DYNAMICS OF SPIRAL GALAXIES

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Bertinoro, May 7-12, 2006

OUTLINE

PART I – Some interesting topics in the dynamics of spiral galaxies ; morphology of spiral galaxies

PART II – Theory of spiral structure in galaxies

PART I
INTERESTING TOPICS

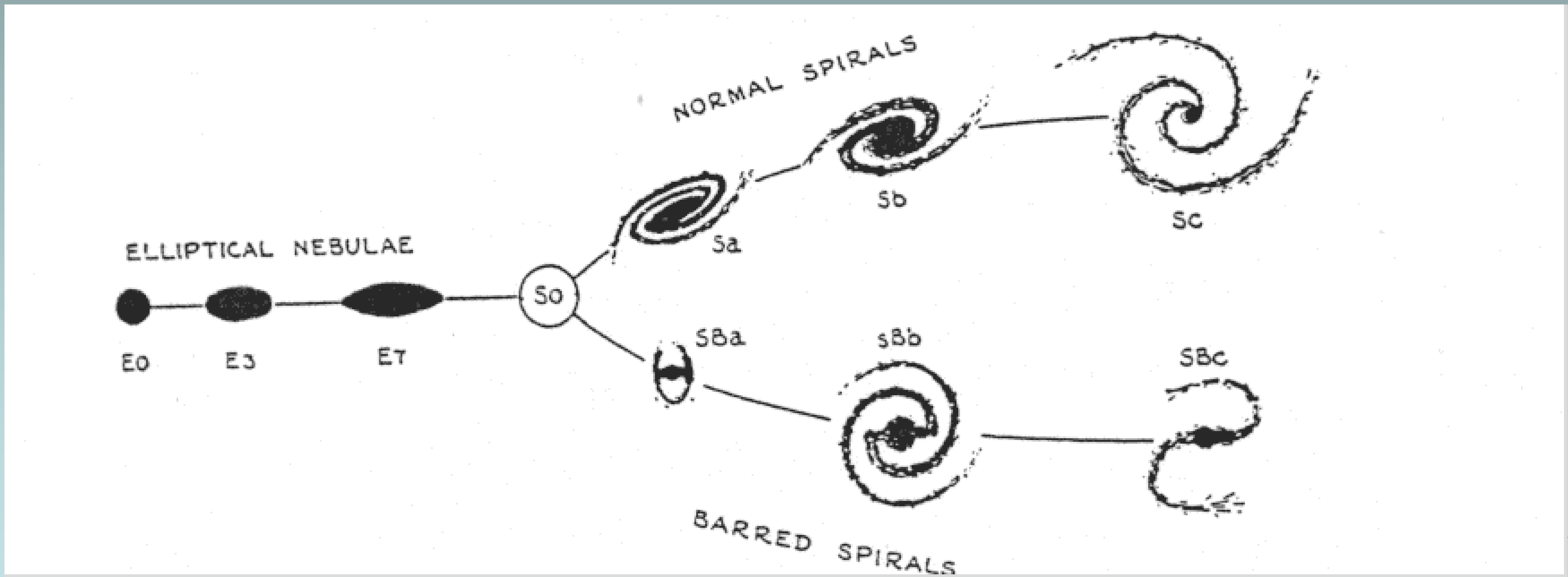
Spiral structure and bars in galaxies (density waves)
Origin of the Hubble morphological sequence

Gas and stars, HI studies
Warps, asymmetries, lopsidedness, extraplanar gas
The Milky Way Galaxy and its globular cluster system

Low surface brightness spiral galaxies
Nuclei, massive black holes, and bulges (Pellegrini)
Dark halos, lensing (Sancisi)
Tully-Fisher and other scaling laws (Verheijen)
Formation and evolution (Stiavelli)
(Stellar populations and chemical evolution)

MORPHOLOGY OF SPIRAL GALAXIES

Spiral structure and bars in galaxies
Origin of the Hubble morphological sequence?

