Scaling Relations of late-type galaxies

- an observational perspective -

- Lecture I Trends along the Hubble sequence
- Lecture II Galaxy rotation curves
- Lecture III Tully-Fisher relations

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Bertinoro, May 2006

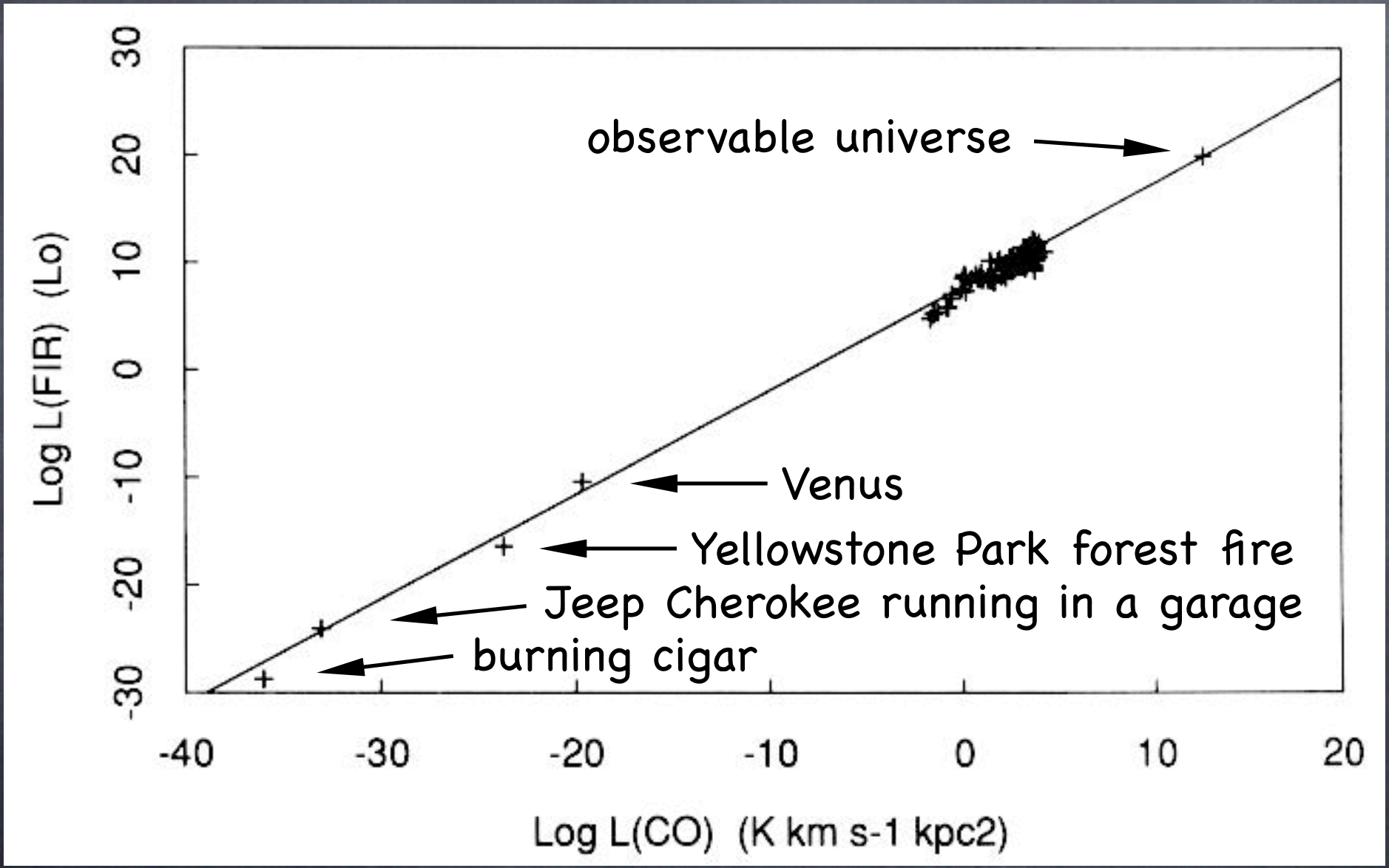
galaxy scaling relations

wide variety of individual peculiarities
→ lost in details

get the `Big Picture' → find a limited set
of meaningful global parameters

- Galaxy formation scenarios (reproduce)
  → internal processes of equilibrium
- Evolution of galaxies (predict)
  → how galaxies grow (statistics)
- Astronomical tools (exploit)
  → large scale structure of Universe

What we learn from scaling relations...



Kennicutt, 1989

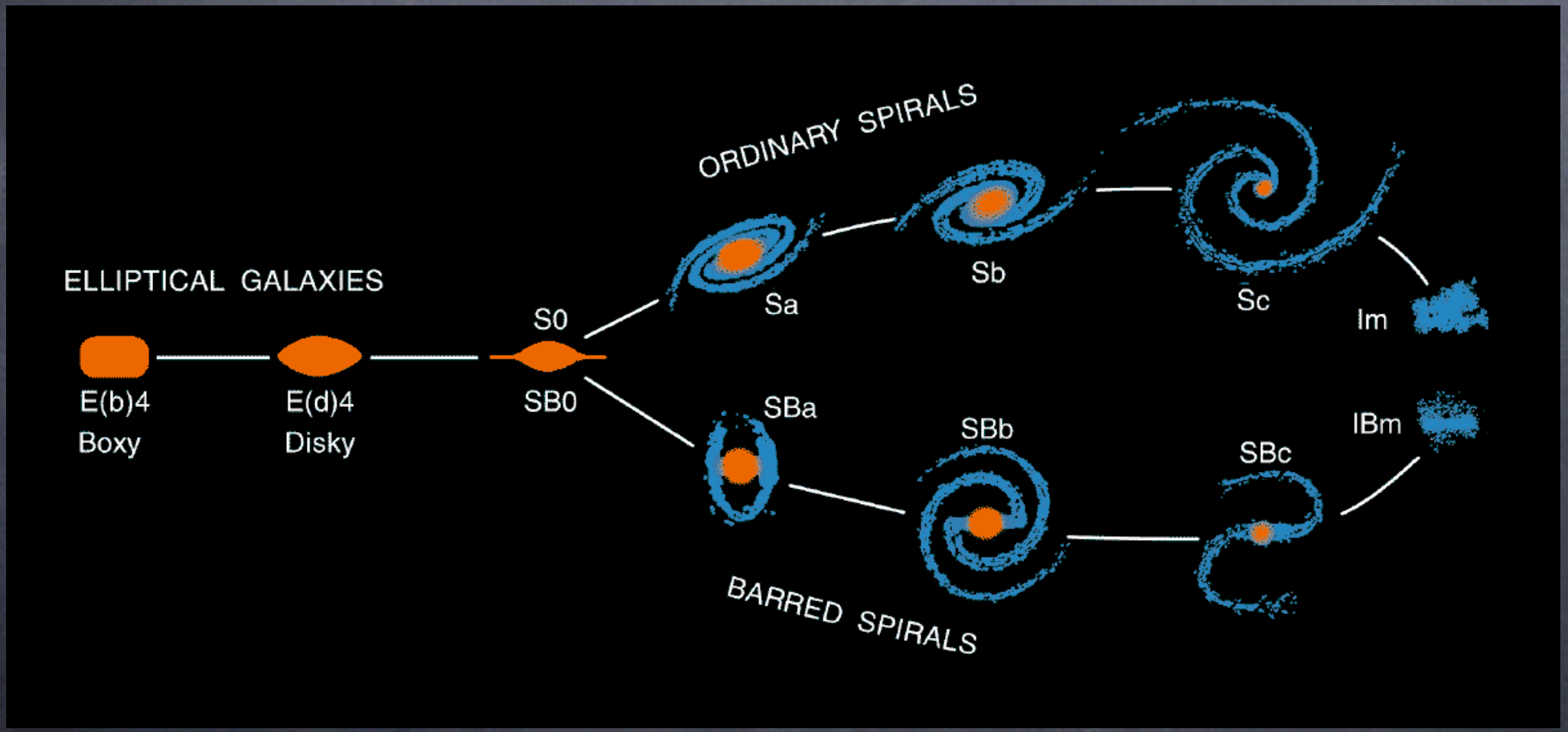
... is sometimes nothing!

Trends along the Hubble sequence

- Morphology
  - structure, environment
- Photometry
  - distribution of light, structure of disks
- Spectroscopy
  - star formation, stellar populations, metallicity
- Gas in galaxies
  - distribution

The Hubble sequence

galaxy classification based on morphology



early-type

late-type

main classification criteria

Basic classes: Sa, Sb, Sc, Sd, Sm, Irr

T-type: 1 3 5 7 9 10

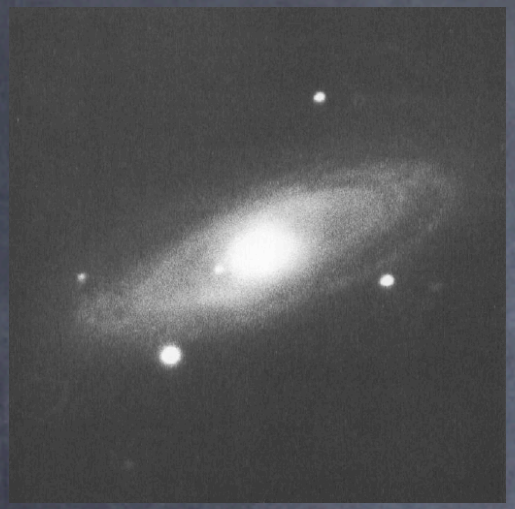
- Primary : Small scale lumpiness
  → star formation indicator
- Secondary: Bulge-to-disk ratio
  → importance of hot component
- Tertiary : Pitch angle, thickness, # spiral arms
  → stability of stellar disk

Not all criteria agree: e.g. Sa with a small bulge

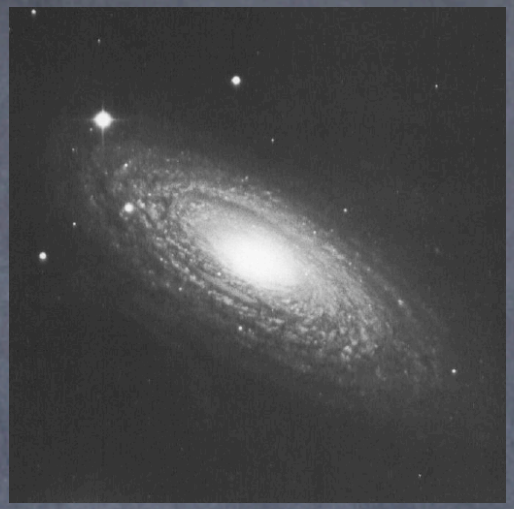
Reality...

Carnegie Atlas of Galaxies

Sa

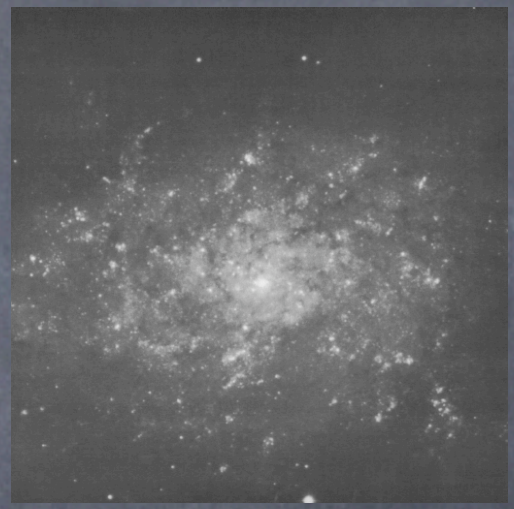


Sb



Sc

Sd

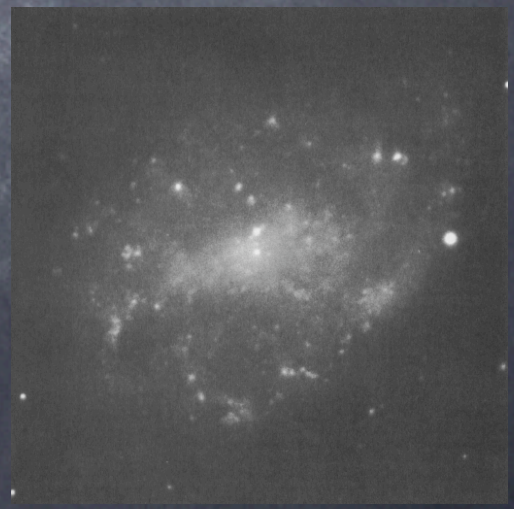


SBa

SBb

SBc

SBd

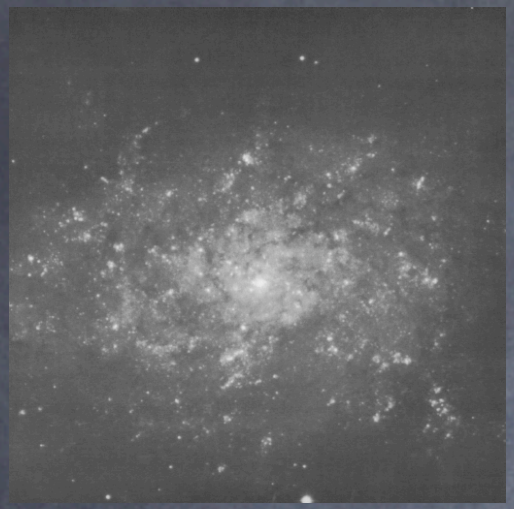


Morphology is not a static quality

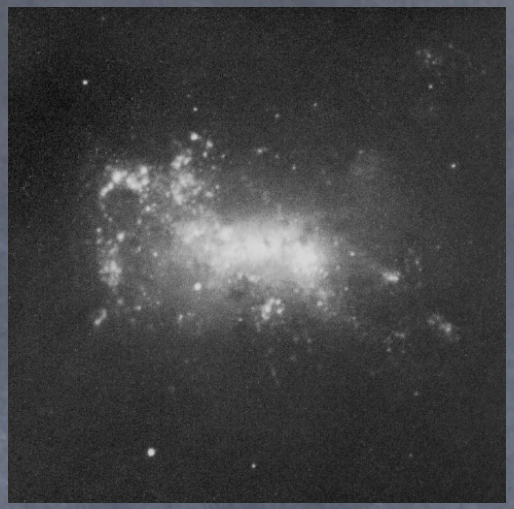
Reality...

Carnegie Atlas of Galaxies

Sd

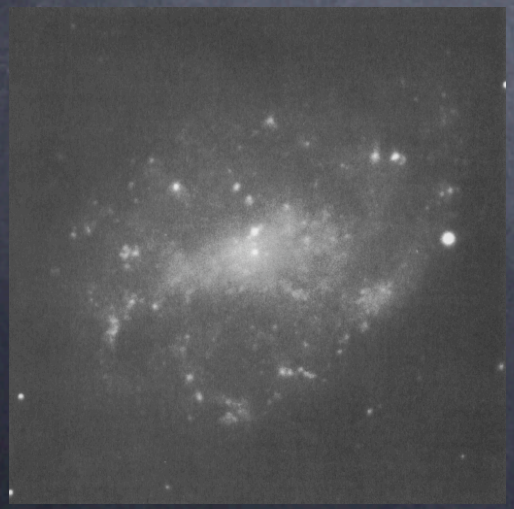


Sm

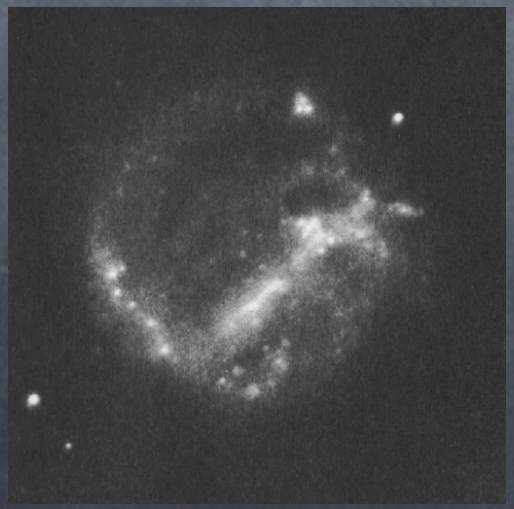


Irr

SBd



SBm



Disk structure is lost.

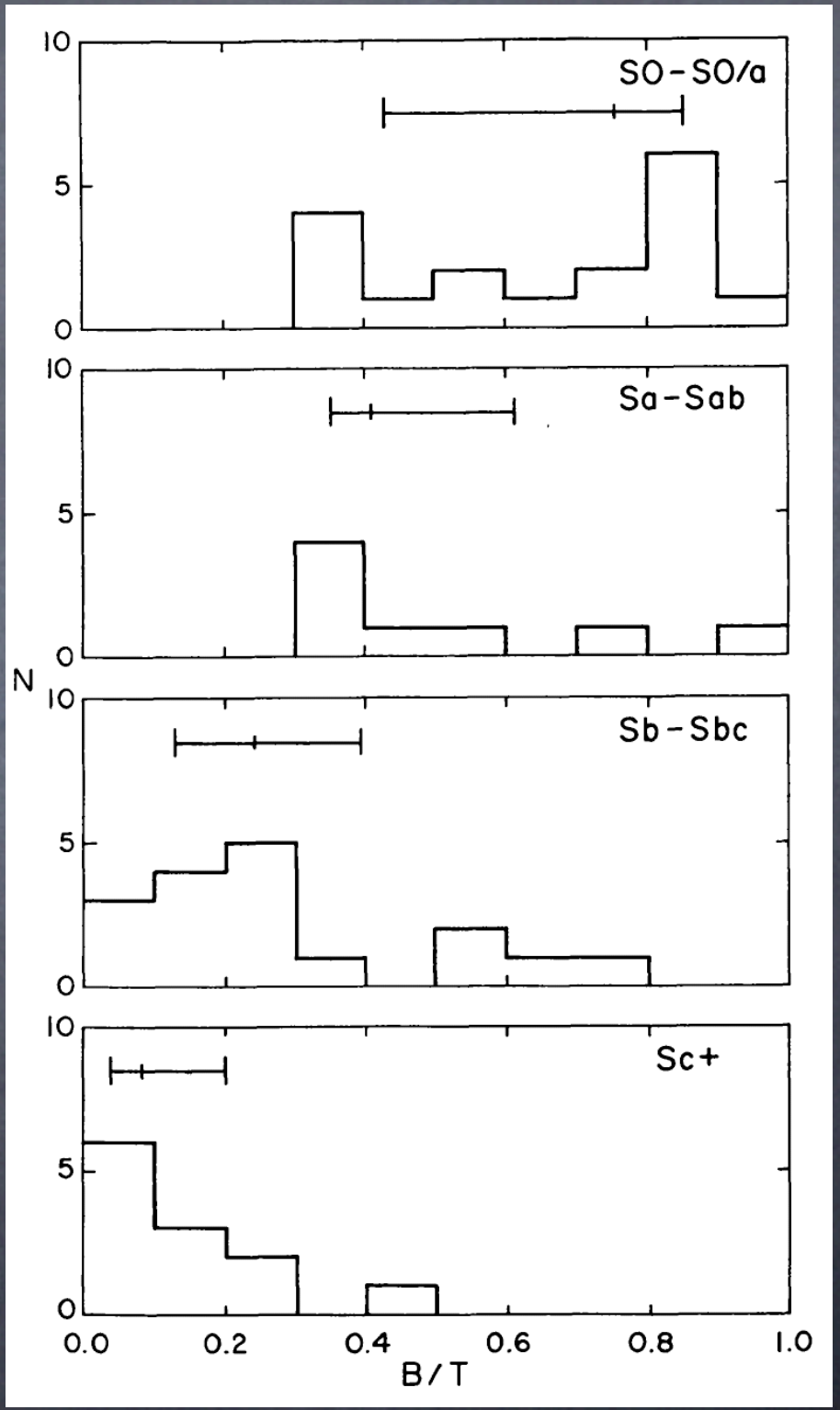
Bulge/Disk ratio

Varies systematically
along Hubble sequence,
but not monotonically.

