VISIR and the Detection of Exo-Planets

Pierre-Olivier Lagage (lagage@cea.fr)

DSM/DAPNIA/Service d'Astrophysique, CEA/Saclay, F-91191 Gif-sur-Yvette Cedex, France

1 Introduction

The study of disk and planets around stars is one of the fields in Astrophysics which has undergone huge progresses the last years. Protoplanetary disks, a key ingredient of star-formation theories, have been imaged, (see the review by M. McCaughrean, these proceedings). More than a dozen of exo-planets have been discovered (see the reviews by M. Mayor, D. Queloz, these proceedings). Debris disks have been imaged, (see the review by P. Kalas, these proceedings).

In this paper, I shortly describe VISIR, the VLT instrument for the mid-infrared, (Sect. 2). Then, I discuss the prospects in using the instrument to detect exo-planets, either indirectly by imaging debris disks (Sect. 3) or directly (Sect. 4).

2 VISIR, the VLT mid-InfraRed Instrument

Since the beginning of the Very Large Telescope (VLT) project, the European Southern Observatory (ESO) has set a comprehensive instrumentation plan which provides a wide range of imaging and spectroscopic facilities from near-ultraviolet to mid-InfraRed (IR). The two mid-IR atmospheric windows, the N-band (7.7-13.5 μm) and the Q-band (16.5-25 μm), will be covered by VISIR, the VLT Imager and Spectrometer for the mid-InfraRed. VISIR is being built by a consortium of two institutes: CEA/Saclay (France) and NRFA/Dwingeloo (The Netherlands). The instrument combines:
1) imaging capabilities over a field up to about 1 arcmin with a choice among three scales (0.075", 0.127", 0.200" per pixel) and with a choice among 27 narrow- and broad-band filters;
2) long-slit (>30") grating spectroscopy capabilities with various spectral resolutions (350, 3200, 25000 at 10μm; 1600, 12500 at 20μm).

The design of the instrument is completed and the manufacturing phase has started (see Fig. 1). For details about the instrument, the reader is referred to the article by Lagage et al. (1998). VISIR will be mounted at the Cassegrain focus of Melipal, the VLT telescope unit number 3, at the beginning on 2001.

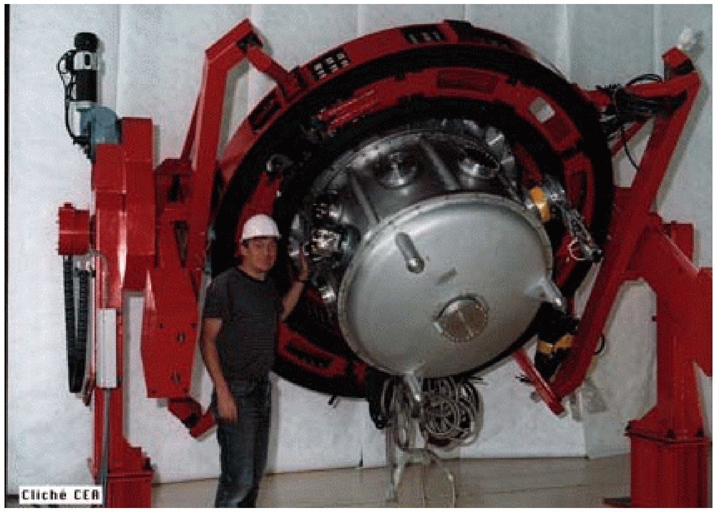

Fig. 1. Picture of the VISIR test cryostat and cable wrap mounted on the integration support.

In terms of performances, the two key issues related to the observing programs discussed hereafter are: the angular resolution and the sensitivity.
In the mid-infrared, the image quality is limited by telescope diffraction effects rather than seeing effects. The diffraction effect on the angular resolution, defined here as the wavelength (λ) over the telescope diameter (D), is 0.25" at 10 μm. The smallest pixel field of view of VISIR (0.075") will allow to oversample the diffraction pattern. Thanks to image deconvolution techniques, we can expect to reach an angular resolution in the 0.1" range.
A typical sensitivity of 1 mJy (10 sigma 1 hour) is expected in the N-band and of 10 mJy (10 sigma 1 hour) in the Q-band. The sensitivity is limited by the noise associated with the huge photon background generated by the atmosphere and the telescope. Note that a large gain in sensitivity is obtained when going from a 3-m class telescope to a 8-m class telescope. Indeed, the observing time needed to reach a given signal over noise ratio when observing a point source, decreases as D^4. One hour of point source observations with VISIR will be equivalent to 2 nights of observations with a mid-IR instrument on a 3.6-m telescope.

