T P E N B N S

A Proposal for a Workshop at the Aspen Center for Physics

Summer 2007

Proposed dates

Preferred: July 29 - August 19

Acceptable: Starting after July 22

Impossible: June 17-July 28

We have two primary constraints.

1. The INT (Univ. Washington) workshop INT-07-2a, *The Neutron Star Crust and Surface*, which will run from June 18–July 20, 2007. At least two of the organizers will be attending that meeting, and many possible participants for our meeting may want to attend the INT workshop as well.

2. A symposium on nuclear astrophysics at Caltech, *Nuclear Astrophysics: Beyond the First 50 Years*, July 24–July 27. This will involve two of the organizers and many of our possible participants as well.

These two meetings will attract many leading international scientists in neutron star physics and nuclear astrophysics to the US. We therefore ask our meeting be timed to be adjacent with this second workshop to maximize international participation. The most critical constraint is with the INT program because of its strong overlap and synergy with this proposal. A very early workshop (before June 17) would be unattractive because the long (5 week) gap to the Caltech symposium would necessitate multiple trips for international nuclear physicists and astrophysicists. Likewise, a very late workshop is also less desirable because of the gap between the INT workshop and this one; in addition there will be a workshop in Santa Fe, *The First Cosmic Explosions*, August 27–31, that will draw off some of our proposed participants.

Proposed length of the workshop: 3 weeks
Other serious constraints: None at this time

Organizers

Brown, Edward F.	Michigan State Univ.	ebrown@pa.msu.edu	+1 517 355-9200 x2420
Heger, Alexander	Los Alamos Nat'l Lab.	alex@ucolick.org	+1 505 667-1184
Kuulkers, Erik	ESAC/ESA	Erik.Kuulkers@esa.int	+34-918131358
Schatz, Hendrik	Michigan State Univ.	schatz@nscl.msu.edu	+1 517 333-6397

Contacts available for consultation . . . . . Brown and Heger
Organizer responsible for ensuring diversity . . . . . Schatz

Proposed Scientific Advisory Committee

The following individuals have agreed to serve in an advisory capacity for the program. Names in boldface have also committed to coming.

Bildsten, Lars	UCSB/KITP
Cumming, Andrew	McGill University
in 't Zand, Jean	SRON
Kalogera, Vicky	Northwestern University
Langanke, Karlheinz	GSI
Wiescher, Michael	Univ. Notre Dame
Woosley, Stanford E.	UCSC

1 Scientific Justification

We are in a renaissance of X-ray astronomy, with a number of observatories of unprecedented capabilities in orbit, including *Chandra*, *XMM*, *INTEGRAL*, and *RXTE*. Together with *BeppoSAX* these facilities have revolutionized the study of galactic X-ray binaries—the brightest X-ray sources in the sky. Many of these are low-mass X-ray binaries (LMXB's) consisting of neutron stars that accrete matter from a low-mass companion star in a close orbit.

With the launch of *RXTE* and *BeppoSAX*, which devoted much time to observing LMXB's, many new discoveries were made that revived the field of accreting neutron stars. Of particular importance are type I X-ray bursts, thermonuclear explosions on the surface of the accreting neutron star. These bursts are the result of the accretion of hydrogen or helium-rich matter from the companion over hours to days. This accumulated matter forms a thin (10 m) layer on the neutron star until the temperature and density at the base of the layer are sufficient for nuclear reactions to ignite. At that point, a thermonuclear runaway ensues that fuses hydrogen and helium into heavier nuclei. The explosive nuclear energy release of typically 10^{38}–10^{40} ergs powers a bright X-ray burst that lasts for 10–100 s. There are about 80 of these systems known in our Galaxy. Because of the X-ray bursts we are able to identify the compact objects in these systems to be neutron stars. Since such X-ray bursts recur on an hourly to daily timescale, these bursts are the most common astrophysical thermonuclear explosions in the universe!

Five years ago (roughly 25 years after the discovery of type I X-ray bursts), superbursts were discovered. These are similar to type I X-ray bursts, but are roughly 1000 times more energetic, recur on a roughly yearly timescale, and last for hours. These bursts are thought to be caused by thermonuclear ignition of the *ashes* of X-ray bursts at much greater densities. In addition to superbursts, over the last decade new observations have revealed a whole range of new phenomena that are moving the field of neutron star research forward at a rapid pace. These include quasi-periodic millisecond oscillations during X-ray bursts, absorption lines in the X-ray spectra during a burst, and monitoring of long-term secular changes in burst behavior as a function of the varying accretion rate. These new observations have opened up new vistas for studying neutron stars. Accretion increases the neutron star's mass, torques the neutron star's spin, and heats the neutron

star's interior. Compared to their isolated brethren, the rich phenomenology of accreting neutron stars allows one to probe the properties of dense matter in entirely new ways.

