1 Scientific Justification

1.1 Mapping Molecular Hydrogen Excitation and Mass in SINGS Galaxies

Galactic evolution is inherently correlated with molecular gas within a galaxy. In the Milky Way Galaxy, we observe molecular gas in dense molecular clouds. The collapse of these molecular clouds triggers a burst of star formation. In other galaxies, we observe molecular gas trigger star formation in spiral arms via the passage of a spiral density wave (Vogel et al. 1988), within nuclear regions of galaxies (Young and Devereux 1991), and at the ends of bars in barred spiral galaxies (Sheth et al. 2000). Thus, molecular gas serves as the fuel for star formation and is fundamentally connected with galaxy evolution.

Prior to the Infrared Space Observatory (ISO) and the Spitzer Space Telescope (Spitzer), much of our knowledge of the conditions of the molecular gas in galaxies came from studies of CO emission and near-infrared H_2 line emission. CO rotational line emission directly traces the mass of the coldest (T = 5 - 100 K) H_2 and near-infrared H_2 emission traces the hot (T $\geq$ 1000 K) H_2. This left the warm (T = 100 - 1000 K) molecular gas unexplored. With Spitzer, the warm (T = 100 - 1000 K) molecular gas is observed through the pure rotational levels of H_2 with lower J H_2 lines tracing the 100 - 300 K H_2 and higher J lines tracing the 300 - 1000 K H_2. The H_2(0-0)S(0) (28.2 μm) and H_2(0-0)S(1) (17.0 μm) lines can both be observed with the Spitzer IRS long-low (LL) modules (14 - 38 μm, with LL1 covering 14 - 21 μm and LL2 covering 21 - 38 μm)(see figure 1); these lines trace the warm (T = 100 - 300 K) molecular gas.

The *Spitzer Infrared Nearby Galaxies Survey* (SINGS) legacy program has surveyed 75 nearby galaxies (Kennicutt et al. 2003). These galaxies range in Hubble type, luminosity, star formation, and nuclear activity. The SINGS legacy has used the Spitzer IRS LL (LL1 and LL2) module in spectral mapping mode to map radial strips across 65 galaxies within their sample. The radial strips cover a range of dynamically distinct regions within galaxies (i.e. nuclei, spiral arms, HII regions, etc.). The strips are roughly 50 x 600 arcsec in area and give us spatially resolved spectra (at a resolution of $\sim$ 5 arcsec) across the galaxies (figure 2). **These strips contain a wealth of data on the spatial distribution of molecular hydrogen yet to be studied.**

We propose to take advantage of the spectacular SINGS IRS LL coverage across both the nuclear regions and disks in order to understand the spatial distribution of the warm (T = 100 - 300 K) H_2 **across a sample of 18 galaxies that have been observed by both SINGS and the Berkeley-Illinois-Maryland-Array Survey of Nearby Galaxies (BIMA SONG) (Regan et al. 2001, Helfer et al. 2003)**. The 18 galaxies (listed in table 1) have been studied as part of BIMA SONG for which we have CO (J = 1 - 0) maps for each galaxy. CO (J = 1 - 0) emission traces the cold (T = 5 - 10 K) H_2 and the maps allow us to understand the spatial distribution of the cold H_2 mass. We will use the SINGS LL data cubes to map the H_2 S(0) and H_2 S(1) lines across the galaxies. From these lines we will model the warm H_2 mass, excitation-temperature, and UV radiation field across the galaxies (Kaufman et al. 2006). We will correlate the cold H_2 (traced by CO emission) with the warm H_2 (traced by the H_2 S(0) and H_2 S(1) emission) in order to understand the relationship between the warm and cold H_2. Additionally, we would like to understand the H_2 excitation mechanisms by comparing the H_2 distribution to UV and optical imagery (U, B, V, R, and H_α) and the mid-infrared spectral diagnostics ([OIV](25.89 μm) as a shock diagnostic and the electron density determined by [SIII](33.48 μm)/[SIII](18.71 μm)). The latter two are also mapped from the SINGS LL data cubes.

