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Mathematical Sciences Research Institute

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Mathematical Problems in Fluid Dynamics

Mihaela Ifrim, Daniel Tataru, and Igor Kukavica

The exploration of the mathematical foundations of fluid dynamics began early on in human history. The study of the behavior of fluids dates back to Archimedes, who discovered that any body immersed in a liquid receives a vertical upward thrust, which is equal to the weight of the displaced liquid. Later, Leonardo Da Vinci was fascinated by turbulence, another key feature of fluid flows.

But the first advances in the analysis of fluids date from the beginning of the eighteenth century with the birth of differential calculus, which revolutionized the mathematical understanding of the movement of bodies, solids, and fluids. The discovery of the governing equations for the motion of fluids goes back to Euler in 1757; further progress in the nineteenth century was due to Navier and later Stokes, who explored the role of viscosity. In the middle of the twentieth century, Kolmogorov's theory of turbulence was another turning point, as it set future directions in the exploration of fluids. More complex geophysical models incorporating temperature, salinity, and rotation appeared subsequently, and they play a role in weather prediction and climate modeling.

Nowadays, the field of mathematical fluid dynamics is one of the key areas of partial differential equations and has been the focus of extensive research over the years. It is perhaps one of the most challenging and

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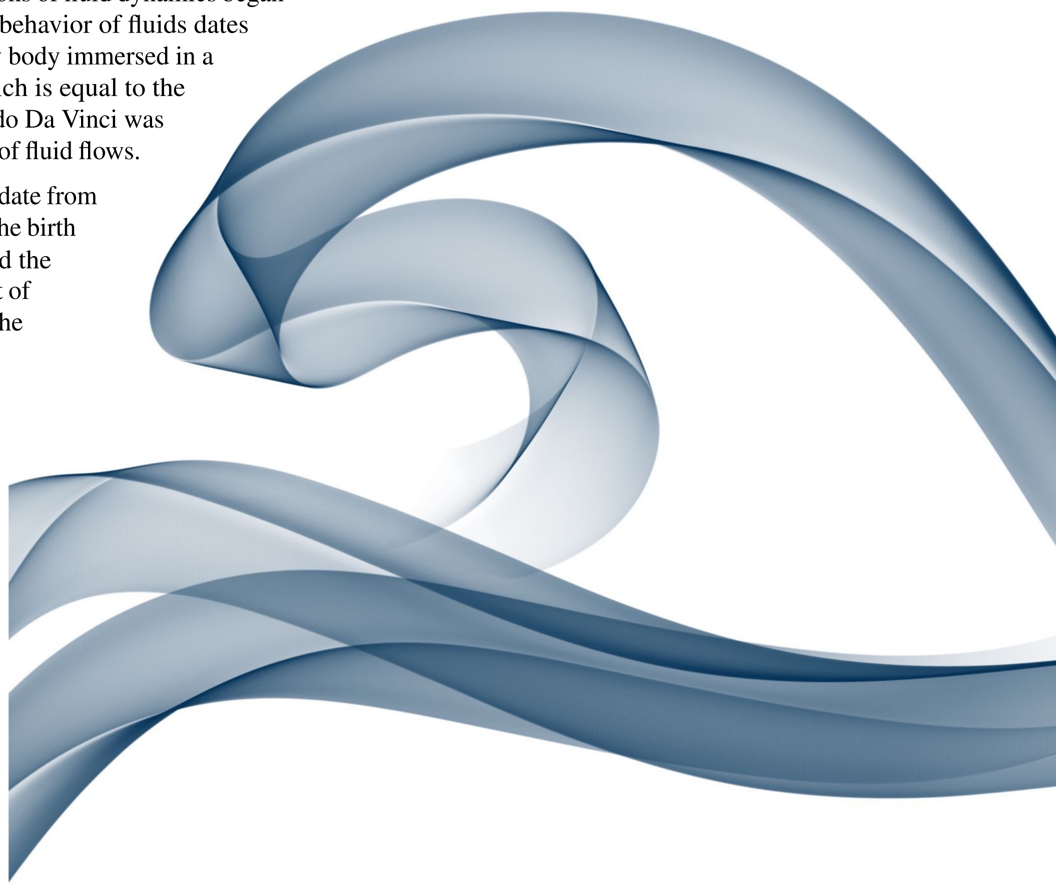
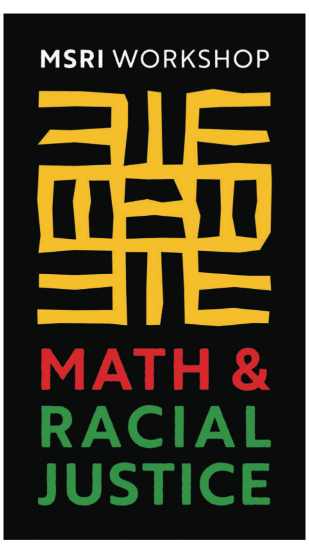


Wave overturning, artistic image by E. Ifrim



MSRI Workshop on Mathematics & Racial Justice

On June 9–11 & June 16–18, 2021, MSRI will host an online workshop to explore the role that mathematics plays in today's movement for racial justice. The workshop will bring together mathematicians, statisticians, computer scientists, and STEM educators as well as members of the general public interested in using the tools of these disciplines to critically examine and eradicate racial disparities in society, and will include sessions on Bias in Algorithms and Technology; Fair Division, Allocation, and Representation; Public Health Disparities; and Racial Inequities in Mathematics Education.

A full description, including the organizers and sponsors, as well as how to register, is on the back cover (page 16) and also available at msri.org/workshops/1012.

The Passing of Isadore Singer

On February 11, we received the sad news that one of MSRI's co-founders, Isadore Singer, had died at age 96. Singer led MSRI's first Scientific Advisory Committee and firmly established its traditions and its primacy in determining MSRI's scientific programs. You can read more about Isadore Singer's legacy in the View from MSRI on page 2.

The View from MSRI

David Eisenbud, Director

Currently all-virtual, MSRI, continues to be active. The spring jumbo (= double-size) program on Mathematical Problems in Fluid Dynamics is off to a good start as reported elsewhere in this newsletter. We're planning for six virtual Graduate Summer Schools this year, and an extraordinary 15 for the summer of 2022 — the most we've ever run.

There's lots more! We'll host a Hot Topics workshop on **Topological Insights in Neuroscience** May 3–11. The National Math Festival, which has been running online events all semester, will climax this April (see page 9 for an update). In June, we'll host a workshop on **Mathematics and Racial Justice**, with topics such as bias in algorithms and public health disparities. The summer undergraduate research program MSRI-UP, serving (mostly) minority students, will study the combinatorics of **Parking Functions**. The program has been amazingly successful in mentoring students into graduate school. One of them, Vanessa Sun, just tweeted: "Happy to announce I'll be at MIT Lincoln Lab this fall doing a data analysis/modeling internship on the Air Traffic Control Systems team. All my thanks to my MSRI-UP family." Our newest summer program, **ADJOINT** (for groups composed mostly of Black mathematicians) continues as well.

The prize MSRI gives jointly with the Chicago Mercantile Exchange (tinyurl.com/cme-msri) was awarded this year to Daron Acemoglu of MIT (see page 10). Last year's prize went to Stanford economist Susan Athey, and the ceremony featured a wonderfully warm and sympathetic interview of Susan by Paul Milgrom (also a recent winner of our prize, and now Nobelist) — it's worth watching and available at vimeo.com/526329241.

Journeys of Black Mathematicians

Other activities are new: for example, George Csicsery is known for films about mathematicians (***N is a Number*** about Paul Erdős was the first, ***Secrets of the Surface*** about Maryam Mirzakhani the most recent — stream them at ZalaFilms.com). With generous support from the Simons Foundation and several MSRI Trustees, George has begun work on a film about the contributions and careers of Black mathematicians in America. It will ultimately focus on young people getting into the field, but will include stories of now-elderly researchers. While waiting for the pandemic to pass, George has been collecting interviews with some of these influential older figures, such as Professors Virginia Newell (lively at 103!) and Scott Williams.

Brady Haran and Numberphile

Brady was awarded the **Order of Australia** for his spectacularly successful work in science — and especially math — journalism. Brady's YouTube channel **Numberphile** is without doubt MSRI's best investment in the public understanding of mathematics. With a subscriber base well over three million and 500 million total "views," the channel charms and inspires audiences from grade school to adult mathematicians like me. Last year Brady added a Numberphile podcast — hour-long interviews across the spectrum from math education and popularization to applied math and the professorate. Two of my favorites are with Roger Penrose and Cliff Stoll; check them out!

