

# DEMON: a Proposal for a Satellite-Borne Experiment to study Dark Matter and Dark Energy

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## ABSTRACT

We outline a novel satellite mission concept, DEMON, aimed at advancing our comprehension of both dark matter and dark energy, taking full advantage of two complementary methods: weak lensing and the statistics of galaxy clusters. We intend to carry out a 5000 deg<sup>2</sup> combined IR, optical and X-ray survey with galaxies up to a redshift of  $z \sim 2$  in order to determine the shear correlation function. We will also find  $\sim 100000$  galaxy clusters, making it the largest survey of this type to date. The DEMON spacecraft will comprise one IR/optical and eight X-ray telescopes, coupled to multiple cameras operating at different frequency bands. To a great extent, the technology employed has already been partially tested on ongoing missions, therefore ensuring improved reliability.

**Keywords:** observational cosmology, space missions, dark matter, dark energy

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## 1. INTRODUCTION

The open question concerning the nature of dark matter and dark energy is certainly one of the most compelling issues of modern astrophysics, that demands new and better observations in order to be answered. Until the physical properties of dark matter can be determined experimentally (something that cannot be done in the laboratory up to now), trying to improve our knowledge about these properties implies improving the current measurement of the cosmological parameters. In particular, in the case of dark energy, the first crucial step is to try to distinguish a cosmological constant model from time dependent quintessence models.

The current best constraints on the cosmological parameters come from the combined results of three different techniques with complementary degeneracies: SNIa experiments, CMB measurements, and the study of galaxy clusters. In addition to these well known methods, weak lensing is emerging as one of the most powerful and robust probes of the large scale structure of the universe and the nature of dark.<sup>1-3</sup>

Several existing and proposed wide-field weak lensing surveys, ground-based\* and space borne† are currently being developed. In order to contribute to the design of possible space missions we present DEMON (Dark Energy and Matter Observational Nexus), a novel concept satellite conceived to study the properties of dark matter and dark energy combining two complementary techniques: weak lensing and clusters statistics.

## 2. OVERVIEW: WEAK LENSING AND CLUSTER STATISTICS

In order to address the above science questions, DEMON will carry out a combined optical/IR and X-ray wide-field survey to provide the required data for weak lensing and cluster statistic studies. Sections 2.1 and 2.2 explain the basis of both techniques and the usefulness of combining them to study the problem of dark matter and dark energy.

### 2.1. Weak lensing

The weak gravitational lensing effect is the deflection of light by large scale structures along the line-of-sight. This produces a coherent distortion of the shape of observed background galaxies (cosmic shear), which contains information about the three dimensional mass distribution of the universe and also about the structure growth with time. The cosmic shear maps obtained from weak lensing surveys can be used to reconstruct the dark matter power spectrum, prove the effect of dark energy in the geometry of the universe (geometrical tests), and measure the cosmological parameters analysing the 3D shear power spectrum in redshift slices (tomography). These maps can be obtained through the statistical properties of the observed ellipticity of galaxies, which requires a large statistical sample of galaxies and very good image quality to measure the galaxy ellipticities reliably.

Since the cosmic shear is only due to gravity, weak lensing does not suffer from galaxy bias uncertainty like the baryon oscillation technique, and is not affected by evolution and/or environmental effects as may be the case for SNIa. In addition, weak lensing offers a unique method to probe the matter distribution in the transition domain from quasi-linear to non-linear scales at medium redshifts which cannot be addressed by any of the other techniques. Studies of cosmic shear already have led to significant constraints on cosmological parameters, most noticeably on the normalisation of the power spectrum.<sup>4</sup>

### 2.2. Cluster statistics

Clusters of galaxies are the largest and most recently collapsed objects in the universe. While their formation and evolution are driven by gravity, their large scale distribution and growth rate are also affected by dark energy. Two methods involving clusters are especially promising in cosmology: determining the redshift evolution of the matter power spectrum, and measuring the redshift evolution of the cluster mass function (the abundance of clusters as a function of mass).<sup>5</sup> Comparing these statistical quantities with those predicted by structure formation theory allow us to measure the cosmological parameters and the equation of state of dark energy.<sup>6</sup>

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\*VISTA (Visible & Infrared Survey Telescope for Astronomy), Pan-STARRS (Panoramic Survey Telescope And Rapid Response System), LSST (Large Synoptic Survey Telescope), CFHTLS (Canada-France-Hawaii Telescope Legacy Survey), KIDS (Kilo-Degree Survey) and DES (Dark Energy Survey)

