Facilities, Equipment, and Other Resources

Co-PIs Henry and Horch will use various telescope/instrument combinations to make the radial velocity/spectroscopic, high-resolution speckle imaging, and photometric follow-up observations. Below we offer details of each telescope/instrument combination. Team members will also use available large datasets, including results from *Gaia* Data Release 2, *Hipparcos/Tycho*, the SuperCOSMOS archive of scanned photographic plates, Pan-STARRS, SkyMapper, 2MASS, and *WISE*. In general, Co-PI Henry's team creates detailed target lists, carries out the radial velocity program, derives metallicities and age estimates for the stars, makes the supporting photometric observations, and synthesizes the population results. Co-PI Horch's team organizes the speckle observations and reduces the data to provide separations, position angles, and magnitude differences in the various filters, applies the overall results to mass-luminosity relations, and compares the derived multiplicity fractions to open cluster work. The two teams coordinate characterization efforts for systems with more than one component, and work together to secure the necessary observing time on various telescopes.

Two elements are key to the observational program: (1) Henry is the Principal Scientist of the SMARTS (Small and Moderate Aperture Telescope System) Consortium, providing oversight of observing programs on the 1.5m, 1.3m, 1.0m, and 0.9m telescopes at CTIO. In particular, Henry is the Operations Manager for the two CTIO telescopes used for this work — the 1.5m and 0.9m — providing guaranteed access and scheduling control to accomplish the survey goals. Funding has been secured from university sources for these two telescopes. (2) Henry and Horch are both members of the Speckle Team that also includes Mark Everett at NOAO, David Ciardi at NExSci/Caltech, Steve Howell at NASA Ames, and Gerard van Belle at Lowell Observatory, among others. The Speckle Team coordinates applications to the Gemini 8.1m, Discovery Channel Telescope (DCT) 4.3m, and WIYN (3.5m) facilities and operates the speckle observing queues for the Team's observations, as well as those for the community.

1 General Notes

Speckle Survey: (1) There are four speckle cameras used for K-KIDS, the original DSSI camera built by Horch at SCSU through a previous NSF award (currently used at Gemini-South and DCT), and three new speckle instruments built by Nic Scott and Steve Howell at NASA Ames working in close collaboration with Horch. These new cameras, called 'Alopeke, Zorro, and NESSI are located at Gemini-North, Gemini-South, and WIYN, respectively. (2) Fainter, more distant stars are observed at the Gemini telescopes and brighter, closer stars are observed at DCT. WIYN is used for supplemental observations. (3) For all speckle runs, observations are typically made in image sets of 1000 frames using 40–60 msec exposures, and $\sim$100 stars can be observed per night. The cameras are outlined below in the order of highest to lowest resolution and from most to least planned observations.

RV and Wide Surveys: (1) As the Principal Scientist for SMARTS, Henry is in charge of operations, including scheduling, for the CTIO 1.5m where radial velocity observations are made and the 0.9m where photometric observations of wide companions are made. (2) From 2003-2018, Henry has secured \$1.6M in funding to support the SMARTS effort, split between GSU and grant sources. We do not request any funding for telescope time in this proposal for either telescope.

2 ’Alopeke on Gemini-North and Zorro on Gemini-South

’Alopeke (Hawaiian for “fox”) and Zorro (Spanish for “fox”) are twin speckle cameras built for the Gemini telescopes as in-residence instruments. ’Alopeke was commissioned at Gemini-North in October 2017 and Zorro is slated for commissioning at Gemini-South in April 2019. Both cameras are fast, low-noise, dual-channel, and dual-plate-scale imagers based on the DSSI (see below) design. Each camera uses two Andor iXon Ultra 888 EMCCD cameras with 1024×1024 detectors. A fixed dichroic splits the input telescope beam at 6740Å, with blue light reflected to the blue filter wheel and red transmitted to the red filter wheel. Because the cameras are permanently mounted, true queue observing can be done like other facility instruments at the Gemini telescopes.

In speckle mode, the cameras provide simultaneous two-color, diffraction-limited optical imaging (FWHM 20 mas at 6920Å) of targets as faint as V=17 in a 6.″7 field of view with pixels 10 mas on the sky. Narrow band filters are used, typically 6920Å and 8800Å, to maintain speckle coherence when observing K-KIDS, which are all brighter than V=12. A wide-field mode is also available, providing two-color imaging with SDSS filters over a 60″ field of view, with 73 mas pixels on the sky.