Congressional Briefings

Maybe it's quixotic? With the AMS we run twice-yearly **Congressional Briefings** to help Congress — the largest US funder of math and science — understand the importance of what we do. Most recently we had to cancel a talk by Cynthia Dwork on "**Differential Privacy**," an elegant mathematical definition of privacy and a method — indeed the only method known — of guaranteeing it. The census this year is using it but, because not everyone "speaks" mathematics, some congressional offices were nervous. Instead of the public Briefing, Karen Saxe (from the AMS) and I digitally escorted Cynthia to speak to a number of congressional staffers. Did we succeed? I think they know more than before…

The Passing of Isadore Singer

MSRI was founded by a triumvirate: **Isadore Singer** and **Calvin (Cal) Moore** recruited **Shiing-Shen Chern**, who had already retired from Berkeley, to be the first Director. Moore became Deputy Director and, among other contributions, organized the administration, the relationship with Berkeley, and the placement, conception and construction of MSRI's building.

Singer led the Scientific Advisory Committee (SAC), and firmly established its traditions and its primacy — advisory in name only, the SAC still exercises the power to determine MSRI's scientific Programs and choose the members. Chern, who always modestly claimed that he did nothing, used his influence and contacts to propel MSRI rapidly to prominence. Chern died in 2004, at 93, and on February 11 we received the sad news that Singer had died, at 96. I'm happy to say that Moore is doing well, at a mere 84.

When I first came to MSRI in 1997 I had the privilege of being mentored, in different ways, by all three. Singer, in particular, was then (again) an MSRI Trustee, and took great interest in seeing that basic research stayed at the forefront of the institute's concerns. Singer knew that private fundraising would help MSRI achieve its potential, and asked Jim Simons for what may have been the very first private donation. Simons likes to complain that, almost as soon as he made the donation, Singer left to go to MIT! However, Singer clearly enjoyed returning: MSRI architect Bill Glass told me that he never saw Is without a smile on his face. MSRI Trustee Dan Freed, a former student of Singer's, shared his reflections in a recent *Quanta Magazine* column.

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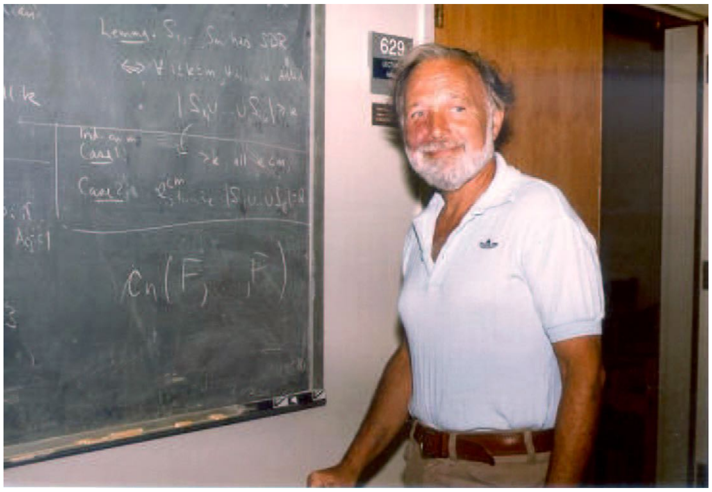


Isadore Singer at MSRI's temporary headquarters in the early 1980s.

Mentoring

My postdoc mentor at Brandeis, David Buchsbaum, also died this year, and I reflected on how lucky I've been with mentors over my whole career, and what a difference that has made for me. I'm proud that MSRI takes the mentoring of postdocs and others very seriously, and has over the years developed a more and more systematic approach, which seems to be highly appreciated. We have been able to preserve our mentoring tradition even in this pandemic, though our postdocs and their mentors are scattered around the globe. You might also be interested in **The Science of Mentoring**, which will be the topic for the 2022 Critical Issues in Mathematics Education workshop.

The Future

Absolute things are easy, though they may be painful. When we learned last March 7 that we would save lives by moving all of MSRI to the virtual world, we acted decisively. Now, as people are slowly being vaccinated, we look forward to welcoming people to our building again! But this poses its own problems. For example:

There are good reasons to keep some of what has changed. Travel to a 1-week workshop leaves a big carbon footprint (airprint?); it's expensive; jetlag can spoil the experience; airplanes and hotels are uncomfortable; spouses and sometimes children at home may be impacted. On the positive side, online workshops can address many more people, and indeed two of our recent workshops had the largest attendance numbers of any MSRI scientific workshop so far! In the survey after one of these a large fraction of respondents said that they preferred the online experience.

On the other hand, at a recent online seminar I outlined these ideas and then asked participants: "Would you travel?" The answer, loud and clear: "We're ready to go!" The benefits of informal contacts in the halls, at teas, at dinner with a few colleagues, . . . are clearly enormous.

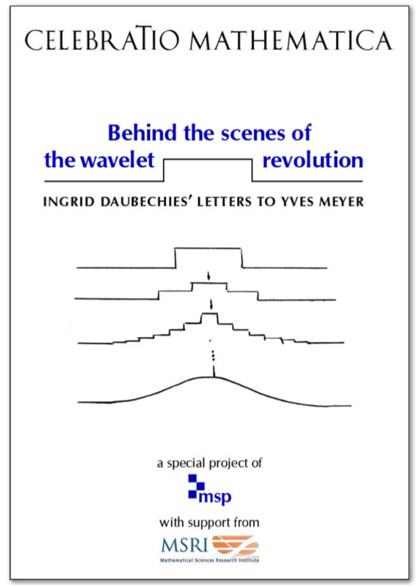
These dual inclinations pose a difficult problem: how to prioritize the experience of different groups. A workshop where Zoom breakout rooms substitute for teas might put the distant participants on a more even footing with those present in person . . . but the latter group might lose. Technology can help; who would have believed a few years ago how well Zoom and similar tools would work today? But the technology is still developing. Should we invest now . . . or wait and invest later?

Whatever the right answers, we believe mathematicians will continue to seek the riches of an in-person visit to MSRI when they can; and we look forward to welcoming YOU to some future program!

MSRI and Celebratio Mathematica *proudly present:*

Ingrid Daubechies' Letters to Yves Meyer

MSRI is pleased to announce publication on *Celebratio Mathematica* (celebratio.org) of the correspondence of Ingrid Daubechies to Yves Meyer, a collection of 17 letters spanning the years 1985–2002. This special project is part of a series of MSRI-sponsored volumes on the *Celebratio* archive about women mathematicians, and brings to light the development of ideas that led to Ingrid Daubechies' remarkable achievement of the mid- to late-80s: the construction of smooth orthogonal wavelets of compact support.



Readers can access the letters in the original French, as well as in English translation, on the *Celebratio* website (celebratio.org/Daubechies_I/articleset/15/); it is also available as a stand-alone PDF booklet on the same page. Scans of the holograph originals can also be viewed directly on *Celebratio* in conjunction with the typeset texts (links to these scans are provided in the booklet, as well).

Yves Meyer provides an introduction that covers the intellectual background of Daubechies' work on wavelet theory and explains the context of the letters in their complete chronology.

While you're at the *Celebratio* website, we invite you to peruse the other MSRI-sponsored volumes selected by members of MSRI's Committee on Women in Mathematics, where you can read original interviews, previously unpublished correspondence, and more:

Joan Birman: celebratio.org/Birman_JS
Dusa McDuff: celebratio.org/McDuff_D
Cathleen Morawetz: celebratio.org/Morawetz_CS
Karen Uhlenbeck: celebratio.org/Uhlenbeck_K

Celebratio Mathematica is a public-interest project of Mathematical Sciences Publishers (msp.org), a non-profit scientific publisher based in Berkeley, Cailfornia.

Mathematical Problems in Fluid Dynamics

(continued from page 1)

exciting fields of scientific pursuit simply because of the complexity of the subject and the endless breadth of applications. Far from being a monolithic field, many active areas in the field of fluid dynamics have emerged over time as a response to the natural need to understand the multitude of associated phenomena and relevant applications.

The connections between fluid dynamics and other fields of mathematics are numerous, including microlocal analysis, harmonic analysis, integrable systems, geometry, and dispersive PDEs. The last few years in particular have brought a renewed interest in the subject and some major developments in several areas, such as water waves, Euler flows, and the Navier–Stokes equations.

