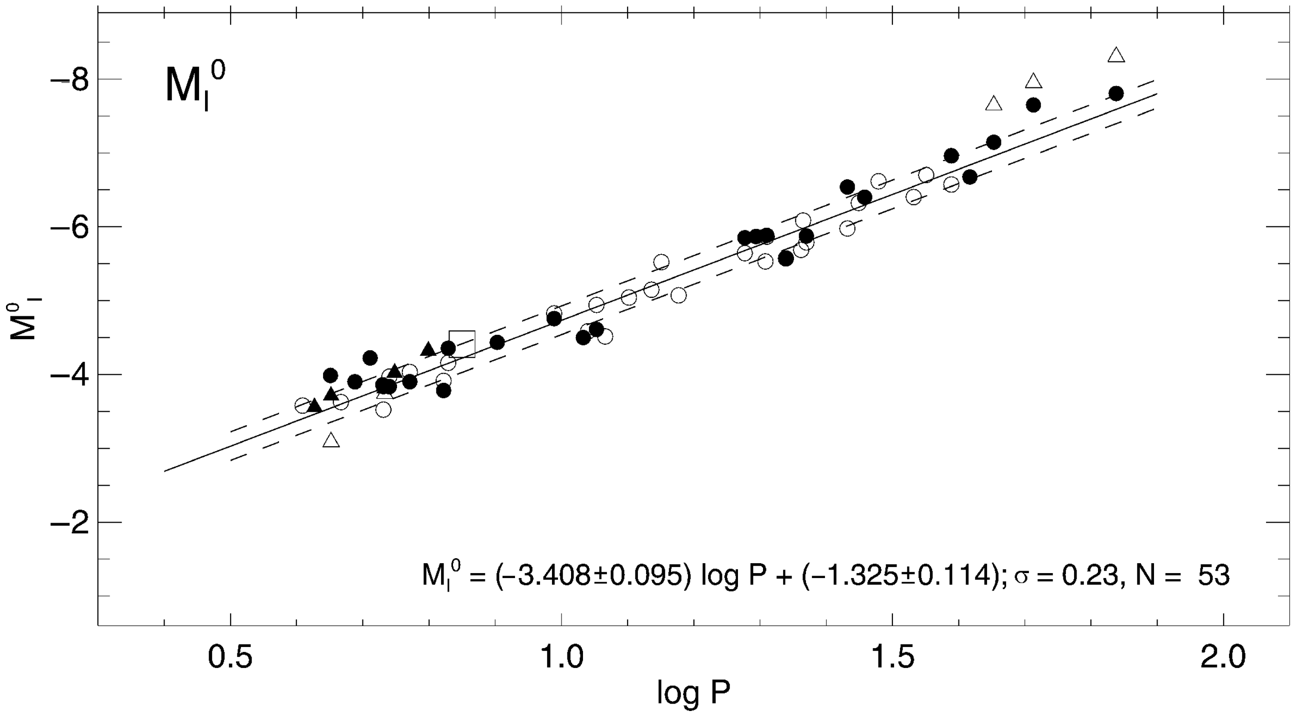
Galaxies

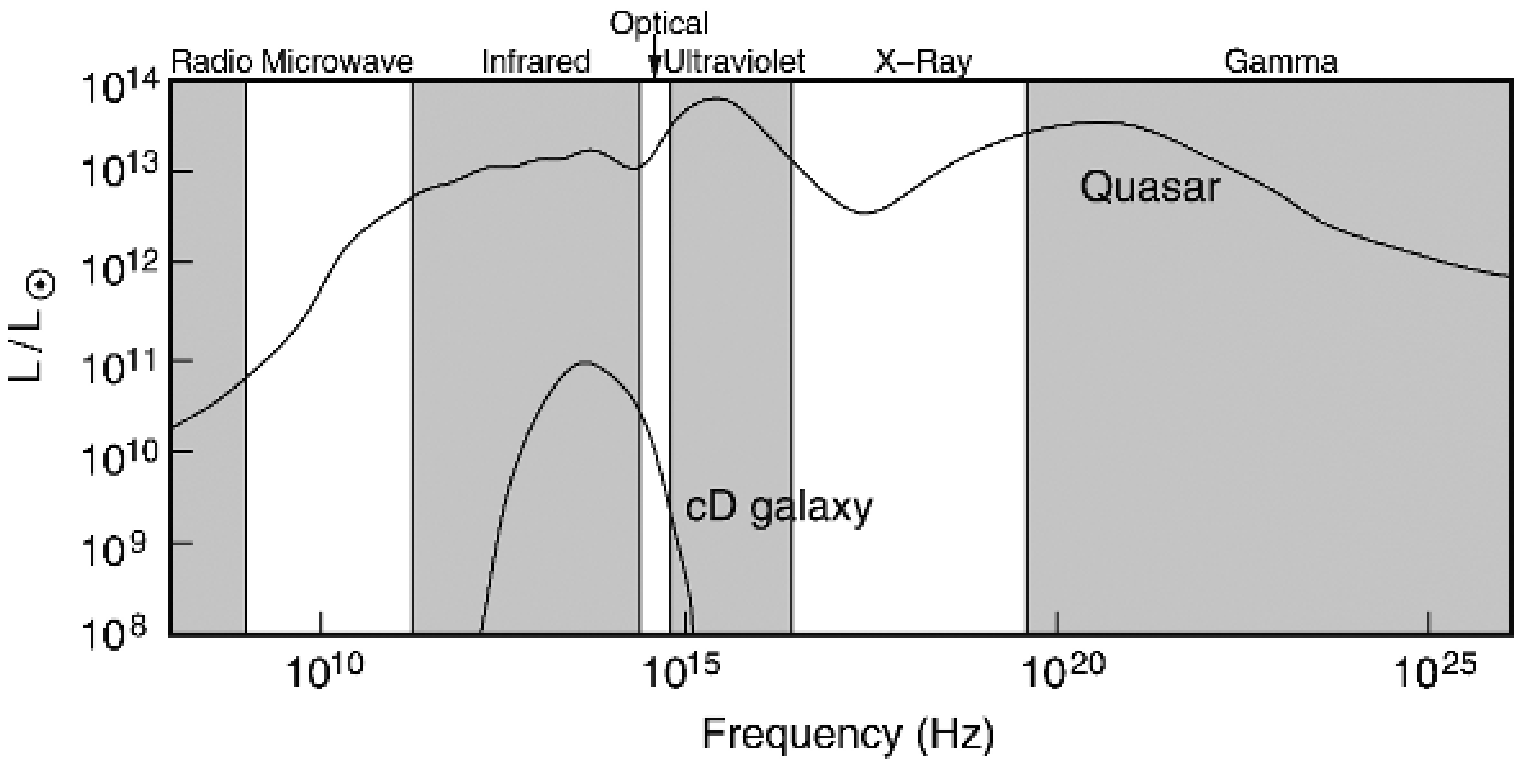
- Hubble's measurement of distance to M31
- Normal versus other galaxies
- Classification of galaxies
- Ellipticals
- Spirals
- Scaling relations

Cepheids in M31



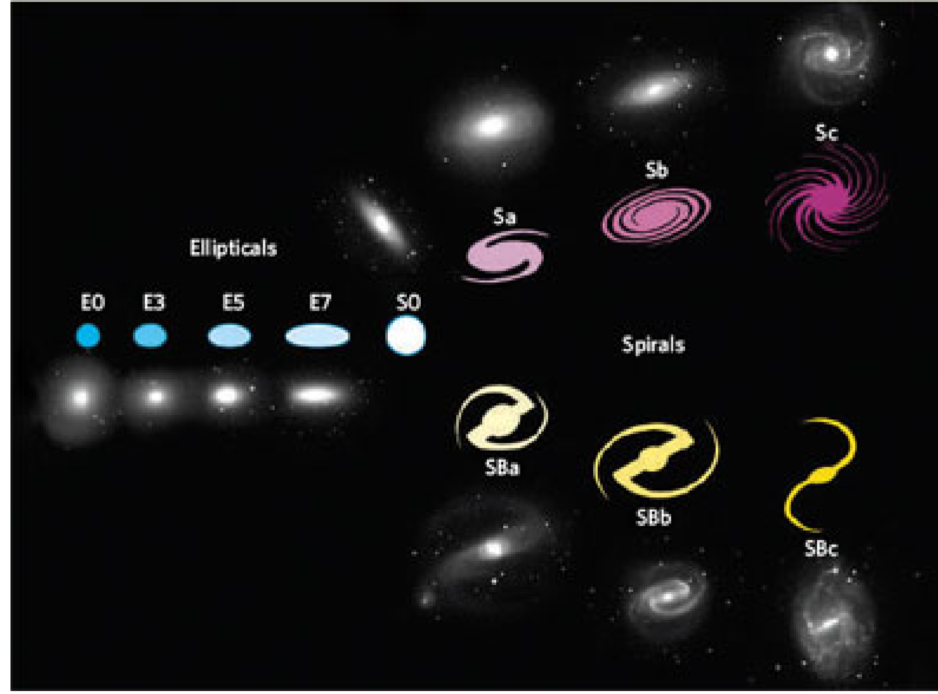
- Up to 1920s, the Milky Way was thought by many to be the whole universe.
- In 1925, Hubble discovered Cepheids in M31 and measured their distance using the period-luminosity relation.
- He found a distance of 285 kpc which is larger than the known size of the Milky Way. Current best estimate is 770 ± 43 kpc.
- This was the start of extragalactic astronomy.

Normal versus other galaxies



- Starlight dominates the SED of normal galaxies.
- SEDs of galaxies with accreting supermassive black holes extend from radio to gamma-rays. Luminosity is higher. These galaxies often appear normal, maybe with an unusually bright nucleus, in optical images.
- Star-forming galaxies with lots of gas/dust have peaks from starlight and thermal dust emission.

