Spinning Slow and Fast: Stellar Atmosphere Models for β Ursae Majoris and α Leonis

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Background

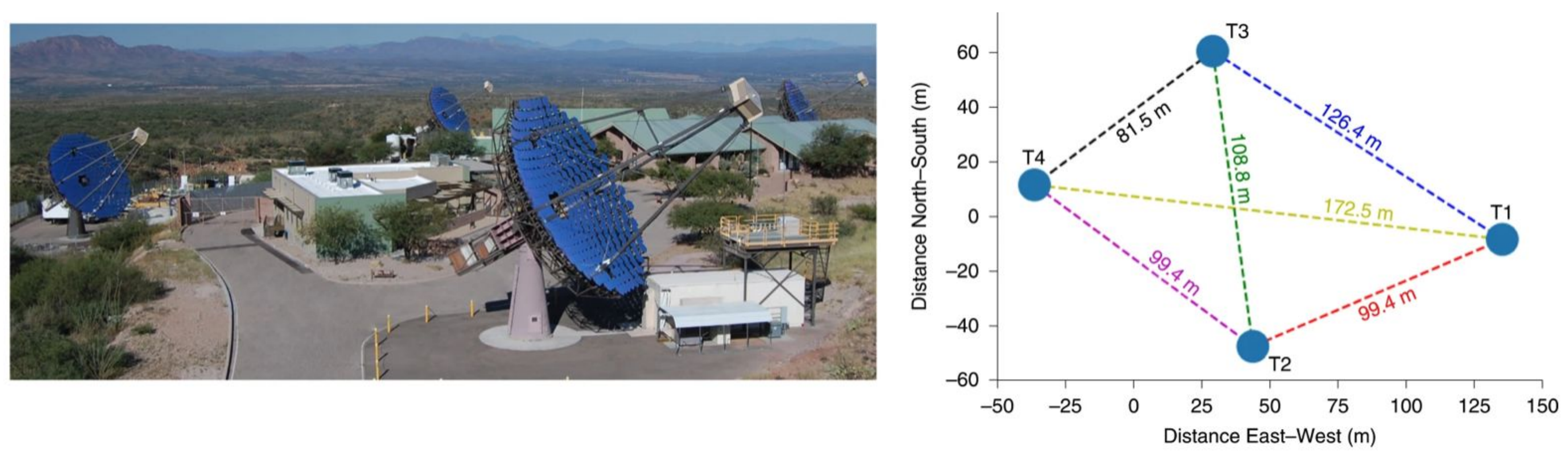

Figure 1: The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is the first experiment to routinely perform Stellar Intensity Interferometry (SII) in the last 50 years. Six unique telescope pairs, yielding six interferometric baselines, can be formed using telescopes T1, T2, T3 and T4. Observations are made at 415 nanometers, in the blue.

Surfaces of both slowly and rapidly rotating stars are being resolved with the VERITAS interferometric telescope array (see Figure 1). These stars are resolved using a technique called stellar intensity interferometry. The observable of interferometry is the visibility, a measure of the interference pattern or correlation of electric currents from each of the six telescope pairs.

Given a model for the intensity, ($I\,(x,y)$, see Figure 2), we compute synthetic visibilities (see Figure 4 and 5) for the slowly rotating β Ursa Majoris and rapidly rotating α Leonis using:

$$V_\lambda(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I_\lambda(x,y)\, e^{i2\pi(ux+vy)}\, dx\, dy \qquad [1]$$

where x and y are positions on the sky and u and v are the positions of the telescopes as seen by a star as it moves through the sky. For model spectra (see Figure 3) we use:

$$F(\lambda) = \int_0^{\pi}\int_0^{2\pi} -\frac{g(\vartheta)}{g_r(\vartheta)} I_\lambda(\vartheta,\phi) R(\vartheta)^2 \sin\vartheta\, \mu(\vartheta,\phi,i)\, d\phi\, d\vartheta \qquad [2]$$

which considers the changes in gravity (g) and radius (R) as a functions of latitude (ϑ) and longitude (ϕ) due to possible rapid rotation as demonstrated by α Leonis.

Model Images and Spectra

Models for the intensity distribution on the sky, $I\,(x,y)$, for each star are shown below (see Figure 2). β UMa has a projected equatorial speed of 45 km/s compared to α Leo's equatorial speed of 343 km/s which significantly distorts its shape.

