DOCUMENT

Euclid Science Management Plan

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CHANGE RECORD

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Update of AO cycle in Table 1	2010-07-20	11	-
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1 INTRODUCTION: PURPOSE AND SCOPE

Euclid is an ESA mission with contributions from ESA Member States and with a potential participation from NASA. In February 2010, Euclid was selected by the Science Programme Committee to enter the Definition phase as a candidate M-class mission in the Cosmic Vision 2015-2025 Plan.

The Science Management Plan defined in this document presents the top-level science management principles of the mission and its main organisational units. It identifies roles and responsibilities of ESA, International Partners, the Euclid Consortium funded by the Member States, and the scientific community at large. The document provides an overview of the mission science objectives and a description of the scientific operations and data processing centres that will be established to generate the outlined scientific data products.

Contingent upon SPC approval of the Science Management Plan, ESA will issue an Announcement of Opportunity for the Euclid Consortium, which will include contributions to the payload and to the scientific ground segment, and an Announcement of Opportunity for Legacy Scientists.

The Science Management Plan will be revised at the end of the Definition phase. The purpose is to ensure that the evolution of the mission's configuration's, including (but not limited to) the international cooperation, the provision of nationally-funded elements, and the time necessary to the processing of the data prior to their being released to the public, can be properly taken into account prior to the implementation phase, and thus provide a solid basis for the mission's science management in the subsequent phases. The revised version will be subject to the same approval cycle as the present version.

2 MISSION OVERVIEW

2.1 Introduction

In the concordance cosmological model, the Universe has evolved from a homogeneous state after the Big Bang, to a hierarchical assembly of galaxies, clusters and superclusters at our epoch. The energy density of the resulting Universe is dominated by two mysterious components. First, 76 % of the energy density is in the form of Dark Energy, which is causing the expansion of the Universe to accelerate in the recent epoch. Second, another 20 % of the energy density is in the form of Dark Matter, which exerts gravitational attraction as normal matter, but does not emit or scatter light. The remaining small fraction of 4% is made up of the ordinary baryonic matter composed of protons and neutrons. Together, Dark Energy and Dark Matter pose some of the most important questions in fundamental physics today.

Euclid is a high-precision survey mission designed to answer these fundamental questions. To do so, Euclid will map the large-scale structure of the Universe over the entire extra-

galactic sky out to redshifts of z=2 (about ten billion years ago), covering the period over which Dark Energy has accelerated the expansion of the Universe. The Euclid mission has been optimised for the measurement of two probes sensitive to Dark Energy: (1) weak lensing and (2) baryon acoustic oscillations.

The weak lensing measurements consist of observing the apparent distortion of the images of galaxies caused by gravitational light deflection from unknown and invisible foreground mass concentrations (dark matter) and moreover modified by the expansion of the Universe. One measures angles between galaxies, dimensionless ellipticities (apparent shapes of the galaxies), and redshifts. Tomographic methods are then applied to map the dark matter in three dimensions and to build the power spectrum of the shape correlation between galaxies as a function of the angular scales. The analysis of this power spectrum, as a function of the redshift of the lensed galaxies, makes it possible to determine the properties of the dark energy component.

Baryon acoustic oscillations (BAO) are the imprint of sound waves from the epoch of recombination, about 400,000 years after the Big Bang, which results in the Cosmic Microwave Background. These waves imprint a standard preferential distance among galaxies that increases as the Universe ages and expands. The details of this "length scale" carry information about how the Universe has expanded at different epochs since the Big Bang. Assuming that the distribution of galaxies reflects the distribution of all matter, the length scale of these oscillations can be measured from the spatial correlation of galaxies. As a standard ruler, BAO provide Euclid with accurate measurements of the Hubble parameter and the angular diameter distance, putting additional constraints on Dark Energy.

By measuring the two probes simultaneously, Euclid will constrain Dark Energy, General Relativity, Dark Matter, and the initial conditions of the Universe with unprecedented accuracy. The two probes require:

- Determination of the shapes and shear of statistical samples of galaxies with a density of 30-40 galaxies/arcmin^2 over the entire extragalactic sky of 20,000 deg^2.
- Determination of the photometric redshift of the weak lensing galaxies with an accuracy of dz/z = 0.05 (requirement) with a goal of 0.03
- A spectroscopic redshift survey over the entire extragalactic sky of the same volume of Universe as the weak lensing experiment by measuring spectroscopic redshifts with $dz/z < 0.001$ over an area of 20,000 deg^2. The survey concentrates on emission line galaxies, with detection limit ~4×10^{-16} erg s^{-1}cm^{-2} for (the Hα) line flux, or H(AB)=19.5 mag for continuum.

The uniqueness of the Euclid data, which cannot be collected other than from space, is reflected in the following key observables for a survey area of 20,000 deg^2:

- Diffraction limited galaxy shear for 30-40 galaxies/arcmin^2 in the visible.
- Photometric redshifts from photometric data in 3 wavelength bands in the 1-2 micron range, down to AB = 24 mag.

- Spectroscopic redshifts > 7×10^7 galaxies with $z>0.5$ in the 1-2 micron wavelength range.

The near-infrared measurements provide homogeneous redshift information as well as access to a redshift range ($1<z<2$) which is very hard to measure from ground.

The nominal observing plan is to carry out a wide survey of the whole extragalactic sky of ~20,000 deg^2 and a deep survey of ~40 deg^2. The Euclid wide survey will produce the following main scientific data sets:

- Diffraction-limited images (~0.16 arcsec FWHM PSF) in a broad band at visible wavelengths (~0.55-0.92 micron) with excellent image quality down to AB = 24.5 mag (10 sigma for an extended source).
- NIR Imaging photometry (~0.3 arcsec pixels) in three NIR bands between 0.92-2 micron down to AB = 24 mag (5 sigma point source)
- NIR Slitless spectroscopy (R=500, λ = 1-2 micron).

The Euclid deep survey will cover some 40 deg^2 of sky with an imaging depth in the visual which is some 2 mag fainter than the wide survey. The deep survey is performed by repeatedly observing the same sky with the wide survey observing mode until the required depth has been reached. The deep survey also yields deep spectroscopic data that can be used to calibrate the photometric redshifts. Thus the data sets from the deep survey are similar to those of the wide survey, but for each region of the deep survey there is a ~40 fold repeat, instead of single coverage.