We have used IRS spectral mapping data acquired though GO - 20138 (PI: K. Sheth) of M51a (the Whirlpool galaxy, NGC 5194) as a test case for our study (Brunner et al., submitted). In working with M51a, **we have developed unique software that takes IRS SL and LL data cubes and creates extinction corrected line flux maps**. Our software processes IRS low resolution data cubes and then runs PAHFIT (Smith et al. 2007) through individual spectra in order to decompose mid-infrared spectra across the data cubes. In doing this, the line flux of every spectral feature at every spatial position in our data cubes is measured and then reconstructed into a map. **These maps are powerful tools for understanding the spatial variation of H_2 and other mid-infrared spectral lines.**

For M51a, we had both SL and LL coverage of an overlapping strip across M51a. We have used our software to map H_2 S(0), H_2 S(1) (both lines in LL), H_2 S(2), H_2 S(3), H_2 S(4), and H_2 S(5) (all four lines in the SL) emission across the galaxy. Figure 3 shows the maps of the H_2 S(0) and H_2 S(1) emission across M51a. We have used these lines to model the excitation-temperature and mass distribution of the warm H_2 across M51a. In figure 4, we show the warm mass distribution compared to the warm H_2 excitation-temperature distribution. We find that the H_2 is warmest within the center of the galaxy and is coolest in the spiral arms (which contain the bulk of the H_2 mass). We also compared the cold H_2 to the warm H_2. In the inner spiral arms, we see offsets in the location of the peak emission within the spiral arms. Why is this? Do we see this in other galaxies? Comparisons to UV imagery, optical imagery, and mid-infrared spectral feature maps can help us to answer these questions.

For the 18 galaxies observed by both SINGS and SONG we will address the following:

1. How does the warm (T = 100 - 300 K) H_2 excitation-temperature and mass vary across dynamically distinct regions within galaxies? The majority of the H_2 mass radiates in the lower energy level H_2 lines. In mapping the H_2 S(0) and H_2 S(1) lines across the LL strips we can model the H_2 excitation-temperature and mass distributions across the galaxies (Rigopoulou et al. 2002, Higdon et al. 2006). In addition to modeling the H_2 excitation and mass across the galaxies, we will use H_2 S(0) and H_2 S(1) line ratios to model the radiation field across the galaxies (Kaufman et al. 2006). This will allow us to undertand how the H_2 excitation and mass vary between the nucleus, spiral arms, inter-arm regions, and dust lanes within the galaxies. We will determine the fraction of warm H_2 that is found in the nucleus, spiral arms, inter-arm regions, and dust lanes of the galaxies. We will also determine how the excitation-temperature and mass change in spiral arms as a function of galactocentric radius. These observations provide constraints on the energy injection processes (i.e. radiative heating, shocks, turbulence) that heat the molecular phases as a function of position in a galaxy.

2. How do the warm and cold H_2 correlate across dynamically distinct regions in galaxies? Are there offsets in the location of the warm and cold H_2? If so,

why? CO (J = 1 - 0) emission traces the cold (T = 5 - 10 K) H_2. The combination of CO data and the H_2 lines for every galaxy will allow us to correlate the different molecular gas phases. Is the warm molecular gas strongly associated with the surface layers of giant molecular clouds or an inter-arm component that is bright in H_2 but devoid of CO? We find that in M51a, the warm and cold H_2 are offset in different regions. Do we observe offsets in the location of warm and cold H_2 in other galaxies? Offsets in the location of the cold and warm H_2 are most likely due to the heating sources (such as massive star formation) which we can examine from U, B, V, R, and H_α data. The U, B, V, R and H_α imagery provide a means to identify actively star forming regions within spiral galaxies and determine the age, metallicity, and star formation rate of actively star forming galaxies (Talbot et al. 1979, Jensen et al. 1981, Calzetti et al. 2005). We will compare optical and UV emission to H_2 mass in order to understand the origin of offsets in the location of cold and warm H_2.

3. How do the warm and cold H_2 **mass correlate with the mid-infrared spectral diagnostics?** The [OIV](25.89 μm) line has been observed to arise from shocks, the stellar winds of Wolf-Rayet stars, high-mass star photoionization, and active galactic nuclei (Schaerer and Stasinska 1999, Lutz et al. 1998, Smtih et al. 2004). With our software, we are able to de-blend the [FeII](25.98 μm) and [OIV](25.89 μm) lines. This allows us to discern regions where shocks are exciting the ISM. If we observe [OIV](25.89 μm) emission coinciding with H_2, this would imply that the H_2 is excited by shocks. Additionally, the ratio of the [SIII](33.48 μm) and [SIII](18.71 μm) lines provide a determination of the electron density in HII regions. Comparison to the H_2 data will allow us to determing the location of cold and warm H_2 to the hot ionized gas (and thus the sites of current star formation) in HII regions. This will allow us to understand the relationship of the hot ionized gas and and the warm and cold molecular gas within the spiral arms of galaxies. We will use our ability to spatially resolve the mid-infrared emission features to discern the excitation mechanism of warm H_2 in dynamically different regions of the galaxies.

