Kenneth Freeman
Bruce Elmegreen
David Block
Matthew Woolway *Editors*

Lessons from the Local Group

A Conference in honour of David Block and Bruce Elmegreen

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Cover Photo: Set within 120 hectares of land with luxuriant and rare vegetation in the Seychelles Archipelago, the Constance Ephelia Hotel was selected as the venue for the Block-Elmegreen Conference held in May 2014. Seen in our cover photograph are one of the restaurants frequented by delegates - the Corossol Restaurant. The restaurant is surrounded by pools of tranquil waters; lamps blaze forth before dinner, and their reflections in the surrounding waters are breathtaking. The color blue is everywhere: from the azure blue skies above, to the waters below. Above the Corossol Restaurant is placed a schematic of a spiral galaxy. From macrocosm to microcosm. Never before has an astronomy group of this size met in the Seychelles. The cover montage was especially designed for the Conference, by the IT-Department at the Constance Ephelia Hotel.

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Preface

The Block-Elmegreen conference (May 2014) celebrates the careers of David Block and Bruce Elmegreen. This year 2014 marks the 60th birthday year of David and the one millionth (base 2) birthday of Bruce. The island of Mahe in the Seychelles archipelago was selected for the meeting. About 50 astronomers from around the planet, many of whom are close collaborators and friends of David and Bruce, attended the conference and presented papers.

The venue for the conference was the Constance Ephelia Hotel. Its facilities are truly unsurpassed, from the conference venue itself to the exquisitely furnished suites and the five restaurants, each with a different theme, from Mediterranean to Chinese. The Gala Dinner was held on the beach at Port Launay. It is a pleasure to thank the entire staff at Constance Ephelia, especially Matthias, Harry and Lindy. We were privileged to have Dr. N. Shah, Chief Executive of Nature Seychelles, to speak to us one evening on conservation in the Seychelles.

The weather prospects for the week of the Conference did not look promising. Predicted was much rain—unusual for the month of May. The weather turned out to be perfect. It rained very hard in the midnight hours, but the mornings were truly beautiful. As Frank Shu once emphasized: "Make all the measurements you can, still no one can predict the weather seven days from now."

David's after-dinner talk on Hubble-Reynolds was attended by astronomers and their partners and appears first in this volume, as did the evening talk in the proceedings of the 2010 Namibia conference. David's talk generated much interest and much discussion during the week! The volume then presents the scientific papers in the same order as they were given at the conference. About 80 % of delegates provided written versions of their talks. A complete list of participants appears toward the end of this volume.

Our thanks go to the Munro family (David, Lil, Sophie, Grace and Tom) for their friendship and encouragement, and to NAMPAK for their corporate sponsorship. We are grateful to Marie-Lou Simaan at Mars Travel in Johannesburg for facilitating the Constance Ephelia Hotel arrangements.

It is a pleasure to acknowledge the support of the University of the Witwatersrand, Johannesburg throughout the organisation of the conference. We are grateful to the Vice-Chancellor Professor A. Habib, the Deputy Vice-Chancellor for Research Professor Z. Vilakazi and the Dean of the Faculty of Science Professor H. Marques for

their support and for their warm hospitality while we were editing the proceedings in Johannesburg. Our special thanks go to Professor Ebrahim Momoniat, Head of the School of Computational and Applied Mathematics at the University of the Witwatersrand, Johannesburg for his encouragement and for granting David the time to focus properly on the logistics for our conference.

We trust that the photographs of conference delegates, and of the conference environs, will bring back happy memories. These photographs (chosen at random) have been placed by the publisher just before the reference lists; they are not linked to the actual author(s) themselves.

Finally I would like to thank the Scientific Organizing Committee, the Local Organizing Committee, the chair persons and all delegates for making this conference so very memorable. Never before has an astronomy group of this size met in the Seychelles archipelago to celebrate the careers of two leading international researchers, David and Bruce!

Johannesburg, South Africa Ken Freeman, Chair, SOC

Editor Ken Freeman (centre) visited South Africa in June-July 2014, where he was hosted by Professor Adam Habib (right), Vice-Chancellor of the University of the Witwatersrand, Johannesburg. At left is David Block. Photo: Fidos Kleovoulou.

We have selected a woodcut initial above (the letter M), to denote the first letter in Milky Way, one of the most massive galaxies in The Local Group.

Geoffrey Chaucer in *The House of Fame*, c. 1380, penned these words:

> See yonder, lo, the Galaxyë
> Which men clepeth the Milky Wey,
> For hit is whyt.

A more modern rendition might be:

> Lift up your eyes; lo, see yonder the Galaxy,
> Which men call the Milky Way,
> Because it is white.

The exquisite foliated and floriated woodcut initials are almost 500 years old, and come from a volume printed by the legendary Jean Petit, in 1527.

Book Note

"Lessons from the Local Group"
The Block-Elmegreen Conference
May 18–May 24, 2014
Seychelles

1 Scientific Organizing Committee

Chair:
Ken Freeman (Australia)
Members:
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David Block (South Africa; Co-chair)
Francoise Combes (France)
Debra Elmegreen (USA)
Bruce Elmegreen (USA; Co-chair)
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Rob Kennicutt (UK)
John Kormendy (USA)
Martin Rees (UK)
Joe Silk (France)
Robert Smith (Canada)
Piet van der Kruit (Netherlands)

2 Local Organizing Committee (LOC)

Chair:
Ken Freeman (Australia)

Members:

David Block (South Africa)
Ebrahim Momoniat (South Africa)
Liz Block (South Africa)
Trevor Gould (South Africa)

LOC Secretariat:

Precious Shabalala

“MY evening came among the alien trees and spoke in a language which my morning stars did not know” (Nobel Laureate Rabindranath Tagore). Sunset at Port Launay, Seychelles. Photograph: Carme Gallart.

Contents

A Walk with Dr Allan Sandage—Changing the History of Galaxy Morphology, Forever

David L. Block and Ken C. Freeman

Abstract It was in 1926 that the most widely used galaxy classification scheme, known as the Hubble classification, was published in the Astrophysical Journal. The author was the American astronomer E. P. Hubble. Several years ago, Dr Allan Sandage took one of us (David) on a walk from his office, to the library at the Carnegie Observatories in Pasadena. What Dr Sandage showed David, left him speechless.

