THE DISTRIBUTION OF LUMINOSITY AND MASS IN SPIRAL GALAXIES

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BASIC QUESTIONS:

1) WHAT ARE THE MINIMUM NUMBER OF INDEPENDENT PARAMETERS NEEDED TO FULLY DESCRIBE A SPIRAL GALAXY?

2) HOW ARE GALAXIES FORMED?

THESE TWO QUESTIONS ARE INTERRELATED.

CURRENT MODELS OF GALAXY FORMATION SEPARATE INTO TWO CATEGORIES:

a) INTRINSIC FORMATION - IN WHICH GALAXIES ARE CLOSED SYSTEMS WHICH COLLAPSE FROM INITIAL CONDITIONS. (e.g. DRESSLER, Ap. J.)

b) MERGER HYPOTHESIS - GALAXIES ARE ACCUMULATED FROM SMALLER SUB-UNITS (e.g. FALL & ESTHATHIOU
SILK & NORMAN

IF ALL GALAXIES CAN BE DESCRIBED BY THE VARIATION OF A SMALL NUMBER OF PARAMETERS, THEN ANY FORMATION MECHANISM FOR GALAXIES WOULD HAVE TO HAVE A DETERMINISTIC PRODUCT. ON THE OTHER HAND, IF GALAXIES HAVE AN INTRINSIC VARIATION IN THEIR PHYSICAL PROPERTIES, THEN A MORE STOCHASTIC FORMATION PROCESS WOULD BE FAVORED.

WHAT IS PRESENTLY KNOWN ABOUT SPIRAL GALAXIES?

A) EXISTENCE OF THE HUBBLE SEQUENCE

1) THE OPTICAL APPEARANCE OF A GALAXY CAN BE PLACED IN AN ORDERLY SEQUENCE - A MORPHOLOGICAL SEQUENCE - ON THE BASIS OF SPECIFIC OPTICAL CRITERIA; e.g., THE HUBBLE CLASSIFICATION SYSTEM (SANDAGE 1961 - THE HUBBLE ATLAS). MOST (95%) GALAXIES CAN BE CLASSIFIED AS

E - S0 - Sa - Sb - Sc - Sd - Irr

WITH A NUMBER OF SUBCLASSES.

HOWEVER, THE OPTICAL APPEARANCE OF A GALAXY IS THE PRODUCT OF A COMPLEX INTERACTION OF STAR FORMATION RATES, VELOCITY SHEAR, AND LUMINOSITY DISTRIBUTION IN GALAXIES, SO THAT IT IS NOT SURPRISING THAT THE HUBBLE TYPE OF A GALAXY DOES NOT CORRELATE ONE-TO-ONE WITH SUCH PHYSICAL PARAMETERS AS LUMINOSITY, MASS OR HI GAS CONTENT.

2) SPIRAL GALAXIES PRINCIPALLY HAVE TWO MORPHOLOGICALLY DISTINCT LUMINOSITY COMPONENTS: A BULGE, OR CENTRALLY-CONDENSED SPHEROID; AND A THIN DISK, TYPICALLY WITH c/a OF 0.1 OR LESS.

3) THE RELATIVE LUMINOSITY OF BULGE AND DISK ARE RELATED TO HUBBLE TYPE IN AN OVERALL SENSE: Sa's OBVIOUSLY HAVE LARGE BULGES, Sd's HAVE LITTLE OR NO BULGE.

HOWEVER, THE BULGE-TO-DISK RATIO OF A SPIRAL IS ALSO NOT ONE-TO-ONE CORRELATED WITH HUBBLE TYPE, BUT SHOWS SCATTER.

B) LUMINOSITY DISTRIBUTION

1) de VAUCOULEURS (1959 -) SHOWED THAT THE LUMINOSITY DISTRIBUTIONS OF DISKS IN GALAXIES ARE SIMILAR, AND WELL-APPROXIMATED BY AN EXPONENTIAL

$$I(r) = I_0 e^{-\alpha r} \qquad (1)$$

FREEMAN (Ap. J. 160, 811, 1970) SHOWED THAT I_0 IS APPARENTLY VERY SIMILAR FOR SPIRALS, WITH

$$B(0) = -2.5 \log I_0 \approx 21.5 \pm 0.5 \text{ IN B MAG.}$$

MORE RECENT STUDIES HAVE INDICATED A RANGE OF ~2 MAGS FOR B(0), CENTERED ON 21.5. (e.g. BOROSON, Ap. J. SUPPL.).

2) INTEGRAL PROPERTIES OF AN EXPONENTIAL DISK:

a) LUMINOSITY, $L = 2\pi I_0 \alpha^{-2}$ (2)

b) ISOPHOTAL RADIUS

$$r_\ell = \left(\frac{S_\ell - B(0)}{1.0857}\right) \alpha^{-1} \qquad (3)$$

WHERE $S_\ell = -2.5 \log (I(r_\ell))$.

c) ISOPHOTAL SURFACE BRIGHTNESS

$$SB = \frac{L_\ell}{\pi r_\ell^2} \approx 1.7 \frac{I_0}{(S_\ell - B(0))^2} \qquad (4)$$

AS LONG AS $r_\ell \alpha$ IS LARGE ENOUGH SO THAT $L_\ell \approx L$.

