University of Toronto
Canadian Institute for Theoretical Astrophysics

Toronto, Ontario M5S 3H8

[S0002-7537(93)03431-6]

The following is an abbreviated version of the 2000 CITA Annual Report. Due to space constraints, we have not included more than a very brief summary of the scientific activities at CITA in 2000. The full report is available on request (from citadmin@cita.utoronto.ca) or on the web (at http://www.cita.utoronto.ca).

1. FOREWORD

The Canadian Institute for Theoretical Astrophysics is a nationally supported research center for studies in theoretical astronomy and related subjects, hosted by the University of Toronto, and receiving research support from an NSERC collaborative special project grant, as well as the Canadian Institute for Advanced Research. CITA's primary missions are to foster interaction within the Canadian theoretical astrophysics community and to serve as an international center of excellence for theoretical studies in astrophysics. This report has been prepared by Jason Fiege, Chris Matzner, and Simon Prunet.

Research at CITA covers a broad range of fields in astrophysical theory. During the 1999/2000 academic year (July 1999 to July 2000), the areas of study included:

• cosmology: early universe, inflation, cosmic defects, big bang nucleosynthesis, microwave background anisotropies, large-scale structure, gravitational lensing, galaxy formation, Lyman alpha clouds;

• dynamics: galactic warps and bars, galaxy interactions and mergers, galaxies in clusters, globular clusters;

• intergalactic and interstellar medium: AGN winds, Galactic HI distribution, molecular clouds, star-forming regions, dust physics;

• stars and compact objects: accretion disks, protoplanetary disks, stellar winds, pulsar magnetospheres, supernovae and gamma ray bursts;

• planetary systems: chaos, planet migration, asteroid belt, extra-solar planets, Uranian moons.

2. PERSONNEL

The research staff of CITA for the 1999/2000 academic year (July 1999 to July 2000) is listed below, along with their primary research interests. We use the symbol † to denote people who have left CITA during the past year, and ‡ to denote those who have joined.

• **Phil Arras**‡ works primarily on spin, magnetic fields, and linear motion of neutron stars. Recent work has focused on linear and nonlinear oscillations in rapidly rotating stars. Other topics of interest are extrasolar planets, neutrino transfer in supernovae, globular cluster evolution, and galactic dark matter.

• **J. Richard Bond**, CITA's Director, works on theoretical problems ranging from the physics of the early universe (in particular, inflation theory), cosmic background radiation, nonlinear evolution of cosmic structure (the cosmic web approach to hydrodynamical simulations, galaxy formation, Lyman alpha clouds, and supercluster formation and evolution), as well as analysis methods for confronting cosmological theories with large cosmological databases. Most recently, he has been heavily involved in the interpretation of data from the BOOMERanG balloon-borne experiment, which measured the cosmic microwave background in unprecedented detail.

• **John Dubinski** works on problems in galaxy formation, evolution and dynamics. After galaxies form, they experience dynamical evolution either through internal instabilities or tidal interactions and merging with other galaxies. Understanding these processes is essential for coming to terms with the mass and scaling relations and the morphological mixture seen in present day spiral and elliptical galaxies. His main tool for studying these processes is N-body simulation and he has developed a parallel treecode which has run simulations containing 10-100 million particles. On the galactic scale, he is studying the origin of bulges through bar-buckling instabilities and the origin of galactic warps through tidal interactions with satellite galaxies. On larger scales he has been studying the dynamical evolution of galaxies in clusters using thousands of well-resolved disk galaxies to explore the importance of merging and interactions on galaxy evolution in the cluster environment.

• **Jason Fiege**‡ works on problems related to star formation and the structure of magnetic fields in star-forming molecular clouds. He is currently developing detailed models of the sub-millimetre polarization patterns observed in molecular clouds, to test theoretical models of the magnetic fields in these regions. He is also working the the support of molecular clouds by Alfvénic turbulence, and developing a self-similar model for the anisotropic collapse of pre-protostellar cores and the formation of bipolar outflows in these regions.

• **Peter van Hoof** studies the late stages of evolution of intermediate mass stars, i.e., post-Asymptotic Giant Branch (post-AGB) stars and planetary nebulae (PNe), and their outflows. The long-term goals of this research are to obtain a large sample of post-AGB stars and PNe, and use this to test stellar evolution models, study mass loss processes and hydrodynamic interactions in the outflows, and deepen our understanding of grain formation and evolution. van Hoof is also rewriting the grain model in the photo-ionization code Cloudy: the new model incorporates a spherical Mie code; it is able to resolve the grain size distribution to arbitrary precision; and it can treat non-equilibrium heating of grains.

• **Robin Humble**‡ develops parallel numerical gravity and hydrodynamics codes for the exploration of such topics as self-gravitating disks, dusty disks, planet and galaxy formation, and cosmology.

• **Lev Kofman** works primarily on cosmology, including physics of the very early universe and the large scale structure.

• **Maxim Lyutikov** works on pulsars (radio emission generation, wave propagation inside magnetosphere, pulsar winds), gamma-ray bursts, planetary dynamics, turbulence.

