The <u>G</u>alactic <u>L</u>egacy <u>I</u>nfrared <u>M</u>id-<u>P</u>lane <u>S</u>urvey <u>E</u>xtraordinaire (GLIMPSE)

I. Why a Galactic Plane Survey?

The inner workings of our own Galaxy are more mysterious than those of galaxies located millions of light years away, mainly because of our unfavorable location in the mid-plane outskirts of the Milky Way's dusty disk. The structure of the Milky Way has been determined primarily by the distribution of atomic hydrogen and carbon monoxide gas which together contain no more than about 10% of the visible mass of the Galaxy, which is mostly in the form of stars. It is believed that the Milky Way is a typical luminous spiral but its detailed structure, especially the inner quadrants, are uncertain. To understand both the Milky Way and external galaxies, we must understand the structure and the physics of the interactions between gas and stars within our own Galaxy, the Milky Way. The GLIMPSE survey will provide a comprehensive view of the stellar and dust content in the inner Galaxy. The broad scope of this unbiased survey will provide a global understanding that studies of narrowly-defined, selected regions cannot. GLIMPSE will enable a wide range of stellar and interstellar science. The GLIMPSE team will focus on two important scientific questions:

1) What is the structure of the inner Galaxy, including the disk, molecular ring, number and location of spiral arms, and central bar as traced by the spatial distribution of stars and IR-bright star formation regions?
2) What are the statistics and physics of star formation as a function of mass, stage of evolution, and location in the Milky Way?

II. Survey Definition

GLIMPSE will be a fully sampled, confusion limited, 4-band near- to mid-infrared survey of the inner two-thirds of the Galactic disk with a spatial resolution of ~2". The Infrared Array Camera (IRAC) will be used to image 240 square degrees at wavelengths centered on 3.6, 4.5, 5.8, and 8.0 µm in the Galactic longitude range10^0 to 70^0 on both sides of the Galactic center and in Galactic latitude $\pm 1^0$. About 780 million resolution elements will be required to cover this area at each wavelength.

The area covered by GLIMPSE contains most of the star formation activity in the Galaxy and ~70% of the molecular gas in the Galaxy. The inner cutoff at $| l| = 10^0$ permits adequate sampling of both ends of the purported ~3 kpc central bar and possibly some of the nuclear bulge stellar population. We expect to determine the asymmetry of the bar (brighter at $l>0^0$) with high accuracy. The outer cutoff at $|l| = 70^0$ includes all of the 5 kpc molecular ring, the Sagittarius spiral arm tangent, and the Norma spiral arm tangent. The Galactic center region is not included because of its extreme background brightness and high confusion limits.

A major motivation for the GLIMPSE program is the complementary high resolution spectral line, infrared, and radio continuum surveys, currently underway or recently completed, that overlap the area GLIMPSE will survey. The spectral line surveys include the Galactic Ring Survey in ^{13}CO and the VLA, Australian, and Canadian HI Galactic Plane Surveys. They are important for assigning distances to stellar groups that can be associated with a particular velocity feature in either HI or ^{13}CO. The infrared surveys include 2MASS, DENIS, and MSX; the combination of 2MASS, DENIS, and GLIMPSE data will provide spectral energy distributions from 0.8 to 8 µm.

The NRAO VLA SKY Survey (NVSS) will delineate other nebulae such as HII regions, supernovae remnants, planetary nebulae, other galaxies, etc.

III. Data Products

The team will provide the following products; a near-instantaneous Bright Source Catalog (BSC; ~20σ), the GLIMPSE Point Source Catalog (GPSC; ~5σ), and a Mosaiced Image Atlas of the entire surveyed area at all four IRAC bands, all of which will be made available via the IPAC data archive. In addition, a set of web modeling tools will be provided that will permit users to analyze and interpret SIRTF and other IR data. The IPAC data archive can cross-reference the GLIMPSE catalogs with other databases in its archive such as 2MASS and MSX. Preliminary versions of the BSC will be released every two months during data acquisition. We expect to catalog $\geq 10^8$ sources detected with $S/N \geq 5$.

IV. Science

The SIRTF GLIMPSE program will 1) produce a complete census of star formation in the surveyed area; 2) measure the stellar disk scale length; 3) delineate the stellar structure of the molecular ring, inner spiral arms and bar as traced by the distributions of stars and star formation regions; 4) determine the luminosity and initial mass functions of all nearby star formation regions and clusters located near the Galactic center down to the stellar limit (or below for the nearest regions); 5) detect all young O and B stars still embedded in their natal clouds; 6) detect and identify young stellar objects (surrounded by circumstellar disks) in nearby star forming regions; 7) determine the mid-IR interstellar extinction law in various dense molecular clouds; 8) investigate the nature of Photo-Dissociation Regions and the density structure within the interstellar medium; and 9) detect a host of other types of stars and nebulae such as supernovae, planetary nebulae, hidden galaxies, OH/IR stars, etc. that will be of interest to a large fraction of the astronomical community. An additional value of a large, unbiased Galactic plane survey is its potential for new discoveries that might otherwise be missed by piecemeal imaging of selected regions. In sections A and B below, we describe in detail the two key research problems the GLIMPSE team will address and in IV. C we suggest other scientific applications of the GLIMPSE data.