The Euclid mission takes full advantage of observing in space, namely acquiring diffraction limited images in the visual and spectroscopy and photometry in the near-infrared between 1 and 2 micron. However, it relies on the addition of ground-based photometric surveys and spectroscopy to fulfil its cosmology objectives. The photometric redshift accuracy required by the weak lensing experiment cannot be obtained alone from the three photometric NIR photometric bands combined with the one band in the visual, as provided by Euclid. It is essential to include all-sky photometry from ground in several photometric bands in the visual. Essential external data are:

- Ground based photometry, covering the same area as the Euclid wide survey;
- Deep spectroscopic redshifts for 10^5 galaxies with AB < 24 mag to calibrate the Euclid photometric redshifts.

It is the task of the Euclid Science Team to foster tight collaborations with complementary ground based photometric surveys and spectroscopic facilities.

2.2 Science objectives

With its wide-field capability and instrumentation enabling high-precision cosmology measurements, Euclid aims to achieve the following science objectives in fundamental cosmology: (1) Euclid will measure the Dark Energy equation of state parameters w_0 and

w_a to a precision of 2 % and 10 %, respectively, from the geometry and structure growth of the Universe. Euclid will thus achieve a Dark Energy Figure of Merit as defined by the Dark Energy Task Force of 500 (1500) without (with) incorporating Planck measurements, thus improving by a factor of 50 (150) upon current knowledge. (2) Euclid will test the validity of General Relativity against modified gravity theories, and measure the growth factor exponent γ to an accuracy of 2 %. (3) Euclid will study the properties of Dark Matter by mapping its distribution, testing the Cold Dark Matter paradigm, and measuring the sum of the neutrino masses to a few 0.01 eV in combination with Planck data. (4) Euclid will improve the constraints on the initial condition parameters by a factor of 2-30 compared to Planck alone. The Euclid survey can thus be thought as the low-redshift, three-dimensional analogue and complement to the map of the high-redshift universe provided by CMB experiments.

Beyond advances in cosmology, the Euclid surveys will also provide unique legacy science in various fields of astrophysics. In the area of galaxy evolution and formation, Euclid will deliver high quality morphologies, masses, and star-formation rates for billions of galaxies out to a redshift of z~2, over the entire extragalactic sky, with a resolution four times better and three near-infrared magnitude fainter than ground-based surveys. The Euclid deep survey probes the "dark ages" of galaxy formation as it should find thousands of galaxies at $z > 6$, of which about a hundred could be at $z > 10$, i.e. probing the era of re-ionisation of the Universe. With Euclid, the majority of the new sources identified by future imaging observatories, from radio to X-rays, will be readily assigned a redshift, out to a redshift of z~2. This adds an enormous power to the science return, as it eliminates the time-consuming phase of redshift follow-up in many studies.

2.3 Mission overview

2.3.1 Scientific Payload

The Euclid payload consists of a Korsch telescope with a primary mirror of 1.2 m diameter. The telescope is designed to provide a large field of view (~0.5 deg^2) offered to two instruments placed behind a dichroic filter: a visible imager (hereafter VIS), and a near-infrared photometer-spectrometer (hereafter NISP). The VIS instrument in combination with the NISP operating in photometry mode supports the weak lensing experiment. The NISP instrument operating in slitless spectroscopy mode is designed to perform the spectroscopic galaxy survey.

VIS contains a CCD based focal plane covering an area of ~0.5 deg^2 with 0.1 arcsec pixel sampling in one wide band spanning the wavelength range ~550-920 nm. The VIS channel will measure the shapes of galaxies with about 0.16 arcsec (FWHM) system point-spread function before pixelisation by the CCD.

NISP employs HgCdTe NIR detectors covering an area of ~0.5 deg^2. It can be operated in photometry mode or slitless spectroscopy mode by means of filterwheels. In photometry

mode, NISP will take images of the sky in three filterbands (Y, J, H) with 0.3×0.3 arcsec pixels. In the slitless spectroscopy mode, a grism is used operating in the wavelength range 1.0-2.0 micron at a constant spectral resolution $\lambda/\Delta\lambda \sim 500$, employing 0.3 arcsec pixels.

2.3.2 Mission Description

The spacecraft will be placed in a large halo orbit around the second Sun-Earth Lagrange point (SEL2) which ensures stable observing conditions. To accomplish the surveys within the nominal mission duration of five years, each instrument has a large field-of-view and the system design is optimised for a sky survey with fast attitude slews to support a step-and-stare tiling mode. Image dithering is achieved at spacecraft level to fill detector gaps and allow correction for cosmic rays. A fine guidance system provides the required pointing accuracy over each dither exposure of about 700 s.

Euclid's primary *wide survey* aims at covering 20,000 deg², i.e. the entire extragalactic sky, thus measuring shapes and redshifts of galaxies to a redshift of z=2 as required for weak lensing and baryon acoustic oscillations.

The photometric redshifts for these galaxies reach a precision of $\sigma_z/(1+z)$= 0.03-0.05. They are derived from three Euclid near-infrared (NIR) bands (Y, J, H in the range 0.92-2.0 micron) reaching AB = 24 mag (5σ, point source) in each, complemented by ground based photometry in visible bands derived through collaborations engaged with ground based projects. To measure the shear from the galaxy ellipticities, tight control is imposed on possible instrumental effects. The variance of the shear systematic errors is less than 10^{-7}.

The baryon acoustic oscillations are determined from a spectroscopic survey with a redshift accuracy of $\sigma_z/(1+z) \leq 0.001$. The Euclid baseline is a slitless spectrometer with constant spectral resolution of $\lambda/\Delta\lambda$ =500, which will detect predominantly Hα emission line galaxies. The limiting line flux level is 4×10^{-16} erg s^{-1} cm^{-2} (7σ for a point source at 1.6 micron), yielding 70 million galaxy redshifts with a success rate in excess of 35 %. The success rate is the fraction of the total amount of detectable galaxies for which the redshifts can be determined.

Euclid's additional *deep survey* covers 40 square degrees. This survey is 2 mag deeper than the wide survey achieved by repeated visits to the same patch of sky.

Options for including ancillary surveys, which could be carried out without affecting the nominal completion of the wide and deep surveys, will be studied during the Definition Phase.

