Stellar feedback on circumcluster gas and dust in 30 Doradus, the nearest super−star cluster.

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Abstract:
Massive stars dominate the evolution of their host galaxies by energetic feedback into the interstellar medium. Therefore, if we wish to understand galaxy evolution, we must understand how massive star clusters process local gas and dust (radiatively and mechanically), and how strong stellar winds interact with the HII region. In particular, the most energetic form of star formation in the universe occurs in super star clusters, which are an increasingly dominant mode of star formation as one looks further back in time. The

only super star cluster near enough to be studied in detail with Spitzer (or any other existing telescope) is 30 Doradus in the Large Magellanic Cloud. 30 Doradus is also the ideal massive cluster to study because it has a very well characterized stellar population, is extremely massive, and has low metallicity.

We propose a complete spectral map of the 30 Doradus region with the IRS low−resolution modules and MIPS/SED mode. Analysis of the fine−structure lines and aromatic features, using sophisticated modeling tools already developed by our team, will allow a complete self−consistent understanding of how this super−star cluster is affecting its circumcluster gas and dust. Understanding the infrared emitting species (dust, PAHs, ionized gas) with this unprecedented level of detail is a necessary step to quantitavely connect the spectra of distant unresolved galaxies to the star formation in those galaxies. This detailed analysis relies on simultaneous mapping of multiple disgnostic line ratios and dust features, and thus can only be accomplished with Spitzer/IRS (many of the diagnostic lines are not observable through the atmosphere). Furthermore, conditions in 30 Dor are known to vary dramatically on small scales, so a spatially and spectrally complete data cube will be the only way to link the physical conditions of the gas, radiation, and dust.

1 Scientific Justification

30 Doradus: an ideal laboratory to study massive star formation and feedback

Massive stars dominate the evolution of their host galaxies by energetic feedback into the interstellar medium (ISM). Stellar ionizing flux is proportional to $M_\star^{3.2}$ (Vacca et al. 1996), so the most massive stars dominate ionization of the ISM despite being less numerous ($N_\star \propto M_\star^{-2.5}$, Salpeter 1955). The mechanical energy produced by winds and supernovae of stars greater than $\sim 8M_\odot$ is more than 1000 times that produced by lower-mass stars (Schaller et al. 1992, Schaerer et al. 1993), therefore any massive stars in a population also dominate mechanical feedback.

In particular, the most energetic form of star formation in the universe occurs in super star clusters (SSCs) containing hundreds to thousands of O and B stars. The likely progenitors of globular clusters, SSCs and their intense clustered mode of star formation are increasingly important to galaxy evolution as one looks back in the universe. Indeed, SSCs may be the best local templates for the burst mode of star formation in Ultraluminous Infrared Galaxies, and for the vigorous star formation that occurred during galaxy assembly between redshifts of 1–3. SSCs produce harder and more intense radiation than other local modes of star formation – this again is more common at higher redshifts, due to lower metallicity and greater star formation density in galaxies.

If we wish to understand galaxy evolution, we must understand how massive star clusters interact with the surrounding ISM. We must understand how clusters process local gas and dust (radiatively and mechanically), and how strong stellar winds interact with the HII region. A proper understanding of local mechanical and radiative feedback will shed light on more widespread effects including the porosity of the HII region and ionization of the diffuse medium, HII region growth and formation of a cluster wind. As an added bonus, spectra of protostars in the map will allow us to directly address how massive cluster feedback quenches or triggers nearby star formation.

30 Doradus in the LMC is one of the best-studied young clusters in the universe, is extremely massive, and has low metallicity: 30 Dor is an ideal place to self-consistently link our detailed knowledge of stellar content to physical conditions in the circumcluster ISM.

30 Doradus: a critical link to understand the infrared spectra of galaxies

Near and mid-infrared (MIR) emission reveals star formation in galaxies from the local group to very high redshift. In the crudest approximation, the dust which enshrouds nascent stars absorbs and re-radiates all stellar energy, thus reflecting the star formation rate. In particular, MIR dust emission is predominantly energized by the UV radiation from massive stars, and is less sensitive to the older and lower-mass stellar population. However, most MIR emission is generated by very small grains and large molecules out of thermal equilibrium in ionized (HII) and photodissociated regions (PDRs). In order to understand star formation throughout the universe, and to trust diagnostics of distant systems, we must study the complex details of HII and PDR physics. The precise nature of circumcluster dust (PAH vs VSG, size distribution, composition; Förster Schreiber et al. 2004) and gas (Devost et al. 2006), the porosity of the HII region (Giammanco et al. 2005), and the effects of shocks and winds (O'Halloran et al. 2006) all strongly affect the MIR spectra of unresolved starbursts.

30 Dor is the only massive extragalactic starburst region nearby enough to study in detail, and only Spitzer can provide the wavelength coverage and spatial resolution required to untangle the various components of its spectrum.

