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Detection and spectral characterization of mature planetary systems using space-based high-contrast imaging

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Abstract

Several projects of space high-contrast imaging telescopes are currently under study for the detection and spectral characterization (R∼50) of mature planetary systems at visible wavelengths, from gas giant planets to super-Earths. We present the science program, instrument concept, and simulations of science performance of one of these projects, SPICES, which was submitted to the M3 ESA Cosmic Vision call. Such an instrument would be able to spectrally characterize ∼300 planetary systems within 15 pc of the Sun.

1. Introduction

The detection and the spectral characterization of planetary systems using direct imaging are challenged by very large brightness ratios between stars and planets at short angular separations. Current facilities on large ground-based telescopes or in space allow adequate contrasts to be reached, and have revealed a few planetary-mass objects in favorable situations: young stars (∼10–100 Myr), low star/planet mass ratios (5–400), and/or large angular separations ($>1''$) [1, 2]. In the coming years, ground-based high-contrast imagers in the near-infrared will push the discovery space of young planets toward Jupiter-mass planets and physical separations down to the snow line (∼5 AU) [3, 4]. To reach mature planets, from gas giants to super-Earths, two complementary approaches are studying: near-infrared high-contrast imagers on extremely large telescopes [5, 6] and space coronagraphs operating at visible wavelengths [7, 8, 9, 10]. We describe below the science motivation and the instrument design of the projects of space coronagraphs under study, with a focus on SPICES (Spectro-Polarimetric Imaging & Characterization of Exoplanetary Systems) [7, 11], a 1.5-m telescope submitted to the ESA Cosmic Vision call for medium-class missions in 2010.

2. Science motivation

The main science driver of space-based high-contrast imaging telescopes is the study of planetary systems as a whole for the understanding of planet formation and evolution. This includes mature planets, which are definitely the main goal of these missions, but also planets with longer periods (>10 AU) around young stars (found by planet finders on the ground) and circumstellar disks (from protoplanetary to debris disks). These instruments also potentially offer discovery capability through surveys around bright/nearby stars. Importantly, they can detect exozodiacal light, which is famously known to hamper the detection of Earth-like planets, down to a few zodis. Therefore, the census these instruments will carry out will be important for future space nulling interferometers.

To satisfy this science driver, SPICES will perform spectro-polarimetry at low resolutions (R∼50) at visible wavelengths (0.45–0.9 μm). Below is a list of topics that this instrument will address:

- the chemical composition and vertical structure of planetary atmospheres;
- the composition and structure of planetary surfaces (for rocky planets);
- the temporal variations in the properties of planetary atmospheres and surfaces;
- the orbital parameters of planets;
- the presence of unknown exoplanets in known planetary systems;
- the physico-chemical properties and morphology of circumstellar dust.

3. Instrument design

The general problem to image directly extrasolar planets near bright stars is well known and emblematic

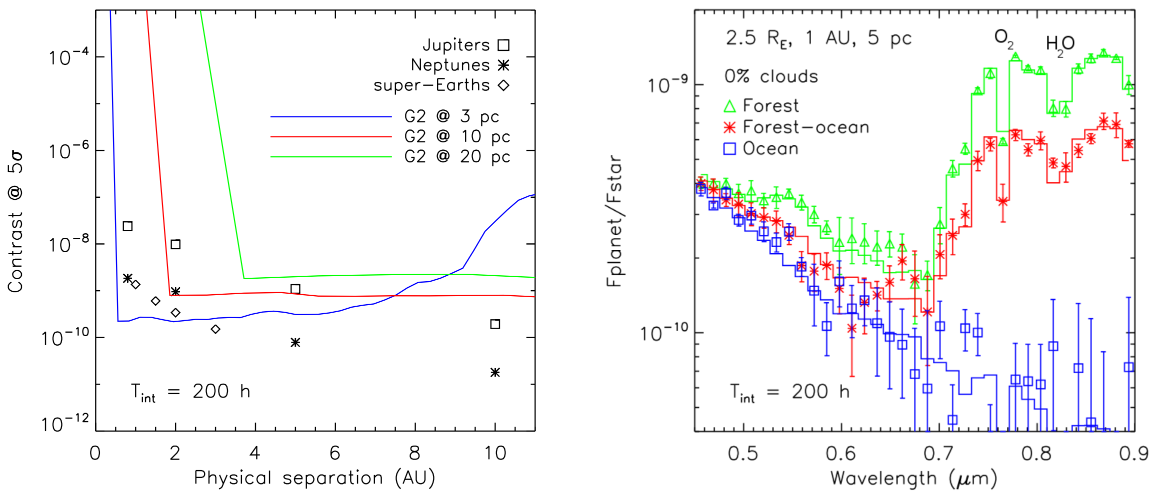

Figure 1: Simulations of performance of a small space high-contrast imaging telescope in detection of mature planets (left) and in spectral characterization of massive rocky planets (right) for a G2-type star, assuming noise contributions from the detector and from the observed star and an integration time of 200 h. Figures from [11].

techniques such as coronagraphy and wavefront control have been developed over the last 15 years to enable high-contrast imaging. The bottom line is to get rid of the diffraction pattern from the star to allow the detection of faint planets. However, the detection and spectral characterization of mature planetary systems require instruments able to tackle star/planet brightness ratios of $\sim 10^8$–10^{10} (Fig. 1), which are 100 to 1 000 times the contrasts achieved by the upcoming planet-finder instruments on the ground [3, 4]. Thus, space-based high-contrast imaging telescopes include a specific instrumentation, which is not available on current or future facilities. Moreover, these very high contrasts have to be achieved at angular separations of $\sim 0.2''$. These instruments have typical diameters of 1.5–2.5 m, so coronagraphs with small inner working angles are needed. Although these instruments have good optical quality, active wavefront control with deformable mirrors at precisions of a few tens of picometers is mandatory to meet the contrast requirements.

For SPICES, the science instrument is an integral field spectro-polarimeter. We show in Fig. 1 performance simulations of SPICES, detailed in [11]. Mature planets would be detected at the separations of the inner planets in the Solar System, in particular super-Earths in the habitable zone of nearby solar-type stars. Comparative exoplanetology would also be feasible, for instance the identification of biosignatures and of the surface for massive rocky planets.

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