Studies of Disks Around Main-Sequence Stars with the VLT

A.-M. LAGRANGE, Laboratoire d'Astrophysique de Grenoble, France

Since the IRAS mission in 1983 it is thinkable to observationally study outer Solar Systems in various stages of evolution, so as to give clues to the scenarios of formation and evolution of planetary systems. This paper reviews the observational work that has been done so far. It will also show how the forthcoming VLT is expected to contribute to a better understanding of these systems, especially thanks to its high angular resolution capabilities and performing IR instruments.

1. Introduction

The IRAS satellite measured unexpected infrared excesses at 25, 60 and 100 μm around some nearby (d ≤ 25 pcs), Main-Sequence (MS) stars. The first such objects known were α Lyr (A0V), α PsA (A2V), β Pic (A5V), and ε Eri (K2V). In some cases the excesses are due to thermal emission from cold (≃ 100 K) dust orbiting the stars (Aumann et al., 1984). Typical sizes of these IR sources range between 10 and 400 AU. These systems might be planetary systems in various stages of evolution. As the central stars are on the Main Sequence, they may even have got time to form planets. Their proximity allows detailed studies: high-resolution imaging of the dust, high-resolution spectroscopy of the gas, if present. As they are numerous – more than 100 such objects are reported and there is evidence that indeed the occurrence of such properties for MS stars is common – statistical studies can also be done.

To better understand these systems, one has to determine their structure (disk?, spatial extension), the sizes (large bodies?), distributions, temperatures of the orbiting material, their chemical composition, and their origin: is the dust the remnant of the protoplanetary disk, or was it produced more recently through collisions of larger bodies? IRAS measurements already brought a wealth of information: the signature of circumstellar (CS) material, the evidence of extended 60-μm emission regions in the four cases mentioned above, the evidence of a relative lack of hot and then close dust, tentatively attributed to former planetary accretion. Nevertheless, these IRAS data are not sufficient to constrain as tightly as possible all the unknown parameters. One in fact needs a large variety of observations: whenever possible, multicolour resolved images of the CS dust, and if not possible, multiwavelength aperture photometry or photometry. The spectral range from UV to radio is important, as cold and hot dust, large or small grains, with different optical properties may be *a priori* present around the candidate stars. The next section shows how a multiwavelength approach has allowed us to describe the CS dust around β Pictoris in detail, and how our knowledge on this disk can still be improved thanks to the forthcoming generation of telescopes. Section 3 will then give the status of knowledge on the other candidates, as well as the results of search for other disks and will give details on the progress expected with the VLT.

2. The Disk Around β Pictoris

2.1 Observations of the dust

2.1.1 Optical images

Shortly after the IRAS results, Smith and Terrile (1984) imaged at 0.89 μm the scattered light from the dust around β Pictoris, with a 2.2-m telescope at Las Campanas (Fig. 1a). The image revealed the dust concentrated in a thin disk, viewed nearly edge-on, from 100 to 400 AU. This was the first image of a disk around an extra-solar Main-Sequence star. To detect it, they had to use a coronograph including a 7″ (diameter) mask to remove most of the stellar light. Even with the coronograph, the scattered light from the star is larger than the disk light. At 100 UA (≃ 7″), the disk magnitude per arcsec^2 is 16, to be compared to β Pictoris magnitude 3.8. Multiband images, from B to I, of the same region of the disk taken at ESO with the 2.2-m telescope led Paresce and Burrows (1987) to conclude that the typical size of the grains responsible for the observed scattered light is larger than 1 μm.

Gledhill et al. (1988) polarization maps of the ≥ 80 AU region of the disk indicated a level of polarization of about 17 %; this, together with the other images, seems to favour the hypothesis that the properties of the grains are close to the ones of zodiacal dust for this region. Optical images of the inner part of the disk have recently been performed with two different techniques: one with antiblooming CCDs (Lecavelier et al., 1992; Fig. 1b), and the other one with tip-tilt correction (i.e. first-order adaptive optics correction) and a coronograph (Golimowsky et al., 1992). In both sets of data, the disk is shown to be present down to 30 AU from the star, but a change in the slope of the surface brightness occurs at typical distances of 80 AU. The antiblooming images, made in various bands, B, V, R and I, moreover show a colour effect close to the star. At 3 arcsec (about 60 AU), a drop in the B band is observed, possibly due to changes in the chemical composition of the grains: grains with lower albedo such as silicates could produce such an effect.

2.1.2 IR and radio observations

IR aperture photometry on β Pictoris has been successfully performed to further constrain the SED and the models (Telesco and Knacke [1991], Knacke et al. [1993] and Aitken et al. [1993]). The observations showed that most of the 10 μm emitting region was closer to the star than 5″ (90 AU). This was directly confirmed by resolved 10-μm images of the thermal emission of the β Pictoris disk with TIMMI at the ESO 3.6-m; this gave for the first time the disk brightness distribution in the thermal IR (see Lagage et al., *The Messenger* No. 75, p. 25, Fig. 1). Spectrophotometry revealed silicate emission at 10.8 μm, suggesting that small grains (≲ 1 μm) should be present close to the star. The silicate spectrum moreover appears to be similar in shape to the one of interplanetary dust which contains crystalline silicates, or to the one of comets. If so, comet-like bodies could then be at the origin of the inner part of the β Pictoris disk. This would also explain the presence in the disk of submicronic particles, which

