# INTERNATIONAL ULTRAVIOLET EXPLORER OBSERVING PROGRAM

Final Technical Report

# ULTRAVIOLET OBSERVATIONS OF SELECTED ASTRONOMICAL SOURCES

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## SUMMARY

This final technical report summarizes the results of the ninth and tenth IUE episode programs listed on the following page. During the 2 year period covered by this report, July 1, 1986 - August 31, 1988, observations and basic data reductions were completed for 4 extragalactic programs which were allocated a total of 9 US1 shifts, and 2 stellar investigations which used 10 US2 shifts. The principal investigator, Jules P. Halpern, and coinvestigators made use of the Goddard RDAF to obtain better signal-to-noise ratio spectra using the Gaussian extraction routines. Highlights of this work include the first IUE observations of H1821+643, the second brightest quasar in the sky, and the discovery of accretion disk emission-line profiles in the elliptical Seyfert galaxy Arp 102B. Both of these observations were accompanied by nearly simultaneous optical spectrophotometry. As a result of the stellar programs, large amplitude variability associated with the rotation periods of the Ap stars 78 Vir and 53 Cam was found. Four refereed papers, one invited IAU talk, and three contributed abstracts, were published by the principal investigator and collaborators under this grant.

IUE PROGRAMS COVERED BY THIS GRANT

| Short Title and Investigators | Year | Shift Allotment | |
|---|---|---|---|
| Elliptical Seyfert Galaxies<br>J.P. Halpern and R. Monier | 9 | 2 US1 | |
| X-ray Selected BL Lac Objects<br>J.P. Halpern and J.O. Patterson | 9 | 3 US1 | |
| Rapid Variations in the Far Ultraviolet Spectrum of the Cool Ap Star 21 Com, J.P. Halpern and R. Monier | 9 | | 4 US2 |
| Variations of Cool Ap Stars with Strong Magnetic Fields, J.P. Halpern and R. Monier | 9 | | 6 US2 |
| A Complete Sample of Bright Seyfert 2 Galaxies<br>J.P. Halpern and R.A. Edelson | 10 | 3 US1 | |
| New X-ray Bright Quasars<br>J.P. Halpern | 10 | 1 US1 | |

## RESULTS OF INDIVIDUAL PROGRAMS

### New X-ray Bright Quasars (XLIJH)

This program was allocated one shift, which was used to obtain a 5 hour SWP and a 2 hour LWP exposure of H1821+643. It is remarkable that this little known X-ray selected quasar ($z=0.297$, $V=14.2$) is the second brightest object in the sky at $z > 0.1$, and had never been observed before by IUE. The SWP spectrum had an optimal exposure in the continuum. After the initial observations on July 29, 1987, we were granted an additional 1/2 shift of Project Scientist's discretionary observing time on Aug. 9 in order to obtain a 2 hour SWP exposure, because the original spectrum was slightly saturated in the Lyman $\alpha$ line. This second observation was conducted by IUE resident astronomer Chris Shrader, who has also studied the HEAO 1 X-ray data on this quasar. Thus, a composite SWP spectrum was created (Fig. 1a) which is optimally exposed in both continuum and lines. This second observation also enabled us to bracket the nearly simultaneous optical spectrophotometry which was obtained by A. Filippenko at Lick Observatory on Aug. 8. Excellent photmetric data was obtained, and the final analysis and publishing of all the data will be done in collaboration with Shrader and Filippenko.

Among the interesting features are a strong O VI $\lambda$1034 line, a number of interstellar absorption lines at zero redshift (Figs. 1a and 2a), and the possible presence of 1 or 2 Ly$\alpha$ forest absorption lines (Fig. 1a). One remarkable discovery is that, despite the decline in sensitivity below 1200 Å, there is strong emission shortward of the Lyman limit (redshifted to 1182 Å, see Fig. 1b). These data are important in view of the claim of possible detection of a Lyman discontinuity using the IUE/Voyager data on 3C 273

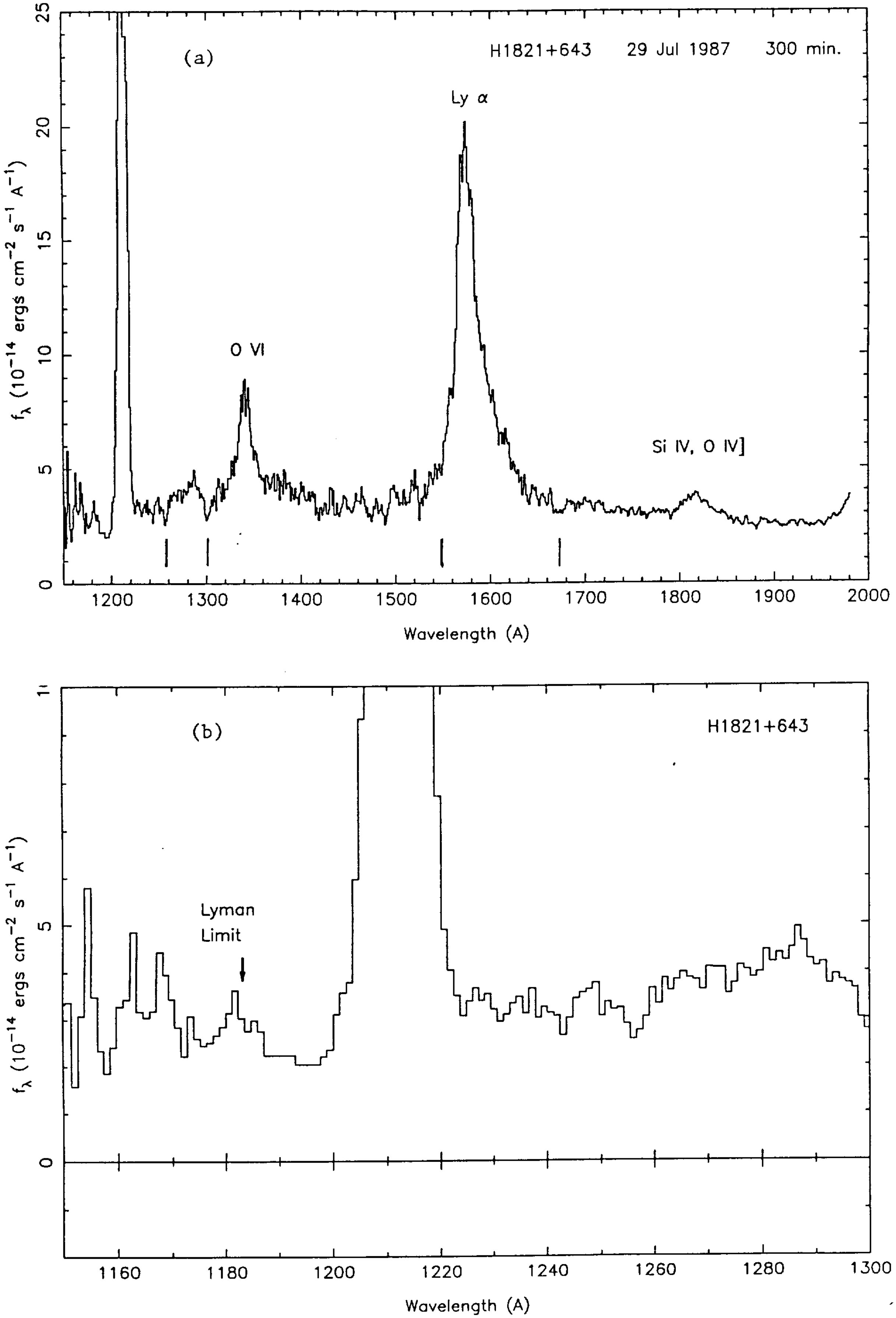



FIG. 1. Composite of SWP 31431 and SWP 31523. (a) Likely interstellar absorption lines are indicated by tick marks. Note also the possible presence of Lyα forest lines between O VI and Lyα. (b) Expanded view showing flux below the Lyman limit.

