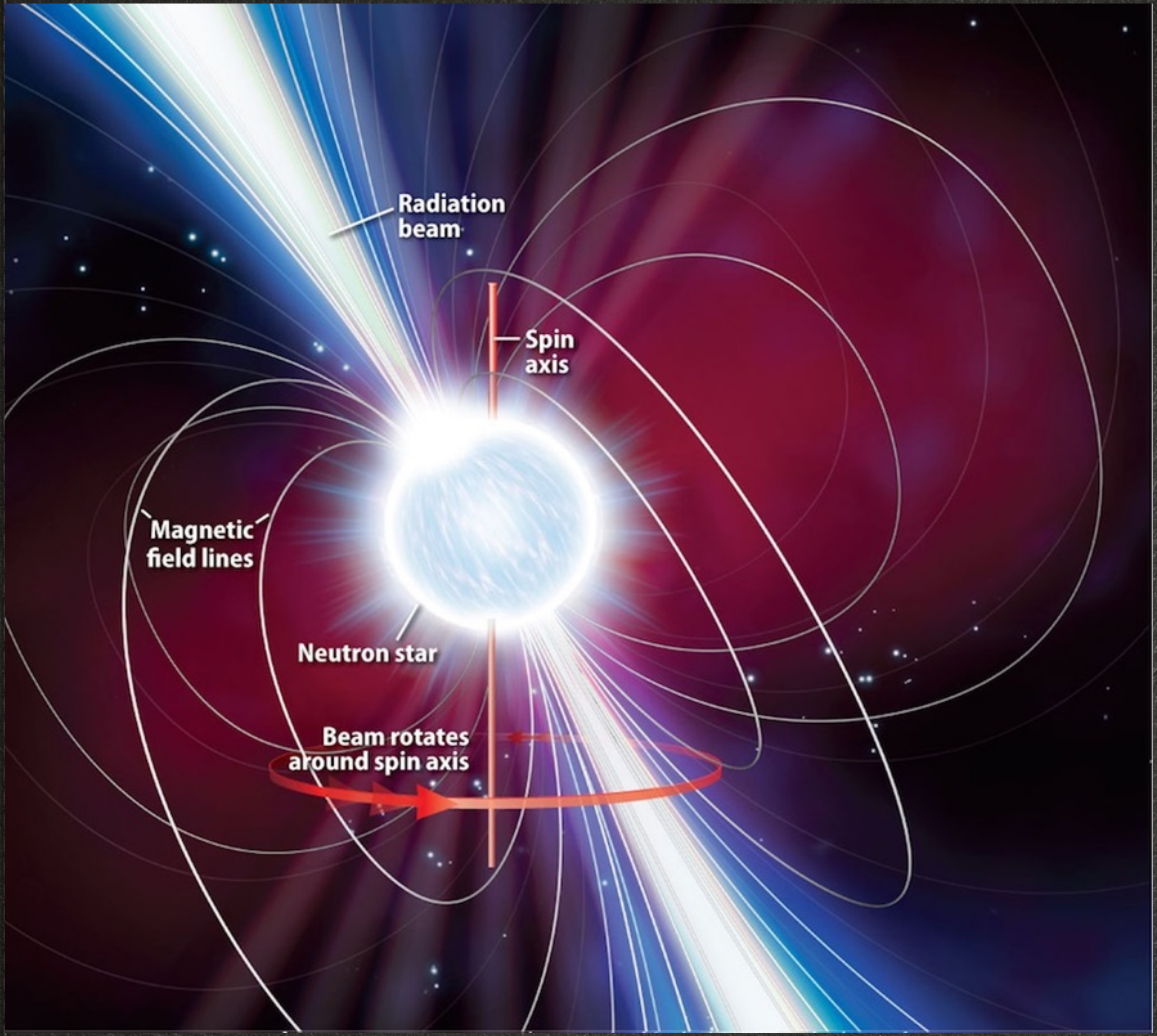
CONSTRAINTS ON POST-EINSTEINIAN PARAMETERS FROM BINARY PULSAR OBSERVATIONS

Remya Nair
eXtreme Gravity Institute, Montana State University

