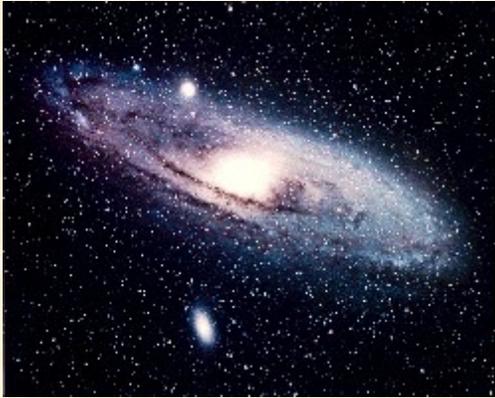


Introduction to Galaxies



- History
- Famous Galaxies
- Catalogs and Atlases
- Classification Schemes



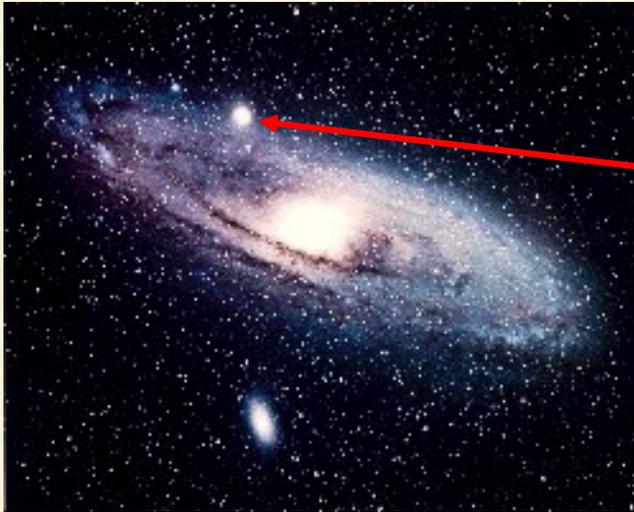
What is a galaxy?

- A gravitationally bound collection of stars
- A galaxy has 10^6 to 10^{12} stars
- Participates in the expansion of the Universe

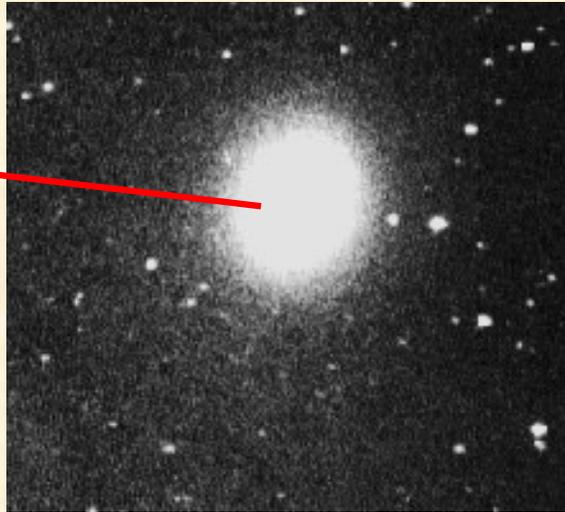
Galaxies - History

- Originally grouped together with other extended sources (nonstellar in appearance) called **nebulae**
 - Early catalog of 110 objects by Messier in late 1700s
- Distinguished visually from other nebulae by
 - distinct continuous spectra (M31, Huggins, late 1800s)
 - spiral structure (Earl of Rosse, mid 1800s)
- Photography revealed many more “spiral nebulae” (Keeler & Curtis 1900).
- Kant (1755) first suggested they were “island universes”.
- Famous Shapley-Curtis debate of 1920 – Curtis argued that spiral nebulae were systems of stars like our Milky Way.
- Hubble (1924) found Cepheid variables in nearby (Local Group) galaxies, placing them outside of the Milky Way.

