Hunt for Molecules
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MOLECULES TOWARDS HD 34078 AND SMALL SCALE STRUCTURE IN TRANSLUCENT CLOUDS

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Abstract. Absorption from several species (like H_2, CH and CH^+) in the spectrum of the runaway O star HD 34078 have been monitored over the last five years in order to investigate the 1 - 100 AU scale structure in foreground molecular material. We present results from this program and discuss the scenario implied by some remarkable peculiarities observed for the intervening gas together with their potential implications for the aim of our project.

1 Introduction

The internal structure of molecular clouds has been a matter of constant interest for many years. This is motivated in part by the fact that modelling of the physical and chemical processes within these clouds is strongly dependent on the spatial distribution of the material.

CO emission maps indicate the existence of a complex spatial structure, often described in terms of "clumps" with a large range of scales (P. Goldsmith, this volume). Since brightness fluctuations are still present at the smallest scales accessible, it is likely that "unseen" structure is present. To get information on the spatial distribution at scales for which mapping is no longer possible, Marscher et al. (1993) used the drift of the line of sight (due to the sun and earth's motion) towards background radiosources. The

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observed variations for H_2CO and OH suggest the presence of AU-sized fragments (see also Liszt & Lucas 2000 for HCO^+ and OH).

However, H_2CO and OH are minor species and their spatial distribution does not necessarily reflect that of other, more abundant constituents, like H_2 molecules or dust grains. The latter largely determine the opacity for continuum UV photons and then the photodissociation and photoionisation rates. In order to study their spatial distribution and measure the fluctuations of the opacity through translucent clouds (which governs the average UV field: cf Boissé et al. 1990), Thoraval et al. (1996, 1997, 1999) have used several techniques to probe extincted fields : i) repeated photometric measurements, ii) analysis of star magnitude and color distributions (a refined version of the star-count method), iii) analysis of brightness fluctuations for galaxies seen through clouds. These methods point towards little *ubiquitous* small scale structure in the distribution of dust grains within translucent clouds (differences between the spatial distribution of the gas and dust grains are not unexpected at small scales due to the inertia of solid particles).

These results altogether show clearly the need for a direct investigation of the major species, H_2, in order to really probe the *density* structure. The successful launch of FUSE offered us a unique opportunity to perform such a program, and to this purpose, we selected a bright although extincted (E(B-V)=0.52) runaway O star, HD 34078. The acquisition of successive FUSE exposures, and in parallel of successive visible spectra, allow us to study the time variation of $N(H_2)$, N(CH), $N(CH^+)$, ... as the line of sight drifts through the cloud (the technique is similar to that used by Frail et al. 1994 who performed repeated 21cm observations of fast moving pulsars to probe the small scale structure in HI gas). The star velocity implies a drift rate of about 20 AU/yr, which gives access to scales in the range 1 - 100 AU if absorptions are monitored over a period of a few years.

2 The observing program and early results

Spectroscopic observations were conducted in parallel in the visible (monitoring of CH and CH^+ absorption lines mainly) and in the far UV (monitoring of H_2 and all other species having transitions in the FUSE range). To date, eight FUSE spectra have been obtained between January 2000 and October 2004.

2.1 CH, CH^+ and DIBs observations

Several good spectra allowing to measure N(CH) and N(CH^+) have been taken by others before our program was undertaken. It was thus possible to extend our study back to 1991. The CH and CH^+ lines in the spectrum of HD 34078 have an intermediate optical depth which gives a good sensitivity to column density variations. Results emerging from these data and from the spectra that we obtained up to 2002 are presented in Rollinde et al. (2003). An increase by about 20% of N(CH) occurred around 1998 while N(CH^+) has remained nearly constant (or possibly decreased somewhat). Unfortunately, the time sampling of the observations prior to 2000 is poor and as a consequence, the shape of the N(CH) increase is badly defined.

Although the observations on which these results are based are not homogeneous (i.e. they were performed by different observers with different instruments) we believe that the N(CH) increase is real for the following reasons: i) for data taken before 1999, astronomers have kindly provided us with their spectra so that we could remeasure all equivalent widths in a homogeneous way (this is especially important for the $CH^+\lambda4232$ line which is blended with a stellar line), ii) the CH data shows a good degree of internal consistency in the sense that before 1997, all values of W(CHλ4300) are "low" (around 50 mÅ) while all values taken after 1998 are high (around 56 mÅ), iii) CH^+ values (which are drawn from the same spectra as CH ones) does not show the same behavior and for this species, results for the two λ3957 and λ4232 lines are mutually consistent.