Sa

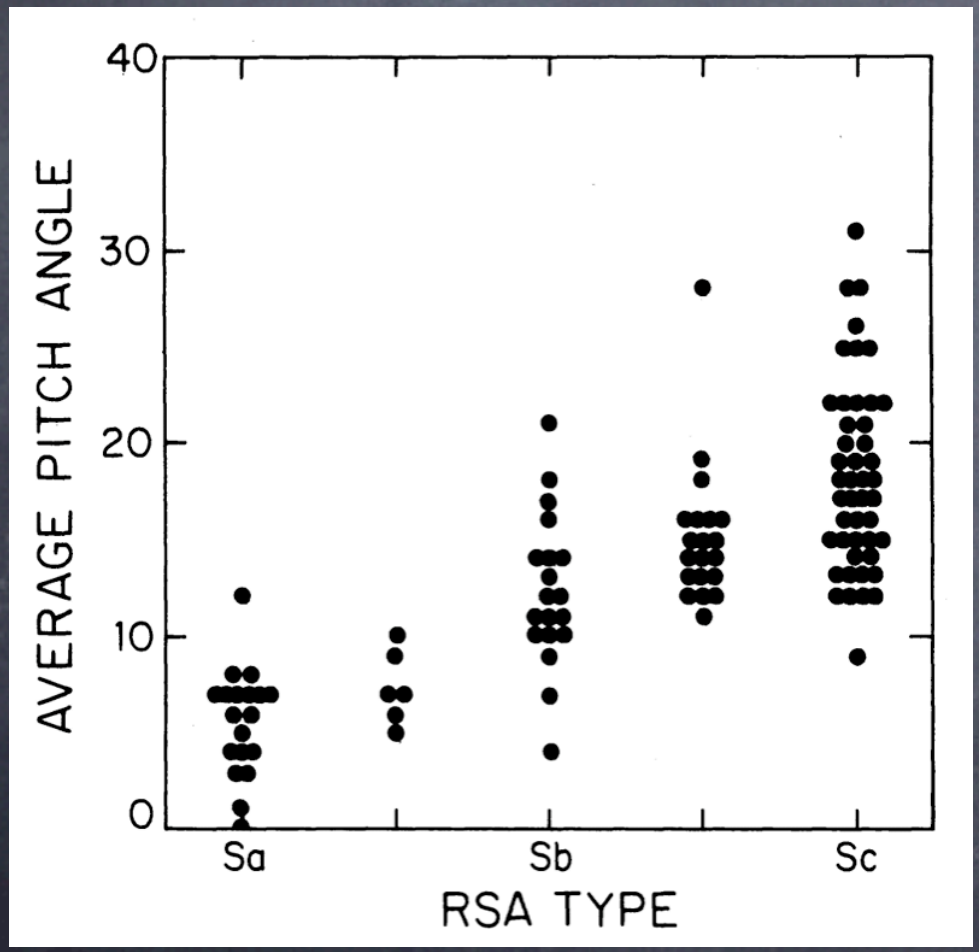
Sb

Sc

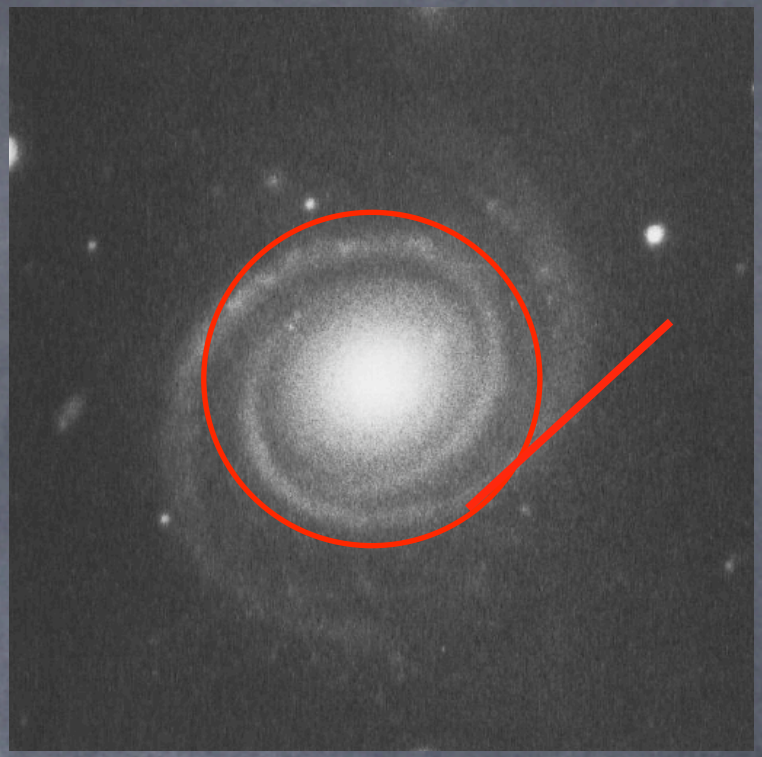


Kent, 1985

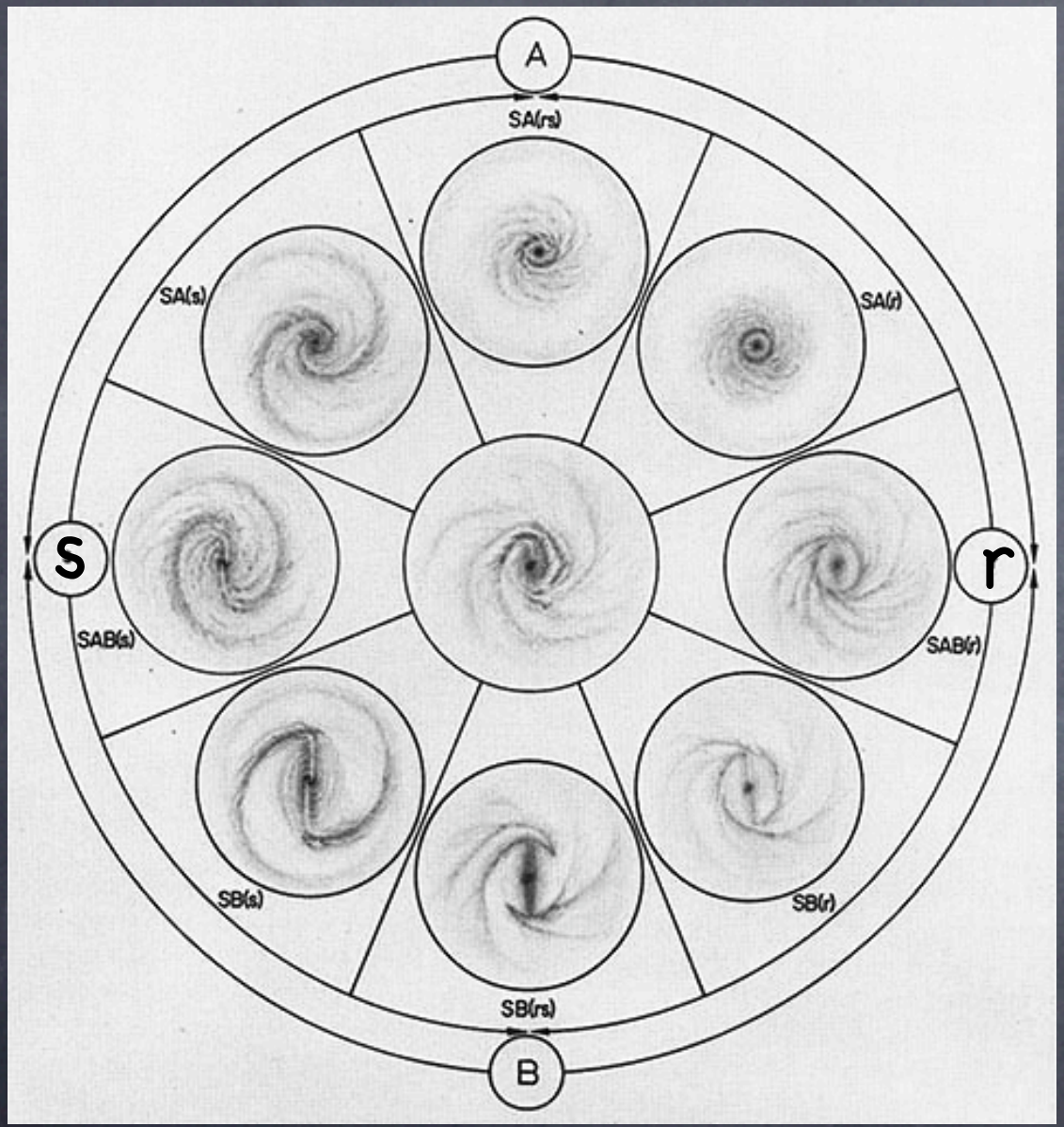
Pitch Angles of spiral arms



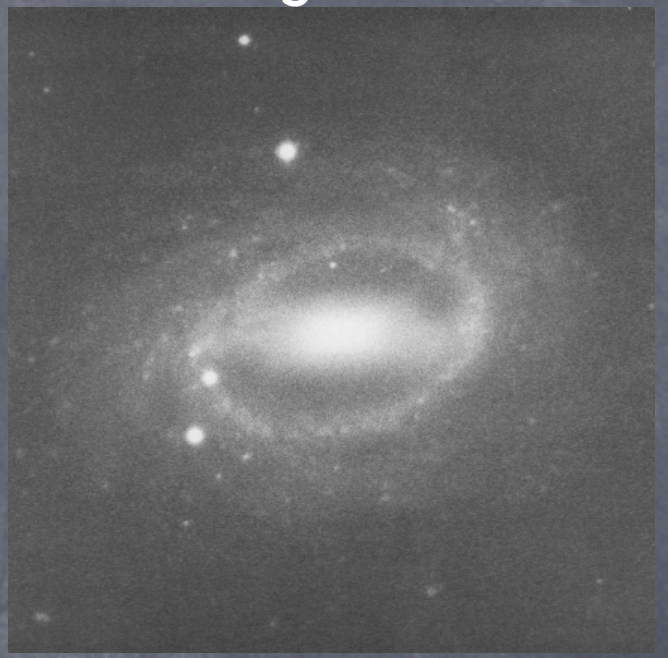
Kennicutt, 1981



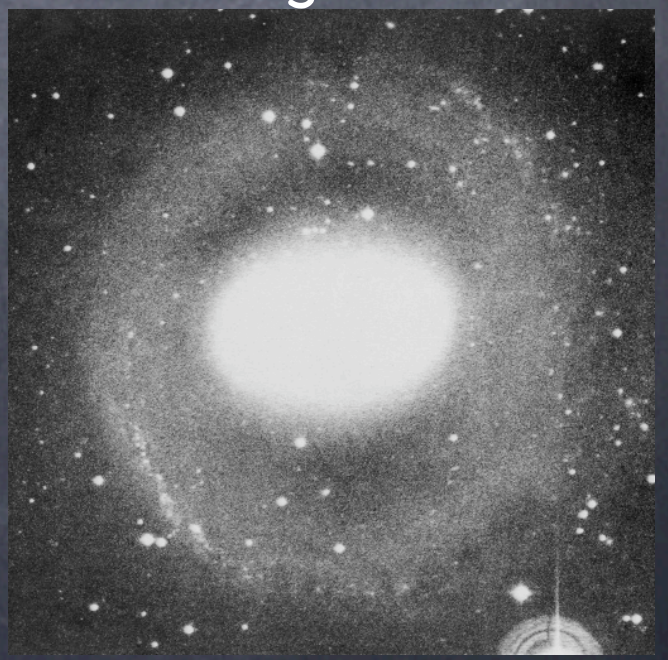
some galaxies have rings



inner ring



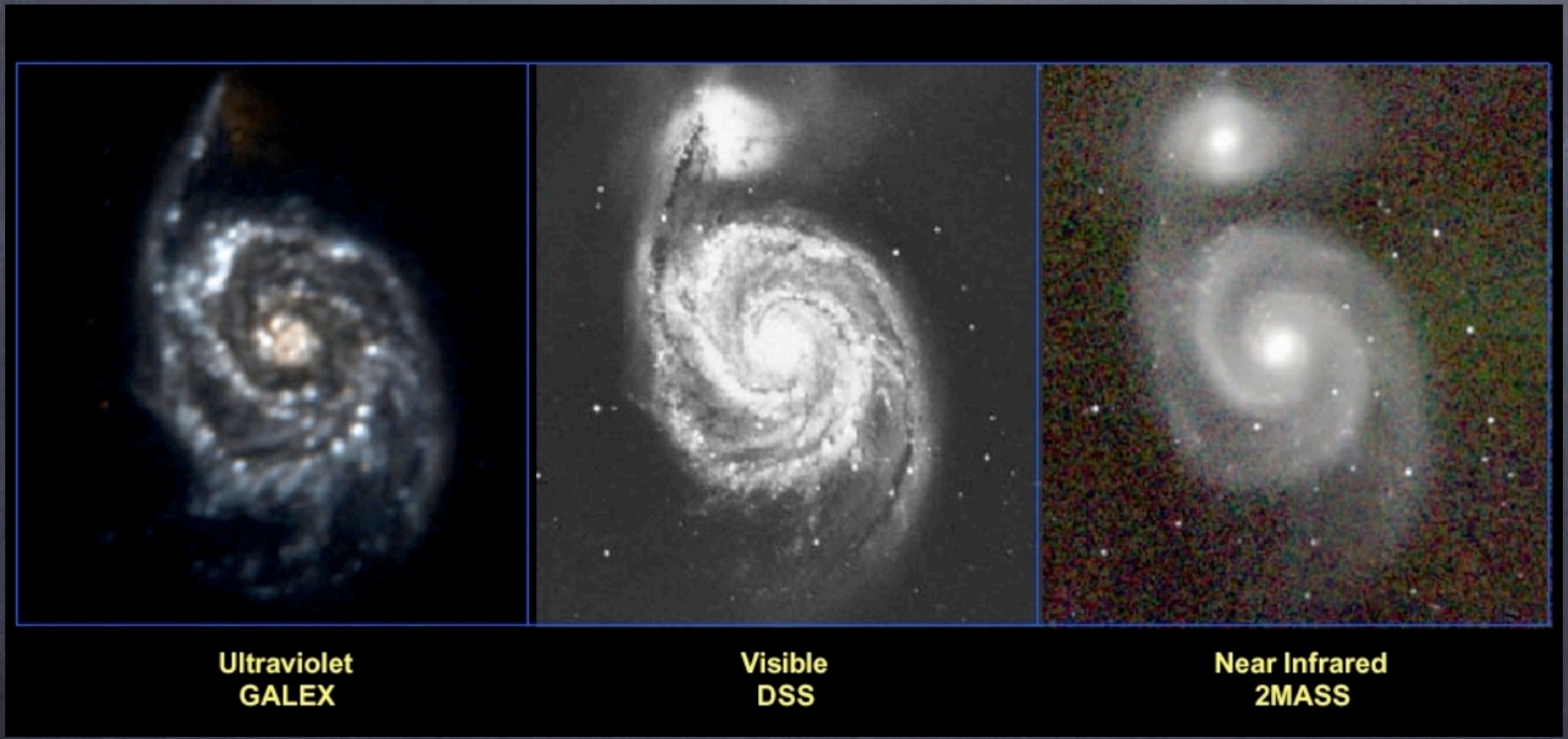
outer ring



mostly associated with
Lindblad resonances

Beware!

Messier 51



young stars

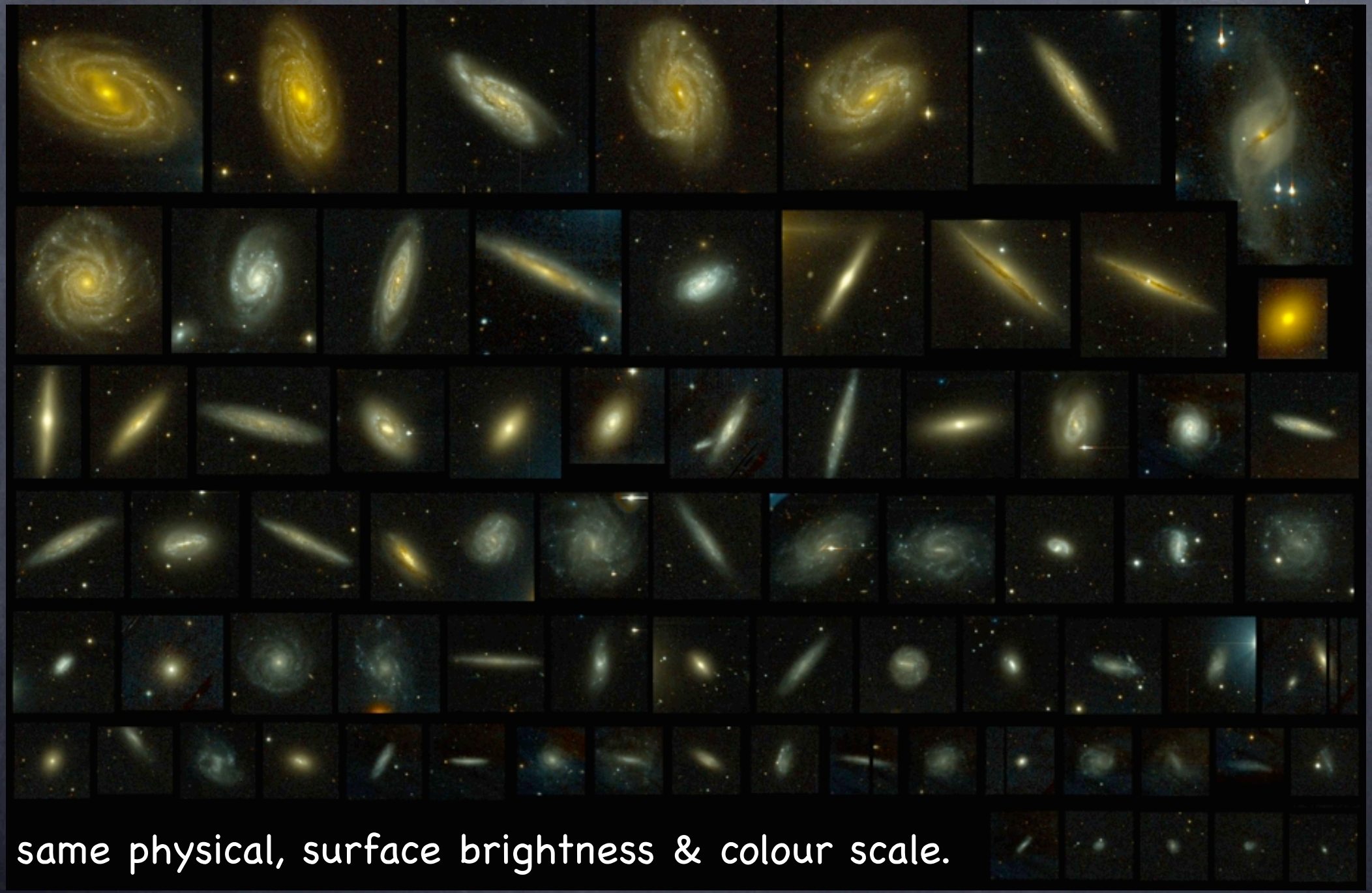
old stars

➢ morphology conveys limited physical information

(e.g. not an evolutionairy sequence)

