Lifting The Veil: A Multiwavelength Study Of The Galactic Plane And Of Its Stellar Remnants

I propose to correlate the new Multi–Array Galactic Plane Imaging Survey (MAGPIS) with existing surveys to construct a detailed, multiwavelength picture of the Galactic plane, and to explore its population of young supernova remnants and pulsars. MAGPIS is a 20– and 90–cm survey by the Very Large Array of sensitivity, resolution, and dynamic range more than an order of magnitude greater than any previously available (Helfand et al. 2005a). I will use my experience with the Sloan Digital Sky Survey (SDSS; York et al. 2000), a large–scale optical survey that, much like MAGPIS, is deeper and more sensitive than any of its predecessors, to guide me in developing my research. My graduate work has focused on correlating SDSS with surveys at other wavelengths to characterize the bulk properties of a class of sources (e.g., SDSS stars and galaxies detected in the ultraviolet by the Galaxy Evolution Explorer; Agüeros et al. 2005a). At the same time, I have used these correlations to search for individual exotic objects (e.g., candidate isolated neutron stars identified from SDSS and the X–ray ROSAT All–Sky Survey; Agüeros et al. 2005b).

Working with Prof. David Helfand at Columbia University, I will analyze the results of correlations of MAGPIS with other recent catalogs of the Galactic plane. A wealth of information about the content of the Galaxy will be obtained in this manner. I will then lead follow–up observations of the young supernova remnants and pulsars found from these correlations. Radio and X–ray observations of several MAGPIS discoveries have been scheduled, but many more interesting objects will be found, and a systematic program will be necessary to explore fully the survey's treasures.

1. Introduction

There is a standard story that astronomers tell when discussing the fate of stars. It is as follows: A star above a given mass will eventually explode, producing a brilliant supernova. Over time the supernova fades from view, but the gas it has ejected into the interstellar medium sweeps up material, forming a shell. A supernova remnant appears, generally invisible to our eyes but potentially among the brightest objects in the sky at other wavelengths. What is left of the star is a highly magnetized object more massive than the Sun but smaller than many asteroids. If aligned correctly, this neutron star is detected as a radio pulsar, beaming radiation at intervals so regular that pulsars are the universe's best clocks. Meanwhile, as the remnant expands, it disturbs the surrounding medium, providing the kick that causes interstellar gas to collapse—leading to the birth of new stars and setting in motion another cycle of stellar life and death.

Nothing in this story is wrong, but the observational evidence for it is still surprisingly thin. No supernova has been seen in the Milky Way since the invention of the telescope; the most recent confident detection is of Johannes Kepler's supernova, in 1604. There are far fewer Galactic supernova remnants—231 in the latest Green (2004) catalog—than one would expect based on the rate of extragalactic supernovae (one every ~ 50 years) and the expected remnant lifetimes ($\sim 10^{4.5}$ years). In particular, remnants younger than Cassiopeia A, which resulted from a supernova 340 years ago, are missing, with a predicted four to seven still awaiting detection (Helfand et al. 2005a). Meanwhile, although neutron stars are certainly detected as pulsars[1], despite intensive observing campaigns there remain many remnants with no apparent associated neutron star, pulsar or otherwise (e.g., Kaplan et al. 2004). While this may be due to selection effects and/or a lack of sensitivity in the searches, it still means that roughly two–thirds of the cataloged remnants in which

[1]More than 1500 are included in the ATNF on–line catalog, http://www.atnf.csiro.au/research/pulsar/psrcat/.

we expect to find a neutron star do not, to the best of our knowledge, host one (see Kaspi & Helfand 2002 for a discussion). Our relatively simple and attractive picture for the evolution of massive stars—and, by extension, for the evolution of our Galaxy—is still in need of much buttressing.

The necessary work cannot be done at optical wavelengths; supernova remnants and neutron stars are generally very faint in that window, and, besides, towards the Galactic Center the obscuration averages ~ 25 mags (Laycock et al. 2005). Instead, surveys at other wavelengths, including the near– and far–infrared, X–ray, and radio, are busy lifting the veil and revealing, in detail, the structure and composition of the plane of the Galaxy. MAGPIS is among the most exciting of these surveys. In its first three years it has produced a catalog of ~ 3000 discrete and ~ 400 diffuse radio sources over 42 deg^2 in the first Galactic quadrant, with a limiting sensitivity for most of the area of 1 to 2 mJy, an angular resolution of $5''$, and a dynamic range of up to $1000:1$ (Helfand et al. 2005a; see Fig. 1). Below I describe a research program to characterize the contents of MAGPIS through correlations with other surveys. In the following section I outline a plan to explore the properties of individual supernova remnants and pulsars found from these correlations.

