# Scientific Objectives of ESO's PRIMA Facility

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## ABSTRACT

ESO is embarking on the construction of a complex and high performance dual feed system that will allow Phase Referenced Imaging and Microarcsecond Astrometry (PRIMA) on the VLT Interferometer on Cerro Paranal in Chile. In this paper, I will describe in some detail the scientific objectives of this facility that drive the technical specifications and justify the chosen priorities. Of particular importance because of its uniqueness and rich variety of scientific applications will be the early development of the components allowing very high precision astrometry on sources such as extrasolar planets, binaries in nearby clusters, microlenses in the halo, and stars in the circumnuclear cluster in the galactic center.

Keywords: VLTI, PRIMA, astrometry, imaging, high resolution, science

## INTRODUCTION

PRIMA will enable VLTI to perform high precision narrow-angle astrometry down to the atmospheric limit of 10 μas, real imaging of objects fainter than K~14 and nulling at contrast levels of $\sim 10^{-4}$. These capabilities will, in turn, enable VLTI to address directly a number of extremely important scientific issues that are currently at the top of the list of challenges for future astronomical high resolution instrumentation.

The first is the detection and characterization of extra-solar planets and their birth environment. This objective requires application of both the astrometric and the imaging capability of PRIMA. The astrometric capability will determine the main physical parameters of planets orbiting around nearby stars already found by radial velocity (RV) techniques including their precise mass, orbital inclination and a low resolution spectrum.

In addition and most importantly, astrometry will allow VLTI to extend the search for planets to stars that cannot be properly covered by the RV technique, in particular pre-main sequence (PMS) stars. The crucial exploration of the initial conditions for planetary formation in the stellar accretion disk as a function of age and composition will be finally possible. The simultaneous image at milliarcsec resolution or better of the accretion disk from which any particular planet is born will add a new and exciting dimension to our understanding of both planetary and stellar formation mechanisms since the complex accretion disk is expected to be the cradle of these objects.

Another key objective for VLTI with PRIMA will be the exploration of the nuclear regions of galaxies including our own. The resolution of the VLTI at 2μ corresponds to 15AU at the galactic center or about 1500 times the Schwarzschild radius of a $10^6$ $M_\odot$ black hole (BH). The first and most important goal will be to test for the presence of a central massive BH by measuring the three-dimensional velocity field of the star cluster centered on IRS16. The VLTI will be able to probe the 3D space motions of stars in the nuclear cluster down to $10^{-4}$ pc of the central source or approximately two orders of magnitude better than currently. This data will certainly provide very precise information on the central mass without the a-priori assumption of isotropic motions. High precision astrometry with PRIMA might even go so far as to probe the central BH to a few times its Schwarzschild radius ($2.5 \times 10^{-7}$ pc).

In the following paragraphs, we briefly describe these and other objectives whose achievement form the basis for the technical requirements set on the PRIMA facility.

## STAR AND PLANET FORMATION

Since 1995, at least 80 objects classified as planets have been unambiguously detected (see compilation in http://www.obspm.fr/encycl/catalog.html) orbiting around nearby solar-like stars. As techniques get better, accuracy improves and surveys get more telescope time, this number is bound to increase dramatically. Already, the statistics of the current searches indicates that planets are found around a few % of the nearby solar- like stars. Since all of the discoveries so far, except Lalande 21185, have been made by means of the reflex velocity (RV) technique, the derived mass of the planet is always a lower limit and the true value will depend on the unknown inclination i of the orbit. This uncertainty disappears for the reflex motion technique used in precision astrometry as planned for the VLTI PRIMA facility.

This is a crucial point since current controversies swirl around the very definition of a planet versus a BD or even a low mass star and this depends entirely on the mass of the object. The latest "planet" discovered around HD168443, for example, has an implied msini of 17 $M_J$ ($1M_J$ = Jupiter mass = 0.001 $M_\odot$) and, therefore, may not be a planet at all but a brown dwarf (BD) since the upper mass limits for planets is ~13 $M_J$. Below this mass, objects never burn deuterium nor generate significant energy from any nuclear reactions. This limit, however, is only empirically determined by the observed mass function and clearly suggests a distinction between the occurrence probability of objects above or below this limit. But this function depends crucially on getting the masses right and the sini term definitely prevents this. Only by performing astrometry on these objects will one get a compelling answer to the question of what is a planet as opposed to a BD. Already, Hipparcos- determined masses of some of the objects in question have shown, in almost all cases, that their masses were underestimated.

Indeed, several formation mechanisms giving rise to a variety of objects (planets, BD or low mass stars) of very different masses are being currently considered:

1) direct fragmentation of a collapsing, rotating interstellar cloud,

2) gravitational instability in an equilibrium disk which has condensed out of the collapse,

3) multiple fragmentation and capture in a system of major and minor fragments and,

4) accretion of solid particles in a disk to form a solid core of a few to 10 earth masses (the gas giant cores of the currently popular planet formation paradigm) followed by rapid accretion of the gaseous envelope.
The formation phase in any of these scenarios might be followed by inward orbital migration due to interaction with the massive accretion disk and consequent loss of angular momentum.

