Euclid Mission – assessment study

David H Lumb[1], Ludovic Duvet[1], René Laureijs[1], Maurice Te Plate[1], Isabel Escudero Sanz[1], Gonzalo Saavedra Criado[2]
Science and Robotic Exploration[1], Technical and Quality Management[2], European Space Agency, ESTEC, Postbus 299, 2200AG Noordwijk, The Netherlands

ABSTRACT

The Euclid mission has been proposed as a powerful probe of Dark Matter and Dark Energy, using complementary space-borne imaging and spectroscopy techniques. The mission concept is being assessed as part of the European Space Agency (ESA) Cosmic Visions 2015-25 programme. The mission concept is described, including some of the critical trade-offs. The scientific performance predictions are briefly presented.

Keywords: Euclid mission, astronomy, telescope, optical, near-IR, dark energy

1 INTRODUCTION

1.1 Dark Energy and Matter

The discovery that the expansion of the Universe is accelerating [1,2] through observation of high-redshift supernovae has been bolstered using independent techniques and observables including the cosmic microwave background, large-scale structure and its variations, x-ray clusters, and the Integrated Sachs-Wolfe (ISW) effect. These data indicate that if General Relativity is to remain valid we require the presence of a mysterious "dark energy" comprising 70% of the universe, and whose gravity is repulsive. Various explanations for the phenomenon have been posited including:

- A cosmological constant: a simple description but with no underlying physics
- Vacuum energy: mathematically equivalent to a cosmological constant; $w = -1$ is consistent with all data, but attempts to estimate its magnitude are many orders of magnitude too large
- Scalar fields: a temporary period of cosmic acceleration, where w varies between -1 and 1, this is possibly related to inflation, and may require new long-range forces
- New gravitational physics: the cosmic acceleration could provide new physics beyond GR,
- Conventional gravitational physics: It may be possible to find an inhomogeneous solution that is observationally consistent, but no model has yet developed

Solving the puzzle of cosmic acceleration has the potential to impact profoundly our understanding of fundamental physics in areas such as explaining the smallness of quantum vacuum energy and extending Einstein's theory,

While many of the important observations to date have been dominated by ground-based telescopes, space-borne instruments (HST for high-redshift SN observations, Chandra for X-ray clusters and WMAP CMB observations) have played critical roles in probing dark energy. Space-based surveys offer the advantages of observations that are unaffected by weather, and by the scattering, absorption, and emission by the atmosphere. They offer a stable observing platform free of time-varying thermo-mechanical loading, and the ability to continuously observe in the anti-sun direction. These advantages for much improved control of systematic errors have motivated a number of mission proposals.

1.2 ESA Cosmic Visions

In 2007 an Announcement of Opportunity for mission proposals was released by the European Space Agency (ESA) for concepts in the domains of solar system and planets, astrophysics and fundamental physics. This call resulted in more than 50 proposals reflecting the broad range of themes articulated in the ESA Cosmic Visions 2015-25 (CV1525) programme [8]. The intention was to solicit ideas for both Medium (M) and Large (L) class satellites; the classes defined

UV/Optical/IR Space Telescopes: Innovative Technologies and Concepts IV,
edited by Howard A. MacEwen, James B. Breckinridge, Proc. of SPIE Vol. 7436,
743604 · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.825279

by a cost to the ESA programme of 450 and 650 M€ respectively. The former class should also require limited technology developments, consistent with a first launch in ca. 2017. A first selection of potential mission ideas was made in order to perform a detailed assessment to allow an eventual confirmation of candidates to proceed to detailed definition and implementation. The first round selection for assessment studies in the 'M'class included *Plato* (exo-planets and astero-seismology), *Cross Scale* (magnetospheric physics), *Marco Polo* (NEO sample return), a Mission of Opportunity European contribution to the JAXA-led mission *SPICA*. More recently the previously studied *Solar Orbiter* was added to the selection list.

Two dark energy probes were proposed, recognizing and confirmed by the ESA Advisory Structure, that this was the most timely and important science topic among the M mission proposals. The two probes were.

- DUNE – All sky visible and NIR imaging to observe weak gravitational lensing [3]
- SPACE – All sky NIR imaging and spectroscopy to detect baryonic acoustic oscillations [4]

A Concept Advisory Team considered these two approaches and recommended a single M-Class Dark Energy Mission. This has been named Euclid in honour of the pioneer of geometry. The merged Euclid concept calls for a survey of the entire extra-galactic sky (20 000 square degrees) where disturbing effects of Galactic foreground signals (stars and dust) are lowest. This all-sky survey enables a simultaneous measurement of two principal dark energy probes:

i) Weak lensing:

Diffraction limited galaxy shape measurements in one broad visible R/I/Z band to AB=24.5 (10σ).

