The extreme physics of Eddington and super Eddington accretion onto Black Holes: a comprehensive study of the "Eddington limit" across mass scales

A proposal for an ISSI International Team

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Abstract

Understanding both the macro- and micro-physics of accretion onto black holes is one of the fundamental goals of Astrophysics, with relevance to measuring the effects of strong gravity and to understanding structure formation in the universe. We propose an International Team to study so-called Eddington-limited accretion, a unique and extreme regime where so much accretion power is liberated that the outward radiation pressure force is comparable to the inward force of gravity. The Team that we have assembled spans a wide range of expertise in order to critically review our understanding of the physics of Eddington-limited accretion onto black holes across a mass scale that spans 8 orders of magnitude, and the physical mechanisms that produce different types of outflows (like disk-winds and relativistic jets). The Team consists of 12 members coming from 4 different continents and 6 different countries, equally balanced between theoretical and observational members with the necessary complementary expertise. The primary goals of the Team will be address key questions related to (i) the physical conditions for Eddington and super-Eddington accretion, (ii) its observational manifestation across a wide range of black-hole mass, and (iii) the implications for accretion-disk geometry and outflows.

Research domain: Astrophysics, Eddington Accretion, Active Galactic Nuclei, Black holes, compact objects

Introduction

Black Holes (BHs) are the most exotic prediction of general relativity, with the strongest possible gravitational fields in the Universe. The black holes known to exist astrophysically range in mass from as small as a few times the mass of the sun to as large as billions of times that mass (so-called supermassive BHs). Probing general relativity in the environment of black holes is one of the fundamental questions of Astrophysics today, one of the main themes of the ESA Cosmic Vision 2015-2025 long term plan, and one of the main drivers for the construction of the next generation of ground-based and space telescopes[1].

Accretion is the process of growth or enlargement of a gravitating object by infall of material. It is a widespread process in our Universe, relevant to the formation of everything from planets to galaxies. Understanding the physics of accretion is therefore of fundamental importance to many areas of Astrophysics. Of particularly interest for this proposal is the understanding of the physics of accretion onto a central BH. Because infalling material generally has significant angular momentum, the flow around the compact object is generally thought to take the form of a rotating accretion disk. This structure is formed independently of the source of the infalling material (from a companion star in the case of a solar-mass BH, or from the gas/dust in a galaxy in the case of a supermassive BH) and it is known to be one of the most powerful energy sources in the universe. In the case of supermassive BHs, accretion has demonstrably affected the evolution of entire galaxies and clusters of galaxies over the course of cosmic time, as demonstrated by the tight relation of the BH mass and the host galaxy bulge mass (e.g., Magorrian et al. 1998, Maduro et al. 2014, Silk & Rees 1998; Di Matteo, Springel & Hernquist 2005).

The energy released by accretion is known to generally drive outflows. All types of disk-accreting astrophysical systems, particularly BHs of any mass, have shown strong evidence of powerful outflows in the form of highly collimated jets (e.g. Livio 1999). It is now also broadly accepted that

1 http://sci.esa.int/cosmic-vision/38657-cosmic-vision-2015-2025-fundamental-laws/

black holes launch massive disk winds that have a significant effect on the accretion disk and possibly jets, whose formation mechanisms are still debated (e.g. Neilsen 2013). These outflows mediate the connection between BHs and their environments. Understanding this feedback from accretion onto supermassive black holes on their surroundings is another main theme of ESA's Cosmic Vision plan.[2]

Naturally, the most powerful black hole sources are those that are accreting at the highest rates, and the only thing that might limit the output from a black hole source is radiation pressure. This gives rise to the concept of the Eddington Luminosity (L_{Edd}), which theoretically corresponds to an outward radiation pressure force that balances the attractive gravitational force acting on the accreting gas. This most astrophysically important of black hole accretion regimes is observed: both accreting stellar mass and supermassive BHs reach luminosities comparable to the Eddington limit. Such systems clearly exhibit strong outflows, and some exhibit truly bizarre variability patterns in their light output, particularly in the case of stellar mass black holes (e.g. Belloni et al. 2002; Altamirano et al. 2011). Although it is of fundamental importance, this regime is still very poorly understood, and there are a host of unanswered questions. These include how the radiation pressure really works in an aspherical flow like an accretion disk, exactly how jets and winds are driven, how radiation can be trapped and advected inward into the flow, and how the flow responds to a whole host of instabilities that are expected in this regime, from "photon bubbles" to thermal instabilities which might drive runaway heating or cooling. The physics here is very rich, and as we discuss below, the time is ripe for making significant progress in understanding it. *The aim of this Team is therefore to critically explore the physics of Eddington-limited accretion onto black holes, and its observational and theoretical implications for the physical mechanisms that produce different type of outflows (like disk-winds and relativistic jets).*

