Resubmission of 17B-0245

NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 31, 2018 **Category:** Stellar Pops (GAL)

Targeted Samples of the Hot Stellar Content in the Southern Sky

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
This proposal is a continuation of our effort to identify the hot stellar component – in particular, pure-hydrogen-atmosphere ("DA") white dwarfs – in the Southern sky. These objects are vital for the absolute color calibration of current and future Southern Sky CCD-based imaging surveys and facilities, such as the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope. In our earliest runs, we primarily identified candidate hot stars by performing u, g-band imaging within the Blanco Cosmology Survey, PreCam Survey fields and SuperCOSMOS survey (Rowell & Hambly, 2011) within the DES footprint. To date, our CTIO-0.9m imaging campaign has observed ∼400 white dwarfs and white dwarf candidates, and our SOAR-4m program has netted 113 spectroscopically confirmed and modeled DA white dwarfs. Building on our previous success, we propose for 2018B (1) to continue CTIO-0.9m u, g-band imaging of potential white dwarfs within the DES footprint; (2) to continue to obtain full *ugriz* imaging for potentially hot white dwarfs from the SuperCOSMOS survey (Rowell & Hambly, 2011); and (3) to continue to perform medium-resolution spectroscopy with the SOAR telescope to classify our candidates from our previous imaging runs, as well as candidates from other sources (e.g., from VST-ATLAS and from *GAIA*), in order to determine their effective surface temperatures and surface gravities. In addition to providing calibration stars for future surveys and facilities, this data set will permit studies of the white dwarf luminosity function and of Galactic structure.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-0.9m	CFIM + 2K	7	grey	Sep - Nov	Sep - Jan
2	SOAR	Goodman	5	grey	Sep - Oct	Sep - Jan
3	SOAR	Goodman	3	grey	Dec - Jan	Oct - Jan
4						
5						
6						

Scheduling constraints and non-usable dates *(up to six lines)*.

Investigators *List the name, status, and current affiliation for all investigators. The status code of "P" should be used for all investigators with a Ph.D. or equivalent degree. For graduate students, use "T" if this proposal is a significant part of their thesis project, otherwise use "G".*

PI: J. Allyn Smith **Status:** P **Affil.:** Austin Peay State University
Physics and Astronomy, 601 College St.; P.O. Box 4608, Clarksville, TN 37044 USA
Email: smithj@apsu.edu Phone: 931-221-6104 FAX: 931-221-6129

PI: Douglas L. Tucker **Status:** P **Affil.:** Fermilab
Fermillab Center for Particle Astrophysics, MS 127, PO Box 500, Batavia, IL 60504 USA
Email: dtucker@fnal.gov Phone: 630-840-2267 FAX: 630-840-8274

CoI: Sahar S. Allam **Status:** P **Affil.:** Fermilab
CoI: Deborah J. Gulledge **Status:** U **Affil.:** Austin Peay State University
CoI: William Wester **Status:** P **Affil.:** Fermilab
CoI: Jamin Welch **Status:** U **Affil.:** Austin Peay State University
CoI: John P. Marriner **Status:** P **Affil.:** Fermilab

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

This proposal is a continuation of our multi-year effort to identify and characterize the hot stellar component – in particular, pure-hydrogen-atmosphere ("DA") white dwarfs (WDs) – in the Southern sky. These objects are vital for the absolute color calibration of current and future Southern Sky CCD-based imaging surveys and facilities, notably the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST). DA WDs are the currently preferred spectrophotometric standards, as they have very simple spectra, they tend not to be variable, and they are relatively abundant (c. 1/sq deg down to $r \approx 17$) (Harris et al. 2006). *The primary goal of this program is to identify the hot (14,000 – 45,000K) WDs which will form the basis of the finalized absolute color calibration for the DES.* In order to achieve the 0.5% absolute color calibration requirements of the DES, we anticipate we would need between 100 and 300 of these hot DA WDs in order to create a final "Golden Sample" of ≈100 that would be equal to the task.