Redshift determination by Photo-z measurements in 3 YJH NIR bands to H(AB)=24 mag, 5σ point source

ii) Baryonic Acoustic Oscillations:

Spectroscopic redshifts for 33% of all galaxies brighter than H(AB)=22 mag,at 5 σ per resolution element, leading to $\sigma_z<0.002$

The science goals have been elaborated and quantified in Table 1

Table 1 Science goals of Euclid

Issue	Target
The nature of Dark Energy	Measure the DE parameters w_o and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Testing General Relativity	Distinguish General Relativity from the simplest modified-gravity theories, by measuring the growth factor exponent γ with a precision of 2%
The nature of 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
The seeds of cosmic structures	Improve by a factor of 20 the determination of the initial condition parameters compared to Planck alone

As for all other M class missions, Euclid has been studied in more detail via two parallel competitive industry activities. The aim of the studies is to provide a more detailed design for the space segment, to elaborate a development plan for the mission implementation and to define interfaces for potential nationally-funded instrument packages. This activity is supplemented with instrumentation studies conducted by potential science institute consortia, and by specific sub-system technical assessments within the Agency. ESA manages and coordinates all the study activities. All mission studies will eventually be presented to the European science communities in December 2009, and the ESA advisory structure will also review the study outputs in order to recommend which missions should proceed to further phase A/B1 definition.

This paper describes the current status of the assessment study for Euclid, reflecting work carried out in industry, the instrument consortia and within ESA.

2 EUCLID CONCEPT

2.1 Mission, Orbit and Observing Scenario

The operational orbit is a large amplitude orbit around the Sun-Earth Lagrange point 2 (L2). This orbit has been chosen because it puts the minimum constraints on the observations. It allows to scan the whole sky outside a ± 30° band around the Galactic polar caps within the mission duration. The launch will be performed with a Soyuz ST 2.1-B from Kourou. It involves a direct insertion from a circular parking orbit close to the equator. The transfer manoeuvres are performed for correcting launcher dispersion and fine-targeting to stable manifold of free insertion libration orbit. The minimum thrust required is 1N for a manoeuvre duration <1day. The transfer trajectory and the operational orbit can be "indefinitely" eclipse-free

Table 2 Mission Summary timeline

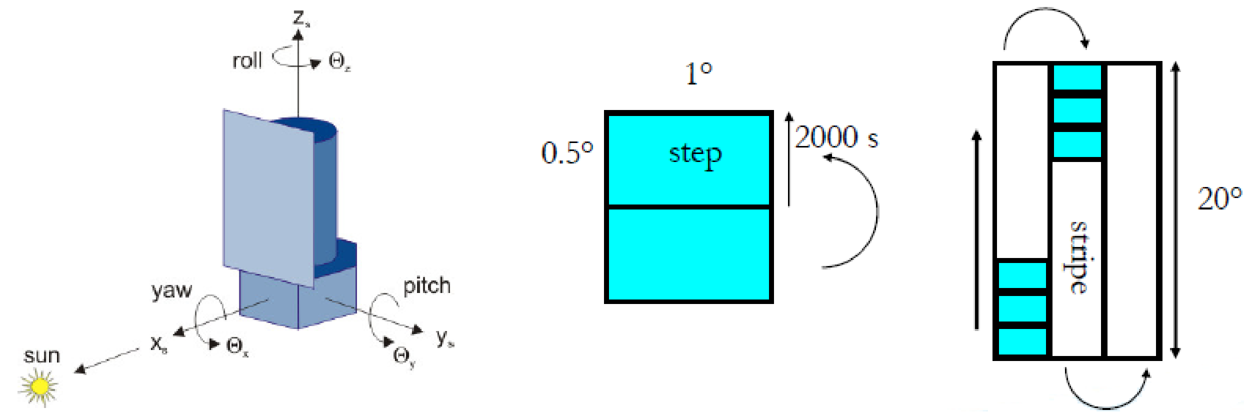
Launch (=L)	01/11/2017 (assumed launch date)
First trajectory correction manoeuvre	L+2 03/11/2017
Additional trajectory control manoeuvres	L+ 5 / L + 20 06/11/2017 / 21/11/2017
Cover ejection	L + 23 TBC 16/11/2017
Outgassing	1 week TBC 17/07/2022 – 01/12/2017
Commissioning	2 months TBC 02/12/2017 – 31/01/2018
Science Operations	4.5 years 01/02/2018 – 31/01/2023
Orbit correction manoeuvres	Every 30 days
End of mission	31/07/2022

For the operational orbit, the maximum Sun-S/C-Earth angle is in the order of order 30^{o}; the in- and out-of plane orbital periods are both close to 180 days; and the currently assumed frequency of station-keeping manoeuvres is 30 days.

For observations, the scanning strategy is to perform a scan in latitude ("stripe") of maximum possible extent in a given time interval, and then to place the next stripe adjacent. This latitude scan is a roll around the Sun direction with the telescope boresight at right angle to the Sun direction (the design allows an angle of telescope boresight to Sun direction between 90° and 120°). The roll in Ecliptic latitude is in the order of magnitude of 15° to 20° per stripe. It consists of step and stare steps ("fields") that are 1° wide and extend 0.5° in roll direction. There is a 2.5% linear overlap between exposures on each side (see Figure 1).

Each "step and stare" period, including slew, settling time and observation is estimated to take ~2000 s. With a constrained Sun-aspect angle of the spacecraft in the order of 1° and the Earth's motion around the Sun, the average rate of the scan in ecliptic longitude is naturally given by the Earth's mean motion divided by the FOV, i.e. after 0.9 days, an adjacent stripe is observed. After ½ year of adjacent stripes the spacecraft is flipped and observes a zone in the opposite hemisphere. This continuous scan strategy is effective, except for the elliptic poles. These are observed with a special strategy, around the equinoxes.

