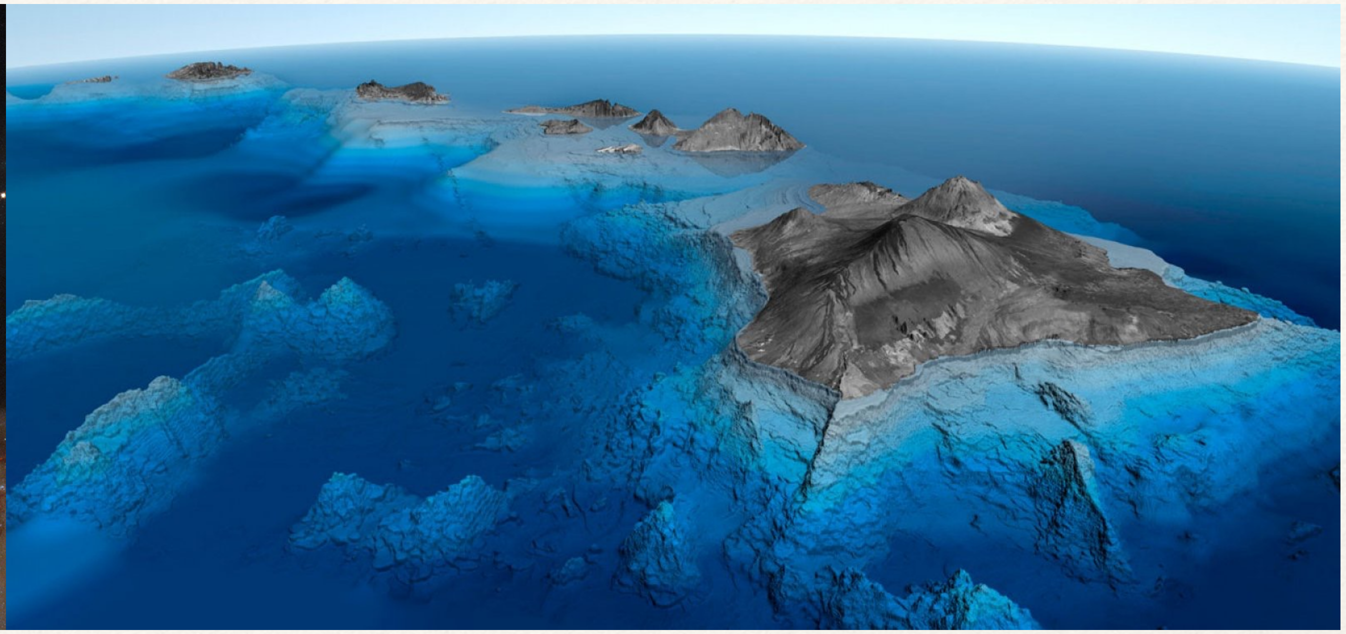


Getting to know the "island universes" out there.

Galaxies I

ASTR 555
Dr. Jon Holtzman

Warm-up

- Consider a galaxy at the end of the red sequence. What would you guess about the following properties of this galaxy?:

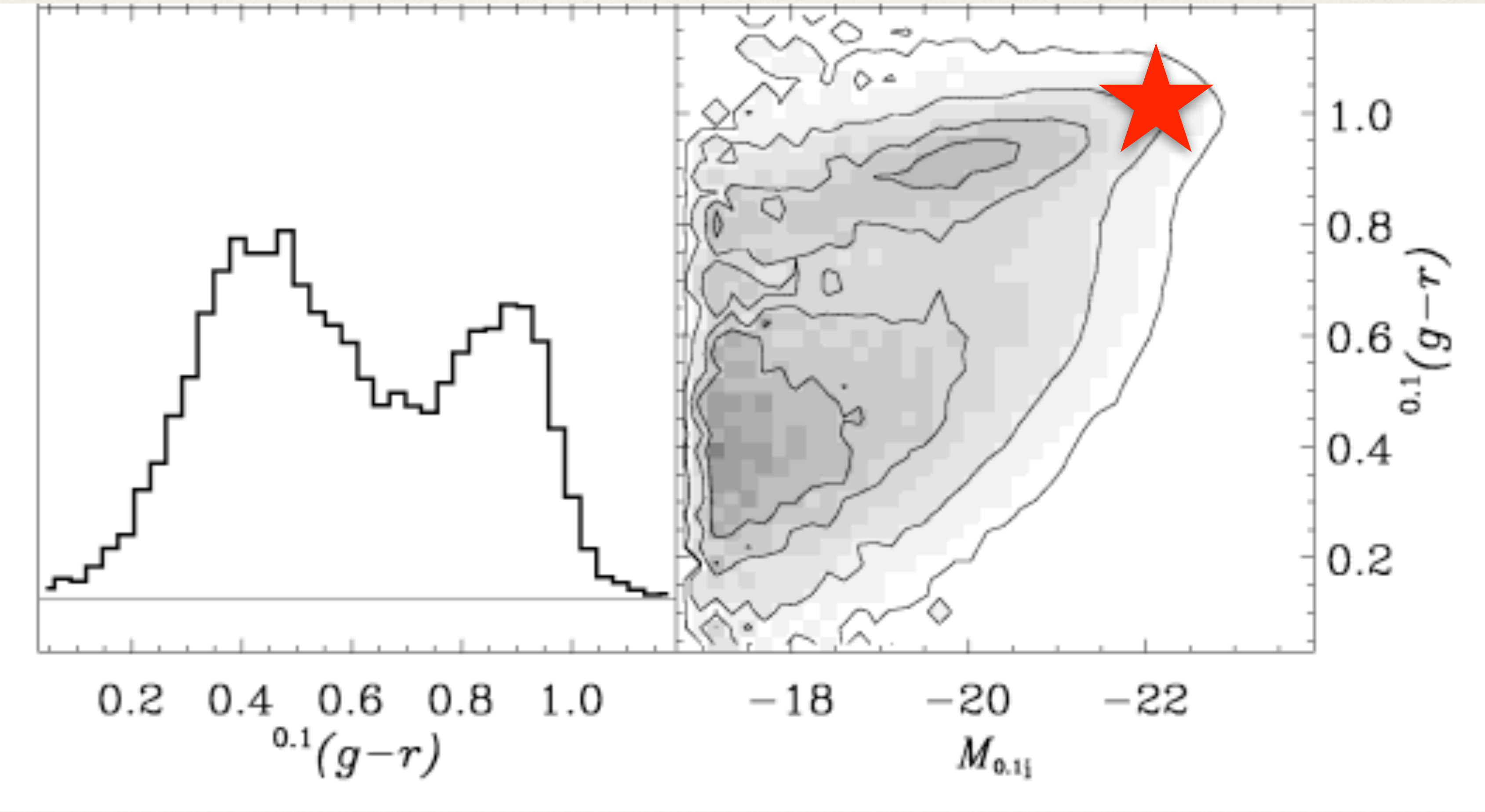
1
- spectrum
- metallicity

2
- alpha/Fe ratio
- v/sigma

3
- isophotal shape
- 3D shape

4
- Sersic n
- inner profile

5
- outer profile
- non-axisymmetric features



http://people.virginia.edu/~dmw8f/astr5630/Topic01/t1_SDSS_montage.html

See Mo, van den Bosch, & White; Figure 2.27

Outline for Today

- Galaxy Population - Spirals/Disks:
  - Components
  - Surface Brightness Profiles
  - Special Features

NGC1232 (ESO)

Galaxy Population - Spirals/Disks

- Disk galaxies are clearly complex systems:
  - Wide range in morphological appearance
  - Wide range in stellar populations
  - Wide range in stellar dynamics
  - Significant cold interstellar medium (ISM)
  - Significant hot gas halos!

NGC1232 (ESO)

Spirals/Disks: Components

- **Disks (thin and thick)**: metal-rich stars/ISM, higher rotational support
- **Bulge**: high stellar densities, higher dispersion support
- **Stellar Halo**: metal-poor stars, globular clusters, low-density hot gas with little rotation
- **Non-axisymmetric Features**:
  - **Bar**: flat, linear stellar distribution
  - **Arm**: pattern within disk

