Anno: 2016 - prot. BIRD163015

Richiesta di finanziamento per Progetto/Assegno di Ricerca

Progetto

1.0 Macroarea di Afferenza del Responsabile Scientifico del Programma di Ricerca Principal Investigator's macroarea

1 - Matematica, scienze fisiche, dell'informazione e della comunicazione, ingegneria e scienze della Terra

1.1 Area Scientifica del Responsabile Scientifico del Programma di Ricerca Principal Investigator's scientific area

01 - Scienze Matematiche

1.2 Responsabile Scientifico del Programma di Ricerca Principal Investigator (PI)

PUTTI	Mario	M
(Cognome/Surname)	(Nome/Name)	(sesso/gender)
PROFESSORE ASSOCIATO	MAT/08	05/05/1959
(Qualifica/Category)	(Settore Scientifico Disciplinare/ Scientific Disciplinary Sector)	(Data di Nascita/Date of Birth)
PTTMRA59E05G224S		DIP. MATEMATICA
(Codice fiscale/Tax code)		(Dipartimento/Department)
0498271319	0498271333	mario.putti@unipd.it
(Prefisso e Telefono/ Code and Phone Number)	(Numero Fax)	(Indirizzo di Posta Elettronica/E-mail Address)

Lingua di compilazione del progetto Language

English

1.3 Area Scientifica del Programma di Ricerca Scientific area of the research program

Area Scientifica Prevalente /Main scientific Area	Scienze Matematiche	(% di afferenza) 80
Area Scientifica/Scientific Area	Scienze della Terra	(% di afferenza) 20
Area Scientifica/Scientific Area		(% di afferenza)

1.4 Titolo del Programma di Ricerca Title

Approximation and Discretization Methods for PDEs on Manifolds for Environmental Modeling

1.5 Abstract del Programma di Ricerca Abstract

The Numerical Analysis group of the Department of Mathematics of the University of Padua works on different topics, ranging from discretization of partial differential equations, approximation theory, numerical linear algebra, convergence acceleration, and applications to industrial and earth-sciences problems. The members of the group feel the need to organize their research in a more coordinated fashion. To this aim, this research project intends to commence a coordinated effort to frame a portion of the research efforts of each member of the group within a common project with a common objective. We believe this is a worthwhile aspiration to achieve visibility and international prominence not only as single researchers but as a group. A non negligible result of this coordinated effort will be the exchange of scientific experiences in three fundamentally different numerical analysis topics that, because of their intimate connections, could be coordinated to achieve innovative results towards more comprehensive developments of modeling tools for industrial and environmental applications. The foundation of this project is to formulate an initial path by recognizing the strength of each group member and drive it, at least on a partial basis, towards a common applied achievement. For this reason we have identified the field of environmental modeling, and in particular, the field of the numerical solution of PDEs on manifolds as a common topic that is sufficiently broad to comprehend all of the personal current research interests of every group member.

1.6 Settori scientifico-disciplinari interessati dal Programma di Ricerca Scientific Disciplinary Sectors

MAT/08	ICAR/01	GEO/11

1.7 Parole chiave Keywords

1. AREA 01 - Mathematics - Numerical Analysis - Partial Differential Equations, Initial Value And Time-Dependent Initial-Boundary Value Problems - FINITE ELEMENTS, RAYLEIGH-RITZ AND GALERKIN METHODS, FINITE METHODS
2. AREA 01 - Mathematics - Numerical Analysis - Numerical Approximation And Computational Geometry (Primarily Algorithms) - QUADRATURE AND CUBATURE FORMULAS
3. AREA 01 - Mathematics - Numerical Analysis - Numerical Linear Algebra - ITERATIVE METHODS FOR LINEAR SYSTEMS
4. FLUID FLOW ON GENERALLY CURVED TOPOGRAPHY

1.8 Curriculum del Responsabile Scientifico del programma di ricerca Principal Investigator's curriculum

Mario Putti (h-index = 21 (Scopus)) received the Laurea degree in Civil Engineering from the University of Padua, Italy in 1985, and the PhD degree in Civil Engineering from the University of California at Los Angeles (UCLA, USA) in 1989. He is currently Associate Professor at the Dept. of Mathematics, University of Padua. He has been involved, both as participant and as principal investigator, in a number of national and international projects financed by national institutions (MIUR, ENEL, ENI-AGIP, CORILA, Municipalities, University of Padua, etc), and international institutions (US-NSF, EU). He was invited to several international conferences as "Invited Speaker" and as "Keynote Lecturer", and has co-organized numerous workshops and international conferences. His research interests concern the development and the analysis of two and three-dimensional models applied to the simulation of environmental processes, making contributions in the field of the analysis of Finite Element, Mixed Finite Element, and Finite Volume methods applied to the solution partial differential equations applied to hydrological processes. Recent interests include uncertainty quantification, ensemble data assimilation, and reduced order modelling, as well as nonlinear coupling of interacting processes characterized by different spatial and temporal scales. He has published over 150 articles in international journals and conference proceedings.

