The Astrophysical Potentials of the MIDI VLTI Instrument

Bruno Lopez[a], Christoph Leinert[b], Uwe Graser[b], Laurens B.F.M. Waters[c], Guy Perrin[d], Tom Herbst[b], Huub Rottgering[e], Daniel Rouan[d], Bringfried Stecklum[f], Reinhard Mundt[b], Hans Zinnecker[g], Patrick de Laverny[a], Markus Feldt[b], Jeffrey Meisner[e], Anne Dutrey[h], Thomas Henning[i], Farrokh Vakili[j]. other associates ???[k]

[a] Observatoire de la Côte d'Azur, UMR 6528, BP 4229, F-06304 Nice cedex4, France

[b] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

[c] Astronomical Institute of the Univ. of Amsterdam, Kruislaan 403, NL-1098 SJ Amst., Netherlands

[d] Observatoire de Paris, DESPA, 5 place Jule Janssen, F-92195 Meudon Cedex, France

[e] Sterrewacht Leiden, P.O. Box 9513, 2300 RA Leiden, The Netherlands

[f] Thüringer Landessternwarte Tautenburg, Sternwarte 5, D-07778 Tautenburg, Germany

[g] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany

[h] IRAM, 300 R. de la Piscine, F-38406 Saint Martin d'Hères, France

[i] Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergäβchen 3, 07745 Jena, Germany

[j] Observatoire de la Côte d'Azur, UMR 6528, 06460 Saint Vallier de Thiey, France

[k]...

ABSTRACT

The mid-infrared interferometric instrument (MIDI) is planned to become operative at the ESO Very Large Telescope Interferometer (VLTI) during the year 2001. The first version of MIDI is designed for use of two telescope beams at 10 μm wavelength. We here present an overview of some of the scientific objectives.

The preparatory work under progress, before first VLTI observations, consists in studying the feasibility of different astrophysical projects (expected visibility, required absolute accuracy of the measurement, required observing time, "strategy" of observation). As examples we will discuss the observations of disks around young stellar objects, of active galactic nuclei, of extrasolar planets and of some evolved stars.

Keywords: VLTI, Mid-Infrared instrument, AGNs, disk of young stellar objects, extrasolar planets, R CrB.

1. THE MIDI INSTRUMENT

Interferometry with the VLTI on Paranal will include the four 8 m telescopes ("unit telescopes" or UTs) as well as three relocatable auxiliary telescopes of 1.8 m diameter (ATs). The first version of MIDI is designed for use of two telescope beams only. Initially MIDI will operate in self fringe tracking mode, whenever the source is bright enough. Using a bright source, the fringe signal allows both to keep the fringes within the coherent range of the instrument and it also provides a coherent reference to integrate. However, the object can be dim so that its fringes are not detected with MIDI in one scan. In some cases, still without any external fringe tracker, an incoherent estimate can be applied. It assumes a scanning across fringes in delay (wherever they are in the modulation range of the instrument) and it includes a "Fourier method". This "Fourier method" consists in integrating the power density

Send correspondence to B. Lopez
B. Lopez: E-mail: lopez@obs-nice.fr

Table 1. General information on the VLTI and the MIDI instrument

Telescope diameter	UTs	8 m
	ATs	1.8 m
Baselines	UTs	47 ... 130 m
	ATs	8 ... 200 m
Resolution	λ / D for 100 m	20 marcsec
Wavelength coverage		N band (8 μm - 13 μm)
	expandable to	Q band (17 μ - 26 μm)
Field of view		$\pm$ 1″
Airy disk (FWHM)	for 8 m UTs	0.26″
at 10 μm	for 1.8 m ATs	1.14″
Sampling time for	for fringe motion	100 ms
fringe measurement	$\leq$ 1 μm rms	
Atmospheric stability	for chopping	200 ms
Detector pixel	size	50 μm
(320 x 240)	Full well capacity	$2 \cdot 10^7$ electrons
	Read out noise	$\sim$ 1000 electrons
Background noise at UTs	from sky	$1.6 \cdot 10^{10}$ photons/sec
(in Airy disk)	from VLTI mirrors	$1.2 \cdot 10^{11}$ photons/sec
Limiting N-magnitude	with UTs	4.0 mag (1 Jy)
without fringe tracking	with ATs	0.8 mag (20 Jy)

spectra of each fringe scan for recovering the contribution of the fringe signal (even if the coherence of the fringes from scan to scan has been lost). The signal to noise ratio using incoherent method is expected to be poorer.

Table 1 provides more information on the instrument. A description of the instrument, principle of measurements, and plans can be found in Leinert and Graser (1998) and Leinert et al (2000).

The institutes involved in the MIDI project are: Max-Planck-Institut für Astronomie, Heidelberg (PI), NOVA (Co-PI), NFRA Dwingeloo, Astronomical Institute Amsterdam, Sterrewacht Leiden, Kapteyn Astronomical Institute Groningen, Observatoire de Paris-Meudon (Co-PI), Observatoire de la Côte d'Azur, Kiepenheuer Institut Freiburg, Thüringische Landessternwarte.

2. FEASIBILITY OF SOME ASTROPHYSICAL PROGRAMS

Based on simulations of the observational signature of each class of object, it is possible for each of the proposed observing programs to predict a "typical" visibility function as well as a required accuracy associated with such an observation. The absolute visibility accuracy required for obtaining scientifically useful results can be constrained by several considerations :

- A dynamics. The dynamics of an interferometer allowing the detection of highly contrasted components of a same object (for example a planet and its parent star) is linked to the smallest amplitude variations that can be measured by the instrument either in the calibrated visibility or in the relative chromatic phase measurement.
- A comparison/test between separate models or between competing theories. It must be taken into account in order to decide exactly what measurements need to be taken to differentiate between them. For example, different models can be created depending on the *a priori* supposed size of the torus of AGNs.
- An analysis of the shape of the visibility curve in different directions of the Fourier plane. In the case of young stellar objects (YSOs) this will allow to analyze the geometry and the orientation of disks.