Our program combines CTIO-0.9m imaging, both to identify candidate hot stars via their $(u - g)$ & $(g - r)$ colors (Fig. 1) and to monitor them for variability over extended periods, and SOAR-4m spectroscopy, to identify DA WDs from their Balmer lines and to obtain sufficiently high-S/N spectra to model their atmospheres. Our target samples have evolved over the years, starting with stars from the Blanco Cosmology Survey (BCS) and the DES precursor PreCam Survey (Kuehn et al. 2013), and later bringing in Rowell & Hambly (2011) SuperCOSMOS WD candidates (starting in 2012B) and the Gentile Fusillo et al. (2017) VST-ATLAS WD candidates (starting in 2017B). Initial results from these earlier observations can be found in Smith et al. (2015) and Gulledge et al. (2017, 2018). So far, our CTIO-0.9m imaging campaign has observed ∼400 WDs and WD candidates, and our SOAR-4m program, due in large part to successful runs in 2017B, has accumulated 113 *spectroscopically confirmed and modeled* DA WDs (out of 146 candidates observed) (Figs. 2&3).

Building on this success, we propose for 2018B (1) to continue CTIO-0.9m u, g-band imaging of potential WDs within the DES footprint; (2) to continue to obtain full *ugriz* imaging for potentially hot WDs from the SuperCOSMOS survey (Rowell & Hambly, 2011); and (3) to continue to perform medium-resolution spectroscopy with the SOAR telescope to classify our candidates from our previous imaging runs, as well as candidates from other sources (e.g., from VST-ATLAS and from *GAIA*), in order to determine their effective surface temperatures and surface gravities. In particular, for the spectroscopic part of the program, we wish to fill in remaining gaps in both the sky distribution and the effective temperature distribution of our sample of confirmed DA WDs within the DES footprint, to obtain additional observations of some of our previously targeted DA WDs to boost the S/N of their observed spectra, to extend our original sample to include GAIA and GALEX-identified candidate white dwarfs, and to extend our sample to areas outside the DES footprint (to help with the calibration of other Southern surveys).

References

Allende Prieto, C., Hubeny, I, & Smith, J.A. 2009, MNRAS, 396, 759
Gentile Fusillo, N. P., Raddi, R., Gänsicke, B. T., et al. 2017, MNRAS, 469, 621
Gulledge, D. J., Tucker, D., Smith, J. A., et al. 2018, AAS #231, #145.05
Gulledge, D. J., Robertson, J. M., Tucker, D. L., et al. 2017, AAS #229, #244.06
Harris, H.C., et al. 2006, AJ, 131, 571
Kuehn, K., et al. 2013, PASP, 125, 409
Rowell, N., & Hambly, N.C. 2011, MNRAS, 1407
Smith, J. A., Tucker, D. L., Fix, M. B., et al. 2015, 19th European Workshop on White Dwarfs, 493, 459
Yanny, B., et al. 2009, AJ, 137, 4377