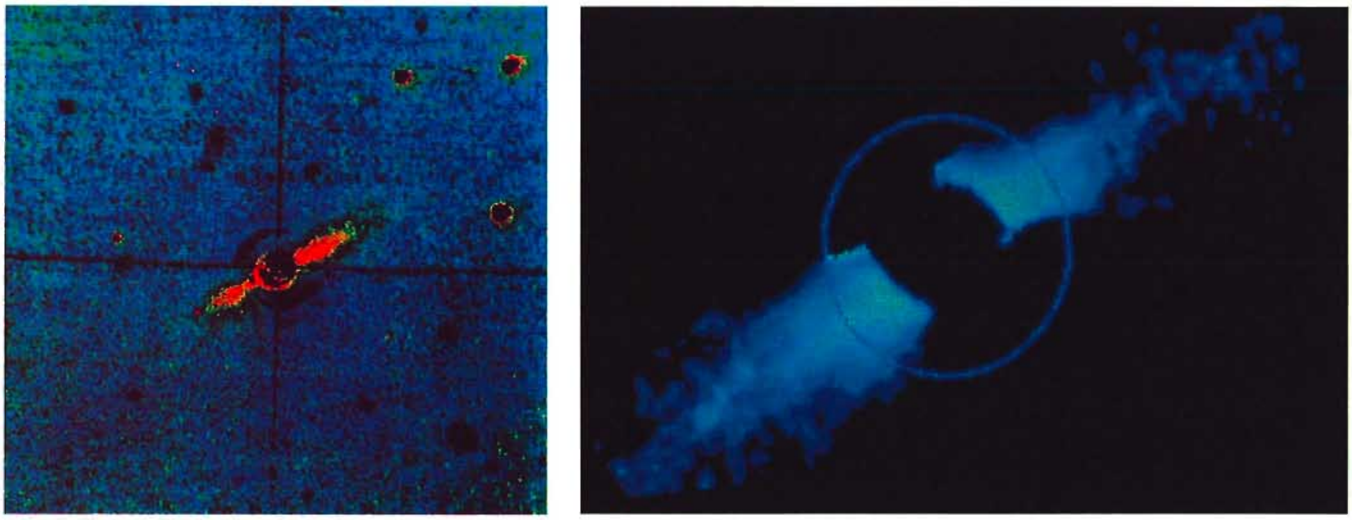

Figure 1: *Optical images of the disk around β Pictoris: (a) the outer part from 7" (100 AU) to about 25" (400 AU) from the central star; (b) the inner part with the disk down to 30 AU; the circle corresponds to about 100 AU in radius.*

cannot be primordial either, as they would have been removed on timescales much smaller than the estimated age of the star under Poyinting Robertson effect or radiation pressure effects.

Chini et al. (1991), with 1.3-mm observations showed that nevertheless larger grains (may be up to mm size) had also to be present around the star. From 800-μm observations, Zuckerman and Becklin (1993) concluded that there are no large amounts of CS cold dust that could have escaped detection by IRAS.

2.2 A model for the dust

Several models have been proposed to explain the available data since 1985 (Diner and Appleby, 1986; Artymowicz, Paresce and Burrows, 1989...). A simple one has recently emerged to explain almost all available observational features. In this model (Backman, Gillet and Whitteborn, 1992) the disk is made of two regions: an outer one containing large (≥ 1 μm) grains, and with a distribution given by the classical images, and an inner part, in which the density distribution follows a less steep law and the size of the grains is small (down to submicronic size). The outer region extends at least to 1000 AU (optical data). The inward extension of the inner region is very model dependent, from 5 to 50 AU. The inner void thus evidenced could be the result of planet accretion. The boundary between both regions has to be between 60 and 100 AU, and could represent the limit of ice sublimation. Then the outer zone might be mostly made of icy material whereas the inner zone might contain more refractory material. Figure 2 summarizes the model.

2.3 Remaining questions

The use of several different and complementary data has obviously permitted to make remarkable insights in the knowledge of the disk since the IRAS discovery. Nevertheless, some important questions are still unanswered:

(1) are there planets already formed?; where is the inner void of material predicted by most models located? (2) what is the chemical composition of the dust?

