REPORT ON THE I.A.U. SYMPOSIUM ON STAR FORMATION

The IAU Symposium 75 on Star Formation was held in Geneva, Switzerland between September 6-10, 1976.

The emphasis of the symposium was on observations particularly on the mm wave and infrared observations which proliferated in the last few years. Observations of molecular clouds received a great deal of attention. Although many of the questions remained unanswered and many controversial issues unresolved, one felt that the progress in our understanding of the Star Formation phenomenon has been impressive.

In his review on Galactic Structure and Star Formation, Frank Kerr emphasised that galaxy formation and star formation are related phenomena. The rate of star formation in the collapse phase of a galaxy may significantly affect the subsequent evolution of the galaxy. Kerr discussed the theoretical work of Gott and Thuan and of Larson in this context.

Star formation is a continuing process in the Galaxy. The presence of globular clusters and halo stars indicates that star formation started before the disc of the Galaxy was formed. The high metallicity in many of these objects indicates that the processing of interstellar material took place in the very early phases. The warp found in the Galaxy may suggest that the outer parts of the disc are still not fully formed and observations of the disc show that stars are forming today.

In reviewing the observations of the disc of our galaxy Kerr pointed out that there is a concentration of molecular clouds, supernova remnants, pulsars between 4 and 8 kpc from the centre. The OSO 3 and SAS 2 observations of high energy γ rays ($E_\gamma >$ 100 Mev) also indicate a peak in this annulus.

Kerr reviewed the recent work by Burton and Gordon on CO. In recent years CO has proved to be the most effective probe for the nonluminous component of the Interstellar Medium. The surveys show that the CO emission is strongly concentrated to the disc (half thickness $\sim$ 100 pc) between 4 and 8 kpc from the glactic centre. The distribution is clumpy on the same scale as galactic hydrogen. Since the excitation of CO lines is believed to be caused by H_2 molecules the CO data has been used to infer the molecular hydrogen density in regions of the galactic disc otherwise un-observable due to obscuration. From such analyses it has been concluded that in the inner regions of the Galaxy most of the hydrogen is in molecular form while in the solar neighbourhood the atomic and molecular densities may be comparable. The CO observations have not shown a definite spiral structure. This has brought in some surprise since molecular clouds being extreme Population I objects should be strongly concentrated in the spiral arms and CO being the best trace constituent of these clouds should have shown this. Although many believe that observations with higher spatial resolution will finally settle this question there was speculation why CO may not show spiral structure at all.

Kerr mentioned the density wave theory of spiral structure and said that Roberts nonlinear version of this theory is the one to be applied to the Galaxy. Although the theory has strong support from observations of other galaxies, in the Galaxy the evidence still seems slender. The abundance studies in external galaxies may be used as a test of the density wave theory and its relation to star formation. Quite a bit of discussion took place on the question whether density waves are essential for star formation. The opinion was divided. The fundamental role of shocks in star formation was recognized by all except Baker and Barker who preferred a thermal phase transformation to cold dense clouds as the initiation of a collapse in the clouds leading to star formation. Woodward's hydrodynamical models of shock-driven implosion of interstellar clouds were also reported. Woodward's work has definitively shown that a standard interstellar cloud develops a flattened pancake shape as it encounters a shock in the intercloud medium. Gravitationally bound subregions form on the surface of this flattened cloud. His work also explains the local inhomogeneities in regions of star formation in terms of various instabilities. Finally Kerr commented upon the theories of rate of star formation and mentioned Talbot and Arnett's recent work on metal enhanced star formation.

