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European Space Agency
Agence spatiale européenne

ESTEC
European Space Research and Technology Centre - Keplerlaan 1 - 2201 AZ Noordwijk - The Netherlands
Tel. (31) 71 5656565 - Fax (31) 71 5656040 www.esa.int

Contribution from:

Science Advisory Team:
TBD

Others:

L. Duvet	ESA/ESTEC
P. Gondoin	ESA/ESTEC
G. Saavedra Criado	ESA/ESTEC

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CHANGE LOG

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Issue 3/3 and earlier: SciRD Issues earlier than Issue 4/0, were released during the Euclid Assessment study phase (May 2008-September 2009). The Euclid Science Study Team appointed during this phase maintained the requirements. **Issue 4/0**: this is a new release of the SciRD serving as a science requirements starting point for the Definition Phase studies. In Issue 4/0 we have removed all requirements/text related to the slit spectroscopy case and we have done some minor rephrasings in the text and requirements. We have kept the requirement numbering compatible with the previous issues.			

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose

This document provides the top level science requirements and the implied top level payload and mission requirements for Euclid, ESAs mission to map the dark Universe. Euclid will tightly constrain the dark energy equation of state and address key cosmological questions.

In response to the first Call for Missions for the Cosmic Visions plan, two dark energy related missions were proposed: “DUNE: the Dark Universe Explorer” by A. Refregier and coworkers, and “SPACE: the Spectroscopic All Sky Cosmic Explorer” by A. Cimatti and coworkers. The two concepts have been merged into Euclid, a single medium class (“Class M”) mission which concentrates on measuring weak lensing (WL) and baryonic acoustic oscillations (BAO).

This Issue 4 of the Science Requirements Document (SciRD) will be the basis for the Euclid mission and payload design during the Definition Phase. Earlier issues of this document (Issue 3 and lower) are superseded by this issue and refer to earlier phases of this mission.

We give a summary of the science case as well as the objectives in Sections 2 and 3 of this document. The full scientific case of Euclid is described in detail in the assessment phase study report [RD10]. Section 4.4.1 – formerly the slit spectroscopy requirements section - has been kept as an empty section to keep the requirement numbering consistent with previous issues of the document.

1.2 Scope

This document covers all Science Requirements of the Euclid mission, and aims at showing clearly the links between science requirements and derived mission and payload requirements, in order to help understand, trace and support the analysis of the relation between the payload/mission specifications on the scientific objectives of the mission.

The science requirements document will be used as a reference for the Euclid Mission Requirements document, which is the basis for the industrial activities.

1.3 Acronyms

BAO	Baryonic Acoustic Oscillations
CV	Cosmic Visions
DE	Dark Energy
DETF	Dark energy task force
DUNE	Dark Universe Explorer
FoM	Figure of Merit
FoV	Field of View
NIR	Near-InfraRed
SciRD	Science Requirements Document
SPACE	Spectroscopic All-sky Cosmic Explorer
TBC, D, W	To Be Confirmed, Done, Written
WL	Weak Lensing

List of symbols

b	Galactic latitude
$D(z)$	Distance-redshift relation – radial
$D_A(z)$	(Angular) Distance redshift- relation – tangential
γ	Growth factor exponent
h	Hubble constant in (km/s)Mpc^{-1}
$h(z)$	Expansion history
k	(inverse) length scale in hMpc^{-1}
λ	Wavelength
$p(k)$	Matter power spectrum
σ	Uncertainty, rms
σ_8	The fractional linear density rms when smoothed with a sphere of radius $8h^{-1}$ Mpc
$w(z)$	Dark Energy equation of state
w_n, w_a	Pivot value of w, and linear variation of w with a, defined in: $w(a)=w_n+(a_{pivot}-a)w_a$, where $a=(1+z)^{-1}$
z	Redshift
Ωm	Matter density

1.4 References

RD01 Abdalla et al. 2007, MNRAS, arXiv:0705.1437 (astro-ph)
RD02 Amara, A., Réfrégier, A, 2007, MNRAS 381, 1018
RD03 Amara, A., Refregier, A.: 2008, submitted to MNRAS, arXiv:0710.5171 (astro-ph)
RD04 Angulo, R. et al. 2008, MNRAS 383, 755 : The detectability of BAOs in future galaxy surveys
RD05 Guzzo, L., et al 2008: Nature 451, 541 : A test of the nature of cosmic acceleration using galaxy redshift distortions.
RD06 Paulin-Henriksson, S., Amara, A., Refregier, A., Voigt, L., S. Bridle S, 2007, to appear in A&A, arXiv:0711.4886 (astro-ph)
RD07 Wang, Y., 2006, ApJ 647, 1: Dark Energy constraints from BAOs.
RD08 Albrecht et al. 2006: Report of the Dark Energy Task Force
RD09 Peacock et al. 2006: Report of the ESO-ESA Working Group of Fundamental Cosmology
RD10 Euclid Assessment Phase Study Report, 2009, ESA/SRE(2009)2

1.5 Document overview

An introduction and overview of the mission based on the science case is provided in Section 2. In Section 3 we present the science objectives and the implied top level science requirements. We try to follow the scheme “objective → method → requirement”, whereby requirement is always at the 4th subsection level. Thus the requirements are explicitly numbered and reflected in the table of contents. The numbering of the requirements facilitates later discussions and change control. Section 4 contains the technical requirements for payload and mission. These requirements are derived from the top level requirements.

With Issue 0/4 of this document, we have removed all text and requirements related to the slit spectroscopy option. This option has been considered during the assessment phase, but was deemed infeasible in the framework of an M-Class Cosmic Visions mission.

2 INVESTIGATING THE DARK UNIVERSE WITH EUCLID

2.1 Euclid Science Case

Several independent observations indicate that the cosmological expansion began to accelerate when the universe was around half of its present age. This conclusion assumes the correctness of General Relativity, and requires that the universe must contain a new component known as dark energy. As a surprising consequence, the dark energy contributes to 76% of the total energy density of the universe, while the contribution of baryonic matter is only 4%. The remaining 20% is composed of dark matter, which, just as dark energy, has no explanation in standard physical theory. Like the accelerated expansion which took place during the early epoch of our universe, commonly known as "inflation", the present acceleration leaves imprints on the different phases of the expansion of the Universe. At the same time, the growth of structures in the Universe is sensitive to the details of the acceleration process, but also to the very nature of the force of gravity, a modification of which might be the alternative explanation of the apparent acceleration. The equation of state of dark energy can thus be constrained from observations of the expansion history of the universe throughout its visible epoch since the decoupling of the microwave background. Complementary, the need for a new theory of gravity can be either ruled out or confirmed from observations of the growth of large scale structure in the Universe.

Euclid is an ESA mission to map the geometry of the dark Universe. The survey mission will investigate the distance-redshift relationship and the evolution of cosmic structures by measuring shapes and redshifts of galaxies and clusters of galaxies. The statistical study of structures in a large volume of the Universe requires a survey of a large fraction of the extragalactic sky. Euclid will address key fundamental cosmological questions. Is dark energy merely a cosmological constant, as first discussed by Einstein, or is it a new kind of field that evolves dynamically with the expansion of the universe? Alternatively, is dark energy instead a manifestation of a break-down of General Relativity and deviations from the law of gravity? What are the nature and properties of dark matter? What are the initial conditions which seed the formation of cosmic structure? The mission is centred on weak lensing and baryonic acoustic oscillations, two powerful and robust probes of the dark Universe. The mission also incorporates other cosmological probes such as galaxy cluster statistics, the integrated Sachs Wolfe effect, and the redshift-space distortions.

Beyond these breakthroughs in fundamental cosmology, the Euclid surveys will 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 $z\sim2$, over the entire extra-galactic sky, with a resolution 4 times better and 3 NIR magnitudes deeper than ground based surveys. The Euclid deep survey will probe the 'dark ages' of galaxy formation as it is predicted to find thousands of galaxies at $z>6$, of which about 100 could be at $z>10$, i.e. probing the era of reionization of the Universe. With Euclid, the majority of the new sources identified by future imaging observatories, from radio to X-rays, will be readily associated to a known redshift, out to a redshift $z\sim2$. This adds an enormous power to the science return of these other projects, as it eliminates the time-consuming phase of redshift follow-up.

2.2 Euclid Scientific Concept

2.2.1 EUCLID'S PRINCIPAL DARK ENERGY PROBES

Euclid will measure the distance-redshift relation and the growth of structure by optimizing its instrumentation and observing strategy to two complementary dark energy probing methods.

