Raptor photonics

Enabling Interferometric Imaging at SWIR Wavelengths

Long baseline optical interferometers are ground-based observatories that study the cosmos in high resolution at visible and infrared wavelengths. An interferometer works differently to conventional imaging telescopes. Starlight is captured with small telescopes that are separated from each other by distances up to a few hundred metres. The output of each telescope is a collimated beam around 10 cm in diameter. These beams are relayed towards a centralised laboratory where they are reduced in size to around 1 cm in diameter, then combined with beams from other telescopes to form interference fringes on a detector. By analysing the fringe patterns obtained from multiple pairs of combined beams, we can reconstruct an image of the target under observation.

The Magdalena Ridge Observatory Interferometer (MROI), depicted in Figure 1, is currently under construction at an altitude of 3100 m in New Mexico, USA. Once complete, it will harness ten 1.4 m-diameter telescopes to conduct observations at wavelengths from 600 nm to 2400 nm. It will be able to resolve features that would only be possible with a conventional optical telescope 350 metres in diameter (i.e. something that would be impractical to build). Figure 2 depicts the simulated performance of the MROI when imaging the surface of a distant red giant star. Figure 3 demonstrates an application closer to Earth in which the MROI will image geostationary satellites to enhance space situational awareness.

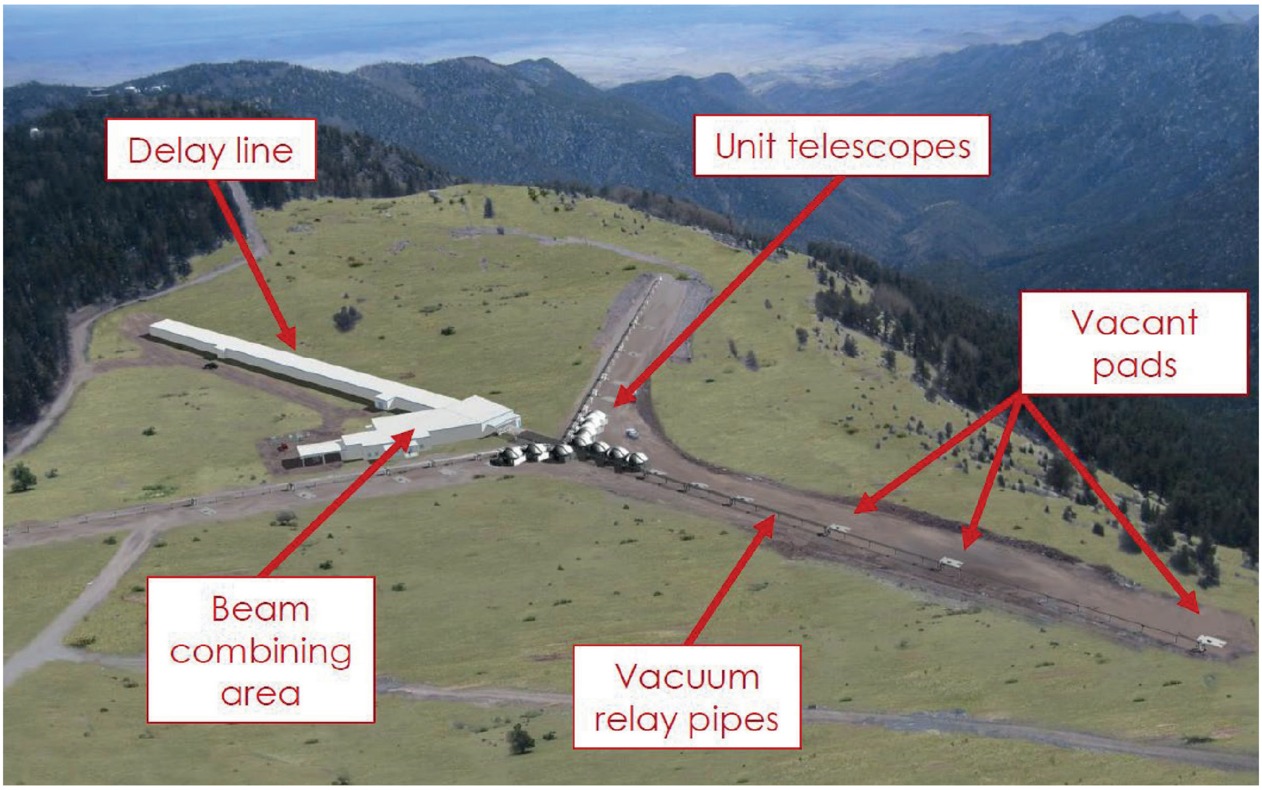

Figure 1: Aerial view of the Magdalena Ridge Observatory site overlaid with graphics of the buildings and infrastructure for the Interferometer. The ten unit telescopes are configured in a Y-shaped array. The telescopes can be lifted and relocated to vacant pads to optimise the interferometer for viewing features of different sizes.