†JDEM (Joint Dark Energy Mission) from NASA-DOE and DUNE (Dark UNiverse Explorer) from CNES, also proposed for ESA's Cosmic Vision

Cluster statistics require mass determination for each cluster, which can be inferred from observables such as the intracluster gas temperature in the X-ray spectrum, and the bolometric X-ray luminosity.<sup>7</sup> Some X-ray surveys of galaxy clusters have measured the power spectrum and the cluster mass function,<sup>8</sup> but not its evolution with redshift. Missions like XMM-Newton with a random survey precludes any studies based on spatial correlation (such as the matter power spectrum). These effects are even more important for the Chandra X-ray Mission and the planned XEUS (X-ray Evolving Universe Spectroscopy Mission) and Constellation-X mission, with their smaller fields of view.

In order to reach estimates with errors of a few percent, observations of ten thousand galaxy clusters in contiguous fields and with well defined completeness are needed.<sup>5</sup> This goal can be efficiently accomplished by a wide-field X-ray survey. In addition, the mass–luminosity/temperature relations needed for cluster statistics studies can be considerably improved with additional mass measurements<sup>9</sup> provided by alternative methods like weak lensing.<sup>10</sup> Since weak lensing and cluster statistics also provide complementary measurements of the cosmological parameters, it is very suitable to combine them in the same mission.

### 3. SCIENCE CASE

The main goal of the DEMON satellite is to provide optimum quality data for weak lensing studies, the scientific requirements are discussed further in Sect. 3.1. On the other hand, since cluster statistic studies are an interesting additional feature for the mission, we intend to take advantage of the X-ray telescopes developed for the eROSITA mission to carry out a simultaneous X-ray survey. The characteristics of such an X-ray survey are explained in Sect. 3.2.

#### 3.1. Weak lensing scientific requirements

Since the weak lensing technique is based on measurements of galaxy shapes, high image quality is a mandatory requirement in order to achieve optimal results. That makes a space-based wide-field survey the natural option to overcome the limitations produced by the degradation of the images in ground based surveys (smearing due to atmospheric seeing, PSF instabilities, weather instabilities and telescope instabilities due to flexures and wind-shake). A space telescope provides a diffraction limited and stable point spread function (PSF) minimising the systematics of the images, and allowing the detection of more faint resolved galaxies.

In order to provide a high sample of galaxies to minimise statistical errors, we need a large sky coverage and a high number density of resolved galaxies for shape measurements.<sup>11</sup> With a limiting magnitude of  $I_{AB} \sim 27$ , a galaxy density of  $\sim 60 - 100 \text{ arcmin}^{-2}$  is expected.<sup>11–15</sup> This provides a galaxy sample with  $\langle z \rangle \sim 1.3 - 1.4$ ,<sup>13, 16</sup> suitable to probe the range<sup>17</sup>  $z = 0 - 2$  in which the effect of dark energy is more prominent.<sup>18</sup> According to Tyson et al.,<sup>11</sup> ellipticity values can be retrieved for galaxies larger than  $1.2 \times \text{PSF}$ . Since galaxies with  $I_{AB} \sim 27$  have mean sizes ( $2 \times$  half-light radius) of  $\sim 0.2''$ ,<sup>14</sup> we need a telescope with a full width half maximum (FWHM) of the PSF  $\leq 0.17''$ . In addition, accurate measurements of galaxy shapes require a FWHM sampling of at least  $2 \times 2$  pixels for a proper PSF deconvolution.<sup>14</sup>

To assess the above scientific requirements, we studied a baseline model consisting of a 2 meter telescope similar to the one suggested for SNAP<sup>19</sup> (SuperNova/Acceleration Probe). We intend to cover  $5000 \text{ deg}^2$  with an exposure time of 4 ks per filter. The instrumentation requirements are described in Sect. 4.1.

Weak lensing tomography also requires the determination of the photometric redshifts of the galaxy sample (too big for spectroscopic redshift measurements) which can be obtained with a targeted accuracy of the order of  $0.03(1+z)$  using 8 filters.<sup>20</sup> Since it is not practical to include them all in a single spacecraft, a ground-based optical wide-field imaging survey done in parallel will be needed to achieve the mentioned accuracy. The minimum requirement for the ground-based survey is a 4 meter diameter optical telescope with a  $3 \text{ deg}^2$  field of view (FOV) operating in the U, B, V, and R bands. Projects of this kind, such as VISTA, KIDS, Pan-STARRS... are currently being developed. The IR filters should be included in the spacecraft, since the sensitivity of ground-based IR observations is severely limited by atmospheric and thermal effects.