• **Peter Martin** studies the interstellar medium. His current projects include a multifrequency analysis of the Canadian Galactic Plane Survey; a study of the collisional excitation and dissociation of molecular hydrogen, with applications to shocks and photodissociation regions; and investigations of the structures and compositions of nebulae using the Hubble Space Telescope.

• **Christopher Matzner**‡ models events related to the birth and death of stars. To address the formation of stars and stellar clusters, he investigates the ways that intense stellar winds mediate the interaction between a newborn star and its parent cloud, and the consequences of this interaction for the efficiency of star formation. He also models supernova explosions, including the motions of shock waves within stars; when these motions become relativistic, they may cause a type of weak gamma-ray bursts (GRBs). Recently, he has been investigating the roles of magnetic fields and beamed outflow in cosmological GRBs and in their afterglows, and also the physics of neutron stars.

• **Norm Murray** has been working primarily on planetary dynamics and planet formation. With former CITA postdoc Matt Holman he identified a class of resonances between Jupiter, Saturn, and Uranus which render the evolution of the outer solar system chaotic. With Phil Arras, former CITA posdocs Brad Hansen and Brian Chaboyer, and Bob Noyes, he has identified strong trends in the metallicity of solar type stars as a function of stellar mass, indicative of pollution. With new CITA professor Chris Thompson, he studied the origin and evolution of magnetic fields in young, convective neutron stars. Finally, he has unearthed evidence of double peaked Balmer line emission in the active nucleus of the well known Seyfer galaxy NGC 5548, a strong indication of the presence of an accretion disk.

• **Ue-Li Pen** works primarily on cosmology, numerical simulations, large scale structure and the cosmic microwave background. Recent research topics include the Sunyaev-Zeldovich effect, alignments of galaxies, gravitational lensing, and science related to the AMIBA cosmic microwave background interferometer.

• **Dmitri Pogosyan** is working on different problems of theoretical cosmology. His work spans the range from the theory of the early Universe and generation of initial cosmological perturbations, to Cosmic Microwave Background theory and analysis, to the modeling of the observed Large-Scale Structure in the Universe and tests on cosmological models, to the observables of galaxy clusters and intracluster structure. Currently he analyses observational data from balloon-borne CMB anistropy experiments to estimate parameters of the cosmological models and develops statistical methods for analysis of the future CMB space missions. Pogosyan also applies techniques originated in cosmology to the studies of the properties of the interstellar medium.

• **Nir Shaviv**‡ works on topics ranging from cosmology to stellar physics and compact objects. Recently, he has concentrated on the behaviour of atmospheres close to or beyond the Eddington limit, on the formation and evolution of photon polarization in the magnetospheres of neutron stars, and on the accurate screening corrections to nuclear reaction rates in the sun.

• **István Szapudi** works primarily on cosmology, including large scale structure and CMB. His focus has been on the application of spatial statistics to extract useful cosmological information from data. For example, higher order statistics of galaxy surveys can constrain our theories on initial conditions (i.e., the physics of the early universe), gravitational amplification of the initial fluctuations, and the dissipative physics of galaxy formations (e.g., biasing). The emergence of huge data sets in the near future, such as megapixel CMB maps, and wide field surveys such as SDSS, of which he is a member of, sparked his interest in conceiving fast methods, which could enable the analysis of these data within human timescales.

• **Ludovic Van Waerbeke** works on different theoretical and observational aspects involving the gravitational lensing by the large scale structures. This includes lensing predictions on the Cosmic Microwave Background (on temperature and polarisation), lensing statistics at small angular scales, analysis of spurious effects (source clustering, lens-lens coupling,...) and the design of lensing-dedicated surveys as well as the control of the systematics and shear measurement.

• **Joseph Weingartner**‡ studies physical processes involving interstellar dust. Many such processes depend sensitively on the grain size; thus one project was the construction of size distributions that are consistent with observations of both thermal dust emission and starlight extinction. Further work includes modeling the charging of grains, gas heating via photoelectric emission from dust, electron-ion recombination on grains, and the forces on grains exposed to anisotropic radiation. Ongoing work on the theory of grain alignment aims to clarify the role of starlight torques.

• **Yanqin Wu**‡ is currently studying stars, compact objects and their surroundings, including oscillations of white dwarfs, neutron stars and main sequence stars, spin evolution of compact objects, and tidal circularization of binary orbits.

3. CITA VISITORS

CITA has a vigorous visitors program bringing a number of Astronomy and Physics faculty members from other Canadian universities and from abroad for both extended stays and shorter visits. The following is a list of all CITA visitors for the 1999/2000 academic year.

