Science with Optical / Infrared Interferometry

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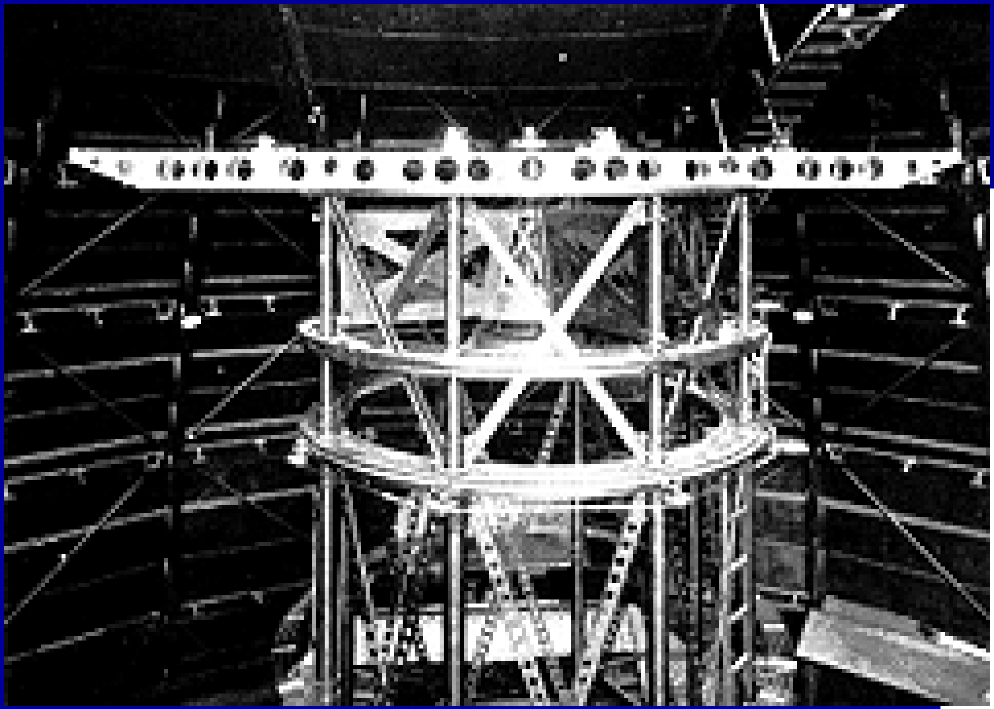
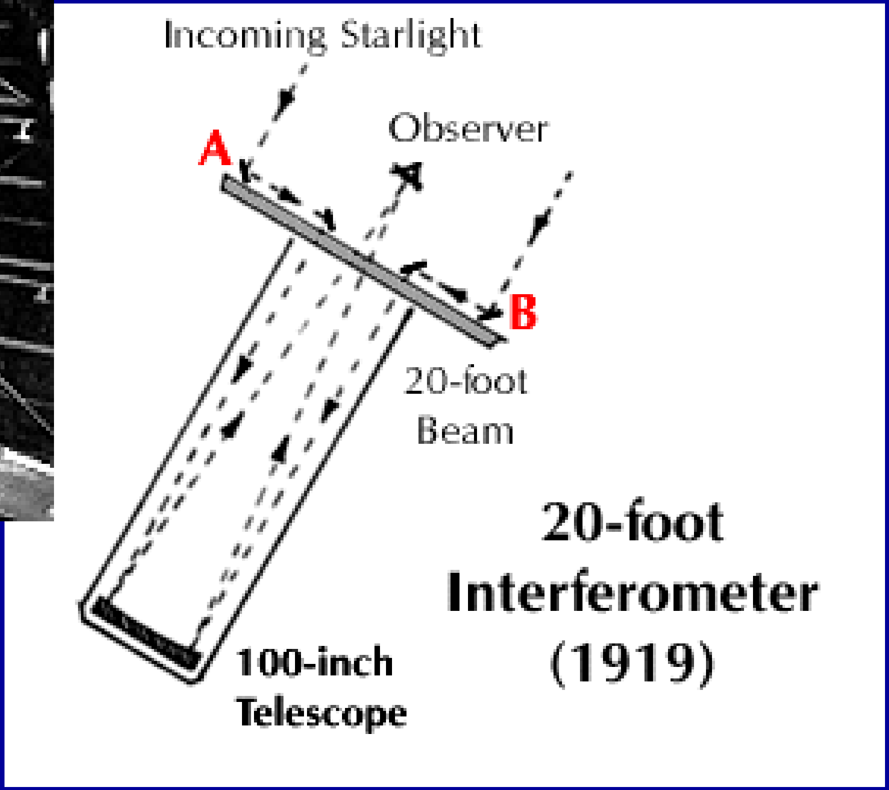
The VLT Interferometer

Why Build a Stellar Interferometer?

- To overcome the resolution limitations of conventional telescopes
- To measure the brightest and nearest stars
  - Angular diameters
  - Binary star orbits
  - Limb darkening
  - Stellar surface structure
  - Stellar positions and proper motions
  - Detection of planets
- To constrain theoretical models that describe stellar astrophysics.
- Now also: fainter objects (AGN etc.)

Michelson's 20 Foot Interferometer on Mt. Wilson





Observing in the Old Days

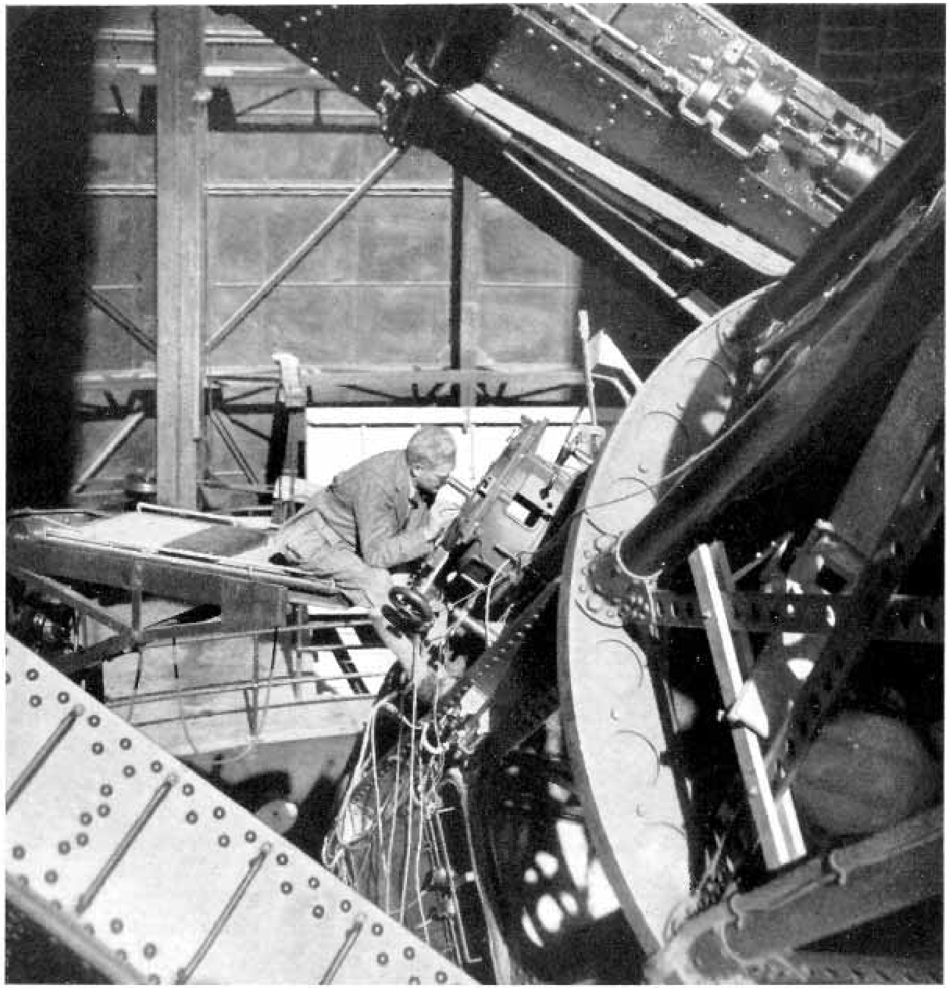
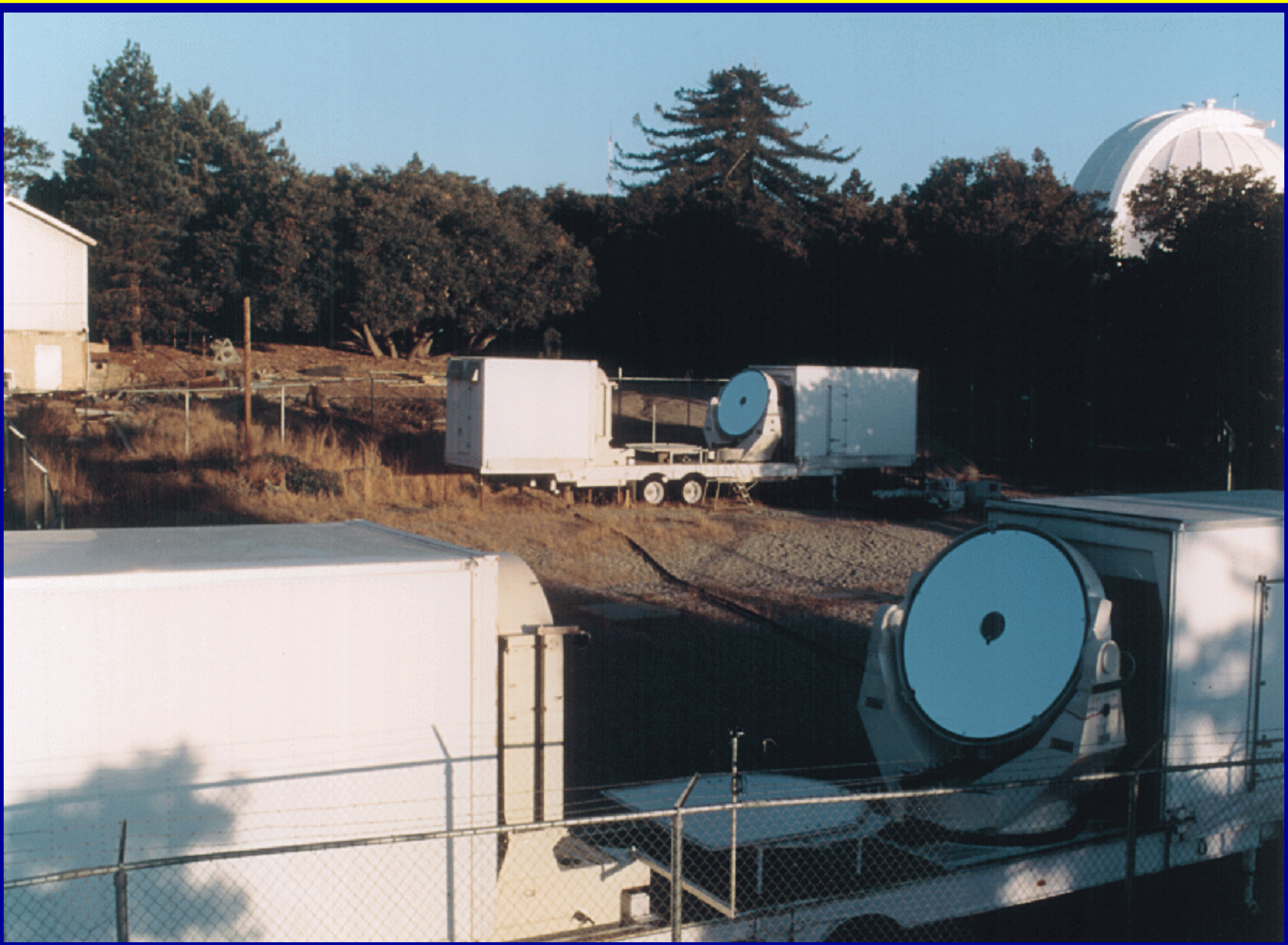
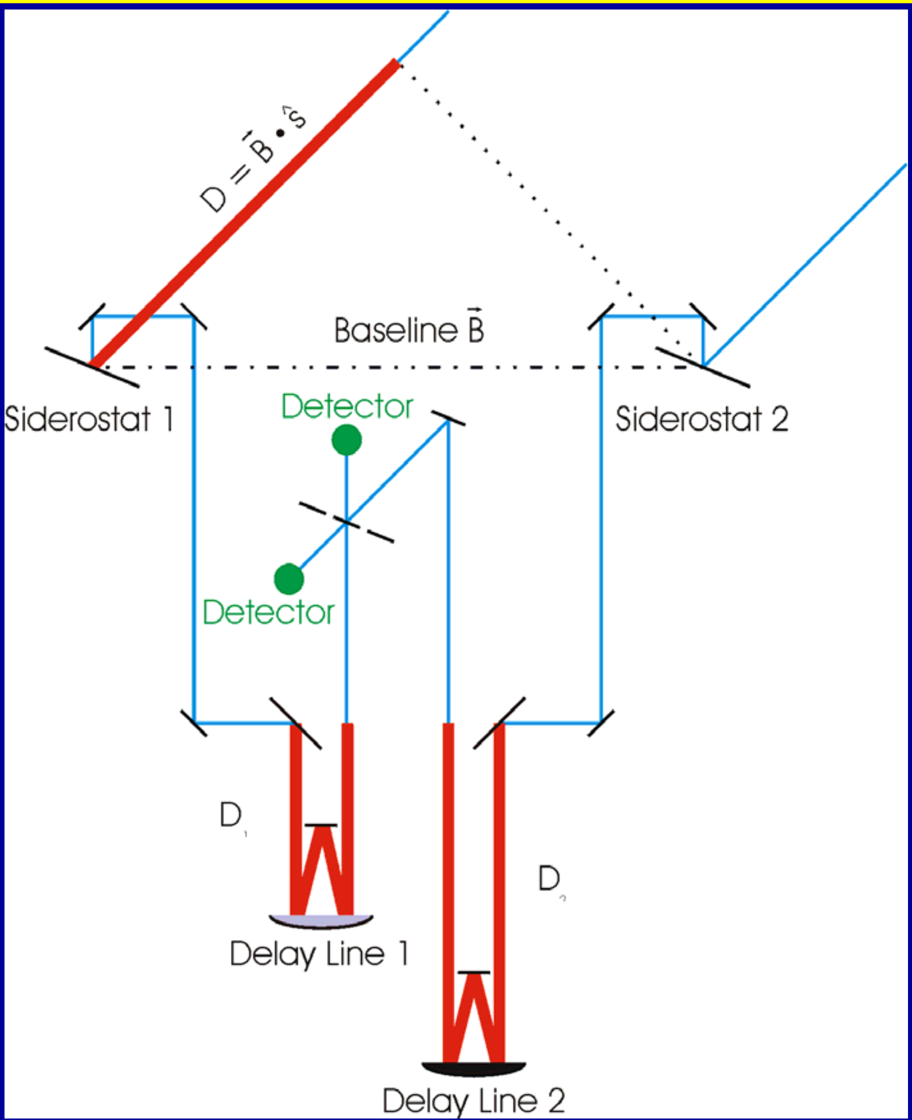


