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CATALOGUE OF SELECTED COMPACT GALAXIES AND OF POST-ERUPTIVE GALAXIES

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A Reminder to the High Priests of American Astronomy and to their Sycophants

> "The scholar's mission requires the study and examination of unpopular ideas, of ideas considered abhorrent and even dangerous.
>
> "Timidity must not lead the scholar to stand silent when he ought to speak.
>
> "In matters of conscience and when he has the truth to proclaim the scholar has no obligation to be silent in the face of popular disapproval.

From
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A Statement by the

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INTRODUCTION

ORIGIN, SCOPE AND PURPOSE OF THE
PRESENT CATALOGUE

I. On Some Principles of Thought and Observation

The compilation of the cosmic objects listed in this catalogue and the preliminary review of some of their characteristics represents one of the results of my attempts during the past five decades to predict and to visualize the existence of as yet unknown aggregations of matter and of radiation, as well as of my consistent efforts to confirm observationally as many as possible of the predictions made.

During much of the past, discovery, invention and research were left to chance and were pursued more or less haphazardly by most scientists. This type of approach not only has been inefficient, both in the use of manpower and means, but it has also led to disastrous results for mankind, as I have stressed in other places [1, 2, 3, 4]. Not only has the unity of science been lost but, in addition, the gap between science and the lay world has been allowed to deepen and to widen steadily.

The following account of some of the developments in astronomy in particular, and the suggestions made are intended to evoke wider perspectives and to invite our successors to make use of them as they see fit, or to top them by their own possibly superior views and more effective procedures for the development of a greater science and a sounder world.

Although in the 1920's I started out as professor of theoretical physics at the California Institute of Teehnology in Pasadena I occupied myself, in addition to the physics of gases, liquids and solids, with abstract astrophysical subjects, such as the "Thermodynamic Equilibrium in the Universe" [(5)], the "Redshift of Spectral Lines Through Interstellar Space" [(6)] and the "Gravitational Drag of Light" [(7)]. I soon became convinced, however, that all theorizing would be empty brain exercise and therefore a waste of time unless one first ascertained what the population of the universe really consists of, how its various members interact and how they are distributed throughout cosmic space.

I consequently engaged in the application of certain simple general principles of morphological research, and in particular the method of Directed Intuition [*] that would allow me to predict and visualize the existence of as yet unknown cosmic objects and phenomena. This approach seemed timely and imperative for the following reasons.

First, we note that again and again scientists and technical specialists arrive at stagnation points where they think they know it all. The period around 1930 certainly was such a time. For instance, quantum mechanics and the Schroedinger wave mechanics had been so successful that even Wolfgang Pauli complained there was nothing left to do in physics but to solve the multibody problems involving atomic nuclei and electrons moving around them, just as there had been nothing left in classical celestial mechanics but to find ever more general and exact solutions for gravitational three- and many-body systems.

Lundmark's work, on extragalactic space as being occupied by myriads of stellar systems had been confirmed by Hubble and others. All types of stars were supposed to have been found and neatly ordered in the Hertzsprung-Russell diagram. All matter was thought to be built up of protons and electrons, and even the exact total number of these particles was known to A. S. Eddington. Furthermore most astronomers were and still are convinced that the redshift observed in the spectra of the distant galaxies is a clear proof for the expansion of the universe, some scatter-brains among them even claiming to know how the rate of this expansion has been changing in time, in spite of the fact that the observational data available are very meager indeed and that actually some of them are difficult to reconcile with the hypothesis of an expanding universe.

The naivety of some of the theoreticians, at all times, is really appalling. As a shining example of a most deluded individual we need only quote the high pope of American Astronomy, one Henry Norris Russell, who in 1927 announced [(5)]: "The main outcome of these extensive investigations maybe stated in a sentence: The characteristics of the stars depend upon the simplest and most fundamental laws of nature, and even with our present knowledge might have been predicted from general principles if we had never seen a star."

Secondly, the most renowned observational astronomers in the 1930's also made claims that now have been proved to be completely erroneous. This retarded real progress in astronomy by several decades since the said observers had a monopoly on the use of the large reflectors of the Mount Wilson and Palomar Observatories, and inasmuch they kept out all dissenters. I myself was allowed the use of the 100-inch telescope only in 1948, after I was fifty years of age, and of the 200-inch telescope on Palomar Mountain only after I was 54 years old, although I had built and successfully operated the 18-inch Schmidt telescope in 1936, and had been professor of physics and of astrophysics at the California Institute of Technology since 1927 and 1942 respectively. E. P. Hubble, W. Baade and the sycophants among their young assistants were thus in a position to doctor their observational data, to hide their shortcomings and to make the majority of the astronomers accept and believe in some of their most prejudicial and erroneous presentations and interpretations of facts.

Thus it was the fate of astronomy, as that of so many other disciplines and projects of man, to be again and again thrown for a loop by some moguls of the respective hierarchies. To this the useless trash in the bulging astronomical journals furnishes vivid testimony.

In view of the following discussion about the newly-discovered extragalactic objects listed in this catalogue it is useful to recall some of the major absurdities that were promulgated about galaxies, clusters of galaxies and other cosmic objects by the high priests of astronomy during the past few decades.

It must be emphasized right at the outset that no one, with the exception of the author [6, 7] has ever clearly stated what a galaxy is, an omission that no doubt will not only baffle every thinking layman but will in particular be judged ludicrous by any true methodologist or professional in morphological research. The strict definition given by the author has also led to a convenient classification, into supergiant, giant, normal, dwarf, pygmy and gnome galaxies, as well as to that of compact galaxies and compact parts of galaxies. Unfortunately my respective proposals have not so far been acted upon by Commission 28 (Galaxies) of the International Astronomical Union. As a consequence some of the most absurd and untenable definitions of quasars, quasistellar objects, "interlopers" have been introduced by A. Sandage [8], M. Schmidt [9] and others to which we shall return later on.

Some of the most glaringly incorrect conclusions drawn by E. P. Hubble and W. Baade that stubbornly persisted in the minds of most astronomers for decades are the following

a. Hubble [10] and Baade [11] never ceased to stoutly maintain that the absolute photographic luminosity function of galaxies may be represented by a Gaussian error curve with a dispersion of only six tenth of a magnitude around some mean value M_{op}. They vehemently denied the existence of galaxies substantially less luminous than about one hundred million suns.
b. As an auxiliary conclusion to a) it was stated that intergalactic space is empty or, at any rate does not contain any matter which can ever be observed.
c. Hubble also studied the distribution of galaxies in cosmic space and affirmed on the basis of both completely faulty observations and incorrect statistics that only about five per cent of all galaxies are members of clusters of galaxies.

Surveying the statements made by Eddington, Russell, Baade and other astronomers I proceeded first of all on the basis of my conviction that there are more things in the sky than even the most imaginative human mind can divine but, that it must be possible to predict at least the existence of some new objects and phenomena through the use of the Morphological Method of Directed Intuition, applying it step by step to more and more general cases.

Subsequent Findings on the Issues a, b, c

a. Dwarf, Pygmy and Gnome Galaxies

I submitted [12, 13, 14, 1] that, if any type of aggregation of matter, that is nuclei, atoms, molecules, living cells or animals and men exist only in certain ranges of size, clustering about some most frequent value, one or several fundamental causes must be at work, none of which applies to galaxies. No deep thinking was needed to conclude that all sorts of material objects, including in particular individual stars and groups of stars containing clouds of dust and gases, must exist spread throughout intergalactic space. If at any given time such formations did not exist, they would of necessity appear eventually because of being ejected from large galaxies as a result of close encounters, as well as byproducts of large scale implosions and explosions.