Classification of galaxies



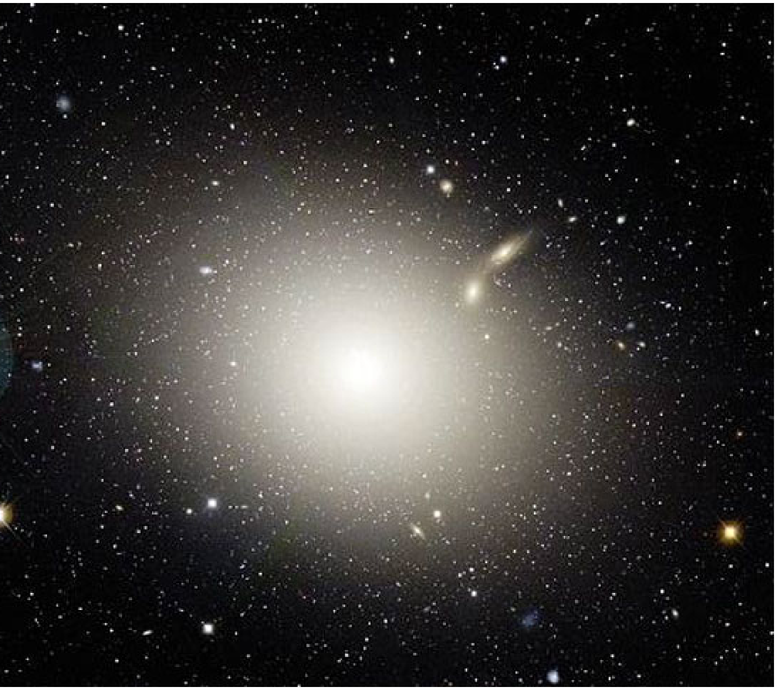
- Ellipticals: En, where n=0 for round, n=7 for oblong.
- Spirals: Sx, where x = indicates brightness of bulge relative to arms, how tightly the arms are wrapped, and the definition of the arms: a (bright, tight, fuzzy), b, c (dim, loose, sharp). Later “d” and ab, bc, cd were added. If the arms have a central bar, then SBx.
- Elliptical galaxies are “early-type”; spiral galaxies are “late-type”.
- Later additions to classification scheme:
- Lenticulars: S0 and SB0, mostly bulge with a little bit of disk typically with poorly defined arms.
- Use of SA, SAB, SB for spirals, where SA = S, SAB = intermediate.
- Sub-classification of irregulars: Irr I (weak structure), Irr II (no structure). Addition of Magellanic cloud types, LMC is an irregular, but is sometimes classified as SBm.

