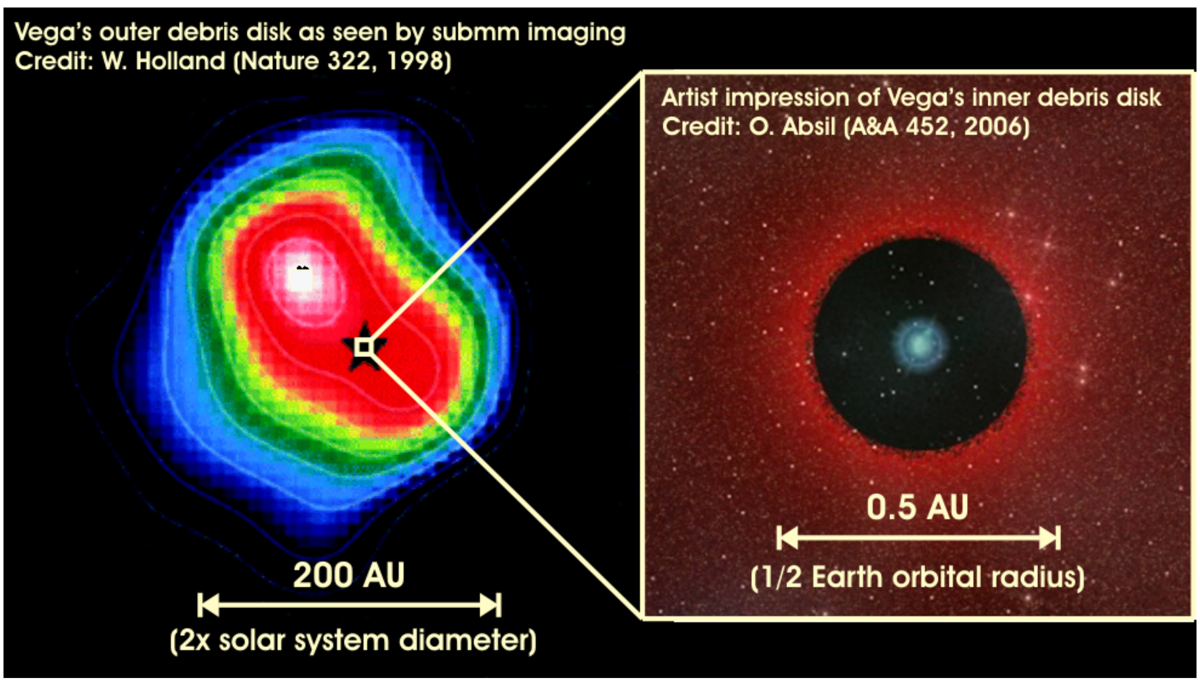
“Exozodiacal Dust Disks and Darwin”

A proposal for an ISSI Team



First resolved detection of an exozodiacal dust component by Absil et al. (2006)

Team coordinators:

JEAN-CHARLES AUGEREAU and ALEXANDER KRIVOV

Abstract

The quest for extrasolar planets has become, over the last decade, one of the main scientific drivers for numerous instrumental initiatives worldwide. Both at ESA and NASA, space-based missions (resp. DARWIN and Terrestrial Planet Finder, hereafter TPF) are currently being designed to directly detect photons from Earth-like planets at mid-infrared wavelengths (e.g. Fridlund, 2004 AdSpR 34). However, as recognised by the space agencies, the presence of warm dust, in the form of an exozodiacal cloud in the habitable zone around nearby stars, might significantly compromise the ability of these missions to reach their goal. Yet, our current knowledge of dust within a few astronomical units around nearby solar-type stars is largely insufficient to feed the DARWIN/TPF design studies with realistic numbers, and the solar system zodiacal cloud is by default systematically used as a reference.

Preliminary ground-based observations conducted by our team recently showed that exozodiacal disks may in fact show structures and brightness levels that significantly depart from the solar system case. Ongoing design studies of DARWIN-like missions are thus based on assumptions on the exozodiacal emission levels which are not representative of the diversity of dust clouds around nearby stars. We therefore deem very timely to start investing significant efforts into intensive modeling and characterisation of exozodiacal disks, in an attempt to uncover possible commonalities and diversities between them and the zodiacal cloud in our Solar System.

Our team workshops will focus on the investigation of extrasolar analogs of the zodiacal cloud in the context of planet detection with future space-based missions such as DARWIN, with a final goal to identify the dominant source of dust production, and to develop a software tool capable of (1) interpreting the currently ongoing observations of exozodiacal dust and (2) predicting the structure and level of circumstellar dust that can be expected around the DARWIN target stars. To this end, we will bring together specialists in extrasolar dust disks and in the Solar System's zodiacal cloud, with the required expertise in modeling, observations, laboratory experiments, instrumentation and space missions. These workshops are intended to facilitate existing and trigger new collaborative projects between the team members and provide a stimulating environment for new ideas.

Scientific Rationale

Motivation and timeliness

As recognised by the European and American Space Agencies, exozodiacal dust in the habitable zone around nearby stars is a source of background flux that must be considered in any effort to image terrestrial planets. The strength of the exozodiacal light intensity in typical stellar systems is not known. In the Solar System, the zodiacal dust is the most luminous component after the Sun, and interestingly, the signature of the Earth is clearly seen as clumps in the zodiacal dust disk. These facts reveal two faces of exozodiacal dust disks. On the one hand, exozodiacal dust might prevent the detection of exo-Earths with future space-based facilities. On the other hand, structures in exozodiacal clouds might be signposts of unseen perturbing planets and small body populations that produce visible dust.

The Solar System's zodiacal dust is produced by collisions among asteroids and by outgassing of comets (Grün 2007, in *Encyclopedia of the Solar System*). A significant fraction ($\sim 20\%$) of nearby stars are also known to host dusty debris disks, which are thought to be aftermaths of planet formation and to derive from collisions in extrasolar Kuiper belts. A fleet of space facilities (HST, ISO, SPITZER and soon HERSCHEL) has been revolutionising the study of debris disks. However, nearly nothing is known about exozodiacal clouds around DARWIN target stars, namely on dust in the inner, planetary region of the extrasolar systems that should stem from "exoasteroids" and "exocomets".

