THE TWO MICRON ALL SKY SURVEY (2MASS): OVERVIEW AND STATUS

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1. Introduction

Beginning in early 1997, the Two Micron All Sky Survey (2MASS) project will map the entire sky in the J (1.13 - 1.37 μm), H (1.50 - 1.80 μm), and K_s (2.00 - 2.32 μm) photometric bands to a 3σ limiting sensitivity of 17.1, 16.4 and 15.6 mag., respectively. Often these flux limits are presented as 10σ values (15.8, 15.1, and 14.3 mag. respectively) since this flux level sets the point source completeness (0.99) and reliability (0.9995) requirements. The pixel size for the survey is $2.0''$. The survey cameras (one for each hemisphere) each contain three NICMOS3 arrays which simultaneously image an $8.5' \times 8.5'$ field in all three survey wavebands. The 1.3m survey telescopes scan steadily in declination at a rate of about one arcminute per second while the telescope secondary mirror tilts in the opposite direction to freeze the focal plane position on the sky. Subsequent frames overlap by 84% so that each pixel on the sky is exposed at six dithered positions relative to pixel centers. The frame exposure time is 1.3 seconds.

The survey will operate until 2001. The Infrared Processing and Analysis Center (IPAC) will reduce the raw survey data to three data products for distribution to the scientific community: 1) A point source catalog containing $\sim 10^8$ objects with positions accurate to $<0.5''$; 2) An extended source catalog containing $\sim 10^6$ objects; and 3) An image product consisting of the co-added survey data presented as 1024x512 FITS images with $1''$ pixels.

The performance of the survey relative to its stated goals has been extensively tested and verified with a prototype survey camera operated at the KPNO 50" telescope. To date this camera has surveyed more than 200 square degrees of sky in a variety of environments.

The details of the scientific rationale for and the technical implementation of 2MASS have been outlined in the an earlier incarnation of these proceedings (Kleinmann *et al.* 1994). Many of the objectives of DENIS parallel those of 2MASS and the present volume contains many illuminating examples of the scientific drivers for these surveys.

Rather than outline these more detailed papers, this contribution will serve to highlight some of the more unique and/or recently developed aspects of the 2MASS hardware implementation, outline the 2MASS survey strategy, and report on the current development status of the project.

2. 2MASS Implementation

2.1. SURVEY PROTOTYPING

The development of 2MASS has benefited greatly from the availability of a single-array prototype camera which, in almost every respect, reproduces the optics and electronics of the three-array cameras to be used the the survey itself. The infrared array behind the filter wheel in the prototype camera is a Rockwell 256x256 NICMOS3 HgCdTe hybrid. In its most recent (and final) incarnation the prototype camera incorporates a seven-element optical design produced by Telic Optics of Marlborough, Massachusetts and shown in figure 1. The optical elements are calcium fluoride and water free fused silica. All surfaces are spherical and of relatively modest curvature, making alignment tolerances rather forgiving. The optics place >90% of the light from a laboratory point source in single pixel for any of the three 2MASS survey bands. At the f/13.5 cassegrain focus of the Kitt Peak National Observatory 50" telescope (where 2MASS prototyping has been conducted) a NICMOS3 pixel corresponds to $2.0''$ on the sky. All lenses are anti-reflection coated to yield a transmission of >98% through each element in all three wavebands. The curvatures of the optical surfaces were constrained to produce a system free of all but the most diffuse reflection

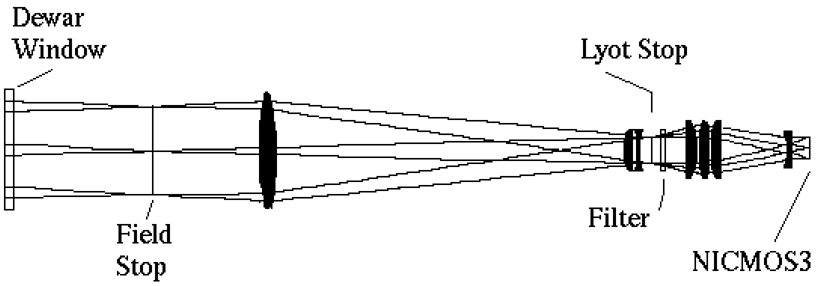

Figure 1. Prototype camera optics.

ghosts. The system has a cryogenic pupil stop located just behind the infrared interference filter and a cryogenic field stop located forward of all of the optical elements at the telescope cassegrain focus.