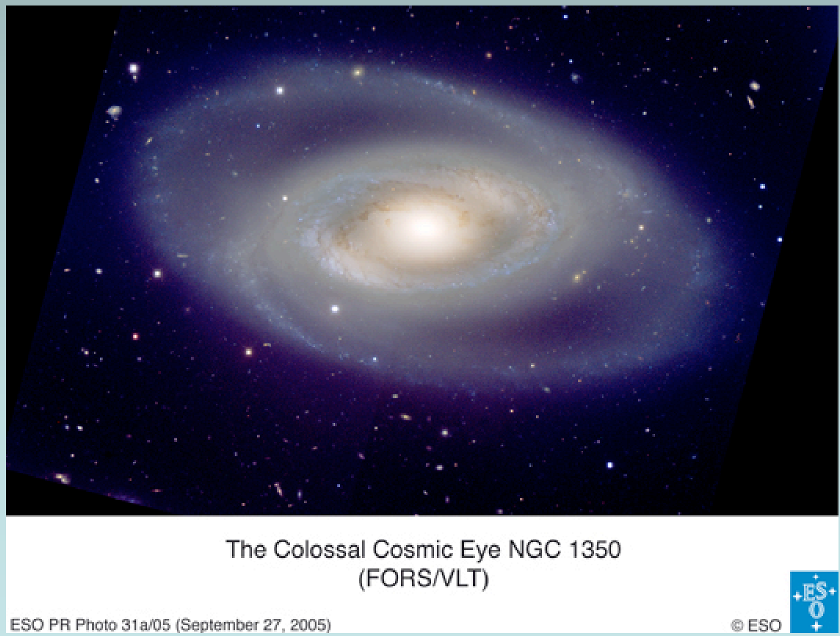


Hubble 1926


Barred Spiral Galaxy NGC 1300
Hubble Heritage


Spiral Galaxy NGC 4622
Hubble Heritage

M81 (NGC 3031)
grand design



NGC 2841
flocculent

M74
(NGC 628)
Sc

NGC 5364 Sc

NGC 2403 Sc

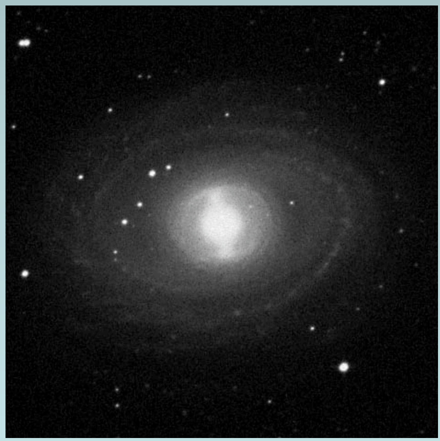
M100
(NGC 4321)
Sc

NGC 2997 Sc

NGC 309 Sc

NGC 2859 SB0

NGC 7743 SBa



NGC 1398 SBb

M83 (NGC 5236)
SBc

M51
(NGC 5194+NGC 5195)

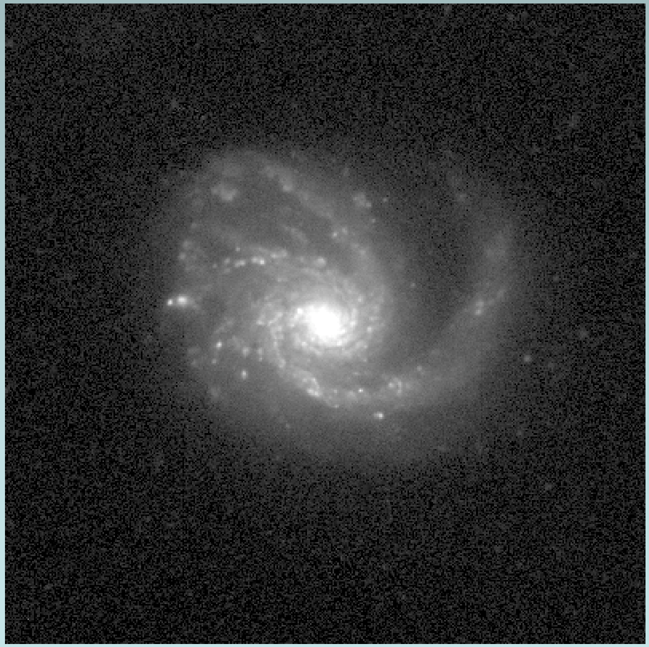
Tidal interaction?

