Symmetry of STRUCTURE

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Abstracts

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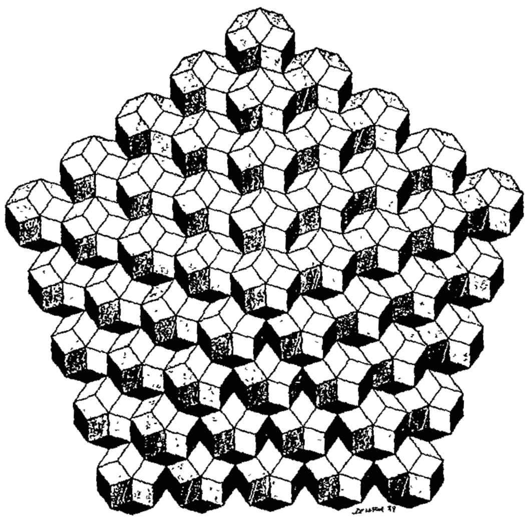

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COSMIC SYMMETRIES WITH MICROCOSMIC SYMMETRY BREAKINGS

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Summary: We argue that symmetries of the Universe may be due to those of microphysics.

Elementary particles and interactions are highly symmetric because of the small number of data characterizing them. However, as soon as building up macroscopic structures, any kind of asymmetry becomes possible via nonsymmetric combinations. So, symmetry, a *necessity* on microscopic scale, tends to survive only as a *possibility* on macroscopic ones. Although natural laws are (almost completely) symmetric in space and time, they do not lead to symmetric phenomena without symmetric initial conditions.

On macroscopic scale, indeed, various asymmetries appear, however, still some symmetry is present as well, which may be

1) remainder of a possible primordial symmetry via symmetric laws of motion;
2) product of an artificial intervention; or
3) outcome of an evolution, when symmetry is a condition of extremal energy (equilibrium), optimal functioning, &c.

On the largest scale Possibility 2) is ruled out because of highly superhuman sizes involved, and 3) too, because of the autocracy of gravity precluding equilibrium or organized functioning there. Still, with growing size symmetry increasingly reappears. Thus chaotic disorder in our medium scale is environed by asymptotic regions of ordered symmetric behaviours both above and below.

To explain the returning symmetry either a "finger of God" is needed to form initial conditions sufficiently symmetric, or His laws may somehow play the rôle of His finger to take care of symmetry (the latter being certainly the more elegant way). Indeed, it is the (not quite absurd) purpose of contemporary cosmology to grasp the whole Universe, together with its space, time, matter and forms, as a direct consequence of the laws of Nature.

The high symmetry of the present Universe means that, despite the fact that it contains the maximum number of constituents, its state can be characterized by means of a minimum number of data, just like a *microobject*. Such an initial state is highly unnatural unless the Universe itself had been a primitive microobject (Lukács & Paál, 1988), an idea quite conform with those of such great cosmologists as Lêmaitre (1958) and Hawking (1984). So the observed symmetry is really intelligible only in a vastly and uniformly expanding Universe. This new-fashioned *argument for the expansion* is quite independent of the observed redshift of the galaxies (and its usual Doppler interpretation), and also of any theory of gravity, which latter ones, however, fortunately point to the same direction.

The most familiar mechanism for driving expansion is the pressure difference, sweeping matter outwards into the *already existing* empty space, but this mechanism is incompatible with the observed *symmetric* endproduct. So there remains only the completely different alternative when the *space itself is expanding* (being "created") between the points *at rest*. Starting with microscopic type initial conditions one may hope to understand the present state of the Universe as the present standing of a competition between forces distroying and restoring symmetry, whose main steps we try to list now according to modern theories.

Even in the contemporary state of art, without knowing the details, existing theories uniquely single out *where* the Universe (a gravitation-dominated system) would become a microobject. This happens when the minimal energy (coming from the uncertainty principle of microphysics) of a quantum particle of localization L lies in the same order of magnitude as the energy correction from its own self-gravity, i.e.

$$E \approx (\hbar c/L) \sim (\hbar c/Lc^2)^2(G/L) \qquad (1)$$

(where G is the Cavendish-constant of gravity), so

$$L \sim (\hbar G/c^3)^{1/2} \equiv L_{Pl} \sim 10^{-33}\ \mathrm{cm} \qquad (2)$$

which is the so called Planck length. At this localization the quantum uncertainty energy and typical fluctuation time are

$$E \sim E_{Pl} \equiv (\hbar c^5/G)^{1/2} \sim 10^{16}\ \mathrm{erg} \qquad (3)$$

$$t \sim t_{Pl} \equiv L_{Pl}/c \sim 10^{-43}\ \mathrm{s}. \qquad (4)$$

The corresponding mass is $\sim 10^{-5}$ g, and the temperature $\sim 10^{19}$ GeV $\sim 10^{32}$ K. This implies that an object with age t_{Pl}, size L_{Pl} and energy E_{Pl} is within one quantum uncertainty from its complete absence, consequently its existence or nonexistence cannot be clearly distinguished. Only essentially different values would require extra explanation. Before the advent of a future quantum gravity theory the above data should be considered the most natural initial conditions, not requiring derivation from any set of *previous* data.

