Interferometric Observations of Mira Variables

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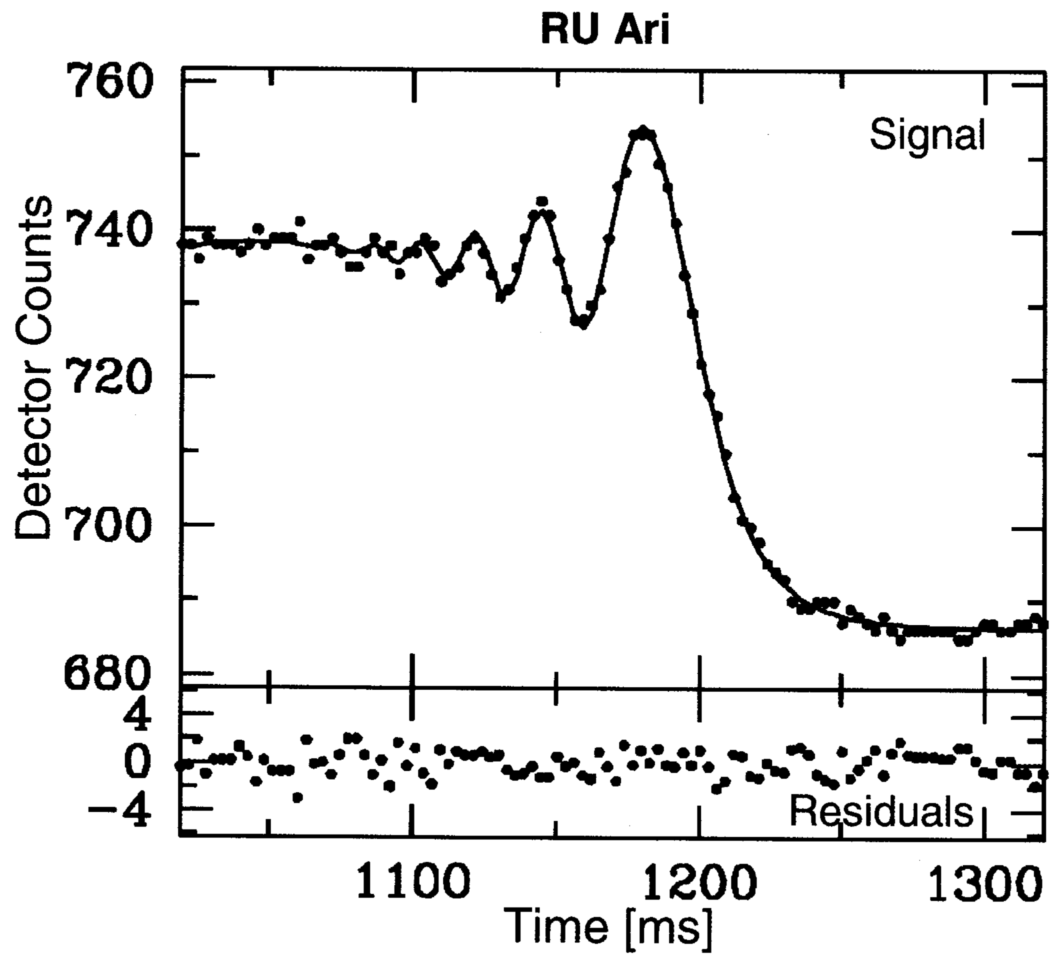
IAU Symposium 210:
Modelling of Stellar Atmospheres
17-21 June 2002, Uppsala, Sweden

History

- Lunar occultation observations
  - First Mira diameters measured over 25 years ago (U Ori; Ridgway, Wells & Joyce 1977)
- Interferometry
  - Aperture masking (Mira; McCarthy, Howell & Low 1978)
  - Speckle (Mira; Bonneau & Laberyie 1973; Mira & R Leo; Laberyie et al 1977)
  - Long Baseline (Mira; Ridgway et al 1992)

Capabilities – Lunar Occultations

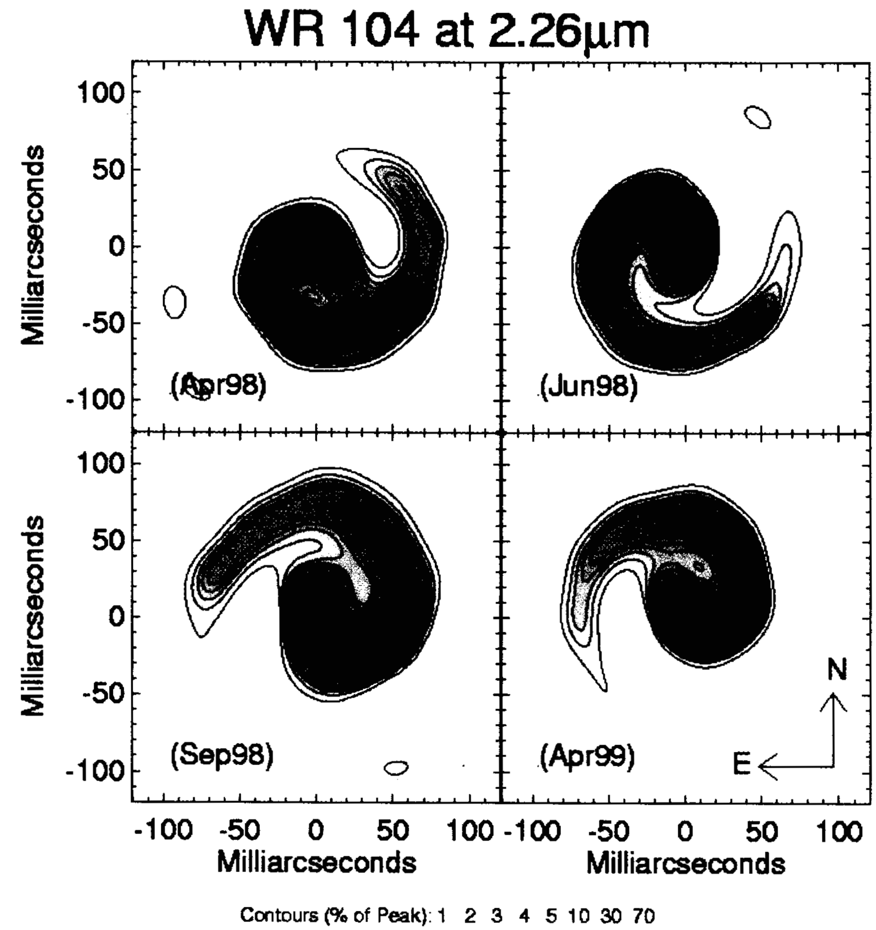
- Limited sky coverage
- Limited epoch coverage
- Single axis
- >1 mas objects
- See work by Richichi et al for modern lunar occultation observations