1.9 Pubblicazioni scientifiche più significative del Responsabile Scientifico del Programma di Ricerca

nº	Pubblicazione
1.	Bonetti Sara, Manoli Gabriele, Domec Jean-Christophe, Putti Mario, Marani Marco, Katul Gabriel G. (2015). The influence of water table depth and the free atmospheric state on convective rainfall predisposition. WATER RESOURCES RESEARCH, vol. 51, p. 2283-2297, ISSN: 0043-1397, doi: 10.1002/2014WR016431 -Impact Factor 3.549
2.	G. Manoli, M. Rossi, D. Pasetto, R. Deiana, S. Ferraris, G. Cassiani, M. Putti (2015). An iterative particle filter approach for coupled hydro-geophysical inversion of a controlled infiltration experiment. JOURNAL OF COMPUTATIONAL PHYSICS, vol. 283, p. 37-51, ISSN: 0021-9991, doi: 10.1016/j.jcp.2014.11.035 -Impact Factor 2.434
3.	Paniconi Claudio, Putti Mario (2015). Physically based modeling in catchment hydrology at 50: Survey and outlook. WATER RESOURCES RESEARCH, vol. 51, p. 7090-7129, ISSN: 0043-1397, doi: 10.1002/2015WR017780 -Impact Factor 3.549
4.	Cassiani Giorgio, Boaga Jacopo, Rossi Matteo, Putti Mario, Fadda Giuseppe, Majone Bruno, Bellin Alberto (2015). Soil-plant interaction monitoring: Small scale example of an apple orchard in Trentino, North-Eastern Italy. SCIENCE OF THE TOTAL ENVIRONMENT, ISSN: 0048-9697, doi: 10.1016/j.scitotenv.2015.03.113 -Impact Factor 4.099
5.	Rossi Matteo, Manoli Gabriele, Pasetto Damiano, Deiana Rita, Ferraris Stefano, Strobbia Claudio, Putti Mario, Cassiani Giorgio (2015). Coupled inverse modeling of a controlled irrigation experiment using multiple hydro-geophysical data. ADVANCES IN WATER RESOURCES, vol. 82, p. 150-165, ISSN: 0309-1708, doi: 10.1016/j.advwatres.2015.03.008 -Impact Factor 3.417
6.	Lourenzo Beirao da Veiga, Gianmarco Manzini, Mario Putti (2015). Post processing of solution and flux for the nodal mimetic finite difference method. NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS, vol. 1, p. 336-363, ISSN: 0749-159X, doi: 10.1002/num.21907 -Impact Factor .859
7.	G. Manoli, S. Bonetti, J. C. Domec, M. Putti, G. Katul, M. Marani (2014). Tree root systems competing for soil moisture in a 3D soil-plant model. ADVANCES IN WATER RESOURCES, vol. 66, p. 32-42, ISSN: 0309-1708, doi: 10.1016/j.advwatres.2014.01.006 -Impact Factor 3.417
8.	R. Maxwell, M. Putti, S. Meyerhoff, J. d. Delfs, I. e. Ferguson, V. Ivanov, J. Kim, O. g. Kolditz, S. Kollet, M. Kumar, S. Lopez, J. Niu, C. Paniconi, Y. Park, M. Phanikumar, C. Shen, E. Sudicky, M. Sulis (2014). Surface-subsurface model intercomparison: A first set of benchmark results to diagnose integrated hydrology and feedbacks. WATER RESOURCES RESEARCH, vol. 50, ISSN: 0043-1397, doi: 10.1002/2013WR013725 -Impact Factor 3.549
9.	D. Pasetto, M. Putti, W. W-G. Yeh (2013). A reduced-order model for groundwater flow equation with random hydraulic conductivity: Application to Monte Carlo methods. WATER RESOURCES RESEARCH, vol. 49, p. 1-14, ISSN: 0043-1397, doi: 10.1002/wrcr.20136 -Impact Factor 3.709
10.	D. Pasetto, A. Guadagnini, M. Putti (2013). A reduced-order model for Monte Carlo simulations of stochastic groundwater flow. COMPUTATIONAL GEOSCIENCES, p. 1-13, ISSN: 1420-0597, doi: 10.1007/s10596-013-9389-4 -Impact Factor 1.612
11.	D. Pasetto, M. Camporese, M. Putti (2012). Ensemble Kalman filter versus particle filter for a physically-based coupled surface-subsurface model. ADVANCES IN WATER RESOURCES, vol. 47, ISSN: 0309-1708, doi: 10.1016/j.advwatres.2012.06.009 -Impact Factor 2.412

12. Adam Siade, Mario Putti, William W-G. Yeh (2012). Reduced order parameter estimation using quasilinearization and quadratic programming. WATER RESOURCES RESEARCH, vol. 48, ISSN: 0043-1397, doi: 10.1029/2011WR011471 -Impact Factor 3.149

<br clear = all>

1.10 Componenti il Gruppo di Ricerca
Research-Unit Participants

1.10.0 Professori e ricercatori anche a tempo determinato dell'Università di Padova
University of Padua Researchers

nº	Cognome	Nome	Dipartimento/Istituto	Area scientifica di ateneo	Qualifica	Settore	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno	Stato della risposta
1.	DE MARCHI	Stefano	DIP. MATEMATICA	01 - Mathematics	Professore Associato confermato	MAT/08	2	2	
2.	MARCUZZI	Fabio	DIP. MATEMATICA	01 - Mathematics	Ricercatore confermato	MAT/08	2	2	
3.	REDIVO ZAGLIA	Michela	DIP. MATEMATICA	01 - Mathematics	Professore Associato confermato	MAT/08	2	2	
4.	SOMMARIVA	Alvise	DIP. MATEMATICA	01 - Mathematics	Professore Associato (L. 240/10)	MAT/08	2	2	
5.	VIANELLO	Marco	DIP. MATEMATICA	01 - Mathematics	Professore Associato confermato	MAT/08	2	2	
6.	PUTTI	Mario	DIP. MATEMATICA	01 - Mathematics	Professore Associato confermato	MAT/08	2	2	

1.10.1 Professori a contratto di cui all'art. 23 della legge 240/2010, altro Personale dell'Università di Padova anche a tempo determinato (personale tecnico-amministrativo, Dirigenti e CEL)
Other University of Padua Staff

nº	Nome	Dipartimento/Istituto	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno

1.10.2 Titolari di assegni di ricerca dell'Università di Padova
University of Padua Research Grants

nº	Cognome	Nome	Dipartimento/Istituto	Area scientifica di ateneo	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno

1.10.3 Studenti di Dottorato di Ricerca dell'Università di Padova
University of Padua Students phD Students

nº	Cognome	Nome	Dipartimento/Istituto	Area scientifica di ateneo	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	FACCA	Enrico	DIP. MATEMATICA	01 - Scienze Matematiche	Dottorando	3	

1.10.4 Professori, ricercatori anche a tempo determinato di altre Università
Other Universities Researchers

nº	Cognome	Nome	Università	Area scientifica di ateneo	Dipartimento/Istituto	Qualifica	Settore	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno

1.10.5 Dipendenti di altre amministrazioni pubbliche, di enti pubblici o privati, di imprese, di istituzioni straniere, soggetti esterni in possesso di specifiche competenze nel campo della ricerca
Other Personnel

nº	Cognome	Nome	Ente	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	MARTINEZ CALOMARDO	ANGELES	University of Padua	Scholar	2	2
2.	PIAZZON	FEDERICO	University of Padua	Scholar	2	2