These new discoveries have raised many open questions. For example, the origin of the millisecond oscillations and the observed frequency drift during the burst is not understood, although the frequency is likely related to the spin frequency and the oscillation is possibly a non-radial surface mode. Superbursts are most likely powered by the explosion of an accumulated layer of carbon at great depth, but observed recurrence times are not consistent with our best estimates of the temperature of the neutron star's crust, and X-ray burst models do not produce enough carbon. Finally, bursts become intermittent at accretion rates above ≈ 0.1 of the Eddington accretion rate, and the integrated burst fluence indicates a mix of stable and unstable burning. This behavior is not reproduced by state-of-the-art, fully-resolved, one-dimensional simulations.

In addition to understanding the phenomenology of X-ray bursts and superbursts for their own sake, these events are important probes of the neutron star's interior. These bursts affect, and are affected by, the temperature of the deep crust and core of the neutron star. As a result, there has been renewed interest in the nuclear processes occurring in the inner and outer crust. For several accreting neutron star systems, the accretion is intermittent and shuts off over periods of several years. During this time, the crust cools and releases the heat deposited by nuclear reactions during the accretion phase. Monitoring of the neutron star provides information on the cooling rate and hence the thermal properties of the crust and core. The heating in the deep neutron star interior comes from electron captures in the outer crust that drive the composition of an accreted fluid element toward neutron drip. There is a great need to understand the nuclear processes involving these nuclei in order to accurately determine the induced crustal heating. What happens beyond neutron drip is under debate: some suggest that neutron captures drive the composition towards equilibrium while others find that electron captures associated with neutron emission continually decrease the nuclear charge until pycnonuclear fusion reactions set in.

2 Description of Proposed Activities

The goal of the proposed workshop is to gather experts in recent observational data, experimental and theoretical nuclear physics, and in numerical and analytic modeling of bursts and superbursts, to nurture the development of new collaborations between experts in different fields, and to draw a roadmap for future research in this field. The tight integration of all these aspects is essential to understand the physics of accreting neutron stars. A particularly important goal is to explore how the wide range of different phenomena can be used to address the more fundamental physics questions concerning the properties of neutron stars and cold dense nuclear matter in general. The organizers and scientific advisory committee represent all of these fields. Among the organizers, Brown and Heger are experts in numerical and analytic modeling, Kuulkers is an authority on observations, and Schatz is a leader in studying the nuclear physics of accreting neutron stars. Among the scientific advisors, we have experts in analytical modeling of accreting neutron stars (Bildsten and Cumming), observations (in't Zand), systems and progenitors (Kalogera), numerical modeling (Woosley), nuclear experiment (Wiescher), and nuclear theory (Langanke).

Currently observations drive theory. Clear theoretical predictions need to be identified that are testable with current and planned observational capabilities. To address the open questions listed above and to use bursts as probes of dense matter physics requires an extremely wide range of

physics input. This includes the physics of nuclei from the proton drip line during X-ray bursts to the neutron drip line in the deep crust; the physics of the nuclear equation of state in the core; the physics of fluid motions during X-ray bursts and superbursts; the physics controlling thermal balance in the crust, and the physics of radiation transport and spectral formation at the photosphere. These physical ingredients must be coordinated with detailed numerical models of X-ray bursts and superbursts. Detailed modeling of X-ray bursts is now an emerging field. For example, we now have a much better understanding of the burst nucleosynthesis via the αp and *rp*-processes. Extending these one-dimensional calculations to two and three dimensions is crucial for understanding the physics of burst oscillations and nuclear flame propagation. Additionally, stellar evolution models can be used to place the bursts in context of the mass transfer history of the binary.

The reason for proposing to hold the workshop at the Aspen Center for Physics (ACP) is that the environment of the ACP is conducive for forging links in this complex field between observers, nuclear physicists, and astrophysicists, as well as fostering ties between theory and numerical modeling. There have been two small workshops on X-ray bursts: in 2003 at the IAS and in 2004 at UCSB (sponsored by JINA). These workshops stimulated efforts that have contributed to some of the recent advances described above. For example, the 2004 workshop (sponsored by the Joint Institute for Nuclear Astrophysics) led to studies of whether rp-process nuclei could be ejected from the neutron star; the nature of the bursts towards the onset of stability; and the role of sedimentation in the burst nucleosynthesis. The larger list of participants and longer duration offered by a Workshop at the ACP would extend such opportunities for new ideas and new collaborations.

The reason for holding such a workshop in summer 2007 is that that year is the perfect time to bring together the various research activities in this area. Over the last years, tremendous observational progress has been made, and first attempts for a theoretical understanding of isolated aspects of the new problems are underway and are likely to have progressed further by then. Holding this workshop summer 2007 is also synergic with the aforementioned INT workshop on nuclear physics in the neutron star crust.