• Rouzbeh Allahverdi
• Stephan Ansoldi
• Celine Anthoine
• Shantanu Basu
• Eric Blackman
• Arnold Boothroyd
• Julian Borrill
• Colin Borys
• Robert Brandenberger
• Eugene Chiang
• Geoff Clayton
• Kim Coble
• Joanna Cohn

- Steve Corly
- Sacha Davidson
- Paolo deBernardis
- Giancarlo Degasperis
- Steve Eales
- John Ellis
- Thomas Erben
- Gus Evrard
- Gary Felder
- Gary Ferland
- Mike Fich
- Jose Franco
- Andrei Frolov
- Juan Garcia-Bellido
- David Goldberg
- Andrei Gruzinov
- Carl Gwinn
- Dick Henriksen
- Jeremy Heyl
- Eric Hivon
- Henk Hoekstra
- Robin Humble
- Werner Israel
- Andrew Jaffe
- Ing-Guey Jiang
- Martin Kerscher
- Daniel Koryani
- Bob Krishner
- Alex Kusenko
- Sun Kwok
- George Lake
- Andrew Lange
- Richard Larson
- Jounghun Lee
- Luis Lehner
- Margo Mandy
- Roberto Maoli
- Johannes Martin
- Silvia Masis
- Brenda Matthews
- Anupam Mazumdar
- Marshal McCall
- Alessandro Melchiorri
- Tom Montroy
- Kin-Wang Ng
- Changbom Park
- Elena Pierpaoli
- Gavin Pringle
- Dmitrios Psaltis
- Elliot Quataert
- Paul Ricker
- John Ruhl
- Re'em Sari
- Douglas Scott
- Ravi Sheth
- Frank Shu
- B. Simmons
- Massimo Staivelli
- Istvan Szapudi
- Peter Thomas
- Scott Tremaine
- Tom Troland
- Greg Ushomirsky
- Vladimir Usov
- Griet Van de Steene
- Rien van de Weygaert
- Katya Verner
- Steve Vogt
- Mark Voit
- James Wadsley
- Eli Waxman
- Martin White
- Tseng Yao-Huan
- Bing Zhang

4. CIAR AND CITA

The Canadian Institute for Advanced Research supports a number of programs chosen for their high intellectual promise and interdisciplinary character. The CIAR Cosmology and Gravity Program has nodes at UBC (Fellows Bill Unruh and Matt Choptuik), at the University of Alberta (Fellows Valery Frolov and Don Page), at the University of Victoria (Fellow Werner Israel and Scholar Julio Navarro), at McMaster University (Fellow Hugh Couchman), at Queen's University (Scholar Mark Chen), at the University of Toronto (Fellows Ray Carlberg and Simon Lilly) and at CITA, where Dick Bond and Lev Kofman are CIAR Fellows and Ue-Li Pen is a CIAR scholar. There is also a large distinguished network of CIAR Associates of this Program around the world. The Program is in its fourth five year period and Scott Tremaine is the Director. The academic interaction between CIAR Fellows and other CITA visitors and researchers, and the administrative cooperation between CITA and CIAR in attracting excellent cosmologists, continues to make Toronto and Canada a lively place for research in theoretical cosmology.

5. SACKLER VISITING ASTROPHYSICIST

CITA received a generous gift from the Raymond and Beverly Sackler Foundation to endow the **Raymond and Beverly Sackler Visiting Astrophysicist Program**. Each year CITA invites an internationally distinguished scholar conducting research in theoretical astrophysics to give two lectures at the University of Toronto. The researcher also meets informally with faculty and postdoctoral fellows at CITA as well as researchers and students in the Department of Astronomy and other departments. The visit is intended to be the highlight of the academic year at CITA.

The first Raymond and Beverly Sackler Visiting Astrophysicist (1997) was Sir Martin Rees from Cambridge University. The second Sackler Visitor was Peter Goldreich of Caltech who visited in September 1998 and gave a public lecture entitled "Planet Formation." Frank Shu was the Sackler Visitor for the 1999/2000 academic year. He visited CITA in October 1999, and spoke on star and planet formation. Jim Peebles will be the Sackler lecturer for the 2000/2001 academic year.

6. CONFERENCES SUPPORTED BY CITA

CITA supports scientific workshops and meetings in Canada on subjects of interest to theoretical astrophysics. Meetings supported by CITA in 1999/2000 were:

• General Relativity and Relativistic Astrophysics: Eighth Canadian Conference (June 99, Montreal)

• Summer Workshop on Particles, Fields and String'99 (August 99, Vancouver)

Preparations were made to host the 15th Kingston Meeting on Theoretical Astrophysics at the Field's Institute (University of Toronto). This conference is the ''CITA Reunion Meeting'' and will cover all areas of astrophysics worked on by CITA researchers since the institute was founded in 1986.

In addition, a collaboration between CITA, McMaster, Waterloo, and Queen's University has produced an active Star Formation Group in the Southern Ontario region which meets monthly to discuss current research topics. Informal weekly seminars also convene to discuss theories and observations of gamma ray bursts.

7. FACILITIES

CITA occupies the 12th floor of the McLennan Physical Laboratories at the downtown campus of the University of Toronto.

CITA's computational facilities have improved dramatically in the past year. Researchers now have access to 32 processor Compaq GS320 computer with 64Gb of RAM. This machine is intended primarily for cosmological simulations, cosmological hydrodynamics, simulations of galaxy formation, and CMB map analysis. However, it is available to any CITA researcher whose research depends on high performance parallel computing. This computer was obtained with a ''Canadian Fund for Innovations'' (CFI) grant, proposed by Peter Martin, Richard Bond, and Ray Carlberg, along with the Atmospheric Physics group and the Chemistry department.

