# The Pre-PRIMA Survey Project:

# Turning the problem around

A. Richichi, F. Delplancke (ESO)

I. Percheron, E. Bakker (NEVEC)

**Abstract :**

**The mature life of the VLT Interferometer and its instrumentation will start with the availability of the PRIMA dual feed facility. Possible extensions of this latter might also be developed for use with second generation instrumentation, making it possible to combine and phase-reference several beams simultaneously. The introduction of the dual feed in interferometry will create a situation similar to that already experienced in Adaptive Optics, namely the fact that most scientific programs will be limited by the availability of a suitable reference star nearby. With sufficient time available in front of us, we propose to turn the problem around and investigate the surroundings of a large number of suitably bright reference stars, to compile a list of interesting objects which could be studied by the VLTI and its dual feed facility. This would permit to obtain accurate astrometry and/or detailed imaging of objects such as brown dwarfs, (micro)gravitational lenses, extragalactic sources. We discuss the needs and strategies to investigate the surroundings of a number of bright stars, using available near-IR surveys, as well as novel dedicated observations.**

# Limitations for interferometric facilities

Interferometry works by measuring the visibility, or fringe contrast, of an astronomical source with a given baseline.
It is estimated that the new generation interferometric facilities, based on 8-10 m telescopes such as the VLTI and the Keck, when aided by adaptive optics (AO), will reach a magnitude limit of 12-13 in the near-infrared.

This restriction is due to physical limitations :

• on the characteristics of currently available detectors,
• on the number of photons that can be recorded in a minimum integration time. The exposure time is generally set to a few milliseconds or tens of milliseconds, limited by the effect of atmospheric turbulence.

To extend significantly this sensitivity limit by integrating for longer times, it is necessary to stabilize the fringes, or in other words to "freeze" the atmospheric turbulence.

The situation is analogous to that encountered for AO. Similarly to what has been done for this latter technique, in the field of interferometry there have been efforts [1] to use a nearby, bright reference star to stabilize and record the fringes. Then, if the science source is within the isopistonic patch [2] [3], integration times can be extended almost arbitrarily.

# The PRIMA Concept

The VLTI will implement the method of using a bright reference stars for fringe tracking, in the PRIMA dual-feed facility (Figure 2). This optical device will permit to inject the light of two stars in the interferometer, which are separated by angular distances <1', and to monitor accurately the optical path differences of the (four) beams.

The main characteristics of PRIMA are summarized in Table 1 (see [4], [5], [6]).

This will permit in practice three main modes of operation (see Figure 1) :

- an **astrometric mode**, in which the angular distance between the two stars is measured with an accuracy as good as 10μas,
- a **faint source mode**, in which the fringes are tracked on the bright reference star, and long integrations are performed on the scientific target, presumably much fainter. It is foreseen to reach magnitudes of about K=20 in this way,
- A **phase-referenced imaging mode**, where one of the two stars (usually the fringe tracking one) is used as a phase-reference (zero) for the science star fringes, allowing aperture synthesis imaging.

# Characteristics of the PRIMA dual-feed facility (1/2)

| | with the UTs | with the ATs |
|---|---|---|
| Minimum star separation | <2" | |
| Maximum star separation | 1' | |
| Maximum differential OPD between the stars | 60 mm | |
| Differential OPD measurement accuracy | 5 nm rms | |
| Fringe tracking accuracy: OPD residual | 70 nm rms | |
| Fringe tracking limiting magnitude (K band) | 12-13 | 9-10 |
| MIDI limiting magnitude with PRIMA (M band) | ~9 | ~6 |
| AMBER limiting magnitude with PRIMA (K band) | ~18 | ~15 |
| Astrometric limiting magnitude with PRIMA (K band ) | 19-20 | 16-17 |

**Table 1:** Characteristics of the PRIMA dual feed facility

# Characteristics of the PRIMA dual-feed facility (2/2)

PRIMA will allow astrometry with an accuracy of 10 μas, over a total observation time of 30 minutes, if the stars are separated by 10”, with the Paranal median atmospheric turbulence (0.65” seeing).

The baseline vector is measured on calibration stars, as usual in interferometry. The OPD caused by the atmospheric turbulence is averaged toward zero by measuring during a long enough period (typically 30 min). The internal OPD is measured by a dedicated high accuracy laser metrology. Thus, the two parameters that can be measured are the angular star separation vector and the object phase, linked to its shape .

