Project QVADIS: Testing the existence of the gravitational anomalies by the study of trans-Neptunian binaries

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Abstract. We point out that some of trans-Neptunian binaries are a natural laboratory for testing the existence of an anomalous gravitational field as weak as 10^{-11} m/s^2 (with the next generation of telescopes the anomalous gravitational field of the order of 10^{-12} m/s^2 might be revealed). The method is based on the measurement of the perihelion precession of the orbit. The unrivalled advantage of tiny trans-Neptunian binaries is that they are the best available realization of an isolated two body system with very weak external and internal Newtonian gravitational field. As a consequence, the known Newtonian precession might be dominated by anomalous perihelion precession. While these measurements are significant independent of any theory they were initially proposed as a crucial test of a new model of the Universe based on the hypothesis that *quantum vacuum fluctuations are virtual gravitational dipoles*. According to the new model, the only content of the Universe is the known Standard Model matter (i.e. matter made from quarks and leptons interacting through the exchange of gauge bosons) immersed in the quantum vacuum "enriched" with virtual gravitational dipoles. Apparently, what we call dark matter and dark energy can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed baryonic matter.

1. Introduction

Precession of orbits is a universal phenomenon; more or less, all orbits precess. The Newtonian precession is zero *only* in an *ideal binary system* (i.e. an *isolated* binary system composed of two *point-like* bodies).

Any non-zero precession in an *ideal binary system* is a *signature of new physics*. More precisely, precession in an ideal binary system exists *only if* the gravitational acceleration $\mathbf{g}$ caused by a point-like body of mass M_b is *not equal* to the Newtonian value $\mathbf{g}_N$ (with the famous magnitude GM_b/r^2). Hence, the precession in an ideal binary system means the existence of an anomalous acceleration $\mathbf{g}_a$ so that $\mathbf{g} = \mathbf{g_N} + \mathbf{g_a}$. Let us note that that the anomalous acceleration can exist even without violation of Newton's law; as shown in a series of papers [1, 2, 3, 4, 5] the anomalous acceleration may be a consequence of the quantum vacuum as a "forgotten" source of gravity (see also the paper "Quantum vacuum as the cause of the phenomena usually attributed to dark matter" in this Proceedings).

If the magnitude of the anomalous acceleration is small with respect to the magnitude of Newtonian acceleration there is a general solution for the perihelion shift per orbit which can be found in Reference [6]. The simplest case is a radial anomalous acceleration of constant magnitude g_a; the corresponding perihelion shift per orbit is given [3] by the following proportionality:

$$\Delta\omega_a = -2\pi\sqrt{1-e^2}\,\frac{a^2}{G(M_b+m)}\,g_a \equiv -2\pi\sqrt{1-e^2}\,\frac{a^2}{G\mu}\,g_a \qquad (1)$$

Here, M_b and m denote the mass of the primary and the mass of the satellite (secondary), while a and e are the semi-major axis and the eccentricity of the orbit. In general, the proportionality (1) allows us to look for anomalous accelerations by measuring the perihelion shift.

It was recently suggested [1, 2, 3, 4, 5] that what we call dark matter and dark energy, can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed Standard Model matter. This result appears as the consequence of the working hypothesis that *by their nature quantum vacuum fluctuations are virtual gravitational dipoles*. In the region of saturation (i.e., a large region around the body in which gravitational dipoles are completely aligned) quantum vacuum is the source of an additional anomalous acceleration towards the center, characterized with a constant magnitude:

$$g_a \equiv g_{qv} = 4\pi G P_{g\,\max} \tag{2}$$

where $P_{g\,\max}$ is a universal constant of the quantum vacuum: *the maximum magnitude of the gravitational polarization density*. Assuming a small eccentricity, equations (1) and (2) lead to

