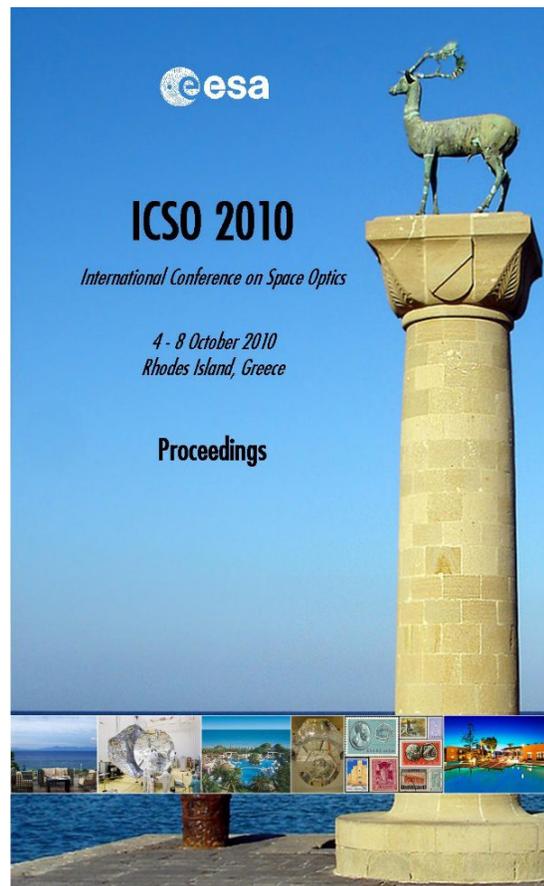


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EUCLID MISSION DESIGN

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ABSTRACT

EUCLID, a medium-class mission candidate of ESA's Cosmic Vision 2015–2025 Program, currently in Definition Phase (Phase A/B1), shall map the geometry of the Dark Universe by investigating dark matter distributions, the distance-redshift relationship, and the evolution of cosmic structures. 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 concept of the EUCLID mission which is fully compliant with the mission requirements. Preliminary concepts of the spacecraft and of the payload including the scientific instruments are discussed.

I. INTRODUCTION

EUCLID is planned as a medium-class mission to study the geometry and the nature of the dark universe [1]. The mission has been derived from DUNE and SPACE, two complementary proposals for ESA's Cosmic Vision 2015–2025 Plan for launch in 2017–2018. In 2008 EUCLID has been selected for an Assessment Phase and for a Definition Phase in 2010. Astrium performed in 2008–2009 an industrial Phase 0 study and currently is performing an industrial Phase A/B1 study. The final selection for Mission Implementation (Phase B2/C/D/E1) is expected for mid of 2011.

The Lambda-Cold Dark Matter (Λ CDM) concordance model is well established for describing the evolution of the Universe from a highly homogeneous state after the Big Bang to a highly inhomogeneous structure of galaxies, clusters and superclusters. This single and simple model self-consistently explains all observed phenomena, though requires the introduction of new components. Only 4% of the Universe are made of baryonic matter. About 20% consists of Dark Matter, a cold, non-baryonic, dissipationless and collisionless quantity required for understanding gravitational effects observed on very large scale structure. The missing 76% of the overall energy density are Dark Energy, which causes the Universe to accelerate its expansion.

Dark Energy is best characterized – in terms of total amount and equation of state – by measuring the geometry of the Universe through the redshift–distance relation and by measuring the growth rate of structures as they collapse under gravitational attraction while the Universe expands. A combination of these two observation methods provides a cross-check on the dark energy dominated model.

EUCLID is a high precision survey mission featuring two independent cosmological probes of geometry and growth rate, which allow for reliable cross-calibration of systematic effects:

- Weak Gravitational Lensing (WL) from a high-resolution imaging survey of shapes of distant galaxies. By correlating a large number of galaxy shapes, small systematic distortions can be measured which result from light bending by matter distributed along the line of sight. Galaxies at different distances yield the mass distribution at different distances and thus information on the shape and growth of the power spectrum of density fluctuations. The geometry of the Universe is deduced from tracking the angular size of features in the density fluctuation spectrum with redshift.
- 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. This length scale, which is accurately known from the Cosmic Microwave Background (CMB) and which amounts to about 150 Mpc in the Λ CDM model, serves as a powerful standard ruler. By measuring its position as a function of redshift allows for directly probing the expansion history and thus the Dark Energy equation of state of the dark energy equation of state parameters. The anisotropy of matter clustering in the redshift space provides a quantitative measurement of the growth rate.

