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The following is an abbreviated version of the 1995 CITA Annual Report. Due to space constraints, we have not included more than a very brief summary of the scientific activities at CITA in 1995. 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 centre 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 centre of excellence for theoretical studies in astrophysics. In this report, we review the main activities at CITA during 1995. This report has been prepared by Robert Malaney and Doug Johnstone.

2. PERSONNEL

2.1 Changes In 1995

Five new staff joined CITA in 1995: Stephane Colom-bi (Fermi National Accelerator Lab), Tarun Souradeep (IUCAA, India), Lloyd Knox (Univ. of Chicago), John Magorrian (Oxford University), and Douglas Johnstone (University of California, Berkeley). They joined research associate Robert Malaney, and research fellows Brian Chaboyer, Matthew Holman, Jim Chiang, Andrew Jaffe, James Murray, Dmitri Pogosyan, Kevin Rauch, Derek Richardson, Jihad Touma, and John Tsai.

A number of our research fellows left during the past year. Arnold Boothroyd took up a Postdoctoral Fellowship at Monash University, Janna Levin took up a Postdoctoral Fellowship at U.C. Berkeley, Izumi Murakami took up a Postdoctoral Fellowship at the National Institute for Fusion Science, Japan, Robert Nelson took up a GRO Fellowship at Caltech, Christophe Pichon took up a Postdoctoral Fellowship at University of Basel, Seshadri Sridhar took up an Assistant Professor position at IUCAA, Pune, David Syer took up a Postdoctoral Fellowship at the Max Planck Institut in Munich, and Christopher Thompson took up an Assistant Professor position at the University of North Carolina.

Faculty and research fellows have been involved in the supervision of several students from the University of Toronto: S.-H. Kim, J. Wadsley and P. Wiegert from Astronomy, and Y. Lithwick and G. Squires from Physics. Two undergraduates, D. Charbonneau from Toronto, and G. Young from Harvard also conducted research at CITA during 1995. Jerry Sellwood from Rutgers University spent a 6-month sabbatical at CITA from January to June 1995.

The research staff of CITA for the year 1995, along with their primary research interests, is listed below. (Notes: [†]has left CITA during 1995; [‡]joined CITA during 1995.)

2.2 CITA Faculty

- J. R. Bond, Professor (Ph.D. Caltech 1979) - *Cosmology: Very Early Universe, Evolution of Cosmic Structure, Dark Matter, Cosmic Background Radiation, Particle Theory*
- N. Kaiser, Professor (Ph.D. Cambridge, 1982) - *Cosmology, Early Universe, Large Scale Structure, Galaxy Formation, Galaxy Clusters, Gravitational Lensing*
- P. G. Martin, Professor (Ph.D. Cambridge 1972) - *Interstellar Matter, Dust, Interstellar Polarization, H₂, H II Regions, Chemical Abundances, Infrared Cirrus, Galactic Plane Survey*
- N. W. Murray, Assistant Professor (Ph.D. UC Berkeley 1986) - *Active Galactic Nuclei, Cataclysmic Variables, Solar System Dynamics, Helioseismology*
- S. Tremaine, Professor and Director (Ph.D. Princeton 1975) - *Stellar Dynamics, Galactic Structure, Solar System Formation and Dynamics, Comets*

2.3 Research Associates 1995

- A. I. Boothroyd[†] (Ph.D. Caltech 1987) - *Collisional Dissociation of H₂; Stellar Evolution: Lithium, Carbon Stars, Surface Abundances, Mass Loss, Solar Models and Neutrinos*
- R. A. Malaney (Ph.D. St. Andrews 1986) - *Nuclear-Neutrino Astrophysics and Cosmology*
- C. Thompson[‡] (Ph.D. Princeton 1988) - *Pulsars, Plasma Physics, Supernovae, Gamma Ray Bursts, Astrophysical Dynamics, Large Scale Structure, Microwave Background Radiation*