- The weak gravitational lensing (WL) method relies on the fact that the distribution of mass along the line of sight distorts the apparent shapes and orientation of galaxies. The matter distribution, and hence cosmological structures, is obtained from the inferred gravitational field causing the weak lensing. This provides a measurement of the effect of dark energy both the geometry and the growth of structure.
- The baryonic acoustic oscillations (BAO) method relies on the distribution of baryonic matter, i.e. a galaxy redshift survey, to infer the redshift-distance relation. The characteristic scale length of structure which can be accurately determined from the cosmic microwave background is used as a standard rod. By measuring this characteristic scale in the galaxy power spectrum (or correlation function) as a function of redshift both in the tangential and redshift directions, one directly probes the expansion history $H(z)$ and thus the equation of state of dark energy $w(z)$. At the same time, the statistical distortion of the clustering pattern is a direct consequence of the growth of structure.

The science concept of Euclid relies on the fact that the combined results of the two principal methods provide very strong constraints on the dark energy equation of state and enable to sort out systematic uncertainties and biases that are inherent to each of the individual probes (Sect 3.1.1.2).

2.2.2 OTHER DARK ENERGY PROBES

Besides the two principal probes for which the mission is optimized, other DE probes can also be addressed with the Euclid survey and will provide additional constraints on the DE equation of state. A list of the Euclid DE probes is given in Table 2.

2.2.3 OBSERVING FROM SPACE

Observing from space provides a well-controlled environment and avoids sources of systematic errors caused by the Earth's atmosphere and thermal variations, which seriously limits similar observations from ground. This will give an unprecedented improvement in the dark energy characterisation in comparison to what can be achieved from ground only.

The Euclid survey will produce a visible image of a large fraction of the extra-galactic sky (20,000 deg^2) at a diffraction limited spatial resolution not possible from ground, and near-infrared (NIR) images in one or more bands of the same area. The sky coverage and depth in NIR photometry cannot be achieved from ground due to the high background emission from the atmosphere.

Euclid will also yield medium resolution (R=500) spectra of about a third of all galaxies brighter than the minimum limiting magnitude of H(AB) = 19.5 mag or with emission line Hα flux of 4×10^{-16} erg cm^{-1} s^{-1} in the same survey area in a wavelength range from 1.0 to 2.0 micron, which is difficult to access from ground for faint galaxies at $1<z<2$ due to the high background emission from the atmosphere. In addition, the high number of atmospheric sky lines requires a higher spectral resolution for a ground based experiment to obtain the same redshift accuracy from space.

This means that each ground-based spectrum would be much bigger on the detector, thus making a massive redshift survey as Euclid unfeasible from the ground.

2.3 Mission Overview

The spacecraft will be placed in a large L2 orbit which will ensure stable thermal and observing conditions. The satellite will be launched on a Soyouz ST-2.1B rocket from Kourou. The nominal mission duration is 5 years and the observations will be done in step-and-stare mode. Image dithering will be achieved at spacecraft level to fill detector gaps and allow correction for cosmic rays. A fine guidance system will provide a relative pointing accuracy of 35mas over one dither exposure of ~500s.

Euclid's primary *wide survey* will cover 20,000 deg^2, i.e. the entire extragalactic sky, thus measuring shapes and redshifts of galaxies to redshift 2 as required for WL and BAO. For weak lensing, Euclid will measure the shape of over 2 billion galaxies with a density of 30-40 resolved galaxies per arcmin^2 in one broad visible R+I+Z band (550-920 nm) down to AB mag 24.5 (10σ, extended object). The photometric redshifts for these galaxies will reach a precision of $\sigma_z/(1+z)$= 0.03-0.05. They will be derived from three additional Euclid near-infrared (NIR) bands (Y, J, H in the range 0.92-2.0 micron) reaching AB mag 24 (5σ, point source) in each, complemented by ground based photometry in visible bands derived through engaged collaborations with ground based projects. To measure the shear from the galaxy ellipticities a tight control is imposed on possible instrumental effects and will lead to the variance of the shear systematic errors to be less than 10^{-7}. The BAO 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 $\lambda/\Delta\lambda$=500, which will detect predominantly Hα emission line galaxies. The limiting line flux level is 4×10^{-16} erg s^{-1}cm^{-2} (point source 7σ 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 from which the redshifts can be determined. Euclid's additional *deep survey* will cover 40 deg^2. This survey will be 2 mag deeper than the wide survey, by frequently visiting the same regions in the wide survey observing mode.

3 EUCLID SCIENCE OBJECTIVES AND TOP LEVEL SCIENCE REQUIREMENTS

3.1 Cosmology Objectives

The primary science outcome of Euclid will be the detailed testing of the current standard cosmological model against the largest feasible observational data sets, with the specific objective of characterising the nature of the Dark Energy based on the combined results of the WL and BAO measurements. Euclid will yield a unique and vast data legacy which is expected to have a large discovery potential in several fields of cosmology, extra-galactic and galactic astrophysics. This legacy is seen as a very important all encompassing science objective.

The properties of dark energy can be quantified by considering its equation of state parameter $w=p/\rho c^2$, where p and ρ are its effective pressure and density. A cosmological constant implies $w=-1$. The simplest alternative quantum field explanations allow w to differ from -1 and to vary with time. Translating from linear time to observable redshift z, we can parameterize the DE state parameter $w(z) = w_0+w_a(1-a)$, with $a=1/(1+z)$ is the scale factor. The parameters w_0 and w_a are the present value and the rate of change of the DE state parameter. Alternatively one can define

$$w(a) = w_p + (a_p - a)w_a,$$

where w_p is the value of the DE state parameter at a pivot point a_p. Here we use both definitions. With this form, the errors on w_p and w_a become uncorrelated and the error on w_p corresponds to the error we would measure for a constant w model. Following Albrecht et al. (2005) [RD08], it is convenient to define a Figure of Merit (FoM_{DE}) as to quantify a given experiment's ability to measure the dark energy equation of state

$$FoM_{DE} = \frac{1}{\Delta w_p \Delta w_a}.$$

This FOM is widely used. By combining all current surveys its value is $FoM_{DE} \sim 10$ (Komatsu et al. 2009).

As well as the geometry, dark energy also affects the growth of structure. The expansion of the Universe acts as a damping term for the growth of density fluctuation so as the expansion rate increases, the growth of structure slows down. Importantly, however, the growth rate $f(a)$ depends also on the gravity theory, which makes it a fundamental probe of modified gravity (see next section). $f(a)$ is well approximated by the phenomenological relation (Wang & Steinhardt, 1998; Amendola & Quercellini, 2004)

$$f(a) \cong \Omega_m(a)^{\gamma_m},$$

where γ_m is the matter growth index $\gamma_m = 0.55 + 0.05[1 + w(a = 0.5)]$, an expression valid for smooth dark energy models like quintessence. In the GR framework, measurements of $f(a)$ represent a fundamental consistency test of our cosmological assumptions, while carrying additional information on $w(a)$ beyond the geometric probes of the expansion rate.

The Euclid mission is designed to address all the sectors of the standard cosmological model. The primary science objectives of the mission are:

- Dark Energy: Measure the DE equation of state parameters w_n and w_a to a precision of 2% and 10% respectively using both expansion history and structure growth. Adopting the DETF definitions, the precisions to be achieved with Euclid implies a FoM > 500, which is at least Stage IV on the DETF scale.
- Test of general relativity: distinguish general relativity from the simplest modified-gravity theories, by measuring the growth factor exponent γ with a precision of 2%.
- Dark Matter: Test the Cold Dark Matter paradigm for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck
- Initial Conditions: Improve by a factor of 20 the determination of the initial condition parameters compared to Planck alone

Table 1: Euclid Primary Science Objectives – see the Euclid Assessment Study Report for full description.

Sector	Euclid Targets

Dark Energy	(i) Euclid *alone* to measure w_p and w_a to 2% and 10% (FoM_{DE} = 500) (ii) Look for deviations from $w = -1$, indicating a dynamical dark energy. (iii) Measure the cosmic expansion history to better than 10% for several redshift bins from $z = 0.5$ to $z = 2$.
Test of Gravity	(i) Measure the growth index, γ_m, to a precision better than 2%. (ii) Measure the growth rate to better than 5% for several redshift bins between $z = 0.5$ and $z = 2$ (iii) Separately constrain the two relativistic potentials Φ and Ψ (iv) Test the cosmological principle
Dark Matter	(i) Detect dark matter halos between a mass scale of $>10^{15}$ to 10^8 M_{Sun} (ii) Accuracy of a few hundredths of an eV on the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy. (iii) Measure the dark matter mass profile on cluster and galactic scales.
Initial Conditions	(i) Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n to 1%; improve constraints on σ_8 and n by over a factor 30 and 2 respectively compared to Planck alone (ii) For extended models, improve constraints on n and α with respect to Planck alone by a factor 2. (iii) Measure the non-Gaussianity parameter f_{NL} to $\pm$ 10.

