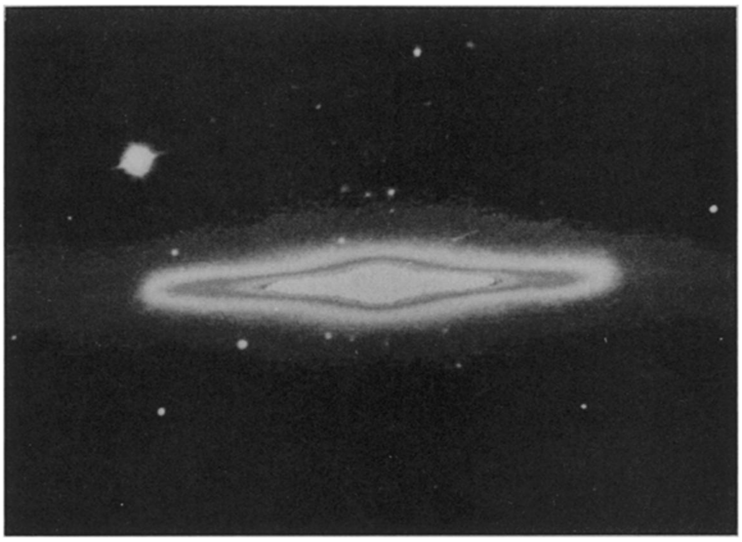
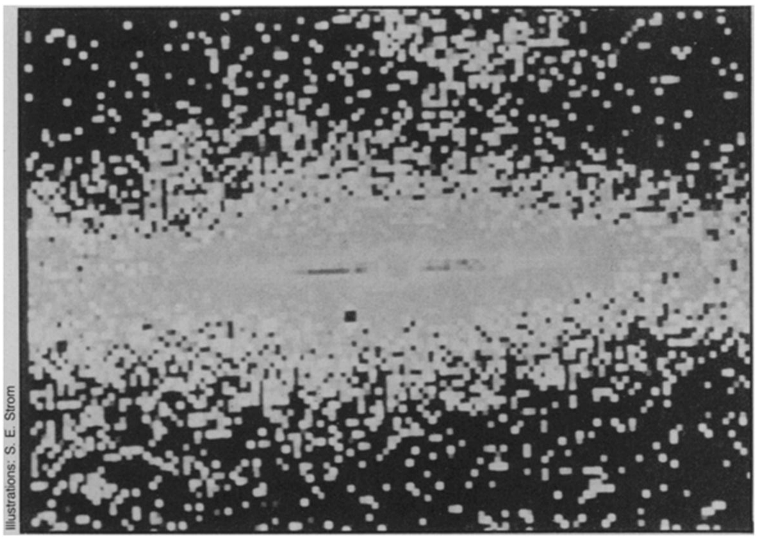
Astration and Galactic Evolution

Star formation may be the key to the progress of galactic evolution

BY DIETRICK E. THOMSEN



Brightness distribution of a representative galaxy. The lightest regions are those where new stars are forming in large numbers. Young galaxies are expected to be especially active in star formation.



Illustrations: S. E. Strom

Distribution of the metal/hydrogen ratio over the same galaxy. Regions showing the highest metal ratios correspond to the bright regions of star formation in the previous picture.

It is the common belief of cosmologists and astrophysicists that galaxies evolve. It may seem obvious, but because there may still be believers in a static universe around, it is worth pointing out the grounds for such a belief. One rests on the modern cosmological theory called big bang. This posits a time when galaxies were not. We live now in a time when galaxies are, so obviously they must have formed in time. Furthermore, the galaxies we see present an array of different shapes that tempt astronomers to arrange them in an evolutionary sequence. Finally there is the basic axiom of physics that we live in a world of constant flux.

