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PI/PD Name: William G Lynch

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.

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PI/PD Name: Pawel D Danielewicz

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: William A Friedman

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Bao-An Li

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☒ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☐ U.S. Citizen ☒ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: ManYee B Tsang

Gender: ☐ Male ☒ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☒ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status: (Select one or more)
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- ☒ None

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2

NSF 00-138 **11/15/02**

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

INT - EAST ASIA AND PACIFIC PROGRAM

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				053343976	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)

386005984

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

Michigan State University

AWARDEE ORGANIZATION CODE (IF KNOWN)

0022905000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

Michigan State University
Contracts & Grants Department
East Lansing, MI. 488241046

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

PERFORMING ORGANIZATION CODE (IF KNOWN)

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Isospin Dependence of Reaction Dynamics**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ **71,020**	**36** months	**03/01/03**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
☐ HISTORIC PLACES (GPG II.C.9)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date _____
☐ HUMAN SUBJECTS (GPG II.C.11)
Exemption Subsection _____ or IRB App. Date _____
☒ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.9)
Chin
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT

Nat.SuperconductingCyclotronLab.

PI/PD FAX NUMBER

517-353-5967

PI/PD POSTAL ADDRESS

South Shaw Lane
National Superconducting Cyclotron Lab
East Lansing, MI 48824
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **William G Lynch**	**Ph.D.**	**1980**	**517-333-6319**	**Lynch@nscl.msu.edu**
CO-PI/PD **Pawel D Danielewicz**	**Ph.D.**	**1981**	**517-333-6330**	**danielewicz@nscl.msu.edu**
CO-PI/PD **William A Friedman**	**PH.D.**	**1966**	**608-262-3051**	**friedman@nucth.physics.wisc.edu**
CO-PI/PD **Bao-An Li**	**Ph.D**	**1992**	**870-972-3086**	**bali@navajo.astate.edu**
CO-PI/PD **ManYee B Tsang**	**PhD**	**1980**	**517-333-6386**	**Tsang@nscl.msu.edu**

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 02-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix A of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix B of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		04/24/01

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

International Programs Cover Page Addendum

Country #1: United States
Country #2: China
Country #3: China

Proposal Category: Cooperative Research (C)

Foreign Counterpart Investigator/Organizer/Host #1:

Name: Jin, Genming
Department: Institute of Modern Physics
Institution: Chinese Academy of Sciences
Address: 363 Nanchang Road
730000,
Lanzhou, China.
Phone: 869314969221
Fax: 869314969201
Email: jingm@impcas.ac.cn

Foreign Counterpart Investigator/Organizer/Host #2:

Name: Xu, Hushan
Department: Institute of Modern Physics
Institution: Chinese Academy of Sciences
Address: 363 Nanchang Road
730000,
Lanzhou, China.
Phone: 869314969221
Fax: 869314969201
Email: hushan@impcas.ac.cn

Foreign Counterpart Investigator/Organizer/Host #3:

Name: Zhuxia, Li
Department: Physics
Institution: China Institute of Atomic Energy
Address: P.O. Box 275(18)
102413,
Beijing, China.
Phone: 861069357208
Fax: 861069357008
Email: lizwux@iris.ciae.ac.cn

For Joint Seminar or Workshop:

Location

City:

Country:

Start Date:

End Date:

Demographics(people that will be supported by this project):

- Number of senior U.S. scientists and engineers (excluding those within 6 years of their Ph.D. and graduate and undergraduate students): 5
- Number of U.S. scientists within 6 years of the Ph.D.(including the PI and/or Co-PI if applicable): 1
- Number of U.S. graduate students: 1
- Number of U.S. undergraduate students: 0
- Number of foreign scientists and engineers (including post-docs, graduate and undergraduate students) associated with the foreign institution. Include only those who will be supported under this NSF proposal. Do not count foreign participants who will be supported by non-NSF funds: 6

Project Summary

Collisions with rare isotope beams offer opportunities to study the properties of compressed and rarified asymmetric nuclear matter. Foremost among these properties is the equation of state of asymmetric nuclear matter. This is an important issue identified in the recent U.S. long-range plan (LRP) for nuclear physics and a fundamental property that governs many aspects of neutron stars. It is also a key component of the reaction program at the NSCL with rare isotope beams and to plans for future facilities such as the Lanzhou storage ring or the Rare Isotope Accelerator, identified as the top priority for new construction in the U.S. LRP for nuclear physics.

The achievement of this goal requires significant improvements in theory and a better understanding of the sensitivities of the experimental observables to the equation of state and other physical properties. We propose a broadly based collaboration between scientists in the U.S. and China to address how such information may be extracted from nuclear collisions. It brings together experts in transport and statistical theories from the U.S. and China along with experimentalists that have unique data relevant to these questions.

The support requested here would allow the development of this collaborative project, which is very close to the scientific interests and expertise of the groups, their institutes and to the overall scientific effort in both countries. It will allow meaningful participation of graduate students and post-docs on this international scientific effort.

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US-China Collaborative Research – Isospin Dependence of Reaction Dynamics

Introduction

Beams of rare isotopes provide opportunities to prepare and study the dynamical evolution of nuclear systems with a range of isospin asymmetries, characterized by $\delta=(N-Z)/(N+Z)$. Such systems can be prepared using beam and target pairs of similar isospin asymmetry. This increases the probability that a spatially uniform local isospin asymmetry $\delta(r)$ may be achieved[1] and renders the systems more suitable for investigating the density dependence of the asymmetry term of the nuclear equation of state (EOS). Alternatively, systems can be prepared using beam and target pairs with very different isospin asymmetries. This isospin "tagging" permits more sensitive tracking of the transport and diffusion of neutrons and protons during collisions, information that is key to testing and refining theoretical models of such collisions.

The neutron star radii, matter distributions, moments of inertia, and the cooling rates of proto-neutron stars are all strongly dependent on the density dependence of the asymmetry term of the nuclear EOS [1,2]. Currently the only terrestrial means of creating and investigating subnormal or supernormal nuclear matter is through the collisions of heavy ions. Recently, progress has been made in placing significant constraints on the symmetric matter EOS [3]. These studies show that current uncertainties in the isospin symmetric terms of the EOS may contribute much less to the overall uncertainty in neutron star characteristics than do the corresponding uncertainties in the density dependence of the asymmetric term [3]. Calculations predict that measurements of both transverse flow and particle emission rates, as a function of the isospin of the emitting system and of the emitted particles, can provide information about the density dependence of the asymmetry term of the EOS. [4-6]

As pioneering measurements are being planned for facilities such as the National Superconducting Cyclotron Laboratory (NSCL), the Lanzhou Storage Ring and the Rare Isotope Accelerator (RIA), the choices of appropriate beams, targets, incident energies and experimental observables require important theoretical input. In particular, theoretical predictions are sensitive to the production of clusters [7], to the local and non-local mean fields, to the isospin dependent

[1] Here, $\delta(r) = (\rho(r)_n - \rho(r)_p)/(\rho(r)_n + \rho(r)_p)$ where ρ_n and ρ_p are the neutron and proton densities.

nucleon-nucleon cross-sections [8] and to the description of nuclear surfaces. For many of the relevant observables, the decay of long-lived bound fragments needs to be carefully handled because the influence of such long-lived decays on the experimental yields is often significant [9]. Thus, improvements in these descriptions are needed before comparisons between such calculations and experimental data can provide definitive constraints on the asymmetry term. Furthermore, additional work is needed to identify the most sensitive observables for constraining the asymmetry term at supernormal densities.

To examine and utilize the scientific opportunities provided by heavy ion reaction studies with rare isotope beams, we have assembled a broadly based theoretical and experimental collaboration. On the theoretical side, the proposed collaboration has expertise in the application of Boltzmann-Uehling-Uhlenbeck (BUU) [10-12] and Quantum Molecular Dynamics (QMD) [13,14] transport theories to study isospin effects in nuclear reactions. The basic inputs to these transport theories are the equation of state, elementary hadron-hadron scattering cross sections and information about the nucleon density profiles in the ground state of the colliding nuclei. We also have the expertise to calculate these quantities consistently using the same modern nuclear interaction within the Brueckner-Hartree-Fock (BHF), Dirac Brueckner Hartree-Fock (DBHF) and Relativistic Mean Field (RMF) approaches [15,16]. In particular, the single-particle potentials, effective masses and the mean-free paths of neutrons and protons in asymmetric nuclear matter were recently calculated within the BHF approach by one of the Chinese PI's. We plan to implement these results into the transport models by making both the isospin-dependent and –independent parts of the mean field momentum-dependent accordingly. In addition, we also have expertise in statistical models such as the Expanding Evaporating Source (EES) model [17] statistical rate equation and the equilibrium Statistical Multifragmentation Model (SMM) [9] to examine isospin effects in multifragmentation. Finally, we have an ongoing experimental program at the NSCL that is obtaining unique experimental data that can motivate these calculations and test their predictions.

The main goal of the current collaboration, which involves both experimentalists and theorists from different institutes in USA and China, is to better understand the dynamics of systems at large isospin asymmetry. We believe that such knowledge will enable us to study the density dependence of the asymmetry term of the EOS using heavy ion collisions. This proposal describes our planned program.

Reactions to be studied

The specific study of the density dependence of the asymmetry term of the EOS requires an experimental program that spans a broad range of incident energies in order to explore a broad range of maximal densities. We first describe some of the differences between intermediate and high-energy heavy ion reactions to provide a context for the models to be used. Then, we discuss some of the observables we plan to explore. Finally, we provide more specific descriptions of the models

Intermediate energy heavy ion reactions:

At incident energies in excess of about E/A=50 MeV, a rapid collective expansion of the combined system occurs during the later stages of a central collision between heavy nuclei [18,19]. Experimental evidence indicates that both intermediate mass fragments (IMF's) with $3 \leq Z \leq 30$ and light charged particles ($Z \leq 2$) are emitted during this expansion stage. The mean field potential for a nucleon, a quantity closely related to the EOS, is usually assumed to have a quadratic dependence on the asymmetry, $E_{sym}(\rho)\delta(r)^2$, where, as given above, $\delta(r) = (\rho_n - \rho_p)/(\rho_n + \rho_p)$ [1,2]. For heavy systems in which the neutron density exceeds the proton density, the effect of this asymmetry term is repulsive for neutrons and attractive for protons. The asymmetry term consequently enhances the dynamical emission of neutrons relative to protons and leads to differences between the flows of neutrons and protons during the collision [20]. The enhancement of neutron emission relative to proton emission is predicted to be sensitive to $E_{sym}(\rho)$, and hence to the sought after density dependence of the EOS.

