Observational Evidence on the Interaction of Orion Population Stars and the Interstellar Medium

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I. Introduction

The Orion population stars are those stars which have only recently formed. It is generally accepted that these stars arose as condensations in the interstellar medium. It follows that they should show strong interactions with that material. In only one case, the nebula near T Tauri (Schwartz 1974) do we have any direct evidence for the interaction between these stars and the interstellar medium. Presumably this is because the typical interactions take place on much larger or much shorter distance scales. The long range interaction of young stars with their environment is discussed in Section II.

It is also generally agreed that Orion population stars are still enshrouded in circumstellar material. There are important questions that have yet to be answered about that material before we can begin to discuss the details of any interaction between these stars and their surroundings. These difficulties are discussed in Section III.

Finally, I have chosen four topics to discuss in somewhat more detail. My aim has been either to urge caution in accepting current interpretations or to put caution aside and suggest new possibilities.

II. Kinematics

One of the first questions that arises about the interaction of newly formed stars with the interstellar medium is how do young stars become separated from their natal clouds. This difficulty arises because it appears that star formation is a very inefficient process. In a typical star forming cloud only one tenth of the cloud mass is in the form of stars. Yet we see relatively young clusters, e.g. the Pleides, which are virtually completely clear of interstellar material.

The difficulty may not lie with a mechanism to remove the stars from the cloud. A process may exist which reexpands the cloud after a critical phase of star formation has been reached. In general modern theoretical work makes the transition to a collapsable state nearly inreversable, certainly reversing the contraction process in a gentle way takes a very long time.

The formation of HII regions around hot stars has long been regarded as a

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good candidate for the dispersal mechanism. Elmegreen and Lada (1977) have discussed an elaborate mechanism for making use of this phenomenon. They propose that the expanding HII region not only clears out a region around the recently formed O stars but also induces the next episode of star formation in a massive elongated cloud. The end result of their process is a sequence of expanding O-associations. An intrinsic part of the Elmegreen-Lada picture is that high mass and low mass stars form under quite different conditions and therefore in different locations. It is by no means clear that the bound young clusters containing relatively massive stars could have formed under such conditions.

This O-association picture probably does not apply to the familiar nearly dark cloud cases. In the case of the Taurus-Auriga complex the structure of the clouds is likely to be too highly disordered for the operation of this mechanism. Other dark cloud complexs are in general simpler, eg. Ophiucus, Corona Austrina, the Chamaeleon clouds but the masses of the clouds, typically several hundred solar masses, are not large enough to support such an O-association picture.

One of the most interesting suggestions for separating cloud and stars is that by Woodward (1976). He envisages star formation to be initiated in a dark cloud by the passage of the shock wave associated with the spiral density wave. The further passage of gas after star formation has taken place will accelerate the cloud but not the stars. Thus the gas cloud will leave the stars behind. We note however that this process must be a nearly impulsive one in order to work. If the cloud is accelerated slowly compared to a crossing time, the stars will continue to be bound to the cloud. In the picture the relative velocities expected between cloud and the star might be quite substantial. If we estimate that groups 50 million years old have no trace of a natal cloud, so that a separation of 100 pc might be appropriate: this implies a relative velocity of 2 km/sec. These parameters are not at all extreme. For the Taurus-Auriga clouds typical crossing times for individual condensations are at most several million years. The ages estimated for the T-Tauri stars in the Taurus-Auriga clouds are approximately the same. Thus if the spiral density wave model of Woodward is operating we might well expect substantial velocity differences to have already developed.

To test this hypothesis requires accurate radial velocities for the dark cloud and the associated Orion population stars. Radio molecular line studies provide extremely accurate radial velocities for the dark cloud material. An extensive survey of dark clouds associated with young stars has recently been carried out by Dieter (1975) using the 6 cm formaldehyde line. High dispersion observations of a large number of cloud stars has required the development of

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red sensitive image tube systems associated with coudé spectrographs (Zappala, 1970). The reasons for this are three fold, the typical T Tauri stars are of late spectral type, they are usually strongly reddened and finally the underlying photospheric spectrum is often veiled in the blue spectral region by a continuous excess. Herbig (1977) has recently completed a radial velocity study of Orion population stars. For the Taurus-Auriga cloud he found a mean radial velocity difference, $\langle \Delta v \rangle$, is the sense star velocity minus cloud velocity of 0.2 ± 0.9 km/sec based on equal weighting of the stars or $+ 0.4 \pm 0.5$ km/sec based on equal weighting of the spectrograms. These results require that the velocity differences between the dark cloud and the embedded stars are less than 2 km/sec.