Figure 1 Sky scanning strategy. (*Left*) Spacecraft rotates about X-axis perpendicular to sun direction. (*Middle*) A Field of 0.5° x 1° is observed for ~2000s, and then the observation steps to an adjoining field (*Right*) A Stripe of ~20° degrees in latitude is covered in 0.5° degree steps, and then an adjacent stripe is constructed in the same way



2.2 Telescope

The heart of the instrument payload is the telescope, designed to offer diffraction limited performance over a field of view of 0.5 square degrees. The requirement is complicated by the need to offer exceptionally well-controlled PSF ellipticity (to facilitate the Weak Lensing measurements), but also to offer a parallel path for the Near-IR spectrometer. For the purpose of the assessment study a common reference design was defined and offered to both industry and instrument consortia as a working point.

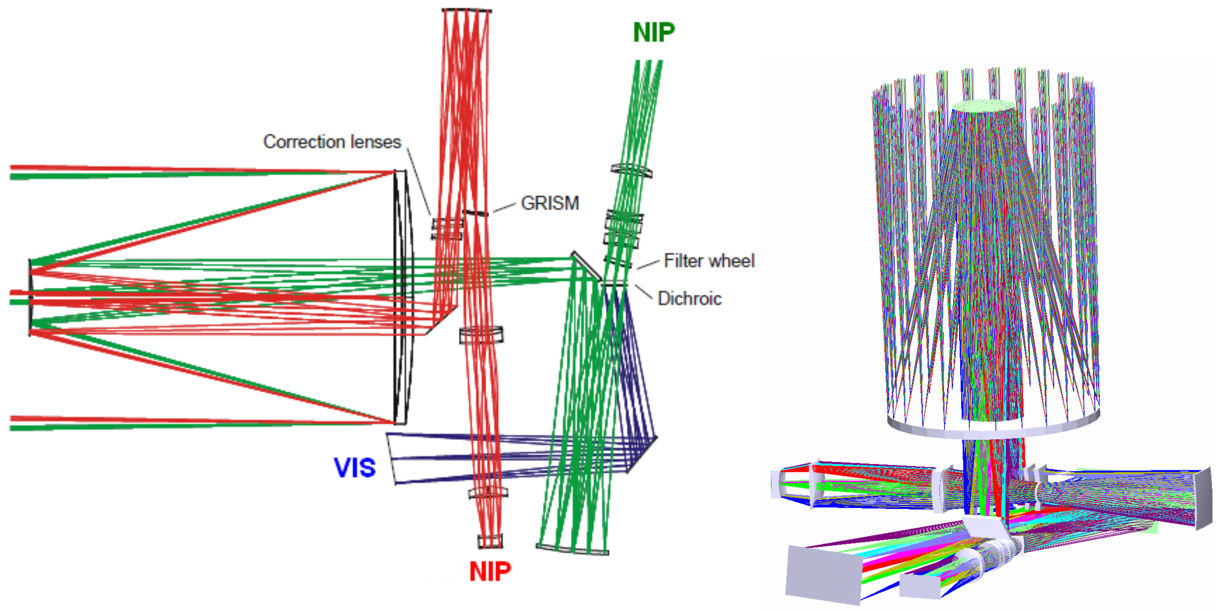
This telescope design is a modified Korsch with a focal exit pupil. The primary diameter is 1.2 meter, with a central obscuration 0.37 m, and a M1-M2 distance ~1.7m. The telescope has focal pupils and light paths for the visible camera (VIS) and near-IR photometer (NIP). VIS and NIP use a common M3 optic. The telescope has an afocal pupil and light path for the near-IR spectrometer (NIS) which uses a different M3. Residual aberrations are corrected out by a simple two lens corrector system positioned in between the M2 and M3. The nominal off axis angle for VIS has been arranged at 0.72°. The plate scale of VIS was set as 0.10 ″/pixel. To ensure excellent coverage for field overlaps, the field of views (FoV's) for all three payloads is roughly 1.0°x 0.5°.

The nominal PSF is diffraction limited (~0.16 arcseconds) as required to properly over-sample galaxy shapes. However to maintain a feasible pixel scale and field of view (0.1", 1°x0.5°) it is preferred to degrade this to ~0.2 arcseconds so as to avoid potential systematic effects of an undersampled PSF, especially with respect to factors that could result in elliptical distributions. Detailed simulations suggest the effect of radially dependent colour terms in the source and PSF will have negligible effect so that a single wide waveband is used for the visible channel. The degraded PSF is difficult to achieve by a simple defocus without destroying the PSF symmetry and therefore the system design effort is trading off a tip-tilt mirror versus more complicated optical solutions with multiple phase apertures. The NIP channel requires only a sampled photometric aperture, and therefore refocusing optics concentrate light into ~0.3" pixels and a physically smaller focal plane. The spectrometer channel requires an imaging capability to ensure cross-registration of dispersed spectra with images of targets in equivalent NIP fields, and therefore the optics has to offer imaging capability of ~0.5".