1.1 Proposed Experiments

We propose a **complete** spectral map of the 30 Dor region (∼5×5 arcmin) with the IRS low-resolution modules and MIPS/SED mode (Figure 1). These spectra contain many important diagnostic lines of ionized gas in the HII region (including [NeII]12.8 μm, [NeIII]15.5, 36 μm, [SIII]18.7, 33.4 μm, [SIV]10.5 μm, [ArII]7.0 μm, [ArIII]9.0 μm, and [OIII]88 μm), lines of neutral and partially ionized gas in the PDR (including [FeII]26.0 μm, [SiII]34.8 μm, perhaps [OI]63 μm, and the pure rotational transitions of H_2), as well as the aromatic features (6.2, 7.7, 8.6, 11.2 μm), and the continuum radiation due to very small transiently heated grains (VSGs) and larger grains in thermal equilibrium. Figure 2 shows a spectrum of the central region of 30 Dor degraded to the IRS and MIPS resolution.

Only with a **high-resolution, spatially and spectrally complete map** can we hope to achieve a self-consistent understanding of the stars and ISM in the 30 Dor super star cluster. The radiation field is expected to vary significantly from point to point leading to large local variations in the conditions in the ionized gas and the processing of small grains and dust. Hints of this have been seen 30 Dor with ISO/CVF (Figure 3, Madden et al. 2006, Galliano 2004) but with insufficient spatial resolution, spectral coverage, and resolution to make a detailed physical analysis linking the gas density and ionization state with the small dust composition as a function of position. (ISOCAM had 1/3 the field of view, 3-5 times lower spatial resolution, less than half the spectral resolution, and more than 50 times poorer sensitivity than these proposed observations, and only extended up to 16μm in wavelength.) The diversity of physical conditions means that this map will effectively be performing many parallel experiments to understand the nature of the circumcluster medium.

<u>We will directly calculate:</u>

- ◦ the spatially resolved physical conditions of the gas: excitation, ionization state, density, and temperature.
- ◦ the spatial distribution and properties of very small grains (VSGs), polycyclic aromatic hydrocarbons (PAHs), and larger grains.
- ◦ the relative local importance of shock versus radiative excitation of the gas.

<u>This will allow us to address the following specific issues:</u>

- ⋆ the effect of decreased metallicity on MIR emission features (both gas and dust).
- ⋆ the effects of radiative and mechanical feedback from a super-star cluster in the carriers of MIR emission (gas and dust).
- ⋆ the contribution to the spatially integrated spectrum of unresolved starbursts from HII regions versus PDRs, and from VSG vs PAH vs larger grains.
- ⋆ the porosity of giant HII regions and circumcluster ISM.
- ⋆ the interaction of stellar winds with circumstellar material to form a cluster wind, and the affect of winds on HII region growth.

1.2 Radiative effects of a super-star cluster: the state of the gas

We will map physical conditions of the gas in the 30 Dor giant HII region and its PDR: ionization state, density, and temperature. Ionization state and the local hardness of the ionizing radiation are probed by fine-structure lines of different ionization states – [SIV/SIII], [NeIII/NeII], and [ArII/ArIII] – and density is calculated from fine-structure lines of the same ionization state – [NeIII] 36.0/15.5μm and [SIII] 33.6/18.7μm (Martin-Hernandez et al. 2002, Morisset et al. 2004).

IR fine-structure line diagnostics are not much affected by either excitation or extinction, in contrast to similar line ratios in the optical. Analysis of optical line ratios is hampered by uncertain extinction corrections, their high excitation energies make them sensitive to gas temperature and they become insensitive to T_{eff} of the radiation field hotter than ~30000K (Morisset et al. 2004).

Observed variations in the ionization conditions of the gas will be compared with the expected radiation field given the known spectral types and locations of all the stars. We will use the numerical code CLOUDY, with which we have extensive experience, to derive the physical conditions in the emitting gas. In this way, we can probe in detail the ionization of the environment by the massive star cluster R136.

The temperature, density, and ultraviolet radiation field in the PDR gas can also be analyzed with MIR spectroscopy. The excitation energies of the pure rotational H_2 transitions S(0)28.2μm, S(1)17.0μm, S(2)12.33μm, and S(3)9.6μm lie at 510, 1015, 1628, and 3153K above ground, respectively. Thus, the low level transitions reflect the gas kinetic temperature and the higher transitions the degree of ultraviolet pumping. It will be difficult to detect these lines with the the low-resolution modules, but not impossible: the S(3) and S(0) lines are relatively unconfused by aromatic or fine-structure emission. [FeII]26.0μm and [SiII]34.8μm, which trace the hottest and densest parts of the PDR, should be detectable in many parts of the region (they are marginally detected in the degraded SWS spectrum of Figure 2, but that spectrum was taken in the HII region, whereas these lines will be stronger in the PDR). Analysis of PDR lines will be accomplished using the sophisticated PDR codes of Co-I Wolfire and collaborators (Kaufman, Wolfire, an Hollenbach 2006, Kaufman, Wolfire et al. 1999). Any detections of [OI]63μm (detected with MIPS/SED in at least one location in the 30 Dor PDR, Figure 4, and mapped at 20" resolution with the KAO, Poglitsch et al. 1995) will help remove degeneracies in the model results.

1.3 Radiative effects of a super-star cluster: the state of the dust (self-consistently with the gas)

We will map the physical properties of very small grains (VSGs), aromatic hydrocarbons, and larger dust grains as a function of location and local radiation field.

