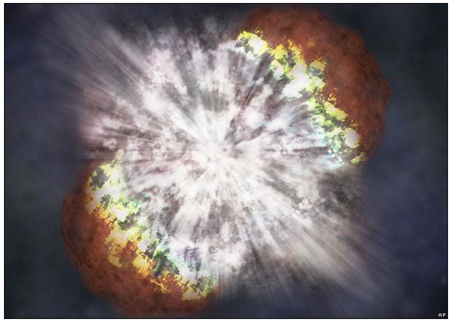
Searching for Extra Spatial Dimensions: A Black Hole-Neutron Star Binary System



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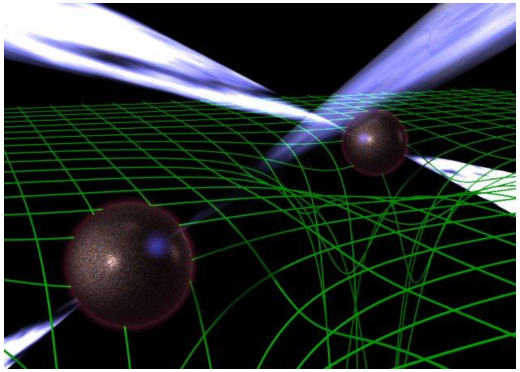
Pheno 2012

May, 8th 2012



Collaborators: John Simonetti, Djordje Minic, Vipin Vijayan & Umair Surani (Virginia Tech)

The Astrophysical Journal Letters, Volume 737, Issue 2, article id. L28 (2011).

Outline

Ingredients

- Enhanced black hole evaporation in warped extra dimensional models (RS 2)
- Binary black hole-pulsar systems

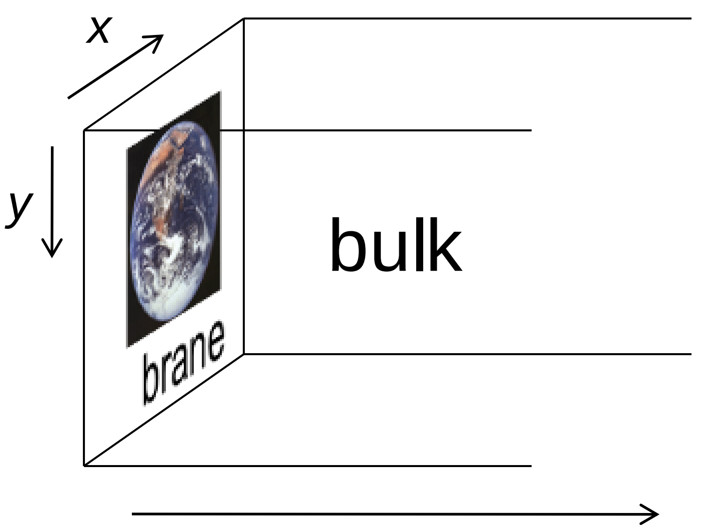
An astrophysical search

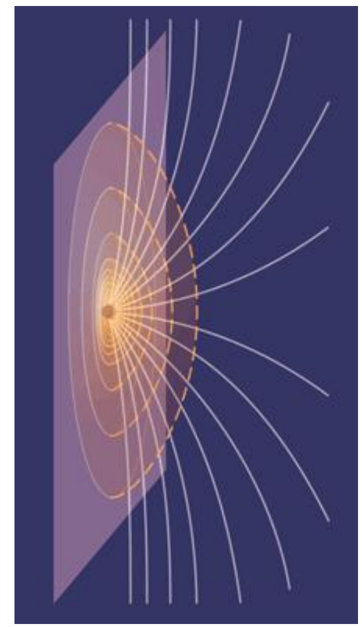
- Evolution of a black-hole-neutron-star binary:

  ~10 micron-scale extra dimension

Infinitely large
“warped” extra dimension

Randall-Sundrum 2
(1999)





Our brane --- flat, positive cosmological constant (tension),
standard model particles/forces confined to the brane

The bulk --- AdS: vacuum, negative cosmological constant, gravity only,
“warped” (redshift scaling factor confines gravitons near our brane)

Emparan, Fabbri, Kaloper (2002)
Emparan, García-Bellido, Kaloper (2003)

Enhanced black hole evaporation rate in RS 2 braneworld, due to a greatly enhanced number of emission modes

$$\dot{m}_{BH} = -2.8\times10^{-7} M_* \,\mathrm{y}^{-1}\left(\frac{m_{BH}}{M_*}\right)^{-2}\left(\frac{L}{10\mu\mathrm{m}}\right)^{2}$$