EUCLID shall 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 2π sr solid angle. This survey will provide a huge scientific legacy for many fields beyond Fundamental Cosmology.

II. MISSION OVERVIEW

The EUCLID Mission consists of a wide-field telescope of 1.2 m aperture diameter and two scientific instruments:

- A visible imager (VIS) for shape and photometric redshift measurements of galaxies up to $\text{mag}_{AB}=24.5$ in the wavelength regime from 550–920 nm.
- A near-infrared spectrograph and photometer (NISP) for photometric redshift measurements of galaxies up to $\text{mag}_{AB}=24$ in the three wavelength bands Y (920–1146 nm), J (1146–1372 nm) and Hp (1372–2000 nm), and for spectroscopic redshift measurements of galaxies up to $\text{mag}_{AB}=19.5$ with a spectral resolution of 500 in the wavelength band of 1000 – 2000 nm.

EUCLID shall observe the extragalactic sky at galactic latitudes $|b| \geq 30$ deg, see Fig. 1 (left). For the wide survey a total sky area of 20.000 deg^2 shall be observed in patches of 100 deg^2 . Embedded into this, for the deep survey a total sky area of 40 deg^2 shall be observed multiply in patches of 10 deg^2 . The sky is sampled in step & stare mode with instantaneous fields of $0.586 \times 0.787 \text{ deg}^2$ (depending on the actual focal plane configuration). Each field is observed in four dither frames to avoid any gaps between the detectors (offset of 115 arcsec or 60 arcsec in latitude and longitude, respectively).

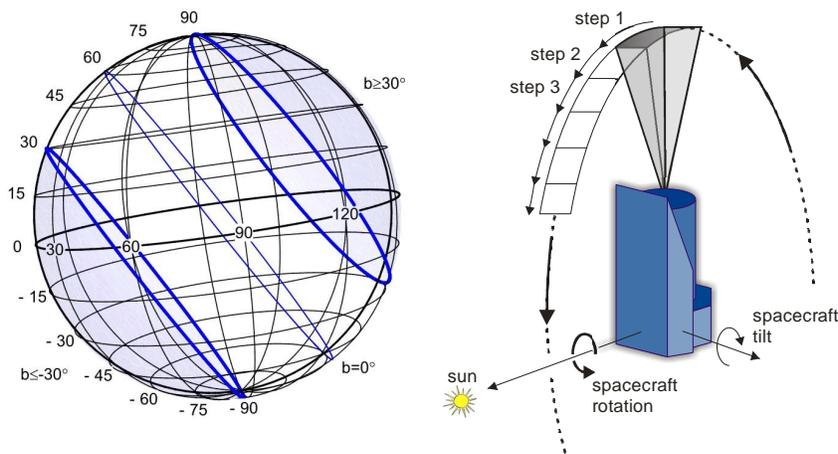


Fig. 1 Extragalactic sky survey geometry in ecliptic coordinates (left) and step & stare sky survey principle (right).

The step & stare sky survey principle of EUCLID is shown in Fig. 1 (right). Nominally one strip is scanned per day (corresponding to 0.787 deg in longitude and about 21 deg in latitude). 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. To overcome the temporal inefficiency around the Equinoxes and at the ecliptic poles, the sky is not scanned along great circles of constant ecliptic longitude but, by tilting the spacecraft, on small or great circles with varying longitudes.

EUCLID shall be launched from Kourou (French Guiana) by a Soyuz ST 2-1B launch vehicle in 2018. A direct transfer is targeted to a large-amplitude free-insertion orbit at the Second Lagrange Point of the Sun-Earth system. The total mission duration shall be 5 years.

III. PAYLOAD CONCEPT

The EUCLID payload module consists of a common payload bench, a telescope and the two scientific instruments VIS and NISP. While the payload bench and the telescope shall be procured industrially, the nationally funded instruments shall be under the responsibility of an instrument consortium (currently subject to an Announcement of Opportunity) [2].

The conceptual block diagram of the EUCLID payload module and the corresponding optical and electrical chains are given in Fig. 2.