1 Editorial Note

The oral version was presented at the Seychelles Conference, as a lecture after dinner. It was open to astronomers and their partners. The Editors have decided to retain the same (non-technical) level for the printed version of the lecture. We remain deeply grateful to Springer for permission to publish large excerpts from our book "Shrouds of the Night" by Block and Freeman (2008).

2 The Years 1920 and 1926

It was in 1926 that the most widely used galaxy classification scheme, known as the Hubble classification, was published in the Astrophysical Journal. The author was the American astronomer E. P. Hubble. Several years ago, Dr Allan Sandage took one of us (David) on a walk from his office to the library at the Carnegie Observatories in Pasadena. What Dr Sandage held in his hands, left one speechless. It exposed Hubble's strategy, masterfully executed by him over a grand numbers of

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years. Hubble calmly failed to acknowledge the sources of his data and/or of his ideas.

In 1920, Hubble published his PhD thesis entitled "Photographic Investigations of Faint Nebulae"—in it, he never developed a classification of his own, but rather made use of a classification by Max Wolf. Plate III of his thesis is entitled: 'Wolf's Classes of Nebulae.'

In the very same year (1920) in which Hubble published his PhD thesis, an unknown "starry messenger" in Britain had devised a morphological scheme of his own . . . But did Hubble ever write a letter to that astronomer, asking him to actually develop a galaxy scheme, prior to 1926? The letterhead in Figs. 1 and 2 is the Randolph Hotel, Oxford, written during one of Hubble's visits to England. We read in Hubble's hand:

"Classification of Spirals. All suggestions on this difficult subject, coming from one of your expertise are extremely welcomed . . . Could you not throw your ideas into the form of a precise classification so we could actually apply it to a large number of nebulae representing the various sizes and degrees of brightness with which we will be dealing? These are only passing thoughts which I offer. The great thing is that the discussion is started. This will eventually lead to something acceptable to us all. Sincerely, Edwin Hubble." (italics, ours)

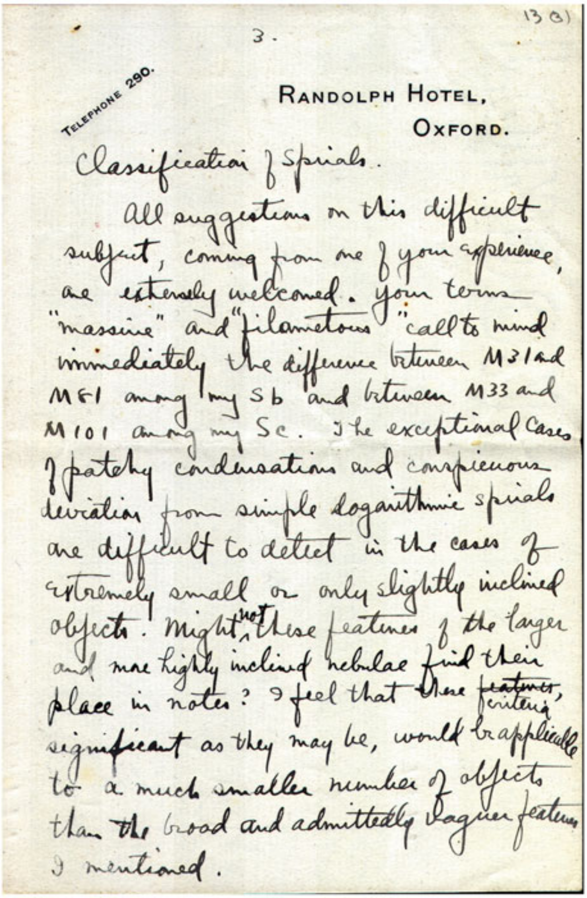
Everyone knows that, in 1926, Hubble recognized three principal form families, and placed galaxies into one of three principal classes: there were elliptical galaxies, spiral galaxies and those with a rather chaotic optical appearance, known as irregular galaxies. Spiral galaxies themselves were separated into two separate families, the normal spirals and those with a central elongated feature, the barred spirals.

Sir John Herschel, working at the Cape of Good Hope (1834–1838), identified spiral structure in the Large Magellanic Cloud as well as a central bar. Sir John used rich imagery—an axis of light—to describe *the bar* which he *visually* discerned in that object.

We are most grateful to astronomer David Malin for drawing our attention to the following quote by Sir John Herschel:

"To the naked eye the greater nubecula (the Large Magellanic Cloud) exhibits the appearance of an *axis of light* (very ill-defined indeed, and by no means strongly distinguished from the general mass) which seems to open out at its extremities into somewhat oval sweeps" (italics, ours).

The recognition of a bar in photographs of spiral galaxies belongs to Heber D. Curtis. Curtis had recognized a class of spirals called the phi-type spirals, but Hubble later suggested that the Greek letter theta better represented this form. The Curtis phi-class was fully recognized in Hubble's final classification system, but Hubble used the terminology of barred spirals instead. Full credit must be given to the great observer Heber Curtis, for being the first astronomer to recognize bars in spiral galaxies. Normal and barred spirals were grouped into three principal morphological classes, of types a, b and c. Hubble used the prefix S for normal spirals and SB for barred spirals. From the multitudes of shapes and forms of galaxies presented on photographic plates, it became relatively simple to speak of three classes for normal spirals (Sa, Sb and Sc) and three types of barred spiral galaxies (SBa, SBb, SBc).



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TELEPHONE 290.