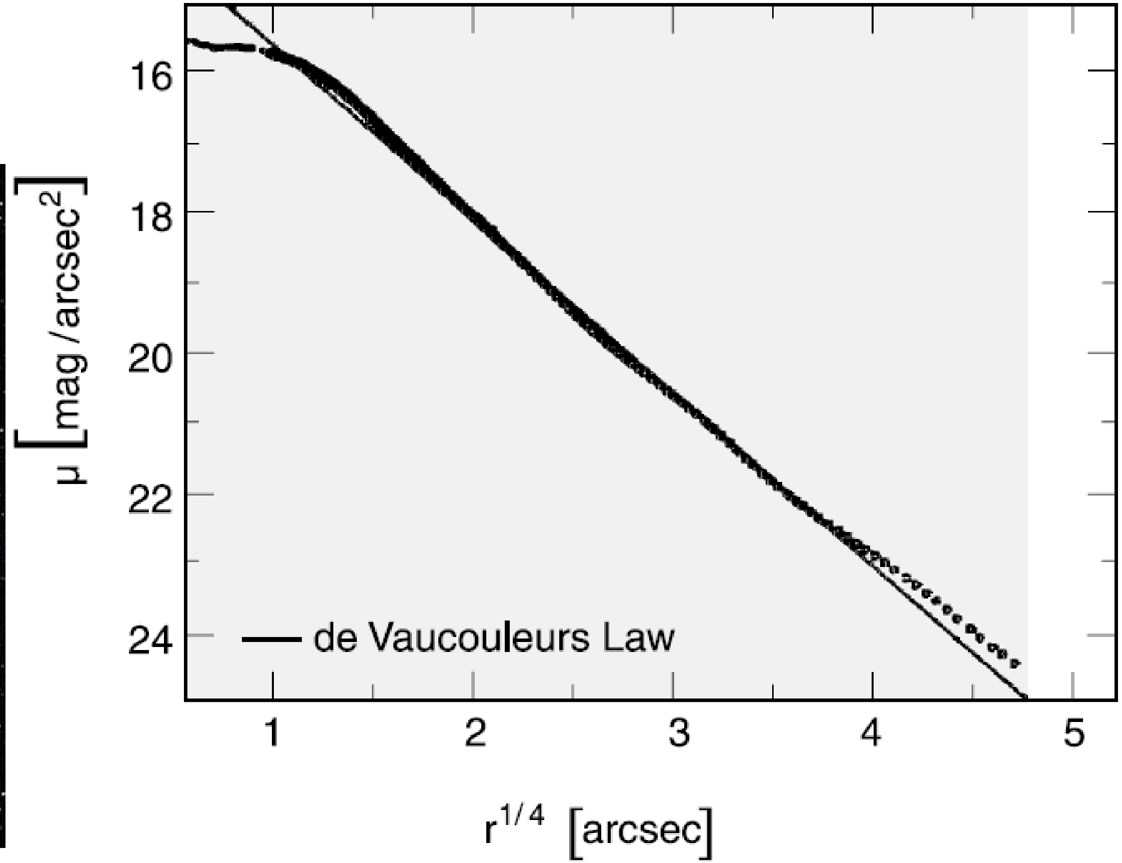
Ellipticals

	S0	cD	E	dE	dSph
M_B	-17 to -22	-22 to -25	-15 to -23	-13 to -19	-8 to -15
$M(M_\odot)$	10^{10} to 10^{12}	10^{13} to 10^{14}	10^{8} to 10^{13}	10^{7} to 10^{9}	10^{7} to 10^{8}
D_{25} (kpc)	10–100	300–1000	1–200	1–10	0.1–0.5
$\langle M/L_B \rangle$	~ 10	> 100	10–100	1–10	5–100
$\langle S_N \rangle$	~ 5	~ 15	~ 5	4.8 ± 1.0	–

- M_B is absolute magnitude in B-band (optical luminosity), *M* is mass in solar masses, D_{25} is extent in optical, diameter where surface brightness of galaxy has dropped to 25 mag/arcsec^2 in B-band images (note surface brightness is independent of distance), $\langle S_N \rangle$ is number of globular clusters relative to M_B.
- Normal ellipticals (E), dwarf ellipticals (dE), dwarf spheroidals (dSph) form a rough sequence in size (physical size, mass, and luminosity).
- Most of the stars in S0 galaxies comes from the bulge which has properties like ellipticals.
- cD galaxies are only found near the centers of dense clusters.
- Blue compact dwarfs (BCDs) are ***not*** ellipticals, they are irregulars (Fig 3.5 of “ellipticals” says the BCD is an irregular).

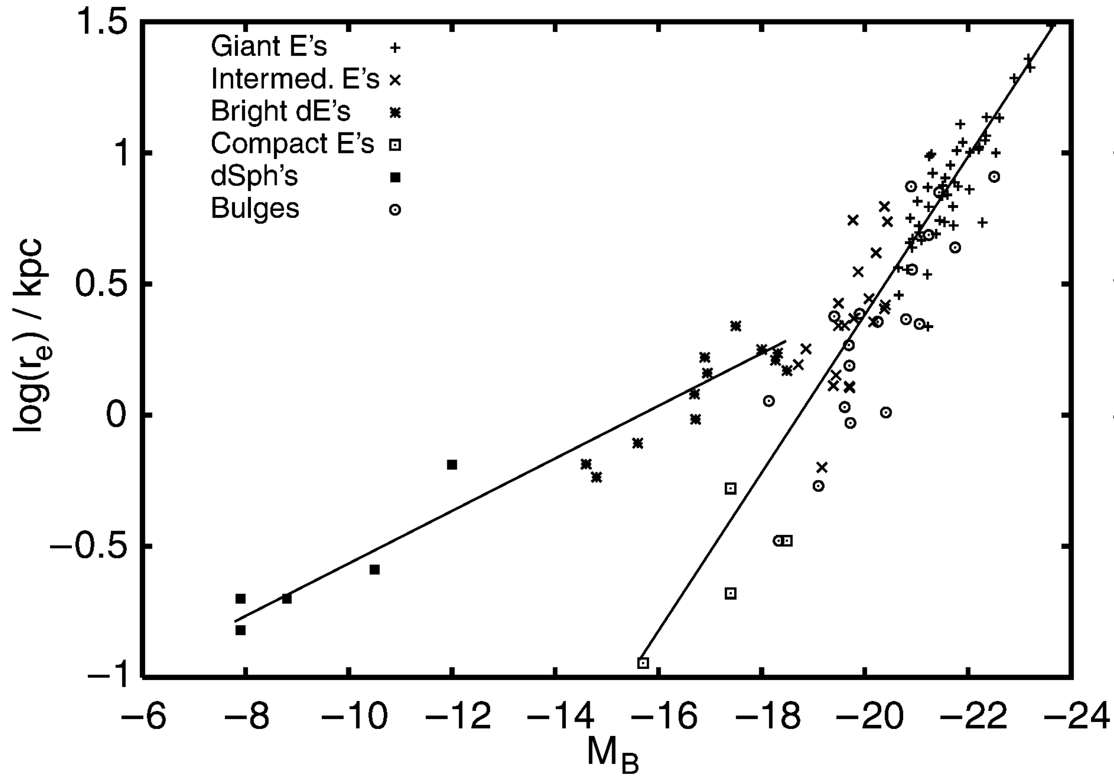
Brightness profiles





- Brightness profiles of ellipticals (and bulges) are well described by the empirical de Vaucouleurs profile, $\mu \sim \exp[-k(r/r_e)^{1/4}]$.
- Deviations at $r < 1''$ are due to seeing (angular resolution), deviations at large r indicate an extended halo.
- cD galaxies have large excess at large radii.

