

ICY BODIES
OF THE SOLAR SYSTEM
IAU SYMPOSIUM No. 263

COVER ILLUSTRATION: ENCELADUS

Enceladus is a small though very active satellite of Saturn that shows water-dominated plumes.

Credit: NASA/JPL/Space Science Institute

IAU SYMPOSIUM PROCEEDINGS SERIES
2009 EDITORIAL BOARD

Chairman

THIERRY MONTMERLE, IAU Assistant General Secretary
*Laboratoire d'Astrophysique, Observatoire de Grenoble,
414, Rue de la Piscine, Domaine Universitaire,
BP 53, F-38041 Grenoble Cedex 09, FRANCE
thierry.montmerle@obs.ujf-grenoble.fr*

Advisers

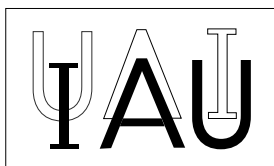
IAN F. CORBETT, IAU General Secretary,
European Southern Observatory, Germany
U. GROTHKOPF, *European Southern Observatory, Germany*
CHRISTIANN STERKEN, *University of Brussels, Pleinlaan 2, 1050 Brussels, Belgium*

Members

- IAUS260
DAVID VALLS-GABAUD, *GEPI - Observatoire de Paris, 5 Place Jules Janssen, 92195 Meudon, France*
- IAUS261
S. A. KLIONER, *Lohrmann Observatory, Dresden Technical University, Mommsenstr 13, 01062 Dresden, Germany*
- IAUS262
G. R. BRUZUAL, *CIDA, Apartado Postal 264, 5101-A Merida, Venezuela*
- IAUS263
J. A. FERNANDEZ, *Departamento de Astronomia, Facultad de Ciencias, Iguá 4225, 11400 Montevideo, Uruguay*
- IAUS264
A. KOSOVICHEV, *Stanford University, 691 South Service Road, Stanford, CA 94305-4085, USA*
- IAUS265
K. CUNHA, *NOAO, Casilla 603, La Serena, Chile*
- IAUS266
R. DE GRIJS, *Hicks Building, Hounsfield Road, University of Sheffield, Sheffield S3 7RH, UK*
- IAUS267
B. PETERSON, *Dept. of Astronomy, 140 West 18th Ave, Ohio State University, 43219 Columbus, USA*
- IAUS268
C. CHARBONNEL, *Geneva Observatory, 51, chemin des Maillettes, 1290 Sauverny, Switzerland*

INTERNATIONAL ASTRONOMICAL UNION
UNION ASTRONOMIQUE INTERNATIONALE

International Astronomical Union



ICY BODIES OF THE SOLAR SYSTEM

PROCEEDINGS OF THE 263th SYMPOSIUM OF THE
INTERNATIONAL ASTRONOMICAL UNION
HELD IN RIO DE JANEIRO, RIO DE JANEIRO, BRAZIL
AUGUST 3–7, 2006

Edited by

JULIO A. FERNÁNDEZ

Departamento de Astronomía, Facultad de Ciencias, Montevideo, Uruguay

DANIELA LAZZARO

Observatório Nacional, COAA, Rio de Janeiro, Brasil

DINA PRIALNIK

Depto. of Geophysics & Planetary Sciences, Tel Aviv University, Tel Aviv, Israel

and

RITA SCHULZ

ESA Research and Scientific Support Department, Noordwijk, The Netherlands



CAMBRIDGE UNIVERSITY PRESS

The Edinburgh Building, Cambridge CB2 8RU, United Kingdom
32 Avenue of the Americas, New York, NY 10013-2473, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock house, The Waterfront, Cape Town 8001, South Africa

© International Astronomical Union 2010

This book is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of the International Astronomical Union.

First published 2010

Printed in the United Kingdom at the University Press, Cambridge

Typeset in System L^AT_EX 2 ϵ

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data

This book has been printed on FSC-certified paper and cover board. FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests. Please see www.fsc.org for information.