CITA also has two powerful Beowulf clusters. A dedicated 28 processor Intel cluster with 8Gb of RAM is funded by John Dubinski and used for his research in galactic dynamics. A second Beowulf cluster with 1Gb of memory is funded by Peter Martin in collaboration with M. Duncan (Queen's) and K. Innanen (York). This cluster is dedicated to computationally intensive simulations in molecular and atomic physics, as well as planetary dynamics. CITA also houses a large SCSI Raid array with a storage capacity of ~550Gb.

CITA researchers also have access to several other multiprocessor machines, including 8 Quad Alpha ES40s. Four of these are equipped with 666 MHz and 8 GB of RAM each, while the remaining 4 have 500 MHz processors and 4 GB of RAM each. CITA also has two older multi-processor machines, including an 8 processor SGI Origin 2000 system with 4Gb of memory, and a 4 processor Compaq AlphaServer 2100 system with 1Gb of memory. Every researcher at CITA has a desktop computer for general use and smaller computational tasks. These are mostly Intel-based personal computers running Linux, although there are several Compaq Alpha workstations, SGI Indigo workstations, SGI Personal IRISes, SUN SPARCstations, and X terminals. All of these systems are networked together, and used either individually or in parallel.

All of these systems are supported by a Sun Ultra 5 backend file and network server, with about 200 gigabytes of disk. CITA's network is fully switched, with 10 and 100 megabit connections to offices (depending on the computers present) and a 100 megabit link to the campus network and the Internet.

Researchers also have access to a number of peripheral devices, including a high-quality colour laser printer, a dye-sublimation colour printer, several inkjet colour printers, a high-speed black-and-white laser printer capable of double-sided printing, an optical scanner, and various tape drives.

8. CITA COUNCIL

CITA is both an Institute within the School of Graduate Studies of the University of Toronto, and a non-profit corporation (CITA, Inc.). Relations between the two CITAs are governed by a Letter of Agreement between CITA Inc. and the University of Toronto that was signed in 1989. The CITA Council consists of eight members, five selected from the CITA Inc. membership of over 50 researchers in co-operation with the Canadian Astronomical Society (of which they must also be members), and two *ex officio*: the Director of CITA and the Dean of the School of Graduate Studies of the University of Toronto or his designate.

Members of CITA Council for the second half of 1999 were:

- Richard Bond, CITA Director
- Richard Henriksen, CITA Chair, Queen's University
- Don Cormack, School of Graduate Studies, U. of T.
- Hugh Couchman, McMaster University
- Martin Duncan, Queen's University
- David Hartwick, University of Victoria
- Kim Innanen, York University
- Don Cormack, School of Graduate Studies, U. of T.

9. SCIENTIFIC OVERVIEW 2000

The research program at CITA encompasses all the major areas in astronomy broken down in the main categories of cosmology, galaxies, interstellar medium, stars and planets. In this report, we review the main activities at CITA during 2000.

9.1 Cosmology

In the 1990's, cosmology has evolved into a mature, detailed science driven by an enormous amount of observational data. Research in cosmology at CITA covers most areas of current interest, including studies of the early universe and the origin of the primordial density fluctuations, the connection to the cosmic microwave background (CMB) temperature fluctuations and the nonlinear evolution via gravitational collapse into galaxies, clusters of galaxies and large-scale structure.

Inflation continues to be a lively area at CITA: especially, the question of how matter arose at the end of inflation (Kofman) and its impact on density fluctuations; both questions lead to observable tests. The alternative, defect-induced structure formation theory, has also been much explored (Pen).

A large effort at CITA currently is centered on the analysis of the CMB data from the BOOMERanG experiment (Bond, Pogosyan, Prunet). CITA researchers have developed fast iterative algorithm for temperature map reconstruction and noise estimation from raw data (Prunet) and carried out the estimation of cosmological parameters from BOOMERanG data (Bond, Pogosyan).

This work is built upon and further advances the expertise in CMB studies developed at CITA over the years. Cosmologists at CITA are building new tools and techniques for interpreting the deluge of new CMB data. The band-power method developed by Bond has been refined and has become the standard method for the presentation of power spectrum constraints by observers (Bond and Knox). Fast techniques based on correlation functions and, more generally, quadratic estimators of the power spectrum, are proposed and being developed (Bond, Contaldi, Pogosyan, Prunet, Szapudi). These techniques provide a crucial speed-up required for the analysis of megapixel maps expected from the upcoming space missions, MAP and Planck. Various pixelization schemes for use with Planck and other experiments have been also been analyzed (Crittenden). Understanding the effect of foreground emission on the high quality observations now available is particularly important and important work is being done at CITA in this pursuit (Prunet, Weingartner).

Precise measurements of CMB fluctuations provide unique constraints on the theories of the early Universe (Bond, Crittenden, Knox, Pogosyan, and Souradeep). Bond, Knox, and Souradeep have been studying how well one can reconstruct the primordial power spectra and the inflation potential from measurements to be done with Plank and MAP, while Bond, Pogosyan, and Souradeep have developed a completely general method for calculating CMB anisotropy in models with non-trivial topology and placed the limits on the topological size of our Universe from COBE data.