Another possibility for separating stars from dark clouds is that the stars have random velocities in excess of the escape velocity. There are at least two plausible mechanisms for achieving this result. The velocities could be due to accelerations produced by external pressures which induced star formation in the cloud. Alternatively the velocities could be the result of equipartition processes acting during the fragmentation stages. We note however that these mechanisms would not give rise to the gravitationally bound clusters. (Arny and Weissmann 1973). *There are a number of T Tauri stars already quite large distances* from dark clouds and it would be important to know whether they traveled there, i.e. had excess velocities or were formed from the rather tenuous medium far from the densest portions of the dark cloud. Unfortunately radial velocity determinations of single stars do not yet have sufficient accuracy to reveal whether these more distant stars have discrepant velocities.

There are three separate means for estimating the sizes of velocity dispersions expected on the hypothesis that the T Tauri stars are dispersing from the dark clouds. First there is the direct estimate of the velocity of escape, Herbig (1977) feels that 0.6 km/sec is appropriate, however he used a mean density for the dark clouds of only 100 cm^{-3}, more appropriate values for the denser parts of the Taurus-Auriga clouds might be in excess of 10^3 cm^{-3}. Thus 1 km/sec seems a reasonable estimate. Dieter (1975) finds a mean velocity dispersion of 1 km/sec for the 6 cm formaldehyde line. Since this line is formed under peculiar excitation and radiative transfer conditions such an estimate might be suspect in detail but it does serve to illustrate the size of random motions present in the dark clouds. Finally from the distances and crude ages of stars far from the dark clouds, we can estimate dispersal velocities on the order of one km/sec.

Observationally this dispersion corresponds to the velocity dispersion per velocity measure. For Herbigs spectroscopic material the dispersion measured per plate is 3.9 ± 0.5 km/sec for the program stars, while for the standard stars it is 4.4 ± 1.0 km/sec. Unfortunately there were only 19 plates of standard stars so that the error in the velocity dispersion comes almost entirely from the uncertainty in the size of the errors of measurement. The largest velocity dispersion allowed within one standard deviation of the observed results is 3.2 km/sec, a not particularly stringant result.

Another way to approach the velocity dispersion problem is to examine proper motions. Unfortunately most proper motion studies have centered on the OB associations (eg. Vaerewyck and Beardsley, 1973 and McNamara 1976) rather than the sparcer and fainter T-associations. A particularly good case for a proper motion study is the Chamealeon dark cloud. At a distance of only 115 pc. (Grasdalen et. al. 1975) it is perhaps the nearest dark cloud. Very early epoch positions for Chamealeon stars can be obtained from the Carte du Ciel exposures of this field taken prior to 1900. Remarkably, six cloud members were recorded on those early photographs.

Modern positions (mean epoch 1974) were measured from 3 red (098) plates taken with the Curtis Schmidt telescope at the Cerro Tollolo Inter-American Observatory, and a glass copy of the European Southern Observatory quick blue survey. The scale of the Curtiss Schmidt was 96.6 "/mm, while the ESO copy had a scale of 67.6 "/mm. All of these measurements were reduced using only reference stars from the General Catalog (Boss, 1936). From the internal agreement between these four plates, we derive an accurate estimate of the standard deviation of a mean modern position as 0."37.

