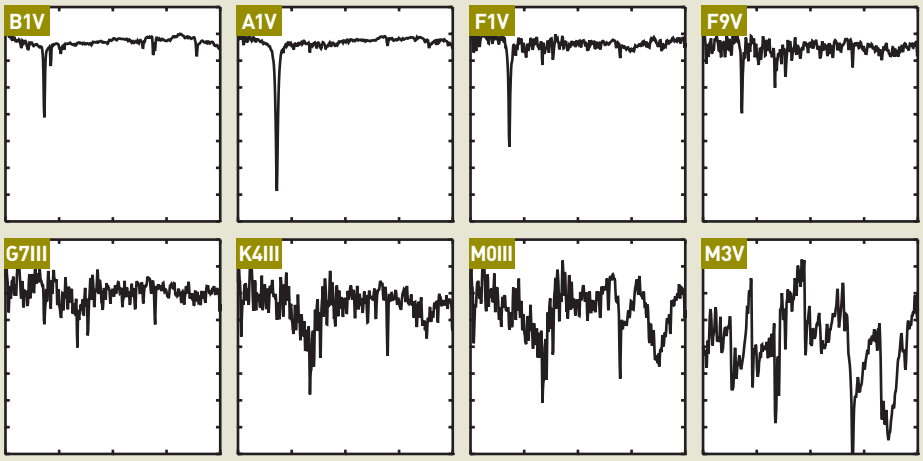
STELLAR SPECTRA



1: Sequence from early to late types derived from Valdes *et al.* (2004). The data have been normalized using a quadratic fit and are plotted from 450 to 650 nm at nm resolution; relative intensity scale is 0.3 to 1.1.

Hubble's galaxy nomenclature

Ivan K Baldry ponders Hubble's naming of late and early type galaxies: did he mean more or less complex in appearance?

ABSTRACT

It is widely written and believed that Edwin Hubble introduced the terms "early" and "late types" to suggest an evolutionary sequence for galaxies. This is incorrect. Hubble took these terms from spectral classification of stars to signify a sequence related to complexity of appearance, albeit based on images, not spectra. The temporal connotations had been abandoned before his 1926 paper on classification of galaxies.

The terms "early" and "late type" in astrophysics have been applied to both stars and galaxies. Spectral classification of stars follows an early-to-late sequence (Kirkpatrick *et al.* 1999) that closely relates to a temperature sequence from hot to cool stars. Morphological classification of galaxies is based on several factors, including ellipticity, the size of the nuclear region relative to the spiral arms, and the smoothness of the image. A commonly used classification is the revised and extended Hubble system (de Vaucouleurs 1959, Sandage 1961, 1975) that is based on Hubble's (1926) original scheme for "extragalactic nebulae", and Reynolds' (1920) earlier ideas. It follows an early-to-late sequence, ellipticals-lenticulars-spirals-irregulars (ignoring the barred/unbarred characteristic). Sandage (2005) has reviewed the history of this development.

At first glance, there appears to be no relation between the early-to-late type sequences of stars and galaxies other than the terminology. Before the implications of $E=mc^2$ (Einstein 1905) became clear, and to explain the Hertzsprung–Russell diagram, it was natural to suppose that stars cooled from early to late spectral types because there was no established mechanism for million-year stability of stellar atmospheres (cf. cooling of brown dwarfs, Burrows *et al.* 1997). There is now a widespread belief that Hubble chose this terminology because he thought that the morphological sequence was also a temporal sequence. For example, Binney and Merrifield (1998) wrote: "Hubble suggested that galaxies evolved from the left-hand end of this sequence to the right. This now discredited speculation lives on in the convention … early-type … late-type galaxies." Coles and Lucchin (2002) noted: "Although it is now not thought this evolutionary sequence is correct, Hubble's nomenclature, in which ellipticals are 'early' type and spirals and irregulars 'late', is still commonly used." Similar explanations can be found in other textbooks (e.g. Tayler 1993, Shore 2003, Carroll and Ostlie 2006). The main aim of this article is to show that these explanations are incorrect, and to illuminate the correct explanation.

