THE UNIVERSAL DIAGRAMS AND LIFE IN THE UNIVERSE

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ABSTRACT. In any statement concerning extraterrestrial life one has to present the best amount of information concerning life as we know it here on earth. One way to do this is to put many classes of known objects in the universe on common plots. I call these plots the "Universal Diagrams". The quantities plotted are mass, luminous output, temperature, size and entropy change. It is interesting to speculate where etraterrestrial life may lie on these diagrams but it seems that it will have to lie in regions more or less occupied by terrestrial life.

1. INTRODUCTION

When one studies the possibility of extraterrestrial life one unavoidably is prejudiced by life here on earth. Indeed, since life has not yet been discovered outside the boundaries of our planet one has to proceed with the simplest and general statements about life as we know it here on earth and hope that these statements apply to life elsewhere. Since the same physics governs animate as inanimate matter, why not compare the simplest properties of all matter and see if one reaches some insights about life that would apply elsewhere? The reasoning here is that our physics is universal and any simple statements about life on earth that result from laws of physics should be applicable elsewhere.

I have chosen to put as many classes of objects in the universe on common diagrams, the universal diagrams. The quantities plotted are mass, size, luminous ouput-or luminosity-surface temperature, angular momentum and entropy change of the universe due to radiation by these objects. Mass is equivalent to energy and for massless particles (e.g. photons) the quantity plotted is E/c^2, where E is the energy and c is the speed of light. Mass and size are perhaps the simplest quantities that one can know about an object and this is the reason why I have chosen them. Luminosity is also important since we only know directly about the presence of luminous matter in the universe. Dark matter, even if it is a major constituent of the universe, is not directly observable. Surface temperature is characteristic of the type of radiation that an object puts out. Finally, entropy change of the universe due to radiation by the

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objects in the universe is the simplest thermodynamic quantity I could think of.

Another worker in the field would not have created identical universal diagrams. The reason for this is that not necessarily the same types of objects would be chosen for the diagrams. I believe, however, that if one were to draw a handful of diagrams the same types of diagrams would probably be chosen. Since the quantities plotted vary by 60 - 100 orders of magnitude, these diagrams are extremely compact and even order of magnitude uncertainties in the plotted quantities do not change the overall appearance of the diagrams. In order to standardize the diagrams I generally have plotted mass as the abscissa except for the temperature -luminosity diagram. In this work, due to shortage of space, I only present one diagram, namely the mass-luminosity diagram.

Black holes are the simplest objects in the universe. Black holes divide the diagrams into two regions; often, as in the case of the mass-size diagram, the region occupied by black holes is inaccessible to our universe (unless of course one were to enter the black hole). A summary of the properties of black holes pertinent here follows.

2. THE UNIVERSAL DIAGRAMS

2.1. Black Holes

Rotating black holes have the event horizon at a distance given by

$$R = GM/c^2 \tag{2.1}$$

and maximum angular momentum given by

$$J = GM^2/c \tag{2.2}$$

where G is the gravitational constant and M is the mass of the black hole. Non-rotating black holes have their event horizon at twice the radius given by (2.1). Relation (2.1) is applicable to maximally rotating black holes and probably large black holes are maximally rotating due to the physics of accretion onto them. Non-rotating black holes have $J = 0$. Primordial mini-black holes would be radiating their energy away (Hawking 1976) and would have decayed away within the age of the universe if their initial mass were less than 5×10^{14} gr (Page 1976a). Rotating mini-black holes would spin down rapidly to a non-rotating black hole before their mass has been given up (Page 1976b). For a non-rotating black hole (and mini-black holes would be such) the luminosity, temperature, entropy and lifetime are given respectively (Hawking 1976, Page 1976a):

$$\begin{aligned} L &\sim 2\hbar c^6 G^{-2} M^{-2} \qquad & S &= 4\pi k G M^2/c\hbar \\ T &= \hbar c^3/(8\pi k G M) \qquad & \tau &\sim 10^{-28} M^3 \text{ sec}, \end{aligned} \tag{2.3}$$

where $\hbar$ is Planck's constant and k is Boltzmann's constant.

2.2. Objects on Diagrams

Black hole quantities are always shown on the universal diagrams. Also, in each diagram the corresponding Planck quantities (e.g. the Planck mass $\sqrt{\hbar c/G}$ etc.) are also shown.

