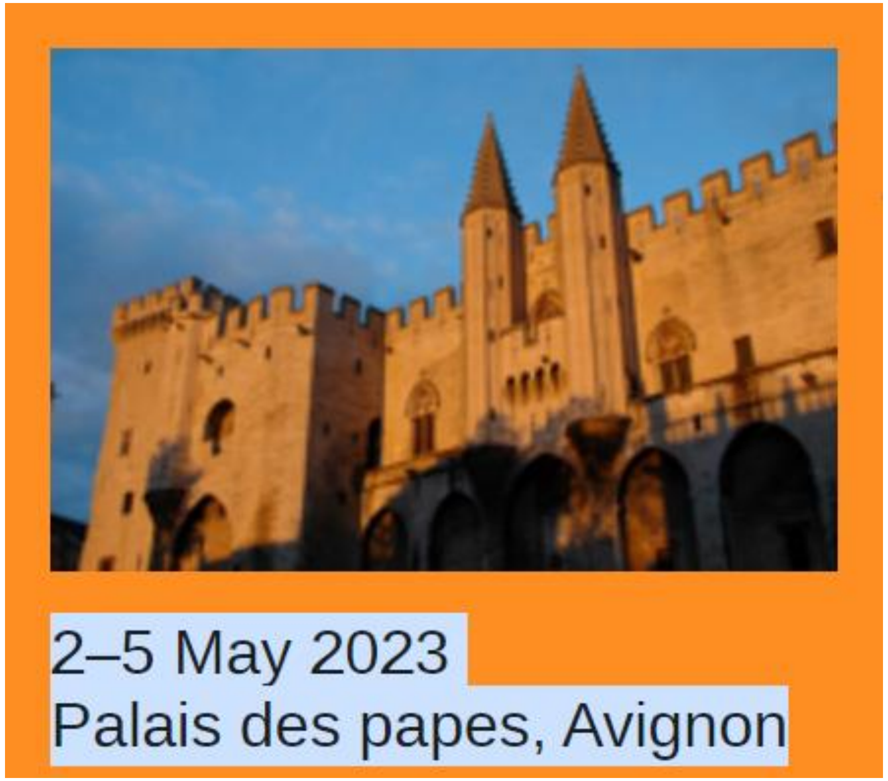
DARK ENERGY IN THE TWO-BODY PROBLEM

Phys. Rev. D **98**, 063531 (2021)
PHYSICAL REVIEW D 107, 064049 (2023)

DAVID BENISTY
WITH ANNE DAVIS AND PHILLIP BRAX



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SIGNS FOR DARK ENERGY

- "Pantheon" - Type Ia Super Nova

Astrophys. J. 859, 101 (2018)

- Cosmic Chronometers

Jimenez & Loeb (2002)

