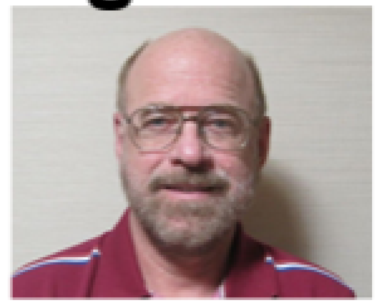
ASHI: All Sky Heliospheric Imager August 22-26 2022 Balloon Flight and Image Data Reduction Progress

Bernard V. Jackson[1#+]



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Abstract

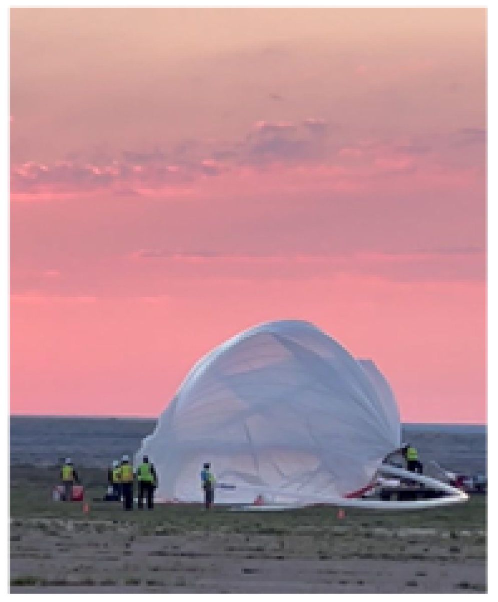
We have conceived, designed, and have evaluated components for an All-Sky Heliospheric Imager (ASHI), suitable for flight on future space missions. ASHI was tested last summer on a NASA-sponsored topside balloon flight; this presentation highlights the images taken and the current state of the image data reduction by this instrument on its successful overnight flight. ASHI is currently being promoted as a hosted payload on a DoD Space Test Program satellite. As a simple, light weight (~6kg), and relatively inexpensive instrument, the ASHI system has the principal objective of providing a minute-by-minute and day-by-day near real time acquisition of precision Thomson-scattering photometric maps of the inner heliosphere. The instrument's unique optical system is designed to view a hemisphere of sky starting a few degrees from the Sun. A key photometric specification for ASHI is 0.1% differential photometry in one-degree sky bins at 90 degrees elongation that enables the three dimensional (3-D) reconstruction of heliospheric density extending outward from near the Sun. The ASHI system, unlike coronagraphs or other planned heliospheric imagers, will maximize the remotely-sensed analysis of heliospheric structures that pass the spacecraft. This is especially important where recent high-resolution Solar Mass Ejection Imager (SMEI) and STEREO Heliospheric Imager (HI) analyses have shown CMEs have an evolving and "corrugated" structure when they pass nearby. A successful space-borne flight will have an order of magnitude more throughput than SMEI or the STEREO HI instrumentation, and provide a far better science and forecast capability than possible before.

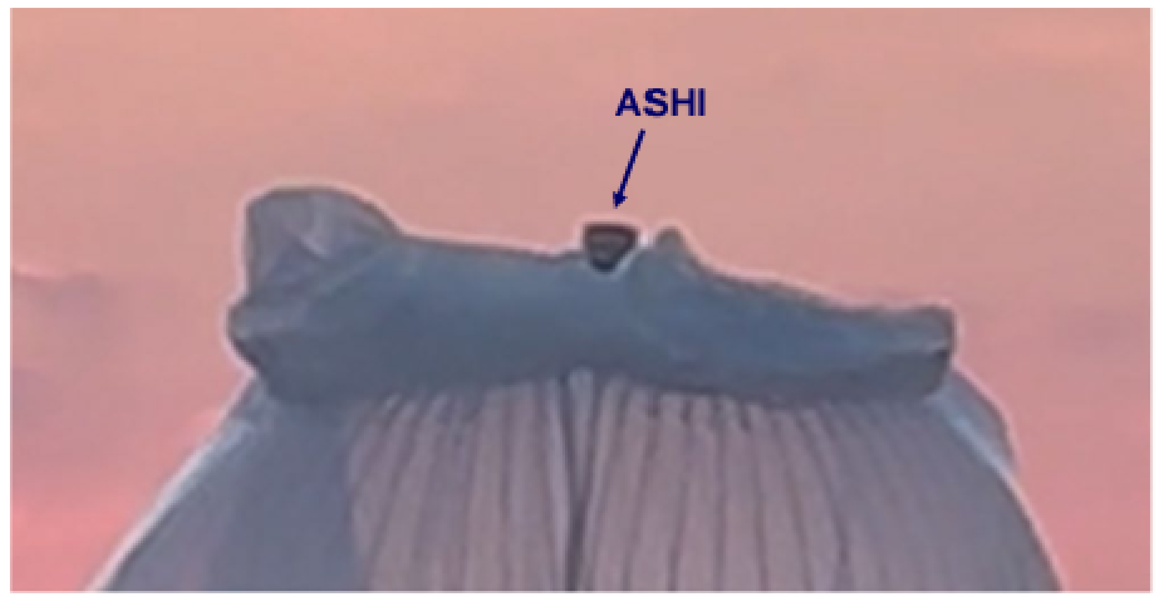
URLS: http://smei.ucsd.edu https://ips.ucsd.edu/stereo https://ashi.ucsd.edu

