

GLIMPSE. I. An *SIRTF* Legacy Project to Map the Inner Galaxy

ROBERT A. BENJAMIN,¹ E. CHURCHWELL,² BRIAN L. BABLER,² T. M. BANIA,³ DAN P. CLEMENS,³ MARTIN COHEN,⁴
JOHN M. DICKEY,⁵ RÉMY INDEBETOUW,² JAMES M. JACKSON,³ HENRY A. KOBULNICKY,⁶ ALEX LAZARIAN,²
A. P. MARSTON,⁷ JOHN S. MATHIS,² MARILYN R. MEADE,² SARA SEAGER,⁸ S. R. STOLOY,⁷ C. WATSON,²
BARBARA A. WHITNEY,⁹ MICHAEL J. WOLFF,⁹ AND MARK G. WOLFIRE¹⁰

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ABSTRACT. The Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE), a *Space Infrared Telescope Facility (SIRTF)* Legacy Science Program, will be a fully sampled, confusion-limited infrared survey of $\frac{2}{3}$ of the inner Galactic disk with a pixel resolution of $\sim 1''$ using the Infrared Array Camera at 3.6, 4.5, 5.8, and 8.0 μm . The survey will cover Galactic latitudes $|b| \leq 1^\circ$ and longitudes $|l| = 10^\circ\text{--}65^\circ$ (both sides of the Galactic center). The survey area contains the outer ends of the Galactic bar, the Galactic molecular ring, and the inner spiral arms. The GLIMPSE team will process these data to produce a point-source catalog, a point-source data archive, and a set of mosaicked images. We summarize our observing strategy, give details of our data products, and summarize some of the principal science questions that will be addressed using GLIMPSE data. Up-to-date documentation, survey progress, and information on complementary data sets are available on the GLIMPSE Web site.

1. MOTIVATION FOR GLIMPSE

The inner workings of our own Galaxy are as mysterious as those of galaxies located millions of light-years away, mainly because of our unfavorable location in the midplane outskirts of the Milky Way's dusty disk. The structure of the Galactic disk has been determined primarily from the distributions of atomic hydrogen (Westerhout 1957) and carbon monoxide, which together contain no more than about 10% of the visible mass of the Galaxy (Scoville & Solomon 1975). The Galaxy is a typical luminous spiral, but its stellar distribution, particularly in the inner quadrants, is poorly known. For example, although there is significant evidence that the Galaxy has a

molecular ring (Scoville & Solomon 1975), the number of stars recently formed in this ring and the resultant appearance of the Galaxy's spiral arms to an outside observer are unknown.

The principal impediment to cataloging the stellar content of the inner Galaxy has been dust obscuration of the visible light from stars. What has been needed is a survey with high sensitivity and angular resolution in the middle infrared and longer wavelengths. The recently completed Two Micron All-Sky Survey (2MASS; Cutri et al. 2001)¹¹ has been an important step in this process, producing a view of the inner Galaxy at wavelengths as long as 2.2 μm . Yet even at these wavelengths, the extinction due to dust significantly compromises our ability to probe the stellar content of the inner Galaxy and obtain accurate measurements of fundamental Galactic parameters.

The Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE),¹² a Legacy Project using the *Space Infrared Telescope Facility (SIRTF)* (see Gallagher, Irace, & Werner 2003 for a description of the full facility) is a project to map the infrared emission from the inner Galaxy over the two strips $|b| \leq 1^\circ$ and $|l| = 10^\circ\text{--}65^\circ$ using the Infrared Array Camera (IRAC; see Fazio et al. 1998). Of all the *SIRTF* Legacy programs, this survey will cover the largest area on the sky (some 220 deg²) and will yield the most panoramic images. With a total observing time of approximately 400 hr, the survey will consist of over 80,000 pointings, each resulting in four simultaneous IRAC images at 3.6, 4.5, 5.8, and 8.0 μm . The GLIMPSE team will use these data to produce a highly reliable

¹ Department of Physics, University of Wisconsin–Madison, 1150 University Avenue, Madison, WI 53706; benjamin@physics.wisc.edu.

² Department of Astronomy, University of Wisconsin–Madison, 475 North Charter Street, Madison, WI 53706.

³ Institute for Astrophysical Research, Boston University, 725 Commonwealth Avenue, Boston, MA 02215.

⁴ Radio Astronomy Laboratory, University of California, Berkeley, CA 94720.

⁵ Astronomy Department, University of Minnesota, 116 Church Street SE, Minneapolis, MN 55455.

⁶ Department of Physics and Astronomy, University of Wyoming, Laramie, WY 82071.

⁷ *SIRTF* Science Center, California Institute of Technology, MS 220-6, Pasadena, CA 91125.

⁸ Carnegie Institution of Washington, Department of Terrestrial Magnetism, 5241 Broad Branch Road NW, Washington, DC 20015.

⁹ Space Science Institute, 3100 Marine Street, Suite A353, Boulder, CO 80303-1058.

¹⁰ Department of Astronomy, University of Maryland, College Park, MD 20742.

¹¹ <http://www.ipac.caltech.edu/2mass>.

¹² <http://www.astro.wisc.edu/glimpse>.

