Assuming the dust composition did not change between March 19 and March 31, and assuming the dust composition to be homogeneous within the 30 arcsec diaphragm, we can compare our (J-H) and (H-K) values to the values derived from the two other sets of observations. The agreement with Hanner and Knacke's data is reasonably good; in the case of Eaton and Zarnecki's measurement, there is some discrepancy for the (H-K) value. A possible explanation could be that Eaton and Zarnecki's results, obtained in a smaller diaphragm (6.2 arcsec) imply a contribution due to dirty ice grains; however, we would expect in this case the same behaviour in Hanner and Knacke's results, which do not appear for (J-H); moreover, the presence of a significant ice contribution in a sphere of about 3,500 km is not expected at a heliocentric distance smaller than 1 AU (Campins and Hanner, 1982). The final conclusion which can be derived from the three sets of measurements is that there is no evidence for absorbing particles in the dust composition of P/Crommelin.

Another information which could be derived from the data comparison concerns the spatial distribution of dust, using the fact that observations were performed in different diaphragms. If the dust is assumed to be ejected radially, isotropically, with a constant velocity, then the dust density at a given distance r from the nucleus varies as r^{-2}, and the number of particles inside a diaphragm of radius δ increases linearly with δ. The observed flux, either in the scattered component or in the thermal component (since the medium is optically thin) is proportional to the number of particles and thus proportional to δ. This linearity has been checked by Becklin and Westphal (1966) on Comet Ikeya-Seki for diaphragms ranging from 20 to 80 arcsec. For smaller apertures, the linear law might be altered by collisional effects or anisotropic dust ejection. However, in our case, this study requires that we are able to monitor accurately the intrinsic variations of the comet's magnitude between March 19 and March 31. The geocentric distance of P/Crommelin remained constant within 2% between these dates; in contrast, the visual magnitude changed rapidly, not only because of the heliocentric distance, but also because of intrinsic cometary activity. Information upon the M_V curve is available from Marsden (1984) but a more complete analysis, involving more data, would be useful.

In conclusion, the preliminary results reported here show the potential interest of near IR photometry for studying cometary dust, especially for future observations of Comet P/Halley. Extension towards higher wavelengths will be necessary to obtain more constraints upon the nature and size of the dust particles. A systematic study with different size diaphragms should allow a good determination of the dust density distribution.

Acknowledgements

We thank Dr. Drechsel for his participation in the observing campaign. We are grateful to Drs. Hanner, Knacke, Eaton and Zarnecki for giving us access to unpublished data. We thank Dr. Festou for helpful comments on this paper.

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Line Profile Shapes in Optical H II Regions

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Some of the most spectacular astronomical photographs and favourite subjects for popular astronomical slide shows are colour pictures of H II regions. Probably every astronomer, both amateur and professional, is familiar with the nebula in Orion, M 42. Shaped like an opened fan, this well-known H II region ("H II" is the technical term for ionized hydrogen) appears to be yellow in its bright core and fades out to red and then a faint bluish hue towards the outer perimeter. Of course, the exact colours and size of the Orion Nebula, M 42, is dependent on the type of colour film used and the amount of light gathered. Longer exposure times tend to make the nebula appear larger, expanding outward in the direction of the fan's perimeter. Short exposures of the nebula (or using the eye instead of film) reveal the presence of four bright stars in its core, the "Trapezium", so named because of their relative geometrical positions. These stars cannot be seen on long-exposure pictures, because the light from the nebular core saturates the film.