Application Note

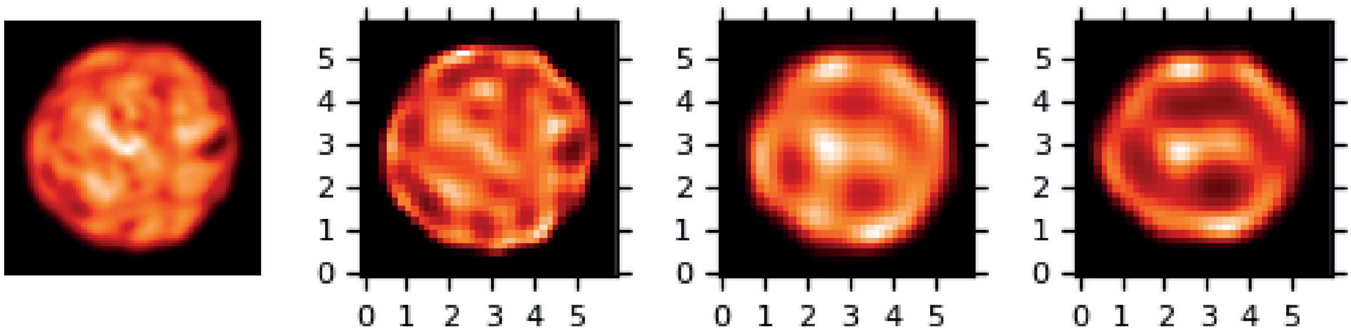

Figure 2: Truth and simulated interferometric reconstruction by the MROI of the surface of a red supergiant star at a distance of 11,000 light years. From left to right: 1. “Truth” (Chiavassa, A., Plez, B., Josselin, E., Freytag, B., “Radiative hydrodynamics simulations of red supergiant stars. I. interpretation of interferometric observations”, Astronomy and Astrophysics, 506, p1351 (2009)). 2. Reconstructed image with 10 telescopes, 3. With 7 telescopes, 4. With 4 telescopes. A more faithful image results from using greater numbers of telescopes, particularly with regard to the locations of hotspots.