Abb. 3. Showing observer at eyepiece of 20 foot interferometer.

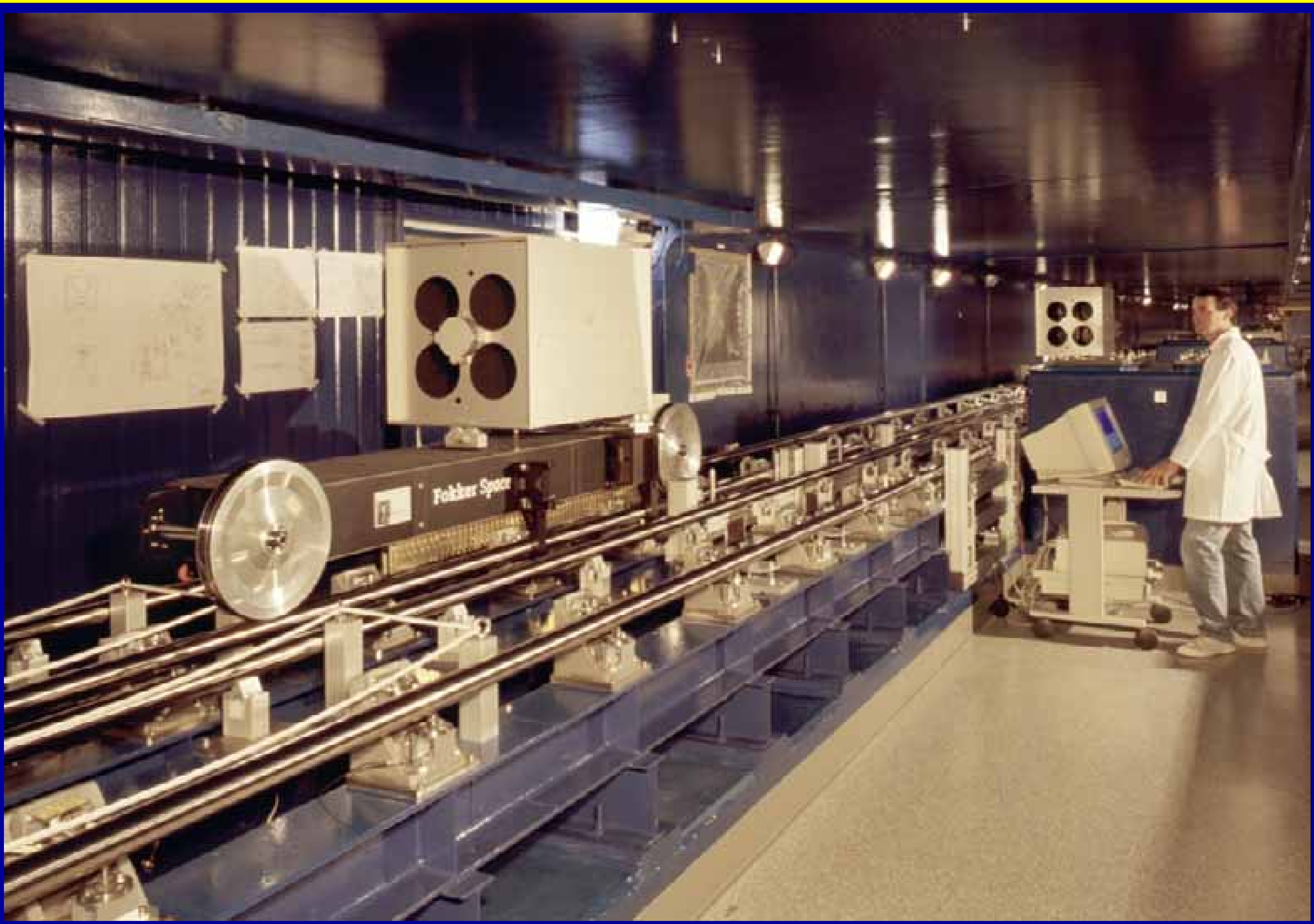
The ISI (Infrared Spatial Interferometer, Mt. Wilson)



Schematic Layout of Michelson Interferometer



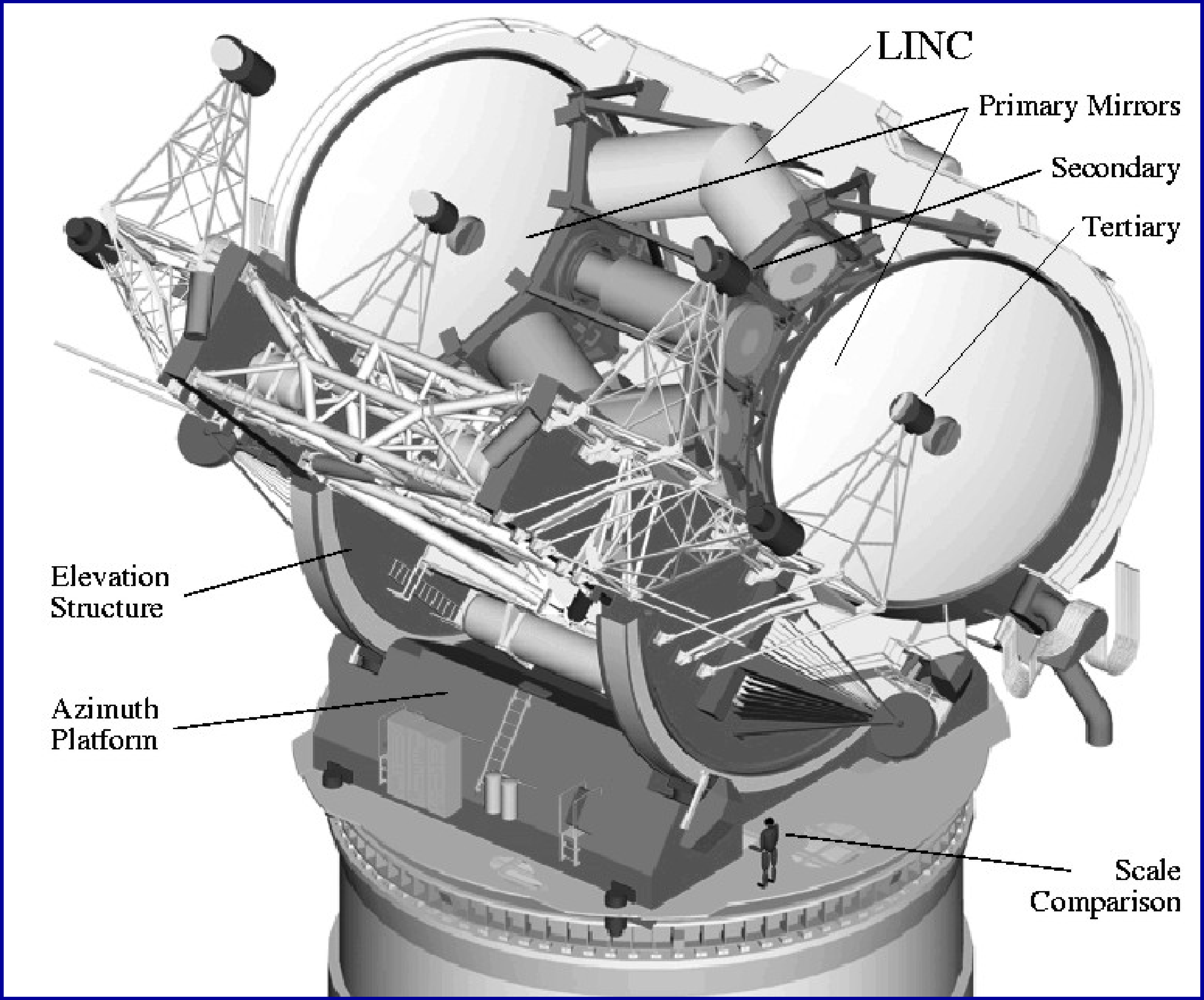
VLTI Delay Lines



The Mark III Interferometer

The Twin Keck Telescopes on Mauna Kea (Hawaii)

The LBT (Large Binocular Telescope, Mt. Graham, AZ)



Stellar Physics

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Fringe Visibility Defined

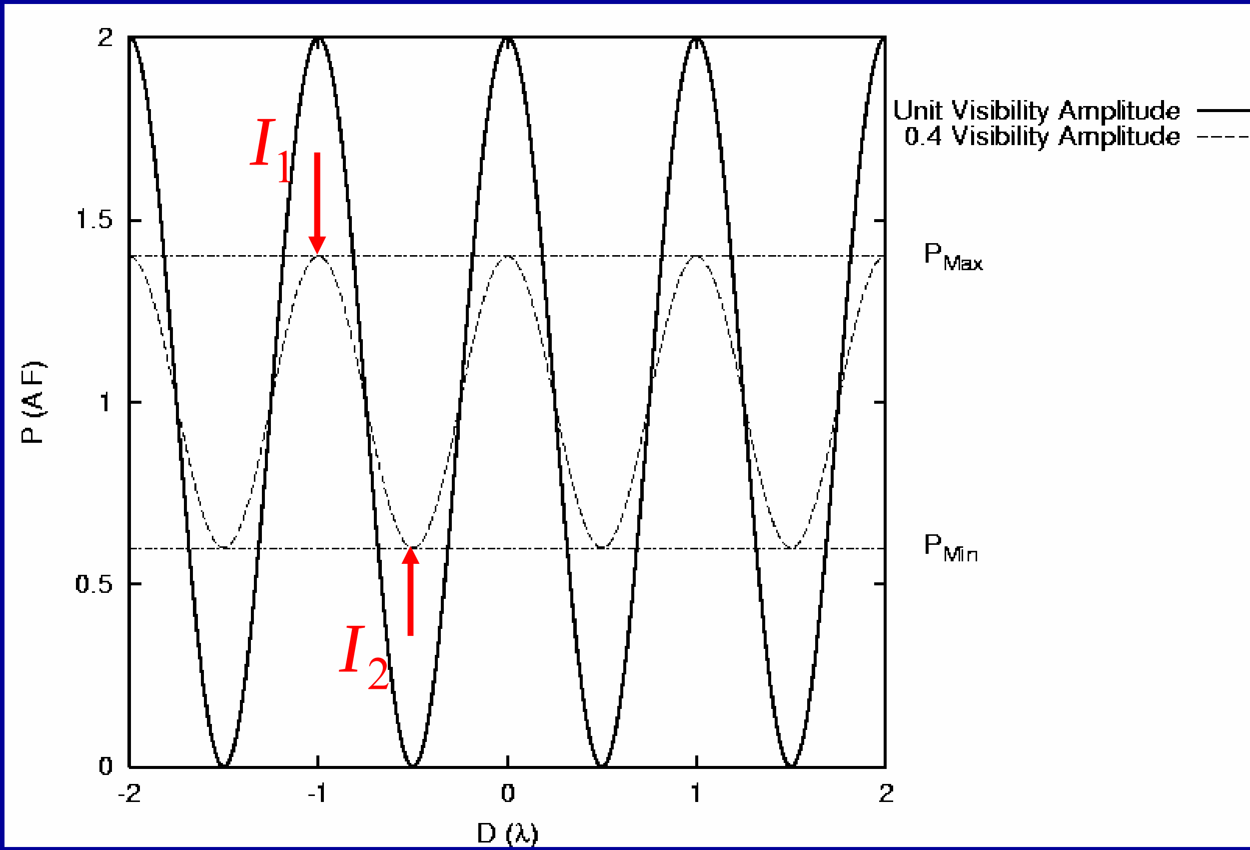
Visibility:

$$V = \frac{I_1 - I_2}{I_1 + I_2}$$

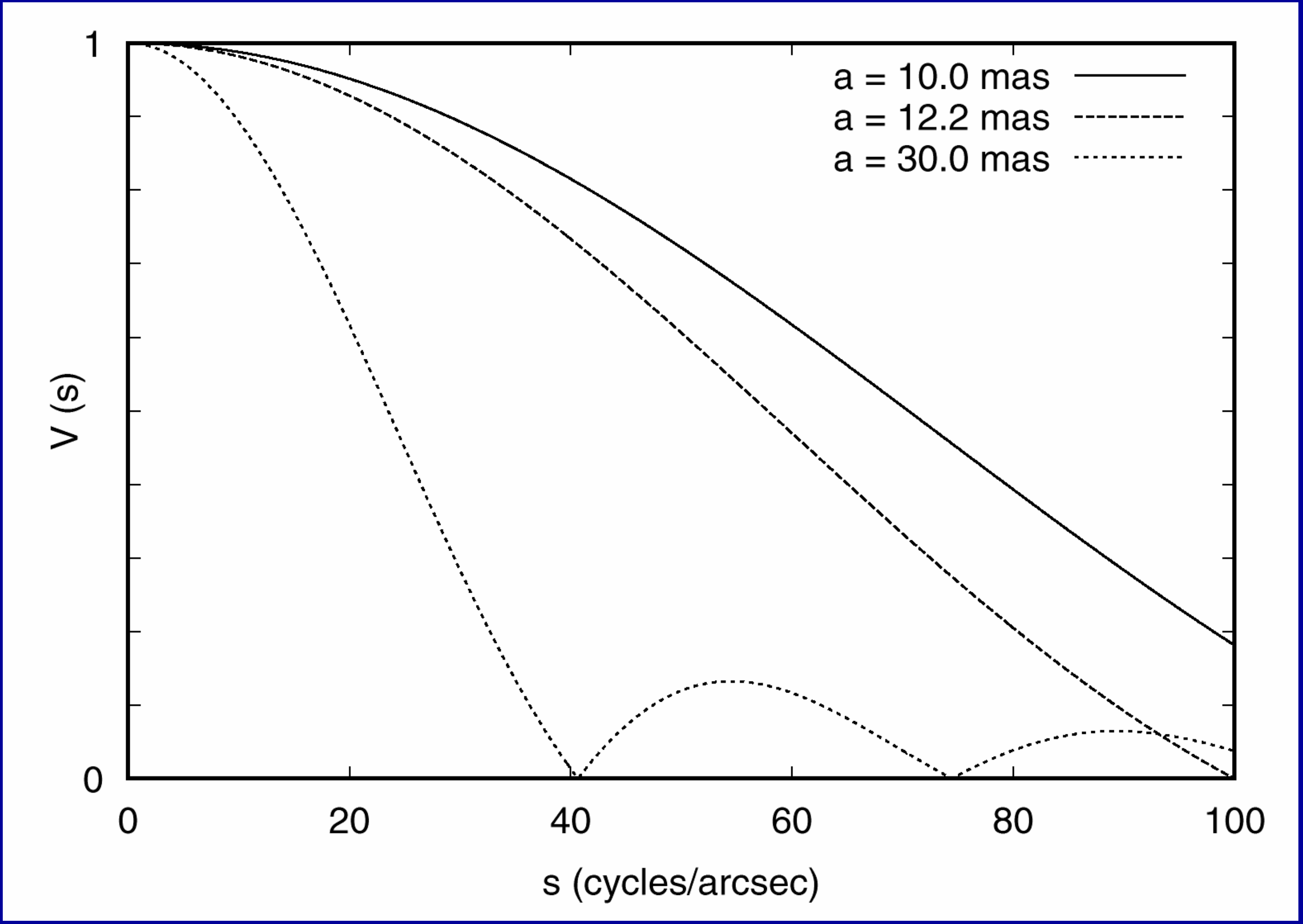
$I_1 =$ bright fringe

$I_2 =$ dark fringe

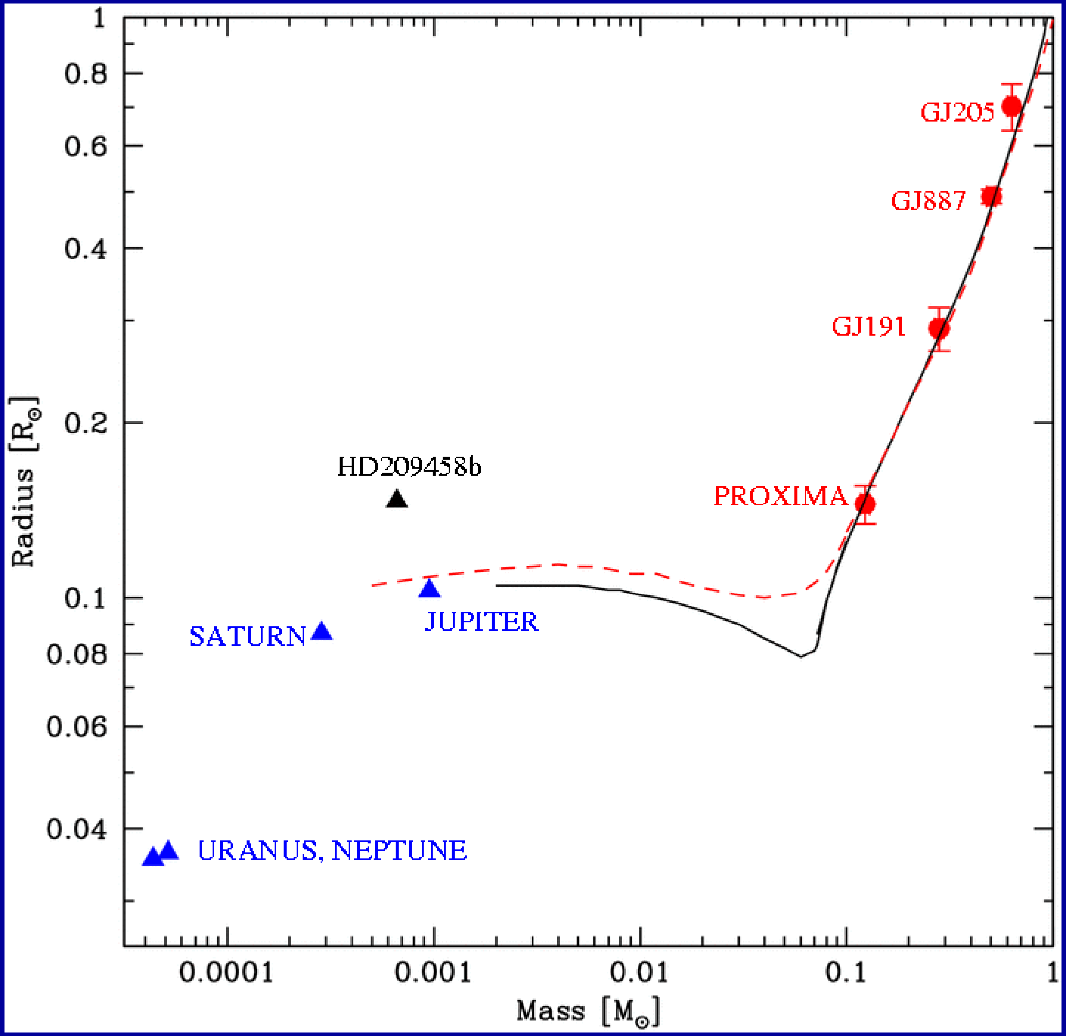
The visibility is a measure of the fringe contrast.



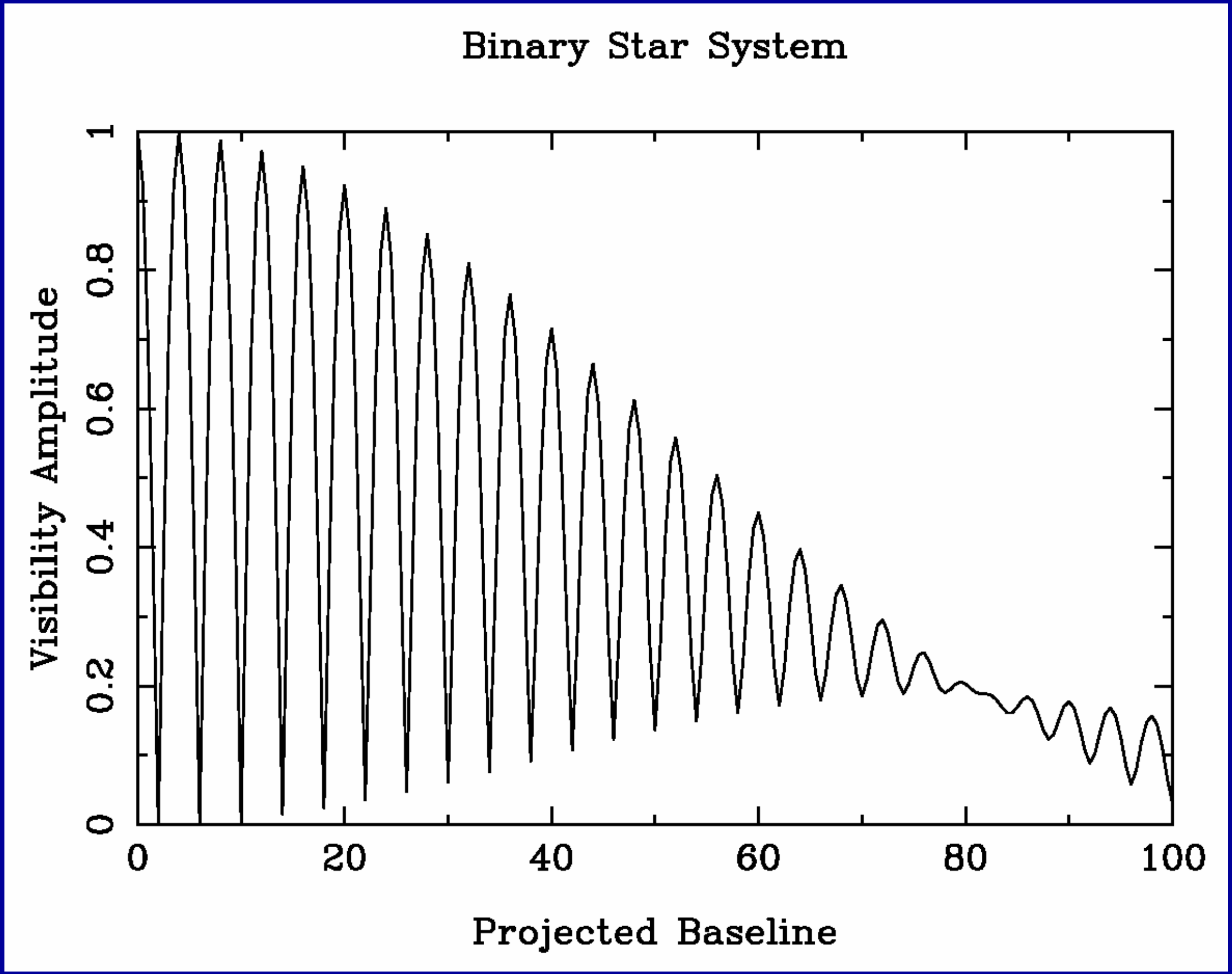
Fringe Contrast ("Visibility") of Uniform Disks



