Aspen Center for Physics

Physical Applications of Millisecond Pulsars

New Tests of Local Lorentz Invariance and Local Position Invariance of Gravity from PULSARs

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Collaborators:

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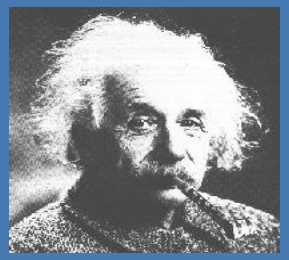
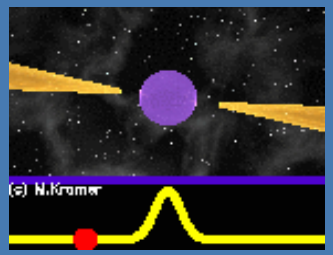




Gravity talks to pulsars...

Max-Planck-Institut für Radioastronomie

PEKING UNIVERSITY 1898

Theoretical Framework: Parameterized Post-Newtonian (PPN)

- Expand gravity theories to the first post-Newtonian order $O(c^{-2})$; ten dimensionless parameters are introduced in the metric, like β (nonlinearity), γ (curvature per mass)

  [Eddington 1922, Robertson 1962, Schiff 1967]

  [Nordtvedt 1968, Will 1971, Will & Nordtvedt 1972]

Local Lorentz Invariance: α_1, α_2, α_3

Local Position Invariance: ξ

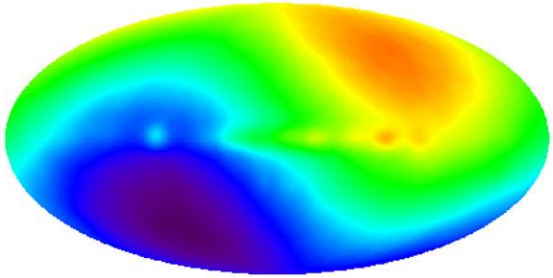
- PPN parameters have different values in different gravity theories [Will 1993, Will 2006]

in GR, $\alpha_1=\alpha_2=\alpha_3=\xi=0$

Local Lorentz Invariance (LLI) Violation

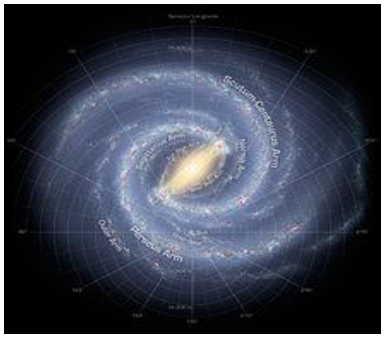
- Local gravity depends on the **velocity** of a system w.r.t. a preferred frame (e.g., the CMB frame)

  [Will & Nordtvedt 1972; Nordtvedt & Will 1972]



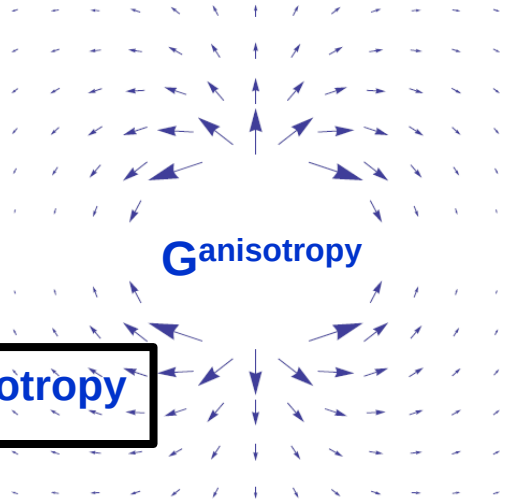
Local Position Invariance (LPI) Violation

- Local gravity depends on the **position** of a system w.r.t. external matter distribution (e.g., the Galaxy) [Mach's principle; Wihtehead 1922; Will 1973]



[Will 1993]

$$G_{local} = G^{isotropy} + G^{anisotropy}$$



Record holders of PPN parameters

- α_1 : 35-yr of Lunar Laser Ranging → **Pulsars**

  [Müller, Williams, & Turyshev 2008]

  improved by a factor of **five** [Shao & Wex 2012]

- α_2 : 4.6-Gyr of Sun's spin → **Pulsars**

  [Nordtvedt 1987]

  improved by **two orders of magnitude** [Shao et al. in prep.]

- α_3 : 21 binary pulsars **Pulsars**

  [Stairs et al. 2005]

- ξ : superconducting gravimeters → **Pulsars**

  [Warburton & Goodkind 1976]

  improved by **five (two) orders of magnitude** [Shao & Wex, in prep.]