The Incompressible Euler Equations

The incompressible Euler equations,

$$\begin{cases} u_t + u \cdot \nabla u + \nabla p = 0 \\ \operatorname{div} u = 0, \end{cases}$$

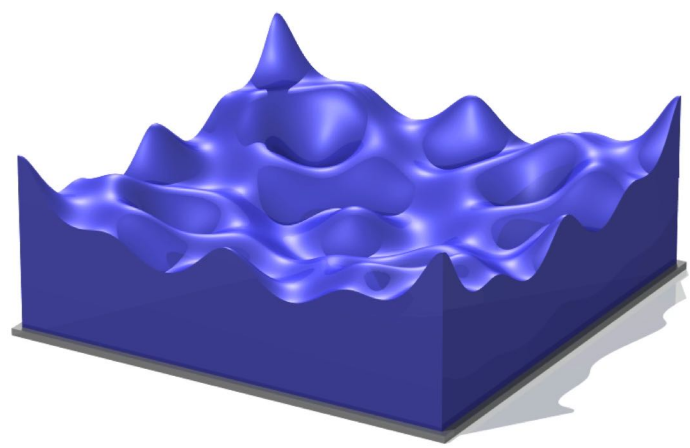
where the vector-valued function $u(x,t)$ is the velocity and the scalar-valued function $p(x,t)$ is the pressure, model the motion of an inviscid fluid with constant density and are thus of fundamental importance in fluid dynamics. The vorticity $\omega = \operatorname{curl} v$ is another key element of the problem, which measures the instantaneous rotation of the fluid.

Even though this is one of the first studied PDEs, it has proven to be mathematically extremely challenging to study. For instance, the global existence of smooth solutions for smooth initial data in 3D is one of the most investigated open problems in PDEs. However, there has been a surge of new results in the area during the recent decade, answering some long-standing open problems and introducing new powerful techniques. This in turn guarantees increased mathematical activity in the immediate future. The main outstanding questions in the mathematical theory of the Euler equations are the questions of global regularity, energy conservation, the inviscid limit problem, long time behavior, inviscid damping, and free-interface problems.

The global regularity problem is perhaps the main open question. In 3D, the Beale–Kato–Majda criterion provides an integral condition for breakdown of solutions, while the Constantin–Fefferman–Majda criterion provides a geometric-type sufficient condition involving the regularity of the vorticity direction. A numerical experiment by Kerr hinted at growth of the oscillation of the vorticity direction, but the question of blow-up/no blow-up remained open. It is widely believed that the blow-up result is in sight and that the recently developed methods will be helpful in this pursuit. In particular, one may expect a blow-up result of the axisymmetric 3D Euler equations along these lines.

On the other hand, it has been known since the 1960s that the 2D Euler equations have a global solution when the initial data belong to the Yudovich class; that is, the vorticity is bounded and integrable. When the data are more regular, it is known that all the Sobolev norms remain finite, while the best known upper bounds for them are double-exponential in time. It remains an open problem whether this bound is sharp — that is, it is not known if the upper bound can be improved or one can construct a rapidly growing solution. This problem may be related to the 3D regularity question, as indicated above.

Recently, there has been substantial progress in the area of energy conservation for the Euler equations, driven by Gromov's convex integration method. Motivated by the idea of energy cascade (that is, the transfer of energy from low to high modes), it was deduced from Onsager's work that the $1/3$ Hölder continuity should provide a natural threshold for energy conservation. After intense study in recent years, this conjecture was recently resolved. However, this seems to be only the start of an exciting direction of research, as implications for turbulence, regularity of solutions, and other aspects of the Euler equations remain to be investigated.



A three-dimensional fully nonlinear standing water wave obtained by combining two simpler standing waves with periods related by a factor of three and optimizing the initial condition to enforce time periodicity. By J. Wilkening

The Incompressible Navier–Stokes Equations

The inclusion of friction in the Euler equations, modeled by the Laplacian and a coefficient of kinematic viscosity $\nu > 0$, leads to the incompressible Navier–Stokes equations,

$$\begin{cases} u_t + u \cdot \nabla u + \nabla p = \nu \Delta u \\ \operatorname{div} u = 0. \end{cases}$$

To better understand the relation between the Navier–Stokes and the Euler equations, we recall some dimensional observations. These begin with the Reynolds number Re, a dimensionless parameter which is inversely proportional to the kinematic viscosity ν. One might hope that, in a well-chosen regime, we can neglect the viscous term $\nu\Delta u$ in the Navier-Stokes equations in comparison with the inertial term $u \cdot \nabla u$ when the Reynolds number is sufficiently large.

The Navier–Stokes equations are, however, a singular perturbation of the Euler equations, since the viscosity ν multiplies the term that contains the highest-order spatial derivatives. As a result, the zero-viscosity or high-Reynolds number limit of the Navier–Stokes equations is an important problem, with implications in turbulence theory.

In his seminal work in 1933, Leray proved that any finite energy initial data (meaning square-integrable data) gives rise to a global-in-time weak solution that satisfies an energy estimate. The fact that the space $L^2(\mathbb{R}^2)$ is scale invariant under the natural scaling $u_\lambda(t,x) = \lambda u(\lambda^2 t, \lambda x)$ also allowed Leray to establish the uniqueness of the solution in two space dimensions. In dimension three, the uniqueness of Leray's weak solutions remains an open problem. Also, despite all the current efforts, the main problem in mathematical fluid dynamics, namely that of large data global well-posedness for the three dimensional Navier–Stokes problem, is still open.

Naturally, all the progress in the study of fluids is intimately linked to advancement of analytical methods. The techniques that played a fundamental role in the numerous contributions include paradifferential calculus, microlocal analysis, wavelets theory, the development of numerical tools, and recently concentration-compactness methods, namely profile decompositions. However, several problems are still unsolved; among these problems, one can mention the different relevant notions of solutions, existence, uniqueness, stability results, blow-up criteria, and the description of their long-time behavior in the case of global existence. The question of possible blow up in finite time of solutions in dimension three is one of the Millennium Prize Problems in mathematics.

Geophysical models, which are used in oceanography and meteorology, involve additional features, such as the Coriolis force, stratification, and large-scale motion. Also, viscosity may vary in different directions, creating asymmetry, and additional parameters, such as the Rossby number, come into play. There have been several important and surprising results on the regularity of geophysical models, such as regularization due to fast rotation and global regularity for the primitive equations of the atmosphere and the ocean. Although a very abundant mathematical and physical literature covers this subject, many regularity and qualitative problems are still open.

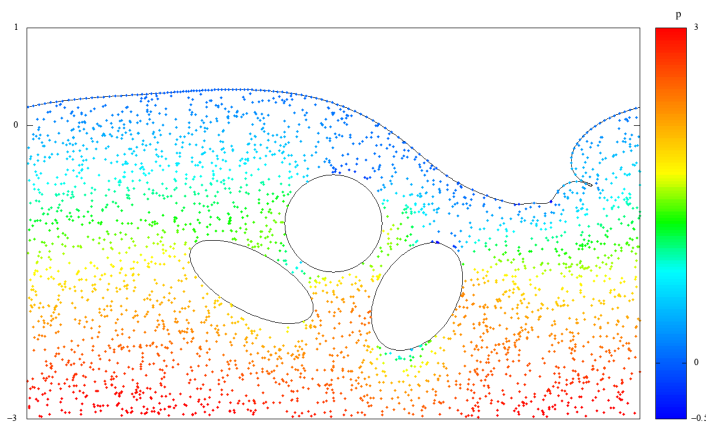
On the other hand, the quasi-geostrophic equation has been proposed as a simplified model for the fluid equations in shallow water (for example, in oceans). Many important results have been proved for this model, including global regularity in the critical case and large-time regularity in the supercritical case. However, the global regularity question remains unanswered in the supercritical regime as well as for the inviscid problem.

In recent years, the field of fluid-structure interaction (FSI) also experienced a large increase in activity. In its basic form, FSI describes motion of an elastic or a solid body immersed in a fluid. The basic questions of local and global existence, as well as the qualitative behavior of solutions, are challenging due to the increased complexity compared to systems involving only fluids, to coupling of equations of different types, and to the presence of an evolving boundary. Such systems are prevalent in nature, and the understanding of their behavior is important in science, engineering, and medicine.

Water Waves and Models

Water waves are interesting physical phenomena that connect to almost every aspect of life on the planet. The interest in the subject came long before appropriate mathematical tools to analyze them were available. The middle of the nineteenth century highlights the beginning of the modern water wave theory, and it has as a central masterpiece the work of Stokes. During that same period, more useful models were developed, and much of it came as a result of observational activities of scientists at that time (for example, Stokes, Russell, Boussinesq, and Saint-Venant). As a consequence, the mathematical world became richer in models that now carry names such as tidal waves, solitary waves, rogue waves, the Korteweg–De Vries (KdV) equation, intermediate long waves, the Boussinesq models for shallow water waves, the Kelvin–Helmholtz instability, Stokes' model for the highest wave, Kelvin's model for ship wakes, and tsunamis.

Overall, there is a wide range of problems that fall under the heading of water waves, depending on a number of assumptions: surface tension, gravity, finite depth, infinite depth, wind, etc., and combinations thereof.



