Assigned Proposal Number:_______

Strategic University Research Partnership Proposal for FY2012
Due Date: December 5, 2011, by 4 PM PST

1. Title of Proposal

Dartmouth Greencube5

2. JPL Principal Investigator
Anthony J. Mannucci

JPL Org. No.: 335G

3. Co-Investigator(s) (University and JPL Co-Is)

Kristina Lynch, Robyn Millan
Dartmouth College
Department of Physics and Astronomy
6127 Wilder Lab
Hanover NH 03755

kristina.lynch@dartmouth.edu
www.dartmouth.edu/~aurora

robyn.millan@dartmouth.edu

4. Total Budget Request for FY12

New Proposal [ ]   Successor Proposal [xxx]

SURP GF included [ ]

Multi-year Student Development Initiative [ ]

Budget Request: $25,040

5. Student Participants
Amanda Slagle, Jon Guinther, Casey Bradshaw, Peter Horak, Patrick Yukman, Stephanie Malek, Thomas Whalen (all Dartmouth undergraduates); 2 new students will be retained in the winter term under the Dartmouth WISP (Women in Science Program). All student emails are first.last@dartmouth.edu

6. Topic Area— Place a "1" next to your primary area and a "2" next to your secondary (optional) area.

Next Generation Leaders and Innovators
[1] Education and Training
[2] Student career path development

***This educational proposal has long-term goals for*:**

Astronomy and Fundamental Physics
[ ] Solar and Space Physics

Robotics, Tele-Robotics and Autonomous Systems
[ ] Sensing
[ ] Autonomy
[ ] Systems engineering

Communication and Navigation
[ ] Internetworking
[ ] Position, navigation and timing

Science Instruments, Observatories and Sensor Systems
[ ] Observatory technology
[ ] In-situ instruments/sensor technologies

7. Objectives— State clearly and concisely the objectives of your work and the expected deliverables.

Overall longterm objectives of the GreenCube program:

The GreenCube project stems from Prof Lynch's and Prof Millan's interests in small, autonomous science payloads for multipayload balloon and auroral sounding rockets, and from future plans for swarms of small, cubesat-like orbiters for future science missions. It is feasible because of the undergraduate students who have been working in our labs for several years, who have taken the shop course and have become familiar with electronics by working on our grant-funded rocket and balloon programs. It is different from these same students working on grant-funded research because it is subject to their own deadlines and structure, and driven by their own interests.

The goals of the GreenCube project are (1) to maintain a scientifically interesting, student-driven

CubeSat development program within Dartmouth Physics; (2) to incorporate new design features into small payloads for Low Cost Access to Space (LCAS)-class auroral sounding rocket proposals; (3) on a longer timescale, to incorporate what we learn into designs for future plans for small orbiters, which potentially could include student-driven cubesats. GreenCube has been supported by JPL-SURP for 5 years now, and we hope to continue this constructive collaboration.

Status of GreenCube program as of fall 2011:

The GreenCube, which was designed and built over the last few years by Dartmouth undergraduates with JPL SURP support, consists of a single board computer (designed by the students with mentoring from our engineers) with power handling, data handling, and digitization of analog inputs, a GPS system, ham radio and DNT radio systems, a 3-axis magnetometer, several thermistors and other sensors, in a 3U-CubeSat-form-factor mechanical housing. We fly the GreenCube payload(s) on meteorological balloons over New Hampshire, reaching altitudes of 30 km, tracking them with real time telemetry, and recovering them successfully every time so far (some half-dozen flights over the past few years). Each year we have a slightly different science or technology focus.

