V CLASSIFICATION RELATED SPECTROPHOTOMETRY BY CLASSICAL TECHNIQUES AND BY NEW REGISTRATION AND DETECTION METHODS

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SPECTROSCOPY WITH NEW DETECTORS

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ABSTRACT

Modern digital spectrophotometric devices allow for a much more rapid gathering of spectroscopic data on stars and galaxies. Colors and line strengths can lead to new classification schemes, and/or physical interpretations of much fainter objects than previously possible. However, the same old conceptual problems of interpretation (e.g. in abundances of G and K stars) remain a serious difficulty. Illustrations of these accomplishments and problems are given.

1. INSTRUMENTAL PROGRESS

The 1970's has been a decade of great instrumental promise for the astronomer who wishes, as always, to observe the next fainter star or galaxy. New digital image tubes, of several working types, have been introduced at the foci of large reflectors. Thus new multi-channel (and multiplex) instruments enable observers to obtain spectra of fair quality on very faint stars. I shall try to list some of these new detectors, discuss their merits and drawbacks in a qualitative manner.

Over the years, the photographic plate has been a fine detector for astronomy. But now we have more. The reader interested in the operating details of the new generation of TV-type detectors has several review papers at his disposal. They are, by now, a little bit dated, but it does not matter much in our context here. The reviews and technical reports are located in the symposium proceedings Astronomical Observations with Television-Type Sensors (Glaspey and Walker, eds. 1973), and in Livingston (1973).

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Successful application of many of these devices is just underway. A review performed in 1980 would likely be rather different.

First, the silicon-vidicon frame integration systems will be discussed. Photons are converted to a charge by the silicon matrix; a read-beam creates an analogue signal, which is measured. Without intensification we depend upon the quantum efficiency of the silicon, which is quite high in the red and near-infrared, a region basically unavailable to the intensified systems. The "barefoot" silicon vidicons can be useful for stellar work if a large number of photoelectrons are to be collected; the data must have a prospectively high S/N ratio. McCord has used it successfully; the reticon diode array type has been employed by Campbell (1977) for stellar spectra in the deep red.

Next we have the intensified version, or SIT - where the end product is still a frame integration on the silicon target (beam-read), but the "front end" is now a fiber-optics face plate (Westphal 1973) which is curved on the inside and coated with an S-20 photocathode. A voltage of $\sim$10 kv is applied to an electrostatic acceleration system, which focuses the energetic electrons on the silicon target. The gain is roughly 2000 times, while now the spectral range is that given by the photocathode and fiber optics bundle. A slight disadvantage of the SIT is the limited dynamic range; the night sky line 5507 Å of [OI] can saturate at low dispersion in about $1^{h}.5$ exposure.

The Hale CTIO observers have made much use of SIT-vidicons, for direct work, and galaxy and quasar low-dispersion spectroscopy. Some stellar spectrophotometry has been reported by Greenstein (1977) and Hesser (1978), and more is likely to appear soon.

A third successful system is the UCSD "digicon"; again a silicon target of individual diodes, each with a lead-out wire, counts individual 15 kv photoelectrons from a S-11 photocathode. The dark current is very low, the peak quantum efficiency is near 4200 Å, and the digicon dynamic range is an excellent 10^8!

Results from this limited coverage (40-512 diodes in one or two array lines), but excellent fidelity system, have been reported on faint objects (quasars, a few white dwarfs) by Beaver (1973), Liebert et al. (1977) and various other Arizona observers.

Space applications with this reliable and hardy device are planned; it is the detector chosen for the Faint Object Spectrograph of Space Telescope, for use in the mid-1980's. A 512-channel digicon should be pretty efficient in this application, although it is not the instrument with the largest multiplex advantage. Good ultraviolet response will be obtained with a bi-alkali photocathode on a MgF_2 faceplate.

A very successful digital image tube in operation at the AAT in Australia, the I. Newton telescope in England, and occasionally at Palomar and Kitt Peak, is the Boksenberg and Burgess (1973) Image Photon Counting System (IPCS). Photoelectron scintillations exhibited by (the last stage of) a high-gain intensifier chain are detected by means of a continuously scanning TV camera, which acts both as a spatial locator, and as a one-frame buffer storage. An on-line mini-computer records position and number of photoevents in each frame (two dimensions, 10^6 pixels in each frame). Some effort has gone into the on-line image processing. Results to date have included spectra of the Doppler cores in Balmer lines of white dwarfs (for rotation limits in the DA's - c.f. Greenstein 1976), many spectra of absorption lines in quasars, and blue variable stars [(Greenstein 1976, Green, Greenstein and Boksenberg (1976)].

A very different approach to new instrumentation puts the initiative into the basic instrumental concept - not the detector. I refer here to Michelson or Fourier Transform Spectrometers. FTS systems have been used previously in the infrared (c.f. Mould 1978ab); now they are working down in the visible region. Recent papers using these new instruments have been published by Pritchet (1977), Pritchet and van den Bergh (1977), Johnson (1977), and Johnson and Wisniewski (1978).

Johnson's system produces the equivalent of "4000-color" photometry, in a new photometric system which has a narrow-band, square-topped filter-like response. The width of each resolution element is 3.8 cm^{-1} (3.8 Å at 1μ). Johnson used the first spectra (4000-10,000 Å) to measure the Balmer and Paschen equivalent widths in bright A stars. Silicon diodes have been used as the detectors.

The Pritchet-van den Bergh FTS spectra (1977), of all common stellar spectral types, covered 3800-6800 Å (the detector was an S-20 photomultiplier) at relatively low resolution [12 Å at 3800 Å, 45 Å at 6800 Å]. Pritchet (1977) then used the stellar data, plus his spectra of the nuclear parts of bright galaxies (M31, M32, and M81 were included) to synthesize their stellar content.

