Title: Intergalactic Star Formation in Tidal Dwarf Galaxies of M81

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The M81 galaxy group consists of several interacting galaxies, including M81, M82, NGC 3077 and NGC 2976. (Appleton et al. 1981 and Boyce et al, 2001). The interaction of galaxies has been shown to produce tidal neutral hydrogen (HI) tails, and these are particularly prominent in M81. Infrared imaging of the spiral arms and tidal tails of M81 has revealed numerous bright star-forming regions and significant amounts of cold dust (Gordon et al, 2004). Recently, two small 'clumps' of bright blue stars were discovered optically in a tidal HI tail of M81 (Durrell et al, 2005). These objects may be newly formed dwarf galaxies or may be stars that are forming outside the galaxy. Color magnitude diagrams (V-I) suggest that stellar formation occurred in these clumps approximately 100 million years ago; over 200 million years *after* the estimated date of galactic interaction (Durrell et al, 2005). Observations of M81 have identified the presence of HI tidal regions (Gordon et al, 2004 and references therein), but all Spitzer images of M81 have not included the coordinates of the TDG objects found by Durrell et al, 2005.

We propose to extend the area of existing Spitzer M81 observations to include the coordinates of these recently discovered tidal dwarf galaxies (TDGs). This will allow us to compare stellar formation in young TDGs with the disc of M81 to determine if the process of star formation differs in debris tails. The close proximity of M81 (3.6 Mpc: Freedman et al, 2001) makes these particular TDGs an ideal target for the study of the formation of stars due to galactic interaction. If metallicity in this area is low it could be analogous to stellar formation in the early universe. This would then be a unique opportunity to study early universe stellar conditions in a region of low redshift.

This proposal will compare stellar formation conditions in TDGs and galactic discs. We propose to use IRAC's capabilities to look for PAH emission, indicating the presence of dust in the debris tails. The mid-IR capabilities of MIPS will provide the thermal properties of this dust. We will then compare these data to the existing observations of M81 (Willmer et al, 2004 and Gordon et al, 2004). These data will allow for a straightforward comparison between star formation properties of the TDGs and the galaxy M81. Very little is known about the TDGs in the proposed observing region, including their IR flux. Thus, the exposure times were estimated by doubling the exposure times for previous observations of the disc of M81. This will allow us to obtain images of greater sensitivity than the already obtained images, allowing us to compare the selected TDGs with the faintest detected objects in M81.

The proposing teacher team members are interested in how stellar evolution is affected by galaxy collisions. A recent Canada-France-Hawaii telescope press release indicated that dwarf galaxies in the tail of M81 may have formed as a result of galactic interaction. John Feldmeier (a contributor to the CFHT research) provided the coordinates of the TDG's, prompting us to pursue the comparison of IR data of the tidal tails with those of M81. Both John Feldmeier and Varoujan Gorjian provided scientific input.

Scientific Merit:

We wish to determine if star formation outside a galaxy occurs in a similar fashion to star formation within a galaxy. Stars rarely form outside galaxies, so we intend to look at extragalactic material expelled due to galaxy collisions, and have chosen M81 because it is relatively close and has undergone a collision resulting in tidal debris tails in which star formation is occurring. Additionally, IR images of M81 using Spitzer already exist so that only images of the specific targeted areas will need to be taken. The infrared capabilities of Spitzer will allow us to see through the cocoon of dust in which these young stars are forming so we can measure their properties.

This proposed research project:

- contributes to understanding star formation in young dwarf galaxies forming in tidal tails produced by galaxy collision
- combines previously collected M81 data with new observations, maximizing use of Spitzer time.
- allows comparison of star formation within a galaxy to that outside a galaxy, and could also allow for comparision of star formation within different TDGs
- contributes to models of stellar formation by providing new data on dwarf galaxies forming in tidal tails (potentially low metallicity environments analogous to early universe)

Educational Merit

Spitzer teachers will have hands-on experience following the same procedures astronomers use to study the Universe. Students and their communities will have access to this process through teacher outreach and collaboration. The reduced data will be accessible by programs available on our home institutions' computers. The teachers will section the images into fits files suitable for use with the Hands-On Universe Image Processing (HOU-IP) software. HOU-IP is a user-friendly data analysis tool that runs in both Windows and Mac operating systems, and is currently used by many high school astronomy students.

Once teachers receive the Spitzer data they will develop lesson plans for students, including use of Spitzer archived data to generate their own research questions. The used archived data will not be limited to M81, as teachers can make use images of other galactic collisions for comparative studies. The activities developed will require students to formulate their own research questions, search the science literature, learn to use archived data, analyze it and write a research paper referencing appropriate sources. Students will develop an understanding for why scientists insist on peer review and reproducible results.