The RV technique is particularly sensitive to close-in massive planets around stars at any distance but only those whose spectra is particularly rich in absorption lines that can be used to determine the radial velocity to the exquisite precision required. In contrast, the astrometry technique favors the intermediate mass planets orbiting at larger separations. Both techniques still have a wide region of overlap, however, that can be conveniently exploited to get to a unique determination of its mass.

It is already clear that planets far different from our own exist in abundance and the theories of planetary formation will have to be substantially revised or expanded to account for them. Pinning down the details of any of these mechanisms will clearly require substantially better observational techniques to uncover new planets and especially to completely characterize them physically and chemically. Consequently, two crucial steps need to be carried out as soon as possible:

1) use the VLTI to enlarge substantially the sample of stars searched for planets to include Pre Main Sequence (PMS), early-type Main Sequence (MS) and low mass stars that the RV technique cannot cover at all so that we are not restricted to the nearby solar- like stars which can only represent a very thin cross section of the planetary zoo and

2) perform very high precision astrometry and high spectral resolution direct imaging of the planets and the gaseous and dust disks out of which they are most likely to form and on which they will impress their peculiar dynamical signatures.

The VLTI as presently designed can accomplish this ambitious but absolutely critical task by relying on its capability to support high precision phase referencing. This characteristic will be critical in order to perform the high precision, narrow angle astrometry required to reach the predicted atmospheric limit of 10 μas accuracy at Paranal. Attainment of this performance will allow the reflex motion induced by an orbiting planet on a star located at the distances shown in Figure 1.

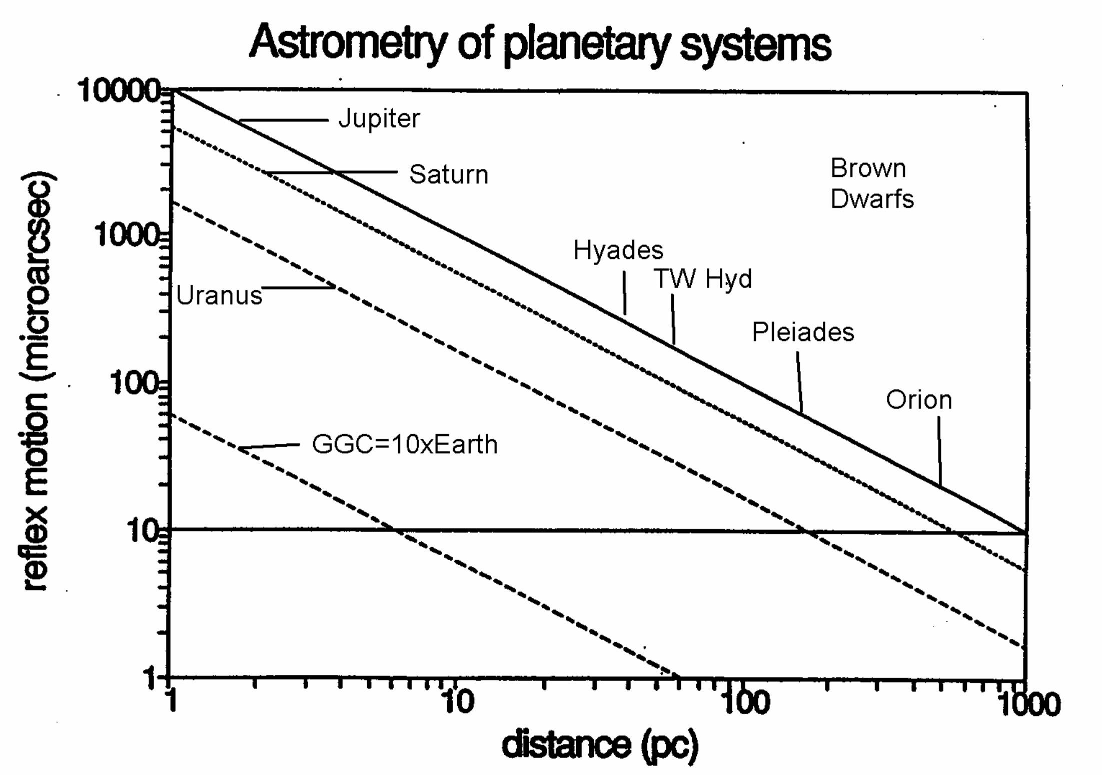


Figure 1. The expected astrometric reflex motion of objects of different masses as a function of distance. The VLTI is expected to measure reflex motions > 10 μas.

This figure shows how the VLTI in its astrometric mode would cope with a planet of a Jupiter, Saturn, Uranus or Gas Giant Core (GGC) of ~10 earth masses placed at either the Jupiter radius of 5 AU as expected for a solar-like star or closer for a cooler companion. Since the closest star forming regions (SFR) are located between ~50 (TW Hyd) and ~140 pc ( Taurus-Auriga) from the Sun, the VLTI would be in the enviable position of easily finding Jupiter-sized planets around stars of any spectral type and, most significantly from the physical point of view, of any age up to the MS. The VLTI then will be able to reach all the way out to Orion to study planets in a wide variety of environments.

