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YSO Studies with Infrared Interferometers

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Abstract. The observational technique of long baseline infrared interferometry provides a unique opportunity for studying the small scale (< 1 AU) structure of young stellar objects, particularly circumstellar disks and multiplicity. The technique of infrared interferometry is briefly described and observations of young stellar objects are reviewed.

1. Introduction

The study of young stellar objects (YSOs) has utilized a range of observational techniques at all wavelengths from X-ray to radio. At size scales less than 1 AU, YSO properties, especially those of circumstellar disks, have been determined using spectroscopy and spectral energy distributions (SEDs). However, directly observing structures at these size scales is hampered by the high angular resolution necessary. Even for the nearest YSOs (d$\sim$50 pc) 1 AU subtends only 0.02 arcsec. The advent of infrared interferometers provides an observational method to directly detect structures on scales less than 1 AU. Infrared observations are well suited to inner disk temperatures and suffer less extinction than in the optical, while the currently available baselines of $\sim$100 meters provide resolution of 4 milliarcsec (mas) at 2 μm.

2. Infrared Interferometry

The basic principles of infrared interferometry are similar to those at the more commonly used radio and millimeter wavelengths. A comprehensive review of optical and infrared interferometry is given in Shao and Colavita (1992). One main difference is that optical and near-infrared interferometers use direct rather than heterodyne detection of the fringe (note that the ISI interferometer which operates at 10 μm is an exception).

A list of ground-based optical and infrared interferometers currently operating and those under construction is given in Table 1. The observational modes used at these facilities are

Visibility amplitude Measurement of how resolved a source is. Used for determining emission region size scales and studying multiplicity.

Astrometry Relative position measurements. Used for orbital determinations.

Facility	# of elements	Element aperture (m)	Max baseline (m)	Wavelength (μm)	Ref.
GI2T	2	1.5	35	0.4-0.8,1.2	1
COAST	5	0.4	100	0.4-0.95,2.2	2
SUSI	13	0.14	640	0.4-0.66	3
IOTA	3	0.45	38	0.5-2.2	4
ISI	3	1.65	30	10	5
NPOI	6	0.6	435	0.45-0.85	6
PTI	3	0.4	110	1.5-2.4	7
CHARA	6	1.0	350	0.45-2.4	8
Keck Interferometer	2(4)	10(1.8)	165	1.6-14	9
VLTI	4(3+)	8.2(1.8)	200	1-20	10
LBT	2	8.4	23	0.3-20	11

Table 1. A list of the current and upcoming ground-based optical and infrared interferometer facilities.

[1]Mourard et al (1994)
[2]Baldwin et al (1994)
[3]Davis et al (1999)
[4]Traub (1998)
[5]Hale et al (2000)
[6]Armstrong et al (1998)
[7]Colavita et al (1999)
[8]McAlister et al (1998)
[9]Colavita and Wizinowich (2000)
[10]Glindemann et al (2000)
[11]Angel and Woolf (1997)

Imaging Only limited demonstrations to date, none on YSOs.

The observational results on YSOs discussed in Section 3 all use visibility amplitudes to directly probe the structure of the infrared emission on size scales from 5 to 10 mas.

3. Results from YSO Observations

Several groups have made observations of YSOs using the IOTA and PTI facilities. Although none of these objects are within the 100 parsec distance range covered by this conference, the results provide unique information on YSO structure. In this section, the published observations to date are summarized and some example data are shown.

Malbet et al (1998) observed FU Ori with PTI at 2.2 μm and resolved the emission. They found that the measured visibility was consistent with accretion disk models. Millan-Gabet et al (1999) made infrared observations of AB Aur at IOTA, where the emission was resolved and PTI, where the emission was over-resolved. The measured characteristic size scale was 0.7 AU and the data were most consistent with a flattened structure. Akeson et al (2000) resolved the emission from both T Tau and SU Aur at 2.2 μm with PTI. The measured visibilities correspond to physical size scales of tenths of AU, larger than predicted by SED-based accretion disk models for these sources. Some example data for SU Aur is shown in Figure 1 (Akeson et al 2001). The averaged data were fit with a Gaussian brightness distribution model to estimate the size scale and inclination of the emission.

