Preface

The remaining irregulars might be arbitrarily placed in the regular sequence as highly peculiar objects, rather than in a separate class. Almost all of them require individual consideration but, in view of their very limited numbers, they can be neglected in preliminary surveys of nebular forms.

Edwin Hubble, *The Realm of the Nebulae (1936)*

Barry Madore was an undergraduate astronomy student in 1966 when one day a fellow classmate approached him and declared, "You've got to see this!" Madore gave him a sidelong glance and asked suspiciously, "What are you talking about?" There was something conspiratorial, possibly licentious, in his friend's tone. "Come on down to the stacks," he said, referring to the university library's collection of science journals.

Madore followed, though more wary than curious. When they got to the stacks, his friend pulled out a volume of the *Astrophysical Journal Supplement* and flipped it open. "Look at these things," he said, wonderingly. Madore, a tall, no-nonsense Canadian who wears a steady, pensive, I-can-see-through-you expression, began thumbing through pages of photographs, six to a page, each in negative format. His thoughtful expression suddenly turned to astonishment at what he was seeing. The photographs were of galaxies, but not the well-proportioned galaxies with which he was familiar. These were uncanny examples of galactic malformations. The name given to this grotesque gallery was *Atlas of Peculiar Galaxies*, and it had been compiled by one Halton Arp of the Mount Wilson and Palomar Observatories. Taking in the mesmerizing variety of galactic mutations, Madore thought that it was certainly a work that lived up to its title.

"It was quite a revelation," recalls Madore, who today applies his astrophysical skills at the California Institute of Technology's Infrared Processing and Analysis Center and the Carnegie Observatories. "To everybody who had grown up and been fed the story by [Edwin] Hubble and Allan Sandage that the vast majority of galaxies were beautiful and textbook symmetrical, to suddenly be exposed to all these pathologically strange objects, was fascinating."[1]

It wasn't the first time a collection of weird-looking galaxies had been assembled. In 1959, the Russian astronomer B. A. Vorontsov-Velyaminov published the positions of 355 peculiar and interacting systems that he had discovered by painstakingly sifting through the National Geographic Society-Palomar Observatory Sky Survey prints.[2] Arp credits Vorontsov-Velyaminov, as well as Palomar's Fritz Zwicky, with doing pioneering work in this field. But it was Arp who possessed both the willingness and technology to conduct a more thorough photographic investigation of these curiosities, something few astronomers in those days were inclined to do because the peculiar specimens were so few in number.

Arp began compiling his *Atlas* in 1962. During that period, galactic morphologists wondered whether some evolutionary or astrophysical trend might become apparent if they were systematically assorted by shape. Thirty years earlier, Edwin Hubble had struggled to come to grips with such a classification system, one that accommodated the shapes of most normal-looking galaxies. The result was his iconographic "tuning fork" diagram.

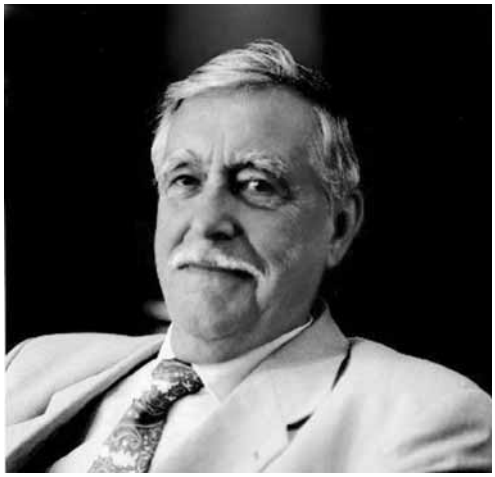


Fig. 1 *Halton C. Arp*

But galaxy classification in the twentieth century has a far richer history than that. Its roots date back to 1922, when a Swedish astronomer named Knut Lundmark began formulating a system to classify "nongalactic" nebulae.[3] In those days, galactic nebulae were considered to be planetaries and bright and dark irregular gaseous nebulae. They were called "galactic" because they could be found largely in and around the galactic plane. These objects also came in "the most wonderful disparity as to form and texture."[4] Lundmark noticed, however, that nebulae high above the galactic plane did not show appreciable differences in their colors, spectra, or magnitudes. He suspected they belonged to a special family of objects, which he called "anagalactic" nebulae.[5] His goal was to work on a "statistical investigation of the known spirals in connection with the question of classifying the non-galactic nebulae."[6]

