ADDENDUM

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Addendum

Addendum: A geodesic principle for strong coupling gravity (2015 *Class. Quantum Grav.* 32 215022)

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The derivation of the geodesic congruence equations $\mathcal{E}_0 = 0 = \mathcal{E}_a$ from equation (3.1), while correct, entails the undesirable restriction $\mathcal{D} = 0$ as defined in (3.6). Since $\mathcal{D} = \sqrt{g} \nabla^{\mu} P_{\mu}$, $g = \det g_{\mu\nu}$, measures the expansion of the congruence the background geometry would be constrained by requiring vanishing expansion, and correspondingly for strong coupling gravity. A derivation without this limitation proceeds as follows. Defining the acceleration by $\dot{P}_{\mu} \coloneqq P_{\nu} \nabla^{\nu} P_{\mu}$ its components can be read off from $\int dt dx \sqrt{g} \xi^{\mu} \dot{P}_{\mu} =$ $\int dt dx \sqrt{g} \left\{ \frac{1}{2} \mathcal{L}_{\xi} g^{\mu\nu} P_{\mu} P_{\nu} - \xi^{\mu} P_{\mu} \nabla^{\nu} P_{\nu} \right\}$. Inserting (3.3) and (3.4) one finds that in the 1 + dcomponents $\dot{P}_{\mu} = (\dot{P}_0, \dot{P}_a)$ the acceleration \mathcal{D} drops out

$$\dot{P}_0 = \mathcal{E}_0 + \frac{\epsilon_g}{N} N^a \mathcal{E}_a, \quad \dot{P}_a = \frac{\epsilon_g}{N} \mathcal{E}_a, \tag{1}$$

showing that $\dot{P}_0 = 0 = \dot{P}_a$ is equivalent to $\mathcal{E}_0 = 0 = \mathcal{E}_a$ alone. Since (3.3) and (3.4) have well-defined strong coupling limits one can define \dot{P}_0^{∞} , \dot{P}_a^{∞} as the coefficients of ξ^0 , ξ^a in the analogous computation, with the result

$$\dot{P}_0 = \epsilon_g \phi e_0(\phi) + N^a \dot{P}_a^{\infty}, \quad \dot{P}_a^{\infty} = \frac{\epsilon_g \phi}{N} [e_0(P_a) - \phi \partial_a N].$$
(2)

Here $\mathcal{D}^{\infty} \coloneqq \epsilon_g e_0(\sqrt{q} \phi)$ cancels and (2) coincides with the scaling limit (A.2) of (1).

In the transcription of the $\partial_a \xi^0$ coefficient from equations (3.22) to (3.23) a term $N^b \mathcal{E}_b^\infty$ has been dropped by mistake and the $\partial_a \mathcal{E}_a^\infty$ term should read $\partial_t \mathcal{E}_a^\infty$. The corrected equation (3.23), i.e. $\delta_{\xi}^\infty \mathcal{E}_a^\infty = \xi^0 \partial_t \mathcal{E}_a^\infty + \mathcal{L}_{\xi}^- \mathcal{E}_a^\infty + \partial_a \xi^0 [e_0(\phi) + N^b \mathcal{E}_b^\infty]$, in combination with (3.19) is equivalent to

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$$\delta_{\xi}^{\infty}\dot{P}_{0}^{\infty} = \partial_{t}(\xi^{0}\dot{P}_{0}^{\infty}) + \xi^{a}\partial_{a}\dot{P}_{0}^{\infty} + \partial_{t}\xi^{a}\dot{P}_{a}^{\infty},$$

$$\delta_{\xi}^{\infty}\dot{P}_{a}^{\infty} = \xi^{0}\partial_{t}\dot{P}_{a}^{\infty} + \mathcal{L}_{\xi}\dot{P}_{a}^{\infty} + \partial_{a}\xi^{0}\dot{P}_{0}^{\infty}.$$
 (3)

Under the strong coupling realization of the diffeomorphism group the acceleration $(\dot{P}_0^{\infty}, \dot{P}_a^{\infty})$ thus transforms like (P_0, P_a) in (3.18) and the conditions $\dot{P}_0^{\infty} - \alpha \dot{P}_0 = 0$, $\dot{P}_a^{\infty} - \alpha \dot{P}_a = 0$, are manifestly gauge invariant. Using $\alpha = \epsilon_g e_0(\phi)/N$ the non-redundant condition on a geodesic congruence in strong coupling gravity is

$$e_0(\phi)P_a - \phi[e_0(\phi) - \phi\partial_a N] = 0. \tag{4}$$

Imposing $\alpha = 0$ reproduces (3.17) but without the undesirable constraint $e_0(\sqrt{q}\phi) = 0$. Note that $\alpha = 0$ does not restrict the 'norm' $\epsilon_g \phi^2$ of (P_0, P_a) to be a spatiotemporal constant.