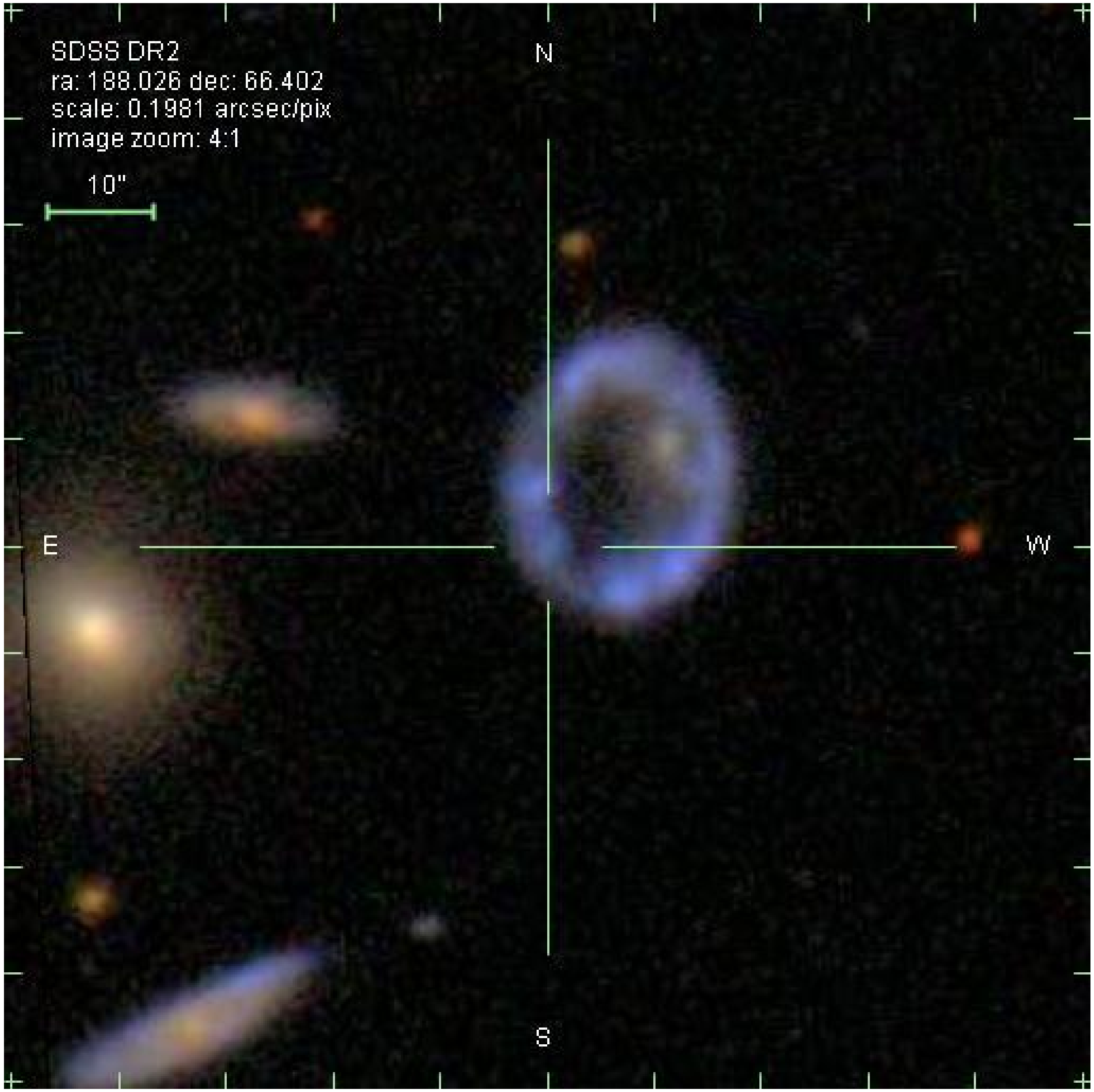
Astr 509: Astrophysics III: Stellar Dynamics

Winter Quarter 2005, University of Washington, Željko Ivezić

Lecture 12: Disk Dynamics,

Spiral Arms and Bars:

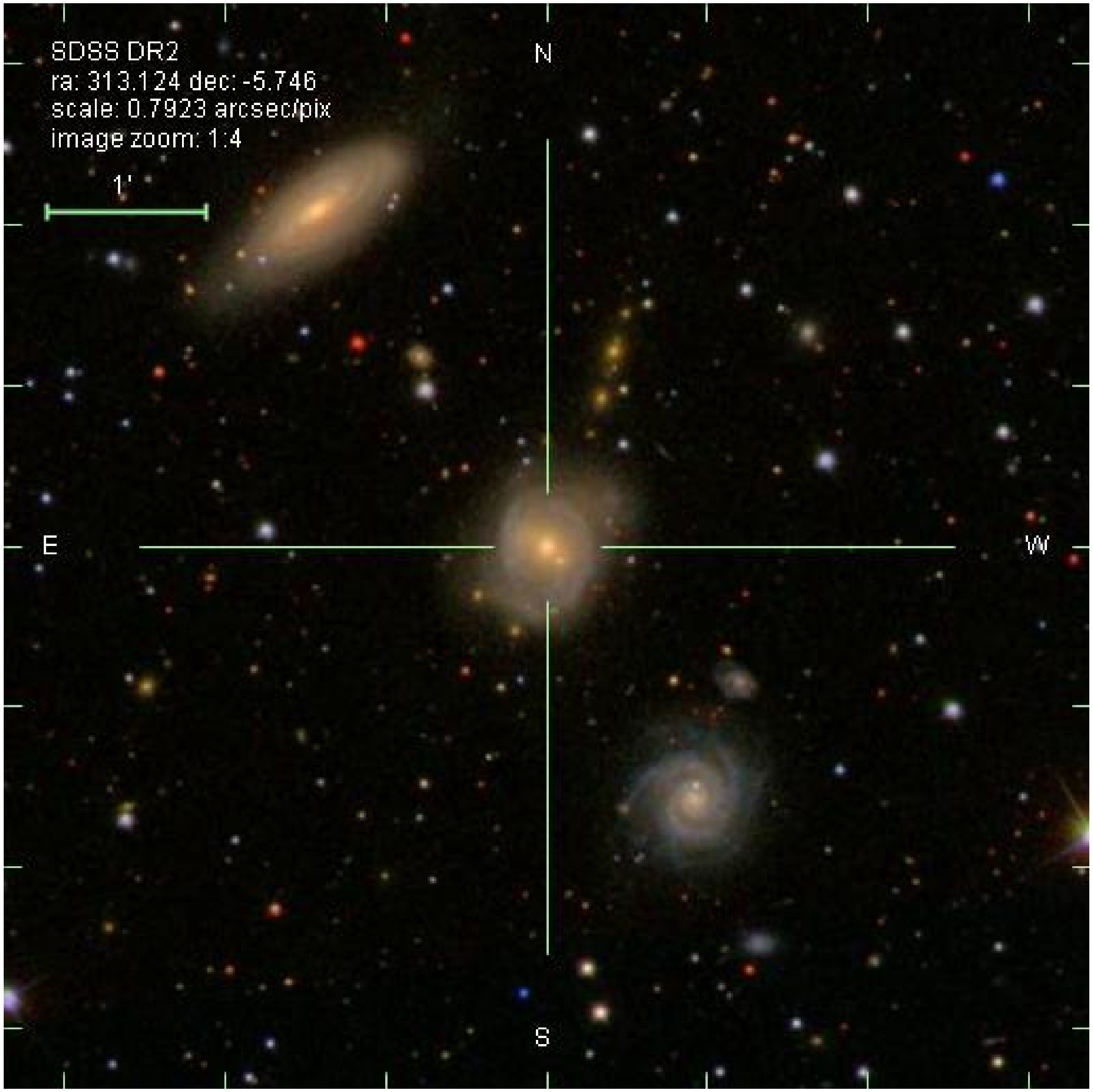
Introduction



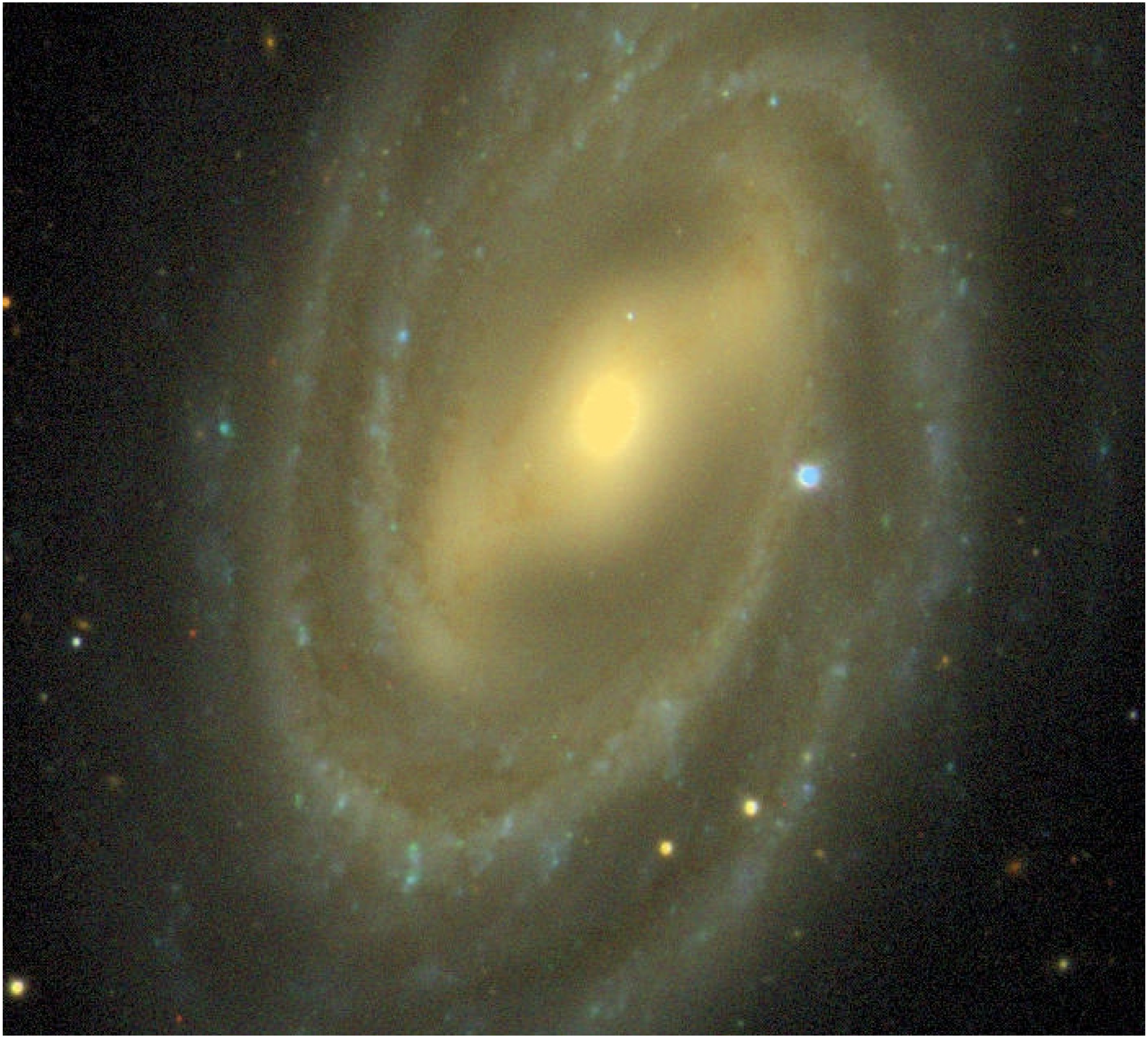
Disk instabilities come in many shapes and forms! The spiral structure is arguably the most beautiful disk instability.