I am, of course, most familiar with the instrument in almost constant use at the 3-m reflector of Lick Observatory. This is the Robinson-Wampler-Miller IDS system. The IDS is a hybrid system-3 Varo intensifiers and an image dissector programmed to sweep over the two (star + sky, star) spectra glowing on the last output phosphor. The great efficiency gain over photographic spectroscopy comes at the photocathode, in this case an "extended S-20", which permits spectral coverage over 3800-8400 Å with the "red" tube. Then there is the multiplex advantage of 2048 simultaneous channels, about 350 really independent resolution elements, in normal focus.

However, the loss in fidelity, compared to 350 ($\Delta\lambda$ = 6Å) photomultipliers, is non-trivial. By fidelity, I mean reproducability at the 1% level, when 10^4 cts/pixel are accumulated. As Livingston (1973) remarked: "The image-tube system is not equivalent to an array of photomultipliers." Scattered light, slight cross-talk between channels, and slowly varying fine-scale structure in the phosphors or the dissector path prevent photometric accuracy in each of the 2048 channels. The memory of the last intensifier phosphor demands that observations of faint sources be attempted before, rather than immediately following a bright object in the observing program.

Still it is wonderful to obtain digital spectra of V = 15^m stars in about 16 minutes (with the 3-m reflector); with observer perserverence and the excellent sky-subtraction of the IDS, galaxies as faint as V = 23 have been successfully observed too (over a couple of years), but that is another talk!

2. SPECTRA OF COOL STARS WITH VARYING METAL/H RATIOS

2.1 Classification Problems of Metal-Poor Dwarfs (and Giants)

It has been known for a long time that abundance anomalies (with respect to the Sun, or the Hyades, for example) can feign an error in spectral type assignment. A metal-poor star, with the photospheric temperature of K0 V may be initially classified as an almost-normal G6 V, or vice-versa for metal-rich stars (Spinrad and Taylor 1969). Metal-poor K giants of the halo population were, at one time, called G dwarfs, because of their absolutely weak lines, and the relatively (for a K giant) high state of ionization shown by the classification ion/neutral metal line ratios.

The montages of spectra I now show, illustrate these phenomena; first we compare (see Fig. 1) the high-velocity [T $\simeq$ 300 km s^{-1}] dwarf G44-25 with a normal K2 V star, HR 6806. Note how well their continua match at $\lambda \geq 5000$ Å. This is taken to mean temperature equality between the stellar pair, a good starting point for a simple comparative abundance study. (Obviously in a detailed comparison between a metal-poor and a normal K dwarf, T(τ) would differ.) We note the weakness of the NaD lines in the high velocity star; neutrals disappear first with lowered overall [M/H] at $T_e \sim 5000°$ K. Of course, it is possible that G44-25 has a real [Na/M] deficiency,

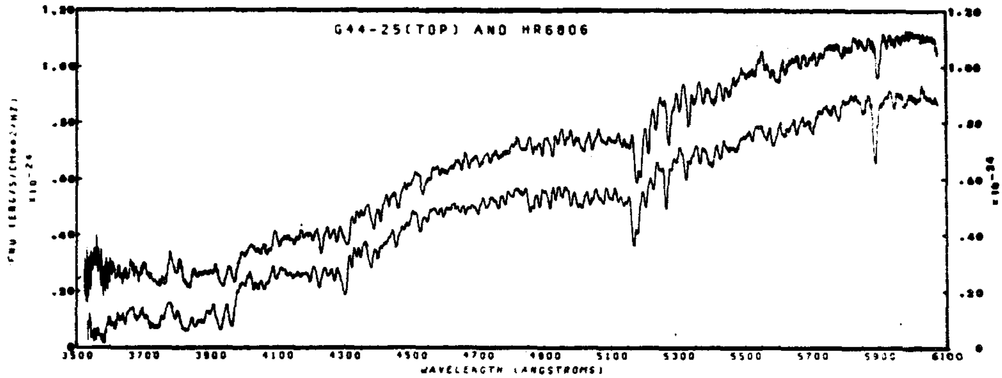

Fig. 1. A montage of Lick IDS spectra compare the high velocity dwarf, G44-25, with the normal K2 V star, HR 6806. The Spectral resolution is 6 Å; note that G44-25 spectrum is offset upwards. The weakness of the neutral metal line in G44-25 is evident.

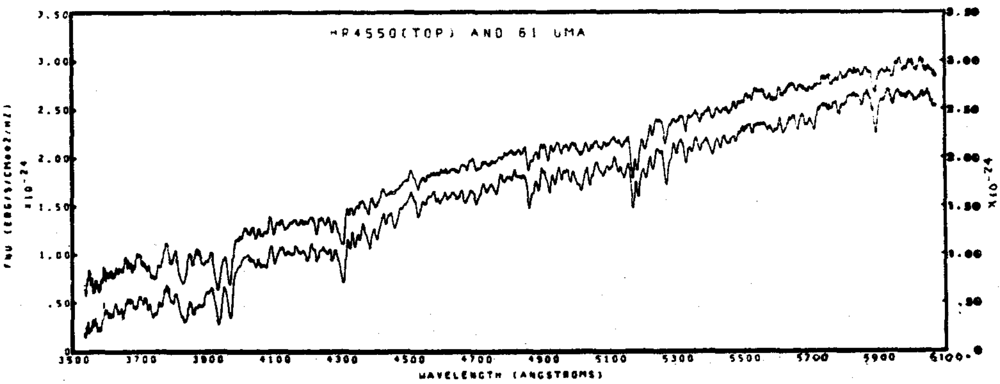

Fig. 2. A montage showing the spectra of HR 4550 = Grw 1830, with 61 UMa, at G8 V. Again, note the good continuum match and the line-weakness at 5000 Å in the metal-poor star, HR 4550 (20 times underabundant).