This capability would, in fact, allow the VLTI to explore, for the first time, both the precise time of formation and the subsequent evolution of planets in all PMS stages leading into and well up along the MS. Since VLTI astrometry is not limited to solar- type stars as is the RV technique, it can also quickly attack and resolve the burning issue related to the strongly implied possibility that the IR excess MS stars like Beta Pic, Fomalhaut and Vega have or have not already formed planets in their observed debris disks. The nulling capabilities of PRIMA will also be crucial in these applications.

The VLTI, by exploiting its dual mode of operation with phase referencing, can, at the same time, probe in considerable detail not only the planet itself through its effect on the motion of the parent star but also the evolution and structure of the proto-planetary/proto-stellar disk from which it eventually must emerge and interact. This affords another unprecedented opportunity to finally understand and pin down the presently uncertain connection between the two phenomena. At the typical distance of the MS early type star IR excess disks, for example, the VLTI IR spatial resolution of a few milliarcsec ensures a clear probe of these disks down to the level of a few tenths of AU resolution at a few AU radii where most of the interaction between a possible planet and the edge of the small particle disk is expected to occur. The expected disk structure open to VLTI with PRIMA might look something like that shown in Figure 2.

Direct detection of photons originating from extra-solar planets gives crucial information on these bodies that cannot be obtained with indirect methods. With direct spectroscopic and photometric observations it is, in principle, possible to determine size, temperature, chemical composition, atmospheric stratification, rotation rate, and the presence of surface features. Because of the faintness of extra-solar planets, and because of the large contrast between planet and parent star, such observations are extremely challenging.

With the VLTI equipped with spatial wave-front filters such as single mode optical fibers, the fringe amplitude can be measured with great precision. This can be used to make measurements of "double stars" with large magnitude difference, such as star-planet systems. Gaseous planets have strong molecular absorption bands. Within the bands, the planet is dark, and the photo-center of the star-planet system is centered on the star itself. Outside the bands, the photo-center is shifted slightly towards the planet. This shift of the photo-center might be detectable as a wavelength-dependent phase shift with the VLTI.

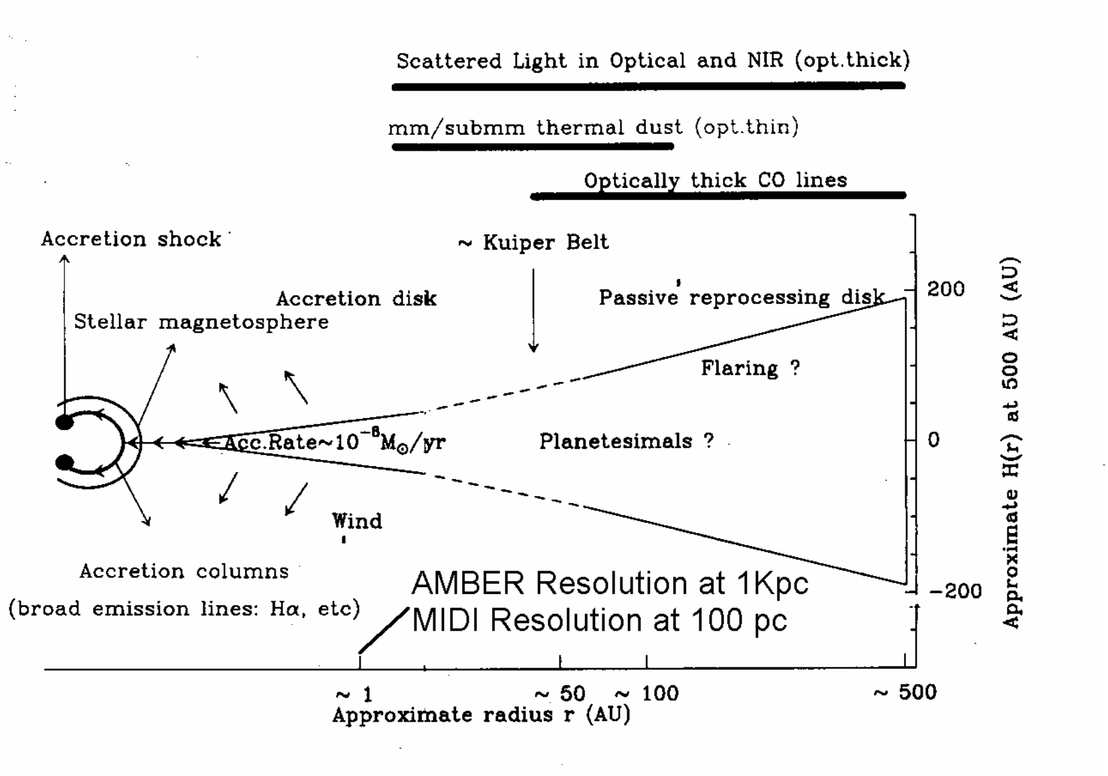


Figure 2. Schematic diagram of the outer regions of the accretion disk around a PMS star adapted from Lopez. Expected VLTI linear resolutions at 2 and 10μ are shown.

