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POSSIBLE EXPLANATIONS OF NON COSMOLOGICAL REDSHIFTS

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This paper is dedicated to the memory of Fritz ZWICKY, pionneer in the field of this colloquium.

Résumé : Après une introduction résumant l'essentiel des faits d'observation à interpréter, la section I étudie successivement différentes suggestions: perturbations de cosmologies relativistes, chronogéométrie de Ségal, cosmologie à explosions successives d'Ambartsumian, variation des constantes physiques, enfin mécanismes de fatigue de la lumière. Une forme particulière de ces derniers mécanismes est discutée dans la section II, où il est montré qu'on peut, grâce à une interaction, décrite en détails, entre les photons de la source et les particules φ (particules scalaires, neutres, de très faible masse et de spin zéro), expliquer les décalages anormaux vers le rouge, mais aussi peut-être (section III) la loi normale de Hubble et le rayonnement à 3 K. Une conclusion montre à quel point le débat reste ouvert.

Acknowledgments : The reviewer would like to emphasize the collective character of this presentation. It could not have been done without the help, notably in the preparation of its extended version (circulated in mimeographed form during the meetings), of Hiroshi KAROJI, Gérard LeDENMAT, Mariano MOLES, Jean-Luc NIETO, Laurent NOTTALE and, last, but not the least, of Jean-Pierre VIGIER.

INTRODUCTION : THE OBSERVATIONAL EVIDENCE.

The contemporary cosmological theories are essentially resting upon a few observational facts: the linear, isotropic Hubble law, and the value of the Hubble constant $H=55 \pm 5 \mathrm{km\ s^{-1} Mpc^{-1}}$, according Sandage (1975); the existence of the isotropic background radiation and its temperature $T \simeq 3$ K; and, to some extent, the local abundances of light elements (^{2}D, ^{3}He,...), considered as being primaeval to the formation of galaxies.

The "normal" redshifts are defined by the normal Hubble law: departures from Hubble law - from its unicity, from its linearity, from its isotropy - are "abnormal" redshifts. We shall not discuss hereafter of their reality. We shall only accept the alleged anomalies for granted, and take them as a basis for discussion.

In an abstracted way, the main significant facts seem to be described as follows :

(a) a few local (sun, stars) redshifts are unaccountable for by any classical effect of motions.

(b) the Hubble law is only verified at the first order. The constant H is inhomogeneous, and anisotropic. Everything behaves as if, in large and dense regions of the Universe (clusters of galaxies), the local value of H(r) were bigger than elsewhere, the observed H resulting from an integration along the line of sight.

(c) objects located at the same distance from us do not have always the same redshift. The fact that they are at equal distances is shown either by their physical association, or by a coherent procedure of distance scaling. In other cases (QSS for example), there are strong arguments against the "cosmological" distance. In general, it seems that compact objects are affected by abnormal intrinsic redshifts.

I - THE INTERPRETATIONS OF THE OBSERVED ANOMALIES.

As well-known, an expanding universe, homogeneous, empty (where the galaxies are only tracers, or so to say, buoys on the sea) is characteristic of the Friedmann solution of the equations of General Relativity (hereafter G.R.). It is able to account for the average Hubble law. To explain the deviations, we might then either perturb the Friedmann solutions, or introduce new additional principles. We might also give up the Friedmann universes, and try to explain simultaneously normal and abnormal redshifts.

1. Perturbations of relativistic cosmologies.

A first way to account for the anomalies if to use a Friedmann model, and to perturb it locally. The importance of inhomogeneous universes has been indeed stressed years ago, as being more realistic than uniform empty universes (bibliography can be found in Mavridès, 1973). Recently, Papapetrou (1976, a,b) and Eisenstaedt (1976) have studied in a very accurate way the possible mathematical solutions of the GR equations when the uniform universe is modified by a spherically symmetric perturbation. With some simplifications of the theory, computations have been actually done by Mavridès (1976) and by Tarantola (1976) to interpret the decrease of H beyond the limits of the local supergalaxy. They have also introduced in the classical models of the G.R., a spherically symmetric perturbation of the density, using more or less approximate solutions of the equations, filling the Schwarzschild vacuole by dense nuclei, trying to insure some continuity of the solution. These local concentrations are found in fast expansion; one can make compatible the mass of the concentration, and its assumed size, with mass and size of a large cluster, or of the Supergalaxy itself. However, these types of solutions are not entirely satisfactory in that they treat the problem of only one concentration, and leave not satisfactorily solved the difficult general problem of fitting (Cauchy's problem) and of combining a number of such deformations.

Along a similar line of thought, Kichenassamy (1976) has attempted to lay the basis for a theory of a clumpy universe, in the G.R. framework. It does not meet the same theoretical difficulties as the models quoted above. But just as them, it leads also to very young ages for clusters of galaxies, since he predicts there $H \sim 600$.

Introducing inhomogeneities in the classical G.R. models is one thing; it means superimposing local expansions onto a global expanding universe, similar to that of the classical bigbang theories.As one knows, the use of a cosmological constant by Friedmann to build expanding models was needed, the static Einstein model being unstable.However, this unstability was linked with the uniformity hypothesis on which the Einstein and Friedmann's models were based. Another way to treat the problem is to get rid of the homogeneity in another way. If we assume the existence of a hierarchical universe, its density is decreasing when radius of the volume taken into consideration is increasing, according a law : $\rho \propto r^{-k}$, with $k \sim 1.7$ (de Vaucouleurs, 1970). If the universe is finite, the larger its radius R, the smaller is its average density. This consideration leads to a new treatment of the G.R. equations, to new models, and should allow to show, in particular, that static models may be stable against local expansions.

Another question has to be asked about these models. The present Universe looks locally inhomogeneous, anisotropic, and even hierarchized; however, the so-called background blackbody 3 K radiation seems to be strongly isotropic, this isotropy giving to the solar motion, with respect to the source of the radiation, a maximum velocity of 300 km s^{-1} (Conklin, 1969, Henry 1971). Assuming that the present day local universe results from the big bang, then we must admit that ten or so billions years ago, the Universe was as uniform as to-day's background radiation, sometimes called "fossil". Fluctuations of density must therefore have progressively appeared. This is one of the difficulties that, in spite of their great ingenuity, models of the Omnès-type (using the Klein-Alfvén hypothesis of a matter-antimatter production of energy, and the physical evolution of this emulsion) cannot explain (Omnès, 1972).