The Euclid instrument and pointing capabilities offer the possibility to carry out additional surveys serving a broad range of scientific topics. Depending on the mission performance, additional surveys which are technically feasible shall be selected through a dedicated AO open to the general scientific community to be issued before the start of the extended mission. This *open survey* phase would start after the nominal core mission time of 5 years.

2.3.3 *Spacecraft*

The launcher and launch facilities are provided by ESA. The satellite will be launched on a Soyouz ST-2.1B rocket from ESA's spaceport in Kourou. To facilitate the unprecedented data rate, Euclid will have X and K band transponders to support the tele-commanding and the science data transfer to ground, respectively. The K band section supports a downlink data volume of 850 Gbit of compressed science data in 4 hours. The attitude and orbit control system of Euclid will be designed such that the on ground reconstructed absolute measurement accuracy will be better than 0.1 arcsec. To achieve the required relative pointing, Euclid will have a fine guidance sensor which is mounted close to the VIS focal plane array.

2.4 Mission phases and milestones

As a Cosmic Vision M-class mission, the Euclid schedule is as follows:

- Start of Definition Phase with two parallel industrial contracts: July 2010
- Down-selection for CV M1/M2 missions: June 2011
- Completion of the Definition Phase (A/B1): December 2011
- Final adoption for the Implementation Phase (B2/C/D/E1): Feb 2012
- Start of the Implementation Phase: July 2012
- Launch (L): end 2018
- L+: Launch and Early Operations Phase (LEOP)
- L+ a few days: start Satellite Commissioning and Payload Performance Verification Phases
- L≤6 months: start Routine Phase
- L+5 years: start mission extension with the Open Survey phase.

2.5 Operations

Mission operations, science operations, and data product generation will be carried out by ESA through the Missions Operations Centre (MOC) and Science Operations Centre (SOC), and by the Euclid Mission Consortium (EMC) managing the Science Data Centres (SDCs), under the scientific coordination of the Euclid Science Team (EST). The total time available for observation will be used to build up the Euclid surveys under the supervision of the EST.

The main elements of the scientific operations are:

- After launch and early operations, Euclid will cruise towards its final station in orbit around SEL2. The cruise will last ~1 month.
- Routine phase starts within ~6 months after launch, once the period of commissioning and performance verification has completed.
- Operations are commanded via a single ground station (Cebreros) with a daily ground communication period of 4 hours

- Scientific operations consist of a pre-programmed sequence of manoeuvres to collect ~0.5 deg² fields at each step-and-stare pointing. During each pointing, 4 dither frames are collected, and the visible imaging, infrared spectroscopy, and photometry data are collected during the same pointing. The sequence of manoeuvres is known far in advance (more than weeks) and is the result of a pre-defined survey strategy.
- Data obtained outside the visibility periods are stored in an on-board mass memory, and later transmitted to ground during the visibility period. The K-band facility will allow science data rates up to 850 Gbit/day.
- Spacecraft and instrument consumables are designed to ensure a mission life time of at least 5 years.
- The main observing plan is to carry out the wide survey (single coverage of the whole extragalactic sky of ~20,000 deg²) and the deep survey (multiple coverage of ~40 deg²). To maintain thermal stability of the payload, the solar aspect angle of the line-of-sight is constrained to close to 90 deg.
- The aim is to complete the wide survey within the nominal mission lifetime. The deep survey is performed at regular intervals throughout the nominal mission.
- At about L+2 years, the spacecraft and payload capabilities, as well as the structure and organisation of the ground segment are assessed for support to the Open Survey Phase.
- The Open Survey Phase starts after the nominal mission time of 5 years.

The large data volume and high-precision measurement requirements of Euclid is handled by the Euclid Science Ground Segment (SGS).

The Euclid SGS will be responsible for the derivation of calibrated data with instrumental fingerprints and removal of cosmic rays (calibration, removal of the instrumental effects, etc) and for requesting to the SOC corrective action in operations. The SGS will also be in charge of higher level data products and the development of simulation pipelines.

The data handling system includes a common archive, the Euclid Mission Archive (EMA) which supports the sharing of data within the project. The Euclid Legacy Archive (ELA) contains the Euclid data open to the general scientific community.

2.6 Member State funded elements: the Euclid Mission Consortium

The Euclid Mission Consortium (EMC) provides:

1. Components of the two instruments VIS and NISP ,
2. Components of the Euclid Science Ground Segment,
3. Science data products to the Euclid Mission Archive,
4. Members of the Euclid Science Team

The EMC is funded by ESA's member states, and selected via an Announcement of Opportunity (AO). The Proposals received in response to the AO are evaluated following the standard ESA procedure involving the ESA Advisory Structure, and followed by approval by the SPC. After the adoption of the mission, the exact responsibility of each party in the Euclid Mission Consortium will be formalised through a Multilateral Agreement (MLA) between ESA and the relevant national funding authorities. A timeline for the selection of the Euclid Mission Consortium is provided in Table 1.

While the procurement of the telescope and instruments are managed separately, they constitute a single high precision cosmology experiment dedicated to a well-focussed objective. As a consequence, their technical design must be carried out and optimised in a coherent fashion. For this reason, once the EMC has been selected, close cooperation with ESA will be required to finalise the design of the payload.

Data processing activities are intimately related to the payload development and will benefit from a high degree of connectivity between the scientists involved. This is achieved through a single consortium, the EMC. Furthermore, through their payload procurement activities, the EMC will ensure expertise in:

- Instrument calibration
- Instrument operations activities
- Instrument science performance

For these reasons, the EMC will have a major stake in the data processing activities.

Involvement of US scientists in the Euclid Science Ground Segment is assumed (see Section 2.8); this entails the provision of one or more Science Data Centres (SDCs). The US SDC(s) will be part of the EMC SGS and the US scientists have the same data access rights as the members of the consortium.

Table 1: Indicative Euclid AO Cycle

Date	Event
July 2010	Release of AOs for a Euclid Consortium and Independent Legacy Scientists
October 29, 2010	Proposals Due
November 2010	Meetings with national funding agencies for the Definition Phase
November 2010-January 2011	Internal evaluation
January 25-26, 2011	AWG recommendation
February 1-2, 2011	SSAC recommendation
February 10-11, 2011	SPC decision
June 21-22, 2011	M-class mission selection
July-October 2011	MLA negotiations with national funding agencies for selected missions
November 16-17, 2011	MLA SPC decision

2.7 The general scientific community

Euclid will produce a massive legacy of deep images and spectra over about half the entire sky. This will be a unique resource for the general scientific community worldwide and will impact all areas of astronomy. To acknowledge this capability of Euclid, two Independent Legacy Scientists are selected through an Announcement of Opportunity open to the general scientific community.