A. Galactic Structure with GLIMPSE

Although the Milky Way is the nearest galaxy, its structure remains poorly understood. GLIMPSE will discover and identify hundreds of new star-forming regions throughout the Galaxy, and these will be used as test masses to delineate Galactic structure. GLIMPSE studies of the angular distribution of young stellar objects will help elucidate the morphology of large-scale Galactic structures, such as the disk, the 5 kpc molecular ring, the extent and locations of spiral arms, and the central bar. Although the GLIMPSE infrared database will identify young stellar objects (YSOs) and their angular distribution, GLIMPSE data must be correlated with gas tracers to obtain reliable distances to the YSOs. Fortunately, new surveys such as the BU-FCRAO Galactic Ring Survey and the Australian Galactic Plane Survey of H I can be used to determine Survey, the Boston University-Arecibo Observatory H I Survey, the VLA Galactic Plane distances throughout the inner Milky Way.

We will use these surveys to establish distances to the star-forming regions discovered by GLIMPSE. For each YSO, we will determine whether it is located at or near a molecular cloud identified in the Galactic Ring, VLA or Australian Galactic Plane

Surveys and thus the likelihood that the two are associated. If so, we will then assign the kinematic distance of the cloud to the embedded infrared YSO. We can resolve the kinematic near/far distance ambiguity by searching for H I absorption in the BU, VLA, or Australian survey.

This method of associating infrared sources with molecular clouds has been attempted before (Scoville & Good 1981), but because of the coarse sampling and resolution of the old infrared and CO surveys, only the largest, most massive star-forming regions could be associated with molecular clouds. With the superior sampling and sensitivity of GLIMPSE, combined with the ability to resolve the near/far distance ambiguity, we can locate infrared YSOs and embedded clusters much more precisely than before and thus establish the locations of star-forming regions throughout the inner Galaxy.

Once the star-forming regions are located, we can deduce the structure of the Galaxy. We are particularly interested in the stellar content of the Galactic ring (an annular peak in the gas distribution about halfway between the Sun and the Galactic Center), the extent and nature of the central bar, the number and location of spiral arms, and possibly the extent and stellar content of the outer regions of the nuclear bulge. GLIMPSE offers the ability to map the structure of the inner Milky Way in unprecedented detail.

B. The Statistics and Physics of Star Formation

Star formation is probably the single most important process that defines the evolution of galaxies and their interstellar medium, and yet we are still woefully ignorant of its basic physics, especially for massive stars. With spatially resolved images showing the structure of star formation regions (SFRs), GLIMPSE can *detect, identify, and quantify* the properties of each evolutionary phase of star formation over a large fraction of the inner Galaxy. A long-standing problem in astrophysics is establishing and understanding the distribution of stellar masses (i.e. the initial mass function, IMF) of stellar clusters in different environments in the galaxy. Since GLIMPSE can detect all stars down to the stellar limit within several kpc, it will be able to determine cluster IMFs in the inner Galaxy with exquisite accuracy.

Massive stars dominate the energy budgets of galaxies, provide most of the heavy element enrichment, and drive much of the turbulent motion in the interstellar medium, yet the evolution of massive stars is very poorly understood. GLIMPSE will further our knowledge of massive stars by accumulating observations of these objects at each stage of their lives from prestellar cores to supernovae. SIRTF/IRAC will make important contributions to understanding each stage of massive star evolution.

1) **Prestellar cores** are dense, cool, gravitationally bound, contracting molecular clouds prior to the formation of a central protostar. They reveal the initial conditions under which star formation begins. Likely precursors of massive star clusters have been detected by Egan et al. (1998; with MSX) and Bacmann et al. (1999; with ISO) in absorption against the galactic plane emission at wavelengths ≤ 8.5 μm. Prestellar cores of individual or multiple star systems have been detected in emission at FIR and submillimeter wavelengths by Ward-Thompson et al. (1994), André et al. (1996), Launhardt & Henning (1997) and Ward-Thompson & André (1998). We expect GLIMPSE to detect several thousand such cores in the inner Galaxy. With IRAC's wavelength coverage and spatial resolution it will be possible to derive density profiles for these cores and to infer their support mechanism(s) (thermal, turbulent,

