A proposal for a new PhD degree in Astrophysics

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November 7, 2013
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I. Executive Summary

The Astrophysics faculty proposes that Vanderbilt offer a new PhD degree in Astrophysics. PhD candidates at Vanderbilt who are studying and conducting research in astrophysics would receive this degree rather than the PhD degree in Physics. Both the new Astrophysics and the existing Physics PhD degree programs will be housed within the Department of Physics & Astronomy in the College of Arts and Science. By offering the PhD degree in Astrophysics, we will become one of about 40 universities in the United States offering similar degrees.

We also request approval for a M.A. in Astrophysics degree, non-thesis option only.

We are motivated to offer this degree in order to improve the national and international visibility and reputation of the astrophysics research activities that already exist at Vanderbilt, to align our program with those at peer institutions, to attract better graduate students into our program, and to improve the long-term employment opportunities in astrophysics-related research and development for our students, including academic postdoctoral and tenure-stream positions, and to allow the faculty to further develop a graduate curriculum that is most appropriate for students pursuing careers in this field.

This proposal was approved by a 16-0 vote (no abstentions) of the faculty of the Department of Physics & Astronomy. The proposed new degree program is cost neutral; that is, it imposes no new expenses on the department, the college, or the university and creates no implied needs for additional resources.

II. Background

Vanderbilt has had an active program in astronomy that began with the birth of the institution. Nashville native Edward Emerson Barnard “was one of the first academic superstars to emerge from Vanderbilt, and one of the only faculty members to have a building named after him... Barnard remains the only person to have received an honorary academic degree from the university.”¹ E. E. Barnard’s affiliation with Vanderbilt began in 1883 and lasted only four years, until he was recruited away from Vanderbilt in 1887. The location of Vanderbilt’s original observatory, where Barnard worked, is marked by the placement of a sundial outside of Rand Hall.

Since the 1940s, the Department of Physics & Astronomy has had between two and four full-time, tenure-stream faculty engaged in research and teaching in astronomy and astrophysics; until the early 1990s, the astronomy and astrophysics faculty had very little extramural funding and ran a graduate program focused exclusively on M.S. in Astronomy candidates. The last student admitted for the M.S. in Astronomy degree graduated in 1993 and that degree program was formally eliminated in 2012.

¹ Bill Cary, in The Vanderbilt Register, October 29 – November 4, 2001 issue.
Very significant changes have occurred in the department in relation to astronomy and astrophysics over the last two decades, with those changes accelerating in the last five years. Professor David Weintraub, hired in 1991, is the first astronomer at Vanderbilt who was hired with the expectation that he build and maintain for the long-term an extramurally funded research program involving PhD students. Under Weintraub’s leadership, the astronomy and astrophysics faculty stopped admitting students into the M.S. in Astronomy program. With the full support and agreement of the faculty of the Department of Physics & Astronomy, Weintraub refocused the efforts of the astronomy and astrophysics faculty on doctoral candidates doing astrophysics research in pursuit of the PhD in Physics, which has enabled Vanderbilt to successfully compete to attract some of the best faculty talent to our campus, beginning with C. Robert O’Dell, NASA’s first Project Scientist for the Hubble Space Telescope, who moved from Rice to Vanderbilt in 2000.

Professor Keivan Stassun, who was hired in 2003, accelerated the modernization of the Vanderbilt astronomy and astrophysics program by leading Vanderbilt into SMARTS, Vanderbilt’s first formalized international institutional partnership in astronomy. Stassun also built the nationally recognized and admired Fisk-Vanderbilt Master’s-to-PhD Bridge Program. In January 2004, Professor Robert Scherrer, a cosmologist, was appointed to serve as the chair of the Department of Physics & Astronomy. In 2007, under Scherrer’s leadership, Vanderbilt hired Professors Andreas Berlind and Kelly Holley-Bockelmann, who quickly led Vanderbilt into our second major international partnership, SDSS III. Soon thereafter, led by Stassun, Vanderbilt became a partner in LSST and was invited to become a member of AURA.

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2 SMARTS = Small and Moderate Aperture Research Telescope System, a consortium that operates four 1-m class telescopes in Chile. Consortium members include Yale University, The Ohio State University, Stony Brook University, Sejong University (Korea), the University of Delaware, Georgia State University, and the NASA Exoplanet Science Institute at CalTech, among others. See: http://www.ctio.noao.edu/noao/content/smart‐consortium

3 SDSS III – Sloan Digital Sky Survey III is an international collaboration mapping out the large scale structure of the universe. SDSS III partners include the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofisica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, Max Planck Institute for Extraterrestrial Physics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University. See: http://www.sdss3.org/

4 LSST = Large Synoptic Survey Telescope. LSST is currently under development and hoping to ‘see first light’ in 2018. Institutional Partners in LSST include Adler Planetarium, Brookhaven National Laboratory, California Institute of Technology, Carnegie Mellon University, Chile, Cornell University, Drexel University, Fermi National Accelerator Laboratory, George Mason University, Google, Inc., Harvard-Smithsonian Center for Astrophysics, Institut de Physique Nucléaire et de Physique des Particules, Johns Hopkins University, Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) - Stanford University, Las Cumbres Observatory Global Telescope Network, Inc., Lawrence Livermore National Laboratory, Los Alamos National Laboratory, National Optical Astronomy Observatory, National Radio Astronomy Observatory, Princeton University, Purdue University, Research Corporation for Science Advancement, Rutgers University, SLAC National
Internally, Stassun, Berlind, and Holley-Bockelmann have developed six graduate astrophysics courses so that, post-2010, our graduate students now have a full complement of lecture courses that cover the basics of modern astronomy and astrophysics. In other words, it is now possible to receive a substantive, PhD-level classroom education in astronomy and astrophysics at Vanderbilt, whereas our PhD students from the middle 1990s and early 2000s (see &IV for details) had to learn their astronomy and astrophysics outside of the formalized graduate curriculum.

The current status of the astronomy and astrophysics program at Vanderbilt is as follows:

- Faculty: four tenure-stream faculty (Weintraub, Stassun, Holley-Bockelmann, Berlind), three of whom have received NSF Astronomy CAREER awards (Stassun, Holley-Bockelmann, Berlind), one of whom received a Sloan fellowship (Berlind), one of whom was a Ford Foundation fellow (Stassun); one distinguished research faculty member (O'Dell).
- Post-doctoral scholars (as of June 2013): 11
- PhD candidates doing astrophysics research in the Department of Physics & Astronomy (as of June 2013): 18
- MS candidates doing astrophysics research in the Fisk-Vanderbilt bridge program (as of June 2013): 8
- Major facilities, partnerships, and associations: SMARTS, SDSS III, LSST, AURA, VIDA (the Vanderbilt Institute for Data-Intensive Astronomy, a 10-year, $5M initiative of the Vanderbilt Provost’s Office)

\(^5\) AURA = Association of Universities for Research in Astronomy. AURA is the institutional operator for the Kitt Peak National Astronomy Observatory (in Arizona), the Cerro Tololo International Observatory (in Chile), the National Solar Observatory (in New Mexico), the twin Gemini Observatories (in Chile and Hawaii), and the Space Telescope Science Institute (which operates the Hubble Space Telescope for NASA and will, after launch, operate the James Webb Space Telescope). AURA membership is by invitation only, and includes Boston University, CalTech, Carnegie Institution of Washington, Fisk University, Georgia State University, Harvard University, Indiana University, Instituto de Astrofisica de Canarieas, Iowa State University, Johns Hopkins University, Kiepenheuer-Institut fur Sonnenphysik, MIT, Michigan State University, Montana State University, New Jersey Inst. of Techn., New Mexico State University, Ohio State University, Penn State University, Pontifica Universidad Catolica de Chile, Princeton University, Rutgers University, Stanford University, Stony Brook University, Swinburne University, Tohoku University, Universidad de Chile, University of Arizona, UC Berkeley, UC Santa Cruz, University of Chicago, University of Colorado, University of Florida, University of Hawaii, University of Illinois, University of Maryland, University of Michigan, University of Minnesota, UNC Chapel Hill, University of Pittsburgh, UT Austin, University of Toronto, University of Virginia, University of Washington, University of Wisconsin, Vanderbilt University, and Yale University. See: [http://www.aura-astronomy.org/](http://www.aura-astronomy.org/)
PhDs in Physics awarded for astrophysics theses: 6 from 1997 through 2006; 10 from 2009 through 2013; 3 anticipated in 2014; at least 8 more anticipated in either 2014 or 2015.

Funding: The astronomy and astrophysics faculty currently manage a portfolio totaling $13.48M ($10.460M external, $2.939M internal), from multiple NASA programs, multiple NSF awards and programs, the Sloan Foundation, the Research Corporation, the Department of Education, and the Center for Astrophysical Research. Total grant funding to the astronomy and astrophysics faculty over the last decade is nearly $20M (about $15M external, $5M internal).

Through our collective efforts over the last two decades, we have built a firm foundation for astrophysics education and research at Vanderbilt. We believe our program is now mature enough to allow Vanderbilt University to take the next step: establish a PhD in Astrophysics degree program.

III. Is Astronomy a Part of Physics? Yes and No.

Astronomy has long been regarded as a very closely allied—yet distinct—field of science from physics, whereas particle physics, nuclear physics, and condensed matter physics have traditionally been considered fields of physics. Astronomy is the study of the physics and physical processes at work beyond the Earth.\(^6\) Thus, astronomers might study stars, interstellar clouds, galaxies, intergalactic space, and the large scale structure of the universe; they might study black holes, white dwarfs, red giants, dark matter, or dark energy; they could focus on the processes of star formation, galaxy birth, or the expansion of the universe; they might measure masses, temperatures, distances, motions or

\(^6\) excluding the study of the Sun (Heliophysics), the interaction of the Sun’s magnetic field with the Earth (Space Physics) and objects in our solar system (Planetary Science)
compositions of the various objects of study. More generally, astronomers make observations, collect data with telescopes, generate computational models, perform analytical calculations, and use an understanding of the laws of physics to interpret telescopic data and to understand the physical processes at work in stars or galaxies or the larger universe.

