HIPO: A High-speed Imaging Photometer for Occultations

E. W. Dunham[a], J.L. Elliot[a,c], T.A. Bida[a], B.W. Taylor[b], P.L. Collins[a], and S. Zoonemat Kermani[a]
[a]Lowell Observatory, 1400 W. Mars Hill Road, Flagstaff, AZ 86001
[b]Boston University, IAR, 725 Commonwealth Ave., Boston, MA 02215
[c]Dept. of Earth, Atmospheric and Planetary Science, MIT 54-422, 77 Massachusetts Ave., Cambridge, MA 02139

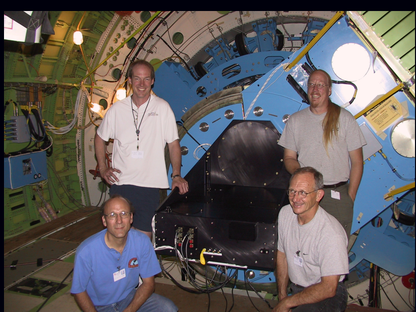
Instrument Description

HIPO is a first generation special purpose instrument for SOFIA. It is a high-speed two-channel imaging photometer that will be used for a variety of time-resolved precise photometry observations, including stellar occultations by solar system objects and transits by extra-solar planets. HIPO is also an important test instrument for the SOFIA telescope and has already been used for ground-based test programs in 2004 and 2008. HIPO includes optimized blue and red channels and it is possible to co-mount FLITECAM for simultaneous observations at two optical bands and one IR band. We have successfully operated HIPO and FLITECAM together, though not yet on the SOFIA telescope. A variety of readout modes and two different CCD types are currently available to provide time resolution ranging from hours to tens of microseconds. The HIPO optical system also contains Shack-Hartmann capability for use in aligning and testing the SOFIA telescope optics.

Flexible observation modes and telescope control are facilitated by TCL scripting and real-time analysis capabilities that are included in the primary data collection program.

A number of upgrades have been made to HIPO over the years, including new user interface computers, a revised control software system, new network switches, improved failure recovery capabilities, and optional smaller and faster CCD detectors. We are working on image motion compensation capability and are considering incorporating grisms. Reconfiguration of the optical layout and detectors within the main structure of the instrument is an effective path for rapid deployment of new capabilities. We are also embarking on a set of laboratory tests to help optimize HIPO for precise photometry applications such as extra-solar planet transit work.

HIPO passed its FAA conformity inspection in 2006 and is ready to proceed to flight status. Our first flight opportunity is presently scheduled for late 2011.



The completed instrument is shown mounted on the SOFIA telescope in 2004 (above left) and the completed rack (above right) is shown in the lab in 2007. The two channel nature of the instrument is evident in the symmetry of the rack layout, broken only by a power control chassis. The laptop computer is not part of the normal rack configuration.

A table of key HIPO performance characteristics is found below.

Key HIPO Performance Characteristics

Parameter	Performance (for CCD47-20)
Read Noise	8e$^-$ at 1 Mpx/s, 5e$^-$ at 666 Kpx/sec, 3e$^-$ at 200 Kpx/sec
Peak Quantum Efficiency	82% (blue), 88% (red); 42% minimum from 350-850 nm
Optics Throughput	66-73% (blue, 0.34-0.64μ) 72-82% (red, 0.46-1.0μ)
Distortion	< 0.25% (red), < 0.50% (blue)
Filters	Johnson UBVRI and Methane, 892 nm / 17.8 nm FWHM
Other optical arrangements	Pupil viewing, Shack-Hartmann, Retroreflection, bare CCD
Unbinned image scale	0.327 (red), 0.331 (blue), .055 (bare CCD) "/pixel
Field of view	5.58' (red), 5.66' (blue), 0.94' (bare CCD)
Image quality	80% encl. light < 2.5 pixel diameter
Maximum Full Frame Rate	2 Hz
Maximum Frame Rate	80 Hz for single optimal 80x80 subframe, binned 3x3
Multiple Subframe Rate	11.5-22.2 Hz for three 80x80 subframes binned 3x3
Time/Position Accuracy	CCD clocking 3.5 μs late (typ), ±5 meters
Stiffness	~0.05 arcsec flexure, ~100 Hz lowest mode frequency

HIPO Data Products

The HIPO detectors include a pair of e2v CCD47-20 and a pair of e2v CCD67 frame transfer CCDs. The split parallel clock and dump gate features of these parts are heavily used in the HIPO readout modes. The CCD67's are smaller and faster than the CCD47s, and we have achieved 400 Hz frame rates with basic occultation mode using a 30x30 pixel, 2x2-binned subframe. Such capability will be useful for telescope testing and image motion compensation.

