Classification of Ultra-Blue Sources in the Kepler Field

Caroline Odden[1]; Sally Seebode[2], Joseph Childers[3], Cindy Melton[4], Matthew McCutcheon[5], David Ciardi[6], Steve Howell[7], Claire Carroll[1], James Falese[1], Emily Field[1], John French[1], Harshita Gaba[1], Sam Khalandovsky[1], Anjali Krishnamachar[1], Heather Mei[1], Gina Sawaya[1], Emily Zhu[1], Austin Tai[2], Mounish Savier[2], Jacob Melton[4], Karun Koppula[5], Sarah Huston[5], Brian Lorenz[5], and Kevin Ward[5]

[1]Phillips Academy (Andover, MA), [2]San Mateo High School (San Mateo, California), [3]Boonshoft Museum of Discovery (Dayton, Ohio), [4]Coral Glades High School (Coral Springs, Florida), [5]Latin School of Chicago (Chicago, Illinois), [6]NExScI/Caltech (Pasadena, California), [7]NASA/Ames Research Center (Moffet Field, California)

Abstract

Our study focused on a **sample of 250 ultra blue sources extracted from the Howell-Everett UBV survey of the Kepler Field**. Utilizing data from this survey, the KIC, 2MASS, GALEX, and WISE, **we generated spectral energy distributions (SEDs) for every object**. We compared these SEDs with known SEDs of a variety of standard blue sources as well as visually examining HEASARC, UBV, DSS, 2MASS, and WISE image data. **Sources were categorized as stars, white dwarfs, cataclysmic variables, active galactic nuclei, x-ray binaries, planetary nebula nuclei, or unknown.**

Results

Main Sequence Stars	112
White Dwarfs	40
Cataclysmic Variables	6
Active Galactic Nuclei	2
Planetary Nebula Nuclei	2
X-Ray Binary	1
Not Yet Identified	87

For a more complete listing of results, please visit: web.ipac.caltech.edu/staff/ciardi/UBOKO_WD_Candidates.html

The Sample

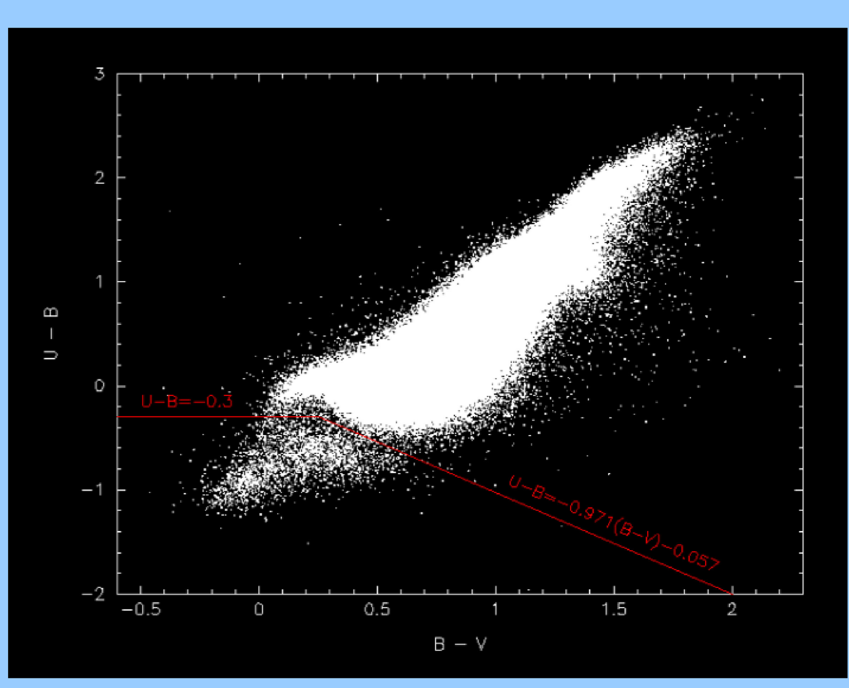


Figure 1: Two-Color Diagram of the Howell-Everett UBV Survey of the Kepler Field

The hot objects selected for our study come from a UBV survey of the Kepler field (Everett, Howell, & Kinemuchi, 2012, PASP, 124, 316). We chose the 250 brightest in the U band from the ~4000 objects under the red line in Figure 1, after ensuring that each had a Kepler Input Catalog identifier.