H II Regions – the Strömgren Theory

On the theoretical side, much has been learned about the nature of H II regions such as the Orion Nebula. An important theoretical breakthrough came when Strömgren, in 1939, published his paper on "The Physical State of Interstellar Hydrogen" (1). Strömgren recognized that ionized hydrogen at typical interstellar densities is transparent to the extreme ultraviolet radiation from hot O and B stars, such as the Trapezium stars in the Orion Nebula. Neutral atomic hydrogen on the other hand should be very opaque to this radiation at wavelengths shorter than $\lambda = 912$ Å. This critical wavelength corresponds to the ultraviolet photon energy necessary to ionize the hydrogen atom, expelling its single electron. The process of absorbing ultraviolet photons and ionizing hydrogen changes the material originally opaque to ultraviolet light to material transparent to subsequent ultraviolet photons. If it were not for the fact that the electrons and protons in an ionized gas occasionally recombine to form atomic hydrogen, all the material in the Milky Way Galaxy could be converted into ionized gas by fewer than 10^4 O5 stars. The process of occasional recombination in an ionized gas makes this gas only partially transparent to the hydrogen-ionizing ultraviolet photons. Thus, an H II region, which is produced whenever a hot O or B star is embedded in a cloud of neutral material, has only a finite extent.

The equilibrium size of the ionized region can be calculated in an approximate way by equating the total number of recombinations per second in a fully ionized gas with the total number of hydrogen-ionizing ultraviolet photons per second emitted by the embedded exciting star (or stars). A more detailed calculation by Strömgren of the ionization/recombination balance of hydrogen at each point in the nebula was thus able to determine its ionization structure. Such a nebula is almost fully ionized in its interior; the degree of ionization x (defined as the ratio of electron density to numerical hydrogen density) drops off from x = 1 (fully ionized) to almost x = 0 (fully neutral) within a narrow transition zone known as the ionization front.

Strömgren's simple calculation was very successful in explaining the occurrence of optical H II regions. We now know that whenever dust is present sufficiently close to the hot exciting star(s), the nebula will appear to be yellow—due to starlight scattered off the surfaces of the dust particles. The reddish appearance is due to light produced by the process of recombination, one of the most prominent electronic transitions within a newly recombined hydrogen atom being the n = 3 to n = 2 (Hα transition. The Hα line is found in the red part of the spectrum (λ = 6563 Å). In fact, by summing up the number of Hα photons emitted per second by the nebulae, it is possible to determine the rate at which recombinations occur and thus the rate at which the exciting stars emit their hydrogen-ionizing ultraviolet photons. Knowing this and something about the densities of gas and dust within the nebula it is possible to construct detailed nebular "models" which match the line strengths of various hydrogen and helium lines and the many "forbidden" lines ("forbidden" only because they do obey the selection rules for simple changes of electronic states) of elements such as oxygen, nitrogen, silicon or sulfur. Actually, the analysis of data works in reverse: from measured line ratios one determines the density and temperature of the ionized gas. One normally has many independent methods at one's disposal for determining nebular conditions, so that internal consistency checks are possible. Combining radio and infrared data with optical and ultraviolet spectra it is possible to make sophisticated analyses of many H II regions.

Progress in the study of optical H II regions has not only been made in the detailed reconstruction of the ionization structure of hydrogen, helium and many other elements in Strömgren-type models, but also in their expected evolution and kinematic properties. Even in his 1939 paper, Strömgren was aware that the hydrogen-ionizing photons have more energy than necessary to merely ionize hydrogen. As shown later by Spitzer (2) this energy excess causes the H II region to heat up to a temperature higher than the surrounding neutral gas. Confirming theoretical expectations, interpretations of typical line ratios yield a fairly uniform temperature of about $T = 10^4$ K in the ionized gas, whereas the neutral gas temperature is generally less than 100 K. One can therefore expect the hot ionized region to expand under the influence of its own internal pressure.

Expansion Models of H II Regions

The expansion motion of the ionized gas will affect the shapes of the emission lines originating in the H II region. A photon emitted from an atom moving away from (toward) the observer will have a wavelength which is longer (shorter) than that expected from an atom at rest. The photon is "red- (blue)-shifted". Observations of these line profile shapes can thus provide an observational test of the kinematic motions predicted by theoretical evolutionary models. Let us first consider three simple kinematic models and their expected Hα and forbidden line profiles.

The first model we will consider is a homogeneous sphere of ionized gas at rest. Such a situation is possible immediately after an ionizing source is suddenly "turned on" in a constant density neutral medium at rest, before the hot ionized gas has had time to expand.

