Ultra-Blue Objects for Kepler Observing (UBOKO)

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Abstract
We propose to generate Spectral Energy Distributions (SEDs) of objects in the Kepler field that have been identified to be very blue; the SEDs will be used to characterize and classify the objects. Using Ultraviolet, Blue and Visual magnitudes (UBV) from a ground based survey of the Kepler Field by Howell and Everett, we have identified ultra-blue objects from a color-color plot of U-B vs. B-V objects. Our research will focus on the ~200 of the brightest objects out of the roughly 4000 ultra-blue objects contained in the UBV survey. By collecting ultraviolet, optical and infra-red photometric data using astronomical archives, including GALEX, MAST, IRSA and NExScI, we will make SEDs of each object and compare them to known SEDs of White Dwarfs (WDs), Planetary Nebula Nuclei (PNNs), Active Galactic Nuclei (AGNs), Cataclysmic Variables (CVs), and X-ray Binaries (XBs). Characterizing the identities of these sources in the Kepler field will facilitate further study and will be used to propose observations with the Kepler space telescope.

Scientific Justification

Kepler is an exoplanet transit discovery mission designed to produce high precision light curves of ~150,000 objects simultaneously. As a result, Kepler is producing the most precise and long-term time-sequence photometric data of objects in our local Milky Way. The instrumental sensitivity allows for detection of variability on the order of micro-magnitudes. While Kepler's primary mission is to find extrasolar planets, its photometric precision and ability to observe thousands of objects at once make it an interesting and useful tool to study the variable nature of objects of all types.

Prior to Kepler launch, a ground survey (the Kepler Input Catalog) was performed to identify targets for transit searching. This survey focused primarily on red objects to identify solar-like main sequence stars with spectral types of F, G, K, and M – thus, the ground survey missed most of the very blue objects in the Kepler field. We expect the ultra-blue objects in the Kepler field to include White Dwarfs, Planetary Nebula Nuclei, Active Galactic Nuclei, and Interacting (X-ray and Cataclysmic) Binary stars.

Background

The following is a description of the types of objects we expect to find during our study.

White Dwarfs (WDs)

White dwarfs are the evolutionary end product for about 97% of all stars. The eventual fate of our Sun will be a WD. After exhausting its nuclear fuel, the dying star expels most of its outer material creating a planetary nebula. The core that remains becomes the white dwarf star with temperatures > 100,000K. WDs cool with time, unless they are actively accreting matter from a companion, as in cataclysmic variables. They are generally carbon/oxygen objects supported by electron degenerate pressure with a thin non-degenerate envelope, which is generally dominated by the presence of hydrogen and/or helium. WDs are chemically differentiated into two broad groups: hydrogen rich or DA classification (*e.g.* Sirius B) and helium rich or DB classification (*e.g.* HZ-29). Additionally, there are very hot white dwarfs (DO), metal rich white dwarfs (DC), as well as a number of types of pulsating white dwarfs. Identifying a large sample of WDs is likely to include members of various classes and allow for interesting follow up science. For example, calculations have shown that 3 years of observation of a very hot white dwarf by Kepler will allow a direct measure of the cooling curve, observations of pulsating white dwarfs enable well defined mass and radius determination, long term monitoring of cooler white dwarfs may reveal theoretically predicted "star quakes".

Planetary Nebula Nuclei (PNN)

Stars of ~1-8 solar masses will typically go through a brief PPN stage near the end of their evolution. When the hydrogen at the star's core has been sufficiently converted into helium, the reduced pressure from the H-He reaction results in a gravitational collapse. As the temperature of the core increases, helium begins to be converted into carbon and oxygen. This results in the star expanding and moving off the main sequence into the Asymptotic Giant Branch (AGB) phase. As the core evolves, the outer layers are shed and ionized, becoming a planetary nebula. With deeper layers of the core exposed, the central star can reach 10^5 K, and thus PNNs are the hottest stars known in our galaxy. The PNN is a short stage (1000's of years) and is a bridge from the AGB and white dwarf stages.