Thaddeus and Lequeux reviewed in detail the work on molecular clouds. Lequeux's review also included a discussion of molecular masers. Thaddeus asserted that molecular clouds are CO clouds. CO is the most abundant trace constituent of molecular clouds and is detectable in every interstellar condensation exceeding a size of about 0.1 pc and a molecular hydrogen density of 100 cm^{-3}. The CO emission contours outline the dark nebulae in the sky and the emission measure correlates well with visual extinction A_V. CO has so far been detected in various isotopic forms e.g. $^{12}C\ ^{16}O$, $^{13}C\ ^{16}O$, $^{12}C\ ^{18}O$, $^{12}C\ ^{17}O$, $^{13}C\ ^{18}O$, etc. Some of the isotopic lines are optically thin and have been used to derive velocities to an accuracy of 0.1 km sec^{-1} and temperatures to 20 – 30%.

Thaddeus remarked that the molecular clouds have always been found associated with H II regions and OB associations. From studies of many regions e.g. M 17, W 3, Cep OB 3, Orion the following schematic picture has emerged. In all these regions the boundary of a luminous H II region and a molecular cloud is sharply delineated by an ionization front. On the luminous side of the front one generally finds a young sub-association of hot stars and farther from this on the same side a more expanded and hence older sub-association. The other side of the ionization front generally contains very young objects like compact H II regions, IR sources and masers. This picture indicates a sequence in age and hence in formation of various objects in any molecular cloud complex. Lada and Elmegreen of the Centre for Astrophysics, Harvard have proposed an interesting theory of star formation to explain these observations. According to the accepted theory of evolution of an H II region soon after an H II region reaches its initial Strömgren radius it tends to expand in the surrounding neutral gas. This sends a shock into the interstelrla medium which eventually separates from the ionization front. In between the ionization front and the shock front there is a dense and cold layer of neutral gas. The conditions in this layer are conducive to star formation. Elmegreen and Lada postulate that massive OB stars form in this layer of gas. Once they form they tend to ionize the neutral gas and produce shocks which go in both directions. The interaction of these secondary shocks with the H II region formed by the previous generation of stars may produce the dense globules commonly found in H II regions. In the forward direction the shock marches ahead of the ionization front and conditions are ripe once more for forming a new generation of stars. This theory adequately explains the age sequence found in the observations of molecular cloud complexes and is based on reasonable mass estimates. However it does not describe how low mass stars form in interstellar cloud complexes. It also requires a first generation of massive stars to start with. It is worth remembering here tnat low mass stars may be forming in completely different physical circumstances tnan massive stars. Low mass stars are conspicuous by their absence in most of the young OB associations.

Thaddeus described in detail the ρOph dark cloud and observations of the Bok globules B 5 and B 335.

Lequeux, in his review, concentrated on the internal kinematics of dense clouds. He discussed the causes and conditions of instability of these clouds and remarked that due to the lack of spatical resolution in the present day mm wave observations individual stellar mass fragments cannot be seen. The evidences of collapse and fragmentation are hence indirect. The major source of information in this respect is the study of mm wave lines, in particular the observations of the CO lines. The ^{12}CO line has a width ot a few kilometres per second while the ^{13}CO line is half to two thirds as wide. The lines are found to be much wider than expected from pure thermal broadening and show complicated structure in their profiles. Lucas's models of steady clouds with supersonic microturbulence have failed to reproduce the relative widths of the ^{12}CO and ^{13}CO lines. Also his models in general produce double peaked profiles which are simpler than what is normally observed. There are theoretical problems with models of supersonic turbulence since such turbulence dissipates very fast. People have therefore argued for collapse or large scale random motions of the clouds to explain the widths of the CO lines. For large scale random motion Zuckerman et al have proposed dense blobs moving supersonically in a low density medium and broadening the CO lines. It is difficult, however, to find an energy source in a cloud to feed into this large scale motion. There is also observational difficulty with this picture since in Orion it has been found that

$$T_b\,(^{12}CO) = T_{IR} = 70°K.$$

This shows that the blobs in orion cover the full solid angle of the antenna beam. Moreover, for the stability of these blobs a hot interblob gas is required but there is no observational evidence for this. Lequeux concluded from observational data that large scale random motions may not be the cause of broadening of the CO lines. He discussed a few convincing cases of collapse. In reviewing the collapse models of Snell and Loren he said that the authors have been able to produce line profiles in good agreement with observations with an assumed velocity distribution within the cloud of the form $v(r) \propto r^{-\frac{1}{2}}$. In all theoretical models so far the requirement of an increasing velocity towards the centre of the cloud had to be fulfilled to produce self absorption in the ^{12}CO line.

