Design of the iLocater Acquisition Camera for the LBT

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Introduction

Existing radial velocity (RV) instruments for planet detection are limited by systematic errors resulting from their seeing-limited design including the use of large, multi-mode fibers leading to modal noise (Jovanovich et al 2014). iLocater, an ultra-precise fiber-fed spectrometer for the Large Binocular Telescope (LBT), operates at the diffraction-limit and will search for Earth-like planets orbiting the nearest stars. The instrument utilizes the LBT's "extreme" adaptive optics (AO) system to provide a diffraction-limited beam in the Y-band (0.95-1.12μm) as shown in Figure 1 (Esposito et al. 2011). This facilitates high-efficiency coupling of starlight into single-mode fibers for the first time, overcoming the modal noise limitation (Crepp 2014).

We present the design of the iLocater acquisition camera which couples starlight from the telescope into optical fibers. We describe the principle of the optical design and present the design of a demonstration system being developed for testing at the LBT in October 2015.

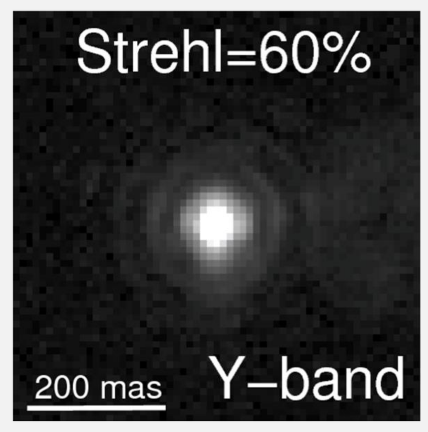

Figure 1: An AO corrected image from the LBT.

Optical Design

Light from the twin dishes of the LBT can be diverted into the Large Binocular Telescope Interferometer (LBTI). A swing-arm containing a 50/50 beamsplitter can be deployed on the DX (right) side of LBTI before the f/15 Gregorian focus of the telescope. This directs light towards an optical board installed as part of the SHARK Forerunner experiment. iLocater will utilize this setup to feed a demonstration system to be commissioned at the LBT in October 2015. The final acquisition camera will not use this swing-arm and will instead use the steering optics of LBTI to divert the light from each telescope dish into independent fiber-coupling systems.

The principle behind both the demonstration and final system is identical. As shown in Figure 2, collimated light enters the system and Y-band light (required for radial velocity measurements) is reflected by a dichroic before being focused onto a single-mode fiber. The transmitted beam (J-band in the final instrument, visible for the demonstrator) is used to monitor the incoming beam and provide any correction required using a steering tip-tilt mirror (not shown).

