Optical Interferometry: Astronomical Application

W. D. Cotton

Introduction

- Current observations limited to large, bright stars
- This is about to change, new generation of interferometers will have:
  - Large apertures, up to 10 m
  - Longer baselines
  - Phase referencing
- Fainter, smaller stars and AGNs will be possible

Past and Current Interferometers

- Michelson
  - 20 foot baseline using 100 inch telescope mount
  - 1921, measured diameter of Betelguese and several other stars
- Intensity interferometer
  - Sydney Univ., Narrabri, NSW, Australia
  - 2 x 6.5 m aperture, baseline to 200 m
  - Incoherent interferometry
  - 1963 – 1975
- Grand Interferometre a 2 Telescopes GI2T
  - CERGA, Calern, France
  - 2 x 1.5 m aperture, baseline to 35 m
- Sydney University Steller Interferometer SUSI
  - Sydney Univ., Narrabri, NSW, Australia
  - 13 x 0.14 m aperture, baseline to 640 m

- MkIII
  - U. S. Navy, Mt. Wilson, CA
  - 3 x 0.05 m aperture, baselines 3 – 31.5 m
- Navy Prototype Optical Interferometer NPOI
  - U.S. Navy, Flagstaff, Az.
  - 6 x 0.6 m aperture, baselines to 435 m
  - Closure phase imaging, visual
  - “Y” shaped array
- Infrared Spatial Interferometer ISI
  - Berkeley University, Mt. Wilson, CA
  - 3 x 1.65 m aperture, baselines to 30 m
  - Heterodyne 10 micron system
- Cambridge Optical Aperture Synthesis Telescope COAST
  - University of Cambridge, Cambridge, UK
  - 5 x 0.4 m aperture, up to 48 m baseline
  - Closure phase imaging, visual/IR
  - “Y” shaped array

- Infrared and Optical Telescope Array IOTA
  - SAO/Obs. de Paris, Mt. Hopkins, Az.
  - 3 x 0.45 m aperture, up to 38 m baseline
  - optical, near IR
- Palomar Testbed Interferometer PTI
  - JPL/Caltech, Mt Palomar, CA
  - 2 x 0.4 m aperture, up to 110 m baseline
- Mitiaka optical and InfraRed Array MIRA
  - National Astronomical Observatory, Japan
  - 2 x 13 cm aperture, 4 m baseline
- Keck
  - Univ. California, Mauna Kea, HI
  - 2 x 10 m, 4 x 1.5 m, baselines to 165 m
- VLTI
  - ESO, Cerro Paranal, Chile
  - 4 x 8 m, 3 x 1.8 m, baselines to 200 m
  - near and mid IR

- CHARA
  - Georgia State (USA), Mt. Wilson, CA
  - 6 x 1 m aperture, baseline to 350 m
  - “Y” shaped array
- Large Binocular Telescope LBT
  - MPIfA/Steward Obs., Mt. Graham, Az
  - 2 x 8.4 m aperature, baseline, 14.4 m baseline
  - Scheduled operations 2004

What is Observable by Optical Interferometry?

- At mas resolution in radio only nonthermal sources observable.
- In Rayleigh-Jeans portion of spectrum a given baseline just has the same resolution of a 1 Jy of the same T_B independent of frequency
- At shorter wavelengths the resolution is higher with the same min. T_B