We would like also to mention in this respect the suggestions made by Souriau (1974,76) noting precisely the isotropy of the background radiation (which gives the impression of an universe in thermodynamical equilibrium) and the anisotropic and inhomogeneous behaviour of the Hubble expansion, he builds new universe equations by introducing a conformal representation group in the writing of the metrics. Souriau thus accounts for many observed facts. Souriau's formulation, as Eisenstaedt's, implies, at long distances, a repulsive action of gravitation, which may possibly explain the fragmented nature of the observed universe.

2. Segal's chronogeometry.

A second class of cosmological explanations puts really in question the very fundaments of G.R.. In this category, of a particular interest is Segal's chronogeometry (1975). The hypotheses are the following :

(a) globally, space is spherical; locally, space-time is however minkowskian.

(b) the physical time differs from that of G.R., globally; for localized states, the difference being unobservably small-this

hypothesis is the most important-.
(c) the theory is based on considerations of symmetry, in particular of group-theoretical properties (conformal invariance) of Maxwell equations.

The hypothesis (b) implies that particles propagating freely in large distance are loosing energy; in other terms, we have here a theory of "geometrically tired light". Incidently, this theory, which has to introduce a time tangential (here, and now) to the observable physical time, shows, if true, that any theory of the "beginning" of the universe is meaningless in this scheme.

We refer of course the reader to Segal's publications. But we would like to mention an interesting test of the theory. This test can be found in the use of supernovae (SN) as local time clocks. The rate of decrease of brightness of a type I SN is assumed to be always the same in the local reference frame, and equal to Δt; it is measured by the terrestrial observer as $\Delta t'$, the rate of decrease in the observer's reference frame. In the classical G.R. description, one has :

$$\Delta t' = \Delta t\,(1 - v_R/c) \tag{1}$$

In the Segal's reformulation, it becomes :

$$\Delta t' = \Delta t\,(1 - 4v_R/c) \tag{2}$$

An analysis by Rust (1974) of several extragalactic SN has been carefully done, and his conclusion seems to favor Segal's chronogeometry. However, the calibration of Rust's sample is far from convincing, according to de Vaucouleurs (1975).

3. Multibang Ambartsumian cosmology.

Without abandonning the concept of some "big-bang", but remaining very close to the observational facts linked with the evolution of galaxies and stars, several astronomers, following Ambartsumian et al. (1960), believe that the evolution of galaxies is always of an explosive nature, giving place to expulsions, explosions... at the scale of clusters of galaxies or of the galaxies themselves, and originating from superdense nuclei. By throwing out any condensation process in the cosmogonic evolution, by making a rule out of the explosive processes, they can indeed explain most of the observational facts earlier mentioned. This theory is, for the time being, only fragmentary, so far as the physical processes of the explosions are concerned hence it is somewhat difficult to discuss it, as there is still a large flexibility in its application to the interpretation of the various kinds of anomalies we have mentionned. However, we see difficulties in fitting these concepts with all the local (solar, etc) abnormal redshifts. But we shall see (section III) that they are perfectly compatible with some of the concepts we may need to explain galactic evolution, in the frame-work of the Ø-mechanism concepts of the observable universe, which we shall describe later (section II).

4. Variation of Physical Constants.

Another class of cosmological explanations enters in the long tradition of the Dirac-Jordan concepts. One has to go back rather early in the history of modern cosmology to find the idea that universal constants would indeed not be constant but time-dependent. (Dirac, 1937). Recently, Brans and Dicke (1961), Hoyle and Narlikar (1971,1972,1974), Dirac himself (1973) have revisited that hypothesis, in the light of the assumed existence of abnormal redshifts, which (they assumed) characterize light coming from locations in the universe where the usual physical constants would not have the same values as in terrestrial conditions.

This renewal of the Dirac hypothesis came indeed at the right time, when it became possible both to assign some limits to the variations, and possibly to evaluate them numerically.

Not all constants can indeed be assumed to vary from one location to another, or with time. It has been shown that at least to distances r of the order of two millions light years (Baum, Florentin-Nielsen, 1975), c, the velocity of light, is not r-dependent; nor is Planck's constant h. Since optical redshifts and 21 -cm redshifts are equal, the fine structure constant ($2\pi e^2/hc$) is not either r-dependent; hence the electron charge is, just as c or h, independant of distance.

But at least, the gravitational constant G could indeed be variable. Using measurements of occultations by the Moon, from

1955 to 1974, Van Flandern (1970,71,75,76) obtains, due to the accuracy of atomic time, a relative variation of the Moon's revolution time around the Earth of $\dot{P}/P \doteq -2\dot{G}/G=(-16\pm10)\ 10^{-11}$ per year; this value leads to a value of the Hubble constant of $H=39\pm24$ km $s^{-1}Mpc^{-1}$, and is corroborated by the study of fossil data over $1.75\ 10^{9}$ years (Weinstein, Keeney, 1975).

Independantly of other possible interpretations of Van Flandern's findings, or of some of their consequences, we may note that they give some weight to the Hoyle-Narlikar concepts. Spatial irregularities of the Universe may indeed induce some inhomogeneity in the physical constants, hence of Hubble's rate of expansion. The local conditions are here the cause for discrepant redshifts.

5. The tired-light mechanisms.

The very possibility of a cosmology that could fit both observations and a few theoretical hypotheses, is so shaken by some authors that the efforts we have just quoted seem somewhat vain, how interesting as they may be as purely mathematical problems. Not to quote too many, let us just mention the opinion of Léon Brillouin , in his posthumous papers (1970 a,1970 b): "either we must assume curvature of the Universe, or we must speak in term of non-zero photon rest mass -and the existence of the latter is confirmed by all aspects of quantum physics..." The tired-light mechanisms have indeed been introduced in this spirit.

(i) Various models of the tired-light mechanisms involving a non-zero photon rest-mass, have thus been discussed. Let us call such mechanisms "Ø-mechanisms" acting on the photons from the source,"the S-photons". We have, from the analysis of the anisotropies, and from the observations of compact objects, some reasons to believe that the Ø-mechanism is linked with the interaction of the S-photons with "something" closely associated with dense media, and of which the density is designated by ρ_φ . The energy loss would be proportional to ρ_φ and to the interaction length. In other terms, the redshift could be described by separating its terms (average Hubble's law, intrinsic redshift, anomalous Hubble's law) as :

$$(3)\quad (\Delta\lambda/\lambda)_j = z_j \simeq \frac{1}{c}\langle H\rangle L_j + \frac{1}{c} A\rho_{\varphi_j} D_j + \frac{1}{c}\langle \Delta H(r)\rangle_j L_j$$

where D_j characterizes the size of the compact object, ρ_{φ_j} its φ-density, and where $\Delta H(r)$ is the local difference $H(r)-\langle H\rangle$.