1.2 Utilizing the SINGS Legacy

Our study will extend the SINGS mission and utilize the data products of the SINGS program. The SINGS legacy has delivered maps of bright infrared emission features from the LL radial strips as part of their data products. They create emission line maps within the CUBISM software and are only able to produce maps of emission features that are very bright across the entire galaxy. The line maps that they have delivered are of [NeIII](15.5 μm) and [SiII](34.8 μm) line emission (Kennicutt et al. 2003). **Our software produces maps of every emission feature in the LL data cubes, even the extremely faint (such as** H_2 **S(0)) or blended lines (such as [OIV](25.89** μ**m) and** H_2 **S(1)) (see figure 3).**

To date, the SINGS legacy **has not** studied the spatially resolved spectra across the SL or LL data cubes. Their studies of atomic features (Dale et al. 2006), PAHs (Smith et al. 2007), and H_2 (Roussel et al., in press) have used aperture averaged spectra over the nuclear regions (and extranuclear HII regions in the case of Dale et al. 2006) of their galaxies. Our software, maps, and analysis of the spatially resolved H_2 are unique and will supplement the SINGS legacy.

2 Technical Plan

The SINGS legacy has provided IRS low resolution data cubes for 65 galaxies. As of data release 4 (DR4), there are 16 galaxies observed by SONG that have publicly available SINGS low resolution data cubes. Two more SONG galaxies will have data cubes available via data release 5 (DR5). The 18 galaxies that we will study are listed in table 1.

Data cubes for individual SINGS galaxies are publically available. They can be found at: http://irsa.ipac.caltech.edu/data/SPITZER/SINGS/galaxies/.

We will also construct CUBISM cube projects (not publicly available) for each of the 18 galaxies that we will be studying. CUBISM is the data reduction software for IRS spectral cubes. Both Brunner and Sheth are experts with the CUBISM software.

Data Analysis: H_2 maps, atomic line maps, and PAH feature maps will be created using the software developed by the PI and Co-Is while working on M51a. Our software has the ability to create maps of spectral features that are extremely faint and/or are blended with other spectral features. This allows the recovery of faint H_2 S(0) emission and the H_2 S(1) line (blended with the PAH 17.0 μm complex). Our software takes both SL and LL data cubes in FITS format, processes them, and then runs PAHFIT through the cubes (Smith et al. 2007). PAHFIT is a mid-infrared spectral fitting routine that decomposes spectra into individual components and measures the integrated line flux of features. In running our software through a data cube, we save the flux measurement for every line from 14 - 38 μm at every spatial position, and in doing so, we create maps of every feature observed in the LL data cubes. This is a very powerful tool for understanding the spatial variation of mid-infrared spectral features, especially the H_2 lines. Figure 3 displays maps of the H_2 S(0), H_2 S(1), [OIV](25.89 μm), [SIII](18.71 μm), and [SIII](33.82 μm) emission across a strip of M51a that has been spectrally mapped with the Spitzer IRS LL modules. The H_2 S(1) line and the [OIV](25.89 μm) lines are blended with spectral features (the 17.0 μm PAH complex and [FeII]25.98 μm)), respectively) but our software is able to map the emission across the entire IRS LL strip.

We will use maps of the H_2 S(0) and H_2 S(1) emission to model the warm (T = 100 - 300 K) H_2 excitation-temperature and mass across the SINGS LL strips. The H_2 S(0) and H_2 S(0) lines place constraints in the H_2 excitation and mass within a galaxy. Additionally, ratios of the H_2 S(0) and H_2 S(1) lines probe the radiation field of dense PDRs and molecular clouds in star forming regions. Brunner and Wolfire will lead the H_2 modeling effort.

We will compare the warm H_2 mass distribution to the cold (T = 5 - 10 K) H_2 mass distribution traced by CO emission. We will use the MIRIAD package to analyze the CO data and we will use WIP to compare the spatial distribution of H_2, CO, and the mid-infrared spectral diagnostics. Brunner will lead the data analysis though it should be mentioned that Brunner, Sheth, Wolfire, and Vogel all have extensive experience with MIRIAD and WIP. Sheth and Vogel were both integral members of the BIMA collaboration and have tremendous insight into the CO data and results. Interpretation of the H_2 results and the comparisons of the H_2 to CO will be shared by Brunner, Sheth, and Vogel. Comparison of the H_2 to the U, B, V, R, and H_α imagery and mid-infrared spectral diagnostics will be shared by Brunner and Dufour. Dufour is an expert on UV, optical, and IR imagery and spectroscopy and will provide insight into the meaning of the comparisons between the H_2 and optical, UV, and IR diagnostic maps.

