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LRP REPORT: PERIMETER INSTITUTE

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1. INTRODUCTION

Perimeter Institute (PI) was founded in 1999 as an independent research institute focused on the greatest challenges facing fundamental theoretical physics in the 21st century, namely, discovering a deeper understanding of the quantum laws of physics and the spacetime arena in which they operate. The Institute now comprises 11 faculty members, 10 associate faculty members cross-appointed to other institutions, and approximately 45 postdoctoral fellows. PI will expand significantly in the next decade, both in terms of faculty and student numbers, and in terms of its research. While retaining its twin focus on quantum theory and spacetime, PI is now broadening its range of research to incorporate insights from physics on all length scales: from subatomic, to mesoscopic condensed matter systems, to cosmology.

Over the coming five years, PI intends to double its faculty to approximately 25 resident faculty members and 16 associate faculty members, distributed over eight fields: Quantum Foundations, Quantum Information, Quantum Gravity, String Theory, Particle Physics, Condensed Matter, Cosmology and Complex Systems. In addition, in fall 2008 PI created a Distinguished Research Chairs program, consisting of three-year appointments where the holder typically spends from one to two months per year at the Institute.

Twenty Distinguished Research Chairs have been appointed to date, including eminent scientists working in areas related to cosmology and astrophysics. These include Stephen Hawking (Cambridge), Neta Bahcall (Princeton), Nima Arkani-Hamed (IAS Princeton), Gia Dvali (New York Univ.), Renate Loll (Utrecht), Malcolm Perry (Cambridge), Ashoke Sen (Harish Chandra Institute), Bill Unruh (UBC), and Mark Wise (Caltech). While retaining their permanent positions at their home institutions, these scientists will visit PI for extended periods to conduct research. It is anticipated that their presence here will spark new research collaborations and be of enormous benefit both to PI and to the wider Canadian scientific community. PI plans to appoint ten more Distinguished Research Chairs in 2010.

2. RESEARCH IN COSMOLOGY

The effort to understand the rules governing the origin and evolution of the universe is a core theme of research at PI. Faculty most closely involved with research in cosmology include Niayesh Afshordi (Associate with Waterloo), Latham Boyle, Cliff Burgess (Associate with McMaster), Luis Lehner (Associate with Guelph), Maxim Pospelov (Associate with Victoria) and Neil Turok. Philip Schuster and Natalia Toro, two young particle theorists with strong interests in dark matter searches, will be joining PI's faculty in September 2010.

Research conducted at PI extends from the very early universe, where high-energy physics and quantum gravity are predominant, to the present-day astrophysical universe, where we are confronted with observational mysteries such as dark matter and dark energy. In recent years, PI researchers have made leading contributions to the idea that the observed acceleration of the universe may be due to a modification of Einstein's theory of General Relativity (GR). Finding modifications of GR that are consistent with all current observational and theoretical constraints is a surprisingly subtle problem. PI researchers have played a central role in figuring out which modifications make sense, and what their predictions are for astrophysical observations.

PI has particular strength in the cosmology of the very early universe. It has expertise in all of the leading theories that are competing to explain the behavior of spacetime near the Big Bang singularity at which our universe apparently began, and the origin of the primordial fluctuations seen in the cosmic microwave background (CMB). Early universe cosmology is particularly exciting since, in the coming years, it is likely to receive qualitatively new observational input, for example from the Large Hadron Collider, direct (underground) dark matter experiments, indirect (astrophysical) dark matter searches, CMB polarization experiments looking for the signature of primordial gravitational waves, or large scale structure observations seeking the imprint of primordial non-gaussianities. By coupling these observations with our expertise in high-energy particle theory, string theory, and quantum gravity, we hope to make major steps forward in our understanding of the laws of nature, the sequence of events in the early universe, and perhaps even the nature of the Big Bang singularity itself.

3. RESEARCH IN STRONG GRAVITY AND BLACK HOLES

During the coming decade, gravitational waves are likely be directly detected for the first time. As these observations improve, a new window on the universe will be opened: gravitational wave astronomy, which will advance fundamental physics and astronomy in many ways. On the one hand these new observations will probe deep into our cosmos, complementing observations in the electromagnetic bands. On the other, they will constitute the unique way to study systems either not radiating electromagnetically or not doing so along our line of sight. The most likely sources of detectable gravitational waves are systems in extreme situations, where gravity plays a fundamental role at the strongest levels thought to be allowed by nature. Consequently waveforms produced by these systems will allow for the testing of theories of strong gravity, directly probing the classical or even semi-classical predictions of prospective quantum gravity theories.