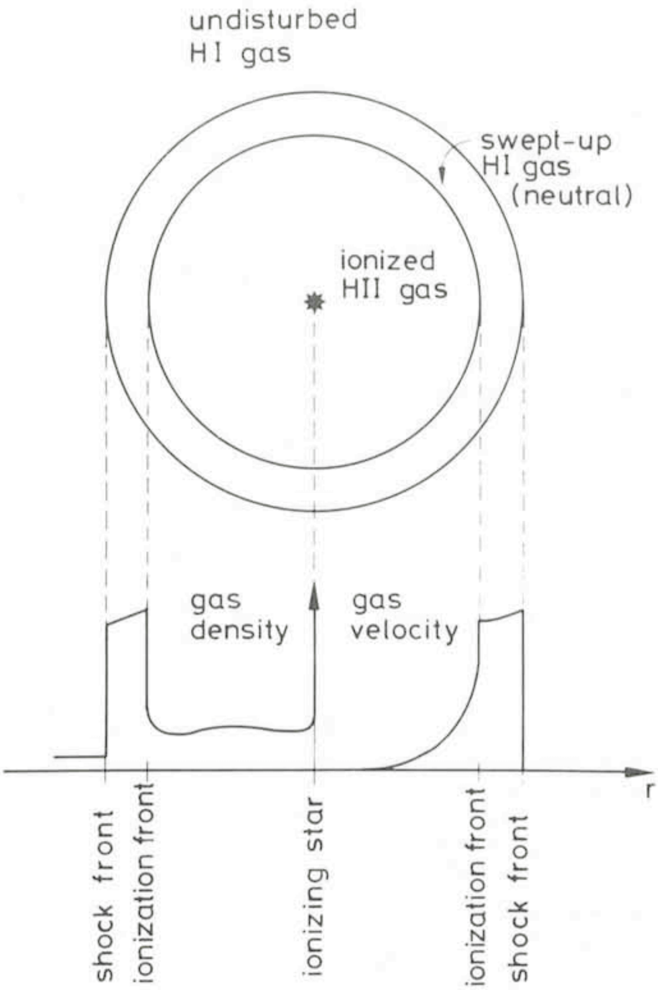

Fig. 1: *Schematic representation of the density and velocity structure of a spherically symmetric, expanding H II region, initially in a constant density medium. The degree of ionization (not shown) would appear to change discontinuously from x = 1 on the inside to x = 0 at the ionization front on the scale of the drawing. The maximum expansion velocity is about 10 km/s, i.e. the sound speed of the ionized gas.*

The second idealized situation we will analyse is depicted schematically in Fig. 1. The ionized gas has attained expansion velocities up to 10 km/s. This velocity is much higher than the sound velocity of the surrounding neutral medium and a shock front forms here. Dense, cool material piles up in front of the ionization front. An earth-bound analogy (admittedly somewhat contrived) is a snowplow with a heated blade, piling up the snow in front of it, while at the same time melting the piled up snow in contact with its hot blade. If the snowplow moves fast enough, more snow can be piled up than melted. The expanding H II region usually does move fast enough that more neutral material is piled up into a dense shell than can be ionized away at the inner boundary of the shell. This type of expansion model has been dealt with extensively in the literature. We shall call it the "classical" expansion model.

An alternative to the "classical" expansion is the so-called "champagne" model (Fig. 2), recently proposed by Tenorio-Tagle (3), which has also been dealt with extensively since 1979. In this model a classically expanding H II region embedded in a molecular cloud encounters the sudden change of density at the cloud's edge. The ionized material is accelerated to a relatively high velocity (up to several times its sound speed) in a direction away from the cloud, because little resistance to expansion is offered by the low density material.