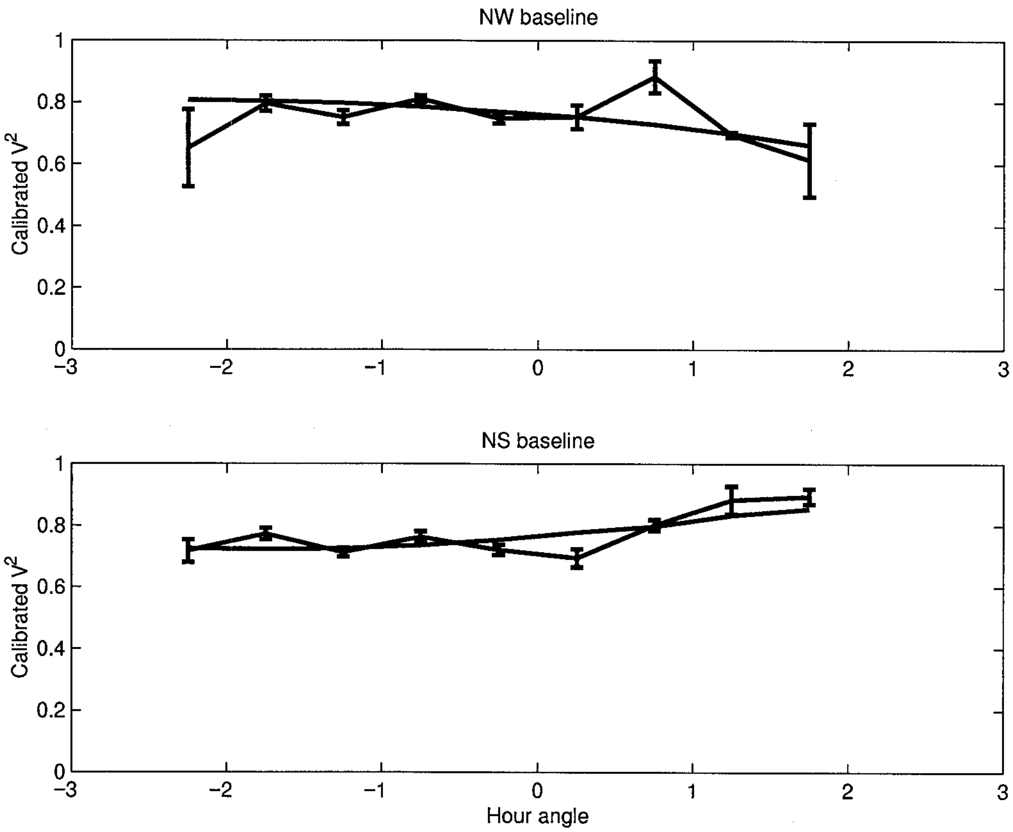

Figure 1. The calibrated squared visilibity for SU Aur from the two PTI baselines. The points are the data averaged by hour angle and the line is a Gaussian brightness distribution model with a FWHM of 1 ± 0.05 mas (0.14 AU), a position angle of $127^{\circ} \pm 5^{\circ}$ and an inclination of $61^{\circ} \pm 3^{\circ}$.

Observations have also been made of the more massive Herbig Ae/Be systems. Millan-Gabet et al (2001) surveyed 15 Herbigs at IOTA and resolved the emission from 11 of the sources. One new binary was discovered. The characteristic size scale of 0.5 to 0.9 AU was larger than expected. The authors found that the visibilities were not consistent with accretion disk models using a radial temperature profile ($T \propto r^{-3/4}$) and favored models with spherical envelopes or thin shells.

Although for many of these observations interpreting the visibility as arising from resolved disk emission is not unique, it is a likely explanation given the disk/stellar infrared flux ratios and the number of sources that have been resolved. These observations do definitely demonstrate that YSOs can be resolved with the current generation of infrared interferometers and that these observations provide unique information on structures less than 1 AU.

4. Future Prospects

The next generation of ground-based infrared interferometers with 3 or more elements, the Keck Interferometer, the Very Large Telescope Interferometer (VLTI) and the CHARA array, will have greatly increased sensitivity and capabilities which will hugely expand the potential for studying nearby young stars. For example, the Keck Interferometer will have a limiting magnitude of 14 at K band. All of these facilities are planning some imaging capability with resolutions in the range of a few to 10 milliarcsec, depending on the baselines and wavelengths used. At a distance of 50 parsec this corresponds to physical size scales of 0.1 to 0.5 AU. In particular, this technique is ideal for studying the inner regions of circumstellar disks.

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