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# The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution

*Edited by*

The Astrophysics  
of Planetary  
Systems:  
Formation,  
Structure,  
and Dynamical  
Evolution

Sozzetti  
Lattanzi  
Boss

Alessandro Sozzetti  
Mario G. Lattanzi  
Alan P. Boss



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THE ASTROPHYSICS OF PLANETARY SYSTEMS:  
FORMATION, STRUCTURE, AND DYNAMICAL EVOLUTION

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*COVER ILLUSTRATION:*

The cover illustration is an image realized by *Effetti*. The upper part of the image is an artist's view of an extrasolar planetary system containing a potentially habitable Super Earth (credits: David A. Hardy's AstroArt). The lower part of the image is a view of 2006 Winter Olympics host city Torino, with the snow-capped Alps in the background. The tall building in the foreground is the Mole Antonelliana, the major landmark of Torino. It is named for the architect who built it, Alessandro Antonelli. Construction began in 1863 and was completed 26 years later, after the architect's death. Initially conceived to be a synagogue, today it houses the National Museum of Cinema. With its 167 m vertical size, it is 0.49 m higher than the Philadelphia City Hall in Pennsylvania (USA), thus holding the record for the tallest masonry building in the world.

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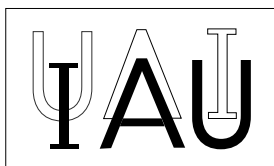
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**THE ASTROPHYSICS OF  
PLANETARY SYSTEMS:  
FORMATION, STRUCTURE,  
AND DYNAMICAL  
EVOLUTION**

**PROCEEDINGS OF THE 276th SYMPOSIUM OF THE  
INTERNATIONAL ASTRONOMICAL UNION  
HELD IN TORINO, ITALY  
OCTOBER 10–15, 2010**

Edited by

**ALESSANDRO SOZZETTI**

*INAF - Osservatorio Astronomico di Torino, Italy*

**MARIO G. LATTANZI**

*INAF - Osservatorio Astronomico di Torino, Italy*

and

**ALAN P. BOSS**

*Carnegie Institution of Washington, DC, USA*



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## Preface

More than 500 planets are now known to orbit main-sequence stars in the neighborhood of our Sun, discovered and characterized using a variety of techniques, both from the ground and in space. On the one hand, the observational data on extrasolar planets show striking properties indeed, likely evidence of the complexity of the process of planet formation and evolution. On the other hand, the large flow of empirical information gathered on extrasolar planets in the Solar neighbourhood is such that in-depth studies are now possible, which allow us to reach a deeper understanding of the mechanisms regulating their formation processes, their internal structure and atmospheres, and their long-term dynamical evolution. Next-generation observatories (both from the ground and in space) and new methods of data analysis have reached a degree of ripeness that the discovery of planets similar to our Earth, for which it might be possible to establish the degree of habitability, appears to be behind the corner. Fifteen years after the first announcement of a Jupiter-mass companion orbiting a normal star other than the Sun, the formation and evolution of planetary systems is now emerging as a new, quickly expanding interdisciplinary research field.

When the vast breadth of exoplanets research is taken as a whole, one then realizes how we're now witnessing the beginning of a new era of comparative planetology, in which our Solar System can finally be put in the broader context of the astrophysics of planetary systems. To this end, help from future data obtained with a variety of techniques will prove invaluable. Planet search surveys, initially focused solely on planet discovery, are now being designed to put the emerging properties of planetary systems on firm statistical grounds and thus thoroughly test the theoretical models put forth to explain their existence. Furthermore, both NASA and ESA are now formulating strategies to establish a logical sequence of missions and telescope construction to optimize the pace and quality of exoplanet discoveries (with both direct and indirect techniques) and address key questions on the physical characterization and architecture of planetary systems.

With the approaching 15<sup>th</sup> anniversary of the 51 Pegb discovery announcement, and considering the quickening pace of development of the exoplanet field, a preliminary program was drafted in 2009 by members of the Scientific Organizing Committee (SOC) for an IAU Symposium focused on addressing two main questions: Where do we stand? What's next? The 276<sup>th</sup> IAU Symposium (IAUS 276) was held in Torino during the week of October 10-15, 2010. At the time of definition of the final scientific program, the broad range of issues in the astrophysics of planetary systems selected to provide answers to these questions was divided in to four main topical sessions: *Planet Formation, Internal Structure and Atmospheres, Interactions, and The Next Decade*. The first three sessions allowed for vibrant confrontations between theory and observations. Datasets of the highest quality, state-of-the-art numerical tools, and increasingly sophisticated theoretical models showed the impressive progress being made in our understanding of planet formation and evolution. The last session provided a forward look into strategic planning exercises of both community and agencies and into ongoing preparations and developments of future ground-based and space-borne observatories devoted to exoplanetary sciences. We warmly acknowledge all the SOC members who actively contributed with their suggestions to shape a strong and attractive scientific program (while making sometimes difficult choices given the large number of talk requests). One major objective achieved during the Symposium was indeed that of connecting scientific results obtained

by ground-based and space-borne research programs for the detection and characterization of extrasolar planets with the grand projects that will contribute to move forward the frontier of research in the field during the next decade. The most recent, exciting discoveries of transiting rocky planets (“Super Earths”) by the Kepler and CoRoT space telescopes were discussed in parallel to unprecedented results obtained with large ground-based facilities, such as the VLT and the Keck Observatories, regarding the characterization of the chemical composition of the atmospheres of nearby exoplanets. From the ground, ambitious project to search for Earth analogs around the nearest stars with the HARPS spectrograph were discussed in the context of the science potential of next generation instruments that will come online during the next decade, such as ESPRESSO on the VLT, or CODEX on the 42-m E-ELT. From space, the heritage of the great results obtained by the Hubble and Spitzer space telescopes (at visible and infrared wavelengths) on the characterization of the structural and atmospheric properties of extrasolar gas giants was shown to form the basis for the design of new challenging exoplanet characterization programs with the next generation of space observatories, such NASA’s JWST and ESA’s Gaia.

