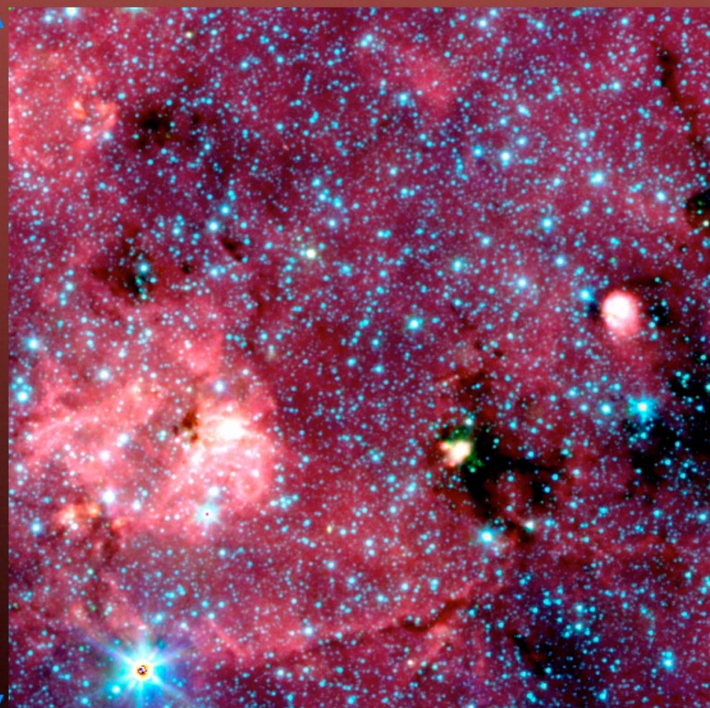
Spitzer Warm Mission: Opportunities to Study Galactic Structure and Interstellar Medium

$l = 24^{\circ}.470$
$b = -0^{\circ}.203$

12` x 12`

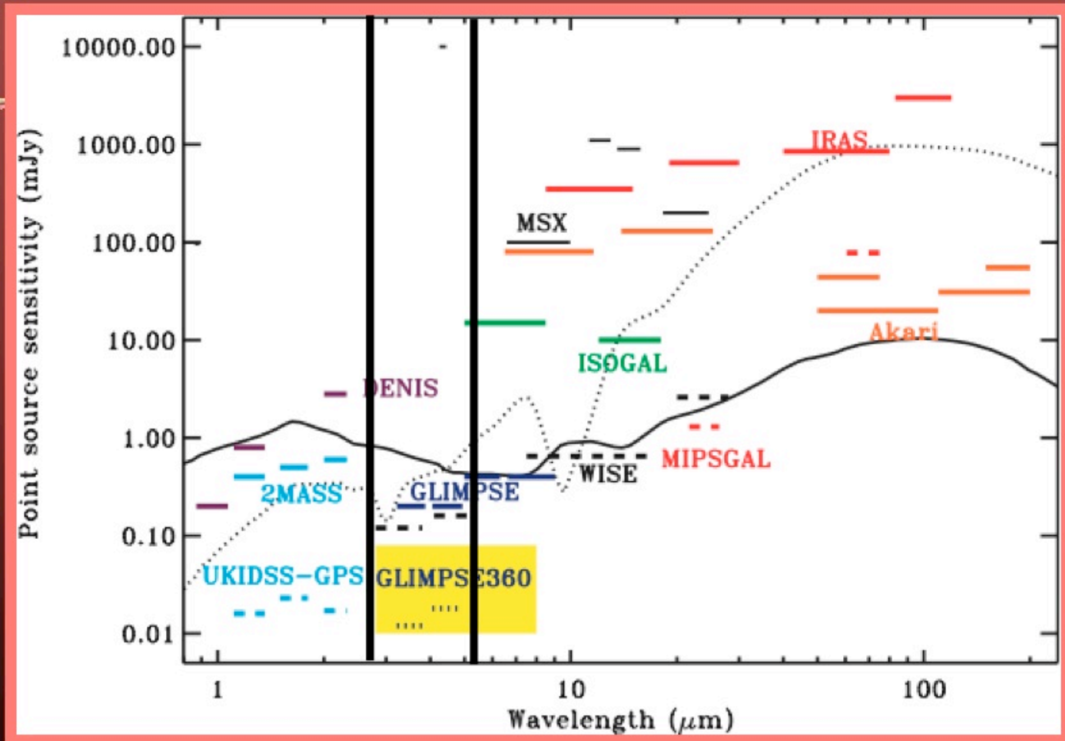


[3.6], [4.5], [8.0]

K, [3.6], [4.5]

Galactic Structure/ISM Group
R. Benjamin, B. Draine, R. Indebetouw, C. Lada, S. Majewski, N. Reid, M. Skrutskie

Galactic Plane Surveys: A Comparison



- The 3.6-4.5 μm region is on the Rayleigh-Jeans tail for stellar blackbody curve.
- It is also the wavelength regime which minimizes the combination of dust extinction and diffuse dust/PAH emission.

- Warm Spitzer mission would allow for a significant fraction of the Galactic plane to be mapped down to 18.4/17.5 magnitude in [3.6]/[4.5] bands.

  This is well matched to the new generation near IR surveys: UKIDSS, Subaru, IAC…

- WISE has sensitivity close to GLIMPSE, but a 6" FWHM PSF at 3.3μm and 4.7μm.

  This give Spitzer a substantial advantage in source confused regions.