with
Nicolas Yunes

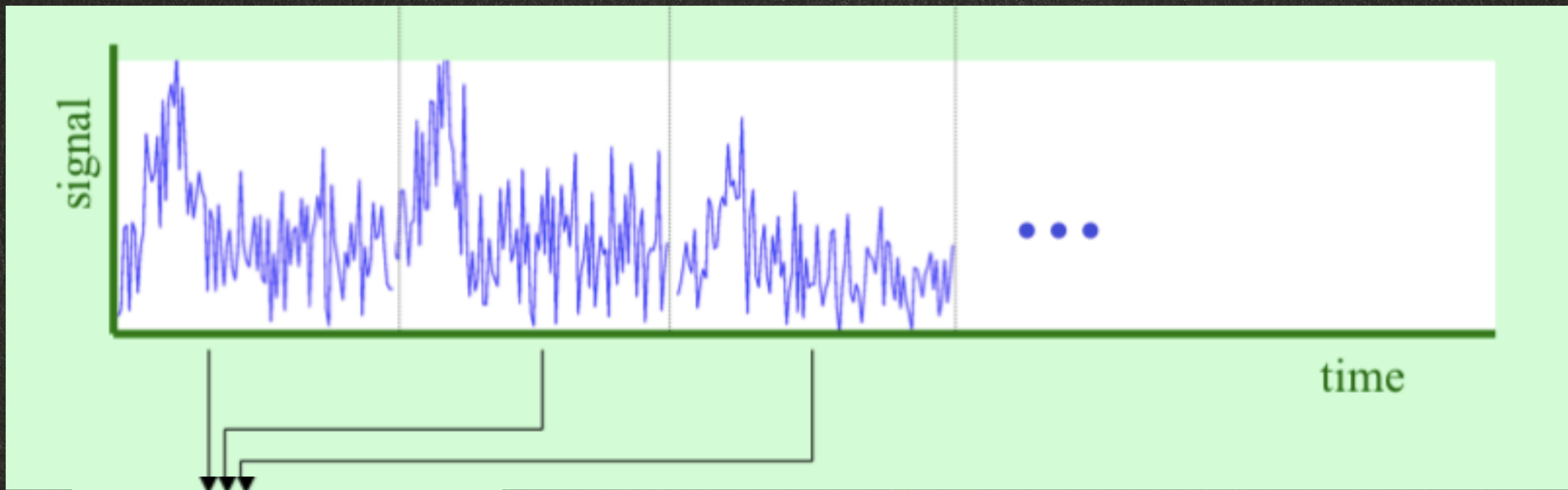
PULSAR



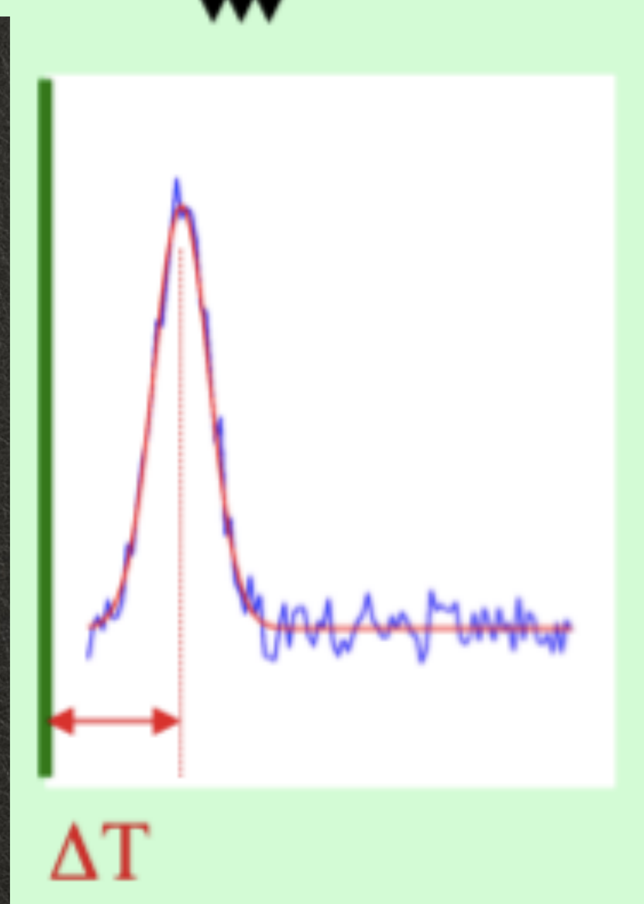
Highly magnetized, rotating neutron stars