The Independent Legacy Scientists are closely involved in the Euclid mission through membership in the Euclid Science Team (EST). Their main responsibility will be to give advice on the support to the general scientific community concerning the usage and availability of the Euclid data.

As part of the response to the AO, each Independent Legacy Scientist shall make a proposal for a legacy data analysis project unique to Euclid. The proposed project shall not address the main cosmological objectives (cf. Section 2.2). The Independent Legacy Scientists may include in their respective proposals a team of collaborators to aid them in the analysis of the data. Proposals shall have a concrete and delimited scope and include a credible data analysis scheme. Research activities in relation with the proposal will not be funded by ESA and will be expected to rely on institutional and national sources for support.

The Independent Legacy Scientists projects shall not impose additional requirements on the mission. However the EST, after proper analysis and evaluation, may recommend changes to the configuration or to the satellite operations that would have a positive impact on Euclid legacy science in general.

The Independent Legacy Scientists and their teams have proprietary access to the Euclid data for the purpose of their respective scientific projects, and follow the rules defined by the EST regarding publications.

Based on a recommendation by the Advisory Structure, the Independent Legacy Scientists will be appointed by ESA for an initial period of three years, renewable through the duration of the mission.

2.8 NASA Partnership and US community

Discussions between ESA and NASA have resulted in a framework agreement for near-term studies and a potential long-term collaboration on the Euclid mission. The top-level conditions for the collaborative framework are the following:

- The total US contribution to the Euclid mission will not exceed ~20% of total mission costs from all contributors (estimated assuming the ESA procurement approach), but excluding scientific preparation and exploitation.
- NASA will participate in the definition phase studies in order to identify together with ESA potential contributions to the Euclid scientific payload. US provision of the near-IR focal plane, readout electronics, and related flight software has been identified as a top candidate. Additional contributions such as hardware for the space-

craft, ground segment contributions, launch segment contributions, etc. will also be investigated jointly with ESA.
- Data processing activities to provide "Level 2" data products (calibrated data with instrumental artefacts and cosmic rays removed, see next section) will also count towards the US contribution. U.S. funding to the selected scientific participants for data exploitation (i.e. data analysis, interpretation) will not be counted against the US contribution to the mission.
- US scientist participants will have access to the scientific data required to carry out their selected and agreed to scientific investigations.
- Possible US participation in, and contributions to, European-led payload elements, provided in response to the ESA Announcement of Opportunity (see below) will count towards the total US contribution of ~ 20%.
- NASA will appoint proportional representation to the Euclid Science Team (see below) up to ~ 20% of the membership.
- Selected US scientists will have the right of first-authorship on a pro-rata fraction of scientific papers (again up to ~20%) published during the relevant proprietary phases, or equivalent metric agreed by the EST. Agreement of authorship of individual papers will be left to the EST with the agencies only intervening in the case of major disagreements.

This ESA-NASA framework agreement is contingent upon the outcome of the US National Research Council's Astronomy and Astrophysics Decadal Survey, which is released in Fall 2010.

3 SCIENCE MANAGEMENT

3.1 Overview and overall responsibilities

The overarching responsibility for all aspects of the Euclid mission rests with ESA's Directorate of Science and Robotic Exploration and its director (D/SRE). During the development phase, D-SRE delegates his responsibility to the ESA Project Manager and his Project Team. The Project Team is responsible for the development, procurement, manufacturing, assembly, integration, test, verification and timely delivery of a fully integrated spacecraft capable of accommodating the telescope and the VIS and NISP instruments, fulfilling the mission requirements and achieving the mission objectives.

While ESA has the responsibility of the overall Euclid mission definition and space segment development, the payload module hardware breakdown and the responsibilities are foreseen as follows:

- ESA is responsible for the telescope opto-mechanical assembly and for the payload module system integration and tests,

- The EMC provides the VIS instrument,
- The EMC provides the NISP instrument,
- The EMC contributes to the integration and tests of the instruments at payload module level, under the control of the spacecraft industrial Prime Contractor,
- ESA procures the VIS CCD detectors and formally delivers them to the EMC. The EMC is responsible for the overall VIS instrument performance. The EMC provides the necessary support to ESA in the CCD detector procurement to ensure that the science requirements are met.
- ESA is the formal interface to NASA for all US-provided hardware. The NISP Focal Plane Assembly (FPA) is assumed to be US procured. The NISP FPA includes NIR detectors, mechanical and thermal hardware, proximity electronics and electronics control unit. The EMC is responsible for the overall NISP instrument performance. The EMC provides the necessary support to ESA to ensure that the science requirements are met.

The EMC, selected by ESA via the Announcement of Opportunity and funded by ESA member states and identified international partners, is responsible for the development, procurement, integration, and verification of the instruments along with the instrument specifications and preliminary resources allocation. In addition, the EMC provides:

- Science Data Centres in charge of the instrument specific data processing and the derivation of higher level science data products (see Section 4).
- Instrument maintenance and operations support
- Quality-controlled data products to the Euclid Legacy Archive

The EMC instrument project manager is responsible for the overall management of the instrument development. The EMC science ground segment manager is responsible for the overall management of the SGS development. Both EMC managers act as interfaces to ESA. This baseline organisation structure will be reviewed throughout the Definition phase and may be modified as part of the SMP revision at the end of the Definition Phase.

ESA's Space Operations Centre (ESOC) implements the Mission Operations Centre (MOC), operates the spacecraft, and delivers telemetry and attitude data to the Euclid Science Operations Centre. ESA's Space Astronomy Centre (ESAC) implements the SOC, which acts as the central node for the mission planning, distributes the Level 1 data products (see Section 4.1) to the other elements of the Science Ground Segment after an initial quality check. The SOC is also responsible for the development and operations of the Euclid Legacy Archive. The SOC populates and maintains the ELA and delivers the data products to the general scientific community.

The Euclid Science Team oversees the preparations and execution of scientific operations, and endorses distribution of the data products to the community via the ELA.