Each teacher has his/her own individual plans for implementation of this program within their school and district. Those plans are described in the following paragraphs:

Linda Stefaniak, Allentown High School**,** teaches 22 sophomores in honors level Chemistry I and 20 juniors and seniors in an astronomy class. She currently uses lessons that incorporate spectra from a variety of wavelengths (x-ray, radio, visible) and will use the Spitzer data to introduce her students to the infrared portion of the EMS. Every year, her students develop original questions in an areas of study and work in teams, or individually, to answer these questions, culminating in a paper for publication in the current year's RBSE journal of student work. They are expected to perform a search of research papers in the ADS Abstract Service similar to the work they propose and are encouraged to write to the authors of these papers. She plans to have her chemistry students help her interpret data from this stellar formation proposal as well as search Spitzer's data archive of hundreds of objects to describe the chemistry of cool stellar objects and the process of nucleosynthesis in targets other than M81. Linda's astronomy students will describe the evolution of stars in high vs. low metal environments and look for instances of galactic collisions that may indicate other locations of similar activity. Linda will present solar and infrared astronomy workshops this summer through Brookdale Community College's Office of Community, and offer a workshop on multi-wavelength astronomy and a second on infrared astronomy for the October 2005 New Jersey Science Teacher's Convention.

Babs Sepulveda (Lincoln High School) teaches 105 freshman and sophomores in Earth Science and 70 juniors and seniors in physics. Like Linda's students, her students learn about atomic structure, spectroscopy, and the electromagnetic spectrum. They will also required to develop original questions in one of these areas of study and work together, in groups, to produce a research paper. She plans to have two of her current physics students work closely with her to learn how to analyze the Spitzer data. Those same students have already agreed to be lab assistants next year. They will serve as peer tutors to help next year's students learn to access the Spitzer archives and analyze the images in order to carry out their research projects. Babs plans to conduct a workshop for middle school teachers in her district this fall. The focus of the workshop will be on using multi-wavelength astronomy in the classroom.

Timothy Spuck (Oil City Area Sr. High School) teaches a year-long space science class, as well as an independent research class. Tim intends to have his students use HOU Image Processing software, and other software to analyze the data for evidence of star formation in the tails of colliding galaxies, and compare this process with star formation found inside the galaxies. He will also attempt to compare this to star formation that occurred many years ago when the universe was much younger. This will be the focus of student research in both classes. Tim will share the student research projects and data with other educators through professional development workshops. He also intends to have members of his local astronomy club work with students on these projects.

Cynthia Weehler (Burbank High School) teaches 100 inner city students (10th-12th grades) in Chemistry classes and is the science coach for 20 students in Academic Decathlon Astronomy Super Quiz. She intends to have her Astronomy students analyze the Spitzer data after an introduction to the EMS and background in star formation processes. This will help develop an understanding of star formation in debris tails vs galaxies. She wants this Spitzer research project to give them their first taste of original research. It will be a unique opportunity for them to produce a research paper that they will present to the San Antonio Astronomical Association, the local amateur astronomy club, and the San Antonio Independent School District's school board. Cindy's Science Research and Design independent study class does original research, and her students will help process this data and contribute to the written paper. Cindy plans to present an infrared astronomy workshop to middle and high school teachers in her district and at the Fall 2005 Conference for the Advancement of Science Teaching (CAST) convention in the Fall '05.

Theresa Roelofsen (Bassick High School) teaches 60 freshmen Physical Science students and 60 10^{th}-12^{th} grade Astronomy students. Like Tim, she plans to use HOU software to introduce students to images of various colliding galaxies, and then use other software to analyze the data for evidence of star formation in the tails of colliding galaxies. She intends to use the Spitzer M81 data (and other archived data) to engage her Astronomy students in designing their own ongoing, in-class, research projects. Specific students enrolled in these classes, who are also members of her after-school PISCES astronomy club, will work closely with her to spearhead specific research groups and they will be given the opportunity to work on M81 related projects with students at another high school. The PISCES program also includes students at Staples High School and Kaye Sullivan, RBSE 2000, thereby allowing the data to be shared with other students/schools. Theresa plans to offer numerous infrared astronomy seminars within her district, specifically targeting middle school teachers who teach units on heat and/or the electromagnetic spectrum. Her students will present their results in reports, papers for the RBSE journal, and presentations to the school PTA. Theresa also plans to present an IR workshop at a regional NSTA convention in 2006.

In the course of conducting research with the Spitzer Space Telescope data, students will gain a fundamental understanding of astronomical research:

- Physical processes that we observe nearby are the same as those occurring at a distance; the Universe is consistent.
- Models (e.g., computer modeling) are used to predict the cause and outcome of events which can't be observed directly;
- Assumptions made when developing new theories are acknowledged
- Theories change as new observations are made
- All available methods are exploited to observe the Universe

The Spitzer project can also reinforce a number of astronomy content teaching areas. Our group of Spitzer Teachers will use Spitzer data in their classrooms to:

- Have students classify the structures of galaxies and predict their motions using modeling in the classroom
- Reinforce concepts of gravity and velocity: demonstrating that both are factors that govern the violence of galaxy collisions
- Show their students how computer modeling predicts interactions between objects that can’t be studied directly
- Have students directly analyze data to identify chemicals such as PAHs and analyze similarities to and differences between tidal tails and undisturbed galaxies
- Identify wavelengths and demonstrate the advantages in using one wavelength over another and the most advantageous conditions for each.
- Explain how scientists develop, support and critique current stellar formation theories.

