Trends along the Hubble Sequence

- ☛ **Metallicity: chemical composition : Zaritsky et al. 94**

Recall : Big Bang formed H, D, ^{3}He, ^{4}He, ^{7}Li.
all other elements formed in (previous) stellar generations (nuclear fusion, SN nucleosynth.)

metallicity Z := mass fraction of everything > ^{4}He

metallicity of the stellar population : luminosity-weighted stellar metallicity from stellar absorption lines in the integrated spectrum

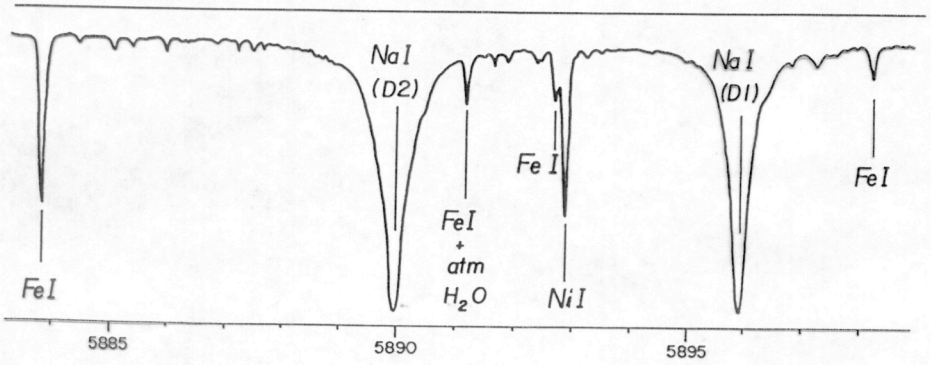


Fig. 3.2. Portion of the solar spectrum in the neighbourhood of the sodium D-lines. Adapted from L. Delbouille, G. Roland & L. Neven, *Spectrophotometric Atlas of the Solar Spectrum*, Liège, 1973

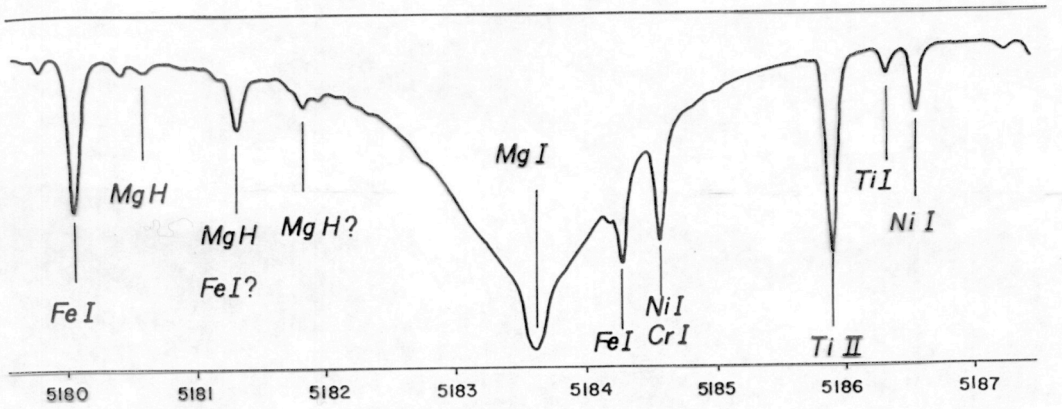
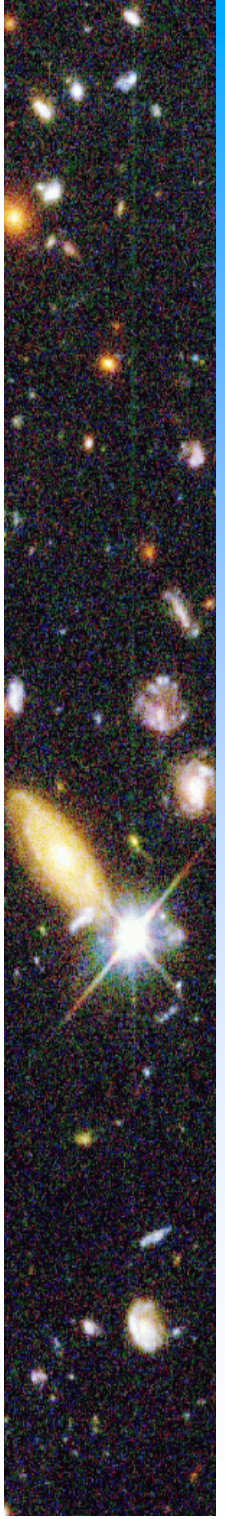


Fig. 3.9. A very strong absorption line of Mg I in the solar spectrum, dominated by damping



Trends along the Hubble Sequence

- **Metallicity: chemical composition**

  metallicity Z := mass fraction of everything > ^{4}He
  solar (photospheric) metallicity $Z_\odot = 0.02$
  metallicity dominated by O, …, C, …, N, ……, Fe, …

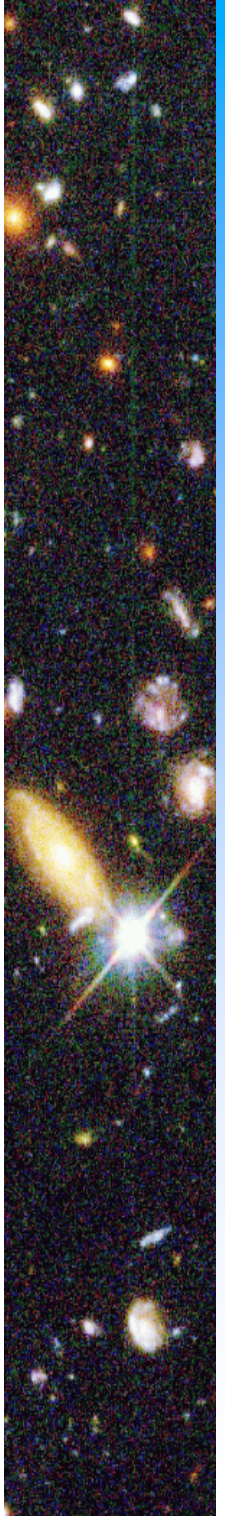
  metallicity of the stellar population :
  luminosity-weighted stellar metallicity from stellar absorption lines in the integrated spectrum

  $$[Fe/H] := \log (X_{Fe}/X_H) - \log (X_{Fe}/X_H)_\odot$$

  X_i := mass fraction of element i

  [Fe/H] = 0 : solar
  [Fe/H] = -1 : 1/10 solar
  [Fe/H] = -2 : 1/100 solar

  [Fe/H] = +0.4 : 2.5 solar



Trends along the Hubble Sequence

metallicity of the InterStellar Medium (= ISM): Z

measured from HII region emission lines (!), expressed in terms of

$$12 + \log (O/H)$$

$O/H := N_O/N_H$ number(!) densities

Transformation into [O/H] requires mass number

$12 + \log (O/H) = 8.9$ for solar abundance $Z_\odot$
$12 + \log (C/H) = 8.6$ for $Z_\odot$
$12 + \log (Mg/H) = 7.6$ for $Z_\odot$
. . . . .
$12 + \log (O/H) = 7.9$ for 1/10 $Z_\odot$