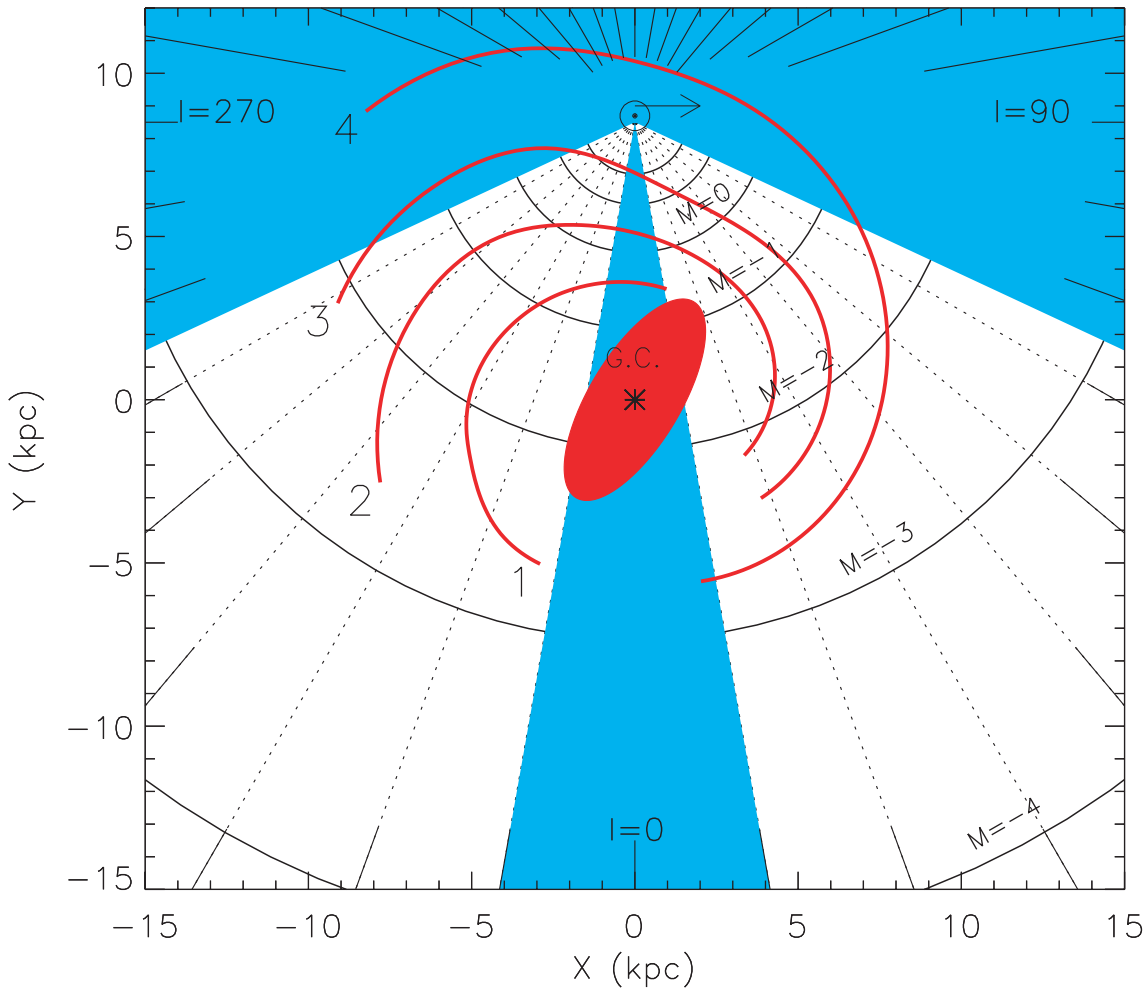


FIG. 1.—Galactic plane, with the Sun at the top, and the direction of solar motion noted with an arrow. The area covered by GLIMPSE is unshaded. The dotted lines are intervals of 10° in longitude. The solid circles indicate the 5σ detection distance for objects with absolute magnitude $M_{8,\mu m} = 2, 1, \dots, -4$ assuming no extinction. Young OB stars ($M = -4.35$) and M giants ($M = -4.24$) will be visible throughout the Galaxy. The approximate positions of Galactic spiral arms (Taylor & Cordes 1993) are indicated with bold lines and are numbered: (1) Norma arm, (2) Scutum-Crux arm, (3) Sagittarius arm, and (4) Perseus arm. The central oval represents the approximate extent of the central bar (Gerhard 2002; Cole & Weinberg 2002), with the Galactic center marked with an asterisk.

point-source catalog, a somewhat deeper point-source archive, a set of mosaicked images, and associated analysis software.

The survey area was chosen to include all of the major known or suspected stellar components of the inner Galaxy (except the central bulge), namely, the outer ends of the Galactic bar, the molecular ring at a Galactocentric radius of $\sim 3\text{--}5$ kpc, the inner disk, and the inner spiral arms and spiral-arm tangencies (see Fig. 1). The inner $\pm 10^\circ$ of the Galaxy are excluded from our survey because of the high background and confusion present there.

The GLIMPSE team will focus on two central science questions:

1. *What is the structure of the inner Galaxy?* What is the structure of the disk and molecular ring? What are the number and locations of spiral arms? What is the nature of the central bar as traced by the spatial distribution of stars and infra-

red–bright star formation regions? In particular, we will address the question of whether the Galaxy is a ringed galaxy by correlating the stellar content with studies of the molecular ring of the Galaxy (Clemens et al. 2000).

2. *What are the statistics and physics of star formation?* How does the nature of star formation depend on mass, stage of evolution, and location in the Milky Way? What will an unbiased infrared survey with well over 2000 star formation regions reveal about the earliest evolutionary stages of star formation? How does the infrared emission change during each of the principal stages of star formation?

The major purpose for GLIMPSE is to provide the community with a Legacy data set complete to a well-defined flux limit suitable for a wide variety of astrophysical investigations. These might encompass population studies of different classes of Galactic objects, including regions of low- and high-mass

TABLE 1
OBJECTS IN THE GLIMPSE SURVEY AREA

Object Type	Number Known in GLIMPSE Region	Examples
<i>MSX</i> point sources	61,321	
<i>IRAS</i> point sources	15,501	
H II regions	1174	M16 (Eagle Nebula), M17, W43, W49, W51
<i>ROSAT</i> point sources	459	
Radio pulsars	264	
Dark clouds	210	Coalsack, Vulpecula Rift, B48, LD N485
Galaxies	157	IRAS 16232–4917, G312.11–0.20
<i>ASCA</i> point sources	144	
Supernova remnants	100	Kes 69, RCW 103, CTB 37A/B, Carina
O/B stars	98	BD –20°5020, BD –15°4930, BD +31°3921
Open clusters	76	NGC 3572, Sco OB2, Sct OB2, Westerlund 1
Planetary nebulae	65	NGC 6537, NGC 6842, IC 4637
Wolf-Rayet stars	50	IC 14-17, Vyl 3, W43 1, The 3
Globular clusters	1	2MASS GC 01

NOTE.—A listing of the objects in the GLIMPSE region with links to various databases and maps showing the positions of these objects can be found at the GLIMPSE Web site, <http://www.astro.wisc.edu/glimpse>.

star formation, highly evolved asymptotic giant branch (AGB) and OH/IR stars, stars with circumstellar dust shells, cool stars of all luminosities, photodissociation regions (PDRs), proto-planetary nebulae, planetary nebulae, Wolf-Rayet stars, open clusters, and supernova remnants. Table 1 lists several classes of objects and the number of these objects already known to exist in the GLIMPSE survey area. GLIMPSE data will also be used to study the infrared dark clouds (Egan et al. 1998) revealed by the *Midcourse Space Experiment* (*MSX*) and the *Infrared Space Observatory* (*ISO*) and will extend the catalog of these objects to smaller sizes and fainter limits.

We expect that GLIMPSE data will be used by the community for investigations that we cannot anticipate. Of all the directions in the sky, the inner Galaxy has heretofore been the most inaccessible because of dust obscuration. The GLIMPSE program will reveal for the first time a wealth of completely new stars, clusters, and galaxies. It is this element of serendipity that makes GLIMPSE a particularly exciting endeavor!

In this paper, we provide a description of the GLIMPSE observing plan (§ 2.1), data processing (§ 2.2), and data products (§ 2.3). Next, we give details on the scientific goals and challenges of the GLIMPSE survey, including high-mass star formation in the inner Galaxy (§ 3.1.1), Galactic structure (§ 3.1.2), Legacy science (§ 3.2), and a description of the data sets that complement GLIMPSE (§ 3.3). A summary is given in § 4.

2. PROJECT DESCRIPTION

SIRTF and IRAC will be used to image two long strips comprising 220 deg² at wavelengths centered on 3.6, 4.5, 5.8, and 8.0 μ m. The area surveyed by GLIMPSE ($|b| \leq 1^\circ$, $|l| = 10^\circ\text{--}65^\circ$) contains most of the star formation activity of the Galaxy, the outer ends of the central bar, all of the Galactic molecular ring, and four spiral arm tangencies. The principal characteristics of GLIMPSE are listed in Table 2. The im-

provements in sensitivity, angular resolution, and areal coverage afforded by GLIMPSE over previous infrared surveys of the Galactic plane are shown in Figure 2.

The GLIMPSE team will provide the following products: a high-reliability GLIMPSE Point Source Catalog containing about 10 million objects, a GLIMPSE Point Source Archive (5σ), and a mosaicked image atlas of the entire surveyed area in all four IRAC bands. All these data products will be made available via the *SIRTF* Science Center (SSC). In addition, a set of Web-accessed modeling tools will permit users to interpret *SIRTF* and other IR data.