Messier Galaxies



M31 – Andromeda



M32



M51 – Whirlpool



M104 - Sombrero



M87



M82 - Cigar

Galaxy Catalogs

- *New General Catalog (NGC)*: includes clusters, nebulae, etc.
 - Visual surveys by Herschels (late 1700s), updated and published by Dreyer in 1888, 7840 entries
 - Modern version: *RNGC* (Sulentic & Tifft, 1983)
 - *Index Catalog (IC)*: supplements with ~5100 more entries
 - *NGC 2000* contains both NGC and IC (electronic version at <http://spider.seds.org/ngc/ngc.html> .
- *Third Reference Catalog of Bright Galaxies (RC3)*, de Vaucouleurs et al. (1991)
 - redshifts, magnitudes, classifications, sizes, etc. for ~23,000 galaxies
- *Revised Shapley-Ames Catalog of Bright Galaxies (RSA)*, Sandage and Tammann (1981)
 - Complete data for 1300 galaxies brighter than $B = 13.2$, with photos

More Catalogs



- *Uppsala General Catalog of Galaxies* (**UGC**), Nilsson, 1973
- *Morphological Catalog of Galaxies* (**MCG**), Vorontsov-Velyaminov et al. (1974)
- *Catalog of Galaxies and Clusters of Galaxies*, Zwicky (1968)
 - Above three from Palomar Sky Survey (POSS)
- *Catalog of Selected Compact Galaxies and of Post-Eruptive Galaxies*, Zwicky et al. (1971)
 - normal, interacting, and Seyfert galaxies (e.g., **I Zw 1**)
 - <http://nedwww.ipac.caltech.edu/level5/Sept02/Zwicky/frames.html>