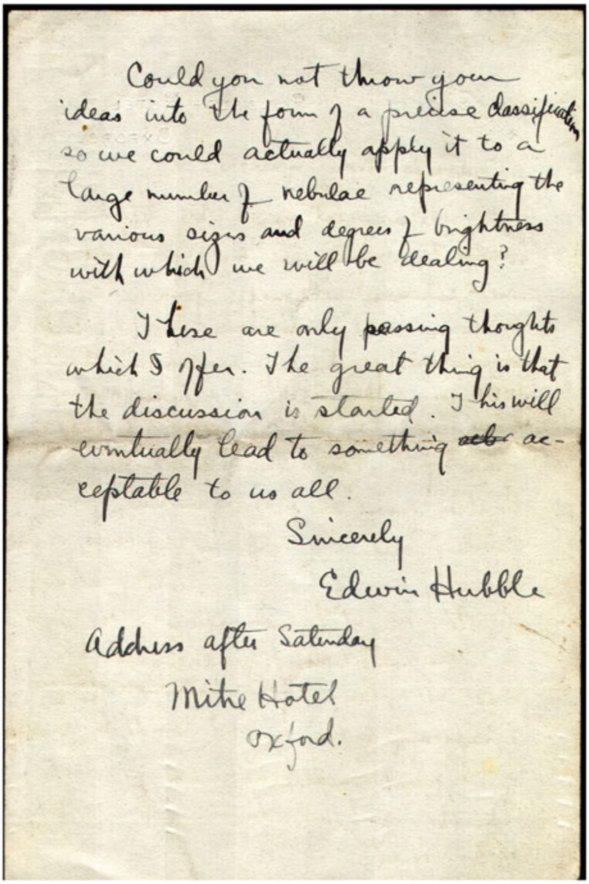
RANDOLPH HOTEL,
OXFORD.

Classification of Spirals.

All suggestions on this difficult subject, coming from one of your experience, are extremely welcomed. Your terms "massive" and "filamentous" call to mind immediately the difference between M31 and M81 among my Sb and between M33 and M101 among my Sc. The exceptional cases of patchy condensations and conspicuous deviation from simple logarithmic spirals are difficult to detect in the cases of extremely small or only slightly inclined objects. Might not these features of the larger and more highly inclined nebulae find their place in notes? I feel that these ~~features~~ criteria, significant as they may be, would be applicable to a much smaller number of objects than the broad and admittedly vaguer features I mentioned.

Fig. 1 The first page of a handwritten letter by Edwin Hubble to master morphologist Mr John Henry Reynolds in Britain. (From the archives of the Royal Astronomical Society of London)

The classification criteria for the Hubble system are threefold: firstly, the size of the central bulge compared to the flattened disk; secondly, the degree of openness or tightness of the spiral arms, and finally, the degree to which the eye can discern newly-born stars contained in clouds of ionized hydrogen gas. In general, Sa galaxies have large bulges, tightly wound spiral arms which are relatively smooth. In contrast, the bulges of Sc galaxies are invariably much smaller or even minute, as to appear point-like as a star ("semi-stellar"); Sc galaxies spawn wide open spiral arm patterns, knotted with newly born stars flooding their environs with energetic ultraviolet photons of light. Galaxies of type a were spoken of by Hubble as "early-type"; those of type c, "late-type".



Could you not throw your ideas into the form of a precise classification so we could actually apply it to a large number of nebulae representing the various sizes and degrees of brightness with which we will be dealing?

These are only passing thoughts which I offer. The great thing is that the discussion is started. This will eventually lead to something acceptable to us all.

Sincerely
Edwin Hubble

Address after Saturday
Mitre Hotel
Oxford.

Fig. 2 The second page of a handwritten letter by Edwin Hubble to Mr John Henry Reynolds. The first sentence at top reads: " Could you not throw your ideas into the form of a precise classification so we could actually apply it to a large number of nebulae . . .?" (From the archives of the Royal Astronomical Society of London)

3 On the Detective Trail

We followed some intriguing historical leads, by traveling to the United States and to the United Kingdom, and our findings below are based on our detailed readings of archival material at the Lowell Observatory in Arizona and the Royal Astronomical Society's archives at Burlington House in London.

The history of the International Astronomical Union's Commission on Nebulae and Star Clusters (Commission Number 28) spanning the period 1922–1925 is particularly rich and archival material is on file both in Arizona and London. Slipher, then acting director at Lowell Observatory, was the president of the Commission during those years. Commission members were the first to have an opportunity to study and react to Hubble's studies on the nebulae and their shapes. In the period 1922–1925, Commission 28 members included Slipher, Hubble, Curtis, W. H. Wright (Lick Observatory), S. I. Bailey (Harvard College Observatory), the venerable Irish astronomer J. L. E. Dreyer and France's G. Bigourdan, the Commission's first president from 1919 to 1922. Also on the Commission was England's Mr J. H. Reynolds.

Herein lies a truly riveting story, in its own right.

The membership of the Commission clearly reads like a who's-who, containing the names of some truly great and pioneering astronomers. But Mr. Reynolds (1874–1949) was not an astronomer by profession, at all. Here was someone whose official occupation lay completely outside the scientific arena. He was the son of a subsequent Lord Mayor of Birmingham, whose company was a major producer and supplier of metal products in Birmingham. The company John Reynolds & Sons (Birmingham) Ltd was famous for its production of cut-nails (as opposed to hand-forged nails).

We conducted a fascinating telephone interview with Mr. Dennis Stamps, a retired director of John Reynolds & Sons, who together with his wife has a considerable knowledge of the Reynolds family history. Mr. Stamps recalls that the production of nails then was an enormously labour intensive process; cut nail factories employed operators and attendants for each machine, and the noise in those factories was deafening. The production of nails was a practice not restricted to only the lower classes. In fact, Thomas Jefferson (President of the United States in the period 1801-1809) was proud of his hand made nails. In a letter he once said: "In our private pursuits it is a great advantage that every honest employment is deemed honorable. I am myself a nail maker." From president downwards, nail making in those days was an very important facet of life. In fact, Jefferson was among the first to purchase the newly invented nail-cutting machine in 1796 and to produce nails for sale. In pre-1850 America, nails were exceedingly scarce; it is said that people would burn old buildings to sift through the ashes for nails. John Reynolds, born in 1874, clearly had a great financial enterprise at hand from his father's company in England which produced cut nails in enormous numbers. Cut nails dominated the marketplace from about 1820 until 1910, signaling the advent of the modern wire nail.

John Reynolds (Fig. 3) became a highly successful and wealthy industrialist. Reynolds purchased a 30-in mirror made by astronomer Andrew Ainslie Common for the sum of 80 £, and he was instrumental in the design of a 30-in reflector telescope which subsequently was transported to Helwan in Egypt. It was the first large telescope to study objects lying well into the southern skies. The 30-in Reynolds reflector at Helwan saw 'first light' in the year 1907, when the first photographs from that telescope were secured.