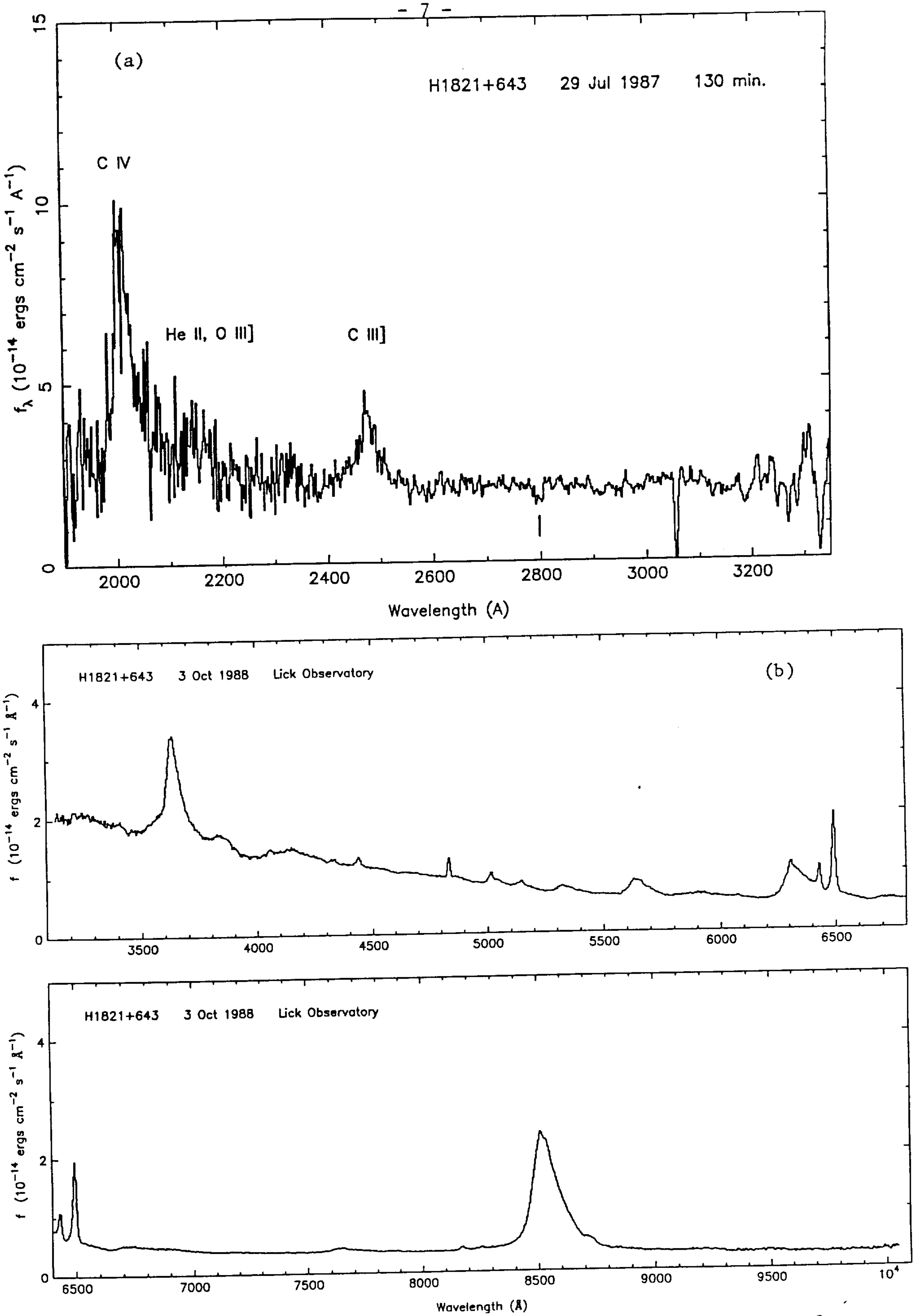



FIG. 2. (a) LWP 11294. Note interstellar Mg II absorption at 2800 Å. (b) Optical spectrum obtained under photometric conditions. Note the excellent match with the IUE flux at 3200 Å.

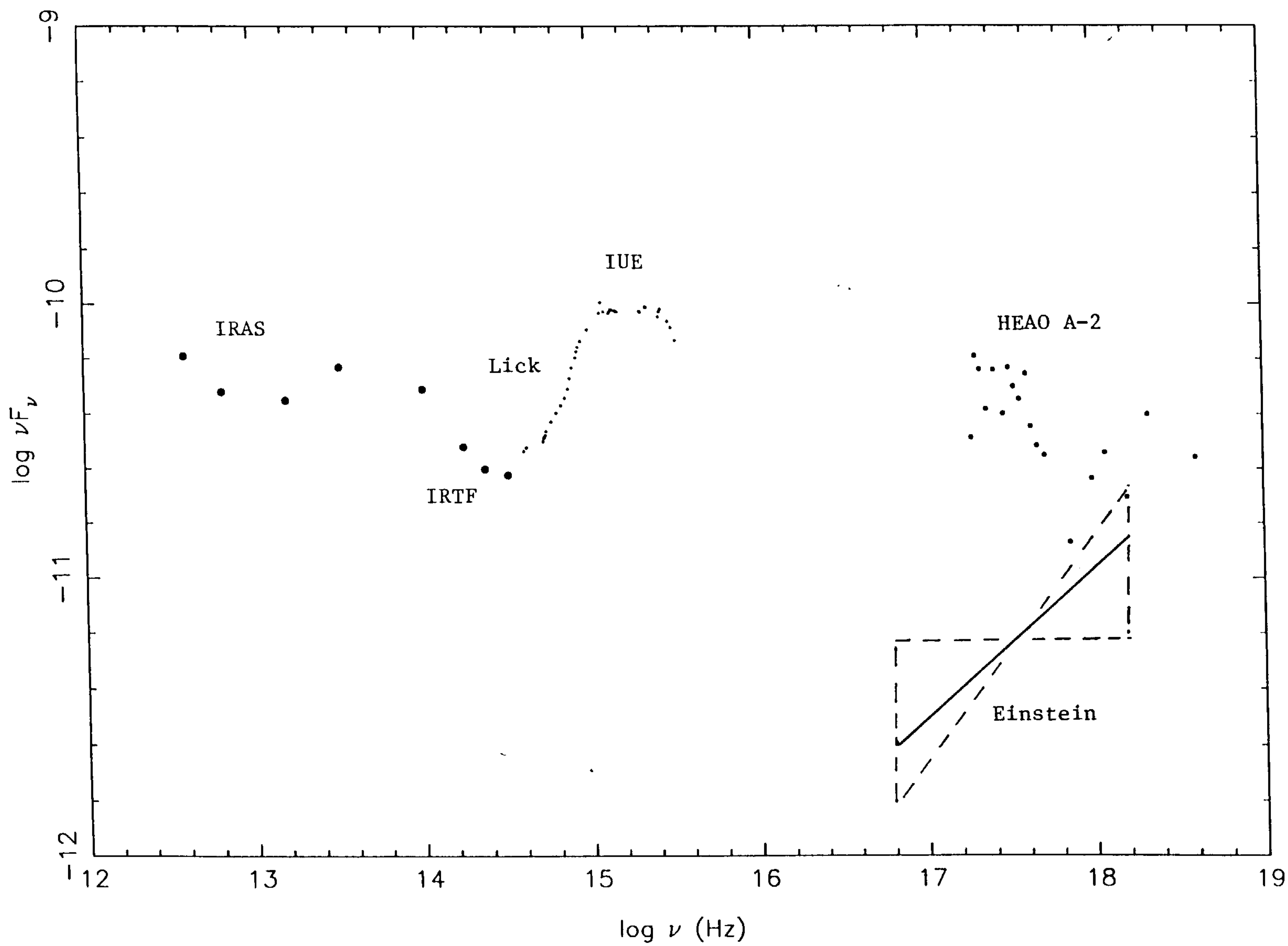



FIG. 3. Continuum spectrum of H1821+643. Note the turnover of the UV bump and the large-amplitude variation between the two X-ray observations. Optical and UV data have been corrected for E(B-V) = 0.085.