While our current knowledge of exozodiacal dust clouds is almost exclusively based on the Solar System, the amount of warm dust that can be expected around nearby main sequence stars is actually one of the main design drivers for the DARWIN/TPF missions. In the context of the Cosmic Vision programme, major design decisions on the DARWIN mission will be taken during the Definition Phase, scheduled for January 2010. We therefore deem it very timely to start investing significant effort into intensive modeling and characterisation of possible exozodiacal clouds, in an attempt to uncover possible commonalities and diversities between them and the zodiacal cloud in our Solar System. Our core team consists of European and American scientists with vast, and mutually complementary, expertise in modeling, observations, laboratory experiments, and instrumentation. It includes both specialists in extra-solar dust disks and experts in the Solar System's zodiacal cloud, thus bringing together two communities that use various approaches.

First observational results and associated questions

Only very recently, hot dust has been unambiguously resolved for the first time around several stars (Vega, τ Cet, ζ Aql) using high-precision near-infrared interferometry at the CHARA Array (Absil et al. 2006, A&A 452; Di Folco et al. 2007, in prep.; Absil et al. 2007, in prep.). The detection principle is based on the small decrease in visibility produced by the resolved circumstellar structure with respect to the expected photospheric visibility, which can best be detected at short baselines (~ 30 m). In the case of Vega, for example, the main outcome of these observations is an accurate estimate of the K-band ($2.2\,\mu$m) flux excess. Based on this sole photometric information, complemented by (much less accurate) archival photometric data at other infrared wavelengths, it has become possible to put useful constraints on the disk morphology, composition and dynamics by using the radiative transfer code of Augereau et al. (1999, A&A 348) and dust optical constants from laboratory measurements (e.g. Mutschke et al. 2004, A&A 423) to reproduce the disk spectral energy distribution. The resolved emission seems to emanate mostly from hot sub-micron carbonaceous grains located within 1 AU from the photosphere, close to their sublimation limit. The total mass and fractional luminosity of these grains have been derived.

These results show that the structure of exozodiacal dust clouds may be very different from the Solar System zodiacal cloud, where the dust is typically composed of silicate grains with sizes in the range 10–100 μm. These observations therefore raise a number of questions, which are of direct pertinence for the preparation of the DARWIN mission. For instance, the mechanisms of the dust production is unclear. It is not known whether or not they are similar to those operating in the solar system. It is not known how different they are in different systems, what is the role of transient events, etc.

Modeling exozodiacal emissions

We will address the question of the *origin of the observed exozodiacal grains* using models the ISSI team members developed for various purposes. Current observations indicate that the exozodiacal dust particles are short-lived and require an active reservoir of parent bodies. Several scenarios will be considered, largely inspired by solar system studies. Exozodiacal dust could originate from the collisional evolution of an extrasolar asteroid belt (Krivov et al. 2006, A&A 455; Thébault, Augereau & Beust 2003, A&A 408), from a high cometary activity (Beust et al. 1996, A&A 310), or from the catastrophic destruction and fragmentation of very massive objects such as planet embryos.

We also aim at identifying the main *stirring mechanism* that initiates and gives rise to the abundant dust production in the habitable zone around stars. Outward migration of giant planets could trigger a cometary shower (Morbidelli and collaborators, 2005, Nature 435), in a mechanism similar to the Late Heavy Bombardment in the solar system[1]. Alternatively, planetesimal trapping in internal mean-motion resonances with a planet might pump up the eccentricity of asteroid- or comet-like objects, that will release dust particles due to collisions or when approaching the star[2]. Further possibilities might include dust avalanches, rotational breakup of larger grains, generation of small dust grains by sublimation, etc.

[1] an event that it thought to coincide with the appearance of life on Earth

[2] a scenario proposed to explain transient spectroscopic events towards the star β Pic (Beust & Morbidelli 2000, Icarus 143)

Studying all these processes requires a very good knowledge of the dust content in the solar system and in debris disks, a profound expertise in the dynamics of large and small solid bodies[3], as well as specific skills to describe collisional and comet evaporation processes. Our team gathers renowned scientists who have an expertise in all the above mentioned research fields, as detailed in the attached CVs. Our team further comprises ESA and NASA representatives (resp. M. Fridlund, and M. Kuchner), involved in the DARWIN and TPF projects, who are also specialists of dusty disks around nearby stars.

Questions to address during the meetings

1 – Our current knowledge of dust in the habitable zone around stars relies on a handful of near-infrared interferometric ground-based observations obtained in 2006 and 2007 by our team, on scarce detection of warm dust with SPITZER, and on the solar system case. Therefore, the very first step toward predicting exozodiacal dust emission will consist in properly *reproducing the available observational evidence with state-of-the-art models* developed within our ISSI team. In the course of our first ISSI meeting, we will in particular address the following questions:

- What can we learn from the first attempts to observe exozodiacal dust, and how can the knowledge of the Solar System's dust cloud help understanding the results?
- How can the existing models of extrasolar (Kuiper Belt-like) debris disks be adapted or generalised to exozodiacal clouds?

2 – The ISSI meetings will be the occasion to critically discuss and identify the *possible dynamical processes* at play, and to explore the potential of each based on numerical simulations. The initial models will simultaneously describe the dust dynamics, transport processes, and collisions or comet evaporation, without addressing the question of the stirring mechanism. The latter mechanism will be discussed in a second step, in close connection with *the presence of planets* as the trigger for the dust production. During the second meeting, we will attempt to answer the following questions:

- What could be the comparative contribution of asteroidal collisions and cometary activity in exozodiacal clouds?
- How frequent could be transient phenomena like the Late Heavy Bombardment in the Solar System?
- To which extent can the detected exozodiacal disks be used as indicators of unseen planets, hence turning the possible weak point of DARWIN-type missions into an advantage?
- Based on dynamical models, and independent observations (e.g. radial velocity techniques), can we place upper limits on the presence of undesired exozodiacal dust around DARWIN targets if assumed to host a planet?

