GRANT PROPOSAL TITLE PAGE

<u>Organizational Endorsement and Approval</u>

Principal Investigator: _____

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Title of Proposed Research: Workshop on *Geometry and Topological Combinatorics* a satellite conference of the International Congress of Mathematicians 2006. Place and Dates: Alcal de Henares (Madrid, Spain), 31 Aug.–5 Sept 2006.

   Areas of Interest of Research: Algebra __ Number Theory __,
        Discrete Mathematics **X̲**, Probability __ Statistics __

Dates of Conference: August 31-September 5th, 2006

List of Reviewers/Nonreviewers Enclosed: __ Yes   **X̲** No

Budget Requested: $15,000

Organizations, other than NSA, that might support the conference, along with requested amounts:

   __ ONR   __ NSF   __ AFSOR   __ ARMY   **X̲** OTHER
Ministerio de Educación y Ciencia, Spanish Government and University of Cantabria. (see budget section)

CONTENTS

1   Summary

This proposal is to request financial support for an international workshop to be held at Alcalá de Henares, Spain from August 31 to September 5, 2006. The proposed workshop will be one of the official satellite events of the International Congress of Mathematicians 2006, the biggest mathematical event that takes place every four years, sponsored by the International Mathematical Union (IMU) and all mathematical societies in the world. The scientific committee for this week-long program are Christos Athanasiadis (U. Athens, Greece), Imre Bárány (A. Renyi Institute, Hungary), Anders Björner (KTH-Stockholm, Sweden), Jesús De Loera (**co-chair** U. California, USA), Günter Rote (Freie U. Berlin, Germany) Francisco Santos (**Chair** U. Cantabria, Spain), and Emo Welzl (ETH-Zürich, Switzerland). The local organizing committee consist of Manuel Abellanas (U. Complutense Madrid, Spain), Pedro Ramos (U. Alcalá, Spain), David Orden (U. Alcalá, Spain), together with Jesús De Loera and Francisco Santos (**Chair**).

To foster the training of students and attract newcomers to this active area, there will be a parallel Summer school "Trends and topics in the future of Combinatorial and Computational Geometry" organized by Ferran Hurtado (U. Politècnica de Catalunya, Spain). The lecturers of the course will be János Pach (Courant Institute NY, USA), and Micha Sharir (Tel Aviv U., Israel). Both events count with the administrative and logistic support of Centre de Recerca Matemàtica, Barcelona, Spain.

The Funding we request will be used to cover lodging and travel expenses for invited speakers and young participants. We especially hope to be able to support U.S. graduate students and recent Ph.D.'s.

2   Organizers

Jesús De Loera (University of California)

Francisco Santos (University of Cantabria)

3   Description

Geometric and topological techniques are becoming a main tool in discrete mathematics. At the same time computer science has devoted efforts to un-

derstand the structure and complexity of discrete geometric structures. Key examples of the objects studied or manipulated are arrangements (of lines and curves and their higher-dimensional analogues), polytopes and polyhedra, lattices, tilings, sphere packings, oriented matroids, simplicial complexes, Voronoi diagrams, etc.

Geometric combinatorics bears strong relations to other vital mathematical areas such as algebra (e.g., toric varieties, symmetry groups, real algebraic geometry), number theory (e.g., lattices, geometry of numbers), topology (e.g., combinatorial manifolds, simplicial complexes), probability theory (e.g., geometric probability), and pure combinatorics (e.g., extremal graph and hypergraph theory). These relations give geometric combinatorics the solid footing to serve as the language and mathematical foundation for attacking problems in many applied fields such as algorithm design, computer graphics, coding theory, mathematical programming, solid modeling and design, crystallography and computational biology. Famous problems such as Kepler's conjecture and Hilbert's third problem, as well as classical works by mathematicians such as Minkowski, Poincaré, Steinitz, Hadwiger, and Erdős, can be considered part of the heritage of geometric and topological combinatorics.