1. ASHI Balloon Flight

The All Sky Heliospheric Imager (ASHI) was flown successfully on a NASA piggyback topside balloon flight from Fort Sumner, New Mexico from early morning 25 August, 2022 and into the night until cut-down the next day at ~3:00 am, near Seligman, Arizona. ASHI can view within 2° of the Sun, but requires a view of the whole sky with no Sun, Moon, or illuminated balloon present in the field of view. At float altitude of 110,000 feet (35 km) the Earth's horizon is 6° below the horizontal, and thus lights on the Earth's surface are well below the field of view. This enabled ASHI to obtain 4591 5-second images of the night sky. For analysis of the modeling analyses that can be made available with an ASHI spacecraft instrument, see Jackson *et al.* (2020).

ASHI Balloon Top Installation





ASHI Balloon Early Morning Inflation

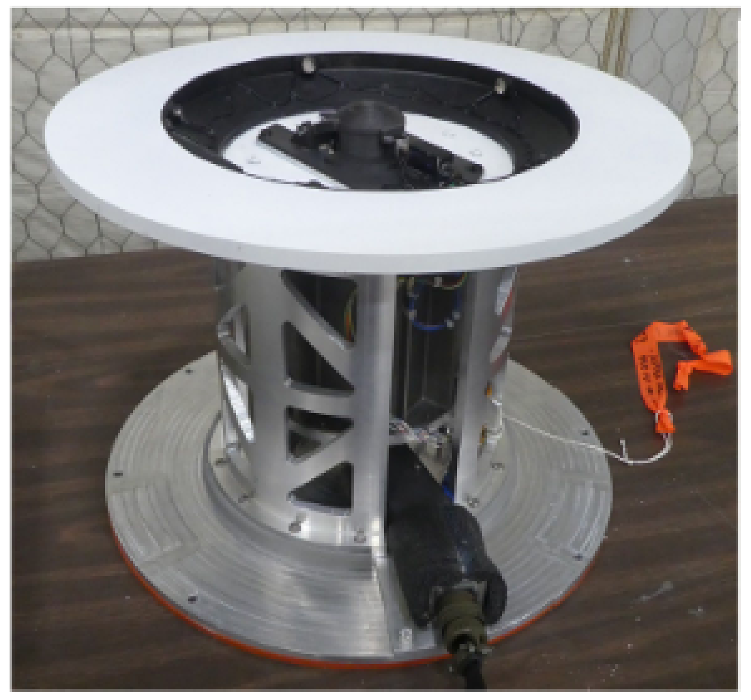
Ready to Launch

Successful ASHI Balloon Launch

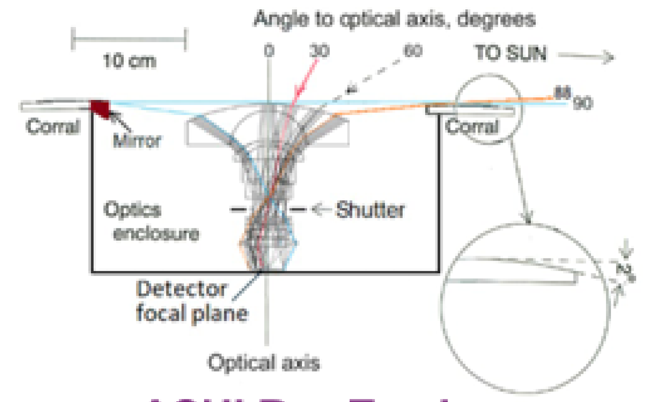
ASHI Recovery

The ASHI system maintained appropriate temperatures throughout the flight, cooled at nightfall, the lens cover opened, and picture taking was successful for 6½ hours. Although ASHI descended from the balloon float altitude of 35 km and landed with the balloon terminal velocity of 60 feet/sec, the instrument sustained only minor scratches on landing. The ASHI hermetic seal was unbroken, and there was no damage to the electronics, corral baffle, lens, or lens cover. For more information about the ASHI flight see https://ashi.ucsd.edu for videos, of the ASHI balloon flight and the instrumentation used.

