EUROPEAN ORGANISATION FOR ASTRONOMICAL RESEARCH IN THE SOUTHERN HEMISPHERE

Scientific Technical Committee 97th Meeting
27 and 28 October 2020

For Recommendation

Science Evaluation of a Hosted Telescope Proposal
High-resolution imaging and spectroscopy of exoplanets (HiRISE)

This document is PUBLIC

Scientific Technical Committee is invited to issue a recommendation to the Director General.
1. **Introduction**

Based on STC-545 all proposals for Hosted Telescopes are evaluated for their science value by a panel selected by the Directors for Science and Operations. The panel consisted of Sergio Sousa (STC), Bruno Leibundgut (ESO) and Alain Smette (ESO). The evaluation considered the astrophysical impact of a proposal submitted to obtain high-resolution spectroscopy of exoplanet atmospheres.

The proposal for the *Characterization of young giant exoplanets at very high spectral resolution with a fibre coupling between SPHERE and CRIRES+* was submitted by a consortium of institutes in France, Germany and the UK. It is led by Arthur Vigan from the Laboratoire d’Astrophysique de Marseille. It proposes to install a fibre link between two ESO facility instruments, SPHERE and the upgraded CRIRES to observe exoplanet atmospheres in direct light at high spectral resolution. The science case of this proposal has already been presented to the OPC at its 105th meeting in November 2019. The OPC “expressed their strong scientific support” for HiRISE.

The panel finds:

The HiRISE proposal offers a unique science capability for a restricted and highly interesting science case. The scientific case has also been strongly supported by the OPC. The technical implementation is described in detail in the proposal and appears rather mature at this stage. The fibre link between two operational facility instruments requires special care in the implementation of the fibre entry at SPHERE and the beam entry in CRIRES. Since CRIRES is awaiting commissioning, its full characterisation has not been done.

Implementation of HiRISE as a visiting instrument is recommended. Any impact on the performance and operations of SPHERE and CRIRES has to be avoided, which requires in-depth reviews before the installation of HiRISE is approved by the observatory. A full characterisation of CRIRES is a prerequisite for HiRISE approval.
2. High-Resolution Imaging and Spectroscopy of Exoplanets (HiRISE)

2.1 Science

The atmospheres of giant exoplanets have been observed in a few instances. Two main techniques can be distinguished: transit spectroscopy or direct light spectroscopy. The first method requires transit observations and is limited by the size and optical depths of the atmosphere. Direct observations of the exoplanet require the separation of the planet light from the host star and can only be achieved through adaptive optics or interferometry. In this case, the limitations are the image quality and the number of photons from the planet atmosphere. Detailed simulations are presented in Otten et al. (A&A submitted; arXiv:2009.01841). It can be expected that this field will expand considerably in the coming years with new techniques and many more planets to observe.

Composition, turbulence and variability provide clues to the planet formation and the conditions in the atmosphere. High spectral resolution of such planet atmospheres yields information on the elemental abundances and radial velocities. The abundances of carbon and oxygen give indications in which conditions and at what distance from the host star the planet formed. Velocity information traces the atmosphere itself. They are the key to model-independent masses, rotational periods and atmospheric variability.

Observations of exoplanets in direct light and at high spectral resolution is currently not offered anywhere. A resolution of about 100000 would offer access to detailed atmospheric composition and critical abundances, enable the determination of temperature-pressure profiles in the atmospheres and checks for specific isotopes or molecules. Deuterated water is an indicator of the formation process through the ratio of deuterium to hydrogen. During the early accretion phase exoplanets also show hydrogen lines. These have been detected in a few cases, but no line shapes could be determined. A high-resolution spectrum would allow astronomers to measure the accretion rate. Monitoring of giant planet atmospheres can show variability in individual emission lines and separate cloud emission. The spectra will further contain information on the planet radial velocity and, connected with the host star radial velocity, provides the mass ratios and potentially indications of exomoons. Line broadening contains information on the rotation rate of the planets and winds. These properties can only be accessed by high-resolution spectroscopy of the planet atmosphere.

There are currently only a handful of exoplanets known where such high-resolution spectroscopy is feasible. It is expected that more candidates will be discovered in current searches and a small sample of exoplanets can be observed. There would be sufficient targets to be observed in a dedicated Large Programme.

No other science cases are presented. HiRISE could potentially benefit other science cases where high spectral and angular resolution are required.

2.2 Implementation and Operations

The HiRISE proposal foresees a fibre link between two ESO facility instruments. The extreme adaptive optics of SPHERE would be used to separate the exoplanet light from the host star and the newly upgraded CRIRES records the high-resolution spectrum. This requires the installation of a fibre feed inside SPHERE, the fibre connecting the two Nasmyth platforms on UT3 and the light beam injection in CRIRES. This implies modifications of operating instruments.

A fibre injection module would be installed in the SPHERE IFS arm. A pickoff mirror extracts the beam and feeds it into a fibre. A tip-tilt mirror ensures accurate positioning on the fibres and a small tracking camera will provide a real-time image of the field and should help in centring the planet light on the fibre. For technical reasons only the H-band will be transmitted through the fibre. Wavelengths outside the H-band are used for the tip-tilt
correction and the tracking camera. The position for the fibre injection bench with the above functionality has been identified within the SPHERE instrument.

A fibre bundle with a science fibre and three reference fibres, connects the two Nasmyth platforms. On the SPHERE side there are four feedback and one centring fibres, while on the CRIRES side the fibre bundle includes an AO-calibration fibre connected to the CRIRES integrating sphere.

The light is fed into CRIRES in the warm optics part. The selected entry is rather tight and two possible implementations are studied. It uses the space on the CRIRES calibration selector unit which is normally reserved for Visitor Gas Cells. While it is installed for HiRise, Visitor Gas Cells will not be available, except if a solution is found that would allow to easily and reliable remove and re-install the Fibre Extraction Module.

Some software development is required since two instruments are used simultaneously. HiRISE plans to use manual control of the SPHERE acquisition of the target. No dual-instrument control software would be developed, and HiRISE would be used exclusively by the proposing team in visitor mode.

2.3 Additional considerations

The proposal is technical very advanced and complete.
Since HiRISE would use two operational instruments, it has to assure that all currently offered modes are unaffected. This requires extensive reviews of the proposed modifications and their impact of the regular operations has to be understood.

The upgraded CRIRES has not been commissioned and its performance needs to be confirmed. As long as regular CRIRES operations are not started, HiRISE implementation cannot be considered. An appropriate time should be defined when CRIRES operations are established and the HiRISE modifications could be contemplated.

While it could be tempting to keep the modifications of HiRISE as facility instrument, the science case seems too limited for a wider use and the development requirements too extensive to warrant such a consideration.

2.4 OPC Recommendation

For completeness the OPC recommendation are reproduce in full here (from the minutes of the 105th meeting of the OPC, November 2019):

In P105 a project named HiRISE was submitted to ESO for consideration. It aims at “Characterisation of young giant exoplanets at very high spectral resolution with a fibre coupling between SPHERE and CRIRES+”. This requires the implementation of a novel fibre-optics system connecting the two instruments. The OPC was tasked with providing a recommendation to ESO on whether to carry out the proposed technical implementation, based on the potential scientific impact. Although the HiRISE extension can likely only observe a small number of exo-planets, the information that could in principle be obtained is of high scientific value. Therefore, OPC expressed their strong scientific support for this project. The Observatory will conduct a technical evaluation to validate project feasibility and determine the in-kind cost (in terms of effort) that will be required for the implementation of this visiting instrument.