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## *EUCLID mission baseline design*

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# EUCLID Mission Baseline Design

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**Abstract**—EUCLID is a mission to accurately measure the accelerated expansion of the universe. It has been selected for implementation with a launch planned for 2020. EUCLID will map the large-scale structure of the Universe over 15.000 deg<sup>2</sup> of the extragalactic sky and it will measure galaxies out to redshifts of  $z=2$ . EUCLID consists of a 1.2 m telescope and two scientific instruments for ellipticity and redshift measurements in the visible and near infrared wavelength regime.

We present a design for the EUCLID space segment, targeting optimum performance in terms of image quality and stability and maximum robustness with respect to performance, resources and instrument interfaces.

**Index Terms**—EUCLID, Dark Energy, ESA

## I. INTRODUCTION

EUCLID is a mission to study the geometry and the nature of the dark universe, with a launch planned for 2020 [1]. It is a survey mission which shall show how the expansion of the Universe and how the matter distribution within the Universe evolved over the last 10 billion years. EUCLID is the second medium-class mission of the ESA Cosmic Vision 2015–2025 programme. After finalisation of the Definition Phase (Phase A/B1) mid of 2012, the mission is currently entering the Implementation Phase (Phase B2/C/D/E1).

The current understanding of cosmology is that the Universe has evolved from a highly homogeneous state after the Big Bang to a highly inhomogeneous structure of galaxies, clusters, and superclusters at our epoch, see Fig. 1.

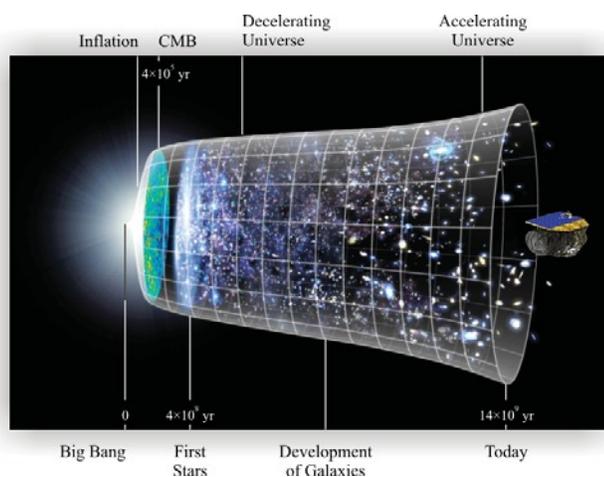


Fig. 1 Expansion history of the Universe. Image adapted from [2].

This, however, necessitates the introduction of two more or less unknown quantities which dominate the energy density of the Universe. Dark matter, constituting 20% of the total energy density, is exerting gravitational attraction but does not emit or absorb light. Dark energy, constituting 76% of the total energy density, is causing the expansion of the Universe to be currently accelerating.

EUCLID is a mission featuring two independent cosmological probes for understanding the nature of dark energy and dark matter by tracking their observational signatures on the geometry of the Universe and on the history of structure formation.

- Weak Gravitational Lensing (WL) from a high-resolution imaging survey of ellipticity of distant galaxies. By correlating a large number of galaxy ellipticities, small systematic distortions can be measured which result from light bending by matter distributed along the line of sight.
- Baryonic Acoustic Oscillations (BAO) refer to a clustering of baryonic matter at certain length scales due to acoustic waves which propagated in the early universe. A typical (co-moving) length scale of 150 Mpc is derived from Cosmic Microwave Background (CMB) observations, and is locked up in the cosmic structures. It serves as a standard ruler, which can be used to trace the accelerated expansion of the universe as a function of cosmic time, by observing the distribution of galaxies as a function of redshift.

In addition, EUCLID provides data for additional independent cosmological probes and legacy science.

## II. MISSION OVERVIEW

EUCLID will perform a systematic survey of galaxies over a large fraction of the observable universe, i.e. over a time scale where Dark Energy became dominant (corresponding to a redshift range of  $0 < z < 2$ ) and over an extragalactic sky area of 15.000 deg<sup>2</sup> (with the goal of 20.000 deg<sup>2</sup>).