ISBN 9780521764889 hardback
ISSN 1743-9213

Table of Contents

| | |
|--|----|
| Preface | ix |
| Organizing committee | x |
| Part I. Overview | |
| Icy Bodies in the New Solar System..... | 3 |
| <i>D. Jewitt</i> | |
| Part II. The Icy Planetesimals and Accretion Processes in the Protoplanetary Disk | |
| The location of the snow line in protostellar disks | 19 |
| <i>M. Podolak</i> | |
| Heavy ion irradiation of astrophysical ice analogs..... | 29 |
| <i>E. Seperuelo Duarte, A. Domaracka, P. Boduch, H. Rothard, E. Balanzat, E. Dartois, S. Pilling, L. Farenzena & E. F. da Silveira</i> | |
| Low temperature CH ₄ and CO ₂ clathrate hydrate near to mid-IR spectra | 33 |
| <i>E. Dartois, B. Schmitt, D. Deboffle & M. Bouzit</i> | |
| Angular momentum of two collided rarefied preplanetesimals and formation of binaries | 37 |
| <i>S. I. Ipatov</i> | |
| Collision probabilities of migrating small bodies and dust particles with planets | 41 |
| <i>S. I. Ipatov</i> | |
| Simulation for Terrestrial planets formation | 45 |
| <i>J. Ji & N. Zhang</i> | |
| Interaction between gas and ice phase in the three periods of the Solar Nebula . | 50 |
| <i>C. Tornow, E. Kührt, S. Kupper & U. Motschmann</i> | |
| Part III. Dynamical Aspects of Icy Bodies. The Oort Cloud | |
| Galactic environment and cometary flux from the Oort cloud..... | 57 |
| <i>M. Fouchard</i> | |
| Sedna, 2004 VN112 and 2000 CR105: the tip of an iceberg..... | 67 |
| <i>R. S. Gomes & J. S. Soares</i> | |
| The discovery rate of new comets in the age of large surveys. Trends, statistics, and an updated evaluation of the comet flux..... | 76 |
| <i>J. A. Fernández</i> | |
| On hyperbolic comets | 81 |
| <i>A. S. Guliyev & A. S. Dadashov</i> | |

| | |
|--|-----|
| Non-gravitational forces and masses of some long-period comets. The cases of Hale-Bopp and Hyakutake | 85 |
| <i>A. Sosa & J. A. Fernández</i> | |
| The contribution of Plutinos to the Centaur population | 89 |
| <i>R. P. Di Sisto, A. Brunini & G. C. de Elía</i> | |
| Influence of Trans-Neptunian Objects on motion of major planets and limitation on the total TNO mass from planet and spacecraft ranging | 93 |
| <i>E. V. Pitjeva</i> | |
| Impactor flux on the Pluto-Charon system | 98 |
| <i>G. C. de Elía, R. P. Di Sisto & A. Brunini</i> | |
| Numerical simulations of Jupiter Family comets; physical and dynamical effects | 102 |
| <i>R. P. Di Sisto, J. A. Fernández & A. Brunini</i> | |
| How to take into account the relativistic effects in dynamical studies of comets . | 106 |
| <i>J. Venturini & T. Gallardo</i> | |
| Part IV. Icy Satellites of the Outer Planets | |
| Interior models of icy satellites and prospects of investigation. | 113 |
| <i>F. Sohl</i> | |
| Long-term evolution of small icy bodies of the Solar System. | 121 |
| <i>D. Prialnik</i> | |
| The surface composition of Enceladus: clues from the Ultraviolet. | 126 |
| <i>A. R. Hendrix & C. J. Hansen</i> | |
| Effect of the tensile strength on the stability against rotational breakup of icy bodies | 131 |
| <i>I. Toth & C. M. Lisse</i> | |
| Ground-based observations of Phoebe (S9) and its rotational dynamics. | 141 |
| <i>E. Y. Aleshkina, A. V. Devyatkin & D. L. Gorshanov</i> | |
| Adenine synthesis at Titan atmosphere analog by soft X-rays. | 145 |
| <i>S. Pilling, D. P. P. Andrade, A. C. Neto, R. Rittner & A. N. de Brito</i> | |
| Water masers in the Kronian system | 147 |
| <i>S. V. Pogrebenko, L. I. Gurvits, M. Elitzur, C. B. Cosmovici, I. M. Avruch, S. Pluchino, S. Montebugnoli, E. Salerno, G. Maccaferri, A. Mujunen, J. Ritakari, G. Molera, J. Wagner, M. Uunila, G. Cimo, F. Schilliro & M. Bartolini</i> | |
| A cometary perspective of Enceladus. | 151 |
| <i>D. C. Boice & R. Goldstein</i> | |
| On the origin of retrograde orbit of satellites around Saturn and Jupiter. | 157 |
| <i>Y. Ma, J. Zheng & X. Shen</i> | |
| Long-term dynamics of Methone, Anthe and Pallene | 161 |
| <i>N. Callegari & T. Yokoyama</i> | |
| How do the small planetary satellites rotate? | 167 |
| <i>A. V. Melnikov & I. I. Shevchenko</i> | |