NGC 1637 Sc

lopsidedness

M101 (NGC 5457) Sc

M99 (NGC 4254) Sc



ESO 510-G13

NGC 5907

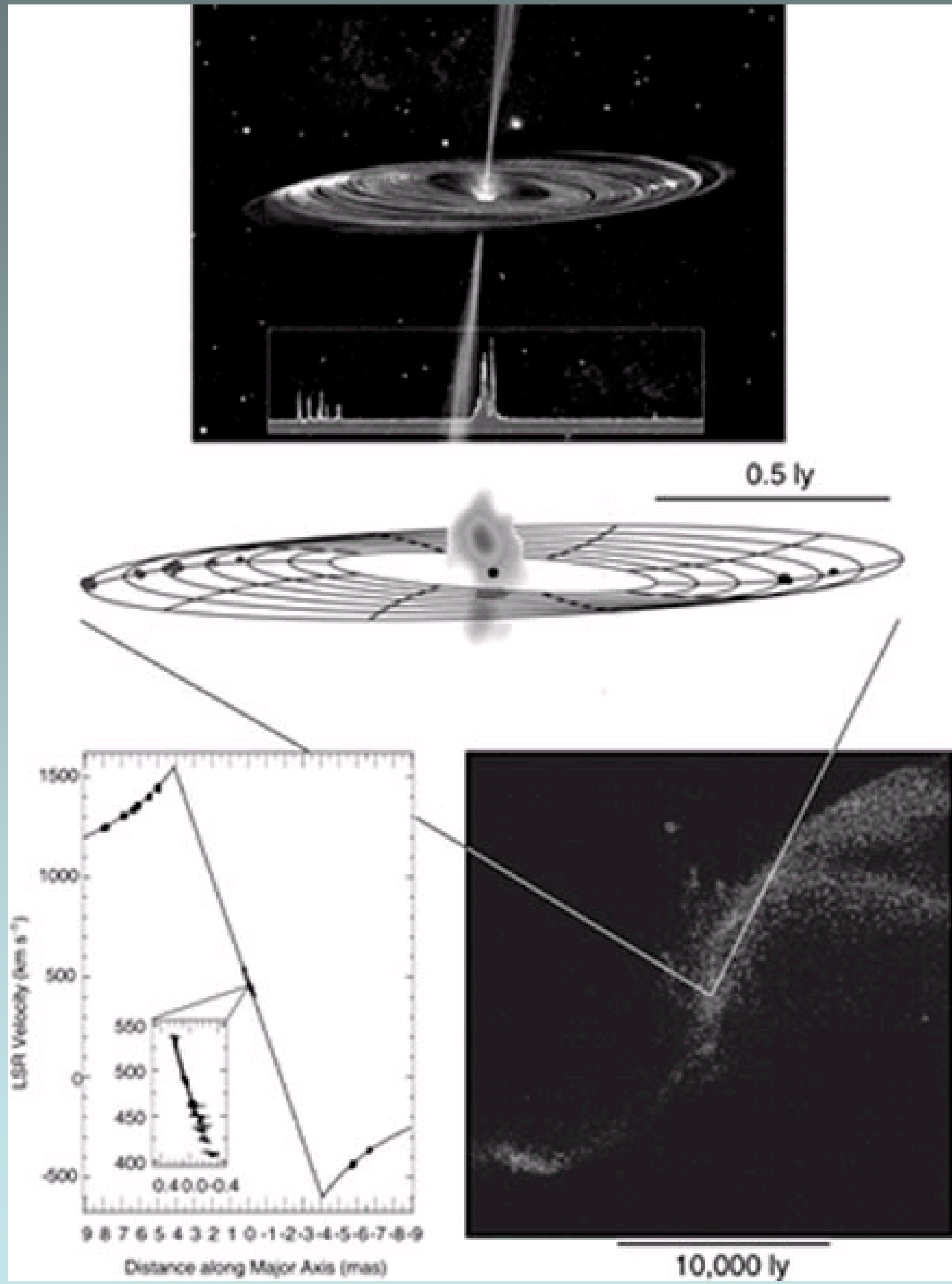
NGC 4565

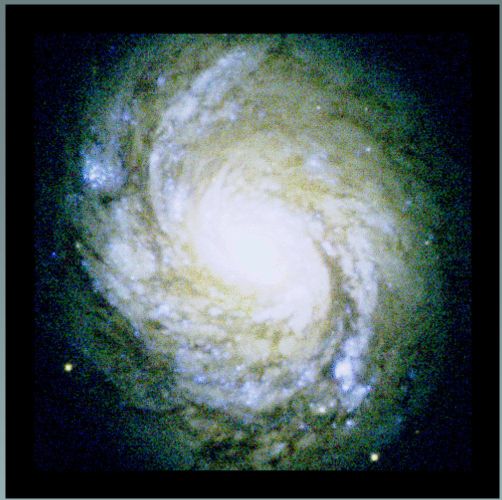
NGC 891

The nucleus of NGC 4258 (M106)

