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SURFACE BRIGHTNESS, STANDARD CANDLES AND q_0

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Nous décrivons les effets de l'évolution ou de la variation de la brillance superficielle et des échelles de taille des galaxies, sur la relation magnitude-décalage vers le rouge. Nous discutons une méthode pour évaluer l'évolution de l'échelle de brillance superficielle. Elle permet de déterminer le paramètre de décélération et de faire une distinction entre le modèle cosmologique en expansion et le modèle du type lumière fatiguée.

I. Introduction

The most direct method of determination of the deceleration parameter (q_0) of the universe is through the study of the redshift-magnitude relation of extragalactic sources. The progress here has been slow because the necessary sources for this study must be standard candles; i.e., must have identical absolute total luminosity (balometric or monochromatic). Below we first show that this although necessary is not a sufficient condition for non-point like (or resolved) sources. We then describe modification of the redshift-magnitude relation for a certain class of non-standard candles using measurement of isophotal surface brightness.

II. Definition of Standard Candles

For point (unresolved) sources of same absolute total luminosity the application of the redshift-magnitude relation is straightforward. However, for such sources there is no observational method for ascertaining their standardness. For extended sources, on the other hand, one must carry out aperture correction (cf. Sandage, 1972a; Gunn and Oke, 1975; Petrosian, 1976) for which one requires a knowledge of the distribution of the surface brightness. Let us consider spherical galaxies with surface brightness distribution[1] $B(r) = B_0 f(r/r_o)$, characterized by a central surface brightness B_0 and a scale r_o. Then it can be shown that the flux density within a circular aperture of radius θ of a source with redshift z is

$$f(\theta) = B_0 r_o^2 \, h(\theta\mathcal{D}/r_o) \; k(z) \Big/ \left[4\pi(1+z)^4 \mathcal{D}^2(q_0, z)\right] \qquad (1)$$
$$h(x) = 2\pi \int_0^x x' \, dx' \, f(x') \; ,$$

where $k(z)$ is the K-correction term, and $\mathcal{D}(q_0, z)$ is the "angular diameter distance" (cf. Weinberg, 1972, p. 422 ; we have set cosmological constant equal to zero) to the source which is proportional to the Hubble radius (c/H_o). It is clear from equation (1) that in order to determine the deceleration parameters we require sources with not only equal absolute total luminosity $L_{tot} = B_0 r_o^2 h(\infty)$ but also sources with the same scale factor r_o. Thus extended sources can be considered as standard candles if they obey the same surface distribution law and have equal central surface brightness and scale parameters.

III. Surface Brightness and Evolution

Assuming a universal surface brightness distribution law we consider evolution of the parameters B_0 and r_o. For extended sources there is an additional relationship, namely, the angular diameter versus metric diameter relation, $\theta = r/\mathcal{D}(q_0, z)$, which could be used for cosmological studies. This again requires a standard metric diameter. Since galaxies have no clear boundaries, the definition of a standard metric diameter is difficult. Instead, one can define an isophotal radius r_o, where the apparent surface brightness has dropped to a specified limiting value, b_{lim}. It is thus clear that the ratio of the average isophotal apparent surface brightness $b_s \equiv f(\theta_s)/\pi\theta_s^2$ to the limiting surface brightness is equal to the same ratio for the absolute surface brightness:

$$b_s/b_{lim} = \langle B(r_s)\rangle / B(r_s) \quad , \qquad (2)$$

[1]Here and in what follows we shall be concerned with monochromatic surface brightness, flux densities and luminosities at a frequency ν

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where $r_s = \theta_s \mathfrak{D}(q_0, z)$ is obtained from (for details cf. Petrosian, 1976)

$$f(r_s/r_o) = 4\pi b_{lim}(1+z)^4 / [B_0 k(z)] \quad , \qquad (3)$$

and $\langle B(r_s)\rangle$ is the average absolute surface brightness within r_s:

$$\langle B(r_s)\rangle / B(r_s) \equiv \eta(r_s/r_o) = 2(r_o/r_s)^2 h(r_s/r_o) / f(r_s/r_o) \qquad (4)$$

It is evident from these equations that the average isophotal surface brightness is independent of the cosmological model and the scale r_o, but depends on redshift and central surface brightness B_0. Thus, measurement of redshift and isophotal surface brightness could be utilized to determine the evolution of the central surface brightness. Note that equation (3) is valid if the cause of redshift is the expansion of the universe (independent of degree of inhomogeneity of distribution of matter), ordinary doppler or gravitational, but it is not valid for models such as the "Tired Light" model. For the latter model the $(1+z)^4$ term in equation (1) and (3) is changed to $(1+z)$. Therefore, the isophotal surface brightness measurement can also be used for distinguishing models such as the Tired Light model from the expanding cosmological model.

