STATUS REPORT ON THE RESEARCH SUPPORTED BY NASA GRANT NAG 5-45

"I.U.E. Observations of Herbig-Haro and Related Objects"

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SUMMARY

Since the beginning of the grant period in 1980 we have obtained and studied I.U.E. spectra of the Herbig-Haro objects H-H 1, H-H 2H, H-H 2G and H-H 32 A. In order to obtain a better understanding of the physics of these intriguing objects and of the formation of the ultraviolet continua and emission lines in H-H objects we have also obtained UV spectra of the Cohen-Schwartz star, the T Tauri star AS 353A and of the reflection nebula NGC 1999 (which is illuminated by the young object V 380 Orionis).

I. HERBIG-HARO OBJECTS

It is well known that the optical emission line spectra of Herbig-Haro (H-H) objects are formed in the recombination regions of shock waves (cf. Schwartz 1975, Böhm, Siegmund and Schwartz 1976, Dopita 1978) and that H-H objects are clumps of matter which apparently have been ejected from certain T Tauri or other young stars (Herbig and Jones 1981) with velocities up to 350 km s^{-1}. The shock velocities determined from the spectra (and corresponding possibly to the velocity of the object relative to the stellar wind) seem to be of the order of 85 km s^{-1} and less.

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The problem which we are studying in our research under grant NAG 45 is: Which additional information on the physical conditions in H-H objects can be obtained by the study of their I.U.E. spectra? When we started this investigation it was far from clear whether the observation of any H-H object would be possible with I.U.E. After all the brightest H-H objects have an apparent visual magnitude of approximately 16 only. Estimates based on the shock wave theory had indicated that a few uv emission lines might just be marginally detectable. It came as a considerable surprise that the first I.U.E. observations of H-H 1 using the SWP camera (Ortolani and d'Odorico 1980) and using the LWR and SWP cameras (Böhm, Böhm-Vitense and Brugel 1981) showed not only some strong emission lines but also, in contradistinction to the optical range, a surprisingly strong continuum (or quasicontinuum). Our further observations of the objects H-H 2H, H-H 2G and H-H 32 Å showed that these objects had ultraviolet continua and emission lines similar to those of H-H 1 (Böhm-Vitense, Böhm, Cardelli and Nemec 1982, Böhm and Böhm-Vitense 1982b). It turned out that H-H 2H is the (so far) brightest H-H object in the uv though H-H 1 is brighter in the optical range. This is entirely compatible with the reddening and extinction determined from the optical data by the [S II] method (Böhm, Siegmund and Schwartz 1976, Brugel, Böhm and Mannery 1981b).

The basic results of our I.U.E. observations of H-H objects are as follows: All observed objects show a continuum flux F_λ which is strong and in general rises towards shorter wavelengths at least down to $\lambda \sim 1400$ Å. The behavior at shorter wavelengths than 1400 Å is difficult to determine since the spectrum is noisy and unresolved and unidentified emission lines may contribute to our "continuum" measurements. (Brugel, Shull and Seab (1982) conclude from a 7 hour exposure that F_λ does begin to turn down towards shorter wavelengths near 1400 Å). It is clear that the uv continuum is a continuation of the faint continuum in the optical range (Böhm, Schwartz and Siegmund 1974, Brugel, Böhm and Mannery 1981a) which also shows an almost monotonic rise towards shorter wavelengths. Optical (200-inch, MCSP) and I.U.E. photometry fit together rather well at least for H-HI (Böhm, Böhm-Vitense and Brugel 1981) and H-H2H.

Turning now to the emission line spectra we find the line fluxes from the higher ionization stages much stronger than expected (and than predicted by the shock wave models which explain the optical spectra). This is especially true for C IV λ1548/50 (which is observed to be about 200 times stronger than predicted in H-H2H) and the blend of O IV and Si IV lines near 1400 A . Surprisingly it turns out that also one of the low ionization lines, namely Mg II 2800 is stronger than predicted by any shock wave model though the discrepancy is by far not as large as for the high ionization lines (Böhm-Vitense, Böhm, Cardelli and Nemec 1982).

How can the ultraviolet continuum and the uv emission lines be explained? The main explanation for the continuum which has been suggested so far attributes it to the two-photon emission of hydrogen (Dopita, Binette and Schwartz 1982, Brugel, Shull and Seab 1982), If this explanation is correct F_λ must decrease shortward of $\lambda\sim$ 1400 A . Brugel, Shull and Seab (1982) seem to have found such a decrease in F_λ in the case of H-H2H. The situation is, however, complicated by the fact the continuum shows additional structure (e.g. a "jump" near $\lambda\sim$ 1700 A°) and that the ratio of the uv continuum to Hβ is larger than expected. Futhermore, there remains of course the problem how to explain the linear polanization which has been observed in the optical part of the continua of some H-H objects (cf. Schmidt and Miller 1979). In general, it seems that a promising explanation of the unexpected uv continuum of H-H objects may be "in sight" but a number of questions have to be answered before we can be certain about this explanation.

The situation is very different with regard to the emission line spectrum.

There have been no detailed suggestions yet on how we could overcome the apparent discrepancy between the optical and uv emission line spectra. It does not seem possible to explain the ionization discrepancy by the superposition of two or more shock waves. An "additional" shock wave which explains the high ionization lines in the uv will also lead, e.g., to a strong [O III] λ 5007 line which contradicts the optical observations. We have recently studied the emission measure of the uv lines. (Böhm-Vitense, Böhm, Cardelli and Nemec 1982). We find that they are practically the same as the emission measure determined from Hβ. This makes it probable (though it does not prove) that uv and optical lines are formed in the same layer.

Studies of the Cohen-Schwartz star and of AS-353A. The discovery by Herbig and Jones (1981) that the H-H objects H-H1 and H-H2 must have been ejected from immediate environment of the Cohen-Schwartz (C-S) star (Cohen and Schwartz 1979) gave us the idea to investigate the C-S star and its immediate environment with I.U.E. We found that the immediate environment of the star, but not the C-S star itself, emits a continuum which (under all reasonable assumptions about the interstellar reddening) increases even more steeply towards short wavelengths than in H-H objects (Böhm and Böhm-Vitense 1982a). This discovery makes it very probable that the large reddening which was found for the C-S star must be generated very close to the star because a "dereddening" of the uv radiation based on the same E(B-V) would lead to implausibly high energy requirements for this radiation.

We have started a similar study of the T Tauri star AS-353A which probably is the energy source of the H-H object H-H 32A. The reductions are still in progress.

Investigation of the dust scattering in NGC 1999. The optical continua of some H-H objects show linear polarization (which in one case, H-H 24A, is higher than 20%). It has been shown (Strom, Grasdalen and Strom 1974, Schmidt and Miller 1979) that at least in some cases dust scattering must be important. In order to better assess the role of this mechanism we study the dust scattering in NGC 1999 which is illuminated by the young object V 380 Orionis and which lies very close to H-H1 and H-H2. We hope that for these reasons the dust properties in NGC 1999 will be similar to those in and near the H-H objects. So far we have obtained one SWP and one LWR spectrum at one place in NGC 1999. We are presently comparing these spectra to those of V 380 Orionis.

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