

Bando Premiali 2012

# Project T-REX: Italian technologies for E-ELT, the largest telescope in the world

## Line of intervention:

**N.1:** Programs and/or projects already positively evaluated, also by other National Administration, or that will apply to European joint calls or that are part of research, technology or R&D international programs allowing to maximize the financial return of the investment, as well as an increase in competitiveness of the applying Institutions in European and international context.



Artist view of the E-ELT (© ESO)

# INDICE

| 1 Coordinator |                 | 3  |    |
|---------------|-----------------|--|----|
| 2             | Activ           | vity Domain  | 3  |
| 3             | Parti           | icipants to the project                                    | 3  |
|               | 3.1             | INAF Participants  |    |
|               | 3.2             | External Participants                                      |    |
|               | 3.2.1           | Documents and Letters of Intent from external participants |    |
|               | 3.3             | Education and training                                     |    |
|               | 3.4             | Governance   |    |
| 4             | Prop            | oosed Key words  | 13 |
| 5             | Obje            | ectives  | 13 |
| 6             | Prep            | paratory activities  | 15 |
| 7             | Project Layout1 |  |    |
|               | 7.1             | OU1: Coordination Unit and Project Management.             |    |
|               | 7.2             | OU2: E-ELT MIRRORS   |    |
|               | 7.3             | OU3: E-ELT CAMERA  |    |
|               | 7.3.1           | WP 3.1 MAORY   |    |
|               | 7.3.2           | WP 3.2 MICADO  |    |
|               | 7.3.3           | WP 3.3 Atmospheric parameters                              |    |
|               | 7.3.4           | WP 3.4 Technology developments for adaptive optics         |    |
|               | 7.4             | OU4: E-ELT HIRES.  |    |
|               | 7.5             | OU5: E-ELT MOS   |    |
|               | 7.6             | OU6. E-ELT PCS   |    |
| 8             | Proj            | ect Costs  | 29 |
|               | 8.1             | Financial return   |    |
| 9             | State           | e of the art and expected results                          | 30 |
|               | 9.1             | State of the art   |    |
|               | 9.2             | Expected Results   |    |
| 10            | Elen            | nents and criteria to verify achievement of project goals  |    |

# 1 Coordinator

## Monica Tosi

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# 2 Activity Domain

| PHYSICAL SCIENCE | The ERC Panel PE9 is entirely devoted to science and technology researches in            |
|------------------|--|
| AND ENGINEERING  | the field of astrophysics and cosmology. The T-REX (Telescope to Reach the               |
|                  | EXtreme) project is active in the framework of the realization of the European           |
|                  | Extremely Large Telescope (E-ELT). As concluded by the ESFRI report, E-ELT is            |
|                  | the first scientific priority of the European astrophysical community, as well as the    |
|                  | first priority for INAF (see INAF's Document for Strategic Vision). E-ELT (and           |
|                  | hence T-REX) falls perfectly in the framework of PE9, with its innovative                |
|                  | technological challenges, aimed at allowing excellence science on the first structures   |
|                  | formed after the Big Bang, on the processes of galaxy, star and planet formation, on     |
|                  | resolved stellar populations, on the presence of life signatures on extra-solar planets. |
|                  | At the same time, the frontier technologies that will developed and applied within       |
|                  | T-REX for the construction of mirrors and instruments to be mounted on E-ELT             |
|                  | falls explicitly and naturally also in the domain of Sensory Devices, activities set of  |
|                  | high priority and strategic relevance for the Country. Moreover, the resulting           |
|                  | technological products can have significant impact also in the domains of Made in        |
|                  | Italy, Space, Human Health, Energy, Actions for Climate. It indeed already               |
|                  | happened in the past that products developed for astronomical purposes were then         |
|                  | used in other fields, even of large commercial effectiveness, from Galileo's lenses to   |
|                  | digital photographic cameras.  |

# 3 Participants to the project

## 3.1 INAF Participants

|                                | National Principal Investigator (PI) and chair of the (coordinating) Operating Unit 1  |
|--------------------------------|--|
| Monica Tosi<br>INAF OA-Bologna | Monica Tosi, Vice-President of INAF, is an astrophysicist specialized in resolved stellar population and galaxy evolution studies. Chair or member of several international committees, among which the ERC Panel PE9, ESO OPC and ESRC, she is very familiar with ESO and the E-ELT project. She is the PI of the T-REX project approved after the 2011 call. |

**CV:** Laurea (M. Sc.) in 1978 in Mathematics/Astronomy at the Rome University (La Sapienza) *summa cum laude*, PostDoc at the Yale Astronomy Department (New Haven, USA), Associate Astronomer at ESO, Visiting Astronomer at the Space Telescope Science Institute (Baltimore, U.S.A), Full Astronomer at the Bologna Observatory, M. Tosi is active in the field of studying various aspects of galaxy evolution. She has developed pioneering research techniques in the field with high international impact, as testified by the number of invited reviews at international symposia and on prestigious international journals. She has published about 130 refereed papers (of which 24 in the last 3 years) and more than 200 contributed papers to international meetings. Her papers have more than 5000 citations, corresponding to an H-index of 40. She has been thesis advisor for undergraduate and graduate students in Astronomy at the Bologna University. For 5 years she has been member

of the Board of professors (*Collegio dei Docenti*) for the Astronomy PhD in Bologna. She has served in many responsibility roles at national and international level. For sake of conciseness, we list here only the ones more relevant for the proposed project: referee for grant assignments to research projects for foreign and international Institutions (NATO, US NSF, Chilean and Swiss NSFs), member of panel PE9 for the selection of ERC Grants for the EU; panel chair in the Time Allocation Committee of the Hubble Space Telescope, panel chair in the OPC for the time allocation at the ESO telescopes, and chair of the whole OPC in 2008; member and then chair of the Visiting Committee of the Space Telescope Science Institute (NASA) in Baltimore (USA) since 2007, member of E-ELT Standing Review Committee at ESO from 2006 to 2011, member and then chair of the Science Committee of INAF from 2008 to 2011, referee for the Italian evaluation Agency ANVUR since 2012, member of the Administration Council and Vice-President of INAF since 2011.

|                   | Coordinator of the Operating Unit 2 (mirrors) and member of Unit 1 (coordination)   |
|-------------------|---|
| Giovanni Pareschi | wavelengths. Project Manager in several R & D projects funded by ASI and ESA, Project                                       |
| INAF OA-Brera     | Scientist of the SIMBOL-X project, he is the PI of the ASTRI/MIUR flagship program. He                                      |
|                   | teaches at the Insubria University and will contribute to this project also by training young scientists and technologists. |
|                   |   |