The size and depth of galaxy redshift surveys will increase dramatically in the next few years and new statistics on the large-scale distribution of galaxies will be available for direct comparison to cosmological theories. CITA researchers are advancing the Cosmic Web paradigm (Bond, Kofman and Pogosyan) and studying the observability of these structures by weak lensing (van Waerbeke), secondary CMB fluctuations such as the Sunyaev-Zel'dovich effect, and x-ray emission (Bond, Kofman, Pen, and Pogosyan). Refined techniques of the weak lensing signal measurement in wide-field surveys has been developed and the first positive detection of the cosmic shear has been reported (van Waerbeke).

Other studies at CITA include: analysis of gravitational instability in mildly non-linear regimes (Scoccimarro and Couchman); simulations of Lyman-alpha absorption at high redshift (Bond); and development of sophisticated N-body and hydrodynamic codes for simulating the complex interplay between gravity, gasdynamics, atomic physics and magnetic fields (Bond, Pen, Dubinski, and Couchman). The main problems that are being tackled with these codes are the evolution of the Lyman-α forest, the formation of galaxy clusters, and the study of galaxy interactions in merging pairs and in clusters. The recent acquisition of a multi-processor Compaq GS320 supercomputer provide advanced computational facilities to aid in these studies.

9.2 Galaxies

Galaxies form out of the gravitational collapse of cosmological density fluctuations in the early universe, settling into the spirals and ellipticals we see today. A complete understanding of their formation and evolution requires detailed dynamical treatment of the disks and spheroids stars as they behave in isolation in response to internal instabilities and as they behave in a cosmic environment where they interact and merge with other galaxies. A big current goal is to understand the dynamical evolution of galaxies over cosmic history as they interact in clusters and the field and are transformed from spirals into ellipticals in mergers. New observations of distant and young galaxies are pressing the need for detailed modelling of galaxy interactions in cosmological environments to test for consistency with the current cosmological paradigm.

Dubinski in collaboration with Geller and Koranyi (Harvard) has been using parallel, N-body simulations to study the galaxy interactions in clusters. The goal of this work is to understand the origin of the morphology-density relationship and the general properties of elliptical galaxies under the hypothesis that they form in mergers of spirals. He has been pushing the limits of current technology, simulating N-body systems of hundreds of disk galaxies falling into a cluster using tens of millions of particles. High resolution is needed to follow dynamical evolution faithfully over a Hubble time. From the analysis of over 200 hundred merger remnants, it appears that the fundamental plane relations for ellipticals result from simple dissipationless merging of spiral galaxies.

Dubinski and Hernquist (Harvard) have also been exploring the merging process of pairs of galaxy at the highest resolution possible using 100 million particles. These simulations reveal new fine details in the development of the tidal debris that surrounds a merger remnant including shells and tidal streams. Shells and streams can be used to determine galaxy mass by modelling their kinematics if detected through observations of planetary nebulae in the outer regions of elliptical galaxies.

9.3 The Interstellar Medium

Stars and the interstellar medium are the two components of the Galaxy, and they have a close and intricate relationship. Stars form out of clouds of gas and dust. Stellar radiation and winds, as well as supernova explosions, play crucial roles in sculpting the ISM.

The Canadian Galactic Plane Survey, for which Martin serves as a scientific director, is conducting an HI and continuum radio survey at 1 arc minute resolution. Combined with other data sets with similar resolution, this provides an excellent resource for studying the interplay between stars and the ISM.

Much of the ISM-related research at CITA focusses on the process of star formation. We know that stars form when dense ''cores'' within molecular clouds collapse under their own self-gravity. Magnetic fields play a crucial role in determining the structure of these objects and in the dynamics of their eventual collapse. Fiege is working with Richard Henriksen (Queen's University) to develop a self-similar model for the anisotropic collapse of magnetized molecular cloud cores. Their model features powerful bipolar outflows that develop as material collapses onto the protostellar object forming at the centre. These jet-like outflows have been observed in nearly all star-forming regions. Matzner also investigates the formation of jets, as well as their effects on the surrounding ISM. The jets drive away material that might otherwise fall onto the protostar, and the combined effect of the jets from multiple protostars acts to destroy the molecular cloud in which they all reside. Thus, the astrophysics of jets has implications for the stellar initial mass function, the efficiency with which mass in molecular clouds is transformed into stars, and the likelihood of forming bound star clusters.

In other studies of molecular clouds, Fiege and Lyutikov are investigating the role of Alfvénic turbulence in supporting the clouds against collapse, as well as the interaction of Alfvén waves with the surrounding ISM. Fiege is developing theoretical tools and software for interpreting maps of polarized sub-millimetre radiation from molecular clouds. This radiation is thermal emission from non-spherical dust grains, and it is polarized because the grains are systematically aligned, with either their relatively long or short axes lying along the magnetic field direction. Thus, sub-millimetre polarization maps contain information on the magnetic field in the cloud. As a member of the *Canadian Consortium for Star Formation Studies*, Fiege uses his polarization modelling techniques to directly compare his models with the excellent polarization maps obtained by his observational colleagues in this group.

Grain physics is also a very active area of research at CITA. Weingartner is working on the theory of grain alignment, focussing on the potentially dominant role played by torques exerted on grains by starlight. Martin works on constraining the grain alignment mechanism using UV polarimetry obtained with the Hubble Space Telescope and the Wisconsin Ultraviolet Photo-Polarimeter Experiment.