For decades astronomers have debated the nature of PNNs – are they single stars or binary systems? Recent evidence from Kepler studies indicates that all 5 of the currently known PNN in the Kepler field are binaries. Identifying a larger sample with in the Kepler field may help resolve this dilemma.

Active Galactic Nuclei (AGN)

An AGN is a region at the center of a galaxy that is very luminous – it produces more radiation than the rest of the galaxy. It is believed that the high luminosity results from matter accreting onto a central black hole. As matter approaches the black hole, an accretion disk is formed (jets are sometimes present as well). The black hole plus the accretion disk comprise the AGN. The accretion structure around the central black holes of AGNs is not well understood.

Measuring correlations and lags between optical and X-ray variations will provide an important test of the AGN models. Kepler is sensitive to inter-band lags more than an order of magnitude shorter than any claimed previously. Identified lags will map the accretion disk using reverberation mapping techniques and place limits on the size and mass of the central engine. Knowing the photometric variability of AGNs would provide information about this structure.

Interacting Binaries (IBs)

Interacting binaries are comprised of a main sequence star or a giant star in orbit around a stellar remnant such as a White Dwarf, Neutron Star or Black Hole. The main sequence or giant star is typically lower in mass than the stellar remnant and the star often transfers material from its surface to the stellar remnant through an accretion that forms around the stellar remnant. If the stellar remnant is high in mass (Neutron Star or Black Hole), the mass transfer is high and the binary often emits X-rays as the matter from the star accretes onto the compact source. The donor star in an X-ray Binary (XB) is typically a giant or super-giant star. If the stellar remnant is a White Dwarf, the mass transfer is lower and the x-ray emission is less. In these systems, the donor star is typically a main sequence star and these interacting binary stars are typically classified as Cataclysmic Variables (CVs). The SEDs from x-rays through infrared may help us distinguish CVs (interacting binaries with low mass primaries, such as White Dwarfs), from XBs (interacting binaries with high mass primaries, such as Neutron Stars or Black Holes).

Areas of Research

High precision photometric monitoring of WDs, PNNs, AGNs, and IBs can provide useful information about the structure and evolution of these objects. If these objects could be observed by Kepler, we could address the following areas of research.

1. How commonly do planets survive the late stages of stellar evolution. High precision light curves from Kepler can be used to search for planets around White Dwarfs. The planets can show themselves, either through transits across the WD or by causing changes in the pulsations of WDs. We can then compare the frequency of planets around WDs to the frequency of planets around normal stars, if a large number of WDs in the Kepler field can be identified.

2. A long standing problem in astronomy is the production of planetary nebulae. It is possible that binary stars are required to produce (most) planetary nebula but little evidence exists one way or the other. High precision Kepler light curves of Planetary Nebulae Nuclei could provide the necessary data to explore these questions. The binary stars in the PNN would be in close orbits and high precision data from Kepler would show modulations in the light curves that single stars would not show.

3. The size and structure of the accretion disk and large torus around the central black holes of Active Galactic Nuclei is still not very well understood. High precision Kepler light curves of AGN could provide information about the photometric variability of AGN and would yield valuable information about these structures.

4. The details of periodic outbursts and accretion structure around the central stars in Interacting Binaries, for example Cataclysmic Variables and X-ray Binaries, are not very well understood. As with AGN, high precision photometric light curves from Kepler could yield a better understanding of the accretion structures in Interacting Binaries.

Before Kepler can study these ultra-blue objects, they first must be identified in the Kepler field. A UBV ground based survey of the entire Kepler Field by Howell and Everett (Everett et al. 2012, PASP, in press) produced a catalog of 4 million sources with UBV photometry. Over 4000 ultra-blue objects were identified using a two color diagram (see Figure 1). Objects below the red line in the diagram are ultra-blue and not on the main sequence. Most likely, these objects are White Dwarfs, Planetary Nebulae Nuclei, Active Galactic Nuclei, and Interacting (Cataclysmic and X-ray) Binaries, but there may also be objects that do not fit these 5 basic categories.