**CV:** He received the Laurea degree in Astronomy at the University of Bologna in 1992 and the PhD in Astrophysics at the University of Ferrara. He has been post-doc fellow of the Italian National Research Council at the University of Ferrara (1996) and ESA (1997, at the Danish Space Research Institute). Since 1998 he is permanent staff member at the Brera Astronomical Observatory/INAF (Milano), involved in research and developments on Optical Technologies (now leading the group founded by O. Citterio). He is author of many scientific publications and invited talks in International conferences, mainly regarding innovative technology and instrumentation for astronomy. He takes/took part in important international projects like INTEGRAL/JEM-X, NHXM/SIMBOL-X, IXO/ATHENA (having been also member of the Telescope Working Group), MAGIC (having been the INAF responsible for the production of mirrors) and CTA (being member of the Project Committee). He is the PI of the ASTRI flagship project of MIUR for the development of the technologies to be used in CTA. He has been member of several national and international boards. From 2006 to 2009 he was the coordinator of "Technology and Instrumentation" macro-area of INAF", while from 2007 to 2011 he was member of the bilateral ASI-INAF board for the planning of the scientific activity common to the two Institutes. Since 2008 he is Director of the Brera Observatory.

|  | Coordinator of Operating Unit 3 (camera) and member of Unit 1  |  |
|--|--|--|
| Emiliano Diolaiti<br>INAF OA-Bologna   | Emiliano Diolaiti is an experienced technologist, specialized in adaptive optics. Thanks to this expertise, he is the Principal Investigator of MAORY, the adaptive optics module expected to be approved soon by ESO (see attached letter 6) to be installed on the E-ELT since first light observations. |  |
| <b>CV:</b> Researcher at INAF – OA Bologna, he graduated in Astronomy in 1997 and obtained the PhD with a thesis |  |  |

**CV:** Researcher at INAF – OA Bologna, he graduated in Astronomy in 1997 and obtained the PhD with a thesis on the design and development of a software code for the analysis of adaptive optics imaging data. He worked on the design and construction of optical-infrared instrumentation for the Very Large Telescope (MAD multi-conjugate adaptive optics demonstrator) and for the Large Binocular Telescope (Large Binocular Camera, LINC-NIRVANA interferometer). He was the principal investigator of a project for the construction of two Infrared Test Cameras for the LBT. He has collaborated in the studies for the E-ELT instrumentation since 2005. He was the principal investigator of the phase-A study of the MAORY multi-conjugate adaptive optics module for E-ELT and he is now coordinating the activities in preparation for the next phases of this project. He is also working on the study of innovative optical solutions for solar concentrators used in renewable energy applications. Author or co-author of more than 140 publications and 50 technical reports. Supervisor of graduation and PhD thesis at the University of Bologna.

|                                  | Coordinator of the Operating Unit 4 (HIRES)  |
|----------------------------------|--|
| Livia Origlia<br>INAF OA-Bologna | Livia Origlia is a scientist with major scientific and technological expertise in high resolution spectroscopy. She is PI of SIMPLE, the Phase A study of a near IR high resolution spectrograph for the E-ELT proposed to ESO. She is now one of the European coordinators for the definition of the international consortium of HIRES. |

**CV**: Master Degree in Physics at the Torino University in 1987; Ph.D. in Astronomy; Student-Fellow at ESO-Garching in 1989-1990; Researcher at the Torino first and at the Bologna (since 1997) Observatories; Associate Professor since 2009. Visiting Professor at several international institutes as ESO, STScI and some prestigious universities in the US. Member of several committees for observing time allocation at the major national and international telescopes. Member of the Scientific & Technical Committee of LBT, of the Science Team of some instrumental projects for the VLT (XShooter, MOONS) and E-ELT (Harmoni). Principal Investigator of two instrumental projects, GIANO for the National Telescope Galileo and SIMPLE for the future Extremely Large Telescope of ESO. Research interests: stellar and galaxy evolution, chemistry and dynamics of star clusters, infrared astronomy and technology. She has published 192 papers, of which 92 on international refereed journals. 13 of the latter have been published in the last 3 years. Her citations lead to an H-index of 33 (see ADS).

|                  | Coordinator of the Operating Unit 5 (MOS) and member of OU1   |
|------------------|---|
| Bianca Garilli   | Bianca Garilli is a scientist with major scientific and technological expertise in multi-object           |
| INAF IASF-Milano | spectroscopy (MOS). She has participated at high level at the main Italian technological projects on MOS. |
|                  |   |

CV: Staff researcher at the Istituto di Fisica Cosmica, Milano since 1985, Associate researcher since 2001. Guest researcher at CfA, High Energy Division, Cambridge, USA (1984, 1985, 1986), ESO (1992, 1993), Laboratoire d'Astrophysique de Marseille (2011). Her research activity has followed two complementary paths: a scientific excursus and a technological excursus, which started with software development and has evolved into participation to project and realization of spectrographs for both ground based and space telescopes. Her participation to such activities have evolved from simple participant, to roles of increasing responsibility, involving coordination of research groups internal to her Institute, at national level and international level (see list). The main topics and projects to which she participated are: a) Scientific Projects: X ray emission from AGNs (1983-1991), Galaxy formation and evolution and Large Scale Structure (1987 till present day), at the beginning this activity was based on small photometric and spectroscopic samples, while in the last ten years she has been involved in most of the largest and most important European cosmological surveys: VVDS, zCOSMOS, MASSIV, VIPERS, VUDS. b) Scientific software development: Reduction and analysis software for optical and NIR data, UE founded projects CosmoLab and Euro3D, UE-OPTICON project Future Astronomical Software Environment, LBT LUCIFER Italian Data Reduction Center. c) Participation to Instruments: VIRMOS, KMOS2, EUCLID-NISP, OPTIMOS-DIORAMAS, VIMOS NIR upgrade, MOONS. Her technological skills in software development, applied also to instrument dedicated environments, together with her scientific experience in astronomical research naturally fit in a context like T-REX, the goal of which being the development of technologies, knowledge and skills required to build instruments suited for the E-ELT. She has already acquired a vast experience in the design and implementation of MOS-like instruments for the VLT (VIRMOS, KMOS, MOONS) and E-ELT (OPTIMOS Dioramas), especially in the domain of observation preparation and reduction software. Her scientific interests and expertise are centered on the large spectroscopic surveys, which require MOS like spectrograph to be realized. The coupling of these two domains of experience allow her to be in an ideal position to take care of scientific and user oriented software topics which are an important part of the design of the big spectrographs of tomorrow. She was Instrument Scientist in the Phase A studies of the instruments KMOS@VLT and OPTIMOS Dioramas@E-ELT. She is currently responsible for the fiber positioning optimization code for the ESO instrument MOONS@VLT. She has published 172 papers on International refereed journals, being first author for 16 of them, and an equal number of publications of various sort (workshops, project documents, non refereed journals). Her works count more than 7500 citations, the H-index being 47.

