Spiral structure in galaxies: a density wave theory based on global modes

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In the 1960s the pioneering work by C.C. Lin and Frank Shu led to the proposal that large-scale spiral patterns in galaxies are associated with density waves, which was followed by a number of successful observational tests; this proposal was based on the working hypothesis that grand-design spiral structure is quasi-stationary. In the 1970s the theory gradually developed in the direction of a coherent dynamical framework based on global modes, coexisting with other small-scale, time-evolving spiral features. Accordingly, galaxy disks are characterized by few, discrete, self-excited global spiral modes, much like the internal "notes" of some pulsating stars. The location of the relevant corotation radii and the morphology of the modes reflect the structural properties of the basic state. In particular, the stars, the interstellar medium, the three-dimensional structure of the system, and the distribution of dark matter in the halo are all important factors that cooperate in various ways, giving rise to the diverse morphologies that are observed. Two important points emerged from the studies of the 1980s, at variance with the picture proposed initially. On the one hand, it was realized that for unbarred structures to be long-lasting in relatively light disks, the cold interstellar medium should not only respond passively to the spiral potential, by giving rise to large-scale shocks (so that newly born stars and HII regions trace the potential minima much like whitecaps trace the crests of ocean waves), but should also play an active role, by guaranteeing the existence of a sufficiently cool, self-regulated state. Yet the interstellar medium alone would be prone to small-scale spiral activity and multi-armed structure, so that the ubiquity of regular spiral patterns with a small number of arms can only be guaranteed by the backbone role of the stellar disk (and the related damping effects at the inner Lindblad resonance), the dynamics of which should be well coupled with that of the gas. On the other hand, it was realized that barred spiral structure can also be interpreted in terms of global modes: in relatively heavy disks, the morphology of the dominant modes is characterized by barred structure and the role of the interstellar medium is expected to be more passive. The key ingredients that explain the excitation of spiral modes, of both barred and unbarred types, are: (1) feedback of density waves from the central regions, so that the inner galaxy and the corotation region may form a sort of resonant cavity for density waves, and (2) amplification by overreflection of density waves at corotation, with transport of angular momentum toward the outer regions. In my presentation I will review the development, the dynamical arguments, and the main astrophysical consequences of the theory. I will then turn to what is believed to be the best modern evidence in support of the theory (in particular, some important results obtained by observing galaxies in the near infrared, starting with the 1990s). I will also describe briefly some recent results, in relation to the disk-halo decomposition of rotation curves and the evidence in favor of light disks. Finally, I will describe a natural interpretation of the often observed prominent spiral structure in the outer gaseous disks, which may offer one more quantitative way to test the modal theory.