In the interim, John Reynolds decided to erect his own observatory at Harborne, by making a mirror of 28-in diameter with his own hands. No mean feat—a mammoth task indeed, for any amateur astronomer today! The telescope at his home "Low Wood" was obviously cumbersome to use, with Reynolds having to work from a heavy observing platform at the upper Newtonian focus of the tube. The 30-in Common mirror at the Helwan Observatory was eventually upgraded and replaced, and the Common mirror made its way back from Helwan to Birmingham. Reynolds decided to replace his 28-in mirror with the slightly larger mirror made by Andrew Common.

Reynolds was a man with a very generous spirit, and when light pollution in Birmingham became increasingly problematic, he decided to donate the instrument

Fig. 3 The starry messenger from Birmingham, the amateur astronomer Mr John Henry Reynolds, who rose to position of President of the Royal Astronomical Society of London. Mr Reynolds was approached by Edwin Hubble to throw his ideas into developing a galaxy classification system, which Reynolds published in 1920. Hubble studied that paper by Reynolds meticulously, and wrote annotations in the margin, including ‘Sa, Sb and Sc’ alongside the classification bins of Reynolds. Reynolds was without equal: undoubtedly one of the world’s most profound thinkers regarding the classification of nebulae (galaxies). (From the archives of the Royal Astronomical Society of London)

to the Commonwealth Solar Observatory—later to become the Mount Stromlo and Siding Spring Observatories in Canberra, Australia. A steel dome of diameter 26-ft was constructed to house the telescope and until the 1950s, this telescope was one of the largest operational telescopes in the Southern Hemisphere.

Here follow some personal reflections by one of us (Ken) upon using the Reynolds telescope to secure photographs:

“The Reynolds telescope was refurbished in 1971 and emerged as a modern instrument. But when I arrived at Mount Stromlo in 1967, the telescope was still in its original state. The photographic camera at the Newtonian focus, situated at the top of the telescope tube, was just as it was in the 1950’s when Gerard de Vaucouleurs made his pioneering observations of southern galaxies. I used the camera to take photographs of nearby galaxies in order to measure profiles of their brightness”.

Determining the brightness of features on photographic plates is a rather messy and imprecise art. The efficiency with which the older emulsions on photographic glass plates stored photons was not high and we had to soak the plates of glass in nitrogen gas to increase their sensitivity. Even with the relatively fast f/4 focal ratio of the Newtonian focus, long exposure times were needed to acquire photographs with a good tonal range.

After the photographic plate was exposed and carefully developed by hand, the distribution of densities of light within the galaxy image could be measured using an instrument known as a microdensitometer, and it was at that point that the real analysis began.

It is fitting to remember that the man after whom the telescope is named "John Reynolds" had conducted his pioneering measurements of light profiles from photographic plates way back in 1913, using essentially the same telescope configuration at his "Low Wood" observatory, before that telescope was donated to Mt. Stromlo.

Acquiring a good photograph was an adventure. Those were eyeball days. Some words of clarification. In today's modern era, astronomers track stars as the earth rotates, by means of autoguiders. An autoguider can keep a telescope locked on to a bright star for hours.

Not so easy, guiding the telescope by eye.

To access the camera at the top end of the Reynolds telescope, the observer was perched on a rickety 2-m wooden stepladder which the observer had to drag around the dome as the telescope tracked across the sky. The camera itself comprised a microscope and photographic plate-holder mounted on a structure that could be moved in two directions.

The observer first pointed the telescope at a desired galaxy and then moved the microscope around to find a guide star (in other words, a star which the telescope would remain fixed on, as the earth rotates). Then the exposure would begin.

The telescope mechanism was far from perfect and constant adjustment was essential. For two or three hours, the observer would keep an eye glued to the microscope and both hands on the adjustment screws that moved the plate holder. If the guide star drifted as the telescope tracked across the sky, the observer moved the plate holder to keep the star central in the microscope. Each hour, the observer had to close the shutter, climb down from the ladder and manually rewind the main gear drive. The goal of every observation was to produce a guided photograph of the galaxy with perfectly round stellar images.

Each exposure was a battle between the observer and the old worn-out telescope gears, with the observer visually guiding the plateholder through the microscope, as the telescope tracked erratically across the sky.

Although the photographic process was notoriously unpredictable, an amazing amount of semi-quantitative astronomy was accomplished. There were some failures but everything mostly worked out well. We all had to develop photographic skills, because we had no other panoramic detectors until the early 1980s when the first of the digital charge coupled devices (CCDs) became available.

Data acquisition and analysis then became much easier and a new era of quantitative astronomy began. I was not sorry to see the end of photography in astronomy, although I know my co-author David deeply feels otherwise!"

John Hart, Head of the Opto-Mechanical Engineering Section at the Mount Stromlo Observatory, recalls that the Reynolds telescope "was very antiquated with decorative holes in a spherically shaped counterweight at the back of the mirror cell. We replaced many parts (during 1969 –1971) and re-machined the base and the centre section of the tube. Design and construction progressed in parallel. The existing mirror was fitted into a new mirror cell. I was a very new engineer at the time and was overawed by the responsibility of the job, which took a couple of years in total. I was in charge of the entire refurbishment. I was the only designer and had about six laboratory craftsmen in the workshop. Among the astronomers I met who used the

Reynolds telescope were Gerry Kron, Ben Gascoigne and Allan Sandage. Sandage only used the Reynolds telescope a couple of times but seemed very happy with it."

In his later years, Ben Gascoigne reminded us that he was allocated nine months of observing time on the 30-in Reynolds telescope in the early 1950s. He recalled his chilly experiences as follows:

"Time was when you worked alone, the telescope all to yourself, in the total dark, and in winter-time slowly freezing to death. But no matter how cold it had been, how difficult, or how successful for that matter, it always ended, dawn came along and you walked home, the sky all pink in the east, the birds tuning up for the day ahead, and just for a little while the world belonged to you. Nothing else I have known was quite like it, and only astronomers have experienced it."

The Reynolds telescope was used by some of the world's foremost galaxy experts of the era, including the late Gerard de Vaucouleurs. Between 1952 and 1955, de Vaucouleurs secured about 250 1-hour exposures of galaxies in the southern skies from Mt. Stromlo. The generosity of John Reynolds was indirectly crucial to the development of the galaxy classification criteria developed by Gerard de Vaucouleurs, as is clearly evident in *Memoirs of the Commonwealth Observatory* No. 13, published in July 1956.