Quantum objects are chosen to show photons as well as protons and electrons as the simplest particles. Atoms and molecules are also shown. Animate objects include organic molecules, small viruses, chromosomes of large organisms and cells. Multicellular objects include bugs, humans and the largest of animals, whales. Objects created by humans include cars, houses, the World Trade Center and a large city. When luminosity, temperature or entropy are plotted I have included explosive objects, luminous objects like lightbulbs and high temperature as well as low temperature fluids. Hypothetical interstellar travelling starships are also shown.

Solar system objects include comets, Ceres (the largest asteroid), the moon and a few planets. Planetary explosive objects are represented by a typical volcanic eruption on earth.

Astronomical objects include stars, collapsed stars (white dwarfs and neutron stars), gaseous nebulae H I and H II regions, molecular clouds, bubbles created by stellar winds, globular clusters, galaxies, clusters of galaxies, superclusters and voids. Quasars as well as the hypothetical accretion disks around stellar and supermassive black holes are also shown.

2.3. Mass-Luminosity Diagram

This is shown in Figure 1. At the microscopic level, the shaded region labelled "quantum limit" is shown for which $L \gtrsim L_P$ and the Planck luminosity is $L_P = c^5/G$. Any radiation process violating the uncertainty principle would have $L \gtrsim (mc^2)^2/\hbar$ where $mc^2 = E$ and E is the energy of the photon. The limit labelled "maximum rate allowed by uncertainty principle provides a boundary above which observable radiation processes cannot lie. Below this limit we have nuclear radiation processes for which the timescale is $\tau \sim 10^{-15}$ (E/MeV)$^{-3}$ sec (Norwood 1976), the common atomic radiation processes with characteristic timescales $\tau \sim 10^{-8}$ sec and the fine-structure radiation processes which typically have $\tau \lesssim$ a few sec (Allen 1964).

All animate matter as well as most man-made objects can be found along a fairly thin strip. Objects on it radiate roughly as black bodies at $T \sim 300$ K and, therefore, follow the relation $L \propto M^{0.66}$. Human beings, for example, radiate about 10^9 erg/sec. The above mentioned animate strip intersects the mini-black hole line at $M \sim 10^{15}$ gr. It roughly extends to macroscopic objects through the planets.

Nebulae follow a similar law $L \propto M^{1-2}$ since they are characterized by a constant surface temperature (equal to 10,000 K for H II regions, 100 K for H I regions and 10 - 30 K for molecular regions).

Galaxies as well as clusters and superclusters of galaxies emit as $L \propto M$ since they have approximately a constant mass to light ratio M/L for each galaxy type. If quasars are supermassive objects accreting gas from their surroundings they would also be expected to follow a $L \propto M$

