Deriving Physical Parameters of Atmosphereless Bodies in the Solar System by Modelling their Thermal Emission

A Planetary Science proposal in response to the International Space Science Institute
2011 Call for International Teams

Rickman[1,2,*], H., Bandfield[3], J. L., Capria[4], M. T., Davidsson[1,†], B. J. R., Emery[5], J. P., Groussin[6], O., Gutiérrez[7], P. J., Helbert[8], J., Jorda[6], L., Mueller[9], T. G., Sprague[10], A. L.

[*] Team coordinator
[†] Vice team coordinator
1) Dept. of Physics and Astronomy, Uppsala University, Sweden
2) PAN Space Research Center, Warsaw, Poland
3) Earth and Space Sciences, University of Washington, Seattle, USA.
4) INAF-IASF, Planetology Department, Rome, Italy
5) Earth and Planetary Sciences, University of Tennessee, Knoxville, USA
6) Laboratoire d'Astrophysique de Marseille, France
7) Instituto de Astrofísica de Andalucía, Granada, Spain
8) Institute for Planetary Research, DLR, Berlin, Germany
9) Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
10) Lunar and Planetary Laboratory, University of Arizona, Tucson, USA

Abstract

We propose a comprehensive study of state-of-the-art *thermophysical models* (TPMs) as applied to a wide variety of atmosphereless Solar System bodies. The need for such a study arises from the recent availability of new thermal data of unprecedented quality, which naturally demand more sophisticated TPMs in order to retrieve information on the nature of the surfaces and structure of the objects. These data are provided by currently active spacecraft such as Deep Impact/EPOXI (comets), Rosetta (asteroids/comet), LRO (the Moon), Dawn (asteroids), and Cassini (Saturnian satellites), in the form of *spatially resolved IR spectroscopy*. In addition, a wealth of *disk-integrated IR observations* from orbiting observatories and groundbased telescopes may allow great progress in physical understanding of the Solar System small bodies at large, if the most relevant TPMs are used for interpretation.

Our project aims to study the capabilities and limitations of TPMs and thereby to provide advice on their use for many different types of objects (e.g., Near-Earth Asteroids, Main Belt Asteroids, Cometary nuclei, Icy satellites, Centaurs and Trans-Neptunian Objects) and for existing thermal observations. It further aims to conduct laboratory emissivity measurements to further advance data interpretation by constraining model parameters, and to lay the foundations for a public database of spatially resolved and disk-integrated thermal observations of small bodies.

We have assembled a small but carefully chosen group of internationally renowned experts on modelling, experimentation and observation of thermal emission from airless bodies. With members from seven countries on two continents, the formation of an ISSI team is the focus point needed to assure long-term work continuity. The facilities, support and financial means provided by ISSI are vital for such a Team effort to be successful.

The envisaged outcomes of the project are: *(a)* recommendations on the use of TPMs in different situations; *(b)* validation of TPM output against "ground truth" from in-situ and lab measurements; *(c)* initiation of a public database for thermal observations of atmosphereless solar system bodies; *(d)* summary of the capabilities and limitations of TPM techniques and outlook to future developments and upgrades of TPM codes; *(e)* identification of remaining open issues and potentially interesting aspects, which might be addressed via future instrumentation for interplanetary missions or via future lab measurements.

Scientific Rationale, Goals, and Timeliness

Remote sensing from ground and from space of near-, mid-, and far-infrared emission from atmosphereless bodies such as Mercury, the Moon, most giant planet satellites, asteroids, comets and transneptunian objects is a major source of information on the mineralogy and physical properties of these bodies (size, shape, albedo, thermal inertia, emissivity, regolith grain size, surface roughness). Such information, in turn, is vital for our understanding of the formation, previous evolution and current properties of the Solar System, thereby contributing also to the study of planetary systems in general. However, data interpretation is extremely complex and depends on the realism of applied thermophysical models, as well as on the availability and quality of necessary laboratory measurements. It is therefore important to constantly re-evaluate current methods and procedures and adjust them for state-of-the-art applications and to the availability of recent high quality thermal measurements. We deem it of special importance at this time to make a focussed effort in view of the increasing rate of close-up S/C exploration and space telescope thermal-IR observations of the objects in question. The ESA Herschel, BepiColombo and Rosetta missions, as well as the NASA LRO[1], MESSENGER[2], Dawn and EPOXI[3] missions, are prime examples. An ISSI Team, as proposed here, would provide an optimal environment for such an effort.

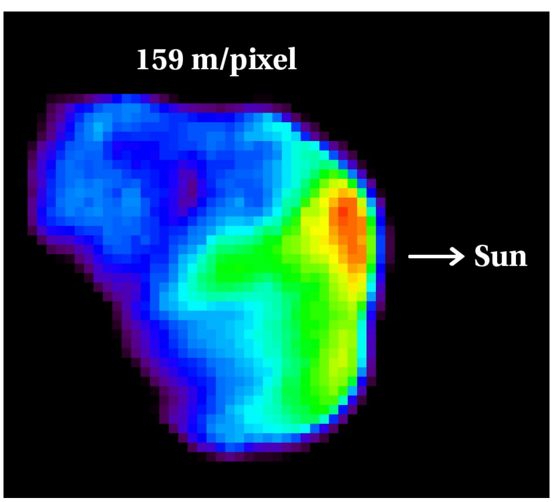
The main *goal* of this Project is to investigate the capabilities and limitations of currently used thermophysical models to reproduce and, more importantly, interpret thermal emission of Solar System bodies. In order to accomplish this goal, we plan to:

- Investigate to what extent currently employed thermophysical models are capable of dealing with real-surface thermal emission effects due to e.g. surface roughness and phase dependent emissivity. For example, LRO Diviner measurements of the Moon reveal that spectral properties of an identically illuminated terrain are changing with emergence angle. Can models reproduce and explain such behaviour in terms of physical surface properties?
- Select suitable datasets of spatially resolved thermal emission data, and apply different models in order to identify differences in derived physical parameters and investigate the reason for such differences. For example, disk-resolved NIR spectra of Comet 9P/Tempel 1 acquired by *Deep Impact* has been analyzed with different techniques, resulting in very different conclusions regarding the thermal inertia and surface roughness – what are the reasons for such differences?
- Investigate if physical parameters derived from spatially resolved data are consistent with those derived from disk-integrated data. For example, compare resolved *Deep Impact* with unresolved *Spitzer* observations of Comet 9P/Tempel 1, as well as resolved *Rosetta* with unresolved *Herschel* observations of Asteroid (21) Lutetia.

[1] LRO: Lunar Reconnaissance Orbiter
[2] MESSENGER: MErcury Surface, Space ENvironment, GEochemistry, and Ranging
[3] EPOXI: EPOCH (Extrasolar Planet Observation and CHaracterization) + DIXI (Deep Impact eXtended Investigation)

- Perform tests to understand the impact of unmodeled phenomena on derived physical parameters. For example, synthetic spectra can be produced for irregular icy TNO[4] model bodies with certain surface roughness and thermal inertia, and ongoing N_2 or CO sublimation. If such synthetic data are analysed and interpreted with standard models that generally *do not* allow for sublimation effects – what errors are introduced in the derived size, albedo, surface roughness and thermal inertia?
- Use the Planetary Emissivity Laboratory at DLR to investigate emissivity and reflectance properties of common minerals, particularly at 3-5 µm where little data is available and where many spacecraft detectors operate.
- Make inventories of commonly applied thermophysical models and study their capabilities and limitations for different types of objects, different wavelength regimes and phase angle ranges.
- Set up databases over available disk-integrated and -resolved observations including availability of auxiliary data like shape, spin-vector information, lightcurve amplitudes, colours, viewing geometries. Also set up databases over available laboratory emissivity measurements.

The in-house availability of relevant thermophysical codes and their application to Solar System bodies are illustrated by previous work of Team members, e.g., studies of the planet Mars by Bandfield [1], of Centaur P/2004 A1 by Capria *et al.* [2], of planet Mercury by Emery, Sprague, and colleagues [3], of Comet 9P/Tempel 1 by Groussin *et al.* [4] and by Davidsson, Gutiérrez, Rickman [5], of Asteroid (21) Lutetia by Lamy, Groussin, Jorda and colleagues [6], of Asteroid (25143) Itokawa by Mueller *et al.* [7], of the Moon by Sprague *et al.* [8]. We also have in-house access to the DLR Planetary Emissivity Laboratory (PEL), with measurements exemplified by Helbert *et al.* [9]. The Team members are deeply involved (often on PI or CoI level) in the ESA Rosetta, BepiColombo, and Herschel missions, as well as the NASA LRO, Spitzer, MESSENGER, Dawn, EPOXI and Stardust-NEXT[5] missions. Hence, the Team has a great deal of expertise in and access to recent and upcoming flyby data, as well as IR observations with past and current space telescopes.



The first-ever temperature map of a comet nucleus. The temperature ranges from 330K at the subsolar point to 260K at the terminator.

Prepared by Olivier Groussin from Deep Impact *1-5µm observations of Comet 9P/Tempel 1 on July 4, 2005. Courtesy of NASA/University of Maryland.*

[4] TNO: Trans-Neptunian Object
[5] NEXT: New Exploration of Tempel 1

The *timeliness* of the Project is evident from Table 1, featuring the main spacecraft missions that deliver spatially resolved spectroscopic data in the infrared. In many cases, data collection, modelling and interpretation is ongoing or will begin in the near future. The advances in modelling and interpretation of thermal emission measurements proposed here will further increase the scientific return from these missions.

Table 1

Spacecraft	IR Instrument	Target	Mission Timeline
BepiColombo	MERTIS (7-14 μm)	Mercury	2014-2021
Dawn	VIR (0.95-5 μm)	(4) Vesta (1) Ceres	2007-2015
Deep Impact / EPOXI	HRI-IR (1-5 μm)	9P/Tempel 1 103P/Hartley 2	2005-2010
LRO	Diviner (8-200 μm)	Moon	2009-2011
MESSENGER	MASCS-VIRS (0.3-1.45 μm)	Mercury	2004-2013
Rosetta	VIRTIS (0.95-5 μm)	(2867) Steins (21) Lutetia 67P/Churyumov-Gerasimenko	2004-2015

Table 2 shows a selection of recent and upcoming orbiting or airborne observatories that provide a wealth of disk-integrated data beyond the visual wavelength range for a large number of Solar System bodies. Since much of the data interpretation and investigation of physical properties of these bodies will take place in the next few years, our Project is right in time to support this process.

Table 2

Mission	Wavelength range	Target	Operations
Akari	NIR/TIR/FIR spectroscopy and photometry	5000 asteroids	2006-2007 (warm mission still active)
Herschel	FIR, sub-mm	Wide range of minor Solar System bodies	2009-2013
SOFIA	NIR-mm spectroscopy and photometry	Dedicated study of minor Solar System bodies	2011 onwards
Spitzer	NIR/TIR/FIR spectroscopy and photometry	Wide range of minor Solar System bodies	2003-2009 (warm mission still active)
WISE	Photometry at 3, 5, 12 and 22 μm	150000 Solar System bodies	2009-2011

To summarize the assets at our disposal and our work plan, we have access to spatially resolved thermal emission data from e.g. LRO Diviner, Deep Impact and Rosetta. Disk-integrated data is available through the ESO archive, various IR all/part sky surveys (IRAS, MSX, Akari), IR space observatories (ISO, Spitzer, Herschel), and different ground-based submm/mm projects (JCMT, CSO, APEX, ALMA). Our basic strategy is to perform test analyses of those data, using different models, to illustrate the effects of model and parameter dependencies and to show how further laboratory work may help constrain the results. We have a range of modelling codes available, developed by our

Team members. Finally, we have access to a new laboratory, where crucially important measurements in the infrared can be performed.

