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Automata Network Models of Galaxy Evolution

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Two ideas appear frequently in theories of star formation and galaxy evolution: 1. Star formation is nonlocally excitatory, stimulating star formation in neighboring regions by propagation of a dense fragmenting shell or the compression of preexisting clouds, and 2. star formation is nonlocally inhibitory, making HII regions and explosions which can create low-density and/or high temperature regions and increase the macroscopic velocity dispersion of the cloudy gas. Since it is not possible, given the present state of hydrodynamic modeling, to estimate whether one of these effects greatly dominates the other, it is of interest to investigate the predicted spatial pattern of star formation and its temporal behavior in simple models which incorporate both effects in a controlled manner. The present work presents preliminary results of such a study which is based on lattice galaxy models with various types of nonlocal inhibitory and excitatory couplings of the local SFR to the gas density, temperature, and velocity field meant to model a number of theoretical suggestions. These models can be viewed as the descendants of the nearest neighbor excitation/local inhibition cellular automata of Gerola and Seiden. These models are also closely related to discrete models for complex systems as embodied by nonlocal cellular automata, coupled map lattices, and artificial neural networks, all of which are known to exhibit a rich array of phenomena. We are particularly interested in relating our models to the behavior of these relatively well-studied systems, especially with respect to their propensities to exhibit phase transition phenomena and more complex "computational" or "cognitive" behavior (e.g. categorization of a continuous range of environmental stimuli).

The present models evolve on a 2-dimensional square lattice with a constant configuration (i.e. no differential rotation, contraction, etc.). There are no external perturbations; the model is driven entirely by its own internal state. The SFR is controlled by the velocity dispersion, or 'temperature', of the gas. Star formation becomes much more probable at a given site when the 'temperature' falls below a critical threshold value, which is a parameter, but star formation itself inhibits further star formation in some neighborhood by increasing the 'temperature'. Lattice sites just outside the inhibitory zone around each star are assumed to form a ring of excitation, meant to represent a fragmenting shell which has propagated from the central star. The excitation is performed by simply decreasing the 'temperature' in the ring. Every site's 'temperature' is assumed to cool exponentially with a time constant that is another free parameter. At each site at each time step, the probability for star formation is taken to be a sigmoid function of the velocity dispersion, so that star formation becomes much more likely when the 'temperature' drops below the threshold of the sigmoid function.

The results of this study are as follows. The model exhibits a variety of oscillations, bursts, and irregular patterns in the global star formation rate. The corresponding spatial patterns are equally diverse ranging from well organized global waves to 'foamy' textures of expanding shells. Intermittent, bursty behavior occurs when the cooling time of the gas becomes greater than the propagation time across the lattice. During bursts, a single wave of star formation spreads across the lattice and then dies out. For shorter cooling times more complex behavior results in which oscillatory and irregular SFRs evolve into one another. The relative strength of the excitatory to inhibitory connections controls the geometry of the pattern of star formation. Strong excitatory connections create coherent fronts of star formation while weak ones lead to isolated star formation regions. We suggest that more detailed models can be used with maps of the spatial distribution of star formation (from Hα say) to diagnose the relative importance of inhibitory and excitatory star formation processes in galaxy evolution.

In the future we plan to include the gas density, differential galactic rotation, different connection geometries, and nonperiodic boundary conditions. We will also study the spatio-temporal patterns of star formation more quantitatively using methods drawn from nonlinear dynamics and complex systems.