The data analysis described here is a massive undertaking and coupled with the analysis of H_2 in M51a (from GO - 20057), it will provide the foundation for PI Brunner's Ph.D. thesis on the spatial distribution of H_2 in nearby galaxies.

Galaxy	RC3 Type
NGC 0628	SAc
NGC 2841	SAb
NGC 2976	SAc
NGC 3184	SABcd
NGC 3351	SBb
NGC 3521	SABbc
NGC 3627	Sad
NGC 3938	SAc
NGC 4321	SABbc
NGC 4569	SABab
NGC 4579	SABb
NGC 4725	SABab
NGC 4736	SAab
NGC 4826	SAab
NGC 6946	SABcd
NGC 7331	SAb
*NGC 0925	SABd
*NGC 5055	SAbc

Table 1: Listed are the 18 galaxies that we will study and the corresponding third reference catalogue (RC3) type. The (*) denotes a galaxy for which the SINGS LL data cubes will be available in SINGS data release 5 (DR5). SINGS LL data cubes are curently available for the 16 other galaxies.

3 Figures and Tables

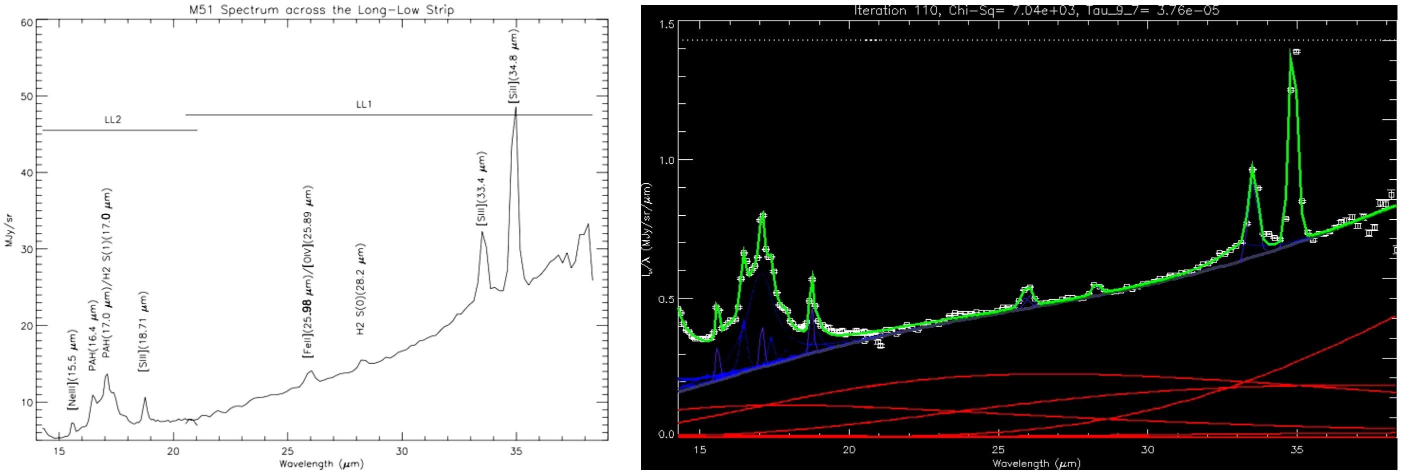

Figure 1: *Left*: A sample LL spectrum taken from the M51 strip (GO - 20138) with spectral features noted. Our study will focus on the H_2 emission across 18 SINGS LL strips. *Right*: We have developed software that processes IRS data cubes and then runs PAHFIT across individual spectra within the data cubes. In doing so, we create maps of all spectral feature between 14 and 38 μm. Here we display a sample PAHFIT spectrum from M51. The green line is the fit to the entire spectrum, the grey line is the fit to the continuum, the blue gaussian-lorentzians are measurements of PAH features, and the purple lines are the gaussian-lorentzian fits to individual spectral lines.