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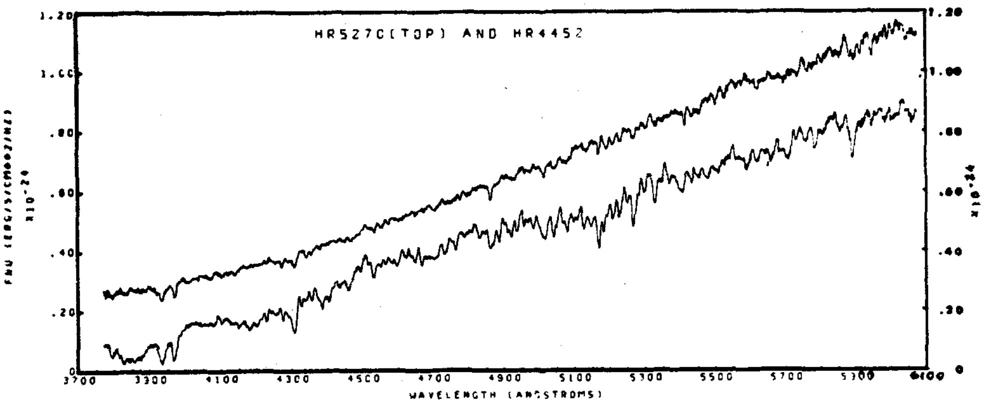

Fig. 3. A montage with the extremely-metal-deficient giant, HR 5270, compared to the normal K2 III star, HR 4452. See the discussion in the text.

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too. Similar remarks apply to Groombridge 1830 = HR 4550, a metal-poor subdwarf, compared in Fig. 2 to the normal G8 V star, 61 UMa. The D lines in HR 4550 are weak, and the intrinsically weak lines between 5701-5713 Å (mostly neutral Fe and Ni lines) are obviously much reduced in the HR 4550 spectrum, compared to that of 61 UMa. Some equivalent widths determined from the Lick IDS spectra of these stars are listed in Table I; that is another easy virtue of the input digital data.

In any case, these illustrations show us why the old photomultiplier measures of the sodium resonance lines were successful and sensitive (damping part of the curve of growth, so relative abundance went as the square of the line strength ratio) ways to locate stars of atypical abundance, at types later than G0 V [c. f. Griffin and Redman 1960, Griffin 1961, Spinrad and Taylor 1969]. The strong-line ions, like H and K of Ca II change very little in these comparative spectra.

In the case of the famous extremely metal-poor giant, HD 122563 = HR 5270, we have compared it to the normal (and roughly equal red color) giant HR 4452. Note in Fig. 3 that the NaD lines are very weak in the metal-poor star (underabundant by 500 x in Fe/H, according to Wolfram 1972). The strongest lines in the HR 5270 spectrum are (in the blue) H and K and of Ca II, Hβ , and marginally 5175 Å of MgI, while in the red, Hβ is the strongest absorption in this cool (∿4600°K) star!

These illustrations have been of relatively bright, well-known stars. But there is no reason why the IDS, if located on a 1-m reflector in a good site, could not produce spectra of many stars, V = 13-14, in reasonable (1^h) integration times. This brings globular clusters into reach for detailed study, along with lots of galactic cluster giant branches, and almost all the stars with known large μ and/or measured parallax.

2.2 Current Work on Globular Cluster Nitrogen Variations

The efforts of photometrists, and some spectroscopic work during the last six years, have awakened the specter of abundance inhomogenieties within individual globular clusters, especially as concerns the light elements(C, N, O) in evolved giant and subgiant stars.

The large width in photoelectric color of the giant branch in ω Centauri and a few other clusters initiated the quest for spectroscopic explanation. Research results by Zinn (1973), Dickens and Bell (1975), Kraft (1975, 1978) and recently by Hesser (1978) have shown a surprising variability in the blue and violet CN, CH,