The ESA Project Scientist defines the Euclid-specific observing requirements based on the scientific guidelines provided by the EST. The PS approves the resulting observing plan produced by the SOC. The approved observing plan is sent to MOC for execution.

The EMC is ultimately responsible for the creation and delivery to ESA of the second and higher level data products.

Software developed specifically for Euclid jointly by ESA and its partners will be put under a worldwide license such as LGPL. In accordance with SPC(2009)6 approval for this action will be sought from the Agency's technology transfer board (ATB).

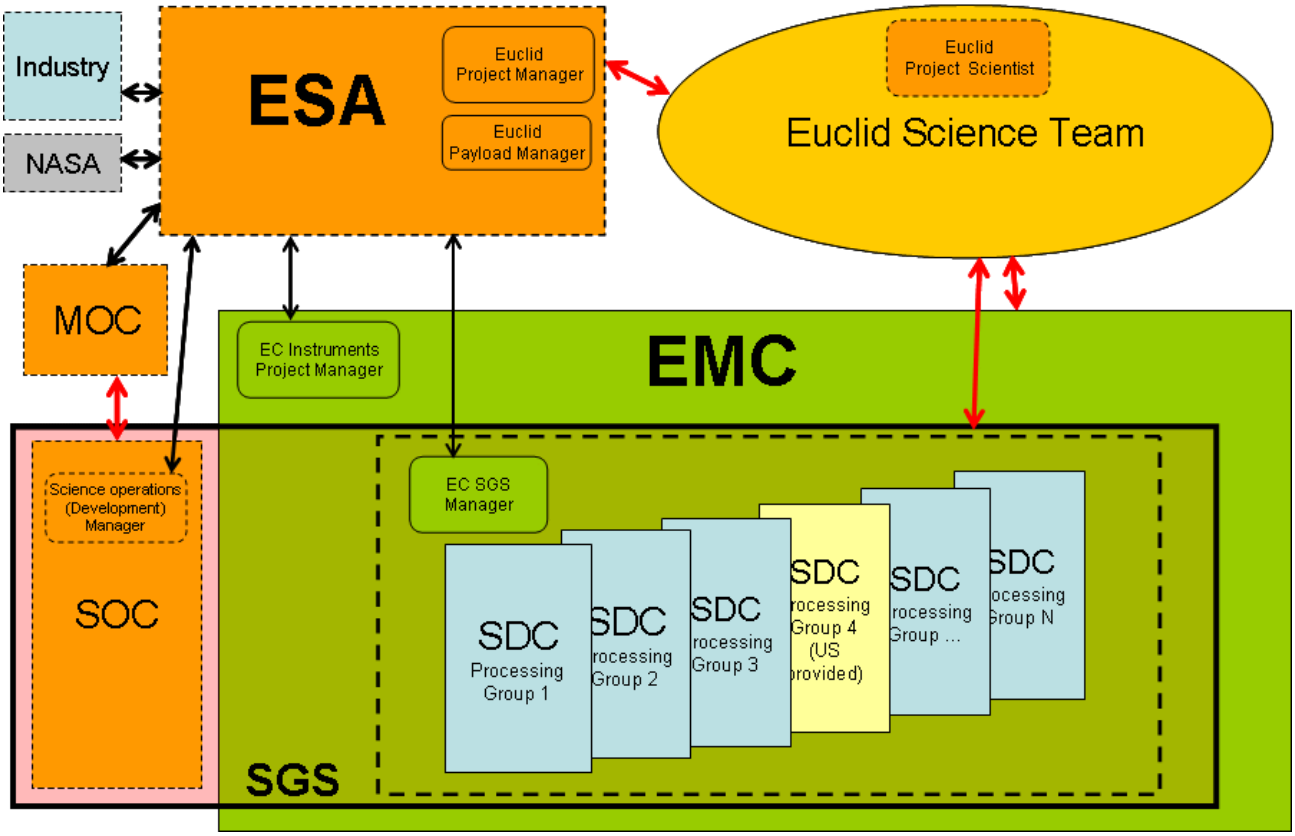

Figure 1: *Parties involved for the science management, arrows indicate main reporting (black) or coordination (red) lines. The Euclid Project Scientist from ESA chairs the Euclid science team. The Euclid science ground segment includes the ESA science operations centre and the science data centres. There can be one or more US provided SDCs. This baseline organisation structure will be reviewed throughout the Definition phase and may be modified as part of the SMP revision at the end of the Definition Phase.*

3.2 Project Scientist

The ESA Euclid Project Scientist (PS) is the Agency's interface with the Euclid Mission Consortium and general scientific community for scientific matters. Within ESA, the PS

liaises with the Euclid Project Manager until completion of the satellite in-orbit commissioning, and thereafter with the Euclid Mission Manager during routine operations.

During all phases of the project, the PS is responsible for coordinating all scientific issues with the ESA Project Team. In particular, the PS will advise the ESA Project and Payload Managers on technical matters when they affect scientific performance. During the development and operational phases, the PS monitors the state of implementation and readiness of the instrument operations and data processing infrastructure. During and after routine operations the PS is responsible for the coordination of the creation of the scientific products, their archival and distribution to the scientific community.

The PS chairs the Euclid Science Team and coordinates its activities.

3.3 Science Team

The Euclid Science Team supports the PS in monitoring the correct implementation of the scientific objectives of the mission and maximising its scientific return. The Euclid Science Team will be formed after selection of the Euclid Mission Consortium through an AO, and will remain in place until the scientific products are delivered to the community. In addition to the ESA Project Scientist who chairs it, the EST is composed of 10 members:

- Two Survey Scientists, who are closely involved in the definition of the surveys and the monitoring of the progress of the surveys;
- Three Instrument Scientists with specific expertise in the Euclid instrumentation, instruments calibrations, and associated data processing. They provide advice on:
  - VIS imaging,
  - NISP photometry,
  - spectroscopy.
- Two Data Processing Scientists, who closely monitor
  - data processing infrastructure and interfaces
  - product generation,
  - simulations pipelines,
  - definition, advising/facilitating procurement, and inclusion of external and/or ground based data.
- Three Legacy Scientists who will give advice on support to the community in the usage and availability of the Euclid data (e.g. documentation, information on data quality, data products definition etc.) and with more specific responsibilities for advising on:
  - additional science catalogues,
  - transient event handling,
  - preparatory and follow-up activities.