2.4 Postdoctoral Fellows 1995

- B. C. Chaboyer (Ph.D. Yale 1993) - *Stellar Evolution: Globular Cluster Ages, Solar Neutrinos, Primordial Li Abundance; Galaxy Formation*
- J. Chiang (Ph.D. Stanford 1993) - *High Energy Emission from Compact Objects: Pulsars, Active Galactic Nuclei; Broad Absorption Line QSOs*
- S. Colombi[‡] (Ph.D. I.A.P., Paris 1993) - *Cosmology, Large-scale Structure, Statistics, N-body Simulations, Perturbation Theory*
- A. Jaffe (Ph.D. Chicago 1994) - *Cosmology, Large-scale Structure, Statistics, Particle Astrophysics*
- M. J. Holman, (Ph.D. MIT 1994) - *Nonlinear Hamiltonian Dynamics, Solar System Dynamics, Asteroids, Comets*
- J. Levin[†] (Ph.D. M.I.T. 1993) - *Early Universe, Cosmology, Gravitation*
- L. Knox[‡] (Ph.D. Chicago 1995) - *Cosmology, Early Universe, Microwave Background Radiation*
- S. J. Magorrian[‡] (D.Phil. Oxford 1995) - *Galactic and*

Stellar Dynamics

- I. Murakami[†] (Ph.D. Tokyo 1992) - *QSO Absorption Systems, Intergalactic Medium, Cluster of Galaxies*
- J. R. Murray (Ph.D. Monash 1994) - *Particle Methods for Astrophysical Hydrodynamics, Cataclysmic Variables, Accretion Disks*
- R. W. Nelson[†] (Ph.D. Cornell 1991) - *Compact Objects, X-ray Binaries, Plasma and Radiative Processes in Strong Magnetic Fields, Galactic Dynamics*
- C. Pichon[†] (Ph.D. Cambridge 1994) - *Galactic Dynamics, Disk Stability, Relativity, Gravitation*
- D. Yu. Pogosyan (Ph.D. Tartu 1990) - *Cosmology, Large-scale Structure, Microwave Background Radiation*
- K. P. Rauch (Ph.D. Caltech 1995) - *Gravitational Lensing, Active Galactic Nuclei, Relativistic Astrophysics*
- D. C. Richardson (Ph.D. Cambridge 1993) - *Solar System Formation and Dynamics, Planetary Rings, Fractal Aggregates, Tree Codes*
- T. Souradeep[‡] (Ph.D. IUCAA 1995) - *Cosmology, Large-scale Structure, Microwave Background Radiation, Early Universe*
- S. Sridhar[†] (Ph.D. Indian Institute of Science 1990) - *Galactic Dynamics, Interstellar Turbulence*
- D. Syer[†] (Ph.D. Cambridge 1993) - *Stellar Dynamics, Dynamics of Accretion*
- J. R. Touma (Ph.D. MIT 1993) - *Solar System Dynamics, Galactic Dynamics*
- J. C. Tsai (Ph.D. MIT 1992) - *Clusters of Galaxies, Dust in Elliptical Galaxies, Star Formation*

Although the bulk of the support for CITA's research staff comes from our NSERC Collaborative Special Program grant and from research grants to individual faculty members, support also came from NSERC Postdoctoral Fellowships (Chaboyer, Richardson), an NSERC International Fellowship (Murakami), and a NATO SERC Fellowship (Syer).

2.5 National Fellows 1995

A program started in 1988 solicits nominations from universities across Canada for "CITA National Fellows." These are research fellows who are jointly supported by CITA and the nominating university; although they work primarily at the nominating university, visits to CITA and collaboration with CITA staff are encouraged. CITA Council awards these fellowships using the same selection criteria as those for CITA research fellowships. The National Fellows in 1995 were:

- M-H. Lee (Ph.D. Princeton 1991), held at Queen's University (1995-1997).
- D. McManus (Ph.D. University of Alberta 1991), held at Dalhousie University (1994-1995)
- D. Salopek (Ph.D. University of Toronto 1989), held at University of Alberta (1993-1995)
- X. Shi (Ph.D. University of Chicago 1994), held at Queen's University (1994-1996)

3. CITA VISITORS

CITA has a vigorous visitors program bringing a number of Astronomy and Physics faculty members from other Ca-

nadian universities and from abroad for both extended stays and shorter visits.

There were over 65 visitors to CITA in 1995.