Our progress on last year's goals is detailed in Section 9 below. Here we focus on the aspects of GreenCube4 work that we propose to continue and develop further in GreenCube5. For GreenCube4 we have focused on new technologies we need to learn in order to move from suborbital to orbital designs: solar panels rather than batteries, different spacecraft controller board options, and orbital dynamics. The students have designed and built an array of triple-junction solar panels based on the UCBerkeley "Cinema" CubeSat design (with thanks to Prof Tom Immel's group for their guidance.) They have also investigated alternatives to our inhouse "K111" 8051-CPU-based controller board, and have built up and used a "SquidBee" open-source wireless sensor mote system (as well as various Droid-phone powered setups). The SquidBee is a low-resource Arduino-based data logger with digital and analog inputs, a radio and power system, and the cabability to record and transmit GPS data. While it is not as capable as some of our inhouse CPU-based or FPGA-based designs, it is simple to develop and use, and readily adaptable to our GreenCube needs. In addition, Sean Currey, one of our senior students last fall, did his senior thesis investigating the orbital dynamics of a swarm of low-altitude CubeSats for a 30-day 300-km altitude mission using STK. We hope to complete our GreenCube4 work in early January, with a balloon flight of the Squidbee-enabled payload carrying solar panels and a monitor thereof (see the Figures at end).

Specifics of GreenCube5 proposed for this year (details in section 8 below):

For GreenCube5 we propose to *focus on the concept of a "swarm" of sensorcraft: how to design, build, test, communicate with, and assimilate the data from 15-20 autonomous vehicles.* Given the logistical difficulties of launching and recovering that many meteorological balloon payloads at once, and given that our long-term goal is lower ionospheric auroral studies which are essentially 2-dimensional because of the strong background magnetic field, we propose this year to temporarily move away from our balloon-borne design and instead use a swarm of autonomous sensorcraft to study the transport of objects by river flows in the nearby junction of the Connecticut River and the White River, by making our sensorcraft buoyant and floating them down the river as an array. We will also continue our ongoing solar panel development work. The assimilation of these approximately 20 separated measurements of position, attitude, and temperature into vector field arrays of data that can be analyzed is an interesting physics problem with strong connections to the interpretation of vector fields of plasma physics data. The data set itself is of great interest to a colleague in our Geography Department, Prof Francis Magilligan, who studies the transport by rivers of large woody debris. The fabrication, test, and use of so many independent sensorcraft as an array of low-resource measurement points is an engineering project with strong connections to spacecraft design; note in particular the recent DARPA "F-6" initiative for clusters of low-resource spacecraft which are wirelessly-interconnected modules working together.
(http://www.darpa.mil/Our_Work/TTO/Programs/System_F6.aspx).

8. Technical Approach— Describe your plan to achieve your objectives. Provide specific tasks, milestones, and responsibilities.

Plan overview:

We propose to fabricate approximately 20 copies of our "Dave" version of the GreenCube spacecraft (see the Figures) developed for GreenCube4, using SquidBee controllers, DNT radios, and GPS receivers, in a modified version of our 3U-Cubesat mechanical housing. Instead of the balloon-borne infrastructure we have used for the past 5 years, we will develop a bouyant and waterproof housing, perhaps with fins such that the orientation of the payload (as recorded by magnetometers) indicates vorticity of the river flow. Some of the cost of the SquidBee electronics purchases can be shared by other technology development grants, but the cost is not excessive: under $200 each for Squidbee, radio, and GPS. The students can build the mechanical housings in our machine shop.

With the scientific guidance of Prof Magilligan in the Geography department, we will arrange the details of the sensors and the array scales to address questions of how rivers transport large woody debris. One specific goal will be to float the array down the exit of the White River toward the Connecticut River, and see how the payloads are caught up in or transported by eddies and flows in the river junction. We will follow the array in a launch with a radio receiver, recording the transmitted data real time. We will recover the payloads to the best of our ability further downstream. A variety of other array launches can be planned and organized during the winter term, for implementation in mid to late spring after the ice melts out and the river is safe to travel.

A significant aspect to this year's project will be a dedicated effort to assimilate and analyze the resulting collected data in a scientific manner, rather than (as in previous years) a purely engineering development focus. There are interesting problems in both the assimilation and use of this 20-point vector measurement and its analysis as a mathematical gridded vector field, and in the geographical and fluid dynamic physics of the resulting geophysical data. We will learn a great deal to prepare us for future long-term goals of orbiting swarms of low-resource ionospheric sensorcraft making observations of plasma physics parameters in the auroral zones, using this geophysical proxy question with interesting science in and of itself.