The seeds of the de Vaucouleurs classification system were clearly born, in part, using the scores of galaxy photographs which Gerard de Vaucouleurs painstakingly secured in Canberra with the 30-inch Reynolds reflecting telescope.

4 Hubble and Reynolds: A Timeline

Reynolds was an individual with enormous vision, and Hubble recognized this. It would be no over-statement to say he was England's foremost observational expert on the morphology of the nebulae, but the letters between Hubble and Reynolds have (for decades) been in the archives.

Here is a timeline:

1920: Hubble publishes his PhD thesis.

1920: Hubble has not devised a classification scheme of his own.

1920: Mr John Reynolds publishes his classification.

Hubble's actual letter from Oxford (Figs. 1 and 2) is undated, but we know that Mr. Reynolds rose to the occasion in 1920. Six years prior to Hubble publishing his classification scheme in 1926, Reynolds devised seven bins or classes pertaining to the shapes of galaxies, which was published in volume 80 of the Monthly Notices of the Royal Astronomical Society.

Of these Reynolds classes, Sandage comments:

> Reynolds types I through VII are clearly identical with the Hubble spiral types Sa, Sb, early Sc, and later Sc. The correspondence is one-to-one.

Sandage recognizes that while Hubble has three spiral types a, b and c, the type c bin spans a wide range of shapes, which Reynolds had taken full cognizance of, by proposing his classes I to VII.

The question before us is therefore, was Hubble aware of the classification scheme devised by Mr. Reynolds in 1920, prior to publishing his seminal classification paper in 1926? The answer is a resounding—yes!

In the Reynolds archives housed at the Royal Astronomical Society, Burlington House, we found a copy of a memo from Hubble, dated July 1923, sent to Vesto Slipher as president of Commission 28. Slipher distributed the memo to members of the Commission. The front page of the memo contains the signature of J. H. Reynolds. In that unpublished memo, entitled "The Classification of Nebulae", Hubble writes to Slipher:

> The published suggestions of J. H. Reynolds are thoroughly sound . . . Reynolds introduced the term amorphous, emphasizing the unresolvable character of much of the nebulosity in non-galactic objects . . . Reynolds (ref. 17) has formulated seven classes of true spirals . . . the first five classes represent a series with increasing degree of condensation in the amorphous matrix of the outer arms.

Reference 17 in Hubble's 1923 memo is none other than the paper of Reynolds, contained in volume 80 of the Monthly Notices of the Royal Astronomical Society. It is abundantly clear that Hubble was fully aware of, and had very carefully studied, the classification scheme of Reynolds proposed in 1920. Although fully referenced in the 1923 memo to Slipher, Hubble moves on to publish his 1926 classification without *any reference* to the source of his classification bins—the classes of Mr J. H. Reynolds.

5 Partial Erasing Is Dangerous

Our conclusions are corroborated by a remarkable historical discovery made by Dr Allan Sandage in Pasadena:

> Remarkably, in the bound Volume 80 of the Monthly Notices that is in the Mount Wilson Observatory library in Pasadena, there are penciled notes in Hubble's handwriting in the margin of page 746 of the 1920 Reynolds paper placed beside the descriptions by Reynolds of his binning classes. Next to each of Reynolds class II, III and IV are the Sa, Sb and Sc notations penciled in by Hubble. Also in the margin is a penciled paragraph of notes. However, much of what is there has been erased, so that although one cannot read the notes, Hubble's Sa, Sb and Sc notations are there. (italics, ours).

While these penciled notes are undated, the 1923 memo by Hubble (a copy of which was sent to Reynolds and which was signed by Reynolds) lays to rest a historical uncertainty unanswered up to the present time— we can definitively say that Hubble had carefully read the Reynolds (1920) paper prior to writing his seminal 1926 work.

It remains a total mystery as to why Hubble makes no mention of the Reynolds classes in his preliminary classification discussion in 1922 or in his definitive 1926 paper; how amazing, in hindsight, to study the handwritten request of Hubble to Reynolds, to "throw your ideas into the form of a precise classification" . . .

The kernel of the system by which astronomers continue to optically classify galaxies today was conceived in the mind of one of Britain's most gifted amateur *astronomers—a man without any formal astronomical training—the great Mr. J. H. Reynolds of Birmingham.*

To be immortalized in the minds of students of astronomy, Hubble needed a diagram to depict his classification classes, but in 1926 he did not have one.

6 Hubble Without a Tuning Fork

As explained by Allan Sandage:

"In the dry academic language of formal science, and with so few working extragalactic astronomers at the time (perhaps only 20 worldwide), without such a diagram there was the danger that the classification system, buried in the language of the Astrophysical Journal, might lay fallow. Why did the diagram become so overwhelmingly important? Despite the excellence of Hubble's 1926 word descriptions of the classification, the diagram is much easier to understand and to remember. It became the visual mnemonic. Indeed, we all learned to classify from it. Only later did we read the verbal descriptions in the 1926 fundamental paper. That was true in my generation. It is true now."

Hubble (1926) has no tuning fork diagram—from whence its origin? The British mathematical-physicist Sir James Jeans (1877–1946), one of the great popularisers of science of his time and a prolific author of popular books, such as "The Universe around Us" (1929), "The Mysterious Universe" (1930) and "The Growth of Physical Science" (1947), came to the rescue. To unravel the interplay between the works of Hubble and of Jeans, we purchased Jeans' books "Astronomy and Cosmogony" as well as "Science and Music." Jeans loved music, and he presented the first tuning fork diagram in 1929 (Fig. 4), seven 7 years before 'Realm of the Nebulae' appeared in print. In chapter XIII of "Astronomy and Cosmogony", Jeans argues that a Y-shaped diagram would be appropriate to graphically represent the classifications suggested by Hubble in 1926.

Hubble publishes the Jeans fork in "The Realm of the Nebulae" in 1936, without any reference to the top panel in Fig. 4.

Hubble very carefully "failed" to acknowledge two of his pivotal sources (Reynolds—Fig. 1—and the schematic by Jeans—Fig. 4) which now bear the name of the Hubble classification and the Hubble tuning fork. As agreed by Allan Sandage, the graphical representation of the Hubble tuning fork must be attributed to Sir James Jeans—a scientist who adored music, and who wrote a famous book "Science and Music", as noted above.