While the emission from dust serves an important function in astrophysics as a magnetic field diagnostic, grains are also major players in the physical processes that determine the conditions in the ISM. For example, energetic electrons are liberated, via the photoelectric effect, from grains exposed to starlight. These electrons transfer their energy to gas atoms during collisions, and this is often the dominant mechanism for converting starlight energy into gas heating. Also, grain surfaces catalyze reactions that, in some cases, proceed only very slowly in the gas phase. Weingartner works on modelling these dust-related processes, with the goal of providing the most accurate possible rates for use in studies of the ISM, given the uncertainties in the grain physics.

These uncertainties can be diminished through improvements in the characterization of grains. Martin probes the nature of dust by studying how its properties vary from one interstellar environment to another. This work employs observations of the extinction and polarization of starlight, as well as the infrared emission from dust.

Martin also works on theoretical determinations of the cross sections for excitation and dissociation of hydrogen molecules colliding with one another. These are needed in order to interpret the emission from regions of star formation and supernova shocks. In addition, Martin is involved in an effort to model the interaction geometry, dynamics, and emission line spectrum of the Orion Nebula. This will provide a benchmark for understanding extragalactic HII regions.

Van Hoof studies the late evolutionary stages of intermediate-mass stars (post-AGB stars and planetary nebulae) and their outflows. In a collaboration with Van de Steene and Wood, an infrared selected sample of post-AGB objects is being assembled. This sample will be used to test stellar evolution models, study mass loss processes and (magneto-)hydrodynamic interactions in the outflows, and deepen our understanding of grain formation and evolution through the post-AGB and PN phase.

Van Hoof is also rewriting the grain model in the photoionization code Cloudy in collaboration with Martin and Ferland. The new model incorporates a spherical Mie code, is able to resolve the grain size distribution to arbitrary precision, and can treat non-equilibrium heating of grains. All these changes permit a much more realistic prediction of the emitted spectrum. The first application will be to model the silicate emission in the Ney-Allen nebula.

9.4 Stars and Compact Objects

While much is understood about the basic structure and evolution of stars, there are still many fundamental questions left unanswered, some of which are tackled in CITA. These questions relate to a wide spectrum of issues ranging all the way from the formation of Stars to the ultimate fate of their remnants.

Numerous are the open questions in the formation of stars. Some are tackled by Fiege who analyzes the formation of protostellar cores, while other questions by Matzner who analyses how these cores, which can have significant inflows and outflows, interact with their environment.

Our sun, which is a mediocre middle aged star, surprisingly has several unanswered questions. Murray studies the excitation of waves in the convection zone of the sun, while Shaviv studies the small but important plasma screening corrections to the nuclear reactions. The most massive stars shine close to or even above their Eddington luminosity limit. Shaviv studies these objects, the wind they generate and how it applies to various stellar and non stellar objects. Other stars could be metally enriched by the falling in of the protoplanetary debris (Arras, Murray).

The death of stars can be particularly impressive if they do so through a supernova. The hydrodynamics of supernova explosions, including the transition to relativistic motion and the possibility of gamma-ray bursts, is studied by Matzner. The stellar graveyard also provides many astrophysical enigmas. Much can be learned about White Dwarfs through their oscillations (Wu). Pulsars which are even more compact objects, offer a rich test bed for a plethora of physical processes. The large pulsar kicks could perhaps be explained using the strong neutrino winds when they form (Arras). Understanding the rich plasma processes around these objects allows the diagnostics of the pulsar magnetospheres (Lyutikov). r-modes have recently been a hot topic since they could generate an interesting gravity wave signal for future gravity wave detectors. Analysis of r-modes and how they saturate is done by Arras, Matzner and Wu.

Neutron stars with very strong magnetic fields open a window to interesting physical processes not accessible terrestrially. The nontrivial thermal emission, for example, is studied by Arras, and the subsequent evolution of the photons through these magnetospheres, by Shaviv.

9.5 Planetary Systems

Phil Arras and Norm Murray have been working with Brad Hansen, Brian Chaboyer, and Bob Noyes on searches for metallicity trends in solar-type stars. They examined a sample of 450 stars with spectroscopic metallicity ([Fe/H]) measurements and Hipparcos parallaxes (which allow for mass and age determinations) they find strong evidence for variations of [Fe/H] with stellar mass. These variations mirror the variations of lithium abundances with stellar mass; the latter are believed to be the result of two or more mixing processes in the outer layers of solar-mass stars. The variations in the sample are consistent with the addition of 0.4 Earth masses of iron some time after the stars reached the main sequence, i.e., after their convection zones thinned (10-100 million years, depending on the stellar mass). A similar analysis of the known planet-bearing stars shows that they have an average [Fe/H] which is highly inconsistent with the hypothesis that the two populations were drawn from the same sample in an unbiased manner. The analysis also hints at a trend similar to that seen in the systems not known to have planets. The amount of added iron required to reproduce the trend is 5 Earth masses.