The theoretical revolution

Bringing together observers and theorists to discuss radiation pressure dominated accretion is particularly timely in view of the fact that numerical simulations are now undergoing a true revolution. Until recently, the best that could be done were localized 3D simulations of a small patch (a "shearing box") of an accretion disk (e.g. Blaes et al. 2011), and 2D (axisymmetric) global simulations (Ohsuga & Mineshige 2011, Takeuchi et al. 2013), both incorporating the effects of radiation pressure, but which treated radiation transport through flux-limited diffusion, even in optically thin regions. Many groups have now greatly improved on this just in the past year. Full radiation transport through the use of variable Eddington tensors has now been achieved in local shearing boxes, with dramatic implications for our understanding of thermal stability in the radiation dominated regime (Jiang et al. 2013). Full transport is also now being attempted for global simulations. Moreover, full 3D simulations with M1 closure schemes for the radiation transport have now been published, using full general relativity (Sadowski et al. 2014). While these do not incorporate full transport, they are significantly better than flux-limited diffusion, and the fact that they are 3D permits the turbulence in the simulation to be long-lived (in contrast to 2D simulations where the turbulence cannot be self-sustaining). A host of problems should now be within reach of these simulations: thermodynamic state transitions, radiation pressure driven outflows, thermal and inflow stability, and to what extent photons become trapped at high accretion rates. Above all, for the very first time, such simulations will be able to generate light curves that can be directly confronted with variability data across the black hole mass scale. In other words, for the first time, theorists are now able to simulate the photons that observers actually observe!

However, this breakthrough has only been achieved recently, and important differences between radiation transport algorithms and issues of numerical resolution still need to be discussed. It is for this reason that we have carefully chosen the theorists in our team to represent many of the major, distinct simulation groups. We have also included people who are experts in the various dynamical instabilities that only exist in this regime (e.g. photon bubbles), which may still not be adequately

2 http://sci.esa.int/cosmic-vision/38658-cosmic-vision-2015-2025-the-universe/

resolved in many simulations. Finally, even the best simulations are currently only able to handle frequency-integrated radiation, i.e. spectra can only be computed after the fact. But again, we have included theorists who are experts in modeling radiation spectra directly from simulations.

Scientific Goals and the timeliness of this project

After many years of observational and theoretical effort, we are now in a perfect position to critically review our current understanding of Eddington accretion onto black holes. The most important aspect of this proposed program is the goal to examine and identify the basic physics (and understand the differences in micro-physics) in systems that cover almost 10 orders of magnitude in mass. Our goal in this proposal is to use the wide range of expertise within our group in order to answer fundamental questions by focusing our efforts along three parallel lines that share the same common thread: "*The physics of Eddington Accretion at all mass scales*". The categories can be summarized as:

- *Physical conditions for Eddington and super-Eddington accretion on compact objects.*
- *The observational manifestation of Eddington or super Eddington accretion.*
- *Accretion disk geometry and outflows.*

This categories cover most of the detailed and important questions needed to understand the physics of accretion at the Eddington rate. Discussions around all three categories will run together and simultaneously, as a friendly and critically constructive "Theory vs. Observations tug of war".

We will meticulously review commonly used assumptions to understand whether the Eddington luminosity is generally (or ever?) a true limit in the case of accretion onto compact objects, and critically examine the evidence for and/or against this assertion. We will reexamine all observational evidence for, and against, the use of L_{Edd} as a physically useful scale for accretion (this assumption underlies work ranging from observational comparison of neutron stars and black holes, to comparison of high luminosity black hole systems of very different masses). Assuming that the disk physics (and disk geometry) change when BH systems reach $\sim L_{Edd}$, we will scrutinize the observational and theoretical evidence for scenarios where the changes are due to radiation forces exceeding gravity and driving outflows, and probe whether other effects like radiation trapping could be more important (or explore whether both are equally important, or mass/spin dependent, etc). One of the main goals of this team will be to identify which aspects of the observed phenomenology (winds, spectral and variability changes) in accreting systems can be attributed to any of the possible physics describing $\sim L_{Edd}$ systems (e.g., are the observed SEDs – spectral energy distributions – for small, intermediate and large BH systems hint consistent with Eddington-limited accretion?). The role of a stellar surface (or lack thereof) should help pinpoint the dominant physical process (e.g. advection versus radiation forces), so we will also use the Team expertise in Eddington accretion onto Neutron Stars.

We will critically explore the relationship between mass accretion rate, luminosity and mass loss rate in winds for black holes of different masses, and try to answer whether current observations can already distinguish whether the winds are driven by magnetic or radiation forces. Understanding outflows in Eddington limited systems and pinpointing the similarities and differences observed from Galactic Black Holes, ultra-luminous X-ray sources (ULXs) and AGNs will be a key goal of this project, and only possible due to the broad expertise brought by the proposed Team. Our results will be tested against the fact that a factor of 10^8 difference in BH mass should reduce the disk surface temperature by a factor of ~100, and reduce the gas density by a factor of $\sim 10^8$. The microphysics may change drastically when we compare BHs which differ in mass by a factor of 10^8, so the observational constraints in AGN and XRBs will likely show us which are the most important physical ingredients for the formation of disk winds and other outflows. For example, opacities are very different in accretion disks around stellar mass black holes and supermassive black holes, and because this is what mediates the coupling between photons and matter, distinct behaviors are expected in these two regimes (e.g. Laor & Davis 2014). Furthermore, we aim to understand where exactly winds originate and are launched. The argument often used by observers is to tie the observed wind velocity to the escape velocity at the radius of origin of the wind. But that radius could simply be where the wind finally achieved the escape velocity, and so the wind could have been produced much closer to the black hole and been (gently) pushed out along a wide range of radii until it gets far enough out to escape. Those two possibilities would suggest very different underlying physics, so it is crucial to understand if we can disentangle them based on the observations and on simulations of these outflows. As mentioned before, mass loss in winds and jets appears to be an integral part of accretion processes in general across a wide range of objects, from young stellar objects to AGNs. Therefore we do not exclude the possibility that our work has much broader implications than just understanding accretion onto BHs.

