OCTOCAM: a fast multi-channel imager and spectrograph proposed for the Gemini Observatory

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ABSTRACT

OCTOCAM has been proposed to the Gemini Observatory as a workhorse imager and spectrograph that will fulfill the needs of a large number of research areas in the 2020s. It is based on the use of high-efficiency dichroics to divide the incoming light in eight different channels, four optical and four infrared, each optimized for its wavelength range. In its imaging mode, it will observe a field of 3'x3' simultaneously in g, r, i, z, Y, J, H, and K_S bands. It will obtain long-slit spectroscopy covering the range from 3700 to 23500 Å with a resolution of 4000 and a slit length of 3 arcminutes. To avoid slit losses, the instrument it will be equipped with an atmospheric dispersion corrector for the complete spectral range. Thanks to the use of state of the art detectors, OCTOCAM will allow high time-resolution observations and will have negligible overheads in classical observing modes. It will be equipped with a unique integral field unit that will observe in the complete spectral range with an on-sky coverage of 9.7"x6.8", composed of 17 slitlets, 0.4" wide each. Finally, a state-of-the-art polarimetric unit will allow us to obtain simultaneous full Stokes spectropolarimetry of the range between 3700 and 22000 Å.

Keywords: Imager, Spectrograph, Multi channel, High time-resolution, Integral field Unit, Spectropolarimeter, Gemini Observatory

1. INTRODUCTION

The decade of the 2020s will be the time of large surveys and giant telescopes. The Universe will be explored with unprecedented depth and cadence thanks to new surveys such as the Large Synoptic Survey Telescope (LSST), the Zwicky Transient Facility (ZTF), etc. Forthcoming Giant telescopes (Giant Magellan, E-ELT, TMT) or the James Webb Space Telescope (JWST) will be only able to study a very limited amount of the most interesting targets. It will be a time when the 8 meter class telescopes will have to be prepared to efficiently fill the gap between the surveys and the giant telescopes. To take advantage of this opportunity, we envision a highly-efficient instrument that will stand out in the characterization and study of the time domain window with simultaneous optical and near infrared coverage.

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Ground-based and Airborne Instrumentation for Astronomy VI, edited by Christopher J. Evans, Luc Simard, Hideki Takami
Proc. of SPIE Vol. 9908, 990840 · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2231862

OCTOCAM has been presented in response to the Gemini Instrument Feasibility Studies (GIFS) call issued in late 2014. The proposed instrument idea was based on a previous instrument study [1,2] which was adapted to the characteristics of the Gemini telescopes, and upgraded giving it further capabilities. The project was selected for a feasibility study which was performed during 2015. In this article we present the scientific motivation and overall characteristics of the instrument.

Table 1. OCTOCAM specifications.

Simultaneous spectral range	Photometry: $grizYJHK_S$ Spectroscopy: 3700-23500 Å
Field of view	Imaging: 3'×3' Spectroscopy: 3' Long slit IFU: 9.7"×6.8"
Plate scale	0.18"/pixel
Average efficiency	Imaging: 41% Spectroscopy: 33%
Maximum frame rate	10 Hz full frame 100 Hz windowed
Observing modes	Multiband imaging Wide band spectroscopy (long slit,IFU) High time-resolution Spectropolarimetry

2. SCIENTIFIC MOTIVATION

The scientific requirements for a workhorse instrument in the 2020s at Gemini indicated the need for a highly-efficient broad-wavelength coverage instrument that would do both imaging and spectroscopy and that would be optimized to explore time-domain Astrophysics. OCTOCAM has been designed to take advantage of a window in the (spectral coverage)-(spectral resolution)-(time resolution) that is not covered by any other single instrument. The overall specifications are displayed in Table 1. Its capabilities allow OCTOCAM to do breakthrough science in many different fields:

- Characterize transients detected by new astronomical surveys, such as LSST, quickly and efficiently.
- Explore fast changing phenomena with high time-resolution simultaneously at all wavelengths.
- Study extreme physics near the event horizon of black holes and the properties of jets at high time-resolution.
- Expand our understanding of stellar explosions at high-redshift.
- Use supernovae to study the evolution of dust and to push the redshift limits of the Hubble diagram.
- Probe the very high redshift Universe and the environment of the first stars using as probes the furthest explosions in the Universe.
- Understand the role of supermassive black holes in galaxy evolution through detailed observation of active galactic nuclei at all redshifts.
- Observe the tidal disruption of stars by supermassive black holes.
- Elucidate the formation and evolution of neutron stars, constrain their equation of state, emission mechanisms, and magnetic fields.

