Concept Paper for

Master of Science in Physics

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on behalf of the
School of Physics and Astronomy
College of Science

Goals and Justification for Proposed Program

The goal of the proposed MS program is to provide a research-based graduate degree in Physics that prepares students to be highly employable across all sectors of the economy and for entry into PhD programs. Just as importantly, coursework offered by the program provides a sought-after general curricular presence and framework in physics that supports numerous other MS and PhD programs throughout RIT's portfolio of STEM graduate programs (particularly within the College of Science and the Kate Gleason College of Engineering). Coursework will provide requisite training in core areas of physics, both for students enrolled in this and other STEM graduate programs, as well as coursework in identified sub-areas of physics corresponding to three program research tracks offered to students. The program contributes in an integral way to RIT's stated mission by delivering curricula and advancing scholarship and research relevant to emerging technologies and social conditions.

This program proposal is largely motivated by recent national data. According to the latest (2011) report on *Physics & Astronomy Master's Initial Employment* [1] from the ***American Institute of Physics (AIP) Statistical Research Center***, during the period 2006-2008 there were an annual average of about 800 exiting MS Physics graduates across the nation. That corresponds to about half of all MS Physics degree recipients if one includes those continuing en route towards earning their PhD. Approximately one-third of those exiting received their MS degree from non-PhD-granting departments, providing firm evidence that demand exists for a "terminal" MS program at RIT. Of particular note, the report finds that nearly one-quarter of exiting Physics master's degree recipients are women. This corresponds to approximately a 22% higher representation of women than one sees among PhD recipients in Physics. The proposed program would therefore have a positive impact on attracting women to Physics and the general graduate STEM population at RIT. As substantiated by the AIP report, graduates of the proposed MS program in Physics will be highly employable across all economic sectors and in a wide variety of fields spanning the private sector, colleges and universities, high schools, and the government. The private sector, which employs about half of the physics MS degree recipients in the workforce, offers a very diverse set of STEM-related career options, with about 40% of these in engineering-related fields. During the period 2006-2008, the median salary for new holders of Physics master's degrees working in the private sector was $62,400. Graduates of our program will also find themselves well prepared and positioned to subsequently pursue a doctoral degree in physics or a related field should they desire to do so.

This program is also critically needed by the growing number of highly research-active faculty in the School of Physics and Astronomy in that it provides a pool of graduate students specifically trained in physics to support their expanding sponsored research efforts. Without these graduate students, faculty research efforts and the School's ability to attract external funding is compromised.

Once the MS program is approved, our intention is to promptly create a five-year BS/MS dual-degree connecting the bachelor's and master's physics programs. This will be mutually beneficial for recruiting and retaining physics students at both the undergraduate and graduate levels. More specifically, when prospective and early-year physics undergraduate students recognize that clear sub-disciplinary tracks are being seeded from above, i.e., those that facilitate desirable programmatic trajectories, they can actively aspire toward attractive options and career paths early on. This will further strengthen our already strong growth in the BS Physics Program that we have been experiencing over the last 15 years（the BS program had 41 majors in 2000, 73 majors in 2006, and 138 in 2013). Obviously, those students who formally enroll in the dual BS/MS degree will also positively impact the Physics enrollment numbers at the graduate level.

Description of the New Program

The proposed MS program will provide its students with advanced core knowledge that crosses the discipline of physics, along with significant coursework and a thesis research experience within a chosen track available in the program. The courses will be delivered at a rigorous physics graduate level, hence entry into the program requires an undergraduate degree in Physics or a closely-related degree containing significant upper-level undergraduate physics coursework. Initially, there will be three general tracks offered by the program:

- *Theoretical and Computational Physics* (TCP)
- *Applied and Experimental Physics* (AEP)
- *Physics Education and Research* (PER)

The field of *Astrophysics* is not included within the Physics MS Program due to the fact that our School already offers MS and PhD degrees in *Astrophysical Sciences & Technology*. Each student in the program will be asked to select their track of choice by no later than the end of their first semester in the program.