This closeness to yet distinctness from physics is manifest in a number of ways. For example, within the National Science Foundation (NSF)—which together with NASA funds virtually all astronomy research—the Division of Astronomical Sciences (AST) is distinct from the Division of Physics (PHY), each with its own grants programs and funding lines for major facilities. Astronomers competing for prestigious CAREER Awards from NSF generally do so within the NSF Division of Astronomy; indeed, all three of the NSF CAREER Awards won by Vanderbilt astronomers Stassun, Berlind, and Holley-Bockelmann have been awarded by the NSF Division of Astronomy. Similarly, the National Academies conduct distinct and separate “decadal surveys”—decade-long priority guidelines for the field—for astronomy and for physics. Vanderbilt’s recent induction as a member of the Associated Universities for Research in Astronomy (AURA) was on the basis of our research portfolio in astronomy as distinct from our research portfolio in physics.

At the same time, some advantages exist due to the relatedness between astronomy and physics. For example, Vanderbilt’s NSF-funded Research Experiences for Undergraduates (REU) program in Physics & Astronomy is jointly funded by the Division of Physics and the Division of Astronomy at the NSF. In addition, some areas of research at Vanderbilt—such as particle physics as it relates to cosmology or materials physics as it relates to astronomical detectors—benefit from straddling the interface between astronomy and physics and thereby qualify for multiple funding streams.

This closeness-yet-distinctness has been present on our campus from the birth of the University, when Vanderbilt’s first Chancellor, Landon C. Garland, was also named Vanderbilt’s first professor of Physics and Astronomy and the department similarly was identified as Physics & Astronomy. Vanderbilt’s astronomy faculty bear formal titles that reflect this as well: One is Professor of Physics (Scherrer), two are Professors of Astronomy (Stassun and Weintraub), and two are Professors of Physics and Astronomy (Berlind and Holley-Bockelmann).

As for the naming of the new degree, there are a variety of examples among Vanderbilt’s peer institutions, including Astronomy, Astrophysics, Astronomy & Astrophysics, and Astrophysical Science. In the end, we have opted for Astrophysics, for its simplicity, because it is generally regarded to be a broader term than astronomy, and because we desire to continue to convey Vanderbilt’s long-standing relatedness between astronomy and physics.

IV. Rationale

For most of the latter part of the twentieth century, the Department of Physics & Astronomy offered a terminal M.S. in Astronomy degree, in addition to the PhD in Physics,
and awarded approximately 1 such degree per year. No students have been admitted to this program since 1991. In the opinion of the present astronomy and astrophysics faculty, the terminal M.S. in Astronomy degree is of little value to potential students and admitting students to the university whose ultimate goal is to earn this degree is of no measurable value to the faculty, the department, or the university. However, since the mid-1990s, the departmental faculty has supported a path of study for our graduate students in which students pursuing the PhD in Physics have had the option of conducting their research programs in astronomy and astrophysics. Such an option for astronomy and astrophysics research within a PhD in Physics degree program also exists at a handful of peer institutions, including the University of Pennsylvania, Brown University, Dartmouth University, the University of Notre Dame, and Carnegie Mellon University.

The first student to follow this path worked with Professor Weintraub and completed his PhD in 1997. He remains active in the field as a research scientist with the Center for High Angular Resolution Astronomy (CHARA) on Mt. Wilson, in California. Two more students finished their PhDs in 2000; one is on the faculty at the University of Tennessee at Martin, the other is a research scientist in the University of Maryland Department of Astronomy. Three more students completed PhDs with astrophysical research components in 2002, 2003, and 2006; they are on the faculties at Trevecca University (Nashville), Colgate University (Hamilton, NY), and the Forschungszentrum Jülich Supercomputing Center (Germany). In total, over the last 15 years (1997 through 2012), 16 students have earned the PhD in Physics from Vanderbilt while doing dissertation projects in astrophysics, including 10 during the years 2009-2013. All of these students remain employed in the field.

In the following ways, the Department of Physics & Astronomy has been evolving to more strongly support the emerging astronomy and astrophysics option:

- Approximately 20% (18 students) of the PhD candidates in the department are following the astrophysics path; eight more students are currently enrolled in the astrophysics track within the Fisk-Vanderbilt Bridge program and are already potential Vanderbilt PhD students in this field.
- In 2007, the Department of Physics & Astronomy increased the size of the tenure-stream faculty in the astronomy and astrophysics group from two to four, returning it to the size it had for most of the 1980s through the late 1990s. But while the department had had four faculty in astronomy and astrophysics before, the 2007-2013 era is the first time during which we have had more than two faculty in astronomy and astrophysics actively mentoring PhD candidates in extramurally funded research programs. This change was intentional, so as to allow the department to begin to offer graduate astrophysics courses without negatively impacting our undergraduate program. The two faculty hired in 2007, Professors Berlind and Holley-Bockelmann, have created four three-credit hour, core graduate astrophysics classes that we offer on a regular basis in addition to a one-credit hour

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7 Indeed, the undergraduate program is stronger than ever: 10 of the 30 physics majors who have completed senior Honors theses in the last six years have earned Honors in Astronomy.
astrophysics course that is offered every semester. When added to the one class created previously by Professor Stassun, the department now has a robust set of graduate astrophysics classes for our doctoral candidates.

- In 2011, the Department of Physics & Astronomy adjusted the options for PhD students such that two separate paths are now open to graduate students: students may concentrate in physics or they may concentrate in astronomy. The difference between these two concentrations is small but meaningful: for the first cohort, all five of the core courses are traditional physics courses; for the students on the astronomy track, however, one of the five core courses is an astrophysics course.

Given that we now have the faculty in place that enable us to offer a robust suite of graduate astrophysics courses, and given that we have established a separate path to the PhD in Physics for students following the astrophysics path, the next logical step for us is to establish an independent PhD degree program in Astrophysics.

Why? National visibility for Astronomy and Astrophysics at Vanderbilt

Vanderbilt was not ranked in the most recent National Research Council (NRC) rankings of graduate degree programs in astronomy and astrophysics because we do not offer such a degree. In order to enhance Vanderbilt’s presence on the national and international stages, we need to appear in these and other rankings. At the biennial meetings of chairs and directors of US-based astronomy and astrophysics departments and programs, we have been associated with Wesleyan and San Diego State University, because we and they have been the only universities to offer the terminal (thesis) MS in Astronomy degree and not the PhD degree in Astronomy. With this new degree, our peer group will include, much more appropriately, Harvard, Princeton, Yale, Chicago, and Johns Hopkins.

Undergraduates considering careers in astronomy and astrophysics typically peruse listings of graduate degree programs in astronomy, in astrophysics, or in astronomy and astrophysics. Vanderbilt, at this time, is not found on any of those lists. Potential students discover us because they want to work with one of our faculty members or because they know someone who previously earned a degree here. To our credit, we are doing well --- joining SMARTS, SLOAN III, LSST, and AURA --- despite being off the grid, but we can and should be doing better. We believe, very strongly, that we will increase the quality of our applicant pool for graduate study if students specifically seeking a graduate degree in astronomy and astrophysics, rather than in physics, discover Vanderbilt on their list of plausible graduate programs to consider.

Why? Physicists and astronomers require different training.

Astrophysics is not simply a branch of physics; astrophysics has developed in parallel with physics over the last 400 years. While on the one hand, the overlap between the two related disciplines is enormous, on the other hand, the divergence between the two disciplines is extremely wide, wide enough that a separate degree program is warranted and is offered at the majority of our peer institutions.
The ‘astronomy core’ path within the PhD in Physics program is the result of a significant amount of compromise on the parts of our colleagues in physics; however, we on the astrophysics side believe that additional adjustments are appropriate and reasonable if we are to provide strong, specialized training to our ‘astronomy core’ graduate students. We realize, though, that those adjustments cannot be made within the confines of the existing PhD in Physics degree program without compromising the integrity of that program. Students awarded the PhD in Physics must be fully trained in and deserving of that degree; we cannot reasonably stretch the requirements for that degree much further.

We believe that the ‘astronomy core’ students should be required to take a larger body of graduate ‘core’ work in astrophysics than they are required to do under the current rules for the PhD in Physics. We do believe that these astrophysics students can benefit by taking courses in fundamental physics, but we think these courses should be chosen from a pre-selected set and that not every core physics course makes sense for every astrophysics student. Since the PhD program in physics has been stretched as far as it can go in order to accommodate the ‘astronomy core’ students, we need to create a separate program to provide the best and most appropriate set of requirements for future ‘astronomy core’ students.

Why? Better tailoring of admissions criteria increases graduate student quality.

Given the difference between the two disciplines and the different training needs for students in physics and astrophysics, two separate programs will be able to focus on similar but different metrics for selecting the best students to admit. Separate degree programs will allow the faculties in the two programs to have direct control over deciding which and how many students to admit each year into each PhD program. With separate degree programs, we believe both programs will benefit by tailoring the new student cohorts to the needs of each program.

IV.A. Comparison to Peer Institutions

The American Institute of Physics identifies 40 astronomy or astrophysics PhD-granting university programs in 2010. *Table 1* identifies the kind of Astronomy programs at the “Top 25” research universities while *Table 2A* is a listing of the 21 other universities in the United States that offer PhDs in astronomy and astrophysics. Together, these two tables provide a complete listing of these programs. This number has fluctuated (in their survey data) from about 38 to 42 over the last 30 years. The total number of PhDs granted in astronomy or astrophysics has fluctuated between about 90 and 160 per year over the last two decades; in the last several years, it has remained fairly steady at 140-160 per year.
Among the Top 25 Universities in the most recent US News & World Report rankings (Table 1; because of a tie, 27 are represented in the survey), 11 offer PhDs in astronomy, astrophysics, or astronomy and astrophysics while 10, like Vanderbilt, have some form of option to do astrophysics research in pursuit of the PhD in Physics (see Table 1). (Note that PhD recipients from these 10 institutions doing astronomy and astrophysics research would not show up in the AIP numbers.) Of the 10 that are like Vanderbilt, only MIT, by
virtue of its Kavli Institute for Astrophysics, is also listed in the NRC rankings of PhD programs in astronomy and astrophysics.

The status quo situation at Vanderbilt --- having graduate students pursue PhDs in physics while doing astrophysics research and pursuing careers in astronomy and astrophysics --- is one that hides rather than showcases our program and our students.