This new optical design saw extensive use at the 50" telescope during a 21 night prototyping run in April/May 1995. During that time >100 square degrees of sky were imaged in all three survey bands. Subsequent analyses of these data has demonstrated that this version of the camera meets or exceeds the Level 1 specifications set for the survey. This exemplary performance has led to the adoption of these optics into the final three-array survey cameras. Infrared Laboratories provided the electronics for the prototype camera. The survey cameras will use a three channel version of the Infrared Laboratories system.

2.2. 2MASS CAMERAS

Two three-array survey cameras are currently being fabricated for 2MASS by Telic Optics. Since the optics in the prototype camera functioned well in all three survey bands, the three-array camera design literally triplicates the prototype camera design. All three bands have the large first element in common. Following this element dichroic mirrors divide the bands. Three identical sets of the remaining optical elements follow the dichroics (Figure 2).

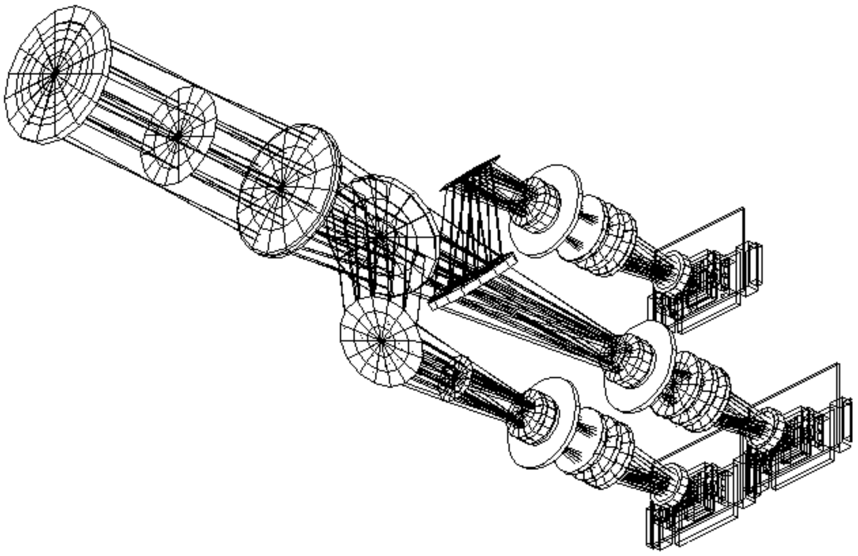

Figure 2. Survey camera optics

The dichroics transmit/reflect >97% of the incident light and permit each band to view the identical region of the sky. A number of degrees of freedom permit alignment of boresites, system pupils, and the cold field stop. In particular, the beam steering mirrors which follow the dichroics permit precise adjustment of the band-to-band boresite, enabling a common field of view to within a few pixels. Rotation stages on two of the three detector mounts permit precision alignment of the three array's rotation about their respective optical axes. This alignment insures that each of the six separate images obtained for a given star fall at different locations relative to a pixel center, since the arrays will be oriented such that a star crosses exactly one column as it moves down the arrays. Pupil alignment is accomplished by precision placement of the arrays relative to their respective optical axes which is accomplished on a large coordinate measuring machine. The cryogenic pupil stop is undersized so that the system illuminates 90% of the primary mirror diameter. An uplooking LN_2 cryostat with an annular 5.5 liter cryogen reservoir houses these optics. The dewar has a hold time in excess of 24 hours.