There are also significant engineering challenges and learning aspects to the development and use of such an array of intercommunicating sensorcraft. The communication protocols of wireless sensor networks are a rapidly advancing technology. The Squidbee hardware and the DNT radio systems are set up to make optimum use of these mesh networks, and we will learn a great deal with applications to our future spacecraft swarm plans. Other student and research groups within Dartmouth are studying similar sensor arrays (Prof Laura Ray's robotics lab in the engineering school, among others) and we hope to develop interactions between our group and theirs.

Tasks and responsibilities:

The various tasks will be divided among the student team. Amanda Slagle will do her senior honors thesis in physics focussing on the data assimilation and analysis of the geophysical vector field measurements. Jon Guinther will focus his junior year Presidential Scholar work on programming and communications protocols. Sophomore Patrick Yukman will focus on the integration of the GPS sensor into the digital inputs of the Squidbee. Peter Horak and Stephanie Malek, who have developed the GreenCube4 solar panel array, may look into a cleaner and more reproducible design that might be used for a variant of the array payloads. First year students will be given the task of redefining the mechanical housing to be bouyant, waterproof, and finned. Recent graduate Max Fagin, currently working on a related project, will direct the student team in developing an efficient and organized process for replicating the payload 20 times; this management task will benefit from the experiences of Prof Millan's BARREL project, wherein she is building dozens of balloon-borne magnetospheric payloads as part of NASA's RBSP project.

Schedule and specific milestones:

Winter term: Complete the GreenCube4 flight and develop a "lessons-learned" list from that experience using the Squidbee. Investigate GPS integration into the Squidbee "Dave" payload. Define the river payloads. Purchase the requisite hardware and develop a plan for multiple fabrication. Design the mechanical housing. Begin fabrication and test. Introduce two new WISP students to the project. Interact with and learn from other Arduino-based projects on campus. Consider and potentially implement

Droidphone hardware into the payloads as well. Continue solar panel development work.

Spring term: Develop and test the arrays of payloads for late-spring river floats. Organize the principal array floating in time for analysis of data within the spring term.

Summer term: Second and/or further floatings, and data analysis thereof.

Fall term: Presentation of data analysis. Discussion of plans for GreenCube6.

Note:
We hope that our sponsors and reviewers at JPL will note that we have requested, at their suggestion in the reviews in 2010, and received from Dartmouth again this year, a substantial reduction of the university overhead costs. This significantly increases our direct funds available to the students compared to previous years. Also note that our introductory (first-year) students are often supported by Dartmouth's WISP program.

9. Award Continuity — If this is a successor proposal, describe the accomplishments of the predecessor award. If this is a Student Development Initiative that you would like to be considered for a multi-year award (up to three years), please describe the benefits of an extended award.

In last year's SURP proposal, we wrote: "*There are several new initiatives to pursue with GreenCube4, together with continued work on the GreenCube3 astronomy sky brightness project and GreenCube2 gravity wave project. We will assess at the end of this fall term (2010) the success and status of the sky brightness project and decide at that point whether and to what extent to continue it into the GreenCube4 year. Since all of our balloons provide GPS data for tracking, we continue to add to our database of atmospheric velocity profiles, which were the focus of GreenCube2, with each flight. New initiatives for GreenCube4 include (a) an investigation of solar panel power handling, a new regime for our group; and (b) the possibility of a launch from the Mars Desert Research Station, as an outgrowth of one of our student's NASA internship this summer. Finally, (c) the students maintain an interest in exploring the possibilities of using the balloons as temporary emergency cellphone repeaters.*

The GreenCube3 sky brightness project included a reflight of the payload in the spring of 2011. This GreenCube3a flight taught us more about how to move toward DNT radio communications, as more capable than our original ham-radio based system. In summer of 2011, we spawned a spinoff project called Altair, which is a separately-funded sky brightness payload development. The Altair group is using our launch and recovery infrastructure to fly a more sophisticated sky brightness payload; their first flight was in the summer of 2011, and they will have a second flight in conjunction with our upcoming GreenCube4 flight this January.

