Entanglement Propagation In Gravity

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Abstract

Einstein's general relativity theory and quantum mechanics are the main pillars of contemporary physics, yet their basic concepts refute each other. As long as existing descriptions of nature contain contradictions, it cannot lead to a unified and correct description. We propose a space mission that tests a new model, which was only published recently by T. Ralph et al., describing how quantum entangled photons are affected in a gravitational field. The mission would also measure the influence of the distance, relative velocities, and the degree of variation from the radially propagating gravitational potential on quantum entanglement, putting quantum theory itself to the test. Our mission will be able to disprove either standard quantum mechanics or demonstrate the Ralph model. The mission support the unification of general relativity and quantum mechanics.

The mission itself consists of two satellites linked to the ESA Optical Ground Station (OGS). One satellite (Albert) will be placed in a 3,000 x 700 km elliptic orbit, while the second (Erwin) into a circular 700 km orbit, launched with a Soyuz Fregat. Both satellites are designed to be identical carrying one photon source, two local detectors, and two telescopes, thus being capable of symmetric, asymmetrical, and bidirectional measurements with both space-space and space-ground links.

1 Science Case: Description

In 1916 Albert Einstein published an article that changed the landscape of physics forever: *The Foundation of the Theory of General Relativity* [1]. Einstein's theory proved itself as a great tool to consistently and repeatedly describe the Universe on the largest scales imaginable. On the contrary, quantum mechanics was originally invented to describe the Universe on atomic and subatomic scales, where the action is in the order of the Planck constant. Erwin Schrödinger [2] introduced the mathematical foundations to describe quantum entanglement, where two or more particles are correlated more strongly than possible by classical means only. This peculiar quantum phenomenon was experimentally demonstrated in 1982 [3]. Both theories are a major building block of our current understanding of nature and both turned out to provide the foundations for many technologies used today. Nevertheless, these two theories contradict each other in a very deep sense, e.g. the way space and time are described. To solve this unsatisfactory situation there has been a large ongoing effort ever since to unify these two theories.

It has been suggested by several authors like Diosi [4], Milburn [5], Penrose [6], Adler [7] and Ralph [8] that gravitational fields affect the correlation of entangled photons.

Here we propose a space mission that is not only designed to be able to observe these effects, but also the influence of the distance, relative motion and the degree of variation from the radially propagat-

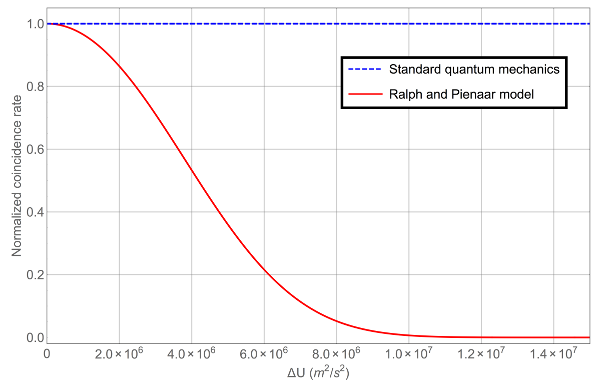

Figure 1: Comparison between the standard quantum mechanics prediction and the Ralph-Pienaar model [8].

ing gravitation potential on quantum entanglement.

2 Science Objective

The objective of our mission is to observe the interaction between gravity fields and entangled quantum states over a wide range of values for the gravitational potential $(0 \leq \Delta U \leq 13\, km^2/s^2)$. In order to do this we will use a source of polarisation entangled photon pairs. The photons will be separated and travel over long distances, experiencing a changing gravitational potential before detected. We will compare the data acquired by the two detectors on the satellites receiving the photons to evaluate the coincidence rate of the photon pairs.