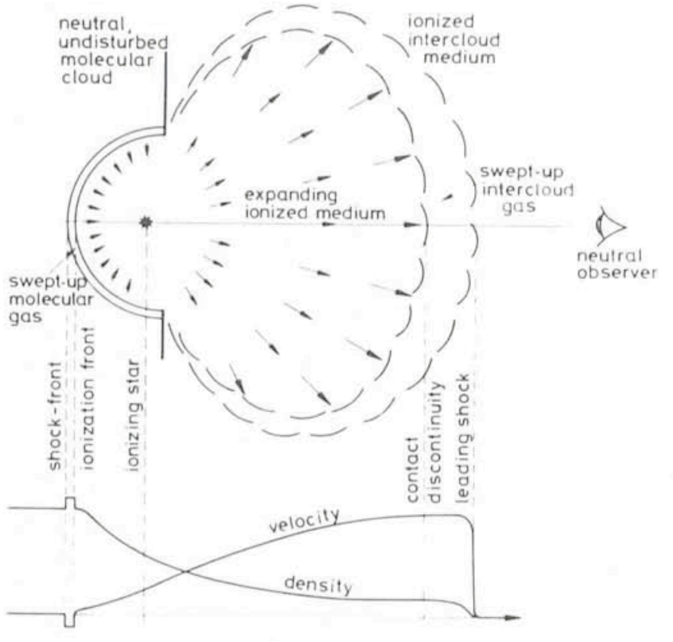

Fig. 2: *Schematic representation of the champagne model for H II region evolution. The H II region appears as a "blister" on the surface of a molecular cloud. It is produced by an O star which has formed inside the molecular cloud and which subsequently erodes out a cavity by ionization. The hot, ionized gas seaks the path of least resistance and expands preferentially away from the cloud, reaching velocities of over 30 km/sec. This high velocity gas is of low density and is therefore difficult to observe directly. The density and velocity structure along a single line of sight, i.e. perpendicular to the surface of the molecular cloud, is shown.*

The ionized material from the molecular cloud "fans" out, its density decreases as it moves further away from the cloud. A champagne-type flow also develops when an ionizing star is located outside (but not too far) from a molecular cloud. The fan-shaped Orion Nebula is typical for what is to be expected from an H II region during its champagne phase and bears little resemblance to what the classical expansion model would predict.

Predictions of Line Profile Shapes

The line profile shapes for hydrogen and oxygen to be expected from each type of model is shown schematically in Fig. 3. In Fig. 4 the results of a single numerical calculation of champagne flow line profiles is given. A variety of line shapes are possible with the champagne model, although the line-of-sight positions close to the ionizing source are only slightly asymmetric and the line centres are only slightly shifted with respect to zero velocity. Since these positions have the strongest emission lines, the total net line fluxes from the nebulae resemble the schematic profiles in Fig. 3.

It is interesting to note that the multiple components displayed in some of the oxygen spectra cannot be seen in the hydrogen spectra. The reason for this should be clear. Due to its lower atomic mass, the hydrogen line will be thermally broadened to a greater degree. Thus, multiple velocity components blend together. Another interesting feature of the theoretical results shown in Fig. 4 is the fact that the multiple velocity components did not arise from several different "blobs" in the champagne flow. Instead, the projected component of ionized gas velocity along a given line-of-sight changed more slowly in some parts of the nebula. This led to higher