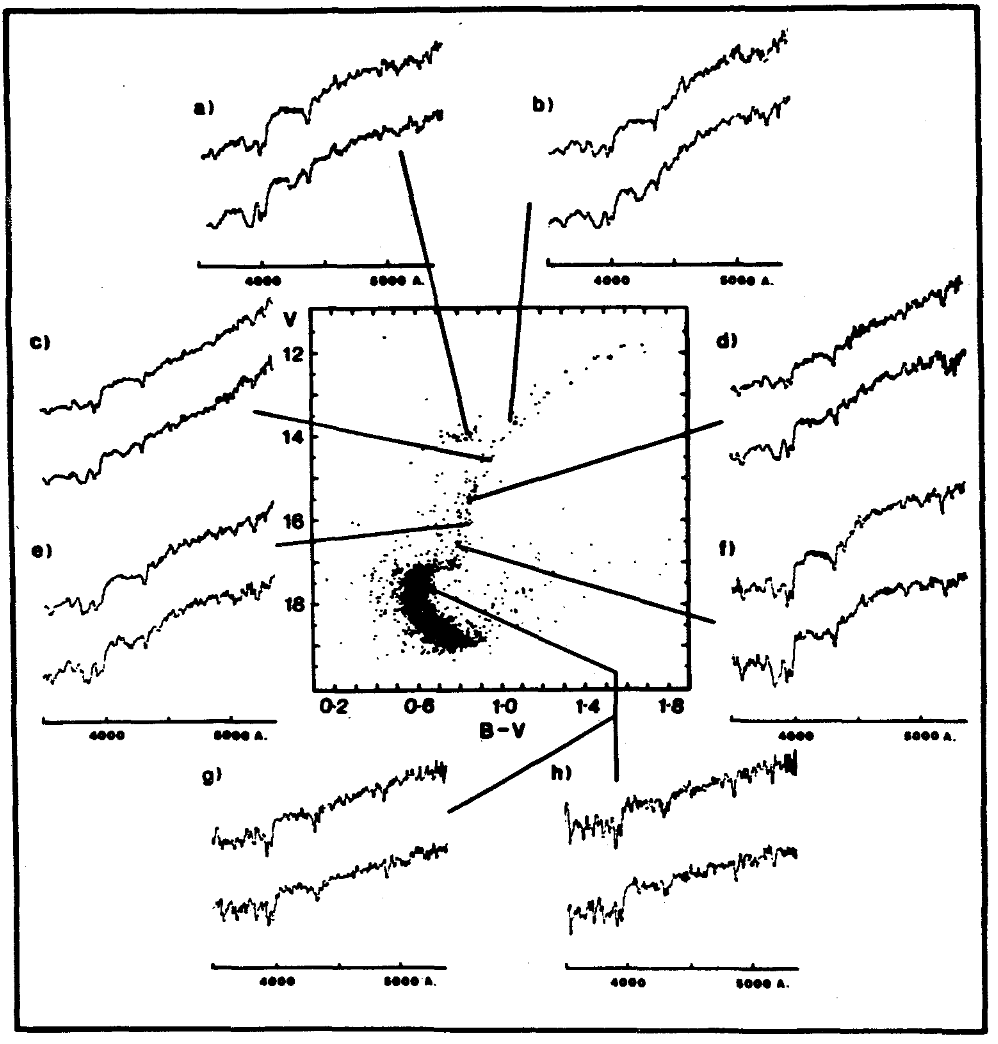

Fig. 4. Hesser's spectra of stars in various portions of the C-M diagram of 47 Tucanae. CN variations can be noted on the pairs of SIT-vidicon spectra (at 3880 Å); this is especially evident in spectral pairs (a) and (d).

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TABLE I

EQUIVALENT WIDTHS OF LINES AND BLENDS IN G AND K STARS: W (Å) TABULATED

Star	Types	Na D	5705 Å Blend
HR 4452	K2 III	1.80	1.30
HR 5270		0.46:	0.30
HR 4550	G8 V	1.29	0.47
61 UMA		1.71	1.30
G44-25	K2 V	1.94	0.11
HR 6806		3.43	1.09

and NH (3300 Å) bands in the spectra of red giants in a given cluster. Hesser's SIT-vidicon scans of some 47 Tuc red giants and subgiants are shown in Fig. 4 (Fig. 2., Hesser 1978). The 3880 Å (0,0) CN band is clearly different in Hesser's marked star pairs. There may be an inverse correlation between NH and CH in M92 giants, but Kraft believes more data is needed to (possibly) tighten up the anti-correlation.

The heavier metals, in the Fe group elements, however, are still thought to reflect the initial abundances, and are (hopefully) invariant and invulnerable to mixing. Surely the mixed material can contain processed N^{14} (at the expense of C^{12}?) A major problem obvious now is whether the mixing extends down to the unevolved main-sequence stars, or even if there is some heterogeneity in the initial main sequence abundances of C, N, and O. Hesser's spectra shown CN variations in the subgiants at $M_V = +3.5$ in 47 Tuc. To check main sequence G8 V stars, $M_V = +5.5$ in 47 Tuc will require good spectra of faint stars, B = 19.6. This can be done with a long and heroic effort, from the ground, with the southern 4-m reflectors.

Are other strong cyanogen stars of Population I (or even SMR stars) N^{14}-rich because of internal mixing? In super-metal-rich stars this is a handy scenario, since N could perhaps cool the outer layers of a red giant, and the then lowered boundry temperature might explain the strong neutral-metal-lines seen in their spectra. However, recent work by Deming, Olson, and Yoss (1977) suggests δ (CN) (as measured photometrically) to be basically correlated with [Fe/H] in evolved and unevolved late-type stars. Thus it would appear unlikely that meridional mixing has been important for "Pop. I" G and K giants. How do we reconcile this idea with the previously mentioned (strong) evidence from the evolved stars in globular clusters?

3. THE OBSERVATIONAL STUDY OF STAR FORMATION

Through conversations with my Berkeley colleagues, Leonard Kuhi and Martin Cohen, I have tried to reconstruct part of their large effort on observations of young stars, especially the T-Tauri stars. Here we seen an example of the dissection of a complex spectroscopic problem by a quantitative analysis made possible with the new detectors.

The Cohen-Kuhi (1978) resume, now in press, discusses the HR diagram positions of the T-Tauri stars, their probable ages, location of formation, and chromospheric emission spectroscopy; the T-Tauri stars and associated objects generally show an underlying photospheric spectrum, often a strong and perhaps variable (emission line and continuum) chromosphere, plus some reddening. How did they disentangle all those things?

In the best cases, a good photospheric spectral type may be derived from the yellow-red IDS scans ($\Delta\lambda$ = 6 Å). The criteria are (roughly): H-Balmer wings in $H\alpha$ and $H\beta$ for B, A, and F stars (the cores are often in emission), for G and K stars they used the relative absorptions in Mg I 5175 Å, the FeI blend at 5270 Å, and the appearance of Na "D", while for M stars (found to be intermediate between V and III gravity from 6385 Å of CaH) the various TiO bandheads and Na "D" were the type criteria. Narrow-band indices were formed from the digital data to compare with our standard star spectra, using the TiO heads over 4955-6159 Å in particular. In the Taurus-Auriga dark cloud complex most of the stars are M's, so Cohen and Kuhi conclude that they have typical masses of $0.5M_\odot$ (see Fig. 5, the HR diagram's theoretical plane).

The chromospheres are strong in the (supposedly) youngest objects; emission lines of H, He, [OI] and Fe II are very prominent in stars like RW Aur and DG Tau (Fig. 6) where only a weak hint of the underlying photosphere is possible. No good spectral assignment is then possible. Intermediate cases like XZ Tau, CI Tau, and YY Ori illustrate (Fig. 7) the appearance of the stellar photosphere, still partly veiled by the chromosphere. In Fig. 8 we show the IDS scan of LkHα197, where Balmer emission lines cover the H lines in the underlying K7 V star.

For these chromospheric emission stars, Cohen and Kuhi find a good correlation between $H\alpha$ and He I 5876 Å fluxes, a good point for a linear detector of large dynamic range.