Experiments to search for and identify such effects have already been started. In particular, the NSCL group studied the collisions of different combinations of ^{112}Sn and ^{124}Sn isotopes using a large area strip detector array (LASSA) in conjunction with the MINIBALL 4π multifragment detection array [21,22]. Included in these measurements are symmetric systems such as ^{124}Sn+^{124}Sn (δ=0.194) and ^{112}Sn+^{112}Sn (δ=0.107) that differ significantly in their isospin asymmetry as well as asymmetric systems ^{112}Sn+^{124}Sn and ^{124}Sn+^{112}Sn. Some of these measurements are discussed briefly in the subsequent sections describing the phenomena to be studied. In the next year, the NSCL group will measure the neutron and proton energy spectra and transverse flow data for the two symmetric systems. These pioneering measurements are our first steps towards a comprehensive program to investigate the dynamics of systems with

extreme isospin using the radioactive beams of the recently completed NSCL Coupled Cyclotron Facility (CCF).

High energy heavy ion reactions:

The high-density behavior of the nuclear symmetry energy is especially important for understanding the internal structure of neutron stars and supernovae explosions [1,2]. The asymmetry term supplies essentially all the pressure supporting the star at densities equal to the saturation density of nuclear matter and at densities twice the saturation value, the asymmetry term may provide up to 70% of the pressure supporting the star [2].

Calculations show that twice the normal nuclear matter density can be reached in the central region of heavy ion collisions at incident energy of 150 MeV per nucleon. Experiments probing this high-density regime can therefore be conducted at the newly completed Coupled Cyclotron Facility. Later, these studies can be followed at higher density and higher asymmetry at GSI and with the next generation of accelerators such as the Rare Isotope Accelerator (RIA) planned in USA, and also with the new facility at RIKEN or the Lanzhou Storage ring currently under construction. Recently, the isospin dependence of pion production rates has been identified as a promising observable for studying the density dependence of the asymmetry term [20]. The collaboration plans to examine this observable more closely and see how this signal is influenced by the momentum dependence of the mean field. We plan extensive calculations to see how to optimize experiments for probing the high-density behavior of the asymmetry term. The insights gained will be useful for better designing experiments at the Coupled Cyclotron Facility and the Lanzhou Storage Ring.

Observables to be investigated

Isospin dependent emission rates in central collisions: light particles

Both the excitation energy and the local isospin asymmetry evolve dynamically during a collision in response to the density dependence of the asymmetry term. This time dependent response can be calculated with transport models such as the Boltzmann-Uehling-Uhlenbeck (BUU) equation [4,10-12,20] and the Quantum Molecular Dynamics (QMD) model [13,14], among others [5,6]. The largest density variations may be expected for central collisions at incident energies where the expansion drives the system to bulk disintegration. Because the

asymmetry term of the EOS in a neutron-rich system is repulsive for neutrons and attractive for protons, it influences the relative emission of neutrons and protons. Indeed, during such an expansion, transport models [6,4] predict that the pre-equilibrium emission of neutrons is increased relative to that for protons, when the density dependence of the asymmetry term is made weaker i.e., $E_{sym}(\rho)$ falls more slowly with decreasing density[2].

The NSCL experimental group is currently planning to measure the neutron and proton multiplicity energy spectra for central $^{112}Sn+^{112}Sn$ and $^{124}Sn+^{124}Sn$ collisions at E/A=50 MeV. BUU transport model calculations of the angle averaged neutron energy spectrum divided by the angle averaged proton energy spectrum for central collisions (b< 5 fm) are shown for the two Sn+Sn systems for different asymmetry dependences of the EOS [23]. There is a clear enhancement for the emission of energetic neutrons for the neutron rich systems with an EOS that has an asymmetry term with weak density dependence (asy-soft). This clearly observable effect diminishes for neutron deficient systems or if the asymmetry term has stronger density dependence.

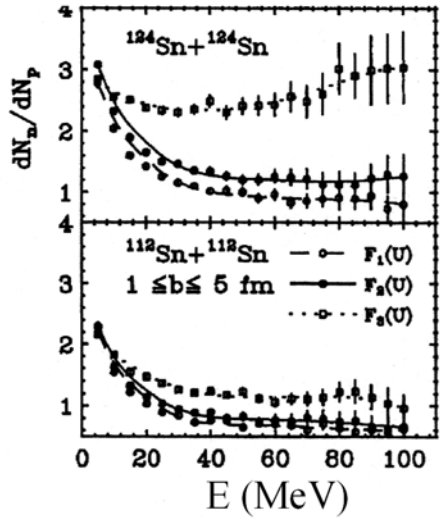

Figure 1: Ratio of neutron spectra averaged over scattering angle to proton spectra averaged over scattering angle as a function of the energy in the center of mass. The upper panel is for $^{124}Sn+^{124}Sn$ reaction and the lower panel is for $^{112}Sn+^{112}Sn$ reaction. In each panel, the upper curve corresponds to the calculations with the asy-soft EOS. The lowest curve corresponds to the asy-stiff EOS. The middle curve corresponds to an EOS with a density dependence of the asymmetry term that is intermediate between the other two [23].

Due to the low efficiencies of neutron detectors, we want to explore the possibility of extracting the same information by high quality comparisons of triton and ^3He spectra [5] using the transport calculations.

One goal of the proposed collaborative research will be to investigate how the inclusion of light clusters modifies nucleon observables predicted by BUU and QMD transport models.

[2] Note: An EOS with weaker density dependence is often termed “softer” and one with stronger density dependence is often termed "stiffer".

Because the QMD transport model also makes predictions for the production of heavier fragments, comparisons of BUU and QMD transport theories can permit one to assess how the production of heavier fragments influences the observables for nucleons and light clusters. Following a strategy frequently employed in the collective flow analyses at much higher incident energies [24], we plan to minimize the sensitivity to the uncertainties in the fragment production mechanism by identifying "coalescence invariant" observables [24] that can be constructed from the energetic light particle spectra and using them to constrain the density dependence of the asymmetry term.

All experimental light particle observables contain contributions from dynamical processes that can be simulated with transport models and slower statistical decay processes that are more accurately calculated by statistical decay codes. At intermediate energies, the kinematical domains populated by dynamical and statistical emission mechanisms are somewhat overlapping, therefore accurate calculations of experimental observables should take statistical decay mechanisms into account. The EES model contains standard nuclear evaporative decay as an option, and its fast and flexible algorithm permits one to explore the interplay between large-scale collective motions and the statistical decay mechanisms [17,25]. One objective of the proposed research is to provide comprehensive predictions for the experimental observables that include both dynamical and statistical decay contributions. We will develop this option using the EES model and will contrast the predictions with that of the equilibrium SMM code that has been developed explicitly to describe bulk multifragmentation [9,26].

Isospin dependent emission rates in central collisions: heavier fragments

We have made first attempts to extract information about the density dependence of the asymmetry term from fragment isotopic yield data for central ^{112}Sn+^{112}Sn and ^{124}Sn+^{124}Sn collisions at E/A=50 MeV. [22,27]. This work involves comparisons of isotope yields from two reacting nuclear systems of similar mass, similar excitation energy, but different charge-to-mass ratio [21,22,27]. In general, we find that the ratios of the measured isotopic yields $Y_1(N,Z)$ and $Y_2(N,Z)$ of two reactions (1 and 2), which occur at the same center of mass energy per nucleon, obey an "isoscaling" law

$$R_{21}(N,Z) = Y_2(N,Z) / Y_1(N,Z) = C \cdot \exp(\alpha N + \beta Z),$$

where C is a normalization constant, and α and β are isoscaling parameters which, to the first order, depend linearly upon the difference in the isospin asymmetry in the two reactions. This

isoscaling behavior is predicted by grand canonical multi-fragmentation theories. In these approaches the isoscaling parameters are related to the temperature and differences in the neutron and proton chemical potentials for the two systems. Microcanonical calculations also respect the isoscaling law as discussed in Ref. [28]. Generally, one expects the isoscaling parameters to depend on the isospin asymmetry and excitation energy per nucleon of the system undergoing multifragmentation, both of which evolve considerably prior to the multifragment breakup.

A hybrid approach calculates fragmentation observables with a statistical model using a source determined by a dynamical model. This approach is frequently employed to calculate fragmentation observables. Two different statistical approaches have been attempted for this latter stage: one, the Expanding Emitting Source (EES) formalism, in which fragments are emitted sequentially from the surface of the system as it expands [17], the other, an equilibrium multifragmentation model such as the Statistical Multifragmentation Model (SMM) formalism [9]. Both of these statistical approaches have been applied to describe central ^{112}Sn+^{112}Sn and ^{124}Sn+^{124}Sn collisions at E/A=50 MeV.

In the EES model, sensitivity to the density dependence of the asymmetry term arises because the separation energies of the fragments from the remainder of the expanded system depend on the symmetry energy [22]. Predictions for R_{21} assuming an asymmetry term of the form $E_{sym}(\rho)\delta(r)^2$, where $E_{sym}(\rho)=23.5(\rho/\rho_0)^{\gamma}$ MeV [22] gives the best agreement with the data for $\gamma=2/3$, corresponding to a relatively soft asymmetry term.

If one assumes, alternatively, that equilibrium is achieved during the breakup and models the multifragment breakup by an equilibrium approach such as the Statistical Multifragmentation Model (SMM), a different picture emerges. Calculations of the multi-fragment decay of this prefragment were performed in ref. [27], and a preference for an asymmetry term with a much stronger density dependence was indicated by the comparison of these calculations to the experimental data [27].

These different predictions reflect different assumptions about the fragmentation mechanism that can be sensitively probed by studying the isospin depedence of multifragmentation. Using information about the density dependent asymmetry term obtained from energetic light particles, we may improve our understanding of the fragment production mechanism.

Flow

The density dependence of the asymmetry term influences the mean fields (potentials) that are felt by the neutrons and protons. Calculations predict that comparisons of neutron and proton transverse collective flow provide special sensitivity to the density dependence of the asymmetry term because the forces generated by the asymmetry term are of opposite sign for protons and neutrons [4]. The NSCL group is planning an experiment to measure the proton and neutron flow; and the flow for light clusters such as d, t, ^{3}He and ^{4}He. The results of this experiment will become available during the timescale of this proposal.To prepare for these measurements, we plan to extend the BUU and QMD formalisms to allow accurate predictions for cluster observables such as the directed transverse flow. By coupling these transport codes to the EES and SMM statistical decay models, we will be able to predict both the dynamical and statistical contributions to the flow observables and determine how best to isolate information relevant to the density dependent asymmetry term.

Isospin diffusion

At low incident energies, the protons and neutrons can be redistributed on a time scale that is faster than the typical timescales for decay. In this sense, one can say that particle emission occurs from a system that is in "isospin equilibrium". As the incident energy is increased above E/A=30 MeV, however, the time scale for emission decreases and anisotropies in the emission patterns may develop, which can allow one to measure the time scales for charge and mass transport and diffusion during the collision.

Peripheral collisions provide an excellent environment for probing these time scales. Experiments have probed charge and mass transport in strongly damped reactions at energies near the Coulomb barrier [29,30] and above [31,32]. Experiments at the CCF will explore these issues with a much greater sensitivity due to larger variation in isospin asymmetry such beams provide. Calculations suggest that at these large asymmetries, the asymmetry term of the nuclear EOS can provide a significant driving force that speeds up the isospin equilibrium. We envision a coordinated experimental and theoretical effort to test these ideas.