Galaxies in Ursa Major

volume-limited sample

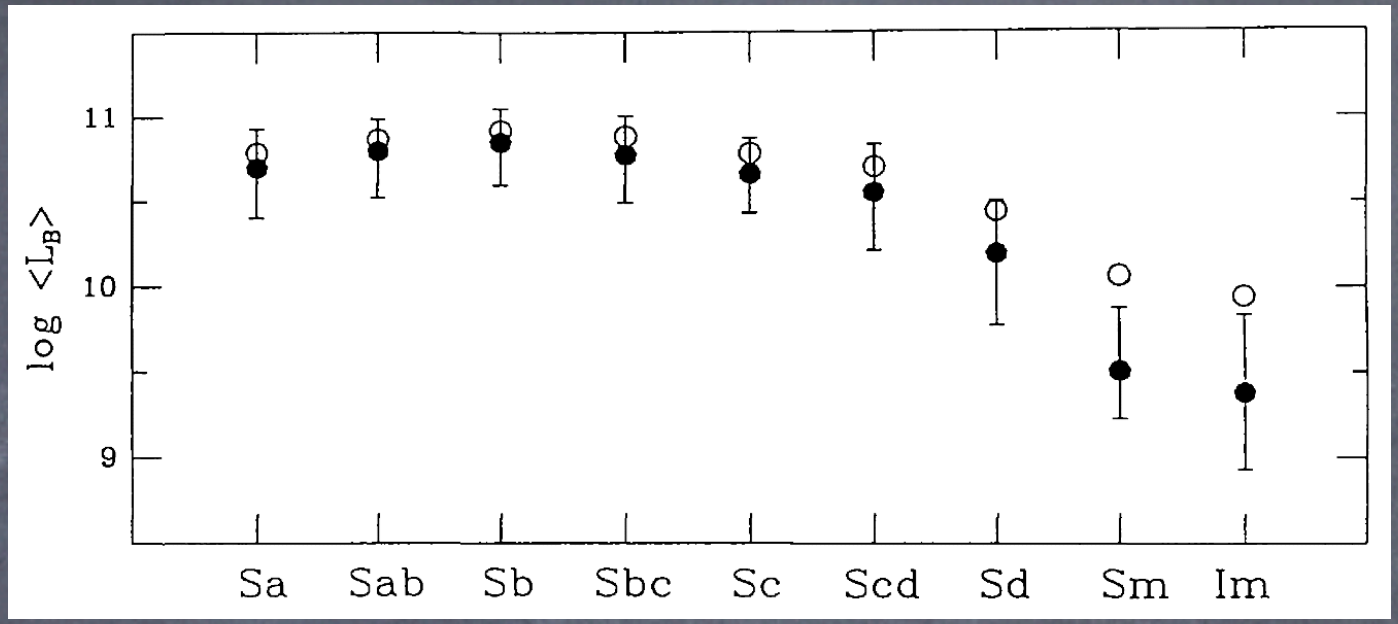


same physical, surface brightness & colour scale.

Luminosity and Colour

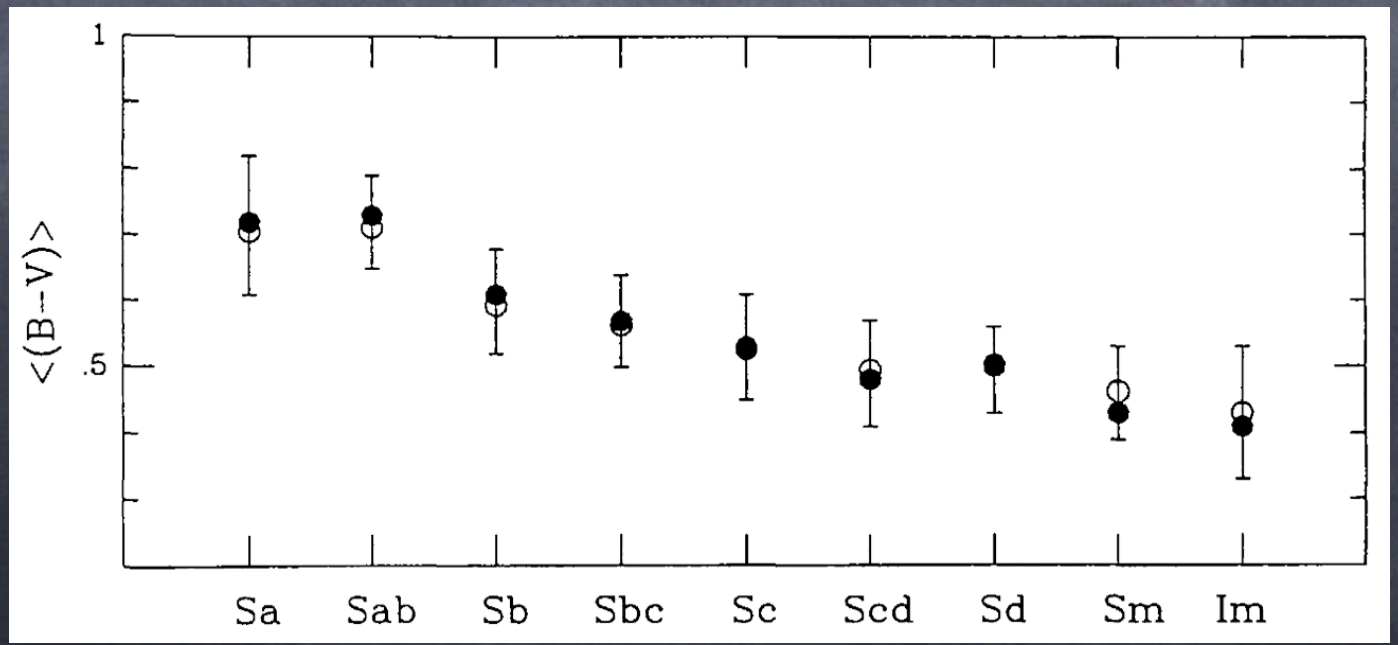
bright

faint



red

blue



Roberts & Haynes, 1994

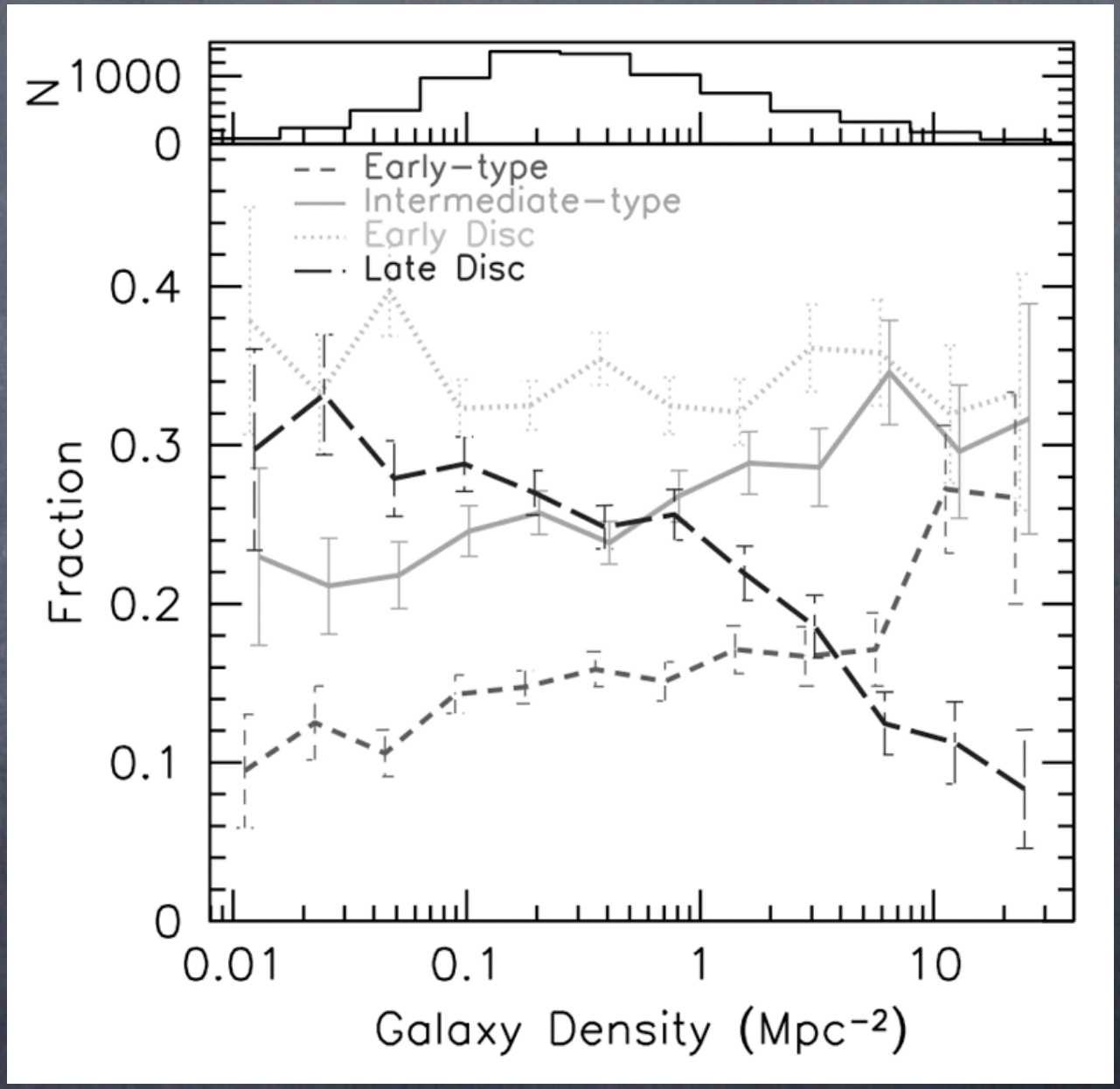
Morphology-Density relation

Morphological mix scales with local galaxy density.

based on SLOAN data

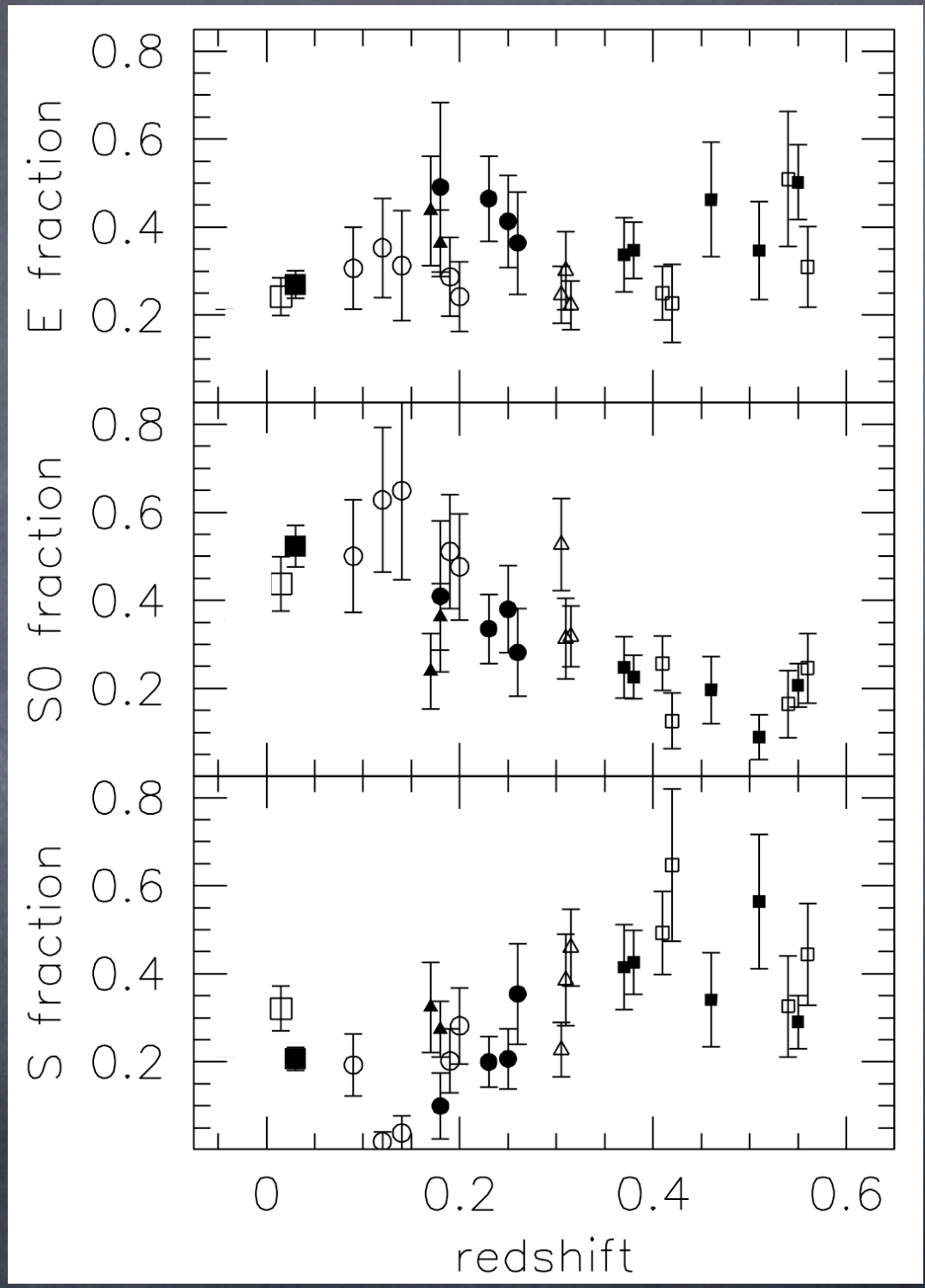
note range in density

Goto et al, 2003



Evolution of morphological mix in clusters.

Galaxy clusters at higher redshifts contain more spirals and less lenticulars.



Fasano et al, 2000

Photometry

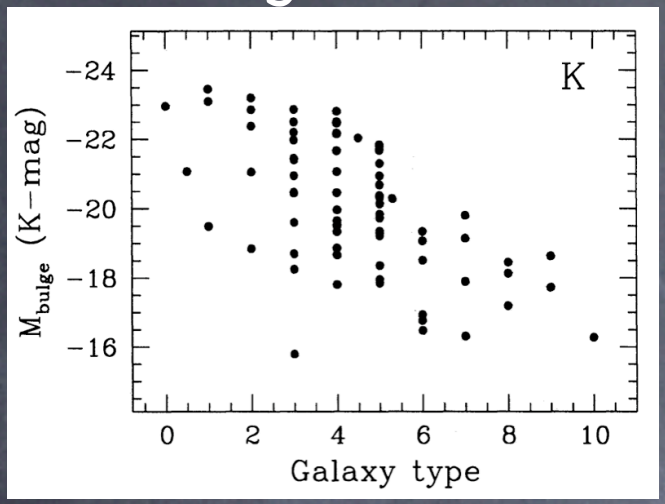
Distribution of light:

- Bulge: Sérsic profile: $I(r) = I_0\ 10^{-b_n(r/r_{eff})^{1/n}}$
- or : $\mu(r) = \mu_0 + 2.5b_n(r/r_{eff})^{1/n}$
- $b_n = 0.87n - 0.14$
- n=4 : de Vaucouleurs
- n=1 : exponential
- Disk: Exponential profile: $I(r) = I_0\ e^{-(r/r_d)}$

