

# The EUCLID-NIS Mission

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**Abstract** Obtaining a measure of the baryonic acoustic oscillations (BAO) is among the top goals of cosmology in the beginning of the XXI Century. Detection of BAOs offers the possibility to test the standard cosmological model, by providing strong constraints on the equation of state of dark energy. The EUCLID-NIS mission proposes to measure BAOs by mapping the 3D distribution of baryons at intermediate redshift,  $1 < z < 3$ . Such map will be derived from spectroscopic redshifts in the J and H bands, for of order  $10^8$  galaxies, from space. In the current design, the instrument utilizes digital micromirror devices (DMD) from Texas Instruments.

## 1 Why measure baryonic acoustic oscillations

The timely importance of measuring BAOs is being emphasized by several devoted papers in this volume. Here, we only summarize the key highlights. In an analysis of the spatial correlation function of galaxies from SDSS data, a well-defined peak of the correlation function was detected [3]. The scale of 100  $h^{-1}$  Mpc separation matches the predicted shape and location of the imprint of the recombination-epoch acoustic oscillations on the low-redshift clustering of matter. The measurement of the precise location of the acoustic peak offers the possibility to test the standard cosmological model, because it can set strong constraints on the equation of state of dark energy.

The current SDSS-based measurement can be improved in several ways. One of those is to move to intermediate redshifts,  $1 < z < 3$ . At these redshifts, besides covering a larger volume of the Universe with less survey effort, we map the Universe at an epoch with a balance of dark energy and dark matter different from today.

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## 2 Survey original idea: the SPACE mission

The EUCLID-NIS concept started out in response to ESA’s Cosmic Vision process. Cosmic Vision is intended to define the broad lines of ESA’s space astronomy missions for the period 2015 to 2025. In response to the Cosmic Vision call for proposals, the SPACE mission was proposed, with PI Andrea Cimatti (Bologna). With a target launch date of 2017, the goal of SPACE was to map the 3-D distribution of galaxies in a redshift volume in the range  $0.8 < z < 2$ , by combining imaging and spectroscopic redshifts for 500 million galaxies, covering  $3\pi$  of the sky down to a magnitude of  $H = 23$  AB magnitudes. These data would provide a precise measurement of the baryonic acoustic oscillation patterns in an epoch 5 to 10 Gyr ago. See [4] and [1] for early descriptions of the SPACE mission.

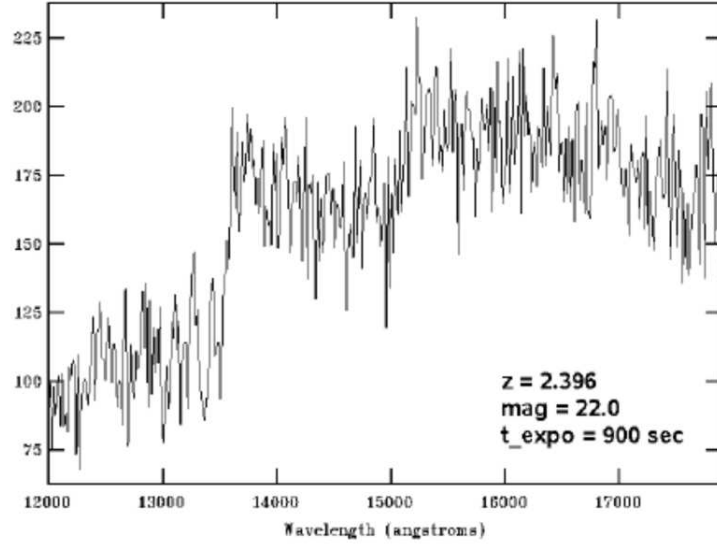
The instrument concept, detailed below, is a moderate-aperture telescope (1.2 m) feeding four identical spectrographs, each of which uses DMD technology for target selection.

