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APreS-MIDI – a Concept for Aperture Synthesis in the MID-Infrared with the VLTI and Future Interferometers

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Abstract: In this article we present the concept of APreS-MIDI (*APerture Synthesis in the MID-Infrared*). This optical extension for the already very successful operating MIDI instrument will allow for the combination of up to four telescope beams. With APreS-MIDI high resolution imaging by aperture synthesis will be possible for the first time in the mid-infrared spectral regime. The optical setup uses a special principle for beam combination, where interference fringes are sampled in the pupil plane. This principle can also be suitable for future interferometers.

1 Introduction

Since end of 2002 MIDI demonstrated impressively the feasibility of interferometric observations in the mid-infrared in connection with the VLTI (Leinert et al. 2004, Jaffe et al. 2004, van Boekel et al. in press). As a two-way beam combiner MIDI gives the scientific community already the opportunity of high-angular observations, but – due to the limited UV-coverage and the lack of phase measurements – it is not able to perform imaging. Interpreting MIDI data requires always a priori information about the objects structure in form of a model. The parameters of such a model are then determined by MIDI observation. In principle, MIDI could perform real imaging with the support of PRIMA in future. This device will provide a reference for the required phase measurement. But since a two-way beam combiner exploits

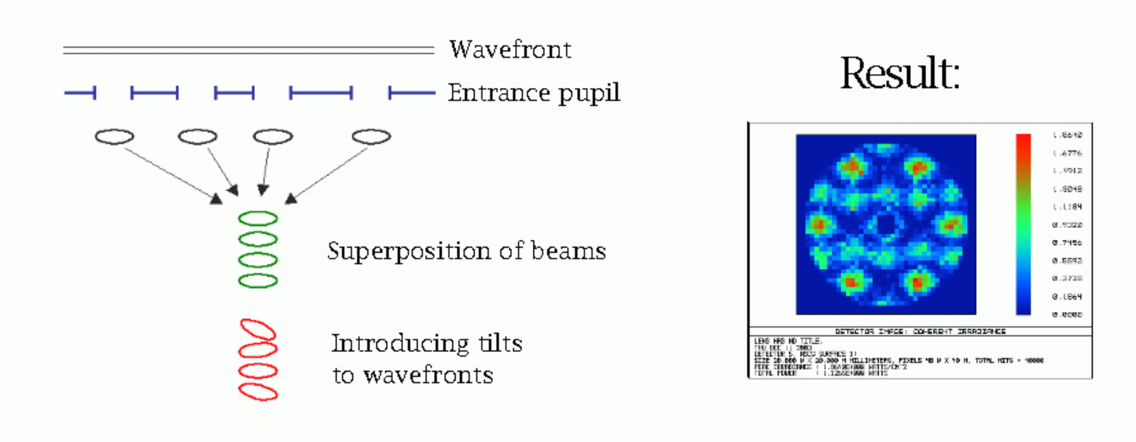

Figure 1: *Left:* Superimposition of four telescope beams in the pupil plane under small tilts. *Right:* Simulated pupil image with fringe pattern.

just a single baseline at a time, it will take a quite long observing time to fill the UV-plane with the necessary measurements.
The extension APreS-MIDI will allow for the combination of up to four telescope beams. Therefore it can overcome the drawbacks of the poor UV-coverage and the lacking phase information of MIDI all at once. With APreS-MIDI the number of simultaneously measured baselines increases up to six and at the same time it will measure up to four closure phase relations. With this amount of information image reconstruction becomes possible within three to five nights of observation.
We present in Section 2 the pupil recombination concept of APreS-MIDI which is proposed for coupling four apertures. Performance estimates of the imaging capability are done in Section 3. In Section 4 we discuss the potential of the described principle for beam combination for future instruments.

2 The APreS-MIDI Principle

The optical concept of APreS-MIDI realizes the combination of four telescope beams in the pupil plane. The four pupils are superimposed with small tilts (see Fig. 1, left). Thus, a fringe pattern is produced in the pupil plane as seen in the simulated image in Fig. 1 (right). One advantage for beam combination in this way is that it can be applied easily to the MIDI instrument, which is then used in the pupil camera mode. The MIDI beam-splitter is moved aside in this mode or – in combination with some minor changings of the optics – can be used for extraction of photometric beams.
The described beam combination in the pupil plane can be provided by an optical setup mounted in front of MIDI (Fig. 2). The key element is a pyramidal mirror with 4 reflecting faces. Images of the target produced by the four telescopes are focused on the surfaces of this pyramidal mirror. Its role is to re-arrange the beams and to send them in form of a bundle to the cold optics of MIDI. At the intermediate focus of MIDIs cold optic the beams passing a special pinhole mask which blocks the disturbing background radiation coming from off-axis sky positions. Finally the beams are imaged by the pupil camera on the detector where the fringe pattern occurs. Note, that the small tilt angles between the pupils producing the fringe pattern