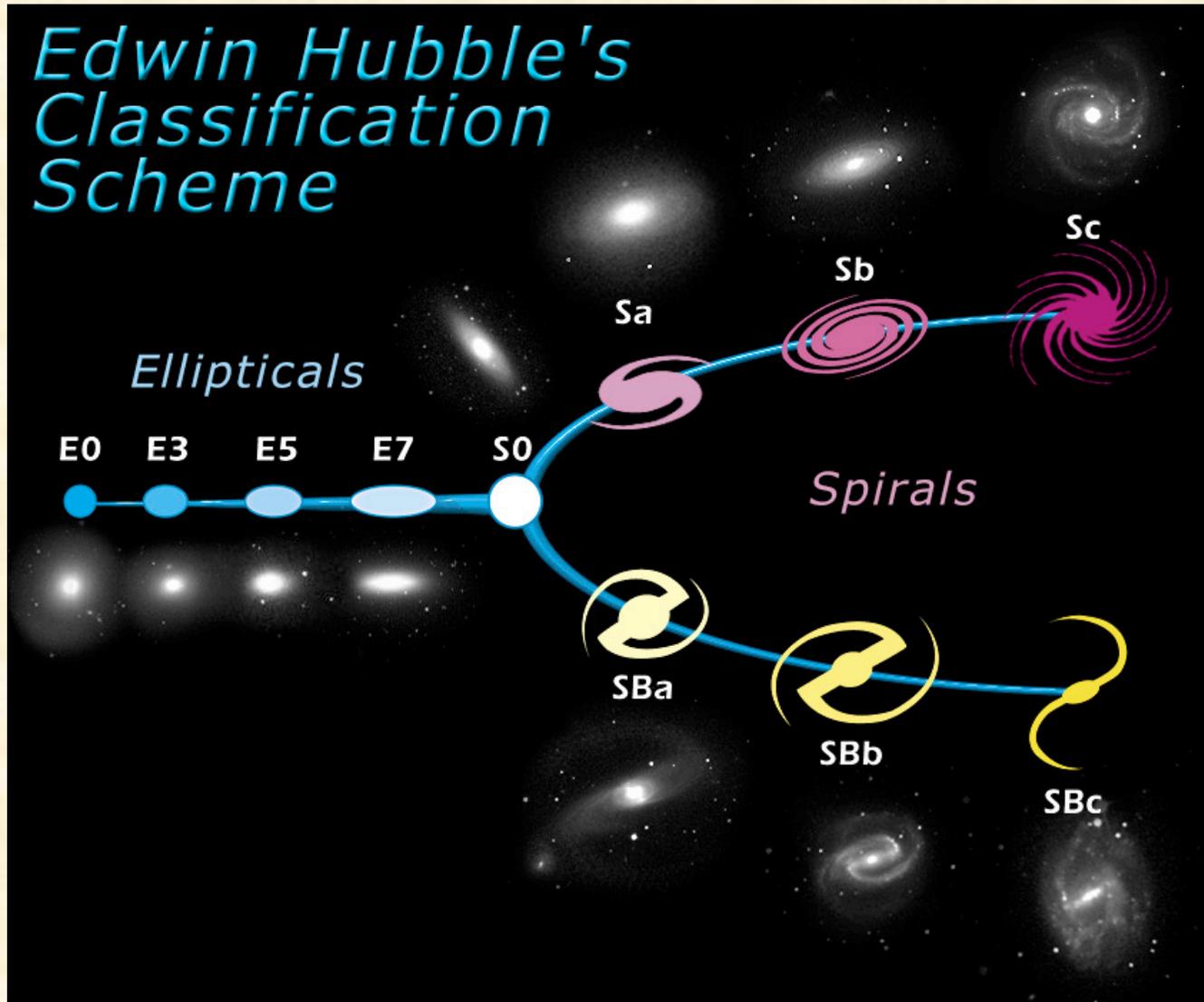
Selected Atlases

- Hubble Atlas of Galaxies, Sandage (1961)
- Atlas of Peculiar Galaxies, Arp (1966)
- Atlas of Galaxies Useful for Measuring the Cosmological Distance Scale, Sandage and Bedke (1988)
- Carnegie Atlas of Galaxies, Sandage and J. Bedke (1994)
 - Includes nearly all 1300 RSA galaxies!

These atlases (and others) are useful for classifying galaxies on a (semi-) objective scale.

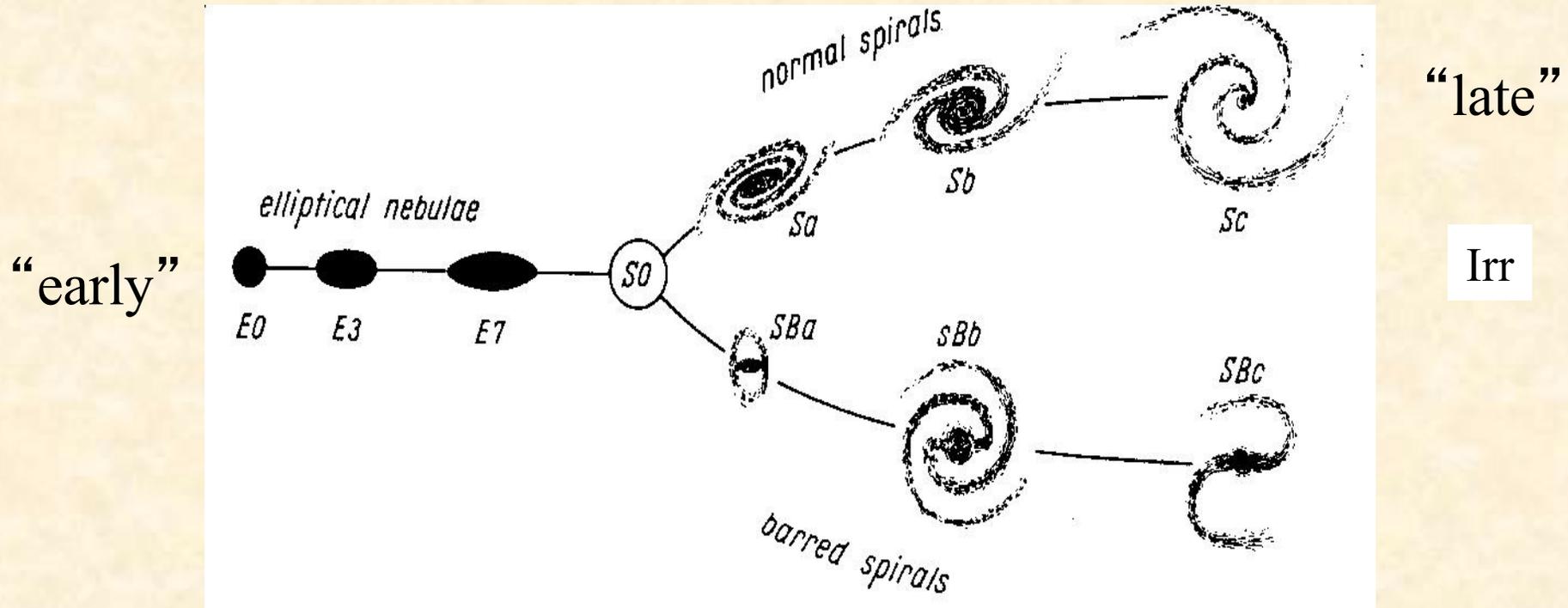
Morphological Classification

- based on visual appearance



Courtesy of Space Telescope Science Institute

Hubble's Tuning-Fork Diagram (*Realm of the Nebulae*, Hubble, 1936)