Expected Output and Public Products

A major contribution from this Project will be a much deeper understanding of the interaction of regolith and deeper rocky materials with electromagnetic radiation. We will provide a sophisticated thermophysical picture of parameters required in electronic computer coding to realistically capture the true character of remotely measured surfaces and near surface interiors. We expect to provide a series of peer reviewed papers that provide a systematic comparison of thermophysical model performances and derived physical parameters, as well as novel emissivity measurements. Based on this, recommendations and guidelines will be formulated. The publications will focus on the following topics.

- Analysis of a selection of thermal emission data from resolved targets, using different thermophysical models. Such a comparison of model performances and sets of derived physical parameters serves to highlight pros and cons of various model assumptions and allows us to evaluate the reliability of fitted physical parameters.
- Case studies where findings from disk-integrated observations and standard models are compared with detailed information collected during flybys of those targets.
- Characterization of differences in thermal emission properties and model requirements of hot rocky asteroidal bodies on the one hand, and cold icy potentially sublimating comets and TNOs on the other.
- Dedicated laboratory emissivity measurements, focusing on properties of relevance for interpreting spacecraft data (NIR wavelength range, temperature and emergence angle dependencies, effects of porosity and roughness).

In addition, in the process of completing these studies, we plan to assemble various inventories of thermophysical models, available observational data as well as laboratory emissivity measurements.

Added Value Provided by ISSI

Our Team is spread over seven countries on two continents. In order to work efficiently and with continuity, we need a place to gather on a regular basis for the next two years. ISSI is internationally known to provide the infrastructure that facilitates collegial and productive discussions. Furthermore, the financial support of ISSI is most welcome. The added value of ISSI to our project is immense. Our project fits very well with the aims of ISSI, since ultimately it strives to improve the use of space mission data on Solar System objects in a way that will benefit the whole scientific community by international collaboration relevant to a suite of ESA and NASA missions.

Confirmed Members

All co-authors of this proposal are confirmed members.

Schedule of the Project

Our Team has already had a 3-day meeting at DLR in Berlin (November 2010), where various projects were discussed. This not only illustrates our dedication to this work, but also gives us a head start. Optimally, we should meet at ISSI once every spring and fall, *i.e.*, twice per year. This is necessary in view of the rather complex work to be performed, which calls for frequent check-points. Each meeting would last for 2-3 days – enough to penetrate the current status of the work, oversee the future plans and possibly identify new directions. In addition, the ISSI project will help establish effective working relationships between Team members that will continue to foster advances beyond the two year project. The two-year period is here divided into four six-month blocks, during which the following activities are foreseen (including "Themes" that are given special attention).

- *Block I (0-6 months).* Kick-off meeting (definition of work assignments, selection of test datasets, detailed planning of computer model runs and laboratory measurements). Perform bulk of inventories, initiate laboratory and modeling work. Theme: Database aspects.
- *Block II (6-12 months).* Second meeting (results of initial modelling and laboratory work, status of inventories). Perform first half of bulk modeling/measurements. Theme: Intercomparison of model output and synergies from targets where we have in-situ data and remote disk-integrated data.
- *Block III (12-18 months).* Third meeting (current status, preparation for round-up modelling and laboratory work in the next six months). Perform second half of bulk modeling/measurements. Theme: Laboratory studies and feedback to models.
- *Block IV (18-24 months).* Final meeting (in-depth analysis of results, final conclusions, detailed planning of ISSI report and publications). Writing the papers and the ISSI report. Theme: Applicability and limitations of models to different types of Solar System objects.

Requested Facilities and Financial Support from ISSI

We do not have any special requests on computer or Internet services apart from the usual ISSI support or on extra funding on top of what ISSI offers by default. However, we would like to make use of the possibility to attach two PhD student to the Team and, if possible, to have a small extra fund to support their travels from Warsaw and Berlin, respectively.

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Contact Information

Name: Hans Rickman (Team Coordinator)
Address: 1) PAN Space Research Center, Bartycká 18A, PL-00716, Warsaw, POLAND
2) Dept. of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, SWEDEN
Phone: +48 (0)22 3816335, +46 (0)18 471 5971
Fax: +48 (0)22 840 3131
Email: hans.rickman@fysast.uu.se

Name: Joshua L. Bandfield
Address: Earth and Space Sciences, University of Washington, Johnson Hall 070 Box 351310, Seattle, WA 98195-1310, U.S.A.
Phone: +1 206 685 1910
Fax: +1 206 543 0489
Email: joshband@u.washington.edu

Name: Maria Teresa Capria
Address: INAF - IASF, Via del Fosso del Cavaliere 100, 00133 Roma, ITALY
Phone: +39 06 4993 4452
Fax: +39 06 206 60188
Email: mariateresa.capria@iasf-roma.inaf.it

Name: Björn J. R. Davidsson (Vice Team Coordinator)
Address: Dept. of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, SWEDEN
Phone: +46 (0)18 4715970
Fax: +46 (0)18 4715999
Email: bjorn.davidsson@fysast.uu.se

Name: Joshua P. Emery
Address: Earth and Planetary Sciences, University of Tennessee, 306 Earth and Planetary Sciences Building, Knoxville, TN 37996-1410, U.S.A.
Phone: +1 865 974 8039
Fax:
Email: jemery2@ utk.edu