The program requires that students earn a minimum of 30 credits in total, consisting of at least 18 course credits and at least 6 research credits, and is designed to be completed over a span of two years. The program is comprised of the following components:

<u>Common Core Courses</u> (12 SCHs)
Students are required to complete the following 4 core courses:

- *Quantum Mechanics I* (new course)
- *Statistical Physics I* (new course)
- *Classical Electrodynamics I* (course already offered, PHYS-611)
- *Mathematical Methods for the Physical Sciences* (already offered for the *Astrophysical Sciences*, i.e., ASTP-610, but is easily generalized to support Physics and Astrophysics)

These courses provide essential knowledge that underpins all three tracks within the program. The core courses are each offered once per year and are normally taken during the first year.

Track-Specific Courses (at least 6 SCHs)
Students must take at least two graduate courses within their chosen track. Track-specific courses are made available at least every other year, and are either offered by the program or by other RIT STEM graduate programs that are approved for the particular track. The following new track courses (with the applicable track(s) shown in parentheses) will be developed by the School of Physics and Astronomy:

- Quantum *Mechanics II* (TCP, AEP, PER)
- *Statistical Physics II* (TCP, AEP, PER)
- *Topics in Soft-Matter and Biological Physics* (TCP, AEP)
- *Scattering and Spectroscopy as a Probe of Matter* (AEP)
- *Atomic-Scale and Other Microscopies* (AEP)
- *Teaching and Learning Physics* (PER)

The following track courses already exist at RIT at the graduate level. (Dean Harvey Palmer has relayed that he is supportive of Physics MS students using KGCOE grad courses as track electives):

- PHYS-612 *Classical Electrodynamics II* (TCP, AEP, PER)
- ASTP-760 *Introduction to Relativity and Gravitation* (TCP)
- ASTP-861 *Advanced Relativity and Gravitation* (TCP)
- IMGS-737 *Physical Optics* (TCP, AEP, PER)
- MCSE-702 *Introduction to Nanotechnology and Microsystems* (AEP)
- MCSE-713 *Lasers* (AEP)
- MCSE-712 *Nonlinear Optics* (TCP, AEP)
- MCSE-731 *Integrated Optical Devices and Systems* (AEP)
- MCSE-771 *Optoelectronics* (AEP)
- MCSE-889 *Quantum Optics* (TCP, AEP)
- MATH-711 *Advanced Methods in Scientific Computing* (TCP)
- MATH-712 *Numerical Methods for Partial Differential Equations* (TCP)
- MCEE-620 *Photovoltaic Science and Engineering* (AEP)
- EEEE-713 *Solid State Physics* (TCP, AEP)
- EEEE-620 *Design of Digital Systems* (AEP)
- EEEE-610 *Analog Electronics* (AEP)

- EEEE-689 *Fundamentals of MEMS* (AEP)
- *Neutrons in Soft-Matter Science: Complex Materials on Mesoscopic Scales* (AEP)—this is one of a number of novel *Cyber-Enabled Collaborative Graduate Education* courses that is offered by and streamed live from Oak Ridge National Lab [2]

Thesis Research (at least 6 SCHs)
In the second year (and/or during summer terms), students undertake a research project within their chosen track under the guidance of a faculty member. Students must defend their thesis, and it is generally expected that they will aim to disseminate their thesis research in a peer-reviewed journal or conference proceeding.

Fit with RIT Academic Portfolio Blueprint

The fit of the proposed MS Program in Physics to the ***six Academic Portfolio Blueprint (APB) characteristics*** follow:

Scholarship, Research, and Creativity
All students, under the guidance of a research-active faculty member, are required to perform an original thesis research project with the goal of disseminating the work in a peer-reviewed journal or conference proceeding. Such research dissemination will strengthen the ability of faculty to attract external sponsored research funding, which in turn will increase the number and quality of research projects made available to students by the faculty.

Innovative Teaching and Learning
The curriculum will make use of technological resources. This includes having an electronic presence for all program courses, embedding computation and simulation components as part of pedagogy, and employing technology that is germane to track-specific courses containing a lab or practical component, as appropriate. Alternative distance delivery opportunities, for example, via *Adobe Connect*, offered by the professional physics community (such as the Oak Ridge *Cyber-Enabled Graduate Education* course listed in the previous section) will be encouraged as a way for students to partially fulfill track-specific course requirements, and at little or no cost to the program. Also, having our program faculty become directly involved in the delivery of these courses presents an excellent opportunity for extending the reach and influence of our program and RIT to venues beyond the campus.