The smallest solids are responsible for the MIR aromatic emission features (also called unidentified IR bands; UIBs). The ratios and shapes of these features are known to vary between sources (Peeters et al. 2002, Joblin et al. 1996, Verstraete et al. 1996) and within sources, 30 Dor in particular (Figure 3). Links have been suggested between feature variations and the charge and chemical structure of the emitting species (in the case of the most promising candidate, PAHs, the degree of peripheral hydrogenation or the incorporation of N atoms). However, studies of this type have largely been limited to comparison between different HII regions and it has been notoriously difficult to identify the key environmental parameters – strength and hardness of the radiation field, density, and metallicity. Furthermore, in extreme radiation fields, the UIB profiles change even further from laboratory spectra, suggestive of a transition from 2D (PAH) molecular structures to 3D, more amorphous species (Crété et al. 1999 in M17), and there is a transition from UIB features to a more featureless VSG continuum in regions of enhanced radiation intensity and/or decreased metallicity (Madden et al. 2005, 2006, Engelbracht et al. 2005). The proposed observations of 30 Dor will provide a uniform dataset and allow us to link the UIBs in different regions with the stellar and gas characteristics to determine the effect of this massive stellar cluster and its intense radiation on the circumstellar aromatic molecules. We will be guided in this analysis by the high-quality Spitzer observations of Galactic aromatic emission (Wolfire and Werner GO and GTO programs), and this study in the LMC will allow an important contrast to Galactic conditions.

The proposed observations will also provide a direct probe of the different dust grain components present. The FIR continuum provides a direct measure of the amount of radiation absorbed by ∼1000Å dust grains. (The detailed shape obtained with MIPS/SED is important to refine this measurement and resolve ambiguities of temperature, emissivity, and size distribution that would be present with 70μm photometry only). This large dust component can be compared to the energy absorbed by very small grains (re-emitted in the 10-30μm continuum) and aromatic hydrocarbons (features discussed in the previous paragraph). We will use the models of Galliano et al. (2003; 2005), which builds on Zubko et al. 2004 and Draine & Li 2001, to model the dust spectral energy distribution in detail.

With our spectral and spatially complete map, we will be able to compare of the nature of the aromatic hydrocarbons and the size distribution of solid grains with the characteristics of the gas and stellar cluster to determine the factors (radiation hardness and strength, gas density, radiative or shock sputtering and destruction) that govern how a stellar cluster affects the surrounding dust.

1.4 Mechanical effects of a super-star cluster

The strong winds of massive stars interact with each other and the surrounding medium to produce shock fronts. We will assess the importance of mechanical feedback on circumcluster material by looking for specific signatures of shocks and their effects.

The effects of shocks on the gas will be observed either directly in our spectra, or using ancillary data (images in optical emission lines or X-rays). Lines of more highly ionized species will be present in the HII region if there is shock or X-ray heating (most likely from wind-wind collisions): [OIV]25.9μm and [NeV]14.3μm and 24.3μm. Shocks in the PDR can preferentially excite [SI]25.3μm and [FeI]24,35μm, and enhance [FeII]26,35μm over the strengths of those lines in unshocked PDRs (Hollenbach & McKee 1989, Tielens & Hollenbach 1985).

The effects of shocks on the dust can be even more dramatic. Galliano et al. 2005 calculate a shift in the grain size distribution of nearby starburst galaxies – enhancement of very small grains (VSGs) at the expense of larger ones, the likely effect of shock fragmentation of grains (see also Jones et al. 1996). Shocks also destroy PAHs and weaken the aromatic emission features (O'Halloran et al. 2006). Effects of shocks on the dust composition will be revealed by modelling dust features (e.g. the 10μm silicate feature in emission) and continua in conjunction with dust processing codes (Jones et al 1996.)

2 TechnicalPlan

2.1 Design of Observations

In order to obtain a comprehensive understanding of the effects of a massive stellar cluster on its environment, it is necessary to build a continuous picture of the inhomogeneous ISM phases (ionized filaments, diffuse ionized and neutral gas, the PDR), variation in the dust composition and properties, and all of the relevant energetic processes (ionizing radiation field, supernova shocks, stellar winds, cosmic rays). All of these parameters are imprinted within the observed spectral features. Focusing on the spatial variations within 30 Dor with IRS and MIPS/SED *mapping* will allow us to disentangle these various effects and then extrapolate to other galaxies.

We are aware of the Brandl, Houck et al. program of 17 single pointed spectra in the 30 Dor region (PID 63). While this data does offer a view into some profound physical phenomena taking place in the 30 Dor region, the non-continuous coverage in both wavelength and location, hampers the ability to build a self-consistent model. It might be possible to construct a map which does not overlap their sparse coverage, but at the expense of extreme (less than a day) roll-angle constraints. In our opinion better science and a better archival data product will result from a contiguous map; in fact systematic effects (latents, sensitivity variation) will likely dominate the uncertaintly of the map, so contiguous coverage is the only way to ensure a clean data product and unbiased comparison of physical conditions in different locations. Figure 1 shows the proposed coverage area.