**Table 2A: Other Research Universities with ASTR PhD Programs**

<table>
<thead>
<tr>
<th>US News Rank</th>
<th>University</th>
<th>ASTR PhD type</th>
<th>NRC ASTR S Ranking</th>
<th>NRC ASTR R Ranking</th>
<th>Host Department</th>
<th>PhDs per year</th>
<th>Tenure Track Faculty</th>
<th>Grad Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Michigan</td>
<td>Astronomy</td>
<td>13-28</td>
<td>11-28</td>
<td>Astronomy</td>
<td>2.2</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>38</td>
<td>Case Western Reserve</td>
<td>Astronomy</td>
<td>...</td>
<td>...</td>
<td>Astronomy</td>
<td>...</td>
<td>5</td>
<td>...</td>
</tr>
<tr>
<td>42</td>
<td>Washington</td>
<td>Astronomy</td>
<td>3-13</td>
<td>8-20</td>
<td>Astronomy</td>
<td>2.8</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>42</td>
<td>Wisconsin</td>
<td>Astronomy</td>
<td>8-25</td>
<td>16-29</td>
<td>Astronomy</td>
<td>3.0</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>45</td>
<td>Illinois</td>
<td>Astronomy</td>
<td>15-30</td>
<td>8-28</td>
<td>Astronomy</td>
<td>3.2</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>45</td>
<td>Texas</td>
<td>Astronomy</td>
<td>8-22</td>
<td>5-26</td>
<td>Astronomy</td>
<td>5.8</td>
<td>22</td>
<td>49</td>
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<tr>
<td>45</td>
<td>Penn State</td>
<td>Astrophysics</td>
<td>2-10</td>
<td>5-14</td>
<td>Astronomy &amp; Astrophysics</td>
<td>2.4</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>53</td>
<td>Boston</td>
<td>Astrophysics</td>
<td>23-33</td>
<td>24-30</td>
<td>Astronomy</td>
<td>2.2</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>55</td>
<td>Maryland</td>
<td>Astronomy</td>
<td>17-31</td>
<td>10-24</td>
<td>Astronomy</td>
<td>3.2</td>
<td>18</td>
<td>40</td>
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<tr>
<td>55</td>
<td>Ohio State</td>
<td>Astronomy</td>
<td>4-14</td>
<td>6-19</td>
<td>Astronomy</td>
<td>2.8</td>
<td>20</td>
<td>27</td>
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<td>Florida</td>
<td>Astronomy</td>
<td>27-33</td>
<td>27-33</td>
<td>Astronomy</td>
<td>2.6</td>
<td>13</td>
<td>33</td>
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<td>Minnesota</td>
<td>Astrophysics</td>
<td>25-33</td>
<td>22-33</td>
<td>Physics &amp; Astronomy</td>
<td>2.4</td>
<td>16</td>
<td>22</td>
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<tr>
<td>71</td>
<td>Michigan State</td>
<td>Astrophysics</td>
<td>15-29</td>
<td>25-33</td>
<td>Physics &amp; Astronomy</td>
<td>1.0</td>
<td>9</td>
<td>15</td>
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<tr>
<td>75</td>
<td>Indiana</td>
<td>Astrophysics; Astronomy</td>
<td>17-32</td>
<td>14-28</td>
<td>Astronomy</td>
<td>1.6</td>
<td>10</td>
<td>16</td>
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<td>75</td>
<td>UC Santa Cruz</td>
<td>Astrophysics</td>
<td>4-17</td>
<td>12-26</td>
<td>Astronomy &amp; Astrophysics</td>
<td>3.2</td>
<td>23</td>
<td>36</td>
</tr>
<tr>
<td>94</td>
<td>Massachusetts (Five College)</td>
<td>Astronomy</td>
<td>...</td>
<td>...</td>
<td>Astronomy</td>
<td>2.2</td>
<td>20</td>
<td>21</td>
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<td>124</td>
<td>Arizona</td>
<td>Astronomy</td>
<td>5-17</td>
<td>5-16</td>
<td>Astronomy</td>
<td>4.0</td>
<td>32</td>
<td>47</td>
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<td>164</td>
<td>Hawaii</td>
<td>Astronomy</td>
<td>16-30</td>
<td>12-29</td>
<td>Physics &amp; Astronomy</td>
<td>3.2</td>
<td>47</td>
<td>29</td>
</tr>
<tr>
<td>...</td>
<td>New Mexico State</td>
<td>Astronomy</td>
<td>12-28</td>
<td>22-33</td>
<td>Astronomy</td>
<td>2.8</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>...</td>
<td>Georgia State</td>
<td>Astrophysics; Astronomy</td>
<td>27-33</td>
<td>28-33</td>
<td>Physics &amp; Astronomy</td>
<td>2.0</td>
<td>10</td>
<td>27</td>
</tr>
</tbody>
</table>
Table 2B is a listing of 13 universities ranked outside of the Top 25 with PhD physics programs --- but not PhD astronomy or astrophysics programs --- with significant research activity in astronomy and astrophysics.

Table 2B: Other Universities hosting major astrophysics research programs

<table>
<thead>
<tr>
<th>US News Rank</th>
<th>University</th>
<th>PhD type</th>
<th>NRC ASTR S Ranking</th>
<th>NRC ASTR R Ranking</th>
<th>Host Department</th>
<th>PhDs per year</th>
<th>Tenure Track Faculty</th>
<th>Grad Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>UNC Chapel Hill</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>10</td>
<td>...</td>
</tr>
<tr>
<td>33</td>
<td>NYU</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics</td>
<td>...</td>
<td>9</td>
<td>...</td>
</tr>
<tr>
<td>35</td>
<td>Rochester</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>9</td>
<td>...</td>
</tr>
<tr>
<td>37</td>
<td>UCSD</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics</td>
<td>...</td>
<td>13</td>
<td>...</td>
</tr>
<tr>
<td>42</td>
<td>UCSB</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics</td>
<td>...</td>
<td>13</td>
<td>...</td>
</tr>
<tr>
<td>58</td>
<td>Pittsburgh</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>16</td>
<td>...</td>
</tr>
<tr>
<td>68</td>
<td>Rutgers</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>11</td>
<td>...</td>
</tr>
<tr>
<td>68</td>
<td>Clemson</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>6</td>
<td>...</td>
</tr>
<tr>
<td>75</td>
<td>Delaware</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>8</td>
<td>...</td>
</tr>
<tr>
<td>75</td>
<td>Alabama</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>6</td>
<td>...</td>
</tr>
<tr>
<td>111</td>
<td>SUNY Stony Brook</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>7</td>
<td>...</td>
</tr>
<tr>
<td>124</td>
<td>Kentucky</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>5</td>
<td>...</td>
</tr>
<tr>
<td>128</td>
<td>LSU</td>
<td>Physics</td>
<td>...</td>
<td>...</td>
<td>Physics &amp; Astronomy</td>
<td>...</td>
<td>8</td>
<td>...</td>
</tr>
</tbody>
</table>

Together, the 61 universities listed in these three tables host almost all of the university-based research activity in the United States in astronomy and astrophysics. (Of course, many smaller universities and colleges have one or a few faculty active in astrophysical research, but almost all PhDs awarded for astronomy and astrophysics research-oriented work come from the institutions listed in Tables 1, 2A, and 2B.)

Among our peers (“Top 25”),

- Nine offer a PhD in astronomy/astrophysics from a department of Astronomy/Astrophysics,
- two (Johns Hopkins, UCLA) offer a PhD in astronomy/astrophysics from a combined department of Physics & Astronomy (i.e., what we propose for Vanderbilt),
- five (Penn, Dartmouth, Rice, Northwestern, Vanderbilt) offer an astronomy/astrophysics dissertation option to students pursuing a PhD in Physics from a department of Physics & Astronomy,
- five offer some opportunity to do research in astronomy/astrophysics while pursuing a PhD in physics from a department of Physics, and
- six effectively have no PhD option at all related to astronomy and astrophysics.

Of the 32 programs identified in these tables that offer PhDs in something other than physics to students doing astronomy/astrophysics research, 20 offer the PhD in astronomy,
7 offer the degree in astrophysics, 2 offer the degree in astronomy and astrophysics, 2 offer separate degrees in astronomy and in astrophysics, and 1 offers a degree in astrophysical & planetary sciences. Clearly, the title of the program is a local decision, with no overwhelming national precedent. However we choose to title our program, if the title includes ‘astronomy’ and/or ‘astrophysics,’ the larger community of professionals and potential graduate students will identify Vanderbilt as a player.

We recognize that a faculty of five in Astrophysics is at the very small end of the peer groups identified in Tables 1 and 2A/B. Case Western Reserve University, for example, also has five tenure-track faculty and offers a PhD in Astronomy. Michigan State has nine, Georgia State and Indiana both have ten, New Mexico State has 11 and Wisconsin has 12. Despite our small size at present, our size is within the demonstrated envelope of PhD in Astronomy and Astrophysics program sizes. More importantly, the proposed new PhD in Astrophysics degree program merely codifies what we are already doing: we are already teaching all the necessary graduate astrophysics courses for our program, we are already regularly mentoring 2-3 students per year toward PhDs (ten in the last four years), and we are already meeting with (as a faculty group) and advising each of our PhD students twice per year in addition to the annual meetings mandated by the PhD in Physics program. In other words, this proposal codifies existing practice, which we have already demonstrated we can handle with great success.

We also note that while we have a core faculty in astrophysics of five, we have unanimous support for this proposed program from our physics colleagues in the Department of Physics & Astronomy. Many, perhaps most, of them already serve on one or more PhD committees for students who would be pursuing the PhD in Astrophysics, were that degree program already in place, and many of them work in overlapping areas of physics (nuclear astrophysics, particle astrophysics, neutrino physics, cosmic ray physics). The strong support of our colleagues is demonstrated, additionally, through the large number who have self-identified as "affiliated faculty" (see Table IV.B.)

V. Educational Motivation

The proposed PhD in Astrophysics will:

- Increase the visibility of the already-exceptional research program at Vanderbilt University internally, locally, nationally, and internationally;
- Invigorate the astrophysics faculty with the goals of establishing and building a nationally and internationally recognized program;
- Contribute to the reputation of Vanderbilt University as an internationally recognized center for cutting-edge scientific research;
- Attract more top-tier graduate students to our program, thus raising the profile of our program, the College of Arts and Science, and Vanderbilt University;
- Improve the post-graduate opportunities for these students;
- Raise the profile of our faculty who represent Vanderbilt in national and international collaborations (LSST; SMARTS; SDSS III) and organizations (AURA);
- Encourage talented young scientists to come to and stay at Vanderbilt University;
- Enhance the value and attractiveness of the Fisk-Vanderbilt Bridge Program;
• Allow the faculty to develop a broad suite of elective astrophysics courses that will expand the didactic experiences of our students.