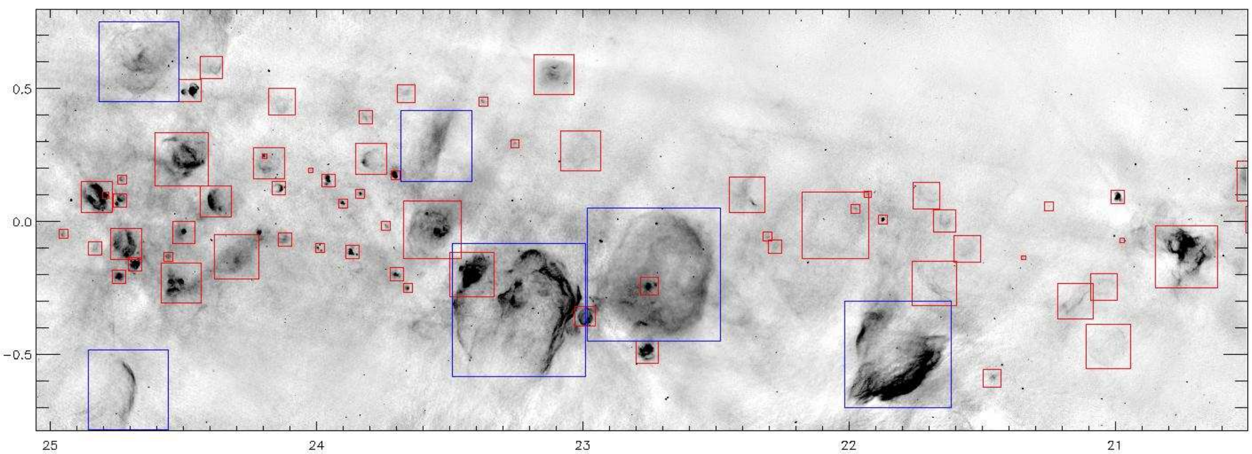

Figure 1: *A MAGPIS strip, with diffuse sources indicated by boxes. The contrast stretch is -0.2 to 4.0 mJy. The six largest objects are known supernova remnants; most of the rest are new sources.*

2. Correlating MAGPIS and Other Surveys of the Galaxy

Surveys of the Galaxy at non–radio wavelengths provide extremely useful complementary data to MAGPIS. For example, comparisons of MAGPIS with mid–infrared data from the Midcourse Space Experiment (MSX; Price et al. 2001) allowed for an initial identification of new MAGPIS supernova remnants. High values of the ratio of radio–to–infrared flux densities indicate regions of non–thermal emission, such as that produced by the remnants, while low values are likely areas of thermal emission, such as HII regions (Helfand et al. 2005a). Much more information remains to be extracted from MAGPIS, however. The spatial resolution ($\sim 20''$) and bright limiting depth (~ 7.5 mags) of MSX render it less desirable for identifying smaller extended MAGPIS sources or point sources. Instead, I will use the Two Micron All Sky Survey (2MASS)[2] and the Spitzer Space Telescope's Galactic Legacy Infrared Mid–Plane Survey Extraordinaire (GLIMPSE; Benjamin et al. 2003), both of which have produced public catalogs[3]. 2MASS mapped the entire sky simultaneously

[2]See http://www.ipac.caltech.edu/2mass.

[3]The much deeper UK Infrared Deep Sky Survey, which will cover the Galactic plane in the 2MASS bands, will also become public during the course of this Fellowship.

in the J (1.25 μm), H (1.65 μm), and K_s (2.17 μm) bands to limits of 15.8, 15.1, and 14.3 mags, respectively. The 2MASS catalogs contain positional and photometric information for $\sim 5 \times 10^8$ point sources and $\sim 2 \times 10^6$ extended sources. GLIMPSE used the Infrared Array Camera on Spitzer to survey 220 deg^2 of the inner Galaxy at 3.6, 4.5, 5.8, and 8.0 μm to limits of roughly 14.2, 14.1, 11.9, and 9.5 mags (Benjamin et al. 2003)[4]. The GLIMPSE catalog contains $\sim 3 \times 10^7$ sources, and its footprint ($10^\circ < l < 65^\circ$ on both sides of the Galactic Center, $|b| \leq 1^\circ$) covers the current MAGPIS area ($5^\circ < l < 32^\circ$, $|b| < 0.8^\circ$). Indeed, MAGPIS is to be extended to match the GLIMPSE area (Helfand et al. 2005a).