|                                    | Coordinator of Operating Unit 6 (PCS) and member of Unit 1 (coordination)   |
|------------------------------------|---|
| Raffaele Gratton<br>INAF OA-Padova | Raffaele Gratton is a worldwide known astronomer, with a large experience in both science and technology; his fields of activity include high spectral resolution of resolved stellar populations and more recently the search for extra-solar planets. Thanks to this wide experience, he is the PCS Project Scientist, a Phase A instrument already approved for E-ELT by ESO; this is possibly the most difficult technological challenge for this project. He is teaching courses at University of Padua, and will also contribute to formation of young scientists and technologists for this project. |

**CV:** Full astronomer at the INAF - Osservatorio Astronomico di Padova, he is internationally recognized as one of the major experts in studies of the chemical composition of stars. He had an important role in studies of extra-solar planets in the last years, too. To this purpose, he designed and built the first entirely Italian high resolution spectrograph for Telescopio Nazionale Galileo and he is the instrument scientist for the Italian part of SPHERE and for EPICS, the ESO VLT and E-ELT Planet Finders. He has been among the founders of the GAPS team for the scientific exploitation of HARPS-N at TNG. He has been professor at Universities of Rome, Padua and Catania, lecturing on Spectrographs and Stellar Atmospheres, being advisor of Master Thesis and nine Doctoral Dissertations; he directed a National School in Astrophysics and has been teacher in various national and international schools. He was member of the Comitato di Consulenza Scientifica of INAF and of the Scientific Technical Committee of ESO. He has also served in the E-ELT and Science Working Group for E-ELT. Within INAF, he has been responsible of the Unità Operativa Telescopi Nazionali and of the Unità Operativa Programmazione. He is among the most cited Italian astronomers worldwide: his about 500 papers – more than 200 of which are on refereed journals, of which 50 in the last three years, have received over 12000 citations. According to ADS, his H-index is 57.

Member of Operating Unit 4: HIRES

Stefano Cristiani INAF OA-Trieste Stefano Cristiani is in charge of all issues related to the E-ELT HIRES instrument, by appointment of the INAF Science Directorate. Thanks to his competence in the field of spectroscopy he has been member, also in responsibility roles, of several consortia that have built ESO instruments of great success.

**CV**: Stefano Cristiani, Senior Astronomer at INAF-Astronomical Observatory of Trieste since 2002 and Member of the INAF Administration Council since 2011, is Co-I of the project ESPRESSO (Echelle Spectrograph for Rocky Exo-planets and Stable Spectroscopic Observations) for the ESO-VLT and has been a member of the Science Team and Executive Board of the project CODEX (COsmic Dynamics EXperiment) for the E-ELT. In his career he has worked at ESO (Fellow, Staff, Associate), both at the headquarters in Garching and in Chile and at the University of Padova (Researcher and Associate Professor), and has gained extensive experience in planning, managing, constructing and operating instruments and telescopes, from the ESO/MPI 2.2m to EFOSC, OPTOPUS, FORS, UVES, X-Shooter, ESPRESSO. He has served as a referee for various journals and research institutions in UK, France, US and for ESO, most recently in the ESO Science Evaluation Panel "Design of a Multi-Object Spectroscopic Instrument or facility" (2011). Main areas of his present research are extragalactic astronomy, cosmology, formation and evolution of galaxies, large-scale structure, quasars, advanced data-analysis methods and he is author of 178 refereed papers on these topics (H index = 53.5 as of Jan 2013).

|   | Member of Operating Unit 1 (coordination) and 4 (HIRES)  |  |
|---|--|--|
| Ernesto Oliva<br>INAF OA-Arcetri  | Ernesto Oliva is a scientist with major scientific and technological expertise in high resolution spectroscopy. Thanks to his skills he has participated to many international projects and committees. He has been project manager of SIMPLE, the Phase A study of a near IR igh resolution spectrograph for the E-ELT proposed to ESO. He has now a pivotal European role for the definition of the international consortium of HIRES. |  |
|   |  |  |
| CV: Doctor in Astronomy cum laude at the University of Bologna in 1980, ESO fellow at ESO headquarters, |  |  |

**CV:** Doctor in Astronomy *cum laude* at the University of Bologna in 1980, ESO fellow at ESO headquarters, Garching bei Muenchen(D), Staff Astronomer at the Arcetri Observatory, Firenze (I) since 1985, Associate professor and "Primo Ricercatore/Tecnologo" at INAF-Arcetri, Firenze (I) since 1995. 2000-2008:Director of

the Telescopio Nazionale Galileo (TNG), La Palma, (E), 1997-1998 Panel member of the ESA-ISO time allocation committee, 1999-2001 Panel member of the ESO-OPC time allocation committee, 2005-2006 Panel member of the HST time allocation committee, 1988-1992 Member of the Technical Committee of the TNG, 1992-2000 Chair of the NICS-TNG (Infrared imager-spectrograph) Instrument Team, 1992-1998 Member of the AdOpt-TNG Instrument Science Team, 1994-2001 Chair of the the ISAAC-VLT Instrument Science Team at ESO, 2001-2003 Project Manager of the NICS-TNG refurbishing project, 2004-present Project Manager and Project Engineer of the GIANO-TNG Instrument, 2007-2011Project Manager and Project Engineer of the SIMPLE-E-ELT Instrument, 2011-present CoPI of the MOONS (Infrared MOS spectrograph) for ESO-VLT, 2011-present CoPI of the refurbishment project of CRIRES-VLT, 2001-2008 Member of the OPTICON-TDF board for the EU access program, 2006-2010 Council Member of the European Astronomical Society. Fields of work and interest are: Theoretical and observational astrophysics (Lines formation, transfer and atomic parameters, Chemical abundances and physical conditions of gaseous nebulae and stellar envelopes, Chemical abundances in stellar photospheres and synthetic spectra of cool stars and brown dwarfs, Stellar populations in stellar clusters and galaxies, Starbursts in galaxies and their relationship to active galaxy nuclei); Data analysis and instrumentation (Study and installation of telescope pointing and tracking correction systems, Development and optimization of systems for the analysis of infrared spectroscopic data, Development of control systems and graphic user interfaces for focal plane instruments, Optical design of optical and infrared spectrographs, Construction and characterization of novel infrared instruments); Management (prioritization and handling of scientific, technical and administrative issues in operating telescope facilities, organization, supervision and prioritization of activities in instruments construction teams). Publications: 177 papers, of which 89 on international refereed journals. His papers have received more than 4000 citations, corresponding to an H-index of 42.