A major problem arose in attempting to redue the Carte du Ciel material. Reference stars taken from the Smithsonian Astrophysical Observatory Catalog (SAO) did not give satisfactory solutions. The standard deviation of the reference star solutions was 1."4. Since previous experience (Eichhorn, 1959) with Carte du Ciel material indicated that the measurements are accurate to 0."3, it appeared that the reference star positions were at fault. In order to improve these positions, modern positions measured from the four Schmidt plates, positions (when available) from the La Plata E catalogue with epochs in the late 1920's or early 1930's, and early epoch positions taken from the General Catalog or from the Melbourne 4 or Melbourne 3 Catalogs as reported in the SAO catalog were combined to yield refined positions and motions. These efforts were moderately successful, using these refined positions the standard deviation of the reference star solutions was 0."61. The derived motions for cloud stars are given in Table 1. These motions as well as those for field stars in an area bounded by $= -75^{\circ}45'$ and $-77^{\circ}15'$ and RA (1950) = $10^h\ 45^m$ and $11^h\ 14^m$ are plotted in figure 1. As is apparent from the figure, the cloud stars have a much smaller dispersion in proper motion than do the field stars. The estimate of the standard deviation for the cloud stars is 0.56 ± 0.18 "/century. Combining the modern errors, with the result from the Carte du Ciel reference solution we obtain a formal estimate for the standard deviation due to errors of measurement

Table 1
Individual Motions of Cha
T-Associations Members

HM#[1]	Name	μα ("/cent)	μδ ("/cent)
4	LHα332-20	-1.5	+1.0
13	CD-76°486	-2.0	+0.7
18	HD 97048	-1.8	-0.1
30	LHα332-21	-2.7	+0.0
	Ced 110	-0.8	+0.1
	HD 97300	-1.3	+0.2
	Mean Cha T-Ass.	-1.7	+0.3

[1]Henize and Mendoza V 1973

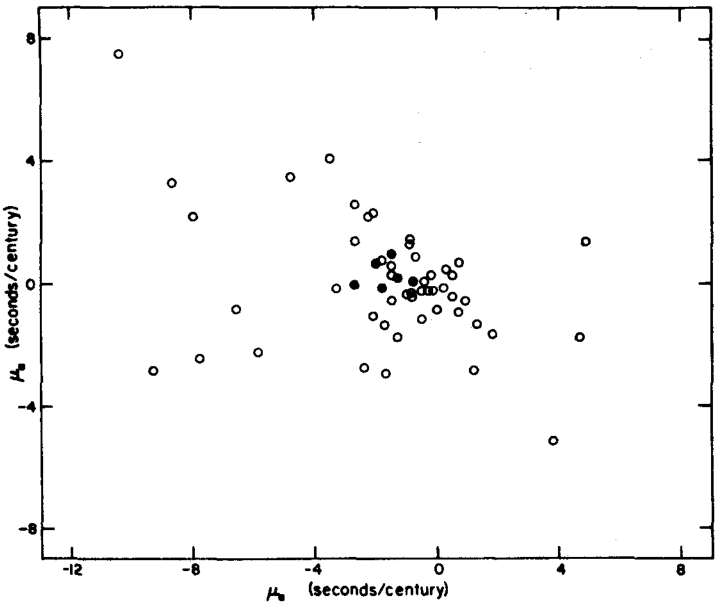

Figure 1
Proper motion diagram for the field of the Chamaeleon dark cloud. Filled circles represent stars associated with the cloud.

of 0.89 "/century. It seems clear, however, that this estimate is spuriously large due to the inaccuracies remaining in the reference star positions. Taking a value of 0."30 for the standard deviation of the Carte du Ciel measures we

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obtain 0.60 "/century as the relevant comparison standard deviation. Using this value we have computed the physical dispersion corresponding to various values of the standard deviation of the cloud member motions. Examining these results,

Table 2
Limits on Velocity Despersion in Cha T-Association

Observed Dispersion +	Apparent Dispersion ("/cent)	Physical Dispersion ("/cent)	Velocity Dispersion (km/sec)
1σ	.74	.43	2.3
2σ	.92	.70	3.8
3σ	1.10	.92	5.0

summarized in Table 2, we see that the proper motions give a mildly more stringent constraint on the velocity dispersion than the radial velocity measurements.

