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

Dragan Slavkov Hajdukovic and Sandra Mitrovic
Institute of Physics, Astrophysics and Cosmology
Cetinje, Montenegro

Mario Gai and Alberto Vecchiato
Osservatorio Astrofisico di Torino, INAF, Pino Torinese, Italy

The 28th Texas Symposium on Relativistic Astrophysics
Geneva, 13-18 December 2015

1

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 realisation 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.

The emerging project QVADIS

Goal

The measurement of the precession of orbits of satellites in trans-Neptunian binaries

Study case

Trans-Neptunian binary system (55637) 2002 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

The emerging project QVADIS

What may be achieved?

The measurement of the perihelion precession of the orbit may reveal 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 detected)

Major theoretical motivation

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.

- Within the theory of virtual gravitational dipoles the anomalous gravity is not in violation of the Newton law; strictly speaking it is even not anomalous gravity, it is just a "forgotten" component coming from the quantum vacuum. "Forgetting" quantum vacuum may be compared with forgetting the dielectric between plates of a capacitor.

Theory:The working hypotheses

(1) Quantum vacuum fluctuations are virtual gravitational dipoles*

*(2) The Standard Model matter** and quantum vacuum are **the only** matter-energy content of the Universe*

* A virtual gravitational dipole: two gravitational charges of the opposite sign at a distance smaller than the corresponding reduced Compton wavelength

**Standard Model Matter means matter made from quarks and leptons interacting through the exchange of gauge bosons

Important Note: We do not modify the Standard Model of Particles and Fields and its understanding of quantum vacuum! Gravity is not included in the Standard Model.

A new model of the Universe?

- A galaxy is a system composed from the Standard Model matter and an invisible halo of the gravitationally polarized quantum vacuum

- This halo acts as an effective gravitational charge *which may explain phenomena usually attributed to dark matter*

- All halos together form a cosmological fluid with negative pressure *what may explain the accelerated expansion of the Universe without dark energy*

- Apparently, what we call dark matter and dark energy may be effects of the gravitational polarization of the quantum vacuum by the immersed Standard Model matter.

- Even more! A cyclic universe with cycles alternatively dominated by matter and antimatter

Quantum vacuum is an "ocean" of virtual gravitational dipoles

Randomly oriented gravitational dipoles (without an immersed body)

The gravitational charge density of the quantum vacuum is zero, what is **the simplest solution to the cosmological constant problem**. A tiny, **effective gravitational charge density** might appear as the result of the immersed Standard Model matter

Halo of non-random oriented dipoles around a body (or a galaxy)
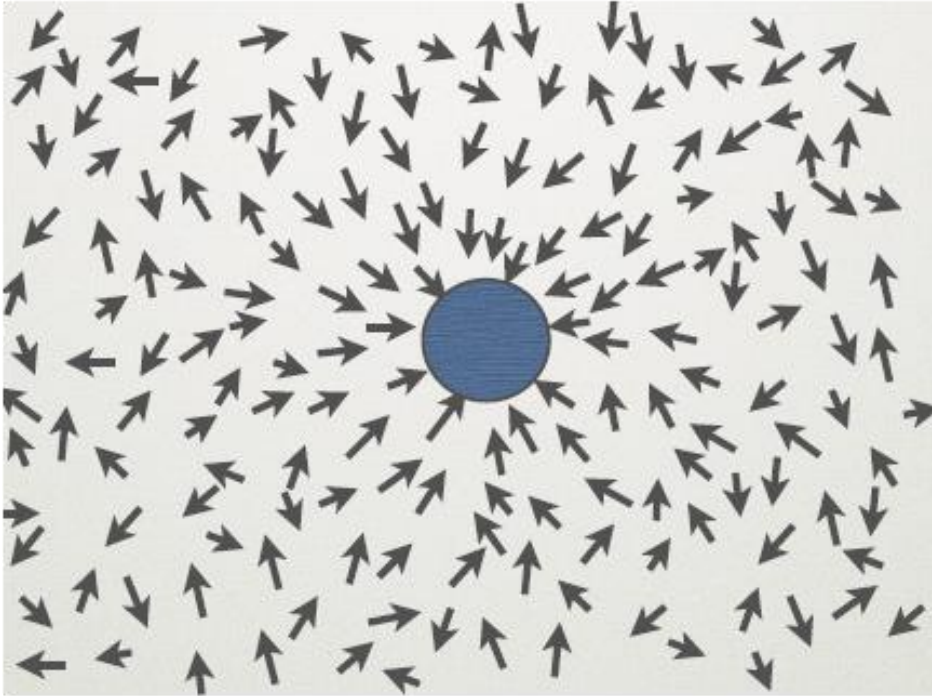
- ❑ **Random orientation** of virtual dipoles **might be broken** by the immersed Standard Model matter
- ❑ Massive bodies (stars, black holes …) but also multi-body systems as galaxies are surrounded by an invisible *halo of the gravitationally polarized quantum vacuum* (i.e. a region of *non-random* orientation of virtual gravitational dipoles)

Dark matter as the local effect of the gravitational polarization of the quantum vacuum

- **Gravitational polarization density** $\vec{P}_g$ i.e. *the gravitational dipole moment per unit volume,* may be attributed to the quantum vacuum.