In a 1925 paper, he listed the main classes of these objects:

- "Globular" nebulae
- "Early" spirals
- "Late" spirals
- Magellanic cloud-nebulae
- Magellanic clouds[7]

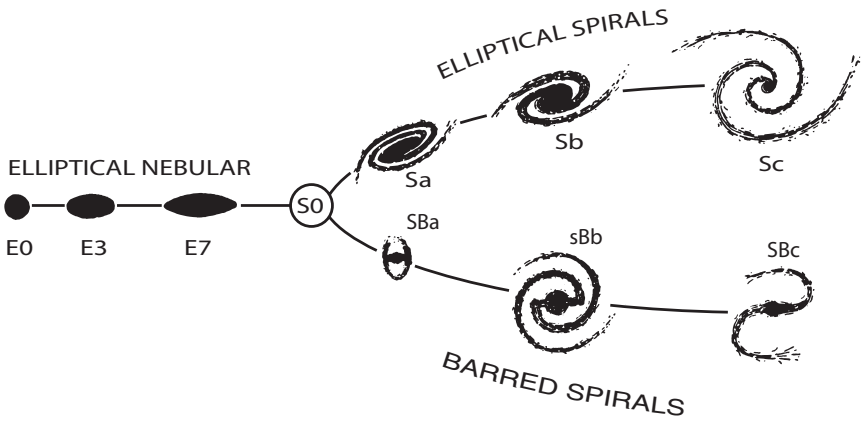


Fig. 2 *This diagram is a schematic representation of the sequences of galaxy classification as presented by Hubble in* The Realm of The Nebulae *where he stated: "A few nebulae of mixed types are found between the two sequences of spirals. The transition stage, S0, is more or less hypothetical. The transition between E7 and SB, is smooth and continuous. Between E7 and Sa, no nebulae are definitely recognized." Courtesy Yale University Press.*

Lundmark also introduced an index to indicate how concentrated the light was at the center of anagalactic nebulae, which he collectively labeled "A." The index range went from 0 (very little concentrated) to 5 (very much concentrated). If the overall shape was, say, elliptical, it was classed as an "e" type. Hence the giant and very much concentrated M87 was classed as an Ae5 galaxy in Lundmark's book. Spirals were "As" and Magellanic types were "Am," and they too could come in concentration ranges from 0 to 5.

Though Hubble came to suspect Lundmark of plagiarizing his own classification scheme (something historians have effectively challenged[8]), it is clear that he wasn't the only one working on classification schemes in the early 1920s. Moreover, you have to hand it to Lundmark that, even though he did not know that spiral nebulae were galaxies, his classification system embraced a wide variety of forms recognized today as being uniquely galactic. For example, he classed one-armed spirals, like Arp 293, as "Aso" types, (one-branched spirals). In addition he described spirals with arms in the form of a "bright ring," a "doubtful connection of the ring with the center (Saturn type)," and "rings or arms connected with the center through a bar." These are all features that apply to many of the Arp galaxies. Although Lundmark was concerned mainly with structural hierarchy, there can be no doubt that he also thought that classifying nebulae, particularly spiral nebulae, could provide a glimpse into how these objects evolve.[9]