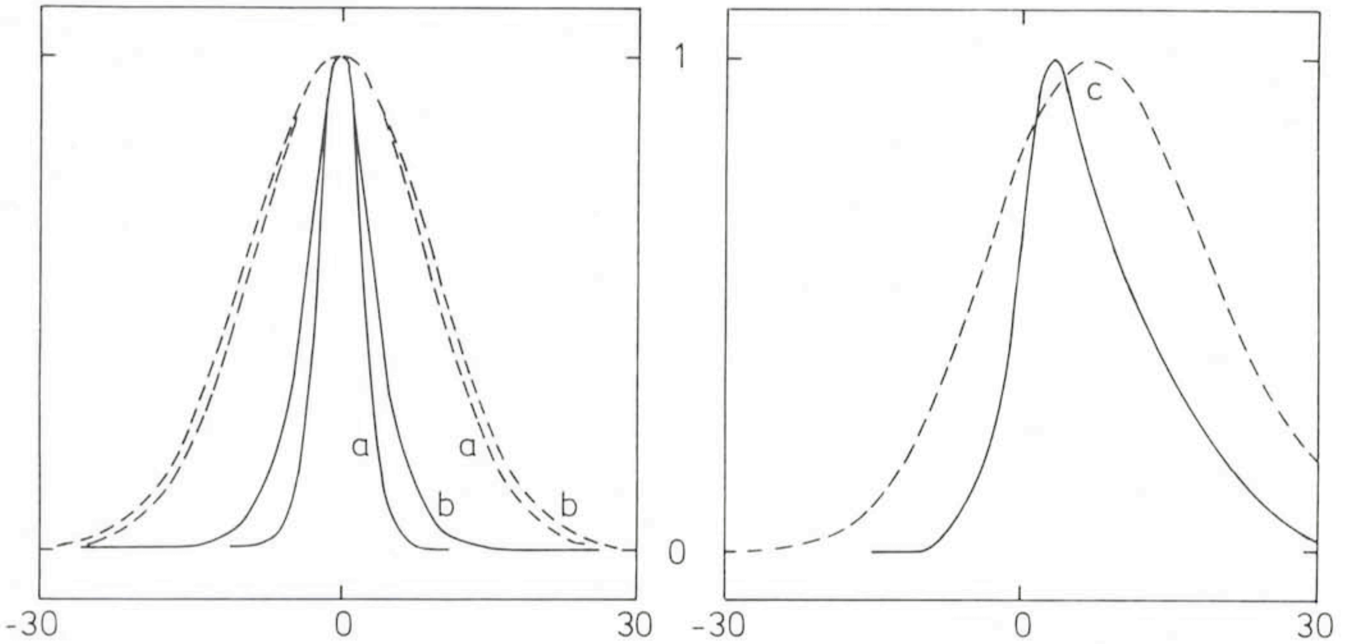

Fig. 3: *Normalized line profiles predicted by H II region expansion models (see text). The dotted curves are for hydrogen, the solid curves for oxygen. The blue part of the spectrum is to the right, corresponding to positive velocities (30 km/s).*

(a) No expansion: the line profiles are "smeared out" by the thermal motions of the emitting atoms and ions. The width of such thermally broadened lines depends on both the gas temperature (here assumed constant, $T = 10^4$ K) and the mass of the emitting particle.

(b) Classical expansion model (see Fig. 1, text): the line profiles are only slightly broader than in (a).

(c) Champagne model (see Fig. 2, text): depending on viewing angle, spatial resolution and position within the nebula a variety of line shapes can be expected (see also Fig. 4). In general one can expect the line centre to be shifted by several km/s and the profiles to be asymmetric by varying degrees. Note that for such asymmetric profiles the maximum line intensity for hydrogen and oxygen may appear to be shifted with respect to one another.