Name: Olivier Groussin
Address: Laboratoire d'Astrophysique de Marseille, Technopôle de Marseille-Etoile, 38 rue Frédéric Joliot-Curie, 13388 Marseille Cedex 13, FRANCE
Phone: +33 4 91 05 69 72
Fax: +33 4 91 66 18 55
Email: olivier.groussin@oamp.fr

Name: Pedro J. Gutiérrez
Address: Instituto de Astrofísica de Andalucía-CSIC, Aptd. 3004, 18080 Granada, SPAIN
Phone: +34 958 230 602
Fax: +34 958 814 530
Email: pedroj@iaa.es

Name: Jörn Helbert
Address: Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft, Institut für Planetenforschung, Berlin-Adlershof, Rutherfordstraße 2, 12489 Berlin, GERMANY
Phone: 49-30-67055-319
Fax:
Email: joern.helbert@dlr.de

Name: Laurent Jorda
Address: Laboratoire d'Astrophysique de Marseille, Technopôle de Marseille-Etoile, 38 rue Frédéric Joliot-Curie, 13388 Marseille Cedex 13, FRANCE
Phone: +33 (0)4 91 05 69 06
Fax:
Email: : laurent.jorda@oamp.fr

Name: Thomas G. Mueller
Address: Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, 85748 Garching, GERMANY
Phone: : +49 89 30000 3499
Fax: + 49 89 30000 3272
Email: : tmueller@mpe.mpg.de

Name: Ann L. Sprague
Address: 1629 E. University Blvd., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, U.S.A.
Phone: +1 520 621 2282
Fax: +1 520 621 4933
Email: sprague@lpl.arizona.edu

Prof. Hans Rickman

CURRICULUM VITAE 19 March, 2010

Born: 14 July 1949, Stockholm, Sweden
Married to Bozenna Rickman

Honors and Awards
The *Edlund Prize* of the Royal Swedish Acad. Sci., 1984
Naming of asteroid no. 3692 (Rickman), 1988
1994 Prize for Best Popular Article in Natural Sciences in *Forskning & Framsteg*, Bank of Sweden Tercentenary Fund, 1995
Swedish Astronomical Society *Nordenmark Lecture*, 2001

Academic Record and Employment
Basic degree ("Phil. Mag.") at Stockholm University 1969
Doctor exam. (appr. Ph.D.) at Stockholm University 1977
"Docent" degree at Uppsala University 1980
Professor of Astronomy at Uppsala University since 2000
Professor at Space Research Center of the Polish Acadademy of Sciences since 2007

Publications
70 refereed scientific papers; more than 20 invited papers (almost always refereed); eight educational compendiums; more than 60 popular astronomy articles

Teaching
Nearly 50 undergraduate courses and 15 graduate courses at Uppsala Univ.
Supervised seven Ph.D.'s at Uppsala Univ. 1988-2003
Jury member at eight PhD dissertations in Sweden, four in France, two in Norway
Lectured at summer and winter schools in France, Austria and Spain

Administrative Experience
IAU Assistant GS 1997-2000; IAU General Secretary 2000-2003
President of IAU Comm. 20 1997-2000; Member of IAU/EC NEO Advisory Committee
Member of ESA/SSWG 1996-1999; ESA/SSAC since 2007
Member of the Swedish Royal Society of Sciences since 1994; Royal Swedish Academy of Sciences since 2001; European Astronomical Society since 1991; International Academy of Astronautics since 2003
Member of ESO OPC (Solar System Panel) 1994-1998; HST TAC (Solar System Panel) in 1994; the Nice Observatory ADION Medal Committee in 2001; ASTRONET Science Vision Working Group, Panel D, 2006-2007
President of the Swedish Astronomical Society 1996-2000
Co-initiator of the "Asteroids, Comets, Meteors" series of international meetings in 1983; co-organizer of the first three meetings
Associate editor of *Earth, Moon and Planets* since 1993
Editor of *IAU Transactions XXIVB, XXVA* and *Highlights* Vol. 12
Editor of the Uppsala Observatory News Service for media 1990-2000
Co-editor of eight international proceedings volumes

PROF. JOSHUA L. BANDFIELD

UNIVERSITY OF WASHINGTON

EDUCATION

University of California, Santa Barbara, Geological Sciences, B.S., 1996

Arizona State University, Geology, Ph.D. 2000

PROFESSIONAL APPOINTMENTS

2008-present, Research Assistant Professor, University of Washington, Seattle

2002-2008 Research Specialist Principal, Arizona State University, Tempe

2000-2002 National Research Council Postdoctoral Research Associate, NASA GSFC, Greenbelt, MD

PUBLICATIONS

Bandfield, J.L., Effects of surface roughness and graybody emissivity on martian thermal infrared spectra, *Icarus*, 10.1016/j.icarus.2009.03.031, 2009.