First efforts to extract information about isospin diffusion for ^{112}Sn and ^{124}Sn isotopes as projectiles and targets are underway at the NSCL. Similar to the approach of ref. [33], we have used symmetric ^{112}Sn +^{112}Sn and ^{124}Sn +^{124}Sn collisions to infer what should be the final isotopic distributions from projectile decay in the absence of diffusion between projectile and target.

Asymmetric ^{124}Sn +^{112}Sn collisions are then used to assess how the isospin difference between projectile and target changes the neutron diffusion. From these measurements, we find the isotope distributions for projectile decay in the asymmetric systems are about what one would expect for symmetric ^{115}Sn + ^{115}Sn collisions and not as neutron rich as one would expect for symmetric ^{118}Sn + ^{118}Sn, which would describe the limit of complete isospin equilibration. Currently, we use the limiting cases represented by the symmetric entrance channels to provide a scale that is independent of the modeling of the secondary decay of the projectile-like residues. We also propose to model the secondary decay of these residues to see whether the calculated final isotopic distributions are consistent with the ones that are measured.

We are now exploring these results within the context of BUU and Quantum Molecular Dynamics (QMD) transport models. These calculations suggest that such measurements of isospin diffusion may be sensitive to the density dependence of the asymmetry term of the EOS. BUU and stochastic mean field (SMF) calculations also suggest that significant numbers of neutrons may be transported to fragments formed dynamically in the neck region between the projectile and target [23]. Both of these dynamical calculations predict the formation and isotopic composition of such neck fragments to be sensitive to the density dependence of the asymmetry term.

Other new experimental observables

In order to understand the internal structure of astrophysical objects such as neutron stars, it is important to study the high-density behavior of the nuclear equation of state. Recently, isospin dependence of pion production [20] has been shown to be sensitive to the density dependence of the asymmetry term through the interplay of the mean field potential and the pion production rates. We believe these promising calculations need to be pursued further in order to better understand what sort of measurements will be needed to constrain adequately the density dependent term. Many calculations will be needed before the understanding of these isotopic effects approach our understanding of flow measurements from which significant constraints on the symmetric matter equation of state have been obtained. The proposed studies will significantly further these aims and will hopefully result in the identification of other new observables that can be used to address this important problem.

Models descriptions and planned improvements

Boltzmann-Uehling-Uhlenbeck and Quantum Molecular Dynamics Models

The Boltzmann- Uehling-Uhlenbeck (BUU) model follows the dynamics of average phase-space distributions of nucleons [10-12]. It predicts the time evolution of the single neutron and single proton phase space distributions and can be extended to predict the production of hydrogen and helium clusters. The numerical techniques employed in the solution of the BUU equation involve solving equations of motion for many "test particles" per nucleon and averaging them to calculate the mean field and to enforce the Pauli exclusion principle [10].

The Quantum Molecular Dynamics model solves the classical A-body molecular dynamics equations, but the solution retains some quantal features due to the inclusion of Fermi motion in the initial state and the inclusion of Pauli-blocking factors in the collision integral [13]. These A-body molecular dynamics equations resemble closely the corresponding test particles equations in BUU; the single neutron and proton distributions for the two models should be similar in many respects. Unlike the BUU model, classical fluctuations are not suppressed; QMD calculations produce a range of bound and metastable fragments in the final state [13]. This can be a positive development for the prediction of fragment observables in the QMD approach, but at the same time the enforcement of the Pauli principle in the QMD model can be more problematic.

For a thorough exploration of the role of isospin in reactions, a very flexible implementation of the isospin-dependent terms in the mean field will be undertaken within the BUU and QMD models. Both the finite-range of the isospin dependent elementary interaction and the momentum-dependent part of the isospin dependent mean field will be investigated. For each change in the mean field, care will be taken to make certain that the initial nuclei in the simulations are the appropriate ground state nuclei for the selected interaction; this will ensure the lack of spurious effects from inadvertently generated collective modes on the subsequent dynamics. This may be easier to achieve in BUU than in QMD simulations. In addition, flexibility will be employed in the implementation of the collision integral so as to allow an exploration of the importance of different medium modifications of cross sections in different isospin channels.

In the proposed collaborative research project, the BUU and QMD models will be

exploited to study the importance of isospin on the emergence of the gross features of a reaction, such as the isospin-weighted flow [4] or the isospin distribution in rapidity [33]. For this, theoretical work needs to be carried out to understand the independent effects of momentum and isospin transport and how both influence the isospin dependence of the nucleon rapidity and transverse momentum distributions. Enhanced pre-equilibrium neutron emission reduces the neutron-to-proton ratio in the dense prefragment that remains behind [6,4]. Measurements of the fragments produced by the breakup of the prefragment are therefore, in principle, sensitive to the density dependence of the asymmetry term. Because the mean field techniques employed in the BUU suppress these fluctuations, however, the model cannot be used directly to follow the fluctuations as they grow to form the fragments. Dynamical fragment production is a prediction of the QMD approach. Whether this can provide an accurate description of the relevant isospin effects in fragment production will be tested.

A special focus will be on observables that probe the isospin degree of freedom. Differences will be examined between the predictions for proton and neutron emission [23], for example, as well as between the triton and ^{3}He emission [5]. While fragment production for mass up to 3 has been incorporated in one of the BUU codes, there has not been an attempt to study the production of higher masses clusters. Alpha particles are especially important because they are abundantly produced and they remove equal numbers of protons and neutrons. If the system has a non-zero isospin asymmetry before alpha emission, alpha particle emission can significantly increase the isospin asymmetry of the remaining system [7]. Therefore it is extremely important to understand how the clusterization mechanisms alter the neutron and proton spectra in figure 1.

One major objective of the collaboration is to identify which measurements are needed to determine the density dependence of the asymmetry term of the nuclear EOS. This latter objective includes identifying possible ambiguities arising from the dependence of such observables on other isospin dependent quantities such as the nucleon-nucleon cross section, for example, and finding a complete set of experimental observables suitable to constrain all ambiguities. The extracted transport model inputs can then be compared to predictions from microscopic nuclear many-body theories such as the BHF, DBHF and RMF by one of the Chinese PI's . Since the EOS and nucleon-nucleon cross sections are calculated simultaneously

from the same elementary interactions within the many-body theories, we can then extract parameters of the fundamental interactions.

Currently there are many BUU and QMD codes with different features including those developed by the PI's. Cross comparisons between the various codes will be performed to investigate the sensitivities to numerical procedures adopted for the implementation of the Pauli-blocking, the preparation of the initial nuclei, the form of the momentum dependence chosen for the mean fields, etc. This will help us to assess how robust the theoretical observables are with respect to variations in the model assumptions adopted in the various dynamical approaches.

Expanding Emitting Source and Statistical Multifragmentation Models

At Wisconsin, a flexible statistical decay model called the Expanding Emitting Source model (EES) model has been developed [17]. This time dependent model, which derives its fundamental formula for particle emission from the Weisskopf evaporation theory, can consider either standard evaporation or statistical emission from a prefragment nucleus that is expanding self-consistently due to thermal pressure or collective radial flow or both [17, 25]. The density dependence of the asymmetry term is incorporated in the energy functional for the prefragment and influences strongly the isotopic composition of the fragments emitted from the surface. The model is fast, flexible and can be configured to calculate the decays of excited prefragments under a variety of initial conditions. It will be used to model the decays of bound remnants produced in transport model calculations. It also provides important baseline predictions for statistical emission against which transport theoretical models for cluster production can be checked.

Recently, the NSCL group and a group at the Universidade Federal of Rio de Janiero developed an improved Statistical Multifragmentation Model [9,34]. Many of the assumptions of this equilibrium multi-particle phase space model are the same as in the original SMM approach described in refs. [26]. It differs from other SMM codes primarily in that it includes much more accurately the structure information required to reproduce the isotopic distributions. This model will be used for the predictions of equilibrated decay of excited prefragments.

Methodology and work plan

The Sn+Sn systems measured by the NSCL group represent a unique set of isotopically resolved multifragmentation data. To this data set, the NSCL experimental group will add

measurements of the flows and emission rates for neutrons, protons, tritons, ^{3}He and ^{4}He. Beyond this, we plan to perform experiments at a range of incident energies utilizing rare isotope beams of extreme isospin composition to maximize the influence of the asymmetry term of the EOS. Such excitation functions will allow one to probe a range of densities in the central collision region. Later experiments will be guided by the results of the model comparison with data. Theoretical studies will also address the physics to be investigated with next generation accelerators such as RIA and the Lanzhou storage ring, e.g. recent suggestions of using pions to study the symmetry terms in high density nuclear matter [20] requires close collaboration between the theoretical and experimental groups to design efficient experiments.

We propose to achieve this close collaboration by interspersing a series of visits of U.S. scientists to China with reciprocal visits of our Chinese colleagues to United States. The U.S. participants will include the 5 principal investigators as well as postdocs and senior graduate students from the universities associated with these PI's. We envision seven 2-week trips by U.S. scientists occurring once a year. Similarly, the Chinese PI's with their postdocs and senior graduate students will visit the States for a total of eight person-months each year. Tentatively, we designate NSCL to be the main meeting place. If it is more effective, the Chinese visitors can travel to either Arkansas or Wisconsin to work closely with the PI at those institutions. During the collaboration meetings at the NSCL, a larger emphasis will be placed on comparisons to the large volume of data accumulated by the NSCL group and to the discussions of future experiments with the NSCL Coupled Cyclotron Facility, Lanzhou Storage Ring and RIA. In addition to these collaboration meetings, our Chinese colleagues, Hushan Xu, Jin Genmin, postdocs and graduate students from Lanzhou will participate in the experimental efforts at NSCL. Similarly, when the Lanzhou Storage Ring comes on line, the experimental group at NSCL will also participate in experiments there. The experimental collaboration will include execution of the experiments as well as analysis of the data collected. Because high-speed network connections exist between all the institutions, collaborative work on all aspects of this project can be effectively continued at NSCL and China between visits.

Mutual benefits

The various groups in the U.S. and China have complementary strengths that facilitate a broadly based approach. We expect this collaboration to allow us to coordinate transport

theoretical efforts in the U.S. and China and to address questions of larger scope than can be addressed by the individual research groups. The combined effort will significantly accelerate our theoretical understanding of the transport of isospin during a nuclear collision and of the density dependence of the asymmetry term of the EOS.

The NSCL experimental group has an extensive set of data that can be used to test theoretical predictions arising from this collaborative effort. The existing Sn+Sn data set with different isospin combinations is currently unique and the planned additional measurements of neutron observables for the Sn+Sn system will permit very careful tests of the theoretical models and eventually significant constraints to our understanding of the asymmetry term of the EOS. Furthermore, the interaction between model development and data analysis should improve the design of future experiments to be performed at the NSCL and to a better understanding of what measurements that should be planned for future rare isotope accelerators such as RIA or the Lanzhou storage ring.