3 Perspectives in Debris Disk Observations

Disks and planets are intimately connected (see D. Lin, P. Artymowicz, these proceedings). Planets are made from protoplanetary disks. Interactions between newly formed planets and "protoplanetary" disks can modify the orbit of the planet, which may "migrate" towards the star. Protoplanetary disks disappear with time, so that main-sequence stars are not expected to be surrounded by a disk. However, collisions between planetesimals or comet sublimation can generate a "second generation" dust disk (for example Weissman 1984); these disks are usually quoted as debris disks. The presence of a planet in such a disk can deeply modify the morphology of the disk through gravitational perturbations of the dust orbit (Paresce 1992, Roques 1994). Such effects have been observed in the solar system (Dermott et al. 1994; Reach et al. 1995). Thus, studying the morphology of debris disks is a way to search for "footprints" of planets.

3.1 Debris disk imaging

The study of debris disks has started with the IRAS discovery of an IR excess around many main-sequence stars (Aumann 1985). The best-studied dust disk is the disk around the star β-Pictoris (see reviews by Artymowicz 1997, by Vidal Madjar et al. 1998 and references there-in). The outer parts of the dust disk were imaged in the visible soon after the IRAS discovery (Smith & Terrile 1984). The inner parts of the disk were imaged 10 years later, thanks to mid-IR observations (Lagage & Pantin 1994, see also Fig. 2). Both the mid-IR images and recent observations in the visible or near-IR (Mouillet et al. 1997) show features (asymmetry, deficit of matter near the star, warp), which indicates the possible presence of planets in the system.

The origin of the disk emission observed in the mid-IR is dust thermal emission; at shorter wavelengths, the origin of the emission is star-light dust scattering; (see the contribution by A.M. Lagrange, these proceedings, for a discussion of the prospects in detecting dust disk in the near-IR). Observations in the mid-IR and in the near-IR (or visible) are complementary. On one hand, a better angular resolution can in principle be obtained at shorter wavelengths, at least when using adaptive optics. On the other hand, only mid-IR observations can reveal the innermost parts of a disk (closest to the star). Indeed, given that the disk emission often dominates over the star emission in the mid-IR (especially in the Q-band), the resolution is not limited by the need of a coronograph, as required at shorter wavelengths. Second, dust thermal emission is isotropic, when dust scattering is anisotropic (forward scattering). Then, different parts of a disk are seen according to the origin of the observed emission and, in the case of an edge-on disk similar to the β-Pictoris disk, the scattered emission is dominated by the outer part of the disk (let's say greater than 30 AU from the star), so that the inner parts are inaccessible, whatever the angular resolution is (Pantin 1996).

Up to now, only two disks have been resolved in the mid-IR, the disk around the β-Pictoris star and recently the disk around HR4796 (Koerner et al. 1998, Jayawardhana et al. 1998). The list should extend rapidly thanks

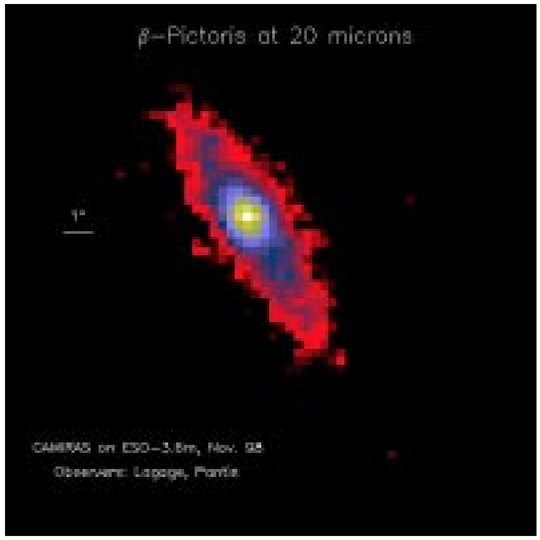

Fig. 2. β-Pictoris dust disk as observed at 20 μm (raw image). North is up; east is left. The pixel field of view is 0.3 arcsec, which means 5.7 AU at the distance of β-Pictoris (19.3 pc). At this wavelength, the disk contribution dominates over the star contribution (not removed here).

to the improved sensitivity obtained with mid-IR imagers mounted on large telescopes. For example, VISIR will be about 100 times more sensitive than TIMMI, the instrument which was used to image for the first time the β-Pictoris dust disk at 10 μm.