3.1.1 APPROACH

3.1.1.1 Combining Principal Probes

A number of cosmological probes have been put forward for measuring the properties of dark energy. In both reports of the DETF [RD08] and the ESA/ESO Working Group on Fundamental Cosmology (WGFC, [RD09]), the four main probes of dark energy are identified as: (i) weak lensing; (ii) galaxy redshift surveys (needed for the BAO measurement); (iii) Type Ia supernova measurements; and (iv) galaxy cluster counts. Other methods are also briefly discussed, but of the four main techniques, weak lensing and galaxy redshift surveys form a unique combination for three key reasons:

(1) As stand alone probes, these are the two most powerful measures of dark energy. Furthermore, as well as having the smallest error bars on the equation of state parameter (w), each one of these two probes is able to place strong constraints on both geometry and structure formation.

(2) The combination of these two probes allows us to control and measure a wide range of systematics. In particular the cross correlation between these two probes allows us to measure and mitigate astrophysical systematics, notably intrinsic alignments for weak lensing and galaxy bias for galaxy redshift surveys.

(3) As well as breaking degeneracies in parameter space, a joint weak lensing and spectroscopic galaxy survey analysis is able to measure both Newtonian potentials, $\varphi(k,z)$ and $\psi(k,z)$, which describe the scalar (density) perturbations in a perturbed LFRW Universe, in order to provide constraints on modified gravity theories.

Conventional wisdom in the dark energy community, which is emphasized in both the DETF and ESA/ESA WGFC reports, is that high precision and accurate measurements will require a combination of two or more probes. The natural conclusion, therefore, from the reasons stated above, is that our best hope of understanding the nature of dark energy will come from a mission that is optimized to give the best possible measures of weak lensing and galaxy redshift surveys. Euclid is such a mission, making it the most promising dark energy probes of any being designed.

According to Euclid's first primary science objective (Table 1), the Figure of Merit (FoM) of the combination will be at least 500, which is 10-20 times higher than a DETF Stage II experiment, making Euclid at least a Stage IV experiment in the DETF scale.

Table 2 summarizes the list of dark Energy probes that can be studied with Euclid.

Table 2: Euclid List of Probes

Observational Input	Probe	Description
Weak Lensing Survey	Weak Lensing (WL)	Measure the expansion history and the growth factor of structure
Galaxy Redshift Survey: Analysis of *P(k)*	Baryonic Acoustic Oscillations (BAO)	Measure the expansion history through D_A(z) and H(z) using the "wiggles-only".
	Redshift-Space distortions	Determine the growth *rate* of cosmic structures from the redshift distortions due to peculiar motions
	Galaxy Clustering	Measures the expansion history and the growth factor using all available information in the amplitude and shape of P(k)
Weak Lensing plus Galaxy redshift survey combined with cluster mass surveys	Number density of clusters	Measures a combination of growth factor (from number of clusters) and expansion history (from volume evolution).
Weak lensing survey plus galaxy redshift survey combined with CMB surveys	Integrated Sachs Wolfe effect	Measures the expansion history and the growth

3.1.1.2 Method

The science concept of the Euclid mission considers a telescope diameter of 1.2m, and the capability to cover large areas of the sky within a realistic mission lifetime. In order to achieve the scientific objectives of Euclid as listed in Table 1, which require a FoM in excess of 500, the survey area of the WL and BAO surveys needs to cover a large fraction of the extragalactic sky of 20 000 deg2.

The Weak Lensing survey involves the measurement of (1) the galaxy shear from the shapes of galaxies down to a limiting magnitude and (2) the corresponding redshift of each galaxy. The galaxy shear is measured in the visible by obtaining diffraction limited images from space. Multi band photometry is employed to obtain the photometric redshift or "photo-z". To achieve the best photo-z accuracy for the required redshift binning, the Euclid WL experiment relies on complementary ground based photometry in visible bands derived through engaged collaborations with ground based projects. The inclusion of these data is an integral part of the Euclid mission design.

The WL survey will address the four primary science objectives as listed in the previous section (Table 1), according to the specified precisions. The WL survey will also form the basis for the measurement of mass-selected cluster counts and the measurement of the ISW effect through a cross-correlation with the Cosmic Microwave Background measurement from WMAP and Planck.

The prime scientific objective of the Euclid wide-field spectroscopic survey is to measure the power spectrum *P(k),* BAOs and growth factor, and exploit them to place stringent constraints on the dark energy equation of state and cosmological parameters in synergy with the WL experiment. The spectroscopic survey will yield the following key measurements:

- Determination of the expansion history $H(z)$ and angular diameter distance $D_A(z)$ to 1-2% accuracy in dz=0.2 redshift bins between z=0.5 and z=2, to probe the evolution of dark energy without assuming a model.
- Determination of the growth rate function $f(a)$ to 2% accuracy in dz=0.2 redshift bins between z=0.5 and z=2, to probe any modification of general relativity.
- Identification of tens of thousands of galaxy clusters over a wide range of redshifts (up to z>2) to derive the evolution of their mass function and therefore place tight and independent constraints on w, σ_8 and Ω_m.
- Use the shape and turnover of the matter power spectrum $P(k)$ in a way complementary to CMB as a probe of primordial fluctuations, matter density, baryonic and neutrino fractions and models of inflation.

The combination of WL+BAO+growth factor +clusters will place the most stringent constraints on the Dark Energy equation of state, cosmological parameters, modified gravity scenarios and large scale structure evolution. The same dataset will allow probing, for free, the formation and evolution of galaxies with unprecedented statistical significance.

Table 3: Euclid mission – summary of capabilities

Category	Item	Provided by Euclid
Accuracies in Dark Energy Parameters: Dark Energy Figure of Merit	Principal Probes	WL and BAO from wide survey
	Additional Probes	See Table 2, from Euclid wide survey
	Photo-z determination	Photometry and spectroscopy from wide survey, complemented by ground based data
	Performance improvement over ground	The Euclid DE FoM shall be at least 500, a factor TBD better than similar ground-based all-sky WL and BAO surveys
Legacy	(1) survey size and depth (2) spatial resolution (3) spectral resolution (4) wavelength coverage	Provided by the Euclid wide and deep surveys (1)-(4) combined will give unprecedented legacy

3.1.2 WEAK LENSING PROBE

3.1.2.1 Survey Geometry

Requirement: The WL survey shall cover at least 20,000 deg^2 (or 2π sr) and provide 30 galaxies per $arcmin^2$ (required, 40 galaxies per arcmin, goal) usable for WL with a median redshift z_m>0.8 (required, z_m>1.0, goal).

This requirement is essential to achieve the target accuracy on cosmological parameters, especially to achieve ~1% error on *w*. It results from trade-off studies aimed at the optimisation of the survey configuration to minimise the errors on dark energy parameters [RD02]. The errors depend on both the area of the survey and the number of galaxies. The requirement can only be fulfilled if the extragalactic sky is covered at high galactic latitudes with $b\geq30$ deg.

3.1.2.2 Shape Measurement

Requirement: Systematic effects shall be controlled to a level where they do not dominate over the statistical errors. This is accomplished if the variance of the residual shear systematics is controlled to an accuracy of $\sigma_{sys}^2<10^{-7}$.

This requirement is essential for the WL survey to reach the cosmological objectives, see [RD03].

3.1.2.3 Photometric Redshifts – statistical error

Requirement: The statistical error $\sigma(z)/(1+z)$ in the photo-z's shall be smaller than 0.05 (requirement) and 0.03 (goal) in the range $0.2<z<2.0$ with a low level catastrophic failures.

Photometric redshifts will be used to group the galaxies in redshift bins with small overlaps. The catastrophic failure fraction (f_{cat}) is defined as the fraction of galaxies whose photo-z lies beyond 3σ (TBC) of the true redshift.

3.1.2.4 Photometric Redshifts – error in the mean

Requirement: The mean of the redshift distribution $n(z)$ of each bin must be known to a precision of $\delta(\langle z_i\rangle)/(1+z)$ <0.002. Higher moments of the distribution must also be known but are less constraining.

This can be achieved with a spectroscopic subsample of about 10^5 galaxies representative of the WL sample [RD01, RD02].