As a consequence of the preceding considerations I started a search for dwarf galaxies with the 18-Inch Palomar Schmidt telescope, after it had been installed in the fall of 1936. Several most interesting stellar systems were presently discovered, among them the Leo I system at R.A. $9^h56.4^m$, Decl. +30°59' (1950) and Sextans I at R.A. $10^h8.6^m$ Decl. -4°8.6^m (1950). The expected high frequency of occurrence of dwarf galaxies was later amply confirmed, first through the discovery of the Sculptor and Fornax systems by Shapley and later by the dozens of objects found with the 48-inch Schmidt telescope on Palomar Mountain. Recently, in connection with the compilation of the objects for the present catalogue I have been able to round out my surveys on underluminous systems through the discovery of compact dwarf galaxies.

The existence of relatively numerous underluminous stellar systems was also confirmed through the discovery of many supernovae that reached a maximum luminosity several magnitudes brighter than the parent galaxy, the first case [(18)] having been the supernova of 1937, $m_p(max) = 8.2$, in IC 4182 ($m_p = 14.0$).

The fact that, except for some outstanding exceptions like George Ellery Hale, the members of the hierarchy in American Astronomy have no love for any of the lone wolves who are not fawners and apple polishers was made clear to me and to my independent friends on many occasions. Thus credit for my discovery of the first dwarf galaxies would have been lost for me if the following statement by Dr. E. P. Hubble had not appeared in THE SCIENTIFIC MONTHLY 52,486 (1941) which Dr. Walter S. Adams, and then director of the Mount Wilson Observatory, had urged him to write.

ZWICKY'S SYSTEMS IN SEXTANS AND LEO

The Scientific Monthly for November 1940, contains an article entitled "Problems of Nebular Research" written by me and illustrated by Mount Wilson photographs. Two unusually Interesting dwarf irregular nebulae, shown on plates facing pages 399 and 401, are called "Baade's System in Sextans" and "Baade's System in Leo" respectively.

These designations are incorrect. They should be "Zwicky's System in Sextans" and "Zwicky's System in Leo." Both nebulae were discovered by Dr. Fritz Zwicky, of the California Institute of Technology, who identified them on photographs with the 18-inch Schmidt reflector, as objects which fulfilled his criteria for dwarf systems of the type in question.

Dr. Zwicky assembled a list of such objects for further investigation with large telescopes. Dr. Baade, with the 100-inch, verified the identification of the two systems under discussion and at the same time determined their distances.

The matter of nomenclature is important because these dwarf systems may play a significant role in cosmological theory. The regrettable error was called to my attention by Dr. Baade and Dr. Zwicky.

Edwin Hubble

This, however, in my career as a physicist and astronomer is one of the comparatively rare incidents in the USA in which the gentlemanly spirit upheld by so many of our great predecessors, among them H. A. Lorentz, H. Poincaré, A. Einstein, Th. von Kármán and the Ehrenfests prevailed, thanks to the interference by Dr. W. S. Adams. Today's sycophants and plain thieves seem to be free, in American Astronomy in particular, to appropriate discoveries and inventions made by lone wolves and non-conformists, for whom there is never any appeal to the hierarchies and for whom even the public Press is closed, because of censoring committees within the scientific institutions.

From theory [(13)] as well as from the discoveries mentioned it follows that the luminosity function of galaxies is monotonely rising with decreasing brightness, that is with (algebraically) increasing values of the absolute photographic magnitude M_p. A first quantitative function could be derived from the study of about 700 clusters of galaxies [(14, 1)], namely

$$N(M_p) = const. \times [10^{0.2(M-M_{max})} - 1] \qquad (1)$$

It must be emphasized that the function (1) represents the overall result for many clusters of galaxies and, for the time being, excluding systems so compact that they could not be distinguished from stars. Whenever individual fields are investigated which contain certain special types of galaxies somewhat different distributions in luminosity may be found.

b. Intergalactic Matter

The presence of luminous intergalactic formations of matter was also promptly traced [(19, 20, 21)] with the 18-inch Schmidt telescope in the 1930's. To this very day only a few astronomers seem to appreciate the importance for cosmology of the existence of luminous clouds [(14)] in the large clusters of galaxies, for instance those in Perseus, Coma, Corona Borealis and Wolf's A-cluster. Also most remarkable are the extended luminous matrices in which so many groups of compact galaxies are imbedded. The majority of the astronomers still seem to be misled by Baade's statement [(22)] that he does not believe that experimental astronomers will accept the existence of intergalactic matter.

The thousands of luminous bridges, plumes, filaments, jets and clouds interconnecting nicely separated galaxies or emanating from them are now generally accepted as real and important. My first reports in the 1940's, however, had been arbitrarily (and illegally) censored by our observatory committee and withheld from publication in any of the regular American Journals. My original paper [(20)] on intergalactic matter therefore appeared in EXPERIENTIA, now mainly a journal for biology. This prompted Dr. S. van den Bergh later on to reprimand me for publishing important discoveries In newspapers like the BASLER NACHRICHTEN (Experientia being printed in Basel).

The widespread presence of intergalactic plasmas consisting of protons and electrons has in the meantime been amply confirmed by the radio astronomers.

c. Clusters of Galaxies

The assertion by Hubble [(10)], Baade and others that galaxies are essentially uniformly and randomly distributed throughout the universe was shown to be entirely erroneous after my first survey of about one hundred nearby clusters of galaxies with the 18-inch Palomar Schmidt telescope [(23)]. The average volume, or cluster cell occupied by one of these (rich) clusters was calculated [(23)] to be a cube (or other space filling polyhedron) of about 40 megaparsecs indicative [**] diameter. A redetermination of this dimension from the analysis of the 10,000 clusters of galaxies listed in the Catalogue of Galaxies and Clusters of Galaxies [(24)] by Zwicky et al., gives very closely the same value.

For completeness it should be mentioned that in a report to Commission 28 (Galaxies) at the August 1967 assembly of the International Astronomical Union in Prague I proposed the following classification of clusters of galaxies.

I. Structural types of clusters of galaxies.
1. Compact
2. Medium compact
3. Open
II. Contents
a. Only Irregular member galaxies
b. Spirals and irregular galaxies
c. All types of galaxies, but few compacts
d. Clusters of the type c, but containing many compacts
e. Mostly elliptical galaxies
f. Clusters of the type e, with many compacts
g. Mostly or exclusively compact galaxies

A cluster of the type 2e thus is medium compact and is made up mainly of elliptical galaxies.

Altogether there are 21 types of clusters in our classification.

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[*] The use of directed intuition is one of the various procedures of the Morphological Approach to Thought and Action that I have developed during the past few decades and

which has been more fully applied in the books listed in the appended bibliography. Back.

** For the definition of indicative absolute cosmic quantities such as lengths, luminosities and masses see F. Zwicky and M. L. Humason Ap. J. 132, 638 (1960). Indicative quantities are calculated on the assumption that the redshift constant is equal to 100 km/sec per million pc. and that the symbolic velocity of recession is strictly proportional to the distance of the object in question. Back.