Of the 3 listed GreenCube4 initiatives, (c) has not developed; (b) is reported on briefly below; and an expanded version of (a) has formed the focus of our efforts this past year. The motivations for (a) were to further our capabilities in the direction of orbiting CubeSat development. This included not only the solar panel development, but also an extensive investigation of other controller board platforms, including Droidphones and the Squidbee Arduino-based system. In addition, last year's senior student Sean Currey did his senior honors thesis on a study of the orbital dynamics of a localized swarm of ionospheric cubesats. The students have developed a prototype solar panel (see Figures) and we have learned a great deal about the use and construction of solar panel arrays. Our flight in January will use the Squidbee controller board and DNT radio system to monitor the performance of the solar panel as it powers a dummy load throughout the flight. We have also investigated the capabilities of Droidphones as small "spacecraft", flying them both on our own payloads and on a Texas high school amateur rocket, as loggers of acceleration and magnetic field. What the group has learned about the Squidbee, together with other Dartmouth groups' investigations using Arduino-based systems, has convinced us to proceed with this system for GreenCube5.

Separately, one of our students, Max Fagin, participated in a NASA Ames internship, as a result of which, he and several of his internship colleagues were scheduled for a rotation at the Mars Desert Research Station (MDRS) from 29 Jan to 12 Feb of 2011. As part of their crew application, Max proposed a launch of GreenCube from a high altitude balloon from the MDRS site. The science justifications for such a flight included the experience of launching such a balloon by an MDRS crew for potential Mars weather observations. Prevailing winds prevented the payload from being launched from MDRS. However, by mooring the payload on a 500 ft tether attached to an ATV, information on telescope tracking and payload stability was collected. Observations from the MDRS Musk observatory are now being used to conduct telescopic observations of similar tethered optical payloads at the University of Victoria, in connection with the spinoff ALTAIR payload.

From my own viewpoint as the students' mentor, one of the significant accomplishments so far this year with GreenCube4 has been an increase in the sophistication of what the students are doing, to the point where they are truly forming the "seed" lab for my research lab.

10. Innovative Features— Describe the new and original features of the proposed work.

We continue to find that the GreenCube project is surprisingly rewarding and effective as a teaching and learning tool. The combination of training that our rocket and balloon lab work gives the students, with the enhancement of then letting them go on to design and run their own investigation, seems to be working well. The GreenCube program is developing a cadre of capable interested students and is now becoming a science project instead of "just" a technology development project.

For the projects proposed for GreenCube5, the students will expand on the existing capabilities of the GreenCube infrastructure, in particular expanding our in-house knowledge of multiple-payload array communication technology, and Arduino-based controller boards. We are pleased to have come up with the proposed collaboration with Prof Magilligan, which allows us to address an interesting science question at the same time as we are developing infrastructure and knowledge for future ionospheric missions.

11. Team Strengths— Describe the strengths each member of the team brings to the proposed effort.

The GreenCube project is an offspring of existing work at the Lynch rocket lab and the Millan balloon lab, and takes advantage of the lab facilities and student training in place for those larger grant-funded projects. All the items listed in the sections above will be done at Dartmouth, under the auspices of our research labs, and this year also with science guidance from Prof Magilligan of Geography. Engineering mentorship will be provided by Dr Kevin Rhoads, Mr David McGaw, and Mr David Collins, who are all engineers in our groups, and by Mr Dwayne Adams, who is the machinist in the Dartmouth Science Division apparatus shop. We look to JPL for suggestions about possible subsystems for the payloads and for possible guidance with automated mesh network communications protocols, as well as any possible connections with the DARPA F6 program or related technology development.

12. Exchange of personnel— Describe any plans to have work performed at JPL by university personnel or at the university by JPL personnel.

N/A: no formal exchanges are planned. However, ***one of the originating students of the GreenCube program (Parker Fagrelius) is now a JPL employee and project manager for the JPL OPALS project, an optical communications project that is part of Phaeton.*** Launch is in one year on ISS. Our current senior student, Amanda Slagle, participated in a JPL summer internship this summer working with Parker and PI Mannucci.

13. Significance and Impact of Results on JPL Missions and Programs—Indicate specific missions/programs or types of missions.

