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SEE COAST, A SPECTRO-POLARIMETRIC IMAGING MISSION TO CHARACTERIZE EXOPLANETS

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Abstract. SEE COAST is a space mission concept submitted to Cosmic Vision in 2007. It is designed for the characterization of giant gazeous planets and possibly Super Earths both in spectroscopy and polarimetry at visible wavelengths (0.4-1.2μm). The SEE COAST concept relies on a series of high contrast imaging techniques like coronagraphy, wavefront control and differential imaging. The strategy of the mission is presented and the instrumental concept briefly introduced.

1 The context

With the ever-growing number of exoplanets discovered with high precision spectrographs and at a lower extent using the transit technique a large number of projects to directly detect these objects have emerged recently. From the ground, current 8-m class telescopes equipped with AO facilities have already started to image some planetary mass objects in some favorable conditions, namely, for very young systems with large separations (>100 AU) and small mass ratios ; ; ; ; ; ; . But the identification of such planets is quite marginal (7 objects) and raise the problem of their formation which is pointing to a stellar formation process rather than a planetary one. In a few years from now (2010-2011), the same telescopes will benefit from extreme AO systems with advanced coronagaphic devices and differential imaging techniques, like SPHERE at the VLT and GPI on Gemini . These instruments will be specialized for the search and spectro-polarimetric characterization of young and/or massive planets in the solar neighborhood achieving contrast of 10^6 to 10^7. In some particular cases Jupiter mass planets could become detectable if physically close to their host very nearby stars (0.5-1 AU) to increase the reflected light contribution. As for the space, JWST by 2015 will probably reach the realm of mature massive planets (1-5 Gyr) and will be able to characterize some of them on 5 to 10 AU orbits ; in the 2-15μm spectral range. On the longer term (2018-2020), Extremely Large Telescopes are foreseen and again high contrast imaging instruments are being studied now to reach higher contrast (10^8 -10^9). We expect spectral characterization of giant gas planets to be feasible in the near IR and polarimetric characterization in the visible. Ideally, a few Super Earths would become detectable and possibly roughly characterized.

At the moment, future projects like TPF or DARWIN are prospective and the need for a clear roadmap has been expressed worldwide. This exercise has been done twice in the US, with the Exoplanet Task Force and the Exoplanet Forum . Similarly in Europe, a team has been appointed by ESA and one by the community. The objective is to trace a roadmap towards the ultimate goal that is the spectroscopy of terrestrial planets in the habitable zone. Reports will become public in 2009.

Several techniques are being proposed in this context. A clear distinction can be made between indirect detection techniques which are able to derive statistics and/or geometrical parameters (mass, radius, orbital parameters). On the other hand, the ambition of direct imaging is to perform a deeper characterization of the planetary atmosphere. It is now mostly admitted that the spectral characterization of Earth-like planets would require previous mission(s) to identify the targets .

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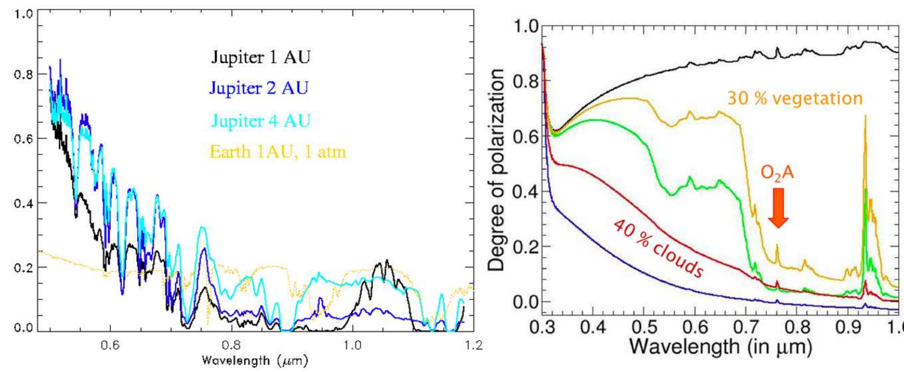

Fig. 1. Spectra for giant gazeous planets (left) and degree of polarization for telluric planets (right) from Stam (2008).

