COLOR DISTRIBUTION OF FAINT GALAXIES AND QUASI-STELLAR OBJECTS

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The apparent colors in a flux-complete sample of galaxies depend on the redshifts and the spectral types in the sample. These in turn depend on both luminosity evolution and evolution of the shapes of the spectra. Thus in principle a great deal about the evolution of galaxies can be learned from complete multicolor surveys, especially now that large samples can be routinely generated by automatic machine measurement. The following will review what has been learned from recent work.

An example is a new survey by workers at Bell Laboratories (Tyson, Valdes, and Jarvis, private communication). Twelve 4-m fields in the two bands J^+ and F are under analysis with new image-classification software by F. Valdes (1982). Similar studies have indicated a distribution with a blue tail or with blue median colors (e.g., Karachentsev 1980; Harris and Smith 1981). The trend to the blue seems to have an amplitude of only a few tenths of a magnitude, and to set in fainter than B = 21. This phenomenon has also been claimed from Schmidt data (Phillipps, Fong, and Shanks 1981), but is not always evident even in fainter samples (cf. color - magnitude diagrams for field regions by Couch 1981). The blue trend has often been taken to be evidence for galaxy evolution. However, Pence (1976) predicted a shift to bluer median colors between B = 22 and B = 24, without evolution; this arises from the differential k-correction between those galaxies with hot spectra and those without.

Koo (1981) has studied complete samples in the four bands UJ^+FN. The random errors and incompleteness factors were evaluated in detail, and are included in the models. These models adopt Bruzual's (1981) evolving energy distributions, and predict what the distribution of galaxies would look like in each cell of color and magnitude. In color - color diagrams, the data show the expected change in

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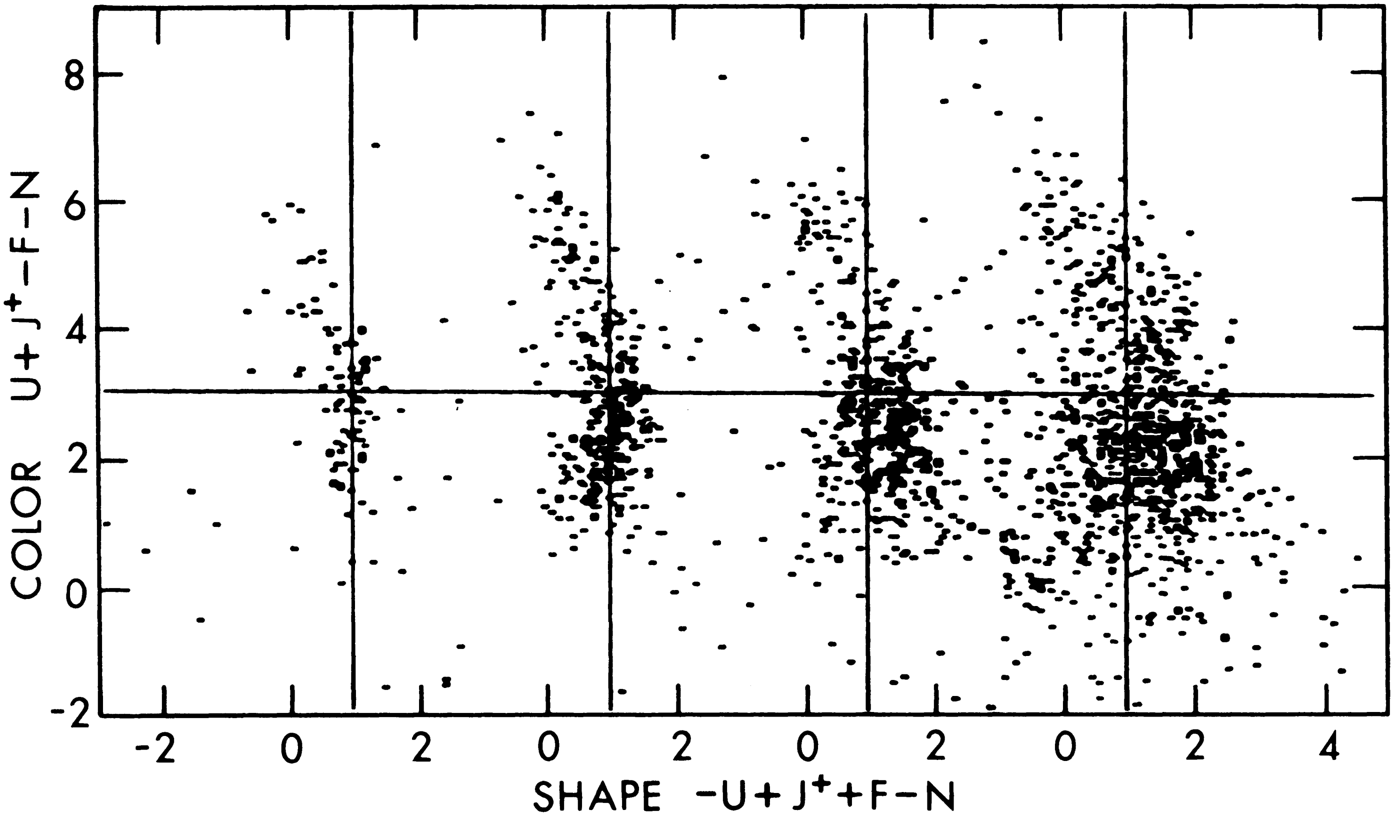