Table 4: Summary of the top level Weak Lensing science requirements

Category	Item	Requirement
Survey Geometry	Survey Area	20 000 deg^2 extragalactic, contiguous
	Galaxy distribution	30 galaxies/$arcmin^2$ (required, 40 galaxies/$arcmin^2$ goal) usable for WL with a median redshift z_m>0.8

Category	Item	Requirement
Systematics	Shear measurement	shear systematics variance $\sigma_{sys}^2 < 10^{-7}$
Photometric redshifts	Statistics	$\sigma(z)/(1+z)<0.05$, 0.03 (requirement, target) with low catastrophic failure rate to build redshift bins
	Calibration	Error in the mean of the n(z) distribution of each bin <0.002, achievable with a subsample of 10^5 spectra

3.1.3 SPECTROSCOPIC REDSHIFT SURVEY: PROBING BARYONIC ACOUSTIC OSCILLATIONS

The cosmological predictions have been obtained assuming slitless spectroscopy with:

1. a wavelength range of 1 – 2 μm, corresponding to a target redshift range of $0.5 < z < 2.0$ for Hα emitters;
2. a best model for the counts and d*n*/d*z* of Hα emitters (Geach et al. 2009 [RD14]); and
3. the currently estimated, and possibly conservative, global (i.e., integrated over all Hα fluxes above the limit) success rate of ~ 35% based on extensive simulations.

The results of simulations show that a competitive value of the FoM (DETF [RD08]) for the slitless spectroscopic survey is obtained for an Hα limiting flux of 4×10^{-16} erg cm^{-2} s^{-1}**,** 7σ at 1.6 micron and unresolved source. This flux limit corresponds to a total estimated number of 7×10^7 redshifts.

3.1.3.1 Spectroscopic Redshift Accuracy

Requirement: The accuracy in the spectroscopic redshift of each detected galaxy shall be better than be $\sigma_{\Delta z} \leq 0.001(1+z)$.

This requirement is based on extensive simulations of the statistical reconstruction of large-scale structure and the successive measurement of the BAO fluctuations in the power spectrum analysis. In case of larger values of $\sigma_{\Delta z}$, the BAO FoM will decrease significantly. Experience with ground-based spectroscopy at resolution R=600 shows that it is possible to reach an uncertainty in the redshift determination of $\sigma_z \approx 3\times10^{-4}(1+z)$. At R = 500, which is our baseline case, the accuracy should scale down to $\sigma_z \approx 5\times10^{-4}(1+z)$.

3.1.3.2 Survey Area

Requirement: the survey area shall be at least 20 000 deg^2.

This minimum area for the wide survey is set by the cosmic variance.

3.1.3.3 Minimum number of spectroscopic redshifts

Requirement: The number of galaxy spectra (and hence redshifts) required to meet the accuracy needed in the BAO measurement for the wide-field survey shall be 4×10^7 as minimum, and 1.5×10^8 as a target.

These values are set by the BAO statistics we have to achieve.

Caveat: the assumption (number of detectable spectra) = (number of redshift) does not hold as there will always be some "redshift success rate" which will make $N_{\mathrm{redshift}} < N_{\mathrm{spectra}}$.

3.1.3.4 Wide Field Survey: Redshift Distribution

Requirement: The median redshift of the wide survey shall be at z~1.1, with an upper quartile at z~1.35.

This requirement sets the depth of the spectroscopic redshift survey, i.e. all galaxies brighter than the minimum limiting magnitude of H(AB) = 19.5 mag or with emission line Halpha flux of 3-5 10^{-16} erg cm-1 s-1. This defines the redshift distribution $n(z)$.

3.1.3.5 Deep spectroscopic subsample for photo-z calibration

Requirement: A spectroscopic subsample of at least 10^5 spectra representative of the galaxies used for WL shall be obtained to calibrate the photometric redshifts.

The Euclid spectroscopic channel is considered not sensitive enough to fulfil the photo-z calibration requirement if one assumes a deep survey which is 2 mag deeper than the wide survey.

Table 5: Summary of the top level spectroscopic channel science requirements

Category	Item	Requirement
Spectroscopic Survey	Redshift Accuracy	$\sigma_z < 0.001$ (1+z) as target
	Survey Area	at least 20 000 deg2
	number of spectroscopic redshifts	Number > $1.5\text{x}10^8$ galaxies as target Number = 7 $\text{x}10^7$ galaxies as minimum
	Limiting magnitude or Hα flux	Emission line flux > 4 10^{-16} erg cm^{-2} s^{-1} (7σ at 1.6 micron, unresolved source) Continuum magnitude: H(AB)=19.5 mag.
	Redshift distributions	Median redshifts of z~1.1 with an upper quartile at z~1.35.
Deep spectroscopic sample	Photo-z calibration	TBD requirement in case of slitless spectroscopy

3.1.4 THE EUCLID DEEP FIELD SURVEY

It has been recognized that the Euclid surveying capabilities will be unique, and can provide in a relatively short period of time a large survey area of high quality images in the visible, deep NIR photometric images and NIR spectroscopy. A deep survey of several tens of square degrees, some 2 magnitudes deeper than the Euclid wide survey would be unprecedented in terms of area, wavelength range, and depth, and can neither be done from ground nor with other (planned) space missions.

3.1.4.1 Euclid Deep Field Survey: Uniqueness

Requirement: Considering Euclid's unique instrument and surveying capabilities, a Euclid Deep Field Survey shall be performed with an area of a few tens of square degrees and depth of 2 magnitudes deeper than the wide survey.

The wide survey not only provides a large amount of additional science information, but it is also necessary for calibration purposes. The survey depth will be achieved by repeating about 40 times the observations of the same fields using the same wide survey observing modes. By carefully choosing the time intervals between the repeats, the deep survey data will be used to monitor the stability of the payload and spacecraft. In addition, a large number of spectra can be used for the calibration of the weak lensing photometric redshift determination.

3.2 Additional Science

In this section we describe the science that can be carried out with Euclid in addition to the Cosmology objectives as given in Section 3.1. The wide and deep surveys will provide a unique legacy which can address many areas of astronomy. The importance of the mission legacy depends on (1) the size and depth, (2) the spatial resolution, (3) the spectral resolution, and (4) wavelength coverage of the survey. The requirements on (1) to (4) follow directly from the WL and BAO spectroscopic redshift survey requirements.

3.2.1 WIDE SURVEYS LEGACY

Besides its Dark-Energy-specific science goals, the combination by Euclid of imaging and spectroscopy over 20,000 contiguous square degrees at high galactic latitude will result in an immense legacy value for the astronomy community, impacting a wide range of science topics. With its high angular resolution imaging (~0.16 arcsec in the optical channel), morphologies will be measured for billions of galaxies out to z~2, together with their optical-infrared colours. The unprecedented Euclid spectroscopic survey will produce at the same time the ultimate three-dimensional map of the distribution of luminous matter, along with the spectral properties of 200 million galaxies, over three-quarters of the lifetime of the Universe. Euclid will therefore trace directly with exquisite statistics the evolution of galaxies within the dark/luminous scaffolding of the Universe measured respectively by weak lensing and galaxy redshifts. Euclid will sample between z= 0.5 and z= 2 a volume of 100 h^{-3} Gpc^3, i.e. 1000 times that of the Sloan Digital Sky Survey.

Such simultaneous combination of high-resolution spatial and spectral resolution, area and depth can only be obtained from space and will allow the community (in addition to the specific cosmology/dark-energy studies) to:

- Obtain a complete census of galaxies over two-thirds of the age of the Universe and measure the evolution of their distribution functions (e.g. luminosity, stellar mass), reconstructing the history of star formation, mass assembly and nuclear activity.
- Investigate how these properties depend on the surrounding large-scale structure (local density, halo merger rate, etc.) as a function of redshift

- Understand the coupled evolution of dark and baryonic matter, by combining the lensing tomography information with the galaxy distribution and their physical properties.

- Follow the assembly and evolution of first massive galaxy clusters by identifying them and measuring their masses independently via weak lensing and spectroscopy.

Of utmost importance is the impact that Euclid will have on future surveys at any wavelength. The Euclid spectro-photometric database will in fact allow straightforward and precise optical identification (thanks to the sub-arcsecond imaging) and distance measurement of millions of objects that will be discovered by forthcoming or planned new survey facilities, like Herschel, Planck, LOFAR, eROSITA, WISE, SKA and SPT. Sunyaev-Zeldovich surveys with SPT (4000 deg^2) and Planck (all-sky) will yield several thousand cluster detections (>10,000 expected with SPT, ~8000 with Planck). The majority of these will be visible and measurable by Euclid, which will provide a unique mean to obtain redshifts and calibrate their mass. Similarly, 50,000 groups/clusters will be readily identified in the eROSITA X-ray survey by simply cross-correlating with the Euclid database. Of these, there will be 20,000 clusters at $z>0.5$ with mass $>10^{14}$ solar, whose mass will be calibrated using the weak lensing shear and correlated to X-ray and optical observables.