Here we discuss the GLIMPSE implementation, data-processing plans, and resulting data products. Up-to-date information on the progress of GLIMPSE observations (including a graphical survey tracker), data reduction, and data releases can be found at the GLIMPSE Web site.

2.1. GLIMPSE Implementation

The orbit, orientation, and viewing limits on *SIRTF* conspire to make mapping the Galactic plane a complex process. Furthermore, the spectacular sensitivity of IRAC/*SIRTF* means that only exceedingly short exposures of the Galactic plane will not be saturated. These issues drive much of the GLIMPSE observing implementation.

Survey strategy.—During standard *SIRTF* operations, IRAC “campaigns,” lasting 10 days to 2 weeks, will be scheduled. A fraction of these IRAC campaigns during the first year will be devoted to the GLIMPSE program, which will observe many IRAC frames tiled together into $\sim 15^\circ \times 2^\circ$ segments of the Galactic plane. Each ~ 30 deg² segment will consist of 35–45 “chained” astronomical observing requests (AORs).¹³ Each

¹³ “Chained” AORs must be carried out within a certain amount of time of each other. For GLIMPSE, the typical maximum separation between AORs is 3 hr.

TABLE 2
SUMMARY OF PRINCIPAL GLIMPSE CHARACTERISTICS

Characteristic	Description
Galactic longitude limits	$ l = 10^\circ\text{--}65^\circ$
Galactic latitude limits	$ b < 1^\circ$
Total survey area	220 deg ²
Total survey time	400 hr
Total resolution elements per band	$\sim 2 \times 10^9$
Total number of IRAC frames per band	$\sim 80,000$
IRAC frame size	5'17 × 5'17 (256 × 256 pixels)
Pixel resolution	1'2 × 1'2
Frame time per visit	2 s
Number of visits per position	2
Frame overlap ^a	14"4 (12 pixels)
IRAC wave bands	3.6, 4.5, 5.8, 8.0 μm
5 σ sensitivity (4 s)	0.2, 0.2, 0.4, 0.4 mJy
Estimated completeness limit for GPSC ^b	1.0, 1.5, 2.0, 2.5 mJy
Saturation limits	180, 190, 570, 470 mJy
Galactic features covered	Outer ends of Galactic bar, molecular ring, four spiral arm tangencies: Norma ($l = 333^\circ$), Scutum-Crux ($l = 30^\circ, 320^\circ$), Sagittarius-Carina ($l = 50^\circ$)

^a Subject to change after the observing strategy validation period.

^b Flux level necessary to achieve 99.5% reliability based on simulated data. These values are subject to change after the observing strategy validation period.

AOR will cover a narrow rectangular strip $0.3^\circ \times (2^\circ\text{--}3^\circ)$ spanning $b \cong -1^\circ$ to $b \cong +1^\circ$, but inclined to the Galactic plane. The inclination angle of the AOR to the Galactic plane depends upon the spacecraft roll angle. For GLIMPSE observations, the roll angle will lie between 15° and 50° from Galactic north. Example AOR sky coverage in the direction of the star formation region W51 is shown in Figure 3.

Each IRAC pointing simultaneously images two adjacent $5'17 \times 5'17$ fields in two bands. An IRAC frame has 256×256 pixels; the 3.6 and 5.8 μm fields coincide on the

sky and the 4.5 and 8.0 μm fields coincide on the sky, but the frame edges of the two fields are separated by 1'.5. The total integration time per position is 2 s. The observations will be stepped by half-frames (128 pixels; 2'.58) along the long axis of the AOR (which could be the spacecraft X- or Y-axis, depending upon the roll angle). Every sky direction in the GLIMPSE region will be visited at least twice. The time separation between the two visits will range from 20 s (the time between pointings) to 3 hr (the time between AORs). The frame overlap along the short axis of the AOR will be 14".4 (12 pixels).

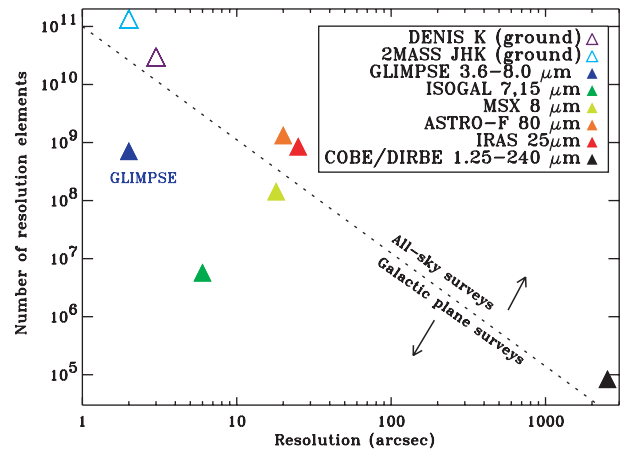
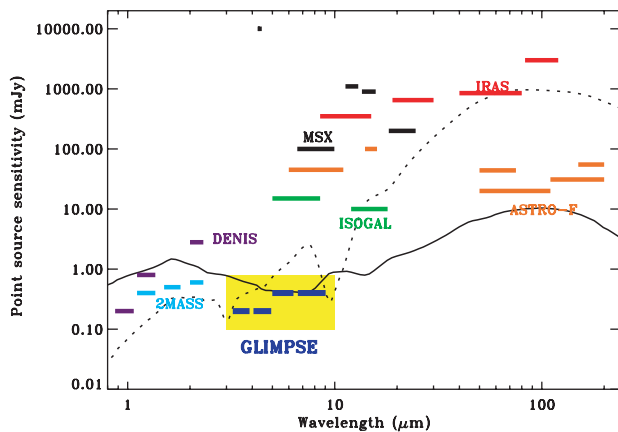


FIG. 2.—(a) Comparison of the GLIMPSE sensitivity limit to the sensitivity of other ground- and space-based infrared surveys. This shows the good match in sensitivity between GLIMPSE and 2MASS. The curves show model spectra of B. Whitney et al. (2003, in preparation) for a $1 L_\odot$ T Tauri star at a distance of 0.7 kpc (solid curve) and a deeply embedded $1 L_\odot$ protostar at a distance of 0.6 kpc (dotted curve). (b) Number of resolution elements vs. resolution for GLIMPSE and other infrared surveys. GLIMPSE will have the largest number of resolution elements of any Galactic plane-only survey and a comparable number of resolution elements to several space-based all-sky infrared surveys.

