

---

VOLUME 23 NUMBER 3



JULY 2010

---

# JOURNAL

OF THE

---

A M E R I C A N M A T H E M A T I C A L S O C I E T Y

---

## EDITORS

Weinan E  
Sergey Fomin  
Gregory Lawler  
Tom Mrowka  
Karl Rubin  
Terence Tao

## ASSOCIATE EDITORS

Noga Alon  
Alexei Borodin  
Robert L. Bryant  
Emmanuel Candes  
Sun-Yung Alice Chang  
Brian Conrad  
Pavel I. Etingof  
Mark Goresky  
Christopher Hacon  
Peter Kronheimer  
Elon Lindenstrauss  
Jacob Lurie  
Haynes R. Miller  
Assaf Naor  
Sorin T. Popa  
Thomas Scanlon  
Freydoon Shahidi  
Karen Vogtmann  
Avi Wigderson  
Lai-Sang Young

---

PROVIDENCE, RHODE ISLAND USA

ISSN 0894-0347

---

*Available electronically at*  
[www.ams.org/jams/](http://www.ams.org/jams/)

## Journal of the American Mathematical Society

This journal is devoted to research articles of the highest quality in all areas of pure and applied mathematics.

**Submission information.** See **Information for Authors** at the end of this issue.

**Publisher Item Identifier.** The Publisher Item Identifier (PII) appears at the top of the first page of each article published in this journal. This alphanumeric string of characters uniquely identifies each article and can be used for future cataloging, searching, and electronic retrieval.

**Postings to the AMS website.** Articles are posted to the AMS website individually after proof is returned from authors and before appearing in an issue.

**Subscription information.** The *Journal of the American Mathematical Society* is published quarterly. Beginning January 1996 the *Journal of the American Mathematical Society* is accessible from [www.ams.org/journals/](http://www.ams.org/journals/). Subscription prices for Volume 23 (2010) are as follows: for paper delivery, US\$313 list, US\$250 institutional member, US\$282 corporate member, US\$188 individual member; for electronic delivery, US\$282 list, US\$226 institutional member, US\$254 corporate member, US\$169 individual member. Upon request, subscribers to paper delivery of this journal are also entitled to receive electronic delivery. If ordering the paper version, add US\$19 for surface delivery outside the United States and India; US\$27 to India. Expedited delivery to destinations in North America is US\$30; elsewhere US\$57. Subscription renewals are subject to late fees. See [www.ams.org/customers/macsfac.html#journal](http://www.ams.org/customers/macsfac.html#journal) for more information.

**Back number information.** For back issues see [www.ams.org/bookstore](http://www.ams.org/bookstore).

Subscriptions and orders should be addressed to the American Mathematical Society, P.O. Box 845904, Boston, MA 02284-5904 USA. *All orders must be accompanied by payment.* Other correspondence should be addressed to 201 Charles Street, Providence, RI 02904-2294 USA.

**Copying and reprinting.** Material in this journal may be reproduced by any means for educational and scientific purposes without fee or permission with the exception of reproduction by services that collect fees for delivery of documents and provided that the customary acknowledgment of the source is given. This consent does not extend to other kinds of copying for general distribution, for advertising or promotional purposes, or for resale. Requests for permission for commercial use of material should be addressed to the Acquisitions Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. Requests can also be made by e-mail to [reprint-permission@ams.org](mailto:reprint-permission@ams.org).

Excluded from these provisions is material in articles for which the author holds copyright. In such cases, requests for permission to use or reprint should be addressed directly to the author(s). (Copyright ownership is indicated in the notice in the lower right-hand corner of the first page of each article.)

---

The *Journal of the American Mathematical Society* (ISSN 0894-0347) is published quarterly by the American Mathematical Society at 201 Charles Street, Providence, RI 02904-2294 USA and is mailed from Providence, Rhode Island. Periodicals postage is paid at Providence, Rhode Island. Postmaster: Send address changes to Journal of the AMS, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA.

© 2010 by the American Mathematical Society. All rights reserved.

This journal is indexed in *Mathematical Reviews*, *Zentralblatt MATH*, *Science Citation Index*<sup>®</sup>, *Science Citation Index*<sup>TM</sup>-*Expanded*, *ISI Alerting Services*<sup>SM</sup>, *CompuMath Citation Index*<sup>®</sup>, and *Current Contents*<sup>®</sup>/*Physical, Chemical & Earth Sciences*. This journal is archived in *Portico*.

Printed in the United States of America.

⊗ The paper used in this journal is acid-free and falls within the guidelines established to ensure permanence and durability.