Speaking on the observations and speculations on molecular masers Lequeux mentioned the two existing beliefs about these objects. Some workers believe that each maser has its own pump and is an individual high density object.. As opposed to this local hypothesis of masers there is a global hypothesis which argues that all the masers are pumped by a common mechanism. This latter hypothesis has derived strong support from the recent observations of W 49 in which several H_2O masers were found to undergo simultaneous variation. No final word was said about the pumping mechanism of OH and/or H_2O masers. It was said however that H_2O masers are younger objects and evolve into OH masers through photodisintegration. Welch from Berkeley reported on the accurate positions of H_2O masers and showed that they are always separate from compact H II regions which generally embed OH masers. The high velocity in H_2O masers was attributed to the interaction of high velocity stellar wind and dense clouds resulting in sputtering of H_2O molecules off grain surfaces. In answer to Field's question of what masers have to do with star formation Lequeux said that when good estimates of masses and sizes of these objects are available one may be able to say if these are protostars. He remarked that the present estimates depend upon the proposed pumping mechanism and hence very uncertain.

In his review on Infrared observations and Star Formation Wynn-Williams described the recent advances in the infrared observational techniques. He included both ground-based and airborne IR astronomy and also listed the objects studied in detail. He discussed a class of objects he called 'protostars' and quoted W3—IR35 RCW57, Mon R2 IRS3, ORION BN, OMC IRS3 as examples. All these objects are characterised by large IR luminosity ($L_{IR} \sim 10^2$–10^5 $L_\odot$), by negligible flux at optical wavelengths and by temperatures of a few hundreds of °K. They also are very weak radioemitters and show a strong absorption feature at 10μ in their spectra. From their association with dust and gas one concludes they are young. According to Wynn-Williams most of these objects are protostellar in nature although some may be highly obscured O stars. The infrared observations of Orion nebula were discussed in detail. The IR observations can be used to infer temperature gradients in the sources. Particular mention was made of such a gradient in Orion nebula with a dependence of the form $T(r) \propto r^{-\frac{1}{2}}$.

The subsequent review was given by Mazger on Radio observations related to Star Formation. Mazger observed that stars form out of interstellar material in the rather restrictive mass interval of $0.08 - 100\ M_\odot$. All OB stars and most stars with masses larger than $1\ M_\odot$ form in open clusters and associations while low-mass stars condense continuously as single stars out of cloudlets. He further observed that 70% of the OB stars are in the mein spiral arms of the Galaxy, 15% are in the nuclear disc and the rest are in interarm regions. The radio observations relate principally to compact H II regions which are believed to be the seats of star formation. Mezger discussed the theoretical work of Krügel et al on the evolution of compact H II regions and said that before an H II region is optically detectable with an exciting star at its centre it probably evolves from an IR source to an ionization-bounded compact H II region to a density-bounded compact H II region within the first half a million years. Mezger asserted that the birth of a massive star in a cloud signals the end of star formation in that cloud. Low mass stars always form first. Strom argued that low mass stars form elsewhere since young clusters do not generally contain them. Spitzer suggested that low mass stars may form first and then evaporate fast from a cluster which should explain their deficiency in clusters.

