Observational Tests of Quantum Extensions of Schwarzschild Spacetime in Loop Gravity

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Background

- General relativity predicts **singularities** where theory breaks down
- **Loop quantum gravity (LQG)** aims to resolve singularities
- LQG models black holes using **polymer-like quantization**
- Can test LQG models observationally, like with galactic center orbits
- This paper tests specific LQG Schwarzschild black hole model

$$b \rightarrow \frac{sin(\delta_b b)}{\delta_b}$$

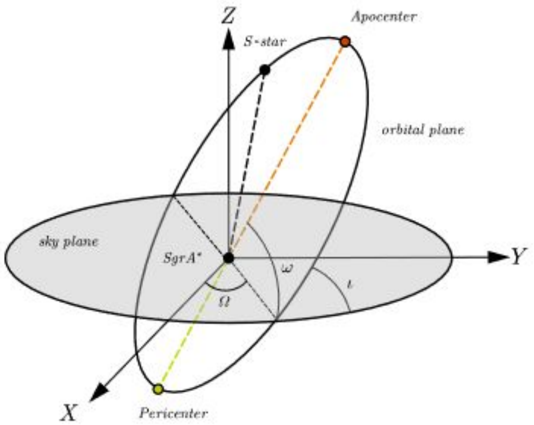
LQG Schwarzschild Black Hole Model

- Uses polymer-like quantization with parameter A_λ controlling quantum effects
- Singularity replaced by **quantum bounce** connecting black hole and white hole regions
- Metric functions quantized using holonomy modifications
- Derived full metric equations for quantum-extended Schwarzschild spacetime
- Massive particle motion transformed to perturbed Kepler problem

$$ds^2 = -f(x)d\tau^2 + \frac{dx^2}{f(x)} + h^2(x)(d\theta^2 + \sin^2\theta d\phi^2),$$

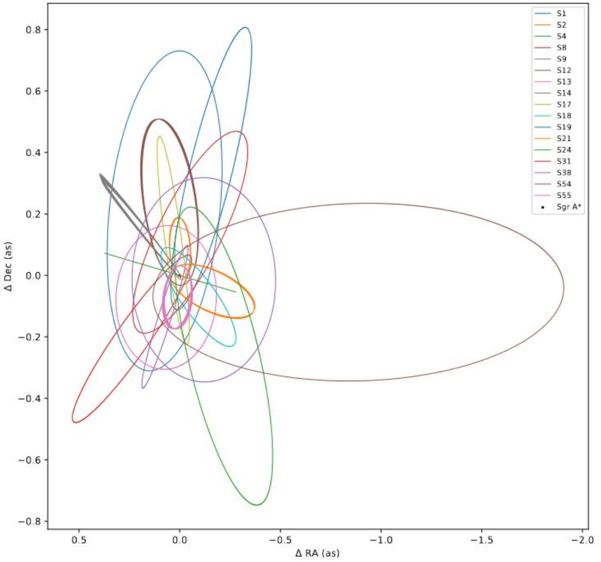
Deriving Pericenter Precession

- LQG effects enter geodesic equation as additional perturbing force
- Causes precession of elliptical orbits of massive particles
- Pericenter advance per orbit depends on mass, semi-major axis, eccentricity
- Also linearly depends on LQG parameter A_λ
- As A_λ increases, precession decreases



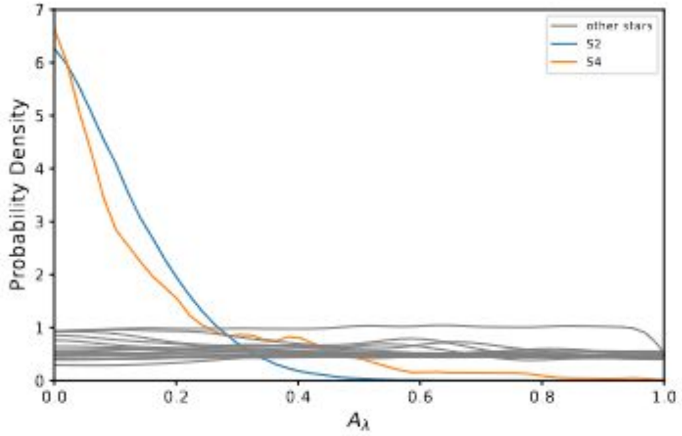
Data Analysis

- Used data on positions, velocities, orbital precession of 17 S-stars orbiting Sgr A*
- Modeled orbits in LQG spacetime and compared to observations
- Accounted for Rømer time delay and relativistic effects
- Performed **MCMC** analysis to constrain A_λ
- Explored 14D parameter space with uniform priors



Result

- Data from S2 star gave strongest constraint on A_λ
- 95% upper limit: $A_\lambda < 0.302$
- Posterior distribution shows peak at $A_\lambda = 0$
- No significant evidence for LQG effects
- Consistent with general relativity



Conclusion

- Provides first constraint on this LQG model using galactic center orbits
- Results consistent with GR, no clear quantum gravity signal
- Demonstrates galactic center useful for testing strong gravity theories
- More data could improve constraints in future work
- Important to keep testing LQG models observationally

Discussion

- Could improve analysis by combining all data in global fit
- Computationally challenging due to large parameter space
- Need to test other LQG black hole models and predictions
- Prospects for tighter constraints from future galactic center observations
- Confronting LQG with observations crucial to develop theory

Citation

[1] J. Yan, C. Liu, T. Zhu, Q. Wu, and A. Wang, "Observational tests of quantum extension of Schwarzschild spacetime in loop quantum gravity with stars in the galactic center," arXiv:2302.10482, 2023.