2.3 VIS (Visible Camera)

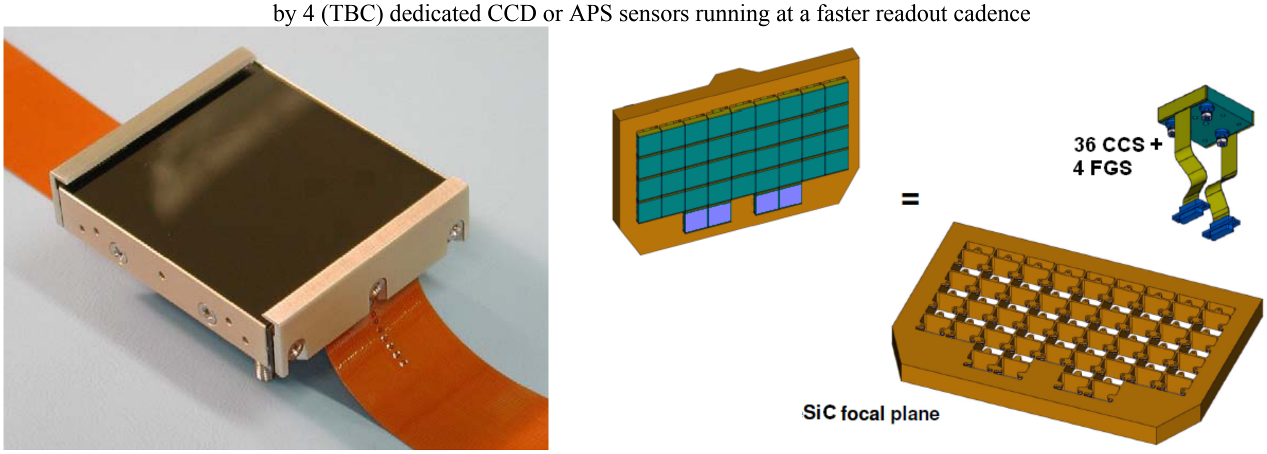
The Visible camera is designed to perform Weak Lensing measurements by wide-field imaging to obtain diffraction limited galaxy shape measurements in one broad visible R/I/Z band. The combination of sensitivity (AB=24.5 at 10σ) and uniformity demands a state of the art CCD camera. The chosen design builds upon European heritage in space-borne CCD arrays like GAIA [5].

Figure 2 (*Left*) Unfolded design for the reference optics configuration. Two separate M3 pick-off mirrors select the imaging and spectroscopy fields of view. The VIS and NIP are spectrally separated (at ~920nm) by a dichroic. (*Right*) A revised version of design with plane mirror folding to ensure the envelope of instruments falls well within the Soyuz fairing limitation, and all focal planes lie in the anti-sun half of the spacecraft



An optimization for field of view, mirror aperture and pixel sampling size has determined that a 1.2 m telescope requires <2000s exposure time per galaxy image. With these parameters we have set a field of view ~1° x 0.5° and a pixel size of 0.1 arcseconds. This demands a focal plane array of ~650M pixels. A baseline CCD imager has been identified to cover the wavelength range 500-920nm, which is the e2v CCD203-82. This device has been qualified for the Solar Dynamics Observatory, to be launched in late 2009. Each CCD comprises 4k x 4k of 12 µm pixels, and an array of 9 x 4 of these devices would adequately cover the field of view. Small intra-chip gaps (<6mm) will be covered by short 'dither" steps of 10's arcseconds, 4 dithers within the nominal 2000s observing duration of the 0.5 square degree field.

Figure 3 Baseline CCD in commercial metal package format 51mm x 61mm - CCD203-82 (left). Conceptual design for the VIS focal plane organization (right). A 9 x 4 array of CCD203-82 devices will be installed into a SiC frame. In order to provide Fine Guidance control of spacecraft pointing to meet the VIS camera requirements, it is envisaged that a neighbouring field of view will be observed by 4 (TBC) dedicated CCD or APS sensors running at a faster readout cadence



The focal plane organization employs the GAIA heritage concept for silicon carbide focal plane bench and integrated proximity electronics for drive and readout of the CCDs. Each front end electronics module provides for two parallel amplifier node readouts per CCD, and with a requirement for readout noise of < 5 electrons r.m.s. a readout rate of ~300kpixel/sec is required, leading to a read out time of <30s. A shutter will be employed during readout, but loss of observing efficiency is mitigated by using this duration for the small slew dither step.

For every ~2000s pointing, the VIS camera produces 4 frames each of 36 CCD image data, or about 38Gbits of data. With the estimated slewing efficiencies, it is anticipated that nearly 20° length or stripe of sky will be covered in a day. The whole data are not expected to be analysed and reduced on board, but all cosmic ray rejection and other data calibration will take place on-ground. Therefore the data is solely treated by compression. With typical expected noise levels, the standard RICE lossless compression algorithm would allow a day's worth of VIS data to be compressible by ~2.8 leading to a daily data rate <500Gbit.

2.4 NIP (Near-IR photometer)

The aim of NIP is to allow redshift determination based on broad band photometric measurements (photo-z) of the sample galaxies. Requirements in brief are:

PSF system:	0.3 arcsec pixels
FoV:	0.5° x 1 °
Wavelength range:	Y: (920 – 1146 nm); J: (1146 – 1372 nm) and an extended H: (1372 –2000 nm). 1000 nm – 2000 nm
Limiting magnitude:	AB = 24.