So even though we cannot watch a galaxy evolve the way we can watch a flower grow, the operative question is not whether galaxies evolve, but how. How they form and how they change is one of the primary questions in astrophysics. To quote the first sentence from a yet unpublished paper by Karen M. Strom, Steven E. Strom, E. B. Jensen, J. Moller and L. A. Thompson of Kitt Peak National Observatory and Trinh X. Thuan of the Hale Observatories: "The synthesis from observation of plausible models of galaxy formation is one of the more challenging problems in modern astronomy." At the moment theorists have put forward three somewhat different theories of how galaxies become what they are, and the task of observers is to see whether observation can provide evidence to distinguish the most plausible among them. Crucial data for the point are the distribution of brightness through a given galaxy under observation and the chemistry of the galaxy, the amount and distribution of metals in it. The metallic distribution is related to the formation of new stars and thus is connected to the question whether or not new stars are forming in galaxies of a given class, an important point in evolutionary theories.

The three theories in question in the observational work of the Stroms and their collaborators concern specifically the formation of elliptical galaxies. Ellipticals are among the simplest galactic shapes and are believed by most astrophysicists to be the earliest or one of the earliest stages in the evolutionary sequence.

One theory, which has been elaborated by Robert F. Dicke, P. J. E. Peebles and J. Richard Gott III, proposes that globular clusters of stars (which do seem to contain some of the oldest stars observable) were first to form out of the pregalaxian universe and that such clusters fell together into elliptically shaped, gravitationally bound aggregates. The second theory, due to R. B. Larson, says that ellipticals formed from the collapse of a protogalactic cloud of matter without the previous articulation of globular star clusters. The third proposal is Alar Toomre's and holds that ellipticals are formed in collisions of two galaxies of another kind, two spirals. Probably none of these is absolutely correct, Steve Strom says, but they give a means to begin thinking about how such things happened.

An important distinction from the observational point of view is that one theory, Larson's, has specific things to say about the process of star formation and chemical development of the elliptical galaxy as it forms. In this picture, as the protogalactic gas falls together, new stars are formed. The nuclear-fusion processes that go on in such stars produce metallic elements, and some of these are thrown off so that the infalling gas is continually enriched in metals. This means that there should be a correlation between regions where new stars are forming and areas that are enriched in metals. So the areas of the galaxy that appear brightest (because of a high density of new stars) should also show the highest ratio of metal to hydrogen (hydrogen being what the pregalactic cloud is mostly made of).

The relationship between brightness and metal distribution is something that observation can hope to check. Since the other two theories have nothing to say about the relation of brightness to metal distribution, finding the relation proposed by Larson would be a support for his theory and, by inference, a point possibly against the others.

The Stroms and collaborators have examined 40 galaxies in the cluster found in the constellation Virgo looking for this relationship. The technique is to examine the galaxies in three colors of light, ultraviolet, violet and red. By combining violet and red images the observers can effectively identify the regions containing the kind of stars that produce the metals. By combining the ultraviolet and violet, they believe they can measure the variation of the metal-to-hydrogen ratio over the face of the galaxy. If Larson is right, the two should match, more or less.

Such a survey, requiring two-dimensional images of a number of galaxies and the comparison of different colored images to produce isophotic plots (for brightness distribution) and isochromic plots (for metal-to-hydrogen ratio) is not a light undertaking. A few years ago it might not have been undertaken at all since it depends heavily on the latest electronic aides to astronomical observation, image intensifiers to amplify faint images and computers, especially Kitt Peak's Interactive Picture Processing System to reduce the data and form the images.

No longer does the astronomer always need to sit with his eyeball frozen to the eyepiece of the telescope and manipulate a camera attached to its focus. Steve Strom sits at a console that looks like a typewriter surmounted by a television screen and types instructions to the computer. What the telescope is doing, under instructions from the computer, is making a series of one-dimensional scans across the face of a galaxy, gradually rotating the scan so as to build up the necessary data points for a two-dimensional image. Each individual scan must be done a large number of times. The procedure of the image intensifier is to build up an image by adding together successive scans so as to cancel out background noise and enhance the appearance of the desired object.

The computer carries all these things in its memory. Strom instructs it to show the result of the first scan along a particular diameter of the given galaxy. The screen pops up with a graph full of noise peaks. Then he asks it to show the results of successive additions, and finally after 32 additions, a virtually noiseless plot with the galaxy showing up sharply in the middle is produced.