Cross-correlation of Planck data with the Euclid galaxy redshift and weak lensing data will be uniquely useful for removing the dominant systematic effect, CMB lensing, in the primordial gravity wave signal from Planck. CMB lensing is the gravitational lensing of the CMB signal by the intervening galaxies. This will help increase the likelihood that the “smoking-gun” signature of inflation, primordial gravity waves, will be discovered at high significance in the Planck data.

The analysis of the shape, turnover and slope of the galaxy power spectrum $P(k)$ would be of immense value to the estimation of the cosmological parameters, as a probe of primordial fluctuations, to tests of inflationary models, and to matter density and baryonic and neutrino fractions studies. The legacy will also provide a database for quasars with $z>7$ and for the study of the cosmic NIR background.

These are only the most obvious examples of the immense legacy impact of Euclid, that will be a crucial support for any future multi-wavelength survey and a gold mine for new discoveries for decades, removing the classical “bottle neck” represented by the follow-up identification and redshift measurement.

3.2.2 DEEP SURVEYS LEGACY

The possibility that Euclid performs a deeper imaging/spectroscopic survey over a few tens of square degrees opens a further broad window of opportunity. With, e.g., infrared imaging to H=25 and spectroscopy to H=24 will sample galaxies with $2<z<5$. Objects at $z>5$ and up to $z\sim10$ can be colour-selected from the Y, J, H photometry. The most massive galaxies at these redshifts will be extremely rare. The large FOV of the Euclid spectroscopic mode, compared to JWST, gives it an enormous advantage: only ~0.3 massive galaxies should be present in the JWST field of view of ~10 $arcmin^2$. EUCLID is the natural complement to JWST for the study of high-redshift galaxies. A significant fraction of these galaxies are expected to have Ly-α emission. At $z\sim6$ the fraction of Ly-α emitters in a Lyman-dropout sample is as high as ~30%.

3.2.3 OTHER SCIENCE OBJECTIVES

With the Euclid payload capabilities, small changes in the survey mode of observations could address different important astronomy topics. Below we list possible areas of astronomy which may be addressed. Opportunities may arise during periods when the wide and deep surveys cannot be carried out in the nominal way. For example, during the equinoxes, the galactic polar caps (b>30 degrees) are poorly visible, and these periods can be dedicated to Milky Way science. Due to the longer expected lifetime of the NIR detectors, search for extra solar planets can be performed using only the NIR detectors during the later stages of the mission.

The feasibility of additional science objectives depends on the implementation of the science requirements of the primary science objectives. We provide a list of science topics, which can be investigated with Euclid, and would provide a major scientific contribution to that topic. Requirements on dedicated observing modes and survey strategies to optimize additional science observations need detailed investigation.

With the present payload and platform capabilities, the following topics in astronomy can be addressed with Euclid, some of which may require special observing strategies:

- Evolution of galaxies and black holes
- Galaxy Clusters
- Nearby Galaxies
- Milky Way science
- Extra-Solar Planets. A microlensing survey in the galactic bulge can provide a statistical census of exoplanets with masses above 0.1 Earth mass and orbits greater than 0.5 AU.
- Milky Way Science. A spectroscopic and photometric survey of the galactic plane. Search for ultra cool objects and brown dwarfs. Inclusion of dedicated galactic targets.
- Spectroscopic and photometric observations of Type Ia supernovae, by frequently targeting the same deep field of a few square degrees.

4 DERIVED REQUIREMENTS ON PAYLOAD AND MISSION

4.1 Payload Optimization

The Euclid payload and mission concept design must fit in the ESA Cosmic Visions M-class envelope. Review of the assessment phase studies has lead to the recommendation that the mission is programmatically feasible only if mass of the payload has a sufficient margin of 30% for a Soyuz ST-2.1B launch from Kourou. In addition, considering that the procurement of the long-lead items for Euclid is critically driving the schedule, it was recommended to constrain the amount of detectors in Euclid to a number significantly lower than envisaged in the Euclid Assessment Study Report [RD10].

These recommendations required serious revisit of the mission and payload concept design, which has been worked out during the optimization period during the first part of the definition phase.

4.2 Visible Imaging

4.2.1 VISIBLE SHAPE MEASUREMENT

Weak lensing measurements place specific constraints on image quality as it relates to the analysis of the shapes of galaxies to determine cosmic shear. In particular, we need to deconvolve the galaxy shapes from the Point Spread Function (PSF). This process involves measuring the PSF from the field stars and using this to correct the shapes of the galaxies in the field.

4.2.1.1 Visible Spectral band

Requirement: A broad red band R+I+Z (550nm – 920nm) shall be used, chosen to be optimal for galaxy shape measurements. The usage of more than 1 filter band can be considered.

Galaxy shapes for gravitational lensing is best measured in the red part of the visible spectrum.

4.2.1.2 Visible Point Spread Function: Size

Requirement: The FWHM size of the system PSF at the reference wavelength of 800 nm shall be between 0.18 and 0.23 arcsec, not including pixelisation.

The size is defined as the Full Width Half Maximum (FWHM) of the PSF averaged azimuthally about the PSF centroid. The system PSF is the final image produced by a point source and takes into account all contributions from the entire system:

- the optics, including light diffraction, geometric aberrations, and manufacturing/alignment errors;
- detector, including cross talk and inter-pixel diffusion;
- smearing, including all the perturbations on the line of sight stability (payload thermo mechanical or thermo optical components, ACS jitter, micro-vibrations);
- The effects of pixelisation are not included.

This requirement together with requirement 4.2.1.3 enables to obtain the number density of resolved galaxies (i.e. with a size greater than the PSF) usable for the weak lensing analysis.

4.2.1.3 Visible Point Spread Function: Sampling

Requirement: The system PSF at 800nm shall be sampled with (CCD) detector pixels subtending less or equal to 0.1 arcsec.

This requirement is coupled to requirement 4.2.1.2. Together they provide the nominal sampling for the shear measurement of resolved galaxies at the sensitivity limit.

To achieve sub-pixel sampling, the array of detector pixels has to be moved with steps in two perpendicular directions that are not integers of the pixel pitch. A commonly used technique to achieve this is dithering of the detector array. This requirement assumes 4 dithers (see below) to allow PSF calibration using stars in the field, and galaxy shape measurements after PSF deconvolution.

4.2.1.4 Visible Point Spread Function: Complexity and Stability

Requirement: The PSF shape needs to be not too complex, in particular:

- the ellipticity of the system PSF shall be less than 20% as a minimum (less than 5% as goal)
- the system PSF shall feature low wings. More than 96% of the central flux (83% of the total flux) should be contained in a diameter of less than 3.0 times the FWHM.

The system PSF also shall have a small number of degrees of freedom for its dynamic variation. By dynamic we mean the part that cannot be calibrated from an image taken at a different time, such as a calibration run. Control of systematics is of crucial importance for the Euclid mission. It is assumed that there are sufficient calibration stars in the field to calibrate the shape of the system PSF.

Requirement: The ellipticity and FWHM of the dynamic part of the PSF shall have small spatial variations over typically 50 arcmin^2 and timescales of ~3 days. The standard deviation of the variations shall be less than 2×10^{-4} absolute and the FWHM stability shall be 0.1%.

The ellipticity of the PSF is defined as $(\mathrm{FWHM}(x)^2 - \mathrm{FWHM}(y)^2)/(\mathrm{FWHM}(x)^2 + \mathrm{FWHM}(y)^2)$, where x and y refer to the major and minor axis of the PSF FWHM contour. The dynamic part of the PSF cannot be calibrated from an image taken at a different time, such as a calibration run. The three days is derived from an initially required stability of 3 wide survey adjacent strips, which is performed in approximately 2-3 days. The 50 arcmin^2 comes from the fact that ~50 bright stars (brighter than a magnitude R=18) are necessary to calibrate the PSF by measuring it from these stars. Stars of this type typically have a number density of 1 per arcmin^2 (RD06).

4.2.1.5 Visible Point Spread Function: wavelength dependence

Requirement: Over the wavelength range 550–920 nm (Req. 4.2.1.1), the peak-to-peak of the variation of the ellipticity and size of the PSF due to wavelength dependence shall be calibratable with residuals to peak-to-peak variations less than TBD.

4.2.1.6 Visible Image Quality: instrument linearity

Requirement: The linearity of the detector response shall be calibratable to a precision of TBD for a S/N dynamic range of 1 to 1000.

PSF calibration process involves measuring PSF from high S/N stars (R~18 mag) and using this to deconvolve the instrument response from low S/N galaxies.

4.2.1.7 Visible Image Quality: stray light

Requirement: The flux per pixel due to diffuse straylight (including sky contamination within and out of the field of view) shall be less than 20% of the flux of the zodiacal light at the ecliptic poles.