The instrument consists of a reducer optics, a filter wheel with 3 band filters, shutter, calibrator, etc and a focal plane array (FPA). The lens optics are fabricated from traditional IR materials including fused silica, ZnSe, CaF2 and S-FTM16

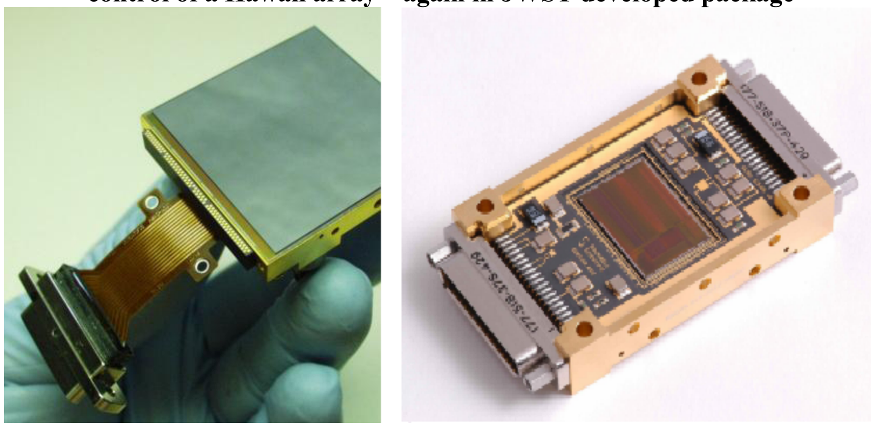
The NIP is coaligned with VIS, sharing the same 3-mirror set, and the instruments are spectrally separated by a dichroic. The number of detectors has been traded off on requirements such as field coverage, spatial resolution, dithering and costs. The FPA comprises 3 x 6 organisation of Teledyne Hawaii-RG IR arrays (2.5 HgCdTe cut-off) that have been subject to qualification for JWST. The H2RG is a pixel array of 2048 x 2048 pixels with a pixel size of 18 µm. [6]. The standard spacing between detectors is 2 mm on 3 sides and on the connector side the distance is 6 mm. The gaps are subject to optimization, however related to higher procurement costs, but represents a good match with the VIS channel coverage

Features of the H2RG ROIC (relevant for EUCLID) are:

- Cutoff wavelength: 2.5 µm
- Amplifier type: Source follower
- Operational temperature of the detector as an impact to SNR and QE: ~100K
- Mean QE (1 -2.4 µm): > 80%
- Number of read-out ports: 32 for fastest readout on the detector
- Sampling concept: Standard noise of ~20 e/s has to be reduced by sampling up the ramp
- Low noise from non-destructive readout and multiple sampling: The pixel amplifier in the H2RG is read out non-destructively, and during a long exposure a large number of sub-frames can be read out and slope fit to reduce the single CDS noise. (Number of Bits= 16)
- Reference pixels: Four rows and columns of reference pixels along each side of the array. These reference pixels track any bias voltage fluctuations over the long (typically 400 second) exposures require. Reference pixel subtraction is essential to achieve the lowest noise performance

- Very low power operation: To read out the H2RG with 32 readout ports, each at 100 kHz pixel rate (1.3 sec full frame readout), the H2RG requires 100 mW power depending on scheme)

Figure 3 (Left) Single packaged Hawaii 2RG array as developed for JWST. (Right) Sidecar ASIC for readout and control of a Hawaii array – again in JWST developed package



The total noise is a combination of readout noise and dark current noise. At ~100K readout noise should dominate, which for the NIP sensitivity requirements must be <10 electrons total noise. For a 150 sec exposure evenly spaced samples "up-the-ramp" [7] to reduce the intrinsic noise from 15 electrons r.m.s. requires > 50 samples and hence 32 parallel readout channels must be used.

The analog-to-digital conversion is than performed by the SIDECAR electronics (System for Image Digitalization, Enhancement, Control and Retrieval), also provided by Teledyne. Additional data processing for noise reduction, glitch and saturation detection are performed in the Data Processing Unit. The 2HRG is connected via a custom flex harness to the SIDECAR. The SIDECAR ASIC is a fully programmable control and digitization system for analog image sensors. It is designed to operate at room temperature as well as at cryogenic temperatures down to 30 K. Due to the immunity of the digital signal transmission which can be LVDS or LVCMOS, the acquisition system can be located several meters away from the ASIC. The basic SIDECAR architecture can be divided into the following major blocks: analog bias generator, A/D converter, digital control and timing generation, data memory and processing, and digital data interface.

The subsystem electronics encompass components such as Instrument Control Unit (ICU), Data Processing Unit (DPU), power supply and harness. The main task of this ICU is control, housekeeping and interfacing with the SVM while the DPU is performing additional data processing. Data handling start from the conversion of a current value into a voltage value inside the H2RG detector and ends in the data base storage on ground. Baseline for data handling is to simplify and reduce all data handling processes in order to avoid complex data processing on-board. However, this approach is in contrast to the high data volume required to reach lowest noise (averaging, integration up the ramp) and gap filling (dithering) For noise reduction and avoidance of saturation (well overfill), the detector needs to be readout every ~1.3sec (i.e. 10µs per pixel). This constrains the number of readout frames for the baselined observation time of 150 sec, and is consistent with noise requirements. The frames are then referenced, checked for glitches and saturation and then averaged to a smaller number of frames. Further noise reduction is achieved by slope fitting of the ~100 frames into each of the 3 colour filter frames. The total amount of data to be transmitted is therefore dependent on the data processing capabilities of the DPU and the related data processing and noise reduction parameters (dithering number, observation time per frame, frame averaging….).