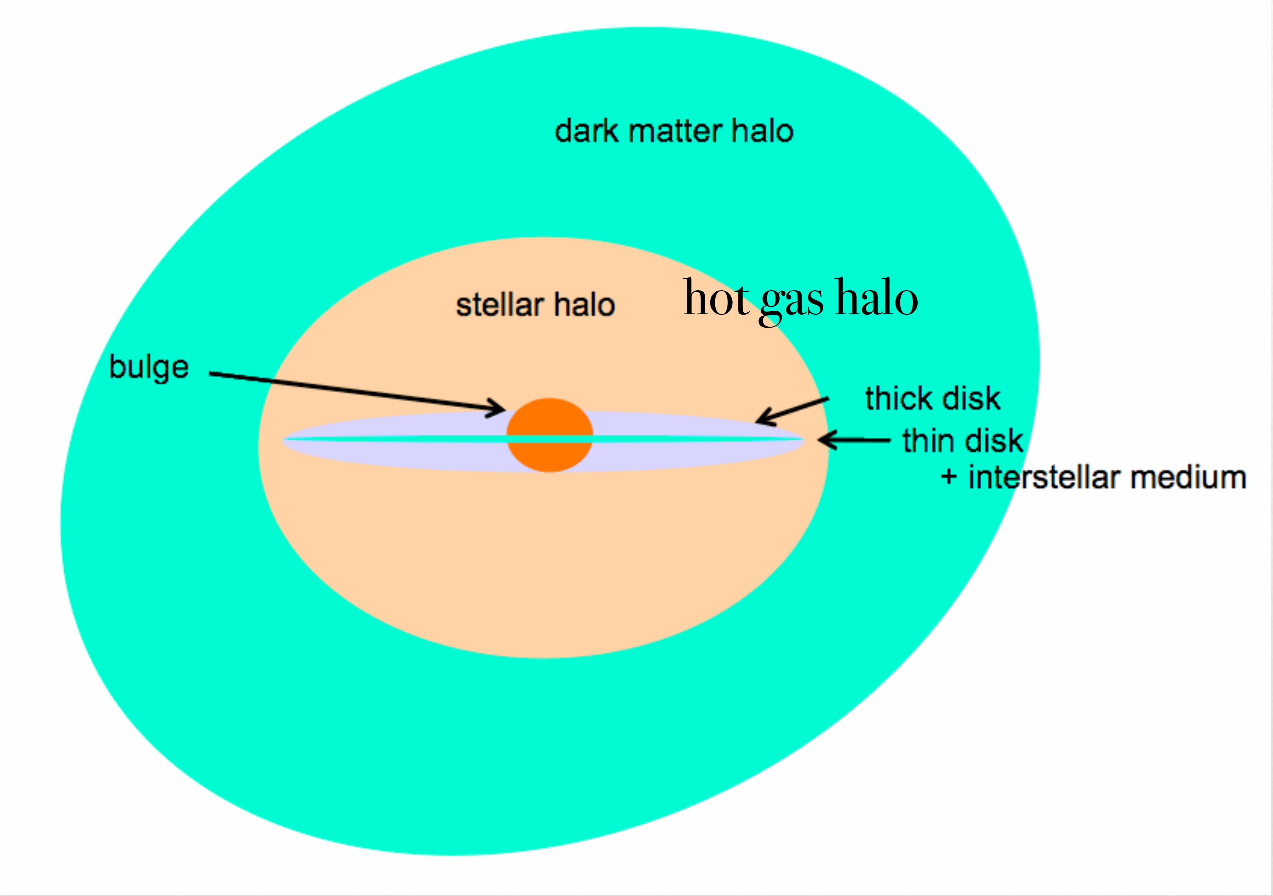


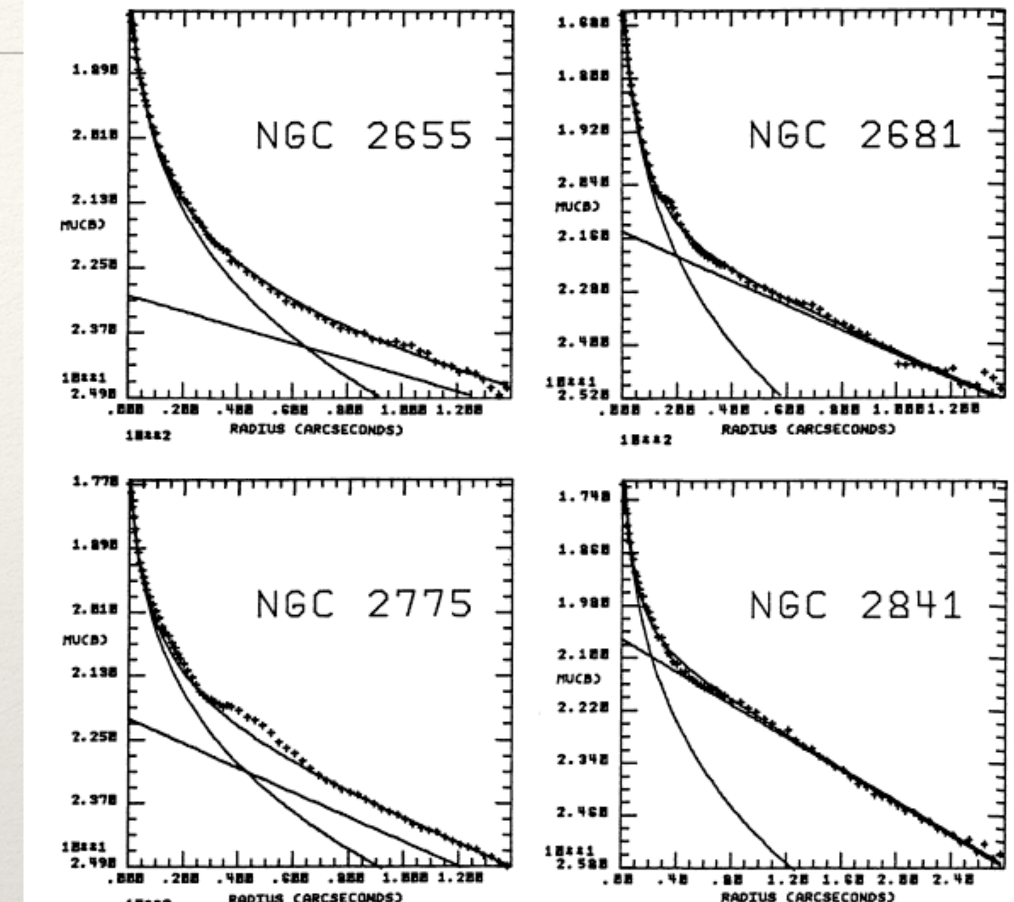
Image: Eline Tolstoy

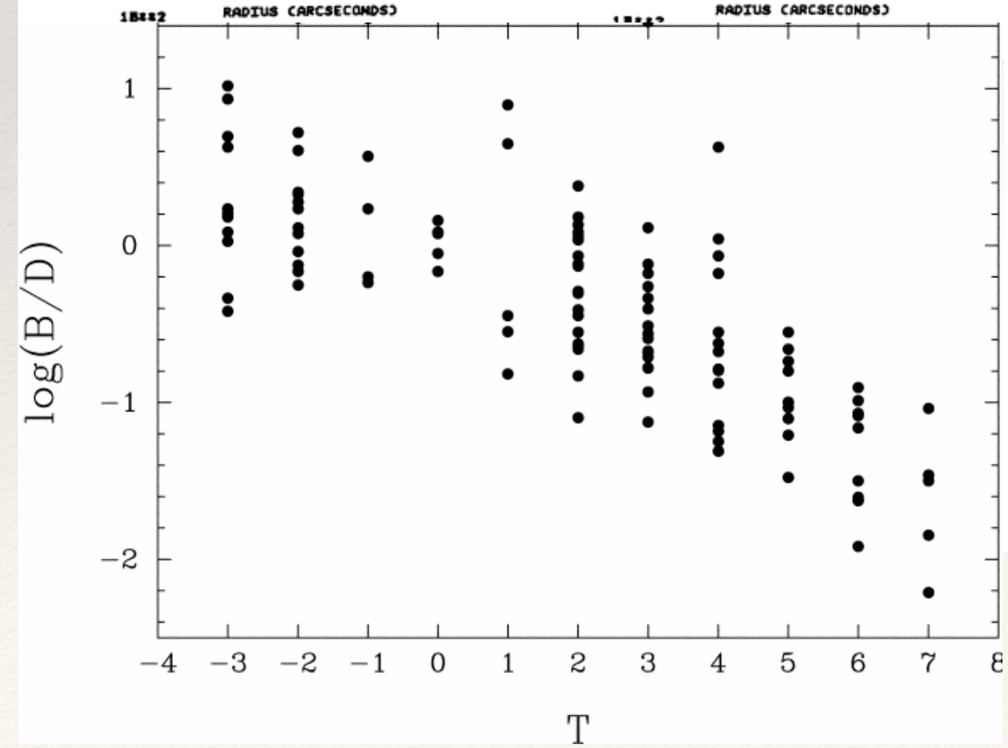
- **Nucleus**: central <10 pc, very high density ISM/star cluster, supermassive black hole
- **Dark Matter Halo**: mildly flattened and/or triaxial, dominates mass at >10 kpc

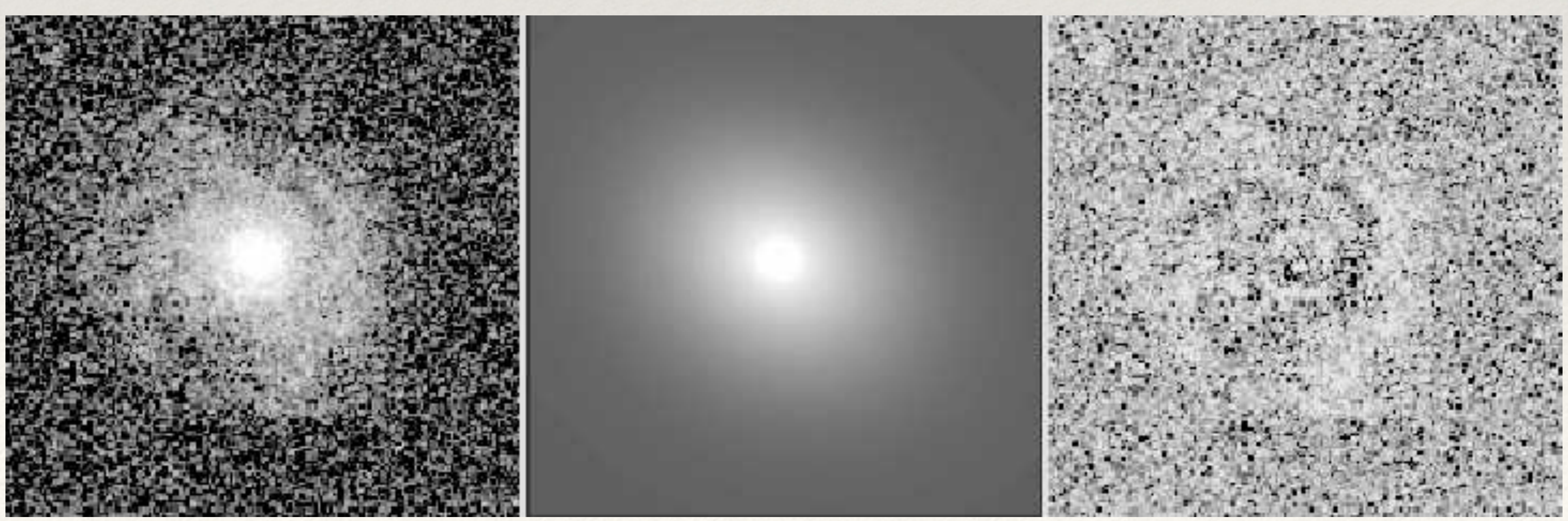
Spirals/Disks: SB Profiles

- Surface brightness profiles of most spiral galaxies are composite:
  - "Bulge-Disk decomposition" splits profile into an exponential disk + Sersic bulge
  - Bulge/Disk ratio (B/D) correlates with morphological type

Boroson (1981)



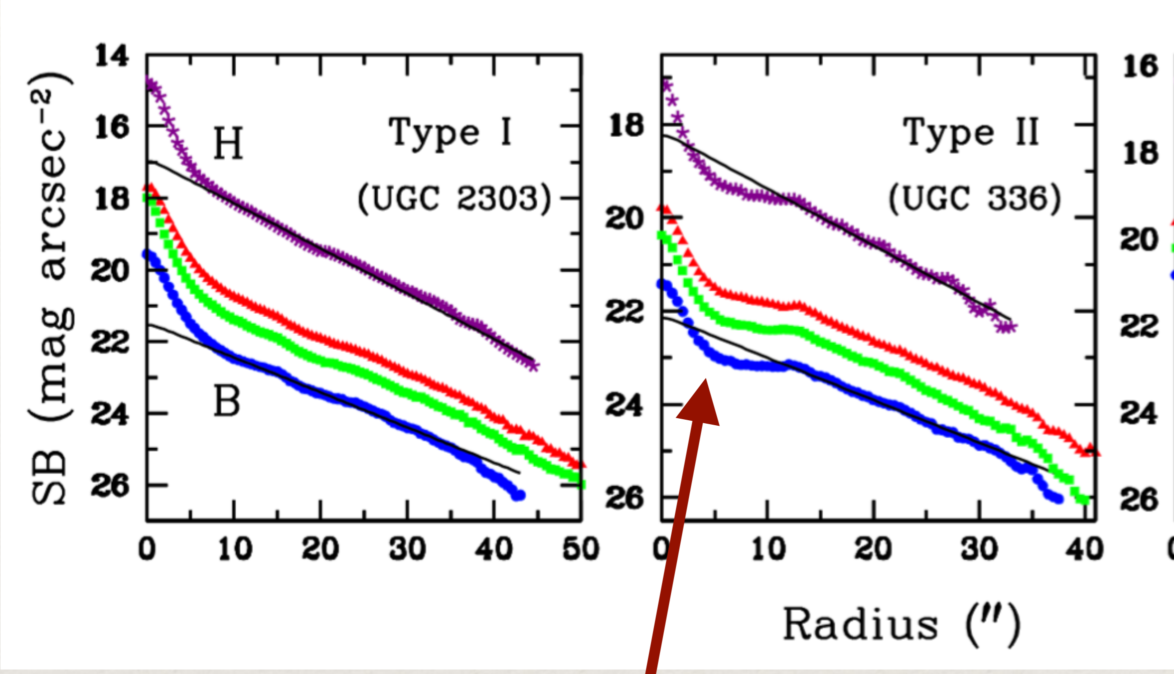




C. Peng (Galfit) 2013

Spirals/Disks: SB Profiles

- "Normal" spirals have similar central surface brightnesses (Freeman 1970)
- Different families of disk profiles exist:
    - **Freeman Type I profiles:**
        - central profile higher than exponential due to central bulge component
    - **Freeman Type II profiles:**
        - central profile shows a depression relative to exponential (more pronounced in bluer bands)



MacArthur, Courteau, & Holtzman 2003

- Dynamical effects of a bar or dust extinction

Spirals/Disks: SB Profiles

- Typical scale length: few kpc
- In ~60% of spirals, disks truncate at ~4 disk scale lengths (Kregel et al. 2002)
    - Easier to see in edge-on systems