Mass-Radius Relation for Low-Mass Stars



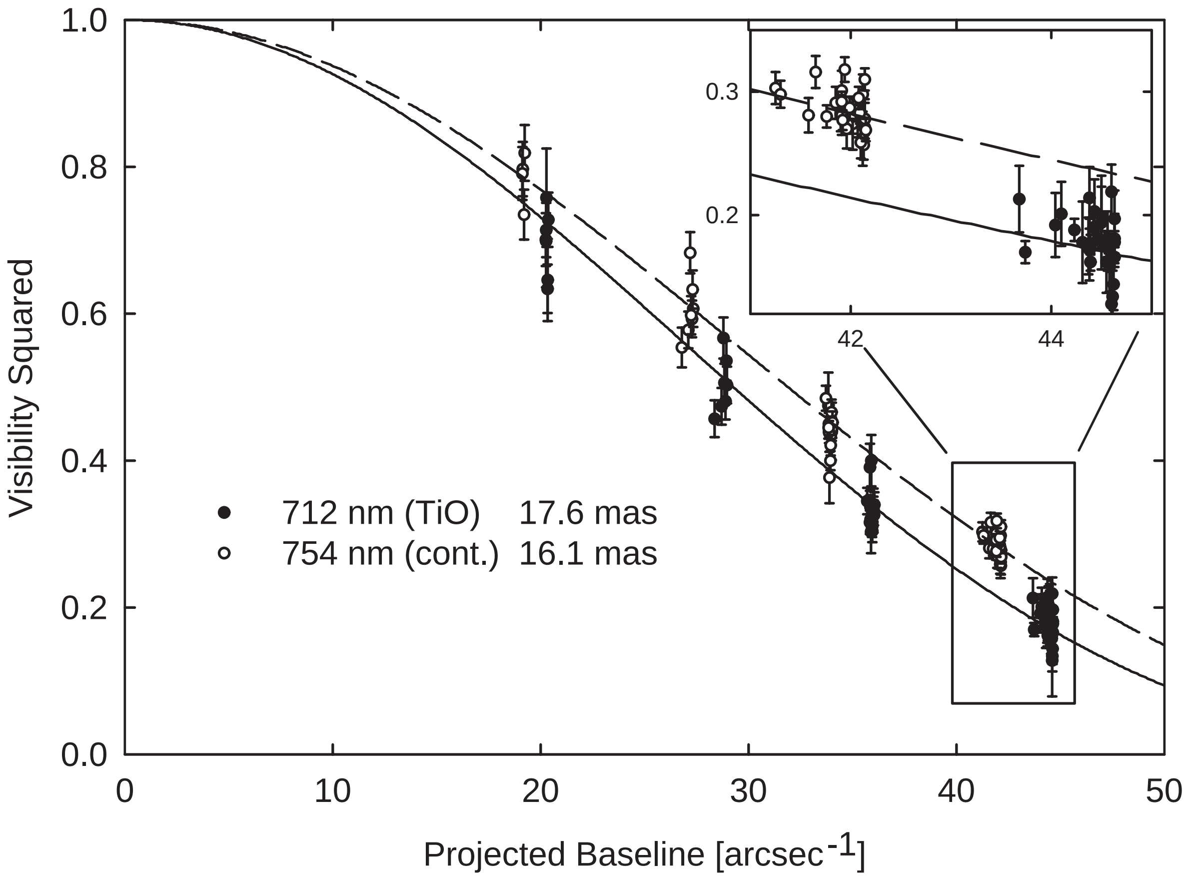
Visibility Curve of a Binary Star

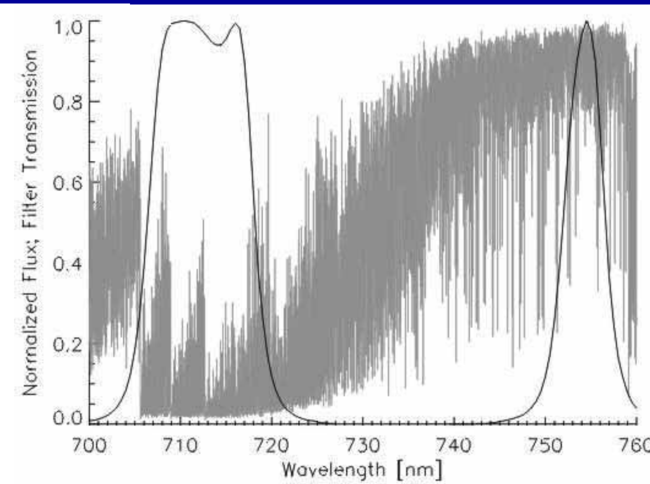


Information from Binary Stars

- Most important are double-lined spectroscopic binaries (SB2s)
- Spectroscopy gives all system parameters except inclination
- Interferometry can measure inclination $\Rightarrow$ can derive masses for both components
- Spectroscopy measures orbit in km/s, interferometry in mas $\Rightarrow$ combination gives distance (dynamical parallax)

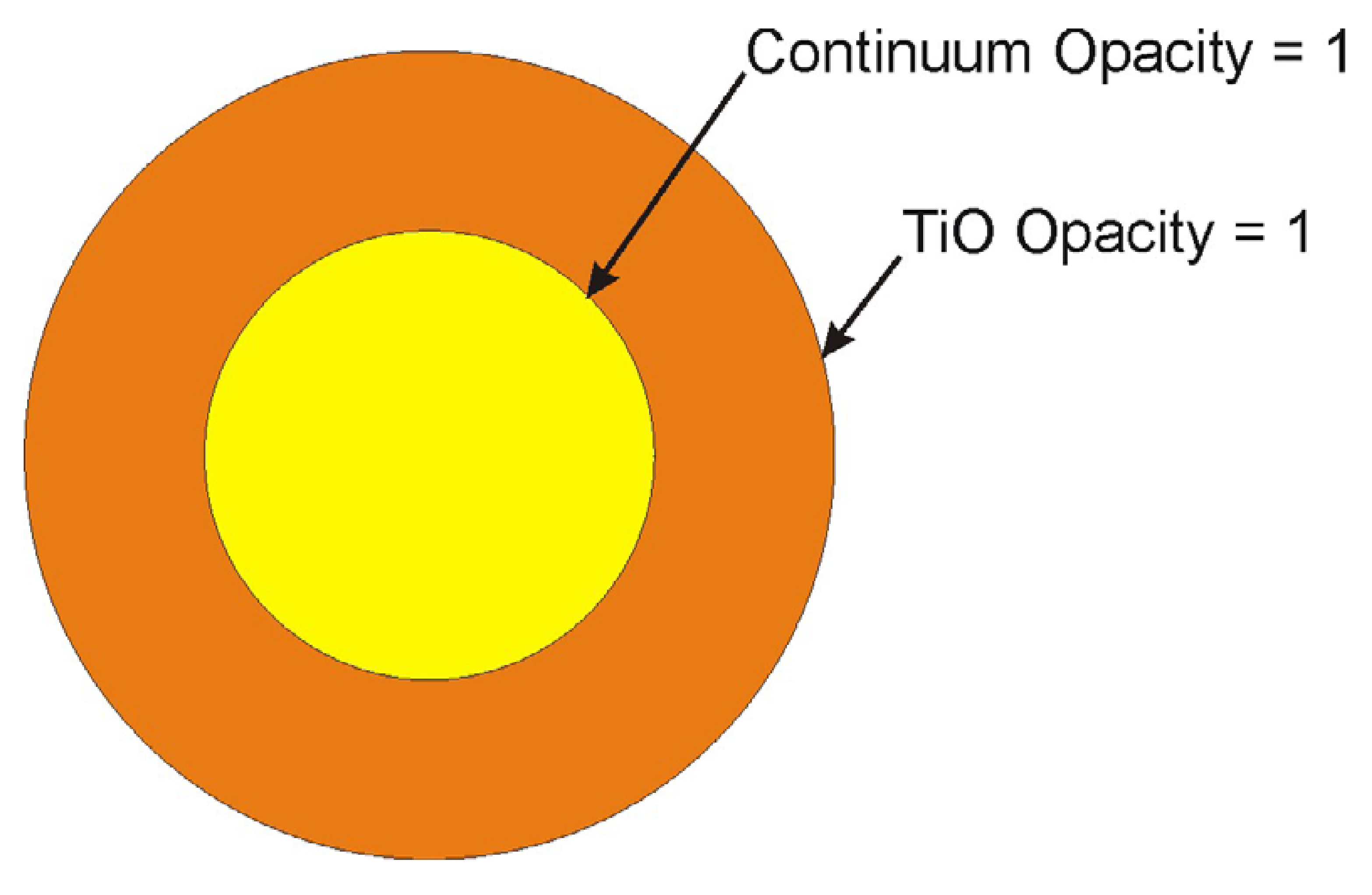
Mk III Diameter Measurements of the Giant Star β Pegasi



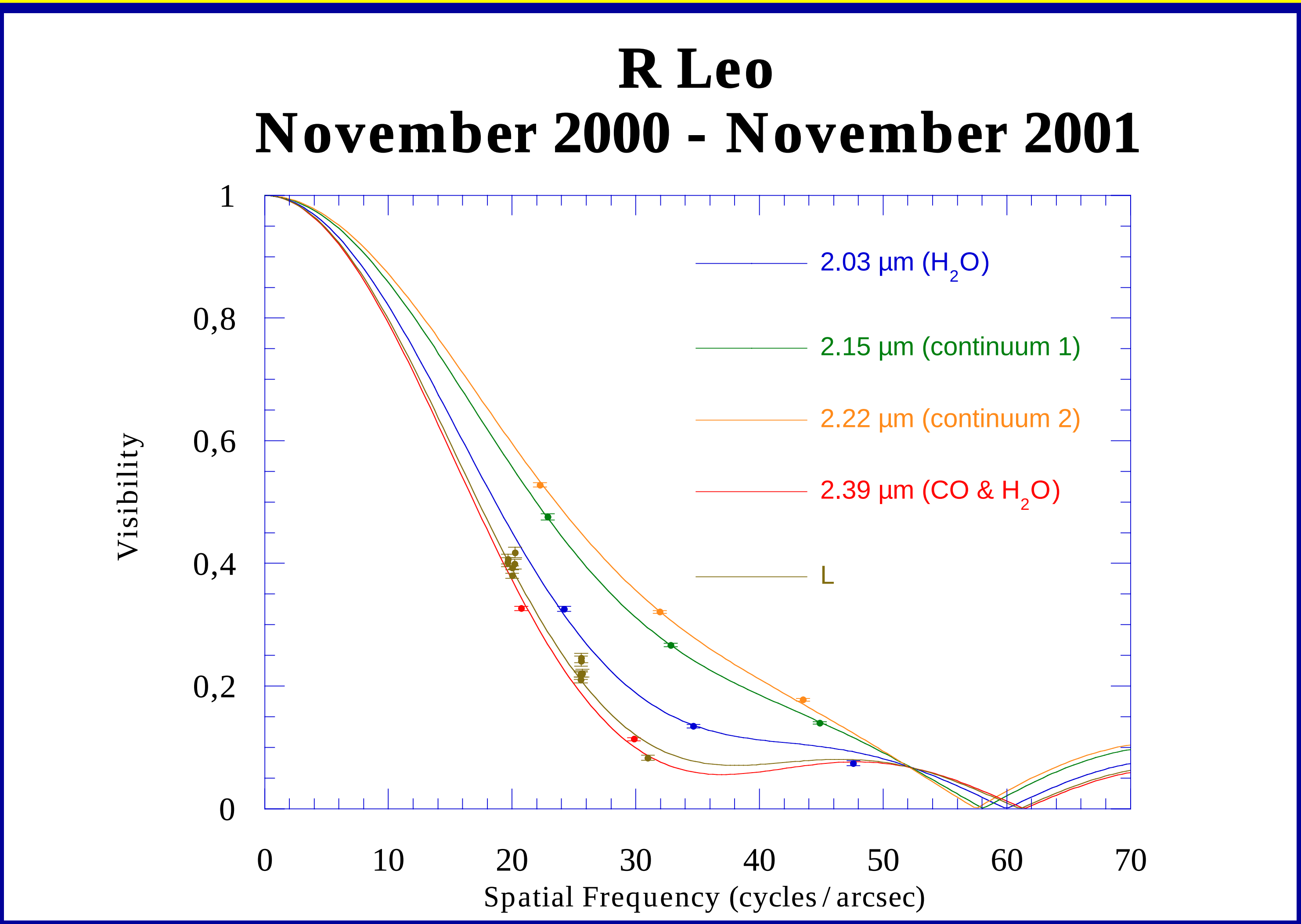


Quirrenbach et al.

