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Ultraviolet Long-Exposure Spectrophotometry of High Excitation Herbig-Haro Objects

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Abstract

Using "two-shift" exposures in the short wavelength (SWP) range of I.U.E. we have obtained ultraviolet spectra of HH 1 and HH 2 with a higher signal-to-noise ratio than previously existing spectra.

The spectra permit us to derive some limited information about the spatial distribution of the emission in different lines and in the continuum. The results for HH 1 show a (spatial) half-width of the image size in the CIV 1548/51 line which is considerably smaller than the spatial half-width for the CIII] 1907/09 line (which in turn is considerably smaller than that of the continuum). In HH 2H the situation is qualitatively similar but the differences in the image sizes are much smaller than in the case of HH 1. The detailed spatial distributions show clearly, however, that the continuum comes mostly from the Herbig-Haro object itself (and possibly its immediate environment) and the that contribution of the general "Orion Reflection Nebulosity" is small. It is interesting to note that the geometrical size of the CIV image of HH 1 is approximately equal to the scale of the point spread function of IUE. It is therefore possible that the CIV emission region is even smaller than indicated by our measurements.

Studying the wavelength dependence of the continua we find the following. The continua of HH 1 and HH 2 show a surprising similarity in their wavelength dependence even in rather small features. Both continua have their maxima (in I_λ) between 1570 and 1580 Å and not near 1410 Å where the two-photon continuum of hydrogen has its maximum. We note that the observed wavelength of the continuum maximum agrees with the position of the maximum of the H_2 continuum, which is formed when the H_2 molecule is destroyed by Lyman continuum photons.

I. Introduction

The ultraviolet spectroscopy of Herbig-Haro (HH) objects has lead to a number of surprising insights into the general properties and the physics of these objects.

The fact that these (optically) rather faint objects which occur in regions of at least moderate extinction could be observed at all with I.U.E. was a considerable surprise initially (Ortolani and d'Odorico 1980, Böhm, Böhm-Vitense and Brugel 1981). The rather high "excitation" (i.e., ionization) character of the short wavelength I.U.E. spectrum (with CIV λ1548/51 and CIII] λ1907/09 being by far the strongest lines) definitely contradicted the plane shock wave models (e.g., Dopita 1978, Raymond 1979, Shull and McKee 1979) which had been selected in order to explain the optical spectra. These discrepancies and difficulties have been reviewed by Schwartz (1983a, b) and Böhm (1983). At the same time it was also found that the continuum, which is typically rather faint in the optical range, rises towards shorter wavelength at least to $\lambda \sim 1550$Å and becomes rather strong in the ultraviolet. The ultraviolet continuum was interpreted as a collisionally enhanced two-photon continuum by Brugel, Shull and Seab (1982, 1983). The optical continuum had been interpreted slightly earlier in an analogous way by Dopita and Schwartz (1981) and Dopita, Binette and Schwartz (1982). Another result of the ultraviolet studies of HH objects was the recognition that their uv continuum indicates an unusually low ultraviolet extinction and that the ultraviolet extinction curve is similar to the "θ Orionis curve" as described by Bohlin and Savage (1981) (cf. Böhm, Böhm-Vitense and Cardelli 1982, Brugel, Shull and Seab 1983).

More recently, it has been shown that the results of optical and uv spectrophotometry can be explained simultaneously with bow shock models (Hartmann and Raymond 1984) at least in the case of HH 1 and HH 2.

In the meantime it has become evident that the "typical" ultraviolet emission line spectrum described above (with strong CIV λ1548/51 and CIII] λ1907/9 lines) seems to

occur only in "high excitation objects" (cf. Böhm 1983 for a description of the distinction between high and low excitation objects) and has been seen so far only in HH 1, HH 2 (Böhm-Vitense *et al.* 1982) and HH 32 (Böhm and Böhm-Vitense 1984). Schwartz (1983c) has found that typical uv line spectra of "low excitation objects", like HH 43 and HH 47 look very different. They seem to show almost exclusively fluorescent lines of the Lyman bands of the H_2 molecule.

It is fascinating that all these results have been found using (typically) 3-7 hour I.U.E. exposures of objects with visual magnitudes of 16 and somewhat fainter. It is, however, also true that some of these spectra were indeed rather faint and noisy and it is not always easy to derive reliable conclusions from them. Mundt and Witt (1983) have emphasized a need for caution in the interpretation of the uv continuum and have argued that the HH 1 and HH 2 continuum may be seriously contaminated by light from the extended "Orion Reflection Nebulosity" (Carruthers and Opal 1977, Witt and Lillie 1978).

With these facts in mind we felt that it is necessary to obtain improved uv spectra at least for the two brightest HH objects HH 1 and HH 2 in order to get more reliable data on the emission line and continuous spectra of these objects. Improved observational material for a determination of the continuum energy distribution and for a check of the two-photon emission theory is important. Furthermore, such observations should also (because of their improved spectrophotometric accuracy) give us better information about the possible continuum contamination by the Orion Reflection Nebulosity. Finally, they would give us fairly reliable data for a continued study of the suspected variability (see Brugel *et al.* 1985) of the emission line spectrum of HH 1.

In order to obtain such data with improved spectrophotometric accuracy we have taken two-shift (1 shift = 8 hours) exposures of HH 1 and HH 2.

II. Observations and Extinction Corrections

The I.U.E. (see Boggess *et al.* 1978) observations have been carried out in the standard way combining the ESA (European) and the consecutive NASA (U.S. 1) shift. Observations of both HH 1 and HH 2 have been performed on January 16 and 17, 1985. The SWP camera (1200 Å $\lesssim \lambda \lesssim$ 1950) has been used at low resolution ($\Delta\lambda \sim 6$Å). Some important information about the observations is presented in Table 1. In the case of HH 2 the aperture has been centered on condensation HH 2H (as it had been done for earlier shorter exposures by Böhm-Vitense *et al.*1982 and Brugel, Shull and Seab 1982). For the HH 1 observation the aperture has been centered on the HH 1 position ($\alpha = 5^h\ 33^m\ 54.^29$; $\delta = -6°47'01''$; 1950 coordinates) given in Herbig's (1974) catalog uncorrected for later proper motions. This appears not to agree exactly with the intensity maximum in the ultraviolet which seems to be somewhat closer to the position of condensation HH 1F (as defined by Herbig and Jones 1981). The position angle of the aperture was $-57°$. Consequently the brightest spot (in the ultraviolet spectral range) of HH 1 was not exactly at the center of the aperture. According to our measurements it occurred near the line-by-line spectrum 25 (between 25 and 26), not at spectrum 28 where the aperture center is located. As we shall discuss below, for some purposes it is actually an advantage that the brightest spot of HH 1 is not centered on the middle of the aperture.

For the purpose of determining the typical Orion reflection nebulosity (ORN) radiation (see Mundt and Witt 1983) in the general region of HH 1 and HH 2 we have obtained a spectrum of an area which is centered 9"E and 29"S of HH 1. This ORN radiation forms a background for the HH 1 and HH 2 radiation and (at least in principle) should be subtracted from the observed continuum in order to obtain the true continuum of the HH objects.

The reductions have been carried out at the Regional Data Analysis Facility at the University of Colorado in Boulder using the individual line-by-line spectra. The extinction correction has been based on a method similar to the one used earlier (cf. Böhm-Vitense *et*

al. 1982, Böhm, Böhm-Vitense and Cardelli 1982, Böhm and Böhm-Vitense 1984). E(B-V) has been determined (Brugel, Böhm and Mannery 1981) using the [S II] method (Miller 1968). Following the now more or less accepted ideas about the ultraviolet extinction in the environment of HH objects (cf. Brugel, Shull and Seab 1983, Böhm, Böhm-Vitense and Cardelli 1982) we have then used a θ Orionis extinction curve (Bohlin and Savage 1981) combined with the E(B-V) information. We have used E(B-V) = 0.38 for HH 1 and 0.46 for HH 2.

III. Results and Discussion

a. Spatially Resolved ("Line-by-Line") Spectra

In connection with recently obtained information about spatially resolved spectra of HH objects in the optical range (cf. Böhm and Solf 1985, Hartigan, Mundt and Stocke 1986, Solf, Böhm and Raga 1986) and with recent theoretical predictions of the *spatial distribution* of emission in bow shocks (Raga and Böhm 1985, 1986; Hartigan, Raymond and Hartmann 1985; Raga 1986) it is worthwhile to try to obtain some information about the spatial distribution of the line and continuum emission in the ultraviolet. We are aware of the difficulties and the considerable uncertainties of such an attempt. Nevertheless, we feel that we can obtain useful information which is (at least) qualitatively reliable. Spatially resolved spectra should also give us better information about the problem (Mundt and Witt 1983) of how strongly the continuum in HH 1 and HH 2 is contaminated by radiation from the "Orion reflection nebulosity" (Carruthers and Opal 1977; Witt and Lillie 1978).

As an example of the type of result which we can obtain we present the line-by-line spectra 24, 26, 28, and 30 of HH 2 in Figure 1. It should be noted that the line numbers quoted (like 24 etc.) increase along the (approximate) direction from the NW to the SE of the object. The distance between two successive line-by-line spectra is approximately 2."1 (see Computer Science Corporation 1984). The line-by-line spectra have been corrected individually for reddening using the procedure described briefly in the preceding chapter.

Figure 1 shows that both the strong lines (specifically CIV λ1548/51 and CIII] λ1907/9) and the continuum have their maximum at (or near) line-by-line spectrum 28.

Analogous results for HH 1 are shown in fig. 2, in which we present the line-by-line spectra no. 24, 25, 26, and 27 for this object. Fig. 1 and 2 show clearly that in the ultraviolet HH 1 is much more compact than HH 2. (Note that in Fig. 2 we have plotted successive line by line spectra while in fig. 1 only every second line by line spectrum is shown.)

In agreement with the different positioning of the two objects on the aperture described in the preceding chapter, HH 2H shows the maximum intensity at line 28 (which is typical for a "correctly" centered object) whereas HH 1 shows its maximum at line 25, in agreement with the fact that it has been centered on the "center" of HH 1 as given in Herbig's (1974) catalog but not on the brightest region, which is probably HH 1F (Herbig and Jones 1981). This shows that our observed spatial intensity distributions are (at least to a considerable extent) determined by the brightness distribution of the object itself and less by the properties of the aperture (or the instrument in general). It is of course understood that the situation would be different if we get too close to the boundary of the aperture.

We conclude that the measured intensity distributions along the aperture are meaningful at least in a qualitative sense.

We have used the line-by-line spectra to measure the line intensity as a function of position for the strong lines. Such measurements have been carried out for HH 1 (CIV λ1548/51, CIII] λ1907/9) and HH 2 (CIV λ1548/51, Si III λ1883-1895, CIII] 1907/9) and are presented in Figure 3. The figure shows that in the case of HH 1 the maximum of the CIV 1548/51 line intensity occurs farther away from the central star than the intensity maximum for the CIII] 1907/9 line. This is in agreement with the predictions from a bow shock model (cf. Hartmann and Raymond 1984; Raga and Böhm 1985; Böhm and Solf 1985). It also could be a consequence of the condensation structure of HH 1 and of the fact that condensation HH 1F is probably hotter than the other condensations and is therefore probably the main source for the CIV 1548/51 but not necessarily for the CIII] 1907/9 line.