3 – An ambitious goal of our meetings would be to merge our sophisticated codes into a *simplified and fast simulation software package to be used by the* DARWIN/TPF *science teams.* During the last ISSI meeting, we will address the following questions:

- What are the possibilities to create a tool for DARWIN to predict the brightness level of exozodiacal dust during the design phase of the mission?
- Which observations of exozodiacal clouds are required before DARWIN, and which precursor instruments/missions are required to guarantee the success of space-based exo-Earth detection missions?

Our ISSI meetings are intended to provide a stimulating environment for new ideas and amalgamation of different views, and facilitate and trigger further multilateral and bilateral collaborative projects between the nodes and individual team members.

[3] These are subject to gravitational forces exerted by planets, as well as to a large array of non-gravitational effects. Important known effects in the Solar System include radiation pressure, Poynting-Robertson and corpuscular drag and the YORP effect, all due to the solar radiation field, Lorentz interactions with the solar magnetic field, and many others.

Goals and Expected Output

Our goal is to use the broad expertise of the team members in interferometric and infrared observations, dust disk modeling, dynamical simulations, and laboratory measurements of dust properties, to produce the *very first realistic models of exozodiacal disks*.

These models are intended to be used to interpret the pioneering interferometric observations of exozodiacal clouds performed by our team, together with archival observations, in particular the constraining results obtained with the SPITZER Space Telescope. Our team wish to transfer this expertise to the DARWIN/TPF community by providing a convenient and versatile tool to predict exozodiacal dust emissions, that will help the scientific teams during the design studies of the missions. This model will make the most of the available expertise of scientists currently spread over Europe and US, in order to prepare future ESA exo-Earth detection missions.

Our results will lead to several publications in refereed journals, as well as to "white papers" to the DARWIN/TPF teams. The complex codes the ISSI team members have developed will be merged into a usable version that will be made available to the community in a form that will be discussed during the ISSI meetings.

Why ISSI?

ISSI qualifies as the preferred site of the workshops, because in the past it has enabled very fruitful activities of scientific teams on various astrophysical issues. ISSI provides a stimulating environment for interdisciplinary discussions among scientists that otherwise lack opportunities to meet and discuss emerging research fields of general interest for space missions such as DARWIN.

List of Participants

Name	Institution	Country	Expertise
Jean-Charles Augereau*	LAOG Grenoble	F	Visible/IR observations, radiative transfer
Alexander Krivov*	Jena University	D	Dust dynamics, collisional models
Olivier Absil	LAOG Grenoble	F, B	Interferometry, DARWIN
Hervé Beust	LAOG Grenoble	F	Planetary dynamics, comet evaporation
Malcolm Fridlund	ESA Noorwdijk	NL	Project scientist on DARWIN, observations of disks
Eberhard Grün	MPIK Heidelberg	D	Solar system dust, space instrumentation, data analysis
Marc Kuchner	NASA Goddard	USA	Dust dynamics, interferometry, TPF
Alessandro Morbidelli	Nice Observatory	F	Planetary dynamics, solar system dynamics
Harald Mutschke	Jena University	D	Optics of dust, laboratory studies
Philippe Thébault	Stockholm Observatory	SE, F	Collisional processes, dust dynamics

* Team coordinators.

Schedule of the Project

Three workshops are planned over the duration of the project. The first two will be plenary meetings of the ISSI team. At a later stage, we will organise a larger workshop, inviting about 10 more scientists to participate at their own expenses. This third workshop will be divided into several topics (Solar System; exozodiacal clouds – modeling; exozodiacal clouds – observations and instrumentation; laboratory). In successive sessions, problems will be addressed by presentations and subsequent discussions in the plenum. Splinter sessions may also be arranged, with the results being reported to the plenum at the end. The Table below summarizes the project schedule:

#	Participants	Duration	Possible dates
1	Core team (10 participants)*	4 days	August-September 2007
2	Core team (10 participants)*	4 days	February-March 2008
3	Core team + invitees ($\sim$20 participants)*	5 days	August-September 2008

* *excluding the PhD students supervised by the core team members, see Financial Requirements section below*

Facilities Required

Meeting facilities: $2\times$ for 10 participants (+ 4–5 PhD students), $1\times$ for $\sim$ 20 participants (+ $\sim$5 PhD students), projection equipment, and access to Internet. The numerical simulations will be performed on fast computers at our home institutes.

Financial Requirements

Subsistence for the 10 scientists of the team is requested to be provided by ISSI. We would also be very grateful if the ISSI could provide support for the about 5 PhD students supervised by the team members. The ISSI team meetings are expected to be an important part of their formation and will be a unique opportunity for them to meet and work with renowned scientists. Reimbursement of travel for two coordinators is requested as well. The same for some of the other members, who cannot fund the travel from the other sources, would be appreciated.

Appendix

Short CVs of the confirmed participants, including their address, telephone, fax, and email.

Jean-Charles Augereau, Team Coordinator with A. Krivov

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Education

- **PhD in Astrophysics**, University of Grenoble, France, Nov. 2000.
  Thesis: *Evolution of Planetary Disks: Observations, Modeling and Instrumental Prospect.*
- **M.Sc. (Physics & Astrophysics)**, ENS Lyon & Nantes University, June 1996.

