DISCUSSION SESSION:
GALAXY FORMATION AND QUASISTELLAR OBJECTS

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Our discussion session focussed on specific topics that overlap both with galaxy formation and QSOs. Since there is no definitive understanding of either, it may well be premature to hope for very much in the way of any fundamental new insights. However observations pertinent to galaxy formation, as well addressing related aspects associated with QSOs, are finally beginning to be reported. This summary presents our filtered perspective on the issues that we raised, that emerged after a lively discussion, which we make no attempt to report verbatim.

1. When did galaxies form?

1.1 Was there a unique formation epoch?

1.2 Do evolving "active" galaxies have any significance for generic galaxy formation?

Spiral galaxy disks form over a Hubble time. Formation was initiated about 10^{10} yr ago, as judged from the age of old disk stars. Ellipticals formed earlier, as did galaxy spheroids. There appears to be a spread in formation epoch for ellipticals, at least as inferred from the range in fractional gas content after a fiducial age of 10^9 yr, varying from 30% to 70%, required to explain the range in galaxy colors and spectra at $z = 0.5$ to 1.

It is reasonable to assume that star–bursting or post–starburst cluster galaxies at $z \sim 1$ have to evolve into "normal" cluster members by the present. The same is not necessarily true for blue field galaxies at high redshift. Starburst galaxies require about 10^{10} yr to evolve into a typically red (V–R ≈ 0.9) population characteristic of present day ellipticals. In conventional evolution models at $z \sim 0.5$, where there is evidence for an enhanced blue population both in the field and in clusters, one has to add an additional degree of freedom, namely the initial mass function, to arrive at a resolution of this possible difficulty. A bimodal IMF,

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with initially enhanced massive star formation relative to the solar neighborhood initial mass function observed today, allows the early starburst phase and associated blue colors to be of short duration, $\lesssim 10^9$ yr. Such an effect, also invoked as a possible explanation of the paucity of low metallicity disk stars in our own galaxy, would bring the predictions of the cold dark matter theory into much closer concordance with observational constraints.

Bimodal star formation might conceivably be induced by strong shearing motions. These are present in spiral arms induced by density waves, in gas stirred up by central bars, and in tidally interacting systems that are undergoing vigorous star formation activity. Bimodal star formation is inferred to occur in many of these regions. One could plausibly imagine that shearing motions would enhance the dissipation and coalescence processes that drive massive molecular cloud, and ultimately, massive star formation. Details of such interactions remain to be evaluated.

1.3 Does clustering modify galaxy formation or evolution? The efficiency at which gas is converted into stars is an essential ingredient in galaxy formation schemes. One pertinent piece of circumstantial evidence is that ellipticals, which are predominantly in dense regions, underwent highly efficient star formation, having formed their stars within 10^9 yr, whereas disks, in regions of relatively low density, formed stars inefficiently and at a lower rate. This suggests that tidal interactions or mergers between galaxies as groups and cluster underwent their initial collapse may have triggered a higher star formation rate, and correspondingly greater efficiency per unit time of converting gas into stars. IRAS observations, which show that a substantial fraction of starburst galaxies have close interacting companions, lend some support to this idea. However many apparently isolated systems are also undergoing starbursts: infall might explain this. The starburst galaxies in distant clusters may be stimulated by ram pressure of cluster gas, but galaxy interactions over a cluster crossing time ($\sim 10^9$ yr) cannot be ruled out.

The cold dark matter theory provides a scenario wherein dwarf galaxies formed at high redshift ($z \sim 10$), and ejected substantial amounts of enriched gas into the intergalactic medium, driven by the winds that are unavoidable in such shallow potential wells. When galaxy groups form, at low redshift, the intergalactic gas is compressed and, especially if some heavy elements are present, cools and can be accreted by some of the numerous dwarf galaxies that formed at high redshift. This would provide a mechanism for occasionally forming apparently young galaxies (e.g. IZw18, Mk36). Theories in which massive ellipticals formed at high redshift ($z \sim 10$), such as the explosion scenario, might also have recourse to gas infall. This provides a means of fueling a delayed starburst: again, this is possible only much later at $z \sim 1$, when galaxy clustering has developed.

There follows a list of questions to which our audience reacted vigorously. Unfortunately, there appeared to be about as many different responses as there were astrophysicists involved in studying these issues. This lack of convergence convinced us that we would be foolhardy to do more than list the questions that were posed.

2. What is relation of QSOs to galaxy formation?

2.1 When did QSOs form?

2.2 What is responsible for QSO turn–on? turn–off?

2.3 Can radio jets trigger galaxy formation?

2.4 Did galaxies form explosively?

3. What is relation of QSO absorption lines to galaxy formation?

3.1 What is origin of Lyman alpha forest? metal–line systems? damped Lyman alpha systems?

3.2 What ionizes the IGM? and when?