Ellipticals: increasing ellipticity →

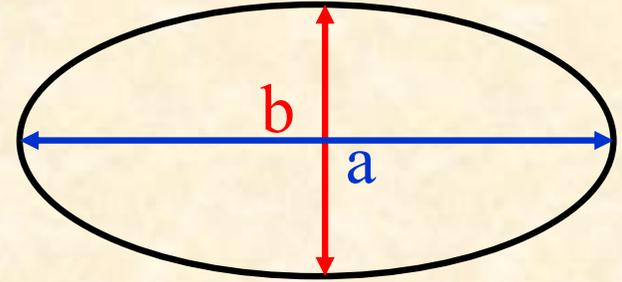
Spirals: decreasing bulge/disk →

decreasing “tightness” of spiral arms →

(Increasing gas and dust →)

(Increasing # of blue (young) stars →)

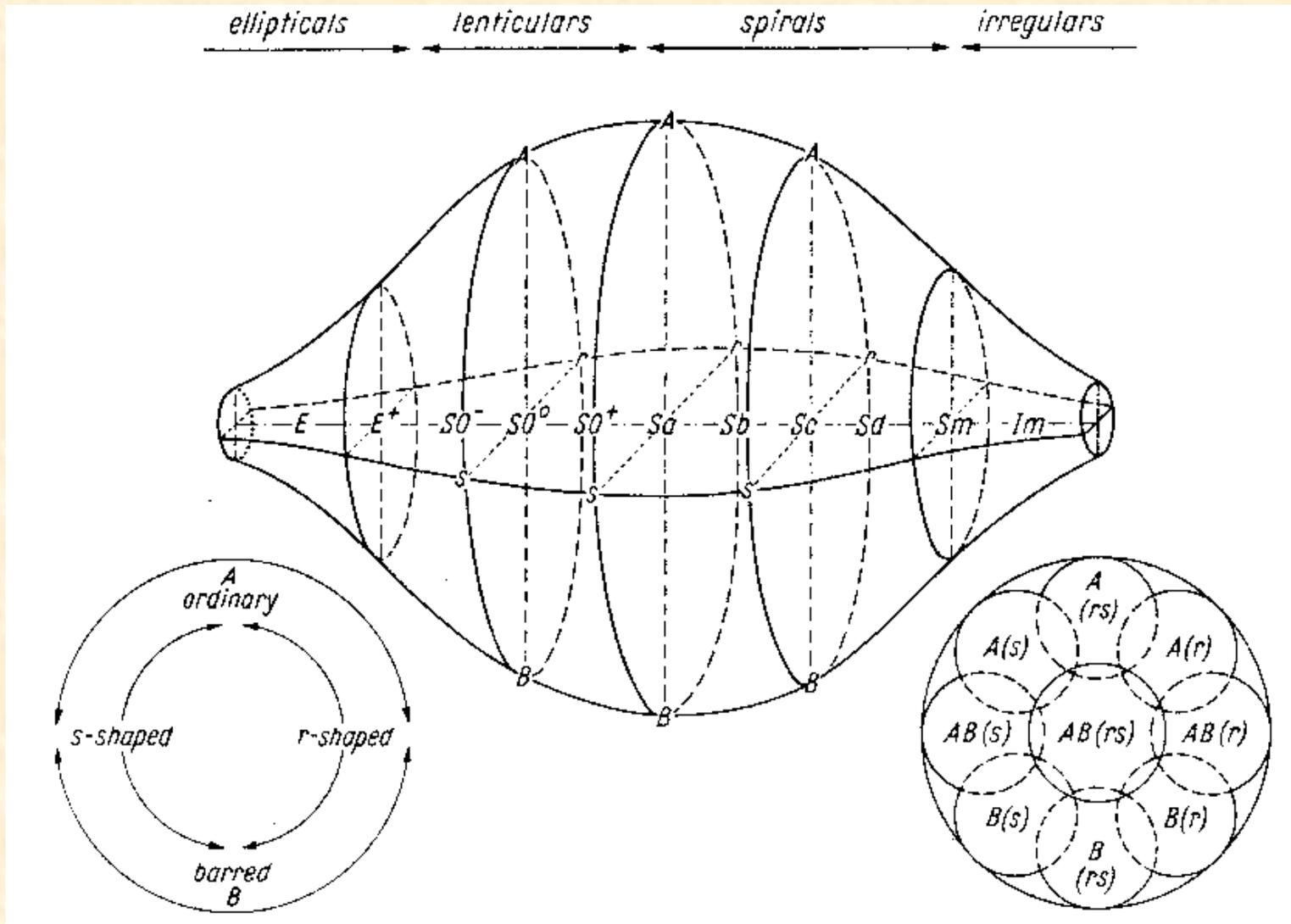
- More morphology:
- a = major axis, b = minor axis
- Ellipticals: E_n , where $n = 10(1 - b/a)$
 - based on appearance only; e.g., a prolate spheroid viewed along its long axis would be classified as E_0
 - Includes cD galaxies, other giant E' s, dwarf E' s, and spheroidal E' s (in order of decreasing luminosity)
- S_0' s and SB_0' s (lenticulars): no spiral arms
 - S_{0_1} , S_{0_2} , S_{0_3} : no dust \rightarrow strong dust lane
 - SB_{0_1} , SB_{0_2} , SB_{0_3} : broad “knobs” \rightarrow well-defined bar
- Spirals: regular and barred
 - b/a gives the disk inclination; $\text{inc.} = \cos^{-1}(b/a)$
 - fraction that are SB' s: 30 – 80% (depends on luminosity, waveband, strength of bar, etc.)