### 3.2. X-ray survey characteristics

The kind of X-ray survey that we can perform with DEMON is determined by: (1) the sky coverage (5000 deg<sup>2</sup>) and exposure time (16 ks per pointing) imposed by the weak lensing mission requirements, and (2) the technical specifications of the X-ray telescopes developed for the eROSITA mission (see Sect. 4.2 for details).

The eROSITA telescopes are optimized for cluster statistics studies. In particular, they provide an angular resolution of  $< 15''$ , suitable to distinguish between galaxy clusters and point-like X-ray sources.<sup>21</sup> With an energy resolution of 130 eV at 6 keV, they also provide an X-ray spectrum with enough resolution to measure the mean cluster gas temperature.

An X-ray instrument composed by 8 of such a telescopes will have a total FOV of 3.55 deg<sup>2</sup>. Combined with an exposure time of  $\sim 64$  ks per pointing, such an instrument will reach a minimum flux of  $8 \times 10^{-15}$  erg cm<sup>-2</sup> s<sup>-1</sup> in the energy range 0.5 – 2 keV. Under this conditions, the DEMON X-ray survey is expected to detect  $\sim 20$  clusters per deg<sup>2</sup> and identify, in the observed region of the sky, all the clusters with a mass  $\gtrsim 2 \times 10^{14}$  M<sub>⊙</sub> up to  $z \sim 1.5$ . Therefore, DEMON will produce a catalog of  $\sim 100,000$  clusters with a mean redshift of 0.75. The flux-selection will avoid the contamination from clusters highly affected by non-gravitational heating, mainly non massive and non relaxed.<sup>8</sup>

The study of the evolution of the matter power spectrum and cluster mass function requires an error  $\sim 0.02$  in the cluster redshift measurements.<sup>5</sup> This information will be provided by the DEMON (combined with the required ground-based survey) with a median accuracy of 0.07 for the redshift of each galaxy. Therefore, redshift measurements of  $\sim 12$  galaxies per cluster will be enough to achieve the required precision.

Another interesting feature of the DEMON compared to other X-ray surveys is that, due to the flux limit and survey area that is going to cover, it will explore a measurement domain that was not done before.

## 4. INSTRUMENTATION

The baseline optical concept will comprise a 2 m diameter optical/IR telescope encircled by eight 0.358 m diameter X-ray telescopes. Below, the optical/IR and X-ray telescopes and detectors are described. The specifications of both instruments are summarized in Tables 1 and 2.

### 4.1. Optical/IR telescope and detectors

The main DEMON optical/IR instrument is a three-mirror anastigmatic Korsch telescope<sup>22</sup> (see Figure 1). This configuration produces an achromatic image limited by diffraction over a planar field of more than 1 deg<sup>2</sup>, and has been used extensively in space. Honeycomb sandwich mirror technology is chosen to minimize the mass of the mirror.

DEMON will be equipped with 4 filters: one optical broad-band filter to measure the galaxy shapes (R+I+z, centered at 0.8  $\mu$ m with 0.2  $\mu$ m width), and 3 IR filters to determine the photometric redshifts (J, H and K).

In the broad band filter, the size of the telescope FWHM PSF is 0.08'', which requires an angular resolution of 0.04''/pixel (to be properly sampled) and a pixel size of 5  $\mu$ m. Since this pixel size is much smaller than the current technology available, the DEMON pointing strategy will take advantage of micro-dithering<sup>23</sup> – the integration time is divided into two sub-pointings separated by half a pixel. This allows us to use a pixel  $\sqrt{2}$  times larger. Combined with a magnifying lens system (to enlarge the image by a factor of 1.5), the PSF can then be properly sampled using 10  $\mu$ m pixels. Since there is no need for this high resolution for the infrared filters, we can use IR detectors with the standard pixel size of 18  $\mu$ m (0.085''/pixel).