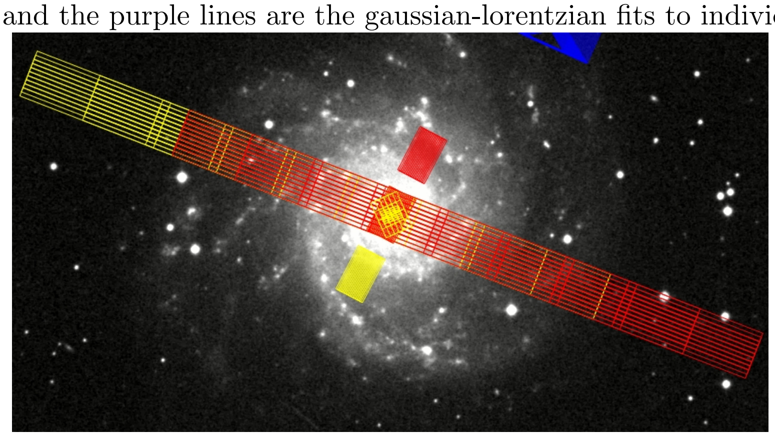

Figure 2: SINGS IRS spectral mapping footprints for NGC 0628. The long red and yellow strips across the galaxy are the LL1 and LL2 coverage respectively. The three smaller parallel rectangles across the central region of the galaxy are the SL1 and SL2 observations. The two smaller sets of footprints over the nucleus are the Spitzer IRS short-high (SH) and long-high (LH) observations. SINGS has acquired similar data sets for 65 galaxies, 18 have been observed by BIMA SONG.

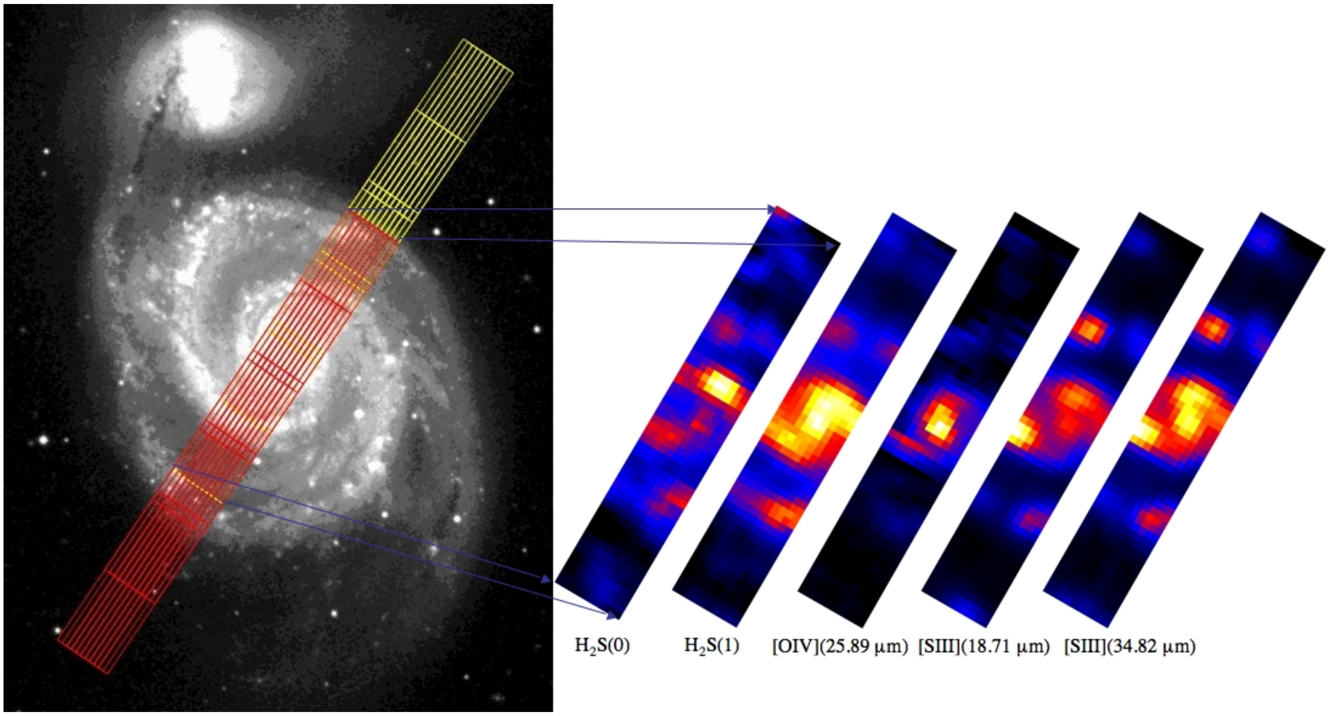

Figure 3: Shown are the IRS LL spectral mapping AORs (*left*) and maps of the H_2 S(0) (28.2 μm), H_2 S(1) (17.0 μm), [OIV](25.89 μm), [SIII](18.71 μm), and [SIII](33.82 μm) lines (*right*) for M51a (GO - 20138). Maps of the individual lines were created with our software. The resolution of each map is 5.08 arcsec/pixel.