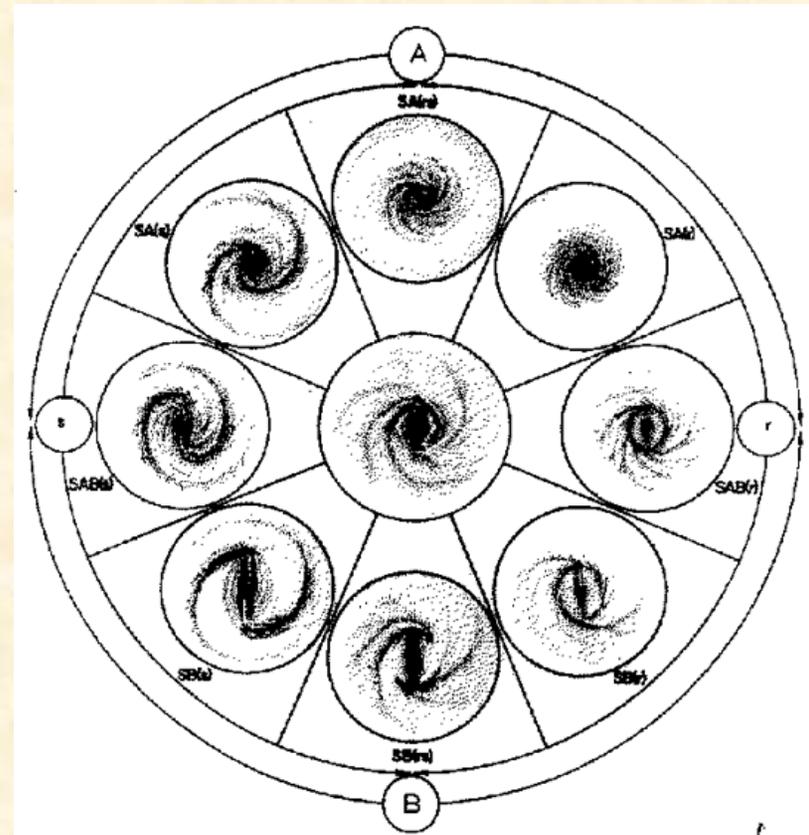
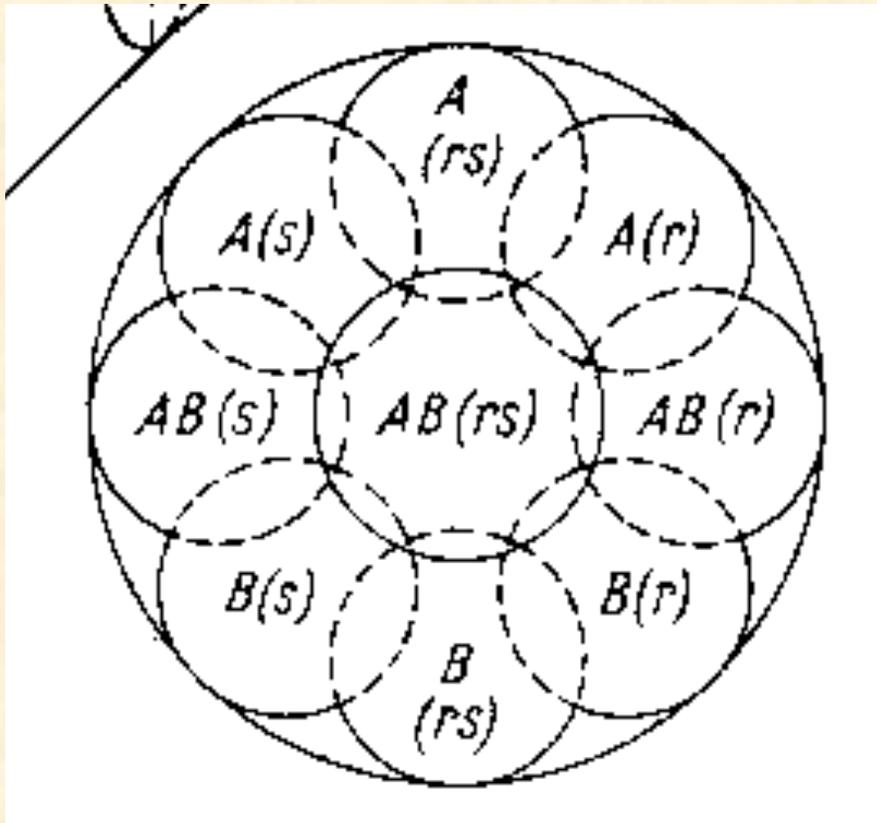
De Vaucouleur's Modifications (used in NED)