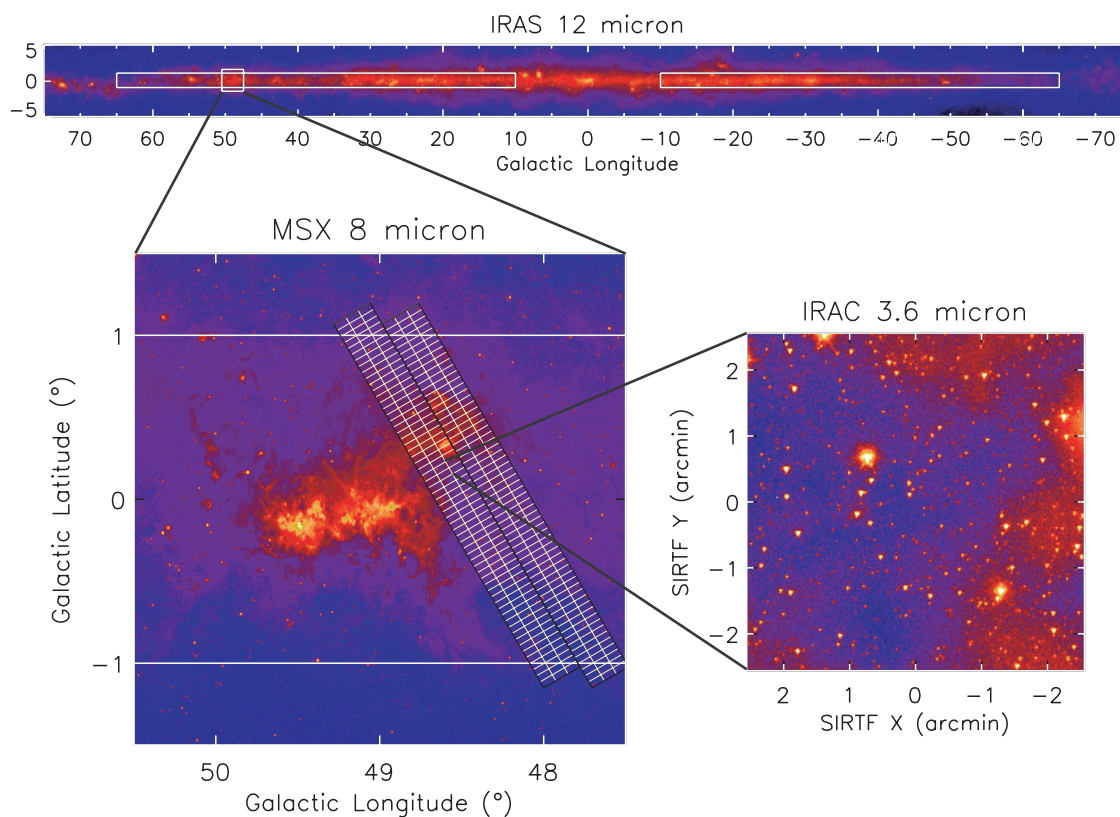


FIG. 3.—Upper figure shows an *IRAS* 12 μm image of the Galactic plane, with long rectangular boxes indicating the region to be covered by GLIMPSE. The subregion on the lower left is an *MSX* 8 μm map (Price et al. 2001) of the star formation region W51. This map shows the location of a set of tiled *IRAC* frames across the image. The black rectangle represents one AOR consisting of about 180 individual $5' \times 5'$ frames. A 15° segment in longitude will typically require about 40 AORs. The subregion of this plot is a synthetic GLIMPSE *IRAC* 3.6 μm frame ($1''$ pixel resolution) containing all the 2MASS point sources in this direction, supplemented with additional, fainter sources using the SKY model described in Wainscoat et al. (1992). The diffuse flux is taken from *MSX* observations.

A typical AOR will take 1.5 hr to complete, yielding $(3\text{--}4) \times (47\text{--}70)$ *IRAC* frames per band. Each $\sim 15^\circ \times 2^\circ$ segment of the Galactic plane will require 35–45 AORs; the entire survey will require eight segments.

Observing strategy validation.—Time will be scheduled during early *SIRTF* operations to validate our observing strategy (OSV). The GLIMPSE OSV region will be chosen to sample a range of stellar densities and diffuse background levels characteristic of the inner Galactic plane. Regions of particularly high stellar density and diffuse background will be included to assess our strategy in the most challenging cases. The OSV will view either W51, G284.3–0.3, G305.2+0.2, or NGC 6334, depending upon *SIRTF* launch date. The goal of these observations is to assure that GLIMPSE data will have the highest reliability point-source extraction and the greatest possible sky coverage, and to prevent the occurrence of gaps in the survey area. GLIMPSE reliability and completeness calculations, which have been based on simulated data, will be tested by these observations. The OSV will consist of four $1^\circ \times 0^\circ.17$ AORs nearly identical to normal GLIMPSE AORs. These will be repeated with varying frame offsets (along the strip direction) and overlaps (between strips). Finally,

GLIMPSE OSV will perform a single $1^\circ \times 0^\circ.17$ AOR to allow us to evaluate the pointing reconstruction accuracy for the full half-hour that it takes to do a single diagonal band across the Galactic plane, testing roll angle uncertainties between AORs, and determining criteria for establishing reliability and completeness. At the end of the OSV period, the outer longitude limits of the survey may be adjusted so that the total survey time does not exceed 400 hr.

Frame details.—The simulated 3.6 μm *IRAC* frame for the W51 region shown in Figure 3 illustrates both the wealth of detail that GLIMPSE will uncover and the significant challenges for processing and analyzing these data. In this region, there are 400–600 2MASS sources per frame, all of which are detectable by GLIMPSE. (See Table 3 for the 5σ sensitivities and estimated flux limits for 99.5% reliability.) Examination of 2MASS and *MSX* data for this region indicates that we should expect two to four saturated sources per frame in the 3.6 μm band, decreasing to an average of one saturated source per frame in the 8.0 μm band.

Timetable and survey tracking.—For our timetable, we give the dates relative to the launch date ($L + n$ months). The OSV data, to validate the survey strategy for GLIMPSE, will be

TABLE 3
GLIMPSE/IRAC, 2MASS, AND MSX CHARACTERISTICS

Survey/Band	λ (μm)	Bandwidth (μm)	Zero Magnitude ^a (Jy)	5 σ Sensitivity (mJy)	Completeness Limit (mJy)	Saturation Limit (mJy)	$A_{\lambda}/N(H)^b$ (10^{-22} cm ² mag)	A_{λ}/A_V^b (10^{-22} cm ² mag)	A_{λ}/A_V^c (10^{-22} cm ² mag)
2MASS/J	1.24	0.25	1592	0.4	0.3–0.8	25230	1.482	0.293	0.293
2MASS/H	1.66	0.30	1024	0.5	0.4–0.9	25720	0.959	0.190	0.190
2MASS/K	2.16	0.32	667	0.6	0.5–1.3	26550	0.593	0.117	0.117
GLIMPSE/IRAC 1	3.55	0.66	289	0.2 ^d	0.4–1.0 ^e	180 ^f	0.237	0.047	0.058
GLIMPSE/IRAC 2	4.49	0.88	183	0.2 ^d	0.7–1.5 ^e	190 ^f	0.153	0.030	0.053
GLIMPSE/IRAC 3	5.66	1.32	131	0.4 ^d	1.0–2.0 ^e	570 ^f	0.103	0.020	0.053
GLIMPSE/IRAC 4	7.84	2.40	71	0.4 ^d	1.2–2.5 ^e	470 ^f	0.161	0.032	0.053
MSX/band A	8.28	3.36	58	30	60	400,000	0.022	0.044	0.053

^a Zero magnitude for *J*, *H*, *K* from 2MASS Explanatory Supplement. Zero magnitude from *MSX* from Cohen, Hammersley, & Egan 2000. IRAC zero magnitudes are interpolated from Table 7.5 in Tokunaga 2000; these may differ by as much as 13% from the final adopted values (M. Cohen 2002, private communication).

^b Extinction curve from Li & Draine 2001

^c Extinction curve from Lutz et al. 1996.