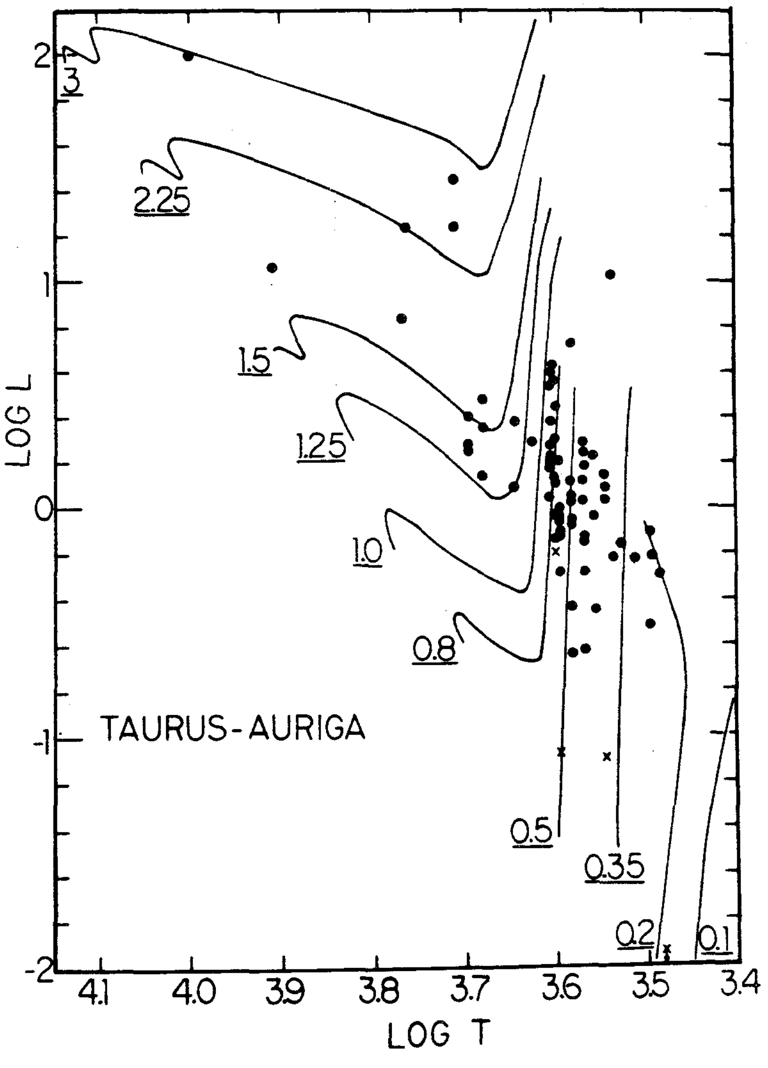

Fig. 5. The theoretical pre-main sequence HR diagram convective construction tracks, with the positions of Tau-Aur young T-Tauri stars indicated (from Cohen and Kuhi). Note most of the objects are and will be M stars.

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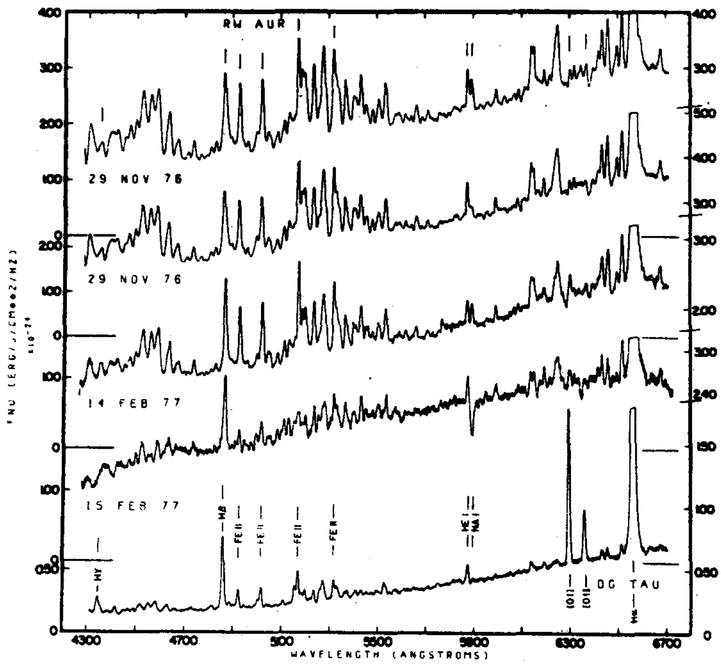

Fig. 6. Strong chromospheric emission in the IDS spectra of T-Tauri stars RW Aur and DG Tau. Note time-changes in RW Aur. For these extreme examples, assignment of an underlying spectral type may not be possible.

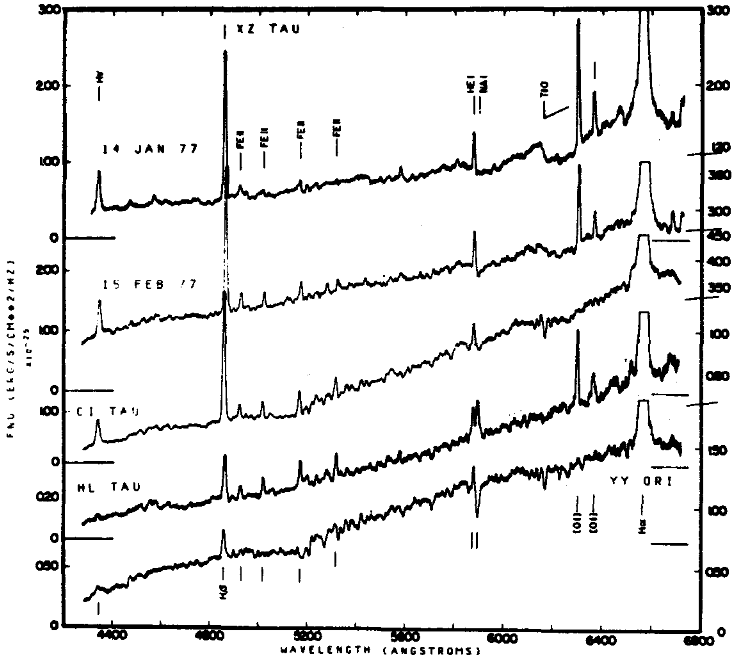

Fig. 7. Spectra of T-Tauri stars with intermediate chromospheric activity; the underlying late-type photospheric absorptions are visible in most of these cases.

