Lagrange points for a point mass satisfy Equation 4.7 from S&G.

$-\frac{GM}{(D-x)^2} \pm \frac{Gm}{x^2} - \Omega^2\left(x - \frac{DM}{M+m}\right) = 0$

With a "Dark Halo" potential, $\mathcal{M}(<r)$ is not constant and, as shown above, $\mathcal{M}(<r) \propto r$

An object at L_1, L_2 will have the same angular speed as the satellite (Ω^2 unchanged)

The major change will be in the first term, $-\frac{G\mathcal{M}}{(D-x)^2}$ which represents the effect of $\mathcal{M}$ at point x

Therefore, $-\frac{G\mathcal{M}(<D-x)}{[D-x]^2} \pm \frac{Gm}{x^2} - \Omega^2\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = 0$

Since $\Omega^2 = \frac{G(\mathcal{M}(<D)+m)}{D^3}$ is unchanged, $-\frac{G\mathcal{M}(<D-x)}{[D-x]^2} \pm \frac{Gm}{x^2} - \frac{G[\mathcal{M}(<D)+m]}{D^3}\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = 0$

$\frac{\mathcal{M}(<D-x)}{\mathcal{M}(<D)} = \frac{D-x}{D} \Rightarrow \mathcal{M}(<D-x) = \mathcal{M}(<D)\frac{D-x}{D}$

$-\frac{G\mathcal{M}(<D)}{[D-x]^2}\frac{D-x}{D} \pm \frac{Gm}{x^2} - \frac{G[\mathcal{M}(<D)+m]}{D^3}\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = -\frac{G\mathcal{M}(<D)}{D[D-x]} \pm \frac{Gm}{x^2} - \frac{G[\mathcal{M}(<D)+m]}{D^3}\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = 0$

$-\frac{G\mathcal{M}(<D)}{D^2[1-\frac{x}{D}]} \pm \frac{Gm}{x^2} - \frac{G[\mathcal{M}(<D)+m]}{D^3}\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = 0$

Using Taylor expansion ($m \ll \mathcal{M}(<D) \Rightarrow x \ll D$), $\frac{1}{1-\frac{x}{D}} \approx 1 + \frac{x}{D} + \frac{x^2}{D^2} + \ldots$

$\Rightarrow \approx -\frac{G\mathcal{M}(<D)}{D^2} - \frac{G\mathcal{M}(<D)x}{D^3} \pm \frac{Gm}{x^2} - \frac{G[\mathcal{M}(<D)+m]}{D^3}\left[x - \frac{D\mathcal{M}(<D)}{\mathcal{M}(<D)+m}\right] = 0$

$-\frac{G\mathcal{M}(<D)}{D^2} - \frac{G\mathcal{M}(<D)x}{D^3} \pm \frac{Gm}{x^2} - \frac{G\mathcal{M}(<D)x}{D^3} - \frac{Gmx}{D^3} + \frac{G\mathcal{M}(<D)}{D^2} = -\frac{2G\mathcal{M}(<D)x}{D^3} \pm \frac{Gm}{x^2} - \frac{Gmx}{D^3} = 0$

$\Rightarrow -2\mathcal{M}(<D)x^3 \pm mD^3 - mx^3 = 0$

$[2\mathcal{M}(<D) + m]x^3 = \pm mD^3$

$$\boxed{\Rightarrow x = \pm r_J = \pm D\left[\frac{m}{2\mathcal{M}(<D)+m}\right]^{1/3} \approx \pm D\left[\frac{m}{2\mathcal{M}(<D)}\right]^{1/3}}$$ [for $m \ll \mathcal{M}(<D)$]