As noted above, one of the most exciting and timely aspects of this proposal is that multiple groups now have tools available to numerically study near- and super-Eddington accretion, and that the proposed Team has members from each of these groups. Among the most general and important questions to be addressed by current and near-term simulations is how energy (both thermal and mechanical) and angular momentum are transported radially and vertically within the accretion flow, when accretion rates are near or above Eddington. This includes quantifying the importance of radiation trapping and studying the relative importance of radiation and magnetic fields in driving outflows. In this context, one of the most exciting things we will do during these meetings is discuss what the current simulations produce, as far as phenomenology (spectra/variability, concentrating on the latest unpublished results), and see if we can match any of them to observations. One related difficulty for the simulations is that they are spatially and temporally limited. Although we expect this to improve in the near future, at the moment it is not possible to run the simulations long enough to see spectral changes in a single simulation. Therefore, we plan to discuss strategies and designs of individual simulations that correspond to different spectral states. The combination of global and shearing box simulations should help us study behavior from very small to very large scales. The observational and theoretical expertise of this team is essential for this part of the project; we plan to discuss how present and future observations could help constrain the parameter space and/or models that theorists are currently working on. Based on these discussions, we plan to design and write new observing proposals for currently available (or soon to be launched – e.g. ASTROSAT, ASTRO-H) observatories.

Summary of the key questions to be addressed by the Team:

- *How far can the luminosity exceed the Eddington limit?*
- *What is the expected angular distribution of the radiation from a high* L/L_{Edd} *system?*
- *What is the expected spectral shape of a high* L/L_{Edd} *system?*
- *What is the expected mechanical wind luminosity of a high* L/L_{Edd} *system?*
- *What is the expected mass loss rate of a high* L/L_{Edd} *system, and how does the mass accretion rate into the black hole compare with the mass supply rate?*
- *What is the structure of radiation pressure driven outflows (smooth vs. clumpy)?*
- *Should jet emission be enhanced or suppressed in such high luminosity systems?*
- *What is the expected dependence on* M_{BH} *for each of the above questions?*
- *What causes the complex, ordered variability observed in high* L/L_{Edd} *stellar mass black holes, and how might this manifest itself at the scale of supermassive black holes?*
- *What is the role of a surface in high* L/L_{Edd} *Neutron Stars and how do observations compare with BH phenomenology?*
- *Which future observations and simulations can help us answer these questions?*

Not all these questions are independent; however we will first treat them separately: for each question we will compile all the clues currently available from observations, and formulate the available robust theoretical constraints. Then we will compare the results obtained for consistency.

This exercise should form the basis for future progress on our understanding of Eddington Accretion.

Added value provided by ISSI

The framework, facilities and reputation of the International Space Science Institute offers a unique opportunity to bring together a diverse group of specialists to discuss state of the art science, without the hassle of worrying about logistic issues which obviously arise when experts from all over the world try to meet. Establishing a collaboration among scientists with *different but complementary* expertise and approaches should result in a deeper understanding of Eddington-accretion physics. For this reason, the proposed Team is well balanced from different perspectives. We chose the city of Bern, as it is a central location for all Team members. Given the current world economical situation, the financial support provided by ISSI has allowed us to guarantee the best Team members. In other words, this framework has the perfect characteristics to allow this small group of experts with common interests to work towards tackling key and challenging aspects of the theoretical and observable physics of Eddington and Super-Eddington accretion onto black holes of different masses.

Team & Schedule

To achieve the goals of this project, a team consisting of experts in both the theoretical and observational aspects of Eddington and super-Eddington accretion is needed. By design, half our team is observational, and half theoretical. The member's scientific profiles cover all the needed expertise for the project, ranging from theoretical modeling of spectra and variability, large scale intensive MHD simulations, and observational studies of these extreme regimes from stellar mass Galactic BHs to supermassive BHs in AGNs, taking into account Neutron Stars and the debated possibility of the existence of intermediate mass BHs in ULXs. This ISSI project will allow us to establish a long-term and fruitful collaboration between experts in complementary specific fields worldwide, which have now agreed to collaborate and contribute to enhance the research in this fascinating field of high-energy astrophysics. The project results will be presented at international conferences and published in internationally recognized journals.

Given that the Team members are coming from 4 different continents and 6 different countries, we propose only two 5 days meetings at ISSI within 18 months of the start of this call. The first meeting will be between July and December 2014, and the second meeting about a year after that.

Facilities and Support Requested

Given that our meetings will involve lots of discussions around reviews/results presented by the different members, we only require the standard ISSI workshop facilities: a meeting room for up to 14 people (i.e. for the 12 core members + possibly 2 young scientists), equipped with data projection facilities, wireless and/or wired internet access, white board and/or paper boards and some printing facilities. Team members will have their own laptops, so no computer facilities are needed. We request support for the living expenses for 12 team members (plus two additional young scientists that we might add at a later date in accordance with the proposal guidelines) and travel support for the Team Leader.

