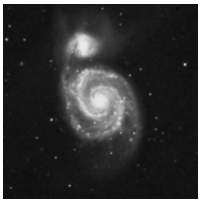
Hwk Set 3
Due Wed Sept. 30
[CO 25.13, 25.14, 25.16, 25.20]

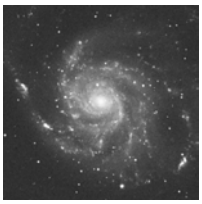
Spiral Structure

[CO 25.3]



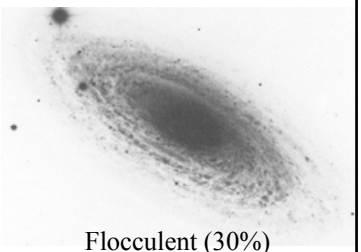
Grand design (10%)

M51



Multi-arm (60%)

M101

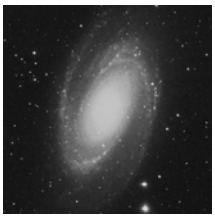


Flocculent (30%)

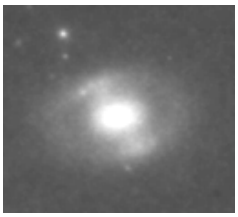
NGC 2841

Inner rings

NGC 7096



M81

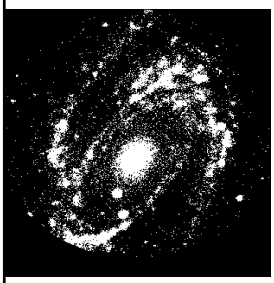


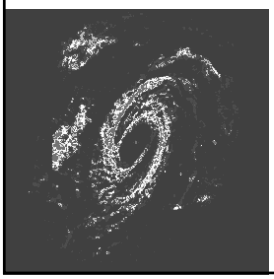
Outer Ring

NGC 4340

M81 spiral structure at different wavelengths

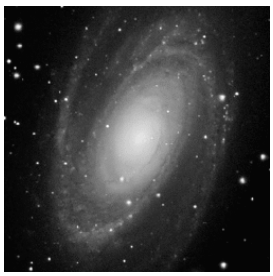
UV: hot stars





21 cm: HI

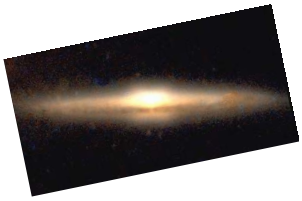
Visible: stars + obscuration

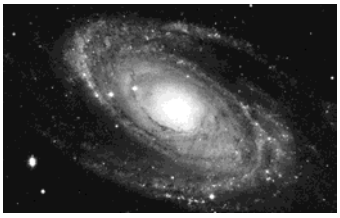


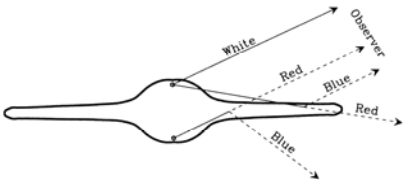
Near IR: late-type stars

Old red population shows small but real spiral density enhancement.

Trailing vs. leading spirals
Which is the near side of the galaxy?







Passage of gas through spiral arms

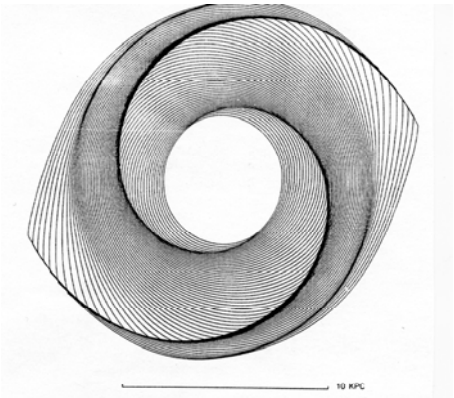
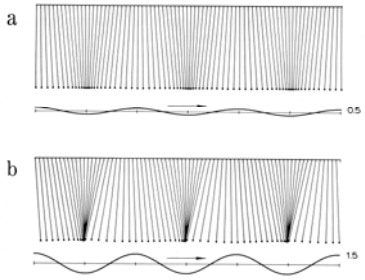