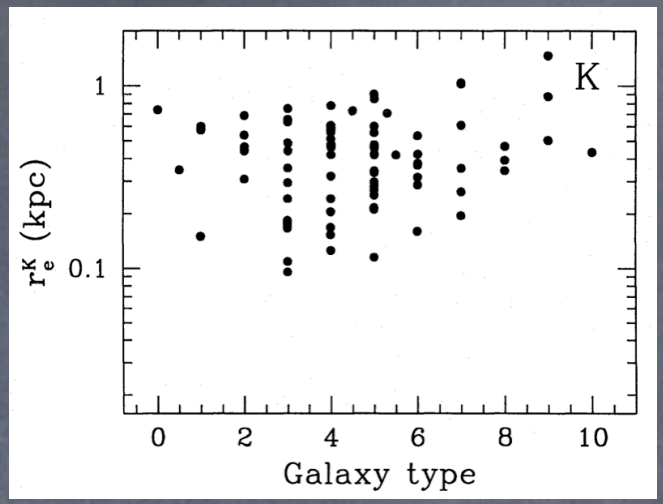
or : $\mu(r) = \mu_0 + 1.086(r/r_d)$

Bulge

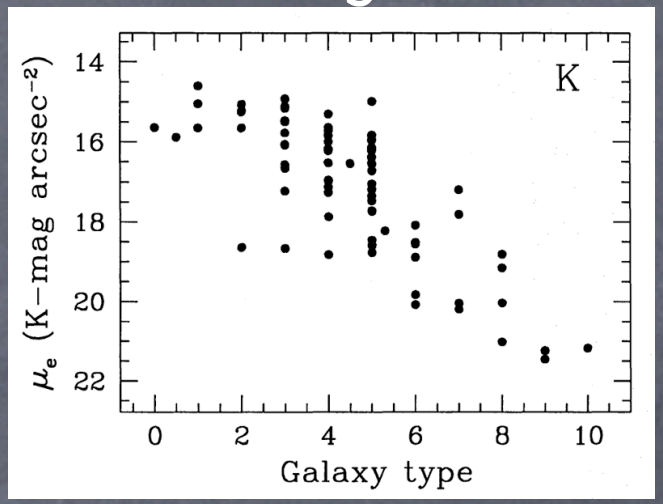
total magnitude



effective radius

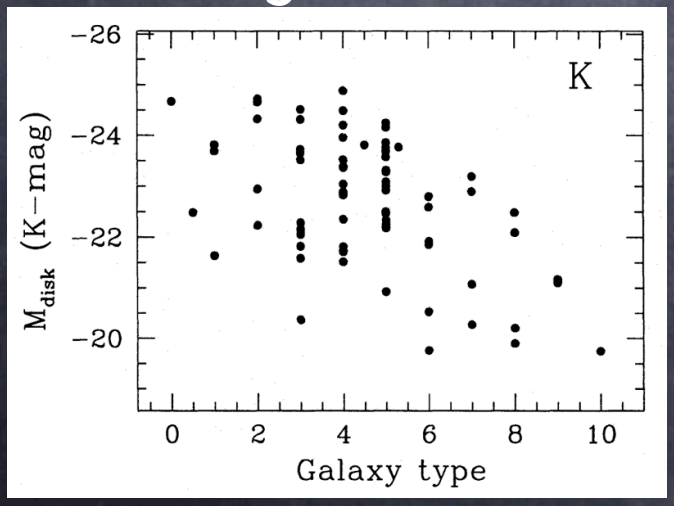


effective surface brightness

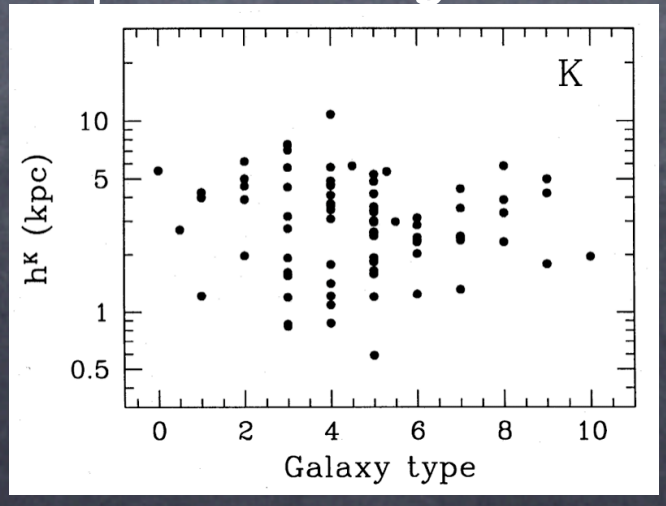


Disk

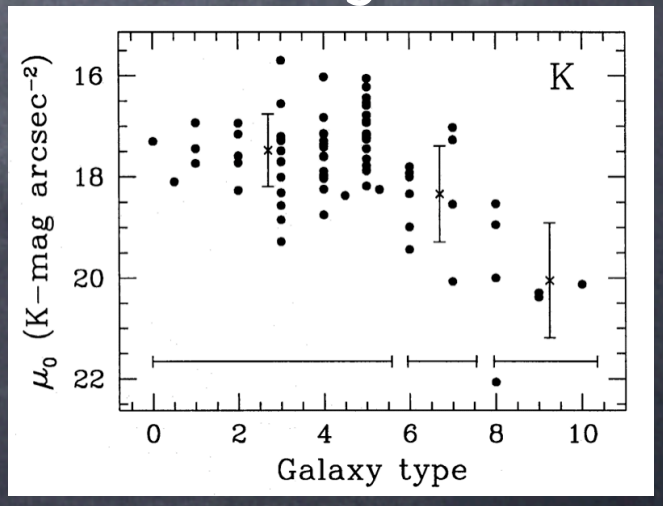
total magnitude



exp. scale length

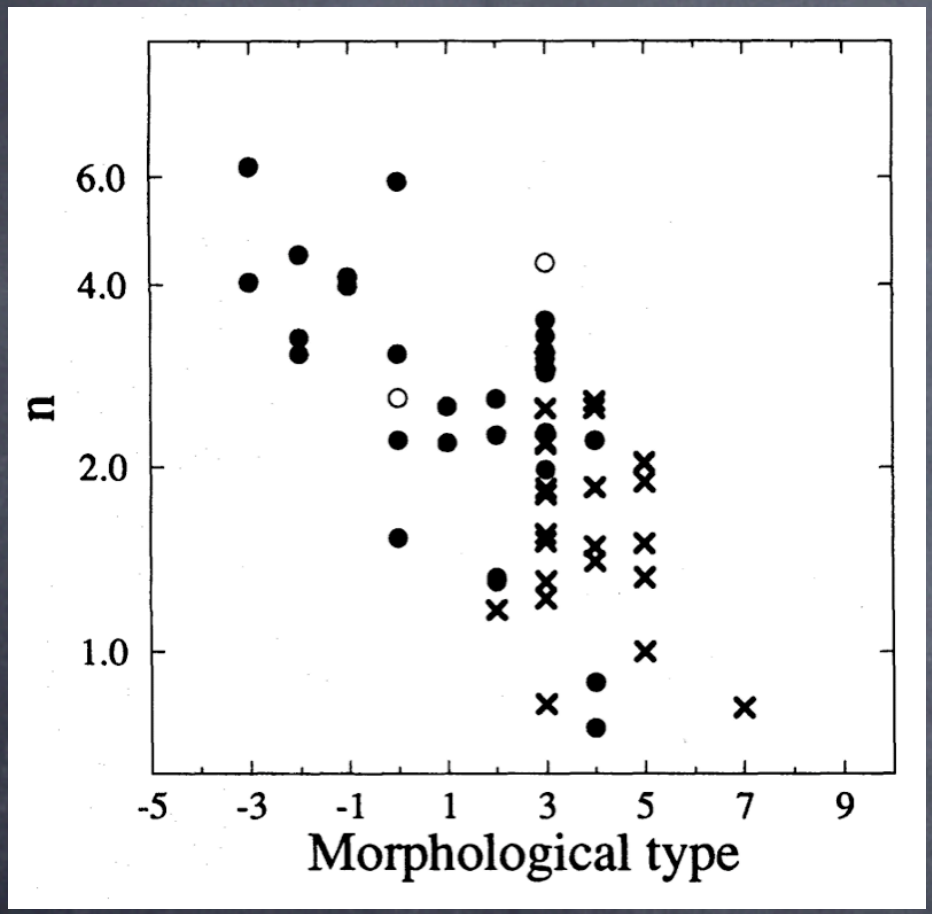


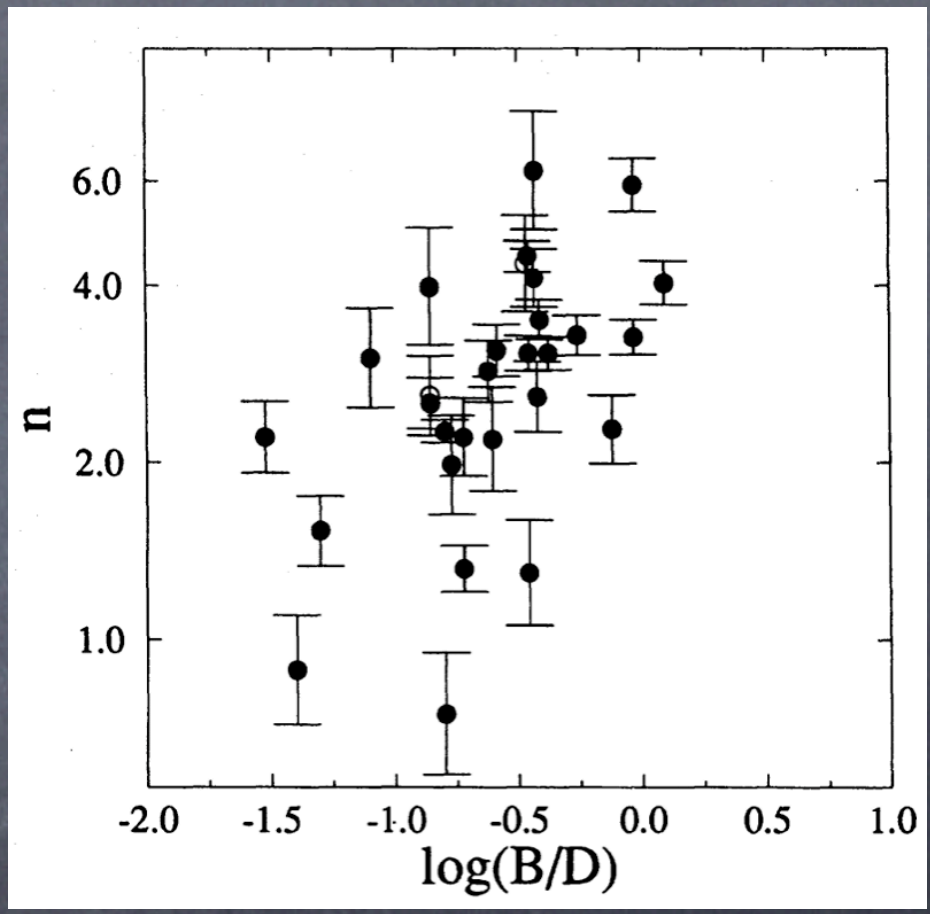
central surface brightness



de Jong, 1996

The concentration of bulge light





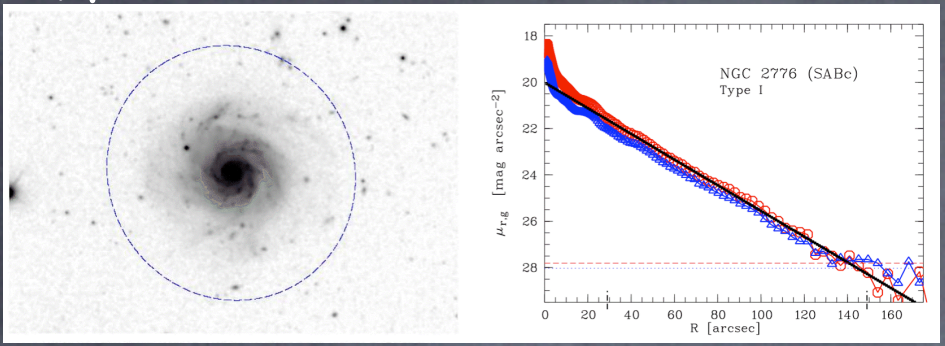
Andredakis et al, 1995

bulges of late-type spirals are less concentrated

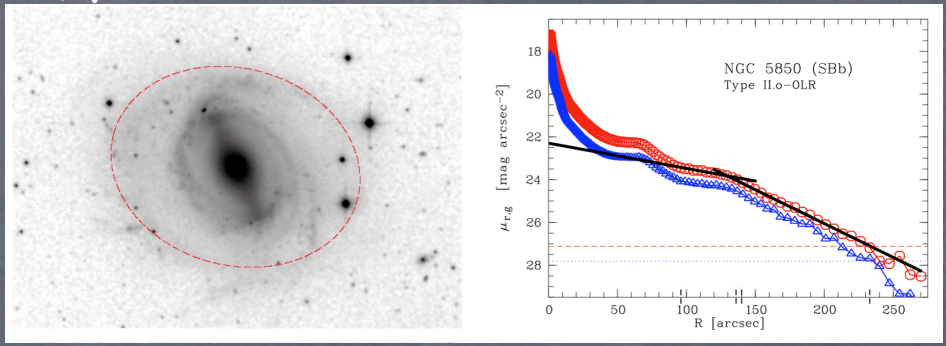
→ pseudo-bulges

Disks are not always exponential

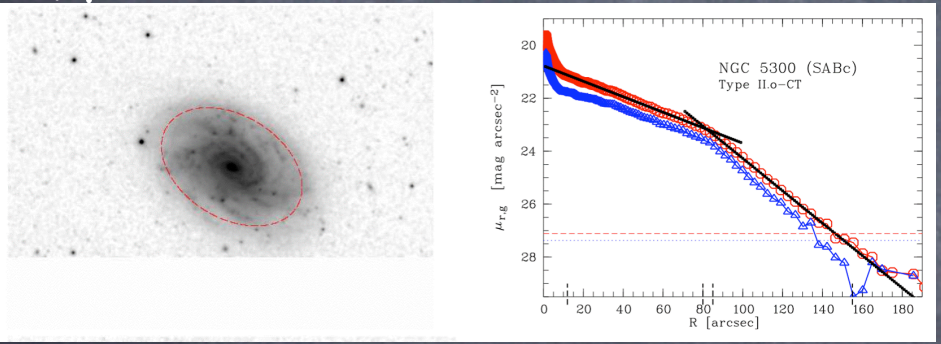
Type I



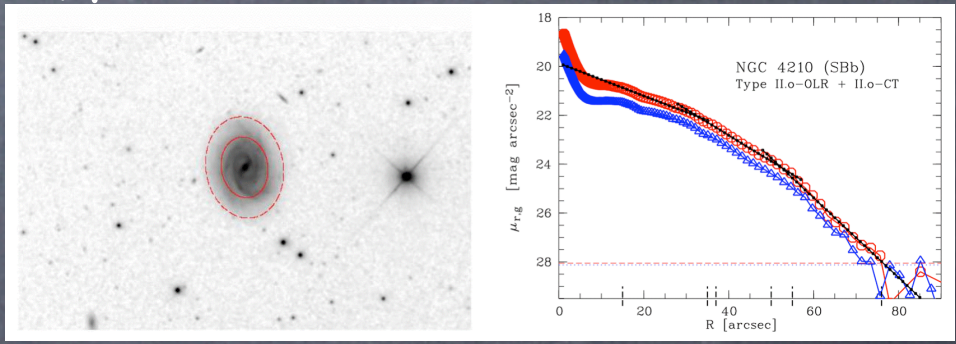
Type II : OLR



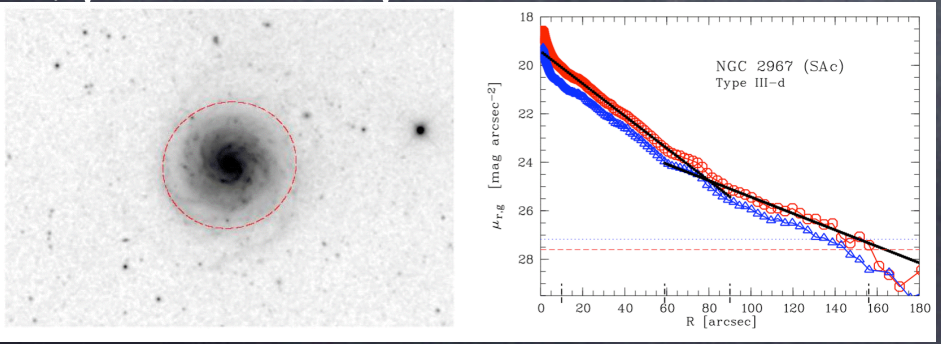
Type II - truncation



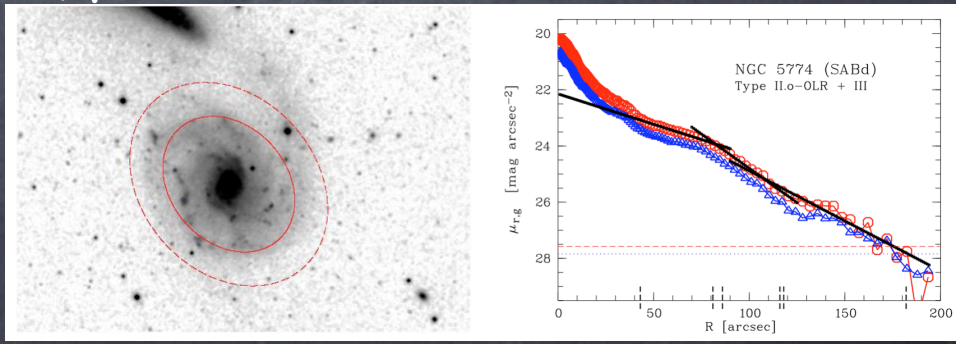
Type II : OLR + truncation



Type III - upturn

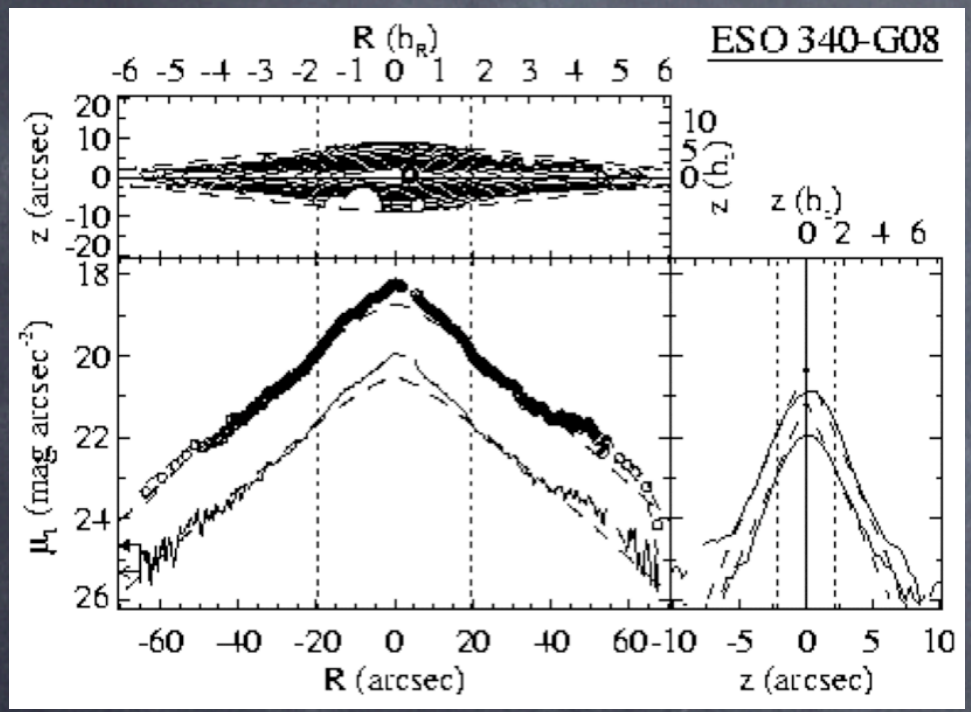


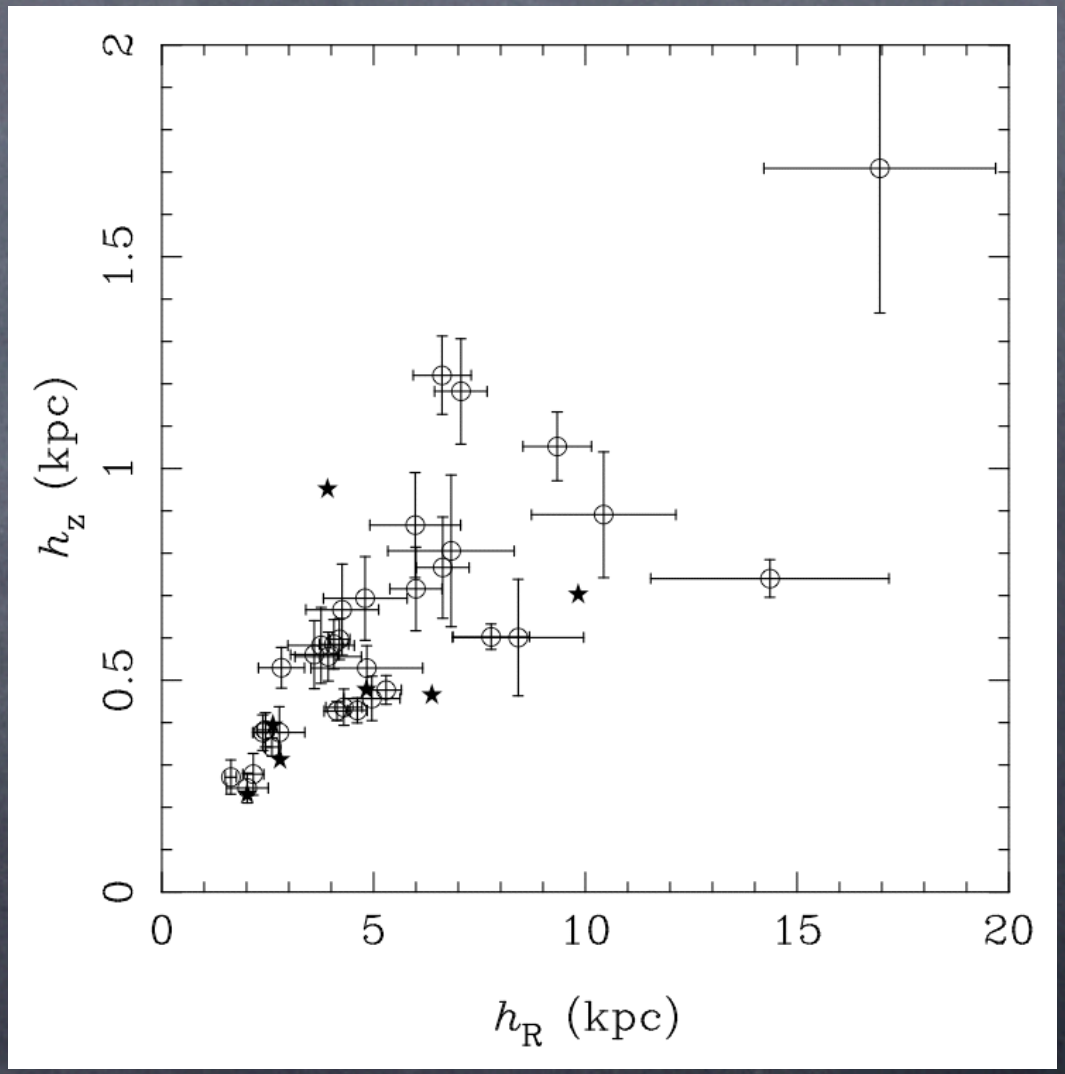
Type II : OLR + III



Pohlen & Trujillo, astro-ph/0603682