objective of this observation was to investigate the "big bump" using well exposed IUE, optical, and X-ray spectra. H1821+643 may be the best candidate for such study, since the moderate redshift allows the IUE spectrum to extend to the Lyman limit. It is the highest redshift object for which a two-component spectrum has been seen in X-rays, and it is brighter in X-rays than the previous "big bump" prototype PG1211+143 (Bechtold _et al_. 1987, _Ap. J_. 314, 699). Careful attention was also be paid to the dereddening of the IUE data, since the estimated E(B-V) = 0.085 from the Stark _et al_. 21 cm survey results in a factor of 2 increase in the UV points. The reddening in the direction of H1821+643 is twice that of PG1211+143.

Figure 3 shows that the peak in the UV spectrum has been detected, and that the flux turns over smoothly well _longward_ of the Lyman limit. This argues that the thermal peak, rather than Lyman continuum absorption, is responsible. A problem with interpretations of thermal components in other low-redshift quasars is that the UV _data_ are never really seen to turn over, although the _fits_ sometimes do. This is a problem, for example, in 3C 273 (Edelson and Malkan 1986, _Ap. J_., 308, 59) and in PG 1211+143. In H1821+643 the detection of the turnover is probably due to a combination of higher redshift and larger black hole mass, which would make the temperature of the inner disk lower. However, one must also be wary of the possibility that Lyman continuum absorption is an intrinsic property of the accretion disks in AGNs (Sun and Malkan 1897; Sun 1989; Scott and O'Dell 1989), and that a suitable smearing of the Lyman edge due to strong Doppler and gravitational effects in the inner disk might cause some of the turnover which is observed.

We also note that quasars at redshifts significantly larger than that of H1821+643 are unsuitable for investigation of the UV bump because of the increased density of Lyman limit absorbers which depress the continuum (Tytler 1982, Nature, **298**, 427; Bechtold et al. 1984, Ap. J., 286, 76). The steepening shortward of Lyα in high redshift objects is probably also due to the Lyα forest. Since no Lyman limit absorbers have been detected with $z < 0.4$, including in H1821+643, it is probably safe to say that the observed continuum is intrinsic. Thus, H1821+643 has nearly the optimal redshift to expose the UV bump without the risk of intervening absorption.

The location of H1821+643 at $(\ell,b) = (94°,+27°)$, and the HI column density of $4\times10^{20}$ cm$^{-2}$, are ideal for the study of interstellar absorption arising in material at a variety of large galactocentric distances. We have almost certainly detected the low-ionization lines listed below, and indicated in Figures 1a and 2a. The high ionization C IV line is listed as an upper limit, since it falls on the side of the Lyα emission. According to the predictions of Savage (1988), we should expect galactic C IV and N V lines with equivalent widths of ~ 0.5 and 0.2 Å, respectively.

| Wavelength | $W_\lambda$ (Å) | ID |
|---|---|---|
| 1256.9 | 1.2 | S II, Si II |
| 1301.4 | 1.6 | O I, Si II |
| 1548.6 | ≤0.6 | C IV |
| 1671.8 | 1.2 | Al II |
| 2795.3 | 3.9 | Mg II |

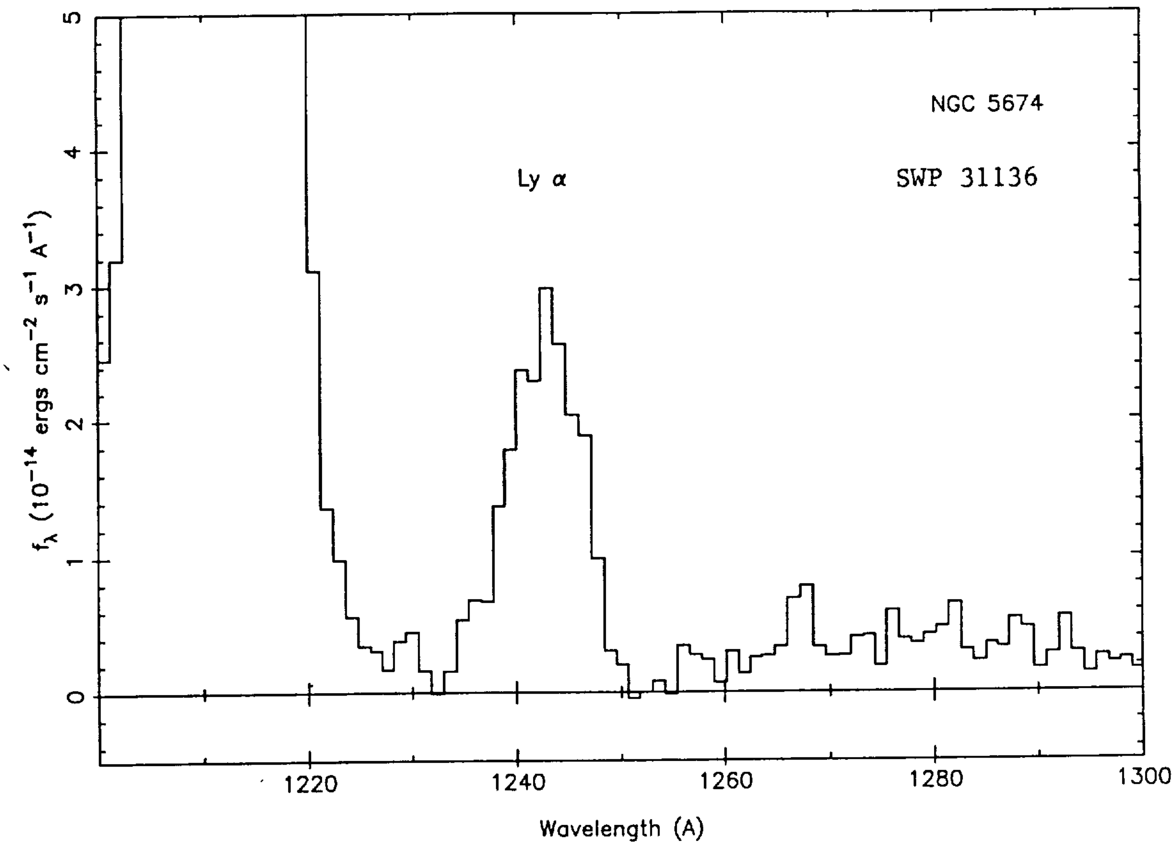
There is also possible structure in the spectrum between Lyα and O VI which might be due to the Lyα forest. Detection of low-redshift Lyα absorption lines is quite feasible using low-resolution spectra of H1821+643.

