Mem. S.A.It. Suppl. Vol. 6, 133
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Memorie della
Supplementi

Observing Asteroids with the VLTI

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Abstract. The Very Large Telescope Interferometer (VLTI) allows direct determinations of asteroid sizes to be obtained. This is crucial to study interesting cases and to asses the reliability of thermal infrared, polarimetric and radar models, the major sources of information on asteroid sizes.

Key words. Solar System: Asteroids – Very Large Telescope: Interferometry.

1. Introduction

The Very Large Telescope Interferometer (VLTI) at the European Southern Obser-vatory (ESO) combines coherently the light from the 4 VLT telescopes (+3 auxiliary 1.8m telescopes) to make interferograms [1].

VLTI can either make interferograms in the near infrared (J,H,K bands, 1-2.2 μm) or in the medium infrared (N band, 9-13 μm). This is accomplished by using two different scientific instruments, AMBER (Near infrared/red VLTI focal instrument) and MIDI (Mid-Infrared instrument for VLTI), respectively.

Physical basis of interferometry is the van Cittert-Zernike theorem (e.g. Haniff (2003)): the Fourier transform of the brightness distribution is the coherence, or visibility function, $V(u, v) = V(B_x/\lambda, B_y/\lambda)$, where B_x and B_y are the components along two orthogonal directions of the projected interferometer baseline, λ is the wavelength and u and v are the spatial frequencies measured in radians^{-1}. Assuming a spatial distribution of the source intensity $I(\mathbf{l})$, where $\mathbf{l}$ is the position vector, expressed in terms of angular coordinates in the sky, the visibility function $V(\mathbf{w})$ is given by:

$$V(\mathbf{w}) = \frac{\int_{-\infty}^{+\infty} I(\mathbf{l}) exp(-i2\pi \mathbf{w} \cdot \mathbf{l}) d\mathbf{l}}{\int_{-\infty}^{+\infty} I(\mathbf{l}) d\mathbf{l}} \tag{1}$$

$\mathbf{w}$ is the vector, the orthogonal components of which are u and v. If the source is a uniform disk of diameter θ and intensity A, Eq. 1 becomes:

$$V(\mathbf{w}) = \frac{\int_{-\theta/2}^{+\theta/2} A exp(-i2\pi \mathbf{w} \cdot \mathbf{l}) d\mathbf{l}}{\int_{-\theta/2}^{+\theta/2} A d\mathbf{l}}, \tag{2}$$

which has a simple analytical solution of the form:

$$V(w_r) \propto 2 \frac{J_1(\pi\theta\, w_r)}{\pi\theta\, w_r} \tag{3}$$

where J_1 is the first order Bessel function and w_r is the radial component of the vector $\mathbf{w}$. Fig.

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[1] see http://www.eso.org/projects/vlti/ for further information on VLTI

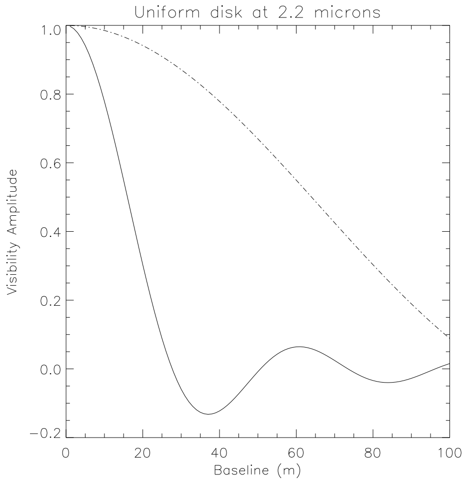

Fig. 1. Continuous line: 20mas uniform disk. Dashed-dotted line: 5mas uniform disk

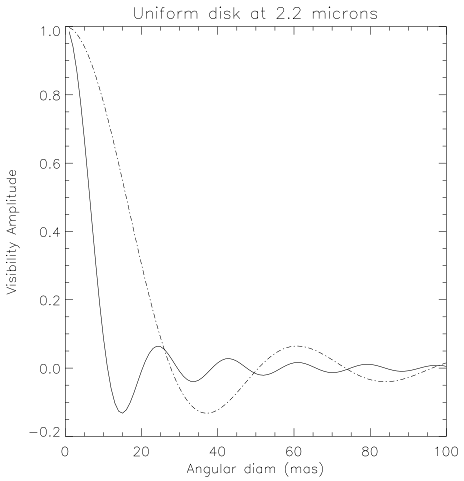

Fig. 2. Continuous line: 50m Baseline. Dashed-dotted line: 20m Baseline

1 shows the visibility at a wavelength of 2.2 μm (K-band) as a function of the interferometer baseline for the case of two disks of uniform brightness with a diameter of 5 and 20 mas, respectively.