Our research will focus on the 200 brightest objects of the roughly 4000 ultra-blue objects. We propose to collect photometric data from across the electromagnetic spectrum using the archival resources of IPAC, NExScI, MAST, and HEASARC and generate spectral energy distributions (SEDs) for these objects. By examining the SEDs and comparing them to our template sources, we expect to identify WDs, PNN, AGN, and Interacting Binaries (CVs and XBs). There are 22 of these objects already identified in the Kepler field. We have used these sources to demonstrate the feasibility of the proposed work and to serve as templates to start our study. There are likely to be objects that do not match our representative SEDs, and further study of these objects for identification will be pursued.

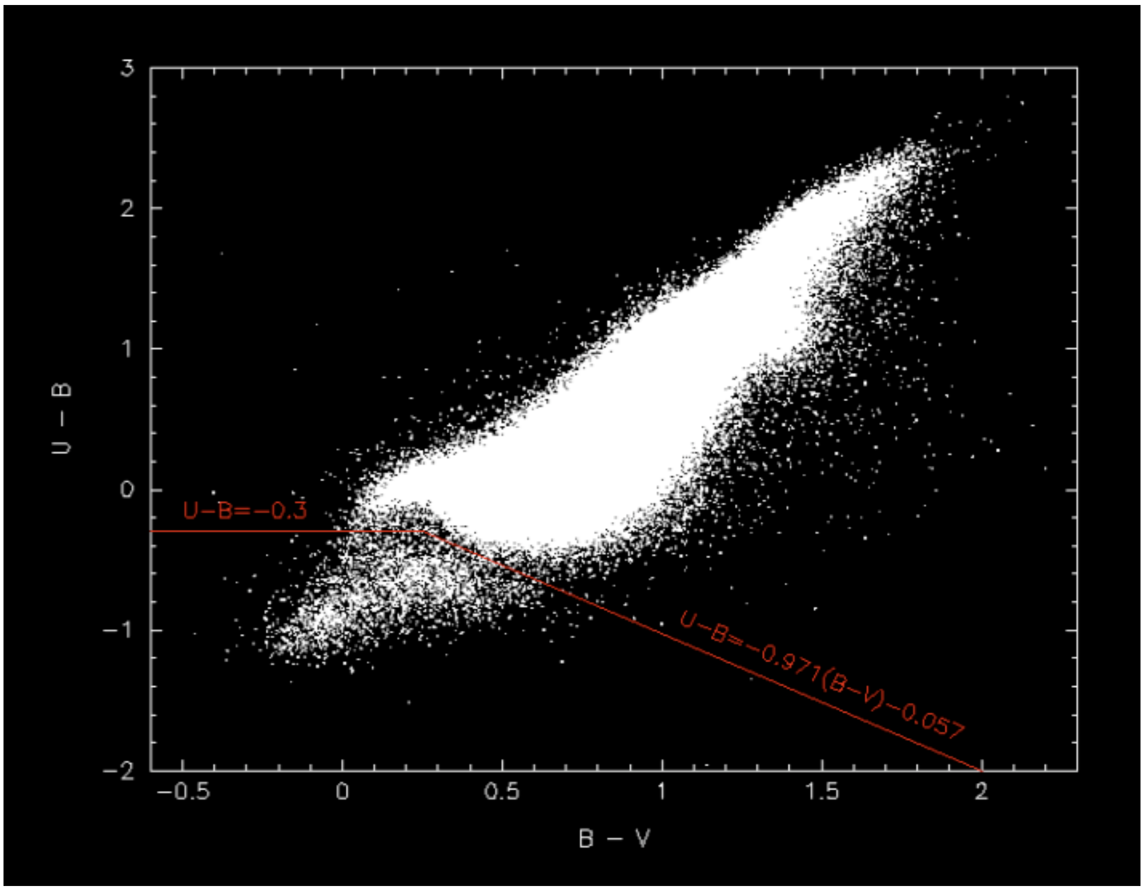


Figure 1: 2-color diagram produced from the UBV survey data. Sources that fall below the red line demark the very blue sources that are the subject of this proposal.