Richichi et al. 1998

Capabilities – Aperture Masking/Speckle

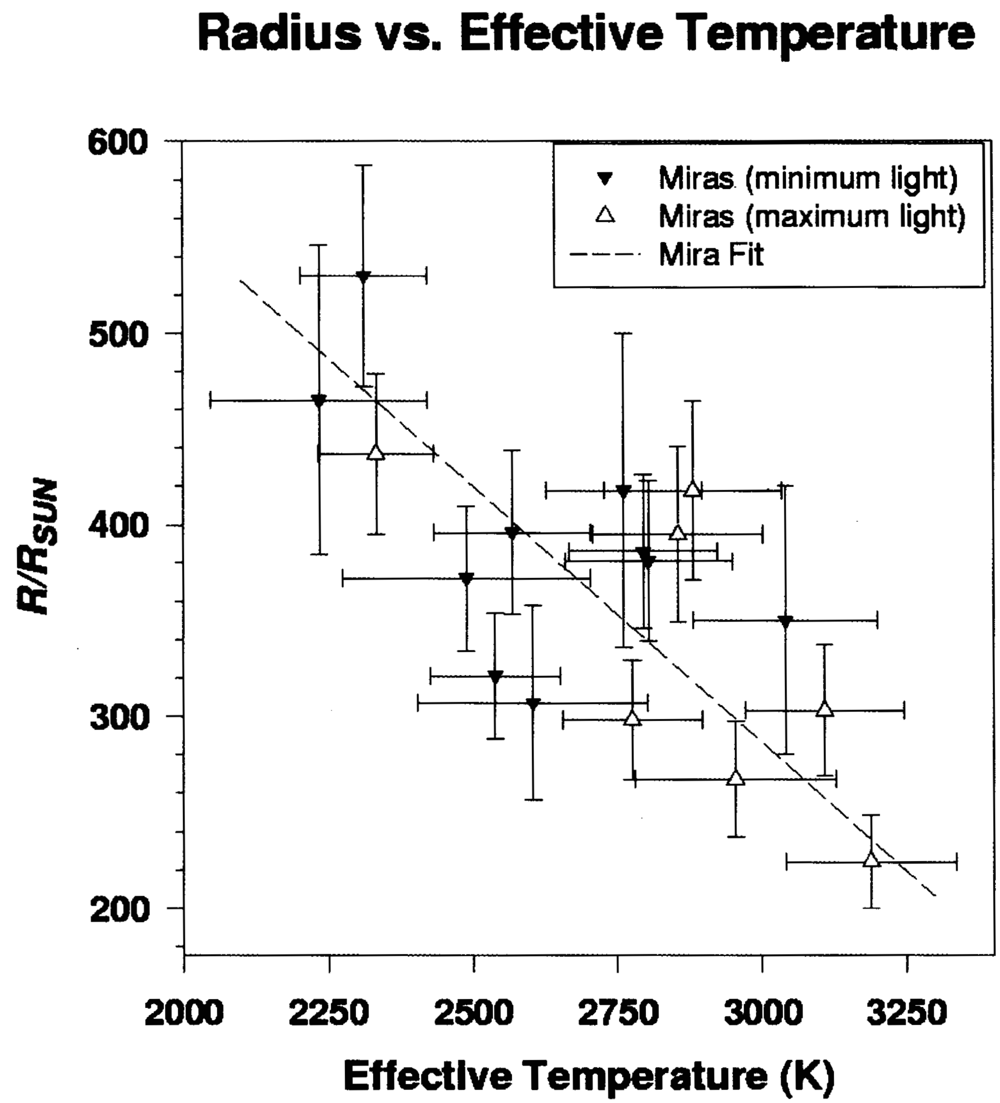
- >20 mas objects: Poorest spatial resolution
- Very rich (u,v) coverage – see work by Danchi, Monnier & Tuthill or Weigelt et al.
- Only a few dozen objects



Tuthill, Monnier & Danchi 1999

Capabilities – Long Baseline

- Limited (u,v) information
- 1-20 mas objects: Highest spatial resolution
  - Largest number (~75) of accessible objects
- Next generation (1-3 years) will routinely measure objects ~0.5 mas in size



van Belle et al. 1996

Currently Active Groups

- Long baseline interferometry
  - COAST: optical, IR
  - IOTA/FLOUR - IR
  - PTI: IR
- Aperture masking / Speckle
  - Berkeley group: Keck
  - COAST: WHT
  - Weigelt et al: SAO 6m
- Lunar occultations
  - Richichi et al – TIRGO
  - Tej et al – Mount Abu

'Current' is loosely defined as having a refereed Mira publication in the last 4 years

CHARM Statistics

- Predominant technique is long-baseline interferometry
  - Table does not even include large datasets currently in analysis
- Richness of aperture masking, lunar occultation data sets should not be ignored
  - AM – (u,v) plane coverage
  - LO – Concurrent photometry

Technique	Obsv'ns	Stars
AM	38	11
FGS	1	1
LBI	77	36
LO	29	15
SPE	4	1
Total	149	49

Catalog of High Angular Resolution Measurements
(CHARM; Richichi & Percheron 2002)

What Can Interferometry Do For *You*?

- Size, surface structure as a function of
  - Wavelength
  - Phase
  - Sizes currently good to ~1-2%
- Pulsation mode?
  - Better distances needed
  - Hipparcos data dubious
- Distance determination
  - Astrometric interferometry

How Does It Work?

- For a 'uniform disk', visibility matches:

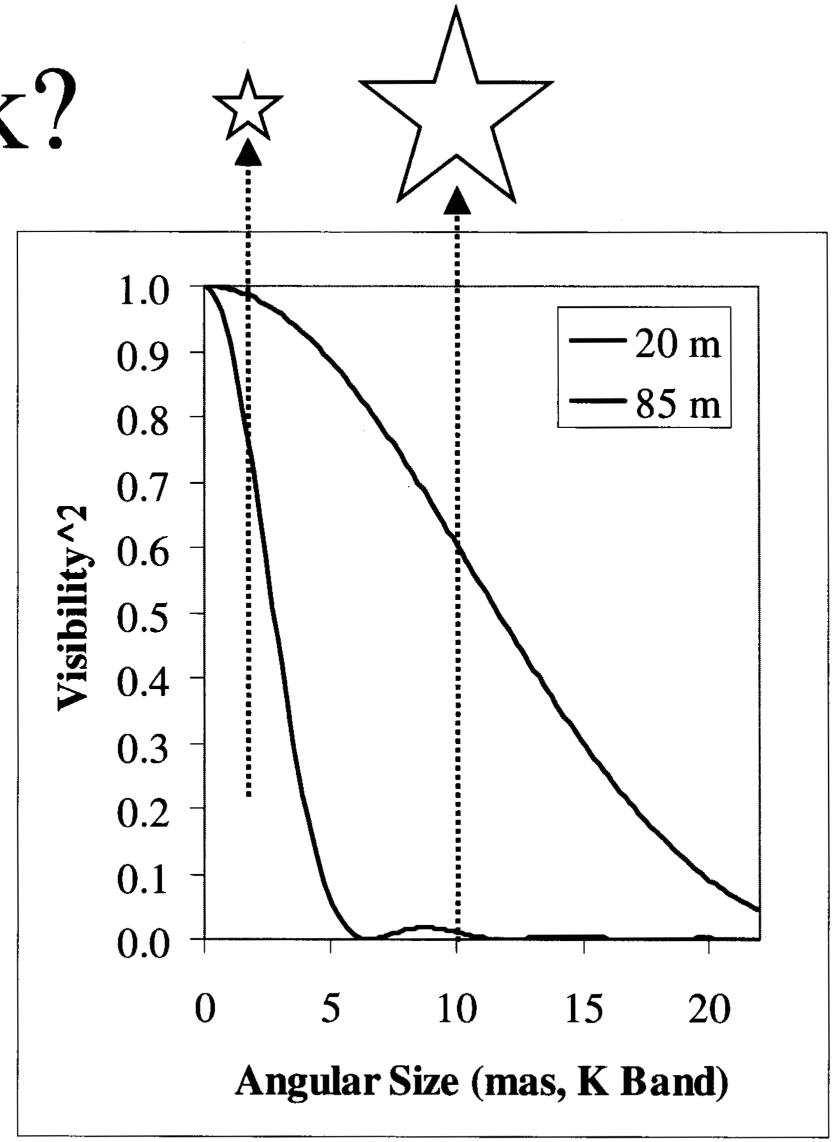
$$V = \frac{J_1(x)}{x} \quad \text{where} \quad x = \frac{\pi \theta B}{\lambda}$$

B is the projected baseline

θ is the stellar disk size

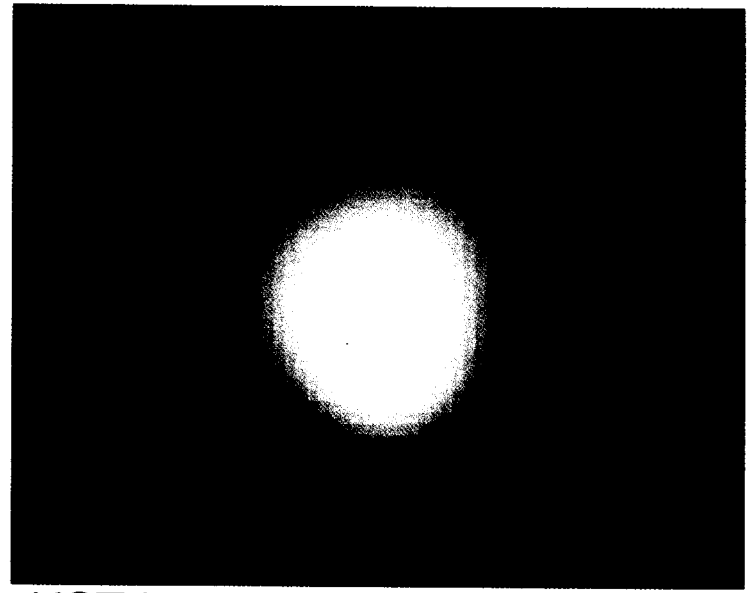
λ is the instrumental wavelength

- Baseline, wavelength known
  - Can solve for θ
- Use V^2 instead of V
  - Unbiased estimator of visibility
  - See Colavita (1999)



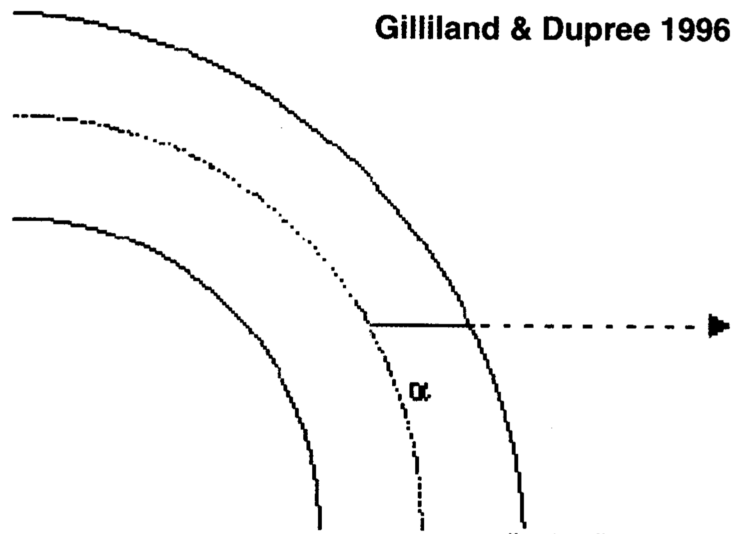
Limb darkening

- Stars are *not* uniform disks
- Gaseous, not solid, sphere
  - End up looking 'into' the star
- Good and bad
  - Have to account for this
  - Measuring this can be used to characterize internal structure of star
  - Direct probe of internal temperature stucture