By and large, the kind of peculiar galaxies that Arp eventually turned up could not simply be pronged onto a tine of the Hubble tuning fork or dropped into one of Lundmark's bins. Even by the middle of the twentieth century, as more peculiar galaxies came out of the woodwork, they still only comprised about 2 percent of the total, and astronomers remained comfortable with shelving them, as Hubble himself had recommended[10]. That didn't mean, though, that peculiar galaxies were completely ignored. Heber D. Curtis of the Lick Observatory had photographed the unusual jet in M87 in 1918, a structure that would later provide a strong link between visual and radio astronomy. And Mount Wilson astronomers Fritz Zwicky, Walter Baade, and Rudolph Minkowski, always on the lookout for new types of objects, were familiar with a variety of unusual galaxies, some of which would eventually be recognized as merging galaxies.

Although Hubble's original tuning fork did not patently include peculiar galaxies, some were classified as such in its subsequent incarnation, the *Hubble Atlas of Galaxies*, compiled by Allan Sandage in 1961, several examples of which Arp included in his *Atlas*.

One of the first serious attempts at including peculiar type galaxies in a classification system arose in 1958, when the French-American astronomer Gerard de Vaucouleurs, working with Allan Sandage, developed a more ambitious three-dimensional classification scheme to accommodate as many galaxy shapes as possible. Known as the de Vaucouleurs Revised Hubble-Sandage system, or VRHS, the system was a three-dimensional schematic that resembled a football, with the major axis of the football arrayed with the primary classes of galaxies from ellipticals through spirals and Sm, and Im types (referring to Magellanic-type galaxies). Another parameter related to the presence or absence of bars, and a third distinguished between ringed and nonringed varieties. Hence, a cross section of the de Vaucouleurs' football would show the main Hubble type galaxy in the center, say Sb, with two main "families" on the vertical axis, normal SA spirals above and barred SB spirals below. Intermediate types SAB occupied the horizontal axis, with S-shaped spirals on the left, and ring-shaped spirals on the right. The other intermediates types would be arranged systematically in the other positions (see Figure 3).

Notwithstanding all the Homeric attempts at galaxy classification, the problem remained that nobody knew what forces shaped normal galaxies, much less peculiar ones. Normal