Since gravitational waves propagate essentially unscattered through space, they carry pristine information of the source that produced them, and planned detectors (like

LISA and the proposed Big Bang Observer) will be capable of detecting sources at cosmological distances. Ultimately, gravitational waves may allow us to directly image the inflationary epoch, or even the big bang singularity itself, a truly tantalising prospect.

Clearly many exciting research opportunities will be opened as gravitational waves are detected and studied in detail. In most cases, fully exploring such systems will require combining efforts and expertise from a number of areas. Perimeter Institutes strengths in cosmology, particle physics, gravity and quantum gravity, coupled with strong visitor and workshop programs, provides a unique environment where fundamental contributions will be fostered.

4. INCREASING ENGAGEMENT WITH EXPERIMENTAL EFFORTS

A major emerging theme in the research conducted at PI is the increasing connections between theory and experiment. In the coming decade, PI plans to greatly expand its ties to experimental and observational centres through collaboration agreements and partnerships which encourage scientific exchange visits and joint activities. PI has recently appointed new faculty in particle physics, with strong interest and involvement in LHC, as well as a five-year postdoctoral fellow working on LIGO. Theoretical physicists can make major contributions to these big science projects and others by proposing interesting new observational tests, by assisting with the analysis and interpretation of data, and by helping to develop ideas for the next generation of experiments.

PI is in the process of creating a GO program for its postdocs which will enable them to visit experimental and observational centres for periods of several weeks, annually. As well as supporting growing connections with LHC and LIGO, it is anticipated links will be established with the Planck satellite; VISTA, VLT, the SKA and other proposed astronomical observatories, SNOLAB and other astroparticle facilities, and LIGO, LISA and other gravitational wave detectors in order to stimulate new experimental and observational tests of fundamental theory.

5. FOSTERING CONNECTIONS IN THE CANADIAN COMMUNITY

PI cooperates with numerous academic partners via cross-appointments, adjunct appointments, joint postdoctoral fellowships, postgraduate training, and numerous joint research events, including the popular PI-CITA days held twice annually in conjunction with the Canadian Institute for Theoretical Astrophysics, CITA. PI has had strong collaborative ties with CITA for several years, and these are expected to deepen in the coming decade as PIs cosmology research team grows. In addition, PIs Affiliate program, currently comprising 96 members, will continue to develop robust national cross-linkages by enabling faculty members from across Canada to come to PI regularly to participate in the Institutes research activities.

6. TRAINING YOUNG RESEARCHERS IN CANADA

In 2008 PI launched Perimeter Scholars International (PSI), an innovative, highly intensive Masters program preparing talented students recruited worldwide for research careers in many areas of theoretical physics. PSI is a collaborative effort with partnering Canadian universities, whose faculty members supervise PSI students during the project phase of the course. Upon completion of the program, students will receive a Masters degree from the University of Waterloo and a Perimeter Scholars Certificate from Perimeter Institute. Courses are taught by outstanding international lecturers as well as dedicated professional tutors, in a syllabus designed to impart strong independent research skills and to expose students to a wide spectrum of cutting-edge topics. It is anticipated that PSI will grow to approximately 50 students per annum over the coming years, feeding many excellent, well-prepared students into the Canadian research community.

7. OUTREACH:

Public outreach is a core component of Perimeters mission and has been since its inception. Outreach can do much to nurture a culture of innovation from the ground up, by conveying scientific principles in understandable terms, and by helping to develop reasoning and problem solving skills.

Perimeter intends to continue to build its highly regarded outreach program, focusing on increasing the awareness of the importance of basic research and the power of theoretical physics; identifying and nurturing the most promising young scientists and encouraging them to pursue scientific careers; engaging in global outreach by promoting the emergence of centres of excellence in the developing world; and by exporting its products and programs to targeted areas internationally.

Programs for students include the annual International Summer School for Young Physicists (ISSYP), which attracts talented high school students from across Canada and around the world, providing advanced lessons on modern physics, and mentoring sessions with researchers, as well as an introduction to the observational side of physics through tours of experimental facilities such as SNOLAB.

EinsteinPlus Teacher Workshops show educators how to effectively convey key concepts in modern physics. PI has also produced several educational products aimed at students and teachers, most of which is made available online. These include several modules for high school students (including one on dark matter) and animations for younger students (including one on Olbers Paradox called Why It is Dark at Night). Future modules on fundamental questions in astrophysics may be developed. For the general public, PI has run a popular public lecture series since 2003, and has held two very well-attended science festivals (EinsteinFest in 2005 and Quantum to Cosmos in 2009), and there is every expectation that these traditions will continue to share the joy and excitement of physics.