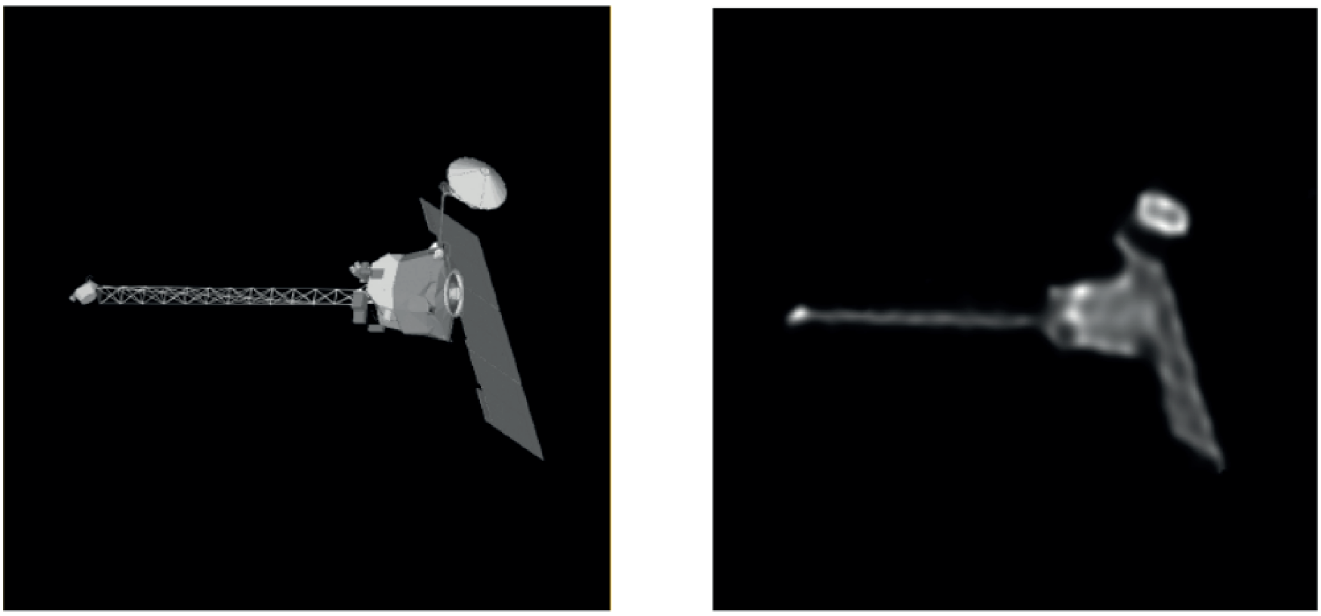

Figure 3: Left: “Truth” image of an Odyssey satellite. Right: Reconstructed image of this satellite based on the simulated performance of the MROI when using 10 telescopes. The satellite is 17 m in length and 35000 km away, so this situation is comparable to imaging a £1 coin from a distance of 50 km.

Interferometric measurements are incredibly sensitive to the alignment of the pairs of beams being combined. For example, an angular drift of 10 µrad during observations is intolerable. An Automated Alignment System (AAS) has been developed for the MROI that will, prior to nightly observing, align the ten beamlines with minimal human interaction. As the night progresses, the AAS will correct thermally-induced drifts.

At the heart of the AAS is an alignment detector called BEASST that is placed in the beam combining laboratory. Similarly to a Shack-Hartmann sensor, it samples the beam pupil with a microlens array. A Raptor Owl 640-II is placed at the focal plane of the microlenses. Figure 4 displays typical image readouts from BEASST, which consist of an array of focal spots. Most beam alignment detectors can only measure either the angle or position of a collimated beam. In contrast, BEASST measures both parameters simultaneously. The beam angle is calculated from displacements of the focal spots while the beam position is determined from the centroid of the pupil intensity distribution.

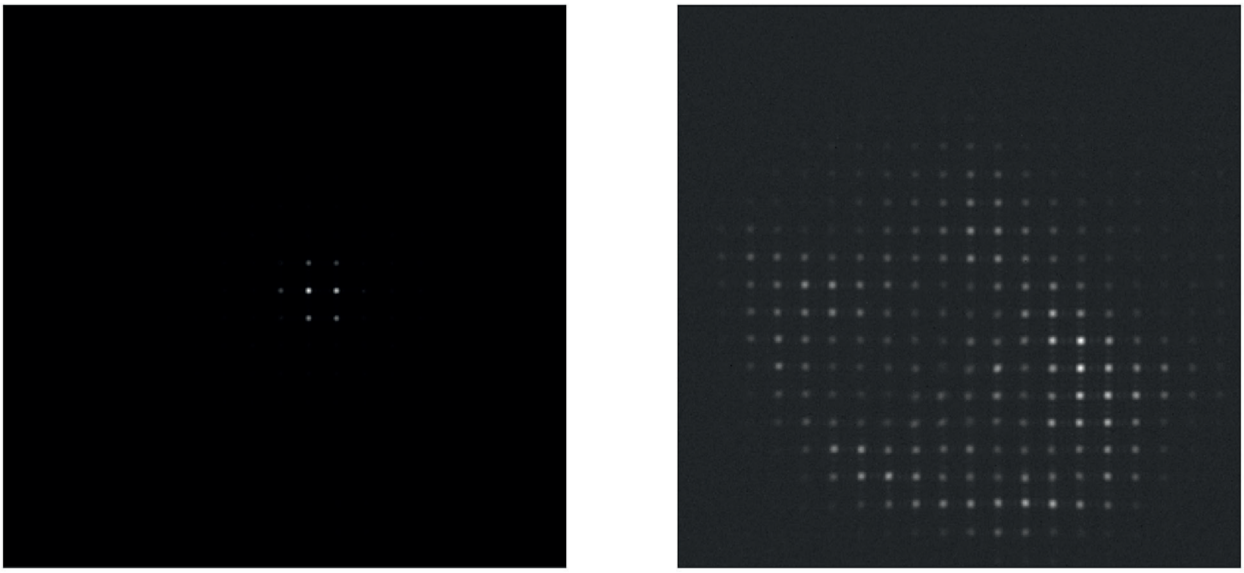

Figure 4: Images captured by BEASST when illuminated with a reference alignment source (left) and with stellar light (right). The low gain mode of the Owl 640-II was used to maximise dynamic range when the reference source was used, while the high gain mode was used to maximise sensitivity when the stellar beam was used. The stellar beam profile is randomly speckled due to its passage through the turbulent atmosphere.