On April 22 1928, Curtis decided to bow-out. He wrote to Slipher:

"My own views as to any nebular classification are so at variance with those of many others who are now more actively engaged in actual work in this field that I think you had better simply 'count me out', and put it down, one member of the Committee dissenting, or something like that." A request to step out of the competition, from the very person who first recognized the bar phenomenon in his phi-type galaxy. In the mind of Hubble, he was the Emperor and custodian of morphological astronomy.

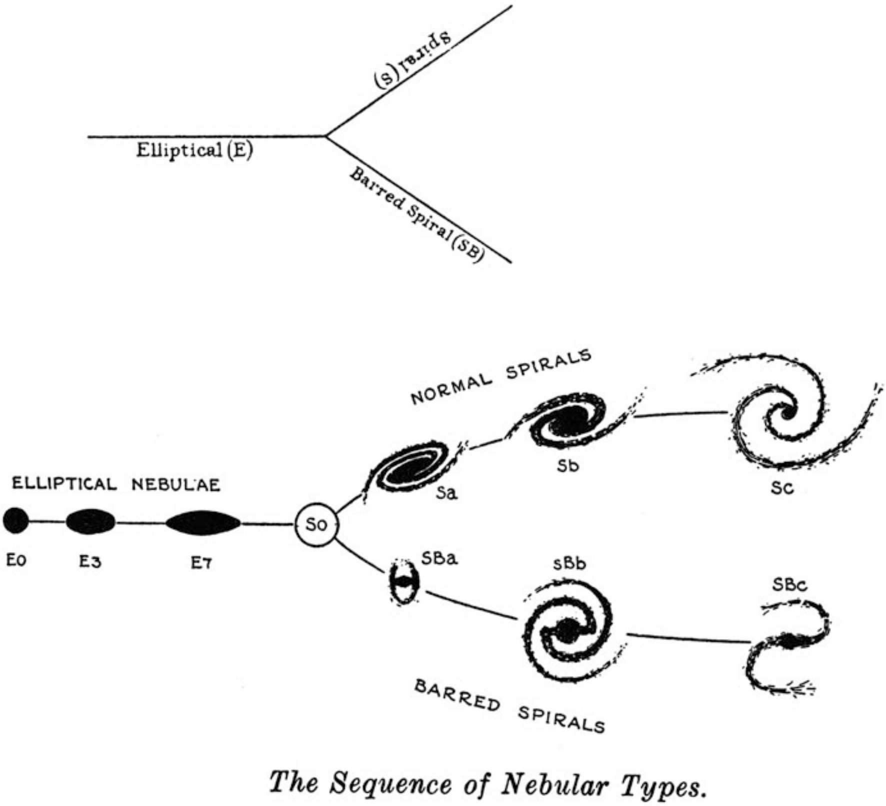


Fig. 4 At top is the tuning fork of Sir James Jeans (1929), rotated by ninety degrees. In 1936, Hubble used the Jeans fork in his book "Realm of the Nebulae"—as illustrated in the lower schematic. Hubble provides no reference to the upper Y-shaped diagram first drawn by Jeans in 1929.

Others, such as Knut Lundmark, presented similar (but not identical) classification schemes, but these were not published in the main-stream journals, and Hubble closely guarded his morphological terrain, *very* closely.

Sandage elaborates:

"[Hubble] guarded its priority in a revealing footnote in part I of his 1926 paper. There he comments on a classification system proposed at about the same time by Lundmark (1926, 1927). Some of Hubble's complaints, which he rarely made public, were unfounded, showing a sensitivity he generally kept hidden. Some of Hubble's accusations are addressed in a partially justifiably acerbic reply by Lundmark (1927), also in a footnote, in Lundmark's near great but largely neglected paper."

A portion of Lundmark's reply, contained in his 'Studies of Anagalactic Nebulae' presented to the Royal Society of Science of Uppsala on May 6, 1927, reads as follows:

"In his paper, E. P. Hubble makes an attack on me which is written in such a tone that I hesitate to give any answer at all . . . I was not then a member of the Commission of Nebulae. I did not have any access whatsoever to the memorandum or to other writings of E. P. Hubble ... Hubble's statement that my classification except for nomenclature is practically identical with the one submitted by him is not correct. Hubble classifies his subgroups according to eccentricity [sic] or form of the spirals or degree of development while I use the degree of concentration towards the centre ... As to the three main groups, elliptical, spiral and magellanic nebulae it may be of interest to note that the two first are slightly older than Hubble and myself. The term elliptical nebulae thus is used by Alexander in 1852 and the term spiral by Rosse in 1845. The importance of the magellanic group has been pointed out by myself [Observatory, volume 47, page 277, 1924] earlier than by Hubble. As to Hubble's way of acknowledging his predecessors I have no reason to enter upon this question here."

Hubble was deeply inspired by the work of Reynolds. We have already discussed one of these at length: the Reynolds classification classes for spiral galaxies, published in 1920.

7 Hubble's Strategy Exposed by Lundmark

Let us stress the kernel of our detective trail, by highlighting one sentence above:

"As to Hubble's way of acknowledging his predecessors I have no reason to enter upon this question here."

The strategy repeats itself below ...

8 The Reynolds Luminosity Profile

A second story ...

In 1913, Mr. Reynolds pioneered the measurement of the profiles of light across the bulges of spiral galaxies, beginning his investigation with the Andromeda Spiral Galaxy.

Reynolds had secured photographs of the Andromeda Galaxy with his 28-inch reflector at 'Low Wood' in October 1912, and then measured the profile of light across its highly prominent bulge.

Using an instrument known as a photomicrometer, supplied by Toepfer of Potsdam, Reynolds found that the light brightness decayed from the centre, outward. Sandage calls this "the famous Reynolds profile" and notes that "Hubble (1930) later generalized [it] by making it scale free [dimensionless]." Today astronomers speak only of the Hubble luminosity profile—but why not the Reynolds (or, at least, the Reynolds-Hubble) luminosity profile? After all, it was Mr. John Reynolds who pioneered that work in 1913. In this regard, Allan Sandage was most emphatic to one of us (David), during a telephonic discussion: the *Hubble luminosity profile* should be called the *Reynolds' luminosity profile*.