Flux densities in the 30 Dor region range between 10 and 300MJy/Sr at 8μm and between 20 and 4000MJy/Sr at 21μm. (In the central 5', typical levels are 50 and 300MJy/Sr at 8 and 21μ, respectively). The brightest levels correspond to 23mJy/pixel and 2.4Jy/pixel at 8 and 21μm, so 14s ramps will not saturate SL. 30s ramps would be in fact be safe in most cases, but a more stringent requirement is saturation in the PUI which would result in undesirable droop across the array. Depending on the roll angle, PUI images can fall on the outer ring of emission (3.5 arcmin from R136), which peaks at 30 and 150MJy/Sr (8/21μm). The red array could saturate during parts of the map if 30s ramps were used.

Spectral features in SL primarily probe the PDR and aromatic features; examining the extent of the PDR in the IRAC image, we conclude that the science requires a sensitivity of 40 MJy/Sr at 8μm, or 3mJy/pixel. 6$\times$14s exposures (3 cycles in SENS-PET which assumes a nodded staring mode observation) obtains a S/N of 10, and when binned up to the same spatial scales as the long-wavelength module, S/N of 60. Given the 6 hr AOR limit, we have chosen a tile unit of 0.8x4 arcmin, requiring 5.3hr. 10 contiguous tiles covers 4.3$\times$4.9 arcmin at all wavelengths (an additional 12 square arcminutes will be mapped in at least one order.)

Sensitivity in the long-wavelength module is primarily driven by analysis of the HII region, its hot dust, and atomic line emission. The weakest 21μm emission in the central HII region is 100MJy/Sr, or 60mJy/pixel. Four 12s integrations (2 cycles in SENS-PET) will obtain a S/N of 20 in LL2 and 40 in LL1. Mapping a 5.3$\times$5.8 arcmin region at all wavelengths can be accomplished in a single 4.9 hr AOR (and also includes an additional 15 square arcmin with at least one order).

The integrated SED of the region combining ISOCAM and KAO shows that the flux density at 70μm is about 0.5 times the flux density at 21μm, so we require a sensitivity of 50MJy/Sr in the MIPS SED, or 100mJy/pixel. Peak fluxes will be less than 1000MJy/Sr, so the 10s ramp can be used. A map with 6$\times$10s obtains S/N $\sim$5. Two 2.8hr AORs at half of that depth each cover 6.8×5.4arcmin, if we use the 3-arcmin chop position as its own map; it is impossible to chop completely off of 30 Dor, so a separate off-field will be required to obtain background measurements. Interleaving the two (off-on-off-on-off) will have the best result, so we have designed a chained set of AORs accordingly.

The total time requested is 81.2 hours.

2.2 Analysis and Modeling

Analysis of the data cube will be a significant task, and as such will most likely be assigned to a full-time graduate student (e.g. one excellent student identified at UVa is a possibility). Reduction and analysis ofthe spectral maps will utilize CUBISM, a tool designed by CoI Smith for the construction and analysis IRS data cubes. Our team has significant expertise with Spitzer data in general, and IRS in particular. Wolfire and Werner will extrapolate their experience with Spitzer IRS mapping of galactic PDRs. Babler, Indebetouw, Hora, Gordon, and Meade contribute their expertise combining large diverse datasets in general, and the SAGE datasets in particular. Engelbracht designed and reduced the MIPS SED data for the SINGS team and is a leading authority in that AOT.

In order to best understand the relationships between dust and gas in 30 Dor, we will need to construct a holistic model that is consistent with the many diagnostics present in the spectra. Again, our team has all of the tools and experience to model the dataset at the required level of sophistication. Only a partial listing of the Co-I's experience follows: Wolfire, Hora, and Galliano are experts in MIR spectral modeling and the associated PDR physics. Tielens, Boulanger, and Madden are among the world's experts on the physics of the dusty ISM of galaxies, including having made many of the significant contributions in this area using ISO data. Gordon, Meixner and Indebetouw have experience modeling radiative transfer in clumpy, dusty clouds.

Our model will begin with the stars, which are responsible for the energetics of the region. 30 Dor has arguably the best-characterized stellar content of any massive cluster. This precise knowledge of all the sources of radiation will allow us to predict the diffuse radiation field at each point in the nebula. We will compare that prediction to the local radiation field implied by the ionization state of the gas, measured in detail from fine-structure line ratios: [SIV]/[SIII], [NeIII]/[NeII], and [ArIII]/[ArII], and modeled with CLOUDY. These ratios are sensitive to ionizing radiation in the range 27.6eV(Ar^{++}) to 41.0eV(Ne^{++}), or equivalently 30000$\lesssim T_{eff} \lesssim$50000K (Morisset et al. 2004). [NeIII]36.0/15.5μm and [SIII]33.6/18.7μm ratios will provide us an accurate measurement of the electron density as a function of position in the ionized gas. Some cross-species indicators are also useful; for example Stasinska (1984) showed that NeIII/SIV increases with gas density.