Figure 1. Koo's color-shape plots for galaxies in SA 68. The four segments are bins of J^+ magnitude: 20-21; 21-22; 22-22.5; 22.5-23. Lines of constant redshift are roughly vertical, and are separated by ~0.25 mag in the shape parameter for each $\Delta z = 0.1$

the position of the centroid with increasing magnitude (Figure 1). In general Koo finds encouraging agreement between data and theory, but there are limitations. For example, the models do not reproduce the curvature in the distribution of points in Figure 1. Whether or not the apparently faint blue galaxies have high redshifts turns out to be a good test for the existence of large evolutionary effects, but the only unambiguous way to tell would be faint spectroscopy (Koo 1983).

Progress in infrared detector technology in the past few years enables measurement of many galaxies near optical detections limits, and in fact some radio source positions were first identified in the near infrared (Grasdalen 1980). Because of the small k-corrections, such observations are especially valuable for work on distant galaxies with cool spectra, like many radio sources. The study of the (K, z) Hubble diagram for radio galaxies is thus a natural first step (Grasdalen 1980; Lebofsky 1981; Puschell, Owen, and Laing 1982; Lilly and Longair 1982). (The evolutionary corrections which apply to the near infrared band may not necessarily be simpler nor smaller than evolutionary corrections in the optical.) High-z radio galaxies which have been measured for infrared colors, like 3C 265, 3C 6.1, 3C 184, 3C 34, and 3C 280, often have very strong narrow lines in the optical band [Spinrad (1982)] and could perhaps be peculiar in continuum shape. Lilly and Longair (1982) pointed out that if the redshift is high, infrared colors cannot distinguish between galaxies with and without a nonstellar power law contribution to the light. For some applications it may turn out that the apparent magnitude is a better redshift estimator than the colors, which if demonstrable would reflect on the true information content of colors.

Ellis and Allen (1982) have measured 47 faint field galaxies in the J band and, of these, 26 galaxies in the K band. The optical color-infrared color diagram can then be used to argue for a particular redshift distribution and morphological type distribution. The idea is thus similar to purely optical techniques discussed by Koo (1981) and Butchins (1981; 1982), except that Ellis and Allen use the fact that the J-K colors at $z = 0$ for most galaxies display only weak dependence on morphological type (Aaronson 1977) — therefore, a universal J-K vs. z relation may exist, at least for sufficiently low z. (For $z \gtrsim 0.25$, the dependence of J-K on z unfortunately is weak.) Six out of the 26 galaxies were found to have unusually red colors, with $\langle J-K \rangle = 1.89$. This would indicate high redshifts, but then one of the calibrating galaxies has $J-K = 1.77 \pm 0.10$ and a spectroscopic redshift of only 0.30. [Some radio-quiet galaxies were found by Lebofsky (1981) to be very blue compared with expectations.]