Our proposed PhD degree in Astrophysics program will enable the astrophysics faculty to direct the education and training of our graduate students in ways that are most appropriate and beneficial to the long-term success of our students. While the PhD in Physics has been adequate for the students who have completed our program, future students would benefit from more classroom time in astrophysics-oriented classes than is possible within the constraints of the PhD in Physics program.

**VI. Academic Requirements and Coursework**

**VI.A. Master of Arts (MA) in Astrophysics**

The proposed Master of Arts in Astrophysics degree\(^{11}\) will be a non-thesis degree. To earn this degree, a student must

- complete the formal course requirements for the PhD in Astrophysics (see &VI.C),
- earn a B average in 28 credit hours of graduate study.

**VI.B. Doctor of Philosophy (PhD) in Astrophysics**

The proposed rules for completion of the PhD in Astrophysics are modeled very closely on the current program for the PhD in Physics.

To earn the PhD in Astrophysics, a student must

- complete 72 semester credit hours\(^{12}\) (formal coursework plus registered research hours) with satisfactory grades in each course (see &VI.C) and an overall average of B (3.00) or higher;
- complete, within this 72 hours, at least 28 hours\(^{13}\) in formal coursework (i.e., not research hours; see &VI.C for details on coursework requirements);
- pass a Qualifying Examination administered by a committee of the Graduate Faculty (see &VI.D);
- write and defend a dissertation. The dissertation is to incorporate an original, publishable contribution to the scientific literature in the student’s field of specialization and must be defended in a public forum.

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\(^{11}\) The choice of the M.A., rather than the M.S., was chosen as a parallel to the non-thesis M.A. currently offered for students in the Ph.D. in Physics program.

\(^{12}\) This requirement meets the standards of The Graduate School, which requires a total of 72 credit hours (formal coursework plus registered research hours) prior to receiving the PhD.

\(^{13}\) This exceeds the minimum of 24 semester-hours of coursework required by the Graduate School.
VI.C. Course Requirements

To earn the PhD in Astrophysics a student must complete a minimum of 28 hours of formal course work, including:

- Six core courses: four three-credit hour courses in astrophysics (ASTR 310, 352, 353, 354), one one-credit hour course in astrophysics (ASTR 355) that must be taken each of a student’s first four semesters in the PhD program, and one three-credit hour course in mathematical methods of physics (PHYS 308), totaling 19 credit hours;
- Three more three-credit hour courses, not including research hours, to make a total of 28 semester hours, taken in any subject relevant to the student’s overall program of graduate study and research (e.g., any 300-level three-credit hour ASTR course; any of PHYS 305, 329a, 329b, 330a, 330b, 341, 360a, 360b; any course(s) approved by the student’s adviser)

A student must earn a grade of B or higher in every course that counts toward the 28 hours of formal coursework. According to Graduate School rules, a student will not receive graduate credit toward the required 72 hours for any course for which a grade below C- is received.

A student who earns a B- or lower grade in any course may, upon approval of the GPC for Astrophysics, retake that course one time or take an alternate exam if one is offered.

The DGS in Astrophysics, with the consent and approval of the GPC in Astrophysics, has the authority to approve exceptions to departmental rules in exceptional circumstances.

Transfer Credit: Students who have taken graduate courses elsewhere may petition the Graduate Program Committee in Astrophysics to have those courses evaluated for transfer credit in order to avoid unnecessary duplication in coursework and speed the student’s entry into research. In order to transfer any number of astrophysics core courses and physics core courses for credit, transfer students must take any one of the astrophysics and/or physics core courses offered at Vanderbilt and earn a grade of A- or better.

Transfer Credit for Bridge Students: We will adhere to the rules in the established Bridge program documents as approved by the Graduate School and the College of Arts and Science (see Appendix A: Bridge Program General Guidelines, Appendix B: memo: Transfer of Credit Hours to Vanderbilt University, and Appendix C: Request for Transfer Credit worksheet).

VI.D. Doctoral Qualifying Oral Examination

The doctoral degree in astrophysics requires students to write and defend a dissertation that presents the results of independent research, most of which will be carried out while enrolled in ASTR 399. To progress to that point and become eligible to enroll in ASTR 399,
each student must first pass the Qualifying Examination to become a Doctoral Candidate. According to the Graduate School bulletin, “the purpose of the Qualifying Examination is to test the student’s knowledge of the field of specialization, to assess familiarity with the published research in the field, and to determine whether the student possesses those critical and analytical skills needed for a scholarly career.”

In astrophysics, the Qualifying Examination requires each student to independently write and orally defend a research proposal. The topic is of the student’s choosing and may be, but does not need to be, the same as his/her current or planned doctoral research project. The Qualifying Examination is administered by the student’s PhD committee. This exam is closed to the public; only the committee members and the student are present. Passing the Qualifying Examination marks the student’s formal entry into dissertation research under the supervision of his/her thesis adviser and the PhD committee.

In preparation for the Qualifying Examination, the student shall a) in consultation with his/her adviser, put together a PhD committee, b) prepare a one-page abstract-outline of the planned research proposal, including the hypothesis and aims, c) meet with the PhD committee to gain approval for turning this idea into a full proposal, d) and write a research proposal (maximum eight pages) that will be made available to the PhD committee at least one week prior to the Qualifying Examination. The timeline for completing the above shall follow the established timeline for the PhD in physics, with the qualifying exam being taken no later than the end of the fourth semester.

During the oral Qualifying Examination, the student defends his/her research proposal. The exam shall be a maximum of two hours in duration. The student is allotted a maximum of 15 minutes to provide an overview of the proposal, during which time committee members will limit questions to points of clarification. The remainder of the two hours is reserved for committee members to ask questions in which the student should be prepared to discuss the general background of the proposal and its significance; to discuss relevant experimental approaches, including their theoretical bases and limitations; to outline anticipated results; and to interpret the meaning of those results. The student should be particularly prepared to discuss the interpretation of alternative results proposed by the committee. Although the primary focus of the questions will be on the research proposal, the committee may and likely will probe the student’s core knowledge of astrophysics.

The committee will decide within one day whether the student has passed the Qualifying Examination. After passing the Qualifying Examination, the student is officially admitted to candidacy for the PhD and earns the M.A. in Astrophysics. If the student is judged to have failed the examination, the committee shall prepare a report within one week, addressing deficiencies in preparation that were evident during the examination; a second attempt at passing the Qualifying Examination may be made by the student within three months of the date of the failed examination. By Graduate School rule, only two attempts are allowed for passing the Qualifying Examination.
VI.E. Publication Requirements

The research in any dissertation project is expected to contribute measurably to scientific progress in the field of specialization; thus, publication in peer-reviewed journals is an essential component of the PhD in Astrophysics research program. While the venue, number, and timing of publications varies according to subfield, students should expect to play a major role in a first paper no later than the end of the third year of graduate study. By the time the dissertation is completed, the student is expected to present to the PhD committee at least one paper in which they played the primary role and that has been accepted in a peer-reviewed journal. Most students are expected to have more than one such paper published or accepted for publication at the time of the dissertation defense.

VI.F. PhD Committee and Defense

The PhD committee administers the Qualifying Examination, subsequently monitors the student’s progress toward the completion of the thesis, and then holds a public defense of the student’s dissertation research. The PhD committee should meet with the student annually to discuss research completed to date, publications planned or in progress, and an estimate of the time, resources, and analysis required for completion of the dissertation project.

The committee consists of at least four, and more typically five, members of the Graduate Faculty. By Graduate School rule, at least one member of the committee must be from outside of the astrophysics program faculty. The composition of the committee is proposed by the adviser in consultation with the student and must be approved by the Director of Graduate Studies (DGS) for Astrophysics (see &VI.I) and then by the Dean of the Graduate School.

VI.G. Admission Requirements

The program will only accept applicants for the Ph.D. in Astrophysics program. Students will not be admitted who intend to earn the M.A. degree as their terminal degree. Incoming students must hold a Bachelor's degree and have the necessary background in physics and in mathematics to be prepared for graduate coursework in astrophysics and physics. The most typical, but not a required, background to be presented would be an undergraduate major in physics. Students must provide their general GRE scores for each section (verbal, quantitative, and analytical writing) and normally also provide a GRE physics score; they must demonstrate strong quantitative and analytical potential and an interest in astrophysics. If the student’s most recent degree is from a university in which English is not the primary language of instruction, then he or she must also submit their TOEFL results. Students must also submit three letters of recommendation and a statement of purpose detailing their desire to study astrophysics. The Graduate Program Committee (GPC) for Astrophysics (see &VI.I), acting as an Admissions Committee, will evaluate and
recommend to the Graduate School for approval or disapproval all applications for admission to the PhD in Astrophysics degree program.

VI.H. Recruitment of Students

Through our Vanderbilt Astronomy Group (http://as.vanderbilt.edu/astronomy/) webpage and the personal contacts of the faculty, we will spread the information about the change in our degree offerings at Vanderbilt. For example, we would update our listing on the American Astronomical Society’s College Departments Offering Astronomy Related Degrees website, which is one of the primary vehicles for undergraduates working to discover options for graduate study in astrophysics.

At this time, we have no plans to increase the size of our graduate student cohort; however, we expect that the overall quality of the students who will apply to and matriculate into our program will improve.

VI.I. Value-Added Advantages for PhD-in-Astrophysics Students

Students in this program will see the value of their PhD degrees from Vanderbilt enhanced in a number of ways. First and foremost, we anticipate a meaningful, positive change in the national and international visibility of our astrophysics program. The enhanced recognition and rising profile of our program should translate into increased and improved opportunities for our students seeking post-doctoral and research scientist positions as well as for those seeking jobs outside of academia.

At a local level, as we attract and matriculate better students into our program, all our students will benefit from their time in classrooms and in conversations with these same students. In addition, as already noted, future students will benefit from more classroom time in astrophysics-oriented classes than is possible within the constraints of the PhD in Physics program.

