

The DENIS & 2MASS Near Infrared Surveys and their Applications in Cosmology

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Abstract

The DENIS and 2MASS near infrared surveys are presented. Their applications in extragalactic astronomy and cosmology are listed. The prospects for a rapid spectroscopic followup survey of a near infrared selected sample of nearly 10^5 galaxies are illustrated with Monte-Carlo simulations.

1. Introduction

Astronomers have traditionally relied upon optical imagery to view the Universe, ever since the early introduction of photographic plates, sensitive to blue light. The main constituents of the Universe in the optical are *galaxies*, and the main constituents of galaxies in the optical are *stars*. In fact, the visible parts of galaxies contain important amounts of gas and non-negligible amounts of dust, and perhaps some dark matter. Moreover, most of the mass in galaxies is thought to be constituted of dark matter residing in near spherical halos. Similarly, on the scale of the Universe, most of the baryons are presumed to be locked up in gas, and most of the mass is believed to be non-baryonic dark matter. Working in the optical, one uses galaxies to trace the matter distribution in the Universe. But galaxies may very well be biased tracers of the underlying matter content of the Universe.

Near infrared (NIR) light is also sensitive to stars, hence to galaxies. But there are important differences.

1) NIR light is typically 10 times less extinguished by dust than optical light. This means that the cores of galaxies, hidden in the optical, are visible in the NIR. This is illustrated in Figure 1, which shows the same galaxy, in blue (B) and NIR (K') light. The white pattern cutting through the galaxy in the blue image, is caused by internal extinction by dust, and is invisible in the NIR image. The galaxy is much more symmetric in NIR light and the shapes of the isophotes from diskly inside to boxy outside can only be seen on the NIR image.

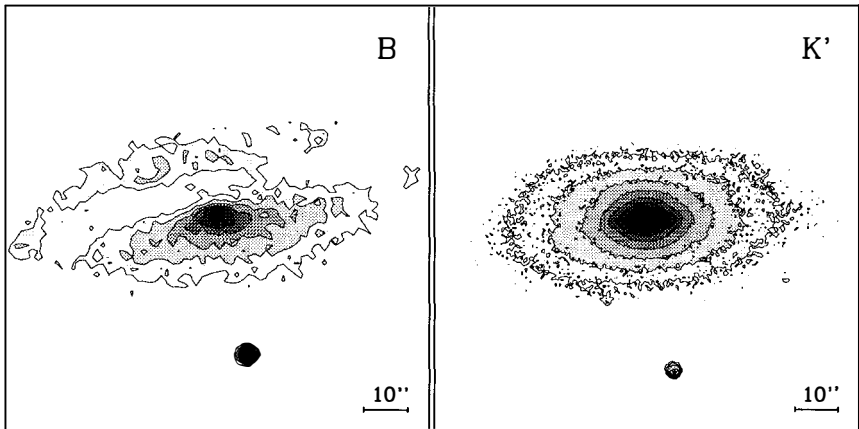


Figure 1. Galaxy NGC 7172, seen in blue (*left*) and NIR (*right*) light.¹⁾ Object at bottom is a foreground star.

2) The second difference is that, contrary to NIR light, optical light is extremely sensitive to populations of newborn stars, because the more massive (and hot) stars are extremely luminous, and are the only very blue stars (for cooler stars, the blue band is in the Wien part of the spectrum). As stars exhaust their nuclear hydrogen and evolve to the red giant branch, they become substantially redder. The more massive ones evolve to cool Red Giants in very short times (a few million years) and continue their evolution and finally blow up as supernovae in even shorter times. The NIR band picks up principally cool stars, while the hot, massive, and young ones, moderately visible as the NIR lies in the Rayleigh-Jeans part of their spectrum, are too rare to contribute significantly to NIR light. As a result, blue light tends to pick up galaxies with very recent star formation, while NIR light is less affected by very recent star formation and traces better the *stellar mass* content of galaxies.

However, NIR light *is* affected by star formation occurring roughly 10 million years

ago, because after 10 million years the typical very massive stars are in their Red Giant or subsequent phases before going supernova. Nevertheless, averaged over all epochs of star formation, the NIR wavelength domain seems to be the optimal one to avoid the effects of star formation.

These differences between optical light and NIR light have several important implications:

1) The lack of extinction allows one to probe the large-scale distribution of galaxies behind the dust-filled plane of our own Galaxy.²⁾

2) The galaxy tracers of the underlying matter distribution in the Universe is less biased by recent star formation in the NIR than in other bands.