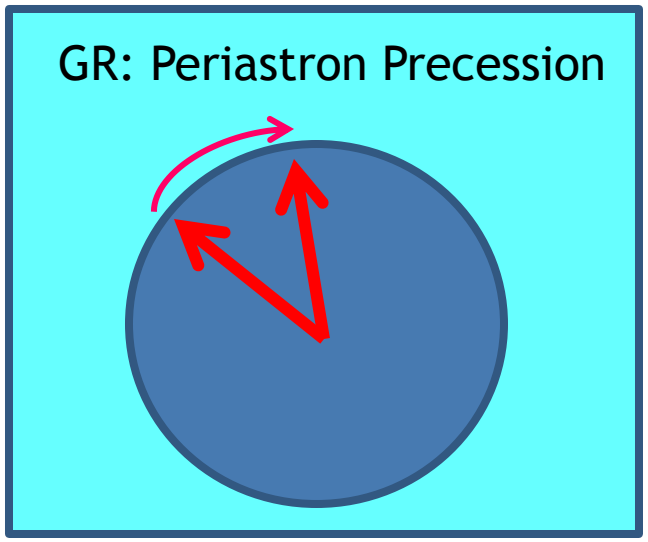
Local Lorentz Invariance

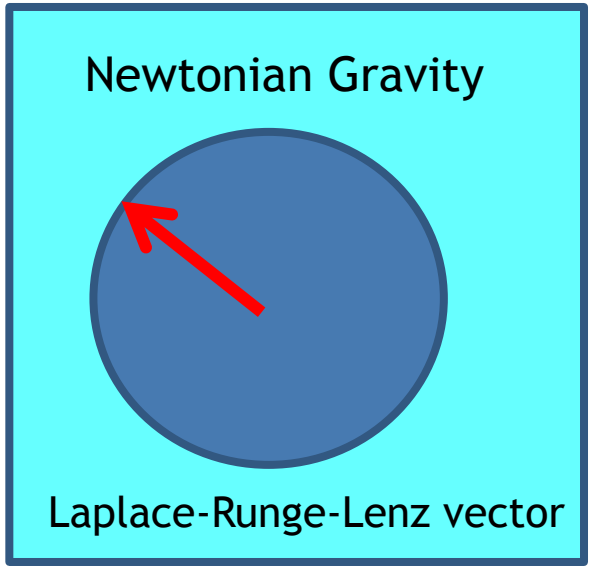
α_1 test [Shao & Wex 2012]

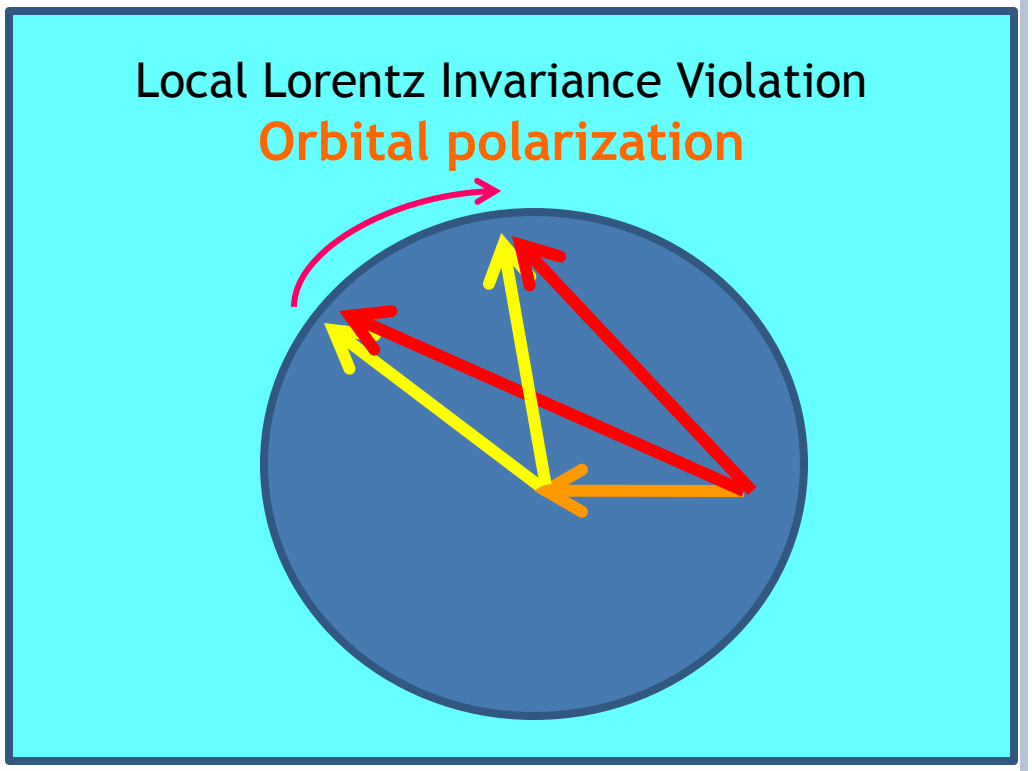
PSR J1738+0333

[Antoniadis et al. 2012; Freire et al. 2012]