The objective of our mission is to measure the normalized coincidence rate $C_{norm} = 1$ of entangled photons as a function of the gravitational potential differences ΔU between remote satellites. Standard quantum mechanics predicts C_{norm} to be equal to 1 regardless of the gravitational potential difference the photons are detected in. A model developed by Ralph and Pienaar [8] predicts a decay in the coincidence rate with the difference of the potential ΔU (Figure 1).

$$C_{norm} = e^{-\frac{\Delta_t^2}{2d_t^2}}, \quad (1)$$

Where $d_t = t_c \times c$ is the coherence length, with t_c coherence time of the source. In the case the two detectors are aligned with the center of the Earth, Δ_t is given by:

$$\Delta_t = M\frac{h}{r_1}, \quad (2)$$

Where M is the the mass of Earth in units of length, r_1 is the distance of the first detector from the center of the Earth and h is the height of the second detector over the first detector in a radial direction. If α is the angle between the position vector of the two detectors (origo at Earth's centre), (see equation 2) is valid only for $\alpha = 0$. For any $\alpha \neq 0$, the model does not provide exact predictions, nonetheless the influence of the gravitational potential should be dependent on the path of the photons.

The scientific objective of the proposed mission is to distinguish between the two theories, when $\alpha = 0$, with a 5σ confidence level.

In case the Ralph-Pienaar model proves to be correct, we want to characterize the whole curve in the range between $C_{norm} = 1$ and $C_{norm} \simeq 0$.

Instead, collecting data when $\alpha \neq 0$, enables us to characterise the expected path dependence of C_{norm}.

3 Measurement Requirements

3.1 Entanglement

In 1964 John S. Bell published an article, proposing an experimentally testable criterion; whether a two-photon system subjected to the experiment is entangled or not [9]. Using a CHSH-Bell-type inequality [10] a correlation parameter S is measured. A classical correlation is constrained within the range $-2 \leq S \leq 2$, whereas for quantum states the correlation parameter can be as high as $2\sqrt{2} \approx 2.8$.

In a quantum optics experiment using pairs of entangled photon states, the two photons are not necessarily detected simultaneously. A two-fold detection of the two photons within a given coincidence window is defined to be a coincident count and the individual counts in the two detectors is called a single count.

We chose photon pairs entangled in their polarisation degree of freedom due to the high maturity of the technology involved. The analysis of correlation in polarisation is done using wave-plates and polarisers. We use the term source visibility to quantify the emitted photon state, this quality is mainly diminished by (uncorrelated) background counts and can be reduced by wavelength filtering and timing filtering.

The signal (photons coming from the source, re-

ceived by the detectors) to noise (background counts detected from starlight and a satellite albedo) ratio shall be higher than 1:5 in order to violate Bell's-inequality.
A set of 100 different gravitational field potential difference measurements shall be performed equally distributed in a range of 0 to 13 km^2/s^2 to characterise the whole curve predicted by Ralph.
For every bin the quality of entanglement (visibility) is evaluated. To be statistically significant, 1,000 counts shall be taken into account. Additionally, the normalised coincident rate at a given gravitational field potential shall be evaluated using at least 10,000 coincident counts in total per bin. In order to define a position for each bin in the gravitational field, the position of the satellites shall be known to a precision of $20\,m$.

4 Instrument Requirement

Due to the long distance between the source and the detector, the link budget is one of the main restrictions for the mission. The orbit necessary to achieve the scientific objective is such that the maximum distance between the two satellites is equal to $9,900$ km.

Using techniques for laser communication we define the attenuation $A = P_T/P_R$ where P_T is the amount of coincidence (mean value) sent and P_R is the amount of coincidence received as:

$$A = \frac{L^2\lambda^2}{D_T^2 D_R^2}\frac{1}{T_T(1-L_P)T_R}, \tag{3}$$

where λ is the wavelength, D_T and D_R are the diameters of the transmitting and receiving telescope, T_T and T_R are the transmission factors of the telescope and L_P is the pointing loss. To minimize the development time of the mission, we select existing telescopes (D_{RT}) to be $D = 13.5$ cm. At the maximum distance between the two satellites along the orbit we get a -56 dB loss for the laser link. Taking existing entangled photon sources into account yielding about 10 MHz of entangled photon coincident counts, we can expect 13 coincidence counts for the maximum distance between the satellites with one detector being next to the source and the other at the remote satellite.
According to the scientific requirement that Ralph et al. predicts, the amount of coincidences gets less over distance. In order to separate this effect from inevitable mispointing at that distance the singles count rate at any detector is also evaluated, which is not affected by the proposed effect.
The effect is only measurable if the emitted entangled photon pairs have a coherence length of less than 1 ps, which defines the maximum allowed coherence length for the source.
To evaluate the entanglement of the source, the link, the analysis module together with the detectors shall have a better quantum visibility than 82%. This is affected by the polarisation mismatch of the channel as well as by the timing of the detectors. The detectors, as well as the time-stamping module shall therefore have a timing jitter of $300ps$, disciplined to a local clock with a stability better then 10^{-12} to achieve the synchronization between the detectors that are receiving the pairs.
In order to fulfill the position requirement of the satellite, the measurement will be calculated on ground using the LCT laser modulation accurate to 1 cm between satellites.

