

Geophysical Research Letters

AN AGU JOURNAL

Aims and Scope. *Geophysical Research Letters* publishes high-impact, innovative, and timely research on major scientific advances in all the major geoscience disciplines. Papers are communications-length articles and should have broad and immediate implications in their discipline or across the geosciences. GRL maintains the fastest turn-around of all high-impact publications in the geosciences and works closely with authors to ensure broad visibility of top papers.

Editors: Noah Diffenbaugh (Editor-in-Chief) (diffenbaugh@stanford.edu, <http://orcid.org/0000-0002-8856-4964>), M. Bayani Cardenas (<http://orcid.org/0000-0001-6270-3105>), Kim Cobb, Meghan Cronin, Andrew J. Dombard, Andy M. Hogg, Tatiana Ilyina (<http://orcid.org/0000-0002-3475-4842>), Gang Lu (<http://orcid.org/0000-0001-5350-2889>), Andrew V. Newman, Merav Opher (<http://orcid.org/0000-0002-8767-8273>), Jeroen Ritsema (<http://orcid.org/0000-0003-4287-7639>), Janet Sprintall (<http://orcid.org/0000-0002-7428-7580>), Julianne Stroeve (<http://orcid.org/0000-0002-0476-381X>), Joel A. Thornton, Paul D. Williams (<http://orcid.org/0000-0002-9713-9820>), Andrew Yau.

Associate Editors: Olivier Bachmann, Rose Cory, Marine Denolle, Ake Fagereng, Valeriy Ivanov, Steven D. Jacobsen, Monika Korte, Mingming Li, Paola Passalacqua, Shafer Smith, Toste Tanhua, Jacob Tielke, Aradhna E. Tripathi, Valiere M. Trouet, Mathias Vuille.

AGU Editorial Team. For assistance with submitted manuscripts, file specifications, or AGU publication policy please contact grronline@agu.org.

For submission instructions or to submit a manuscript visit: <http://grl-submit.agu.org>.

The journal to which you are submitting your manuscript employs a plagiarism detection system. By submitting your manuscript to this journal you accept that your manuscript may be screened for plagiarism against previously published works.

Geophysical Research Letters accepts articles for Open Access publication. Please visit <http://olabout.wiley.com/WileyCDA/Section/id-406241.html> for further information about OnlineOpen.

Publication Charges. The publication charge income received for *Geophysical Research Letters* helps support rapid publication, allows more articles per volume, makes possible the low subscription rates, and supports many of AGU's scientific and outreach activities. Publication charge information can be found here: <http://publications.agu.org/author-resource-center/>.

To encourage papers to be written in a concise fashion, there is an excess length fee. For *Geophysical Research Letters* the fee is assessed only on the equivalent of more than 12 publication units. The excess length fee does not apply to review articles, and the editor may waive the fee on a limited number of concisely written papers that merit being longer. There is no charge for color in any format.

Copyright and Photocopying. Copyright © 2017. American Geophysical Union. All rights reserved. No part of this publication may be reproduced, stored or transmitted in any form or by any means without the prior permission in writing from the copyright holder. Authorization to copy items for internal and personal use is granted by the copyright holder for libraries and other users registered with their local Reproduction Rights Organisation (RRO), e.g. Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923, USA (www.copyright.com), provided the appropriate fee is paid directly to the RRO. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works or for resale. Special requests should be addressed to: publications@agu.org.

Disclaimer. The Publisher, American Geophysical Union, and Editors cannot be held responsible for errors or any consequences arising from the use of information contained in this journal; the views and

opinions expressed do not necessarily reflect those of the Publisher, American Geophysical Union, and Editors, neither does the publication of advertisements constitute any endorsement by the Publisher, American Geophysical Union, and Editors of the products advertised.

Individual Subscriptions. Member subscriptions are available through members.agu.org or by contacting the AGU Member Service Center. The Service Center is open from 8:00 a.m. to 8:30 p.m. Eastern time: +1 202 462 6900, +1 800 966 2481; Fax: +1 202 777 7393; e-mail: service@agu.org. Questions about meetings or membership will be referred to the appropriate staff.

Publisher. *Geophysical Research Letters* is published on behalf of the American Geophysical Union by Wiley Periodicals, Inc., 111 River St., Hoboken, NJ, 07030-5774, +1 201 748 6000.