In the case of random orientation of dipoles

$$\vec{P}_g = 0$$

In the case of saturation*

the gravitational polarization density has the maximal magnitude

$$P_{g\,\max} = \frac{A}{\lambda_m^3}\frac{\hbar}{c}$$

*Saturation: all dipoles are aligned with external gravitational field

- The most plausible theoretical estimate:

$$P_{g\,\max} \approx 0.06\,kg\big/m^2 \approx 28.5\,M_{Sun}\big/pc^2$$

Dark matter as the local effect of the gravitational polarization of the quantum vacuum

- The spatial variation of $\vec{P}_g$, generates a gravitational bound charge density of the quantum vacuum
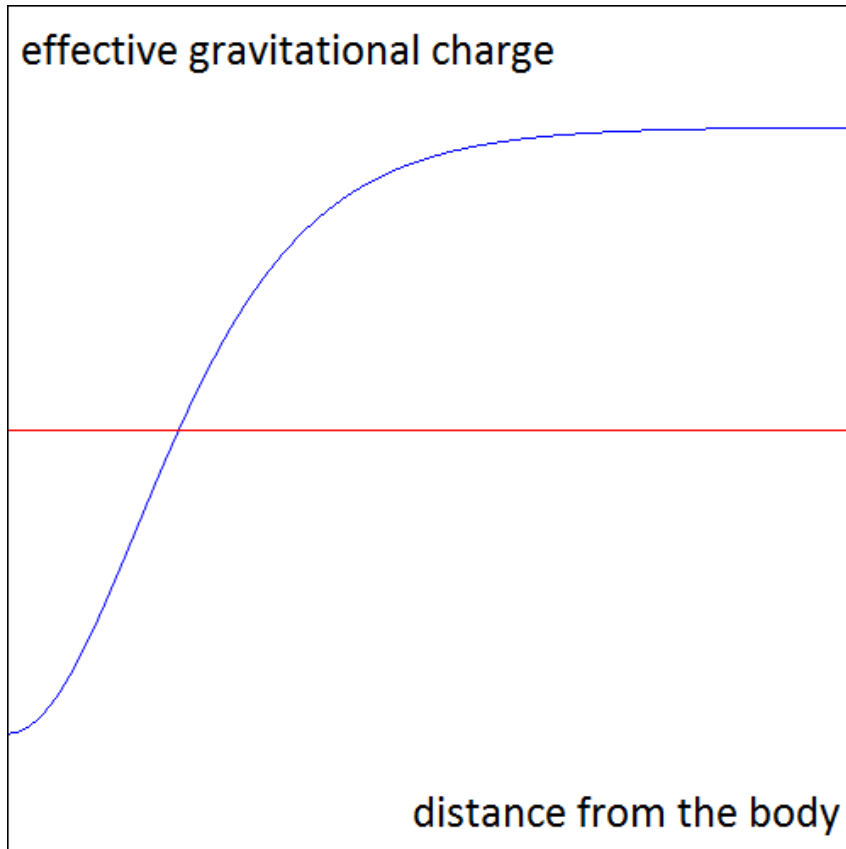
$$\rho_{qv} = -\nabla \cdot \vec{P}_g$$

- In the simplest case of spherical symmetry

$$\rho_{qv}(r) = \frac{1}{r^2}\frac{d}{dr}\left(r^2 P_g(r)\right); \; P_g(r) \equiv \left|\vec{P}_g(r)\right|$$

- Preliminary calculations based on this equation lead to the intriguing agreement with empirical results for galaxies. References: Hajdukovic [2,6,8,10-16]

How the effective gravitational charge of a body depends on distance from it

effective gravitational charge

distance from the body

- **The effective gravitational charge** of a body (blue line) increases from the "**bare**" charge measured at its surface to a constant maximum charge at a large distance from the body
- Competing gravitational field of other bodies can prevent the effective gravitational charge to increase above a limit presented by the red line
- The maximum effective charge can be reached only if other bodies are sufficiently far