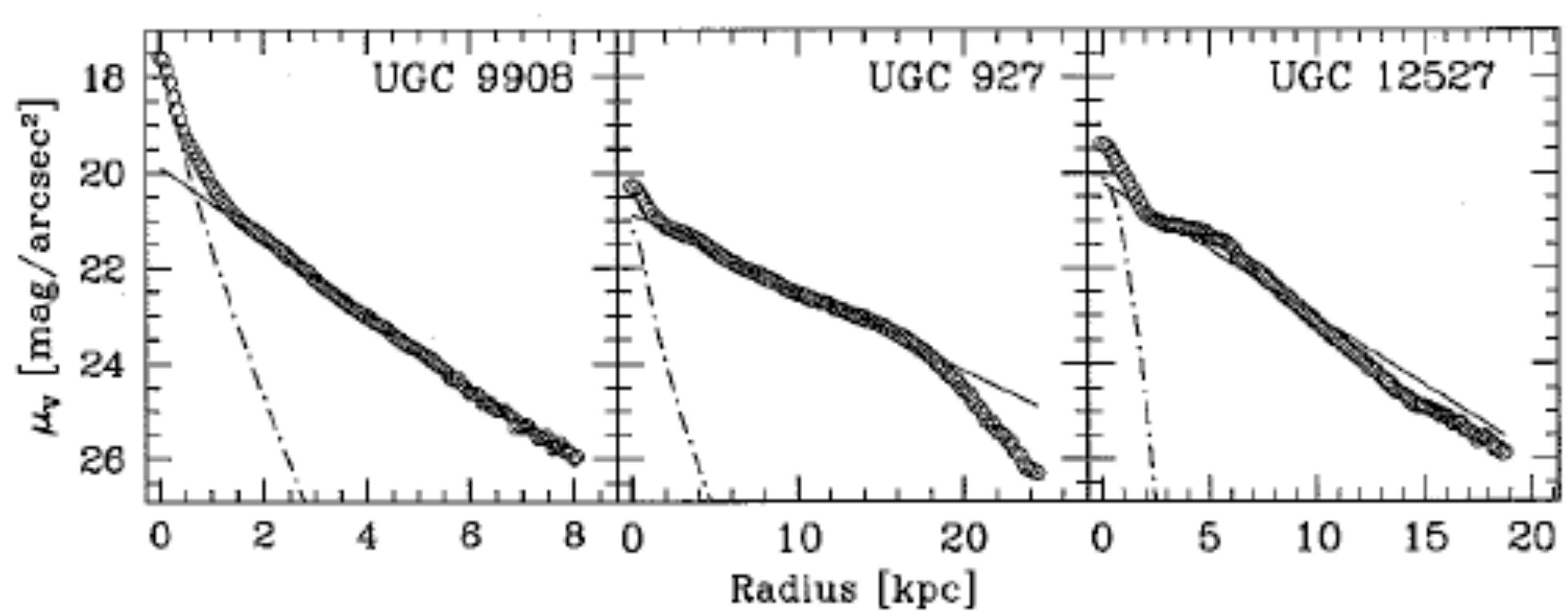
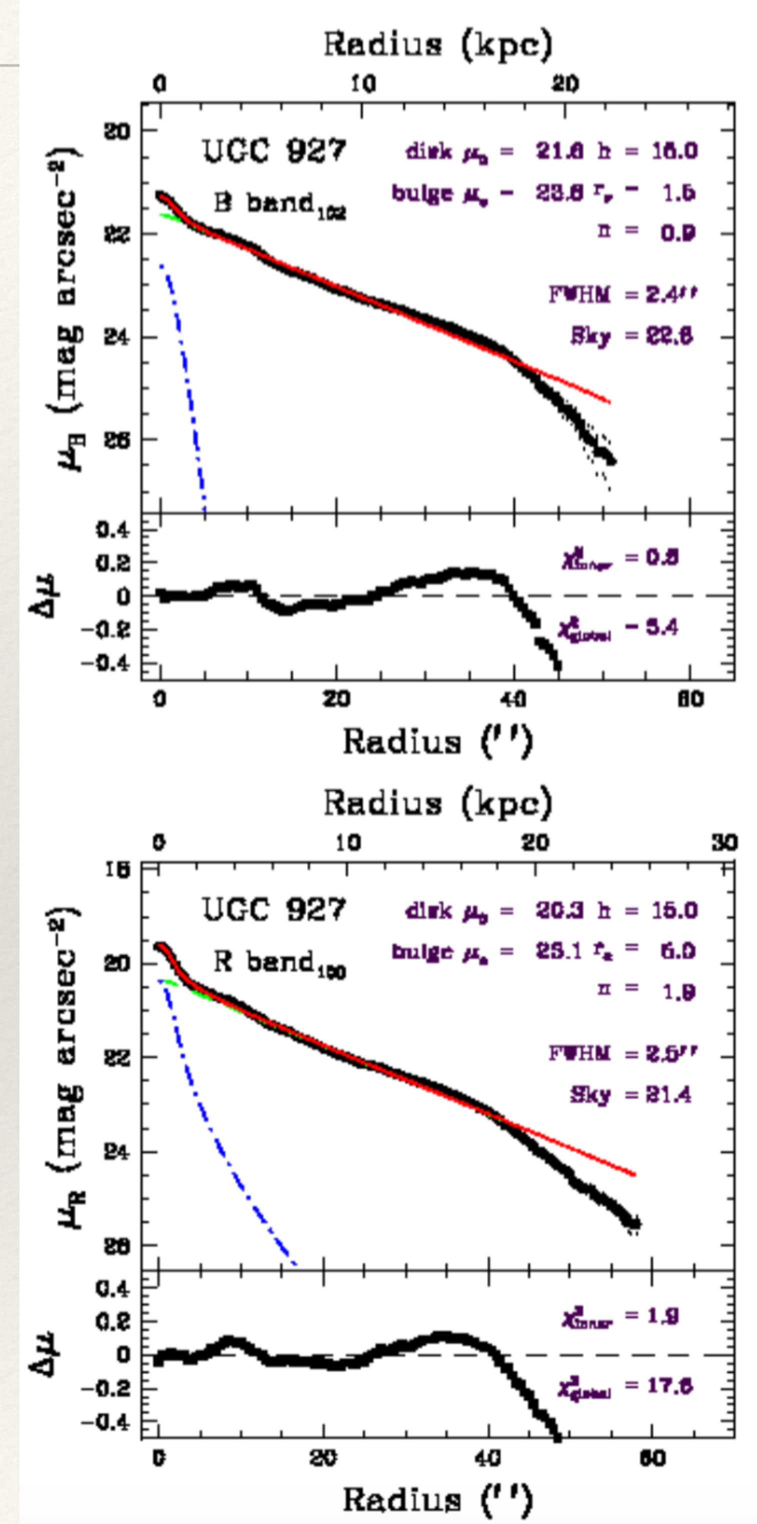


Fig. 2.19. The surface brightness profiles of three disk galaxies plus their decomposition in an exponential disk (solid line) and a Sérsic bulge (dot-dashed line). [Based on data published in MacArthur et al. (2003) and kindly made available by L. MacArthur]



MacArthur, Courteau, & Holtzman 2003

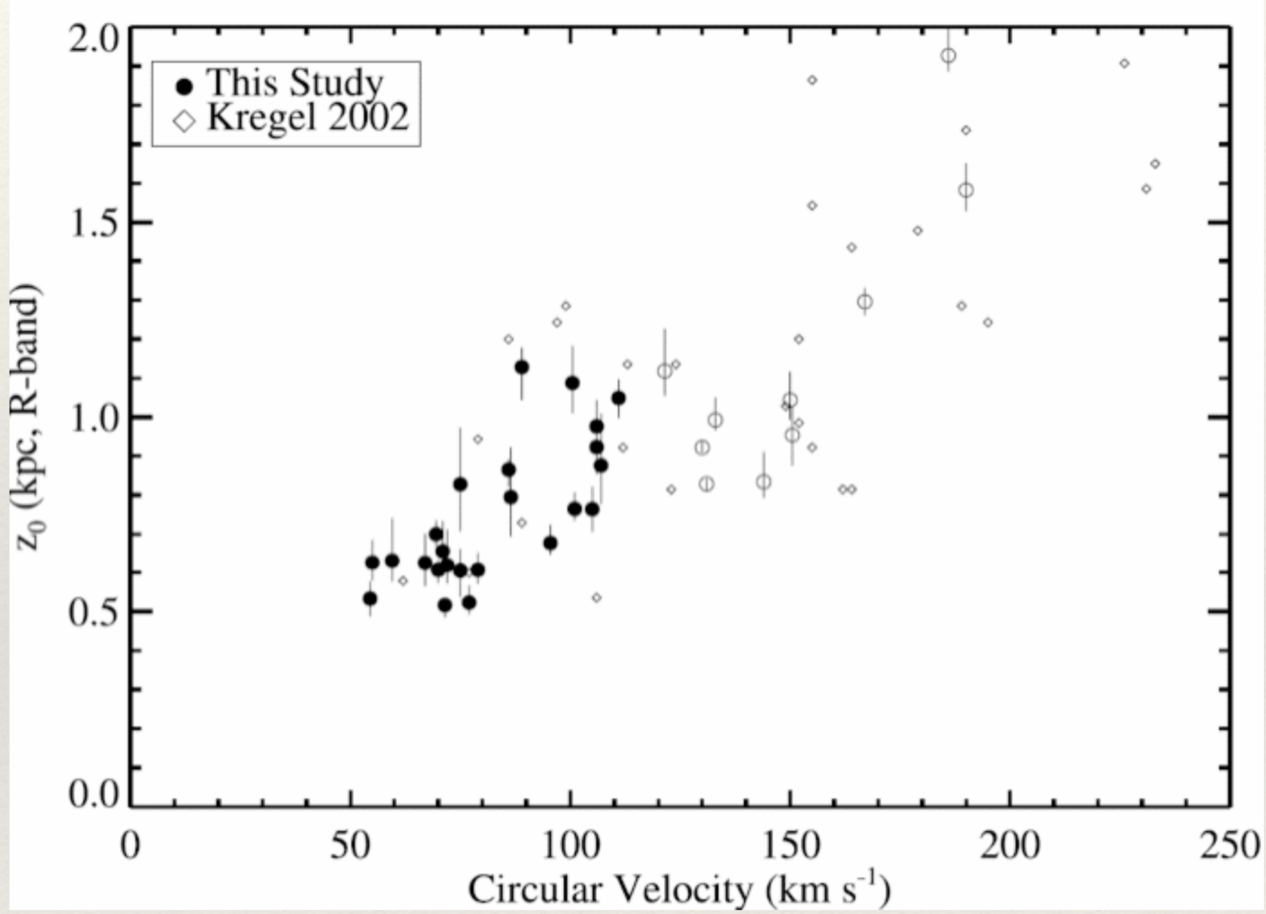
Spirals/Disks: SB Profiles

- Disks are not infinitely thin:
  - Vertical luminosity distribution characterized by z_s, exponential scale height:

$$I(z) \propto \exp -|z|/z_s$$

- Typical scale height $z_s \sim 0.1\ r_d$
- Scale height may change with radius

Joachim, Dalcanton 2006, ApJ, 131,226



- More luminous galaxies (higher circular velocities) may have thicker disks

Spirals/Disks: SB Profiles

- Sometimes need two exponentials to fit vertical profile
- "Thick disk" can differ in stellar velocities and chemical abundances

