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The SIRTF Galactic Plane Survey

Executive Summary

The SIRTF-Galactic Plane Survey (SIRTF-GPS) is a fully-sampled IRAC and MIPS mapping at Galactic latitudes $|b| \leq 1^{o}$and $|l| = 10^{o}$ to 70^{o} on both sides of the Galactic Center. Using all 7 SIRTF bandpasses, the SIRTF-GPS will reveal the full *content of the Milky Way as a stellar system* and *the statistics and variations of star formation* with minimal impact from extinction. It will be the only unbiased mid- far-infrared study of the Galactic Plane at the 1-2″ spatial resolutions comparable to optical and near-IR surveys, while reaching sensitivities of 0.2-0.4 mJy in the IRAC bands and 10-20 mJy at 24/70 μm. Going as deep as any SIRTF pointed observation ever can go in the Galactic plane, the SIRTF-GPS reaches the confusion limit ($\sim$ 0.2 mJy) at IRAC bands and the confusion or background limited MIPS bands. It enables science programs that cannot be replicated by any SIRTF GO programs or any other telescope.

• The SIRTF-GPS will produce a *complete census* of star formation activity in the inner Milky Way, including, for the first time, the *spatially-resolved*, luminous stellar constituents of the youngest, most heavily-attenuated star formation regions (ultra-compact H II regions, hot cores, and pre-stellar cores).

• The SIRTF-GPS will measure the stellar disk scale length of the Milky Way and the stellar structure of the molecular ring, inner arms, and bar as traced by the distributions of stars and star formation regions.

• The SIRTF-GPS will determine the luminosity functions of young stars, clusters, and UC H II regions, as well as a census of pre-stellar molecular cloud cores for all nearby star formation regions in the Galactic Plane.

• Our team will publish the near-term observing plan and areas observed for access by the community, as well as a *near-instantaneous* **Bright Source Catalog** *updated frequently via the web*, to be completed 2 months after data acquisition. This catalog will list the brightest sources (> 2 mJy for IRAC bands, >40 mJy for MIPS bands) suitable for immediate followup spectroscopy with the IRS by other GO programs.

• A mosaiced image database will be produced to promote easy multi-wavelength comparisons with other surveys.

• Our team will provide a **Faint Source Catalog** and an **Extended Source Catalog** with photometry, astrometry, and morphologies of $\sim 10^{8}$ objects expected above the 5σ detection level. These catalogs will be released in 2 month increments for immediate use by the community, with the final release coming 8 and 10 months, respectively, after final data acquisition.

• The survey region is selected to maximize overlap with other large-scale Galactic Plane surveys. These include the Galactic Ring Survey (^{13}CO), the VLA, Southern, and Canadian Galactic Plane Surveys (H I), the NRAO VLA Sky Survey (radio continuum), 2MASS (JHK) and DENIS (IJH), MSX, and ISOGAL. These overlaps, especially with 2MASS/DENIS, will greatly increase the scientific yield of the SIRTF survey.

• The spacecraft time required is 396 hours for IRAC and 385 hours for MIPS: a total of 781 SIRTF hours (<20% of the total time available for Legacy programs).

1. SCIENCE PLAN

1.1. Overall Motivation

The inner workings of our own Galaxy are more mysterious than those of galaxies located millions of parsecs away, mainly because of our unfavorable location in the midplane outskirts of a dusty disk. The Milky Way is a typical luminous spiral of the types seen to large distances. Understanding its structure and the fundamental processes and interactions between gas and stars within it would benefit all galactic and extragalactic research programs. A SIRTF Galactic Plane survey will provide a comprehensive view of the entire stellar and dust content in the inner Galaxy. The broad scope of these data will provide a global understanding that narrowly confined selected regions cannot, and they will provide vital information regarding two basic scientific questions: **(a) What is the structure of the inner Galaxy, including the disk, molecular ring, and bar, as traced by the spatial distribution of stars and IR-bright star forming regions (SFRs)? (b) What are the statistics and physics of star formation? What are the properties of various stages of star formation, and how do they vary with location?** The first question involves the appearance of the inner Galaxy to an outside observer, vital for accurately comparing it to other galaxies. The second question involves the *details* of the star formation process by considering young, but heavily-obscured, clusters which can be resolved spatially for the first time with SIRTF. Only the broad view of a survey can answer these global questions. In addition, there are many other interesting scientific problems that can be illuminated by the survey data (see §1.4.)

1.1.1. Survey Overview

We propose an unbiased, confusion limited SIRTF survey of the Galactic plane ($|b| \leq 1^o$) in the inner Milky Way (from $|l| = 10 - 70^o$), using all 7 filters of the IRAC and MIPS cameras. The inner Galactic plane contains thousands of star forming regions, most of the molecular gas of the Galaxy, a ring of gas at 4 – 5 kpc from the center surrounding a region with a relative paucity of gas, a factor of 3 change in chemical abundances, and a Galactic bar. The ring is the most likely location of the best examples of isolated, cluster mode, and spiral-arm driven star formation. Thus, the inner galaxy is a superb laboratory for studying astrophysics under a wide variety of conditions and environments. SIRTF is the ideal instrument to determine the structure of the inner galaxy because it will be able to detect every OB star still surrounded by dust: locally, about 10% of the total OB population (Wood & Churchwell 1989). Even low-mass protostars can be detected in all star-forming clouds out to several kpc because of their high accretion luminosities. Each stage of star formation can be identified by its spectral energy distribution (SED) (Wood and Churchwell 1989; André, Ward-Thomson & Barsony 1993; Lada & Wilking 1984; Lada 1987; André & Montmerle 1994). In those star formation regions (SFRs) with known distances, luminosities and other physical properties can be quantified. A Galactic plane survey will provide a census of the relative numbers of protostars of different masses in SFRs within ∼8 kpc of the sun. This will also address one of the great puzzles of star formation, namely the apparent constancy of the initial mass function (IMF) over a wide range of physical conditions. The IMF has important implications for molecular cloud fragmentation, Galactic and extragalactic stellar population synthesis, chemical evolution of galaxies, and numerous feedback mechanisms in the ISM and galaxies.

There have been other NIR/MIR surveys, but SIRTF is **far** superior in both spatial resolution and detection limits. The other surveys are (a) ISOGAL, with 7 and 13 μm filters, but with a 6″ pixel size ($\sim 4 \times$ SIRTF) and a detection limit of ∼10 mJy ($20 - 50 \times$

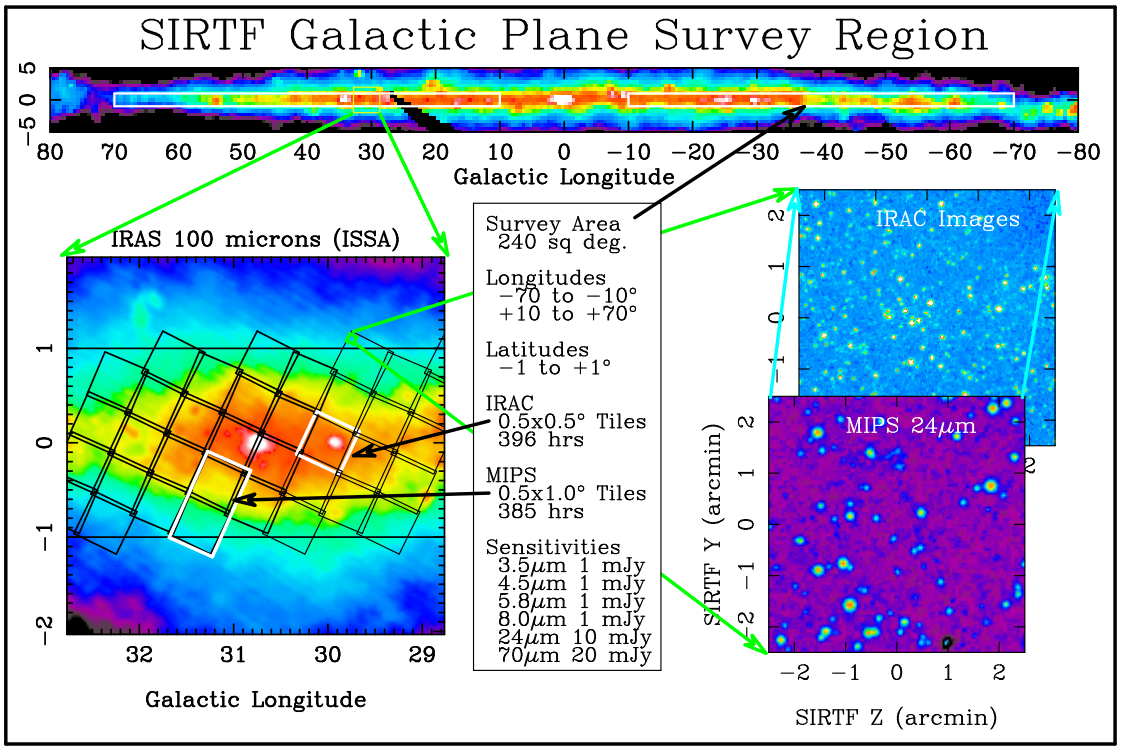

Figure 1. Overview of the SIRTF Galactic Plane Survey

SIRTF); (b) MSX, with 4 – 21 μm filters, 18″ pixels, and a few×100 mJy detection limit ($\sim 200 \times$ SIRTF); and (c) IRAS, with $> 60''$ pixels and detection limits of $> 1000 \times$ SIRTF.

1.1.2. Justification for Survey Limits

In order to avoid the extreme background brightness and the severe confusion of the Galactic center, we propose to survey $|l| \geq 10^{\rm o}$ on both sides of the center of the Galactic plane. This inner longitude cutoff allows complete coverage of virtually all inner disk targets while providing adequate sampling of the regions purported to contain both ends of the ∼3 kpc bar in the center of the galaxy. A primary motivation is to image as much of the inner galactic plane as possible within reasonable time constraints. The outer longitude cutoff, $|l| = 70^{\rm o}$, was chosen because all of the 5 kpc inner ring will be included, the line of sight is approximately tangent to the Sagittarius spiral arm, and there is overlap with numerous radio and IR surveys (see below). Beyond $l = 70^{\rm o}$, kinematic information is less useful for establishing distances. The latitude limits will be $|b| \leq 1^{\rm o}$ because the molecular emission is mostly confined to this region. The total area to be surveyed is thus 240 square degrees. A confusion limited IRAC and saturation or background limited MIPS survey requires 781 (see §2) hours of SIRTF clock time.

The benefits of a SIRTF survey of the plane within the central part of the Galaxy are immensely increased by previous or planned surveys in almost all wavelengths available to astronomers. An extensive CO survey in the proposed region was carried out by Sanders *et al.* (1986). High resolution radio surveys are: the Galactic Ring Survey in ^{13}CO (PI: J. Jackson); the Southern Galactic Plane Survey (SGPS) in H I(PI: John Dickey); the VLA Galactic Plane Survey (VGPS) in H I (PI: R. Taylor and co-PI: J. Dickey); the Canadian

Galactic Plane Survey (CGPS) in H I. In addition, the 2MASS (JHK) and DENIS (IJH) surveys (Epchtein 2000 and ref. therein), along with ISOGAL and MSX, will strongly complement the SIRTF survey. The combination of SIRTF with the emission line studies in the same region will allow distance determinations of many clusters and clouds. In contrast, the outer galaxy disk spans an enormous solid angle (too large to adequately survey with SIRTF) and has a much lower rate of star formation activity.

Some GTO targets fall within the proposed survey area, such as programs by Fazio (deep imaging in M17SW) and Houck (W51 IRAC images). We do not propose repeating GTO observations.

1.2. Basic Science Question 1: Structure of the Inner Milky Way

Radio line studies reveal complex and interesting structure in the inner galaxy that involves organized motions of gas clouds responding to the Galactic gravitational potential and other, more complex, forces. Questions concerning the nature of the central bar near the Galactic center, the ring of molecules located about halfway between us and the center, and the inner spiral arms have been addressed over the past few decades using analyses of large-scale Galactic surveys in CO and H I. However, neither of these probes reveal what the stars are doing and where new stars have formed.

We propose to use SIRTF to reveal key aspects of the structure of the central bar, the molecular ring, and the inner galaxy spiral arms. We will do so by analyzing the distributions of star formation regions (SFRs) in the inner Galaxy. These SFRs will form a well-distributed set of test particles for mapping and probing structures. We show below how a wide-field IRAC and MIPS survey will be used to answer key questions about the inner Galaxy. This first unobscured survey of the stellar content will allow us to determine whether the Milky Way is a ring galaxy, the extent of the bar, the stellar disk scale-length (which is vital for dynamical models), and the nature of the stellar spiral structure. Our ultimate goal is to develop the first substantial "face-on" map of infrared luminosity for the inner galaxy.

1.2.1. Galactic Structure Focus 1: The Molecular Ring

How much star formation is there in the molecular ring? Since the ring contains some 70% of all molecular gas in the galaxy, it should be the dominant star-forming structure. Yet to date, direct measurement of the star formation rate in the ring has been done only for the most luminous H II regions (Kurtz *et al.* 1994). Where in the ring are the stars forming? How does the gas surface density or pressure correlate with the star formation rate there? How does the ring's star formation efficiency compare with starburst regions in other galaxies? What is the structure of the ring on spatial scales finer than revealed by the multi-arcmin radio surveys?