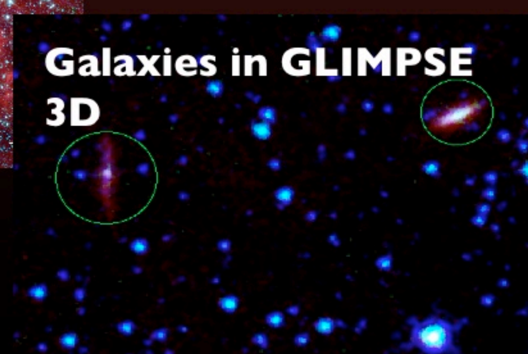
The GLIMPSE example

Goals

1. To provide a uniform stellar census of the Galaxy.
2. To provide an unbiased survey of star formation in the inner Galaxy.
3. To discover new objects hidden behind dust and new classes of objects bright at mid IR wavelengths.

Refereed Papers (as of June 2007)

Topic	Team	Others
SFR	9	9
YSO's	9	0
X-ray	0	9
Evolved *s	1	4
ISM	3	2
Clusters	2	2
Disks	2	1
SNR	0	3
Masers	0	3
Gal Struct	2	0
ExGal	0	1
Total	**28**	**34**



GLIMPSE

- PI: Ed Churchwell
- 400 hours/320,000 *Spitzer* /IRAC frames
- 3.6, 4.5, 5.8, 8.0 μm @ 2x2 sec
- |*l*|=10-65° and |*b*|<1°

GLIMPSE 2

- |*l*|<10° and |*b*|<1-2°

GLIMPSE 3D

- |*l*|<30 and |*b*|=1-4° Selected longitudes

Vela/Carina

- l=255-295°
- Follows warp

Mapping Strategies: Coverage vs Depth

A full Galactic plane survey with Spitzer will need to consider the tradeoff between sky coverage and survey depth.

Coverage determined by large scale features or populations to be studied in the Galaxy, *particularly those areas most affected by extinction.*

Features

• Stellar thin disk, bar(s), bulge, inner spiral arms, *outer spiral arms, thick disk, warp, flares, truncation radius, satellite galaxies, 3D map of dust/gas*.

Populations

• Star formation regions, molecular cores, stellar clusters, YSOs, AGBs, WRs, PN, masers, counterparts to X-ray/γ-ray sources, substellar objects.

Mapping Strategies: Coverage vs Depth

Depth determined by (1) luminosity of tracer populations, (2) extinction, (3) confusion. We consider two bracketing strategies for a 6000 hour program.

GLIMPSE style (Benjamin et al 2003)	*GLIMPSE360 style (Stauffer et al 2007)*
Two 2 seconds integrations	Four 12 second integrations w. HDR
0.55 sq deg/hour	0.23 sq deg/hour
$m_{lim}[3.6]=14.1$ $m_{lim}[4.5]=14.2$	$m_{lim}[3.6]=18.4$ $m_{lim}[4.5]=17.5$
For all longitudes*, $\|b\| \leq 4.6°$	For all longitudes*, $\|b\| \leq 1.9°$

* Assuming the 338 sq deg already covered by GLIMPSE was resurveyed.

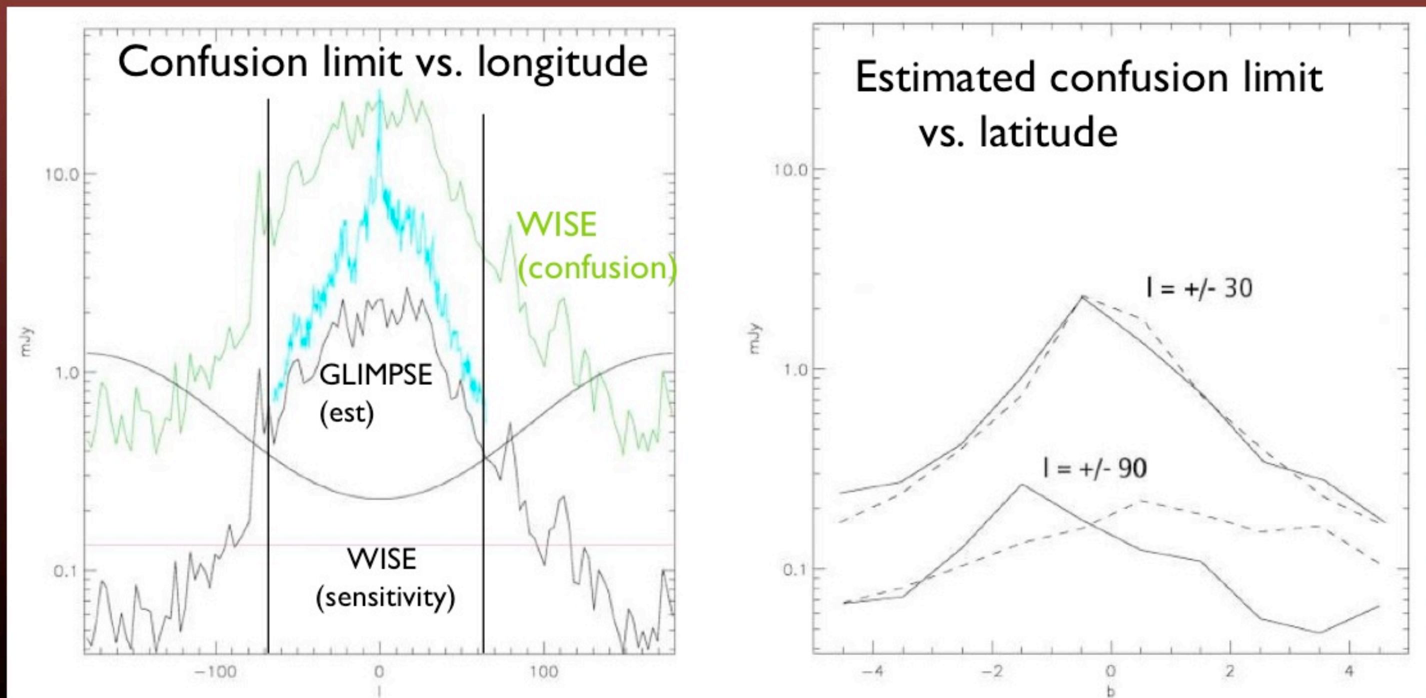
Detection distance (no extinction) for tracer populations (M Cohen, priv comm)