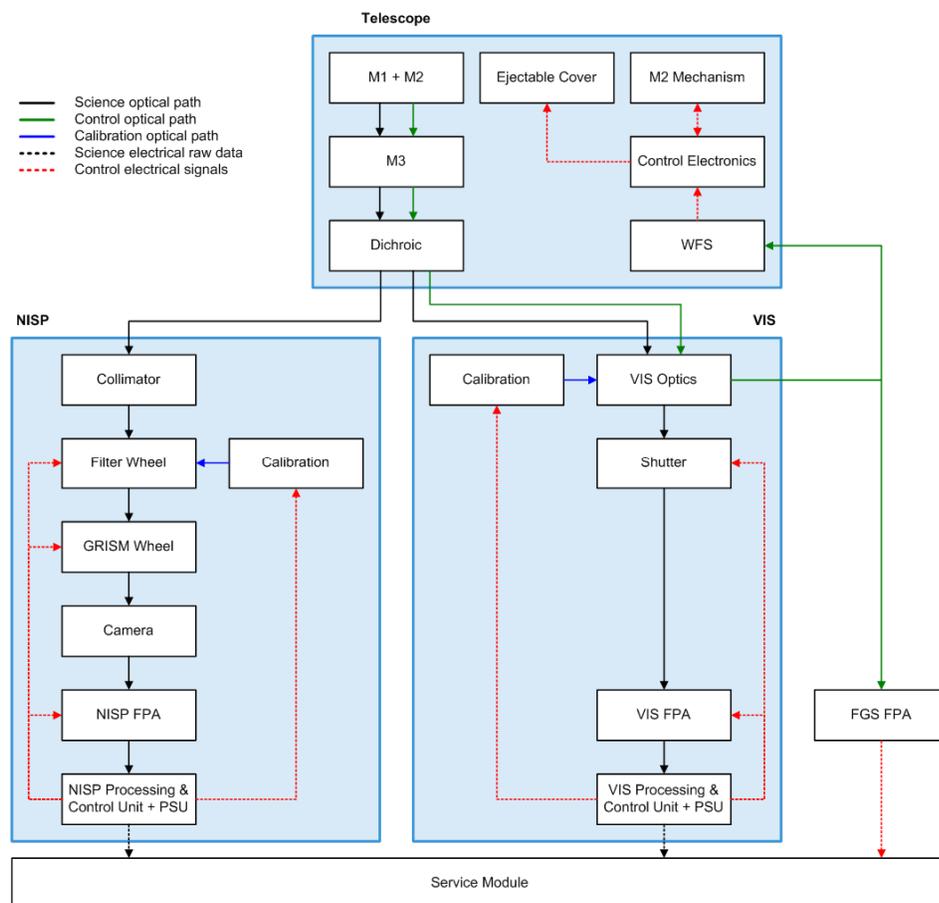


Fig. 2 Payload module conceptual block diagram.

- The industrial part of the payload module consists of a three-mirror telescope, of the dichroic mirror(s) separating the signals of the two instruments, of a common optical bench, supporting the telescope and the instruments, of an ejectable cover, and of a wavefront sensor (WFS) including the corresponding control electronics and M2 mechanism. 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 (or 6×5) CCD's (e2v, CCD 203-82, 0.1 arcsec/pixel plate scale), a dedicated processing and control unit, a calibration unit, and a shutter. The interface between the VIS instrument and the telescope is the focal plane.
- The NISP instrument consists of refractive optics, filter and grism wheels, a focal plane assembly with 4×4 (or 4×3) HgCdTe detector arrays (Rockwell, Hawaii 2RG, 0.3 arcsec/pixel plate scale), a dedicated processing and control unit, and a calibration unit. The interface between the NISP instrument and the telescope is the exit pupil of the Korsch telescope.

The current status of the payload module optical design as developed by ESA is given in Fig. 3 [3]:

- The telescope is a three-mirror Korsch configuration with an 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 field of view (FoV) is $0.79 \times 0.83 \text{ deg}^2$, and the focal length is 24.5 m. At the telescope's exit pupil the dichroic is located.
- The VIS instrument corresponds to the reflected output of the dichroic. It has a FoV of $0.704 \times 0.787 \text{ deg}^2$ (for 6×6 CCD's). The required integration time per frame (dither positions) is 511 s.
- The NISP instrument corresponds to the transmitted output of the dichroic, which contains a refractive focal reducer and collimator optics (6 lenses), filters for spectral band selection in photometry mode and a grism for spectral dispersion in spectroscopy mode (both with refraction power). It has a FoV of $0.78 \times 0.8319 \text{ deg}^2$ (for 4×4 Detectors). The total integration time per frame (dither positions) is 568 s.