We propose to analyze the counts of SFRs versus longitude, using the ^{13}CO line velocities to provide distances, to establish the star formation rate in the molecular ring. Also, in conjunction with gas surveys, we will use the SFR distribution to resolve and compare the structure of the ring on both sides of the Galactic center (known from radio surveys to differ). We will measure the correlation of star formation efficiency with gas surface density to test models of star formation in disk galaxies.

Co-I Jackson will lead the Galactic Structure science team in publications related to the molecular ring.

1.2.2. Galactic structure Focus 2: Spiral Arms and the Inner Disk

What is the nature of the spiral arms and disk in the inner galaxy? Where are the spiral arms located? What are the properties of the arms and of the interarm regions? Radio observations have given some clues for the gas, but we lack solid answers for the stars and SFRs. We need to know whether new stars are formed on the leading or trailing edges of gas arms, and how the stars formed in arms and in interarm regions differ.

A comparison of the K band and 240 μm data from DIRBE (Drimmel 2000; Drimmel & Spergel 2000) show that K band (stellar light) longitude profiles have broad prominent features that 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 (Georgelin & Georgelin 1976; Russeil *et al.* 1998). Similar behavior of optical and NIR emission is also seen in other galaxies (Rix & Zaritsky 1995; Grosbol & Patsis 1998). Only with the high angular resolution available from SIRTF can one hope to confirm this behavior in our Galaxy, particularly to account for the effects of regions of high obscuration and to verify that the integrated light is not dominated by individual objects (Rhoads 1998; Drimmel & Spergel 2000). This survey will produce a substantially improved data set for models of gas dynamics, star formation and evolution in the inner Galaxy (Englmaier & Gerhard 1999).

A SIRTF Galactic plane survey will also reliably constrain the value of the stellar disk scale length, one of the most important parameters in specifying Galactic structure and mass models. Dehnen & Binney (1998), who calculated an extremely thorough set of mass models for our Galaxy, call this the "most important parameter", noting it is uncertain by nearly a factor of 2. This difference makes a large difference in the inferred dark matter halo mass, and whether the Galaxy has a "maximal" disk – the most mass the disk (as opposed to the halo) can have, given the constraint of Galactic rotation.

Our survey area contains three of the purported four star-forming arms of the Galaxy, including their tangent points: the Norma arm, the Scutum-Crux arm, and the Sagittarius-Carina arm. We will analyze the counts of SFRs with longitude to establish concentrations signifying tangent directions. In order to establish where new stars are born within the gas arms, we will link SFRs to dense gas concentrations, thereby providing kinematics and, in many cases, distances. With these, we will measure the relative arm/interarm star formation efficiency. We will also use these correlations to establish where new stars are born within the gas arms. We will analyze the flux distributions of the SFRs to deduce the relative luminosity functions for regions in and between spiral arms. While we intend to concentrate on SFRs as a tracer of structure, we note that other tracers may be used. For example, Harmon & Gilmore (1988) selected Mira variables using IRAS colors to estimate the shape of the Galactic bulge.

Co-I Benjamin will lead the Galactic Structure science team in publications related to the spiral arms and disk.

1.2.3. Galactic Structure Focus 3: the central bar

What is the nature of the central bar? Where is the central bar? Noncircular motions of gas in the inner 3 – 4 kpc of the Galaxy have suggested that there is a moderately strong bar, and the COBE/DIRBE data have confirmed its existence (Freudenreich 1998). Figures 5-7 of that work show an asymmetric longitude distribution of IR light out to 30°. Its central brightness is ∼130% of the disk stars at JHK, with about the same colors, but the model developed requires a large number of assumptions (and 47 free parameters). Our survey will provide new constraints on this important global feature of our Galaxy. We need to

accurately describe the (l, b) and (R, θ) of the bar end to constrain and test models of the bar. Refined models in turn will allow development of better gas kinematic descriptions for regions near the bar, permitting better separation of gas in the bar from gas in the disk.

We will analyze the counts of SFRs and other stellar tracers (cool giants and AGB stars) versus longitude to locate the central bar ends, and the counts versus (l, b) to measure the tilt of the bar. We will measure the relative flux ratio of SFRs at the bar ends on either side of the Galactic center to establish the relative distances of the ends. We will also use existing observations of the gas (e.g., the Galactic Ring Survey in ^{13}CO) to determine the radial velocities of the SFRs near the bar ends, separating the bar and disk kinematics.

Co-I Bania will lead the Galactic Structure science team in publications related to the central bar.

1.2.4. Star Formation Regions (SFRs) as probes of Galactic structure

To perform the analyses identified in the preceding sections, we need to see deeply into the inner galaxy and to identify "test particles" that have an adequate volume density. We have elected to use SFRs as our test particles, understanding that they are tracers of active star formation and not overall stellar mass. SFRs are useful because they are associated with dense molecular gas, which enables linking the observed radial velocities of dense cloud cores to the SFRs embedded in them. These velocities, when combined with a rotation curve, give the galactocentric distance to the SFR. Recently, H I self-absorption analyses of high angular resolution observations have been used to resolve the remaining near-far distance ambiguity (Gibson *et al.* 2000). By combining ^{13}CO and H I data with infrared photometry, distances and luminosities to inner galaxy SFRs will be developed for a substantial sample.

At a distance of 8.5 kiloparsecs, a young stellar cluster of diameter 1 pc (Cox 2000) will subtend 24″. Therefore, many SFRs will be well resolved (particularly with IRAC) and differentiated from individual bright supergiants. Detecting these regions in the 24 and 70 μm bands will signify the presence of cooler dust in the SFRs. Comparing the dust distribution with the ^{13}CO maps will confirm the star formation nature of these objects and yield the velocities and kinematic distances. The results will allow us to map the inner Galaxy star formation.

A conservative estimate shows that we should detect several thousand SFRs. Wood & Churchwell (1989) found ∼1200 UC HII regions, shrouded in dust, in the region of the SIRTF-GPS. The radio recombination line survey of Lockman *et al.* (1996) sampled only the brightest clusters and detected ∼500 H II regions in our survey area. For a typical size of 1 pc, the faintest of Lockman's SFRs will have a surface brightness 40 times larger than the MIPS detection limit at 24 μm, and even brighter at 70 μm. With the luminosity function for OB associations found in other galaxies (McKee & Williams 1997, and references therein), this should lead to 8000 to 20,000 detections for SIRTF.

1.3. Basic Science Question 2: What are the Statistics and Physics of Star Formation?

Star formation is arguably the single most important process that defines the evolution of galaxies and the interstellar medium (ISM) in them, and yet we are still woefully ignorant of its basic physics. Star formation drives the energy budgets of galaxies, heavy element enrichment, and much of the turbulent motions in the ISM. With spatially resolved images showing the structure of SFRs, the SIRTF-GPS can *detect, identify,* and *quantify* the properties of each evolutionary phase of star formation over a large fraction of the Galaxy.

Determining the statistics and physics of star formation requires high spatial resolution to resolve the stellar populations and ISM content in each SFR.

1.3.1. Massive Star Formation

The SIRTF-GPS will show details of the massive star formation process within ~8 kpc of the Sun by providing structural details of SFRs in each evolutionary stage. The basic stages for massive star evolution are: **Prestellar cloud cores → hot cores → Ultra-compact H II regions → classical H II regions.**

Prestellar or "starless" cores of molecular clouds

Prestellar cores are dense, gravitationally-bound, contracting regions that contain no protostar (an object in quasihydrostatic equilibrium that is still accreting mass, and producing its luminosity by nuclear burning and/or gravitational energy). These objects are the initial stages of star formation and tell us the conditions under which star formation begins. In the MSX Galactic Plane Survey (8 μm), Egan *et al.* (1998) detected ~5000 "IR-dark clouds" in quadrants I and IV, silhouetted against the bright background. Whether or not any particular dark cloud is gravitationally bound depends upon the density profile, or cloud size and mass. Bachmann *et al.* (1999) used ISO (5 and 8.5 μm) to determine the density profiles for ~12 clouds. The SIRTF-GPS should see several thousand of these clouds, with density profiles measured using IRAC images. The clouds will provide an important statistical basis for understanding the conditions necessary to initiate cloud collapse, one of the major mysteries of star formation.

Warm stars will be seen through heavy, but varying, extinction behind different portions of prestellar cores. Since all but the coolest stars occupy a small area in SIRTF color-color plots, *their SIRTF colors will provide the interstellar dust extinction law within dense clouds for the first time.* The spatial resolution and sensitivity of *ISO* were too poor to provide good colors for individual stars with the required large amount of extinction. Outside of these cores the extinction is too low to provide a meaningful measurement of the extinction law.

After the prestellar phase, evolution is different for massive and low-mass stars. The distinction is whether hydrogen begins burning before the Kelvin-Helmholtz contraction time (massive stars) or after. Massive stars produce hot molecular cores; low-mass stars have circumstellar IR-bright disks embedded in dust envelopes.

Hot molecular cores

Dense, hot, massive molecular regions that are heated by one or more rapidly accreting massive proto-stars are called "hot molecular cores". Hunter *et al.* (2000) has tabulated general properties of these objects. The central massive H-burning star is accreting matter so fast ($> 10^{-3}$ $M_\odot$ yr^{-1}!) that the ionization front is closely confined by the infalling gas. The volume of ionized material is too small to be detected with radio free-free emission. The cores are luminous enough (typically 10^5 $L_\odot$) to warm their clouds to large distances ($\sim$ 1 pc). SIRTF's imaging capabilities will allow us to resolve and to study the physical conditions across these envelopes. *SIRTF will be able to detect every hot core in the Galaxy* in the surveyed area at $\lambda \geq 8\,\mu$m (although the 70 and 160 μm bands may be saturated in the nearest objects). It will provide SEDs in the MIR to FIR for the first time and morphologies on arcsecond scales.

Ultracompact H II regions (UC H IIs)

UC H IIs are the next stage in the evolution of massive stars. They are small, dense, luminous, and still deeply embedded in their natal molecular cloud. The central stars

have ceased accretion, thus permitting the radiation from the star to form a detectable H II region. UC H IIs are bright tracers of newly formed O- and early B-stars in the Galaxy. Like their hot core predecessors, *they can be detected by SIRTF throughout the Galaxy.* Thus, SIRTF will give us the entire population of embedded O and B stars in the surveyed area. They can be identified by their FIR colors (Wood and Churchwell 1989), and those within about 9 kpc should be resolved at wavelengths $\leq$24 μm, which will permit determinations of their physical properties with radius. The value of high spatial resolution observations cannot be overemphasized for these objects. Until now, fluxes have been obtained in the MIR to FIR with low resolution data that are strongly contaminated by confusion and background emission. Modeling will be vastly improved with access to new SIRTF data.

1.3.2. Low-mass pre-main sequence stars (= "YSOs", Young Stellar Objects)

YSOs are surrounded by an accretion disk and may be embedded in a dust cocoon. They occur in all nearby SFRs in the surveyed region. SIRTF will detect and identify every one above the IRAC confusion limit. The evolutionary stages of low-mass stars have distinctive SEDs from Class 0 (dominated by accretion luminosity of the disk plus star, but radiated by the infalling dust envelope) through Class III (dominated by emission from the central star), see André, Ward-Thomson & Barsony 1993; and Lada & Wilking 1984; Lada 1987; André & Montmerle 1994. The ability to detect and identify these objects on the basis of their SEDs permits us to perform statistical studies of evolutionary stages of low-mass proto-stars in a variety of density environments.

In the nearest SFRs, SIRTF should detect stars down to the stellar mass limit, although they may be difficult to identify, since observationally we know almost nothing about their SEDs longward of 4 μm. Burrows *et al.* (1997) have calculated some models, but these remain to be tested. A SIRTF survey will provide the number of objects occupying each range of evolutionary phases, the luminosity and initial mass functions, and the location of the members, down to the stellar mass limit.

PI Churchwell and Co-I Whitney will lead the Star Formation science team in publications.

1.3.3. Compact OB clusters

Compact OB clusters present a serious challenge to our understanding of massive star formation. How can the stellar densities be so high that the mean separation of stars is less than the Jeans Lengths for reasonable cloud temperatures? For example, the Trapezium cluster in Orion would require a cloud temperature of $\sim$500 K (Bonnell *et al.* 1998) using the Jeans criterion, far hotter than observed. NGC 3603 is even more anomalous. Compact clusters may be the result of star formation via protostar *mergers* (Bonnell *et al.* 1998; Stahler *et al.* 2000). Clarke, Bonnell, and Hillenbrand (2000) discuss the possible relationship between cluster density and the highest stellar mass. Massive star formation via mergers not only produces compact clusters, but may also alter the IMF. SIRTF data on the IMF, stellar density distribution, location of massive stars, associated dust and gas properties, location in the Galaxy, and frequency of occurrence of massive clusters will be of crucial importance to our understanding of star formation.

Co-I Kobulnicky will lead the Star Formation science team in publications related to the evolutionary sequence of massive star clusters.

1.3.4. Summary

The SIRTF-GPS will provide a census of all the stages of evolution (down to a given mass limit depending on distance) in every SFR in the inner Galaxy that can be sufficiently spatially resolved, with each stage of evolution identified by SEDs independent of distance. Most of the SFRs will have kinematic distances from ^{13}CO or H I lines that will permit determination of luminosities, space densities of the stars in the SFRs, and other physical properties. This will provide a global database from which the IMFs of many SFRs can be derived.