The distribution and nature of the VSG and PAH components will be determined by modeling the spectrum (determining the best-fitting contributions of VSG continuum and PAH templates). In particular, one of us (Smith) has written a tool PAHFIT designed to decompose the PAH features, continua, and emission lines in a self-consistent way. PAHFIT willbe used to measure PAH band ratios at al locations, and simultaneously measure and correlate those feature strengths with the line emission. The PAH ionization state may be able to be constrained using the 7.7/11.3μm feature ratios (Hony et al. 2001, Bakes et al. 2001), and the degree of hydrogenation using (12+12.7)/11.3μm (Joblin et al. 1996).

As members of the SAGE team, we have access to some of the most comprehensive multiwavelength data on the LMC, so we will be able to include optical through FIR photometry to constrain our spatially resolved spectral model, and make sure that the molecular (Mizuno et al. 1999) and atomic (Brüns et al. 2005) gas distributions are consistent with our model. This type of complete analysis has been used successfully to learn about entire low-metallicity galaxies (Galliano et al. 2005), and has shown itself to be even more powerful in a spatially resolved model of N66 (Contursi et al. 2000). The analysis proposed here will aid tremendously in analysis of more distant galaxies.

This data cube will be a benchmark dataset for Spitzer, doubtless fueling additional analysis for years to come. We will combine the spectral data cube in a uniform way with the multiwavelength photometry collected for the SAGE project (optical, NIR, IRAC, MIPS, CO, HI) to form one of the most comprehensive datasets on a starburst or giant HII region yet assembled.

3 Legacy Data Products Plan

This is not a Legacy proposal. However, as most Co-Is are members of the SAGE Lecacy program to image the LMC with IRAC and MIPS, we intend to make our reduced spectral cube publicly available in a format that is most compatible with the multiwavelength images released by SAGE.

4 Figures and Tables

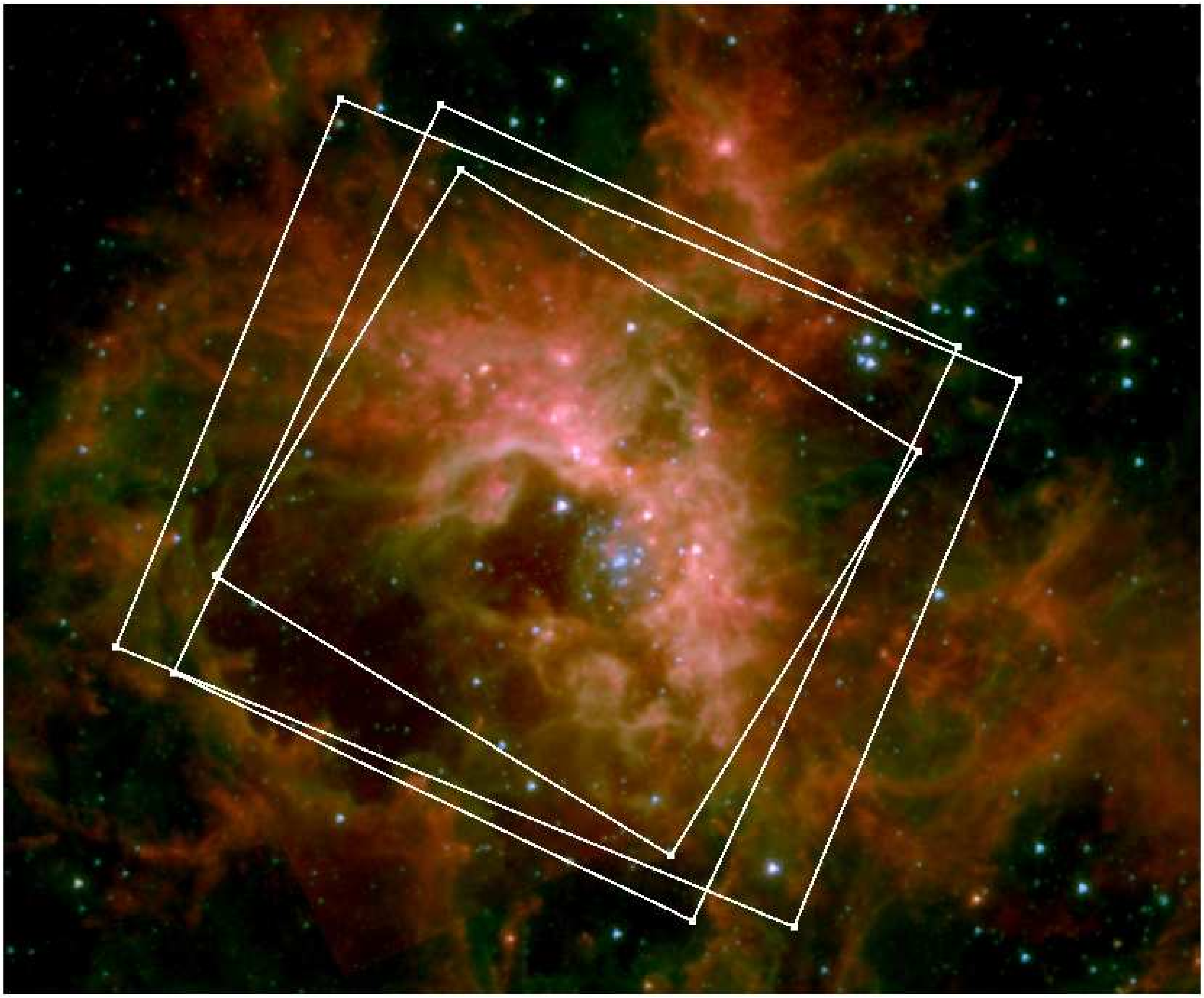

Figure 1: IRAC Image of 30 Dor at 3.5,4.5, and 8.0μm showing the region to be mapped. The rectangles are only the region of complete spectral coverage in each mode (SL,LL) – as seen in the observations summary table, there is a significant extra area mapped in only one order. The rectangles are, from smallest to largest, SL, MIPS/SED, and LL. The size of the SL map is 4.3×4.9 arcmin, or 65×74 pc.