References

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Education:

- Licenciatura en Astronomia, with Honours, 2003, Facultad de Ciencias Astronomicas y Geofisicas de La Plata, Universidad de La Plata, Argentina
- PhD, Astronomy, Thesis: "Different manifestations of accretion onto compact objects", Universiteit van Amsterdam, 2008

Employment:

- Senior Research Fellow from the Royal Society, University of Southampton, 2013-Present
- Postdoctoral Researcher, University of Amsterdam, 2008-2013

Publication Statistics (ADS)

- 210 publications, with 1465 citations (as March 27, 2014)
- 15 and 41 first author Refereed and non-Refereed publications, respectively, with a total of 354 citations.
- H-index of 20 (19 from refereed publications only)

Relevant publications for this proposal

- *The phase lags of high-frequency quasi-periodic oscillations in four black hole candidates,* Mendez M., Altamirano D., Belloni T. & Sanna A. 2013, MNRAS, 435, 2132
- *Discovery of a 34 Hz quasi-periodic oscillation in the X-ray emission of GRS 1915+105,* Belloni T. & Altamirano, D., 2013, MNRAS, 432, 19
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- *The Faint "Heartbeats" of IGR J17091-3624: An Exceptional Black Hole Candidate,* Altamirano et al. 2011, ApJ, 742, 17.

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EDUCATION

- *1980* High-School Diploma at C. Beccaria School in Milano
- *1986* Master Degree in Physics at Università degli Studi di Milano with a thesis on "Study of the X-ray emission from the binary system LMC X-3: Analysis of data from the EXOSAT satellite", Supervisor Prof. A. Treves

EMPLOYMENT HISTORY

1986-1987 IFCTR-MILANO Software production and X-ray/UV data analysis (EXOSAT and IUE satellites)
1988-1994 FELLOWSHIP MPE-GARCHING Member of the local ROSAT group. Responsible for the timing-analysis package for the ROSAT data analysis. Research in the field of X-ray binaries, cataclysmic variables and active binaries
1984-1996 MARIE-CURIE FELLOWSHIP, ASTRONOMICAL INSTITUTE "A. PANNEKOEK", UNIV. AMSTERDAM Research in the fields of X-ray binaries and active binaries
1996-1999 POSTDOC, ASTRONOMICAL INSTITUTE "A. PANNEKOEK", UNIV. AMSTERDAM Research in the fields of X-ray binaries and active binarie
1999-2009 ASSOCIATE ASTRONOMER INAF-OAB Research in the fields of X-ray binaries, ultra-luminous X-ray sources and active galactic nuclei
2009- "PRIMO RICERCATORE" INAF-OAB Research in the fields of X-ray binaries, ultra-luminous X-ray sources and active galactic nuclei

EXTERNAL POSITIONS

2012-2013 UNIVERSITY OF SOUTHAMPTON Leverhulme Visiting Professor

RESEARCH INTERESTS

- Accretion onto compact objects of low- and high-mass (white dwarfs, neutron stars, black holes of stellar, intermediate and galactic mass)
- Time series analysis of periodic and aperiodic signals. Rapid variability from compact objects
- Accretion-ejection connection in accreting compact objects. Ejection of relativistic jets
- Observational evidence of effects of General Relativity in the strong-field regime and fundamental physics in astronomy

RELEVANT PUBLICATIONS (2014 ONLY)

- Motta, S.E., Muñoz-Darias, T., Sanna, A., Fender, R., Belloni, T., Stella, L., 2013 *"Black hole spin measurements through the relativistic precession model: XTE J1550-564"*, MNRAS, 439, L65
- Pintore, F., Zampieri, L., Wolter, A., Belloni, T., 2014, *"Ultraluminous X-ray sources: a deeper insight into their spectral evolution"*, MNRAS, tmp/385
- Curran, P., et al., 2014, *"The evolving polarized jet of black hole candidate Swift J1745-26"*, MNRAS, 437, 3265
- Motta, S.E., Belloni, T.M., Muñoz-Darias, T., Stella, L., Fender, R., 2014, *"Precise mass and spin measurements for a stellar-mass black hole through X-ray timing: the case of GRO J1655-40"*, MNRAS, 437, 2554

PUBLICATION STATISTICS (FROM ADS AS OF 2014 MARCH 25)

Total number of publications on refereed journals: 264 (past 5 years: 87)
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Education

BSc with First Class Honours, Physics, 1983, Queen Mary College, University of London, UK.

DPhil, Physics, Thesis: *The Stability of Thick Accretion Disks*, 1986, International School for Advanced Studies (SISSA), Trieste, Italy.

Employment

Professor, Department of Physics, UCSB, 2004-present.

Associate Professor, Department of Physics, UCSB, 1998-2004.

Assistant Professor, Department of Physics, UCSB, 1993-1998.

Research Associate, Canadian Institute for Theoretical Astrophysics, University ofToronto, 1989-1993.

Chaim Weizmann Research Fellow, California Institute of Technology, 1986-1989.

Selected Recent Publications

A model of the steep power law spectra and high-frequency quasi-periodic oscillations in luminous black hole X-ray binaries; Dexter, J., & Blaes, O., 2014, MNRAS, 438, 3352.

Physical Properties of the Inner Shocks in Hot, Tilted Black Hole Accretion Flows; Generozov, A., Blaes, O., Fragile, P. C., & Henisey, K. B., 2014, ApJ, 780, 81 (10 pp).

Effects of Local Dissipation Profiles on Magnetized Accretion Disk Spectra; Tao, T., & Blaes, O., 2013, ApJ, 770, 55 (9 pp).

Variability from Nonaxisymmetric Fluctuations Interacting with Standing Shocks in Tilted Black Hole Accretion Disks; Henisey, K. B., Blaes, O., & Fragile, P. C., 2012, ApJ, 761, 18 (14pp).