Sequences in complexity of appearance

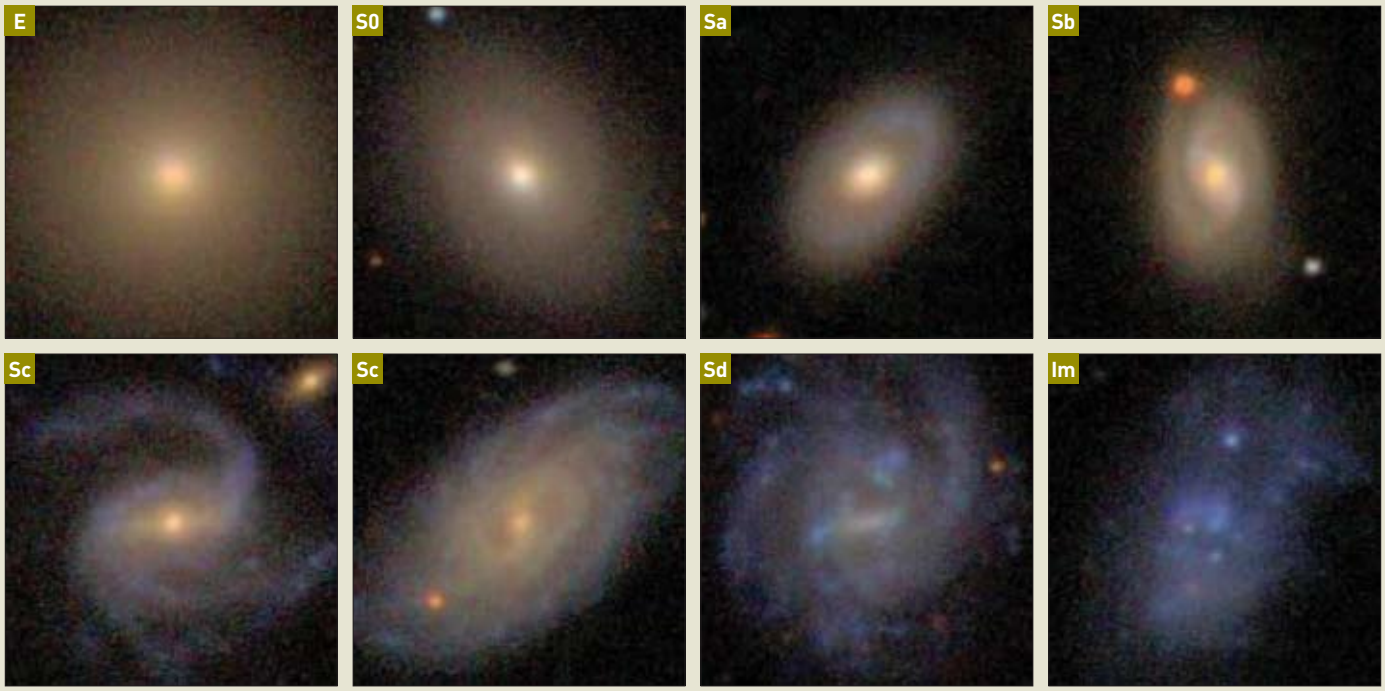
The temporal meanings of "early" and "late" were questioned for stellar spectra by the early 1920s because of, for example, the discovery of red giants and the suggestion of a nuclear timescale by Eddington (1919). Stratton (1924) quotes a 1922 IAU report: "The terms … are very convenient. It is well, however, to emphasize that they denote positions early or late in the spectral sequence … without any necessary connection whatever with an early or late stage of physical evolution." Responding to a suggestion by Hepburn (1924) that the terms be dropped, Stratton said, presciently: "It may be doubtful whether words so strongly entrenched in the literature of the subject can now be displaced." In fact they have not been.