Local Lorentz Invariance α_1 : Orbital polarization



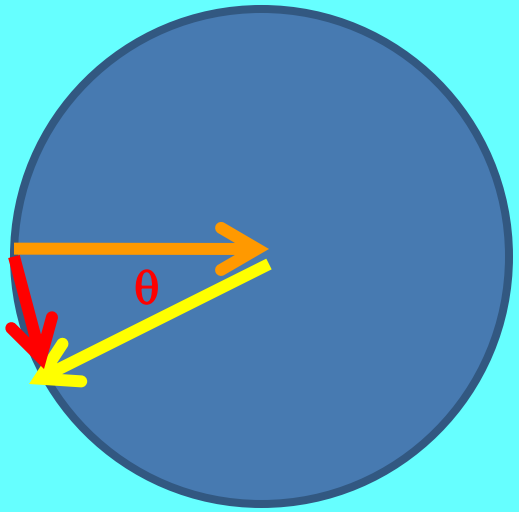




Damour & Esposito-Farèse 1992
Will 1993
Shao & Wex 2012

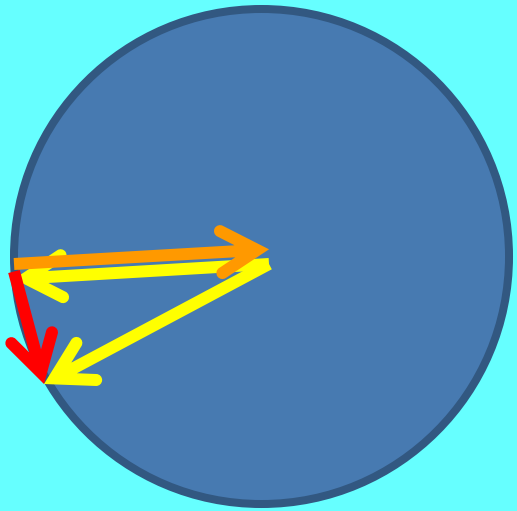
PROBABILISTIC TEST

Damour & Esposito-Farèse 1992



ROBUST TEST

Shao & Wex 2012



$$\hat{\alpha}_1 = -0.4^{+3.7}_{-3.1} \times 10^{-5} \quad (95\%\ \text{C.L.})$$

PSR J1738+0333 [Antoniadis et al. 2012; Freire et al. 2012]

Local Lorentz Invariance

α_2 TEST [Shao et al. in prep.]

PSRs B1937+21 & J1744-1134

Local Lorentz Invariance α_2 : Spin precession

- Solar spin alignment

  [Nordtvedt 1987]

$$\Omega^{\rm prec} = -\frac{\alpha_2}{2}\left(\frac{2\pi}{P}\right)\left(\frac{w}{c}\right)^2 \cos\psi$$

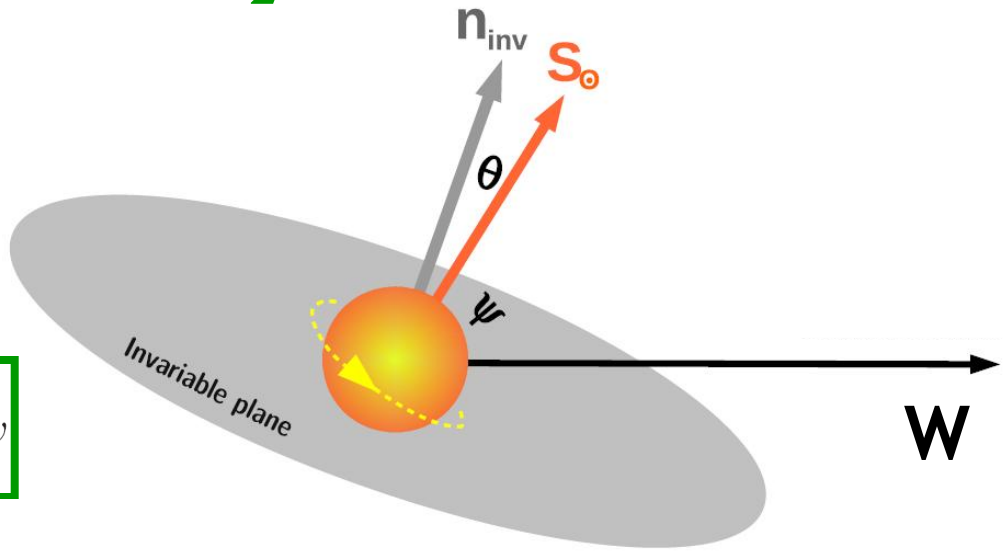
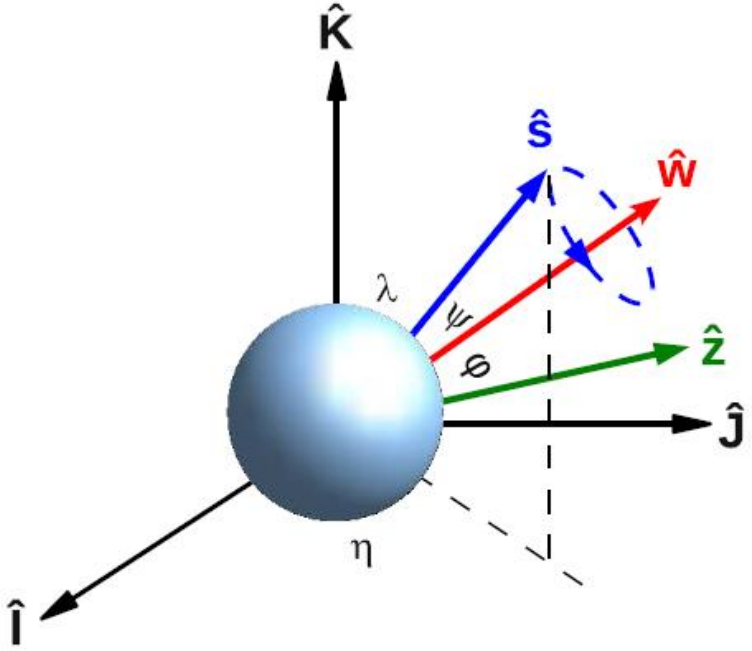


Figure from Shao & Wex, in prep.