VI.J. Administrative Structure and Changes

Director of Graduate Studies and Graduate Program Committee in Astrophysics: The Department of Physics & Astronomy will establish a Graduate Program Committee (GPC) in Astrophysics, separate from the GPC for Physics, that will administer this program. The chair of the Department of Physics & Astronomy will appoint one of the astrophysics faculty (see Table 4A) to serve as Director of Graduate Studies (DGS) in Astrophysics and as chair of the GPC for Astrophysics. This administrative structure is modeled on the administrative structure of Vanderbilt School of Engineering’s Department of Electrical Engineering and Computer Science, which houses separate PhD programs in Electrical Engineering and in Computer Science and manages those two distinct programs with a unique DGS and GPC for each program and on the Vanderbilt School of Medicine’s Department of Pathology, Microbiology and Immunology, which hosts separate PhD
programs in Cellular and Molecular Pathology and in Microbiology and Immunology, each with its own DGS and GPC. This parallel administrative structure model is also that used by the UCLA Department of Physics & Astronomy, which offers both a PhD in Physics and a PhD in Astronomy, and the University of Minnesota School of Physics and Astronomy, which offers both a PhD in Physics and a PhD in Astrophysics.

The chair of the department, in consultation with the DGS, will appoint a minimum of one other member of the regular astrophysics faculty to serve as a member of the GPC for the PhD in Astrophysics. The DGS for Astrophysics and the members of this committee will serve at the pleasure of the department chair. The DGS for Astrophysics will be the official spokesperson for the astrophysics program to the Department of Physics & Astronomy, including to the department chair and in regular communications, as required, to the DGS for Physics; in matters in which the department chair chooses, the DGS for Astrophysics will also serve as its representative in matters related to University policy and programs. The DGS for Astrophysics will also enlist the support of the astrophysics faculty in various roles (e.g., advising, curriculum development, recruiting) in support of the astrophysics program and will consult regularly with the DGS in Physics. The GPC in Astrophysics will meet with each PhD candidate in Astrophysics at the end of every semester to monitor progress toward the degree, thereby institutionalizing a review process that the Astrophysics faculty, as a whole, have been using since 2009 to closely track the progress of graduate students in their classes and in their research.

Admissions: This GPC for Astrophysics will establish admissions standards and norms for applicants to the PhD in Astrophysics program. The DGS for Astrophysics, working with the GPC for Astrophysics, will make all admissions decisions for the astrophysics PhD program beginning in the first full academic year after final approval of this degree program by the Board of Trust of Vanderbilt University. Together, the DGS for Astrophysics, the DGS for Physics, and the chair of the Department of Physics & Astronomy will structure a set of admissions goals for each year (the number of students to be admitted to each program; the allocation of TA positions to students in each program); those negotiated decisions will be bounded by constraints established by the Office of the Dean of the College of Arts and Science for the department, as a whole, for the number of available TA positions and the number of admissions offers that the department may extend each year.

Curriculum: The GPC for Astrophysics will serve as the curriculum committee for graduate ASTR courses, providing oversight for the academic and intellectual integrity of the astrophysics program. This committee will have oversight of all requirements for this program. Changes in the curriculum, including changes to existing courses and the approval of new courses, must be approved by the GPC for Astrophysics and a vote of the full astrophysics faculty (see Table 4A) and the chair of the department. When necessary and appropriate, those changes will then be forwarded by the department chair to the appropriate College of Arts and Science and/or Graduate School committee(s) for approval.

Examinations: Faculty instructors are responsible for the exams in their courses, including alternate written exams when applicable.
Self-Assessment: Self-Assessment will be done in the same way as is currently done for the PhD program in Physics. See Appendices D (Astrophysics Ph.D. Program Learning Outcomes Assessment Plan), E (Assessment Form for Course Work), F (Assessment Form for Qualifying Exam), G (Assessment Form for Ph.D. Thesis Proposal), and H (Assessment Form for Ph.D. Defense).

VI.K. Comparison of Required Coursework to Peer Institutions

In Table 3, we compare the course requirements (total regular courses, required ASTR courses, required PHYS courses) in 32 programs offering PhDs in astronomy/astrophysics.

As is evident from the data in Table 3, the formal course requirements for virtually all PhD programs in astronomy and astrophysics require coursework only in astronomy and astrophysics. Very few PhD degree programs in astronomy and astrophysics have formal course requirements in traditional areas of physics. Of the 26 degree programs offered by the 25 Astronomy departments offering PhD degrees in astronomy and astrophysics, 22 of them have no formal requirements for physics courses (the physics necessary for their students is embedded within the astronomy and astrophysics courses). Of the six doctoral degree programs in astronomy and astrophysics offered by joint departments of Physics & Astronomy, two have no formal physics course requirements and two require only a ‘mathematical methods of physics’ course.

The proposed set of course requirements for the Vanderbilt program --- astronomy and astrophysics courses plus a mathematical methods of physics course --- is very much within the range of what peer institutions require of their PhD students.
Table 3: Comparison of Course Requirements\textsuperscript{A} with Peer Institutions

<table>
<thead>
<tr>
<th>Institution</th>
<th>Total Required Classes</th>
<th>Required ASTR Classes</th>
<th>Required PHYS Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornell</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Princeton</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>UC Berkeley</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Harvard</td>
<td>6</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Indiana (astronomy)</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Illinois</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Arizona</td>
<td>8</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Virginia</td>
<td>8</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Maryland</td>
<td>8</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Columbia</td>
<td>8</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Ohio State</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Michigan</td>
<td>8.33</td>
<td>7</td>
<td>0\textsuperscript{B}</td>
</tr>
<tr>
<td>Indiana (astrophysics)</td>
<td>9</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Yale</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Texas</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Penn State</td>
<td>10</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Florida</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>10</td>
<td>9</td>
<td>1\textsuperscript{C}</td>
</tr>
<tr>
<td>UC Santa Cruz</td>
<td>11 (quarters)</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>New Mexico State</td>
<td>11</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Boston</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>CalTech</td>
<td>11</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Washington</td>
<td>12 (quarters)</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Case Western Reserve</td>
<td>12</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Chicago</td>
<td>17 (quarters)</td>
<td>8</td>
<td>2\textsuperscript{D}</td>
</tr>
<tr>
<td>Hawaii</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Johns Hopkins</td>
<td>8</td>
<td>5</td>
<td>1\textsuperscript{F}</td>
</tr>
<tr>
<td>Michigan State</td>
<td>8</td>
<td>5</td>
<td>3\textsuperscript{G}</td>
</tr>
<tr>
<td>Vanderbilt (proposed)</td>
<td>8</td>
<td>4</td>
<td>1\textsuperscript{F}</td>
</tr>
<tr>
<td>UCLA</td>
<td>10 (quarters)</td>
<td>9</td>
<td>1\textsuperscript{F}</td>
</tr>
<tr>
<td>Minnesota</td>
<td>10</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Georgia State</td>
<td>11</td>
<td>8</td>
<td>3\textsuperscript{E}</td>
</tr>
</tbody>
</table>

\textsuperscript{A} not counting 1 credit hour courses or research hours
\textsuperscript{B} 1.33 courses must be in Physics, Mathematics, or Statistics
\textsuperscript{C} Classical Electrodynamics
\textsuperscript{D} Math Methods or Quantum Mechanics I; E&M or Quantum Mechanics II
\textsuperscript{E} chosen from Classical Mechanics, Statistical Mechanics, E&M, and Quantum Mechanics
\textsuperscript{F} Mathematical Methods
\textsuperscript{G} Classical Mechanics, Statistical Mechanics, Classical Electrodynamics
VI.L. Course Availability

All astrophysics faculty are members of the Department of Physics & Astronomy. In steady state, we anticipate that the astrophysics faculty will offer two to four three-credit hour, 300-level ASTR courses each year in addition to offering the one-credit hour ASTR 355 course every semester. ASTR 310, 352, 353, and 354 are now offered no less often than on a four-semester, one-class-per-semester cycle. ASTR 322 is now offered in alternate years. PHYS 308 is taught every year. Additional graduate level PHYS courses listed in &VI.C are taught every year.

This teaching schedule permits all entering PhD candidates in astrophysics to complete the complete suite of graduate astrophysics and physics courses during their first four semesters.

VI.M. Beyond the For-credit Curriculum

The training of PhD candidates in astrophysics goes beyond formal coursework and the doctoral research project.

Journal Club: All graduate students in this program are expected to attend a weekly, one-hour journal club. At each Journal Club meeting, one or two students make a presentation, explaining a recently published paper in the astrophysical literature. Each student is expected to make at least one presentation at Journal Club each semester. In this forum, students gain experience in presenting research to an audience and receive feedback from faculty and their peers on their presentation. One graduate student each year is responsible for organizing the Journal Club presentations and maintaining the Journal Club website.

AstroLunch: All graduate students in this program are expected to attend a weekly one-hour lunch meeting at which the group informally discusses recently published or submitted papers. One graduate student each year is responsible for organizing the AstroLunch papers and updating the Astro Wiki to keep the community informed about the papers that will be discussed each week.

Department Colloquium: The Department of Physics & Astronomy holds weekly, late-afternoon colloquia during the academic year. All graduate students in this program are expected to attend all colloquia with an astrophysics orientation and at least a selection of other colloquia.

National and International Meetings: All graduate students in this program are expected to attend several national and/or international astronomy and astrophysics conferences during their tenure as graduate students; they are expected to attend conferences at which they will make research presentations.
VI.N. Can Students Switch from Physics to Astrophysics?

Current students who are pursuing the astronomy core option in pursuit of the PhD in Physics, whether they have already advanced to candidacy or have not yet taken the Qualifying Examination, will have a choice between earning the PhD in Physics or the PhD in Astrophysics provided they have or can satisfy the established course requirements for the PhD in Astrophysics and their PhD committee agrees that the focus of that student’s dissertation project is appropriate for the astrophysics degree. The DGS for Astrophysics will inform the DGS for Physics and the dean of the Graduate School of any changes in intended degrees. This change in the designation of a degree will be an option for students immediately after final approval of this degree program by the Board of Trust.

After approval of this program, students admitted specifically to the PhD in Astrophysics program are not, by default, also admitted to the PhD in Physics program (and vice versa). Such students who wish to switch from one to the other PhD program within the department would have to apply for admission to the other program; there is no guarantee that students admitted into one program will later be admitted into the other program.