$$T_B = \frac{c^2 \ S}{2k_B \nu^2 \theta^2} = \frac{S \ D^2}{2k_B}$$

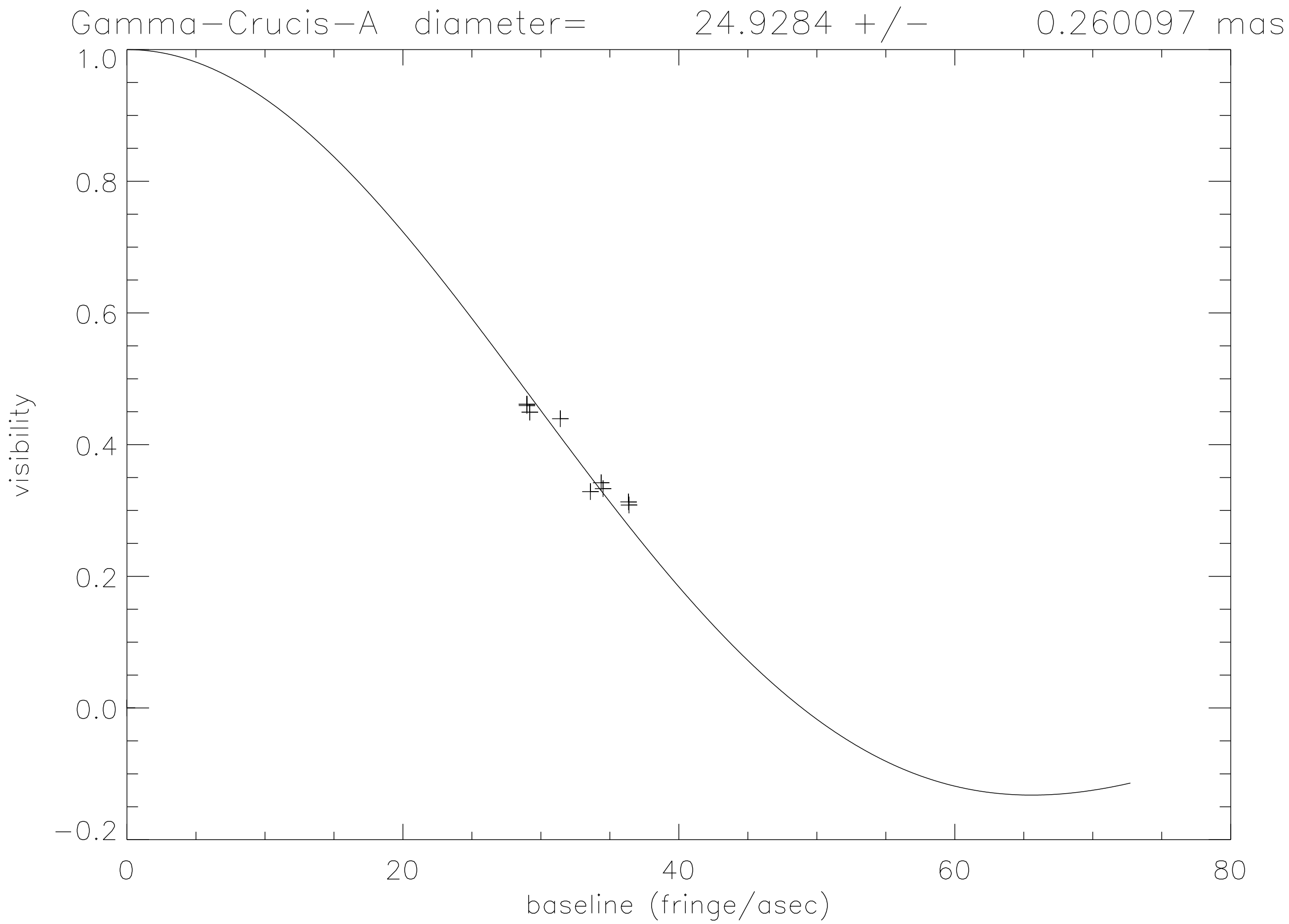
- Thermal source can be seen at mas resolution in IR/optical.
  - Stars, protostars
  - Dust disks, shells
  - AGN core, inner jet and dusty torus
- Most current interferometers only measure amplitudes so must model fit

Exoplanets

- Astrometric measurements compliment radial velocity.
  - Radial velocity only measures v sin i
  - Astrometry + radial velocity gives better orbit fit
  - Radial velocity biased towards small separation
  - Astrometry biased towards large separation
- Direct detection of Jupiter–like planets
- Direct detection of Earth–like planets requires space interferometer
- Presence of life may be indicated by IR ozone bands

Effective temperatures

- Effective temperature needed to verify theoretical models
- Spectra of cool stars are heavily line blanketed
  - Hard to measure effective temperature spectroscopically
  - Need diameter and bolometric flux
- Simple model fits sufficient for disk diameter



Gamma Crucis A as measured by VLTI/VINCI

Limb darkening

– Cool stars have extended envelopes
– May have center-to-limb brightness changes (limb darkening)
– May be modeled with sufficient data.