4.2.1.8 Visible Image Quality: Cosmetic

Requirement: The combined effect of glitches (including cosmic rays) and dead pixels shall be removable to less than a few percent (5%, TBD) of pixels in the images.

Requirements on dead pixel clustering properties are TBD. A common technique to reduce the impact of glitches and dead pixels is to use dithering (see below, Req. 4.5.1.5).

4.2.1.9 Visible Image Quality: distortions

Requirement: geometrical distortions on scales of 1 arcsec (*i*) shall be lower than 1% anywhere in the FOV and (*ii*) shall be calibrated with residuals at a level of less than 0.1 percent.

This is to control the shapes of the lensed galaxies with respect to possible instrument systematics.

4.3 NIR Photometry

Accurate measurement of the photometric redshift of distant galaxies (0<z<3) requires space based photometry in the NIR.

4.3.1.1 NIR wavelength bands

Requirement: The NIR photometry shall be carried out at least 3 wavelength bands, in particular Y (920-1146nm), J(1146-1372nm), and Hp(1372-1600nm) (Hp(1372-2000nm, goal).

These bands (designated Y, J, and Hp) provide the ideal synergy with ground based surveys complement to meet the photometric redshift requirements.

4.3.1.2 NIR spatial resolution

Requirement: To achieve the needed photometry, the resolution in the centre of the J band (1259 nm) shall be between 0.3 and 0.36 arcsec (system PSF FWHM) with a plate scale less or equal to 0.3 arcsec per pixel.

A sampling of ~1 pixel per system PSF FWHM or slightly higher would give the best photometric results for point sources and is related to intra-pixel response, as most of the energy would fall within 1 detector pixel with a minimum background emission contribution.

4.3.1.3 Relative Photometric Accuracy for photo-z

Requirement: the “final” relative photometric accuracy (i.e. at the end of the data processing) shall be less or equal to 0.5% for the photometry supporting the photometric redshifts.

This number applies to the uniformity within a field and among areas on the sky. The final calibration includes the off-line data processing of the fields, which assumes additional ground-based information (secondary standard stars) and the possibility of “self calibration” based on consistencies in the (redundant) Euclid data.

As long as the relative accuracy is met, the absolute photometric accuracy can be constructed from the data afterwards. Enough statistics will be available from standard stars to obtain a consistent absolute photometric calibration of TBD final accuracy.

4.3.1.4 NIR Image Quality: stray light

Requirement: The flux per pixel of diffuse straylight (including sky contamination within and out of the field of view) shall be less than 20% of the flux of the zodiacal light at the ecliptic poles.

Table 6 Summary of technical requirements for the Visible Imaging and Near-Infrared Photometry channels

Visible Shape Measurement Channel		
Spectral band	1 broad red band	R+I+Z (550– 920nm)
PSF	Size (FWHM 800nm)	Azimuthal average between 0.18 and 0.23 arcsec
	Sampling (at 800 nm)	CCD pixelsize = 0.1 arcsec
	Complexity	'Well behaved' (see text)
	Ellipticity	Less than 5% target on the full FoV < 20% as a maximum
	Stability	Ellipticity and FWHM rms variation less than 0.02% over 50 $arcmin^2$ (corresponding to 50 calibration stars)
	Chromatic	Wavelength dependence of PSF 'calibratable'
Image Quality	Cosmetics	< few % of bad pixels per exposure
	Linearity	Instrument calibratable for S/N 1-1000
	Distortion on 1" scale	< 1% anywhere in the FoV calibrated at 0.1% level
	Diffuse straylight	Stray light level less than 20% of zodiacal background at the ecliptic poles
NIR Photometric Channel		
Spectral bands	3 bands	Y (920-1146nm), J(1146-1372nm), Hp(1372-1600nm) Goal: Hp(1372-2000nm)
PSF	Size	System: 0.30 to 0.36 arcsec FWHM in J band
	Sampling	Less or equal to 1 pixel per FWHM in J band
Image quality	Diffuse straylight	Stray light level less than 20% of zodiacal background at the ecliptic poles

4.4 NIR Spectroscopy

4.4.1 OBTAINING NIR SLIT SPECTRA (*SECTION DELETED*)

4.4.2 OBTAINING NIR SLITLESS SPECTRA

4.4.2.1 Slitless Spectroscopy Baseline

Requirement: Slitless or other multi-object spectroscopy shall be used for the spectroscopic redshift survey.

The parameters to be considered are: number of grisms needed to cover appropriately the total observed spectral range (≈ 1.0 – 2.0 μm, see req. 4.4.2.3), the spectral resolution, the field of view, the number of visits per field, the effects of spectral crowding/blending, the observing strategy in order to observe each field with different telescope orientations to mitigate the crowding/blending problems, the redshift accuracy, the limiting flux for the Hα emission line, the expected redshift measurement success rate, the expected number of line misidentifications, the fraction of incorrect redshifts, the FoM and accuracy on the Dark Energy EOS.

A TBD fraction of the spectroscopic redshifts coming from the slitless or other multi-object spectroscopy can be used to calibrate the photo-z redshifts (see Sect 4.5.2).

4.4.2.2 Emission line flux limit, continuum magnitude limit

Requirement: the flux limit for an unresolved emission line shall be less than 4×10^{-16} erg cm^{-2} s^{-1} (7 sigma, point source) at 1600 nm, and the continuum magnitude limit is H(AB) = 19.5 mag.

The numbers have been confirmed by simulations. The uncertainty in the H(AB) limit is ~0.5 mag.

4.4.2.3 Spectral range

Requirement: the spectral range shall be 1.0-2.0 micron (required, <1.0 to >2.0 micron goal) to ensure the detection of spectral features expected for the redshift distributions of the galaxy samples.

4.4.2.4 Spectral Resolution

Requirement: The spectral resolution for a point source shall be $R = \lambda/d\lambda = 500$ constant to ±20, where $d\lambda$ = resolution element = 2 detector pixels.

4.4.2.5 Slitless spectroscopy success rate

Requirement: the success rate shall be larger than 35% (fraction) at the Hα flux limit according to req. 4.4.1.2.

With the success rate or *detection efficiency* we mean the number of redshifts that can be retrieved from the available targets above the given detection limit.

4.4.2.6 Acquisition of NIR image

Requirement: A NIR image of the same field as covered by the slitless spectrograph shall be acquired with a depth which is sufficiently deep to always allow an association between an emission line (without continuum) detected in the dispersed image with a counterpart in the field image.

The NIR image is necessary for providing the positions of the objects, to derive accurately the zero-point of the wavelength scale (crucial for BAOs), to remove ambiguities with zero order spectra contamination, to derive the object sizes and orientations in order to enable the correct definition of the extraction aperture of the spectra as well as the flagging of contamination of spectra.

Following Req. 4.4.2.2 the field image must be deeper than H(AB)<19.5 mag or 4×10^{-16} erg cm^{-2} s^{-1} (7 sigma, unresolved source). The Euclid photometry channel H-band exposure would provide a depth of H(AB) < 24 mag, which satisfies this requirement.

4.4.2.7 Wavelength scale and zero point accuracy of the dispersed image

Requirement: the maximum error in the wavelength of a given spectral resolution element shall be less than 50% (TBC) fraction of that spectral element.

This requirement addresses both the wavelength zero point calibration as well as the accuracy in the wavelength scale of a spectrum. For a given spectral resolution R (see Req. 4.4.2.4), the redshift accuracy one can derive from one detected unresolved line is ~fraction/R. In the case of for example R=500 and a fraction of 0.5, we obtain for the wavelength error contribution $\Delta z \leq 0.5/500=0.001$, in accordance with Req. 3.1.3.1. As can be derived from Req. 4.4.2.4, a 50% fraction corresponds to 1 detector pixel in the dispersed image.

The wavelength zero point is driven by the accuracy which can be achieved in the mapping of the sources in the field image (req. 4.4.2.6) onto the dispersed image, to provide the object positions. This mapping is governed by two essential sources of uncertainty: (1) the distortions (including displacements) due to the optical elements in the instruments providing the field image and the dispersed image, and (2) temporal distortions due to varying observing conditions, e.g. due to temperature variations.

On ground and also with HST it is common practice to periodically acquire a direct image in a given filter (J or H band, TBC) with the spectrometer to calibrate out the time dependent distortions. The measurement frequency depends on the timescale of the time dependent field distortions. In this case there must be the facility to use a filter and take a direct image of some astrometric field to establish the transformation from the RA, Dec catalogue (from NIP) to the slitless instrument from in-orbit data. In practice, and for integrity of the wavelength information, a short direct image through the slitless instrument taken periodically with a filter is enough to align the pointing to the RA, Dec catalogue together with the time independent field distortions.