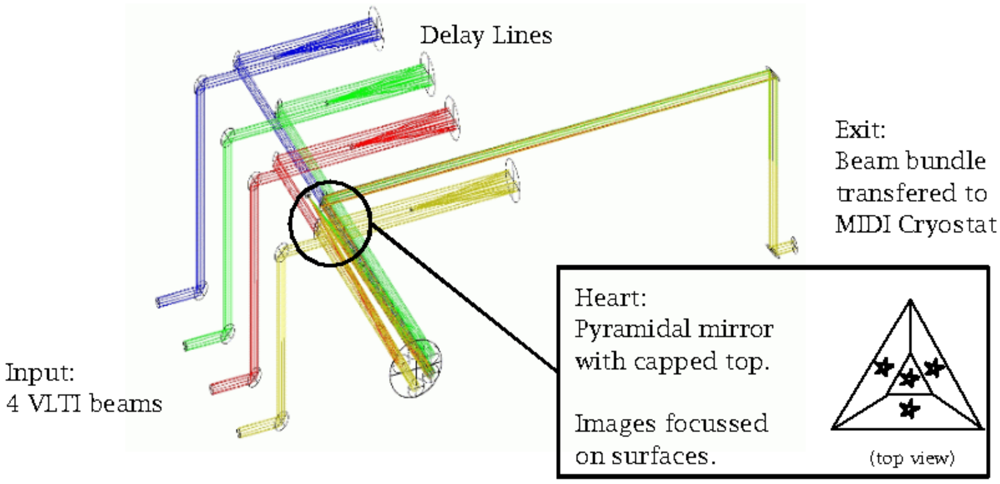

Figure 2: The APreS-MIDI optical setup. The four incoming beams are re-arranged and sent in form of a bundle to the MIDI entrance window.

is directly linked to the angle which remains between the beams after the reflection onto the pyramidal mirror.
The analyze of the fringe pattern can be done by Fourier transformation of the image. Each set of fringes results in a peak in the Fourier domain where it yields the complex visibility information corresponding to the spatial frequency sampled by one of the six baselines.

3 Performance

Potential targets for high-angular imaging in the mid-infrared are all kind of objects with warm dusty environments, since warm dust radiates efficiently in this spectral regime. The advantage over conventional MIDI measurements is that objects can be studied without possible ambiguities when interpreting only visibilities. Typical targets are for instance the inner region of accretion disks around Young Stellar Objects, where structures like gaps possibly indicate the process of planet formation. In the field of Cool Late Type Stars and Hot Stars, it is the mechanism of mass loss and dust formation which could be understood better. Characteristics of the dust tori of Active Galactic Nuclei could possibly be determined by reconstructing images of some typical sources representing the family of Seyfert galaxies.
For testing the imaging capability of APreS-MIDI together with the VLTI we performed numerical simulations. First, an image of a typical target, a T Tauri disk with an inner cavity, were produced by radiative transfer simulations (Fig. 3, left). The Fourier transform of this image has then been sampled by simulating the UV-coverage of the VLTI (Fig. 3, center). In this experiment, we assumed a four telescope recombination using the ATs during three observing nights. The telescope locations are assumed to be changed after each night. With 10 snapshots taken each night this corresponds to the measurement of 180 visibilities and of 120 phase closure relations. From these data set we were reconstructing an image using the Building Block algorithm (Hofmann & Weigelt 1993).The result is displayed in Fig. 3 (left). The inner rim of the cavity is clearly recognizable. This experiment demonstrates that APreS-MIDI can allow for high resolution imaging in the mid-infrared with a reasonable amount of observing time.