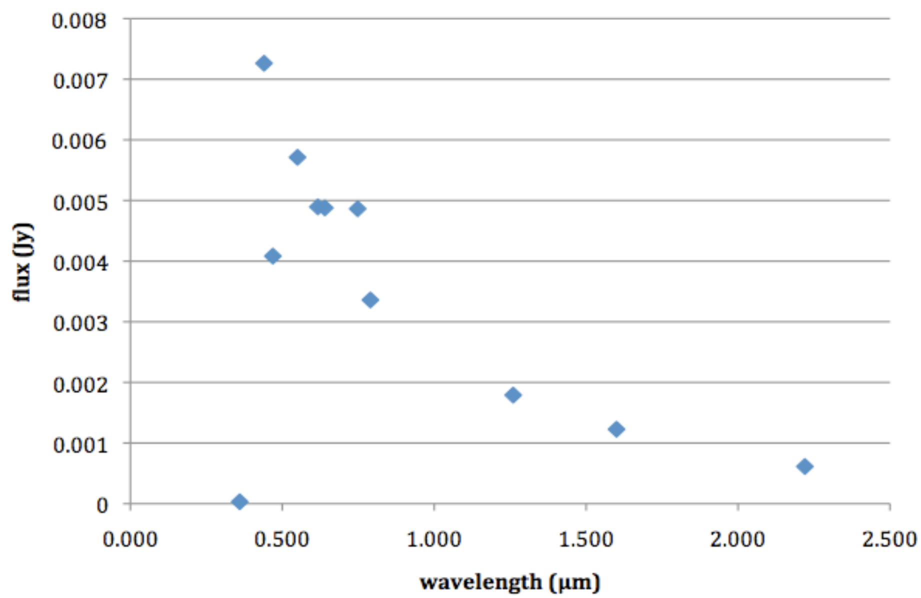
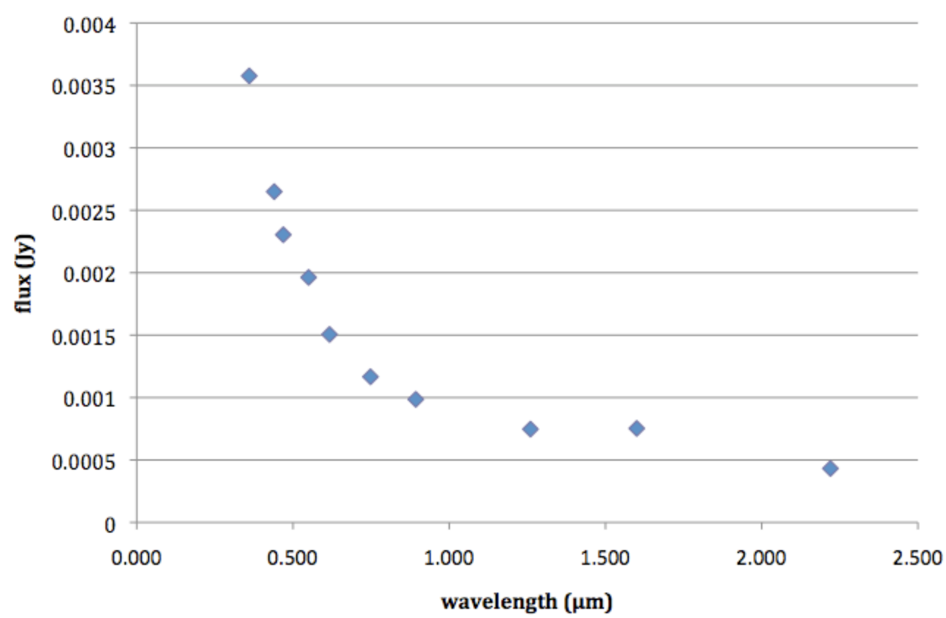
Pilot Study

To determine the feasibility of collecting archival data and classifying these objects, 22 objects were identified in the Kepler field from a list of known WDs (7), PNNs (5), AGNs (4) and CVs (6). There are no known XBs in the Kepler field, so data was collected on the classic x-ray binary Cyg X-1. Data were collected on these objects in the ultraviolet using the Galex archive, and in the optical and infrared using the Kepler Archive. Data were found on all types of objects and typical SEDs are shown in the figures below.

