Computationally Intensive Astrophysics

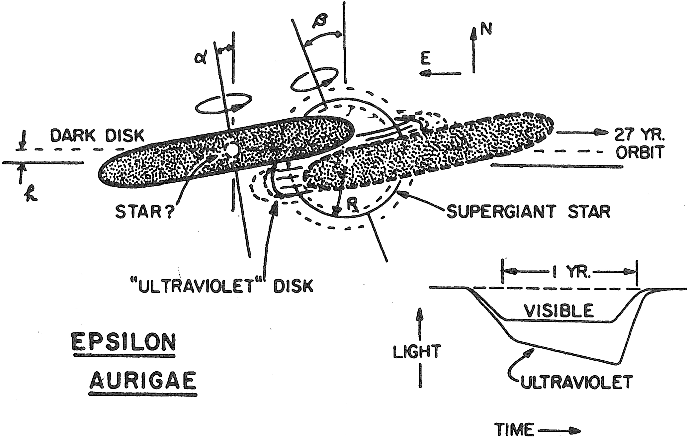
Brian Kloppenborg

July 30, 2009

Outline

1. Epsilon Aurigae - An Extreme Binary Star
   - Palomar Testbed Interferometer
   - New Data
     - CHARA
     - IRTF and SPEX
2. Bow Shocks
   - Motivation
   - Detection Method
   - Results

Current Model of ϵ Aurigae



Model of ϵ Aurigae System (NASA, 1985)

Palomar Testbed Interferometer

Aerial View of PTI and the 200" Palomar Telescope
(Gerald van Belle)

- PTI Operated by the Michelson Science Center on behalf of CalTech and NASA-JPL
- Maximum Baseline, 110 meters
- Resolution 1.67 - 2.18 mas (8.1 - 10.5 nano-radians)

Palomar Testbed Interferometer

The Astrophysical Journal, 689: L137–L140, 2008 December 20

INTERFEROMETRIC STUDIES OF THE EXTREME BINARY ϵ AURIGAE: PRE-ECLIPSE OBSERVATIONS

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ABSTRACT

We report new and archival *K*-band interferometric uniform disk diameters obtained with the Palomar Testbed Interferometer for the eclipsing binary star ϵ Aurigae, in advance of the start of its eclipse in 2009. The observations were intended to test whether low-amplitude variations in the system are connected with the F supergiant star (primary), or with the intersystem material connecting the star with the enormous dark disk (secondary) inferred to cause the eclipses. Cepheid-like radial pulsations of the F star are not detected, nor do we find evidence for proposed 6% per decade shrinkage of the F star. The measured 2.27 ± 0.11 mas *K*-band diameter is consistent with a 300 solar radius F supergiant star at the *Hipparcos* distance of 625 pc. These results provide an improved context for observations during the 2009–2011 eclipse.

Subject headings: binaries: eclipsing — stars: atmospheres — stars: fundamental parameters — techniques: interferometric

CHARA

Mt. Wilson Today, (Georgia State University)

- Operated by Georgia State University and collaborators.
- Six 1-meter Telescopes
- 15 possible baselines from 31 to 331 meters
- One of two operating ranges: 2.0 - 2.5 μm
- 0.6 mas resolution

Observations and Results

CHARA Observations:

- 2008-09-19
- 2008-11-07
- 2008-11-08
- 2008-12-10

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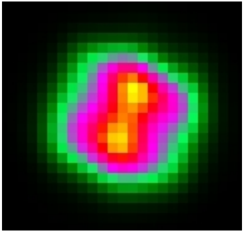

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Scale: $0.16 \frac{mas}{pixel}$
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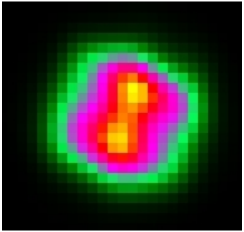

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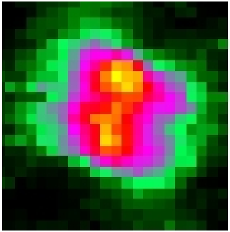
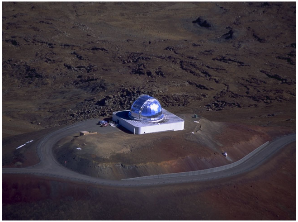
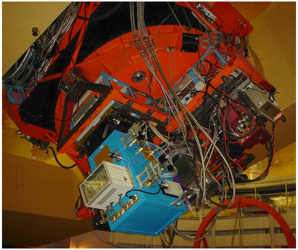