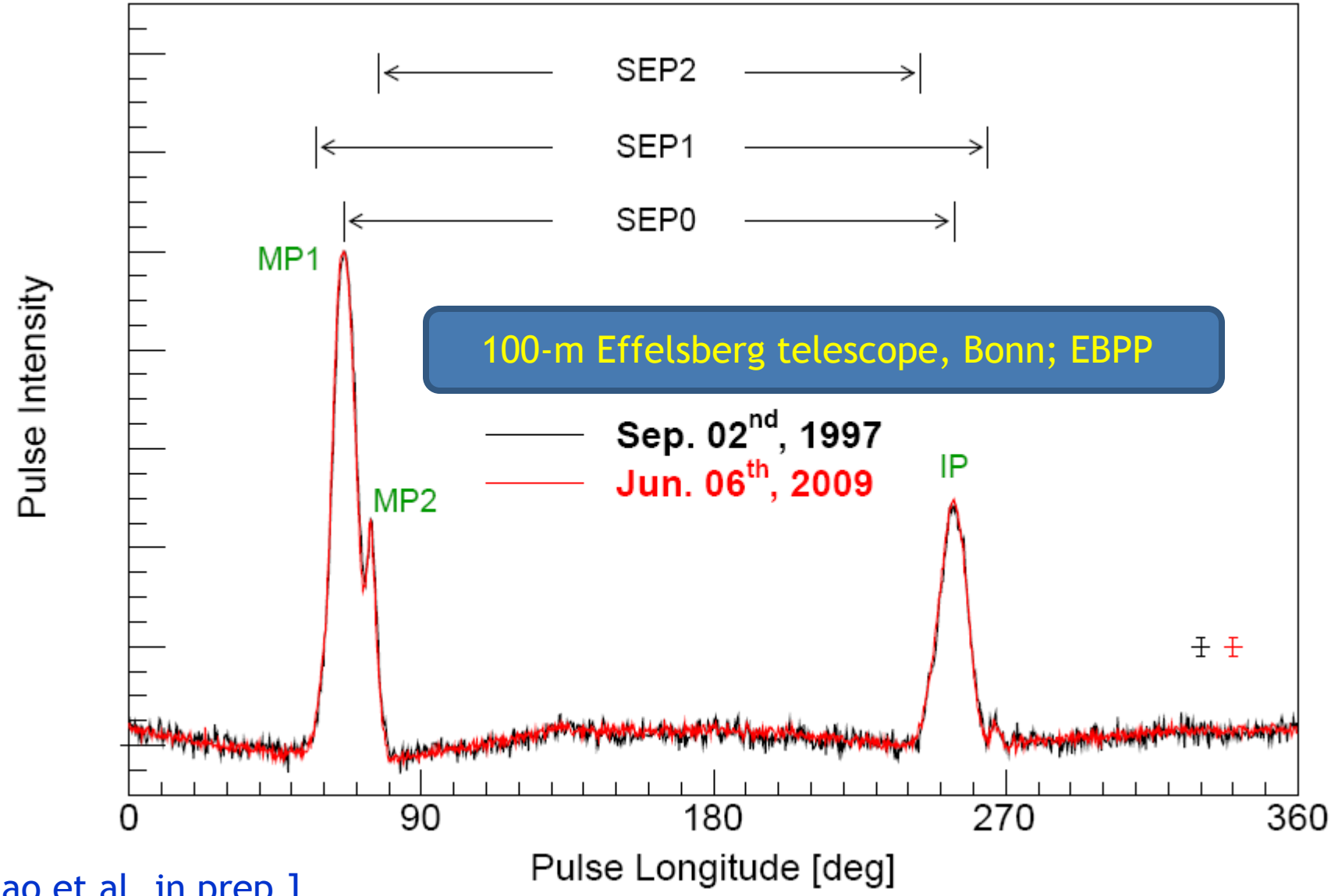
- Spin precession of solitary pulsars

  [Shao et al. in prep.]

  free science (PTA PSRs)