1.4. A Springboard for the Astronomical Community

The SIRTF-GPS will be used by the community to discover new astrophysical phenomena and peculiar objects, as well as to address a wide range of open questions. This was the case for IRAS, ISO, 2MASS, and other large surveys. The increased spatial resolution and sensitivity of the SIRTF images over IRAS, ISO, and MSX will allow many types of objects to be placed in particular volumes in the multidimensional SIRTF plus 2MASS color-color plots. Because of the large extinction, the Galactic plane is precisely the area where one can expect the most serendipitous discoveries. The 2MASS survey, for example, recently discovered two new globular clusters and a Messier-type galaxy (Hurt *et al.* 2000). A SIRTF Galactic plane survey should provide even more new objects and surprises. Below is a sample of some expected science.

1.4.1. PhotoDissociation Regions (PDRs)

PDRs are defined to include all regions where soft UV photons ($E < 13.6$ eV) play an important role in the chemistry or heating of the gas (Hollenbach & Tielens 1999). In the diffuse ISM they dominate both the warm (8000 K) and cool ($\sim$ 100 K) phases (Wolfire *et al.* 1995) where the H is mainly neutral and C, Si, S, and Fe are singly ionized. PDRs also include the warm photodissociated surfaces of molecular clouds and extend to depths of $A_V \sim 5$, where enough UV photons exist to affect the chemistry of C and O. Their NIR spectrum is dominated by the "Unidentified Infrared Bands" at 3.3, 6.2, 7.7, 8.6, and 11.3 μm, almost surely arising from polycyclic aromatic hydrocarbon (PAH) molecules, although their exact charge states, size distributions, and hydrogen coverages are not well known. *ISO* and the Japanese *IRTF* missions have shown that in the diffuse ISM (and often circumstellar gas as well) the 6.2 to 11.2 μm bands, produced by PAH$^+$ ions have common ratios, independent of the 3.3 μm feature from neutral PAHs (Tielens *et al.* 1999; Chan et al. 2000). The IRAC 3.6 μm filter is sensitive to the 3.3 μm feature from neutral PAHs; the 5.8 and 8.0 μm filters are sensitive to PAH$^+$, while the 4.5 μm filter contains no PAH features and monitors the continuum. For regions where there is not too much confusion from the background, the SIRTF-GPS will allow these features to be followed deeply into PDRs with favorable geometries. Differences in the PDRs with various Galactic radii will be especially interesting. Variations in the size distributions of PAHs are potentially observable from the ratio of IRAC 5.8 to 8 μm responses; larger PAHs emit selectively at longer wavelengths (Roelfsema *et al.* 1996). These size changes will help constrain mechanisms of PAH production and destruction, currently unknown.

1.4.2. The chaotic structure of the ISM

Turbulence, as reviewed in Armstrong *et al.* (1997), Lazarian (1999), and Stutzski (1999), extends over spatial scales ranging from a few AUs to kiloparsecs and over complex velocity profiles of emission lines. SIRTF images will provide the power spectrum (Fourier components in wavenumber space) of the density fluctuations. In favorable geometries,

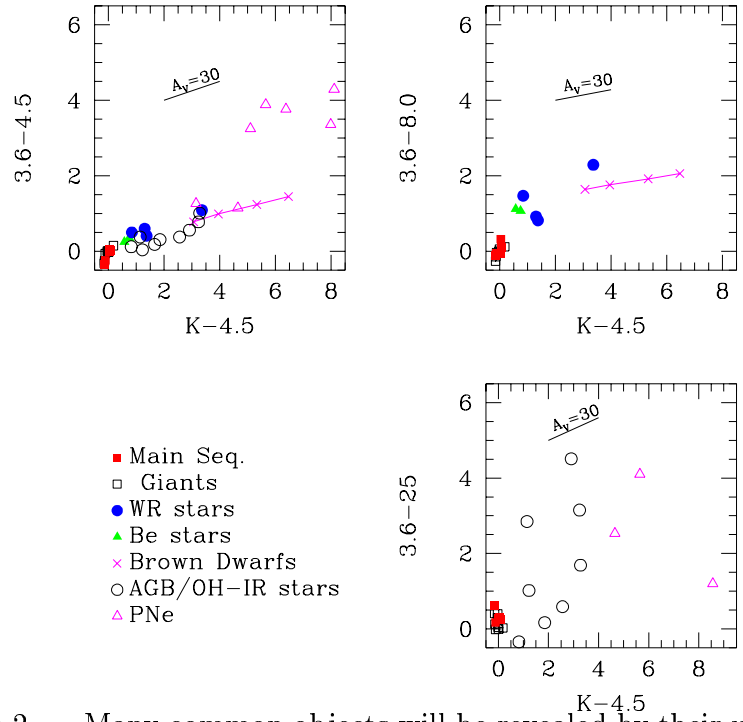

Figure 2. Many common objects will be revealed by their unique SIRTF colors, as shown here.

comparison of the SIRTF structures with the ^{13}CO and H I emissions leads to important insights regarding the distribution of density and velocities (Lazarian & Pogosyan 2000). With its high spatial resolution, SIRTF data can resolve the problems arising from overlapping velocity structures projected onto the same region on the sky.

Co-Is Wolfire and Lazarian will lead in publications related to PDRs and the structure of the ISM.

1.4.3. A Stellar Census

A census of objects will be a major scientific return of the SIRTF survey. The luminosities of various types of stars in the SIRTF bandpasses will usually not be well known in advance, but the experience of IRAS has shown that peculiar objects often segregate into regions in color-color plots. The combination of SIRTF with 2MASS data will often greatly aid in the identification of a particular stellar type. Figure 2 shows colors of a few types of stars.

Special red giant stars.

Habing (1996) has reviewed the properties of cool giants. **AGB** (Asymptotic Giant Branch) stars, while undergoing rapid mass loss and dust ejection, provide excellent laboratories for the physics of dust formation in stars of differing initial chemical compositions, as well as serving as tracers of the Galactic history of formation of intermediate masses (5 – 8 $M_\odot$). Their colors depend upon their C/O ratios (see Waters *et al.* 1998 for *ISO* spectra). Fainter AGBs (mostly O-rich) will be seen anywhere in the galaxy. The most luminous AGBs, the **Pre-planetary nebula** stars, might be problematic for color determinations because they might will probably saturate the SIRTF detectors even if located across the galaxy. **Miras** are, of course, strongly variable at optical wavelengths but are much less so in the NIR. Many of these will probably saturate the SIRTF detectors. **OH/IR stars** are O-rich giants surrounded by a dust shell that provides strong MIR emission as well as masering of the OH microwave lines.

Other objects

Many other types of stars will be detected with SIRTF, and the distributions of luminous ones can be mapped throughout much of the galaxy if the colors are sufficiently unique to determine their luminosities. Such types are **Wolf-Rayets** and **Luminous Blue Variables** (e.g., P Cygni), which have strong stellar winds that are bright in the NIR via free-free emission (see Nugis *et al.* 1998). The coolest WR stars, type WC8 and later, produce dust that will enable them to be located anywhere in the Galaxy. **Be stars** have smaller mass loss rates than Wolf-Rayets but are so bright that they can be located throughout most of the Galaxy. The **nuclei of planetary nebulae** sometimes possess powerful winds that make them rather bright in the NIR. *ISO* MIR spectra of **Planetary nebulae** often show strong H_2 (especially at 6.99 μm) and Unidentified IR Band emissions (e.g., Pottasch & Beintema 1999; Kwok *et al.* 1999) that should allow them to be identified at large distances. Radio emission reveals many supernova remnants in the Galactic plane, and the SIRTF-GPS will provide their colors and probably lead to the discovery of many more.

2. TECHNICAL IMPLEMENTATION PLAN

2.1. Observing Technique

The survey will be accomplished with overlapping "tiles", nominally 0.5^ox0.5^o for IRAC and 0.5^ox1^o for MIPS. Covering the survey area with small tiles is necessary because of the 3 and 6 hour, respectively, maximum AOR limits. The SIRTF boresight angle (roll angle) changes significantly with Galactic longitude during the time spanned by the survey window. However, it is vastly more efficient to map in instrument coordinates than Galactic coordinates. Thus, we will map at the current SIRTF roll angle and accept some sawtooth coverage of the latitude limits (see Fig. 1). The 0.5^ox0.5^o tile size represents a best compromise between observing efficiency and survey edge effects (sawtooth). Larger tiles would waste area coverage at the survey boundaries. Smaller tiles would be less efficient due to instrument and spacecraft overheads. Our proposal planning team, in consultation with SSC staff, will prepare AORs to maximize area coverage and telescope efficiency.

2.2. Observing Modes Within Each Tile

We will use the IRAC mapping mode to map a rectangular grid of 6 rows x 6 columns with a step size of 295″ (overlap of 12″) in all 4 IRAC bands. This will produce a tile size of 0.5^ox0.5^o. SPOT calculations indicate that the required integration time is 1485 s/tile using the minimum frame time of 12 s in conjunction with the "High Dynamic Range" mode which provides 2 s and 0.4 s readouts as well as the 12 s frame. Rejection of cosmic rays will be performed by comparing the 12 s exposures with the 0.4 s and 2 s frames. Our sensitivity requirements are met using the shortest integration time of 12 s. Below, we show that in the Galactic plane, SIRTF becomes *confusion limited* in the IRAC bands for frame times longer than about 5-8 s, so longer exposures will not be useful. Covering 240 sq. degrees with IRAC requires 1485 s/tile × 960 tiles = 396 hours of SIRTF time.

For MIPS we will employ the fast scanning mode using 1^o scan lengths and 6 scan legs with 302″ cross steps on both the forward and return legs. The 160μm data will be acquired, even though the spatial coverage is incomplete in fast scan mode. At 160μm, many regions of the Galactic Plane will be saturated so the incomplete coverage is acceptable for purposes of extracting the large scale structures. SPOT computations indicate that 2890 s are required to cover 0.5 sq. degree in this mode. Mapping 240 sq. degrees will require 385 hours of SIRTF time.

The total observing request for MIPS and IRAC is 781 hours. Scheduling constraints are relatively modest – all observations can be completed in the window between 2002 August to 2003 November. At each galactic longitude, the observing window is narrower, ranging from 41 days near the galactic center to 70-90 days at longitude 70 degrees. However, the window moves in date with longitude, so that the full survey could be completed in just six months.

2.3. Tile Overlap vs Scheduling Requirements

Neighboring tiles will be overlapped by ∼8% to provide photometric cross-checks, establish coordinates, provide a small sample of objects surveyed on different epochs, and to insure complete coverage of the survey region (except for pre-selected bright source avoidance areas). The amount of tile overlap necessary was estimated based on the need to provide some scheduling margin. For example, if two neighboring tiles overlap by 8%, then they can have relative orientation misalignments of up to 5 degrees and still completely cover the sky region between them. This allows the observing scheduling to be relatively flexible, as the SIRTF roll angle changes by a maximum of 0.9 degrees per day at longitude 70 degrees, and only 0.1 degrees per day at the galactic center. This flexibility is needed for our survey to mesh with the 1-2 week "campaign" mode planned for MIPS and IRAC. Under this plan, MIPS might operate for 1-2 weeks, followed by IRAC operating for 1-2 weeks. Thus, although our MIPS and IRAC 0.5^ox0.5^o tile maps will be oriented somewhat differently, the entire 240 degree survey region will be covered without gaps. The more difficult orientation angle matching will be from one MIPS tiled region, spanning 1-2 weeks, to the next session of MIPS operation following an IRAC period. For most of the inner galaxy, our 8% overlap between map tiles will be adequate for matching up these consecutive blocks of MIPS (or IRAC) maps.

Obviously larger degrees of overlap would reduce scheduling concerns even more. However, this comes at the price of mapping speed and total area covered by the survey. We established the 8% overlap goal based on the need to map at nearly 85% efficiency (a small overlap goal) and the need to accept 1-2 week observing gaps (a large overlap goal).

2.4. Sensitivity and Confusion Limits

In the IRAC bands, we will achieve the desired sensitivities of $\sim$ 1 mJy in the shortest possible integration times. We will reach the confusion limit in under 12 s., even in regions of high zodiacal background. In order to model the effects of confusion in the Galactic plane, we generated simulated IRAC datasets at 4.5 μm based on extrapolations of infrared K-band luminosity functions (Cowie *et al.* 1994; Eaton *et al.* 1984) at $l = 45^o$, $b = 0^o$, and including the zodiacal background levels (Reach 2000). Automated crowded field photometry with PSF fitting (e.g., DAOPHOT, DoPHOT) recover 95% of the stars down to $M_M = 15$, but only 50% of the stars at $M_M = 16$. Thus, depending on the stellar density of each survey field, we expect to be confusion limited at $M_M = 15 - 16$ ($\sim$ 0.2 mJy) and similarly for the other IRAC bands.