Relations between galaxy properties



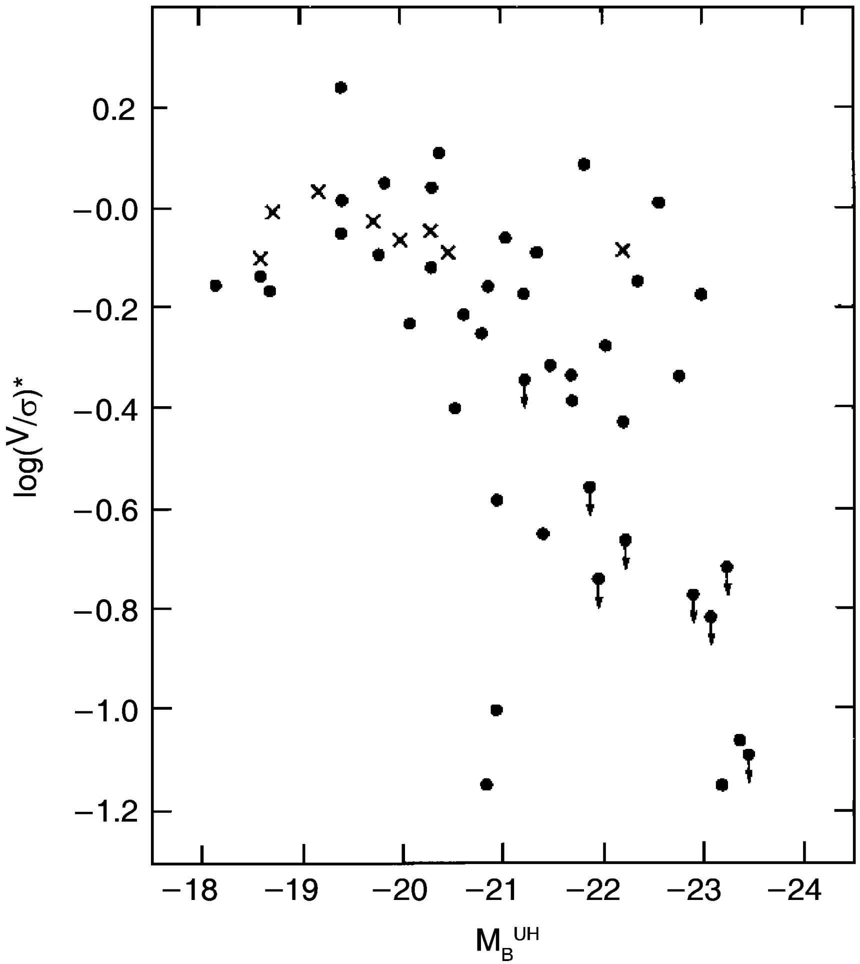
- Correlations between galaxy observables suggest that there are relatively few fundamental parameters affecting the properties of elliptical galaxies.
- This plot may suggest different evolutionary tracks for dSph's and dE's versus other E's and bulges.

Why are (some) ellipticals not round?

- An elliptical galaxy is essentially a ball of stars. The instantaneous positions of the stars determine the gravitational potential. Given the instantaneous velocities one can then find the stellar orbits.
- Near collisions between stars would randomize the velocities and eventually isotropize the position distribution. The time scale for this to occur is $t_{\rm relax} \sim t_{\rm cross}$ $(N/\ln N)$. For a "typical" galaxy, $t_{\rm cross} \sim 10^8$ yr and N $\sim 10^{12}$, so $t_{\rm relax} \sim 10^{19}$ yr, much longer than the age of the universe.