The Infrared Laboratories three-array readout electronics clock all 12 quadrants of the three arrays simultaneously. Twelve 16-bit analog-to-digital converters digitize the signals with a pixel dwell time of 3μs. A full readout of the array requires 52ms. Images are acquired using doubly correlated sampling consisting a single readout immediately following array reset and a second readout 1.3 seconds later. The prototype observations have shown that the first readout can be used alone as a 52ms exposure to produce calibrated photometry of sources that saturate the array in the 1.3s exposure time, thus extending the dynamic range of the survey by $\sim$4 magnitudes.

At the time of this writing the first survey camera is undergoing final alignment and test in preparation for a test observing run at the Kitt Peak 50" telescope in about a month's time. All parts of the second survey camera have been fabricated and assembly of this camera will begin as soon as the first camera has been commissioned.

2.3. 2MASS TELESCOPES

The 2MASS project is purchasing two equatorial 1.3m telescopes from M3 Engineering of Tucson, Arizona. Each telescope incorporates a zero-expansion $f/2$ parabolic ULE primary with a ULE secondary designed to yield a cassegrain focal ratio of $f/13.5$. Slewing and tracking are implemented via servo motors attached to friction drives. Each axis will be encoded to a small fraction of an arcsecond by Heindenhain encoding tapes whose output will close the feedback loop to the servomechanisms. The telescope frame is athermalized via a metering scheme which uses zero expansion materials to maintain the separation between the primary and secondary mirror. Residual focus variations will be removed by monitoring the temperature of principal members of the telescope structure. In survey operations the telescope tracks in right ascension while the telescope scans at $\sim 1'$/s in declination. Each telescope is equipped with a scanning secondary mirror which, smoothly tilts to counter the declination motion of the telescope for the 1.3s exposure time. During array readout the secondary flies back to its starting position to freeze a new region of the sky displaced by 16% of the height of the array so each star is imaged six times. An IBM-compatible PC running PCTCS on the dome floor will control the telescope.

At the time of this writing the first telescope is being assembled at M3 engineering while the spherical grinding of the primary mirror is complete and aspherizing has begun. This first telescope will be delivered to Mt. Hopkins at the end of 1996.

3. Survey Strategy

3.1. MAPPING

The primary unit of 2MASS data will be a $6°$ long scan in declination. The scan will be $8.5'$ wide – corresponding to the extent of the array in the RA direction. The sky will be mapped in declination bands which overlap by $\sim 20'$ at the north and south ends. Within a declination band the strips will overlap by 10% ($0.85'$) in RA. Because weather statistics for the Southern Hemisphere suggest that the southern part of 2MASS will run more efficiently than in the North, the dividing line between "hemispheres" for 2MASS will be at $+12°$. The hemispheres will overlap by two degrees permitting direct tests of uniformity between hemispheres all around the sky.

If time permits, at the completion of the survey the secondary mirror will be rotated by $90°$ to conduct scans around the sky in the right ascension direction through the center of each declination band. These observations will provide spatial correlation between the $6°$ long declination strips and improve uniformity around the sky.

3.2. CALIBRATION

A 2MASS calibration observation consists of six repeated scans of a $1°$ strip obtained in the standard survey scanning mode with the standard survey exposure time. The 2MASS calibration strategy is under development at this time. Current plans call for 12 "standard strips" in each hemisphere distributed evenly in RA plus two standard strips passing through each of the celestial poles (to permit transparency measurements at constant airmass at any instant during the survey). Each strip will contain a flux calibrator, however *every* star in the strip will be used to determine airmass and zero-point corrections. Standard observations will be made in pairs at no longer than 2 hour intervals. DENIS and 2MASS have already begun discussions to coordinate calibration sources between the projects in order to establish a common calibration and present results on a uniform photometric system.