Currently, the U.S. and Chinese scientists are collaborating informally via e-mails and occasional visits. It is difficult to work effectively without more frequent face-to-face scientific contacts. It is also very difficult to involve graduate students and post-docs in this effort because face-to-face meetings are absolutely essential for their involvement to be fruitful. Such meetings are difficult without travel funds and other resources.

The support requested here would allow these meetings to proceed and allow the development of this collaborative project, which is very close to the scientific interests and expertise of both groups. It will allow meaningful participation of graduate students and post-docs from both countries on this international scientific effort. The support will bring the two prominent women PI's on this proposal into broader contact with young scientists, increasing the visibility of women as scientific role models and encouraging the participation of young women in the physical sciences in both countries.

Furthermore, the program will be beneficial to all institutes involved and to the overall scientific effort in both countries. The importance of such projects to the Chinese science program is evidenced by their commitment of 200,000 yuan a year to provide local support to the US scientists and travel support to the Chinese scientists.

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[23] Bao-An Li, Phys. Rev. Lett. **78** (1997) 1644.

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[33] F. Rami et al., Phys. Rev. Lett. 84, 1120 (2000).

[34] W.P. Tan, in preparation (2002).

William G. Lynch

National Superconducting Cyclotron Laboratory
Michigan State University, E. Lansing MI 48864

a. Professional Preparation

University of Colorado	Physics	BA	(1973)
University of Washington	Physics	Ph.D.	(1980)

b. Appointments

Professor	Dept of Physics and Astronomy, Michigan State University 1992.
Assoc. Prof.	Dept of Physics and Astronomy, Michigan State University 1987.
Assist. Prof.	Dept of Physics and Astronomy, Michigan State University 1984.

c. **Publications :** 182 published papers and 53 invited talks

(i) 5 Publications Relevant to Proposal:

1. Imaging Sources with Fast and Slow Emission Components, G. Verde, D.A. Brown, P. Danielewicz, C.K. Gelbke, W.G. Lynch, M.B. Tsang. To be published in Phys. Rev. C.
2. Fragment Isotope Distributions and the Isospin Dependent Equation of State, W.P. Tan, B-A. Li, R. Donangelo, C.K. Gelbke, M-J. van Goetherm, X.D. Liu, W.G. Lynch, S. Souza, M.B. Tsang, G. Verde, A. Wagner and N.S. Xu, Phys. Rev. C 64, 051901 (2001).
3. Nuclear isotope thermometry; S.R. Souza, W.P. Tan, R. Donangelo, C.K. Gelbke, W.G. Lynch and M.B. Tsang, Phys. Rev. **C62**, 064607 (2000).
4. Fragment Isotope Distributions and the Isospin Dependent Equation of State, W.P. Tan, B-A. Li, R. Donangelo, C.K. Gelbke, M-J. van Goetherm, X.D. Liu, W.G. Lynch, S. Souza, M.B. Tsang, G. Verde, A. Wagner and N.S. Xu, Phys. Rev. C 64, 051901 (2001).
5. Examining the cooling of hot nuclei; H. Xi, M. J. Huang, W. G. Lynch, S. J. Gaff, C. K. Gelbke, T. Glasmacher, G. J. Kunde, L. Martin, C. P. Montoya, S. Pratt, and M. B. Tsang, W. A. Friedman, P. M. Milazzo, M. Azzano, G. V. Margagliotti, R. Rui, G. Vannini, M. D'Agostino, M. Bruno, M. L. Fiandri, F. Gramegna, A. Ferrero, I. Iori, A. Moroni, F. Petruzzelli, P. F. Mastinu, Phys. Rev. C57, R467 (1998).

(ii) 5 Other Publications

1. Dynamical Emission and Isotope Thermometry, H.F. Xi, G.J. Kunde, O. Bjarki, C.K. Gelbke, RC. Lemmon, W.G. Lynch, D. Magestro, R. Popescu, R. Shomin, M.B. Tsang, A.M. Vandermolen, G.D. Westfall, G. Imme, V. Maddalena, C. Nociforo, G. Raciti, G. Riccobene, F.P. Romano, A. Saija, C. Sfienti, S. Fritz, C. Groß, T. Odeh, C. Schwarz, A. Nadasen, D. Sisan, K.A.G. Rao, Phys. Rev. C 58, (1998) R2636.
2. W.A. Friedman and W.G. Lynch, Phys. Rev. C28, 16 (1983).
3. Fragmentation of neck-like structures; C.P. Montoya, W.G. Lynch, D.R. Bowman, G.F. Peaslee, N. Carlin, R.T. de Souza, C.K. Gelbke, W.G. Gong, Y.D. Kim, M.A. Lisa, L. Phair, M.B. Tsang, J.B. Webster, C. Williams, N. Colonna, K. Hanold, M.A. McMahan, G.J. Wozniak, and L.G. Moretto, Phys. Rev. Lett. 73 (1994) 3070.
4. Multifragmentation in E/A = 35 MeV collisions: evidence for Coulomb-driven breakup? M. D'Agostino, G.J. Kunde, P.M. Milazzo, J.D. Dinius, M. Bruno, N. Colonna, M.L. Fiandri, C.K. Gelbke, T. Glasmacher, F. Gramegna, D.O. Handzy, W.C. Hsi, M. Huang, M.A. Lisa, W.G. Lynch, P.F. Mastinu, C.P. Montoya, A. Moroni, G.F. Peaslee, L. Phair, R. Rui, C. Schwarz, M.B. Tsang, G. Vannini, and C. Williams, Phys. Rev. Lett. **75** (1995) 4373.
5. Fragment Distributions for Highly Charged Systems, C. Williams, W.G. Lynch, C. Schwarz, M.B. Tsang, M.J. Huang, H.C. Hsi, D.R. Bowman, C.K. Gelbke, M.A. Lisa,

G.F. Peaslee, L. Phair, D.O. Handzy, J. Dinius, M-C. Lemaire, S.R. Souza, G. Van Buren, R.J. Charity, L.G. Sobotka, G.J. Kunde, U. Lynen, J. Pochodzalla, H. Sann, W. Trautmann, D.Fox, R.T. de Souza, G. Peilert, A. Botvina, and N. Carlin; Phys. Rev. C 55, (1997) R2132.

d. Synergistic Activities

Chair of Nuclear Chemistry Gordon Conference 2000. Development of LASSA and HiRA strip detector arrays for nuclear structure, reactions and astrophysics research. Convenor nuclear reactions working group at RIA town meeting. GANIL review committee. Intermediate and high school teaching training via the NSCL PAN program.

e. Collaborators & Other Affiliations

(i) Active Collaborators: L. Beaulieu, A.S. Botvina, R.J. Charity, A. L. Caraley, M. D'Agostino, C. B. Das, S. Das Gupta, B. Davin, R. de Souza, F. Deak, R. Donangelo, W.A. Friedman, S. Hudan, I. Iori, G. J. Kunde, A. Kiss, K. Kwiatkowski, Y. Larochelle, R. Lacey, T. Lefort, R. Lemmon, B-A. Li, M. A. Lisa, U. Lynen, D. Magestro, A.Z. Mekjian, L. Moretto, A. Moroni, A. Nadasen, G.F. Peaslee, L. Phair, J. Pochodzalla, G. Raciti, W.U. Schroeder, C. Schwarz, Z. Seres, W. Shen, L.G. Sobotka , S. Souza, W. Trautmann, J. Toke, R. Vandenbosch, V. Viola, A. Wagner, G. Wozniak, H. S. Xu

(ii) Graduate & Postdoctoral Advisors:

Prof. John Cramer, University of Washington
Prof. C. Konrad Gelbke, NSCL/Michigan State University

(iii) Thesis Advisor and Postgraduate-Scholar Sponsor:

Wen-Chien Hsi,Cornelius Williams, Min Jui Huang, J. Dinius, Richard Shomin, Wanpeng Tan, Tianxiao Liu, Paul Hosmer,Mark Wallace, Carlos Montoya, Roy Lemmon, Andreas Wagner, Hushan Xu,Giuseppe Verde, Marc-Jan Van Goethem

Total Number of Grad Students Advised: 12
Total Number of Postdoctoral Scholars sponsored: 7

Biographical Sketch – Pawel Daniel Danielewicz

a. Education and Training

Warsaw University	M.S. Physics (with distinction)	1977
Warsaw University	Ph.D. Physics	1981
Lawrence Berkeley Laboratory	Postdoctoral Associate	1981-84

b. Appointments

Professor	Physics and Astronomy Dept. and National Superconducting Cyclotron Lab., Michigan State Univ.	1996-
Associate Professor	Physics and Astronomy Dept. and National Superconducting Cyclotron Lab., Michigan State Univ.	1988-96
Assistant Professor	Physics Dept. Warsaw Univ.	1985-90
Senior Associate	Physics Dept. Warsaw Univ.	1981-85
Associate	Physics Dept. Warsaw Univ.	1978-81
Junior Associate	Physics Dept. Warsaw Univ.	1976-78

d. Publications

Related

1. Spectator Response to Participant Blast, L. Shi, P. Danielewicz, and R. Lacey, Phys. Rev. C **64**, 034601 (2001).

2. Medium Corrections in the Formation of Light Charged Particles in Heavy Ion Reactions, C. Kuhrts, M. Beyer, P. Danielewicz and G. Roepke, Phys. Rev. C **63**, 034605 (2001).

3. Effect of Cluster Formation on Isospin Asymmetry in the Liquid-Gas Phase Transition Region, L. Shi and P. Danielewicz, Europhys. Lett. 51, 34 (2000).

4. Determination of the Mean-Field Momentum-Dependence using Elliptic Flow, P. Danielewicz, Nucl. Phys. **A673**, 375 (2000).

5. The Clustered and Neutron-Rich Low Density "Neck Region" Produced in Heavy-Ion Collisions, L. G. Sobotka, J. F. Dempsey, R. J. Charity, and P. Danielewicz, Phys. Rev. C **55**, 2109 (1997).

Other

1. Clocking Hadronization in Relativistic Heavy Ion Collisions with Balance Functions, S. Bass, P. Danielewicz, and S. Pratt, Phys. Rev. Lett. **85**, 2689 (2000).

2. Partons in Phase Space, D. Brown and P. Danielewicz, Phys. Rev. D **58**, 094003-1 (1998).

3. Effects of Compression and Collective Expansion on Particle Emission from Central Heavy-Ion Reactions, P. Danielewicz, Phys. Rev. C **51**, 716 (1995).

4. Transverse Momentum Analysis of Collective Motion in Relativistic Nuclear Collisions, P. Danielewicz and G. Odyniec, Phys. Lett. **157B**, 146 (1985).