The fact that CH apparently displays more small scale structure than CH^+ is quite surprising since in models invoked to explain the large abundance of CH^+, this species has to be produced in small localized regions (shocks or vortices, as proposed by Falgarone & Puget 1995).

2.2 FUSE observations and implications

Regarding H_2, absorption lines from the J = 0 and J = 1 levels (which gives the dominant contribution to the total column density) are damped. One might think that such heavily saturated lines are poorly sensitive to N(H_2) variations. In fact, even a moderate increase in N results in a significant broadening of the absorption (see Figs. 8 and 9 in Boissé et al. 2005). Further, the spectral shape of the expected variation is well defined a priori and independent on any assumption on the velocity distribution of the gas.

Finally, several H_2 lines being present, one can easily check the consistency of results drawn from all profiles (note that these profiles are broad enough to be fully resolved by FUSE).

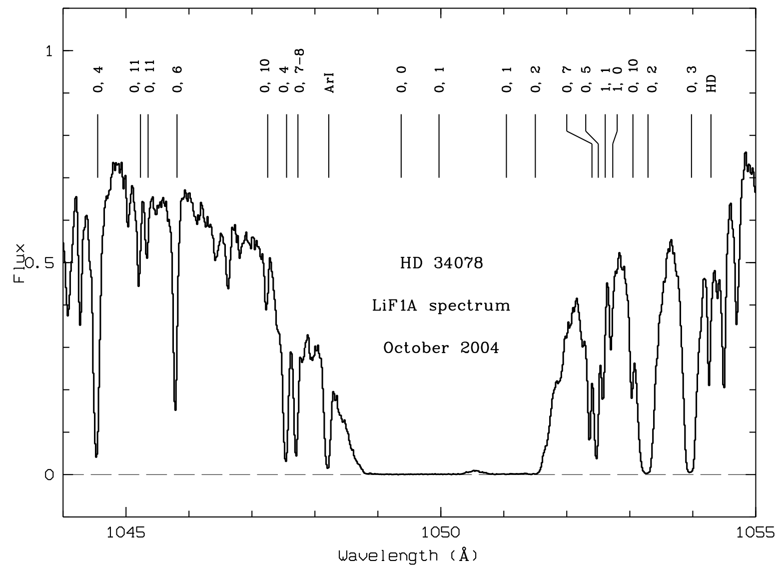

Fig. 1. Portion of the October 2004 LiF1A spectrum (flux units are arbitrary), illustrating the variety of H_2 levels (indicated by their (v, J) values) from which absorption is detected

The analysis of the first five spectra (Jan. 2000 to Oct. 2002) shows no clear variation of N(H_2) (hence no pronounced structure over scales ranging from 5 to 50 AU; Boissé et al. 2005). Unfortunately, no far UV spectrum of HD 34078 has been taken before 1998; therefore, we cannot check whether N(H_2) has increased in a similar way as N(CH).

One striking feature of the FUSE spectra is the presence of a large number of absorption lines arising from highly excited H_2 levels, as illustrated in Fig. 1. The highest level from which we detect absorption is (v = 0, J = 11), 10^4 K above the ground level, while for most other lines of sight, no absorption is detected from levels above J = 7 (one remarkable exception being HD 37903; see Meyer et al. 2001). Further, already in the J = 2, 3, 4, ... states, the relative amount of H_2 is well larger than for "standard" lines of sight (cf the excitation curve given in Fig. 6 by Boissé et al. 2005).

To account for these unusual absorptions and for the characteristics observed for other molecular species like CH, CH^+, CN (which apparently do not differ much from what is seen on other lines of sight), we proposed a scenario involving i) gas surrounding the O star and strongly illuminated by it; ii) a cloud located well in front of HD 34078. This latter component is responsible for absorption from H_2 (J = 0, 1) and all other molecular species while the first component accounts for highly excited H_2.