Millisecond pulsars: fast and very stable rotation

PULSAR TIMING



David Nice



Fold signals → Pulse profile

Cross correlate the data profile with a standard profile

↓

TOA

'Average arrival time'

PULSARS IN BINARY ORBITS

Observations show periodic variation in pulse arrival time

Incorporate motion of the pulsar as it orbits the COM of the binary

Five Keplerian parameters - Orbital period, projected semi-major orbital axis, orbital eccentricity, longitude of periastron, epoch of periastron passage

Including relativistic effects due to strong gravitational field

Five Post- Keplerian parameters - Orbital decay, relativistic advance of periastron, Einstein delay, Shapiro delay

Post- Keplerian parameters ~ f(m1,m2,Keplerian parameters)

Observation of two PK parameters determine the masses uniquely

TESTING GENERAL RELATIVITY

Measurements of post-Keplerian parameters

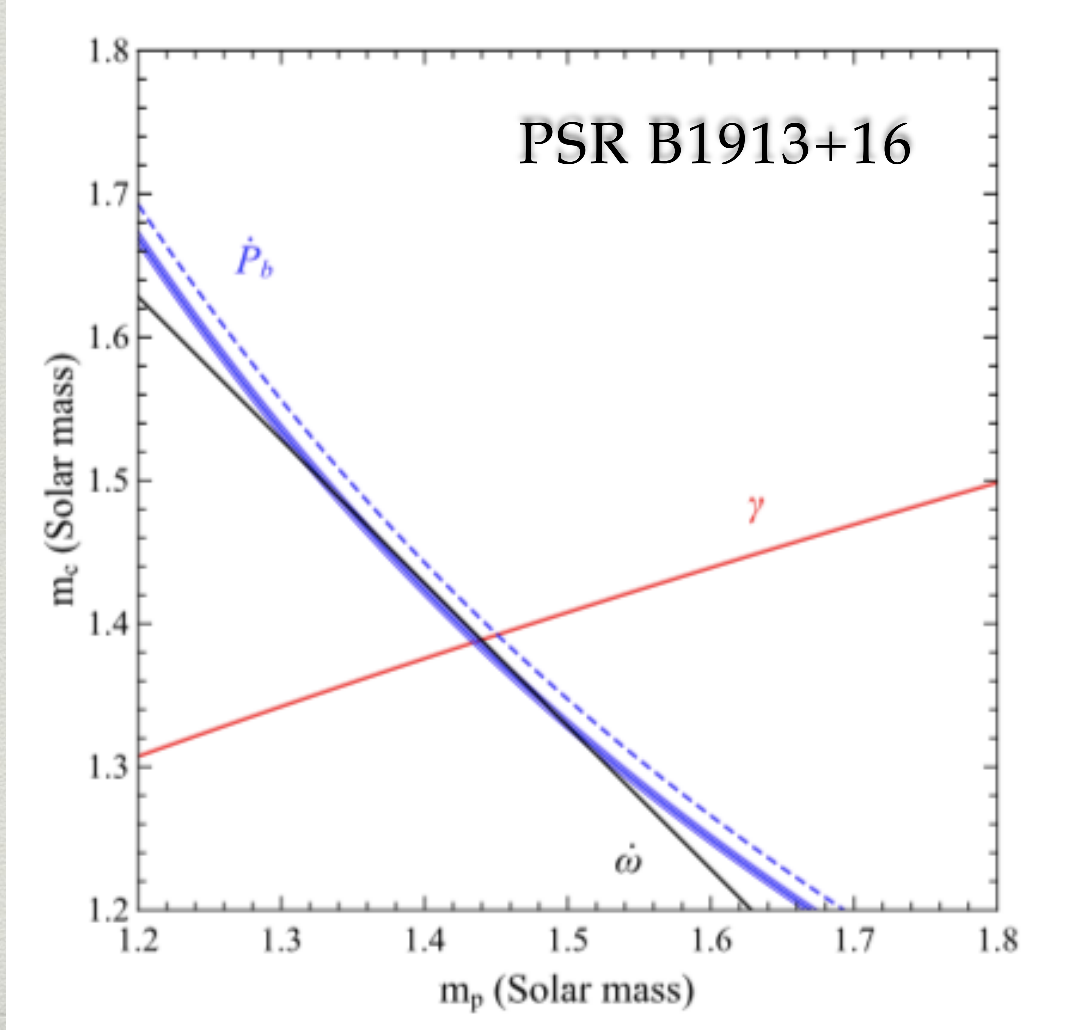
Advance of periastron $\dot{\omega} = 3G^{2/3}c^{-2}(P_b/2\pi)^{-5/3}(1-e^2)^{-1}(m_1+m_2)^{2/3}$