3. INSTRUMENT OVERVIEW

OCTOCAM is an imager and spectrograph that, through the use of high-efficiency dichroics, will simultaneously observe in 8 channels (4 optical + 4 near-infrared). It will obtain simultaneous imaging in g, r, i, z, Y, J, H, K_S with a field of view of 3'×3', or single shot spectroscopy covering the range from 3700 to 23500 Å using a 3' long slit. Its state-of-the-art detectors, will allow it to perform high-time resolution observations, as well as to do classical observations with negligible dead time between exposures. OCTOCAM will be also equipped with a 9.7"x6.8" integral field unit (IFU) and a full stokes spectropolarimeter with a broad visible and near-infrared coverage that will be unique on an 8 m class telescope. Figure 1 gives a schematic view of OCTOCAM's structure identifying the main elements of the instrument.

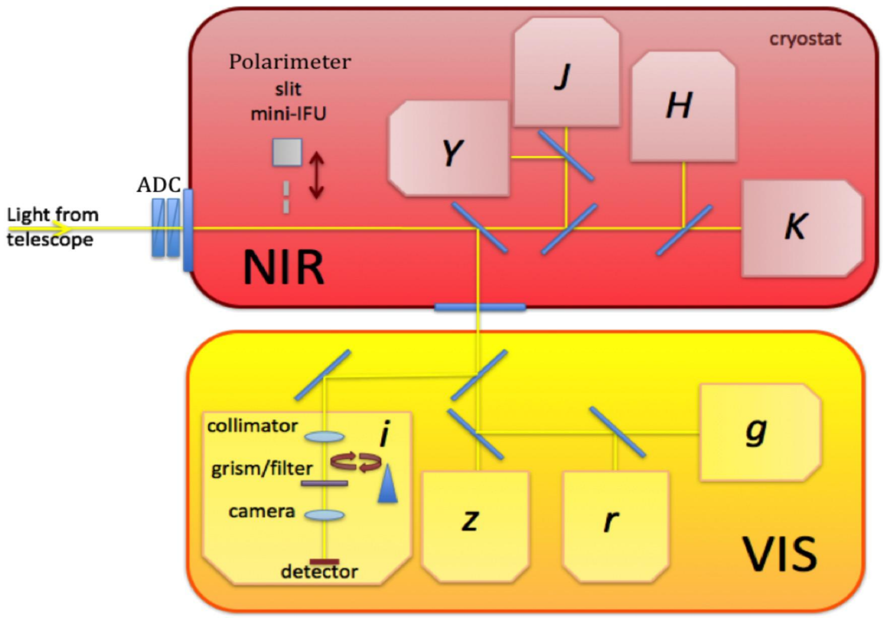

Figure 1. Schematic view of OCTOCAM, highlighting the NIR assembly, hosted in a cold environment within a cryostat and the VIS arms, at room temperature.

4. OPTICAL DESIGN

OCTOCAM uses a single focal plane for all arms, with a single slit feeding all the arms in the spectroscopic mode. This guarantees that the different arms will be always observing the same piece of sky, independently of instrument flexures. The focal plane and the NIR optics are hosted in a cryogenic chamber while the VIS ones are at room temperature. It is equipped with an atmospheric dispersion corrector placed before the entrance of the cryostat. High-efficiency dichroics split the light into the eight arms, each optimized for a specific wavelength range to ensure maximum efficiency. The first dichroic is placed inside the cryostat, and divides the NIR light that stays in the cold chamber and the VIS light that exits through a second window towards a warm bench. The light of each arm is collimated, leaving space for filters and/or grisms that are placed in the parallel beams which then get focused again onto the detectors by camera lensed that are optimized for each arm. In some cases, part of the collimator lenses are shared by different arms to limit the amount of optics and constrain the size and weight of the instrument. Figure 2 shows the optical layout of the optical an near infrared arms of the instrument.