Class	d_{GL} [4.5]	d_{GL360} [4.5]
K0,1 III	6.7 kpc	40.2 kpc
K2,3 III	9.6 kpc	57.8 kpc ← Red clump giants
M0 III	32.1 kpc	193.2 kpc
G2 V	1.1 kpc	6.8 kpc
late M V	0.2 kpc	0.9 kpc

Note that ~90% of all IRAC sources are expected to be giants.

Confusion

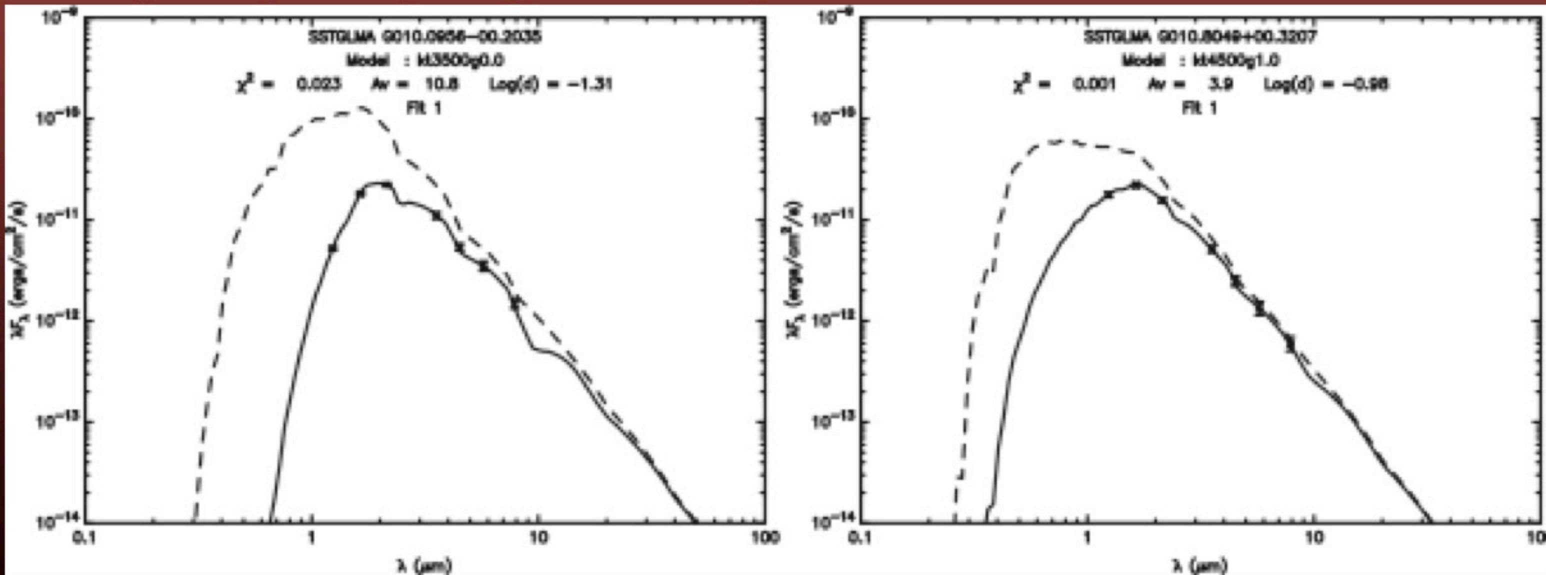
The best mapping strategy will need change as a function of Galactic latitude/longitude due to confusion. Using near IR and mid IR data obtained to date, it should be possible to accurate estimate the confusion limit as a function of direction.



GLIMPSE estimated confusion limit (using MSX) vs. longitude for 2" FWHM beam (black) and 6" FWHM beam (green). Smooth black line represents a K3 III at 20 kpc.

The value of [3.6] and [4.5]

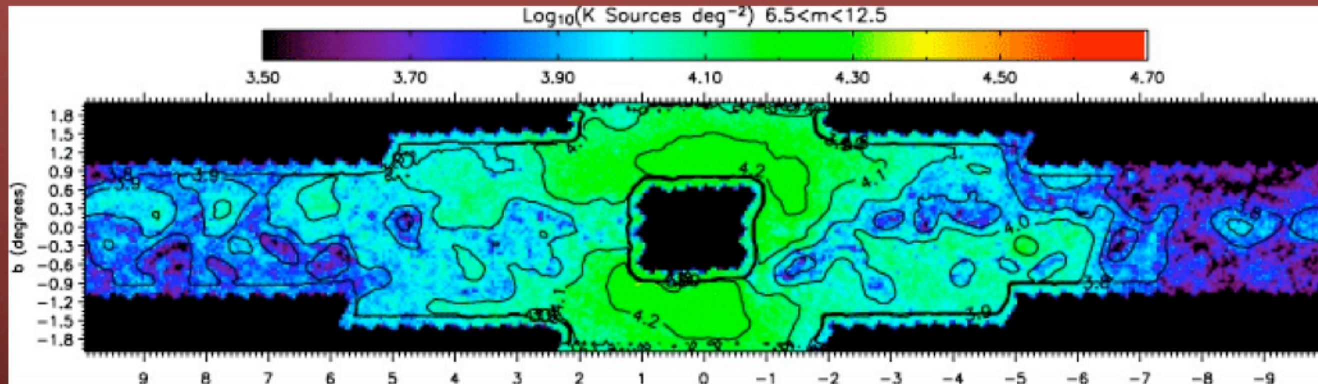
For ordinary giants, the [3.6] and [4.5] bands fall on the Rayleigh-Jeans tail of the blackbody spectrum which means that the colors of all stars should be (almost) zero (in magnitude units).