In Figure 3 we show graphically that the sensitivity limits for the IRAC 3.6/4.5 μm bands for integration times of less than 12 s. The confusion limit is reached well before the background limit due to zodiacal light. A dashed line indicates the 0.4 s saturation level (the shortest frame rate available in high dynamic range mode). The expected flux density of common astronomical objects from 0 to 10 kpc appear as colored lines with labels. Bare main sequence stars down to A0V can be detected as far as 10 kpc in most of the IRAC bands. K and M giants, providing the most numerous detections in the Galaxy, are easily

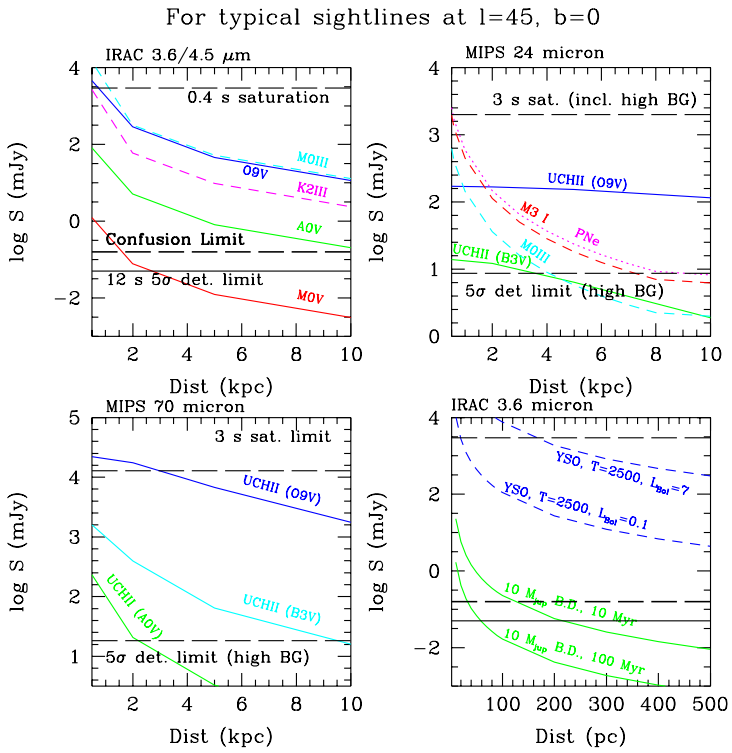

Figure 3. The SIRTF-GPS will reveal different types of Galactic objects, including main sequence stars, Ultra-compact H II regions (UCH II), young stellar objects with a variety of bolometric temperatures and luminosities, and brown dwarfs (BD).

seen to 20 kpc.

In the MIPS bands, we will be background limited along most sightlines due to Galactic ISM emission. As noted in the SIRTF background estimation memo (Reach 2000), there is no analytic model for the background due to the ISM. For planning purposes, we have adopted the average "high" background value of 65 MJy/str (24 μm) and 32 MJy/Str (70 μm) from the SIRTF proposal documents. For an average sightline, these high backgrounds will reduce the effective dynamic range by half in a few$\times$10 s and cause saturation within minutes. At 160 μm, some regions of the Galactic plane will cause saturation in under 10 s. Thus, for MIPS we use the fast scanning mode to ensure the shortest possible integration times. In practice, our planning team will examine each field using the IRAS maps (IRSKY tool) to gauge the background levels and avoid detector saturation in regions of extreme surface brightness.

In Figure 3 we show the 3 s saturation limits and 5σ detection limits for high-background regions at 24 μm (upper right) and 70 μm (lower left). Colored lines with labels show the flux densities for common astronomical objects as a function of distance. Bare main sequence stars are labeled with spectral types. At 24 μm, M giants and supergiants are easily detected out to distances of 4 kpc. Ultracompact H II regions which re-emit all the host star's energy in the infrared (Faison *et al.* 1998) are denoted by their main sequence types w/dust. Planetary nebulae and ultracompact H II regions containing massive stars down to B3V can be seen to distances of many kpc. At the lower left we show the flux densities for common astronomical objects such as massive stars within compact H II regions which can be seen to distances of 10 kpc or more. In the lower right panel we show the detectability of brown dwarfs (Burrows *et al.* 1997) and young stellar objects

with a range of temperatures and luminosities cataloged by Chan *et al.* (1996).

In the entire survey region, we expect to detect $\sim 10^8$ stellar sources down to $M \sim 15$ in each IRAC band and down to ~10 mJy in the 24 μm and 70 μm bands. Table 1 shows a rough estimate of the number of objects, by astronomical type, that we expect to detect in the survey region.

Table 1. Expected Number of Detected Objects

Class	N
O3-B0V	9000
Supergiants	8000
KIII	4×10^7
MIII	2×10^6
AGB+OH/IR	2000
T Tauri	800
PNe	300
Star Formation Regions	few$\times$1000
Starless Cores	$>$1000

2.5. Background Removal

We will use IRSKY (IRAS & COBE data) to forecast galactic and zodiacal backgrounds for planning MIPS observations. IRSKY is an observational planning tool supported by IPAC that displays IRAS images with the Kelsall *et al.* (1998) zodiacal light model subtracted. At present it does not allow users to do their own subtraction. We trust that the SSC will develop this capability, extremely important for almost all SIRTF users. Where available, 2MASS data will augment IRSKY for planning IRAC observations. The galactic component contributes both background, which affects detector dynamic range, and the signal we seek to measure.

2.6. Summary

The survey we are proposing is the most sensitive map that can be made of the galactic plane with SIRTF at each wavelength, since we reach the three natural sensitivity limits:
- The saturation limit at the longest wavelengths ($\geq$70 μm);
- The background limit in the mid-IR (24 μm);
- The confusion limit in the IRAC bands.

Thus, our maps will be as good as any that can be obtained with SIRTF or any other telescope regardless of the integration time or observing strategy.

The infrared is so important for studies of all kinds of objects in the inner galaxy, that without this survey there will be many GO proposals to map specific regions within this area. Such a piecemeal approach inevitably would cost more telescope time because of the higher overhead. It would be less useful as a community resource because of its non-uniform sensitivity. Our SIRTF-GPS will be an important resource for follow-up IRS and other observations.

The more profound cost of the piecemeal approach is that we will not know what we have missed. We know that there are many star formation regions in the inner galaxy which have not yet been discovered. We can be confident that there are other kinds of objects, some perhaps completely unexpected, that will show up in this survey. SIRTF is the only telescope, existing or proposed, that will be capable of a survey of the galactic plane down to the natural sensitivity limits set by confusion and background emission. For the sake of the next generation of Galactic astronomers it is crucial for us not to miss this opportunity.

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4. DATA PROCESSING AND ANALYSIS

Our proposed survey will encompass ∼34,600 individual IRAC pointings and several thousand MIPS scans for a total of ∼500,000 data frames. Scientific analysis on a data volume of this magnitude requires the use of specialized post-pipeline products and tools. We propose to create and deliver to the SSC several key products that will assist users of the proposed observations. We will provide:

- a series of point and extended source catalogs, with incremental updates to aid the scientific community for follow-up proposals. All versions (initial, incremental, final) will be available via a Web database portal;
- mosaiced images for each bandpass;
- analysis tools and a simple mosaic viewer.

The individual products are described briefly below. Subsequent sections provide additional detail regarding the flow of the data processing and key issues related to data management and hardware requirements.

4.1. Data Products

4.1.1. The Catalogs

Source catalogs are a fundamental tool to answer the scientific questions posed above. Consequently, the generation of such catalogs, for both point and extended sources, is one of our primary post-pipeline products and will be the initial focus of our analysis efforts.

We will produce a series of catalogs with the final products containing astrometric, photometric and morphological parameters for all sources detected above the 5σ level. The schedule of release dates for the various catalogs is shown in Table 2. The first product will be a Bright Source Catalog (BSC), with the limit set at approximately the 20σ level (or ∼10 mJy for IRAC and ∼100 mJy at 24 μm). The release of the first BSC is timed to be available for Guest Observer proposals, such as spectroscopic followups. The other point source catalog (PSC) and the extended source catalog (ESC) will be released in increments. Each release should reach the 5σ level, but will be restricted to a limited range in galactic longitude. Updated versions of released catalogs will occur periodically (about every 2 months) in order to incorporate any improvements in the subtraction of various background sources: zodiacal light, diffuse galactic background, extended red emission, galaxies, and solar system bodies (see § 2.5) and the re-processing of the Basic Calibrated Data products due to changes in SIRTF calibration pipeline.

The development efforts will begin with established packages for point and extended source photometry (e.g., DAOPHOT, DoPHOT). Subsequent work will focus on algorithm modification and performance optimization for the unique aspects of the proposed dataset.

Table 2. Catalogs and Proposed Release Dates

Catalog	Release Date
Bright Source (BSC) - initial	D+2
BSC - updates	every 2 months
BSC - final	E+2
Point Source (PSC) - increment 1	E+0
PSC - increments 2, 3, 4	E+2, E+4, E+6
PSC - final	E+8
Extended Source (ESC) - increment 1	E+0
ESC - increments 2, 3, 4, 5	E+3, E+6, E+9, E+12
ESC - final	E+12

D = date of data acquisition commencement. Increments are in months.
E = date of data acquisition termination.

4.1.2. Mosaiced Images

The ability to examine regions larger than an individual image can be crucial in addressing many science issues. The manner in which our survey will be obtained (i.e., §2.2) produces images of adjacent fields that are likely to be rotated with respect to each other. The issue of geometric distortion must also be addressed. To aid in the analysis process, we will produce a series of mosaics at each observed wavelength that can be combined to generate images of a region of an arbitrary size and location. An extensive body of algorithms and implementations already exist, particularly within the IRAF environment (in the NOAO and WFPC packages). Subsequent development will match these routines to the SIRTF instruments and observing strategy.

4.1.3. Data Analysis Software

Additions to Analysis Packages

In addition to the set of basic processing tools developed as part of our post-pipeline data product efforts (e.g., zodiacal light subtraction, source identification, etc.), we will produce "add-ons" to the extensive suite of reduction/analysis packages currently in use by the astronomical community. These packages, typically implemented either in IRAF or IDL, already possess powerful tools for automated analysis of point sources and for surface photometry of extended sources such as galaxies. We will develop and implement additional algorithms for more specialized tasks such as photometry on diffuse objects. Additional development work will also focus on surface photometry and isophotal fitting for diffuse objects. Analysis routines created by our project will be written either as IDL routines or as an add-on IRAF package. Given our philosophy of building upon existing routines whenever possible, the final choice of environment for a particular task may depend upon that of the initial implementation.

We will also produce a simple image viewer tool. The motivation behind this development effort is the easy visualization of the post-pipeline image mosaic and the need to examine regions around specific objects of interest. A special aspect of our viewer will be the capability to combine the seven SIRTF bands to create psuedo-color representations. Other features will be the ability to choose an arbitrary image size and resolution (up to that of the underlying data). This tool will be implemented as an add-on package for the IRAF and IDL environments.

It is expected that these tools will have broad use (i.e., beyond a galactic survey). Consequently, they will be developed in collaboration with the SSC and other Legacy groups in order to avoid needless duplication of effort and products.

Web Modeling Tool

We will provide Web-accessible theoretical modeling tools for the analysis of SIRTF data. We already have in place several well-known and user tested WEB based tools for the analysis of PhotoDissociation Regions (PDRs) and dust continuum observations, as shown in Figure 4. We will enhance and tailor these tools for specific SIRTF modes (spatial resolution and bandpass) in order to optimize the scientific returns from the planned observing program.

The Web Infrared Tool Shed (WITS) contains two "toolboxes", the PDR Toolbox (PDRT) and the Dust InfraRed Toolbox (DIRT). These toolboxes provide an extensive grid of PDR and dust continuum models which are used to analyze IR observations. Included are PDR line emission diagnostics (based on Kaufman *et al.*, 1999), model SEDs, grain temperatures, and intensity profiles (based on Wolfire and Cassinelli 1986). The tools are

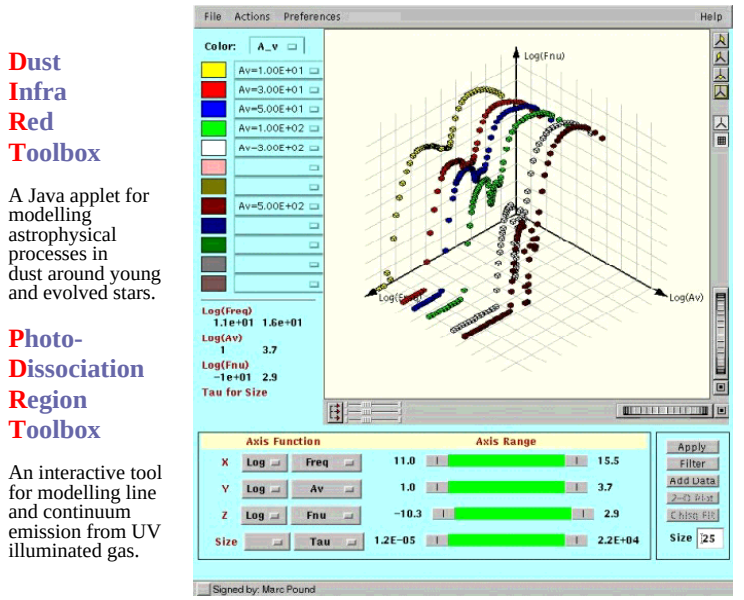

Figure 4. A screen-dump of the user interface for the WEB Infrared Tool Shed

currently in use by many individuals and groups, e.g., ISO, BIMA, MSX, SCUBA, and AST/RO observers.

Modifications we will make to the various tools include: the ability to input SIRTF IRAC and MIPS observations and find the best-fit model; the radiative effects of small grains and PAHs; the ability to retrieve models from a wide range of parameter values (L_{star}, T_{eff}, $\tau_{extinction}$, density distribution laws, PAH abundances); and estimates of mid- and far-IR line intensities, which will be valuable for follow-up observations with other instruments.

4.2. Data Processing and Management

An overview of the data flow is illustrated in Fig. 5, covering the complete cycle from the ingestion of SIRTF data to the export of products for delivery to SSC. We provide brief descriptions of the data management and processing issues below.