In most quantum field theories the completely particleless states do not necessarily possess zero energy density, even if in these states there is complete homogeneity, isotropy, stationarity, &c. All these uniform backgrounds are called *vacua*. So a vacuum may differ from Nothing, but still it represents the local (not absolute) minimum of energy and complete absence of any structure. Of them one possesses the maximal microscopic or internal symmetry in the sense that all of the expectation values of the fields vanish, but generally this is *not* the one with zero energy. The most natural initial condition is *maximal symmetry*, and then the nonvanishing energy of this state will be very important in the following history.

If then the Universe was in expansion, then the specific energy of its particles (temperature) was diminishing from T_{Pl}. When the radiation density is already negligible compared to this nontrivial vacuum energy density, the further expansion has no more diminishing effect on the density. Henceforth (for a while) the particle content is negligible, the rate of space creation is prescribed by elementary constants, and there is a simultaneous energy creation as well, to keep the density $(E/V)=\epsilon$ constant. Since $E=Mc^2$, we may speak of creation of mass, and matter as well. Conservation law is not expected to hold for energy, being conditional upon *time symmetry*, not present in an expanding Universe. According to the equations of General Relativity (Hawking & Ellis, 1973), any expanding system with a constant energy density ϵ_0 must have *negative* pressure P via

$$0 = dE+PdV = d(\epsilon_0 V)+PdV = (\epsilon_0+P)dV \qquad (5)$$

so $P=-\epsilon_0$, indeed. (Eq. (5) is well known from thermodynamics too, expressing the adiabaticity of expansion.) Since in the relativity theory the source of gravitational acceleration is not simply $M=E/c^2$ but $M_{eff}=(E+3PV)/c^2$, with negative pressure a negative gravitational effect appears accelerating the expansion. The distance R between two points of the substratum at rest changes according to the rule of classical form

$$\tfrac{1}{2}\dot{R}^2 = \tfrac{1}{2}v^2 = GM/R = (4\pi/3)(\epsilon_0/c^2)R^2 \qquad (6)$$

but here M is already time-dependent according to (5). Hence

$$\dot{R} \sim R \ \ \text{->}\ \ R \sim \exp(t/t_0). \qquad (7)$$

This exponential expansion is called *inflation* (Guth, 1981). As it is intuitively clear, inflation - like that of a baloon - increases regularity and symmetry. During this very rapid expansion, therefore, there are *simultaneous creations* of

space (volume)
matter (energy or mass) and
symmetry (uniformity).

Then we have managed to find a *natural way from a symmetric microuniverse to a macrouniverse preserving or even increasing its symmetries*. However, we shall have to pay for it immediately with the decrease of microscopic symmetries. The state in a high energy *vacuum* is not stable because there are other vacua below. Indeed, today the cosmic expansion is decelerating, antigravity does not act. Therefore, the fields must have gone to another vacuum level, with lower energy *and* symmetry (maybe in subsequent steps). During this transition energy was released in the form of particles, so becoming structured. This change is analogous with the solidification of water, so it is called phase transition, and contains a *symmetry breaking*.

According to present theories as e.g. Grand Unification, there were 3 kinds of deterioration of symmetry of the actual state almost simultaneously: (Barrow, 1983)

1) Appearance of nonzero expectation values of quantum

fields. Then inhomogeneities also might appear, because of incoherent domains of "nucleation" of the new phase.

2) Generation of nonzero rest masses for *some* particles. With these, symmetries for interchanging between different particles ceased.

3) With this proper time appeared, so the possibility of spontaneous decay, permitting the start of developing *asymmetry* in the *matter-antimatter* ratio.

Now we have arrived at the hot, radiation-dominated Universe. Here P>0, therefore with the space creation energy and mass are being destroyed. Antigravity has ceased, so there is no more smoothening of irregularities. Comparing the two epochs:

	Vacuum-dominated	Radiation-dominated
Expansion:	$\dot{R} \sim R$	$\dot{R} \sim R^{-1}$
Irregularity:	$\partial\epsilon/\epsilon \sim R^{-2}$	$\partial\epsilon/\epsilon \sim R^{2}$

which are just symmetric formulae in R instead of time. Our present world is from 60 orders of magnitude from L_{Pl}, and can be reached by spending ~30-30 orders of magnitude of expansion in both epochs.

In the cooling matter below T~3000 K neutral atoms were formed. Since then light has been unable to prevent gravitational contraction of *local* density excesses. Thus there is a spontaneous breaking of (spatial) symmetry on medium scale: homogeneity & isotropy decreases to spherical symmetry centered at random places. Then formation of galaxies, stars and planets begins, giving a possibility to life.

Therefore the history of Universe can be narrated as that of the symmetries. The present state still contains a substantial number of symmetries, but the symmetry groups are not maximal. (E.g. spatial homogeneity and isotropy but not full space-time symmetry on largest cosmic scales; spherical symmetry but not homogeneity & isotropy on macroscopic scales; SU(3)xSU(2)xU(1) symmetry but not SU(5) on microscopic scales). And even the remaining symmetries may be *weakly* violated as right-left (parity) symmetry in *weak* interaction.

Without symmetries the Universe would be too disordered to permit to grow anything highly organized, and too complicated to be understood. On the other hand with complete symmetry no observer could have separated itself from the rest of the Universe. So *partial symmetry seems to be a necessary condition for the existence of a Universe habitable by intelligent beings.*

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