Part V. Icy Dwarf Planets and TNOs

| | |
|--|-----|
| Physical and dynamical characteristics of icy “dwarf planets” (Plutoids) | 173 |
| <i>G. Tancredi</i> | |
| Surface properties of icy transneptunian objects from the second ESO large program | 186 |
| <i>F. E. DeMeo, M. A. Barucci, A. Alvarez-Candal, C. de Bergh, S. Fornasier, F. Merlin, D. Perna & I. Belskaya</i> | |
| The Dark Red Spot on KBO Haumea | 192 |
| <i>P. Lacerda</i> | |
| Water alteration on (42355) Typhon? | 197 |
| <i>A. Alvarez-Candal & M. A. Barucci</i> | |
| Ground based observation of TNO targets for the Herschel Space Observatory. . | 201 |
| <i>R. Duffard, J. L. Ortiz, A. Thirouin, P. Santos-Sanz & N. Morales</i> | |

Part VI. Transition Objects

| | |
|--|-----|
| Dynamics, origin, and activation of Main Belt comets | 207 |
| <i>N. Haghhighpour</i> | |
| Are the Main Belt comets, comets? | 215 |
| <i>J. Licandro & H. Campins</i> | |
| Material properties of transition objects 3200 Phaethon and 2003 EH1 | 218 |
| <i>J. Borovička, P. Koten, P. Spurný, D. Čapek, L. Šrbený & R. Štork</i> | |
| Modeling the effects of a faint dust coma on asteroid spectra | 223 |
| <i>J. M. Carvano & S. Lorenz-Martins</i> | |
| The unusually frail asteroid 2008 TC3 | 227 |
| <i>P. Jenniskens, M. H. Shaddad & The Almahata Sitta Consortium</i> | |
| Searching for minor absorptions on D-type asteroids | 231 |
| <i>T. Mothé-Diniz</i> | |
| The distribution of Main Belt asteroids with featureless spectra from the Sloan Digital Sky Survey photometry | 237 |
| <i>A. O. Ribeiro & F. Roig</i> | |
| Dynamical maps of the Inner Asteroid Belt. | 240 |
| <i>T. Michtchenko, D. Lazzaro, J. M. Carvano & S. Ferraz-Mello</i> | |
| Magnetite microspheric particles from bright bolide of EN171101, exploded above the Trans-Carpathians mountains on Nov. 17, 2001 | 244 |
| <i>K. I. Churyumov, R. Y. Belevtsev, E. V. Sobotovich, S. D. Spivak, V. I. Blazhko & V. I. Solonenko</i> | |
| The meteoroid above Mediterranean Sea on July, 6th 2002 was a fragment of a cometary nucleus? | 246 |
| <i>K. I. Churyumov, V. G. Kruchynenko, L. S. Chubko & T. K. Churyumova</i> | |
| The solar cycle effect on the atmosphere as a scintillator for meteor observations | 249 |
| <i>A. Pellinen-Wannberg, E. Murad, N. Brosch, I. Häggström & T. Khayrov</i> | |