The community answered even more enthusiastically than we could hope for. The great interest in the Symposium can be easily quantified in terms of its sheer numbers: 12 invited review talks (“(IR)” in the table of contents), 27 invited talks (“(I)” in the table of contents), 39 oral contributions (“(C)” in the table of contents), and some 120 posters, whose authors had the opportunity to illustrate with 2-minute presentations within five dedicated daily poster popups sessions (a significant fraction of this volume is devoted to the poster papers, arranged according to their topic in a sequence echoing that of the oral sessions). Overall, the Symposium entertained 218 astronomers (of which 27% were female) from 27 countries. The enthusiasm and professionalism of the participants crucially helped in making IAUS 276 an overwhelming success.

The choice of Torino as the Symposium venue was deemed timely as the conference would fall during a particular period of large-scale celebrations: the Torino Astronomical Observatory concluded in 2010 the celebrations of the 250<sup>th</sup> anniversary from its foundation, Torino was the 2010 European Capital of Science, hosting the Euroscience Open Forum, and significant preparations started in 2010 for the great celebrations of the 150<sup>th</sup> anniversary of the Unification of Italy in 2011 (Torino having been the first capital of unified Italy). While not being a famous beach or ski resort, Torino has been rediscovered in recent years as an important tourist destination. After hosting the 2006 Winter Olympics, and at the end of a 20-year long redevelopment plan which is unparalleled in Europe since the one carried out by the city Barcelona in the 1980’s, Torino is today in the top ten of the most visited cities in Italy. It was a cause of major satisfaction to hear the impressions of many of the participants (and their accompanying guests), who confessed to having thoroughly enjoyed the unexpected beauties of Torino.

The success of IAUS 276 was not only *scientific*, but also *logistic*. The smoothness of all activities related to the Symposium, and the virtually non-existent organizational “glitches” is the result of the extraordinary joint efforts of a large number of people. The Torino Astronomical Observatory members of the Local Organizing Committee (LOC) worked very hard to make this conference both enjoyable and highly memorable. Particular thanks to Maria Sarasso, Umami Abbas, Tullia Carriero, Richard Smart, and Roberto Silvotti for their dedication in taking care of all organizational aspects with lucidity, calmness, and professionalism. An excellent team of people helped the LOC in coordinating the daily activities at the Torino Incontra Conference Center (Roberta Ghiringhelli,



Alessandra Quaranta, Maurizio Pesce, Deborah Busonero, Sebastiano Ligorì, Alberto Riva). The schedule of the meeting was quite compressed, and the fact that we could always end the sessions in perfect time is particularly due to the professionalism and efficiency of Roberto Morbidelli (Torino Astronomical Observatory), Massimo d'Ambrosio and Marco Gonzatto (Torino Incontra), who chased speakers and poster presenters across the whole of the conference venue, made sure all presentations worked correctly, and ran smoothly all display operations from inside the slide room. Alessandro Spagna (Torino Astronomical Observatory) is to be warmly thanked for providing all the exquisite Symposium pictures (available at [http://iaus276.oato.inaf.it/IAUS\\_276/index.htm](http://iaus276.oato.inaf.it/IAUS_276/index.htm)), some of which are included in this volume. We gratefully acknowledge David Charbonneau, who failed to assign the prize (a large bottle of Canadian maple syrup of the highest quality) for the 100<sup>th</sup> transiting planet discovered during the Symposium, but generously left it behind for us to enjoy it thoroughly.

Finally, a special thought goes to Ummi, for always being there and providing crucial support at any time.

Extrasolar planets and the search for life in the Universe are topics of particular appeal for the general public. It was thus natural to offer, in parallel to the Symposium science activities, a strong public outreach program to the wider community. Two scientific lectures open to the public were scheduled at the Planetarium of Torino during the time of IAUS 276, delivered by prominent actors in the exoplanet arena (Dr. David W. Latham and Prof. Sara Seager). The public lecture given by Prof. David Charbonneau at the historic Gobetti Theater in downtown Torino proved a very successful means of dissemination of the latest hot results in the field to the greater public. In addition, a long reportage on the Symposium with interviews to David Charbonneau, Sara Seager, Bill Borucki, and the SOC Chair by Dr. Silvia Rosa Brusin was broadcasted on the public (RAI) national TV channels in October 2010, and more than 25 articles covering IAUS 276 appeared on local, national, and international news media during the same timeframe.

It is a great pleasure to acknowledge the patronage and generous financial contributions of the public and private sponsors listed on page *xvii* of these Proceedings. Their support made the idea of IAUS 276 come true. Essential travel sponsorship for young graduate students and early-stage researchers was generously provided by IAU.

Very special thanks go to the Regione Piemonte and Thales Alenia Space S.p.A. for providing the funds that made the realization of this volume possible.