II. The Morphological Method of Directed Intuition. Specific Predictions

Intuition instead of more or less aimlessly roaming the field may be directed by staking out a path with the aid of certain principles and pegs of knowledge. At first a fairly broad path is advisable, which, in the course of the study in question can be narrowed more and more to achieve specific results. Directed intuition leads to correct predictions, discoveries and inventions with very much greater probability than haphazard intuition. Some of the basic principles and pegs of knowledge that have been useful in directing intuition in astronomy are as follows.

1. The principle of the flexibility of scientific truth

This principle states that no statement that is made in finite terms can be absolute [1, 25]. (The fact that the statement just made is also subject to this fate can be shown to be irrelevant.)

For instance, the uncertainty principle of quantum mechanics cannot be strictly true since it claims absolutely that

$$\Delta x \cdot \Delta p_x > h$$

This would mean that the product of the uncertainties Δx and Δp_x in the determination of the position x (on a straight line) and the linear momentum p_x can never be smaller than Planck's constant h.

On the basis of the principle of the flexibility of scientific (or communicable) truth I venture to predict that, once we can observe both the light quanta and the gravitons involved in the Compton effect for instance, the position and momentum of a particle at a given time will be determinable to any degree of accuracy desired. This thought has stimulated me to obtain some preliminary data on the properties of gravitons, deriving them from the fact, discovered by me but contested by masses of unbelievers, that there exist no bona fide clusters of stable or stationary clusters of galaxies [26].

2. The morphological approach

Actually my occupation with the principle of the flexibility of scientific truth led me to the development of a universal methodology of thought and procedure which I have named the MORPHOLOGICAL APPROACH ([1, 2, 3, 4]). The fact that no absolute communicable truth can ever be formulated objectively in finite terms suggests that progress may always be achieved through the application of the morphological procedure of NEGATION AND CONSTRUCTION. Stating it simply, one may choose any axiom or absolute statement others believe in, deny its absolute truth value and proceed to generalize it, confident that one will thus produce new discoveries and inventions.

To be technically or humanly useful, any negation must be followed by some positive construction or some generalization of the original statement which is being questioned. Such constructions and generalizations may be conceived of most easily if one avails himself of the various methods developed by morphological research. The space available here is too limited to allow us to describe these methods, except to state that the main purpose of all of them is to explore all possibilities and all interrelations among objects, phenomena and concepts that may be relevant for the successful and optimal realization of any scientific, technical or human project. Briefly, some of the methods described in the literature are

The method of the systematic field coverage,
The method of the morphological box,
The method of the extremes,
The method of negation and construction,
The method of directed intuition,
and others.

3. Directed intuition in astronomy

We shall be concerned here mainly with the prediction and visualization of the existence of as yet unknown bodies in cosmic space. Instead of brainstorming, which is equivalent to fumbling through the garbage of the mind, we direct our intuition along the following guide lines, beacons or sign posts.

The Boltzmann-Gibbs principle

This principle states that, if forces of attraction between dispersed particles are at work, stationary aggregates will eventually result and a variety of objects formed. Such processes of condensation of necessity release potential energy which is liberated as radiation or as kinetic energy of some of the matter that is being dispersed. All condensations can take place either slowly or rapidly. In the latter case we speak of implosions and associated explosions, that is of ejection of matter at velocities superior to any that originally existed in the system in question.

Families of objects

Objects formed as a result of the condensation of matter cover large ranges of compactness or average density. Gaps in the sequences of objects only appear to exist because the life times of some of them are short or, because they are difficult to see or to detect.

The fundamental question arises as to how compact aggregations of matter can become. This obviously must depend on the number of elementary particles involved, that is, on the mass M_0 we start with. As dispersed matter contracts, a total amount ϵ of electrical, nuclear or gravitational energy will be liberated. The system thus looses the mass $\Delta M = \epsilon / c^2$ and its resulting effective mass M_{eff} will be

$$M_{eff} = M_0 - \Delta M = M_0 - \epsilon/c^2 \quad (2)$$

Designating the maximum mass ΔM that can be lost as M_L, the determination of M_L is of prime interest for our understanding of the large scale distribution of matter in the universe. We shall have to mobilize both theory and observation to find out whether M_{eff} can ever become zero or even negative, that is, $M_L = \epsilon / c^2 > M_0$. If this should be the case we would have the following complementary juxtaposition of the behavior of positive and negative charges e^+, e^- and positive and negative masses M^+, M^-, namely

e^+ repels e^+, e^+ attracts e^-, e^- repels e^-,

and (3)

M^+ attracts M^+, M^+ repels M^-, M^- attracts M^-.

Leaving the scheme (3) open for future discussion by the application of theories more complete than the present general theory of relativity and quantum mechanics, we submit a few cases in which it would be profitable to determine the maximum possible "packing fractions" as functions of M_0, that is

$$f(M_0) = M_L/M_0. \quad (4)$$

As I have shown elsewhere [27], two cases must be considered, namely free systems and systems that are subjected to external pressure. Among the latter I have discussed aggregates of neutrons under high pressure which are located, for instance, in the centers of some types of stars. This led me to the prediction of the existence of nuclear goblins [27, 28] as very special and interesting objects of nuclear density.

We here, however, restrict ourselves to the discussion of a few gravitationally self-contained aggregates of matter that are not subjected to any integral external pressure.

Nuclear fusion and crystallization

We consider for instance a neutral swarm of protons and electrons which may condense into hydrogen atoms, hydrogen molecules, and so on, or be directly fused to iron atoms, which then condense into the solid crystalline phase of iron. Starting with say 6.02×10^{23} H-atoms, equal to about $M_0 = 1$ gram, we shall end up with an iron crystal of $M_{\mathrm{eff}} = 0.99$ grams, during which series of processes an energy of $0.01\ c^2 = 9 \times 10^{18}$ ergs will have been released.

Complete annihilation and condensation into gravitons

If the iron crystals mentioned in the previous paragraph could be completely annihilated, that is radiated away, we should end up with an object of $M_{\mathrm{eff}} = 0$ and density $\rho = 0$, that is with empty space, and the whole initial mass M_0 would have been radiated away as electromagnetic radiation.

On the other hand it is conceivable that complete annihilation of matter is not possible and that we shall end up with gravitons as the ultimate condensates of the original cloud of protons and electrons. From the fact that there are no clusters of clusters of galaxies, and the resulting possibly finite range of the gravitational forces, I have derived [(29)] a preliminary value

$$m_G = 5.65 \times 10^{-64}\ grams \qquad (5)$$

for the rest mass of the gravitons. Speculating wildly that these might have diameters of the order of the fundamental length

$$d_G = (Gh/c^3)^{1/2} = 4.05 \times 10^{-33}\ cm \qquad (6)$$

the gravitons would have to be assigned a mass density of the order of

$$d_G = 2 \times 10^{34}\ grams / cm^3 . \qquad (7)$$

amply justifying their high penetrating power and perhaps establishing them as representatives of OBJECT HADES of the smallest effective mass.

Specific objects associated with basic lengths

There are a number of characteristic lengths that can be obtained by combinations of the fundamental physical constants. Strong reasons can be advanced that every one of these lengths is associated with some specific state of matter. Bohr's length $d_B = h^2 / 4\pi^2\ m_e\ e^2$ of course is well known as the determinant for the sizes of atoms, molecules and the elementary spacings in crystal lattices. How these lengths can be used for directing one's intuition in the search for new types of bodies in the microscopic, macroscopic and cosmic realms has been discussed elsewhere [(30, 37)].