There is one positive result for a measured velocity dispersion. McNamara (1976) has measured the proper motions of Orion cluster stars and find a true velocity dispersion of 2.2 ± 0.4 km/sec. Unfortunately the significance of this result is not immediately clear. This velocity dispersion corresponds to a viral mass of $5x10^4$ $M_{\odot}$. The modern estimates for the mass of dark cloud material still remaining in the Orion A complex are near to this figure, so that one is not forced to ascribe this velocity dispersion to causes other than gravitation.

Finally, I would like to point out that Solar System may contain information concerning when the sun left the dark cloud environment. The comet cloud surrounding the solar system is a very large structure, minimum estimates for its diameter range from ¼ to ½ pc. (Oort 1963). If this cloud developed when the sun was still embedded in its natal cloud, it seems difficult to imagine the sun could retain much of the comet cloud as the system passed out of the dark cloud. In particular we note that for a density of only $100cm^{-3}$, the ambient material interior to a comets orbit has a mass comparable to the sun's mass. This leads me to assume first that the comet cloud evolved from the solar nebula and second that it evolved after the sun was largely freed form its natal cloud. Thus studies of the evolution of the comet cloud may tell us about the time scale for separating stars from their dense birth places.

III. Models of the Circumstellar Material

One of the principal questions that needs resolution from observational evidence is the detailed structure of circumstellar material in the pre-main sequence phases of evolution. Less than five years ago there was apparently general agreement on a relatively simple picture of mass outflow. The emission lines, especially those of hydrogen, were considered to come from a large volume at least several times larger than the stellar radius. The Sobolev solutions for the emission line profiles originally derived for the much hotter P Cygni type stars were applied to the T Tauri stars with a moderate degree of success (Kuhi 1964).

More recently Kuan (1975) has made more elaborate, largely self-consistent models of the flow that satisfy both the line profiles and the relative intensities of the Balmer emission lines. This model has been expanded further to include the blue continuum. This is now recognized not to be a super-position of many emission lines, but a genuine continuum excess than can dominate over the photospheric flux even to wavelengths as long as 6500Å. (see Walker 1972, Grasdalen et. al. 1975, Herbig 1977). Since most T Tauri stars do not show the balmer discontinuity in emission the excess emission is hypothesized to come from optically thick clumps in the flow regions quite close to the star. An extension of this hypothesis is that the infrared flux also arises from free-free emission in the flow. Rydgren, Strom & Strom (1976) have demonstrated the plausibility of this hypothesis by detailed matching of a large number of energy distributions.

On the other hand, a number of infall models have recently been proposed. Most of these models have been proposed in order to satisfy the recent hydrodynamical calculations (eg. Larson, 1972, Appenzeller and Tscharnuter, 1974) which seem to require long (up to several times 10^5 years) periods of infalling material. Perhaps the most straight forward of these are the "Sobolev" models calculated by Bertout (1977) and applied by Wolf, Appenzeller and Bertout (1977) to S CrA. So far those outflow models have not been made as self-consistant as those of Kuan and further the complex velocity - radius relations required appear largely but not entirely ad hoc.

A radical departure has been suggested by Ulrich (1976). He has proposed that all T Tauri stars have infalling material. In his model the origin of the emission lines is directly at the stellar surface. The emission line profile is due to material falling from rather large distnaces with preserved angular momentum onto the surface of the star. This hypothesis naturally produces a disk of material surrounding the star. The fact that its presence is suppressed in all the emission line calculations seriously undermines the credibility of this model.

Finally there is the viscous disk model of Lynden-Bell and Pringle (1974). This model seeks to explain the broad band energy distribution of the pre-main-sequence stars. The excess infrared emission is due to a low temperature disk. Since a wide range in temperatures are present in the disk a broad energy distribution is produced, in agreement with observation. Further, their model may produce a high temperature zone of interaction between the disk and the photosphere, thus accounting for the blue continuum. The most important piece of evidence we have on the possible connection between the infrared and blue excesses is the work by Rydgren (1976) on the near infrared colors of T Tauri stars. He demonstrates that one can understand the (J-H), (H-K) colors on the assumption that they are produced by a normal stellar photosphere and a free-free emission spectrum. The major point is that a free-free like spectrum extends all the way down, from the wavelengths of strong IR excess $\lambda>3\mu$, to a wavelength of 1.25μ. Since the blue continuum extends upwards past 6000Å, it seems entirely natural, as well as economical to connect them. This is the most direct observational evidence against the model of Lynden-Bell and Pringle.

