DENIS – A FORTHCOMING NEAR INFRARED SURVEY

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ABSTRACT

DENIS[1] will be a complete deep near infrared survey of the southern sky, made with the objective of providing full coverage in 2 near infrared bands (J at 1.25μm and K at 2.2μm) and one optical band (I at 0.8μm), using a ground-based telescope and digital array detectors. The products of this survey will be databases of calibrated images, extended sources, and small objects. In addition, catalogs of small and extended sources will be produced. We expect the survey to be completed within five years; restricted access to the databases is possible during the second half of the survey. The production of catalogs (to be distributed) will take a few additional years.

1. The DENIS Survey

DENIS (DEep Near Infrared Survey of the Southern Sky) is a joint project of 18 European and South American Institutes, aiming to provide digitized maps of the southern sky in a spectral region, similar to that of the TMSS[2] carried out some 25 years ago, but providing a sensitivity 10 magnitudes deeper. Using the 1-m photometric telescope of ESO, on La Silla, the southern celestial hemisphere will be fully mapped simultaneously in three bands, namely J (1.25μm), K$'$ (2.2μm) and I (0.8μm), using CCD and NICMOS array detectors. The spatial resolutions and anticipated limiting magnitudes will be $3''$, $3''$ and $1\farcs5$, and $16^{\rm m}$, $14\fm5$ and $18^{\rm m}$, respectively. The survey will start in mid '93, with an expected duration of at least four years.

The observations will be performed in step-and-stare mode, using "strips" as basic units. Each strip is $12'$(one frame) wide in RA, and 30° long in declination, consisting of 180 overlapping frames. For telescope pointing and brightness calibration purposes additional frames will accompany each unit. DENIS will yield a huge quantity of data - one million survey fields will be observed, providing some TBs of data.

The 0.8-2.2μm spectral range corresponds to the peak emission of several different species of astronomical objects. DENIS will provide essential information on the low-mass end of the luminosity function: M dwarfs, subdwarfs and brown dwarfs, of which a large number - about 10^4 - are expected to be detected. DENIS will complement the IRAS data in studies of evolved stars, and will yield a complete census of AGB stars even in the Magellanic Clouds. The survey will enable study of the giant stars in the star-forming annulus of the Galaxy, as well as in the galactic Bulge. The number of galaxies observed will probably exceed one million. The normal galaxies in the sample (z = 0.05 - 0.2) will not be affected by evolution effects, offering unique possibilities to trace the distribution of mass in the Universe.

ESO has granted this project the Key Program status, and provided up to 75% observing time on the 1-m telescope during the planned data acquisition period. The EEC granted 350 kECUs for the project through its Science Program.

2. Data Analysis Centers

The ultimate goal of this project is to provide the astronomical community with a complete digitized infrared map of the southern sky and a catalog of extracted objects. Easy access to such data is essential.

The aspect of computer analysis starts at the data acquisition site, La Silla, of the ESO, where the enormous amount of raw data will be recorded on DAT tape. There data will be transferred to the two European Data Analysis Centers, at the Sterrewacht Leiden and at the IAP in Paris, for further processing. There are two such centers necessary due to the data quantity and associated complexity of reduction.

The Leiden Data Analysis Center (LDAC) will extract objects, ranging from point sources to small extended sources, parameterize them, and archive them into a source catalog. The Paris Data Analysis Center (PDAC) is responsible for archiving and preprocessing the raw data to provide a homogeneous set of data suitable for both the Leiden and Paris data analysis streams. The PDAC will also extract and archive images for the sources flagged by the LDAC as extended, and possibly also creating a catalog of galaxies. Both DAC's are working in close collaboration, supplementing each other, to perform a coherent and complete data reduction and analysis task.

Final archiving on permanent media (e.g. CD-ROM), primarily for the catalogs, will be achieved after the completion of the survey, other aspects of the archiving are under discussion with ESO. The distribution to the scientific community will be handled through the "Centre de Données de Strasbourg" (CDS).
The products that will be delivered are:

- A Bright Source Catalog extracted in real-time at La Silla for preliminary investigation and to prompt objects for astronomical interest.
- Small Object Database that can be remotely interrogated. A condensed form of this database is the Small Source Catalog.
- Extended Source Catalog in the form of an image database and catalog (of galaxies) that can be remotely interrogated.
- Processed Frame Database of the full surveyed sky, again remotely accessible. Possibly an additional database of selected areas will be available containing mosaiced images, mosaicing of frame sets will also be possible.