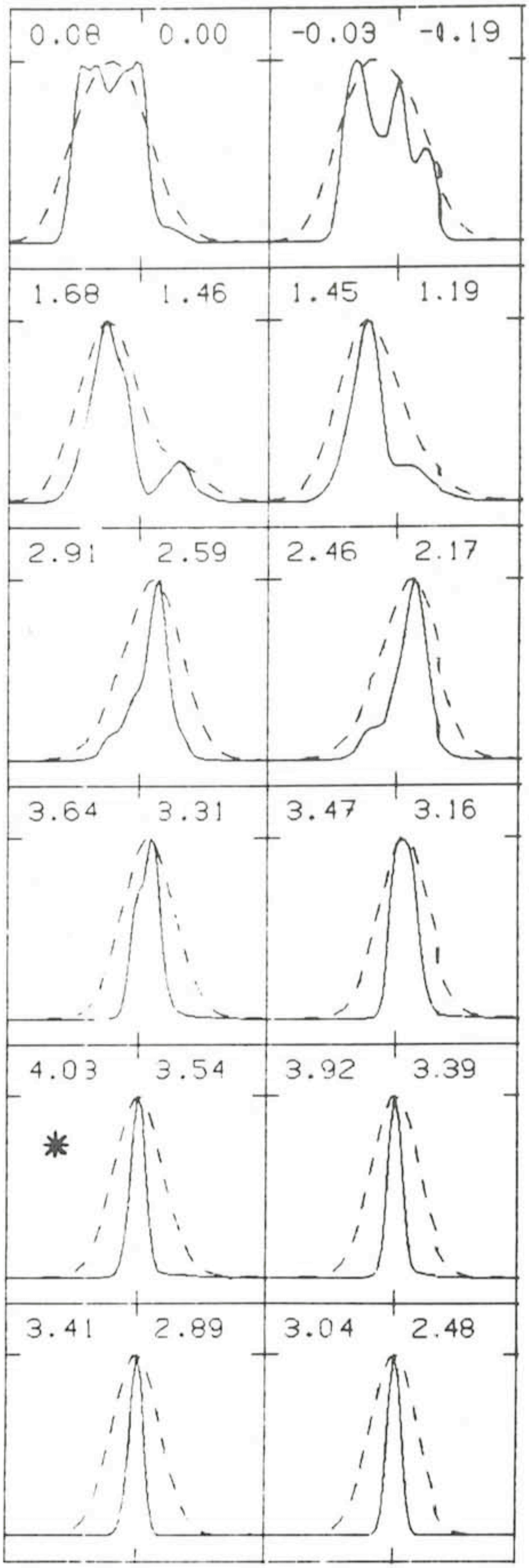

Fig. 4: *Normalized line profiles of oxygen (solid curves) and hydrogen (dotted curves) at selected positions in an H II region during the champagne phase (4). The velocity scale runs from −60 km/s to +60 km/s. The logarithm of the line strengths for oxygen (hydrogen) are given in the upper left (right) corner of each box. The "starred" box displays the profiles at the line-of-sight centred on the projected position of the ionizing source. More details are given in (4).*

integrated column densities at some parts of the spectrum than at others. Two extreme (theoretical) cases leading to line splitting are shown in Fig. 5. Thus, the common interpretation of line splitting in H II regions, multiple filaments or sheets of high density ionized material, should be viewed with greater skepticism.

Observations of M 8, the Lagoon Nebula

The Lagoon Nebula, an H II region, and its associated star cluster, NGC 6530, lie near the inner edge of the Sagittarius spiral arm, about 6,000 light-years from the solar system. Three bright O stars (HD 165052, 9 Sagittarii, Herschel 36) are probably members of the star cluster and the main sources of ionizing photons for the nebula. Lynde and O'Neil (5) interpreted their spectroscopic observations of M 8 as four H II regions, one surrounding each of the O stars with the exception of the bright Hourglass Nebula which is located between Herschel 36 and the associated molecular cloud. Parameters for each of these H II regions are given in Table 1. The relative locations of these H II regions, one behind the other in the order given in Table 1 (the Hourglass Nebula is furthest from the earth and closest to the background molecular cloud), is consistent with the interpretation of Lada and co-workers (6) that M 8 is an H II blister on the surface of the molecular cloud.

TABLE 1: THE H II REGIONS COMPOSING M 8 (5)

Star	Size in light-years	Gas density atoms/cm^3	Effective temperature of star
HD 165052	90	1	37,500
9 Sgr	9.6	100	37,500
H 36	3.3	250	35,000
Hourglass	1.0	4,000	35,000

The interpretation of M 8 as four superimposed constant density H II regions, each with a very different gas density and size, seems to be very unlikely. Most likely M 8 is a fan-shaped champagne flow with a continuously varying gas density which is being viewed face-on. The O stars are probably at different distances from the molecular cloud — as suggested by Lynds and O'Neil — so that the resulting champagne flow is somewhat more complicated than that predicted by the simplest models with a single ionizing source. In spite of this, M 8 should be an excellent candidate for studying and comparing line profile shapes with model predictions.