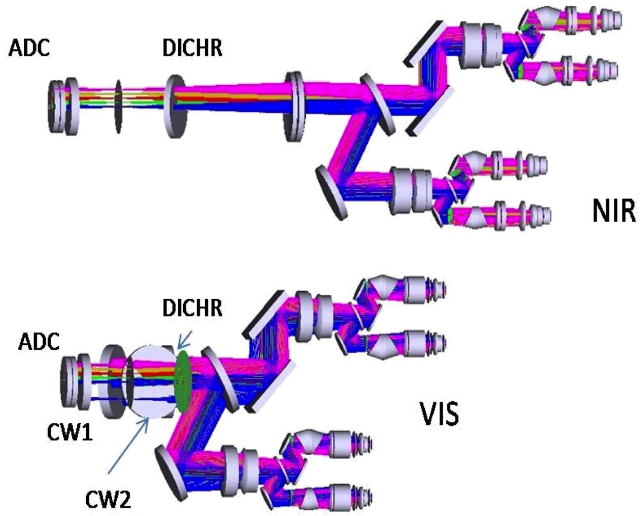

Figure 2. The optical layout is divided into two units, the optical (top) and the near-infrared (bottom) arms, held to a common optical bench to constrain flexures.

5. MECHANICAL DESIGN

Compactness, light-weight, stiffness, and accessibility are the main drivers of the mechanical design. A support frame, together with a stiff bench limits the instrument flexures with respect to the telescope. VIS and NIR arms are mounted back-to-back to ensure that any internal flexures are coupled and can be easily dealt with. The instrument benefits from a single focal plane, guaranteeing that the light from the same sky area is delivered to all arms. Figure 3 gives a general view of the instrument assembly.

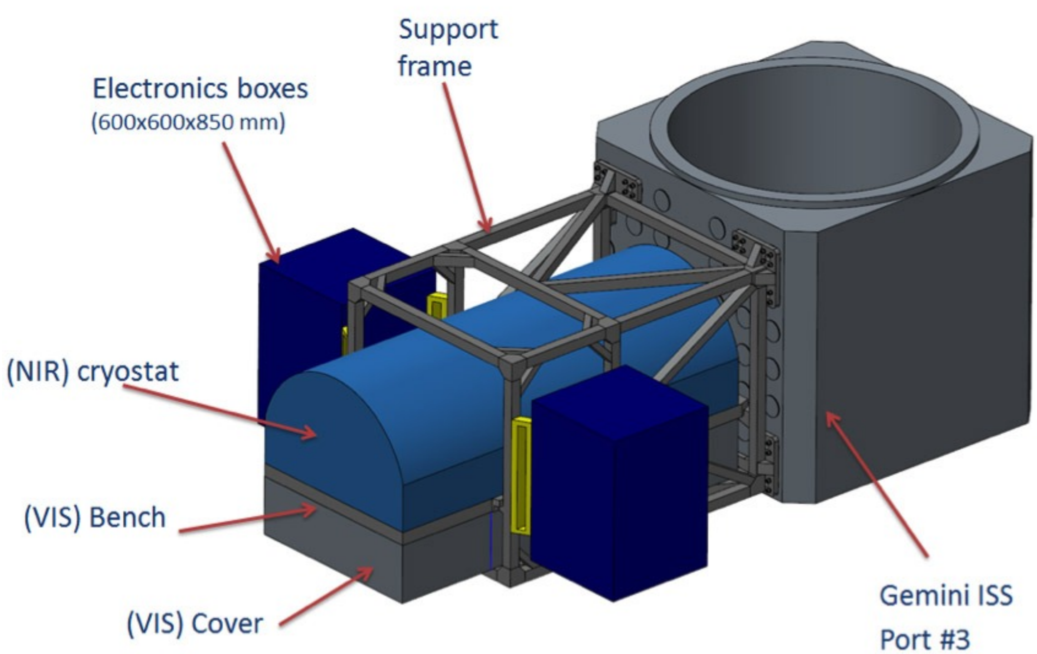

Figure 3. View of the mechanical design of OCTOCAM.

6. DETECTORS

OCTOCAM uses e2v frame transfer detectors in the optical, and Hawaii 2RG in the NIR. To achieve the required resolution, the region of the detector used for spectroscopy is larger than for imaging (see Fig. 4). Time resolutions of 10 Hz can be achieved with full frame images, and even higher cadences can be reached by using windowed modes.