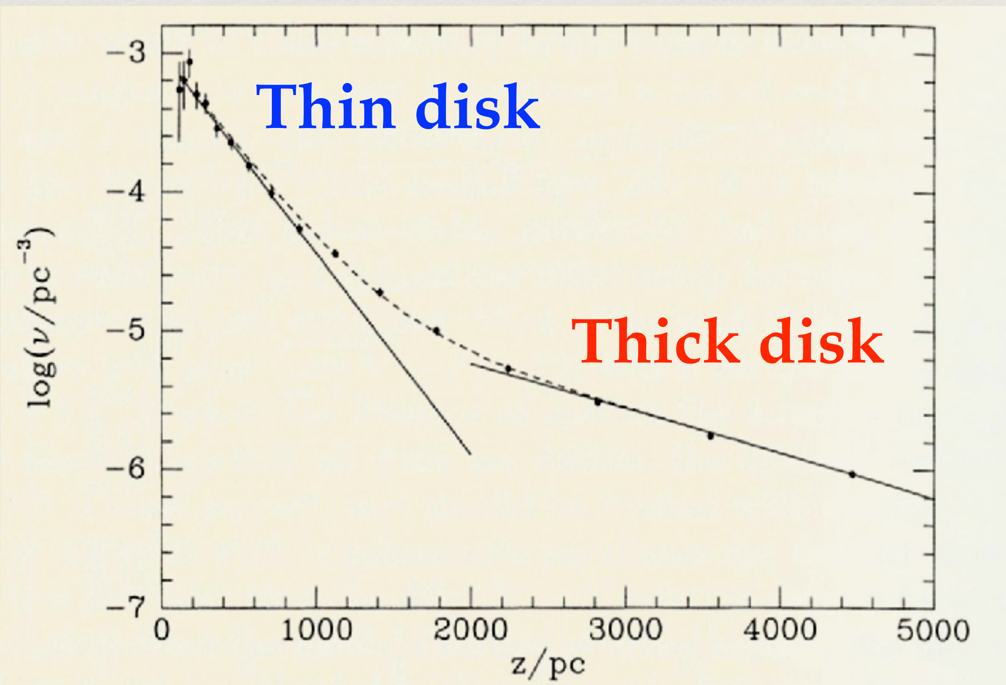
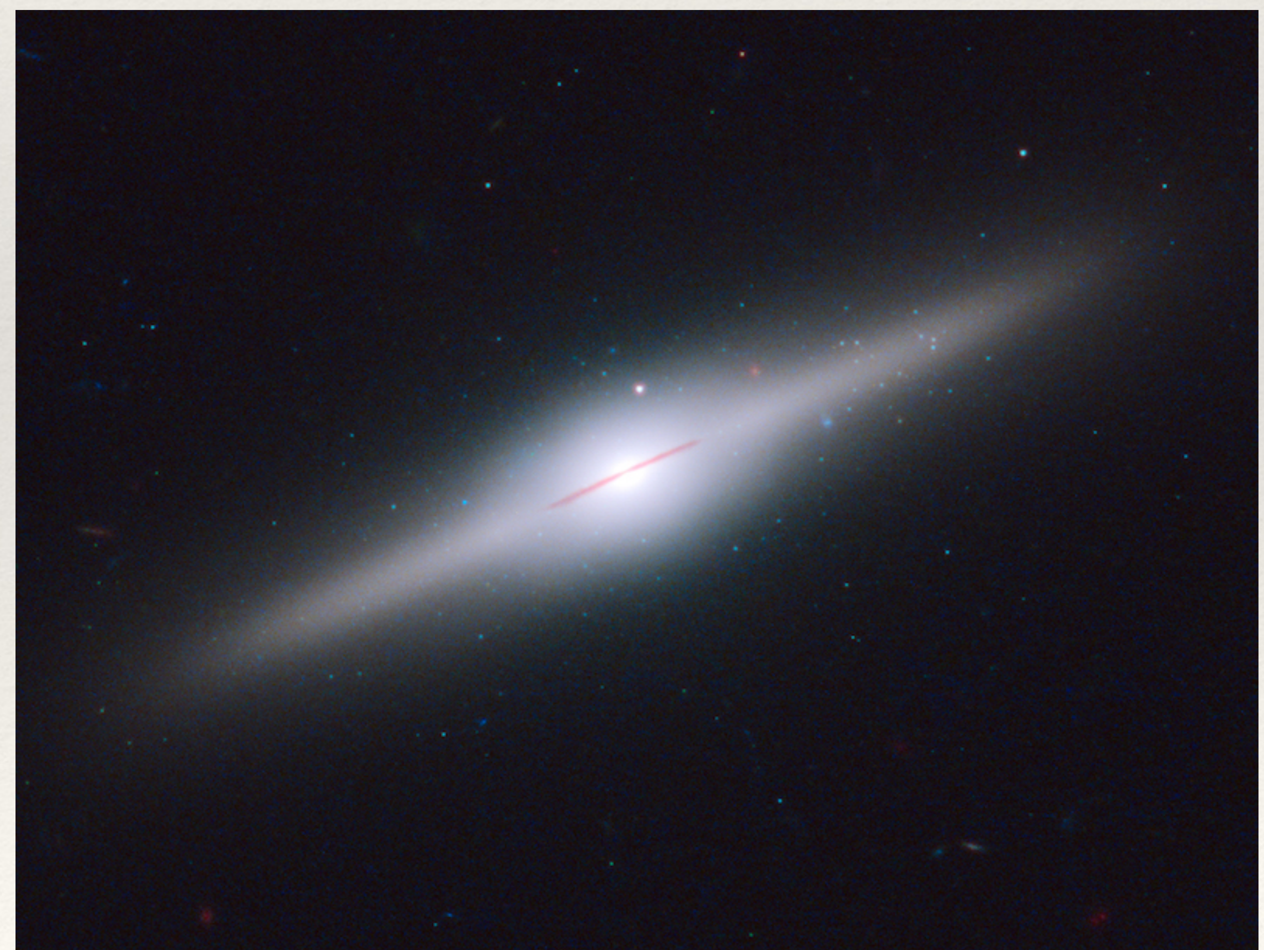


Figure 10.25 The space density as a function of distance z from the plane of MS stars with absolute magnitudes $4 \leq M_V \leq 5$. The full lines are exponentials with scale heights $z_0 = 300\,\mathrm{pc}$ (at left) and $z_0 = 1350\,\mathrm{pc}$ (at right). The dashed curve shows the sum of these two exponentials. [From data published in Gilmore & Reid (1983)]

- Much debate about thick disk origin — in situ formation, migration of stars, accretion of stars from satellites, vertical heating from minor mergers?



https://aasnova.org/2017/12/06/exploring-our-galaxys-thick-disk/

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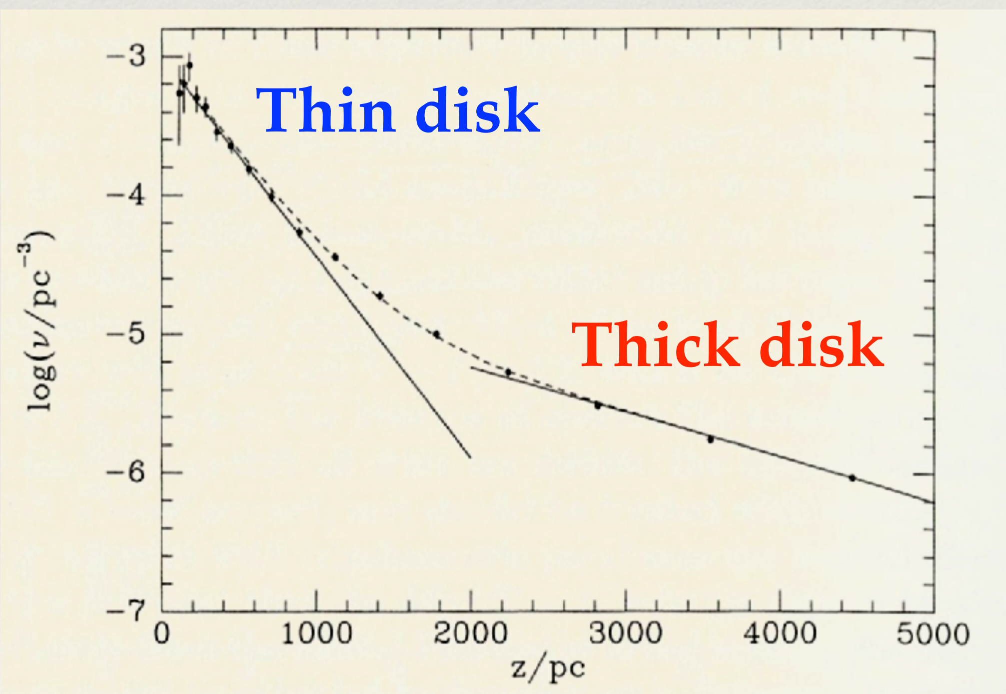

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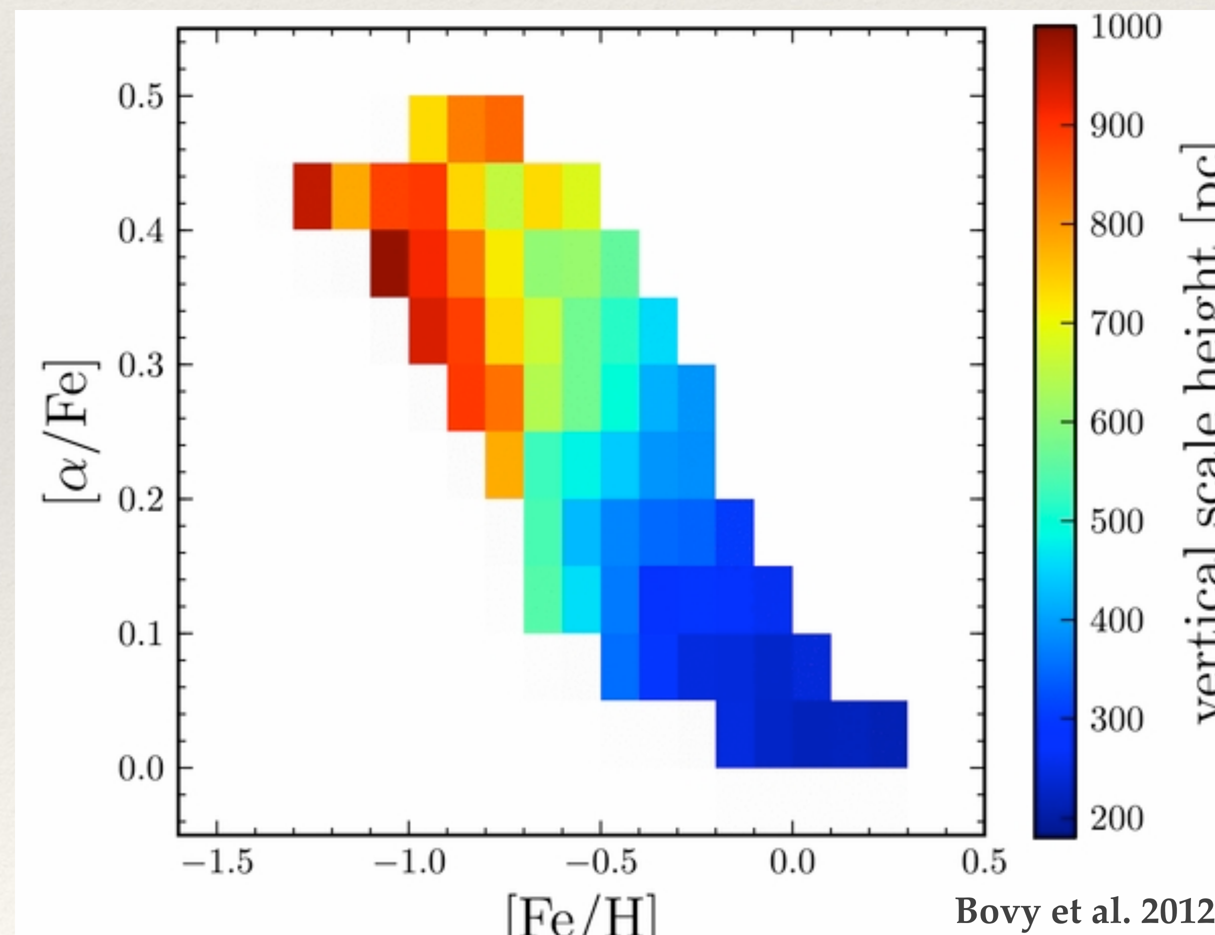

Spirals/Disks: Warps

- Inner disks typically very flat
- Outer disks are not always perfectly flat, e.g., may see warps in the outer regions, often right around truncation radius

ESO 510-G13 (NASA/STScI)

van der Kruit & Freeman 2011

Thought Question

- What properties would you expect to see in the bulge of a spiral galaxy?

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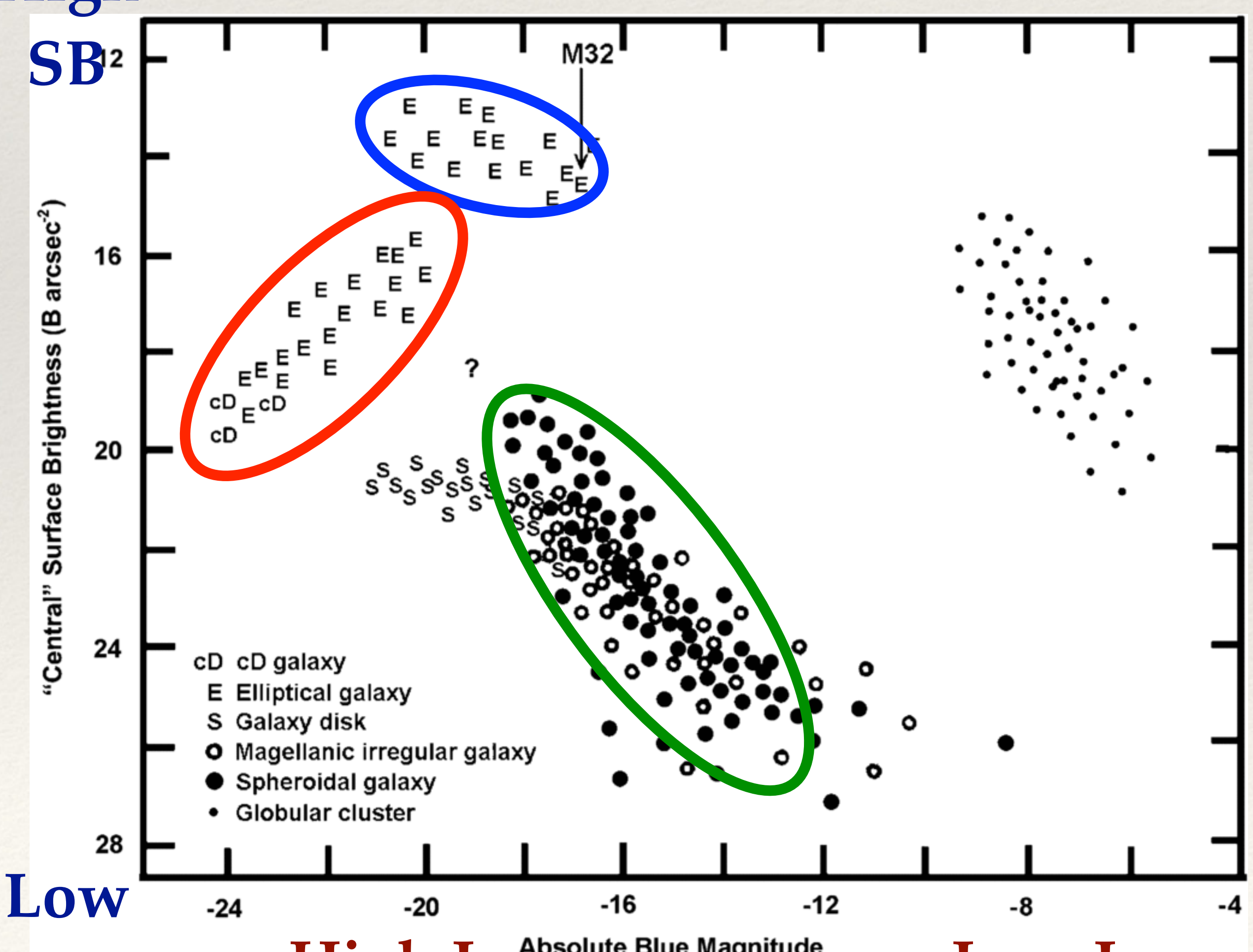
High SB