3.3. VERIFICATION OF DATA QUALITY

During survey operations 2MASS must determine 1) whether a given night's data is of sufficiently good quality to warrant further reduction and 2) that the long term uniformity and calibration of the survey remains consistent over the four year survey duration. On a nightly basis, the telescopes will acquire data whenever the potential for photometric conditions exist. An on-site scheduling computer will establish an observing program for each night. Unobserved strips will be give priority according to their accessibility over the remaining lifetime of the survey. Software either on site or at IPAC will examine the standard star observations and stars appearing in the overlap region between strips to determine whether the data appears of good quality internally. In addition, the output of a boresited 5μm photometer will be recorded all night and used to detect light cirrus. Finally the system operator will include a log file reporting personal observations and reports of other observers on the mountain.

The longer term stability of the 2MASS system will be monitored by intercomparison of all observations of the standard strips discussed above. In addition, 2MASS will target ten $6^\circ \times 6^\circ$ regions for repeated observation. The repeatability of these "mini-surveys," selected to sample a variety of source-count environments, will be a further check on the overall stability of the 2MASS reductions. Finally, the two independent hemispheres will overlap by 2° providing a test of uniformity around the entire sky.

4. Data Products and Distribution

Tapes will be delivered to IPAC directly from the mountain(s). IPAC will reduce the survey data day-for-day and produce three data products for distribution to the scientific community: 1) A point source catalog containing $\sim 10^8$ objects with positions accurate to $<0.5''$; 2) An extended source catalog containing $\sim 10^6$ objects; and 3) An image product consisting of the co-added survey data presented as 1024x512 FITS images with $1''$ pixels. These data will be distributed to the astronomical community by the NSSDC or an equivalent agency.

The first data release will occur 18 months following the initiation of survey observations. This first release will include the first 12 months of survey data products. Subsequent releases are scheduled at 12 month intervals through the life of the survey. IPAC will also archive the raw survey data for future use. At the end of the survey the 2MASS project plan calls for a global reprocessing of the entire database to supplant the incremental releases described above.

5. 2MASS Science

2MASS is funded to produce a uniform infrared image of the entire sky and data products meeting the project's Level 1 specifications. The proposal which initiated 2MASS outlined the science *enabled* by 2MASS but did not request funding to carry out those programs and did not establish a proprietary period for scientific use of the data by the project staff. Since some level of scientific analysis is desirable in order to ferret out insidious problems with the data, the science team has carried out initial follow-up of the prototype camera data. For similar reasons the IRMOWG and the

2MASS External Review board have recommended that 2MASS pursue funding for "key projects" which 1) exercise the data products, 2) generate tools to improve the accessibility of the data to the broader community, and 3) provide reduced datasets (e.g. a list of sources with anomalous infrared colors) for observational follow-up by the community. The 2MASS science team has developed key project proposals in each of the major survey science areas: extragalactic structure, rare color-selected objects, and Galactic structure.

Initial follow-up observations of 2MASS prototyping data have revealed a range of interesting phenomena. Spectroscopy of sources selected to have anomalous infrared and infrared/visible colors (using digitized plates as the basis for the visible identifications) have revealed an extremely red infrared-luminous quasar and a number of extremely low-mass stars, including the coolest field star discovered to date (Kirkpatrick *et al.* 1996). A redshift survey of sources in the direction of the Coma galaxy cluster and Abell 262 have revealed an unexpected wealth of structure out to z=0.2 (Schneider *et al.*, this volume). These observations, which derive from only the initial efforts to examine the tiny fraction of the sky observed during the prototyping phase of 2MASS, hint at the richness of the vast databases to come from 2MASS and DENIS.

6. Project Schedule

2MASS will begin operations in Northern Hemisphere in the Spring of 1997. The Northern Hemisphere site is near the existing 48/60" telescopes at Mt. Hopkins. This northern hemisphere facility will operate for just under 4 years, completing its portion of the survey in late 2000. This survey start date places the first release of 2MASS data products in late 1998.

2MASS will begin in the South in Spring 1998 at a site at Cerro Tololo which is adjacent to the GONG installation. Owing to better weather at the southern site, the southern component of the survey will end before the northern component in spite of its later start and greater sky coverage.

References

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