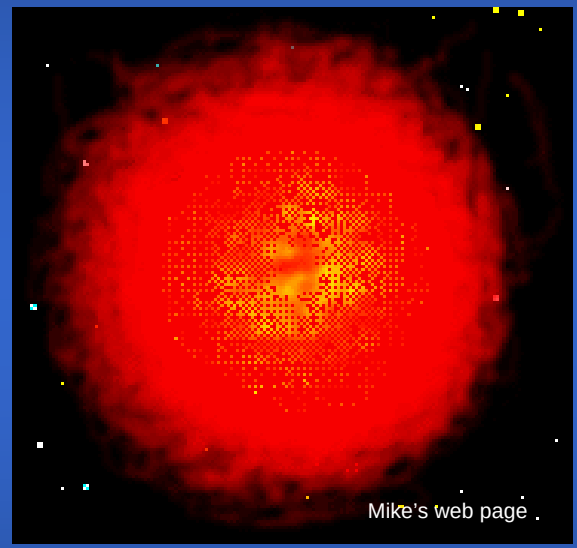
Detection of Asymmetries in AGB Stars



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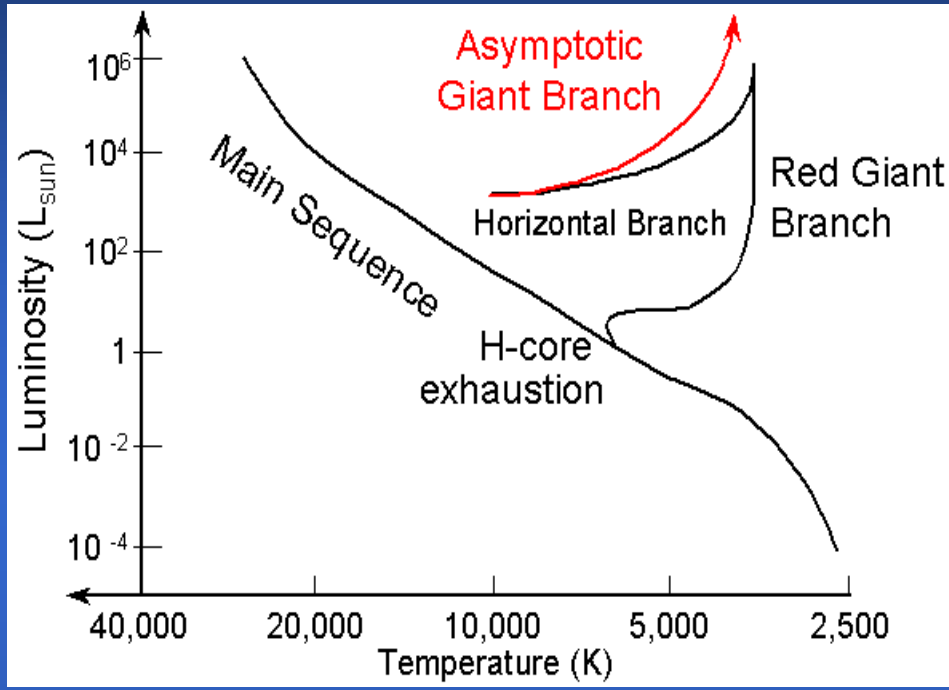
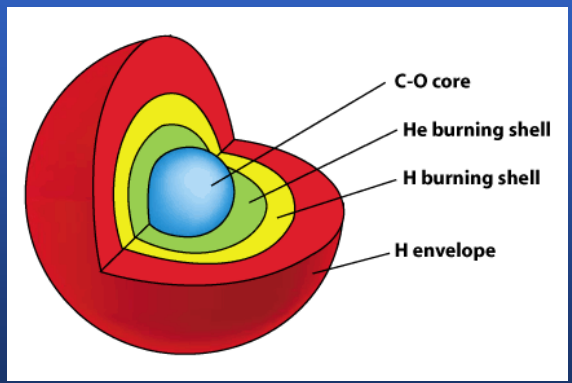
Kamuela, HI 96743

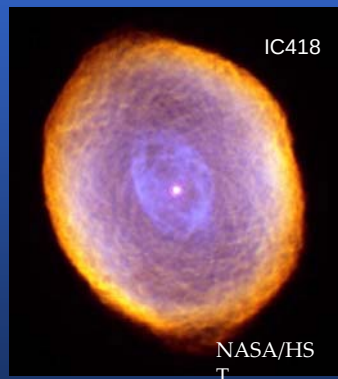
2005 Michelson Fellows Symposium: October 20-21, 2005