Solar photospheric abundances

→ B. Pagel : Nucleosynthesis & Chem. Evol. of Galaxies

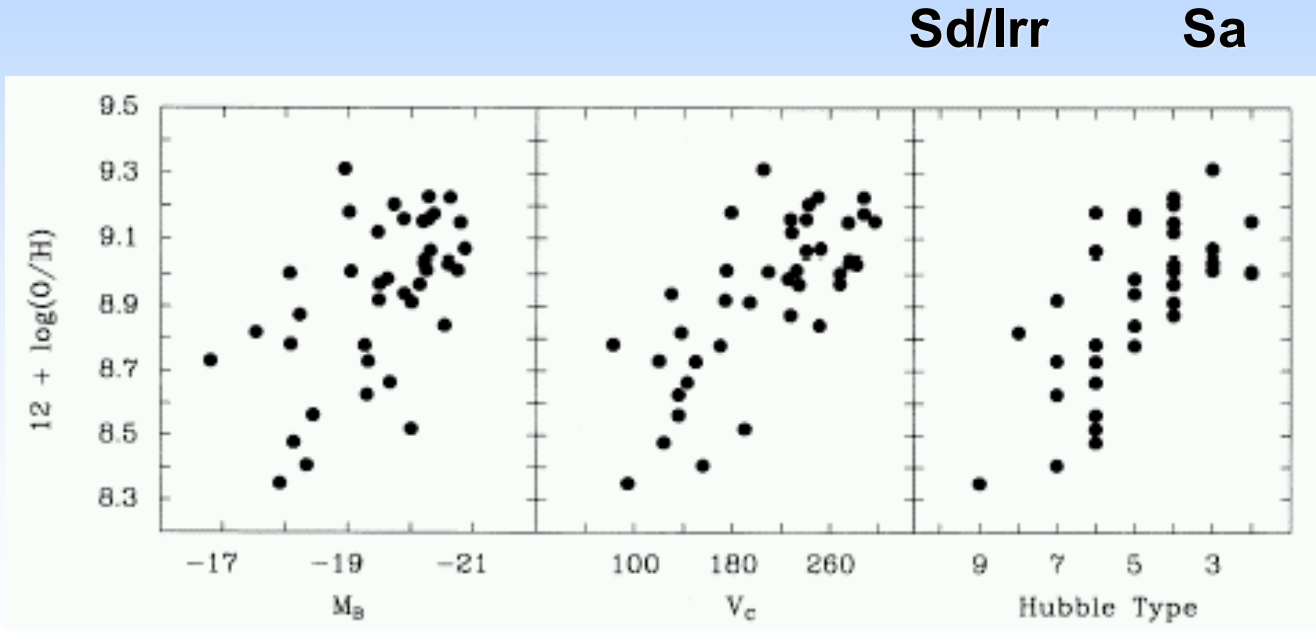
Trends along the Hubble Sequence

- **Metallicity: Zaritzky et al. 1994**

  trend of HII region metallicities among spiral types

  radial gradients in HII abundances across disks

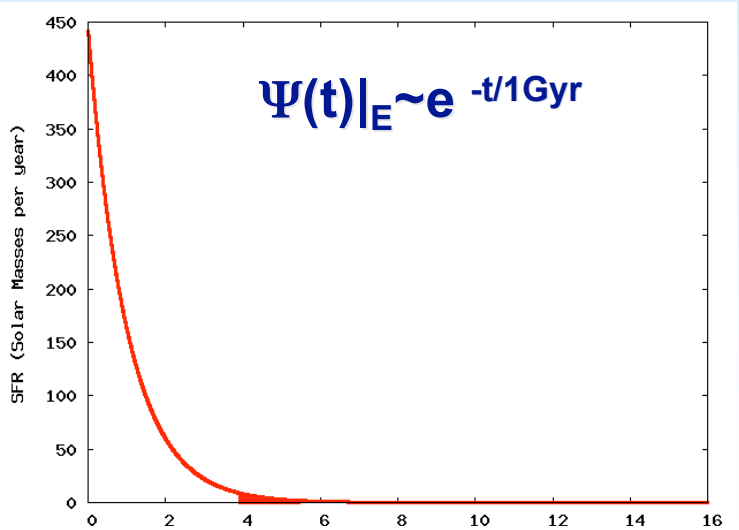
  ➜ compare metallicities at 1 R_e

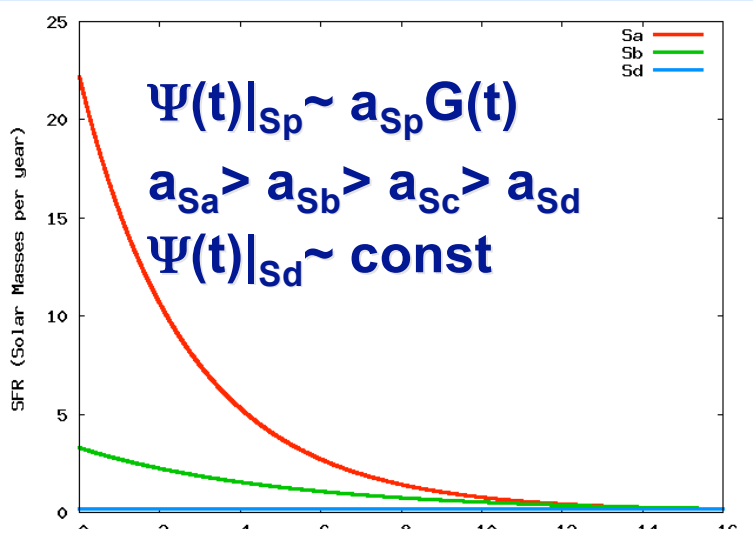


Trends along the Hubble Sequence

- Morphology : Bulge/disk light ratio ✔
- Colours
- Spectra
- SFR_0
- Luminosities
- Composition: stars, gas, dust ✔
- Metallicities: chemical composition