Compact stars

Instead of starting out with 6×10^{23} hydrogen atoms to make a crystal of iron we now choose a cloud of about 10^{57} of them and let them condense into a star of the type of the sun. In this case the loss of mass due to the liberation of gravitational potential energy will be of the order of

Sun:

$$\Delta M \simeq 1.7 \times 10^{-8} M_{\odot}. \qquad (8)$$

The next step in condensation might lead us to a white dwarf star with a mass density of the order of ~ 10^{6} grams/cm^{3} and a loss of mass accompanying its condensation from a dispersed cloud of H-atoms of,

White Dwarf:

$$\Delta M \simeq 2 \times 10^{-4} M_{\odot}. \qquad (9)$$

Progressing to further pseudostable and even more compact configurations, and bypassing the possibility of pygmy stars, we come to the neutron stars[31, 1] with a mass density greater than 10^{12} grams / cm^{3} and a mass loss due to the gravitational energy liberated in the transition from the dispersed state equal to

Neutron Star:

$$\Delta M \simeq 0.1 \times M_{\odot}. \qquad (10)$$

I first presented the possibility of neutron stars in my lectures on astrophysics at the California Institute of Technology in the spring of 1933, suggesting that they are formed by implosions from ordinary stars, with resulting liberation of tremendous energy. That could explain the extraordinary luminosity of supernovae and the ejection of cosmic rays [32, 33, 34] of sufficient intensity to account for the observations and consisting of all nucleons with individual energies up to 5×10^{19} esu or 1.5×10^{22} electron volts. In recent years all of these predictions have been confirmed. But during the intervening thirty years from 1933 until 1965 astronomers chose to ignore my theories and predictions. In 1959 A. G. W. Cameron wrote [35], "With the discovery of hydrogen-to-helium conversion processes and other mechanisms of nuclear-energy generation, together with the studies of stellar evolution and white dwarf star models, it became generally believed that white dwarf stars were the inevitable end points of stellar evolution.... Apparently only Zwicky has continued to believe that neutron stars were formed in supernova explosions." As late as 1964, H. Y. Chiu summed [36] "The other alternative that neutron stars may be the remnants of supernovae has so far been accepted only with skepticism. Moreover there is no astronomical evidence yet that such stars even exist."

In November 1933 I presented the theory of the origin of supernovae and of cosmic rays as being caused by the implosion of stars into neutron stars in a big physics seminar at the California Institute of Technology. A staff correspondent, whom I had briefed on the subject after the seminar, reported as follows in the Los Angeles Times of Dec. 8, 1933, partly with remarkable accuracy,

Mount Wilson Observatory astronomers and California Institute of Technology scientists whispered excitedly to each other as Zwicky unfolded what his associates characterize as probably the most daring theory of cosmic ray origin.

Dr. Zwicky's theory provides the first theoretical picture of the strangest heavenly bodies known to astronomers, the super-temporary star (supernova).

Only two such phenomena have been observed in historical times, Tycho's star of 1572 in our own Milky Way and the star of 1885 in the great Andromeda nebula.

The old astronomer's data regarding the 1572 star, according to Zwicky, were accurate enough for him to calibrate many of the star's peculiar qualities. At the start Zwicky estimates this star measured about 500,000 miles in diameter, ... , then in less than a week this diameter shrank to only nineteen miles, being compressed into this small ball of neutrons.

The speaker, a former collaborator of Dr. Albert Einstein in Switzerland filled six blackboards with equations, the last of which demonstrated that the present intensity of cosmic rays as recorded near the Earth is almost exactly that to be expected if the rays emanate from these neutron stars of which one is born every 1000 years in galaxies like our Milky Way.

In contradistinction to the professional astronomers, who ignored my views for thirty years, the reporters kept going strong on supernovae, neutron stars and cosmic rays, at least for a few years. In the Los Angeles Times of January 19, 1934, there appeared an insert in one of the comic strips, entitled "Be Scientific with Ol'Doc Dabble" quoting me as having stated

"Cosmic rays are caused by exploding stars
which burn with a fire equal to 100 million
suns and then shrivel from 1/2 million miles
diameters to little spheres 14 miles thick."
Says Prof. Fritz Zwicky,
Swiss Physicist

This, in all modesty, I claim to be one of the most concise triple predictions ever made in science. More than thirty years had to pass before the statement was proved to be true in every respect. I think even David Hilbert would have been pleased since, in his will (as relayed to me by Professor H. Kienle, former director of the Observatory at Göttingen) he had left us with the admonition to be brief in all writings and to try to present our life's work in ten minutes.

Ultimate compact bodies. Objects HADES ΩH.

We shall not dwell here on the question as to how many pseudostable types of compact cosmic bodies there might exist [(30)] between the neutron stars and the configurations of ultimate limiting mass $M_{\mathrm{eff}} = M_0 - M_L$. Some of these have recently been given the name "Black Holes." This, however, in my opinion is an unfortunate misnomer, since they are not holes at all, but objects of the greatest compactness. I have therefore proposed to call [(30)] them OBJECTS HADES ΩH. Some suggestions were also made in another place [(30)] as to what objects HADES might consist of. But these will not be further elaborated here except for a few remarks later on as to how and where objects HADES of large initial masses might be found.

4. Galaxies

In order to achieve a fruitful meeting of the minds among astronomers who, at the present time seem to be highly confused on the subject of galaxies, we propose first to formulate operationally useful definitions of the cosmic objects which we are going to discuss, to be followed by a short history of the discovery of compact galaxies.

Definition of what a galaxy is.

Two possibilities come to mind. In the first place we might attempt to state what galaxies are composed of and thus arrive at a definition similar to those given for molecules or rocks, for instance. On the other hand we must not necessarily go into any details regarding the composition of the objects in question, which actually we would be quite unable to do at the present time. I therefore propose to define various classes of galaxies simply in terms of their absolute luminosities or their masses, quite regardless of what types of matter and of radiation they might be composed of.

In parenthesis it is useful to recall that, before the sixteenth century, astronomers did not know that the Milky Way is mostly composed of stars. Thus the name "Galaxy" for the Milky Way system, as derived from the Greek word "galactos," meaning milk. Incorrectly, astronomers continued to speak of the Milky Way system as the Galaxy even after it was recognized that it consists mostly of stars. Likewise, the extragalactic nebulae are called galaxies, although those known until recently mostly consist of stars.

During the past few years compact and very luminous extragalactic systems have been discovered, which may not contain any conventional stars at all but probably are composed of more or less hot gases with neutron stars and objects HADES imbedded in them. Paradoxically, some astronomers appear to hesitate calling these new objects galaxies, although that designation, in view of the meaning of the word "galactos" would be far more appropriate than to call stellar systems galaxies.

In view of the present uncertainty concerning the material contents of the various extragalactic systems. I propose to define and to classify them simply by conveniently chosen ranges of mass and absolute luminosity, as shown in the schemes (11) and (12).