Table 2. The different T Tauri disk models which are here considered

Model and some "sensitive" parameters	Visibility estimate	Required absolute accuracy	Comments
"Flat" T Tauri disk with grain radius from 0.01 to 5 μm	around 0.9 (for a 200 m baseline) depending on the disk inclination	a few percent to be sensitive to the shape of the image	pessimistic model provides a small apparent image
Same as above with a grain size distribution from 0.01 to 10 μm	a little more resolved than above	a few percent	apparent size of the images slightly larger than above
"Flared" disk with grain radius from 0.01 to 10 μm	more resolved than the 2 other models	a few percent	"optimistic" model ?

2.1. Star formation and Young Stellar Objects (YSOs)

Studies of YSOs and regions of star formation are a very active field of research in astrophysics, which will certainly benefit a lot from observations at high spatial resolution (see Natta 1997, Eislöeffel and Dougados 1997, Ménard 1997, Beckwith 1995, Men'shchikov and Henning 1997, Men'shchikov et al 1999). One of the great advantages of YSO studies with the VLTI are the relatively large fluxes of many of these stars over a broad range of IR wavelengths. In nearby star formation regions like Hydra (d $\approx$ 70 pc) or like Taurus-Auriga or Lupus (d $\approx$ 150 pc) , one finds many so-called classical T Tauri stars (CTTSs) with K magnitudes of 5 – 7 and N (10 μm) magnitudes of 2 – 5 (with a few stars of even N = 0.5 mag). Note that in southern nearby (d $\approx$ 140 pc) low-mass star formation regions, more than 150 TTSs are known of which at least 30% are bright enough to be observable with the VLTI in the 2 – 10 μm range. At the distance of these objects, the resolution of the VLTI at 10 μm is around 16 mas (for a 130 m baseline) and corresponds to a linear extent of 2.2 AU. The closest regions of massive star formation observable from Paranal (like Orion) are at about three times larger distances.

These young stars are surrounded by disks of gas and dust in which planetary formation is thought to occur. Understanding the physics of such protoplanetary disks is then the necessary step to understand how planets form. In order to prepare an observing program related to YSO's, we estimate, using a model of the disk, the visibility function and the accuracy which is required in the visibility measurement to perform some relevant science. The goal is also to determine which are the "sensitive" astrophysical parameters that will be efficiently constrained from MIDI observations. We here, for example, consider a T Tauri star (a YSO of about 1 $M_\odot$) with a disk mass of about 10^{-3}-10^{-2} $M_\odot$ and located at 150 pc. For creating a realistic image of a T Tauri disk, the radiative transfer of the "star" light (assumed to be a blackboby) through the disk of dust, is simulated by using a Monté-Carlo method (see Lopez and Perrin 2000 for details concerning the method). There are several "sensitive" astrophysical parameters included in the modeling of the dust disk which have a strong effect on the 10 μm observational signatures. Among them are the size of the dust grains and the assumed geometry of the disk : considering large dust grains allows for example an efficient scattering of 10 μm radiation, thus enhancing slightly the apparent size of the disk; considering a flared disk allows the outer part of the disk to be heated more efficiently, thus also enhancing the apparent size of the disk at 10 μm (see Figures 1 and 2). The figures for a disk inclination of 75 degrees and less are dominated by the unresolved star and by the bright inner regions of the accretion disk itself. For the 80-90 degree inclinations the star and the bright inner regions are obscured from view which is why the visibility drops off so fast. The unpleasant bumpiness of the visibility curves in some of our Figures is related to artefacts in our present radiative transfer models that we are improving.

The Table 2 summarizes the different models which have been considered here, their corresponding 10 μm visibility estimates and associated required visibility accuracy.