➜ $\langle SFR \rangle_{HT}(t)$



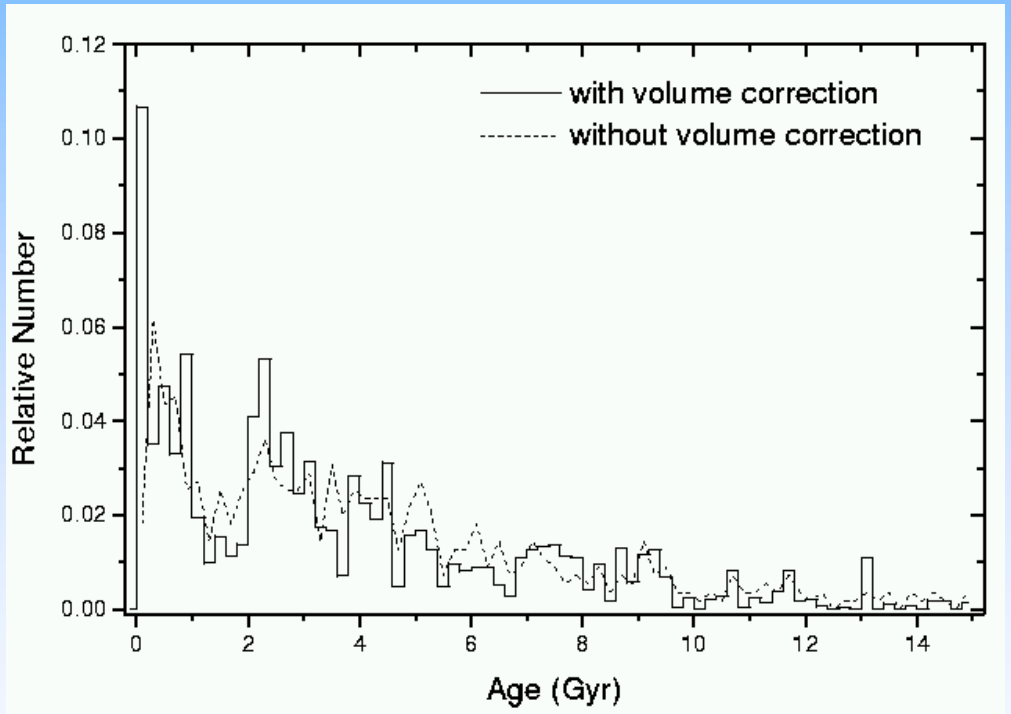


The Star Formation History of the Milky Way

Sbc galaxy

Rocha-Pinto xxx, Rocha-Pinto & Maciel xxx

from individual star age and metallicity determinations



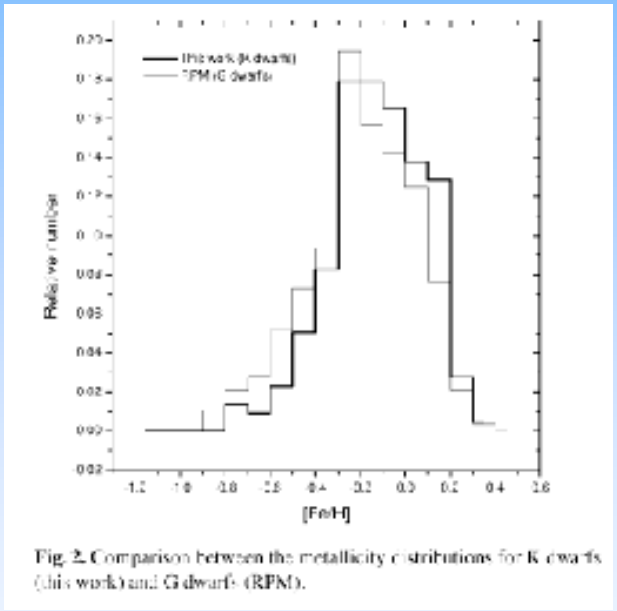
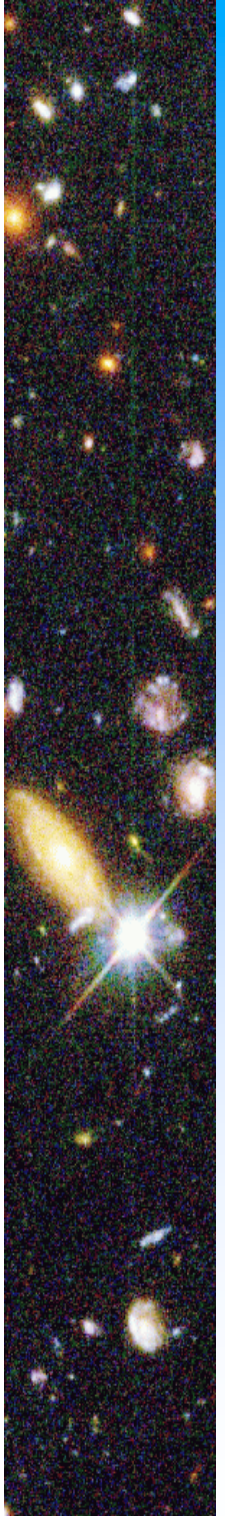


Fig. 2. Comparison between the metallicity distributions for K dwarfs (this work) and G dwarfs (RPM).

Short-term (10^8yr) fluctuations by factor <4 around simple model SFH

Broad (>factor 10) stellar metallicity distribution

<[Fe/H]> < 0, subsolar



★ The Hubble Sequence of Normal Galaxies

+ barred spirals

★ Dwarf Galaxies

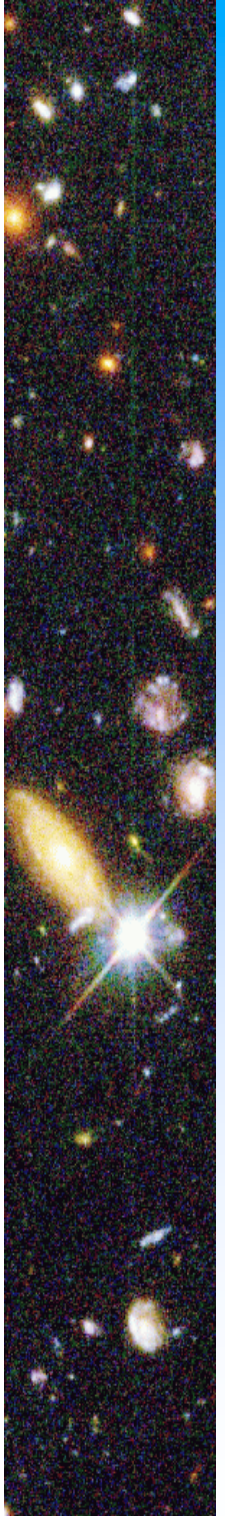
= by far the dominant galaxy type by numbers

dE . . . dSph . . . dI

Blue Compact Dwarf Galaxies BCDGs

★ "Hubble Parallel Sequence" of Low Surface Brightness Galaxies LSBGs

★ "Exotic" Galaxies : Starburst, interacting, Radio, Seyfert, Liner, Infrared Ultraluminous, ERO, SCUBA, Lyman Break , QSO host, . . . galaxies