Especially interesting is the relatively small spatial extent e.g., of the CIV emission region in HH 1. If we use fig. 3 to determine a half-width of the spatial distribution we find a value of approximately 2.3 "lines" or approximately 5" (seconds of arc) (the spatial scale of the line-by-line spectra is discussed in Computer Sciences Corporation 1980, 1984). It should be noted that 5" is of the same order as scale of the point spread function (Computer

Science Corporation 1984) and that it is therefore possible that the CIV 1548/51 source in HH 1 could be even considerably smaller. This agrees with the predictions from bow shock models. The emission source for the CIII] 1907/9 line in HH 1 is somewhat, though not very much, larger than the CIV emission source. It has a half-width of 3.0 "lines" ~ 6."5.

In HH 2 (HH 2H and environment) the CIV emission region is more extended (a half-width of 4.5 lines ~ 9."6). In this object the spatial extent of the CIII] 1907/9 emission has a half-width of approximately 5.2 lines ~ 11."2. The size of the Si III 1893 emission region is almost identical to that of the CIII] 1907/9 line.

The determination of the corresponding distribution of the continuum emissions is highly interesting but more difficult than in the case of the strong emission lines. It is an important question whether the continuum is formed "in situ" in basically the same regions as the emission lines (cf. Brugel, Böhm and Mannery 1981, Dopita, Binette and Schwartz 1982, Brugel, Shull and Seab 1982), whether it is a dust scattered stellar continuum (cf. Strom, Grasdalen and Strom 1974, Schmidt and Miller 1979, Cohen and Schmidt 1981) or whether, at least in some cases, it is partially or fully identical with the radiation from the very extended Orion reflection nebulosity (Mundt and Witt 1983). It is clear that the measurement of the spatial distribution of the continuum emission can give us some useful information in this context.

It should be emphasized that the continuum measurements are difficult and somewhat uncertain because the continuum is relatively faint. This is especially true for the outer "wings" of the spatial emission distribution.

In fig. 4 we have plotted the continuum intensity binned into three wavelength intervals (as indicated) as a function of "line-number" (of the "line-by-line spectra"). The intensity maximum for HH 1 (as in the case of the strong emission lines) occurs at line 25 or 26. This clearly indicates that a considerable part of the continuum has its maximum intensity

between "line" 25 and 26, at the same place or, at least, very close to the maximum of the emission line intensity. This shows that the continuum is, at least to a considerable extent, not formed in a diffuse background but in the HH object itself. The fact that the object has been centered approximately on line 25 and not on the center of the aperture makes this conclusion more convincing. (It shows that the agreement between the maximum positions of emission lines and continuum cannot be easily attributed to properties of the spatial instrumental profile.)

The relative spatial dependence of the continuum for the different bins (1250-1550 Å), (1550-1750 Å), and (1750-1950 Å) shows slight differences which are too small to be considered as real. Since the noise in the range 1750-1950 Å is smaller than in the shorter wavelength ranges we assume that the measurements in this λ-interval show best the typical spatial variation of the continuum emission. In fig. 4 we see that the half-width for the spatial intensity distribution of the continuum in HH 1 is approximately 4.9" lines $\sim$ 10."6. This is about twice as large as the half-width of the emission region for CIV 1548/51 in the same object (see above.)

For HH 2H (and its environment) we have a qualitatively similar situation. The continuum now shows its maximum near line 28 (as do the strong emission lines, see above). For the 1750-1950 Å wavelength range we find a half width of about 5.7 lines $\sim$ 12."2. This is somewhat but not very much larger than the half-widths of the emission regions of the lines CIV 1548/51 (9."6) and CIII] 1907/9 (11."2) in the same object.

The problem of the spatial distribution of the continuum emission is of course closely related to the question of how much the Orion reflection nebulosity (ORN) contributes to the apparent continuum of the objects HH 1 and HH 2 (Mundt and Witt 1983). Though the diagrams in fig. 4 already show that the contribution of the ORN is, at most moderate, it is certainly important to study this question in greater detail. The best approach is obviously to obtain spectra completely outside of the HH objects but not too far away.

Such a spectrum will probably show the ORN spectrum only and can be subtracted from the HH spectra. We have obtained one such ORN spectrum (see table 1)...

b. Integrated Spectra

For a comparison to the spectra of other HH objects and for further studies of emission processes in HH objects it is useful to present integrated spectra which normally have a better signal-to-noise ratio than the spatially resolved spectra.

In fig. 5 we present the integrated spectra of HH 1 and HH 2. As in the case of the line-by-line spectra the extinction correction has been carried out using a "θ Orionis" extinction curve (Bohlin and Savage 1981). E(B-V) = .46 has been used for HH 1 and E(B-V) = .38 was applied in the case of HH 2 (Brugel, Böhm and Mannery 1981b). In both cases we see the continuum (or quasi-continuum) of Herbig-Haro objects and the well-known emission lines of "high excitation" HH objects (cf. Böhm 1983) including the CIV 1548/1551, the CIII] 1907/1909, the Si III 1883/1892, OIII] 1661/1666 and the Si IV 1393/1402 lines. In both objects CIV 1548/1551 is the strongest and the CIII] 1907/1909 is the second strongest line in agreement with earlier results (Ortolani and d'Odorico 1980, Böhm, Böhm-Vitense and Brugel 1981, Brugel, Shull and Seab 1982, Böhm-Vitense *et al.* 1982). Not all the lines mentioned occur in the spectra of both objects (see fig. 5).

The spectrum of HH 2 shows a relatively high signal to noise ratio (for an I.U.E. spectrum of an HH object) and offers a good opportunity to obtain useful information about the still somewhat enigmatic energy distribution of HH continua. Though the situation is somewhat less favorable for HH 1 we have also used its spectrum for a re-determination of the continuous energy distribution.

We have eliminated all known emission lines and reseau marks from the measured spectra as well as we could and then smoothed the continuum (once) over 50 Å intervals. The result is presented in fig. 6. The continua of the two objects show a considerable similarity. For this reason we considered it appropriate to show in addition to the continua of the individual objects HH 1 and HH 2 also an "average continuum" of the two objects in fig. 6. Because of the higher signal-to-noise ratio in HH 2 we consider the detailed structure in the continuum of this object as more reliable than the structure of the HH 1 continuum.

There is some evidence that the continuum in HH objects is due to collisionally enhanced two-photon emission (Dopita, Binette and Schwartz 1982, Brugel, Shull and Seab 1982). In the optical range the evidence for this identification seems to be rather convincing, at least in the case of some HH objects (Dopita, Binette and Schwartz 1982, Böhm, Brugel and Olmsted 1983). In the ultraviolet the situation is certainly more complex. There were already earlier indications (Brugel, Shull and Seab 1982) that the continuum has a complicated structure as a function of wavelength. This is clearly confirmed by our observations. It is interesting that the structure is more detailed in HH 2, the object in which the signal-to-noise ratio is higher. We consider this as an indication that the detailed structure is, at least in part, real.

In both objects the maximum occurs at $\lambda \sim 1580$ Å. One of the most obvious features of the continuum of the two objects is the very steep decline from $\lambda \sim 1580$ Å to $\lambda \sim 1700$ Å (this steep gradient was first discovered in HH 2 by Brugel, Shull and Seab 1982).

Fig. 6 shows that we do not see a "pure" two-photon continuum. It is certainly possible that the two-photon continuum contributes in an important way to the observed spectrum but the detailed structure must be due to other processes. It is interesting that the continua of HH 1 and HH 2 show such great similarity in their structure. Both have their maxima in the λ-interval 1570-1580 Å and not near 1410 Å as one would expect

for the two-photon continuum (note that F_λ has been plotted in Fig. 6). We note that the fluorescent H_2 continuum studied by Dalgarno, Herzberg and Stephens (1970) and by Duley and Williams (1980) has a relatively sharp peak at $\lambda \sim 1570$ Å and a somewhat lower peak near $\lambda \sim 1480$ Å in qualitative agreement with our observations. There is however no *quantitative* or detailed agreement between the predicted H_2 continuum and our data. The observations do not show, for instance, an additional peak at $\lambda \sim 1530$ as predicted by the theory of Dalgarno, Herzberg and Stephens (1970). On the other hand the gap between the 1570 and 1530 Å peak is rather narrow and occurs at $\lambda \sim 1550$ (see Dalgarno, Herzberg and Stephens 1970). Furthermore, the smoothing of our data over 50 Å intervals would tend to make the gap disappear. It is therefore probable that it is almost completely filled by the strong CIV 1548/51 emission line and that it is consequently not detectable in low resolution spectra. In summary we find that there is some moderately convincing evidence for the presence of the fluorescent H_2 continuum though it is not as clear as one would like to see it. We consider it as important that the highest peak of the continuum occurs near 1580 Å and is rather narrow, in agreement with the predictions for the H_2 continuum. If this interpretation is correct it is interesting to note that the continuum is formed in the destruction process of H_2 molecules (cf. Duley and Williams 1980) and requires the presence of a radiation field shortward of $\lambda \sim 912$ Å. It is relevant in this context that H_2 is also observed in the uv spectrum of *low excitation* HH objects (Schwartz 1983c) but in that case one sees fluorescent lines which are excited by the Ly α line. All this, of course, certainly does not contradict the possibility that a sizeable fraction of the ultraviolet continuum could be due to two-photon emission. In fact, as mentioned above, the optical data make it rather probable that this is really the case.

Conclusions

The "two-shift exposure" spectra of HH 1 and HH 2 permit us to derive information about the spatial distribution of the ultraviolet line and continuum emission in and near

these objects. They also allow us to obtain an improved energy distribution of the ultraviolet continuum and thereby help us to identify the possible continuum emission processes. From these observations we draw the following conclusions:

1. In HH 2 (with the aperture centered on HH 2H) we find rather similar spatial distributions for the strong emission lines CIV 1548/51, Si III 1883/1895, CIII] 1907/09 and for the continuum at all wavelengths (in the SWP range). The spatial half-width of the emitting region in CIII] 1907/09 and Si III 1883/95 (11."2) is slightly larger than the corresponding half-width for CIV 1548/51 (9."6). The spatial half-width of the continuum (12."2) is almost identical to that for the CIII] and Si III emission lines. We consider this fact as a strong indication that the continuum is formed essentially in the same volume as the emission lines and is not mostly due to the Orion reflection nebulosity or other background radiation.