The DEMON focal plane is a ring with a partially vignetted area in the center, where the detectors are situated in four 20'  $\times$  40' rectangular areas (see Figure 2). The four filters are settled in one direction to cover the same FOV, which requires an orthogonal scanning strategy. In total DEMON will have 128 CCDs (2627 $\times$ 2627 pixels each) for the broad-band filter, and 80 IR pixel arrays (2335 $\times$ 973 pixels each) for each of the IR filters.

The SNAP collaboration have successfully developed a new type of large format back-illuminated p-channel CCDs with 10.5  $\mu$ m pixels, specially suitable for space.<sup>24</sup> Therefore, the development of 10  $\mu$ m pixels will not be a technical problem. For the IR detectors we can use HgCdTe devices from Rockwell with a 2.5  $\mu$ m wavelength cut-off.

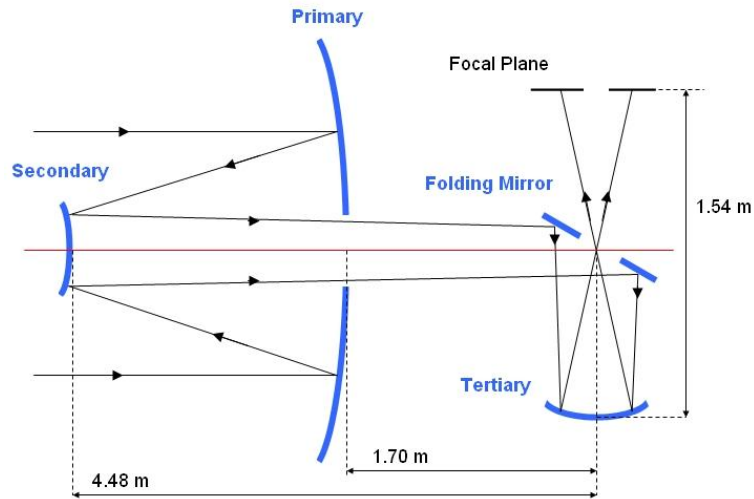


Figure 1. The optical mirror system (not to scale), without magnifying lens system.

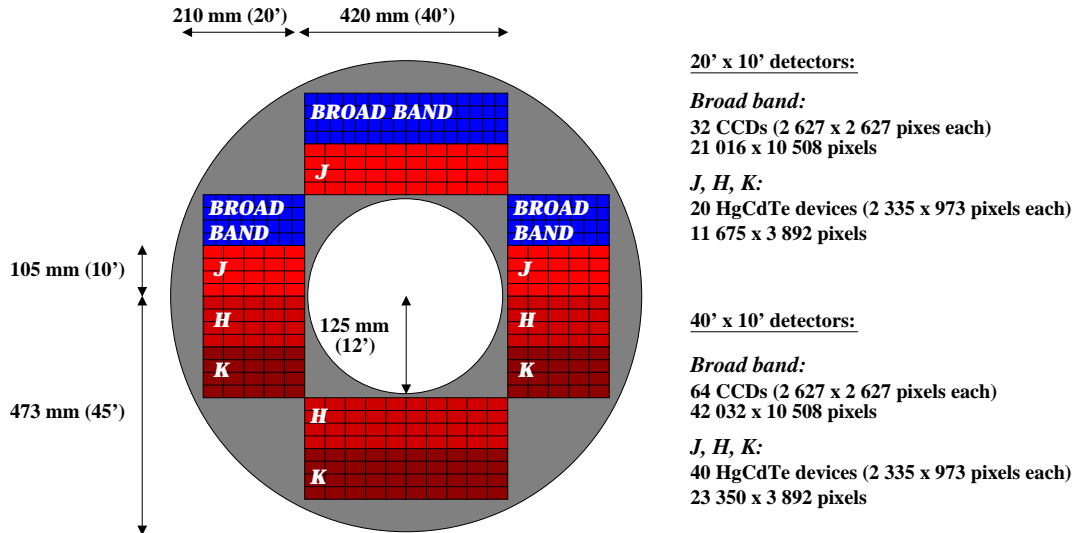


Figure 2. Optical/IR focal plane and detectors.