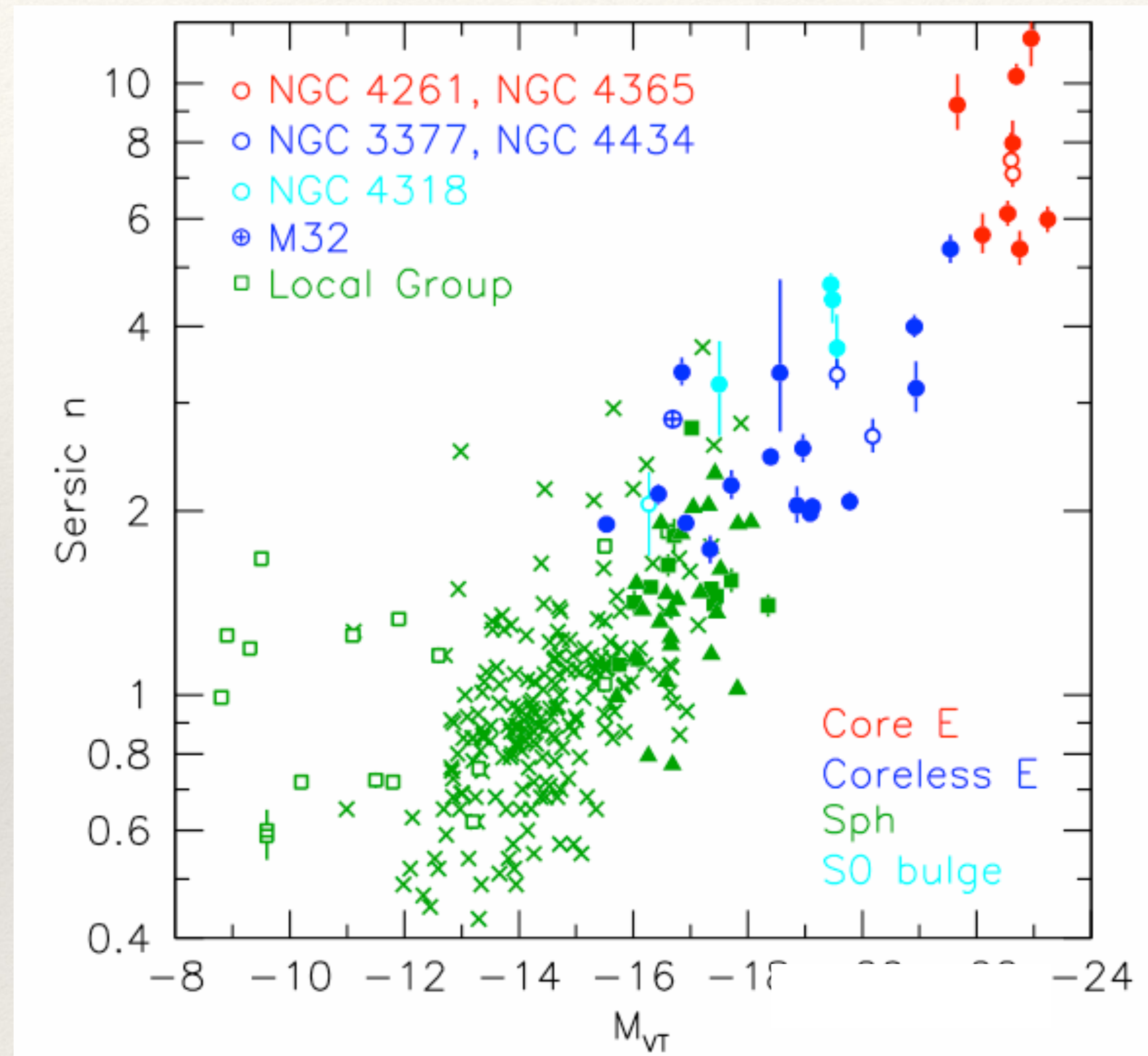


Low SB

High L

Low L

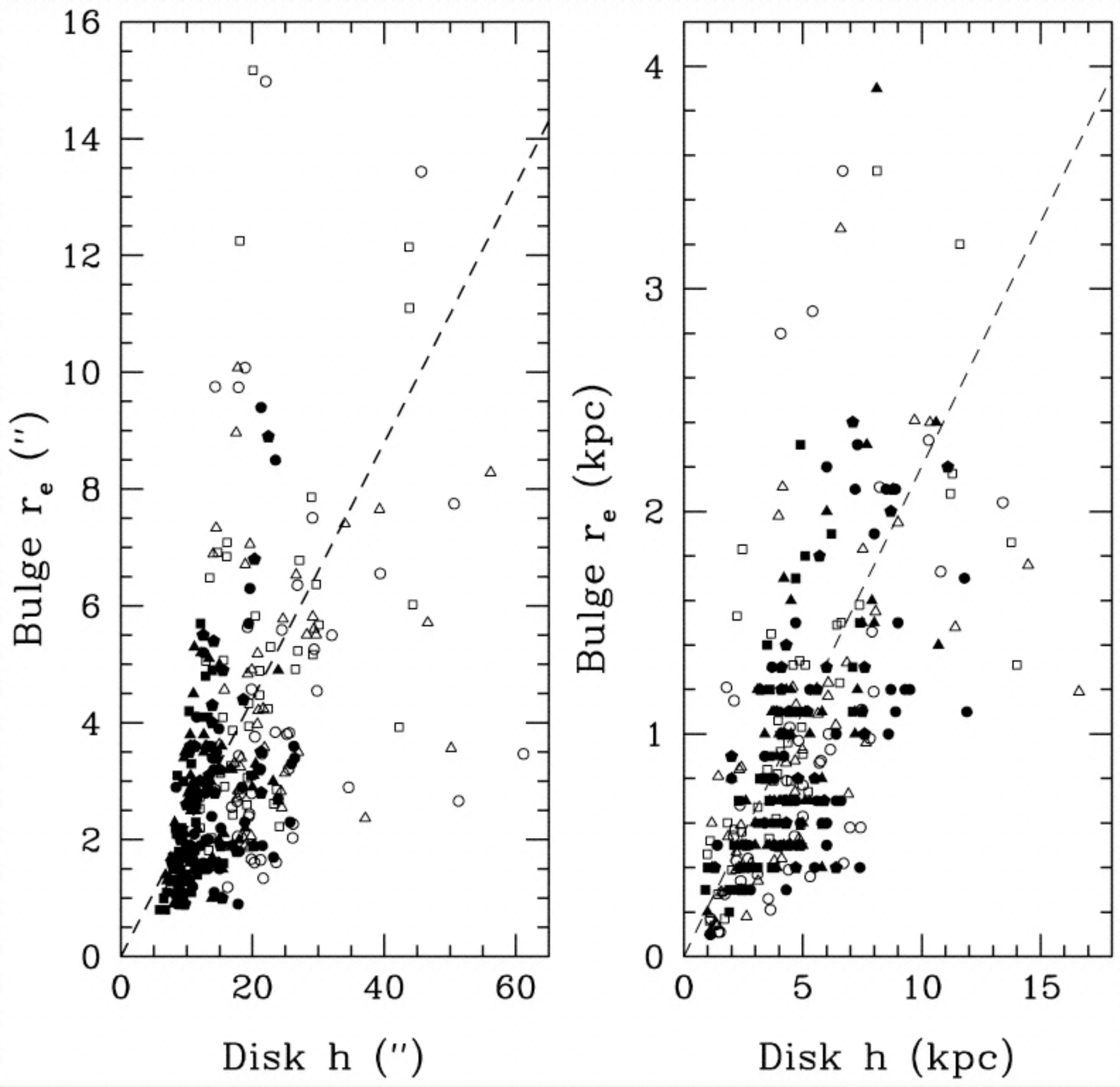
Kormendy 2009



Kormendy 2006

Spirals/Disks: SB Profiles

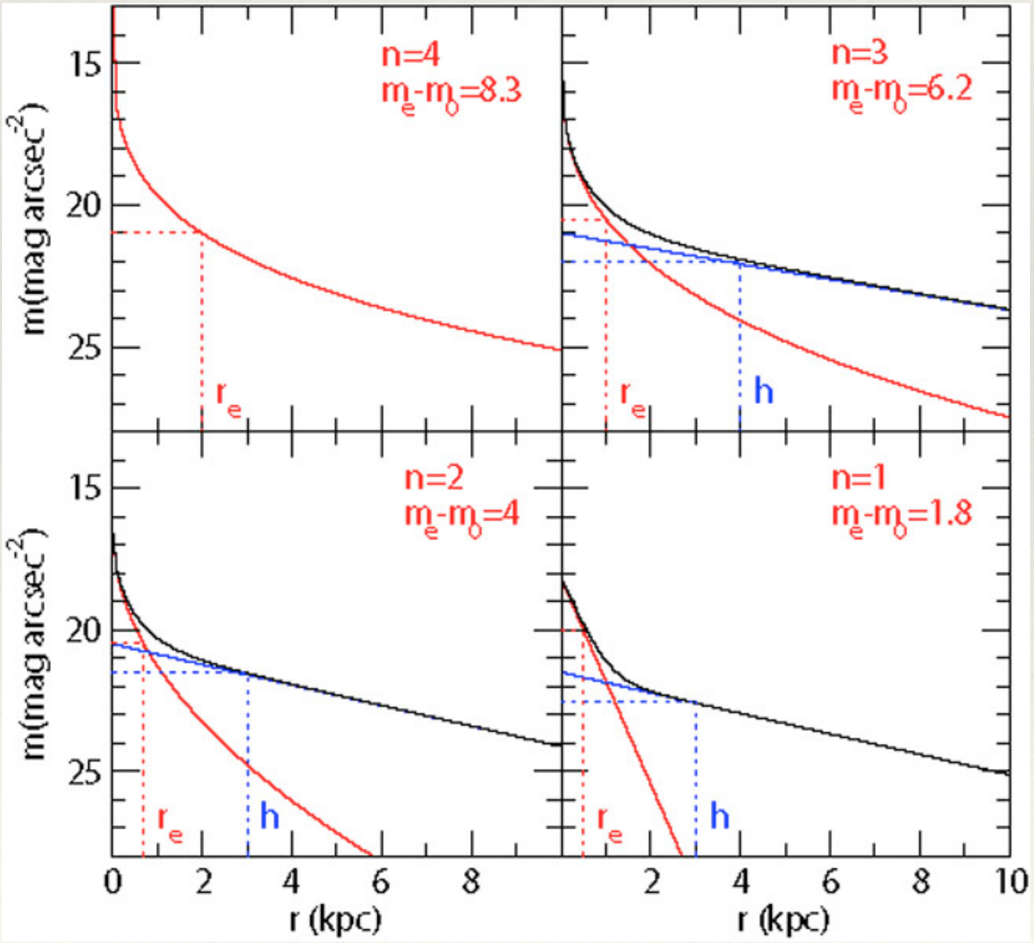
- Disk is well fit by an exponential profile (n~1)
    - Disk scale lengths r_d typically several kpc
- Rough correlation between bulge scale length and disk scale length