2. In HH 1 we see a more pronounced difference in the sizes of the emitting regions. The half-width of the CIV 1548/51 emitting region ($\sim$ 5") is smaller than that of the CIII] emitting region (6."5). Both are considerably smaller than the half-width of the continuum emitting region ($\sim$ 10."6). The spatial halfwidth for the CIV lines is roughly comparable to the scale of the I.U.E. point-spread function, and it is therefore possible that the emitting region for the CIV lines could actually be considerably smaller. It is important that for the lines as well as the continuum the maximum of the emission occurs approximately at the same place (between line 25 and 26, which is not at the center of the aperture. see above). This indicates again that at least a considerable part of the continuum radiation is very probably generated in the same volume as the emission lines. In this case the continuum emission distribution seems to have a tail pointing towards the central star (i.e., downstream if the HH 1 emission comes from the type of bow shock described by Choe, Böhm and Solf 1985). The spatial distribution shown in fig. 4 shows a qualitative similarity to the spatial distribution of the Hα intensity contained in the position-velocity diagrams given by Böhm and Solf (1985). In general the uv observations

of HH 1 have a spatial intensity distribution somewhat analogous to the spatial intensity distribution found in optical emission lines, which in turn can be interpreted as bow shock emission (Choe, Böhm and Solf 1985, Raga and Böhm 1986.

3. ...

4. The (spatially) integrated spectra have a sufficiently high signal-to-noise ratio so that a determination of the energy distribution of the continuum and a fairly good separation of at least the stronger emission lines from the continuum can be carried out. (This is especially true for HH 2.)

5. The energy distribution of the continua based on a smoothing over 50 Å intervals (shown in fig. 6) exhibits a number of interesting properties including the following.

a. The continuous spectra of HH 1 and HH 2 show a surprising similarity even in rather small details (see fig. 6). This shows that such detailed features are not simply due to noise. It is interesting to note that HH 2 which has a higher signal-to-noise ratio than HH 1 shows even somewhat more detailed features than HH 1. This again can be considered as an indication of the reality of these details.

b. Two very obvious features of both spectra are the very steep intensity decline from (say) $\sim$ 1620 Å to $\sim$ 1700 Å (which was first mentioned by Brugel, Shull and Seab 1982) and the fact that the maximum of the intensity I_λ occurs in both objects between 1570 Å and 1580 Å.

c. We note that the position of the maximum in I_λ does not occur at the wavelength where the two-photon continuum (Spitzer and Greenstein 1951, Drake and Ulrich 1981) has its maximum ($\sim$ 1410 Å) but does agree rather well with the position of the maximum of the H_2 continuum described by Dalgarno, Herzberg and Stephens (1970) and Duley and Williams (1980) which is formed in the destruction of H_2. Earlier observations already contained some indications of this fact, but the new long exposure spectra show this

result rather clearly. We conclude that the two-photon continuum may well contribute considerably to the continuous spectrum of HH 1 and HH 2 in the wavelength range of (say) 1300 Å $\leq \lambda \leq$ 1900 Å (it very probably is the main contributor to the continuum of at least some HH objects in other wavelength ranges, see Dopita, Binette and Schwartz 1982, Böhm, Brugel and Olmsted 1983) but that the detailed features in fig. 6 must be due to other mechanisms which also contribute in an important way to the continuum in this wavelength range. We suspect that the H_2 continuum which is formed in the destruction of H_2 plays an important role in HH 1 and HH 2. It is interesting that such an effect occurs in high excitation objects while fluorescent *emission lines* of H_2 (excited by Lα radiation) play an important role in the ultraviolet spectra of low excitation HH objects (Schwartz 1983c).

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Table 1

Long Exposure I.U.E. Observations of HH 1 and HH 2

Date	Exposure Time (min.)	Camera and Image number	Aperture	Position of Aperture Center	Observer
Jan. 16, 1985	729	SWP 24914	Large	HH 1[a]	Bührke, Böhm
Jan. 17, 1985	860	SWP 24919	Large	HH 2H	"
Apr. 6, 1983	406	SWP 19660	Large	05-33-54.3,−06°47′31″ (ORN)[b]	Witt, Mundt

[a] Centered on the position given in Herbig's (1974) catalogue (see text)

[b] Observation of the background radiation due to the Orion reflection nebulosity (see text)

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Figure Captions

Fig. 1 - The "line-by-line" spectra of HH 2, showing the spatial dependence of the line and continuum emission in this object. The line numbers (e.g. "L 24") are stated in the upper parts of the individual diagrams. L 28 corresponds to the center of HH 2H as given in Herbig's (1974) catalogue. The spectra have been "smoothed" by replacing every spectrum by the average of 3 neighboring spectra centered on the spectrum number shown (e.g. L 24 is the average of the spectra 23, 24 and 25). Note that only every second spectrum is shown in the diagram. The spectra have been corrected for extinction (see text).

Fig. 2 - The line-by-line spectra for HH 1. In this case the intensity maximum (probably corresponding to condensation HH 1F, see Herbig and Jones 1981) occurs approximately at line 25. Because of the small geometrical scale of the object, the successive "line-by-line" spectra 24, 25, 26 and 27 are shown (without omitting intermediate spectra as in fig. 1). Otherwise, the same remarks as for fig. 1 apply. The spectra have been corrected for extinction (see text).

Fig. 3 - The spatial dependence of the line intensity I in HH 1 and HH 2 for the emission lines "CIV 1550" (i.e. 1548/51), "CIII 1907" (i.e. 1907/09) and SiIII 1883/95 (shown only for HH 2).

Fig. 4 - The relative spatial distribution of the continuum emission for three different wavelength bins in HH 1 and HH 2. The intensities have been arbitrarily normalized to the same value at "line" 26 (HH 1) and 28 (HH 2). The "line numbers" identify the position along the aperture and have the same meaning as in fig. 1 and 2.

Fig. 5 - The integrated ultraviolet spectra (integrated over the whole object) for HH 1 and HH 2. The same extinction correction as in fig. 1 and 2 (see text) has been applied. Note that different intensity scales have been used for HH 1 and HH 2.

Fig. 6 - The continuum of HH 1, HH 2 and the "average" continuum. After eliminating the known emission lines, a single "smoothing" (taking a "running" mean) over 50 Å intervals has been applied to both objects. Note the great similarity of the continuum energy distributions in both objects. See text for a discussion of the details of the energy distribution.