2 Philosophy and strategy

The detection of the first exoplanetary systems has shown a diversity of mass and orbital distributions and has indicated that the Solar System is not representative of planetary systems in general. Diversity and Open-mindedness must thus be the keywords for future exoplanet exploration. Importantly, a consensus is now emerging that habitable planets are not restricted to just Earth-size bodies: Super-Earths with masses up to a tens of Earth's mass may well be habitable. Super-Earths are defined as planets for which terrestrial concepts apply: ocean/continents, planet tectonics, volcanism, habitability.

As described in the previous section, current and committed projects from ground and space are not capable of studying these Super Earths, except for the ELTs which presumably will obtain some rough characterization in the near IR. As we know that these worlds are numerous and many detections are still to come from Radial Velocity surveys, we consider that a mission optimized to study this class of objects is at the moment a valuable program rather than an identification mission for finding Earth-mass planets. In the framework of exoplanet exploration, a space telescope operated in the visible would be very much complementary to what is foreseen on ground-based projects. Therefore, this approach has the advantage to provide scientific data to characterize planets and explore their diversity without the need of a previous mission to find these targets.

This is precisely the purpose of the SEE COAST (Super Earth Explorer - Coronagraphic Off-Axis Space Telescope) proposal to the ESA Cosmic Vision in 2007. Several mission concepts for direct detection were proposed in this frame but none were selected. A new call for proposal will be issued in a couple of years and in the meantime we are intended to progress on the concept definition of SEE COAST.

3 Science case

Our main objective is the spectroscopic and polarimetric characterization of mature jovian planets and Super Earths in order to explore the planetary diversity at lower masses. These classes of objects represent an intermediate topic in between the capabilities of ground based instruments and future long term missions like DARWIN. Therefore, a mission like SEE COAST could be operated in parallel to ELTs on the ground with the objective to contribute to the characterization of the lowest mass gaseous planets and the most massive telluric ones.

Several physical parameters are of interest in the SEE COAST program:

Mass: Msin i is obtained from RV data. Several observations along the orbit will constrain the inclination angle and hence the mass.

Atmosphere: visible spectrum is rich and provides spectral features of water, oxygen, methane and CO_2 (at $1.25\mu m$, Fig. 1). In addition, the Rayleigh scattering gives the column density of clear atmosphere above clouds or solid surface. Also, the polarization of reflected light has wavelength dependence and is a tracer of clouds coverage and haze (Fig. 1).

Surface: oceans and continents have a different temperatures and albedos (a factor of 5). The planetary flux and polarization signals are thus modulated by the planetary rotation ; . The period of this rotation gives the duration of the day for these planets and is important to constraint planetary formation mechanisms as the

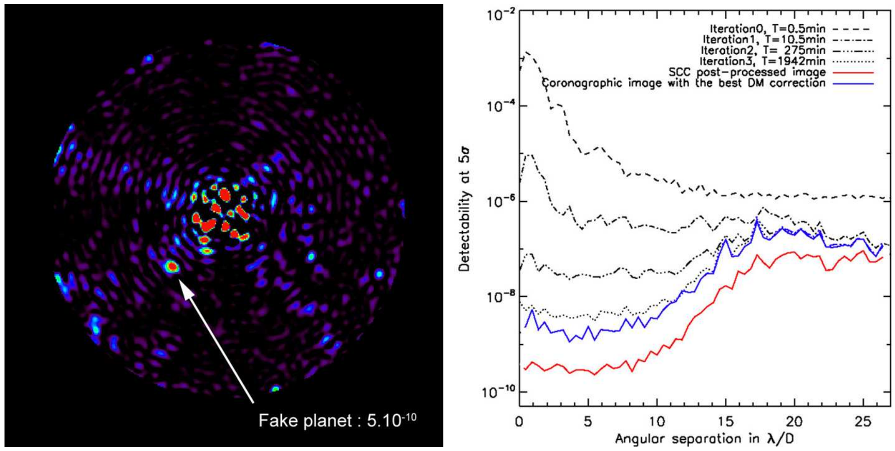

Fig. 2. Laboratory experiment of a multi-sage phase mask obtained at the Observatoire de Paris (left) and simulation of detectability with WF control in a 1.5 m space coronagraph (right).

presence of a magnetic field.