JOURNAL OF THE AMERICAN MATHEMATICAL SOCIETY  
CONTENTS

Vol. 23, No. 3

July 2010

Benjamin Enriquez and Gilles Halbout, <a href="#">Quantization of quasi-Lie bialgebras</a> .....	611
Oleg Yu. Imanuvilov, Gunther Uhlmann, and Masahiro Yamamoto, <a href="#">The Calderón problem with partial data in two dimensions</a> .....	655
Alexander S. Merkurjev, <a href="#">Essential <math>p</math>-dimension of <math>\mathbf{PGL}(p^2)</math></a> .....	693
Hélène Esnault and Olivier Wittenberg, <a href="#">On abelian birational sections</a> .....	713
Minhyong Kim, <a href="#">Massey products for elliptic curves of rank 1</a> .....	725
Harm Derksen, Jerzy Weyman, and Andrei Zelevinsky, <a href="#">Quivers with potentials and their representations II: Applications to cluster algebras</a> .....	749
János Kollár and Sándor J Kovács, <a href="#">Log canonical singularities are Du Bois</a> .....	791
Bruce Kleiner, <a href="#">A new proof of Gromov's theorem on groups of polynomial growth</a> .....	815
Pietro Caputo, Thomas M. Liggett, and Thomas Richthammer, <a href="#">Proof of Aldous' spectral gap conjecture</a> .....	831
Valery A. Lunts and Dmitri O. Orlov, <a href="#">Uniqueness of enhancement for triangulated categories</a> .....	853

## Editors

Weinan E  
Department of Mathematics  
Fine Hall  
Princeton University  
Princeton, NJ 08544 USA  
weinan@math.princeton.edu

Sergey Fomin  
Department of Mathematics  
University of Michigan  
530 Church Street  
Ann Arbor, MI 48109-1043 USA  
fomin@umich.edu

Gregory Lawler  
Department of Mathematics  
University of Chicago  
5734 S. University Avenue  
Chicago, IL 60637 USA  
lawler@math.uchicago.edu

Tom Mrowka  
Department of Mathematics  
Massachusetts Institute of Technology  
77 Massachusetts Avenue, Room 2-367  
Cambridge, MA 02139-4307 USA  
mrowka@math.mit.edu

Karl Rubin  
Department of Mathematics  
University of California, Irvine  
Irvine, CA 92697-3875 USA  
krubin@math.uci.edu

Terence Tao  
Department of Mathematics  
University of California, Los Angeles  
405 Hilgard Avenue  
Los Angeles, CA 90095-1555 USA  
tao@math.ucla.edu

## Associate Editors

Noga Alon, Tel Aviv University, Israel  
Alexei Borodin, California Institute of Technology  
Robert L. Bryant, Duke University  
Emmanuel Candes, California Institute of Technology  
Sun-Yung Alice Chang, Princeton University  
Brian Conrad, Stanford University  
Pavel I. Etingof, Massachusetts Institute of Technology  
Mark Goresky, Institute for Advanced Study, Princeton  
Christopher Hacon, University of Utah  
Peter Kronheimer, Harvard University  
Elon Lindenstrauss, Princeton University  
Jacob Lurie, Massachusetts Institute of Technology  
Haynes R. Miller, Massachusetts Institute of Technology  
Assaf Naor, New York University, Courant Institute  
Sorin T. Popa, University of California, Los Angeles  
Thomas Scanlon, University of California, Berkeley  
Freydoon Shahidi, Purdue University  
Karen Vogtmann, Cornell University  
Avi Wigderson, Institute for Advanced Study, Princeton  
Lai-Sang Young, New York University–Courant Institute

## Assistant to the Editorial Board

Cheryl A. Cantore  
Princeton University  
133 East Pyne  
Princeton, NJ 08544 USA  
cheryl@princeton.edu

## Editorial Information

Information on the backlog for this journal can be found on the AMS website starting from <http://www.ams.org/jams>.

In an effort to make articles available as quickly as possible, articles are posted to the AMS website individually after proof is returned from authors and before appearing in an issue.

A Consent to Publish and Copyright Agreement is required before a paper will be published in this journal. After a paper is accepted for publication, the Providence office will send a Consent to Publish and Copyright Agreement to all authors of the paper. By submitting a paper to this journal, authors certify that the manuscript has not been submitted to nor is it under consideration for publication by another journal, conference proceedings, or similar publication.

### Information for Authors

**Initial submission.** The AMS uses Centralized Manuscript Processing for initial submission. Authors should submit a PDF file using the Initial Manuscript Submission form found at [www.ams.org/submission/jams](http://www.ams.org/submission/jams) or should send one copy of the manuscript to the following address: Centralized Manuscript Processing, JOURNAL OF THE AMS, 201 Charles Street, Providence, RI 02904-2294 USA. If a paper copy is being forwarded to the AMS, indicate that it is for the *Journal of the AMS* and include the name of the corresponding author, contact information such as email address or mailing address, and the name of an appropriate Editor to review the paper (see the list of Editors above).

