EVOLVING QUESTIONS ABOUT GALAXIES

Are the ways galaxies change as they age dominated by environmental factors, inborn characteristics or a combination?

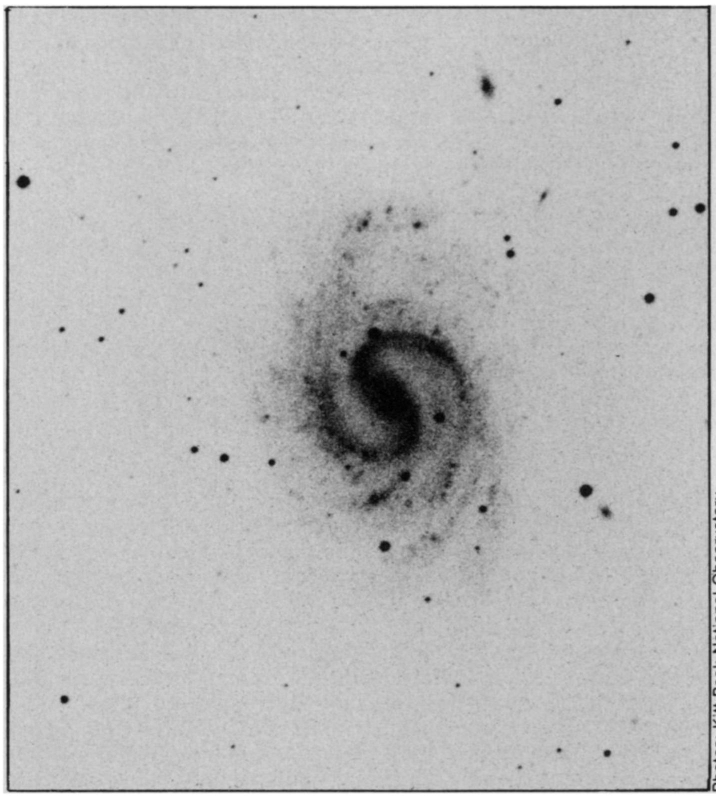
BY DIETRICK E. THOMSEN

Nature or nurture is an old question in human psychology. How much of what a human being is is determined at birth and how much is due to environmental influences? Since some modern psychologists appear to rule out any effects of conscious choices on the part of the individual concerned, the analogy can be drawn to the physics of galaxies, even though galaxies are not conscious beings.

Galaxies develop and change over billions of years, presumably according to the laws of physics and not according to any conscious choices of their own. How much of this development proceeds from causes present in the galaxies at the moment they are formed—programmed in from the beginning—and how much is caused by factors in the environment they inhabit—such things as the presence of intergalactic gas or whether or not a given galaxy is a member of a cluster of galaxies?

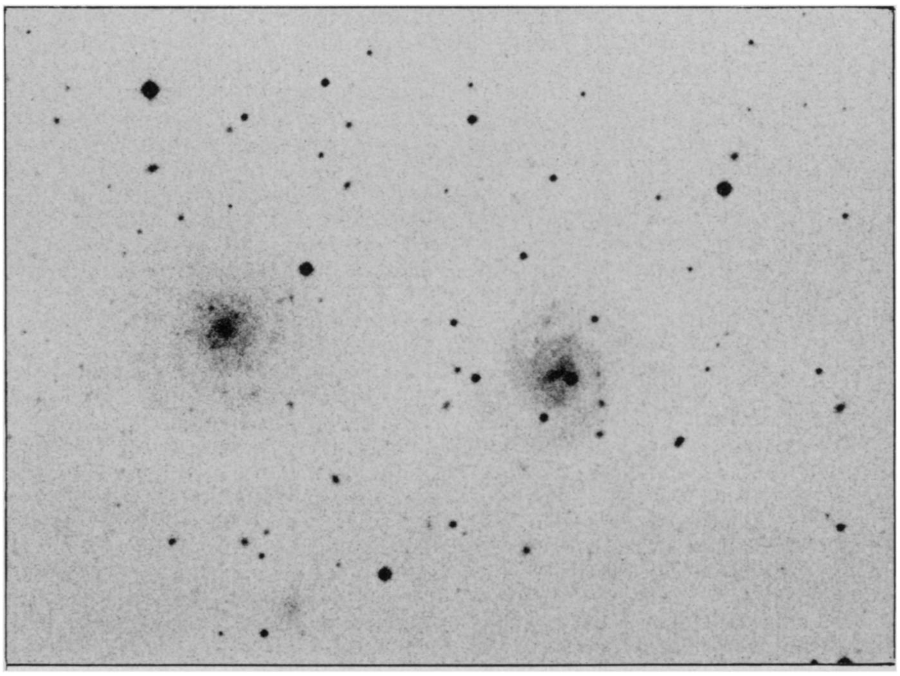
Observation so far appears to show that environmental factors definitely influence the development of a galaxy, but such factors may not tell the whole story. Continuing study raises the basic question again and again in respect to different details. For example, galaxies differ according to whether they are in the middle or on the edge of a cluster. Should this be interpreted to mean that they somehow "know" where they will eventually reside at the moment when they are formed (it is not clear at the moment whether galactic clusters came first or developed as later associations of already formed galaxies), or that the difference in environment leads to the difference in appearance? An astronomer who has been heavily involved in the study of galactic evolution, S. E. Strom of Kitt Peak National Observatory, sums up the present situation by saying, "We are really in a time of ferment."

