulae. Stars were the clews [sic] which led to distances" (Hubble, 1936, p. 84). Hubble's reading of events was therefore more complicated than those textbook accounts that would follow. It is maybe not surprising that it largely dropped from sight, but we would be misreading a complicated process and doing a disservice to the many astronomers involved in the process of discovery that changed the spirals from solar systems into galaxies to ignore it.

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3 On the issue of discovery in modern history of astronomy, see also, among others, Kragh and Smith (2003), Dick (2015), Smith (2021) and Pelte (2024). Kragh and Smith (2003) analyse Kuhn's views ondiscovery and textbook accounts of the history of scienceas part of a broader discussion of what is meant by discovery with particular reference to the notion of the discovery of the expanding universe.

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