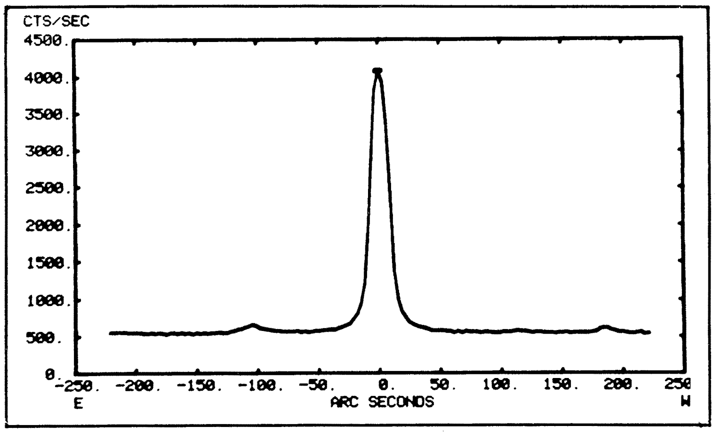


Illustration: S. E. Strom

An astronomical revolution that looks unobtrusive: Computer printout of the sum of 32 scans across a galaxy. Graph is brightness (photon counts) versus angular distance from center of the galaxy.

The data thus derived are fed to the picture processor, which builds up two-dimensional images for each of the colors used (which are determined by filters placed in the telescope) and does the necessary adding and subtracting of the images. One can then take photographs of the images made by the picture processor, and—*voilà*—one is on the way to comparing theory and observation.

To make a long and painstaking story short, the results come out much as the Larson theory would have them—collapse of a protogalactic cloud directly into an elliptical-shaped galaxy. And that leads the Stroms and collaborators to further questions of galactic evolution. Steve Strom describes one of them as a problem of "heredity versus environment. It's kind of a gamble," he says, "and it may not work."

The starting point is that galaxies come in clusters. The clusters fall into several categories, but for the purpose at hand two general ones suffice: those that are rich in spirals, where disk-shaped galaxies are dominated by spirals that are actively forming stars, and spiral-poor clusters, dominated by systems that are not actively forming stars. (The supposed evolutionary progress is elliptical to spiral to disk.) Is the difference in formation due to a difference in the rate of galactic evolution? Do some galaxies go through the various stages and end new star formation sooner than others because of some factor inherent in them from birth. Is the difference in the two classes of clusters due to an effect of the environment in which a particular cluster finds itself?

Recent X-ray observations give a clue that may indicate environment is the reason. The X-rays show hot matter in the intergalactic space of some clusters. It happens that the same clusters are spiral poor. "[James E.] Gunn and Gott worked out what's happened," Strom says. The galaxies move around in the clusters, and the momentum of the disks as they move through the intergalactic medium that shows up in the X-ray observations created a ram pressure that drove the interstellar gas, the hydrogen out of which new stars form, out of the disks. If that happens early, stellar evolution of the galaxy ceases and so does chemical evolution. The galaxy is prematurely aged.

What the Stroms and their collaborators hope to do is to use the observing technique they have developed to study disks in both spiral-rich and spiral-poor clusters. They will be looking for metal-poor disks in spiral-poor clusters (indicating an early end to evolutionary progress) and metal-rich disks in spiral-rich clusters (indicating continuing evolution). "It should be easy to see a dramatic difference," Steve Strom says.

Another possibility to which they want to apply the technique is to study changes in the kinds of stars formed in galaxies, the ratio of stars of low mass to those of high mass, the chemical evolution being mostly related to the formation of high-mass stars. They want to search for systems in which chemical evolution was truncated. If it happened early, it may provide a snapshot of how disk systems evolve. "Current wisdom has it that disks finished star formation early on," he points out. "I'm not convinced." Galaxies with low surface brightness may still be forming stars, he suggests, but not in large enough numbers to look bright. Or, in other words, in certain galaxies something—its nature is yet to be found out—has retarded star formation, but not stopped it completely. Some galaxies may take a long time to form a large fraction of their stars, he says.

All in all, it's a large observational scheme. If the technique of comparing brightness and color distribution works throughout as well as hoped, it may provide a thread on which to hang details of a theory of galactic evolution from the gassy chaos of the pregalactic universe through ellipticals and spirals to disks. And it may show how details of star formation ("astration" to use the newly coined word) and chemical changes affect progress along the line. □