Classification of cosmic objects according to mass:

$$\begin{array}{ll} \textit{Supergiant galaxies} & M/M_{\odot} > 10^{10} \\ \textit{Giant} \quad '' & 10^{10} > M/M_{\odot} > 10^{8} \\ \textit{Normal} \quad '' & 10^{8} > M/M_{\odot} > 10^{6} \\ \textit{Dwarf} \quad '' & 10^{6} > M/M_{\odot} > 10^{4} \\ \textit{Pygmy} \quad '' & 10^{4} > M/M_{\odot} > 10^{2} \\ \textit{Gnome} \quad '' & 10^{2} > M/M_{\odot} > 1 \end{array} \qquad (11)$$

Classification according to absolute photographic, visual or bolometric luminosity L:

$$\begin{array}{ll} \textit{Supergiant galaxies} & L/L_{\odot} > 10^{10} \\ \textit{Giant} \quad '' & 10^{10} > L/L_{\odot} > 10^{8} \\ \textit{Normal} \quad '' & 10^{8} > L/L_{\odot} > 10^{6} \\ \textit{Dwarf} \quad '' & 10^{6} > L/L_{\odot} > 10^{4} \\ \textit{Pygmy} \quad '' & 10^{4} > L/L_{\odot} > 10^{2} \\ \textit{Gnome} \quad '' & 10^{2} > L/L_{\odot} > 1 \end{array} \qquad (12)$$

We emphasize again that galaxies of the same class, as defined by (11) or (12), may of course be very different from one another, both as to their structures and their material and radiative contents. Some of the most striking differences in their structures are the nuclei, central cores and discs, knots, spiral arms, halos, jets, plumes and so on. In extreme cases of compactness all of the mass or luminosity may be concentrated in a small core (compact galaxies) or there may be no core at all, the galaxy simply consisting of a more or less irregular body of matter and of radiation.

Compact galaxies

Galaxies during the past two hundred years have been listed in increasing numbers in various catalogues, the newest one being the six volumes compiled by Zwicky and his collaborators [(24)]. Until recently the NGC and IC catalogues, containing about 13,000 objects were the most widely used. The objects contained in the NGC and IC were generally thought to cover all types of possible galaxies. It does not seem to have occurred to any astronomers observing and analyzing objects listed in these catalogues that none among them show any average surface brightness, photographically or visually, greater than that corresponding to the twentieth magnitude per square second of arc. After discovering galaxies of very much greater average surface luminosity I proposed [(7)], in keeping with these findings, to call compact any galaxy as a whole, or any part of a galaxy, whose surface brightness, photographically, visually or bolometric ally is greater than that which corresponds to the 20th magnitude per square second of arc in any chosen wavelength range.

Compact galaxies

$$\sigma \lesssim 20/arcsec^2 \qquad (13)$$

Among the well known nearby galaxies, Messier 32, the companion of the great nebula in Andromeda, Messier 31, has an average surface brightness $\sigma \simeq 20.5/\text{arcsec}^2$ and therefore does not quite rate as a compact galaxy. Some astronomers mistakenly believe that if M32 were put at a much greater distance it would appear as a compact galaxy. Actually this may be the reason why compact galaxies were not discovered long ago. Obviously many observers must have seen them on their photographic plates, but apparently thought that they were just ordinary run of the mill objects like M32, located at a great distance.

III. History of the Discovery of Compact Galaxies

Almost from the beginning of my theoretical investigations, 40 years ago, into that their maximum masses were at least equal to those of dwarf galaxies, that is the existence of dense cosmic bodies, I was aware of the fact that such objects existed, equal to $10^6\ M_\odot$ or greater and whose surface brightness satisfies the condition (13). As mentioned above, the nucleus of M31 is obviously one of those objects. M. L. Humason first in 1940 showed it to be an almost stellar object, elliptical in shape and with apparent diameters of about 2. 5 and 1. 5 seconds of arc. Assigning it a total apparent photographic magnitude $m_p = 12.8$, its surface brightness becomes $\sigma = 14.5/\text{arcsec}^2 \ll \sigma_{crit} = 20.0/\text{arcsec}^2$. Compared with the overall appearance of ordinary galaxies it is thus a very compact object indeed.

In addition to the conclusions arrived at from theory alone, the existence of compact nuclei and cores in some of the regular galaxies [(38)] provided additional assurance that isolated compact galaxies, which are not surrounded by any "suburban" formations such as halos and spiral arms, must also exist. Indeed,

> **First.** The theoretical principles described in the preceding in themselves convince us that, up to the limit of the mass densities in the various objects HADES, aggregates of ever increasing compactness must be formed, either slowly or implosively. Also, on the way to ΩH there will always occur a series of pseudostable stationary formations [(7)].
> **Second.** The existence of compact nuclei in M31 and M32, with masses of the order of $10^7\ M_\odot$ strikingly supports the conclusion of the theory that, either by slow accretion or fast implosion, aggregates are being formed in aging ordinary

galaxies that are far more compact and luminous (per unit volume) than these galaxies themselves.

Third. From the theoretical principles mentioned and the observations on compact nuclei of stellar systems it follows that, under certain circumstances these no doubt can "swallow up" the surrounding "suburban" populations and thus become stellar-like objects of high surface brightness. On the other hand, isolated compact objects will result from the head-on collision of two extended galaxies which contain compact nuclei or cores. In such a collision the "suburban" formations will essentially be stopped or widely dispersed into intergalactic space, while the cores, because of their high surface loading and inner cohesion will continue their flight and end up as isolated compact galaxies in cosmic space, stripped of all their retinue.

Humason-Zwicky star No. 46

From the considerations presented in the preceding and, after having discovered the predicted irregular dwarf galaxies and dispersed intergalactic matter, I set out to search for the compact objects whose formation must have given rise to the existence of the many aggregates of dispersed matter in cosmic space. As chance would have it, the first quasistellar-like body, with an indicative absolute luminosity equal to that of a bright galaxy was found accidentally as I was surveying the north polar galactic cap for faint blue stars in a search for white dwarfs, pygmy stars and distant blue normal stars. In fact, the object now known as HZ 46, on films obtained with the 18-inch Palomar Schmidt telescope in 1938 appeared to me as a star and was listed as such [39, 40]. Humason, during the following years obtained spectra of all of the 48 HZ stars that I had discovered. To our surprise HZ 46 showed a strong blue continuum with emission lines superposed, from whose redshifted position a symbolic velocity of recession of 13,418 km/sec was derived. Since $m_p = 14.8$, it follows that the indicative absolute magnitude of HZ 46 is equal to $M_p = - 20.8$, making it a supergiant galaxy with a very compact core and two curved wings extending to opposite sides of it. G. Haro and W. J. Luyten vastly extended the original search for faint blue stars in high galactic latitudes, using in particular the 48-inch Palomar Schmidt telescope (see for instance Boletin de los Observatorios Tonantzintla y Tacubaya 3, 37, 1962). Again it was found later on that many of the objects which appeared stellar on the 48-inch Schmidt plates (especially on the three-image plates on which the limiting magnitude was lowered by one to two units) are actually compact galaxies as I strongly emphasized at the First Conference on Faint Blue Stars [40] at Strasbourg in August 1964 and again, a month later at the Galilei 400th anniversary convention In Padua [41]. At the 1964 Assembly of the IAU at Hamburg I had presented my first list of 210 compact and eruptive galaxies. The first blue "star" of the Haro-Luyten collection to be identified [41] with one of the extragalactic objects on List I was BL2012 = I Zw 26 located at R.A. $11^h 22.7^m$ and Decl. +54°40' (1950). At my suggestion, Dr. J. Berger in Paris, who previously had been working with me in Pasadena on the spectra of faint blue stars, and my wife, in 1964 systematically searched for coincidences of objects in the blue star lists of Haro, Luyten and others with known compact galaxies and quasistellar radio sources. The most striking find, by Berger, was that the "Tonantzintla" object PHL 2871 proved to be identical with the quasistellar radio source 3C9 which had the greatest redshift known at that time ($z = \Delta\lambda / \lambda = 2.01$).