$M_{BH} = 4\ 10^7\ M_{sun}$

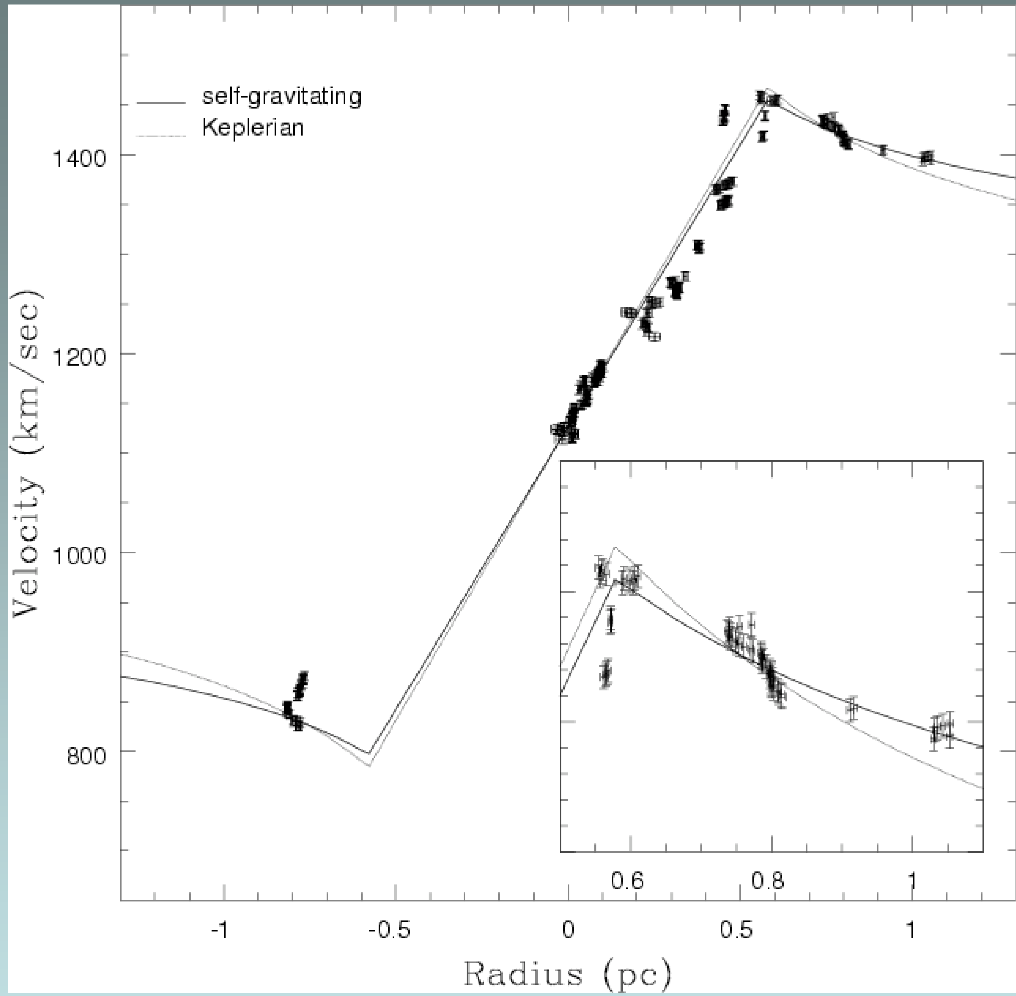
Miyoshi et al. 1995





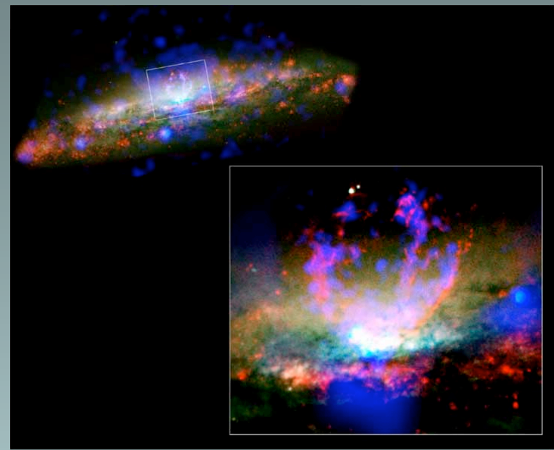
The nucleus of NGC 1068 (M77)

