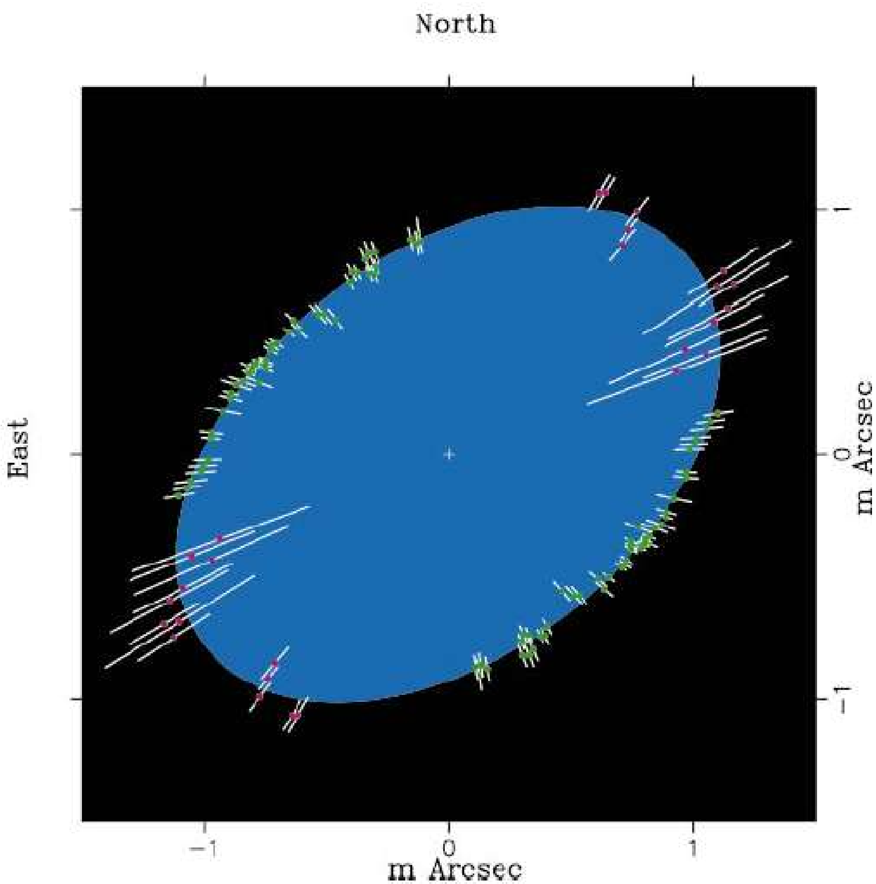
The Polarization of Achernar (α Eri, B3Vpe)

David McDavid
Department of Astronomy
University of Virginia

Abstract

Recent near-infrared measurements of the angular diameter of Achernar (the bright Be star alpha Eridani) with the ESO VLT interferometer have been interpreted as the detection of an extremely oblate photosphere, with a ratio of equatorial to polar radius of at least 1.56 +/- 0.05 and a minor axis orientation of 39 +/- 1 degrees (from North to East). The optical linear polarization of this star during an emission phase in 1995 September was 0.12 +/- 0.02% at position angle 37 +/- 8 degrees (in equatorial coordinates), which is the direction of the projection of the rotation axis on the plane of the sky according to the theory of polarization by electron scattering in an equatorially flattened circumstellar disk. These two independent determinations of the orientation of the rotation axis are therefore in agreement. The observational history of correlations between H-alpha emission and polarization as found in the literature is that of a typical Be star, with the exception of an interesting question raised by the contrast between Schroder's measurement of a small negative polarization in 1969-70 and Tinbergen's measurement of zero polarization in 1974.5, both at times when emission was reportedly absent.

New ESO K-band interferometry



"*The spinning-top Be star Achernar from VLTI-VINCI*"

Domiciano de Souza et al. 2003, A&A, 407, L47

$2a/2b = 1.56 \pm 0.05$

$\theta = 39° \pm 1°$
(minor axis)

A truly distorted star?

- “observed true photospheric distortion with negligible envelope contribution”
  - Hα spectrum from same time + model: emission estimated $\leq 3\%$ across whole line => envelope emits $\leq 12\%$ of photospheric continuum
  - Yudin (2001) reported zero intrinsic polarization
  - distance 44.1 ± 1.1 pc
  - equatorial radius $12.0 \pm 0.4\ R_{\odot}$
  - max polar radius $7.7 \pm 0.2\ R_{\odot}$

Implications

- Assumptions:
  - B3V ($M \cong 6\ M_{\odot}$, $T_p \cong 20{,}000$ K)
  - $v_e \sin i = 225$ km s^{-1} (line profiles)
- Domiciano de Souza et al. say:
  - $R_e = 12.0\ R_{\odot}$

    => No conventional model (radiation transfer + von Zeipel law $T_{eff} \propto g_{eff}^{0.25}$ for gravity darkening + Roche approximation for gravitational potential) can reproduce the observed highly oblate ellipse, for any inclination.
  - So, must investigate internal angular momentum distribution, differential rotation, effect of gravity darkening on line profiles.