(ii) The "something" to which the S-photons are loosing energy will be called φ-particles. In essence, the reasoning leading to their existence is comparable to Pauli's prediction of the existence of neutrinos. The Ø-mechanism ($\varphi-\gamma$) interaction) must satisfy the following physical constraints :

(a) the Ø-mechanism must always give a redshift, whatever the energy of the S-photon, as redshifts are always observed all over the spectrum (from the metric waves to the UV) of astrophysical observations. This implies that the φ-particles must be sufficiently massive with respect to the S-photons.

(b) Each mechanism, individually, corresponds to a loss of energy $(\delta\nu/\nu)_i$. Such a loss must be pratically independant of the energy of the S-photon (from 10^9 to 10^{16} Hz): the equality of redshift in optical and radio ranges has been amply demonstrated.

(c) Each mechanism, individually, corresponds also to a deflection of the S-photon. The angular value of this deflection, $\delta\theta_i$ must be small enough for the images of the sources not to be smeared out (strong forward scattering). In other terms (conservation of momentum), the mass of the "something" must be sufficiently weak with respect to electron mass. In any case a small $\delta\theta_i$ implying a small $(\delta\nu/\nu)_i$, a great number of collisions will be necessary to explain the observed redshifts. Given Nj the number of collisions, corresponding to the S-photons coming from a source G_j, one has :

(4) Total deflection : $\theta = \Sigma\,\delta\theta_i = \sqrt{N_j}\ \delta\theta_i$

(5) Total redshift : $\begin{cases} Z/(1+Z) = \Delta\nu/\nu = 1 - \prod_{i=0}^{N_j} \left[1-(\delta\nu/\nu)_i\right] \\ \text{for small values of } Z : \quad z \cong \Sigma(\delta\nu/\nu_i) = N_j\,(\delta\nu/\nu)_i \end{cases}$

The condition of having, for a given redshift, no sensible resulting deflection will impose a lower limit upon N_j.

(d) The fluctuations ΔN_j of the number of collisions N_j, affecting the various S-photons from a given source G_j, impose a broadening of the line proportional to $\sqrt{N_j}$. Hence to insure a relative negligible broadening for a given redshift, we shall have also to impose a lower limit to N_j.

(e) Finally the $\emptyset$-mechanism must not violate the laws of QED and its predictions, which have been checked in many occasions at the laboratory scale.

(iii) Discussion of the possible $\emptyset$-mechanisms. The φ-particle may be an electron, another photon, or possibly a new type of particle . Various proposals have been made, as follows.

(a) The hypothesis of a Compton effect (γ -e collision) is the first one which comes to the mind. This hypothesis, discussed in this context by Ter Haar (1954) is however incompatible with observations, because of the excess of angular deflection (lack of forward scattering) , due to the high value of the electron mass.

(b) Another hypothesis implies the intervention of the gravitational field. Assuming the photon has a non-zero rest mass, it clearly loses energy (through emission of gravitational wavelets) when moving in an external gravitational field. This would amount to a γ -graviton interaction. That type of physics has been proposed by Bogorodsky, 1940, following a line of thought initiated by Einstein and Infeld (1934; see also Schatzman,1955, Couderc, 1954). An hypothesis of the same nature has been developped by Furth (1964).

This type of theory might indeed explain the Hubble law (in a curved universe), but probably cannot account for anomalous redshifts(low value of the gravitational constant, and very low upper limit of the photon's rest-mass).

(c) Finlay-Freundlich (1953,54 a,b,c) and after him, Max Born (1954 a,b) , have considered photon-photon interactions, and have proposed phenomenological formulae where the redshift of the S-photon is proportional to the energy density of the intervening radiation field. The hypothesis of Finlay-Freundlich was severely criticized by Ter Haar (1954) and Mc Crea (1954) on the basis that the necessary cross-section would have to be much higher than the cross-sections predicted in two-particle-scattering processes studied by Euler and Kockel (1935).

(d) Another form of the γ -γ interaction, involving direct collisions, has been proposed by Roberts and Vigier (1971) and

Pecker et al. (1972,a,b,c, 1973). Without entering in the details of their proposal, let us point out that instead of assuming a proportionality of the effect with the energy radiation density, they preferred a proportionality to the number of photons (of any energy) per unit of volume (photon density) as did earlier Blum and Weiss (1967). This proposal has been duly criticized in that it implied also too high a cross section, given the experimental values of Weiss and Grodzins (1962), as noted by Cohen and Wertheim (1973). It has been also criticized in that it violates conditions (ii) (b), the cross-section being a function of frequency, and (ii) (c), the deflection being noticeably large (see Woodward and Yourgrau, 1973; Aldrovandi et al. 1973, Chastel, 1976). It seems now difficult to us to introduce any direct γ -γ interaction able to satisfy all the necessary requirements.

(e) One could also think of γ-ν interactions, assuming that neutrinos, as well as photons, have a very small rest mass. According however to present laboratory knowledge, such interactions, at low neutrino energies, are certainly quite weak.

(f) Returning to the preceeding constraints (section I,5,ii), we are thus finally led to the idea that one must introduce a very light particle (φ-particle), since everything heavier than an electron is obviously to be excluded. Such a particle should be neutral, and interact weakly with ordinary matter. This particle is indeed not new in the literature : on one side, theoretical arguments have led de Broglie (1947) to postulate a new pseudo-scalar light neutral leptonic boson φ, which constitutes the spin-zero singlet associated with the γ spin-1 particle. On the other side, the existence of such a particle has been assumed by Bahcall et al. (1972), to account for the observed defect of solar neutrinos. The proposed interaction between a particle φ and a γ is obviously not an electromagnetic interaction and the photon must have a non-zero rest mass. The mass of the φ must be larger than the photon mass, to insure energy loss for the S-photon (see above, condition (ii) (a)). Hence, the following unequalities must be verified :

(6) $$0 < m_\gamma \ll m_\varphi \ll m_e$$

This theory can be considered as rather natural, in the light of the concept of a massive photon, resulting of the combination of two particles of spin 1/2, possibly neutrinos. In this case, the photon satisfies the Maxwell equations with a supplementary mass term (Proca's equation). The combination gives place not only to a photon but to a neutral, light, pseudoscalar particle: this is precisely the φ-particle. There is nothing astonishing in the fact that it has been unobservable so far: such particles are certainly not strongly coupled with matter, since they are neutral. The only possibility to observe them is to do it undirectly (just as for neutrinos) and by the fact that their existence is necessary, in the framework of this theory, to the energy and momentum conservation. Observed defects in the black-body radiation (Lecomte ,1962) are possibly a confirmation of this point of view.