- Three main classes of spirals: SA (formerly S), SAB (weak bar), and SB (strong bar)
- More spiral subclasses (e.g., ab, bc)
- Extended spirals to “later” subtypes: d, m
 - d: very loose arms, very small or no bulge
 - m: weak, often “stubby” spiral structure like LMC (SBm)
 - Sequence: a, ab, b, bc, c, cd, d, dm,m
 - Irregulars become Im (like SMC)
- Inner structure: r (ring) or s (spiral)
 - Ex) The Milky Way is thought to be SAB(rs)bc
- Prefix “R”: outer ring
- Suffix P: *peculiar*
- For small galaxies, dIrr and dSph (spheroidal) are often used.

De Vaucouleur's Original Scheme (Graphical)



Example for Spiral Subtype bc

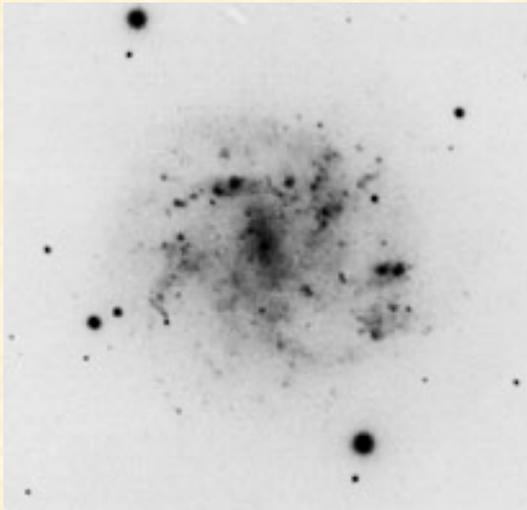


Hubble Stage (T) (from Binney & Merrifield, p. 155)

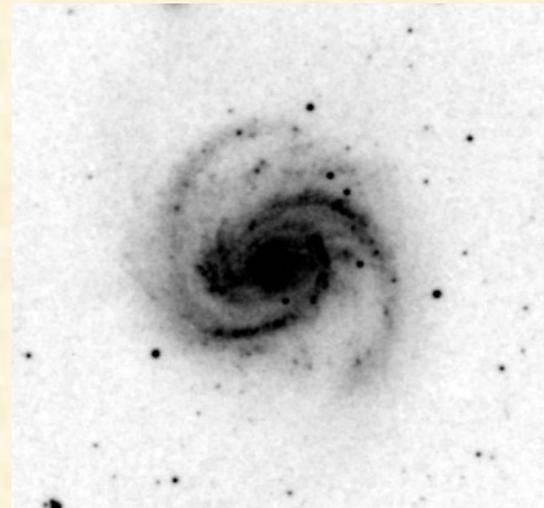
Hubble	E	E-S0	S0	S0/a	Sa	Sa-b	Sb	Sb-c	Sc	Sc-I	Irr
De Vauc.	E	S0 ⁻	S0 ⁰	S0 ⁺	Sa	Sab	Sb	Sbc	Scd	Sdm	Im
T	-5	-3	-2	0	1	2	3	4	6	8	10