At the Gemini telescopes we make observations of the fainter, more distant, stars in the survey to reach the innermost regions, and make confirmation and follow-up observations for the closest binaries. Close binaries are those with separations <200 mas that will be targeted to provide the best possible separation, position angle, and magnitude difference measurements. These are also the systems that will wrap orbits the soonest and will provide early results of orbital statistics. Our ambitious goal is to make 3000 observations in 30 nights during three year proposal period, requiring 5 clear nights each year on each Gemini telescope. In 2018, the Speckle Team secured 19 nights on Gemini-North with ’Alopeke as well as 19 nights on Gemini-South with DSSI (to be replaced by Zorro in 2019). Thus, we believe we will be successful in securing the needed time for this project over the next three years. We anticipate using wide-field mode in poor weather conditions, when we can gather useful data for wider binaries.

3 DSSI on DCT

The Differential Speckle Survey Instrument (DSSI) was built by Horch at SCSU in 2007-2008. It is the prototype for the other three speckle cameras used for this project. Various upgrades were made between 2008 and 2011, including two Andor 887 EMCCDs that have been used since 2011. DSSI collimates the input beam and splits it using a dichroic, into blue and red components that are passed through filters and then focused onto the two EMCCDs. The EMCCDs are fast enough that the galvanometer mirrors are no longer needed to provide a raster scan of speckle images (as was done from 2008–2011); instead they sit at fixed voltages that center the image on each chip, which have a 512×512 pixel format. DSSI is a very well-traveled instrument, being used from 2008-2013 at WIYN, 2014-present at DCT, 2012-2016 at Gemini-North, and 2016-present at Gemini-South.

DSSI has become a popular visitor instrument at DCT, and once Zorro has been commissioned at Gemini-South, DSSI will be located at DCT for the forseeable future, where stars as faint as V=15 can be observed. The faintest K-KIDS stars have V=12, so the entire sample is well within the limits of DSSI at DCT. The primary efforts at DCT are to observe the closest, brightest K dwarfs and to follow-up potential companions for confirmation. At DCT, DSSI provides simultaneous two-color, diffraction-limited optical imaging in a 2.″6 field with pixels 20 mas on the sky. As an Adjunct Astronomer at Lowell Observatory, Horch can request time on the DCT, and has typically been awarded 2 nights per year that are used exclusively for K-KIDS.

4 NESSI on WIYN

The NASA Exoplanet Star and Speckle Imager (NESSI) was commissioned at WIYN in October 2016. NESSI is used to make additional observations of K-KIDS when time in the Speckle Team queue is available. Previously resolved systems are observed at WIYN to provide data points useful for orbit mapping. NESSI is based on the DSSI dual-channel concept, with upgrades including filter wheels with a choice of both narrow-band and SDSS filters, better control software, and a wide-field mode. The speckle mode of NESSI produces data that are very similar to DSSI at WIYN, imaging comfortably to V=14, with pixels that are 18 mas on the sky. The wide field mode gives an option for imaging fields that are 80″ on a side and pixels that are 81 mas on the sky. The detectors used are Andor 888 EMCCDs that have a 1024×1024 pixel format and can be read out at speeds as fast as 30 MHz. Mark Everett is the NESSI instrument scientist at Kitt Peak and is a member of the Speckle Team, which runs the speckle queue for the NN-Explore program at WIYN.

5 CHIRON on CTIO/SMARTS 1.5m

The radial velocity program is carried out at the CTIO/SMARTS 1.5m, which is equipped with CHIRON, a high-resolution optical spectrograph that was built specifically for radial velocity surveys. It was designed for high throughput and stability and provides a fixed spectral range of 4150–8800Å (Tokovinin et al. 2013). Wavelength calibrations are done using a ThAr lamp or iodine cell. We use CHIRON in "slicer mode" that provides R = 79000 spectra, and calibrate the wavelength scale using the ThAr lamp.

The 1.5m has been operated by the SMARTS Consortium since 2003, but was temporarily closed in June 2016. Co-PI Henry reopened the telescope in June 2017 and took over full Operations Manager duties. Henry, Research Scientist Wei-Chun Jao, graduate students Leonardo Paredes and Hodari James, and new SMARTS observer Rodrigo Hinojosa (on-site in Chile) work together to carry out the K-KIDS program, in concert with other science programs by NOAO, Chilean, and other SMARTS astronomers. Henry has secured $50K/year (250 hours at $200/hour) from GSU to buy the telescope time and the K-KIDS team earns an additionl 10% of time (240 hours) for running telescope operations. Assuming 15% time lost to weather and telescope issues (the first year of operations provided data on 92% of nights), there are 416 hours/year to make observations. K-KIDS are observed for 900 seconds each visit, and three stars are observed/hour after including overheads for slew and setup. Thus, 1250 observations can be made each year, or 3750 observations of K-KIDS during the three years of effort outlined here.