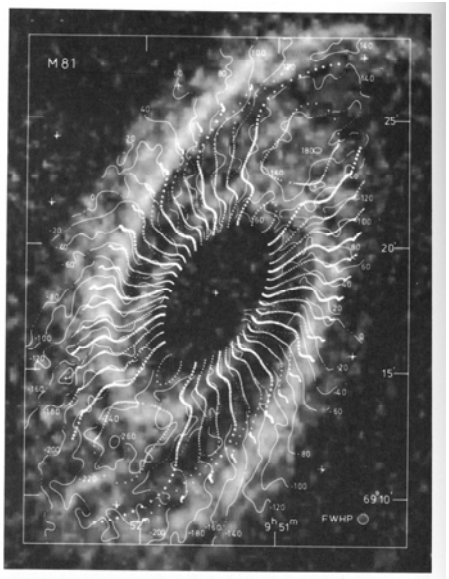
Figure 12.33. The streamlines of gas from a theoretical model of the spiral galaxy M81 (NGC3031, type Sb). (From H. Visser, *Astr. Ap.*, **88**, 1980, 159.)

Calculated streamlines for gas

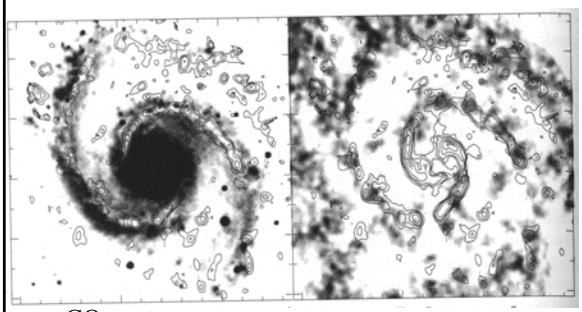
Response of gas to density waves



- Simple pendulum model
  - Each pendulum = 1 gas cloud
  - For large amplitude forcing, pendulums collide.
  - ➔ shock fronts in spiral arms
- HI map (right) shows velocity jumps at spiral arms.

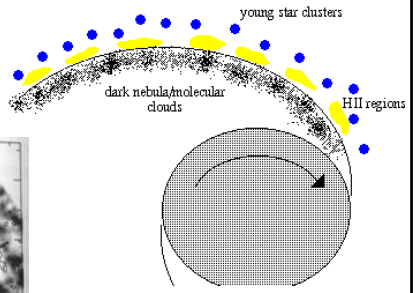


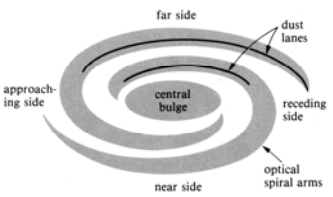
Molecular clouds on inner edges of arms



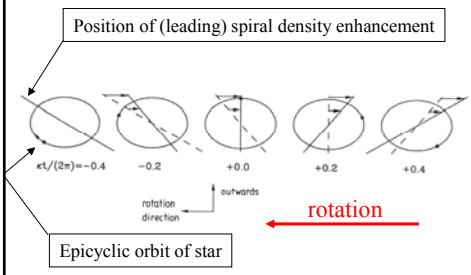
CO contours over red image

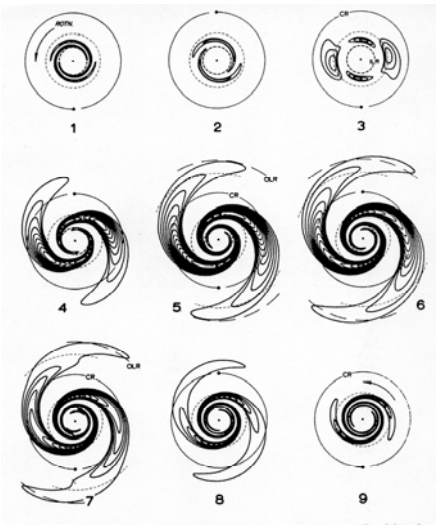
CO contours over 21 cm map





Swing Amplification

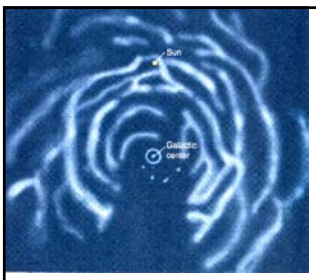




While it is swinging around, the spiral arm moves at about same angular speed as star.

Automatically converts any leading spirals into much stronger trailing spirals.

Time steps = ½ of co-rotation period at CR.