The vast majority of young stars are observed to have a disk-like distribution of material during part of, or sometimes their entire PMS life. This disk, believed to be the location where planets are born, dissipates on a time-scale of about 400 Myrs, as evidenced by ISO observations of young stars and by the impact record of the Moon in our own solar system. We know from observations of exo-planets that the early phase of a planetary system is a very dynamic period in which planets can migrate and large bodies are continuously formed and collisionally destroyed. These processes modify the composition of gas and dust in the disk, and change the spatial distribution of material. Direct observations of the circum-stellar environment of young stars are urgently needed in order to better understand this crucial period in the evolution of proto-planetary systems, and make a link with the history of our Solar system as recorded by planets, asteroids, comets, the Kuiper belt and Oort cloud, and interplanetary dust.

The distribution of material surrounding young stars is a hotly debated issue. The trouble is that the spectral energy distribution is not unique in constraining the geometry of the circum-stellar material. Disk models as well as spherical dust shell models are equally successful in describing the infrared emission from young stars. The sub-millimeter interferometric maps have shown that the cold dust and gas are in a disk-like geometry, but the data have not been conclusive yet when it comes to the near-IR and mid-IR spectral region, due to a lack of spatial resolution. This will change with the commissioning of VLTI and its first science observations. We will be able to settle the case for disks, haloes, or a combination of both.

A direct measurement of the size of a disk constrains the density structure and the nature of the dust in the disk. Since the temperature of dust is a function of grain size, the simultaneous measurement of the temperature and location of the dust will set limits on the average size of the particles. The grain size distribution is believed to be a sensitive indicator of the degree of processing that has taken place in the disk. In addition, the measurement of disk size at several wavelengths (combining near-IR, mid-IR and sub-mm ALMA measurements) will constrain the geometry of the disk and test disk models with and without flaring outer disks.

The spectral capabilities of VLTI will allow us to measure the location of several dust components, such as the warm amorphous silicates, the crystalline silicates and the Polycyclic Aromatic Hydrocarbons (PAHs). Analysis of ISO data suggests that the PAHs observed in some Herbig Ae/Be stars are, in fact, located in the flaring outer part of the disk, but this needs confirmation from direct imaging with VLTI.

Young stars also exhibit a large variety of different phenomena, such as infrared excesses, luminosity variations and highly collimated jets with velocities of several hundred km/s. These phenomena suggest the presence of strong magnetic fields. Understanding the inner regions of proto-stars, including their accretion disks and jets, is an important area of current research and is related to the question of how our own solar system formed. The similarity of some young stars to AGN, particularly the so-called classical T-Tauri stars, means that progress in understanding the physics of star formation may have important implications for extra-galactic astronomy.

A major program for the VLTI/PRIMA is to study systematically the rich circum-stellar environments of young stars at a resolution of about 2 mas, which corresponds to ~10 stellar radii (0.1 AU) for the nearest star-forming region (d = 50pc). The factor of twenty improvement in resolution over HST provides access to the phenomena which occur in the inner regions around young stars and should provide important input to the theoretical models. Although even VLTI will not be able to resolve the innermost parts of the accretion disk where material is presumably funnelled via magnetic fields onto the stellar surface and where other parts of the rotating magnetosphere accelerate and collimate the outflowing matter, observing just outside these regions should allow meaningful extrapolations.

Very few direct studies of circum-stellar disks have been performed so far, because this requires high resolution in the near- and mid IR domains. Important parameters yet to be determined include the morphology of circum-stellar disks, the temperature distribution, the relative contributions from scattered stellar light and thermal disk emission, the disk chemical composition and the properties of dust grains.

In a few objects, minima in the broadband spectrum have been tentatively attributed to zones cleared by a planet or faint companion, although different interpretations based on material properties also are possible. These gaps lie around 1AU and would be detectable with the VLTI. The determination of visibility curves at 2 and 10μ should indicate the interesting candidates but imaging will be required to study the phenomenon with its asymmetries due to the presence of the orbiting object. Generally, the distribution of dust and gas and the spatial distribution of temperature can be measured and will clarify the initial conditions for possible planet formation.

The question of how proto-stellar jets are accelerated and collimated should also be addressed with the VLTI. Important constraints on models can be derived from observations beyond about 10 stellar radii. A start has been made with HST and ground-based telescopes, and studies of jet width as a function of radius show that at least some proto-stellar jets have full opening angles of greater than 50º for small distances from the star. A similar behaviour has been predicted by theoretical models in which the jets are accelerated and collimated by rotating magnetospheres and in which one expects large jet opening angles for radii much smaller than the light cylinder, which is expected to have a radius of about 30 to 100 AU for typical rotation periods for T Tauri stars of a few days.