Delivery Terms and Legal Title. Where the subscription price includes print issues and delivery is to the recipient's address, delivery terms are Delivered at Place (DAP); the recipient is responsible for paying any import duty or taxes. Title to all issues transfers FOB our shipping point, freight prepaid. We will endeavour to fulfil claims for missing or damaged copies within six months of publication, within our reasonable discretion and subject to availability.

GEOPHYSICAL RESEARCH LETTERS, (ISSN 0094-8276), is published semi-monthly by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ 07030-5774.

Periodical Postage Paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to GEOPHYSICAL RESEARCH LETTERS, John Wiley & Sons Inc., C/O The Sheridan Press, PO Box 465, Hanover, PA 17331.

Journal Customer Services. For institutional subscription information, claims and any enquiry concerning your journal subscription please go to www.wileycustomerhelp.com/ask or contact your nearest office.

Americas: Email: cs-journals@wiley.com; Tel: +1 781 388 8598 or +1 800 835 6770 (toll free in the USA & Canada).

Europe, Middle East and Africa: Email: cs-journals@wiley.com; Tel: +44 (0) 1865 778315.

Asia Pacific: Email: cs-journals@wiley.com; Tel: +65 6511 8000.

Japan: For Japanese speaking support, Email: cs-japan@wiley.com; Tel: +65 6511 8010 or Tel (toll-free): 005 316 50 480.

Visit our Online Customer Help available in 7 languages at www.wileycustomerhelp.com/ask.

Production Editor. For assistance with post-acceptance articles and other production issues please contact GRLprod@wiley.com.

Access to this journal is available free online within institutions in the developing world through the AGORA initiative with the FAO, the HINARI initiative with the WHO, the OARE initiative with UNEP, and the ARDI initiative with WIPO. For information, visit www.aginternetwork.org, www.who.int/hinari/en/, www.oaresciences.org, or www.wipo.int/ardi/en.

ISSN 0094-8276 (Print)
ISSN 1944-8007 (Online)

View this journal online at <http://grl.agu.org>

Cover: Figures 1 and 2 from Morlighem et al. presenting a new high-resolution bed map of the Greenland ice sheet and ocean bathymetry, with a seamless transition across glacier termini. The map combines mass conservation and newly collected ocean bathymetry data from NASA's Oceans Melting Greenland (OMG) Mission and includes bathymetric data from previous marine surveys. See also Morlighem et al. [pp. 11,051–11,061, doi: [10.1002/2017GL074954](https://doi.org/10.1002/2017GL074954)].

Space Sciences

- 10,796** *Fei He, Xiao-Xin Zhang, Wenbin Wang, and Weixing Wan*
Different Evolution Patterns of Subauroral Polarization Streams (SAPS) During Intense Storms and Quiet Time Substorms (<https://doi.org/10.1002/2017GL075449>)
- 10,805** *Robin Ramstad, Stas Barabash, Yoshifumi Futaana, Masatoshi Yamauchi, Hans Nilsson, and Mats Holmström*
Mars Under Primordial Solar Wind Conditions: Mars Express Observations of the Strongest CME Detected at Mars Under Solar Cycle #24 and its Impact on Atmospheric Ion Escape (<https://doi.org/10.1002/2017GL075446>)
- 10,812** *Casey L. Flynn, Marissa F. Vogt, Paul Withers, Laila Andersson, Scott England, and Guiping Liu*
MAVEN Observations of the Effects of Crustal Magnetic Fields on Electron Density and Temperature in the Martian Dayside Ionosphere (<https://doi.org/10.1002/2017GL075367>)
- 10,822** *Maureen L. Nietiadi, Philipp Umstätter, Iyad Alabd Alhafez, Yudi Rosandi, Eduardo M. Bringa, and Herbert M. Urbassek*
Collision-Induced Melting in Collisions of Water Ice Nanograins: Strong Deformations and Prevention of Bouncing (<https://doi.org/10.1002/2017GL075395>)
- 10,829** *Roger P. Leyser, Suzanne M. Imber, Stephen E. Milan, and James A. Slavin*
The Influence of IMF Clock Angle on Dayside Flux Transfer Events at Mercury (<https://doi.org/10.1002/2017GL074858>)

