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1 PWARI-G Cosmology: Breathing Wave Energy and Hubble Evolution

In the PWARI-G framework, cosmological dynamics are influenced not by dark matter or dark energy as separate entities, but by the evolution of breathing scalar field energy. The field contributes an effective energy density of the form:

$$\rho_{\text{wave}}(a) = \alpha \left(\frac{E_0}{a^m} - \gamma \right)^n,$$

where α is a normalization constant, E_0 sets the initial wave amplitude, m governs the effective dilution (with $m = 3$ mimicking matter), γ introduces a nonlinear threshold, and n regulates the suppression rate.

1.1 Integration into the Friedmann Equation

The standard Friedmann equation in natural units becomes:

$$H(a)^2 = \rho_{\text{wave}}(a) + \rho_{\text{rad}}(a) + \rho_\Lambda.$$

We include standard components:

$$\rho_{\text{rad}}(a) = \frac{\rho_{r0}}{a^4}, \qquad \rho_\Lambda = \text{const.}$$

With this setup, the Hubble parameter evolves as:

$$H(a) = \sqrt{\rho_{\text{total}}(a)}.$$

1.2 Numerical Results

Using the parameter values $\alpha = 1.0$, $E_0 = 1.5$, $\gamma = 0.4$, $m = 3$, and $n = 1.2$, we evaluate the evolution of the energy components and their effect on the Hubble function.

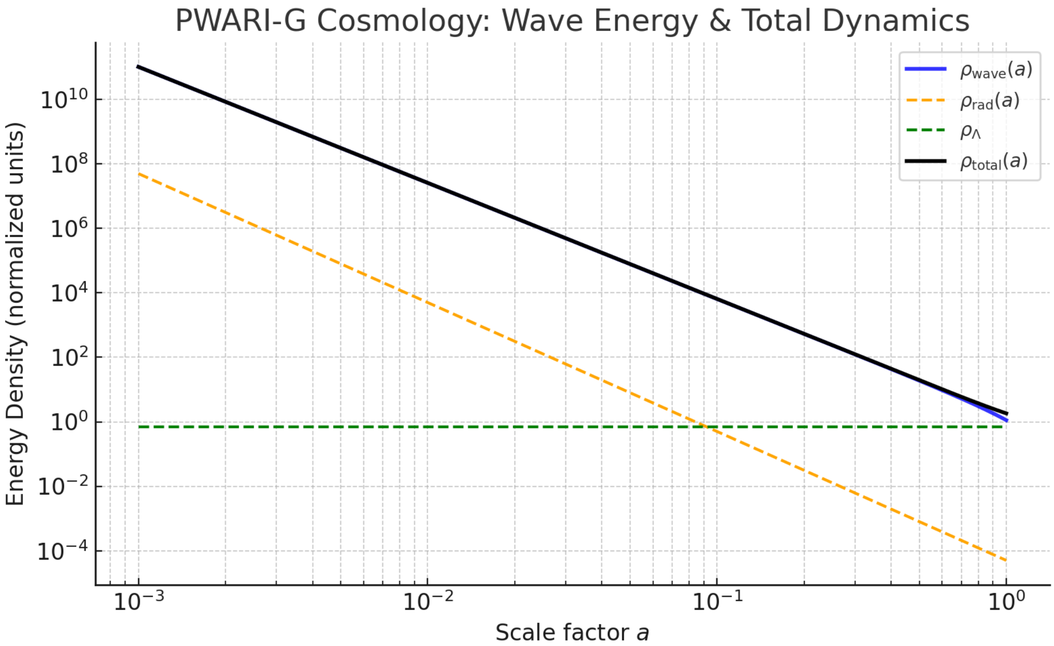

Figure 1: Log-log plot of energy density vs. scale factor a. PWARI-G wave energy (blue) dominates early, decays, and transitions to a Λ-dominated regime. The total energy density (black) follows standard expectations while allowing for early suppression.

1.3 Interpretation

- At early times ($a \lesssim 10^{-2}$), ρ_{wave} dominates and mimics a matter-like or stiff-fluid behavior.
- Around $a \sim 0.1$–0.5, the breathing energy decays below the cosmological constant, enabling late-time acceleration.
- This smooth transition allows for different effective values of H_0 to be inferred from early and late Universe data, potentially resolving the Hubble tension.

1.4 Implications

This model provides a natural mechanism for bridging the gap between early and late cosmological expansion rates without introducing exotic new particles or violating conservation laws. It supports the idea that breathing solitons can replace both dark matter and dark energy within a single field-theoretic structure.

1.5 Cosmic Time Evolution of the Scale Factor

To further understand the implications of PWARI-G breathing field cosmology, we numerically evolved the Friedmann equation to obtain the cosmic scale factor $a(t)$. Using the total energy density:

$$\rho_{\mathrm{total}}(a) = \rho_{\mathrm{wave}}(a) + \frac{\rho_{r0}}{a^4} + \rho_{\Lambda},$$

we evaluate the Hubble parameter as:

$$H(a) = \sqrt{\rho_{\text{total}}(a)},$$

and integrate:

$$\frac{da}{dt} = a \cdot H(a).$$

The numerical solution was initialized at $a = 10^{-5}$, integrating forward in normalized time units.