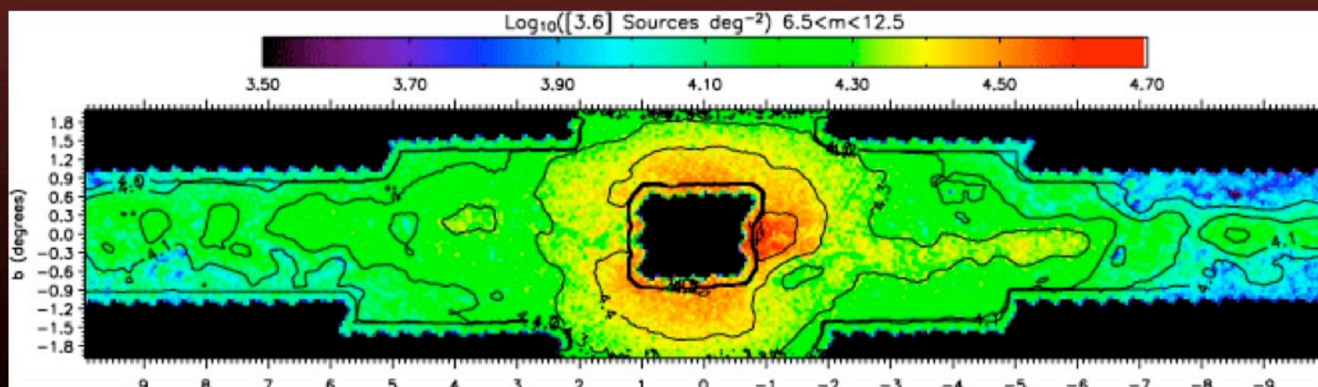
However the combination of Spitzer and near IR data allow for <u>*three*</u> *key improvements in studies of Galactic structure: (1) More sources, (2) accurate extinction correction, and (3) (possibly) sensitivity to surface gravity.*