(*L* is the length scale of warp)

Lifetimes for *stellar-mass* black holes
< age of the universe

The "Binary Pulsar"
PSR 1913+16

Weisberg and Taylor 2005

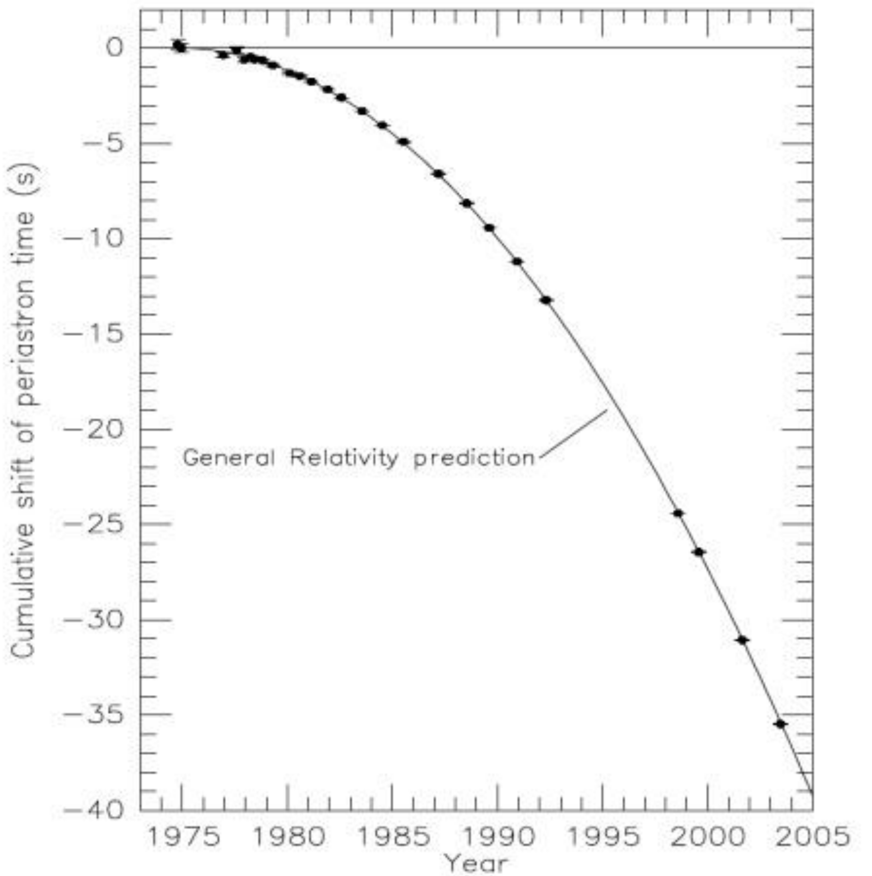
$a_p \sin i$ = 2.3417725(8) s

e = 0.6171338(4)

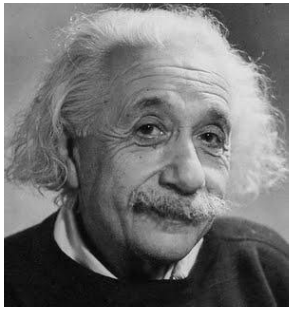
P = 0.322997448930 days (7.75 hours)