Local Galaxies

Low surface brightness galaxies : Es, disks, dwarfs

parallel sequence to Hubble sequence

LSB Es, dEs, dSphs: old stellar pops, no gas (diff. to detect)

Sagittarius dSph (Ibata+95), Canis Major (Lewis+04)

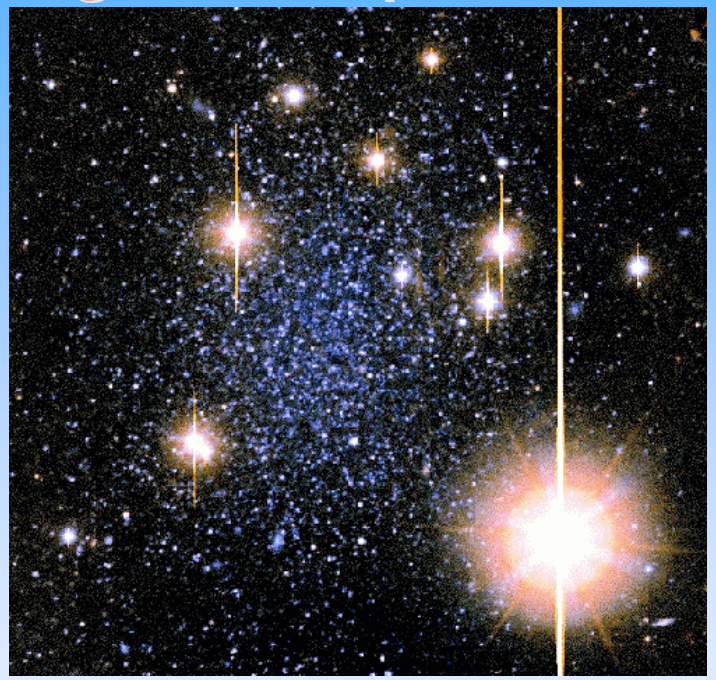
LSB disks and irregulars : very gas-rich, low SFR,
Malin-1 young stellar pops, low metallicity
? old stellar component ?
? formation epoch ?
? late formation or slow evolution ?
? why ?

in isolation or low gal. dens. environm. !

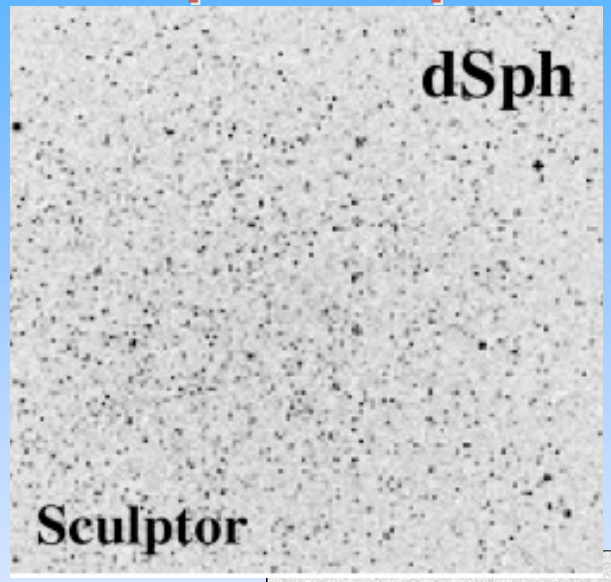
Local Galaxies

LSB Es, dEs, dSphs: old stellar pops, no gas

Pegasus dSph

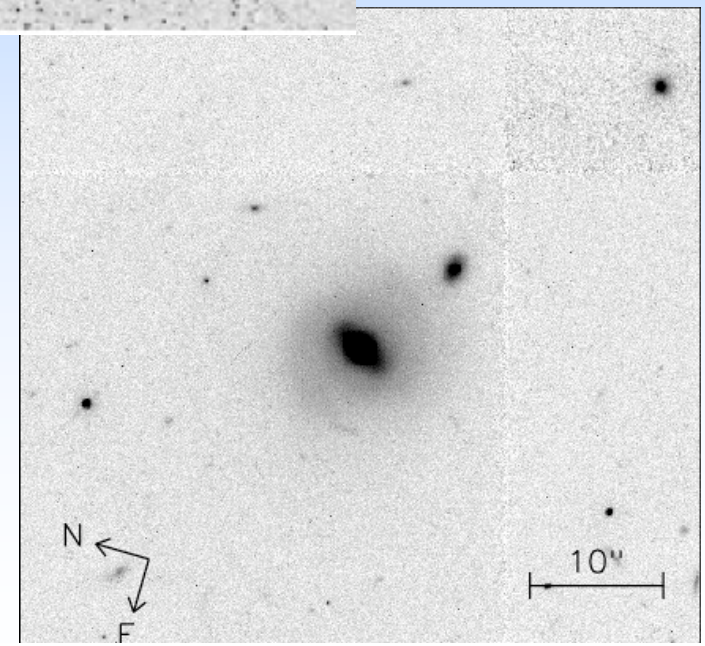


Sculptor dSph



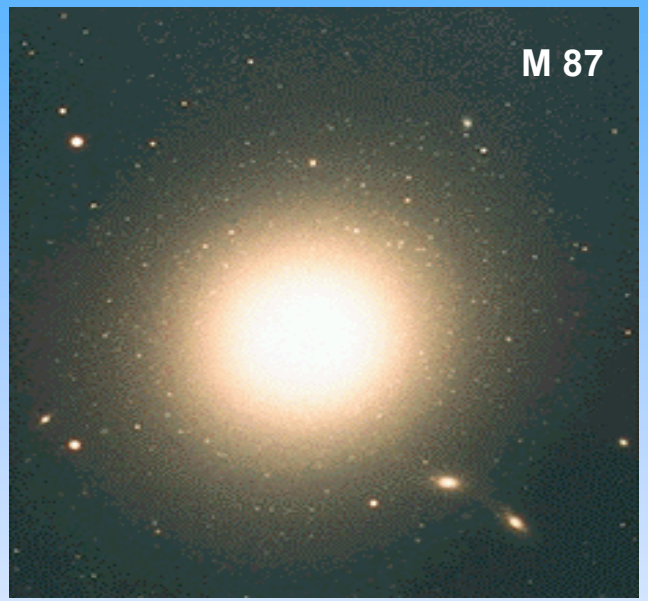
LSB disks and irregulars : very gas-rich, low SFR,