5 Scientific Product

The data acquired on the satellite, such as the timestamp of the singles will be transmitted from the satellite to the ground station infrastructure data center. In order to determine the ΔU, a GPS position associated with any measurement interval of the counts is recorded.
The coincident counts will be used to evaluate the Bell's inequality (CHSH) for every gravitational field potential difference measured (100 measurement are specified in the scientific requirements section).
In order to be able to refute one of the two models (classical quantum mechanics, predicting no influence of the potential difference ΔU on the measured coincidences, and Ralph's model) we resort to the physicists community's convention of obtaining a number of measurements such that for each bin (set of values ΔU we consider to be equal) the error bar with standard deviation of 5σ does not intersect with more than one of the two curves in Figure 1.
While the relative velocity and the distance between the two satellites ($\Delta v_r, d$ respectively) are not driving the mission design – a wide range of ΔU automatically yields a wide range of $\Delta\ d$ – only a post-

mission analysis will provide insight into if and how those parameters affect the measurements. We do not know of any theories predicting those effects, but recalling that there are experiments solely dedicated to measuring the influence of distance [1] and relative velocity [2] on this correlation, it is interesting to prove this on a larger scale.
The measured as well as the analysed data will be stored by ESA and be made available to the scientific community. Publication and presentation in scientific journals and conferences will be made. Dissemination will happen though public lectures and press conferences, as well as articles and newspapers.

6 Mission Requirements

To fulfill the science requirement of the mission two satellites are needed in orbit around the Earth and at least one ground station. This kind of configuration will allow to use 30% of measurement time exploiting the different satellite to satellite and satellite to ground link combinations. In contrast with only one satellite the useful time for the measurement will be between 6 and 10% (depending on the orbit). Moreover, with a satellite to satellite link the effect of the atmosphere can be avoided, which would introduce an additional loss of 4 dB or more and also may affect the results of the correlation measurement. Finally, with two satellites on two different orbits a wider range of distances between source and detector and of gravitational potential differences can be achieved. Mainly, the lower value of ΔU can approach the 0, while the satellite to ground link is limited by the altitude of the satellite (lower bounded by the atmosphere). Every satellite has to implement two telescopes, that may be used both as transmitter and as receiver, and one source.
The mission will launch two satellites into space and uses a ground station to achieve the scientific goal of the mission. One satellite called *Albert* will be orbiting on a 3,000 x 700 km elliptic orbit, while the second called *Erwin* orbits at a circular 700 km orbit. This garanties that all specified gravitational field potentials are accessible as defined in the scientific objective section.
Both satellites are identical and each one has one entangled photon source, two polarization analysis detector modules and two telescopes on board. Asymmetrical (local and remote photon detection), bi-direccional (two Alberts and two Erwins simultaneously) and local detection modes of operation are feasible.

[1] http://arxiv.org/pdf/quant-ph/0607182v2.pdf
[2] http://arxiv.org/pdf/quant-ph/0007009v1.pdf

7 Spacecraft Design Requirements

Based on the mission requirements, we have assessed the budgets, key drivers, and system requirements. The spacecraft payload consists of a scientific instrument payload comprising of the entangled photon source, local detectors, LCD, and the polarization analysis module. All detector signals are associated with a time-stamp with a precision of $200ps$ as presented in the instrument requirement section above. The local time-stamp needs to be disciplined by a Rubidium-clock, which already has space heritage to the stability of the required 10-12$/Delta\ s/s$. The scientific payload is depicted in figure 2.

Table 1: Budgets.