A specific side goal of this workshop is to compile a classification of X-ray burst phenomena from both observational and theoretical perspectives, and to determine and quantify the key discrepancies and model insufficiencies that still exist. We envision this as a set of notes from the sessions that would be typed up and made available to the community via the web. This document should answer the questions: What are the main problems? What are some possible solutions? How can they be tested? If the participants are sufficiently interested, we will consider producing a proceedings from this workshop and publishing it in a journal such as *New Astronomy Reviews*. The proceedings would serve as a roadmap for future research directions in this field.

Because of the interdisciplinary nature of this field, we envision holding four morning "tutorials" on observations, theory and modeling, nuclear physics, and systems and progenitors. These would be spread out over the three weeks, and in addition there would be a 2–4 other morning topical sessions. Afternoons would be free for discussion and could be used by working groups that arise from these sessions. Once per week there will be a lunch/afternoon session devoted to brainstorming projects for future collaborations, and to work on the side goal.

3 Possible Participants

Below are listed possible participants, organized by area of expertise. There are a total of 94 individuals listed, of whom 13 are women (female participants are marked with an asterisk). We indicate postdocs (15 listed) with a †. To avoid future confusion, we note that these lists also include people listed from the organizers and Scientific Advisory Committee. Of the potential participants more than 50 have alreday committed they will apply (inidicated by "$^+$") should the program be approved.

Observations

Bazzano, Angela*$^+$	INAF/IASF, Rome
Bhattacharyya, Sudip	Univ. Maryland
Brandt, Soren	DNSC, Denmark
Casares, Jorge$^+$	IAC
Chakrabarty, Deepto$^+$	MIT
Charles, Phil	SAAO
Chenevez, Jerome	Danish National Space Center
Cocchi, Massimo	INAF/ISAF, Rome
Cornelisse, Remon†	Southampton Univ.
Cottam, Jean*$^+$	NASA/GSFC
Fennimore, Ed$^+$	LANL
Galloway, Duncan†$^+$	Univ. Melbourne
Heise, John	SRON$^+$
Hynes, Robert	Louisiana State Univ.
in 't Zand, Jean	SRON
Jonker, Peter	SRON$^+$
Juett, Adrienne*†	Univ. Virginia
Kaaret, Philip$^+$	Iowa Univ.
Kuulkers, Erik$^+$	ESA
Lewin, Walter$^+$	MIT
Markwardt, Craig	NASA/GSFC
Muno, Michael†	UCLA
Paerels, Frits$^+$	Columbia Univ.
Revnivtsev, Mikhail$^+$	MPA
Rutledge, Robert	McGill Univ.
Steeghs, Danny$^+$	CfA
Strohmayer, Tod	NASA/GSFC
Swank, Jean*$^+$	NASA/GSFC
Wachter, Stefanie*	Caltech
Wijnands, Rudy$^+$	Univ. Amsterdam

Nuclear Data: Theory

Brown, Alex^{+}	MSU
Carlson, Joesph	LANL
Gupta, Sanjib†$^{+}$	MSU
Haensel, Pawel	Warsaw
Hoffman, Rob	LLNL
Langanke, Karlheinz^{+}	GSI
Martinez-Pinedo, Gabriel	GSI
Möller, Peter^{+}	LANL
Pruet, Jason	LLNL
Reddy, Sanjay^{+}	LANL
Thielemann, Friedel	Basel
Yakolev, Dima	Ioffe Physico-Technical Inst., St. Petersburg

Nuclear Data: Experiment

Buchmann, Lothar	TRIUMF
Blackmon, Jeff	ORNL
Clark, Jason†$^{+}$	Yale
Iliadis, Christian	UNC
Kratz, Karl-Ludwig^{+}	Universität Mainz
Lynch, Bill^{+}	MSU
Parker, Peter	Yale
Rehm, K. Ernst^{+}	ANL
Schatz, Hendrik^{+}	MSU
Sherrill, Brad^{+}	MSU
Tsang, Betty*$^{+}$	MSU
Wiescher, Michael^{+}	Univ. Notre Dame

Astrophysics Theory

Arras, Phil	UCSB/KITP
Bildsten, Lars^{+}	UCSB/KITP
Brown, Edward F.$^{+}$	MSU
Chabrier, Gilles	Ecole Normale Supérieure de Lyon, CRAL
Chang, Phillip†	UCB
Cumming, Andrew^{+}	McGill Univ.
Gnedin, Oleg^{+}	Ohio State Univ.
Fisker, Jacob†$^{+}$	Univ. Notre Dame
Heger, Alexander^{+}	LANL
Heyl, Jeremy	UBC
Jose, Jordi	Institut d'Estudis Espacials de Catalunya
Levin, Yuri^{+}	Leiden Univ.