The direct image can be with a filter (J or H band being the obvious choice) or could be filter-less, thus exactly matching the slitless spectroscopy passband. This approach requires accurate repeatability of the filter wheel holding the grism, since any non-repeatability must be at the level of small fractions of a pixel in order not to compromise the wavelength accuracy (a crucial requirement for the BAO experiment). In high latitude fields the number of late type stars may not be sufficient to perform adjustment of the wavelength zero point.

4.4.2.8 System PSF size and sampling

Requirement: The size of the PSF at 80% encircled energy shall be less than 1 arcsec (TBC) in imaging mode and better than 1 pixel in cross dispersion (spectroscopic mode).

4.4.2.9 Observing Strategy: number of images

Requirement: A number of spectrally dispersed images shall be acquired over each elementary field of view, the integration time being driven by the spacecraft dither strategy.

4.4.2.10 *Observing strategy: rotation or sub-aperture*

Requirement: For each elementary field 4 (TBC) rotation angles will be selected, or 4 (TBC) sub-samples of the spectral apertures will be filtered.

4.4.2.11 *Diffuse straylight limit*

Requirement: The flux per pixel of diffuse straylight shall be less than 20% of the flux of the zodiacal light at the ecliptic poles.

The diffuse straylight includes sky contamination within and out of the field of view.

Table 7: Spectroscopic channel Requirements

Spectroscopic Channel Requirements		
Wavelength Range	Spectroscopy Mode	1.0-2.0 micron baseline <1.0 and >2.0 micron goal
Spectral Resolution	500±20	Variations over the wavelength range are small
Wavelength accuracy	For all identifiable spectra on the array	0.5 wavelength resolution element or 1 detector pixel
Depth	For emission line galaxies	$< 4\times10^{-16}$ erg cm^{-2} s^{-1} (7σ, at 1.6 micron, unresolved source)
	Continuum	H(AB) = 19.5 mag (5 sigma per spectral element)
Slitless spectroscopy success rate	Fraction of all detectable emission line galaxies	>35%
Image Quality	System PSF and Sampling	80% of encircled energy of point source: (1) within 1 arcsec in image mode (2) better than 1 pixel in cross dispersion in spectroscopic mode
Observing Strategy	Several spectral images per field of view	4 (TBC) rotation angles, or 4 (TBC) sub-samples of the spectral apertures
Level of straylight in the FoV	< 20% of the Zodiacal light at the ecliptic poles	

4.5 *Survey Characteristics*

4.5.1 WEAK LENSING WIDE SURVEY

4.5.1.1 Wide Survey Area

Requirement: To achieve the statistics described above, a wide survey shall be performed over a large fraction of the extragalactic sky (larger or equal to 20,000 deg^2).

The extragalactic sky covers high galactic latitudes (b>30deg) while avoiding the galactic bulge.

4.5.1.2 Wide Survey Depth

Requirement: The survey depth in terms of AB magnitude limit shall be R+I+Z_{AB} =24.5 (10σ extended source), assuming a PSF FWHM of 0.23 arcsec in this band.

Requirement: To meet the photometric redshift requirement, the depth in each of the Y, J and H NIR bands shall be 24 AB (5σ point source).

This depth yields the required 30 galaxies/arcmin^2 useful for lensing with a median redshift z_m >0.8.

4.5.1.3 Wide Survey Scanning Strategy: Contiguous Patches

Requirement: The wide survey needs to be performed in patches contiguous in time and larger than 20×20 deg^2 to ensure homogeneous image quality on scales relevant for weak lensing.

According to the adopted Euclid survey strategy, a patch (of ~20×20 deg^2) is made of contiguous strips of 20 degrees.

4.5.1.4 Wide Survey Scanning Strategy: field overlap

Requirement: the total overlap between adjacent images shall be 2.5% on each side.

This is needed to derive astrometric and photometric solutions as well as shape measurement cross–checks.

4.5.1.5 Wide Survey Scanning Strategy: VIS and NIP dithering

Requirement: at least 4 dithers shall be performed with the VIS imaging channel to cover the detector gaps such that 95% of the pixels of the coadded image has at least 3 exposures, and more than 60% of the pixels have 4 exposures. The signal-to-noise ratio specification shall be met after 3 exposures.

Requirement: at least 4 dithers shall be performed for each band of the NIP channel for gap filling between the detectors and sub-pixel information, such that 95% of the pixels of the coadded image has at least 3 exposures, and more than 60% of the pixels has 4 exposures. The signal-to-noise ratio specification shall be met after 3 exposures.

One "dither" corresponds to one stable exposure. Dithering is needed in the visible and NIR imaging channels to fill the gaps between the detector arrays, to mitigate the effect of clusters of bad pixels, to improve the PSF calibration and galaxy shape measurement from sub-pixel information, to provide for a distortion map, and to allow for cross-correlations between exposures. The requirement is based on a typical cosmic ray rate.

Table 8: Weak Lensing Survey Requirements

Weak lensing wide survey requirements		
Duration	Less than 4.5 year	
Survey Strategy	Area	20,000 sq degrees, |b| > 30º
	Contiguous patches	>20º x 20º
	Overlap	2.5% on each side of an image

	Dithers	≥ 3-4 dithers covering detector gaps
Depth	Shape Measurement Channel	$R+I+Z_{AB} > 24.5$ (10σ extended source)
	Photometric Channel	$Y_{AB} > 24$ (5σ point source)
		$J_{AB} > 24$ (5σ point source)
		$H_{AB} > 24$ (5σ point source)

4.5.2 WIDE SPECTROSCOPIC SURVEY

See reqs. 3.1.3.2, 3.1.3.3 and 3.1.3.4

Table 9: Spectroscopic Redshift Survey Requirements

Spectroscopic Wide Survey		
Duration	Less than 4.5 year	
Survey Strategy	Area	20000 sq degrees, $\|b\| > 30°$
	Overlap	Not required (TBC)
	Geometry	Contiguous patches
	Dithers	Not required
Depth	Line flux < 4×10^{-16} erg cm^{-2} s^{-1} at 1600 nm (7σ, point source), and continuum magnitude limit H(AB) = 19.5 mag (TBC)	
Success rate	>35%	

4.5.3 EUCLID DEEP SURVEY

The objectives of the Deep Survey are: (1) to provide the Euclid additional science, in particular to investigate galaxy formation with very high statistical confidence (see Section 3.2.2), (2) to obtain spectroscopic redshifts required to calibrate the photometric redshifts needed for the weak lensing experiment, and (3) to support the calibration of the visible PSF by repeatedly visiting the same fields on the sky.

In view of the importance of the wide survey in relation to the Euclid science objectives, the implementation of the deep survey must not impair the quality and completeness of the wide survey.

For the NIS slitless spectra, the wide survey limiting magnitude H(AB)=19.5 mag is more than 2 magnitudes higher (i.e. brighter) than the NIP limiting magnitude of H(AB)=24 mag. If we adopt the deep survey strategy as outlined below, the NIS data are not sufficiently deep to obtain a spectroscopic subsample of $\sim10^5$ spectra for the NIP photo-z calibration down to AB=24 mag (cf Reqs. 4.5.3.5 and 4.5.3.6). Nevertheless, such a deep survey from space with a slitless spectrometer provides a unique opportunity to obtain an unprecedented data set, both for scientific as well as for cross-calibration purposes. The slitless deep survey data can be used to calibrate the WL target selection function.

The deep survey is based on the requirements listed in the following sections and the requirement given in Section. 3.1.3.5. Assuming that the instruments operate in parallel, the building of the deep spectroscopic survey will also yield an imaging survey with the same increase of depth of ~2 magnitudes. The effect of the different FoVs for the VIS/NIP on the one hand and the NIS on the other hand has to be assessed (TBD).

4.5.3.1 WL Deep Survey Strategy: stacking of exposures

Requirement: A deep imaging survey shall be built from multiple visits similar to the wide survey scans.

The method of selecting the targets for slit spectroscopy down to H(AB)=24 mag is under discussion. We are presently considering the options (1) to use the imaging mode of the spectroscopic channel and increase the limiting magnitude to 24 mag, or (2) use the NIR photometric channel to perform a (pre-)selection of the spectroscopic targets.

Method (2) considers the construction of a catalogue using the NIS/VIS data containing all spectroscopic candidates in a given field down to H(AB)=24 mag. The NIS imaging exposure will be used to determine the position an orientation of the array on the sky. Using the catalogue, the DMD will be set after a selection of a TBD fraction of the candidates with H(AB) < 24 mag. The target selection can be random but can also be based on scientific considerations – e.g. high (photo-)z galaxies.