In spite of all of these facts being known to him in 1964, A. Sandage of the Mt. Wilson Observatory in May of 1965 attempted one of the most astounding feats of plagiarism by announcing [42] the "Existence of a Major New Constituent of the Universe: The Quasistellar Galaxies." Equally revealing, for the perennial tie-up of all hierarchies with hordes of sycophants was the fact that the Editors of the Astrophysical Journal published the above mentioned paper by Sandage on May 15, 1965, admittedly on the very same day that they had received it. This was done in glaring violation of the rule that all manuscripts submitted must be reviewed by competent experts before being published. Mr. Sandage's paper certainly would have been rejected by any professional in the field, because the new types of objects that he claimed to have discovered, among them for instance "Tonantzintla"256 at R.A. $22^h 22.8^m$ and Decl. -16°54', epoch 1950.0, Ton. 730, and others clearly belonged to the class of compact galaxies [43, 44], both as to their structures and their spectra.

Also, it had long before Mr. Sandage been stressed by the author [39, 40], that many of the objects included in the surveys for faint blue stars by Zwicky, Luyten, Haro and others would be found to be extragalactic systems of stellar appearance. Sandage's earthshaking discovery consisted In nothing more than renaming compact galaxies, calling them "interlopers" and quasistellar galaxies, thus playing the interloper himself [42].

Again, disregarding all previous statistical studies made on the distribution of faint blue stars and stellar objects in breadth and depth of space [40, 43] Sandage advanced his own analysis [42], drawing from it some of the most wonderful and fearful conclusions about the large scale structure and the evolution of the universe that were completely erroneous. Among these perhaps the most ridiculous is that "he gave the first determination of the rate of change of the expansion of the universe" as entered by Sandage himself, for the benefit of the general public, in his column in Who's Who in the World of Science (Marquis Inc. 1968).

In sharp contrast to their ready and uncritical acceptance of all sorts of childish phantasies and stolen Ideas, the Editors of the Astrophysical Journal exhibited an almost unbelievable lack of tolerance and good judgement by rejecting my first comprehensive and observationally well documented article on compact galaxies (see insert facsimili letter of the editor of the Ap. J.). My original articles, except for a short note of the meeting of the American Astronomical Society, 1963 in Tuscon, forcibly had to be first published in French [46], Polish [47], German [48] and Russian [49] journals (in Russian). A considerable number of the basic findings on compact galaxies were already mentioned in these first short papers, as will be discussed further on.

THE UNIVERSITY OF CHICAGO
THE ASTROPHYSICAL JOURNAL
YERKES OBSERVATORY
Williams Bay, Wisconsin

Editorial Office

April 3, 1964

Dr. F. Zwicky
Department of Astrophysics
California Institute of Technology
Pasadena, California

Dear Dr. Zwicky:

We sincerely regret our inability to publish the enclosed communication, COMPACT GALAXIES, which was submitted as a Letter to the Astrophysical Journal. Communications of this character are outside the scope of this Journal.

Yours sincerely,

S. Chandrasekhar
Managing Editor

SC/sbs
Enclose

Assembling the objects for the present Catalogue

So far the author has been engaged in two undertakings, namely, first to assemble compact galaxies, galaxies with compact parts, eruptive and post-eruptive galaxies casually, while working on the extended six volume catalogue of galaxies and clusters of galaxies (CAT) by Zwicky [(24)] et al. This casual work was done essentially in the period from 1960 to 1968. As a result about 2300 objects were gathered in seven lists [(50)] and distributed among astronomers interested in observing them. It must be strongly emphasized that these compact galaxies were chosen at random, as the writer noticed them while working on the 10,000 clusters of galaxies contained in the CAT. They do not therefore represent suitable material for an overall comprehensive statistics concerning their distribution in cosmic space.

Second, in order to make possible a statistical study of those compact galaxies that can be readily distinguished from stars on limiting plates taken with the 48-inch Palomar Schmidt telescope I have started a complete survey of these objects in twelve fields covering about 450 square degrees from R.A. 12^h00^m to 13^h20^m and Decl. -3° to -21°. From my preliminary results it appears that about 5,000 compact galaxies, galaxies with outstanding compact parts and post-eruptive galaxies will thus be located, that is about ten per square degree. A thorough survey of all of the unobscured areas of the sky should therefore produce between 200,000 and 300,000 objects of the type that have been included in the present catalogue. If more refined methods are used, for instance a search with large Schmidt telescopes equipped with full size objective transparent gratings, millions of compact galaxies will no doubt be located that cannot now be distinguished from stars on ordinary direct photographic plates.

IV. Principal Characteristics of Compact and Post-Eruptive Galaxies

Shortly after some of the theoretical predictions concerning compact extragalactic aggregates had been confirmed observationally, the following statement was included in the report of the director of the Mount Wilson and Palomar Observatories (Yearbook No. 62 of the Carnegie Institution of Washington 1962/63),

A systematic search on 48-Schmidt telescope plates was undertaken for exceedingly compact galaxies that are actually difficult to distinguish from stars. Spectra obtained by Zwicky show that they run the whole range from ordinary G and K types to systems showing only emission lines and no continuum. It is conjectured that radio sources such as 3C48 and 3C273 lie at the end of this sequence, and an attempt will be made to test whether intermediate systems are weak radio sources.

Brief reports on the observations and the theory of compact and of post-eruptive galaxies have appeared in all of the subsequently Yearbooks Nos. 63 to 70 of the Carnegie Institution of Washington, while details can be found in the special articles and reviews listed in the two appended bibliographies. We therefore here give only a short tabulation of some of the outstanding characteristics of the objects included in this catalogue.

Structural Features

Restricting ourselves to features that can be seen in the ordinary photographic and visual ranges of wave lengths, we are only interested in those objects which exhibit nuclei, cores, discs and prominent knots of surface brightness greater than the 20th magnitude per square second of arc, as stated already.

In the limit we may have extremely compact galaxies of diameters smaller than a fraction of a second of arc that cannot even be distinguished from stars with the 200-inch Hale telescope and whose surface brightness actually far exceeds the 20th magnitude per square second of arc. In addition there exist quasistellar objects of this type that have associated with them faint jets, plumes, spiral arms, halos or filaments connecting them with other galaxies, the two patchy interconnected compacts at R.A. $8^h55.8^m$ and Decl. +6°31' (1950.0) being examples of this type. As the luminosity of the external formations increases relative to that of the compact central body, we enter the realm of galaxies endowed with compact parts that in the end merge with the extended and conventional families of ordinary galaxies which contain only insignificant parts of high surface brightness.