2.1.0 Pubblicazioni scientifiche più significative dei componenti il gruppo di ricerca (docenti dell'ateneo di Padova)
Relevant publications of the Research Group (Universtity of Padua Researchers)

nº	Pubblicazioni
1.	DE MARCHI STEFANO, ROBERT SCHABACK (2010). Stability of Kernel-Based Interpolation. ADVANCES IN COMPUTATIONAL MATHEMATICS, vol. 32, p. 155-161, ISSN: 1019-7168, doi: 10.1007/s10444-008-9093-4 Impact factor 1.438
2.	Stefano De Marchi, Gabriele Santin (2013). A new stable basis for radial basis function interpolation. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 253, p. 1-13, ISSN: 0377-0427, doi: 10.1016/j.cam.2013.03.048 Impact factor 1.077
3.	Stefano De Marchi, Gabriele Santin (2015). Fast computation of orthonormal basis for RBF spaces through Krylov space methods. BIT, vol. 55, p. 949-966, ISSN: 0006-3835, doi: 10.1007/s10543-014-0537-6 Impact factor 1.156
4.	G. Deolmi, F. Marcuzzi (2013). A parabolic inverse convection-diffusion-reaction problem solved using space-time localization and adaptivity. APPLIED MATHEMATICS AND COMPUTATION, vol. 219, p. 8435-8454, ISSN: 0096-3003, doi: 10.1016/j.amc.2013.02.040 Impact factor 1.6
5.	Crafa, Silvia and Marcuzzi, Fabio and Virgulin, Marco (2014). Computing from LaTeX: automated numerical computing from LaTeX expressions.
6.	BOS L, CALVI, J.P, LEVENBERG N, SOMMARIVA A, M. VIANELLO (2011). Geometric Weakly Admissible Meshes, Discrete Least Squares Approximations and Approximate Fekete Points. MATHEMATICS OF COMPUTATION, vol. 80, p. 1601-1621, ISSN: 0025-5718, doi: 10.1090/S0025-5718-2011-02442-7 Impact factor 1.313
7.	L. Bos, S. De Marchi, A. Sommariva, M. Vianello (2010). Computing multivariate Fekete and Leja points by numerical linear algebra. SIAM JOURNAL ON NUMERICAL ANALYSIS, vol. 48, p. 1984-1999, ISSN: 0036-1429, doi: 10.1137/090779024 Impact factor 1.664
8.	F. Piazzon, M. Vianello (2013). Small perturbations of polynomial meshes. APPLICABLE ANALYSIS, vol. 92, p. 1063-1073, ISSN: 0003-6811, doi: 10.1080/00036811.2011.649730 Impact factor .684
9.	G. Da Fies, M. Vianello (2012). Trigonometric Gaussian quadrature on subintervals of the period. ELECTRONIC TRANSACTIONS ON NUMERICAL ANALYSIS, vol. 39, p. 102-112, ISSN: 1068-9613 Impact factor 1.261
10.	L. Bos, M. Vianello (2012). Subperiodic trigonometric interpolation and quadrature. APPLIED MATHEMATICS AND COMPUTATION, vol. 218, p. 10630-10638, ISSN: 0096-3003, doi: 10.1016/j.amc.2012.04.024 Impact factor 1.349
11.	Gaspare Da Fies, Marco Vianello (2013). On the Lebesgue constant of subperiodic trigonometric interpolation. JOURNAL OF APPROXIMATION THEORY, vol. 167, p. 59-64, ISSN: 0021-9045, doi: 10.1016/j.jat.2012.11.009 Impact factor .896
12.	Gaspare Da Fies, Alvise Sommariva, Marco Vianello (2013). Algebraic cubature by linear blending of elliptical arcs. APPLIED NUMERICAL MATHEMATICS, vol. 74, p. 49-61, ISSN: 0168-9274, doi: 10.1016/j.apnum.2013.08.003 Impact factor 1.036
13.	Da Fies G., Vianello M. (2014). Product Gaussian quadrature on circular lunes. NUMERICAL MATHEMATICS, vol. 7, p. 251-264, ISSN: 1004-8979, doi: 10.4208/nmtma.2014.1319nm Impact factor .767
14.	Alvise Sommariva, Marco Vianello (2015). Polynomial fitting and interpolation on circular sections. APPLIED MATHEMATICS AND COMPUTATION, vol. 258, p. 410-424, ISSN: 0096-3003, doi: 10.1016/j.amc.2015.02.013 Impact factor 1.6
15.	Sommariva Alvise, Vianello Marco (2015). Compression of multivariate discrete measures and applications. NUMERICAL FUNCTIONAL ANALYSIS AND OPTIMIZATION, vol. 36, ISSN: 0163-0563, doi: 10.1080/01630563.2015.1062394 Impact factor .542
16.	Alvise Sommariva (2013). Fast construction of Fejér and Clenshaw-Curtis rules for general weight functions. COMPUTERS & MATHEMATICS WITH APPLICATIONS, vol. 65, p. 682-693, ISSN: 0898-1221, doi: 10.1016/j.camwa.2012.12.004 Impact factor 1.996
17.	Gerard Meurant, Alvise Sommariva (2013). Fast variants of the Golub and Welsch algorithm for symmetric weight functions in Matlab. NUMERICAL ALGORITHMS, ISSN: 1017-1398, doi: 10.1007/s11075-013-9804-x Impact factor 1.005
18.	SOMMARIVA A, VIANELLO M (2015). Compression of multivariate discrete measures and applications. NUMERICAL FUNCTIONAL ANALYSIS AND OPTIMIZATION, vol. 36, p. 1198-1223, ISSN: 0163-0563, doi: 10.1080/01630563.2015.1062394 Impact factor .542
19.	BREZINSKI C, REDIVO ZAGLIA M (2013). Padé-type rational and barycentric interpolation. NUMERISCHE MATHEMATIK, vol. 125, p. 89-113, ISSN: 0029-599X, doi: 10.1007/s00211-013-0535-7 Impact factor 1.551

20.	C. Brezinski, M. Redivo-Zaglia (2014). The simplified topological epsilon-algorithms for accelerating sequences in a vector space. SIAM JOURNAL ON SCIENTIFIC COMPUTING, vol. 36, p. A2227-A2247, ISSN: 1064-8275, doi: 10.1137/140957044 Impact factor 1.94
21.	Brezinski C., Redivo-Zaglia M. (2015). Convergence acceleration of Kaczmarz's method. JOURNAL OF ENGINEERING MATHEMATICS, vol. 93, p. 3-19, ISSN: 0022-0833, doi: 10.1007/s10665-013-9656-3 Impact factor 1.069

2.1.1 Pubblicazioni scientifiche più significative dei componenti il gruppo di ricerca (altri partecipanti al progetto)
Relevant publications of the Research Group (Other participants)

Bergamaschi L. & A. Martinez. Efficiently preconditioned inexact Newton methods for large symmetric eigenvalue problems. Opt. Meth. & Soft, 30:301322, 2015.