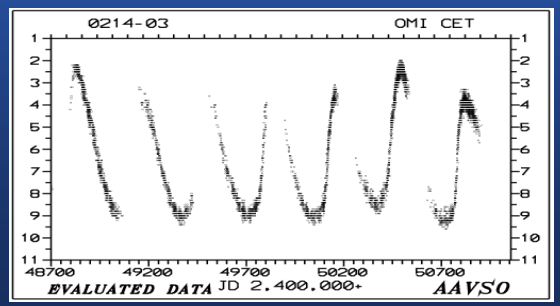
Mira Stars and Stellar Evolution

- Mass: < 8 M_{Sun}
- Sizes: ~ 2 AU
- Low Surface Temperature: ~ 2200K
  - Molecular formation in their atmosphere atmosphere
  - Dust formation in stellar wind
- Mass loss: 10^{-7} – 10^{-6} M_{Sun}/yr
- Pulsation:
  - Period: 80 – 1000 days
  - Visual brightness change: 10 - 1000
  - ΔL_{IR} ~ 1 magnitude
  - Mass loss through shock wave, dust formation









Surface Brightness Distribution

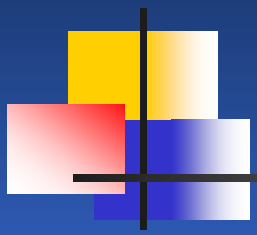
- Complex and time dependent center-to-limb brightness profiles
  - Complex, extended and Dynamic atmosphere
  - Presence of Circumstellar gas and dust shells
  - Possible asymmetry
    - Surface features – star spot
    - Asymmetric shells - Localized dust/molecules formation formation
- Mapping program at IOTA
  - Characterize the brightness distribution of Mira stars
  - Characterize Mira pulsation

Science Questions

- What are the mechanism(s) responsible for asymmetry?
- How common are photospheic asymmetries in AGB stars?
  - Impact on derived stellar parameters
- Is there a correlation between stellar pulsation and asymmetries?
- What is the evolution time scale of observed asymmetry?
  - to understand the physics
- What is the role of binarity in observed photometric asymmetry?
- What are the conditions for water formation in stellar atmosphere? – temperature, density, opacity, etc.

Layout of my talk

- Instrumental Setup
- Stability of Visibility & Closure phase measurements
- An Asymmetric survey conducted at IOTA IOTA
- Detection of molecular shells & spots
- Mapping of Mira stars with IOTA, ISI & VLBA
- Near future plans: Spectro-interferometry



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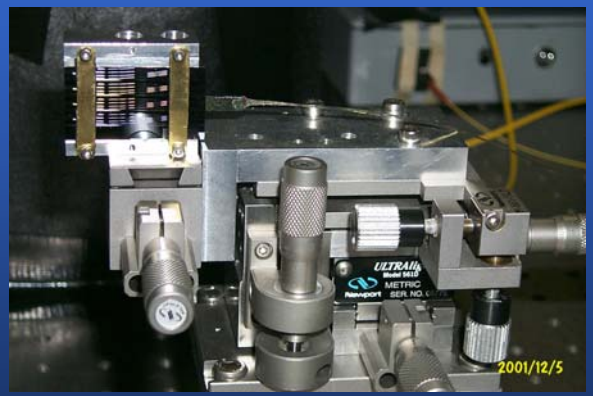
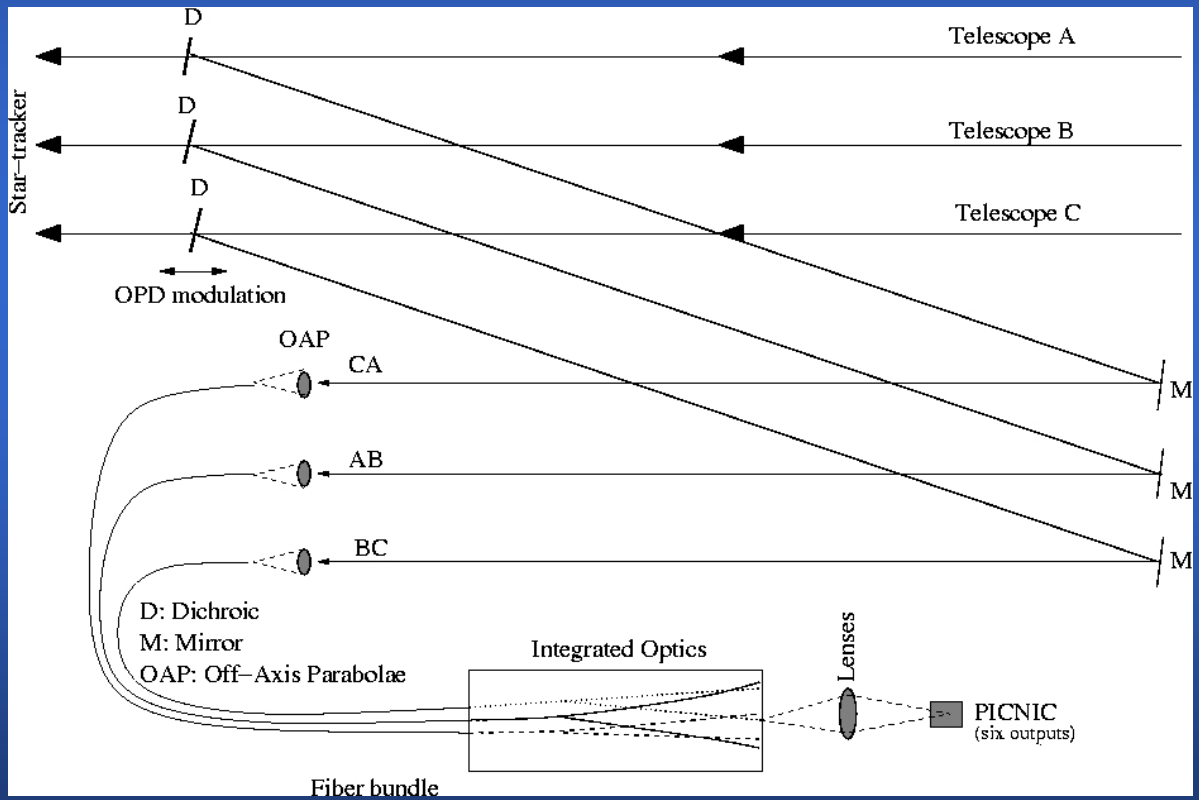
Collaborators