This model is remarkably successful in explaining the observed properties of the gas. However, the observed absence of any velocity shift between the two components appears in this scenario as a pure chance coincidence, as is the presence of H_2 in the vicinity of HD 34078.

3 Is the absorbing gas associated to HD 34078 ?

In fact, other observations are difficult to understand in the two-component model mentioned above. The CH/H_2 ratio is larger than the well defined average value - $4.0\ 10^{-8}$ - by a factor of about 4, and further, the N(CH) increase would imply a very large volumic densities if attributed to a new intervening clump (Rollinde et al. 2003). Moreover, Galazutdinov et al. (2006) have noted anomalies in the position and profile of some diffuse bands in the visible spectrum of HD 34078, as compared to other stars.

From an analysis of the visible nebular emission around HD 34078, G. Herbig (1958) concluded that IC405 is the result of a chance encounter between the O star and dense interstellar material. Observations of the far UV nebulosity by France et al. (2005) is also consistent with such a scenario. We are then led to consider that not only the highly excited H_2 but also the low temperature molecular gas is associated with HD 34078. However, merging the two components into a single one located close the O star rises several questions : i) how can we understand the observed large abundance for molecular species such as H_2, CO, CH, CH^+ (these are expected to be nearly fully photodissociated in the steady-state PDR model used to explain the high H_2 excitation) ? ii) how can the bulk of H_2 gas be at a temperature as low as 77 K in the vicinity of an O9 star ?

Most of the questions listed above can probably be solved if one considers that, due to the very large star velocity (about 150 km/s), the arrival of HD 34078 near the cloud has been very sudden, implying a recent and sharp increase in the radiation field (we estimate that the timescale of this variation is of the order of a few 10^5 years). In such a situation, steady-state models are inappropriate : photoionisation and photodissociation fronts that develop as the star approaches move relatively slowly in the cloud (Bertoldi & Draine 1996) and HD 34078 will get rapidly nearly in contact with them. In this picture, molecular gas beyond these fronts remains relatively unaffected. The temperature of dust grains adjusts rapidly to the increasing UV field but heating of the gas by thermal contact with solid particles is probably significantly delayed (hence the success of our initial two-component model in explaining the characteristics of all observed species).

In order to ensure that HD 34078 is really associated with the molecular cloud seen in absorption, we mapped the CO(2-1) and CO(1-0) emission around HD 34078 using the IRAM 30m telescope. In the initial two-component model proposed, CO molecules lie in a cloud that is unrelated to HD 34078; in such a picture, the CO emission map should not display any distinctive feature at the O star position. On the opposite, observations clearly indicate that both the CO integrated line intensity and velocity field are correlated with the position of HD 34078 (paper in preparation).

4 Conclusions and prospects

The new data acquired strongly supports the scenario proposed by G. Herbig. Although this statement has to be justified by detailed modelling, it seems that time-dependent effects can explain the coexistence of highly excited H_2 and cold molecular gas close to HD 34078.

What are the implications of such a scenario regarding the aim of our project ? First, one can imagine that the density structure of gas located beyond the photodissociation front is not (or little) affected by the passage of HD 34078. If so, time variations of absorption lines arising from the cold component truly probes the spatial distribution of molecular species inside a standard translucent cloud. A number of visible spectra have been recorded since 2002; it will therefore be possible to study the variations of CH and CH^+ with a good time sampling and examine what is the implied structure. If significant variations are detected for CH and/or CH^+ over the period during which the FUSE spectra were obtained (2000 - 2004), one can search for correlations with variations in $N(H_2)$.

The FUSE spectra also allow us to investigate the variations of absorption lines from highly excited H_2, over a time interval of nearly 5 years. Many H_2 lines from levels above (v = 0, J = 8) have a small or intermediate optical depth and thus provide a good sensitivity to relative column density changes. Variations in the amount of the material located at the interface of the stellar wind and of the ambient cloud can have several origins : i) instabilities that develop in the bow shock, ii) variations in the stellar wind, iii) presence of structure in the swept gas. Since bow shocks associated with large star velocities are expected to be relatively stable (Dgani et al 1996), studying variations of the high excitation H_2 lines might be also be a valuable tool to probe the structure in the gas swept by the bow shock. No detailed variability analysis has been done yet for these lines, but careful examination of the five first FUSE spectra revealed no conspicuous change.

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