Appendix R: Sample Undergraduate Research Project Outlines

Student research changes as it progresses. The outlines below are guides, and each outcome in the tables below can be completed by different students.

Outcomes:
1) Poster presentation at a science conference.
2) [*school title – honor project, sr thesis etc.*] or a significant contribution to a refereed journal paper submission

R.[1, 2] The B/R Ratio in [Nearby Galaxies, M31 and M33]

Students will determine the empirical ratio of blue to red Helium burning stars, study which uncertain model parameters can improve model predictions, and apply the best models to reinterpret the integrated light of galaxies.

Objective	Execution Plan	Outcome
Select sample of Red and Blue Helium burning stars from literature database	R.1 Select one galaxy with clear Helium burning sequences (Dalcanton et al., 2009). R.2 Select Helium burning stars from an unobstructed region of M31 and M33	1
Create a synthetic stellar population with canonical models	Derive star formation history of region Create CMDs, luminosity functions	
Compare the data to the canonical model		1
Repeat steps for several galaxies (R.1), regions of M31/M33 (R.2)		1
Assess how models can improve to better fit data	Mock data tests of mass loss, convection, nuclear reaction rates, other interesting physics	2
Create final version of stellar models and refit data set	Repeat steps above with best fitting model	2

R.3 Blue Helium Burning Stars or Massive Main Sequence, Should Anyone Care?

Massive Main Sequence stars and older, lower mass blue Helium burning stars can overlap in optical colors and luminosities. Students will work to understand when this occurs, and to what extent it affects our understanding of a galaxy's history.

Objective	Execution Plan	Outcome
Model nearby galaxies that show no apparent BHeB stars, but clear locus of RHeB stars.	Repeat steps of R.1 to assess contamination of BHeB stars and the MS	1
Assess BHeB – MS contamination for unresolved sources.	Apply modeled star formation history (accounting for MS contamination and ignoring BHeB contribution) to a spectral energy distribution code to predict SEDs of distant galaxies	
Compare differences in SED accounting for BHeB-MS contamination and not.		
Assess metallicities and ages of galaxies BHeB-MS contamination effects most.	Model SEDs with and without BHeB stars at several ages and metallicities and compare results	2

R.[4, 5] Understanding [Low, High] Metallicity AGB Stars: [Nearby Galaxies, M31 and M33] from Optical to Infrared

Students will model the observed luminosity functions and CMDs of AGB populations varying interesting AGB parameters in multiple wavelengths and comparing their models to data.

Objective	Execution Plan	Outcome
Select sample of AGB stars from literature database	R.4 Select one galaxy with optical-IR photometry (Boyer et al., 2015 or Dalcanton et al., 2012). R.5 Select from an unobstructed region of M31 and M33	1
Create a synthetic stellar population with canonical AGB models	Derive star formation history of region Create CMDs, luminosity functions	1
Compare the data to the canonical model		1
Repeat steps for several galaxies (R.4), regions of M31/M33 (R.5)		1
Assess how models can improve to better fit data	Mock data tests of mass loss, dredge up efficiency, convection, other interesting physics	2
Create final version of stellar models and refit data set	Repeat steps above with best fitting model	2

R.6 Are all of the UV Bright Stars in the Center of M31 Binary Stars?

Students will investigate the radial distribution of UV-bright stars in the center of M31 and compare it to the radial distribution of X-ray binaries and the underlying stellar population.

Objective	Execution Plan	Outcome
Produce radial distribution of observed UV bright stars	Select stars on UV CMD Assign selected stars to M31 radial bins Fit functional form to stellar density distribution	1
Produce radial distribution of low-mass X-ray binaries	Repeat process using database of M31 low-mass X-ray binaries (e.g., Voss & Gilfanov 2007)	1
Produce radial distribution of the underlying stellar population	Calculate the total integrated flux in each radial bin from Spitzer data as a proxy (Barmby et al., 2006)	1
Compare and comment on the distributions of each source		2

R.7 The Characteristics of Planetary Nebulae in the Central Regions of M31

Students will discover new planetary nebulae, characterize them, and compare them to published catalogues.

Objective	Execution Plan	Outcome
Identify PNe in the new data	Derive color and magnitude selection function using HST imaging and databases of known PNe in M31 (e.g., Merrett et al., 2006).	1
Describe newly discovered PNe	Thumbnail images, CMDs, luminosity functions	
Discuss PNe in context of literature discovery		2
Produce radial distribution of PNe	Assign new and literature PNe to M31 radial bins Fit functional form of stellar density distribution	
Compare and comment on PNe distribution compared to other stellar populations.		

A Research Primer

I expect to train researchers at all undergraduate levels. For the first several weeks, students receive tutorials on stellar evolution, stellar populations, and python programming[1] following the lesson plans I have written in the past but tuned to the needs of the individual. The lessons outlined below could also supplement a computational physics course. All items are accompanied by mini-lectures and readings. Active participation in discussion and completed exercises are part of each outcome.

Objective	Execution Plan	Outcomes
Understand basics of stellar evolution: structure equations, equation of state, observed vs. calculated parameters. Additional topics: R.1-3 tracks will focus on Helium burning phases R.4-7 tracks will focus the AGB phase.	Exercises: The equations of stellar structure, approximately solved by hand (surface and core relations, scaling relations); python script using polytropic and homology relations.	Table of stellar parameters. Script to solve and plot approximate stellar structure given a data table.
Understand stellar evolution in context of stellar populations, stellar clusters, and galaxies. Additional topics: distance modulus, interstellar extinction.	Exercises: Determining the center of the Milky Way with Globular Clusters; The ages of stellar clusters	Write a function to plot stars on an HR diagram given data from a stellar cluster and nearby stars.
Introduced to stellar evolution modeling Additional topics: Tracks vs. isochrones, the initial mass function, star formation histories	Exercises: Exploring the initial mass function, populating a HR diagram, deriving a star formation history	Write a function to plot stellar tracks on an HR diagram and of a stellar cluster and nearby stars. Advanced students: Write a function to populate an isochrone based on an IMF.
Milestone: Student has a simple synthetic stellar population code		Compare data to their model

References

Barmby, P., et al. 2006, ApJ, 650, L45
Boyer et al., 2015, ApJS, 216, 10
Dalcanton, J. J., et al. 2009, ApJS, 183, 67
—. 2012, ApJS, 198, 6
Merrett, H. R., et al. 2006, MNRAS, 369, 120
Voss, R. & Gilfanov, M. 2007, MNRAS, 380, 1685

[1] I maintain python code repositories on github that are used in student research projects at UC Berkeley, UT Austin, Harvard University, and The University of Washington.