On figure 1 we present (dashed lines) the expected variation of the ratio $b_s/b_{lim} = \eta(r_s/r_o)$ for two different surface brightness distribution functions $f(r/r_s)$, assuming B_0 = constant. To demonstrate the sensitivity of the test to evolution (or variation) of B_0, we also show here (solid lines) the ratio of the parameter η assuming evolution $B_0(z) = B_0(0)(1+z)^\beta$ to its value with no evolution. For Tinsley's (1972) theoretical evolutionary models $\beta = 1$, and $\beta = 3$ is the expected value for the Tired Light model.

IV. Deceleration Parameter

The measurements of the isophotal surface brightness could provide not only information about the evolution of the surface brightness of galaxies, but more important, it would allow a more reliable determination of q_0. Once the evolutionary law $E(z) = B_0(z)/B_0(0)$ of the central surface brightness is known it can be used in equation (1) for correcting the redshift-magnitude relation for this effect. Unfortunately, the evolution

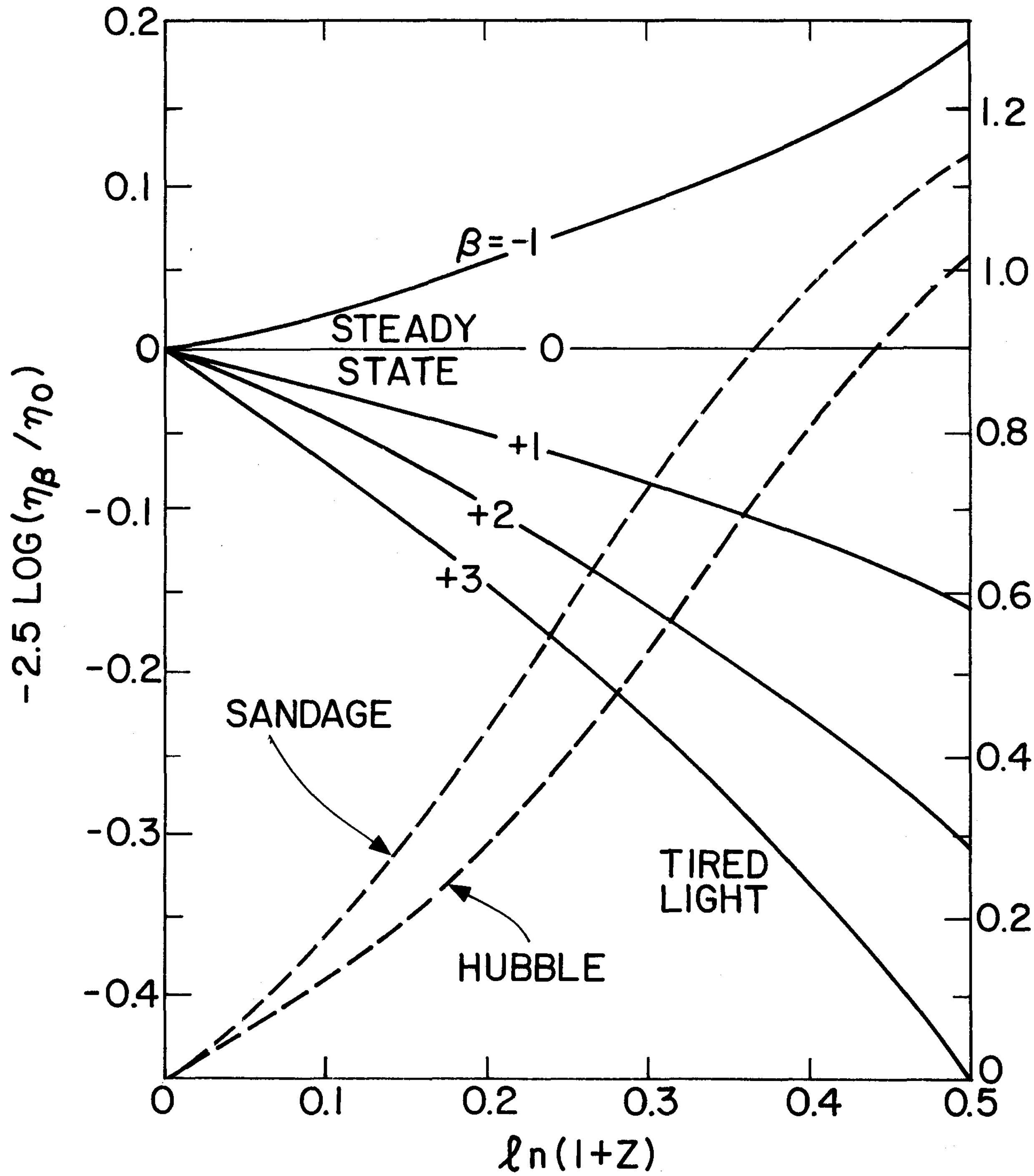

Figure 1. Variation of the parameter η with redshift. The two dashed lines (right hand scale) give variation of η for the Sandage (1972b) composite curve, and for the Hubble law $f(r/r_o) = (1+r/r_o)^{-2}$. The solid curve gives the ratio of η with evolutionary law $(1+z)^\beta$ to η in absence of evolution for the Hubble law. The results for the Sandage data are similar.

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or variation of the scale parameter r_o remains unknown and cannot be determined observationally. One has to rely on theory (tested for its reliability by observations of nearby galaxies) for determination of variation of r_o with central surface brightness (and other parameters) and hopefully with redshift. For example, observations of nearby ellipticals indicate an inverse linear relationship between scale r_o(more accurately core radius) and central surface brightness. This may not be a universal relationship for galaxies of all masses since Oemler's (1973, 1975) observed average isophotal surface brightness-isophotal absolute luminosity correlation agrees with the $r_o \propto B_0^{-1}$ relationship only for galaxies with highest to intermediate total luminosity. For less luminous galaxies the observations can be fitted assuming r_o = constant. Whatever the relationship between r_o and B_0 once it is determined and ascertained to be independent of redshift, It can then be used in the redshift-magnitude relation for correction of the evolution (or variation) of r_o .