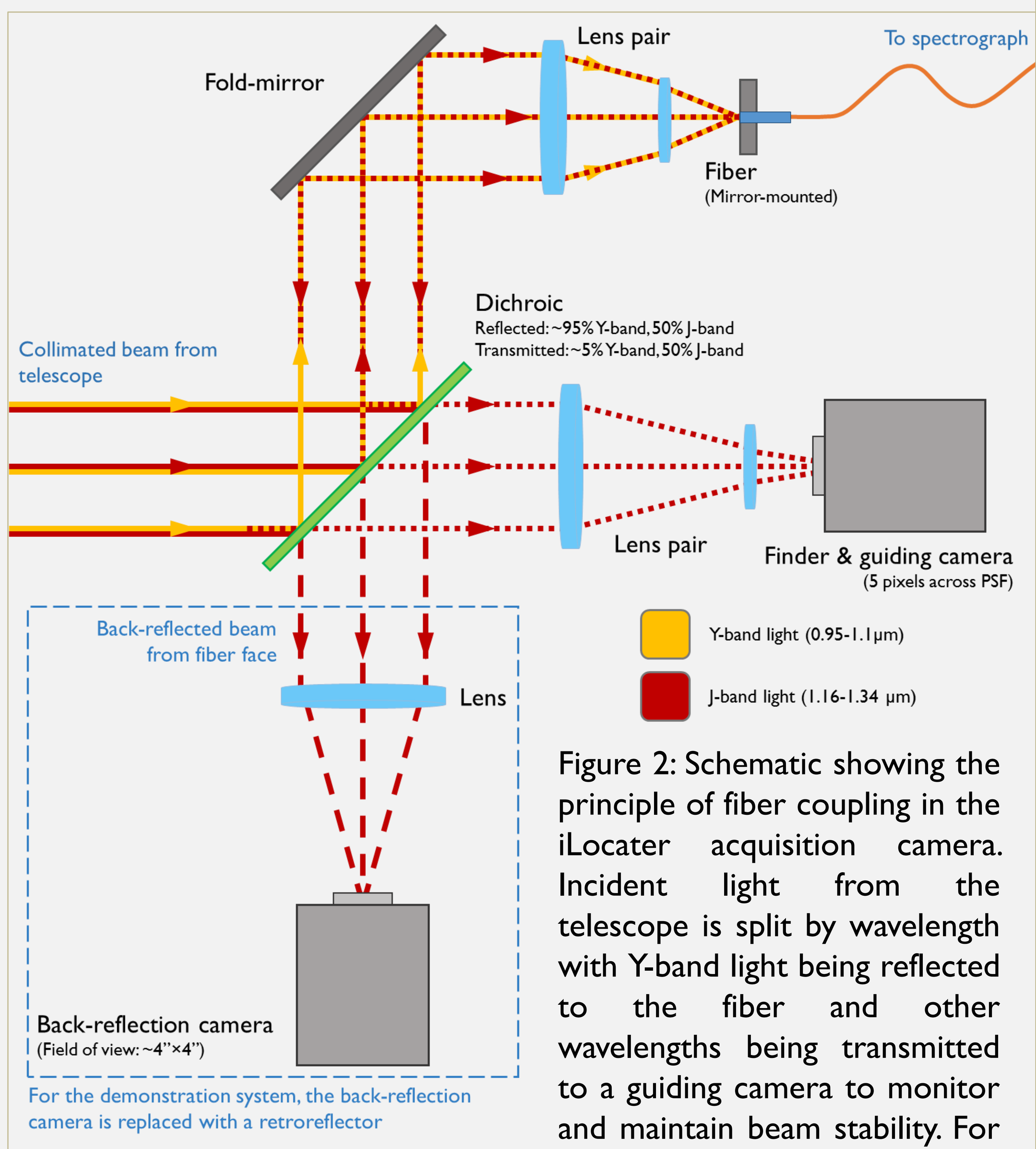

Figure 2: Schematic showing the principle of fiber coupling in the iLocater acquisition camera. Incident light from the telescope is split by wavelength with Y-band light being reflected to the fiber and other wavelengths being transmitted to a guiding camera to monitor and maintain beam stability. For the final system, J-band light will be used for monitoring while for the demonstrator system, visible light is used.

In the final acquisition camera system, the fiber will be mirror-mounted to provide a back-reflected beam which can transmit through the dichroic onto another imaging camera. This detector can also be used to identify the fiber position through a back-illumination process. A similar alignment technique is achieved with a retroreflector for the demonstration system.

Laboratory testing at the University of Notre Dame using the design shown in Figure 2 and Figure 3 has demonstrated monochromatic and broadband coupling efficiencies of >70% when coupling to an Airy diffraction pattern. The theoretical maximum coupling efficiency for this type of system is 78% (Shaklan and Roddier 1988).