Strom reviewed the work on T Tauri stars. He included Herbig emission stars and Herbig-Haro objects in his review. All these objects are believed to be in the pre mainsequence phase and hold clue to the mysteries of stellar birth. Both T Tauri stars and Herbig emission stars have emission lines in their spectra, have large IR excess and show variability in emission and polarization. The lines show P Cygni profiles and are indicative of mass flow in the outer envelopes. Rydgren and collaborators have proposed models of T Tauri stars based on the idea that the emission lines are formed in a hot envelope. They have found a correlation between the youngness of a T Tauri object and the amount of mass flow. They have also observed that the mass outflow rate decreases as the stars move closer to the main sequence. Strom mentioned other models due to Cohen and workers and Gahm and his collaborators. Special reference was made to Roger Ulrich's work where he argues for mass inflow rather than mass outflow. There is a curious object namely yy Ori which shows all the T Tauri chracteristics but for the H_α line which has an inverse P Cygni profile. Herbig conjectured that the yy Ori phenomenon might be due to mass inflow. In all other examples the case of mass outflow is rather convincing.

In an interesting short report Kuhi from Berkeley showed that the atmospheric activity in T Tauri stars is correlated with their rotation in the sense that the H_α-emission objects show high rotation velocities while the non-H_α objects are slow rotators. There was quite a bit of discussion on the masses of T Tauri stars since all mass estimates are indirect. Strom said that the Herbig emission stars might be heavier than the T Tauri objects and the latter probably have masses lower than 2 $M_\odot$. In any case this was more of a speculation than hard observational fact. In another short report Taylor from Caltech discussed the observations of three condensations near θ^2 Ori which are identified in OI λ8446 photographs. These objects are supersonically moving away from θ^2 Ori at about 80 km sec^{-1}. The nature of these objects is still not known.

The theoretical work on star formation was covered in two reviews. The first by Mestel was of a general nature called the Theoretical Processes in Star Formation. He began with a discussion of Jeans' criterion and went on to the topic of magnetic fields in clouds. The problem of dissipation of angular momentum in a contracting cloud also received attention. Mestel ended his review with a description of various people's work on limits of fragmentation. Larson spoke on Models of Collapse and reviewed the work on simple spherical, axisymmetric and three-dimensional hydrodynamic collapse. He included besides his own the work by Bodenheimer and collaborators and by Appenzeller and coworkers. All these theoretical investigations involve very elaborate and complicated computational procedure. Only the results of these calculations were discussed. A curious phenomenon occurs in models of axisymmetric collapse where a ring develops and grows through accretion. The result according to Larson is highly sensitive to the distribution of angular momentum. Bodenheimer spoke on some very recent three-dimensional computations he and Black had done and said that the development of a ring was not due to imposing an axial symmetry on a collapsing cloud. In the full scale three-dimensional calculations also the ring develops and after one rotation period it tends to break up into blobs. Bodenheimer spoke of a hierarchy of ring formation and breakup and hoped that when these calculations are complete answers to such fundamental questions as how a cluster forms and how the angular momentum problem resolves may be obtained.

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WORKSHOP ON PLASMA PHYSICS

This workshop held at the Physical Research Laboratory, Ahmedabad, between November 29 and December 11, 1976 was attended by a number of participants from all over India and eight participants from the U.S.A.

Broadly speaking, this workshop covered the areas of MHD and Plasma Turbulence, Nonlinear Wave Phenomena, Computer Simulation techniques, Laser plasmas and Beam-Plasma Interactions. There were no contributed papers. Besides the review talks, sometimes two or three by one person, there were three parallle working groups every afternoon. Inspite of the ample time allocated for discussions during each lecture, very often these lively discussions had to be taken up again by the working groups.

The working group on Computer Simulation Techniques was led by Dr. D.W. Forslund, of Los Alamos Scientific Laboratory. For most of our participants, this was a new technique and they almost had to learn from a scratch. Dr. Forslund left no stones unturned to make sure that at least some of our younger participants pick up the technique to the extent that they on their own could use it once the workshop was over. In this regard, speaial mention should be made of Dr. B. N. Goswami, of PRL, Ahmedabad, who along with Dr. Forslund managed to successfully run the computer code before the workshop was over.