4.2.1. Wisconsin Database

The database will be implemented in Oracle 8i residing on a Sun Microsystems UltraSparc computer. The core database schema will be implemented in the first 3 months of the program. The basic schema will consist of separate tables for each instrument-bandpass pair and post-pipeline product. Such a structure provides an efficient and natural way to import/export data, as well as to update and propagate changes in the state of the SIRTF and ancillary data. Refinements of the database structure will be modified and implemented in a modular way as the post-pipeline products and tools are developed. Revisions and modifications during Phase 1 will be executed on a separate "development" database. Changes to the database can be easily accomplished by using products like Rational Rose Enterprise Software coupled with Oracle's Enterprise Manager. All revisions will be implemented in a scheduled manner to avoid conflicts with other ongoing development tasks. Backups of

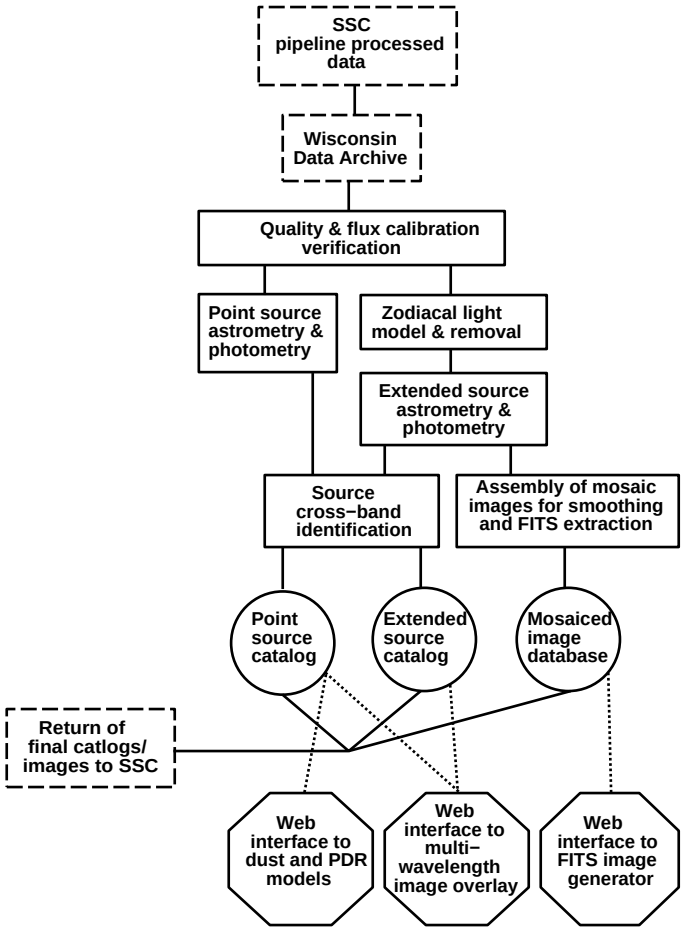

Figure 5. Flow chart giving an overview of the data processing cycle.

the database will be executed on a regular time schedule in both cold (shutdown) and hot (in-service) modes, providing both long and short-term recovery of all transactions.

In addition to database transactions from incremental processing of the data (i.e., local reprocessing of individual frames, source extraction), allowances in data entry must be made for the delivery of bulk data sets from SSC and other sources (including possible local reprocessing outside of database infrastructure). Such bulk data loads will be accomplished through a series of modularized scripts (implemented in Perl) that will include a wide selection of data integrity, validity, and constraint checking.

4.2.2. Post-pipeline Processing and Analysis

Our initial efforts will focus on the Basic Calibrated Data (BCD) products. We will perform flux calibration and geometric distortion correction verifications. Such checks will be especially important to compare with 2MASS, MSX, ISO and IRAS maps from the same regions during the early part of the data acquisition phase. The pipeline data processing plans detailed in the SIRTF observer's manual (SOM) for IRAC and MIPS will meet virtually all calibration needs of the Galactic Plane Survey. A team within the project is tasked with monitoring and providing feedback on this issue (§ 5.2.2.). Consequently, we anticipate changes at or below BCD level will be incorporated into the local database directly through bulk loading of SSC-reprocessed images.

The bulk of the analysis work is embodied in the catalog and mosaic products (§ 4.1.1. and 4.1.2.). Much of the development work during Phases 1 and 2 will involve process

and parameter tuning of already existing algorithms for the unique aspects of the SIRTF data. We anticipate productive "cross-pollination" with the SSC and their BQD source catalog efforts. During Phases 2 and 3, the large number of data frames and the high density of sources will make the production and updating of the catalogs our most resource-intensive task, both in terms of personnel and hardware (see § 4.3. and 5.). In this light, and given the additional burden and difficulty of automated catalog cross-referencing, our efforts will focus on cross-referencing only within our dataset. Although initial catalogs will include separate entries for each bandpass, updates and final release versions will provide cross-reference information: i.e., source X in MIPS 24 μm image XX will be linked to its occurrence (as source Y) in MIPS 70 μm image YY.

4.2.3. Product Accessibility

All products will be available via a read-only Web interface at Wisconsin as well as through regular shipments to the SSC. The design of our database and processing flow significantly simplifies the issues related to delivery of products to the SSC. The flexibility of the Oracle software and the vast number of publicly available tools greatly minimize the impact on the Team. The schedule for product delivery is given in §5.

4.3. Hardware Requirements

Aside from the large volume of data generated in this survey[1] the hardware requirements are specifically driven by two distinct, but related, issues: (1) Store and serve a large database (300-400 Gbytes), with individual objects up to tens of Megabytes, and (2) reasonable turn-around for reprocessing large amounts of data (e.g., in response to changes in BCD products). The first requirement can be met by several dual-processor architectures with fast disk arrays. Meeting the second need requires significantly more computing power. For example, a complete re-extraction of the point source catalog from all of the IRAC data is estimated to take *about 1800 CPU hours on a Pentium III 450 MHz processor!* This was calculated using DAOPHOT on a simulated confusion-limited 256x256 IRAC frame where approximately 1/3 of the 13,000 sources were at or above the 5σ level. Modern (i.e., 1 GHz Intel/AMD or 450 MHz Sparc) processors offer roughly a factor of two decrease in that estimate, with 8 such processors representing a baseline solution. Two Sun Ultra 80 Model 4450 quad-processors (4 x 450 MHz) or their equivalents fulfill both requirements and offer operating system compatibility with the SSC exported pipeline software, as well as separate hosting for the development and research databases (§ 4.2.1.).

[1]There are 34,560 IRAC pointings $\times$ 3 images/pointing in high-dynamic range mode $\times$ 4 filters $\times$ 256^2 array $\rightarrow$ 55 Gbytes of raw image data. The addition of MIPS scans plus all the calibration files implies a data volume of $\sim$300 GB for the entire survey.

5. PROJECT SCHEDULE AND MANAGEMENT PLAN

The project schedule is designed to deliver the Bright Source, Point Source, and Extended Source Catalogs on the shortest possible timescale consistent with our personnel and budget. Tasks are distributed throughout the project to achieve high functionality, low FTEs, and rapid data turnaround (see Fig. 6).

5.1. Project Schedule

Phase 1 (12/2000 to ~8/2002):

12/2000 Start funding Legacy Programs. Begin development of post-pipeline and analysis tools.

01/2001 Entire team meets in Madison to discuss responsibilities, timelines, and operational issues. PI and sub-team leaders meet later in month with SSC staff in Pasadena. Survey Planning Team begins planning observing strategy. Begin post-pipeline software development, Web modeling tools, and Web image viewer.

02/2001 Hardware and Software Definition Team makes recommendations.

04/2001 Hire first post doctoral fellow (PDF1): project data manager, with scientific and computer systems skills. Survey Planning Team visits SSC to consult on observing strategy. Computers and commercial database software are in place. Begin configuring and implementing database software (with consultant).

06/2001 Hire PDF2, an astronomer with computational skills. Begin development of Web portal tool.

09/2001 Hire PDF3, an astronomer with computational skills. First visit of catalog consultant to discuss content, layout, and mechanisms for building the catalogs. Hire graduate students at BU and at UW.

10/2001 Deliver AORs to SSC.

11/2001 First progress review at SSC (PI, PDF1 & 3, Kobulnicky, Wolff, Whitney). Discuss AORs, post-pipeline reduction tools, Web portal tool.

12/2001 Web portal tool installed.

04/2002 Post-pipeline reduction tools ready to reduce data.

05/2002 Post-pipeline, Web portal tool available to SSC for review. Entire team meets in Madison to discuss readiness for Phase 2.

Because of uncertainties in launch date, we will use the notation D + x for x months after the initial data acquisition, and E + x to denote dates after the end of data acquisition.

Phase 2 (~8/2002 to 8/2004)

D + 0 Start of survey data collection. PI and Kobulnicky to SSC for a week to validate observing strategy.

D + days Begin building the bright source catalog immediately as data are processed through the post-pipeline reduction system. Release it in installments every two months to SSC and the Web. Make any necessary modifications to post-pipeline software in response to live data. Verify flux calibration, positions, etc. of first data via cross checks with other catalogs.

01/2003 Web image viewer installed.

D + 0.5 Revise AOR parameters if required in response to on-orbit performance.

D + 3 Begin extracting first science from data already obtained.

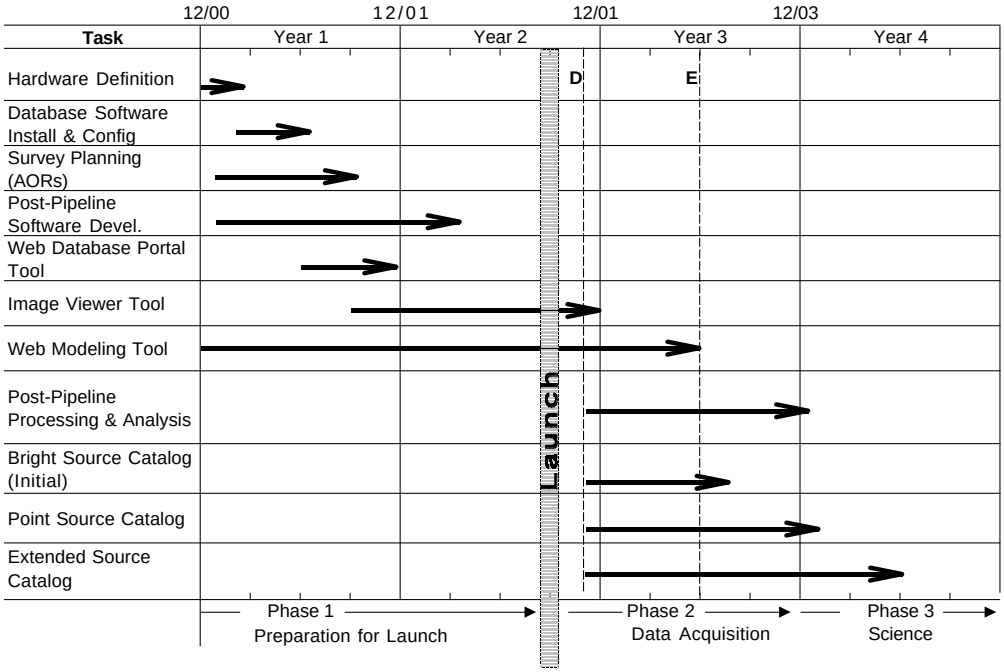

Figure 6. Task Schedule

D + 4 Second progress review at SSC (PI, sub-team leaders).
D + 5 Team meets in Madison. .
D + X Presentation of first results at first AAS meeting after D + 0.
E + 2 Initial version of the complete Bright Source Catalog posted on Web.
E + 8 Initial version of the Point Source Catalog complete and on the Web.
E + 12 Initial version of the Extended Source Catalog complete and on the Web.

Phase 3 (8/2004 –)

E + 14 Focus on publications.
E + 16 Third progress review at SSC (Leaders of all sub-teams plus PI).
E + X Presentation of results at US and international meetings.

Fig 6 shows a schematic of the task schedules. The beginning of data taking (D) and end of data taking (E) are assumed.

5.2. Management Plan

The day-to-day management of the project will occur via frequent meetings of the various sub-team leaders with the PI. The team as a whole will have a weekly telecon to discuss problems, questions, operational issues, etc. This mode of operation has proven very effective during the project definition and proposal preparation phase and we will continue this throughout the project.

Churchwell will be the overall project director. He will be the liaison with all the teams within the project. His job will be to facilitate communication between teams, help keep teams on schedule, and act as spokesman for the project. Close ties with the SSC will be

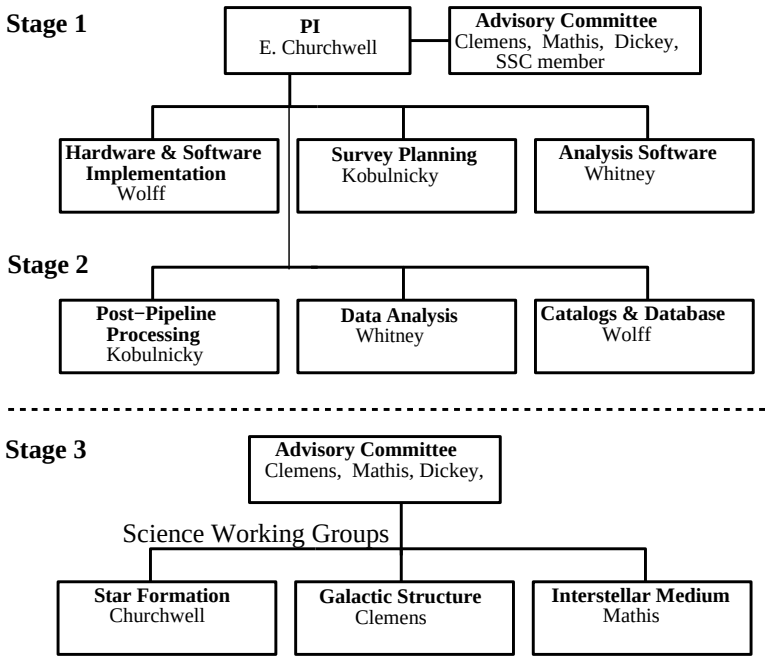

Figure 7. Project Management

maintained and a list of key contact persons within SSC and other Legacy programs will be kept.