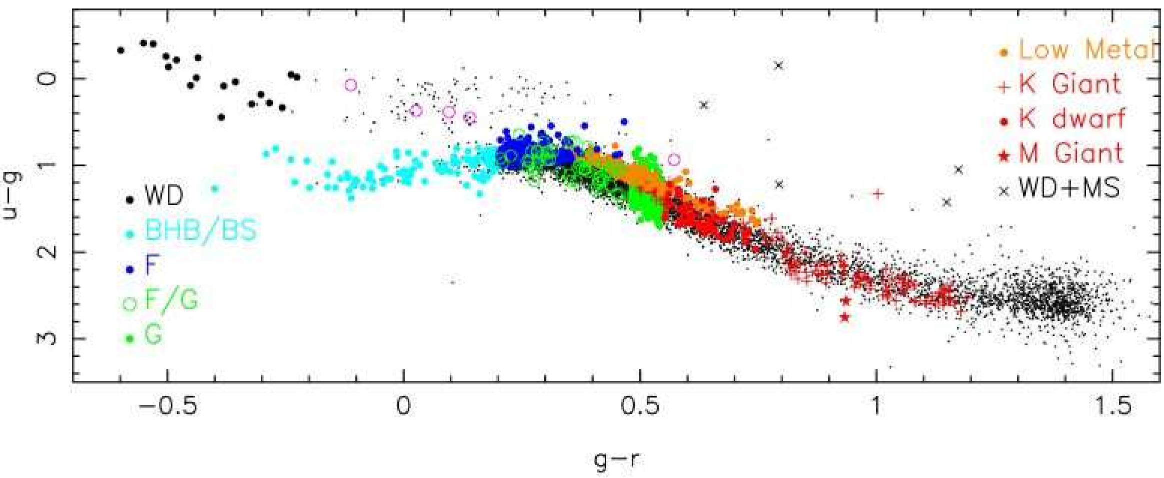

Figure 1: Fig. 3 of Yanny et al. (2009) - target selection categories for the Sloan Digital Sky Survey (SDSS) SEGUE program. $(u-g)_0$,$(g-r)_0$ color-color plot showing the different SEGUE target categories. Note the "Low Metal" category hugs the blue side of the stellar locus in $(u-g)_0$. (©AAS)

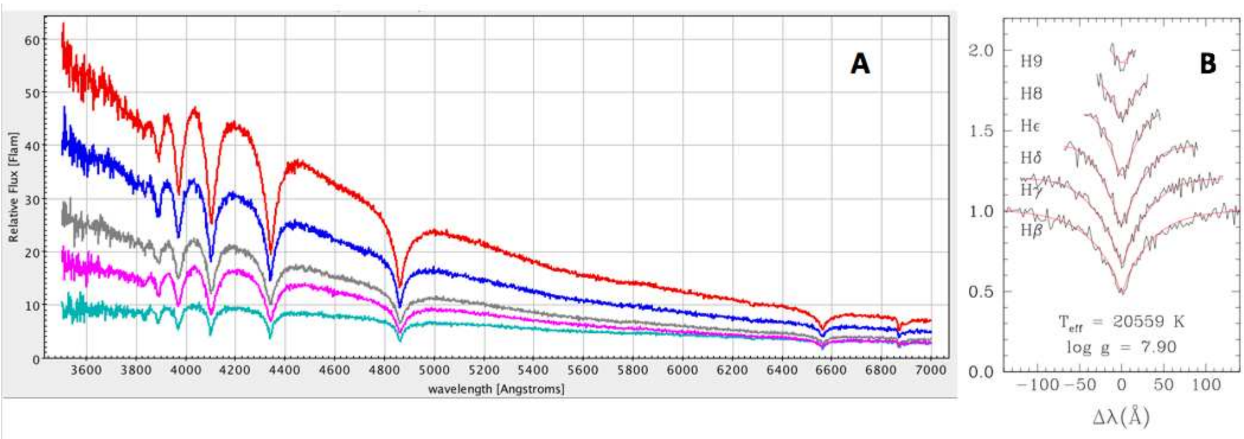

Figure 2: Representative sample of cleaned spectra from the Dec. 2014 SOAR run (Fig. 2A), and an example of one of the model fits (Fig. 2B). Note that all spectra from all our SOAR runs have been modeled by our expert modeler (Pier-Emmanuel Tremblay); see further information in the caption of Fig. 3 below.