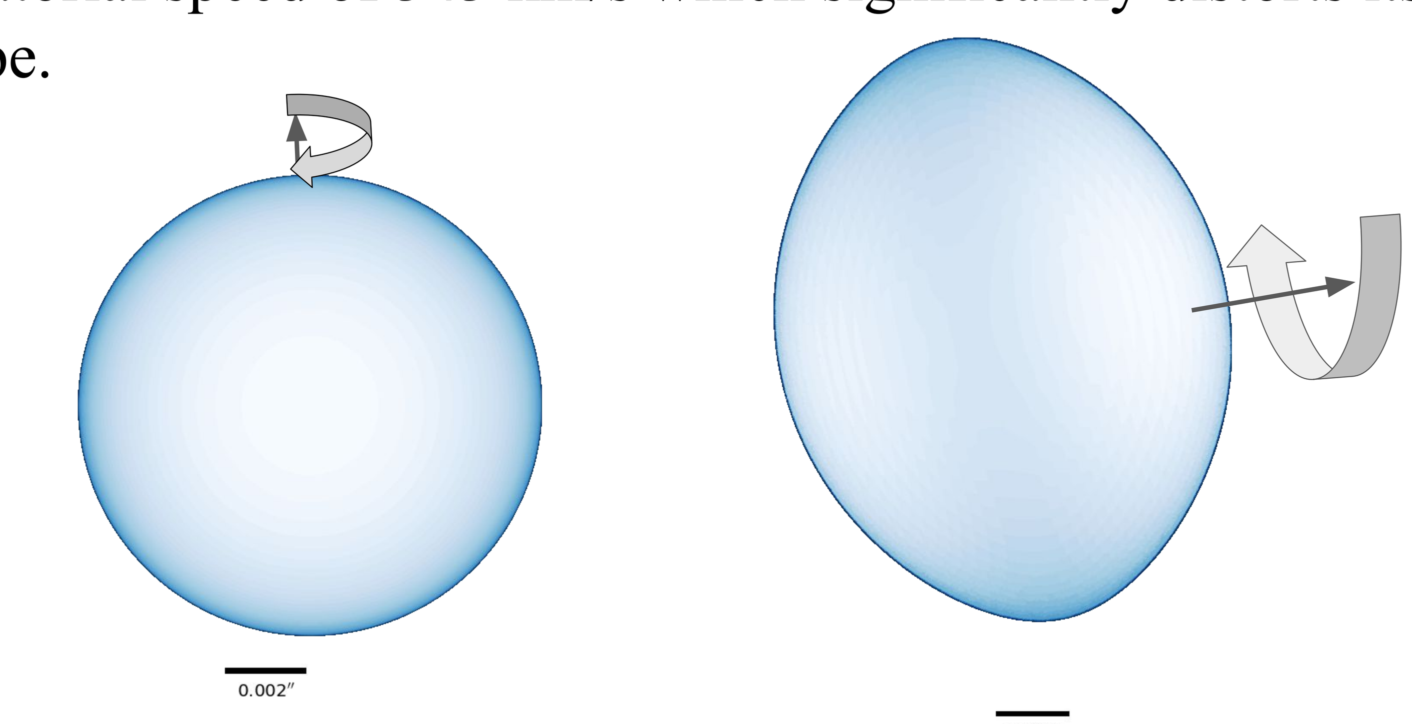

Figure 2: Slow rotator β UMa (left) is spherical at the 0.5% level, while the fast rotator α Leo is 30% larger along its equatorial axis than its polar axis. The scale bar, 0.002 arcseconds, shows the angular size on the sky, about 900,000 times smaller than the angular size of the full moon.