VII. Academic Performance

All students must maintain an overall grade point average (GPA) of a 3.0 (B) or higher in their didactic coursework. Students’ progress will be monitored by the DGS for Astrophysics, their adviser, and via in-person, semi-annual reviews conducted by the GPC for Astrophysics. If a student’s overall GPA drops below 3.0, he or she will be placed on academic probation. If the GPA remains below 3.0 after one additional semester, the student risks loss of his or her funding. If the GPA remains below 3.0 after two additional semesters, he or she may be dismissed from the program. Continued financial support is contingent upon maintaining an overall GPA of 3.0 and good academic standing.

VIII. Astrophysics Faculty, Affiliated Faculty and Areas of Expertise

The astrophysics program will draw on the astrophysics faculty (Table 4A) as well as on affiliated faculty (Table 4B) with strong interests in astrophysical research.

The affiliated faculty are those who expect to serve regularly on committees for Astrophysics PhD candidates and/or Fisk-Vanderbilt Bridge students studying astronomy and astrophysics and/or those whose research overlaps both the astrophysics and physics domains (e.g., cosmology, particle physics, high energy nuclear physics, neutrino physics, cosmic rays) and/or those who provide critical resources for graduate students in astrophysics (e.g., the ACCRE supercomputer center; the Tier 2 CMS Computing Resource) and/or those who teach courses with significant astrophysics content (e.g., PHYS360a/b) and who have requested that they be identified as such.
**Table 4A: Astrophysics Faculty**

<table>
<thead>
<tr>
<th>Faculty Member</th>
<th>Title, Affiliations</th>
<th>Research areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andreas Berlind</td>
<td>Assistant Professor of Physics &amp; Astronomy</td>
<td>Large scale structure and galaxy formation</td>
</tr>
<tr>
<td>Kelly Holley-Bockelmann</td>
<td>Assistant Professor of Physics &amp; Astronomy</td>
<td>Black holes, dark matter, gravitational waves, galaxy formation</td>
</tr>
<tr>
<td>C. Robert O’Dell</td>
<td>Distinguished Research Professor of Physics &amp; Astronomy</td>
<td>Gaseous Nebulae</td>
</tr>
<tr>
<td>Keivan G. Stassun</td>
<td>Professor of Astronomy</td>
<td>Star formation; eclipsing binaries; extrasolar planets</td>
</tr>
<tr>
<td></td>
<td>Director, Vanderbilt Data-Intensive Astrophysics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Co-Director, Fisk-Vanderbilt MA-PhD Bridge Program</td>
<td></td>
</tr>
<tr>
<td>David A. Weintraub</td>
<td>Professor of Astronomy</td>
<td>Formation of stars and planets</td>
</tr>
<tr>
<td></td>
<td>Director, Program in the Communication of Science &amp; Technology</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4B: Affiliated Faculty**

<table>
<thead>
<tr>
<th>Faculty Member</th>
<th>Title, Affiliations</th>
<th>Research areas</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>David J. Ernst</td>
<td>Professor of Physics</td>
<td>Neutrinos</td>
<td>Co-adviser, Bridge program students</td>
</tr>
<tr>
<td>S. Victoria Greene</td>
<td>Stevenson Professor of Physics</td>
<td>RHIC and LHC experiments, studying quark-gluon plasma (nuclear astrophysics)</td>
<td></td>
</tr>
<tr>
<td>Will Johns</td>
<td>Associate Professor of Physics</td>
<td>Experimental particle physics</td>
<td></td>
</tr>
<tr>
<td>Thomas W. Kephart</td>
<td>Professor of Physics</td>
<td>Theoretical elementary particle physics theory</td>
<td>Teaches PHYS 360a/b</td>
</tr>
<tr>
<td>Charles F. Maguire</td>
<td>Professor of Physics</td>
<td>RHIC and LHC experiments, studying quark-gluon plasma (nuclear astrophysics)</td>
<td>Project Director of the Vanderbilt Tier 2 CMS computing resource</td>
</tr>
<tr>
<td>Robert S. Scherrer</td>
<td>Professor of Physics</td>
<td>Cosmology, dark energy, dark matter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chair, Department of Physics &amp; Astronomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paul S. Sheldon</td>
<td>Professor of Physics</td>
<td>Experimental particle physics</td>
<td>Director, ACCRE Supercomputer Center</td>
</tr>
<tr>
<td>Julia Velkovska</td>
<td>Professor of Physics</td>
<td>RHIC and LHC experiments, studying quark-gluon plasma (nuclear astrophysics)</td>
<td></td>
</tr>
<tr>
<td>Thomas J. Weiler</td>
<td>Professor of Physics</td>
<td>Fundamental particle physics theory, dark matter, cosmic rays, neutrinos</td>
<td>Teaches PHYS 360a/b</td>
</tr>
</tbody>
</table>
IX. Course descriptions

ASTR 310. Radiative Processes
Electromagnetic radiation from astrophysical sources. Radiative transfer; blackbody radiation; atomic and molecular absorption and emission; radiation from moving charges. [3]

ASTR 322. Methods in Observational and Computational Astronomy
Principles and techniques including accurate measurement of astronomical distance, data handling and error analysis, computer programming. Four to six experiments such as determination of Earth’s radius, distance to the Moon, refraction by the atmosphere, distance to a star cluster. Scheduled evening sessions at Vanderbilt Dyer Observatory. [3]

ASTR 351. Special Topics in Astrophysics
Current topics in solar, planetary, stellar, interstellar, galactic, and extragalactic astrophysics, celestial mechanics, large-scale structure and/or cosmology. [1-3]

ASTR 352. Stellar Astrophysics
Physics of stellar structure and evolution, including nuclear energy generation, equations of state, and heat transfer by radiation, conduction, and convection. Numerical stellar models. Observational aspects of stellar astrophysics. [3]

ASTR 353. The Structure and Dynamics of Galaxies
The stellar, gaseous, and dark matter content of galaxies; their internal bulk properties, structure, kinematics, and dynamics. Equilibrium and stability of stellar systems. Orbit theory, the gravitational N-body problem, relaxation, dynamical friction, and the Fokker-Plank equation. Galaxy evolution from the standpoint of stellar populations, the initial mass function, chemical evolution, and galaxy interactions. [3]

ASTR 354. Structure Formation in the Universe

ASTR 355. Order-of-Magnitude Astrophysics
Order-of-magnitude estimates on astrophysical problems. May be repeated for credit more than once. Students may enroll in more than one section of this course each semester. [1]

ASTR 369. Master’s Thesis Research [0]
ASTR 379. Non-candidate Research
Research prior to entry into candidacy (completion of Qualifying Examination) and for special non-degree students. [Variable credit: 0-12]

ASTR 390. Independent Study
May be repeated for credit more than once, but students may earn only up to 3 credits per semester of enrollment. [1-3]

ASTR 399. PhD Dissertation Research [0-12]

ASTR 399e. Half-time PhD Dissertation Research
For students who have completed 72 hours and devote a half-time effort to dissertation research. [0]

Next, we list the graduate PHYS courses most appropriate and relevant to PhD candidates in astrophysics. PhD candidates will not be limited to these courses, as they may find other courses in PHYS as well as courses in MATH or in engineering or in medicine that are appropriate for their course of study. The courses chosen by each student are subject to the approval of their adviser and the DGS for Astrophysics.

PHYS 305. Particle and Continuum Mechanics
Least action principle, Lagrange formalism, conservation laws, two-body problem, small-amplitude vibrations, non-inertial reference frames, canonical formalism, rigid body motion, continuous media, and field theory. Includes programming on scientific work stations. [3]

PHYS 308. Mathematical Methods for Physicists
Linear spaces and operators; matrix algebra; differential equations; Green’s function; and complex analysis. May include variational calculus; perturbation methods; group theory. [3]

PHYS 329a. Advanced Electrodynamics
Electrostatics, potentials, boundary value problems, multipole moments, polarization, magnetostatics, Maxwell’s equations, electromagnetic wave propagation, dissipative and conductive media. [3]

PHYS 330a. Quantum Mechanics
Wave and matrix forms of the theory, transformation theory, theory of angular momentum, systems of indistinguishable particles, approximate methods of solution, energy levels and scattering processes, and introduction to relativistic quantum mechanics. [3]
PHYS 341.  Statistical Mechanics
Phase space, entropy and reversibility; ensemble theory; Fermi and Bose Statistics; systems of interacting particles; equation of state, critical phenomena, and phase transitions; pairing and superfluidity. [3]

PHYS 360a.  General Relativity and Cosmology
Einstein's geometric theory of gravity in terms of tensor analysis and differential geometry. Einstein's field equations are derived and solutions are discussed. Applications of general relativity are explored, including those to very strong gravitational fields, gravitational collapse, neutron stars, black holes, and quantum gravity. Topics in cosmology will include red shifts and cosmic distance relations, big bang cosmology, primordial nucleosynthesis, the very early universe and inflationary cosmologies. Prerequisite: consent of instructor. [3]

PHYS 360b.  General Relativity and Cosmology
Continuation of 360a. Einstein's geometric theory of gravity in terms of tensor analysis and differential geometry. Einstein's field equations are derived and solutions are discussed. Applications of general relativity are explored, including those to very strong gravitational fields, gravitational collapse, neutron stars, black holes, and quantum gravity. Topics in cosmology will include red shifts and cosmic distance relations, big bang cosmology, primordial nucleosynthesis, the very early universe and inflationary cosmologies. Prerequisite: consent of instructor. [3]

X.  Other Programmatic Issues

Additional Workload of faculty: Currently, one of the astrophysics faculty serves on the GPC for Physics each academic year. With this new program, at least two of them would serve on the newly constituted GPC for Astrophysics. One of them would be tasked to chair the newly created GPC for Astrophysics.

Advising: as we anticipate no net growth in our graduate student population, we anticipate no net change in advising responsibilities.

Teaching assignments and responsibilities: As has been the case since time began (i.e., for at least the last 60 years), the primary teaching responsibility of the astrophysics faculty will continue to be the complete suite of undergraduate and graduate ASTR courses. Ultimately, the chair of the Department of Physics & Astronomy makes the final teaching assignments; however, traditionally, the chair has assigned the authority for decisions as to the teaching assignments for ASTR classes (Who teaches what class? What classes are offered which year and which semester?) to a senior faculty member in the astronomy group. We anticipate no changes in these decision-making and assignment-making processes.
XI.  Financial Issues: No New Costs for Implementation

Additional faculty costs to establish this program: none. Establishment of this new degree program does not require the addition of any new faculty and does not require any changes in the teaching assignments of the faculty identified in this proposal as affiliated with this program.