It should be emphasized that many of the red and very red compact galaxies included in this catalogue do not satisfy the condition 13) in the photographic range of wave lengths but only in the red or perhaps only in the infrared. Furthermore, it is quite possible that there exist galaxies that are not compact in the optical or any of the adjacent ranges of wave lengths. They may, however, be bright in the regions of the radio waves and of X-and γ-rays, indicating that temporary implosions and eruptive processes take place in them which produce specific non-thermal radiations at high intensity.

The distribution of the surface brightness in isolated compact galaxies may either be fairly flat throughout the whole system or it may rise more or less steeply towards the center, occasionally culminating in stellar-like peaks of enormous surface brightness and diameters equal to a small fraction of a second of arc, such as are found for the nuclei of some of the Seyfert galaxies. The variable compact I Zw 1 at R.A. $0^h51.0^m$ and Decl. +12°25' is a case in point. (We remark in parenthesis that all coordinates given in this catalogue refer to the epoch 1950.0.)

Many of the compact galaxies are found to be associated either with ordinary galaxies, with other compacts, or with combinations of both. One beautiful system of this kind is I Zw 96 at R.A. $14^h43.3^m$ and Decl. +51°35', showing a central E0 galaxy and several bridges and jets connecting It to a number of other objects, two of which have redshifts closely equal to that of the central galaxy. The symbolic velocity of recession, as determined by Sargent [67] from both absorption and emission lines, is $\langle V_s \rangle = 27094$ km/sec. [*]

Pairs and multiplets of compacts are unusually common. Often the various component objects are remarkably equal in structure, luminosity and color. In some extreme cases two or more compacts are imbedded in a more or less luminous matrix and may be in close contact, or almost coalescent. These systems offer particularly favorable conditions for the determination of reliable values of the masses involved, which can be obtained from the study of the differential redshifts of the various components. The object I Zw 4 at R.A. $1^h20.7^m$ and Decl. +34°19' is a good example of this type of coalesced system [15].

Although small groups of compacts are very common, only a very few clusters composed mainly of compact galaxies have been found [55, 69]. On the other hand, clusters of elliptical galaxies often contain many compacts. Some examples are shown in the Appendix of this catalogue. The Leo A and B clusters are examples of aggregates that contain many blue compact galaxies [52].

Colors of compact and of post-eruptive galaxies

As was to be expected from our general theoretical considerations, compact galaxies show a much wider range of color and of spectra than the ordinary galaxies. Some of the basic reasons for this fact are as follows. As galaxies contract, either slowly or implosively, or, as the cores of ordinary galaxies grow in mass and compactness because of the accretion of stars and dispersed matter from the surrounding suburban formations, several important events take place. The radiation density inside of the compact objects increases and eventually causes the surface layers of the constituent stars to evaporate. These stars thus become blue and move towards earlier spectral types. The ever denser and faster moving interstellar gas clouds further help to whittle down the stars while their constituent ions, atoms, radicals and molecules get excited and give rise to a variety of sharp emissions. As the compactness of the galaxy grows, direct collisions [7] between stars become more frequent, causing their partial destruction and giving rise to ejection of various forms of matter. In the limit, collisions at velocities of several thousands of kilometers per second will result in the formation of neutron stars [51, 53] and eventually of the appearance of objects of the type HADES (ΩH) [30]. This will lead to the production of neutron star studded compact galaxies and compact galaxies rich in ΩH objects, that is models of cosmic bodies which we need to understand both the physics of the radioquiet ultracompact galaxies as well as of the radio waves emitting quasars. On this view the latter represent simply a relatively rare "pathological" species of the very much more numerous compact galaxies. They differ from radioquiet compact galaxies only because they have temporarily associated with them tenuous clouds of plasmas that emit the radio waves by synchrotron radiation or some other mechanism. One of the possible origins of such temporary plasmas lies in the ejection of gas clouds that result from implosions in compact galaxies. Quasars and quasistellar or ultracompact galaxies thus all belong to the general family of compact galaxies as integrally defined by the condition 13.

Some of the compact galaxies listed in our catalogue were found to be identical with already known radio sources, such as 3C371, 3C390.3, 4C35.6 and others. Although only a few dozen compact galaxies have been tested so far for their radio emission, it would appear that the great majority among them do not give rise to radiation intensities observable on the Earth of more than about one quarter of a flux unit (10^{-26} W m^{-2} Hz^{-1}).

Of great interest are those compact dwarf galaxies that observationally seem to be indistinguishable from giant H II regions in nearby galaxies. Among these the best investigated are [16, 70] II Zw 40 at R.A. $5^h 53.1^m$ and Decl. +3°24' and I Zw 18 at R.A. $9^h 30.5^m$ and Decl. +55°27'. These two systems were found to be strong emitters of 21 cm radiation [17]. The fact that they are either very young systems, as measured in terms of the age of the Earth for instance, or that the luminosity function of the newly formed stars in them differs radically from that found in our galaxy confronts current cosmological theories with the greatest difficulties. An intensive search for similar objects is highly desirable.

Absolute luminosities and masses of compact galaxies

So far compact systems have been found with luminosities in the range from dwarfs to supergiant galaxies. Assuming that the redshifts observed in the spectra of all types of galaxies are essentially all cosmological in origin, the supergiant galaxies so far investigated lie in a range of indicative absolute visual magnitudes $-20.0 > M_V > -23.0$. This may be compared with an average $M_V = -21.7$ for radio galaxies, a range $-15.4 > M_V > -20.2$ for Seyfert galaxies and a range $M_V = -22.5$ (for 3C47) to $M_V = -25.7$ (for 3C273) for quasistellar radio galaxies. These findings give additional support to our contention that quasistellar radio sources are but special limiting cases of compact galaxies.

Preliminary determinations of the masses of the most massive compact galaxies indicate that values as high as 10^{13} $M_{\odot}$ exist, that is twenty times as high as those characteristic for the most massive supergiant common galaxies [15, 16, 67].

The spectra of compact galaxies

The overwhelming majority of the spectra of ordinary galaxies, as listed for instance by M. L. Humason [71] and associates, are of the following types. Elliptical and S0 galaxies show almost exclusively spectra of the type G, while the spectra of normal and barred spirals cover the range from F0 to about G7, with only a handfull of the type A. A small fraction of the ordinary galaxies also show the Balmer, [O II] and [O III] lines in emission.

The recent investigations of compact galaxies have added a great number of spectral types to those previously known. And there seems to be no end in sight to the discoveries still to be made, especially if investigations are extended to both sides of the optical range of wave lengths.

Generally it may be stated that so far, in the optical range of wave lengths the following types of spectra of compact galaxies have been observed.

Emission Spectra:

a. Blue and red continuous and apparently completely featureless spectra.
b. Strong or weak continua with only λ3727 of [O II] in emission.
c. Strong or weak continua with only the Balmer lines in emission.
d. Strong or weak continua with the Balmer lines, [O II] and [O III] in emission.
e. Strong or weak continua with many combinations of permitted lines of H, He, Fe II etc. and of forbidden lines of [O II], [O III], [O I], [Ne III], [Ne V], [S II] etc. The complexity of combinations will of course grow as the observations are extended into the ultraviolet, or lines are redshifted into the optical regions, as is the case for most quasars.

Unique are a few very bright compacts, with stellar cores showing emission lines, conspicuously many of Fe II, and similar to those of the well known but less luminous Seyfert galaxies. The variable blue compact I Zw 1 is one of the outstanding examples of this class [72].