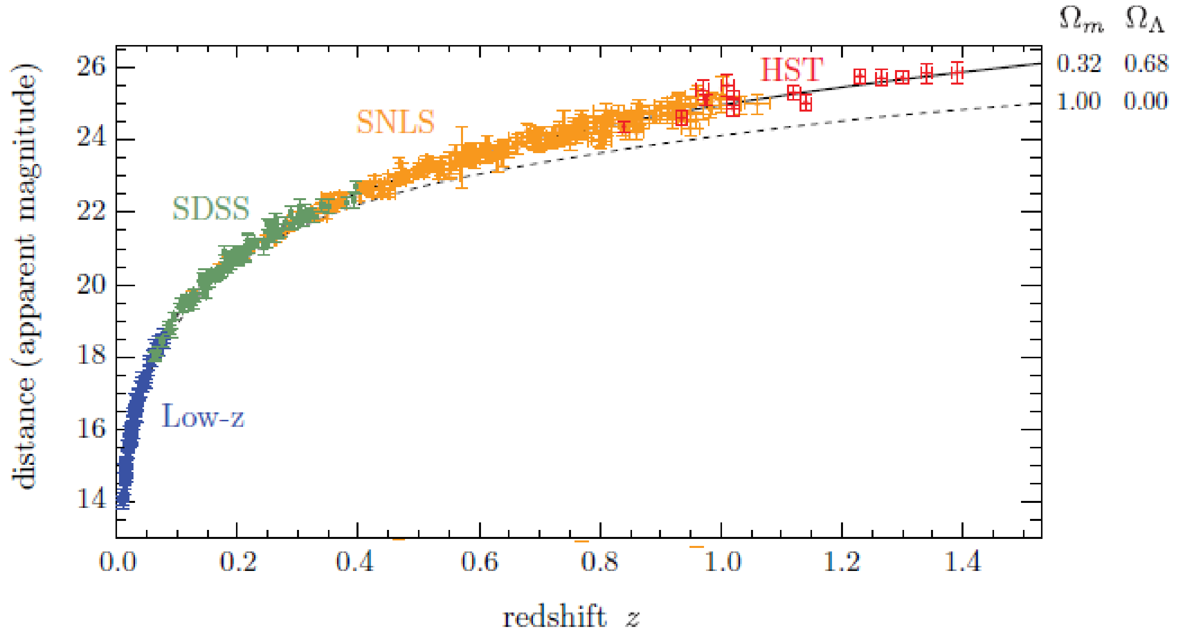
- Baryon Acoustic Oscillations

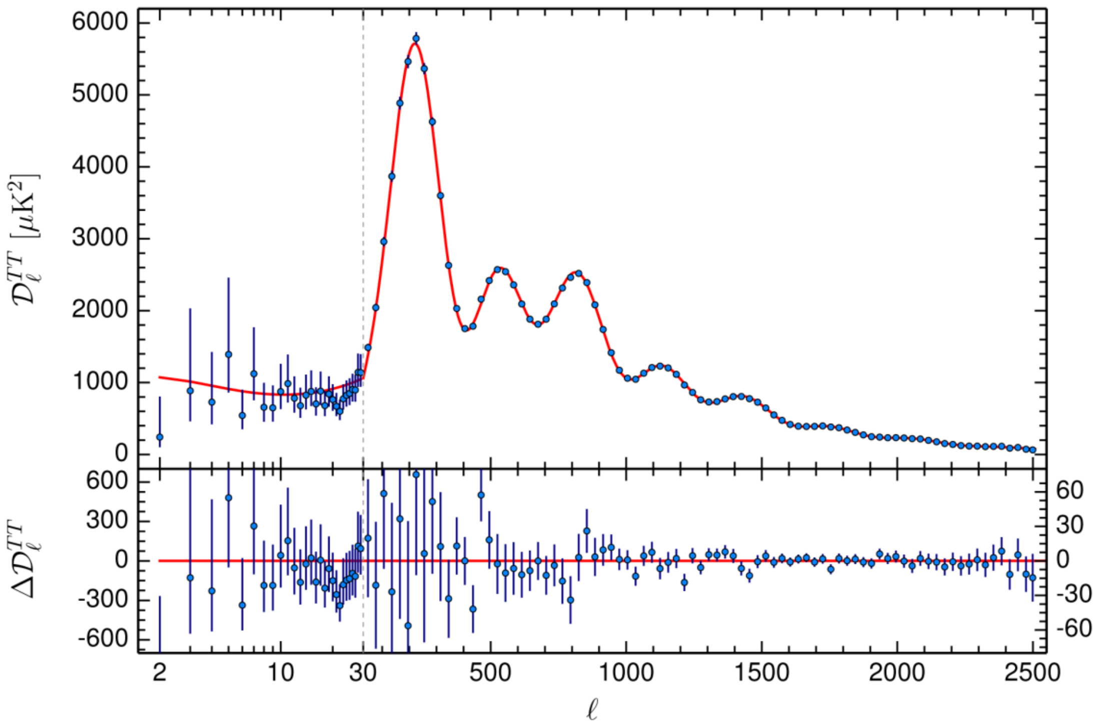
Phys. Rev. D 92, 123516 (2015)

- Cosmic Microwave Background

(Planck 2018)

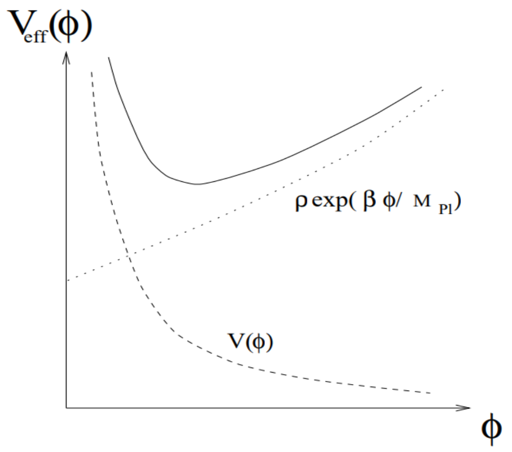
- Others…





Chameleon Dark Energy
Ph. Brax, C. van de Bruck, A. C. Davis, J. Khoury, A. Weltman

CHAMELEON DARK ENERGY IN ORBITAL MOTION



- Non minimal coupling between DM and scalar DE

$$S = \int d^4x\sqrt{-g}\left\{\frac{M_{Pl}^2 R}{2} - \frac{(\partial\phi)^2}{2} - V(\phi) + \mathcal{L}_m(\psi_m, A^2(\phi)g_{\mu\nu})\right\}$$

- The impact of conformal (β) and disformal (Λ) couplings:

$$\bar{g}_{\mu\nu}^{(J)} = (1+\beta\,\phi)g_{\mu\nu}^{(E)} + \frac{2}{\Lambda^2}\phi_{,\mu}\phi_{,\nu}$$

$$G_{eff} = G\,(1+2\,\beta^2)$$

- In two body motion:

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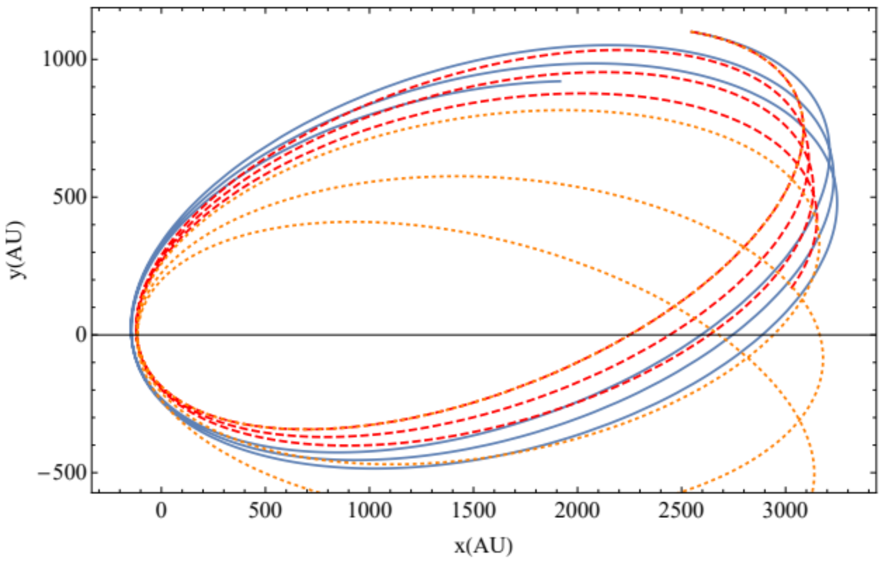
Philippe Brax, Anne-Christine Davis

$$\Delta\theta = \frac{6\pi G_N M}{ac^2(1-e^2)}\left(1 - \frac{2}{3}\beta^2 + \frac{5\beta^2 M}{6\pi\Lambda^4 p_0^3}\right)$$