Additional staff costs to establish this program: none. This new degree program does not require the addition of any new staff persons. The existing support staff for the Department of Physics & Astronomy would manage approximately the same number of PhD candidates in the department as they currently support after this degree program is implemented. The only difference will be that the students will be partitioned into two different degree programs rather than two separate core paths through a single degree program.

Additional graduate student support costs to establish this program: none. This new degree program does not require the addition of any new funds for the support of graduate students. At this time, 23 TA slots are allocated, annually, to the Department of Physics & Astronomy. A small number of these are used to support entering and second year PhD students in physics who are following the core in astronomy. Normally, the four TA positions allocated to ASTR 103 and the one allocated to ASTR 102 are assigned to students on the astronomy core path, provided five such students are in need of and eligible for college-based support. If fewer than five astronomy core students need support as TAs, the unneeded slots are assigned by the Physics laboratory director to other graduate students. Similarly, if more than five astronomy core students need and are eligible for support, they are assigned TA slots in support of PHYS classes.

We anticipate that this current arrangement would continue: the four TA slots allocated to ASTR 103 and the one TA slot allocated to ASTR 102 would be available for PhD candidates in astrophysics first and to PhD candidates in physics second. Similarly, the TA slots allocated to PHYS courses would be available to PhD candidates in physics first and to PhD candidates in astrophysics second. On average, these TA positions allow us to bring five new graduate students into our program every two years (2.5 new students per year, assuming each student is on TA support for two years). Research grants to program faculty would continue to support PhD candidates in astrophysics in the later years of enrollment.

Additional costs to establish the position of a GPC Chair in Astrophysics: none. A new position, the Director of Graduate Studies for Astrophysics (and Chair, Graduate Program Committee for Astrophysics) would be established. The DGS for Astrophysics will have parallel duties (e.g., graduate admissions, graduate advising) to those of the DGS for Physics, albeit for a program with fewer students. At this time, the DGS for Physics is compensated in the form of limited course relief. If the chair of the Department of Physics & Astronomy and the dean of the College of Arts and Science determine that the duties of the DGS in Astrophysics merit similar compensation, such compensation would be covered by existing resources.
XII. Graduate Catalog Text

The graduate catalog will require a number of changes.

1. The entire (though brief) section identified as “Astronomy” should be deleted.

2. The text for the Department of Physics & Astronomy requires some revisions:

   - Under DEGREES OFFERED: delete “Astronomy: Master of Science”;
   - Revise first paragraph to reflect that the information references only the PhD in Physics degree and research appropriate thereto;
   - Third paragraph: change “The PhD degree ...” to “The PhD degree in Physics ...”;
   - Delete the last paragraph;
   - Delete “on page 75 for Astronomy” and “for Physics” from last sentence.

3. Add a new section headlined as “Astrophysics.” The complete text of that new section follows:

Astrophysics

DIRECTOR OF GRADUATE STUDIES David A. Weintraub

PROFESSORS Robert S. Scherrer, Keivan G. Stassun, David A. Weintraub

ASSISTANT PROFESSORS Andreas Berlind, Kelly Holley-Bockelmann

DISTINGUISHED RESEARCH PROFESSOR C. Robert O'Dell

AFFILIATED FACULTY Thomas Kephart, Thomas Weiler

DEGREES OFFERED:

ASTROPHYSICS. Master of Arts, Doctor of Philosophy

ASTROPHYSICS is the study of the Universe on all physical scales—from nuclear reactions inside stars to the expansion of the Universe as a whole—generally focusing on objects and physical phenomena beyond our own Solar System. Areas of study include: stars (stellar astrophysics), their birth (star formation) and their death (stellar evolution); the discovery and characterization of other solar systems (exoplanetary science); the material between the stars (interstellar medium); large ensembles of stars (star clusters) and their interactions (stellar dynamics); our Milky Way galaxy and its local group of galaxies (Galactic astrophysics); other galaxies (extragalactic astrophysics), their birth (galaxy formation) and their evolution (galactic evolution); the structure of the Universe as a whole (large scale structure); and the origin and evolution of the Universe itself (cosmology). Astrophysics also includes the study of fundamental physics—forces, particles, the nature of matter and energy—in the astronomical context, including: particle astrophysics (e.g., solar neutrinos), gravity-wave physics, the extreme physics of compact objects (e.g., black holes), dark matter, and dark energy. Astrophysics involves experimental techniques (observational astrophysics), generally involving images or spectra from telescopes on the ground and/or space, or analysis of archival datasets (data mining); theory, which includes
the application of physics first-principles to derive fundamental physical laws or relationships; *modeling techniques* (computational astrophysics), which generally involves use of massive computing resources to simulate complex objects and phenomena; and *information science* (astro-informatics), which includes development and application of algorithms for the analysis, deployment, and curation of large datasets (data-intensive astrophysics).

The Master of Arts in Astrophysics is awarded to students who earn a B average in a minimum of 30 credit hours of graduate study and complete the formal course requirements for the PhD in Astrophysics.

The PhD degree in Astrophysics requires 72 hours of graduate work, including 28 hours of formal course work, including six core courses (16 credit hours) of core graduate courses in astrophysics, 3 credit hours of core graduate courses in physics, and 9 credit hours of elective graduate courses in astrophysics and/or physics or an approved field. A student must earn a grade of B or higher in every course that counts toward these 28 hours. The remaining credit hours may be earned through some combination of dissertation research and approved lecture courses.

Course descriptions begin on page ##.
Appendix A: Bridge Program General Guidelines

Guidelines for the Fisk/Vanderbilt Masters-to-PhD Bridge program
Version: August 15, 2005
Prepared and approved by: Keivan Stassun & David Ernst (Vanderbilt Physics & Astronomy), Arnold Burger (Fisk Physics), Carolyn Dever (Vanderbilt A&S Dean’s Office), Eugene Collins (Fisk Dean’s Office)

I. General

The Fisk-Vanderbilt Masters-to-PhD Bridge Program was designed by Fisk and Vanderbilt faculty dedicated to expanding opportunities for students to succeed in earning a PhD. At this time there are four participating Vanderbilt PhD programs: (1) Department of Physics & Astronomy, (2) Interdisciplinary Graduate Program in Materials Science, (3) Biomedical Research Education and Training (BRET), and (4) Biological Sciences. This program is intended for motivated students who seek careers in the physical or biomedical sciences, but who may need (or want) additional coursework, training, or research experience before beginning PhD-level work. The program is flexible and highly individualized to the goals of the student. Courses are selected to address any gaps in undergraduate preparation, and research experiences are designed to help pave the way for PhD-level work in the chosen area of study. While at Fisk, students enjoy regular interaction with Vanderbilt faculty and graduate students. This includes access to research facilities and instructional opportunities at Vanderbilt and, in some cases, Masters thesis work performed under the supervision of Vanderbilt faculty. In all cases, we develop mentoring relationships between students and faculty that will foster a successful transition from the Masters to the PhD.

II. Admission to Fisk and to the Fisk-Vanderbilt Bridge program

A. The student must first apply for admission to the Fisk MA program in physics, biology, or chemistry. Admission to the Fisk Masters program is decided by the Fisk faculty following Fisk’s standard admissions procedures. This is a prerequisite to admission to the Bridge program.

B. The student should indicate on the Fisk application that they wish to be considered for the Fisk-Vanderbilt Bridge program. The general GRE (and for some programs the subject GRE as well) is ultimately required for admission to the Vanderbilt PhD program. Students already at Fisk and in good standing may also request admission to the Bridge program. This must be done at least one year prior to the planned completion of the Fisk MA degree.

C. Admission to the Fisk-Vanderbilt Bridge program will be determined by the Fisk-Vanderbilt Bridge program steering committee, consisting of three faculty members each from Fisk and Vanderbilt, and specifically including the co-directors of the Bridge program appointed by the respective deans of each campus (presently Keivan Stassun at Vanderbilt and Arnold Burger at Fisk).
III. Facilitating a Successful Transition to the PhD: Programmatic Elements

It is the explicit goal of the Fisk-Vanderbilt Bridge program that students in the program will be well known to a number of Vanderbilt faculty by the time that they are ready to apply to the Vanderbilt PhD program, thus allowing for an admissions decision that is more holistic in nature, and informed by more personal experience, than is often possible in the admissions process. Indeed, fostering individual mentoring relationships between Fisk students and Vanderbilt faculty is at the very heart of the Bridge program, and is the key metric by which its success is to be evaluated. To this end, the Bridge program includes the following key elements:

A. Students admitted to the Bridge program receive full financial support in an amount that is standard for full-time graduate research assistants at Fisk University. Funding will be provided through a combination of institutional support and extramural support, as appropriate, for a minimum of two years and a maximum of three years.

B. Upon admission to the Bridge program, the student will be assigned, in addition to a primary Fisk adviser, a secondary Vanderbilt adviser. For students who are certain of the area of research interest, the secondary adviser will be matched to that interest. The role of the secondary adviser is to serve as a mentor and as an expert on the rules and procedures at Vanderbilt.

C. Students in the Bridge program, in addition to the interactions with their advisers, will meet at least two times per year (in approximately December and May) with the Fisk-Vanderbilt Bridge program committee to review progress and receive guidance.

D. Students in the Bridge program are required to participate in supervised research, either at Fisk or at Vanderbilt, during at least the second academic year of the program. Regardless of whether the research is primarily supervised by a Fisk or a Vanderbilt adviser, the involvement of a Vanderbilt adviser in the research and in the thesis committee is expected and encouraged.

E. Students in the Bridge program are required to participate in supervised research at Vanderbilt during each summer of the program. These will be paid research internships in an amount that is standard for summer research assistants at Vanderbilt University. Funding will be provided through a combination of institutional support and extramural support, as appropriate.

F. Students in the Bridge program will be eligible to: cross-register for Vanderbilt courses; receive a discounted Vanderbilt parking permit; receive a Vanderbilt photo ID card; receive a Vanderbilt email account; access Vanderbilt library facilities; receive a city bus pass for transportation to and from Fisk.