2. The DENIS and 2MASS Surveys

With these advantages in mind, two consortia have set out to map the sky at NIR wavelengths: DENIS (DEep Near Infrared Southern Sky Survey) and 2MASS (Two Micron All Sky Survey). The characteristics of the two surveys are given in Table 1.

Table 1: The DENIS and 2MASS surveys

	DENIS	2MASS
Institutions	Meudon, IAP, Leiden ...	UMass, IPAC, CfA ...
Hemispheres	South ($\delta < 2^\circ$)	North + South
Telescopes	ESO 1m	2 new 1.3m
Color bands	I (0.8 μm), J (1.25 μm), K_s (2.15 μm)	J , H (1.65 μm), K_s
Detector	CCD 1024 ² (I), NICMOS-3 256 ² (JK)	NICMOS-3 256 ²
Pixel size	1'' (I), 3'' (JK)	2''
Quantum efficiency	0.4 (I), 0.65 (JK)	0.65
Exposure time	8 s (I), 9 \times 1 s (JK)	6 \times 1.3 s
Read-out noise	8 e^- (I), 30 e^- (JK)	30 e^-
Observing mode	Stop & Stare	Freeze-Frame Scan
Scan geometry	12' \times 30'	8' \times 6'
Survey years	1996–2000	1997–2000 (N), 1998–2000 (S)
Primary data	4000 GBytes	19 000 GBytes
Cost	\$3 million	\$30 million

Notes: The NIR exposures are dithered for better angular resolution.

3. Cosmological Applications

The applications of NIR surveys such as DENIS and 2MASS for extragalactic astronomy and cosmology have been described elsewhere^{3,4,5,6,7)} and are briefly outlined again here.

3.1 Statistical properties of NIR galaxies

The large sample sizes ($> 10^4$, 10^5 , and 10^6 galaxies in K , J , and I , respectively, for DENIS⁵) will help study correlations between properties.

3.2 Two-dimensional structure of the local Universe.

Catalogs of groups and clusters will be obtained from the galaxy lists extracted from the survey images. Statistical measures of large-scale structure will be obtained (such as the angular correlation function and higher order functions, counts in cells, and topological measures), in particular statistics on the full sphere from 2MASS data. Not only are NIR bands cleaner than optical bands to study the large-scale distribution of galaxies in the Universe (because less sensitive to recent star formation), but the multi-color aspect of the DENIS and 2MASS surveys allows one to see how all this 2D structure will vary with waveband, and indicate possible biases when going from one waveband to another. The alternative is that any such difference in 2D structure may be a reflection of selection effects, but we are working hard on avoiding this. Moreover, NIR surveys will probe the largest local concentration of matter, the *Great Attractor*, which is situated roughly right behind the Galactic Plane⁸), and contains the closest rich cluster of galaxies.⁹ Unfortunately, although extinction is beaten at low galactic latitudes, confusion with stars becomes a serious issue, for example on the accuracy of the photometry of fairly bright galaxies.¹⁰

3.3 Color segregation

Instead of studying structure versus waveband, one can study the inverse problem of understanding colors as a function of structure, hence environment. Color segregation is a potentially powerful probe of three dimensional morphological segregation of galaxies in the Universe (*e.g.*, the fact that the cores of galaxy clusters have the highest fraction of galaxies with elliptical morphological types).

3.4 Normalization of galaxy counts at the bright-end

Counting galaxies as a function of apparent magnitude provides better results at the faint-end than at the bright-end, simply because the bright-end suffers from very poor statistics (in the local uniform Universe, galaxy counts rise roughly as $\text{dex}[0.6 m]$). If our Local Group sits in an underdense region, we should see a lack of galaxies at the very bright end of the galaxy counts, which is brighter than the DENIS and 2MASS complete/reliable extraction limits. However, the error bars in recent studies^{11,12,13}) are too large to draw firm conclusions, and very wide-angle surveys such as DENIS and 2MASS will bring them down.

3.5 Mapping interstellar extinction

Among the many ways one can map the interstellar extinction in our Galaxy, one is to use galaxy counts^{14,15}), since the count normalization is shifted downwards when galaxies are extinguished. Galaxy colors may provide better extinction estimates.⁶)

3.6 Cosmic Dipole

With its full sky coverage, 2MASS will be able to probe the *cosmic dipole*, which computes the vector sum of the flux *vectors* from the detected extragalactic objects, and which should be close to the peculiar acceleration of our galaxy, assuming that galaxy NIR light is a good tracer of the total mass content of the Universe. In particular, it will be interesting to compare the cosmic dipole with that obtained with the sparser IRAS galaxy samples.