In addition, the survey area is currently being mapped in hard X–rays (0.4 to 10 keV) by the XMM–Newton Observatory (Jansen et al. 2001). Only the ~ 400 point sources in the first three deg^2 of overlap with MAGPIS have been published (Hands et al. 2004) and none of the diffuse emission, such as that associated with supernova remnants, has been explored. I will therefore begin by creating a radio/infrared/X–ray source catalog. The combination of radio and infrared information will allow us to identify and distinguish new supernova remnants and HII regions, while being more sensitive to fainter and smaller sources than with the MAGPIS/MSX correlations described above. Adding the X–ray data will allow us to search for positionally coincident radio, infrared, and X–ray extended emission—as is expected, for example, in canonical composite supernova remnants, where a radio shell harbors a smaller, central radio/X–ray pulsar wind nebula powered by the young neutron star at its heart (e.g., remnant G16.7 + 0.1; Helfand, Agüeros, & Gotthelf 2003).

That neutron star may not be a pulsar, or it may be misaligned and evade detection as a pulsar. However, identifying it may still be possible from the proposed multiwavelength correlations. Provided it is young, the neutron star should be detected as a thermal X–ray source by XMM–Newton. The difficulty is that any extended radio/infrared remnant is likely to contain a number of X–ray sources with too few counts for X–ray spectroscopy to determine directly which is the neutron star (Kaplan et al. 2004). Fortunately, neutron stars have high X–ray to optical/infrared flux ratios, while likely "contaminants" such as background active galactic nuclei (AGN), nearby flaring stars, etc., do not. The matched infrared/X–ray data are therefore ideal for finding the neutron stars by elimination. This process is very similar to that by which I identified candidate isolated neutron stars from correlations of the Sloan Digital Sky Survey and the ROSAT All–Sky Survey (Agüeros et al. 2005b). Of immediate interest will be the number of new supernova remnants found by MAGPIS with and without obvious associated neutron stars; follow–up observations will be necessary to confirm the presence or absence of a neutron star. It may also be possible to identify "missing" neutron stars in remnants that previously were surveyed with insufficient sensitivity.

A very different question I will examine is the nature of the X–ray binaries detected from these correlations—distinguishable from background AGN, at least to first order, by the absence or weakness of associated radio and infrared emission (the X–ray spectra may also provide a way to separate Galactic and extragalactic sources; e.g., Hands et al. 2004). There is currently much debate about the abundance in the Galactic Center of high–mass X–ray binaries and of cataclysmic variables. This debate relates directly to the Galactic star formation history: the presence of high–mass X–ray binaries, in which matter from a 10 or 20 solar–mass star accretes onto a degenerate companion, implies recent episodes of massive star formation. By contrast, cataclysmic variables, where the donor is a low–mass star, are longer–lived. If they dominate the stellar population detected at hard X–rays, tidal disruptions of globular clusters, in which cataclysmic variables form preferentially, might be the main process shaping the central Galactic stellar population (Laycock et al. 2005 and references therein). I will lead the program to characterize the MAGPIS X–ray binaries

[4]See also http://www.astro.wisc.edu/glimpse/glimpsedata.html.

with a combination of optical/infrared deep imaging and spectroscopy. Columbia University is a partner in the MDM Observatory on Kitt Peak, AZ. The Observatory has two telescopes (2.4 and 1.3 m) and is equipped with imaging cameras and optical and infrared spectrographs. I have extensive experience with spectroscopy: using the Dual Imaging Spectrograph on the 3.5–m telescope at Apache Point Observatory, NM, I have obtained spectra for more than 700 stars as part of my thesis work identifying optical counterparts to ROSAT All–Sky Survey sources.

Finally, the MAGPIS/infrared correlations will reveal much about the dust content of the Galaxy, allowing for a detailed temperature mapping of dust in the MAGPIS area, for example. While this is a new area of research for me, it presents great opportunities for local collaborations—for example, with Prof. David Schiminovich, whose interests include dust and the structure of the interstellar medium.