Experience

- **Staff Astrophysicist**, Laboratoire d'Astrophysique de Grenoble (LAOG) (Jan 2005 – present).
  Lecturer in Astrophysics (planet formation), Mathematics and Optics
  PhD supervisor of J. Olofsson (2006–2009)
- **European Union FP5 Network fellow**, Leiden Observatory, The Netherlands (Nov 2002 – Dec 2004).
  EU Research Training Network: *"The origin of planetary systems"*.
  Member of the *Spitzer Space Telescope c2d Legacy Team.*
- **CNES Research Fellow** (French spatial agency), CEA/Saclay, Astrophysics dept, France (Nov 2000 – Nov 2002).

Research interests

- Radiative transfer in circumstellar dust disks – Dust optical properties
- Mid-infrared spectroscopy of solid-state features in dust disks with the SPITZER Space Telescope
- Coronagraphic imaging of dust disks, with the HUBBLE Space Telescope and ground-based adaptive optics systems – Near-infrared interferometry
- Dynamics of Extra-Solar Planetary Systems

Selected publications

- *Circumstellar material in the Vega inner system revealed by CHARA/FLUOR* ,
  Absil, O.; di Folco, E.; Mérand, A.; Augereau, J.-C. et al., 2006, A&A **452**, 237
- *Discovery of an 86 AU Radius Debris Ring around HD 181327*,
  Schneider, G.; Silverstone, M. D.; Hines, D. C.; Augereau, J.-C. et al., 2006, ApJ **650**, 414
- *HST/NICMOS2 observations of the HD 141569 A circumstellar disk*,
  Augereau, J. C.; Lagrange, A. M.; Mouillet, D.; Ménard, F., 1999, A&A **350**, 51
- *Structuring the HD 141569A circumstellar dust disk. Impact of eccentric bound stellar companions*, Augereau, J. C. and Papaloizou, J. C. B., 2004, A&A, **414**, 1153
- *On the AU Microscopii debris disk. Density profiles, grain properties, and dust dynamics*,
  Augereau, J.-C. and **Beust, H.**, 2006, A&A, **455**, 987
- *Dust production from collisions in extrasolar planetary systems. The inner β Pictoris disc*,
  Thébault, P., Augereau, J. C. and **Beust, H.**, 2003, A&A **408**, 775
- *3. Solar System Formation and Early Evolution: the First 100 Million Years*,
  Montmerle, T.; Augereau, J. C.; Chaussidon, M.; Gounelle, M.; Marty, B.; **Morbidelli, A.**, 2006, Earth, Moon, and Planets, Volume **98**, Issue 1-4, pp. 39-95
- *c2d Spitzer-IRS spectra of disks around TTauri stars. I. Silicate emission and grain growth*
  Kessler-Silacci, J.; Augereau, J.-C.; Dullemond, C. P. et al., 2006 ApJ, **639**, 275

Alexander V. Krivov, Team Coordinator with J.-C. Augereau

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Education

- **D. Sc.** (Habilitation), St. Petersburg University, 2002.
- **Ph.D.**, Celestial Mechanics and Astrometry, Leningrad University, 1988.
- **M.Sc. with distinction**, Astronomy, Leningrad University, 1983.

Experience

- **Professor of Astrophysics**, University of Jena (2004 – present).
- **Research Scientist**, University of Potsdam (2000 – 2004).
- **Associate Professor**, St. Petersburg University (1992 – 2001).
- **Research Scientist**, Leningrad University (1983 – 1992).

Research interests

- Interplanetary, circumplanetary, and circumstellar dust.
- Extrasolar planetary systems.
- Orbital dynamics.
- Relativistic celestial mechanics and astrometry (past)

Fellowships

- Alexander von Humboldt Foundation, Germany (1999-2000)
- Jozef Mianowski Foundation, Poland (1997)

PhD theses supervised

Valeri V. Dikarev (1996–1999), Martin Makuch (2002–2004),
Torsten Löhne (2005–present), Martina Queck (2005–present)

Memberships

International Astronomical Union, Division of Planetary Science / AAS,
Euro-Asian Astronomical Society, COSPAR (associate)

Selected publications

(from a total of 1 book and 60 refereed papers)

- *The Paradoxical Universe* (175 problems in astronomy), V.V. Ivanov, A.V. Krivov, and P.A. Denissenkov, 1997, St. Petersburg University Press. 144 pp. (in Russian).
- *On the Nature of Clumps in Debris Disks*, A.V. Krivov, M. Queck, T. Löhne, and M. Sremčević, 2007, A&A **462**, 199–210.
- *Dust Distributions in Debris Disks: Effects of Gravity, Radiation Pressure and Collisions*, A.V. Krivov, T. Löhne, and M. Sremčević, 2006, A&A **455**, 509–519.
- *Evolution of a Keplerian Disk of Colliding and Fragmenting Particles: A Kinetic Model with Application to the Edgeworth-Kuiper Belt*, A.V. Krivov, M. Sremčević, and F. Spahn, 2005, Icarus **174**, 105–134.
- *Towards Understanding the β Pictoris Dust Stream*, A.V. Krivov, N.A. Krivova, S.K. Solanki, and V.B. Titov, 2004, A&A **417**, 341–352 .
- *Size Distributions of Dust in Circumstellar Debris Discs*, A.V. Krivov, I. Mann, and N.A. Krivova, 2000, A&A **362**, 1127–1137.
- *Detection of an Impact-Generated Dust Cloud around Ganymede*, H. Krüger, A.V. Krivov, D.P. Hamilton, and E. Grün, 1999, Nature **399**, 558–560.
- *Dynamics of Dust near the Sun*, A.V. Krivov, H. Kimura, and I. Mann, 1998, Icarus **134**, 311–327.
- *Circumplanetary Dust Dynamics: Effects of Solar Gravity, Radiation Pressure, Planetary Oblateness, and Electromagnetism*, D.P. Hamilton and A.V. Krivov, 1996, Icarus **123**, 503–523.

