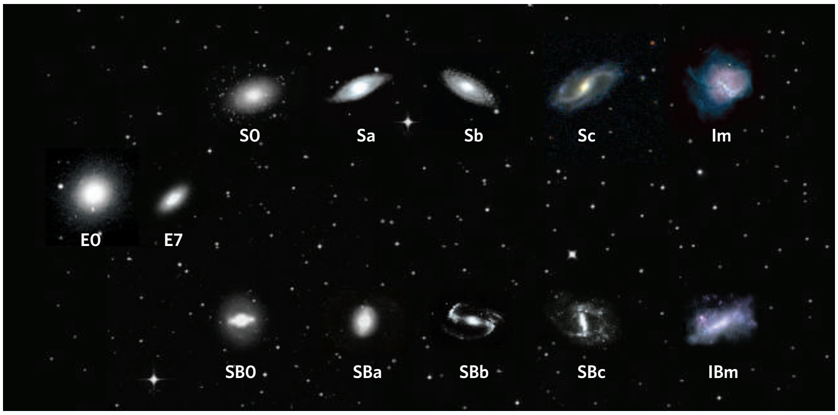
GALAXY MORPHOLOGY

# Out of order

Recent observations of vast numbers of galaxies may pose problems for the galaxy classification scheme proposed by Edwin Hubble.

**Sidney van den Bergh**




**Hubble's 'tuning-fork' diagram of galactic classes, including normal and barred counterparts.**

Galaxies are like people: the better you get to know them, the more peculiar they often seem. Classifying and explaining the appearance of objects that occur in such an array of shapes, masses and sizes is a major challenge. As astronomer Allan Sandage wrote recently: "The danger in devising a classification from scratch is that, if the classifier has preconceived notions of what those explanations might be, then the classification becomes circular if it is later used to provide the explanation." To complicate matters, the Hubble Space Telescope (HST) has shown that the appearance of galaxies, like that of people, changes systematically with age.

Modern galaxy classification systems evolved from the 1926 work of Edwin Hubble. He placed galaxies on a linear sequence E0–E7–Sa–Sb–Sc, with ellipticals designated as E and spiral galaxies S. In this sequence, E0s are round ellipticals; E7s are highly flattened ellipticals; Sa galaxies have large elliptical-like cores surrounded by smooth, tightly coiled spiral arms; Sb galaxies have smaller cores and more open arms; and Sc galaxies have small cores that are surrounded by very open, patchy, spiral arms. Hubble also noted a dichotomy between normal and barred spirals (as shown in the figure). He labelled galaxies that did not fit comfortably into his classification scheme 'peculiar'.

We now know that there are two classes of peculiar object: normal galaxies that have been catastrophically reshaped by violent tidal encounters or mergers, and irregular galaxies that contain bright young stars and no nuclei, and show no regular spiral structure. Unexpectedly, the normal and barred counterparts Hubble observed for spirals extend to irregular galaxies (such as Megellanic irregulars (Im and IBm); see figure).

Ten years after formulating his classification system, Hubble suspected that an additional class — which he dubbed S0 galaxies — might need to be interposed between spirals and ellipticals. This idea was strengthened by observations made by his successors during the next two decades. However, the fit of S0s into Hubble's tuning-fork diagram has always been uncomfortable. They tend to be fainter than either elliptical or Sa galaxies, not intermediate between them as might be expected.

Subsequent work has only complicated the picture. HST observations have shown that the morphology of galaxies changes systematically with look-back time. Like humans, young galaxies develop fast. They gain mass from mergers with lesser galaxies and from inflow of gas, then grow old slowly as their structure relaxes and their stellar content ages and evolves. HST images have shown that elliptical and Sa galaxies settle into a stable morphology very early on, whereas Sc galaxies take much longer.

Luminous nearby Sc galaxies have well-ordered spiral arms, whereas distant ones show chaotic spiral structure. For look-back times of up to five billion years, spirals look like standard nearby objects in HST images. At greater light travel times they appear more and more peculiar. And, at redshifts corresponding to a look-back time of about ten billion years it becomes difficult or impossible to shoehorn them into the Hubble tuning-fork diagram. So, the Hubble classification scheme breaks down entirely for galaxies at distances greater than ten billion light years.

Taken at face value, the Hubble classification scheme suggests that galaxies (with the possible exception of S0s) lie on a single continuous sequence ranging from E through Sa, Sb, Sc and Im. But this seems to conflict with modern, high-precision observations of the luminosities and colours of enormous samples containing tens of thousands of galaxies. Such observations strongly suggest that galaxies fall into two distinct zones in a colour-luminosity diagram. It is not clear how the apparent dichotomy of galaxy characteristics, seen in the distribution of galaxies over the colour-luminosity diagram, can be reconciled with the continuous change of galaxy characteristics along the Hubble classification sequence.

Astronomers generally agree that the Hubble sequence results from changes in population mix, with ellipticals containing mostly old stars and Im galaxies comprising mainly young ones. But the apparent dichotomy shown by galaxies when classified by colour and luminosity is attributed to the different properties of 'high-' and 'low-mass' galaxies. The apparent dichotomy between the sequence of high- and low-mass galaxies arises because shock heating of gas in galaxies more massive than $10^{12}\ M_{\odot}$ abruptly halts star formation, whereas cooling and star formation can continue in galaxies with lower masses. A grand unifying scheme that incorporates both the continuity of the Hubble diagram and the dichotomy in the galaxian colour-magnitude diagram does not yet seem to be in sight.

Albert Einstein and many others have commented on the effectiveness of mathematics for formulation of the laws of nature. As a result, science sometimes evolves in those directions in which mathematics can be applied. However, several areas, including friction, turbulence and morphological classification, remain largely in the mathematical wilderness. Progress in galaxy morphology has mainly resulted from the remarkable human capacity to recognize patterns. This suggests that a deeper understanding of the nature of the differences between galaxies in the colour-luminosity diagram may come from careful inspection of the images of the brightest ones. ■

**Sidney van den Bergh is at the Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council, 5071 West Saanich Road, Victoria, British Columbia, V9E 2E7, Canada.**