The workshop will discuss discrete geometric objects with an emphasis on the interactions with algebra, combinatorics, and topology and applications . We expect the general areas of polytopes, point configurations, packings and coverings, lattices, geometry of numbers, tilings, oriented matroids, etc., to be represented by the leading experts in the world.

There are several exciting topics of research that will be represented at our workshop. Let us discuss some examples: Key issues about the combinatorial structure of convex polytopes and (possibly unbounded) polyhedra have seen active work and progress. This includes extremal problems on polytopes, e. g. in connection with the Generalized Lower Bound Theorem (Sharir, Welzl), the toric h-vector for non-rational polytopes (Ishida), f-vectors of d-dimensional polytopes (Eppstein, Kalai, Kuperberg, Pfeifle, Ziegler), the construction of 0/1-polytopes with "many facets" (Bárány), as well as the study of cubical polytopes (Billera, Ehrenborg, Joswig, Ziegler).

The discrete geometry of polyhedra and lattices is connected to Algebraic Geometry. Toric varieties are algebraic varieties that come with a "polyhedral dictionary" from which one can read off algebraic invariants. Ideas from

algebraic geometry and Hopf algebras have been extremely useful in studying f-vectors of convex polytopes, all starting from the famous proof of the g-theorem and its generalizations (work of Bayer, Billera, Ehrenborg, McMullen, Novik, Sottile, Stanley). The study of discriminants and algebraic polynomial systems has motivated further study of oriented matroids and triangulations enormously in the last few years culminating with Santos's example of a disconnected space of triangulations (De Loera, Reiner, Santos). There are also exciting connections to representation theory and singularity theory in the problem of counting lattice points in polytopes (Barvinok, De Loera, Stanley), and several exciting new ideas in discrete optimization have their foundation in the algebraic combinatorics of polytopes (work of Barvinok, De Loera, Onn).

Topological structures appear often in Combinatorics and Convexity. For example, in enumerative combinatorics one can often be rephrased in terms of geometric questions. Examples of these are problems on posets and their order complexes, Grassmannians, and oriented matroids (Björner, Ehrenborg, Feichtner, Kozlov, Stanley, Ziegler). The investigation of questions about colorings and chromatic numbers of graphs has found interesting topological obstructions (work by Kozlov, Matousek, Ziegler). Oriented matroids have representations in terms of topological arrangements (Lawrence, Schwartz). Oriented matroids themselves continue to be the focus of very active research due to the breakthrough work of MacPherson and the notion of combinatorial differential manifolds. (Anderson, Richter-Gebert, Santos). Geometric discrepancy theory has been strongly linked to problems involving randomized geometric algorithms, most notably in their derandomization. There is a continued importance of lattices, packings, and tilings to applications (Bezdek, Fejes Tóth, Hales, Henk, Lagarias, Sloane, Wills).

The workshop will consist of 20 hours of workshop lectures, the rest of the time participants can attend the courses in the summer school courses or work on research projects. There will be five key-note speakers chosen among the leading figures of today's discrete mathematics and eight more researchers as additional invited speakers. They have been chosen to be a cross-section of leaders, young people, and other experts in the targeted areas of the workshop. Finally, to give opportunity to all researchers to expose their work, we will have a poster session and a session of contributed talks, open for submission to all researchers and students that participate in

the workshop.

Our tentative list of key-note invited speakers is (two of them are still to be confirmed): Alexander Barvinok (U of Michigan, USA), László Lovász (Microsoft, USA), Neil Sloane (Lucent Technologies, USA), Richard P. Stanley (MIT, USA), and Terence Tao (UCLA, USA). The rest of invited speakers are Eva Maria Feichtner (ETH-Zürich), Stefan Felsner (TU Berlin), Gil Kalai (Jerusalem), Jiří Matoušek (Prague), Isabella Novik (U of Washington), Victor Reiner (U of Minnesota), Ileana Streinu (Smith College), Günter Ziegler (TU Berlin),

The field of geometric and topological combinatorics is booming and we wish to spread the benefits of the event as broadly as possible. We wish to fund several U.S. graduate and postdoctoral students as possible. We will advertise the event widely, inviting applications for partial funding, with special encouragement to women, minorities, students and recent Ph.D.'s. We will actively advertise the event.