For our purposes, a naive, empirical extrapolation of the redshift density of the Lyα forest determined at redshifts greater than 1.5 (Murdoch et al. 1986, Ap. J., 309, 19; Tytler 1987, Ap. J., 321, 69) predicts that we would find 1.6 lines with equivalent width greater than 0.36 Å between z = 0 and z = 0.297, the region accessible with our quasar. The noise threshold in this region of our spectrum is approximately 0.5 Å. Therefore, it will be necessary to obtain several more spectra to reach the required noise threshold, and to establish the repeatability of the apparent structure.

A Complete Sample of Bright Seyfert 2 Galaxies (SYJJH)

Three shifts were allocated, out of four requested, for the observation of four Seyfert 2 galaxies. Together with 4 galaxies already observed by IUE, this set of objects comprises a magnitude limited sample of 8 spectroscopically selected Seyfert 2 galaxies from the CFA redshift survey. The sample was specifically chosen to be unbiased as to continuum properties, since it was selected purely on the basis of emission-line ratios. Of the four proposed targets, NGC 3362 could not be observed because of earth occultation. Therefore, the three US1 shifts in June and July of 1987 were used to obtain SWP and LWP spectra for NGC 1144, NGC 3982, and NGC 5674. The primary objective was to determine whether the continuum emission from Seyfert 2 galaxies is generally powered by accretion onto a massive compact object, as appears to be the case in Seyfert 1 galaxies. Only in the case of NGC 1068 is there definite evidence for nonstellar UV continuum in a Seyfert 2 galaxy (Monier and Halpern 1987, Ap. J. (Letters), 315, L21). The UV spectra will be used together with optical and X-ray data to search for an accretion disk spectrum or a nonthermal power law. In addition, the Lyα fluxes can be used to test theoretical modifications of the Case B hydrogen recombination line ratios which have been derived specifically for Seyfert 2 galaxies.

Reduced spectra of two of the three objects are shown in Figures 4 and 5. Continuum light was detected weakly in in all three objects, although it may be mostly starlight. In the case of NGC 3982, the continuum emission is definitely extended, since at least 2 separate regions of emission are seen in the large aperture. The Gaussian extraction (GEX) routines were used to improve the reliability and signal-to-noise ratio of the weak continuua in NGC 1144 and NGC 5674. This could not be done in the case of NGC 3982, since the



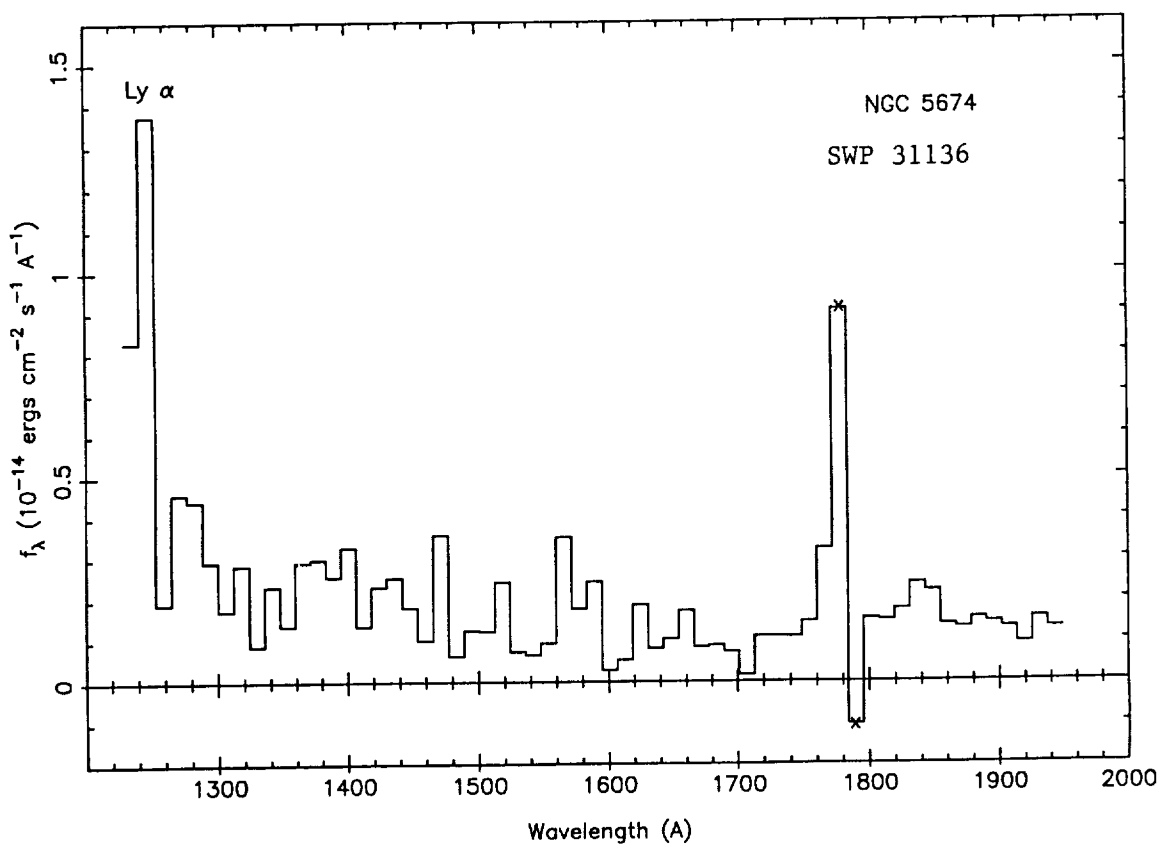
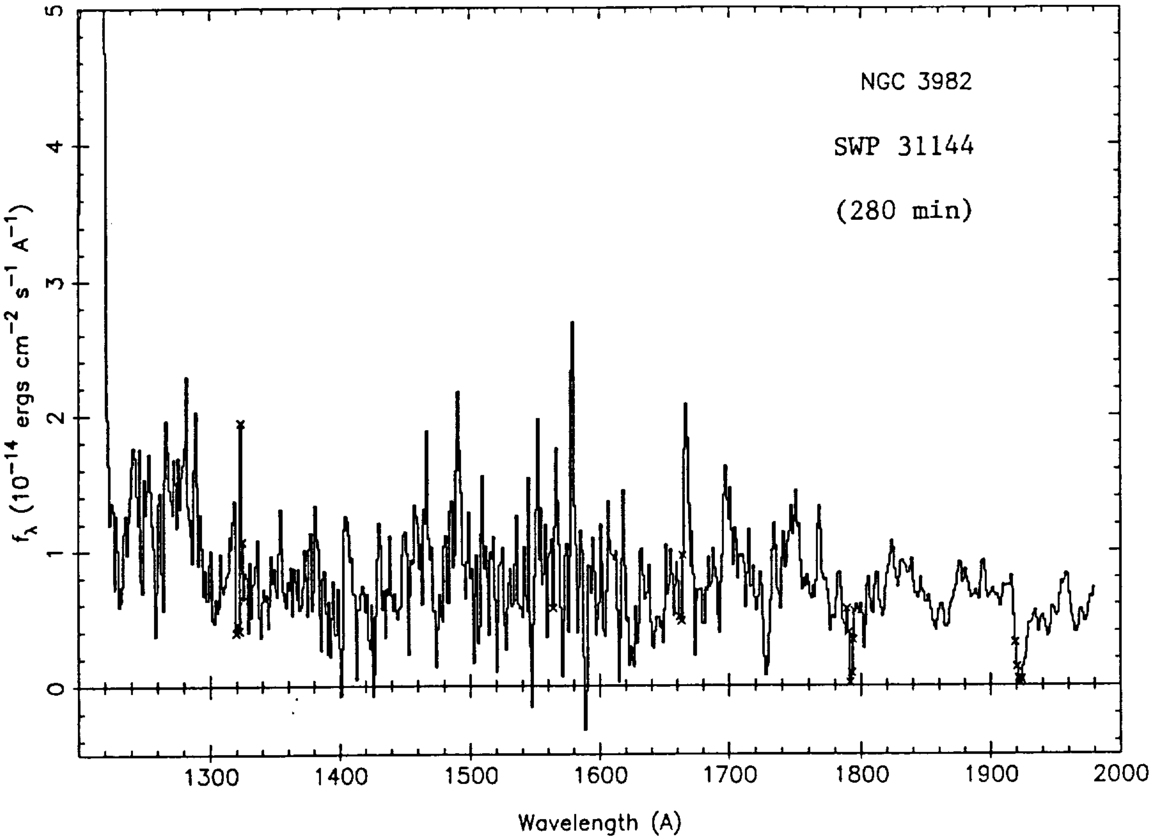