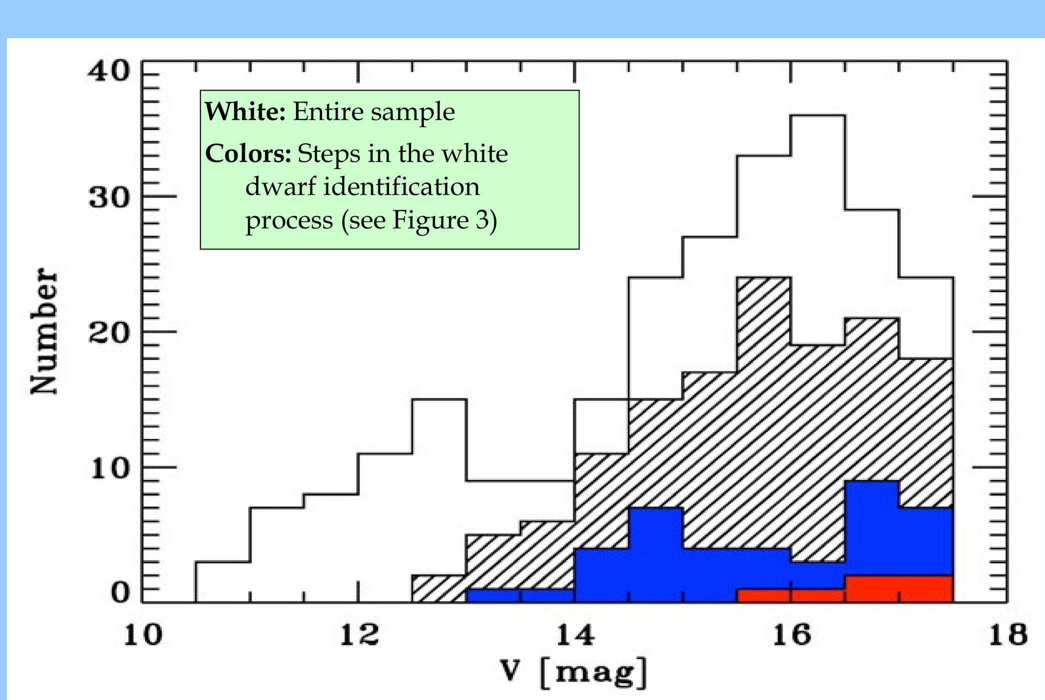
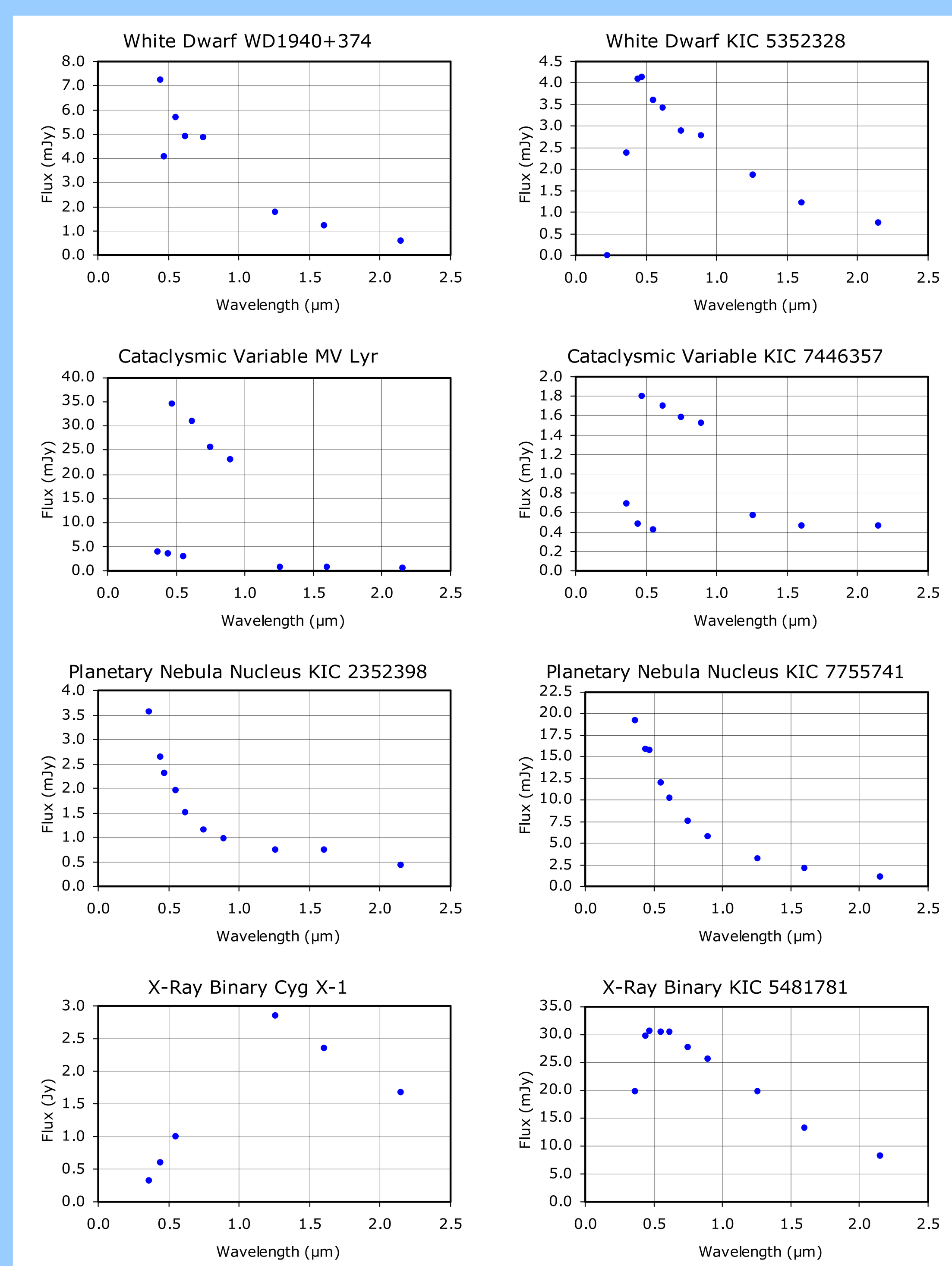