The phase-referenced imaging dynamic range will be limited by the number of baselines rather than by the visibility and phase measurement accuracies, which will be better than 1%.

# Sky coverage of PRIMA

For the purpose of this presentation, we concentrate ourselves on the modes (faint source mode and phase-referenced imaging mode) which require a reference star.

It is clear that, with a limiting magnitude of about H or K~12 for the reference star, the sky coverage of this method of observation will not be complete (see Table 2).

| | **Mean 0°-90° Gal. Lat** | | | **Gal Lat 90°** | | |
|---|---|---|---|---|---|---|
| Mv | Log dens | Number density | | Log dens | Number density | |
| < | (sqdeg^-1) | (sqdeg^-1) | (sqarcmin^-1) | (sqdeg^-1) | (sqdeg^-1) | (sqarcmin^-1) |
| 14 | 2.56 | 363 | 0.10 | 2.01 | 102 | .03 |
| 15 | 2.94 | 871 | .24 | 2.27 | 186 | .05 |
| 16 | 3.29 | 1950 | .54 | 2.54 | 347 | .10 |
| 17 | 3.64 | 4365 | 1.21 | 2.78 | 603 | .17 |
| 18 | 3.95 | 8913 | 2.48 | 3.02 | 1047 | .29 |
| 19 | 4.2 | 15849 | 4.40 | 3.2 | 1585 | .44 |
| 20 | 4.5 | 31623 | 8.78 | 3.4 | 2512 | .70 |

**Table 2:** Sky coverage (from “Mean star densities from "Handbook of Space Astronomy and Astrophysics", Zombek, Cambridge Univ. Press, 1990”)

# The Pre-PRIMA Survey Project

## Rationale

From the sky coverage fractions presented in Table 2 and figure 3, it follows that the use of PRIMA will be limited to a certain number of bright guide stars. On the other hand, the number of sources within the potential sensitivity limit is so high, that there will be no shortage of sources to observe around these bright stars. In particular, it is anticipated that the applications will cover all classes of astronomical sources, from young stars to faint extragalactic sources.

To make the best use of the sensitivity limit in the relatively small sky areas available, it is sensible to investigate ahead in depth small areas of the sky around potential bright reference stars (see Figure 5). For this, a project is being outlined between ESO and NEVEC, to carry out a survey around a number of such stars (see the poster "NEVEC : NOVA VLTI expertise center").

# The Pre-Prima Survey Project (1/2)

**Selection of reference objects :**

The selection will be done by investigating different lists of natural guide stars (NGS) for adaptive optics and other sky survey catalogues. We could also use the preliminary version of the VLTI catalogue (ref [7] and figure 3), which is a compilation of published high angular resolution measurements (long baseline interferometry, aperture masking on big telescopes like Keck, WHT, SAO, and lunar occultations).

**Pre-selection of scientific objects nearby a reference object:**

Areas around each reference object (see above) will be cross-correlated with:

- Catalogues at various wavelengths, from optical to IR (IRAS), X-rays (Rosat), and radio (NVSS, FIRST, WENSS)
- Archive data (HST, ESO, La Palma)

An example of such a cross-correlation is given in Fig. 4 (Gezari catalogue).

# The Pre-Prima Survey Project (2/2)

**Novel Dedicated observation** around the reference objects will be done including deep imaging of the fields around the reference objects using a large telescope with Adaptive Optics and with the option of using coronographic techniques.

These observations will include (see Fig. 5):

- deep imaging (magnitudes and variability of objects, morphological selection),
- wide-range, low-medium resolution spectroscopy (to characterize extragalactic objects),
- high resolution spectroscopy (for special targets),
- monitoring of flux and radial velocity variations when required.

**Following these observations the Scientific targets will be characterised :**

- Accurate relative position to the reference object
- Estimation of object type
- Estimation of magnitude
- Estimation of angular diameter, if available.

# Anticipated Results

We will provide a data base containing around a few tens (which could be extended to more than 100) scientific targets with their associated bright reference NIGS (Natural Interferometric Guide Star).

This catalogue will include:

- Accurate relative position to the reference object,
- Estimation of object type,
- Estimation of magnitude,
- Estimation of angular diameter, if available,
- Associated astronomical calibrator from the VLTI calibrator list.

# Schedule and manpower

This project will be a joint effort between ESO and NEVEC. We anticipate that the survey will be completed in 2005. Estimation of efforts required and the estimated schedule are given in the Table 3.