Experiential Learning
The thesis research requirement fulfills the experiential learning expectation for the program. All thesis projects are applied to real-world problems relevant to the physical world and the betterment of society and humankind.

International and Global Education
The discipline of physics, historically and by its nature, is an international enterprise involving numerous collaborations between and among academicians and government agencies,

including the long-term planning and sharing of state-of-the-art facilities, around the globe. The faculty and students in the MS Physics Program will unavoidably participate in these conversations and will continue to engage with international collaborators. The aforementioned alternative distance delivery opportunities for program faculty with national labs and other entities will inherently bring about connections with the international scientific community. A memorandum of understanding is currently being arranged between RIT and Universidade Federal Do Rio Grande Do Sol (UFRGS) in Brazil to forge research and educational connections between the RIT School of Physics and Astronomy and the UFRGS Institute of Physics—our proposed MS program will no doubt benefit this initiative. Similar articulated agreements between other potential international partners such as France, India, Japan, and Sweden are currently being actively pursued by the School.

Synergy and Interdisciplinarity

Because physics provides the underpinnings of all natural and applied sciences, as well as engineering, it crosses all STEM disciplines. Specific interdisciplinary synergies between the proposed program and other academic units and research centers in both COS and across the campus are described in the section on "Synergy with Other Programs" that follows.

Inclusive Excellence

As emphasized previously, based on national data collected by the American Institute of Physics which shows that nearly one-quarter of Physics master's recipients are women, we expect that the proposed MS Program in Physics will positively impact attracting women students to Physics and the general graduate STEM population at RIT—and more so than would a physics Ph.D. program. COS's Women in Science program will provide career mentoring, networking opportunities, and general support for female students in the program. Graduate students in the program can also act as effective role models and mentors for STEM undergraduates from underrepresented populations engaged in physics research in our school, for example, those supported by the RIT McNair Scholars Program. An added goal of the Physics MS Program is to act as an effective academic bridge for underrepresented minority students. This goal connects to a recent initiative by the American Physical Society promoting such bridge programs that provide minority students with graduate coursework and academic mentoring that would help them thrive and gain entry into PhD programs [3].

Here are some of the program features contributing to the fit of the Program to the ***four APB criteria***:

Centrality

The program will enhance RIT's overall reputation by contributing in a significant way to RIT's stated mission aimed at developing and delivering curricula and engaging in scholarship and research that plays a role in advancing emerging technologies and improving conditions within society. This is true even beyond the confines of the proposed program in that a portfolio of graduate-level physics courses being requested by a number of STEM programs and students around the campus will become available. There is an increasing demand at RIT for more advanced courses in physics and, in some cases, these turn out to be an essential component

for the graduate education of students in certain programs (for example, Microsystems Engineering, Astrophysical Sciences & Technology, and Imaging Science). Just as importantly, the projects associated with the research component of the program almost always tend to be interdisciplinary in character, producing natural and lasting collaborations with faculty colleagues in almost every college at RIT.

Marketability

Based on available national and regional data, RIT's Office of Enrollment Management and Career Services projects that the program will realistically be able to reach and sustain a steady-state enrollment of 20-25 students, with about half of this population entering internally through the BS/MS Physics dual-degree program. An MS Program in Physics also elevates the marketability of other RIT STEM graduate programs. An example, although anecdotal, was relayed by a very strong woman applicant who respectfully declined admission to the Astrophysical Sciences & Technology PhD Program: "*…in order to succeed in research and academia, I feel that I will need the opportunity to strengthen my physics base knowledge through graduate level physics courses.*" Program marketability information is provided in the included section on *Enrollment Management Expectations and Sustainment*.

Quality

The quality of this program largely hinges on the qualifications of our faculty to offer it. All of the current 22 tenure-track physics program faculty, as well as the 14 non-tenure-track faculty, in the School of Physics and Astronomy have a Ph.D. degree in Physics or a closely related field. A large fraction of the current faculty have recent experience supporting and supervising graduate students in other RIT STEM programs including Astrophysical Sciences & Technology, Materials Science & Engineering, Chemistry, Applied Mathematics, Microsystems Engineering, Electrical Engineering, Imaging Science, Computer Science, and Sustainability. Additionally, a majority of the faculty have acted as research mentors in support of the individualized senior capstone research projects required for all students in the BS Physics Program. In a typical recent year, the RIT physics faculty publish 60-80 peer-reviewed papers and attract about $1-2M in external sponsored research funding. The School feels well positioned to launch the Physics MS Program.