Absorption Spectra

f. Continua with the Balmer lines, D-lines of Na I, H and K of Ca II, λ4226 of Ca I and the G-band in various combinations.

Mixed Spectra

g. Many combinations of the types a) to f). Occasionally $H\alpha$, $H\beta$, $H\gamma$ appear in emission while the higher members, from $H\delta$ to $H\theta$ are in absorption.

As to the widths of the spectral lines, they may all be sharp, all broad or, the forbidden lines are sharp and the permitted lines are broad.

Very broad Balmer lines in absorption have for instance been observed for VII Zw 475 at R. A. $12^h33.7^m$ and Decl. +81°53' indicating a velocity dispersion of the order of 9000 km/sec for the constituent stars of the system. It is also possible that the set of the H and K lines appears twice in the spectrum of this compact galaxy because of an Einstein gravitational redshift of 10,600 km/sec between the core (19,900 km/sec) and the halo (9300 km/sec). Analogous cases are I Zw 22 at R.A. $9^h55.9^m$ and Decl. +51°45' , with $<V_s>$ = 25, 270 km/sec for the core and 14,230 km/sec for the halo. Another possible case of this character is I Zw 126 at R.A. $15^h45.9^m$ and Decl. +37°21' with $<V_s>$ = 31, 300 km/sec for the core and 11,880 km/sec for the halo.

It will be very important to further check these conjectured interpretations of the mentioned spectra which t obtained just prior to my retirement. If the above stated conclusions can be confirmed, the contention, that the large redshifts of the quasars might be partly due to the Einstein effect will in great probability also be found to be true.

It should be added that the existence of smaller gravitational redshifts, of the order of 1000 to 2000 km/sec between the cores and the outskirts of compact galaxies almost certainly has been observed in the spectra of the compacts I Zw 188, I Zw 198, I Zw 206 and I Zw 208.

Finally I here wish to emphasize that all of the above mentioned compacts should by all means be observed with one of the powerful old fashioned instruments, such as the nebular spectrograph of the Palomar Hale telescope. Records obtained with the presently available image tubes are much too poor to show the detailed structural features necessary to check whether or not the differences in the symbolic velocities of recession of the order of 10,000 km/sec are due to the Einstein effect.

Variability of compact galaxies

The first variable compact galaxy, IV Zw 29, located at R.A. $0^h39.5^m$ and Decl. +40°3' was discovered by Zwicky [(69)] in 1964. It is radio quiet and it also is the first galaxy ever to have been found variable in its output of light. The hundreds of films and plates obtained by Zwicky at Palomar in his search for supernovae show IV Zw 29 to have been variable in the range [(73)] $16.0 < m_p < 18.2$.

Another optically variable but radio quiet compact is I Zw 187 at R.A. $17^h37.1^m$ and Decl. +50°15'. Its spectrum was found to be featureless by Zwicky [(16)] and later on also by Oke and collaborators [(74)].

The most interesting variable compact galaxy investigated so far is I Zw 1 at R.A. $0^h51.0^m$ and Decl. +12°25', the spectrum of which is similar to that of the Seyfert galaxies, with many emission lines of Fe II showing [(72)]. Its average photographic apparent magnitude, from records of the past forty years, is m_p = 14.3. With a symbolic velocity of recession V_s = 18, 150 km/sec this corresponds to an average indicative absolute photographic magnitude M_p = - 22.0. Outburst lasting from a few days to a few weeks, however, have occurred on several occasions that increased the brightness of I Zw

1 by about one magnitude. At the peak of such outbursts the indicative absolute photographic magnitude was M_p(max) ≃- 23.0. Implosive and explosive events in I Zw 1 therefore produced increases in its luminosity of the order of 10^{11} times that of the sun, or about thirty times that of a bright supernova at maximum. These findings possibly confirm the conjectures previously advanced by Zwicky [(7)] that in very compact galaxies, with masses of the order of 10^{12} $M_\odot$ and greater, one or more of the following events will take place.

> **First,** in the most massive compact stellar systems about one thousand head-on collisions between stars moving with velocities of thousands of kilometers per second must be expected, [**] each one of them producing one or more neutron stars and outbursts of light equalling that of several billion suns. Statistically it will also happen that several dozen collisions may occur within a few days and thus give rise to outbursts of light equalling 100 billion times that of the sun, as observed.
> **Second,** the kinetic energy of the gas clouds ejected in a supernova outburst is not usually converted into light. This, however, will happen if a supernova explodes in the interior of a compact galaxy, so that its luminosity is increased manyfold.
> **Third,** collisions between massive and dense interstellar clouds may be responsible for the sudden increases in luminosity such as they have been observed for I Zw 1 and other variable compacts.

It will be of the greatest importance that the variable compacts mentioned here, as well as others, be observed as often as possible with small telescopes, actually a fruitful task for amateurs. Large and sudden outbursts of luminosity should be reported immediately, so that observers with large telescopes can obtain spectra near the peaks of these events and thus collect data that will eventually allow us to confirm or to discard the abovementioned three conjectures.

Encounters and collisions among galaxies

In addition to internal implosions and explosions that produce compact and post-eruptive galaxies, close encounters between galaxies and the resulting gravitational tidal actions are of great importance, as I have emphasized on many ocassions [(75, 76)]. Most interesting, however, are the cases in which a compact galaxy, or possibly an object HADES, has pierced another galaxy at great speed, leaving either a track of luminous gas clouds and emission line knots, or an almost straight channel swept clean of its original occupants of stars and gas or dust clouds. In the Appendix I present the "crossed galaxy" at R.A. $23^h15.7^m$ and Decl. +3°54' as a possible case of this kind.

Objects HADES in the centers of compactclusters of galaxies

It may be conjectured that very compact galaxies may ultimately collapse into configurations of the type of objects HADES ΩH, thereby losing most of their effective mass and luminosity. If this for instance happens to many centrally located members of a cluster of compact galaxies, one consequence will be that the average symbolic velocity of recession of the brightest members of the afflicted cluster will be markedly lower than it would be expected from the average, though admittedly very rough redshift-apparent magnitude relation. One possible interesting case in point is the cluster Zw Cl 0257.8 + 3542 which contains the radio source 4C 35.6. The apparent photographic magnitude m_p = 17.6 for its brightest central member is much too faint for its observed symbolic velocity of recession of 14070 km/sec, which one actually would expect to be of the order of 52000 km/sec.

Also, in some clusters containing many objects ΩH in the center, the brightest galaxies may be found on the outskirts of the cluster rather than in the central regions, thus producing a segregation reverse from that usually found.

Conclusion

Finally it is worth noticing that, the fewer parameters one uses to define a class of objects, the richer this class becomes. Thus compact galaxies have simply been defined as containing more than one star and having an apparent surface brightness greater than a certain critical value corresponding to the 20th magnitude per square second of arc. Because of this broad definition the class of compact galaxies includes all objects (or parts of objects) listed in this catalogue as well as radioquiet and radio emitting quasars, certain Markarian galaxies and many objects as yet to be discovered.

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[*] Sargent, in his extensive paper on compact galaxies [(67)] unfortunately has incorrectly designated all objects from Zwicky's list No. 1. Starting from I Zw 3 all following I Zwn's in Sargent's paper must be given the original designation I Zw (n+1), thus for instance, I Zw 23 in Sargent's paper is really I Zw 24. Back.

[**] per year Back.

V. Acknowledgements

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