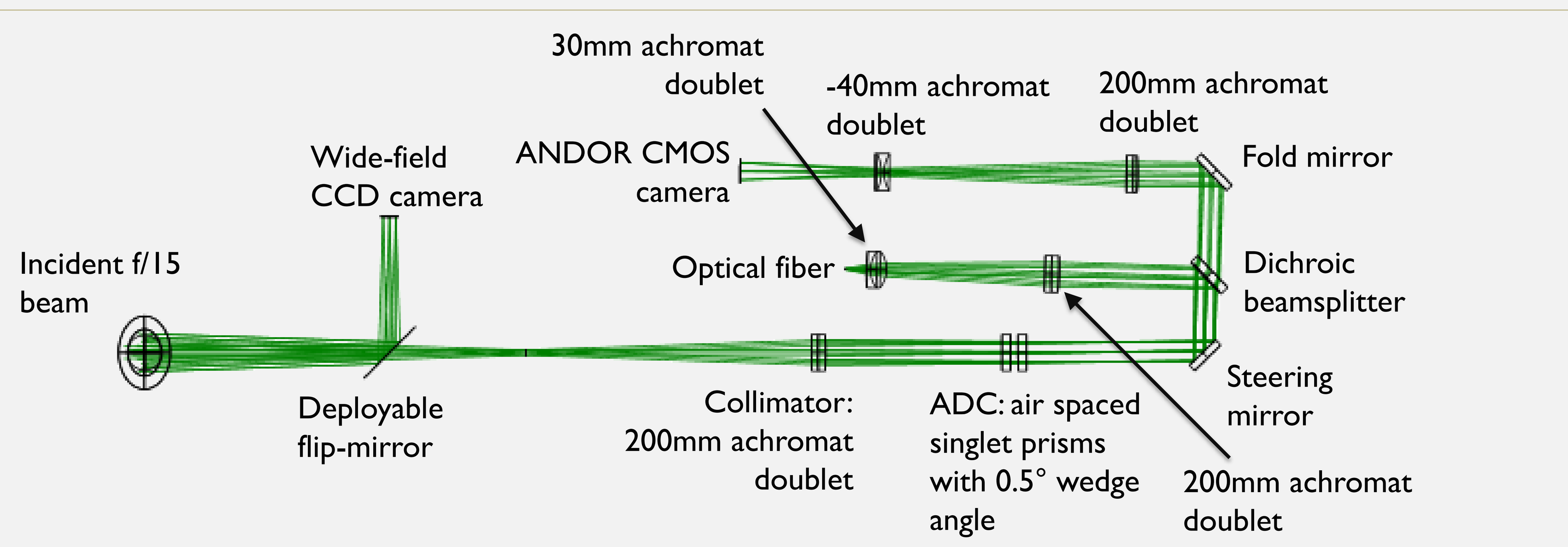

Figure 3: Zemax model of the iLocater demonstrator acquisition camera. Light enters from the telescope on the left and is collimated using a 200mm achromat doublet. The beam is then divided using a dichroic beamsplitter before being re-imaged to provide the correct plate-scale at the fiber coupling and imaging planes.

LBT & LBTI

iLocater will use the existing infrastructure of the Large Binocular Telescope Interferometer (LBTI) to deliver light to its acquisition camera. The LBT AO system has demonstrated the ability to deliver Y-band images with a 60% Strehl-ratio (Figure 1). This allows for efficient coupling of starlight into single-mode fibers.

The acquisition camera will use two locations on LBTI: one for a demonstration system and the other for the final instrument (shown in Figure 4). The demonstrator will utilize the infrastructure of the SHARK Forerunner instrument on the DX (right) side of the telescope to test single-mode fiber coupling. The final acquisition camera will be located at a new set of instrument ports located after the beam combiner of LBTI, where the two telescope beams will be independently coupled to individual single-mode fibers.