Bergamaschi L. & A. Martinez. RMCP: Relaxed mixed constraint preconditioners for saddle point linear systems arising in geomechanics. Comp. Methods App. Mech. Engrg., {221--222}:{54--62}, 2012.

Martinez, A. Tuned preconditioners for the eigensolution of large SPD matrices arising in engineering problems. Num. Lin. Alg. Appl., 23 (3): 427-443, 2016.

Piazzon, F. Bernstein Markov Properties and Applications, Ph.D. Dissertation, University of Padova, 2016

2.2 Curriculum scientifico dei Componenti il Gruppo di Ricerca
Participants' curriculum

STEFANO DE MARCHI is Associate Professor in the Department of Mathematics at the University of Padova, Italy, since 2009. His research interests are in the area of Approximation Theory and Numerical Integration, Kernel Methods, Radial Basis Functions and Partition of Unity. He has visited numerous institutions worldwide and given a number of invited seminars. He has actively participated to numerous interneational conferences and contributed to the organization of several international conferences and workshop. He is the editor in chief of Dolomites Research Notes on Approximation , and is in the editorial board of f Journal of Pure and Applied Mathematics: Advances and Applications and The Scientific World Journal, mathematical analysis. He has served in numerous committees in several Universities and has coordinated a number of Masters and Bachelor thesis projects as well as several PhD students. He has co-authored more than 100 publications in refereed journals and conference proceedings.

MICHELA REDIVO ZAGLIA is Associate Professor of Numerical Analisis since 1989. He is currently serving at the Department of Mathematics of the University of Padua. She has been invited as visiting professor to numerous institutions in Europe, Africa, China and Hong Kong, and has delivered several scinetific seminars. She has participated to a number of international conferences and has contributed to the organization of several conferences and workshops. She belongs to the editorial board of three international journald ((Int. J. of Applied Mathematics and Eng. Sciences, Dolomites Research Notes on Approximation e Numerical Algorithms). She has participated in several PhD commitees in Italy, France, Portugal and Morocco and is a member of the PhD school in Mathematical Sciences at the University of Padova. Her principal research interests are related to extrapolation and convergence acceleration methods, orthogonal polynomials, and the numerical solution of linear systems of equations. She has published software and Matlab toolboxes, and has co-authored more than 70 papers in refereed journals and conference proceedings.

ALVISE SOMMARIVA is Associate Professor at the Department of Mathematics at the University of Padova since 2014. He has contributed to the organization of several international conferences and workshops and has been invitied to deliver seminars and presentations in a number of international venues. He his active reviewer for several numerical analysis journals. He has co-supervised a number of Masters and Bachelor Thesis projects. His principal research interests lie in the area of numerical approximation theory and Numerical integration. He has co-authored more than 40 papers in refereed journals and conference proceedings.

MARCO VIANELLO is associate professor of Numerical Analysis at the Dept. of Mathematics of the University of Padova (from October 1, 2000-present) His research interests include the following topics. Multivariate approximation theory: algebraic and trigonometric polynomials, numerical cubature. Approximation of matrix exponentials and exponential integrators for ODEs/PDEs. Asymptotics/numerics of special functions: 2nd order differential and difference eqs./systems, fast summation. Constructive-numerical methods for integral equations and transforms. Numerical functional analysis. He is the managing editor of the electronic journal Dolomites Research Notes on Approximation, and has been guest editor for a number of special sessions in Numerical Algorithms and Dolomites Research Notes on Approximation. He has supervised three PhD students and a number of Masters and Bachleors thesis project. He is the authors of several presentation to international conferences and seminars and has contributed to the organization of several conference and workshops. He is the the author and co-author of more than 100 papers in the fields of Numerical Analysis and Mathematical Analysis with 24 coauthors, published in 44 international journals and book series, and of several software packages.

2.3 Stato dell'Arte: base di partenza scientifica nazionale ed internazionale
State of the Art

Shallow water equations are classically used as models of environmental fluid dynamics when the horizontal (longitudinal and lateral) components of the flow field are predominant with respect to the vertical components. This is the so called Shallow Water (SW) hypothesis. Applications of SWE range from large-scale ocean modeling [HI06] to atmospheric circulation [HO04], from river morphodynamics [LA06] to dam break and granular flows [IV14] to avalanches [GR99].

Digital Terrain Models (DTM) are generally approximated as Euclidian surfaces. A lot of research has been devoted to the geometric characterization of DTMs [OR14], but very little is known on how to describe the flow of water on surfaces with important and spatially varying curvatures. The presence of curvatures (hills, valleys, mountains) on the soil surface is most often ignored, thus neglecting local non-linear phenomena that may become relevant at small to intermediate scales. Starting from the the Shallow-Water equation written in covariant form using a local reference system with origin on the bottom surface to take into full consideration the effects of the surface geometry [BU04,FE16], Finite Volume/Discontinuous Galerkin type discretization methods are the most promising approaches to solve the ensuing hyperbolic system of equations on surfaces.

The field of numerical solution of PDEs on manifold is in its infancy (see [DZ13] for a recent review) and requires a wide range of mathematical competences that forms an ideal framework for the purpose of this project. In terms of applications to environmental problems, we singled out the problem of simulating landslide and avalanche dynamics, as well as of water flow on hydrological hill-slopes for flood prediction, tsunami modeling, atmospheric circulation modeling, etc. All these applications require appropriate definition of nonlinear systems of PDEs on Euclidean surfaces that can be as simple as a sphere, in the case of global atmospheric circulation (a well known problem), or more complex as in the case, e.g., of avalanche and landslide dynamics or water flow on hillslopes, where several open issues are still present.

The typical derivation of the SW equations is based on the integration of Navier-Stokes equations over the fluid depth in combination with an asymptotic analysis enforcing the SW assumption that states generically that phenomena occurring along the bottom surface are prevalent. For almost flat bottom topographies, fluid depth is evaluated along the direction normal to the bottom surface. The SW approximation, essentially stating that the fluid normal velocity is small compared to the horizontal components, is then used within the depth integration process to arrive at the conclusion that pressure is hydrostatically distributed along bottom normals.