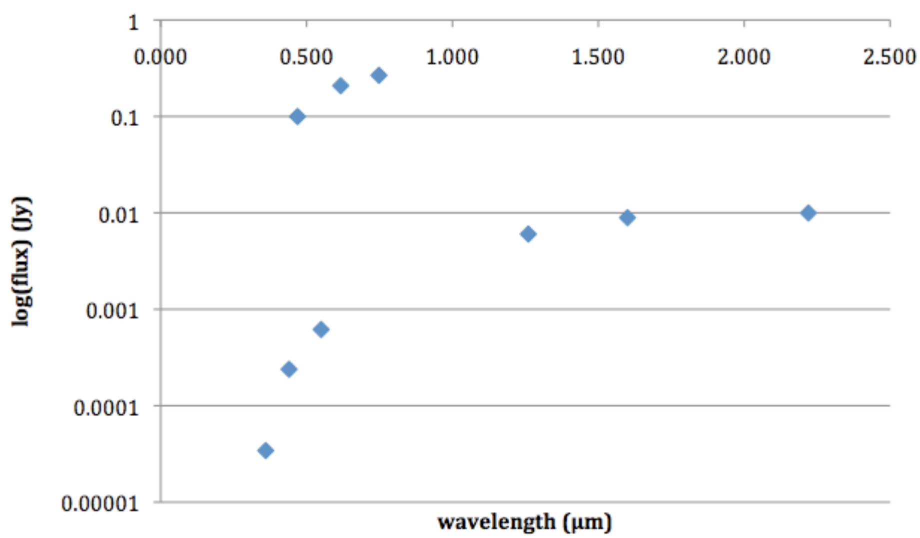
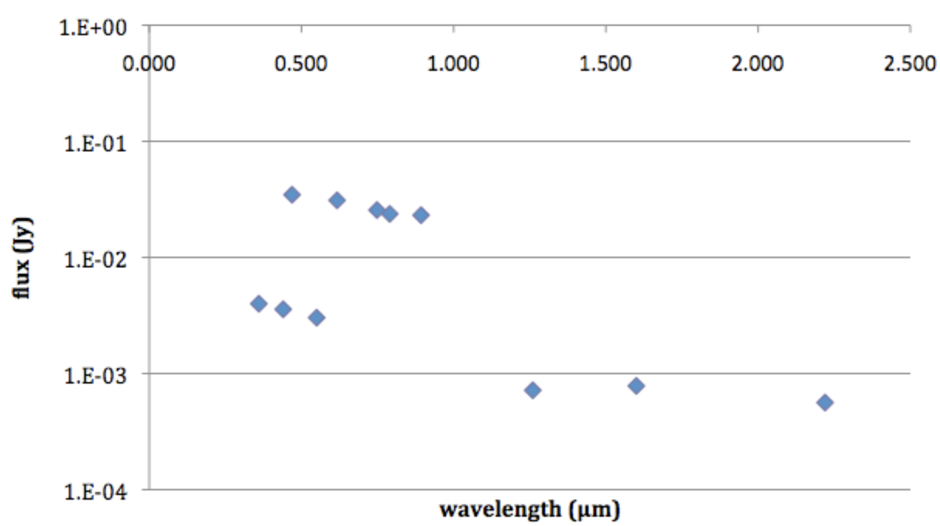
Comparison of Spectral Energy Distributions (SEDs)

Comparing the SEDs of our template sources, we note there are some distinguishing characteristics that will allow us to classify ultra-blue objects.