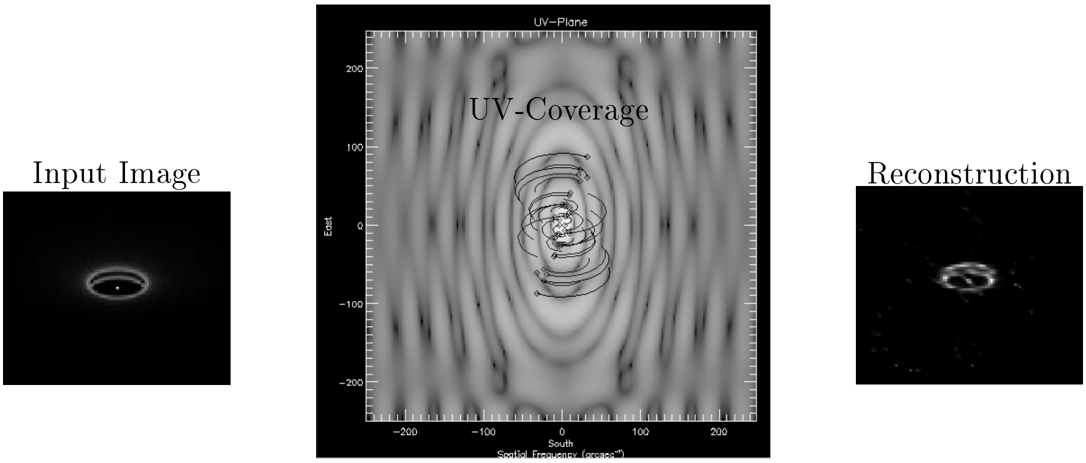

Figure 3: *Left:* Simulated input image of a T Tauri disk with an inner cavity of 4 AU radius equivalent to 25 mas in this experiment. *Center:* The UV-Plane with tracks corresponding four ATs used in three different configurations (one per night). *Right:* The reconstructed image. The bright inner rim of the cavity is clearly recognizable. In this experiment, noise was not considered.

Table 1 gives an overview of the expected performance of APreS-MIDI. Next to general parameters, which are determined by the VLTI uv-coverage, some significant parameters of MIDI are listed for comparison. The lower sensitivity of APreS-MIDI results from the additional optical elements and the fact, that the correlated flux of a source is spread into more fringe peaks in the Fourier domain according to the higher number of baselines used simultaneously.

Table 1: Performance of APreS-MIDI compared to MIDI.

General Parameters	
Angular resolution: 10 mas at 10 microns (200 m AT-baseline)	
Field of view : corresponding to Airy disc sizes at 10 microns: 0.25 arcsec with UTs, 1 arcsec with ATs	
MIDI	**APreS-MIDI**
1 baseline, no closure phases	4 tel.: 6 baselines, 4 closure phases 3 tel.: 3 baselines, 1 closure phase
no interferometric imaging	imaging by aperture synthesis
spectral resolution: R=230	1 with filters: R = 30
N = 8.5 with UTs* N = 5.5 with ATs*	N = 7.5 with UTs* N = 4.5 with ATs*

* Limiting Magnitude, $10\,\sigma$ detection of V=1 in 1000 s considered, filter bandwidth 1.5 μm, external fringe tracking assumed (for APres-MIDI reqiered).

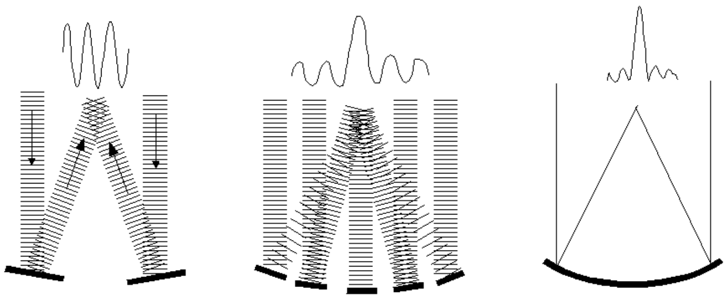

Figure 4: Beam combination in the pupil plane results under special conditions in an image in the pupil plane (see text).

4 Conclusions

The described principle – also known as "beam combination with densified images" – has some interesting properties. One is, that under special conditions an image occurs directly in the pupil plane. This should be explained in a qualitative way here. It is easy to see, that the frequency of fringes in the pupil plane increases with the tilt between two incoming beams. Furthermore, the resulting fringe contrast and phase are depending on the objects Fourier component sampled by the given baseline. If we now consider several combined beams and ensure, that their tilts are proportional to the baselines between them, the resulting fringe patters sums up the all Fourier components of the object in a correct way. As a result an image occurs in the pupil plane when increasing the number of beams. This circumstance is illustrated in Fig. 4. For an infinity number of beams the situation is equal to that of a full aperture focused by a parabolic mirror.

Acknowledgments

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