3. Confirming Candidate Supernova Remnants and Pulsars

MAGPIS was explicitly designed to address the absence of young supernova remnants in our current catalogs. It is sensitive enough to find remnants with luminosities 0.01% that of Cassiopeia A, the brightest remnant in the radio, and will detect a remnant in the Galactic plane equivalent to that produced by Supernova 1987A from its third birthday on (Helfand et al. 2005a). And the survey has not disappointed: Helfand et al. (2005a) have identified 49 new supernova remnants, including 16 with diameters between $5'$ and $10'$, which quadruples the known number of remnants that size. Even more impressive are the 30 new remnants with diameters smaller than $5'$—six times as many as are currently known. At a characteristic distance of 10 kpc, such remnants have radii less than about 7 pc; for typical expansion velocities of 10^3 to 10^4 km s^{-1}, this implies ages of less than $\sim 10^4$ years. The real excitement, however, is in MAGPIS's detection of remnants with diameters of $40''$ to $45''$. Using the same approximations as above, these remnants are less than 250 years old, and therefore younger than Cassiopeia A, the youngest known Galactic remnant.

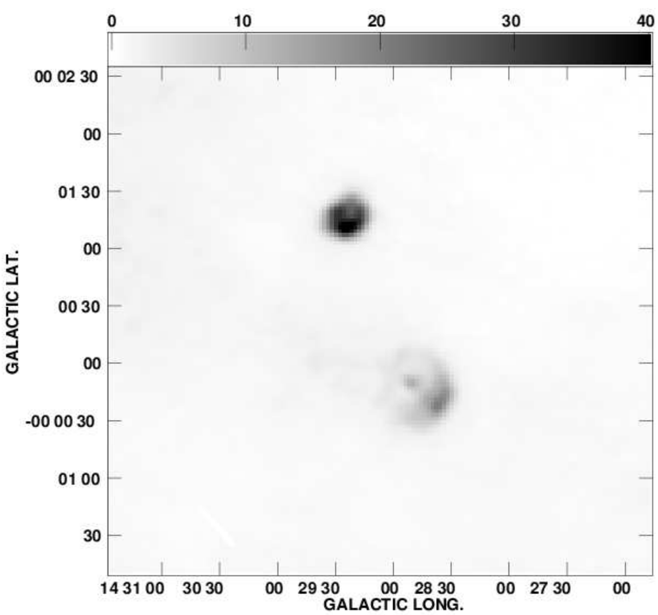

Figure 2: *The MAGPIS 20–cm image of G14.4 − 0.0, a new supernova remnant that appears to be younger than Cassiopeia A. The central source is clearly visible. The bright source to the North has a 20–μm counterpart, suggesting it is a compact HII region.*

There is clearly a lot of work to be done with these remnants, and some is underway. Chandra X–ray Observatory observations are scheduled to explore the properties of the three youngest new remnants detected to date (see Fig 2.). These data will give us insight into a currently unsampled phase in remnant evolution, namely the time between turning 18 (the age of 1987A) and turning 300 (roughly Cassiopeia A's age when radio observations began). During this period, remnants transition from free (linear) expansion to Sedov–Taylor (adiabatic) expansion (Agüeros & Green 1999), but the details of this transition are observationally undetermined, and its dependence on variables such as the Galactic environment is unknown.

Additional Chandra observations of another remnant, $G12.7 - 0.0$, will search for the young pulsar that appears to be powering the wind nebula clearly visible in the 90–cm image of the remnant. There are only about half a dozen known pulsars under 2000 years old (Wang 2002), and, here again, our understanding of the early evolution of these objects, and of their relationships to the surrounding remnants, is poorly constrained. Observations of associations such as that in $G12.7 - 0.0$ give us fundamental insight into a host of physical processes, including the physics of supernovae (reflected in the distribution of the pulsars' spin rates, magnetic field strengths, and velocities), the energetics of early remnant evolution (obtained by mapping the structure of the wind nebulae), and the structure of pulsar magnetospheres (investigated by examining the X–ray and radio pulses profiles) (Kaspi & Helfand 2002).