5. Quantum Theory of Nonequilibrium Processes, P. Danielewicz, Ann. Phys. (N.Y.) **152**, 239, 305 (1984).

e. Synergistic Activities

1. Reaction Theory for Nuclei Far From Stability, Institute for Nuclear Theory Workshop, 2002, Lead Organizer.

2. Nuclear Theory Midwest Get-Together, Argonne, 2001, Chair.

3. Nuclear Reactions and Bulk Properties of Matter, Town Meeting on Nuclear Structure and Nuclear Astrophysics, Durham, 2000, Convener.

4. Nuclear Reactions, C. Bertulani and P. Danielewicz, textbook in preparation.

5. Science that Counts in the Workplace, K-12 Teacher Guide and Student Book, TERC, Kendall/Hunt, Fall 2002, contributor.

f. Collaborators & Other

(i) Collaborators: S. Bass, P. Bozek, D. Brown, C. Kuhrts, R. Lacey, W. Lynch, M. Petrovici, M. Ploskon, L. Shi, R. Shyam, B. K. Srivastava, B. Tsang

(ii) Advisors: J. M. Namyslowski

(iii) Thesis Advisor for: David Brown (Lawrence Livermore Lab.), Lijun Shi (Michigan State U)
Postdoctoral Sponsor for: Piotr Bozek (Institute for Nuclear Research, Cracow), Steffen Bass (Duke University), Pol-Bernard Gossiaux (Nantes University)

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Education:

Ph.D. Massachusetts Institute of Technology, Cambridge MA, 1966
B.of E.P. Cornell University, Ithaca, NY, 1961

Positions held :

1980-present: Professor of Physics, University of Wisconsin-Madison
1973-1980: Associate Professor of Physics, University of Wisconsin-Madison
1970-1973: Assistant Professor of Physics, University of Wisconsin-Madison
1967-1970: Instructor, Princeton University, Princeton, NJ
1966-1967: NSF Postdoctoral Fellow, Neils Bohr Institute, Copenhagen, Denmark

Adjunct and Visiting Positions held :

1985-present: Adjunct Professor, Department of Physics, Michigan State University, East Lansing, MI
1984-1985: Visiting Professor, Department of Physics, Michigan State University, and NSCL , East Lansing, MI
1982-1983: Adjunct Professor, Department of Physics, Michigan State University, East Lansing, MI
1981-1982: Visiting Professor, Department of Physics, Michigan State University, and NSCL , East Lansing, MI

Honors and Awards :

1997: Fellow of Institute of Advanced Study, Indiana University
1989: Elected to Fellowship of American Physical Society
1966: NSF Postdoctoral Fellow
1961: NSF Graduate Fellow
1961: Woodrow Wilson Graduate Fellowship

Other Professional Activities:

Member, Program Advisory Committee, National Superconducting Cyclotron Laboratoryi, MSU, 1994-1998; Organizer, Midwest Nuclear Theory Get-Together, 1999.

Publications etc. : 102 articles in refereed journals, 36 talks published in conference proceedings, 22 unpublished invited talks, and 62 colloquium and seminar talks.

a. Five closely related recent publications:

1. Nuclear thermometers from isotope yields, (with M.B.Tsang et al.) Phys. Rev.Lett.**78**, 3836 (1997).
2. Examining the cooling of hot nuclei,(with Xi et al.), Phys.Rev.**C57**, R462 (1998).
3. Isospin independence of H-He "thermometer" to N/Z ratio of sources produced in central 112Sn+112Sn and 124Sn+124Sn collisions at E/A = 40 MeV (with G.Kunde et al.), Phys.Lett.**B416**, 56 (1998).
4. Are the largest products of fragmentation residues?, Phys.Rev.**C60**, 044603 (1999).
5. Isotopic scaling in nclear reactions, (with M.B.Tsang, et al.) Phys.Rev.Lett.**86**, 5023 (2001).

b. Five other publications:

1. Barrier top resonances and heavy ion reactions (with C.J. Goebel), Annals of Physics **104**, 145 (1977).
2. Heavy ion projectile fragmentation: a reexamination, Phys.Rev. **C27**, 569 (1983).
3. Statistical formalism for particle emission (with W.G. Lynch), Phys. Rev. **C28**, 16 (1983).
4. Rapid massive cluster formation, Phys. Rev.**C42**, 667 (1990).
5. Measurement of temperature in nuclear reactions, (with D.Morrissey and W.Benenson), Annual Reviews of Nuclear and Particle Science Vol.**44**, 27 (1994).

List of Collaborators: C.K. Gelbke, W.G. Lynch, M.B. Tsang, V. Viola, R.T.deSouza, R. Bougault, H. Oeschler.

Graduate Advisor : H. Feshbach

Postdoctoral Supervisors: G.E. Brown

Bao-An Li

a. Professional Preparation

Lanzhou University	Physics	BS (1983)
Michigan State University	Physics	Ph.D. (1992)

b. Appointments

Associate Prof., Department of Chem. and Physics, Arkansas State University, 2000-present
Assistant Prof., Department of Chem. and Physics, Arkansas State University, 1998-2000
Associate Research Scientist at the Cyclotron Institute and Adjunct Assistant Professor at the Department of Physics, Texas A&M University, 1994-1998
Postdoc, Hahn-Meitner-Institut, Berlin, Germany, 1992-1994

c. Publications: 1 book , 85 refereed papers, 35 invited talks , 51 seminars and contributed talks.

(i) 5 publications Relevant to the Proposal:

1. Isospin Physics in Heavy-Ion Collisions at Intermediate Energies, Eds. Bao-An Li and W.U. Schröder , NOVA Science Publishers, Inc. (2001, New York), ISBN 1-56072-888-4.
2. Probing the High Density Behavior of Nuclear Symmetry Energy with High Energy Heavy-Ion Collisions
   Bao-An Li, Phys. Rev. Lett. 88, 192701 (2002).
3. Neutron-Proton Differential Flow as a Probe of Isospin-Dependence of Nuclear Equation of State, Bao-An Li, Phys. Rev. Lett. 85, 4221 (2000).
4. Equation of State of Asymmetric Nuclear Matter and Collisions of Neutron-Rich Nuclei, Bao-An Li, C.M. Ko and Zhongzhou Ren, Phys. Rev. Lett. 78, 1644 (1997).
5. Isospin Dependence of Transverse Flow in Heavy-Ion Collisions at Intermediate Energies, Bao-An Li, Zhongzhou Ren, C.M. Ko and S.J. Yennello, Phys. Rev. Lett. 76, 4492 (1996).

(ii) 5 Other Publications:

1. Isospin Non-Equilibrium in Heavy-Ion Collisions at IntermediateEnergies.
   Bao-An Li and S.J. Yennello, Phys. Rev. C52, R1746 (1995).
3. Isospin Physics in Heavy-Ion Collisions at Intermediate Energies, Bao-An Li, C.M. Ko and W. Bauer, Topical Review, International Journal of Modern Physics E, V7, 147, (1998).
3. Isospin Relaxation Time in Heavy-Ion Collisions at Intermediate Energies,
   Bao-An Li and C.M. Ko, Phys. Rev. C57, 2065 (1998)
4. Differential Flow in Heavy-Ion Collisions at Balance Energies,
   Bao-An Li and A.T. Sustich, Phys. Rev. Lett. 82, 5004 (1999).
5. Bubbles and Drops in Superheated and Supercooled Nuclear Matter,
   Bao-An Li, Scott Pratt and Philip J. Siemens, Phys. Rev. C37, 1473 (1988).

d. Synergistic Activities

Co-organizer of one international workshop, reviewer/referee for National Science Foundation, Physical Review Letters, Physical Review C, Physics Letters B, Nuclear Physics A, Journal of Physics G, Europhysics Letters, International Journal of Modern Physics, Journal of Arkansas Academy of Sciences, Books/Cole Publishing and NOVA Science Publishers Inc. Judge of Northeast Arkansas Science Fairs, co-organizer of Northeast Arkansas Astronomy Sky-Watch Club

e. Collaborators & Other Affiliations

(i) Collaborators: W. Bauer, W. Benenson, L. Chkhaidze, T. Djobava, L. Kharkhelauri, C.M. Ko, R. A. Lacey, Z.W. Lin,. J.B. Natowitz, E. Norbeck, R. Pak, Marek Ploszajczak, S. Pal, J. Randrup, N.T.B. Stone, A. Sustich, W. Udo Schröder, M.A. Tilley, G.D. Westfall, C.Y. Wong, S.J. Yennello, B. Zhang

(ii) Ph.D. and Postdoc Advisors

Ph.D. Advisor: W. Bauer, Michigan State University
Postdoc Advisor: D.H. E. Gross, Hahn-Meitner-Institute, Berlin, Germany

Manyee B. Tsang
National Superconducting Cyclotron Laboratory
Michigan State University, E. Lansing MI 48864

a. Professional Preparation:

California State College, Bakersfield	Mathematics	BA (1973)
University of Washington	Chemistry	Ph.D. (1980)

b. Appointments:

Professor	NSCL, Michigan State University 1995-present
Adjunct Prof.	Dept of Physics and Astronomy, Michigan State University 1993-present
Physicist	NSCL, Michigan State University, 1984-1995.

c. Publications: Refereed Papers: 167, Invited Talks: 37

(i) 5 Publications Relevant to Proposal:

1. Fragment Isotope Distributions and the Isospin Dependent Equation of State, W.P. Tan, B-A. Li, R. Donangelo, C.K. Gelbke, M-J. van Goetherm, X.D. Liu, W.G. Lynch, S. Souza, M.B. Tsang, G. Verde, A. Wagner and N.S. Xu, Phys. Rev. C 64, 051901 (2001).
2. Nuclear isotope thermometry; S.R. Souza, W.P. Tan, R. Donangelo, C.K. Gelbke, W.G. Lynch and M.B. Tsang, Phys. Rev. **C62**, 064607 (2000).
3. Isotope Scaling in Nuclear Reactions, M. B. Tsang, W.A. Friedman, C.K. Gelbke, W.G. Lynch, G. Verde, H. Xu, Phys. Rev. Lett. 86, 5023 (2001).
4. Liquid-Gas Phase Transition in Nuclear Multifragmentation, S. Das Gupta, A.Z. Mekjian and M.B. Tsang, Adv. Nucl. Phys. Phys. Rev. C 64, 044608 (2001).
5. Isospin fractionation in nuclear multifragmentation, H.S. Xu, M.B. Tsang, T.X. Liu, X.D. Liu, W.G. Lynch, W.P.Tan and G. Verde, L. Beaulieu, B. Davin, Y. Larochelle, T. Lefort, R.T. de Souza, R. Yanez, V.E. Viola, R.J. Charity, and L.G. Sobotka, Phys. Rev. Lett. ***85***, 716 (2000).