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Dr. MARIA TERESA CAPRIA

Date and place of birth: Montichiari (BS), Italy, September 10, 1954
Organization: INAF - IASF
Current position: Senior researcher at the Institute for Space Astrophysics, Planetology Department, Rome, Italy

CURRICULUM VITAE

- Graduated in computer sciences in 1979;
- 1979-1982, research associate, National Institute of Nuclear Physics (INFN), Rome
- 1984, temporary position, German Aerospace Center (DLR), Munich (Germany)
- Entered CNR in 1987;
- Chief of the Department of Planetary Sciences of Istituto di Astrofisica Spaziale (IASF) from 1996 to 1998;
- 2004, visiting professor, National Astronomical Observatory of Japan, Mitaka (Tokyo)
- First Researcher at IASF since 2007;

EXPERIENCE

- Field of expertise: comet nuclei, Kuiper Belt Objects and icy bodies modeling (thermal evolution and activity); analysis of high resolution comet spectra; spacecraft instrumentation (operations, observation strategy, data archiving)

Experience in space missions:

- Co- Investigator of the VIRTIS experiment for the Rosetta "cornerstone" ESA mission
- Co- Investigator of the VIR experiment for NASA's DAWN mission.
- Deputy co-PI of the SIMBIOSYS experiment of the ESA cornerstone mission BepiColombo
- Member of the ESA/NASA Joint Science Definition Team for Titan Saturn System Mission (2008)

OTHER

- 1997-2003, member of the Organizing Committee of the Commission 15 of International Astronomical Union (IAU)
- Vice-Chair of the COSPAR Sub-Commission B1 on Space Related Studies of Small Bodies in the Solar System
- Chair of the Steering Committee of the International Planetary Data Alliance (2007-2009)
- Member of the Editorial Board of Space Science Reviews
- Asteroid 39336 named Mariacapria for her contribution to the development of planetary sciences.

RECENT RELEVANT PUBLICATIONS

- M.T. Capria, A. Coradini, M.C. De Sanctis et al., Thermal modeling of the active Centaur P/2004 A1 (LONEOS), *Astronomy & Astrophysics*, 504, 249, 2009
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Dr. Björn J. R. Davidsson

Personal details
Birth date (Nationality): May 24, 1974 (Swedish)

Research Interests
Thermophysical modeling of comets and asteroids; DSMC modeling of comet comae; DDA modeling of light scattering; radiative transfer in solid particulate media; tidal breakup mechanics.

Education
1994-1998: Master of Science (Major in Physics), Uppsala University (UU), Sweden.
1998-2003: PhD in Theoretical Astrophysics, UU, Sweden.

Employment history
May 2003 – Apr 2005: Research Fellow, ESA/ESTEC, Noordwijk, The Netherlands
Sep 2005 – Feb 2010: Research Associate, Dept. of Physics and Astronomy, UU, Sweden
Oct 2008 – Apr 2009: Visiting Scientist, Jet Propulsion Laboratory, Pasadena (CA), USA
Since Mar 2010: Researcher, Dept. of Physics and Astronomy, UU, Sweden

Awards
2002: *Planetary Sciences Best Student Paper Award* for 2001 (The Planetary Division of the Geological Society of America / The Meteoritical Society)
2003: Naming of *Asteroid (11798) Davidsson*
2009: The *Edlund Prize* (The Royal Swedish Academy of Sciences)

Memberships
Co-I of the Rosetta/OSIRIS Science Team
The American Astronomical Society
IAU Commission 15 (Organizing Committee member)

Publications and Reviews
31 publications in refereed journals, 12 as first author (4 as single author). h-index 12.
Referee of 16 research articles and 3 international grant applications

Invited Talks
Ten invited talks or seminars at international conferences or research institutes.

Examples of Teaching (T) and Publich Outreach (PO)
T: Celestial Mechanics 2006, 2007, 2008. Mechanics 2010.
PO: Co-editor the official Royal Swedish Academy of Sciences poster *The Nobel Prize in Physics 2002*
PO: Co-author of the *Swedish National Encyclopedia*

Dr. Joshua P. Emery

Earth and Planetary Sciences, University of Tennessee
306 Earth and Planetary Sciences Building
Knoxville, TN 37996-1410
(865) 974-8039
jemery2@utk.edu

Education

December 2002: PhD in Planetary Sciences (minor in Geosciences); Univ. Arizona, Tucson
May 1995: Bachelor of Science in Astronomy and Physics; Boston University

Research Interests

The goal of my research is to contribute to the understanding of the formation and evolution of the Solar System and the distribution of organic material. As an observational planetary astronomer, I apply the techniques of reflection and emission spectroscopy and spectrophotometry of primitive and icy bodies in the near- (0.8 to 5.0 μm) and mid-infrared (5 to 50 μm) to address these topics. The Jupiter Trojan asteroids have been a strong focus of my research because they are a key group for distinguishing several models of Solar System evolution and for understanding the prevalence of organic material. I also regularly observe Kuiper Belt objects, icy satellites, and other asteroid groups to understand the state of their surfaces as relates to these topics.

Employment History

2008 – present: Research Assistant Professor, University of Tennessee.
2005 – 2008: Principal Investigator, SETI Institute.
2002 – 2005: Research Scientist, SETI Institute (NASA Ames contractor).
1998 – 2002: Graduate Research Associate, University of Arizona.

1995 – 1998: Graduate Research Assistant, University of Arizona.

Professional Organizations

American Astronomical Society / Division of Planetary Sciences
American Geophysical Union

Selected Publications

Mueller, M., F. Marchis, **J.P. Emery**, A.W. Harris, S. Mottola, D. Hestroffer, J. Berthier, M. di Martino 2010. Eclipsing binary Trojan asteroid Patroclus: Thermal inertia from Spitzer observations. *Icarus* 205, 505-515.

Campins, H., **J.P. Emery**, M. Kelley, Y. Fernàndez, J. Licandro, M. Delbó, A. Barucci, E. Dotto 2009. Spitzer observations of spacecraft target 162173 (1999 JU3). *A & A* 503, L17-L20.

Emery, J.P. C. Dalle Ore, D.P. Cruikshank, Y.R. Fernandez, D.E. Trilling, J.A. Stansberry 2007. Ices on (90377) Sedna: Confirmation and compositional constraints. *A&A* 466, 395-398.

Emery, J.P., D.P. Cruikshank, J. Van Cleve 2006. Thermal emission spectroscopy (5.2 – 38 μm) of three Trojan asteroids with the Spitzer Space Telescope: Detection of fine-grained silicates. *Icarus* 182, 496-512.