Mid IR gives more sources than Near IR

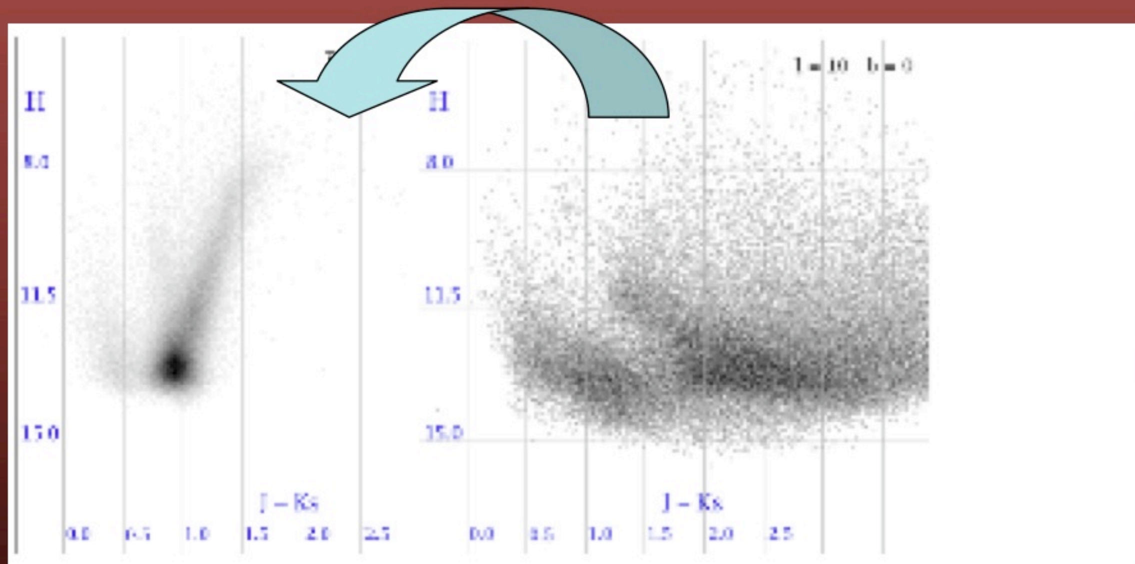
2MASS K band



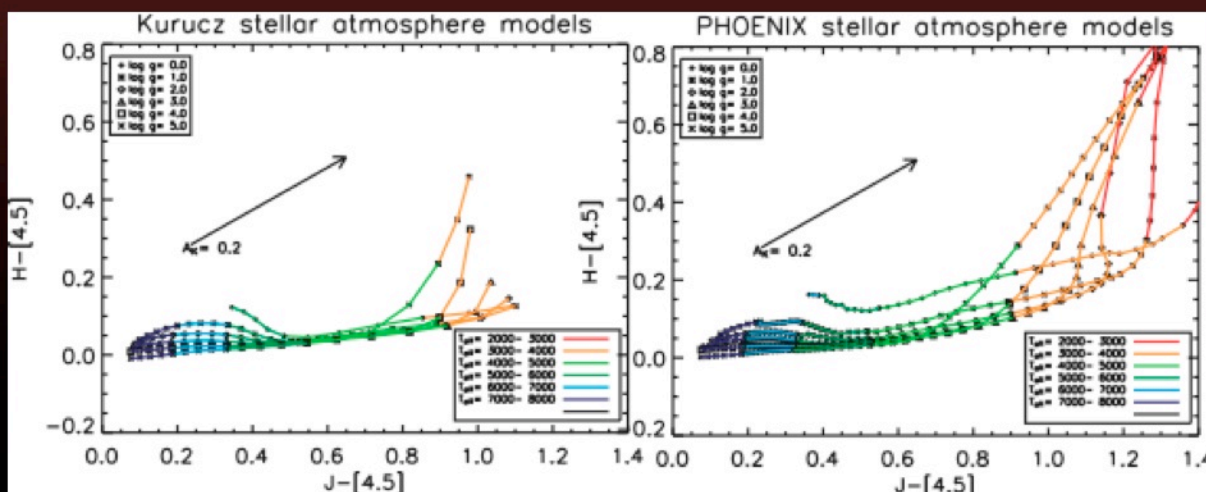
Spitzer/IRAC Channel 1



Extinction Correction



Comparison of CMD for l=10, b=0 field with Baade's window

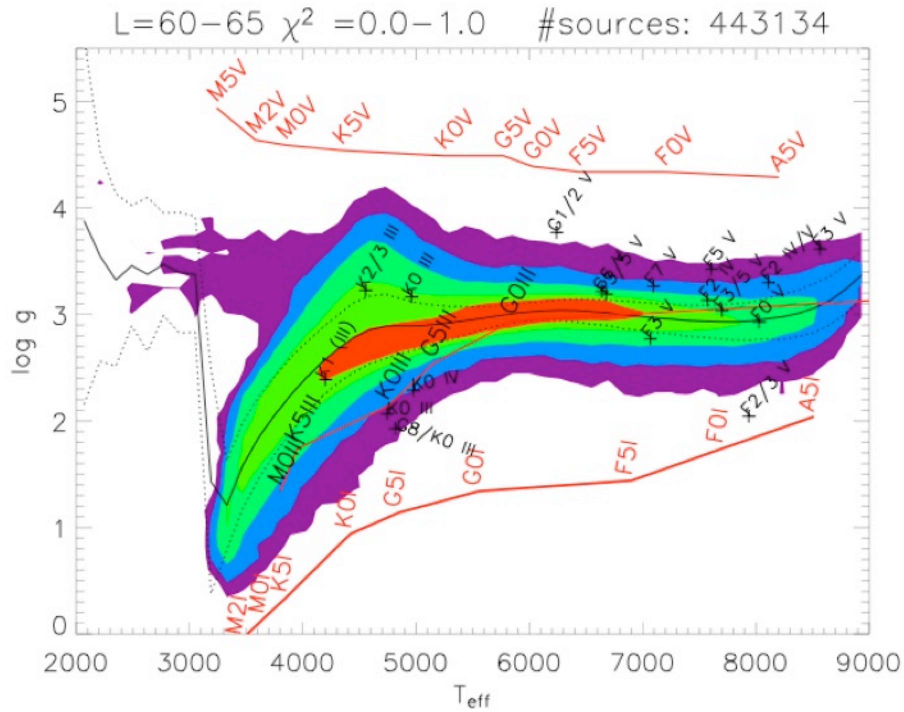


Mid-IR data provides information necessary for accurate extinction correction.

Stellar and YSO SED fitting

www.astro.wisc.edu/protostars

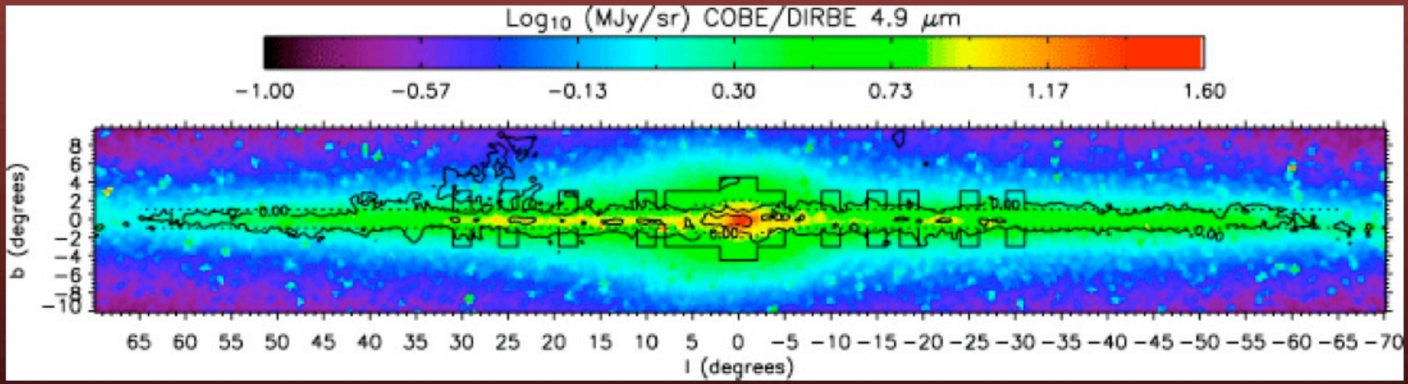
3. Sensitivity to surface gravity?