**Table 3 :** Estimated manpower and schedule

| Description | Estimated manpower (man/months) | Estimated schedule |
|---|---|---|
| • Selection of reference stars<br>• Preselection of scientific targets | 14 | Middle 2002 |
| • Data reduction<br>• Characterization of scientific sources<br>• Dedicated observations | 28 | **End of the survey : middle 2005** |
| • Miscellaneous | 6 | |

# References


[1] **The palomar testbed interferometer**, Colavita, M. M.; Wallace, J. K.; Hines, B. E.; Gursel, Y.; Malbet, F.; Palmer, D. L.; Pan, X. P.; Shao, M.; Yu, J. W.; Boden, A. F.; Dumont, P. J.; Gubler, J.; Koresko, C. D.; Kulkarni, S. R.; Lane, B. F.; Mobley, D. W.; van Belle, G. T., ApJ, 510, 505, 1999

[2] **Differential piston angular anisoplanatism for astronomical optical interferometers**, S. Esposito, A. Riccardi, B. Femenia, A&A, 353, L29, 2000

[3] **Considerations about the differential piston for adaptive optics interferometry,** B. Femenia, M. Carbillet, S. Esposito, A. Riccardi, SPIE conference : "astronomical telescopes and instrumentation 2000", 2000

[4] **Phase-referenced imaging and micro-arcsecond astometry with the VLTI**, F. Delplancke, S. Leveque, A. Glindemann, P. Kervella, L. d'Arcio, SPIE conference : "*Astronomical telescopes and instrumentation 2000*", 2000

[5] **PRIMA - The VLTI Dual Feed System**, A. Glindemann, S. Lévêque, *From Extrasolar Planets to Cosmology: The VLT Opening Symposium*, Proceedings of the ESO Symposium held at Antofagasta, Chile, 1-4 March 1999. Edited by Jacqueline Bergeron and Alvio Renzini. Berlin: Springer-Verlag, 2000. p. 468

[6] **PRIMA: study for a dual-beam instrument for the VLT Interferometer**, Quirrenbach A., Coude Du Foresto V., Daigne G., Hofmann K. H., Hofmann R., Lattanzi M., Osterbart R., Le Poole R., Queloz, D., Vakili F., Proc. SPIE Vol. 3350, p. 807-817, *Astronomical Interferometry*, Robert D. Reasenberg; Ed. (SPIE Homepage) 1998.

[7] **The VLTI Main Source Catalogue**, A. Richichi, I. Percheron, 2000, VLT-TRE-ESO-15000-2416