4   Budget

NSA funds will be used to support part of the travel, lodging and per diem expenses of U.S. speakers and participants, key-note speakers included. Spanish funds will cover all other participants. Awards will follow NSA guidelines. We will pay a maximum award of $30 per diem. For participants from the U.S. $700 will be the upper limit for tickets. All graduate students (U.S and European) will receive a reduced lodging stipend as they will be offered dorm facilities at the university with special reduced price. Some of the speakers will already be in residence at ICM 2006 as part of the program, thus we maybe able to reduce expenses that way (airfares in particular).

The total estimated cost for the workshop is $31,950. We hope to receive substantial financial support by the Spanish government, the University of Alcalá, and the National Security Agency. We will receive free logistic support from Centre de Recerca Matematica and the University of Alcalá (e.g. classrooms, projectors, mailing, posters, etc). National Security Agency is asked to provide $15,750, while the Spanish Ministry of Education and the University of Alcalá haven been asked for the rest.

	Agency Support	Cost Share	Total Cost
1. AIRFARE			
5 key-note speakers speakers @ $700 per trip	$3500	$0	$3500
8 speakers @ 700 per trip	$0	$5600	$5600
10 U.S. graduate students or postdocs @ $700 per trip	$7000	$0	$7000
10 European graduate students or postdocs @ $400 per trip	$0	$4000	$7000
2. MEALS			
5 key-note speakers @ $30 per day for 5 days	$750	$0	$750
8 speakers @ $30 per day for 5 days	$0	$1200	$1200
10 U.S. graduate students or postdocs @ $30 per day, 5 days	$1500	$0	$1500
10 European graduate students postdocs @ $30 per day, 5 days	$0	$1500	$1500
3. LODGING			
5 key-note speakers $60 per day for 5 days	$1500	$0	$1500
8 speakers @ 60 per day for 5 days	$0	$2400	$2400

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10 U.S. graduate students      $1500            $0              $1500
postdocs @ $30 per day,
5 days.


European graduate students    $0               $1500           $1500
postdocs @ $30 per day,
5 days.


7. INDIRECT COSTS              none incurred

TOTAL ESTIMATED COSTS    $15750            $16200          $31950
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5   Personnel

A CV and relevant bibliography for the Principal Investigator, Jesus De Loera (co-chair of the event) as well as that of the main spanish organizer, Prof. Francisco Santos are attached. The other members of the scientific committee will only collaborate on the construction of the program. The local organizing committee will deal with logistics, planning.

6   Facilities and Equipment Available.

The workshop will take place in the Historical building of the University of Alcalá (it was constructed in the 15th century and is part of UNESCO's world heritage sites). The university of Alcalá will give lecture rooms, projectors, and all necessary facilities. There is a lecture hall which seats 100 comfortably and can accommodate 120. There is a mathematics library on the premises, and the full library service of the University of Alcalá is available to all participants. There will also be internet access and several rooms reserved for people that want to have scientific discussions in smaller groups. The town of Alcalá is 20 kilometers from Madrid, and it has excellent train connections with Madrid.

7 CV and Relevant Information of PI

7.1 Jesús A. De Loera

Education

Ph.D.	Cornell University, Applied Mathematics, April 1995.	
M.S	Cornell University, Applied Mathematics, February 1993.	
M.A.	Western Michigan University, Mathematics, May 1990.	
B.S.	National University of Mexico, Mathematics, May 1989.	

Professional Experience

Employment History

<u>2005-to present</u>: Full Professor, Dept. of Mathematics, UC Davis.

<u>2002-to 2005</u>: Associate Professor, Dept. of Mathematics, UC Davis.

<u>1998-to 2001</u>: Assistant Professor, Dept. of Mathematics, UC Davis.

<u>1998-1999</u>: Visiting Professor, Department of Computer Science, Swiss Federal Institute of Technology Zürich (ETH-Zürich).

<u>1995-1998</u>: Visiting Assistant Professor of Mathematics and Postdoctoral fellow at the Geometry Center, University of Minnesota.