(ii) 5 Other Publications:

1. Rare Isotope Production Near the Neutron Drip Line, W.A. Friedman, M.B. Tsang, D. Bazin, W.G. Lynch, Phy. Rev. **C62**, 64609 (2000).
2. Nuclear Arrhenius-Type Plots, M.B. Tsang and P. Danielewicz, Phys. Rev. Lett. **80**, 1178 (1998).
3. Nuclear Thermometers from isotope yield ratios, M.B. Tsang, W.G. Lynch, H. Xi and W.A. Friedman, Phys. Rev. Lett. **78,** 3836 (1997).
4. Isospin independence of the H-He double isotope ratio "thermometer"; G.J. Kunde, S. Gaff, C.K. Gelbke, T. Galsmacher, M.J. Huang, R. Lemmon, W.G. Lynch, L. Manduci, P. Persram, P. Popescue, R.M. Ronningen, L.G. Sobotka, D.K. Agnihotri, B. Djerroud, W.U. Schöder, W. Skulski and J. Toke, Phys. Lett. **B416**, 56 (1998).
5. Polarization, Dynamics, and Nonequilibrium Complex-Fragment Emission; M.B. Tsang, W.G. Lynch, R.M. Ronningen, Z. Chen, C.K. Gelbke, T. Nayak, J. Pochodzalla, F. Zhu, M. Tohyama, W. Trautmann, and W. Dunnweber; Phys. Rev. Lett. **60** (1988) 1479.

d. Synergistic Activities:

(i) Co-ordinate the monthly publication and distributions of the Nuclear Physics Preprint (http://www.nscl.msu.edu/news/nscl_library/preprints/)

(ii) Co-Organize 12 national and international conferences and advisor to 2 international conferences

(iii) Referee for Nuclear Physics A, Nuclear Instrument and Methods A, Physical Review Letters, Physical Review C, Physics Letter B.

(iv) Development of web-based list of upcoming nuclear physics conferences (http://www.nscl.msu.edu/news/nscl_library/confer/index.html)

(v) Development of web-based depository of electronic manuals (http://www.nscl.msu.edu/userinfo/nuclelec/manuals/home.html)

e. Collaborators & Other Affiliations:

(i) Active Collaborators: L. Beaulieu, A.S. Botvina, R.J. Charity, A. L. Caraley, M. D'Agostino, C. B. Das, S. Das Gupta, B. Davin, R. de Souza, F. Deak, R. Donangelo, W.A. Friedman, S. Hudan, I. Iori, G. J. Kunde, A. Kiss, K. Kwiatkowski, Y. Larochelle, T. Lefort, R. Lemmon, B-A. Li, M. A. Lisa, U. Lynen, D. Magestro, A.Z. Mekjian, L. Moretto, A. Moroni, A. Nadasen, G.F. Peaslee, L. Phair, J. Pochodzalla, G. Raciti, W.U. Schroeder, C. Schwarz, Z. Seres, W. Shen, L.G. Sobotka , S. Souza, W. Trautmann, J. Toke, R. Vandenbosch, V. Viola, A. Wagner, G. Wozniak, H. S. Xu

(ii) Graduate & Postdoctoral Advisors:

Prof. C. Konrad Gelbke, NSCL/Michigan State University -- **Post Doc Mentor**
Phone : 517-355-4530; e-mail : GELBKE@ NSCL.MSU.EDU
Prof. Robert Vandenbosch, University of Washington -- **PhD Advisor**
Phone : 206-543-4080; e-mail : V@NPL.WASHINGTON.EDU

(iii) Thesis Advisor and Postgraduate-Scholar Sponsor

Michal Mocko, Physics graduate Student (2002-present)
Xiaodong Liu, Physics Graduate Student (1998-present)
Marc Jan Vangoethem (2000-present)
Giuseppe Verde, Postdoc (1999-2001)
Michael Famiano, Postdoc (2002- present)
Hushan Xu, Visiting Scholar (1998-2000)
Hongfei Xi, Postdoc (1996-1999)
Wen-qing Shen, Visiting Scholar (1995 summer)
Li Zhuxia, Visiting Scholar (2002 summer)
Lyudmila Andronenko, Visiting Scholar (2002 summer)

SUMMARY PROPOSAL BUDGET YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Michigan State University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **William G Lynch**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **William G Lynch - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Pawel D Danielewicz - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **William A Friedman - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Bao-An Li - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **ManYee B Tsang - none**	**0.00**	**0.00**	**0.00**	**0**	
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**5**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**0**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**0**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**10,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **11,200**					
4. OTHER **640**					
TOTAL NUMBER OF PARTICIPANTS (**4**) TOTAL PARTICIPANT COSTS				**11,840**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**1,500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**500**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**2,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**24,340**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **(Rate: , Base:)**					
TOTAL INDIRECT COSTS (F&A)				**0**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**24,340**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **24,340**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **William G Lynch**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Michigan State University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **William G Lynch**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **William G Lynch - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Pawel D Danielewicz - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **William A Friedman - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Bao-An Li - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **ManYee B Tsang - none**	**0.00**	**0.00**	**0.00**	**0**	
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**5**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**0**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**0**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**10,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **11,200**					
4. OTHER **640**					
TOTAL NUMBER OF PARTICIPANTS (**4**) TOTAL PARTICIPANT COSTS				**11,840**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**500**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**1,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**23,340**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **(Rate: , Base:)**					
TOTAL INDIRECT COSTS (F&A)				**0**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**23,340**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **23,340**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **William G Lynch**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET — YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Michigan State University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **William G Lynch**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **William G Lynch - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Pawel D Danielewicz - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **William A Friedman - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Bao-An Li - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **ManYee B Tsang - none**	**0.00**	**0.00**	**0.00**	**0**	
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**5**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**0**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**0**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**10,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **11,200**					
4. OTHER **640**					
TOTAL NUMBER OF PARTICIPANTS (**4**) TOTAL PARTICIPANT COSTS				**11,840**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**500**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**1,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**23,340**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **(Rate: , Base:)**					
TOTAL INDIRECT COSTS (F&A)				**0**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**23,340**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **23,340**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **William G Lynch**

ORG. REP. NAME*

FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **Michigan State University**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **William G Lynch**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **William G Lynch - none**	**0.00**	**0.00**	**0.00**	$ **0**	$
2. **Pawel D Danielewicz - none**	**0.00**	**0.00**	**0.00**	**0**	
3. **William A Friedman - none**	**0.00**	**0.00**	**0.00**	**0**	
4. **Bao-An Li - none**	**0.00**	**0.00**	**0.00**	**0**	
5. **ManYee B Tsang - none**	**0.00**	**0.00**	**0.00**	**0**	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	**0.00**	**0.00**	**0.00**	**0**	
7. (**5**) TOTAL SENIOR PERSONNEL (1 - 6)	**0.00**	**0.00**	**0.00**	**0**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	**0.00**	**0.00**	**0.00**	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	**0.00**	**0.00**	**0.00**	**0**	
3. (**0**) GRADUATE STUDENTS				**0**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**0**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**0**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**0**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**0**	
2. FOREIGN				**31,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **33,600**					
4. OTHER **1,920**					
TOTAL NUMBER OF PARTICIPANTS (**12**) TOTAL PARTICIPANT COSTS				**35,520**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**2,500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**1,500**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**0**	
TOTAL OTHER DIRECT COSTS				**4,000**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**71,020**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**0**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**71,020**	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ **71,020**	$

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **William G Lynch**

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget Justification Page

Travel in support of the proposed cooperative research activity is requested from the National Science Foundation over a three-year period. The support would cover one trip each for seven US scientists each year. The scientists include the 5 PI's, one postdoctoral associate and one graduate student. The transportation cost of each trip is $1200 USD cross-pacific airfare plus $300 USD plane transportation within China. Support of local lodging and meals will be provided by our foreign host (as allowed under the receiving-side-pays model).

In addition, the requested support will cover the subsistence costs of eight man-month trip each year for the Chinese scientists which may include students and postdocs from Lanzhou or Beijing in addition to the four Chinese PI's. Lodging and meals are estimated to be $1400 per month per person (as allowed under the receiving-side-pays model). The health insurance for foreign scholars at MSU is $80.00 per month per person.

The travel cost for 7 US scientists is $1,500x7 =$10500 USD.

The subsistence and insurance cost for one Chinese physicist is $1400+$80USD per month. For eight man-month, the total is $1480x2x4=$11840.

Communication, publication and supplies cost = $1000.00 per year except in the first year, we allow an extra $1000.00 for communication software or supplies to allow efficient exchange of research information.

Total budget request for three years is ($10,500 + $11840 + $1000) x 3 + 1000 = $71 ,020

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **William Lynch**	Other agencies (including NSF) to which this proposal has been/will be submitted. **None**

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Operation of the National Superconducting Cyclotron Laboratory at Michigan State University as a National User Facility and Support for its Research Program

Source of Support: **NSF**

Total Award Amount: $ **14,460,000** Total Award Period Covered: **11/1/01-10/31/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **2.4** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Development of a High Resolution Charged Particle Array/Rad Beam Expt

Source of Support: **NSF**

Total Award Amount: $ **349,322** Total Award Period Covered: **9/15/99-8/31/02**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Nuclear Multifragmentation at Intermediate Energies

Source of Support: **NSF**

Total Award Amount: $ **9,760** Total Award Period Covered: **2/1/00-1/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Collision Dynamics of Nuclei with High Isospin Asymmetry

Source of Support: **NSF**

Total Award Amount: $ **36,000** Total Award Period Covered: **01/01/02- 12/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Isospin Dependence of Fragmentation and Spallation Reactions

Source of Support: **NSF**

Total Award Amount: $ **47,700** Total Award Period Covered: **08/01/02-07/31/05**

Location of Project: **Michigan State University/PNPI, Russia**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Non-equilibrium and Isospin Effects in Nuclear Fragmentation

Source of Support: **NSF**

Total Award Amount: $ **15,800** Total Award Period Covered: **2/1/03-1/31/05**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Isospin Effects in Projectile Fragmentation and Multifragmentation

Source of Support: **NSF**

Total Award Amount: $ **28,800** Total Award Period Covered: **2/1/03-1/31/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Isospin Dependence of Reaction Dynamics

Source of Support: **NSF**

Total Award Amount: $ **71,020** Total Award Period Covered: **3/1/03-2/28/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Pawel Danielewicz**

Other agencies (including NSF) to which this proposal has been/will be submitted: **None**

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: **Heavy-Ions Reactions at the Energy and Isospin Frontiers**

Source of Support: **NSF**

Total Award Amount: $ **720,000** Total Award Period Covered: **6/15/00-5/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **2** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: **Collision Dynamics of Nuclei with High Isospin Asymmetry**

Source of Support: **NSF**

Total Award Amount: $ **36,000** Total Award Period Covered: **1/1/02-12/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: **Isospin Dependence of Reaction Dynamics**

Source of Support: **NSF**

Total Award Amount: $ **71,020** Total Award Period Covered: **3/1/03-2/28/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [ ] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: [ ] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has been previously funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **William Friedman**

Other agencies (including NSF) to which this proposal has been/will be submitted: **None**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Non-equilibrium and Isospin Effects in Nuclear Fragmentation**

Source of Support: **NSF**

Total Award Amount: $ **15,800** Total Award Period Covered: **2/1/03-1/31/05**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☒ Current ☐ ☐ ☐

Project/Proposal Title: **Research in Theoretical Nuclear Physics**

Source of Support: **NSF**

Total Award Amount: $ **517,000** Total Award Period Covered: **6/1/00-5/31/03**

Location of Project: **University of Wisconsin**

Person-Months Per Year Committed to the Project. Cal: Acad: **1** Sumr: **2**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Isospin Dependence of Reaction Dynamics**

Source of Support: **NSF**

Total Award Amount: $ **71,020** Total Award Period Covered: **3/1/03-2/28/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

---

*If this project has been previously funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Bao-An Li**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Theoretical Study of Ultra-Relativistic Heavy-Ion Collisions at RHIC and Isospin Physics with Radioactive Beams**

Source of Support: **NSF**

Total Award Amount: $ **97,000** Total Award Period Covered: **08/15/00 - 07/31/03**

Location of Project: **Arkansas State University main campus**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **2.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

---

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

 USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Man-Yee Tsang**

Other agencies (including NSF) to which this proposal has been/will be submitted.