Time delay $\gamma_E = G^{2/3}c^{-2}(P_b/2\pi)^{1/3}em_2(m_1+2m_2)(m_1+m_2)^{-4/3}$

↓

$$m_1 = 1.4398 \pm 0.0002 M_\odot \qquad m_2 = 1.3886 \pm 0.0002 M_\odot$$

Weisberg et al., 2010



N. Wex, 2014

Any further pK measurements can be used as tests of the theory

TESTING GENERAL RELATIVITY

Model dependent tests

Test predictions from individual theories

GR $$\dot{\omega}_{GR} = \frac{3n_b}{1-e^2}\frac{V_b^2}{c^2}$$

$$V_b \equiv (GMn_b)^{1/3}$$

$T_1(\alpha_0, \beta_0)$ $$\dot{\omega}^{T_1} = \frac{n_b}{1-e^2}\left(\frac{3-\alpha_p\alpha_c}{1+\alpha_p\alpha_c} - \frac{m_p\alpha_p^2\beta_c + m_c\alpha_c^2\beta_p}{2M(1+\alpha_p\alpha_c)^2}\right)\frac{V_b^2}{c^2}$$

$$V_b = (G_*(1+\alpha_p\alpha_c)Mn_b)^{1/3}$$

Model independent tests

Devise tests that give generic predictions to test model independent deviations from GR

PPE FRAMEWORK

Deform the GR waveform with model independent parameters

$$\tilde{h} = \tilde{h}_{GR}(1 + \alpha f^a) \exp^{i\beta f^b}$$

Recover GR

$$(\alpha, a, \beta, b) = (0, a, 0, b)$$

BD prediction

$$(\alpha, a, \beta, b) = (0, a, \beta_{BD}, -7/3)$$

GW amplitude depends on rate of change of orbital frequency

↓

$$\dot{E} = \dot{E}_{GR}(1 + \alpha(4\eta)^c u^a)^2$$

$$\dot{F} = \dot{E}(dE_b/dF)^{-1}$$

GW phase depends on rate of change of orbital frequency

↓

$$\dot{E} = \dot{E}_{GR}\left(1 + \pi^2 \mathcal{M}^2 \beta (4\eta)^d b(b-1) u^{b-2} \left(\frac{d^2\psi_{GR}}{df^2}\right)^{-1}\right)$$