Member of Operating Unit 1 (Coordination) and 3 (camera)

Roberto Ragazzoni INAF OA-Padova Guru of innovative Italian technological projects in astrpphysics, he is known and appreciated worldwide for his revolutionary technological ideas, and for the success of his realizations. Thanks to his expertise he is member of several committees in ESO. He also provides perfect examples of how astrophysics can impact completely different fields, like ophthalmology. He is in charge of a regular course at the University of Padova. He will contribute to this project also to the formation of new scientists and technologists.

CV: Graduated summa cum laude in Astronomy in 1990 at the University of Padova, Researcher Astronomer at the Astronomical Observatory of Padova, Scholar Research in Astronomy in Tucson, University of Arizona, in 2001 he became Full Astronomer at the Astrophysical Observatory of Arcetri, in 2002 he is awarded of the "Wolfgang Paul Prize" from the Alexander von Humboldt foundation, since 2006 he is Full Astronomer at the Astronomical Observatory of Padova. From 1985 to 1989 he works at the private company CSA in Rovigo for the development of automation of waterplants. Between 1990 and 1992 he works at the "Consorzio Padova Ricerche" for the development of the Active Optics system of the Telescopio Nazionale Galileo. He conceives the optical design of the Rosetta's Wide Angle Camera, currently flying in the Solar System. In 1995 he takes a one year scholarship in US, where he conceives the pyramid wavefront sensor. Between 1995 and 1998 he is responsible of the first Adaptive Optics system in Italy, that is later mounted at the Telescopio Nazionale Galileo. He is in charge of the alignment of the Telescopio Nazionale Galileo, and he studies propagation of laser beams in the atmosphere. In 2000 he publishes on Nature the first three dimensional measurements of the turbulence and conceives the method for the correction of the atmospheric turbulence known as "layer oriented". Conceives the Prime Focus Correctors for the Large Binocular Telescope in Arizona and builds the system for the atmospheric correction system known as MAD that works successfully in 2007 at the Very Large Telescope, in Chilean Andes. He is in charge of the alignment of the wide field Italian telescope VST, again in Chile. He holds a patent for the analysis of aberrations in the human eye. From 2003 he is responsible of the NIRVANA interferometer for the LBT telescope in Arizona, a collaboration between Italy and Germany. He teaches the Course "Astrophysical Laboratory I" from 2004 at the University of Padova in the framework of the master in Astronomy. He teaches the Course on "Optical systems and their history" in the same University for the degree in ophthalmology". He is Author of more than 300 papers, of which about one hundred on refereed international journals.

|                                      | Member of Operating Units 1 (coordination) and 2 (mirrors)   |
|--------------------------------------|--|
| Filippo Maria Zerbi<br>INAF OA-Brera | Filippo Zerbi is head of the Central Scientific Unit II "Ground Based Projects" of the INAF<br>Science Directorate. Technologist of great experience he contributed in a substantial way to the<br>success of many instruments built for ESO. His reliability and prestige are the basis for the<br>assignment to Italy of the construction of the adaptive optics mirror M4 for the E-ELT by ESO<br>and of the corresponding financial allocation to Italian Industries and INAF itself. Member of the<br>PhD faculty group at University of Insubria, in this project he will contribute also to the formation<br>of young scientists and technologists. |

CV: Graduated in Physiscs in 1993 at the University of Pavia (110/110 cum laude), PhD in Astronomy in 1998, since 2007 is "First Researcher" at INAF Osservatorio Astronomico di Brera. Active in the field of Stellar Astrophysics (Astroseismology), High Energy Astrophysics (GRBs) and in the field of astronomical instrumentation, he has been Principal Investigator of the REM project (2000-2005), technical responsible of the Italian Participation to MIRI for JWST (2000-2003), National Technical Responsible of the X-shooter spectrograph for VLT (2002-2009), coordinator of the Integrated Activity (new materials and processes) in the EU Project OPTICON (2004-date), member of the E-ELT Instruments Project Office at ESO (2006-2010), System Engineer in the project CODEX for E-ELT (2008-2010), technical responsible of instrument NISP for the ESA mission EUCLID (2008-2011), System Engineer of the spectrograph ESPRESSO for VLT (2009-date). He is active inside INAF with strategic and coordination responsibilities. Member of the TNG Instrumentation reference group (2001), of the technical-scientific committee of the 3rd department of INAF (2002-2005), Italian representative in the LBT Tiger Team (2003-2005), responsible of the "service for infrastructures and national laboratories" of the INAF Department of Projects (2005-2008). Member of the scientific-technical committee of the Lombardy Aerospace District (2009-today). He is currently head of the Scientific Central Unit II "Ground Based Projects" of the INAF Science Directorate. He has been advisor of many Laurea Thesis in Universities in the Milano area and of 9 PhD thesis in Italian, European and American Universities. He is author or co-author of 256 publications listed in NASA-ADS

In addition to the main INAF participants listed above, there are 90 more INAF researchers and technologists distributed over the following institutes: Osservatorio Astrofisico di Arcetri (hereafter OAA), Osservatorio Astronomico di Bologna (OABo), Osservatorio Astronomico di Brera (OABr), Osservatorio Astronomico di Capodimonte-Napoli (OACN), Osservatorio Astronomico di Catania (OACt), Osservatorio Astronomico di Padova (OAPd), Osservatorio Astronomico di Roma (OARm), Osservatorio Astronomico di Trieste (OATs), Istituto di Astrofisica Spaziale di Bologna (IASFBo), Istituto di Astrofisica Spaziale di Milano (IASFMi).

We point out the high fraction of women responsible for the Operating Units (3 out of 6) and participating to the various activities. Among the participants, there is also a young woman, responsible for one of the WPs of OU3, who is a rare example of reverse brain drain, and is now senior researcher at OAA. We also point out the large presence of scientists, less than 35 year old, mainly in our education and formation plan (undergraduate and graduate students and postdocs), but also among the participants.

