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# The Exoplanet Characterization Observatory (EChO): the Next Tool to Study Exoplanet Atmospheres

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## Abstract

The Exoplanet Characterization Observatory (EChO) is an ESA mission currently being assessed for an expected launch in 2020-2022. EChO will be the first dedicated mission to investigate exoplanet atmospheres and will highly impact our understanding of those worlds by providing continuous visible to mid-infrared spectral coverage of a wide range of planets, from gas giants to low-mass planets. During its five-year lifetime EChO will allow us to measure the chemical composition of the exoplanet atmospheres, their temperature, albedo and atmospheric circulation mechanisms, and for the first time put the atmospheric properties of the planets in our Solar System on the wider context of planetary systems in the Universe. In this talk I present EChO to the Spanish astronomical community by providing a description of the science of the mission, some design details, and the anticipated Spanish contribution to the project.

## 1 Introduction

The search for planets orbiting around other stars is now a mature field, as the number of planets discovered so far reveals. At the time of this presentation almost 800 exoplanets have been discovered, of which more than 200 transit their host star (i.e. periodically cross in front and behind it producing a transit or eclipse). In addition, the Kepler mission currently lists more than 2000 objects as transiting exoplanet candidates to be confirmed[1].

Remarkably, not only does the number of exoplanet discoveries continue to grow exponentially with time, but the masses and sizes of the planets found are smaller each time, to the point that we have already detected some planets with estimated masses close to the mass of Earth, e.g. $\alpha$ Cen B b [1] and Kepler-42 d [2].

[1]http://kepler.nasa.gov

The next ground-breaking step in this field involves deciphering the atmospheric characteristics of those alien worlds, from identifying molecules that can be linked to the presence of life in rocky exoplanets, to comparing the characteristics of gaseous exoplanet atmospheres to those of planets in our own Solar System.

There are currently two ways to detect an exoplanet atmosphere; one is direct imaging and the other one is via transits. As technology improves, direct imaging will eventually become the technique of choice to characterize exoplanet atmospheres. In fact, the first results using this technique have already been reported in [3], where from a spectrum between 3.88 and 4.10 $\mu$m of the directly imaged planet HR8799c [4], the study concludes that the continuum atmospheric emission from this planet differs significantly from existing models. However, direct imaging is still at its very early stages and, at present, transiting planets provide the best way to study exoplanet atmospheres.

Transiting planets have orbits oriented in such a way that the planet crosses in front and behind the star once every orbit. Those events, called respectively *primary* and *secondary* transits (or eclipses), provide a wealth of information about the atmospheres of the planets. In the case of primary eclipses, we can measure the chemical composition of a planet's atmosphere, and the distribution of those chemicals from what is called a *transmission spectrum*, i.e. when light from the star crosses through the atmosphere of the planet the chemicals in that atmosphere absorb part of that light producing the transmission spectrum of the planet. The transmission spectrum can be measured by subtracting the spectrum of the system collected during transit from spectra collected outside of transit. In the case of the secondary eclipses, we can measure directly the flux emitted by the planet, which provides information about its atmospheric temperature, albedo and the efficiency of atmospheric energy circulation mechanism, as well as chemical composition.

In the past few years we have witnessed several results in this field. The initial detection of Na I in the transmission spectrum of the gas giant HD209458b [5] has been followed in recent years by the detection of H I, O I, C II, $CH_4$, $H_2O$, K I and CO in several other gas giants [6, 7, 8, 9, 10, 11, 12, 13, 14]. The road towards the atmospheric characterization of smaller planets has now also been started with the detection of the atmosphere of the super-Earth GJ1214b by several groups [15, 16, 17], which reveals a featureless atmospheric spectrum suggesting that this super-Earth has a cloud-free atmosphere mainly composed of hydrogen or water.