Lord Rosse in 1845 “discovered” spiral structure in M51 (this is an HST image of M51)

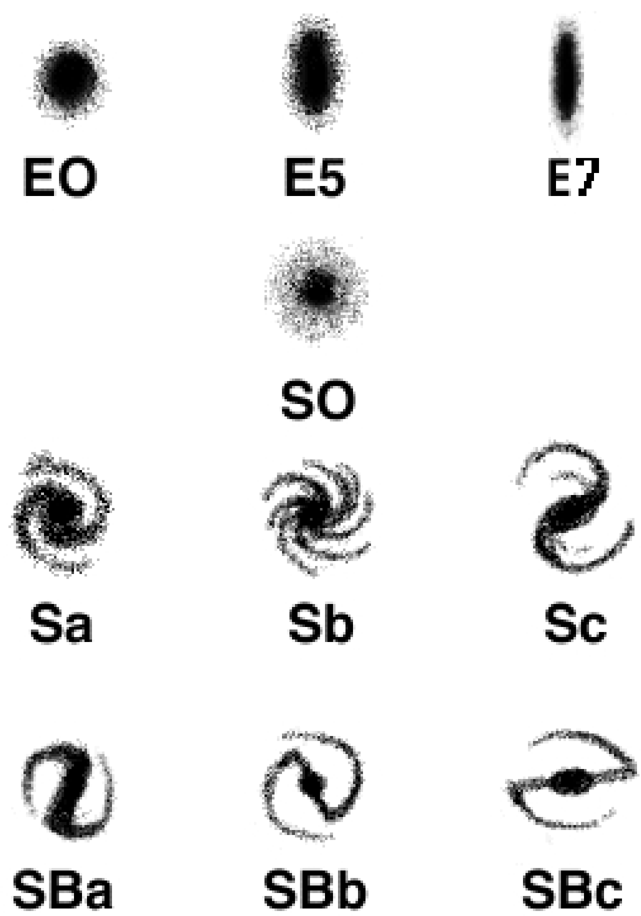
Bonus Homework: what is the shape function (c.f. eq.6-9) for M51?



Not all spirals are alike!

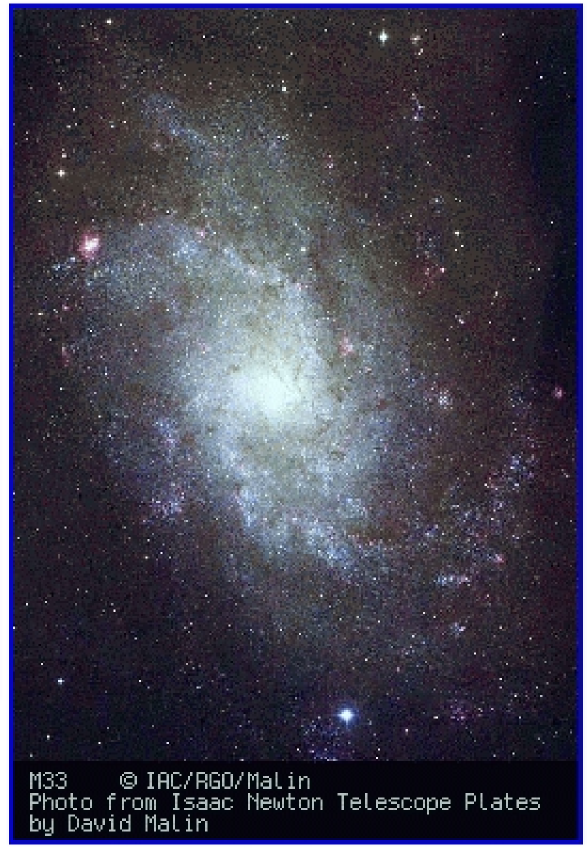


Hubble's Morphological Classification



- Broadly, galaxies can be divided into ellipticals, spirals, and irregulars
- Broadly, spirals are divided into normal and barred (similar frequencies): S and SB
- The subclassification (a, b, or c) refers both to the size of the nucleus and the tightness of the spiral arms. For example, the nucleus of an Sc galaxy is smaller than in an Sa galaxy, and the arms of the Sc are wrapped more loosely.
- The number and how tightly the spiral arms are wound are well correlated with other, large scale properties of the galaxies, such as the luminosity of the bulge relative to the disk and the amount of gas in the galaxy. This suggests that there are global physical processes involved in spiral arms.

A ``grand-design''spiral seen face-on.



A flocculent spiral with ragged spiral arms.

