I. INTRODUCTION

Acceleration expansion is a consequence of observational data \cite{1,2}. The role of this epoch is for dark energy (DE) \cite{3}. A new stringy motivated model of DE is Holographic dark energy (HDE). Also recently it has been proposed New-agegraphic dark energy (NADE) from a quantum mechanical point of view. To classify models of DE Sahni et al \cite{4} introduced the statefinder pair \{r, s\} given by,

\begin{align}
    r &\equiv \frac{\ddot{a}}{aH^2}, \\
    s &\equiv \frac{r - 1}{3(q - 1/2)}.
\end{align}

As usual \(a, H\) denote the scale factor and the Hubble parameter. Also \(q\) is the deceleration parameter is defined by,

\begin{equation}
    q = -\frac{\ddot{a}}{aH^2}.
\end{equation}

In a model of DE trajectory in \(r, s\) plane classifies the model’s behavior \cite{5,6}. Following the modification proposal of gravity it is possible to label the DE to gravity corrections \cite{7-10}. Our main goal in this paper is to study this pair in Loop quantum gravity (LQG) introduced \cite{11} and was developed \cite{12,13}.

The plan of this paper is as following: In Section 2 we have calculated the deceleration parameter and statefinder parameters for Loop quantum gravity. Section 3 deals with Holographic dark energy (HDE) and in section 4 we do the evaluations for New Agegraphic dark energy (NADE). In section 5 we provide a detailed and comparative graphical analysis. Finally the paper ends with a general discussion in section 6.

II. LOOP QUANTUM GRAVITY MODEL

Following the idea of loop Quantum Gravity (LQG), universe evolved as an outstanding effort to describe the quantum effect of our universe \cite{14-18}. Recently it has been reported that loop quantum cosmology is in relation to the teleparallelism mechanism of gravity as a geometrical theory on torsion \cite{12}.

Following the cosmological evolution of LQC \cite{19} the new Friedmann equation reads \cite{20,22}

\begin{equation}
    H^2 = \frac{\kappa^2}{3}\rho \left(1 - \frac{\rho}{\rho_1}\right).
\end{equation}

Here \(\kappa^2 = 8\pi G\) and \(\rho_1 = \sqrt{3\pi^2\gamma^3G^2}\hbar\) defines the ”critical loop quantum density” and \(\gamma\) is the dimensionless Barbero-Immirzi parameter. \(\rho = \rho_m + \rho_D\) represents the total cosmic energy density, which is a sum of energy density of DM (\(\rho_m\)) and the energy density of DE (\(\rho_D\)).
The conservation equations are

\[ \frac{\dot{\rho}}{D} + 3H (1 + \omega_D) \rho_D = 0, \quad (4) \]

\[ \frac{\dot{\rho}_m}{m} + 3H \rho_m = 0. \quad (5) \]

Using (3) and the conservation identities, we can obtain the modified geometric Raychaudhuri equation

\[ \dot{H} = -\frac{\kappa^2}{2} (\rho + p) \left( 1 - 2 \frac{\rho}{\rho_1} \right). \quad (6) \]

Let the dark energy obey the equation of state \( p_D = \omega_D \rho_D \). Using this expression for \( p_D \) and using the expression \( \rho_T = \rho = \rho_D + \rho_m \) for total cosmic energy density \( \rho \) we get,

\[ \dot{H} = -\frac{\kappa^2}{2} (\rho_D + \rho_m + \omega_D) \left( 1 - 2 \frac{\rho_D + \rho_m}{\rho_1} \right). \quad (7) \]

We define two dimensionless density parameters as follows,

\[ \Omega_D = \frac{\kappa^2 \rho_D}{3H^2}, \quad \Omega_m = \frac{\kappa^2 \rho_m}{3H^2}. \quad (8) \]

The deceleration parameter in terms of these dimensionless density parameters is given by,

\[ q = -1 + \frac{3}{2} (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right). \quad (9) \]

From the expression of \( r \), we have a relation between \( r \) and deceleration parameter \( q \) as,

\[ r = 2q^2 + q - \frac{\dot{q}}{H}. \quad (10) \]