IV. Selected Topics

From the range in proposed hypothesis it seems clear that any kind of detailed understanding of the circumstellar configuration in T Tauri stars has yet to be achieved. In what follows therefore, I will present my own views about some of the present difficulties.

A. Photometric Variability

A point of view that seems to be gaining a great deal of credence is that the optical variability of T Tauri stars is due to variations in the blue excess continuum. In this picture a stable configuration on its hydrostatic equilibrium track is hypothesized as the central object. This point of view has been observationally supported by the work of Gahm et al. (1974) on the photometric variations of RU Lupi through the visible spectral region. Rydgren, Strom and Strom (1976) have pointed out that several types of color variation with magnitude changes can be understood as the basis of the hypothesis that the blue "shell" continuum is the only component that is varying. They also cite the case of the star SR 13 in the Ophiucus dark cloud as support for their connection of the blue continuum with the infrared excess. For SR 13 a long term fading was observed at both visible and infrared wavelengths. However contrary evidence, at least in terms of day to day variations, has been presented by Cohen and Schwartz (1976). They observed on the same nights at both visible and infrared wavelengths. In reporting infrared variability they have relied entirely on the internal assignment of error bars, ignoring any possible systematic effects. As a consequence I believe their reports of infrared variability are to be considered as the extreme upper limits. It is, however, very clear from their data that large changes in the ultraviolet flux can occur with little or no change in infrared flux. Tus the variability arguments are by no means conclusive in connecting the infrared and blue excesses. Also we have to be reasonably careful in asserting that the optical variability is due solely to the blue continuum. First there are, as pointed out by Rydgren, Strom and Strom, stars without strong blue excesses which are nonetheless variable. Perhaps the most dramatic example is T Tauri itself, which does not have a strong blue excess yet is highly variable. Second the related Ae and Be stars associated with nebulosity, (HES)

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(Herbig 1960) can also be variable. (e.g. Breger 1974) In their case, however, there is not evidence for an excess blue continuum. (Strom et. al. 1972) Variations in these stars thus have to be ascribed to changes in temperature or radius; or to variable obscuration by circumstellar material. To state the case positively; at least now we know one of the mechanisms, albeit sketchy, that contribute to the variability of some pre-main-sequence stars.

B. YY Orionis Stars

Increasing attention is being directed to a subset of the T Tauri-like pre-main-sequence stars; the YY Ori stars. (Kuhi 1975, Appenzellar and Wolf 1977). This class was first isolated by Walker (1972). The fundamental criterion for membership in the class is spectroscopic. At one time or another a YY Orionis star shows inverse P Cygni profiles associated with its emission lines. In this case, the absorption component is to the red of the emission line rather than to the blue, as in the case of the normal P Cygni profile. Under the simple Sobolev picture such profiles would be produced by an inward flow. Photometrically these stars are distinquished by large ultraviolet excesses. The most perplexing property of these stars is their rapid spectroscopic variability. The inverse P Cygni profile can disappear on a time scale comparable to or less than a day (Walker 1972, Wolf, Appenzeller and Bertout 1977). At the same time central or slightly redshifted absorption components may be present. Energetic considerations rule out the reversal of the entire flow as a plausible explanation for the rapid changes in the line profiles. A model that comes to mind is that lumps of material are ejected and then fall back to the surface. It seems difficult to reconcile these stars with the infalling models required by the theoretical investigations. A natural suggestion is that the YY Orionis stars are the binary pre-main-sequence stars. The gas streams that one expects in such systems provide a ready explanation for the rapid variation of the absorption lines.