IV. Admission to the Vanderbilt PhD program

Admission to the Vanderbilt PhD program will be decided by the standard admissions procedures of the relevant Vanderbilt graduate program. The policy of Vanderbilt’s graduate programs is to admit students for whom the total of the evidence strongly indicates that the student is capable of completing the PhD degree. Bridge students are not automatically guaranteed admission to Vanderbilt. The expectation is that a Bridge student who has satisfied the requirements in this document will receive “fast track” consideration by the Vanderbilt admissions committee as having demonstrated strong potential for success in the Vanderbilt program. All students in the Vanderbilt PhD program receive financial support, in the form of
Teaching Assistant and/or Research Assistant support, for a minimum of four years.
Requirements for admission to the Vanderbilt PhD program through the Bridge Program are:

A. Complete the requirements for the Fisk MA degree in physics. Admission can be offered contingent upon the student completing the Fisk degree.

B. Bridge students are required to satisfy the same general requirements as regular “direct admit” PhD students with respect to the core courses. In particular, students must maintain a minimum 3.0 GPA overall, and must achieve A or B grades in the “core” courses (e.g., for physics, these are Mechanics, E&M, Stat Mech, and Quantum), with at most one B- grade permitted in a core course. Core courses must be taken either at Vanderbilt or their approved equivalents taken at Fisk; Vanderbilt courses and their Fisk equivalents will be counted as satisfying the core requirements at Vanderbilt (provided the above minimum grades are achieved).

C. Take at least one core course at Vanderbilt. Additional courses at Vanderbilt are highly recommended. The student must receive at least a B grade in each core course taken at Vanderbilt (at most one grade of B- is permitted). Note that for practical reasons, in general a student must take at least half of the required core PhD courses at Vanderbilt. For example, in physics the six required core PhD courses are Mechanics, E&M I and II, Quantum I and II, and Statistical Mechanics, but only three of these (Mechanics, E&M I, and Quantum I) are offered at Fisk. Similarly, in astronomy, all of the core PhD courses are offered only at Vanderbilt.

D. Meet for an interview on around December 15 with the Director of Graduate Studies of the Vanderbilt PhD program to which the student intends to apply in January. The purpose of the interview is for the DGS to meet the student, to learn from the Bridge Program steering committee whether the student has satisfactorily completed the requirements in this document, and to learn the student’s research interests in order to effectively advance the student’s application in the deliberations of the Graduate Admissions committee.

E. Complete the Vanderbilt application for the relevant PhD program by the January 15 deadline of the year for which Fall admission is being sought. Applications for admission to Vanderbilt at other times of the year are discouraged as a vast majority of financial support is on a yearly cycle the starts with the Fall semester. Links to all application forms are available from the Bridge program website (see below).

F. A minimum of three letters of recommendation: one from the student’s Fisk adviser, one from the student’s Vanderbilt adviser, and one from a Vanderbilt faculty who has taught the student a course (in some cases a faculty member may satisfy more than one of the above criteria). More than three letters is encouraged.

Note: While a Fisk student, all of the student's academic and financial matters will be handled through Fisk University, and while a Vanderbilt student, all the student’s academic and financial matters will be handled through Vanderbilt University.

Up-to-Date Program Information: [http://www.vanderbilt.edu/gradschool/bridge]
Appendix B: Transfer of Credit Hours to Vanderbilt University

DATE: June 7, 2012

TO: Graduate students in Physics & Astronomy

RE: Transfer of credits hours to Vanderbilt University

Transferring your course work credit hours to Vanderbilt is not automatic but it is fairly simple. Below is the procedure for requesting your course work to be transferred to your Vanderbilt student record.

* Please complete the attached transfer request spreadsheet.

* Submit your request to the Director of Graduate Studies (DGS) Prof. Julia Velkovska, julia.velkovska@Vanderbilt.Edu via Administrative Assistant Donald J. Pickert don.pickert@vanderbilt.edu Contact Don if you have any questions about the form.

* The Graduate Program Committee (GPC) will review your request. If not approved, the GPC will inform you why or ask for further information.
If approved, a letter from the DGS will then be sent to the Graduate School for final approval by the Graduate School Dean, Richard Hoover. Once approved, you will see your transfer credit hours on your VU transcript.

Only graduate courses with a B or better can be transferred. For a Ph.D. degree, a maximum of 48 hours may be transferred. Grades earned on transfer credit WILL affect your VU Graduate School Grade Point Average (GPA), if courses transferred are to be counted as didactic hours. (Research work does NOT count as didactic hours.)

The Ph.D. degree requires at least 72 hours of graduate work for credit, of which a minimum must be 24 hours in formal, didactic course and seminar work in the Vanderbilt Graduate School.

“Formal, didactic course work” is approved courses taken for credit other than thesis and dissertation research courses. Students should check departmental regulations for the number of “formal course” hours required for their particular program. (28 for Physics & Astronomy).

If a student wishes to transfer credit hours, and the GPC considers those courses comparable to ones at VU, then the Graduate School will accept them as essentially replacements for the VU courses. In other words, GPC-approved transfer credit hours will apply towards the required 24 hours in formal, didactic course and seminar work in the Vanderbilt Graduate School.
Appendix C: Request for Transfer Credit Worksheet

<table>
<thead>
<tr>
<th>COURSE ID (SUB+NUM)</th>
<th>TITLE OF COURSE</th>
<th>CREDIT HRS</th>
<th>QUAL HRS Y/N</th>
<th>GRADE</th>
<th>INSTITUTION</th>
</tr>
</thead>
</table>

Submitted by (DGS):
Date of request:
Approved:

Please provide marked school transcript.
**Mission Statement:** The mission and objective of the graduate program in astrophysics in the Department of Physics and Astronomy is to train scholars and to promote research. The faculty seeks to provide every student with a thorough grounding of knowledge in the field of astrophysics and mastery of the methods of productive scholarship. The means to accomplishing this mission include coursework, a qualifying examination, an evaluation of a thesis proposal, and the completion and public defense of a thesis or dissertation.

<table>
<thead>
<tr>
<th>Learning Outcomes</th>
<th>Assessment Methods and Procedures</th>
<th>Results</th>
<th>Planned Improvement Based on Assessment Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge and mastery of the foundations, principles, and methodologies of discovery in astrophysics</td>
<td>Evaluation of learning outcomes in each course using procedures designed by course faculty.</td>
<td>1) Core: Collect graded final exams from 5 students</td>
<td>2) Order-of-Magnitude: 5 students – oral presentations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3) electives</td>
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<tr>
<td>2. Integration of knowledge, through analysis and synthesis, with the methods of research and discovery in the field of astrophysics</td>
<td>A qualifying examination comprising a written research proposal and an oral presentation defending the proposal. The examination is administered by the student’s Ph.D. committee in conjunction with the departmental graduate program committee during the 4th semester of studies.</td>
<td>Written communication</td>
<td>Originality</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Feasibility and merit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Familiarity with research literature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oral communication</td>
</tr>
<tr>
<td>3. Ability to conceptualize, design, and plan independent, systematic inquiry to be demonstrated in a concrete thesis proposal for a research that will</td>
<td>Evaluation of a thesis proposal during the 3rd year of graduate studies by the student’s Ph.D. committee</td>
<td>Written communication</td>
<td>Originality</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Scientific merit</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Familiarity with research literature</td>
</tr>
<tr>
<td>Result in a new contribution to knowledge in the field of astrophysics</td>
<td>Oral communication</td>
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<tr>
<td>4. Demonstrated competence in the conduct of independent inquiry; compilation of a written account of such inquiry, its outcomes, and conclusions</td>
<td>Evaluation of a thesis or dissertation, and publication record by the student's Ph. D. committee; a public thesis defense</td>
<td>Written communication, Originality, Scientific merit, Publication record, Oral communication</td>
<td></td>
</tr>
</tbody>
</table>


**Appendix E: Assessment Form for Course Work**

### Evaluation Form for course work

To GPC subcommittee: Based on evaluation of the performance of a sample of at least 5 students, please fill the rubrics below and transmit to DGS.

<table>
<thead>
<tr>
<th></th>
<th>Exemplary</th>
<th>satisfactory</th>
<th>unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core courses</td>
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<tr>
<td>Breadth courses</td>
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<tr>
<td>Seminar</td>
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<tr>
<td>Elective courses</td>
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</tbody>
</table>

**Additional Comments:**
Evaluation Form for Qualifying examination

DATE:________________________
Student: ______________________

To Ph.D. committee: Please fill the rubrics below and transmit to student and DGS.

<table>
<thead>
<tr>
<th></th>
<th>Exemplary</th>
<th>satisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>unsatisfactory</td>
<td></td>
</tr>
<tr>
<td>Written communication</td>
<td></td>
<td></td>
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<tr>
<td>Originality</td>
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<tr>
<td>Feasibility and merit</td>
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<tr>
<td>Familiarity with research literature</td>
<td></td>
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<tr>
<td>Oral communication</td>
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<td></td>
</tr>
</tbody>
</table>

Additional Comments:
Appendix G: Assessment Form for PhD Thesis Proposal

**Evaluation Form for Ph.D. thesis proposal**

DATE:________________________
Student: ______________________

To Ph.D. committee: Please fill the rubrics below and transmit to student and DGS.

<table>
<thead>
<tr>
<th></th>
<th>Exemplary</th>
<th>unsatisfactory</th>
<th>satisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written communication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Originality</td>
<td></td>
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<tr>
<td>Scientific merit</td>
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<tr>
<td>Familiarity with research literature</td>
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<tr>
<td>Oral communication</td>
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<td></td>
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</tr>
</tbody>
</table>

Additional Comments:
Appendix H: Assessment Form for PhD Defense

**Evaluation Form for Ph.D. defense**

DATE:________________________
Student: __________________________

To Ph.D. committee: Please fill the rubrics below and transmit to student and DGS.

<table>
<thead>
<tr>
<th></th>
<th>Exemplary</th>
<th>satisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>unsatisfactory</td>
<td></td>
</tr>
<tr>
<td>Written communication</td>
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<tr>
<td>Originality</td>
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<td></td>
</tr>
<tr>
<td>Scientific merit</td>
<td></td>
<td></td>
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<tr>
<td>Publication record</td>
<td></td>
<td></td>
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<tr>
<td>Oral communication</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Additional Comments:**