I will assist with the analysis of these new Chandra data; I have worked to interpret X–ray supernova remnant observations made with both XMM–Newton (Helfand, Agüeros, & Gotthelf 2003) and Chandra (Helfand et al. 2005b, in prep.). While impressive, however, this early yield of young MAGPIS supernova remnants and pulsars is just the tip of the iceberg. As detailed above, there is still much work to be done before all of the interesting candidate remnants are identified from correlations of MAGPIS and other surveys. Accordingly, once a list is established, I will work with the MAGPIS team to conduct radio follow–up observations at the Very Large Array (VLA) of tentatively identified supernova remnants. Multifrequency scaled–array observations, which use the different possible VLA configurations and also provide polarization data, are required to confirm these candidates and to disentangle overlapping thermal and non–thermal extended sources.

Follow–up radio and/or X–ray observations using the VLA, the Green Bank Telescope (GBT), Chandra, and XMM–Newton will then allow us to search for and characterize the associated neutron stars. I have recently obtained time with the GBT (scheduled for January) to search for companion millisecond pulsars to low–mass white dwarfs, a proposal I wrote in collaboration with Dr. Fernando Camilo, who is also at Columbia. In addition, I have been granted Chandra time to confirm isolated neutron star candidates I identified as part of my thesis work. I am confident that, with the help of Prof. Helfand and of other members of Columbia's Supernova Remnant and Pulsar Group, I will be able to build on these experiences and contribute significantly to the exciting new view of our Galaxy and of its stellar remnants that MAGPIS will give us.

From School To Sky: Bringing Underrepresented Students And Their Teachers Into Astronomy

The future of astronomy in the United States depends on developing in students from traditionally underrepresented groups the talents and passion to be successful scientists. Below I describe an outreach program through which I will reach these students, directly and indirectly, while they are still in high school: directly, by working with programs such as the Science and Technology Entry Program at Barnard College (Columbia University) to develop a series of astronomy lectures and activities for their students, and indirectly, by participating in teacher–training activities such as those organized by the American Museum of Natural History. This outreach program builds on relationships I have developed with a number of organizations in New York City, and on work I have done as a graduate student to understand and address the "leaky pipeline" that causes us to lose many of these students before they become astronomers.

1. Increasing Diversity in Astronomy

> A few months ago, we met a young woman preparing to graduate from the University of Washington (UW). As a child Yasmin owned a telescope and hosted star parties near her home in Eastern Washington. As a high school student she studied math and sciences; as a UW first year she loved her observational astronomy course. When we met, she had just returned from Italy, which she visited as a student in a history of astronomy class whose highlights included a visit to Galileo's home. A better opening to the biography of a future astronomer would be hard to write. Yet Yasmin did not major in astronomy.[5]

As much as any statistic, it was encounters like this one that motivated me to examine how to address the lack of diversity within astronomy. In 2002–03, with two other graduate students, I researched and wrote a diversity plan for our department: *To Feed, To Fix: Diversity and the Astronomy Pipeline at the University of Washington* (Agüeros, Covey, & West 2003)[6]. In writing *To Feed, To Fix*, we had two goals: "...to increase the effectiveness of our outreach at the K–12 level, and in particular to influence students who may never have considered a career in astronomy" and "to identify the resources required to recruit and retain talented women and minority astronomy students at the undergraduate and graduate levels."

One of the ways we have sought to achieve these goals is through a new program housed in our department, the Pre–Major in Astronomy Program (Pre–MAP), for which I co–wrote the proposal (Agüeros & Covey 2005). Pre–MAP was one of only 13 projects to be funded by the President's Diversity Appraisal Implementation Fund, which received proposals from across the University of Washington. Pre–MAP is for incoming first–year students from groups that are historically underrepresented in astronomy[7] and have an interest in science and mathematics. In addition to taking an introductory astronomy course, Pre–MAP students learn astronomical research techniques in a small seminar taught by a graduate student and apply these techniques to actual research projects designed by members of the department (involving the use of archival Hubble Space Telescope data, for example). Pre–MAP students also receive mentoring and guidance from the graduate student throughout their first year at the university. Our hope is that Pre–MAP will both increase the number of students drawn to the astronomy major and help reduce the rate of attrition among underrepresented students studying science. Our first Pre–MAP cohort has just started at the UW, and I am now helping to develop plans for the long–term future of the program—for example, by tightening its relationship with the state Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR–UP), one of a number of potential "feeder" programs.