FIG. 4. A 285 minute SWP exposure of the Seyfert 2 galaxy NGC 5674. The full width of Lyα is ~8 Å, slightly broader than the instrumental resolution. The Lyα flux is 2.2x10(-13) ergs $cm^{-2}s^{-1}$.



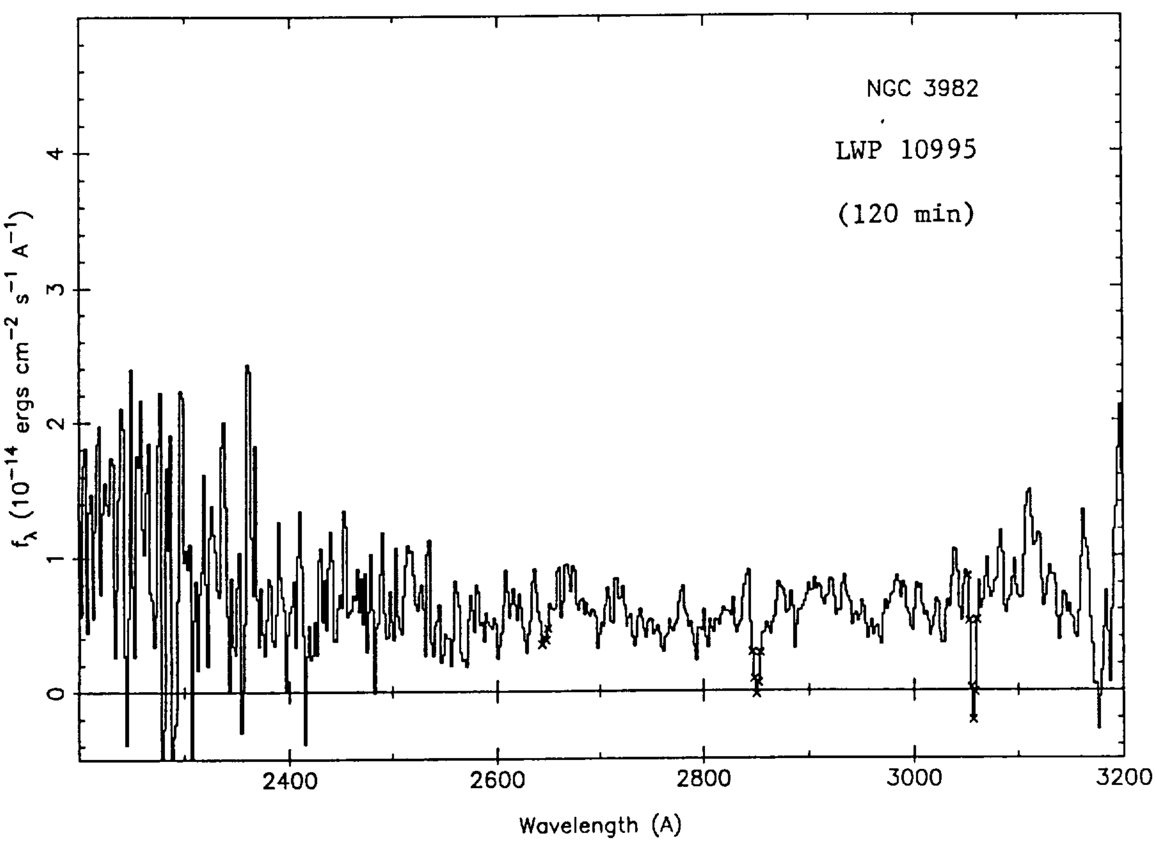




FIG. 5. The continuum emission from the Seyfert 2 galaxy NGC 3982 is clearly extended in the slit. These data are the standard MELO extractions for extended or trailed spectra. No emission lines were detected.

profile in the direction perpendicular to the dispersion is distinctly non-Gaussian. Rather, the emission comes from at least two distinct regions, each of which may be extended. The nature of the ultraviolet continuum will be addressed after a careful comparison with optical spectrophotometry is completed. The only emission line detected was Ly$\alpha$ in NGC 5764. The flux is $2.2 \times 10^{-13}$ ergs cm$^{-2}$ s$^{-1}$, and the width is 8 Å FWHM, or somewhat greater than the resolution of $\sim 5$ Å.

Elliptical Seyfert Galaxies (EGIJH)

Arp 102B and NGC 6212, rare examples of elliptical Seyfert galaxies, are subjects of yearly optical monitoring by Halpern and Filippenko. The IUE observations in July of 1986 were accompanied by simultaneous optical spectrophotometry. Arp 102B has double-peaked Balmer line profiles which might be interpreted as evidence for a binary black hole. However, optical monitoring over a 5 year period have not revealed the radial velocity variations (see Figure 6a) which would be expected for a binary black hole of typical mass. Halpern and Filippenko (1988, Nature, 331, 46) showed that this null result restricts the sum of the masses of any hypothesized binary black hole to greater than $2\times10^{9}$ $M_{\odot}$, an unlikely circumstance given the low luminosity. Thus we conclude that the binary model is virtually ruled out for Arp 102B.

The IUE exposures show only weak continuum in the in the 1600 - 3000 Å range at a level which is consistent with an extrapolation of the optical continuum (mostly starlight). There is no evidence for a power-law or "big bump" spectrum in the ultraviolet, although the X-ray flux is sufficient to account for the emission lines via photoionization. The only emission line detected in the ultraviolet is Ly$\alpha$. Figure 7a shows that the Ly$\alpha$ line is quite different from H$\alpha$, since it is much narrower than the Balmer lines and is single peaked. Although a radiation event contaminated the Ly$\alpha$ line near 1240 Å, careful removal of it from the ELBL file using BSPOT resulted in an acceptable spectrum. In any case, the conclusion that the Ly$\alpha$ line is narrower than H$\alpha$ is safe, since the radiation event is narrower than the FWZI of the emission line. This IUE result also strongly argues against the binary black hole hypothesis, which would require the Ly$\alpha$ line to be double peaked.