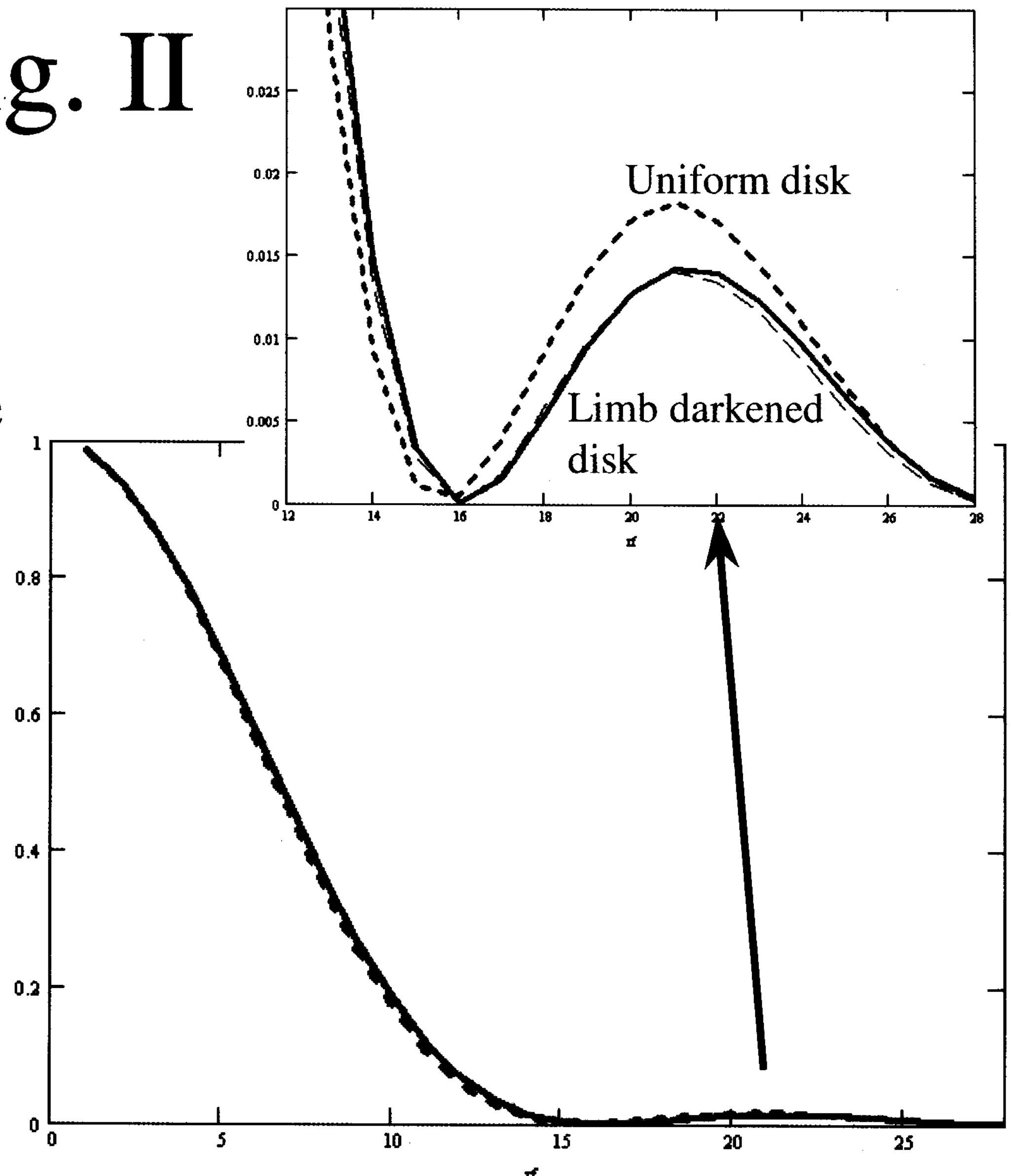
HST Image of α Ori - Betelgeuse

Gilliland & Dupree 1996



Limb darkening. II

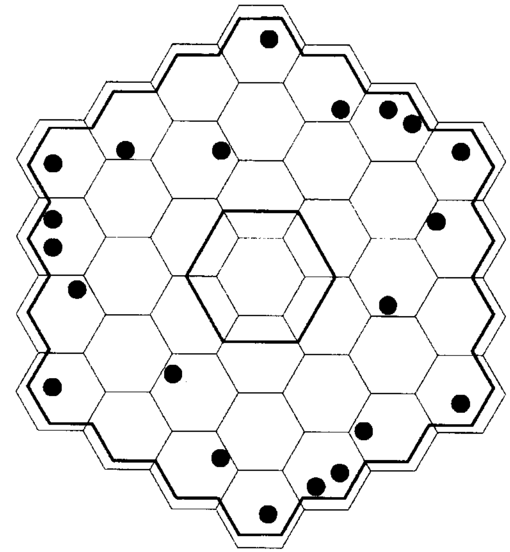
- Effects are less striking in the near-IR
- Most of the effects are seen at the higher spatial frequencies
- Acceptable to do a UD fit, and scale
  - Corrections are ~1.5% for main seq.
  - Higher for evolved stars
  - Gives the size of the mean radiating surface



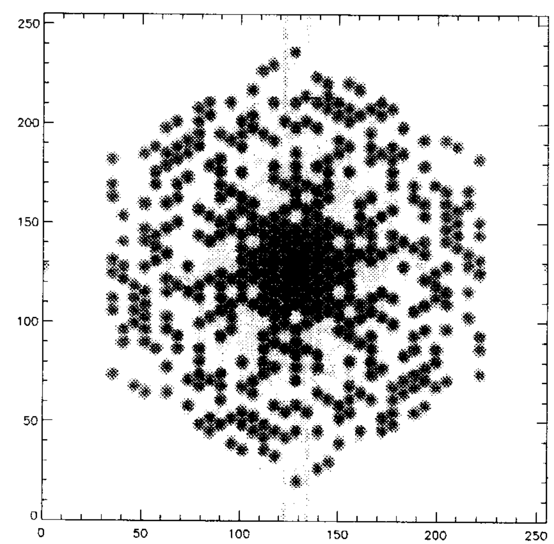
A-type Star Model (Claret et al. 1995)

Aperture Masking

- Transforms single large aperture into N-element interferometer
- Results in a wealth of image information
  - Closure phases, amplitudes
- Limits
  - Brightness limit derived from mask hole size, atmospheric coherence time
  - Resolution limit dictated by aperture radius