The field of exoplanet science is now moving so fast that, just a few months after the end of IAUS 276, spectacular new discoveries are already looming on the horizon. This Proceedings volume serves two important purposes: It provides a detailed still picture of the state-of-the-art of the field fifteen years after the first discovery announcement, and with the breadth of its scope, it constitutes a tribute to the extraordinary diversity and dynamism of research in planetary systems astrophysics. As much as we enjoyed assembling it, we trust the readers will enjoy perusing this volume, and find the motivation and inspiration for the next Symposium on exoplanets astrophysics.

*Alessandro Sozzetti (SOC Chair, Lead Editor), Mario G. Lattanzi (LOC Chair), and Alan P. Boss  
Torino, Italy, and Washington D.C., USA, January 2011*

## THE ORGANIZING COMMITTEE

### Scientific

Y. Alibert (Switzerland)	T. Michtchenko (Brazil)
A. Boss (USA)	R. Nelson (UK)
D. Charbonneau (USA)	N. Santos (Portugal)
D. Fischer (USA)	D. Queloz (Switzerland)
K. Gozdziewski (Poland)	H. Rauer (Germany)
R. Gratton (Italy)	I. Ribas (Spain)
T. Guillot (France)	A. Sozzetti (Chair, Italy)
J. Laskar (France)	G. Tinetti (UK)
D. Latham (USA)	W. Traub (USA)
T. Mazeh (Israel)	J.-L. Zhou (China)

### Local

U. Abbas	M. Sarasso
T. Carriero	R. Silvotti
M.G. Lattanzi (Chair)	R.L. Smart
R. Morbidelli	A. Spagna

### Acknowledgements

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Thales Alenia Space S.p.A.,  
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Camera di Commercio di Torino,  
UNESCO,  
Città di Torino,  
Provincia di Torino,  
and  
Regione Piemonte,  
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**CONFERENCE PHOTOGRAPHS**

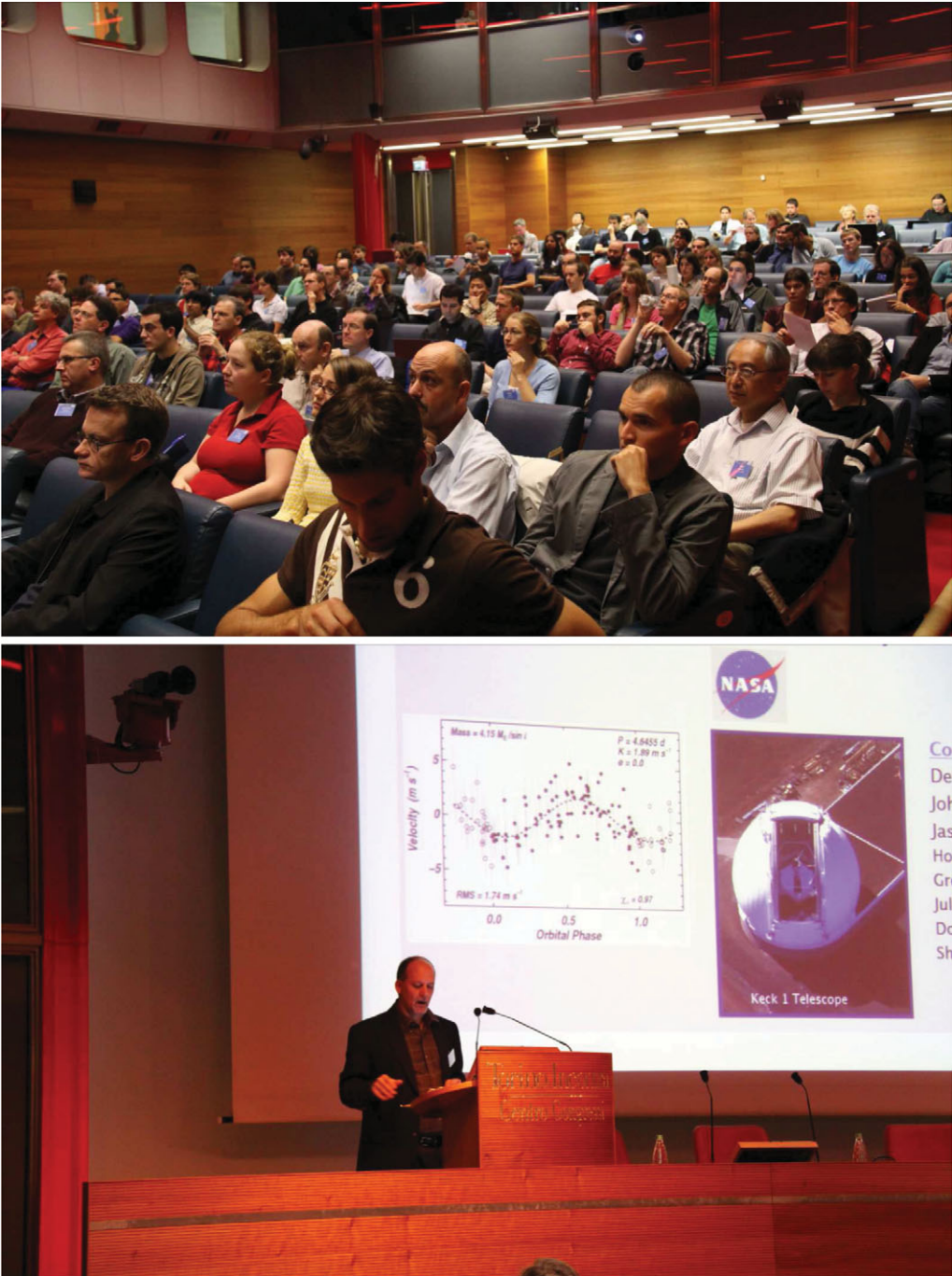


**Figure 1.** IAUS 276 Group Picture in Piazzale Valdo Fusi, in front of the Symposium venue.





**Figure 2.** Top: the Scientific Organizing Committee. Bottom: the Local Organizing Committee and the SOC Chair.



**Figure 3.** Top: the participants attending the opening session of IAUS 276 in the Cavour Hall of the Torino Incontra Conference Center. Bottom: Professor Geoff Marcy addressing the audience during the opening review talk of the Symposium.