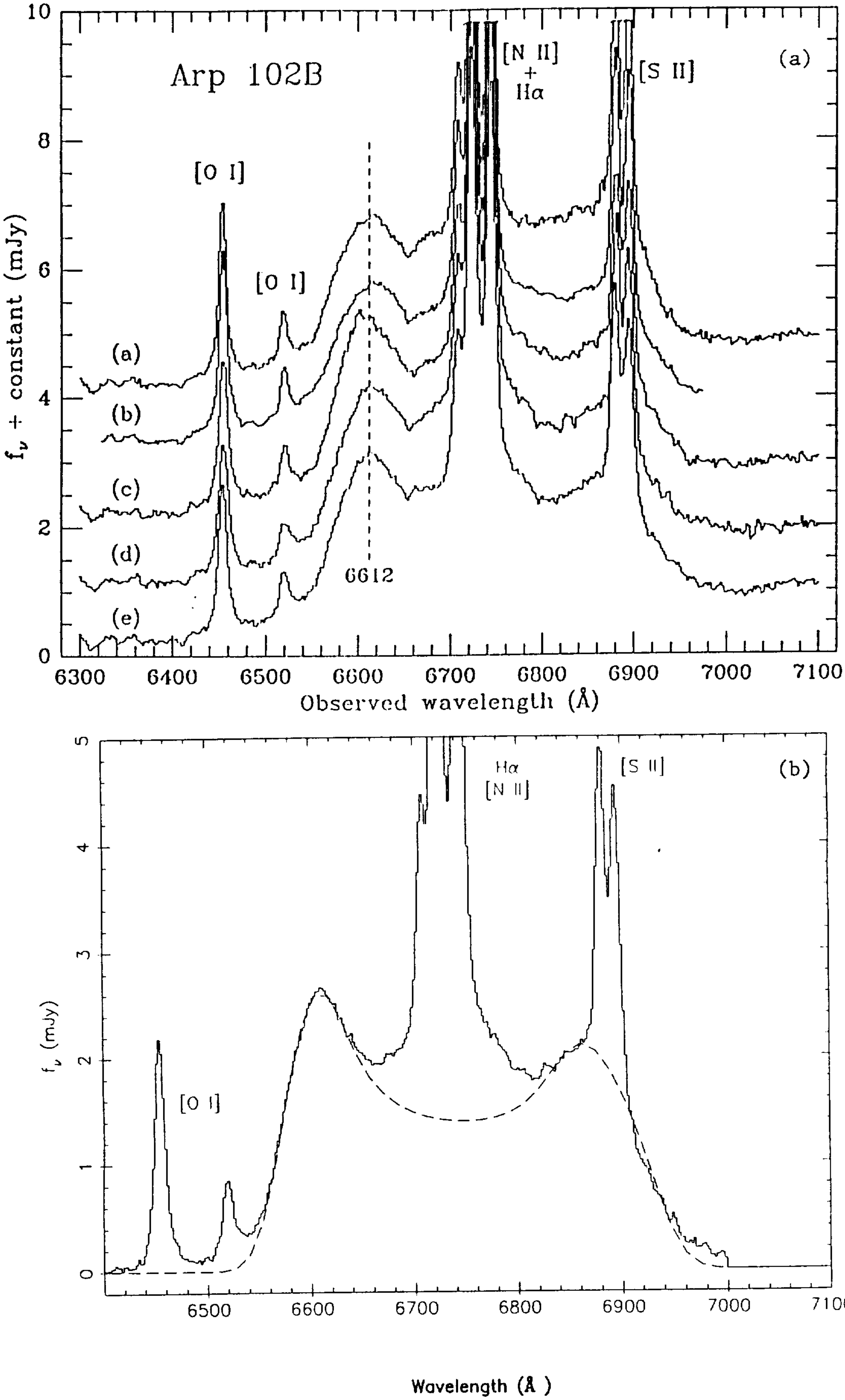



FIG. 6. (a) Spectra of the Hα line of Arp 102B over a five year period, from Halpern and Filippenko 1988, Nature, 331, 46. (b) An accretion disk line profile fit to the broad Hα line, from Chen and Halpern 1989, Ap. J., submitted.

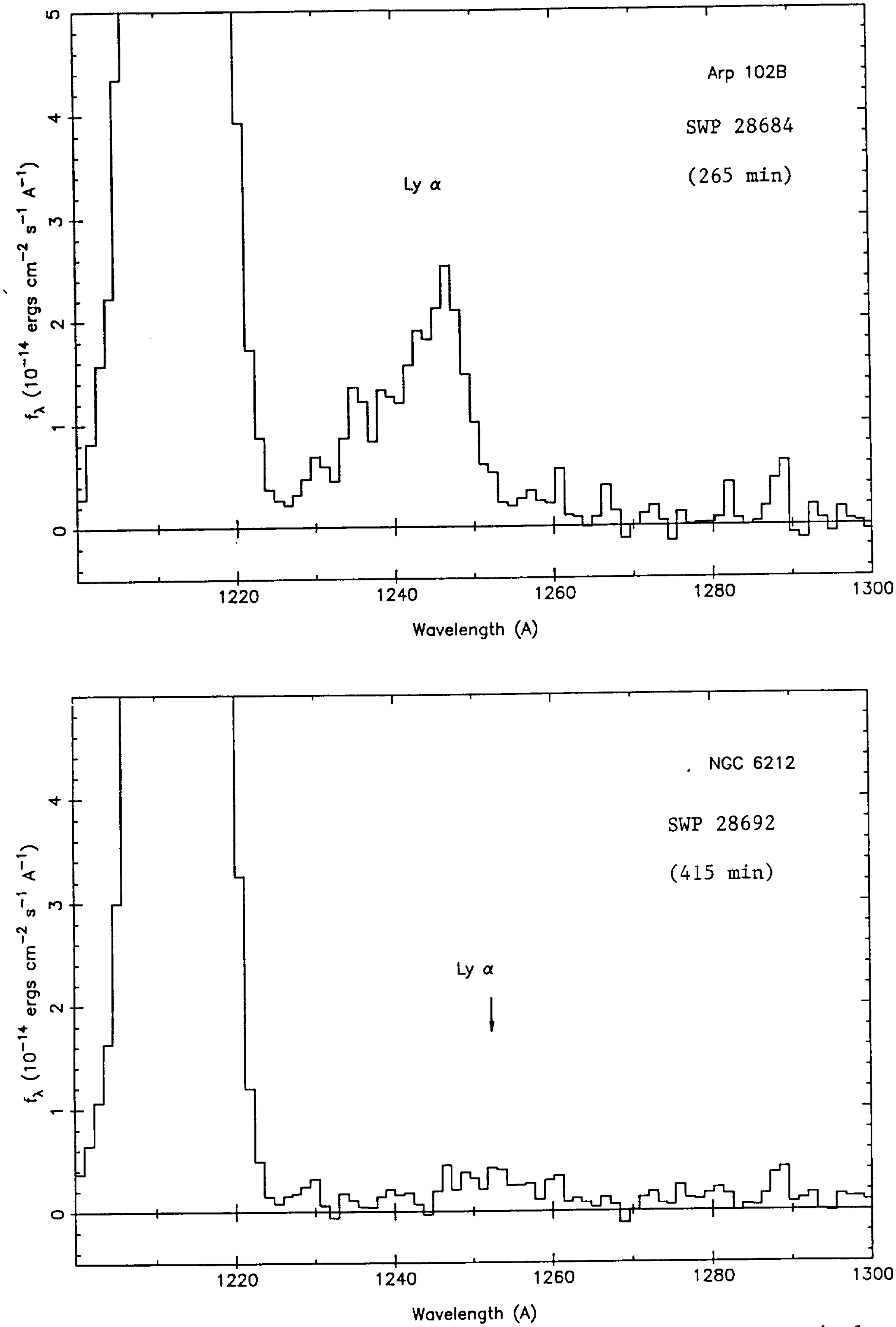



FIG. 7. These two elliptical Seyfert galaxies have similar optical continua, but Arp 102B has brighter optical lines than NGC 6212. Lyα was detected only in Arp 102B, but it was contaminated by a nearby radiation event around 1240 Å.