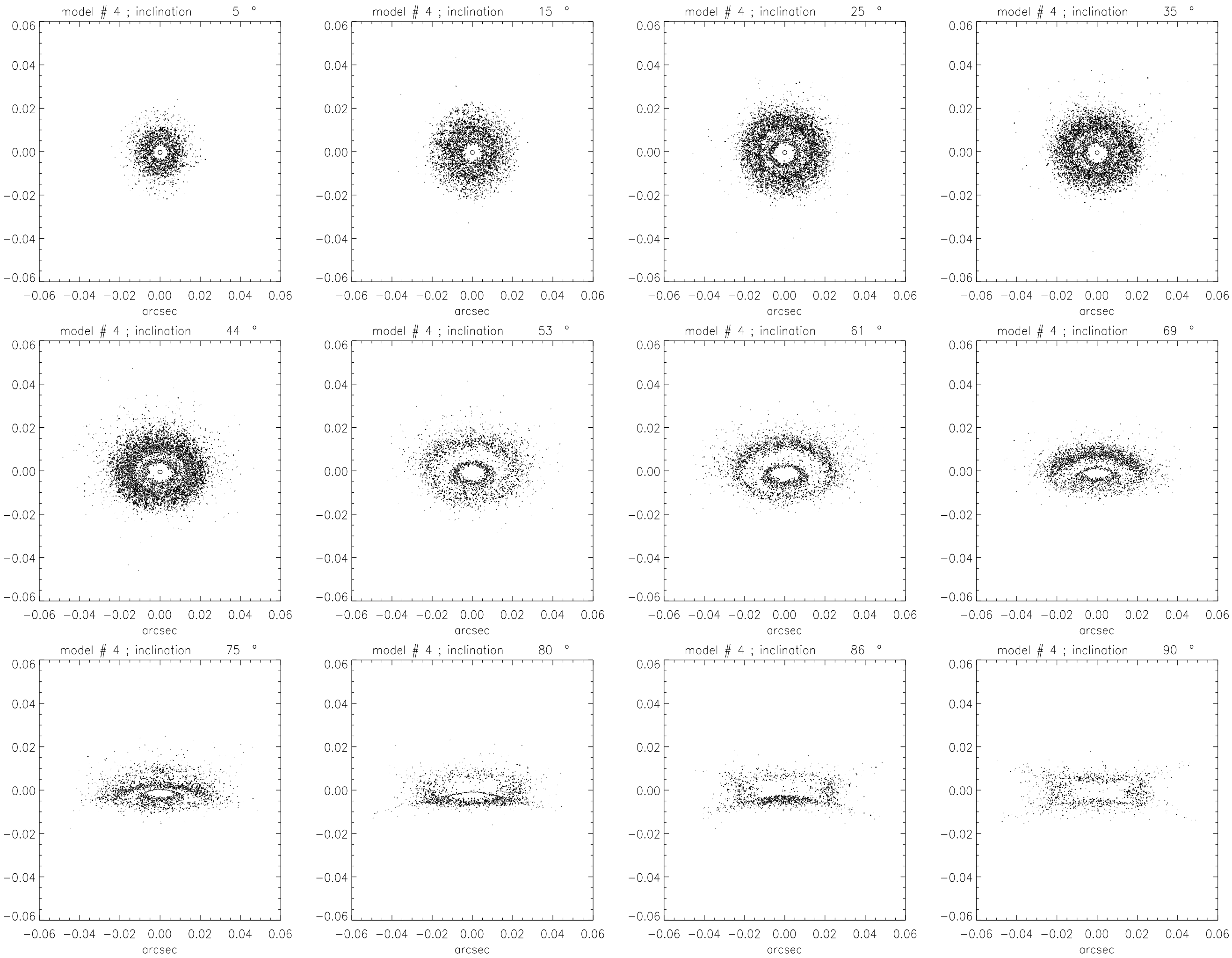

Figure 1. 10 μm simulated images of a T Tauri object ("Flared" disk model) for different inclinations. The object is supposed to be located at 150 pc.

As a conclusion regarding this category of object, it can be stated that the longest VLTI baselines should be employed because the dip in the visibility curves is limited even when the 200 meter available baseline is used (corresponding to about $200 \cdot 10^5 rd^{-1}$ on the curves). In order to observe some strong visibility variations we would prefer objects whose disks are seen edge-on. Of course the few close T Tauri located at a distance of 50-100 pc will offer better conditions for observations. Other categories of YSO are also to be considered (disk of second generation objects like the beta Pictoris disk, Herbig Ae/Be stars which are more massive and more luminous than T Tauri stars).

2.2. The torus of active galactic nuclei.

The now canonical view of AGN is that they are powered by the exchange of gravitational energy into thermal energy in a compact accretion disk surrounding a massive black-hole. In the current attractive "unified" model of active galactic nuclei, all AGN are surrounded by an optically thick obscuring torus; its orientation with respect to our

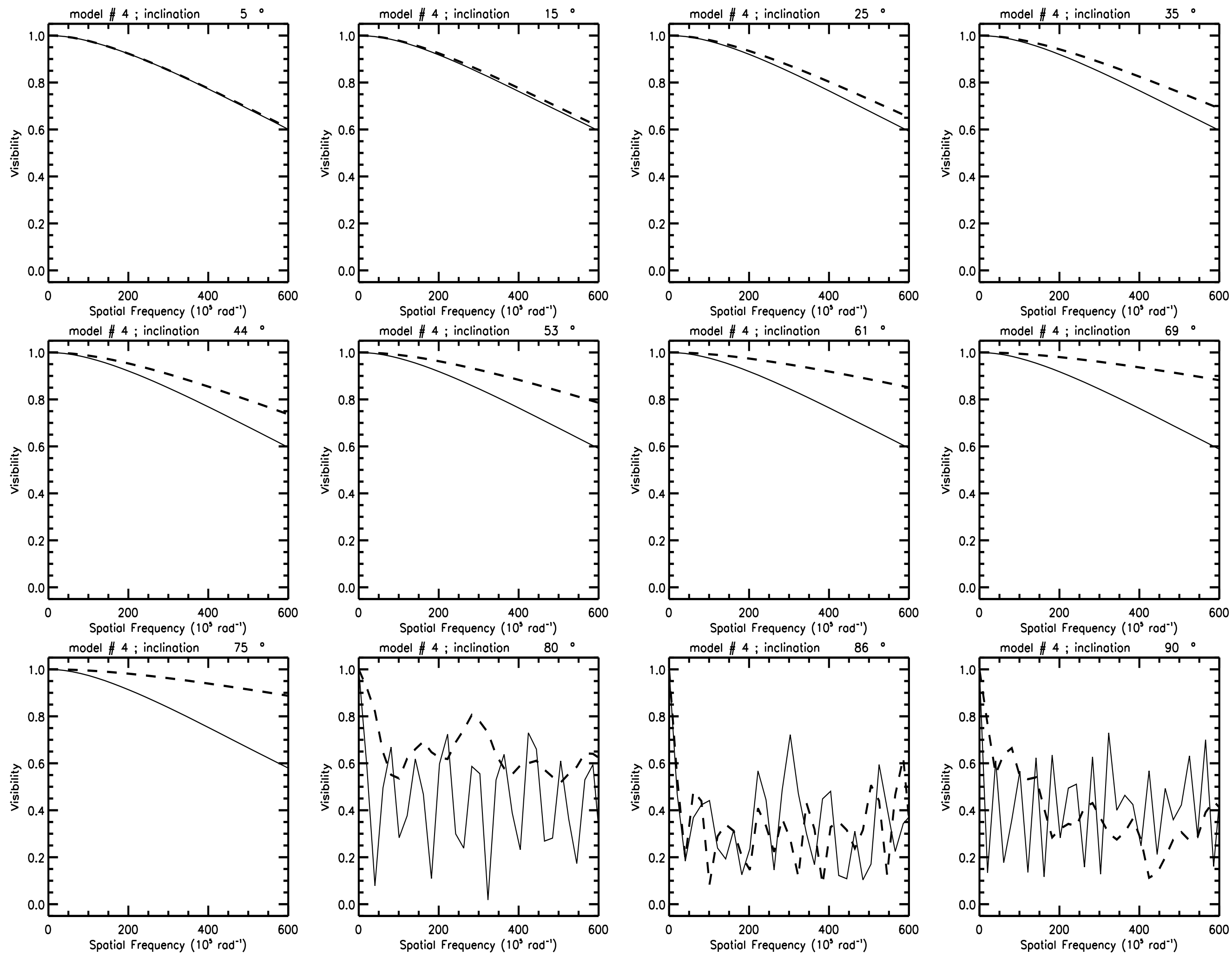

Figure 2. Predicted visibility cuts in 2 perpendicular direction of a T Tauri ("Flared" disk model) for different inclinations. The object is supposed to be located at 150 pc.