Malin-1



Local Galaxies

Normal (= big) galaxies : Ellipticals



~ spheroidal e:= 1-b/a, $0 \le e \le 0.7$

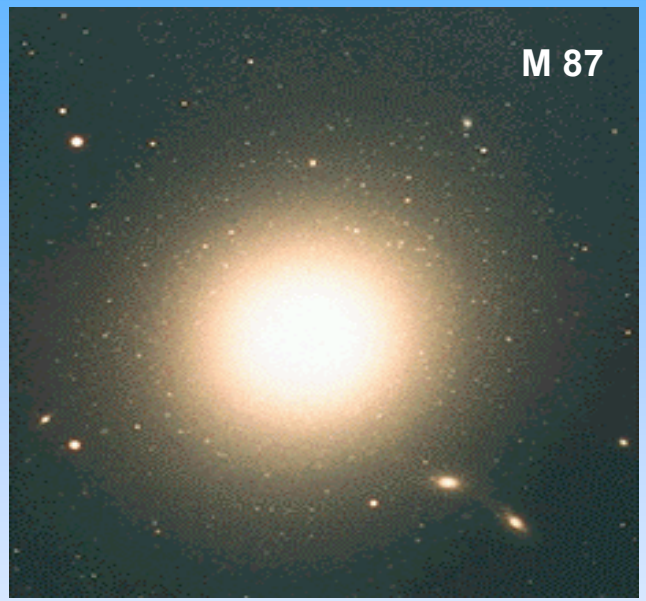
de Vaucouleurs $r^{1/4}$-surface brightness profile

R_e := effective radius
= half light radius
I_e := intensity within R_e

$$I(R^\star) = I_e \exp\left(-7.67 \cdot \left[\left(\frac{R^\star}{R_e}\right)^{\frac{1}{4}} - 1\right]\right)$$

Local Galaxies

Normal (= big) galaxies : Ellipticals



disky – boxy Es
low-L – high-L

old, low-mass stars

K-star type spectrum, red colours

no HI, no molecular gas, no SF

X-ray gas $10^{6 \cdots 7}$ K in halos to >400 kpc, ~5% M_{tot}

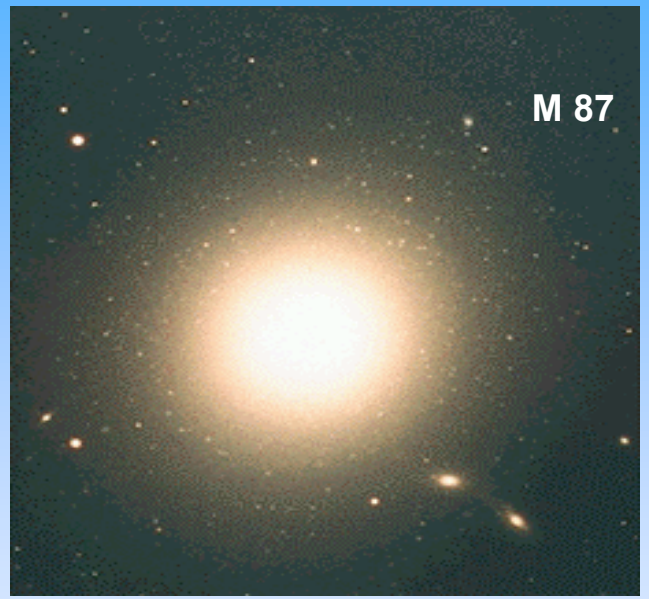
wide range in mass : $10^9 \ldots 10^{14}\ M_\odot$

wide range in luminosities : $-25 \le M_B[\mathrm{mag}] \le -12$
cD . . . . . dE

$10 \le M/L \le 100$ (in solar units $[M_\odot / L_\odot]$)

Local Galaxies

Normal (= big) galaxies : Ellipticals



no/slow rotation (big/dwarf Es)

dynamically hot : high stellar velocity dispersion

extended systems of Globular Clusters < 200 kpc, (0 - few in dEs, 100s - 1000s in Es, 10.000 in cDs)

gradients in colour & metallicity

1.boxiness, counter-rotating cores, ripples & shells in ~ 50% Es,

2.circumnuclear molecular gas & SF in some Es,

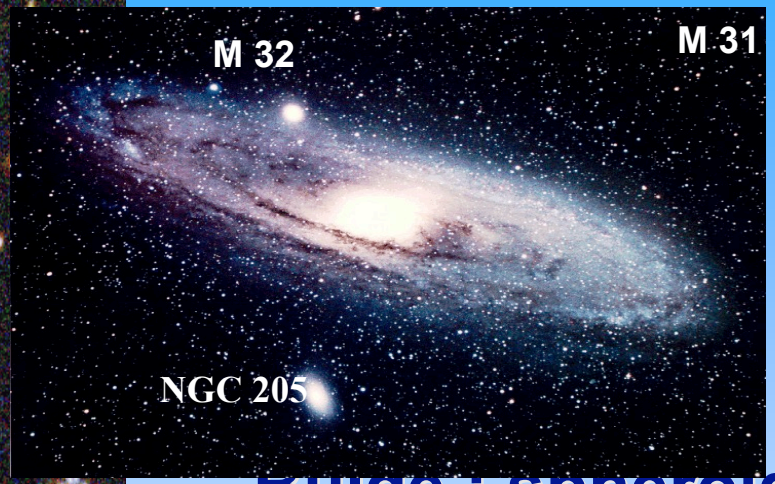
1., 2. indicate past/recent interaction

➜ Initial Collapse vs. hierarchical accretion scenarios for formation of elliptical galaxies