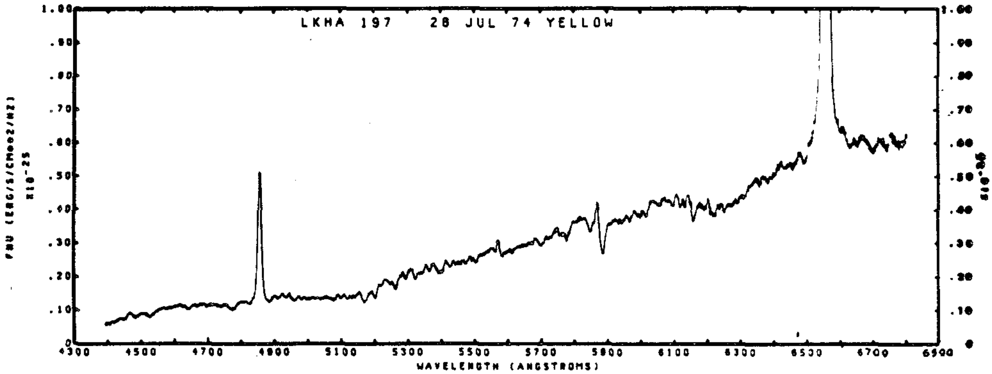

Fig. 8. An IDS scan of LkH 197, a K7 V T-Tauri star, with only strong H Balmer emission lines.

To go back a step, they determine the star's effective temperature from the photospheric type; for the luminosity determination a reddening and extinction correction from the continuum shape compared to unreddened standards [The Balmer decrement proved unreliable, because of some collisional excitation?], an apparent scanner V magnitude and an infrared magnitude were needed, along with the usual indirect distance estimate. Hence bolometric luminosities are used in Fig. 5. The convective-radiative tracks used for different stellar masses from from Grossman and Graboske (1971), Taam (1978), Bodenheimer (1965) and Iben (1965) for masses 0.1 to $3.0M_\odot$. Many of the T-Tauri stars appear to lie on the convective pre-main sequence tracks, especially in Tau/Aur, where five times as many seem to be "convective" as opposed to being on the radiative evolutionary portions.

Work on the physical interpretation of the chromospheric spectra by Calvet and Kuhi is underway; first indications favor a "thick chromosphere", which can be important in both line and continuuum radiation (especially at short λs).

4. THE SPECTRA OF LOW-LUMINOSITY STARS

4.1. M Dwarfs and Sub-Dwarfs

Long-ignored by most classifiers and especially by astrophysicists, the M dwarfs are little stars beginning to receive the attention they commend by sheer numbers. Relative abundances, with respect to an internally defined field main-sequence (it would be

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important and difficult to use the Hyades lower main-sequence) and a model-atmosphere grid have been determined by Mould (1978a,b). Using the Kitt Peak FTS, Mould obtained spectra of high resolution in the 2.0μ window. He found his M subdwarfs to be underabundant in metals, with Gl205 metal-rich ([m/H] ∿ +0.5). This is an important beginning, of which we shall soon hear directly from Jeremy Mould.

Another propertly of M subdwarfs is that they are often spectroscopic "hydride stars". I discuss these creatures, briefly, next.

I think the hydride stars were first discovered by Jesse Greenstein, that superb collector and recognizer of unusual stellar spectra. All of the M dwarfs usually show some hydrides of calcium, magnesium, and now even of CaO, in their yellow-red spectra [see Fig. Fig. 9, in which seven normal M dwarfs with a progression (downwards) of increasing TiO strength and (R-I) color are illustrated]. These hydride bands have been known since the work of Ohman (1936) and Keenan (1957). However, some M dwarfs have much stronger MgH and CaH bands. The hydride stars observed by Jones (1973), Mould (1976) and by Liebert, Stauffer, Kron, and myself, are often stars of high proper motion. The paper by Kron (1977) and the thesis of Smethells (1974) and research by Bidelman all indicate a rough correlation of "hydrideness" with proper motion. Here (in Fig. 10) we illustrate three extreme cases; note the strength of the MgH bands (5100, 5200 Å) and, most strikingly, CaH at 6385 and 6970 Å. The Mg index of Kron (1977) would be over 40 for these three stars (off the diagram in that PASP paper); note that other atomic features suggest a spectral type of late K for the 3 hydride stars, so TiO-confusion with the hydride bands here is minimal. G95-59 and G165-47 are parallax stars, about two magnitudes below the old disk main sequence. Why are the hydrides strengthened in fainter stars? Is it a gas pressure effect, or one of molecular equilibrium change with a lowered metal-to-hydrogen ratio [TiO, CO, H_2O competition with hydrides as a f(m/H)]? Perhaps we will hear more from Jones on this point.

Just for fun, Liebert, Kron, and Spinrad (1978) have recently obtained good scans of VB 10, at M_V = +18.9 (dM8e?). This very red main-sequence dwarf has a spectrum (Fig. 11) which illustrates why it makes sense to utilize red and IR colors and magnitudes for such stars. The spectrum shows CaOH, along with TiO, but many of the bands appear with relatively low contrast against the continuum, probably because they have saturated and spread out. The most temperature-sensitive TiO bands are listed in Table II. Note the relatively abrupt and bright continuum peaks at 6500, 7000, and 7500 Å; at low dispersion for a very faint object they could be confused with quasar (broad) emission peaks, a considerable error in distance and redshift.