Instrinsic disc emission and the Soft X-ray Excess in AGN; Done, C., Davis, S., Jin, C., Blaes, O., & Ward, M., 2012, MNRAS, 420, 1848-1860.

Local Radiation MHD Instabilities in Magnetically Stratified Media; Tao, T., & Blaes, O., 2011, ApJ, 742, 8 (14pp).

Dissipation and Vertical Energy Transport in Radiation-Dominated Accretion Disks; Blaes, O., Krolik, J. H., Hirose, S., & Shabaltas, N., 2011, ApJ, 733, 110 (24pp).

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Testing Accretion Disk Theory in Black Hole X-ray Binaries; Davis, S. W., Done, C., & Blaes, O. M., 2006, ApJ, 647, 525

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Relevant Publications	*Line Driven Winds and the UV Turnover in AGN Accretion Disks* Laor, A. & **Davis, S. W.**, 2014, MNRAS, 438, 3024 *On the Thermal Stability of Radiation Dominated Disks* Jiang, Y.-F., Stone, J. M. & **Davis, S. W.**, 2013, ApJ, 778, 65 *Saturation of the MRI in Strongly Radiation Dominated Accretion Disks* Jiang, Y.-F., Stone, J. M. & **Davis, S. W.**, 2013, ApJ, 767, 148 *Ultraluminous X-ray Sources Powered by Radiatively Efficient Two-Phase Super-Eddington Accretion onto Stellar Mass Black holes* Socrates, A., & **Davis, S. W.** 2006, ApJ, 651, 1049 *Testing Accretion Disk Theory in Black Hole X-ray Binaries* **Davis, S. W.**, Done, C. & Blaes, O. M. 2006, ApJ, 647, 525 A fulll NASA ADS linked list is maintained at http://www.cita.utoronto.ca/∼swd under the "Publications" link.

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Major Grants & Awards	NRC fellowship, NASA/GSFC USA (1990-92)
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	PPARC advanced fellowship, Durham (1994-1999)
	PI of PPARC standard grant (1996-1999: Dr Piotr Zycki £104,500)
	PI of PPARC standard grant (2000-2003: Dr Marek Gierlinski: £131,000)
	PI of PPARC standard grant (2004-2007: Dr Gierlinski/Schurch £167675)
	Co-PI of STFC standard grant (Dr Matt Middleton £341,969 2009-12)
	Co-Pi of STFC bridging grant (Dr Mineo/Sutton £281,962 2012-14)
Major Community Service	Chair of Chandra TAC 2008/2012
	Chair of XMM-Newton TAC 2010-12
	STFC Astronomy Grants Panel member 2010-12
	Chair of ESA INTEGRAL users group 2005-07
	ESA Astronomy Working group member 2001-05

Research Impact

Black holes are one of the most exotic concepts of modern physics – space so warped that even light is trapped inside. Some of their enormous gravitational potential energy can be released in as material spirals in towards the event horizon, and this energy often emerges in the form of X–ray radiation. My research focuses on bringing together both observational and theoretical aspects of accretion physics. An indicator of my success is that my 193 refereed papers to date (March 2014) have a total citaton count of 8076, a normalised citation rate of 2480, and an H-index of 51.

I have supervised 5 PhD (one of whom, Adam Ingram, won the RAS thesis Prize) and 3 MSc by research students (one of whom, Jeanette Gladstone, went on to win the AAS HEAD thesis prize).

P. Chris Fragile

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EDUCATION

University of Notre Dame	Physics	**Ph.D., 2001**
University of Notre Dame	Physics	**M.S., 2000**
Duke University	Physics	**B.S., 1993**

APPOINTMENTS

Assistant Professor College of Charleston, Charleston, SC, 2005-present

Postdoctoral Researcher UC Santa Barbara, Santa Barbara, CA, 2004-2005

Adjunct Faculty Las Positas College, Livermore, CA, 2002-2004

Postdoctoral Researcher Lawrence Livermore National Laboratory, Livermore, CA, 2001-2004

Arthur J. Schmitt Fellow University of Notre Dame, Notre Dame, IN, 1997-2001

Milstar Crew Commander 4th Space Operations Squadron, USAF, Falcon AFB, CO, 1993-1997

HONORS AND AWARDS

KITP Scholar, Kavli Institute of Theoretical Physics (2011-13)
Phi Kappa Phi Honor Society (2012)
Distinguished Research Award, College of Charleston (2010)
J. Tinsley Oden Faculty Fellowship, University of Texas at Austin (2006)

SELECTED PUBLICATIONS

- M. A. Abramowicz & **P. C. Fragile**, *Foundations of Black Hole Accretion Disk Theory*, Living Reviews in Relativity, 16, 1 (2013)
- **P. C. Fragile**, A. Gillespie, T. Monahan, M. Rodriguez & P. Anninos, *Numerical Simulations of Optically Thick Accretion onto a Black Hole - I. Spherical Case*, Astrophysical Journal Supplement Series, 201, 9 (2012)
- **P. C. Fragile**, *Effective Inner Radius of Tilted Black Hole Accretion Disks*, Astrophysical Journal, 706, L246 (2009)
- **P. C. Fragile** & D. L. Meier, *General Relativistic Magnetohydrodynamic Simulations of the Hard State as a Magnetically-Dominated Accretion Flow*, Astrophysical Journal, 693, 771 (2009)
- **P. C. Fragile**, O. M. Blaes, P. Anninos, & J. D. Salmonson, *Global General Relativistic MHD Simulation of a Tilted Black-Hole Accretion Disk*, Astrophysical Journal, 668, 417 (2007)

CURRENT RESEARCH GRANTS

\$189,653	**P. C. Fragile** (PI) *RUI: Numerical Simulations of Optically Thick Accretion onto Black Holes*, NSF AST (9/12-8/15)
\$75,000	**P. C. Fragile** (PI) *Radiation Transport in Numerical Simulations of Black-Hole Accretion Disks*, ORAU/ORNL HPC (4/10-3/14)

RESUME - Ari Laor

ACADEMIC DEGREES

Year	Department	Institution	Degree
1981	Physics	Tel-Aviv University	B.Sc. (Cum Laude)
1990	Astrophysics	Tel-Aviv University	Ph.D.