Local Galaxies

Normal (= big) galaxies : Spirals Sa, Sb, Sc, Sd

B/D light ratio ↘ for Sa . . . Sd



narrow range in luminosities

$-21 \leq M_B[\text{mag}] \leq -16$

bulge + disk + halo

B D H

Bulge : spheroidal E0 - E4, old (+young ?) stars

Disk : stars, gas, dust, SF, young open clusters

Halo : old metal-poor stars & old Globular Clusters

Stellar disks : exponential luminosity profile

$\mu(r) = \mu_o \exp(-r/r_o)$ (Freeman 70)

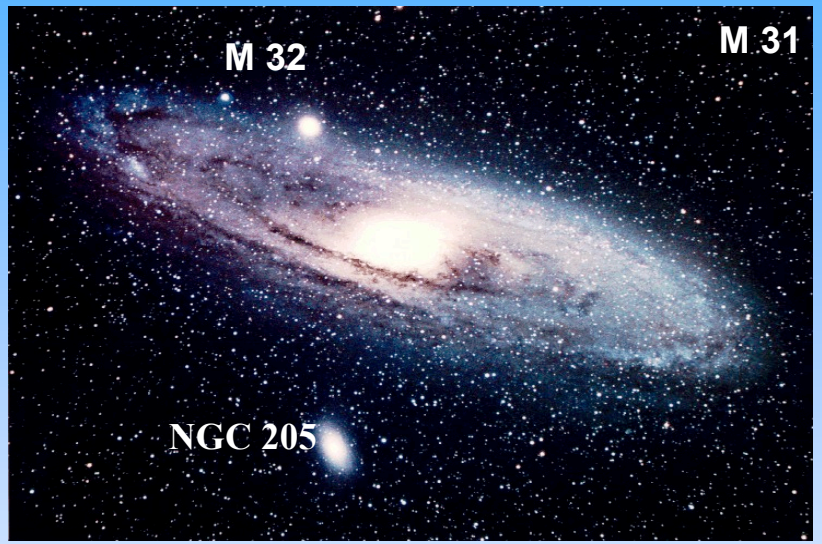
μ_o : central surf. brightness ~ 145 $L_\odot / pc^2$ narrow range !

r_o : scale length ~ 2 . . . 5 kpc

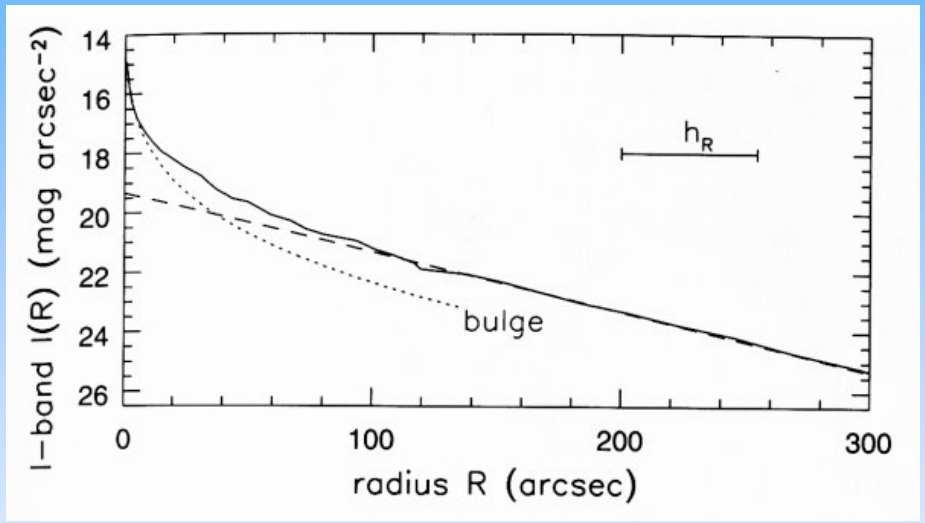
Stellar disks end @ Holmberg radius R_H : $R_H \sim 5\, r_o$

Local Galaxies

Normal (= big) galaxies : Spirals Sa, Sb, Sc, Sd



bulge - disk decomposition



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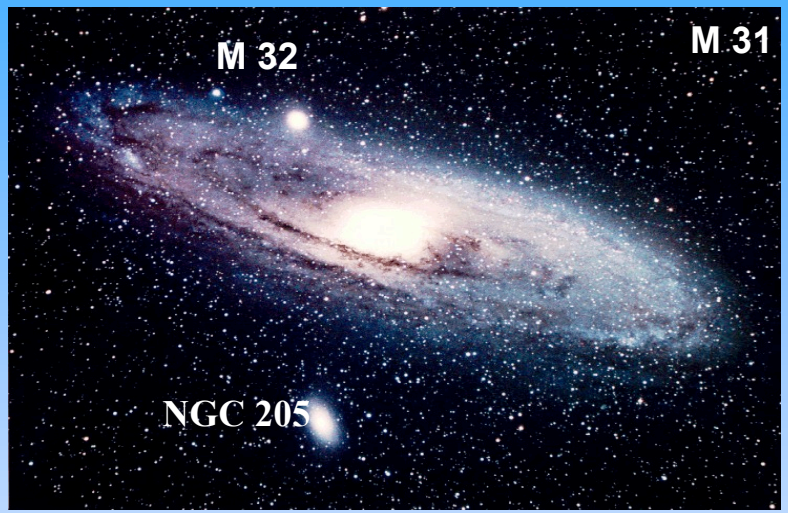
r_o : scale length ~ 2 . . . 5 kpc