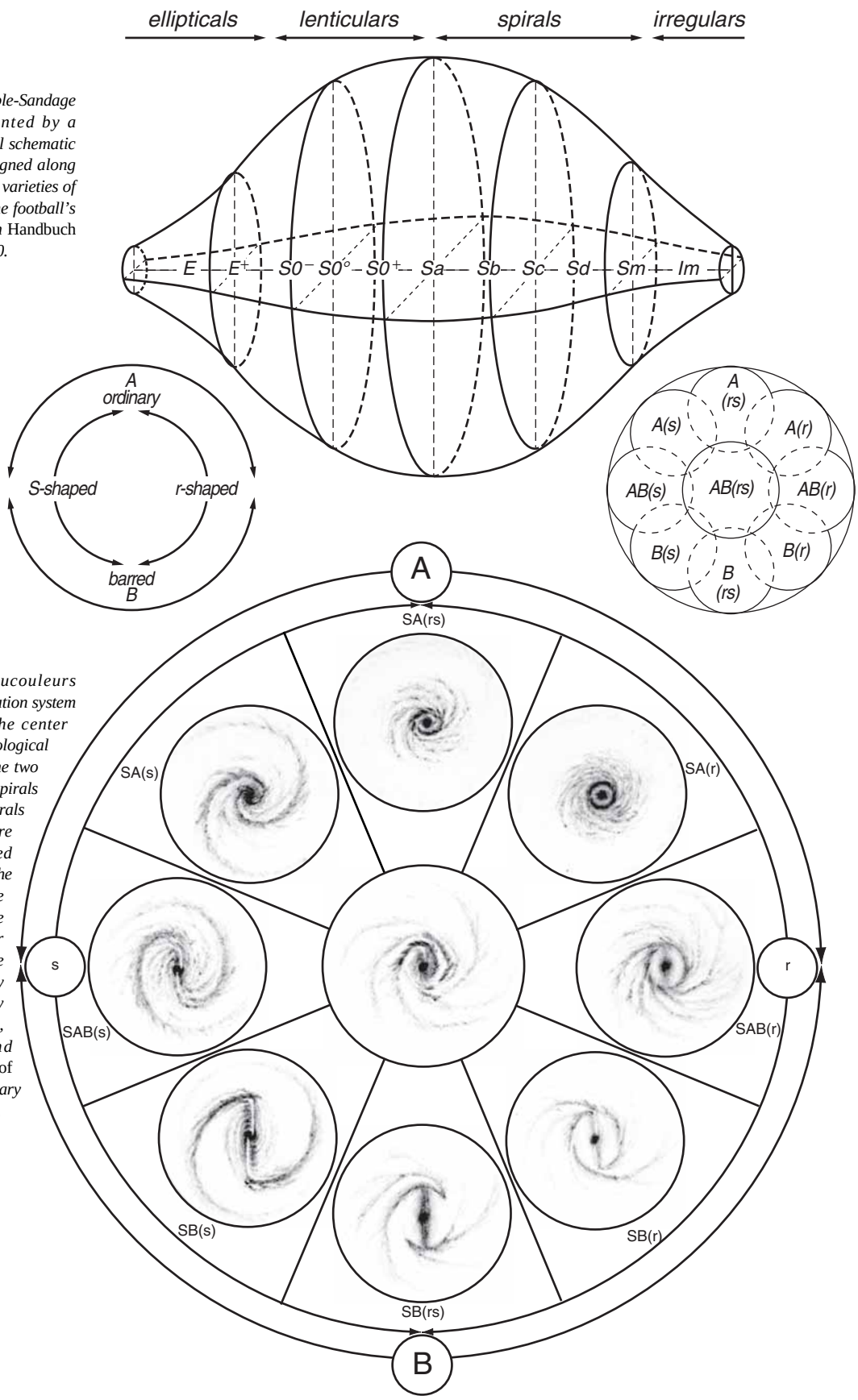


Fig. 3
The de Vaucouleurs Revised Hubble-Sandage system, or VRHS, is represented by a football-shaped three-dimensional schematic with the primary galaxy types aligned along the major axis of the football. The varieties of these forms are arranged along the football's periphery. Originally published in Handbuch der Physik, *Vol. 53, 1959, 275–310.*

A cross section of the de Vaucouleurs three-dimensional galaxy classification system shows a typical Sb spiral at the center surrounded by its various morphological forms. On the vertical axis are the two "family" extremes—ring-shaped spirals SA(rs) and ring-shaped barred spirals SB (rs). On the horizontal axis are the main "varieties" of barred spirals, SAB(s), or S-shaped on the left, and ring-shaped SAB (r) on the right. Intermediate versions of the Sb form are arrayed in the other positions. Hence, as you move around the circle, one galaxy morphs into the other. Originally published in Handbuch der Physik, *vol. 53, 1959, 275–310, and reprinted in* Reference Catalogue of Bright Galaxies, *first edition, January 1, 1964, University of Texas Press.*

galaxies, at least, displayed recognizable patterns—corkscrews, pinwheels, and spheres—forms that hinted at some underlying, and hopefully apprehensible, dynamic. Peculiars on the other hand defied description. God only knew what forces shaped them. Moreover, it must be remembered that the *Atlas* was published at a time when galaxy-galaxy interactions were considered highly unlikely. Therefore, it was tacitly understood by established researchers that peculiar galaxies were best contained in academic asylum where they could wail and rattle their chains without distracting those outside the walls. This is why Barry Madore couldn't believe his eyes when he first saw Arp's *Atlas*. He was looking upon galactic bedlam.

