# OBSERVATIONAL TESTS OF THE BOW SHOCK THEORY OF HERBIG-HARO OBJECTS

K.-H. Böhm and A. C. Raga
Astronomy Department, Univ. of Washington, Seattle, WA 98195, U.S.A. and

J. Solf
Max-Planck-Institut f. Astronomie, Königstuhl, 69 Heidelberg, F.R.G.

ABSTRACT. We discuss four different tests of the bow-shock theory of Herbig-Haro objects, emphasizing especially tests based on position-velocity diagrams and on the appearance of "double layer" structures in the spatial maxima of the high- and low-velocity components of the emission lines. Though this latter effect is surprising, it is a fundamental consequence of the bow shock theory.

## 1. INTRODUCTION

It is now generally accepted that 1. typical Herbig-Haro (HH) objects move radially away from a young star (Herbig and Jones 1981). 2. HH objects often trace highly collimated bipolar outflows (Mundt 1986). 3. the HH emission line spectrum is formed in the recombination region behind a shock wave (Schwartz 1975). Recently there has been increasing evidence that in a number of cases the line emission is actually formed in bow shocks (as expected e.g. in front of an interstellar bullet or of the working surface of a jet). The first observational evidence came from (spatially integrated) flux ratios in the optical and ultraviolet range (Hartmann and Raymond 1984) and the study of spatially resolved high resolution emission line profiles ("position-velocity diagrams", see Böhm and Solf 1985).

## 2. THE PRESENT STATE OF OBSERVATIONAL TESTS OF THE THEORY.

Our computations (Raga and Böhm 1985, 1986; Raga *et al.* 1986; Raga 1986) show that there are at least four different tests of the bow shock theory available now, namely 1. the comparison of the observed and theoretical (spatially integrated) line fluxes (as done by Hartmann and Raymond 1984), 2. the comparison of observed and predicted postion-velocity diagrams, 3. the study of "double layers" of high and low velocity maxima which are seen, e.g., in the observations of HH 32 (Solf *et al.* 1986) and are also predicted by the theory. 4. the comparison of observed and predicted monochromatic images of HH objects. In this note we shall emphasize tests 2. and 3. . The results of these four different tests make it very probable that, at least in some cases, bow shocks are really responsible for the emission line formation in HH objects. As an illustration of an application of test 2, we show a comparison of the observed spatially resolved line profiles of H$\beta$ and [O III] 5007 in HH 1 with the bow shock predictions for these lines. There are indications that the agreement can be further improved by a more sophisticated selection of parameters.

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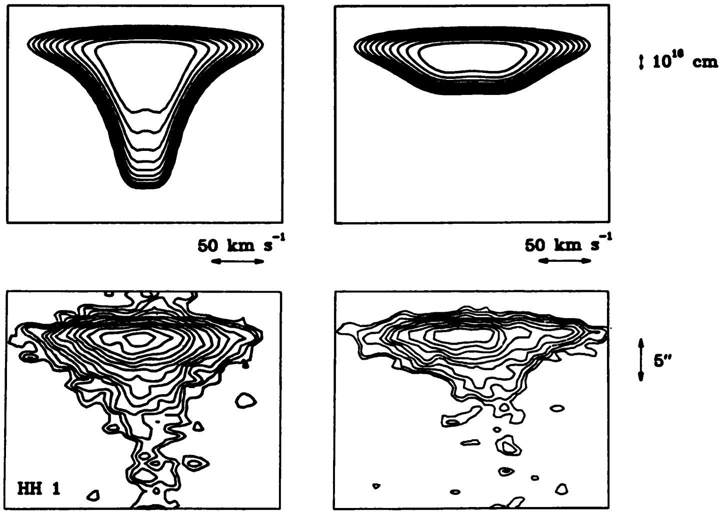

Fig. 1 - Comparison of the observed and predicted position-velocity diagrams for Hα (left) and O III 5007 (right) in HH 1.

## 3. THE DOUBLE LAYER TEST

In HH 32 one sees typically double-peaked lines (cf. Solf *et al.* 1986). It turns out that in all condensations (A, B, C and D) the spatial maximum of the low velocity peak of the line profile occurs about 0.″5 - 1.″0 farther away from the central star (AS 353A) than that of the high velocity peak. This was found for all slit orientations. Plotting these results on an image of the HH 32 complex one finds a surprising arrangement of "double layer" structures which seem to be rather enigmatic at first sight. Surprisingly it turns out that just such an effect is predicted by the bow shock theory (Raga *et al.* 1986) if all four condensations form individual bow shocks. Interestingly, the theory also predicts that the spatial separation of the two velocity components will be much larger in the bow shocks in which the bow shock axis forms only a small angle with the line of sight. This makes understandable why the effect is relatively easily detected in HH 32 but not in some other objects. We feel that this test is a rather strong indication of bow shocks in at least some HH objects.

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