Component	Mass [kg]	Data	Power [W]
LD	3	4GB/orbit	10
T	53	-	160
EPS	5	-	10
MUX	1	-	1
I	62	4GB/orbit	181

Table 2: Critical points and mitigations.

	Critical Points	Mitigation
LD	Optical alignment	Dedicated breadboard
	Polarisation control	PID
T	Pointing accuracy	Previous test
EPS	Light coherence length	Previous test
	Optical alignment	Dedicated breadboard
MUX	Mechanical Precision	Previous test

7.1 Subsystem Requirements

The following requirements were derived from the mission and payload requirements

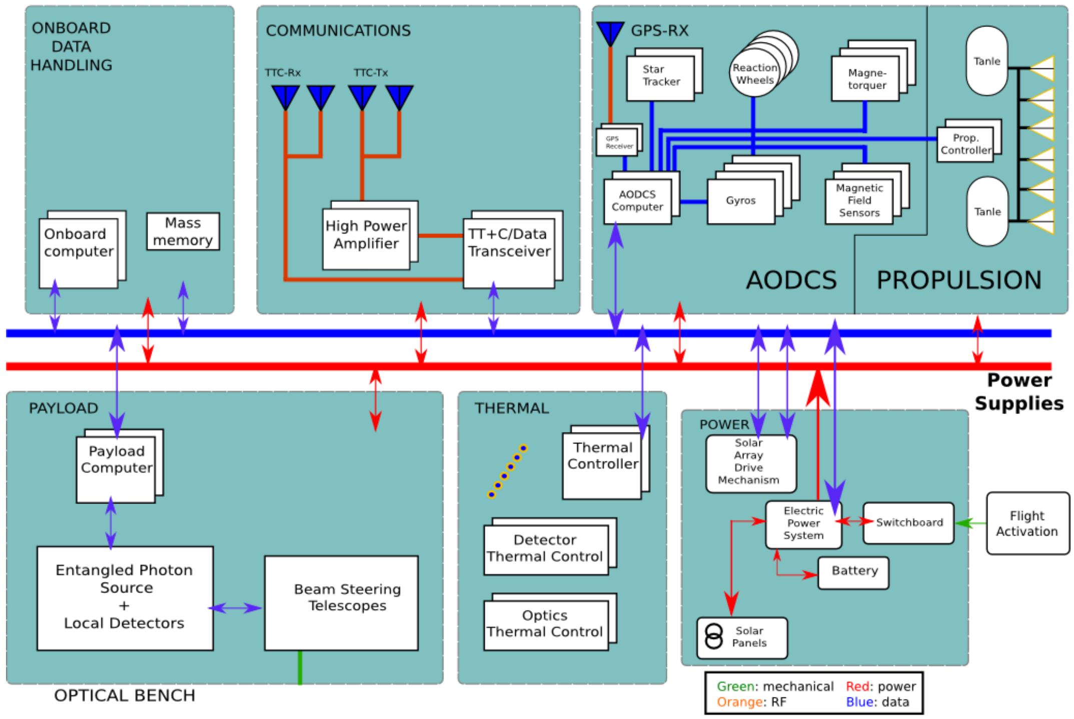

Figure 2: Baseline architecture of the entire satellite system.

There shall be 2 satellites for performing space-based optical links. The mission shall not have any single-point failures. Each satellite shall accommodate two laser communication terminals enabling dual links. The system shall be compatible with a Vega or Soyuz launch from Kourou. Measurements at the satellite as receiver shall be at a sun angle greater than 10 deg. The system shall allow the space-space link to be continuously operated for at least 33% of the mission life. The system shall provide a gravitational potential difference in the range of 0 to 13 km^2/s^2 at a minimum resolution between measurements of $1 \cdot 10^5$ m^2 s^2. The system shall provide at least 1000 points for the coalignment of transmitter and receiver with the gravitational potential (at zero inter-satellite angle). The system shall provide measurements across the range 0.1866 to 73° inter-satellite angle. The system shall respect all relevant deorbit or standards for that orbit. Measurements with ground as receiver shall occur between local sunset and sunrise (too much noise in sunrise). The measure need to have a minimum number of coincidence to be able to affirm that a possible changement of coincidence is non-compatible with a classical view. The system shall be compatible with operations through the Van Allen belt. The system shall output all raw experimental data at the ground station. Each satellite shall incorporate a full duplex TTC link.