In addition to Hubble's classification, there are different types of spiral structure: grand design spirals, with clearly outlined and well organised globally correlated spiral structure, and flocculent (fluffy) spirals with many small short globally uncorrelated spiral arms

Theories of Spiral Structure

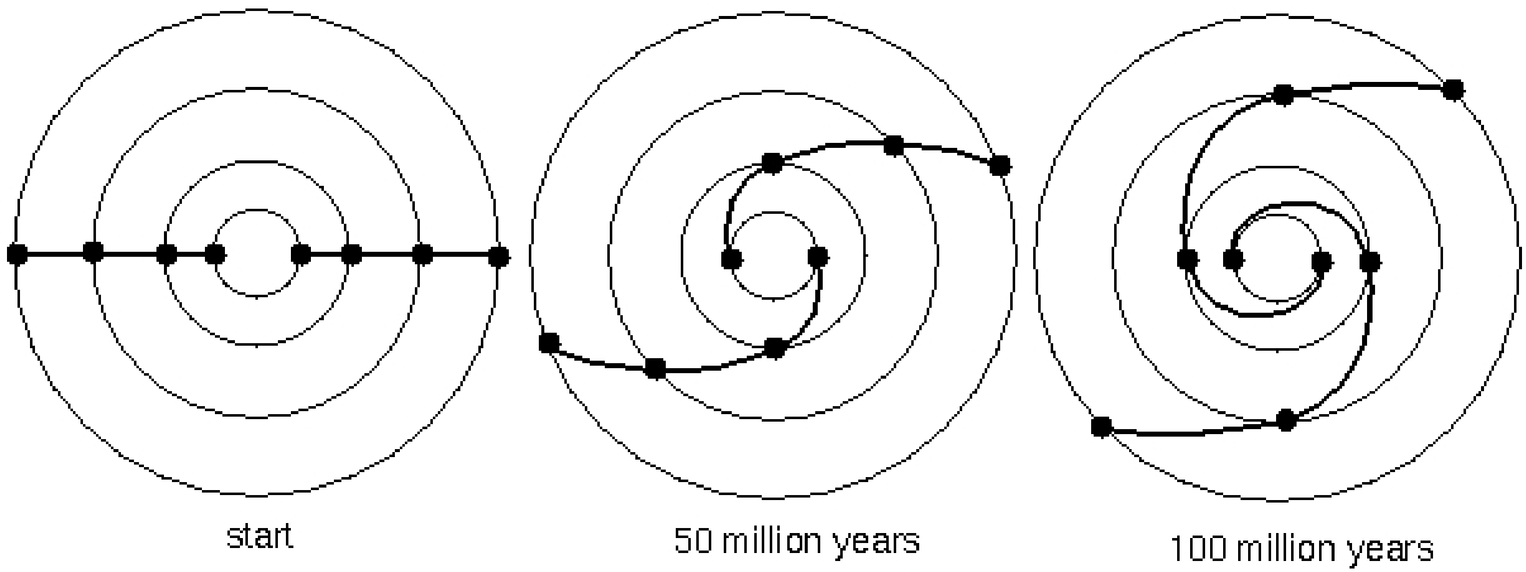
Despite 50 years of work, spirals are not very well understood. It seems clear now that the spiral structure of galaxies is a complex problem without any unique and tidy answer.

Differential rotation clearly plays a central role, as well as global instabilities, stochastic spirals, and the shocks patterns that can arise in shearing gas disks when forced by bars.

There are (at least) two popular theories, one of which is more commonly used to explain grand design spirals, the other for flocculent spirals.

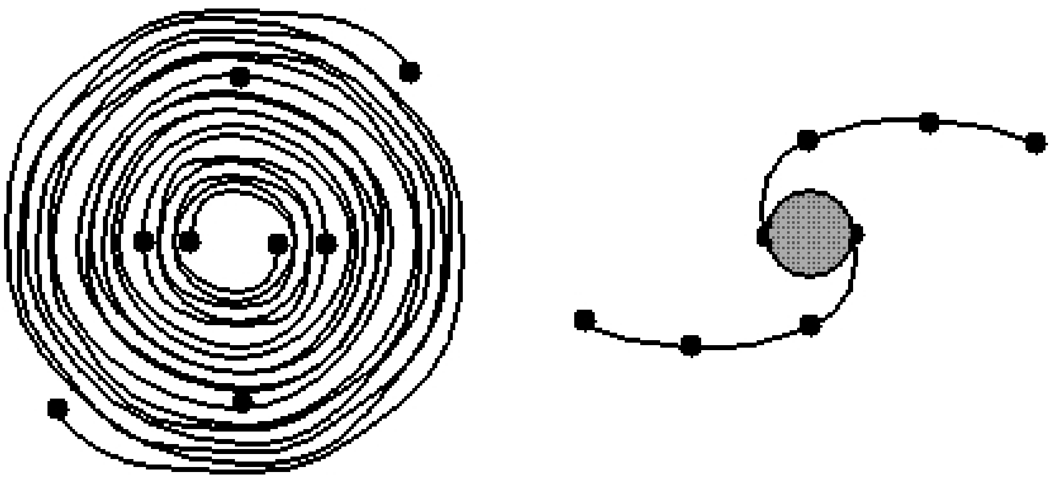
But before proceeding: **winding problem** (Lindblad)

Winding problem



Differential rotation: stars near the center take less time to orbit the center than those farther from the center. Differential rotation can create a spiral pattern in the disk in a short time.

