back into the A-type stars. The resulting large difference in effective temperatures means that the match is very poor, and the more prominent metal lines indicate quite a different "metallicity type" than the weaker or "background" metallic lines. The cautions and caveats mentioned in the previous section in the context of classifying the intermediate Population II stars are of even greater importance here. In short, these stars really need to be classified on an extension of the MK system that would permit the use of metal-weak standards, such as that of Gray (1989); Gray has provided fragmentary "preliminary sequences" of standards that may be used for halo dwarfs, although new digital spectra indicate that a number of those standards are in need of significant revision. The spectral types in Figure 6.13 are our best efforts based on Corbally's system (Corbally 1987).

HD 19445, a halo G2 dwarf, is also compared in Figure 6.17 with HD 119516, a halo G0 "giant" (actually, a red horizontal branch star). This comparison shows that the usual luminosity criteria are operative in these halo stars, even though the ionized-to-neutral ratios are somewhat different from what one would expect in Population I stars (i.e. the lines of ionized species are stronger relative to the neutral lines than we see in Pop I stars of the same luminosity class: see discussion in the previous section).

It turns out that HD 140283 is actually slightly evolved off the main sequence; it is properly termed a halo "turn-off" star. Notice that its spectrum is very similar to that of HD 19445, except that some of the prominent low-excitation lines (such as Fe I $\lambda\lambda$4046, 4383, and Ca I λ4226) appear weaker in HD 140283. Apart from this weakening (which may be due to a difference in the gravities of the two stars, as similar effects can be seen in the MK standards), the standard luminosity criteria give no hint that HD 140283 is evolved relative to HD 19445. We have thus classified HD 140283 as a dwarf even though we know, from external information, that it is evolved.

It is immediately clear from hydrogen-line strengths alone that BD +25° 1981 is considerably hotter than the other two halo stars in Figure 6.13. Indeed this star, while on the main sequence, is hotter than the turnoff indicated by other halo dwarfs. It appears that BD+25° 1981 is a good example of a halo field blue straggler (see Carney et al. 2005).

6.5 CHEMICALLY PECULIAR F-TYPE STARS

6.5.1 The ρ Puppis Stars

The ρ Puppis stars are a group of unusually late, probably evolved Am-type stars (see §5.4.1). ρ Puppis, the prototype of the group, used to be classified as a δ Delphini star, but the designation "δ Delphini" has now been dropped by most astronomers because of confusion over the characteristics of stars that should be included in the "δ Del" group. Before we discuss the ρ Pup stars in detail, let us review the history of the δ Del group to illustrate why this designation has been dropped.

The δ Del stars were first recognized as a class by Bidelman (1965) who defined them as "metallic-line stars ... in which the difference between the metallic-line type and the K-line type is rather small." Stars satisfying such a description would now be included in the group of *proto-Am* stars, another term for stars that show mild Am characteristics. Cowley (1968) classified a number of stars as δ Del, giving a slightly different definition as stars in which "the metallic-line spectrum resembles that of an F2 IV star but the hydrogen and ionized calcium lines are very narrow." Morgan & Abt (1972) classified a number of δ Scuti variable stars (these are A and early-F main-sequence pulsating stars), including δ Del, and found them to be inhomogeneous spectroscopically. Some of these stars appear normal and others show weak Ca II K & H lines. Later, Malaroda (1973, 1975) classified a number of stars that show similar peculiarities to the peculiar δ Scuti stars as δ Del stars. Houk, in the Michigan reclassification of the HD stars (see references under Houk in the bibliography), has consistently classified stars that appear to be late Am stars as "Fm δ Del". It is clear from this survey of the literature that different classifiers have meant different things when they have classified stars as δ Del.

Gray (1989) reclassified many of the bright δ Del stars and found that they fall into four groups. A number of these stars appear essentially normal, and were probably put into the δ Del class on the basis of their narrow spectral lines, a consequence of low rotational velocities. Another subset of these stars again look essentially like normal, evolved F-type stars, with, perhaps, a minor strengthening of the metallic-line spectrum. This group includes δ Scu. The third group, including δ Del itself, are proto-Am stars. It is interesting to note that δ Del is a high-amplitude double-lined spectroscopic binary, lines of which may be resolved at quadrature in classification spectra. This double-lined nature creates a dramatic change in the appearance of the spectrum of this star. Finally, the only subset of the "δ Del" stars that appear to form a distinct and interesting class of stars are the stars ρ Pup, θ Gru, HD 103877, and possibly τ UMa.