(iv) At his stage, we reckon that hypotheses 1 (perturbations to Friedmann cosmologies), 2 (chronogeometry) do not account for observational facts related to local effects (introduction,1); hypothesis 3 (multibang cosmology) can account for effects a and c, but not for effect b of the introduction; hypothesis 4 (variation of constants) cannot account for the effect b either; most of the hypotheses 5 meet difficulties we have described.

Without excluding other possible mechanisms, the only theory, so far, which seems to us a proper explanation for the three types of effects mentionned in the introduction, is thus the Ø-mechanism, involving γ-φ interactions between the S-photon and a new particle, the φ-particle, as briefly described above. The next section is devoted to a detailed study of this mechanism.

II - The Ø-MECHANISM. DETAILED TREATMENT.

1. Kinematics and dynamics of the interaction.

We shall describe hereafter only the essential feature of the interaction, leaving aside the lagrangian (hamiltonian) formulation (described in Marić et al. 1976, a,b).

As well-known, the standard description of an interaction between two particles implies the exchange of intermediate particle. The interaction, moreover, must satisfy the conservation laws of energy-momentum and angular momentum.

This can be represented by a second-order graph, which has been shown to be the only one to be considered of this limited degree of complexity (see figure 1). The energy momentum conservation law can be expressed as follows :

$$(7) \qquad E_1+W_1 = E_2+W_2 \quad ; \quad \vec{k}_1+\vec{p}_1 = \vec{k}_2+\vec{p}_2$$

where, in any reference frame, the index 1 designates the incoming states, the index 2 the outgoing ones. E and W represent respectively the γ and φ energies, $\vec{k}$ and $\vec{p}$ denoting the corresponding vector momenta. Spin conservation is insured by the total angular momentum conservation.

As already said, the two incoming particles, γ and φ, have a non-zero mass satisfying unequality(6). As we focus our attention on the loss of energy of the incoming (which will be directly observed after the interactions), it is convenient to work in the φ-rest frame. There, the photons must be relativistic with respect to the φ's; hence, one can show that we have:

$$(8) \qquad W_1 m_\gamma / E_1 m_\varphi \ll \sqrt{1/2}$$

This unequality essentially means that incoming photons lose energy by passing through a lower energy φ-bath; it insures a redshift - not a blueshift. Then, one has $W_2 = m_\varphi c^2 + T$; so that the kinetic energy T lost by the photon, and gained by the φ is $T = E_1 - E_2$. The γ is deflected by an angle $\delta\theta$, the φ by an angle $\delta\varepsilon$. The kinetic energy can then be expressed using the momentum conservation (to eliminate stage 2 of the collision) from its expression :

$$(9) \qquad T = \frac{E_1^2 \,(1 - \cos\delta\theta)}{m_\varphi c^2 + E_1 (1 - \cos\delta\theta)}$$

The resulting cross-section σ is obtained by the integration of the differential cross section $d\sigma$ (for all photons having lost an energy between T and T + dT). To insure a strong forward scatering, $d\sigma/dT$ has to be very large for small values of T (i.e. for small photon deflections). We then see that a function of the form $d\sigma/dT \propto 1/T$ would indeed satisfy this requirement. It is generally not the case; however, there exists a well-known case in the literature, where this condition is verified. It concerns the scattering of neutrinos by electrons (interaction $\nu_e - e^-$) where the intermediate particle exchanged is a vector boson W (Bethe, 1935, Bardin et al. 1970, and Clark, Pedigo, 1973). Indeed these authors have succeeded to define an effective hamiltonian, and to derive from its expression a differential cross-section of the correct form. We shall now use two important ideas to treat the $\gamma - \varphi$ interaction.

First, we assume that one can treat hadrons (fermions or bosons) as combinations of quarks (which are fermions of integer charge). Second, following Pati and Salam (1974), we admit that there is a certain symmetry (Vigier, 1976) in the way hadrons and leptons have to be treated, so that we can consider very light bosons (such as γ and φ) as combinations of spin 1/2 fermionic leptons and antileptons (neutrinos and antineutrinos, for example). Hence, we can build an interaction by the combination of two interactions of the type $\nu_e - e^-$. As experimentally checked in the case of hadrons, we shall consider the two combined interactions as independant. The interaction graph is as follows: (figure 2)

FIGURE 1

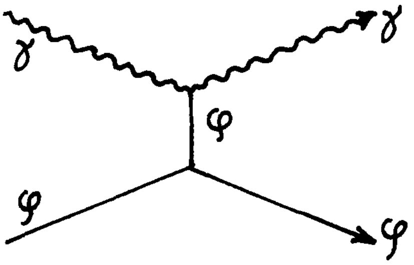

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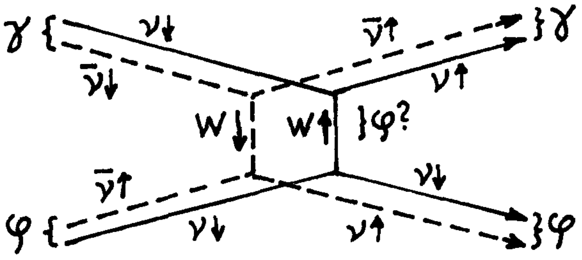
FIGURE 2



The combination of the two bosons can be thus symbolically written as an effective exchange of a scalar particle (φ?) of spin zero between the γ and the φ. Moreover, as pointed out by

Pati and Salam, (1974), particles such as the φ and γ bosonic leptons can have strong mutual interaction.

The effective hamiltonian can be explicitely written and leads to :

$$(10)\qquad \frac{d\sigma}{dT} = K\,\frac{E_1 - T}{E_1 T}$$

where k is an integration constant (Marič et al. 1976, a,b), and which obviously favors a strong forward scattering. In the computation of the total cross-section, one can thus now assume $\delta\theta$ to be small. One can thus simplify the expression (9) of T :

$$(11)\qquad T \simeq \frac{E_1^{2}(\delta\theta)^2}{2 m_\varphi c^2}$$

Using this expression, the fractional energy loss can be written :

$$(12)\qquad \delta\nu/\nu = \delta z = T/E_1 = E_1(\delta\theta)^2/2m_\varphi c^2$$

We can finally compute the total z and total θ, corresponding to N collisions, using relations (4) and (5). One obtains:

$$(13)\qquad \ln\left(1 - \frac{\Delta\nu}{\nu}\right) = -E_1\theta^2/2m_\varphi c^2$$

One can show that the value $m_\varphi \lesssim 10^{-48}$g is compatible with the minimum angular sizes ever observed for QSS.