The author was allotted 12 nights of observing time with ESO's 1.4 m Coudé Auxiliary Telescope (CAT) in August 1983. Poor weather conditions (high winds and clouds) resulted in a loss of about two thirds of the observing time. Even in the remaining third, observing was sometimes restricted to inconvenient areas of the sky. It was possible to keep the CAT dome open for a full night only once. The other eleven (exasperating) nights were spent opening and closing the dome, watching the wind meter and keeping an eye on the humidity. Still, a number of high resolution spectra ($10^5 \triangleq 3$ km/s) were obtained in the spectral regions $\lambda\lambda$6535–6590 and $\lambda\lambda$4990–5025 at several selected positions in the M 8 region. Detailed line profiles of H_α, [N II] 6548, 6584 and [O III] 5007 were extracted from the data. Some of these are shown in Fig. 6.

There are several features of the spectra shown in Fig. 6 and other spectra taken but not shown here which can be termed "typical" for champagne-type flows. First of all, the lines are much broader than the thermal width; a radial velocity dispersion of 10–20 km s^{-1} can be surmised after removal of thermal and instrumental broadening. Secondly, indications of multi-

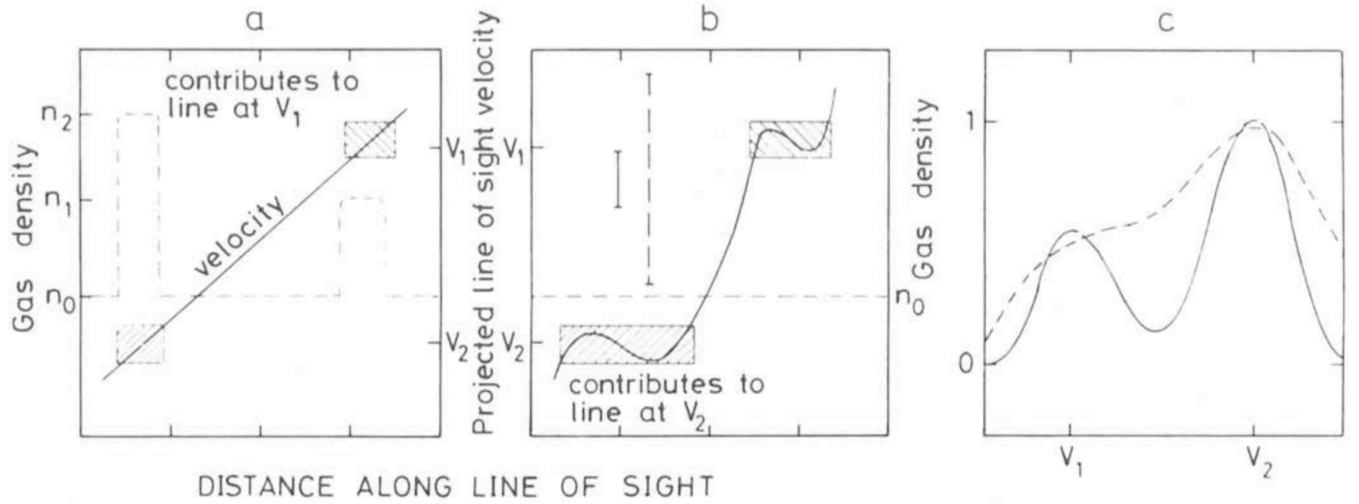

Fig. 5: *Two hypothetical situations leading to line splitting. The density and gas velocity are depicted as dashed and solid curves, respectively, in (a) and (b).*

(a) Two high density clumps of material lying along the line-of-sight of the observer have different radial velocities, v_1 and v_2.

(b) The variation of velocity in a constant density medium leads to long integration paths (and high column densities) at certain wavelengths. The error bars show amounts of thermal broadening for oxygen (solid bar) and hydrogen (dashed bar).