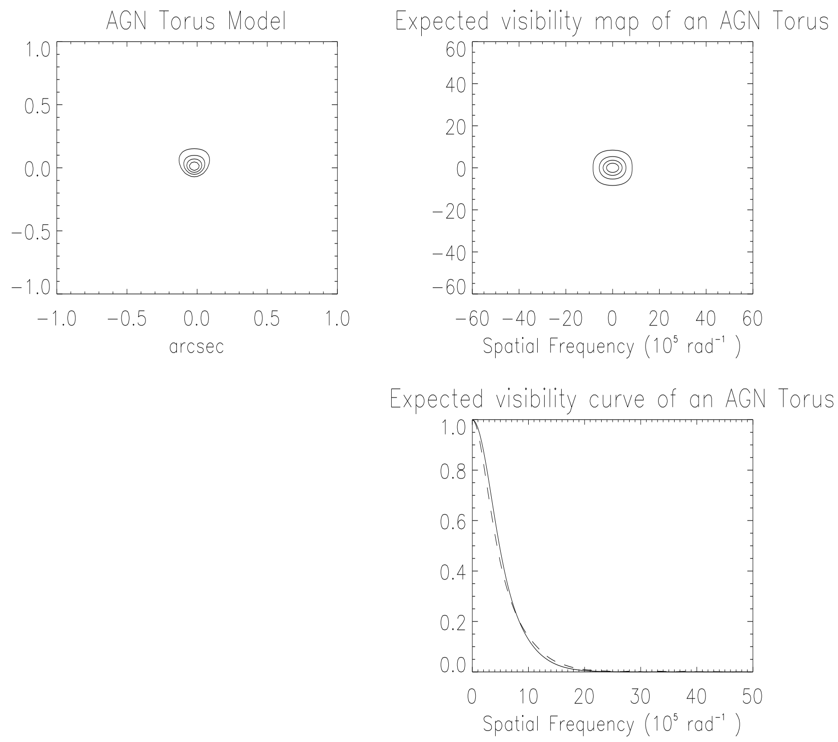

Figure 3. 10 μm image, visibility map and 2 perpendicular visibility cuts corresponding to a torus model (such as NGC1068) viewed at an angle of 60 degrees.

line of sight determines whether we see the object as a Type I (Seyfert 1) or Type II (Seyfert 2) – (For reviews see Antonucci 1993 and Urry and Padovani 1995).

The important issues in understanding AGN are therefore whether dust tori exist and whether the physics of such tori can be constrained well enough that many of the differences between AGN can be understood. In the case of NGC1068, several recent observations suggest the presence of a molecular/dusty torus seen nearly edge-on (see for example Rouan et al 1998).

High resolution imaging by MIDI at 10 μm is an area of strong interest. At 10 μm the view towards the heart of the galaxy is not hampered by extinction of dust in the galaxy and is not confused by stellar emission. MIDI should therefore allows for the unambiguous detection of dust tori. It could contribute to constrain a number of important physical parameters of the torus, including the inner and outer radius, its density and temperature structure. A number of models for obscuring tori have been proposed. The Figures 3 and 4 show the images obtained from the dust torus model of Granato et al. (1997). The torus model displayed here has an optical depth at visible wavelengths of $A_V = 150$ (about 12 at 10 μm). Images and their corresponding visibility maps are displayed for a torus inclination angle of 60 and 90 degrees (edge-on viewing corresponding approximately to the expected inclination of the NGC1068 torus).

As a conclusion regarding this class of object, for which the Seyfert 2, NGC 1068 (N=17.8 Jy) is the most luminous and the closest one, it appears that the UTs have to be employed for reasons of sensitivity. It also appears that the shortest available baselines and/or shortest projected baselines are to be preferred. The visibility curves indeed fall off sharply, in fact the predicted visibility curves show that with a 10 meter baseline (corresponding to about $10.10^5 rd^{-1}$ on the curves) the visibility is sharply reduced (which for reasons of sensitivity and direct fringe tracking can be problematic). For the more distant objects and for those where the torus is not seen edge-on, this should not be as critical a concern. An absolute accuracy between a few percent and 10 percent in the visibility measurements (from a few to 10% of V=1) will be sufficient to get some very fresh and novel results in this field of research. If the accuracy of the measurement were limited to 10 percent, and if the object were not seen nearly edge-on, it might be

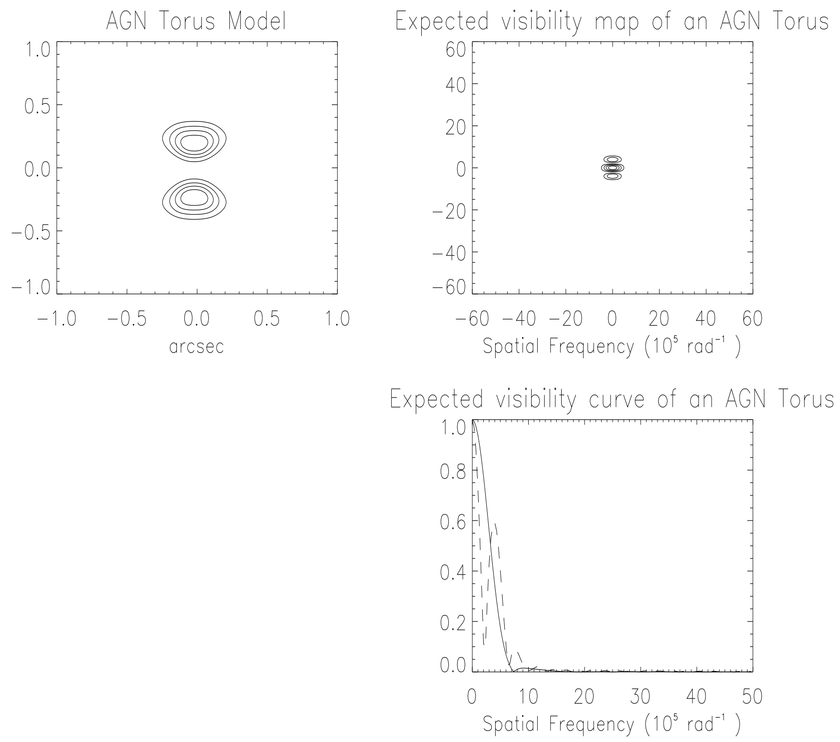

Figure 4. 10 μm image, visibility map and 2 perpendicular visibility cuts corresponding to a torus model (such as NGC1068) viewed at an angle of 90 degrees (edge-on viewing).

pointless to observe in many UV directions to fill the Fourier plane because the expected visibility variations would be too small compared to that accuracy.

