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The VERITAS Stellar Intensity Interferometry (VSII) Survey of Stellar Diameters

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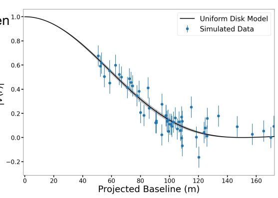
Abstract

The VERITAS Imaging Air Cherenkov Telescope (IACT) array was augmented in 2019 with high-speed focal plane electronics to allow its use for Stellar Intensity Interferometry (SII) observations. Since January 2019, The VERITAS Stellar Interferometer (VSII) recorded more than 250 hours of moonlit observations on 39 different bright stars and binary systems ($m_V < 3.74$) at an effective optical wavelength of 416 nm. These observations resulted in the measurement of the diameters of several stars with better than 5% resolution. This poster describes the status of the VSII survey and analysis.

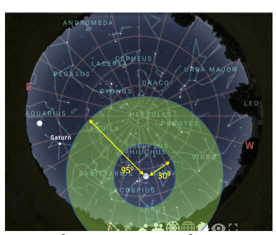
Selection of Survey Targets



The suitability of a target for any given night of observation depends upon multiple factors. These include source-specific characteristics (stellar classification and magnitude, stellar diameter, and single/binary/multiple star configuration), observatory Characteristics (latitude/longitude, telescope mirror diameters, telescope separations, electronic noise, and optical efficiencies), and astronomical considerations (Source RA/Dec, number of hours observable on a given night, seasonal nighttime visibility of the source). VSII uses the public domain ASIIP software package[1,2] to identify and rank the suitability of potential sources for any given observation night.

ASIIP simulations are performed for a specified SII observing week during the year, and potential observation targets (drawn from several catalogs, including the JMMC catalog [3] are ranked according to the estimated error in the determination of the stellar diameter. For example, large diameter stars (>1 mas) may be poorly fit if the source can only be observed directly overhead on a given night. In contrast, smaller stars (< 0.5\ mas) may be unresolved if the observations are constrained to low elevations on a given night. At the beginning of the observing night, the simulated visibility curves for each target (e.g. Figure above: simulation of VSII observations of Bellatrix (γ Ori) on the night of 2/27/21) are reviewed, and An observing sequence of 2-5 stellar observations is generated. Then, the observing plan is sequenced to provide an appropriate set of observation hours and baselines for each target to result in a high quality measurement of each visibility curve.

Effect of Moon Angle on Observational Planning



VSII observation are performed during full/near-full moon phases. The presence of moonlight places several restrictions on the observability of specific stars on a given night. The effects include moonlight shining directly on the focal plane, and the increased of background light created by scattered moonlight due to cloud reflections and Mie/Rayleigh scattering, Successful SII measurements can be be made if the source is reasonably bright ($m_V < 3.0$) and the angle between the target source and the moon is restricted to 30° < moon angle < 95°.

This constraint severely restricts the locations of accessible targets on any given night (Figure above) [3]. Because the moon's sky location moves eastward across the night sky by ~13° each night, the region of sky accessible for SII observations changes each night. Care must be taken to ensure that observations appropriate baselines for constraining the visibility curve are accessible on a given night. Multi-night campaigns of short orbital period binary systems (e.g. Spica) must be carefully scheduled in order to avoid gaps in the orbital Phase coverage due to changing moon angle constraints.

In practice, observations of dimmer magnitude stars ($m_V > 3.0$) are generally difficult under full/near-full moon conditions. Observations of these dimmer stars must be scheduled to complete before moonrise or after moonset.

References

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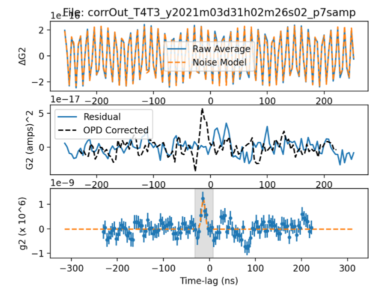
[3] Duvert, G. et al., VizieR Online Data Catalog: JMDC: JMMC Measured Stellar Diameters Catalogue., VizieR Online Data Catalog 2345, November 2016.
[4] Abeysekara, A. U. *et al.*, Demonstration of stellar intensity interferometry with the four VERITAS telescopes, *Nature Astronomy 2020* https://www.nature.com/articles/s41550-020-1143-y
[5] Matthews, N., Intensity Interferometry Observations with VERITAS, PhD Dissertation Univ. of Utah (2020).

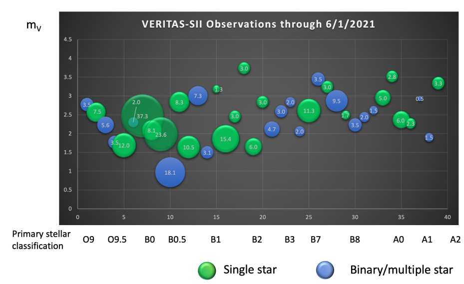
Data Analysis and Extraction of Visibility Curves



Raw data from individual source observations are processed on-site into a "correllelogram" using a pipelined two-telescope cross-correlation algorithm that the FPGAs host in the VSII Data Acquisition crates. Once the correllelogram for each two-telescope combination is computed, each correllelogram is analyzed to extract the magnitude of the visibility at the specific telescope separation. The above Figure illustrates the analysis steps of each two-telescope correllelogram. This procedure is complicated by the presence of RF 79 Mhz noise in the raw data.

First, the raw correllelogram is fitted for a noise model, including a dominant 79 Mhz component and several side frequencies. The weighting of each component is iteratively adjusted to match the raw correllelogram data until the values converge on a satisfactory fit (Figure above, upper panel). Next, the residual between the noise model and the raw data is calculated, and the residual data is corrected for the changing optical path delay during the observation using the known projected distance difference between the two telescopes to the target (Figure above, middle panel). Finally, a Gaussian fit is used to extract the peak of the visibility curve at the expected time lag between telescopes (Figure above, bottom panel). The visibility curve is then calculated using the measured visibility peaks and known telescope separations for every telescope pair in the observation. The final visibility curve must be corrected for the presence of night sky background. After this correction, a suitable stellar diameter model is fitted to the visibility curve to extract a reliable measurement of the stellar diameter [4,5].

Summary of VSII Survey Observations



Since December 2019, VSII has performed more than 250 hours of SII observation on 39 different astronomical targets. The survey includes 21 single stars and 18 binary/multiple star systems ranging in magnitude from $0.97 < m_V < 3.74$. The primary stellar classification ranges from O9 through A2. The Figure above illustrates the number of observation hours on each target as a function of stellar classification (temperature), stellar magnitude m_V, and single/binary star system classification. This plot includes VSII observations through June 1, 2021. The observation exposure is weighted towards longer observation hours for bright ($m_V < 2.5$) O/B0/B1 stars, but there are a substantial number of observation hours spent probing the sensitivity of VSII to dimmer B7/B8/A stars ($2.5 < m_V < 3.5$). Both single stars and multiple stars are broadly represented across visual magnitude and stellar classification.

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