OPEN DISCUSSION; SESSION II (Chairman: Butler W. Burton)

BURTON: We may now open our discussion. I think it would be a good idea if the three speakers came forward to be in access of microphone and overhead projector. While they are coming forward I would comment that most of you will recognise that there are a number of very controversial aspects to the topics presented by our speakers. In studies of the molecular content of our Galaxy and nearby other galaxies conversion of CO intensities to H_2 densities remains a particularly controversial matter. The life time of large clouds is a subject of controversy. Spectra of sizes and masses of clouds is something about which there is a great deal of discussion. The extent to which CO traces the blue light and even the extent to which CO traces the amount of star formation is also a very controversial item. Perhaps some of these things will come up during the open discussion now. Who would like to address a question to one of our speakers?

TUTUKOV: Could you compare the three very important rates which describe the star formation in our Galaxy as well as in other galaxies? These rates are: the rate of the processing of galactic gas through spiral arms, the rate of the processing of galactic gas through giant molecular clouds, and the star formation rate.

BURTON: Which of you would like to address these questions of rates?

STARK: The star formation rate: I'm not really an expert on any of these numbers, but I believe the star formation rate is a few solar masses per year in the Galaxy as a whole. The very crude estimate of the rate at which a giant cloud will double in size is approximately one galactic year regardless of its position in the Galaxy, so that is several tens of millions of years. One important point is that below some threshold, molecular clouds will not tend to accumulate mass. It is essentially a gravitational instability; just at that threshold, which might be at a mass of $1 \times 10^5 M_\odot$ or so, the cloud is not going to accumulate any material at all on average. It will tend to accumulate almost $10^6 M_\odot$ in 10^8 years.

TUTUKOV: I am convinced that all the three rates which I named are very important for the calculation of the most common properties of star formation in galaxies.

STARK: I agree on their importance, but the rates are unfortunately still largely unknown.

J.-P. Swings (ed.), Highlights of Astronomy, 525–530.

BURTON: Perhaps it is relevant in this context to wonder also about a fourth rate, namely the rate of destruction of a giant molecular cloud, which must proceed rather rapidly.

WANNIER: This is mainly addressed to Tony Stark. I recall a difficulty in HI maps of the Galaxy which may possibly affect your CO survey. When using galactic rotation to infer a radial distance, velocity structure translates into distance uncertainties. Could the arm/inter-arm contrast be even larger than you observe due to large peculiar velocities?

STARK: That certainly is a worry. Certainly Prof. Burton here was instrumental in pointing out these worries with the HI data but I do think that in CO data the problem is considerably less acute because those features in the HI were low contrast "lumps" on top of a generally broad emission. What I am doing involves not so much study of emissivity as counting of clouds, and cataloguing them. I try to draw a boundary and try then to find the size of a cloud. There are regions of several kpc^2 with no giant clouds at all, whereas if you simply take the number of giant clouds in the Galaxy and divide by the area of the Galaxy, you would expect some number like 20 or 30; the contrast is really quite high in giant clouds.

WANNIER: I was asking whether the contrast could be larger?

STARK: It is possible, yes. Certainly, the size of these voids will be very much reduced by the dispersion of the material in the arms.

BURTON: Isnt't it true though that the operational definition of an interarm region is a region devoid of molecular emission?

STARK: Yes, my operational definition.

LOCKMAN: On that same point, when you were testing your hypothesis on all giant molecular clouds that lie in the spiral arms, how do you define the spiral arms and, particularly, where do you put the Orion cloud?

STARK: That is a very good point. The only clean way to do this for our Galaxy, I think, is to point out that there are places where there are no giant clouds, and to essentially give up trying to find where they actually are. I think studies of other galaxies are really the best way to resolve this question. I use a sort of tautological definition: I define the spiral arms to be where the giant clouds are. But the point is that the voids exist and the voids have no giant clouds in them.

LOCKMAN: But the word spiral may be a little bit misleading?

STARK: Certainly, yes, there is no way of telling for our Galaxy, particularly with the distance ambiguity, what is going on. On the other hand, in the outer galaxy Thaddeus and co-workers have shown that the Carina arm, which I think most people would agree is spiral-like in position-to-velocity, does in fact have a very high concentration of molecular clouds.

LINDBLAD: When arriving at the conclusion that the CO velocity gradient across the spiral arm in the Andromeda galaxy is in agreement with the density-wave theory, where in that galaxy would you have to place co-rotation in order to reach that agreement?

RICKARD: That question should be addressed to Stark, because he has worked on this subject. There is a paper by Ryden and Stark, so would it be unfair of me to hand this over to you?

STARK: In our paper we merely pointed out that there was this observational phenomenon occurring with the molecular material and put no density-wave interpretation upon it.

RICKARD: Then I really don't have an answer for it, since I did not have enough time to sit down and work out those things before preparing my talk. However, I shall try to look at that before doing the write-up.

WILLIAMS: I refer to the difficulty in inferring H_2 masses from the CO data. Along several lines of sight in our Galaxy, amounts of solid CO are comparable to that in the gas. Thus, it is quite possible that clouds exist in which nearly all CO is condensed on the grains, and thus would be unobservable. Do the authors agree?