## 3.2 External Participants

|  | Bruno Marano is the Italian delegate in the ESO Council since 2003 and chair of ESOs Scientific Strategy Working Group. He has also been member and chair of the   |  |
|--|--|--|
| Bruno Marano   | LBT Sc.Advisory Committee. Professor of Laboratory Astrophysics at the Bologna   |  |
| Bologna University   | University, he has been member of its Academy Senate and Dean of the Science<br>Faculty. His specific role in T-REX will be to coordinate the education and<br>formation activities for undergraduate and graduate students. |  |
| OT MARKED /  |  |  |
| CV: Master Degree (Laurea) in Physics summa cum laude in 1969 UniBo, Assistant Professor in Astronomy in   |  |  |
| 1975, Associate professor in Astrophysics in 1982, Full Professor in Astronomy and Astrophysics in 1987.   |  |  |
| Member of the ESO Scientific Technical Committee (1993-1997), member of the National (Italian) Council for |  |  |
| Astronomical Research (1991-1999), member of the Scientific Advisory Committee of the Large Binocular      |  |  |
| Telescope Project (chair 95-01), Director of the Astronomical Observatory, Bologna, from 1988 to 2001,     |  |  |
|  |  |  |

Director of the Department of Astronomy, Bologna University (2000-2006), National coordinator of two PRIN (Research Projects of National Interest), member of the Academic Senate, Bologna University (2005-2008; 2010-2012), Dean of the Science Faculty, Bologna University (2010-12). Main scientific interests: Large scale structure in the Universe, Study of nearby super-clusters (Perseus, Linx-Gemini) and of their general statistical properties, deep cosmological surveys (VIMOS, z-Cosmos), Globular Clusters in M31: study of their kinematics, mass of the galaxy, complete samples of faint quasars, multi-wavelength studies (optical, X-rays, radio) of deep samples, contribution of the resolved sources to the X-ray Background, new generation ground based telescopes. He has publishe 141 papers, of which about 100 on refereed international journals. According to ADS, the H index is 39. Italian delegate in the Council of the European Southern Observatory - www.eso.org since 2003, appointed by the Foreign Affair Ministry and the Ministry for University and Science.

|                    | Alessandro Marconi is Chair of the ESO Science and Technology Committee        |
|--------------------|--|
|                    | (STC). He is Professor at UniFi where he is in charge of the Astrophysics      |
| Alessandro Marconi | Lectures for the Master Degree in Physics, specialized in Astrophysics, of the |
| Firenze University | Firenze University. He will contribute to T-REX thanks to his role within ESO  |
|                    | and to his education activity with undergraduate and graduate students.        |
|                    |  |

CV: AM got his master degree in Physics on 1993 at the University of Florence. From 1996 to 1997, he has been graduate student research assistant at the Space Telescope Science Institute. He got the PhD in Astronomy at the University of Florence on May 1998 and his thesis has been awarded the Livio Gratton prize for the best Italian PhD thesis in astronomy on 1999. From October 1997 to October 2006 he has been research astronomer (tenure position) at the Arcetri Astrophysical Observatory (INAF). Since November 2006 he is associate professor at the Department of Physics and Astronomy of the University of Florence. AM research activity is based on spectroscopy and photometry at optical and infrared wavelengths, mainly with the Hubble Space Telescope and the telescopes of the European Southern Observatory (ESO). In recent years he has also performed studies of optical interferometry with the VLT Interferometer. The topics of his research activities are: supermassive black holes (BH; mass measurements, relations with host galaxy and AGN activity); Active Galactic Nuclei (AGN; physical conditions of the Broad and Narrow Line Regions); metal abundances in starburst galaxies and the cosmological evolution of the mass-metallicity relation. AM is or has been coordinator of research units (UdR) in projects funded by the Ministry of School, University and Research (PRIN-MIUR) or by INAF (PRIN-NAF); he is an UdR coordinator in a funded PRIN-MIUR 2010-2011 project. At the end of 2012, AM has published 116 articles on international refereed journals, 26 of which during the last three years. According to the ISI Web of Knowledge, his refereed publications have received 5100 citations in 3480 articles (excluding self-citations). On average, each publication has therefore received about 44 citations with an overall H-index of 37. In the last few years he has received over 20 invitations for colloquia or talk in international congresses. He is or has been member of several international committees: in particular in 2009 he has been named as the Italian representative in the Scientific and Technical Committee (STC) of European Southern Observatory (ESO) and since 2012 he has also been named chair of the same committee. Prof. Marconi teaches the course "An Introduction to Astrophysics" during the third year of the bachelor (compulsory for all students), the course "Cosmology" (during the first year of the master and mandatory for all students of the Astrophysics curriculum) and the course of "Physics of Galaxies" (during the second year of the master). He is member of the PhD board of professors and responsible for the Astronomy curriculum of the PhD.

#### Bologna University

The University of Bologna, with its origin dating back to year 1088, is the oldest University in the western world (the word University itself was coined at its foundation). Teaching of Astronomy is formally reported since 730 years, and might be much older. The Astronomy section of the Department of Physics and Astronomy numbers 20 permanent staff members. As former Astronomy Dept. it had the highest rate of publication of Uni.Bo. A Bachelor degree in Astronomy (3 years), a Master degree in Astrophysics and Cosmology (two years) and a Ph.D. course in Astronomy (3 years, on average 6 graduate students per year) are the main educational activities. Both research and teaching are run in strong cooperation with researchers of the National Institute (INAF). University staff cooperates in a number of research projects and in the development of instrumentation in Radio, Optical, X-ray. Among the most recent activities related to optical Astronomy, UniBo has been

involved in building a module for the NIRVANA interferometer for LBT and in the FP7 program "EELT preparation" led by ESO, with a specific role in the study of the AO system (MAORY).

#### Florence University The University of Florence (UniFi) is one of the largest universities and research organization in Italy: it has roughly 2000 tenure professors and researchers, roughly 1600 technicians and administrative assistants and over 1900 between PhD students and PostDocs. UniFi has a very extensive educational offer covering all disciplines with twelve Faculties, 139 Schools (bachelors and masters), and over 54,000 students, a quarter of which is coming from outside Tuscany. UniFi has been recently reorganized in 24 departments, among which the Department of Physics and Astronomy offering all the three levels of education: the bachelor in Physics and Astronomy, the master in Physical and Astrophysical Sciences (with the Astrophysics Curriculum) and the PhD in Physics and Astronomy (with Astronomy Curriculum). On average between 5 and 10 master degrees in Astrophysics are awarded every year, and 2-3 PhD students are enrolled. Both the master and the PhD in Astronomy take advantage of a close connection with the Astronomers of the Arcetri Astrophysical Observatory, part of INAF: they are officially responsible for several semester-long courses, and they are members of the PhD board of professors. The Department of Physics and Astronomy is also very tightly connected with LENS, the European Laboratory for Non-Linear Spectroscopy, which is an excellence center of UniFi and with which there are many undergoing collaborations among which that related to the development of the Infrared Laser Comb for HIRES. A. Marconi teaches the course "An Introduction to Astrophysics" during the third year of the bachelor (mandatory for all students), the course "Cosmology" (during the first year of the master and mandatory for all students of the Astrophysics curriculum) and the course of "Physics of Galaxies" (during the second year of the master). He is member of the PhD board of professors and responsible for the Astronomy curriculum of the PhD.