ACADEMIC APPOINTMENTS

From-to	Institution	Rank/Position
8/2008-1/2009	IAS, Princeton	Member
5/2000-	Technion, Haifa	Associate Professor
10/1995- 5/2000	Technion, Haifa	Senior lecturer
1993-1995	Caltech, Pasadena	Research fellow
1990-1993	IAS, Princeton	Member
1986-1990	Tel-Aviv University	Research assistant

PUBLIC PROFESSIONAL ACTIVITIES

Chandra, XMM, Israel Science Foundation, ESO, review panels
2006- 2011 Scientific Editor for *The Astrophysical Journal*

PUBLICATIONS 2013-2014

Refereed papers in professional journals

1. J. Stern & A. Laor *Type 1 AGN at low z- III.The optical narrow-line ratios.* 2013, Monthly Notices of the Royal Astronomical Society, 431, 836-857

2. A. Baskin, A. Laor & F. Hamman *The average absorption properties of broad absorption line quasars at 800 ¡ rest ¡ 3000 , and the underlying physical parameters.* 2013, Monthly Notices of the Royal Astronomical Society, 432, 1525-1543

3. Y. Meiron & A. Laor *The kinematic signature of the inspiral phase of massive binary black holes*, 2013, Monthly Notices of the Royal Astronomical Society, 433, 2502-2510

4. J. Stern, A. Laor & A. Baskin *Radiation pressure confinement - I. Ionized gas in the ISM of AGN hosts.* 2013, Monthly Notices of the Royal Astronomical Society, in press, 21 pages

5. A. Laor & S. Davis *Line-driven winds and the UV turnover in AGN accretion discs.* 2014, Monthly Notices of the Royal Astronomical Society, in press, 15 pages

6. A. Baskin, A. Laor & J. Stern *Radiation pressure confinement - II. Application to the broad-line region in active galactic nuclei.* 2014, Monthly Notices of the Royal Astronomical Society, in press, 17 pages

Joseph Neilsen — Curriculum Vitae

Education and Employment

MIT Kavli Institute for Astrophysics and Space Research, Hubble Postdoctoral Fellow — 2014 – 2017

Boston University, Einstein Postdoctoral Fellow — 2012 – 2014

MIT Kavli Institute for Astrophysics and Space Research, Postdoctoral Associate in High-Resolution X-ray Astrophysics — 2011 – 2012

Harvard University, PhD Candidate, Astronomy — 2006 – 2011

Selected Relevant Publications

Neilsen, J., et al. "A Link Between X-ray Emission Lines and Radio Jets in 4U 1630–47?" 2014, *ApJ*, 784, L5

Chakravorty, S., et al. "The Thermodynamics of X-ray Binary Winds Mapped to Accretion States." 2013, *MNRAS*, 436, 560

Neilsen, J. "The Case for Massive, Evolving Winds in Black Hole X-ray Binaries.". 2013, *AdSpR* 52, 732

Polyakov, Y. S., et al. "Stochastic Variability in X-ray Emission from the Black Hole Binary GRS 1915+105." 2012, *AJ*, 143, 148

Neilsen, J., et al. "Radiation Pressure and Mass Ejection in the ρ State of GRS 1915+105." 2012, *ApJ* 750, 71

Neilsen, J. and J. Homan. "A Hybrid Magnetically/Thermally-Driven Wind in the Black Hole GRO J1655-40?" 2012, *ApJ*, 750, 27

Ponti, G., et al. "Ubiquitous equatorial accretion disk winds in black hole soft states." 2012, *MNRAS*, 422, 11

Neilsen, J., et al. "Accretion Disk Wind Variability in GRS 1915+105." 2012, *MNRAS*, 421, 502

Neilsen, J., et al. "The Physics of the 'Heartbeat' State of GRS 1915+105." 2011, *ApJ* 737, 69

Neilsen, J. and J. C. Lee. "Accretion disk winds as the jet suppression mechanism in the microquasar GRS 1915+105." 2009, *Nature*, 458, 481

CURRICULUM VITAE

Name:	Hagai Netzer
Date and place of birth:	2.4.1945, Israel

Education

1969 - 1972 B.Sc. in Physics, Tel Aviv University, Cum Laude

1972 - 1975 Ph.D. in Astronomy, University of Sussex, U.K.