Ideal flow around three elliptical obstacles shortly before the free surface folds over and collides with itself in a splash singularity. By J. Wilkening

The underlying equations for water waves are the incompressible Euler equations, but with a key simplification added. Specifically, under the assumption of either irrotationality or constant vorticity (in 2D), such problems reduce to equations of motion for the free surface of the fluid; this was first observed by Zakharov about 50 years ago.

We briefly describe the equations that serve as background for these problems. As written below, they assume infinite depth and both gravity and surface tension, but they have suitable counterparts in other interesting physical frameworks. The water domain at time t is denoted by $\Omega(t)$, with boundary $\Gamma(t)$ representing the water surface at time t.

The fluid velocity is denoted by u and the pressure by p. Then u solves the Euler equations inside $\Omega(t)$,

$$\begin{cases} u_t + u \cdot \nabla u + \nabla p = -g\mathbf{j} \\ \operatorname{div} u = 0 \\ u(0,x) = u_0(x), \end{cases}$$

while on the free boundary one has the dynamic boundary condition

$$p = -2\sigma\mathbf{H} \text{ on } \Gamma(t),$$

and the kinematic boundary condition

$$\partial_t + u\cdot\nabla \text{ is tangent to } \bigcup_t \Gamma(t).$$

Here $\mathbf{H}$ is the mean curvature of the boundary, σ represents the surface tension, g is the gravity, and $\mathbf{j}$ is the unit vector pointing upward in the vertical direction.

Under the additional assumption that the flow is irrotational, one can write u in terms of a velocity potential ϕ as $u = \nabla\phi$, where ϕ is harmonic in $\Omega(t)$, with appropriate decay at infinity. Thus ϕ is determined by its trace on the free boundary $\Gamma(t)$. Denote by η the height of the water surface as a function of the horizontal coordinate. Following Zakharov's formulation, one introduces $\psi = \psi(t,x)$ to be the trace of the velocity potential ϕ on the boundary, $\psi(t,x) = \phi(t,x,\eta(t,x))$. Then the dynamics can be described as the evolution of the pair of variables (η,ψ):

$$\begin{cases}\partial_t\eta - G(\eta)\psi = 0\\[1ex] \partial_t\psi + g\eta - \sigma\mathbf{H}(\eta) + \dfrac{1}{2}|\nabla_x\psi|^2 - \dfrac{1}{2}\dfrac{(\nabla_x\eta\cdot\nabla_x\psi + G(\eta)\psi)^2}{1+|\nabla_x\eta|^2} = 0,\end{cases}$$

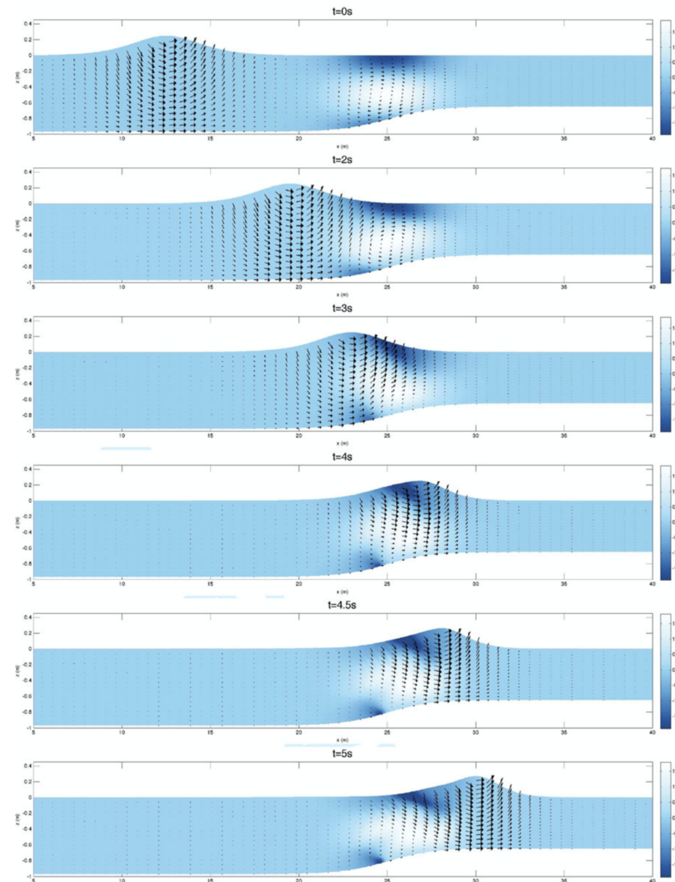
where G represents the Dirichlet to Neumann map associated to the fluid domain. This is the *Eulerian formulation* of the gravity capillary water wave equations, expressed as an evolution of the free interface. Over the years many other formulations were used to study this problem; indeed, one can view the parametrization of the free boundary as a form of gauge freedom. The *Lagrangian formulation* is another traditional framework. In 2D we also have the *conformal coordinates*, or the *arc-length formulations*, which all turned out to be very useful!

Depending on the scale we consider, water wave phenomena can be described by different sets of equations capturing different aspects of nature. At smaller length scales, surface-tension-driven ripples affect remote sensing of underwater obstacles. At intermediate length scales, waves in the mid-ocean affect shipping, and near the shoreline they influence the coastal morphology (and hence the ability to navigate along shore). At larger length scales, waves such as tsunamis and hurricane-generated waves can cause devastation on a global scale. Across all length scales, an exchange of momentum and thermal energy between ocean and atmosphere occurs, affecting the global weather system and the global climate.

From a mathematical viewpoint, water waves pose rich and interesting challenges. The first is of course the local well-posedness question. Many results are already known here, though open questions still remain. Once the existence question gets a positive answer, the next step is to understand the long time dynamics of the solutions.

On one hand, not all water waves exist globally. As everyone knows, splash-like singularities do occur in real life, and have also been recently proved to exist mathematically. There is, however, no breaking or overturning criterion that would allow one to predict the occurrence and the location of wave breaking or overturning in terms of the properties of the initial data, as one can do for simpler model equations such as the Burgers or Camassa–Holm equations. Another interesting question is to understand the singularities which might form at the wave crest where no overturning occurs. Is this possible? Despite intense work, this question remains largely open. Currently, we have a number of examples of waves where an angular crest propagates in time, but no examples at all where an angular crest forms from smooth data.

On the other hand, suppose that we are looking at water waves with small initial data, say of size $\epsilon \ll 1$. What can we say then about the lifespan of the solutions, as a function of ϵ? An optimal result would precisely capture the fact that at a certain point in time the solution's behavior changes. A quadratic lifespan (ϵ^{-1}) is trivial, while a cubic lifespan bound (ϵ^{-2}) requires a delicate normal form type analysis in the quasilinear context. A definitive answer is still elusive, and will very likely depend on the specific problem which is being considered.



Water wave propagation over nontrivial topography and vorticity, by D. Lannes

Finally, one may also ask whether global-in-time solutions exist, and also what their asymptotic behavior at infinity would be. This question is better defined in the context where the initial data are both small and localized. There are two potential expected patterns, (i) dispersive decay, where waves are spreading spatially while decaying uniformly in time, and (ii) solitary waves, which have a fixed profile moving with constant velocity. Then one may broadly formulate a *soliton resolution conjecture*, which asserts that any small and localized data lead to a global solution which resolves into a dispersive part and possibly also a solitary wave.

This is, in full generality, an open problem, with existing results applying only in special cases where there are no small solitons. We remark that this question is closely related to the similar one for certain model problems, such as KdV or Benjamin–Ono as well

Focus on the Scientist: Mihaela Ifrim

Mihaela Ifrim is one of the organizers of this semester's program on Mathematical Problems in Fluid Dynamics. Her outstanding research contributions span a broad range of topics in nonlinear partial differential equations, including nonlinear dispersive equations and fluid mechanics, with connections to harmonic analysis and general relativity.

Mihaela Ifrim

Mihaela was born in a small village in Romania and discovered her passion for mathematics early on, as an avid problem solver, as well as a competitor in mathematics Olympiads. She began her studies at the University of Bucharest, where she completed her bachelor's degree in mathematics as part of a small, select group oriented toward research. She then continued with her master's degree jointly at the University of Bucharest and Scoala Normala Superioara, affiliated with the "Simion Stoilow" Institute of Mathematics of the Romanian Academy. For her Ph.D., Mihaela came to the U.S., where she completed her degree at UC Davis.

While still in graduate school, Mihaela joined a seminar I was running at UC Berkeley on water waves and quickly became the most enthusiastic participant. This is when I learned about the beautiful work in her Ph.D. thesis that ingeniously combined normal form ideas and Hamiltonian flows in order to prove a highly sought-after, long-time well-posedness result for a model water wave problem introduced earlier by Majda.