Schematic presentation of regions
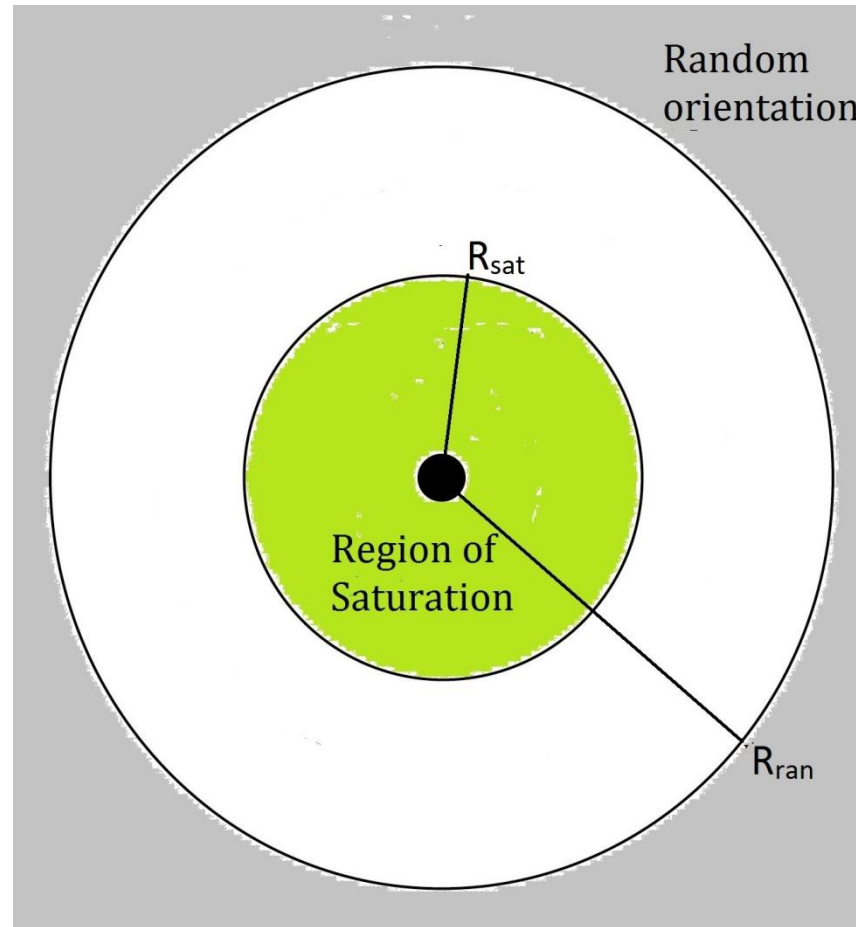
Gravitational effect of the quantum vacuum in the region of saturation

- *In the region of saturation*, quantum vacuum produces a constant gravitational field oriented towards the center

$$g_{v\max} = \frac{GM_v(r)}{r^2} = 4\pi GP_{g\max}$$

- The most plausible theoretical estimate is

$$g_{v\max} \approx 5 \times 10^{-11}\, m\big/ s^2$$

- If such an acceleration exists it causes a retrograde precession of the perihelion of the Satellite in a binary; precession per orbit in radians is:

$$\Delta\omega_{qv} = -8\pi^2 P_{g\max} \frac{a^2}{\mu}$$

$a\ and\ \mu$ are respectively the semi-major axis of the orbit and the total mass of the binary. This may be tested within the Solar system!

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: $\quad \Delta \omega_N = \dfrac{3\pi}{2} \left(\dfrac{T_P}{T_{Sun}} \right)^2 \quad \cong 6$ mas/orbit
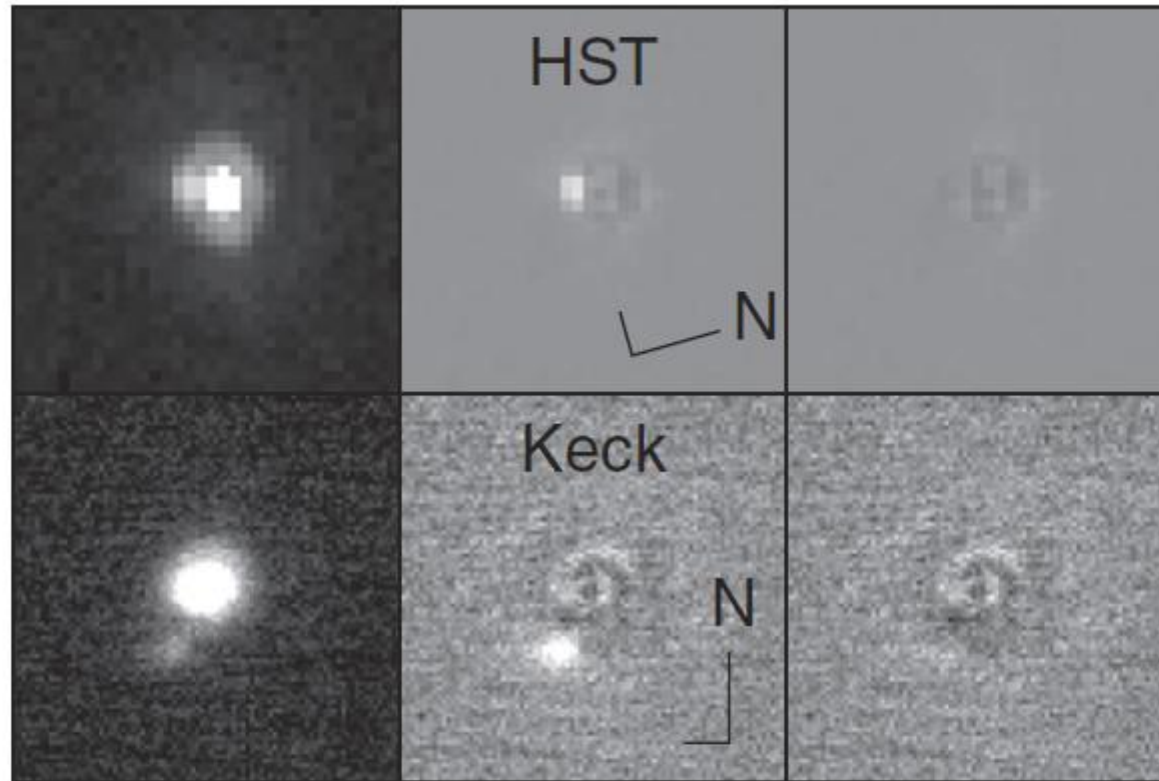
Estimated precession from vacuum polarisation: $\quad \boxed{\Delta \omega_{qv} \simeq 0.23 \text{ arcsec/orbit}}$

[Hajdukovic, 2014, hal-00908554]

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

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.