Most sources fit along giant track! Perhaps due to depression of 4.5 μm flux due to CO and SiO fundamentals? (Cohen, priv. comm)

Galactic Structure Goals for the Spitzer Warm Mission

1. Vertical structure of stellar bar/disk

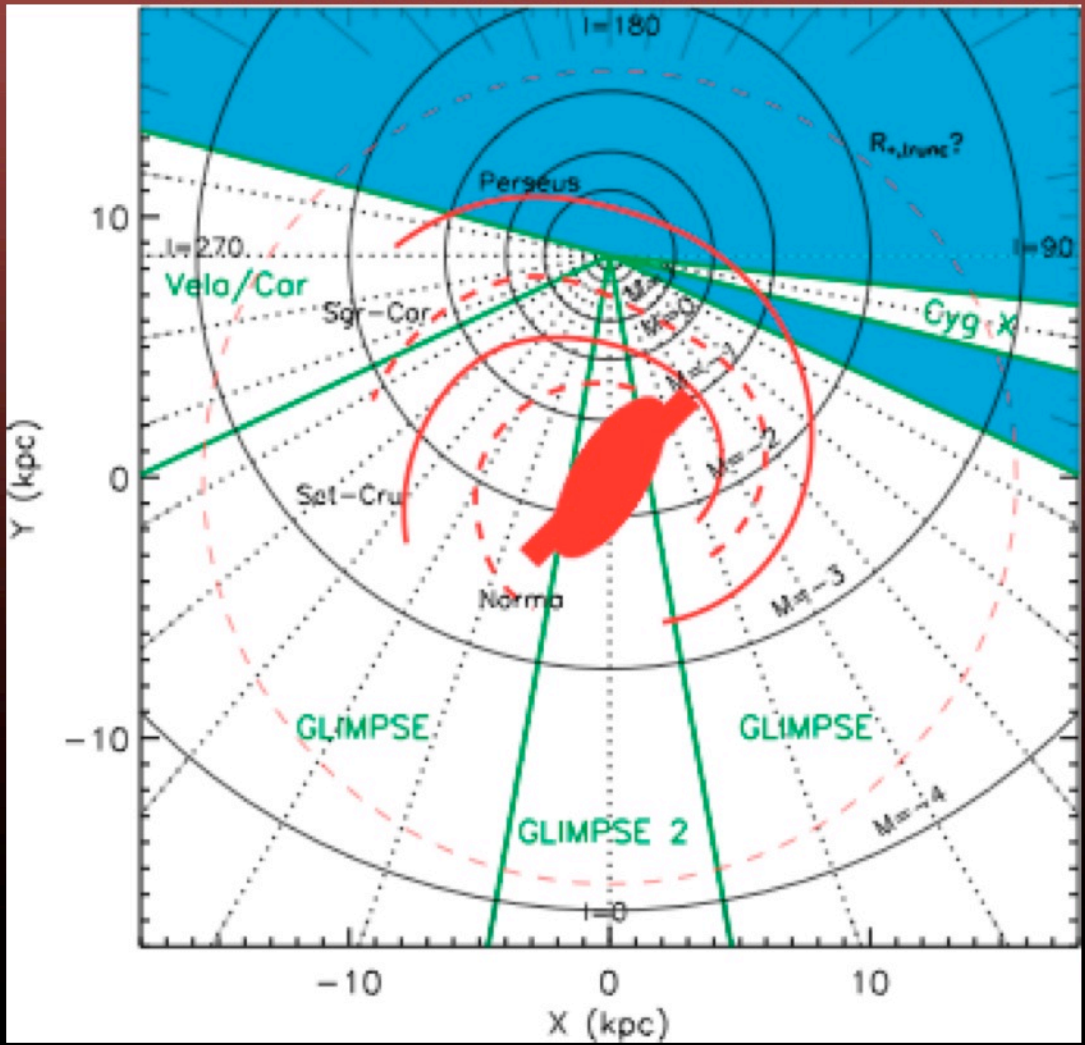


The Galaxy is the only galaxy in the universe where we can resolve vertical structure into populations and components:

- Vertical structures of bars have been unconstrained.
- Near IR studies have been severely limited by strong extinction over the same angular scales as the vertical stellar structures themselves.

Galactic Structure Goal for the Spitzer Warm Mission

2. Edge of stellar disk of Galaxy
   - *Expected at $4R_{*}$~16 kpc.*
3. Stellar spiral structure of the Galaxy
   - *Use red clump and star formation tracer to follow arms.*
4. Stellar warp
   - *Determine extent to which it follows gas warp.*
5. Galactic satellites and tidal streams
   - *Many (up to 20!) satellites expected to lie oriented along plane.*



ISM goals for the Spitzer Warm Mission

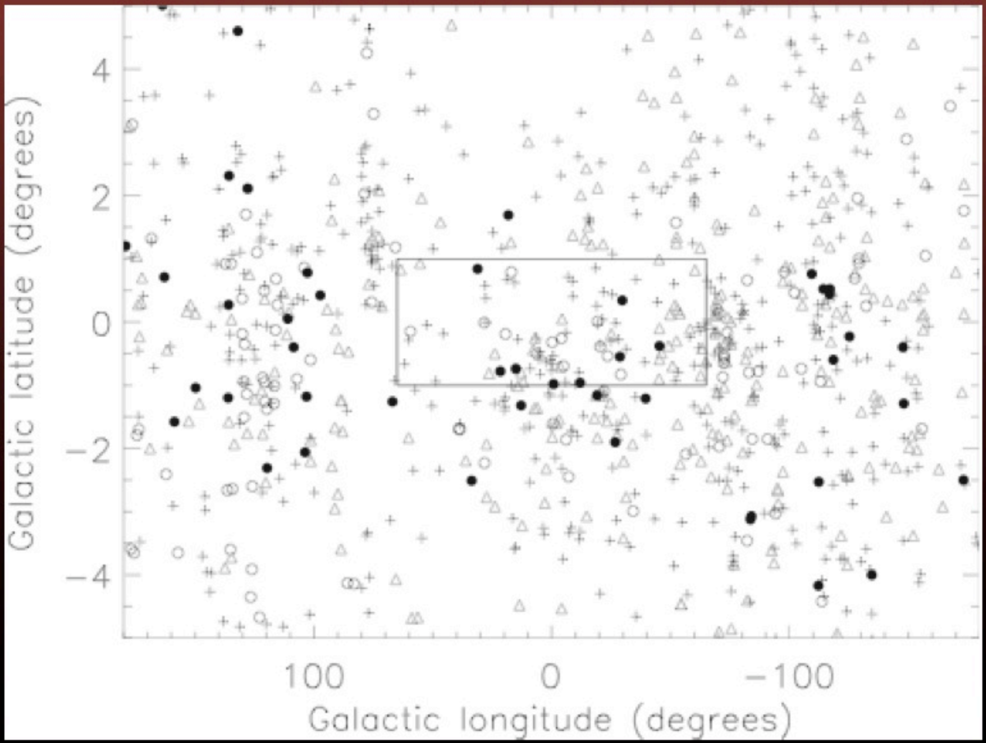
[3.6] band: PAH 3.3 μm emission (C-H stretching mode) makes a significant contribution to diffuse flux.