We must note however that some models show that (a) the torus should be smaller and (b) a real torus may be much less smooth than the models. A smaller torus and/or a torus less smooth that the one assumed in the models produce a less resolved visibility curves. These difference between competing theories/models will be used for selecting the best VLTI configurations for the strategy of observations.

2.3. The direct observations of a few extrasolar planets.

Since the first detection of a hot giant planet orbiting around the star 51 Peg, several very exciting results have been obtained in detecting planets outside our solar system.

Two direct prospective methods have been proposed that can allow the VLTI to observe the radiation coming from a 51 Peg b like-planet : the absolute visibility measurement (Coudé du Foresto, 1999, Mariotti et al 1996), and Differential Interferometry (DI) (Lopez and Petrov 1999, see also Quirrenbach 1999 and Van Belle 1999). DI is based on the variation with wavelength of the visibility and/or the phase of the interferometric fringes produced by a star and planet system. This yields a sampling of the visibility ratio and phase difference which are related to the spectrum and angular position of the planet. Thus, one of the main advantages of the method is that, in addition to the planet orbit, it gives a direct measurement of the planetary spectrum providing information concerning the physical conditions in the planetary atmosphere. The Figure 5 displays, as a function of wavelength and for different semi-major axis of the planet orbit, the variations of $V(t/P, B/\lambda_1)/V(t/P, B/\lambda_2)$ (the visibility ratio between 2 diffrent wavelengths) and $\Delta\Phi(t/P, \lambda_2, \lambda_1)$ (the phase difference between 2 diffrent wavelengths) assuming a spectral channel of reference with $V(t/P, B/\lambda_2) = 1$ and $\Phi(t/P, \lambda_2) = 0$. Due to the fact that with the 80 meters baseline considered here, the system star + planet is just barely resolved at 10 μm, the analysis of the phase variations (because of its slope at the origin) with wavelength may be preferred instead of the analysis of the visibility curve.

The modeling assumes a sun-like star at a distance of 10 pc and a planet size of 1.4 Jupiter radii. A value of 0.3 for the albedo has been considered. The study displayed in Figure 5 are for passive planets radiating on all their surface.

The potential accuracy of the VLTI in J, H, K and N bands which will be covered by the AMBER (near-infrared) and MIDI (mid-infrared) instruments is shown in the Figure 5. The fundamental noise sources taken into account are the read out noise of the detector and the source and background photon noise. Not considered here is the stability of the instrument that we expect to be partly nulled by the relative differential method.

We assume that the J, H, K and N bands are each splitted into 5 spectral channels. Estimations have considered two possible total observing times (0.5 and 5 hours), each consisting of many short exposures of 100 ms. We assume that the 8 meter UT telescopes are used for this measurement.

We conclude that apparently in the N band, an effective observation time of about 5 hours will be needed to detect a system with a separation ranging from 0.03 to 0.1 AU. Planets like τ Boo b and 51 Peg b appear to be very good candidates for the first attempts of observations using the proposed method.

It is worth noting that at 10 μm, due to the "large" luminosity of the planet, the accuracy to reach in the measurement is relaxed by a factor 100 with regard to the near infrared. Thus, even if the situation at 10 μm with MIDI appears less favorable compared to the near infrared region with regard to the background noise level, it may nevertheless be, that from the VLTI internal "stability" point of view, it is easier to implement this method in practice at 10 μm. A study concerning the use of the VLTI for DI is under progress.

It is not excluded also that a direct calibration of the visibility curve (visibility vs. wavelength curve and/or visibility points taken at different baselines) observed with MIDI may lead to a direct detection. An absolute accuracy (see Figure 5) of 10^{-3} is required on the visibility curve which is not impossible to reach if MIDI can provide several visibility points with an accuracy of 10^{-2} that can be properly calibrated and averaged (in phase for example with the planet position on its orbit) together to reach the required 10^{-3} (assuming that the noise contributions of the hundred data points are independent and not resulting from systematic errors).

2.4. The case of R CrB, a category of evolved stars.

The detection of inhomogeneities in the circumstellar dust distribution and the study of their time variations around R Coronae Borealis stars should greatly improve our understanding of the formation and the evolution of these post-AGB stars as well as the formation of dust around these rather hot stars.

The R Coronae Borealis (R CrB) stars are born-again giant stars for which two evolutionary scenarios have been proposed : either a merger of two white dwarfs or a final He-shell flash in a post-AGB star (Clayton 1996). From an observational point of view, these evolved stars are characterized by high luminosities (0.3-1$\times 10^4 L_\odot$), effective temperature between 5 000 and 20 000 K, a mass-loss rate around $10^{-6} M_\odot$/year and show drastic variability.

Their visual lightcurve is indeed characterized by unpredicted decreases of up to 8 magnitudes with a time-scale of weeks. It has been proposed that such fadings could be due to obscurations of the star surface by newly formed dust clouds.

The presence of such inhomogeneities in the dust distribution around the central star is also consistent with the non-detection of similar declines at longer wavelengths since the IR emission comes from extended material heated by the star which is not obscured during a decline. Furthermore, there is good evidence that dust forms only over a small solid angle of the stellar surface or is ejected preferentially at the equators or the poles (Clayton et al., 1997). The question of the location of the dust formation is not yet settled since at least two scenarios have been proposed: either the dust is formed very close to the stellar surface ($\sim$ 2 R_{star} or even less) or it is formed in more distant regions at $\sim$ 20 R_{star} (Feast 1997).