…and reconstructed orbit
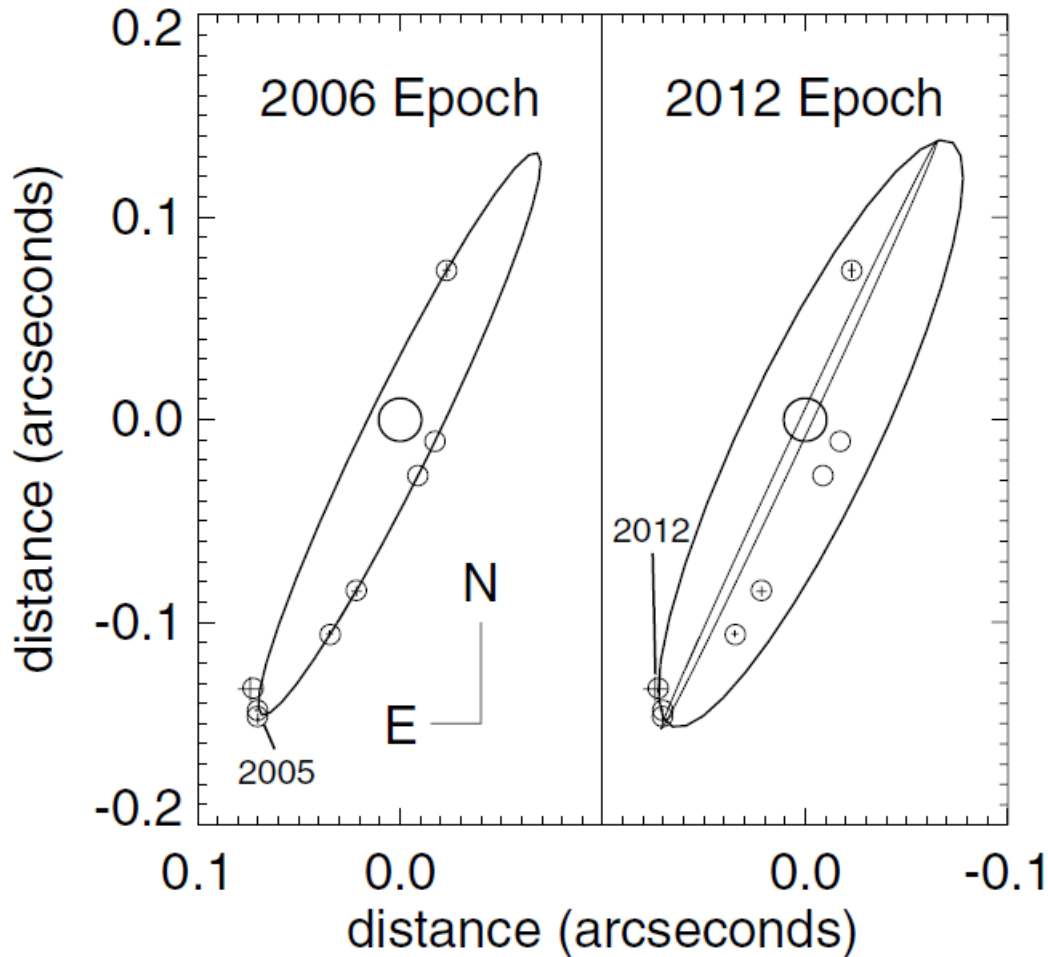
Semi-major axis angular amplitude: ~150 mas