(c) Resultant line profiles for cases (a) and (b) (schematic). The hatched boxes in (a) and (b) show the projected velocities contributing to the emission at v_1 and v_2. The solid curve (for example [N II] or [O II] forbidden lines) can show splitting, whereas the hydrogen line profile (dashed curve) may show little or no indication splitting.

ple components and marked asymmetries are present, which can be most clearly seen in the [N II] and [O III] lines. The lines' complexity increases as line-of-sight positions in the peripheral zones (away from the Hourglass Nebula) are considered.

There is a surprising feature which is barely discernable in the H_α profile of Fig. 6b. This line displays extended wings out to -38 km s^{-1} blue-shifted with respect to the position of maximum and +58 km s^{-1} (red-shifted) at an intensity level of a few per cent of the maximum. This effect will be difficult to explain by a simple champagne flow alone. If M 8 is a "blister" on the surface of the molecular cloud, expanding towards us, then why is such a large red-shifted contribution (implying velocities $\sim$ 50 km s^{-1} away from the observer) present? Scattering by moving dust can broaden spectral lines. A photon emitted away from us by an atom moving towards at 20 km s^{-1} which is then scattered towards us by a dust particle moving away from us at 20 km s^{-1} will appear to be red-shifted by 60 km s^{-1}. How likely is this situation? Probably it is not too likely. The interpretation of M 8 will require more detailed models. The observational results from M 8 and their interpretation will be the subject of a forthcoming paper.

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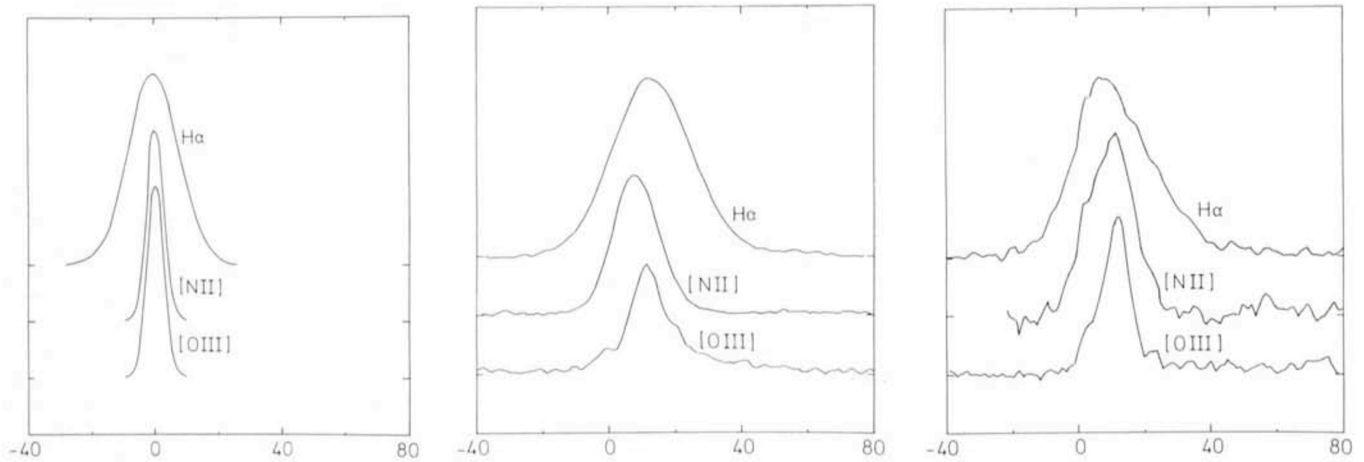

Fig. 6: *Line profiles of H_α, [N II] 6584 and [O III] 5007. Zero velocity has been arbitrarily set to reference frame of the earth.*

(a) Theoretical profiles expected from a $T = 10^4$ K ionized gas at rest. The profiles have been spread out by the measured Coudé Echelle Spectrograph's instrument profile at a spectral resolution of 10^5 (corresponding to 3 m s^{-1}).

(b) Measured profiles at a position in the north part of the Hourglass Nebula. The intensity scale is in arbitrary units.

(c) Measured profiles at a position 86 arcseconds to the north-east of the Hourglass Nebula. The net intensity of the lines at this position is about a factor of four lower than those of 6b).