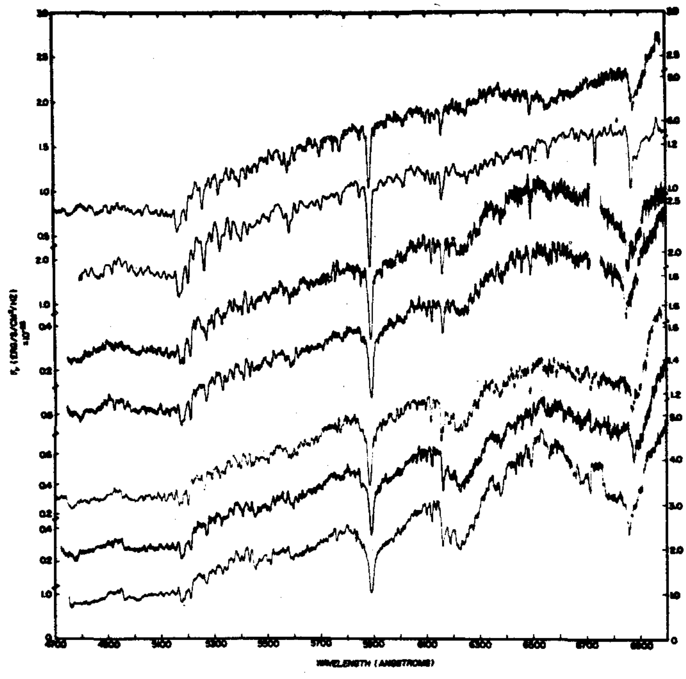

Fig. 9. A montage of IDS spectra of normal K7 V-M dwarfs, with the progression of TiO band strength increasing downwards.

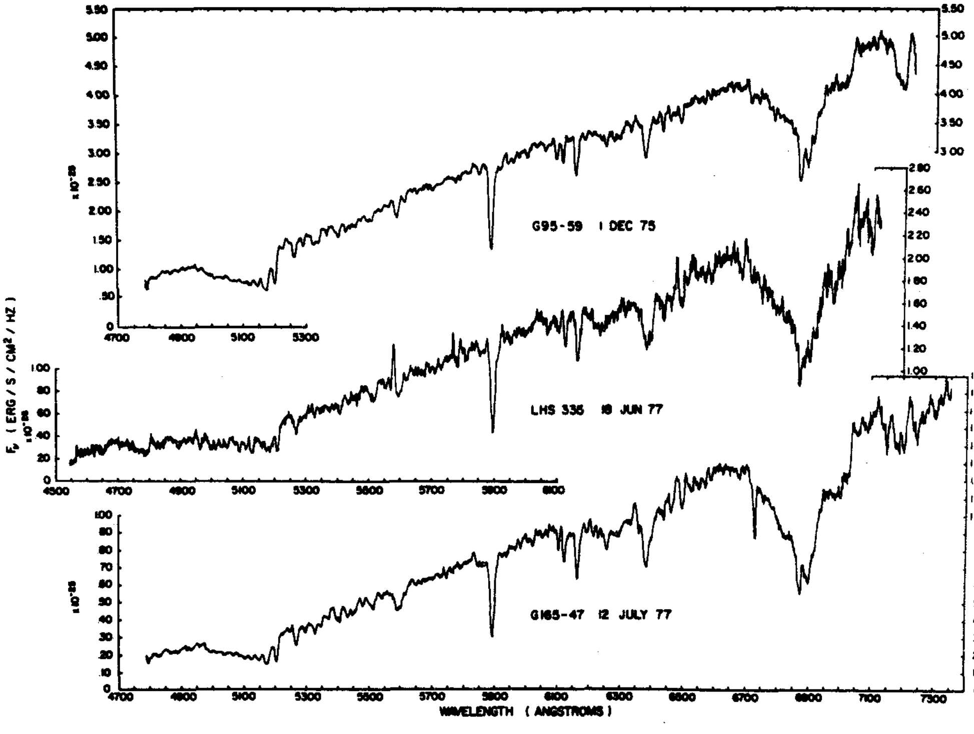

Fig. 10. IDS spectra of hydride stars near K7-M0 V. These are all likely subdwarfs; note the great strength of CaH 6900 A compared to the top stars illustrated in Fig. 9.

4.2 Digital Spectra of Degenerate Stars

Liebert's (1974,1977) work on the DF white dwarf Ross 640 demonstrated some of the instrumental gains of the new detectors over conventional photographic spectra; weak Hα and Hβ absorptions (W_λ = 5.3, 1.3 Å respectively) were first seen in Liebert's IDS spectra of this H-poor white dwarf. Still there is very little hydrogen, compared to helium, $N_H \simeq 3 \times 10^{-4} N_{He}$.

A very new and exciting insight on collapsed stellar magnetic fields has been made possible by digital spectra of faint white

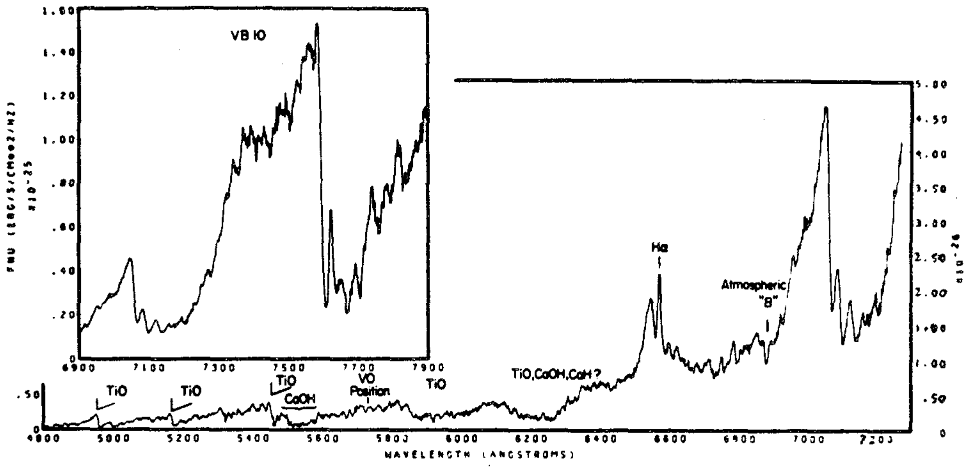

Fig. 11. An IDS spectrum sum for the very faint main sequence dwarf VB 10. Note weak Hα emission, and the strong continuum peaks.