System unresolved by

conventional telescopes
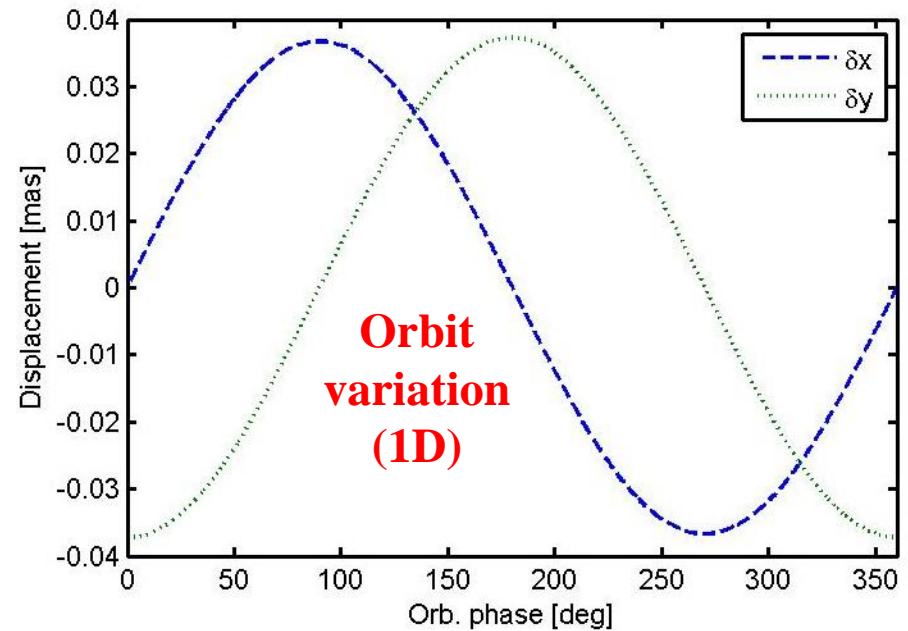
Faint visible magnitude:

- 20 mag primary

- 22 mag secondary

Observing problem - I

Orbit variation over 5 years

Unperturbed orbit (1D)

Orbit variation (1D)
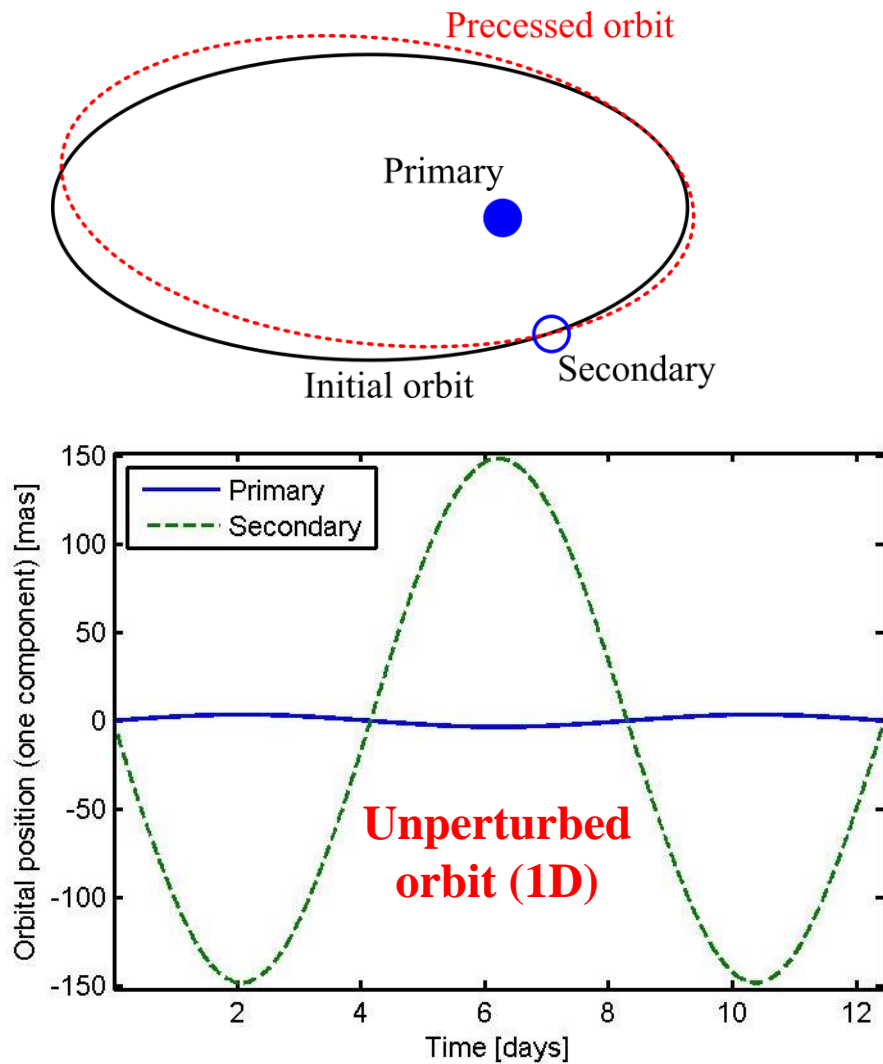
Challenge: reliable μas astrometry on faint objects, narrow field

[Gai & Vecchiato, 2014, arXiv:1406.3611]