8 Spacecraft Subsystems and Operation

8.1 Orbit

In order to achieve mission goals an orbit fulfilling these goals is needed. Several orbit candidates were evaluated according to the criteria listed below.

- Maximum difference of gravitational potential per orbit: 13.8 km^2/s^2
- Inter-satellite visibility ratio: 33% per orbit
- Ground station (GS): satellite measurements done in GS eclipse - 5% per orbit.
- Inter-satellite angle minimized: 0 angle every 8 hours
- Launch opportunities: 1 launch only

These criteria are based on the mission requirements, and enabled the limiting of the candidate orbits down to the final orbit, seen in Figure 3.

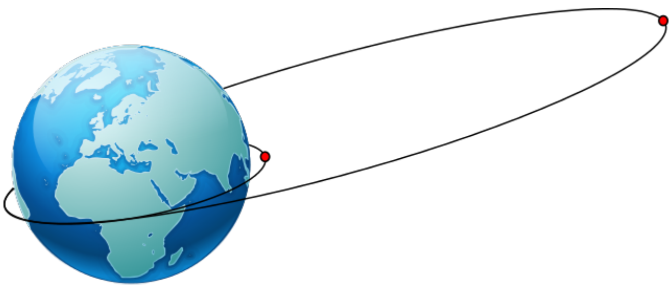

Figure 3: Final designed orbit (not to scale).

The final, chosen orbit then supplies the conditions seen leftmost in list 7.1.

8.2 Launcher

The Soyuz Fregat (hereafter referred to as Fregat) will be used as the launcher, given its high reliability and the matching of payload capability with the mission payload's mass. Because two satellites need to be brought into orbit a carrying structure is needed to accommodate the satellites into the launcher fairing. This structure, the SYLDA-S, has still to be developed for Soyuz specifically, but it can be thought of as a smaller version of the SYLDA 5 dual launch system of Ariane 5. The SYLDA-S will weigh no more than 500 kg.
Albert will be placed on top of Erwin (with the dual launch system in between). Erwin will be deployed first in the circular orbit and after the apogee is raised (by the Fregat's upper stage), Albert will be deployed. Finally the Fregat's upper stage will be de-orbited by reducing its perigee so that it will cross the Earth's upper atmosphere, which will gradually reduce the Fregat's apogee until it will finally burn up in the atmosphere (which will happen in 5 orbits time for a perigee of 100 km). The amount of rocket propellant for the Fregat's whole mission will add up to 833 kg. The pricetag for such a launcher is €75 million.

8.3 Propulsion

The propulsion system, required by the mission, is intended for three functions seen in table 8.3.

- Deorbiting: 134 m/s (5% margin)
- RCS desaturation: 20 m/s (100% margin)
- Collision avoidance: 10 m/s (safe - side estimate for a 0.001 collision probability for mission lifetime)

The engine is hydrazine chemical propulsion, with a 230 Isp, resulting in total of 71.2 kg of propellant needed for the duration of the mission.

8.4 Deorbiting

The performance needed of the satellites in order to deorbit is based on the higher, elliptical orbit. Thus, at the end of its mission Albert will apply its propulsion system at apogee in order to decrease its perigee to 200 km altitude. This will cause the apogee of the satellite to slowly degrade, so as to drop into the atmosphere in 2 years time. Erwin will also be deorbited at the same time, but the actual orbit degradation into atmosphere will occur much sooner.

8.5 Radiation Environment

Radiation is a concern when navigating though the Van Allen belts; it manifests itself as total radiation dose experienced by a spacecraft throughout its lifetime, noise in detectors, single event upsets and latchup. These can be mitigated on the software level with error detection & correction algorithms and on the hardware level with more shielding. By modelling the total ionising dose in SPENVIS the required shielding for the most sensitive instruments was found.