Later, we were fortunate to have her as a Simons postdoc at UC Berkeley for several years. Since 2017, Mihaela has been a Clare Boothe Luce Assistant and then Associate Professor at the University of Wisconsin–Madison.

Research wise, one of Mihaela's main interests has been in free boundary problems, beginning with her work on long-time solutions for water waves, and then on free boundary problems for compressible gases. Along the way, this has led to the introduction of several key ideas and methods which are by now standard in the field. Her contributions were recognized by a Sloan Research Fellowship, as well as an NSF CAREER award.

More recently, she has also done some very exciting work on long-time dynamics for nonlinear wave models, with more in this direction in preparation. Some of these problems are connected to general relativity, as well as to stellar dynamics in astrophysics.

In addition to her research, Mihaela is a highly sought mentor and advisor. Last summer, in the middle of the pandemic, we were scheduled to run a summer graduate school together at MSRI. All other summer schools were canceled, but Mihaela was adamant we run our school regardless, pandemic or not! This led to an unforgettable experience, for us and also for the 50 participating students. Several of her undergraduate mentees and one of her graduate students were part of the school.

Right now, with the ongoing MSRI program running virtually, Mihaela is the heart of the program and a key part of everything, whether mentoring and doing research with graduate students and postdocs, running and participating in seminars, keeping us all connected on Gathertown, or "zoom bombing" the postdocs' social hour!

— Daniel Tataru

as to the stability question for solitary waves, which is another hot topic in water waves.

Applied Perspectives in Water Waves

The complexity of the modern theory of water waves makes it absolutely necessary to supplement theoretical studies with both careful modeling and extensive numerical investigations. In particular, the question of exploring boundary conditions (for example, shores, floating objects) is of special interest and a key research subject within the program. This is also related to many environmental issues such as submersion risks in coastal areas, erosion, etc.

Another fundamental issue in the water wave theory is to understand the generation of water waves in a numerical or experimental wave tank. This corresponds to the problem of the controllability and observability of the water-wave equations. The main open question is to study the generation of water waves by the immersion of a solid body (called a plunger), or by the oscillation of a solid portion of the boundary. Laboratory experiments on water waves also face the difficulty of wave reflection against the boundaries of the basin. A similar problem appears in simulations, since for obvious computational reasons one has to work in a bounded domain. These experimental issues both stand to benefit from some mathematical insights and may shed light on the behavior of water waves.

Wave-structure interactions, and more specifically the dynamics of floating structures, is a topic of growing interest due to its links with the marine energy sector (offshore wind turbines, wave energy converters, etc). On top of the dynamics of water waves, which are already complex on their own, one needs to understand the evolution of the immersed part of the floating structure. This is of course a coupled dynamics: the water waves exert a force on the structure, which then through its own displacement acts back on the waves. Moreover, in the long term, one should describe a network of converters, therefore with more intricate coupling.

The dynamics of the contact line between the fluid and the solid object is a difficult free boundary problem in itself. The main difference when considering the shoreline problem (vanishing depth) is that the boundary condition at the contact line is not kinematic anymore, so that Lagrangian methods, for instance, do not seem applicable. This raises complex initial boundary value problems, which can be assessed in situations of increasing complexity: 1D before 2D, nondispersive models like NSW before weakly nonlinear models like Boussinesq, and finally the full water-wave equations.

Mathical Book Prize Winners Celebrate Math in Youth Literature

Outstanding Fiction and Literary Nonfiction

MSRI has announced the 2021 winners of the Mathical Book Prize, which recognizes outstanding fiction and literary nonfiction for youth ages 2–18. The Mathical Prize, now in its seventh year, is selected annually by a committee of Pre-K–12 teachers, librarians, mathematicians, early childhood experts, and others.

Mathical

BOOK PRIZE

This year's selection committee was co-chaired by **Elizabeth (Betsy) Bird**, collection development manager of the Evanston (Illinois) Public Library system and reviewer for Kirkus and the New York Times, and **Candice Price**, Assistant Professor of Mathematics at Smith College and co-founder of the website Mathematically Gifted and Black.

The 2021 Mathical Prize Winnners Are . . .

Pre-K: *Lia & Luís: Who Has More?*, by Ana Crespo (Charlesbridge)

Grades K–2: *The Animals Would Not Sleep*, by Sara Levine (Charlesbridge)

Grades 3–5: Seven Golden Rings: A Tale of Music and Math, by Rajani LaRocca (Lee & Low Books)

Grades 6–8: *How We Got to the Moon: The People, Technology, and Daring Feats of Science Behind Humanity's Greatest Adventure* by John Rocco (Crown Books for Young Readers/Random House Children's Books)

Grades 9–12: *Grasping Mysteries: Girls Who Loved Math*, by Jeannine Atkins (Simon & Schuster)

Honor Books

The following Mathical Honor Books were also announced by the selection committee:

Pre-K: *One is a Piñata: A Book of Numbers*, by Roseanne Greenfield Thong (Chronicle Books)

Grades K–2: *Billions of Bricks: A Counting Book about Building*, by Kurt Cyrus (Henry Holt & Co. Books for Young Readers); *Bird Count*, by Susan Edwards Richmond (Peachtree); and *Counting the Stars: The Story of Katherine Johnson, NASA Mathematician*, by Lesa Cline-Ransome (Simon & Schuster)

Grades 3–5: *Numbers in Motion: Sophie Kowalevski, Queen of Mathematics*, by Laurie Wallmark (Chreston Books); *Pass Go and Collect $200: The Real Story of How Monopoly Was Invented*, by Tanya Lee Stone (Henry Holt & Co. Books for Young Readers)

Grades 6–8: *Can You Crack the Code?: A Fascinating History of Ciphers and Cryptography*, by Ella Schwartz (Bloomsbury Children's Books)

Grades 9–12: *David Blackwell and the Deadliest Duel*, by Robert Black (Royal Fireworks Press); *It's a Numberful World: How Math Is Hiding Everywhere*, by Eddie Woo (The Experiment Publishing)

Award Support and Outreach

The Mathical Book Prize is awarded by the Mathematical Sciences Research Institute (MSRI), in partnership with the National Council of Teachers of English (NCTE) and the National Council of Teachers of Mathematics (NCTM), and in coordination with the Children's Book Council (CBC). It is made possible with support from the Firedoll Foundation and Joan and Irwin Jacobs. MSRI thanks the the Patrick J. McGovern Foundation for previous sponsorship.

MSRI also partners with organizations including First Book, School Library Journal, the Books for Kids Foundation, and others to distribute Mathical titles nationally to children in need. Additional resources to support educators, librarians, and families can be accessed at mathicalbooks.org.

What's the Big Idea? — The National Math Festival Game Show

On February 16, 2021, the Young People's Project hosted What's the Big Idea: A Game Show Featuring Students and Mathematicians as part of the 2020–21 National Math Festival. (Festival events are continuing through through April 2021, and we will have a round-up of this year's events in the Fall Emissary.)

The Young People's Project (YPP) brings together middle school students and high school mentors to celebrate, encourage, and motivate mathematical learning. The organization's focus is around math literacy, near-peer mentorship, and social justice. YPP trains high school students, and then employs them as Math Literacy Workers, to develop interactive games to improve their own math literacy, and to use them to improve the literacy of their younger peers.

The event was planned over about four months by a group of CMLWs (College Math Literacy Workers), MLWs (High School Math Literacy Workers), and middle school YPP volunteers. The student judges and host visible on camera were only part of the group it took to plan and run the event.

On game day, participants logged into Zoom to see mathematicians make short presentations at the middle, high school, and college levels. Attendees voted live on Zoom in four categories: math content (clarity), "people talk" (relatability, the language used in the presentation), visuals (presentation style), and curiosity.

Student Leaders

Older students in the YPP organizing group coordinated the work of younger students and mentored them through the process, which included each of the younger students making a 30-second video sharing research into the life of a mathematician of their choosing.

This work required students' balancing act between their school lives, their math literacy work with YPP, and the additional venture of designing and producing the Game Show. In the words of host Shawn Bernier, a student at Wheaton College in Norton, Massachusetts:

> Middle schoolers, high schoolers, and college students from the Young People's Project started this math challenge journey in the beginning of October of 2020. The main frame of this challenge is to have mathematicians presenting big ideas in mathematics in what we like to call 'People Talk.'
>
> This challenge demonstrates their passion for math in front of people of all ages and begins to shatter some of the perceptions of math being confusing and hard. We also hope this challenge calls attention to culturally responsive, grounding, and sustaining approaches to engage young people with mathematics.
>
> In the backdrop of our planning, we were all in a global pandemic, and we as students experienced the negative effects that it had on school and more focused in our math classes.