None

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Development of a High Resolution Charged Particle Array/Rad Beam Expt

Source of Support: **NSF**

Total Award Amount: $ **349,322** Total Award Period Covered: **9/15/99-8/31/02**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Nuclear Multifragmentation at Intermediate Energies

Source of Support: **NSF**

Total Award Amount: $ **9,760** Total Award Period Covered: **2/1/00-1/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Operation of the National Superconducting Cyclotron Laboratory at Michigan State University as a National User Facility and Support for its Research Program

Source of Support: **NSF**

Total Award Amount: $ **14,460,000** Total Award Period Covered: **11/1/01-10/31/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **2.4** Acad: Sumr:

Support: [X] Current Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Collision Dynamics of Nuclei with High Isospin Asymmetry

Source of Support: **NSF**

Total Award Amount: $ **36,000** Total Award Period Covered: **01/01/02- 12/31/03**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.3** Acad: Sumr:

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title:

Isospin Dependence of Fragmentation and Spallation Reactions

Source of Support: **NSF**

Total Award Amount: $ **47,700** Total Award Period Covered: **08/01/02-07/31/05**

Location of Project: **Michigan State University/PNPI, Russia**

Person-Months Per Year Committed to the Project. Cal: **1** Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Non-equilibrium and Isospin Effects in Nuclear Fragmentation

Source of Support: **NSF**

Total Award Amount: $ **15,800** Total Award Period Covered: **2/1/03-1/31/05**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Isospin Effects in Projectile Fragmentation and Multifragmentation

Source of Support: **NSF**

Total Award Amount: $ **28,800** Total Award Period Covered: **2/1/03-1/31/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Isospin Dependence of Reaction Dynamics

Source of Support: **NSF**

Total Award Amount: $ **71,020** Total Award Period Covered: **3/1/03-2/28/06**

Location of Project: **Michigan State University**

Person-Months Per Year Committed to the Project. Cal: **0.5** Acad: Sumr:

Facilities

National Superconducting Cyclotron Laboratory at Michigan State University

The NSCL is the premier intermediate energy heavy ion and radioactive beam facility in the Western hemisphere. The experimental facilities at the NSCL include two superconducting cyclotrons and a fragment separator, which allow the in-flight production of radioactive ion-beams by fragmentation of a primary beam. The upgraded facility came into operation last summer. The upgrade increases the available secondary beam intensity by about 3-4 orders of magnitude. The new facility is well suited for multifragmentation investigations with stable as well as radioactive beams, especially for the study of nuclear collisions of nuclei with extreme isospin symmetry. The laboratory has a versatile complement of experimental devices including the fixed 4- π detector array and the miniball, a portable 4-π detector array. In addition, the NSCL group is currently building a high resolution Si array, which will provide good isotope, high energy and high angular resolution. The latter array has been funded by the US National Science Foundation through a Major Research Initiative grant and by the Michigan State University.

The proposed collaboration will require access to the network of high speed workstations at the NSCL facility and to the library of multifragmentation data amassed by the NSCL group. It will also require internet access to the computers in China utilized by the Chinese group. All of these capabilities are presently on hand.

The Institute of Modern Physics, Lanzhou and Computing Resources in China

The institute of Modern Physics is the premier heavy ion accelerator in China. The Heavy Ion Research Facility in Lanzhou (HIRFL) consists of the ECR Ion Source, including 3 ECR ion sources, two of them have 10GHz high frequency and another one with 14.5 GHz high frequency. A superconductor ECR ion source with two high frequency machines is currently under construction; a Sector Focusing Cyclotron which provides heavy ion beams from C to Xe in the energy region of 9—1.5MeV/u, a Separator-Sector Cyclotron which delivers the intermediate energy heavy ion beams of C to Xe with energy up to ~100MeV/u, a Radioactive Ion beam Line with solid angle acceptance $\Delta\Omega$>7 mrad, momentum acceptance ΔP>10% and mass resolution power $A/\Delta A$=400, and four Experimental Terminals for reaction mechanism and nuclear structure research. The Cooling Storage Ring(CSR) are now under construction and it is scheduled to be completed in 2004. CSR aims to increase the accelerated ions up to Uranium, the energy up to 900MeV/u for light heavy ions and down to 400MeV/u for U beam. It will further improve beam intensity (10^9 pps) and quality (momentum resolution is 10^{-5}-10^{-6}). Access to high speed network and high performance computers are presently available both in Lanzhou and in the China Institute of Atomic Energy, Beijing. These should allow researchers to communicate via internet in between visits and to exchange scientific information.

Gen-Ming Jin

a. Professional preparation

Tsinghua University, Physics BS (1967)

b. Appointments

Professor, Institute of Modern Physics, CAS, 1995-present

Associate Professor, Institute of Modern Physics, CAS, 1988-1995

Assistant Professor, Institute of Modern Physics, CAS, 1980-1988

Visiting Research Scientist, Grand Acceleratear National d'ions Lourds (GANIL) 1986-1988

c. Publications: 70 refereed papers

Publications relevant to this proposal:

1. D.Q.Fang, W.Q.Shen, J.Feng, X.Z.Cai, J.S.Wang, Q.M.Su, H.Y.Zhang, P.Y.Hu, Y.G.Ma, Y.T.Zhu, S.L.Li, H.Y.Wu, Q.B.Gou, G.M.Jin, W.L.Zhan, Z.Y.Guo, G.Q.Xiao, **Measurements of Total Reaction Cross Sections for Some Light Nuclei at Intermediate Energies**, Phys. Rev. C61, 064311 (2000)
2. Zhi-Yong He, Gen-Ming Jin, Bao-Buo Zhang et al., **Emission time scale for light charged particles from symmetric and asymmetric fission processes for ^{40}Ar+^{197}Au reactions at 25MeV/nucleon.** Phys. Rev. C57 (1998) 1824.
3. Zhang Li, Jin Genming et al. **Observation of new neutron-rich nuclide ^{208}Hg** Phys. Rev. C49 (1994) R592
4. Xiao Zhi-Gang, Jin Gen-ming, Wu He-yu, et al., **Experimental probe to the isospin-dependence of hot nuclei in reaction ^{40}Ar+^{112,124}Sn at 30MeV/u,** Chinese Physics Letter 18 (2001) 1037
5. Zhang Fengshou, Li Wenfei, Jin Genming, Progress of isospin dependent transport theories and isospin effects in the heavy ion collisions at intermediate energy (in Chinese), **Progress in Physics** Vol. 2, No. 4 (2001) 70--494

d. Synergistic Activities

Co-organizer of the China-Japan joint nuclear physics symposium, and the Seventh China - Japan Symposium on Materials for Advanced Energy Systems and Fission & Fusion Engineering.

Associate Editor-in-chief of the journal 'high energy physics and nuclear physics'. Editor-in-Chief of the journal 'Review of nuclear physics'

Zhuxia Li

a. Professional Preparation

Graduated from Dept. Physics, Zhejiang University in 1964

b. Appointments:

1964-1979, research assistant in Institute of Atomic Energy, Beijing, China
1979-1981, research associate, State University of New York at Stony Brook, USA
1979-1989, research associate in Institute of Atomic Energy, Beijing, China
1987-1989, research fellow of Alexander von Humboldt Stiftung, Germany
1987-1994, associate professor in China Institute of Atomic Energy
1994- present, full professor in China Institute of Atomic Energy

c. Publications:

a) 5 Pulications relevent to the proposal:

1. Isospin effect on nuclear stopping in intermediate energy Heavy Ion Collisions, Qingfeng Li and Zhuxia Li, Chinese Physics Letters,19 (2002)32.
2. Probing equilibrium with respect to isospin degree of freedom in intermediate energy heavy ion collisions, Qingfeng Li and Zhuxia Li, Phys. Rev. C64 (2001) 064612.
3. Isospin dependence of nucleon-nucleon elastic cross section, Qingfeng Li, Zhuxia Li,Guangjun Mao, Phys. Rev. C62 (2000) 014606.
4. The Isospin Distribution of Fragments in Reaction 96Ru+96Ru, 96Ru+96Zr, 96Zr+96Ru, and 96Zr+96Zr At Beam Energy 400MeV/n, Qingfeng Li, Zhuxia Li, Modern Physics Letter A (2002) in press.
5. Momentum Dependent Vlasov-Uhlieng-Uhlenbeck Calculation of Mass Dependence of the Flow Disappearance in Heavy Ion Collisions, Zhou Hongbo, Li Zhuxia, Zhuo Yizhong, Phys. Rev. C50 (1994) R2664.

b) 5 Other Publications (part of publications on HIC)

1. Transition to Delta Matter of Hot and Dense Nuclear Matter with Relativistic Mean Field Theory of Non-Linear σ and ω Model, Li Zhuxia, Mao Guangjun, Zhuo Yizhong, Walter Greiner, Phys. Rev. C56 (1997) 1570.
2. Self-Consistent RBUU Equation for Delta Distribution Function, Mao Guangjun, Li Zhuxia, Zhuo Yizhong, Phys. Rev. C53 (1996) 2933.
3. The Study of the In-Medium NN Inelastic Cross Section from Relativistic Boltzmann-Uehling-Uhlenbeck Approach, Mao Guangjun, Li Zhuxia, Zhuo Yizhong, Phys. Rev., C49 (1994) 3137.
4. Medium effects on the NN inelastic cross section in relativistic heavy ion collisions, Guangjun Mao, Zhuxia Li, Yizhing Zhuo, Ziqiang Yu, Phys. Lett. B327 (1994) 183.
5. Equilibration Process in Relativistic Heavy Ion Collisions with Relativistic VUU, Li Zhuxia, Zhuo Yizhong, Guyinqi, Sun Zhemin, Yu Ziqiang, M.Sano, Nucl. Phys. A559 (1993) 603.

d. Synergistic Activities

1999 winner of the Wu You-Sun Award of the Chinese Physical Society;
co-organizer of one international workshop, member of the editing board of Chinese Physics Letters (1983-2000), reviewer/referee for National Natural Science Foundation of China, Chinese Physics Letters, Communication of Theoretical Physics, High

Energy and Nuclear Physics (in Chinese).

e. Other Affiliations:

Adjunct Professor, Dept. of Physics, Tsinghua University; Insitute of Theoretcal Physics; Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerators in Lanzhou.

