Science with Optical / Infrared Interferometry

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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

Binary Star System

![Visibility Amplitude vs Projected Baseline graph](image)

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Information from Binary Stars

- Most important are double-lined spectroscopic binaries (SB2s)
- Spectroscopy gives all system parameters except inclination
- Interferometry can measure inclination ⇒ can derive masses for both components
- Spectroscopy measures orbit in km/s, interferometry in mas ⇒ combination gives distance (dynamical parallax)
Mk III Diameter Measurements of the Giant Star $\beta$ Pegasi

Projected Baseline [arcsec$^{-1}$]

Visibility Squared

- 712 nm (TiO) 17.6 mas
- 754 nm (cont.) 16.1 mas

Quirrenbach et al.
Schematic Model of Extended Stellar Atmosphere

Continuum Opacity = 1

TiO Opacity = 1
IOTA / FLUOR Data on the Mira Star R Leonis

R Leo
November 2000 - November 2001

Visibility

Spatial Frequency (cycles/arcsec)

- 2.03 µm (H₂O)
- 2.15 µm (continuum 1)
- 2.22 µm (continuum 2)
- 2.39 µm (CO & H₂O)
- L
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 $\zeta$ 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

\[ R_{\text{min}} = 20 \text{AU} (300 R_\odot), \quad \dot{V}_{\max} = 0.2 \text{c} \]

\[ \langle \dot{V} \rangle \sim 7 \text{ mas/month}, \quad \langle \dot{V}/d\dot{t} \rangle \sim 1.5 \text{ mas/month} \]

\[ \Delta \phi = 300 \mu\text{as/orbit} \]

2 light days

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NGC 1068 as Seen in the Radio and by NACO at 5 \( \mu m \)
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 → tests of stellar atmospheres, calibration of projection factors in Cepheid measurements
  - Phase shift across absorption lines → 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