2.4 Future observations of the dust

2.4.1 Detection of planets

Direct detection of planets in the next decades is thinkable but needs dedi-

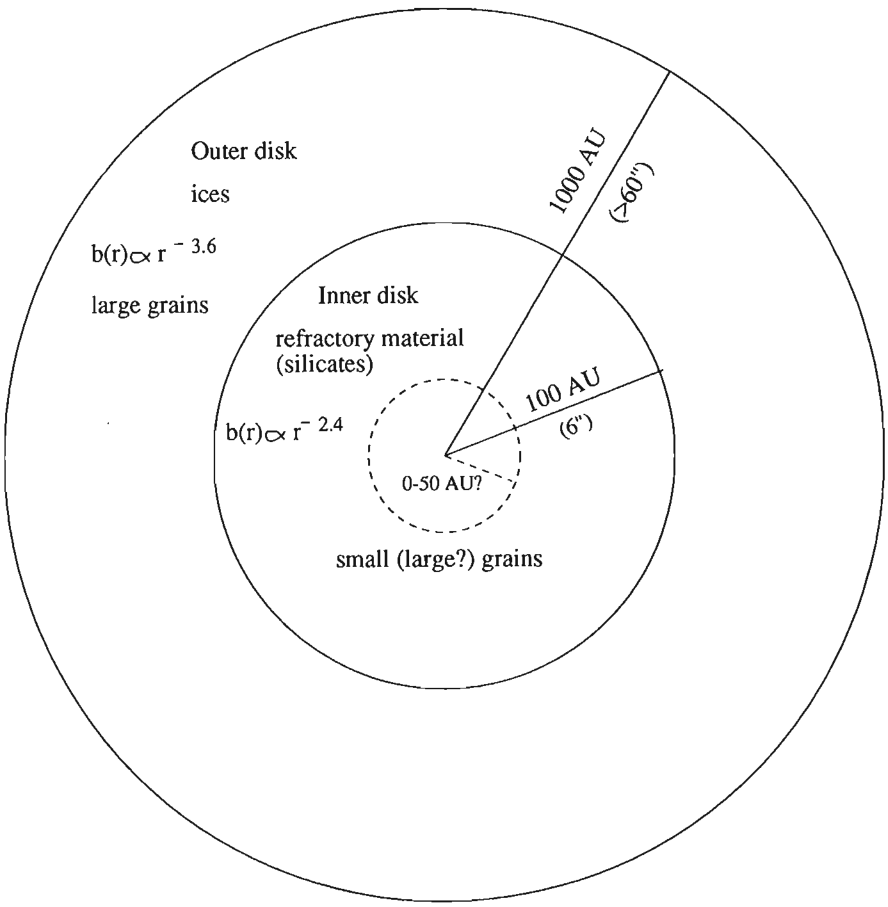

Figure 2: *Model for the β Pictoris disk.*

cated instrumentation (Watson et al., 1991). The basic problem is to detect $\Delta M \geq 25$ for Jupiter-like planets close to very bright objects ($\leq 1''$). This implies use of dedicated coronographs (apodizers), but also a very high image quality and then use of adaptive optics on the next generation of ground-based telescopes and dedicated instrumentation (Angel, 1994) or space observatories. Malbet, Shao and Yu (1994) have recently suggested an active system to correct for the imperfections of the primary and secondary mirrors of HST so as to possibly detect Jupiter-like planets around near-by stars.

Direct evidence of planets via Doppler shift has also been investigated in the previous years; it requires very accurate spectroscopy (precision of 10 m/s), and then also dedicated instrumentation.

Signatures of planets may relatively more easily be found in further investigating the structure of the disk (presence of gaps, location of inner void, asymmetries). Indeed, a planet is expected to produce gaps in the disk because of its gravitational perturbation on the close-by small grains (see for instance Sicardy et al., 1993). To detect such small-sized signatures (AUs), one first needs high angular resolution. Space observations (with HST), free of atmospheric distortion, or ground-based observations with adaptive optics are necessary. To observe very faint structures close to a very bright object, one needs a high dynamical range within a small spatial region. Coronographic techniques or use of antiblooming detectors are obviously needed.

2.4.2 Structures in the disk

Observations with the FOC and coronograph on the refurbished HST are expected to provide diffraction-limited images from 1150 to 6500 Å, with a high efficiency towards 4000 Å. They are expected to test gaps down to 0.2″ in size, i.e. 3 AU in the best case, and then hopefully test masses smaller than 0.1 $M_\odot$ located at distances down to 20 AU from the star (Norman and Paresce, 1989). Near-IR diffraction-limited coronographic images with CONICA on the VLT will enable us to reach roughly similar performances, slightly better if we compare the resolution at 1 μm ($\simeq 0.03''$) to the HST 0.4 μm one. Ground-based observations have the advantage of flexibility and offer the possibility to use dedicated masks. High-resolution images will also test the inner void down to less than 3 AU from the star.

FORS will unfortunately work at lower angular resolution (0.3″ in the best case) as it will give seeing-limited images. So