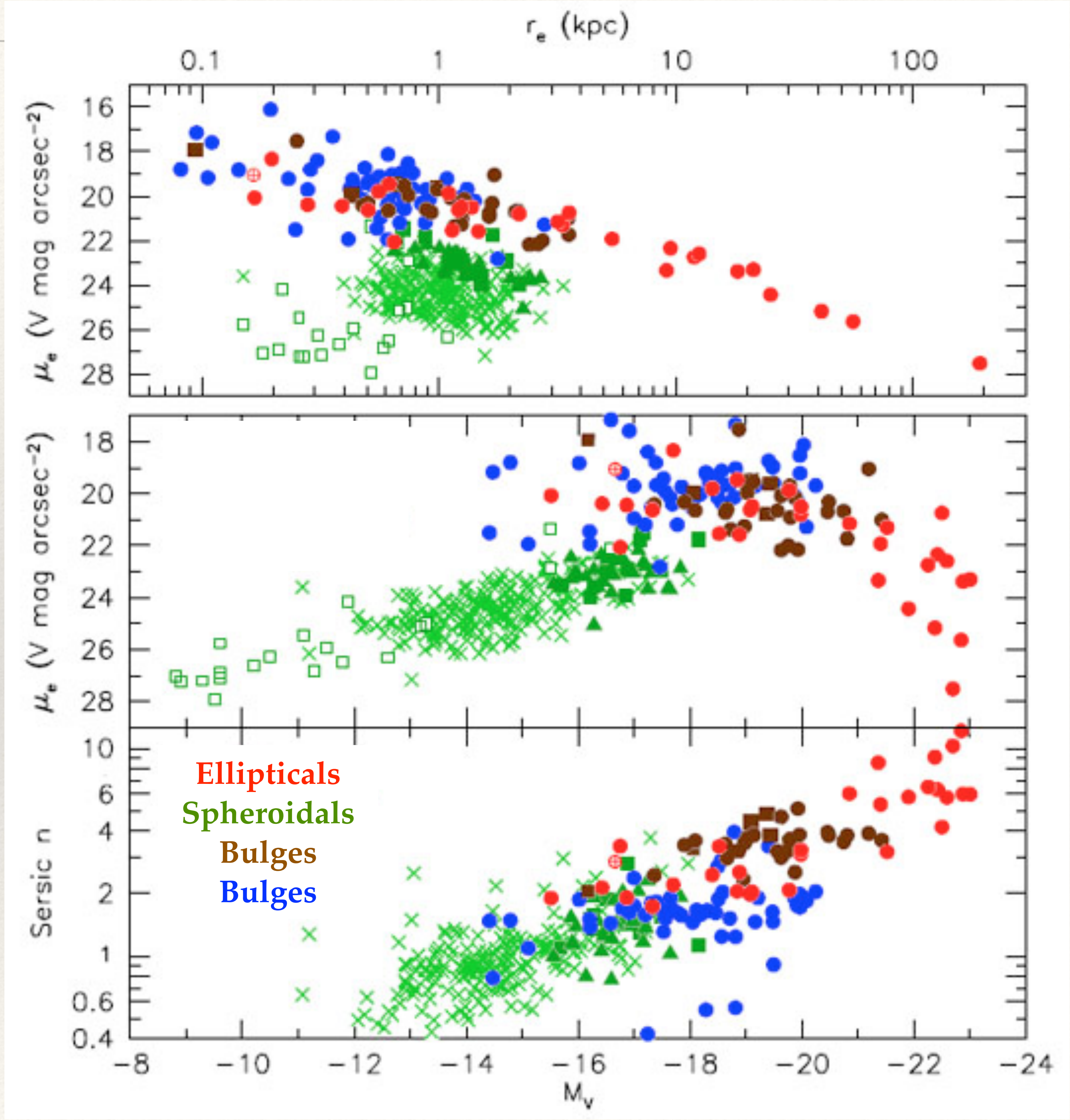
Macarthur, Courteau, & Holtzman 2003

Spirals/Disks: SB Profiles

- Bulges show a range of Sersic ***n***, similar to ellipticals



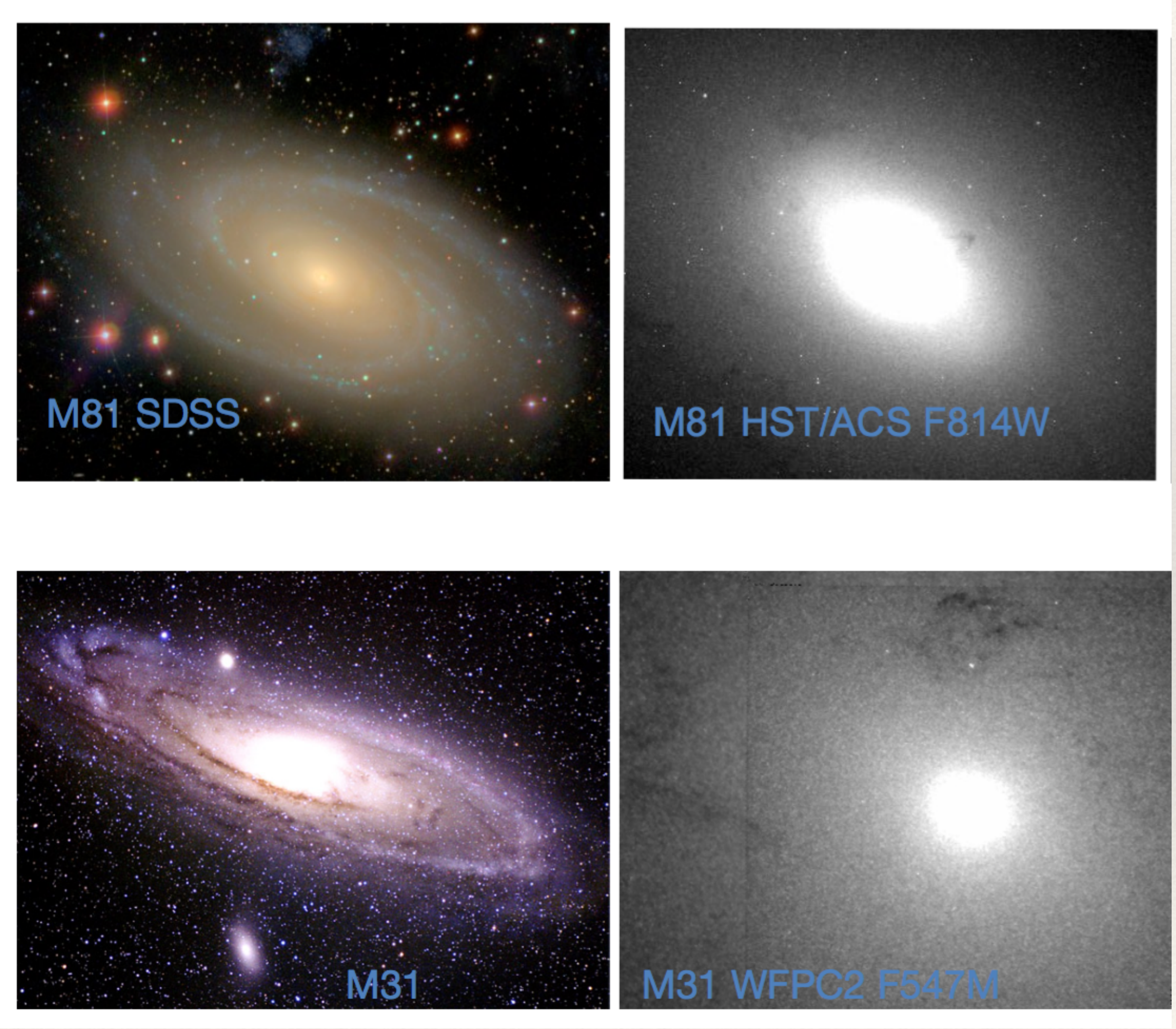
Gadotti 2009



Kormendy et al. 2008

Spirals/Disks: SB Profiles

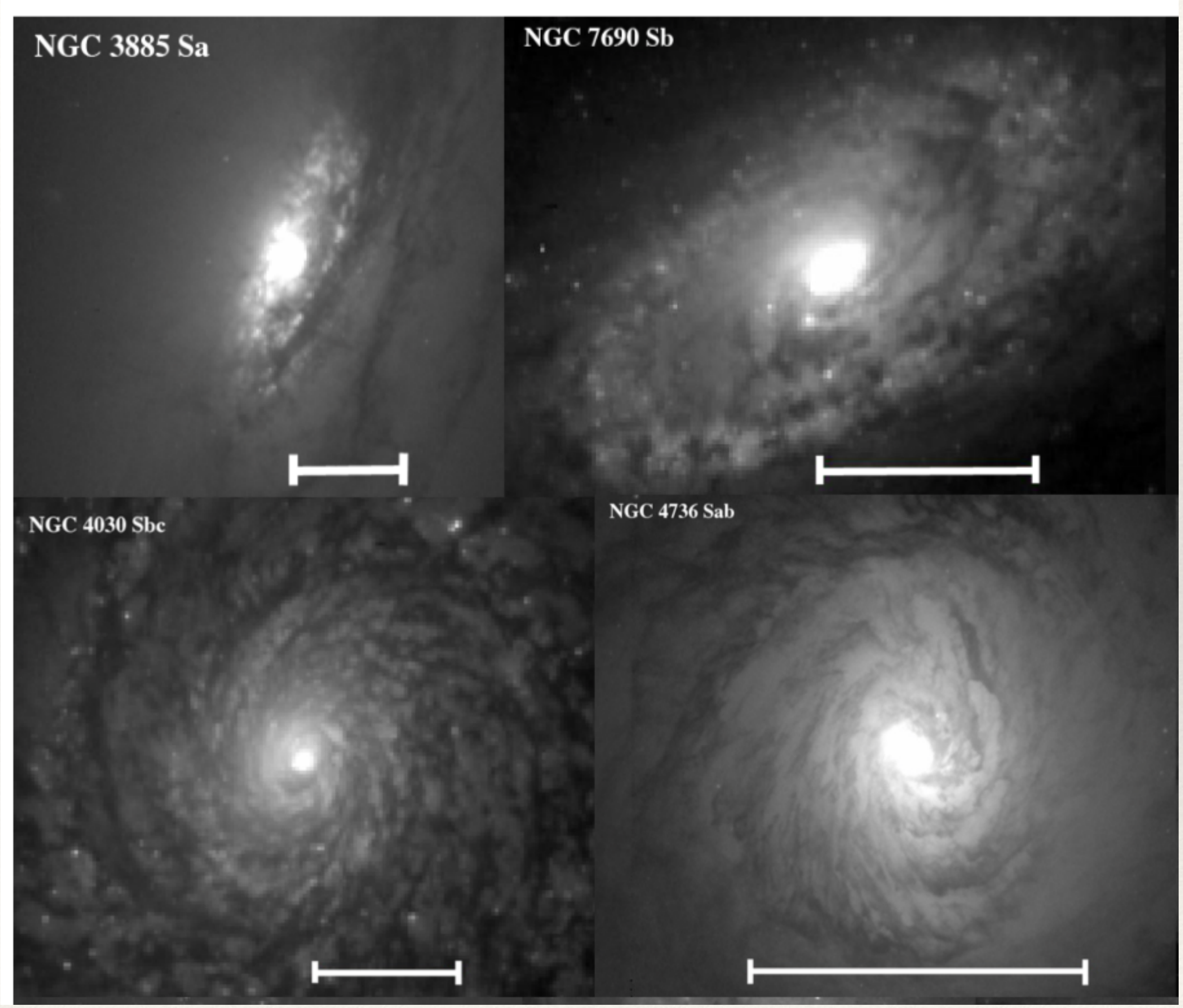
- Two types of bulges:
- **Classical bulges** are like “little elliptical galaxies surrounded by a disk” (Renzini 1999)
  - Sersic n > 2
  - high velocity dispersion
  - no spiral structure