VLTI with PRIMAcan also investigate possible connections between variations of the central star and the formation of new knots in the jet. For a jet speed of 300 km/s, a new knot resulting from an outburst would move outwards and be detectable after a few days, allowing its proper motion to be accurately measured. This is similar to VLBI observations of QSO jets. The need to pursue these observations with high spectral resolution (R >1000) and within 1-2 days because of the high proper motion of the knots (up to 1 mas/day) probably will require the inclusion of the UT on the basis of current brightness estimates.

## GRAVITATIONAL MICROLENSING

Micro-gravitationnal lensing happens when a galactic massive object (star black-hole) passes close to the line of sight of a background star. The light coming from the latter is amplified by a large factor and this event can be detected by photometric surveys (OGLE, MACHO ... or COROT in the future). The observation of the temporal variation of the photometric curve brings a lot of information about the lensing object but it is not possible to disentangle its mass and its distance. And the mass of these, usually invisible, objects is of primary importance for estimating the dark mass of the galaxy.

However, when looking at the micro-lensing event with a very high angular resolution, one could see that the background star is split in two images whose relative intensities and sizes vary during the event, as shown in Figure 3. Measuring the actual separation of the images and/or their relative intensities solves the indetermination problem: the mass of the lensing object can be evaluated independently from its distance (as long as the distance to the background source is known, using e.g. parallaxes).

The separation and/or relative intensities of the split image can be measured in two ways using interferometry, the observation being triggered by a photometric alert:

a) measuring simple visibilities, using the model of a binary star and fitting the model parameters (distance and relative intensities) to the visibility-versus baseline measurements. This requires access to several baselines (from 16 to 200m) and high accuracy on the visibilities (<1%) but no phase.
b) measuring the astrometric wobble of the image photocenter using PRIMA in its astrometric mode. The parallax of the background object can also be measured with PRIMA.

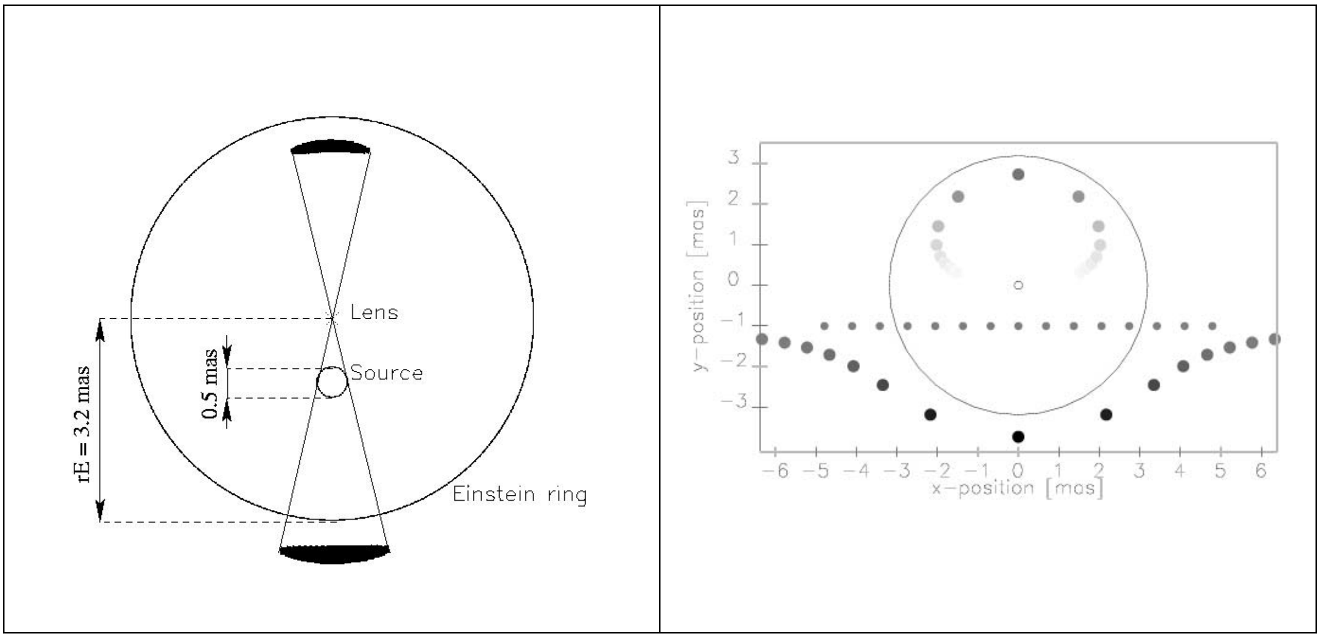


Figure 3. Illustration of a micro-lensing event in the Galactic Bulge. At left a time sequence. At right, the central position with the image elongation effect. Lens mass = 10 solar masses; lens distance = 4 kpc; source distance = 8 kpc; Einstein radius = 3.2 mas; impact parameter (closest approach lens-source) = 1 mas; source size = 0.5 mas.