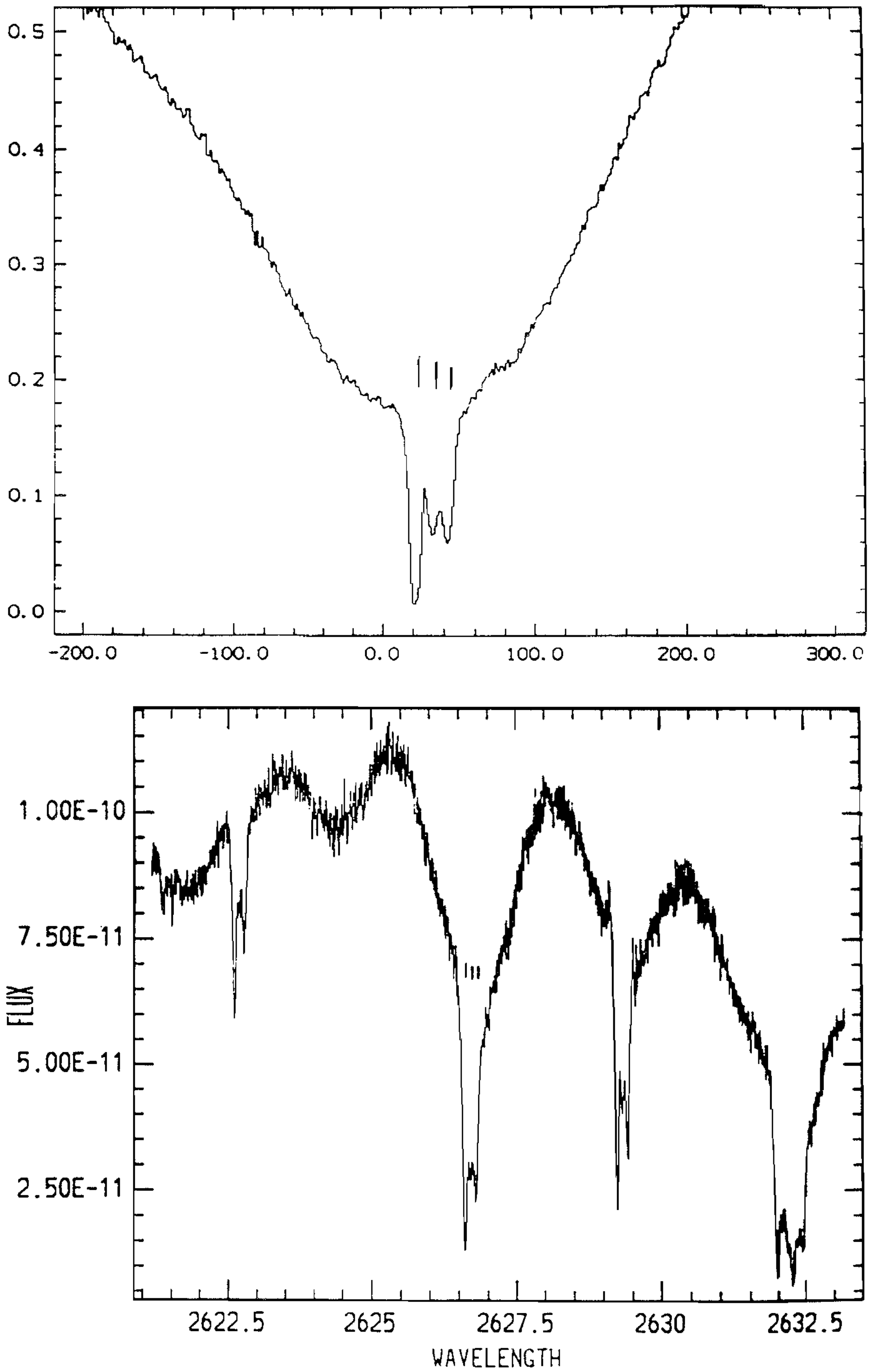

Figure 3: *Variations in the CS lines of β Pictoris: simultaneous high-resolution observations of redshifted lines in Calcium II K (ESO) and Fe II (HST).*

in principle, one could get the same type of information on 4-m-class telescopes if identical instruments were available. Adaptive optics correction in the visible, *even partial*, would drastically improve the image quality, and then the science to be done with. As an example, partially corrected (factor of 4 times the diffraction limit, which is quite a reasonable limit to be obtained when using the AO correction developped for the IR) images at 4000 Å would give a resolution of less than 0.05″ (i.e. 0.8 AU), comparable to the fully corrected HST images. Of course, this assumes that the pixel size would correctly sample the resolution.

Next step, VLTI images with a resolution of 0.001″ would enable us to obtain details of less than 0.02 AU, otherwise undetectable, over a relatively large field of view (8″).

2.4.3 Radial distribution of the dust; optical properties of the grains

To further constrain those parameters, the best strategy is again to per-form *multiwavelength* imaging, from the UV to the radio. The combination of disk responses from the UV to the IR at very high resolution with HST and CONICA images, and FORS, with, hopefully, at least partially corrected images in the optical range will undoubtedly bring a wealth of information.

10 and 20 μm structure of the disk with resolutions of 0.3 and 0.6″ with MIIs (see below) will also help to further constrain the models. Compared to the present TIMMI performances, a gain of more than a factor two might be expected. This is of course crucial. The lower resolution in this wavelength range compared to the visible or near-IR domains is partly balanced by the fact that conversely to the visible or near-IR domains, there is no need fo a coronograph. Direct imaging with ISOCAM up to 20 μm, with a nevertheless lower angular resolution, between 3 and 6″, but a higher sensitivity, or with ISOPHOT aperture photometry up to 200 μm are also expected to further constrain the description of the disk.

The chemical composition of the disk will be further investigated with ISO, especially via spectroscopy: water ices as well as silicates can be searched for, with a very good sensitivity. From the ground with MIIS, at higher resolution, silicate bands will be investigated with spectro-imaging or long-slit spectroscopy. Also, polarimetric and multiband observations with FORS should bring valuable information on the nature of the grains.

2.5 The gas

2.5.1 The stable gas

β Pictoris, viewed edge-on, is well suited for absorption line studies of its CS gas. The star exhibits indeed sharp absorptions at the bottom of the rotationally broadened photospheric lines of ionized elements present around the star (see Fig. 3). Those lines have been extensively studied in the optical range at high resolution ($R=10^5$) with the CES (Hobbs et al., 1985; Vidal-Madjar et al., 1986) and very recently at $R=10^6$ with the UHRF at AAT (Crawford et al., 1994), and in the UV with IUE (Kondo and Bruhweiler, 1985) and HST (Boggess et al., 1991; Vidal-Madjar et al., 1994; Lagrange et al., 1994), so as to investigate the composition of the CS gas, its density and location in the disk. A detailed review of the results is given in Lagrange (1994). The CS elements observed up to now in the stable gas are neutral: NaI, FeI, CI, and mainly singly ionized, close to the star (FeII), MnII, CaII, ZnII...). The total Hydrogen density column is 10^{18} cm^{-2} and the typical electronic density ranges between 10^3 and 10^6 cm^{-3}.