Based on these 2 possible scenarios, images and their corresponding visibilities were simulated (Figure 6 and 7). A drop of the visibility down to V = 0.3 may be expected for a 100 meter baseline. There are several contributions in the visibility curves : 1- one is the central star contribution which is in fact negligible (this is not directly readable in the presented visibility curves but the star just contributes to 1:100 of the 10 μm received flux); 2- an other contribution is the one of the dust envelope (the clump is not the only component of our model, it is supposed to be inside a large spherical envelope), the large dust envelope creates in the visibility curves the resolved low frequency component; 3- an other contribution is the one of the clump itself, it can be resolved with the VLTI if it is as large as the clump of our second model, in this case it may produce a continuous drop of the visibility in the frequency range of the VLTI as observed for model 2; 4- a last contribution is related to the separation between the clump and

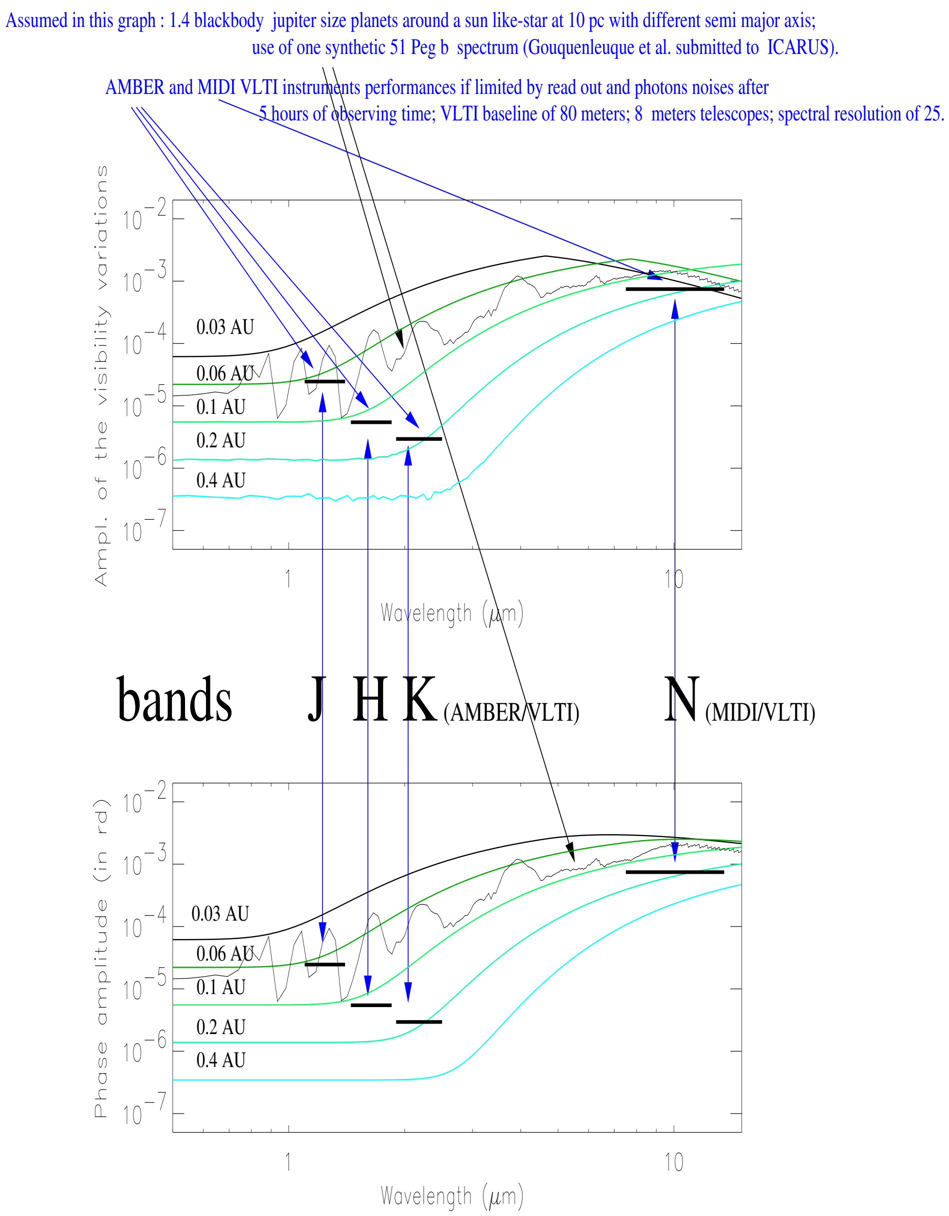

Figure 5. Direct extrasolar planet detection with the VLTI - This graph represents the comparison between the expected signal and some of the fundamental noise sources (not considered here : the VLTI stability and the atmosphere and delay line tunnel air induced noise which may affect the differential method done between several wavelengths).

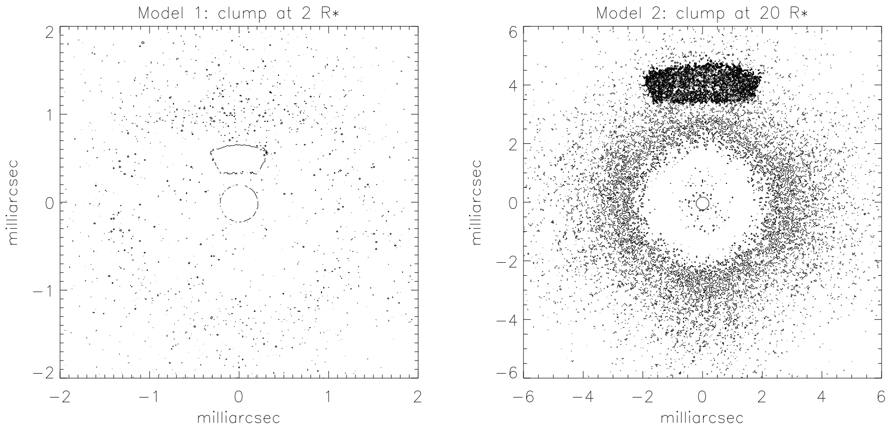

Figure 6. Simulated images at 10 μm of the circumstellar environment of an R CrB variable. During a decline, these models suppose that the clump is located between the star and the observer (assumed to be towards the top of the page in this representation).