^d 5 σ sensitivity for a 4 s integration using IRAC.

^e Flux limits for the Point Source Catalog/Archive are based on assuming a reliability of ≥ 0.995 for the Point Source Catalog and are based on simulations. Limits may change after observing strategy validation period.

^f Diffuse source saturation limit for GLIMPSE/IRAC bands in units of MJy sr^{-1} can be obtained by multiplying the point-source number (in mJy) by $30/\sqrt{N_{\text{pix}}}$, where N_{pix} is the number of pixels in the point-source point-spread function; $30/\sqrt{N_{\text{pix}}} = 9.2$ for band 1 and decreases to 7.0 for band 4.

acquired at approximately $L + 4$. Data acquisition for the full survey will begin after OSV data are analyzed and the survey strategy is validated, and will continue for about 9 months. The observability of a section of the Galactic plane as a function of Galactic longitude and time of year is shown in Figure 4.

The first installment of the GLIMPSE Point Source Catalog will be delivered to SSC at $L + 9$; the first installment of the mosaicked data and GLIMPSE Point Source Archive will be delivered at $L + 15$. Updates to each of these data products will be provided at 6 month intervals after the first release dates. The final version of all GLIMPSE data products will be delivered to SSC at $L + 27$. Documentation of the GLIMPSE survey will be available shortly after launch ($L + 2$); updates will be provided with the data releases. A preliminary version of the GLIMPSE Legacy Science Data Products document is

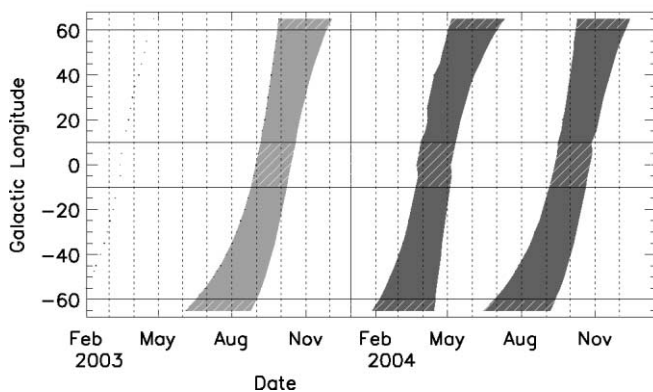


FIG. 4.—Visibility of the Galactic plane to *SIRTf* as a function of date and Galactic longitude. This can be used to judge when a particular part of the GLIMPSE region is likely to be observed.

already available on our Web site and will be available from the *SIRTf* Science Center.

2.2. Data Processing

The SSC will deliver basic calibrated data (BCD) from the GLIMPSE IRAC observations to the GLIMPSE team. BCD will have gone through the following steps: validation, addition of header keywords, sense of InSb flux flipped, conversion to floating point, correction for dichroic flip, normalization by Fowler number and barrel shifts, corrections of electronic bandwidth limitations, subtraction of dark/bias frames, correction for multiplexer bleed, correction for first-frame effects, linearization, flattening, detection of radiation hits, subtraction of sky darks, flux calibration, and detection of latents. The positional information will be good to $1''.4$, and the photometric accuracy should be better than 10% early in the mission. BCD will also contain several ancillary data files, including the raw data, and several mask images that contain information on cosmic rays, linearity corrections, etc. A complete description of the processing that goes into generating the BCD is given in § 6.3 of the *SIRTf* Observers' Manual.¹⁴

The GLIMPSE team will further process these data using an automated pipeline (a “post-BCD” pipeline) to correct for remaining instrumental artifacts, extract and cross-identify point sources, and mosaic the images. The resulting GLIMPSE Point Source Catalog and Archive and the set of mosaicked images will be released to the astronomical community via the SSC. These released data will be more useful than the original BCD, since they will benefit from the GLIMPSE team's experience in analyzing IRAC data in crowded and confused

¹⁴ <http://sirtf.caltech.edu/SSC/documents/som>.

fields that have bright and positionally varying background emission.

The data reduction will occur at the University of Wisconsin–Madison using a network of LINUX workstations. The GLIMPSE pipeline is parallelized and will simultaneously use multiple processors; data flow will be controlled using OPUS pipeline software (Swade & Rose 1999). Locally, the data will be stored using the commercial database system Oracle 9i, Release 2.

We have divided the Post BCD pipeline into a few key levels with clearly defined steps within each. In order, these levels are as follows:

1. *Data verification.*—Observed AORs are verified and checked to make sure the AOR was properly executed. The data are checked to verify that all SSC pipeline steps were carried out and checked for simple artifacts such as excessive cosmic-ray hits and instrumental and down-link problems. The Quick-Look Validation Tool (QLVT) is used for spot-checks of frames and to inspect frames with flagged problems.¹⁵

2. *Basic processing and mask propagation.*—The data are corrected for the zodiacal background (Gorjian, Wright, & Chary 2000). Pixels affected by stray light or banding¹⁶ or that are in the wings of saturated sources are flagged and corrected wherever possible. An error mask for these pixels is created.

3. *Point-source extraction.*—Flux density and position of point sources are determined using DAOPHOT (Stetson 1987). Positions of the brighter sources are checked against the 2MASS Point Source Catalog. Statistics are computed for the residual images and used to assess the extraction process. Flux calibration is also spot-checked.

4. *Band merging.*—The point source lists obtained in the eight pointed observations (two passes each in four bands) are merged to produce the input for the generation of the GLIMPSE Point Source Catalog and GLIMPSE Point Source Archive.

5. *Mosaicked image production.*—The data are resampled and registered to a Galactic coordinate system, and IRAC frames are background matched, if necessary. The resulting images are turned into tiles of mosaicked images of $20' \times 20'$. The pixel size for these images is not yet finalized but will be approximately $0''.6$.

6. *Point-source photometry on the mosaicked image.*—The mosaicked images are used to perform point-source photometry. The resulting source list is then band-merged with source list from single-frame data.

7. *GLIMPSE Point-Source Catalog and Archive generation.*—Sources found in mosaicked and single frames are cross-

identified. Appropriate quality and reliability filters are applied to generate the GLIMPSE point-source products.

2.3. Data Products

There are four principal data products that will result from the GLIMPSE program:

1. The GLIMPSE Point Source Catalog (GPSC, or “the Catalog”). The flux limit for this catalog will be determined by the requirement that the reliability be $\geq 99.5\%$. We currently estimate this flux limit to be 1.1 mJy at $3.6 \mu\text{m}$ and 2.5 mJy at $8.0 \mu\text{m}$. The $8 \mu\text{m}$ channel has a brighter limit due to the increased diffuse background from PAH emission near $7.7 \mu\text{m}$ in the Galactic plane. The Catalog photometric uncertainty will be less than 0.2 mag. For each IRAC band, the Catalog will provide fluxes (with errors), positions (with errors), the density of local point sources, the local sky brightness, and flags that provide information on source quality and any anomalies present in the data. The Catalog is expected to contain $\sim 10^7$ objects.

2. The GLIMPSE Point Source Archive (GPSA, or “the Archive”), consisting of point sources with signal levels $\geq 5 \sigma$ above the local background, to approximately a flux limit of 0.2–0.4 mJy. The photometric uncertainty is expected to be less than 0.2 mag. The information provided will be the same as for the Catalog. The Archive will contain $\sim 5 \times 10^7$ objects.