The visible magnitudes of the events recorded up to now range between 13 and 16. Future survey programs will extend the range toward the faint end but bright event occurrence is limited by the very low probability of such events. Thus PRIMA is needed with both methods, at least to stabilize the fringes on an instrument like AMBER or VINCI and increase the limiting magnitude. The surveys are concentrated on the galactic bulge and on the Magellanic clouds, where the density of background stars is high and the probability of micro-lensing events is the highest. The galactic bulge allows the observation of lensing objects located in the galactic plane, while the Magellanic clouds give access to halo objects. In both cases, the probability to find a suitable guide star close to the event is very good.

The event durations range from some hours to several months or a year. From a duration of one week, the VLTI could be easily pointed to the object several nights in a row or distributed on the full event duration. At least 2 baselines have to be used for each observation in order to fit both model parameters or to measure the 2-dimensional photocenter wobble. To be detected by the photometric surveys, the increase in magnitude has to be at least of 10%. For the galactic bulge case, it corresponds to lensing objects bigger than 1 solar mass. In the Magellanic Cloud case, the object is even more massive. These kinds of events give visibility and astrometric signatures much larger than VLTI and PRIMA accuracies.

In conclusion, all detected (amplification > 1%) photometric events, bright enough to be observed with the VLTI and PRIMA, can be resolved by the interferometer and solved for the mass of the lens. Moreover, if the lens is complex (star with a planet or a companion), the interferometric characterization of the event could bring much more information on the lens structure than the photometry alone.

## THE GALACTIC CENTER

The central 0.1 pc of our Galaxy will be an important target for VLTI at wavelengths from 2 to 10µ. The resolution of the VLTI at 2µ corresponds to 15AU at the galactic center.or about 1500 times the Schwarzschild radius of a $10^6$ $M_{\odot}$ BH. The first and most important goal will be to test for the presence of a central massive BH by measuring the three-dimensional velocity field of the star cluster centered on IRS16. The current limits for the enclosed mass as a function of distance from Sgr A* are shown in Figure 4 together with a number of possible theoretical models of the mass distribution.

High precision proper motion and radial velocities can be determined by VLTI at very small distances from the center of the star cluster, where observations with single telescopes are limited by crowding. Recent measurements have provided good evidence for the presence of a massive BH but the observational uncertainties still limit knowledge of the physical properties of the enclosed mass. The VLTI will be able to probe the 3D space motions of stars in the nuclear cluster down to $10^{-4}$ pc of the central source or approximately two orders of magnitude better than now as can be seen from Figure 4. This data will certainly provide very precise information on the central mass without the a-priori assumption of isotropic motions. High precision astrometry with PRIMA might even go so far as to probe the central BH to a few times its Schwarzschild radius ($2.5*10^{-7}$ pc).

Another very important goal for the VLTI will be detailed observations of the infrared sources close to the position of SgrA*. It is presently unclear whether any of the objects found at 2.2µ is the true counterpart of the compact radio source. The study of a potential IR counterpart of SgrA* would give completely new insights into the vicinity of the central object of our Galaxy, and could perhaps give us a direct view of the putative accretion disk. In addition, the high angular resolution of the VLTI will enable us to obtain infrared spectra of individual stars in the very crowded galactic center region. It will thus be possible to make a census of the stellar population in this area, to check whether there is ongoing star formation in the vicinity of the galactic center, and to search for ``peculiar'' stars, which may be the remnants of stellar collisions. Observations at 10µ would also reveal the distribution of warm dust associated with SgrA*.

Observing the galactic center is quite a challenging task for the VLTI because of the high density of sources and the small field of view. Hybrid configurations formed by combining the UTs with the AT will give good coverage of the (u,v) plane, in particular when the technique of multi-frequency synthesis is employed. The arrays location in the southern hemisphere is another significant advantage of the VLTI in the study of the galactic center.