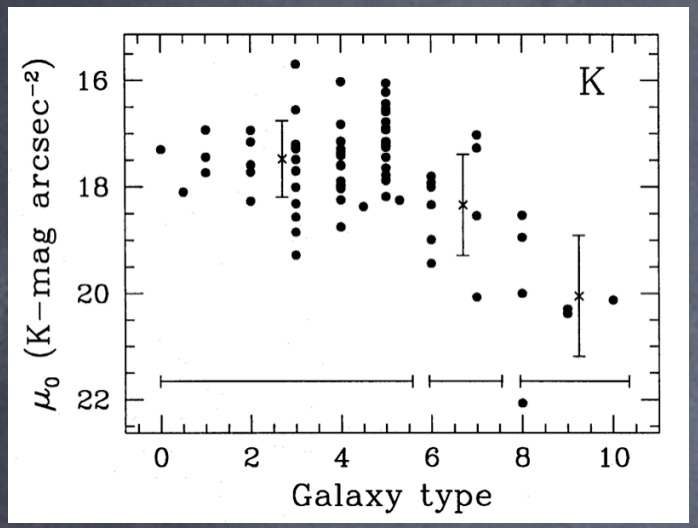
Studies of edge-on galaxies: scale height vs scale length



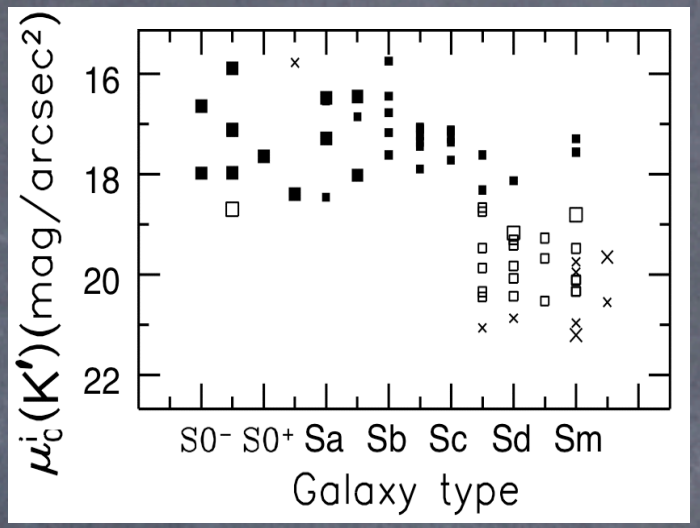


Kregel et al, 2002

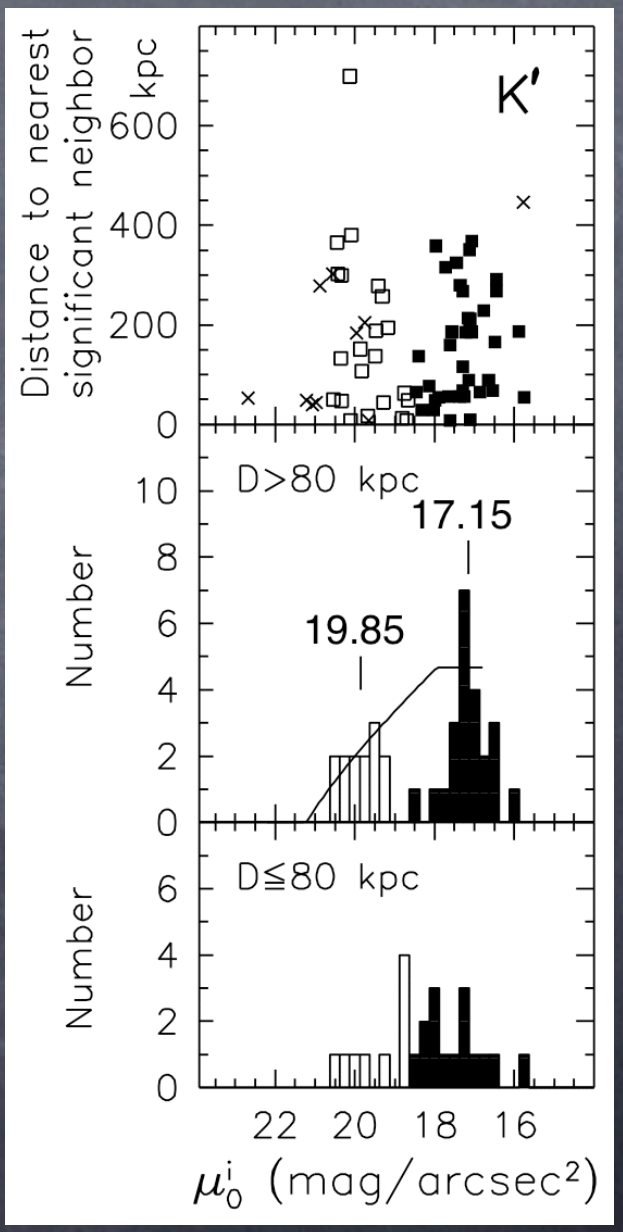
A bimodal distribution of μ_o



de Jong, 1996



Tully & Verheijen, 1997



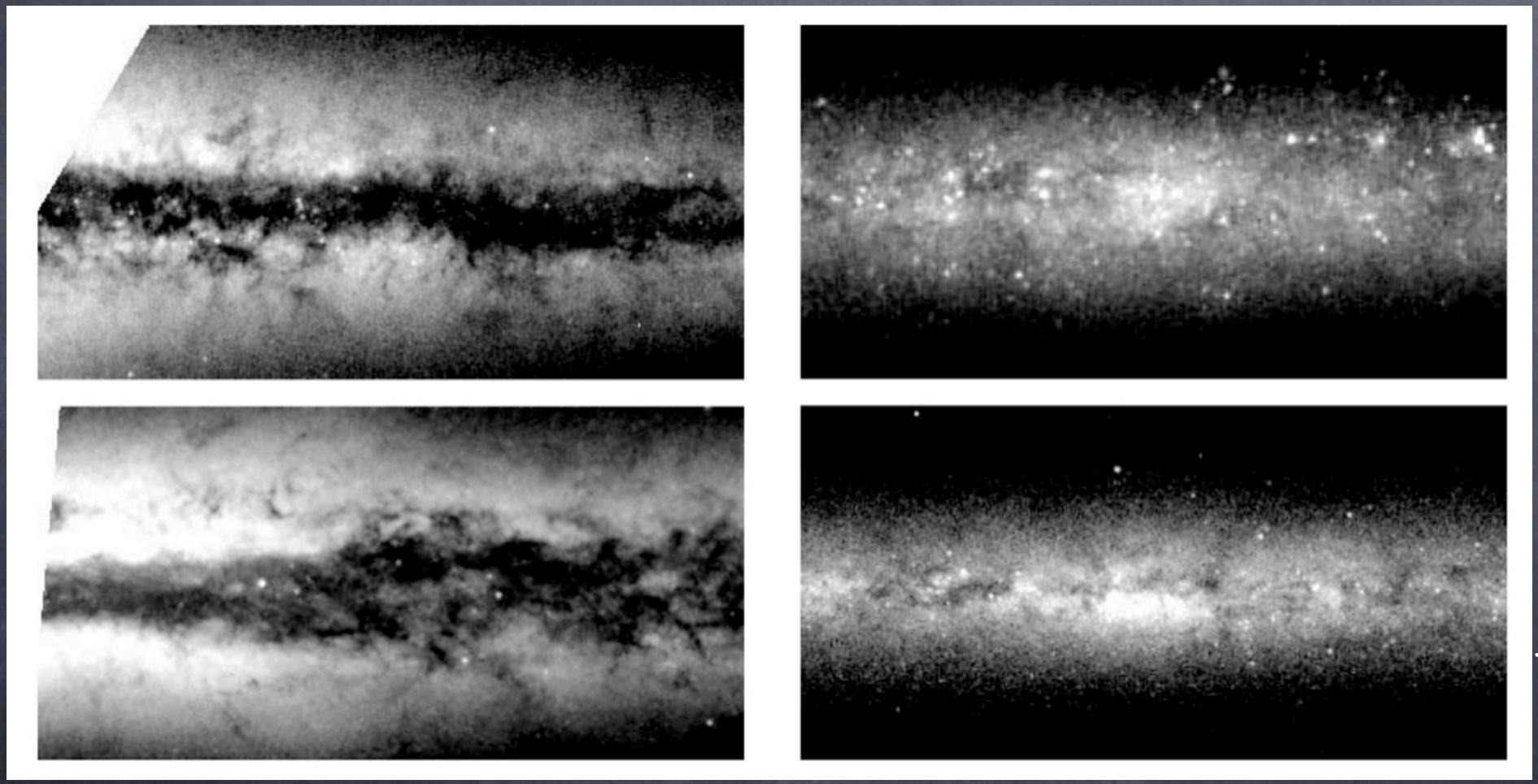
Isolated stellar disks prefer either High or Low surface brightness.

Bimodality now also seen in other properties like thickness of dustlanes (Dalcanton, 2004).

bimodality of dustlane morphology

high mass galaxies
V_{rot} > 120 km/s

low mass galaxies
V_{rot} < 120 km/s



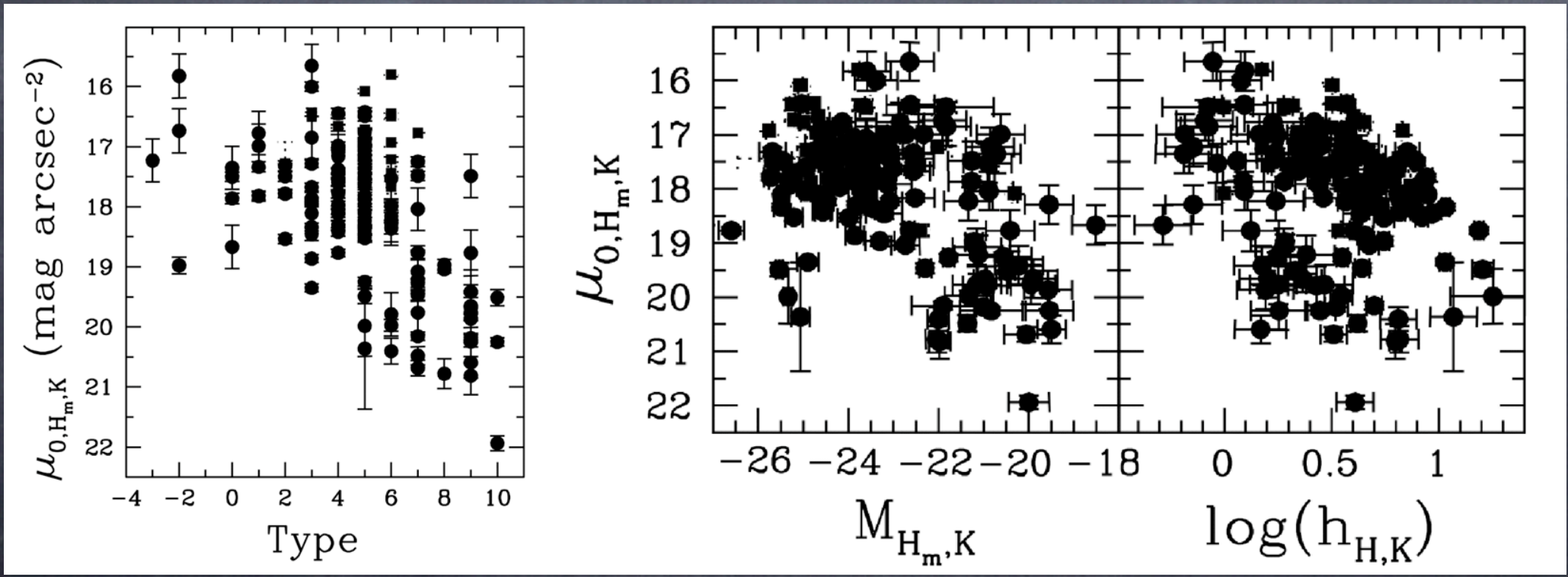
Dalcanton et al, 2004

concentrated dust

diffuse dust

probably related to dynamical stability of disk

more hints for bimodality



MacArthur et al, 2004

Summary
the distribution of light

Sa	Sm
early-type	late-type
red	blue
bright	faint
HSB disk	LSB disk
bright bulge	faint bulge
$r^{1/4}$ bulge	exp. bulge
tight arms	loose arms

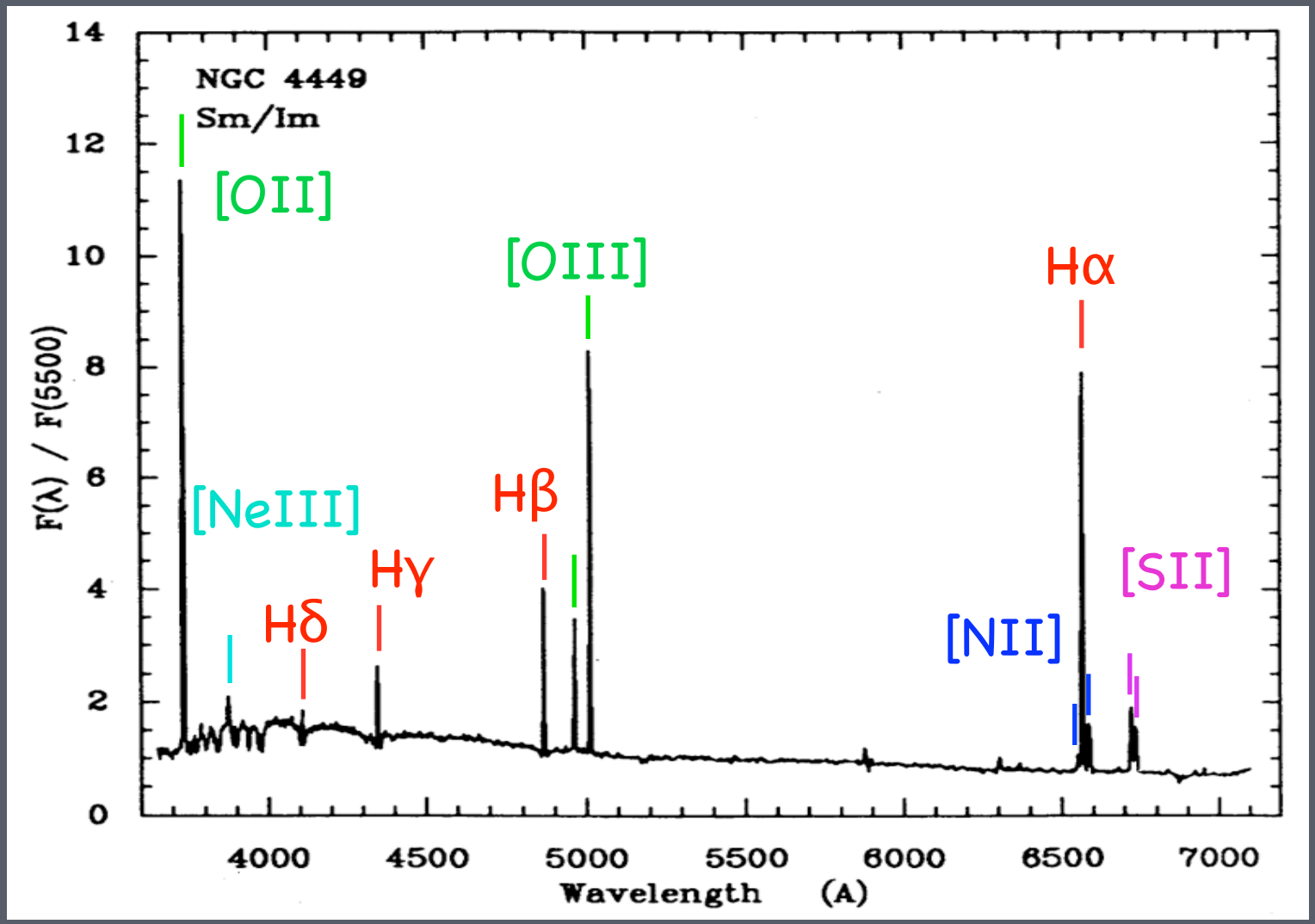
- disk scale height correlates with disk scale lengths
- bimodal distribution of surface brightness, dust lanes