[4.5] band: H_2 lines (0-0 S(9), 4.695μm, 0-0 S(10, 4.41 μm), 0-0 S(11) 4.181 μm)
PAHs C-D stretching model (if PAHs are heavily deuterated)

- Galactic observations can resolve much of the stellar flux from the true diffuse flux to provide guidance for extragalactic observations (Flagey et al 2006).
- Bright [4.5] band emission could lead to discovery of many more embedded molecular outflows in a Galactic plane survey.
- Longer wavelength context need to interpret [3.6] and [4.5]. This is available from MSX, ISO, etc. Diffuse emission is probably "value added" science for a Spitzer Warm mission.

Star Cluster Goals for the Spitzer Warm Mission

Stellar clusters are important because one can derive ages from isochrone fitting. One of the primary problems with studying low latitude clusters is degeneracy of age, distance, and reddening/extinction in the isochrone fitting. *IRAC data will help break that degeneracy.*

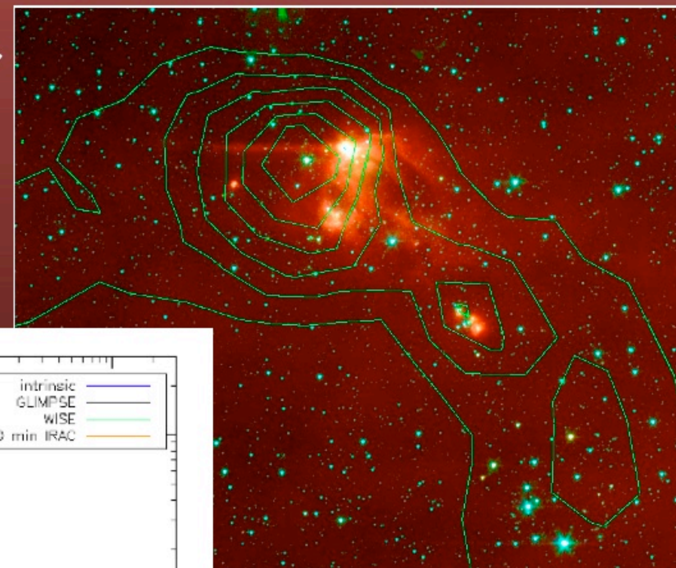


Survey Limit	Open clusters
GLIMPSE	101
|b|<2°	529
|b|<3°	679
|b|<4°	783

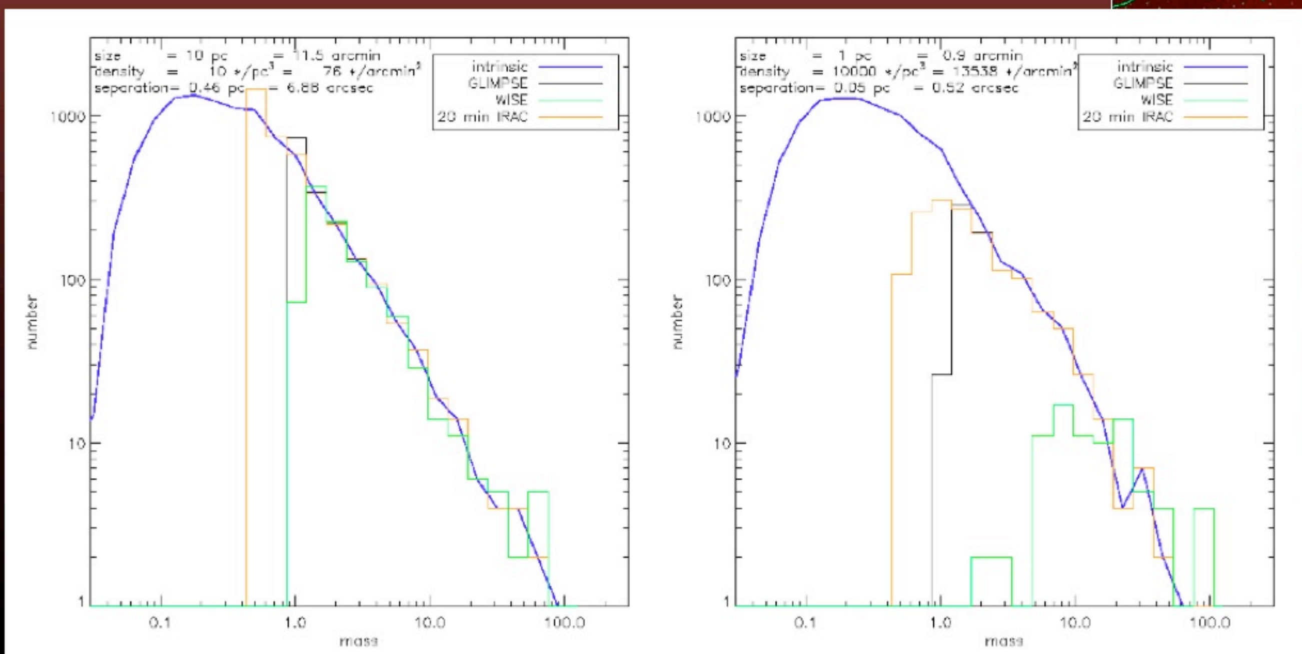
Some subset of clusters could be done to greater depth with a targeted survey.