The time derivatives of the dimensionless density parameters \( \Omega_m \) and \( \Omega_D \) are given as,

\[ \dot{\Omega}_m = \Omega_m H (2q - 1). \quad (11) \]

\[ \dot{\Omega}_D = \Omega_D H (2q - 3\omega_D - 1). \quad (12) \]

Using equations (8) to (12) we get,

\[ r = 2 \left[ -1 + \frac{3}{2} (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right]^2 - 1 + \frac{3}{2} (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \]

\[ -\frac{1}{H} \left[ \frac{3}{2} \left( -\Omega_m H \left( -3 + 3 (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right) - \Omega_D H (-3 - 3\Omega_D + 3 (2 - \Omega_m - \Omega_D) \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right] \]

\[ + \frac{3}{2} \left( 2 - \Omega_m - \Omega_D \left( \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right) - \frac{1}{\left( \Omega_m + \Omega_D \right)^2} \left( \omega_D \Omega_D (\Omega_m H (-3 + 3 (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) ) \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \]

\[ \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) + \Omega_D H (-3 - 3\Omega_D + 3 (2 - \Omega_m - \Omega_D) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) ) \right) \right]. \quad (13) \]
\[
\begin{align*}
s &= \left[ -3 + \frac{3}{2} \left( 2 - \Omega_m - \Omega_D \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) - \frac{1}{2} \Omega_m \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) - \frac{3}{2} \Omega_m \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) \right]^{-1} \\
&\times \left\{ -1 + \frac{3}{2} \left( 2 - \Omega_m - \Omega_D \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right)^2 - \frac{3}{2} \right\} \left( 2 - \Omega_m - \Omega_D \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \\
&- \frac{1}{2} \left[ \frac{3}{2} \left( -\Omega_m H \left( -3 + 3 \left( 2 - \Omega_m - \Omega_D \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right) \right) - \Omega_D H \left( -3 - 3\Omega_D + 3 \left( 2 - \Omega_m - \Omega_D \right) \right) \\
&\times \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right] \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) + \frac{3}{2} \left[ 2 - \Omega_m - \Omega_D \left( \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} + \frac{\omega_D \Omega_D H}{\Omega_m + \Omega_D} \left( -3 - 3\Omega_D \\
&+ 2 \left( 2 - \Omega_m - \Omega_D \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right) \left( \Omega_m H \left( -3 + 2 - \Omega_m - \Omega_D \right) \right) \right) \left( 1 + \frac{\omega_D \Omega_D}{\Omega_m + \Omega_D} \right) \right] \\
&- \Omega_m \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) - \Omega_D \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) \right] .
\end{align*}
\]

**III. HOLOGRAPHIC DARK ENERGY**

For HDE [23, 24] following the naive idea of Cohen et al [25] we write the following equation for DE energy density:

\[ \rho_{vac} \sim \Lambda_{UV}^4 \sim M_p^2 L^{-2} . \]  \hspace{1cm} (15)

or equivalently [26]

\[ \rho_H = 3c^2 M_p^2 L^{-2} , \]  \hspace{1cm} (16)

where \( c \sin O(1) \) is the holographic parameter and L is the IR-cutoff of the universe. with future event horizon of the universe as the IR cutoff, we have:

\[ R_h = a \int_t^\infty \frac{dt}{a} = a \int_a^\infty \frac{da'}{Ha'^2} . \]  \hspace{1cm} (17)

Using equation (16) and conservation equation (4) the equation of state(EoS) parameter for holographic dark energy is given by,

\[ \Omega_D = \frac{1}{3} \left( -1 - \frac{2}{c} \sqrt{\Omega_D} \right) , \]  \hspace{1cm} (18)

where \( \Omega_D \) is the dimensionless density parameter of holographic dark energy(HDE) and the time derivative of the dimensionless density parameter for HDE is given by,

\[ \Omega_D' = \Omega_D H \left( 1 - \Omega_D \right) \left( 1 + \frac{2}{c} \sqrt{\Omega_D} \right) . \]  \hspace{1cm} (19)