Hubble to Reynolds:

"I find myself thinking along with you and *constantly following up suggestions which arise from your papers* . . . I brought along . . . a paper, ready for publication, on the distribution of luminosity in the images of non-galactic nebulae . . . This last follows up *your pioneer work on the Andromeda and other spirals* . . ." (Italics, ours). Constantly following up suggestions from the papers of Reynolds? No sense of precisely how fundamental Reynolds was to Hubble in "The Realm of the Nebulae", where the source of the luminosity profile (Reynolds 1913) is not referenced.

Mr. Reynolds was elected a Fellow of the Royal Astronomical Society of London in 1899 (at age 25), served as Treasurer in 1929–1935 and President during the period 1935–1937. Mr. Reynolds is one of the only persons ever to rise to the rank of President of the Royal Astronomical Society, whose official occupation was not an astronomer. Reynolds was among the last of the great amateur scientists. His technical skills in using photographic plates for quantitative intensity measurements were unsurpassed for the time and his vision has influenced generations.

In popular astronomical textbooks, we only read of the *Hubble* classification classes, the *Hubble* tuning fork and the *Hubble* luminosity profile for elliptical galaxies.

Behind the stage loomed the giant Mr. Reynolds, a man whose name is almost unknown to students of astronomy.

As fundamental as the Hertzsprung-Russell diagram is to stellar astronomy, so the "Hubble" tuning-fork has become a Rosetta stone in the classification of galaxies.

Astronomy textbooks will not change; the *Hubble classification scheme* and the *Hubble tuning fork* will continue to be taught to students worldwide; but may it be a source of much inspiration to younger readers that some of the grandest of ideas in the area of galaxy morphology did not spring forth from a professional astronomer trained at one of the world's prestigious Universities, but rather from the mind of Mr. John Henry Reynolds —a student of the heavens above—a gifted amateur who simply was passionate about the wonders to behold in the Night Sky, and who devoted a large sector of his energies and finances to spearheading new cosmic horizons.

Were Reynolds and Jeans the only astronomers to be sidelined (not referenced) by Hubble? No. Two immediate names spring to mind: Vesto Slipher and Georges Lemaître. Glaringly absent in Hubble (1929) are all references as to where Hubble sourced almost all of his radial velocity data: from V.M. Slipher of Lowell. For the 22 velocities in Hubble (1929), he gives references for only four of them (NGC 6822, 221, 224, 5457) which Hubble credits to his assistant Humason. What about the source for the majority of 18?

Slipher's name: buried in the sands of time, by Hubble (1929). The strategy of Hubble had succeeded in a scintillating fashion, yet again.

It of course was Lemaître who first determined the rate of expansion of the universe (e.g., Kragh and Smith 2003), two years prior to Hubble (1929); see Fig. 5. Could it perhaps be true, that Hubble never knew about Lemaître's paper (published in French) prior to "The Realm of the Nebulae" in 1936? We have in our possession a book "The Expanding Universe" (published in 1933) authored by Sir Arthur Eddington – and which is inscribed by Hubble himself (Fig. 6). The date of Hubble's handwritten inscription is February 1934.

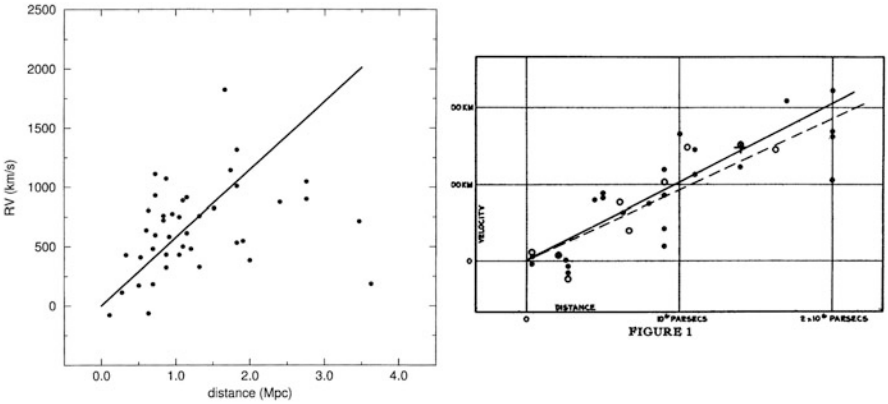


Fig. 5 *Left hand panel*: The data used by Lemaître (1927) to yield the first empirical value of the rate of expansion of the Universe in which v/r is predicted to be constant (see Eq. 24 in his paper. Lemaître derived values of 625 km/s/Mpc and 575 km/s/Mpc. The solid line at left has a slope of 575 km/s/Mpc and is reconstructed by H. Duerbeck. Right hand panel: The radial velocity—distance diagram published by Hubble, 2 years later, in 1929, with a "best slope" of 530 km/s/Mpc. (Left hand panel: courtesy H. Duerbeck).

In that book "The Expanding Universe", Eddington cites Lemaître six times, and Hubble twice. Eddington gives full credit to Georges Lemaître as the first one to fuse relativistic theory with astronomical observations:

"The deliberate investigation of non-static solutions was carried out by A. Friedmann in 1922. His solutions were rediscovered in 1927 by Abbé G. Lemaître, *who brilliantly developed the astronomical theory resulting therefrom* . . ." (italics, ours)

"During a visit to Cambridge, Albert Einstein stayed with Arthur Stanley Eddington and his sister Winifred. For Einstein it was an opportunity to be updated on cosmological matters. On Friday, 10 January 1930, Eddington had attended a lecture by Willem de Sitter, who, in a meeting of the Royal Astronomical Society, had talked about Hubble's observationally found linear relationship between the radial velocities of distant spiral nebulae and their distances (Hubble 1929). Neither de Sitter nor Eddington could provide a theoretical explanation, although both agreed that it had to be the consequence of some cosmological manifestation. The discussion of the two scientists was published in The Observatory (February 1930), whereupon George Lemaître sent them his publication of 1927. There he had shown that redshifts were the signature of an expanding universe, and that such redshifts depended linearly on the nebular distances (Lemaître 1927). Both, Eddington as well as de Sitter, immediately accepted Lemaître's theory of a dynamic universe; they published their opinion in March and May 1930." (Nussbaumer, in press).