  → pulse profile variations

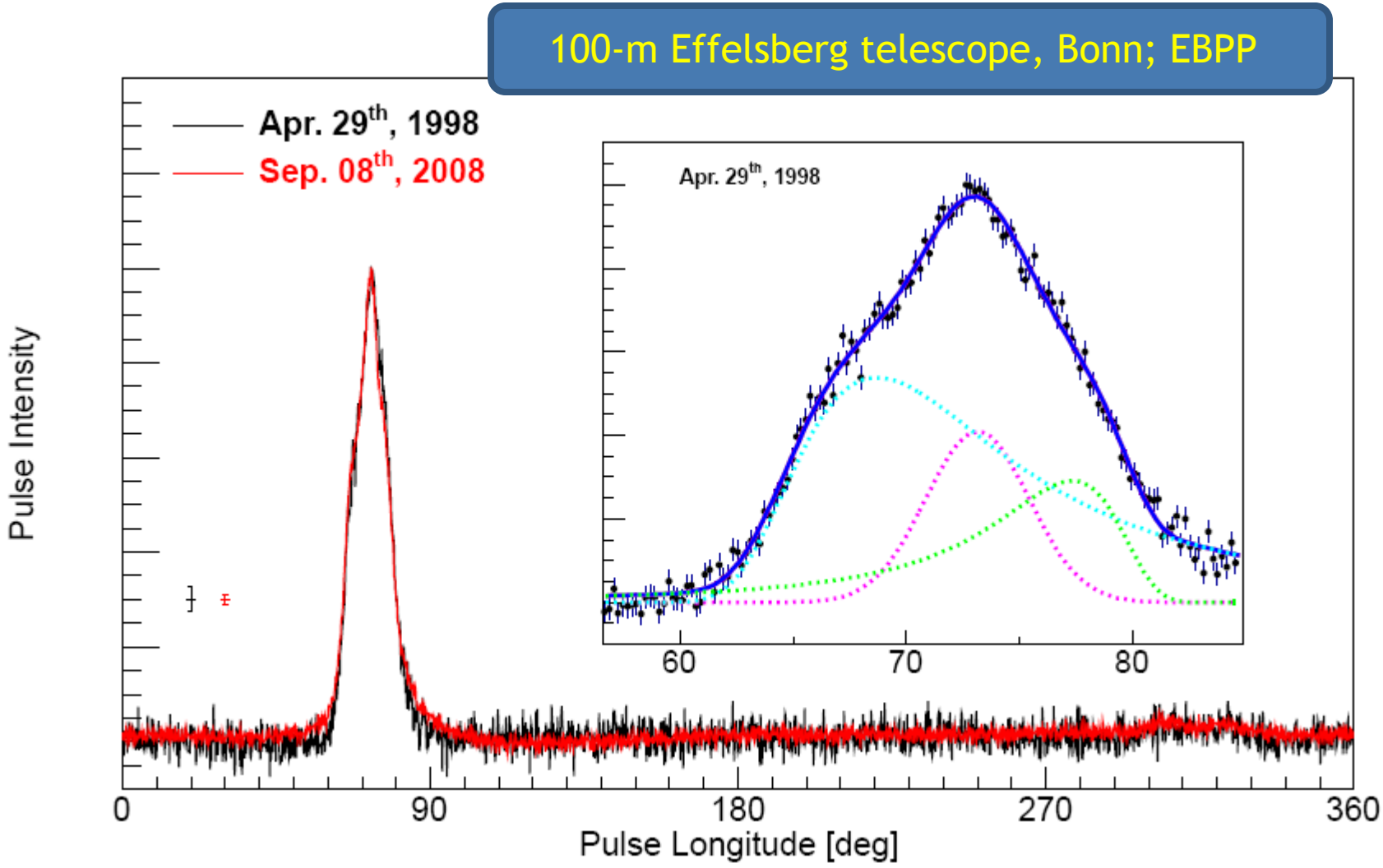
EXTREMELY STABLE PULSE PROFILES: B1937+21



[Shao et al. in prep.]