The EUCLID Mission consists of a Korsch telescope with a free aperture of 1 m<sup>2</sup> and a field of view of 0.763×0.709 deg<sup>2</sup>, off-axis by 0.45 deg, and two scientific instruments which are provided by the EUCLID Consortium [3]:

- A visible imager (VIS) for shape measurements of galaxies up to  $\text{mag}_{AB}=24.5$  in the wavelength regime from 550–920 nm. The VIS instruments requires from the telescope a point spread function (PSF) with a full width of half maximum (FWHM) of  $<0.142$  arcsec and an ellipticity of  $<13\%$  at any point within the field of view (FoV), specified at 800 nm wavelength.
- A near-infrared spectrograph and photometer (NISP) for photometric redshift measurements of galaxies up to  $\text{mag}_{AB}=24.5$  in the three wavelength bands Y (920–1146 nm), J (1146–1372 nm) and Hp (1372–2000 nm) to obtain the NIR part of the photometric redshift determination, and for spectroscopic redshift measurements of galaxies up to  $\text{mag}_{AB}=19.5$  with a spectral resolution of 250 in the wavelength band of 1000–2000 nm enabling a redshift resolution of  $\sigma_z/(1+z) \leq 0.1\%$ . The NISP instrument requires from the telescope PSF maximum radii of 50% and 80% encircled energy ( $r_{EE}$ ) of 0.245 arcsec and 0.511 arcsec, respectively, specified at 1486 nm wavelength.

Lagrange Point of the Sun-Earth system [4], see Fig. 3. A total nominal scientific operational lifetime of 6 years is planned.

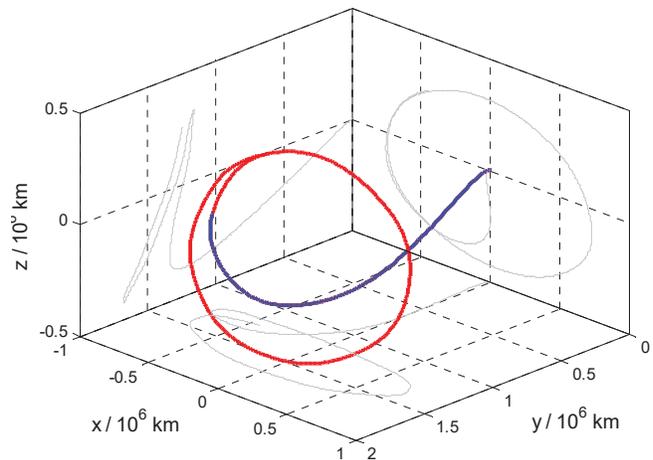


Fig. 3 EUCLID mission reference orbit. The period until the last transfer correction manoeuvre is indicated by blue color.

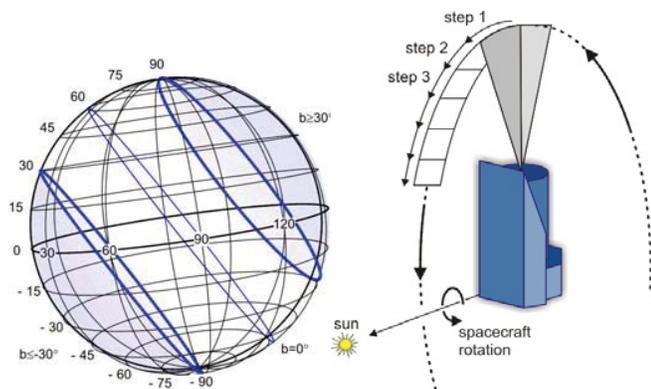


Fig. 2 Extragalactic sky survey geometry in ecliptic coordinates (left) and step & stare sky survey principle (right).

EUCLID will observe the extragalactic sky at galactic latitudes  $|b| \geq 30$  deg, see Fig. 2 (left). The wide survey will cover a total sky area of  $15.000 \text{ deg}^2$  and will embed the deep survey with a total sky area of  $40 \text{ deg}^2$ . The sky is sampled in step & stare mode, see Fig. 2 (right). Each field is observed in four dither frames to avoid any gaps between the detectors (offset of 100 arcsec and 50 arcsec in latitude and longitude, respectively).

Nominally the sky is scanned along Meridians to the ecliptic, allowing for one strip per day. This is achieved (in ecliptic longitude) by the natural rotation of the operational orbit around the Sun and (in latitude) by a spacecraft rotation around the Sun-spacecraft axis, where the sunshield is oriented perpendicular to it (solar aspect angle  $\text{SAA}=90$  deg). For the sake of increased temporal efficiency (in particular around the Equinoxes and at the ecliptic poles) and of mission flexibility some limited deviation are allowed ( $\text{SAA}=89\dots121$  deg).