Wei Zuo

a. Professional Preparation

Lanzhou University, Physics	**BS (1987)**
Lanzhou University, Physics	**Ph.D. (1992)**

b. Appointments

Prof., Institute of Modern Physics, Chinese Academy of Science	**1997-present**
Assistant Prof., Institute of Modern Physiscs, Academy of Science	**1994-1997**
Postdoc, Laboratori Nazionali del Sud, Istituto Nazionale di Fisica Nucleare, Italy	**1997-1999**
Postdoc, Institute of Modern Physics, Chinese Academy of Science	**1992-1994**

c. Publications: 45 refereed papers

(i) 5 publications Relevant to the Proposal:

1. Equation of State of Asymmetric Nuclear Matter, U. Lombardo and Wei Zuo, Chap. 1 in Isospin Physics in Heavy-Ion Collisions at Intermediate Energies, Eds. Bao-An Li and W.U. Schröder , NOVA Science Publishers, Inc. (2001, New York), ISBN 1-56072-888-4.
2. Nuclear Stopping as a probe for in-medium nucleon-nucleon cross sections in intermediate energy heavy ion collisions, Jian-Ye Liu, Wen-Jun Guo, Shun-Jin Wang, Wei Zuo, Qiang Zhao, Yan-Fang Yang, Phys. Rev. Lett. 86 (2001) 975.
3. Asymmetric Nuclear Matter from Extended Brueckner-Hartree-Fock Approach, Wei Zuo, I. Bombaci and U. Lombardo, Phys. Rev. C60 (1999) 024605.
4. Single Particle Properties in Neutron Matter from Extened Brueckner Theory, Wei Zuo, G.Giansiracusa, U.Lombardo, N.Sandulescu and J.Schulze, Phys. Lett. B421 (1998) 1.
5. Mean Free Path in Nuclear Matter from Extended Brueckner Theory, Wei Zuo, U. Lombardo and H.-J.Schulze, Phys. Lett. B432(1998)241.

(ii) 5 Other Publications:

1. Isospin Effects in the Processes of Multifragmentation and Dissipation at Intermediate Energy Heavy Ion Collisions, Jian-Ye Liu, Yan-Fang Yang, Wei Zuo, Shun-Jin Wang, Qiang Zhao, Wen-Jun Guo, Phys. Rev. C63 (2001) 054612.
2. Nuclear EOS with a Three-body Force, A. Lejeune, U. Lombardo and Wei Zuo, Phys. Lett. B477 (2000) 45.
3. Self-energy Effects on the Superfluidity in Neutron Star Matter, U. Lombardo, P. Schuck, and Wei Zuo, Phy. Rev. C64 (2001) 021301.
4. Algebraic Dynamical Approach to the su(1,1)⊕h(3) Dynamical System: A Generalized Harmonic Oscillator in an Extenal Field, Wei Zuo and Shun-Jin Wang, J. Phys. I7 (1997) 749.
5. Correlation Dynamics of Green Function, Shun-Jin Wang, Wei Zuo and W. Cassing, Nucl. Phys. A573 (1994) 245.

d. Collaborators

I. Bombaci, G. Giansiracusa, Jian-Ye Liu, Jun-Qing Li, U. Lombardo, F. Mathiot, N.Sandulescu, Sun-Jin Wang

e. Ph.D. Advisor

Ph.D. Advisor: Shun-Jin Wang, Lanzhou University

Hushan Xu

a. Professional Preparation

China University of Science and Technology, Physics **BS (1984)**
Institute of Modern Physics, the Chinese Academy of Science, Physics **Ph.D. (1997)**

b. Appointments

Professor, Institute of Modern Physics, CAS, China, **2001-present**
Research Associate, Department of Chem., Indiana University, USA, **2000-2001**
Research Associate, National Superconducting Cyclotron Laboratory, Michigan State University, USA, **1998-2000**
Associate Prof., Institute of Modern Physics, CAS, China, **1994-1998**
Research associate, Institute of Modern Physics, CAS, China, **1990-1994**
Visiting Scientist, Institute of Physical and Chemical Research (RIKEN), Japan, **1989-1990**
Research Assistant, Institute of Modern Physics, CAS, China, **1984-1989**

c. Publications:

(i) 5 Publications Relevant to the Proposal:

1. Isospin Fractionation in Nuclear Multifragmentation, H.S. Xu, M.B. Tsang, T.X. Liu, X.D. Liu, W.G. Lynch, W.P. Tan, G. Verde, A. VanderMolen, A. Wagner, H.F. Xu, C.K. Gelbke, L. Beaulieu, B. Davin, Y. Larochelle, T. Lefort, R.T. de Souza, R. Yanez, V.E. Viola, R.J. Charity and L. G. Sobotka, Phys. Rev. Lett. 85, 716 (2000)
2. Fragment Isospin as a Probe of Heavy-ion Collisions, H. Xu, R. Alfaro, B. Davin, L. Beaulieu, Y. Larochelle, T. Lefort, R. Yanez, R.T. de Souza, T.X. Liu, X.D. Liu, W.G. Lynch, R. Shomin, W.P. Tan, M.B. Tsang, A. vander Molen, A. Wagner, H.F. Xi, C.K. Gelbke, R.J. Charity, L.G. Sobotka, A.S. Botvina, submitted to Phys. Rev. C. Rapid Comm. (2001).
3. Isospin Scaling in Nuclear Reactions, M.B. Tsang, W.A. Friedman, C.K. Gelbke, W.G. Lynch, G. Verde, and H.S. Xu, Phys. Rev. Lett. 86, 5023 (2001)
4. Neutron-proton Asymmetry of Midvelocity Material in an Intermediate-energy Heavy-ion Collisions, L.G. Sobotka, R.J. Charity, D.K. Agnihotri, W. Gawlikowicz, T.X. Liu, W. Lynch, U. Schroder, J. Toke, H.S. Xu, Phys. Rev. C 62, 031603(R) (2000)
5. The target dependence of N/Z ratio of projectile-like fragments produced in 30 MeV/u ^{40}Ar induced reactions, Xu Hushan et al., Chinese Physics Letter, 14, 413 (1997)

(ii) 5 Other Publications:

1. Isospin Fractionation in Nuclear Fragmentation, G. Verde, H.S. Xu, T.X. Liu, W.G. Lynch, W.P. Tan, M.B. Tsang, A. VanderMolen, A. Wagner, H.F. Xi, C.K. Gelbke, L. Beaulieu, B. Davin, Y. Larochelle, T. Lefort, R.T. de Souza, R. Yanez, V. Viola, R.J. Charity, L.G. Sobotka, Nucl. Phys. A 681, 299c (2001).

2. Isoscaling in Statistical Models, M. B. Tsang, C. K. Gelbke, X. D. Liu, W. G. Lynch, W. P. Tan, G. Verde, H. S. Xu, W. A. Friedman, R. Donangelo, S. R. Souza, C. B. Das, S. Das Gupta, and D. Zhabinsky, Phys. Rev. C 64, 054615 (2001)
3. LASSA: A Large Area Silicon Strip Array for Isotopic Identification of Charged Particles, B. Davin, R.T. de Souza, R. Yanez, Y. Larochelle, R. Alfaro, H.S. Xu, A. Alexander, K. Bastin, L. Beaulieu, J. Dorsett, G. Fleener, L. Gelovani, T. Lefort, J. Poehlman, R.J. Charity, L.G. Sobotka, J. Elson, A. Wagner, T.X. Liu, X.D. Liu, W.G. Lynch, L. Morris, R. Shomin, W.P. Tan, M.B. Tsang, G. Verde, J. Yurkon, Nucl. Instr. and Meth. Phys. Res. Section A 473, 301 (2001).
4. Fluctuation Measurement of the Isotope Projectile-like Products in the Dissipative Process of $^{19}F+^{51}V$ Reaction, Wang Qi, Lu Jun, Xu Hushan, et al., Physics Letter B 388, 462(1996)
5. Measurement of $^{8}Li(\alpha,n)^{11}B$ Reaction Cross Section at Energies of Astrophysical Tntrest,R.N.Boyal,…,H.S.Xu,et al., Phys.Rev.Lett. 68, 1283 (1992)

d. Collaborators & Other Affiliations

(i) Collaborators: Wenlong Zhan, Yongtai Zhu, Genmin Jin, Guoqing Xiao, Heyu Wu, Zhigang Xiao, Liming Duan, Songlin Li, Zhiyu Sun, Hongwei Wang, Wenfei Li

(ii) Ph.D. and Postdoc Advisors

Ph.D. Advisor: Yongtai Zhu, Institute of Modern Physics, CAS, China

Postdoc Advisors: B. M. Tsang, Michigan State University, USA
W. G. Lynch, Michigan State University, USA
R.T. de Souza, Indiana University, USA
V. Viola, Indiana University, USA

IMP
Institute of Modern Physics, CAS
363 Nanchang Road, 730000 Lanzhou, China

May 15,2002

To Whom It May Concern:

We support the multi-institutions China-US collaborative proposal to study the dynamics of heavy ion reactions proposed by Prof. Jin Genming of the Institute of Modern Physics (IMP) at Lanzhou and Prof. William G. Lynch of Michigan State University. The proposal involves scientists from the Institute of Modern Physics, Lanzhou and the Institute of Atomic Energy, Beijing, in China, Michigan State University, Arkansas State University, Jonesborough and the University of Wisconsin, Madison in the United States. We believe the concerted effort will make an impact on the current understanding of the reaction dynamics in heavy ion reactions and may lead to our understanding of the density dependence of the symmetry energy in the nuclear equation of state. Based on the purpose mentioned above, IMP agrees to cover the local expense for all the US scientists, who will visit China in connection with the proposed research. We also agree to provide the transportation costs for the four Chinese principal investigators (PI), Drs. Jin Genming, Zuowei, Xu Hushan and Li Zhuxia to visit the National Superconducting Cyclotron Laboratory at Michigan State University in connection with the proposed research. Each Chinese PI plans to visit MSU once a year for two months. Hence IMP will allocate 200 000 yuan per year for this project during the project excution.

In addition to hosting the US collaborators during their visit in China, we will provide assistance to visa applications, housing, office support and a safe and secure working environment. We are confident that the collaboration will lead to fruitful results.

Sincerely yours,

Zhan Wenlong
Director of Institute of Modern Physics

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