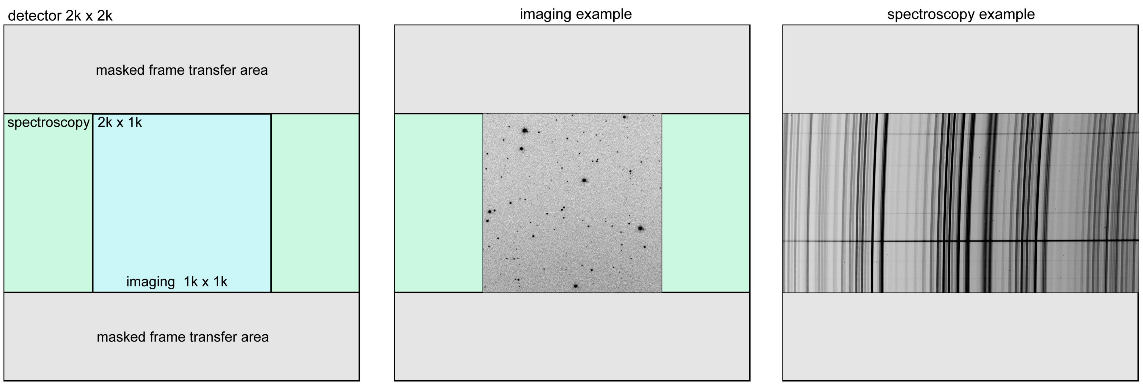

Figure 4. Layout of the optical frame transfer detectors of OCTOCAM. An increased detector area in the spectroscopic mode allows a higher spectral resolution.

7. INTEGRAL FIELD UNIT

Taking advantage of the long slit design of the instrument, we are proposing to add an integral field unit (IFU, see Fig. 5), based on an Advanced Image Slicer design [3], with an area of 9.7 x 6.8 in 17 slices of 0.4. As the only large area IFU simultaneously covering this wavelength range on an 8 m telescope, it will be a unique asset for Gemini, opening the window for new science niches.

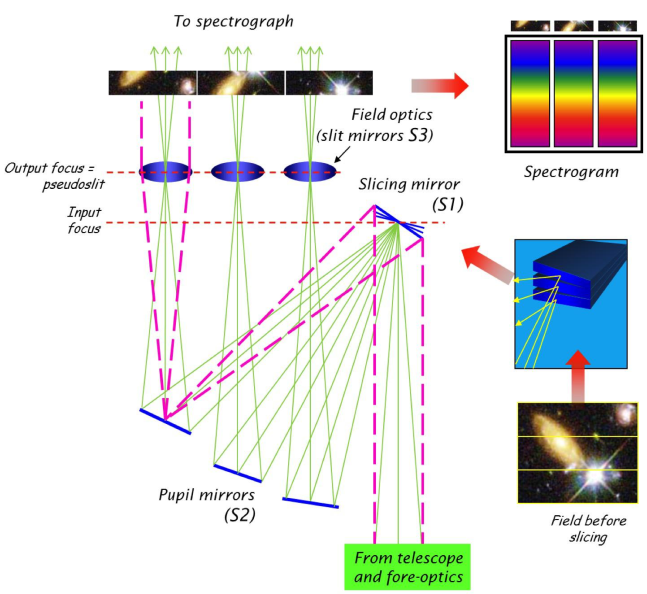

Figure 5. An integral field unit will make use of the 3' long slit with which OCTOCAM was designed to provide an integral field coverage of 9.7" x 6.8"

8. SPECTROPOLARIMETER

OCTOCAM will have the first broadband spectropolarimeter on an 8 m telescope. The design will be based on a broad band polycromatic modulator, which will allow us to obtain spectropolarimetry in the range between 3700 and 22000 Å [4]. An additional high-resolution mode for continuum spectropolarimetry at high cadence will be also included [5]. Figure 6 schematically shows the setup of the focal plane and output spectra while using the spectropolarimeter, with a science aperture and two sky apertures used for calibration purposes. For each aperture, a polarizing beam-splitter produces two spectra, that, together with the time-stepped polychromatic modulator, furnish high-accuracy dual-beam spectropolarimetry.