The originality of the project resides in placing a NIR spectrograph above the atmosphere. This gives several fundamental advantages:

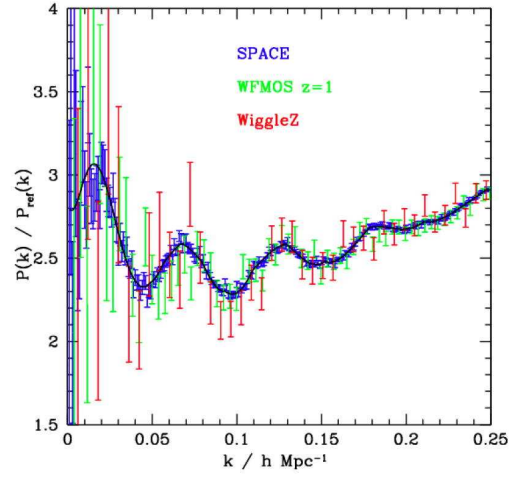
1. The spectral energy distributions of most galaxies are brighter in the NIR than in the optical. This is specially so for red, massive galaxies that contribute the most to drawing the walls and filaments of the cosmic web.
2. By avoiding the strong and variable NIR emission of the Earth’s atmosphere, integration times needed to secure a spectroscopic redshift are exceedingly short.
3. At redshifts above  $z = 1$ , the NIR spectral domain contains several strong nebular emission lines of the rest-frame optical spectrum of galaxies, which facilitate the determination of spectroscopic redshifts. E.g., *J*-band spectroscopy covers the  $H\alpha$  line at  $z > 0.8$ , and the  $O[III]\lambda 5007$  line at  $z > 1.4$ , and  $O[II]\lambda 3727$  at  $z > 2.2$ .

The power of space NIR spectroscopy for redshift determinations is demonstrated in Figure 1, where we see a simulated spectrum of a  $H_{AB} = 22$  galaxy at  $z = 2.396$ . Fifteen minutes is all it takes to obtain a spectrum sufficient to secure a spectroscopic redshift determination based on absorption lines.

How much improvement is to be expected in the definition of the matter power spectrum from SPACE/EUCLID-NIS? Figure 2 shows the power spectrum plotted to reveal BAOs, for SPACE, and for current or planned surveys. WiggleZ is an on-going survey of emission line selected galaxies at  $z \approx 0.7$ . WFMOS is a spectroscopic, ground-based survey proposed for Subaru. The statistical power of the SPACE BAO measurement is around an order of magnitude better than that expected from WFMOS.



**Fig. 1** Simulated spectrum of a passive galaxy of magnitude  $H_{AB} = 22$  placed at  $z = 2.396$ , as observed with EUCLID-NIS after a 900 second exposure. The CaII H+K lines are clearly visible at  $\lambda \sim 13500\text{\AA}$ .



**Fig. 2** The appearance of BAO in selected ongoing and future surveys. The blue points show the measurements expected from the full survey volume of SPACE. The black solid line represents the theoretical model for the BAO.

## 2.1 Additional scientific motivations

The impressive database of galaxy photometry and spectra will feed a large amount of additional scientific projects. We highlight a few of them here:

**Growth rate of cosmic structures:** the survey will provide a large, deep, and well selected map of the cosmic web 8 Gyr ago, allowing for a measurement of the growth rate of cosmic structures by comparing with  $z = 0$  data.

**Abundance of massive clusters:** tens or hundreds of clusters will be found, and membership accurately determined using with spectroscopic redshifts. The assembly history of galaxy clusters is strongly sensitive to dark energy, but on smaller scales than BAOs. They hence provide complementary information on dark energy.

**Formation and evolution of galaxies:** galaxy properties such as star formation rates, metallicities, excitation and dust extinction would be easily derived from the spectra, providing key information in an important epoch for mass assembly [2].

**Quasars:** the survey would provide spectra for large samples of quasars, delivering information on the formation and evolution of massive black holes at  $z > 7$ .