C. Infrared Spectroscopy

Infrared spectral features would be a great aid in unraveling the physical origin of the infrared continuum in pre-main-sequence object. Rydgren, Strom and Strom (1976) have reported tentative identifications of the silicate feature near ten microns for a handful of T Tauri stars. As yet there have been no low resolution (R = 100) ten micron spectral scans reported for HES's or T Tauri stars. Cohen (1975) has reported such low resolution scans in the wavelength range from two to four microns for a large number of Orion population objects. His observations revealed no spectral features except in the two extraordinary objects FU Ori and V1057 Cyg. They showed an absorption band due to water near 2.4μm.

Recently I have carried out a survey of the brightest HES's looking for the Brackett Alpha line of atomic hydrogen at 4.05μm. The observations were made with the 1.3-m telescope at Kitt Peak National Observatory using a liquid nitrogen cooled spectrometer equipped with an InSb detector. The spectral resolution element in second order was 80 Å. The observations are plotted in Figure 2.

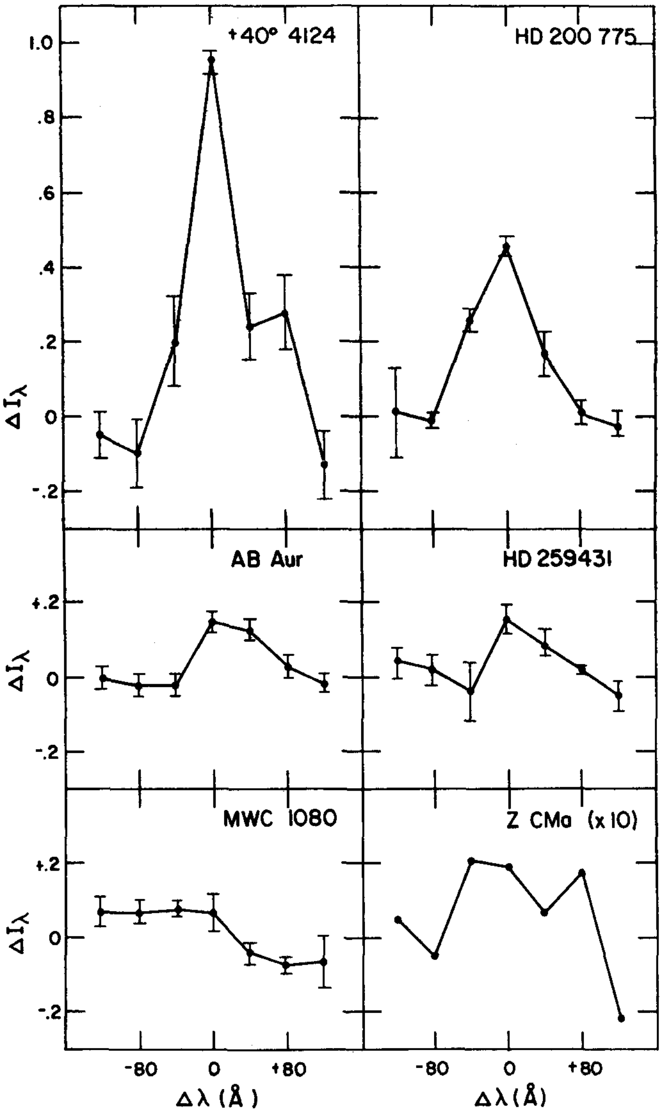

Figure 2
Brackett α profiles for a number of Herbig emission line stars. The residual intensity ΔIλ is in units of the nearly continuum.

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Clearly, in a number of cases the Br α line has been detected as an emission feature. Curiously the Br α and H α line strengths, both measured in units of their local continuum, are correlated. This is surprising since presumably the background continua arise from quite different causes. Near Hα the continuum is due to a stellar photosphere, while near 4μm the continuum is entirely due to the infrared excess. Further, the amount of the infrared excess varies by a large factor from star to star and is not correlated with the equivalent width of Hα. Given the small sample size, this correlation may be supurious. However, we note that Vrba (1975) found an anomalous feature in the polarization of these stars near 6500 Å. The size of the polarization anomaly also correlated closely with the equivalent width of Hα. The polarization feature observed by Vrba may be related to the peculiar broad spectral feature observed in the reflection nebula known as the red rectangle (Greenstein and Oke 1977).