Winding problem



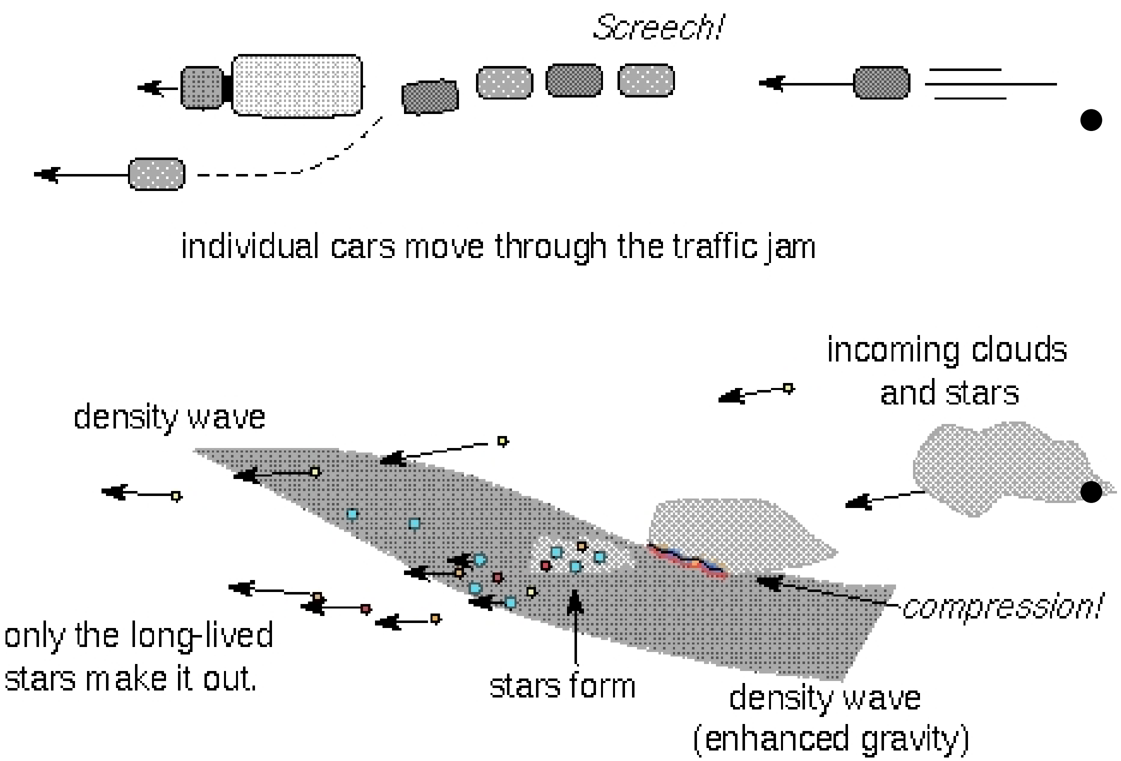
Prediction: 500 million years **Observation:** 15,000 million years

The problem: most spiral galaxies would be tightly wound by now, which is inconsistent with observations.

Spiral arms cannot be a static structure (i.e. at different times, arms must be made of different stars)

Density Wave theory

C.C. Lin & F. Shu (1964-66)



Spiral density waves are like traffic jams. Clouds and stars speed up to the density wave (are accelerated toward it) and are tugged backward as they leave, so they accumulate in the density wave (like cars bunching up behind a slower-moving vehicle). Clouds compress and form stars in the density wave, but only the fainter stars live long enough to make it out of the wave.

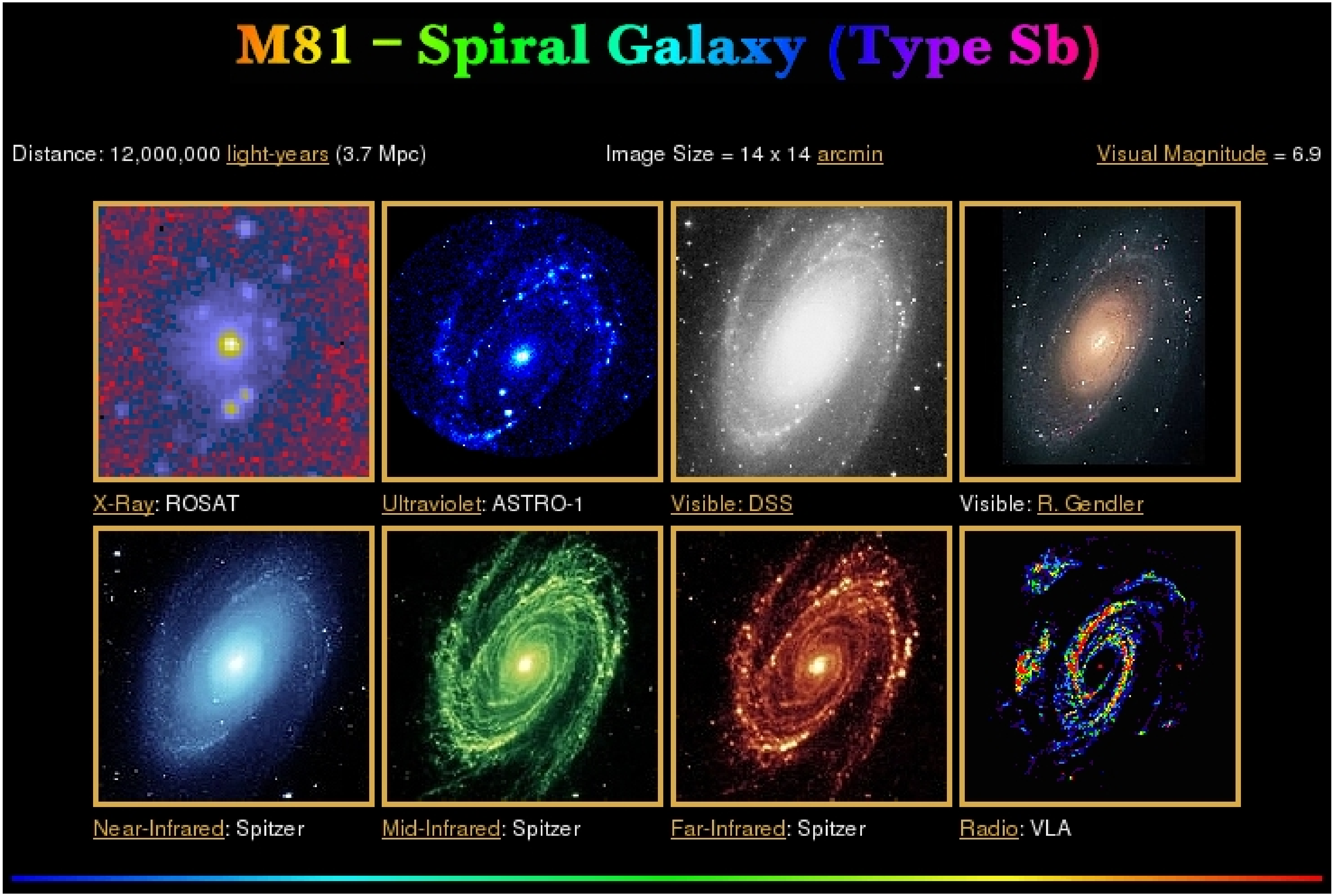
- This is the preferred model for grand design spirals.
- The spiral arms are over-dense regions which move around at a different speed than star: stars thus move in and out of the spiral arm
- How these density waves are set up is unclear, but it may have to do with interactions. Once they are set up, they must last for a long enough time to be consistent with the observed number of spiral galaxies