Emery, J.P., D.M. Burr, D.P. Cruikshank, R.H. Brown, J.B. Dalton 2005. Near-infrared (0.8 – 4.0 μm) spectroscopy of Mimas, Enceladus, Tethys, and Rhea. *Astron. Astrophys.*, 435, 353-362.

Emery, J.P. and R.H. Brown, 2003, Constraints on the surface composition of Trojan asteroids from near-infrared (0.8 – 4.0 μm) spectroscopy, *Icarus*, 164, 104-121.

Emery, J.P., A.L. Sprague, F.C. Witteborn, J.E. Colwell, R.W.H. Kozlowski, D.H. Wooden, 1998, Mercury: Thermal Modeling and Mid-infrared (5-12 μm) Observations, *Icarus*, 136, 104-123.

Dr. Olivier Groussin

Astronomer

Contact

Laboratoire d'Astrophysique de Marseille
Technopôle de Marseille-Etoile
38 rue Frédéric Joliot-Curie
13388 Marseille Cedex 13 France
Tel: (+33) 4 91 05 69 72
Fax: (+33) 4 91 66 18 55
Email: olivier.groussin@oamp.fr

Publications

45 refereed publications in the scientific field of ***small bodies in the Solar System***
More than 70 presentations in international conferences

Professional experience

2007-now	Assistant Astronomer - Laboratoire d'Astrophysique de Marseille, France
2006-2007	Postdoc position (CNES) - Laboratoire d'Astrophysique de Marseille, France Rosetta mission Supervisors: F. Rocard and P. Lamy
2004-2006	Postdoc position (NASA) - Univ. of Maryland, USA Deep Impact mission Supervisor: M. A'Hearn
2003-2004	Postdoc position (DLR) - German Aerospace Center (DLR Berlin), Germany Cometary nuclei Supervisor: E. Kührt
2001	Theaching, University of Aix-Marseille II, France Computing (Unix System) - 82 hours
2000	Theaching, University of Toulon and Var, France Computing (C language) - 48 hours

Education

1999-2002	Thesis in Astronomy - Laboratoire d'Astrophysique de Marseille, France Cometary nuclei and their activity processes Supervisor: P. Lamy
1997-1999	Master, University of Aix-Marseille II, France Particle Physics, Mathematical Physics, Modelling
1994-1997	Licence, University of Nantes, France Physics

Honors and awards

"Postdoc Initiative" programme from the French Ministry of Research (2006)
"Postdoc Initiative" programme from the French Ministry of Research (2004)
Graduate school fellowship (1999-2002)
Master school fellowship (1998-1999)
Asteroid (16280) Groussin named in honor

Dr. PEDRO J. GUTIERREZ

PERSONAL

Name: Pedro J.Gutierrez **Birth date and place**: July, 2nd, 1972. Spain.
Working Address: Instituto de Astrofísica de Andalucía, Glorieta de la Astronomía, s/n, 18008 Granada, Spain.
Phone: +34 958 230 602
Email: pedroj@iaa.es

EDUCATION

- Ph. D. Physics, 2001, University of Granada, Spain
- DEA. (Spanish degree equivalent to M.S.) Applied Physics, 1998, University of Granada, Spain.
- B.Sc., Fundamental Physcis, 1996, University of Granada, Spain.

PROFESSIONAL EXPERIENCE

- 2008-, Spanish Research Council Staff Member. Instituto de Astrofísica de Andalucía, Granada, Spain.
- 2005-1008. Postdoctoral contracts at the Instituto de Astrofísica de Andalucía-CSIC, Granada, Spain.
- 2003-2004. ESA External Fellowship at Laboratoire d'Astrofísique de Marseille, CNRS, Marseille, France
- 2002. Postdoctoral contract at the Laboratoire d'Astrofísique de Marseille, CNRS, Marseille, France
- 1998-2001. Predoctoral contract at the Instituto de Astrofísica de Andalucía-CSIC, Granada, Spain

RESEARCH

Successful PI or Co-I of 15 Spanish projects (funded by different spanish institutions, e.g. Ministerio de Educación y Ciencia, CSIC, etc.).

Associated scientist in a NASA project (Roses-07, PI. Nalin Samarasinha, Planetary Science Institute, Tuckson, Arizona)

Co-Investigator of the Instrument OSIRIS of the Rosetta Mission (present PI Holger Sierks, former PI: Horst Uwe Keller)

Member of the scientific committee of two international conferences.

Autor and Co-author of more than 40 publications on ISI journals.

RESEARCH INTEREST

- Thermal and structural effects on the evolution of small Solar System bodies.
- Early evolution of planetesimals.

Dr. Jörn Helbert

Planetary physicist
Institute for Planetary Research, DLR
Rutherfordstrasse 2
12489 Berlin
Germany
joern.helbert@dlr.de

Personal details:
Date of birth: 6.11.1968

Education:
Free University Berlin, German, Ph.D., 2003
University of Braunschweig, Germany, Diplom in Physics, 1997

Professional positions:

2007-present	CoPI and Project Manager of MERTIS on BepiColombo, Institute for Planetary Research, DLR
2005-2006	Science and Project Manager of MERTIS on BepiColombo, Institute for Planetary Research, DLR
2004-2005	Scientific Researcher, Institute for Planetary Research, DLR
2002-2004	Scientific Researcher, Department for Optical Information Systems, DLR
1998-2002	Graduate Research Assistant, Physics of Small Bodies Group, Institute for Planetary Exploration, DLR
2001	Research Scholar, Southwest Research Institute, San Antonio, Texas
1996-1997	Graduate Research Assistant, Institute for Geophysics, Technical University of Braunschweig
1996	Graduate Research Fellow, Space and Atmospheric Physics Group, Imperial College London, UK, Advisor: Prof. Andre Balogh, Dr. Malcom Dunlop
1995	Graduate Research Fellow, Pylos, Greece