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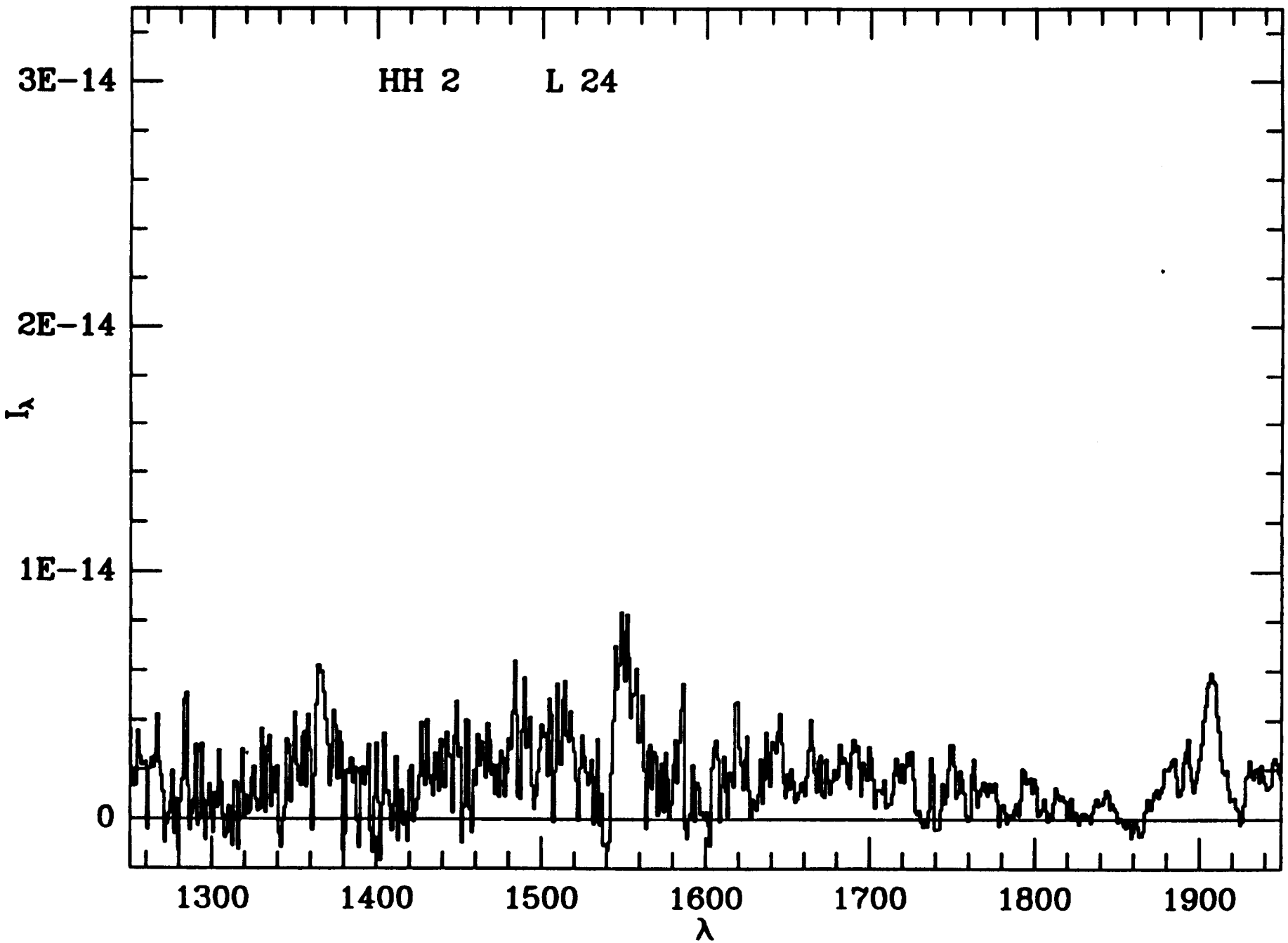
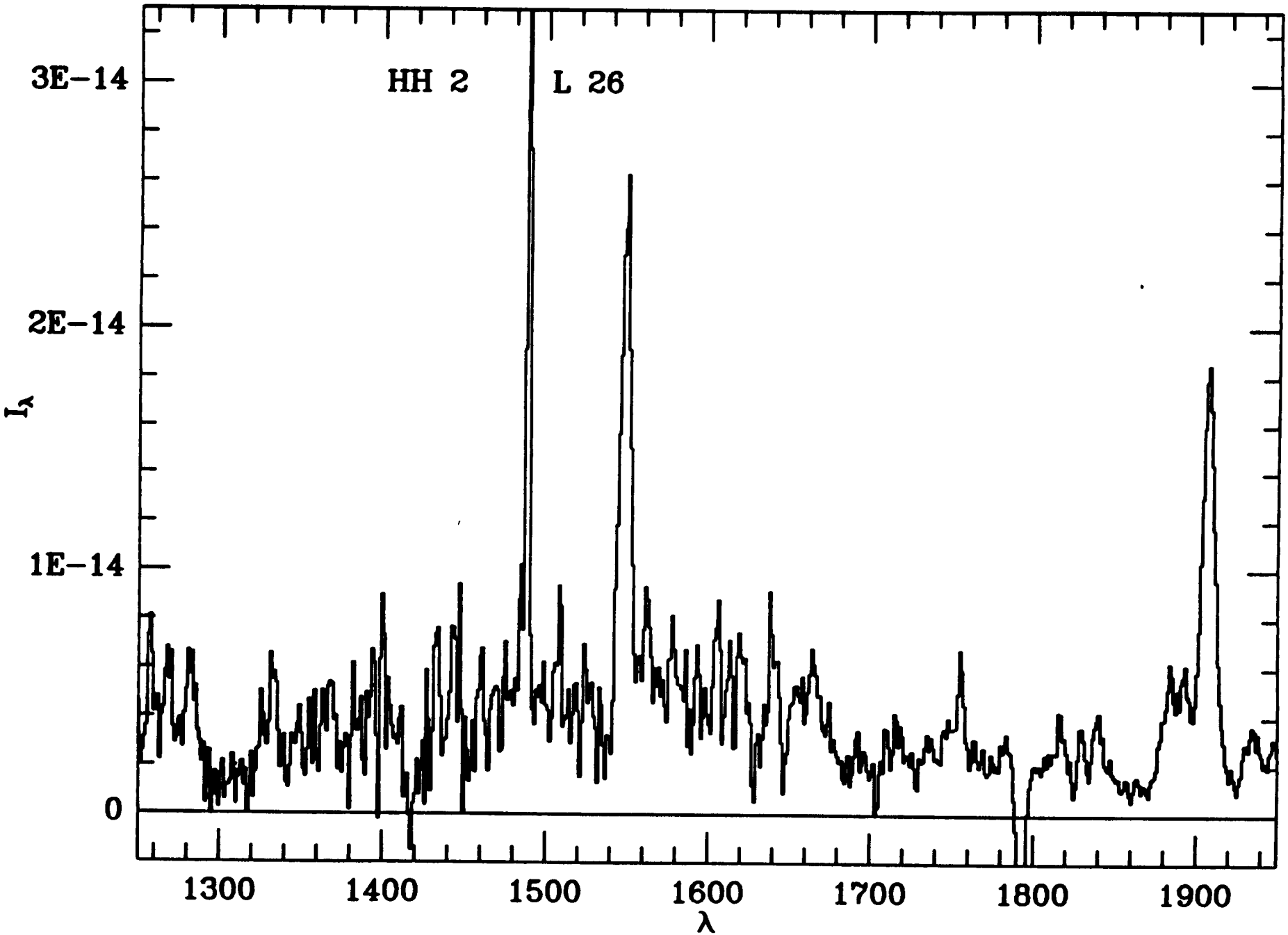
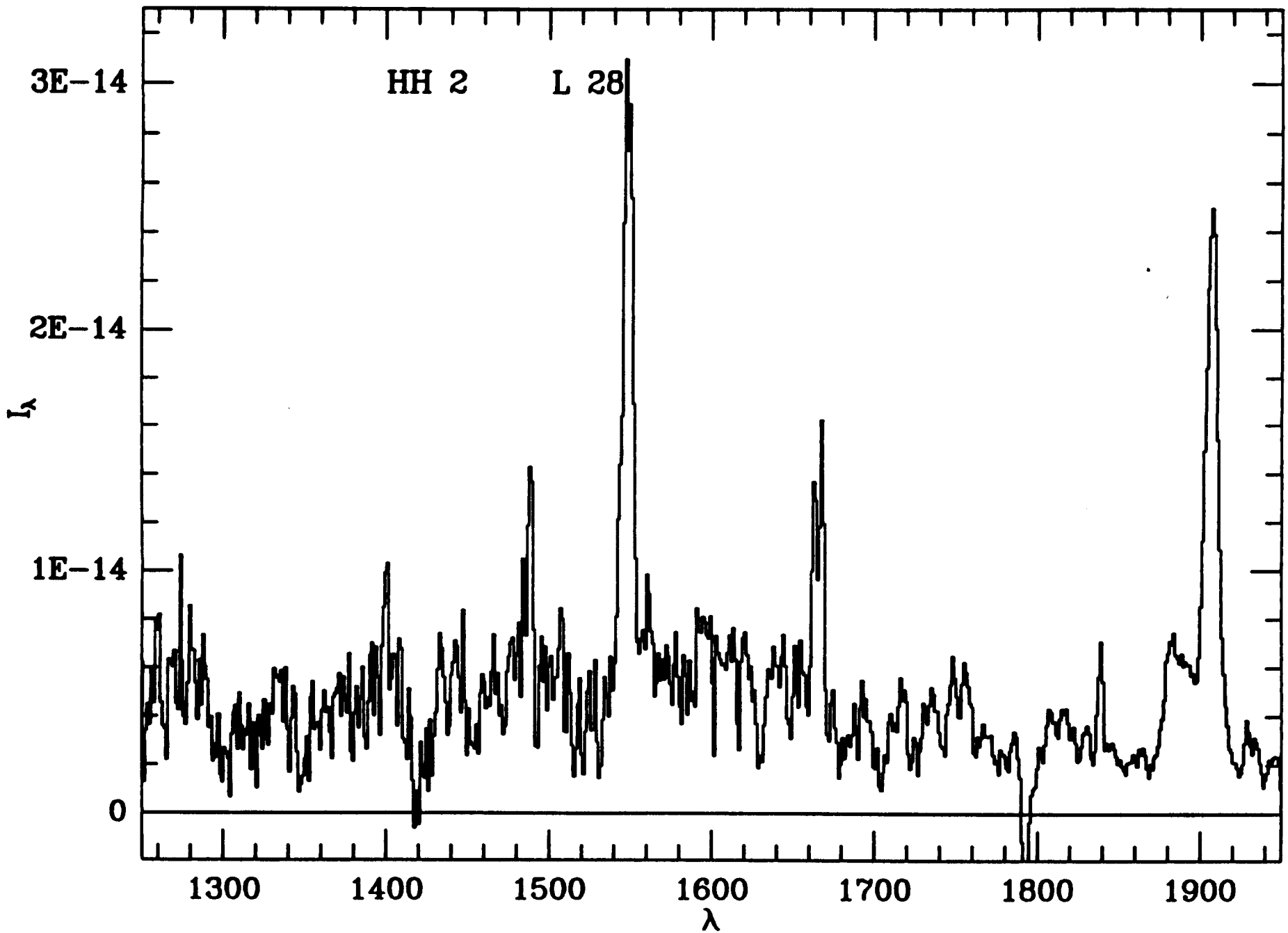
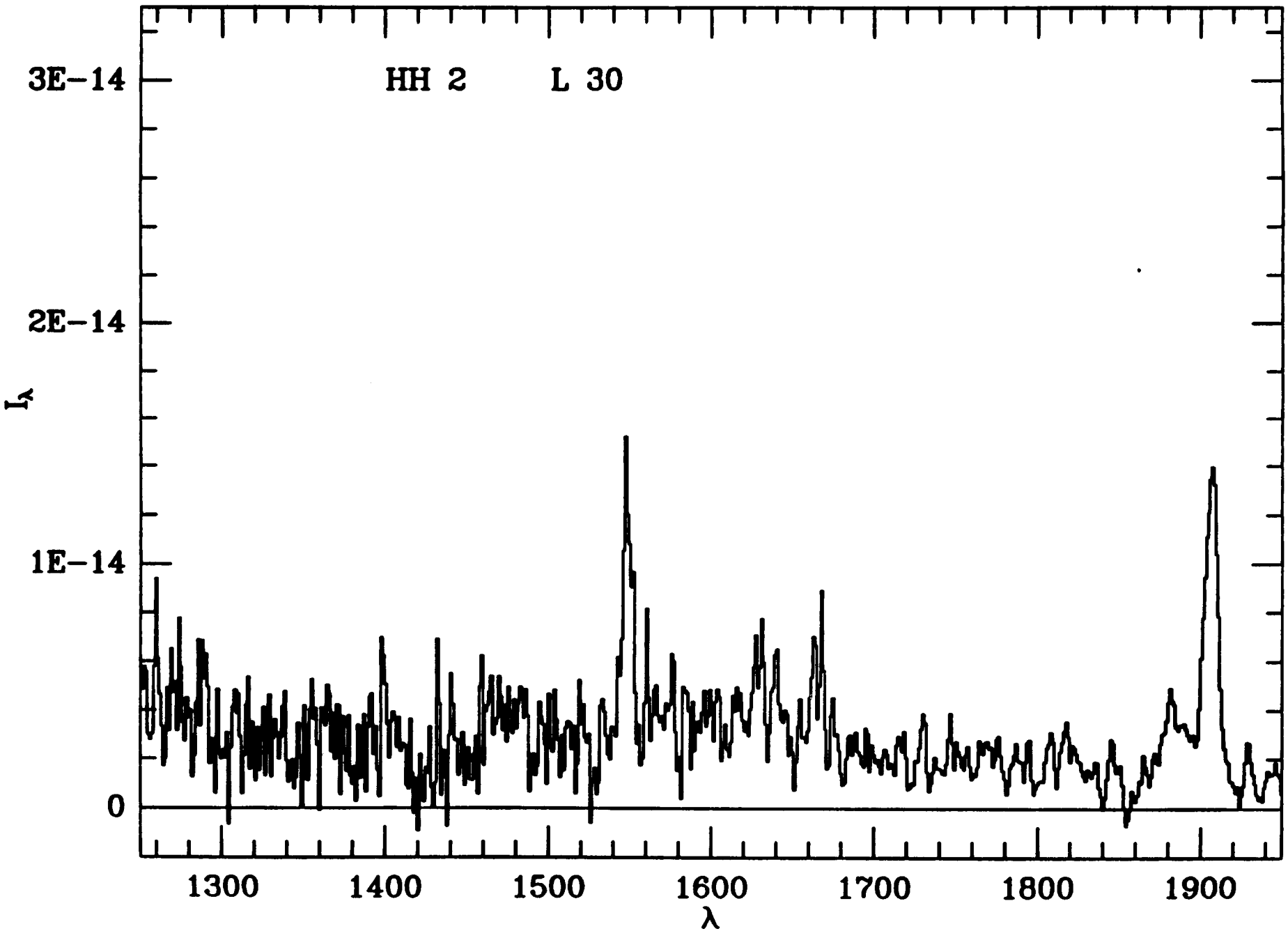