- Possibly related to mergers “heating up” stellar velocities

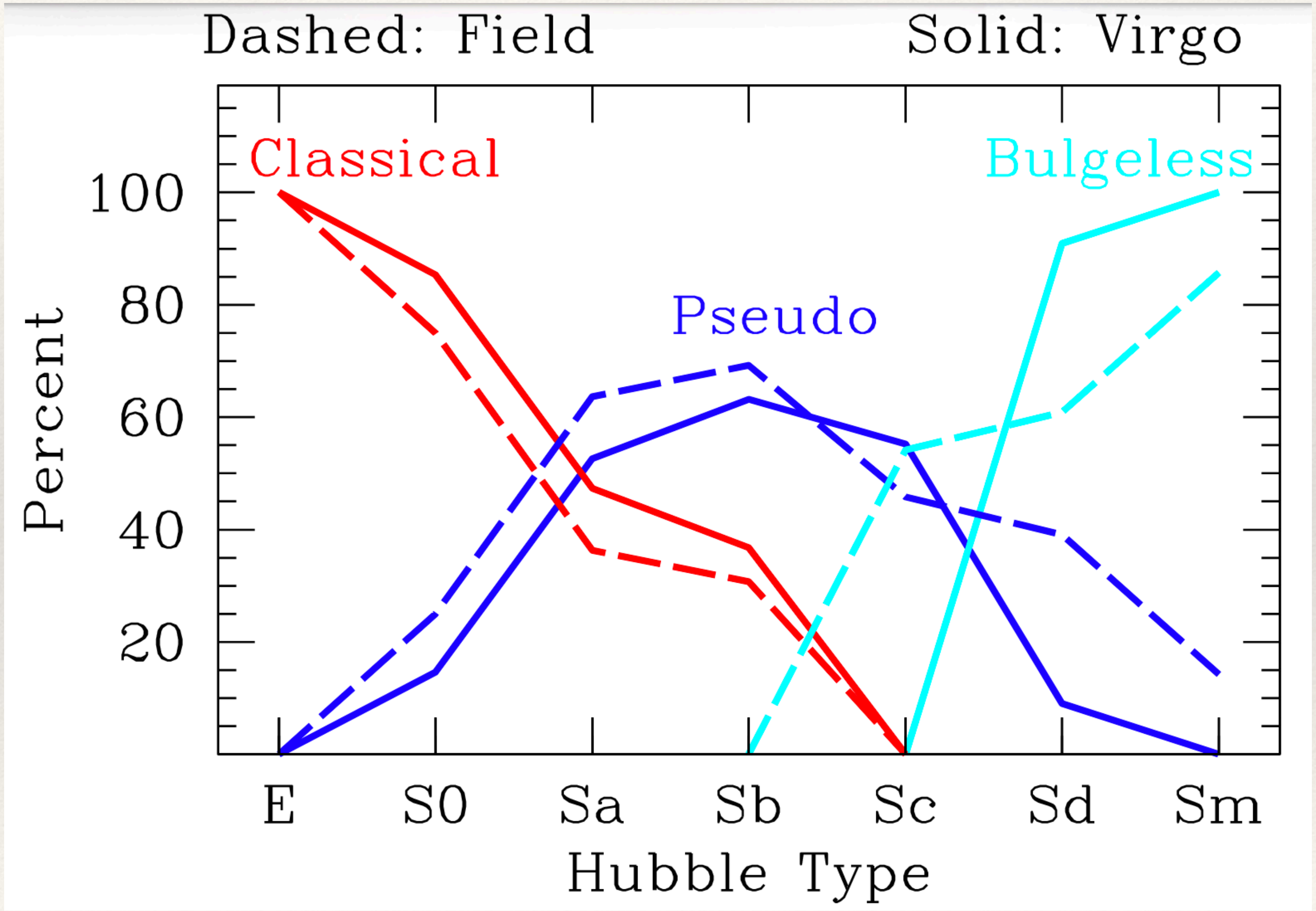
Spirals/Disks: SB Profiles

- “**Pseudobulges**“show disk-like properties:
    - Sersic n < 2
    - low velocity dispersion
    - may originate from disk, be related to bars
    - "secular evolution"



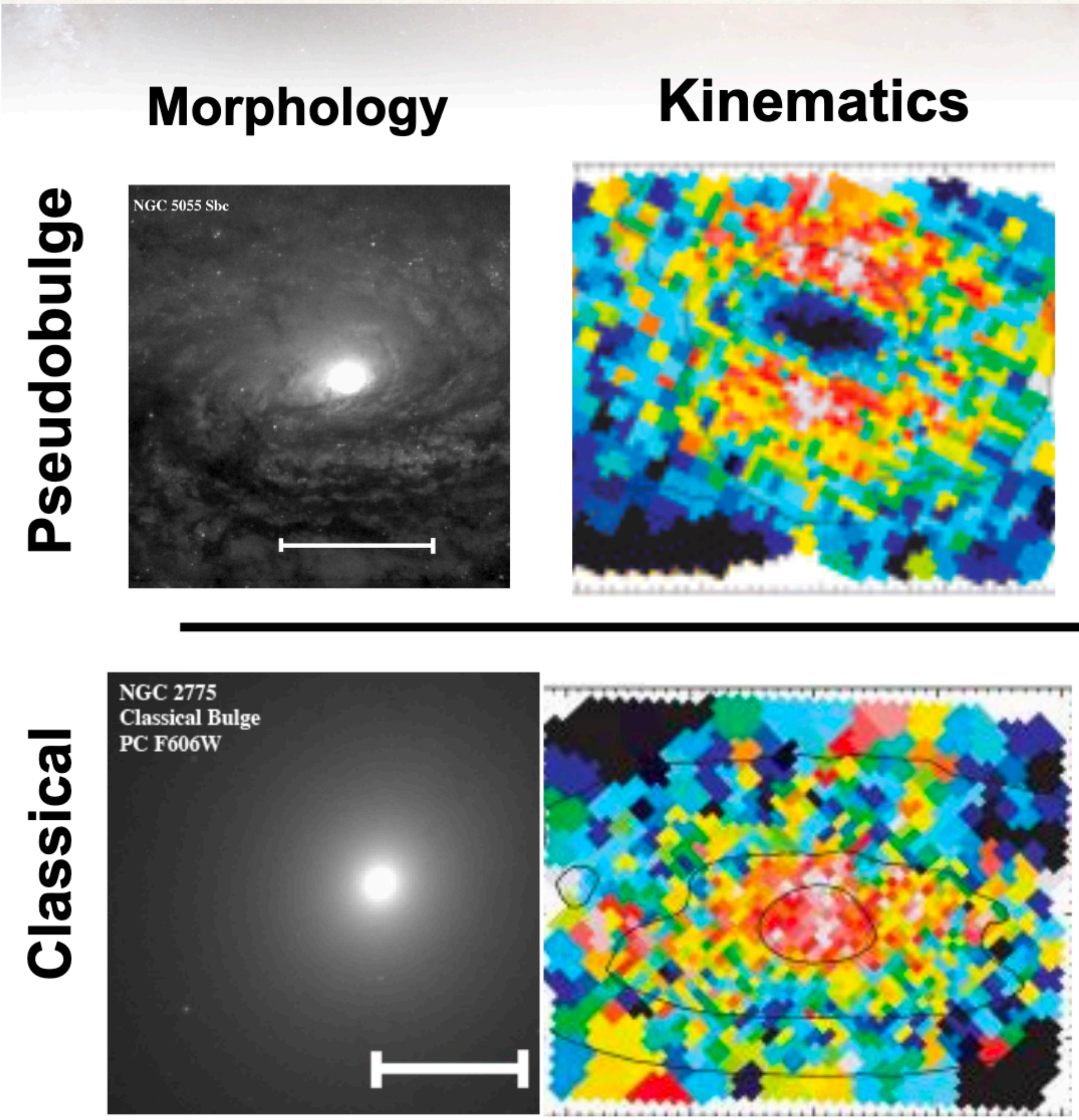
Spirals/Disks: Bulge

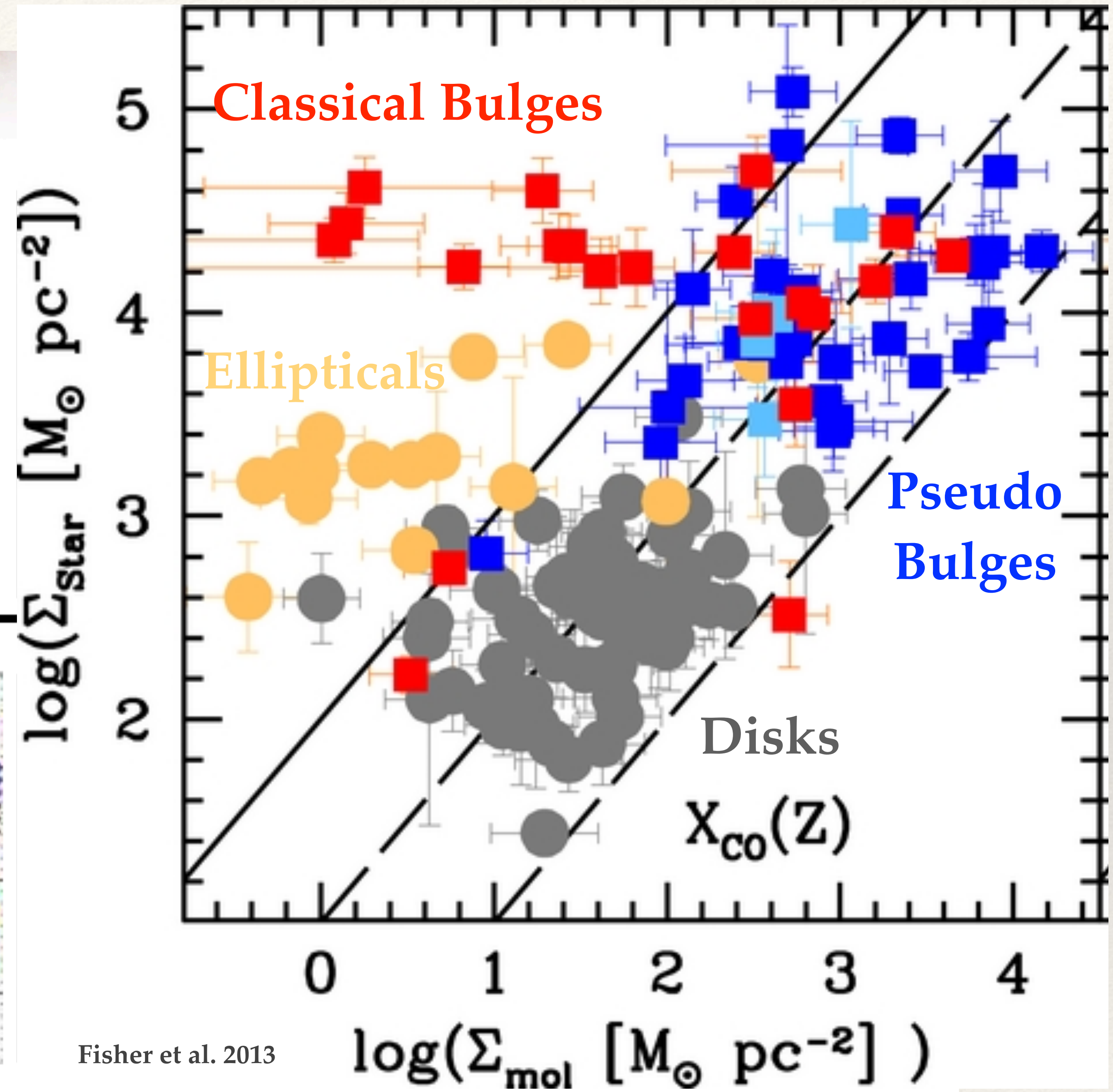
- Pseudobulges are very common (~75%)
- particularly in Sa-Sc galaxies
- particularly in barred galaxies