$$\Delta\omega_{qv} \approx -8\pi^2 \frac{a^2}{\mu} P_{g\,\max} \tag{3}$$

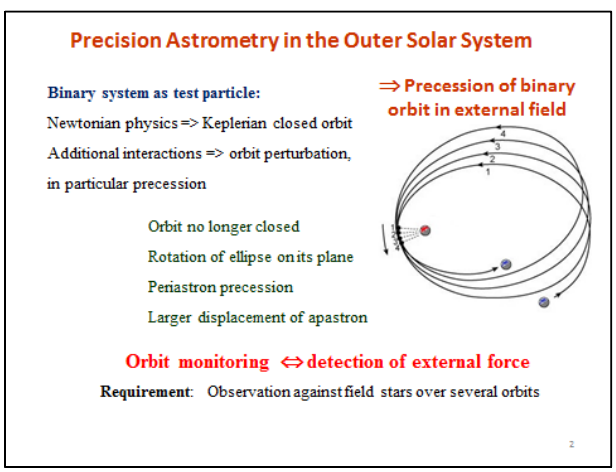
This simple proportionality permits the possibility of determining the universal constant of quantum vacuum related to its gravitational properties) by simple measurement of perihelion precession.

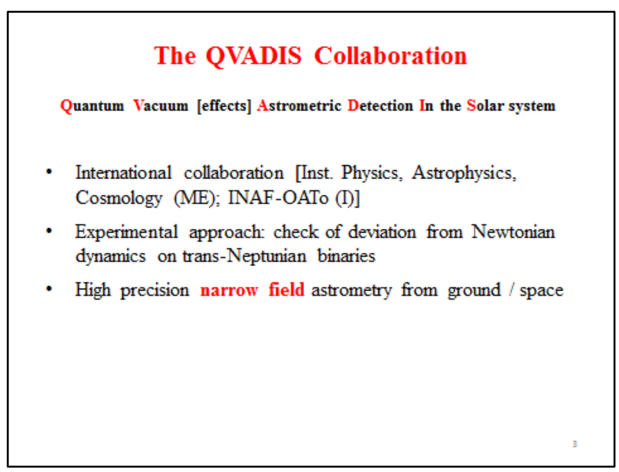
The most plausible theoretical estimates (waiting the eventual astronomical confirmation) are

$$P_{g\,\max} \approx (0.06 \pm 0.02)\,kg/m^2 \approx 28.5\,M_{Sun}/pc^2\,;\;\; g_{qv} \approx 5\times10^{-11}\,m/s^2 \tag{4}$$

Of course the ideal binary system doesn't exist. However, the unrivalled advantage of tiny trans-Neptunian binaries is that they are the best available realization of an isolated two body system with very weak external and internal Newtonian gravitational field. As a consequence, in some binaries, the known Newtonian precession might be dominated by anomalous perihelion precession. Hence, as will be more clear from the feasibility study in the next section, some of trans-Neptunian binaries are a natural laboratory for testing the existence of an anomalous gravitational field as weak as 10^{-11} m/s^2 (with the next generation of telescopes the anomalous gravitational field of the order of 10^{-12} m/s^2 might be revealed).

2. Study case: UX25





Study case: UX25

UX25 Mass	1.25×10^{20} kg
UX25 Semimajor axis	42.869 AU
UX25 Orbital Period	280.69 years
Satellite Semimajor axis	4770 km
Satellite Orbital Period	8.3094 days
Satellite Eccentricity	0.17

Trans-neptunian binary system

Newtonian precession from the Sun: $\Delta\omega_N = \frac{3\pi}{2}\left(\frac{T_P}{T_{Sun}}\right)^2 \cong 6$ mas/orbit

Estimated precession from vacuum polarisation: $\Delta\omega_{qv} \simeq 0.23$ arcsec/orbit

[Hajdukovic, 2014, hal-00908554]

Cumulative effect on 5 years (~200 orbits): 46 arcsec

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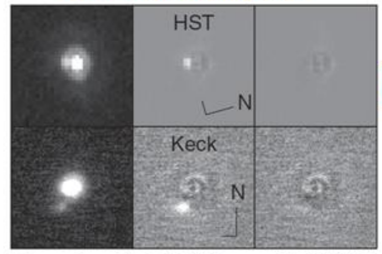
Previous observations...