Observation setup

Multiple images taken over orbital period along several orbits

Determination of positions and velocity against field stars
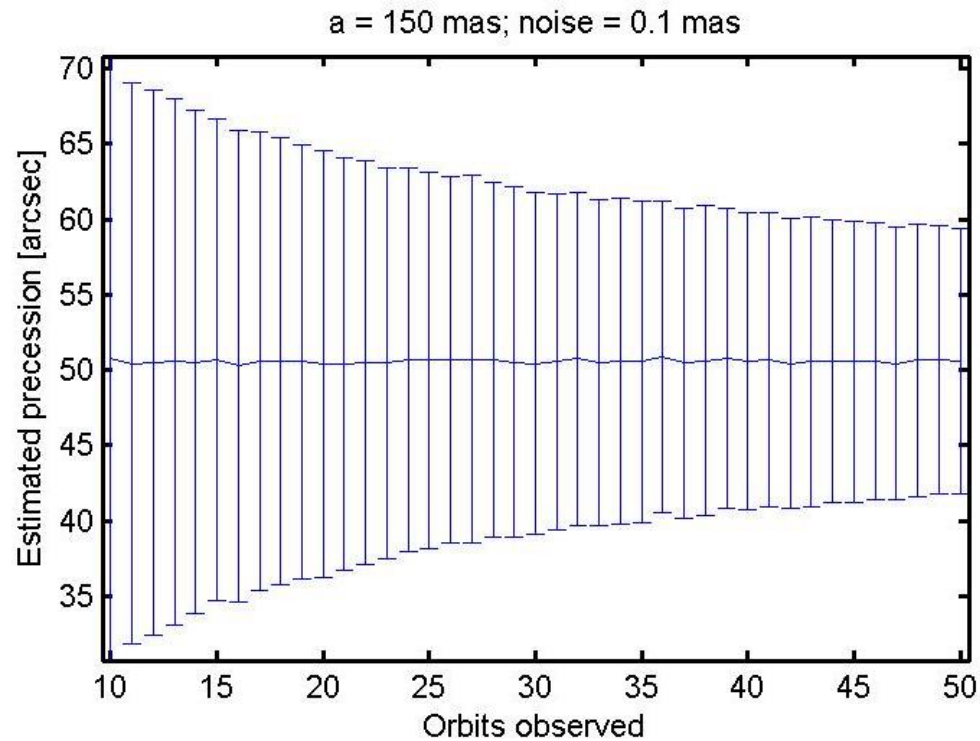
Orbital fit: parameter estimate
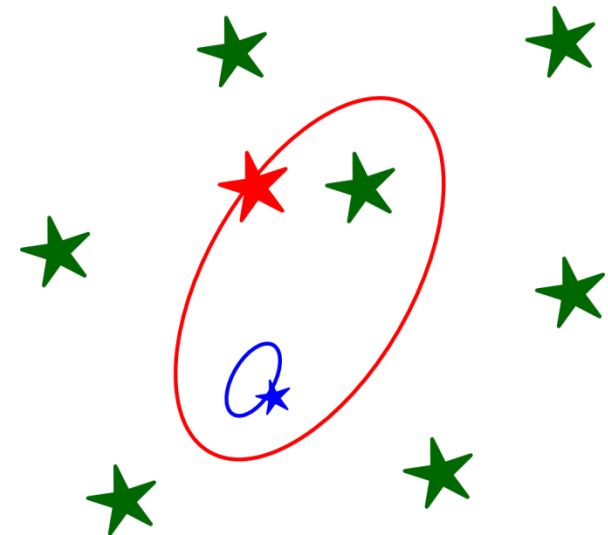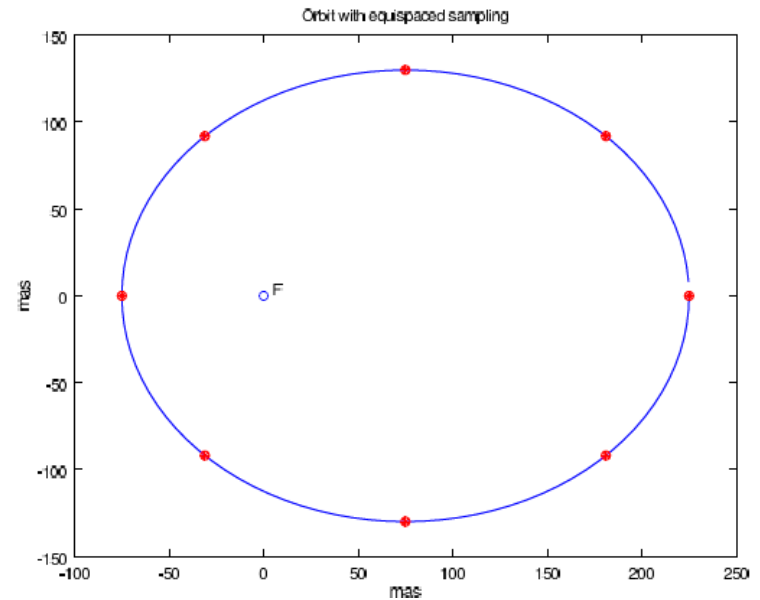
Observing problem - II

