Algol with MIRC

Fabien Baron, John Monnier, Stefan Kraus
University of Michigan
Algol (Beta Persei), the “Demon Star” or “Blinking Demon”, is derived from the Arabic "Ra's al Ghul" for the Demon's Head.

It’s the "evil eye" of Medusa, changing brightness and color.

Algol is a compact triple-star, d= 92.8 light-years

7.3 million years ago it passed within 9.8 light years, apparent magnitude of -2.5
Algol inner pair A-B

Prototype of Algol-type eclipsing variables.

A: main sequence B8V, $3.8M\odot$, $2.9R\odot$
B: subgiant K2IV $0.8\square M\odot$, $3.5R\odot$

A-B separated by 1/10 Earth-Sun distance

“semi-detached” configuration”:
- Algol B fills its Roche Lobe
- Algol A roughly spherical

Circular orbit + synchronous rotation periods

*QuickTime™ and a YUV420 codec decompressor are needed to see this picture.*
The Algol “paradox”

Normal binary:
the most massive star evolves faster and enters giant phase first

Algol case:
the less massive star, Algol B, is already red giant
the more massive, Algol A, is still within the main sequence

Answer
= Mass Transfer
Light curve analysis

- Typical light curve
- Potential star spots on Algol B
- Reflection effect
  - B is heated by A radiation, easy computation
  - Negligible effect on A
- Affected by Algol C
### Algol A, B and C

<table>
<thead>
<tr>
<th></th>
<th>Algol A</th>
<th>Algol B</th>
<th>Algol C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral type</td>
<td>B8V</td>
<td>K2IV</td>
<td>F1IV</td>
</tr>
<tr>
<td>Mass (M_☉)</td>
<td>3.8</td>
<td>0.82</td>
<td>1.80</td>
</tr>
<tr>
<td>Radius (R_☉)</td>
<td>2.88</td>
<td>3.54</td>
<td>1.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Notation</th>
<th>A–B</th>
<th>AB–C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of periastron (HJD)</td>
<td>T</td>
<td>2 445 739.0030</td>
<td>2 446 931.4</td>
</tr>
<tr>
<td>Period</td>
<td>P</td>
<td>2.87 days</td>
<td>680.05 days</td>
</tr>
<tr>
<td>Semimajor axis</td>
<td>a</td>
<td>2.3 mas - 14.1 R_☉</td>
<td>94.61 mas - 582.9 R_☉</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>e</td>
<td>0.00</td>
<td>0.225</td>
</tr>
<tr>
<td>Inclination</td>
<td>i</td>
<td>82.31°</td>
<td>83.98°</td>
</tr>
<tr>
<td>Argument of periastron</td>
<td>ω</td>
<td>-</td>
<td>310.29°</td>
</tr>
<tr>
<td>Longitude of the ascending node</td>
<td>Ω</td>
<td>47°</td>
<td>312.26° - 180° !</td>
</tr>
</tbody>
</table>

Pan et al. 1993
Roche lobe overflow from the companion produces a tidal stream which free falls from the inner Lagrangian point towards the primary under the influence of gravity and the Coriolis force.

Hot/cold spots may also be detected on A and B

Peterson et al., Nature 2010 persistent asymmetric magnetic field structure along A-B

Algol and interferometry

- Labeyrie 1974
- Soderhjelm 1980, speckle interferometry
  - Coplanarity of A-B and AB-C orbits?
- McAlister & Hartkopf 1988
- Pan et al. 1993, with Mark III, AB-C
  - Perpendicular orbits
  - 180 ambiguity corrected on $\Omega_2$... but in the wrong direction
- Czismadia et al. 2009
  - A-B, using CHARA CLASSIC data (~20 points), and VLBI
  - Orbit derived partially from Pan results...
- Zavala/Hummel 2010
  - A-B (marginally resolved) + C, using NPOI + VLBA + Hall Telescope