If we consider the case of the sun, the fact that there seems to be a displacement, without broadening, of the spectral lines implies $\delta\nu/\nu < 2\ 10^{-9}$ per collision or $N > 100$. One then obtains, for $\Delta\nu/\nu > 2/3$, the limit $N > 5\ 10^{8}$ collisions. Hence the deflection, per collision, has to be smaller than 10^{-10} radians - a very small deflection indeed... It is satisfied if (i) m_φ satisfies the above written unequality; (ii) N is large enough.

From expression (11), and from the equation (10) one can write for the average fractional (i.e. per collision) loss of energy :

$$(14)\qquad \left\langle\frac{T}{E_1}\right\rangle = \frac{1}{\sigma}\int_{m_\varphi c^2}^{E_1} \frac{T}{E_1}\frac{d\sigma}{dT}\,dT \simeq \frac{K}{2\sigma}$$

When a photon γ is passing through a φ-bath, of particle density $\rho_\varphi(r)$, there are $N = \sigma\,\rho_\varphi(r)dr$ collisions, and the energy loss is :

$$(15)\quad \frac{dE}{E} = \frac{d\nu}{\nu} = -dN < \frac{T}{E_1} > = -\sigma \rho_\varphi(r) < \frac{T}{E_1} > dr = -\frac{K}{2}\, \rho_\varphi(r) dr$$

This redshift is indeed independant of the frequency of the incident photons as required. The redshift law can thus be written :

$$(16)\qquad 1 + z = \exp \left\{ \frac{K}{2} \int_{(L_j)} \rho_\varphi(r) dr \right\}$$

To predict the redshift, or to interpret the observed redshift, the problem is now to compute the density ρ_φ of φ-particles, and to know K, or (if we know N)to know σ . From observational data, assuming that relation (15) is correct, one could then deduce the product $K\rho_\varphi$.

All that we can know, so far, is thus the product of the cross section by the density of φ-particles - but nor each of the two separately; hence one can think of two types of interactions : weak interactions, implying a large number of φ-particles, or on the contrary, strong interactions with a moderate number of φ-particles. A physical choice between strong and weak interactions must thus be made at this stage to implement our model. This choice implies a determination of the ρ_φ distribution.

2. Discussion of the particular case of strong φ-γ interactions.

Assuming the interaction φ-γ to be strong, the assumption that the φ's are in statistical equilibrium with the γ's has been developped in particular cases, and shown to be compatible with observations (Mérat et al., 1974, Jaakkola et al.,1975), in some specific cases. It means that $\rho_\varphi = 1/2\, \rho_\gamma$ as the φ's have only one spin state, and the transverse photons have two of them. It means also $T_\gamma = T_\varphi$, T_γ and T_φ being respectively the temperature of each type of particles in the medium in consideration. Then the φ-particles satisfy the Planck-type relation $\rho_\varphi = \frac{\alpha}{2} T^3$ where α is of the order of 30, as it is well known that the γ satisfies $\rho_\gamma = \alpha T^3$.

The solar case, in spite of the uncertainties of the observations, will have to be used, to determine ρ_φ ; and from ρ_φ, the cross-section σ. The observed redshift is of the order of 2.10^{-7}. A discussion of the case shows that, in order to get this redshift, but no broadening of the redshifted lines, we have to assume a number of collisions at least equal to 100, or an energy loss, per collision, of $\delta\nu/\nu \leq 2\ 10^{-9}$. These collisions act on a path length of the order of the solar radius, $R_\odot = 7.10^{10}$ cm. According the relation $N \cong \rho_\varphi \sigma R_\odot$ and, taking $\rho_\gamma = 15(6000)^3 = 5\ 10^{13}$ (assuming the radiation temperature to be near 6000 K), one finds then $\sigma \leq 0.3\ 10^{-22}$ cm^2- a value typical indeed of what is usually called "strong interactions". The value of K can be determined from the observed redshift and relation (15). One finds : $K \simeq 10^{-30}$ cm^2.

Our first comment to this estimation is that there is no reason for this statistical equilibrium between the φ's and the γ's to be a general phenomenon. In particular there is no reason to believe that coherent sources (such as radio-antennas, lasers, etc...) always satisfy this equilibrium condition and we shall see later that, in free space, the φ-decay gives another situation where this is not satisfied either. For the time being, however, we leave this question open, as long as the five conditions listed (section I,5,ii) are fulfilled. Provided one finds a correct value for ρ_φ , they will be satisfied using the values of σ or of K we have just determined in the solar case.

Another comment is that some observations bring support to the introduction of a φ-particle :

(l) Various observers have noted, in the laboratory, some line asymetries in hot plasmas, affecting for example Balmer lines (Wiese, 1974) or Krypton lines (Rowley, Hamon, 1963). These observations can be interpreted by the type of redshift we have described (Marič et al. 1976,a,b).

(ii) The defect of solar neutrinos has also been interpreted by several authors (Bahcall et al.,1972) as due to the interactions involving a particle of the φ -type, i.e. by the decay $\nu_e \rightarrow \varphi + \nu_\mu$ (see also Molès, Vigier, 1974).

(iii) Some observed astrophysical so-called γ-jets (for references, see Collins et al. 1973) can be explained by a neutral very light primary particle (the φ-particle) producing the e^+e^- pairs through inelastic scattering processes. The cross-section of this inelastic process leads to an astonishingly high cross section $\backsim 3.10^{-25} cm^2$.

