CONCLUDING REMARKS

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It would be vain to attempt to summarize the cornucopia of new information and ideas about star formation that this conference has laid before us, or to pronounce upon the current status of our understanding of the subject. Clearly what has been learned so far, while impressive, is just a beginning; many basic questions were discussed extensively at the meeting, but most of them are still far from being clearly answered. The issues addressed but not resolved included the origin of the observed outflows from young objects; the dynamics and evolution of star-forming clouds, and the possible role of magnetic fields; the parameters that determine star formation rates, and the relation between the star formation rate and the gas content of galaxies; the form and possible variability of the stellar initial mass function; and the definition, nature, and causes of "starbursts". These questions, and many others discussed at the meeting, will provide material for years of continuing research before all of the answers become clear.

However, instead of dwelling further on problems that have already been discussed at length, I shall devote the remainder of my remarks to mentioning some additional questions that were only briefly touched on at the meeting but will need to be addressed more thoroughly, perhaps at future meetings, before we can claim to have a complete understanding of star formation. It should be apparent, for example, that while much attention has been given to such highly visible effects as bipolar jets, explosive phenomena, and starbursts, trying to understand star formation by studying its most spectacular and energetic manifestations is like trying to understand social history by studying newspaper headlines: they tell you all about the spectacles and the catastrophes, but not much about the everyday life underlying them. Clearly it is one thing to observe and describe an event such as a major accident or natural disaster, and quite another thing to try to reconstruct the detailed sequence of events that led to the catastrophe; however, until this has been done, one cannot really claim to have understood what happened. So it is in trying to understand star formation: it is one thing to study the energetic phenomena that are observed for example in the Orion Nebula region, or on a much larger sale in starbursts, but before we can claim to understand how stars form, we must also establish the sequence of events that led to the current activity in Orion or to the onset of starburst activity in galaxies like M82.

Evidently we need to understand the whole life history of a star-forming cloud or region, including its dull everyday life and development before it was capable of generating energetic activity. We would like to know, for example, what was happening in the Orion region before the present molecular cloud began to form

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massive stars. Was the present cloud material previously in the form of diffuse gas, or in a number of smaller atomic or molecular clouds, or in some kind of sheetlike or shell structure? Can we identify "proto-Orion" regions that will eventually evolve into something like the present Orion molecular cloud? Ultimately, it will be important to be able to identify evolutionary sequences of star-forming clouds and complexes, because this is the only way that we will be able to clarify with confidence how star-forming regions develop. Achieving such an ambitious goal will require both extensive data and a much better theoretical understanding of the physical mechanisms by which self-gravitating clouds and complexes can evolve from one state to another.

Since the processes of cloud formation and evolution form part of a larger galactic "ecological cycle" in which interstellar matter is continually being transformed and cycled from diffuse to aggregated form and back again, it is important also to understand how star-forming clouds are eventually destroyed and what happens to their material afterward. Is the cloud material widely dispersed as low-density ionized gas, or as expanding shells of atomic gas? Does a significant fraction of it survive in the form of smaller dense clouds? Is some of it converted by supernova explosions into a hot shock-heated medium? And how does the hot dilute gas produced by ionization or by shock heating eventually cool and condense back into a form that can be collected by gravity into new star-forming clouds and complexes? It is clear that many physical processes will need to be understood, but so far the various ways in which interstellar matter can be cycled between different phases have barely begun to be addressed in the literature. For many years theorizing about the interstellar medium has been dominated by the attention given to supernovae and shock-heated gas, while less energetic phenomena such as ionization, as well as the apparent existence of a widespread photoionized component of the interstellar medium, have been relatively neglected. Possibly the effects of supernovae have been overestimated; it also appears not to have been widely remarked upon in the interstellar medium literature that far more matter is cycled through H II regions and through a "warm ionized medium" than is cycled through a hot shock-heated medium. As much as one hundred solar masses of gas may be ionized by O stars per year in our Galaxy, making this by far the dominant mechanism for recycling dense cloud material back to a more diffuse form. At any rate, it is clear how little we yet understand about the processes of mass and energy transfer in the interstellar medium; perhaps the time is ripe for a comprehensive re-examination of these questions.

It is equally important to understand evolutionary effects on galactic scales and to be able to identify evolutionary sequences of galaxies if we are to establish clearly how star formation progresses in galaxies. In starburst systems, for example, the underlying galaxy presumably spent most of its life as a relatively normal object, but a recent disturbance apparently caused gas to be accumulated near the center and triggered an episode of exceptionally vigorous star formation. Can we identify pre-starburst galaxies, and thus observe directly some of the processes leading to the occurrence of starbursts? It would be of interest, for example, to understand the recent history of the two nearest and best studied starburst galaxies, M82 and NGC 253, and how they came to produce starbursts. Tidal interactions and mergers have been widely implicated as causing at least the more spectacular starbursts, but neither M82 nor NGC 253 is obviously tidally distorted; can gas accretion also be a direct cause of starburst activity?

The evolution and ultimate fate of starburst systems is also a topic of interest. We would like to know, for example, what M82 will look like when its starburst fades, and how it will have been changed by the occurrence of a starburst near its center. Can we identify post-starburst galaxies, and thus trace the evolution of starbursts? Is there a relation, evolutionary or otherwise, between starbursts and active galactic nuclei? How do the superluminous infrared galaxies fit into an overall picture of galactic evolution? Several speakers at the conference addressed these questions in at least a preliminary way; obviously such questions will merit much more attention in the future because they bear not only on our understanding of star formation but also on our understanding of the development of galactic nuclei.

Equally important to understand are the dull inactive galaxies like M31, which as we have heard has a very low rate of star formation. M31 has traditionally been regarded as a galaxy very similar to our own, so it is surprising that its star formation rate is an order of magnitude smaller. Is our Galaxy unusually active, or is M31 unusually inactive, or is there some crucial difference in the gas content or dynamics of the two systems? Could they represent different stages in the evolution of normal spiral galaxies? Although the answers to even such basic questions are not yet known, at this conference we have seen displayed a new generation of data of impressive quality that are beginning to make it possible to study star formation "microscopically" in our Galaxy and other nearby systems; eventually it should thereby be possible to understand differences in the overall star formation rates in galaxies in terms of observed differences in the properties of individual star-forming clouds or regions. Indeed, it is now becoming possible to address such old questions as the relation between the star formation rate and the content, distribution, and dynamics of gas in galaxies with a whole new level of sophistication; thus we can look forward in the near future to much better observational answers to these questions, and this should in turn make possible a much better theoretical understanding of the processes by which stars form.