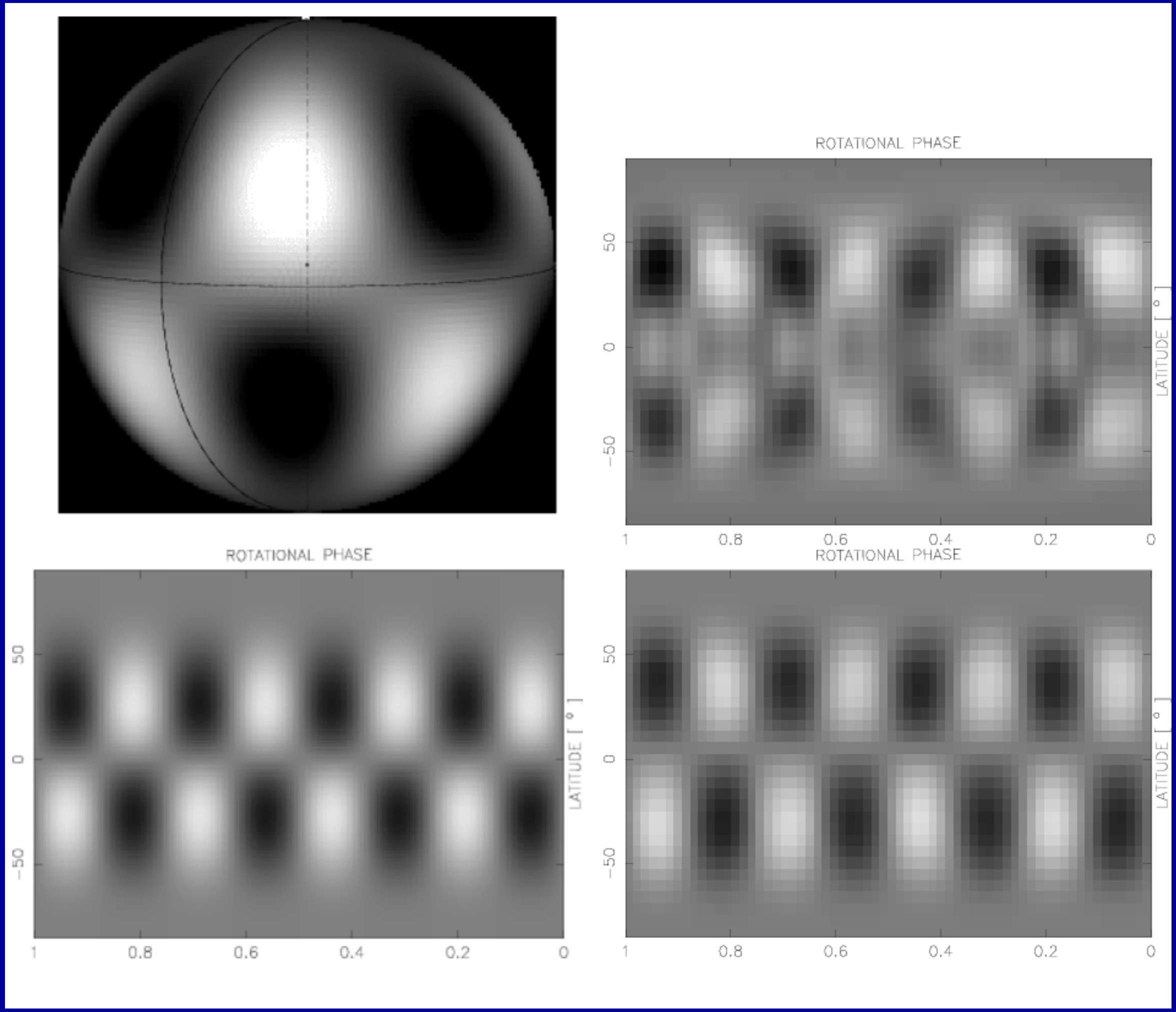
Schematic Model of Extended Stellar Atmosphere



IOTA / FLUOR Data on the Mira Star R Leonis



Mapping Pulsations with Doppler Tomography and Interferometry



Left: Model

Right: Simulated Reconstruction without and with interferometry

Circumstellar Disks, Winds, and Outflows

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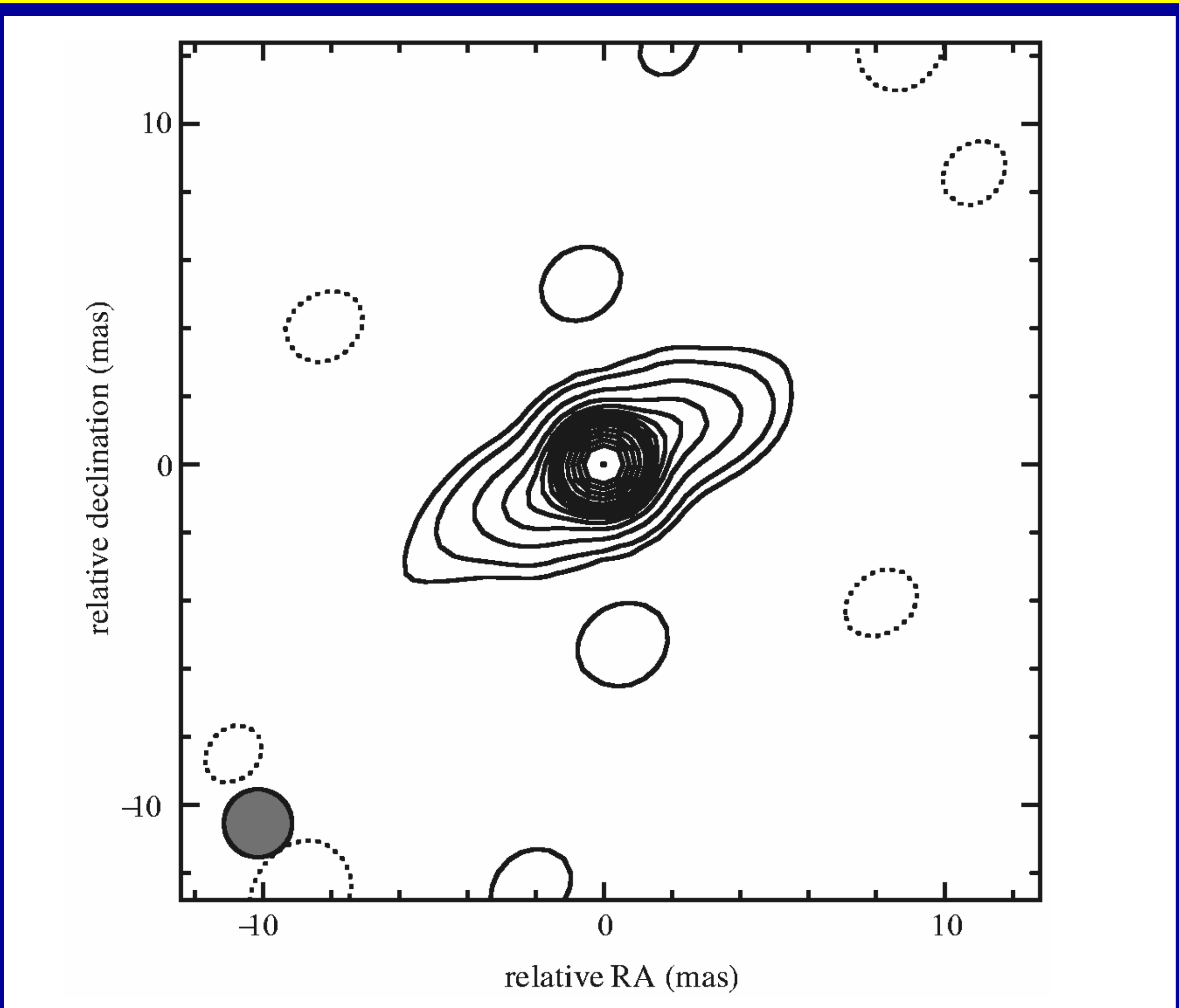
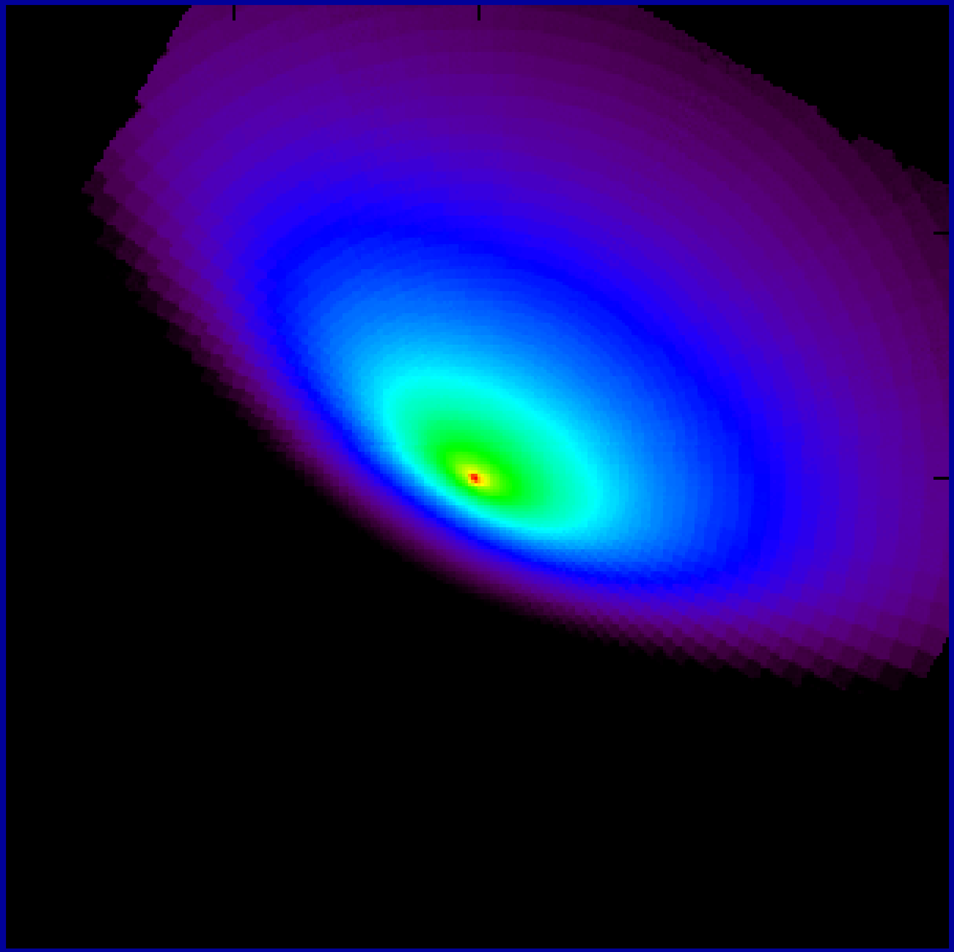
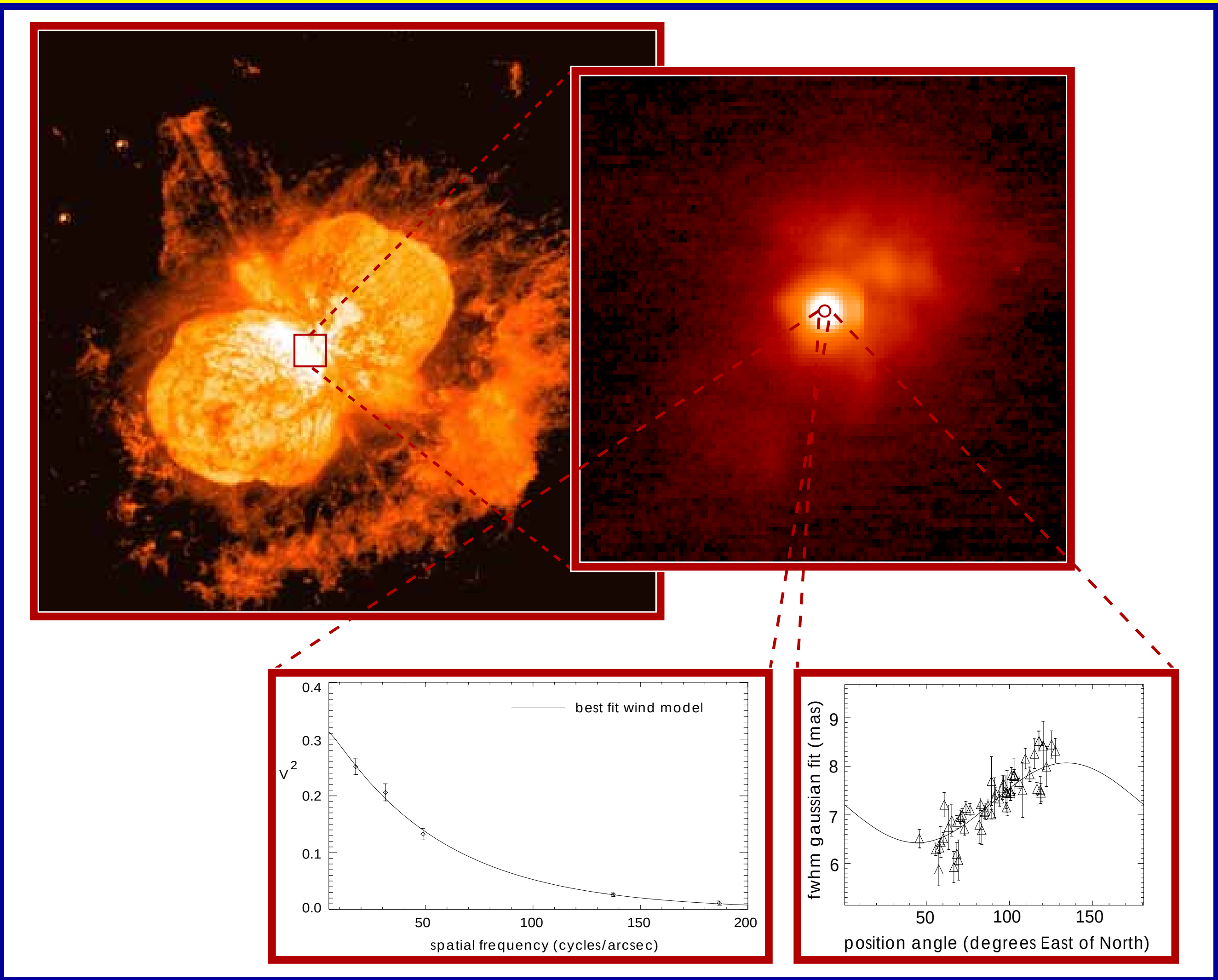
COAST Synthesis Image of the Be Star ζ Tauri