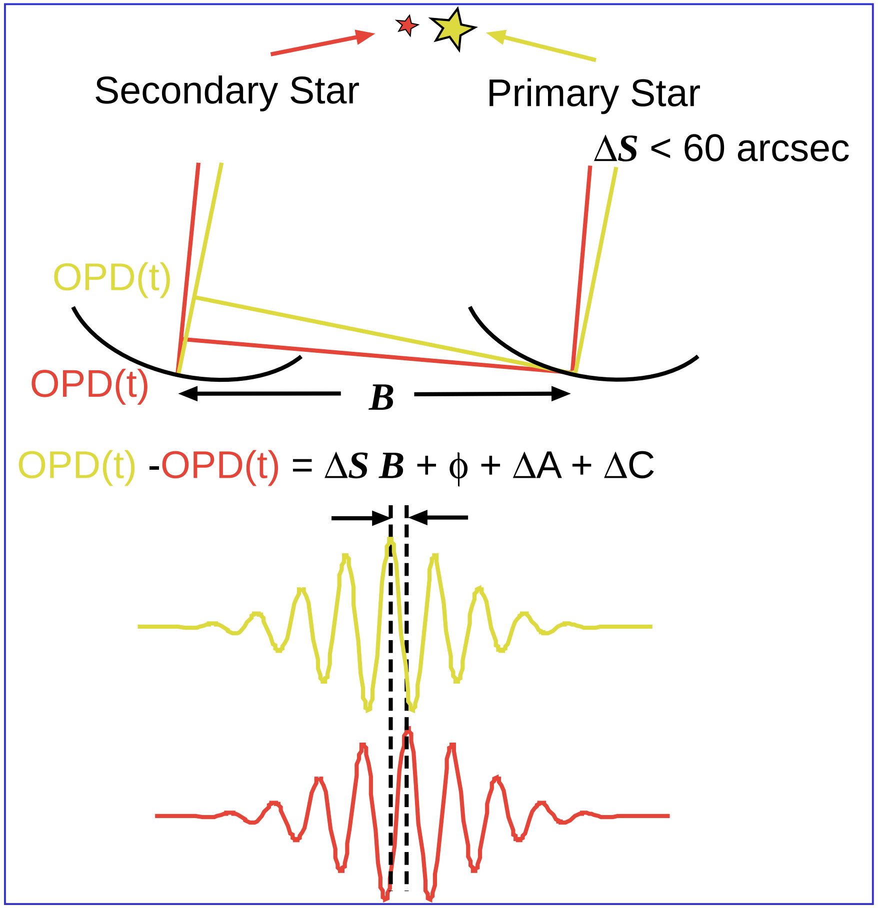


**Figure 1**: Principle of phase referenced imaging and astrometry with an interferometer

The OPD difference between primary and secondary star is determined by the sum of the product of ΔS - the angular separation vector of the stars - and the baseline vector B, of the phase f of the visibility function of the secondary star, of the OPD caused by the turbulence, ΔA, and of the internal OPD, ΔC.