An alternative model was developed by Chen, Halpern, and Filippenko (1989, Ap. J., 339, 000), who calculated line profiles for a Keplerian disk, including relativistic effects which were not treated rigorously in previous papers. We found an excellent fit to the Hα line of Arp 102B (see Figure 6b), yielding an accurate determination of several parameters of the disk. The inner and outer radii are ~ 350 and ~ 1000 in units of $GM/c^2$. The inclination angle is 32° ± 6°. Both the models and the data show that relativistic effects of Doppler boosting and gravitational redshift cause marked asymmetries in the line profile. We conclude that the line profile of Arp 102B shows the best evidence for an accretion disk in any AGN.

We note that there is no evidence for the blueshifted or redshifted peaks in the Lyα line. In fact, the red side of the line is consistent with the IUE resolution, so that approximately half the flux may be coming from the narrow-line region. The total Lyα flux is $2.8 \times 10^{-13}$ ergs $cm^{-2}$ $s^{-1}$. If we attribute half the Lyα flux to the narrow-line region, then the ratio of narrow Lyα/Hβ is 12. The ratio of narrow Hα/Hβ is 4.3. These ratios are typical of moderately reddened Seyfert 2 galaxies. On the other hand, the virtual absence of broad displaced peaks in Lyα is probably due to large optical depths in the disk. For example, we may place an upper limit of ~ 1 on the ratio Lyα/Hβ at the wavelengths of the blue or red peaks.

The absence of a UV bump can probably be attributed to the instability of the inner, radiation-pressure dominated region of the accretion disk. The Lightman-Eardley instability probably drives the inner disk to a hot, ion-supported torus. The primary energy output of an ion torus is either synchrotron emission in the infrared, or inverse Compton scattered X-rays. The inner radius of the line emitting region can be identified with the boundary between the thin, outer disk and the geometrically thick (optically thin) inner ion torus. Thus, there is no part of the disk which can emit thermally in the UV. A self-consistent model incorporating all of the observations and previous theoretical ideas about accretion disks has been submitted for publication (Chen and Halpern 1989, Ap. J. submitted).

The overall continuum flux distribution of NGC 6212 is very similar to that of Arp 102 B, but its emission lines are much weaker. Lyα was not detected in the 415 min SWP spectrum of NGC 6212 (see Figure 7b). Yearly optical monitoring has shown that the Balmer lines are widly variable, changing by a factor of 3 in flux from year to year (Halpern and Filippenko 1986, Astr. Ap., 191, 1019). The Hα flux was weak at the time of the IUE observation in 1986, and the broad Hα totally disappeared in 1987 (Halpern and Filippenko, in preparation). Perhaps these large excursions are also responsible for the absence of ultraviolet lines in 1986. Interpretation of these results will try to relate the unusually large amplitude variability in the lines to the elliptical morphology, which may yield some clue to the rarity of Seyfert nuclei in elliptical galaxies.

X-ray Selected BL Lac Objects (XLIJH)

The purpose of this investigation is to test the hypothesis that X-ray selected BL Lacs have flatter optical/UV power laws than other BL Lac objects, as suggested by Halpern et al. (1986, Ap. J., 302, 711). Three US1 shifts were dedicated to obtaining SWP spectra of three new X-ray selected BL Lacs, H0414+009, 1E1415+259, and H1101-232. The spectra were rereduced using the standard Gaussian extraction routines at the Goddard RDAF to optimize the signal-to-noise ratio. A faint, featureless continuum was detected in each case, confirming their BL Lac nature. The ultraviolet spectra will be combined with published and unpublished optical spectra obtained by the P.I. and others to measure the continuum slope.

Rapid Variations in the Far-UV Spectrum of 21 Com (CPIJH) and
Variations of Cool Ap Stars with Strong Magnetic Fields (APIJH)

The objective of these programs was to search for variability of the temperature and abundances which might be attributed to variation of the average magnetic field over the surface of the star. The Ap stars 78 Vir and 53 Cam were chosen because they have known rotation periods and magnetic field variations. Spectra covering most of the rotational phases of the 78 Vir were obtained in high-resolution and low-resolution mode. In addition, there was partial phase coverage for 53 Cam. A total of 10 US2 shifts were allocated to the three stars in these two programs, for which 63 high dispersion and 33 low dispersion exposures were obtained. Very large changes in UV flux were detected which are correlated with rotational phase. In 78 Vir, the maximum modulation is about 50%, and in 53 Cam, it is 100%. The variations are greatest at the shortest wavelengths in the SWP (see Figure 8), and they are