Spectroscopy

spatially integrated spectra

Sa

Sb



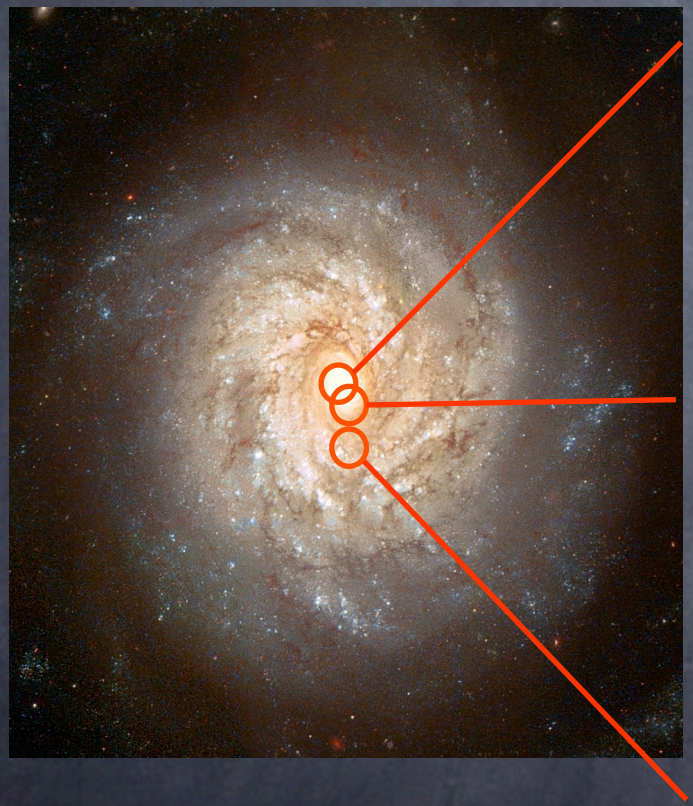
Sc

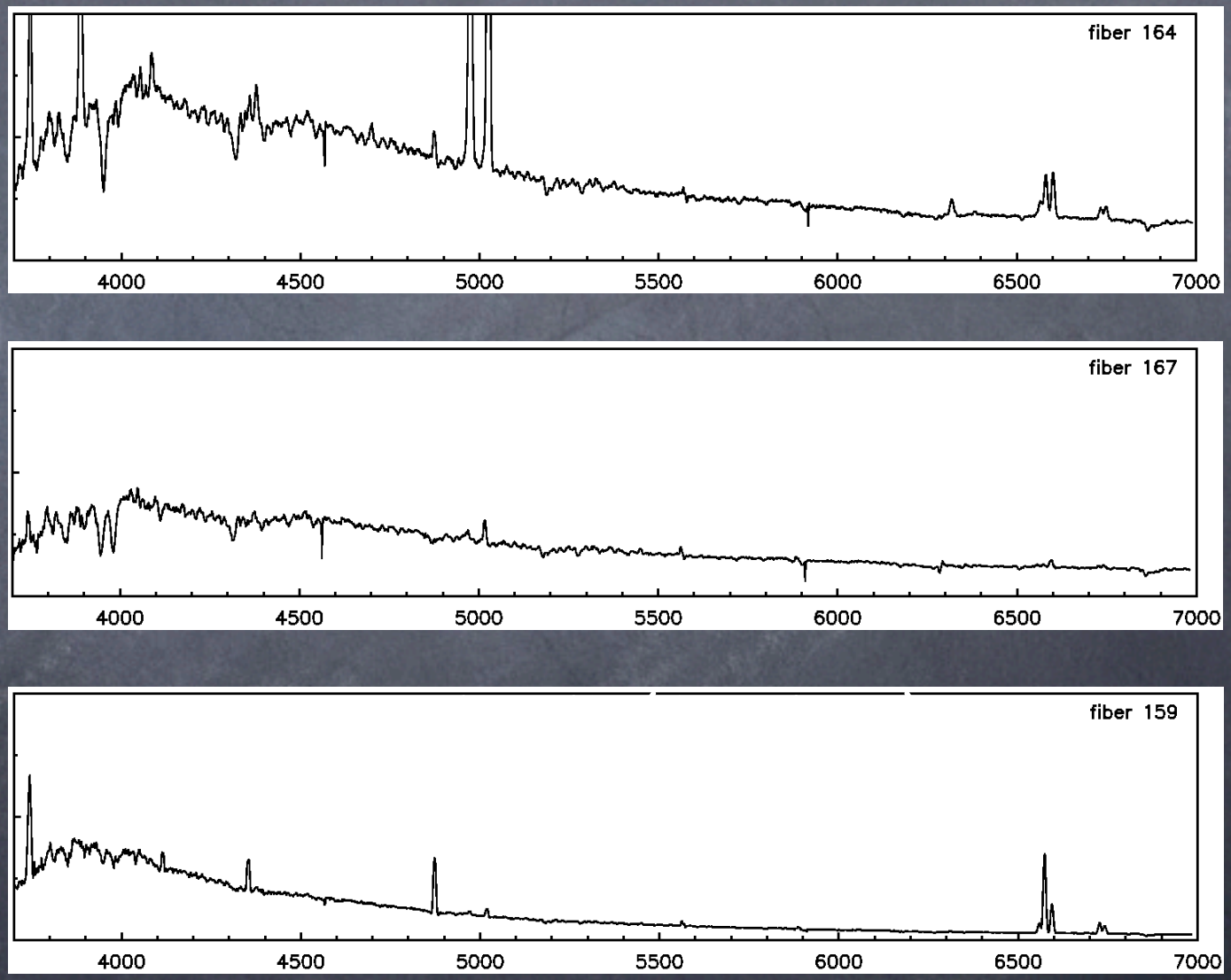
Sm/Im

Kennicutt, 1992

Spectral variations within galaxies

NGC 3982

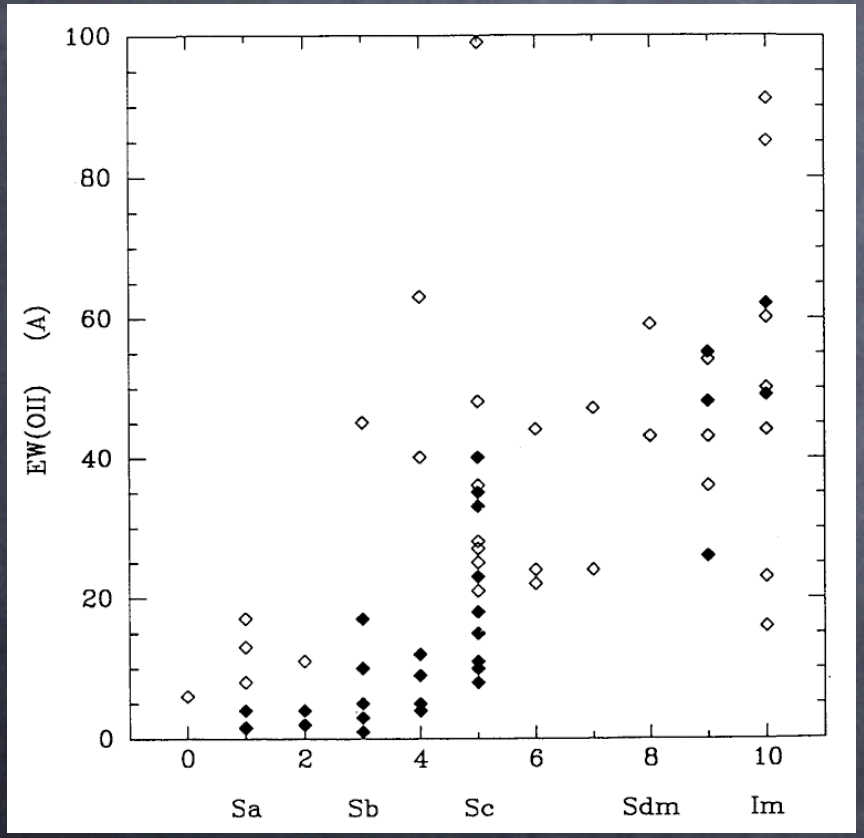




Spectroscopy

spatially integrated spectra - equivalent widths

EW([OII])

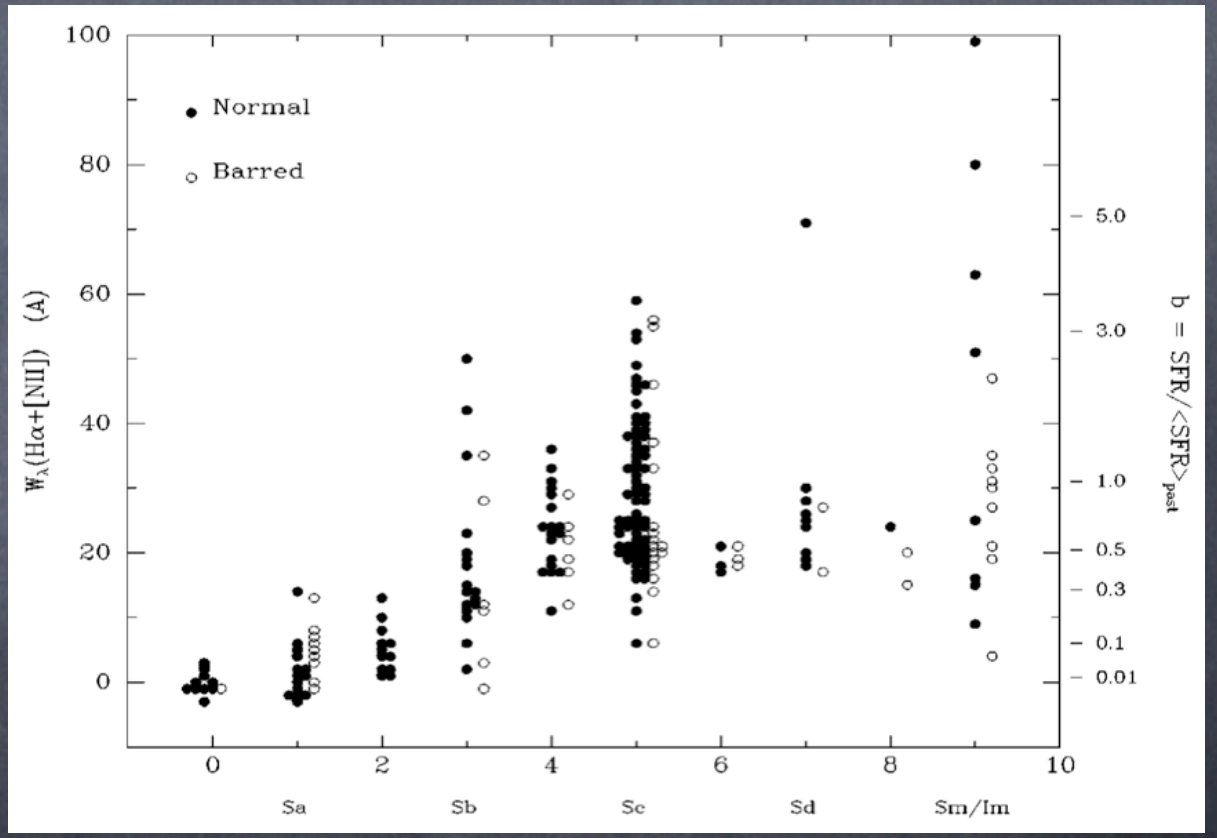


Sa Sb Sc Sd Sm

Kennicutt, 1992

EW(Hα + [NII])

$\frac{SFR}{\langle SFR \rangle_{past}}$



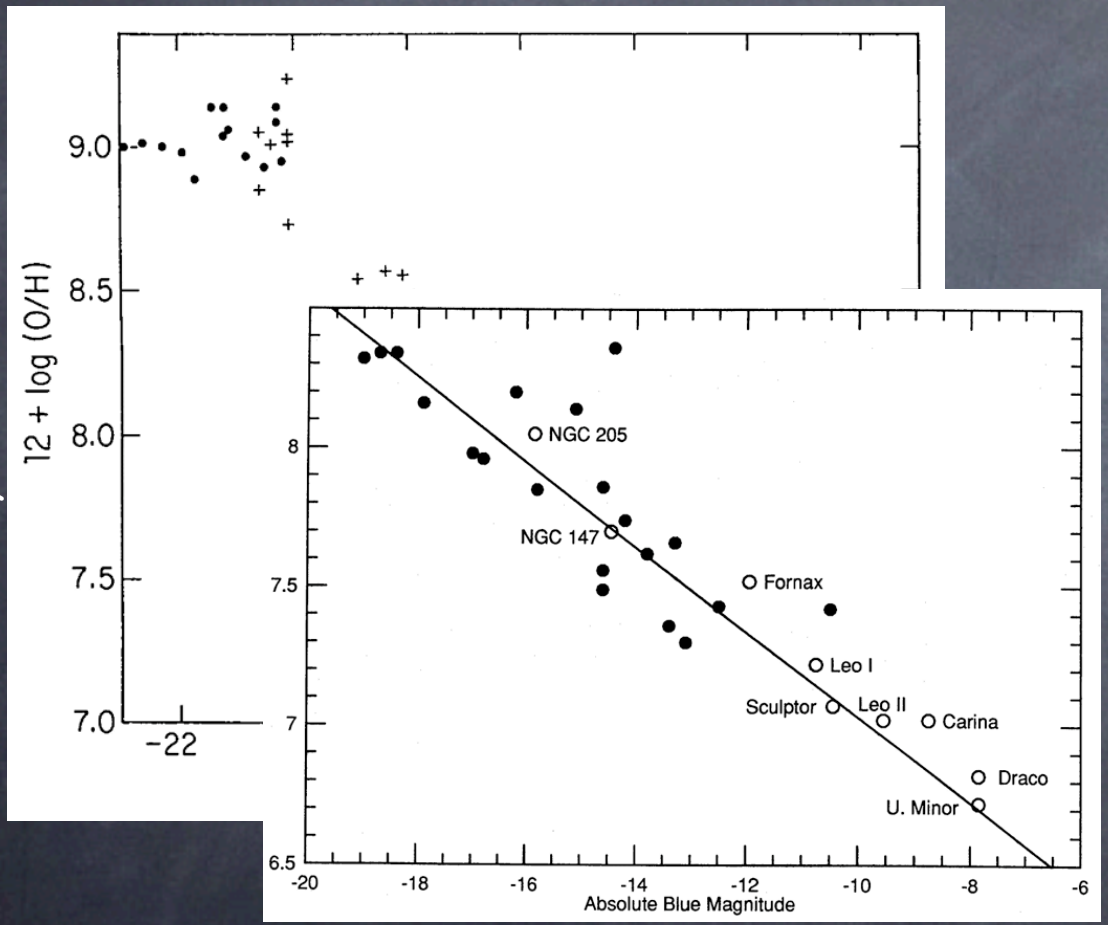
Sa Sb Sc Sd Sm

Kennicutt, 1998

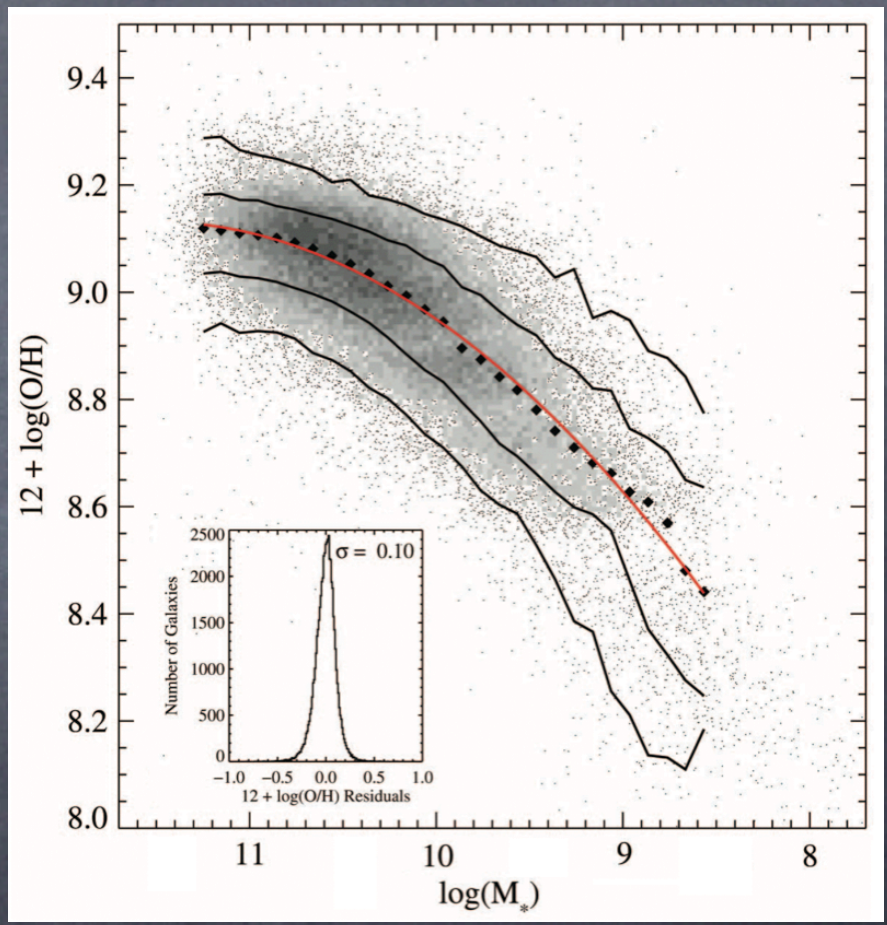
Spectroscopy

oxygen abundances

Roberts & Haynes, 1994



Skillman et al, 1989



Tremonti et al, 2004

Spectroscopy

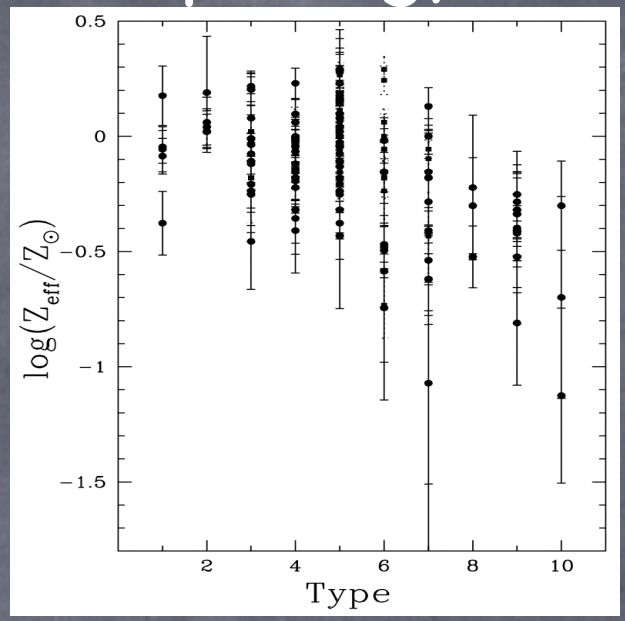
effective metallicities

$$\mathrm{Log}(Z_{eff}/Z_{\odot})$$

Morphology

high

low



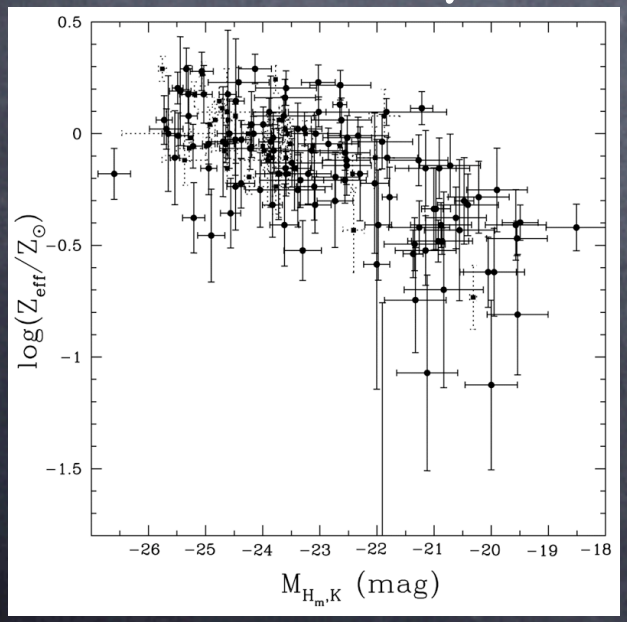
MacArthur et al, 2004

Sa Sm

Luminosity

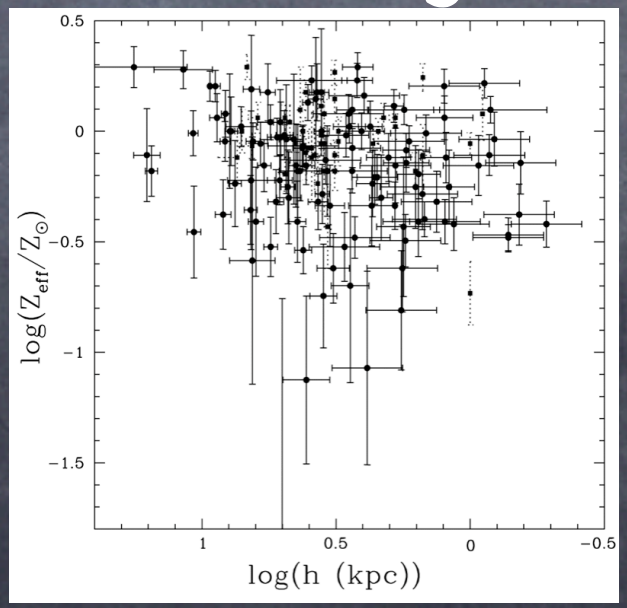
high

low



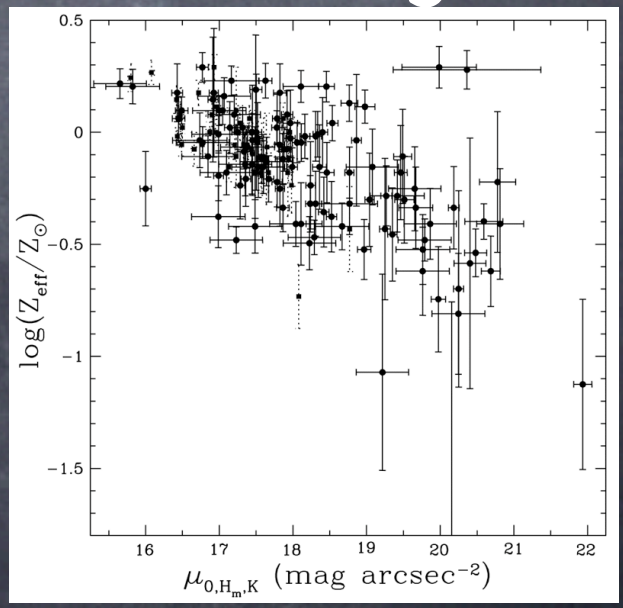
bright faint

Scale length



large small

Surf. bright.