EXTREMELY STABLE PULSE PROFILES: J1744-1134

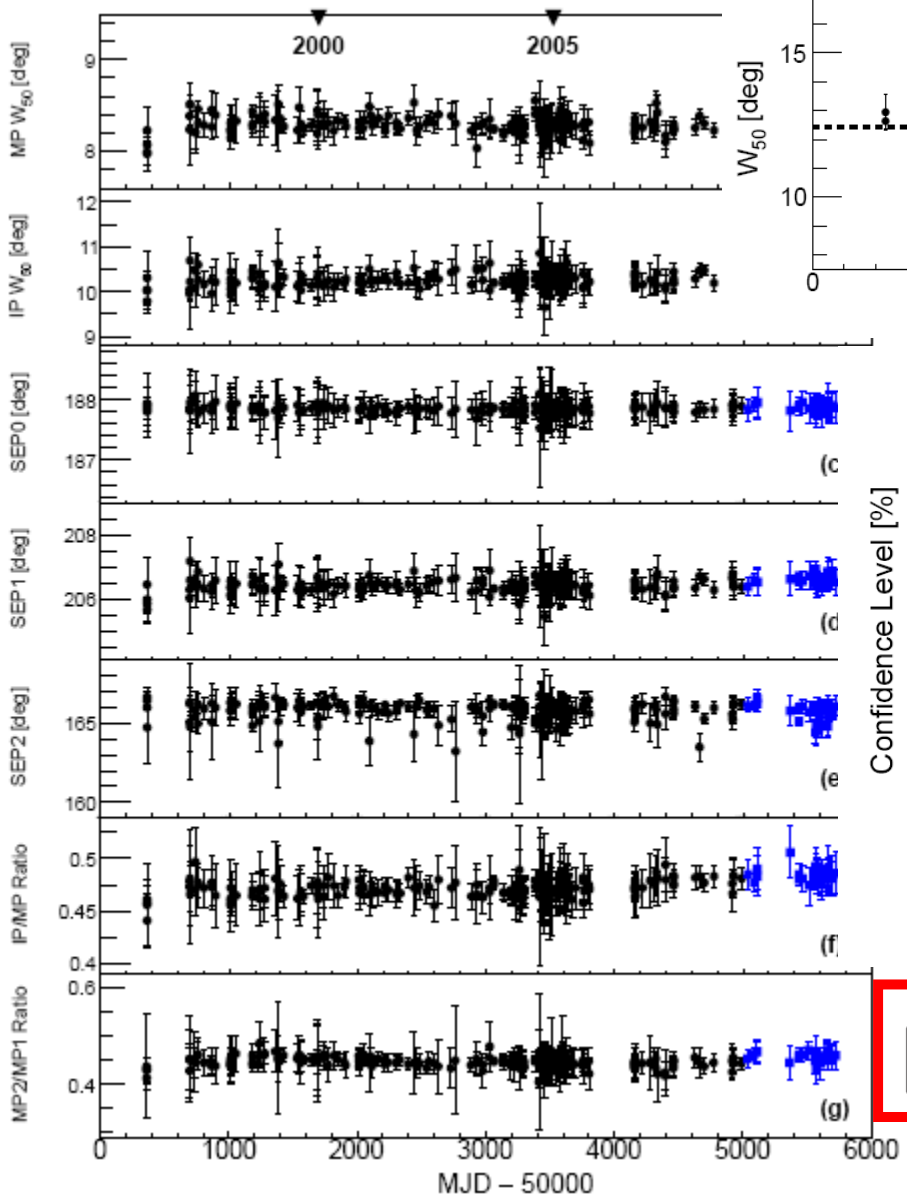
100-m Effelsberg telescope, Bonn; EBPP



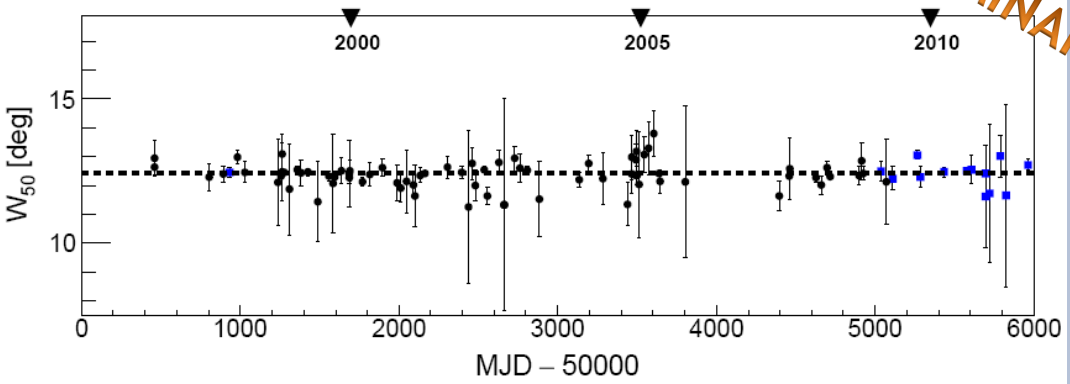
[Shao et al. in prep.]

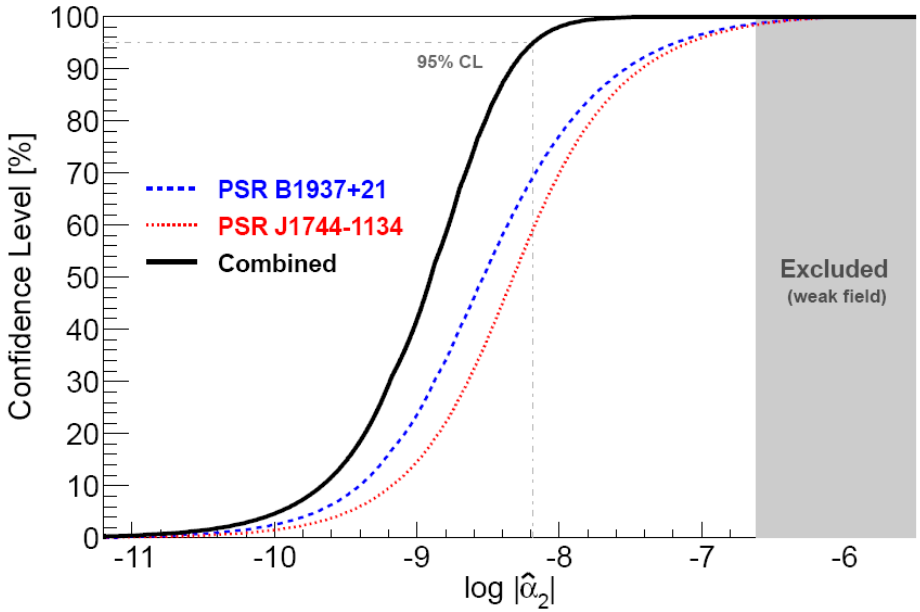
PRELIMINARY

PSR B1937+21



PSR J1744-1134





$$|\hat{\alpha}_2| < 6.6 \times 10^{-9}\,, \quad (95\%\ \mathrm{CL})$$

[Shao et al. in prep.]