Thesis Advisor: Bernd Sturmfels

Collaborators in last four years: Welleda Baldoni-Silva (Rome), Matthias Beck (Binghamton), Alexander Below (Deutsche Bahn), Lewis Bowen (U. Indiana), Mike Develin (AIM), Raymond Hemmecke (U. Magdeburg), Matthias Köppe (U. Magdeburg), Tyrrell McAllister (Davis), Bernd Sturmfels (UC Berkeley),Richard. Stanley (MIT), Francis Su (Harvey Mudd), Shmuel Onn (Haifa), Elisha Peterson (Oxford), Bernd Sturmfels (Berkeley), Francisco Santos (Cantabria Spain), Fumihiko Takeuchi (Tokyo), Jürgen Richter-Gebert (Münich), Michele Vergne (Paris), Robert Weismantel (Magdeburg), Ruriko Yoshida (Duke).

Current Graduate Students: David Haws, Susan Margulies, Tyrrell McAllister.

Former Students and Postdoctoral Associates in the last five years:
Maya Ahmed, Ruchira Datta, Raymond Hemmecke, Ruriko Yoshida.

Ten Selected Publications

Five most relevant publications

1. J.A. De Loera, R. Hemmecke, M. Köppe, R. Weismantel "Integer polynomial optimization in fixed dimension", to appear in *Mathematics of Operations Research.*

2. A. Below, J. A. De Loera and J. Richter-Gebert "The complexity of finding small triangulations of convex 3-polytopes", *Journal of Algorithms*, 50, 2004, 134–167.

3. J.A. De Loera, F. Santos, and J. Urrutia, "The number of geometric bistellar flips of a triangulation", *Discrete and Computational Geometry.* ,21, No.1, 1999, 131-142.

4. J.A. De Loera, S. Hoşten, F. Santos and B. Sturmfels, " The polytope of all triangulations of a point configuration", *Documenta Mathematica J. DMV.*, 1, 1996, 103-119.

5. J.A. De Loera, "Non-regular triangulations of products of simplices",*Discrete and Computational Geometry.* 15, 1996, 253-264.

Other significant publications

6. J.A. De Loera, E. Peterson, F. Su, "A polytopal generalization of Sperner's lemma" *Journal of Combinatorial Theory* (A), 100, 2003, 1–26.

7. J.A. De Loera and W. Morris Jr., "Q-matrix recognition via secondary and universal polytopes", *Mathematical Programming*, 85, 259–276 (1999).

8. J.A. De Loera, B. Sturmfels, and R. R. Thomas, " Gröbner bases and triangulations of the second hypersimplex", *Combinatorica.* 15, (3), 1995, 409–424.

9. J.A. De Loera, "Gröbner bases and graph colorings", *Beiträge zur Algebra und Geometrie.* 36, (1), 1995, 89–96.

10 J.A. De Loera, C. Athanasiadis, V. Reiner and F. Santos, " Projections of cyclic polytopes and their fiber polytopes.", *European Journal of Combinatorics*, 21, No.1, 2000, 19–47.

7.2   Francisco Santos

Education

Ph.D.	Universidad de Cantabria, Mathematics, June 1995.
B.S	Universidad de Cantabria, Physics, September 1996.
B.S.	Universidad de Cantabria, Mathematics, June 1991.

Professional Experience

Employment History

<u>1997-to present</u>: Associate Professor ("Profesor Asociado de Universidad"), Dept. of Matematicas, Estadistica y Computacion, Universidad de Cantabria.

<u>Ago.-Dec. 2003</u>: Research Professor, Mathematical Sciences Research Institute, Berkeley, CA.

<u>Oct.-Dec.2001</u>: Visiting Associate Professor,Dept. of Mathematics, UC Davis.

<u>Jul.1996-Feb. 1997</u>: Assistant ("Profesor Ayudante"), Dept. of Matematicas, Estadistica y Computacion, Universidad de Cantabria.

<u>Jan-Dec 1996</u>: Post-doctoral fellow, Mathematical Institute, University of Oxford.