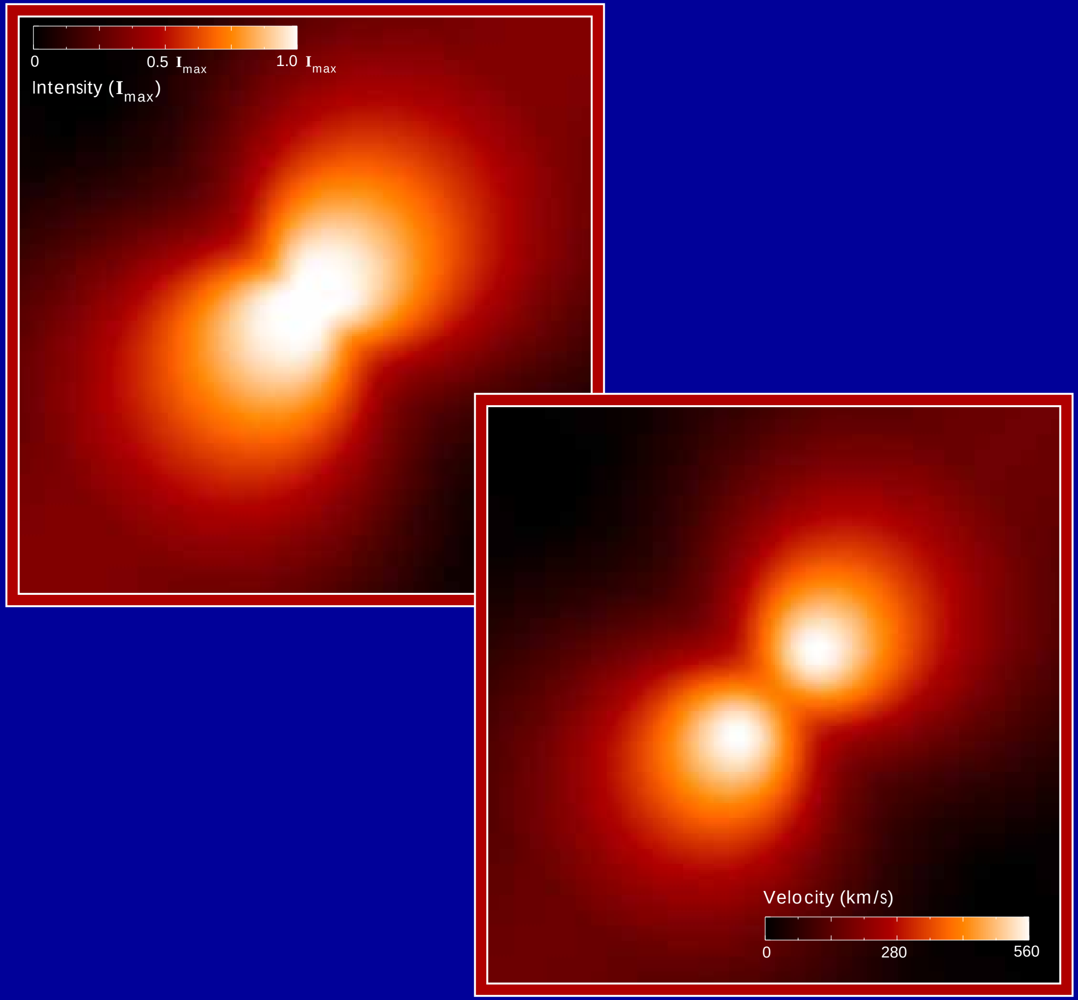
Model of a Main-Sequence Disk at 10 μm



The η Carinae Nebula (WFPC2, NACO, VLTI)



Model of η Carinae



Galactic Nuclei

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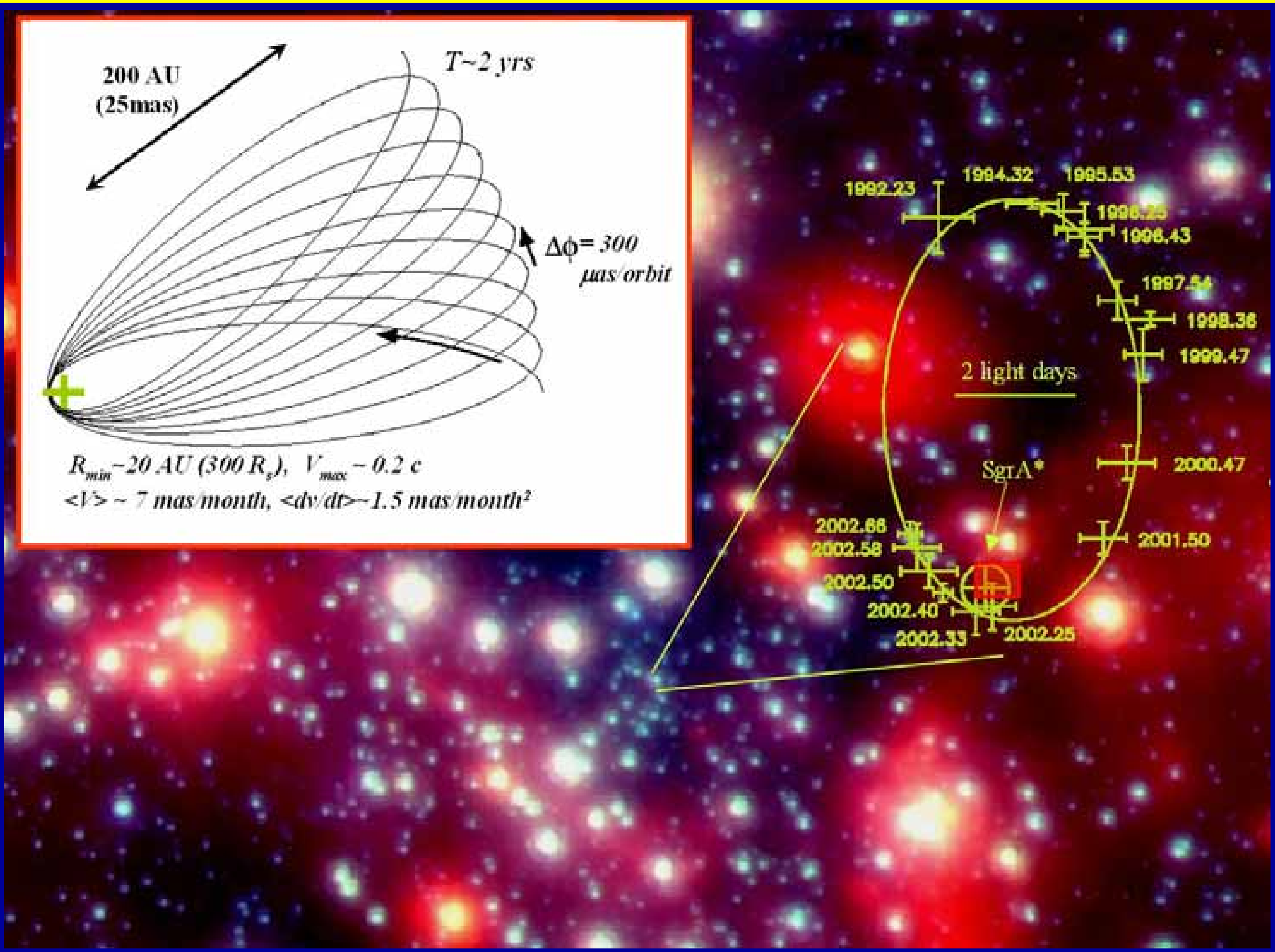
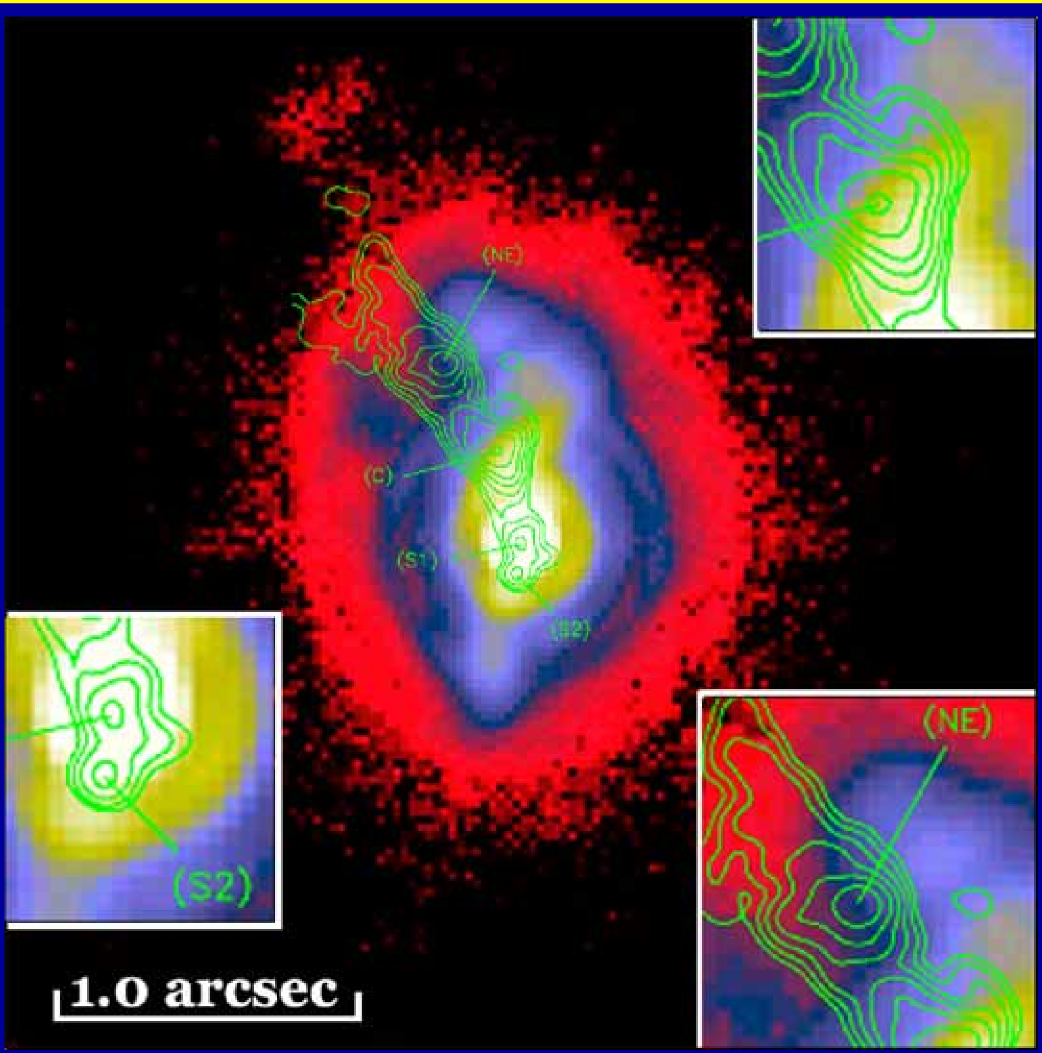
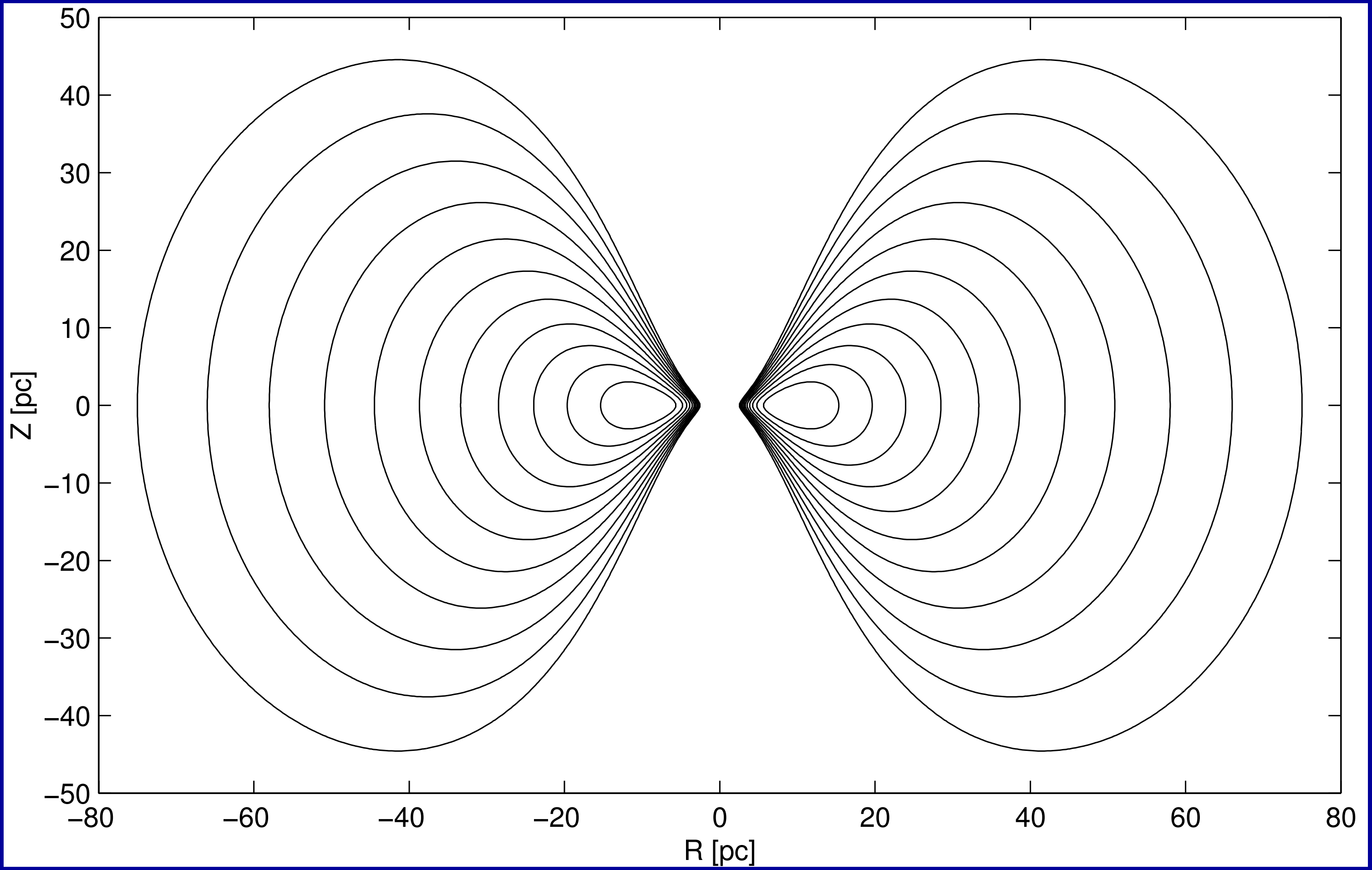
The Central Few Arcseconds of Our Galaxy