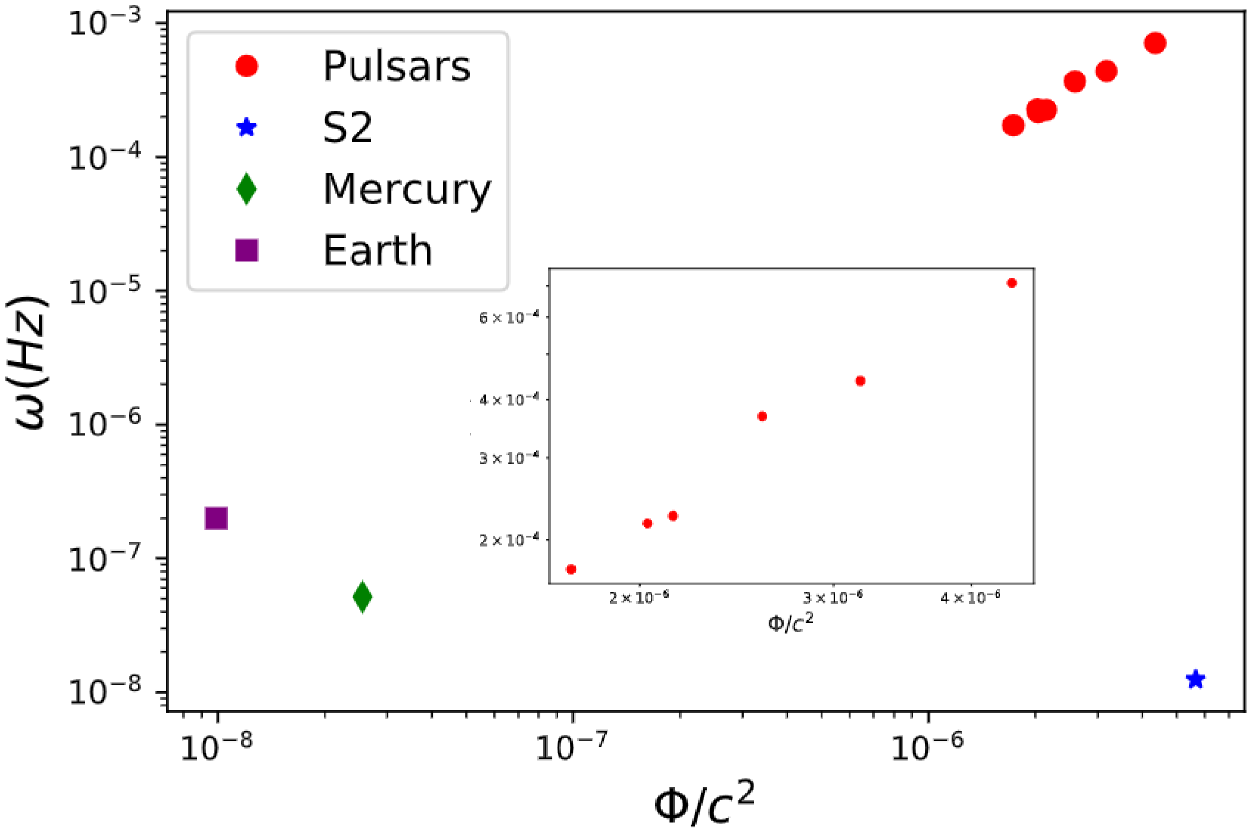
POST KEPLERIAN PARAMETERS

$$\dot{\omega} = \frac{(mT_\odot)^{2/3}}{1-e^2}\left(\frac{2\pi}{P_b}\right)^{5/3}\left[3-2\beta^2+\frac{5\lambda_\omega}{2\pi T_\odot \Lambda^2}\right]$$

$$\dot{P} = \frac{-195\pi T_\odot^{5/3}}{5}\left(\frac{P_b}{2\pi}\right)^{-5/3}\frac{m_p m_c}{m^{1/3}}\left[\left(1+\frac{\beta^2}{3}\right)f_1(e)+\frac{5}{18}\frac{\beta^2(2+\beta^2)^2}{(1+2\beta^2)^2}\left(f_2(e)-12\lambda_\omega f_3(e)\right)\right].$$