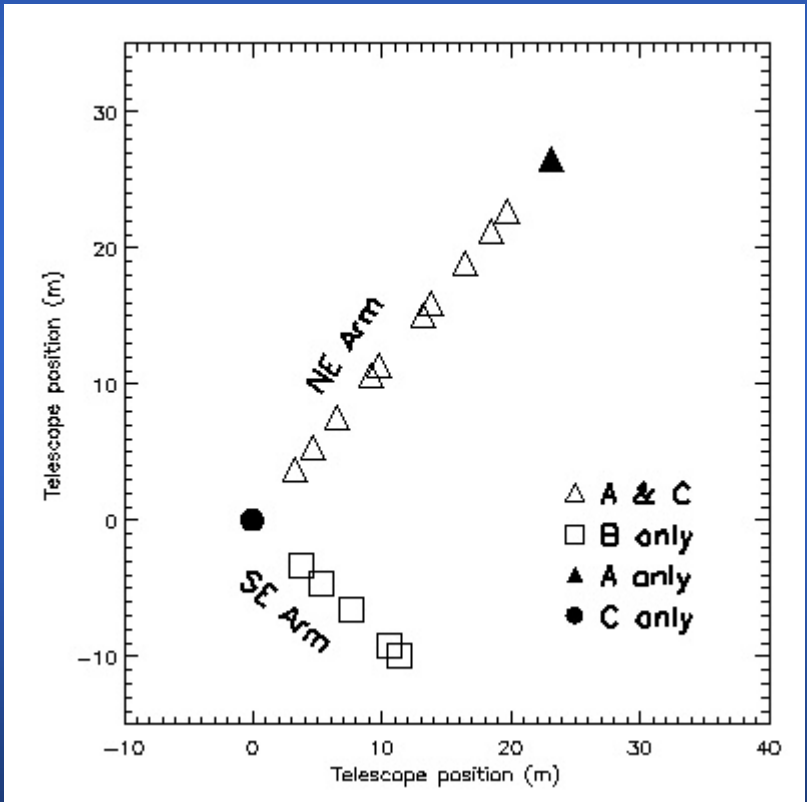
- Jean-Philippe Berger (Grenoble, France)
- Nathaniel Carleton (CFA)
- William Cotton (NRAO)
- William Danchi (NASA/Goddard)
- Marc Lacasse (CFA)
- Herve Le Coroller (CARA)
- Rafael Millan-Gabet (NASA/JPL)
- Jayadev Rajagopal (NASA/Goddard)
- John Monnier (Univ. of Michigan)
- Ettore Pedretti (Univ. of Michigan)
- Peter Schloerb (UMass, Amherst)
- Peter Schuller (CFA)
- Charles Townes (Univ. Calif. At Berkley)
- Wesley Traub (JPL/CFA)
- Lee Ann Willson (Iowa State Univ.)
- IOTA team (CFA) & IONIC team (Grenoble, France)