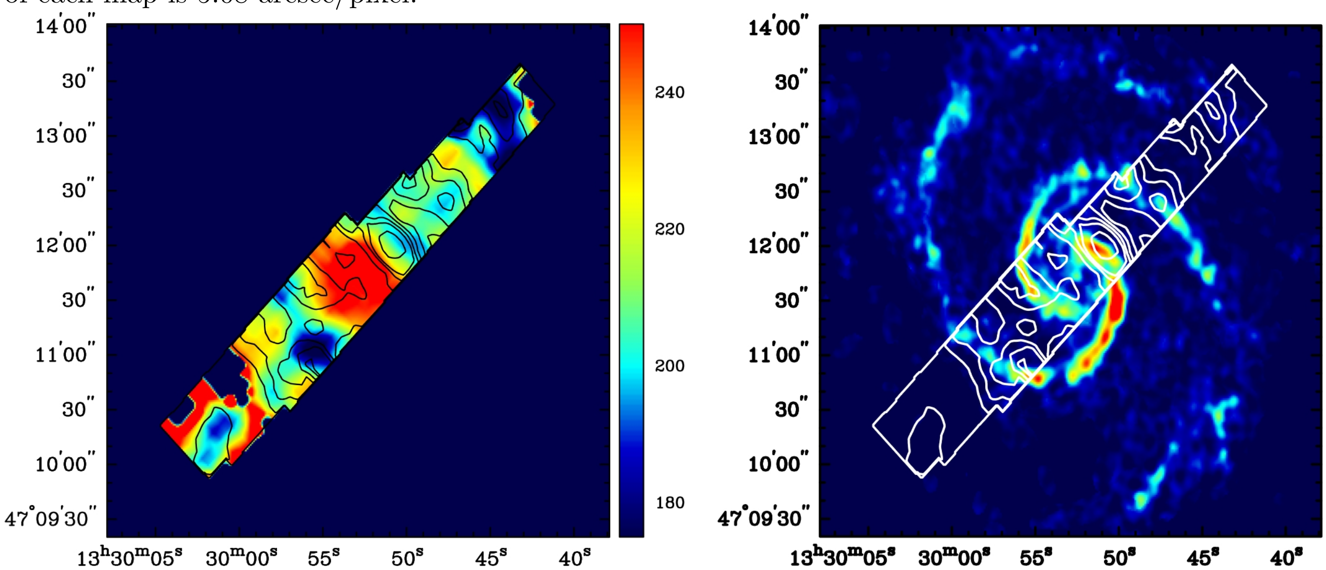

Figure 4: *Left*: Map of the warm (T = 100 - 300) H_2 mass distribution (in contours) plotted over the excitation-temperature distribution (in color). The excitation-temperature is in units of Kelvin; the contours are spaced at 0.5, 0.3, 0.25, 0.20, 0.12, and 0.06 M_{sun}/pc^2. *Right*: Comparison of the warm H_2 mass to the cold (T = 5 - 10 K) H_2 that is traced by CO (J = 1 - 0) emission. The contours are the same as in the plot on the *left*. The CO map of M51 was obtained by BIMA SONG. Note the offset of the warm H_2 mass contours from the CO emission in the spiral arms.

4 References

Brunner et al., 2007, submitted
Calzetti et al. 2005, ApJ, 633, 871
Dale, D. et al., 2006, ApJ, 646, 16
Helfer et al., 2003, ApJS, 145, 259
Higdon et al., 2006, ApJ, 648, 323
Jensen et al. 1981, ApJ, 243, 716
Kaufman et al. 2006, ApJ, 644, 283
Kennicutt et al., 2003, PASP, 115, 928
Lutz et al., 1998, A&A, 333, L75
Regan et al., 2001, ApJ, 561, 218
Rigopoulou et al., 2002, A&A, 389, 374
Roussel et al., 2007, TBD
Sheth et al., 2000, ApJ, 532, 221
Smith et al., 2004, ApJS, 154, 199
Smith et al., 2007, ApJ, accepted (currently on astro-ph/0610913)
Schaerer and Stasinska, 1999, A&A, 345, L17
Talbot et al., 1979, ApJ, 229, 91
Vogel et al., 1988, *Nature*, 334, 402
Young and Devereux, 1991, ApJ, 373, 414

5 Brief Resume/Bibliography

Student PI: Gregory Brunner is a graduate student at Rice University and a 2006-2007 Spitzer Visiting Graduate Student Fellow. During the fellowship he worked with Kartik Sheth on IRS spectral mapping data of M51a. He has developed software that takes IRS low resolution data cubes and creates line flux maps of every spectral feature in the data cube. He has submitted a draft of the results of a study of the H_2 emission, excitation, and mass across M51a that he completed during the Spitzer Visiting Graduate Student Fellowship. His thesis will combine the research proposed here with his ongoing research at SSC to study the spatial distribution of H_2 in nearby galaxies.

