private communication), although there is some uncertainty in luminosity class.

An alternative is that one is merely seeing an excitation phenomenon, that stars with $M > M_{\text{crit}}$ are necessary to excite the CO molecules and those with $M < M_{\text{crit}}$ are unable to excite. The basic argument against this possibility is that the disappearance of CO emission seems to be correlated with the disappearance of HII regions as well[2]. HII and CO regions have very different excitation characteristics and, hence it seems unlikely that they could both be made to vanish simultaneously by altering a single source of excitation.

A crucial point to the present argument is that a supernova be able to disrupt the molecular cloud. Molecular clouds have mass up to $\sim 10^5\ M_\odot$ and density $\sim 10^4$ cm^{-3}. Such large clouds have a gravitational binding energy of $\sim 2 \times 10^{50}$ erg and an atomic/molecular binding energy $\sim 3 \times 10^{51}$ erg. Thus, a healthy supernova should be able to disrupt a cloud as massive as this if all its energy is utilised for this purpose. Mouschovias[4] argues, however, that a supernova in such a cloud will pass from the adiabatic Sedov phase to the isothermal, or snowplow, phase long before the shock produced by the supernova reaches the surface of the cloud. If this were the case only the momentum at the onset of the isothermal phase, not the energy of the supernova, would be available. The initial momentum of a typical supernova, $(2M_{\text{SN}}E_{\text{SN}})^{1/2}$, is capable of giving an outward velocity of $v \sim 3.2$ km s^{-1} $((M_{\text{SN}}/10M_\odot)E_{51})^{1/2}M_{\text{cl},4}{}^{-1}$. The escape velocity is $v_{\text{es}} \sim 4.5$ km s^{-1} $(M_{\text{cl},4}{}^{1/3}\ n_4{}^{1/6})$. Thus, a $10^4\ M_\odot$ cloud can be disrupted by a supernova of $\sim 20\ M_\odot$, roughly the mass we are considering.

Molecular clouds, like stars, follow a fairly steeply decreasing mass function. While the details are not fully agreed on, one can argue that a typical cloud probably contains of order $10^4 M_\odot$; that the $10^5 M_\odot$ clouds are observationally striking, but not representative. In particular, $10^4 M_\odot$ is probably a more typical mass for the molecular clouds surrounding the young open clusters with which we are especially concerned. Thus we conclude that supernovae are the likely cause of disruption of most molecular clouds, even if only their momentum, not their full energy is utilised.

For a $10^4 M_\odot$ cloud with uniform density of 10^4 cm^{-3} the radius (R) is 2.2 pe, the dissociation energy is $\sim 3 \times 10^{50}$ erg and the binding energy $\sim 4 \times 10^{48}$ erg. A supernova of $10 M_\odot$ and 10^{51} erg will sweep up its own mass entering the Sedov phase at $R \sim 0.2$ pc and $t \sim 30$ yr. This adiabatic phase will end at ~ 0.5 pc and ~ 300 yr when the radiation cooling time drops below the expansion timescale. The rapid leakage of radiation will begin at temperature, $T \sim 1 \times 10^7$ K for these high densities and be further enhanced at $T \sim 10^6$ K when recombination radiation from heavy ions becomes very strong. An HII region will then race ahead of the original shock front dissociating the cloud. This will lead to a loss of thermal energy and eventually the ionisation energy as the cloud expands and recombines. For a $10^5 M_\odot$ cloud the HII region is probably unable to totally dissociate the cloud. On recombination, the Lyman α flux will be re-radiated from grains as a burst of 10 μm radiation which will escape from the cloud.

Thus while the details are different because of the dense cloud, the evolution of the explosion may be qualitatively similar to the standard picture[5] and we conclude that Mouschovias' arguments concerning the energetics are basically correct. A more careful treatment would incorporate possible density gradients in the cloud. A decreasing density outward, as is observed in many clouds, might serve to prolong the Sedov phase. A step function from low to high density due to a pre-existing H II region would lead to reflected shocks and perhaps an elimination of the already rather brief Sedov phase. These details are presently under consideration in a program which will lead to detailed numerical calculations.

In the simplest picture, the longest lived very bright phase, and hence the one most likely to be observed, may be the Sedov phase. There is an appreciable flux of radiation in this phase, primarily thermal bremsstrahlung, even though it is not sufficient to effect the shock dynamics. This flux of soft X rays will probably be absorbed on grains, raising them to several hundred K and again will be seen in the 10 μm range. The estimated flux is $\sim 5 \times 10^6\ L_\odot$ for a time of about 100 yr. If supernovae occur in our Galaxy with a mean time interval $\lesssim 40$ yr then the present number of events could be $\gtrsim 3$ if they each last ~ 100 yr. Kwan and Scoville[6] have suggested that the Becklin–Neugebauer object may be the site of an explosion.