One could think of the following survey strategy: if the catalogue selection is a random fraction of for example 33%, then 120 exposures of a given field would give an average total integration time of 6.3x6.3=40 exposures for all galaxy candidates in the field (2 mag = factor 6.3). The numbers can be tuned depending on the construction of the selection catalogue (TBC), such that the required minimum deep survey area is met.

In case of slitless spectroscopy, there is no selection of the targets. The slitless spectroscopy for the deep survey will be as deep as H(AB)<21.5 mag or $0.5\text{-}0.8\times10^{-16}$ erg cm^{-2} s^{-1}.

4.5.3.2 WL Deep Survey Strategy: frequency of visits

Requirement: Visits of the same field shall be evenly distributed over the lifetime of the mission.

This requirement ensures the monitoring of the PSF at regular intervals during the mission.

4.5.3.3 WL Deep Survey imaging depth

Requirement: The imaging depth of the deep survey shall be 2 mag deeper than that of the wide survey with R+I+Z < 24.5 mag.

This requirement implies about 40 visits of the same deep field area.

The spectroscopic channel enables a Deep Survey over a field of a few square degrees (e.g. ≈ 40 deg^2). In the Deep Field survey, most of the spectroscopic sample will be a flux-limited selection down to a limiting magnitude of R+Y+Z=24.0 with no colour or photo-z cuts. A fraction of objects (e.g. very high-z galaxy candidates) may be observed as compulsory targets in each visit. The cumulative sky surface density to H =24.0 is ≈ 125,000 galaxies deg^{-2}. Given a sky coverage of 40 deg^2, we expect to obtain spectra and derive spectroscopic redshifts for about 4 10^5 galaxies at $0 < z < 6$ even with a low sampling rate of 10%.

4.5.3.4 *Deep Survey Geometry and Area*

Requirement: A spectroscopic deep survey shall be performed with a total area of at least 40 deg^2**,** complete for galaxies with R+I+Z < 24.5 mag, and consisting of patches with a minimum size of 10 deg^2.
Requirement: The deep survey shall contain at least 2 patches.

4.5.3.5 *Deep Survey Spectroscopic Limiting Magnitude for slit spectroscopy*

Requirement: the deep-field spectroscopic survey shall have at least 10^5 galaxies with a limiting magnitude H(AB) = 24.0 mag in order to match the depth of the near-IR photometric channel and of the visible (R+I+Z) imager

R+I+Z=24 mag (AB) corresponds to about H(AB)=24, depending of the colours of the targets (TBD). The deep survey is 2 mag = factor 6.3 deeper than the wide survey. The implied total integration time (without overheads) for the spectrum of a deep field target is equivalent to ~40 wide survey exposures.

The equivalent S/N requirements are the same as for the wide survey where H(AB)=22 mag (see req. 4.5.1.4). Simulations showed that at this limiting magnitude, the success rate in redshift measurements is high for all types of galaxies (see the PDD for more information).

4.5.3.6 *Deep Survey Spectroscopic Limiting Magnitude for slitless spectroscopy*

Requirement: not applicable

4.5.3.7 *Deep Survey Strategy: completion, frequency of visits, and coverage of patches.*

Requirement: deep survey patches shall be acquired in successive order, i.e. the measurements of a patch have to be completed as good as possible before moving to the next patch. As a goal, the frequency of the visits of a given patch shall be twice a month (once every 14-16 days).

With “coverage” we mean the area surveyed in wide survey mode. Assuming that the wide and deep surveys are intertwined, a duty cycle of 32-36 fields per day, and that the completion of a wide survey patch (of 400 deg^2 plus 10% overlap) can be accomplished within one month, the amount of time available for the deep survey is equivalent to~2-5 days per month. In this period it is possible to carry out 3-8 visits where an entire patch of 10 deg^2 is covered.

Table 10 Deep survey parameters

Deep Survey		
Duration	The total fractioned time is less than 4 months	
Survey Strategy	Area	> 40 deg^2
	Geometry	More than 2 patches larger than 10 deg^2
	Visits	Stack built from wide survey like sub images evenly timed over the course of the mission
Imaging Depth	All imaging channels	2 mag deeper than wide survey

Spectroscopic Survey Depth for slit spectroscopy	Magnitude limit	H(AB) < 24.0 mag corresponding to R+I+Z < 24.5
Spectroscopic Survey Depth for slitless spectroscopy	Magnitude and emission line flux limit	TBD

4.5.4 WIDE SURVEY COMPLETENESS REQUIREMENTS

The margins for the Euclid mission are tight: the wide survey scanning strategy needs to be well optimized even with a nominal mission time of 5 years. From an operational point of view it is important to assess the required completeness of the survey due to the tight viewing constraints and due to the fact that it is not possible to trade survey depth for survey area once the field observing mode has been fixed. In the following, the completeness requirements are provided at the different scales in area dictated by the wide survey characteristics.

4.5.4.1 Wide survey completeness

Requirement: To meet the science objectives, the total wide survey area to be collected shall be more than 95% of the required area of 20,000 deg2. The wide survey shall be contained in two contiguous areas at the two hemispheres with no holes due to missed patches.

This requirement addresses possible situations where e.g. due to system events the survey cannot be completed in the nominal survey period. For Euclid, the area surveyed scales directly with the dark energy Figure of Merit, hence the choice of the 95% level. We must cover the two hemispheres without holes, i.e. the “missed” patches should be along the edges of the areas.

4.5.4.2 Wide survey patch completeness

Requirement: In case a nominal patch of 400 deg^2 cannot be completed in the allocated amount of observing time at a given epoch, the “lost” fields shall be situated at the edge of the patch.

This means that “holes” should be avoided inside a patch due to “missed” fields, and rescheduling is necessary to trade the hole for a “lost” field at the edge of patch. A field can be declared missed if (1) no pointing was performed, (2) the science quality of a pointing was insufficient, or (3) the observing procedure went wrong, as was indicated in the S/C or instrument House Keeping. A minimum number of missed fields (TBC) will define a “missed” patch.

4.5.4.3 Wide survey field completeness

Requirement: For a given field, the presence of *one* non-responsive detector array for each of the VIS or NIP instruments can be tolerated during the field observing sequence. In case of a larger number of non-responsive detector arrays for VIS or NIP, and in case of one or more non-responsive detector arrays for NIS, the planned survey scanning strategy or the field observing sequence shall be modified.

One non-responsive detector array for NIS (of 2Kx2K pixels) implies a loss of 1/8 of the survey area in the present configuration.

4.5.4.4 Wide survey image completeness

Requirement: in case of the presence of clusters of bad pixels invalidating the dithering requirement 4.5.1.5, the planned scanning strategy or the field observing sequence shall be modified.

4.6 Photometric and Spectroscopic Calibration Requirements

4.6.1 PHOTOMETRIC ACCURACIES

For photo-z relative photometric accuracy, see Req 4.3.1.3
For spectroscopy target selection photometric accuracy, see Req. 4.4.17

4.6.2 STRAYLIGHT SUPPRESSION

See Req. 4.2.1.7 (VIS), Req. 4.4.1.8 (NIP), Req. 4.4.2.11 (NIS slit), Req. 4.3.1.4 (NIS slitless)
Straylight levels are defined as a fraction of the zodiacal light background at the ecliptic poles.

4.6.3 IN ORBIT CALIBRATION REQUIREMENTS

The following table gives a summary of the envisaged dedicated in-orbit calibration operations to be performed on a regular basis throughout the mission. The table has been derived from the discussions during the CDF pre-assessment; its contents have to be confirmed.

Table 11: envisaged in-orbit calibration observations to be performed regularly during the mission.

Channel	Calibration Type	Measurement Type	frequency	Comment
Visual imaging	Detector	Dark Exposures	Daily	Use shutter?
	Detector	Flat Fields	Daily	On-board Lamp
	Photometry	Routine exposure of known field	Monthly	Field includes calibration targets Deep field exposures
NIR imaging photometry	Detector	Dark Exposures	Weekly	Use filterwheel?
	Detector	Flat fields	Weekly	On-board Lamp
	Photometry	Routine exposure of known field	Monthly	Deep field exposures
NIR spectroscopy	Detector	Dark Exposures	Weekly	
	Detector	Flat Fields	Weekly	
	Photometry of imaging mode	Routine exposure of known field	tbd	Deep field exposure?
	Wavelength	Calibration lamp exposure	Monthly	
	Spectro-photometry	Measurement of spectro-photometric standard stars	tbd	Use routine survey data?

5 GROUND BASED DATA REQUIREMENTS (TBW)

TBW

6 GROUND SEGMENT REQUIREMENTS (TBW)

TBW