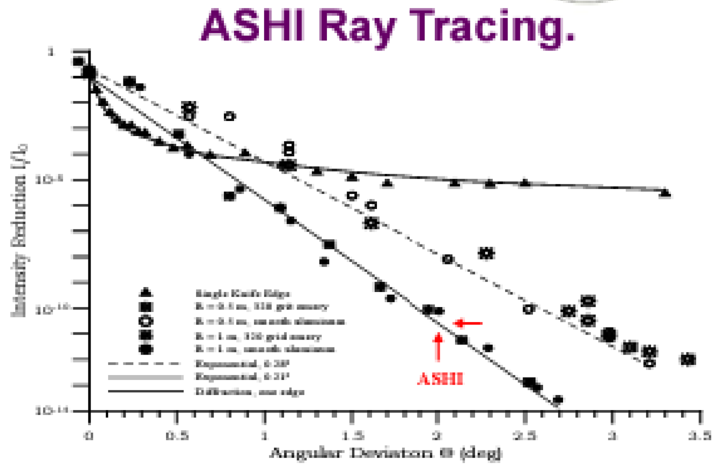
2. ASHI Instrument



ASHI As Flown By Balloon



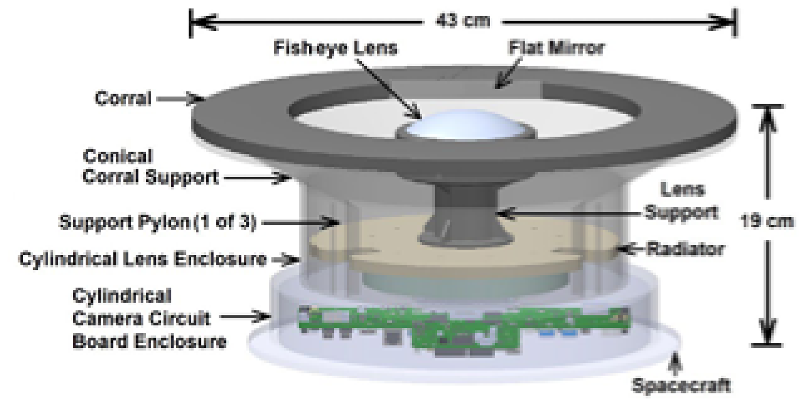
ASHI Ray Tracing.



ASHI Corral Sunlight Rejection

Instrument Specifications:

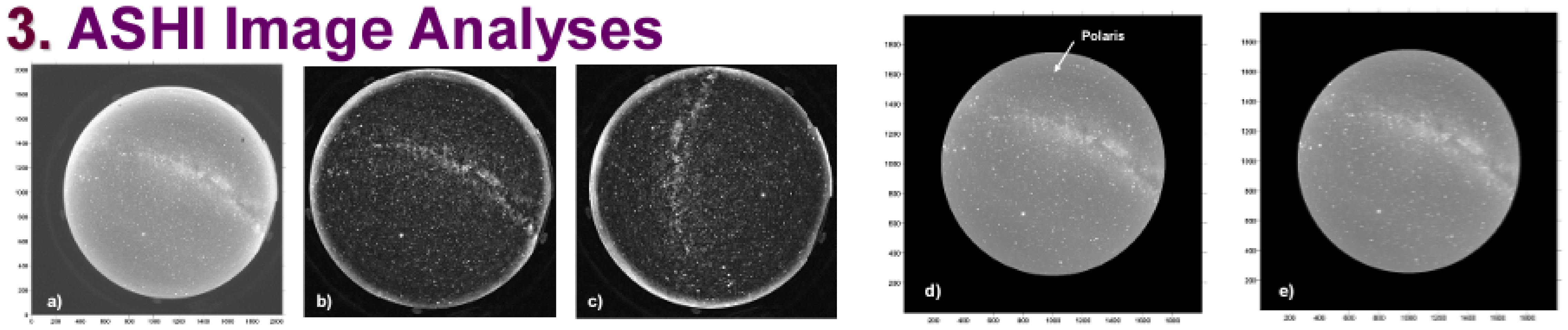
FOV:	176° (2½° from Sun outward)
Mass:	~6 kg
Size:	43 × 19 cm
Power:	8w nominal, 15 max, 3 st by
Data Latency:	2 hours