For bed shapes with more general geometries, the assumption of hydrostatic pressure distribution questionable and models are less developed. The early work of Savage and Hutter (SH) [SH89, SH91] posed the foundation for these studies by developing a formulation of the SW model in local curvilinear coordinates and based on depth integration along the normal to the topography, an approach valid only for small and essentially one-dimensional bottom curvatures. In the multidimensional case the extension of the SH model is nontrivial. After the first attempt made by [GR99], [BW04] proposed a set of models that relax the assumptions of flat topography. The most advanced of these models approximates the vertical velocity profile as a linear variation within the fluid layer, leading to a second order approximation of the SW equations. However, validity limitations in the case of strongly varying surface curvatures are not yet completely resolved. SW equations for gravity driven fluids were studied also in the Non-Newtonian case by [FE10].

2.4 Descrizione del Programma di Ricerca
Description of the research program

The field of numerical solution of PDEs on manifold is in its infancy (see [DZ13] for a recent review) and requires a wide range of mathematical competences that forms an ideal framework for the purpose of this project. In terms of applications to environmental problems, we singled out the problem of simulating landslide and avalanche dynamics, as well as of water flow on hydrological hill-slopes for flood prediction, tsunami modeling, atmospheric circulation modeling, etc. All these applications require appropriate definition of nonlinear systems of PDEs on Euclidean surfaces that can be as simple as a sphere, in the case of global atmospheric circulation (a well known problem), or more complex as in the case, e.g., of avalanche and landslide dynamics or water flow on hillslopes, where several open issues are still present. The expertise of the group members is well suited to tackle this problem, in terms of contributions in forms of building blocks ranging from advanced numerical linear algebra, needed to solve the large, sparse, and often highly ill-conditioned linear systems that arise from the discretization of PDEs in general, to approximation theory needed to evaluate via appropriate quadrature rules the integrals arising from FEM or spectral-based discretization of the PDEs, to, obviously, discretization methods, to driving and control of the discretized models for optimal incorporation of observed quantities via data assimilation method and solution of inverse problems. As can be seen from the group publications, all this expertise is present within the NA group, and it is the purpose of the present project to try to coordinate the group efforts towards present and future common developments. Obviously, this had to be done discretely to preserve the identity and independence of each member, but it is the group opinion that some coordination would be beneficial and precursor of future rewards in terms of visibility and potential in the search for external (e.g. EU) funding. WE believe that this effort needs some initial funding dedicated mainly towards the participation of group members to international conference and workshops.

In the following paragraphs,we briefly describe the research program we have agreed upon. The description is organized in work-packages that are ranked and exposed in terms of model-derivation priority not of importance. The are:

WP1. Derivation of the equations.
WP2. Discretization methods.
WP3. Functional approximation and quadrature on manifolds.
WP4. Numerical linear algebra, model reduction and convergence acceleration.

WP1. Derivation of the equations.

Shallow water equations are classically used as models of environmental fluid dynamics when the horizontal (longitudinal and lateral) components of the flow field are predominant with respect to the vertical components. This is the so called Shallow Water (SW) hypothesis. Applications of SWE range from large-scale ocean modeling [HI06] to atmospheric circulation [HO04], from river morphodynamics [LA06] to dam break and granular flows [IV14] to avalanches [GR99].

Digital Terrain Models (DTM) are generally approximated as Euclidian surfaces. A lot of research has been devoted to the geometric characterization of DTMs [OR14], but very little is known on how to describe the flow of water on surfaces with important and spatially varying curvatures. The presence of curvatures (hills, valleys, mountains) on the soil surface is most often ignored, thus neglecting local non-linear phenomena that may become relevant at small to intermediate scales.

The typical derivation of the SW equations is based on the integration of Navier-Stokes equations over the fluid depth in combination with an asymptotic analysis enforcing the SW assumption that states generically that phenomena occurring along the bottom surface are prevalent. For almost flat bottom topographies, fluid depth is evaluated along the direction normal to the bottom surface. The SW approximation, essentially stating that the fluid normal velocity is small compared to the horizontal components, is then used within the depth integration process to arrive at the conclusion that pressure is hydrostatically distributed along bottom normals.

For bed shapes with more general geometries, the assumption of hydrostatic pressure distribution questionable and models are less developed. The early work of Savage and Hutter (SH) [SH89, SH91] posed the foundation for these studies by developing a formulation of the SW model in local curvilinear coordinates and based on depth integration along the normal to the topography, an approach valid only for small and essentially one-dimensional bottom curvatures. In the multidimensional case the extension of the SH model is nontrivial. After the first attempt made by [GR99], [BW04] proposed a set of models that relax the assumptions of flat topography. The most advanced of these models approximates the vertical velocity profile as a linear variation within the fluid layer, leading to a second order approximation of the SW equations. However, validity limitations in the case of strongly varying surface curvatures are not yet completely resolved. SW equations for gravity driven fluids were studied also in the Non-Newtonian case by [FE10].

The approach we are using is slightly different, and takes origin from our recent work [FE16]. In the case of a generally curved bottom, the essence of the SW approximation requires that the integration path along which depth averaging is performed be at any point orthogonal to the fluid velocity. Our objective here is to maintain the two-dimensionality of the SW models, since reduction from three to two dimensions allows efficient numerical computations as well as circumventing the intricate definition of turbulence closures, but, at the same time, we want to address the question of approximate integration along the cross-flow paths. The first step, reported in [FE16], derives a SW model based on integration along a direction locally normal to the bottom surface. The SW equations are integrated along the normal direction using a covariant form the NS equations written with respect of a local curvilinear coordinate systems. A careful construction of this reference system allows us to discuss limitations and criticalities of the procedure and to identify the cross-flow surface as the correct depth-integration path.
In this project we propose to study the approximation error that arises when depth integration follows the normal direction instead of the cross-flow path. We note that, contrary to the normal direction, along the cross-flow path the pressure does vary hydrostatically, thus allowing a straight forward integration operation leading to the effective and exact reduction of the system of equations. The objective of this project is to arrive at appropriate corrections to the pressure profile along the normal direction taking into account the actual geometry of the cross flow paths. Next, assuming that for sufficiently shallow water depths normal integration is accurate up to large orders of approximation, we propose to use a multilayer approach so that the normally averaged equations can be used in each layer. Thus, each layer interface needs to be determined numerically and the geometrical quantities of the numerically recovered interlayer surface needs to be evaluated. The key to make this approach applicable is to estimate the errors that are introduced within the layer when the normal is used in place of the cross-flow paths. These errors need to be used to define interface correction equations that allow an accurate (in the order parameter) determination of the flux exchanges at the interface between layers. This is equivalent to finding a correction to the pressure profile along the bottom normal that takes into account its deviation from the hydrostatic condition.