high low

Spectroscopy

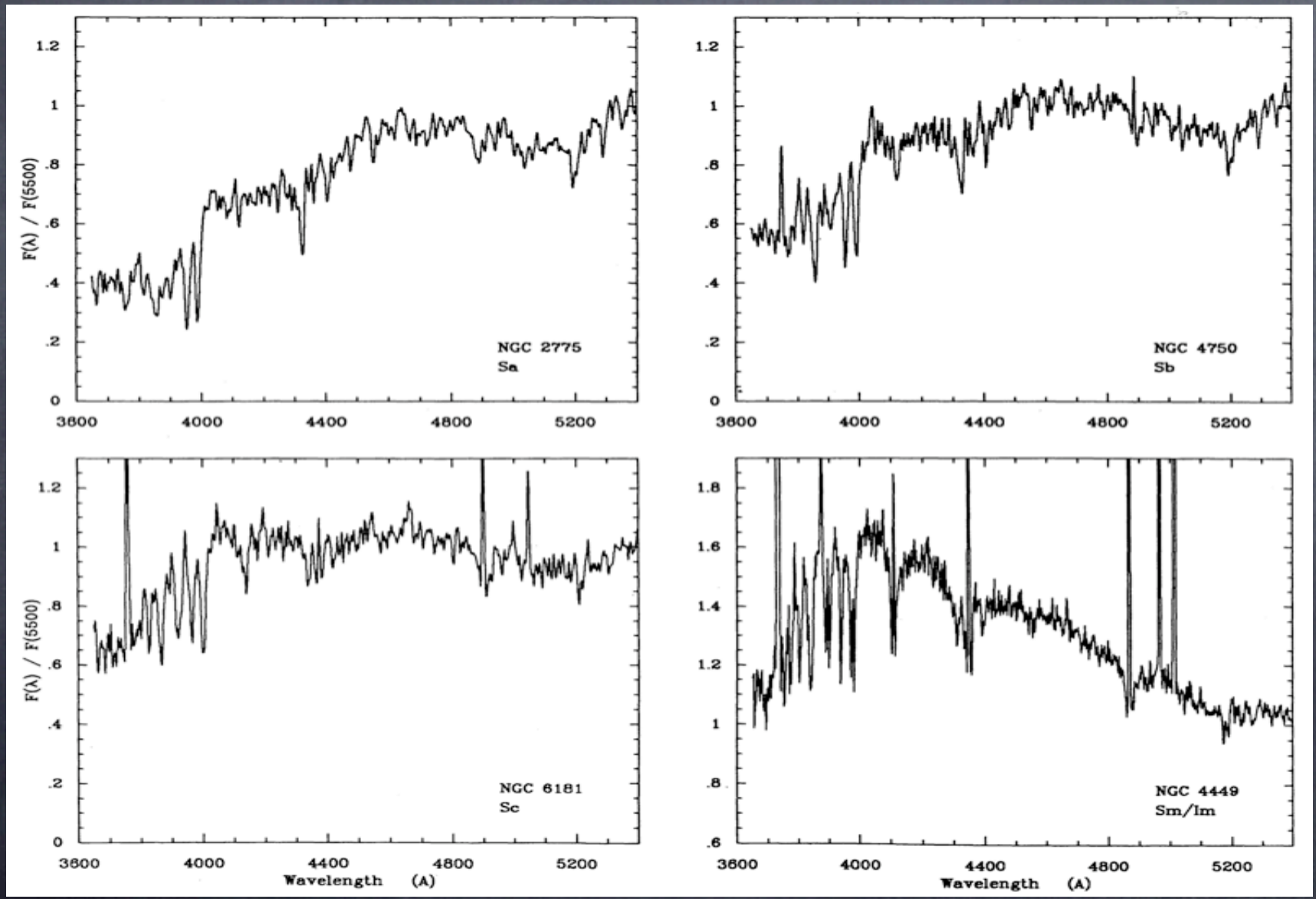
spatially integrated spectra - changing continuum

Sa

Sb

Sc

Sm/Im



Kennicutt, 1992

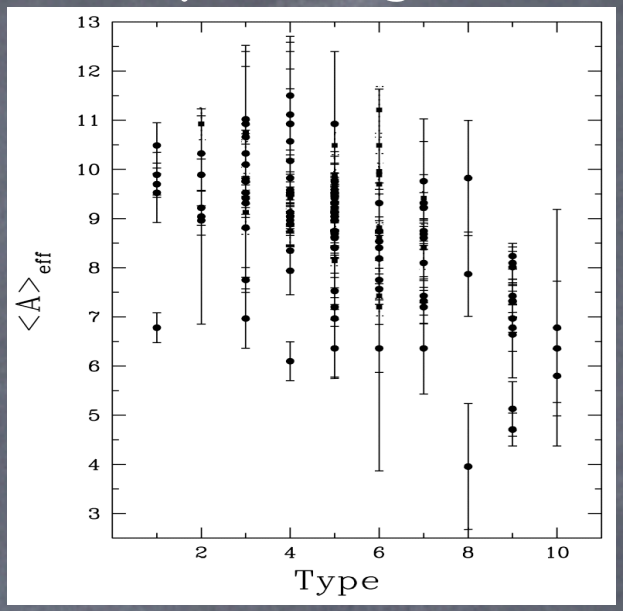
Spectroscopy

effective ages $\langle A \rangle_{eff}$

Morphology

old

young



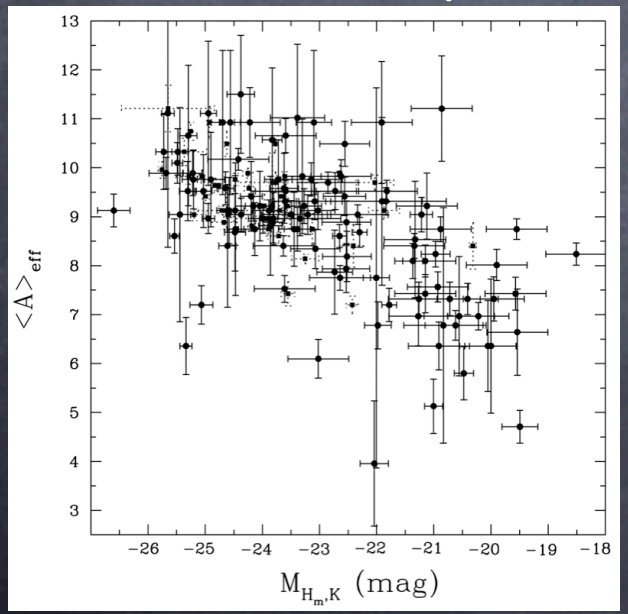
MacArthur et al, 2004

Sa Sm

Luminosity

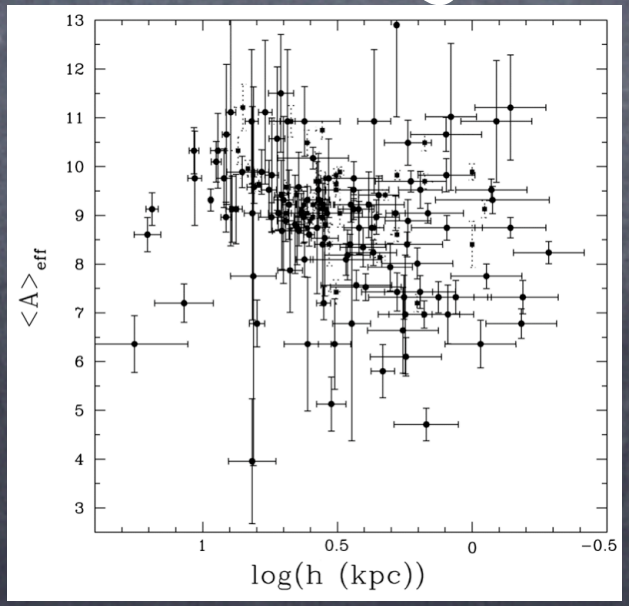
old

young



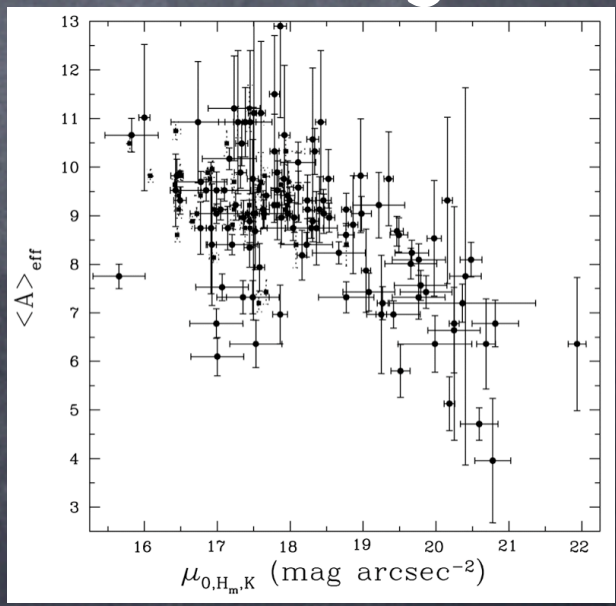
bright faint

Scale length



large small

Surf. bright.



high low

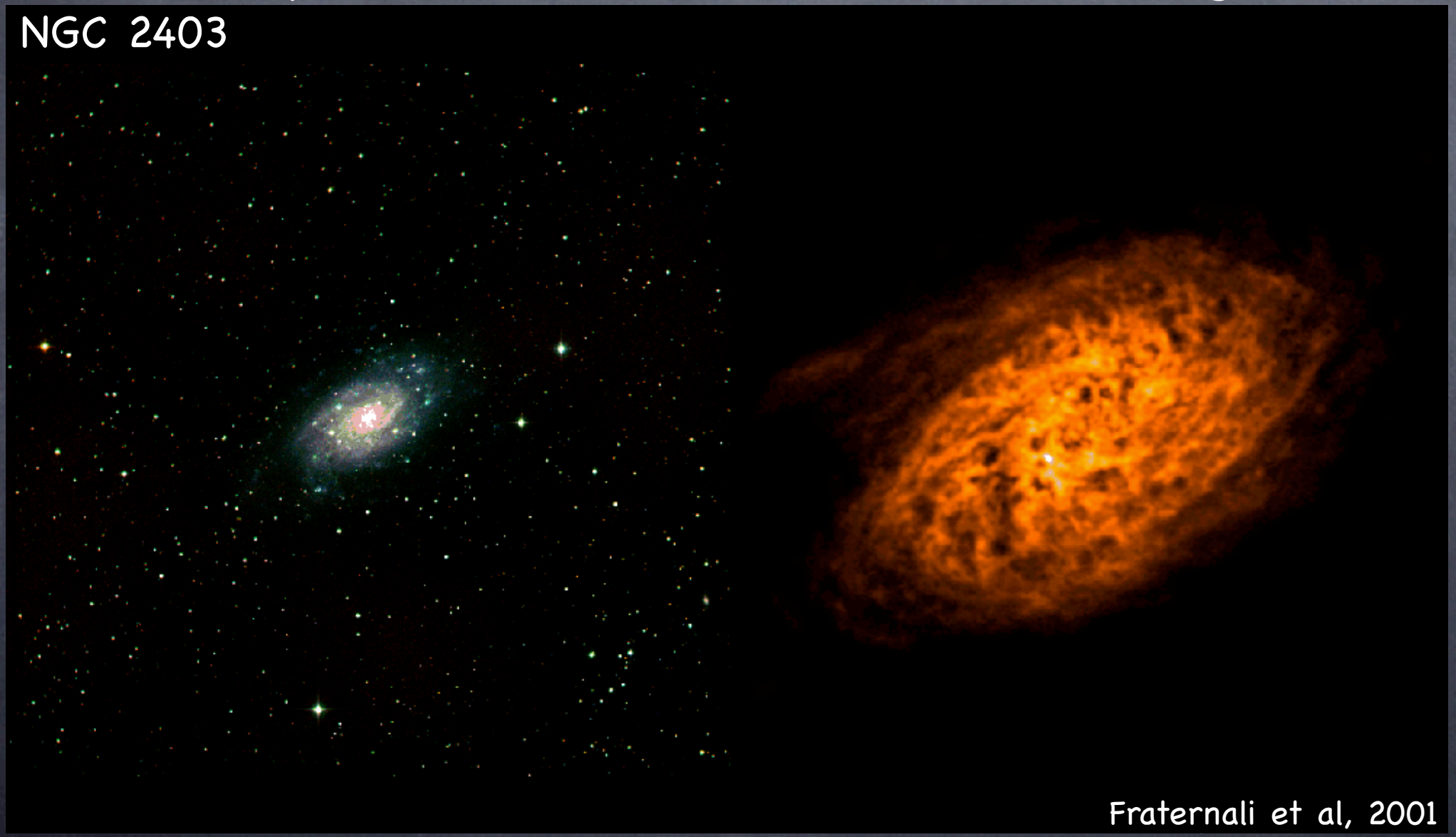
Summary - spectroscopy

Sa	Sm
early-type	late-type
weak emission lines	strong emission lines
low specific star formation	high specific star formation
older stellar populations	younger stellar populations
higher metallicities	lower metallicities

Gas content

optical

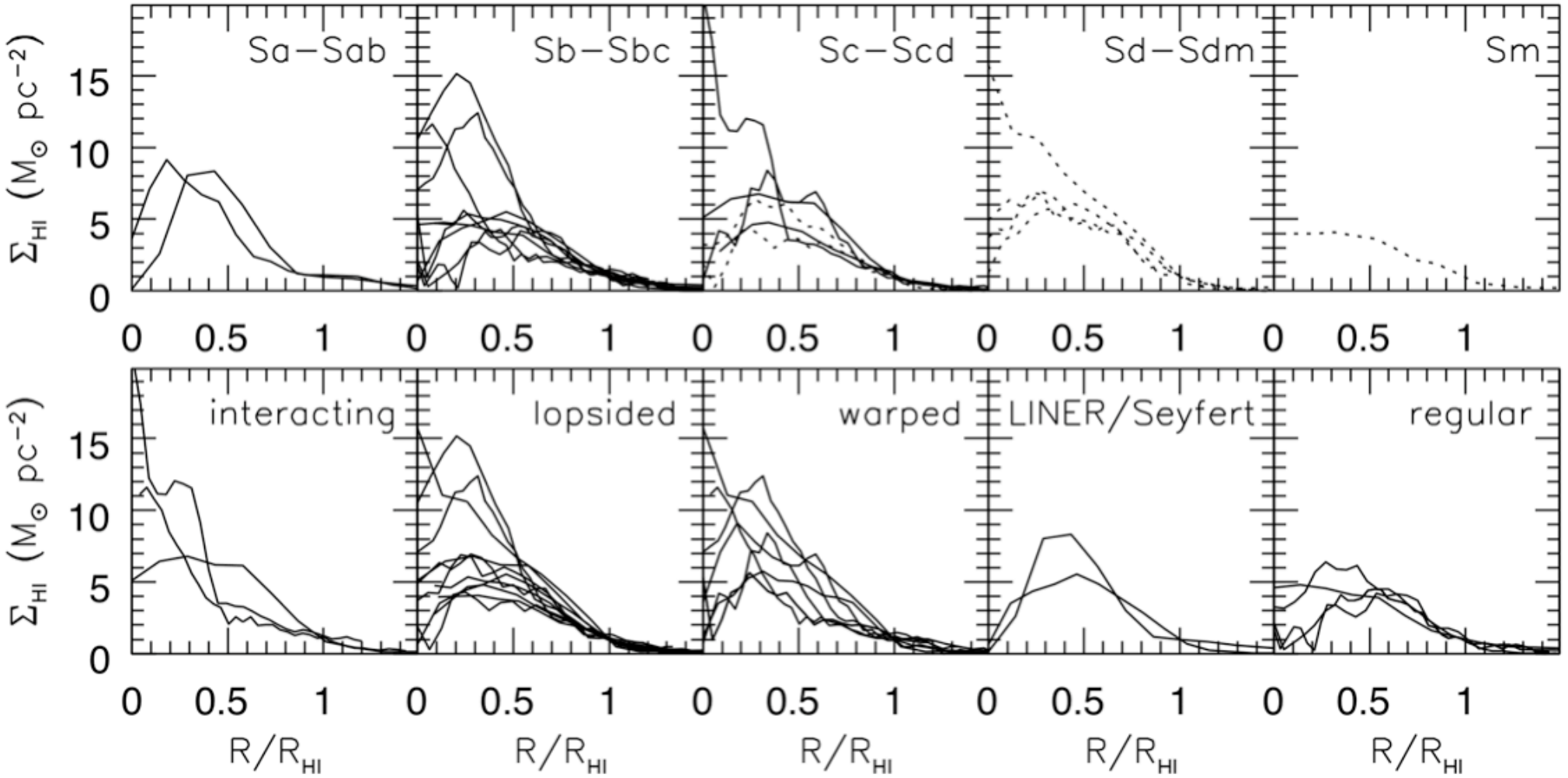
atomic hydrogen



same scale!