Madej, Jerzy	Warsaw Univ.
Miller, Cole	Univ. Maryland
Morsink, Sharon*$^{+}$	Univ. Alberta
Narayan, Ramesh^{+}	CfA
Özel, Feryal*$^{+}$	Univ. Arizona
Page, Danny^{+}	UNAM
Peng, Fang*†$^{+}$	Chicago
Piro, Tony†$^{+}$	UCB
Potekhin, Alexander^{+}	Ioffe Physico-Technical Inst.
Psaltis, Dimitrios	Univ. Arizona
Spitkovsky, Anatoly†$^{+}$	KIPAC/SLAC
Sunyaev, Rashid	MPA
Taam, Ron	Northwestern Univ.
Titarchuk, Lev	George Mason Univ.
Truran, James T.	U Chicago
Wasserman, Ira	Cornell
Watts, Anna*†$^{+}$	MPA
Weinberg, Neven†$^{+}$	UCB
Woosley, Stan$^{(+)}$	UCSC
Zane, Sylvia*	MSSL, UK
Zingale, Mike	SUNY Stony Brook

Systems and Progenitors

Baraffe, Isabelle*	Ecole Normale Supérieure de Lyon, CRAL
Belczynski, Chris†	NMSU
Deloye, Chris†$^{+}$	Northwestern Univ.
Langer, Norbert^{+}	Utrecht Univ.
Kalogera, Vicky*$^{+}$	Northwestern Univ.
Nelemans, Gijs^{+}	Nijmegen Univ.
Podsiadlowski, Philip	Oxford
Pols, Onno^{+}	Utrecht
Rappaport, Saul^{+}	MIT
Rasio, Fred^{+}	Northwestern Univ.

Appendix

A Replies / Letters of support

Attached we provide a few select of the replies that we received on our request whether people would be willing to commit to apply for the workshop if it was funded. This was not a solicitation of support letters.

A.1 Karlheinz Langanke

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Dear Alex

as I told you already on the phone, I am certainly very interested in
attending the workshop. further, I promised to help perhaps to
organize if wished

Best regards  Karlheinz

Karlheinz Langanke
GSI Darmstadt                          Tel:   +49 6159 71 2747
Planckstr. 1                           Fax:   +49 6159 71 2990
D-64291 Darmstadt                      Mobil: +49  162 2354602
Germany
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A.2 Alexander Potekhin

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Dear colleagues,

By this e-mail message I confirm that I would consider to apply
for a workshop on the Physics of Explosive Nuclear Burning on
Neutron Stars. I concur with your opinion that such a workshop is
needed in view of the impressive progress in observations of
accreting neutron stars and X-ray bursts, and the discovery of
superbursts. Such a workshop, which would put together the
specialists in nuclear physics, neutron star theory, and
observations, would be certainly very useful for fostering the
study of these objects and phenomena.

Best regards,

Sincerely yours,

Alexander Potekhin
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Alexander Potekhin [Cand.Sci.(PhD), Senior Res. Sci.]
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http://www.ioffe.ru/astro/DTA/palex/palex.html

A.3 Sanjay Reddy

Dear Alex,

I would be interesting in coming to the workshop - for the entire three weeks. The subject is very exciting and the timing is very appropriate. You should however be aware the next summer June 18-July 18 there will be an INT program on Neutron Star Crusts. I plan to be there for this meeting. Please keep this in mind when deciding on the dates.

Cheers,

Sanjay

Sanjay Reddy
Staff Scientist
Theoretical Division
Los Alamos National Lab.
Tel: 505 665 0455

A.4 Jurek Madej

Dear Colleaugues,

I thank you very much for mailing to me your note regarding your proposal on the workshop "The Physics of Explosive Nuclear Burning Bn Neutron Stars" in 2007. The subject of this workshop is extremely important for me and, personally, I am interested very much in the success of the submission of your project.

(...)

Best regards,

Jurek Madej

A.5 Ramesh Narayan

Dear Ed et al.,

I am very glad that you are proposing this workshop to the Aspen Center for Physics. I would certainly be interested in coming for at least part of the time (...) so please feel free to mention my interest when you submit the proposal.

Good luck with the proposal!

Ramesh Narayan

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Ramesh Narayan
Thomas Dudley Cabot Professor of the Natural Sciences, Harvard University
Harvard-Smithsonian Center for Astrophysics telephone: (617) 496 9393
60 Garden Street, MS 51 fax: (617) 495 7093
Cambridge, MA 02138, U.S.A. e-mail: narayan@cfa.harvard.edu
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A.6 Feryal Ozel

Hello organizers,

I would be very interested in attending a workshop on neutron star bursts in Aspen. I would very likely want to stay the whole 3 weeks (especially if it's in the second half of the summer).

Great idea and I hope the proposal goes through easily. Regards,

Feryal

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