If we are truly to fix the leaky pipeline, however, working with underrepresented students is necessary but not sufficient. My experiences as a student–teacher in the New York public schools while in the Barnard College Education Program, and later as an NSF Graduate Teaching Fellow in K–12 Education at Thurgood Marshall Elementary School in Seattle, have made me extremely

[5] From the Pre–MAP proposal, available at http://www.astro.washington.edu/premap/ (Agüeros & Covey 2005).

[6] Available at http://www.astro.washington.edu/gradpages/Diversity_plan.html.

[7] Defined here as women, African Americans, Latinos, Native Americans, Southeast Asians, Pacific Islanders, and first–generation college students.

aware of the importance of collaborating with teachers. I have seen first hand how crucial curriculum development is, for example. At Thurgood Marshall I was privileged to work for three years in a $4^{\text{th}}/5^{\text{th}}$ grade Bilingual Orientation Classroom for non–native English speakers. When I first arrived, there was virtually no mathematics instruction, and what there was was limited to exercises from a 3^{rd} grade curriculum. I helped the teacher adapt an inquiry–based mathematics curriculum to the needs of her students, who varied in age, mathematics ability, and English skills[8], with little correlation between any two of the three. For many, the math period became a release from the pressures of speaking English, and quite a few revealed themselves to be talented mathematicians.

I plan to apply the lessons from these experiences to my outreach work as an NSF Postdoctoral Fellow. I have been involved in one form of teaching or another for about a decade, and I do not intend to stop now. I will work directly with underrepresented high school students with an interest in mathematics and science to develop their interest in astronomy. Furthermore, I believe that the participation of practicing scientists in the development of science curricula is indispensable if we are to inspire students to develop their mathematic and scientific skills while young. I will therefore also join in science teacher–training workshops, with the aim of integrating astronomy and astronomical activities into their curricula. In the next section I introduce the programs I have identified that will provide me with access to underrepresented students with an interest in mathematics and science, and the course I will teach these students. In the section that follows I identify ways in which I will work with these students' teachers.

2. Teaching Astronomy to Underrepresented High School Students

2.1 The Partner Programs: STEP & DDC

The Barnard College Science and Technology Entry Program (STEP) aims to give historically underrepresented and/or economically disadvantaged students an opportunity to pursue their love of mathematics and science. Barnard's STEP is geared towards students in 9^{th} through 12^{th} grades who attend public or independent schools in New York City, and works with approximately 50 to 60 students each year. A STEP student participates in a 20–week program during the academic year, with most of the activities taking place on Saturdays. A typical Saturday schedule includes an hour of tutoring, some counseling—for example, about selecting high school classes—an English composition class, a mathematics class, and a science class (usually either chemistry or physics). STEP also offers SAT preparatory courses and workshops on topics such as applying to college and choosing where to attend.

At Columbia College, the Double Discovery Center (DDC) also works with students who are statistically considered at risk of not completing high school or ever entering college. The DDC offers academic programs and advising with the goal of having its students graduate from high school, enroll in college, and graduate with college degrees (in 2000–01, 95% of DDC seniors graduated high school, and 90% enrolled in college[9]). The DDC's Upward Bound program focuses on high school students, working with roughly 150 a year, and is structured much like STEP, with academic classes on Saturdays during the school year. Both programs also have five– to six–week summer academies with classes, tutoring, counseling, etc.

2.2 The Course: The Solar System and Beyond

I propose to adapt an introductory Solar System course taught at the University of Washington and teach it to a combined group of STEP and DDC 11^{th} and 12^{th} graders over the programs'

[8] The students were 8 to 11 years old; from Asia, Latin America, and Africa; and some had never been to school.

[9] From http://www.columbia.edu/cu/college/ddc/history.html. By comparison, a Manhattan Institute report found in 2002 that only 70% of city students complete high school within seven years of initial enrollment, and only 50% do so within four years. See http://www.manhattan-institute.org/html/cr_26.htm.

10–week "semesters" of Saturdays. Given the recent NASA missions to Mars and Saturn/Titan, the encounters of the Deep Impact and Stardust probes with comets Tempel 1 and Wild 2, and the numerous detections of extrasolar planets over the last decade, there is a wealth of topical data and images that will, I believe, excite the imagination of these students. (Using the format of an introductory college–level course will also help prepare the students for at least one aspect of the undergraduate experience.)