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Education

- ◇ **Ph.D. in Science**, orientation Astrophysics, University of Liège, March 2006.
  Thesis: *Astrophysical studies of extrasolar planetary systems using infrared interferometric techniques.*
- ◇ **M.Phil. in Science**, orientation Astrophysics, University of Liège, June 2003.
  Thesis: *GENIEsim: the GENIE Science Simulator.*
- ◇ **Diploma in Physical Engineering**, University of Liège, June 2001.
  Thesis: *Nulling Interferometry with IRSI-Darwin: Detection and Characterization of Earth-like Exoplanets.*

Experience

- ◇ **Marie Curie Intra-European Fellowship**, Laboratoire d'Astrophysique de Grenoble (November 2006 – present).
- ◇ **FNRS Research Fellow** with the Belgian National Fund for Scientific Research under Prof. J. Surdej, University of Liège (October 2002 – September 2006).
- ◇ **External expert** at ESA/ESTEC (December 2001 – November 2004).
- ◇ **IAP Fellowship** of the Belgian Interuniversity Attraction Pole P5/36 under Prof. J. Surdej, University of Liège (September 2001 – September 2002).
- ◇ **Marie Curie Host Fellowship** at Observatoire de Paris-Meudon under Prof. P. Léna, (September 2001 – August 2002).

Research interests

- ◇ Circumstellar dust disks, extrasolar planets, life outside the Solar System.
- ◇ Optical/infrared stellar interferometry.
- ◇ High contrast imaging: nulling interferometry, coronagraphy.

Selected publications

- ◇ *Coronagraphic imaging of three weak-line T Tauri stars: evidence of planetary formation around PDS 70*, Riaud P., Mawet D., Absil O., Boccaletti A., Baudoz P., Herwats E. and Surdej J., 2006, A&A, **428**, 317–325.
- ◇ *First Results from the CHARA Array. VII. Long-Baseline Interferometric Measurements of Vega Consistent with a Pole-On, Rapidly Rotating Star*, Aufdenberg J., Mérand A., Coudé du Foresto V., Absil O., Di Folco E., Ridgway S., Sturmann J., Sturmann L. ten Brummelaar T., Turner N., Berger D. and McAlister H., 2006, ApJ **645**, 664–675.
- ◇ *Circumstellar material in the Vega inner system revealed by CHARA/FLUOR*, Absil O., Di Folco E., Mérand A., Coudé du Foresto V., **Augereau J.-C.**, Aufdenberg J., Kervella P., Ridgway S., Berger D., ten Brummelaar T., Sturmann J., Sturmann L., Turner N. and McAlister H., 2006, A&A **452**, 237–244.
- ◇ *Performance study of ground-based infrared Bracewell interferometers. Application to the detection of exozodiacal dust disks with GENIE*, Absil O., den Hartog R., Gondoin P., Fabry P., Wilhelm R., Gitton P. and Puech F., 2006, A&A **448**, 787–800.
- ◇ *Instrumental Stability Requirements for Exoplanet Detection with a Nulling Interferometer. Variability Noise is a Central Issue*, Chazelas B., Brachet F., Bordé P., Mennesson B., Ollivier M., Absil O., Labèque A., Valette C. and Léger A., 2006, Applied Optics **45**(5), 984–992.
- ◇ *Annular Groove Phase Mask Coronagraph*, Mawet D., Riaud P., Absil O. and Surdej J., 2005, ApJ **633**, 1191–1200.

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Education

- ◇ **Habilitation à diriger des recherches**, orientation Astrophysics, Université Joseph Fourier, May 1998.
  Thesis: *La dynamique des disques circumstellaires évolués de type β Pictoris*
- ◇ **Ph.D. in Physics**, orientation Astrophysics, Université Paris VII, March 1991.
  Thesis: *Dynamique interne du disque protoplanétaire autour de l'étoile β Pictoris*
- ◇ **DEA in Astrophysics**, Université Paris VII, June 1988.
- ◇ **Master degree from the Ecole Polytechnique**, Ecole Polytechnique, Palaiseau (France), June 1987

Experience

- ◇ **Astronome-adjoint**, Laboratoire d'Astrophysique de Grenoble (December 1993 – present).
- ◇ **Post-doc fellow** at the "Service d'Astrophysique (SAP)" of the CEA, "Centre d'études Nucléaires de Saclay", Saclay (France) (November 1991 – June 1993).
- ◇ **Graduate student** at IAP (Institut d'Astrophysique de Paris), Paris, under the supervision of Dr. A. Vidal-Madjar (September 1988 – September 1991).
- ◇ **D**irector of the FOST team (Stellar and Planetary formation, 33 people) of the Laboratoire d'Astrophysique de Grenoble (December 2006 – present)
- ◇ **M**ember of the scientific committee of the "Programme National de Planétologie"
- ◇ **Ph. D. Supervisor of :**
  - · Cyrille Karmann, *Le phénomène FEB et l'évolution des systèmes planétaires* (1999 – 2002)
  - · Rémy Rèche, *Etude dynamique de l'environnement circumstellaire dans les systèmes multiples jeunes* (2005 – present)

Research interests

- ◇ Circumstellar debris disks, extrasolar planets
- ◇ Formation of planetary systems, dynamical evolution of planetary systems
- ◇ Celestial mechanics, symplectic integrators
- ◇ Dynamics of multiple stellar systems

Selected recent publications (refereed)

From a total of 46 refereed publications, with 17 as first author

- ◇ Beust H., *Symplectic integration of hierarchical stellar systems*, 2003, A&A **400**, 1129
- ◇ **Augereau J.-C.**, Beust H., *On the AU Mic debris disk. Density profiles, grain properties, and dust dynamics*, 2006, A&A **455**, 987
- ◇ Duchêne G, Beust H., Adjali F., Konopacky Q.M., Ghez A.M., 2006, *Accurate stellar masses in the multiple system T Tauri*, A&A **457**, L9
- ◇ Beust H., Dutrey A., *Dynamics of the young multiple system GG Tauri. II. Relation between the stellar system and the circumbinary disk*, 2006, A&A **446**, 137
- ◇ Beust H., Valiron P., *High latitude gas in the β Pictoris system. A possible origin related to Falling Evaporating Bodies*, 2007, A&A, in press, astro-ph/0701241
- ◇ Beust, H. and **Morbidelli, A.**, *Falling Evaporating Bodies as a Clue to Outline the Structure of the β Pictoris Young Planetary System*, 2000, Icarus, **143**, 170

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Education

- **Ph.D. in Astrophysics**, University of Stockholm, Sweden, May 1987.
  Thesis: *Carbon Monoxide and Infrared studies of the L1551 starforming region*
- **Fil. Kand (Bachelor of Science)**, University of Stockholm, 1982.