Financial Viability

The program will efficiently make use of existing physical, financial, and faculty resources currently available within the School, including many courses that already exist in COS and KGCOE. Resource needs primarily associated with incremental faculty are detailed in the included cost model analysis, and are based on the projected enrollment plan.

Synergy with Other Programs

The program integrates naturally and substantially with numerous disciplines, other programs, and colleges at RIT. Students will benefit from numerous graduate course options offered by KGCOE and COS, as shown in the *Description of the Program* section. Quoting an email from

Harvey Palmer, Dean of KGCOE, "*I am definitely supportive of the proposal.*" On the flip side, even in the absence of a Physics graduate physics program at present, beginning in 2013-14 the School of Physics & Astronomy began offering a two-semester graduate sequence to support students enrolled in existing science and engineering programs on campus, i.e., *Classical Electrodynamics I & II*, which is one of the main course sequences in the Physics MS Program. This sequence was put in place primarily to satisfy the new course requirements for one of the tracks in the Astrophysical Sciences & *Technology* (AST) program. Unexpectedly, in addition to the 5 AST (4 PhD, 1 MS) students, there were also 2 Microelectronic Engineering (MS) students, 1 Imaging Science (PhD) student, and 1 Microsystems Engineering (PhD) student also enrolled; 1 upper-level undergraduate Physics student also regularly sat in on the classes. The demand for the first-time offering of this sequence was significantly higher than expected, and the instructor relays that the performance-level of the students in this advanced class was very impressive. A recent survey of the AST students shows that there is also a substantial demand for a graduate-level *Quantum Mechanics* sequence, even though this is not currently a requirement for any track in that program. This points to the possibility that there may be significant interest among the more theoretically-inclined AST PhD students in first earning an MS in Physics as a stepping stone to the AST PhD Program.

Courses offered by the program in the area of Physics Education Research will undoubtedly be attractive to any students interested in STEM education. These courses could easily be delivered in a dual-level fashion for both undergraduate and graduate students, making these courses sustainable and cost effective. The proposed course in *Teaching and Learning Physics*, for example, would clearly support students participating in the rapidly growing *Learning Assistant* (LA) program evolving within COS and the RIT-Nazareth *Tech2Teach Program* that facilitates a pathway for STEM students considering a career in secondary education [4].

All in all, clear synergies abound between the proposed program and other graduate programs and research centers at RIT, with the closest overlaps with the following:

Academic Programs	Research Centers, Labs, & Clusters
Astrophysical Science & Technology (PhD, MS)	Center for Comp Relativity & Gravitation
Imaging Science (PhD, MS)	Nanopower Research Laboratory
Microsystems Engineering (PhD)	Center for Applied & Comp Mathematics
Sustainability (PhD)	Center for Detectors
Applied & Computational Mathematics (MS)	Semiconductor/Microsystems Fab Lab
Microelectronic Engineering (MS)	Science/Math Education Research Collab
Material Science & Engineering (MS)	
Physics (BS)	

Administrative Structure for the New Program

The MS Program in Physics will be administered by COS's School of Physics and Astronomy, which currently houses the Physics BS Program, as well as the Astrophysical Sciences &

Technology PhD and MS Programs. A Director for the MS Physics Program will report to the Head of the School, and will coordinate the program's operation and student recruitment.

Enrollment Management Expectations and Sustainment

Dr. James Miller, Senior Vice-President for Enrollment Management & Career Services, and Diane Ellison, Assistant Vice-President in Graduate Enrollment Services, reviewed the proposed program. Here is the direct response to Dr. Mike Kotlarchyk (Head, School of Physics & Astronomy) from Dr. Miller on February 26, 2014 concluding that a steady-state enrollment of 22 students in the program each year is a realistic projection, with about half of the students coming from new external candidates and about half coming through the BS/MS Physics Program:

Dear Mike,

Diane Ellison and I have reviewed original concept paper as well as subsequent iterations shared to date. We provide this input, based on current model offering three tracks containing three common courses, two of which are new, and six additional courses to support the tracks. The target population is full-time from within and outside RIT. As noted in Diane Ellison's previous memo to you the market is competitive with various competitive funding models for students in place.