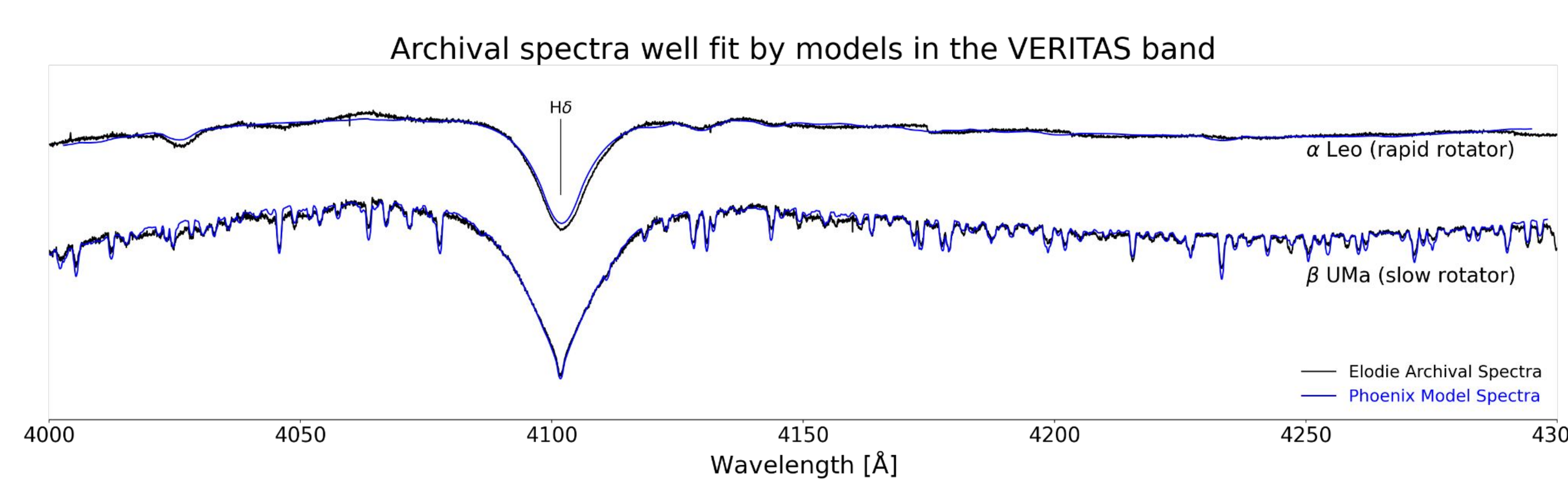

Figure 3: Model spectra from Equation [2] for α Leo (top) and β UMa (bottom) compared to observed spectra. The rapid rotation of α Leo broadens strong Hδ line and washes out many of the weaker spectral lines seen in slow-rotator □ *UMa.*

References

VERITAS photo in Figure 1 is from Abeysekara et al. (2020) in *Nature Astronomy*, 4, 1164 and VERITAS baselines are from Davis, Matthews and Kieda (2020) in *Journal of Astronomical Telescopes and Systems,* 6 , 3.

Parameters for α Leo from Che, X., Monnier, J. D., Zhao, M., et al. 2011, ApJ, 732, 68. Parameters for β UMa from Adelman, S. J. 1996, MNRAS, 280, 130

Model atmospheres were computed using the PHOENIX code, see Hauschildt and Baron (1999) in *Journal of Computational and Applied Mathematics,* 109, 41.

Archival spectra retrieved from Elodie Archive, http://atlas.obs-hp.fr/elodie.

Python code development was aided using notebooks at **cocalc.com**. Visibility and flux computations performed on ERAU Vega cluster using Fortrans codes PHOENIX, VIS and VEGA.