8.6 Structures & Configuration

The bus is cubic shaped with dimensions of 1.3 x 1.3 x 1.3 m^3 and a mass of 900 kg. The design drivers for the configuration of the satellite are the visibility of the telescopes between the satellites and the ground station, the precise alignment of the telescopes, as well as the alignment of the satellites in order to reduce reflection of the sunlight from the surface of one satellite to the other. The latter is important to reduce the noise of detection of entangled photons. In figure 4 and figure 5 is the outer and inner configuration of the satellite shown. Two telescopes are mounted on two different sides, which makes an angle of visibility of 270°

possible and this provides visibility in the selected orbit configuration. The space qualified laser communication telescopes of Tesat Spacecom are able to align separately from the satellite in the full hemispherical half-space. Additionally, the satellite itself can be attitude controlled in a very high precision, due to three star trackers, reaction wheels, magnetic torquers and a thruster propulsion onboard. In this way, the sunlight reflection on the surfaces of the satellites between each other can be minimized while retaining the optical link stability. The solar arrays are adjustable in all degrees of freedom in order to minimize the sunlight reflection. In the eclipse a battery will provide the system with electrical power.

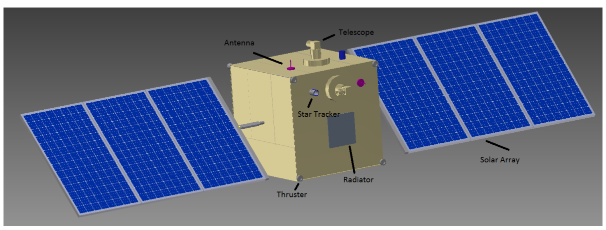

Figure 4: Spacecraft's outer configuration.

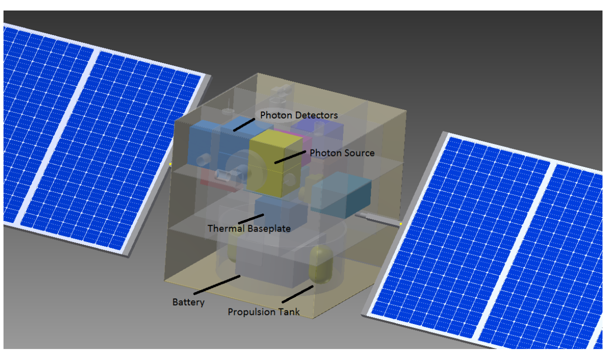

Figure 5: Spacecraft's inner configuration.

8.7 Thermal Control System

In order to meet the thermal requirements the thermal control system is designed as shown in 6. For maintaining a stable temperature of the system, the thermal balance between the spacecraft and the environment was calculated. The hot case (spacecrafts in full operation and sunlight) yields a radiators surface area of 3.2 m^2, so in order to achieve the required temperature stability the system is fitted with active thermal control in the form of thermo-electrical heaters, sensors, temperature monitoring and control. In the cold case (electronics in standby mode and spacecraft in the Earth's shadow), where the temperature can be critically low. In this case heating will be applied in order to keep the system's temperature stable. Active electro-thermal control of the baseplate with a stability of ± 3 ° C is aimed for. The payload will be shielded and actively temperature controlled to reach this goal. The photodetector will be cooled to 243 K by means of thermo-electrical elements. The subsystems are fitted with sensors, radiators, thermo-electrical heaters and coolers to ensure monitoring and control of the payload's temperature and the spacecraft's structure is covered by MLI to insulate it from the sunlight.

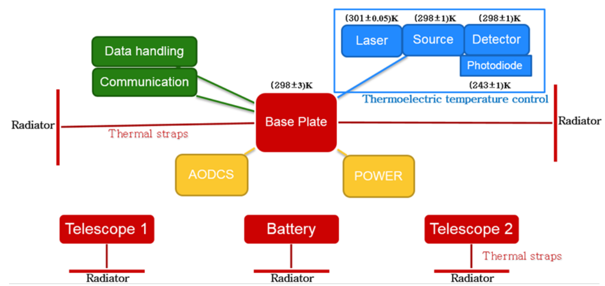

Figure 6: System's thermal control system.

8.8 Data Handling & Control

The main source of data is the payload itself, with data rates per orbit for Albert and Erwin being 4GB and 3.1GB, respectively being downloaded to the ground based infrastructure using a RF-channel when available.

The chosen on-board computer is LEON3-FT, which thanks to it inbuilt versatility is capable of handling both the MIL-STD-1553 procotol intended for data interfacing with the subsystems, and the high datarate Spacewire - protocol for the payload data transfer.