The first page must contain a *descriptive title* that is short, but informative; useless or vague phrases such as “some remarks about” or “concerning” should be avoided. Although an abstract is not required upon initial submission, upon acceptance authors will be requested to supply an abstract for the electronic version of this journal. The AMS offers free worldwide access to the electronic abstracts. An abstract should be at least one complete sentence and at most 300 words. No abstracts appear in the printed journal starting in 1998. Included with the footnotes to the paper should be the 2010 *Mathematics Subject Classification* representing the primary and secondary subjects of the article. The classifications are accessible from [www.ams.org/msc/](http://www.ams.org/msc/). The Mathematics Subject Classification footnote may be followed by a list of *key words and phrases* describing the subject matter of the article and taken from it. Journal abbreviations used in bibliographies are listed in the latest *Mathematical Reviews* annual index. The series abbreviations are also accessible from [www.ams.org/msnhtml/serials.pdf](http://www.ams.org/msnhtml/serials.pdf). To help in preparing and verifying references, the AMS offers MR Lookup, a Reference Tool for Linking, at [www.ams.org/mrlookup/](http://www.ams.org/mrlookup/).

**Electronically prepared manuscripts.** The AMS encourages electronically prepared manuscripts, with a strong preference for  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$ . To this end, the Society has prepared  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  author packages for each AMS publication. Author packages include instructions for preparing electronic manuscripts, samples, and a style file that generates the particular design specifications of that publication series. Articles properly prepared using the  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  style file and the `\label` and `\ref` commands automatically enable extensive intra-document linking to the bibliography and other elements of the article for searching electronically on the Web. Because linking must often be added manually to electronically prepared manuscripts in other forms of  $\mathcal{T}\mathcal{E}\mathcal{X}$ , using  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  also reduces the amount of technical intervention once the files are received by the AMS. This results in fewer errors in processing and saves the author proofreading time.  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  papers also move more efficiently through the production stream, helping to minimize publishing costs.

$\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  is the highly preferred format of  $\mathcal{T}\mathcal{E}\mathcal{X}$ , but author packages are also available in  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{T}\mathcal{E}\mathcal{X}$ . Those authors who make use of these style files from the beginning of the writing process will further reduce their own efforts. Manuscripts prepared electronically in  $\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  or plain  $\mathcal{T}\mathcal{E}\mathcal{X}$  are normally not acceptable due to the high amount of technical time required to insure that the file will run properly through the AMS in-house production system.  $\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  users will find that  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-}\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  is the same as  $\mathcal{L}\mathcal{A}\mathcal{T}\mathcal{E}\mathcal{X}$  with additional

commands to simplify the typesetting of mathematics, and users of plain  $\text{T}_\text{E}\text{X}$  should have the foundation for learning  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-L}\text{A}\text{T}_\text{E}\text{X}$ .

Authors may retrieve an author package for *Journal of the AMS* starting from [www.ams.org/jams/jamsauthorpac.html](http://www.ams.org/jams/jamsauthorpac.html) or via FTP to [ftp.ams.org](ftp://ftp.ams.org) (login as `anonymous`, enter your complete email address as password, and type `cd pub/author-info`). The *AMS Author Handbook* and the *Instruction Manual* are available in PDF format from the author package link. The author package can also be obtained free of charge by sending email to [tech-support@ams.org](mailto:tech-support@ams.org) (Internet) or from the Publication Division, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. When requesting an author package, please specify  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-L}\text{A}\text{T}_\text{E}\text{X}$  or  $\mathcal{A}\mathcal{M}\mathcal{S}\text{-T}_\text{E}\text{X}$  and the publication in which your paper will appear. Please be sure to include your complete email address.

**After acceptance.** The source files for the final version of the electronic manuscript should be sent to the Providence office immediately after the paper has been accepted for publication. The author should also submit a PDF of the final version of the paper to the Editor, who will forward a copy to the Providence office. Accepted electronically prepared manuscripts can be submitted via the Web at [www.ams.org/submit-book-journal/](http://www.ams.org/submit-book-journal/), sent via email to [pub-submit@ams.org](mailto:pub-submit@ams.org) (Internet), or sent on diskette to the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. When sending a manuscript electronically via email or diskette, please be sure to include a message indicating in which publication the paper has been accepted. No corrections will be accepted electronically. Authors must mark their changes on their proof copies and return them to the Providence office. Complete instructions on how to send files are included in the author package.

**Electronic graphics.** Comprehensive instructions on preparing graphics are available from [www.ams.org/authors/journals.html](http://www.ams.org/authors/journals.html). A few of the major requirements are given here.