STARK: I'm not familiar with that work, but I certainly would agree that there are a variety of effects which clearly make it difficult to use ^{12}CO as a very good measure of the true gas-phase H_2 abundance. I did not go into any detail about the effects that we suspect. There certainly does clearly seem to be a temperature-related effect, because the ^{12}CO line is optically thick and thus very sensitive to the ambient temperature. There does seem to be a change in the mean cloud temperature of the ensemble of clouds as you move around in the Galaxy. There is clearly a metallicity effect in terms of the actual CO/H_2 ratio, not to mention the $^{12}C/^{13}C$ ratio. This is just another element in this immense disorder of truths.

RICKARD: The first work on CO brightness versus dust contents was done by Dickman; a subsequent larger study was done by Frerking, Langer and Wilson. In both of these studies of nearby clouds, there was considerable variation in the calibration of the CO-to-H_2 conversion; it is only the average of all of those values that was taken by others and applied as an effective universal constant. I think in fact that there is no such universal constant. Never in any of my work have I implied that there was in fact a direct relation between CO surface brightness and H_2 column density. Although, it is certainly true that when you detect CO there is very likely to be molecular hydrogen along the line of sight and it is a very useful kinematic tracer.

BURTON: In regard to your question I would like to comment that I see as part of the answer the importance of recognising gradients across the Galaxy in temperature, for example, and gradients in abundance ratios of the various constituents. These gradients are to be the subject of discussion tomorrow morning. Are there more questions? Dr van Woerden.

VAN WOERDEN: Rickard suggests that the decrease in the CO/HI ratio in galaxies with increasing distance from the Virgo Cluster centre is due to stripping of hydrogen, while the CO resists stripping. I suggest that the resistance to stripping of CO is not due the higher density of CO clouds, but rather to the fact that they are concentrated in the inner parts of galaxies, where the potential well is deeper. This view is supported by the fact that - as shown by Warmels at Groningen/Westerbork and by Van Gorkom and Kotanyi at the VLA - galaxies in the Virgo Cluster core have smaller HI disks than those in the periphery; hence galaxies in the core tend to be stripped of hydrogen in their outer parts, but may retain it in their inner parts, where the CO is also concentrated.

RICKARD: I would not disagree. I'm sorry I gave the wrong impression.

ZINNECKER: A question to Dr Rickard: How is Verter's CO luminosity function defined? Is beam-size involved? Is it based on a complete sample? And a question to Dr Stark: Is the agglomeration process of giant molecular clouds in spiral arms actually the same as the large-scale Parker-Jeans instability?

BURTON: First the question on the definition of the CO luminosity function.

RICKARD: I'm not quite sure what you mean. The luminosity was discussed in Verter's Ph D thesis. She just assumed that there would be some distribution of the number with luminosity, and then attempted to determine the rough shape of the distribution through the use of a maximum likelihood approach using non-parametric statistical analysis. You don't like that?

ZINNECKER: I'm concerned with far simpler problems: First of all, when you look at the Galaxy with a certain beam size...

RICKARD: O-o-oh! I'm sorry, I should have mentioned that what Verter did was to focus on galaxies for which there was sufficient mapping data so that she could compute a total CO flux on the basis of some axi-symmetric model. In her case she chose to use exponential models. Stark et al. in the Virgo cluster work have actually fitted a variety of both flat and exponential models. This all refers to extrapolated total CO luminosities and so sensibly accounts for the beam size.

ZINNECKER: Is it a magnitude-limited sample?

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RICKARD: No, it is not in the case of the Virgo one. The Virgo one is based essentially on all data that existed at the time, no matter where it came from or what its quality was. Verter simply attempted to account for the variety of effects. That makes it difficult to work with, yes. The Virgo cluster ones was done for a uniform sensitivity limit.

STARK: The second question was what do I mean by agglomeration: it is a sort of global gravitational instability, where essentially the mass centres of the giant molecular clouds are induced by gravitational and hydrodynamic effects. The growth rates of those clouds, and precisely what those effects are, and whether they involve magnetic fields, I'm not able to say. I simply point to the observational evidence in favour of that.

MATHIEU: I have a question to Tony Stark about the Rosette work. In Leo Blitz's thesis work he found clumps in the Rosette - fairly massive clumps - 3000-10000 $M_\odot$. Are the clumps consistent with those you find, are they in addition to those clumps, or are those clumps breaking up into smaller clumps?

STARK: The Rosette data that I showed was due to Blitz and Stark (1986, January 15 - Ap J). Yes, these clumps are smaller than Leo's original clumps and, in fact Leo's original clumps were about the same size as his beam then, and these clumps are only somewhat larger than our beam now. I have no doubt whatsoever that the filling factor of molecular material inside these clumps is very small.

MATHIEU: I will make sure I understand. Leo's large clumps: are they breaking up into small clumps or are these additional clumps?

STARK: Yes, they are breaking up into small clumps and there are additional clumps, which would have been missed in his original low-sensitivity, large-beam map.

BURTON: Before lunch we have time for one more question.

FREEMAN: I have a question on the structure of individual giant molecular clouds. If you were to represent their surface density distribution (in radius) as a power law to zero-th approximation, what would the power be?

STARK: It depends on what order of approximation you are willing to take. I don't know the answer now, sorry; I will try to put it in the write-up of my talk.

BURTON: There have been a number of papers that address the subject of power-law distributions of clouds and clump sizes but I think in regard to both your question and the earlier question, the lower limit to the clump size has not yet been reached because it is always hovers around the resolution. Isn't that correct?

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STARK: Yes.

BURTON: I thank the speakers.

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