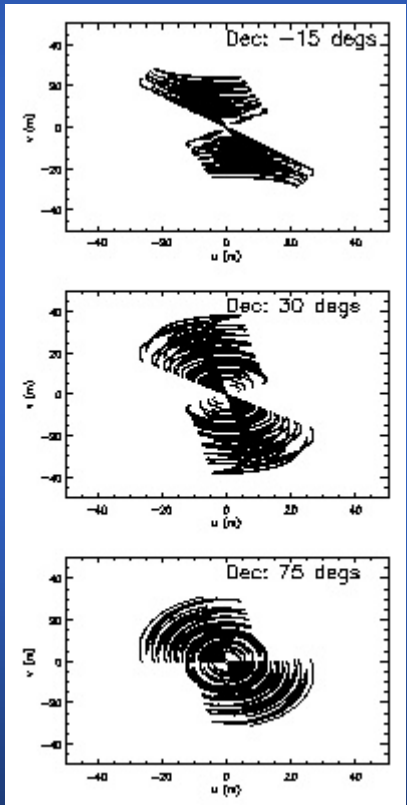
IOTA-IONIC instrument



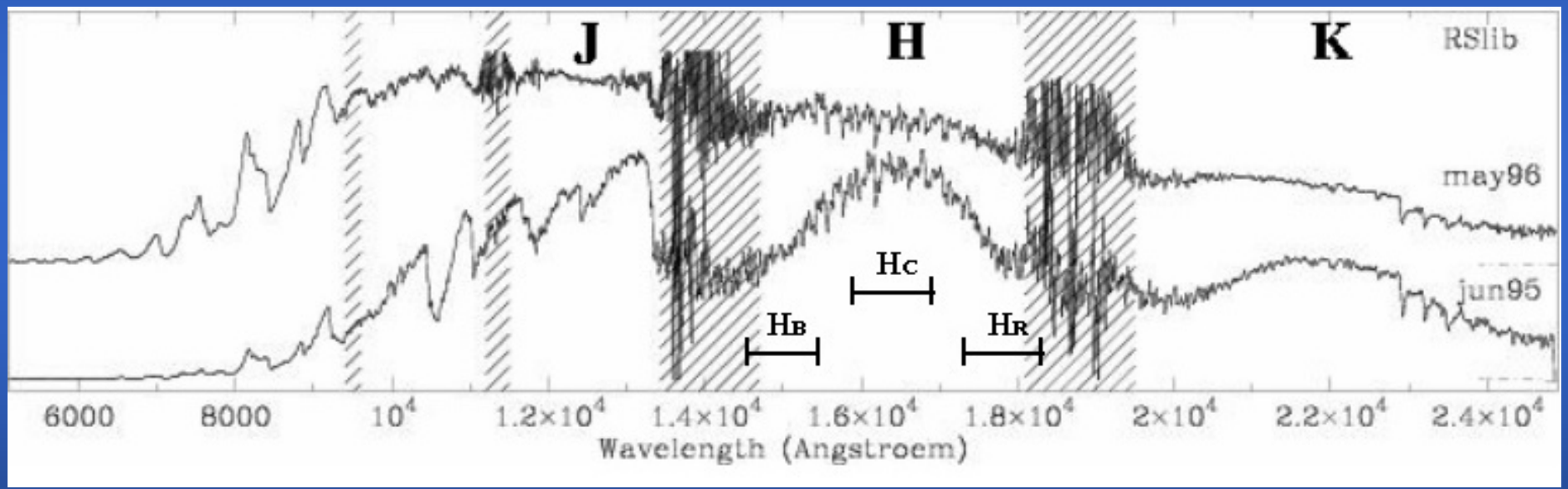


IOTA Array Geometry & UV coverage

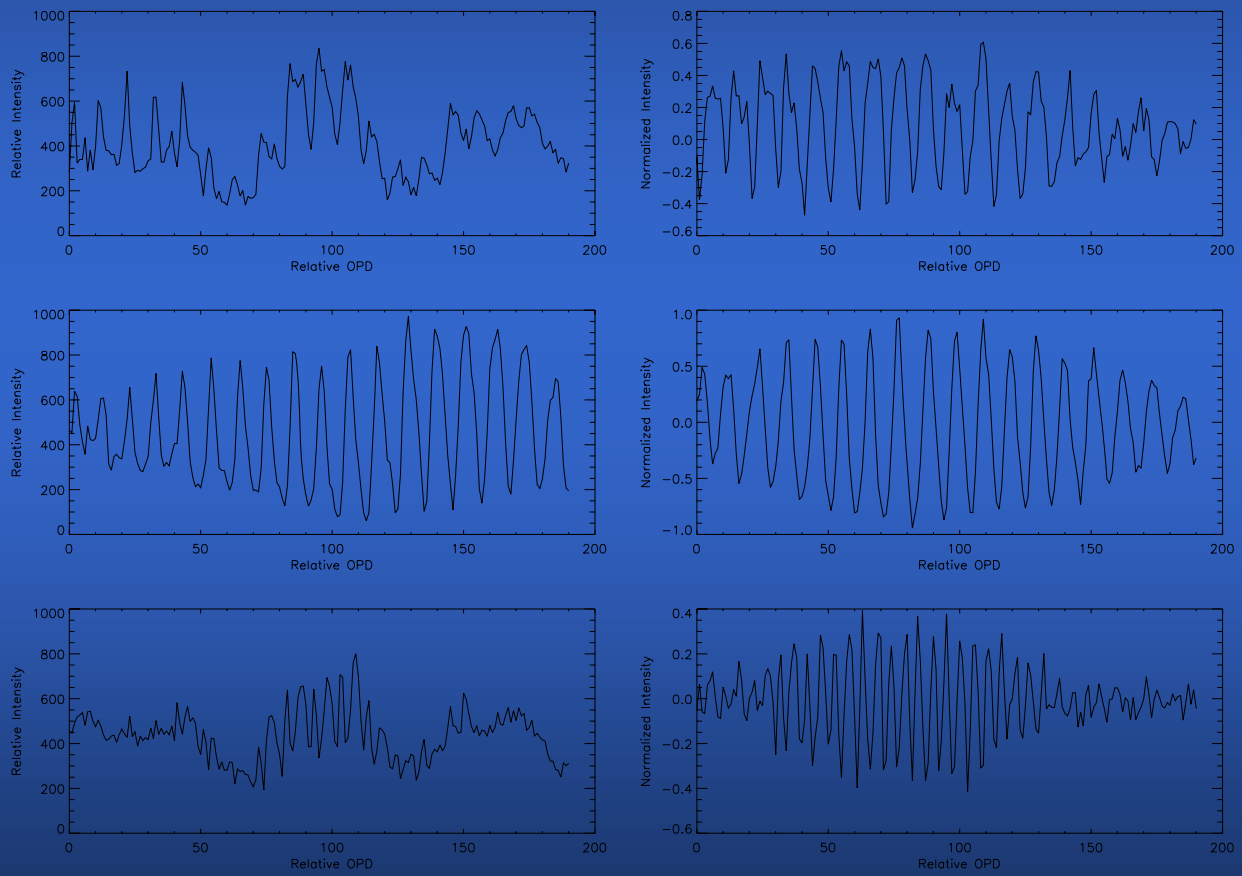




NIR Spectrum of the Mira Star RS Lib



IOTA data of R Ser (13th Mar 2003)



Ragland et al., SPIE, 2004