An Advisory Subcommittee consisting of Mathis (chair), Dickey, Clemens, and a member of the SSC will meet monthly with the PI (via telecon for Clemens, Dickey, and the SSC member) to advise on strategy for dealing with problems as they arise. This committee will be the overall advisory group for the entire project. They will keep abreast of the project, anticipate problems and recommend solutions before they become serious, track schedule delays, and help advise on the scientific goals as the project evolves. A diagram of the Project Management is shown in Fig 7

5.2.1. Phase 1 (12/2000 to Launch)

During this phase four sub-teams will be formed with the following functions:

Hardware and Software Implementation Team (start 12/2000): Wolff (leader), Kobulnicky, Whitney, database consultant. The hardware and software configuration needs of the project in consultation with SSC will be determined and implemented (including design, acquisition, and implementation of core database schema). Commercial software (e.g., Oracle 8i) and hardware acquisition will be complete by by 04/2001. Team will dissolve after implementation of the core database structure and the maintenance tools.

Survey Planning Team (12/2000 to beginning of Phase 2): Kobulnicky (leader), Benjamin, Whitney, PDF1, Clemens, Churchwell. This group will work with the staff at SSC to define the most efficient techniques to fully sample the survey area with IRAC and MIPS cameras. They will also be responsible for constructing AORs.

Analysis Software Development Team (12/2000 to beginning of Phase 2): Whitney (leader), Wolff, Kobulnicky, PDF 2 & 3, Wolfire. This group will be responsible for obtaining or developing software analysis tools for removal of IR background (e.g., zodiacal light, background galaxies, etc.), modeling of point source photometry and extended source brightness distributions. They will be responsible for providing end-user documentation. This group will also assume database management duties after dissolution of the Hardware and Software Implementation Team.

Web Tools Development Team (12/2000 into year 3): Wolfire (leader), PDF3, Jackson. Ensure that database Web interface is operational and continue development of the modeling tools.

5.2.2. Phase 2 (~8/2002 to ~8/2004)

Three sub-teams will be active during this period:

Post Pipeline Processing Team: Kobulnicky (leader), PDF1, Whitney, Benjamin. All members of this team will reside in Madison. This team will meet daily to assess data quality of each BCD or BQD installment (verify fluxes, positions, remove CR hits), correct for background as required, merge MIPS and IRAC observations larger than a single AOR, and track what remains to be done. This group is also responsible for monitoring and providing spot checks of calibration effects and trends and for working with the SSC and other Legacy projects to provide feedback to the pipeline process.

Data Analysis Team: Whitney (leader), PDF 2, PDF 3, grad student, Wolff, Wolfire, Seager. This team will be responsible for producing the higher level products such as SEDs, color-color plots, source identifications, identifications across SIRTF bands, and producing the final point source and extended source catalogs.

Catalog and Web Tools Managers: Wolff (leader), Wolfire. This team will be responsible for inserting newly reduced data and maintaining the integrity of the catalogs. They will also assume database management responsibilities. They will interact with the Catalog Consultant (see cost plan narrative).

5.2.3. Phase 3

During Phase 3, activity will shift to scientific working groups as the data analysis phase begins to taper off. These working groups will be responsible for producing scientific publications. They will generally be constituted as follows:

- Galactic Structure: Clemens, Bania, Jackson, Benjamin, Dickey
- Star formation: Churchwell, Seager, Whitney, Kobulnicky, Cassinelli, Wolfire
- Interstellar Medium: Mathis, Lazarian, Wolfire, Wolff, Churchwell

The new postdocs and grad students will also contribute heavily to the above endeavors.

Team Members

The team assembled for this project has a wide range of scientific expertise, a strong publication record, a good mix of ages and experience from grad students to senior scientists, and several who have experience with large surveys and data management. A brief statement of each team member's affiliation and areas of scientific interest follows:

University of Wisconsin

Bob Benjamin	Theory of the ISM and galactic structure
Joe Cassinelli	Theory of stellar atmospheres and stellar winds
Ed Churchwell	Star formation; compact HII regions; molecular clouds. Member of the ISO galactic abundance gradient team
Henry Kobulnicky	Nebular abundances, HII regions, thermodynamics of the ISM, dynamics of galaxies
Alex Lazarian	Dust properties; theory of the ISM and turbulence
John Mathis	Theory and observations of HII regions, dust, ISM, and atomic abundances
PDF 1	Data manager/astronomer. Will spend significant time at SSC, especially in Phase 1.
PDF 2 & 3	Astronomers with computational skills
Database Consultant	During the first year a consultant will be hired to assist with the installation and configuration of the database software, as well as provide Team training. A necessary qualification is extensive experience in design and management of large research databases. This person will be necessary only in the first year.
Catalog Consultant	A person who has had experience building large catalogs; will act as an advisor to quality control of the catalogs. Such a person might be someone from the 2MASS project, the Sloan survey, or STScI.

Space Science Institute

Barbara Whitney	Radiation transfer (Monte Carlo techniques), theory and observations of star formation.
Michael Wolff	Theory and observations of interstellar and interplanetary dust properties, including radiative property calculations.

Boston University

Tom Bania	Large scale structure of the ISM, galactic structure, molecular clouds. Co-I on the Galactic Ring Survey
Dan Clemens	Galactic structure; ISM; Co-I of the Galactic Ring Survey.
Jim Jackson	Star formation; molecular clouds. PI of the Galactic Ring Survey.

Institute for Advanced Study (Princeton)

Sara Seager	Theory of brown dwarfs & substellar objects.

University of Minnesota

John Dickey	Observation and theory of the ISM, galactic structure, interstellar turbulence. Co-I of the VLA H I GPS and PI of the H I southern GPS.

University of Maryland

Mark Wolfire	Theory and observations of PDRs, radiation transfer, molecular clouds, star formation.

6. Summary Vitae & Publications Lists

EDWARD BRUCE CHURCHWELL

Education:

1963 B. A., Mathematics and Physics, Earlham College, 1963
1967 M. S., Astrophysics, Indiana University, 1967
1970 Ph. D., Astrophysics, Indiana University, 1970

Positions Held:

1965–70 Graduate Student, Indiana University
1968–70 Graduate Student, National Radio Astronomy Observatory
1970 Post Doc., National Radio Astronomy Observatory
1970–72 Heinrich Hertz Post Doctoral Fellow, Max-Planck-Institut fur Radioastronomie, Bonn, Germany
1972–77 Staff Scientist, Max-Planck-Institut fur Radioastronomie, Bonn, Germany
1977–79 Assistant Professor, University of Wisconsin-Madison
1979–83 Associate Professor, University of Wisconsin-Madison
1983– Professor, University of Wisconsin-Madison

Publications: Over 125 publications in refereed journals and numerous review articles. Publications related to this proposal are listed below.

Pankonin, V., Churchwell, E., Watson, C., Bieging, J. 2000, "A Search for the Earliest Stages of Massive Protostars", ApJ, in prep.

Hunter, T., Churchwell, E., Watson, C., Cox, P., Benford, D.J., Roelfsema, P.R. 2000, "350 μm Images of Massive Star Formation Regions", AJ, 119, 2711.

Churchwell, E. 1999, "Massive Star Formation," in The Origin of Stars and Planetary Systems, eds. C. J. Lada and N. D. Kalyfis, Kluwer Acad. Pub., Netherlands, p. 515-552.

Kurtz, S., Cesaroni, R., Churchwell, E., Hofner, P., Walmsley, C.M. 2000, "Hot Molecular Cores and the Earliest Phases of High-Mass Star Formation," in Protostars and Planets IV, ed. V. Mannings, A. P. Boss, & S. S. Russell, Univ. Az. Press, Tucson, p. 299- 326.

Faison, M., Churchwell, E., Hofner, P., Hackwell, J., Lynch, D. K., Russell, R. W. 1998, "Infrared Spectroscopy of Ultracompact H II Regions," ApJ, 500, 280.

Churchwell, E. 1997, "Origin of the Mass in Massive Star Outflows," ApJ, 479, L59.

Afflerbach, A., Churchwell, E., Werner, M. W. 1997, "Galactic Abundance Gradients from IR Forbidden Lines in UC H II Regions," ApJ, 478, 190.

Wolfire, M. G., Churchwell, E. 1994, "Circumstellar Dust Emission Models," ApJ, 427, 889.

Wood, D.O.S., Churchwell, E. 1989, "Massive Stars Embedded in Molecular Clouds: Their Population and Distribution in the Galaxy," ApJ, 340, 265.

THOMAS M. BANIA

Education:

1977 Ph.D., Astronomy, University of Virginia
1973 M.Sc., Astronomy, University of Virginia
1971 A.B., Brown University

Positions Held:

1993– Professor, Boston University
1990–91 Chairman, Astronomy Department, Boston University
1989– Trustee, Northeast Radio Observatory Corporation (NEROC)
1987–93 Associate Professor, Boston University
1981–87 Assistant Professor, Boston University
1980–81 Visiting Assistant Professor, University of Virginia
1978–80 Research Associate and Lecturer, Cornell University
1976–77 Research Associate, Arecibo Observatory, N.A.I.C.

Research Areas: Radiospectroscopy; Galactic Structure; Interstellar Medium

Publications: Publications related to this proposal are listed below.

1983 Bania, T. M., & Lockman, F. J., "A Survey of the Latitude Structure of Galactic HI on Small Angular Scales," *Astrophysical Journal Supplement Series*, 54, 513.

1993 Kuchar, T. A., & Bania, T. M., "The Structure of the Interstellar Medium Surrounding the Rosette Nebula," *Astrophysical Journal*, 414, 664.

1994 Ingalls, J. G., Bania, T. M., & Jackson, J. M., "Atomic Carbon in the High Latitude Molecular Cloud MBM 12," *Astrophysical Journal Letters*, 94, 431.

1997 Stark, A. A., Bolatto, A. D., Chamberlin, R. A., Lane, A. P., Bania, T. M., Jackson, J. M., & Lo, K-.Y., "First Detection of 492 GHz [CI] Emission from the Large Magellanic Cloud," *Astrophysical Journal Letters*, 480, L59.

1997 Ingalls, J. G., Chamberlin, R. A., Bania, T. M., Jackson, J. M., Lane, A. P., & Stark, A. A., "Atomic Carbon in Southern Hemisphere High-Latitude Clouds," *Astrophysical Journal*, 479, 296.

1980 Bania, T.M ., & Lyon, J. G., "OB Stars and the Structure of the Interstellar Medium: Cloud Formation and Effects of Different Equations of State," *Astrophysical Journal*, 239, 173.

1986 Bania, T. M. & Stark, A. A., "Clump 2: An Inner Spiral Arm?" *Astrophysical Journal Letters*, 306, L17.

1987 Bania, T. M., Rood, R. T., & Wilson, T. L., "Measurements of the ^{3}He Abundance in the Interstellar Medium," *Astrophysical Journal*, 323, 30.

1990 Pound, M. W., Bania, T. M., & Wilson, R. W., "Sub-parsec Clumping in the Nearby Molecular Cloud MBM12," *Astrophysical Journal*, 351, 165.

1992 Rood, R. T., Bania, T. M., & Wilson, T. L., "Detection of Helium-3 in a Planetary Nebula," *Nature*, 355, 618.

ROBERT A. BENJAMIN

Education:

1994 Ph. D., Astronomy, University of Texas–Austin

1987 B. A., Physics and Mathematics, Carleton College

Positions Held:

1997– Post-Doctoral Researcher, Physics Department, University of Wisconsin-Madison

1994-1997 Post-Doctoral Researcher, Astronomy Department, University of Minnesota

Awards:

1994 NASA Graduate Student Research Fellow

1995 Minnesota Supercomputer Institute Fellowship

Publications:

2000 Benjamin, R.A. "Vertical Shear in the Galactic Interstellar Medium" in "Astrophysical Plasmas: Codes, Models, and Observations", eds. S. J. Arthur, N. Brickhouse, and J. Franco, RevMexAA(SC), 9, 256.

2000 Callaway, M.B, Savage, B.D., Benjamin, R.A., Haffner, L.M., & Tufte, S.L. "Observational Evidence of Supershell Blowout in GS 018-04+44: The Scutum Supershell", ApJ, 532, 943.

2000 Benjamin, R.A. & Shapiro, P.R. "The Spectrum of Cooling Galactic Fountain Gas", ApJS, submitted.

1999 Wakker, B. P., Howk, J.C, Savage, B.D., van Woerden, H., Tufte, S.L., Schwarz, U.J, Benjamin, R.A., Reynolds, R.J., Peletier, R.F., and Kalberla, P.M.W., "Accetion of Low-Metallicity Gas by the Milky Way", Nature, 402, 388.