**Stars:** The survey will provide NIR spectra for tens of thousands of Milky Way stars, selected by NIR flux and hence biased toward the low-mass and brown dwarf regime.

### 3 Merging of SPACE and DUNE

Similar in size to SPACE, DUNE (PI A. Refregier, CEA, France) is an M-type mission presented in response to ESA'S Cosmic Vision process. Also similar to SPACE, DUNE is devoted to the detection of BAOs by mapping of the 3-D distribution of matter at redshifts  $1 < z < 2$ . Different to SPACE, DUNE is an imaging mission, which intends to use imaging to detect the 3D distribution of matter in the Universe through gravitational lensing which distorts the random orientation of galaxy images. DUNE is presented elsewhere in this volume by F. Castander.

In 2008 May, ESA recommended that SPACE and DUNE should merge into a single mission that would carry out the imaging and spectroscopic programs. The merged program has been named EUCLID. EUCLID-NIS is the NIR spectroscopic program, while EUCLID-VIS+NIP is the optical and NIR imaging. EUCLID-NIS remains led by PI A. Cimatti (Bologna).

### 4 The SPACE mission and instrument description

While ESA's recommendations call for a reduction of the scope, size and complexity of the EUCLID-NIS program in comparison with SPACE, the extent of such descopeing is far from decided as of this writing. I will therefore focus the rest of this paper in summarizing the SPACE instrument concept, which in any case provides a reference design for EUCLID-NIS.

### 4.1 Mission Requirements

These are the top-level scientific requirements for the EUCLID-NIS mission:

1. To provide galaxy redshifts over 20,000 square degrees with a redshift accuracy of  $\sigma(z) < 0.001$ .
2. The mission duration is 5 yr.
3. Redshifts should be provided for  $N > 160$  million galaxies, complete to  $H_{AB} \sim 22$  (wish:  $H_{AB} \sim 22.5$ ).
4. Sample selection should be based on NIR flux, as a proxy for mass selection.

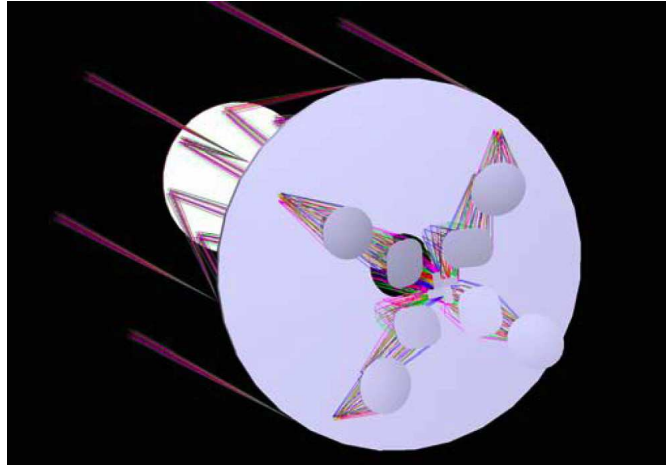
### 4.2 Mission specifications

To implement the above requirements, the following mission concept was put together:

1. The instrument will be a NIR spectrograph, operating in  $Z$ ,  $Y$ ,  $J$  and  $H$  bands, passively cooled.
2. The instrument shall have imaging capabilities in the  $H$  band, for photometry and for target acquisition.
3. Target acquisition will be carried out using DMD (Digital Micromirror Devices) from Texas Instruments (fall-back: slitless spectroscopy).
4. The multiplex gain will be such as to allow to obtain redshifts for 160 million galaxies in 5 years, with an expected integration mean time of 1500 seconds per galaxy.
5. The instrument will have a large field of view (FOV) of 0.5 square degrees.
6. The spectral range will be  $0.9 < \lambda < 1.7$ , at a spectral resolution of  $R = 400$ .
7. The survey will have two depths: a wide-field survey (WFS) reaching  $H_{AB} = 22$  or 22.5, and a deep survey (DS) reaching  $H_{AB} = 24$ .