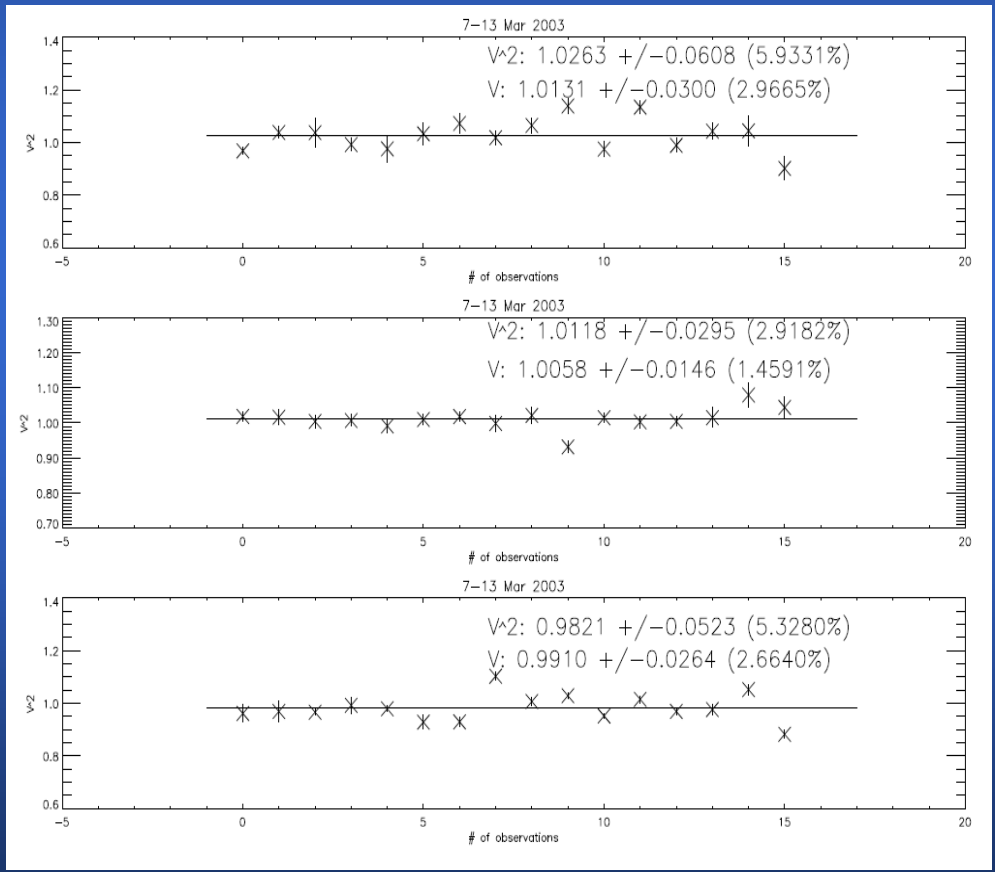
Estimation of visibility amplitude

- The fringe power is estimated from the power spectrum after background subtraction
- The fringe power is a measure of the coherence factor and hence the visibility

$$V^2 \propto \mu^2$$

- Target visibility is calibrated against nearby calibrators.