**Table 1.** Specifications of the optical/IR system.

Parameter	Value
Telescope	3-mirror system
Focal length	24 m
Effective focal length	36.12 m
Primary mirror diameter	2000 mm
Primary mirror thickness	400 mm
Secondary mirror diameter	466.7 mm
Tertiary mirror diameter	1066.7 mm
Fold mirror diameter	489.3 mm
Baffle length	0.7 m
FOV	0.9deg <sup>2</sup> (0.23 deg <sup>2</sup> each filter)
Optical angular resolution	0.04"/pixel (at 0.8 $\mu\text{m}$ )
IR angular resolution	0.10"/pixel
Image stability	0.03"
Filters	Broad-band (0.6 – 1 $\mu\text{m}$ ), J, H, & K (600 – 2500 nm)
Optical detector	2.6k $\times$ 2.6k CCDs of 10 $\mu\text{m}$ pixels
IR detector	2.3k $\times$ 973 HgCdTe devices of 18 $\mu\text{m}$ pixels

**Table 2.** Specifications of the X-ray system.

Parameter	Value
Focal length	1600 mm
Diameter of one mirror system	358 mm
Baffle length	600 mm
Telescope size (diameter/length)	0.4 m /2.6 m
FOV	0.473 deg <sup>2</sup>
Angular resolution	< 15" (at 1 keV)
CCD size	19.2 $\times$ 19.2 mm <sup>2</sup>
Pixel size	75 $\times$ 75 $\mu\text{m}^2$
Readout time	50 ms
Energy range	0.5 – 10 keV
Energy resolution	130 eV at 6 keV
Effective collecting area	2656 cm <sup>2</sup>
Total Grasp	753.6 cm <sup>2</sup> deg <sup>2</sup> (at 1 keV)

## 4.2. X-ray telescope and detectors

The DEMON X-ray instrument consists of eight X-ray telescopes with a design similar to that developed for the eROSITA mission. Telescope specifications are explained in detail in the eROSITA Mission Definition Document ([www.mpe.mpg.de/erosita/MDD-6.pdf](http://www.mpe.mpg.de/erosita/MDD-6.pdf)).

Basically, each X-ray telescope is composed of 54 nested Wolter-I mirror shells (paraboloid+hyperboloid optics), with 27 outer shells to enhance the effective area at low energies. The optical design of the X-ray mirror system has hexagonal geometry, optimised to achieve maximum sensitivity between 0.5 and 10 keV. The mirrors are fabricated using a nickel-galvano plating, coated with gold to enhance their reflectivity. Each mirror module has its own CCD-detector, mounted in its own housing and equipped with its own electronics. The CCD size of 19.2  $\times$  19.2 mm<sup>2</sup> corresponds to a FOV of 41.2'  $\times$  41.2'. The X-ray detectors are based on the pn-CCD principle, although they have a smaller pixel size (75  $\times$  75  $\mu\text{m}^2$ ) and shorter readout time than regular pn-CCDs. The semiconductor laboratory of MPE are already fabricating these kind of detectors.

**Table 3.** Orbital parameters.

Parameter	Value
$\Theta_{\text{inclination}}$	5 deg
Altitude	600 km
Velocity	7.6 km s <sup>-1</sup>
Period	1.61 h
$t_{\text{eclipse}}$	28 min

**Table 4.** Estimated masses and power requirements of the spacecraft components.

Subsystem	Mass	Power
Propellant	500 kg	
Spacecraft structure & Harness	280 kg	
Telescope structural support	160 kg	
Optical mirror system	120 kg	
Optical/IR detectors	200 kg	480 W
X-ray telescope & detectors	700 kg	110 W
Power system	250 kg	130 W
Thermal control & Multi-layer insulation	100 kg	900 W
Attitude control	90 kg	250 W
Electronics & Telemetry	100 kg	110 W
<b>Total</b>	<b>2500 kg</b>	<b>1980 W</b>

## 5. SPACECRAFT ORBIT AND SCANNING STRATEGY

In order to achieve the scientific objectives of the mission and to meet the spacecraft's operational requirements, we have chosen a circular low-earth orbit (LEO) with the parameters given in Table 3. This particular orbit was chosen to avoid the Van Allen radiation belts and the South Atlantic Anomaly, both of which would prejudice X-ray observations. The selected LEO will also facilitate ground control and data download procedures. Because of atmospheric drag, periodical corrective maneuvers (carried out by thrusters) will be needed to reposition the spacecraft into its desired orbit. The propellant mass required for these maneuvers has been computed at 500 kg (for a 5 year mission). In total, the spacecraft's dry mass is 2000 kg (20% margining included), which fits well within the transport capabilities of 5500 kg of a Soyuz rocket launched from Kourou into the desired LEO orbit (see Table 4 for details).