Model Visibilities

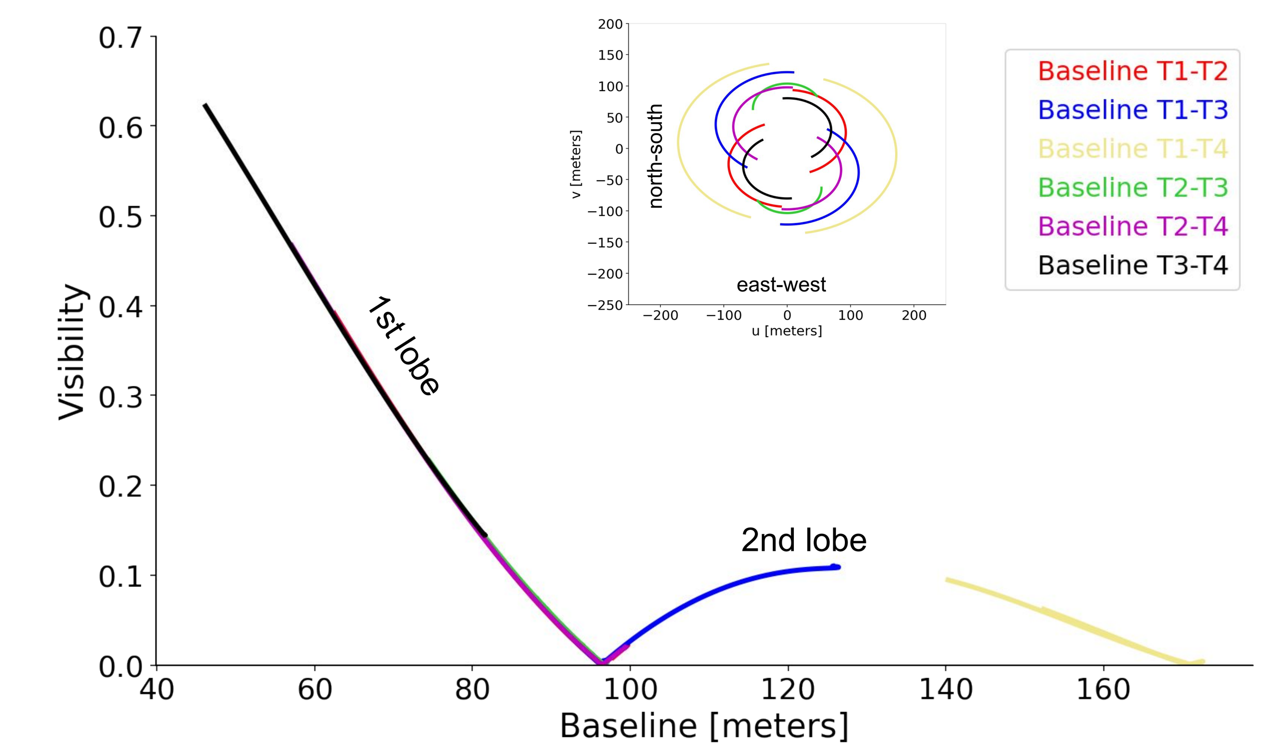

Figure 4: Model visiblities from Equation [1] for β UMa are single valued in the 1st and 2nd lobes indicating the star is circularly symmetric and not distorted. The T1-T3 and T1-T4 baselines have the highest resolution and sample the 2nd lobe.

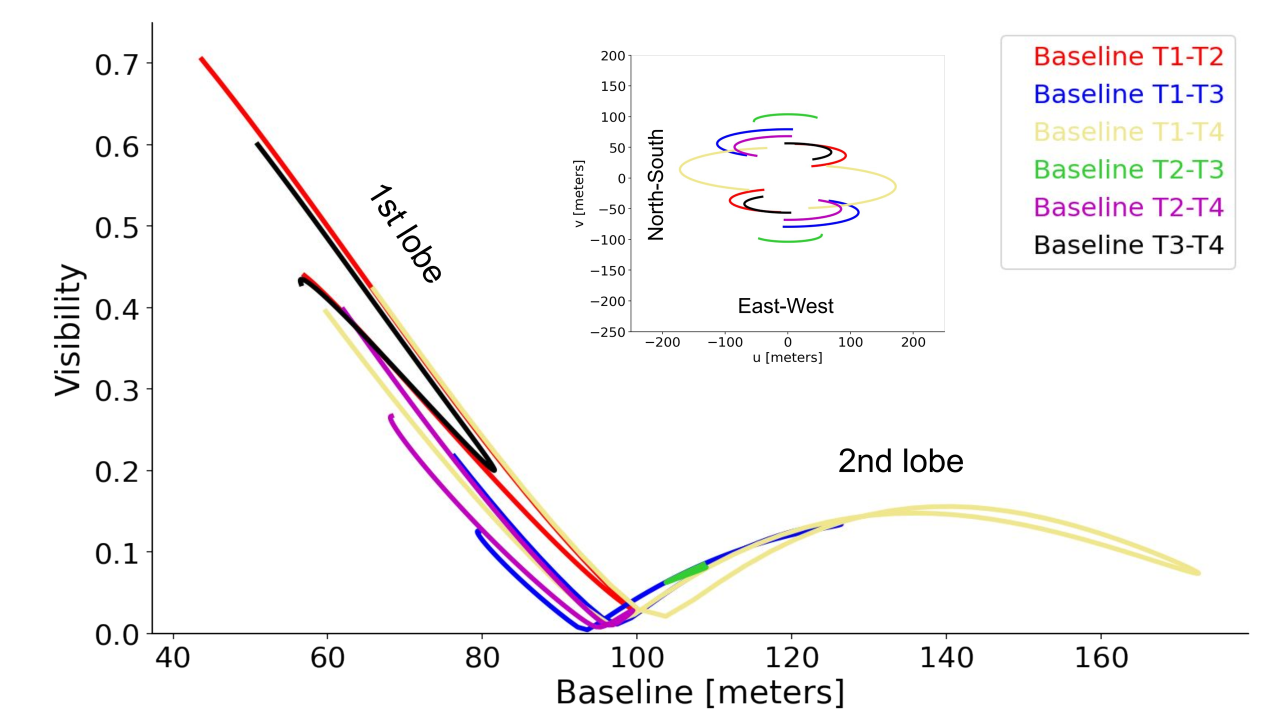

Figure 5: Model visiblities from Equation [1] for α Leo are multi-valued in the 1st and 2nd lobes indicting rotational distortion. The T1-T3 visibilities are the lowest in the 1st lobe because they measure the wider equatorial axis (~North-South) of α Leo , while the T1-T4 visibilities are among the highest in the 1st lobe because they measure along the narrower polar axis (~East-West) of α Leo.

Results

The rotational distortion of α Leo is sampled by 5 of the 6 VERITAS SII baselines, with the visibility expected to vary by 126% at 80 meters, depending on the position angle of the telescope pair. In contrast, β UMa is sampled by 3 of the 6 baselines, but the visibility varies by 1.25% at 80 meters.