Stability of Visibility measurements



- **Internal Errors**
  ~ 0.5 %
- **External Errors**
  ~ 2.5 %

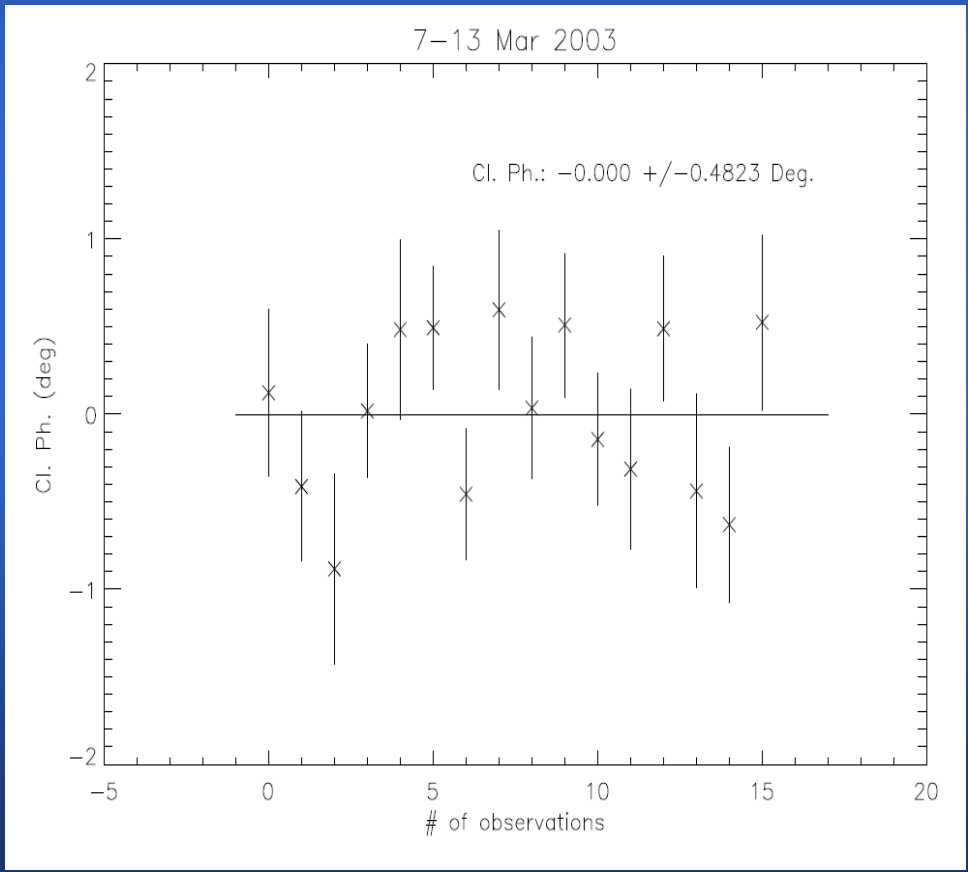
Closure Phase

- Closure phase is a good observable independent of telescope-specific phase-shifts.
- Closure phase is the sum of the phases of the the baselines forming closed triangle.
- Closure phase is also the phase of the bispectrum (triple product of the complex complex visibilities around a closed triangle).

Estimation of Closure Phase

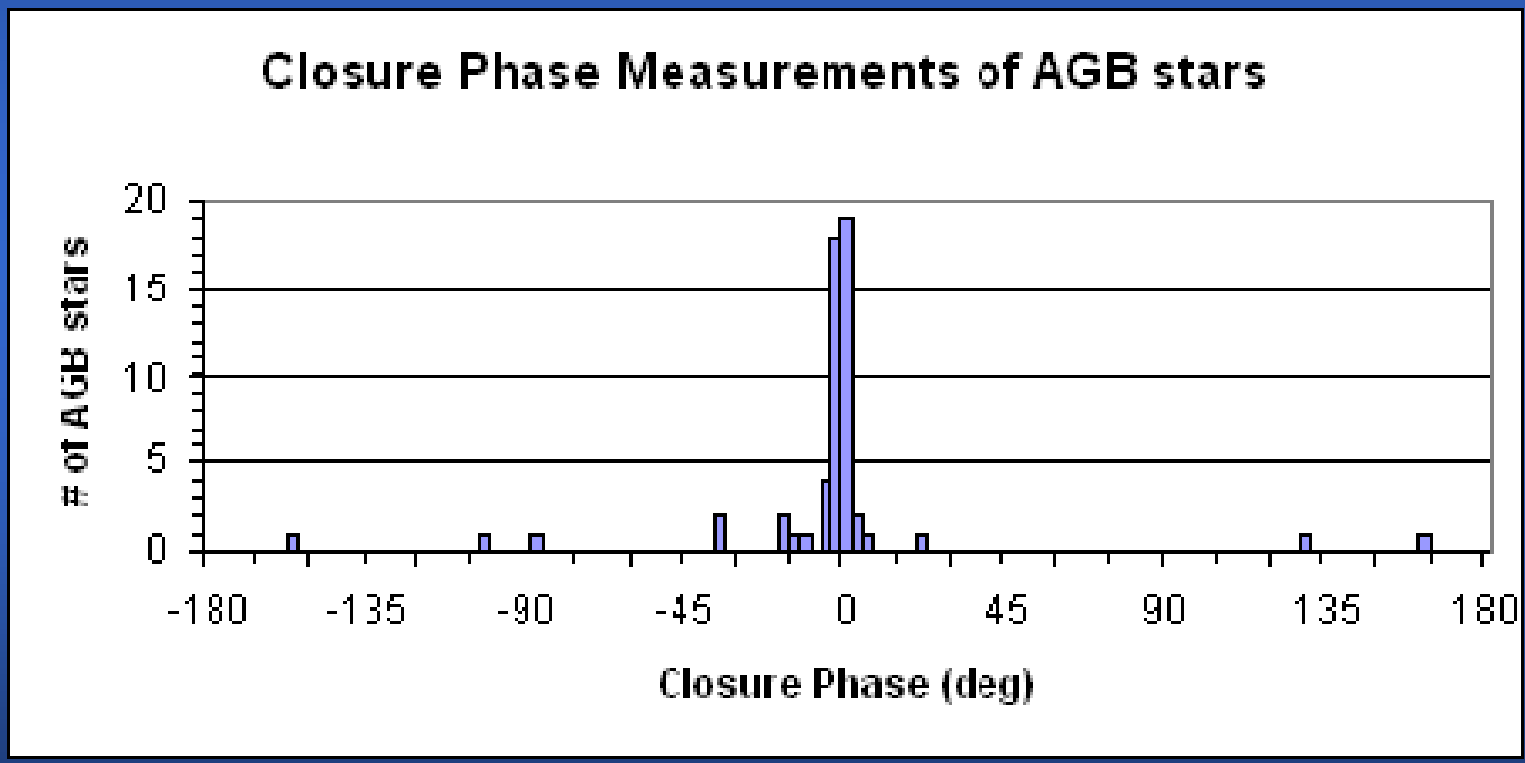
- The triple product of the three baselines are taken. taken.
- The real & imaginary parts of the triple products products are averaged separately.
- The arc-tangent of these components give closure phase.
- Instrumental closure phase is estimated using a using a set of calibrators and is subtracted from from the raw closure phase of the target.

