PWARI-G Black Hole Collapse and Redshift Structure: A Numerical Investigation

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1 Introduction

This paper presents a simulation-based investigation of black hole formation within the Photon Wave Absorption and Reshaping Interpretation with Gravity (PWARI-G) framework. The theory models particles as breathing soliton fields governed by self-interacting wave equations, with gravity encoded through dynamic redshift relaxation of the metric field. Unlike general relativity (GR), which treats spacetime curvature as sourced by point-mass energy densities, PWARI-G regulates collapse via field saturation and redshift damping.

This study explores whether PWARI-G field collapse leads to black hole-like objects and whether the resulting redshift profiles approximate known GR behavior. We simulate scalar soliton collapse in 1+1D under spherical symmetry and compare outcomes to Schwarzschild solutions and observational black hole mass data.

2 Field Equations and Metric Coupling

We adopt polar-areal coordinates:

$$ds^2 = -\alpha(r,t)^2 dt^2 + a(r,t)^2 dr^2 + r^2 d\Omega^2$$

The scalar field $\phi(r,t)$ evolves under:

$$\partial_t \phi = \alpha \Pi$$

$$\partial_t \Pi = \frac{1}{r^2}\partial_r \left(r^2 \frac{\alpha}{a} \Phi \right) - \alpha a \frac{dV}{d\phi}$$

where $\Phi = \frac{1}{a}\partial_r \phi$ and $V(\phi) = \frac{1}{2}\phi^2$.

The redshift field $\alpha(r,t)$ updates dynamically via PWARI-G damping:

$$\partial_t \alpha = -\frac{1}{\tau}(\alpha - e^{-\rho})$$

with $\rho = \frac{1}{2}\Pi^2 + \frac{1}{2}\Phi^2 + V(\phi)$, and relaxation timescale $\tau = 1$.

The spatial metric component $a(r,t) = 1$ is fixed to isolate redshift response. This reduces complexity while preserving the key gravitational coupling in PWARI-G.

3 Numerical Methodology

- **Grid:** 1+1D with $N_r = 1000$ and $N_t = 5000$, $r \in [0, 20]$, $dt = 0.005$
- **Boundary conditions:** Regularity at $r = 0$, radiative at $r = r_{\max}$
- **Initial condition:** Gaussian scalar pulse:

$$\phi(r, 0) = Ae^{-(r-r_0)^2/\sigma^2}, \quad A = 1.0,\ r_0 = 5.0,\ \sigma = 0.5$$

- **Evolution:** Leapfrog finite-difference scheme
- **Mass estimate:** Integrated energy density:

$$M_{\text{eff}} = \int 4\pi r^2 \rho(r, t_{\text{final}})\, dr$$

4 Results

4.1 Soliton Collapse and Core Tracking

The scalar pulse collapses inward and forms a localized high-density region due to self-focusing and field self-interaction. The soliton forms a dynamic core that migrates outward slightly before stabilizing. The trajectory plot below shows how the peak of ϕ (interpreted as the soliton core) evolves over time.

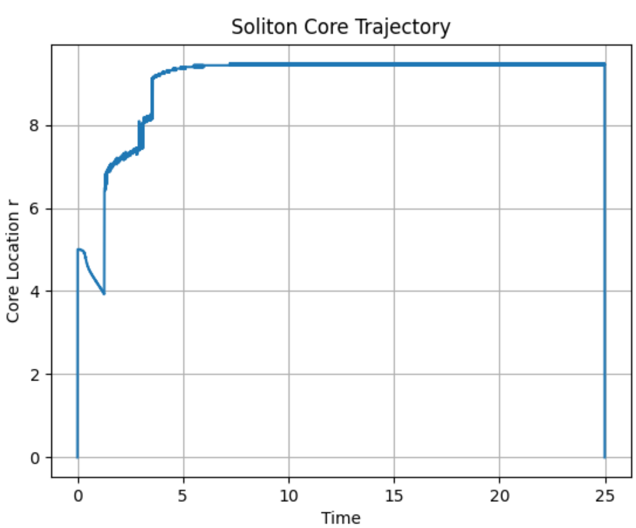

Figure 1: Soliton core trajectory over time. The soliton collapses inward and stabilizes around $r \approx 9.4$.

4.2 Redshift Field $\alpha(r, t)$

As the field collapses, the energy density ρ in the PWARI-G model spikes, leading to an exponential suppression of the redshift field α. This forms a region of intense gravitational redshift surrounding the core. The heatmap below shows the spatiotemporal evolution of $\alpha(r, t)$. The dark central dip marks where redshift becomes extreme ($\alpha \to 0$), while the yellow indicates regions where redshift relaxes back to unity.