[M. E. Brown, ApJL 2013]

Figure 1. Observations of the 2002 UX25 system with *HST*/HRC and Keck LGS-AO/NIRC2. The northward orientation arrow is 0.25 arcsec long, for scale. In the first column, we show the image of both 2002 UX25 and its satellite. From this image we simultaneously fit a PSF to both the primary and satellite. In the second column we show the image with the primary part of the fit subtracted. In the final column we show both components subtracted. The *HST* observation is from JD 2453939.98322 and is the most blended of the detections.

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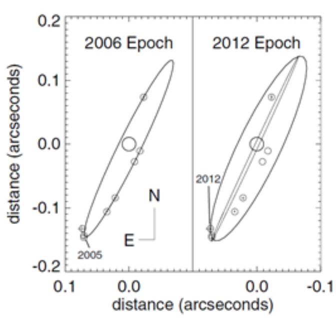
...and reconstructed orbit



Semi-major axis angular amplitude: ~150 mas

System unresolved by conventional telescopes

Faint visible magnitude:

- 20 mag primary
- 22 mag secondary

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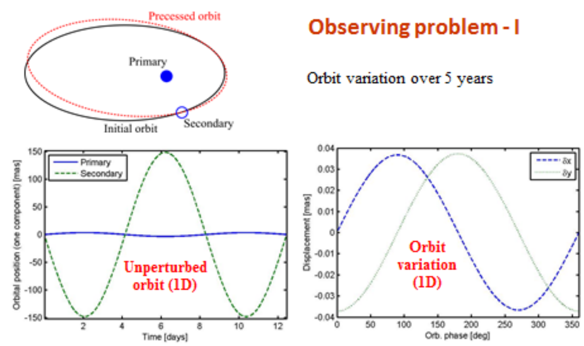
Observing problem - I



Orbit variation over 5 years

Challenge: reliable µas astrometry on faint objects, narrow field

[Gai & Vecchiato, 2014, arXiv:1406.3611]

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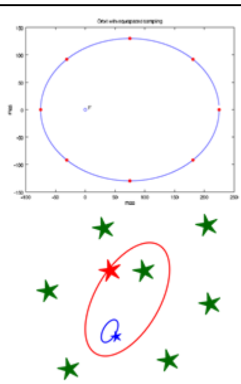
Observation setup

Multiple images taken over orbital period along several orbits

Determination of positions and velocity against field stars

Orbital fit: parameter estimate



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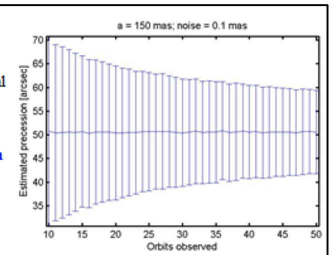
Observing problem - II

Small variation of observed vs. nominal orbital positions over a few years

Requirement: few µas final precision

Small field (~10-20 arcmin) to have several reference stars (e.g. from Gaia)



Simulation for ~100 µas precision on individual measurements

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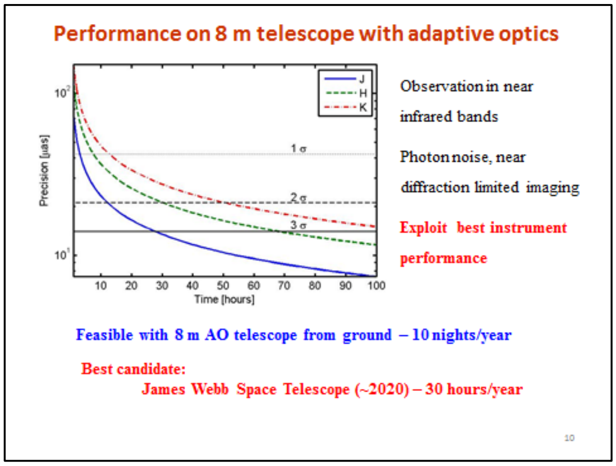