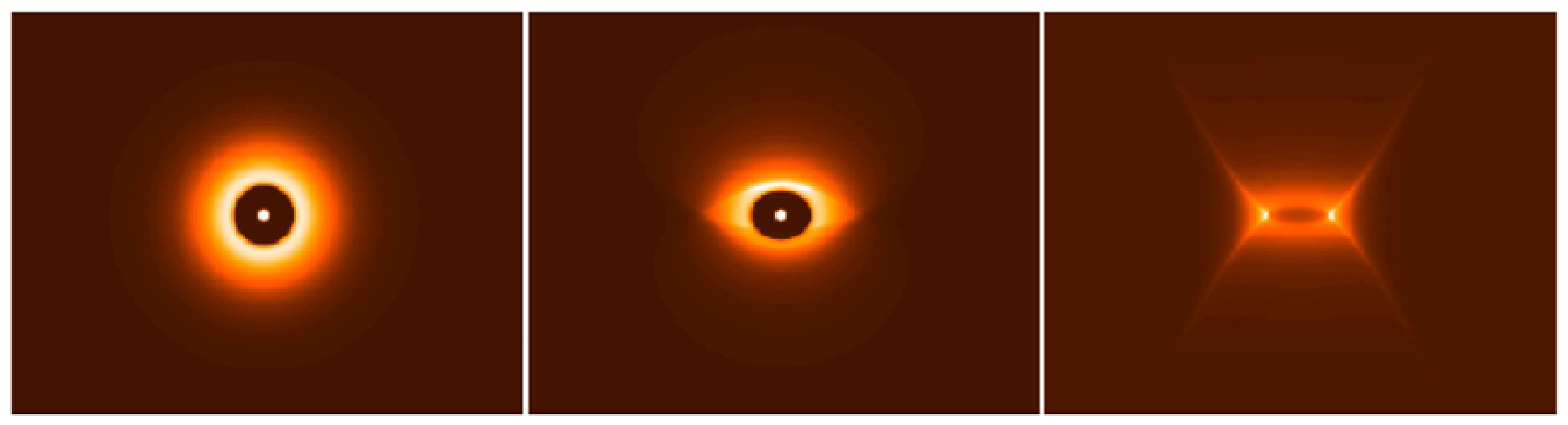
NGC 1068 as Seen in the Radio and by NACO at 5 μm



Model of an AGN Torus



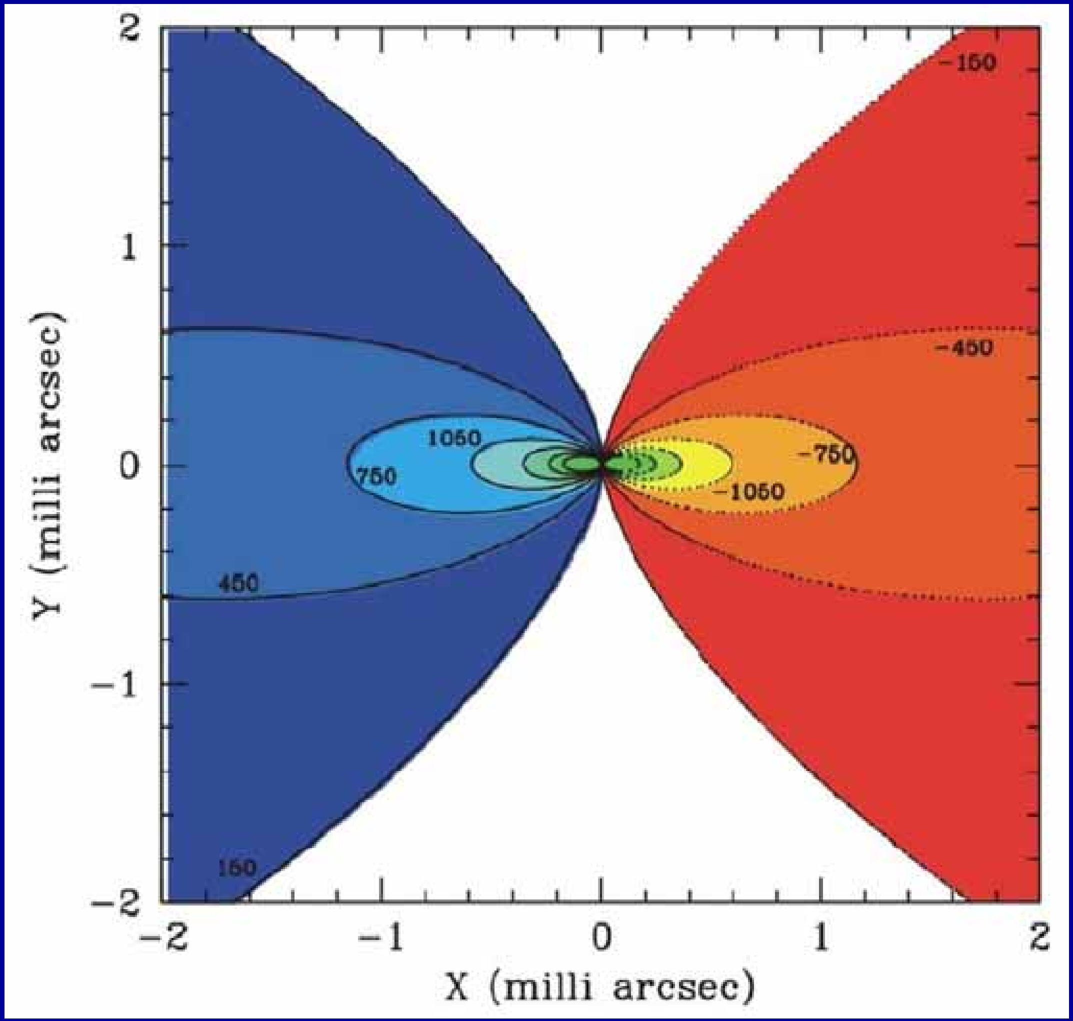
Appearance of Torus as a Function of Inclination



MIDI: The First Scientific Instrument of the VLTI

- Built by German / Dutch / French Consortium
- Delivered to Cerro Paranal in 2002
- Commissioning proceeding well
- First exciting scientific results
- Example: NGC 1068
  - Nearby Active Galactic Nucleus
  - Prototype for Central Engine hidden by dust
  - First direct detection of small dust component

Iso-Velocity Contours for Model of 3C273



Interferometric Imaging

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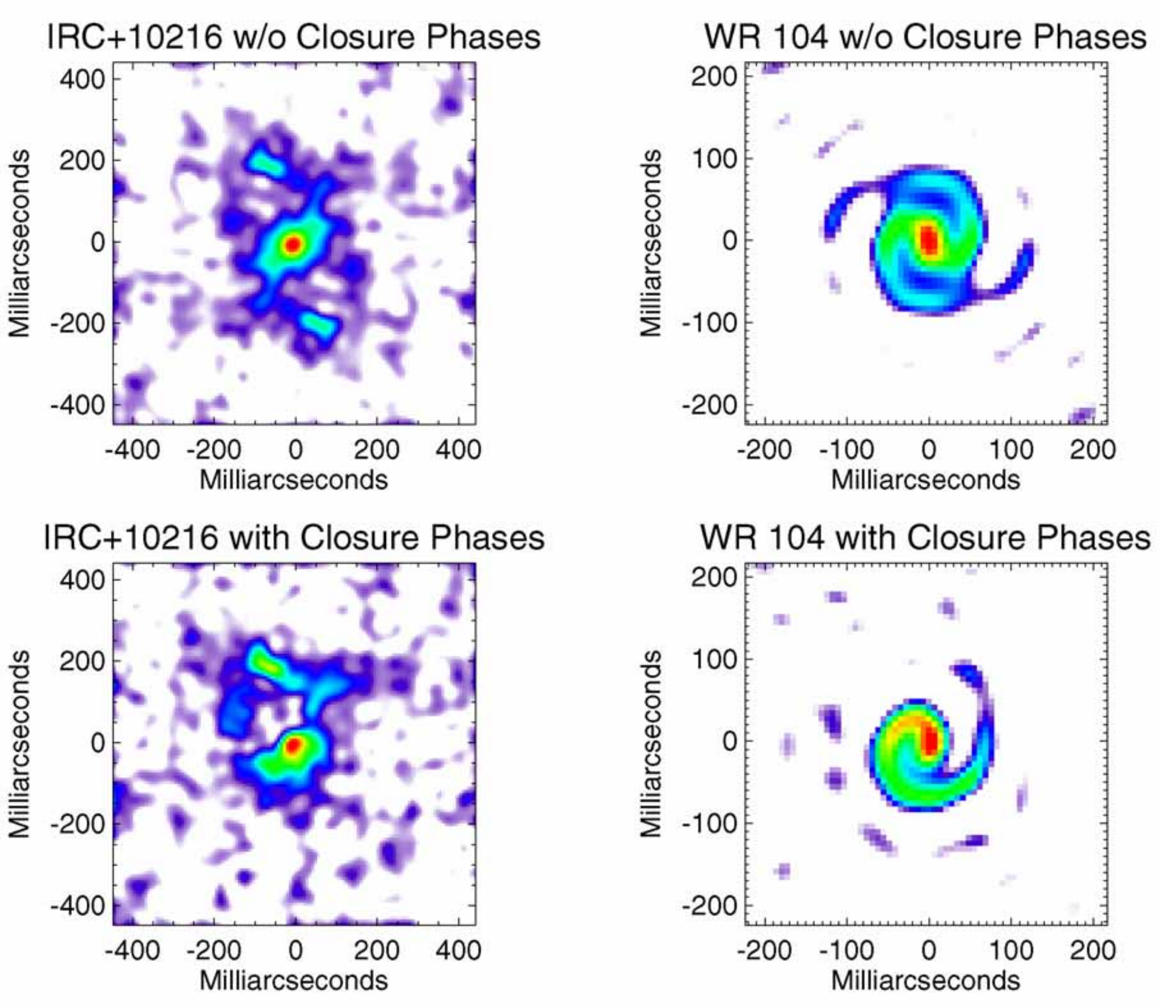
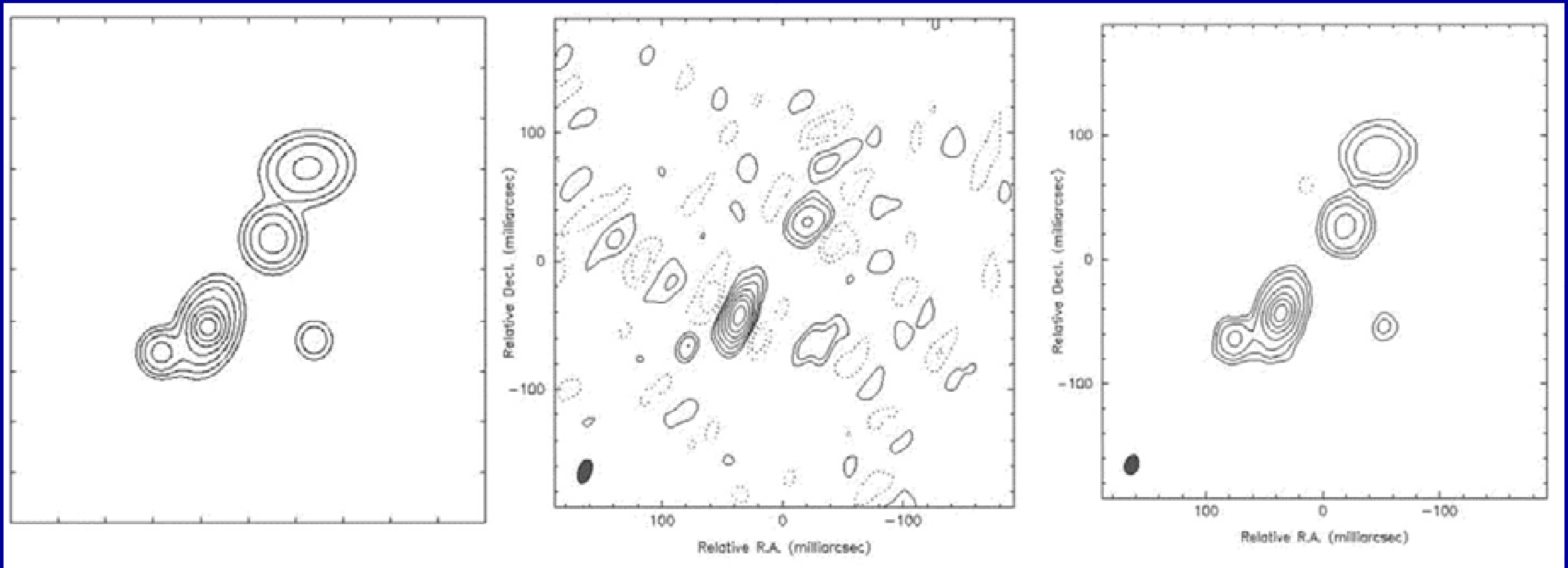
Images from Keck Aperture Masking (Tuthill et al.)

