A new nonstationary rotating cosmological model is developed which describes the evolution of the observed Universe, since its properties are in good agreement with recent astronomical observations. It is demonstrated that the energy density of cosmological rotation can play a role of dark energy and induce the accelerated expansion of the Universe detected recently. In some situations when the causality parameter of the rotating cosmological model is negative, the cosmological rotational energy can be represented as phantom matter that violates the weak energy condition \( p + \varepsilon \geq 0 \). The suggested cosmological model has no initial singularity, that is, the cosmological rotation can prevent the formation of the singularity.

As is well known, recent cosmological measurements have demonstrated that expansion of the observed Universe (Metagalaxy) is accelerated [1], and the average density of matter in the Universe \( \rho \) is equal to the critical value \( \rho_c \), so that the planeness parameter \( \Omega = \rho/\rho_c \) is of the order of unity, and the spatial curvature of the Universe is equal to zero [2, 3]. The accelerated expansion of the Universe is explained by the influence of the cosmological term \( \Lambda \) determining the energy density in vacuum or the quintessence – the slowly varying scalar field [4, 5]. Both these factors are called dark energy. Its relative density is about 70% of the total density of matter in the observed Universe. Violation of the strong energy condition \( 3p + \varepsilon \geq 0 \) is typical of this Universe, so that the pressure of the dark energy is negative, and the equation of state has the form \( p + \varepsilon = 0 \). A more careful analysis of observations has demonstrated that for invisible matter of this type, the weak energy condition \( p + \varepsilon \geq 0 \) has a high probability of being violated [6, 7]. Invisible matter having this property is called phantom matter. It is described by the equation of state \( p = (\gamma - 1)\varepsilon \) with the negative barotropic index \( \gamma < 0 \), which results in the inequality \( p < -\varepsilon \).

The other type of invisible matter with conventional gravitational properties called latent mass or dark matter [8] was discovered even earlier. Its relative contribution to the total mass of the Universe is about 25–27%. As a result, the observed matter (stars, galaxies, congestions of galaxies, etc.) is less than 4% of the total Metagalaxy mass. Therefore, in practice the evolution of the observed Universe is determined by unobservable matter, including dark energy (or phantom matter) and dark matter. We will characterize the latter by the energy-momentum tensor of an ideal liquid with density \( \rho \) and pressure \( p \) and choose a system of units in which the velocity of light \( c = 1 \).

In the present work, we suggest another mechanism of the accelerated Universe expansion in the present epoch, namely, as a consequence of its rotation with angular velocity \( \omega \). It turns out that the rotational energy density \( \varepsilon_\omega = 2\omega^2/\kappa \), where \( \kappa = 8\pi G \) and \( \omega \) is the angular rotation velocity of the reference frame attached to Universe matter, plays the same role as the vacuum energy density \( \Lambda/\kappa \) and promotes the acceleration of the volume Universe expansion \( D = V^k_\kappa \) \( (k = 0, 1, 2, 3) \), where \( V^k \) is the 4-velocity of the reference frame – the monad \( (V^k V_k = 1) \). This is clearly seen from the Landau–Richaudkhuri equation [9] which for a homogeneous nonstationary cosmological model has the form

\[
\frac{dD}{dt} = -\kappa (\varepsilon + 3p)/2 + \Lambda + 2\omega^2 - 2\varepsilon - D^2/3 + A^k_\kappa.
\]
Here $A^i = V^k {\omega}^i_a V^a$ is the acceleration of the reference frame, $\omega^2 = \omega^i_\alpha \omega^\alpha_i$, $\omega^i = \epsilon^i_{\alpha \beta \gamma} V^\alpha V^\beta V^\gamma/2$ is the vector of angular velocity of the reference frame, $\sigma$ is the shift ($2\sigma^2 = \sigma^i_\alpha \sigma^\alpha_i$), $\sigma^i_\alpha$ is the spurless component of the deformation rate tensor of the reference frame $D^i_\alpha = h^\alpha_{\beta \gamma} V^\beta (m, n)/2$ and $h^i_\alpha = V^i V^\alpha - g^i_\alpha$ is the effective metric tensor of the space-like hypersurface orthogonal to the monad $V^k$. From Eq. (1) it can be seen that the cosmological term $\Lambda$ plays the same role as the rotational energy density $2\omega^2/\kappa$. They both promote the expansion acceleration and in principle, can be interchangeable.

Generally, the rotational energy is described by the rotational energy density tensor $\hat{T}^i_\alpha$. Its components within the monad formalism [10] are expressed in an explicit form by projecting its components onto the monad – the 4-velocity of the reference frame and the space-like hypersurface orthogonal to it with the effective metric tensor $\hat{h}^i_\alpha$.

From the structure of rotational energy tensor (2) it follows that the effective pressure is always negative, as for the vacuum energy density tensor described by the cosmological term $\Lambda$ or as for phantom matter.

Based on the foregoing, we suggest a cosmological model with rotation that describes the evolution of the observed Universe (Metagalaxy) after the 1st inflation stage and the phase transition which, in our opinion, is in agreement with the observed cosmological data. By analogy with the standard model based on the theory of hot Universe, it has the initial Friedman evolution stage, but without initial singularity, as it must be after the phase transition according to the theory of the expanding Universe [11, 12], followed by the accelerated exponential expansion (the second inflation) observed in the present epoch. In the suggested model, dark matter described by the energy-momentum tensor of a continuous medium (probably anisotropic to compensate for possible anisotropy caused by rotation):

$$T^i_\alpha = (p + p)V^i V^\alpha + (\pi - p)k^i k^\alpha - p g^i_\alpha. \quad (3)$$

is taken into account in addition to the rotation whose energy plays the role of dark energy. Here $p$ and $\pi$ are the pressure components and $k^i$ is the anisotropy vector ($k^i k^j = -1$ and $k^i V^j = 0$).

To describe the homogeneous rotating and expanding Universe with the effective plane spatial cross section, we suggest the metric

$$ds^2 = dt^2 - a(t)^2(dx^2 + k\exp(2\lambda x)dy^2 + dz^2) - 2b(t)\exp(\lambda x)dy dt. \quad (4)$$

Here $a(t)$ and $b(t)$ are scale factors determined from Einstein’s equations and $k$ and $\lambda$ are constants. Moreover, the constant $a$ can be called the causality parameter, because a closed time-like curve passes through each point of the space-time in the static case for $k < 0$, while for $k > 0$ such curves are absent, and the causality is restored. The parameter $\lambda$ specifies the intensity of rotation, because the angular rotation velocity $\omega$ of the reference frame attached to matter (3) for the examined model is given by the formula

$$\omega = \lambda b(t)(2a(t)^{-1}(ka^2 + b^2)^{-1/2}. \quad (5)$$

This metric is a generalization of the Gödel metric [13] for the stationary rotating homogeneous cosmological model to a nonstationary case (we obtain the Gödel metric for $a(t) = b(t) = 1$ and $k = -1/2$). The metric given by Eq. (4) for $a \neq b$ describes an anisotropic rotating cosmological model with shift $\sigma$:

$$\sigma = b(b - da/dt - a - db/dt)/a(ka^2 + b^2). \quad (6)$$

For $a(t) = b(t)$, we obtain the metric for a homogeneous rotating nonstationary cosmological model without shift [14].