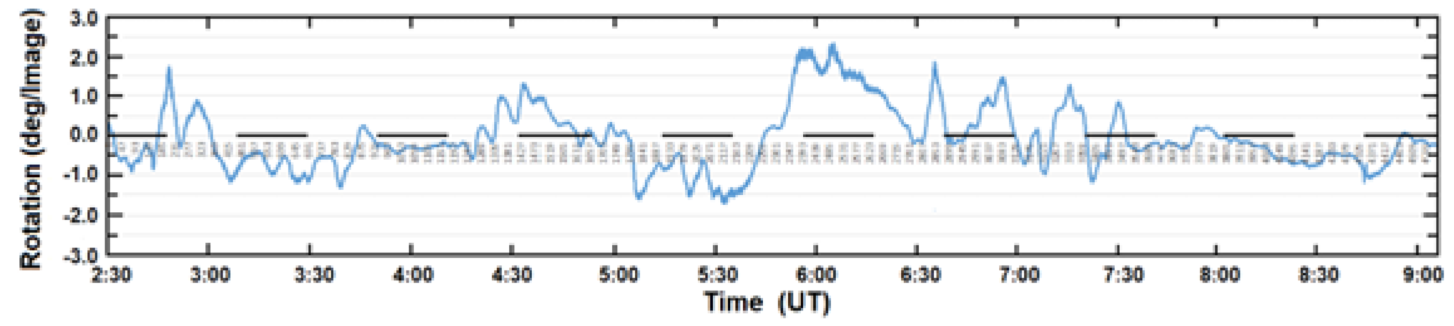
ASHI Spaceflight Configuration

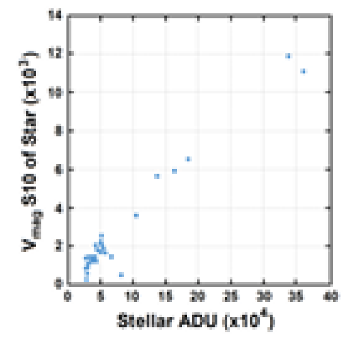
The ASHI system is a instrument designed to view nearly a hemisphere of sky in Thomson scattered light. To do this it must reduce light from the Sun, Moon, and glints from the spacecraft by at least 15 orders of magnitude to view the sky 90° from the Sun-Earth line. The unique 2° curved corral baffle shields the lens from these bright objects by over ten orders of magnitude to the level of the stellar brightness. A good optical-quality lens further reduces the background light to the required level. This allows ASHI to view the heliosphere from 2½° of the Sun to nearly 180° away from it. Although tested thoroughly in a laboratory (Buffington, 2000), until the NASA balloon flight the corral was never flown in space before. On this balloon flight there was no evidence of ground light illumination of the inner top of the baffle that would indicate stray light scattering around the corral baffle curve.

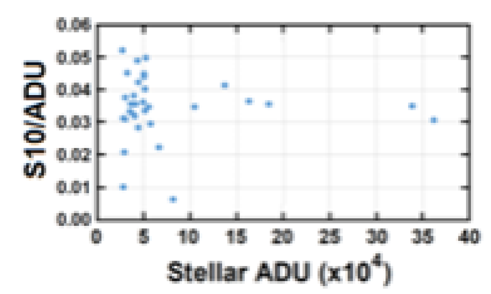
3. ASHI Image Analyses



a) Raw image (#4170) is shown with b) and image #4355 c) with the stellar signal enhanced to map the sky above the balloon as it rotates and travels westward through the night. d) A composite of 50 images (#4150 to #4199) is rotated so that the north celestial pole is at the top. e) The 50-image composite is stretched to remove a small effect of the non-linear fisheye lens mapping.