Experience

- **Staff Scientist,** European Space Agency (July 1989 – present).
- **Research fellow,** European Space Agency (February 1988 – June 1989).
- **Post Doc** Queen Mary College, London (July 1987 – January 1988).
- **Graduate fellowship** Stockholm University (September 1982 - June 1987).
- **Undergraduate fellowship** University of Stockholm under L. Nordh, & University of Groningen under Prof. R. van Duinen (January 1979 – August 1982).

Research interests

- Circumstellar dust disks, extrasolar planets, life outside the Solar System.
- Star formation, formation of planetary systems.
- Molecular outflows and jets

Selected publications

- *Observations of the molecular disk surrounding the protostellar binary L1551 IRS5*, Fridlund, C.V.M., Bergman, P., Pilbratt, G., Tauber, J., White, Glenn J., 2002, A&A **382**, 573
- *The 1.2 mm image of the β Pictoris disk*, Liséau, R., Brandeker, A., Fridlund, M., Olofsson, G., Takeuchi, T., Artymowicz, P., 2003, A&A **402**, 183.
- *The spatial structure of the β Pictoris disk*, Brandeker, A., Liséau, R., Olofsson, G., Fridlund, M., 2004, A&A **413**, 681.
- *The Darwin Mission*, Fridlund C.V.M., 2004, AdSpR, **34**, 613.
- *Methanol in the L1551 circumstellar disc:* , Glenn J. White, C.W.M. Fridlund, Per Bergman, Anji Beardsmore, Rene Liseau, Mark Price, 2006, ApJL**651**, L41.
- *Comparative planetology and the Search for Life Beyond the Solar System*, Charles A. Beichman, Malcolm Fridlund, Wesley A. Traub, Karl R. Stapelfeldt, A. Quirrenbach, Sara Seager, 2006, in Protostars & Planets V, invited chapter, B. reipurth, D. Jewitt, K. Keils (eds.) page 915–928

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Education

- **Ph.D.**, Physics, University of Heidelberg, 1970.
- **Diploma**, Physics, University of Heidelberg, 1968.

Experience

- **Senior Scientist**, Max-Planck-Institut für Kernphysik, Heidelberg (1974 – present).
- **Research Associate** at LASP, Univ. of Colorado, Boulder (2007 – present).
- **Researcher** at Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu (2000 – 2007).
- **Visiting scientist**, Lunar and Planetary Institute, Houston (1982).
- **Senior Research Associate** of NRC, Jet Propulsion Laboratory (1981 – 1982).
- **Visiting Researcher**, NASA Ames Research Center (1972).
- **Visiting Researcher**, NASA Goddard Space Flight Center (1971 – 1972).
- **Research Assistant**, Max-Planck-Institut für Kernphysik, Heidelberg (1970 – 1974).

Research interests

- Planetary physics and astronomy.
- Laboratory study of impact processes.
- Development of space instrumentation for detection/analysis of extraterrestrial dust.
- Analysis of data from space borne experiments and astronomical observations.

Space missions

- Helios, Galileo, Ulysses, Cassini, Giotto, Nozomi, ISO, Rosetta, New Horizon, Bepi Colombo.
- Observer at groundbased observatories, with ISO, HST and Spitzer.

Honors

Several NASA and ESA Awards; Asteroid 1981 EY20 named (4240) "Gruen"; Fellow of the American Geophysical Union in 2000; Foreign Associate of the Royal Astronomical Society 2001; Kuiper Price of the Division for Planetary Sciences of the Amer. Astron. Soc. 2002; David Bates Medal of the European Geophysical Society 2003; University of Canterbury Visiting Erskine Fellow, Sep. – Oct. 2004; Space Science Award, COSPAR, 2006.

Professional Societies

German Physical Society, German Astronomical Society, American Geophysical Union, American Astronomical Society, COSPAR (ISCB and B.1), International Astronomical Union (Commissions 15, 21 and 22).

Selected publications

- *Solar System Dust*, In: *Encyclopedia of the Solar System, second edition*, Grün, E., 2007,L.A. McFadden, P.R. Weissman, T.V. Johnson, Academic Press, 621-636.
- *Foreword. Physics of Dusty Rings: History and Perspective*, Grün, E., I. de Pater, M. Showalter, F. Spahn and R. Srama, 2006, Planetary and Space Science, 54, 837-843.
- *2002 Kuiper prize lecture: Dust Astronomy*, Grün, E.; Srama, R.; Krüger, H.; Kempf, S.; Dikarev, V.; Helfert, S.; Moragas-Klostermeyer, G., 2005, Icarus, 174, 1-14, 787–800.
- *The interplanetary dust complex and comets, Comets II*, Sykes, M. V.; Grün, E.; Reach, W. T.; Jenniskens, P., 2004, M. C. Festou, H. U. Keller, and H. A. Weaver (eds.), University of Arizona Press, Tucson, p.677-693.
- *The Dusty Heliosphere*, In: *The Century of Space Science*, Grün, E., 2001, Kluwer Academic Publishers, 1163-1189.
- *Interplanetary Dust*, Grün, E., Gustafson B.A.S., Dermott S., Fechtig H., (Eds.), 2001, Springer, Berlin, Heidelberg, New York, 295-346.