Now the expression for the state parameter \( r \) is given by,
\[ r = \frac{1}{2c^2 (\Omega_m + \Omega_D)^3} \left[ -6\Omega_m^2 c \left( \frac{19}{3} - \frac{43}{6} \Omega_m + \Omega_m^2 \right) \Omega_D^3 + 10\Omega_m^6 - 9c\Omega_D^4 + (30\Omega_m - 26 + 2c^2) \Omega_D^5 \right. \]

\[ (25c - 33c\Omega_m) \Omega_D^2 + (20 + 30\Omega_m^2 - 8c^2 + 12\Omega_m c^2 - 74\Omega_m) \Omega_D^4 - 45 \left( \frac{77}{45} \Omega_m + \frac{2}{5} + \Omega_m^2 \right) c\Omega_D^7 \]

\[ + (10\Omega_m^3 + 6c^2 - 42\Omega_m c^2 - 54\Omega_m^2 + 24c^2\Omega_m^2 + 48\Omega_m) \Omega_D^3 - 27 \left( \frac{40}{27} + \Omega_m^2 - \frac{95}{27} \Omega_m \right) \Omega_m c\Omega_D^5 \]

\[ + \left\{ (20c^2 - 6) \Omega_m^3 + (-74c^2 + 12) \Omega_m^2 + 28\Omega_m c^2 \right\} \Omega_D^2 + 6\Omega_m^2 \left( \Omega_m^2 - \frac{29}{3} \Omega_m + \frac{19}{3} \right) c^2 \Omega_D \]

\[ -18\Omega_m^5 \left( \Omega_m - \frac{10}{9} \right) c^2 \right]. \tag{20} \]

The expression for the state parameter \( s \) is given by,

\[ s = \left[ \left\{ -\frac{1}{2} c (\Omega_m + \Omega_D) \Omega_m \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) - \frac{1}{2} c (\Omega_m + \Omega_D) \Omega_D \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) \right\} \frac{\Omega_D^2 - \Omega_m^2 + (\Omega_m + \Omega_D) \Omega_m^2 + \left( -1 - \frac{5}{2} \Omega_m \right) c\Omega_D^3 - \frac{3}{2} \Omega_m c \left( -\frac{4}{3} + \Omega_m \right) \Omega_m c (\Omega_m + \Omega_D)^2 \right]^{-1} \]

\[ \frac{1}{6} \left[ -2c^2 (\Omega_m + \Omega_D)^3 \Omega_m \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) - 2c^2 (\Omega_m + \Omega_D)^3 \Omega_D \left( 1 - \frac{3H^2 (\Omega_m + \Omega_D)}{\rho_1} \right) \right. \]

\[ \left. + \left\{ (10 + \Omega_m) a - 6\Omega_m^2 + 42\Omega_m - 48 \right\} c\Omega_m^2 \Omega_D^3 + \left\{ 6\Omega_m^5 - c\Omega_m^2 \Omega_D^3 + \left( 18\Omega_m - 2c^2 - 10 \right) \Omega_D^5 \right\} \right) \]

\[ + c \left( -1 - 3\Omega_m \right) \Omega_D^7 + ((2 - 6\Omega_m) c^2 - 34\Omega_m + 4 + 18\Omega_m^2) \Omega_D^1 - 3 \left( \Omega_m^2 + 3\Omega_m - \frac{2}{3} \right) c\Omega_D^5 \]

\[ -6\Omega_m \left( \left( \Omega_m - \frac{2}{3} \right) c^2 - \Omega_m^2 - \frac{8}{3} + 5\Omega_m \right) \Omega_D^3 - c\Omega_m \left( -12 + \Omega_m^2 + 7\Omega_m \right) \Omega_D^5 - 2 \left( -12 - 2\Omega_m + \Omega_m^2 \right) c^2 \]

\[ -6\Omega_m + 3\Omega_m^2 \Omega_D^1 + a - 4\Omega_m^6 + 8c\Omega_m^2 \Omega_D^4 + \left( -16 + 12\Omega_m + 4c^2 \right) \Omega_D^5 \]