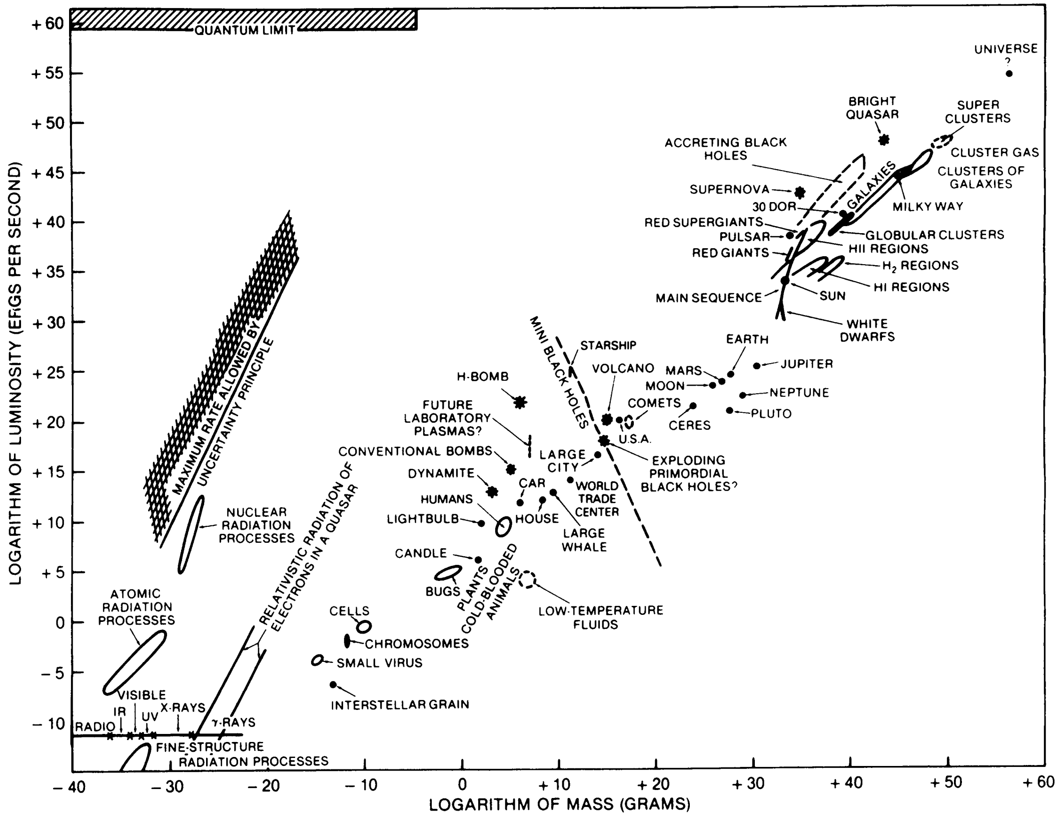

Figure 1

law for accretion near the Eddington limit. Stars follow a L $\propto$ M^{γ} law, $\gamma \sim 3$-4. Supernovae are believed to produce a luminous output of about 10^{49} erg irrespectively of their type or the mass of the collapsing star. I have also put the luminous output of the universe although such a quantity is probably meaningless since the way we define luminosity it requires an external observer and no such observer can of course be found for the universe. For the universe I have computed L assuming a spherical universe with radius equal to 10^{28} cm and black body temperature equal to 3 K. I find L $\sim$ $5\text{x}10^{54}$ erg/sec. Curiously enough this is equal, within an order of magnitude, to the luminous output of visible matter in the universe computed by a variety of methods!

3. CONCLUSIONS

Simple versions of the mass-size diagram have been given elsewhere and will not be repeated here (cf. Carr and Rees 1979). The other diagrams which I have drawn are the temperature-luminosity diagram, the mass-angular momentum diagram and the entropy change due to radiation by objects in the universe. The last one was chosen since information about the lifetime of objects is contained in it and because entropy is a very important thermodynamic quantity.

One of the most important conclusions that one draws from these diagrams is that what we normally refer to as "the universe" with R $\sim 10^{28}$ cm and M $\sim 10^{56}$ gr is not in any other way different than the rest of the objects that it is supposed to contain. In particular, when one examines the mass-size and mass-angular momentum diagrams one finds no obvious convergence of the various parameters plotted to what we would expect for the universe.

As far as animate life in the universe is concerned, Carr and Rees (1979) have shown that if life is considered to exist on planetary surfaces, the maximum size of living creatures weakly depends on the energy released in reactions of complex molecules. Examining Figure 1 we see that intelligent creatures on other planets would likely not exceed human masses by a few orders of magnitude. Their buildings and artifacts would also not exceed human artifacts by a similar factor; these estimates obviously refer to creatures living in oceans. If a hard surface is a prerequisite for technological intelligence, beings from other planets would likely not differ greatly from the size of man-at least as far as quantities on the universal diagrams are concerned.

It is interesting to observe from Figure 1 that explosive objects created by man depart from the animate strip by large factors (see the luminous output of, for example, one megaton H-bomb). It seems that objects created by man's frontiers of technology (see also low-temperature fluids) depart from the animate strip in the vertical direction by many orders of magnitude. Starships travelling at "modest" speeds of 0.1 - 0.9 the speed of light depart from the animate strip by similar factors as the H-bombs. I agree with other scientists in the present conference that interstellar travel is such a difficult enterprise that it is difficult to see based on our present knowledge how it could be carried out at all. I would add that interstellar travel is as desirable as an H-bomb explosion. These are not moral statements; they are based on examination of the universal diagram presented here. The reader is welcomed to draw his or her conclusions based on the universal diagram presented here and to create his or her own universal diagrams.

4. REFERENCES

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