3. Processes affecting the equilibrium of φ-particles.

If ρ_φ is strongly correlated with the density of matter (as is, obviously, the density of photons), the observed "abnormal redshifts" can be explained by the mechanism described above. It is important to know how closely are in general the γ and φ concentrations linked to the matter concentration. Let us first consider any φ-particle, produced by any process. It will interact with other particles and of course, with the γ's, and it will in general gain energy; the spectrum of the φ's is enriched in its high energy tail; they will give back this energy to the photon field by inelastic scattering processes producing high energy γ-jets. The γ-φ interactions, involving for the photons a very small deflection angle per collision, cannot isotropize the S-photons, unless at enormous distance scales. The isotropization distance corresponds to a large number N_{is} of collisions; $\delta\theta$ being the deflection caused by a single collision, the isotropization corresponds to a total deflection angle of the order of 1 radian. Hence the isotropization distance $L_{is\,\varphi\cdot\gamma}$ is of the order of the mean free path $\ell = 1/\sigma\rho_\varphi$, multiplied by N_{is}, which is of the order of $1/(\delta\theta)^2$. One has thus :

$$(17) \qquad L_{is\,\varphi\cdot\gamma} = N_{is}/\sigma\rho_\varphi = 1/\sigma\rho_\varphi(\delta\theta)^2 \backsim 1/\rho_\varphi . 3\,10^{-23} . 10^{-20}$$

As ρ_φ is so far undetermined, we can only say this value of $L_{is\,\varphi\cdot\gamma}$ is probably very large. We shall come back on its value as soon as we shall find some way to compute ρ_φ . On the other hand, let us consider the φ-φ interactions, assuming, as in the preceding interaction graphs, that there exists an "effective" intermediate scalar particle and a cross section of the order of the one involved in the φ-γ interaction; the isotropization distance can then be estimated as in the case of the φ-γ interaction. The main difference is that the deflection angle ω is indeed much larger than $\delta\theta$, as the φ-φ interaction can be shown easily to be an elastic isotropic scattering. Hence the value of $L_{is\,\varphi\text{-}\varphi}$ is several orders of magnitude lower than $L_{is\,\varphi\text{-}\gamma}$. Its exact value can be estimated from kinematical considerations, since the mass of the φ -particle determines fully the angular deflection per collision; one finds easily :

$$L_{is\,\varphi\text{-}\varphi} = 1/\sigma\rho_\varphi\, 10^{-8} \tag{18}$$

Assuming for $\sigma_{\varphi\text{-}\varphi}$ the same order as for the cross section $\sigma_{\varphi\text{-}\gamma}$, and the same value for ρ_φ , we see that $L_{is\,\varphi\text{-}\varphi}$ is <u>10^{12} times smaller</u> than $L_{is\,\varphi\text{-}\gamma}$.

What other processes could affect the φ -particles?

We have mentioned earlier the fact that φ-γ collisions might be inelastic and give place to γ -jets, and to electron-positron pairs. Obviously, we might think of many inelastic processes. One of the most interesting, and a very likely one indeed, would be the $\varphi \rightarrow \gamma$ decay, i.e. : $\varphi \rightarrow \gamma + \gamma$

Thus, in an isotropized field of φ -particles, we shall find an associated isotropic γ -bath, of locally produced photons (L-photons). This process being not reversible, we must postulate some other inelastic processes by which the φ -particles would be produced in the vicinity of matter. In the absence of new experiments or observations, we cannot obviously say more at this time about them.

But let us consider that φ -bath and its equilibrium. It will satisfy the well-known Planck relations, within a distance equal to the isotropization distance, around the matter concentration with which we assume it to be associated. This yields:

$$h\nu_\gamma = \frac{1}{2} h\nu_\varphi \quad ; \quad T_\gamma = \frac{1}{2} T_\varphi \quad ; \quad \rho_\gamma = \frac{1}{8} \rho_\varphi$$

We can come back now to the isotropization lengths. One finds it easily , for $T \cong 3\,K$, $\rho_\varphi \backsimeq 3000$; hence $L_{is\,\varphi\text{-}\gamma} \sim 10^{39}\,cm$ — a distance much larger than the size of the observable universe(about 10^{30} cm). $L_{is\,\varphi\text{-}\varphi}$ is equal to about 300 Mpc. But taking $\sigma_{\varphi\text{-}\varphi} \sim 10^{-20}$ instead of $\sigma_{\gamma\text{-}\varphi} \sim 3\; 10^{-23}$, we find a distance of about 1 Mpc. This distance is intermediate between the galactic size and the supergalactic size. In any case, it can be considered as "local".

Collisions between the φ's and the γ's cannot isotropize the S-photons. But φ-φ collisions isotropize the φ's, at a relatively small distance, thus producing isotropic L-photons as well.

III - POSSIBLE MORE GENERAL CONSEQUENCES OF THE ϕ-MECHANISM.

One might now ask the question : could such a ϕ-mechanism explain part, or even the totality of Hubble's observed general redshift, as well as it accounts for its anomalies? And if so, could it explain other features of the observed universe, generally associated with expansion, such as the background 3 K radiation?

This would mean that the observed Hubble constant is an average over distance of a local Hubble constant, linked with the local density of φ-particles, i.e. :

$$(19) \qquad \frac{d\nu}{\nu} = -\frac{1}{c}\,H(r)dr = -(K/2)\,\rho_{\varphi}(r)dr$$

It is also quite obvious that the redshift associated with various objects - sun, star, galaxy, quasars ...- depends upon the φ-bath associated with the source. If one accepts the assumption that, due to the processes earlier described, this φ-bath is in a near equilibrium situation ($\rho_{\varphi} = (1/2)\rho_{\gamma}$) with solar γ-radiation bath, (not to be confused with the L-photons), one is led to conclude that their density is $\sim 15\ T^3$, where T is, locally, the temperature of the radiation. This allows to write the <u>local intrinsic source redshift</u> as :

(20) $H(r)dr = A\,c\,T^3(r)dr$, where $A = \frac{K}{4}\alpha$, α being of the order of 30.

The parameter A can be derived from solar data, in spite of their unaccuracy; we shall accept the values $7.10^{-30} \leqslant A \leqslant 4.10^{-29}$ as a reasonable range. This value is compatible with the various other observational abnormal redshifts.

When applied to the <u>general ("cosmological") redshift</u>, one must integrate along the line of sight the value of H(r).

To determine the values of $H_i(r)$ and T(r) in different regions of the universe, we shall start from the idea that the L-photons (local isotropic γ-bath) just correspond to the observed 3 K background radiation, -noting that, in any tired-light mechanisms, it is very difficult, (as noted by Puget and

Schatzman (1974)) to identify the background blackbody radiation with a reasonable combination of redshifted S-photons; the later are indeed probably much weaker than the L-photons, and at a smaller temperature, as we shall see : they might constitute some real background radiation, in the centimetric-metric range of radiations, which seems compatible with recent observations (Reber 1968).

The relation between H(r) and T (r) is here as follows, taking only into consideration the L-photons. We get :

$$H(r)\,dr = A\,c\,8\,T_{\gamma}(r)^{3}\,dr \qquad (21)$$

The factor 8 corresponds to the relation : $T_{\varphi} = 2\ T_{\gamma}$.