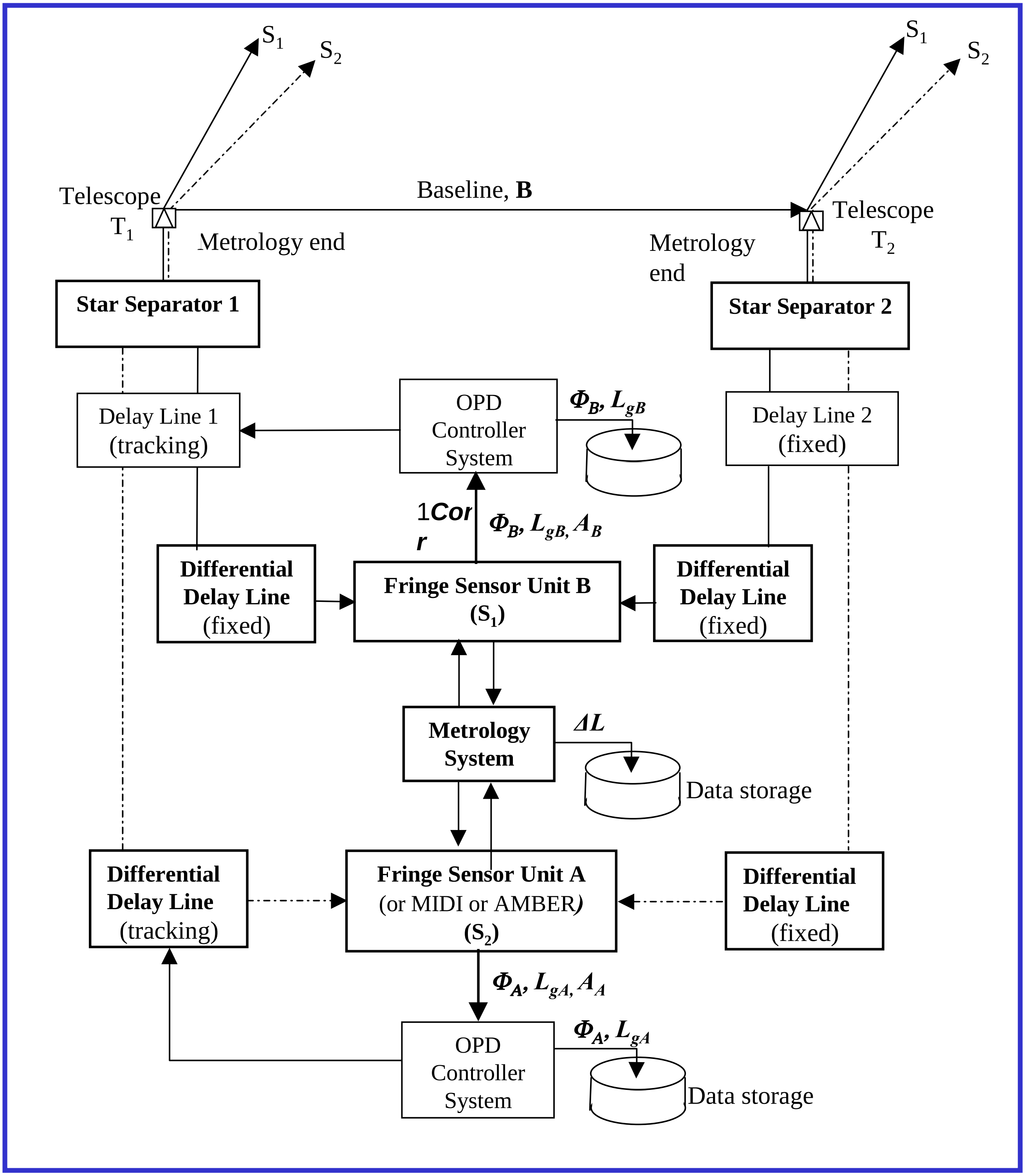


**Figure 2:** Functional block diagram of the VLTI and the PRIMA components.

$\Phi_A$, $\Phi_B$ : fringe phase measured by the FSUA / FSUB,
$L_{gA}$, $L_{gB}$ : group delay measured by FSUA / FSUB,
$A_A$, $A_B$ : fringe amplitude measured by FSUA / FSUB,
$\Delta L$ : differential OPD measured by metrology.