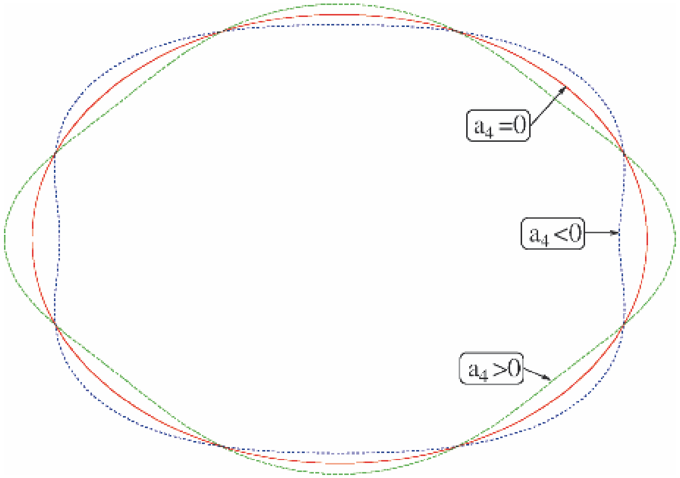
Rotational flattening

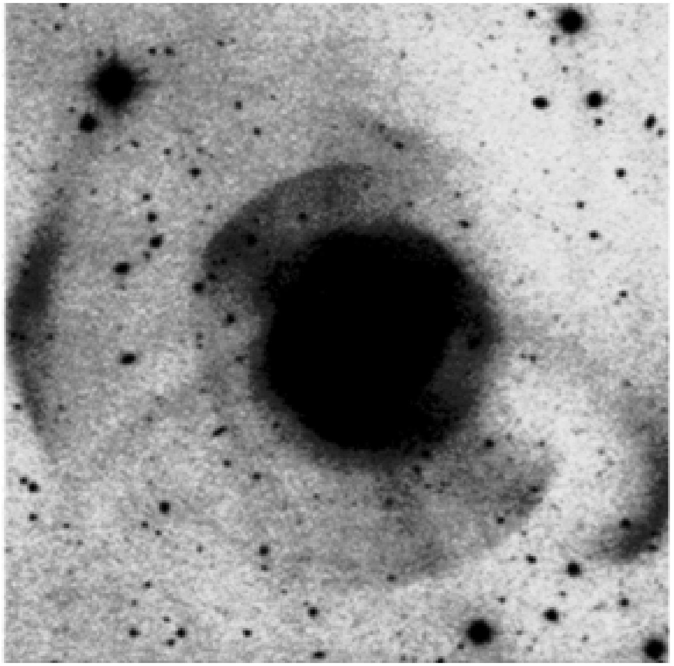
- If the stellar velocity distribution has a net spin, then position distribution will bulge outwards at the equator.
- The ratio v_{rot}/σ determines the ellipticity where v_{rot} is the rotation velocity and σ is the velocity dispersion.
- Rotation velocity is centroid of velocity distribution along a line of sight, dispersion is width of velocity distribution.
- (V/σ)* is v_{rot}/σ divided by the value that would produce the observed ellipticity.
- Rotation flattening works for some bulges and less luminous ellipticals.



Dots are ellipticals, crosses are bulges

Fine structure





- Some ellipticals deviate from simple ellisoids.
- Ellipticity and major axis can vary versus radius ("isophote twist").
- Isophotes may not be ellipses, either "disky" ($a_4 > 0$) or "boxy" ($a_4 < 0$).
- About half of ellipticals show "shells" or "ripples". These are groups of stars on similar orbits with low velocity dispersion.
- Fine structure and failure of rotational flattening for large ellipticals suggests complex evolution.

Spiral galaxies

	Sa	Sb	Sc
M_B	−17 to −23	−17 to −23	−16 to −22
$M\ (M_\odot)$	10^9–10^{12}	10^9–10^{12}	10^9–10^{12}
$\langle L_{\rm bulge}/L_{\rm tot}\rangle_B$	0.3	0.13	0.05
Diam. (D_{25}, kpc)	5–100	5–100	5–100
$\langle M/L_{\rm B}\rangle\ (M_\odot/L_\odot)$	6.2 ± 0.6	4.5 ± 0.4	2.6 ± 0.2
$\langle V_{\rm max}\rangle$(km s^{-1})	299	222	175
$V_{\rm max}$ range (km s^{-1})	163–367	144–330	99–304
Opening angle	$\sim 6°$	$\sim 12°$	$\sim 18°$
$\mu_{0,\rm B}$ (mag arcsec^{-2})	21.52 ± 0.39	21.52 ± 0.39	21.52 ± 0.39
$\langle B - V\rangle$	0.75	0.64	0.52
$\langle M_{\rm gas}/M_{\rm tot}\rangle$	0.04	0.08	0.16
$\langle M_{\rm H_2}/M_{\rm HI}\rangle$	2.2 ± 0.6 (Sab)	1.8 ± 0.3	0.73 ± 0.13
$\langle S_{\rm N}\rangle$	1.2 ± 0.2	1.2 ± 0.2	0.5 ± 0.2