Stellar disks end @ Holmberg radius R_H : $R_H \sim 5\, r_o$

$\mu(R_H) = 26.5$ mag arc sec^{-2} ~(1 - 2)% night sky

Local Galaxies

Normal (= big) galaxies : Spirals Sa, Sb, Sc, Sd



disks dynamically cold : $\sigma \ll v_{rot}$

HI disks 3 × more extended than stellar disks

molecular gas (thin disk) CO

dust disks 1.5 × more extended than stellar disks

SF ongoing in disk/spiral arms

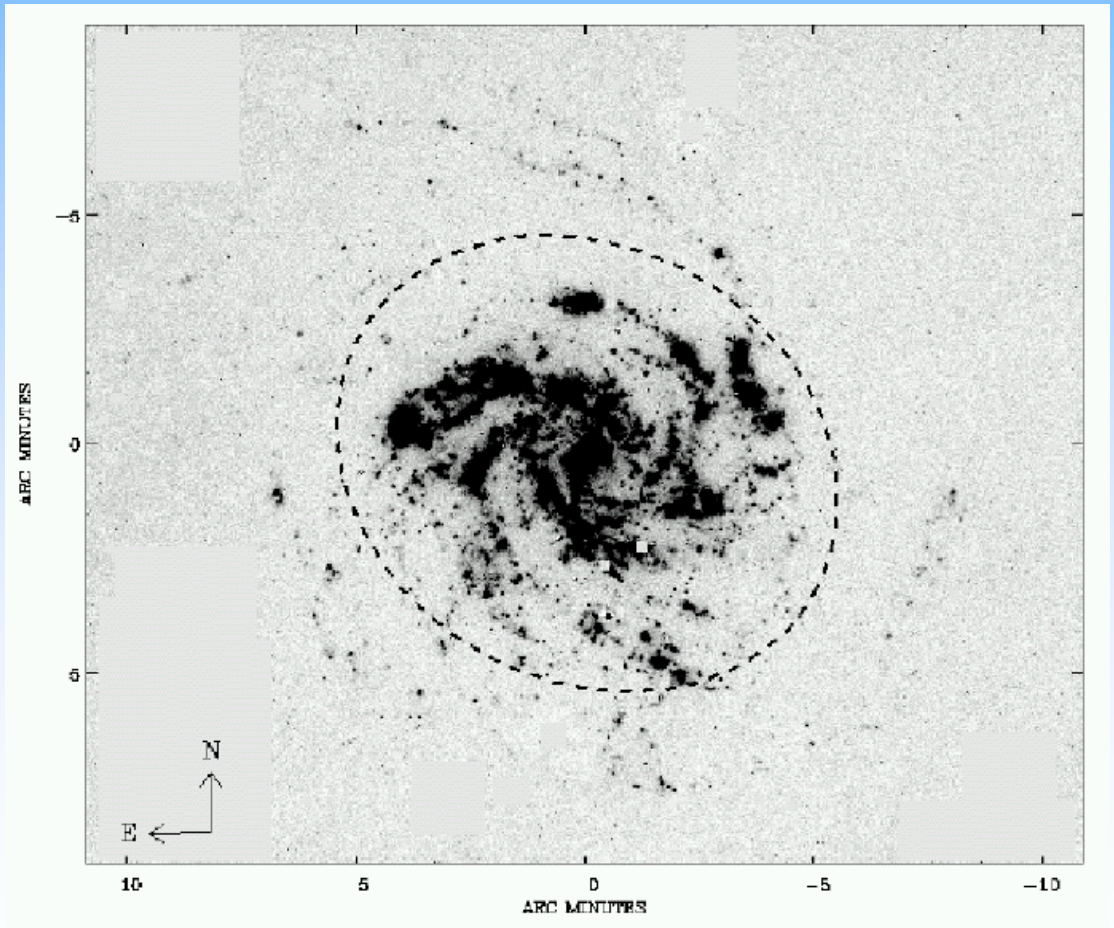
SF more extended than stellar disk

(Hα: Ferguson+98,van Zee+98, GALEX-UV: Thilker+07)

➜ Stellar disks grow from inside out

Local Galaxies

Ferguson+98 : Hα emission from HII regions beyond the optical radius in spirals



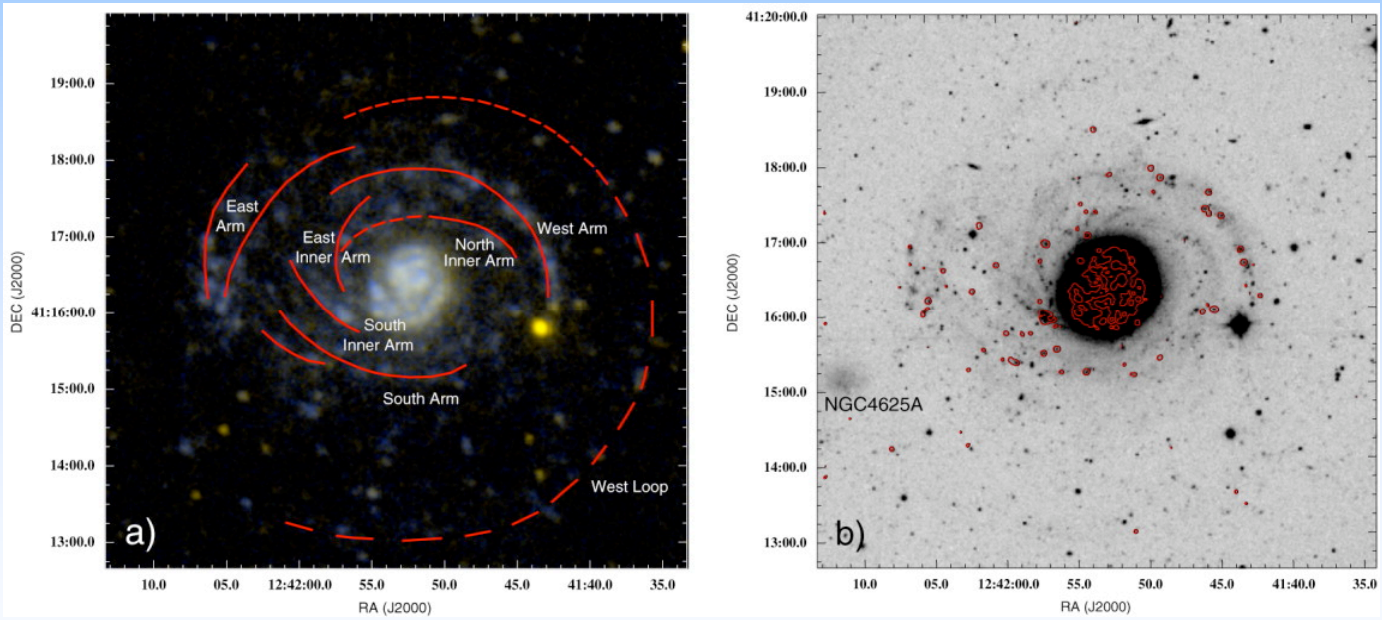
Local Galaxies

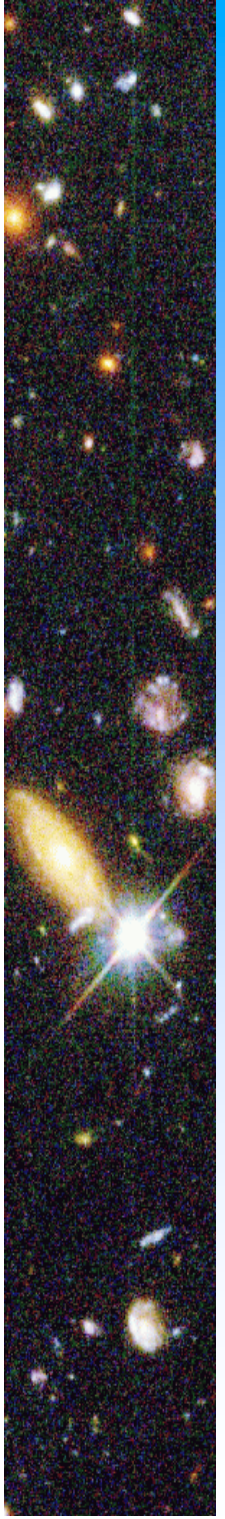
Thilker+07, Gil de Paz+05 : Galex UV emission from hot young stars beyond the optical radius in spirals