3. Mosaicked images for each band, each of approximately $20' \times 20'$ angular coverage. About 9000 FITS formatted images will be tiled to smoothly cover the entire survey area, using a Galactic coordinate system. The pixel resolution has not been finalized but will be about $0''.6$.

4. The Web Infrared Tool Shed (WITS), a Web interface to a collection of model infrared spectra of dusty envelopes and PDRs, updated for IRAC and Multiband Imaging Photometer for *SIRTF* (MIPS) bandpasses. WITS currently resides on servers at IPAC.¹⁷ The interface contains two “toolboxes”: the Dust Infrared Toolbox (DIRT) and the Photodissociation Region Toolbox (PDRT), which provide databases of circumstellar shell emission models and PDR emission models. Users can input data and retrieve best-fit models. DIRT output includes central source and dust shell parameters; PDRT output consists of gas density, temperature, incident UV field, and IR line intensities.

3. GLIMPSE SCIENTIFIC CHALLENGES

The GLIMPSE project will produce a rich data set that can be used for numerous and diverse investigations. Here we discuss some of the expected scientific uses of this survey and several complementary data sets. We first discuss the principal science goals of the GLIMPSE team: a census of star formation

¹⁵ The Quick-Look Validation Tool (QLVT) is a quality assessment tool developed by team member Mark Wolfire, which simultaneously displays four IRAC frames, data masks, and ancillary 2MASS/MSX data. The interface allows a user to insert comments and mark potentially bad pixels.

¹⁶ Banding refers to streaks that prelaunch tests suggest might appear in the rows and columns radiating away from bright sources in the 5.8 and $8.0 \mu\text{m}$ bands. The severity of this effect will be determined on-orbit.

¹⁷ <http://www.ipac.caltech.edu>.

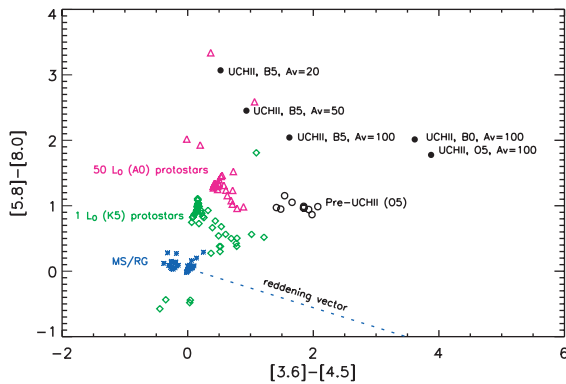


FIG. 5.—IRAC color-color diagrams of model protostars calculated by B. Whitney et al. (2003, in preparation) with both axes in magnitudes. Filled circles are ultracompact H II models, with various values of $A(V)$. The open circles are for a model of a ultracompact H II precursor (O star embedded in an infalling envelope and accretion disk). Several viewing inclinations are plotted for this model. Open triangles show different inclination models for intermediate-mass protostars (here, A0) from early protostar stage to remnant disk. Open diamonds are similar models for low-mass pre-main-sequence stars (K5). Only sources that are detectable to a distance of 2 kpc are plotted (i.e., the more pole-on, less reddened sources). The main sequence and giant branch are plotted as asterisks (MS), with the reddening line shown by the dotted line. Reddening is actually “blueing” in the longer wavelength bands, based on the interstellar medium (ISM) model of Li & Draine (2001), because of the strong silicate absorption features usually observed in these objects. GLIMPSE will improve our understanding of the opacity in this wavelength range.

in the inner Galaxy and a study of Galactic structure as determined by the distribution of stars. This is followed by a discussion of community science and complementary data sets.

3.1. GLIMPSE Team Science Goals

The GLIMPSE survey will uncover for the first time a huge number of stars in the inner Galaxy. As a result, it will be the survey of choice for those interested in the stellar structure of the Galaxy. Moreover, since the preponderance of star formation in the Galaxy is expected to occur in the inner Galaxy, studies using GLIMPSE will be able to characterize star formation in a wide range of environments. These are the two principal goals of the GLIMPSE science team.

3.1.1. Star Formation in the Inner Galaxy

The GLIMPSE team will address several fundamental questions regarding star formation in the inner Galaxy using the GLIMPSE data products. These include the following:

At what rate are stars forming in the inner Galaxy? Conservatively, we expect that analysis of GLIMPSE data will reveal several thousand star formation regions (SFRs). A search of the SIMBAD database lists over 1000 H II regions in our survey area; *MSX* 8 μm images of the GLIMPSE survey area indicate that there are many more to be found (Cohen & Green 2001). Extrapolation from the luminosity functions of OB as-

sociations in other galaxies (McKee & Williams 1997) suggest that there should be several thousand SFRs in our survey area. SFRs and other Galactic clusters are about 0.7 pc in diameter (Harris & Harris 2000) and will subtend $\geq 10''$ at 15 kpc. Nearby clusters will spread across arcminutes and will be partially resolved into individual stars and protostars. CO, H I, and radio continuum surveys (see § 3.3) will also allow us to carry out targeted searches for star formation in the inner Galaxy.

What are the spatial and mass distributions of lower mass stars in massive SFRs? Because of high extinction and the low luminosity of low-mass stars in massive SFRs, we know very little about the spatial and mass distributions of low-mass ($M < 1-2 M_{\odot}$) stars associated with massive SFRs. GLIMPSE data can be used to delineate both the spatial and mass distribution of lower mass stars in nearby (few kiloparsecs) star formation regions.

How does star formation vary as a function of position in the Galaxy? Since GLIMPSE will allow for an unbiased sample of massive star formation in the inner Galaxy, it will allow us to search for variations in star formation properties, i.e., cluster density, initial mass function, and gas content, in a wide range of Galactic environments.

How many low-mass SFRs in the inner Galaxy have been hidden until now? SFRs that contain only stars later than spectral type B3 are not easily detected in radio continuum searches but will be detected by GLIMPSE. In the nearest SFRs, GLIMPSE data could be used for a census of the properties of intermediate-mass pre-main-sequence stars.

How does the infrared emission of SFRs change over time? GLIMPSE data will provide information on the stellar content of all of the principal stages of massive star formation, summarized recently in Churchwell (2002). Figure 5 demonstrates that these stages are expected to have significantly different IRAC colors.

3.1.2. Galactic Structure

There are three main questions that the GLIMPSE team seeks to address using GLIMPSE data:

1. *Does the Galaxy have a stellar ring?* The Galactic molecular ring contains some 70% of all molecular gas in the Galaxy and should be the dominant star-forming structure in the Milky Way (Clemens et al. 2001). On this basis, Kennicutt (2001) suggests that our Galaxy should be classified as an SB(r)bc pec. Where in the ring are the stars forming? How do the properties of the gas correlate with star formation? How does the ring’s star formation efficiency compare with starburst regions in other galaxies? Comparison of GLIMPSE data with the ^{13}CO maps of this region of the Galaxy should yield answers to these important questions.