From observed values of H, we can deduce local values of T, and vice versa. To account for the local T = 3 K background radiation, we first admit that its spatial scale is smaller than a few Mpc, hence that the choice of $\sigma_{\varphi\text{-}\varphi}$ has to be oriented towards the larger values. We found compatible with it a rather large value of H; it is of course somewhat a fictitious value, as, at those small scales, real motions are masking completely the Hubble redshift.

We consider now, that, within reasonable doubts (unaccuracy of some of the observed data, very temptative character of our theory), we have made a suggestion able, with further refinements, and further observational evidence, to account well for the abnormal redshifts and promisingly with the general redshift and the background radiation.

CONCLUSION

Let us now consider the observable universe. Fluctuations of mass density, φ- density, photon density etc... are there characteristic of a hierarchy. Very dense objects are producing photons which are redshifted in the near vicinity of the source itself by its own φ-bath. Moreover, any S-photon is redshifted on the way from the source to the observer.

The radius of the universe, because of its hierarchical nature, is much larger than hitherto assumed. Estimates of $z=10^5$ are not unreasonable. It is even conceivable to have an open universe as suggested recently by Gott et al. (1974,1975). Since we have no direct empirical proof of the expansion's existence (the apparent Hubble law being possibly accounted for completely by the φ-mechanism) we can conceive of an Einstein static universe with a very large value for its radius R; in the case of a hierarchical distribution of density,such universes might be stable. Nothing keeps us from thinking of an universe infinite in its past duration. We must still account for two strong arguments in favor of the existence of a big bang at time zero.

The first one is the very much used argument of the arrow of time, according for example Layzer, 1976. To this concept, we can reply that it is only valid for an isolated system of negligible mass : in an isolated system of large mass, local concentrations (and not homogeneization) have a tendancy to be built up. We infer from this (not to speak here of the effect of the internal levels of energy of particles) that the Clausius macroscopic definition of entropy meet the microscopic definition of Gibbs only at small scale. At large scale, the whole second principle has possibly to be revisited, and is probably not valid under the form it is generally expressed. We are now working at this problem.

The second very much used argument is the fact that the present-state Galaxy contains too much deuterium and helium to have been built by thermonuclear reactions in the galactic lifetime. Hence it comes from the big bang... To this we must reply that if the building of He and D before the galactic formation is a possible reply, there are many other ways to solve this question : i.e. impoverishment of galaxies in hydrogen due to early stages of evolution of a galaxy is possible (Pecker 1972) through violent expulsion by UV excess radiation. Expulsions of that sort can give place to double radio-sources, which in their turn condense again in groups of galaxies, as could be the case of the companions of NGC 7331. In this picture, and if we admit an infinite life-time for the Universe, we are not through with explaining by that process the galactic composition. We must also explain the fact that after a great number of events, there is still some hydrogen left. Let us not forget that all elements have a finite-even if very large- life-time : so that all of them eventually turn back to hydrogen. Moreover, they may be at some localized points in the universe, such as in the nucleus of very active objects (young galaxies, i.e. possibly supercompact objects), fusion processes, leading, at very high local temperatures, to an equilibrium composition containing much hydrogen (small bangs). In any case, the evolution of the universe, its basic thermodynamics have to be looked at as that of out-of-equilibrium systems, which never reach equilibrium in the classical sense. A statistically steady universe, but locally strongly fluctuating, is quite conceivable in this light - but we are still far from a completely self-consistent picture of this sort.

At his point, we claim that a global coherent description of the observable universe is still far from reach for everybody, so that more observations, by more powerful instruments, are still badly needed. We claim also that these observations have indeed to be the basis of our discussion, instead of a priori concepts (of doubtful validity) on the universe as a whole. To give a measure of how far we still are from a conclusion, we would like to remind the reader of the two tests proposed long ago by Hubble and Tolman :

The first test is based on the count of distant galaxies. Various authors believe they have verified the test; others still think that no conclusion can be so far derived from the counts of extragalactic objects - radio or visible. Intergalactic matter still complicates the problem.

The second test implies an analysis of the relation between apparent dimensions of galaxies and their luminosities. It is still less near to be conclusive than the first test, due to the enormous diversity of the compacity of extragalactic objects.

In front of this situation, we can quote the very sentence which concludes Hubble and Tolman's paper : "Until further evidence is available, both the present writers wish to express an open mind with respect to the ultimately most satisfactory explanation of the nebular redshift, and in the presentation of observational findings, to continue to use the phrase "apparent" velocity of recession. They both incline to the opinion, however, that if the redshift is not due to recessional motion, its explanation will probably involve some quite new physical principles".

Some of the possible "new physical principles", we have tried to review in this paper. As heretic as they may seem to some scientists, we would like to have them discussed seriously. We want to make a plea for heresy, and to express a strong word of caution in front of implicit dogmas.

At this point, and to conclude, we would like to quote an ironical comment by Alfvén (1974,76). He considers the big bang as "a wonderful myth, which deserves a place of honour in the columbarium which contains already the indian myth of a cyclic universe, the chinese cosmical egg, the biblical myth of creation in six days...", to conclude that "...Nothing is gained if we try to place another myth in the place which the big bang occupies now".

At least, we may consider the debate as still widely opened.

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DISCUSSION

G. PAAL: Some Comments on Observational Tests of the Expansion of the Universe: We seem to have fairly good evidence to state that the "tired-light hypothesis" applied to the general Hubble effect (not the possible local deviations from it proposed by Prof. Pecker) is incompatible with the observational data now available. Indications to support this statement appeared already in 1971 (Paál, Astrophys. 7, 257; Peebles "Physical Cosmology" p. 180). In 1973 (Proc. IAU Symp. No. 63. p. 251) I have presented a surface brightness - redshift relation, SB(z), for rich clusters of galaxies, which shows a highly significant deviation from $SB \sim (1+z)^{-1}$ expected in "tired-light cosmologies" and also in Segal's "chronometric cosmology". In these unchanging world there is no place for overall evolution (with a time scale of just about the "Hubble time") to explain the deviation of observed relation from the predicted one. The angular size of distant clusters are found to be twice as large as predicted in these static models! - An even stronger objection can be made in connection with Segal's cosmology in which the predicted angular diameter - redshift relation has the form $\theta \sim (1+z)/\sqrt{z}$. This theoretical relation, if fitted to the observed one at small distances, deviates from them by a factor of 3 or more at larger redshifts, both in case of clusters of galaxies (Paál, 1971; Bahcall, Astrophys. J. 186, 699, 1973) and brightest cluster members! Clearly no selection effect or systematic observational error can account for these enormous discrepancies.