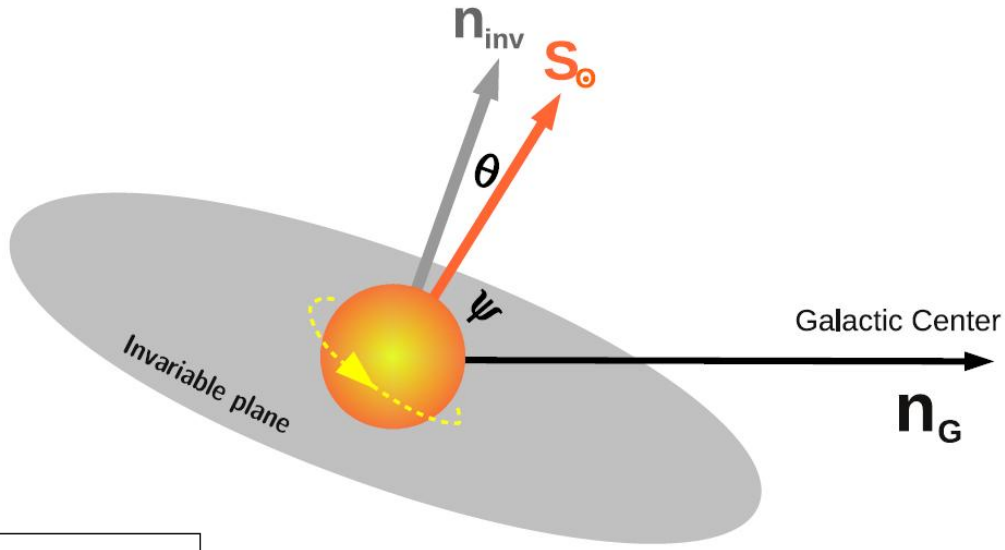
Local Position Invariance

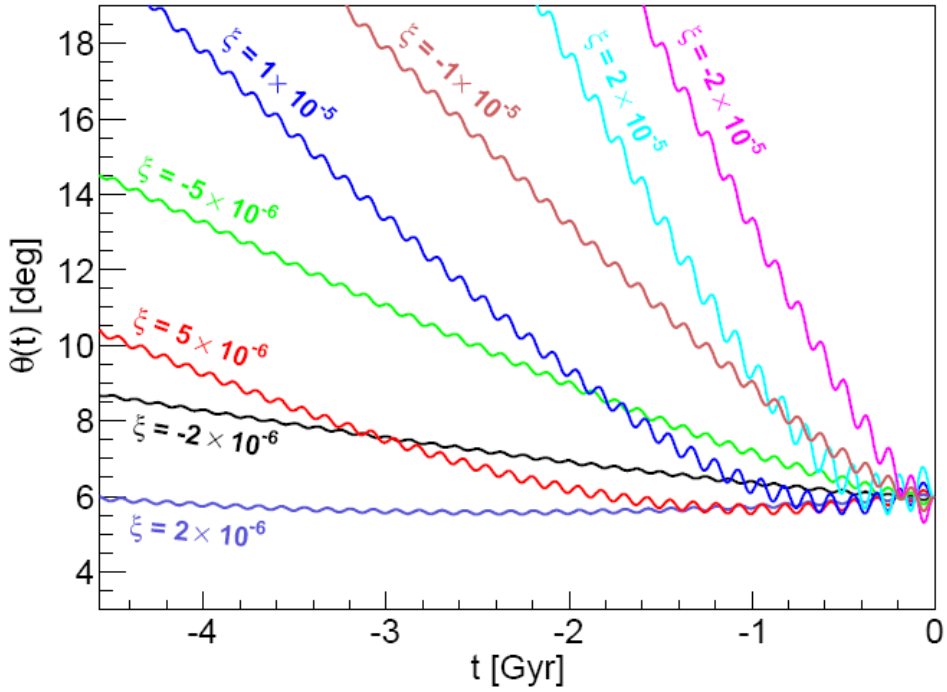
ξ TEST [Shao & Wex, in prep.]

PSRs B1937+21 & J1744-1134

Local Position Invariance ξ : Spin precession

- Solar spin alignment
  [Nordtvedt 1987]