4. A spectroscopic followup

There is much to be gained from knowing the third dimension in any galaxy survey. In particular, the statistics of the 3D galaxy distribution can be studied, and projection effects are virtually eliminated, although the 3D statistics are messed up by peculiar velocities. 3D color segregation can be studied as well as the convergence of the cosmic dipole with distance. And finally one gains access to the internal kinematics of structures.

For these reasons, a spectroscopic followup of the DENIS and 2MASS samples are highly desirable. In particular, DENIS will extract with high completeness and reliability over $\simeq 160\,000$ galaxies at $J < 14.4$.⁵⁾ Only 25 000 galaxies are expected in the largest complete and reliable *K*-band sample⁴⁾, although if cooling of the DENIS optics is implemented this Autumn, as scheduled, this number could be multiplied by three to four. The following discussion attempts to optimize the time for obtaining the largest complete *J* selected spectroscopic sample.

4.1 Simulated galaxy samples

To begin, galaxy samples are simulated with random positions in a uniform Universe, random blue galaxy luminosities from a Schechter¹⁶⁾ luminosity function, random bulge/disk ratio, disk inclination, and galactic latitude, plus scatter in the surface brightness versus luminosity relations for bulges and disks. Working separately on bulges and disks, the blue and NIR apparent magnitudes of each component are estimated using standard colors, *k*-corrections (the effect of redshifting a spectrum through a fixed observation wavelength filter), but no luminosity evolution. Samples of typically 25 000 galaxies are simulated with $z < 0.25$ and $L > 10 L_*$, and subsamples of typically a few thousand galaxies are extracted with apparent magnitude limits in the blue or the NIR.

4.2 Mean galaxy surface brightness within fiber apertures

The surface brightness of galaxies are well represented by $\Sigma = \Sigma(0) \exp[(-r/r_1)]^\beta$, where $\beta = 1$ for exponential disks and $\beta = 1/4$ for $r^{1/4}$ bulges. The mean surface magnitude within a circular aperture centered on the galaxy is then

$$\langle \mu \rangle = \mu_0 - 2.5 \log \{ 2[1 - (x+1) \exp(-x)]/x^2 \}, \quad (1)$$

for exponential disks and

$$\langle \mu \rangle = \mu_0 - 2.5 \log(8/[b^8 x^2]) - 2.5 \log \gamma(8, bx^{1/4}), \quad (2)$$

for $r^{1/4}$ bulges. Here, $b = 7.67$ and

$$\gamma(8, bx^{1/4}) = 5040 - \exp(-bx^{1/4}) \sum_{k=0}^7 \frac{7!}{k!} (bx^{1/4})^k, \quad (3)$$

and, in both cases, $x = \theta_{6b}/(2\theta_1)$, with the angular radius $\theta_1 = \text{dex}[-0.2(m - \mu_0)]/c^{1/2}$ is the angular scale length for exponential disks and the angular effective radius for $r^{1/4}$ bulges, and where $c = 2\pi$ for exponential disks and $c = 8! \pi/b^8 = 0.0106$ for $r^{1/4}$ bulges. We correct the mean surface brightness for inclination and internal extinction of the disk, for Galactic extinction, and for k -corrections and cosmological dimming ($\Sigma \sim (1+z)^{-4}$).

Because spectroscopy of nearby galaxies is done in the optical (we know very little of galaxy spectra in the NIR), one has to be careful when making optical observations of a NIR selected sample. Figure 2 shows the optical surface magnitudes (eqs. [1-3], corrected as explained above) versus NIR magnitude for a $J < 14.1$, subsample and illustrates that the lowest surface brightness galaxies (which are the most difficult to obtain spectra for, see below) are distant ellipticals.

4.3 Time constraints for different instruments

The number of spectroscopic nights required to achieve a complete J -limited sample in the southern hemisphere has been estimated for different telescopes in the Southern hemisphere with additional Monte-Carlo simulations. The mean surface magnitudes of galaxies, computed over different fiber sizes, are converted to observing times for continuum $S/N = 5$, assuming that all telescopes have the same transmission from sky to detector, and normalizing to the published¹⁸⁾ performance of FLAIR-II, a 92-fiber spectroscope on the very wide-field (6° Schmidt) UKST telescope in Australia. The maximum time to reach $S/N = 5$ is recorded for each set of N_f galaxies (where N_f is the number of fibers), after the galaxies have been first sorted by galactic latitude.