However, to demonstrate the application of the isophotal surface brightness measurements, let us assume r_o = constant. As evident from equation (3) the redshift dependent terms such as the evolutionary law, the K-correction(and intergalactic absorption, if present, which we ignored) can be lumped together. Furthermore, it is not even necessary to evaluate these terms individually or collectively for determination of q_0 . In equation (3) one can choose a redshift dependent (instead of a constant) limiting isophotal surface brightness, $b_{lim}(z)$, such that for each galaxy $b_s(z)/b_{lim}(z)$ is the same. This insures that $\eta(r_s/r_o)$ and consequently r_s/r_o will be the same for all galaxies; i.e., this defines a standard metric radius r_s which can then be used in the angular radius-redshift relation

$$\theta_s = (r_s/r_o)\ r_o/\mathfrak{D}(q_o, z) \qquad (5)$$

for direct determination of q_0 (for constant r_o). A similar method can be devised if r_o has a known dependence on B_0. Note that once equations (2) to (4) are utilized for evaluation of r_s equation (1) and (5) become identical.

In summary, the isophotal surface brightness measurements can be

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used to standardize the central surface brightness of galaxies, but the standardization of the scale parameter remains beyond observations. To convert elliptical galaxies into a class of truly standard candles we must still rely on theory.

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DISCUSSION

J.-C. PECKER: I am not quite sure your test (the test No. 2 of Hubble and Tolman, I believe) is really a good test for tired-light theories - which may explain abnormal redshifts without implying anything on evolutionary processes.

V. PETROSIAN: As shown in figure 1 of my paper the expected variation of average isophotal surface brightness (or the quantity η) with redshift for the tired-light model is identical to that of expanding models with $(1 + z)^3$ evolution. Or equivalently a $(1 + z)^{-3}$ evolution in tired-light model gives the same result as the expanding models with no evolution.