ORBITAL DECAY - PPE PARAMETERS

Connecting GW luminosity with binary pulsar observations

$$\frac{\dot{P}}{P} = -\frac{3}{2}\frac{\dot{E}}{E_b}$$

Corrections to the orbital decay

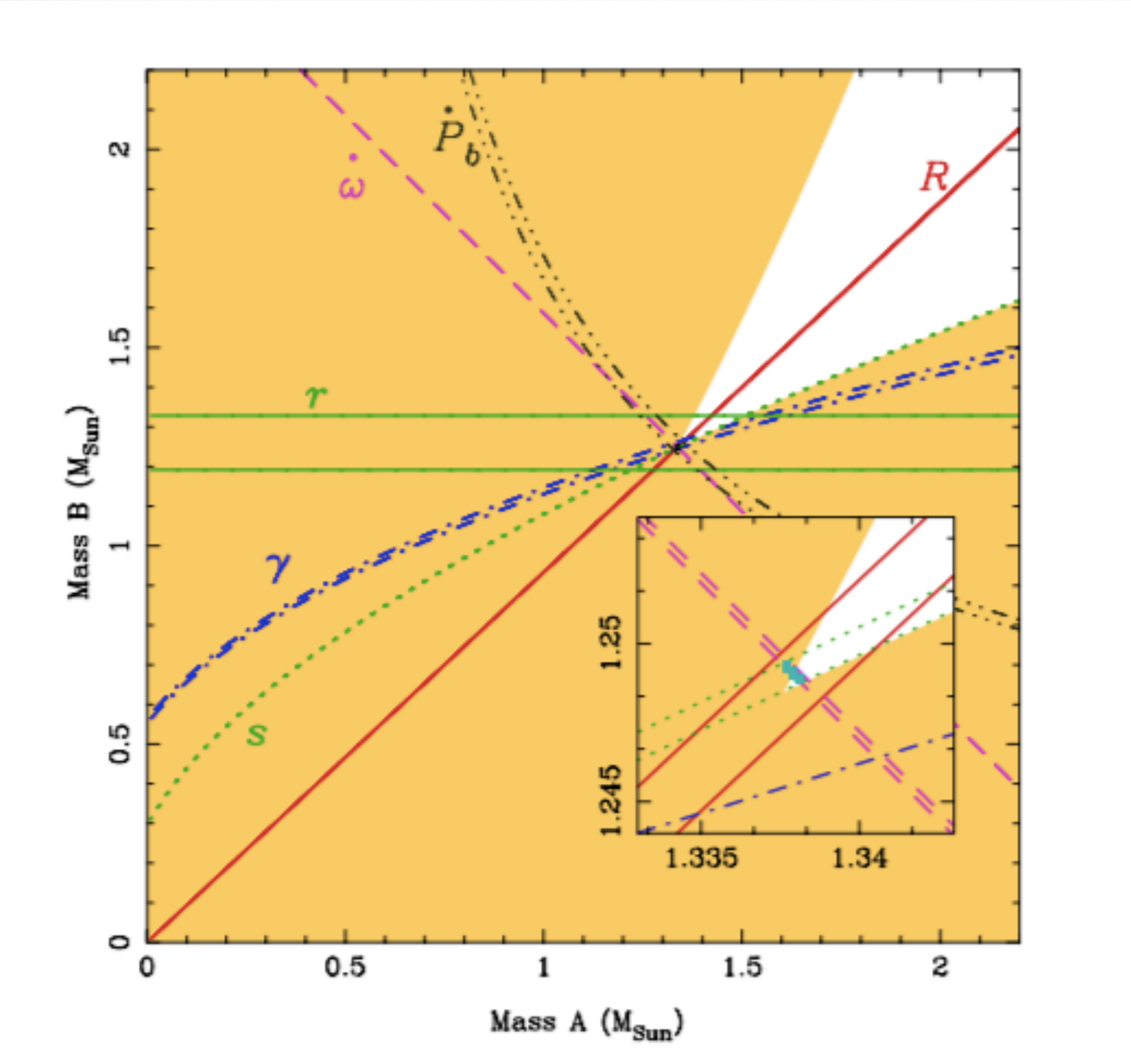
$$\frac{\dot{P}}{P} = \left(\frac{\dot{P}}{P}\right)_{GR} [1 + 2\alpha(4\eta)^c u^a]$$

$$\frac{\dot{P}}{P} = \left(\frac{\dot{P}}{P}\right)_{GR} \left[1 + \frac{48}{5}\beta(4\eta)^d b(b-1)u^{b+5/3}\right]$$