2.1 The Leiden Data Analysis Center (LDAC)

The LDAC will concentrate on the extraction of "small objects" from the DENIS images at all three proposed wavelength bands. Production of a catalog will be done during the survey data acquisition and should result in a first-order data product at the end of the observing period. The derivation of object parameters will be based solely on image properties; no *a priori* astronomical information will enter this catalog.

All the objects above the 5σ noise level will be extracted. The objects will be de-blended and their positions calculated using the frame centers computed with the help of cross-identifications with Input Catalog sources (see Sec. 3.). In order to improve the positional accuracy, strip-wide astrometric solutions will be computed. The small objects will be photometrically calibrated using a set of DENIS standards distributed around the southern sky.

Basic information to be stored in the catalog consists of astrometric position, photometric intensity, image classification, and geometry. These parameters will be derived using the moments, up to second order, of each objects pixel distribution. As the pattern analyzer recognizes the object's, cumulative sums of pixel intensity (at all three passbands) are calculated, and intensity-weighted and unweighted pixel positions are stored.

All this will result in the creation of the Small Object DAtabase (SODA). The SODA will grow continuously during the survey period. The SODA will be a relational database storing four main entities: Objects, Frames, Strips, and The Survey. The latter entity will dominate the view of future users. Each entity will keep the following information in the form of attributes:

- Objects: x, y, x', y', I, J, K, flags(border, single/blended, saturated, extended, near glitch, [I,J,K]detected/assumed), local S/N quality, local background level, here x, y are the pixel positions within a frame (first moments), x' and y' are the second moments of the intensity distribution. I, J, and K are the zeroth moments (fluxes). Many flags are kept to store conditions of the source extraction.
- Frames: center, exp-time, grey-filter etc.; where center stores the derived Ra and Dec of the frame, exp-time gives the total exposure time for the frame (addition of sub-frame exposures), and grey-filter is a flag denoting the use of a grey filter during exposure.
- Strips: date, weather, observer etc., where date is the date and time (GMT) of the observations, weather stores information on the weather conditions, such as seeing, distance to the moon etc.
- Survey: none.

The known relations in the database are:

- Survey-strip: This table contains a list of all strips with their identification and whether they are normal survey strips, or additional observations.
- Strip-frame: A set of tables containing a list of frame id's belonging to this particular strip.

- Frame-object: A large set of tables describing which objects belong to this particular frame.
- Object-object: This table contains information about the degree of blended of the sources. It links the individual objects that were decomposed in a de-blending operation.
- Frame-frame: This type of table stores the links between objects observed in different frames but found to be identical on positional arguments.
- Strip-strip: This type of table stores the links between objects observed in different (consecutive) strips, but found to be identical on positional arguments.
- Object-IC: A table storing the connections between the extracted objects and the Input Catalog (currently the GSC sec).

The database is perceived by the user as one table, containing a mix of the above attributes. The output from searches through the SODA may be used as input to the tools for visualization, basic statistics, etc., such as plotting packages (e.g. Mongo, GNUplot) or statistical analysis packages (e.g. SAS, BLISS). After the data-acquisition period the SODA will be available for the scientific community through computer networks. The LDAC will process the database further, merging the objects on the overlapping areas and possibly cross-correlating them with existing astronomical catalogs. We call the final product Small Source Catalog.

Statistical studies will be carried out to assess the quality of the catalog. These studies will quantify the completeness, reliability, source confusion[6] of the catalog, and provide measures of the variability of sources, and of their positional and photometric accuracy. For those studies a small fraction of the southern sky (about 2%) needs to be observed repeatedly (about five times during the survey).

2.2 The Paris Data Analysis Center (PDAC)

The PDAC will perform a number of processing steps to prepare the data for further processing/analysis. First a de-glitching of the frames at all wavelengths needs to be performed. The second processing step is the flat-fielding of the strip images using flat-fields derived by the real-time processing on the mountain. The third step is shuffling the frames around to obtain color-grouped sets of data for each pointing position (the raw tapes are single channel “isochromatic” data tapes).