TABLE II

TEMPERATURE SENSITIVE TiO BANDS IN COOL DWARFS

Name	M_V	I(4948)/I(4964)	I(5159)/I(5175)
Wolf 359	16.6	2.34	2.07
G51 -15	17.0	3.05	3.50
VB 10	18.9	7.5	4.1

dwarfs with very large fields. A minority of hot degenerates have almost unrecognizable spectra, which may be largely due to H and He I lines seen in unfamiliar places (Greenstein 1976, Liebert *et al.* 1977).

The detectability of surface fields by the Zeeman splitting of hydrogen Balmer lines lead to early negative results because of the great Stark widths of these features in the spectra of the brighter DA stars. For fields less than 10^5 Gauss, the linear Zeeman splitting between the two circularly polarized components is small (10 on Greenstein's Palomar prime-focus spectrograms).

But theoretically, hope prevailed! If the evolving star's general magnetic flux were conserved during its evolution and contraction from an initial surface (ad hoc) 10 Gauss field, the white dwarf field could easily exceed 10^5 Gauss. Of course, in most stars this simple idea fails; mass loss may carry away both angular momentum and the magnetic flux. Still, a few degenerates could have really large B fields exposed, if circumstances go their way . . . Now what does this mean for the spectroscopist?

For $B > 10^7$ G the quadratic term in the Zeeman-perturbed Hamiltonian, H^m will become important; recall eq. (1) [omitting the angular dependence terms in the equation]:

$$(1) \quad H^m = \frac{eB}{2mc} + \frac{e^2b^2}{2cm^2} .$$

For these very large fields the 2nd term dominates, and the quadratic Zeeman effect splits and blueshifts both the π and Σ components.

In the case of the star GD 90, a DAF; Hα, Hβ, and Hγ are split and broadened to the extent that they were initially unrecognized (Greenstein 1976). The surface field is about 5×10^6 G. A more spectacular case was recently discovered by Liebert et al. (1977), who observed the hot white dwarf Feige 7. Feige 7 has a rich optical spectrum with variable (broadband) circular polarization. The polarization observations indicate rotation with a period of 2^h2; spectra obtained with the Lick IDS and with the UCSD Digicon at Steward Observatory fit Zeeman patterns of H and neutral He with a mean field of 19 megagauss. The star, in fact, provides the first empirical confirmation of the theoretical quadratic Zeeman spectra of H and He I at such a high B field strength. The Hβ components, for example, covers 4540 to 5030 Å. 4471 of He I appears at 4400 Å.

Another amusing possibility at large surface B field levels, is that free electrons, radiating at their cyclotron frequency [2.8 x 10^6B hz] may be visible as a broad line in the infrared. No observational attempt to detect a stellar cyclotron line has, to my knowledge, been attempted.

5. SOME FUTURE PROSPECTS

In closing, I would like to attempt a forward look in the broad area of spectral classification of the future.

An exciting new area, for faint object pundits, will be digital array detectors behind a grism, or other dispersing device which yields intermediate dispersion over a reasonable field. The detectors could be CCD's or the IPCS or something else; with a large reflector one should be able to obtain digital spectra of all stars and galaxies and (??) within a square degree or two to about 21st magnitude. With the CCD this could open up the window, $\lambda > 8000$ Å, also.

Another possibility, for brighter stars, is a numerical classification based upon a template used for radial velocity, like the Griffin machine. The offset in spectral class from the template standard will be a well-determined amplitude at the stellar velocity peak.

And finally, from the dark sky of a satellite like ST, we have the hope of classification and search in forbidden spectral regions (see Code's talk in this colloquium), and the hope of observing even fainter objects. It would be instructive, for example, to apply classification criteria to the spectra of globular clusters in the Virgo cluster, when ST is operational in the mid-1980's. Certainly, a review like this one will be badly dated at that time, if our science advances at its current pace.

I would like to acknowledge the assistance of John Stauffer in many aspects of preparing this review. I also thank Jim Liebert, Rich Kron, Jim Hesser, Len Kuhi, Martin Cohen, Jeremy Mould, and Bob Kraft for useful discussion.

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DISCUSSION

Blanco: You have mentioned various new multiplex type detectors that are now being tried, such as the Vidicon, the Digicon, the Charge Coupled Device (CCD), and the Charge Integrating Device, (CID). Can you comment about which of these devices is or are likely to become generally useful in the near future?

Spinrad: In the future I think the CCD/CID show the best prospects at $\lambda > 5000$ Å. The IPCS (Boksenberg) is the one likely to be the best in the blue. Right now the IDS and the Digicon are still providing a great deal of frontier research.

Andersen: A recent, detailed discussion of new detectors is found in the Proceedings of IAU Colloquium No. 40 (Paris, 1976). I believe that in many respects the new-generation detectors are much more suitable for spectral classification than for spectrophotometry. They are fine for studying the variation in intensity ratios of observed features in a series of spectra of the same resolution observed with the same detector. The moment one attempts to determine true continuum and equivalent widths for comparison with theory, one runs into the deleterious effects of the wide extensions of the instrumental profile discussed several years ago by Griffin. It appears that scattered light inside the detector may be much more severe than from the rest of the system, grating included, and in many cases the limited dynamic range of the new detectors prevents adequate determination of the amount of scattered light.

Schmidt-Kaler: We have recently summarized and compared in a tabulation the most important performance characteristics of multi-element detectors which are presently or soon will be available (R. Rudolph, W. Schlosser, Th. Schmidt-Kaler, H. Tüg, 1978, Astron. and Ap. 65, L5, 1978). This is not the report on the merits of the various systems with the inside information from 18 laboratories.

Jaschek: You mentioned the "hydride stars." Could you specify the references to these stars?

Spinrad: I would list Smethell's thesis and work by Kron (1977, Publ. Astron. Soc. Pacific), and earlier papers by Öhman (1936) and by Keenan ($\sim$1957) and references on MgH and CaH in K and M dwarfs. Work is in progress by Liebert, Dahn and Stauffer.

Keenan: In response to Dr. Jaschek's question about Spinrad's reference to hydride stars, the best acount of SiH was given by Dorothy Davis in Pub. Astron. Soc. Pacific in the early 1940's. General references are in a review in Vistas in Astronomy.