a –
bright bulge
tight arms
smooth arms

c –
dim bulge
loose arms
knotty arms

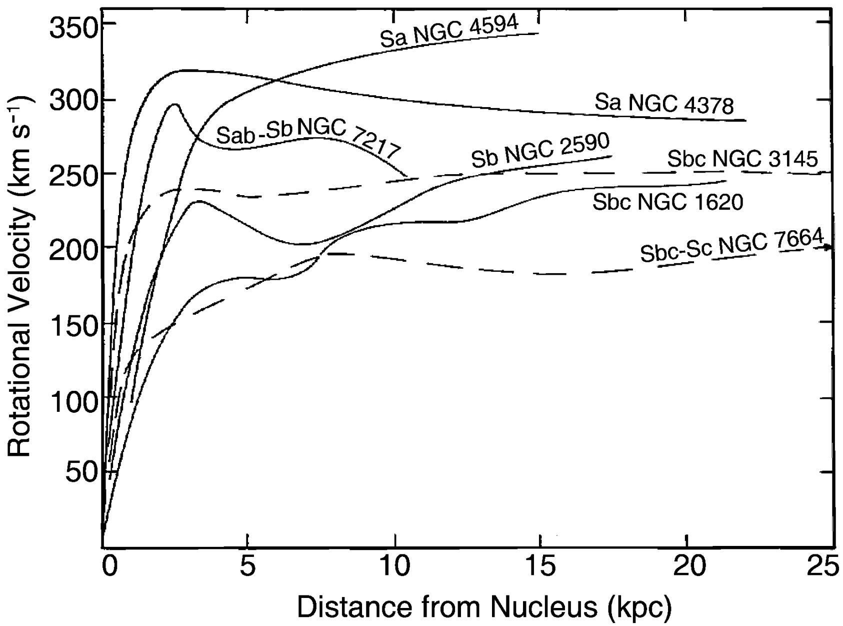
similar masses
and luminosities

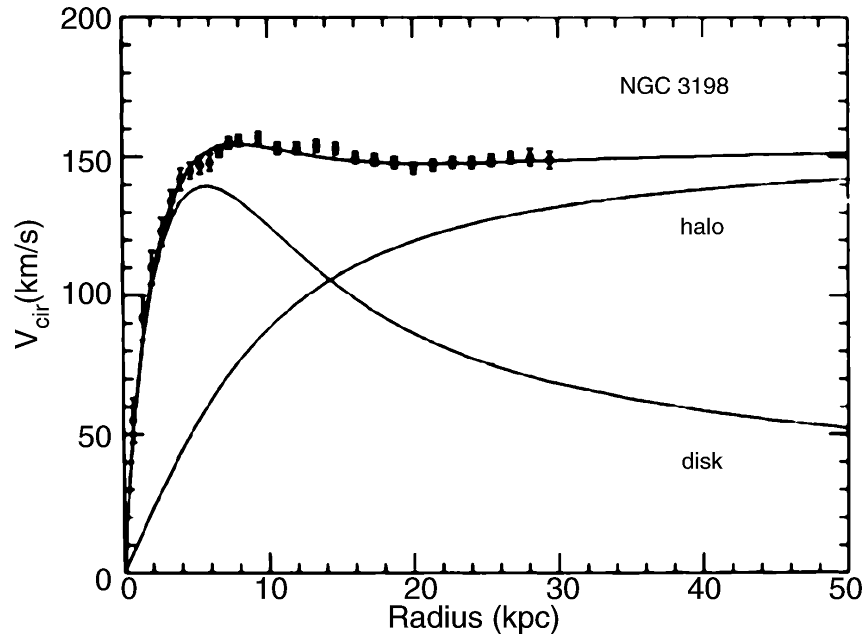
Brightness profiles

- Brightness profiles of bulges are well described by the empirical de Vaucouleurs profile, $\mu \sim \exp[-k(r/r_e)^{1/4}]$.
- Brightness profiles of disks are roughly $\mu \sim \exp[-k(r/h)]$.
- Central surface brightness of disks (at $r = 0$) are similar for different "normal" spirals.
- Spirals have halos extending to at least 100 kpc.

- There are also "low surface brightness" (LSB) galaxies that are dimmer and harder to study.

Rotation curves and dark matter





- Rotation curves of essentially all spirals are roughly flat at large radii. From Newton, $v^2(R) = GM(R)/R$, v = constant suggests presence of dark matter with density profile $\rho(r) \sim r^{-2}$.
- Satellites orbiting at large radii suggest no edge to dark matter halo, at least to 100 kpc. Note that $M \sim R$ for dark matter, so the total mass of a galaxy is undetermined as long as its halo edge is unknown.
- Sa's tend to have larger maximum orbital velocity (v_{max}) than Sc's.