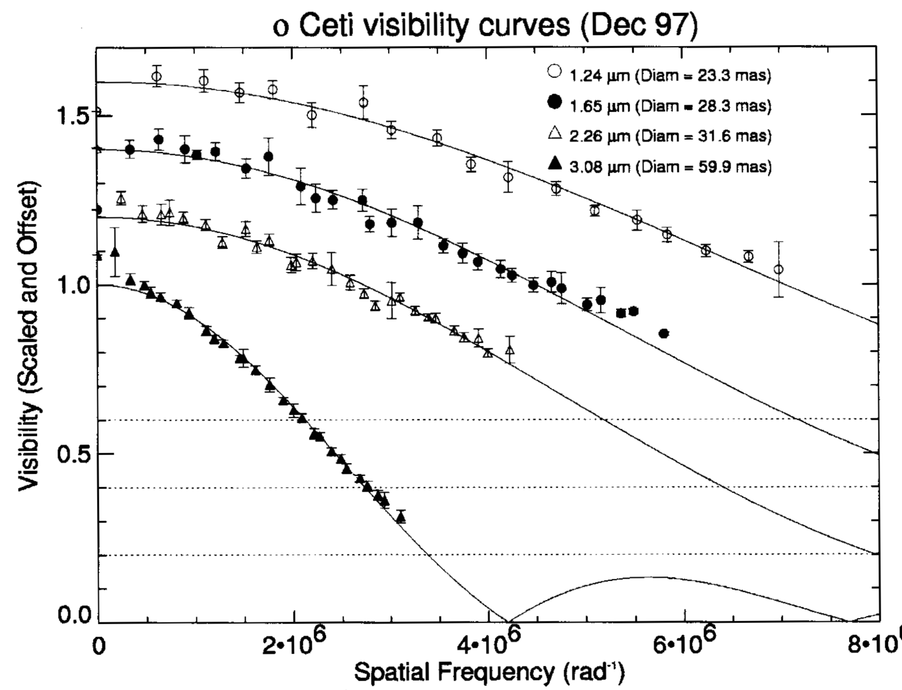
Mask for 10m Keck 1



Resultant Power Spectrum

Keck Observations – o Ceti

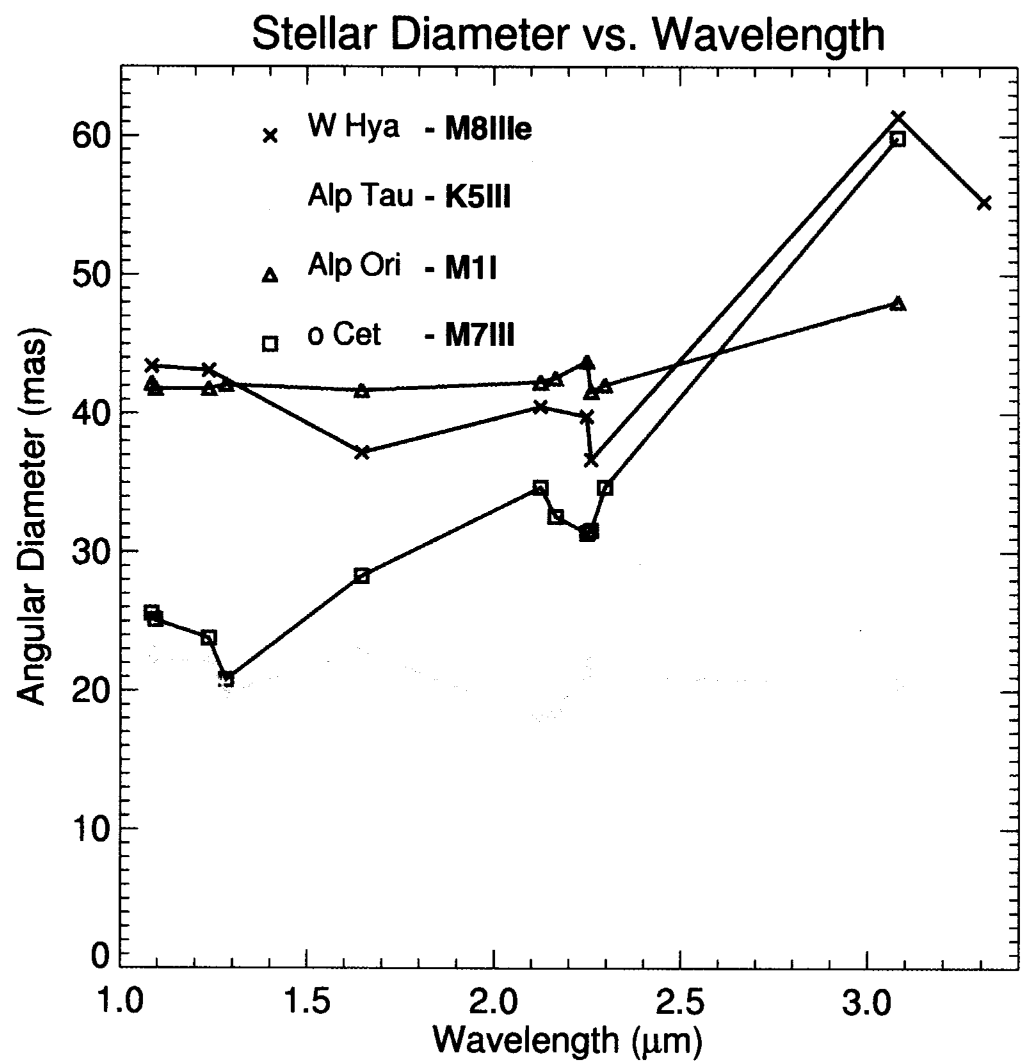
- Lots of spatial frequencies sampled
- Marked enlargement at 3.08μm
- Size enhancement due to molecular absorption of ??



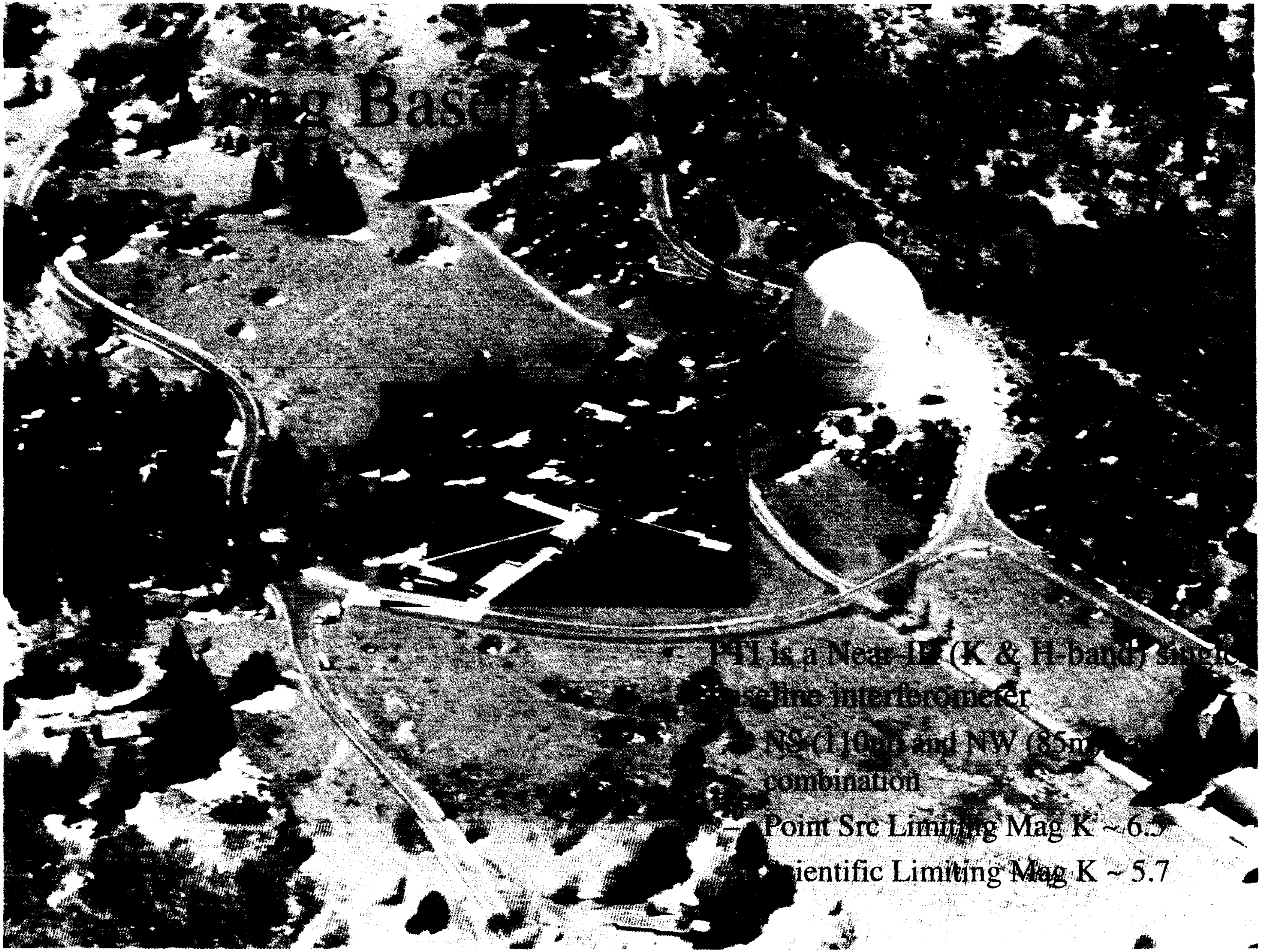
Tuthill, Danchi & Monnier (1999)