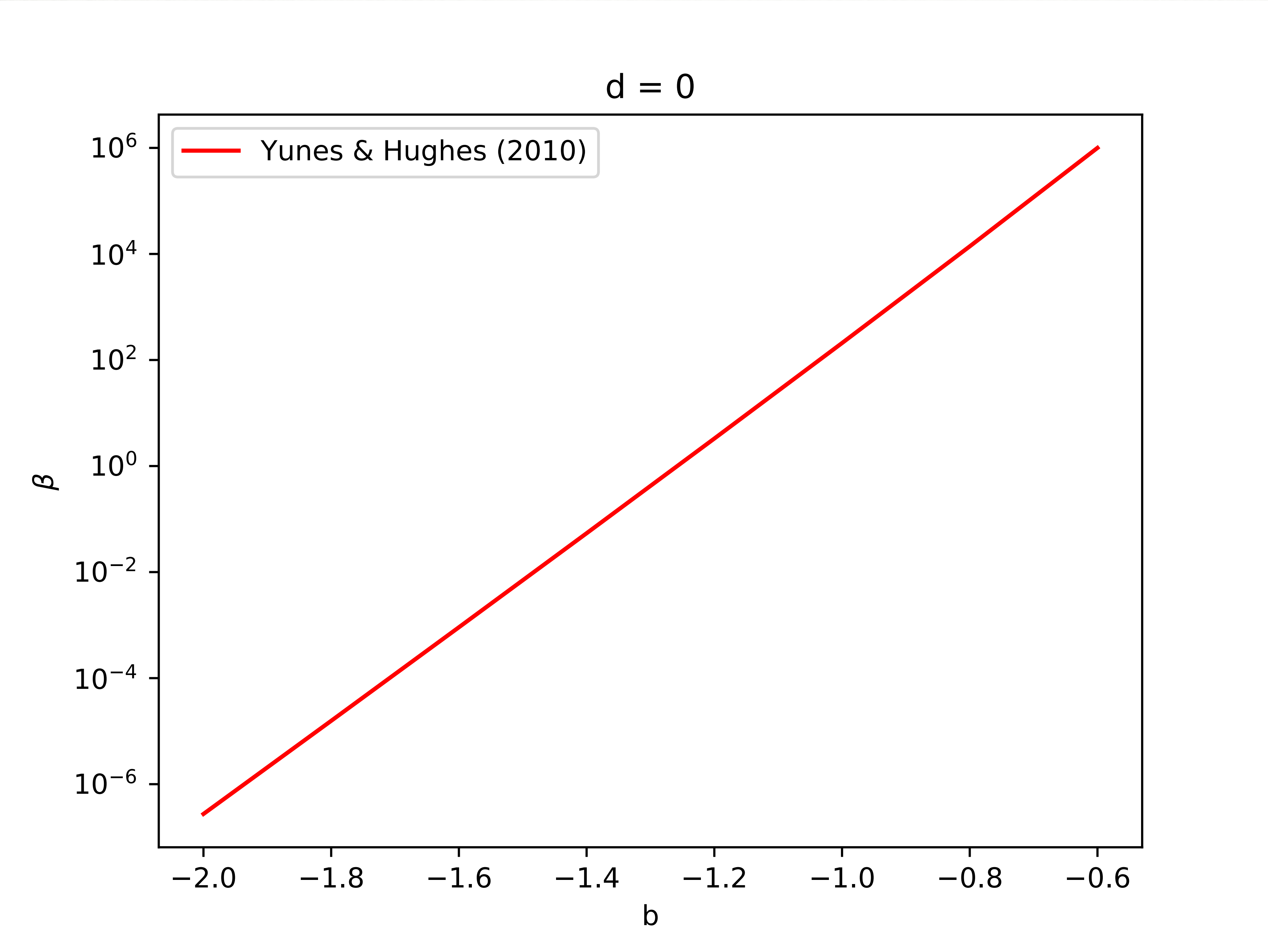
TESTING GENERAL RELATIVITY

Double Pulsar : J0737 - 3039A/B

Kramer and N. Wex, 2009, N Wex 2014.