Mission involvements

CoPI:	MERTIS on BepiColombo
	SERTIS on LEO
Co-Investigator:	VIRTIS on Venus Express
	PFS on Mars Express and Venus Express
	WISDOM and HP^3 on ExoMars

Participating scientist: NASA MESSENGER

Honors, Awards and Offices:

2008-2010	Graduate of the Helmholtz Management Academy for high potentials
2006-2007	Mentee in the DLR Mentoring program
2006	Research sabbatical at Brown University, Providence, awarded by DLR for special achievements
2002	Scholarship for European High-Level Summerschool on Planetary Geology
2001-2003	Research Scholarship awarded by the German Research Foundation

Convenor of several conference sessions on Venus Express, Mars Express and Mercury

Professional Societies:
American Geophysical Union, American Astronomical Society - Division for Planetary Science, Asian-Oceanic Geoscience Society, Deutsche Physikalische Gesellschaft

Teaching:

2004	Introduction to comparative Planetology – The terrestrial Planets, Natural History Museum, Berlin
2004	Introduction to comparative Planetology – The outer Solar System, Natural History Museum, Berlin
2005	Introduction to remote sensing and comparative planetology, Natural History Museum, Berlin

Dr. Laurent Jorda

Born Jan. 23, 1967 in Paris (France), French, married
Laboratoire d'Astrophysique de Marseille
38 rue Frédéric Joliot-Curie
13388 Marseille Cedex 13
Tel: +33 (0)4 91 05 69 06
Email: laurent.jorda@oamp.fr

Education:

Oct. 1992 – Dec. 1995	PhD thesis in Astrophysics at Paris-Meudon Observatory - University of Paris VII. "Study of Cometary Atmospheres at Visible Wavelengths and Comparison with Radio Observations". Supervisor: J. Crovisier.
Sept. 1989 – June 1990	Postgraduate (Master 2) degree in Astrophysics - University of Paris XI.
Sept. 1988 – June 1989	Bachelor Degree Honours (Master 1) in fundamental Physics - University of Paris XI.
Sept. 1985 – June 1988	Bachelor degree (Licence 3) in fundamental Physics - University of Paris XI.

Employment history:

Since Nov. 2000	**Assistant Astronomer** at Marseilles Astrophysics Laboratory (France) in the Solar System Group.
May 1996 – Oct. 2000	**Post-doctoral fellow** at the Max-Planck-Institute for Solar System Research (Germany).
Feb. 1996 – Apr. 1996	Short-term contact at the Marseilles Space Astronomy Laboratory (France).
Feb. 1991 – June 1992	Military service as **"Coopérant"** at the European Southern Observatory (Chile).

Research:

Characterization of the individual and statistical properties of cometary nuclei and asteroids: size, shape, geomorphology, rotational parameters, surface thermal and photometric properties from remote and in-situ ground- and space-based observations. Study of the properties of cometary dust: size and mass distributions, composition, dust-to-gas ratio from visible images of cometary dust tails. Recent work includes the development of a three-dimensional reconstruction technique to retrieve the surface topography of small bodies from visible images and the study of the dust cloud ejected during the Deep Impact space experiment.

Dr. Thomas G. Mueller

Max-Planck-Institut fuer extraterrestrische Physik, Giessenbachstrasse, 85748 Garching, Germany
E-Mail: tmueller@mpe.mpg.de

Education:

- Science Staff at the Max-Planck-Institut fuer extraterrestrische Physik (MPE) in Garching, Germany since Jan 2002
- ESA Science Staff in the ISO project, Villafranca, Spain (Oct 1998 - Dec 2001)
- Post-doc at the Max-Planck-Institut fuer Astronomie (MPIA) in Heidelberg, Germany and Villafranca, Spain (Aug 1997 - Sep 1998)
- PhD Student at the University of Heidelberg and the Max-Planck-Institut fuer Astronomie (MPIA) in Heidelberg, Germany (Aug 1994 - Jul 1997)

Project involvements/observing experience:

- PI of "TNOs are Cool: a survey of the trans-neptunian region", a large 400 hour Herschel Key Programm
- calibration contributions (based on thermophysical modeling of asteroids) for all relevant infrared space missions in the last 15 years, including Herschel, Spitzer, Akari, ISO
- ground based & air-borne mid-IR, submm, mm, cm observing programmes

Scientific focus:

- thermophysical modelling of small bodies in the solar system
- physical and thermal characterisation of individual NEAs, MBAs, TNOs
- extraction of solar system targets from infrared surveys
- establishment of asteroids as new class of far-IR/submm standards for groundbased, airborne and space-based projects

Selected publications:

Mueller et al. 2011, Thermo-physical properties of 162173 (1999 JU3), a potential flyby and rendezvous target for interplanetary missions, A&A 525, 145

Mueller et al. 2010, "TNOs are Cool": A survey of the trans-Neptunian region I. Results from the Herschel science demonstration phase (SDP), A&A 518, 146

Hormuth, F. & Mueller, T.G. 2009, Catalogue of ISO LWS observations of asteroids, A&A 497, 983

Mueller, T.G., Lellouch, E., Boehnhardt, H. et al. 2008, TNOs are Cool: A Survey of the Transneptunian Region, Earth, Moon & Planets 105, 209

Hasegawa, S., Mueller, T.G., Kawakami, K. et al. 2008, Albedo, size, and surface characteristics of Hayabusa-2 sample-return target 162173 1999 JU3 from AKARI and Subaru observations, PASJ 60, 399