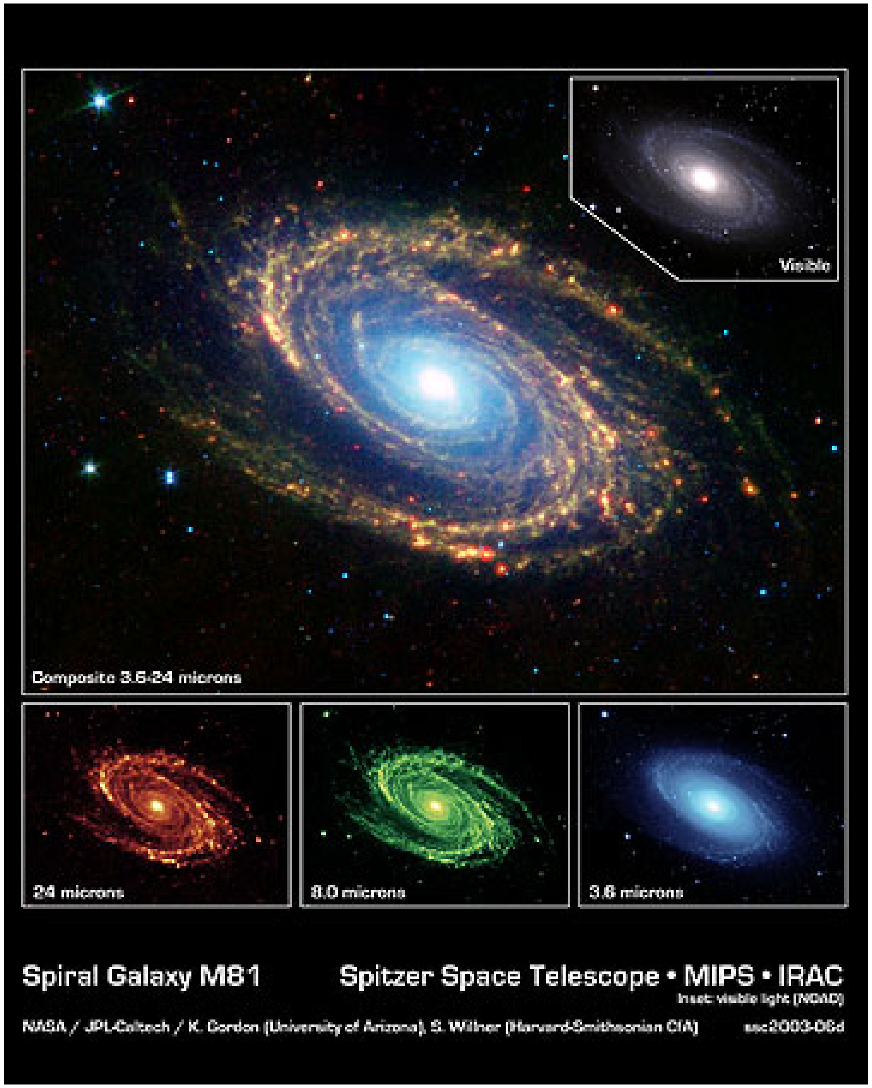
Stochastic Self-Propagative Star Formation