| | |
|---|-----|
| Study of meteoroid stream identification methods | 253 |
| <i>R. Rudawska & T. J. Jopek</i> | |
| Part VII. Physical Processes in Comets | |
| Recent polarimetric observations of comet 67P/Churyumov-Gerasimenko | 259 |
| <i>A.-C. Levasseur-Regourd, E. Hadamcik, A. K. Sen, R. Gupta & J. Lasue</i> | |
| Secular light curves of comets | 263 |
| <i>I. Ferrín</i> | |
| Cometary nature of the 1908 Tunguska cosmic body | 269 |
| <i>F. S. Ibadov, S. S. Grigorian & S. Ibadov</i> | |
| On the relationship between gas and dust in 15 comets: an application to comet 103P/Hartley 2 target of the NASA EPOXI mission of opportunity | 272 |
| <i>G. C. Sanzovo, D. Trevisan Sanzovo & A. A. de Almeida</i> | |
| Spectroscopic studies of comets 9P/Tempel 1, 37P/Forbes and C/2004 Q2 (Machholz) | 277 |
| <i>E. Picazzio, K. I. Churyumov, L. S. Chubko, I. V. Lukyanyk, V. V. Kleshchonok, A. A. de Almeida & R. D. D. Costa</i> | |
| Cometary gas relations 1P/Halley | 281 |
| <i>M. R. Voelzke</i> | |
| Near infrared photometry of comet C/2005 E2 (McNaught) | 285 |
| <i>E. Picazzio, E. Figueredo, A. A. de Almeida, C. Mendes de Oliveira & K. I. Churyumov</i> | |
| Some active processes in comet icy nuclei: nucleus splitting and anti tail formation | 289 |
| <i>K. I. Ibadinov, A. M. Buriev & A. G. Safarov</i> | |
| A simple model for the secular light curve of comet C/1996 B2 Hyakutake | 293 |
| <i>E. Rondón & I. Ferrín</i> | |
| Observations of comets and minor planets at Kiev comets station (585) | 298 |
| <i>A. R. Baransky, K. I. Churyumov & V. A. Ponomarenko</i> | |
| Part VIII. Space Missions to Icy Bodies: Past, Present and Future | |
| New Horizons: encountering Pluto and KBOs | 305 |
| <i>L. A. Young & S. A. Stern</i> | |
| The Rosetta Mission: comet and asteroid exploration | 312 |
| <i>R. Schulz</i> | |
| Deep Impact ejection from Comet 9P/Tempel 1 as a triggered outburst | 317 |
| <i>S. I. Ipatov & M. F. A'Hearn</i> | |
| Author index | 323 |
| Object index | 325 |
| Subject index | 328 |

Preface

The study of the different populations of solar system small bodies is very important for understanding the accretion process in the protoplanetary disk, the different materials that condensed, and even the origin and transport of life among different worlds. This is particularly true for the ice-rich planetesimals formed beyond the snowline. Space missions, like Stardust, Deep Impact and Cassini, are bringing to us new insight about icy bodies like comets and satellites of the outer planets. Particularly interesting is the possibility that liquid water might have been present in the interiors of large icy bodies in the past, or even at present. Large surveys like Catalina, LINEAR and the upcoming Pan-STARRS or the Large Synoptic Survey Telescope (LSST) will allow us to improve our knowledge about the size and space distribution of populations of icy bodies like comets, Centaurs and TNOs.