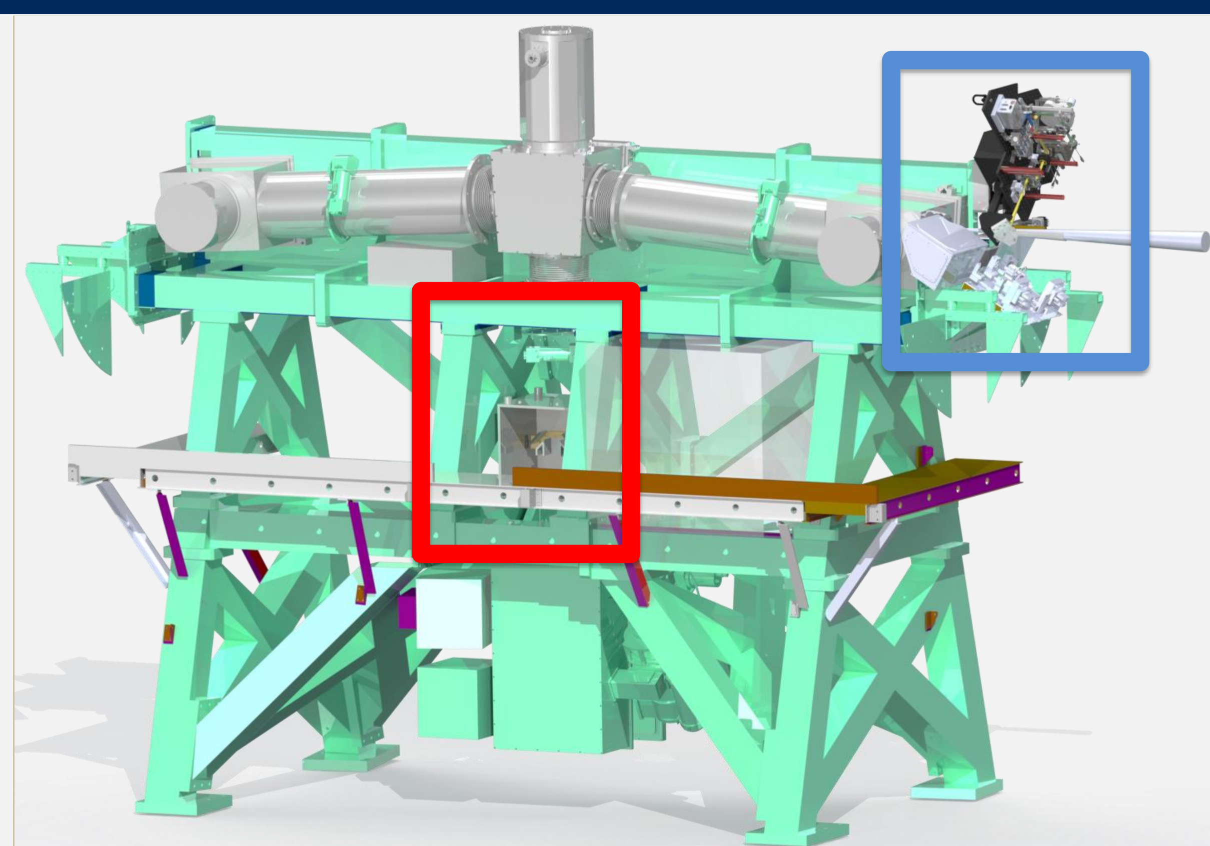

Figure 4: LBTI structure showing the locations of the acquisition camera. The site shown in blue intercepts the telescope beam before the LBTI vacuum chamber and is the location for the demonstration system, while the site in red is for the final instrument.

Demonstration System Design

To investigate and test the efficiency of coupling starlight into single-mode fibers at the LBT, a demonstration system will be used on-sky at the telescope in October 2015. The system design is shown in Figure 5.

The f/15 beam from the telescope enters at the lower left corner. It is imaged with a wide-field camera and controlled using a pair of fold mirrors to ensure target acquisition and beam alignment. The beam is then collimated prior to passing through a 0.5° wedge-angle prism pair to correct for atmospheric dispersion. A fast steering mirror provides precise beam control into the remainder of the optical system.

1	Wide-field camera	7	750mm EFL focusing lens pair
2	200mm FL collimator	8	ANDOR Zyla Camera
3	ADC	9	Power monitoring channel
4	Steering mirror	10	Fiber focusing lens pair
5	Dichroic beamsplitter	11	5-axis fiber stage
6	Retroreflector		

Figure 5: The iLocater acquisition camera demonstration system.

A dichroic beamsplitter splits the incident light into a reflected component containing Y- and J-band light and a transmitted beam containing other wavelengths (see Figure 2). The transmitted beam is imaged onto a high-speed ANDOR Zyla 5.5 CMOS detector to allow incident beam positioning and monitoring. The reflected beam is focused using a pair of achromatic doublet lenses to provide the correct magnification and numerical aperture for single-mode fiber coupling. The optical fiber is mounted on a 5-axis piezoelectric driven stage with a micro-step resolution of ~10nm. Ultra-precise positioning is vital for effective high-efficiency coupling.

Coupling efficiency is calculated by temporarily diverting the incident fiber beam to a power monitoring channel. This focuses the beam onto a low-flux power meter to give a measure of incident power for a specific target. This power is compared to the output from the coupled single-mode fiber to determine the coupling efficiency.

References

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