Lecture Notes 1972
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CONTENTS OF GALAXIES

I. Outline of Topics to Consider

1) What

    stars - luminosity fcn., H-R diag.
    gas - constituents
    photons
    dust
    cosmic rays
    gravitational and magnetic fields

2) How much

    mass, luminosity

3) Form and distribution

    morphology
    kinematics and dynamics

II. Morphology

Directly observable -

(distribution of surface brightness in photographic spectral region)

Hubble - updated as Sandage, A. R. "The Hubble Atlas of Galaxies" Carnegie Inst. Wash. Publ. #618, 1961.

deVaucouleurs (in Handbuch der Physik); "Catalogue of Bright Galaxies."

Basic criteria - relative prominence of nucleus vs. arms } for spirals and barred spirals
tightness of winding } for spirals and barred spirals
apparent axial ratio - for ellipticals

Like spectral types for stars, the morphological classes of galaxies form the independent parameter against which other quantities are compared.

Correlations -

1) with spectra - system of Morgan (1958 & 1959)
"early type" galaxies have "late type" spectra range late A to K

2) with luminosity and/or mass - system of van den Bergh
Ap. J. 121, 215 (1960) Sc, Ir galaxies
more lum. galaxies have better-developed spiral structure (longer arms of higher surface brightness) and greater central concentration of light. (better defined nuclei)

less luminous objects - patchy arms, low surface brightness, poorly defined nuclei.

Ap. J. 121, 558 (1960) Sb galaxies
same criteria - classes run from I to III for Sb and from I to V for Sc, Ir.

III. Mass

Rotation curves

1) optical spectra of indiv. HII regions - e.g. Brandt (1965) for M33.

2) optical long-slit spectra - stellar absorption lines and some distributed [OII] emission - lots of papers by the Burbidges and K. H. Prendergast.

3) optical Fabry-Perot spectroscopy of Hα and [NII], both in HII regions and distributed - Courtès and collaborators.

4) 21-cm measurements

All are V_r measurements, as fcn. of (α, δ) - need symmetry arguments to translate into circular motions, fit individual points to a smooth curve.

For a flat, thin-disk galaxy

$$V_r(r,\theta) = S + V_c \cos\theta \cos i + E \sin\theta \cos i + V_z \sin i$$

a) polynomial expansion (arbitrary # of parameters) favored by Burbidges, does not permit extrapolation to total mass - just mass contained within cylinder of radius = distance of outermost data point.

b) Brandt family of curves (3 parameters) generalization of curve suggested by Bottlinger (1933) for MWG.

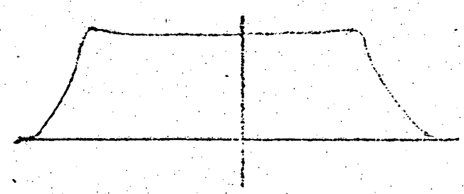
$$V_c = A_r/(1 + [Br]^n)^{3/2n} = \frac{(r/R_m)V_m}{[\frac{1}{3} + \frac{2}{3}(r/R_m)^n]^{3/2n}}$$

$$M_t = \frac{A^2(1 + c/a)}{B\ G} \quad \text{or} \quad \frac{M_t}{M_\odot} = 6.77 \times 10^4 (1+c/a)\ 1.5^{3/n} R_m D V_m^2$$

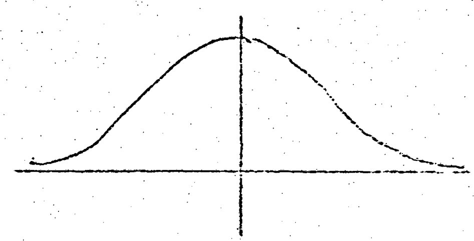
for R_m in ['], D in Mpc, V_m in km/

Many galaxies are too small to determine R_m from radio data, so just get a global velocity profile. In this case only V_m, but not R_m or n, can be obtained from the data. In practice, make estimate from assuming average values of n and R_m/a, where a = optical major axis length. (Roberts used n = 3, $R_m/a = 1/6$ — for M33 $n \sim 1.0$, $R_m/a \sim 1/3$.)

For rotating galaxy, velocity profile



For galaxy with predominent radial or random motions. Use this for some irregular galaxies, and for optical spectra of E galaxies. Then apply virial theorem



for a galaxy with assumed gaussian density distrib. $\rho = \rho_o \exp[-r^2/2a^2]$ and get

$$M_t/M_o = 2.7 \times 10^4 \, Da(\Delta V)^2$$

a = avg. opt. diameter in '
D in Mpc
ΔV = full W at HP of vel. prof.