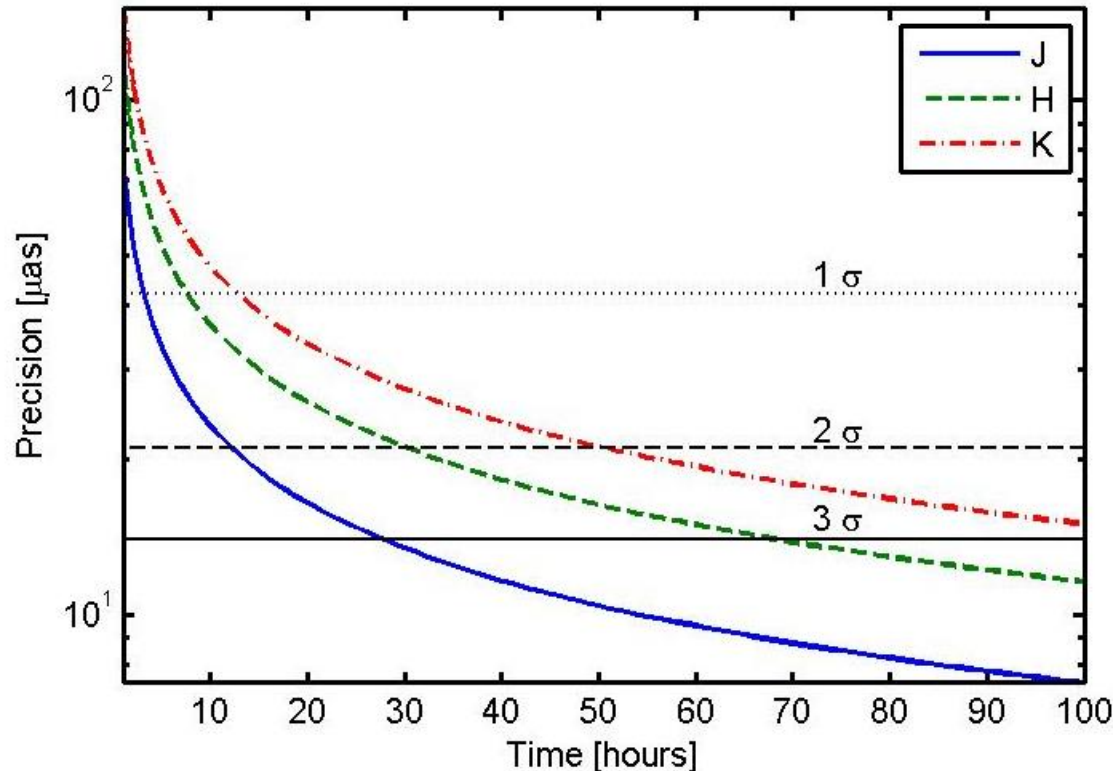Small variation of observed vs. nominal orbital positions over a few years

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

Performance on 8 m telescope with adaptive optics

Observation in near infrared bands

Photon noise, near diffraction limited imaging

Exploit best instrument performance

Feasible with 8 m AO telescope from ground – 10 nights/year

Best candidate: James Webb Space Telescope (~2020) – 30 hours/year

Reminder: Quantum vacuum in QED
## an "ocean" of virtual electric dipoles

In QED quantum vacuum can be considered as an omnipresent "ocean" of virtual electric dipoles (for instance electron-positron pairs) with random orientation

Reminder: Quantum vacuum in QED
# a halo of the polarized quantum vacuum

- The random orientation of virtual dipoles can be perturbed by a very strong electric field

- Example: The electric field of an electron at the distance of its Compton Wavelength is of the order of **10^{14} V/m**. Such a strong field perturbs the random orientation

Electron "immersed" in the quantum vacuum produces around itself **a halo** of non-random oriented virtual electric dipoles, i.e. **a halo of the polarized quantum vacuum**.
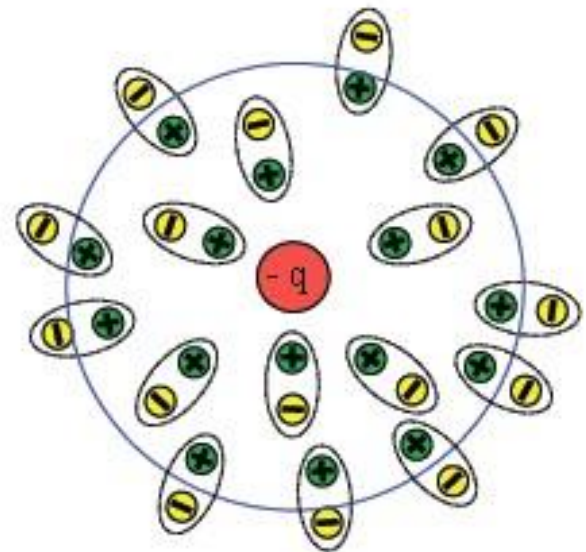
Reminder: Quantum vacuum in QED
the effective electric charge of electron