Science enrichment classes in both programs can be up to an hour and a half in length, which is perfect for mixing lecturing and hands–on activities. A session on the Jovian system, for example, could begin with a short historical introduction, first of the mythological roots of the names of the planet and its satellites, and then of Galileo's observations of the planet and their impact. Because Jupiter is the first of the gas giants, the lecture would then describe in some detail its composition, emphasize the absence of what we would call a surface, and describe some of the strange properties of its atmosphere (the helium rain, for example). The associated activity would turn to the Galilean moons, and ask the students to use images of an eruption of Pele on Io to measure the size of the plume and the velocity of the ejecta—and compare this to volcanism on Earth.

The final session might explore the topic of life in the Universe. The students would hear about our longstanding fascination with life on Mars, and examine for themselves Schiaparelli's images of the red planet and its infamous canals. We would then discuss the potential for life under Europa's ice or perhaps in Titan's lakes, and then move to the inhospitable "hot Jupiters" that are being found around other stars, ending with a look at future missions such as Kepler and the Terrestrial Planet Finder that will search for Earth–like planets. In the associated activity, the students would "detect" their own extrasolar planets by deriving the masses of the planets around 51 Pegasus and HD 195019 from the variations of these stars' radial velocities.

In addition to in–class activities, observing nights for the students to see the planets for themselves will be scheduled at the Rutherford Observatory, on the roof of the Columbia astronomy building. Finally, a visit to the American Museum of Natural History will be arranged, with the students exploring the Rose Center for Earth and Space and completing an activity on different types of meteoritic rocks in the Arthur Ross Hall of Meteorites.

2.3 Feasibility

Over a decade ago, while an undergraduate at Columbia College, I got my first ever teaching job as a mathematics tutor for STEP, and I worked there until I graduated in 1996. In 1997 Saul Davis (then, as now, STEP's director) hired me as a teacher for the STEP summer program. For five weeks I taught two intensive mathematics classes, one three days a week and one four days a week. I was also given free reign to design an astronomy course, and I taught an introductory Solar System course to a group of 15 students, focusing on Mars and NASA's Pathfinder mission. Mr. Davis has expressed his enthusiasm for adding my Solar System course to the STEP Saturday morning schedule. STEP students are terrific and I look forward to working with them again.

While I do not have the same history with the DDC, I am very familiar with the organization, and have discussed working with the DDC with Ms. Yvonne Maldonado, the current assistant director of the Upward Bound program, and with Mr. Olger Twyner, the program director. They are also willing to offer my course to their students and to explore other possible collaborations.

This course is the first step in developing long–term relationships with the DDC and STEP students, and I will seek out other opportunities for students who are interested in deepening their interest in astronomy. Since both programs have summer academies, it may be possible, for example, to develop a program in the spirit of Pre–MAP through which students join in astronomical research and receive mentorship from astronomers.

3. Helping Train Science Teachers

3.1 The Partner Institutions: AMNH & Columbia

The American Museum of Natural History (AMNH) is the premier public scientific institution in New York, and it is incredibly active in providing training to science teachers. It offers everything from one–day training programs to several–day workshops that help teachers develop activities and enrich their curricula. There are also seminars taught by scientists that the teachers can take for graduate school credit.

The Summer Research Program for Secondary School Science Teachers was established 15 years ago at Columbia University to give science teachers practical research experience; through the summer of 2005, 171 (mostly high school) teachers from New York and New Jersey have participated. Teachers in the Program join research teams and work on research projects full time for eight weeks over the course of two consecutive summers. In addition, the teachers meet once a week as a group to discuss current science topics in informal seminars, to share their research experiences, and to discuss science pedagogy.

3.2 Teacher–Training Activities & Feasibility

Selecting a specific AMNH program with which to work is difficult a priori. In discussions I have had with Dr. Laura Danly, the senior manager of the Astrophysics Education Department, she has emphasized AMNH's enthusiasm for partnering with scientists to develop and conduct the Museum's teacher–training programs. Accordingly, I will work with her and with the AMNH professional development specialists to identify programs where my expertise will be most useful.

One such program may be the Teacher Renewal for Urban Science Teaching (TRUST), a collaboration between the Museum and colleges in the City University system. TRUST selects 30 science teachers–to–be and certified teachers seeking dual certification in science for a year–long series of courses, lectures, and workshops. Once I have taught my introductory solar system course, I could participate in the two–week TRUST summer institute and discuss how to adapt the course for the teachers' purposes. In turn, the teachers would help me improve the course by educating me about their students' needs and the New York City curricular requirements, for example.