Planets

- 10,838** *Rohini S. Giles, Leigh N. Fletcher, Patrick G. J. Irwin, Glenn S. Orton, and James A. Sinclair*
Ammonia in Jupiter's Troposphere From High-Resolution 5 μ m Spectroscopy (<https://doi.org/10.1002/2017GL075221>)
- 10,845** *C. M. Fowler, L. Andersson, S. R. Shaver, J. P. Thayer, J. D. Huba, R. Lillis, M. E. Usanova, J. Espley, R. E. Ergun, J. Mcfadden, P. R. Mahaffy, J. E. P. Connerney, M. Benna, M. Elrod, D. L. Mitchell, C. Mazelle, and B. M. Jakosky*
MAVEN Observations of Ionospheric Irregularities at Mars (<https://doi.org/10.1002/2017GL075189>)

Solid Earth

- 10,855** *Keiko Kuge*
Seismic Observations Indicating That the 2015 Ogasawara (Bonin) Earthquake Ruptured Beneath the 660 km Discontinuity (<https://doi.org/10.1002/2017GL074469>)
- 10,863** *Philippe Dales, Pascal Audet, and Gerrit Olivier*
Seismic Interferometry Using Persistent Noise Sources for Temporal Subsurface Monitoring (<https://doi.org/10.1002/2017GL075342>)
- 10,871** *M. Ichihara and S. Matsumoto*
Relative Source Locations of Continuous Tremor Before and After the Subplinian Events at Shinmoe-dake, in 2011 (<https://doi.org/10.1002/2017GL075293>)
- 10,878** *Daniel A. Frost and Barbara Romanowicz*
Constraints on Inner Core Anisotropy Using Array Observations of P'P' (<https://doi.org/10.1002/2017GL075049>)
- 10,887** *Zhi Geng, Audrey Bonnelye, Mian Chen, Yan Jin, Pierre Dick, Christian David, Xin Fang, and Alexandre Schubnel*
Elastic Anisotropy Reversal During Brittle Creep in Shale (<https://doi.org/10.1002/2017GL074555>)
- 10,896** *Ting Yang, Louis Moresi, R. Dietmar Müller, and Michael Gurnis*
Oceanic Residual Topography Agrees With Mantle Flow Predictions at Long Wavelengths (<https://doi.org/10.1002/2017GL074800>)
- 10,907** *Tatsuya Kubota, Tatsuhiko Saito, Wataru Suzuki, and Ryota Hino*
Estimation of Seismic Centroid Moment Tensor Using Ocean Bottom Pressure Gauges as Seismometers (<https://doi.org/10.1002/2017GL075386>)
- 10,916** *N. Catalán, K. Bataille, and R. Araya*
Depth-Dependent Geometry of the Liquiñe-Ofqui Fault Zone and Its Relation to Paths of Slab-Derived Fluids (<https://doi.org/10.1002/2017GL074870>)

- 10,921** *Louis De Barros, Anne Deschamps, Anthony Sladen, Hélène Lyon-Caen, and Nicholas Voulgaris*
Investigating Dynamic Triggering of Seismicity by Regional Earthquakes: The Case of the Corinth Rift (Greece)
(<https://doi.org/10.1002/2017GL075460>)
- 10,930** *Huilin Wang, Michael Gurnis, and Jakob Skogseid*
Rapid Cenozoic Subsidence in the Gulf of Mexico Resulting From Hess Rise Conjugate Subduction
(<https://doi.org/10.1002/2017GL074959>)
- 10,939** *S. Kaboli, P. C. Burnley, G. Xia, and H. W. Green II*
Pressure Dependence of Creep in Forsterite Olivine: Comparison of Measurements From the D-DIA and Griggs Apparatus (<https://doi.org/10.1002/2017GL075177>)
- 10,948** *Magali I. Billen*
Insights Into the Causes of Arc Rifting From 2-D Dynamic Models of Subduction (<https://doi.org/10.1002/2017GL075061>)
- 10,958** *Mingduo T. Dong and William H. Menke*
Seismic High Attenuation Region Observed Beneath Southern New England From Teleseismic Body Wave Spectra: Evidence for High Asthenospheric Temperature Without Melt (<https://doi.org/10.1002/2017GL074953>)
- 10,970** *Chunquan Wu and Eric G. Daub*
Modeling Low-Frequency Earthquake Recurrence Patterns (<https://doi.org/10.1002/2017GL075402>)
- 10,977** *Aaron Bufer, David P. S. Bekaert, Ekbal Hussain, Bodo Bookhagen, Douglas W. Burbank, Jessica A. Thompson Jobe, Jie Chen, Tao Li, Langtao Liu, and Weijun Gan*
Temporal Changes in Rock Uplift Rates of Folds in the Foreland of the Tian Shan and the Pamir From Geodetic and Geologic Data (<https://doi.org/10.1002/2017GL073627>)
- 10,988** *M. Deen, E. Wielandt, E. Stutzmann, W. Crawford, G. Barruol, and K. Sigloch*
First Observation of the Earth's Permanent Free Oscillations on Ocean Bottom Seismometers
(<https://doi.org/10.1002/2017GL074892>)
- 10,997** *Tae-Kyung Hong, Junhyung Lee, Donggeun Chi, and Seongjun Park*
Seismic Velocity Changes in the Backarc Continental Crust After the 2011 M_w 9.0 Tohoku-Oki Megathrust Earthquake
(<https://doi.org/10.1002/2017GL075447>)
- 11,004** *M. Mouyen, A. Canitano, B. F. Chao, Y.-J. Hsu, P. Steer, L. Longuevergne, and J.-P. Boy*
Typhoon-Induced Ground Deformation (<https://doi.org/10.1002/2017GL075615>)