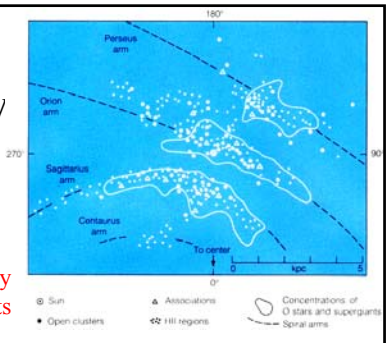


From HI (21 cm observations) assuming circular rotation.

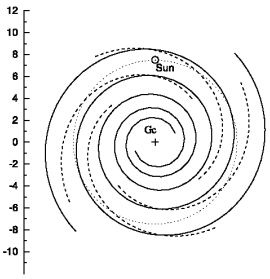
Spiral Structure of the Milky Way

Hard to measure, because we are inside it.

Map of nearby young objects



- Recent model
  - Lepine et al (2001) ApJ 546, 234.
- ➔ mix of
  - 2-armed mode
  - 4-armed mode
- Sun at ~ co-rotation radius.



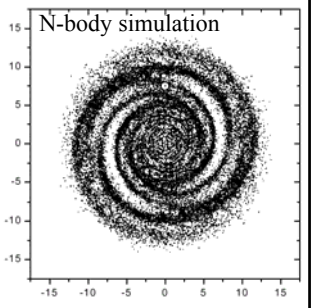
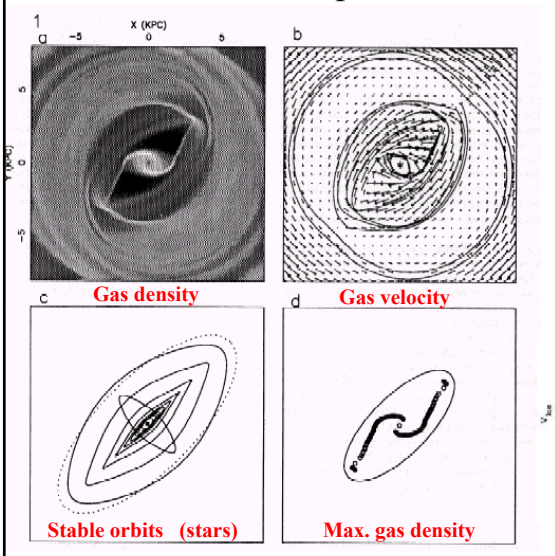
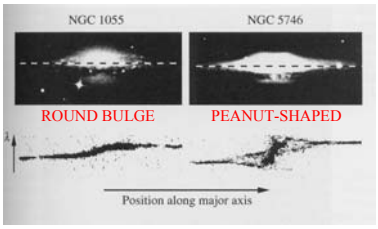


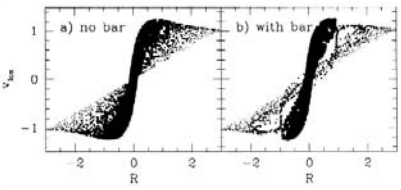
FIG. 3.—Visible structure of the Galaxy derived for the best model (superposition of 2 + 4 self-sustained wave harmonics) by means of cloud-particle simulation. The scale is indicated in kpc. Note that the model is not valid for radii smaller than about 2.5 kpc.

Orbits in Barred Spirals



Kinematics of gas, in [NII]
[BM] Fig 4.60





movie
Movie

- Gas avoids "co-rotation" radius in barred potential.
- Causes "Fig-8" shape in rotation curve.

Summary: Density Waves?

- Evidence showing density waves *do* occur.
  - Old, red stars show spiral density perturbation.
  - Molecular clouds form on inner edges of spiral arms.
  - HI gas flow shows discontinuity due to shocks at inner edges of spiral arms.
  - Bright young stars also in narrow arms.
    - Observed width $\Delta\theta \sim t_*(\Omega - \Omega_p)$, as predicted.
- Are these waves self-sustaining over 10^{10} years? Problems:
  - Lin-Shu theory is linear; does not predict whether waves will grow or decay.
  - How are density waves initially formed?
- The usual interpretation
  - Density waves need a driving force
    - Satellite galaxy at co-rotation radius (M51)
    - Bars
  - Otherwise, act to prolong life of transitory phenomena.
  - Other mechanisms probably also important.
    - Swing-amplification efficiently builds up temporary trailing spirals.