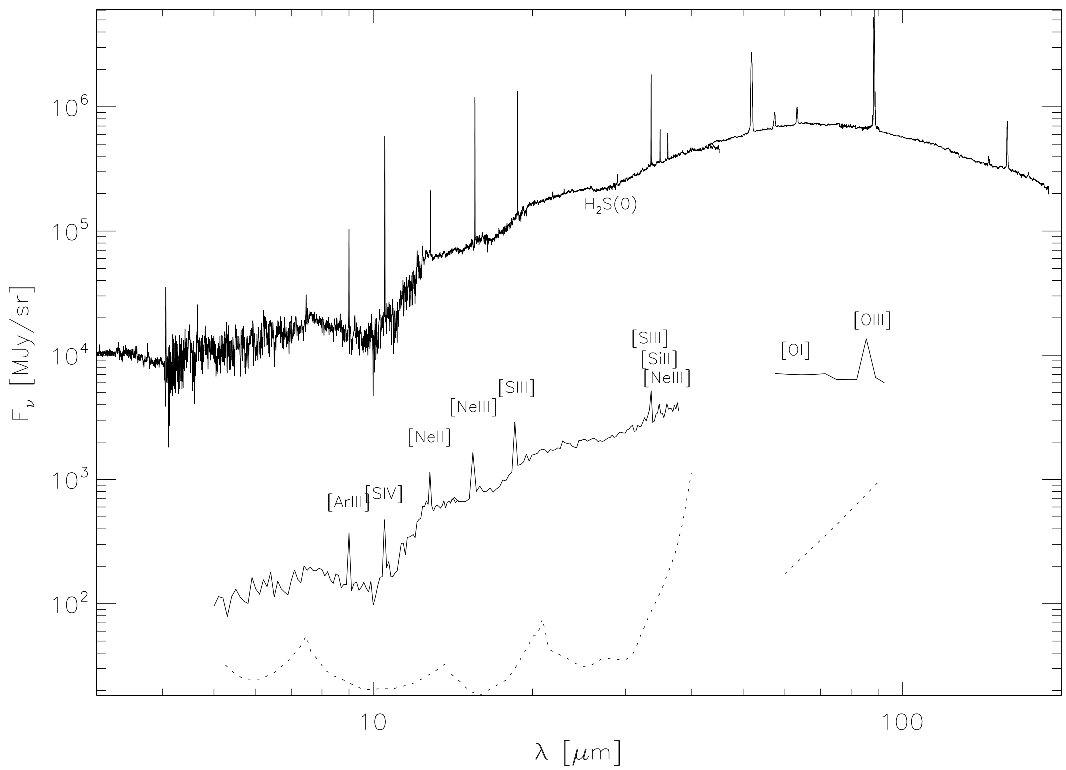

Figure 2: (Spatially integrated) spectra of 30 Doradus region. ISO SWS+LWS is shown at full resolution at the top (offset in flux), and degraded to IRS/low and MIPS/SED below. The surface brightness scale is correct for the synthetic IRS spectrum, and is the average over the ISO apertures (∼20×30" for SWS, see Verstraete et al. 1996 for ISO aperture placement). Diagnostic lines are marked, as well as the sensitivity of the proposed map (signal-to-noise 10 per spectral element in a 4×4" spatial resolution element).

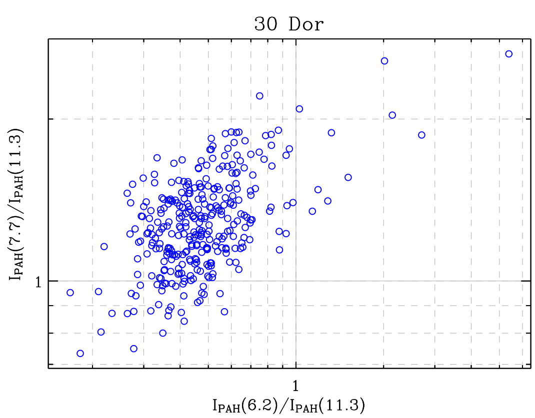

Figure 3: Variation of the PAH band ratios as a function of position in 30 Dor from Galliano (2004) and Madden et al. (2006).