Then the processed frames (strips) will be stored in the Processed Frame Database (PROFDA) and also sent to the LDAC for further processing. The PROFDA will later allow mosaicing the individual images. The raw data will also be kept on DAT tapes in the PDAC. Another database produced and maintained at the PDAC will be the Data Tracking - Survey Information Database (DAT-SIDE). This database allows verification of the observing strategy goal, full mapping of the southern sky, and also keeps track of the data quality and storage administration.

The return flow of data from the LDAC, that most likely will be through international networks, will involve astrometric calibration and the extracted source information. At the PDAC a version of the SODA is kept; the astrometric information will be stored in the DAT-SIDE. From the SODA the extended sources are recognized and using data-tracking information the extended source parameters and maps are derived. This will include, in many cases, doing mosaicing. The results are stored in a final Extended Source Database.

As a direct spinoff from the Extended Source Database, the Extended Source Catalog will contain cross-identifications and source classification through the merging with the Lyon Extragalactic Database.

3. The Input Catalog

DENIS needs an Input Catalog to get positional information "from the sky" (supplementing the information "from the telescope"), and to give some *a priori* indication on the presence of very bright sources or the absence of sources in the field. The only existing catalog deep enough to contain at least one source per frame is the HST Guide Star Catalog[3,4,5]. (One can expect 7 GSC stars per frame, compared to the expected average value of 100 sources per frame for DENIS.) For the purpose of the survey the CDS will combine the multiple entries of the same GSC object, and supply better coordinates for the sources present in the TYCHO catalog from the HIPPARCOS mission (when HIPPARCOS data will be available). Because the brightest stars are missing from the GSC, a supplement will be obtained from the Bright Star Catalogue. In order to enable real-time access to the Input Catalog the GSC will be re-structured using a simple file-structure based on $10'$ constant declination strips and about $12'$ wide fields in each strip. In this way a query for Input Catalog sources in a frame would need to access six catalog fields (files), each containing less than 10 sources (average).

4. The Small Source Catalog (SSC)

4.1 Description

The SSC is expected to contain some 10^8 sources (in the K band), out of which more than 10^6 are galaxies. Stars brighter than $7^{\rm m}$ above the limiting magnitude will give a saturated signal - this range can be somewhat extended using a grey filter. The SSC will be extracted from the SODA, removing astronomically less interesting information, and merging multiply observed objects.

4.2 Quality estimates

The LDAC has been testing its source extraction algorithm using synthetic data of the form produced by the actual data acquisition equipment, and preprocessed at the PDAC. Sets of synthetic images at I-band and K'-band wavelength have been produced using a dynamical range of 10^6. We adopted a uniform spatial distribution function, and a magnitude distribution function according to the Soneira distribution. The micro-scanning technique was mimiced through the production of sub-images shifted with respect to the original by the micro-scanning step (0.33 pixel) and then combining these subimages in the same way the micro-scanned images will be combined during real-time processing. Images with different numbers of stars (200 – 5000) were made.

Knowing the input parameters: stellar position and magnitude, we could test the quality of the object extraction algorithm by determining an artificial calibration curve and an estimate of the completeness/reliability/confusion measures.

The photometric accuracy can be assessed from a synthetic calibration curve that shows the regime of noise-dominated extractions ($M_I > 16\overset{m}{.}5$) and that of the overexposure effects ($M_I < 9\overset{m}{.}5$). The actual standard deviation in the photometric parameter derived from this analysis shows high that accuracy is achieved over a large range in magnitudes. The photometric accuracy of the object extraction (rms error) will be about $0\overset{m}{.}01$ just below the saturation limit, and $0\overset{m}{.}2$ at the faint cut-off.

The positional accuracy will be influenced mainly by the systematic errors of the GSC[7] which on average are about $1''$. The relative rms errors (within a DENIS frame) will be in the order of $0\overset{''}{.}1$. After the TYCHO catalog from the HIPPARCOS mission becomes available (we expect one TYCHO star per DENIS frame), the positional errors can be reduced to the order of a few tenths of arcseconds.

In a simulation with 1000 input positions, 967 objects were detected. From the missed 33 objects only 1 could be detected by eye as an individual object on the flank of a larger source, the others were missed due to confusion effects.

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6. References

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