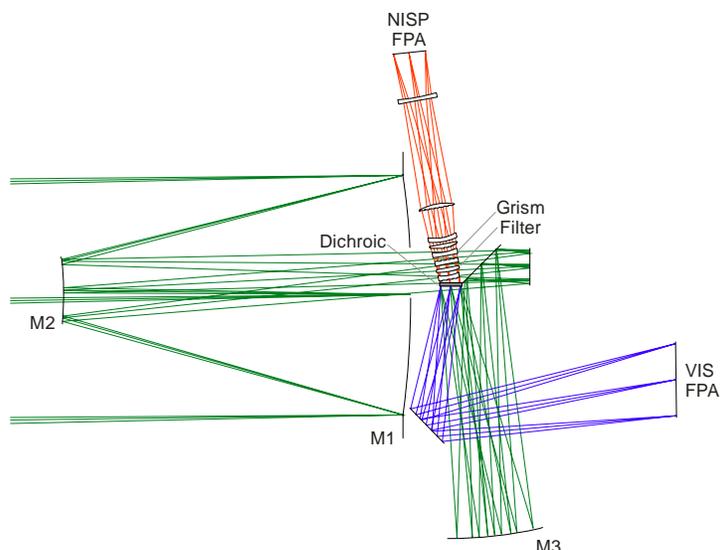


Fig. 3 Payload module optical design (folded for proper 2D view) [3].

The main design drivers for the payload module are:

- A high opto-mechanical stability required to guarantee the specified stabilities for ellipticity and full width of half maximum (FWHM) of the system point spread function (PSF).
- Clearly defined and verifiable interfaces between the telescope and the instruments.
- Accommodation of the self-contained instruments VIS and NISP, which are developed and verified independently from the telescope.
- The required payload temperature and focal plane temperature to minimize thermal background and the detector dark current for the NISP instrument.

To optimally cope with the design drives and to comply with the mission constraints, the following design guidelines are considered:

- The EID-A [4] specifies the temperatures of the detectors and of the payload to limit the dark current and the thermal background. The focal planes for VIS and NISP require temperatures of 150 K and 100 K, respectively. The temperature of the payload compartment is specified as 150 K. Concerning the thermal background the payload temperature could be increased up to 193 K (driven by NISP photometry). By introducing a cold compartment around the NISP FPA the payload temperature could be increased even further, e.g. to 235 K for a cold compartment temperature below 168 K. A payload temperature as low as 150 K is advantageous in terms of thermal stability but limits the available materials for the telescope. A telescope completely made of Silicon Carbide (i.e. including optical bench, mirror structure and mirrors), appears as optimum in terms of mass and thermo-elastic sensitivity.
- For achieving the highest thermal stability, a passive thermal control of the payload is advantageous (as no disturbances are induced by the control itself). The drawbacks are long thermal settling times after change of the external thermal loads (change in solar aspect angle). With decreased thermal stability requirements, active thermal control – at least of the instrument cavity – could reduce the impact of transient thermal dissipation.
- The thermal decoupling is maximised by using iso-static interfaces with low thermal conductivity between the instruments and the payload bench and between the payload bench and the service module.
- The telescope contains a baffle for decoupling of the telescope from the sunshield thermal variations and for blocking straylight (mainly emerging from bright stars within the FoV). An ejectable telescope cover is required to avoid mirror contamination within the launcher and to avoid direct sunlight during the cruise phase.
- The instrument radiators are located in opposite Sun direction for optimum efficiency. This requires an additional folding mirror within the NISP instrument.
- For optical correction of the M2 position – potentially needed after cool-down or change in solar aspect angle – a control loop with a five axis M2 positioning mechanism and a wavefront sensor located in the VIS focal plane is considered.

The preliminary payload module concept elaborated by Astrium is shown in Fig. 4. The payload bench is the core of the payload architecture. On top side it carries the telescope (primary mirror, secondary mirror and support structure) and on bottom side the telescope tertiary mirror, the dichroic and the instruments. For the payload bench and the telescope an a-thermal design completely made of Silicon Carbide is considered. Each instrument has an independent structure and interfaces the payload bench with iso-static mounts. The entire payload is passively cooled to 150 K. The dry mass of the payload module is estimated to about 660 kg including proper subsystem margin.

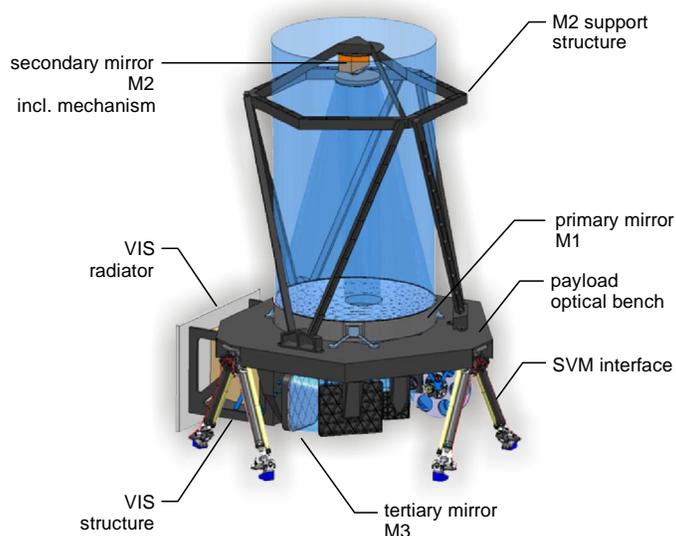


Fig. 4 Preliminary payload module concept.