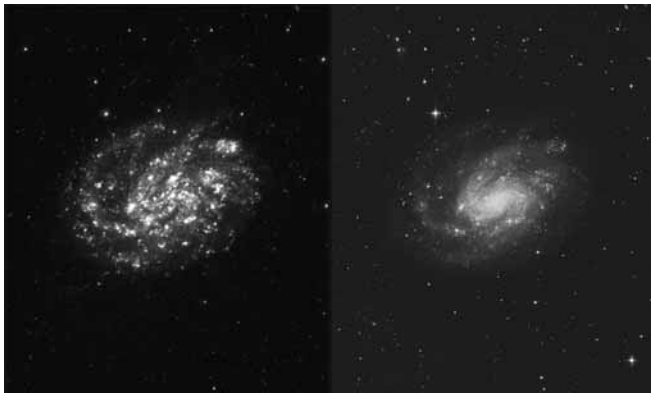
Arp's *Atlas* unlocked the asylum door and threw away the key. But though the "inmates" were now free to rave out in the open, astronomers could still point out that there weren't that many of them to matter statistically. They were freaks and they were few. Two developments, however, would change that.

Since Hubble's day, astronomers have classified galaxies according to their appearance at visual wavelengths—in blue light. But the advent of radio, ultraviolet, and near-infrared observations has shown that a galaxy's appearance can substantially morph with wavelength. A normal spiral can appear distinctly abnormal depending on whether it is seen in ultraviolet or near-infrared light. Dust as well as its core energy output can also affect a galaxy's appearance at wavelengths other than those in the visual band.

The second development didn't dawn until 1995 and 1996 when the Hubble Deep Fields North and South brought to light thousands of previously unknown fragmented and distorted galaxies extending out to the edge of the visible Universe, each within a parcel of sky no larger than a pin-point. Assuming these two opposing directions were not special exceptions to the overall distribution of galaxies, there had to be tens of billions of such galaxies dispersed across the sky. The remarkable Hubble Ultra Deep Field, released in March 2004, has further confirmed this.

Taken together, the multiwavelength observations and deep-field findings have significantly altered astrophysicists' ideas of what a normal galaxy is. In fact, there are *no* "normal" galaxies. As Arp presciently wrote in his preface to *Atlas of Peculiar Galaxies*, "when looked at closely enough, every galaxy is peculiar."[4]

Forty years later, Halton Arp's *Atlas* continues to fascinate, though it has been long out of print—until now. We have reproduced the original images from scans provided by Barry Madore beginning on page 11. The *Atlas'* significance today transcends its intriguing assortment of galactic exotica in that it demonstrates how much more dynamic *any* galaxy can be when freed from its closed, static box and allowed to run amuck with other galaxies. Modern observations have not only proven the importance of galactic interactions (and, Arp would add, "ejections"), but have also shown that galaxies evolve over billions of years. They aren't butterflies pinned inertly to a mounting board but dynamic systems that are forever changing. They don't now look the way they did in the past, and they certainly won't resemble themselves in the future.



When looked at closely enough, every galaxy is peculiar. A view of NGC 300 in ultraviolet light (left) reveals that the galaxy's hot spots of star formation extend all the way to its nucleus, something not apparent in the smooth, symmetrical arms of the same galaxy viewed in visual, blue light (right). Left image, GALEX; right image Digital Sky Survey.

In this respect, Arp's *Atlas of Peculiar Galaxies* has been of inestimable value to astrophysics, and it continues to serve today. Like great art, it cannot be improved upon or augmented. Neither can its author who, as readers will discover, is every bit as unique. It is illuminating to consider that the *Atlas* emerged at a turning point in the history of astrophysical research, a time when one had to be more thorough and yet more daring to get to the bottom of the Universe. To do this in a practical sense meant obtaining the best observations possible, questioning all assumptions, and, more important, forgoing one's inherent fear of being wrong.

Atlas of Peculiar Galaxies is just as much an embodiment of these ideals as it is the first bold look at a new, and startling, assortment of galaxies that, astronomers are only now realizing, dominate the Universe.