$M_{BH} = 8\ 10^6\ M_{sun}$



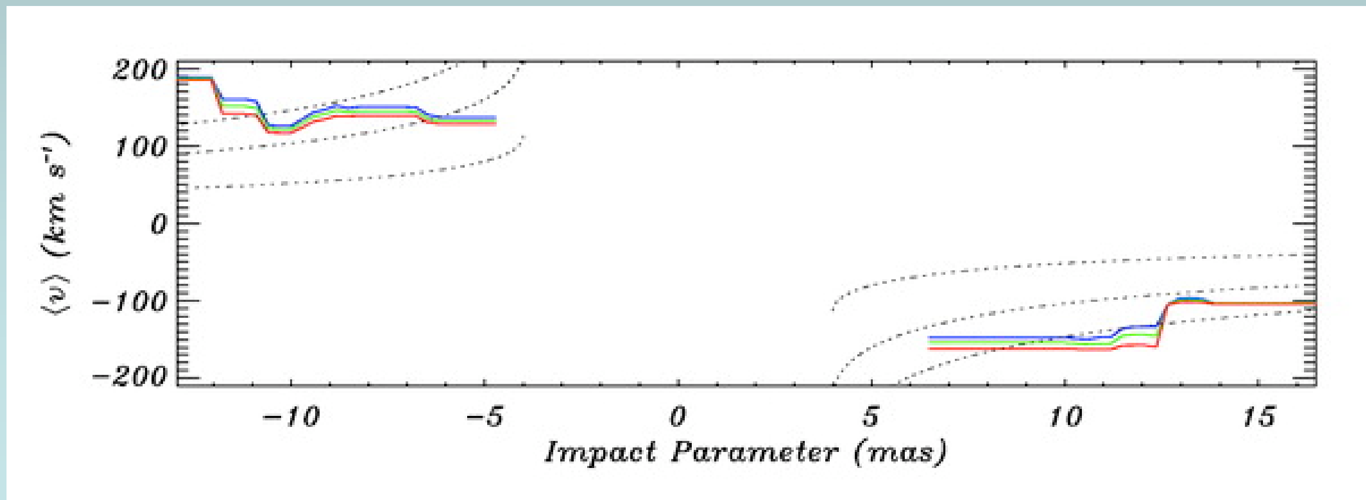
Fit to the rotation curve from the water maser emission by a self-gravitating accretion disk model. Data from Greenhill & Gwinn 1997. (Lodato & Bertin 2003)

An accretion disk with flat rotation curve: The nucleus of NGC 3079



(Kondratko, Greenhill, Moran 2005)

M_{BH} = $2\ 10^6\ M_{sun}$



4 mas = 0.34 pc

PART II – THEORY OF SPIRAL STRUCTURE

KINEMATICS, DIFFERENTIAL ROTATION, EPICYCLES

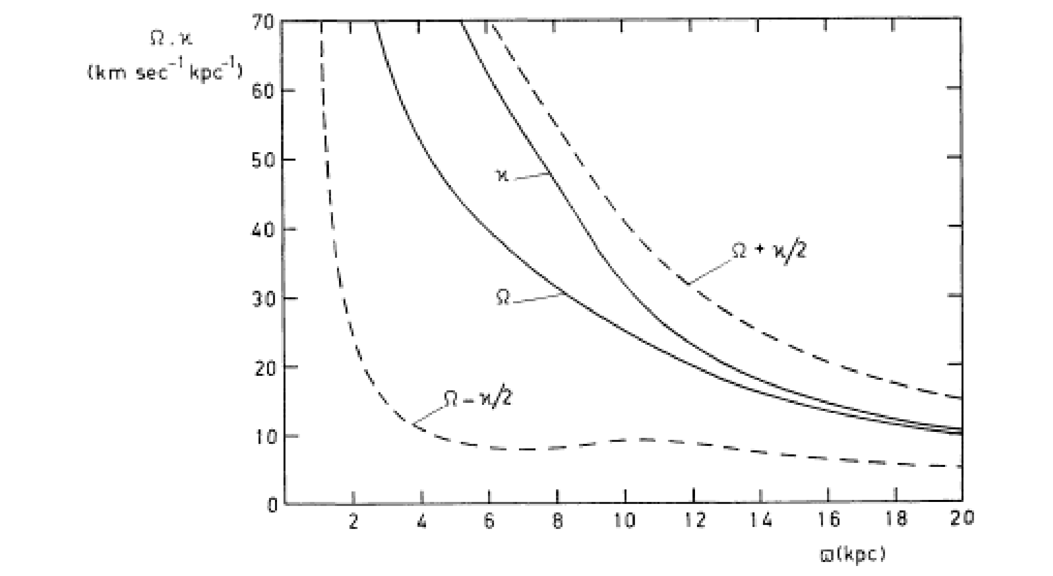
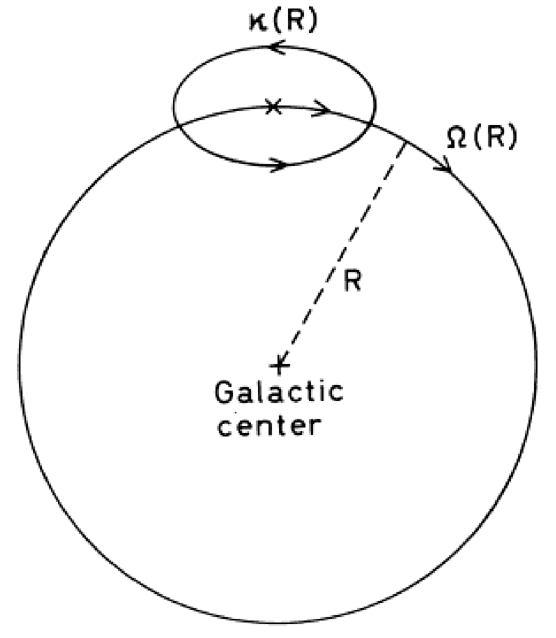