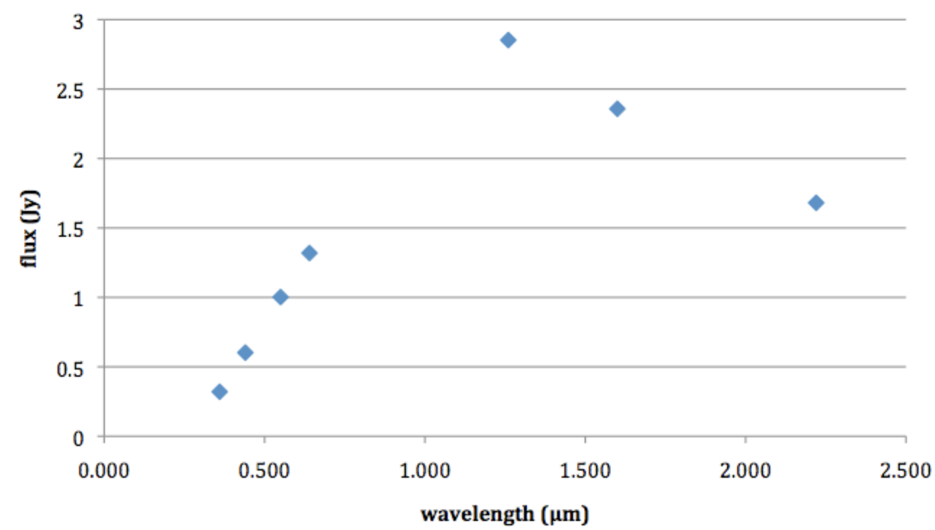
WD and PNN SEDs show black body curves with a maximum wavelength bluer than 0.5 µm. The template DA WD peaks around 0.44µm in the B filter, and drops dramatically in U band filter due to the Balmer jump. PNNs are hotter than all of the other objects indicated by a rapidly rising SED with no clear maximum wavelength.

<table>
<tr><th>Object</th><th>SED</th></tr>
<tr><td>White Dwarf
WD1940+374</td><td>
</td></tr>
<tr><td>Planetary Nebula
Nuclei
KIC 2352398</td><td>
</td></tr>
</table>

The SEDs of AGNs and CVs are different in form from the SEDS for WDs and PNNs. The SED of an AGN is plotted on a logarithmic scale as the flux in the g,r,i bands (0.469, 0.617 and 0.748 μm respectively) dominates the graph. However the SED of an AGN will vary as a function of the object red shift. The CV SED shows a bimodal distribution in the blue. This is due to some of the archival data obtained during an outburst and some being obtained during minimum light. Correlation of our ultra-blue sources with X-ray observations will help identify these sources.

Active Galactic Nuclei KIC 7130593	
Cataclysmic Variable MV Lyr	

As with WDs and PNNs, the SED of a high mass XB (Cyg X-1,) also shows an approximate black body curve, but its maximum wavelength is around 1.2μm, in the J band filter.

High Mass X-Ray Binary Cyg X-1*	

* Cyg X-1 is not in the Kepler field. Currently, there are no identified XRBs in the Kepler field. CygX-1 is presented here for comparison of high mass x-ray binary SED.

The above graphs and data analysis represent our initial distinctions between the SEDs of objects in our pilot study. Our understanding of SED's appearance will evolve over time as more objects are viewed and classified.

Proposed Work Plan

We propose the following plan of study:

1. We will determine the 200 brightest ultra-blue objects found by the ground based UVB survey. These fall in the region below the red line indicated on the UBV color-color diagram (Figure 1).
2. To better characterize these objects, we will collect archival photometric data and produce SEDs for each source.
3. We will use Janskys as our standard for reporting photometric flux. In most cases, this will require converting our data from magnitudes.
4. We will compare the SEDs of the unclassified ultra-blue objects to the SEDs presented in Pilot Study.
5. In addition we will use the NExScI Kepler Light curve service to determine which (if any) of the unknown objects are already included in the regular Kepler download.