An interesting question concerning this gas is whether or not it is coupled to the CS dust, and whether or not they have a common origin. Vidal-Madjar et al. (1986) suggested that the gas close to the star could be the result of the evaporation of small grains at typical distances of 0.5 AU.

2.5.2 The variable gas; comets around β Pictoris?

Observations of β Pictoris at different epochs evidenced important infall of clumpy gas towards the star, with velocities sometimes as high as 300 km s^{-1} (see Fig. 3). This infall was tentatively attributed to evaporation of km s^{-1} sized, comet-like bodies grazing the star. Numerical simulations of such an event appeared to reproduce quite satisfactorily the variable lines (Beust et al., 1991, and references therein). Extensive monitoring of the variations both in the visible with CES, and in the UV with IUE, undertaken in 1985 and still going on now, has brought strong support to this scenario. It has also been shown (Mouillet et al., 1994) that the electronic densities and temperature of the infalling gas are very high, as predicted by models (Beust and Tagger, 1993).

This scenario can also account for the otherwise unexplained detections of infalling overionized species: A1 III and C IV (Lagrange et al., 1989; Deleuil et al., 1993, Vidal-Madjar et al., 1994) as well as the recent detection of molecular CO around β Pictoris.

A still open question is the triggering mechanism of these infalls observed at a high rate (a few hundreds of km-sized objects per year). Some possibilities have been suggested: perturbing bodies, collisions between km-sized bodies (Beust et al., 1991b, Gor'kavyz, 1994), which certainly deserve deeper investigations.

A chemical analysis of the variable gas can further test the cometary scenario. Visible and HST high-resolution and high S/N observations as well as ultra-high-resolution observations should bring decisive answers.

3. Other IR Excess Main Sequence Stars; Search for Disks

Most of the observational work done so far on α Lyr, α PsA and ε Eri, and to a lower extent on the other MS IR excess stars has been to observe them in the IR and radio domains, most of the time in photometry, but also in the optical range, to try to resolve CS disks. Also spectroscopic searches for β Pictoris-like stars have been performed.

3.1 IR and radio observations

Far-IR and radio observations on α Lyr, α PsA and ε Eri showed that those objects exhibit excesses at all these wavelengths, sometimes extended (Harvey et al., 1984; Chini et al., 1991; and more recently Zuckerman and Becklin, 1993b). 800-μm maps showed that around these objects there is no important amount of cold dust which could have escaped detection by IRAS. Minimum masses of $6\cdot10^{-3}$, $2\cdot10^{-2}$ and less than $7\cdot10^{-4}$ $M_\odot$ are deduced for the CS dust responsible for the 800-μm emission around Vega, Fomalhaut and ε Eri respectively.

Other IR excess MS stars have also been studied in some detail; a review of the current knowledge on these objects can be found in Lagrange (1994).

3.2 Spectroscopic search for CS gas

No atomic gas has so far been detected around any of the first four IR excess MS stars (Hobbs, 1985). Yamashita et al. (1993) also failed to detect CS ^{12}CO around α Lyr, α PsA and ε Eri. These non-detections should bring constraints to the production/destruction rates of CO around these objects. Spectroscopic similarities have been searched for in the CaII and NaI lines of a number of IRAS excess or already known shell A-B stars. Among more than 80 stars thus observed (Lagrange-Henri et al., 1990), very few exhibit spectroscopic similarities in these lines with β Pictoris. Some of them do show variations possibly similar to the β Pictoris ones. In conclusion, even though no strong correlation has been found up to now between the presence of CS dust and CS gas, some IR excess stars deserve further high-resolution spectroscopic studies. For these bright objects, the resolution of the instrument is a more important factor than the telescope collecting surface.

3.3 Optical search for disks

Many efforts have been made to find new IR excess candidates in the IRAS database and to detect disks around these candidates. Smith, Fountain and Terrile (1991) extensively surveyed 100 stars with their coronograph and did not find any disk. There might be several reasons for these negative results:

– the disk phase is very transient.
– the disks are too faint to be detected with the techniques used so far. Actually, among the IR MS excess stars,