CONSTRAINTS ON PPE PARAMETERS

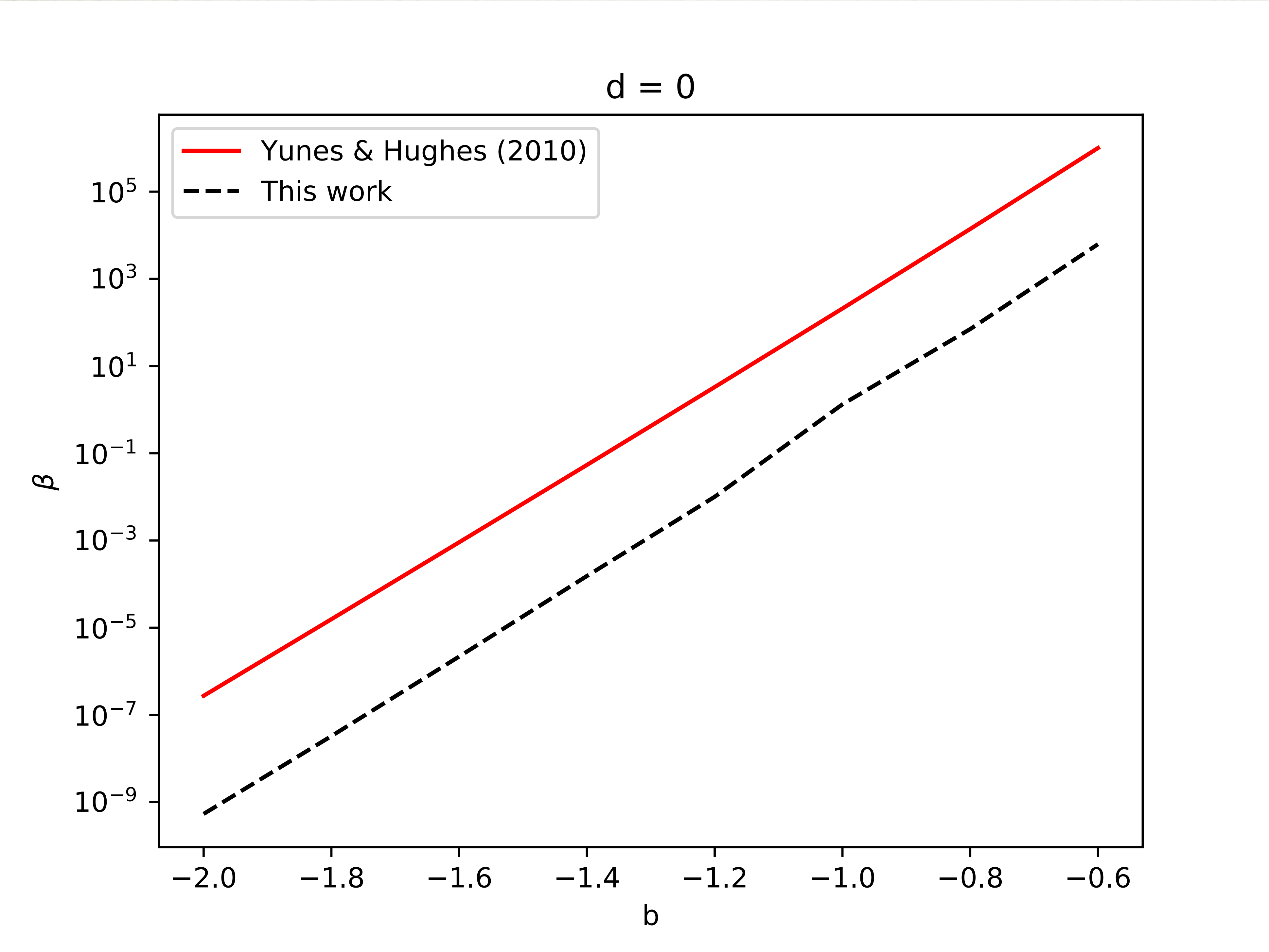


J0737-3039

$$\left(\frac{\dot{P}}{P}\right)_{obs} = \left(\frac{\dot{P}}{P}\right)_{GR} (1+\delta)$$