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Education and Employment

- **Astrophysicist**, NASA Goddard Space Flight Center (July 2005 – present).
- **Hubble Fellow, Russell Fellow, and Council of Science and Technology Fellow** Princeton University, (September 2003 – June 2005).
- **Michelson Postdoctoral Fellow**, Harvard-Smithsonian Center for Astrophysics (September 2000 – August 2003).
- **Ph.D. in Astronomy with a Minor in Physics**, Caltech, 2000.
  Thesis: *Exozodiacal Dust*
- **A.B. Physics, Astronomy and Astrophysics**, with honors, Harvard University, June 1994.

Relevant Experience and Awards

- **Marquis Who's Who in America** (2006 – present).
- **NASA Discovery Proposal Science Teams:** New Worlds Discoverer, Eclipse, FKSI, SPIRIT, (July 2005 – present).
- **Terrestrial Planet Finder Coronagraph Instrument Concept Study Teams:** CorCam, CorSpec, and Mag30Cam (2006 – 2007).
- **Terrestrial Planet Finder Science and Technology Definition Team**, Chair, Committee on Circumstellar Disks (2005 – 2006).
- **Scientific Organizer**, Aspen Winter Conference on Planet Formation (2005).
- **Science PI**, Keck Interferometer Nuller Commissioning Science Team (2003 – present).
- **Solar System Dust Panel**, Planetary Science Decadal Survey (2001).

Research interests

- Extrasolar Planets, Circumstellar Disks
- Coronagraphy, Interferometry.
- Planet Formation, Dynamics of Planetary Systems.

Selected publications

- *Modeling Exozodiacal Dust Detection with the Keck Interferometer*, Kuchner, M.J. and Serabyn, E. 2007, ApJ, submitted
- *The Dust Cloud Around the White Dwarf G29-39*, Reach, W.T. Kuchner, M.J. von Hippel, T., Burrows, A., Mullally, F., Kilic, M. and Winget, D. 2005, ApJ, **635**, 161.
- *Eighth-Order Image Masks for Terrestrial Planet Finding*, Kuchner, M. J., Crepp, J. and Ge, J., 2005, ApJ, **628**, 466.
- *The Dynamical Influence of a Planet at Semimajor Axis 3.4 AU on the Dust Around Eridani*, Moran, S.M., Kuchner, M.J., and Holman, M.J. 2004, ApJ, **612**, 1163.
- *The Geometry of Resonant Signatures in Debris Disks with Planets*, Kuchner, M.J. and Holman, M.J., 2003, ApJ, **588**, 1110.
- *A Coronagraph with a Band-Limited Mask for Finding Terrestrial Planets*, Kuchner, M.J. and Traub, W.A. 2002, ApJ, **570**, 900.
- *Structure in the Dusty Debris Around Vega*, Wilner, D.J., Holman, M.J., Kuchner, M.J., and Ho, P.T.P. 2002, ApJ, **569**, L115.
- *A Search for Resonant Structures in the Zodiacal Cloud with COBE DIRBE: The Mars Wake and Jupiter's Trojan Clouds*, Kuchner, M.J., Reach, W.T., and Brown, M.E. 2000, Icarus, **145**, 44.

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Education

- ◇ **D. Sc.**, University of Nice, 2002.
- ◇ **Ph.D. in Science**, Mathematics, University of Namur, 1991.
- ◇ **M.Sc.**, Physics, University of Milan, 1988.

Experience

- ◇ **Staff Astronomer**, Observatoire de la Côte d'Azur (1993 – present).
- ◇ **Post Doc**, Observatoire de la Côte d'Azur (1992 – 1993).

Research interests

- ◇ Origin of solar system.
- ◇ Evolution of planetary systems.
- ◇ Orbital dynamics.

Major scientific activities

Co-editor of Icarus, 2000–present; Associate editor of Celest. Mech. and Dynam. Astron., 2001–present; co-editor of the book Kuiper Belt (U. Arizona Press); coordinator of the panel on Solar System Origin and Primordial Evolution of the French National Program of Planetology; chair of the LOC of the 2004 meeting of the Division on Dynamical Astronomy of the Amer. Astron. Soc.; member of the SOC of Commission 7 of IAU.

Recent Invited lectures in international meetings

Goldschmidt conference, plenary session (Cologne, 2007); Nobel Symposium "Physics of Planetary Systems" (Stockholm, 2007); Division of Dynamical Astronomy meeting (Ann Harbour, 2007); ESO workshop "Observing Planetary Systems" (Santiago, 2007); IAU Symposium 236 "Near Earth Objects, our Celestial Neighbors: opportunity and Risk" (Prague, August, 2006); Protostars Planets V (Hawaii, 2005); JENAM 2005, (Liege, Belgium, 2005); Saas-Fee Advanced Course on "Trans-Neptunian Objects and Comets" (Wengen, Switzerland, 2005).

Selected publications

(from a total of 1 book and 90 refereed papers)

- ◇ *Modern Celestial Mechanics; Aspects of Solar System Dynamics*, A. Morbidelli, Taylor & Francis/Cambridge Scientific Publishers.
- ◇ *Terrestrial planet formation with strong dynamical friction*, O'Brien, David P.; Morbidelli, Alessandro; Levison, Harold F., 2006, Icarus, **184**, 39.
- ◇ *Iron meteorites as remnants of planetesimals formed in the terrestrial planet region*, Bottke W.F., Nesvorny D., Grimm R.E., Morbidelli A., O'Brien D., 2006, Nature, **439**, 821–824.
- ◇ *Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets*, R. Gomes, H.F. Levison, K. Tsiganis, A. Morbidelli, 2005, Nature, **435**, 466.
- ◇ *The chaotic capture of Jovian Trojan asteroids during the early dynamical evolution of the Solar System*, A. Morbidelli, H.F. Levison, K. Tsiganis, R. Gomes, 2005, Nature, **435**, 462.
- ◇ *Origin of the orbital architecture of the giant planets of the solar system*, K. Tsiganis, R. Gomes, A. Morbidelli, H.F. Levison, 2005, Nature, **435**, 459.
- ◇ *The Yarkovsky-driven origin of Near Earth Asteroids*, A. Morbidelli, D. Vokrouhlicky, 2003, Icarus, **163**, 120-134.
- ◇ *From magnitudes to diameters: the albedo distribution of Near Earth Objects and the Earth collision hazard*, A. Morbidelli, R. Jedicke, W.F. Bottke, P. Michel, E.F. Tedesco, 2002, Icarus, **158**, 329–342.
- ◇ *Source regions and timescales for the delivery of water to Earth*, A. Morbidelli, J. Chambers, J.I. Lunine, J.M. Petit, F. Robert, G.B. Valsecchi, K. Cyr, 2000, Meteoritics and Pl. Science, **35**, 1309-1320.