Mathematician Panelists

The mathematicians themselves came from settings as diverse as Educational Testing Service (Jessica Andrews-Todd), data scientist for the Milwaukee Brewers (Michael Dairyko), Massachusetts Institute of Technology (John Urschel), the University of Kentucky (Andrés Vindas Meléndez), risk and capital optimization analyst at State Street Corporation (Fega Okwa), and Williams College (Pamela E. Harris). Some of the mathematician panelists serve in industry professions, while others are completing their coursework or teach and research at the university level.

Attendees and Response

About 1,600 individuals pre-registered for the event — which represented a total of about 6,800 people, with families and school classes making up the difference. On the day, there were 856 live attendees in Zoom, with many screen-sharing with classes on event day and even more sharing the feed afterward, as well as accessing a series of follow-up blog posts.

Comments on event day show some of the reach of this event:

> I am LOVING the event, this format, and that students are the hosts. Thank you so much for making this opportunity available publicly.

> Thank you so much for providing this opportunity for students to experience math and to hear from students/individuals at different levels! — Monica Roland, Mathematics Teacher, Savannah, GA!

> Will this be recorded? I would love to replay a part for my college students who are Early Childhood Education majors. We have evening classes so I could not invite them to attend.

> Never thought of .9999999 repeated as 1. Very interesting.

> Soooo glad I am on this zoom. There are soooo many ways I want to use this in my college class. Such a great motivator-all of the presenters.

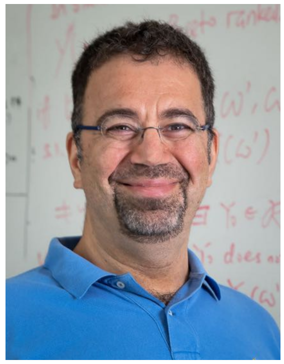
> Thank you so much! Very interesting topics even a couple that have been or will be addressed in my 8th/9th math classes this year!

> Thank you for everything from Maria Montessori middle school in San Diego, CA!

> Thank you so much guys!!!!! #GO #MATH

CME Group–MSRI Prize

The 15th annual CME Group–MSRI Prize in Innovative Quantitative Applications was awarded to **Daron Acemoglu** (pictured) of the Massachusetts Institute of Technology. The award ceremony and a panel on the “Perils and Promise of Big Data” will be held online on May 5, 2021.



L. Barry Hetherington

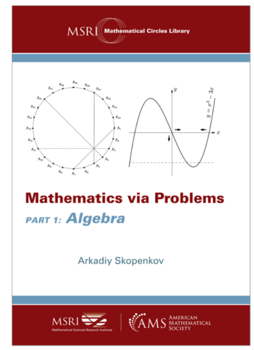
Daron Acemoglu

Dr. Acemoglu is an Institute Professor and the Elizabeth and James Killian Professor of Economics in the Department of Economics at MIT. He is an elected fellow of the National Academy of Sciences (United States), the Science Academy (Turkey), the American Academy of Arts and Sciences, the Econometric Society, the European Economic Association, and the Society of Labor Economists. He is author of five books, including *Why Nations Fail* (joint with James A. Robinson), which was a New York Times bestseller in 2012. Dr. Acemoglu’s recent research focuses on the political, economic and social causes of differences in economic development across societies; the factors affecting the institutional and political evolution of nations; and how technology impacts growth and distribution of resources and is itself determined by economic and social incentives.

The annual CME Group–MSRI Prize is awarded to an individual or a group to recognize originality and innovation in the use of mathematical, statistical, or computational methods for the study of the behavior of markets, and more broadly of economics. You can read more about the CME Group–MSRI Prize at at tinyurl.com/cme-msri.

Math Circles Library

The latest volume in the Mathematical Circles Library series has just been released. MSRI and the AMS publish the series as a service to young people, their parents and teachers, and the mathematics profession. *Mathematics via Problems: Part 1: Algebra* by Arkadiy Skopenkov, the first of three translated volumes from Russian, provides sequences of problems that allow high school students (and some undergraduates) with a strong interest in mathematics to discover and recreate much of elementary mathematics and start edging into the sophisticated world of topics such as group theory, Galois theory, and so on, thus building a bridge (by showing that there is no gap) between standard high school exercises and more intricate and abstract concepts in mathematics. The book is based on classes taught by the author at different times at the Independent University of Moscow, at a number of Moscow schools and math circles, and at various summer schools. Explore the entire collection of MSRI Mathematical Circles Library titles at bookstore.ams.org/MCL.



Call for Proposals

All proposals can be submitted to the Director or Deputy Director or any member of the Scientific Advisory Committee with a copy to proposals@msri.org. For detailed information, please see the website msri.org/proposals.

Thematic Programs

The Scientific Advisory Committee (SAC) of the Institute meets in January, May, and November each year to consider letters of intent, pre-proposals, and proposals for programs. The deadlines to submit proposals of any kind for review by the SAC are **March 1**, **October 1**, and **December 1**. Successful proposals are usually developed from the pre-proposal in a collaborative process between the proposers, the Directorate, and the SAC, and may be considered at more than one meeting of the SAC before selection. For complete details, see tinyurl.com/msri-progprop.

Hot Topics Workshops

Each year MSRI runs a week-long workshop on some area of intense mathematical activity chosen the previous fall. Proposals should be received by **March 1**, **October 1**, and **December 1** for review at the upcoming SAC meeting. See tinyurl.com/msri-htw.

Summer Graduate Schools

Every summer MSRI organizes several two-week long summer graduate workshops, most of which are held at MSRI. Proposals must be submitted by **March 1**, **October 1**, and **December 1** for review at the upcoming SAC meeting. See tinyurl.com/msri-sgs.

Call for Membership

MSRI invites membership applications for the 2022–23 academic year in these positions:

Research Professors	by October 1, 2021
Research Members	by December 1, 2021
Postdoctoral Fellows	by December 1, 2021

In the academic year 2022–23, the research programs are:

Floer Homotopy Theory
Aug 22–Dec 21, 2022
Organized by Mohammed Abouzaid, Andrew Blumberg, Kristen Hendricks, Robert Lipshitz, Ciprian Manolescu, Nathalie Wahl

Analytic and Geometric Aspects of Gauge Theory
Aug 22–Dec 21, 2022
Organized by Laura Fredrickson, Rafe Mazzeo, Tomasz Mrowka, Laura Schaposnik, Thomas Walpuski

Algebraic Cycles, L-Values, and Euler Systems
Jan 17–May 26, 2023
Organized by Henri Darmon, Ellen Eischen, Benjamin Howard, David Loeffler, Christopher Skinner, Sarah Zerbes, Wei Zhang

Diophantine Geometry
Jan 17–May 26, 2023
Organized by Jennifer Balakrishnan, Mirela Ciperiani, Philipp Habegger, Wei Ho, Hector Pasten, Yunqing Tang, Shou-Wu Zhang

MSRI uses **MathJobs** to process applications for its positions. Interested candidates must apply online at mathjobs.org **after August 1, 2021**. For more information about any of the programs, please see msri.org/programs.

Focus on the Scientist: Igor Kukavica

Igor Kukavica is an outstanding mathematician who has made remarkable contributions to many different questions in the study of partial differential equations. He is one of the organizers of this semester's program on Mathematical Problems in Fluid Dynamics, which is a central line of research in Igor's work.


Igor Kukavica

Igor grew up in Ljubliana, Slovenia. He received his Ph.D. in 1993 from Indiana University under the supervision of Ciprian Foias. He was a Dickson Instructor and Assistant Professor (1993–1997) at the University of Chicago, where he worked with Peter Constantin, and then joined the University of Southern California in 1997, where he is a Professor. His fundamental contributions to the analysis and theory of partial differential equations have been widely recognized. He was awarded an Alfred P Sloan Fellowship and received numerous honors.

Igor is very productive and is known for his energy and his generosity towards junior colleagues. To date, he has co-authored more than 140 research articles. He has had several longstanding and ongoing collaborations. With Mohammed Ziane, they have co-authored over thirty articles over the past fifteen years. Their collaboration has led to several important advances in the study of the Navier–Stokes equations: they were among the first to obtain one-component/one-direction regularity criteria guaranteeing the smoothness of Leray–Hopf solutions to the Navier–Stokes equations. They have also worked on the global regularity problem for the 3D primitive equation; in particular, he and Ziane obtained the first proof for Dirichlet boundary conditions. Igor is a pioneer in the study of Gevrey and analytic regularity properties for the Navier–Stokes, Euler, Ginzburg–Landau, Kuramoto–Sivashinsky, and other equations, with applications that for instance include quantifying the determining modes for these models. Examples include his work with Zoran Grujic concerning analytic smoothing of the Navier–Stokes equations with Lebesgue initial datum on bounded domains, his work with Ciprian Foias on the determining modes for Kuramoto–Sivashinsky, or his work with the second author (Vicol) concerning the analyticity radius for solutions of the incompressible Euler equations.