Wavelength Dependence of Size

- Size variations are linked to spectral type



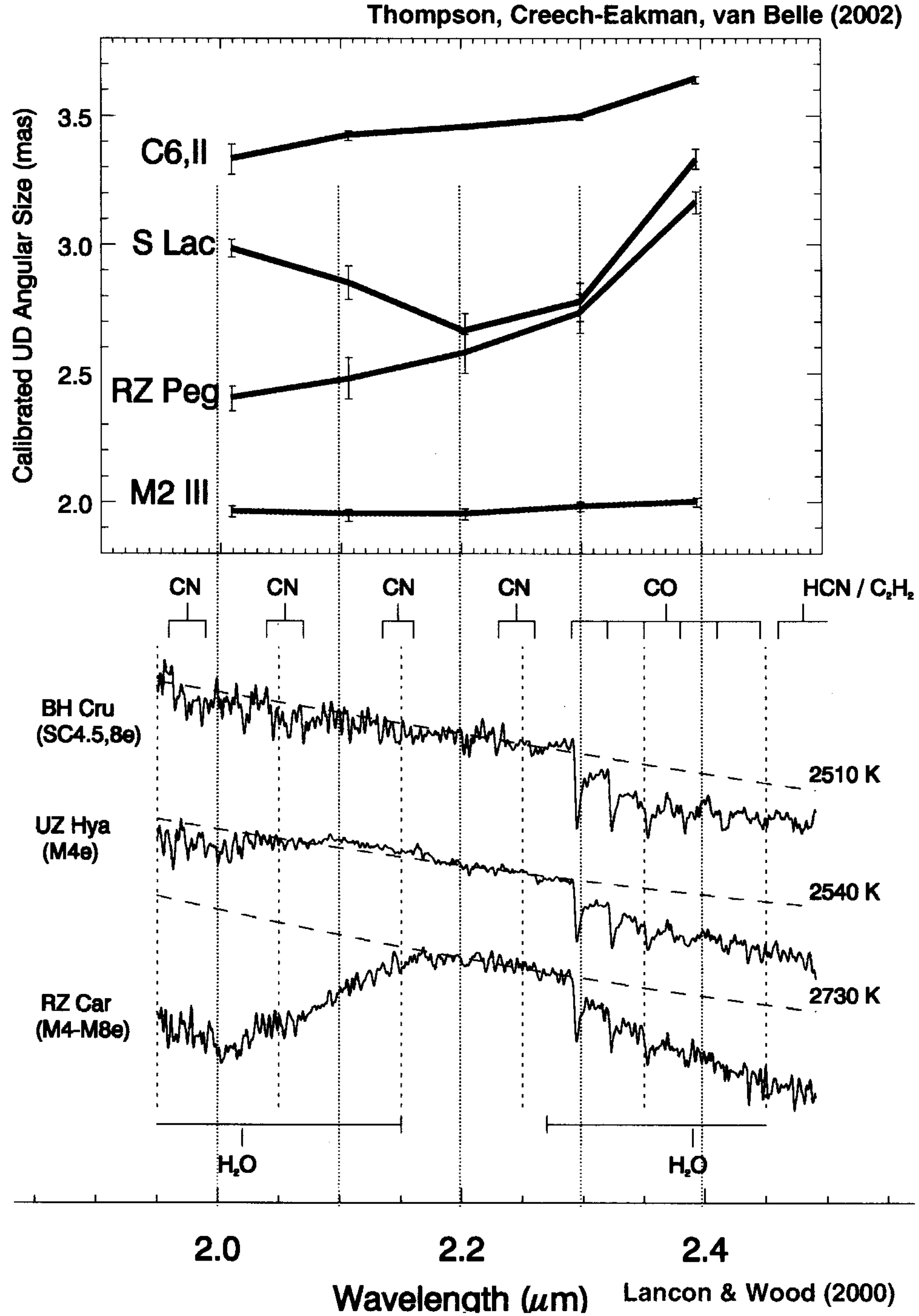
Tuthill, Danchi & Monnier (1999)



ong Base
PTI is a Near-IR (K & H-band) singl
aseline interferometer
NS (110m) and NW (85m)
combination
Point Src Limiting Mag K ~ 6.5
ientific Limiting Mag K ~ 5.7