As rule of thumb, VLTI can obtain visibility measurement when $0.9 > V(w_r) > 0.2$. Size information can thus be obtained for objects, whose visibility falls in that range. At VLTI, baselines ranging from 46 up to 130m are available with the UTs (the 8.2m telescopes). However, if we consider that an object can be observed up to an airmass of 2, the 46m-baseline projects on the sky to a 23m baseline. Fig. 2 shows the visibility amplitude as a function of the angular diameter of the disk for a 20m and a 50m baseline.

2. Observability of asteroids with VLTI

2.1. Using AMBER for observing in the near-infrared at VLTI

On the basis of Fig. 2 it can be seen that VLTI, in the K–band, can provide size information for asteroids having apparent angular sizes smaller than 15 mas. It is interesting to estimate how many (and which) real objects satisfy this condition.

A rough estimate of an asteroid diameter can be obtained from its absolute magnitude, H, and by assuming a plausible value for the albedo. The diameter, D, the H value and the albedo p_V are related by Eq. 4 (e.g., Fowler & Chillemi (1992)):

$$D(km) = \frac{1329}{\sqrt{p_v}} 10^{-H/5} \tag{4}$$

If we assume for sake of simplicity that asteroids are observed at geocentric distances Δ equal to $a - 1$, where a is the semimajor axis of their orbits, we can derive their apparent angular diameters. At present (Feb. 2005), there are almost 235,000 asteroids contained in the Orbit Database of the Minor Planet Center (MPCORB file[2]). More than 210,000 asteroids meet the conditions to have an angular diameter smaller than or equal to 15 mas, assuming $p_V = 0.11$ and $\Delta = a - 1$. But very few of them are bright enough to be observed with VLTI.

Limiting magnitude for observing with AMBER at VLTI is K∼12. We remind that typical V-J values for asteroids are of the order of 1.5 magnitudes (objects being brighter in the IR). Generally, the objects gain 0.5 - 0.7 mag, going from H to K. The limiting V mag

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[2] http://cfa-www.harvard.edu/iau/mpc.html

is therefore ∼14. We have calculated asteroid V magnitudes assuming that all observations are carried out when their actual heliocentric distance is equal to their orbital semi-major axis ($r = a$), the geocentric distance Δ is equal to $a - 1$, and the phase angle is 0^0 (at opposition). Fig. 3 and Fig. 4 show the angular diameter of asteroids as a function of their V mags in the case of p_V=0.11, average albedo for main belt asteroids, and p_V=0.30, average albedo for NEAs (Delbò 2004), respectively.

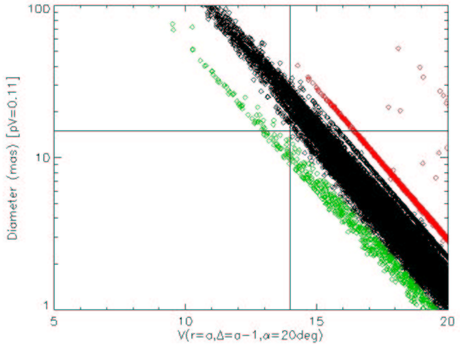

Fig. 3. Black: MBAs; Red: Jupiter-Trojans; Green: NEOs assuming pV=0.11. The asteroids that can be observed with VLTI are those objects with an angular diameter smaller than 15 mas and brighter than V=14.

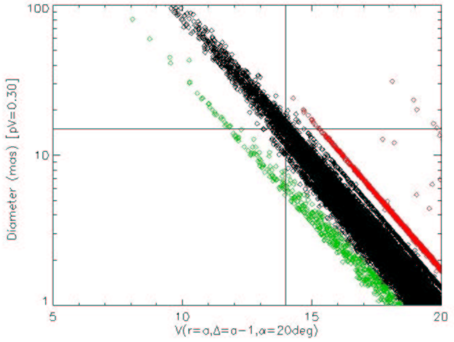

Fig. 4. Black: MBAs; Red: Trojans; Green: NEOs assuming pV=0.30. See Fig. 3 for further details