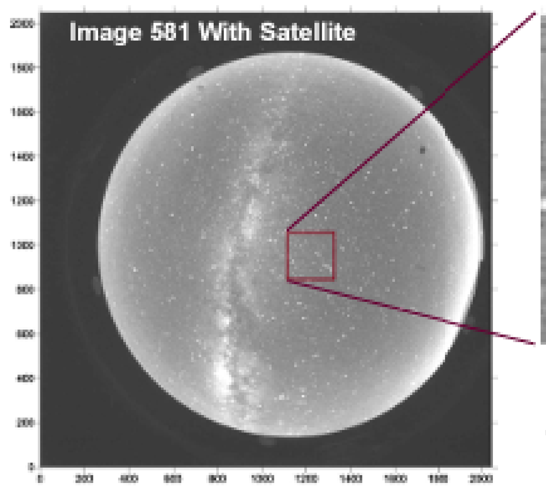


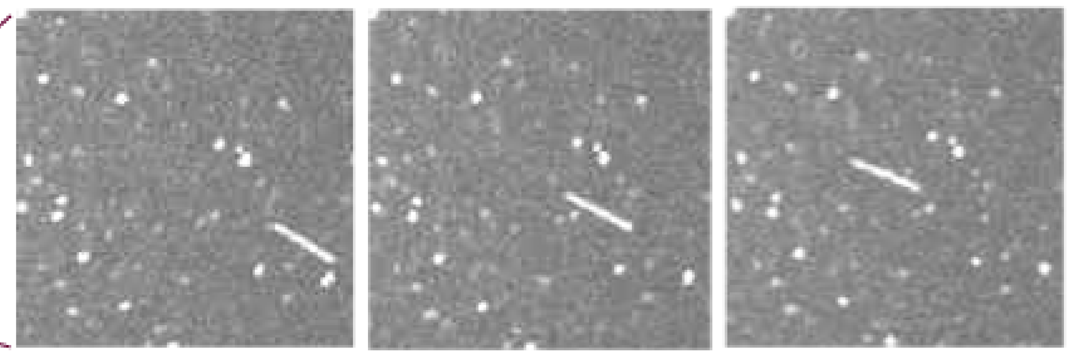




Left above is the balloon rotation rate through the night in degrees per image for the 6½ hours of data accumulation. This rate was higher than expected, and broadened the stellar image point spread function at the outside edge of the FOV somewhat. Above right is group of stellar V magnitude brightness values on an ASHI image in S10 versus the star's analog to digital unit (ADU) camera measurement value, and the ratio of the star's S10 versus its ADU value. The SMEI S10/orbit lower limit 90° from the Sun was ~0.03 S10 with stars removed and the other sources of light kept constant. With the ASHI balloon CMOS camera known to have a 1-electron read noise, a conversion of ~1 ADU/electron, and assuming the read noise quadrature's down, it will take ~1100 ASHI images to get below this limit. Thus, the above shows that for the ASHI balloon flight, a little less than a two-hour (1440 ASHI balloon composite image) is approximately equivalent to a 140-minute orbital view from SMEI 90° from the Sun.

To the right find observations of a satellite present in the ASHI images. Hundreds of these objects are readily viewed in single ASHI balloon images. Although removed in the heliospheric composite images because they move rapidly, they can nevertheless be easily tracked by careful data editing.





Images 581, 582, 583 showing a satellite motion streak in the night sky that is present in the all sky image to the left.

4. Conclusions:

There is far more to do to provide good images from the balloon flight ASHI instrument, and indeed even more from the ASHI spacecraft instrument; we have only gone part way in this effort to date. Once the images above are placed into sidereal coordinates, the stellar signals will be mapped and removed. This will go in hand with the removal of other sources of light including airglow, obviously present around the periphery of the balloon images. Following, the images can be translated into heliographic coordinates, and Sun-centered skymaps where the zodiacal light is removed and modeled (unnecessary in the balloon images, but very necessary to provide long-term satellite-based images of corotating heliographic structures in density). In the ASHI balloon images this will serve to provide evidence of the outward-moving heliosphere from these data, and then algorithms to provide correlation tracking, and thus heliospheric speeds of outward-flowing material from ASHI images.

References:

Buffington, A., 2000, 'Improved design for stray-light reduction with a hemispherical imager', *Appl. Optics*, 39, 2683-2686.

Jackson, B.V., Buffington, A., Cota, L., Odstrcil, D., Bisi, M.M., Fallows, R.F., and Tokumaru, M., 2020, 'Iterative Tomography: A Key to Providing Time-dependent 3-D Reconstructions of the Inner Heliosphere and the Unification of Space Weather Forecasting Techniques', Frontiers in Astronomy and Space Sciences, 19 pages, doi: 10.3389/fspas.2020.568429.