4. CIAR AND CITA

The Canadian Institute for Advanced Research (CIAR) supports a number of Programs chosen for their high intellectual promise and interdisciplinary character. The CIAR Cosmology Program has nodes at UBC (Director and Fellow Bill Unruh, Fellow Ian Affleck), at the University of Alberta (Fellows Valery Frolov, Werner Israel and Don Page) and at CITA, where Dick Bond and Nick Kaiser are CIAR Fellows. The intellectual 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. FACILITIES

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

CITA's primary compute servers are Digital Alpha AXP systems. A 64 Mb 3000/400S and a 256 Mb 3000/500S were the first two acquired (1993). CITA and CITA grantholders also own a 50% share in a pair of AlphaServer 2100 4/200 systems (four CPUs each; 256 Mb in one system, 1024 Mb in the other), acquired in late 1994. One of the 4/200 servers will be upgraded to a 5/250 early in 1996, approximately doubling its computational power for most applications.

The compute servers are supplemented with a network of four AXP workstations, eleven Silicon Graphics Indigos and Personal IRISes, eight Sun SPARCstations, and approximately a dozen X terminals. The SGI systems are used to support research activity demanding 3-D scientific visualization. The disk capacity available to the network currently exceeds 65 Gb.

Several Sun-3/50 workstations are still in service, now used primarily by short-term visitors and by students. We are planning to phase out our remaining Sun3s over the next year or two, replacing them with X terminals and/or more powerful workstations.

Acquisitions include a Tektronix dye-sublimation colour printer, for producing high-quality colour prints and transparencies.

All CITA offices are being provided with fibre-optic and category-5 copper cabling, to provide a framework for higher-bandwidth network connections. A switched 10Base-T ethernet hub will be in place later this year, replacing our old thinwire network.

6. 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 seven members, five selected from the

CITA Inc. membership of over 50 researchers in cooperation 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 1995 were:

- Pierre Bastien, Université de Montréal
- John Britton (Vice-Dean, School of Graduate Studies, University of Toronto)
- Hugh Couchman, University of Western Ontario
- Dave Hartwick, University of Victoria
- Richard Henriksen, Queen's University, Chair
- George Mitchell, St. Mary's University
- Scott Tremaine, CITA Director

7. CONFERENCES SUPPORTED BY CITA

CITA supports scientific workshops and meetings in Canada on subjects of interest to theoretical astrophysics. Meetings supported by CITA in 1995 were:

Sixth Canadian Conference on General and Relativistic Astrophysics, May 25-27 1995, University of New Brunswick (organizers: C. Dyer, J. Gegenberg, D. Hobbil, G. Kunstatter, R. Mclenaghan)

8. SCIENTIFIC ACCOMPLISHMENTS 1995

Research at CITA covers a broad range of fields in astrophysical theory. Here, we give a brief overview of the research activities in 1995.

Research in cosmology included such topics as large scale structure, the early universe, and gravitational lensing. Dick **Bond** and Simon White organized a workshop at the Institute for Theoretical Physics on "Cosmic Background Radiations and Galaxy Formation" partly as an effort to produce an accurate database of angular power spectra covering all of theoretical parameter space; a needed resource for the CMB community. Other CMB work included computations of angular anisotropies in models with light massive neutrinos, techniques for determining inflation-inspired cosmological parameters from the CMB anisotropy data at COBE and half-degree scales, such as spectral indices for primordial fluctuations, σ_8 , and Λ , and collaboration on a balloon-borne one-degree angular scale CMB anisotropy determination. Studies of large scale structure dealt with the emergence of vorticity in cosmic flows, the morphologies of galaxy clusters, universe topologies consistent with COBE observations, the presence of filamentary structures (cosmic webs) in the galaxy distribution on large scales, simulations of Lyman alpha clouds using smooth particle hydrodynamics, cluster structure in Cold+Hot Dark Matter models with one to three massive neutrino components, and a consideration of measurement errors in cell extractions from galaxy surveys. Research on gravitational lensing included an algorithm for non-linear cluster lens reconstruction from the distortion of faint background galaxies, development of a cluster surface density estimator using weak distortions and applications of weak lensing models to the clusters A2218, A2390, and

A2163. Finally, weak lensing was detected by Nick **Kaiser** and Gerry Luppino (Hawaii) in front of the cluster MS1054 at $z=0.84$.