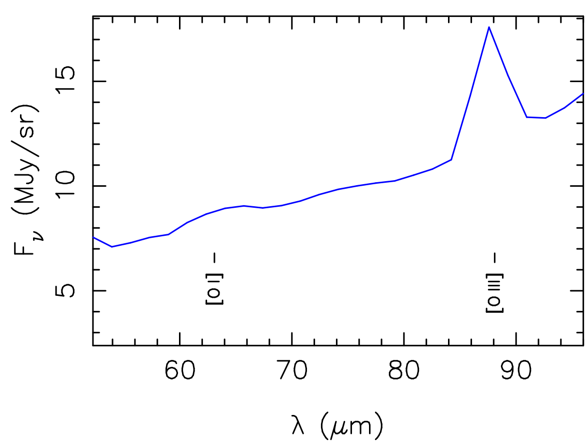

Figure 4: Actual spectrum of 30 Dor taken with MIPS/SED during in-orbit checkout. The [OIII] line is easily detected; the [OI] line is weak but can be observed in some positions.

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6 Brief Resume/Bibliography

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Brain Babler and Marilyn Meade are accomplished data analysts with GLIMPSE.
Francois Boulanger and Xander Tielens are leaders in studying all aspects of the ISM.
Charles Engelbracht designed and reduced the MIPS SED data for SINGS. He has recently studied the effects of radiation on small grains and PAHs.
Frederic Galliano is an NRC fellow at NASA/Goddard with extensive experience modeling the SEDs of galaxies, their star formation, and dust properties.
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Joe Hora is the IRAC instrument team Program Scientist.
Suzanne Madden has extensive experience with IR spectroscopy from ISO, IR extragalactic observations and modelling of dust and gas properties.
Margaret Meixner studies IR diagnostics of gas and dust in circumstellar environments and PDRs. She is PI of the SAGE Spitzer legacy program to survey the LMC.
JD Smith studies massive stars and their effects on ISM. He has developed at least two relevant software tools: CUBISM and PAHFIT.
Linda Smith studies young massive stars, starbursts, and unresolved super star clusters.
Uma Vijh has used spectroscopy of extended nebulae to study PAHs.
Mike Werner, Spitzer project scientist, has studied numerous aspects of the ISM.
Mark Wolfire is an expert on modeling the physics of gas and dust in PDRs.

Selected Publications; see also References above

Spitzer Survey of the LMC, Surveying the Agents of a Galaxy's Evolution (SAGE) I: Overview and Initial Results: Meixner, Gordon, Indebetouw, Hora, et al, 2006, AJ, submitted

Outflows from Massive YSOs as Seen with IRAC: Smith, Hora, et al. 2006, ApJ, in press

30Doradus a Rosetta Stone to decipher spectra from infrared galaxies: Boulanger et al. 2006, Spitzer conference on Galaxy Evolution:

Three-dimensional Models of Embedded High-Mass Stars: Effects of a Clumpy Circumstellar Medium: Indebetouw et al. 2006, ApJ, 636, 362

Mid-IR spectro-imaging observations with the ISOCAM CVF: Final reduction and archive: Boulanger et al. 2005, A&A, 436, 1151

The Wavelength Dependence of Interstellar Extinction from 1.25 to 8.0μm Using GLIMPSE Data: Indebetouw, Mathis, Babler, Meade et al. 2005, ApJ, 619, 931:

Blue Luminescence and the Presence of Small Polycyclic Aromatic Hydrocarbons in the Interstellar Medium: Vijh, Witt, & Gordon, K. D. 2005, ApJ, 633, 262

New IR Emission Features and Spectral Variations in NGC 7023: Werner et al. 2004, ApJS, 154, 309

Australia Telescope Compact Array Survey of Candidate Ultracompact and Buried H II Regions in the Magellanic Clouds: Indebetouw et al. 2004, AJ, 128, 2206:

Neutral Atomic Phases of the Interstellar Medium in the Galaxy: Wolfire, McKee, Hollenbach, & Tielens 2003, ApJ, 587, 278:

Realistic ionizing fluxes for young stellar populations from 0.05 to 2$\times$ $Z_\odot$ Smith, L.J. et al., 2002. MNRAS, 337, 1309.

7 Observation Summary Table

AOT	Int/ pixel (s)	AOR duration (hr)	number of AORs	size (all λ)[a]	size (some λ)
IRS/SL	176.0	5.3	12	4.3×4.9	6.9×4.9
IRS/LL	117.6	4.9	2	5.3×5.8	7.9×5.8
MIPS/SED	251.6	2.8	2	6.8×5.4	6.8×5.4

[a] We list the region covered by both orders as “all wavelengths”, and the larger area covered by at least one order as “some wavelengths”.

There are 74.5 hrs total in IRS AORs, and 6.4 hrs total in MIPS AORs.

8 Status of Existing Observing Programs

SAGE (20203; PI Meixner, CoIs Babler, Boulanger, Engenbracht, Gordon, Horan, Indebetouw, Madden, Meade, Smith, Tielens, Vijh, Werner): Observations are complete as of November 2005. IRAC and MIPS data processing is approximately one third complete and data validated for a portion of the processed data. One paper has been submitted for publication and two conference presentations.

249 Indebetouw Fellowship: Imaging data was taken last year and has been reduced. Ancillary NIR data has been collected at two telescopes and reduced. Spectroscopy targets have been selected and entered. Publications on the outer Galaxy and LMC are in prep, one on a Galactic region is within a week of submission.