- Dimensionless quantity

$$\lambda_\omega = \frac{(\omega\beta/\Lambda)^2}{(1-e^2)^3},$$

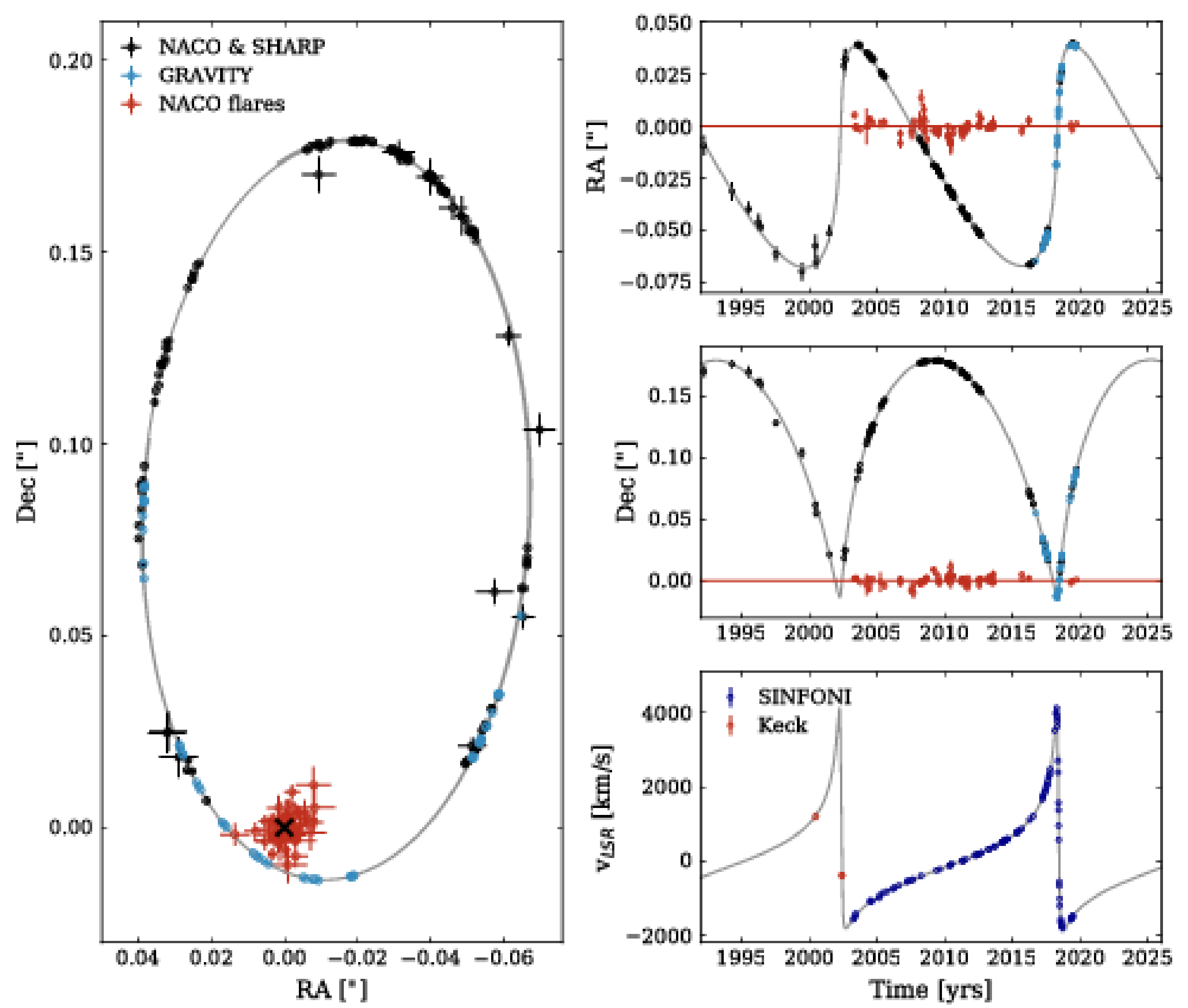


Detection of the Schwarzschild precession in the orbit of the star S2 near the Galactic centre massive black hole

GRAVITY Collaboration *Astron.Astrophys.* 636 (2020) L5

SGR*A AND THE S2 STAR

- More then 20 years of measurements.
- Gravity collaboration can detect the S2 presession.

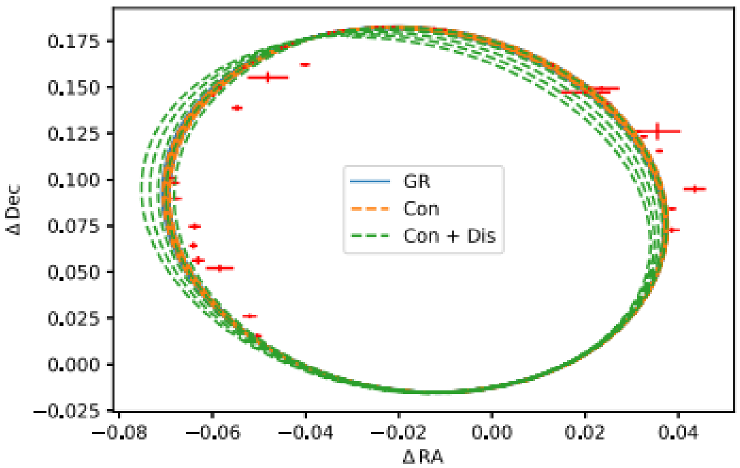


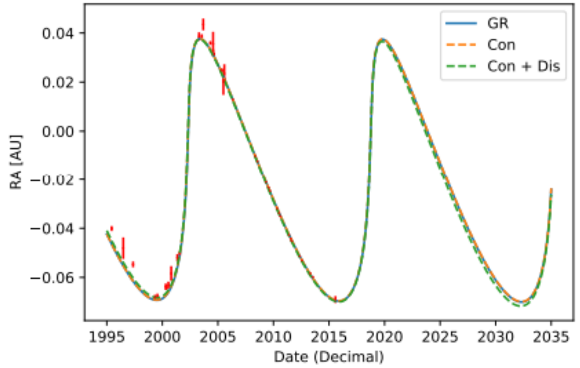
David Benisty, Anne-Christine Davis *Phys.Rev.D* 105 (2022) 2, 024052