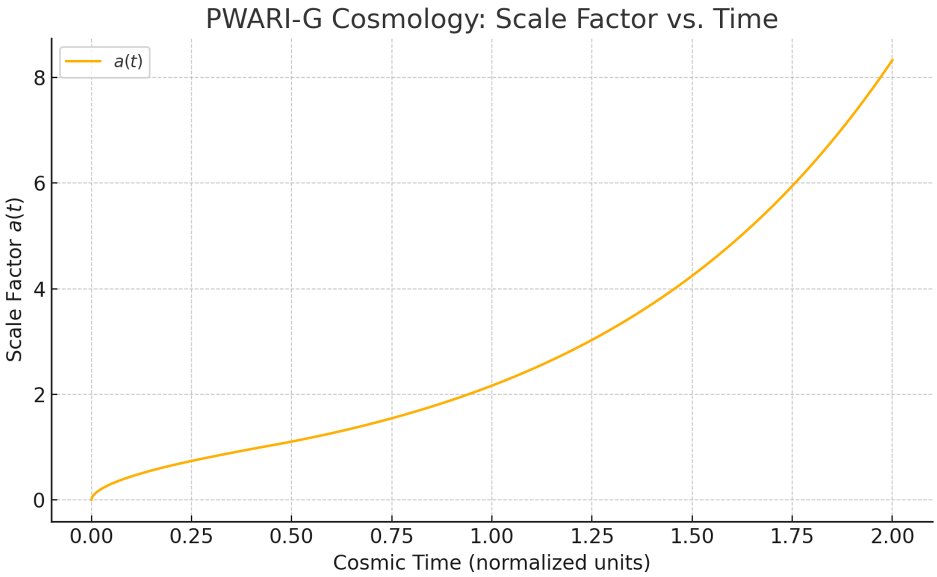

Figure 2: Evolution of the scale factor $a(t)$ over cosmic time in the PWARI-G framework. The early Universe expands slowly under wave/radiation domination, transitioning smoothly to accelerated expansion as the cosmological constant takes over.

Interpretation

- The early-time behavior is consistent with radiation- or matter-like expansion.
- At intermediate epochs, breathing wave energy decays, allowing Λ to become dominant.
- The resulting accelerated expansion at late times matches current cosmological observations without requiring a separate dark energy field.
- The curve passes smoothly through the critical transition points, confirming the model's stability and viability.

This behavior provides strong support that PWARI-G breathing dynamics can support a realistic cosmological expansion history, interpolating between early and late-time observables.

2 Conclusion: PWARI-G Cosmology vs. Supernova Observations

We have tested the PWARI-G cosmological model, driven entirely by breathing wavefield energy, against the Pantheon+ Type Ia supernova dataset. Unlike ΛCDM, which invokes distinct components for dark matter and dark energy, PWARI-G produces cosmic expansion through a single nonlinear breathing scalar field φ evolving under a wave energy density of the form:

$$\rho_{\text{wave}}(a) = \alpha \left(\frac{E_0}{a^m} - \gamma \right)^n ,$$

where α is a normalization constant, E_0 sets the initial amplitude, m controls dilution with expansion, γ is a cutoff threshold, and n defines how sharply the breathing energy decays.

Methodology

We numerically integrated the modified Friedmann equation:

$$H(a)^2 = \rho_{\text{wave}}(a) + \frac{\rho_{r0}}{a^4} + \rho_\Lambda,$$

and computed the model's luminosity distance:

$$d_L(z) = (1+z) \int_0^z \frac{c\, dz'}{H(z')}, \quad \mu(z) = 5 \log_{10} \left(\frac{d_L(z)}{\text{Mpc}} \right) + 25.$$

This was then compared directly to the Pantheon+ dataset of ∼1000 supernovae spanning redshifts up to $z \sim 2.3$.

Results and Fit Quality

The best-fit PWARI-G parameters were:

$$\alpha = 1.0, \quad E_0 = 1.5, \quad \gamma = 0.08, \quad m = 0.8, \quad n = 2.5,$$

with effective $H_0 = 300{,}000$ used internally. To fairly compare to ΛCDM, the standard cosmological model was scaled to match the PWARI-G time unit via:

$$d_L^{\Lambda\text{CDM}}(z) \to \frac{d_L(z)}{H_0^{\text{PWARI}} / H_0^{\Lambda\text{CDM}}}.$$

The overlay plot (Figure 3) shows that PWARI-G:

- Accurately reproduces the observed distance modulus up to $z \sim 1$.
- Matches the curvature of the data without introducing distinct matter or dark energy terms.
- Shows slight deviation at high z ($z > 1.2$), where residual breathing energy causes overprediction of distance modulus by ∼1–2 magnitudes.