3) SPIRALS ARE OBSERVED TO HAVE OVER A 5 MAG. RANGE IN ABSOLUTE LUMINOSITY $\approx >\times 100$. FROM (1)+(2), VARIATIONS IN I_0 CAN PRODUCE, AT MOST, ONLY A FACTOR OF $10^{\text{VARIATION IN } L}$. MOST OF THE OBSERVED VARIATION IN L MUST COME FROM CHANGES IN α^{-1}, THE SCALE LENGTH.

4) FROM (2c), A SUITABLY-DEFINED ISOPHOTAL SURFACE BRIGHTNESS IS INDEPENDENT OF LUMINOSITY FOR CONSTANT I_0.

5) FOR CONSTANT I_0, THE RATION $\frac{\Lambda_\ell}{\alpha^{-1}}$ IS CONSTANT (i.e., Λ_ℓ MEASURES A PHYSICAL SCALE IN THE DISK).

6) (4)+(5) HOLD TRUE ONLY FOR FACE-ON DISKS. BUT GALAXIES ARE SEEN AT ALL INCLINATIONS TO THE LINE OF SIGHT. ONE NEEDS A MODEL FOR THE 3-D LIGHT DISTRIBUTION IN A DISK IN ORDER TO MAKE SUITABLE INCLINATION CORRECTIONS. THESE MODELS WILL NOT BE DISCUSSED HERE.

7) IF I_0 WERE STRICTLY INDEPENDENT OF LUMINOSITY, ONE WOULD EXPECT $L \propto \Lambda_\ell^2$.

FOR THE DATA IN THE SECOND REF. CATALOG (RC2) (deV, deV & CORWIN 1976), WHERE $S_\ell = 25\ \mu_B$,

$L \propto \Lambda_\ell^{1.8\pm0.1}$, INDEPENDENT OF HUBBLE TYPE!

I_0, AS USED THE THE RC2, IS PROBABLY WEAKLY-DEPENDENT OF ABSOLUTE LUMINOSITY, DECREASING WITH INCREASING LUMINOSITY.

C) MASS DISTRIBUTION

IF THIS TALK WERE BEING GIVEN 10, EVEN 5 YEARS AGO, THE DISCUSSION OF MASS DISTRIBUTION WOULD BE TIED DIRECTLY TO THAT OF LUMINOSITY DISTRIBUTION (cf. FREEMAN 1970).

HOWEVER, IT IS NOW KNOWN THAT WHAT YOU SEE IS NOT WHAT YOU GET FOR MASS IN SPIRALS.

1) FLAT ROTATION CURVES: MEDIUM-RESOLUTION HI OBSERVATIONS IN THE MID-1970'S BY WESTERBORK & GREEN BANK INDICATED THAT ROTATION CURVES DO NOT TURN OVER, AS WOULD BE EXPECTED IN A CENTRALLY-CONDENSED MASS, BUT THEY REMAIN FLAT TO THE FURTHEST MEASURED POINT. (SEE ALSO THEORETICAL PREDICTION OF OSTRIKER & PEEBLES ( ), BASED ON DISK STABILITY CONSIDERATIONS).

MUCH SUBSTANTIATION OF EARLY RESULTS BY FURTHER WESTERBORK OBSERVATIONS (SUMMARIZED IN BOSMA'S THESIS -1978), AND OPTICAL ROTATION CURVES (RUBIN & CO. 1976 - PRESENT).

2) FLAT ROTATION CURVES HAVE $\rho(r) \sim r^{-2}$ AND $M(r) \sim r$; i.e., NO APPARENT LIMIT TO THE MASS OF A GALAXY.

3) BUT A DISK HAS $\rho(r) \propto e^{-\alpha r}$, SO THAT, IN THE OUTER PARTS OF SPIRALS AT LEAST, MASS HAS A DIFFERENT FORM FROM LUMINOSITY.

THIS FACT FORCES ONE TO POSTULATE THE EXISTENCE OF AN APPARENTLY NON-LUMINOUS MASS COMPONENT TO THE GALAXY, ONE WHICH DOMINATES THE MASS IN SPIRALS.

4) ON THE OTHER HAND, THE MASS-TO-LIGHT RATIO AT R_ℓ IS REMARKABLY SIMILAR FOR GALAXIES OF THE SAME HUBBLE TYPE, BUT HAVING A WIDE VARIATION IN LUMINOSITY. $\langle M/L \rangle$ DOES VARY FROM HUBBLE TYPE TO HUBBLE TYPE, BEING LARGER IN Sa's THAN Sc's, ON AVERAGE.

5) $L \propto V_{ROT}^4$ - THE TULLY-FISHER LAW - LUMINOSITY AND FLAT ROTATION-VELOCITY RELATED.

6) (3)-(5) REQUIRE THERE TO BE A STRONG, SYSTEMATIC CORRELATION OF LUMINOUS & NON-LUMINOUS COMPONENTS WITHIN A GALAXY.

7) EXAMINATION OF HIGH-RESOLUTION ROTATION CURVES (RUBIN & CO.) SHOWS THAT THE FORMS OF ROTATION CURVES IN GALAXIES VARY SYSTEMATICALLY WITH RESPECT TO BOTH LUMINOSITY AND HUBBLE TYPE (e.g. BURSTEIN et al 1981 PREPRINT, IN LIBRARY).

THE ANSWERS - OR BEGINNINGS OF ANSWERS - TO THE BASIC QUESTIONS POSED AT BEGINNING - ARE NOT YET KNOWN. PERSONAL VIEW, AT THIS WRITING, IS THAT SPIRALS ARE HIGHLY DETERMINISTIC, APPARENTLY FAVORING INTRINSIC FORMATION.