**Figure 4.** Top: Dr. David Latham coordinating the discussion time as Chairman of one of the sub-Sessions on transiting planets. Bottom: a bird's eye view of one of the poster popup sessions.



**Figure 5.** Top: interaction between participants was frequent at the posters viewing area, in which they were exposed for the duration of IAUS 276 in the Torino Hall. Bottom: participants had no trouble standing in line during coffee breaks in order to savor the highly praised espresso.





**Figure 6.** Top: Prof. David Charbonneau during his Public Lecture at the Gobetti Theater in downtown Torino. Bottom: the inside of the historic theater, once the Royal Savoy family's private entertainment place.



**Figure 7.** Top: a view of the conference dinner in the Senate Hall of Palazzo Madama.  
Bottom: SOC and LOC Chairs





**Figure 8.** Women in Astronomy: a significant fraction (27%) of the participants to IAUS 276 were female researchers at either an early or advanced stage of their careers. Women represented  $\sim 40\%$  of the LOC, 20% of the SOC,  $\sim 20\%$  of the (invited or contributing) speakers,  $\sim 40\%$  of the poster presenters, and  $\sim 40\%$  of the grant recipients.



**Figure 9.** Top: one of the groups of participants gathering at the entrance of the Venaria Reale royal residence, a World Heritage site just outside Torino. Bottom: a group of participants enjoying the Great Gallery, or ‘Galleria di Diana’