1998 Benjamin, R.A., Skillman, E.D., & Smits, D. P. "Improving Predictions for Helium Emission Lines", ApJ, 514,307.

1998 Benjamin, R.A. "What is the Reynolds Number of the Reynolds' Layer?", in Interstellar Turbulence, eds. J. Franco & A. Carraminana (Cambridge University Press), p. 49.

1997 Benjamin, R.A. and Danly, L., "High-Velocity Rain: The Terminal Velocity Model of Galactic Infall," ApJ 481,764.

1997 Benjamin, R.A., "High-Velocity Clouds: The Importance of Drag", in The Physics of Galactic Halos, ed. H. Lesch, R.-J. Dettmar, U. Mebold & R. Schlickeiser.

1996 Benjamin, R.A., Venn, K.A., Hiltgen, D.D., & Sneden, C., "The Distance to a X-ray Shadowing Cloud in Ursa Major", ApJ, 464, 836.

1996 Hayward, T.L., Saizar, P., Gehrz, R.D., Benjamin, R.A., Mason, C.G., Houck, J.R., Miles, J.W., Gull, G.E. & Schoenwald, J., "The Mid-IR Evolution of Nova V1974 Cygni", ApJ, 469, 854.

1993 Dinerstein, H.L. & Benjamin, R.A.,"The Evolution of the Infrared Spectra of Classical Novae", Rev. Mex. Astron. Astrofis. 27, 33.

1993 Swartz, D.A., Clocchiatti, A., Benjamin, R., Lester, D.F., and Wheeler, J.C., "Supernova 1993J as a Spectroscopic Link Between Type II and Type Ia Supernovae", Nature, 365, 232

JOSEPH P. CASSINELLI

Education:

Ph.D. (Astronomy), University of Washington, Seattle, 1970

Recent Positions Held:

Professor, University of Wisconsin-Madison
Assistant (1973-1977), *Associate* (1977-1981), *Full* (1981-present), *Chairman*, (1986-1989)
Visiting Scientist, High Altitude Observatory, Boulder Colorado, 1998.
Visiting Professor, University of Glasgow, Scotland, Fall 1998.

Recent Professional Activities:

Elected Member, Organizing Committee IAU Working Group on Active B Stars. 1994-
Elected Member, Organizing Committee IAU Working Group on Hot Massive Stars. 1995-
Member, Scientific Organizing Committee, "Magnetic Fields across the HR Diagram" Meeting to be held in Santiago Chile, Jan 2001.

Some Recent Relevant Publications, J. Cassinelli :

"Equatorial Wind-Compression Effects Across the H-R Diagram" (1996) ApJ **459**, 671. Ignace, R., Cassinelli, J. & Bjorkman, J.E.

"Inference of steady stellar wind v(r) laws from optically thin emission lines III. Inversion of total line intensity distributions" (1998) Ignace, R., Brown, J. C., Milne, J. E., & Cassinelli, J. P., A&A **337**,223.

"Stagnation and Infall of Dense Clumps in the Stellar Wind of τ Scorpii" (2000) Howk, J., Cassinelli, J.P., Bjorkman, J.E., & Lamers, H.J.G.L.M. ApJ. 534, 348

"Hot Star Polarimetric Variability and the Nature of Wind Inhomogeneities" (2000) Brown, J.C., Ignace, R. and Cassinelli, J.P. A&A **356**, 619.

"Wolf-Rayet wind structure and optical variability" (2000) Li, Q., Brown, J.C., Ignace, R., Cassinelli, J.P., & Oskinova, L.M., A&A, 357, 233.

"The Velocity Laws of Wolf-Rayet Stars as derived from Infrared Line Observations" 2000) Quigley, M., Cassinelli, J. P. & Ignace R. to be submitted to ApJ

Recent book: *Introduction to Stellar Winds*, (1999) H.J.G.L.M. Lamers & J.P. Cassinelli. (Cambridge Press)

D. P. CLEMENS

Education:

1989 Ph. D., Physics, University of Massachusetts
1983 M.S., Astronomy, University of Massachusetts
1980 M.S., Physics, University of Massachusetts
1978 B.S., Physics, University of California at Davis
1978 B.S., Electrical Engineering, UC Davis

Positions Held:

1999– Director, Institute for Astrophysical Research, Boston University
1994– Associate Professor, Boston University
1988–94 Assistant Professor, Boston University
1987–88 Adjunct Assistant Professor, University of Arizona
1985–87 Bart J. Bok Fellow, University of Arizona
1978–84 Research Assistant, University of Massachusetts

Selected Primary Refereed Publications

"Massachusetts–Stony Brook Galactic Plane CO Survey: The Galactic Disk Rotation Curve," Clemens, D.P., ApJ, **295**, 422 (1985).

"Massachusetts–Stony Brook Galactic Plane CO Survey: II. (ℓ,V) Maps of the First Quadrant," Clemens, D.P., Sanders, D.B., Scoville, N.Z., and Solomon, P.M., ApJS, **60**, 297 (1986).

"Where Massive Stars Form: The Association of Radio H II Regions and CO Clouds in the Northern Milky Way," Waller, W.H., Clemens, D.P., Sanders, D.B., and Scoville, N.Z., ApJ, **314**, 397, (1987).

"The Large–Scale Distribution of Molecules in the Northern Galactic Disk," Clemens, D.P., Sanders, D.B., and Scoville, N.Z., ApJ, **327**, 139 (1988).

"A Catalog of Small, Optically–Selected Molecular Clouds: Optical, Infrared, and Millimeter Properties," Clemens, D. P., and Barvainis, R., ApJS, **68**, 257 (1988).

Selected Secondary Publications

"Bok Globules and Small Molecular Clouds: Deep IRAS Photometry and ^{12}CO Spectroscopy," Clemens, D. P., Yun, J. L., and Heyer, M. H., ApJS, **75**, 877 (1991).

"Radial Dust Density Profiles in Small Molecular Clouds," Yun, J. L., and Clemens, D. P., ApJ, **381**, 474 (1991).

"Discovery of Outflows from Young Stellar Objects in Bok Globules," Yun, J. L., and Clemens, D. P., ApJL, **385**, L21 (1992).

"Near-Infrared Imaging Survey of Young Stellar Objects in Bok Globules," Yun, J. L., & Clemens, D. P., AJ, 108, 612 (1994).

"Infrared Spectral Energy Distributions of Young Stellar Objects in Bok Globules," Yun, J. L., and Clemens, D. P., AJ, 109, 742 (1995).

JOHN MILLER DICKEY

Education:

1979 Ph. D., Astronomy, Cornell University
1974 M. S., Astrophysics, Cornell University
1972 B. S., Physics, Stanford University

Recent Positions Held:

1990– Professor, University of Minnesota
1996–1997 Visiting Fellow, Australia Telescope National Facility (sabbatical)
1988–1989 Visiting Fellow, University of Leiden (sabbatical)
1985-90 Associate Professor, University of Minnesota
1982–85 Assistant Professor, University of Minnesota

Recent Awards:

1996 Sabbatical Fellowship, Australia Telescope National Facility
1988 Sabbatical Fellowship, Netherlands Foundation for Research in Astronomy
1988 Sabbatical Fellowship, Bush Foundation
1982–1985 Fellowship, Sloan Foundation

Publications: 88 publications in refereed journals. Recent publications related to this proposal are listed below.

1999 Dickey, J.M., McClure-Griffiths, N.M., Gaensler, B.M., Green, A.J., Haynes, R.F., and Wieringa, M.H., "The Southern Galactic Plane Survey", *New Perspectives on the Interstellar Medium, ASP Conference Series 163* ed. A.R. Taylor, T.L. Landecker, and G. Joncas, Astronomical Society of the Pacific (San Francisco), p. 27.

2000 Dickey, J.M., Mebold, U., Stanimirovic, S., Staveley-Smith, L., "Cold Atomic Gas in the Small Magellanic Cloud," *Ap. J.* 536, 756.

2000 McClure-Griffiths, N.M., Dickey, J.M., Gaensler, B.M., Green, A.J., Haynes, R.F., and Wieringa, M.H., "Two Large H I Shells in the Outer Galaxy," *A. J.* 119, 2828.

2000 Marx-Zimmer, M., Herbstmeier, U., Dickey, J.M., Zimmer, F., Staveley-Smith, L., and Mebold, U., "A study of the cool gas in the Large Magellanic Cloud. I. Properties of the cool atomic phase - a third H i absorption survey," *A.& A.* 354, 787.

1999 Lavezzi, T.E., Dickey, J.M., Casoli, R., and Kazes, I., "A Dual-Transition Survey of CO in the Coma Cluster of Galaxies," *A. J.* 117, 1995.

1999 Kobulnicky, H.A., and Dickey, J.M., "Detection of Cold Atomic Clouds in the Magellanic Bridge," *A. J.* 117, 908.

1999 Stanimirovic, S., Staveley-Smith, L., Dickey, J.M., Sault, R.J., and Snowden, S.L., "The large-scale HI structure of the Small Magellanic Cloud," *M.N.R.A.S.*, 302, 417.

1997 Dickey, J.M., "Absorption of the Linear Polarization of the Galactic Background Radiation by the 21 Centimeter Line of H I," *Ap. J.*, 488, 258.

1994 Dickey, J.M., Mebold, U., Marx, M., Amy, S., Haynes, R.F., and Wilson, W., "The Australia Telescope survey of 21-cm absorption in the Magellanic System", *A & A*, 289, 357.

1990 Dickey, J.M., and Lockman, F.J., "HI in the Galaxy", *Ann. Rev. Astron. Astrop.*, 28, 215.

JAMES M. JACKSON

Education:

1986 Ph.D., Massachusetts Institute of Technology
1981 B.S., Pennsylvania State University

Positions Held:

1996– Associate Professor, Boston University
1996–98 Assistant Director, Center for Astrophysical Research in Antarctica
1990–96 Assistant Professor, Boston University
1988–90 Research Physicist, Max-Planck-Institut für Physik und Astrophysik
1986–88 Postdoctoral Research Scientist, UC Berkeley

Research Areas: Radio and Infrared Astronomy; Starburst Galaxies; Interstellar Medium

Publications: Publications related to this proposal are listed below.

1997 Ingalls, J. G., Chamberlin, R. A., Bania, T. M., Jackson, J. M., Lane, A.P., & Stark, A. A., "Atomic Carbon in Southern Hemisphere High-Latitude Clouds," *Astrophysical Journal*, 479, 296.

1997 Stark, A. A., Bolatto, A. D., Chamberlin, R. A., Lane, A. P., Bania, T. M., Jackson, J. M., & Lo, K.-Y., "First Detection of 492 GHz [C I] Emission from the Large Magellanic Cloud," *Astrophysical Journal*, 480, 59.

1998 Kraemer, K. E., Jackson, J. M., & Lane, A. P., "[O I] 63μm Absorption in NGC6334," *Astrophysical Journal*, 503, 785.

1999 Jackson, J. M., & Kraemer,K. E., "Photodissociation Regions and HII Regions in NGC6334," *Astrophysical Journal*, 512, 260

1999 Kraemer, K. E., Deutsch, L. K., Jackson, J. M., Hora, J. L., Fazio, G. G., Hoffman, W. F., & Dayal, A., "The Mid-Infrared Properties of Three Star Forming Sites in NGC6334," *Astrophysical Journal*, 513, 275

1995 Jackson, J. M., Paglione, T. A. D., Carlstrom, J. E., & Rieu, N.-Q.,. "Submillimeter HCN and HCO^+ Emission from Galaxies," *Astrophysical Journal*, 438, 695

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1999 Jackson, J. M. & Kraemer, K. E., "Photodissociation Regions and H II Regions in NGC6334," *Astrophysical Journal*, 512, 260.

2000 Bolatto, A. D., Jackson, J. M., Wilson, C. D., Moriarty-Schieven, G., "Submillimeter Observations of IC 10: The Dust Properties and Neutral Carbon Content of a Low-Metallicity Starburst," *Astrophysical Journal*, 532, 909.