Six members (one Survey Scientist, the VIS and the spectroscopy Instrument Scientists, the Data Processing Scientists and one Legacy Scientist), will be leading scientists in the Euclid Mission Consortium and their names and designated functions within the EST will be

identified in the proposal in response to the AO. Two members, one Survey Scientist and the NISP photometry Instrument Scientist, will be appointed by NASA. Two Independent Legacy Scientists and any associated teams are selected through a separate AO issued by ESA.

The EST members are appointed by the ESA director of Science and Robotic Exploration. In case a member of the EST needs replacing, the ESA Director of Science and Robotic Exploration will appoint the successor, upon proposal from the EMC or NASA, depending on the member's appointment. The replacement of an Independent Legacy Scientist will be recruited through an AO issued by ESA at the appropriate time.

The ESA Project Manager, ESA Mission Manager (after launch), ESA Payload Manager, NASA Project Manager, ESA Science Operations (Development) Manager, EMC Instrument Project Manager, and EMC Science Ground Segment Manager have standing invitations to attend all meetings and participate in all activities of the EST as non-voting members.

To discharge its responsibilities, the EST mainly relies on the technical information provided by the EMC and ESA Project. However, if deemed necessary, the PS may request external scientific consultant(s) to conduct an independent review of any of the activities which normally fall under the responsibility of the EST and EMC.

The EST acts as a focus for the interest of the scientific community in Euclid. The EST advises the PS on:

- maximising the scientific return of Euclid within its programmatic constraints, while at the same time insuring that the development of the mission remains compatible with the main scientific objectives
- the scientific aspects of the development of the instruments and spacecraft
- the formulation, optimisation, and maintenance of the observing guidelines and the calibration strategy
- the definition and coordination of the supporting ground based observational programs
- the definition of data rights and publication policy within the guidelines established in this document
- the promotion of public awareness and appreciation of the Euclid mission, and supporting ESA in its outreach efforts
- the analysis of the data
- the supervision and authorisation of the release of the final scientific data products to the community, including scientific publications
- the organisation of the data archive(s)

In general, the members of the EST are expected to monitor and give advice on all aspects of Euclid which affect its scientific performance. In particular, they participate in major project reviews, and perform specific tasks as needed during the development and

operation phases.

The EST, in consultation with ESA, is responsible for the definition of the external data required by the Euclid mission to achieve its scientific goals. They will coordinate the availability of the data. The EST monitors the collection of these datasets prior to launch to ensure that the science requirements can be fulfilled within the nominal mission time. The Data Processing Scientists monitor the procurement of the external data for the Euclid Science Ground Segment. The EST, once constituted, will decide on which EST member will be the lead contact to the parties providing external data.

3.4 Steering Committee

A Multi-Lateral Agreement (MLA) will be established between ESA and the EMC funding agencies to formalise the commitments and deliverables of all parties. A Euclid Steering Committee with representatives from the national funding agencies and ESA will be set up to oversee the activities of the EMC and the timely fulfilment of the obligations of all parties to the MLA.

The Euclid Steering Committee will participate to the periodic milestone reviews of the EMC to monitor the status and progress of the EMC.

4 THE EUCLID GROUND SEGMENT

4.1 Overview

Euclid will return an unprecedented volume of data for astronomical space missions, roughly four times as much as Gaia. The Euclid Mission Consortium (EMC) in collaboration with ESA provides a framework for the end-to-end handling of the Euclid data. The Euclid *Science Ground Segment* (SGS) consists of the Euclid SOC and the EMC ground segment components. In this section a broad overview is given of the Euclid ground segment and its main elements: MOC, SOC, and the EMC.

The Euclid data processing system contains “data processing levels” and their associated “data levels”. Data levels consist of all data produced by the corresponding data processing level including intermediate data. The criterion for the definition of a specific data level is that it can be implemented separately from the others and forms a closed and complete part of the data processing chain. Each data level has corresponding quality controls. The list of data levels includes:

- External Data. Quality-controlled data from existing missions and ground-based surveys which are used for calibrations, photometric redshift derivations, and simulation validations before and during the mission.
- Level S (Simulation) data. Pre-launch simulations and modelling impacting on calibrations and observing strategies. Massive Monte Carlo simulations are likely to

be required post launch to assess systematic effects and derive meaningful uncertainties on the final cosmological parameters.

- Level 1 data. Unpacked and checked telemetry and housekeeping data, and standard processed data with basic detector signatures removed. These signatures include e.g. flat fielding and dark current.
- Level 2 data. Calibrated data and intermediate data products produced during the calibrations. Calibrated data have all instrumental fingerprints removed. Dithered images have been coadded; spectra have been extracted
- Level 3 data. Science-ready data products, mostly catalogues to achieve the various science goals of the mission.

All relevant Euclid data items will be stored and published into a Euclid Legacy Archive (ELA). The ELA is the public subset of a Euclid Mission Archive (EMA) containing all quality controls and intermediate products.

The Mission Operations Centre (MOC) operates the spacecraft and delivers the telemetry and flight dynamics products to the SGS.

The SOC acts as the central node for the mission planning; it performs Level 1 data processing and populates the EMA with the science and housekeeping telemetry after a first quality check for further processing by the EMC. The quality check at the SOC directly feeds back to the mission planning by means of rescheduling of defective observations. The SOC develops, maintains, populates and operates the ELA, which is the vehicle for delivering data products to the general scientific community.

Teams within the EMC will process the Euclid data from Level 1 to higher data levels during all phases of the mission. The EMC is organised in groups mapped onto the main data processing functionalities e.g.:

- Galaxy Ellipticity
- Photometric redshifts
- Spectroscopic redshifts
- Simulations
- Additional science catalogues
- Transient detections

Beside the SOC, the SGS consists of Science Data Centres (SDCs) responsible for the science data processing, the generation of the Level 2 and Level 3 data products, and the development of simulation packages to support the development and testing of the operational pipelines.

The EMC has the responsibility of providing integrity, security and the appropriate level of quality control. The EST, via the SOC, authorises data access to the EMA and ELA.

Level 3 includes pre-defined science data products (3D galaxy power and dark matter power spectra, tomography, high order statistics, mass reconstruction maps) but does not include data analysis beyond the production of catalogues and basic 2-point statistics or

cosmological interpretation of data (joint analyses of data, dark energy studies, cosmological parameters, growth and growth rate of structures, galaxy biasing, test gravity, neutrino mass constraints, galaxy clustering, etc...).