## Participants

Ummi **Abbas**, INAF - Astronomical Observatory of Torino, Italy abbas@oato.inaf.it  
 Yann **Alibert**, University of Bern, Switzerland alibert@space.unibe.ch  
 Roi **Alonso**, Geneva Observatory, Switzerland roi.alonso@unige.ch  
 Leonardo **Andrade de Almeida**, National Institute for Space Research, Brazil leonardo@das.inpe.br  
 Daniel **Angerhausen**, German SOFIA Institute, Germany daniel.angerhausen@gmail.com  
 Alberto **Anselmi**, Thales Alenia Space SpA, Torino, Italy Alberto.Anselmi@thalesaleniaspace.com  
 Serena **Arena**, CRAL/ENS, Lyon, France serena.arena@ens-lyon.fr  
 Paola **Ballerini**, INAF - Astronomical Observatory of Catania, Italy pballerini@astropa.unipa.it  
 Mauro **Barbieri**, INAF - Astronomical Observatory of Padova, Italy mauro.barbieri@oapd.inaf.it  
 Richard K. **Barry**, NASA-GSFC, Greenbelt MD, USA richard.k.barry@nasa.gov  
 Jean-Philippe **Beaulieu**, Institut d'Astrophysique de Paris, France beaulieu@iap.fr  
 Andreas **Becker**, University of Rostock, Germany andreas.becker@uni-rostock.de  
 Bjoern **Benneke**, MIT MA, USA bbenneke@mit.edu  
 David **Bennett**, University of Notre Dame IN, USA bennett@nd.edu  
 Willy **Benz**, University of Bern, Switzerland wbenz@space.unibe.ch  
 Carolina **Bergfors**, Max Planck Institute for Astronomy, Germany bergfors@mpia.de  
 Andrea **Ettore Bernagozzi**, Astron. Obs. of the Aosta Valley, Italy andrea.bernagozzi@gmail.com  
 Enzo **Bertolini**, Astronomical Observatory of the Aosta Valley, Italy direttore@oavda.it  
 Bertram **Bitsch**, Universitat Tubingen, Germany bertram.bitsch@uni-tuebingen.de  
 Isabelle **Boisse**, Institut d'Astrophysique de Paris, France iboisse@iap.fr  
 Aaron **Boley**, University of Florida, Gainesville FL, USA aaron.boleymail@gmail.com  
 Emeline **Bolmont**, Laboratoire d'Astrophysique de Bordeaux, France bolmont@obs.u-bordeaux1.fr  
 Mariangela **Bonavita**, University of Toronto, Canada bonavita@utoronto.ca  
 Aldo Stefano **Bonomo**, Laboratoire d'Astrophysique de Marseille, France aldo.bonomo@oamp.fr  
 William **Borucki**, NASA Ames Research Center CA, USA William.J.Borucki@nasa.gov  
 Alan **Boss**, Carnegie Institution of Washington DC, USA boss@dtm.ciw.edu  
 David **Brown**, University of St Andrews, UK djab@st-andrews.ac.uk  
 Joanna **Bulger**, University of Exeter, UK joanna@astro.ex.ac.uk  
 Adam **Burgasser**, UCSD, La Jolla CA, USA aburgasser@ucsd.edu  
 Deborah **Busonero**, INAF - Astronomical Observatory of Torino, Italy busonero@oato.inaf.it  
 Susana Cristina **Cabral de Barros**, Queen's University Belfast, UK s.barros@qub.ac.uk  
 Juan **Cabrera**, DLR German Aerospace Center, Germany juan.cabrera@dlr.de  
 Elena **Carolo**, INAF - Astronomical Observatory of Padova, Italy elena.carolo@oapd.inaf.it  
 Ludmila **Carone**, University of Koln, Germany ludmila.carone@uni-koeln.de  
 Tullia **Carriero**, INAF - Astronomical Observatory of Torino, Italy carriero@oato.inaf.it  
 Marco **Castronuovo**, ASI Headquarters, Roma, Italy marco.castronuovo@asi.it  
 Alberto **Cellino**, INAF - Astronomical Observatory of Torino, Italy cellino@oato.inaf.it  
 Stefano **Cesare**, Thales Alenia Space SpA, Torino, Italy Stefano.Cesare@thalesaleniaspace.com  
 Gilles **Chabrier**, CRAL/ENS, Lyon, France chabrier@ens-lyon.fr  
 David **Charbonneau**, Harvard-Smithsonian CfA MA, USA dcharbon@cfa.harvard.edu  
 Sourav **Chatterjee**, Northwestern University, IL, USA souravchatterjee2010@u.northwestern.edu  
 Armando **Ciampolini**, ALTEC SpA, Torino, Italy armando.ciampolini@altec.space.it  
 Andrew **Collier Cameron**, University of St Andrews, UK acc4@st-and.ac.uk  
 Alexandre **Correia**, Universidade de Aveiro, Portugal correia@ua.pt  
 Vincent **Coude du Foresto**, LESIA, Paris Observatory, France vincent.foresto@obspm.fr  
 Elisabeth **Crespe**, CRAL/ENS, Lyon, France elisabeth.crespe@ens-lyon.fr  
 Bryce **Croll**, University of Toronto, Canada croll@astro.utoronto.ca  
 Szilard **Csizmadia**, DLR German Aerospace Center, Germany szilard.cszizmadia@dlr.de  
 Mario **Damasso**, Astronomical Observatory of the Aosta Valley, Italy mario.damasso@studenti.unipd.it  
 Cilia **Damiani**, INAF - Astronomical Observatory of Catania, Italy damiani@oact.inaf.it  
 Melvyn **Davies**, Lund Observatory, Sweden mbd@astro.lu.se  
 Ernst **de Mooij**, Leiden Observatory, Netherlands demooij@strw.leidenuniv.nl  
 Magali **Deleuil**, Laboratoire d'Astrophysique de Marseille, France magali.deleuil@oamp.fr  
 Elisa **Delgado Mena**, Instituto de Astrofısica de Canarias, Spain edm@iac.es  
 Annalisa **Deliperi**, INAF - Astronomical Observatory of Torino, Italy deliperi@oato.inaf.it  
 Brice-Olivier **Demory**, MIT, MD, USA demory@mit.edu  
 Xavier **Dumusque**, Geneva Observatory, Switzerland xavier.dumusque@unige.ch  
 Natalia **Dzyurkevich**, Max-Planck Institute for Astronomy, Germany natalia@mpia.de  
 Jason **Eastman**, The Ohio State University, OH, USA jdeast@astronomy.ohio-state.edu  
 Anne **Eggenberger**, Grenoble Observatory, France anne.eggenberger@obs.ujf-grenoble.fr  
 Carlos **Eiroa**, Universidad Autonoma de Madrid, Spain carlos.eiroa@uam.es  
 Sebastian **Elser**, University of Zurich, Switzerland sebastian.elser@uzh.ch  
 Becky **Enoch**, University of St Andrews, UK bel2@st-andrews.ac.uk  
 Anders **Erikson**, DLR Institute of Planetary Research, Germany anders.erikson@dlr.de  
 Daniel **Fabrycky**, University of California, Santa Cruz, CA, USA daniel.fabrycky@gmail.com  
 Francesca **Faedi**, Queen's University Belfast, UK f.faedi@qub.ac.uk  
 Fabio **Favata**, ESA, Netherlands Fabio.Favata@rssd.esa.int  
 Mario **Flock**, Max-Planck Institute for Astronomy, Germany flock@mpia.de  
 Eric **Ford**, University of Florida, Gainesville, FL, USA eford@astro.ufl.edu  
 Andrea **Fortier**, University of Bern, Switzerland andrea.fortier@space.unibe.ch  
 Luca **Fossati**, The Open University, UK l.fossati@open.ac.uk  
 Richard **Freedman**, SETI Institute, NASA Ames Research Center, CA, USA freedman@darkstar.arc.nasa.gov  
 Misato **Fukagawa**, Osaka University, Japan misato@iral.ess.sci.osaka-u.ac.jp  
 Pavel **Gabor**, Vatican Observatory, Vatican City p.gabor@jesuit.cz  
 Mario **Gai**, INAF - Astronomical Observatory of Torino, Italy gai@oato.inaf.it  
 Marina **Galvagni**, University of Zurich, Switzerland galva@physik.uzh.ch  
 Daniele **Gardioli**, INAF - Astronomical Observatory of Torino, Italy gardiol@oato.inaf.it  
 Nikolaos **Georgakarakos**, ATEI of Western Macedonia, Greece georgakarakos@hotmail.com  
 Paolo **Giacobbe**, University of Trieste, Italy paologiacobbe85@gmail.com  
 Neale **Gibson**, University of Oxford, UK Neale.Gibson@astro.ox.ac.uk