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Born on February 16th, 1962
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Education

- **Ph.D. (Dr. rer. nat.)**, Friedrich Schiller University Jena, 1992.
  Thesis: *Structural characterization of fluoride coatings by infrared spectroscopy and spectroscopic ellipsometry (in German).*
- **Diploma in Physics**, Friedrich Schiller University Jena, 1987.
  Thesis: *Electron microscopic structural characterisation and optical scattering properties of carbon coatings (in German).*

Experience

- **Research scientist**, Astrophysical Institute and University Observatory (AIU) Jena (1997 – present), head of astrophysical laboratory (since 2005).
- **Research scientist**, Max Planck Research Group "Dust in Star Forming Regions" at FSU Jena, Prof. Th. Henning, (1992 – 1996).
- **Research student and scientific assistant**, Institute for Solid State Physics, FSU Jena, Prof. G. Schirmer (1987 – 1992).

Research interests

- Optical and spectroscopic properties of solid materials with relevance to cosmic dust from ultraviolet to submm wavelengths including temperature dependence
- Experimental and theoretical particle optics - light absorption and scattering depending on grain size, shape and agglomeration
- Condensation of nanoparticles from the gas phase by laser-based techniques, characterization of their structural and optical properties

Selected publications (2006)

- Th. Posch, H. Mutschke, M. Trieloff, Th. Henning, "Infrared spectroscopy of calcium-aluminium-rich inclusions - analog material for protoplanetary dust?", Astrophys. J., **656** (2006), 615.
- A. Tamanai, H. Mutschke, J. Blum, G. Meeus, "The 10 micron infrared band of silicate dust: a laboratory study comparing the aerosol and KBr pellet techniques", Astrophys. J. Letters, **648** (2006), L147
- C. Jäger, H. Mutschke, F. Huisken, R. Alexandrescu, I. Morjan, et al., "Iron-carbon nanoparticles prepared by CO2 laser pyrolysis of toluene and iron pentacarbonyl", Applied Physics A, **85** (2006), 53
- C. Koike, H. Mutschke, H. Suto, T. Naoi, H. Chihara et al. "Temperature effects on the mid-and far-infrared spectra of olivine particles", Astron. Astrophys., **449** (2006), 583
- M. Schnaiter, M. Gimmler, I. Llamas, C. Linke, C. Jäger, H. Mutschke "Strong spectral dependence of light absorption by organic carbon particles formed by propane combustion", Atmospheric Chemistry and Physics Discussions, **Vol. 6** (2006), pp 1841-1866
- A.C. Andersen. H. Mutschke, Th. Posch, M. Min, A. Tamanai, "Infrared extinction by homogeneous particle aggregates of SiC, FeO and SiO2: Comparison of different theoretical approaches", J. Quant. Spectr. Rad. Transfer, **100** (2006), 4

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Education

- ◇ **Habilitation à diriger des recherches**, Université Paris–VII, 2005.
- ◇ **Ph.D.**, Université Paris–VII, 1997. Thesis: *Planetesimal accretion in perturbed systems.*
- ◇ **M.Sc.**, Université Paris–XI, 1993.

Experience

- ◇ **Associate Professor of Astrophysics**, Observatoire de Paris (1998 – present).
- ◇ **Post–Doc fellow**, Université Paris–VII (1997 – 1998).
- ◇ **Graduate student** under the supervision of Pr. André Brahic, Université Paris–VII (1994 – 1997).
- ◇ **Ph. D. Supervisor of :**
  - · Anna Grigorieva, *Dynamical and Physical modeling of dusty debris discs*, Stockholm Observatory (2005 – present).
  - · Mauro Barbieri, *Sélection du Champ d'Observation pour une Mission Spatiale Consacree à la recherche de Planètes Extrasolaires*, Université Paris–VII/Padua Observatory (2002 – 2005).

Research interests

- ◇ Circumstellar dust and gas.
- ◇ Extrasolar planetary systems.
- ◇ Planetary formation in binary stars.
- ◇ Trans Neptunian Objects (past).

Selected publications

- ◇ *Relative velocities among accreting planetesimals in binary systems: The circumprimary case*, Thébault, P., Marzari, F., Scholl, H., 2006, Icarus, **183**, 193.
- ◇ *Upper limit on the gas density in the β Pictoris system*, Thébault, P. , **Augereau, J. C.**, 2005, A&A, **437**, 141.
- ◇ *Planetary formation in the γ Cephei system*, Thébault, P., Marzari, F., Scholl, H., Turrini, D., Barbieri, M., 2004, A&A, **427**, 1097.
- ◇ *Dust production from collisions in extrasolar planetary systems. The inner β Pictoris disc*, Thébault P., **Augereau, J.-C.**, **Beust, H.**, 2003, A&A, **408**, 775.
- ◇ *Colors and collision rates within the Kuiper belt: problems with the collisional resurfacing scenario*, Thébault, P., Doressoundiram, A., 2003, Icarus, **162**, 27.
- ◇ *Falling Evaporating Bodies in the β Pictoris system, Resonance refilling and long term duration of the phenomenon*, Thébault P., **Beust, H.**, 2001, A&A, **376**, 621.