2.5 NIS (Near-IR Spectrometer)

The NIS focal plane is very similar to that of NIP. However the array is limited to only 2x4 chips in order to read out the spectra. The optical design of NIS fulfils the following instrument requirements:

PSF system (imaging):	0.5 arcsec
Spectral resolution:	500 ±20 , with a spectral element covering 2 pixels at 1259 nm
FoV:	0.5° x 1°

Wavelength range: 1000 nm – 2000 nm

Limiting magnitude: Hα line 5×10^{-16} ergs cm^{-2} s^{-1}.

The instrument provides two different operation modes: the imaging mode for target cross-identification and location with NIP, and the spectroscopic mode. The dispersive grism element is illuminated with a high quality collimated beam and placed in the pupil plane to avoid ghost images at the detector. The collimating optics also provide low wavefront error at the pupil plane, which is essential for the further optical path downstream. At the focal plane of the instrument the image quality is diffraction limited and has minimal distortion. The space allocation of the instrument requires it to be folded adequately.

With a slitless design, the identification of objects to their zero wavelength position, and the minimization of source overlap and confusion is critical. The NIS pick-off mirror ensures that the field of view is separated ~1° from the VIS/NIP, and therefore the registration of image locations between NIS and NIP must remain very stable between calibrations (assuming a non-dispersed image is not used for every field to reduce overheads). Furthermore the source confusion must be minimized by using a number of different spectral rotations via moving the relatively large grism between frames, or by using wavelength filtering to readout different portions of spectra at the same rotation. Spectral rotation places a more stringent requirement on the focal plane organization to accommodate the imaging field size *plus* the spectral extent (>600 pixels if properly sampled). For NIS the enhanced zodiacal background that results from slitless mode of operation actually eases the requirement of detector readout noise, but places more emphasis on good pixel response uniformity.

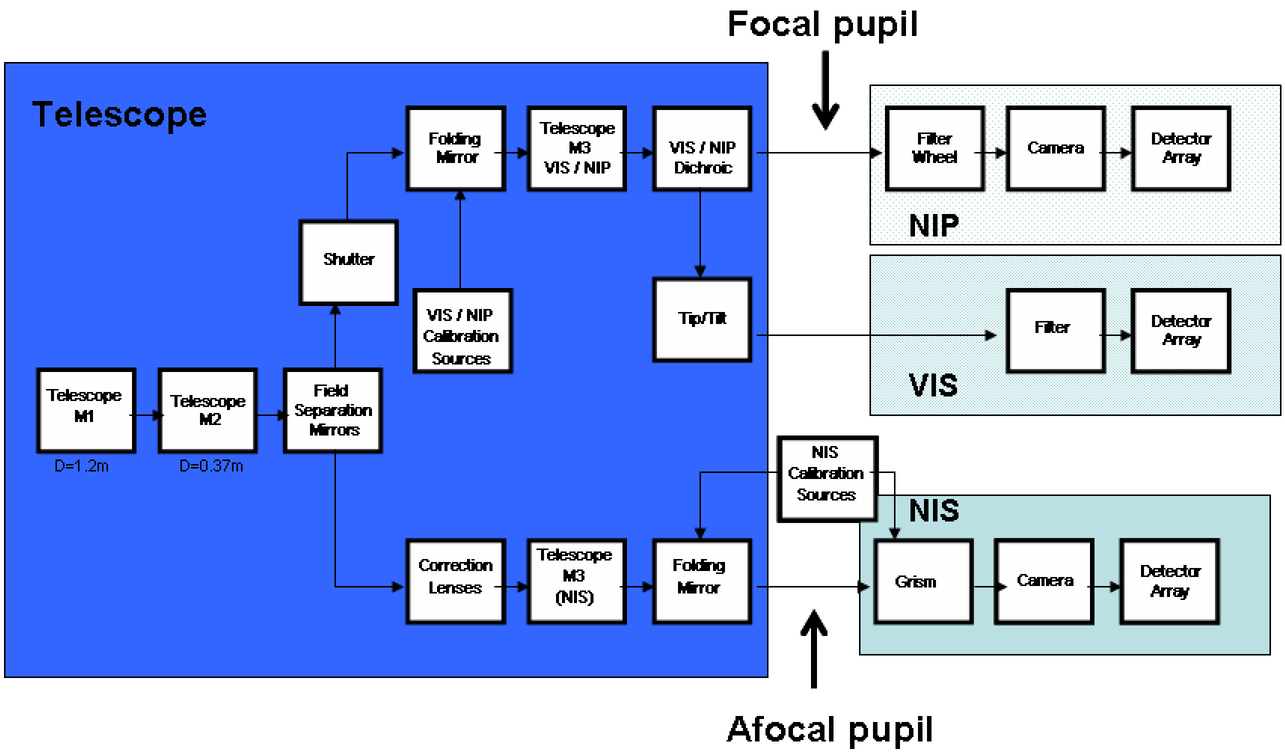
Digital Micromirror Device

Although not considered in the baseline design, a slit spectrometer design is being studied in parallel. This uses a MEMS optical device with miniature steerable mirror facets to select target galaxies from each field, and to minimize background from outside the optimized aperture. The TI Cinema chip is subject to prequalification activities to judge its suitability for space applications. The significant improvement in potential science performance afforded by a slit spectrometer must be traded against the technology readiness level achieved, as well as the increased complexity of optics.

