

# JOURNAL

# 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**

Brian Conrad Sergey Fomin Elon Lindenstrauss Tom Mrowka Assaf Naor Igor Rodnianski

## **ASSOCIATE EDITORS**

Noga Alon Denis Auroux Andrea Bertozzi Roman Bezrukavnikov Alexei Borodin **Emmanuel Candes** Sun-Yung Alice Chang Henry Cohn Christopher Hacon Lars Hesselholt Mikhail Khovanov Gregory Lawler William P. Minicozzi II Maryam Mirzakhani Sorin T. Popa Peter Sarnak **Thomas Scanlon** Freydoon Shahidi Karen Vogtmann Avi Wigderson

## PROVIDENCE, RHODE ISLAND USA

ISSN 0894-0347 (print) ISSN 1088-6834 (online)

Available electronically at 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.

**Publication on the AMS website.** Articles are published on 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 and is also accessible electronically from www.ams.org/journals/. Subscription prices for Volume 28 (2015) are as follows: for paper delivery, US\$380 list, US\$304 institutional member, US\$342 corporate member, US\$228 individual member; for electronic delivery, US\$334 list, US\$267.20 institutional member, US\$300.60 corporate member, US\$200.40 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\$5 for delivery within the United States; US\$19 for surface delivery outside the United States. Subscription renewals are subject to late fees. See www.ams.org/journal-faq for more journal subscription information.

Back number information. For back issues see 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.** Individual readers of this publication, and nonprofit libraries acting for them, are permitted to make fair use of the material, such as to copy an article for use in teaching or research. Permission is granted to quote brief passages from this publication in reviews, provided the customary acknowledgment of the source is given.

Republication, systematic copying, or multiple reproduction of any material in this publication is permitted only under license from the American Mathematical Society. Permissions to reuse portions of AMS publication content are handled by Copyright Clearance Center's RightsLink<sup>®</sup> service. For more information, please visit: http://www.ams.org/rightslink.

Translation rights and licensed reprint requests should be sent to reprint-permission @ams.org.

Excluded from these provisions is material for which the author holds copyright. In such cases, requests for permission to reuse or reprint material 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.

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

10 9 8 7 6 5 4 3 2 1 20 19 18 17 16 15

The Journal of the American Mathematical Society (ISSN 0894-0347 (print); ISSN 1088-6834 (online)) 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.

<sup>© 2015</sup> 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* and in *CLOCKSS.* 

Printed in the United States of America.

# JOURNAL OF THE AMERICAN MATHEMATICAL SOCIETY CONTENTS

April 2015

Vol. 28, No. 2

# Semyon Dyatlov, Resonance projectors and asymptotics for r-normally hyperbolic trapped sets 311 Danny Calegari and Alden Walker, Random groups contain surface subgroups 383 David Bate, Structure of measures in Lipschitz differentiability spaces 421 Steve Hofmann, Carlos Kenig, Svitlana Mayboroda, and Jill Pipher, Square function/non-tangential maximal function estimates and the Dirichlet problem for non-symmetric elliptic operators 483 Amir Mohammadi and Hee Oh, Ergodicity of unipotent flows and Kleinian groups 531

Artur	Avila.	On the	Kotani-Last	and	Schrödinger	conjectures	 579
muun .		On one	HOULIN Last	and	Semounger	conjectures	 010

## Editors

Brian Conrad Department of Mathematics Stanford University 450 Serra Mall Building 380 Stanford, CA 94305-2021 USA conrad@math.stanford.edu

Elon Lindenstrauss Einstein Institute of Mathematics, Givat Ram The Hebrew University of Jerusalem Jerusalem, 91904, Israel elon@math.huji.ac.il

Assaf Naor New York University-Courant Institute Warren Weaver Hall 1305 251 Mercer Street New York, NY 10012, USA naor@cims.nyu.edu Sergey Fomin Department of Mathematics University of Michigan 530 Church Street Ann Arbor, MI 48109-1043 USA fomin@umich.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

Igor Rodnianski Department of Mathematics Massachusetts Institute of Technology 77 Massachusetts Avenue, Room 2–249 Cambridge, MA 02139-4307 USA irod@math.mit.edu

## Associate Editors

Noga Alon, Tel Aviv University, Israel Denis Auroux, University of California, Berkeley Andrea Bertozzi, University of California, Los Angeles Roman Bezrukavnikov, Massachusetts Institute of Technology Alexei Borodin, Massachusetts Institute of Technology Emmanuel Candes, California Institute of Technology Sun-Yung Alice Chang, Princeton University Henry Cohn, Microsoft Research New England Christopher Hacon, University of Utah Lars Hesselholt, Nagoya University Mikhail Khovanov, Columbia University Gregory F. Lawler, University of Chicago William P. Minicozzi II, Johns Hopkins University Maryam Mirzakhani, Stanford University Sorin T. Popa, University of California, Los Angeles Peter Sarnak, The Institute for Advanced Study and Princeton University Thomas Scanlon, University of California, Berkeley Freydoon Shahidi, Purdue University Karen Vogtmann, Cornell University Avi Wigderson, Institute for Advanced Study, Princeton

## **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 electronically published on the AMS website individually after proof is returned from authors and before appearing in an issue. A Consent to Publish is required before we can begin processing your paper. 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. All articles submitted to this journal are peer-reviewed. The AMS has a single blind peer-review process in which the reviewers know who the authors of the manuscript are, but the authors do not have access to the information on who the peer reviewers are. 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 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/. 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/msntml/serials.pdf. To help in preparing and verifying references, the AMS offers MR Lookup, a Reference Tool for Linking, at www.ams.org/mrlookup/.

Electronically prepared manuscripts. Manuscripts should be electronically prepared in  $\mathcal{A}_{\mathcal{M}}S$ -IAT<sub>E</sub>X. To this end, the Society has prepared  $\mathcal{A}_{\mathcal{M}}S$ -IAT<sub>E</sub>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  $\mathcal{A}_{\mathcal{M}}S$ -IAT<sub>E</sub>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.

Authors may retrieve an author package for Journal of the AMS starting from www.ams.org/jams/jamsauthorpac.html or via FTP to 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 or from the Publication Division, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. When requesting an author package, please specify 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/, sent via email to pub-submit@ams.org, or sent on CD to the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA.

When sending a manuscript electronically via email or CD, please be sure to include a message indicating in which publication the paper has been accepted. 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. 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 computergenerated 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%.

Any graphics created in color will be rendered in grayscale for the printed version unless color printing is authorized by the Managing Editor and the Publisher. In general, color graphics will appear in color in the online version.

AMS policy on making changes to articles after publication. Articles are published on 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 published to the AMS website, changes cannot be made in place in 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 electronically published.

Corrections of critical errors may be made to the paper by submitting an errata article to the Editor. The errata article will be published electronically, will appear in a future print issue, and will link back and forth on the Web with the original article.

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/. 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.

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 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.	28,	No.	<b>2</b>
------	-----	-----	----------

## April 2015

Semyon Dyatlov, Resonance projectors and asymptotics for <i>r</i> -normally	
hyperbolic trapped sets	311
Danny Calegari and Alden Walker, Random groups contain surface	
subgroups	383
David Bate, Structure of measures in Lipschitz differentiability spaces	421
Steve Hofmann, Carlos Kenig, Svitlana Mayboroda, and Jill Pipher,	
Square function/non-tangential maximal function estimates and the	
Dirichlet problem for non-symmetric elliptic operators	483
Amir Mohammadi and Hee Oh, Ergodicity of unipotent flows and	
Kleinian groups	531
Artur Avila, On the Kotani-Last and Schrödinger conjectures	579