The telescopes will be allowed to shift within a cone aligned with the Earth's rotational axis with a maximum semi-aperture angle  $\theta_{\text{sa}} = 21$  deg. This will avoid bringing the Earth, the Sun and the plane of the Milky Way into the instrumental FOV. The exact pointing range will also depend on the specific position of the Earth along its orbit. The selected value of  $\theta_{\text{sa}}$  allows, in principle, the coverage of about 15000 deg<sup>2</sup> of the sky around the Earth's north and south poles. The sky will be sampled in concentric circles while the center of each FOV will be shifted by 10'' every two orbits in accordance with detector array technical requirements.

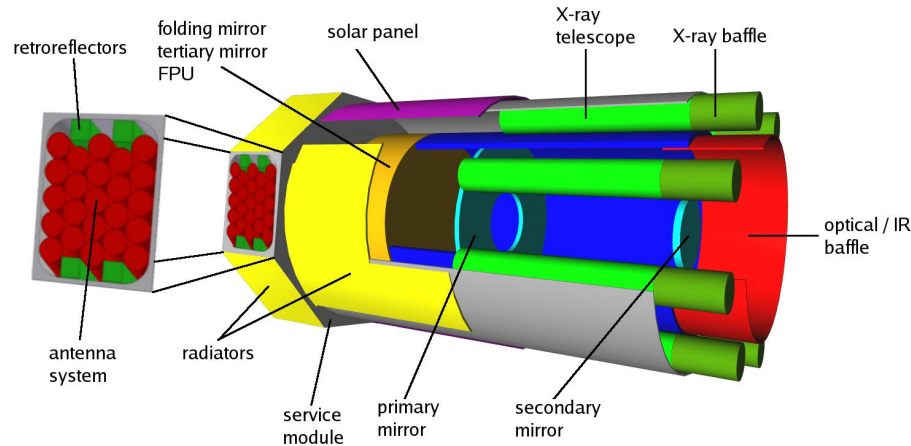
With an exposure time of 16000 s for each pointing, this configuration is expected to reach the scientific demands for a 5000 deg<sup>2</sup> survey in a 4.5 years mission (including 68% efficiency).

## 6. SPACECRAFT ENGINEERING

### 6.1. Spacecraft design

The DEMON spacecraft is divided in two main parts: the main body and the service module.

The main body is a 6 m high cylinder with 2.6 m of diameter. It contains the optical/IR and X-ray telescopes and detectors, the solar panels, and a radiator to cool the X-ray focal planes. To avoid any direct stray light into the mirror system, the optical/IR telescope will be protected by a cylindrical deployable baffle with a total



**Figure 3.** The design of the spacecraft.

**Table 5.** Estimated costs for a five years mission.

Part	Cost
Main telescope	50 M€
Optical/IR camera	80 M€
X-ray instrument	16 M€
Platform	200 M€
Launcher	50 M€
Ground support	100 M€ (20 M€/yr)
Ground observations	12.5 M€ (2.5 M€/yr)
<b>Total</b>	<b>508.5 M€</b>

length of 110 cm (70 cm outside the main tube of the telescope). Each X-ray telescope has also its own cylindrical baffle with a total length of 60 cm.

The service module is an octagonal box which is 1.1 m high and 3.75 m in diameter. The lateral sides include the phased array antenna system. The bottom side has two antennas, the Soyuz connection ring and radiators. At the sides of the service module there are two solar sensors, two star trackers and 12 thrusters. Inside the service module there is the thermal control system, the attitude control system, the power conditioning devices, the electronic devices, the telemetry and telecommand devices and the batteries.

An artist impression of the satellite is shown in Fig. 3.

## 6.2. Power system

During most of the orbit, the power of the spacecraft will be supplied by a solar array built from ultra triple junction solar cells of GaInP<sub>2</sub>, GaAs, and Ge. The solar array will also charge batteries that will be used during the eclipses and in particular circumstances when greater amounts of power are needed. Lithium-ion batteries will be used since these have a large interval of allowed operational temperatures (248 K – 268 K) facilitating thermal control.

The power needed for the different subsystems of the spacecraft are listed in Table 4. It amounts to a total required power of 1980 W. The necessary size of the solar array is therefore 14.7 m<sup>2</sup> taking into account the losses of energy during conversions, the cell efficiency and deterioration of components with time.

## 6.3. Thermal control

In order to minimize the radiative exchange and ensure the insulation, the satellite is wrapped with layers of aluminized mylar and covered with a special white paint.