One thing that is coming out of the ferment is a feeling that different galaxies have different histories. "Are we really sure they form the same way in different parts of the universe?" Strom asks. At



The arms of a spiral galaxy are believed to represent a standing wave pattern. Most star formation takes place in them. This is NGC 4535.

Photos: Kitt Peak National Observatory



Spirals with low surface brightness may be younger than brighter ones. NGC 4411 (a & b).

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the moment we're not even sure they all formed at the same time. The work of Strom and his collaborators yields evidence that can be interpreted to mean that different galaxies formed at different times and that formation of new galaxies may even be possible at this late date in the history of the universe.

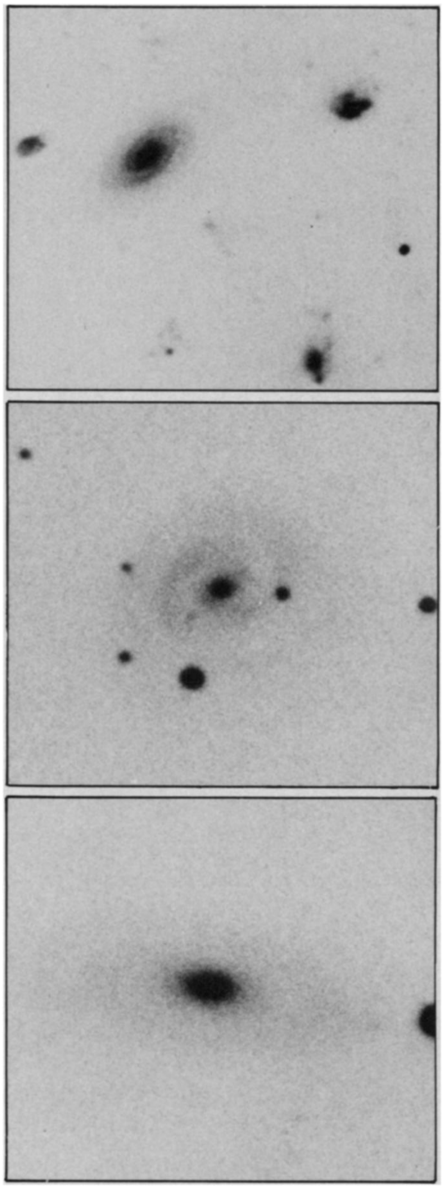
Such a notion goes against the grain of classical thinking. The common theory is that galaxies all began at the same time, something like 10 billion years ago, and they all have been running along more or less parallel tracks since then. The epoch of galaxy formation is an important time in cosmological histories since it represents the first articulation of organized lumps in what was previously a universe evenly spread with matter. Now it appears that some galaxies at least may be younger than 10 billion years, and younger by different amounts.

The major vehicle for the study of galactic evolution and how environment may or may not affect it is gas, the gas within a given galaxy and the gas in the space surrounding it, particularly the intergalactic gas in galaxy clusters. The presence or absence of such gas and its chemical composition are the most important data.