Polarimetric observations of Achernar (original sources)

Epoch	p (%)	θ (°)	Reference
1968.1	0.03 ± 0.01	26 ± 10	Serkowski (1970)
1968.9	0.02 ± 0.01	46 ± 14	Serkowski (1970)
1969–70	0.011 ± 0.004	136.2 ± 10.4	Schröder (1976)
1974.5	0.001 ± 0.005	…	Tinbergen (1979)

Emission history

- 1963: no Hα emission
- 1965: strong Hα emission
- late 1960s and early 1970s: no emission seen
- 1974–1978: Hα developed from pure absorption to strong emission

1995 multiwavelength campaign

- Gerrie Peters (USC): **IUE** – uv spectroscopy
- Doug Gies (CHARA): **AAT** – optical spectroscopy
- David McDavid (Limber Obs): **CTIO** – *UBVRI* pol

spectroscopy

- correlated variability of 145 nm flux and line profiles => low-order *g*-mode nonradial pulsation
- prograde for observer, period 1.25 ± 0.05 d

polarimetry

Filter	p (%)	θ (°)
U	0.12 ± 0.05	40 ± 12
B	0.14 ± 0.04	41 ± 8
V	0.11 ± 0.05	45 ± 13
R	0.10 ± 0.06	25 ± 17
I	0.13 ± 0.06	34 ± 13

Conventional view

- Same assumptions:
  - B3V ($M \cong 6\ M_\odot$, $T_p \cong 20{,}000$ K)
  - $v_e \sin i = 225$ km s^{-1} (line profiles)
- "*Stellar Masses and Radii Based on Modern Binary Data*", Harmanec (1988):
  - $R = 3.86 \pm 0.33\ R_\odot$
- "*Model Atmospheres for Rotating B Stars*", Collins et al. (1991):
  - $R_p = 4.6\ R_\odot$
  - $v_c = 410$ km s^{-1} => $R_e < 6.9\ R_\odot$
- ***Clear disagreement with VLTI radius.***

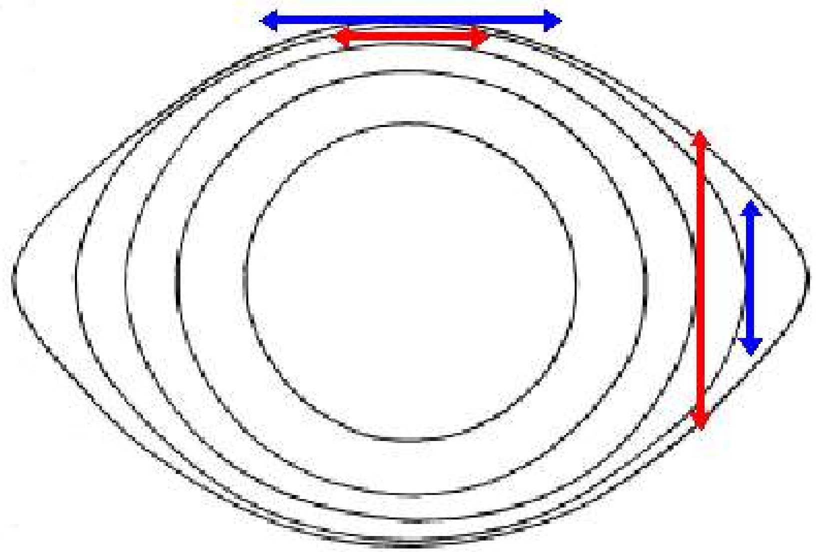
Problems

- If the VLTI measurement corresponds to the photosphere of the rotationally distorted underlying B star with no Hα-emitting disk, it should have a nonzero net polarization due to electron scattering in its outer atmosphere.
- This is inconsistent with Tinbergen's observation of zero polarization in 1974 at a time when Hα showed pure absorption.
- The observational history of correlations between Hα emission and polarization is that of a typical Be star, *with the exception of Schröder's measurement of a small negative polarization in 1969–1970 when emission was absent*. (???)

Doubts about VLTI results

- based on fit of an ellipse to observed squared visibilities V^2 translated to equivalent uniform disk angular diameters
  - ambiguous meaning of “radius” for stars with extended atmospheres: effects of limb darkening, wavelength dependence, and (for rapid rotators) gravity darkening
  - interferometer response functions depend on polarization
- the two axes were calibrated with two different stars
- polarization history of Achernar

Polarization and rotational distortion



- polarization by electron scattering in rotationally distorted stellar atmospheres (Roche example)
- net p can be either + (↕) or − (↔) depending on combination of temperature, inclination, oblateness, and wavelength of observation
  - equator dominates – greater projected surface area
  - pole dominates – hotter, brighter, forward peaking of radiation field (steeper source function gradient)