MACIM

IRTF



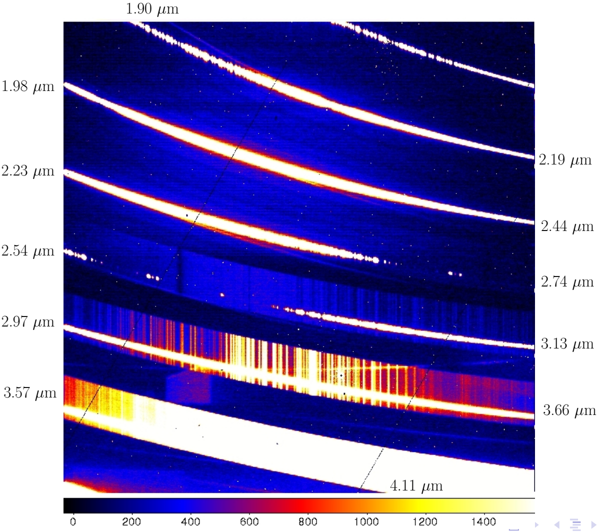
IRTF, (NASA IRTF)



SPEX, (NASA IRTF)

- IRTF
  - Operated and managed for NASA by the University of Hawaii
  - 3.0 m infrared optimized Telescope
  - Located atop Mauna Kea Hawaii
- SPEX
  - 0.8 - 5.4 μm cross-dispersed spectrograph.

Observation and Results



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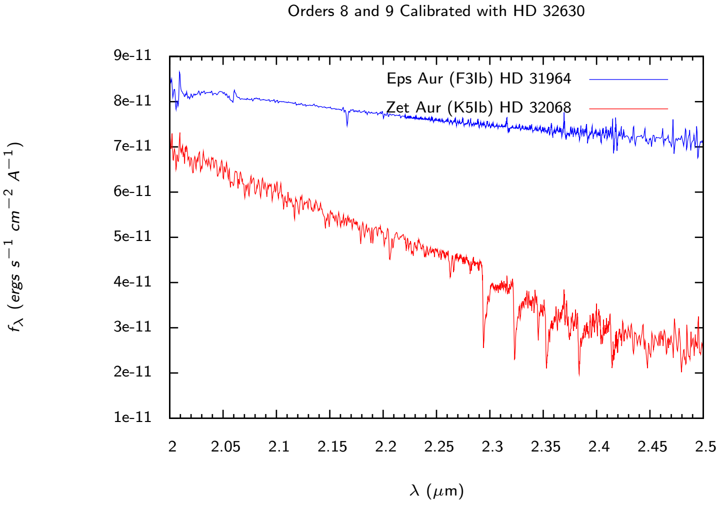

Eps Aur data shifted upward by 6×10^{-11}

Bow Shocks


LL Ori, (NASA and The Hubble Heritage Team (STScI/AURA))


Mira, (NASA/JPL-Caltech)

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3. Plan and apply for follow up observations.

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  - Large Survey: 278 square degrees.
  - High Resolution: 5 $\frac{mas}{pixel}$ at 24 μm, 15 $\frac{mas}{pixel}$ at 70 μm.
- Strong support for this type of research inside the department.

Interstellar Bow Shocks

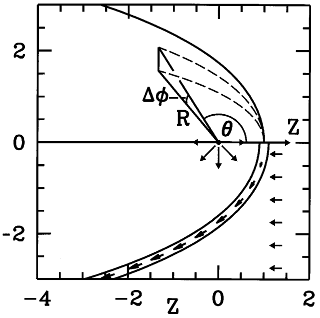


Diagram of a wind-driven Bow Shock (Wilkin, 1996)