Stability of Closure Phase Measurements



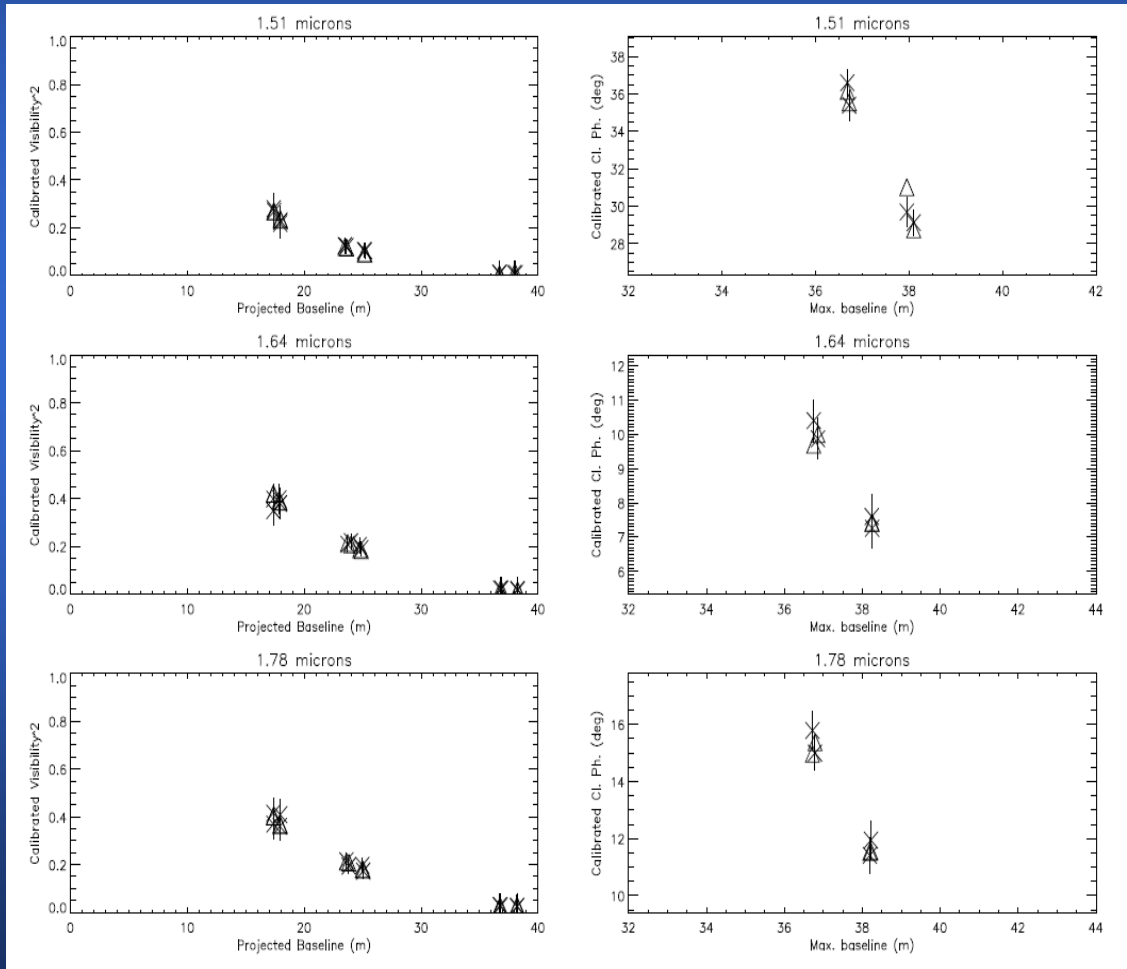
- **Internal Errors**
  ~ 0.4 deg
- **External Errors**
  ~ 0.5 deg