To assist you in planning, I am sharing ***two planning scenarios: one assumes a 2016 start with BS/MS and MS both commencing in fall 2016; the second assumes an MS start in 2015 or 2016 with BS/MS commencing one year later.*** *In the second scenario I am making an assumption that NYS approval is forthcoming in summer 2014 to allow a full marketing cycle. If NYS approval is not forthcoming until 2015, then the start should simply be moved from 2015 to 2016.*

Note that any BS/MS enrollees are considered new graduate enrollees at the point they are classified level 6 in RIT's student records system. This distinction is important for assessing the overall financial viability of your proposal.

Scenario One: MS and BS/MS commencing in 2016
Given desired quality thresholds, we believe it is realistic to project 6-7 new external MS candidates and 5-7 BS/MS candidates. Overall, I estimate 10 new in the first year, with 12-13 new in each subsequent year.

For purposes of planning I suggest using the following FTE figures: Year 1, 10; Year 2, 20; Year 3, 22; year 4 and beyond, 22.

Scenario Two: MS starts in 2015; BS/MS follows one year later*.*
New enrollment is likely to be 6-7 in year one and 12-13 in year two and beyond.

For purposes of planning I suggest using the following FTE figures: Year 1, 6; Year 2, 17; year 3, 22; Year 4 and beyond, 22.

For each scenario above, a 35% discount rate should be used for year 1. For year 2 and beyond use a 27-30% discount rate.

Mike, please let me know if you need more.
Jim

We are choosing to pursue **Scenario One** above, where we start the program for both the MS and the BS/MS students in fall 2016. Per Dr. Miller's email, a 35% tuition discount rate would be applied in Year 1 of the program and a 27-30% discount rate would be applied in Year 2 and beyond. Partial financial support will be available in the form of teaching assistantships funded by the School and some students will receive full stipend funding and/or summer support from faculty-sponsored research grants.

Impact on Resources

The base resources to support the MS Program in Physics will primarily come from the existing space and facilities currently available within the School of Physics & Astronomy (SoPA) and the College of Science, as well as from other existing academic and research infrastructure alliances and cost-sharing arrangements currently in place with other colleges, laboratories, and centers around campus. However, in steady state, to annually offer the 2 new core courses, to offer a sufficient number of courses to support the three proposed tracks (where School faculty teach at least 4 of such courses each year), and to supervise the MS thesis projects each year, there will be the need for 2 FTE additional tenure-track faculty (and associated office space). Start-up packages are being requested for the two new faculty. There will also be a need for some desk space for the grad students we would be unable to accommodate in research laboratories. Teaching release of one course per year is requested for the faculty member taking on the role of MS Program Director. Administrative staff assistance will be provided by existing personnel in the School.

The required cost model analysis template accompanies this concept-paper submission.

Conclusion

The MS Program in Physics will complement and be integral to supporting the existing and developing portfolio of STEM graduate programs in science and engineering across RIT. Through both coursework and research, the program will produce graduates having marketable training and skills known to be desirable in all sectors of the economy and in a wide variety of fields. It will also provide very strong preparation to those who decide to continue on for PhD-level training in Physics and related fields. We expect that the existence of the three tracks at the graduate level will also have the significant additional benefit of boosting retention in and strengthening recruitment and program marketability aimed toward our undergraduate population of physics students. This will be enhanced by putting in place a BS/MS dual degree program in Physics. The MS program will add further vitality to the overall research enterprise at RIT by elevating collaborations that cross disciplines and programs. Additionally, the mere presence of a graduate program in Physics and the availability of physics graduate students in support of research will have a positive impact on the success rate for faculty submitting proposals for sponsored projects.

References

[1] *AIP Focus on Physics & Astronomy Master's Initial Employment* (2011), http://aip.org/statistics/reports/physics-astronomy-master%E2%80%99s-initial-employment

[2] http://neutrons.ornl.gov/education/graduate/

[3] http://www.apsbridgeprogram.org/institutions/bridge/

[4] http://www.rit.edu/cos/tech2teach