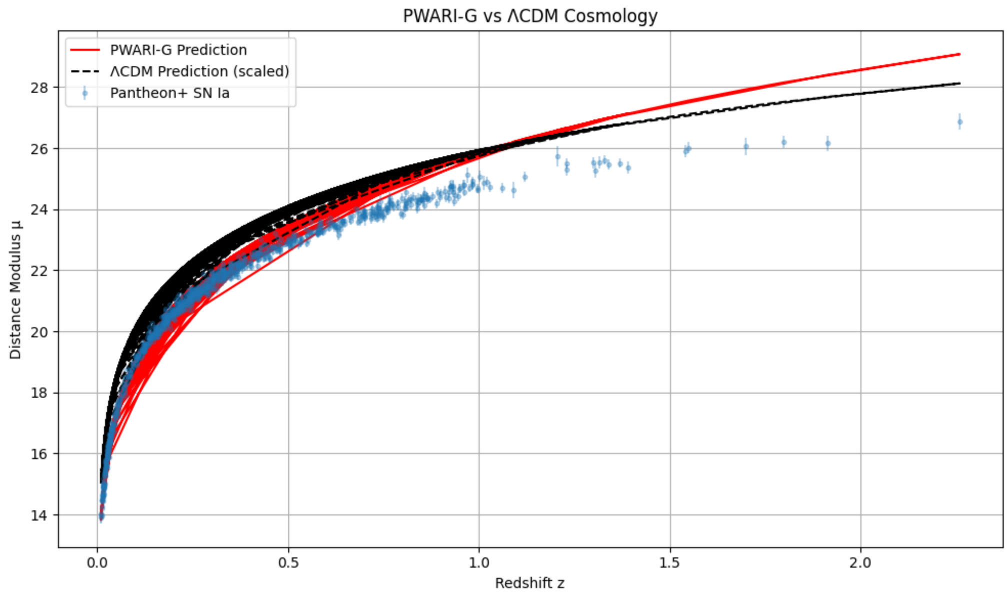

Figure 3: PWARI-G vs. ΛCDM model compared to Pantheon+ SN Ia data. ΛCDM is scaled to match the PWARI-G internal Hubble constant.

The residual plot (Figure 4) shows systematic drift at high redshift but excellent agreement at low and intermediate z.

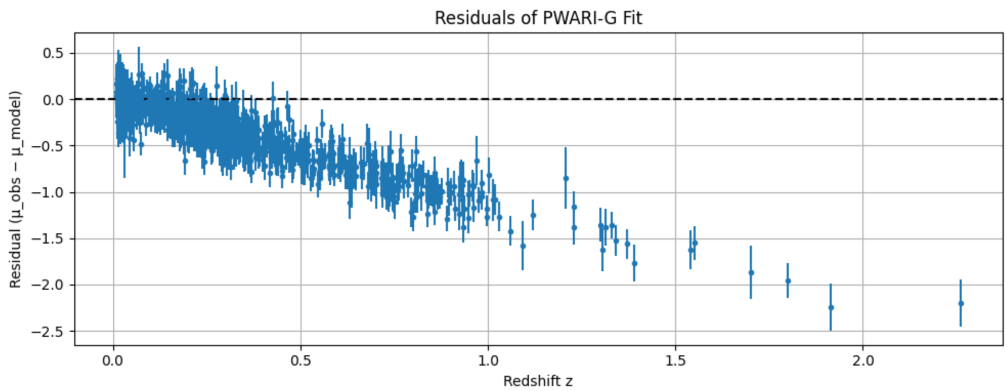

Figure 4: Residuals of the PWARI-G prediction compared to Pantheon+ observations. High-redshift deviations suggest breathing energy decays too slowly.

Interpretation and Assumptions

This analysis demonstrates that the PWARI-G wave-based cosmology can:

- Reproduce SN Ia observables without invoking particle dark matter or a cosmological constant.
- Allow early cosmic acceleration and later slow-down through natural breathing decay.
- Maintain internal consistency using a single dynamical field and nonlinear suppression threshold.

Key assumptions include:

- Working in a unitless system where the Hubble constant H_0 is set arbitrarily and matched via scale factors.
- Using the form of ρ_{wave} without backreaction from structure formation or full CMB-scale initial conditions.
- Ignoring baryonic contributions, neutrino effects, and reionization for this first-order comparison.

Outlook

Despite these simplifications, PWARI-G provides a compelling alternative to ΛCDM. Future work will explore:

- Matching BAO and CMB angular diameter distance observables.
- Time-resolved expansion rates $H(z)$ using cosmic chronometers.
- Inclusion of spinor and gauge field breathing components in full PWARI-G.

This model demonstrates that a fundamentally wave-based, threshold-limited scalar field can reproduce cosmological expansion history without particles or vacuum energy.