Biosignatures: One can search for spectral signatures of 1) organic materials, and 2) by-products of photosynthesis. On Earth, a strong increase of the albedo due to the vegetation is seen at $0.72\mu m$; , but the red-edge can be at different wavelengths on other planets. Photosynthesis produces O_2 (at $0.76\mu m$), and its derivative O_3 (at $9.6\mu m$) but conversely their presence is not a direct proof of biological activity and hence the abiotic production of these species must be investigated.

4 Mission concept

Based on astrophysical requirements the technical aspects of a mission to detect and characterize exoplanets down to close-by Super-Earths can be derived. The philosophy is a simple and compact telescope and spacecraft to reduce cost and development time, the complexity and requirements for achieving high contrast being relayed to the focal instrument. Here, a 1.5-2 m class off-axis telescope is needed to reach a reasonable amount of targets (giant planets and close-by super-Earths) providing high contrast can be obtained at 2 or 3 λ/D. The focal instrument should provide spectroscopy as well as polarimetric measurements in a narrow field of view (3×3") between 0.4 and 1.25 μm. The optical implementation of such a concept deserve a thorough study but Integral Field Unit are promising. For that, the heritage of SPHERE and EPICS will be a major advantage for the technical aspects and instrumental modelling.

In the previous SEE COAST study we identified 3 main critical aspects or sub-systems, namely: 1/ the wavefront errors (WFE), 2/ the system to suppress the starlight (coronagraph), and 3/ the system to perform calibration and hence further improvement of the contrast. WFE requirements can be obtained with good optical quality at the primary mirror but we also investigated the performance of a dedicated focal plane wavefront sensing (Fig. 2). Implementation of deformable mirrors in space are also being studied around the world. The coronagraphic device should provide high contrast (10^6 - 10^7), high throughput (>50%) and smooth chromaticity. In that context, several concepts are being prototyped (Fig. 2). Finally, further starlight rejection can be obtained with appropriate calibration technique either using spectral or polarimetric signatures of planets with respect to stars. Preliminary performance of SEE COAST was addressed with simulations for the Cosmic Vision proposal. Two examples of simulated spectra for a Jovian planet and a Super Earth are shown in Fig. 3. More details of the SEE COAST project can be found in Schneider et al. (2008).

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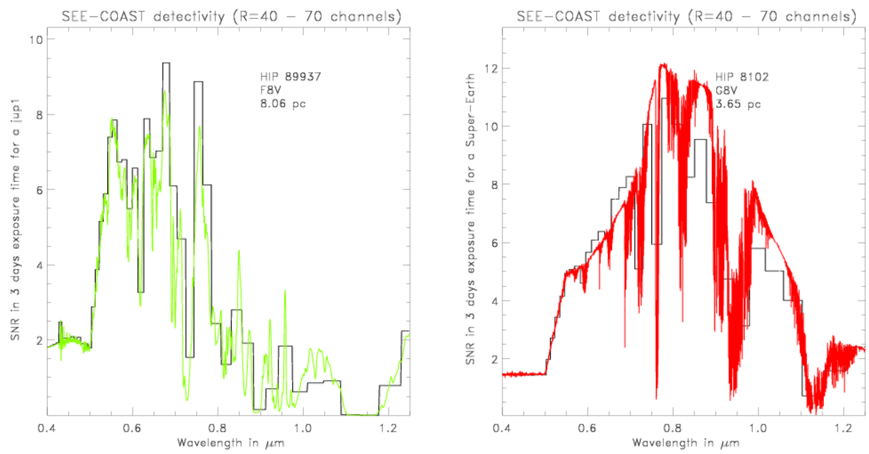

Fig. 3. Instrumental simulations were made for Cosmic Vision to assess the capabilities of SEE COAST. Two examples are shown for illustration here for a mature Jovian planet (left) and a Super Earth of 2.5 Earth radii (right).

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