We have suggested in this note that there exists an upper limit to the mass of stars which explode, ~ 15–$20M_\odot$. This upper limit might exist because of differences in internal structure at the state just before iron core collapse in the final stages of evolution. This possibility leads to the suggestion that stars earlier than BO do not explode because they collapse to make black holes, a notion which is consistent with a suggestion made previously by Wheeler and Shields[7]. Alternatively, these massive stars are known to lose mass and the possibility exists that their mass is reduced to that of a BO before significant evolution from the main sequence can occur (T. Mazurek, personal communication). In this case, the changes in the internal structure, if any, are unclear.

In either case, if this conjecture about an upper mass limit to supernovae proves to be true, quantitative, but perhaps not qualitative, changes might have to be made in notions of nucleosynthesis. Stars from, say, $10M_\odot$ to $20M_\odot$ would still be available as sites of explosive nucleosynthesis and, because of the steep mass function, these are most of the stars which would contribute anyway.

Another important ramification of this suggestion is that star formation would cease with the supernova explosion and the dissolution of the cloud. This picture thus accounts very naturally for the observed inefficiency of star formation in molecular clouds.

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Molecular images by electron-wave holography

IMAGES of electron clouds in gas-phase atoms have been photographed[1,2] at a resolution limit of 0.1 Å through a two-stage holographic microscope based on Gabor's principle of image reconstruction[3]. Information encoded on to holograms with electron radiation in the first stage was transformed into a portrayal of electron density in the second stage with the aid of an optical laser. Suitable pictures of gas-phase molecules could not be obtained because of signal-to-noise problems. These problems have now been overcome to a considerable extent and we report here the reconstruction of spherically averaged molecular images displaying light atoms in the vicinity of heavy atoms. Bond lengths can easily be measured with a ruler.

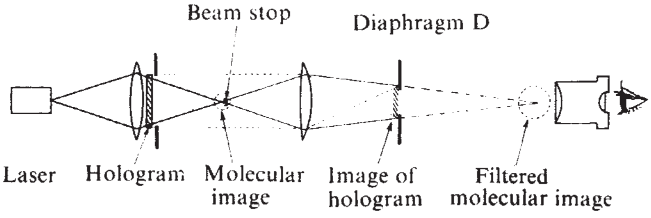
To make holograms yielding high resolving power, it is necessary to produce a broad reference wave that can be mixed coherently with waves emanating from the object under scrutiny. Stringent mechanical stability is also essential. Optical path length differences between the reference beam (source to detector) and object waves (source to object to detector) must not vary during recording by more than a fraction of a wavelength. To achieve these requirements in optical holography, great care must be taken. To achieve them with electron holography, where wavelengths are only one 1/100,000 as long, would be virtually impossible unless the reference beam diffuser were locked internally in the molecular system to be viewed. In atomic holography this was accomplished very naturally for electron cloud objects by scattering the incident wave from the atomic nuclei associated with the electron clouds. In this study of molecules a heavy atom in each molecule served to scatter a strong reference beam. In both cases, then, each particle in the sample to be investigated carries around its own reference wave diffuser, as it were, and produces its own hologram. Holograms from all particles in the sample fall on top of each other. Therefore, the reconstructed images also all fall on top of each other. Instead of seeing individual atoms or molecules we see the average of an ensemble. If all members are identical the images are not degraded. Because our molecular objects are in the vapour phase to reduce extraneous scattering, they have chaotic orientations. Accordingly, we see only the spherical average. This might seem disappointing, but it should be noted that any individual, free molecule in any given quantum state is inescapably diffuse in orientation, and spherically delocalised in the ground quantum state.

For our first molecular investigation we chose AsF$_5$, an example where five light 'object' atoms (fluorine) are packed with D$_{3h}$ symmetry around a central heavy atom (arsenic). What we should expect to see and do in fact see in the reconstructed image is a spherical shell of atomic fluorines. The radius of this shell corresponds to the mean As–F bond length.