HIPO uses ARC (Leach) Generation II CCD controllers. We have made substantial modifications to the DSP code in the PCI interface card to use DMA data transfers across the PCI bus using the Gen III process. This results in robust performance in the presence of bus contention and allows simultaneous CCD data acquisition and disk writes. A circular buffer approach is used to allow very long time series data files to be obtained. The HIPO time series data files are 3-dimensional FITS files with the third dimension being time. Single Frames and Find are 2-D FITS files.

The CCD readout DSP code for the timing card has also been extensively modified. HIPO supports subframes using the approach provided by ARC, but the generalized ARC binning approach had too much overhead to meet the HIPO data rate requirements. We use in-line code in the serial read loop for serial binning factors of 5 or less and the generalized approach, with its speed penalty, for larger binning factors. HIPO also uses a hardware triggered readout approach for most of its time series modes to insure accurate and deterministic timing. Software timing is optional.

CCD Readout Mode Descriptions

Single Frames

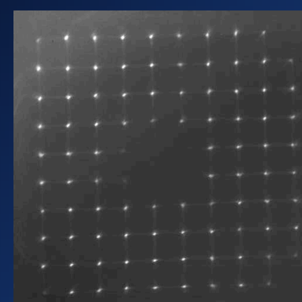
This mode simply takes a 2-dimensional image and stores it to disk. It is used for low speed work such as occultation prediction astrometry, measurement of gyro alignment and drift, general photometry, and Shack-Hartmann testing (right).

Find Mode

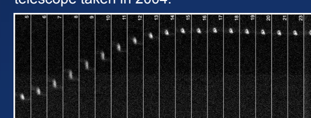
This mode is an adaptation of single frames in which images are obtained continuously until stopped. They are not stored, but the final image may optionally be stored. It is normally used in field acquisition.

Basic Occultation Mode

This is the most general, but slowest, of the HIPO time series readout modes. It provides full support for multiple subframes and there is no preferred subframe location. On each trigger a full frame transfer is done and readout of the storage area is overlapped with the next integration in the image area. The frame rate depends on the location(s) of the subframe(s), binning factor, and details of the clock timing. For typical occultation use frame rates of 10-50 Hz are possible with the CCD47 and 400 Hz with the CCD67.



HIPO Shack-Hartmann image of the SOFIA telescope taken in 2004.



HIPO fast dots time series resolving the risetime of the SOFIA chopping secondary during tests in 2008. The interval between images is exactly 1 ms.

Fast and Pipelined Occultation Modes

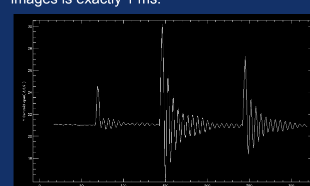
These are variants of basic occultation mode with improved duty cycle (fast) and frame rate (pipelined). These improvements come at the expense of requiring a single subframe located at the bottom of the imaging area of the CCD. Pipelined occultation imposes the additional constraint that the subframe height be nearly an odd integral submultiple of the image store area's height. These modes can achieve frame rates of 50-100 Hz with the CCD47 and will be used mainly for SOFIA testing.

Slow Dots and Strip Scanning (TDI) Modes

Like the special occultation modes, slow dots requires a single subframe located at the bottom of the image area, and with the constraint that the frame height be nearly an integer submultiple of the image store area's height. On each trigger the subframe is read out with the split parallel clocks being ganged together. For a subframe height of one pixel this becomes strip scanning or TDI mode.

Fast Dots Mode

Fast dots obtains a finite string of images using the CCD as a charge storage register. On each trigger the CCD parallel clocks shift the accumulated charge image down by the subframe height. When the first charge image is at the serial register the shutter closes and the entire CCD is read out. Fast dots can achieve frame rates of ~2 KHz for ~40 images with the CCD47.



Centroid position for images in a pipelined occultation time series taken in the lab using an artificial star light source. The light source was tapped three times to introduce oscillations. The subframe size was 40x54 pixels with an 80 Hz frame rate.

References

1. Dunham, E.W., "The Optical Design of HIPO: A High-speed Imaging Photometer for Occultations", Proc. SPIE 4857, 62-72, (2002).
2. Dunham, E.W., J.L. Elliot, T.A. Bida, and B.W. Taylor, "HIPO – A High-speed Imaging Photometer for Occultations", Proc. SPIE 5492, 592-603 (2004)
3. Taylor, B.W., E.W. Dunham, and J.L. Elliot, "Performance of the Lowell Observatory Instrumentation System", Proc. SPIE 5496, 446-454, (2004)
4. Dunham, E.W., J.L. Elliot, T.A. Bida, P.L. Collins, B.W. Taylor, and S Zoonematkermani, "HIPO Data Products", Proc SPIE 7014, 70144Z (2008)