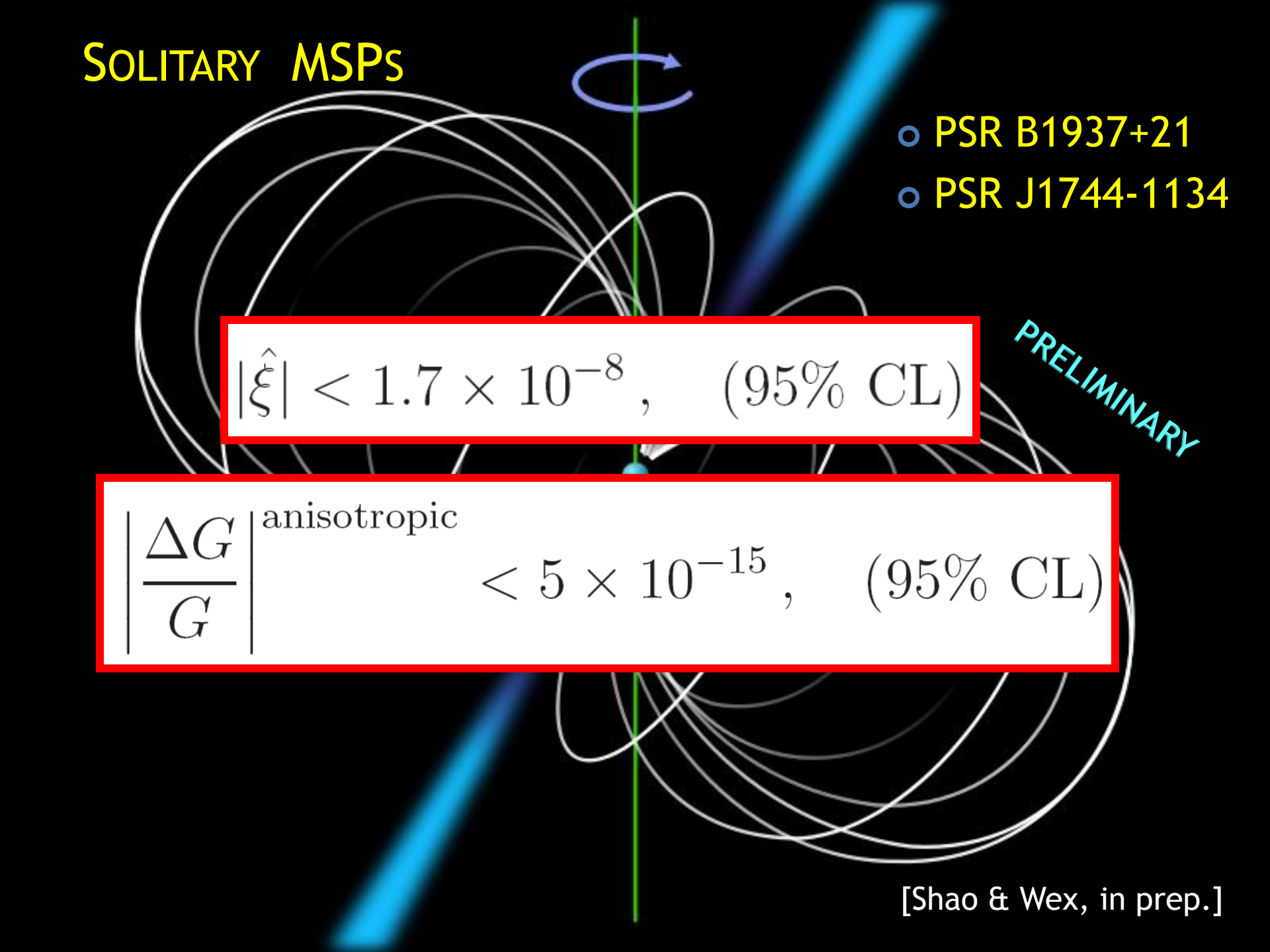




$$|\xi| < 5 \times 10^{-6}$$

[Shao & Wex, in prep.]

SOLITARY MSPS



- PSR B1937+21
- PSR J1744-1134

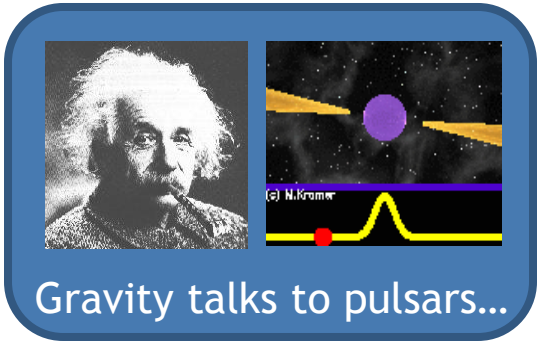
$$|\hat{\xi}| < 1.7 \times 10^{-8}\,, \quad (95\%\ \mathrm{CL})$$

PRELIMINARY

$$\left|\frac{\Delta G}{G}\right|^{\mathrm{anisotropic}} < 5 \times 10^{-15}\,, \quad (95\%\ \mathrm{CL})$$

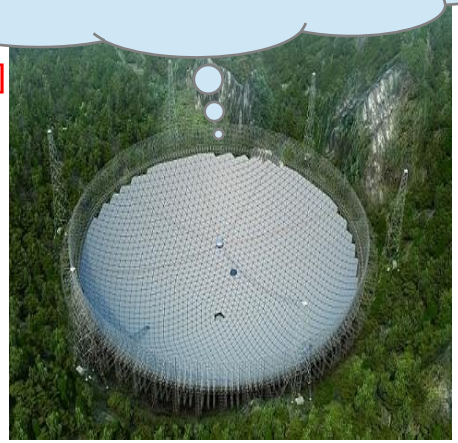
[Shao & Wex, in prep.]

DICUSSIONS



- Horava gravity, TeVeS gravity, SME, etc
- Weak-field limits vs strong-field limits
  - nonperturbative effects [Damour & Esposito-Farèse 1993]
  - perturbative effects [Nordtvedt 1968]
- Further improvements
  - continuous observations: $T_{obs}^{-3/2}$
  - new technologies, better sensitivities…
  - finding new systems: FAST, SKA, etc

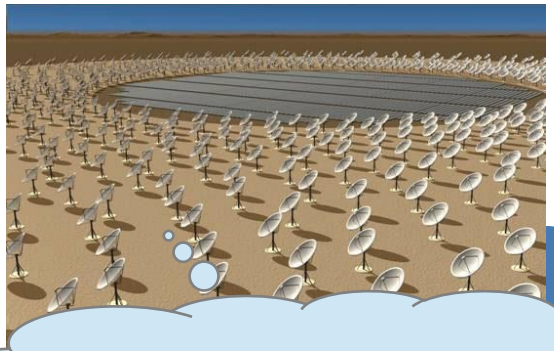
FAST; expected by 2016




Parkes


Effelsberg


Arecibo


SKA; expected by 2020