An Overview of the SPACE Mission Proposal

M. ROBBERTO(1), A. CIMATTI(2) AND THE SPACE SCIENCE TEAM(*)

(1) Space Telescope Science Institute, Baltimore, MD, 21218, USA (robberto@stsci.edu)
(2) Dipartimento di Astronomia, Università di Bologna, Italy (a.cimatti@unibo.it)

Summary. — SPACE (SPectroscopic All-sky Cosmic Explorer) is a class-M mission proposed to ESA for the Cosmic Vision 2015-2025 call and recently promoted to the next assessment study phase. SPACE will produce the first all-sky spectroscopic survey of the Universe, taking spectra of more than 500 million galaxies over a wide range of redshifts. SPACE will operate in slit mode (MEMS) at $R \sim 400$ between $0.8$ and $1.8 \mu m$ down to $AB \sim 23$, providing redshifts to an accuracy of $\Delta z \sim 0.001$, regardless on the presence of bright emission lines, together with the most relevant physical and evolutionary properties. The catalog of spectroscopic redshift will allow to place the ultimate constraints on the Baryon Acoustic Oscillations and the nature of Dark Energy. By obtaining the first 3-D all-sky map of the Universe at $z \sim 2$ and beyond, SPACE will trace the growth rate of cosmic structures, the large scale structure of luminous baryons and its cosmic evolution. Besides the all-sky survey, SPACE will carry out a deep extragalactic survey over an area of $\sim 10$ sq. deg., enabling a most powerful supernova search program, and a galactic plane survey in integral field mode. Approximately 30% of the time will be open. Due to its versatility, SPACE is a “self-sufficient” observatory which can attack and solve the most compelling questions on the nature of the Dark Energy without complementary data from the Earth or space. Its unique wide-field capabilities in the near-IR make SPACE the ideal complement to JWST, ALMA, and the future 25-50 m telescopes.

1. – Introduction

All-sky surveys represent the workhorses of astronomy. Following the continuous advances in detector technology, astronomers in the last decades have imaged the sky with increasing resolution and sensitivity over several decades of the electromagnetic spectrum. However, a deep spectroscopic survey of the Universe has never been done. To collect hundreds of millions of spectra of faint galaxies is a daunting task, posing extreme requirements on the multiplexing capability of the instrumentation and on the

(*) The complete list of the SPACE science team members is available at www.spacesat.info
integration time with the largest telescopes. From the Earth surface the situation appears especially hopeless in the near-IR, the most important wavelength range for cosmological studies, due to the atmospheric background and opacity gaps which limit the sensitivity and prevent continuous observations of the main spectral features at various redshifts. The common wisdom is that these observations are presently impossibly expensive[1] and therefore near-IR multiband photometry is the only way of obtaining photometric redshifts for large samples of galaxies. “Photo-z’s” still require formidable investments of telescope time for calibration, remain vulnerable to errors and have limited accuracy.

Yet the scientific return of an all-sky survey in the near-IR performed in full spectroscopic mode would be enormous. A catalog of spectral redshifts for hundreds of million of galaxies would allow to build the 3-d atlas of the universe. The distribution of galaxies would allow measuring the Baryonic Acoustic Oscillations (BAOs) caused by sound waves propagating through the primordial plasma in the early Universe and imprinted in the matter distribution. Detecting and measuring the BAOs at different redshifts one can jointly constrain the geometry of the Universe and its content as a function of redshift[2]. The same dataset would simultaneously allow an accurate assessment of the growth of structures over the last 10 billion years, providing a method to discriminate between theories of dark energy and theories of modified gravity proposed to explain the acceleration of the universe[3, 4]. Besides redshifts, having the spectra of millions of galaxies at redshift larger than $z \sim 1$ would enable unprecedented investigations into the formation, evolution, and interaction of galaxies in the history of Universe, providing a long lasting legacy to be data mined for the years to come.

We have envisioned a space mission that can accomplish these goals and proposed it to the European Space Agency in response to the call for the First Planning Cycle of the Cosmic Vision 2015-2025 program. It is called SPACE (SPectroscopic All-sky Cosmic Explorer) and is intended as a class-M mission led by the European Space Agency in collaboration with the space agencies of the ESA member states and NASA.

2. – The SPACE mission

SPACE will produce the three-dimensional evolutionary map of the Universe over the past 10 billion years by taking spectra of more than $0.5 \times 10^9$ galaxies over the 3$\pi$ sr of sky unobscured by the Galaxy. SPACE will operate in the near-IR (0.8-1.8$\mu$m) with resolving power $R = \lambda/\Delta\lambda \simeq 400$ and exploit MEMS devices to perform slit-spectroscopy. We have envisioned a core science program composed by:

1. The SPACE All-Sky Survey, which will reach $AB \simeq 23$ with $SNR = 5$ per resolution element, targeting approximately 6,000 galaxies simultaneously across a 0.4 square degree field of view. Since there is no input catalogue of sources at these faint magnitudes, at each pointing SPACE will preliminary perform H-band imaging down to $AB \simeq 23$ for source selection, producing as a byproduct the deepest all-sky imaging survey ever in the near-IR. For each field SPACE will automatically extract an unbiased, stellar mass selected sample of galaxies selecting approximately every third galaxy. Switching into a multi-slit spectroscopic mode, SPACE will take near-IR spectra at magnitudes unreachable from the ground, fully exploiting the low celestial background at L2. Spectra will allow to precisely locate $(\Delta z \sim 0.001)$ each galaxy in space. In approximately 2.5 years SPACE will cover $\sim 70\%$ of the sky detecting with unprecedented accuracy BAO patterns in the Universe between 5 to 10 billion years ago. By dividing the the sample of galaxy
redshifts in slices of width $\Delta z \sim 0.5$ and measuring the BAO signature in each slice, SPACE will achieve a 0.5% accuracy in the BAO scale measurement from these redshift slices, far superior to that expected from any other planned survey, as illustrated by Figure 1. The all-sky survey will also allow measuring the growth of structures[3][4], and enable a large variety of studies of objects selected regardless of their spectral properties (e.g. presence of bright emission lines).

2. A deep spectroscopic survey of a smaller 10 deg$^2$ area, targeting $\simeq 2$ million galaxies over to AB=26 and $2 < z < 10$. The SPACE Deep Survey will discover an enormous number of primordial galaxies at very high redshifts, assembling samples from as far back as 500 million years after the Big Bang. It will reveal a large number of Ly-$\alpha$ emission galaxies, star forming galaxies, rare examples of passively evolving galaxies at the earliest epochs, and the earliest QSOs. It will address the formation and early evolution of galaxies from the epoch of first light. Timing the Deep Survey observations with periodic intervals, SPACE could discover $\sim 2300$ Type Ia Supernovae taking their spectra with an efficiency an order of magnitude higher than SNAP, thanks to its large field of view.

3. Using MEMS devices SPACE can operate in integral field mode (Hadamard transforms). We therefore envision a third core program aimed to perform an integral field Galaxy Survey of a 1 degree strip centered around the Galactic plane at $AB \simeq 20$, similar to the GLIMPSE survey of the Galaxy done with Spitzer at longer wavelengths, but deeper and in spectroscopy.

Besides these core science programs, approximately 1/3 of the 5 years lifetime of SPACE will be made available for GO programs.

3. – SPACE configuration

The design of SPACE exploits payload and spacecraft components and concepts that are largely heritage from previous missions (Hershel, Planck, NIRSPEC/JWST) with the exception of the MEMS devices, which in our case are micromirror devices instead of microshutters as in NIRSPEC. Tables summarize the main technical facts of SPACE.

4. – Conclusions

SPACE will have a wide impact on astronomy. It will make an enormous contribution by providing the highest precision measurement of BAOs, the definitive measurement of the power spectrum of density fluctuations and its turnover, the tightest constraints on the nature of the dark matter and gravity by measuring the evolution of the cosmic expansion rate and the growth rate of cosmic large-scale structure, the characterization of the large scale distribution of galaxies, the study of the Galaxy and stars, and virtually impact every field of astronomy. Its wide-field, high-sensitivity infrared spectroscopic capability will remain unique for the foreseeable future. The datasets from the SPACE core and GO programs will represent a long lasting legacy that will be data mined for many years to come.

REFERENCES
Table I. – \textit{SPACE MISSION SUMMARY}

| Characteristic | Value |
|----------------|-------|
| Telescope diameter | 1.5m |
| Wavelength range | 0.8-1.8 \(\mu\text{m}\) (0.6 – 1.8\(\mu\text{m}\) possible) |
| Overall mass | \(\simeq 1500\) kg |
| Orbit/Launcher | L2/Soyuz |
| Launch date | Mid 2017 |
| Mission Duration | 5 years |
| Total field of view | \(51' \times 27'\) (0.4 sq. degree) |
| Total nr. of apertures | 8.8 million |
| Aperture field of view | \(0.75'' \times 0.75''\) |
| Dispersing element | Prism \(R \sim 400\) |
| Detector technology | HgCdTe 0.4-1.8m, 2k\(\times\)2k |
| Nr. of detectors | 16 (4 mosaics of 2 \(\times\) 2 chips) |
| QE | \(\geq 75\%\) average |
| Readout noise | \(5e^-/\text{multiple read}\) |
| Observing modes | Wide field imaging, slit, slitless and integral field spectroscopy (Hadamard) |

Fig. 1. – \textit{Left:} the appearance of BAO in selected ongoing and future surveys. The measured power spectrum has been divided by a featureless reference spectrum to show the BAO more clearly. WiggleZ is an on-going survey of emission line selected galaxies at \(z \sim 0.7\). WF-MOS is a spectroscopic, ground-based survey proposed for Subaru. 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. The high frequency sampling and small errors of \(P(k)\) from SPACE mean that we will achieve the definitive measurement of the BAO. The statistical power of the SPACE BAO measurement is around an order of magnitude better than that expected from WF-MOS. \textit{Right:} The joint 68\% confidence interval constraints on the dark energy equation of state parameter (\(w_0\)) and its evolution with redshift (\(w_a\)). Several datasets can be combined to improve the constraints. SPACE will dramatically improve our knowledge of \(w_0\) and \(w_a\).
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