magnetic, rotation, etc.). In addition, it will be possible to determine the extinction law in the 3 – 8 μm range in dense clouds, an issue about which some controversy currently exists (see Lutz et al. 1996)

ii) Precursors of UC HII regions are dense, massive, hot, luminous molecular cores that are heated by one or more rapidly accreting massive proto-stars. Several authors (Hunter et al. 2000 and references therein) have tabulated their properties. The central massive hydrogen-burning proto-star is accreting matter so rapidly ($\sim 10^{-3}$ M_o yr^{-1}) that the ionization front is confined by the in-falling gas to a volume too small to be detected via radio free-free emission. However, the cores are luminous enough (typically $\sim 10^5$ L_o) to heat the ambient medium to large distances (~1 pc). SIRTF/IRAC imaging capabilites will allow us to resolve and study the physical conditions across these envelopes. *GLIMPSE will detect every hot core in the Galaxy in the surveyed area, provide SEDs from 3.6 to 8 μm (from~1 μm with 2MASS), and morphologies on arcsec scales.*

iii) UC HII regions are small (typically $< 10^{17}$ cm), dense, luminous HII regions still deeply embedded in their natal molecular cloud and ionized by a newly formed O star that has ceased accretion. They can be identified by their IR colors and observed morphologies. *These objects are IR-bright tracers of newly formed O and B stars that can be detected by SIRTF/IRAC throughout the entire Galaxy.* GLIMPSE will detect the entire population of embedded O and B stars in the surveyed area. SIRTF's high resolution will permit determination of accurate SEDs and derivation of physical properties with radius.

iv) Classical HII regions and supernovae represent the later stages of massive star evolution about which much is already known from optical and radio studies. GLIMPSE will contribute to a better understanding of the processes occurring in the boundaries between the ionized and neutral gas and dust. In particular, IRAC images will reveal obscured star formation in elephant trunks, Bok globules, and columns such as those associated with M16.

Massive stars appear to form in clusters along with a range of associated lower mass stars. Compact OB clusters, such as Orion and NGC3603, present a serious challenge to our understanding of massive star formation. Their stellar densities are so high that the mean separation of stars is less than their Jeans lengths for reasonable natal cloud temperatures. Such clusters may be an indication that massive star formation occurs in these regions via mergers of low to intermediate mass proto-stars (Bonnell et al. 1998; Stahler et al. 2000). *GLIMPSE data on the IMF, stellar density distributions, and frequency of occurrence of compact OB clusters will provide crucial information on the physics of compact clusters. GLIMPSE will show whether all massive star formation occurs in compact clusters.*

An evolutionary sequence has also been identified for low-mass stars. Low-mass pre-main sequence stars are surrounded by an equatorial accretion disk and are embedded in a dust cocoon (depending on evolutionary stage). The evolutionary stages of low-mass pre-main sequence stars have distinctive SEDs ranging from Class 0 (dominated by accretion luminosity, but radiated by the in-falling dust envelope) through Class III (dominated by direct stellar emission). The SEDs of low-mass proto-stars are primarily determined by the relative contributions to the emergent infrared flux produced in the surrounding dust cocoon, the accretion disk, and the proto-star "photosphere". The ability to detect and identify the evolutionary stage of these objects via their SEDs permits statistical studies of the evolution of low-mass proto-stars in a variety of density environments. *GLIMPSE will provide the number of objects occupying each evolutionary phase, the luminosity and initial mass functions, and the location of the members down to the stellar mass limit or below (depending on distance).*

C. A Springboard for the Astronomical Community

The GLIMPSE team will focus on the two key problems discussed above, but a wide range of other astrophysical problems can be addressed using GLIMPSE data. For example, because PAH spectral features fall within three of the four IRAC bands , GLIMPSE data will reveal the properties of dust, especially small dust grains, in a wide variety of astrophysical environments. The spatial power spectrum provided by IRAC images will make it possible to study the chaotic (turbulent) structure of the ISM. A census of stellar types including AGBs, OH/IR stars, pre-planetary nebula stars, Miras, WR stars, luminous blue variables, Be stars, young supernovae, and winds of planetary nebula nuclei will be possible with GLIMPSE data. Many of these can be identified by their IR colors, or a combination of their positions, IR colors, and ancillary data. The winds from O stars and WR stars will be detectable to large distances via their IR excess emission above the stellar continua. This will provide a flux limited determination of mass loss rates for all O and WR stars in the survey area. *Finally, serendipitous discoveries, which often open entirely new avenues of enquiry, will doubtless give rise to some of the most interesting science to emerge from the GLIMPSE program.*

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