3.2 Dust composition

Spectroscopic studies of debris disks in the mid-IR are also crucial. Indeed, mid-IR dust features, such as silicate features, can help in identifying the nature of the dust orbiting the star and hopefully in understanding the origin of the dust.
Comparison of mid-IR spectra of the dust around β-Pictoris (Knacke et al. 1993, Aitken et al. 1993) with spectra of comets, have led to the claim that the β-Pictoris dust is generated from the sublimation of comets. Of special interest was the presence of crystalline olivine in both comets and β-Pictoris. The presence of crystalline olivine was first identified in comet Halley (Campins & Ryan 1989); crystalline olivine was also present in large quantities in comet Hale-Bopp and was identified as forsterite (Crovisier et al. 1997). However, it should be pointed out that not all comets feature silicate dust (Hanner et al. 1994). Furthermore, ISO/SWS observations have shown that crystalline olivine dust was present in various environments, such as young stellar objects (Waelkens et al. 1996) or evolved objects (Waters et al. 1998); the origin

of such a dust is not yet well understood. Thus, the link between the dust around β-Pictoris and comets is not as straightforward as usually thought.

Additional studies of dust both in comets and in debris disks is definitively needed to progress. The spectroscopic mode of VISIR will be well adapted to such studies.

4 Giant Exo-Planet Direct Detection

We have to face two main problems when trying to detect directly an exo-planet.
The first issue is a sensitivity issue. The flux expected from a giant exo-planet is now well calculated, (F. Allard these proceedings). In the following, we only consider the detection of an exo-planet at a temperature in the range 450-100 K, typical of the mid-IR radiation. Given the sensitivity discussed in Sect. 2, only giant planets (7-12 M_{jup}) at a distance of less than 5-10 pc and at a relatively high temperature in the range 450-350 K can be detected by VISIR. For example, the flux expected at 10 μm for a 7 M_{jup} exo-planet

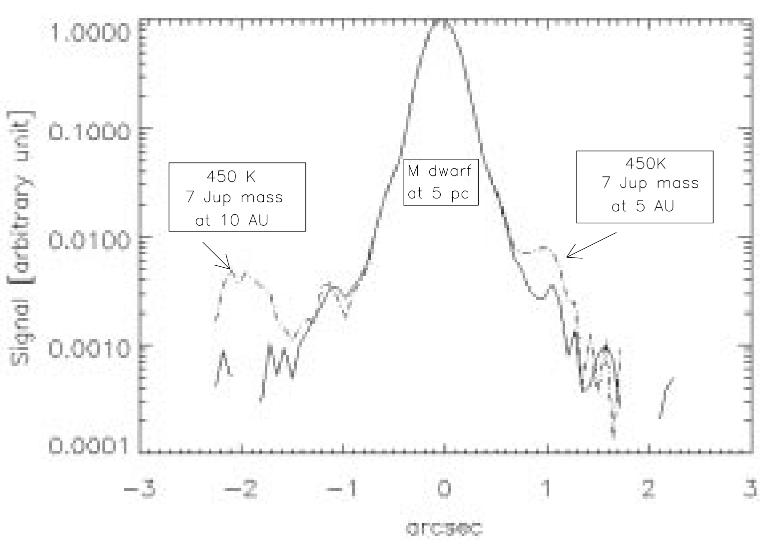

Fig. 3. Cut along an axis of an image simulating the 11 μm signal expected in VISIR from a system made of two 7 M_{jup} exo-planets at 450 K, orbiting respectively at 5 AU and 10 AU from a M-dwarf located at 5 pc from us. The diffraction by the telescope and a seeing of 0.4" in the visible have been taken into account, as well as the background noise generated by the atmosphere and the telescope. Solid line: star alone; dashed-dotted line: star + companions.

at a temperature of 450 K and located at 10 pc from the Earth is of 1/3 of mJy (Burrows et al. 1997, Marley private communication); the age of such a planet is 200 Millions years. A 12.6 M_{jup} exo-planet will be at 300 K at an age of 4.2 Billions years and will emit a flux of 1/30 mJy, if located at 10 pc. The second issue is the contrast in brightness between the hosting star and the planet. As already mentionned in Sect. 2, the main limitation to the angular resolution is the diffraction by the telescope. The signal at respectively 1" and 2" from a point star is respectively 1/300 and 1/10000 of the central signal. These numbers have to be compared with the intensity contrast between a star and its planet. If we consider a solar type star and a 7 M_{jup} planet at 450 K, the contrast is 1/4500. A more favourable case is obtained when the hosting star is a M-dwarf; in this case, the contrast is only 1/200 and the exo-planet can be easely detected (see Figure 3). Note that a giant planet (2/sin(i) M_{jup}) orbiting closeby (semi-major axis of 0.2/sin(i) AU) Gl876, a M dwarf located at 4.7 pc from us, has already been detected indirectly, by the radial-velocity technique (Delfosse et al. 1998).

Thus, the direct detection of giant exo-planets with an instrument like VISIR appears possible for a limited, but plausible, range of parameters.

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