WP2. Discretization methods for PDEs on manifolds.

The numerical solution of PDEs on manifolds has gained recent attention for the variety of applications to real world problem. It is still an open field of research with only limited consolidated experiences (see [DZ13] for a recent review on the subject) with several open questions.

In this project we are interested in both the numerical solution of parabolic equations as well as hyperbolic systems. For the case of a parabolic equation, which in our context arises from a simplification of the NASW, we will work mainly on developing appropriate preconditioners for the solution of the large sparse systems of linear equations, described in WP4.
The case of systems of hyperbolic equations is less advanced [DZ13] and requires several improvements over existing approaches. In this project, we will start from the Finite Volume (FV) discretization of the NASW equations developed in [FE16]. This approach uses a standard Godunov-like method (first order) with a Force-like flux definition that does not require the solution of the Riemann problem at cell interfaces. The approach is dictated by the presence of variable metric coefficients within the flux functions, requiring special treatment to arrive at accurate and efficient, albeit approximate, Riemann solvers [RO04]. We will study the effects of standard approximate Riemann Solvers (RS) when used to the case of variable coefficient fluxes extending the work of [RO04] to triangular cells. We will then start extending the FV approach towards a full implementation of higher order Local-Discontinuous-Galerkin (LDG) methods, which we deem more fitting for the solution of hyperbolic PDEs on manifolds. In this context, the work performed in WP3 will be fundamental to be able to accurately evaluate the integrals defining the LDG formulation, that we recall are defined on numerical generated surfaces.

A different approach at discretization will be based on using RBF interpolates for the solution of the NASW. In the recent paper [C15] the authors propose a new method for multivariate approximation (with examples in 2 and 3 dimensions) which allows to interpolate large scattered data sets stably, accurately and with a relatively low computational cost. The idea we are pursuing is based on the typical Partition of Unity approach whereby RBF interpolants are used as local approximants together with locally supported weight functions. Hence, a large problem can be decomposed into smaller ones, allowing to work with a large number of nodes. Starting the seminal papers [FLF11, FMcC12], that proposed Gaussian interlpolants that are stable and accurate to yield the well known RBF-QR and the RBF-Direct methods, we move to a more general approach that uses a truncated Singular Value Decomposition (SVD) [DeMS13, DeMS15] to achieve stability. Our idea is to compute/produce a stable RBF basis in each PoU subdomain to yield a local interpolation problem that is both stable and accurate, since the local approximation order is preserved for the global fit. The benefits of this approach are amplified by the fact that, while in the global case a large number of truncated terms of the SVD must be dropped to preserve stability, in a local PoU technique requires only few terms are eliminated.

WP3. Functional approximation and quadrature on manifolds.

This work package will be devoted to the study and development of numerical methods and computational algorithms aimed at the accurate approximation of functions supported on manifolds and the consequential derivation of accurate quadrature rules. The WP is subdivide into two subtopics:

Polynomial Meshes and Approximation on Manifolds

Polynomial Meshes are geometry-dependent discretizations of a d-dimensional compact set, that are suitable for polynomial least-squares approximation and contain good subsets of Fekete and Leja type for polynomial interpolation (computable by standard numerical linear algebra algorithms). In particular, polynomial meshes can be a tool for numerical approximations in pluripotential theory (computation of the multivariate transfinite diameter and of the pluripotential Green function). Some promising computational results have been obtained in the Ph.D. dissertation quoted below, based on the theory of polynomial meshes and measures with the Bernstein-Markov property (equivalence of L^2 and L^inf norms in polynomial spaces). We plan to extend theory and algorithms for polynomial meshes to approximation on manifolds, in particular on algebraic varieties.

Computational SubPeriodic Harmonic Analysis

SubPeriodic Harmonic Analysis concerns trigonometric approximation on subintervals of the period. It is connected to the theory of Fourier Extensions (Boyd, Huybrechs, Adcock, et al.), to the recent theory of nonperiodic trigonometric approximations (Tal-Ezer), and to multivariate approximation and cubature on regions defined by circular arcs, such as planar circular sections and surface/solid sections of sphere, cylinder and torus (for example sectors, lenses, lunes, quadrangles, collars, slices, caps). The algorithmic part, e.g. subperiodic barycentric interpolation, or computation of subperiodic orthogonal bases and expansions, has still to be developed. There are several potential multivariate applications, for example modelling/simulation in spherical and toroidal geometry (in particular, geomathematical applications such as geomagnetic field modelling at regional scales, or spectral methods tailored on regions where curvature plays a relevant role).

WP4. Numerical linear algebra, model reduction and convergence acceleration.

Two main problems are tackled in this WP, all related to the fact that application of SW models to real world problems, and in particular to simulation of debris flow of interest to the hydraulic group of the University of Padova, needs the calibration of physical parameters based on in-situ measurements. This is a difficult inverse problem whose solution requires the use of computationally efficient PDE-constrained optimization algorithms. Another important problem is related to the estimation of the uncertainty of the model solution, given the intrinsic uncertainty of in-situ measurements, such as, e.g., rainfall intensity, geometry of channels and valleys, etc. These two problems are generally casted within a stochastic framework, whereby the original PDE becomes a stochastic PDE whose solution must be sought via various acceleration of the Monte Carlo method. To make this approach computationally feasible it is essential to derive reduced order models that are capable of describing the solution of the original full-scale model with the accuracy necessary within a Monte-Carlo method but that are computationally efficient so that hundred if not thousand of simulations can be run in reasonable time. To this aim, reduced order models (ROM) try to project the original full order model (FOM) into a subspace spanned by carefully selected FOM solutions. This is achieved using principal component analysis or singular value decomposition. It is the aim of this WP to develop efficient reduction techniques for the SW model. Starting from previous work developed by the NA group ([PA13a,b], [PA12], [SI12]), we will study ROM methods for the NASW both in terms of Reduced Basis [QU11] and POD [KU02] both as direct simulators or as preconditioners for krylov-based linear solvers [PA16].
Within this context, in principal component analysis, eigenfunctions of the solution leads to approximations depending on the number of terms kept. The coefficients of these approximations are computed by Galerkin methods. We will study how the sequence of these approximations could be accelerated by a well chosen extrapolation algorithm, leading to efficient algorithm that enhance the convergence and thus the accuracy of the developed ROMs.