#### Insubria University

The University of Insubria has been founded in 1998, it presents the peculiarity, among the Italian Universities, to experiment a new bipolar model of organization, with two main seats located in Como and Varese. In this context, the PhD courses in Astronomy and Astrophysics at the Univ. of Insubria, carried out in collaboration with the University of Pavia and the INAF Institutes Brera Astronomical Observatory and IASF-Mi, is addressing the need in the University system of Lombardia to have a programme of studies specifically regarding astronomical and space sciences. Relativistic astronomy and cosmology, main fields of interest of the teachers, represents also the main topics of the PhD courses. New lines of research are under development in the field of astronomical instrumentation and of numerical astrophysics. Together with important international collaborations, the regional context of Lombardy is particularly lively in astrophysics and space sciences, with important national Institutes operating in the territory, including the Brera Astronomical Observatory and the IASF-Mi Institute of INAF. Both Institutes are part of the PhD consortium and host many research activities related to the courses.

| Padova University  |
|--|
| The Padova University (UniPd) is one of major Italian universities. It was founded in 1222 and was one of the    |
| most prominent universities in the early modern Europe. It is among the earliest Universities in the world, and  |
| the second oldest one in Italy. Famous also for having had Copernicus and Galileo as leading professors, UniPd   |
| still is one of the reference universities in Italy. As of 2010, UniPd had approximately 65,000 students, coming |
| from all over Italy. UniPd is structured in 32 Departments, including the Physics and Astronomy department       |
| "Galileo Galilei". UniPd offers three levels of formation in Astronomy (Bachelor, Master, and PhD), with about   |
| 60 new Bachelor degree students/year, 20 new Master students/year, and 10 PhD students/year. The PhD             |
| (Doctoral) School is run in close collaboration with staff astronomers of the nearby INAF-Osservatorio           |
| Astronomico of Padova, who are members of the Board of Professors, and can be thesis supervisors. Doctors        |
| with a degree from the Doctoral School in Astronomy at UniPd have a high rate of academic success. Among         |
| the 50 Students who had a PhD in Astronomy in Padova before 2002, 77% have permanent position in an              |
| Astronomy Department or Astronomical research institution, in Italy or abroad. About 85% of the 128 PhDs         |

from the Doctoral School in Astronomy of Unipd are still working as astronomers, with contracts or permanent positions.

#### Glyndwr University, UK

Based in Wrexham but with campuses and facilities around North East Wales, Glyndŵr University champions the spirit of enterprise and an outward-facing philosophy. Inspired by Welsh hero Owain Glyndŵr, it aims to be bold, inspiring and enterprising in everything it does. The courses are tailored to be relevant to industry and professional applications. The University works closely with partners in business including Airbus, the BBC and Active Childcare to ensure our graduates get the skills they need to gain employment. 2010 saw the launch of the <u>Advanced Composite Training and Development Centre</u>, the result of a groundbreaking partnership between the University, Airbus, Deeside College and the Welsh Government. The center is a prime example of how the partnership approach keeps the University at the forefront of advances in technology and skills in key industry sectors. Glyndŵr University's courses are in international demand. From London to the Far East, the university is developing a diverse and rich community of learning. The University Research Centre for Materials, Engineering and Manufacturing brings together several strands of inter-related research including advanced composite materials, large scale precision optics, water soluble polymers, photovoltaics and fluid dynamics. The University is involved in research projects from small scale, such as helping local businesses in solving issues, to very large scale, such as helping develop advanced optical technologies for the world's largest astronomical telescope, to be built at the <u>European Southern Observatory</u>.

Other participants affiliated to Universities are: S. Cavazzani (UniPd, OU3), G. Cosentino (UniBo, OU3), F. Leone (UniCt, OU6), S. Ortolani (UniPd, OU3), G. Piotto (UniPd, OU4), A. Pizzella (UniPd, OU3).

#### Participating Companies (see attached letters):

Criotec Media Lario Microgate Pecchioli Research Selex Galileo Tomelleri

#### 3.2.1 Documents and Letters of Intent from external participants

We attach to the proposal the following documents and letters:

All. 1: Contract ESO – Adoptica for M4 All. 2: Contract Microgate - INAF for M4 All. 3: Delibera CdA INAF authorizing attachment 2 All. 4: Contract Opticon All. 5: Letter Opticon on INAF financial support for the E-ELT adaptive optics All. 6: Letter from ESO for Maory All. 7: Letter of Intents by Criotec for Hires All. 8: Letter of Intents by Pecchioli Research s.r.l. for Hires All. 9: Letter of Intents by Prof. Marano (UniBo) All. 10: Letter of Intents by Prof. Marconi (UniFi) All. 11: Letter of Intents by Astrel Instruments for MOS All. 12: Letter of Intents by Forestal s.r.l. for MOS All. 13: Letter of Intents by Hyperteach s.r.l. for MOS All. 14: Letter of Intents by Media Lario Technology All. 15: Letter of Intents by Tomelleri s.r.l. All. 16: Letter of Intents by Ditta Selex Galileo All. 17: Letter of Intents by Università dell'Insubria All. 18: Letter of Intents by Glyndwr University

## 3.3 Education and training

This project plans to promote research, technology and formation activities in a coordinated way, with the aim of developing new frontier technologies useful for the entire national and international science communities. The project scheme, based on the synergy between different fields and expertise, provides the basis for the creation and formation of new experts and professional profiles of extremely high specialization.

E-ELT is a long term project, where: 1) the timeframe of the project, which foresees the telescope in operation in ten years from now, b) the need of developing "extreme" technological solutions, in the telescope itself, in the adaptive optics system, in the focal instrumentation, c) the perspective technological transfer require, for the full success of the Italian participation, a wide involvement of younger generations, graduate and postgraduate students. More than in other cases, education can not be an isolated and independent task of the University, but must be an intrinsic part of the project development. Correcting past habits in national Astronomy, it is now recognized that the development of advanced instrumentation must rely on researchers educated up to the PhD level. The integration, into the project, of high education processes is not an option, but a must.

The Italian Universities involved in the project (Bologna, Catania, Florence, Insubria and Padua) have a long standing record of interaction, and often of integration, with the local INAF institutes. This enables the students to be exposed to the most recent developments of the astronomical instrumentation. Thesis activities are a natural common ground for Universities and INAF, both at the level of graduation and of PhD, supported by the University and by INAF. Very successful theses have been already devoted to advanced astronomical instrumentation both from ground and from space. This cooperation has led to the formation of skilled and competent researchers, who are now the backbone of a number of WPs in the present proposal. We are confident we are in the conditions to ensure the needed integration between the development of the project and the education and formation of the next generation of experts in the subject.