Figure 2: V Magnitudes of Target Objects

Developing the Procedure

22 test objects previously identified and not in the target sample were used to evaluate the feasibility of the proposed method and to serve as templates for the various kinds of objects we hoped to find. Fluxes were found for up to 17 wavelengths per object: UBVJHK, ugriz, GALEX nearUV & farUV, and WISE infrared W1-W4.



Known Object Template (Left)
Best Fit Classification Example (Right)

Follow-up Spectroscopy

After initial classification, we obtained spectra for a number of our sources. Those determined to be main sequence stars were nearly 100% correct. Some sources that were challenging to classify (interesting or multiple component SEDs, those without Kepler light curves, or those we could not classify at all) were observed and are listed below. Periods listed were determined from Kepler light curve observations.

KIC ID	Umag	SED Classification	Comments
2570259	16.1	Unknown	Likely Planetary Nebula Nucleus, period near 5 days
3426313	15.6	Unknown	Possible CV
4473530	14.2	Possible CV	CV?
4828345	12.6	Possible CV	Likely δ Sct
5340370	17.1	Cataclysmic Variable	Likely δ Sct
5481781	12.8	X-Ray Binary	Variable source, period near 3.6d, now V near 18
6042560	16.7	White Dwarf	White Dwarf
7346018	16.4	Unknown	White Dwarf
7755741	13.4	Plan. Neb. Nucleus	Planetary Nebula Nucleus, period near 0.9 days
8490027	16.7	White Dwarf	Cataclysmic Variable?
8683556	17.5	Cataclysmic Variable	Cataclysmic Variable
10198116	16.3	White Dwarf	White Dwarf

We gratefully acknowledge funding support from the NASA Astrophysics Data Program and the NASA/IPAC Teacher Archive Research Program

Identifying White Dwarfs

We fit each of the 250 UBV source to a hot main sequence star using an on-line SED fitting program (collegeofsanmateo.edu/astronomy/seds.asp). Assuming hot main sequence stars will only be found in the galactic disk, objects with a fitted distance greater than 10kpc become white dwarf candidates. For this subset of 138 sources, we refit the SED assuming a white dwarf radius, yielding a new distance and temperature. Using a relation between white dwarf temperature and absolute magnitude (Limoges & Bergeron 2010, ApJ, 714, 1037), the absolute magnitude of the candidate white dwarfs were calculated. A separate absolute magnitude was calculated from the new fitted distance and the V magnitude. Those objects with temperature-derived and distance-derived absolute magnitudes within 0.2 magnitudes of each other were considered to be the most likely white dwarf candidates.