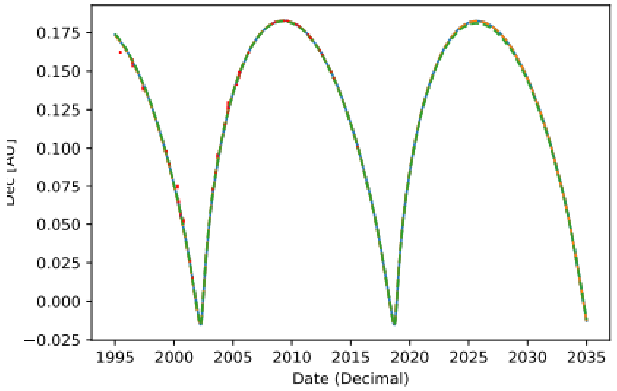
SGR*A, THE SOLAR SYSTEM AND CASSINI

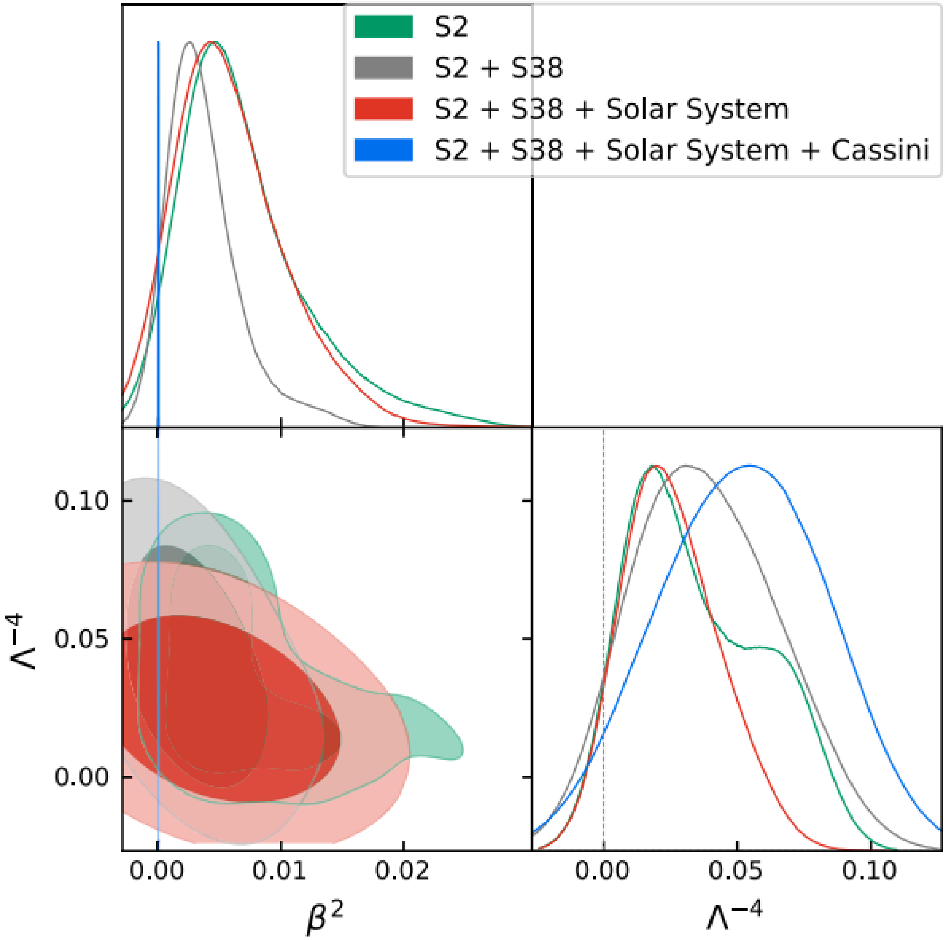
$$\beta^2 = (4.71 \pm 5.90) \times 10^{-3}$$