Administrative PI: Reginald Dufour is a professor in the Department of Physics and Astronomy at Rice University. His interests are observational astrophysics of star forming galaxies, HII regions, and shell nebulae.

Co-I: Kartik Sheth is a research scientist at Spitzer Science Center and a member of the Spitzer IRS instrument team.

Co-I: Stuart Vogel is a professor of astronomy and the director of the lab for millimeter-wave astronomy at the University of Maryland. His main research interests are star formation and galaxy evolution.

Co-I: Mark Wolfire is a research scientist at the University of Maryland. He is an expert on modeling photo-dissociation regions.

Selected references relevant to this proposal from the team:

Brunner, G., Sheth, K., Armus, L., Helou, G., Schinnerer, E., Vogel, S., and Wolfire, M., 2007, submitted

Dufour, R.J., Talbot, R.J., Jensen, E.B., and Shields, G.A., 1980, ApJ, 236, 119

Rubin, R.H., Dufour, R.J., Colgan, R.J., Liao, S.W., Harrington, J.P, Levine, D.A., and Lord, S.D., 2002, RMxAC, 12, 106

Moore, B.D., Hester, J.J., and Dufour, R.J., 2004, AJ, 127, 3484

Buckalew, B.A., Kobulnicky, H.A., and Dufour, R.J., 2005, ApJSS, 157, 30

Sheth, K., Regan, M.W., Vogel, S.N., and Teuben, P.J., 2000, ApJ, 532, 221

Sheth, K., Vogel, S.N., Regan, M.W., Teuben, P.J., Harris, A.I. and Thornley, M.D., 2002, AJ, 124, 2581

Sheth, K., Blain, A.W., Kneib, J-P., Frayer, D.T., van der Werf, P.P., and Knudsen, K.K., 2004, ApJL, 614, 5

Vogel, S.N., Rand, R.J., Gruendl, R.A., and Teuben, P.J., 1993, PASP, 105, 666

Vogel, S.N., Kulkarni, S.R., and Scoville, N.Z., 1988, *Nature*, 334, 402

Wolfire, M.G., McKee, C.F., Hollenbach, D., and Tielens, A.G.G.M., 2003, ApJ, 586, 278

Wolfire, M.G., Hollenbach, D., McKee, C.F., Tielens, A.G.G.M., and Bakes, E.L.O., 1995, ApJ, 443, 152

6 Status of Existing Spitzer Programs

This section should provide the status of any Spitzer programs (observing or AR/TR) on which the PI or ANY of the CoIs are PI or technical contact (TC). This section should NOT have any figures. This section should NOT provide a comprehensive history of every Spitzer program in which you have EVER been involved. If you have more than 5 programs, you may just provide a summary paragraph. If you feel a list of your 10 most recent Spitzer publications really MUST be included, put them here.

Administrative PI R. Dufour is a Co-I on GO - 3412, GO - 20049, and GO - 20057. The GO - 3412 IRS observations of HII regions in M83 have been analyzed and submitted for publication to MNRAS. The GO - 20049 IRS observations of HII regions in M33 have been completed and preliminary results have been published in MNRAS. The GO - 20057 IRS observations are pending completion and analysis of the data is ongoing.

Co-I K. Sheth is the PI for GO - 20138. GO - 20138 IRS observations of M51a have been reduced and analyzed and the results for H_2 in M51a have been submitted.

Co-I M. Wolfire is PI on GO - 3679, GO 20012, GO- 20097, and GO - 30295. For GO - 3679, GO - 20012, and GO - 20097 all of the data has been taken and are currently under analysis. Results from of the analysis of PDRs from GO - 3679 presented in Povich et al., 2007, ApJ. Results for the analysis of data from of GO - 3679 and GO - 20097 on H_2 in PDRs is in preparation.

7 Financial Contact Information

Provide the contact information for the appropriate person in the institution's Sponsored Research Office (or equivalent) for the PI and Co-I's that require funding support.

For PIs G. Brunner and R. Dufour
Dr. Heidi L. Thornton
heidi@rice.edu
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Office of Sponsored Research MS-16
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Houston, TX 77005-1892
713-348-6204

For Co-I K. Sheth
Eloise Kennedy
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Image Processing and Analysis Center
MS-220-6
Pasadena, CA 91125
626.395.1801

8 Cost Plan and Budget Narrative

Put the descriptive budget narrative here. It should describe how the funds will be allocated. There is no page limit to the narrative. Fill in the cost plan table (Spitzer Cycle-4 Budget). Cost plans are limited to one year duration (for Cycle-4: Oct 2007 - Sep 2008) and the funds must be used within 2 years of the award.