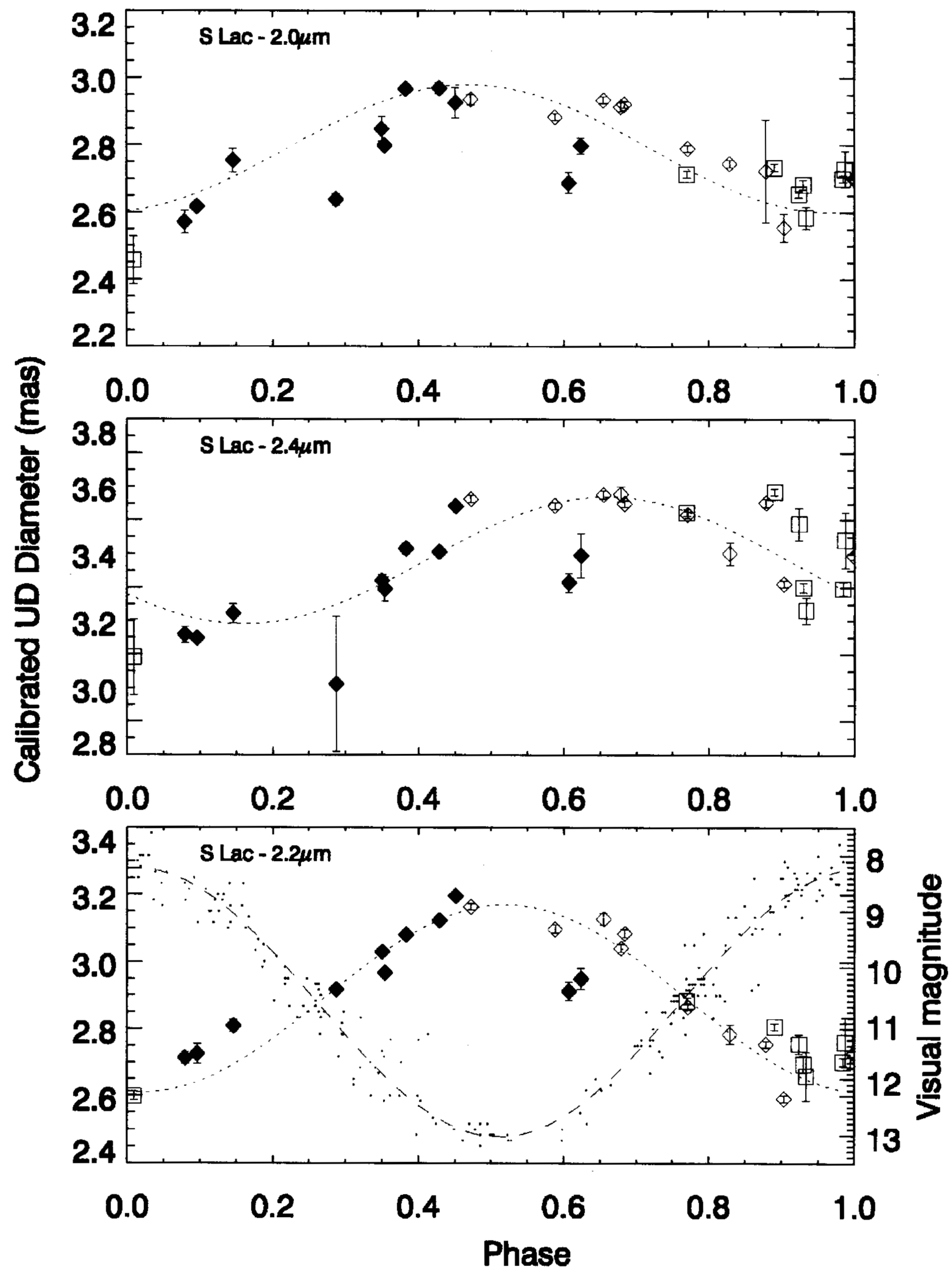
Wavelength Dep. of Size. II

- Varies with stellar type
  - Carbon Miras, non-Miras – Steeply sloped
  - O-rich Mira – ‘U’ shape
  - M giant - flat
- Linked to atmospheric chemistry, structure



Phase Lags: O-rich Mira

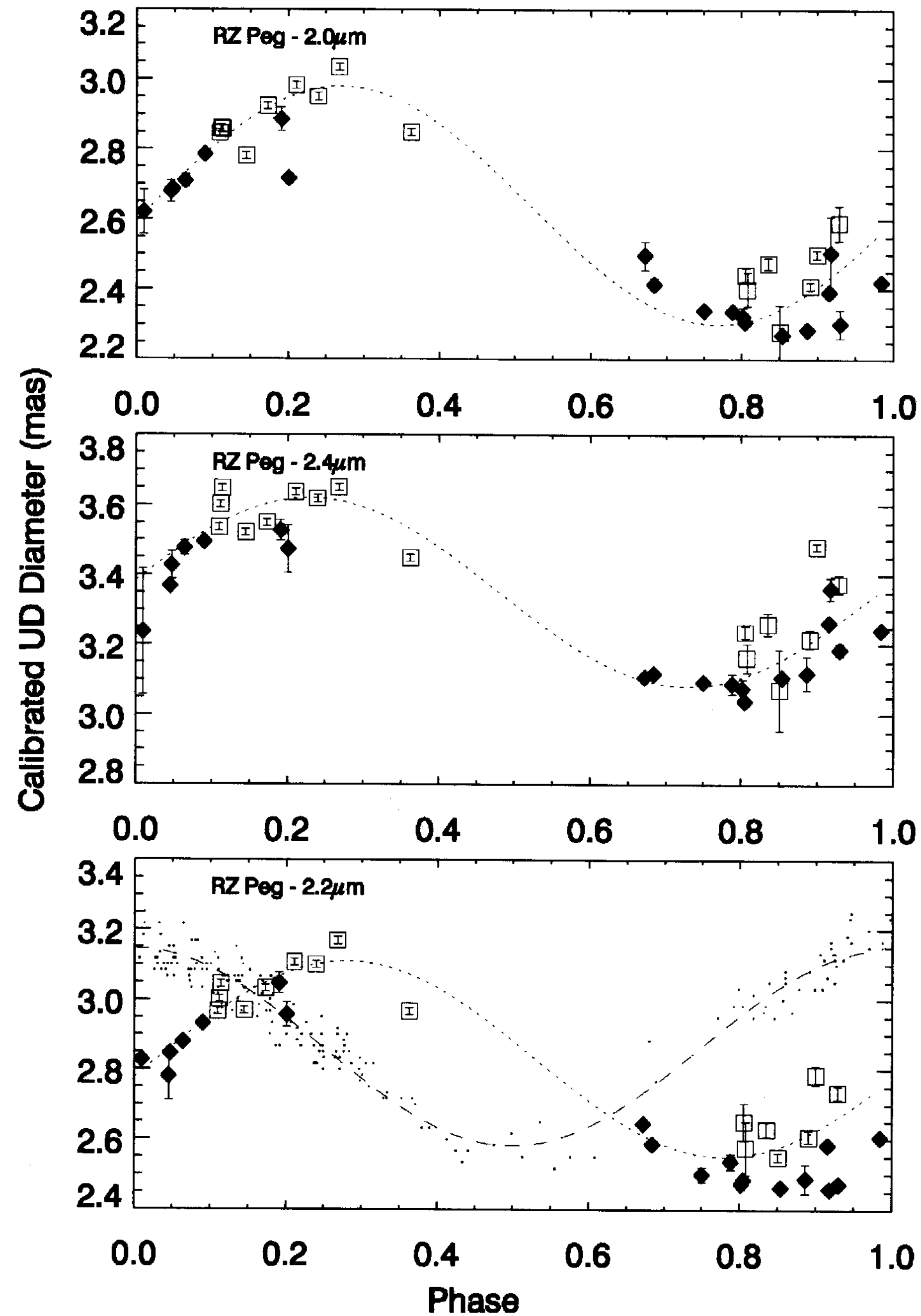
- Comparison of narrowband sizes as a function of phase for S Lac
- 2.4µm size has a ~30d lag behind 2.0, 2.2µm windows



Thompson, Creech-Eakman, van Belle (2002)