In Hubble's 1926 paper, the footnote on p326 is revealing: "Early and late, in spite of their temporal connotations, appear to be the most convenient adjectives for describing relative positions in the sequence… They can be assumed to express a progression from simple to complex forms. An accepted precedent for this usage is found in the series of stellar spectral types. There also the progression is … from the simple to the complex … the temporal connotations … have been deliberately disregarded." Furthermore, Hubble (1927) noted: "The nomenclature, it is emphasized, refers to position in the sequence, and temporal connotations are made at one's peril. The entire classification is purely empirical and without prejudice to theories of evolution."

By the early 1920s the temporal connotations of "early" and "late" had been largely disregarded for stellar spectra. Hubble knew this and used the terminology choosing the direction of the morphological sequence based on the apparent complexity of stellar spectra. Figure 1 shows spectra of eight stars put in order of their spectral classification, and figure 2 shows eight galaxies in order of their morphological classification. From these figures, we can see the unification of the terminology such that, in general, earlier types are simpler in appearance and later types are more complex in appearance for both stellar spectra and galaxy images. (It is worth bearing in mind that both these phenomena would have been observed on black-and-white photographic plates in the 1920s.)

While this definition is subjective, it is a coherent starting point for explaining these terms in teaching astrophysics. And it is related to physical phenomena – for example, dependence of

GALAXY MORPHOLOGIES



2: Sequence from early to late types derived from Nakamura *et al.* (2003) classifications and Sloan Digital Sky Survey colour images (Nieto-Santisteban *et al.* 2004) scaled as per Lupton *et al.* (2004). Types are as indicated.

absorption transitions on atmospheric temperature in stars, and star-formation triggering in galaxies. The history of science is simplified in science textbooks because their primary aim is "persuasive and pedagogic" (Kuhn 1996). Yet the particular inaccuracy discussed in this paper, while minor, does a disservice to Hubble and observational astronomy, without aiding clarification.

Mature astronomy

By the early 20th century, astronomy was a mature science, and in the mid-1920s the concept of "extragalactic" had only recently been largely accepted. Hubble's 1926 paper is the first to use this term in a published title. Hubble was a careful observational astronomer and it is clear from his 1926 and 1927 papers, quoted above, that he assumed the temporal implications of "early" and "late" had been dropped prior to his usage of them. He would not have presumed to establish a theory of galaxy evolution at this stage. Even in his more comprehensive book published a decade later (Hubble 1936), he was strictly neutral on evolution. He was, however, influenced by Jeans' development of liquid rotating spheroids and did earlier hint at evolution based on Jeans' dynamics, even as he insisted that his classification was strictly based on morphology with no interjections about origins (Sandage 2005).

Why should Hubble have not used the terms "simple" and "complex"? The problem is that these would have preempted theory. In fact, many morphologically classified early-type galaxies have been shown to have complicated internal dynamics (de Zeeuw *et al*. 2002). The terms "simple in appearance" and "complex in appearance" are clunky in comparison with "early" and "late", and it should be noted that the complexity of appearance is a guide to the order of the sequence, not the definition. For stellar spectra, the order is generally quantified by the strengths of various absorption bands. For morphological classification of galaxies, there is no consensus on the most useful quantification. Hubble (1936) considered the sequence as a "progression in dispersion or expansion" of spiral arms. There are many alternatives for galaxy classification (Sandage 2005) but Hubble's scheme is part of common systems today.

In summary, when introducing the terms "early" and "late" for the morphological classification of galaxies, the historical context is explained incorrectly in many texts. I have shown that the logical reason relates to the complexity of appearance within the sequence. This reason should improve a student's grasp of why these, apparently arbitrary, terms are used for both stars and galaxies. Rather than abandoning the terms, I propose that Hubble's intention be kept in mind when using them, for the temporal connotations should by now be well and truly dispelled. ●

Ivan K Baldry, Astrophysics Research Institute, Liverpool John Moores University.

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