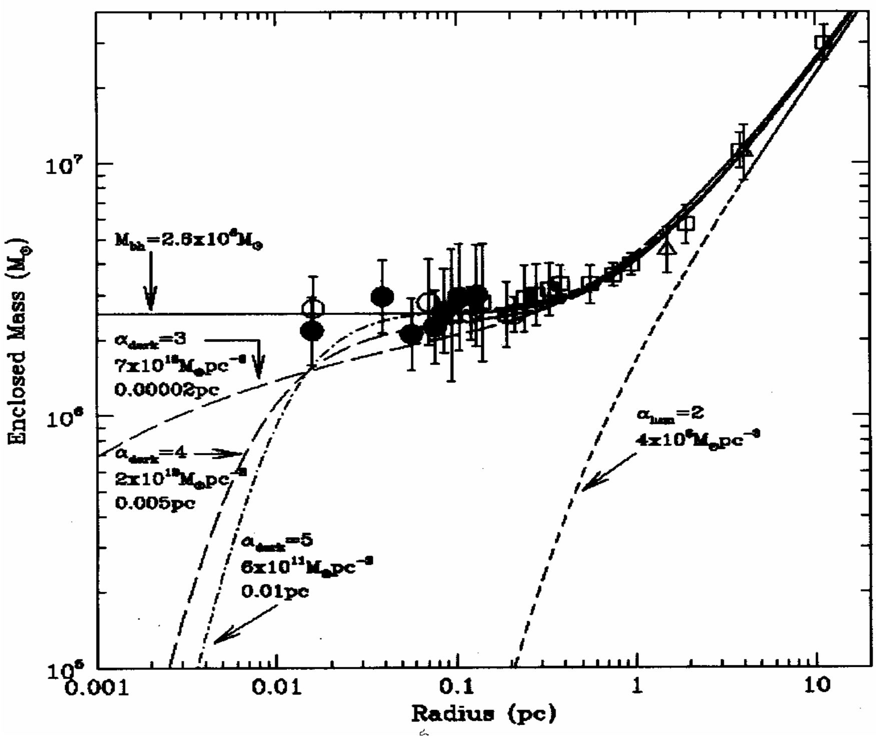


Figure 4. Enclosed mass around SgrA* as a function of projected distance from Ghez et al. 1998. The models correspond to power law dark clusters made up of stellar remnants, BD or even elementary particles with various values of the index alpha. Currently such models with alpha > 3 cannot be ruled out.

## EXTRAGALACTIC SOURCES

Active galaxies have compact nuclei that can be so luminous that they outshine a whole galaxy. These cosmological beacons are so bright that they can be seen out to the earliest 5% of the age of the universe. These objects are unique laboratories for testing models of early galaxy evolution. There is much evidence that these active galaxies contain massive BH, the central engine of the physical processes that give rise to a large number of energetic phenomena. The most important questions in this area include the relation of the AGN phenomenon to galaxy formation and the physics of the formation and evolution of the massive BH. A recent clue to answering these questions is the strong indication that a large fraction of all the galaxies contain massive BH and that the mass of the BH directly scales with the mass of the spheroid of the host galaxy.

The now canonical view of AGN is that they are powered by the exchange of gravitational energy for thermal energy in a compact accretion disk surrounding the BH. In the currently popular and attractive “unified” model of AGN, they are all surrounded by an optically thick obscuring torus whose orientation with respect to our line of sight determines whether we see the object as a Type I ( Seyfert 1 or quasar ) or Type II ( Seyfert 2 or radio galaxy). A drawing of the unified model for the core of the AGN is shown in Figure 5. The inner accretion disk which feeds the massive BH directly is surrounded by the broad line region (BLR). In the BLR, dense compact clouds move at a high speed through a more tenuous medium giving rise to broad optical emission lines. The BLR is surrounded by the optically thick torus composed of dust and molecular and neutral gas. If the torus hides the central region from our view, the direct high energy phenomena associated with the nucleus are more difficult to observe. Then, the object does not show the broad lines and is classified as Type II. If the object is viewed sufficiently close to the polar axis as shown in Figure 5, a very bright nucleus is observed and the optical spectrum shows the broad lines. It will be classified as Type I.

Although this picture is capable of explaining a large number of observed physical characteristics of various classes of AGN, it is still unclear whether other mechanisms contribute to, or even, dominate over the scenario in which orientation and the putative torus play such a major role. It has even been argued that, in a subset of AGN, the main power source is not a BH but supernova explosions produced within a central starburst region and that time variability may play a crucial role in the perceived differences between AGN. The important issues to be clarified are, therefore, whether dust tori in AGN exist at all and whether the physics of such torii can be constrained well enough that most of the differences between AGN can be understood completely.