Table 3 Summary of Instrument parameters and performance

	VIS	**NIP**	**NIS**
Plate Scale	0.1 arcsec	<0.3 arcsec	R=500 in 2 pixels
PSF (FWHM)	0.18-0.22 arcsec	0.3 – 0.36 arcsec	< 0.5 arcsec
Magnitude (AB)	24.5	24	$5\ 10^{-16}$ erg cm^{-2} s^{-1} (eqvt AB mag 19.1)
SNR	14.3	7.1	5/spectral element
Radiometric aperture	1.3 arcsec	0.5 arcsec	3 x 5 pixels
Sky background	22.3	22.1 (J)	$10^{(-17.75-0.73(\lambda-0.61))}$ Erg cm^{-2} s^{-1}Å$arcsec^{-2}$
Overlapping frames to reach SNR	3 out of 4	3 out of 4	4
Detectors	4 x 9 CCD	3 x 6 Hawaii2RG	2 x 4 Hawaii2RG
Pixel Size	12 μm	18 μm	18 μm
Frame duration	500 s	160 / 210 / 100 s Y / J / H	460
Field duration (incl dithers)		2100s	
Time for 300 sq degree patch (incl 85% efficiency)		17 days	

Figure 4 Payload block diagram



2.6 System

The constraint of M Class missions' cost also impacts the preferred launcher, and the baseline is to use a Soyuz-Fregat, whose payload capability to L2 is ~2.16 tonnes not including adapter. The launcher fairing allows a satellite diameter ~3.2 m. A natural physical arrangement is for a Payload Module (PLM) and Service Module (SVM) to be separated. The design of SVM has been considered, using heritage from Herschel (supporting a cryogenic payload at L2, but launched on Ariane V) and GAIA (high stability optical payload at L2, also Soyuz-Fregat launched).

For the 2017 launch schedule the Technology Readiness Level (TRL) must >5 – 6 by the end of definition phase (2011). The system study has not identified any critical elements for the SVM, but it is worth noting some of the particular requirements of Euclid sub-systems that is driven by the payload and operations:

AOCS
The VIS camera in particular places extremely stringent attitude stability requirements to ensure that the PSF is not degraded, especially in respect of ellipticity (i.e. orthogonal axes of AOCS must be identically performant). A CCD pixel size projection of 0.1 arcseconds demands that the Relative Pointing Error (RPE) must be budgeted for ~0.025 arcsec (1σ) over any (500 second) image accumulation. The Absolute Pointing Error (APE) of 10 arcsec (1σ) is required to ensure that neighbouring image fields have the desired overlap. Absolute Pointing Knowledge of 0.1 arcsec (1σ) is also necessary to ensure the NIS target locations can be traced accurately to the equivalent field imaged by VIS/NIP.

The pointing stability requirement also demands a Fine Guidance Sensor (FGS) is implemented, and which must be located in the focal plane with the VIS instrument, as this is driving instrument for the stability.

Propulsion
Chemical propulsion is to be used for transfer corrections, and monthly station-keeping corrections. Reaction wheels have been discounted as the actuator, because the noise budget is too high for the RPE, unless the TRL of magnetic bearing RW can be advanced in time. Cold gas micropropulsion is the preferred option in that case. For attitude control, 0.5° slew manouvers and ~70" dither steps, a set of balanced 1mN thrusters are considered, and a budget of ~50kg nitrogen is required. The propellant tanks of standard size define the height of the spacecraft service module.

Communications

For the high data rate ~850Gbit/day, a K-band capability is required. Because of the strong variation of the K-band link margin with the ground station elevation and the atmospheric propagation conditions, the calculation of the expected link performance requires a statistical model, but the following parameters for the calculation of the Euclid link budget have been assumed: 95% availability (calculated on yearly average conditions); Elevation = 20°; 4h/ day maximum pass duration. An ESA 35m ground station antenna is assumed. A steerable 40cm dish on the spacecraft is required

Data Handling

A key driver for the centralised data handling sub-system (PDHU) is to analyze the non-destructive readouts of the Near-infrared arrays and to provide the processing power for the "follow-up-the-ramp" sampling, necessary for noise reduction and cosmic ray glitch removal. Next the PDHU provides data-compression for the science instruments, and windowing/centroiding for the FGS.

Table 4 Estimated science data rate

	VIS	NIP	NIS	Total
# Detectors	36	18	8	
Pixels/detector	16M	4M	4M	
Bits/pixel	16	16	16	
Raw Data/frame	9.7 Gbit	1.2 Gbit	0.5 Gbit	
Frames/field	4	12	4	
Fields/day	36	36	36	
Raw data/day	1397 Gbit	518 Gbit	72 Gbit	1987 Gbit
Compression factor	2.8	2.5	1.5	
Data / day	499 Gbit	207 Gbit	48 Gbit	754 Gbit
Margin				10%
TOTAL				830 G bit /day

Assuming a data volume of 850Gbit per day together with 3 days storage capability, the mass memory size should be ~2.6Tbit. With 25% margin for memory cells degradation and similar margin on overall memory size for additional working space, this gives approximately 4Tbit of required memory. This can be covered by 3 boards of flash NAND assuming one board provides 2Tbit storage capacity (one additional board covers board failures) and compared to SDRAM the higher degradation of flash memory devices. NAND flash is selected because of much higher storage density and lower power consumption compared of SDRAM. In addition, NAND flash is non volatile and needs no power for storage only.

