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.

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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.

<table>
<thead>
<tr>
<th>Refereed Papers</th>
<th>(as of June 2007)</th>
</tr>
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<tbody>
<tr>
<td><strong>Topic</strong></td>
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<td>SFR</td>
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<td>YSO’s</td>
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</tr>
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<td>Masers</td>
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<td>Gal Struct</td>
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<tr>
<td>ExGal</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>28</strong></td>
</tr>
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</table>

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**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/\gamma-ray sources, substellar objects.
Mapping Strategies: Coverage vs Depth

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

**GLIMPSE style (Benjamin et al 2003)**
Two 2 seconds integrations
0.55 sq deg/hour
\[ m_{\text{lim}}[3.6] = 14.1 \quad m_{\text{lim}}[4.5] = 14.2 \]
For all longitudes*, \(|b| \leq 4.6^\circ\)

**GLIMPSE360 style (Stauffer et al 2007)**
Four 12 second integrations w. HDR
0.23 sq deg/hour
\[ m_{\text{lim}}[3.6] = 18.4 \quad m_{\text{lim}}[4.5] = 17.5 \]
For all longitudes*, \(|b| \leq 1.9^\circ\)

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

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

<table>
<thead>
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<th>Class</th>
<th>(d_{\text{GL}}[4.5])</th>
<th>(d_{\text{GL360}}[4.5])</th>
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<tbody>
<tr>
<td>K0, I III</td>
<td>6.7 kpc</td>
<td>40.2 kpc</td>
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<tr>
<td>K2,3 III</td>
<td>9.6 kpc</td>
<td>57.8 kpc</td>
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<tr>
<td>M0 III</td>
<td>32.1 kpc</td>
<td>193.2 kpc</td>
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<tr>
<td>G2 V</td>
<td>1.1 kpc</td>
<td>6.8 kpc</td>
</tr>
<tr>
<td>late M V</td>
<td>0.2 kpc</td>
<td>0.9 kpc</td>
</tr>
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</table>

Red clump giants

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.

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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 three 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

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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.
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)

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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.
2. Edge of stellar disk of Galaxy
   • Expected at $4R_{*}\sim 16$ 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.

<table>
<thead>
<tr>
<th>Survey Limit</th>
<th>Open clusters</th>
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<tbody>
<tr>
<td>GLIMPSE</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
</tbody>
</table>

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 12CO contours. These observations are not yet confusion limited. (Kerton & Brunt 2003)

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

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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 $A_V \sim 30-40$ cores. More evolved starless cores can reach $A_V \sim 75-100$ mag.

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

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

**Requirements:** There are $\sim 100$ objects known, with sizes of $\sim 10$ 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 existing/anticipated coverage and confusion limits, the most natural strategy will divide into
   - Inner galaxy (-90 < l < 90°, b=±5°): 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)