IV. SPACECRAFT CONCEPT

The EUCLID spacecraft consists of three major modules:

- A payload module (PLM) containing all functionalities required for the scientific measurements. It is designed to guarantee the required performance by highest thermo-elastic stability.
- A service module (SVM) containing all functionalities and equipment required to support the PLM for the scientific observations. It contains in particular the attitude and orbit control system (AOCS).
- A sunshield for protecting the PLM from solar irradiance. It thus guarantees the thermal stability for the telescope and the instruments.

For the definition of a reference design for the service module (SVM) the following design guidelines have been considered:

- 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 as, e.g., GAIA.
- The SVM is of hexagonal shape with a central cylinder for supporting the launch loads from the PLM to the launch vehicle adapter (1194SF). The SVM structure is made of Aluminium honeycomb with CFRP facts. Multi-layer insulation (MLI) is used to enclose the sides.
- The SVM equipment is mounted on the radial panels and on the bottom floor. The chemical propulsion tank is mounted equatorially inside the central cylinder and the cold gas tanks are polar-mounted inside the SVM.
- The sunshield is of panel-type with 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. Its canted shape and the support struts are driven by the stiffness requirements.
- The payload is protected from external thermal variations by high performance MLI at the back side of the sunshield and at the top side of the SVM.
- 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 ΔV of 68.2 m/s (including margin).
- The attitude and orbit control system (AOCS) is responsible for the required spacecraft attitude during all mission phases and in particular for high pointing accuracy during science observation. The

stringent pointing stability requirements (25 milli-arcsec rms over 500 s, TBC) require high performance AOCS sensors as active pixel sensor star trackers, an inertial measurement unit, and fine guidance sensor located in the telescope focal plane. A cold gas micro-propulsion system is the baseline for the science mode step manoeuvres.

- For telemetry, tracking and control an X-band communication system with two hemispherical low-gain antennas is considered. The science data 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 60 Mbit/s is required.

The preliminary spacecraft concept elaborated by Astrium is shown Fig. 5. The telescope is protected by a straylight baffle and the whole payload module by a thermal cover. The dry mass of the spacecraft is estimated to about 1600 kg including proper subsystem margins and 20% system margin. The total launch mass of about 1840 kg is well within the launch vehicle capacity of 2160 kg.

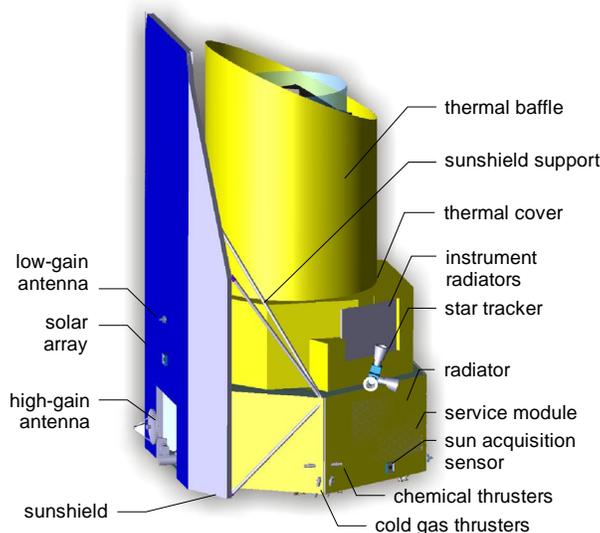


Fig. 5 Preliminary spacecraft concept.

V. CONCLUSIONS AND OUTLOOK

The preliminary concepts for the spacecraft and the payload module indicate that the EUCLID mission is compliant with the mission requirements and is feasible within the technical and programmatic constraints. The mission is currently investigated in industrial Phase A studies and the instrument designs are consolidated by the instrument consortium.

The mission appears compatible with the medium-class mission constraints on planning, technology readiness and costing. The technical concepts are well established and any risks are mainly introduced by the tight schedule with a launch date already in 2018.

VI. ACKNOWLEDGEMENTS

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