# Sky distribution in the VLTI catalogue as seen from Paranal

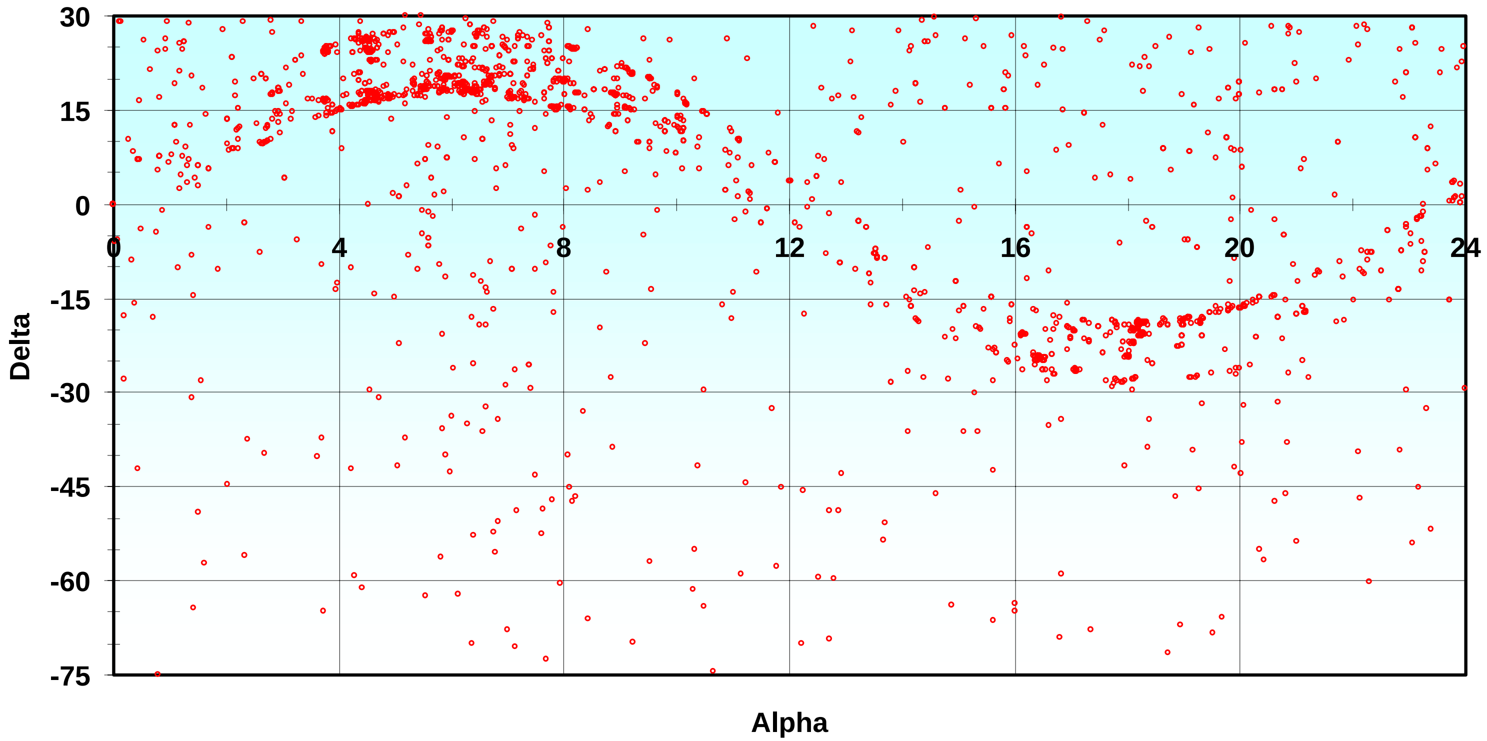


**Figure 3 :** Sky distribution of objects seen from Paranal in the VLTI catalogue [7].

The present version of the VLTI catalogue includes published high angular resolution measurements from long baseline interferometry, aperture masking on big telescopes, and lunar occultations (the zodiacal distribution of the objects observed by this latter technique accounts for the characteristic shape). The objects in the catalogue are brighter than K=10. In the preliminary study these objects will be used as reference stars.

# Sky distribution in the VLTI catalogue (potential scientific objects)

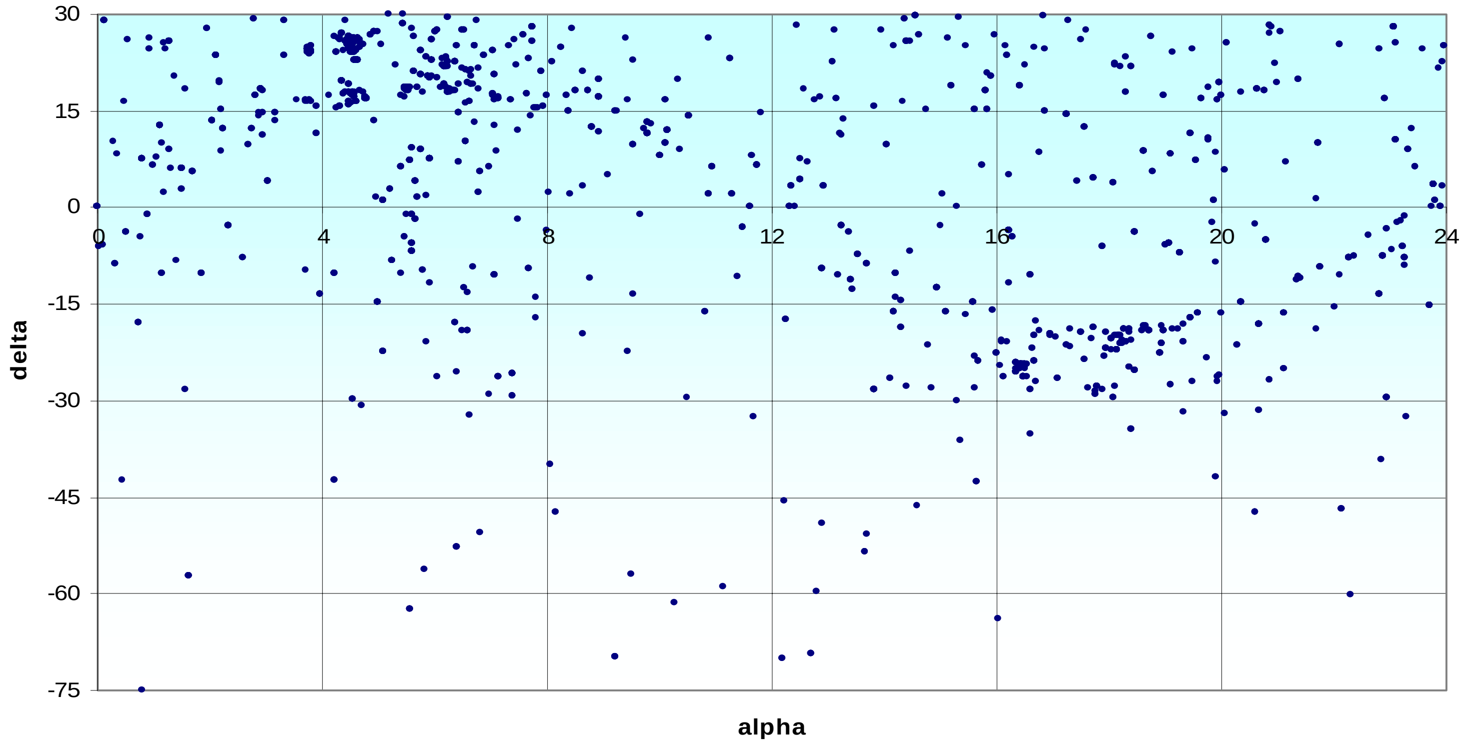


**Figure 4 :** Preliminary sky distribution of objects around the reference stars in the VLTI catalogue [7].

The catalogue used here is the Gezari catalogue of Infrared Observations.
The parameters of the query were :

- radius less than 30 arcsec around the reference objects,
- K<=20.