Fisher & Drory 2011

Spirals/Disks: Bulge





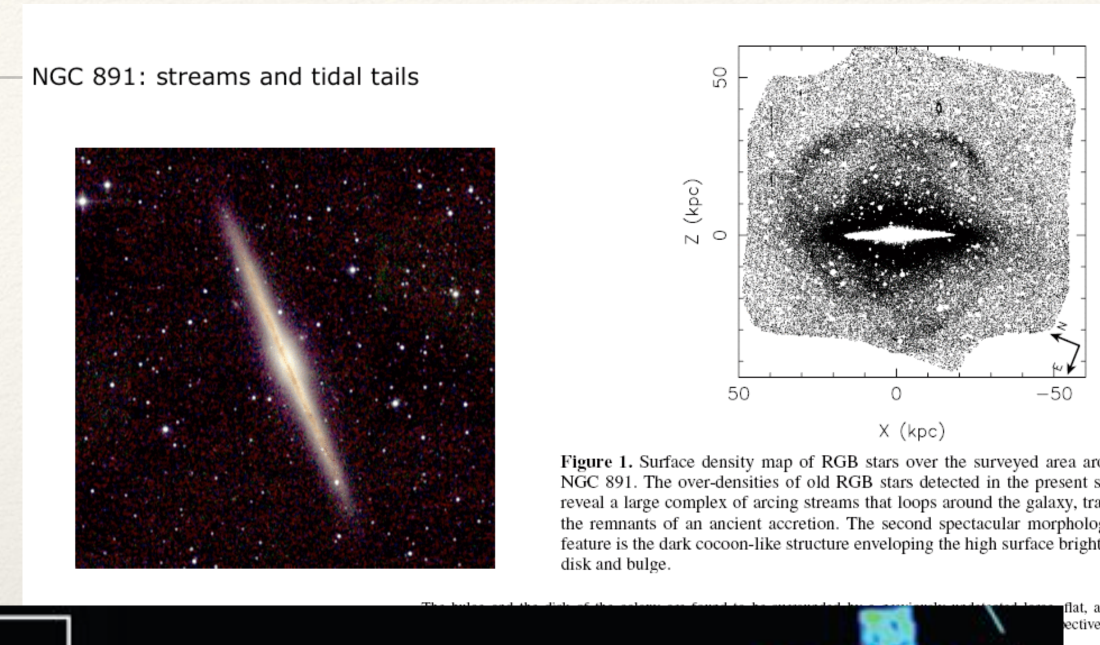
Fisher et al. 2013

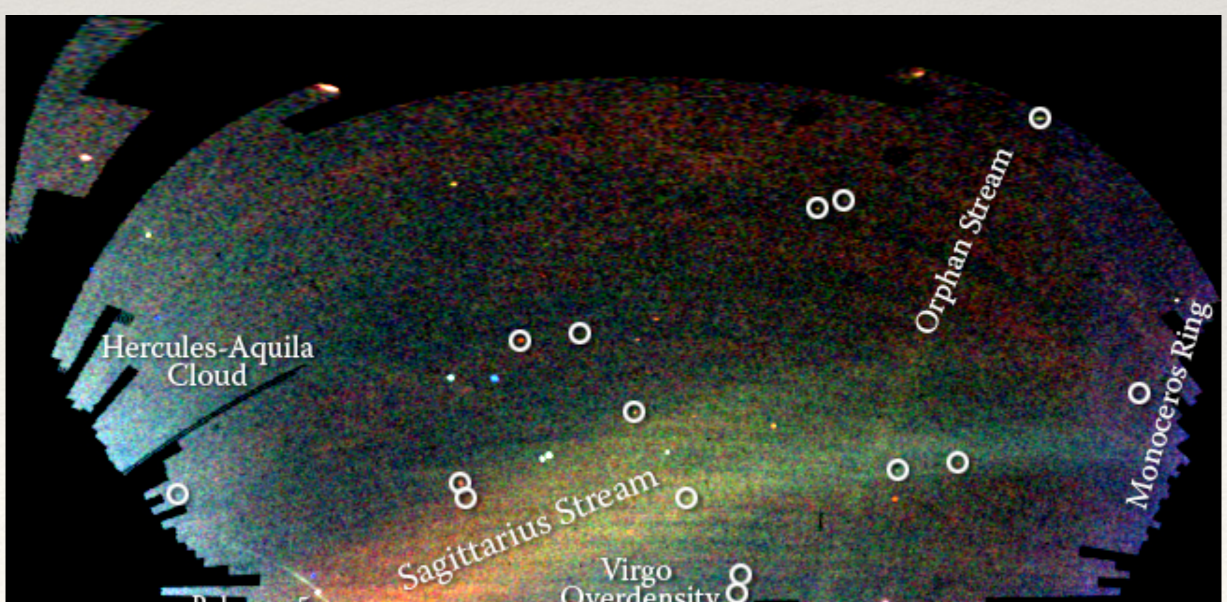
Morphology: Carollo et al. 1997; Kormendy & Kennicutt 2004
Kinematics: Fabricius et al. 2012, Falcon-Barroso 1996, Kormendy 1993,
SFR : Fisher 2006; Fisher et al 2009, 2013; Peletier & Balcells 1996; Gadotti & dos Anjos 2001
Sersic Index & Structure: Fisher & Drory 2008, 2010; Gadotti 2009

Spirals/Disks: SB Profiles

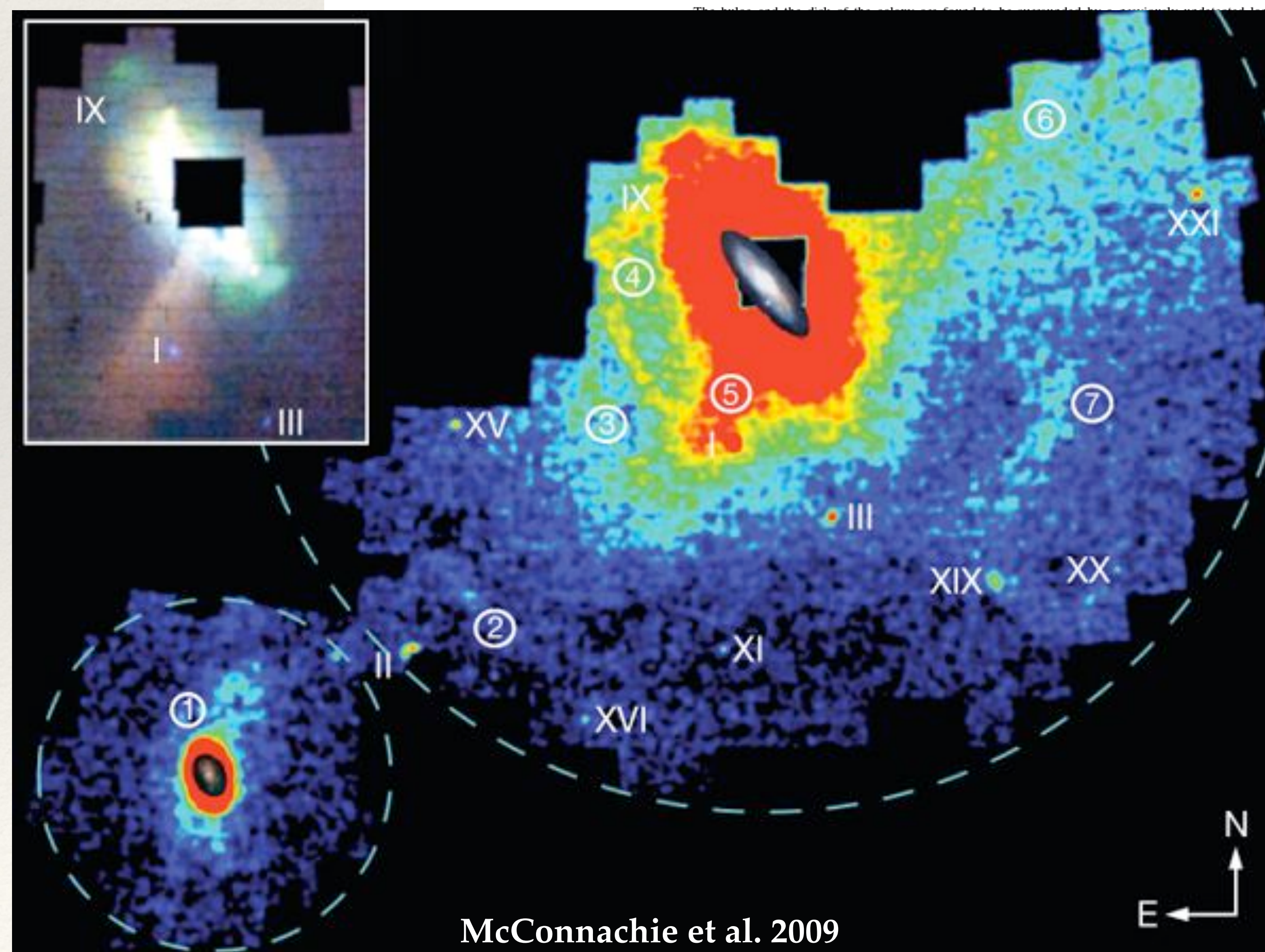
- Spiral galaxies can have **stellar halos** out to ~100s of kpc
- Roughly spherical or moderately flattened but sometimes with significant substructure, e.g., stellar streams

$$\rho \propto r^{-3}$$





Milky Way "Field of Streams" (V. Belokurov , SDSS)

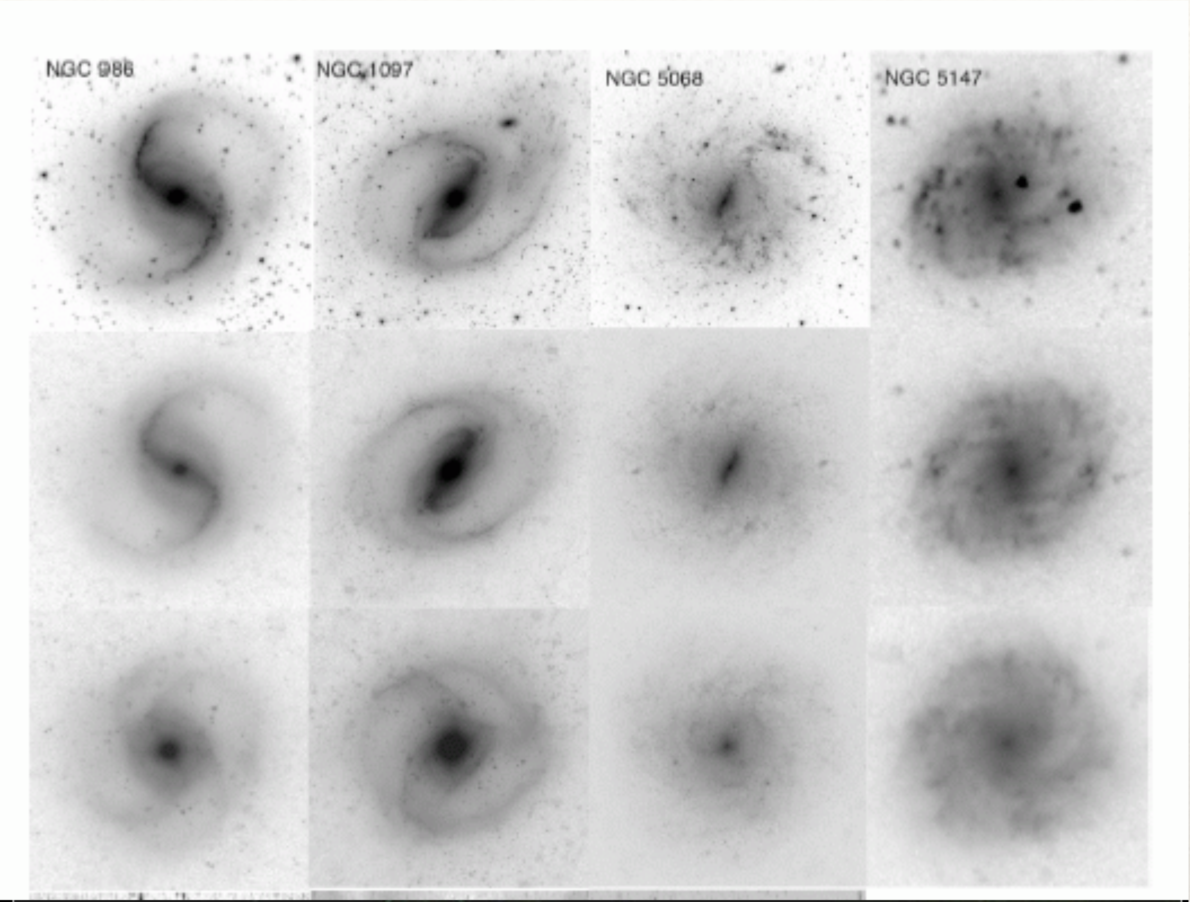


McConnachie et al. 2009

Spirals/Disks: Bars

- **Non-axisymmetric features — Bars:**
  - Many disk galaxies (~50-70%) have bars
    - axis ratios of 2.5 - 5
    - stars on elongated orbits
    - factor of 2-3 boost in mass density
  - Likely form due to dynamical instability in disk
  - Perturb axial symmetry — redistribute angular momentum, perturbs orbit, and drive gas towards center
  - Inner regions may become vertically unstable and resemble bulges edge-on, e.g. **"X"** or **"peanut-shaped" bulges**

Elmegreen et al. 2011



Elmegreen et al. 2011

Spirals/Disks: Arms

- **Non-axisymmetric features — Spiral Arms:**
  - Variety of morphologies: ”grand-design”, “multi-arm”, or “flocculent”
  - Regions of enhanced star formation
    - Prominent in blue light due to luminous, hot, young stars
    - Visible in red light and gas as well, so not entirely young
    - Mass contrast < luminosity contrast --> spiral arms may not be some fundamental property