HH 2
L 24
3E−14
2E−14
1E−14
0
I_λ
1300
1400
1500
1600
1700
1800
1900
λ

Fig. 1a


HH 2
L 26
3E−14
2E−14
1E−14
0
L_λ
1300
1400
1500
1600
1700
1800
1900
λ


HH 2
L 28
3E−14
2E−14
1E−14
0
L_λ
1300
1400
1500
1600
1700
1800
1900
λ


HH 2
L 30
3E−14
2E−14
1E−14
0
I_λ
1300
1400
1500
1600
1700
1800
1900
λ

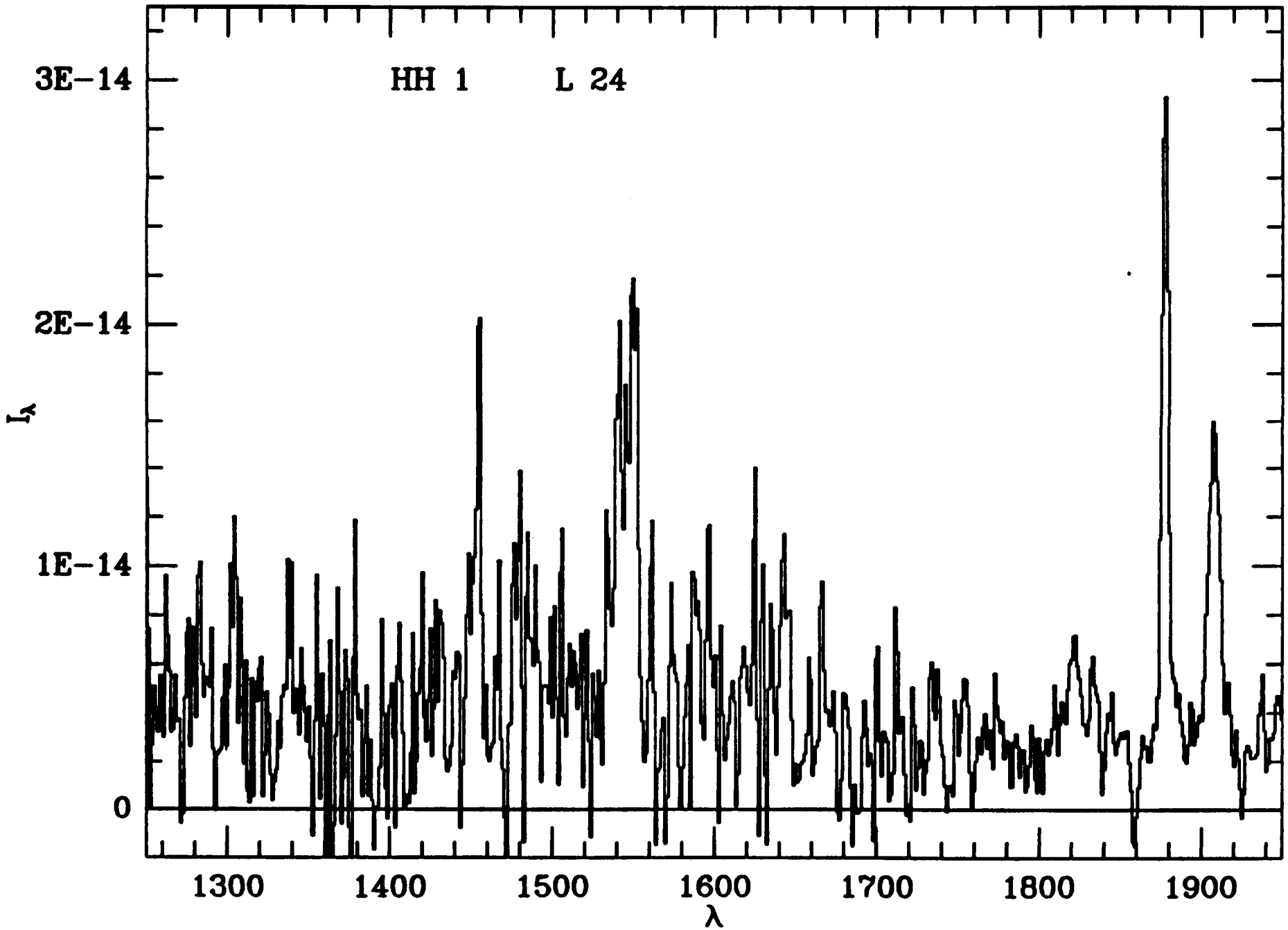
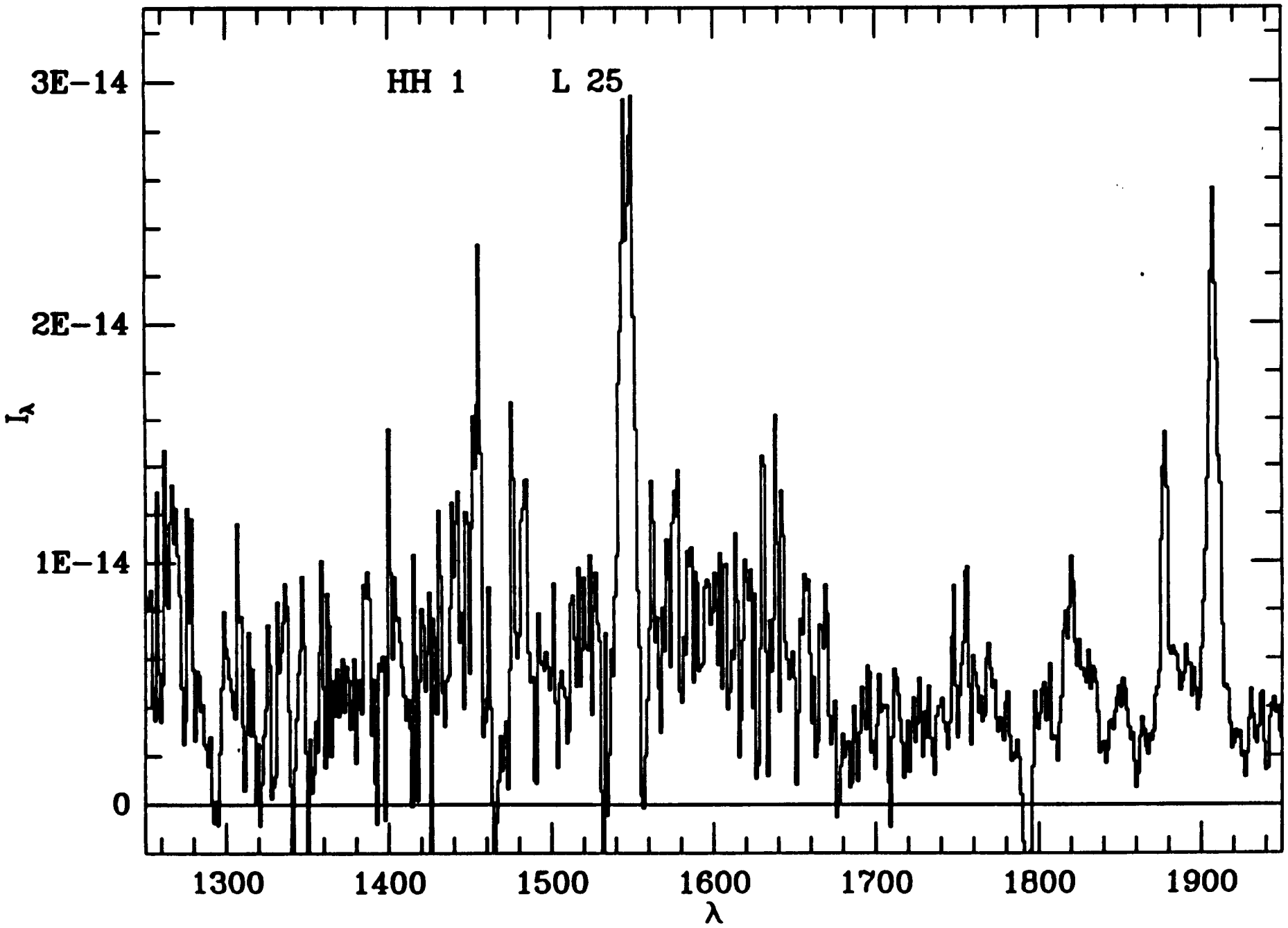
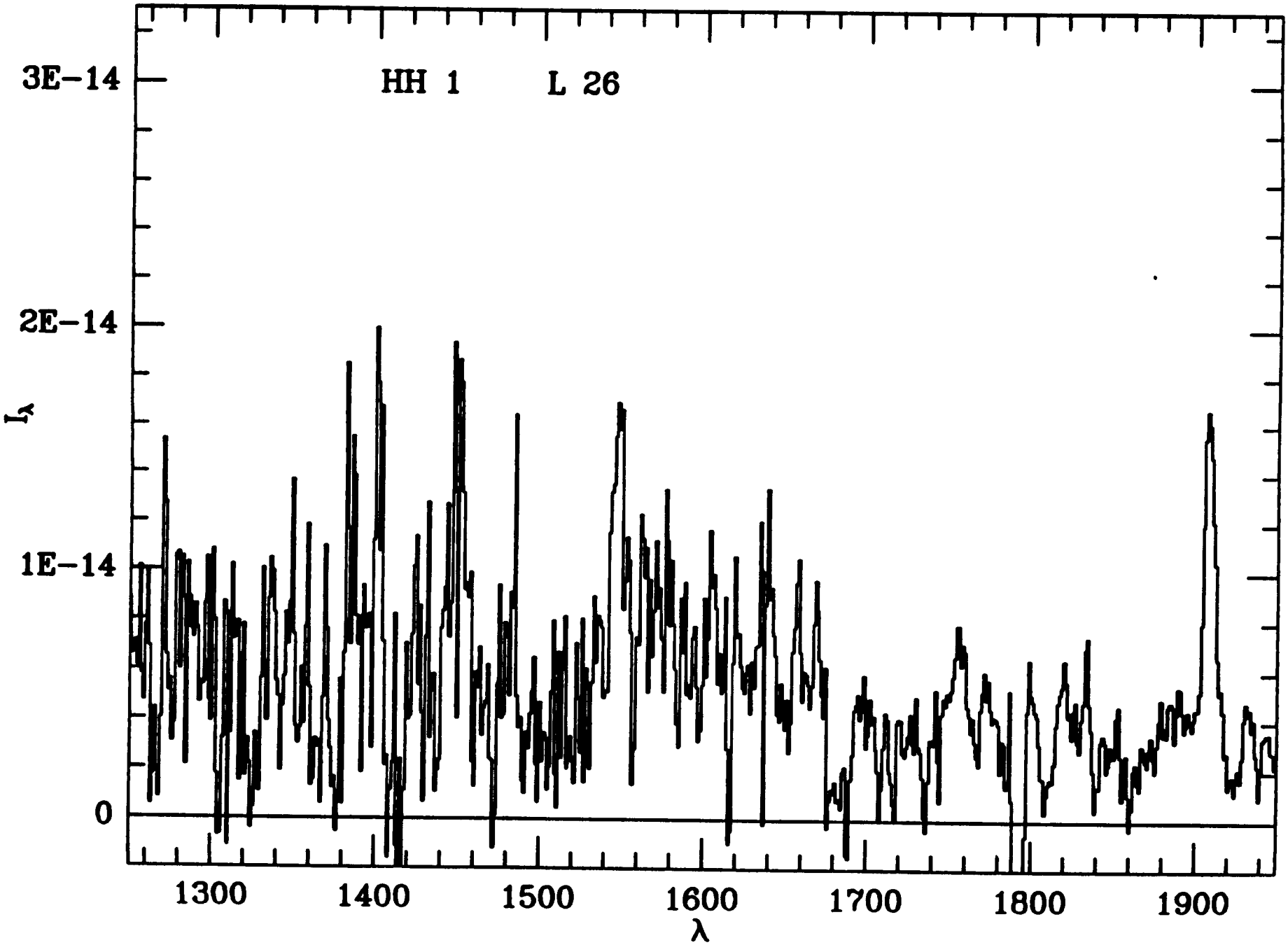
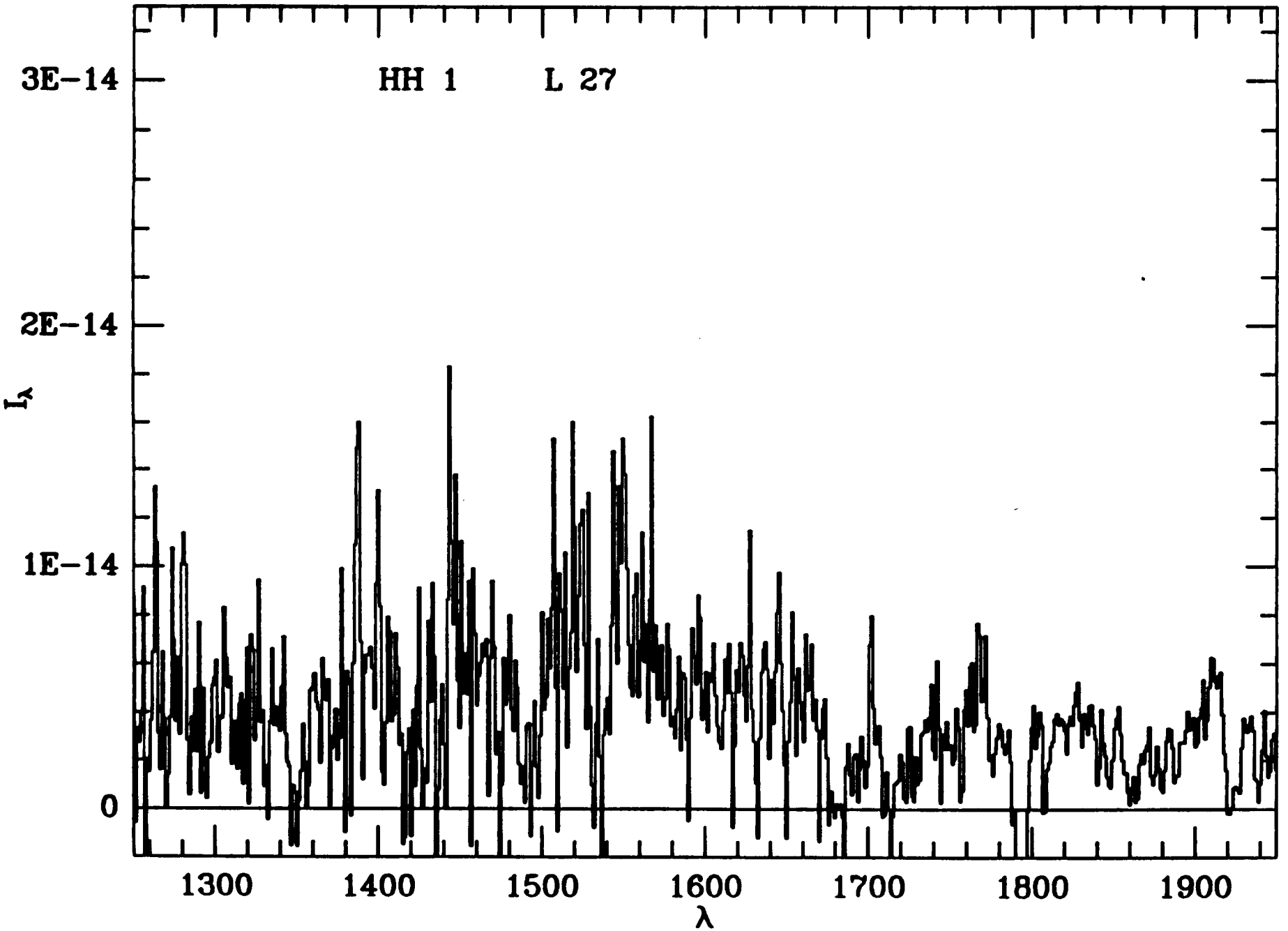