Archival and Theoretical Research proposers must send three paper copies of the institutionally endorsed cost plan and narrative to the SSC by Friday, February

24 2007, 5:00 pm (PST).

The Spitzer Science Center's postal mailing address is:
Spitzer Science Center
California Institute of Technology
Mail Code 314-6
1200 East California Boulevard
Pasadena, CA 91125
USA

Below is the narrative for the Rice University Cost Plan (R. J. Dufour, administrative PI) for which the proposal PI, Greg Brunner, is a graduate student. The total of the Rice cost plan for the 1 year period beginning 1 October 2007 is $81,765. Separately Dr. Kartik Sheth of the Spitzer Science Center is requesting $15,000 support during this period though SSC. CoIs Vogel and Wolfire of the University of Maryland are not requesting separate support. Therefore, the total support requested for this archival project is $96,765.

The primary direct cost items are salaries for G. Brunner and R. Dufour. Since the scientific PI will be a third-year graduate student in October 2007, the stipend will be $24,700 per year (assuming he will qualify for Ph. D. candidacy in September 2007). Brunner just completed six months of residency at SSC as a Graduate Student Fellow working with Sheth et al. on H_2 mapping of M51. Currently this is being prepared for publication and also will be submitted and defended by Brunner for Ph.D. candidacy during the summer of 2007. If this proposal is approved, then the described research will be a major part of Brunners Ph.D. dissertation. As noted in the proposal, Brunner will be analyzing 2D IRS observations and mapping of molecular hydrogen properties across 18 galaxies previously observed by SINGS, which is a massive amount of data reduction, including comparison with IR-visible imagery of the galaxies. Realistically, such a large project will take longer than a year, but here we are limited to proposing for the first year of research (given some will have already been done by the time the funding is in place). Currently Brunner is being supported by AURA/HST grants involving UV-optical imagery/spectroscopy of emission nebulae and can only work part time on the Spitzer H_2 mapping. However, this should be nearly completed in late 2007 so he will be able to pursue this proposed research full time when funding is in place.

R. Dufour is a Professor of Physics and Astronomy at Rice University and has been at Rice since 1976 studying star-forming galaxies and nebulae. He will be Brunners primary thesis advisor and administrative PI for this project. He is requesting one month of summer salary support ($10,395). Dufour expects to become involved in the project scientifically as well as administratively at a level of approximately 3 weeks per semester (Rice permits up to 50% of the academic time for research during the 9-month school year) and 1 month during the summer.

Other direct cost items include $4,200 in travel for Brunner to take 5-day trips to SSC to consult with Sheth, to the University of Maryland to consult with Vogel and Wolfire, and one domestic scientific meeting (e.g. AAS) to present the results of this research. Additionally, $4,200 is requested for publication costs (approximately two 15 page ApJ or AJ articles) -which is arguably conservative given the large amount of data and galaxies proposed to be studied. Modest amounts is requested for research materials and supplies ($600) and computer services ($1200 – IDL, user fees, and maintenance support). No equipment is requested, all of the hardware (and software) necessary for the project is in place at Rice.

Therefore the direct costs are $35,095 (salaries), $4,200 (travel), and $6,000 (publications, maintenance, and supplies) = $57,332 total. Fringe benefits on the salaries is $12,307 and indirect costs are $24,453. Therefore, the total is $81,785 for the Rice University share of the project cost.

Table 2: Spitzer Cycle-4 Budget 1 Oct 2007 – 30 Sep 2008

Narrative				
Footnote	Cost Element			
	Direct Labor Hours (by labor category)	Hours	Rate	Amount
	G. Brunner - Student PI	12 months	2058.33/mo	24,700.00
	R. Dufour - Admin. PI	1 month	10,395.00/mo	10,395.00
	Fringe benefits (see attachments)			12,037.00
	Total Direct Labor			47,132.00
	Overhead	Base	Rate	
	See attachments			24,453.00
	Total Overhead			24,453.00
	Material Costs			
	Material Burden			
	Total Material			
	Subcontract Cost			
	Subcontract Burden			
	Total Subcontract			
	Other Direct Cost (ODC)			
	Travel, Publication, Computer Costs			10,200.00
	Total ODC			10,200.00
	Sub-Total Cost			81,785.00
	Total General & Administrative			
	Total Cost			81,785.00