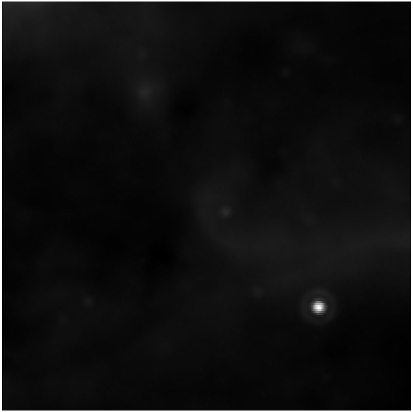
Equation for shape of a isotropic axisymmetric wind-driven bow shock (Wilkin, 1996)

$$R(\theta) = R_0 \csc\theta \sqrt{3(1-\theta\cot\theta)} \qquad (1)$$

where R_0, the standoff distance, is:

$$R_0 = \sqrt{\frac{\dot{m}_w V_W}{4\pi\rho_a V_*^2}} \qquad (2)$$

Hough Transforms



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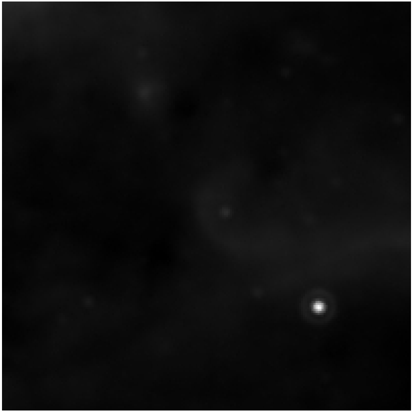
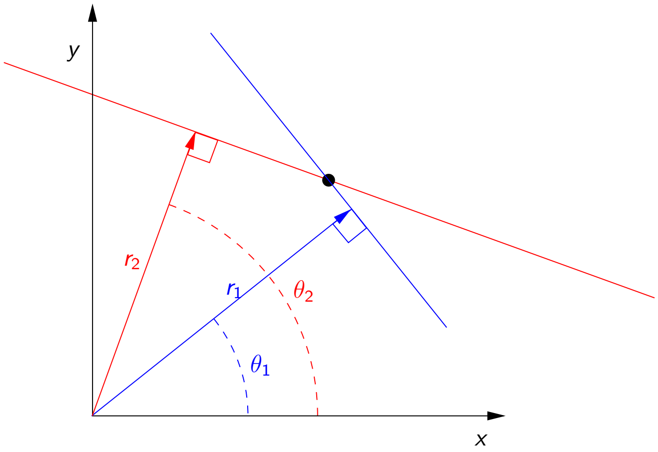


Hough Transform

- Feature extraction technique that finds objects based upon a voting algorithm.
- Candidate objects are local maximia in the voting parameter space.
- Developed for machine analysis of bubble-chamber photographs.

Hough Transform Example



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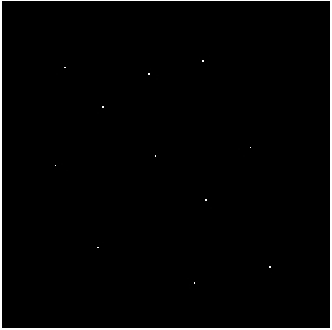

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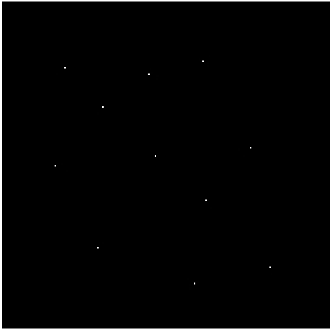

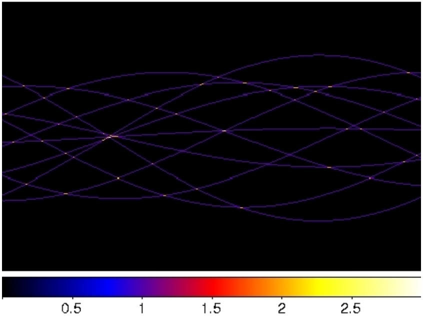

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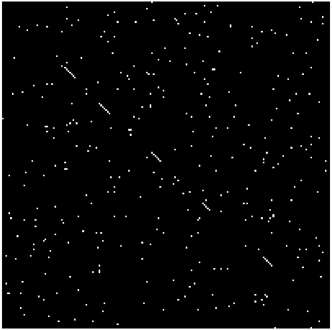

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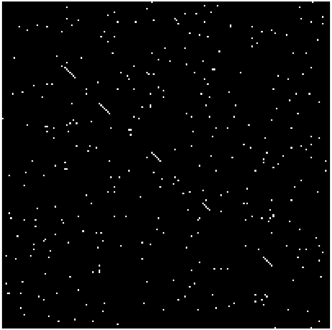
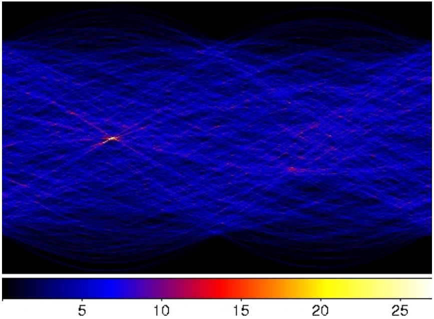