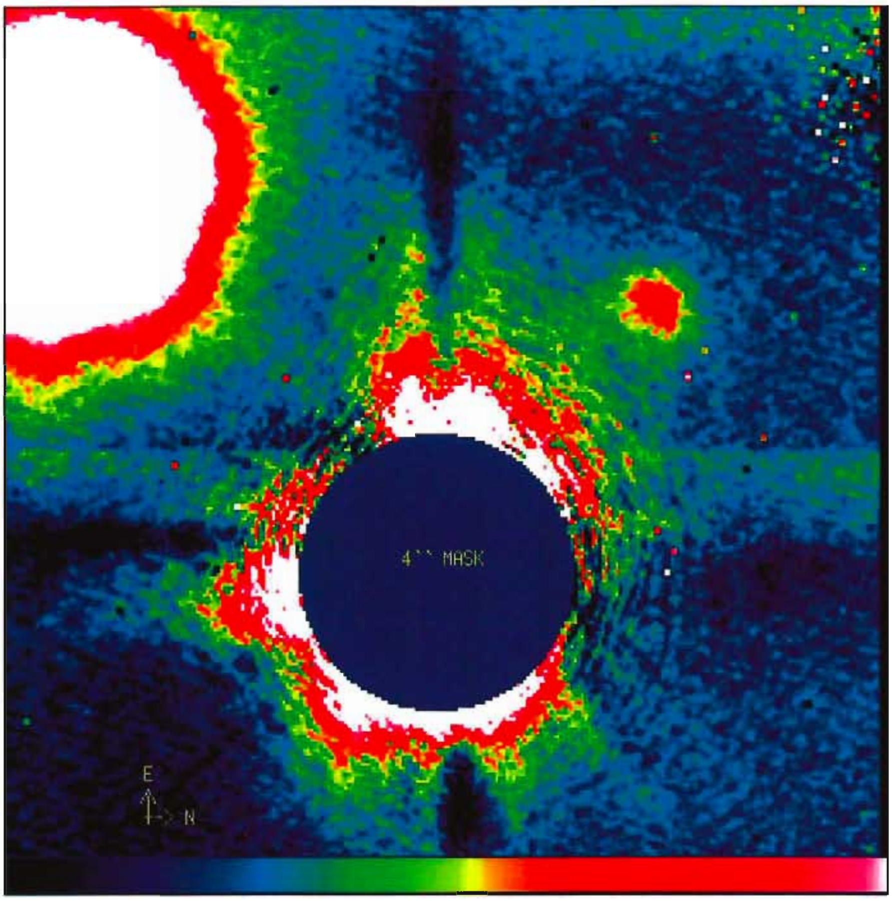

Figure 4: *COME-ON+ observations with a coronograph of the close environment of the IRAS excess MS star HR 4796 (H band, 300 sec exposure). The observations were made with a 2" (diameter) mask. On the present image, the dark disk is a 4" software mask used to hide the immediate vicinity of the physical mask, which in this case contains no useful information. A faint object (m ≃ 16) is detected at less than 5" from the 5th magnitude HR 4796.*

β Pictoris exhibits the highest disk luminosity.

- the disks are unfavourably oriented. An inclination of the disk with respect to the line of sight obviously increases its magnitude, but also makes it much more difficult to detect it with the available techniques.
- the grains are no good scatterers in the visible.
- the candidate star environment is complex and other, colder field objects contribute to the part of IRAS large beam fluxes.
- the dust is closer to the star than in the β Pic disk and cannot be detected with 5–20" masks. This is certainly true for some objects such as 51Oph (Waters, Cote and Geballe, 1988), HR4796 and HD98800 (Zuckerman and Becklin, 1993; Jura, 1993), for which models show that the CS dust lies within 1" from the star. However, in most cases, the largest part of the dust cannot be too close as it would produce a 12-μm excess detectable with IRAS.

To significantly progress in the study of the close environment of those stars, and detection of disks, one needs to observe closer to the stars and/or have a much better sensitivity further away.

The next section focuses on the expected progress with the VLT in the domain of CS disk detection around other stars. Of course, once detected, an approach similar to the one adopted for the study of the β Pictoris disk should be followed.

3.4 Observations of disks with the VLT

3.4.1 CONICA

To observe very faint signatures very close to bright objects, one needs high image quality as well as coronographs or antiblooming detectors. Again either space observatories (HST) or ground-based diffraction-limited telescopes are needed.

Recent coronographic observations with the COME ON + system at the ESO 3.6-m telescope have already demonstrated that small masks can be used indeed: sizes down to 0.8" in diameter have been tested, and we expect to use even smaller sizes, hopefully down to the first Airy ring. Actually, the most tricky point is to stabilize the object behind the mask. Also, these coronographic COME-ON + observations demonstrated that high dynamic ranges could be reached as well (see Fig. 4; Beuzit et al., 1994).

With CONICA on the VLT one can reasonably expect to observe down to less than 0.1" from the star. For typical distances of 10–50 pcs, it means distances closer than 5–25 AU. The field of view, 15" of CONICA is indeed well suited for the study of the inner parts of the disks. The possible inner void of material can be tested. The gain in the scientific output with the high resolution facility provided is obvious. In summary, CONICA + coronograph is very well suited for observations of the close environment of the candidates, and disk detection, from 0.1" to 7".

3.4.2 FORS

With the present FORS specifications, only outer parts of the disk will be observed (≥ 0.6"), but the gain in sensitivity, thanks to the higher collecting surface and the use of better detectors is a very promising issue. Figure 5 gives for the candidates proposed by Backman and Paresce (1993) in their master list of IR excess stars the expected disk luminosities in the visible (scattered light), assuming the dust distribution is similar to the β Pictoris one, and fractional luminosities of the disks are 100 times lower than the β Pictoris one. The differences in distances and stellar luminosities have been taken into account. One sees that the ≥ 7" regions, accessible to classical coronographs on 2–4-m telescopes are very faint. FORS + coronograph should in principle detect the disks. Polarimetric facilities will provide useful information to further characterize the disks. Again, even partly corrected visible images would result in a significant gain, as they would enable us to observe more inner parts of the disks with very high sensitivities. Also, interferometric VLTI observations would enable us to test the innermost parts of the disks.