We plan to fund with this project 7 PhD fellowships (UniBo: 1 for OU3; UniCt: 1 for OU4; UniFi: 2 for OU4; UniInsubria: 2 for OU2; UniPd: 1 for OU3 and 1 for OU6). A similar, or higher, number of master theses will be proposed in the participating Universities.

## 3.4 Governance

This project adopts (with only minor variations) the same organization structure of the T-REX proposal approved in response to the 2011 call for *progetti premiali*. This governance scheme has indeed turned out to be effective and able to fulfil all the project requirements.

The national PI and Coordinator is the official contact point of the T-REX project. She is responsible of its management and of the allocated resources. She is flanked by the coordination Operating Unit 1 (OU1), whose members are the coordinators of the other OUs as well as experts selected for their national or international roles of great advantage for the project (see Section 7.1). OU1 is in charge of coordinating the activities of the whole project, controlling and evaluating the activities of the other Units, and of interacting with the INAF Head Quarters and other public and private bodies. In particular, OU1 is responsible for the coordination of the education and formation activities with undergraduate and graduate students in the Universities that collaborate to T-REX.

Coordinator of OU1 is the PI of the whole T-REX project. Coordinators of the other Operating Units are the scientists who had highest level international roles in the field of reference.



#### Scheme of T-REX' Governance.

# 4 Proposed Key words

- 1. Universe Science: astrophysics and cosmology, solar and extra-solar planets, astrobiology
- 2. International cooperation
- 3. Adaptive Optics, mechatronics, metrology, control systems, cryogenic
- 4. Scientific and technological know-how

## 5 Objectives

The European Extremely Large Telescope (E-ELT) is an infrastructure considered of top priority in the European Roadmap for Research Infrastructures (ESFRI) and also in the INAF Document of Strategic Vision. E-ELT will be the world largest telescope and will guarantee the leadership to Europe for ground-based optical astrophysics for decades. The European Southern Observatory (ESO), an intergovernmental European organization, of which Italy is one of the major members, is in charge of the construction and the management of this amazing telescope. The E-ELT construction project and its instrumentation realisation were approved by ESO on December 2012, thanks also to the crucial Italian vote and to the previous assumption of responsibility from INAF.

E-ELT will be one of the most important projects with larger European investment of this decade. Therefore, the participation to this project is strategic at the highest level, and we want to ensure that the scientific and economic investment leads to important image and economical returns for Italy, for INAF, for the Italian astrophysical community, and for the Italian system of research, training, education and technology as a whole.



Figure 1. E-ELT Model (© Swinburne Astronomy Productions/ESO).

The final E-ELT project features a telescope with a primary mirror with 39 m diameter, able to provide images with highest spatial resolution, thanks to the use of very innovative adaptive optics. This capability will allow us to get unprecedented sensibility and image resolution, applicable to a great variety of scientific programs. The main E-ELT scientific goals are: 1) study of the re-ionization epoch and the first stars that were responsible for

it, 2) study of the first galaxies formed after the Big Bang, 3) study of the formation of galaxies, stars and planets, 4) detection of extra-solar planets able to host forms of life and their direct observation.

The E-ELT dimensions and the required performances impose to adopt opto-mechanical, metrological, engineering and architectural solutions completely original and innovative. Studies carried out in the last years demonstrate the need to investigate in more detail a number of key issues to warrant the achievement of the objectives/targets of the project. This is mandatory to allow Italian industries to achieve in due time the capability for the development and realization of this important European endeavour. E-ELT is about to enter the construction phase, and it is essential to consolidate as soon as possible the position of INAF, Universities and Italian industries in the international context of the project, and to develop the technologies and expertises needed to deal with this ambitious project.

A crucial aspect is the reinforcement of the synergy among Italian Research Institutions and Italian industries of excellence. Thanks to their very high competitiveness in this field, they can obtain commitments greater than the financial investments that Italy will allocate to the project. E-ELT is also an extraordinary occasion for the training of young researchers and technologists and for the creation of new job opportunities.

The activities of innovative technology related to E-ELT can also originate new ideas that can be applicable to others fields, such as the sensorial devices (which the astrophysical technologies are explicitly part of). Other fields where major astrophysics project often have a great impact are medical technologies, monitoring of climate variations, information and communication technologies, *Made in Italy*, renewable energy.

The main objectives of the T-REX project can be summarized as follows:

- **1.** Consolidate the role of INAF and Italian Universities in the international consortia that form in view of the realization of E-ELT instruments.
- 2. Support the executive design phase of the E-ELT instrumentation, including the improvements of buildings and labs.
- **3.** Develop enabling technologies to guarantee the feasibility of the E-ELT instruments.
- 4. Promote processes of integration between Research Institutions, Universities and Industries.
- **5.** Foster the training of young researchers finalized to the employment, from highly qualified personnel involved in the design and realization of E-ELT instrumentation.
- **6.** Renew the scientific/industrial international cooperation, reinforcing the involvement of Italian companies in the E-ELT instrumentation design and construction phases.
- 7. Guarantee the level of the scientific and industrial *know how* and its accretion, appraising the intellectual property.
- **8.** Favour the technological transfer from the astronomical instrumentation sector to other fields, as energy applications from renewable sources, biomedical technologies, information and communication technologies, production technologies focused on nano-electronics via lithography techniques and the monitoring of climate variations.

All these goals can be reached during the T-REX long-time duration, with results quantifiable year by year. During the brief period of the funding assigned on October 2012, the project demonstrated already its effectiveness, receiving letters and contracts from ESO, other European funds, and capturing attention to the on-going activities from international Institutions and from Italian companies. T-REX reinforces the Italian astrophysics community during the negotiations for the creation of the international consortia proposing new E-ELT instruments. The support of the Italian funding Authorities will be crucial to obtain high level positions in these consortia.

T-REX will guarantee a suitable training to young specialized people. If it is funded next year, it will allow us to train a good number of undergraduate students and to have 7 PhD grants in various Universities in different geographical areas, also thanks to the participation and to the lectures given by INAF staff.

T-REX permits to collaborate at the highest level with the ESFRI European projects for infrastructures, providing a suitable and coordinated answer at national level. Already during this first year of funding, T-REX, together with the INAF Science Directorate, has assumed the role of reference point to foster the participation to similar cooperation projects in agreement with MIUR and the European and International Community. T-REX proposes itself as an organizational model that develops synergic actions between the research system, the university high educational system and the productive system in view of the globalization of the research.

## 6 **Preparatory activities**

The E-ELT project has been worked out by ESO, in collaboration with the community of member States, through a series of preparatory activities and design studies. This section describes the technical, scientific and programmatic background of the present proposal and the main activities to which INAF has contributed more significantly.