2.5 Obiettivo del Programma di Ricerca e, nel caso di assegni di ricerca, indicazione dei risultati attesi dall'attività dell'assegnista/assegnisti previsti alla fine del prio anno e a conclusione della ricerca
Short-term and long-term goals and expected results

The objective of the proposed research programs are here summarized in cathegories linked to the WPs described in the Description of the research program.

OBJ1: Derivation of the Shallow Water Equations
OBJ2: Numerical Discretization of the SWE on surfaces
OBJ3: Numerical approximation of integrals on surfaces
OBJ4: Reduced Order Models and Inverse problems

OBJ1: Derivation of the Shallow Water Equations

- analysis of the normal approximation of the cross-flow paths. This is a very ambitious task, but nonetheless we state this here as a major pluri-annual objective.
- analysis the accuracy in the order parameter of the normally averaged shallow water equation.
- determination of the error of the NASW with respect to the cross-flow path in order to define the multi-layer approach is probably beyond reach in a two-year program.

OBJ2: Numerical Discretization of the SWE on surfaces

- definition and extension of the approximate Riemann solver on triangular cells in a curved domain
- derivation and analysis of Discontinuous Galerkin methods to extend the currently available finite volume method
- derivation and analysis in the case of smooth solutions of RBF methods

OBJ3: Numerical approximation of integrals on surfaces

- Polynomial Meshes and Approximation on algebrai varieties
- Application of Computational SubPeriodic Harmonic Analysis to flow on manifolds.

OBJ4: Reduced Order Models and Inverse problems

- Derivation and analysis of ROMS for the SWE on manifolds
- ROM-based preconditioning of nonsymmetric Krylov-Based solvers
- Convergence acceleration of POD based ROMS

References

[BO04] Bouchout,F., Westdickenberg, M. (2004) Gravity driven shallow water models for arbitrary topography, Commun.Math.Sci., 2(3), 359-1227.

[BO12] L. Bos and M. Vianello, (2012). Subperiodic trigonometric interpolation and quadrature, Appl. Math. Comput. 218

[C15] R. Cavoretto: Two and three dimensional partition of unity interpolation by product-type functions, Applied Mathematics & Information Sciences 9(2015), 1-8.

[CFMc14] R. Cavoretto; G. E. Fasshauer; M. McCourt, An introduction to the Hilbert-Schmidt SVD using iterated Brownian bridge kernels, Num. Algorithms 68(2) (2014), 393-422.

[CDeMDeRPS16] R. Cavoretto, S. De Marchi, A. De Rossi, E. Perracchione and G. Santin: Partition of unity interpolation using stable kernel-based techniques, accepted by App. Numer. Math. (2016).

[DeMSW05] S. De Marchi, R. Schaback and H. Wendland: Near-Optimal Data-independent Point Locations for Radial Basis Function Interpolation, Adv. Comput. Math. 23(3) (2005), 317--330

[DeMSc10] S. De Marchi and R.t Schaback: Stability of Kernel-Based Interpolation, Adv. Comput. Math. Vol. 32(2) (2010), 155-161.

[DeMS13] De Marchi, S; Santin, G.: A new stable basis for radial basis function interpolation. J. Comput. Appl. Math. 253 (2013), 1-13.

[DeMS15] De Marchi, Stefano; Santin, Gabriele: Fast computation of orthonormal bases for RBF spaces through Krylov spaces methods, BIT Numerical Math. 55(4) (2015), pp. 949--966.

[DeMIdSa16] S. De Marchi; A. Idda and G. Santin: On the rescaled method for RBF approximation, sumitted to the proceeding of Approximation Theory 15, San Antonio (TX) 22-25 May 2016.

[FE16] Fent, I., Balsemin, L., Putti, M., Canestrelli, A., Gregoretti, C., Lanzoni, S.. (2016). Modeling shallow water flows on general terrains, J. Fluid Mech., submitted.

[FL09] N. Flyer, G.B.Wright (2009). A radial basis function method for the shallow water equations on a sphere. Proc. R. Soc. Lond. Ser. A Math. Phys. Eng. Sci., 465(2106), p1949.

[FL14] N. Flyer, G.Wright, B.Fornberg (2014). Radial basis function-generated finite differences: A mesh-free method for computational geosciences. In W. Freeden, M. Z. Nashed, and T. Sonar, edts, Handbook of Geo-mathematics, Springer Berlin Heidelberg, p1.

[FLF11] B. Fornberg, E. Larsson, and N. Flyer. Stable computations with Gaussian radial basis functions. SIAM J. Sci. Comput., 33(2):869-892, 2011.

[FMcC12] Fasshauer, Gregory E.; McCourt, Michael J.: Stable evaluation of Gaussian radial basis function interpolants. SIAM J. Sci. Comput. 34 (2012), no. 2, A737-A762.

[FU13] E.J. Fuselier, G.B.Wright (2013). A high-order kernel method for diffusion and reaction- diffusion equations on surfaces. J. Sci. Comput., 56, p535.

[GE16] M. Gentile, A. Sommariva and M. Vianello, (2016) Polynomial approximation and quadrature on geographic rectangles, Appl. Math. Comput. to appear

[GR99] Gray, J. M. N. T., Wieland, M. & Hutter, K. (1999) Gravity-driven free surface flow of granular avalanches over complex basal topography. Phil. Trans. R. Soc. A 455 (1985), 1841-1874.

[IV14] Iverson, R. M. & George, D. L. (2014) A depth-averaged debris-flow model that includes the effects of evolving dilatancy. I. Physical basis. Proc. R. Soc. Lond. A 470 (2170), 20130819-20130819.

[HI06] Higdon, R. L. (2006) Numerical modelling of ocean circulation. Acta Num. 15, 385.

[HO04] Holton, J. R. (2004) An introduction to dynamic meteorology. Burlington, MA: Elsevier Academic Press.

[HU05] K.Hutter, Y.Wang, S.P.Pudasaini. (2005). The Savage-Hutter avalanche model: how far can it be pushed? Phil. Trans. R. Soc. A. 363, p1507.