$$\Lambda > 0.08\ MeV$$



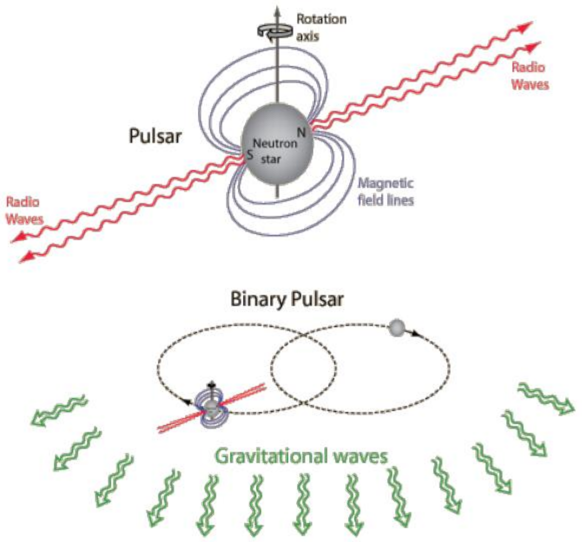


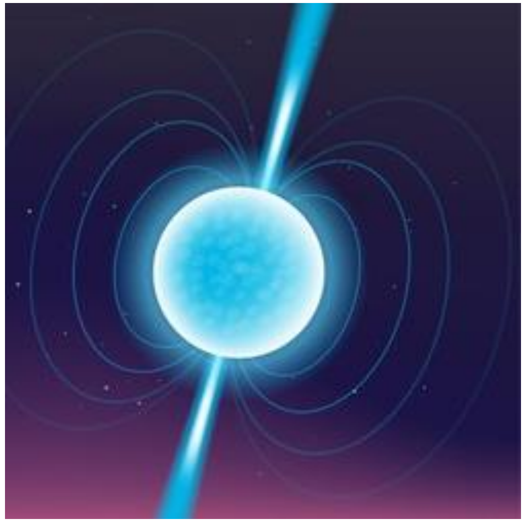


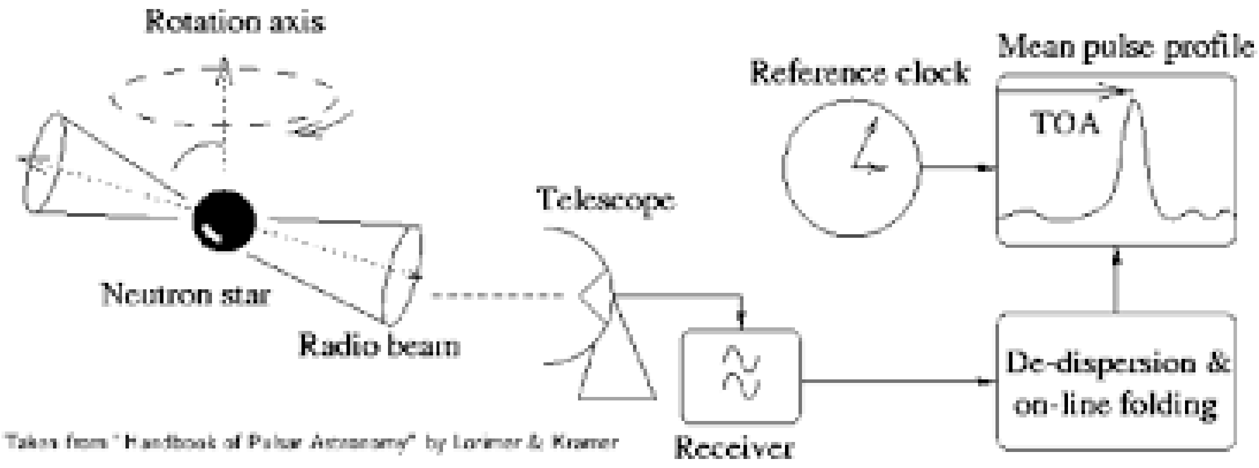


PULSAR AND A COMPANION

- Model independent approach for GW emission.
- Pulsar and companion (Hulse & Taylor, ApJ 1975)







Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer

TWO IMPORTANT PULSAR EVENTS

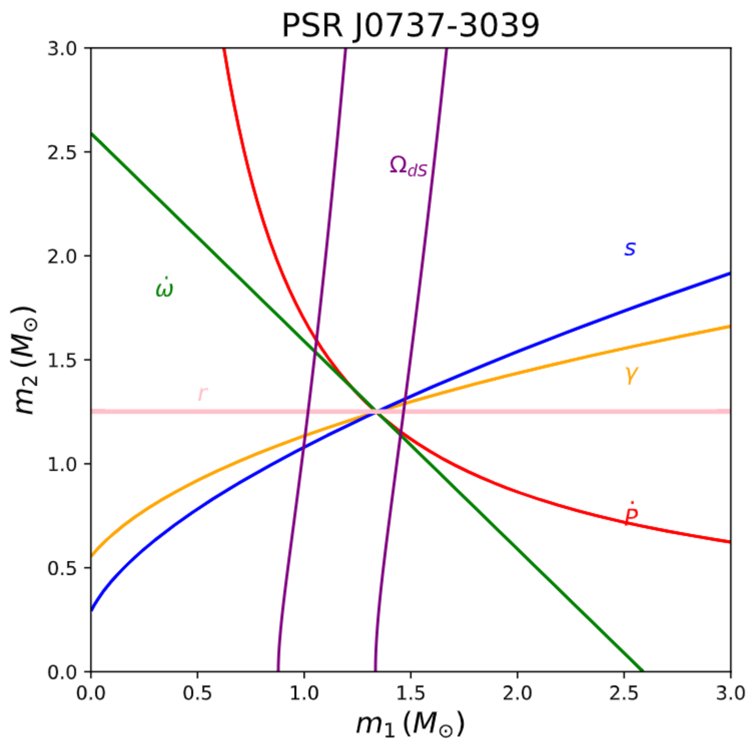
Astrophysical Journal, 829:55 (10pp), 2016 September 20

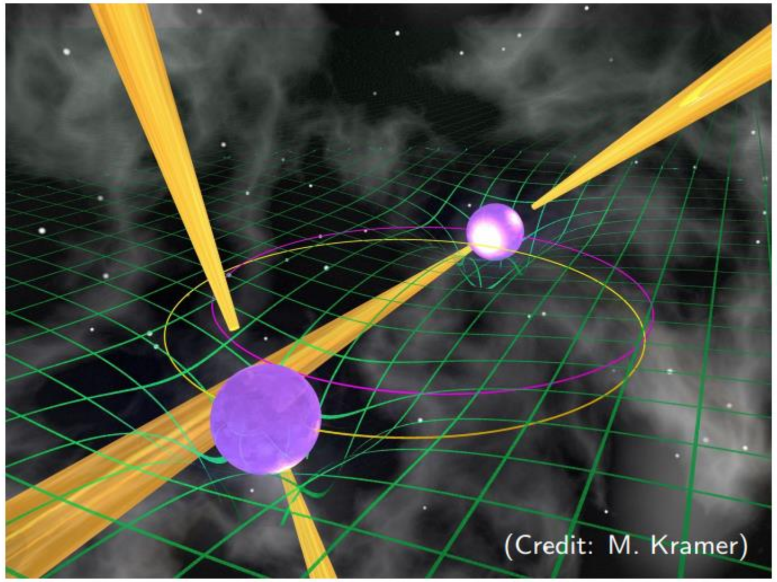
- Hulse Taylor Pulsar PSR B1913+16.