- Michaël **Gillon**, University of Liège, Belgium  
 Roberto **Gilmozzi**, ESO, Germany  
 Vincenzo **Giorgio**, Thales Alenia Space SpA, Torino, Italy  
 Jonay I. **Gonzalez Hernandez**, Instituto de Astrofísica de Canarias, Spain  
 Raffaele **Gratton**, INAF - Astronomical Observatory of Padova, Italy  
 John Lee **Grenfell**, Technische Universität, Berlin, Germany  
 Olivier **Gressel**, Queen Mary University, London, UK  
 Sheng-hong **Gu**, Yunnan Astronomical Observatory, China  
 Octavio Miguel **Guilera**, Universidad Nacional de La Plata, Argentina  
 Tristan **Guillot**, Observatoire de la Côte d'Azur, France  
 Nader **Haghighipour**, University of Hawaii, HI, USA  
 Yasuhiro **Hasegawa**, McMaster University, Canada  
 Artie **Hatzes**, Thüringerr Landessternwarte Tautenburg, Germany  
 Mathieu **Havel**, Observatoire de la Côte d'Azur, France  
 Ravit **Helled**, UCLA, CA, USA  
 Coel **Hellier**, Keele University, UK  
 Teruyuki **Hirano**, University of Tokyo, Japan  
 Matthew **Holman**, Harvard-Smithsonian CfA, MA, USA  
 Douglas **Hudgins**, NASA Headquarters, Washington DC, USA  
 Nawal **Husnoo**, University of Exeter, UK  
 Shigeru **Ida**, Tokyo Institute of Technology, Japan  
 Ray **Jayawardhana**, University of Toronto, Canada  
 Sheng **Jin**, Purple Mountain Observatory, China  
 Anders **Johansen**, Lund Observatory, Sweden  
 Paul **Kalas**, University of California, Berkeley CA, USA  
 Lisa **Kaltenegger**, Max-Planck Institute for Astronomy, Germany  
 David **Kirsh**, McMaster University, Canada  
 Laszlo **Kiss**, Konkoly Observatory, Hungary  
 Rainer **Klement**, Max-Planck Institute for Astronomy, Germany  
 Wilhelm **Kley**, Universität Tübingen, Germany  
 Ludwik **Kostro**, University of Gdansk, Poland  
 Ulrike **Kramm**, University of Rostock, Germany  
 Nobuhiko **Kusakabe**, National Astronomical Observatory of Japan, Japan  
 Pierre-Olivier **Lagage**, CEA-IRFU, France  
 Anne-Marie **Lagrange**, Laboratoire d'Astroph. de Grenoble, France  
 Dong **Lai**, Cornell University, NY, USA  
 David **Latham**, Harvard-Smithsonian CfA, MA, USA  
 Mario G. **Lattanzi**, INAF - Astronomical Observatory of Torino, Italy  
 Jeremy **Leconte**, CRAL/ENS, Lyon, France  
 Alain **Léger**, IAS, Paris, France  
 Monika **Lendl**, Geneva Observatory, Switzerland  
 Sebastiano **Ligori**, INAF - Astronomical Observatory of Torino, Italy  
 Giuseppe **Lodato**, University of Milano, Italy  
 Christophe **Lovis**, Geneva Observatory, Switzerland  
 Wladimir **Lyra**, American Museum of Natural History, NY, USA  
 Avi M. **Mandell**, NASA-GSFC, Greenbelt, MD, USA  
 Geoffrey W. **Marcy**, University of California, Berkeley CA, USA  
 Rosemary **Mardling**, Monash University, Australia  
 Michele **Martino**, ALTEC SpA, Torino, Italy  
 Soko **Matsumura**, University of Maryland, MD, USA  
 Anne-Sophie **Maurin**, Laboratoire d'Astrophysique de Bordeaux, France  
 Satoshi **Mayama**, Graduate Univ. for Advanced Studies, Japan  
 Tsevi **Mazeh**, Wise Observatory, Tel Aviv University, Israel  
 Farzana **Meru**, University of Exeter, UK  
 Yamila **Miguel**, Universidad Nacional de La Plata, Argentina  
 Eliza **Miller-Ricci Kempton**, University of California, Santa Cruz, CA, USA  
 Roberto **Morbidelli**, INAF - Astronomical Observatory of Torino, Italy  
 Christoph **Mordasini**, Max Planck Institute for Astronomy, Germany  
 Amaya **Moro-Martin**, Centro de Astrobiología (CSIC-INTA), Spain  
 Andres **Moya**, Centro de Astrobiología (CSIC-INTA), Spain  
 Alexander **Mustill**, University of Cambridge, UK  
 Smadar **Naoz**, Northwestern University, IL, USA  
 Norio **Narita**, National Astronomical Observatory of Japan, Japan  
 Marie-Eve **Naud**, University of Montreal, Canada  
 Sergei **Nayakshin**, University of Leicester, UK  
 Richard **Nelson**, Queen Mary University, London, UK  
 Vasco **Neves**, Universidade do Porto, Portugal  
 Andrzej **Niedzielski**, N. Copernicus University, Torun, Poland  
 Anna **Nobili**, University of Pisa, Italy  
 Aake **Nordlund**, Niels Bohr Institute, Copenhagen, Denmark  
 Claudia **Orlando**, Liceo Scientifico "Leonardo da Vinci", Pescara, Italy  
 Mahmoudreza **Oshagh**, Universidade do Porto, Portugal  
 Fabio **Pagan**, SISSA, Trieste, Italy  
 Eric **Palle**, Instituto de Astrofísica de Canarias, Spain  
 Olja **Panic**, ESO, Germany  
 Neil **Parley**, University of St Andrews, UK  
 Karla **Peña Ramirez**, Instituto de Astrofísica de Canarias, Spain  
 Francesco **Pepe**, Geneva Observatory, Switzerland  
 Hagai **Perets**, Harvard-Smithsonian CfA, MA, USA  
 Giovanni **Picogna**, University of Padova, Italy  
 Elke **Pilat-Lohinger**, University of Wien, Austria  
 Ennio **Poretti**, INAF - Astronomical Observatory of Brera, Italy  
 michael.gillon@ulg.ac.be  
 Roberto.Gilmozzi@eso.org  
 Vincenzo.Giorgio@thalesaleniaspace.com  
 jonay@iac.es  
 raffaele.gratton@oapd.inaf.it  
 lee.grenfell@dlr.de  
 o.gressel@qmul.ac.uk  
 shenghonggu@ynao.ac.cn  
 oguilera@fcaglp.unlp.edu.ar  
 tristan.guillot@oca.eu  
 nader@ifa.hawaii.edu  
 hasegaw@physics.mcmaster.ca  
 artie@tls-tautenburg.de  
 mathieu.havel@oca.eu  
 rhelled@ucla.edu  
 ch@astro.keele.ac.uk  
 hirano@utap.phys.s.u-tokyo.ac.jp  
 mholman@cfa.harvard.edu  
 Douglas.M.Hudgins@nasa.gov  
 nawal@astro.ex.ac.uk  
 ida@geo.titech.ac.jp  
 rayjay@astro.utoronto.ca  
 qingxiao.jin@gmail.com  
 anders@astro.lu.se  
 kalas@berkeley.edu  
 lkaltene@cfa.harvard.edu  
 kirshdr@mcmaster.ca  
 kiss@konkoly.hu  
 klement@mpia.de  
 wilhelm.kley@uni-tuebingen.de  
 fizlk@univ.gda.pl  
 ulrike.kramm2@uni-rostock.de  
 nb.kusakabe@nao.ac.jp  
 pierre-olivier.lagage@cea.fr  
 lagrange@obs.ujf-grenoble.fr  
 dong@astro.cornell.edu  
 dlatham@cfa.harvard.edu  
 lattanzi@oato.inaf.it  
 jeremy.leconte@ens-lyon.fr  
 alain.leger@ias.fr  
 monika.lendl@unige.ch  
 ligori@oato.inaf.it  
 giuseppe.lodato@unimi.it  
 christophe.lovis@unige.ch  
 wlyra@amnh.org  
 Avi.Mandell@nasa.gov  
 bhovers@astro.berkeley.edu  
 mardling@sci.monash.edu.au  
 michele.martino@altespace.it  
 soko@astro.umd.edu  
 maurin@obs.u-bordeaux1.fr  
 mayama\_satoshi@soken.ac.jp  
 mazeh@post.tau.ac.il  
 farzana@astro.ex.ac.uk  
 ymiguel@fcaglp.unlp.edu.ar  
 elizamr@ucolick.org  
 morbidelli@oato.inaf.it  
 mordasini@mpia.de  
 amaya@cab.inta-csic.es  
 amoya@cab.inta-csic.es  
 ajm233@ast.cam.ac.uk  
 snaoz@northwestern.edu  
 norio.narita@nao.ac.jp  
 naud@astro.umontreal.ca  
 sn85@astro.le.ac.uk  
 R.P.Nelson@qmul.ac.uk  
 vasco.neves@astro.up.pt  
 aniedz@astri.uni.torun.pl  
 nobili@dm.unipi.it  
 aake@nbi.dk  
 orlando.jetlag@gmail.com  
 moshagh@astro.up.pt  
 pagan@sisssa.it  
 epalle@iac.es  
 opanic@eso.org  
 neil.parley@st-andrews.ac.uk  
 karla@iac.es  
 Francesco.Pepe@unige.ch  
 hperets@cfa.harvard.edu  
 giovanni.picogna@studenti.unipd.it  
 elke.pilat-lohinger@univie.ac.at  
 ennio.poretti@brera.inaf.it