effective electric charge
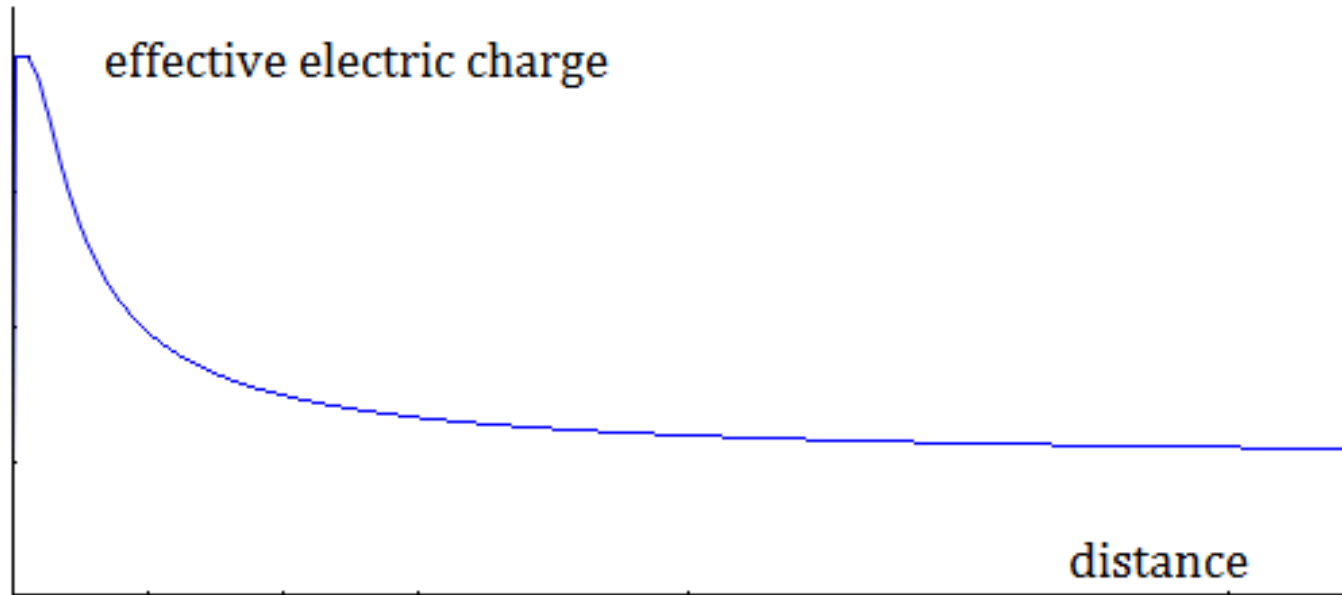
distance

❑ The halo screens the "bare" charge of an electron; what we measure is the effective electric charge which *decreases* with distance!

❑ The effects of screening are not significant after a characteristic distance (which is of the order of the Compton wavelength)

Reminder: Lamb shift
Quantum vacuum has impact on orbits of electrons in atoms

- Quantum vacuum, as "ocean" of virtual electric dipoles **has a tiny impact (but impact!) on the "orbits" of electrons in atoms**. It is known as the Lamb shift.

- Of course the best system to study the Lamb shift is the atom of antihydrogen because it is a binary system without complications of a many-body system.

- Immediate question: Can quantum vacuum as an eventual "ocean" of virtual gravitational dipoles have impact on orbits of satellites in binaries.

Reminder: Quantum chromodynamics Illuminating example: the structure of proton

6. Inner structure of a proton revealed at HERA
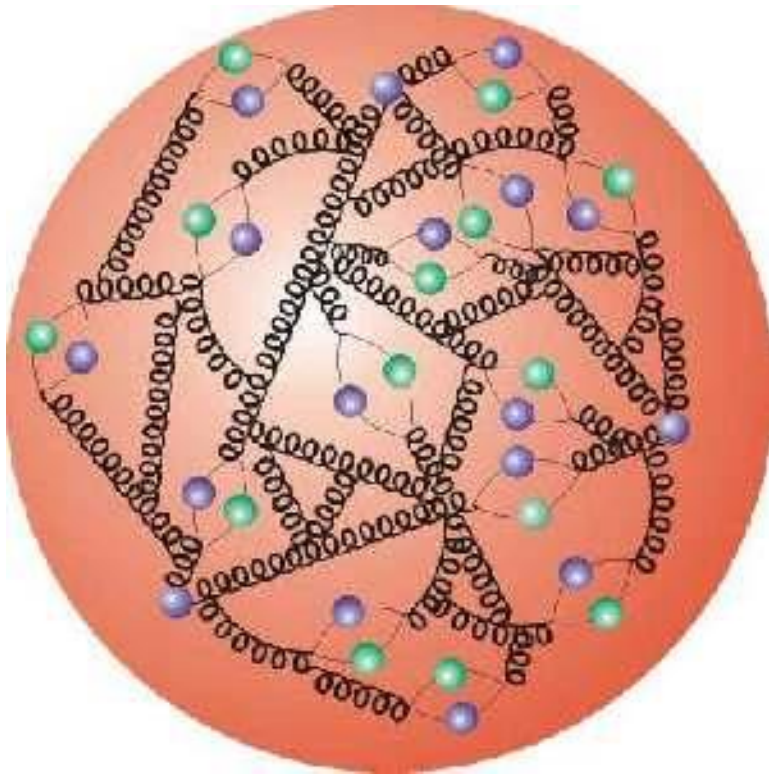
- Black spirals represent gluons while purple-green particles denote *virtual* quark-antiquark pairs (up to 100 of these quark/anti-quark pairs are "visible" at any instant!). Note that there are three more quarks (two up, one down) than anti-quarks. These are the three valence quarks we would normally refer to when speaking of the proton

- Switching off the quantum vacuum in the Universe would destroy protons and neutrons! Quantum vacuum is the root of our existence!