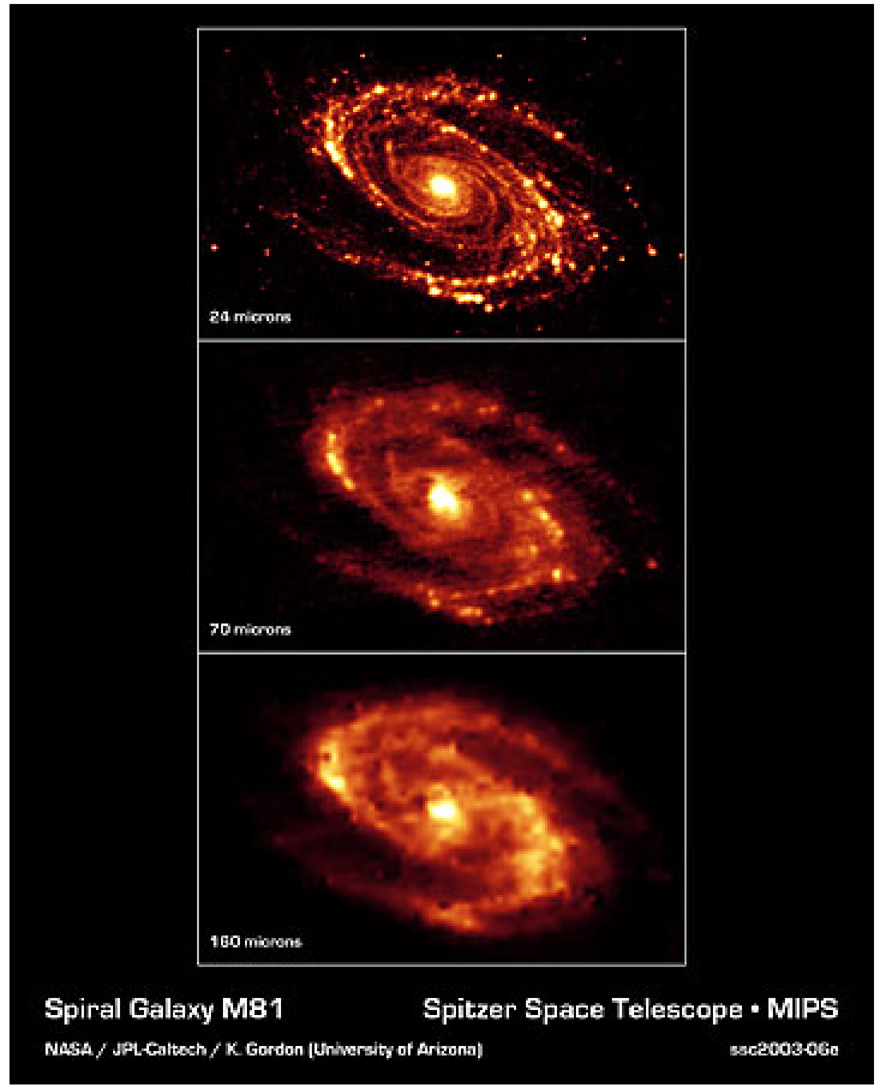
- This model probably cannot explain grand design sprials, but it may account for flocculent spiral structure.

- Ongoing star formation triggers star formation in areas adjacent to it. As the galaxy rotates, differential rotaion leads to the appearance of a spiral pattern.

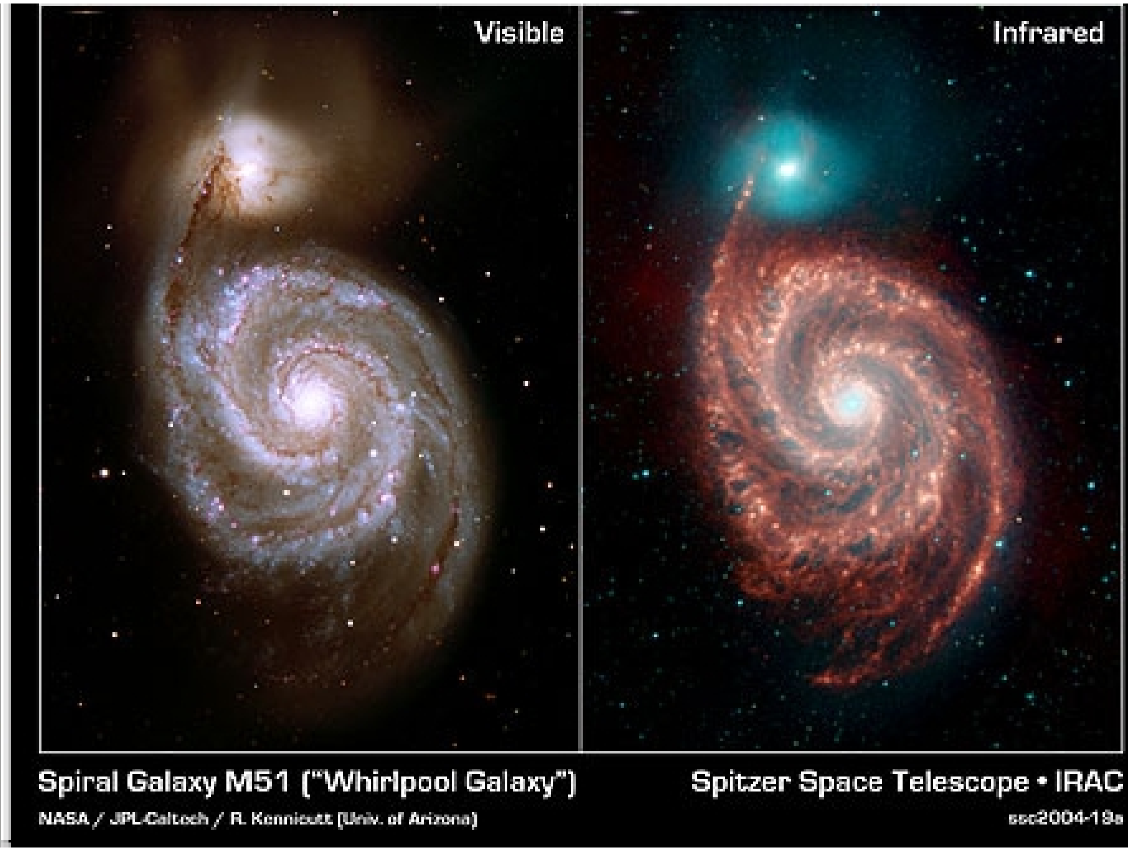
Spiral arms are made of short-lived massive blue stars!