The few detections of exoplanet atmospheres so far focus on individual planets. Also, most of the available spectra come from assembling results from different groups at specific wavelengths, which might introduce potentially large systematics due to the usage of different instruments not designed for this kind of observations or different analysis approaches, or due to intrinsic temporal atmospheric variability of the planets. Therefore, further progress in this field involves building new instruments designed specifically to study exoplanet atmospheres. One giant step forward in this field would be the construction of a fully dedicated space mission that provides simultaneous coverage of exoplanets transmission and emission spectra, from optical to the mid-infrared, as well as homogeneous observations of a large sample of exoplanets, from hot-Jupiters to Super-Earths, so we can study their atmospheric properties as "exoplanet classes" instead of as individual objects. That mission is the Exoplanet

Characterization Observatory (EChO).

# 2 The EChO Mission

The Exoplanet Characterization Observatory (EChO) is a European Space Agency (ESA) mission currently being assessed as a M-class satellite mission to be launched in 2020-2022 [18]. EChO will be fully dedicated to investigate exoplanetary atmospheres, addressing the suitability of planets for life and placing the physics of Solar System planetary atmospheres into a wider context.

EChO will consist of a $1.2 - 1.5$ meter, on-axis Cassegrain telescope equipped with a multi-channel spectrometer simultaneously covering wavelengths from 0.4 to 16 $\mu$m, at resolutions $R = 300 - 30$, depending on wavelength. Stability is one of the key factors for EChO to achieve the sensitivity levels necessary to detect exoplanetary atmospheric features and to allow for repeated observations of transits over periods of a few hours to weeks or months. Therefore, both the telescope and the instrument will be kept at $T < 50$ K via both passive and active cooling. Strict pointing and alignment requirements will also be key.

The satellite is expected to be launched on a Soyuz-Fregat rocket and will consist of three main modules (see Fig. 1): the payload module containing the telescope and instrument, a service module containing all the functionalities and equipment required to control and operate the payload, and a multi-layer sunshield to protect the payload from solar irradiance and ensure thermal control. The satellite will be placed into a large halo orbit at L2 (radius 800,000 km) and will have an expected lifetime of five years.

## 2.1 Science and Target List

EChO will provide a wealth of information about a wide range of planets. By observing transiting planets both outside and during primary and secondary eclipse repeatedly, we will be able to:

- Measure the albedo, temperature and atmospheric composition of planets down to super-Earth size ($\sim$ 1.5 Earth radii) under different environmental conditions, i.e. orbiting stars of different spectral types at different orbital separations.

- Determine correlations between atmospheric conditions and stellar irradiation levels and understand the distribution of energy in the planets by observing simultaneously their optical albedo and infrared emissions.

- Observe temporal and spatial variability of the thermal/chemical atmospheric structure of exoplanets and from that learn about the dynamics, circulation processes, thermochemical equilibrium processes and photochemistry of exoplanetary atmospheres. Variability observations will be particularly important in the case of highly eccentric planets.

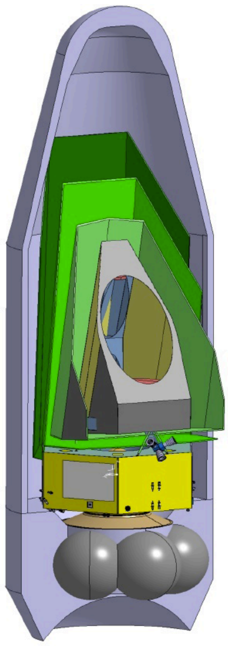

Figure 1: EChO modules and spacecraft design configurations under the Soyuz-Fregat fairing.

In addition, EChO will allow us to search for Exomoons (we estimate that moons down to $\sim$ 0.33 Earth radii will be detectable around EChO's targets), and to identify potential biosignatures in the atmospheres of super-Earths in the habitable zone of cool stars.

EChO will not be a planet discovery mission; its objective will be to characterize the atmospheres of exoplanets already discovered by other facilities. Given the typical amplitude of exoplanetary atmosphere signatures ($10^{-3}$ – $10^{-5}$ times the flux from the star) bright parent stars will be best. Simulations yield brightness thresholds for EChO observations of V $\sim$ 12 for G-K stars with Jupiter to Neptune size planets, and K $\sim$ 9 for M stars with super-Earths in the habitable zone.

