

Title: Possible Astrophysical Observables of Quantum Gravity Effects near Black Holes

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Abstract: Recent implications of results from quantum information theory applied to black holes has led to the confusing conclusions that requires either abandoning the equivalence principle (e.g. the firewall picture), or the no-hair theorem (e.g. the fuzzball picture), or even more unpalatable options. The recent discovery of a pulsar orbiting a black hole opens up new possibilities for tests of theories of gravity. We examine possible observational effects of semiclassical quantum gravity in the vicinity of black holes, as probed by pulsars and event horizon telescope imaging of flares. Pulsar radiation is observable at wavelengths only two orders of magnitude shorter than the Hawking radiation, so precision interferometry of lensed pulsar images may shed light on the quantum gravitational processes and interaction of Hawking radiation with the spacetime near the black hole. This paper discusses the impact on the pulsar radiation interference pattern, which is observable through the modulation index in the foreseeable future, and discusses a possible classical limit of BHC.

A Potential Astrophysical Test of Quantum Gravity

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Overview

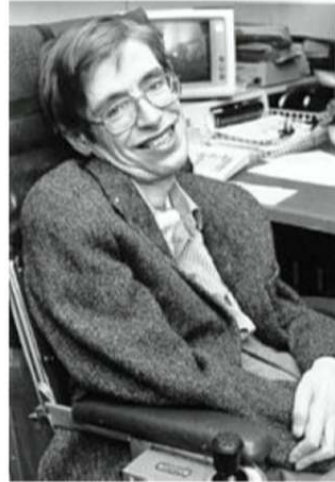
- ▶ First pulsar orbiting black discovered in 2013!
- ▶ Hawking Information problem
- ▶ Strings, Firewalls, Fuzzballs
- ▶ Pulsar lensing

Magnetar PSR J1745-2900



(credit: MPIfR/Ralph Eatough) mysterious discovery in 2013,
orbiting galactic center black hole. Rafikov-Lai (2006): precision
GR test?

Black Hole Information



Hawking (1974): black holes radiate: $T = hc/k_B r_s \sim \mu\text{K}$. High entropy: number of photons emitted $\sim mc^2/k_B T \sim S/k_B \sim 10^{77}$. Very slow: one photon of $\lambda \sim r_s \sim \text{km}$ each $\lambda/c \sim \text{ms}$. (1981): information loss? Evaporation is a Schwinger mechanism, does not depend on inside of black hole.



Dilemma

- ▶ No Hair: all black holes look identical after a short time (hour?)
- ▶ radiation only depends on outside of BH
- ▶ emitted radiation does not depend on formation history
- ▶ leads to microscopic time irreversibility of physics!
- ▶ breakdown of causality/unitarity?
- ▶ An initial pure state evolves into mixed state after a Page time (half the mass is lost).

Entropy solution

- ▶ string theory to the rescue!
- ▶ Strominger-Vafa (1996): counting of microstates
- ▶ unitarity saved?
- ▶ Stringy counting not possible in classical limit: what happens with Hawking's argument?

Firewalls: kill the messenger

- ▶ Almheiri, Marolf, Polchinski, Sully (2012)
- ▶ Schwinger pair creation at horizon: maximal entanglement
- ▶ late time photons must correlate with early photons: purity
- ▶ Quantum monogamy of entanglement violated!
- ▶ Solution: firewall near horizon kills would-be experimentalists/reporters who reveal violations
- ▶ Hawking 2014: microscopic violation of time reversibility?

Orders of orders of magnitude

- ▶ Saha, partition function: $\frac{P(n_1)}{P(n_0)} = \frac{g_1}{g_0} \exp\left(-\frac{\Delta E}{k_B T}\right)$
- ▶ probability to observe in substantially non-Schwarzschild state:
- ▶ $\Delta E \sim mc^2$
- ▶ $\frac{\Delta E}{k_B T} \sim 10^{77}$
- ▶ $S_1 \sim k_B \log g_1 \gtrsim 10^{77}$
- ▶ no-hair may be a great mis-estimate, off by 10^{77} orders of magnitude!

Fuzzballs

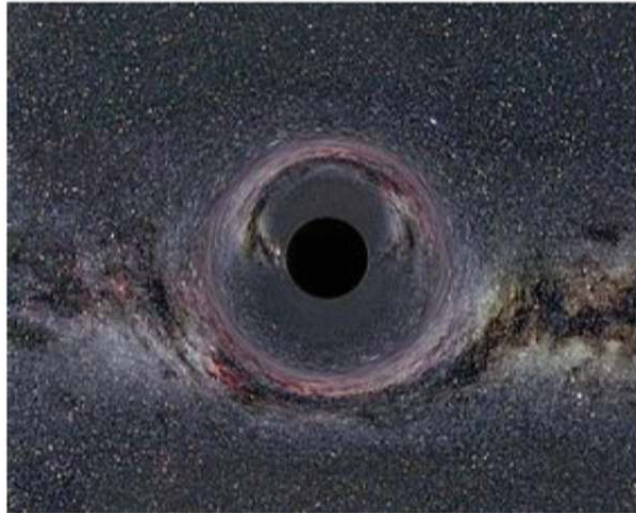


Samir Mathur+ (2002+): solutions to Hawking problem must be either non-local or hairy.