Multiple Star Systems

– Close multiple star systems need interferometric resolution.
– Need for orbital dynamics (get masses)
– Images can show distortions of envelope

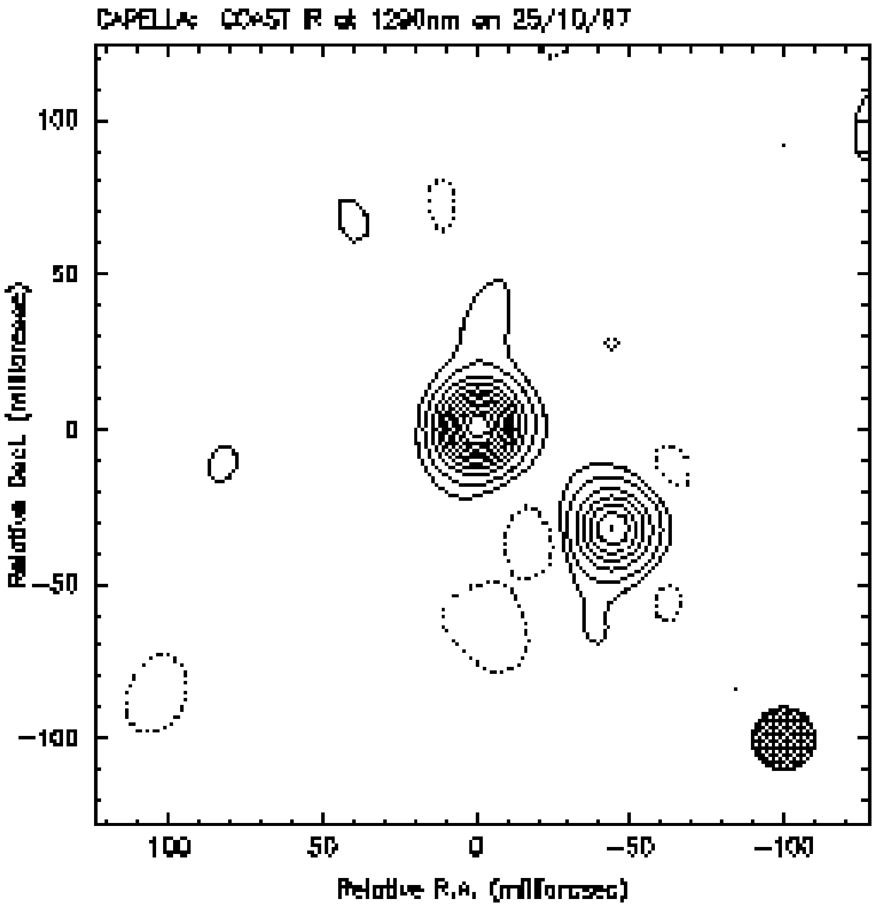
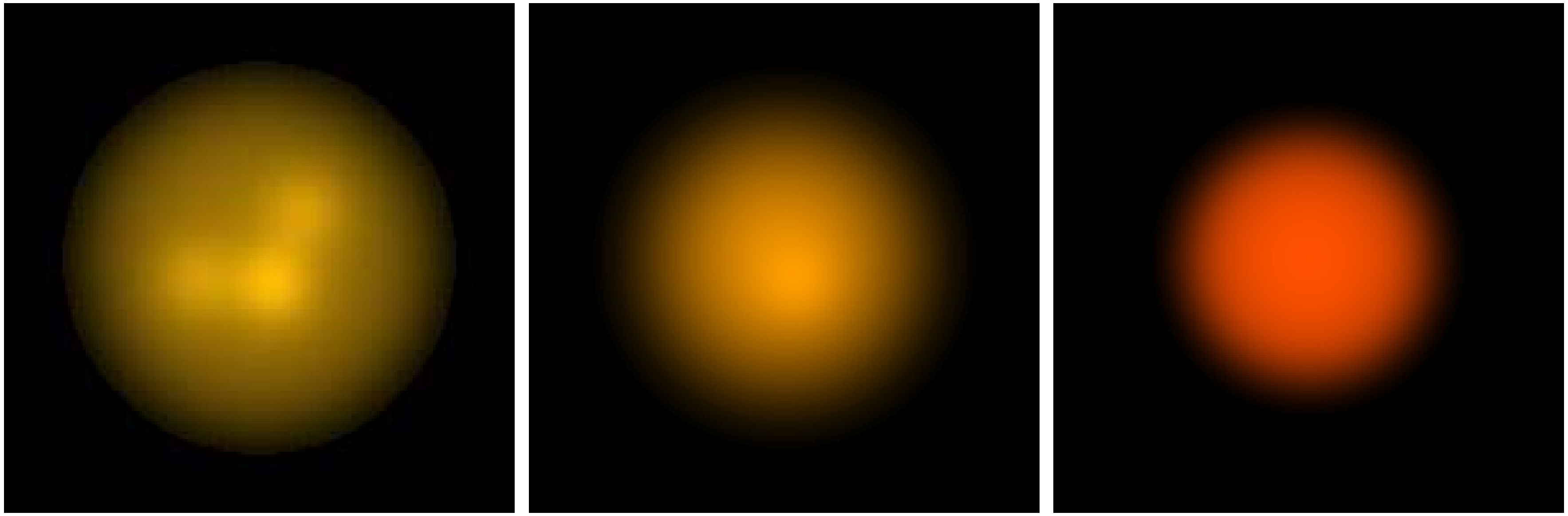