Further Classification of Spiral Arms

- Van den Bergh Luminosity Class: I \rightarrow V
 - long, organized arms \rightarrow choppy, unorganized arms
 - most luminous \rightarrow least luminous (not a great correlation)
- Elmegreen & Elmegreen (1982): 12 arm classes
 - Class 1 – multiple arms, fragmented (“flocculent”)
 - Class 12 – two long symmetric arms (“grand design”)

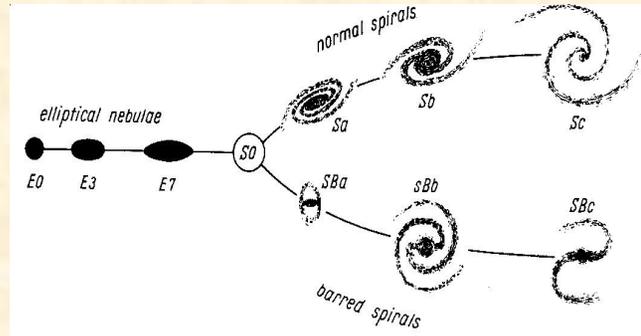


NGC 2500 – flocculent

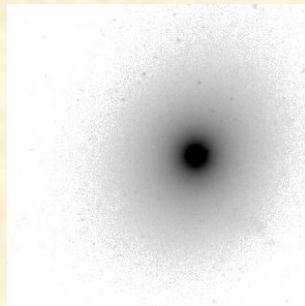


NGC 4321 – grand design

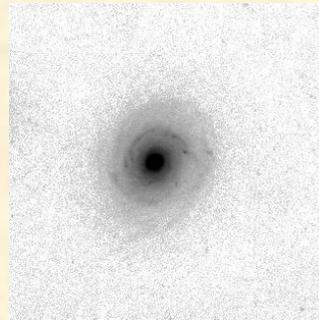
The Classification Game



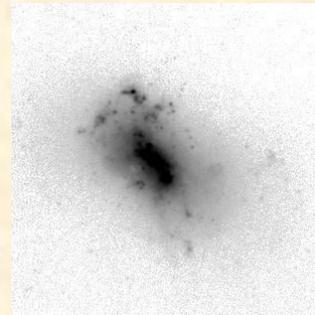
Irr



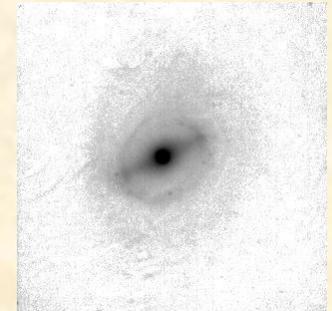
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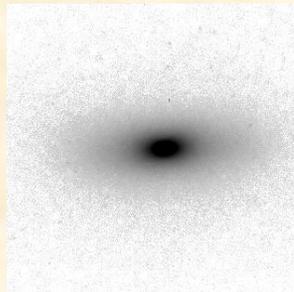
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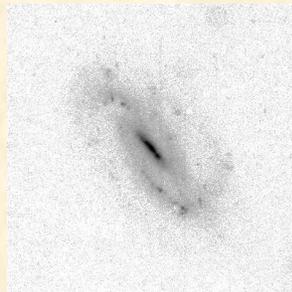
3.



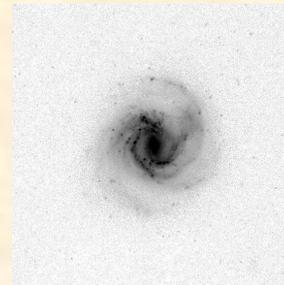
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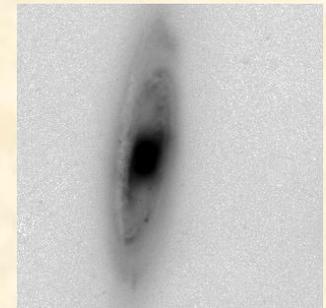
5.