For the first stage of our holographic microscope we used the apparatus previously used for atoms[2], but we reduced the numerical aperture twofold, to $f/2.3$. Resolving power was sacrificed to record with maximum faithfulness the strongest holographic interference fringes. Holograms were recorded on Process plates by scattering 40-kV electrons ($\lambda = 0.06$ Å) from a fine jet of AsF$_5$ vapour at 20 torr and filtering the electrons through an r^3 rotating sector. This filter is deliberately weaker than the 'Rutherford filter'[2] adopted for monatomic samples to bring out the detail of the light atoms more strongly. Once obtained, the holograms were reduced 18-fold by rephotographing on Kodak 120-02 holographic plates.

Rendering the light atoms visible in the presence of the heavy central atom required a new design for the second, reconstruction stage of the microscope. As before, the desired image is a component of the Fraunhofer diffraction pattern of the hologram. But the holographic fringes corresponding to the As–F bonds are comparatively subtle, and the reconstructed image of fluorine atoms lies very close to the intense 'undiffracted' zero-order beam transmitted by the hologram. (The radius of the molecular image occurs at about the tenth ring of the Airy diffraction pattern produced by the holographic aperture. The beam stop illustrated in Fig. 1 screens through the third Airy ring.) If left at its natural level, this zero-order beam overwhelms the desired image. In principle, the most efficient way of getting rid of the unwanted beam without distorting the molecular image would be to cancel it with another, properly modulated, beam in a Mach–Zehnder interferometer[2]. In practice, it proved much simpler and adequately effective to use a technique suggested by Professor Emmett Leith, namely to remove the zero-order beam differentially by the 'spatial domain filter'[4] illustrated in Fig. 1. An internal calibration of the magnification afforded by the second stage of the microscope could be made easily by measuring the interference spots produced by a 100 line per inch Ronchi grating placed over the hologram.

Fig. 1 Schematic drawing of optical reconstruction stage of holographic microscope. The unwanted beam passing undiffracted through the holographic fringes is largely screened out by the beam stop; most of the remainder is skimmed off by diaphragm D which passes the image-forming rays.



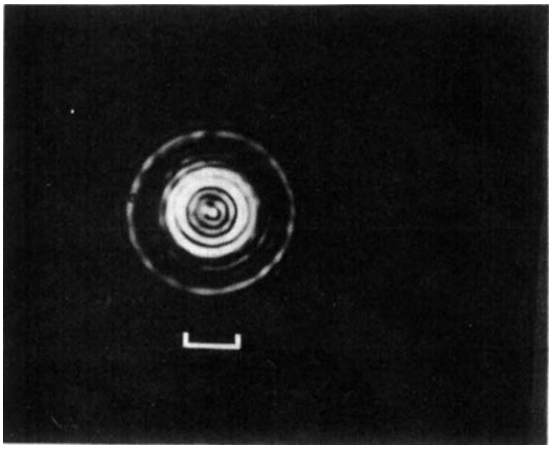


Fig. 2 Holographic image of rotational average of AsF$_5$ molecules at 70 million power; spherical shell of fluorine atom density plainly visible at 1.6 Å radius. Scale bar 1 Å.

A reproduction of an image of the rotationally averaged AsF$_5$ molecule at an Abbe resolution limit of 0.2 Å is shown in Fig. 2. Because of the curvature of the spherical shell of fluorines, the maximum density of the projected image lies a few hundredths of an angstrom unit inside the actual mean bond length of 1.68 Å (ref. 5). In principle it would be possible to deconvolute the projected density in Fig. 2 and determine the amplitude of vibration of the As–F bonds from the breadth of the fluorine shell, but this has not yet been done. Since the computed[2] depth of focus of our microscope at the numerical aperture used is about 4 Å and, hence, is appreciably greater than the As–F distance, the three-dimensional aspect of the spherical image is largely lost. As is the case in conventional holography there are 'extraneous contributions' to the image arising from incoherent scattering and from the square of the object amplitude. In heavy exposures the latter contributions show up as shells revealing the F· · ·F non-bonded distance occurring at $\sqrt{2}\, r_{\mathrm{AsF}}$, and vestiges of the non-bonded distance at about $\sqrt{3}\, r_{\mathrm{AsF}}$. Indeed, given a molecule without a single dominant heavy atom, the laser reconstruction would yield series of concentric shells the profile of which would be closely related to the radial distribution function of internuclear distances in the molecule.

For many years electron diffraction patterns have been measured with microdensitometers sensitive to changes in absorbance of a few parts per ten thousand. Molecular structures have then been deduced by computer analysis of diffracted intensities. In our technique, a much more direct display of structural information is provided immediately by the optical Fourier spectrum of the electron hologram. Although the new technique is not yet competitive in accuracy with the well established scattering techniques, it may find a useful role. Whether analogous techniques can be worked out to study oriented molecules is a challenging problem for the future.

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