Hydrology and Land Surface Studies

- 11,012** *Mohammad Reza Najafi, Francis W. Zwiers, and Nathan P. Gillett*
Attribution of Observed Streamflow Changes in Key British Columbia Drainage Basins
(<https://doi.org/10.1002/2017GL075016>)
- 11,021** *Ahmad A. Behroozmand, Rosemary Knight, Mike Müller-Petke, Esben Auken, Adrian A. S. Barfod, Ty P. A. Ferré, Troels N. Vilhelmsen, Carole D. Johnson, and Anders V. Christiansen*
Successful Sampling Strategy Advances Laboratory Studies of NMR Logging in Unconsolidated Aquifers
(<https://doi.org/10.1002/2017GL074999>)
- 11,030** *Kuai Fang, Chaopeng Shen, Daniel Kifer, and Xiao Yang*
Prolongation of SMAP to Spatiotemporally Seamless Coverage of Continental U.S. Using a Deep Learning Neural Network (<https://doi.org/10.1002/2017GL075619>)
- 11,040** *Wei Hu, Qiang Xu, Gonghui Wang, Gianvito Scaringi, Mauri Mcsaveney, and Pierre-Yves Hicher*
Shear Resistance Variations in Experimentally Sheared Mudstone Granules: A Possible Shear-Thinning and Thixotropic Mechanism (<https://doi.org/10.1002/2017GL075261>)

The Cryosphere

- 11,051** *M. Morlighem, C. N. Williams, E. Rignot, L. An, J. E. Arndt, J. L. Bamber, G. Catania, N. Chauché, J. A. Dowdeswell, B. Dorschel, I. Fenty, K. Hogan, I. Howat, A. Hubbard, M. Jakobsson, T. M. Jordan, K. K. Kjeldsen, R. Millan, L. Mayer, J. Mouginot, B. P. Y. Noël, C. O'Cofaigh, S. Palmer, S. Rysgaard, H. Seroussi, M. J. Siegert, P. Slabon, F. Straneo, M. R. van den Broeke, W. Weinrebe, M. Wood, and K. B. Zinglensen*
BedMachine v3: Complete Bed Topography and Ocean Bathymetry Mapping of Greenland From Multibeam Echo Sounding Combined With Mass Conservation* (<https://doi.org/10.1002/2017GL074954>)
*This article is part of a Special Section—The Arctic: An AGU Joint Special Collection
- 11,062** *Laura L. Landrum, Marika M. Holland, Marilyn N. Raphael, and Lorenzo M. Polvani*
Stratospheric Ozone Depletion: An Unlikely Driver of the Regional Trends in Antarctic Sea Ice in Austral Fall in the Late Twentieth Century (<https://doi.org/10.1002/2017GL075618>)