EUCLID will be launched from Kourou (French Guiana) by a Soyuz ST 2-1B launch vehicle in 2020. A direct transfer is targeted to a large-amplitude free-insertion orbit at the Second

### III. SYSTEM OVERVIEW

For the EUCLID spacecraft a design has been derived during Phase A/B1 which allows for satisfying all the scientific requirements of the mission. The spacecraft features a payload module (PLM), consisting of the telescope and the scientific instruments VIS and NISP, a sunshield for ensuring a stable thermal environment, and a service module (SVM) providing all the service functionalities to the scientific mission (attitude and orbit control, data handling, communication, etc.), see Fig. 4.

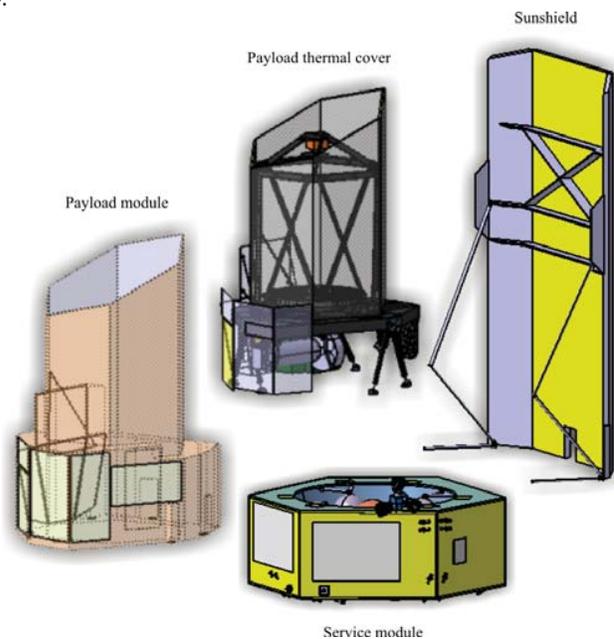


Fig. 4 EUCLID system overview.

#### IV. PAYLOAD DESIGN

The EUCLID payload module consists of a common bench, a telescope and the two scientific instruments VIS and NISP. While the optical bench and the telescope will be procured industrially, the nationally funded instruments will be developed by the EUCLID Consortium [3]. The conceptual block diagram of the EUCLID payload module is given in Fig. 5. It shows the interfaces and the share of responsibility between the industrial consortium and the instrument consortium.

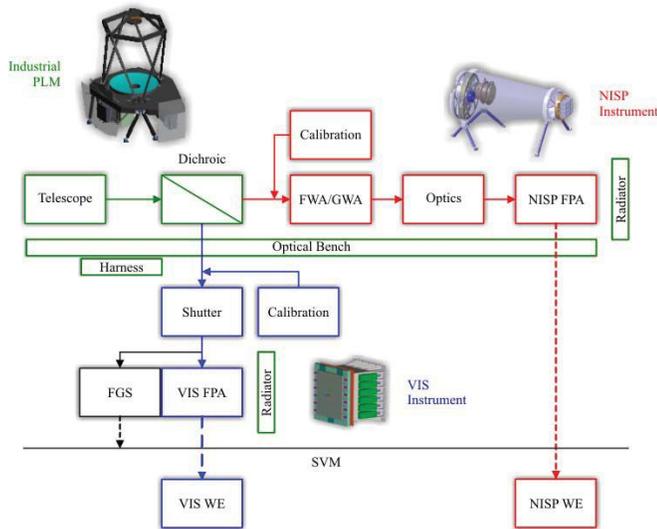


Fig. 5 EUCLID payload module conceptual block diagram. The colors indicate the corresponding responsibilities (instrument images adapted from [1]).

- The industrial part of the payload module consists of the three-mirror telescope, folding mirrors, the dichroic mirror, a common optical bench, the harness (including the instrument harness), and the instrument radiators. The industrial part also includes – as part of the AOCS – a fine guidance sensor (FGS) located in the VIS image plane.
- The VIS instrument consists of a shutter, a focal plane assembly (FPA) with 6×6 CCD's (e2v, CCD 273, 0.1 arcsec/pixel plate scale), a calibration unit, and warm electronic units (WE) located within the SVM (control and data processing unit, power and mechanism control unit).
- The NISP instrument consists of a filter wheel and GRISM wheel assembly (FWA/GWA), refractive optics, a focal plane assembly with 4×4 Hawaii 2RG (Teledyne, 0.3 arcsec/pixel plate scale), and warm electronic units (WE) located within the SVM (detector control unit, data processing unit, instrument control unit).