Fuzzballs

- ▶ constructive stringy solutions of some eigenstates: no horizon for no entropy
- ▶ classical Black Holes are superpositions of “naked” microstates
- ▶ analogous to giant complex quantum molecule
- ▶ evades Hawking’s argument: no Schwarzschild background
- ▶ multipole deviation from GR $\sim (r_S/r)^{l+2}$
- ▶ alternative to firewall: destruction of observer

Lens

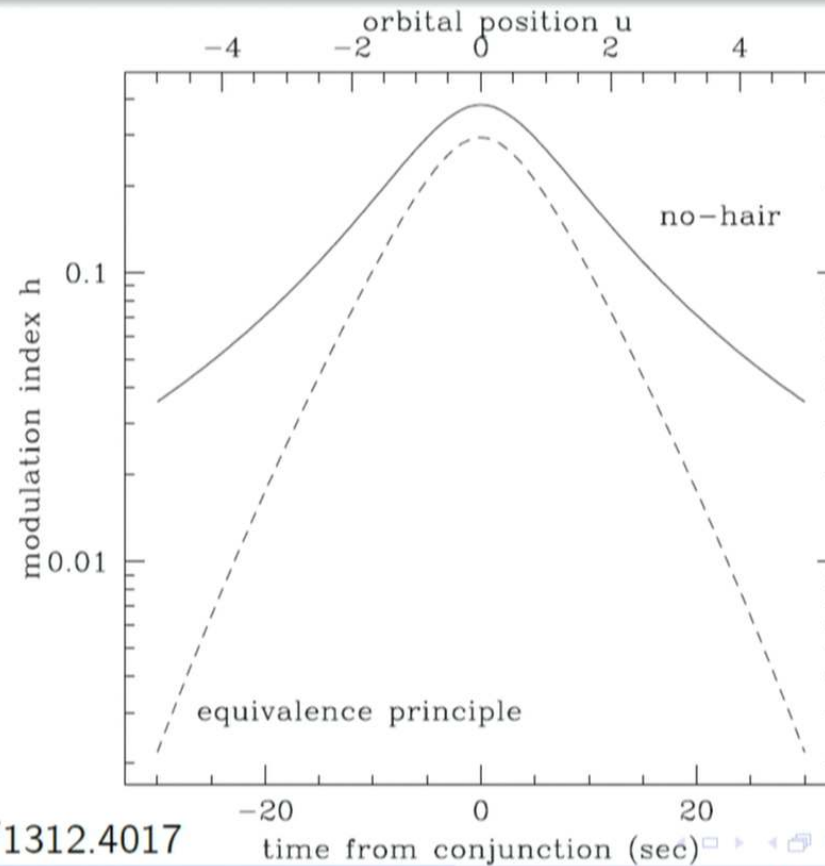


(credit: wikipedia) multiple imaging of pulsars: Boyle+ (2011+), Pen+ (2011+): interference of lensed images. Measure space-time metric to \sim mm at Einstein radius.

Lensing Prospects

- ▶ ideal setup: pulsar orbiting BH at $\sim 10,000r_S$
- ▶ inclination similar to Einstein radius $\sim 1^\circ$
- ▶ two main images form double slit interferometer (Young) near conjunction
- ▶ quantum entanglement with BH
- ▶ quantum lens: expect image decoherence $\sim 10^{-6}r_S \sim \text{cm}$
- ▶ order unity effect in scintillation pattern

Quantitative test



Pen 2013: arxiv/1312.4017

time from conjunction (sec)

U. Pen

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New surveys



10 pulsar-neutron star binaries, 1 pulsar-BH binary known. New surveys (e.g. SKA, CHIME+) will increase number 10+ fold.



Horizon

- ▶ LIGO: impact on gravitational wave emission?
- ▶ could think of final inspiral as a gravitational waves propagating in a fuzzy background?
- ▶ Event Horizon Telescope: strong lensing?
- ▶ measure collapsed states, or generate a fuzzy image?

Conclusions

- ▶ Astrophysical test of quantum gravity?
- ▶ Promising future if high inclination BH-PSR binaries are discovered
- ▶ large cylinder telescopes (e.g. CHIME+) for searching
- ▶ scientific test for some scenarios of quantum gravity:
coherence of pulsar scintillation
- ▶ potential implications for LIGO, EHT