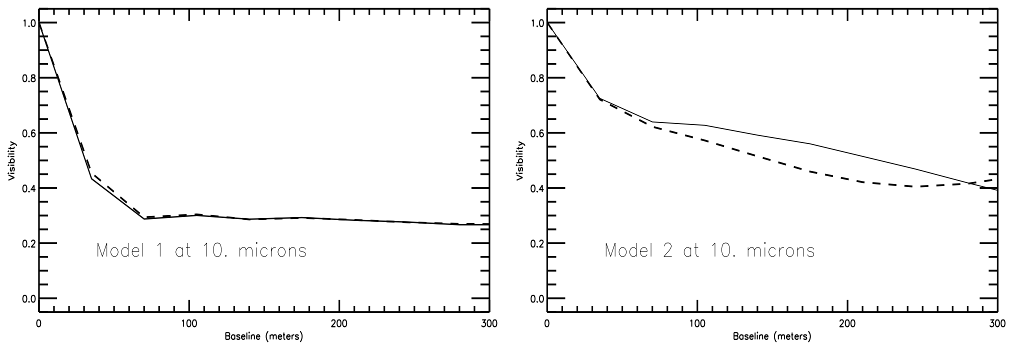

Figure 7. Visibility functions with respect to the baseline for Model 1 & 2 (left and right columns, respectively) at 10 μm. In each panel, the thick and dashed lines represent the visibility functions calculated in two perpendicular directions. The dashed line represents the star/clump direction.

the star, in model 2 the large assumed separation of 20 stellar radii produces a sensible contribution in the visibility, this appears in the cut made along the direction star/clump, some assymetry in the visibility may thus be observed. An absolute accuracy from of a few to ten percents seems reasonable for getting some good observational constraints regarding the physics of R CrB envelope and differentiate between the proposed model parameters.

Table 3. General scientific requirements and estimated feasibility for several projects of interest for MIDI

objective	required sensitivity	visibility accuracy	estimated targets	estimated feasibility	novelty	baseline length	minimum observing time
Active Galactic Nuclei	N $\geq$ 4	from 10^{-1} to 10^{-2}	a few to a few 10	to be defined	yes	small ones to be preferred	a few hundred seconds
Young Stellar Objects	N $\leq$ 4	10^{-2}	$\geq$ 100	high	yes	large ones to be preferred	from tens to a few hundred seconds
Extra-solar Planets	N $\geq$ 4	from 10^{-3} to 10^{-4}	a few or none	low	yes	$\geq$ 80 meters	a few hour
Pulsations and Stellar Surfaces	N $\leq$ 4	from 10^{-2} to 10^{-4}	to be defined	high	no		
Circum. Dust Red Giant, Supergiant	N $\leq$ 4	from 10^{-2} to 10^{-3}	several 100	high	no	from small to large ones (RCrB example)	a fraction of second
Binaries	N $\leq$ 4	from 10^{-1} to 10^{-2}	from tens to hundreds	high	no		

3. THE MIDI ASTROPHYSICAL POTENTIAL - SCIENTIFIC REQUIREMENTS AND ESTIMATED FEASIBILITY FOR SEVERAL PROJECTS

Our goal is to quantify the potential of MIDI and to determine the optimum strategy of observation for each observing program. The strategy of observations is supposed to provide :

- a minimum observing time for reaching a sufficient signal to noise ratio required by the science objectives.
- the size of telescopes to use (2 ATs versus 2 UTs).
- the choice of baselines, their length and orientation. Concerning the choice of the optimum baselines, we have developed a program named SIMVLTI aimed at searching for the best configuration for detecting (from a given assumed image) the largest visibility variations, providing the best differentiation between model parameters based on competing theories. The SIMVLTI program will be particularly useful when the shape and orientation of the object is *a priori* known.
- the temporal sampling of the observations, to be considered if the object is variable and/or if baseline changes have to be combined with other sources.
- a chopping requirement (for example the chopping may not be useful in the DI mode of observation)
- a fringe tracker requirement.

The scientific programs of most interest for MIDI are shown in Table 3.

The column **Required Sensitivity** shows that the limiting magnitude N = 4 for self fringe tracking (10 sigma detection in 0.1 second) provided by MIDI (using UTs) is sufficient for most objectives to observe some objects of each type. However the study of active galactic nuclei would strongly benefit from an improved sensitivity. The column **Visibility Accuracy** shows an estimated range of absolute accuracy which is required for doing useful science (see the section "Feasibility of some astrophysical programs" on how we came to some of these values).

The column **Estimated Targets** gives the estimated number of objects in each class available for observation with MIDI and considering the sensitivity allowed by the VLTI. The column **Estimated Feasibility** gives an indication of the difficulty of meeting the requirements imposed by each kind of observation. The column **Baseline Length** gives the preferred choice of length from the above models' considerations. For example one recommendation for the AGN program is to use short VLTI baselines (due to the assumed model), since objects like NGC1068 are quickly resolved. YSOs, on the other hand, will require large baselines to be resolved at all.

The column "Novelty" indicates whether the proposed study will be undertaken for the first time at 10 μm and/or with a long baseline interferometer, thus opening new frontiers of investigation. The remaining programs will extend previous interferometric programs to a larger number of objects and/or to a new level of spectral and spatial resolution.

The column **Required Observing Time** gives the minimum time to spend observing an object in order to reach an accuracy required by our science objectives. According to the estimated sensitivity of MIDI (using UTs), the observation of a N=4 object of V=1 (visibility of an unresolved object) could be done in 0.1 s (fringe sampling time) and will provide an absolute δV of 0.1 (averaging across the entire wavelength band of the instrument). There are several cases here to consider for deriving from predicted values of V and δV an estimate of the required minimum observing time (see below in the next subsections). We assume that MIDI is in self fringe tracking mode and that the observing time we estimate is the minimum observing time to spend on the object for each desired baseline (projected baseline) (not taking into account overheads and chopping if needed).

3.1. Case of bright objects

In the case of RCrB stars, we will have many targets sufficiently bright to easily perform self fringe tracking using MIDI alone. In fact 2 or 3 of the selected objects of our program should be bright enough to be observed with ATs (entailing a 3.2 magnitude penalty). For example the prototype of this class of object RCrB itself has a 10 μm flux of nearly 40 Jy. But let us assume that the UTs are used to observe an object of magnitude N=2, and that an absolute accuracy of 0.01 for each measured visibility point is required. The number of frames required is provided by, Num = $(10^{0.4\times(N-N_{limit})})^2 \times (0.1/\delta V)^2$. Based on our expected signal-to-noise ratio of 10 per frame at N_{limit}=4, we would then require only about 3 frames of 0.1 second each to perform a single observation with this accuracy.