Radial distributions of the gas

Ursa Major galaxies

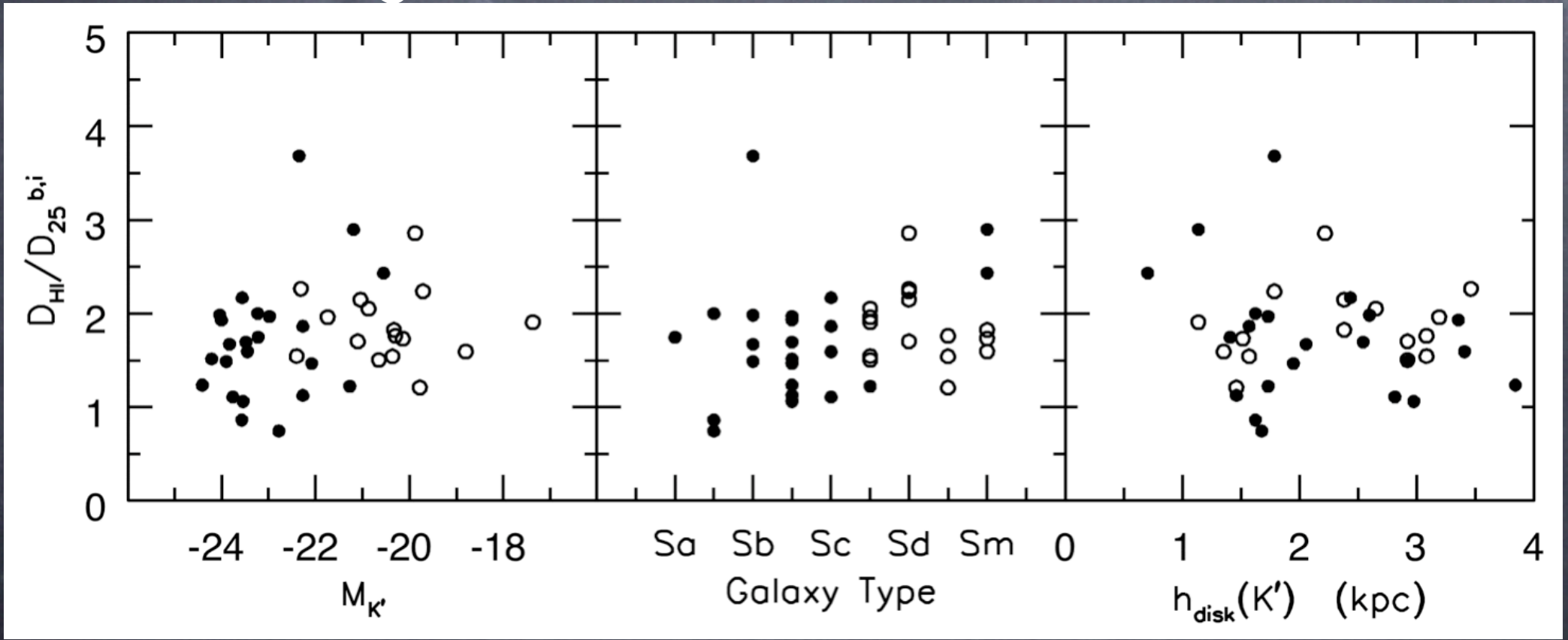


Verheijen & Sancisi, 2001

Large range in central concentrations

Relative diameters of gas disks

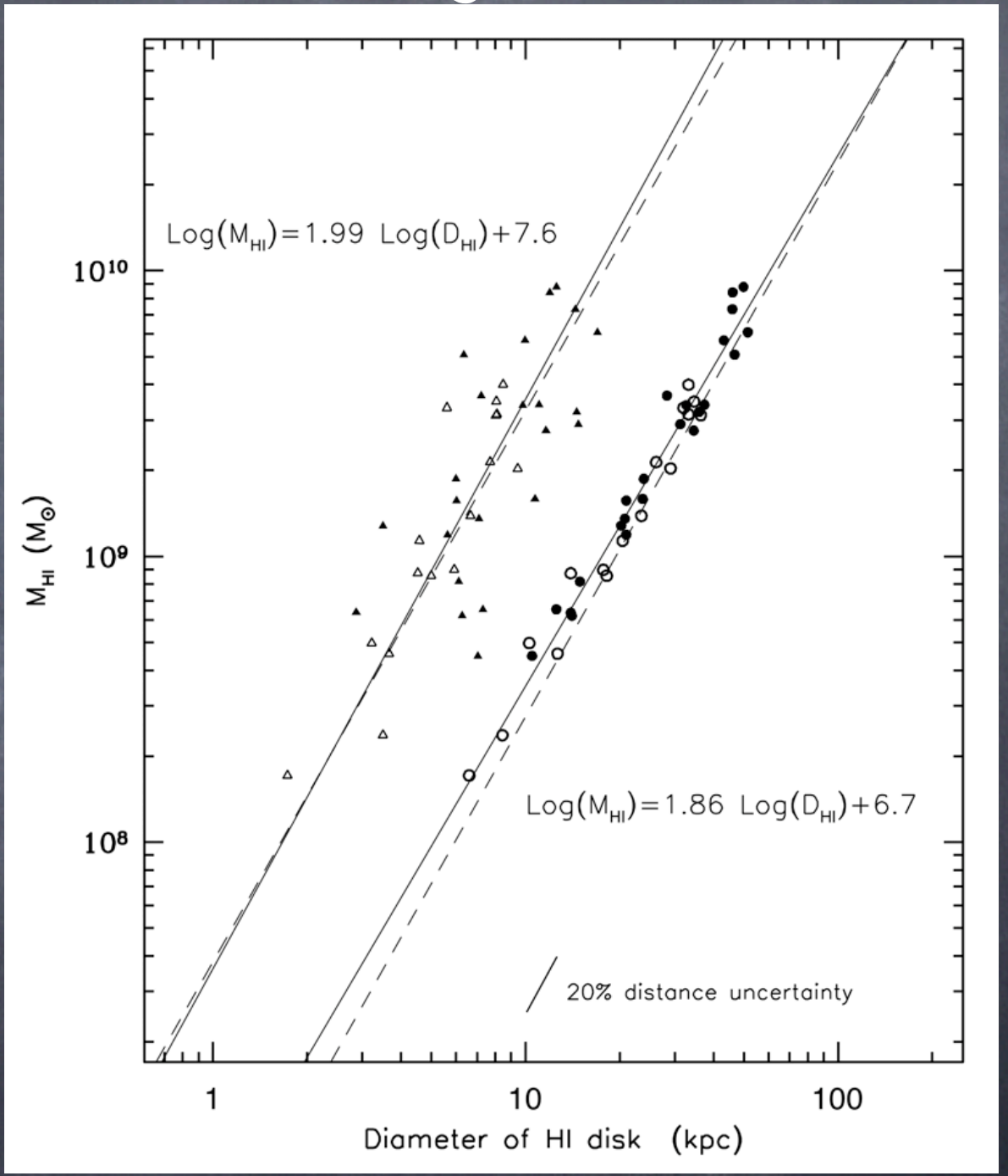
Ursa Major galaxies



Verheijen & Sancisi, 2001

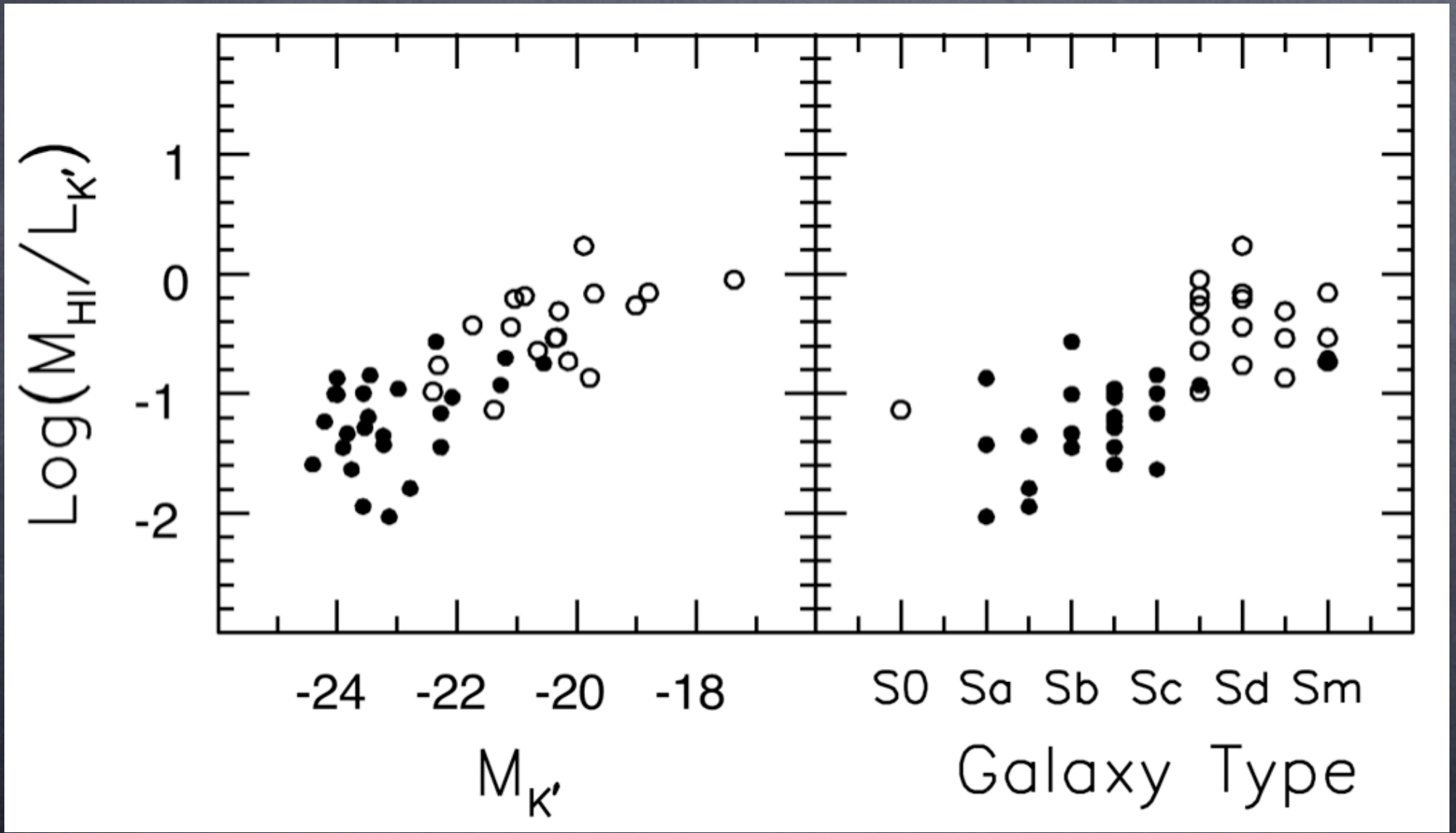
Ursa Major galaxies

Gas disks have similar effective surface densities, independent of their size.



Verheijen & Sancisi, 2001

Fainter late-type spirals contain relatively more gas.



Verheijen & Sancisi, 2001

molecular gas in galaxies

optical

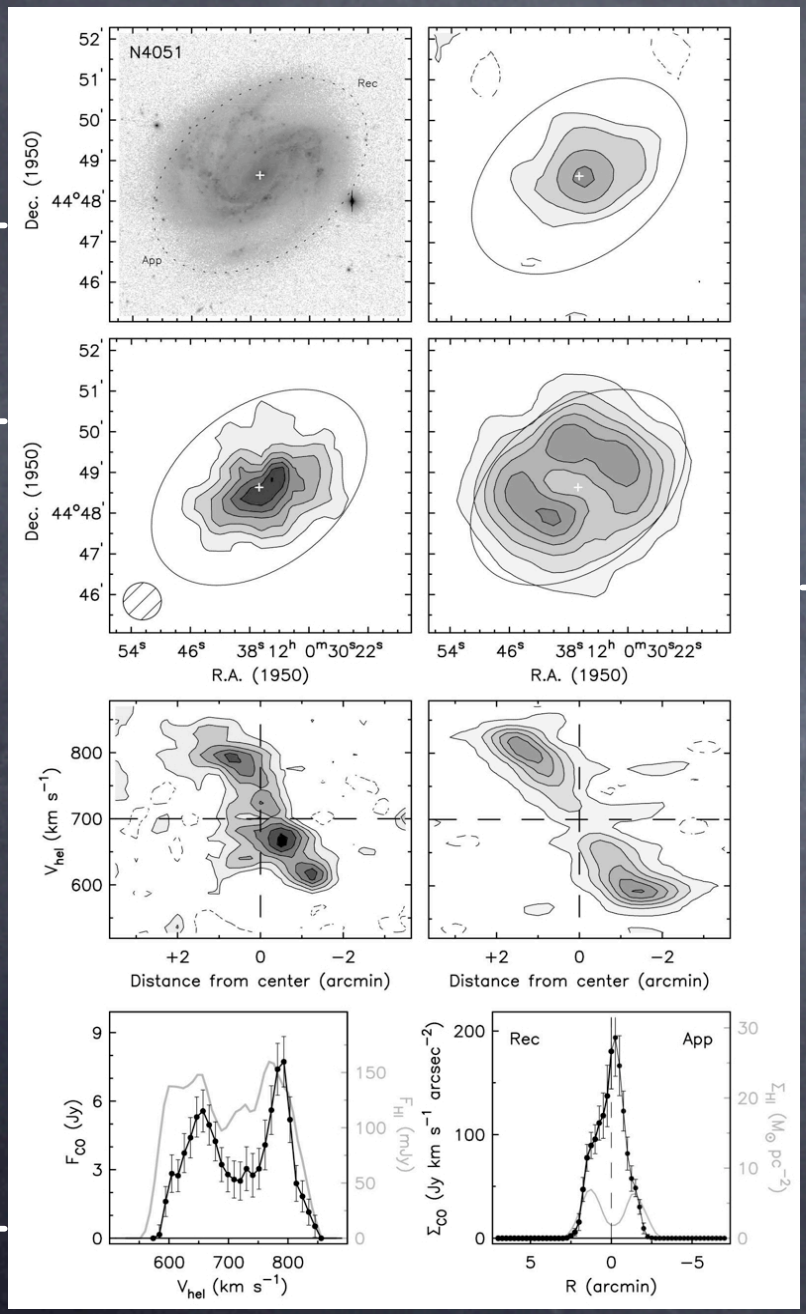
CO map

radio continuum

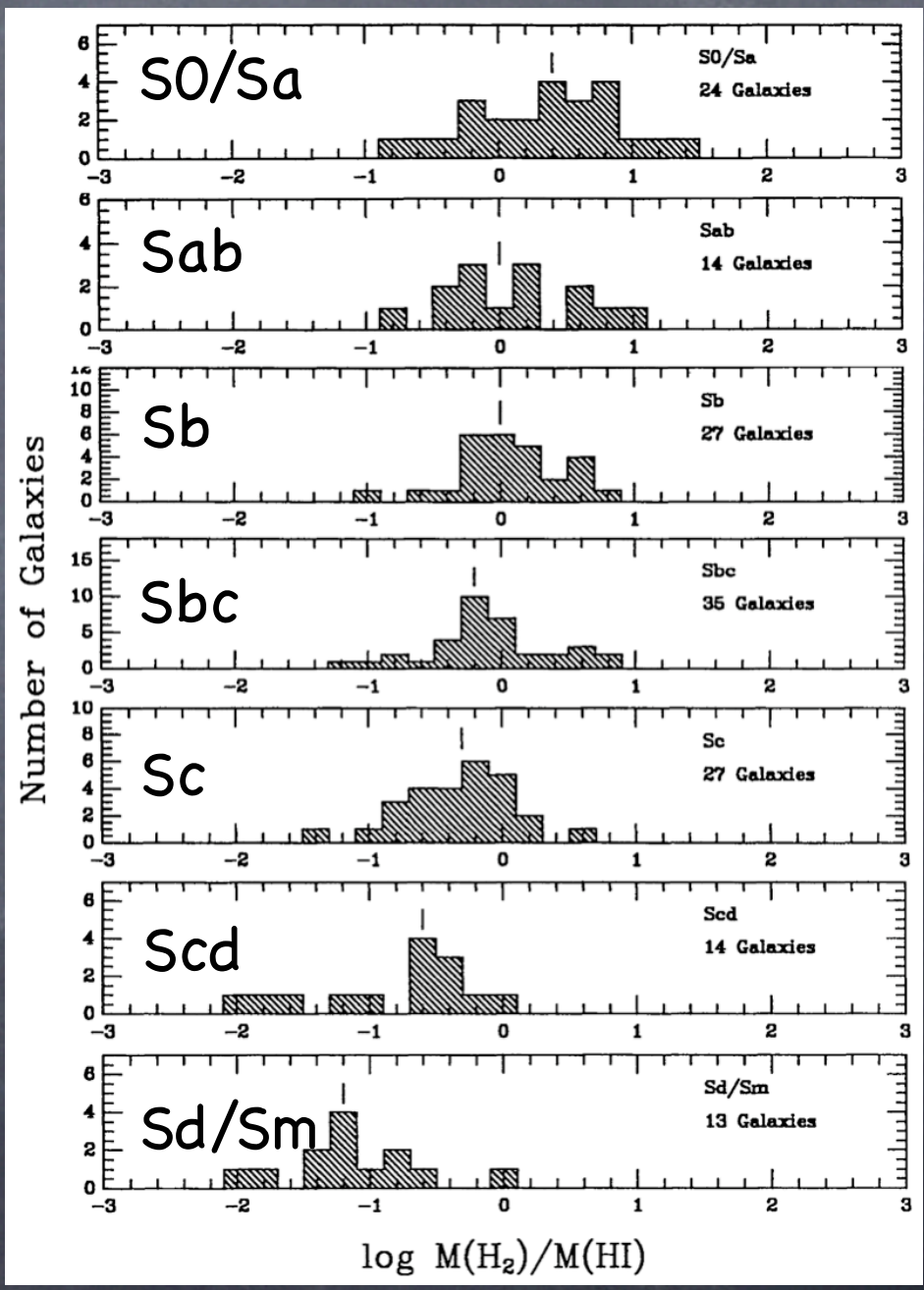
HI map

global profiles

radial profiles



Chung et al, 2006



Young & Scoville, 1991

Summary - gas content of spirals

- gas disks are typically seen out to larger radii than stellar disks
- Spiral arms continue into outer gas disk
- radial gas profiles show a large variety
- gas disks have similar effective mass surface densities
- late-type galaxies have a larger relative atomic gas content
- late-type galaxies have a smaller relative molecular gas content