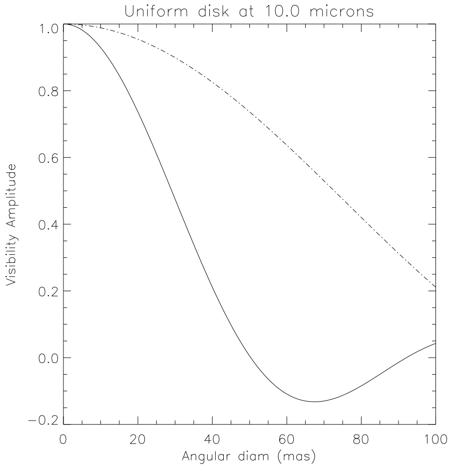

Fig. 5. Visibility amplitude as a function of the angular diameter of the disk for a 20m and a 50m baseline at 10 μm. Continuous line: 50m Baseline. Dashed-dotted line: 20m Baseline

It is clear from Fig. 3 and 4, that Near-Earth Asteroids (NEAs) are the most suitable class of minor bodies for which AMBER can be used to determine the diameter. On the other hand, only very small, nearby and high albedo main belt asteroids can be investigated by means of this instrument.

2.2. Using MIDI for observing in the thermal infrared at VLTI

For a given baseline, the minimum achievable angular separation is proportional to λ, so we can assume that observing with MIDI at VLTI in the N-band, size information for asteroids with angular sizes smaller than $15 \times 10/2.2 = 68.2 \sim 70$ mas, are accessible. Fig. 5 shows the visibility amplitude as a function of the angular diameter of the disk for a 20m and a 50m baseline at 10 μm.

At 10 μm the solar light reflected by asteroids is negligible compared to their thermal infrared emission. Limiting flux for observing with MIDI is ∼ 1 Jy. We have used the Standard Thermal Model (STM) of Lebofsky et al. (1986) to calculate asteroid thermal infrared fluxes. Fig. 6 shows thermal IR fluxes

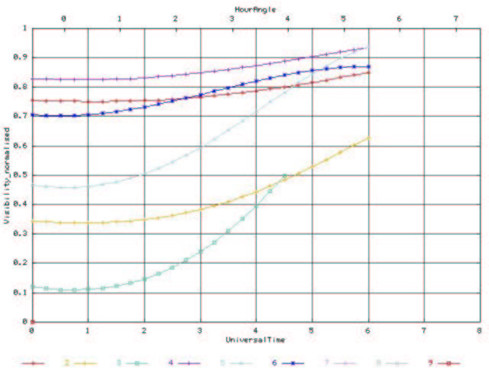

Fig. 7. Normalized visibilities for the near Earth asteroid 6611 simulated on April 28, 2005 from VisCalc (see www.eso.org/observing/etc/preview.html). Different colors correspond to different baselines.

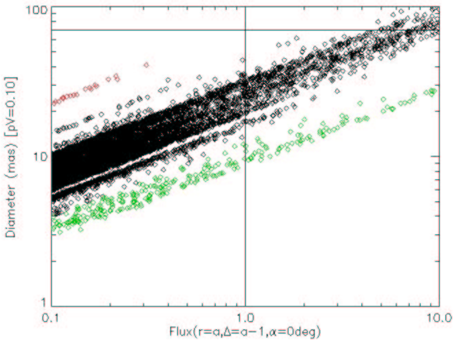

Fig. 6. Thermal Infrared flux calculated at 11.7 μm as a function of asteroid angular diameter, assuming p_V=0.11. Black: MBAs; Red: Trojans; Green: NEOs. About 500 asteroids are measurable at ∼10 microns

as a function of the angular diameter for asteroids in the MPC database. It is clear that the assumption of $r = a$, $\Delta = a - 1$, and $\alpha = 0$ is not a good approximation in the case of NEAs.

However, NEAs are good targets to be studied with MIDI, as demonstrated by Fig 7 where the normalized visibility in the case of the NEA 6611 is shown, during its close approach to the Earth on April 28, 2005. The asteroid has an approximate diameter of 2 km, and it will have an apparent angular size of about 20 mas.

3. Conclusions

VLTI has the unique capability of measuring directly the sizes of small asteroids (well below 30 km in diameter) and represents one of the most powerful means to improve the knowledge of such a kind of celestial objects, never observed with interferometric techniques before. This kind of observation is crucial to verify the validity of thermal infrared, radar and polarimetric models.

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