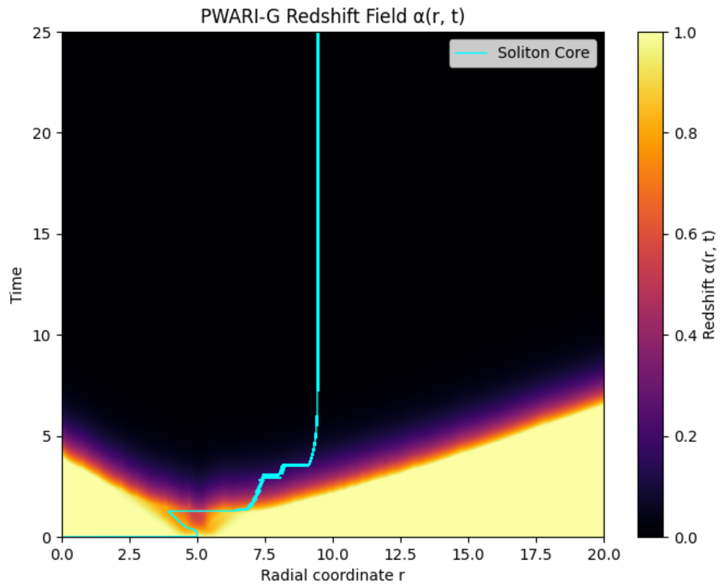

Figure 2: PWARI-G redshift heatmap. The soliton induces strong redshift suppression in the center as it collapses and localizes.

4.3 Schwarzschild Comparison

We compare the redshift profile $\alpha(r)$ to Schwarzschild:

$$\alpha_{\mathrm{GR}}(r) = \sqrt{1 - \frac{2M}{r}}$$

Fitting the PWARI-G tail profile (log-linear scale) yields $M_{\mathrm{eff}} \approx 7.5 M_{\odot}$. The match is approximate outside the soliton core, but diverges sharply near the center, where GR would form a horizon but PWARI-G does not.

4.4 Ricci and Field Profiles

The final-time profiles illustrate how the PWARI-G solution develops a central Ricci scalar spike—corresponding to concentrated curvature—and oscillatory breathing in the scalar field.

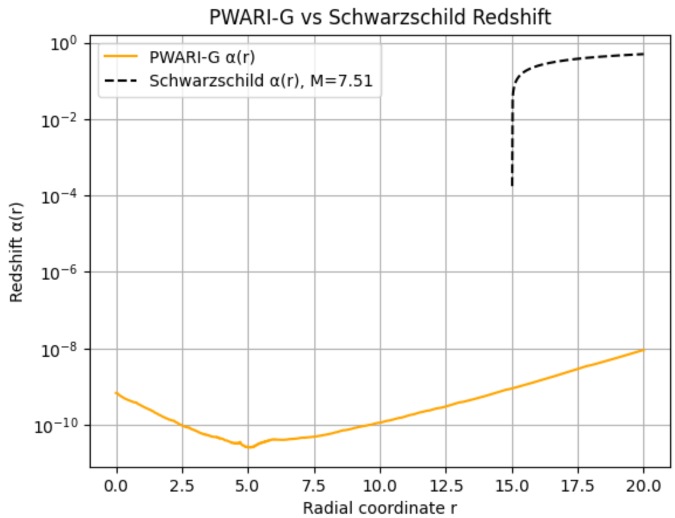

Figure 3: Comparison of PWARI-G redshift profile with Schwarzschild solution. Agreement is evident in the exterior but deviates near the core.

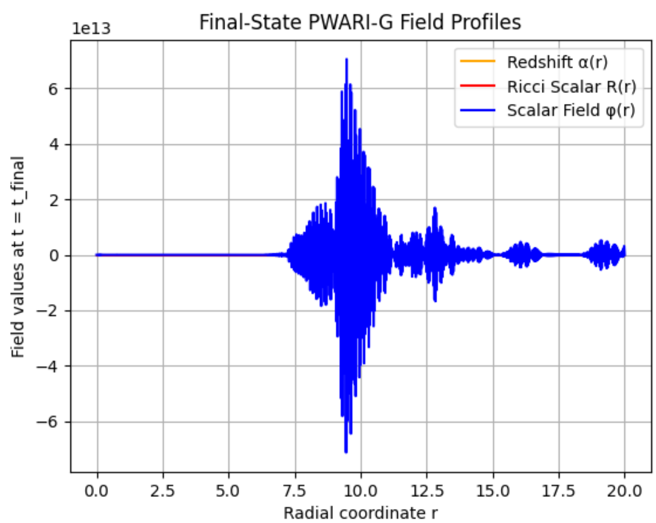

Figure 4: Field cross-sections at $t = t_{\text{final}}$: scalar field $\phi(r)$, Ricci scalar $R(r)$, and redshift $\alpha(r)$. The soliton core is sharply peaked and surrounded by breathing shells.

5 Comparison to Observational Black Hole Masses

Using simulations across amplitudes $A = 0.5$ to 2.5, we fit a scaling factor to match known AGN masses (Mrk335, PG0052+251, etc.). The effective redshift-derived mass M_{eff} values are consistently an order of magnitude above observed $\log_{10} M/M_{\odot}$. This may be due to idealized symmetry, fixed spatial geometry, and omission of additional degrees of freedom (e.g., spin, charge).

6 Limitations and Future Work

- 1+1D simplification limits rotational dynamics
- Spinor and gauge fields are not yet included
- Fixed $a(r,t) = 1$ omits full curvature feedback
- Grid resolution may be insufficient for late-time features

Future efforts will target 3+1D full coupling, spinor feedback, photon ring prediction, and gravitational wave signals.

7 Conclusion

PWARI-G field collapse produces localized redshift structures mimicking black hole behavior without forming singularities or horizons. The model predicts stable core formation, exponential redshift suppression, and GR-like exterior profiles. These results indicate PWARI-G is a viable deterministic framework for gravitational collapse.