Marcy Paskowitz and Norm Murray have been using all the stray cycles on Dolphin and Porpoise, the new Compaq multiprocessor machines, to study the evolution of eccentricity of a Jupiter-mass body embedded in planetesimal disk with $\sim$10 0.1 to 1 Earth mass bodies. The smaller bodies suffer a variety of fates, including ejection following a close encounter with ''Jupiter,'' collision with other Earth mass objects, falling into the sun, and capture into resonance with ''Jupiter.'' The latter bodies drive up the eccentricity of ''Jupiter,'' somtimes to values as high as 0.7 or 0.8.

PUBLICATIONS

The publication list includes all papers published or submitted in 2000 by the CITA staff, or by visitors if a substantial portion of the work was done at CITA.

CITA-2000-01 Roman Scoccimarro *The Bispectrum: From Theory to Observations*

CITA-2000-02 Roman Scoccimarro, H.A. Feldman, J.N. Fry, J. Frieman *The Bispectrum of IRAS Galaxies*

CITA-2000-03 Ludovic Van Waerbeke, Yannick Mellier, Thomas Erben, J.C. Cuillandre, Francis Bernardeau, R. Maoli, E. Bertin, H.J. Mc Cracken, O. Le Fevre, B. Fort, M. Dantel-Fort, B. Jain, Peter Schneider *Detection of correlated galaxy ellipticities on CFHT data: first evidence for gravitational lensing by large-scale structures*

CITA-2000-04 Lev Kofman, Patrick Greene *On the Theory of Fermiotic Preheating*

CITA-2000-05 K. Benabed, Francis Bernardeau, Ludovic Van Waerbeke *CMB B-polarization to map the Large-scale Structures of the Universe*

CITA-2000-06 Martin Kerscher, István Szapudi, Alex Szalay *A comparison of estimators for the two-point correlation function*

CITA-2000-07 Fiona Hoyle, István Szapudi, Carlton Baugh *Higher Order Clustering in the Durham/UKST and Stromlo-APM Galaxy Redshift Surveys*

CITA-2000-08 István Szapudi, Stphane Colombi, Adrian Jenkins, Jrg Colberg *Experimental Cosmic Statistics II: Distribution*

CITA-2000-09 István Szapudi, Stphane Colombi, Adrian Jenkins, Jrg Colberg *Experimental Cosmic Statistics I: Variance*

CITA-2000-10 István Szapudi, Enzo Branchini, Carlos Frenk, Steve Maddox, Will Saunders *The luminosity dependence of clustering and higher order*

CITA-2000-11 István Szapudi, Alex Szalay *The variance of a new class of N-point correlation*

CITA-2000-12 Renata Kallosh, Lev Kofman *Supergravity and Cosmology*

CITA-2000-13 Changbom Park *Cosmic Momentum Field and Mass Auctuation Power Spectrum*

CITA-2000-14 Jason Fiege, Ralph Pudritz *Polarized Sub-Millimetre Emission from Filamentary Molecular Clouds*

CITA-2000-15 Thomas Erben, Ludovic Van Waerbeke, E. Bertin, Yannick Mellier, Peter Schneider *How accurately can we measure mean gravitational shear?*

CITA-2000-16 Gary Felder, Lev Kofman *The Dynamics towards equilibrium after preheating*

CITA-2000-17 Simon Prunet, C.B. Netterfield, E. Hivon, B.P. Crill *Iterative map-making for scanning experiments*

CITA-2000-18 Ue-Li Pen, Jounghun Lee, Uros Seljak *Detection of Galaxy Spin Correlations in the Tully Catalog*

CITA-2000-19 Yanqin Wu, Christopher D. Matzner, Phil Arras *R-modes in Neutron Stars with Crusts: Turbulent Saturation, Spin-down, and Crust Melting*

CITA-2000-20 Christopher D. Matzner *Feedback from Protostellar Outflows in Star and Star Cluster Formation*

CITA-2000-21 Joseph C. Weingartner, B. T. Draine *Dust Grain Size Distributions and Extinction in the Milky Way, LMC, and SMC*

CITA-2000-22 Joseph C. Weingartner, B. T. Draine *Photoelectric Emission from Interstellar Dust: Grain Recoil Forces and Gas Heating*

CITA-2000-23 Christopher D. Matzner, Christopher F. McKee *Efficiencies of Low-Mass Star and Star Cluster Formation*

CITA-2000-24 A. Thion, Yannick Mellier, Francis Bernardeau, Thomas Erben, Ludovic Van Waerbeke *A numerical study of cosmic shear statistics*

CITA-2000-25 R. Maoli, Yannick Mellier, Ludovic Van Waerbeke, Peter Schneider, B. Jain, Thomas Erben, Francis Bernardeau *Cosmic shear with the VLT*

CITA-2000-26 Changbom Park, J. R. Gott & Y. J. Choi *Topology of Galaxy Distribution in the Hubble Deep Fields*

CITA-2000-27 Ludovic Van Waerbeke, Yannick Mellier, Thomas Erben, J.C. Cuillandre, Francis Bernardeau, R. Maoli, E. Bertin, H.J. Mc Cracken, O. Le Fevre, B. Fort, M. Dantel-Fort, B. Jain, Peter Schneider *Cosmic shear with the CFHT*

CITA-2000-28 István Szapudi, Marc Postman, Tod R. Lauer, William Oegerle *Observational Constraints on Higher Order Clustering up to z 1*