A variety of problems are in some way connected with counts of quasi-stellar objects, such as statistics relating to gravitational lenses, the evolution of nonstellar light in galaxies, the integrated X-ray background, and the incidence of radio-quiet BL Lac objects. Many techniques to isolate samples of QSO's have been developed, but the classical UV-excess criterion continues to be competitive (e.g., Formiggini et al. 1980; Notni 1980; Richer and Olson 1980; Usher and Mitchell 1982; and Arp and Surdej 1982). Brighter surveys pick up stars like white dwarfs and sdB's, but it can be argued that this contamination problem should be less severe at faint limits. On the other hand, a critical problem is that galaxies may have colors like QSO's; faint blue galaxies greatly outnumber QSO's,

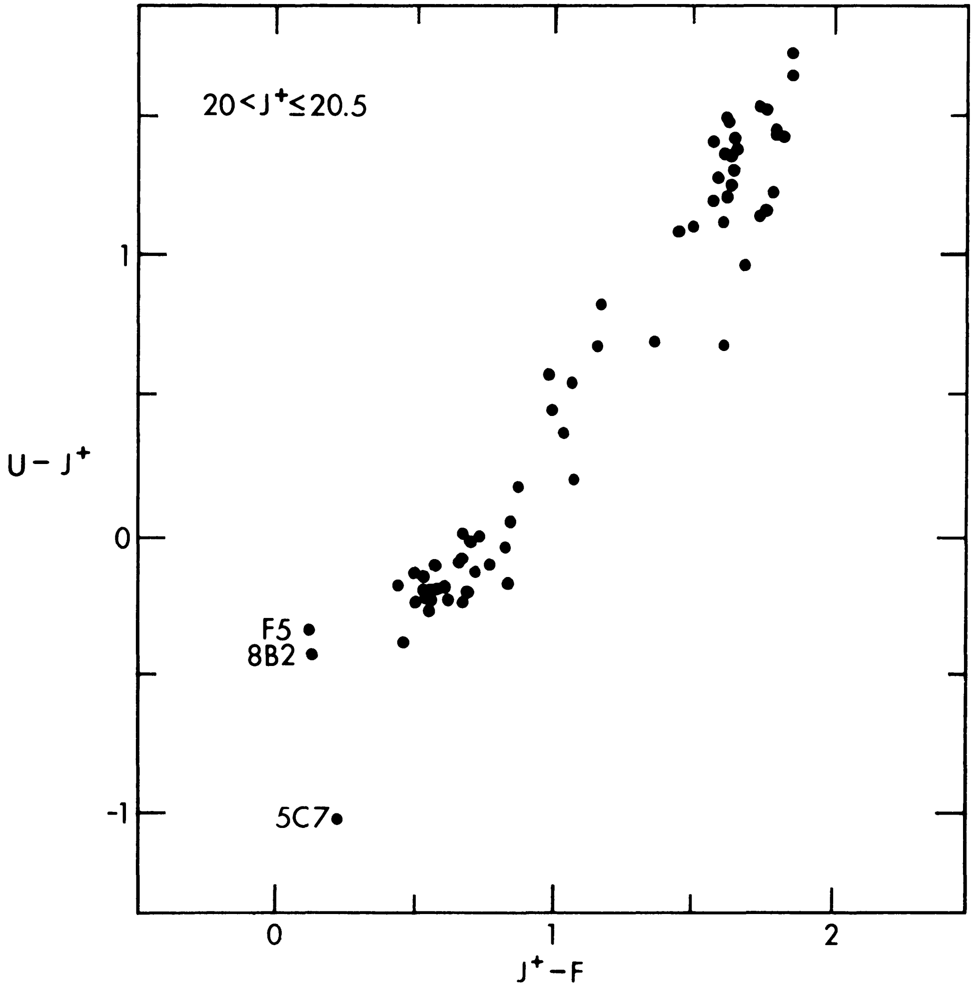

Figure 2. U-J⁺ vs. J⁺-F for stellar objects in SA57.

and may be only marginally larger than the seeing disk. Koo and Kron (1982) used eight 4-m plates to obtain accurate colors and image sizes for all objects in the field of SA 68. They found that the total optical light from QSO's is converging for B $\gtrsim$ 21; also, almost all of the objects which did not have the colors of ordinary stars had UV excess (see also Kron and Chiu 1981). An important qualification of Koo and Kron's work was the lack of spectroscopic verification. In the meantime, Koo and Kron (unpublished) have repeated the survey for the field of SA 57, for which some spectroscopic checks are available (Kron and Chiu 1981). Figure 2 shows a color - color diagram for all stellar objects within a half-magnitude interval, with three known QSO's identified. The other magnitude intervals confirm the accuracy of the color classification, so the contamination from hot stars should indeed be small. Still, this demonstration does not test the nature of the B = 22.5 candidates (see Koo 1982).

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