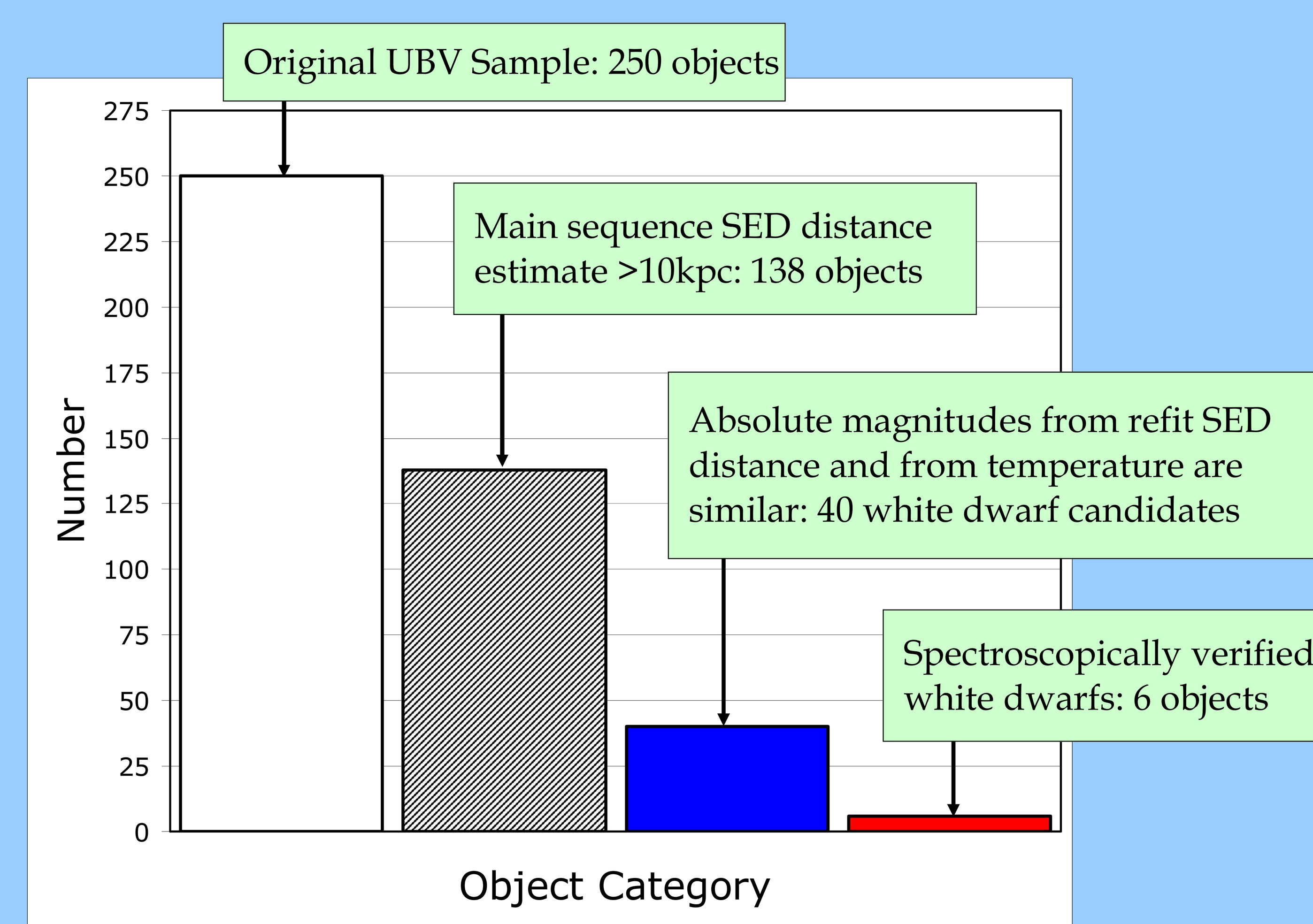


Figure 3: Steps in Identifying White Dwarfs

Below we present a two-color diagram of all 250 ultra-blue objects in the sample, highlighting the above steps in identifying the white dwarfs. The spectroscopic confirmation of six white dwarfs and the local grouping of candidates provide confidence for our method.