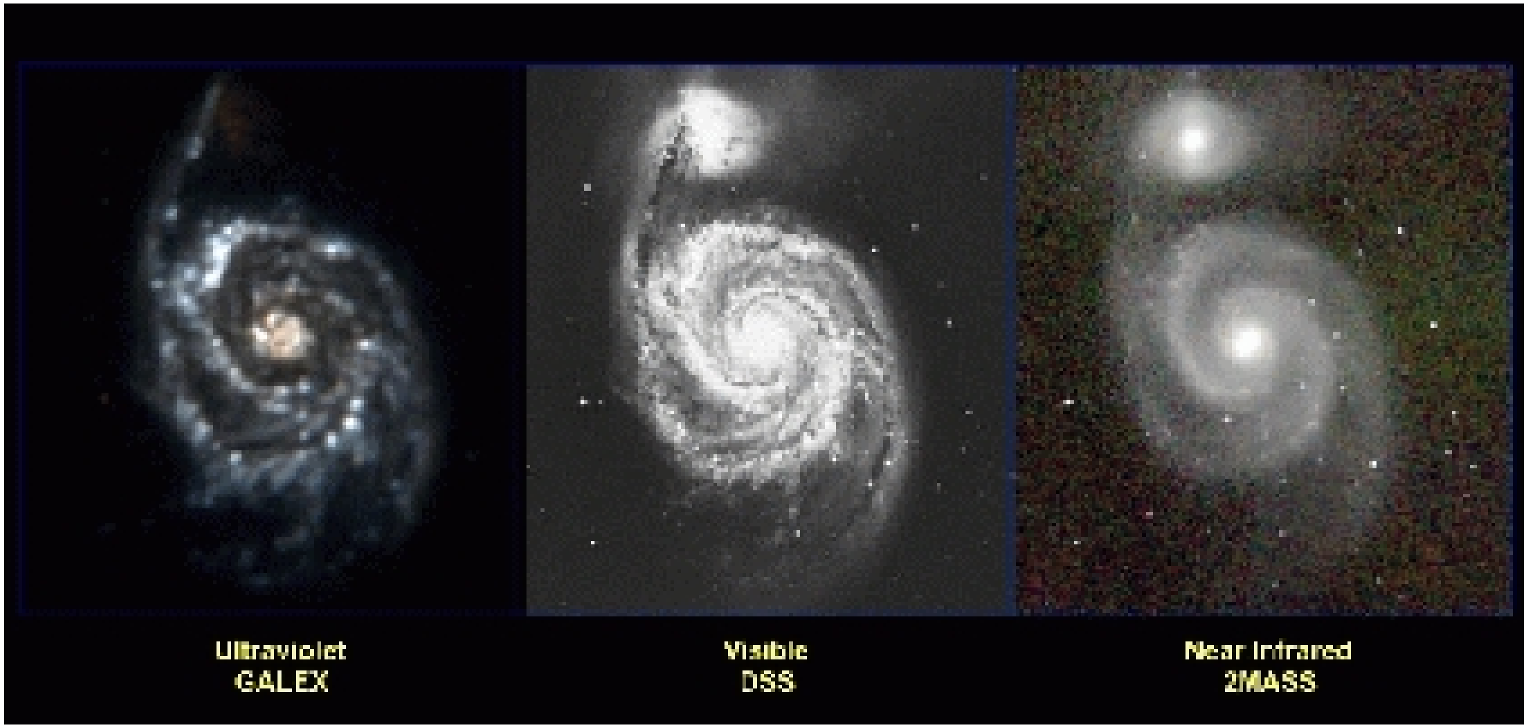

M81 – Spiral Galaxy (Type Sb)
Distance: 12,000,000 light-years (3.7 Mpc)
Image Size = 14 x 14 arcmin
Visual Magnitude = 6.9
X-Ray: ROSAT
Ultraviolet: ASTRO-1
Visible: DSS
Visible: R. Gendler
Near-Infrared: Spitzer
Mid-Infrared: Spitzer
Far-Infrared: Spitzer
Radio: VLA


Visible
Composite 3.6-24 microns
24 microns
8.0 microns
3.6 microns
Spiral Galaxy M81
Spitzer Space Telescope • MIPS • IRAC
Inset: visible light (NOAO)
NASA / JPL-Caltech / K. Gordon (University of Arizona), S. Willner (Harvard-Smithsonian CfA)
ssc2003-06d


24 microns
70 microns
160 microns
Spiral Galaxy M81
Spitzer Space Telescope • MIPS
NASA / JPL-Caltech / K. Gordon (University of Arizona)
ssc2003-06c

M81 as seen by GALEX


Visible
Infrared
Spiral Galaxy M51 ("Whirlpool Galaxy")
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / R. Kennicutt (Univ. of Arizona)
ssc2004-19a



Note that the smaller galaxy (NGC 5195) is not visible in GALEX image (left, compare to figs. 6-1 and 6-4 from the textbook)

There is no doubt that spiral structure is associated with (short-lived) hot stars.

Andromeda Galaxy
GALEX

Andromeda Galaxy
Visible light image (John Gleason)

The Sombrero Galaxy (VLT ANTU + FORS1)

ESO PR Photo 07a/00 (22 February 2000)

Disks contain a lot of dust! Spiral arms are almost exclusively seen in disks with a lot of gas and dust, unlike bars which are often seen in galaxies without ISM. Bars are not a wave of star formation – they are orbital features.