2. *What is the nature of the spiral arms and disk in the inner Galaxy?* Observations have given clues for the gas (H I and CO), but we know little about the stars and SFRs. Are stars formed on the leading or trailing edges of gas arms? How do

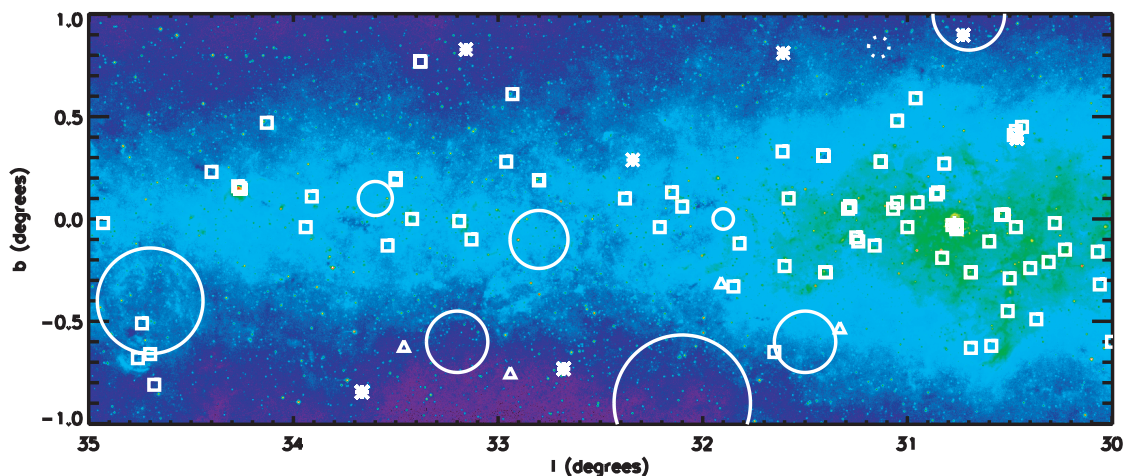


FIG. 6.—*MSX* 8 μm image of a 10 deg^2 piece of the GLIMPSE survey region, with the positions of the following classes of objects noted: OB stars (*asterisks*), H II regions (*squares*), planetary nebulae (*triangles*), supernova remnants (*solid circles*), and open clusters (*dotted circles*). Most of the diffuse emission in this image is due to PAHs. The prominent star formation region at ($l = 30^\circ 8$, $b = 0^\circ 0$) is W43, which is obscured optically ($A_V \approx 30$ mag). The angular resolution of *MSX* was $18''$ as compared to the $1''.2$ resolution expected from *SIRTF/IRAC*.

the stars formed in arms and in interarm regions differ? Drimmel & Spergel (2001) show that K -band (stellar light) profiles are consistent with a two-armed logarithmic spiral model, while the 240 μm (dust emission) is consistent with a four-armed H II region distribution (Taylor & Cordes 1993). GLIMPSE data will allow us to determine the positions of individual star formation regions, account for regions of high obscuration, and determine if the integrated light observed by the *Cosmic Background Explorer (COBE)*'s Diffuse Infrared Background Experiment (DIRBE) is dominated by individual objects. GLIMPSE data will also allow us to identify different tracer populations (SFRs, OH/IR stars, IR carbon stars, etc.) and their spatial distributions. The resulting information will help test models of gas dynamics, star formation, and evolution in the inner Galaxy (Englmaier & Gerhard 1999).

GLIMPSE data will also help constrain values of the scale lengths for the thin and thick stellar disks. Measuring the ratio of the thin-to-thick disk scale length will constrain the merger history of the Galaxy (Quinn, Hernquist, & Fullager 1993). Measuring the scale length of the thin disk will establish whether the central mass distribution of the Galaxy is stellar or dark matter dominated.

3. *What are the principal properties of the central stellar bar of the Galaxy?* *COBE/DIRBE* data have shown the global distribution of the bar (Freudenreich 1998; Gerhard 2002). 2MASS studies using IR carbon stars have also traced the structure and possibly the age of the Galactic bar (Cole & Weinberg 2002). GLIMPSE data will allow us to extend these studies, look for star formation at the ends of the bar, and explore the connection between the bar and inner spiral arms.

3.2. Community Science from GLIMPSE Data

The wide variety of objects contained in the GLIMPSE survey region is illustrated in Figure 6, which shows the positions of many types of objects overlaid on an 8 μm *MSX* map of a section of the GLIMPSE survey region. With the higher sensitivity and angular resolution of GLIMPSE, together with the color-select possibilities of seven or more photometric bands (GLIMPSE+2MASS+*MSX*), data from GLIMPSE will allow the astronomical community to evaluate the statistics, spatial distribution, and internal structures of numerous classes of Galactic objects as well as providing new probes of the interstellar medium. These include studies of stellar populations, PDRs, extinction, as well as serendipitous discoveries.

Stellar population studies.—Using a combination of 2MASS and *MSX* data toward a sample of previously classified objects in the Large Magellanic Cloud, Egan, van Dyk, & Price (2001) showed that the mid-IR 8 μm band provides an important “lever arm” that allows color separation of many classes of objects. Planetary nebulae, H II regions, and some classes of C- and O-rich AGB stars have very red mid-IR colors. Other attempts to develop mid-IR and near-IR color selections focus on infrared carbon stars using $J-K_s$ versus K_s (Cole & Weinberg 2002), young stellar objects (YSOs) using ISOGAL [7]–[15] versus [15] (Felli et al. 2002), brown dwarfs (Burrows et al. 1997), and carbon stars, OH/IR stars, planetary nebulae (PNe), Herbig AeBe stars, compact H II regions, and massive YSOs using a combination of 2MASS J , H , and K and *MSX* 8 μm (Lumsden et al. 2002).

PDRs.—The near/mid-IR spectrum of photodissociation regions at the surface of molecular clouds is dominated by emission bands at 3.3, 6.2, 7.7, 8.6, and 11.3 μm , probably

TABLE 4
SUMMARY OF INFRARED SURVEYS

Survey	Wave Bands (μm)	Resolution (arcsec)	Coverage	Sensitivity	Web Site
GLIMPSE	3.6, 4.5, 5.8, 8.0	≤ 2	$ l = 10^\circ\text{--}65^\circ, b \leq 1^\circ$	0.2, 0.2, 0.4, 0.4 mJy ^a	http://www.astro.wisc.edu/glimpse
2MASS	1.22, 1.65, 2.16	2	All-sky	0.4, 0.5, 0.6 mJy	http://www.ipac.caltech.edu/2mass
DENIS	0.97, 1.22, 2.16	1–3	$\delta = +2$ to -88°	0.2, 0.8, 2.8 mJy	http://cdsweb.u-strasbg.fr/denis.html
MSX	4.1, 8.3, 12, 14, 21	18.3	$l = 0^\circ\text{--}360^\circ, b \leq 5^\circ$	10000, 100, 1100, 900, 200 mJy	http://www.ipac.caltech.edu/ipac/msx
ISOGAL	7, 15	6	$ l \leq 60^\circ, b \leq 1^\circ$ ^b	15, 10 mJy	http://www-isogal.iap.fr
IRAS	12, 24, 60, 100	25–100	All-sky	350, 650, 850, 3000 mJy	http://www.ipac.caltech.edu
Astro-F ^c	8.5, 20, 62.5, 80, 155, 175	5–44	All-sky	20–100 mJy	http://www.ir.isas.ac.jp
COBE/DIRBE ^d	1.25–240	0 ^o .7	All-sky	0.01–1.0 MJy sr ⁻¹	http://lambda.gsfc.nasa.gov

^a Best effort 5σ limit for sources in the GLIMPSE Point-Source Archive; the GLIMPSE Point-Source Catalog will contain only sources at about the 20σ level to insure high reliability.