CITA members also worked on galaxies, the intergalactic medium, and active galactic nuclei. Examples of research include the effect of the intergalactic medium's pressure on the evolution of dwarf galaxies, the chemical enrichment of Lyman α clouds at high redshift, high energy emission from active galactic nuclei, and collaboration as part of the EGRET science team on determining the contribution to the diffuse extragalactic background by emission from gamma-ray blazars. Norm **Murray** has collaborated on a radiatively driven disk wind model for the broad absorption line signatures for QSOs, including implications for Seyfert galaxies, radio loud quasars and radio quiet quasars. Other research focused on the ionization structure of disks illuminated from a central source, and utilized the redshift evolution of the neutral hydrogen density to calculate the evolution of star formation rates and elemental abundances in the universe.

Several CITA members have worked on the interstellar medium, studying the properties of grains and their observational signatures, the rate coefficients for collisions between H_2 and H and between two H_2 molecules, the potential energy surfaces of H_3 and He- H_2 , the N/O abundance ratio within the Orion Nebula, and the evolution and infrared emission of dust in normal large elliptical galaxies. Peter **Martin** was part of an international consortium (PI Russ Taylor, Calgary) which was awarded an NSERC CSP grant to facilitate data reduction and science analysis of the DRAO Galactic Plane survey in HI and radio continuum at 1 arc minute resolution. The mosaiced images, combined with infrared data from IPAC, CO data from FCRAO, and radio continuum observations from MRAO will provide a large-scale yet detailed picture of the galactic disk.

Several CITA members worked in the fields of galactic and stellar dynamics. This work included the derivation of an algorithm for numerically implementing linear stability analysis on *any* round galactic disk, an inversion technique for the recovery of the underlying distribution function for observed galactic disks, and the consideration of resonance as a mechanism by which stars in the thick disk acquire their large vertical velocity dispersion and scale height. Also, linear instability in galaxy models, bending modes in galactic disks, mechanisms for galactic warps and the angular momentum relaxation rate in nearly Keplerian clusters were investigated. Scott **Tremaine**, as part of a large HST collaboration explored the implications of a high-resolution photometric survey of the centres of 60 elliptical galaxies and spiral bulges revealing two classes, "resolved-core" and "power-law" galaxies. This collaboration also obtained high-resolution spectroscopy of the centre of the galaxy NGC 3115 using CFHT and HST, confirming that a $10^9 M_\odot$ dark object exists at its centre. N-body simulations of the interaction of a galactic disk with a responsive dark matter halo have probed the conditions necessary for disk warps.

An SPH code has been used to investigate accretion disk outburst phenomena in cataclysmic variables, in particular the periodic "superhump" phenomena peculiar to SU Uma

stars. Also, protostellar collapse models including the pre-heating effects of accretion luminosity have been examined. Other projects have investigated FU Orionis outbursts, non-linear Alfvén wave turbulence in dense relativistic, magnetized plasma, emission from neutron stars with strong internal magnetic fields, and γ -ray emission from ultraluminous relativistic MHD winds. Stellar physics and nucleosynthesis research included the study of mixing below the base of the convective envelopes in low-mass RGB and AGB stars, a demonstration that ${}^7\text{Li}$ can be created via cool bottom processing in low mass red giant stars, and a study of the structure of the Sun using helioseismic data. Detailed study of globular cluster ages using stellar evolution codes produced a probability distribution for the mean age of the oldest globular clusters with a best estimate of 14.6 ± 1.7 Gyrs.

CITA researchers have also been active in studies of solar system formation, evolution, and dynamics. Work in this field has included an examination of the breakup of comet Shoemaker-Levy 9, an investigation into the phenomenon of inelastic collapse in granular media, and possible evolutionary scenarios for the extra-solar planetary systems discovered around 51 Pegasus, 47 Ursa Majoris, and 70 Virginis. Other studies include an investigation into chaos at high order mean motion resonances in the outer asteroid belt, and a numerical investigation of allowed configurations of spinning, self-gravitating, viscous fluids. Scott Tremaine has continued to study the long-term evolution of the solar system, collaborating with Jihad Touma on an efficient numerical technique to solve the secular equations of motion to all orders in eccentricity and inclination and first order in the masses, and examining parallelization of N-body schemes in the case of small N.