The first ideas for this Symposium were raised during the 2006 IAU General Assembly, in Prague. At that time we felt that the great volume of new information about the different Solar System “icy bodies” would justify the proposal of a dedicated symposium, to be held in conjunction with the next IAU GA. Since its approval as part of the scientific program of the Rio de Janeiro IAU GA, we then aimed to attract planetary scientists from the different sub-areas and from a broad geographical distribution. To achieve this we took advantage of the fact that the IAU offers for this purpose a generous allotment of travel grants to assist colleagues with financial difficulties.

We are quite happy with the result: we received about 190 registrations, from which about 130 participants finally attended the symposium from around 20 different countries. The program was divided into 15 scientific sessions with 11 invited speakers, 48 oral contributions and 72 poster contributions, these discussed in three dedicated poster sessions. One key general review was also presented, as for the other symposia during the GA. The topics addressed in the symposium covered different aspects of icy bodies going from formation conditions in the protoplanetary disk, reservoirs and dynamical transport within the solar system, physics, space missions, and transition objects comet-asteroid, the latter a hot topic given the observation of activity in some main-belt asteroids. Last but not least, the relevance of icy bodies for life on Earth and elsewhere in the solar system was also addressed, in particular given the possibility that some large icy satellites of the Jovian planets might contain subsurface oceans. We present here part of the contributions to the symposium organized following the corresponding scientific program.

We are grateful to the IAU EC and Division Presidents for having selected this symposium to be held in conjunction with the XXVIIth General Assembly, an occasion when astronomers from all the fields of astronomy are gathered together. It is important to notice that this was the only symposium fully devoted to planetary sciences, an area that has had a great development in the last few decades. It is a great pleasure to acknowledge the members of the SOC, which ensured a very interesting scientific program, as well as the support from the National Organizing Committee of the XXVIIth IAU General Assembly. The comfortable venue and the wonderful city of Rio de Janeiro resulted in the perfect setting for a memorable meeting.

*Julio A. Fernández, Daniela Lazzaro, Dina Prialnik, Rita Schulz, Editors
Montevideo, Rio de Janeiro, Tel Aviv, Noordwijk, November 30, 2009*

THE ORGANIZING COMMITTEE

Scientific

| | |
|---------------------------------------|------------------------------------|
| M.A. Barucci (France) | H. Campins (USA) |
| J.A. Fernández (co-chair, Uruguay) | S. Ferraz-Mello (co-chair, Brazil) |
| M.P. Haynes (IAU, ex-officio) | Z. Knežević (Serbia) |
| K. Meech (USA) | K. Noll (USA) |
| D. Prialnik (Israel) | H. Rickman (Sweden) |
| R. Schulz (co-chair, The Netherlands) | I. Toth (Hungary) |
| G. Valsecchi (Italy) | J.-I. Watanabe (Japan) |

NOC of the XXVIIIth IAU General Assembly

| | |
|--------------------|----------------------|
| D. Lazzaro (chair) | B. Barbuy (co-chair) |
| A. Bruch | L. da Silva |
| F.X. de Araújo | J.R. de Medeiros |
| E. Janot-Pacheco | S.O. Kepler |
| S. Lorenz-Martins | W.J. Maciel |
| M.G. Pastoriza | A. Silva-Valio |
| L.P.R. Vaz | T. Villela |

Acknowledgements

The symposium is sponsored and supported by the IAU Division III (Planetary Systems Sciences) and by the IAU Commissions No. 7 (Celestial Mechanics & Dynamical Astronomy), No. 15 (Physical Studies of Comets & Minor Planets), No. 20 (Positions & Motions of Minor Planets, Comets & Satellites), No. 22 (Meteors, Meteorites & Interplanetary Dust) and No. 51 (Bio-Astronomy).

The National Organizing Committee gratefully acknowledge the founding by the
 International Astronomical Union,
 Ministério da Ciência e Tecnologia – MCT,
 Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES/MEC,
 Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq/MCT,
 Observatório Nacional – ON/MCT,
 Laboratório Nacional de Astrofísica – LNA/MCT
 Astronomy & Astrophysics
 Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro – FAPERJ
 Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP
 and
 Prefeitura do Rio de Janeiro.