J.-C. PECKER: The angular diameter, in the tired-light theory, is not necessarily identical to that of a Newtonian - Euclidian universe. The "smearing" of images must start somewhere, not to be negligible. I fail to see that Dr Paál's interesting study really contradicts the tired-light mechanism, even when the latter is applied to the whole of the observed redshift; more study has indeed to be done.

E. SOLHEIM: Your tired-light theory predicts a change in the energy of the photon while it travels through space. How stringent will the Planck law $E \cdot \lambda = \hbar c$ be satisfied?

I will mention observations at McDonald Observatory showing no changes in the product $E \cdot \lambda$ for quasars with redshift up to $z = 1.6$ (Solheim, Barnes, Smith, Astrophys. J., 209, 330, 1976).

The tired light theory has obviously to predict a strict Planck law for small distances or small z-values, but at $z = 1.6$ there might be deviations that could be compared with the limits set by the observations mentioned above.

J.-C. PECKER: The only reply is to say that the effect of a non-zero rest mass of the photon could be on c (light velocity); but it would be inefficient, taking into account the upper limit for the photon mass $(m < {}^{-48}\ g)$.

J.P. VIGIER: My first comment is that some of the theories Prof. Pecker discussed, i.e. the variability of constants (Hoyle-Narlikar) and tired-light mechanisms, can (and should) be tested in the laboratory. In Grenoble Dr. Baum presented observations which suggest that there is no variation of e, $\hbar$, c (and m_e) within values of $z \leq 0{,}4$ I believe. This implies that Arp's "monsters" (if confirmed) cannot be interpreted in that way.

My second comment is that any tired-light mechanism (which evidently implies something new in the theory of light) will finally succeed (or fall) in the laboratory. There are some preliminary results which point towards some new property of photons. The first is that one has observed (Wiese 1974) in H_α, H_β, H_γ lines in hot plasmas an unexplained asymmetry towards the red. Very recent profile calculations (Vidal and al. 1973) yield perfectly symmetric profiles while it is seen that at wing intensities of only a few percent of peak intensity the red wing becomes ~ 10 percent stronger than the blue one. The same property has been observed in the $\lambda = 6058$ Å of Krypton 86 (Rowley and Hamon 1963) and on the ${}^1S_3 - {}^3P_{10}$ transition of Kr 86. Both effects could be explained (Maric, Moles, Vigier 1976) by a φ intervention.

Moreover we do not claim any originality in the φ-proposal. Introduced by de Broglie (1940) the φ has been revived by Bahcall and al (1972) to account for the observed defects of solar neutrinos. Strong indirect evidence (Collins and al 1973) for the existence of such a particle comes from the observation of γ-jets (which produce e^+e^- pairs) which seem to originate from a very light neutral scalar particle. This could also explain Auger-type cascades (of γ's) observed by the Uhuru satellite. It might also take away the energy lost by photons crossing rich clusters of galaxies (Karoji, Nottale 1976, Karoji et al. 1975).

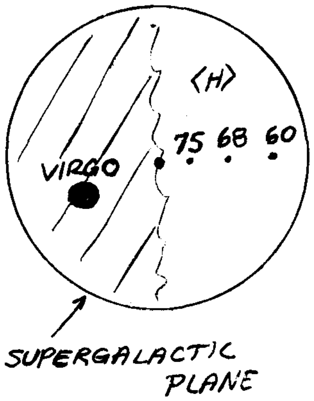
My third comment is, that the question of the φ's origin should be handled heuristically. In some cases (Merat et al 1974) we have assumed γ - φ thermal equilibrium but this needs a separate discussion in each case. For example there is no reason to believe that coherent γ - φ thermal equilibrium but this needs a separate discussion in each case. For example there is no reason to believe that coherent γ-sources(such as radio antenna, lasers or masers) satisfy this equilibrium condition so that one cannot expect any strong dispersion of radio waves by radio-waves or any significant break up in maser observations since these types of sources would not emit any significant φ density. In the same way there is no reason to believe that narrow emission lines observed in QSO sources originate on the total QSO surface. One must avoid brutal extensions of the $\delta z = AT^3L$ expression.

M. REES: Can you propose any plausible quasar geometry that permits you to get a large anomalous redshift without getting unexceptably broad emission lines? This is an important question since an explanation of quasar redshifts is presumably one of the main goals of your theory.

J.-C. PECKER: I will return to this in the general discussion. However, why should the so-called "non-conventional" find a reply to all questions raised, when the "conventional" admit that they cannot?

V. RUBIN: I think we all agree that it would be nice to settle even a few small points at this colloquium so I would like to set to rest the statement that H decreases outward in the Supergalaxy. This notion arose from

Sandage's Sc I data, for which $\langle H \rangle_{ScI} \sim 60$, $\langle H \rangle_{ScII} \sim 70$, and $\langle H \rangle_{ScIII} \sim 80$, as I remember it. Thus when these data are used to the r dependence of H in the supergalactic plane, it looks in the anti-Virgo region as the figure shows. This apparent decrease in H with r arises because Sc III galaxies are observed only to smaller r than Sc IIs and ScIs; Sc IIs are observed to smaller r than Sc Is. This dependence of H on luminosity class was first pointed out by Le Denmat and discussed by others (see my paper at this conference).



J.-C. PECKER: The real argument is as follows according to Le Denmat, Niéto et al. (Nature 257, 773, 1975; Astron. Astrophys. 45, 219,) and N. Durand (Thesis, Paris University):

1) If one accepts Sandage and Tammann's calibration, one finds different H values for different luminosity classes i.e., $H_{ScI} = 61 \pm 7$, $H_{ScI-II} = 68 \pm 10$, $H_{ScII} = 78 \pm 6$, with ST's nearby sample. On the contrary, van den Bergh's calibration has been shown to be internally coherent: $H_{ScI} = 109 \pm 12$, $H_{ScI-II} = 109 \pm 15$, $H_{ScII} = 114 \pm 9$.

2) But with van den Bergh's calibration, H depends on distance. One finds a significant decrease with ST's "unbiased" sample (STV and VI), but part of it is a consequence of radial velocities' limits. However, the decrease is still present for the whole sample for which no bias affects a (H, D) plot. A least square regression method gives in the supergalactic anticenter direction $H = -0.51\ D + 135$, $r = 0.39$, significant at the $3{,}7\sigma$ level.

3) Independent data by N. Durand lead to the same decrease.