The compact housing of the Raptor Owl 640-II allows ten BEASSTs to be placed in close proximity without blocking the multitude of light beams that propagate in the laboratory. Its low power consumption is also helpful, since dissipated heat induces air turbulence that disturbs alignment on fast timescales. Furthermore, its optional compatibility with the GigE interface has been critical in our application in which the controlling computer is located far from the cameras. Multiplexing the ten cameras will be trivial since their images can be streamed to any PC connected to the network.

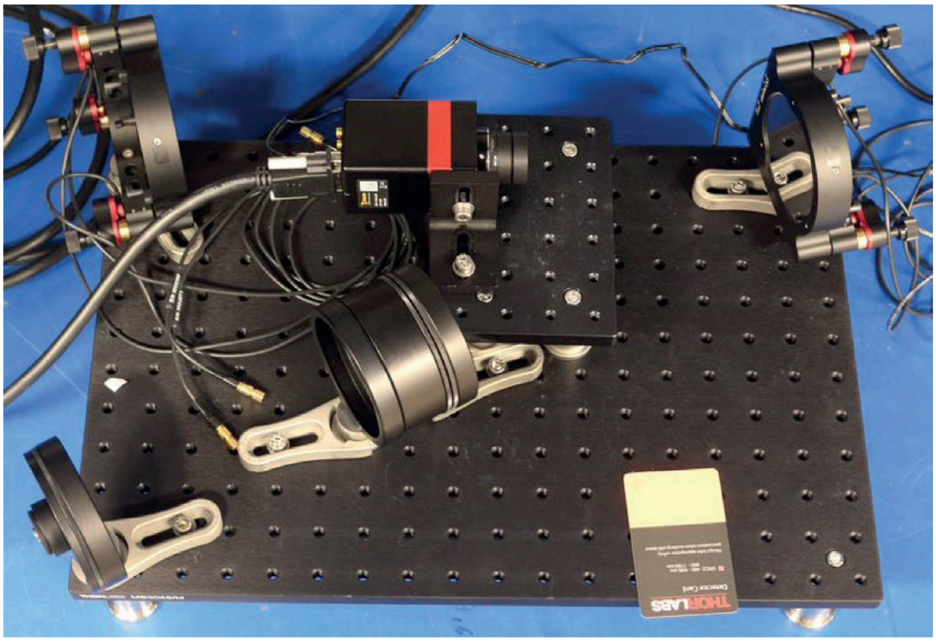

Figure 5: Raptor Owl 640 built into a setup for diagnosing the collimation of an invisible light beam.

Recently a prototype of BEASST was deployed at the Observatory. The Owl 640-II was essential for a number of commissioning measurements. For example, it was used to diagnose the collimation of an invisible reference light beam (see Figure 5). In another application it streamed images at 120 Hz to identify the cause of high frequency alignment disturbances (see Figure 6). Finally, it was used to detect stellar light in the beam combining laboratory for the first time (see Figure 7), which was an important milestone for the MROI.

