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Contributory: Dynamical analysis of Bianchi type-IX cosmology with a scalar field mediated dark sector interaction

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The recent DESI DR2 preference for a time-varying dark-energy equation of state, together with the long-standing difficulty of explaining why an initially anisotropic universe should evolve toward isotropy, motivates the study of interacting dark-sector models in anisotropic backgrounds. We investigate the dynamics of Bianchi type-IX cosmologies containing pressureless dark matter coupled to dark energy in the form of a quintessence scalar field ϕ with exponential potential $V(\phi) = V_0 e^{-\lambda\phi}$. Energy exchange between the two dark components is mediated by the scalar field through the interaction term $Q = \kappa\beta\dot{\phi}\rho_{\text{DM}}$, where $\kappa^2 = 8\pi G$ and β is a dimensionless coupling. Because Bianchi-IX models generically recollapse, the Hubble scalar H vanishes at the moment of maximum expansion, where the expansion-normalized variables of the standard Wainwright-Ellis formalism diverge. We therefore adopt the D -normalized phase-space formalism of Hewitt, Uggla, and Wainwright, which compactifies the state space and remains regular through the recollapse, including the moment of maximum expansion at which $H = 0$. Together with the modified conservation equations for the two dark components, the Einstein Klein Gordon system reduces to a closed autonomous polynomial dynamical system, whose fixed points we classify by linear stability analysis, supplemented by center-manifold theory for the non-hyperbolic points. The fixed points shows the kinetic-dominated, coupling modified matter dominated, curvature scalar, scalar field dominated and coupled scaling families; the last is the anisotropic analogue of the Amendola scaling attractor. Restricting to the initially expanding, isotropizing trajectories, we map the region of the (λ, β) plane in which anisotropic Bianchi-IX models approach an accelerating Friedmann Robertson Walker state.

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