At present, about 100 of the $\sim$ 800 identified exoplanets meet the criteria to be observable by EChO. The current sample of targets includes a few super-Earths and Neptunes, but it is still biased towards more massive planets. However, given ongoing and planned new surveys the distribution of targets is expected to significantly change in the next decade, before EChO is launched, as illustrated in Fig. 2.

## 3 The Spanish Contribution to EChO

Our EChO consortium includes more than 100 scientists and engineers from the United Kingdom, France, Italy, Spain, Germany, Denmark, Belgium and the United States. Each of these countries contributes to different parts of the mission. Here we focus on the anticipated

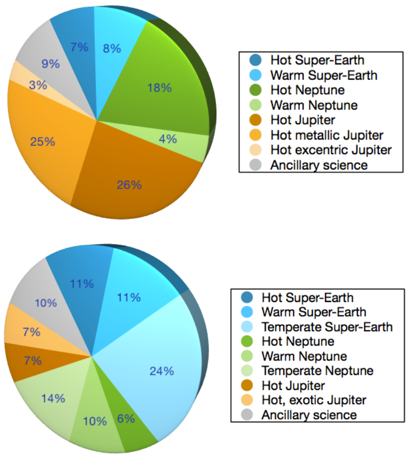


Figure 2: Expected distribution of EChO's observing time given the present availability of targets and the expected availability of targets in a decade.

Spanish contribution. Spain is involved in various aspects of EChO's construction and design, including hardware, software and simulations.

- *Hardware*: the EChO spectrometer will be divided into four (possibly five) channels covering a wavelength interval from 0.4 to 16 $\mu$m: a visible channel (VIS), which includes a fine guiding system (FGS), a near infrared channel (SWIR), a middle infrared channel (MWIR), which could be splinted into two, and a long wave infrared channel (LWIR). Spain will build the optics and mechanics of the SWIR channel. The SWIR channel will work from $\sim$ 2.45 to 5.45 $\mu$m, with a resolution of at least 300 over the full wavelength range. As illustrated in Fig. 3, the optics will be placed in an aluminum enclosure with a volume of $\sim$ $240 \times 210 \times 210$ $mm^3$ and a mass of $\sim$ 8 kg. For more details see [19].

- *Software*: Spain will also contribute to the Ground Segment and On-board software of the mission. We will be part of the Science Data Centre (DC) and will contribute with software for processing, archiving and distribution of the EChO science data products and to the final instrumental corrections before data delivery. Spain has also proposed to be in charge of evaluating the performance and optimizing the on-board data processing, and of the preliminary characterization of the Input Catalog targets as part of the Science Preparation Management phase.

- *Simulations*: Finally, Spain will contribute with the generation of the pre-launch Data Control Unit (DCU) simulator. The DCU will be a digital unit with processing capabilities and will host the warm front-end electronics of all the spectrometer channel detectors. It will also implement the instrument commanding, the science and housekeeping data acquisition, on-board spectra pre-processing and data conversion and packeting. For more details see [20].

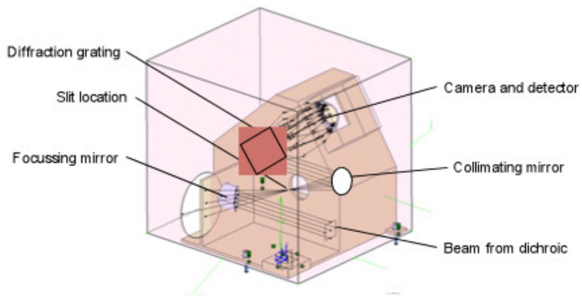


Figure 3: Near infrared channel (SWIR) module outline including its optical design and mechanical envelope (diagram courtesy of G. Ramos Zapata).

The Spanish institutes currently involved in these contributions are the ICE (CSIC-IEEC), CAB (CSIC-INTA), INTA, IAA and IAC.

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