8.9 Power and Mass Budget

The power and mass budget for each subsystems is listed in tab. 3. The solar array is dimensioned taking solar efficiency of 30 %, transformation efficiency of 70 % and eclipse time of 44 % into account. The solar array area is calculated to be 8 m^2 to provide the system's peak power. A battery will provide the system with power during eclipse.

Table 3: Nominal power (NP), peak power (PP) and mass (M) budget. Incl. 20 % margin.

Subsystem	NP (W)	PP (W)	M (kg)
Instrument	307	397	177
Instr. thermal c.	75	125	39
Data handling	4	8	6
Attitude det. & contr.	139	204	39
Propulsion	1	13	95
Power	25	63	129
Communications	23	116	72
Harnessing	0	0	37
Struct. & therm.	32	257	155
Total	**727**	**1420**	**903**

8.10 Payload

The payload is an entangled photon source which is able not just to generate pairs of polarization entangled photons at high rates but also to detect them. The payload has an entangled photon source, a pair of local detectors and two telescopes in order to send the photons out in free space. The technology of the payload was not driven the mission objectives, therefore COTS and the best available technology was chosen in order to achieve the payload requirements.

8.11 Optical Link Budget

The optical link operate at 800 nm and provide a 10 MHz source brightness. The operating range goes from 100 km to 10000 km. Every satellites will have on board two TESAT LCT terminal, properly modified to remove fiber optics in telescope to prevent loss of polarisation. The optical link has to achieve a signal to noise ratio 5 and to ensure the local detectors not to saturate.
As already discussed in section 4, in the worse scenario, when the distance between the two satellites is maximum, the total loss of the link is 55.7 dB and a signal to noise ratio higher than 9 is expected.

8.12 Communication and Tracking

The scientific data produced during the mission is downlinked through a 8GHz X-band channel. The link is capable of downlinking 4.58 GB data per orbit at a worst - case 5000 km range, assuming a 12 m reception antenna, with an ample E_b/N_O ratio of 26 dB.
The main limitation in the link is the bandwidth needed - roughly 15 MHz - but is not a driving requirement.

The TTC in turn is handled through a 2.2 GHz S-band link capable of exchanging 45 MB data per orbit at the worst case range of 5000 km, having a E_b/N_O ratio of 10 dB when a 7 m reception antenna is used.

8.13 Attitude Determination and Control System

The attitude of the satellites has to be controlled, in order to maintain the desired contact between the satellites and the ground. A 0.1° pointing accuracy (to within 3 σ) is needed, to be within the wide-field camera FoV of 0.16°. 70Nm of disturbance torques have to be handled. The position and time also have to be known. Rate gyros, magnetic field sensors, and GPS are used to determine attitude, position and time. A star tracker is used for pointing, and the wide-field camera of the LCT does the fine-pointing. Reaction wheels are the main means of attitude control. The wheels require a momentum dump of 7.2 Nms per day, done using the onboard thrusters.

9 Ground Segment

The EPIG mission will be coordinated by the Mission Operations Centre (MOC), ESOC and telemetry and telecommand will take place though the ESTRACK ground station network. Data will also be coming from the Optical Ground Station (OGS) telescope, such as ESA's telescope station in Tenerfie (Spain). Users can request telecommunication via ESOC to conduct certain experiments aboard and all data (housekeeping and scientific) will be stored in an archive available to the users.

10 Traceability Matrix

The traceability matrix is given here in the form of a list to enable the reader to relate the goals of the scientific mission with the intended solutions in the end.

- **Scientific objective** To observe the interaction between gravity and entanglement over a wide range of values for the gravitational potential.

- **Measurement requirements** SNR greater than 1:5 for Bell's inequality violation is requiere. Dividing the dU range (0 to 13 Km2/s2) in 100 equally spaced bins, at least one point in each bin is needed. 1000 coincidences needed in every bin for a statistically relevance. Total of 10000 coincidences needed for each bin for comparing standard quantum and Ralph's theory at 5sigma.