6.

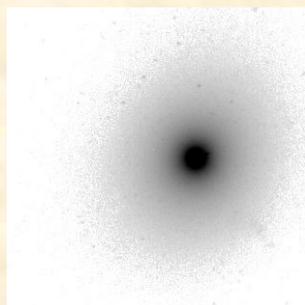


7.

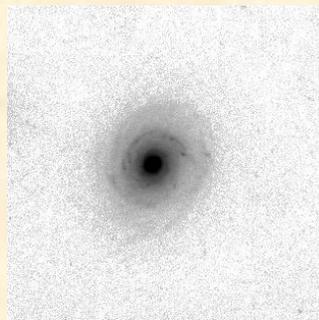


8.

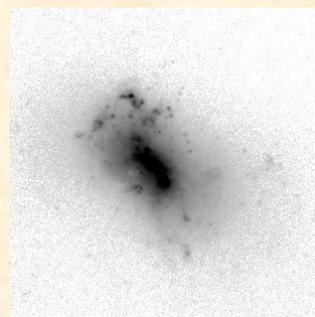
The Classification Game



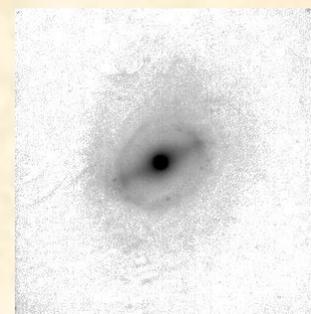
1. E1



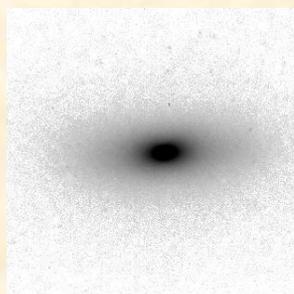
2. Sb



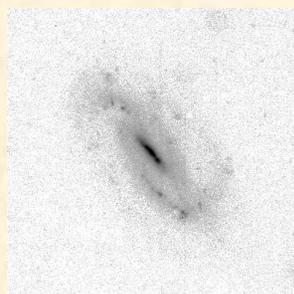
3. Irr



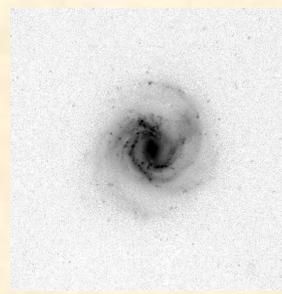
4. SBb



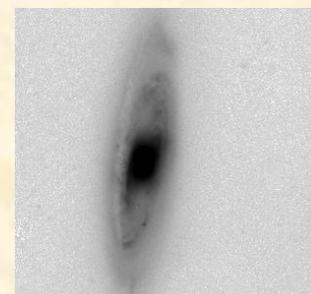
5. S0



6. SBc



7. SBb



8. Sa

Finding Galaxies: Large-Area Surveys

Waveband	Survey	Telescope	Coverage
Optical B and R bands	Palomar Sky Survey (POSS-I), 1960	Palomar 48" Schmidt	-30 to +90°
B, R, I bands	POSS-II, 1999	"	0° to +90°
Optical B and R bands	ESO/SERC Southern Sky Survey, 1980	UK 1.2-m, ESO 1-m Schmidt	-90° to 0°
B, R, I bands	2 nd SERC, 2000	UK 1.2m Schmidt	-90° to 0°
Near- IR: J, H, K _s	Two Micron All Sky Survey (2MASS)	Mt.. Hopkins 1.3m CTIO 1.3-m	All sky
Radio 1.4GHz	NRAO VLA Sky Survey	Very Large Array	-40 to +90°
H I 21cm	Bell Labs H I Survey	Bell AT&T 20-foot	-40 to +90°
Mid-IR:12, 25, 60, 100μm	IRAS (Infrared Astronomical Satellite)		All-sky
EUV: 70-760Å	EUVE (Extreme Ultraviolet Explorer)		All-sky
Soft X-rays: 0.1- 2 keV	ROSAT (Roentgen Satellite)		All-sky
Hard X-rays: 14 – 195 keV	Swift BAT Survey		All-sky
γ-rays: 0.1 MeV –30 GeV	CGRO (Compton Gamma-Ray Observatory)		All-sky
UV:1500, 2300 Å	GALEX (Galaxy Explorer)		All-sky