The primary datasets will be collected from online tools including:
Kepler Input Catalog and UBV Survey at MAST
Kepler Archive at NExScI, including the light curve viewer.
GALEX Archive at HEASARC
2MASS and WISE archives at IRSA
SIMBAD for the identification of previously known objects

Timeframe

- March to July 2012
  Gather archival photometric data and produce SEDs for the ultra-blue sources discussed in this proposal.
- July 2012
  Meet as a group in Pasadena to compare the SEDs, discuss results, and draw conclusions.
- August to December 2012
  Finalize analysis and conclusions, and prepare presentation for the AAS meeting in January.

Educational Rationale

Our research team is comprised of a museum educator from Dayton, Ohio, an observatory supervisor in Massachusetts, and four science educators, from Florida, Illinois, Massachusetts and California. We are all dedicated towards improving science education in high school by providing students better and more authentic research experiences. Along with these working professionals there will also be approximately *8 – 10* high school aged students involved in the research and presentation of findings.

Team UBOKO will immerse themselves in general astronomy concepts and build research skills to ensure the success of UBOKO project. Some of these concepts and skills are listed below.

- understand general properties of light, the electromagnetic spectrum and black body emitters
- collect archival photometric data.
- convert between flux units, specifically magnitude to Janskys
- produce spectral energy distributions, SEDs
- manipulate data and generate graphics using Excel spreadsheets

With appropriate background schema in place, both educators and student learners will experience authentic scientific research in a true collegial manner. Data acquisition and analysis will take place separately at individual schools as well as together for 3 days during the summer. Communications between team members will take place via regular teleconferences, extensive use of the wiki, and email. A scientific and education poster will be created and presented by the UBOKO team at the 2013 American Astronomical Society Winter Meeting in Long Beach, California.

Beyond the official research process, the group will engage in a variety of education and public outreach activities. Presentations will be made by Team UBOKO teachers and museum educators at local, regional, state, and national science gatherings (e.g. NSTA (National Science Teachers Association), AAS, school professional development, school boards, astronomy club monthly meetings, etc.). Teachers and students will also develop related classroom activities that can be utilized with their own students as well as shared with other teachers and students across the United States. These activities will be disseminated broadly via the NITARP Wiki and website, and through educational presentations.

Specific locations and opportunities for each educator are presented below:

Education Component at Boonshoft Museum of Discovery (J. Childers)
I am the Astronomy Educator at the Boonshoft Museum of Discovery in Dayton, Ohio. Since we have the only public planetarium in southwest Ohio we have many opportunities for astronomy outreach to both educators and the general public alike.

Each June our museum hosts an amateur astronomy convention; I have presented in each of the preceding three years and anticipate another opportunity to speak this year and next about NITARP. In addition, the museum is affiliated with a very active amateur astronomy club, the Miami Valley Astronomical Society. I have given lectures at their meetings on several occasions, and am scheduled to talk at least twice more in 2012 about professional/amateur collaboration and my NITARP activities. I also retain many contacts from my time as a graduate student and amateur astronomer in Indiana prior to my museum work. The Muncie Astronomy Club has invited me to talk about NITARP, and I anticipate being able to speak at the Indiana Family Star Party as well. I would seek also to speak at other western Ohio and eastern Indiana clubs and star parties.

Our museum also enjoys an excellent reputation with local school systems. Each fall our education department hosts a Science, Technology, Engineering and Mathematics (STEM) Teachers' Workshop for professional development credit for local teachers, and I am scheduled to present about NITARP this year. There have been a few inquiries about special projects for gifted students that we might recommend, and while the timeframe of these has not yet matched NITARP's there is definitely potential to find a group of focused students to work with on the project.

Education Component at Latin School of Chicago (M. McCutcheon)
As a mathematics and physics instructor, I will select four to five students at Latin School of Chicago to work directly on the UBOKO project. In addition to performing research we will share our relevant experiences of acquiring and analyzing data, and working with professional scientists with other students at our school.