M_{pulsar} = 1.4414 +/- 0.0002 M_*

$M_{companion}$ = 1.3867 +/- 0.0002 M_*



dP/dt = (1.0013 +/- 0.0021) dP/dt_{GR}



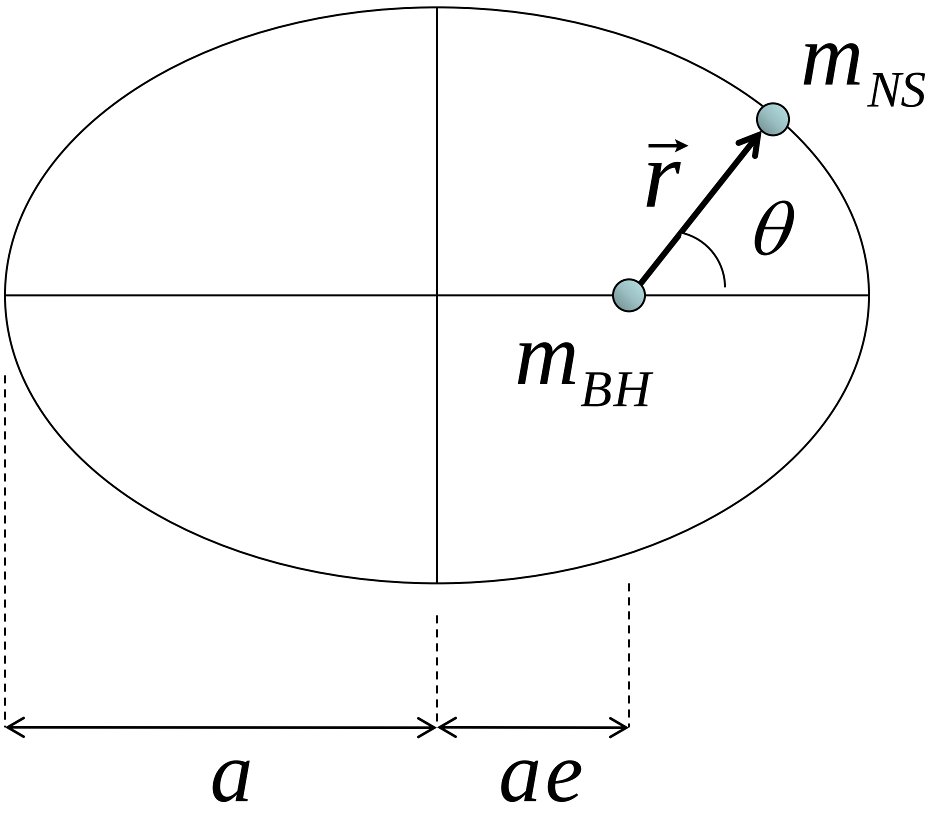
Hadjidemetriou (1963, 1967)
Binary systems with isotropic mass loss

$$\dot{a} = -a \frac{1 + 2e\cos\theta + e^2}{1 - e^2} \frac{\dot{m}}{m}$$

$$\dot{e} = -(e + \cos\theta) \frac{\dot{m}}{m}$$

$$\langle \cos\theta \rangle = -e$$

$$\dot{a} = -a \frac{\dot{m}}{m} = -a \frac{\dot{m}_{BH}}{m_{BH} + m_{NS}}$$



The Assembled Ingredients

$$\dot{a} = -a\frac{\dot{m}}{m} = -a\frac{\dot{m}_{BH}}{m_{BH} + m_{NS}}$$

$$\dot{m}_{BH} = -2.8\times10^{-7}\,M_*\ \mathrm{y}^{-1}\left(\frac{m_{BH}}{M_*}\right)^{-2}\left(\frac{L}{10\,\mu\mathrm{m}}\right)^{2}$$

__*A "Binary Pulsar ballpark"*__

P = 7.75 hours

BH mass = 3 M_* NS mass = 1.4 M_*

$$a = 2.26\times10^{9}\ \mathrm{m} = 3.25\ R_*$$ (KIII)

$$\dot{a} = 16\,\mathrm{m\,y^{-1}} \left(\frac{a}{3.25R_*}\right)\left(\frac{m_{BH}}{3M_*}\right)^{-2}\left(\frac{m_{BH}+m_{NS}}{4.4M_*}\right)^{-1}\left(\frac{L}{10\mu\mathrm{m}}\right)^{2}$$

$$P,\ a,\ \text{and}\ m = m_{BH} + m_{NS}$$

must satisfy Kepler's third law at any moment, so…

$$\dot{P} = \frac{3}{2}\frac{P}{a}\dot{a}\left(1 - \frac{1}{3}\frac{\dot{m}}{m}\frac{a}{\dot{a}}\right) = 2\frac{P}{a}\dot{a}$$

$$\dot{P} = 0.40\,\mathrm{ms\,y^{-1}} \left(\frac{P}{7.75\,\mathrm{hours}}\right)\left(\frac{m_{BH}}{3M_*}\right)^{-2}\left(\frac{m_{BH}+m_{NS}}{4.4M_*}\right)^{-1}\left(\frac{L}{10\mu\mathrm{m}}\right)^{2}$$

Precision on orbital period determination for PSR 1913+16

+/- 0.0016 ms y^{-1}

0.40 ms y^{-1} / 0.0016 ms y^{-1} = 25 sigma

Accepting 3 sigma results for a BH-NS binary system, we could set limits to

L ~ 3.5 microns


Thank you!!