The optical design of the PLM has been developed by ESA and is characterised as follows:

- The telescope is a three-mirror Korsch configuration with a 0.45 deg off-axis field and an aperture stop at the primary mirror. The entrance pupil diameter is 1.2 m, the optically corrected and not vignetted FoV is 0.79×1.2 deg<sup>2</sup>, and the focal length is 24.5 m. At the telescope's exit pupil the dichroic is located.
- The reflected output of the dichroic is imaged on the VIS focal plane. It has a FoV of 0.787×0.709 deg<sup>2</sup>.
- The transmitted output is fed to the NISP instrument. It has a FoV of 0.763×0.722 deg<sup>2</sup>.

The major drivers for the EUCLID PLM design are:

- High optical quality and opto-mechanical stability to guarantee the specified image quality and image quality stability requirements. These are specified in terms of ellipticity and FWHM of the system PSF for VIS channel and in terms of encircled energy radius for the NISP channel.
- Robust interfaces between the telescope and the instruments, in particular in terms of passive cooling capability, which is challenging for the VIS FPA proximity electronics and for the NISP detectors operating at a temperature below 100 K.
- A cold environment (<150K) is required by the two instruments to minimize radiation effects on the VIS FPA and thermal background and detector dark current for NISP.
- Low mass for compatibility with launch on Soyuz.

For the EUCLID payload module a design has been derived during Phase A/B1. The main features are:

- The payload structural and material concept is determined by the manufacturability and achievable quality of the primary mirror, by the capability of equalising thermal distortions, the total mass and the heritage. Building on the experience from Gaia [5] featuring similar (and actually more challenging) requirements, Astrium decided to make the entire PLM (bench, mirrors, structure) of Silicon Carbide (SiC). This allows an athermal design with very low thermo-elastic sensitivity thanks to the homogeneous telescope deformation and the low coefficient of thermal expansion (CTE). The capability of SiC for extreme light-weighting ensures minimum payload mass.
- The payload thermal concept is determined by the compatibility to the instruments (requiring a temperature of 150 K), the achievable thermal stability, and the compatibility to available technologies. Astrium decided for passive cool-down below 150 K for telescope and instruments cavity (much colder than 240 K, the maximum temperature compatible with the allowed thermal background for NISP). This avoids

dedicated thermal compartments for the instruments and minimises the radiator size. Passive thermal control allows for highest thermal stability and minimum heating power. The resulting settling times after change of the solar aspect angle are compatible with the operational scenario and mission timeline.

- The PLM is protected by a thermal baffle which decouples from the sunshield thermal variations and which blocks straylight emerging from bright stars within the FoV.
- The thermal decoupling between the PLM and the SVM is maximised by using iso-static interfaces with low thermal conductivity.
- The instruments VIS and NISP are connected iso-statically to the PLM bench. For the fine guidance sensor (FGS) a dedicated support structure has been designed which allows accommodation within the VIS focal plane but which decouples the FGS completely from the VIS instruments.

The payload module design elaborated by Astrium within Phase A/B1 is shown in Fig. 6. It allows optimum thermo-elastic stability and minimum mass. The design is fully compatible with the mission requirements. The total PLM mass is estimated to 630 kg, including warm electronics located within the SVM.

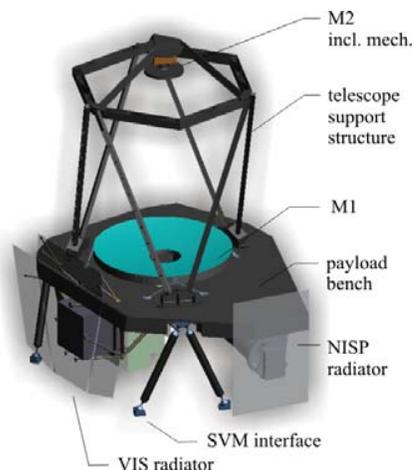


Fig. 6 EUCLID payload module design.