FIG. 1. Angular velocity Ω, epicyclic frequency κ, and related quantities for the 1965 Schmidt model of the Galaxy.



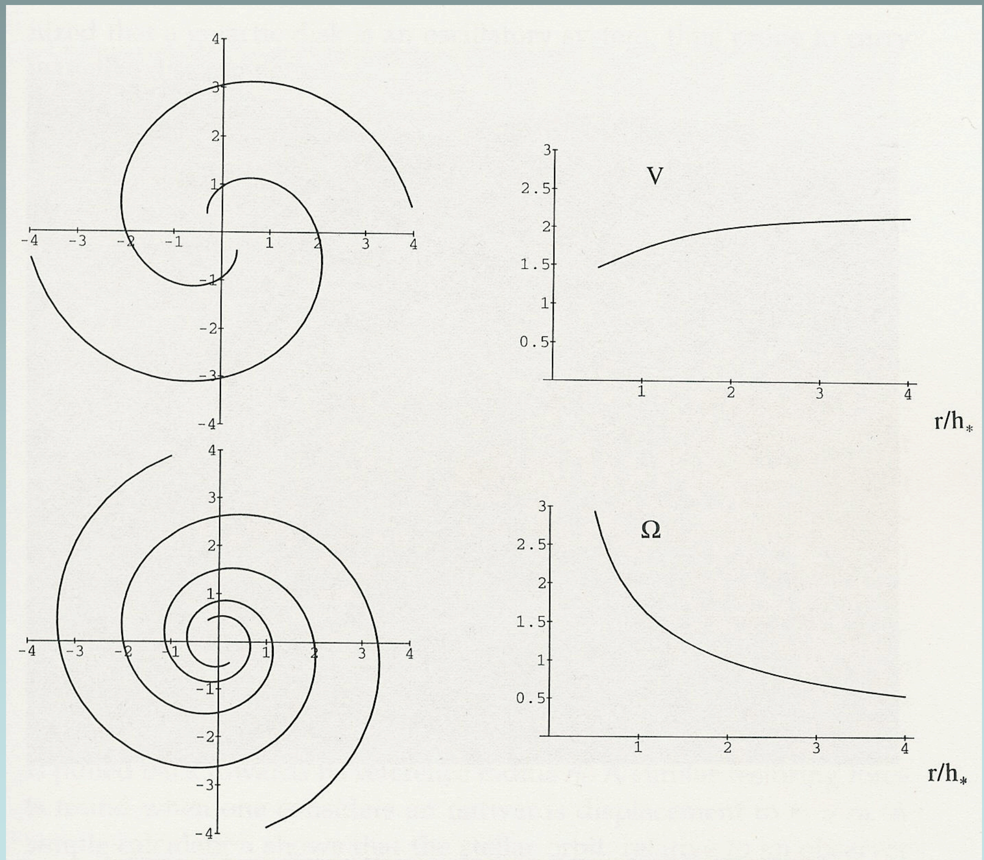
$$\kappa^2 = 4\Omega^2\left(1 + \frac{1}{2}\frac{d\ln\Omega}{d\ln r}\right); \Omega^2 = \frac{1}{r}\frac{d\Phi}{dr}$$

κ epicyclic frequency
Ω differential rotation

(note that, in the 60s, dark halos did not exist!)