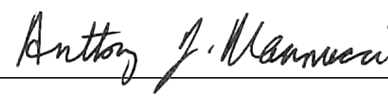
This proposal addresses JPL's interests in enhancing student preparation for a professional career in space systems/science at JPL or elsewhere. The students will gain experience with instruments of particular interest to JPL, such as GPS and magnetometers, as well as with analysis techniques for multi-point in-situ geophysical observations.

14. Plans for Follow-on Funding— Provide a realistic assessment of future funding potential. Discuss how this proposal may enhance the probability of such funding.

The near-term goals seen as extensions to this seed project include both NASA/LCAS sounding rocket science proposals, and the NSF CubeSat program. The SURP funding we have already received has gotten the Dartmouth CubeSat program established as a balloon-borne student spacecraft program. This is critical before a full-up science investigation could be competed; it is also in and of itself a worthy student-based project. Our GreenCube program is now moving into the realm of science investigations, and is developing a solid base of interested students involved in the program. In parallel, we are also using NH state EPSCOR funding to investigate the incorporation of CubeSat compatible instrumentation onto sounding rocket platforms; this project was the basis of a recent Master's degree student, Phil Bracikowski, who was one of the original GreenCube undergraduates. We will fly a version of this in winter 2012 from Poker Flat Alaska, together with the work of another graduate student in the group, Lisa Gayetsky (NSF/Career funding), who is developing an ion thermal sensor, the "PIP", which we hope to fly in the lower ionosphere on swarms of CubeSats.

A related spinoff of the GreenCube program has been the Altair balloon payload developed by Dartmouth Adjunct Professor Yorke Brown; he has used the GreenCube flight infrastructure and student interest to further the scientific goals of our GreenCube3 program on sky brightness measurements into a scientifically competitive program. Similarly, should our GreenCube5 program work out well, Prof Magilligan is very interested in variants of the river-flow study relevant to his work.

15. JPL Principal Investigator Signature

Name: Anthony J Mannucci Signature: 

16. JPL PI Division Manager (or designee) Signature

Name: Signature:

17. University Co-Investigator Signature

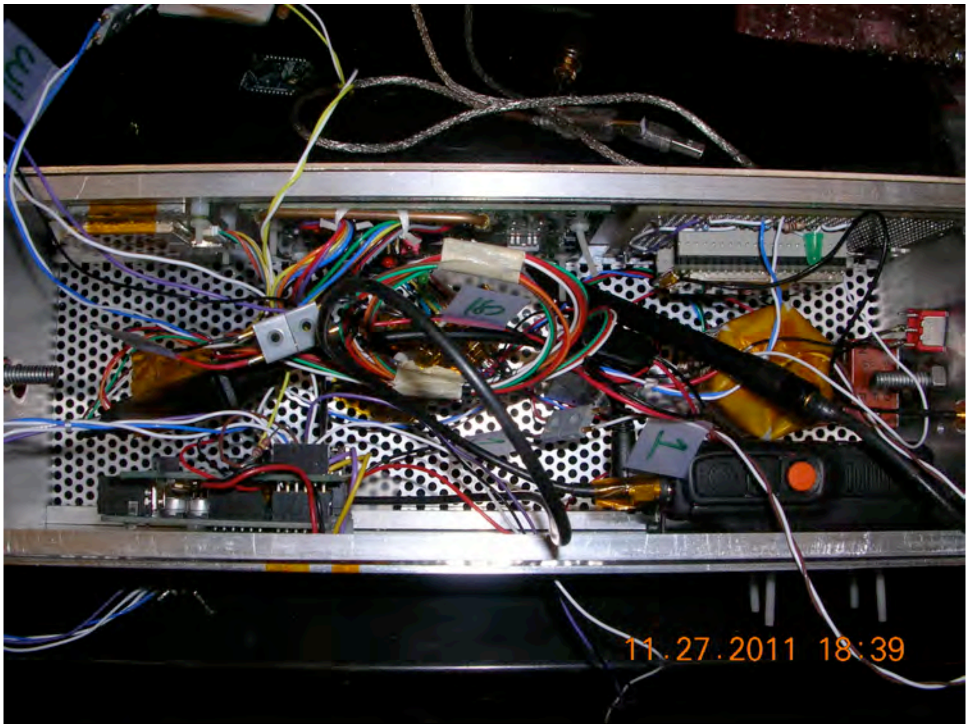
Name: Kristina A Lynch Signature:

18. University Representative with Signature Authority, if required by university (signature may also be provided instead on a letter attached with university budget backup)

Name: Signature:

19. Figures, Graphics, Tables, etc.

Some images of GreenCube4 efforts. Top: the “Dave” 3U GreenCube4 payload. Bottom left: the Squidbee controller hardware within Dave. Bottom right: the triple-junction solar panel array which the Squidbee-based Dave payload will monitor.



20. SURP Budget Sheet

Category	Year 1	Year 2	Year 3
DIRECT COST			
1. **Salaries**— *(Itemize) Only "itemize" the person names or job classifications and the number of hours for each. Show one total $ salary figure for labor.* *Itemize names and hours (or FTE) here A. Mannucci 24 hrs*	$1.83	$0	$0
2. **Labor Fringe** — *Employee Benefits*	$0.94	$0	$0
3. **Cat A Labor**— *(Itemize) Only "itemize" the person names or job classifications and the number of hours for each. Show one total $ figure for labor.* *Itemize names & hours here*	$0.0	$	$
4. **Procurements–PO (Equipment, Materials and Supplies)** *(Itemize)* *Itemize here*	$0.0	$	$
5. **Procurement–RSA (or PS) for University Subcontract(s)** *(Important! See notes #1 and #2 below)* *Itemize and indicate whether the subcontract will be a RSA or PS type.*	$20.0	$0	$0
6. **Procurements– PS** *(Itemize)* *Itemize other (non-university) subcontracts*	$0.0	$	$
7. **Services**— *(Itemize) Include all in-house services at JPL* *Itemize here*	$0.0	$	$
8. **Domestic Travel**— *Itemize where and why*	$0.0	$	$
9. **Other**—*(Itemize) (Chargebacks, etc.)*	$0.14	$0	$0
10. **Total Direct Costs** *(total of dollars 1 through 9)*	$22.91	$0	$0
ALLOCATED DIRECT COSTS (ADC)			
11. **Total Allocated Direct Costs (ADC)** *ADC rates apply to SURP proposals, but not MPS. See your section administrator for help applying the current ADC rates for the various categories of direct costs above.*	$2.13	$0	$0
12. **TOTAL BUDGET REQUEST** **(***See Note #3 below.)* *Sum of Item #10 and #11*	$25.04	$0	$0

Note #1: You must attach a budget breakdown from each university partner. There is no page limit and the format is the university's choice. The budget breakdown should be adequate for reviewers to understand labor, procurements, subcontracts, services, travel, and university overhead.

Note #2: Use a "RSA" type of subcontract to send funds to your university partner, except for the following circumstances. If your proposal involves hardware or software deliveries or if government furnished property will be sent to the university, then a RSA subcontract will not be allowed. Under these circumstances, use a "PS" type of subcontract. The ADC rates for these two types of subcontracts are significantly different and it is important to make the distinction in your planning stages.

Note #3: Consider using the new institutional online Price Estimate Generator (PEG) for your budget estimation. Type "PEG" in your browser and follow instructions for requesting access.

21. Budget Details for University Partner(s)

BUDGET - SUMMARY			
AGENCY:	JPL		
TITLE:	Dartmouth Greencube 5		
Principal Investigator:	Kristina Lynch		
START DATE:	3/1/2012		
END DATE	2/28/2013		
		Dartmouth	
		Year 1	
		3/1/2012	
		2/28/2013	
PERSONNEL			**TOTAL**
Undergraduates		$12,261	$12,261
FRINGE BENEFITS (9%)		$1,103	$1,103
TOTAL SALARIES		**$13,364**	**$13,364**
TRAVEL		$700	$700
SUPPLIES		$3,500	$3,500
TOTAL DIRECT COST		**$17,564**	**$17,564**
OVERHEAD	*58.00%*	$2,436	$2,436
TOTAL COST		**$20,000**	**$20,000**
Overhead base (less UG support/fringe):			
$4,200			