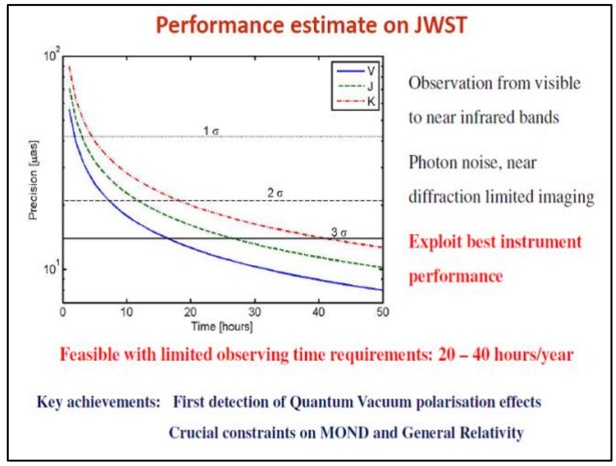

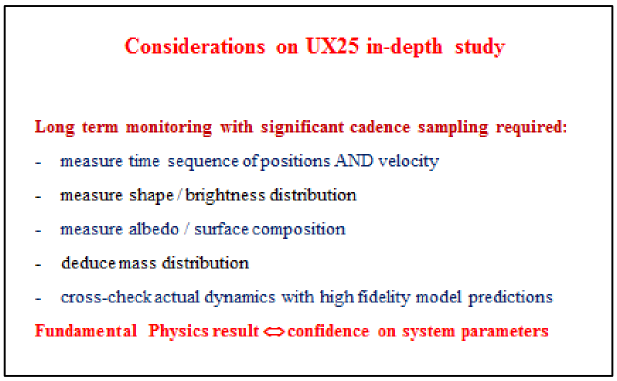

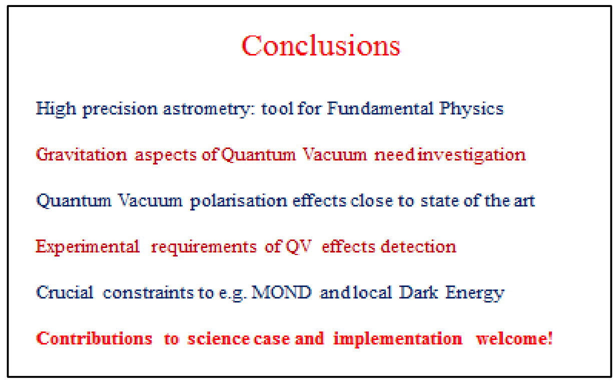

References

[1] Hajdukovic D S (2011) Is dark matter an illusion created by the gravitational polarization of the quantum vacuum *Astrophysics and Space Science* **334** 215-218

[2] Hajdukovic D S (2012) Quantum vacuum and dark matter *Astrophysics and Space Science* **337** 9-14

[3] Hajdukovic D S (2013) Can observations inside the Solar System reveal the gravitational properties of the quantum vacuum? *Astrophysics and Space Science* **343** 505-509

Hajdukovic D S (2014) Testing the gravitational properties of the quantum vacuum within the Solar System *Preprint* hal-00908554v3

[4] Hajdukovic D S (2014) Virtual gravitational dipoles: The key for the understanding of the Universe *Physics of the Dark Universe* **3** 34-40

[5] Hajdukovic D. S. (2016). What if quantum vacuum fluctuations are virtual gravitational dipoles? Preprint hal-01254678, to appear in J. Phys.: Conf. Ser. Antimatter and Gravity (WAG 2015)

[6] Murray C D and Dermott S F (1999) Solar system dynamics. Cambridge University Press, Cambridge