$$\beta \leq \frac{5}{48b(b-1)} \frac{\delta}{(4\eta)^d u^{b+5/3}}$$

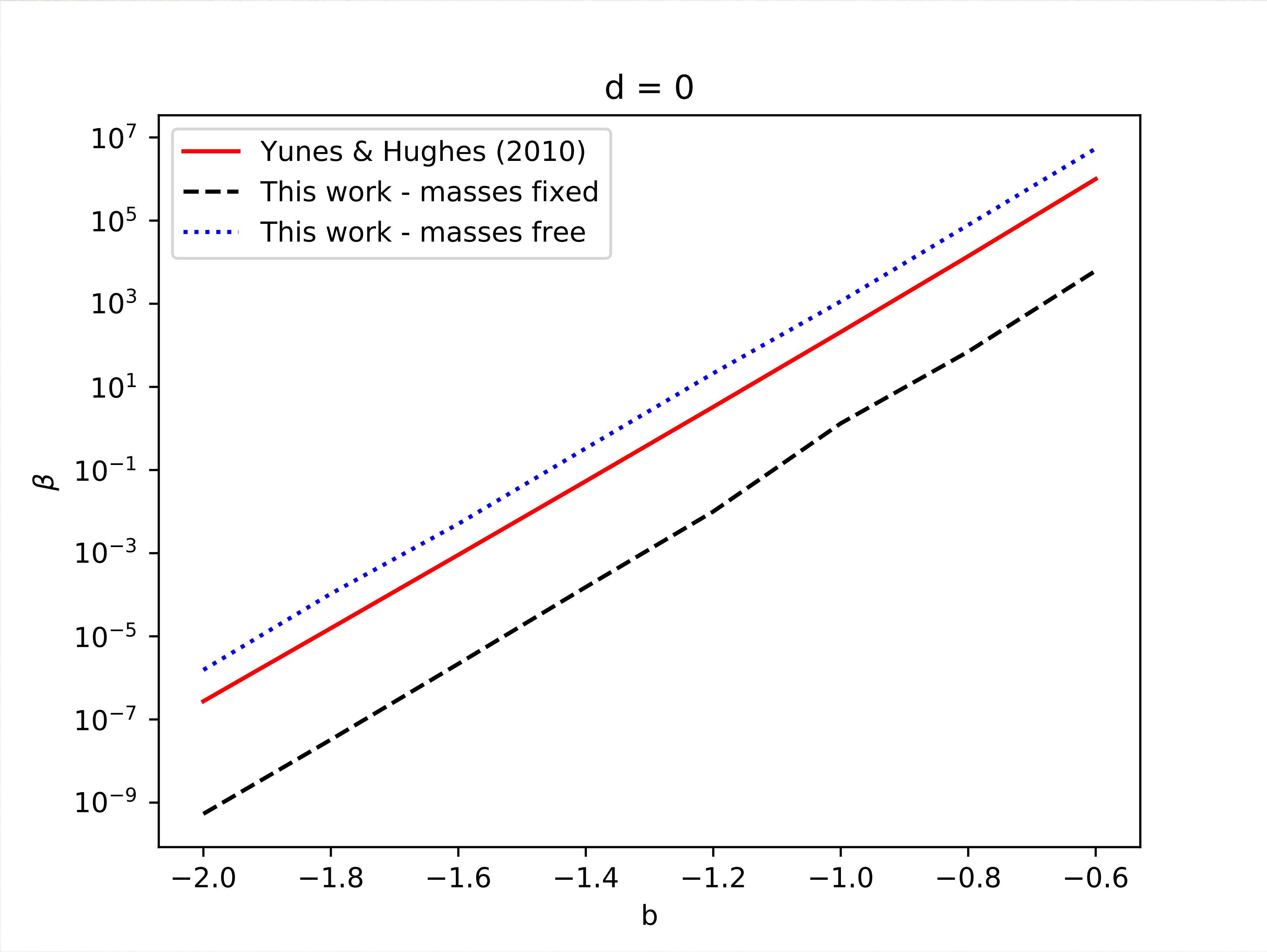
CONSTRAINTS ON PPE PARAMETERS



J2222-0137
J1012-5307
J0348-0432
J0737-3039
J1909-3744
J1738-0333

masses fixed(??)

CONSTRAINTS ON PPE PARAMETERS



J2222-0137
J1012-5307
J0348-0432
J0737-3039
J1909-3744
J1738-0333

$$m \sim \mathcal{N}(\mu, \sigma)$$

ONGOING

- Finding similar constraints on amplitude corrections
- Compute the mapping between other post-Keplerian parameters and ppE corrections

LOOKING AHEAD

Testing deviations from GR using GW by employing a Bayesian analysis of the ppE framework — we presented the most stringent constraints obtained on the ppE corrections from binary pulsar observations that can be used as informative priors for the Bayesian study.

REFERENCES

- Testing relativistic gravity with Radio pulsars - N. Wex, arXiv:1402.5594
- Fundamental theoretical bias in gravitational wave astrophysics and the parameterized post-Einsteinian framework - N. Yunes & F. Pretorius, Phys. Rev. D **80**, 122003