T_0 (MJD)	52144.90097849(3)
$x \equiv a_1 \sin i$ (s)	2.341776(2)
e	0.6171340(4)
P_b (d)	0.322997448918(3)
ω_0 (deg)	292.54450(8)
$\langle\dot{\omega}\rangle$ (deg yr^{-1})	4.226585(4)
γ (ms)	0.004307(4)
$\dot{P}_b^{obs}$	$-2.423(1) \times 10^{-12}$
δ_θ^{obs}	$4.0(25) \times 10^{-6}$
$\dot{x}^{obs}$	$-0.014(9) \times 10^{-12}$
$\dot{e}^{obs}$ (s^{-1})	$0.0006(7) \times 10^{-12}$
Shapiro Gravitational Propagation Delay Parameters	
Damour & Deruelle (1986) Parametrization	
s	$0.68^{+0.10}_{-0.06}$
r (μs)	$9.6^{+2.7}_{-3.5}$

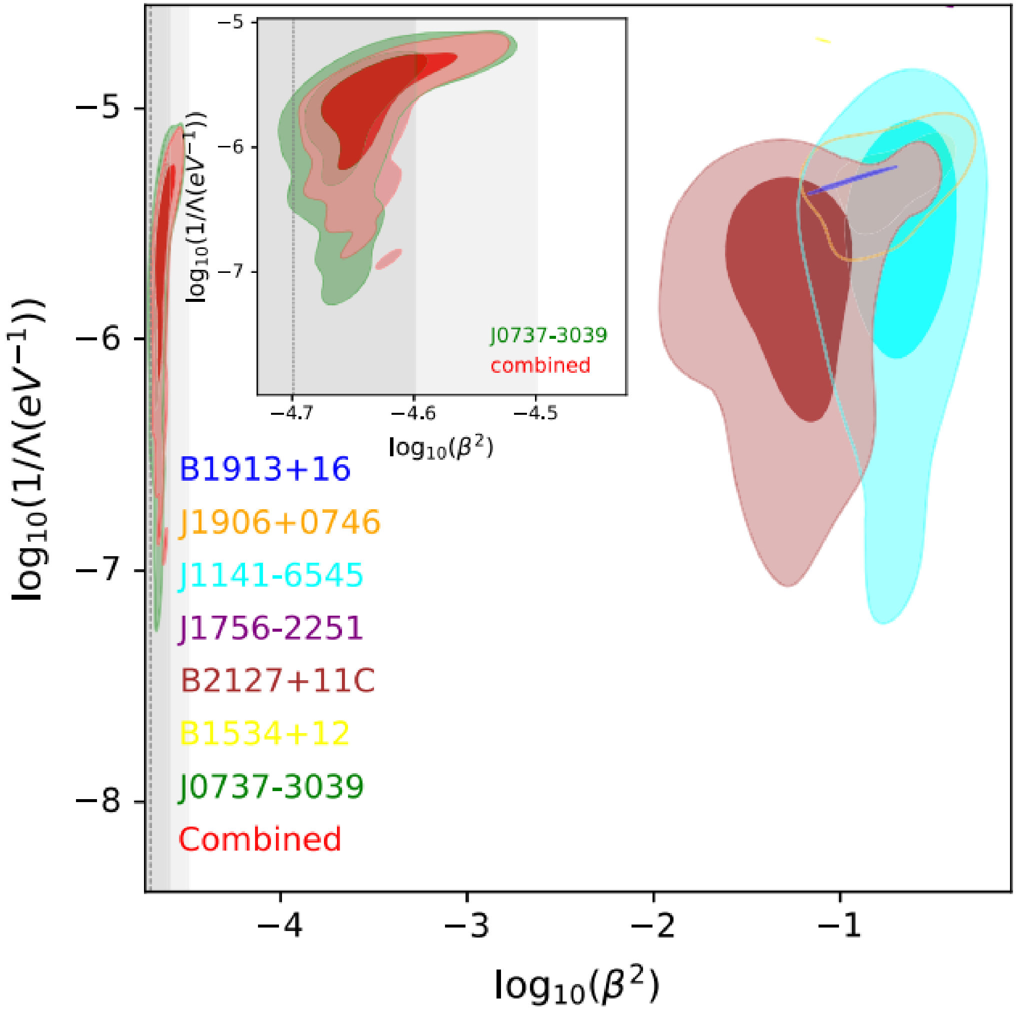
- The double pulsar PSR J0737-3039 PHYSICAL REVIEW X 11, 041050 (2021)

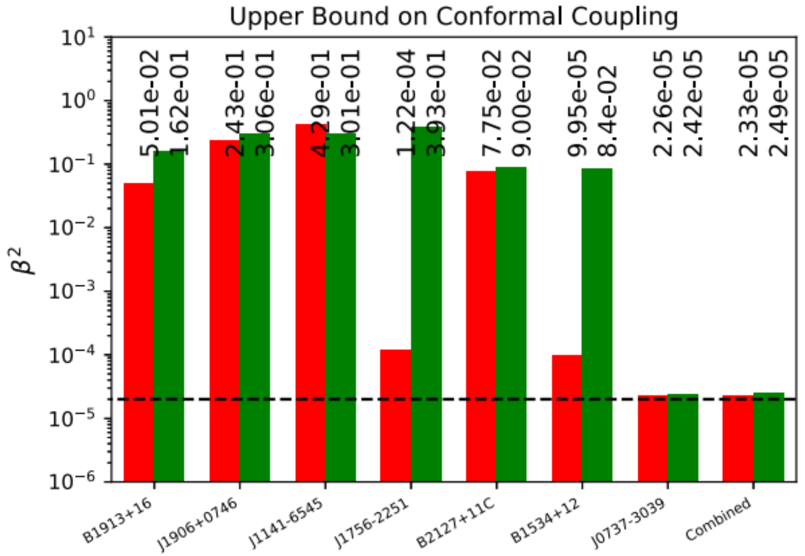
Orbital period, P_b (day)	0.102 251 559 297 3(10)
Projected semimajor axis, x (s)	1.415 028 603(92)
Eccentricity (Kepler equation), e_T	0.087 777 023(61)
Epoch of periastron, T_0 (MJD)	55 700.233 017 540(13)
Longitude of periastron, ω_0 (deg)	204.753 686(47)
Periastron advance, $\dot{\omega}$ (deg yr^{-1}) [c]	16.899 323(13)
Change of orbital period, $\dot{P}_b$	$-1.247920(78) \times 10^{-12}$
Einstein delay amplitude, γ_E (ms)	0.384 045(94)
Logarithmic Shapiro shape, z_s	9.65(15)
Range of Shapiro delay, r (μs)	6.162(21)
NLO factor for signal prop., q_{NLO}	1.15(13)
Relativistic deformation of orbit, δ_θ	$13(13) \times 10^{-6}$
Change of proj. semimajor axis, $\dot{x}$	$8(7) \times 10^{-16}$
Change of eccentricity, $\dot{e}_T$ (s^{-1})	$3(6) \times 10^{-16}$