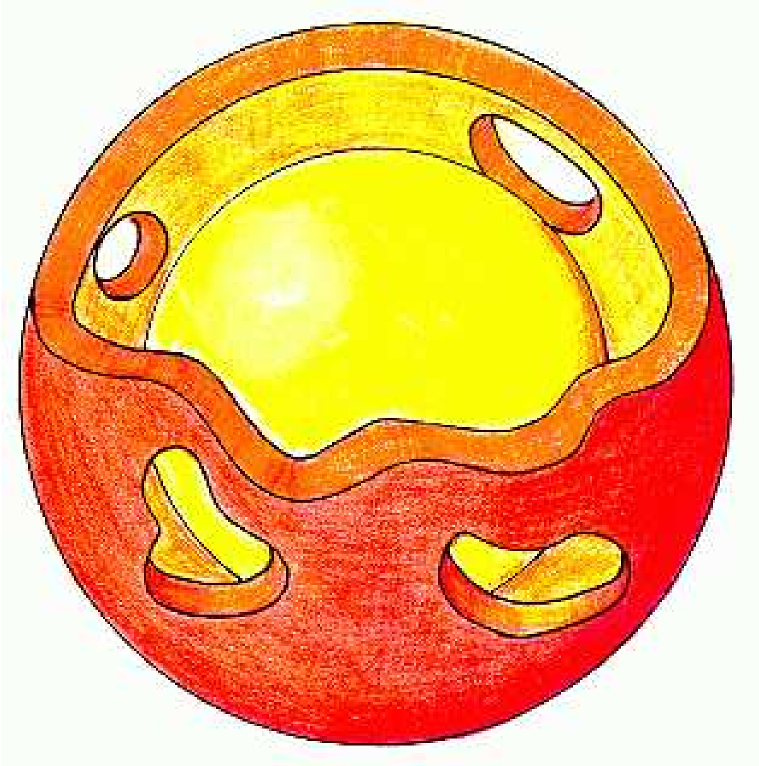
Image of binary star Capella as observed by COAST at 1.3 micron

Star spots

- Can image surface of giant stars
- Cooler stars may have large spots.



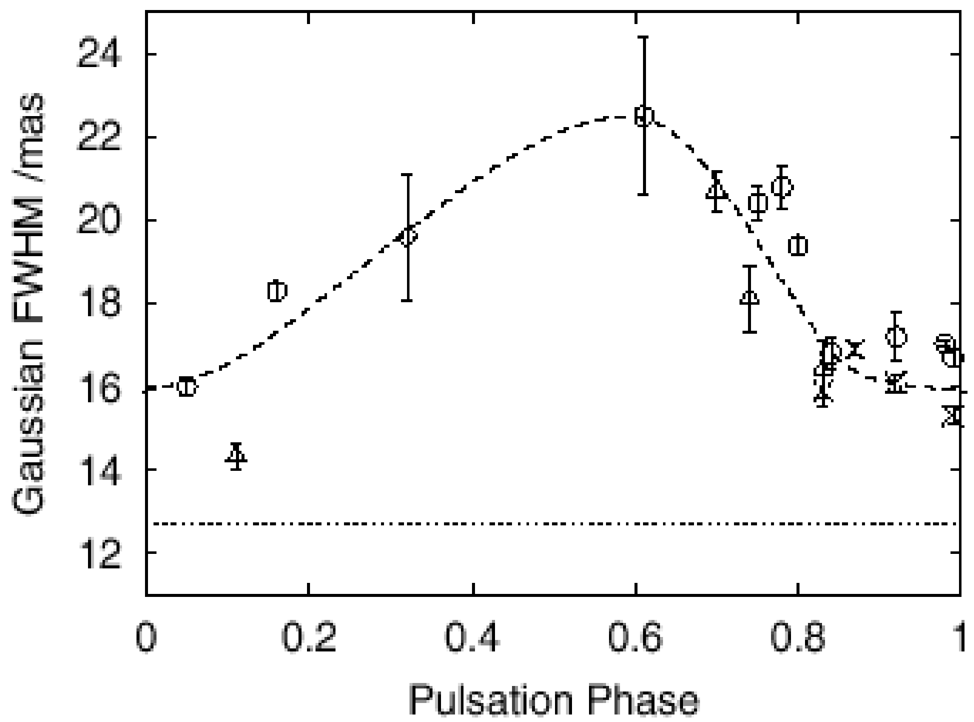
Betelguese at 700, 905, 1290 nm as observed by COAST(700, 905 nm) and WHT (1290 nm) (Young et al. 2000, MNRAS 315, 635)