PUBLICATIONS

The publication list includes all papers published or submitted in 1995 by the CITA staff, or by visitors if a substantial portion of the work was done at CITA. Some papers published in this period were included as "submitted" or "in press" in the 1994 annual report.

- Bond, J.R.**, 1995, "Implications of the Background Radiation for Cosmic Structure Formation," in *The Evolution of the Universe*, Dahlem Workshop Report, Wiley.
- Bond, J.R.**, 1995, "Signal-to-Noise Eigenmode Analysis of the Two-Year COBE Maps," *Phys. Rev. Lett.*, **74**, 4369.
- Bond, J.R.**, 1995, "CMB Broad-Band Power Spectrum Estimation," *Astrophysical Letters and Communications*, **32**, 63.
- Bond, J.R.**, 1995, "How Well Can Cosmological Parameters Be Estimated from CMB Observations?," *Astrophysical Letters and Communications*, **32**, 75.
- Bond, J.R.**, Kofman, L. and **Pogosyan, D.**, "How Filaments are Woven into the Cosmic Web," *Nature*, in press.
- Boothroyd, A. I.**, **Keogh, W. J.**, **Martin, P. G.**, and Peterson, M. R., "A Refined H_3 Potential Energy Surface," *J. Chem. Phys.*, in press.
- Boothroyd, A. I.**, and **Malaney, R. A.**, "Cosmological Implications of ${}^3\text{He}$ Destruction on the Red Giant Branch," *Ap. J.*, submitted (astro-ph/9512133).

- Boothroyd, A. I.**, and Sackmann, I.-J., "The CNO Isotopes: Deep Circulation in Red Giants and First and Second Dredge-up," *Ap. J.*, submitted (astro-ph/9512121).
- Boothroyd, A. I.**, Sackmann, I.-J., and Wasserburg, G. J., 1995, "Hot Bottom Burning in Asymptotic Giant Branch Stars and Its Effect on Oxygen Isotopic Abundances," *Ap. J. Lett.*, **442**, L21-L24.
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- Buote, D.A. and **Tsai, J.C.**, 1995, "The Reliability of X-Ray Constraints of Intrinsic Cluster Shapes," *Ap. J.*, **439**, 29-41.
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- Chaboyer, B.**, "Halo Star Evolution," in *Stellar Evolution: What Should Be Done?*, eds. A. Noels, M. Gabriel, N. Grevesse and P. Demarque (Liège: Institut d'Astrophysique), in press.
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- Chaboyer, B.**, Demarque, P., Guenther, D.B., Pinsonneault, M.H., and Pinsonneault, L.L., 1995, "Ages of Galactic Globular Clusters from the New Yale Isochrones," in *The Formation of the Milky Way*, ed. E.J. Alfaro and G. Tenorio-Tagle (Cambridge: Cambridge University Press), 289-292.
- Chaboyer, B.**, Demarque, P., and Pinsonneault, M.H., 1995, "Stellar Models with Microscopic Diffusion and Rotational Mixing I: Application to the Sun," *Ap. J.*, **441**, 865-875.
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- Chaboyer, B.**, Demarque, P., and Sarajedini, A., "Globular Cluster Ages and the Formation of the Galactic Halo," *Ap. J.*, in press.
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- Clarke, C.J. and **Syer, D.**, 1996, “A mechanism for fast-rise FU Orionis outbursts,” *M.N.R.A.S.*, **278**, L23.
- Cornish, N.J. and **Levin, J.J.**, “Chaos, Fractals and Inflation,” *Phys. Rev. D*, in press.
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- Jura, M., Ghez, A., White, R., McCarthy, D.W., Smith, R.C., and **Martin, P.G.**, 1995, “The Fate of the Solid Matter Orbiting HR 4796A,” *Ap. J.*, **445**, 451-456.
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