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Education:

1997 Ph. D., Astrophyiscs, University of Minnesota
1991 B. S., Physics & Astronomy, with Honors, University of Iowa

Positions Held:

1999– Hubble Postdoctoral Fellow, Univeristy of Wisconsin
1997-99 Hubble Postdoctoral Fellow, University of California Santa Cruz
1994–97 NASA Graduate Student Research Fellow
1993–94 UNIX/PC Sys. Admin., U. Minnesota Astronomy Department
1992 Research Assistant, Minnesota Infrared Astronomy Group

Research Areas: Observational optical/infrared/radio astronomy of star formation and galaxy dynamics, chemical abundances

Publications: 20+ publications in refereed journals. Some recent publications:

Creese, M., Jones, T. J., & **Kobulnicky, H. A.**, "Red and Infrared Polarimetry of Highly Reddened Stars in the Galactic Plane" 1995, AJ, 110, 268

Kobulnicky, H. A., Dickey, J. M., Sargent, A. I., Hogg, D. E., & Conti, P. S., "Aperture Synthesis Observations of Atomic and Molecular Gas in the Wolf-Rayet Starburst Galaxy He 2-10" 1995, AJ, 110, 116

Kobulnicky, H. A., & Skillman, E. D., "The Peculiar HI Kinematics of the Wolf-Rayet Starburst Galaxy NGC 5253" 1995, ApJL, 454, L121

Kobulnicky, H. A., & Skillman, E. D., "Elemental Abundance Variations and Chemical Enrichment by Massive Stars in Starbursts I:NGC 4214" 1996, ApJ, 471, 211

Skillman, E. D., Bomans, D. J., & **Kobulnicky, H. A.**, "ISM Abundances in the Pegasus Dwarf Irregular Galaxy" 1996, ApJ, 474, 205

Kobulnicky, H. A., & Skillman, E. D., "Elemental Abundance Variations and Chemical Enrichment by Massive Stars in Starbursts II: NGC 1569" 1997, ApJ, 489, 636

Kobulnicky, H. A. & Zaritsky, D., "On the Chemical Properties of Star-Forming Emission Line Galaxies at z=0.1 — 0.5" 1998, ApJ, 511, 118

Kobulnicky, H. A., Kennicutt, R. C., & Pizagno, J., "On Measuring Nebular Chemical Abundances in Distant Galaxies Using Global Emission Line Spectra" 1999, ApJ, 514, 544

Taylor, C. L., **Kobulnicky, H. A.**, & Skillman, E. D., "CO Emission in Low Luminosity Starforming Galaxies" 1999, AJ, 117, 2746

Kobulnicky, H. A. & Dickey, J. M., "Detection of Cold Atomic Gas Clouds in the Magellanic Bridge" 1999, AJ, 117, 908

Garnett, D. R., & **Kobulnicky, H. A.**, "Distance Dependence in the Solar Neighborhood Age-Metallicity Relation" 2000, ApJ, 532 1192

Pisano, D. J., **Kobulnicky, H. A.** , Guzman, R., & Gallego, J., "The Neutral Hydrogen Content of Compact Emission Line Galaxies in the UCM Survey" 2000, AJ, *in press*

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Degrees:

1995	**Ph.D.**, Applied Mathematics, University of Cambridge (U.K.)
	Thesis Title: *Statistical Study of Astrophysical Processes*
1988	M.Sc., Theor. Physics, Moscow Institute of Physics and Technology (MIPT)
1986	B.Sc., Astrophysics (high honors), MIPT

Positions:

June 1999 - present	Assistant Professor, Univ. of Wisconsin
Sept 1998 - June 1998	Long-term Senior Fellow, CITA
Sept 1995 - 1998	Research Associate,
	Princeton University Observatory
May 1995 - July 1995	Visiting Postdoctoral Researcher, CfA
Dec 1994 - Aug 1995	Postdoctoral Research Fellow,
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Professional Associations:

American Astronomical Society
International Astronomical Union

Field of Research: Theoretical Astrophysics

Physics of Interstellar and Circumstellar Dust
MHD Processes: Reconnection and Dynamo
Interstellar Turbulence
Star Formation

Awards and Scholarships:

Visiting Professor at Caltech, June-July 2000
Visiting Fellowship at CfA, Harvard Univ.: May-July 1995,
The Isaac Newton Scholarship at Cambridge Univ.: 1991-1994,
Cambridge Overseas Trust Award: 1991-1994,
Soros Foundation Visiting Scholarship

Publications:

43 publications in refereed journals
40 non-refereed publications, 59 patents

JOHN S. MATHIS

Education:

1956 Ph. D. (magna cum laude), Astronomy, Calif. Inst. Tech.
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Positions Held:

1996— Professor of Astronomy,Emeritus. Univ. of Wisconsin-Madison
1968-1996 Professor of Astronomy, Univ. of Wisconsin-Madison
1963-1968 Associate Professor, Univ. of Wisconsin-Madison
1959-1963 Assistant Professor, Univ. of Wisconsin-Madison
1957-1959 Assistant Professor of Astronomy, Mich. State Univ.
1956-1957 NSF Postdoctoral Fellow, Yerkes Observatory

Awards and Positions Held:

1975-1976 U.S. Senior Scientist Awardee, Alexander-von-Humboldt Foundation, Federal Republic of Germany. Repeat, 1980.
1985-1991 Vice-Pres., President, Commision 34 (Interstellar Matter), IAU

Publications: Over 100 publications in refereed journals.

2000 Wakker, B., & Mathis,J.S. "Dependence of Gas Phase Abundances on Column Density", ApJ (Letters), submitted

2000 Mathis, J. S., "The Warm Ionized Medium in the Milky Way and Other Galaxies", ApJ, in press

2000 Mathis, J.S., "Properties of interstellar dust", Jour. Geophys. Res., 105, 10269

1999 Voschinnikov, N., & Mathis, J.S. "Calculating Cross Sections of Composite Interstellar Grains", ApJ, 526, 257

1996 Mathis, J.S. "Dust Models with Tight Abundance Constraints", ApJ, 472, 643

1994 Mathis, J.S. "The origin of variations in the 2175 A extinction bump", ApJ, 422, 176

1990 Mathis, J.S. "Interstellar Dust and Extinction", ARAA, 28, 37

1989 Cardelli, J.A., Clayton, G.C., & Mathis, J.S. "The relationship between infrared, optical, and ultraviolet extinction", ApJ, 345, 245

1977 Savage, B.D., & Mathis, J.S. "Observed properties of interstellar dust", ARAA, 17, 73

1977 Mathis, J.S., Rumpl, W., & Nordsieck, K.H. "The size distribution of interstellar grains", ApJ, 217, 425

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1994 B. Sc., Mathematics and Physics, University of Toronto

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Positions Held:

1999– Member, Institute for Advanced Study

1995–99 Research Assistant, Harvard University

1995–98 Teaching Fellow, Harvard University

Research Areas: Extrasolar Planet Atmospheres; Brown Dwarfs; Radiative Transfer

Publications: Publications related to this proposal are listed below.

Seager, S., Whitney, B. A., & Sasselov, D. D. 2000, "Light Curves and Polarization of the Close-in Extrasolar Giant Planets", ApJ, 540, 504

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Seager, S., & Whitney, B. A. 2000, "Photometric Light Curves of Close-in Extrasolar Giant Planets", in *From Giant Planets to Cool Stars*, eds. C. Griffiths & M. Marley, ASP Conf. Ser., 212

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Positions Held:

1999– Research Scientist, Space Science Institute
1998-99 Vice President, Prism Computational Sciences
1997–98 Assistant Scientist, Fusion Technology Institute, University of Wisconsin
1995–97 Assistant Researcher, Space Science and Engineering Center, University of Wisconsin
1989–95 Physicist, Solar & Stellar Physics Division, Smithsonian Astrophysical Observatory

Publications: Over 45 publications in refereed journals. Publications related to this proposal are listed below.

2000 A. Natta & B. A. Whitney, "Models of Scattered Light in UXORs," AA, in press.

2000 S. Seager, B. A. Whitney, & D. D. Sasselov, "Photometric Light Curves and Polarization of Close-in Extrasolar Giant Planets," ApJ, in press.

1999 A. K. Dupree, B. A. Whitney, & L. Pasquini, "Evolution of Chromospheric Activity: M67 Red Giants," ApJ, vol. 520, pp. 751-762.

1999 S. J. Kenyon, K. Wood, B. A. Whitney, & M. J. Wolff, "Forming the Dusty Ring in HR 4796A," ApJL, vol. 524, L119-L123.

1998 K. Wood, & B. A. Whitney, "Scattered Light Signatures of Magnetic Accretion in Classical T Tauri Stars," ApJL, vol. 506, L43-L45.

1998 M. Gómez, B. A. Whitney, & K. Wood, "A Survey of Optical Jets and HH Objects in the ρ Ophiuchi Cloud Core," AJ, vol. 115, pp. 2018-2027.

1997 B. A. Whitney, S. J. Kenyon, & M. Gómez, "Near Infrared Imaging Polarimetry of Embedded Young Stars in the Taurus-Auriga Molecular Cloud," ApJ, vol. 485, pp. 703-734.

1997 M. Gómez, B. A. Whitney, & S. J. Kenyon, "A Survey of Optical Jets in the Taurus Embedded Sources," AJ, vol. 114, pp. 1138-1153.

1994 N. Calvet, L. Hartmann, S. J. Kenyon, & B. A. Whitney, "Flat Spectrum T Tauri Stars: The Case for Infall," *Astrophysical Journal*, vol. 434, p. 330-340.

1993 B. A. Whitney, G. C. Clayton, R. E. Schulte-Ladbeck, N. Calvet, L. Hartmann, & S. J. Kenyon, "Spectrum of the 'Invisible' Companion of Z CMa Revealed in Polarized Light," ApJ, vol. 417, p. 687-696.

1993 B. A. Whitney & L. Hartmann, "Model Scattering Envelopes of Young Stellar Objects. II. Infalling Envelopes," ApJ, vol. 402, p. 605-622.

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1993 Ph. D. (magna cum laude), Astronomy, University of Wisconsin–Madison

1988 B. S. (summa cum laude), Physics and Mathematics, Marquette University

Professional Experience:

2000– Associated Researcher, New York Center for Studies on the Origins of Life

1995– Scientist, Space Science Institute

1994–95 Visitor, Center for Astrophysics and Space Astronomy, University of Colorado

1993–94 Scientist, Wide Field/Planetary Camera, University of Wisconsin

1990–93 Resident / Technical Support Astronomer Pine Bluff Observatory (Spectropolarimeter), University of Wisconsin

Selected Peer-reviewed Publications:

Misselt, K. A., Gordon, K. D., Clayton, G. C.,**Wolff, M. J.**, and Witt, A. N. 2000, "The DIRTY Model II. Self-consistent Treatment of Dust Heating and Emission in a 3-D Radiative Transfer Code," ApJ, submitted.

Clayton, G. C., Gordon, K. D., and **Wolff, M. J.** 2000, "Magellanic-Cloud-type Interstellar Dust Along Low Density Sightlines in the Galaxy," ApJS, in press.

Larson, K. A., **Wolff, M. J.**, Roberge, W. G., Whittet, D. C. B., and He, L. 2000, "Size distribution of dust toward HD210121 as determined from extinction," ApJ, 532, 1021.

Wolff, M. J., Code, A. D., and Groth, E. J. 2000, "Imaging of Central Stars of High Excitation Planetary Nebulae with WFC and WFPC2," AJ, 119, 302.

Kenyon, S. J., Wood, K., Whitney, B. A., and **Wolff, M. J.** 1999, "Forming the Dusty Ring in HR 4796A," ApJ, 524, L119.

Clayton, G. C., Kerber, F., Gordon, K. D., Lawson, W. A., **Wolff, M. J.**, Pollacco, D. L., and Furlan, E. 1999, "The Ever-Changing Circumstellar Nebula Around UW Centauri," ApJ, 517, L143.

Martin, P. G., Clayton, G. C., and **Wolff, M. J.** 1999, "Ultraviolet Interstellar Linear Polarization V. Analysis of the Final Dataset," AJ, 510, 905.

Wolff, M. J., Clayton, G. C., and Gibson, S. J., 1998, "Modeling Composite and Fluffy Grains: II. Porosity and Phase Functions," ApJ, 503, 815.

Clayton, G. C., Green, J. M., **Wolff, M. J.**, Zellner, N., Code, A. D., and Davidsen, A. F. 1996, "Astro-2 Observations of Interstellar Dust and Gas in the Large Magellanic Cloud," ApJ, 460, 313.

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Wolff, M. J., Clayton, G. C., and Meade, M. R. 1993, "Ultraviolet Linear Interstellar Polarization I. The Applicability of Current Dust Grain Models," ApJ, 403, 722.

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1992-1994 Senior National Research Council Associate at NASA Ames Research Center.
1990-1992 Postdoctoral Fellowship. Harvard Smithsonian Center for Astrophysics.
1988-1990 Postdoctoral Research Assistant. Department of Astronomy and Astrophysics, University of Chicago.
1985-1987 National Research Council Associate. NASA Ames Research Center.

SELECTED PUBLICATIONS:

M. G. Wolfire, A. G. G. M. Tielens, & D. Hollenbach, "Physical Conditions in Photodissociation Regions: Application to Galactic Nuclei", 1990, ApJ, 358, 116.

M. Wolfire, & E. Churchwell, "Circumstellar Dust Emission Models", 1994, ApJ, 427, 889.

M. G. Wolfire, D. Hollenbach, C. F. McKee, A.G. G. M. Tielens & E. L. O. Bakes, "The Neutral Atomic Phases of the Interstellar Medium", 1995, ApJ, 443, 152.

M. G. Wolfire, C. F. McKee, D. Hollenbach, & A. G. G. M. Tielens, "The Multiphase Structure of the Galactic Halo: High Velocity Clouds in a Hot Corona", 1995, ApJ, 453, 673.

M. L. Luhman, S. Satyapal, J. Fischer, M. G. Wolfire, et al., "Infrared Space Observatory Measurements of a [C II] 158 Micron Line Deficit in Ultraluminous Infrared Galaxies", 1998, ApJ, 504, L11.

M. J. Kaufman, M. G. Wolfire, D. J. Hollenbach, & M. L. Luhman "Far Infrared Submillimeter Emission from Galactic and Extragalactic Photo-Dissociation Regions: Models" 1999, ApJ, 527, 795.

R. C. Young Owl, M. M. Meixner, M. Wolfire, A. G. G. M. Tielens, J. Tauber "HCN and HCO+ Images of the Orion Bar Photodissociation Region", 2000, ApJ, in press.

M. Pound, M. Wolfire, L. Mundy, P. Teuben, & S. Lord "WEB-based Dust Continuum Analysis Tools", 2000, in ADASS IX, eds., D. Crabtree, N. Manset, & C. Veillet (San Francisco: ASP), in press.