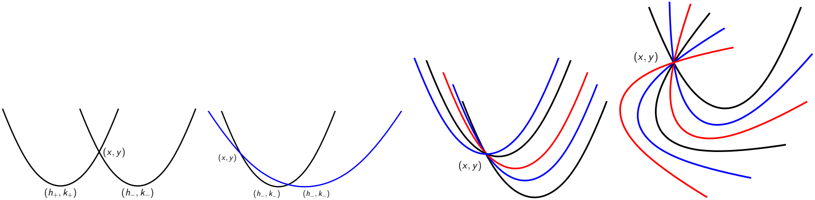
Hough Transform for Parabolas

Parameterized Parabola:

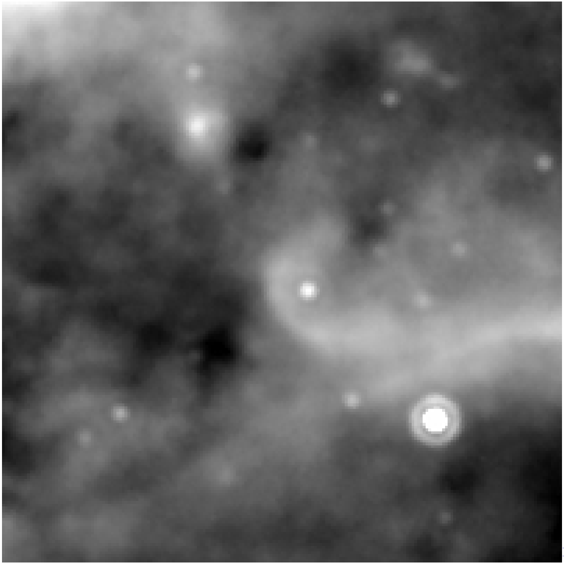
$$x(t) = \pm 2at + h \qquad\qquad y(t) = at^2 + k$$

Offsets to potential Apex Locations:

$$\begin{aligned} h'_{\pm} &= \mp 2at\cos(\theta) + at^2\sin(\theta) \\ k'_{\pm} &= \mp 2at\sin(\theta) - at^2\cos(\theta) \end{aligned}$$



Preprocessing



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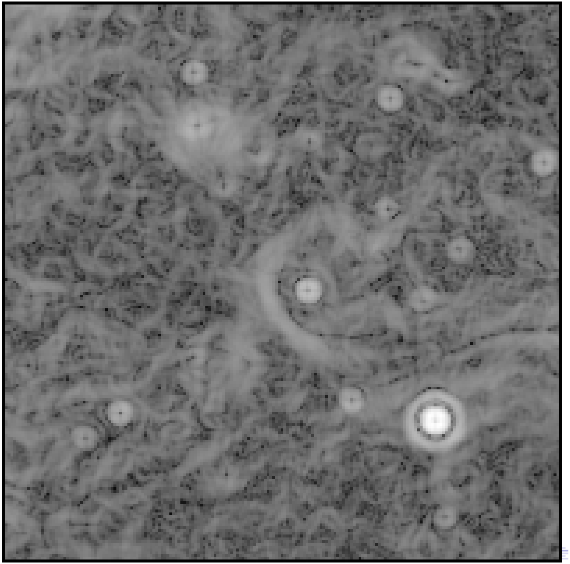

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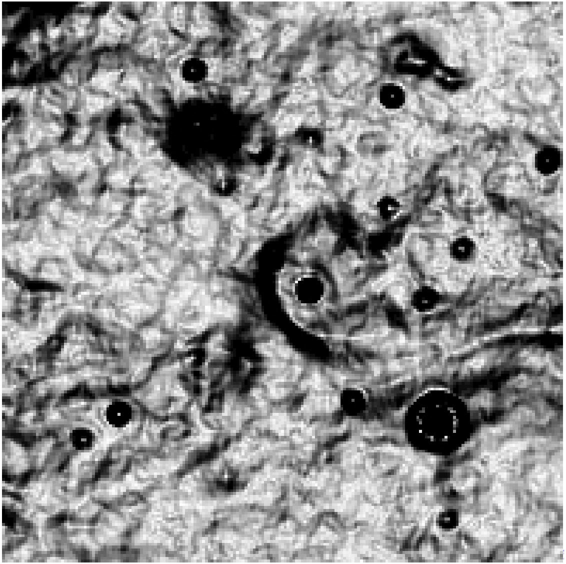