Academic and Professional Experience

Dates	Institution & Department	Position
1975–1977	Tel Aviv University, Physics and Astronomy	Post-Doctoral Fellow
1977–1979	Tel Aviv University, Physics and Astronomy	Lecturer
1977–1979	University of Texas at Austin, Astronomy	Assistant Professor
1979–1982	Tel Aviv University, Physics and Astronomy	Senior Lecturer
1983–1987	Tel Aviv University, Physics and Astronomy	Associate Professor
1980–1983	Tel Aviv University, Physics and Astronomy	Director, Wise Observatory
1983–1984	University of Texas at Austin, Astronomy	Associate Professor
1984–1985	Royal Greenwich Observatory	Royal Society Visiting Fellow
1985–1989	Tel Aviv University, Physics and Astronomy	Chairman, Department of Astrophysics
1987–2009	Tel Aviv University, Physics and Astronomy	Professor
1990–1991	Tel Aviv University, Physics and Astronomy	Director, Wise Observatory
1991–1992	NASA/Goddard Space Flight Center	Senior NRC fellow
1994–2001	Tel Aviv University, Physics and Astronomy	Director, Sackler Institute of Astronomy
1994–2011	Tel Aviv University, Physics and astronomy	Jack Adler Chair of Extragalactic Astronomy
1998–2000	Tel Aviv University	Member, Board of Governors
2003		Associate, Royal Astronomical Society
2005–2006	MPE Garching	Humboldt fellow
2009	Tel Aviv University	Professor Emeritus

References

Netzer, H., & Trakhtenbrot, B. 2014, , 438, 672

Du, P., Hu, C., Lu, K.-X., et al. 2014, ApJ, 782, 45

Wang, J.-M., Du, P., Valls-Gabaud, D., Hu, C., & Netzer, H. 2013, Physical Review Letters, 110, 081301

Slone, O., & Netzer, H. 2012, , 426, 656

Mor, R., & Netzer, H. 2012, , 420, 526

Trakhtenbrot, B., Netzer, H., Lira, P., & Shemmer, O. 2011, ApJ, 730, 7

Netzer, H., & Marziani, P. 2010, ApJ, 724, 318

Netzer, H. 2009, ApJ, 695, 793

Netzer, H., Lira, P., Trakhtenbrot, B., Shemmer, O., & Cury, I. 2007, ApJ, 671, 1256

Kaspi, S., Brandt, W. N., Maoz, D., et al. 2007, ApJ, 659, 997

Netzer, H. 2006, ApJ, 652, L117

Chelouche, D., & Netzer, H. 2003, , 344, 233

Chelouche, D., & Netzer, H. 2003, , 344, 223

Wang, J.-M., & Netzer, H. 2003, A&A, 398, 927

Netzer, H., Laor, A., & Gondhalekar, P. M. 1992, , 254, 15

Laor, A., Netzer, H., & Piran, T. 1990, , 242, 560

Netzer, H. 1987, , 225, 55

Netzer, H. 1985, , 216, 63

BIOGRAPHICAL SKETCH FOR CHRISTOPHER S. REYNOLDS

Professional preparation

Undergraduate	University of Cambridge, UK	Theoretical Physics	BA, 1992
Graduate	University of Cambridge, UK	Astrophysics	Ph.D., 1996
Postdoctoral	University of Colorado at Boulder	High-energy astrophysics	1996–2001

Appointments

2009–	Professor of Astronomy, University of Maryland, College Park
2005–2009	Associate Professor of Astronomy, University of Maryland, College Park
2001–2005	Assistant Professor of Astronomy, University of Maryland, College Park
1998–2001	Senior Research Associate & Hubble Fellow, University of Colorado, Boulder
1996–1998	Postdoctoral Research Associate, University of Colorado, Boulder

Awards/honors

2014–2015	Simons Fellowship in Theoretical Physics
2013	Hintze Lecturer (Oxford)
2012	Biermann Lecturer (Max Planck Institute for Astrophysics, Garching, Germany)
2005	Helen B. Warner Prize (American Astronomical Society)
1998–2001	Hubble Fellowship

Selected publications relevant to Proposal

1. *The spin of supermassive black holes*,
   C.S.Reynolds, 2013, Classical and Quantum Gravity, 30, 4004
2. *Constraints on Compton-thick winds from black hole accretion disks: can we see the inner disk?*,
   C.S.Reynolds, 2012, ApJL, 759, L15
3. *Global Simulations of Accretion Disks: Convergence & Comparisons with Local Models*,
   K.A.Sorathia, C.S.Reynolds, J.M.Stone, K.Beckwith, 2012, Astrophysical Journal, 749, 189
4. *Low-frequency Oscillations in Global Simulations of Black Hole Accretion*,
   S.M.O'Neill, **C.S.Reynolds**, M.C.Miller, K.A.Sorathia, 2011, ApJ, 736, 107
5. *Connections Between Local and Global Turbulence in Accretion Disks*,
   K.A.Sorathia, **C.S.Reynolds**, P.J.Armitage, 2010, ApJ, 712, 1241
6. *On the time variability of geometrically-thin black hole disks I : The search for modes in simulated disks*, **C. S. Reynolds**, M. C. Miller, 2007, ApJ, 692, 896

Synergistic Activities

2014–	AAS/HEAD Vice Chair (to become Chair in 2016)
2013	NASA Astrophysics 30 year Roadmap, panel member
2009–2010	NRC/Astro2010 Decadal Survey, member of Panel on Galaxies Through Cosmic Time
2003–2008	Chandra Users Committee, member and (from 2005–2008) chair
1993–present	Public engagement activities, including regular public talks

Graduate Students and Postdocs Supervised

Postdoctoral Advisor for Dr. Barry McKernan (2003–2005), Dr, Tamara Bogdanovic (2006–present), Dr. Sean O'Neill (2007–2010), Dr. Margaret Trippe (2009–present), Dr. Abdu Zoghbi (2011–present), Dr. Javier Garcia (2011–present), Dr. Francesco Tombesi (2011–present).