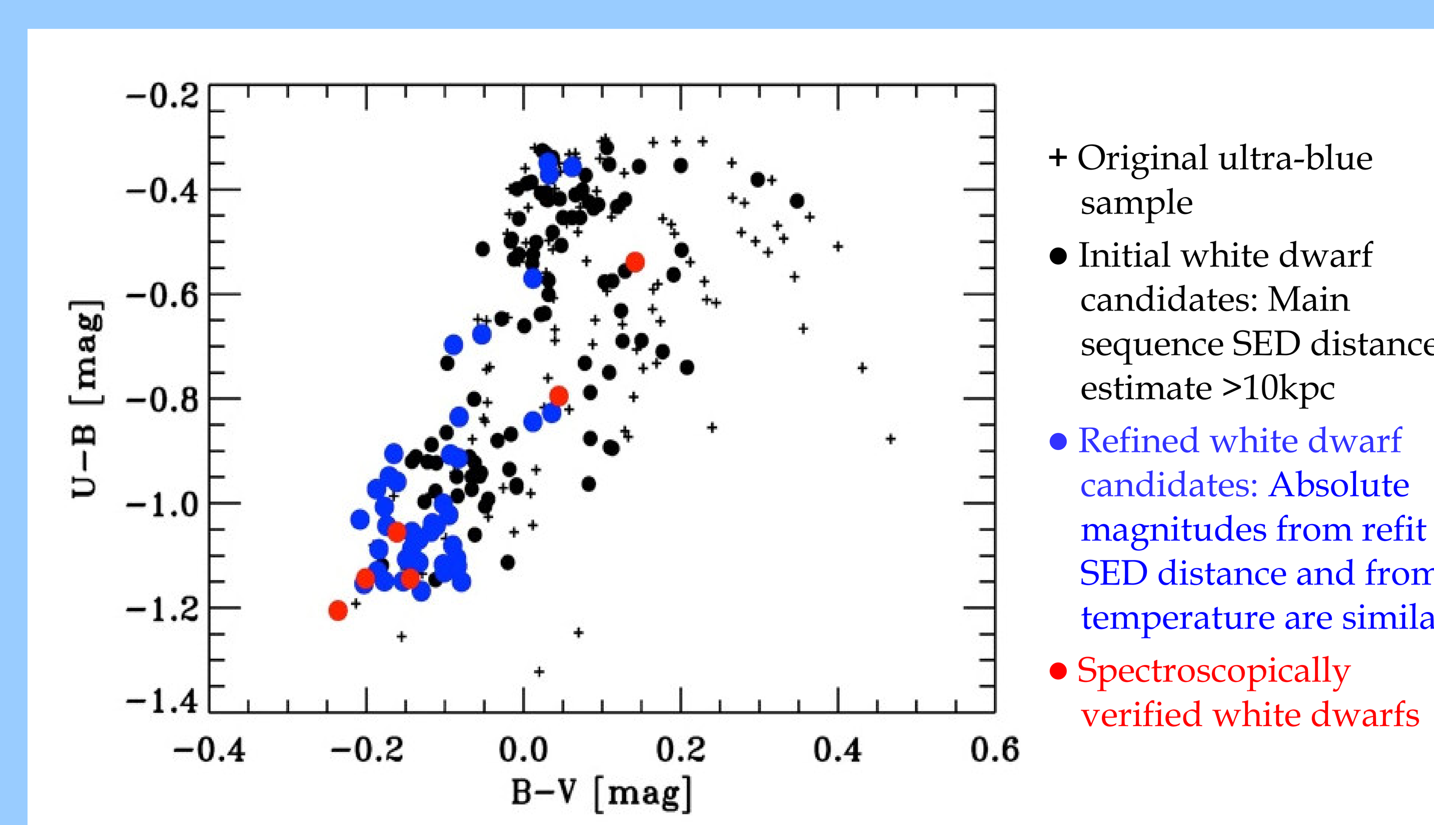


Figure 4: Two Color Diagram of Sample Objects Highlighting White Dwarf Candidates

Further Investigation

This first application of our method demonstrates that SEDs can quite effectively identify hot objects. Several avenues for further investigation present themselves:

- Obtain Kepler light curves for the variable sources identified by follow-up spectroscopy.
- Obtain spectra of all the 40 white dwarf candidates.
- Identify the 87 objects which are neither hot main sequence stars nor white dwarfs nor a cataclysmic variable, planetary nebula nucleus, etc.
- Expand the sample to include more hot objects from the Howell-Everett UBV Survey.