4.2 The role of the Euclid Mission Consortium in the SGS

Via the Euclid Mission Archive, the SOC will make available the Level 1 data to the EMC for further processing. Starting from the Level 1 data, the EMC carries out the following SGS tasks:

- In close collaboration with the SOC, define and maintain the instruments modes of operation to maximise the scientific return of the mission.
- Calibration of the science data including the removal of cosmic ray events, instrumental effects and systematics.
- Preparation of simulated data to support accuracy and performance analysis, optimisation studies and the design, development, and testing of the entire data analysis environment.
- Preparation of data analysis algorithms, which includes galaxy shear analysis, photometric redshift determination, spectroscopic redshift determination, and other slitless spectroscopy analysis.
- The design, development, procurement, and operation of all aspects of the hardware and software processing environment necessary to fulfil their responsibilities in the reduction of the mission data throughout the simulation, mission operations and the final catalogue production phases.
- The procurement, handling and processing of any additional ground-based astronomical data that may prove necessary for achieving the mission scientific objectives.
- Maintenance of the EMA for processing and quality control

The EMC contributes in close corporation with the SOC, to the design, development and operation of the EMA.

4.3 ESA commitments

4.3.1 Ground Station

The ground station is under the responsibility of ESA and will support a daily telemetry and telecommanding communications period of 4 hours during nominal operations, and longer periods during the Commissioning and Performance Verification phases. The station is equipped with a K-band channel receiver, to support the science data rate of the satellite (~850 Gbit/day).

4.3.2 The Missions Operations Centre

The satellite is controlled from the ESA Mission Operations Centre (MOC), via the Cebreros ground station. The Project delegates to ESA's Space Operations Centre (ESOC)

the design, development, validation, and operation of the MOC. The MOC is in charge of:

- monitoring spacecraft health and safety,
- monitoring instruments safety by ensuring that payload housekeeping data remains within predetermined limits,
- alerting the SGS of all significant anomalies and/or deviations from the nominal behaviour of the spacecraft
- executing predetermined procedures to safeguard the spacecraft and payload, and preserving data integrity
- controlling the spacecraft attitude and maintaining its orbit
- handling telemetry/telecommands for both spacecraft and instruments
- supporting the SGS on all aspects concerning spacecraft operations
- converting SOC requests for pointing and instrument control to spacecraft commands and uplinking them
- daily stripping of the payload data and housekeeping from the telemetry stream, ordering them by (spacecraft) time and making the data available to the SOC
- derivation of the spacecraft pointing history
- archiving the full telemetry data for a period of no less than 10 years.

4.3.3 The Science Operations Centre

The Project delegates to ESA's Science and Astronomy Centre (ESAC) the design, development, validation, and operation of the Science Operations Centre (SOC). The SOC is the only interface to the MOC during routine operations, and is in charge of the following satellite and payload operations specific tasks:

- planning the surveys, based on observing guidelines by the EST,
- scheduling the spacecraft slews,
- scheduling the exposures,
- handling instrument operations/maintenance requests from the EMC,
- monitoring the survey performances,
- first-level quality control (consistency of telemetry frames),
- rescheduling,
- requesting MOC action via predefined procedures and sequences of telecommands.

The SOC receives the housekeeping, pointing, and science data from MOC and derive the Level 1 products for ingestion into the EMA. The Level 1 processing includes conversion of telemetry frames from the spacecraft in science files, and a first processing pass thereby removing the basic detector signatures and adding pointing information to the frames.

The SOC is responsible for the ELA, for contributing in close corporation with the EMC to the design, development, and operation of the EMA, and for the management of the access rights to the EMA.

The SOC takes the lead in the overall design and engineering of the SGS, and, under scientific supervision of the EST, organises and manages the end-to-end tests, to validate the SGS data processing pipelines, interfaces, and operational processes.

5 SCIENCE PRODUCTS

5.1 Overview

Three types of science products will be generated by the Euclid project:

- **Scientific data products:** these are the deliverables resulting from the mission, which will be made available to the general scientific community, and which will form the basis for scientific research and publications. Their nature and delivery schedule are described in more detail in Section 5.2 below.
- **Scientific publications:** which are intended to appear in the scientific literature, having undergone scientific validation and peer review. Issues associated with such publications are discussed in Section 5.3 below.
- **Education and outreach materials:** whose purpose is to maintain the public at large informed of the progress and scientific results of the mission, and which are normally. Outreach issues are discussed in Section 5.4.

5.2 Scientific data products

The data products include not only the processed frames or images but also quality control information. The quality control information ensures traceability of the input data sets as well as the processing steps applied. Level 3 incorporates ground based information in the derivation of the data products. A preliminary list of deliverable data products include:

Level 1 data:
- Raw images from VIS and NISP
- Images and spectral dispersion images with basic detector signatures removed and associated calibration data.
- Processed housekeeping data, such as pointing history files

Level 2 data:
- Calibrated and co-added images from VIS and NISP – validated for cosmology analysis
- PSF model and optical distortion maps
- Coadded spectra

Level 3 data:
- Catalogues (including redshift, ellipticities, shear, etc)
- Dark matter mass maps
- Shear and galaxy correlation functions and covariance errors

- Additional science catalogues

Transients:

- Transient events data: include derived transient category (e.g. supernova candidates, solar system object, etc), target position and possible finding chart with target.

5.2.1 Data delivery scheme

In view of the effort to prepare a data release and to achieve a level of homogeneity and consistency in the processed data, the Euclid data are released to the general scientific community (also referred to as the "public") on an annual basis. The data are made available via the Euclid Legacy Archive.

The first year of Level 1 data are released to the public 2 months after the collection of the last data of that year. The two months is the time required to perform Level 1 processing of one year of Euclid observations, about 100 Tbyte of raw uncompressed telemetry data.

After public release of the Level 1 data, the EMC has a one year period to prepare the cosmology validated Level 2 and Level 3 data products for release to the public.

The subsequent parts of the Euclid surveys are released on an annual basis along with the progress of the surveys.

Products obtained from the transient data analysis pipelines (positions or mini-maps of transient event locations) will be made public immediately to enable quick follow up observations, e.g. to obtain SN-Ia lightcurves.