- **Instrument requirements** Link shall not exeed 60dB. Aussuming telescope diameter 13,5 cm; pointing precision at 0,1 urad a 56 dB loss for laser link at max inter-sat distance of 9900 Km is anticipated; Requireing a 10MHz coincidence rate source. Photons coherence length of 1 ps. Source, link and polarization analysis module (all together) with a visibility better than 82% is required. Coincidences analysis in post-procession: detector and time stamping with time jitter less than 300ps disciplined to a local clock with stability better than 10E-12 is required.

- **Scientific products** 100 values of correlation parameter S equally spaced over DU range 0-13 Km2/s2 (Bell's test). 100 values of normalized coincidence rate spaced as above (Ralph's theory test).

- **Mission requirements** To test possible configurations (sat-sat, sat-ground, sat-ground-sat) covering dU range specified: 2 satellites, 1 ground station; 1 source and 2 detectors in each satellite and in the ground station. Orbit req: dU range $0 - 13.84 Km^2/s2$ to fit measurment req; 30% in time sat-sat visibility to fit a mission lifetime of 2-3 years. Orbit req fulfilled with 1 circular orbit of radius 700 Km and 1 elliptical with 700 Km perigee, 3000 Km apogee.

- **Spacecraft requirements** Launcher req: 1 Soyuz Fregat with 833 Kg propellant, to fit orbit req. Satellite propulsion req: hydrazine chemical propulsion, 230 Isp, 70 Kg propellant, for orbit control. Other sat req: radiators 3,2 m^2. $\pm$ 3° temperature control. Photodetector cooled at 243 K. Power budget: nominal 0,6 kW in total.

10.1 Risk Table

The risk associated with the project is listed in the following table.

event	risk (A-E)	severity (1-5)
low TRL not ready in time	D	2
failure of payload	D	2
insufficient radiation shielding	C	3
underestimation of straylight	C	3
fibre switching mechanisms	D	3

11 Development Plan

In the development of the mission, great emphasis was put on to design the mission to minimize the development of the required technology. Most of the components to have already flight heritage (TRL 9). Some of the scientific payload subcomponents are currently at the stage of TRL 4-5. Importance shall be put on the further development of the entangled photons source to meet the requirement for the coherence length of less than $1ps$, requiring proper crystal design and geometry and optimization of the optical focal parameters.

12 Cost

The total mission costs of EPIG are estimated to be €570 million. The main components over which these costs are divided are: The launcher (15%), the ground segment and operations (35%), and the space segment (50%). The total cost to ESA of approximately €510 million makes this an M-class mission. These costs are based on parametric cost estimation methods.

13 Conclusion

It is a long standing problem in contemporary physics to unify Einstein's theory of relativity and quantum mechanics. As long as an existing description of nature contains contradictions, it cannot lead to a unified description, to useful explanations, or even to a correct description of nature. In natural science, one can only falsify one or more competing

theories by an properly designed experiment. T. Ralph and his co-worker put an alternative model forward, by extending quantum mechanics and predicting an effect standard quantum mechanics cannot. It is actually one of the few, if not only effect predicted, which can be tested with the current state of technology.
In this mission proposal we present a mission designed to be able to falsify between these two models by sending so called quantum entangled photons to and from different gravitational field potentials. The outcome of the missions in terms of science should not be underestimated. If successful in finding the effect, with the statistical significance as defined in this document, our mission could then easily contribute to the next breakthrough to a post-relativistic and post-quantum theory. A new era is dawning.

14 Acronyms

ADCS	Attitude Determination and Control System
AODCS	Attitude Orbit Determination
APD	Avalanche PhotoDiode
CHSH	Clauser, Horne, Shimony, Holt
EDRS	European Data Relay Satellite
EPS	Entangled Photon Source
ESA	European Space Agency
FoV	Field of View
GB	GigaByte
GPS	Global Positioning System
kg	KiloGram
LD	Local Detector
M	Mass
MLI	MultiLayer Insulation
MOC	Mission Operations Center
MUX	Output Multiplexer
NP	Nominal Power
PP	Peak Power
TCC	Telemetry, Tracking and Command
TRL	Technical Readiness Level
RF	Radio Frequency
Rx	Receiver
SNR	Signal to Noise Ratio
SYLDA	SYstème de Lancement Double Ariane
T	Terminal
TTC	Telemetry Tracking Command
Tx	Transceiver
W	Watt

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