\[ + (30\Omega_m - 26) c\Omega_D^2 + (18\Omega_m - 10) c^2 + 12\Omega_m^2 + 16 - 40\Omega_m \right) \Omega_D^1 + \left( 86\Omega_m - 42\Omega_m^2 - 20 \right) c\Omega_D^5 \]

\[ + \left\{ (-46\Omega_m + 30\Omega_m^2 + 6) c^2 + 32\Omega_m + 4\Omega_m^3 - 24\Omega_m^2 \right\} \Omega_D^3 - 26\Omega_m \left( \Omega_m^2 - \frac{51}{13} \Omega_m + 2 \right) c\Omega_D^5 \]

\[ + 22\Omega_m \left( -\frac{39}{11} \Omega_m + \frac{13}{3} \Omega_m^2 \right) c^2 \Omega_D^2 + 6c^2 \Omega_m \left( -10\Omega_m + 6 + \Omega_m^2 \right) \Omega_D - 18\Omega_m^3 \left( \Omega_m - \frac{10}{9} \right) c^2 \right]. \tag{21} \]
FIG. 1: (Top Left) Time evolution of HDE density parameter and logarithmic scale factor. (Top Right) Evolutionary behavior of HDE density parameter versus logarithmic scale factor. (Bottom Left) Time evolution of statefinder parameter $r$. (Bottom Right) Time evolution of statefinder parameter $s$. While plotting, we adopted the following fixing of free parameters: $a(0) = 1$, $\dot{a}(0) = H_0 = 74$, $\Omega_D(0) = 0.73$, $c = 0.5$, $\rho_1 = 0.187$.

IV. NEW AGEGRAPHIC DARK ENERGY

Now for Agegraphic dark energy \[28, 28, 30–32, 32, 33, 36, 37\] we write \[34, 35\],

$$\rho_\Lambda \sim \frac{1}{t^2 M_p^2} \sim \frac{M_p^2}{t^2}. \tag{22}$$

Now $M_p$ is the reduced Planck mass. So the dark energy density $\rho_A$ of NADE model \[36, 37\] has the form,

$$\rho_A = 3n^2 M_p^2 \eta^{-2}, \tag{23}$$

where $3n^2 \sim \mathcal{O}(1)$ and $\eta$ is a conformal time.

Combining equations (21), (22) and conservation equation (2) the NADE equation of state(EoS) parameter is obtained as,

$$\Omega_D = -1 + \frac{2}{3na} \sqrt{\Omega_D}. \tag{24}$$
The time derivative of the dimensionless density parameter of NADE is given by,

$$\dot{\Omega}_D = \Omega_D H (1 - \Omega_D) \left( 3 - \frac{2}{na} \sqrt{\Omega_D} \right). \quad (25)$$

The expression for the state parameter $r$ is given by,

$$r = \frac{1}{2n^2a^2(\Omega_m + \Omega_D)^3} \left[ 6na \left( 3 - \frac{11}{2} \Omega_m + \Omega_D^2 \right) \Omega_m^2 \Omega_D^2 + 10\Omega_D^6 - 9na\Omega_D^{12} + (30\Omega_m - 26) \Omega_D^5 \right]$$

$$-21na (-1 + \Omega_m) \Omega_D^2 + (20 + 30\Omega_m^2 - 74\Omega_m) \Omega_D^4 - 9(\Omega_m - 6) n \left( \Omega_m - \frac{1}{3} \right) a\Omega_D^2 + (10\Omega_m^3 - 54\Omega_m^2)$$

$$+ (48 - 18n^2a^2) \Omega_m + 2n^2a^2 \Omega_D^3 + 9n \left( -\frac{16}{3} + \frac{1}{3} \Omega_m + \Omega_D^2 \right) a\Omega_m \Omega_D^2 + (-6\Omega_m^3 + (-18n^2a^2 + 12) \Omega_m^2$$

$$+ 24n^2a^2\Omega_m \right) - 18n^2 \left( \Omega_m - \frac{1}{3} \right) a^2\Omega_m^2 \Omega_D - 18n^2a^2\Omega_m^3 \left( \Omega_m - \frac{10}{9} \right). \quad (26)$$