In the case of a typical YS0 with a magnitude of N=4, in order to reach a 0.01 absolute accuracy we would need about 200 frames, or an observation of 20 seconds duration. But suppose we also wished to take advantage of MIDI's spectroscopic capabilities and determine the visibility with an RMS error of .01 in each of 10 independent spectral regions (also corresponding to 10 different points on the u-v plane). This could be accomplished with an observation of 200 seconds duration. These observation times are simply those required to reduce the noise level in the raw visibility determinations. They do not include the additional time required to perform photometric chopping and other essential overhead including observations of calibrator stars.

3.2. Case of objects which are at the limit of detection

The above conservative estimates allow for self fringe tracking by the MIDI instrument itself in the case of unresolved objects at magnitude N=4. This is based on an expected signal to noise ratio of 10 per 100 millisecond "frame" given our present notions regarding the hardware and background radiation levels. However given our estimate of the atmospheric coherence time at Paranal, the actual fringe shift between consecutive frames using this time scale is only about 1 μm RMS.

It is felt that tracking or estimation of the atmospheric OPD on a continuous basis can thus easily take advantage of the strong correlation between data received over multiple frame periods, substantially reducing the required raw signal to noise ratio. This is particularly true in the spectrally dispersed modes of operation that will commonly be used, since it then becomes possible to "see" the white light fringe even when there is an OPD offset of several or many wavelengths (depending on whether the low resolution prism or the medium resolution grism is employed). Coherent techniques for optimally employing spectrally dispersed interferometric data have been analyzed and simulated (Meisner 1995) and promise to offer fairly reliable tracking of the atmospheric OPD even with sources almost two magnitudes fainter than quoted. Even an unresolved source 2.5 magnitudes dimmer than the above quoted figures may allow for continual estimation of the OPD variations, albeit with frequent ambiguities, and the resulting determination of the OPD can still be employed as a phase reference for coherently estimating the fringe visibility. At this very marginal signal level OPD tracking errors and ambiguities will begin to degrade the accuracy of visibilities thereby obtained, but in general the error statistics of estimation errors affecting the phase reference can be gauged and their effect on the coherence of the interferometric signal corrected. In the very worst case the OPD estimation error will reach about .7 radians RMS, causing a reduction in the measured visibility of $e^{-.7^2/2} = .78$, requiring the result to be calibrated for this reduction. Note that this will also increase the required observation time by a factor of $.78^{-2} = 1.63$

The advantage of 2.5 magnitudes in absolute sensitivity is equivalent to tracking on a resolved object whose visibility has fallen to .1. Such is the case for AGN's which will likely be resolved to below V=.1 even using the shortest baselines. These and other overresolved or dim objects might then become observable using self fringe tracking. As computed above, an object of magnitude N=4, would require a 200 second observation in order to attain a visibility error of .01 RMS at 10 independent wavelengths. In the case of an object at the limit of fringe tracking, then the optical path difference estimation error would increase the required observation time to at least 320 seconds (see above), but probably more if ambiguous determinations of the OPD are encountered.

4. CONCLUSION

The goal of the present paper is to show our contribution to a preparatory work under progress which consists in studying the feasibility of different astrophysical projects (expected visibility, required absolute accuracy, required observing time, "strategy" of observation).

We show for example that the shortest VLTI baselines of the UTs have to be prefered for the study of AGNs. While the observations of the disk of young stellar objects will benefits of large (200 meters) baselines.

Regarding the case of extrasolar planet detection at 10 μm, this is a project that appears challenging but not unfeasible. Of course the final/real performance of the VLTI/MIDI instrument in being able to accuratly calibrate the data for reaching a high dynamics will determine the feasibility of extrasolar planet observation.

Regarding the sensitivity of MIDI, we have considered in this paper the MIDI operation in self tracking mode and show that for astrophysical objects like AGNs the performance of MIDI may be limited. It must be noticed that we have studied the NGC 1068 case among about ten other AGNs, and that it may not be correct to make a general conclusion based on this unique example. This supposed limitation is due to the fact that AGNs are faint and their visibility may be fastly resolved. The implementation of a method pushing as far as possible the N magnitude limit of the self fringe tracking mode and the use of an external fringe tracker seems crucial for this important astrophysical topic.

REFERENCES

Antonucci R., 1993, ARA&A 31, 473

Beckwith S.V.W., 1995, in Science with the VLT, proceedings ESO worshop, ed. J.R. Walsh and I.J. Danzinger, p. 53

Clayton G. C., 1996, PASP 108, 225

Clayton G. C., Bjorkman, K. S., Nordsieck K. H., 1997 ApJ 476, 870

Coudé du Foresto V., 1999, "ESO-VLT Opening Symposium", Antofagasta Chile, Ed. F. Paresce.

Eislöeffel J., Dougados C., 1997, in Science with the VLTI, proceedings ESO worshop, ed. F. Paresce, p. 240

Feast M. W., 1997, MNRAS 285, 339

Granato G. L., Danese L., Franceschini A., 1997, ApJ 486,147

Leinert Ch., and Graser U., 1998, SPIE 3350, 389

Leinert Ch. et al, 2000, This conference.

Lopez B. and Petrov R.G., 1999, "ESO-VLT Opening Symposium", Antofagasta Chile, Ed. F. Paresce.

Lopez B. and Perrin J.-M., 2000, A&A 354, 657

Mariotti J.-M., Coudé du Foresto V., Perrin G., 1996, AAS DPS meeting 28, 1207

Meisner J., 1996, "Atmospheric delay tracking in a long-baseline optical stellar interferometer," Optical Engineering 35, pp. 1927-1935

Men'shchikov A.B., Henning Th., 1997, A&A 318, 879

Men'shchikov A.B., Henning Th., Fischer, O., 1999, ApJ, 519, 257
Ménard F. et al., 1997, in Science with the VLTI, proceedings ESO worshop, ed. F. Paresce, p. 248
Natta A., 1997, in Science with the VLTI, proceedings ESO worshop, ed. F. Paresce, p. 237
Quirrenbach A., 1999, "ESO-VLT Opening Symposium", Antofagasta Chile, Ed. F. Paresce.
Rouan D., Rigaut F., Alloin D., Doyon R., Lai O., Crampton D., Gendron E., Arsenault R., 1998, A&A 339, 687
Urry C. M., Padovani P., 1995 PASP 107, 803
Van Belle G., 1999, "ESO-VLT Opening Symposium", Antofagasta Chile, Ed. F. Paresce.