The three stars ρ Pup (the brightest), θ Gru, and HD 103877 are the prototypes of the ρ Puppis class of stars. These stars, which appear to be late Am stars (all three show the "anomalous luminosity effect," see §5.4.1) are outstanding because (1) their hydrogen-line types are F5, remarkably late for Am stars, and (2) their luminosity types, as determined from the Fe II, Ti II $\lambda\lambda$4172–9 blend, and Sr II $\lambda\lambda$4077 and 4216 lines, are extreme, ranging from II–III to Ib. While these luminosity types probably do not reflect the true evolutionary state of these stars, being due to the anomalous luminosity effect (HD 103877 shows this effect to an extreme), there is little doubt that these stars do lie well above the main sequence, and thus are evolved. For instance, the absolute visual magnitude of ρ Puppis is $M_V = 1.41$, suggesting the star is a subgiant or giant. Figure 6.14 shows the spectral characteristics of these stars, including the very pronounced anomalous luminosity effect in HD 103877.

The star ρ Pup is itself very interesting, and has been the subject of a number of studies. Of great interest is that fact that it is a δ Scuti pulsator with a large amplitude (see Mathias et al. 1997). The star HD 40765, another ρ Pup star, is also

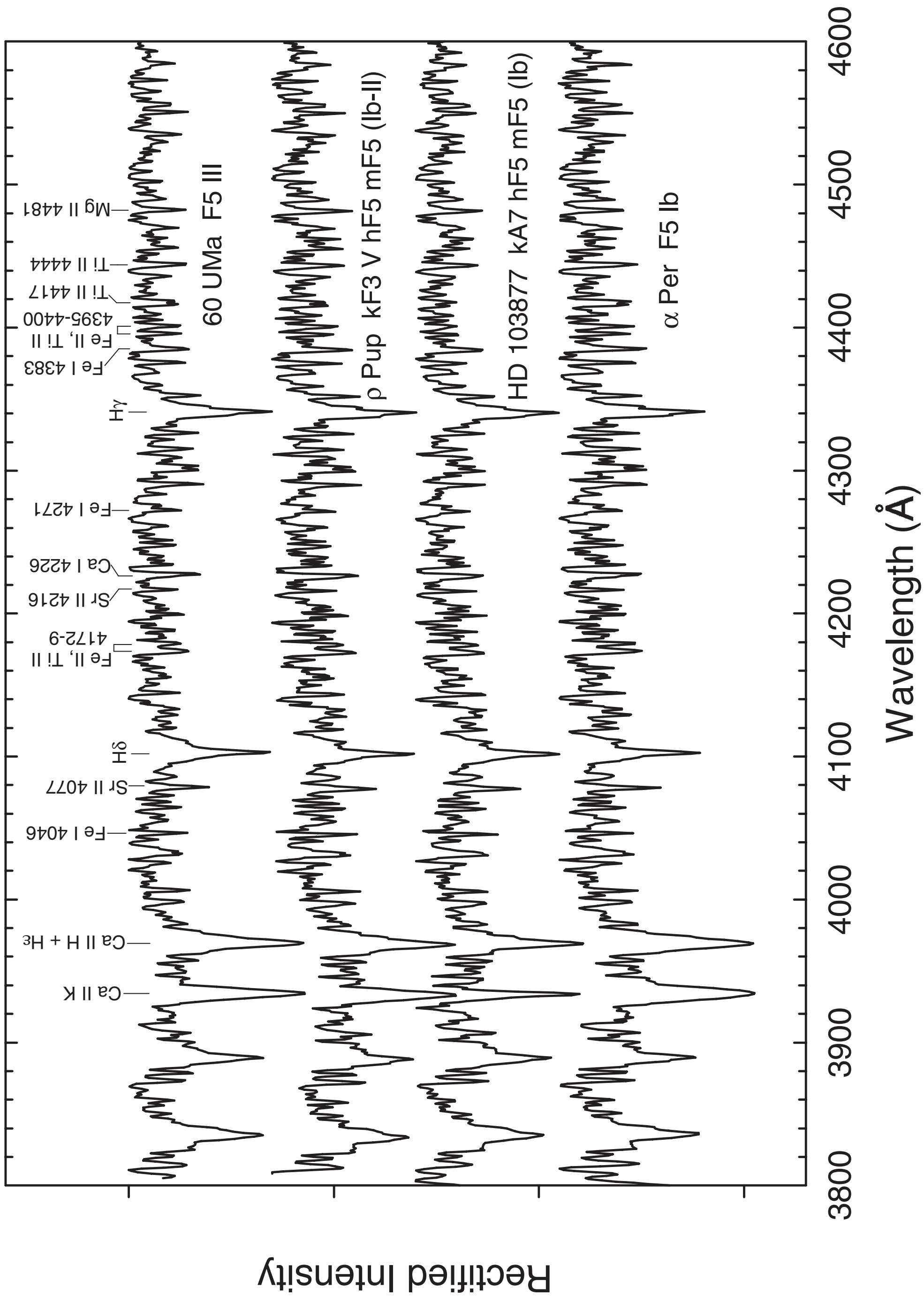

Figure 6.14 Two ρ Puppis stars, ρ Pup itself and HD 103877, compared with two MK standards. The luminosity types of the ρ Pup stars are based on Sr II λ4077, λ4216, and the Fe II, Ti II $\lambda\lambda$4172–8 blend. Note the strong anomalous luminosity effect in HD 103877, revealed by strengths of lines of ionized metals between $\lambda\lambda$4383 and 4444.

a δ Scu pulsator (Kurtz et al. 1995). This is significant because δ Scu pulsation is generally very rare among Am stars. This is thought to be the case because helium has settled in Am star atmospheres, resulting in the loss of the helium convection zone. The engine for the δ Scuti pulsations is connected with helium ionization in this zone, and so it makes sense that Am stars are generally not δ Scuti pulsators. Thus, the presence of δ Scuti pulsation in ρ Puppis stars suggests this zone is still intact, or has been re-established. Indeed, this observation may be consistent with the scenario that ρ Puppis stars were Am stars during their main-sequence lifetimes, have now evolved off the main sequence and, as a consequence, are developing deep convection zones as they expand and cool (Kurtz 1976). The co-existence of pulsation and the Am phenomenon in these stars suggests that we have caught them at a point before convection has entirely erased their Am abundance peculiarities.