E.g. NGC 4625

Galex: FUV

deep B-band





Local Galaxies

Normal (= big) galaxies : Spirals Sa, Sb, Sc, Sd

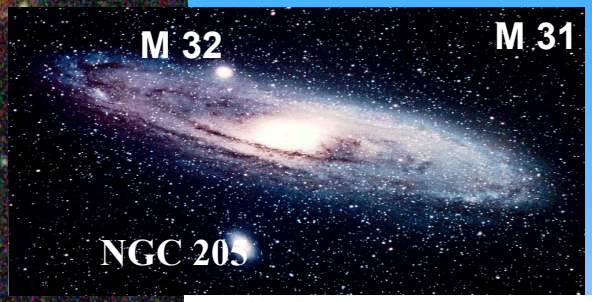
Masses within 1 R_H : $3 \cdot 10^{10}$ . . . $9 \cdot 10^{11} M_\odot$

Sa	Sb	Sc	Sd
SFRo(Sa) <	SFRo(Sb) <	SFRo(Sc) <	SFRo(Sd)
G/(S+G)(Sa) <	G/(S+G)(Sb) <	G/(S+G)(Sc) <	G/(S+G)(Sd)
~0.05	~0.15	~0.3	>0.5
Z(Sa) >	Z(Sb) >	Z(Sc) >	Z(Sd)
(B-V)(Sa) >	(B-V)(Sb) >	(B-V)(Sc) >	(B-V)(Sd)
M/L(Sa) >	M/L(Sb) >	M/L(Sc) >	M/L(Sd)
~6.2	~4.4	~2.6	(Rubin+82)

MW : M_B=-19.4, M31: M_B=-20.5,

Local Galaxies

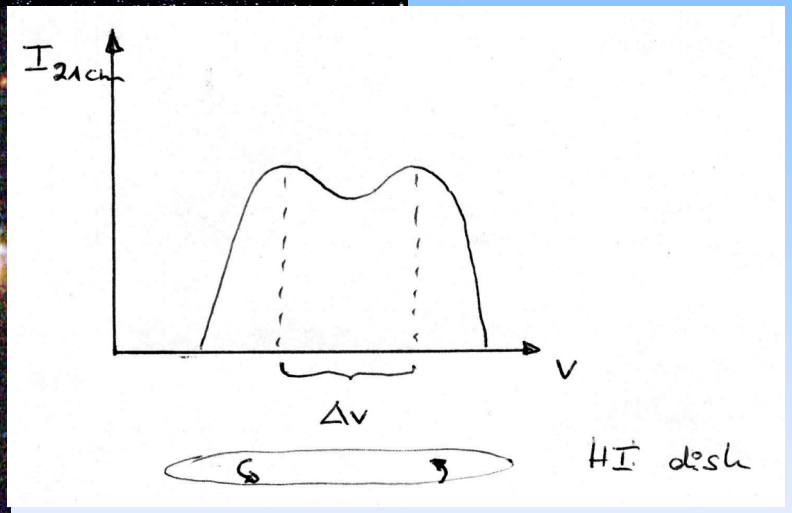
Normal (= big) galaxies : Spirals Sa, Sb, Sc, Sd

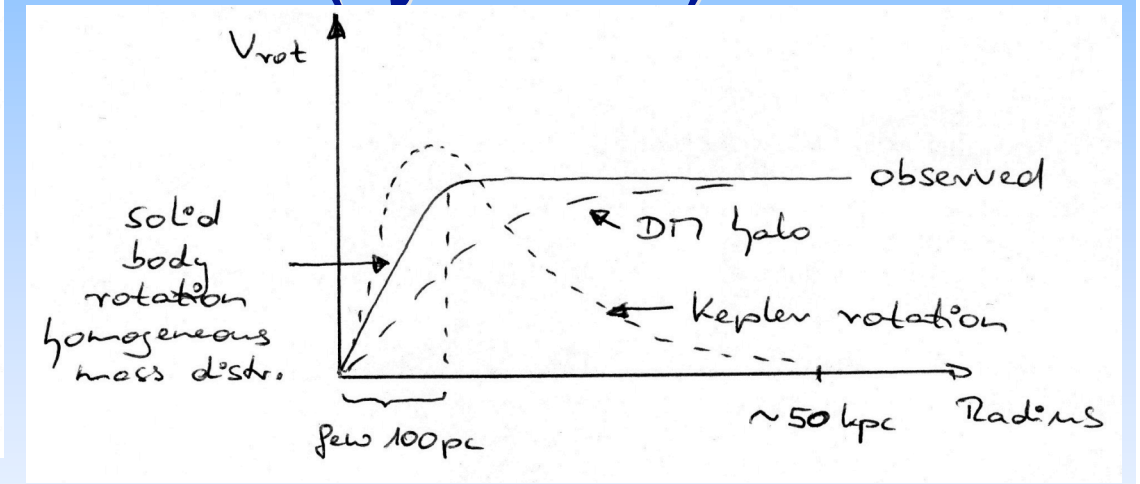


differential rotation

$120 \text{ km/s} \leq v_{rot} \leq 240 \text{ km/s}$

rotational velocity ➔ total (dynamical) mass





rotation curves ➔ Dark Matter halos

disks : gradients in
- color
- extinction
- metallicity
- stellar age

Local Galaxies

Dwarf galaxies : dE, dSph, dI

dE : mini-E 10^7 . . . 10^9 $M_\odot$
red, old, metal-poor

dSph : mini-S0
red, ?old?, ?metal-poor?

dI : irregular : HI, CO, SF
blue, young stars
low metallicity