Loredana **Prisinzano**, INAF - Astron. Obs. of Palermo, Italy  
 Didier **Queloz**, Geneva Observatory, Switzerland  
 Andreas **Quirrenbach**, Heidelberg University, Germany  
 Natalie **Raettig**, Max-Planck Institute for Astronomy, Germany  
 Heike **Rauer**, DLR Institute of Planetary Research, Germany  
 Sean **Raymond**, Laboratoire d'Astrophysique de Bordeaux, France  
 Zsolt **Regaly**, Konkoly Observatory, Hungary  
 Martin **Reidemeister**, AIU Jena, Germany  
 Alberto **Riva**, INAF - Astronomical Observatory of Torino, Italy  
 Adrian **Rodríguez Colucci**, Universidade de São Paulo, Brazil  
 Leslie **Rogers**, MIT, MA, USA  
 Cristoforo **Romanelli**, ALTEC SpA, Torino, Italy  
 Johannes **Sahlmann**, Geneva Observatory, Switzerland  
 Roberto **Sanchis-Ojeda**, MIT, MA, USA  
 Esther **Sanroma Ramos**, Instituto de Astrofísica de Canarias, Spain  
 Alexandre **Santerne**, LAM, France  
 Maria **Sarasso**, INAF - Astronomical Observatory of Torino, Italy  
 Sara **Seager**, MIT, MA, USA  
 Damien **Ségransan**, Geneva Observatory, Switzerland  
 Franck **Selsis**, Laboratoire d'Astroph. de Bordeaux, France  
 Eugene **Serabyn**, JPL, CA, USA  
 Johnny **Setiawan**, Max-Planck Institute for Astronomy, Germany  
 Michael **Shao**, JPL, CA, USA  
 Avi **Shporer**, LCOGT, University of California, Santa Barbara, CA, USA  
 Roberto **Silvotti**, INAF - Astronomical Observatory of Torino, Italy  
 Richard **Smart**, INAF - Astronomical Observatory of Torino, Italy  
 Ignas **Snellen**, Leiden Observatory, Netherlands  
 Frank **Sohl**, DLR Institute of Planetary Research, Germany  
 Filomena **Solitro**, ALTEC SpA, Torino, Italy  
 Alessandro **Sozzetti**, INAF - Astronomical Observatory of Torino, Italy  
 Alessandro **Spagna**, INAF - Astronomical Observatory of Torino, Italy  
 Vlada **Stamenkovic**, DLR, Germany  
 Rachel **Street**, Las Cumbres Observatory, CA, USA  
 Mark **Swain**, JPL, CA, USA  
 Yuhei **Takagi**, Kobe University, Japan  
 Yasuhiro **Takahashi**, Grad. Univ. for Advanced Studies, Japan  
 Stuart F. **Taylor**, National Tsing Hua University, Taiwan  
 Giovanna **Tinetti**, University College, London, UK  
 Wesley **Traub**, JPL, CA, USA  
 Amaury **Triaud**, Geneva Observatory, Switzerland  
 Stephane **Udry**, Geneva Observatory, Switzerland  
 Ana L. **Uribe**, Max Planck Institute for Astronomy, Germany  
 Diana **Valencia**, Observatoire de la Cote d'Azur, France  
 Sylvie **Vauclair**, LATT/OMP, France  
 Allona **Vazan Shukrun**, Tel Aviv University, Israel  
 Ernesto **Vittone**, ALTEC SpA, Torino, Italy  
 Eduard **Vorobyov**, Southern Federal University, Russian Federation  
 Frank W. **Wagner**, DLR Institute of Planetary Research, Germany  
 Xiao-bin **Wang**, Yunnan Astronomical Observatory, China  
 Joshua **Winn**, MIT, MA, USA  
 Paul **Withers**, Boston University, MA, USA  
 Patricia **Wood**, Keele University, UK  
 Günther **Wuchterl**, Thüringer Landessternwarte, Germany  
 Chao-Chin **Yang**, American Museum of Natural History, NY, USA  
 Olga **Zakhzhay**, Main Astronomical Observatory NAS, Kyiv, Ukraine  
 Maria Rosa **Zapatero Osorio**, CSIC-INTA, Spain

