Essential ingredients for chiral gravitational waves from 2-form fields

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2-form+dual 2-form [B. Altschul et al. (2010)]

[T. Manton and S. Alexander (2024)]

$\mathcal{L} \supset B^{\mu\nu}\tilde{B}^{\alpha\beta}R_{\mu\nu\alpha\beta} \rightarrow$ **Gravitational parity violation**

Our work: Ghost-free 2-form + dual 2-form→Chiral GWs?

Ghost-free 2-form [L. Heisenberg and G. Trenkler (2020)]

$$\mathcal{L} = \frac{M_{\rm Pl}^2}{2}R - \frac{1}{12}H_{\mu\nu\rho}H^{\mu\nu\rho} + \beta B^{\mu\nu}B^{\alpha\beta}L_{\mu\nu\alpha\beta} - V(X)$$

- (Kalb-Ramond, KR) 2-form field:

$$B_{\mu\nu}$$

- Dual 2-form field:

$$\tilde{B}_{\mu\nu} \equiv \frac{1}{2}\varepsilon_{\mu\nu\alpha\beta}B^{\alpha\beta}$$

- Double dual Riemann tensor:

$$\begin{aligned} L_{\mu\nu\alpha\beta} \equiv\ & R_{\mu\nu\alpha\beta} + R_{\mu\beta}g_{\nu\alpha} + R_{\nu\alpha}g_{\mu\beta} \\ & - R_{\mu\alpha}g_{\nu\beta} - R_{\nu\beta}g_{\mu\alpha} \\ & + \frac{1}{2}R\left(g_{\mu\alpha}g_{\nu\beta} - g_{\mu\beta}g_{\nu\alpha}\right) \end{aligned}$$

- Field strength:

$$H_{\mu\nu\rho} \equiv 3\nabla_{[\mu}B_{\nu\rho]}$$

Methods & Results (1)

- Construct 4D action from $B_{\mu\nu}, \widetilde{B}_{\mu\nu}, R_{\mu\nu\alpha\beta}$.

  $\supset$ Ghost DoFs $\rightarrow$ Constrain the coefficients of these terms to zero.

  Redefining of 2-forms $\rightarrow$ The action can be brought into the same form as that studied by L. Heisenberg & G. Trenkler (2020).

$$\mathcal{L} = \frac{M_{\mathrm{Pl}}^2}{2} R - \frac{1}{12} F_{\mu\nu\rho} F^{\mu\nu\rho} + \beta A^{\mu\nu} A^{\alpha\beta} L_{\mu\nu\alpha\beta} - V(X_A, Y_A)$$

$$A_{\mu\nu} = B_{\mu\nu} + \alpha \widetilde{B}_{\mu\nu}, \quad F_{\mu\nu\rho} := 3\nabla_{[\mu} A_{\nu\rho]}, \quad X_A := A^{\mu\nu} A_{\mu\nu}, \quad Y_A := A^{\mu\nu} \widetilde{A}_{\mu\nu}$$

- Inconsistency with the isotropy $\rightarrow$ Introduce triplet of 2-form fields.

$$\mathcal{L} = \frac{M_{\mathrm{Pl}}^2}{2} R - \frac{1}{12} F^{(a)}_{\mu\nu\rho} F^{\mu\nu\rho}_{(a)} + \beta A^{\mu\nu}_{(a)} A^{\alpha\beta}_{(a)} L_{\mu\nu\alpha\beta} - V(X, Y) + \mathcal{L}_{\mathrm{m}}$$

$$F^{(a)}_{\mu\nu\rho} := 3\partial_{[\mu} A^{(a)}_{\nu\rho]}, \quad X := A^{\mu\nu}_{(a)} A^{(a)}_{\mu\nu}, \quad Y := A^{\mu\nu}_{(a)} \widetilde{A}^{(a)}_{\mu\nu}$$

Methods & Results (2)

- Conditions that tensor perturbations should satisfy

Ghost-free	$U > 0$
Real propagation speed	$U > 2\beta\dot{H}$

$$U := -2\beta H^2 + V_X$$

- Chirality of GWs

  Picking up parity violating term from the action

  →Chiral GWs arise if

  the potential depends on Y and consequently $\phi_E \neq 0.$