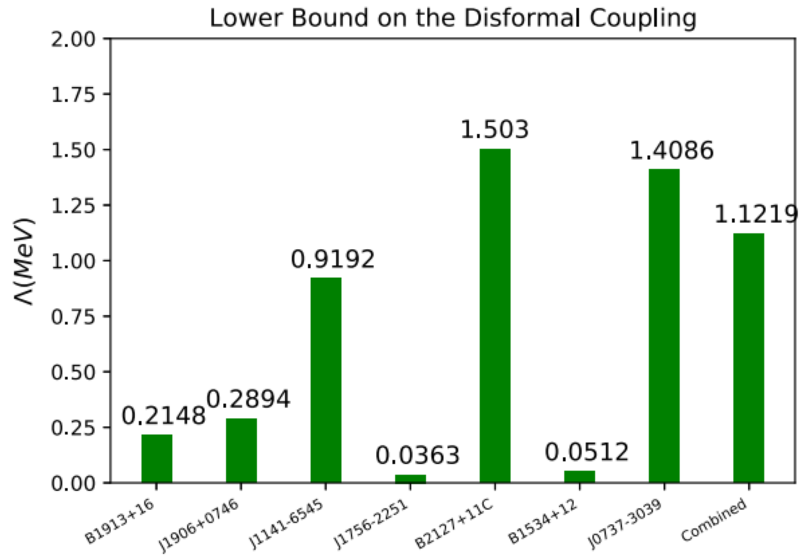




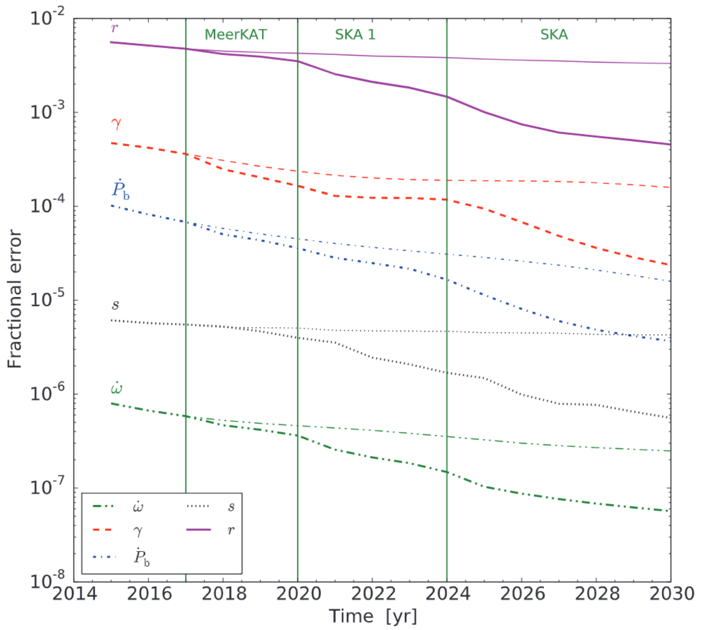
DARK ENERGY INTERACTIONS CONSTRAINTS







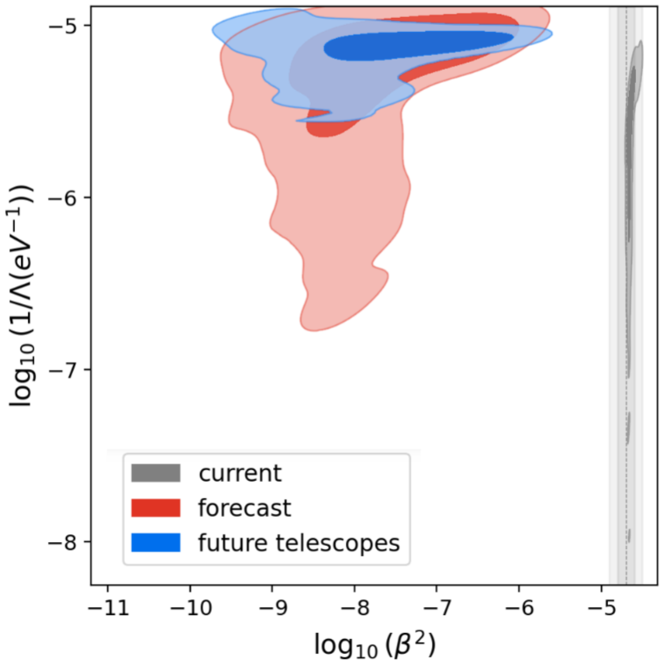
SPIN ORBIT AND SPIN-SPIN COUPLINGS



Marcel S. Kehl et al

- Gravity Probe B: $\beta^2 = (2.963 \pm 2.045) \cdot 10^{-3}$
- The double Pulsar will give better constraints on MoG.

Benisty, Brax, Davis – to be published



SUMMARY AND FUTURE RESEARCH

- Two body problem with DE interactions
- Galactic Center Constrains.
- Mean Anomaly solution for MoG
- Post Keplerian Parameters
- Pulsar Time array constraints