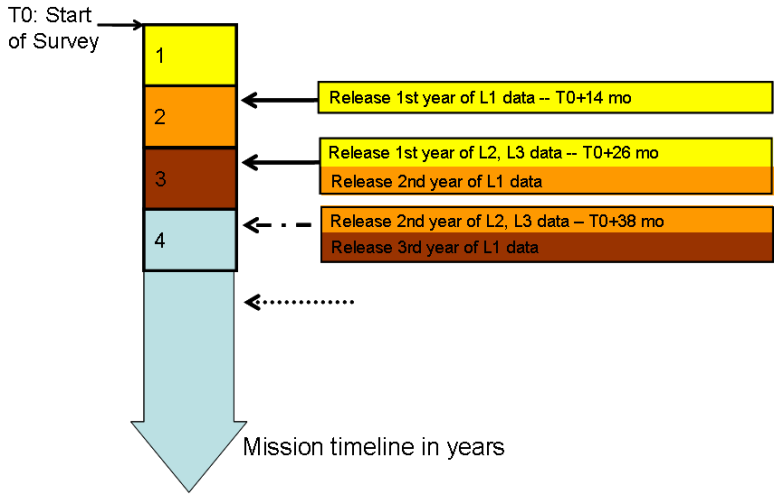

Figure 2: *Scheme for Euclid data release to the general scientific community. The first year of Level 1 data are released 14 months after the start of the Euclid routine phase; the higher level data are released 1 year later.*

The EST will define the validation procedures for each data level that shall be applied before data releases. The validation shall involve the SOC and the EMC SGS team.

The data delivery scheme may be revised at the end of the Definition phase, subject to the advice of the Advisory Structure.

5.3 Scientific data rights and publication policy

The ownership, access, use, and dissemination of Euclid raw and calibrated data and of information, data and intellectual property produced by the analysis of data shall be governed by Chapter III, Sections II and III of the Rules on Information, Data and Intellectual Property, ESA/C/CLV/Rules 5 (Final), as adopted by the ESA Council Resolution on the Rules concerning Information, Data and Intellectual Property, ESA/C/CLV/Res. 4 (Final).

The policy set down here reflects the wish to:

- Deliver to the general scientific community scientific data and results of the highest quality within the shortest possible time.
- Acknowledge the work and effort put into the project by members of the EMC by giving them exclusive access to Euclid data for a limited period of time.

The proprietary period is the period starting from acquisition of a given dataset until public release of this dataset. The following scientists involved in Euclid will have proprietary access to the data: the members of the EST and their associated teams, scientists in the EMC, scientists in the US-provided components in the SGS, and scientists in the SOC.

It is envisaged that different subsets of investigators will analyse different scientific aspects. Thus the division of the work among the investigators will be done on a topical basis.

Approximately one year after the start of the implementation phase (i.e. July 2012+1 year) the EST will prepare a Euclid Core Programme of research topics and their corresponding investigators. The core programme covers all Euclid science objectives to be investigated by all proprietary data rights holders, spanning both the fundamental cosmology goals described in Section 2.2, as well as the legacy science topics. All Euclid-involved scientists can take part in the Euclid Core Programme. The core programme will be presented to the ESA Advisory Structure for endorsement.

The Euclid Core Programme of research topics will be reviewed by the EST one year before launch, at which time it may be modified to take into account new scientific developments or significant changes in the structure of the consortium.

All scientific publications prior to the end of the proprietary period, resulting from the Core Programme, must be approved by the EST. All publications resulting from the Euclid Core Programme have to undergo scientific validation by an EST-coordinated publication board. The EST will take into account the pro-rata distribution of the lead authors, or equivalent metric agreed by the EST, of the core programme publications: 20% of US-affiliated authors, 5% of ESA-affiliated authors employed by ESA and the remaining fraction for the

consortium. Papers by the independent legacy scientists undergo the EST scientific evaluation but are not taken into account for the purpose of computing the balance of publication distribution.

5.4 Public relations, education and outreach plan

Euclid has a strong outreach potential: it provides multi-colour high resolution images comparable to those of HST of half of the entire sky. In combination with the redshift information, a 3-dimensional map can be obtained of billions of resolved galaxies and galaxy clusters of a large volume of our visible Universe.

ESA and its partners in the mission should address the many scientific questions which can be addressed by Euclid from both an outreach and an educational aspect. This requires both the necessary skills and resources to provide a continuous production of the required materials which consist of a high quality website, text at many levels (children booklets, secondary school material, press-releases, popular science-level material), simulations, audio-visual aids, etc. These skills and resources will be developed both within ESA as well as within the EMC and EST.

ESA will be responsible for planning and carrying out education and outreach activities related to Euclid. In addition, a general outline will be requested in the AO in the form of a public relations plan. This plan must be formally agreed and adhered to by the EST. The plan will take into account that:

- ESA has the lead on all applications of education and outreach within the data rights framework described in section 5.3.
- The members of the EST and the EMC have a duty to support ESA with regards education and outreach
- ESA will give credit to members of the EST and the EMC regarding scientific and technical results when applicable.

ACRONYMS

AO	Announcement of Opportunity
ATB	Agency Technology and Product Transfer Board
AWG	Astronomy Working Group
BAO	Baryon Acoustic Oscillations
CCD	Charge coupled device
CMB	Cosmic Microwave Background
CV	Cosmic Vision
ELA	Euclid legacy archive
EMA	Euclid mission archive
EMC	Euclid Mission Consortium
ESAC	European Space Astronomy Centre
ESOC	European Space Operations Centre
EST	Euclid Science Team
ESTEC	European Space Research and Technology Centre
FPA	Focal Plane Assembly
FWHM	Full width at half maximum
ILS	Independent Legacy Scientist
LEOP	Launch and Early Operations Phase
LGPL	Lesser General Public Licence
MLA	Multi-Lateral Agreement
MOC	Mission Operations Centre
NASA	National Aeronautics and Space Administration
NIR	Near infrared
NISP	Euclid's NIR spectroscopy and photometry instrument
PS	Project Scientist
PSF	Point spread function
SDC	Science Data Centre
SEL2	2nd Sun-Earth Lagrange point
SGS	Science Ground Segment
SMP	Science Management Plan
SN	Supernova
SPC	Science Programme Committee
SSAC	Space Science Advisory Committee
SOC	Science Operations Centre
SRE	Science and Robotic Exploration
US	United States of America
VIS	Euclid's visual instrument