Although Eddington (1933) well understood who discovered the expanding universe, credit (for whatever reason) now rests Hubble. As clearly emphasized in Hubble's book "Observational Approach to Cosmology" published in 1937, Hubble himself was in favour of a stationary universe: *"On the other hand, if the recession factor is dropped, if red-shifts are not principally velocity shifts, the picture is simple*

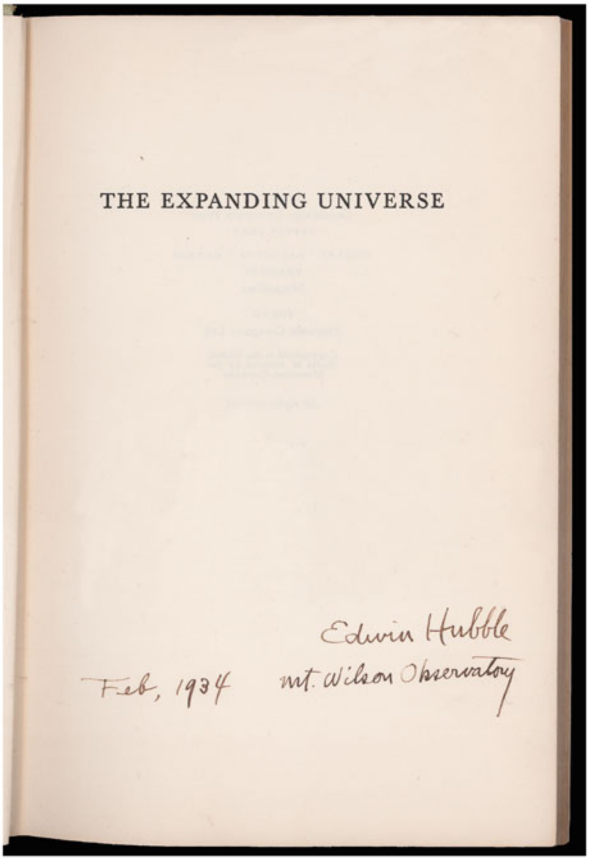


Fig. 6 A book signed by Edwin Hubble, dated 1934. The book, entitled "The Expanding Universe" was authored by Sir Arthur Eddington in 1933. Eddington (unlike Hubble) was very meticulous in his referencing: Eddington cites Lemaître six times, and Hubble twice. Already in 1923, Eddington included Slipher's redshifts in his "Mathematical Theory of Relativity"

and plausible" and *"Observations at the moment seem to favour one picture [the stationary universe], but they do not rule out the other [redshifts being velocity shifts]."* (Words in square brackets: ours). The point we do wish to highlight is this: Hubble was fiercely territorial about the (radial velocity, distance) graph. Fiercely territorial indeed: "*... I consider the velocity-distance relation, its formulation, testing and confirmation, as a Mount Wilson contribution and I am deeply concerned in its recognition as such.*" (A letter from Hubble to de Sitter, dated 21 August 1930). The territorial strategy spills over in the referencing style for the redshifts: Slipher is not referenced in Hubble (1929), at all.

In the index of "The Realm of the Nebulae" (1936) one alphabetically finds the names of many astronomers, from Baade, Walter to Reynolds, John to Zwicky, Fritz. Generally, as footnotes. But the focus are the achievements of Hubble. No mention of Reynolds (1920). The reader is blissfully unaware of the masterful eclipsing of the classification of Reynolds (1920), by Hubble. The game is on. The outcome: very serious. Hubble knows this. Hubble, as Emperor of the Nebulae, also knew precisely how to write glowing letters to some colleagues, whom he would intentionally eclipse. We see this in "The Realm"—Hubble does makes mention of a short paper by Reynolds, published in *The Observatory*, in 1927, but what about the seeds for the Hubble classification scheme? *Would it not have been honorable for Hubble to inform the world that he (Hubble) had approached Reynolds to actually devise a classification scheme* (Figs. 1 and 2)—*one which now universally carries Hubble's name only?*

An accurate timeline is provided by van den Bergh (2011):

> 1927: Lemaître derives the expansion rate of the Universe and explains its expansion in terms of the general theory of relativity.
> 1929: Hubble repeats Lemaître's work with essentially the same data and obtains similar results.

A delightful read is a book "Discovering the Expanding Universe" co-authored by Nussbaumer and Bieri (2009); the foreword is by Allan Sandage (Fig. 7). Nussbaumer and Bieri emphasize, in no uncertain terms, that "Hubble himself was exceedingly partial in selecting his references. Even in his influential *The Realm of the Nebulae*, published in 1936, he avoided any reference to Lemaître (Hubble 1936). Was he afraid that a gem might fall from his crown if people became aware of Lemaître's pioneering fusion of observation and theory two years before Hubble delivered the confirmation?" Our conjecture, partly based on thoughts by a colleague of Hubble, is that Hubble returned from the IAU General Assembly held in Leiden in 1928, brimming with ideas. The time was ripe for confirming a more accurate (radial-velocity, distance) correlation.

ESO Director General Tim de Zeeuw writes: "The history of science contains examples where the credit did not go to the actual discoverer. This appears to be the case as well for the discovery of the expanding universe." For a detailed historical read, see Block (2012).

In future astronomy books, we would urge authors that a crucial entry should be under L—to honor Lemaître. He first developed the astronomical theory of an expanding universe in 1927, and is now (correctly) regarded as the scientist of one of the greatest discoveries of all time: the Expanding Universe.

The 30-inch Reynolds telescope at Mt. Stromlo was totally destroyed by the bush fires which devastated sections of Canberra in January 2003. But the legacy of Mr. John Henry Reynolds (1874–1949) lives on.

Why Hubble behaved in the manner he did, we will never know. A naked emperor he stands, for all to observe his strategy. How appropriate to cite "The Emperor's New Clothes" (Danish: Kejserens nye Klæder), a short story by Hans Christian Andersen in 1837. Two weavers promise the Emperor a new suit of clothes which are invisible to those unfit for their positions, stupid, or incompetent. When the Emperor parades before his subordinates in his new clothes, a child cries out, "But he isn't wearing anything at all!"

Tragically, Edwin Hubble was a man with a highly opaque mask. Few ever penetrated it.