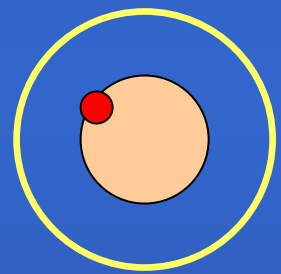
Results of our survey searching for asymmetric stars



Ragland et al., submitted to ApJ (lett)

Shell+Spot model fit to U Her Data Data



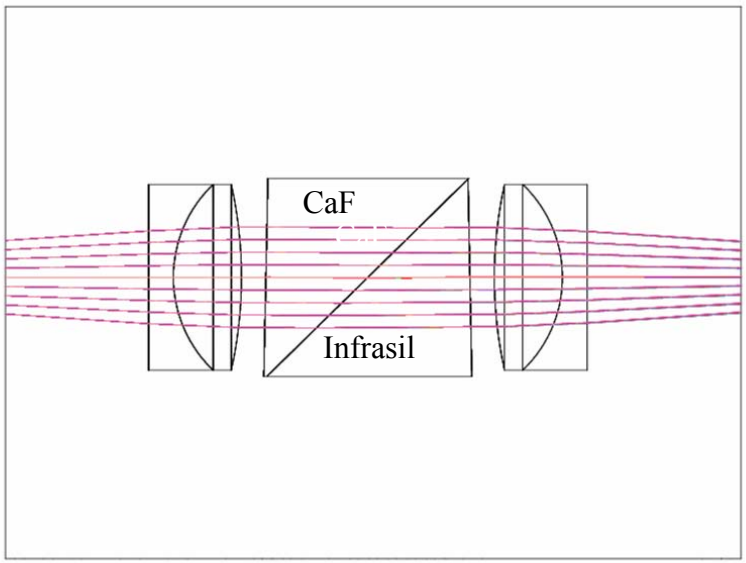


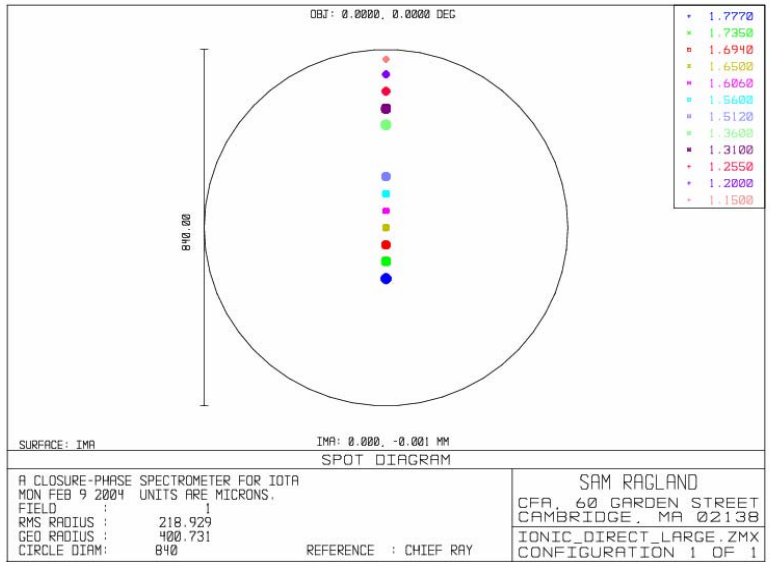
The Mira Imaging Project

- **Funded by NSF**
  - **Sam Ragland, PI** (2005-2007)
- **Three Imaging Interferometers**
  - IOTA: Photosphere & molecular atmosphere
  - VLBA: SiO maser
  - ISI: Dust shells

Near Future Plan: Spectro-interferometry

- **Low-resolution Spectrograph**
  - Design: **Sam Ragland,** et al. **Proc. SPIE 4838**, p1225, 2003)
  - Upgraded with a direct view prism.





- Close to completion!
- Improve observing efficiency.
- Differential phase measurements.

Conclusions

- IOTA/IONIC instrument provides stable visibility and and closure phase measurements (~ 2.5 % accuracy in in the visibility amplitude and ~ half-a-degree in closure closure phase).
- We find that Photospheric asymmetries are common in common in AGB stars at the level of a few % of stellar stellar brightness.
- We detect molecules layers around mira stars from our our interferometric observations in the H band.
- We began a coordinated mapping program in the near-near-infrared, mid-infrared and millimeter wavelength wavelength using IOTA, ISI and VLBA imaging interferometers

Infrared Optical Telescope Array (IOTA)

Infrared Spatial Interferometer Array (ISI)

Courtesy: ISI web page

Very Long Baseline Array (VLBA)

Courtesy: VLBA web page