Werner is the PI of a number of GTO programs, including the Fab 4 collaboration which is studying the four prominent resolved debris disks found by IRAS. As of this writing, 8 papers based on the use of Werner’s GTO time have appeared in refereed publications, another half dozen are submitted or in the final stages of preparation, and there have also been numerous conference presentations. Werner is also the PI of Program 20132 which was selected in GO Cycle 2. The data gathering is well under way for that program, and the analysis is about to begin. Recent Publications from Werner’s GTO Program include: “Exploring Terrestrial Planet Formation in the TW Hydrae Association”: F.J.Low, P.S.Smith, M.Werner et al, ApJ 631, 1170 (2005); and “A Spitzer Study of Dusty Disks around Nearby, Young Stars”: C.H.Chen, B.M.Patten, M.W.Werner, et al, ApJ 634, 1372 (2005).

PI Wolfire is PI on GO1 program 3697 and GO2 programs 20097 and 20012. We have received all of the data from our GO1 program and partial data sets from our G02 programs. We have created an IDL pipeline to process the large data sets produced by these observations. First we use the cleaning program imfclean produced by the Cornell group to average bad pixels using the SSC rogue pixel maps as a guide. This subroutine is the core program in the irsclean program released by the SSC. Next, we extract spectra from the BCDs using subroutines extracted from SMART. We have removed the GUI features of these subroutines so that an entire AOR can be processed with only a single mouse click and selected parameters are passed using keywords. We can extract either full slit spectra or half slit spectra as appropriate for our maps. Overlapping slit positions are then averaged. Orders are trimmed according to the recommendations of the IRS team. An approximate

SLCF is applied, and zodiacal light is removed according to background estimates in SPOT, or from background spectra if available.

Gordon is the TC of the MIPS ERO program 717 to study M81. Data published in "Spatially Resolved Ultraviolet, H-alpha, Infrared, and Radio Star Formation in M81", Gordon et al. 2004, ApJS, 154, 215. Gordon is the TC of the MIPS GTO program 60 to study the HII regions in M101. Almost all of the data have been obtained and results presented at the Spitzer meetings in Fall 2004 and 2005. A paper discussing the main results of this program is in preparation. Gordon is the TC of the MIPS GTO program 99 to study M31. The data have all been obtained and an analysis of the infrared morphology of M31 published in Gordon et al. 2006, ApJ, 638, L87. Additional papers on comparison of the MIPS images to other wavelength data are in preparation by members a large international collaboration which seeded around the MIPS observations. Gordon is the PI of the GO-2 program 20146 to study the diffuse interstellar extinction curve in the Spitzer infrared. Over 1/2 of the data have been obtained, analyzed, and a progress report was presented at the Jan 2006 AAS meeting.

Hora is technical contact on two GTO programs. PID68 is a study of stellar ejecta, conducted in collaboration with a MIPS GTO program (W. Latter, PID 77). The IRAC observations are complete, the MIPS photometry and scan maps are complete, the MIPS SED mode and most of the IRS observations have not been obtained yet. One journal paper and one conference paper on the IRAC results have been published, as well as two AAS posters. Papers on the Helix nebula and a summary paper of the IRAC sample are in preparation. PID125 is a program to image fields in the LMC and SMC. These were conducted to prepare for our survey proposal for the entire LMC, which was successful last year (the "SAGE" survey, Meixner et al., PID 20203). The LMC data from PID125 is included in a SAGE overview paper which has been submitted. The SMC field data is being analyzed in conjunction with HST-ACS data of the same field. A poster was presented at PP-V and at the January AAS meeting, and a paper is in preparation.

9 Proprietary Period Modification

There are no modifications to the proprietary period.

10 Justification of Duplicate Observations

There is a sparse irregular grid of 17 staring-mode IRS spectra (PID 63, Houck/Brandl) in 30 Dor. The science goals outlined here cannot be accomplished by only sampling a handful of positions in the nebula, so in our opinion there is no scientific conflict. It may be possible design AORs to not overlap those already existing, but only with extremely stringent timing (<1 day) timing, and in fact negligible or no time would be saved, once the extra AOR overhead was added. Furthermore, breaking up our complete map would result in degraded data quality from transient effects.

11 Justification of Targets of Opportunity

There are no ToO observations.

12 Justification of Scheduling Constraints

The SL map needs to be taken close together in time for the roll angle variation to not cause gaps. Overlap between the individual AORs has been provided to allow some flexibility, and they have been placed in an appropriate sequence. Furthermore, the placement of the AORs depends on the execution date, so that is also constrained. We have an automatic program to generate new AORs iteratvely with the SSC schedulers when the execution date and BIC are decided.

The SL and LL maps each have dedicated off/sky observations, and these should also be taken near in time to the target maps. They have been grouped together accordingly.

The MIPS map needs to be taken interleaved with its off/sky positions in order to properly track latents and sensitivity variations. These 5 AORs have been chained accordingly.

13 Data Analysis Funding Distribution

PI Indebetouw (VA): 35%
CoIs Meade&Babler (WI): 25%
CoIs Gordon, Engelbracht, JD Smith (AZ): 20%
CoI Wolfire (MD): 20%

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