HH 1
L 24
3E−14
2E−14
1E−14
0
L_λ
1300
1400
1500
1600
1700
1800
1900
λ

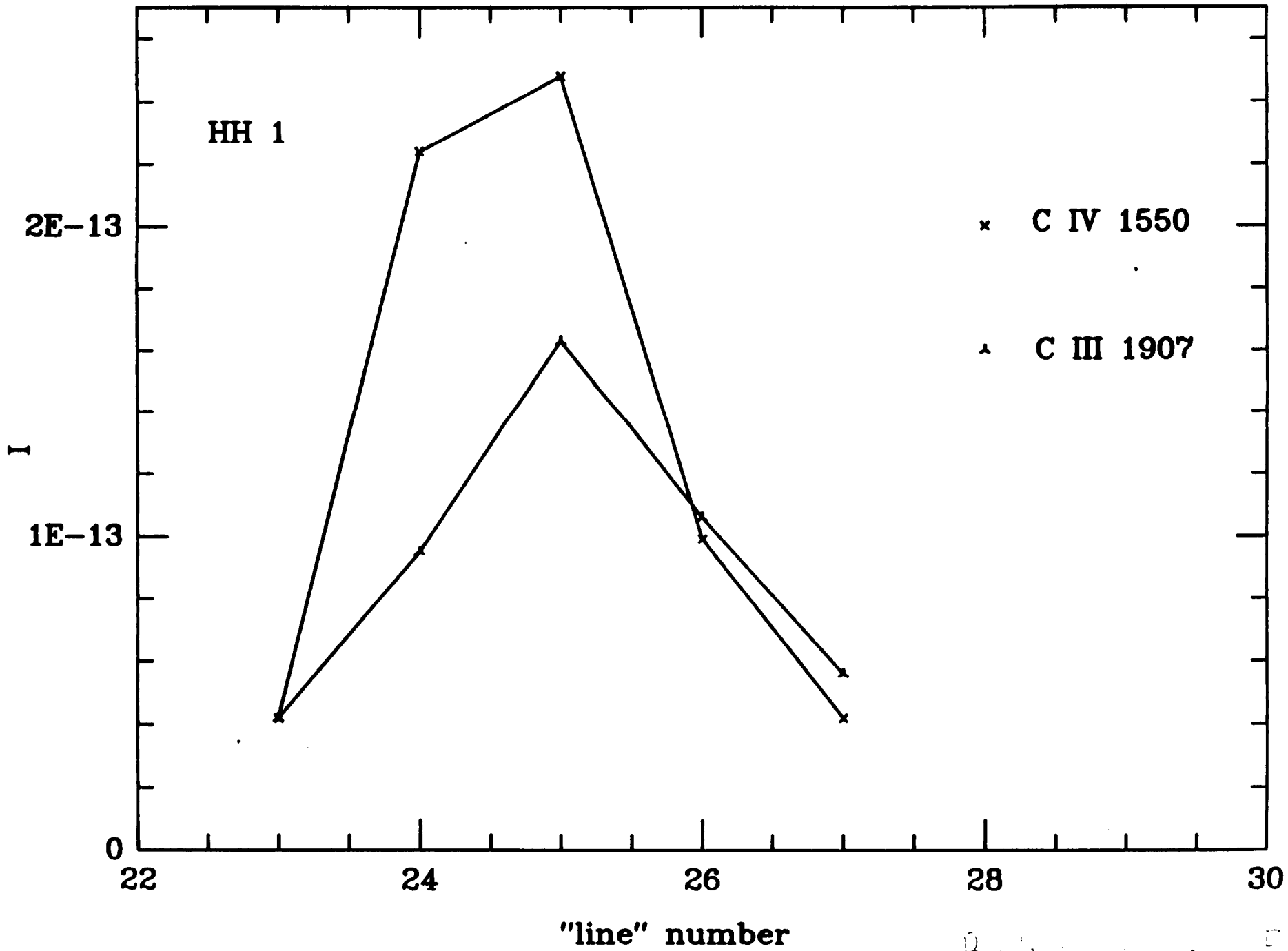
Fig. 2a



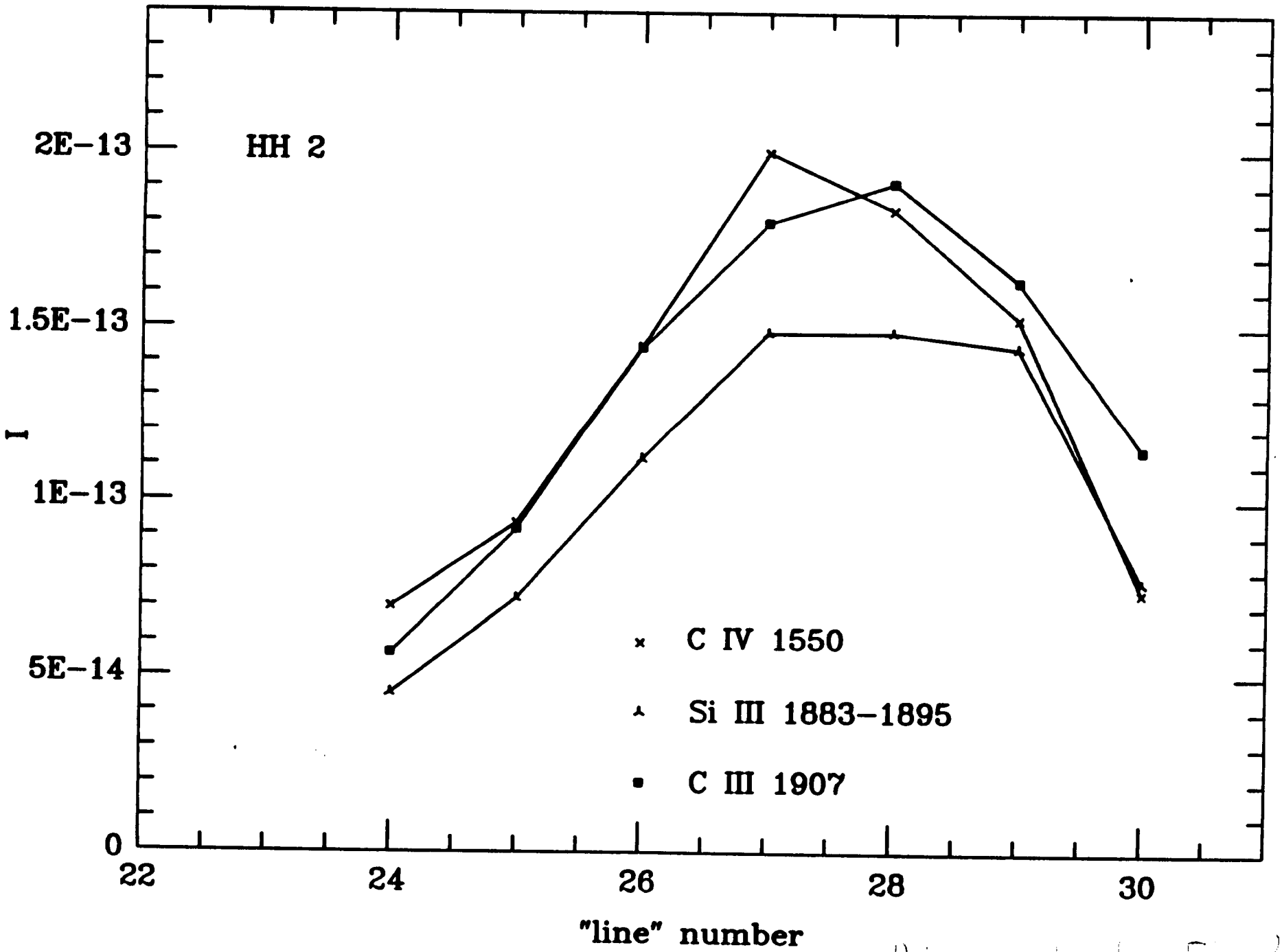
Böhm et al., Fig 2b


HH 1
L 26
3E−14
2E−14
1E−14
0
I_λ
1300
1400
1500
1600
1700
1800
1900
λ

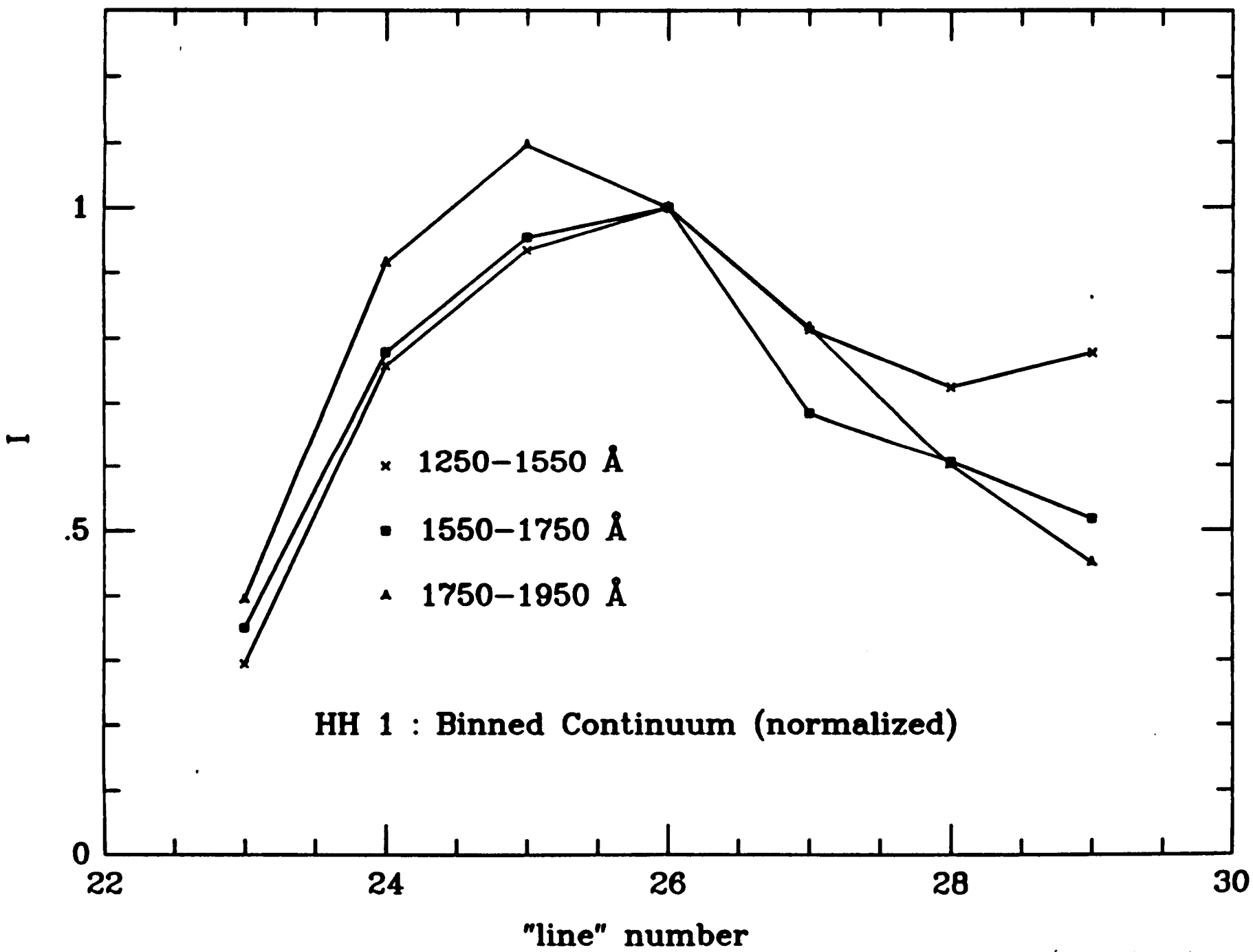

HH 1
L 27
3E−14
2E−14
1E−14
0
I_λ
1300
1400
1500