Mueller, T.G. & Barnes, P. 2007, 3.2 mm lightcurve observations of (4) Vesta and (9) Metis with the Australia Telescope Compact Array, A&A 467, 737

Mueller, T.G., Sekiguchi, T., Kaasalainen, M., Abe, M., Hasegawa, S. 2005, Thermal infrared observations of the Hayabusa spacecraft target asteroid 25143 Itokawa, A&A 443, 347

Mueller, T.G., Abraham, P., Crovisier, J. 2005, Comets, Asteroids and Zodiacal Light as Seen by ISO, Space Science Reviews 119, 141

Mueller, T. G., Sterzik, M. F., Schuetz, O. et al. 2004, Thermal infrared observations of near-Earth asteroid 2002 NY40, Astronomy and Astrophysics 424, 1075-1080

Mueller, T. G. & Blommaert, J. A. D. L. 2004, 65 Cybele in the thermal infrared: Multiple observations and thermophysical analysis, Astronomy and Astrophysics 418, 347-356

Mueller, Thomas G. 2002, Thermophysical analysis of infrared observations of asteroids, Meteoritics and Planetary Science 37, 1919-1928

Mueller, T. G. & Lagerros, J. S. V. 2002, Asteroids as calibration standards in the thermal infrared for space observatories, Astronomy and Astrophysics 381, 324-339

Dr. Ann L. Sprague

BIOGRAPHICAL SKETCH

EDUCATION: 1969, B.S. Syracuse University, Geology; 1982, M.A. Astronomy, Boston University; 1990, Ph.D. University of Arizona, Planetary Science.

Sprague is a Planetary Scientist at the Lunar and Planetary Laboratory (LPL), The University of Arizona. She is a recognized specialist in spectroscopy of planetary atmospheres and surfaces. She is a Participating Scientist on the MESSENGER spacecraft with emphasis on interdisciplinary studies focused on gaining insight to Mercury's formation. Along with Robert Strom she published *Exploring Mercury: The Iron Planet* (Springer/Praxis, 2003). Dr. Sprague is a pioneer of the use of mid-infrared spectroscopy for the study of planetary surfaces and atmospheres and was a co-convener of the forward looking and successful "THERMAL EMISSION SPECTROSCOPY AND ANALYSIS OF DUST, DISKS, AND REGOLITHS" workshop held in Houston, TX in April of 1999. Dr. Sprague and her colleagues have used cutting edge ground-based and air-borne instrumentation to make identifications of mineral types on Mercury, and to identify thermal infrared emitting molecules (hot water vapor and hydrocarbons) in the Jovian stratosphere following the impact of Comet SL-9. In addition, she has, along with her colleagues studied the thermal infrared spectral signatures of Vesta and the HED meteorites. Dr. Sprague has also published extensively on the relationship of the thin atmosphere of Mercury to its surface and the dynamics of Mars' atmosphere as revealed by the quantitative analysis of the abundance of atmospheric argon obtained from instruments on the Mars Odyssey Spacecraft.

MOST RELEVANT PEER-REVIEWED PUBLICATIONS:

Sprague, A. L. et al. (1992). The moon-Mid-infrared (7.5- to 11.4 μm) spectroscopy of selected regions. *Icarus* **100**, 73-84.

Sprague, A. L. et al. (1994). Mercury: Evidence for anorthosite and basalt from mid-infrared (7.3-13.5 μm) spectroscopy. *Icarus* **109**, 156-167.

Sprague, A. L., et al. (1996). Water Brought into Jupiter's Atmosphere by Fragments R and W of Comet SL-9. *Icarus* **121**, 30-37.

Emery, J. P. et al. (1998). Mercury: Thermal Modeling and Mid-infrared (5-12 μm) Observations. *Icarus* **136**, 104-123.

Sitko, M. L. et al. (1999).Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths. *Publications of the Astronomical Society of the Pacific* **111**, 1593-1594.

Shkuratov, Y., et al. (2000).Thermal Emission Indicatrix for Rough Planetary Surfaces at Arbitrary Heating/Observing Geometry. *Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths* **196**, 221-230.

Sprague, A. L. (2000). Thermal Emission Spectroscopy and Data Analysis of Solar System Regoliths. *Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths* **196**, 167-186.

Sprague, A. L. et al. (2000). Mid-Infrared (8.1-12.5 μm) Imaging of Mercury. *Icarus* **147**, 421-432.

Sprague, A. L. et al. (2002). Mercury: Mid-infrared (3-13.5 μm) observations show heterogeneous composition, presence of intermediate and basic soil types, and pyroxene. *Meteoritics and Planetary Science* **37**, 1255-1268.

Cremonese, G. et al. (2004). MEMORIS: a wide angle camera for the BepiColombo mission. *Advances in Space Research* **33**, 2182-2188.

Helbert, J. et al. (2007). A set of laboratory analogue materials for the MERTIS instrument on the ESA BepiColombo mission to Mercury. *Advances in Space Research* **40**, 272-279.

Sprague, A. L. et al. (2009). Spectral emissivity measurements of Mercury's surface indicate Mg- and Ca-rich mineralogy, K-spar, Na-rich plagioclase, rutile, with possible perovskite, and garnet. *Planetary and Space Science* **57**, 364-383.

Gillis-Davis, J. J. et al. (2009). Pit-floor craters on Mercury: Evidence of near-surface igneous activity. *Earth and Planetary Science Letters* **285**, 243-250.

Donaldson Hanna, K., and Sprague, A. L. (2009). Vesta and the HED meteorites: Mid-infrared modeling of minerals and their abundances. *Meteoritics and Planetary Science* **44**, 1755-1770.