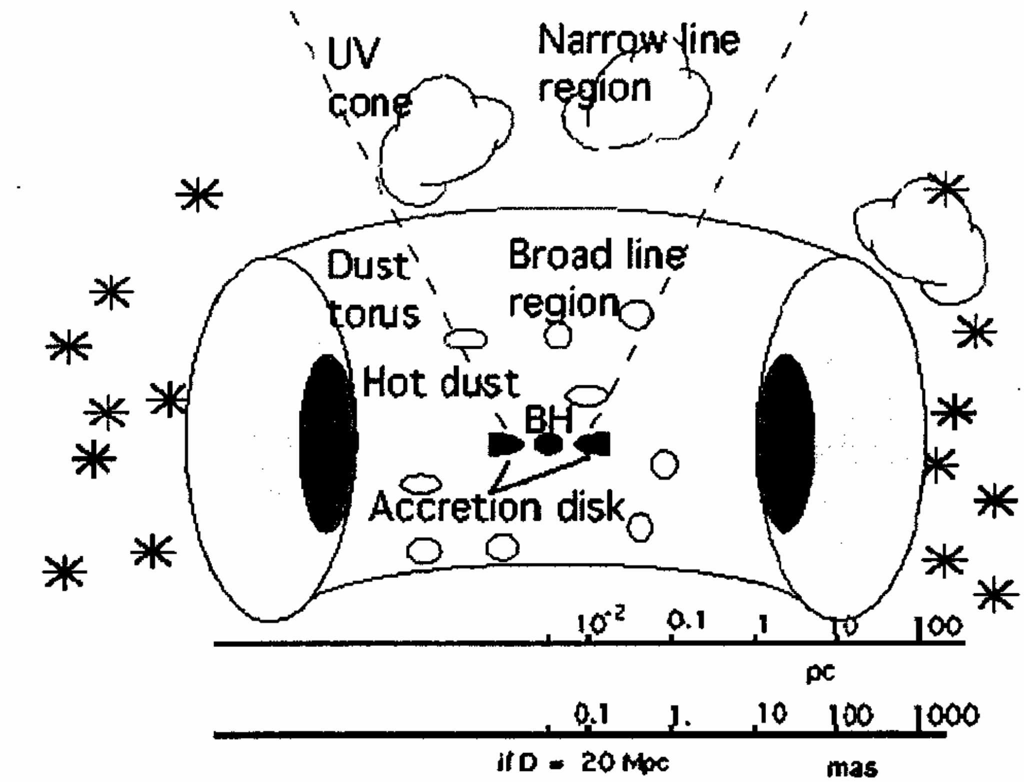


Figure 5. Drawing of the possible structure of the core of an AGN at 20 Mpc distance indicating several of the main components.

As is quite apparent from Figure 5, high resolution imaging with the VLTI of the nearest AGN (Cen-A is at ~ 3.5Mpc) has a crucial role to play in this area especially with MIDI at 10 and 20μ. At these wavelengths, 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. The VLTI should, therefore, allow the unambiguous detection of dust torii and constrain their inner and outer radius and density and temperature structure. A number of models and geometries for obscuring torii have been proposed. The models range from extended 100 pc scale torii having moderate optical depths to much more compact ones with very high optical depths and, possibly, some with warped disks. All of these models can be severely constrained or eliminated easily by VLTI observations.

In any case, all of these ideas are still completely in the realm of speculation. No one has observed in the innermost core of an AGN so far and it should be stressed that there are still a number of serious theoretical difficulties with these models. Systematic observations with an instrument such as the VLTI will be able to establish the field on solid ground. Moreover, only an interferometer like VLTI can resolve the physical structures and motions within the BLR, between the dusty torus and the accretion disk of AGN. The intermediate region with the inner part of the jet extended over about 1pc and the outer part extended over ~ 1Kpc outside the obscured core will be easily accessible to IR imaging with AMBER and with moderate spectral resolution.

For reasons that are not understood, but are probably related to the way galaxies form, there are many more AGN at high redshifts than locally. The space density of high-luminosity AGN at z~2 is $10^2$-$10^3$ times greater than at the present epoch. About 20-30 nearby Seyfert galaxies are bright enough to be used as references for fringe tracking. For these, the central parsec will be probed in the optical and infrared. It is also useful to probe larger scales in more distant objects, to trace any cosmological evolution.

If fringe tracking cannot be done on the object itself, a nearby reference star can be used. It is thus important to search for new objects (radio selected or by-products of planned surveys) located near bright stars. Calculations for the adaptive optics system on a unit telescope in the visible predict a sky coverage of about 1%.This number increases by a factor of 4-5 if the correction is done in the near infrared and becomes even greater in the mid-infrared. A catalogue of bright stars in the near infrared is needed to search efficiently for observable objects.

## SUMMARY

ESO is defining and prioritizing the key science drivers for each phase of the PRIMA program and the technical specifications that flow from them. This article briefly presents these science goals as they currently stand. The list is not meant to be frozen or complete, but rather is intended to stimulate community reflection and comment. The kind of data which interferometry will access is so far beyond our current experience that it is inherently difficult to specify a definitive science justification. Indeed, much of the prospects are more in the nature of the unexpected. Although optical interferometry carries within it the potential to revolutionize whole areas of astronomy, it suffers currently from the difficulty to exactly foresee the details of the revolution. No one yet has peered into the very core of an AGN, for example, as the VLTI surely will and one can only speculate by engaging in risky extrapolations as to what one might find there. This is especially true since interferometric performance is still not well understood for a large class of sources which are extended on the scale of a few Airy disks.

In any case, it is still relatively straightforward to foresee, at least in general terms and on the basis of the expected VLTI performance parameters just described, the areas of research where VLTI is most suited to providing the kind of potential breakthroughs that we currently require in order to better understand our universe. Although the VLTI targets are mainly located in our relatively local universe due to the limitations in sensitivity inherent in high spectral and spatial resolution interferometry even with large telescopes, the impact of these breakthroughs on our knowledge of the furthest reaches of the observable universe cannot be underestimated. This is especially true when one considers that much of the universe consists of stars and fundamental information on stellar formation, the IMF, binarity, ages and distances are crucial in unravelling the mysteries of galaxy and structure formation, the reionization of the IGM by the first stars etc.

Other research areas that the VLTI can contribute to significantly and deeper development of many of the topics covered in this document can be found in the proceedings of the ESO workshop “ Science with the VLTI”, ESO Astrophysics Symposia Series, ed. F.Paresce, Springer-Verlag, Berlin, 1997 and in the document “Scientific Objectives of the VLTI” by F.Paresce that can be found at http://www.eso.org/projects/vlti/science/VLTIscienceMarch2001.pdf.

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