As outlined in detail in the main proposal, the primary goals of the RV program during the next three years are to (1) make single observations of 1500 more K dwarfs to measure metallicities, age indicators, and reveal SB2s, (2) expand the number of K dwarfs surveyed with high-precision velocities to 1000, by making at least 6 observations/star for those not yet observed (primarily) in the Keck/HIRES and ESO/HARPS programs.

6 CCD Imager on CTIO/SMARTS 0.9m

Photometric observations at $UBVRI$ (particularly VRI) will be made at the CTIO/SMARTS 0.9m of some K dwarfs to characterize the primaries and companions and to provide the basic fluxes needed to deconvolve photometry for systems with separations >2″, particularly those without magnitudes in *Gaia*. Members of the RECONS team have used the 0.9m and its optical Tek 2Kx2K camera that has a field 16.′8 on a side and pixels 401 mas on the sky on more than 1500 nights since 1999 to make photometric and astrometric observations. We have made observations of stars with VRI = 6–21 at the 0.9m, with photometry accurate to 0.03 mag except for stars with magnitudes fainter than 20.

Henry has been an integral part of SMARTS (Small and Moderate Astronomy Research Telescope System) since its inception in February 2003, and has managed operations of the CTIO 0.9m for the past 15 years. He has handled scheduling and supporting observations carried out by users and Chilean staff, upgrades to the facility (e.g., a new Telescope Control System and new Torrent CCD Controller), and financial considerations.

7 Universities

Georgia State University

Georgia State University (GSU) is a public research university with a student population of 32,000 at the primary campus in downtown Atlanta, of which 25,000 are undergraduates. The student body is 42% African-American, 25% white, 13% Asian, 10% Hispanic, and 10% other, making GSU one of the most diverse non-HBCU institutions in the country. Thus, GSU provides an avenue to students who might otherwise not be involved in astronomy, or science in general.

Co-PI Henry's RECONS group currently includes one Research Scientist and five graduate students, who are as diverse as the undergraduate population, including one African-American, one Asian, and one Hispanic member, as well as a transgender student. Researchers working in the RECONS group all have office space and desktop computers in the GSU Department of Physics & Astronomy, as well as portable laptops that are used to work off site, including at the telescopes. The department provides network level support in a Linux environment with Python, IDL, and IRAF computing.

Southern Connecticut State University

Located in New Haven, CT, Southern Connecticut State University (SCSU) has more than 10,000 students, roughly one third of whom are minority students, including 16% African-American, 12% Hispanic, and roughly 5% other non-white ethnicities. Historically, the Physics Department at SCSU has an very good record of attracting women and members of underrepresented ethnic groups, who each form 20–30% of typical graduating classes in Physics. Recent students in either the B.S. or M.S. programs in the Department have been born on all continents except Australia and Antarctica. SCSU opened a new science building in 2015, providing a modern facility with unique features to interest students in research, and SCSU has significant scholarship resources for economically disadvantaged students in the STEM disciplines.

Co-PI Horch's group currently includes Co-PI Dana Casetti as a Research Scientist, five graduate students, two of whom are women, and one undergraduate student. In the last three years, Horch's group has included one man from Central America, one Asian/African-American woman, and one African woman. Each student has access to her/his own computer, and Casetti has generated the funds for her own computer resources, including a workstation on campus and one at home. Horch is in charge of two research spaces in the new science building: (1) the Astronomy Control Room, where he and his students have conducted remote observations at both Gemini telescopes, DCT, and WIYN, and (2) the Astronomical Instrumentation Lab, where he recently completed the Southern Connecticut Stellar Interferometer, a modern intensity interferometer used in astronomical observations of bright stars. Components of that system include two picosecond timing correlators, two 0.6-m telescopes, and three Single Photon Avalanche Diode (SPAD) detectors. The lab also has two 25-cm telescopes for public outreach and two high-grade CCD detectors that can be used with imaging projects with the 0.6-m telescopes.