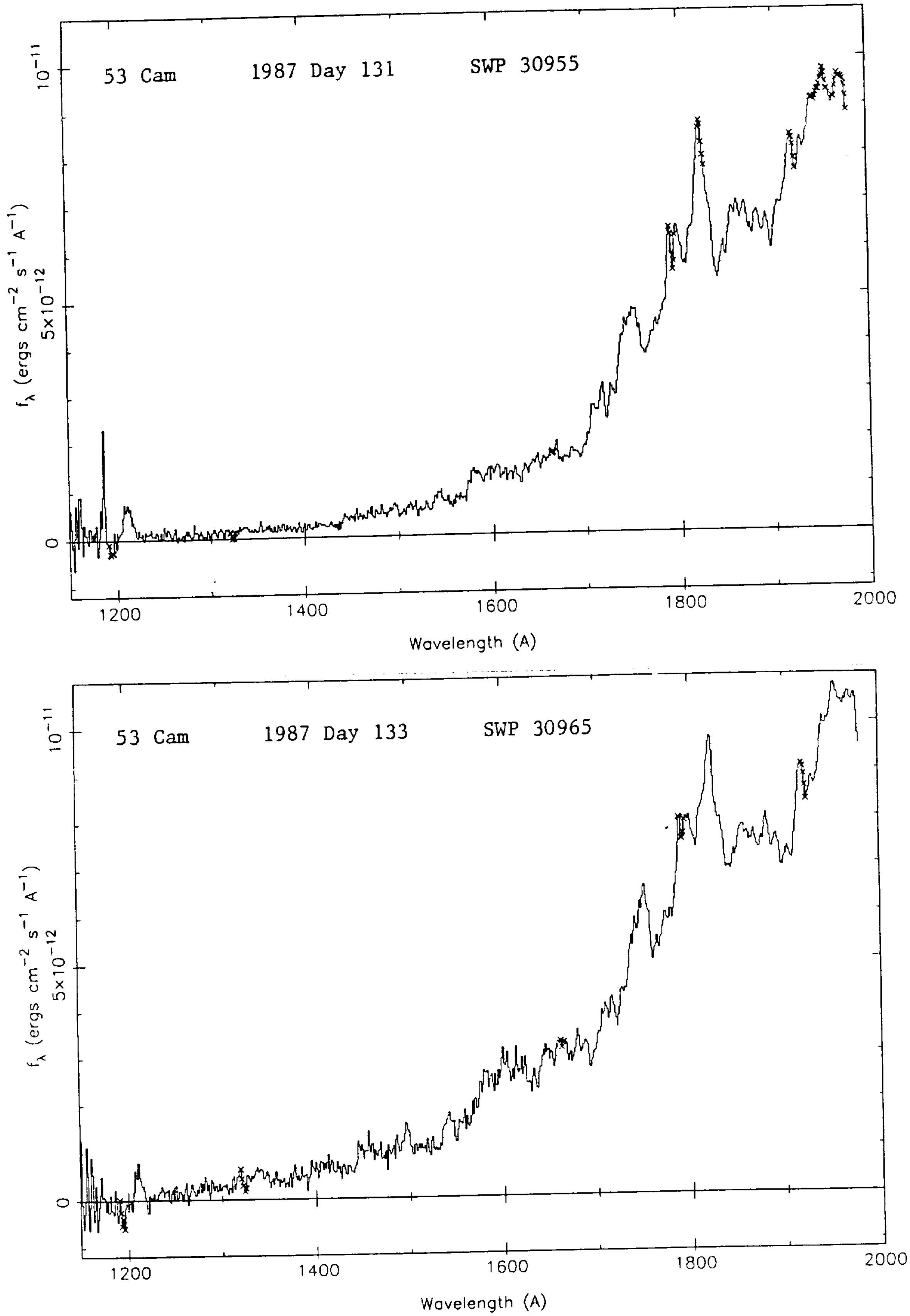



FIG. 3. SWP spectra of 53 Cam separated by 0.25 in rotation phase. The flux changes by 100% at wavelengths shorter than 1600 Å. At 1900 Å, the variation is only 15%.

negligible in the LWP, confirming that this is a temperature effect. In 21 Com, the variations were small.

We have fluxed the high-dispersion spectra using the absolute calibration given for the SWP and LWP by Cassatella, Ponz, and Selvelli (1982). The resulting absolute fluxes of the high-dispersion and low-dispersion spectra agree in detail at roughly the 5% level, which permits the variability study to make use of both low- and high-dispersion data simultaneously. We are conducting a comprehensive search for variable absorption lines in all orders of the high dispersion spectra. As a part of this analysis, we found it necessary to develop a system for compact storage and display in order to get an overview of the large quantity of high dispersion data. Simply printing all the spectra in a compact yet readable form required ~ 350 pages of high-resolution laser printer output (e.g., see Figure 9).

The next phase of this continuing project involves the synthesis of high quality template spectra for each star by averaging many exposures. From this point, the search for variability will proceed by a combination of visual inspection and automatic computer analysis. We will develop simple software tools to accomplish this task in systematic and reliable manner.

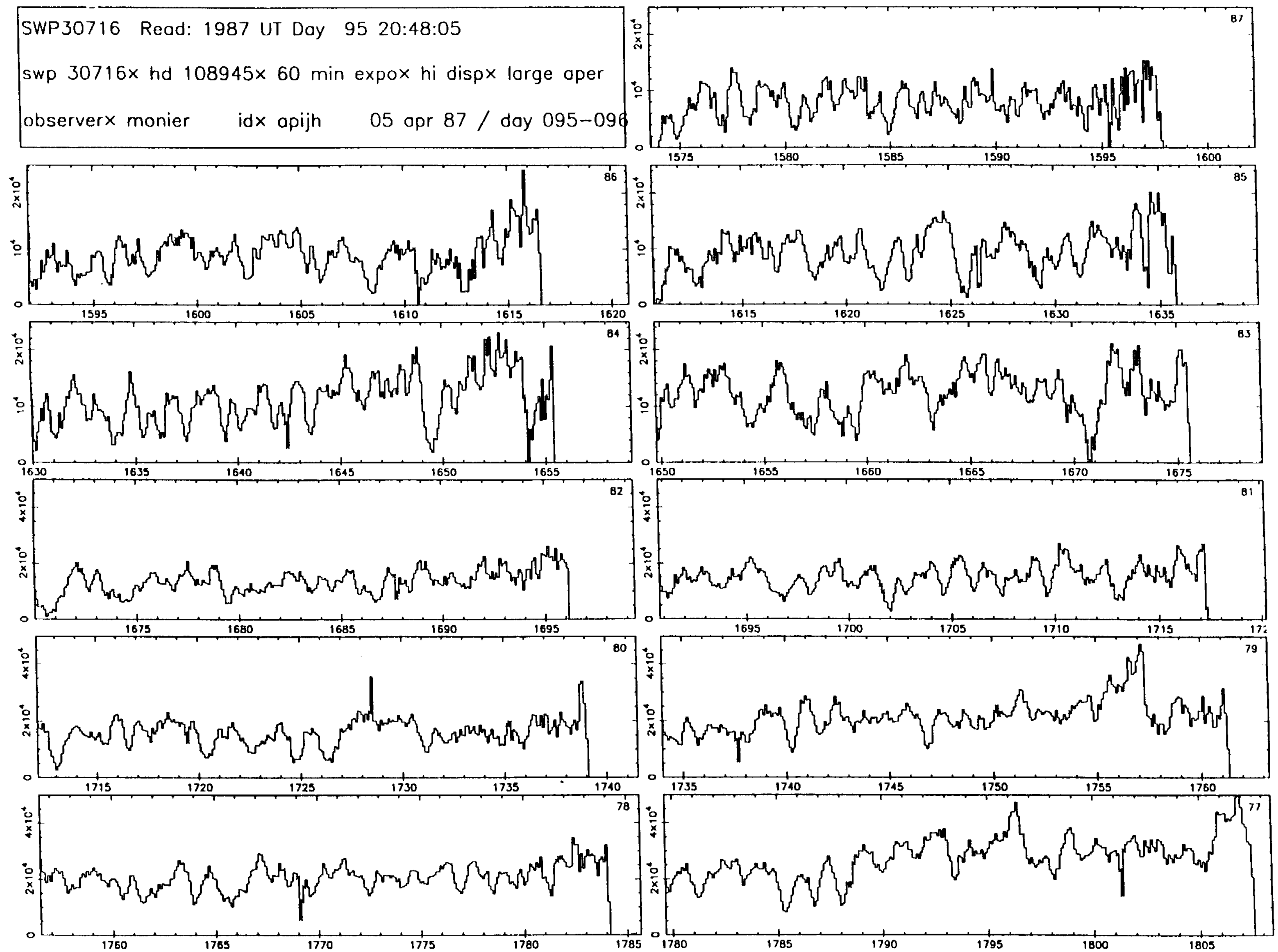



FIG. 9. Showing 11 orders of the high-dispersion spectrum of 21 Com. A binning of 3 pixels has been applied (without smoothing). This is one page out of ~350 which display all of our high-dispersion spectra of Ap stars.

# PAPERS PUBLISHED OR SUBMITTED UNDER THIS GRANT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2. "The X-ray Spectrum of NGC 1068," R. Monier, and J.P. Halpern, Ap. J. (Letters), 315, L21 (1987).

3. "A Test of the Massive Binary Black Hole Hypothesis: Arp 102B," J.P. Halpern and A.V. Filippenko, Nature, 331, 46 (1988).

4. "Arp 102B: Kinematic Evidence for a Relativistic Keplerian Disk", K. Chen, J.P. Halpern and A.V. Filippenko, Bull. A.A.S., 120, 645 (1988).

5. "Structure of Line-Emitting Accretion Disks in AGNs: Arp 102B," K. Chen, and J.P. Halpern, Ap. J., submitted (1988).

6. "Structure of Line-Emitting Accretion Disks in AGNs," K. Chen, and J.P. Halpern, Bull. A.A.S., 20, 000 (1988).

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