Several teachers from the Summer Research Program at Columbia have been involved in astronomy research in recent years with Prof. David Helfand, my proposed postdoctoral adviser, who has strong ties with the Program. I will develop appropriate research projects with his assistance, and take the lead in contacting the Summer Research Program and recruiting teachers to join the Supernova Remnant and Pulsar Group. I will then work with the recruited teachers to ensure that they acquire the skills necessary to conduct their research, and I will act as their primary contact as they progress. I will also attend one of the Program's weekly seminars to give an introduction to the Astronomical Society of the Pacific's *The Universe at Your Fingertips* (what better introduction than to have the teachers complete "What's Your Sign?", one of the activities debunking astrology?). Finally, I will make myself available to any teacher who wishes to collaborate outside of these programs. If invited, I will happily talk to their students, and I will of course provide assistance in further integrating astronomy into their science courses.

The Research Program's director, Mr. Jay Dubner, has expressed his full support for this proposal, and he has invited me to attend one of the weekly seminars during the summer of 2006. This will allow me to familiarize myself with the Program and to begin identifying the teachers' needs. I will also be able to start working immediately with teachers during the 2006–07 school year. Mr. Dubner has suggested that I might, for example, help organize an insider's tour of the AMNH's Rose Center for Earth and Space for the participant teachers as a first step toward strengthening connections between the Program and the Museum.

Why Columbia?

My proposed postdoctoral adviser, Prof. David Helfand, was one of the principal investigators for the Faint Images of the Radio Sky at Twenty–cm (FIRST) survey (Becker, White, & Helfand 1995), and is now one of the principal investigators for MAGPIS. His expertise in interpreting radio survey data is second to none, and he is also one of the community's foremost experts in the study of supernova remnants and pulsars. Columbia's Astrophysics Laboratory includes a number of other experts in radio and high–energy observations of supernova remnants and neutron stars. In particular, Dr. Eric Gotthelf (X–ray observations of remnants and pulsars) and Dr. Fernando Camilo (radio observations of pulsars), with whom I have worked in the past, will be on hand to assist me in developing the expertise required to complete some of the science described here.

Furthermore, three years is a short amount of time in which to implement an effective outreach program. At Columbia I will be able to take advantage of my own existing relationships with programs that target underrepresented high school students and of Prof. Helfand's longstanding ties to the Research Program for Science Teachers and to the Astrophysics Education Department at the American Museum of Natural History. This will considerably ease the difficulties of establishing useful working relationships with these entities, and my proposed outreach relies on the existence of this network—not available to me at a different institution in another city.

Long–Term Career Goals

I was drawn to the NSF Postdoctoral Fellowship the moment I first heard of it, and I am very excited by the prospect of spending three years as a Fellow at Columbia. My research experiences—particularly a summer spent as an REU student at the Arecibo Observatory—are the major reason I decided, many years ago, to pursue a career in astronomy. I look forward to exploring the new MAGPIS supernova remnants and pulsars for the duration of the Fellowship, and, I suspect, well beyond. But I have always felt the need to invest in teaching and outreach. I was certified to teach high school physics as an undergraduate; I spent a year as the public education coordinator for the Mullard Radio Astronomy Observatory in Cambridge, England; I wrote several science articles for the general public for a UW publication, *Northwest Science and Technology*, on topics ranging from the familiar (gravitational wave astronomy) to the alien (six gill sharks); and I continue to challenge the underrepresentation of certain groups within our field. Sharing my enthusiasm about science is just as rewarding as tackling research questions, and I am grateful that the NSF has designed a fellowship that recognizes the importance of both. And guided by Prof. Helfand, a leading astronomer and a committed teacher and mentor, I can only improve as a researcher and as an educator.

Astronomy has been very good to me. I have spent much of my adult life invested in work that I find fascinating, frequently assisted by people whose company I enjoy—and often in places that I did not know but grew to love, such as Cambridge and Tokyo. I would like nothing more than to continue on this path, to immerse myself in the research I find so rewarding, to deepen collaborations and friendships that are just beginning to bear fruit, and to enable others to explore the world through astronomy in the same way I have. The Fellowship would be a great first step.