Research advisor to the following University of Maryland Graduate Students: Mark Avara (2010–present), Laura Brenneman (2003–2007), Alex Fitts (2013–present), David Garofalo (2002–2007), Drew Hogg (2013–present), Edmund Hodge-Kluck (2008–2011), Franziska Köckert (2003–2006), Anne Lohfink (2010–present), Halim Nalbant (2002), Kareem Sorathia (2007–2011), John Vernaleo (2002–2008), Lisa Winter (2004–2008), Yuxuan Yang (2001–2006).

ALEKSANDER SĄDOWSKI
Curiculum Vitae

Harvard-Smithsonian Center for Astrophysics
60 Garden Street, Cambridge, MA 02138 USA
617 496 7948 asadowski@cfa.harvard.edu

ACADEMIC QUALIFICATIONS:

Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Poland
Astrophysics Ph.D. (with honors), 2011

University of Warsaw, Poland
Astrophysics M.Sc. (with honors), 2006

APPOINTMENTS:

2011 — 2014
ITC Postdoctoral Fellow, Harvard-Smithsonian Center for Astrophysics

2014 — 2017
Einstein Postdoctoral Fellow, MIT Kavli Institute for Astrophysics and Space Research

GRADUATE AND POSTDOCTORAL ADVISORS

Postdoc Advisor (2011 — 2014)

Prof. R. Narayan (Harvard-Smithsonian Center for Astrophysics)

Graduate Advisor (2007 — 2011)

Prof. M. A. Abramowicz (Nicolaus Copernicus Astronomical Center, Poland and Goteborg University, Sweden)

Ph.D. thesis: "Slim Accretion Disks Around Black Holes"

MOST RELEVANT PUBLICATIONS FOR THE PROPOSAL

1. Numerical simulations of super-critical black hole accretion flows in general relativity, Sądowski, A., Narayan, R., McKinney, J. C., & Tchekhovskoy, A. MNRAS, 439, 503 (2014)

2. Energy, momentum and mass outflows and feedback from thick accretion discs around rotating black holes, Sadowski, A., Narayan, R., Penna, R., & Zhu, Y. 2013, MNRAS, 436, 3856 (2013)

3. Semi-Implicit Scheme for Treating Radiation Under M1 Closure in General Relativistic Conservative Fluid Dynamics Codes, Sadowski, A., Narayan, R., Tchekhovskoy, A., Zhu, Y., MNRAS, 429, 3533 (2013)

4. GRMHD Simulations of Magnetized Advection-Dominated Accretion on a Non-Spinning Black Hole: Role of Outflows, Narayan, R., Sadowski, A., enna, R. F., Kulkarni, A. K., MNRAS, 426, 3241 (2012).

Roberto Soria —Curriculum Vitae

Education, qualifications

PhD (2000): Research School of Astronomy & Astrophysics, Australian National University.
Dissertation: "Accretion Processes in Black-Hole Binaries".
Supervisor: Dr. Kinwah Wu (University of Sydney).

BSc + Hons (1994): Dept of Physics, University of Turin (110 cum laude, highest score).
Honours Thesis: "Space-time Measurements in the Gravitational Field of a Kerr Black Hole".
Supervisor: Prof. Fernando de Felice (University of Padova).

Work experience

2011– now: Senior Research Fellow, International Centre for Radio Astronomy Research (ICRAR); based at the Curtin Institute of Radio Astronomy (Perth).
2008–2010: Leverhulme Fellow, Mullard Space Science Laboratory, University College London.
2004–2007: Marie Curie Fellow, Harvard-Smithsonian Center for Astrophysics.
2000–2004: Research Fellow, Mullard Space Science Laboratory, University College London.

Selected Awards and honours

- Joint PI of a successful Australian Research Council Discovery Project ($300,000 over 3 years) for the study of X-ray binary jets (November 2011).
- Curtin University Senior Research Fellowship (Australia, 2011).
- Chinese Academy of Sciences Research Fellowship (2010, declined).
- Early Career Leverhulme Fellowship (UK; 2008).
- Marie Curie Outgoing International Fellowship (EU; 2004).

Refereed publication summary (ADS)

- 99 refereed publications published or in press with 2145 citations, 521 normalized citations.
- 43 first-author papers (849 citations).
- H-index = 29; normalized h-index = 11.

Selected publications relevant to this proposal

- "Super-Eddington mechanical power of an accreting black hole in M83", Soria, R., Long, K. S., Blair, W. P., Godfrey, L., Kuntz, K. D., Stockdale, C., & Winkler, P. F. 2014, Science, 343, 1330.
- "The fading of two transient ULXs to below the stellar-mass Eddington limit", Burke, M. J., Kraft, R. P., Soria, R., et al. 2013, Astrophys. J., 775, 21.
- "Bridging the gap between stellar-mass black holes and ultraluminous X-ray sources", Soria, R. 2007, Astrop. & Sp. Science, 311, 213.
- "Kinematics of the Intermediate-mass Black Hole Candidate HLX-1", Soria, R., Hau, G. K. T., & Pakull, M. W. 2013, Astrophys. J., 768, L22.
- "Eccentricity of HLX-1", Soria, R., 2013, Mon. Not. R. Astron. Soc., 428, 1944.