Due to instrumentation requirements, the service module and payload operates at different temperatures. For this reason they must be kept thermally insulated from each other. The service module is maintained at a temperature between 278 K and 303 K using a passive cooling system consisting of two radiators. The radiators are placed on the cold side of the service module to carry off the heat produced inside by the detector's electronic boards, attitude control, propellants, power and communication system and electronic internal dissipation. The batteries are thermally isolated and equipped with heaters controlled by thermostats. The two star trackers are cooled with Peltier coolers.

### **6.3.1. Thermal control of the IR detector**

Active cooling is required for the IR detector since the focal plane has to be kept at 150 K. For this purpose there are 16 thermoelectric pumps and 32 spares. Each pump has an absorption capacity of 1.22 W and a required power supply of 43.5 W. A radiator is placed on the cold side of the spacecraft to radiate this power.

### **6.3.2. Thermal control of the X-ray detector**

The focal plane of each X-ray detector has to be maintained at an operating temperature of 213 K in order to achieve optimal functionality and energy resolution. Since the adopted attitude strategy maintains one side of the spacecraft hidden from the sun and the earth (except for 1.5 minutes per orbit), passive cooling is a possible solution. The total heat flux coming from the albedo and IR radiation of the earth at that cold side was computed with the ESARAD software for different positions of the spacecraft along the orbit. Based on this result, we plan to use radiators and heat-pipes to cool the X-ray detectors. To avoid overheating the CCD focal plane during the hot cases along the orbit, active elements will support the cooling. Since the mirror system operate at ambient temperature, heaters with thermostats are mounted on the mirror modules in order to maintain temperature stability (e.g.  $293 \pm 2$  K).

## **6.4. Attitude control**

The thermal control requires two  $180^\circ$  slews of the spacecraft every orbit: a direct slew, and a retrograde slew to return the spacecraft to its initial position (similar to the strategy adopted by eROSITA). Due to the short period of the orbit, the slew rate should be of the order  $1^\circ/\text{sec}$  (a quarter spin must be done in less than two minutes).

To accomplish the survey strategy, the spacecraft should be able to make slews in all three directions. Therefore, 4 momentum wheels (one for each axis) are used for the actuators. The spacecraft includes a spare momentum wheel in case one of the others breaks down. Twelve hydrazine thrusters are used for momentum dumping, orbital corrections and to assist in more demanding maneuvers, such as the  $180^\circ$  slew.

To guarantee a high spacecraft stability, we have three different types of attitude control movements: maneuver, pointing and stability mode. For this purpose three types of sensors are used: two sun sensors, two star trackers, and two space inertia reference units. The maneuver mode consist of retrieving data from the two sun sensors and performing a fast slew. In the pointing mode, the star trackers permit more precise maneuvers. Finally, the stability mode is required for long time exposures when maximum stability is necessary. In this case, the space inertia reference unit (that uses the data from six gyroscopes) gives a precision of one arcsecond per hour. The use of a kilo-Hertz satellite laser ranging system as a backup has also been envisaged.

## **6.5. Communication**

The DEMON communication, telemetry tracking and command (TT&C) segment will be based on reliable radio frequency (RF) technology in the Ka-band, since this is the only band which will be able to offer sufficient telemetry capacity. In a few years, the Ka-band technology will be fully space qualified and tested on several space-borne missions. The specifications of the memory and telecommunication subsystems are shown in Table 6.

**Table 6.** Parameters of the memory and telecommunications subsystem.

Parameters, Hardware	Values, Annotations
Frequency of the Ka-band TT&C	25.5-27 GHz (alternatively 37-38 GHz)
Bandwidth efficient modulations <sup>28</sup>	OQPSK/PM, OQPSK I/Q, SOQPSK, FQPSK-B, etc.
Forward error correction codes	Turbo Code, Reed-Solomon; FPGA implementation
SSPAs	max. 1 $W_{RF}$ each, in all 60 $W_{DC}$ for power system
Telemetry data rate	500 Msps up to 1.2 Gsps (fair weather)
SSMM with lossless data compression	min. 500 GBit at end-of-life; on-board SAN
CCDs uncompressed raw data rate	max. continuous 160 Mbps
Data rate for SSMM / Compression factor	60 Mbps / $\sim 3$
Ground stations	Kourou and Malindi, each with 500 s of visibility per orbit

### 6.5.1. Space segment

The baseline concept for the science and telemetry link are compact and efficient Ka-band solid-state power amplifiers (SSPAs), together with a “semi-active” conformal phased array antenna, Butler-like matrices, and MMIC phase shifters.<sup>25-27</sup> The antenna has no moving part, as demanded for extremely fine pointing accuracy. The power transferred from the antenna system to the spacecraft is kept constant in order to minimize negative effects from a temperature change into the optical payload.