loredana@astropa.inaf.it  
 didier.queloz@unige.ch  
 A.Quirrenbach@lsw.uni-heidelberg.de  
 raettig@mpia.de  
 heike.rauer@dlr.de  
 rayray.sean@gmail.com  
 regaly@konkoly.hu  
 martin.reidemeister@astro.uni-jena.de  
 riva@oato.inaf.it  
 adrian@astro.iag.usp.br  
 larogers@mit.edu  
 cristoforo.romanelli@altecspace.it  
 Johannes.Sahlmann@unige.ch  
 rsanchis@mit.edu  
 mesr@iac.es  
 alexandre.santerne@oamp.fr  
 sarasso@oato.inaf.it  
 seager@MIT.EDU  
 Damien.Segransan@unige.ch  
 franck.selsis@obs.u-bordeaux1.fr  
 gene.serabyn@jpl.nasa.gov  
 setiawan@mpia.de  
 michael.shao@jpl.nasa.gov  
 ashporer@lcogt.net  
 silvotti@oato.inaf.it  
 smart@oato.inaf.it  
 snellen@strw.leidenuniv.nl  
 frank.sohl@dlr.de  
 filomena.solitro@altecspace.it  
 sozzetti@oato.inaf.it  
 spagna@oato.inaf.it  
 Vlada.Stamenkovic@dlr.de  
 rstreet@lcogt.net  
 swain@s383.jpl.nasa.gov  
 takagi@stu.kobe-u.ac.jp  
 yasuhiro.takahashi@nao.ac.jp  
 astrostuart@gmail.com  
 g.tinetti@ucl.ac.uk  
 wtraub@jpl.nasa.gov  
 Amaury.Triaud@unige.ch  
 stephane.udry@unige.ch  
 uribe@mpia.de  
 valencia@oca.eu  
 sylvie.vauclair@ast.obs-mip.fr  
 allonava@post.tau.ac.il  
 ernesto.vittone@altecspace.it  
 vorobyov@astro.uwo.ca  
 frank.wagner@dlr.de  
 wangxb@yao.ac.cn  
 jwinn@mit.edu  
 withers@bu.edu  
 p.wood@epsam.keele.ac.uk  
 gwuchterl@TLS-Tautenburg.de  
 cyang@amnh.org  
 zkholga@mail.ru  
 mosorio@cab.inta-csic.es