Thermal

The thermal control of the instrument guarantee the VIS focal plane CCD to be at around 150 K, while the front end proximity electronics and payload Interface Module require to be at room temperature. For the Infra Red focal planes, the Hawaii detector and Sidecar ASIC operate at around 100 K, and again the IM is at room temperature. For the Telescope it is arranged for no thermal background to impact onto the NIR focal planes. Its temperature must be stabilised to around 1 mK over 500 s in order to meet the ellipticity stability specification (0.02% over 500 s).

As arranged for other L2 missions (Herschel, Planck) the SVM has to be thermally de-coupled from the PLM with low-conductive mounts and by multi-layer insulation, either to establish different temperature levels at PLM and SVM, and to obtain a significantly better temperature stability at PLM level compared to SVM level. This sun shield protects the payload module from any incident sun light. The sunshield, the thermal baffles, and the PLM telescope itself have to be designed such that the required PLM temperatures are met by passive means.

Overall Configuration and Budgets

To reach a mechanical support for an optical payload module the SVM primary structure is realized in a shape of a Central Cylinder which enables a load path from the actual launcher interface of 1194 mm to the interface points of the payload with an increased diameter of around 1700 mm. Around the Central Cylinder there are 6 to 8 Equipment Panels radially and equidistantly arranged over circumference. They serve for the mechanical interface to the PLM instrument as well as stiffener for the top and bottom planes. These planes have an outer diameter of ~3.1m. The top plane carries also the sunshield, which protects the PLM instruments from direct Sun light and thermal loads. The primary structure is constructed from stiff Aluminium honeycomb panels with CFRP/Aluminium face-skins to keep it light and to avoid thermo-elastic distortions.

The sunshield is combined with the solar array and shields the PLM from solar irradiance, by ±5° in spacecraft azimuth, and +5 to -45° in spacecraft elevation. The PLM is covered by a thermal baffle which is highly reflective for reflecting off the residual thermal radiation from the sunshield backside and cooling down the telescope and instruments passively. The shape of the sunshield is adapted from Herschel. Its width is limited by the Soyuz fairing, the height of the sunshield (5000 mm) is driven by the required solar array size of 9 m^2 and by the PLM height.

Table 5 Estimated System Budgets

Payload Mass (kg incl maturity margin)	800
SVM Sub-systems Mass (kg incl maturity margin)	700
Dry Mass	**1500**
System Margin 20%	300
Propellant	120
Adapter	100
Est Euclid Launch mass	**2020 kg**
Launcher capability	**2150 kg**
Payload Nominal Power (W)	400
SVM Sub-system (W)	750
Harness and PCU losses	65
System Margin (20%)	250
Total Power	**1465W**

3 CONCLUSIONS

Euclid would be a very powerful survey mission providing high quality imaging and spectral data for simultaneous observations of two key probes of the dark component of the Universe. The studies to date have identified a feasible solution, compatible with the baseline scanning and observing strategy that can be implemented within the constraints of an ESA Cosmic Visions 'M' class mission.

Subject to a successful selection, the Euclid mission will proceed to more detailed definition and trade-off, to elaborate and close any remaining open trades or differences in implementation proposed by industry and consortia. This would be conducted during subsequent activities in industry during the period 2010 – 2011. In parallel the identified Technology Development Activities needed to raise the TRL of critical subsystems will be initiated. An ESA announcement of opportunity for the science teams, to be funded by National Agencies, is anticipated in early 2010. This would include some of the instrument provision and also the ambitious and challenging science data processing, calibration and interpretation needed to transform the daily 850Gbit science data stream into an accessible archive.

AKNOWLEDGEMENTS

The support of the industry teams conducting the parallel assessment studies is gratefully acknowledged: Astrium EADS led by O Wallner, and Thales Alenia led by A Anselmi. Additional contributions have come from the instrument consortia, led by the original PI's of the DUNE and SPACE proposals (A Refregier and A Cimatti respectively).

REFERENCES

[1] Riess, A., Filippenko, A., Challis, P, et al., Astron.J.116, 1009(1998)
[2] Perlmutter , S., Algering, G., Goldhaber, G., et al., Astrophys.J.517, 565 (1999)
[3] Refregier, A., Exper.Astron.23, 17 (2009)
[4] Cimatti, A., Robberto, M., Baugh, C., et al, Exper.Astron.23, 39 (2009)
[5] Laborie, A., Pouny, P., Vetel, C. , et al, Proceedings 5th Intl Conf on Space Optics (ICSO 2004) ESA SP-554, 767 (2004)
[6] Van Derlofske,Beletic , J.W. Blank, R.Gulbransen, D. al Proc. SPIE, 7021, 70210H (2008)
[7] Finger, G., Dorn, R., Eschbaumer, S., et al, Proc SPIE 7021, 70210P (2008),
[8] Cosmic Vision: Space Science for Europe 2015-2025ESA Brochure BR-247 2005
[9] Cimatti, A., Zerbi, F., Valenciano, L. et al, Proc SPIE 7436 in press (2009)