CITA-2000-29 István Szapudi *Cosmic Statistics of Statistics: N-point Correlation*

CITA-2000-30 Nir J. Shaviv *The theory of steady state super Eddington winds and its application to novae*

CITA-2000-31 G.C. Van de Steene, P.A.M. van Hoof, P.R. Wood *Near-infrared and Br-gamma observations of post-AGB stars*

CITA-2000-32 Yanqin Wu, Peter Goldreich *Gravity-Modes in ZZ Ceti Stars: IV. Amplitude Saturation by Parametric Instability*

CITA-2000-33 Yanqin Wu *Combination Frequencies in the Fourier Spectra of White Dwarfs*

CITA-2000-34 David C. Fox, Ue-Li Pen *Gravitational Lensing by Galaxy Groups in the Hubble Deep Field*

CITA-2000-35 Robert G. Crittenden, Priyamvada Natarajan, Ue-Li Pen, Tom Theuns *Spin induced galaxy alignments and their implications for weak lensing measurements*

CITA-2000-36 Jounghun Lee, Ue-Li Pen *Galaxy Spin Statistics and Spin-Density Correlation*

CITA-2000-37 Nir Shaviv, Giora Shaviv *The Electrostatic Screening of Nuclear Reactions in the Sun*

CITA-2000-38 Maxim Lyutikov, Eric Blackman *GRBs from unstable Poynting dominated outflows*

CITA-2000-39 Maxim Lyutikov *Looking into Pulsar Magnetospheres*

CITA-2000-40 Maxim Lyutikov, Vladimir Usov *Precursors of gamma-ray bursts: a clue to the burster's nature*

CITA-2000-41 Maxim Lyutikov *Inertial Instability of Accretion Disks with Relativistic* Electrons

CITA-2000-42 Maxim Lyutikov, Roger Blandford, George Machabeli *Coherent Mechanisms of Pulsar Radio Emission*

CITA-2000-43 Pengjie Zhang, Ue-Li Pen *Deprojecting Sunyaev-Zeldovich statistics*

CITA-2000-44 Uros Seljak, Juan Burwell, Ue-Li Pen *Sunyaev-Zeldovich effect from hydrodynamical simulations: maps and low order statistics*

CITA-2000-45 A. Refregier, E. Komatsu, D.N. Spergel, Ue-Li Pen *The Power Spectrum of the Sunyaev-Zel'dovich Effect*

CITA-2000-46 Kin-Wang Ng *Complex Visibilities of Cosmic Microwave Background Anisotropies*

CITA-2000-47 Griet C. Van de Steene, Peter R. Wood, P.A.M. van Hoof *H alpha emission line profiles of selected post-AGB stars*

CITA-2000-48 Ludovic Van Waerbeke, Takashi Hamana, Roman Scoccimarro, Stephane Colombi, Francis Bernardeau *Weak Lensing Prediction at Intermediate Scales*

CITA-2000-49 Joseph C. Weingartner & B.T. Draine *Forces on Dust Grains Exposed to Anisotropic Radiation Fields*

CITA-2000-50 R. Maoli, Y. Mellier, Ludovic Van Waerbeke, P. Schneider, B. Jain, T. Erben, F. Bernardeau, B. Fort, E. Bertin, M. Dantel-Fort *Cosmic Shear with ANTU/ FORS1: an optimal use of Service Mode observation*, The Messenger 101, 10 October 2000.

CITA-2000-51 R. Maoli, Y. Mellier, Ludovic Van Waerbeke, P. Schneider, B. Jain, T. Erben, F. Bernardeau, B. Fort, E. Bertin, M. Dantel-Fort *Cosmic Shear and Clusters of Galaxies*

CITA-2000-52 I. Szapudi, S. Prunet, D. Pogosyan, A. Szalay and J.R. Bond *CMB analyses via Correlation Functions*

CITA-2000-53 A. Lange, ..., J. R. Bond, ..., B. Netterfield, ..., D. Pogosyan, S. Prunet, ... (the BOOMERanG collaboration) *First Estimations of the Cosmological Parameters from BOOMERanG*

CITA-2000-54 A. Jaffe, ..., J. R. Bond, ..., B. Netterfield, ..., D. Pogosyan, S. Prunet, ... (the BOOMERanG and MAXIMA-I collaboration) *Cosmology from Maxima-1, BOOMERanG and COBE/DMR CMB Observations*

CITA-2000-55 S. Colombi, D. Pogosyan, T. Souradeep *Tree structure of the Percolating Universe*

CITA-2000-56 A. Lazarian, B. Pichardo, D. Pogosyan and E. Vazquez-Semadeni *Emissivity Statistics in Turbulent, Compressible MHD Flows*

CITA-2000-57 Nir J. Shaviv *Super Eddington Atmospheres and their Winds*

CITA-2000-58 Mahmoud Aburihan, Jason D. Fiege, Richard N. Henriksen, Thibaut Lery *Protostellar Evolution during Time Dependent, Anisotropic Collapse*

CITA-2000-59 Griet C. Van de Steene, Peter A.M. van Hoof, Peter R. Wood *Properties of post-AGB stars with IRAS colors typical of planetary nebulae*

Jason Fiege
Chris Matzner
Simon Prunet