One cannot do justice to Igor's interests in such a short text. Indeed, he has studied many questions of varied natures. These include the study of the existence of weak and strong solutions for models of fluid-structure interaction, in works with Amjad Tuffaha, Irena Lasiecka, Mohammed Ziane, and Mihaela Ignatova. We also note his advances on the vanishing viscosity limit problem (either Kato-type criteria or assuming smoothness of the initial datum) and on unique continuation and Carleman estimates for Navier–Stokes equations and other parabolic problems.

Igor has a true collaborative spirit. He is well known for mentoring and guiding his junior colleagues, and as such, he has had twelve Ph.D. students (seven of them are currently working in academia) and has worked with six postdoctoral associates. In recognition of this, he recently received the USC Mentorship Award.

— Thomas Alazard and Vlad Vicol

Named Positions, Spring 2021

Chern, Eisenbud, and Simons Professors

Thomas Alazard, École Normale Supérieure Paris-Saclay
Mihaela Ifrim, University of Wisconsin–Madison
Nicolas Burq, Université Paris-Sud
Jean-Yves Chemin, Sorbonne Université
Anne-Laure Dalibard, Université Pierre-et-Marie-Curie
Raphaël Danchin, Université Paris-Est Créteil (Val-de-Marne)
Jean-Marc Delort, Université Sorbonne Paris-Nord
Charles Doering, University of Michigan
Juhi Jang, University of Southern California
Herbert Koch, Rheinische Friedrich-Wilhelms-Universität Bonn
Irena Lasiecka, University of Memphis
Vladimir Sverak, University of Minnesota Twin Cities
Sijue Wu, University of Michigan

Named Postdoctoral Fellows

S. Della Pietra: Matthew Novack, New York University, Courant Institute
Berklekamp: Hui Zhu, University of Michigan
Uhlenbeck: Albert Ai, University of Wisconsin–Madison

Clay Senior Scholars for 2021-22

Universality and Integrability in Random Matrix Theory and Interacting Particle Systems (Fall 2021)
Alice Guionnet, École Normale Supérieure de Lyon
Herbert Spohn, Technische Universität München

The Analysis and Geometry of Random Spaces (Spring 2022)
Nikolai Makarov, California Institute of Technology

Complex Dynamics: From Special Families to Natural Generalizations in one and Several Variables (Spring 2022)
Mikhail Lyubich, Stony Brook University

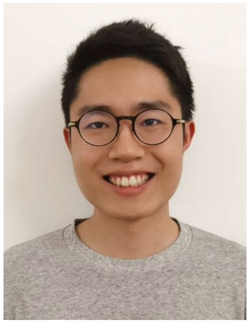
The Clay Mathematics Institute awards its Senior Scholar awards to support established mathematicians to play a leading role in a topical program at an institute or university away from their home institution.

MSRI is grateful for the generous support that comes from endowments and annual gifts that support faculty and postdoc members of its programs each semester.

Named Postdocs — Spring 2021

Berlekamp

Hui Zhu is the Berlekamp Postdoctoral Fellow in the Mathematical Problems in Fluid Dynamics program. Hui earned his undergraduate degree in 2014 from Tsinghua University. He was then admitted with a scholarship to the École Normale Supérieure in Paris, where he was advised by Thomas Alazard. Hui obtained his Ph.D. from Université Paris-Saclay in 2019 under the supervision of Thomas Alazard and Nicolas Burq. During the fall of 2019, he was Viterbi Postdoctoral Fellow in the Microlocal Analysis program at MSRI. Since 2020, he has been a James Van Loo Postdoctoral Fellow and Assistant Professor at the University of Michigan. His research aims to understand the propagation of wave packets and interaction between wave packets for nonlinear dispersive equations, and particularly their applications in the propagation of singularities, control theory, scattering theory and turbulence theory. In his work, he has applied various techniques from microlocal analysis to study the controllability of gravity-capillary water waves. He also introduced new tools to study the propagation of singularities for quasi-linear dispersive equations. *The Berlekamp fellowship was established in 2014 by a group of Elwyn Berlekamp's friends, colleagues, and former students whose lives he touched in many ways. He was well known for his algorithms in coding theory, important contributions to game theory, and his love of mathematical puzzles.*



S. Della Pietra

Matthew Novack is the Stephen Della Pietra Postdoctoral Fellow in the Mathematical Problems in Fluid Dynamics program. Matt studied mathematics and jazz guitar performance at the University of Illinois, where he earned his undergraduate degree in 2013. At that time, he also received the mathematics department award for outstanding graduating seniors, awarded annually to two students. Matt then earned his Ph.D. from the University of Texas under the direction of Alexis Vasseur. Before participating in the MSRI program, he was a Courant Instructor and Keller Postdoctoral Fellow at New York University; during the academic year 2021–22, he will be a member at the Institute for Advanced Study. Matt works on hydrodynamic equations, particularly questions related to the existence, uniqueness, and stability of solutions. Matt's recent work has used convex integration methods to demonstrate the existence of wild solutions to a number of fluid equations. In particular, a recent work (joint with Buckmaster, Masmoudi, and Vicol) constructs solutions to the Euler equations with deep connections to phenomenological theories of turbulence and intermittency. *The Stephen Della Pietra fellowship was established in 2017 by the Della Pietra Family Foundation. Stephen received his Ph.D. in mathematical physics from Harvard University. He is a partner at Renaissance Technologies, a board member of the Simons Center for Geometry and Physics, and treasurer of the National Museum of Mathematics in New York.*

Uhlenbeck

Albert Ai is the Uhlenbeck postdoctoral fellow in this semester's Mathematical Problems in Fluid Dynamics program. Albert completed his undergraduate studies at Princeton University and then came to the University of California, Berkeley in order to pursue his Ph.D. under Daniel Tataru. He defended it in 2019 and was awarded the Herb Alexander Prize for an outstanding dissertation in pure mathematics. He is now a Van Vleck Visiting Assistant Professor at the University of Wisconsin–Madison. Albert works on low regularity solutions of water wave equations that describe the movement of the interface between a perfect incompressible irrotational fluid and air in a gravitational field, as well as on related problems. *The Uhlenbeck fellowship was established by an anonymous donor in honor of Karen Uhlenbeck, a distinguished mathematician and former MSRI trustee. She is a member of the National Academy of Sciences and a recipient of the 2019 Abel Prize, the AMS Leroy P. Steele Prize, and a MacArthur "Genius" Fellowship.*

Forthcoming Workshops

Apr 12–30, 2021 (VIRTUAL) : *Recent Developments in Fluid Dynamics*

Apr 29, 2021 (VIRTUAL) : *Critical Issues in Mathematics Education 2021: Initiating, Sustaining, and Researching Mathematics Department Transformation of Introductory Courses for STEM Majors*

May 3–11, 2021 (VIRTUAL) : *Hot Topics: Topological Insights in Neuroscience*

June 09-18, 2021 (VIRTUAL) : *Workshop on Mathematics and Racial Justice*

August 18-20, 2021: *Connections Workshop: Universality and Integrability in Random Matrix Theory and Interacting Particle Systems*

August 23-27, 2021: *Introductory Workshop: Universality and Integrability in Random Matrix Theory and Interacting Particle Systems*

September 20-24, 2021: *Hot Topics: Regularity Theory for Minimal Surfaces and Mean Curvature Flow*

For more information about any of these workshops, as well as a full list of all upcoming workshops and programs, please see msri.org/workshops. Pending ongoing COVID-19 disruptions, some workshops may be held online.

Puzzles Column

Joe P. Buhler and Tanya Khovanova

The first two problems in this issue's column were created by Catriona Agg, a school maths teacher in Cambridge, England, who has an extraordinary ability to construct geometric puzzles that can be done by (sometimes quite involved) algebraic exertion, or by (sometimes quite ingenious) geometric observations. Catriona's puzzles are accompanied by her colorful, felt-tip-drawn diagrams, which are reproduced here with her permission. Further examples can be found in Ben Orlin's online "11 Geometry Puzzles that Drive Mathematicians to Madness," which also includes speculations by Tim Gowers, Mike Lawler, and John Baez about how Catriona could possibly be so prolific in producing such clever puzzlers. You can also find many more puzzles on her twitter feed at @Cshearer41.