IV. Luminosity

From integral of surface brightness or (for small galaxies) from on-off photometry

catalogs Holmberg (1958) - photographic — limiting radius 27.5 m/sq"
deVaucouleurs (1964) - photoelectric — 25 m/sq"

statistical conversion for diameters

$$\log D\ (Ho) = 0.83 \log D\ (deV) + 0.31.$$

and for tl. magnitudes

$$m_{pg} = 0.98\ B(0) - 0.12 \quad Sa, Sb$$
$$0.99\ B(0) - 0.24 \quad Sc, Ir$$

As one might expect, magnitudes (and also colors) of galaxies with same apparent diameter are fainter (and redder) than average for their morphological type if the galaxies are highly inclined.

Roberts showed that a similar opacity effect is observable also in the measurements of HI masses. Thus, even the low density HI attains appreciable optical depths over path lengths of several kpc.

V. Mass-to-Luminosity Ratio

Reasonably constant within each morphological type. Thus, van den Bergh's work indicates that dwarf Sc and Ir systems exist, but all Sb are giants. Work by Sersic and deVaucouleurs extends the pattern to earlier galaxy types; no dwarf Sa, but dwarf E do exist, as well as giant E.

M/L ratios for galaxies range from 5-7 for typical Sc to 40-100 for typical E. Comparing these with M/L ratios for individual stars (.01 at B5V, 12 at K5V, 60-150 for M dwarfs and white dwarfs) leads one inescapably to the conclusion that a large fraction of the mass of galaxies is tied up in faint stars and/or nonluminous matter.

VI. Stars

Distribution and luminosity function

Young stars - hot, bright and massive - define spiral arms, but contribute remarkably little to either total light or mass of even the late spirals.

Determine luminosity function by star counts - done for Magellanic Clouds, M31, M33. In M33, $m = 20.2 \rightarrow M = -4$. deVaucouleurs counted $\sim$ 2000 stars. But these contribute < $\sim$ 1/3 of light in B filter. Ideally should have counts in at least 2 colors to distinguish OB stars from red supergiants.

Walker (1967) showed smooth elliptical distribution of MII giants in M33 - no trace of spiral arms in this Sc galaxy. Contrast photos of M51 (Hα interference filter, standard blue, Zwicky composite).

VII. Gas

% of galaxy mass as HI (M_{HI}/M_t) increases from E (<1%) to Ir (>20%)

Element abundances indistinguishable from galaxy to galaxy or for different parts of a galaxy for He, Oxygen.

But nitrogen appears to vary both with galaxy type and as function of r within a galaxy.

Within a given morphological type, bluer galaxies tend to have more HI.

HII region diameters appear to have a limiting size - mean diameter of 3 largest HII regions in a galaxy used by Sandage (1962), Hodge to determine distances to galaxies.

<u>Partial Bibliography</u> (see review articles for more extensive lists)

<u>Review Articles</u>

Roberts, M. S. (1963) The Content of Galaxies: Stars and Gas Ann. Rev. Astr. & Ap. 1, 149.

Roberts, M. S. (1969) Integral Properties of Spiral and Irregular Galaxies. A. J. 74, 859.

Roberts, M. S. (1972) The Gaseous Content of Galaxies. I.A.U. Symposium 44, 12.

<u>Galaxy Classification</u>

Sandage, A. (1961) The Hubble Atlas of Galaxies. Carnegie Inst. Wash. Publ. No. 618.

deVaucouleurs, G. (1959) Classification and Morphology of External Galaxies. Handbuch der Physik 53, 275.

van den Bergh, S. (1960) I: A Preliminary Luminosity Classification of Late-Type Galaxies. II: A Preliminary Luminosity Classification for Galaxies of Type Sb. Ap. J. 131, 215 and 558.

Morgan, W. W. (1958,59) A Preliminary Classification of the Forms of Galaxies According to their Stellar Population I & II. P.A.S.P. 70, 364/71, 394.

<u>Rotation Curves</u>

Brandt, J. C. (1960) On the Distribution of Mass in Galaxies. I. The Large Scale Structure of Ordinary Spirals with Applications to M31. Ap. J. 131, 293.

Brandt, J. C. and Scheer, L. S. (1965). A Note on Functions Relating to Galactic Structure. A. J. 70, 471.