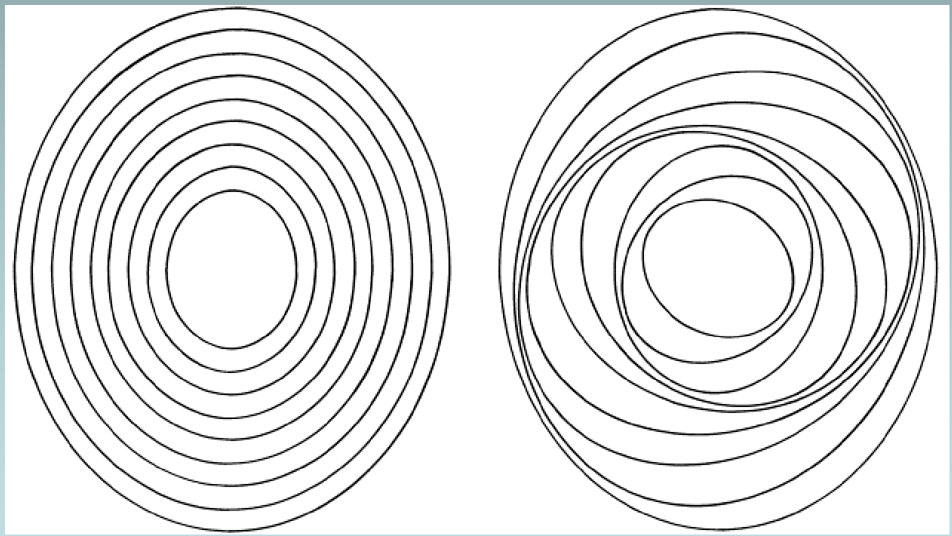
THE WINDING DILEMMA

Differential rotation would rapidly (in a couple of turns) stretch any arm into a tightly wound spiral structure:
How can we reconcile this fact with the observations of so many galaxies with open arms?



LINDBLAD'S KINEMATIC WAVES

B. Lindblad's kinematic waves: the beginning of the density wave theory



THE PROBLEM OF SPIRAL STRUCTURE (Oort, 1962)

Focus on grand design,
i.e., regular, large-scale spiral structure:

- Primarily gaseous or primarily stellar arms?

- How is spiral structure generated?
- How does it persist?

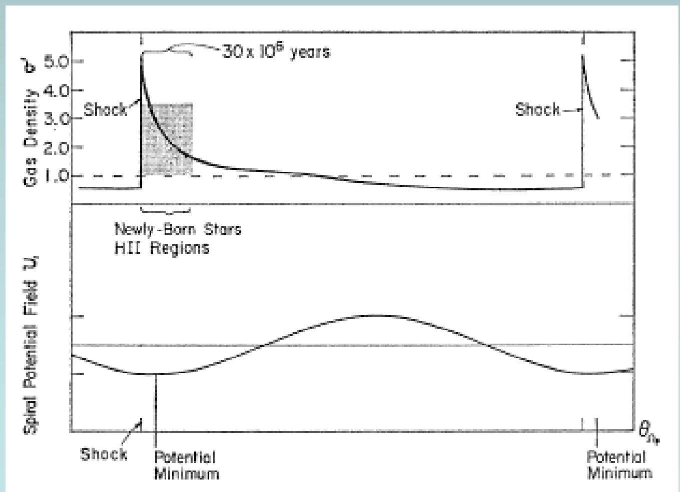
THE PROBLEM OF SPIRAL STRUCTURE

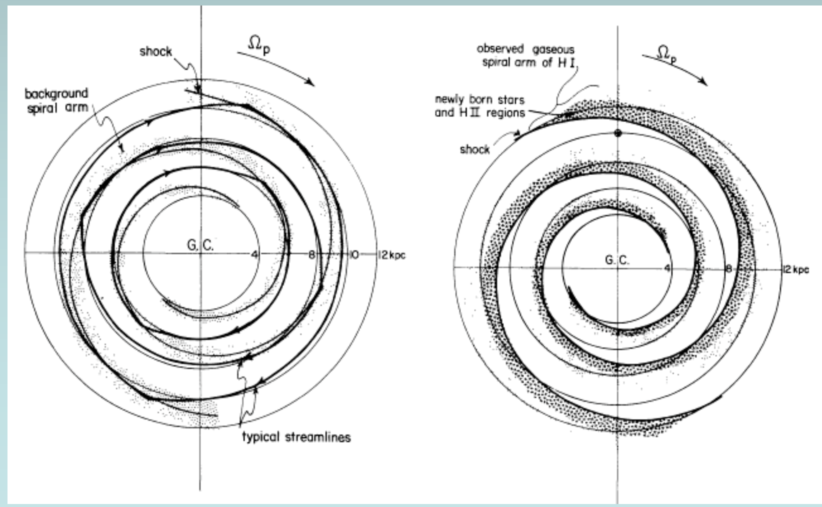
In relation to the large scale:

- **Why certain spirals are barred and others are not?**
- **How do we explain the different degrees of regularity in the observed spiral structure?**
- **How do we explain flocculent spiral structure?**
- **Why trailing structure?**
- **Why is grand-design generally two-armed?**
- **Why do we often see different coexisting morphologies?**
- **How do we explain the Hubble morphological classification?**
- **What sets the amplitude of the observed structure?**

THE SHOCK-WAVE PATTERN

Because the rotation of the disk is differential, a quasi-stationary pattern will be moving supersonically with respect to the interstellar medium over most of the galaxy disk. If its amplitude is large enough, shocks will be generated and these, in turn, will favor star formation.





W.W. Roberts 1969

Visser's study of M81

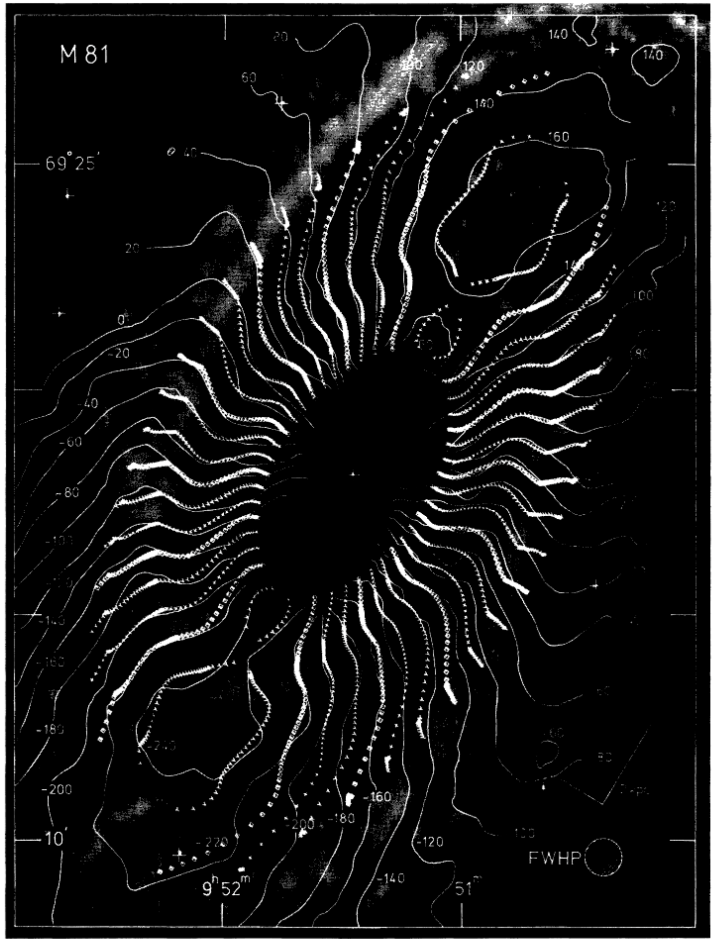
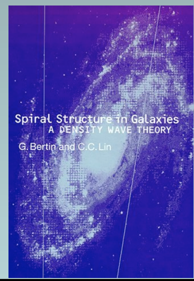


Fig. 5. The radial-velocity field of the final model (symbols) together with the observed velocity field (full and dashed lines) at an angular resolution of 50″, superimposed on a radiograph of the density distribution of the atomic hydrogen at 25″ resolution. See also the caption of Fig. 4

Visser 1980

FOUR DYNAMICAL SCENARIOS

	Quasi-stationary	Rapidly evolving
Internal origin	Discrete spectrum; one or few self-excited modes 	Continuous spectrum, regenerative spiral structure **P.O. Lindblad 1960; Goldreich & Lynden-Bell 1965**
External origin	Discrete spectrum, damped modes. Orbiting satellite?	Continuous spectrum. “One-shot” tidal interactions **A. Toomre 1980**