There are not many ρ Pup stars known, and discovering more members of the class would be of great interest. A graduate student of one of us (ROG) is currently working on this problem. Prime candidates for this search would be the Fm δ Del stars classified by Houk.

6.5.2 F-type λ4077 Strong Stars and Barium Dwarfs

In the course of an "early result" program undertaken by Bidelman and MacConnell to discover astrophysically interesting stars on the objective-prism plates intended for the Michigan HD reclassification program carried out by N. Houk, Bidelman (1981, 1983, 1985) classified 20 F-type stars as "λ4077 strong," meaning that the Sr II λ4077 line appears abnormally strong in these stars. These stars are distinguished from the late-type Ap Strontium stars (see §5.4.2) on the basis of their temperature types; all of these stars have spectral types between F5 and early G, considerably later than that of any Ap star. Later photometric and spectroscopic analysis by North (see North et al. 1994, and related papers) revealed that some of these stars are late Am or "δ Del" (ρ Pup—§6.5.1) stars, but that a number are genuine late-F, early-G dwarfs with not only a strontium overabundance, but also overabundances of other *s-process* elements including barium. These stars are now known as *barium dwarfs*. Other barium dwarfs have been discovered and analyzed by Tomkin et al. (1989), Edvardsson et al. (1993), Porto de Mello & da Silva (1997), and Gray & Griffin (2007). Figure 6.15 illustrates the spectra of two of these barium dwarfs, HR 107, an F5 dwarf, and HR 5338, an F8 dwarf.

Inspection of Figure 6.15 shows that the distinguishing classification feature of the F-type barium dwarfs is not an enhanced Ba II λ4554 line (the enhancement of this resonance line of Ba II is only marginally detectable in classification-resolution spectra), but exceptionally strong lines of Sr II λ4077 and λ4216. The reader will recall that Sr II λ4077 and λ4216 are primary luminosity criteria for the late F-type stars, but the other luminosity criteria indicate that these stars are main-sequence objects. Many of these stars are also slightly metal-weak, and they, as well, can show peculiarities in the G-band, in that the G-band can be slightly strong or weak compared with the hydrogen-line type.