Phase Lags: Carbon Mira

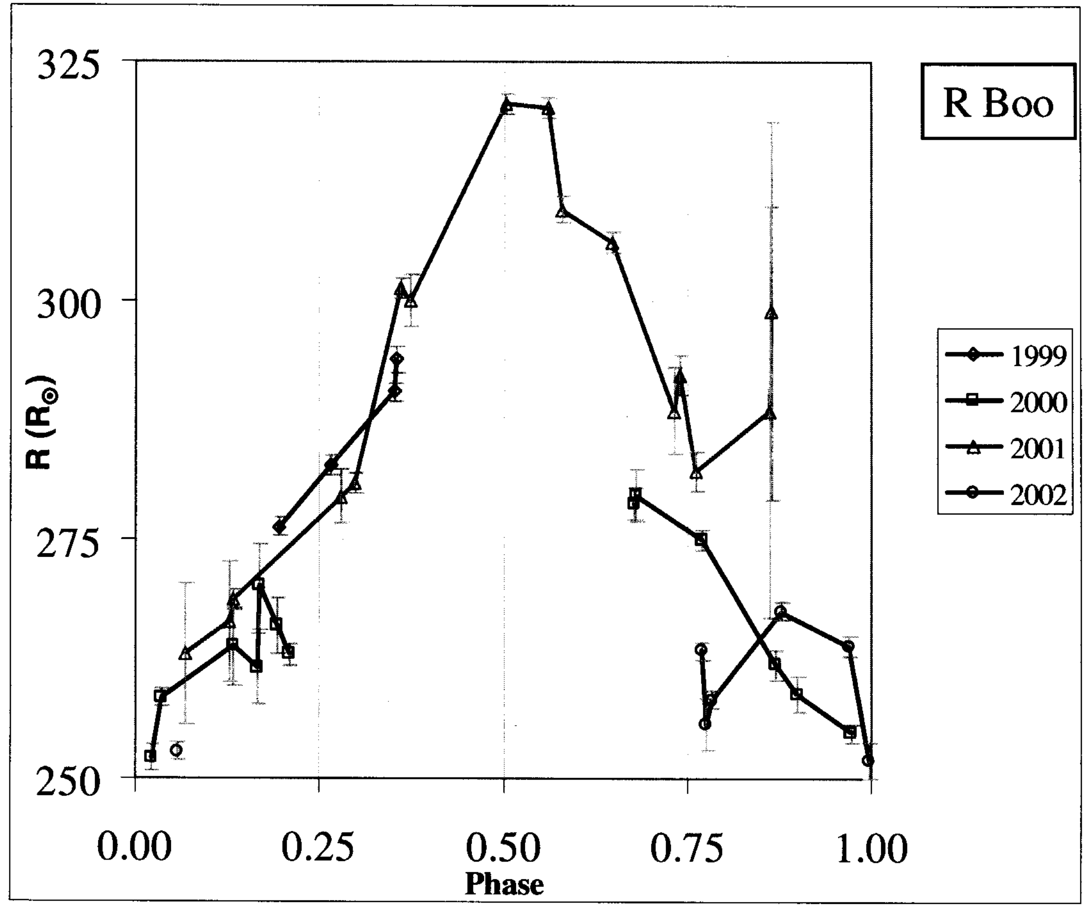
- No significant phase lag see for RZ Peg
- Atmosphere is thick or thin but not grey



Thompson, Creech-Eakman, van Belle (2002)

Long Term Monitoring

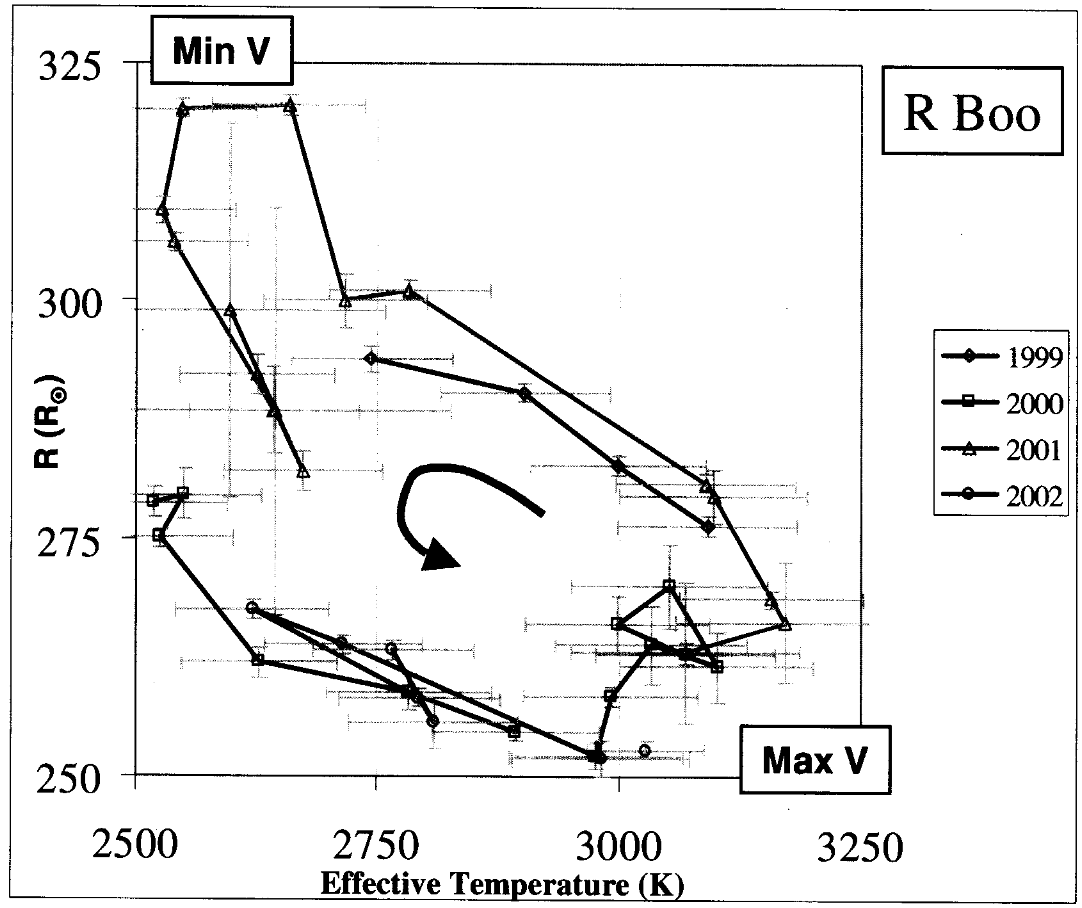
- Individual stars have 4+ years of angular size measurements
- Radius variations
  - Seen to be ±10%
  - Repeatable from year to year
  - Min radius at max light



Thompson, Creech-Eakman, van Belle (forthcoming)

Long Term Monitoring

- Radius-Temp diagram shows cyclic, repeatable variations



Thompson, Creech-Eakman, van Belle (forthcoming)

What Can *You* Do For Interferometry?

- Help guide the observations
  - Identify particular phase or wavelength "sweet spots"
  - Many next-generation instruments currently in definition phase
- Help bridge the gap between model and observables

What's to come?

- Already proceeding with engineering observations
  - Keck Interferometer – 1.8m outriggers
  - VLTI – 1.8m auxiliary telescopes
  - CHARA
  - NPOI - Recently demonstrated 6-way combination