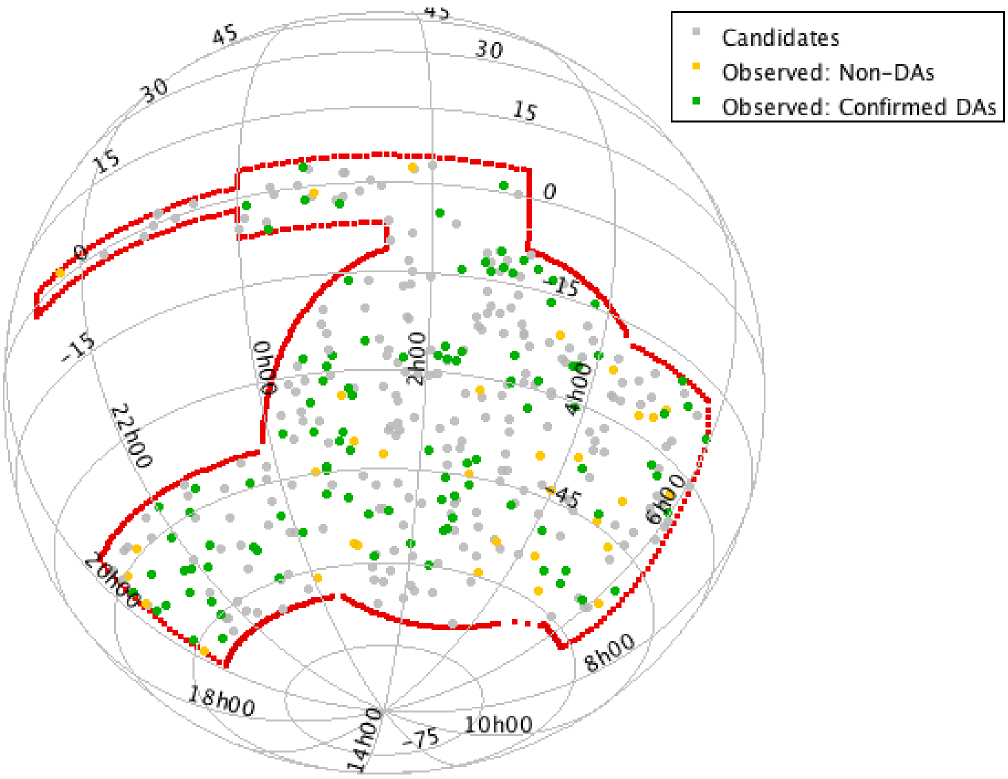

Figure 3: 3D spherical representation of the sky in (RA,DEC) showing the status of our SOAR spectroscopic followup program from our previous runs (in 2014B & 2017B). A set of targets were drawn from the sample of mag=16.5−17.5 white dwarf candidates from Rowell & Hambly (2011)'s SuperCOSMOS and Gentile Fusillo et al. (2017)'s VST-ATLAS catalogs, plus a handful of repeats from our CTIO-1.5m and ARC-3.5m programs. Of these 420 candidates *(gray symbols)*, 146 were observed. Modeling was attempted on all 146 candidate white dwarfs observed. Of those 146, 113 were confirmed as DA white dwarfs *(green symbols)*, and 33 were classified as non-DAs or uncertain *(yellow symbols)*. The red outline shows the borders of the DES footprint.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

This proposal is to obtain both *ugriz* imaging to identify additional white dwarf candidates and to obtain medium resolution spectroscopy to verify and classify of our brighter candidates from other sources. We will address the imaging and the spectroscopy in turn.

Imaging: Our goal here is to add to the list of DA white dwarfs which could be used as spectrophotometric standards *and which lie within the DES footprint.* As noted in the Scientific Justification, $u - g$ colors are an efficient filter for extracting DA white dwarfs from the general background of stars. We plan to make use of the full DES data set (Years 1-5), which already has *grizY* imaging to help with photometric classification and covers the full intended DES 5-year footprint. Most of the DES area has been observed almost 9 times in all 5 filters, which helps weed out variables. In addition, we will continue targeted *ugriz* imaging of potential hot DAs from the SuperCOSMOS survey.

Spectroscopy: We would like to continue our successful spectroscopic programs from 2017B and before.

In 2014B, our targets were primarily drawn from mag=16.5−17.0 candidates from the Rowell & Hambly (2011) SuperCOSMOS Sky Survey white dwarf catalog, supplemented with a handful of repeat targets from our earlier CTIO-1.5m and ARC-3.5m programs (Fig. 3a). (Our CTIO-1.5m program targeted mag<16.0 candidates, and our ARC-3.5m program tended to target equatorial candidates.) We note that the Rowell & Hambly catalog contains no spectroscopic information: it is merely a catalog of candidate white dwarfs identified by their proper motions. For 2014B, we were able to observe 51 of our 141 targets with the SOAR Goodman spectrograph; of the 51 observed targets, we were able to classify 30 as white dwarfs, 5 as possible white dwarfs, and 16 as not white dwarfs. See Figure 2.

For 2017B, we expanded the magnitude range of our targets (to mag=16.5−17.5) and continued observing within the DES footprint – in particular, covering the extreme western edge (RA=20h to 24h) of the DES footprint, as well as the gap between the DES SPT area and the DES equatorial area (DEC=-10deg to -40deg). We also targeted a subsample (mag≈16–17.5) VST ATLAS high-confidence southern WD-sample within the DES footprint from Gentile Fusillo et al. (2017).