3.4.3 MIIS

Another important issue is expected from 10–20-μm observations on diffraction-limited 8-m-class telescopes. Actually, the 20-μm window is more promising for early-type MS stars than the 10-μm one since, with the exception of two cases, there has been no detection of 10-μm excess, while 20-μm excess has been detected in all cases (Auman and Probst, 1991). The expected resolu-

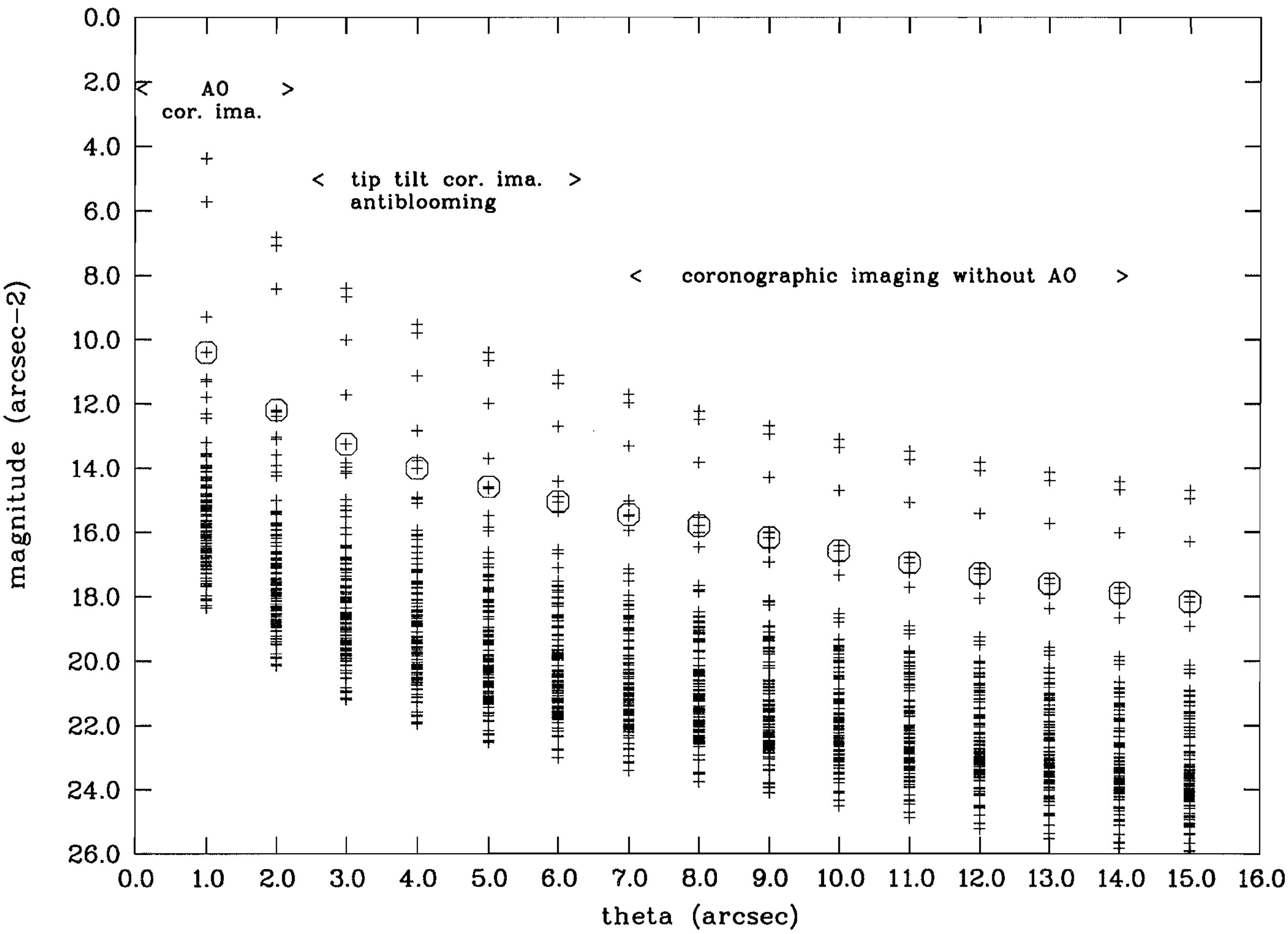

Figure 5: *Expected disk magnitude per arcsec as a function of angle for the candidate stars proposed by Norman and Paresce (1993). The disks are supposed to be similar to the β Pictoris one (same intrinsic brightness and same radial distribution). An arbitrary, but reasonable factor of 100 in the relative disk luminosity compared to the β Pictoris one has been taken. Circles are the values for the β Pictoris disk.*

tion of 0.6″ is well suited to resolve the 20-μm emitting region for these nearby objects. In most cases, one should detect extended structures. Long-slit spectroscopy in the 17-μm silicate band range can also be performed.

4. Conclusions

The study of outer planetary systems will help to understand the way those systems form and evolve. Very important observational work will certainly be devoted to this subject in the next years and decades. The disk around β Pictoris has been successfully studied with various approaches: imaging, photometry (dust) and spectroscopy (gas). For β-Pictoris as well as for the other candidates, significant progress is expected from observations in the UV (HST), visible, near and mid-IR (ground-based diffraction-limited 10-m-class telescopes; ISO) and radio. Diffraction-limited images in the near IR should enable us to detect other disks close to the star; 20-μm imaging is expected to study the inner part as well, with less angular resolution, but in the thermal domain; optical imaging should enable us to detect more remote parts of the disks. Table 1 summarizes for the first generation of VLT instruments what kind of observations and science can be done on the β Pictoris disk and on the other stars.

The author thanks A. Vidal-Madjar, A. Lecavelier and D. Mouillet for fruitful discussions and P. Corporon for his help in some parts of the work.

TABLE 1.