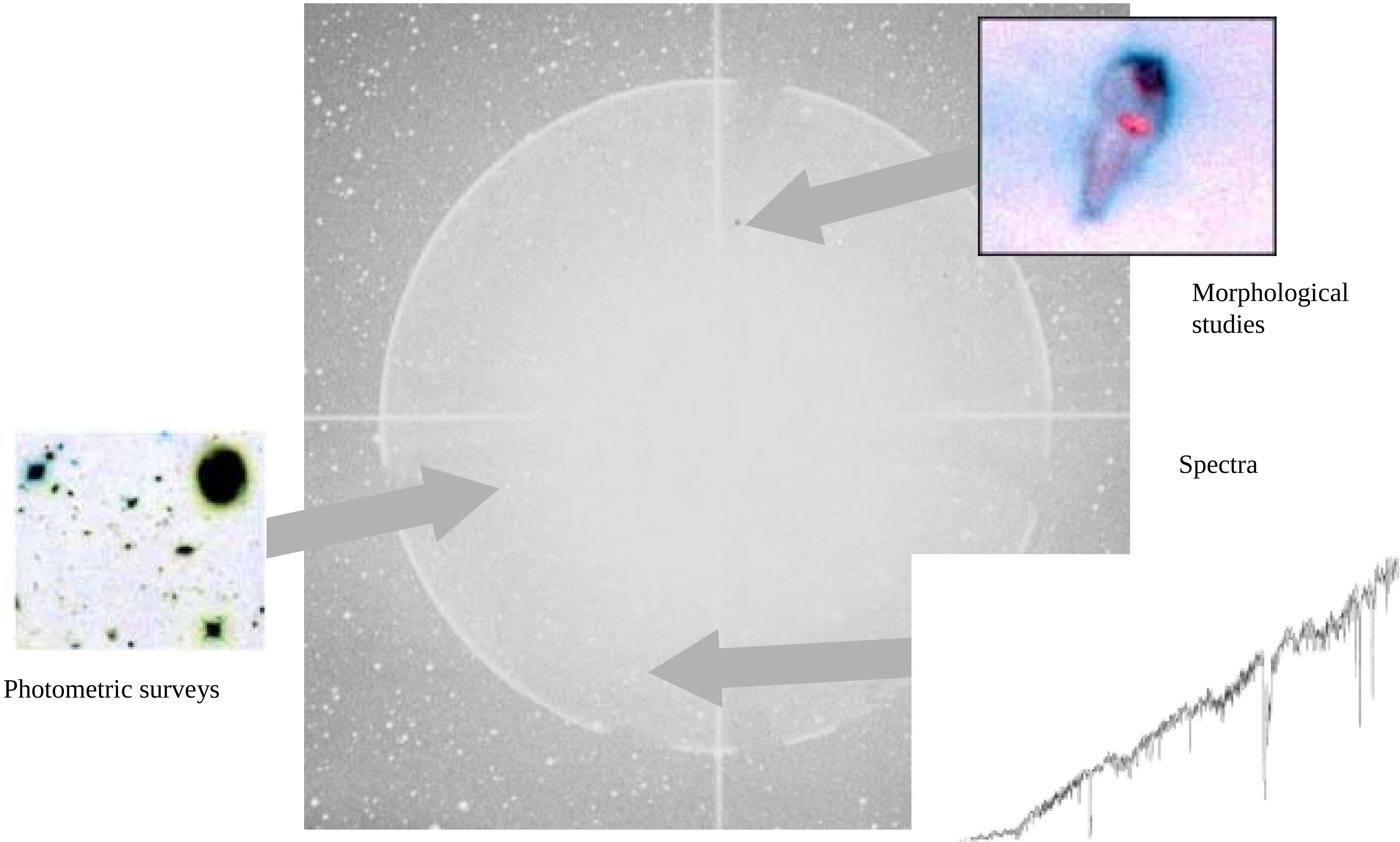


**Figure 5** : Archive and survey fields around very bright stars are often saturated on an area of several arc seconds or more around the star. Many potential PRIMA targets could be hidden in this unsurveyed zone.