The expression for the state parameter $s$ is given by,

$$s = \left[ (\Omega_m + \Omega_D)^2 \left\{ \frac{1}{2} na (\Omega_m + \Omega_D) \Omega_m \left( 1 - \frac{3H^2(\Omega_m + \Omega_D)}{\rho_1} \right) + \frac{1}{2} na (\Omega_m + \Omega_D) \Omega_D \right. \right.$$  

$$\left. \left( 1 - \frac{3H^2(\Omega_m + \Omega_D)}{\rho_1} \right) + (-2 + \Omega_m) \Omega_D^2 + \Omega_D^3 + \frac{3}{2} na \left( \frac{2}{3} + \Omega_m \right) \Omega_D + \frac{3}{2} na \left( -\frac{4}{3} + \Omega_m \right) \Omega_m \left\} \right]^{-1}$$

$$\frac{1}{6} \left[ 2n^2a^2(\Omega_m + \Omega_D)^3 \Omega_m \left( 1 - \frac{3H^2(\Omega_m + \Omega_D)}{\rho_1} \right) + 2n^2a^2(\Omega_m + \Omega_D)^3 \Omega_D \left( 1 - \frac{3H^2(\Omega_m + \Omega_D)}{\rho_1} \right) \right.$$  

$$-6na \left( 3 - \frac{11}{2} \Omega_m + \Omega_D^2 \right) \Omega_m^2 \Omega_D^2 - 10\Omega_D^6 + 9na\Omega_D^{12} + (26 - 30\Omega_m) \Omega_D^5 + 21na (-1 + \Omega_m) \Omega_D^2$$

$$+ (-30\Omega_m^2 - 20 + 74\Omega_m) \Omega_D^4 + 9(\Omega_m - 6) n \left( \Omega_m - \frac{1}{3} \right) a\Omega_D^2 + (-10\Omega_m^3 + 54\Omega_m^2 + (-48 + 18n^2a^2) \Omega_m$$

$$-2n^2a^2) \Omega_D^3 - 9n \left( -\frac{16}{3} + \frac{1}{3} \Omega_m + \Omega_D^2 \right) a\Omega_m \Omega_D^2 + (6\Omega_m^3 + (-12 + 18n^2a^2) \Omega_m^2 - 24n^2a^2\Omega_m) \Omega_D^2$$

$$+ 18n^2 \left( \Omega_m - \frac{1}{3} \right) a^2\Omega_m^2 \Omega_D + 18n^2a^2\Omega_m^3 \left( \Omega_m - \frac{10}{9} \right). \quad (27)$$

Figures shown with caption Fig.1 describe the evolution of cosmic parameters of holographic dark energy. Here the top left and top right figures, the evolution of dark energy density parameter and evolution of scale factor. As is shown, the parameter $\Omega_D \to 1$ as $\ln a \to 2$. Moreover the loop quantum corrected $r$ and $s$ parameters are plotted in the bottom two figures, which show that they asymptote to 2 and 0.66 in the allowed range of time. Moreover the figures under the caption Fig.2 depict similar behavior quantitatively.
FIG. 2:  (Top Left) Time evolution of NADE density parameter and logarithmic scale factor. (Top Right) Evolutionary behavior of NADE density parameter versus logarithmic scale factor. (Bottom Left) Time evolution of statefinder parameter $r$. (Bottom Right) Time evolution of statefinder parameter $s$. While plotting, we adopted the following fixing of free parameters: $a(0) = 1$, $\dot{a}(0) = H_0 = 74$, $\Omega_D(0) = 0.73$, $n = 0.5$, $\rho_1 = 0.187$.

V. CONCLUSION

The statefinder parameters $r$ and $s$ have been calculated for a Universe described by Loop quantum cosmology. Two dark energy models, namely Holographic dark energy and New Agegraphic dark energy have been considered and the statefinder parameters are calculated for these models separately in loop quantum cosmology. The trajectories in the $r$-$t$ and $s$-$t$ planes for these dark energy models characterize their individual properties. Unfortunately, due to the complicated nature of statefinder parameters, we were unable to plot $r$-$s$ diagrams.

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