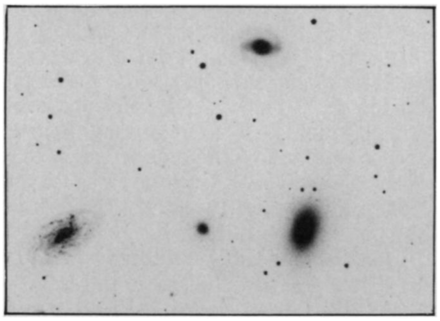
In the beginning all gas was hydrogen. Supposedly, galaxies began as condensations of neutral hydrogen. The neutral hydrogen, formed in the early history of the universe (along with some deuterium), served as the raw material for the formation of the first generation of stars. The nuclear fusion processes in these stars formed heavy elements, and through stellar winds and stellar explosions the galactic gas, and possibly also the intergalactic gas, is gradually enriched in heavy elements. So the concentration of heavy elements in a galaxy's gas, especially metals, can be a clue to its evolutionary stage.

Stars of the second and later generations are enriched in heavy elements from the beginning, and this can distinguish them from first generation stars. When a galaxy uses up its gas or when the gas is driven out of it, star formation ceases. The galaxy, which up until then has been a spiral, gradually loses its arm pattern and evolves to a featureless disk.

Clearly, the sweeping of gas from a galaxy, which can be done by a shock wave formed as the galaxy moves through the intergalactic medium, is an important environmental effect on evolution. To see whether the theory can be made to fit the facts, Strom and collaborators studied intermediate cases—25 galaxies that, by their appearance, should have been just recently stripped of their gas. These are smooth-armed spirals, some of which show weak arm patterns. If the evolutionary scheme is correctly deduced, the ones with the weak arm patterns should be more evolved (closer to featureless disks) than the strong arm ones. The spectrographic evidence fits the hypothesis: The strong arm galaxies are bluer than the weak arm



A sequence of smooth arm spirals that shows decreasing strength of arm pattern: NGC 3860, NGC 1268, IC 2951.



A single sky field may contain several galaxies of different classes and brightness.

ones. The processes of stellar development and metal enrichment should make a galaxy get redder as it evolves. Furthermore, there appear to be wisps of matter in the intergalactic space near some of these galaxies, wisps that appear to be gas driven from the nearby galaxies and in which stars are forming. Strom would like to study these wisps spectrographically to see whether they show the velocities that would be correct for matter driven out of the galaxies they are suspected of coming from.

But there are situations that cannot be explained so easily on the basis of environmental influences alone. Take a collection of spiral galaxies with appreciably lower surface brightness than usual for spirals. Low surface brightness implies fewer stars. Does the presence of fewer stars mean that these galaxies have been making stars for the same ten billion years as all others only at a slower rate, or does it mean that star formation began later?

Examination shows that the low surface brightness galaxies have several times the hydrogen content of brighter ones, which is consistent with the formation of fewer stars. They also turn out to be bluer. This means they are dominated by first-generation stars, and that would imply that star formation began later. Of course they could just have been sitting there for billions of years waiting for star formation to begin. An important question is whether these low surface brightness galaxies are surrounded by clouds of hydrogen. Strom and his co-workers are going to to the National Radio Astronomy Observatory to try to find out. (Neutral hydrogen is detectable only by radio.) If they find such clouds, says Strom, it will be hard to defend the older ideas that all galaxies were born ten billion years ago.

Or take the case of the disk galaxies in the middle of clusters versus those on the edges of clusters. Evidence from the Coma cluster and the Hercules cluster shows that the disks in the outer parts of clusters are generally larger than those in the middle. A larger disk implies more stars. Why? Did star formation in the bigger disks go on longer? Are the bigger disks surrounded by clouds of gas that is undisturbed by the intergalactic medium for some reason? Maybe star formation really is triggered in different galaxies at different times. We do not know enough about the triggering mechanism to tell, Strom says.

Still more curious is the consistency of the size difference between inner and outer galaxies. Galaxies don't start out knowing whether they are going to wind up in the centers or on the edges of clusters, says Strom. Or do they? Some astronomers, notably Jeremiah Ostriker of Princeton University, would insist that the difference is environmental: The smaller disks were stripped of raw material for star formation sooner than the larger disks. But to sustain that argument, says Strom, we have to learn a good deal more about the dynamical history of the clusters, how and through what sort of intergalactic matter the galaxies have moved. On the other hand, the difference may go back to something programmed into the galaxies at their formation. "If I were going to stick my neck out," says Strom, "I might say the galaxies do know." □