Submit files for graphics as EPS (Encapsulated PostScript) files. This includes graphics originated via a graphics application as well as scanned photographs or other computer-generated images. If this is not possible, TIFF files are acceptable as long as they can be opened in Adobe Photoshop or Illustrator.

Authors using graphics packages for the creation of electronic art should also avoid the use of any lines thinner than 0.5 points in width. Many graphics packages allow the user to specify a “hairline” for a very thin line. Hairlines often look acceptable when proofed on a typical laser printer. However, when produced on a high-resolution laser imagesetter, hairlines become nearly invisible and will be lost entirely in the final printing process.

Screens should be set to values between 15% and 85%. Screens which fall outside of this range are too light or too dark to print correctly. Variations of screens within a graphic should be no less than 10%.

**AMS policy on making changes to articles after posting.** Articles are posted to the AMS website individually after proof is returned from authors and before appearing in an issue. To preserve the integrity of electronically published articles, once an article is individually posted to the AMS website but not yet in an issue, changes cannot be made in place in the paper. However, an “Added after posting” section may be added to the paper right before the References when there is a critical error in the content of the paper. The “Added after posting” section gives the author an opportunity to correct this type of critical error before the article is put into an issue for printing and before it is then reposted with the issue. The “Added after posting” section remains a permanent part of the paper. The AMS does not keep author-related information, such as affiliation, current address, and email address, up to date after a paper is initially posted.

Once the article is assigned to an issue, even if the issue has not yet been posted to the AMS website corrections may be made to the paper by submitting a traditional errata article. The errata article will appear in a future print issue and will link back and forth on the Web to the original article online.

**Secure manuscript tracking on the Web.** Authors can track their manuscripts through the AMS journal production process using the personal AMS ID and Article ID printed in the upper right-hand corner of the Consent to Publish form sent to each author who publishes in AMS journals. Access to the tracking system is available from [www.ams.org/mstrack/](http://www.ams.org/mstrack/). An explanation of each production step is provided on the Web through links from the manuscript tracking screen. Questions can be sent to [jams-query@ams.org](mailto:jams-query@ams.org).

**T<sub>E</sub>X files available upon request.** T<sub>E</sub>X files are available upon request for authors by sending email to [file-request@ams.org](mailto:file-request@ams.org) or by contacting the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. The request should include the title of the paper, the name(s) of the author(s), the name of the publication in which the paper has or will appear, and the volume and issue numbers if known. The T<sub>E</sub>X file will be sent to the author making the request after the article goes to the printer. If the requestor can receive Internet email, please include the email address to which the file should be sent. Otherwise please indicate a diskette format and postal address to which a disk should be mailed. **Note:** Because T<sub>E</sub>X production at the AMS sometimes requires extra fonts and macros that are not yet publicly available, T<sub>E</sub>X files cannot be guaranteed to run through the author's version of T<sub>E</sub>X without errors. The AMS regrets that it cannot provide support to eliminate such errors in the author's T<sub>E</sub>X environment.

**Inquiries.** Any inquiries concerning a paper that has been accepted for publication that cannot be answered via the manuscript tracking system mentioned above should be sent to [jams-query@ams.org](mailto:jams-query@ams.org) or directly to the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA.

JOURNAL OF THE AMERICAN MATHEMATICAL SOCIETY  
CONTENTS

Vol. 23, No. 3

July 2010

Benjamin Enriquez and Gilles Halbout, <a href="#">Quantization of quasi-Lie bialgebras</a> .....	611
Oleg Yu. Imanuvilov, Gunther Uhlmann, and Masahiro Yamamoto, <a href="#">The Calderón problem with partial data in two dimensions</a> .....	655
Alexander S. Merkurjev, <a href="#">Essential <math>p</math>-dimension of <math>\mathrm{PGL}(p^2)</math></a> .....	693
Hélène Esnault and Olivier Wittenberg, <a href="#">On abelian birational sections</a> .....	713
Minhyong Kim, <a href="#">Massey products for elliptic curves of rank 1</a> .....	725
Harm Derksen, Jerzy Weyman, and Andrei Zelevinsky, <a href="#">Quivers with potentials and their representations II: Applications to cluster algebras</a> .....	749
János Kollár and Sándor J Kovács, <a href="#">Log canonical singularities are Du Bois</a> .....	791
Bruce Kleiner, <a href="#">A new proof of Gromov's theorem on groups of polynomial growth</a> .....	815
Pietro Caputo, Thomas M. Liggett, and Thomas Richthammer, <a href="#">Proof of Aldous' spectral gap conjecture</a> .....	831
Valery A. Lunts and Dmitri O. Orlov, <a href="#">Uniqueness of enhancement for triangulated categories</a> .....	853

Journal of the American Mathematical Society

VOLUME 23

NUMBER 3

PAGES 611-908

JULY 2010



0894-0347(201007)23:3;1-L