1600
1700
1800
1900
λ

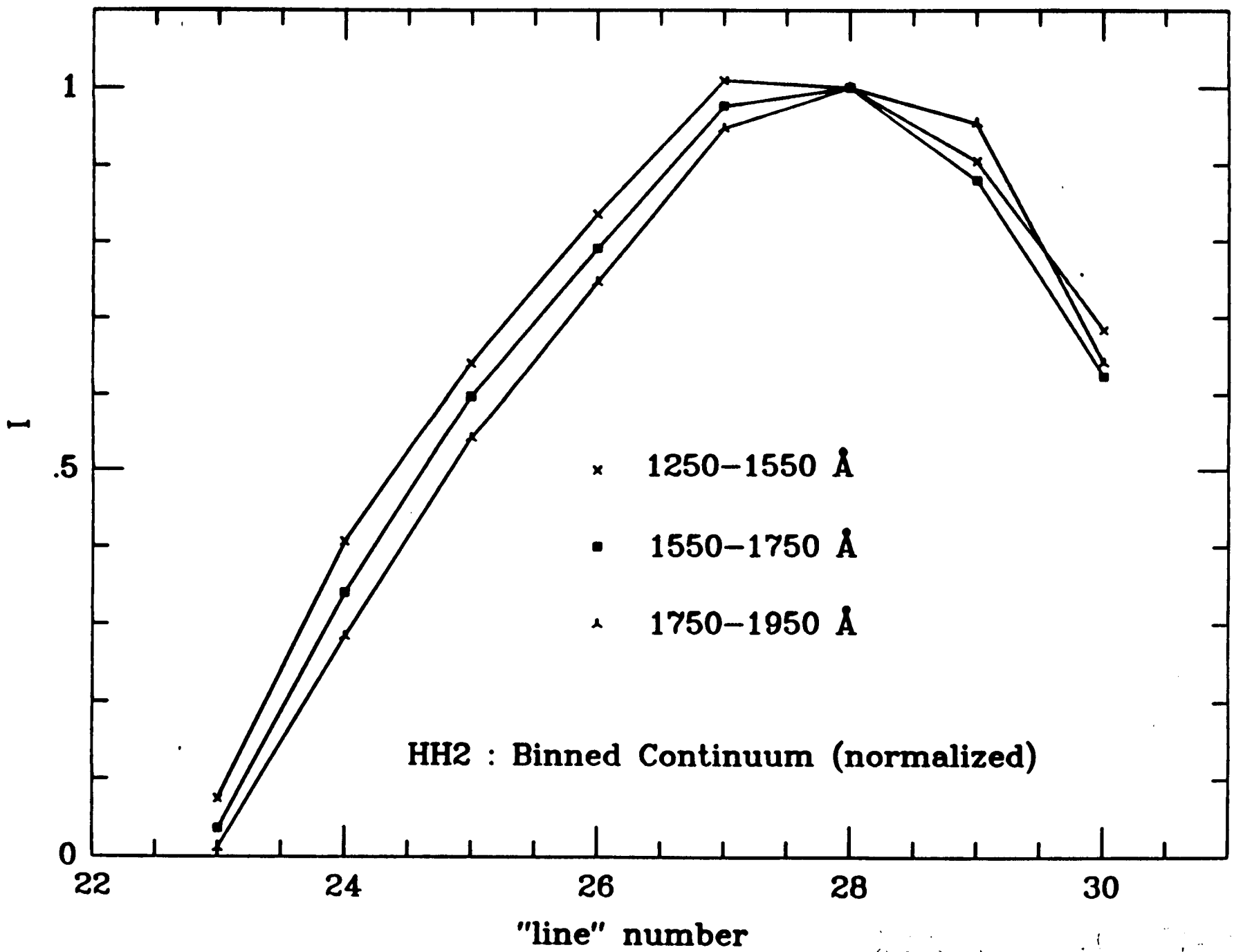


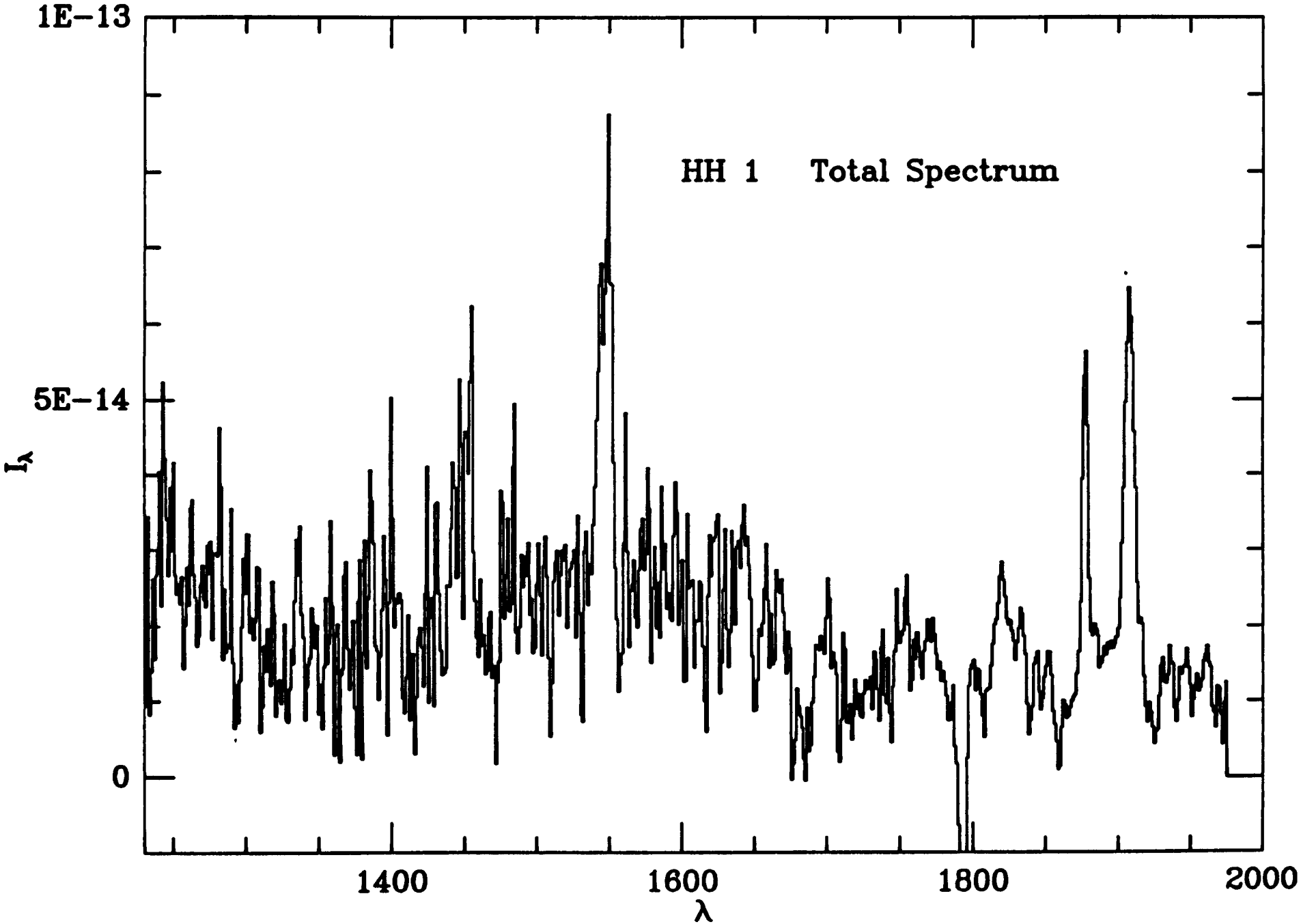
B... Fig. 3a

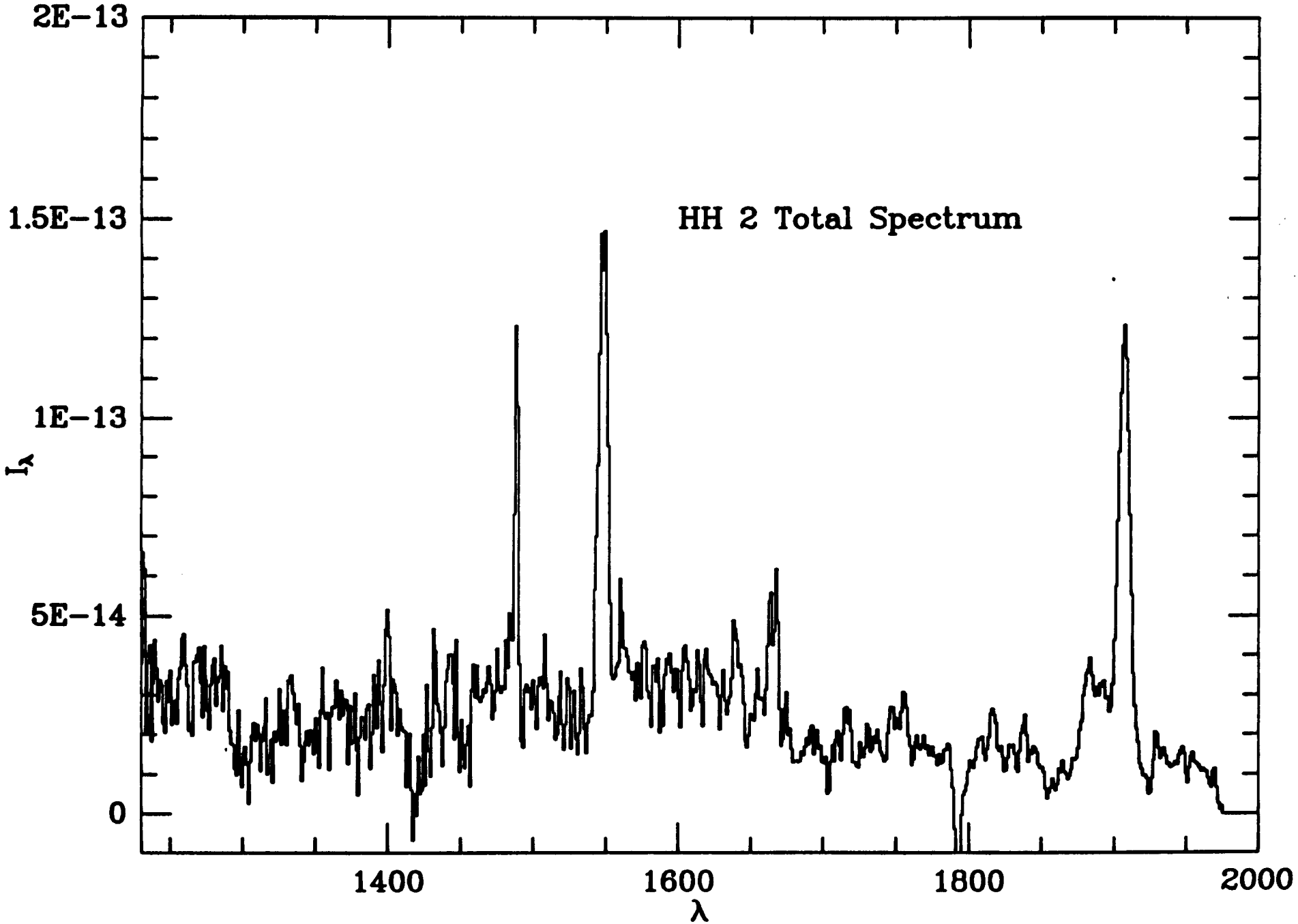


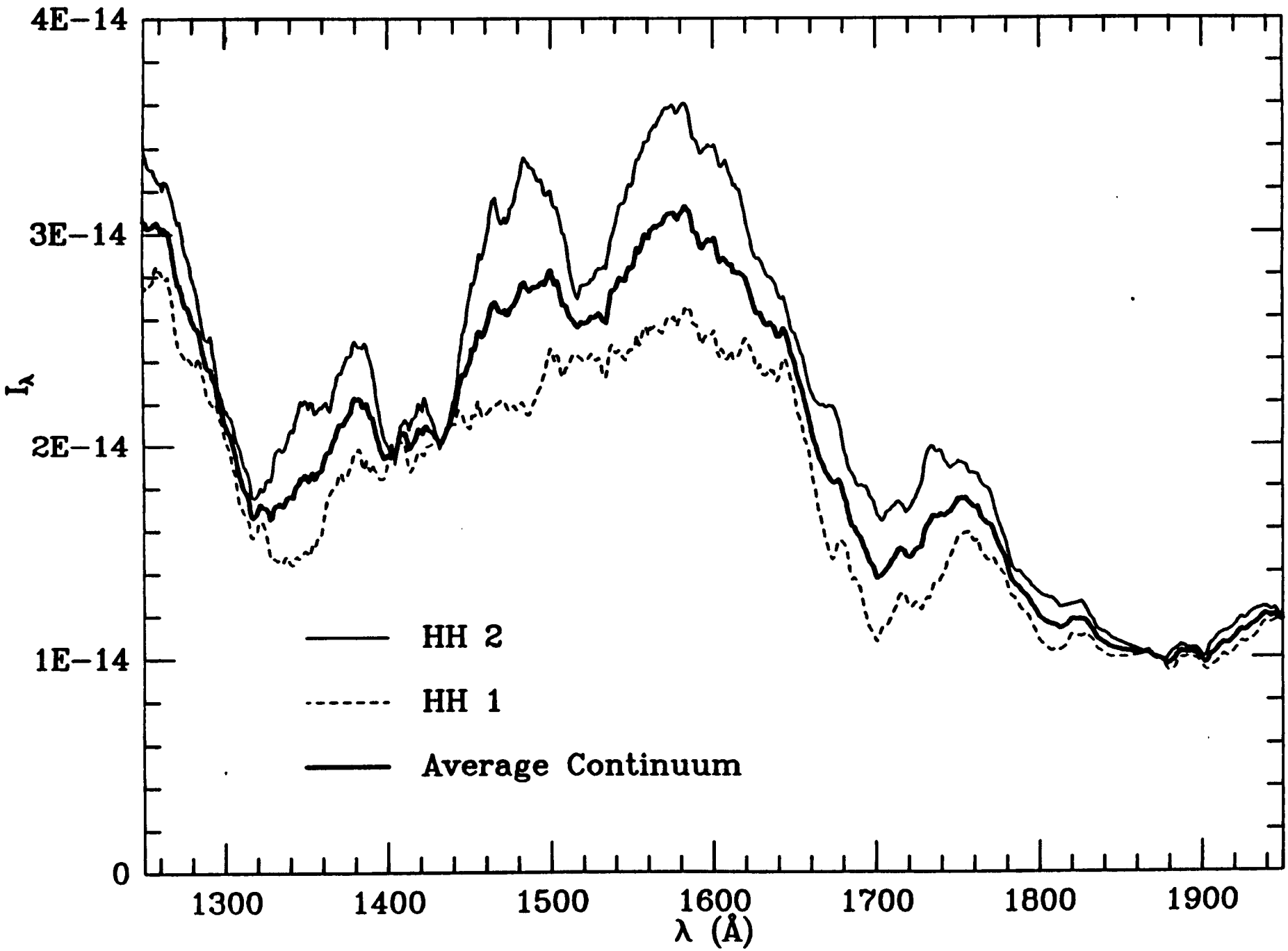
Bo[illegible] et al., Fig. 3b


1250–1550 Å
1550–1750 Å
1750–1950 Å
HH 1 : Binned Continuum (normalized)
I
0
.5
1
22
24
26
28
30
"line" number


1
.5
0
22
24
26
28
30
"line" number
I
1250–1550 Å
1550–1750 Å
1750–1950 Å
HH2 : Binned Continuum (normalized)


HH 1 Total Spectrum
1E−13
5E−14
0
I_λ
1400
1600
1800
2000
λ


HH 2 Total Spectrum
2E−13
1.5E−13
1E−13
5E−14
0
I_λ
1400
1600
1800
2000
λ


4E−14
3E−14
2E−14
1E−14
0
L_λ
1300
1400
1500
1600
1700
1800
1900
λ (Å)
HH 2
HH 1
Average Continuum