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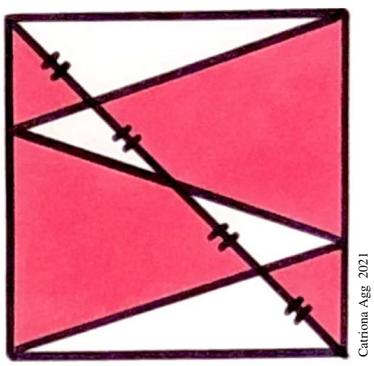
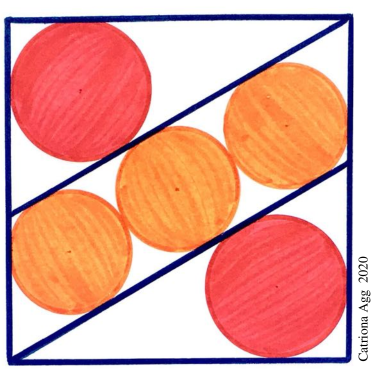
1. What fraction of the square is shaded?



2. "Five Circles in a Square." The total red area is 24. What is the total orange area?



3. Factor 2021, in your head! (Presumably some of you did this one already, earlier this year.)

4. Does there exist a 19-gon inscribed in a circle, with no two sides of equal length, whose angles are all an integer number of degrees?

Comment: This problem appeared on the 2020 Moscow Mathematical Olympiad.

5. Define a sequence x_i by setting

$$\begin{cases} x_i = 1 & \text{for } 1 \leqslant i \leqslant 2021 \\ x_{i+1} = x_i + x_{i-2020} & \text{for } i \geqslant 2021. \end{cases}$$

Prove that the sequence has 2020 consecutive terms that are divisible by 2021.

Comment: This has been repurposed from a similar problem (A3 on the 2006 Putnam), brought to our attention by its appearance in the new MAA Press book by Kiran Kedlaya, Daniel Kane, Jonathan Kane, and Evan O'Dorney that gives an extensive discussion of the problems on the 2001 through 2016 Putnam exams.

6. Alice and Bob know that during the "round of 16" in the NCAA basketball tournament, they will be in different cities in a situation where they can communicate only via a very expensive two-way communication channel that transmits a single bit at a time. They know that Alice will know which two teams are playing, but not who won, and Bob will know who won. Find a communication protocol that enables Bob to communicate to Alice who won by exchanging exactly three bits.

Comment: We heard a more general version from Alon Orlitsky long ago (it appears in a 1989 paper), but this version was brought to our attention by the fantastic new book *Mathematical Puzzles* by Peter Winkler.

7. A combination lock has three dials, each of which can be set in any one of four positions. The lock opens if two dials are correct. What is the smallest number of positions that are guaranteed to open the lock if they are all tried.

Comment: We first heard this from Elwyn Berlekamp; a slightly harder variant is in Winkler's book.

8. Show that every positive integer can be written as a sum of numbers of the form $2^a 3^b$ in such a way that no summand is a divisor of some other summand.

Comment: Paul Erdős asked this question long ago, and it appeared as the first question on the 2018 Putnam exam.

9. Tetrahedral hats have become all the rage, and a group of n people, for some large n, have hats on their heads that are shaped like regular tetrahedrons: four vertices, six edges, four faces. Moreover, everyone wears their hats so that the vertices can be unambiguously labeled as front, left, right, and top.

A referee goes around and puts a visible mark on a randomly chosen edge of each of the n hats. At a specified signal, the players simultaneously name a vertex on their hat. The players collectively win if and only if *all* of the players name a vertex on the marked edge on their hat. All the usual rules apply: everyone can see all hats but their own, the players have a strategy session the night before, no communication (covert or otherwise) is allowed during the game, and their statements are exactly simultaneous.

What strategy gives the players their highest chance of winning?

Comment: Any player's statement has probability $1/2$ of being true, so the "everyone guess" strategy has probability $(1/2)^n$ of succeeding. There are (at least two) clever strategies that give probability $1/3$ of success (for any n). That is conjectured to be the best possible value, and a few upper bounds have been proved, but none particularly close to $1/3$. This question is due to Chris Freiling.

Send your thoughts to the authors at puzzles@msri.org. Solutions will be posted online by July 2021.

2020 Annual Report

We gratefully acknowledge the supporters of MSRI whose generosity allows us to fulfill MSRI's mission to advance and communicate the fundamental knowledge in mathematics and the mathematical sciences; to develop human capital for the growth and use of such knowledge; and to cultivate in the larger society awareness and appreciation of the beauty, power, and importance of mathematical ideas and ways of understanding the world.

This report acknowledges grants and gifts received from January 1 – December 31, 2020. In preparation of this report, we have tried to avoid errors and omissions. If any are found, please accept our apologies, and report them to development@msri.org. If your name was not listed as you prefer, let us know so we can correct our records. If your gift was received after December 31, 2020, your name will appear in the 2021 Annual Report. For more information on our giving program, please visit www.msri.org.

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There are many ways to support MSRI with a donation or a planned gift. *A planned gift in the form of a bequest may enable you to make a substantial gift to MSRI, ensuring that the institute remains strong in the future. Planned gifts may help reduce capital gains and estate taxes. Friends who include MSRI in their will or have made other stipulations for a gift from their estate become members of the Gauss Society and receive invitations to our Museion dinners and to a reception during the annual Joint Mathematics Meeting.* ***To learn more about the Gauss Society and other ways to support MSRI****, please contact Annie Averitt, Director of Advancement and External Relations, at 208-221-1704 or aaveritt@msri.org.*

Hilbert Society

$100,000 per year and/or $1 million lifetime giving

We recognize our most generous and loyal supporters whose leadership and commitment ensure MSRI continues to thrive as one of the world's leading mathematics research centers.

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Andrew Viterbi

Museion Society

$5,040 – $25,000+

The Museion Society, named after Musaeum, the Hall of the Muses in ancient Alexandria, recognizes our leadership donors in annual and endowment giving.

Euclid

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Priscilla Chou
May Chu
Stephen Della Pietra & Pam Hurst-Della Pietra
Vincent Della Pietra & Barbara Amonson
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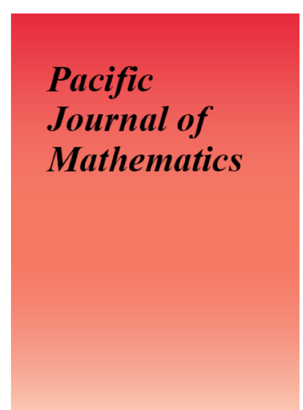

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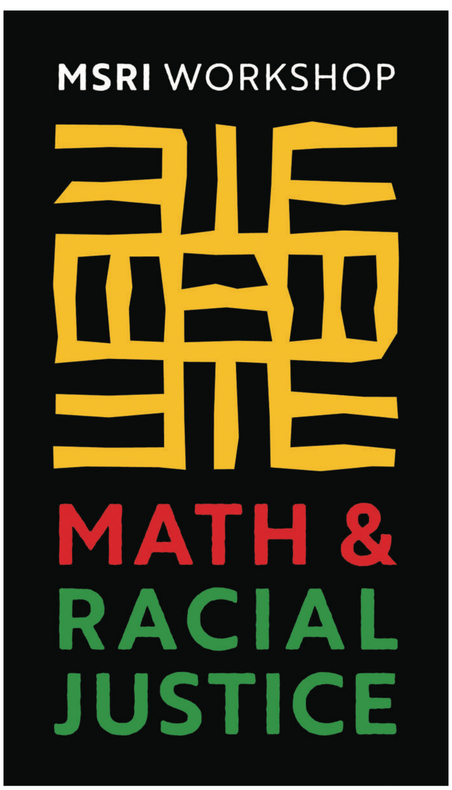

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June 9–11 & June 16–18, 2021 | ONLINE WORKSHOP

The overarching goal of the Workshop on Mathematics and Racial Justice is to explore the role that mathematics plays in today's movement for racial justice. For the purposes of this workshop, racial justice is the result of intentional, active and sustained anti-racist practices that identify and dismantle racist structures and policies that operate to oppress, disenfranchise, harm, and devalue Black people. This workshop will bring together mathematicians, statisticians, computer scientists, and STEM educators as well as members of the general public interested in using the tools of these disciplines to critically examine and eradicate racial disparities in society. Researchers with expertise or interest in problems at the intersection of mathematics, statistics and racial justice are encouraged to participate. This workshop will take place over two weeks and will include sessions on Bias in Algorithms and Technology; Fair Division, Allocation, and Representation; Public Health Disparities; and Racial Inequities in Mathematics Education. Learn more and register at msri.org/workshops/1012.

Organizers: Caleb Ashley (Boston College), Ron Buckmire (Occidental College), Duane Cooper (Morehouse College), Monica Jackson (American University), Omayra Ortega (lead; Sonoma State University), Robin Wilson (lead; California State Polytechnic University, Pomona)

This workshop is sponsored by the American Mathematical Society, the Center for Minorities in the Mathematical Sciences, the National Association of Mathematicians, the National Science Foundation, and the Society for Industrial and Applied Mathematics.