For 2018B, we intend to fill in remaining gaps in both the sky distribution and the effective temperature distribution of our sample of confirmed DA WDs within the DES footprint, to obtain additional observations of some of our previously targeted DA WDs to boost the S/N of their observed spectra, to extend our original sample to include GAIA and GALEX-identified candidate white dwarfs, and to extend our sample to areas outside the DES footprint (to help with the calibration of other Southern surveys).

Based on the success of our 2014B/2017B SOAR Goodman spectrograph observations, we believe a similar setup will be ideal for continuing this program though.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

APSU is a 5% partner in the WIYN 0.9m observatory at KPNO. The PI will use a portion of the allocated time on that telescope to support the imaging portion of this project for the WD candidates north of declination -20 degrees. However, none of our team has access to spectroscopic instruments other than through NOAO facilities.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

⋆ 2016B-0113: We were awarded one 5-night run in October 2016 on the 0.9m for u, g, r, i, z-band imaging but no spectroscopic time. This run was only marginally successful, 4 of the 5 nights were non-photometric; one was only open for a half-night.

2016B-0261: We were awarded a four half-night run in September 2016 on the WIYN 3.5m for u, g, r, i, z-band imaging and HYDRA spectroscopy for exo-planet studies of the open cluster Dolidze-35. This run was only marginally successful, the half-night of image was successful and those data are being reduced. The first 2 hours of the remaining three half-nights were successful for obtaining spectra of the brightest cluster members; Hurricane Newton claimed the rest of the time.

2017A-0241: We were awarded a two-night run in June 2017 on the WIYN 3.5m for HYDRA spectroscopy to continue the exo-planet studies of the open cluster Dolidze-35 which were claimed by weather in 2016B. We obtained data on both nights, and an undergraduate is in the process of reducing and analyzing the data.

⋆ 2017B-0245: We were awarded eleven nights run in Nov 2017 on CT-0.9m/CFIM for imaging; roughly half were non-photometric but still usable for monitoring WD candidates for variability. The data are in the process of being reduced. We were also awarded a total of seven nights on the SOAR-4m/Goodman spectrograph (two in August 2017, two in January 2018, and an extra three nights in late-October/early-November after the primary mirror re-coating was postponed). Of these 7 nights, 3 were completely weathered out, but 4 were mostly clear to photometric. All these data have been processed and the reduced spectra have been fit to atmosphere models.

Observing Run Details for Run 1: CT-0.9m/CFIM + 2K

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

The primary objective of this run is to continue the photometric measurement and monitoring of the proper motion selected WDs in the SuperCOSMOS survey. These data will allow photometric selection of hot WDs and a rough atmosphere selection (DA vs. non-DA) for potential spectroscopic follow-up and modeling. The well modeled spectra will then provide excellent calibration sources for the DES and later the LSST. There are roughly 1100 candidates in the DES footprint between $r = 16$ and $r = 18$. For this run, we wish to focus on 210 of our better and brighter candidates in the DES footprint, especially those which are not visible from Kitt Peak (which we follow-up using APSU time on the WIYN-0.9m).

Based on previous experience on the CTIO-0.9m, we find exposure times of (450, 120, 120, 120, 180) seconds in (u, g, r, i, z) provide adequate S/N for a typical $r \approx 16.5$ white dwarf. Since we already have *griz* photometry for most of these candidates from either the DES itself or other sources, we plan to focus primarily on u, g imaging for this run, although we will obtain full *ugriz* imaging for a small subset for quality control purposes.

Assuming an readout overhead of 20 seconds per exposure and a typical between-target slew of 110 sec, we calculate a total time per target of 450sec(u) +120sec(g) + 20sec + 20sec + 110sec = 720sec (12 min). So, for all 210 targets, we arrive at a total time of 12min×210=2520min. To perform good photometry, we want to add 33% overhead for standards, yielding 2520min×1.33=3360min=56 hours, or seven 8-hour nights.

Instrument Configuration

Filters: ugriz	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 20 to 06

Dec. range of principal targets (degrees): -20 to -65

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Observing Run Details for Run 2: SOAR/Goodman

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We will select targets primarily in the magnitude range $16.0 < r < 18$ – bright enough to obtain a high S/N spectra ($S/N \approx 30$) in a reasonable amount of time – but faint enough to avoid the saturation limit of a typical DES science exposure ($r \approx$16.0). Our primary sources for targets are the SuperCOSMOS proper motion database of candidate white dwarfs by Rowell & Hambly (2011) and the Gentile Fusillo et al. (2017) VST ATLAS catalog of high-confidence southern white dwarf candidates. The highest priority targets from these sources will be those for which we have obtained *ugriz* imaging using the CTIO-0.9m, CTIO-1.0m or WIYN-0.9m and which lie within the DES footprint.