Instrument	Resolution	Science	Why the VLT?
CONICA	0.02–0.15″	β Pictoris: structure of the inner disk (gap, inner void, inhomogeneities) other stars: detection of disks, disk structure inner void	high angular resolution id
MIIS	0.3–0.6″	β Pictoris: structure of the disk at 10 and 20 μm angular resolution spectro-imaging of the silicate bands other stars: structure of the disks at 20 μm spectro-imaging of the silicate bands	angular resolution id
FORS	seeing	other stars: detection of disks, polarization	very good sensitivity

References

Angel, J.R.P., 1994, *Nature* **368**, 203.
Auman H.H., et al., 1984, *ApJ* **278**, L23.
Auman H.H., and Probst, R.G., 1991, *ApJ*, **368**, 264.
Artymowicz P., Burrows C. and Paresce F., 1989, *ApJ* **337**, 494.
Backman and Paresce, 1993, Protostars and Planets III, Levy, E.H., Lunine, J.I. and Matthews, M.S. Ed., University of Arizona Press.

Backman D.E., Gillet F.C. and Witteborn F.C., 1992, *ApJ,* **385**, 670.
Beust H., Vidal-Madjar, A., Ferlet, R., Lagrange-Henri, A.M., 1991, *A&A* **241**, 488.
Beust H., Vidal-Madjar, A., Ferlet, R., 1991, *A&A* **247**, 505.
Beust, H., and Tagger, M., 1993, *Icarus* **106**, 42.
Beuzit et al., 1994, *A&A*, to be submitted.
Boggess, A., Bruhweiler, F.C., Grady, C.A., Ebbets, D.C., Kondo, Y., Trafton, L.M., Brandt, J.C. and Heap, S.R., 1991, *ApJ* **377**, L49.
Chini R., Krugel E., Shsutov B., Tutukov A. and Kreysa E., 1991, *A&A* **252**, 220.
Crawford, I.A., Spyromilio, J., Barlow, M.J., Diego, F., and Lagrange, A.M., 1994, *Mon. Not. R. Astron. Soc.,* **266**, L65–L68.
Deleuil, M., Gry, C., Lagrange, A.M., Vidal-Madjar, A., Ferlet, R., Moos, T.A., Livengood, T.A., Ziskin, D., Feldman, P.D. and McGrath, M., 1993, *A&A,* **267**, 187–193.
Diner, D., and Appleby, J., 1986, *Nature* **332**, 436.
Gledhill, T.M., Scarrott, S.M. and Wolstencroft, R.D., 1991, *Mon. Not. R. Astron. Soc.* **252**, 50.
Golimowsky, D.A., Durrance, S.T., and Clampin, M., 1993, *AJ* **105**, 1108.
Harvey, P., Wilking, B.A. and Joy, M., 1984, *Nature* **307**, 441.
Hobbs, L.M., Vidal-Madjar, A., Ferlet, R., Albert, C.E., Gry, C. 1985, *ApJ* **293**, L29.
Jura M., Zuckerman, B., Becklin, E.E. and Smith, R.C., 1993, *ApJ* **418**, L37.
Knacke, R.F., Fajardo-Acosta, S.B., Telesco, C.M., Hackwell, J.A., Lynch, D.K. and Russell, R.W., 1993, *ApJ* **418**, 440.
Kondo, Y., Bruhweiler, F.C., 1985, *ApJ* **291**, L1.
Lagage, P.O., 1994, *Nature*, in press.
Lagrange, A.M., Ferlet, R., Vidal-Madjar, A., 1987, *A&A* **173**, 289.
Lagrange, A.M., Ferlet, R., Vidal-Madjar, A., Beust H., Gry, C., Lallement, R., 1990, *A&A Sup.* **85**, 1089.
Lagrange A.M., et al., 1994, *A&A*, submitted.
Lagrange A.M., 1994, in "Planetary systems: formation, evolution and detection"; 2nd TOPS conference.
Lecavelier, A., et al., 1992, *A&A* **274**, 877.
Malbet, F., Shao, M and Yu, J., 1994, in "SPIE Symposium Astronomical Telescopes and Instrumentation for the 21st Century".
Mouillet, D., et al., 1994, *A&A* submitted.
Norman, C. and Paresce, F., 1989, in "Formation and evolution of planetary systems".
Paresce, F. and Burrows C., 1987, *ApJ* **319**, L23.
Sicardy, B., 1994, in *Asteroids, Comets and Meteors*, 1993 (A. Milani and Di Martino Eds.), Kluwer Academic Publ., in press.
Smith B.A., and Terrile, 1984, *Science* **226,** 1421.
Smith B.A., Fountain J.W. and Terrile R.J., 1992, *A&A* **261**, 499.
Telesco C.M. and Knacke R.F., 1991, *ApJ* **372**, L29.
Vidal-Madjar, A., Hobbs, L.M., Ferlet, R., Gry, C., Albert, C.E., 1986, *A&A* **167**, 325.
Vidal-Madjar et al., 1994, *A&A*, in press.
Waters, L.B.F.M., Cote, J. and Geballe, T.R. 1988, *A&A* **203**, 348.
Watson et al., 1991, Applied Optics **30**, N 22, 3253.
Yamashita, T., et al., 1993, *ApJ* **402**, L65.
Zuckerman, B., and Becklin, E.E., 1993, *ApJ* **406**, L25.
Zuckerman, B., and Becklin, E.E., 1993, *ApJ* **414**, 793.