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Status of the VERITAS Stellar Intensity Interferometry (VSII) System

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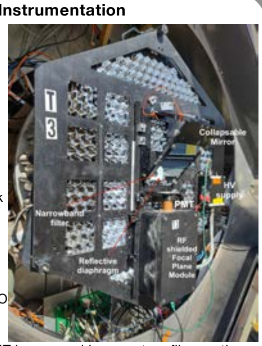
Abstract

The VERITAS Imaging Air Cherenkov Telescope array (IACT) was augmented in 2019 with high-speed focal plane electronics to allow the use of VERITAS for Stellar Intensity Interferometry (SII) observations. Since that time, several improvements have been implemented to increase the sensitivity of the VERITAS Stellar Intensity Interferometer (VSII) and increase the speed of nightly data processing. This poster will describe the use of IACT arrays for performing ultra-high resolution (sub-milliarcsecond) astronomical observations at short visible wavelengths. VSII has been in regular 4-telescope operations on a lunar-monthly (full-moon/rear-full-moon period) cadence since December 2019, recording more than 260 hours of observations to date.

VERITAS Optical Telescopes & VSII baselines

The VSII Observatory uses the optical telescopes of the VERITAS γ-ray Observatory. The VERITAS Observatory [1] consists of an array of 4 IACTs located at an altitude of 1268 m.a.s.l at the F.L. Whipple Observatory near Amado, AZ. Each IACT contains an f/1.0 12 m-diameter segmented Davies-Cotton reflector employing 345 hexagonal facets, resulting in 110 m^2 of light-collecting area. The physical baselines between telescope pairs range from 80-175 m. The Davies-Cotton reflector design creates approximately a 4 nanosecond spread to photons arriving at the telescope's focal plane. The combination of large telescope primary mirror area, fast optics, and 100+ meter telescope baselines enables VSII to provide sub-milliarcsecond angular resolution at short optical wavelengths (B/V bands)[2,3].

VSII Focal Plane Instrumentation



Each VERITAS telescope is instrumented with a removable VSII Focal Plane Plate (FPP) that is mounted in front of the 499-pixel VERITAS camera. The FPP instrumentation employs a collapsible 45° mirror that reflects the starlight from the 12-m Davies-Cotton reflector onto an SII focal plane diaphragm. The diaphragm mount includes a reflective screen and central aperture for a Semrock FF01-420/5-2 narrowband optical filter[4]. A Hamamatsu super-bialkali R10560 photomultiplier tube (PMT), located behind the Semrock filter, converts the starlight flux Into a photocurrent which is amplified by a 200 Mhz bandwidth FEMTO preamplifier, and transmitted to the telescope Data Acquisition (DAQ) system via a 45 m shielded coaxial cable. The PMT is powered by a custom fiber-optic controlled battery-powered High Voltage supply[5]. The PMT and the preamplifier Are located within a sealed RF shielded enclosure to reduce RF pickup noise. These sealed units are called Focal Plane Modules (FPMs).

Zero Baseline Upgrade

In June 2021, a specialized 'zero baseline (ZB) beamsplitter' FPP was constructed and deployed on VERITAS Telescope 1. The ZB FPP adds a non-polarizing 50-50 beamsplitter after the narrowband Semrock filter. Two independent FPMs mounted perpendicular to each other on the FPP read out the split optical beam. Special care is taken to ensure the FPMs do not share a common ground connection on the FPP to eliminate ground-loop noise pickup. Each FPM uses independent batteries, HV supplies, signal cables, and DAQ systems in the trailer. Successful commissioning of the ZB FPP was performed using SII observations on June 24-26, 2021.

References

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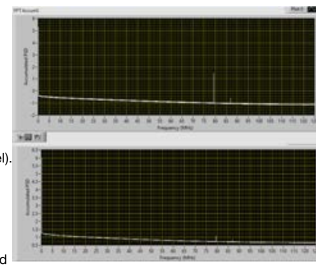
[5] Cardon, R. et al., A Fiber Optic controlled High Voltage System for Stellar Intensity Interferometry, *Proc. 36th International Cosmic Ray Conference*, PoS(ICRC2019) July 2019.
[6] https://www.sevensols.com/index.php/products/wr-len

RF Noise Reduction

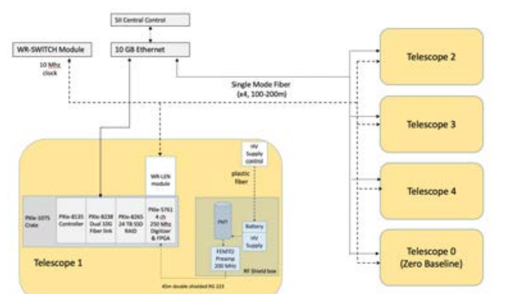


Each PMT is completely encased in a tight-fitting brass tube to reduce RF pickup into the PMT dynodes. However, FFT analysis of data from each SII PMT in December 2020 revealed the presence of both persistent and transient RF noise in the FFT spectrum (Figure left, upper panel). Prominent RF pickup specific to the FLWO observatory site is observed at a measured frequency of 79 MHz.

Additional RF shielding was added To the FPPs in January 2021 to reduce RF pickup. The PMT and the preamplifier were fully encased in an RF shielded enclosure (FPM). The FPM enclosure reduced the RF pickup in each SII channel by a factor of 8 or more (Figure left, lower panel).

Addition tests have demonstrated that additional RF shielding of the 45 m RG-223 coaxial cables can reduce the 79 MHz pickup by another factor of 3 or more. These cables are expected to be retrofitted with additional RF shielding in Summer 2021.

VSII Data Acquisition System



Each telescope's DAQ system uses an independent PXI Express (PXIe) crate with a high-speed backplane (4 GB/sec) to provide local data recording. The crate holds a high-speed PXIe-8135 controller and is linked to a high-speed (700 MB/sec) 24 TB SSD RAID disk (NI-8265). Each PMT signal is continuously digitized at 250 MHz by a 12-bit, DC-coupled NI-5761 FlexRio Module. The 250 MHz digitization rate provides a sampling period that matches the 4 nsec time dispersion of the VERITAS optics. The digitized data from each PMT is truncated to 8 bits and merged into a single continuous data stream by a Virtex-5 FPGA processor. The data stream is transported across the high-speed PXIe backplane and recorded to the RAID disk. A White Rabbit timing system[6] uses single-mode fiber (SMF) optic links to distribute a centrally generated 10 MHz clock to each SII DAQ system telescope with a <200 psec RMS precision. The VSII DAQ system is controlled using LabView software.

Future Improvements

In Fall 2021, the VERITAS-SII system will begin the installation of several additional improvements to increase VSII's operation efficiency and sensitivity. These improvements will include:

- Upgrade of RAID storage at each telescope to 100TB. This storage will accommodate a full week of VSII observations during the longest winter nights of the observing season.
- Development of improved narrowband optical filters. The updated filter will be custom designed to correct for the shift of bandpass frequency at non-zero incidence angles. When installed, these filters are expected to increase Signal-to-Noise (S/N) by a factor of 1.5-2.0.
- Automation of the telescope pointing corrections. The focal plane's CCD focal plane camera will be used to determine when a star is drifting from the SII photosensor. A machine learning algorithm will identify misalignments and send real-time corrections to each telescope's tracking position.
- Recoating of the VERITAS 12 m diameter primary mirror segments. The improved reflectivity will increase S/N by an additional factor of 1.5.

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