For these stars we can also form the ratio of Hα to Brα. This ranges from 50 to 300 (for MWC 1080). These ratios are much larger than we would expect from optically thin sources. The most straight forward explanation is that the Balamer series optically thick, resulting in an enhancement or Hα.

Because they are fainter, the T Tauri stars are observationally more difficult. Fig. 3: present results for 2 of the brightest T Tauri stars. Certainly

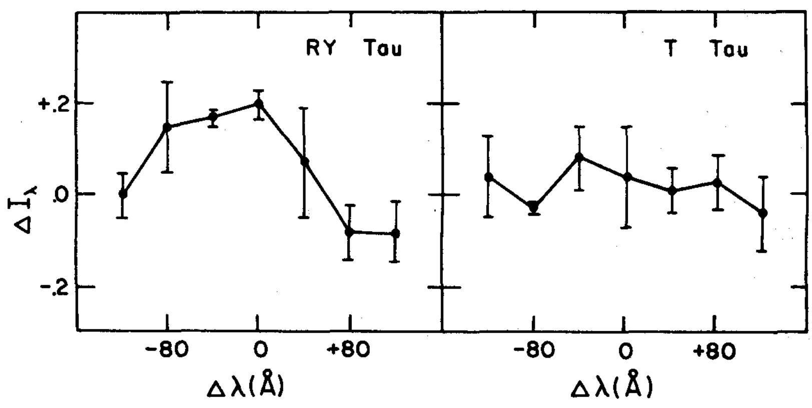

Figure 3
The Brackett α region for two T Tauri stars.

only upper limits can as yet be placed on the Brα line emission from these stars.

D. Pre-Main-Sequence Objects as the Source of Interstellar Grains.

That solar nebulae might be a significant source of interstellar grains has already been proposed a number of times (see e.g. Herbig 1970). I would like to

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point out that one of the most viable alternatives to this idea, grain production in the atmospheres of cool evolved stars, runs into serious difficulties.

Since the depletion factors in the interstellar medium for elements like Mg, or Si are approximately a factor of ten (Morten et.al 1973) we are forced to conclude that virtually all of the interstellar medium has passed through the grain formation site. The cool stars then have a great drawback as a possible grain formation site. The C^{12}/C^{13} ratios observed in giant or supergiant stars are always less than 30 and for the stars which show the strongest evidence for grain formation, the coolest and most luminous, the ratio are generally much lower (Tomkin, Luck and Lambert 1976). The C^{12}/C^{13} ratio observed in the interstellar medium is greater than 30 (Matsakis et. al., Wannier et.al 1975). This contradiction appears to rule out late type stars as a significant grain formation site. Thus the pre-main-sequence objects become good candidates for the primary source of interstellar grains.

References

Appenzeller, I. and Tscharnuter, W. 1974, Astron. and Ap., 30, 423.
Appenzeller, I. and Wolf, B. 1977, Astron. & Astrophys. 54, 713.
Arny, T. and Weissman, P. 1973, A. J. 78, 309.
Bertout, C. 1977, Astron. & Astrophys. 58, 153.
Boss, B. General Catalogue of 33, 342 Stars for the Epoch 1950. Carnegie Inst. Wash. Publ. 468. (Washington 1936)
Breger, M. 1974, ApJ. 188, 53.
Cohen, M. 1975, MNRAS 173, 279.
Cohen, M. and Schwartz, R.D. 1976, MNRAS 174, 137.
Dieter, N.H., 1975, ApJ. 199, 289.
Eichhorn, H. 1957, A.J. 64, 2.
Elmegreen, B.G. and Lada, C.J. 1977, ApJ. 214, 725
Gahm, G.F., Nordh, H.L., Olofsson, S.G., and Carlborg, N.C.J. 1974, A. & A., 33, 399.
Grasdalen, G., Joyce, R., Knacke, R.F., Strom, S.E., and Strom, K.M. 1975, A.J. 80, 117.
Greenstein, J.L. and Oke, J.B. 1977, PASP, 89, 131.
Herbig, G.H. 1960, ApJ. Supplement 4, 337.
Herbig, G.H. 1970, Mém. Soc. Roy, Sci. Liege, Ser 5, 19, 13.
Herbig, G.H. 1977, ApJ. 214, 747.
Henize, K.G. and Mendoza V, E.E., 1973 ApJ. 180, 115.
Kuan, P. 1975, ApJ. 202, 425.
Kuhi, L.V. 1964, ApJ. 140, 1409.
Kuhi, L.V. 1975, PASP 87, 502.
Larson, R.B., 1972, MNRAS 157, 121.
Lynden-Bell, D. and Pringle, J.E. 1974, MNRAS 168, 603.
Matsakis, D.N., Chui, M.F., Goldsmith, P.F., and Townes, C.H. 1976, ApJ. 206, L63.
McNamara, B.J. 1976, A.J. 81, 375.
Morton, D.C., Drake, J.F., Jenkins, E.B., Rogersen, J.B., Spitzer, L. and York, D.G. 1973, ApJ. 181, L103.
Oort, J.H. 1963 p. 665 in The Muon, Meteorites and Comets, Middlehurst, B.M. and Kuiper, G.P. ed. (University of Chicago Press, Chicago).
Rydgren, A.E. 1976, PASP 88, 111.
Rydgren, A.E., Strom, S.E. and Strom, K.M. 1976, 1976, ApJ. Supple., 30, 307.
Schwartz, R.D. 1974, ApJ. 191, 419.
Strom, S.E., Strom, K.M., Yost, J., Carrasco, L., and Grasdalen, G. 1972, ApJ.