Science and engineering data are buffered in the solid-state mass memory (SSMM) on board, and loss-less compressed with a consultative committee for space data systems (CCSDS) compliant solution. This data is subsequently down-linked via the telemetry system and antenna to the ground station.

### 6.5.2. Ground segment

The orbit of DEMON enables the usage of ground stations with low cost, commercial Ka-band front-ends in Kourou/French Guiana and Malindi/Kenya. Beside the broadband telemetry link from the spacecraft to the ground stations, data relay system satellite services will be used with inter-orbit links (IOL) in Ka-band for telecommand and real-time engineering telemetry.

DEMON will also use several link management techniques for optimization, such as site-time diversity with selective re-transmission, short term forecast driven weather adaption, and error control coded operations.

## 7. CONCLUSIONS

This paper presents a new concept mission for a satellite aimed at provide better constraints on the cosmological parameters and, in particular, studying the evolution of the dark energy equation of state with time.

The innovate concept of the DEMON spacecraft is to carry out a combined optical/IR and X-ray survey of 5000 deg<sup>2</sup> to perform weak lensing and cluster statistics studies. The satellite will be complemented by one of the ground-based wide-field surveys currently under development.

For the optical/IR part of the survey, we investigated a baseline optical concept similar to the one proposed by SNAP. To satisfy the scientific requirements, the proposed telescope requires an additional magnification of 1.5 to sample the FWHM PSF with  $2 \times 2$  pixels using CCDs of 10  $\mu\text{m}$ . The derived consequences in the technical telescope design and image quality should be investigated in detail to determine the feasibility of this baseline.

For the X-ray part of the mission, we explore the possibility to include 8 X-ray telescopes in the spacecraft, taking advantage of the technology developed for the eROSITA mission. The result is an X-ray survey with a flux limit of  $8 \times 10^{-15}$  erg cm<sup>-2</sup> s<sup>-1</sup>, 10 times more sensitive than DUO<sup>29</sup> and 5 times more sensitive than eROSITA.

Therefore, the DEMON 5000deg<sup>2</sup> X-ray survey is expected to discover 10 times more cluster per deg<sup>2</sup> than DUO (with 6000deg<sup>2</sup> survey) and even more clusters of galaxies than eROSITA (with an all-sky survey). With

this amount of clusters we expect to obtain the best results so far from number density and power spectrum studies.

The final spacecraft is 7.1 m high and 3.75 m wide (at its broadest parts). It has an estimated mass of 2500 kg, which is well within the transport capabilities of a Soyuz rocket into the desired LEO orbit. The estimated cost of the spacecraft is 510 M€ (see Table 5 for details).

Compared to SNAP, DEMON will perform a bigger survey and can be launched using a cheaper rocket. It also has the advantage of providing a proper sample of the FWHM PSF (and therefore better data quality for weak lensing studies), something which cannot be achieved by SNAP<sup>30</sup> or JEDI.<sup>31</sup> This, combined with the potential of the simultaneous X-ray survey, makes DEMON a very interesting concept design to be investigated for a future satellite to study dark matter and dark energy.

We also note that, although DEMON is optimized for a weak lensing survey, the high quality of the observations and the wide sky coverage of the survey will provide valuable data for other studies, like strong lensing systems, baryonic wiggles, galactic structure or detailed studies of clusters of galaxies. Due to the characteristics of the X-ray instruments, DEMON will also contribute to the study of the intracluster medium and galaxies with active nuclei (AGNs). Furthermore, a number of faint objects will be identified as future targets for narrow field instruments performing pointed imaging observations, like XEUS.

Finally, the planned far-infrared surveys based on the Sunyaev-Zel'dovich (SZ) effect (e.g. the ESA Planck mission and South Pole Telescope) will produce the redshift dependent cluster mass function and the power spectrum with different systematics compared to the DEMON X-ray survey, permitting for a very important cross-check of the two cosmological techniques to be made.

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