Global Star Formation Goals for Spitzer Warm Mission

Spitzer can complete the unbiased census of star formation in the outer Galaxy, including the Carina spiral arm tangency and the length of the Perseus Arm.



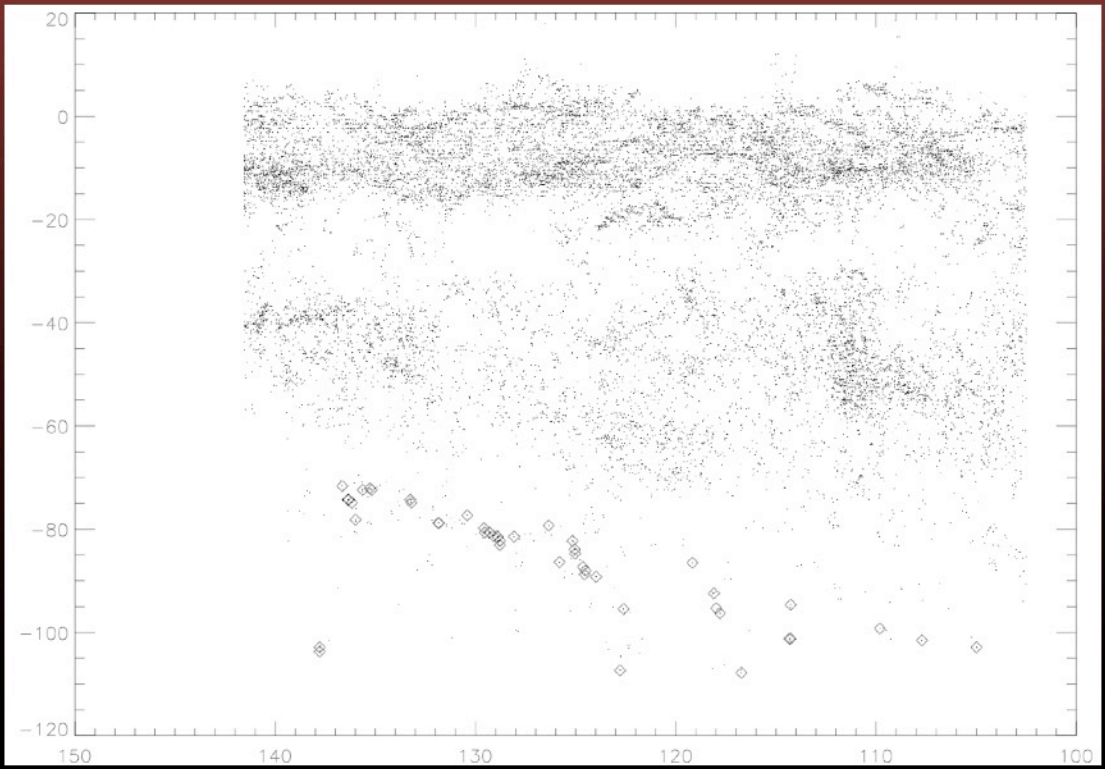
72 sec integration of G124 with ^{12}CO contours. These observations are not yet confusion limited. (Kerton & Brunt 2003)



Simulated mass function for Spitzer/WISE for two different cluster densities.

A Targeted Outer Galaxy Star Formation Survey

Outer galaxy star formation regions have been identified by correlation of CO with IRAS point sources. This catalog has 6700 associates, each of which could be observed with 1-2 IRAC pointings. If one wanted to observe all such regions for two minutes, a ~300 hour project would ensue.



Longitude vs. V_{LSR} for IRAS/CO associations in the outer MW from Kerton & Brunt (2003)

IR extinction in Targeted Dense Cores/Dark Clouds

Dense Cores: Quantitative knowledge of detailed structure of dense cores is critical for setting initial conditions of star formation theory and testing protostellar collapse models. IR extinction mapping can provide unique info about density structure, and near IR can only probe A_V~30-40 cores. More evolved starless cores can reach A_V~75-100 mag.

Requirements: Typical integration times of 10 minutes. Cores need to be of order ~2 arcmin in size, yielding only a few dozen targets.

IR Dark Clouds: Clouds have A_V~40; thought to be sites of future cluster formation. Warm Spitzer could provide extinction mapping compined with JHK to mitigate foreground star contamination (IRDCs are sufficiently distance that foreground contamination is significant.

Requirements: There are ~100 objects known, with sizes of ~10 arcmin. Integration of 240-480 seconds would be required.

Summary

The Spitzer Warm Mission should complete the mid-IR survey of the Galactic plane, both in longitude with variable extent in latitude.

1. IRAC Band 1 and 2 can be combined with near IR to construct a 3D view of **both** the stars and the dense gas of the Galaxy.
2. Given the exisiting/anticipated coverage and confusion limits, the most natural strategy will divide into
   Inner galaxy ($-90 < l < 90°$, $b=\pm5°$): GLIMPSE-like coverage
   Outer galaxy: GLIMPSE360-like up to b=±1.5-2.0 with limited vertical extensions.
3. Shorter, targeted surveys should be performed for certain classes of objects (selected open clusters, globular clusters, dense cores, dark clouds, low density outer galaxy SFRs)