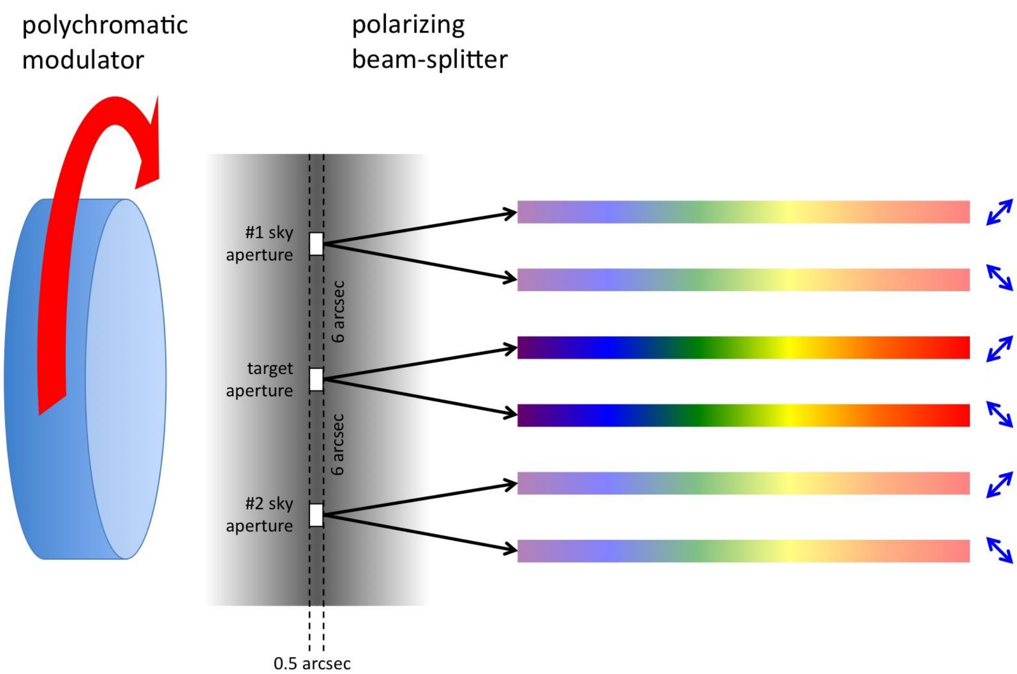

Figure 6. Scheme of the polarizing unit. After going through the polychromatic modulator, the light is divided by a polarizing beam-splitter. The unit has two apertures, one for the science target and the others for sky calibration.

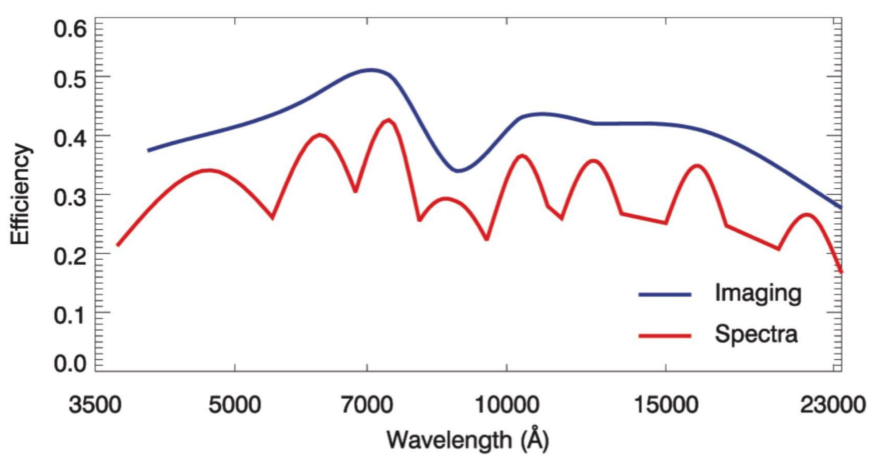

Figure 7. Expected efficiency of OCTOCAM in both imaging and spectroscopy modes.

9. OPERATIONS AND PERFORMANCE

Simultaneous multiband observations make OCTOCAMs calibrations robust and fast. There will be only one set of filters and only one set of grisms, so that the night time calibrations will demand an almost negligible amount of time. Furthermore, the 8-band acquisition that will come for free when spectroscopy is performed, will allow a very robust spectrophotometric calibration of the final products. The observing software will allow the user to tune the observing parameters of each arm individually to optimize the performance of OCTOCAM. Its fast detectors, allow for a very efficient duty cycle, almost eliminating the time lost between exposures, boosting the productivity of the observatory. Figure 7 shows the efficiency of the instrument, including all optics and detectors.

ACKNOWLEDGMENTS

The feasibility study of OCTOCAM has been supported by funding from the Association of Universities for Research in Astronomy (AURA). We acknowledge support from internal funds at Southwest Research Institute. AdUP and CT acknowledge support from Ramón y Cajal fellowships and from the Spanish national project AYA 2014-58381-P.

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