Figure 3 shows the comparison of the different available (or soon to be) or potential (FIFI, FLAIR IIIa,b,c) instruments. Only 60 to 85 nights are required for an 80000 galaxy sample limited to $J < 13.7$ on an upgrade of FLAIR II, with more fibers and automatic configuration. This would correspond to one year at 50% pressure on the UKST telescope (which is also used for Schmidt plate photographic surveys).

Discussions are currently underway for upgrading FLAIR II and performing a spectroscopic followup to DENIS. These involve Q. Parker and M. Colless in Australia, W. Saunders in Edinburgh, and V. Cayatte, H. Di Nella, R. Kraan-Korteweg, G. Paturel and others in France. Our target is to complete the spectroscopic survey in 2000 or 2001, starting towards the end of the DENIS survey.

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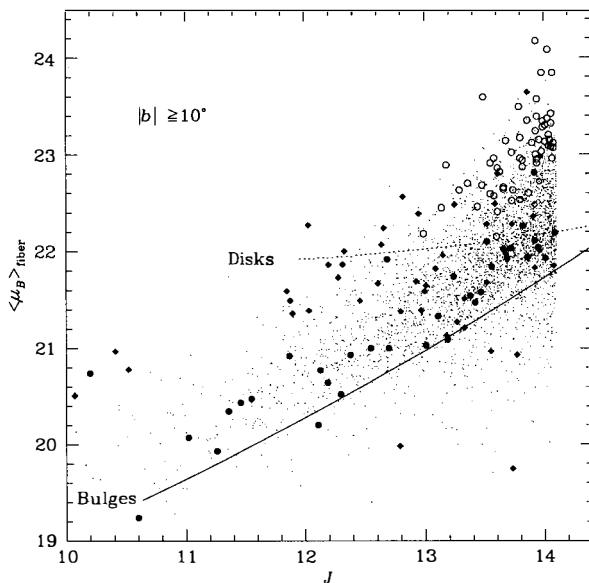


Figure 2. Simulation of surface magnitudes of galaxies, averaged over FLAIR 6.7'' fibers, as a function of NIR J magnitude for an NIR selected selected sample of 3300 galaxies, with galactic latitude $|b| > 10^\circ$. Late-type spiral galaxies ($\geq 90\%$ of disc) are shown as *diamonds* and elliptical galaxies ($\geq 90\%$ of bulge) by *circles*. The *full symbols* correspond to nearby galaxies ($z \leq 0.03$) and the *open symbols* to distant galaxies ($z \geq 0.1$). Galaxies with intermediate bulge/disc ratio, as well as galaxies at intermediate redshift are shown as *points*. The *curves* represent the theoretical relations for nearby galaxies (for bulges we have adopted a luminosity dependent central surface magnitude¹⁷), with colors corresponding to a reddening at the galactic pole of 0.17. Discs and bulges above their respective theoretical curves have greater reddening, cosmological dimming, and k -correction. Discs below the theoretical disc curve are inclined.

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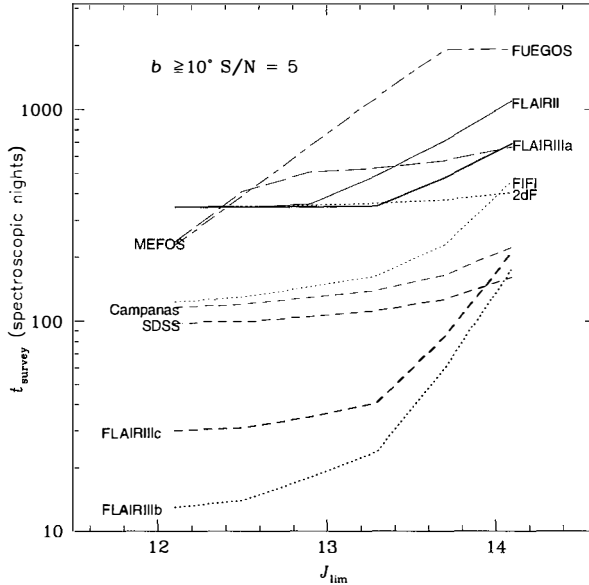


Figure 3. Estimates of time in spectroscopic nights to complete *without loss of galaxies* a survey with $|b| \geq 10^\circ$ and $S/N \geq 5$, using mean surface brightnesses within fibers, for the simulated galaxy sample. FLAIR IIIa would have 150 fibers, with slow day-time configuration. FLAIR IIIb and IIIc would have 250 fibers with respectively 30 and 10 minute on-telescope configuration. FIFI is a copy of MEFOS that could easily be mounted at the SAAO in South Africa.

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