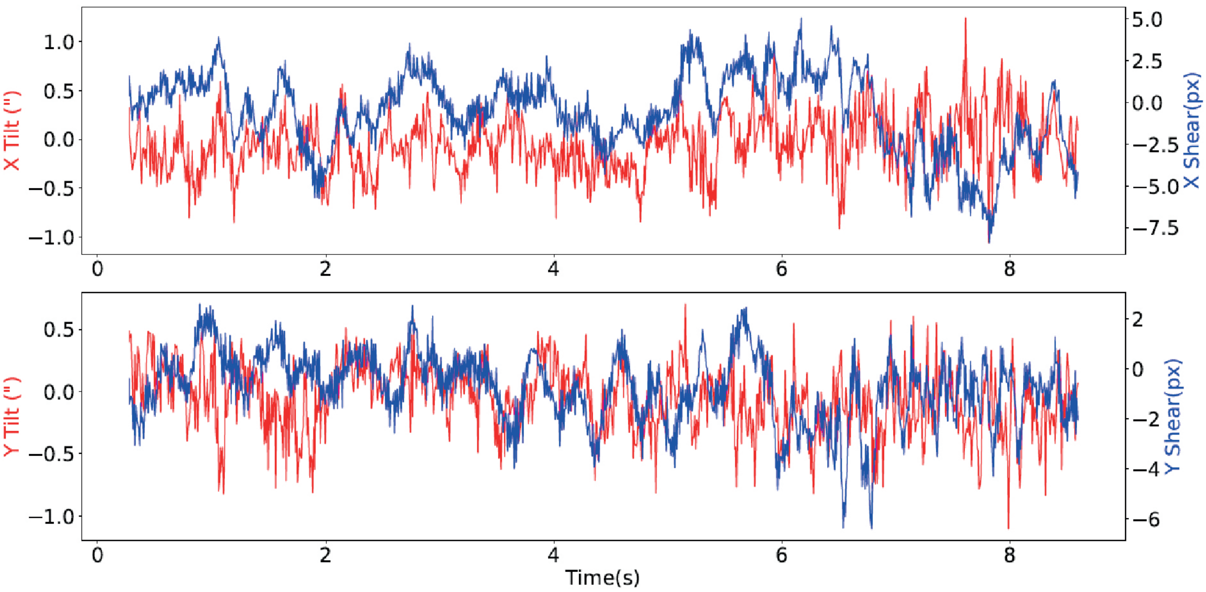

Figure 6: Characterisation of alignment disturbances using BEASST images that were captured at 120 Hz by the Raptor Owl 640-II. Plotted against elapsed time are the extracted beam alignment parameters: the angle (tilt), coloured red, and the position (shear), coloured blue. The top and bottom plots correspond to the horizontal (X) and vertical (Y) directions, respectively. We identified fluctuations at frequencies up to 60 Hz.

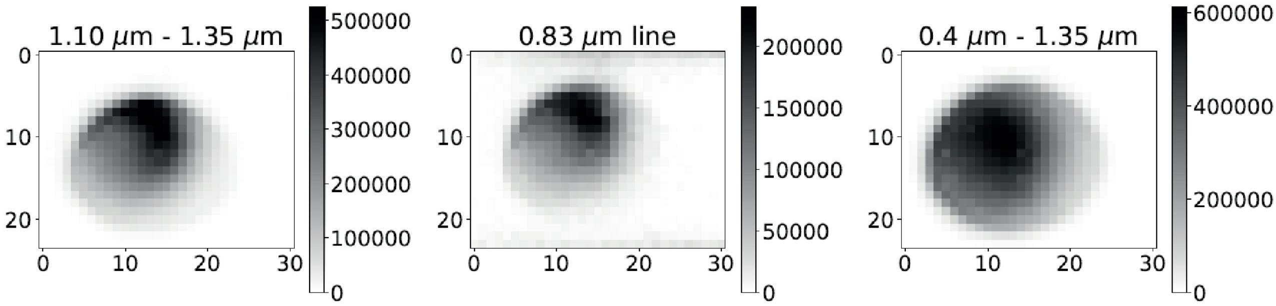

Figure 5: "First light" pupil images captured by BEASST using light from star HIP 102422. The hyperspectral range of the Raptor Owl 640-II between 600 nm and 1700 nm allowed observations at various bandpasses that assisted the interpretation of the results. Note that these images are reduced from the style of images shown in Figure 4 (i.e. they are not direct images of the star).

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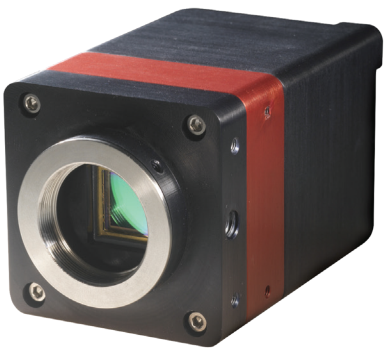

Benefits of the Raptor Owl 640-II:

- **Low read noise in high gain** | For looking at dim star light
- **High dynamic range in low gain** | For bright reference sources for alignment
- **Sensitivity to visible, NIR and SWIR wavelengths** | For looking at a variety of light sources for alignment
- **120 Hz frame rate** | For characterising beam alignment fluctuations
- **Compact body** | Units are going to be placed in tight space envelopes
- **Low power consumption** | To minimise heat dissipation and air currents in the lab
- **Compatibility with CL-GigE frame grabber** | Easy to multiplex

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