- 11,071** *Y. Choi, M. Morlighem, E. Rignot, J. Mouginot, and M. Wood*
Modeling the Response of Nioghalvfjærdsfjorden and Zachariae Isstrøm Glaciers, Greenland, to Ocean Forcing Over the Next Century (<https://doi.org/10.1002/2017GL075174>)
- 11,080** *A. C. A. Rudy, S. F. Lamoureux, S. V. Kokelj, I. R. Smith, and J. H. England*
Accelerating Thermokarst Transforms Ice-Cored Terrain Triggering a Downstream Cascade to the Ocean (<https://doi.org/10.1002/2017GL074912>)
- 11,088** *B. Gerling, H. Löwe, and A. van Herwijnen*
Measuring the Elastic Modulus of Snow (<https://doi.org/10.1002/2017GL075110>)

Oceans

- 11,097** *J. H. LaCasce*
The Prevalence of Oceanic Surface Modes (<https://doi.org/10.1002/2017GL075430>)
- 11,106** *Muchamad Al Azhar, Zouhair Lachkar, Marina Lévy, and Shafer Smith*
Oxygen Minimum Zone Contrasts Between the Arabian Sea and the Bay of Bengal Implied by Differences in Remineralization Depth (<https://doi.org/10.1002/2017GL075157>)
- 11,115** *E. R. Maúre, J. Ishizaka, C. Sukigara, Y. Mino, H. Aiki, T. Matsuno, H. Tomita, J. I. Goes, and H. R. Gomes*
Mesoscale Eddies Control the Timing of Spring Phytoplankton Blooms: A Case Study in the Japan Sea (<https://doi.org/10.1002/2017GL074359>)
- 11,125** *Jianliang Huang*
Determining Coastal Mean Dynamic Topography by Geodetic Methods (<https://doi.org/10.1002/2017GL076020>)

Climate

- 11,129** *Max D. Holloway, Louise C. Sime, Claire S. Allen, Claus-Dieter Hillenbrand, Pete Bunch, Eric Wolff, and Paul J. Valdes*
The Spatial Structure of the 128 ka Antarctic Sea Ice Minimum (<https://doi.org/10.1002/2017GL074594>)
- 11,140** *Saïd Qasmi, Christophe Cassou, and Julien Boé*
Teleconnection Between Atlantic Multidecadal Variability and European Temperature: Diversity and Evaluation of the Coupled Model Intercomparison Project Phase 5 Models (<https://doi.org/10.1002/2017GL074886>)

Atmospheric Science

- 11,150** *C. A. Barton and J. P. McCormack*
Origin of the 2016 QBO Disruption and Its Relationship to Extreme El Niño Events (<https://doi.org/10.1002/2017GL075576>)
- 11,158** *Olivier Boucher, Christoph Kleinschmitt, and Gunnar Myhre*
Quasi-Additivity of the Radiative Effects of Marine Cloud Brightening and Stratospheric Sulfate Aerosol Injection (<https://doi.org/10.1002/2017GL074647>)
- 11,166** *C. Ole Wulff, Richard J. Greatbatch, Daniela I. V. Domeisen, Gereon Gollan, and Felicitas Hansen*
Tropical Forcing of the Summer East Atlantic Pattern (<https://doi.org/10.1002/2017GL075493>)
- 11,174** *C. L. da Silva, R. M. Millan, D. G. McGaw, C. T. Yu, A. S. Putter, J. LaBelle, and J. Dwyer*
Laboratory Measurements of X-Ray Emissions From Centimeter-Long Streamer Corona Discharges (<https://doi.org/10.1002/2017GL075262>)
- 11,184** *Wenju Cai, Guojian Wang, Agus Santoso, Xiaopei Lin, and Lixin Wu*
Definition of Extreme El Niño and Its Impact on Projected Increase in Extreme El Niño Frequency (<https://doi.org/10.1002/2017GL075635>)
- 11,191** *L. P. Babich*
Radiocarbon Production by Thunderstorms (<https://doi.org/10.1002/2017GL075131>)
- 11,201** *Paul D. Williams, M. Joan Alexander, Elizabeth A. Barnes, Amy H. Butler, Huw C. Davies, Chaim I. Garfinkel, Yochanan Kushnir, Todd P. Lane, Julie K. Lundquist, Olivia Martius, Ryan N. Maue, W. Richard Peltier, Kaoru Sato, Adam A. Scaife, and Chidong Zhang*
A Census of Atmospheric Variability From Seconds to Decades (<https://doi.org/10.1002/2017GL075483>)

RESEARCH LETTER

10.1002/2017GL075395

Key Points:

- Collisions between nanoscopic ice grains are explored using molecular dynamics simulations
- Collision-induced heating leads to grain melting in the interface of the colliding grains
- Collision dynamics is strongly influenced leading to grain sticking and deformation

Correspondence to:

H. M. Urbassek,
urbassek@rhrk.uni-kl.de

Citation:



Nietiadi, M. L., Umstätter, P., Alabd Alhafez, I., Rosandi, Y., Bringa, E. M., & Urbassek, H. M. (2017). Collision-induced melting in collisions of water ice nanograins: Strong deformations and prevention of bouncing. *Geophysical Research Letters*, 44. <https://doi.org/10.1002/2017GL075395>

Received 21 AUG 2017

Accepted 12 OCT 2017

Accepted article online 19 OCT 2017

Collision-Induced Melting in Collisions of Water Ice Nanograins: Strong Deformations and Prevention of Bouncing

Maureen L. Nietiadi¹, Philipp Umstätter¹, Iyad Alabd Alhafez¹, Yudi Rosandi² , Eduardo M. Bringa³, and Herbert M. Urbassek¹ 

¹Fachbereich Physik und Forschungszentrum OPTIMAS, Universität Kaiserslautern, Kaiserslautern, Germany, ²Department of Geophysics, Universitas Padjadjaran, Jatinangor, Sumedang, Indonesia, ³CONICET and Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Mendoza, Argentina

Abstract Collisions between ice grains are ubiquitous in the outer solar system. The mechanics of such collisions is traditionally described by the elastic contact theory of adhesive spheres. Here we use molecular dynamics simulations to study collisions between nanometer-sized amorphous water ice grains. We demonstrate that the collision-induced heating leads to grain melting in the interface of the colliding grains. The large lateral deformations and grain sticking induced considerably modify available macroscopic collision models. We report on systematic increases of the contact radius, strong grain deformations, and the prevention of grain bouncing.

1. Introduction

In the outer solar system, ice particles are ubiquitous (Gudipati & Castillo-Rogez, 2013); they appear as interplanetary dust particles (Grün, 2007; Tielens, 2005), in planetary rings (Esposito, 2010), and in the dust tails of comets (Bentley et al., 2016; Langevin et al., 2016). In the early history of the solar system, they contributed to the protoplanetary disk from which ultimately planets, moons, and other bodies of the solar system emerged (Blum, 2010; Birnstiel et al., 2016). Collisions between such particles may lead to particle agglomeration or fragmentation and thus determine their size distribution (Bridges et al., 1996; Dominik & Tielens, 1997). In addition, also silicate dust particles may be covered by an ice layer the properties of which will be relevant for the collision outcome.

The description of grain collisions is usually based on the contact mechanics of elastic adhesive bodies, such as the Johnson-Kendall-Roberts (JKR) theory (Johnson et al., 1971). For the case of macroscopic ice grains—in the range of millimeters or above—this approach allows to describe experimental data successfully (Bridges et al., 1996; Higa et al., 1998; Schäfer et al., 2007; Krijt et al., 2013).

Wettlaufer (2010) proposed that ice melting can drastically influence the collision dynamics of water ice grains. He focused on collisions of larger bodies, and of small grains with large, meter-sized bodies. He found that apart from the low-speed fusion and the higher-speed bouncing regimes, at even higher speed the collision partners may agglomerate again (so-called reentrant agglomeration regime) due to collisional melting or other solid-solid phase transformations that dissipate collisional energy. His results are relevant for the physics of the protoplanetary disk as a model to prevent the so-called accretion bottleneck (Armitage, 2010), which lets meter-sized agglomerates lose contact with the disk and spiral fast into the central star thus preventing planet formation; due to the collisional fusion mechanism, meter-sized agglomerates can grow fast enough to avoid this bottleneck.

Collisions between nanoscopic ice grains, on the other side, are relevant for the initial stages of grain growth in the protoplanetary disk beyond the snow line, where small grains may grow through collisional accretion to larger objects (Chokshi et al., 1993; Dominik & Tielens, 1997). Collisional melting and the suppression of the bouncing regime may result in a faster buildup of larger agglomerates.

Here we explore to what extent the collision of nanoscopic ice particles can be described by macroscopic contact theory. Using molecular dynamics (MD) simulation, we show that collision-induced heating may melt