References (con't.)

173, 353.
Tomkin, J., Luck, R.E. and Lambert D.L. 1976, ApJ. 210, 694.
Ulrich, R.K., 1976, ApJ. 210, 377
Vaerewyck, E.G. and Beardsley, W.R. 1973, ApJ. 182, 121.
Vrba, F.J. 1975, ApJ. 195, 101.
Walker, M.F. 1972, ApJ. 175, 89.
Wannier, P.G., Penzias, A.A., Linke, R.A. and Wilson, R.W. 1976, ApJ. 204, 26.
Wolf, B., Appenzeller, I. and Bertout, C. 1977, Astron. & Astrophys. 58, 163.
Woodward, P.R. 1976, ApJ. 207, 484.
Zappala, R.R. 1970 Lick Obs. Bull. No. 610.

D I S C U S S I O N of paper by GRASDALEN:

R.N. THOMAS: In referring to Sobolev models you really refer to atmospheric regions of large velocity gradient. But the real point is the behaviour of those regions where the velocity gradient is small - which really distinguishes between "chromospheric" and "extended atmosphere" models. We believe the former, and also that such will help resolve your IR problem.

GRASDALEN: I agree and hope the Brackett α observations will help resolve these questions.

VAN'T VEER: In order to obtain an answer to the angular momentum problems, we need determinations of the rotational velocity of the underlying photosphere. What was the observed rotational velocity?

APPENZELLER: In the case of CoD - 35° 10525 the line of sight component of the equatorial rotational velocity (as determined from the profiles of the HeI and HeII emission lines) cannot be larger than about 50 km s^{-1}. (The late-type absorption lines are less suited for determining the rotation velocity since the strong lines are normally broadened by saturation while the weak lines tend to be blended).

WEYMANN: Does the observation that late type stars differ from the interstellar medium in C isotopes necessarily imply that the grains still could not come from late-type stars, as distinct from the bulk of the interstellar gas?

GRASDALEN: The important point is that a large fraction of the heavy elements, especially silicon, are in the grains, thus, a similar fraction of the carbon was at the grain formation site.

APPENZELLER: I would like to comment on your interesting suggestion that the YY Orionis stars are close binaries. I do not think that this can be the case. First, YY Orionis stars seem to be too numerous compared to the frequency of close binaries among the normal stellar population. Second, high resolution Coudê spectrograms which we obtained for two of these objects (S CrA and CoD-35° 10525) allowed us to measure the radial velocity of the pure emission lines(HeI, HeII, CaII) and (in the case of CoD - 35° 10525) of the late-type absorption lines quite accurately. We were not able to detect any time variations. This seems to rule out the binary character of at least these two objects.

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