Stellar populations

	Sa	Sb	Sc
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Diam. (D_{25}, kpc)	5–100	5–100	5–100
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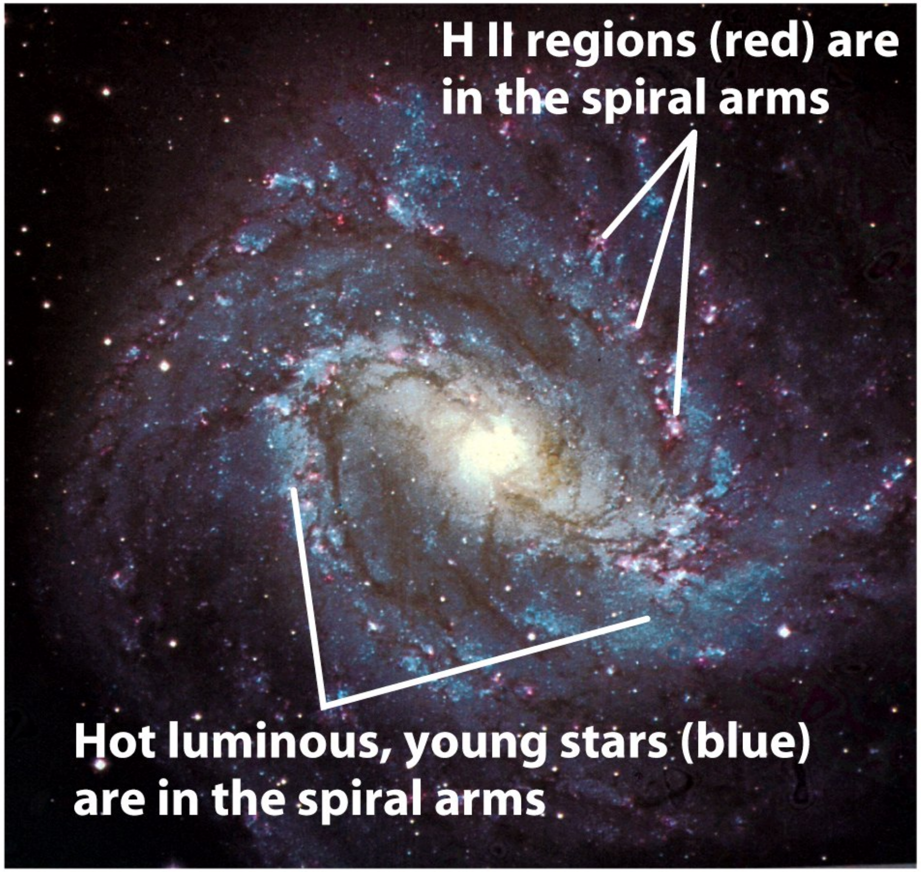
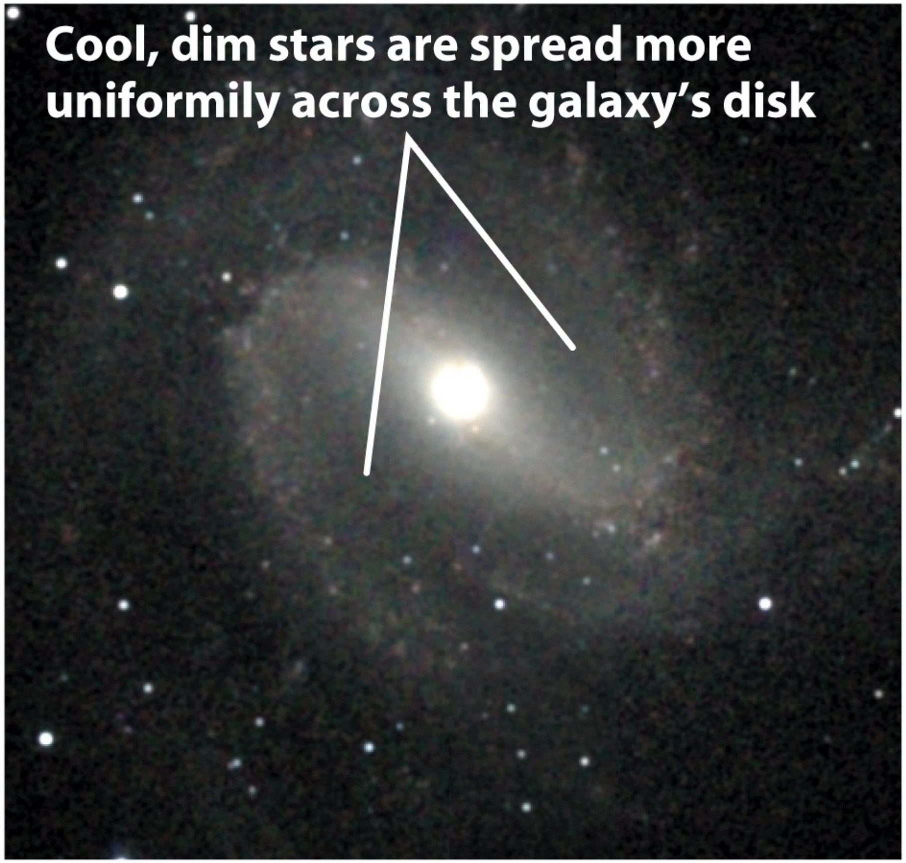
$\langle M_{H_2}/M_{HI}\rangle$	2.2 ± 0.6 (Sab)	1.8 ± 0.3	0.73 ± 0.13
$\langle S_N\rangle$	1.2 ± 0.2	1.2 ± 0.2	0.5 ± 0.2

- Later spirals (c) are bluer (B-V is smaller) and have more gas than earlier spirals (a). This means they have more active star formation.
- The outer regions of spirals are bluer than the centers. Due to old stars in the bulge and metallicity. Metal rich stars are redder. There are more metals in the inner regions due to more past star formation.
- Early type spirals have more globular clusters (normalized to galaxy luminosity). S0's and ellipticals have even more globular clusters and cD galaxies have the most.

Spiral arms



Visible-light view of M83



Near-infrared view of M83

- Spirals arms contain young, hot, massive stars and are density waves of active star formation

For next class

- Keep a list of terms you don't understand and e-mail it to philip-kaaret@uiowa.edu
- Read 3.4, 3.6-3.7
- Work on HW #2 due Wednesday 8/29