As the school Coordinator of Science Research, I will have in-house workshops with colleagues discussing astronomy research. Our research experience may be included in our physics class units relating to astronomy and our courses in astronomy affecting students from 8^{th} -12^{th} grades. My NITARP experience will enhance all of my interactions with the teachers of these courses.

I will present my research experience at local symposiums and conferences, such as the Illinois Science Teachers Association and local astronomy groups, and possibly national ones as well, such as the National Science Teachers Association or the American Association of Physics Teachers.

Education Component at Coral Glades High School (C. Melton)

Students from Coral Glades High School that will be working on this program will become proficient in working with analytical tools and archived data. An important aspect of this study is to engage our under-represented students in the process of science as an opportunity to develop a methodology of working with the spectra of objects they might be unfamiliar with.

Specific education and outreach goals include the presentation by students and teacher of the research results at the 2013 American Astronomical Society Meeting; the development of spin-off projects; the presentation of spin-off projects at regional science competitions; and the development of workshops for students to discuss laboratory modules developed with respect to SEDs.

In addition, teacher lead professional development will include quarterly presentations providing updates to our school's Parent Teacher Student Organization (PTSO) community; presentation of project results at the Florida Science Teachers Association Meeting; and updating our local science teachers on project status at our quarterly meetings.

Education Component at Phillips Academy (C. Odden)

I teach physics and astronomy at Phillips Academy, a high school of 1100 students in Andover, Massachusetts. I also supervise the Phillips Academy Observatory, which houses a 16-inch DFM Engineering telescope. The observatory is equipped with a spectrograph and an SBIG camera with a full set of Bessel UBVRI Photometric Filters.

The NITARP experience will add practical applications to my courses when discussing binary stars, Kepler, and blue objects. The UBOKO research will serve as a starting point for students interested in doing research. Students will use our facilities on campus to augment the data on the UBOKO objects of interest and to pursue other research ideas generated from their experience with NITARP.

I will present several short talks to a) describe our research process b) encourage educators to start research projects at their school c) encourage other teachers to think about applying to the NITARP program. I plan to address the following audiences:

1. Afternoon presentation to *Science Topics*, a professional organization of public school teachers in Andover, MA. 1.5 hours, Fall 2012

2. Presentation to Astronomy teachers from the greater Boston area. A daylong workshop to be held on the Phillips Academy campus. 6 hours, June 2013
3. Astronomy teachers from independent schools in the greater Hartford area. 2 hours, Fall 2012
4. Presentation to several astronomy educators at a small conference in Colorado. 1hour, March 2012
5. As the supervisor of the observatory on campus, I am called upon to give presentations on campus on a regular basis – to local alumni, perspective students, etc. I will take advantage of these events to talk about NITARP, and will involve my students in the presentations whenever possible. 3 hours, 2012-2013 academic year

Education component at San Mateo High School (S. Seebode)
Selected students will become proficient at accessing archived data, plotting SEDs, identifying blue objects and sharing their results. These students are members of an active astronomy club and will use their acquired skills to do future research working with spectra and SEDs as well as educate future club members to continue their projects. Future research will be shared through local science fairs and AAS meetings as finances allow.

The experience and information learned through this project will be shared at the California Science Teachers Association's (CSTA) meeting in 2013, our school board, as well as local chapters of the Astronomical Society and community groups like rotary and American Association of University Women (AAUW).

Participation in NITARP will enrich every UBOKO team member (students and teachers) as they experience authentic research as part of a multi-disciplinary team. In addition to enhancing each learner's knowledge of astronomy and the research process, this experience will increase interest in and the ability to pursue other research opportunities.

Archive URLs:
http://archive.stsci.edu/kepler/kic10/search.php
http://exoplanetarchive.ipac.caltech.edu/
http://galex.stsci.edu/GalexView/
http://irsa.ipac.caltech.edu/
http://simbad.u-strasbg.fr/simbad/