Based on the GHTS ETC and on our experience during our 2014B and 2017B runs, we expect to achieve our goals ($S/N \approx 30$) with total integration times between 180 sec (for r =16.0) and 1200 sec (for r =18.0). To help with cosmic ray rejection, we plan to break each target total integration time into 3 exposures each. We expect that we can observe $\sim$15−20 targets per night, weather permitting. At this rate, we should be able to hit at total of 60−80 targets over a 4-night run.

Our end goal is a Golden Sample of 100 well-observed and modeled DAs spread over the DES footprint and with effective temperatures between 14,000K and 45,000K to push the absolute color calibration to the 0.5% level (note: the absolute color calibration of the SDSS was at $\sim$ 1% level, using $\sim$ 10 spectrophotometric standards). Having a large sample over this area of the sky (5000 sq deg) permits additional cross-checks to test the calibrations. Previous work (e.g., Allende Prieto et al. 2009; Eisenstein, private communication) indicates that substantial culling is required to attain such a Golden Sample; so the larger the initial set, the better. In the end, we estimate we will need an initial sample of at least 300 WDs.

Instrument Configuration

Filters: None	Slit: 1.5	Fiber cable:
Grating/grism: 400 l/mm	Multislit: no	Corrector:
Order: 1st	λ_{start}: 3500	Collimator:
Cross disperser:	λ_{end}: 7500	Atmos. disp. corr.: yes

R.A. range of principal targets (hours): 20 to 06

Dec. range of principal targets (degrees): -10 to -70

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

We prefer the blue camera for this run.

Observing Run Details for Run 3: SOAR/Goodman

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We will select targets primarily in the magnitude range $16.0 < r < 18$ – bright enough to obtain a high S/N spectra ($S/N \approx 30$) in a reasonable amount of time – but faint enough to avoid the saturation limit of a typical DES science exposure ($r \approx$16.0). Our primary sources for targets are the SuperCOSMOS proper motion database of candidate white dwarfs by Rowell & Hambly (2011) and the Gentile Fusillo et al. (2017) VST ATLAS catalog of high-confidence southern white dwarf candidates. The highest priority targets from these sources will be those for which we have obtained $ugriz$ imaging using the CTIO-0.9m, CTIO-1.0m or WIYN-0.9m and which lie within the DES footprint.

Based on the GHTS ETC and on our experience during our 2014B and 2017B runs, we expect to achieve our goals ($S/N \approx 30$) with total integration times between 180 sec (for r =16.0) and 1200 sec (for r =18.0). To help with cosmic ray rejection, we plan to break each target total integration time into 3 exposures each. We expect that we can observe ∼15−20 targets per night, weather permitting. At this rate, we should be able to hit at total of 60−80 targets over a 4-night run.

Our end goal is a Golden Sample of 100 well-observed and modeled DAs spread over the DES footprint and with effective temperatures between 14,000K and 45,000K to push the absolute color calibration to the 0.5% level (note: the absolute color calibration of the SDSS was at ∼ 1% level, using ∼ 10 spectrophotometric standards). Having a large sample over this area of the sky (5000 sq deg) permits additional cross-checks to test the calibrations. Previous work (e.g., Allende Prieto et al. 2009; Eisenstein, private communication) indicates that substantial culling is required to attain such a Golden Sample; so the larger the initial set, the better. In the end, we estimate we will need an initial sample of at least 300 WDs.

Instrument Configuration

Filters: None	Slit: 1.5	Fiber cable:
Grating/grism: 400 l/mm	Multislit: no	Corrector:
Order: 1st	λ_{start}: 3500	Collimator:
Cross disperser:	λ_{end}: 7500	Atmos. disp. corr.: yes

R.A. range of principal targets (hours): 20 to 06

Dec. range of principal targets (degrees): -10 to -70

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

We prefer the blue camera for this run.

NOAO observing proposal LaTeX macros v3.0.