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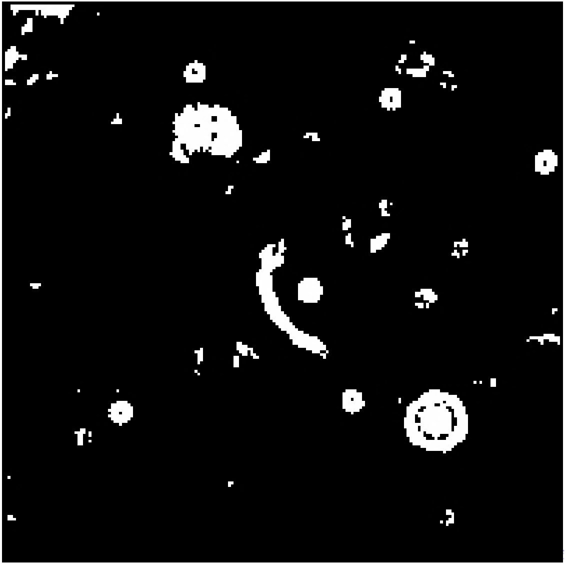

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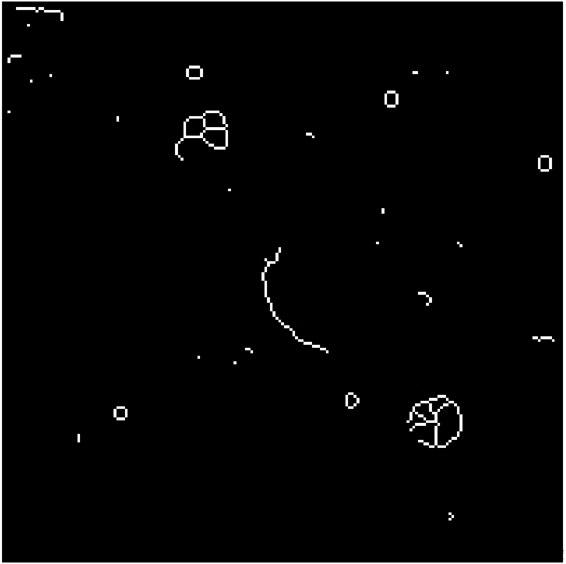

Results

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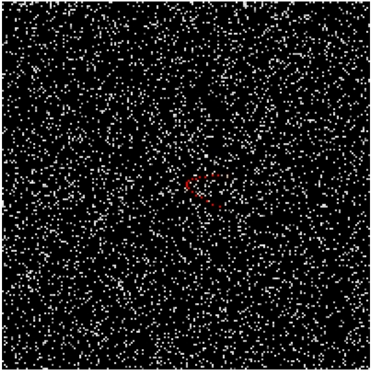

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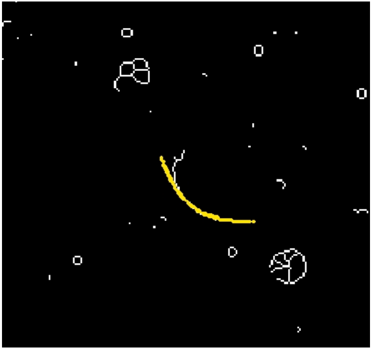

- Positive Detection in all test cases
- Positive Detection in 10% Random Noise image
- Positive Detection in Real Image

Next Steps

- Improve the algorithm's speed.
- Apply the method the remainder of the μm MIPSGAL catalog.
- Identify the parent star to which a bow shock candidate belongs.
- Attempt to determine the 3D space motion of the ISM if the parent star's proper motion has been previously determined.
- Apply for follow-up spectroscopic observations of shock region.
- Cross correlate the above information with known information about the ISM.

Acknowledgements

- Dr. Robert Stencel
- Ming Zhao (University of Michigan)
- Bobby Bus (IRTF)