Model of Betelguese spots (Young et al. 2000, MNRAS 315, 635)
– See deeper in IR to hotter layer.
– Outer layers opaque in R from TiO bands but see hot convection cells.

Pulsating AGB stars

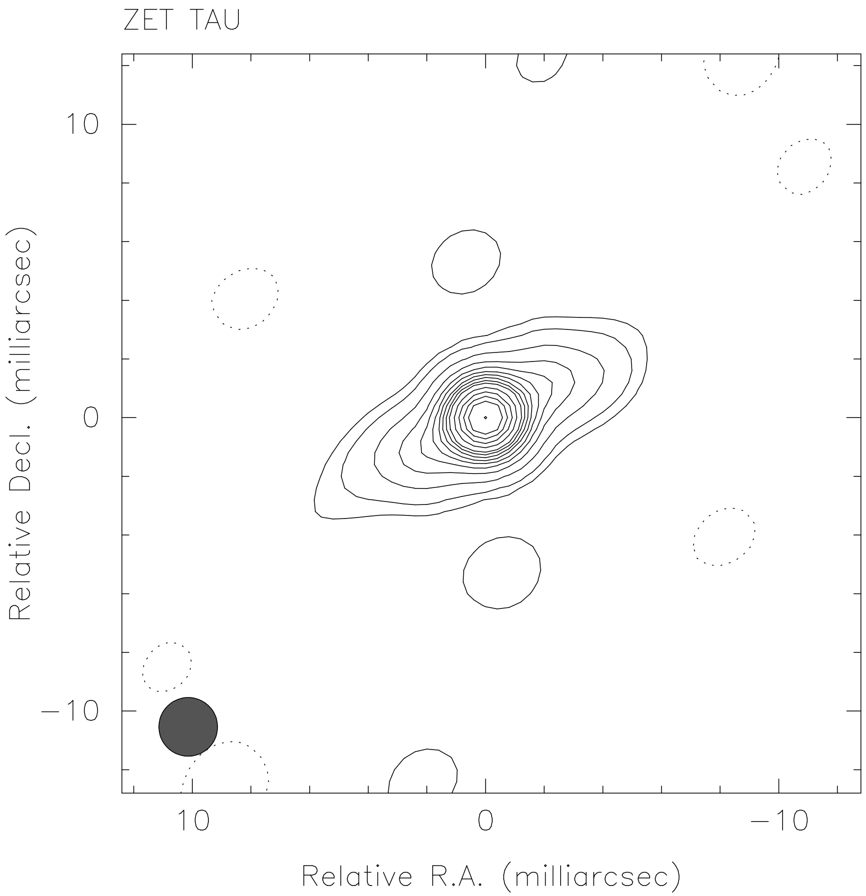
- Pulsation mechanisms and circumstellar envelopes not well understood
- Need diameter and effective temperatures measurements to validate models
- Extended atmospheres have many molecules whose structure can be studied



Variation of diameter of the Mira χ Cygni
from COAST (Young et al., 2000, MNRAS, 18, 381-386)

Ae / Be stars

- These hot stars have an extended emission line envelope
- Optical/IR emission from dense equatorial disk



Zeta Tauri COAST H_α image courtesy Amanda George

Young Stellar Objects (YSOs)

- Protostars show structure on a wide variety of scales
- Many are in heavily obscured regions so need be observed at long wavelengths
- Many have protoplanetary dust disks
- Need very good resolution or very good calibration

Dust disks / shells

- Much of the dust in the ISM comes from mass ejections from evolved stars
- Can study dust formation region
- Dust formation in pulsating stars may be episodic

AGNs

- AGN core and inner jet will be visible
  - Can study jet on scales that are optically thick in radio
- Dusty torus should be visible in the IR
- Not currently observable but soon.