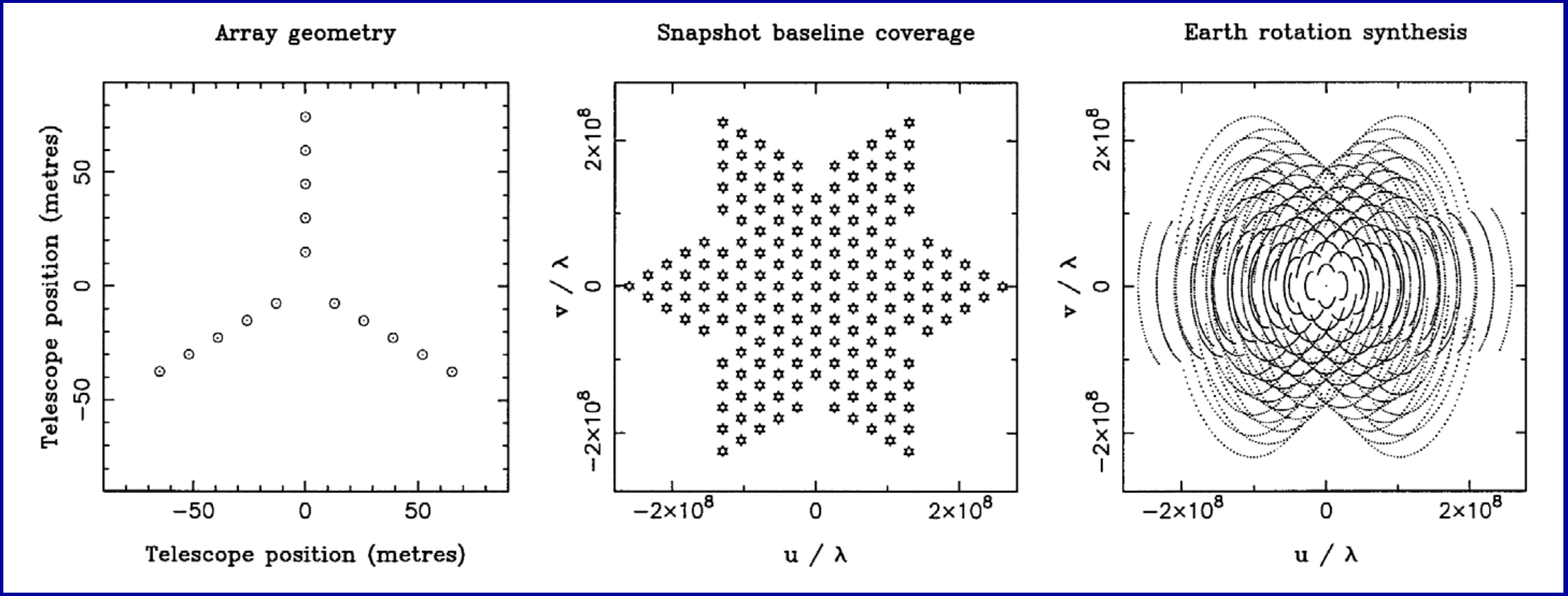


Phase information is needed to recover asymmetric structure.

VLTI Imaging Simulation with Four and Eight Telescopes



A Y-Shaped Configuration

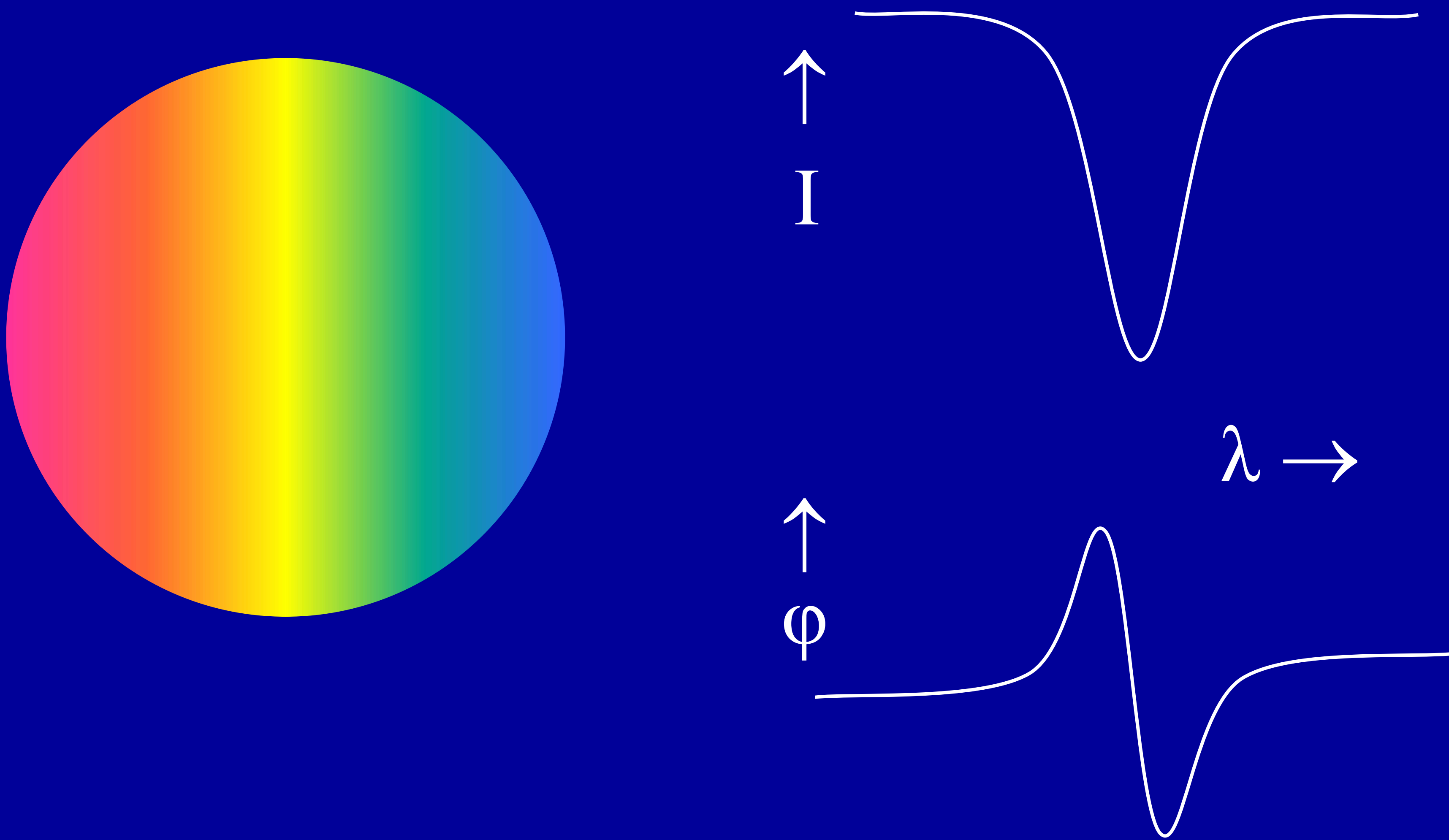


Aerial View of the NPOI Array

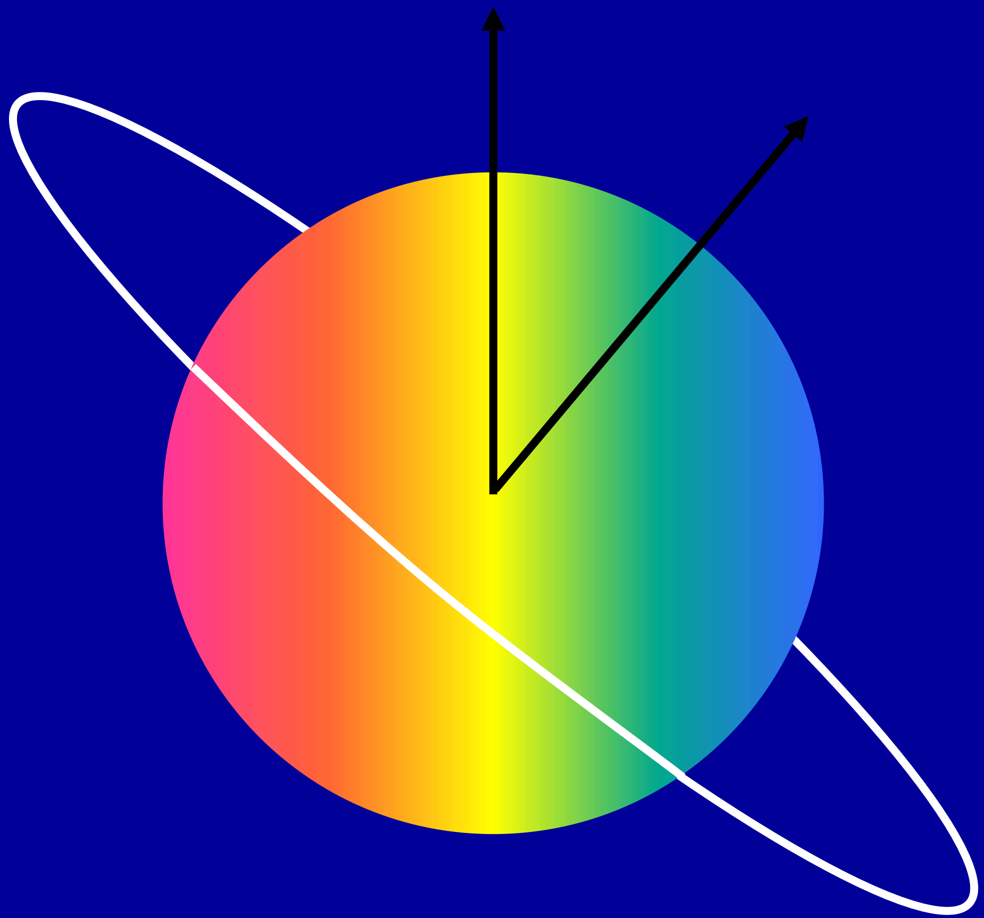
Interferometric High-Resolution Spectroscopy

- Combination of interferometry with high-resolution spectroscopy is very powerful
  - Limb darkening profiles in absorption lines $\rightarrow$ tests of stellar atmospheres, calibration of projection factors in Cepheid measurements
  - Phase shift across absorption lines $\rightarrow$ orbits of very close binaries, direct measurement of stellar rotation
  - Surface structure of chemically peculiar stars
  - Trace shocks in Mira atmospheres
- Need $R \approx 20{,}000 \ldots 100{,}000$

Interferometer Phase across Stellar Absorption Line



Combination of Astrometry with Spectro-Interferometry



Information from Orientation of Rotation Axis

- Alignment of components in wide binary systems
  - Mechanism of binary star formation
  - Angular momentum distribution in multiple systems
- Orientation of planetary orbit with respect to stellar rotation axis
  - Correlate with planetary masses, orbital eccentricities
  - Probe eccentricity pumping mechanisms