^b Survey contained only selected fields in this region, totaling 16 deg².

^c Launch planned 2004 February.

^d DIRBE photometric bands are 1.25, 2.2, 3.5, 4.9, 12, 25, 60, 100, 140, and 240 μm . We report the diffuse flux sensitivity rather than point-source sensitivity due to the large beam size.

arising from polycyclic aromatic hydrocarbon (PAH) molecules (Peeters et al. 2002 and references therein). Figure 6 shows that this emission is a striking characteristic of the MSX maps of the Galactic plane. GLIMPSE data can be used to characterize the spatial distribution of different charge states of PAH to constrain the chemistry and evolution of PDRs. The IRAC 3.6 μm band is sensitive to the 3.3 μm feature from neutral PAHs; the 5.8 and 8.0 μm bands are sensitive to PAH⁺, while the 4.5 μm band contains no PAH features and thereby monitors the continuum (Bakes et al. 2001).

Turbulence and structure in SFRs.—A comparison of the infrared brightness fluctuations in SFRs with the spectral line information from CO and H I observations can yield information about the source of ISM turbulence by using the velocity channel analysis technique of Lazarian & Pogosyan (2000).

Interstellar extinction.—Data from GLIMPSE will allow studies of interstellar reddening in dense dusty regions and diffuse environments, using the colors of stars that lie behind dark clouds. This will allow testing near/mid-infrared extinction models, two of which are given in Table 3 (Li & Draine 2001; Lutz et al. 1996). Since extensive grain coagulation occurs in the inner regions of dense clouds, the IR extinction law could be quite different between very dense clouds such as the MSX dark clouds (Egan et al. 1998) and presently observable regions. GLIMPSE data will allow a vital characterization of the variation of extinction properties with environment.

Serendipity.—Since the inner Galaxy is the region of the sky with the greatest extinction, it is also the direction in which one is most likely to make serendipitous discoveries. The recent 2MASS discoveries of new globular clusters in the Galactic plane (Hurt et al. 2000) and galaxies in the “zone of avoidance” (Jarrett et al. 2000) hint at the possibilities for GLIMPSE.

3.3. Complementary Data Sets

The value of the GLIMPSE data products will be enhanced by the availability of complementary IR and radio data sets. The basic characteristics of the IR surveys are given in Table 4. Data sets that we anticipate will be the most useful and that will play important roles in the GLIMPSE team science studies are as follows:

1. *2MASS.*—This survey (Cutri et al. 2001) provides an ideal companion data set to GLIMPSE, with an excellent match in both sensitivity and angular resolution for many types of objects. Many objects will have GLIMPSE+2MASS magnitudes in a total of seven near-IR and mid-IR bands! This will allow for a wide variety of different possible color selections and spectral energy distributions (SEDs) from ~ 1 to 8 μm . The GLIMPSE bands provide crucial mid-infrared information.

2. *MSX.*—The MSX (Price et al. 2001) survey provides a good match to the GLIMPSE/IRAC 8 μm band. The MSX data set will be particularly useful for studies of diffuse emission. It provides a good complement to the GLIMPSE data for bright sources, since the saturation limit of GLIMPSE is only slightly brighter than the faint detection limit for MSX.

3. *Arecibo/Green Bank Telescope/Australian Telescope Compact Array Surveys of GLIMPSE H II regions.*—This data set resolves the distance ambiguities to many massive star formation regions. The data include more than 100 objects with resolved distance ambiguities that will be published and made available on the GLIMPSE Web site.

4. *Milky Way Galactic Ring Survey (GRS).*—A Boston University and Five College Radio Astronomy Observatory collaboration, this is a large-scale ¹³CO $J = 1 \rightarrow 0$ molecular line survey of the inner Galaxy between latitudes -1° to $+1^\circ$ and longitudes $18^\circ\text{--}52^\circ$, with an angular resolution of 22" and a

velocity resolution of 0.3 km s^{-1} (Simon et al. 2001). It is available through the GRS Web site.¹⁸ GRS will be completed by winter 2003.

5. *The International Galactic Plane Survey.*—This survey will map the Milky Way disk in the H I 21 cm line with a resolution of $1'$ and 1 km s^{-1} over the entire GLIMPSE survey area. The data cubes will be available on-line.¹⁹ The Southern Galactic Plane Survey is also available on-line.²⁰

There are several other surveys that will provide a useful complement to GLIMPSE. These include the ISOGAL survey at 7 and $15 \mu\text{m}$ (A. Omont et al. 2003, in preparation; Felli et al. 2002), which provides complementary data for the inner Galaxy region not covered by the GLIMPSE survey, and the planned all-sky *Astro-F* survey at $8.5\text{--}175 \mu\text{m}$, which will provide an extension to large Galactic latitudes and longitudes, although at lower resolution and sensitivity than GLIMPSE (see Table 4). High angular resolution X-ray surveys of the Galactic plane using *Chandra* (Grindlay et al. 2003)²¹ and *XMM* (Helfand et al. 2002) will also provide a useful comparison to GLIMPSE data in selected regions of the Galactic plane.

4. SUMMARY

The GLIMPSE project will allow us to study, for the first time, the stellar content of the inner Galaxy with high angular resolution and a minimum of extinction. The GLIMPSE team and others will use these data to study Galactic stellar structure, characterizing the stellar content and star formation in the Galactic bar and inner spiral arms. It may allow us to ascertain whether the Galaxy is a ringed spiral. In addition, the data will be used to study the distribution and statistics of star formation throughout the Galaxy.

The survey will use the IRAC instrument on *SIRTF* to image 220 deg^2 in four bands ($3.6, 4.5, 5.8,$ and $8.0 \mu\text{m}$) with a pixel resolution of $1''.2$. It will cover two strips spanned by $|b| \leq 1^\circ$ and $|l| = 10^\circ\text{--}65^\circ$, a region covering the outer ends of the

Galactic bar, the molecular ring, and four spiral arm tangencies. The resulting data set will be the most panoramic produced by *SIRTF*.

The principal data products from the GLIMPSE team will be a high-reliability GLIMPSE Point Source Catalog (GPSC) with about 10 million sources and approximate flux limit of 1.0 mJy ($3.6 \mu\text{m}$ band) to 2.5 mJy ($8.0 \mu\text{m}$ band), a GLIMPSE Point Source Archive (GPSA) with about 50 million sources and an approximate flux limit of $0.2\text{--}0.4 \text{ mJy}$, a set of mosaicked images for each band, and a set of Web-based analysis tools. The first release of the GPSC will be 9 months after the launch of *SIRTF*, and the first installments of the GPSA and mosaicked images will be 15 months after launch. These data products and the supporting documentation will be updated at 6 month intervals and will be complete 27 months after launch.

GLIMPSE data will drive a wide range of scientific investigations including the search for rare, bright Galactic objects, stellar population studies, studies of Galactic structure, high angular resolution studies of diffuse emission in PDRs, and studies of extinction in the near- to mid-infrared. The science from GLIMPSE data will fuel observing programs and scientific investigations for decades. The probability of serendipitous discoveries is high for the GLIMPSE survey. We expect that it will lead to the discovery of new stellar clusters and galaxies hidden behind what had previously been an impenetrable wall of dust. We eagerly look forward to providing this resource to the community.

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