### 4.3 Instrument concept

**Optics:** SPACE's payload concept implements a 1.2m two-mirror telescope feeding four identical spectrographs (Fig. 3). The field of view is split using a pyramid and a reimaging system. At the intermediate focal plane of each channel sits the target selection device, the DMD. The post-focal plane optics contain all-reflective collimator, prism, and camera, which deliver the spectrum on a  $4096 \times 2048$  NIR array from Teledyne (ex Rockwell).



**Fig. 3** One proposed payload design for SPACE. A 1.2m aperture telescope focusses the sky onto the four-way pyramid, which sends the light along four identical paths. In each, a first set of optics images the sky onto an intermediate plane where the DMD resides, for target acquisition. The second set of optics is the spectrograph proper. This design is likely to change in the combined EUCLID mission.

**Focal plane devices:** DMDs are a class of Micro-Electronic Mechanical Systems (MEMS) developed by Texas Instruments and commercially available for large-format cinema displays. DMDs consist of an array of square mirrors,  $13.68\ \mu\text{m}$  on a side with a  $0.68\ \mu\text{m}$  gap, which can be addressable individually, and oriented into one of two positions, at  $\pm 12$  degrees, which provide on-off orientations. When oriented ON, the light reflected off the face of the mirrors gets sent to the spectrograph; in the OFF position, light gets reflected into a light sink.

While similar in functionality, DMDs should not be confused with MSAs (micro-shutter arrays) implemented in ESA's IRMOS instrument onboard JWST. MSAs operate in transmission, whereas DMDs operate in reflection.

DMDs provide for a mechanically simple means for target selection in multi-object spectroscopy, with few mechanically moving parts. Their main draw-back is that, despite their commercial availability, they are not space certified. Space certifications of DMDs is part of the instrument development plan for EUCLID-NIS. A consortium made by Visitech (Norway), LAM (France), IASF-Bo, IASF-MI and INAF-OABO (Italy) will be specifically responsible of the tests and analysis performed in different Consortium laboratories until early 2009.

If DMDs were to be rejected, several fall-back options are being considered. One includes a fixed-pattern of slitlets that would provide spectroscopy of sources randomly falling on them. The fall-back option of slit-less spectroscopy is being studied as well.

**Electronics and software:** the processing needs of EUCLID-NIS are stringent. They include control and operation of the DMDs, mechanical control of the spectro-

graphs moving parts, control and readout of the detector array, and data processing prior to transmission to Earth.

## 5 EUCLID-NIS team

EUCLID-NIS is being developed by a consortium of institutions from Italy, France, UK, Spain, Austria, Germany, and Norway. The project is led by the PI Andrea Cimatti (Bologna, Italy) who will be assisted by the Advisor Massimo Robberto (STScI, Baltimore, USA) and by a Science Advisory Team. Each Consortium country will appoint a member of the Science Advisory Team. For financial matters, a Co-I board will collaborate with the PI. The Instrument Scientist is J.P Kneib, assisted by J.-G. Cuby (both at LAM, Marseille, France).

Spanish institutions include the Instituto de Astrofísica de Canarias (IAC), and the Universidad Politécnica de Cartagena (UPCT). While work package allocation is not completed at the time of this writing, Spain is likely to contribute in the following areas:

**IAC:** building on the experience on space electronics obtained during its involvement in Planck (radiometer electronics box of the LFI) and in the PACS instrument in Herschel (signal processing unit), the IAC has proposed to lead the development of the on-board digital processing unit of EUCLID-NIS. In addition IAC plans to contribute to ground-based data analysis; science and simulations. Co-Is: Rebolo, Zapatero-Osorio, Balcells.

**UPCT:** the Astrophysics group at the Universidad Politécnica de Cartagena, applying their previous experience in astronomical instrumentation software (e.g., Fast-Cam), plan to contribute to the development of the on-board software. Co-I: Villo.

## References

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