Thesis Advisor: Tomás Recio

Collaborators in last four years: Mike Develin (AIM), Lewis Bowen (U. Indiana), J.A. De Loera (UC Davis), Bernd Sturmfels (UC Berkeley), G. Rote (F.U. Berlin), I. Streinu (Smith College), Herman Servatius (Worcester Polytechnique), Brigitte Servatius (Worcester Polytechnic), Walter Whiteley (), Raymund Seidel (U. of Saarbrucken), David Orden (U. of Alcala), Ruth Haas (Smith College), Diane Souvaine (Tufts U), Christos A. Athanasiadis (U. of Athens), Miguel Azaola (GMV, a spanish technological corporation), Achill Schürmann (U. of Magdeburg), F. Vallentin (CWI Amsterdam), Ferran Hurtado (U. Politecnica de Catalunya), Alberto Marquez (U. of Seville).

Current Graduate Students: Pilar Sabariego, Neila Campos.

Former Students and Postdoctoral Associates in the last five years:
David Orden, Miguel Azaola, Daciana Bocis.

Five most relevant publications

1. F. Santos, A point configuration whose space of triangulations is disconnected J. Amer. Math. Soc. 13:3 (2000), 611-637

2. F. Santos, Triangulations of oriented matroids Mem. Amer. Math. Soc., volume 156, number 741, American Mathematical Society, 2002.

3. F. Santos, Non-connected toric Hilbert schemes. Mathematische Annalen, 332:3 (2005), 645-665

4. B. Huber, J. Rambau and F. Santos, The Cayley trick, lifting subdivisions and the Bohne-Dress Theorem on zonotopal tilings J. Eur. Math. Soc. (JEMS) 2:2 (2000), 179-198

5. J. A. De Loera, S. Hosten, F. Santos, B. Sturmfels, The polytope of all triangulations of a point configuration Doc. Math. J. DMV. 1 (1996) 103-119

Other significant publications

6. L. Bowen, J. A. De Loera, M. Develin, F. Santos, The Gromov norm of the product of two surfaces. Topology 44:2 (March 2005), 321-339

7. R. Haas, D. Orden, G. Rote, F. Santos, B. Servatius, H. Servatius, D. Souvaine, I. Streinu and W. Whiteley, Planar Minimally Rigid Graphs and Pseudo-Triangulations, Computational Geometry: theory and Applications 31:1-2 (May 2005), 31–61.

8. G. Rote, F. Santos and I. Streinu, Expansive motions and the Polytope of Pointed Pseudo-Triangulations In Discrete and Computational Geometry – The Goodman-Pollack Festschrift (B.Aronov, S. Basu, J. Pach, M. Sharir, eds), Algorithms and Combinatorics 25, Springer Verlag, Berlin, June 2003, pp. 699-736.

9. F. Santos, Triangulations with very few geometric bistellar neighbors Discrete Comput. Geom. 23:1 (2000), 15-33

10 M. J. Gonzalez-Lopez, T. Recio, F. Santos, Parametrization of semial-gebraic sets, Math. Comput. Simulat., 42 (1996) 353-362.

8   Other Sponsors

PI	Institution	Source	Project	Amount	Period
De Loera	UC Davis	NSF	DMS-0073815	$ 188,857	7/2003- 6/
Santos	U. Cantabria	Spanish Government	MTM2005-08618-C02-02	$ 225,000	12/2004- 12
(*) De Loera & Santos	UC Davis	NSA	Geometric Combinatorics Workshop	pending	31/08/2006-05/09
(*) Santos & De Loera	U. Cantabria & UC Davis	Spanish Government	Geometric Combinatorics Workshop	pending	31/08/2006-05/09
(*) Santos & De Loera	U. Cantabria & UC Davis	University of Alcalá	Geometric Combinatorics Workshop	pending	31/08/2006-05/09

NOTE: All grants marked with (*) means funds are pending for approval.

9   Propietary Data

Not applicable.

10   Confirmation of Indirect Rates

Not applicable.