Much confusion about the $180^\circ$ ambiguity!
MIRC data on Algol - nights

- 22 nights spread over 3 years
  - Thanks to PJ & Chris, JDM, Ming, Etorre, Steve
- Average quality
  - Bad seeing, 3T, Ks grism experiment
- But good uv coverage

| UT2006Oct09  | S2-E2-W1-W2 |
| UT2006Oct11  | S2-E2-W1-W2 |
| UT2006Oct12  | S2-E2-W1-W2 |
| UT2006Oct16  | S2-E2-W1-W2 |
| UT2006Oct16  | S2-E2-W1-W2 |
| UT2007Oct04  | S1-E1-W1-W2 |
| UT2007Nov23  | S1-E1-W1-W2 |
| UT2008Aug18  | S1-E1-W1-W2 |
| UT2008Aug19  | S1-E1-W1-W2 |
| UT2008Aug20  | S1-E1-W1-W2 |
| UT2008Aug21  | S1-E1-W1-W2 |
| UT2008Sep03  | S2-E2-W1-W2 |
| UT2008Sep06  | S2-E2-W1-W2 |
| UT2008Sep07  | S2-E2-W1-W2 |
| UT2009Aug10  | S1-E1-W1-W2 |
| UT2009Aug11  | S1-E1-W1-W2 |
| UT2009Aug12  | S1-E1-W1-W2 |
| UT2009Aug13  | S1-E1-W1-W2 |
| UT2009Aug18  | S1-W1-W2   |
| UT2009Aug19  | S1-E1-W1-W2 |
| UT2009Aug20  | S2-E2-W1-W2 |
| UT2009Aug21  | S2-E2-W1-W2 |
| UT2009Aug24  | S2-E2-W1-W2 |
MIRC data on Algol C
MIRC data on Algol A-B
Model fitting - 1

• Night by night approach
  – $P(A-B) = 2.87$ days, $\Delta \theta = 5^\circ$/hour, $\Delta \rho = \text{few } 0.1 \text{ mas}$
  – Algol C does not move much but strong effect on closure phases

• Uniform ellipses (as a first step) relative to Algol A
  – Position $(\rho, \theta)$, size, axis ratio, angle, flux ratio
  – Primary can be fixed to circular
  – Bandwidth smearing effect on Algol C, elongated along its $\theta$ axis

• High number of dimensions (min 14) + multimodal
  – Combination of grid search with Levenberg
  – Nested sampling (new MCMC technique with Hill Climbing and evidence/model selection implementation)
Model fitting - 2

ALGOL_12Aug09e

Secondary 1.6846475

Tertiary
Model-fitting - 3

- Consistant p.a. sizes and fluxes
  - Algol C elongated as expected
  - Eclipse Aug 11 needs more work

- Correct fits, not great on most nights
  - gravity darkening, limb darkening + other effects
Image reconstruction - 1

BSMEM reconstructions
First resolved images of A-B

Algol Reconstruction - 12 Aug 2009

Zoom on Algol A-B

Zoom on Algol C
Image reconstruction - 2

Need to distinguish between components
• Fluxes, sizes, positions consistent with literature
• Possible detection of the proximity effect
  – Roche lobe filling + binary reflection, TBC
• Difficulties:
  – few nights have enough data/uv coverage
  – those who do suffer from temporal smearing
  – Algol C bandwidth, difficult to correct with BSMEM
  – few “useful” pixels/noise overfitting, bad photometry
• New image reconstruction software to come
  – optimized for low degrees of freedom (new paradigm)
  – simultaneous model fitting/image reconstruction
Orbit fitting and evolution

• Several possibilities
  – from current grid search results: investigated
  – from the image photocenter locations
  – directly from the data, add to current model fitting scheme
    • This adds $7 \times 2 - 4 = 10$ more parameters
    • More local minimas/degeneracies: nested sampling

• 3D star rotation (shape from mode fitting) and Roche lobe parameters as a function of distance

• Preliminary result:
  – Pan/Csimadia A-B orbit easily refined (0.5 mas off/yr)
Conclusion

• Model fitting
  – Non uniform components (limb darkening, gravity darkening, reflection effect), Roche lobe
  – Add modeling of temporal/spectral smearing effect

• Image reconstruction
  – Spot detection at other epochs ?
  – Proximity effect analysis
  – Upcoming image reconstruction software
  – Use of the model fitting results as prior

• Improvement upon current orbit + movie !

• Ks vs H band