Our team of teachers will be giving professional development presentations and workshops to other teachers as part of efforts to improve teaching at the local, state and national levels. As part of this professional development program we will give other educators access to our activities in these general areas:

- The properties of light, spectra and its uses
- The advantages of imaging in different wavelengths; determining which one to use for a certain purpose
- Gravity’s role in violent events like galactic collisions; how to teach typical “black box” problems like studying events that happen over a long time frame
- Star formation processes; how atoms and molecules that build stars, planets and life are formed
- The formulation of scientific questions
- Use of technology and considerations in building a new space telescope
- Use of scientific data sets available through the Spitzer Science Center archive, 2MASS, and other publicly available sources that students can use to do authentic research
- Interpretation of scientific claims and identification of the popular media’s misconceptions.

Target: RA: 9h 57 33
Dec: 68 33 55

Proposed Observation Time

IRAC: 3.6 microns (12 x 12 sec exposures)
4.5 microns (12 x 12 sec exposures)
5.8 microns (12 x 12 sec exposures)
8.0 microns (12 x 12 sec exposures)

Total IRAC time = 288 seconds plus overhead and slew time = 751.3 seconds

MIPS: 24 microns (3 sec exposures x 4 cycles)
70 microns (3 sec exposure x 4 cycles)

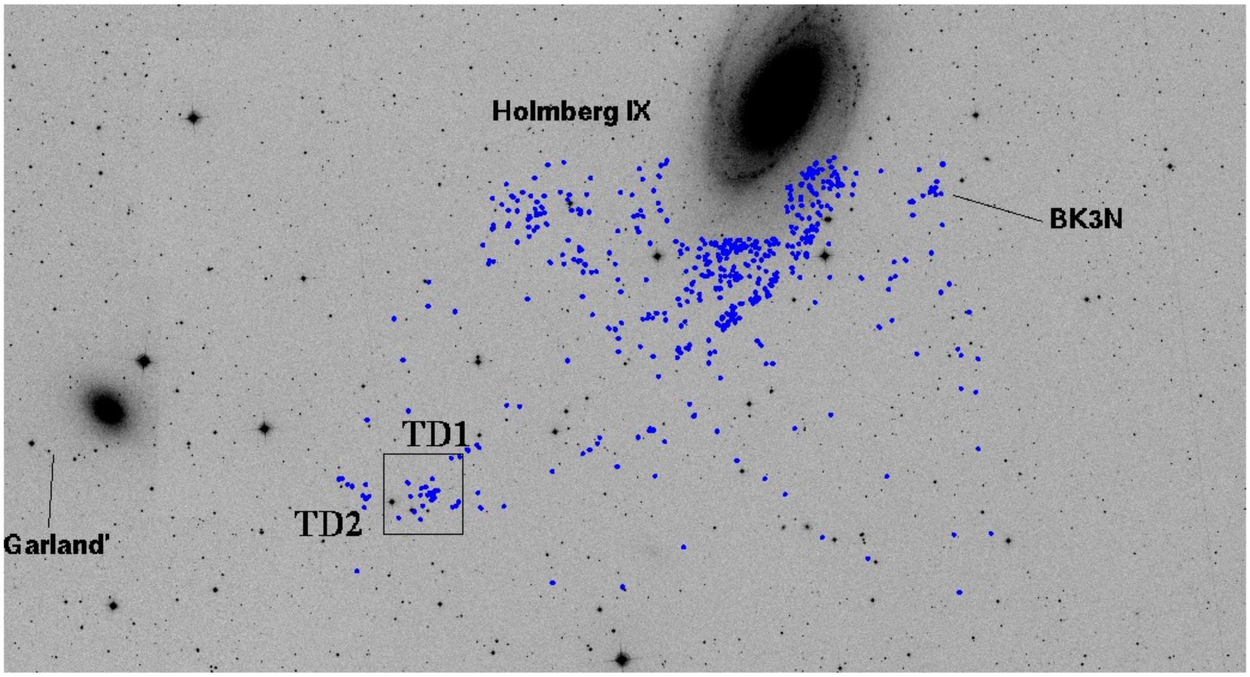
Total MIPS time = 212 seconds plus overhead = 744.7 seconds

Total observing Time = 1496 seconds (25 minutes)

**The far IR capabilities of MIPS will allow us to measure the temperature of any such dust (via a blackbody curve); however, (for the moment), we have eliminated this from our AOR. If time permits, we would still like to add this observation to our AOR (it would require an additional 20 minutes).

Visibility: M81 and nearby dwarf galaxies are visible in 66 day windows of opportunity

2005 Mar 06 through May 11
2005 Oct 22 through Dec 29
2006 Mar 14 through May 19


Holmberg IX
BK3N
TD1
TD2
Garland'

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      POSITION:  RA_LON=9h59m37.00s,  DEC_LAT=+68d39m10.0s, PM_RA=0.0",
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