## V. SPACECRAFT DESIGN

Besides the payload module, the EUCLID spacecraft consists of the service module and the sunshield. The major drivers for the spacecraft design are:

- High spacecraft pointing stability to guarantee the specified image quality and image quality stability requirements. Besides the optical design and the payload properties, the residual pointing error is the major contributor to the image quality budgets (ellipticity and FWHM).

- Highly stable thermal environment for the PLM, also in case of significant changes in SAA between two fields.
- High volume of science telemetry to be stored and downloaded by a dedicated high-gain antenna (HGA) operating in K-band (25.5–27 GHz).
- Mass saving design options to ensure the overall Soyuz launch capability of 2160 kg [4] and the required system mass margin of 20%.

For the EUCLID spacecraft a design has been derived during Phase A/B1. The main features are:

- The structural concept has been evolved specifically to meet the requirements of the EUCLID mission but – regarding the requirement on high technology readiness – also to take direct benefit of previous mission with comparable requirements.
- The service module (SVM) is of hexagonal shape with a central cylinder for supporting the launch loads from the PLM to the launch vehicle adapter (for mass saving reasons the dedicated GAIA adapter will be used). The SVM structure is made of Aluminium honeycomb with CFRP facts.
- The sunshield is of panel-type with high-performance MLI insulation behind it. It is combined with the solar generator. The size is driven by the size of the payload and the size of the solar array (8.9 m<sup>2</sup>). Its canted shape and the support struts are driven by the stiffness requirements.
- The attitude and orbit control system (AOCS) is responsible for the required spacecraft attitude during all mission phases. The stringent pointing requirements (a few milli-arcsec over the field duration of 565 s, driven by the image quality requirements) ask for a high performance AOCS, including a fine guidance sensor (FGS) located in the VIS focal plane and a cold gas micro-propulsion system for the science mode field dither and field step manoeuvres. The cold gas system allows for best pointing performance, at the cost of mass and limitations w.r.t. mission extension. Due to the low thrust level of 1 mN maximum, the manoeuvre times are rather long but still compatible with the specified timeline per field.
- The chemical propulsion system is a monopropellant hydrazine system operating in blow-down mode. It is required for transfer dispersion correction, mid-course correction and orbit maintenance at the operational orbit with a total  $\Delta V$  of 61 m/s (including margin). Fuel sloshing is minimized by use of a membrane tank.
- For telemetry, tracking and control an X-band communication system with two hemispherical low-gain antennas is considered. The science data (750 GBit/day) is down-linked via a steerable K-band high-gain antenna. For the daily available downlink-time of 4 hours a data rate of about 75 Mbit/s is required.

The spacecraft design elaborated by Astrium is shown Fig. 7. The total spacecraft dry mass of about 1840 kg – including proper subsystem margins and 20% system margin – is compatible with the Soyuz launch capacity.

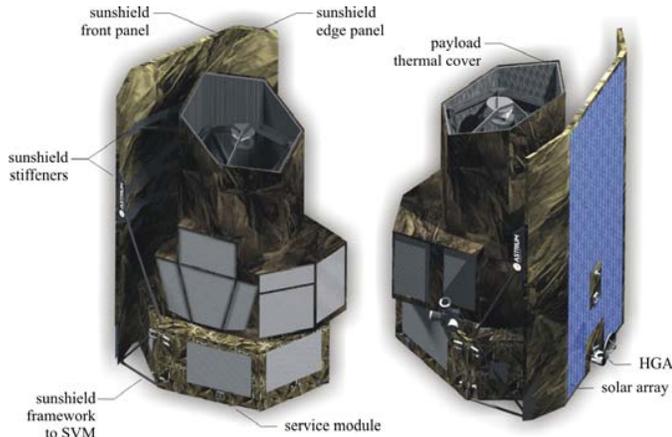


Fig. 7 EUCLID spacecraft design.

#### VI. CONCLUSIONS AND OUTLOOK

The spacecraft design elaborated by Astrium within Phase A/B1 of the EUCLID mission is characterized by its compliance to the mission requirements and interfaces, by its

robustness in terms of heritage, technology readiness and growth potential, and by its flexibility w.r.t. mission operations, interfaces (in particular to the instruments) and procurement approach.

The EUCLID mission is feasible. The risks are at a manageable level and a launch in 2020 appears realistic.

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