[KU02] Kunisch K, Volkwein S. (2002) Galerkin proper orthogonal decomposition methods for a general equation in fluid dynamics. SIAM J. Num. Anal. 40:492-515
[RO04] Rossmanith, J. A., Bale, D. S., & LeVeque, R. J. (2004). A wave propagation algorithm for hyperbolic systems on curved manifolds. J. Compu. Phys., 199(2), 631-662.

[LA06] Lanzoni, S., Siviglia, A., Frascati, A. & Seminara, G. (2006) Long waves in erodible channels and morphodynamic influence. Water Resour. Res. 42, W06D17.

[OR14] Orlandini A., Moretti G., Gavioli A. (2014). Analytical basis for determining slope lines in grid digital elevation models. Water Resour. Res., 50, p526.

[PA13a] D. Pasetto, M. Putti, W. W-G. Yeh (2013). A reduced-order model for groundwater flow equation with random hydraulic conductivity: Application to Monte Carlo methods. WATER RESOURCES RESEARCH, vol. 49, p. 1-14, ISSN: 0043-1397

[PA13b] D. Pasetto, A. Guadagnini, M. Putti (2013). A reduced-order model for Monte Carlo simulations of stochastic groundwater flow. COMPUTATIONAL GEOSCIENCES, p. 1-13, ISSN: 1420-0597

[PA12] D. Pasetto, M. Camporese, M. Putti (2012). Ensemble Kalman filter versus particle filter for a physically-based coupled surface-subsurface model. ADVANCES IN WATER RESOURCES, vol. 47, ISSN: 0309-1708

[PA16] D. Pasetto, M. Ferronato, M. Putti. (2016). A reduced order model-based preconditioner for the efficient solution of transient diffusion equations. Int. J. Numer. Meth. Engnrg. In press

[PI16] F. Piazzon, Bernstein Markov Properties and Applications (2016), Ph.D. Dissertation, University of Padova.

[QU11] A. Quarteroni, G. Rozza, A. Manzoni, (2011). Certified reduced basis approximation for parametrized partial differential equations and applications. J. Math. Ind. 1:3

[SZ13] R. Schaback and B. Zwicknagl: Interpolation and Approximation in Taylor Spaces, J. Approx. Theory 171 (2013), 65--83.

[S14] R. Schaback: Greedy sparse linear approximations of functionals from nodal data, Numerical Algorithms 67(3) (2014); 531-547.

[SS16] Santin G. and Schaback R.: Approximation of eigenfunctions in kernel-based spaces, Adv. Comput. Math. (2016), online.

[SH89] Savage, S. & Hutter, K. (1989). The motion of a finite mass of granular material down a rough incline. J. Fluid Mech., 199(-1), p.177

[SH91] Savage, S. and Hutter, K. (1991). The dynamics of avalanches of granular materials from initiation to runout. Part I: Analysis. Acta Mechanica, 86(1-4), pp.201-223

[SI12] A.Siade, M. Putti, W. W-G. Yeh (2012). Reduced order parameter estimation using quasilinearization and quadratic programming. WATER RESOURCES RESEARCH, vol. 48, ISSN: 0043-1397

2.6 Elementi e modalità per la valutazione dei risultati finali
Criteria for final evaluation

The research results should be evaluated in terms of number of papers submitted for publication to refereed journals and the number of international conferences where results of the project have been presented. We consider this last evaluation metric of fundamental importance in particular given that the main objective of the program is to coordinate the actions of the group members towards a common strategy. Another important metric would be the particpation to international projects and meeting for the organization of international projects related to the topic of environmental modeling. This we consider the following priorities as important to evaluate the success of the project:

- participation of group members to international conferences
- publications with the NA group in the aknowledgements
- participation of group leaders (members) to coordination meetings for international project preparation
- coordinated training and of masters students and co-supervision of thesis projects

2.7 Informazioni aggiuntive
More informations

<br clear = all>

3.0 Costo del Programma
Program Cost
3.1 Assegni di ricerca da attivare in questo Programma di Ricerca
Research Grants

n°	Attività specifica nel progetto e competenze	Durata complessiva (mesi)	Costo complessivo assegno (1) (euro)	Quota cofin disponibile (2) (max 50%)	Tipologia dei fondi utilizzati a cofin (3)	Quota cofin chiesta al dipartimento
	TOTALE		**0.000**	**0.000**		**0.000**

3.2 Richiesta di attrezzature di importo superiore a 5.000 Euro
Equipments (> Eur 5.000)

n°	Descrizione attrezzatura da acquistare	Costo previsto (euro)
	TOTALE	**0.000**

3.3 Eventuale cofinanziamento del progetto

n°		Tipologia dei fondi utilizzati a cofin	Quota cofin disponibile
1.	Cofinanziamento del progetto	Fondi commerciali Mario Putti	5.000
	TOTALE		**5.000**

3.4 Costo complessivo del Programma di Ricerca
Overall budget and breakdown of costs

	Descrizione	Costo complessivo assegno (1) (euro)
Materiale inventariabile/Durables		
Materiale di consumo e funzionamento/ Consumables/Running costs	We are asking for 5000 euros as a contribution for publications of open access papers in highly ranked international journals	5.000
Congressi e missioni/ Conferences and University business trips	two conference participation in Europe or one outside Europe on a two-year span. Hence, assuming that the total amount for travel, lodging, and conference fee is approximately 1500 Euros per European conference, and taking into consideration scale effects due to the large number of members of the research group (9), we request 1500*8 = 12000 Euro/year, for a total of 24000 euros. We add to this 1000 Euros as a contribution to the participation of the group members to meetings organized for the coordination of project proposals.	25.000
Servizi esterni/External services		
Assegni di ricerca/Research Grants	(vedi punto 3.1)	
Attrezzature scientifiche	(vedi punto 3.2)	

di importo superiore a 5.000 Euro / Equipments (> EUR 5000)		
TOTALE		**30.000**

Dichiarazione / Declaration

Il presente progetto NON prevede sperimentazione animale

Ai sensi decreto legislativo 196/03 sulla "Tutela dei dati personali" i dati contenuti nella domanda di finanziamento sono trattati esclusivamente per lo svolgimento delle funzioni istituzionali dell'Ateneo.
Incaricato del trattamento dei dati è il Cineca.

Il Responsabile della Ricerca: ....

Padova lì, 21/06/2016 23:00