In the period 2005-2009 INAF was involved in the "ELT Design Study", led by ESO and funded by the European Union's Framework Programme 6 (contract 011863). The project focused on preparatory activities and on the development of enabling technologies for E-ELT, including adaptive optics – an excellence field of INAF, as recognized all over the world. In the E-ELT concept, adaptive optics is integrated in the telescope structure. This requires the construction of a 2.5 m diameter mirror (named "M4") to be deformed by 6000 actuators with a typical period of 1 millisecond. Italian industries and research organizations have given a fundamental contribution to the study of the E-ELT M4 adaptive mirror. A similar mirror, unique around the world, had already been built for LBT by the Italian companies ADS and Microgate, achieving exceptional performances. These industries were in a very favourable position to be awarded the contract for the M4 construction: it is well known that they are the only ones in the world to hold the required *know-how* having shown that one of the most critical components of the E-ELT project is feasible. Two parallel studies were conducted and it turned out that the successful idea is the one proposed by ADS and Microgate in collaboration with INAF (see Attachments 1, 2 and 3).

A very competitive and cost-effective technique is that for the construction of the concave mirrors (about 800) that will be assembled in a mosaic forming the M1 primary mirror. The Italian firm Media Lario, developed from a spin-off originated by INAF to build X-ray optics for SAX in the early 90's, has achieved a very high level of qualification in the realization of components made of special materials, in particular mirrors, for space and ground-based applications (SAX, Swift, XMM, e-Rosita, MMT, ALMA, MAGIC and CTA). This firm has developed a new technology for the construction of mirrors on the basis of continuous know-how exchange with INAF (OABr) and it is going to propose it to ESO in a few weeks.

In parallel with the advanced telescope design, in the period 2007-2010 ESO funded a set of conceptual Phase A studies for focal plane instruments: 9 "scientific" instruments and 2 adaptive optics modules to complement the adaptive optics system integrated in the telescope itself. INAF had a fundamental role in these studies, contributing to the Phase A of MICADO and MAORY (currently ELT-CAM), SIMPLE and CODEX (currently ELT-HIRES), OPTIMOS (currently ELT-MOS), EPICS (currently ELT-PCS). Two studies (MAORY and SIMPLE) were led by an INAF PI, and in several studies INAF researchers and technologists covered primary roles (project manager, system engineer, project scientist). Part of these activities were further developed in the context of a specific project funded by the European Union's Framework Programme 7 ("Preparing for construction of the European Extremely Large Telescope", contract INFRA-2007-2.2.1.28), in which INAF was actively involved.

More studies funded by ESO are currently on going, conducted by INAF researchers and dedicated to the characterization and forecast of atmospheric parameters having a strong impact on astronomical observations, and on adaptive optics in particular (MOSE project), and to the study of high performance technologies for wave-front sensing in adaptive optics with natural stars only.

The activities for the consolidation of the consortia that will build the instruments are in progress. In this context INAF is strongly involved in the first light instrument ELT-CAM, formed by the sub-systems MAORY and MICADO: in the case of MAORY, INAF currently is the candidate lead institute of the project. INAF is also actively working to re-enforce its role in the consortia that will build the subsequent instruments (ELT-HIRES, ELT-MOS, ELT-PCS).

The T-REX project itself, funded for the first time in the framework of the call "progetti premiali 2011", has had and is having a fundamental importance, allowing INAF to acquire unique equipments to face the E-ELT instruments construction, to consolidate the involved research teams, to start research and development activities for the mitigation of the inherent risks of these projects, and to favour a network of excellence Italian firms operating in the field. In the first year the T-REX Operating Unit 1 (coordination) has decided to allocate most of the awarded funds to long-term investments, preparatory for the projects with the highest temporal priority and the highest success probability in ESO calls, but also well suited for subsequent exploitation by INAF. It has thus been decided to devote significant funds allocation to the activities related to the mirrors, rewarded by the contract assigned by ESO to ADS and Microgate (see attachment 1) and indirectly to INAF (see attachments 2 and 3), to the integration facility for MAORY (the instrument with Italian PI-ship close to be approved by ESO, see letter by ESO, attachment 6) and to the recruitment of young promising researchers that could learn the INAF excellence *know-how* and get adequately trained to propose themselves as experts in the forthcoming phases of construction and scientific exploitation of the E-ELT.

T-REX has also a leading role in establishing links between INAF and ESO on several aspects of the on-going initiatives in preparation for the E-ELT calls (the T-REX national coordinator has been and is still member of ESO committees) and in informing the whole Italian astrophysical community on the E-ELT project. A web site including the main information on the "progetto premiale" (<u>www.bo.astro.it/premiale.elt</u>) has been recently created; moreover T-REX has organized a national meeting devoted to informing the community about the E-ELT project and the related "progetto premiale". This meeting (held on 14 January 2013 at the University of Bologna) was attended by high level representatives of ESO, all T-REX responsibles and all the INAF executives (President, Administration Council, Science Committee, Scientific Director). All INAF researchers and associates (i.e. personnel from Universities and other Research Institutes) were also invited to attend. Considering the success of this event, we intend to repeat the meeting as soon as there is new relevant information for the community.

# 7 Project Layout

T-REX is a long-term project, started in 2012 in response to the 2011 call for *progetti premiali* and with natural duration of at least 3 years. It has a two-fold goal: 1) organize the activities to maximize the exploitation of the Italian scientific and technological excellences, and 2) have a triggering and pivotal role in the international context for the assignment of the ESO contracts. In this respect, its natural duration should be based on the ESO timescale for the approval of the various instruments and corresponding consortia. Without information on the ESO timescales (that depend also on third Countries) and on the Ministry (MIUR) policy about renewing approved projects, in the following we show the time distribution of T-REX activities only for the first year. Actually, possible additional years would have time organization absolutely similar to these ones, only possibly distributed in a different manner over the various WPs (as already applied from last year proposal to this one).

T-REX is organized with 6 Operating Units (OU), one (OU1) in charge of the project coordination, and each of the others devoted to the activities relative to each of the E-ELT instruments in which Italy is more involved. Some of the OUs are organized in sub-projects (WPs), related to distinct and specific activities, while others are naturally mono-thematic and have only one WP. The detailed scheme of the OUs and corresponding WPs is shown in the next figure:



| Month  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|--|---|---|---|---|---|---|---|---|---|----|----|----|
| OU 1 Project Management                      |   |   |   |   |   |   |   |   |   |    |    |    |
| OU 2 ELT-MIRRORS                             |   |   |   |   |   |   |   |   |   |    |    |    |
| OU 3 ELT-CAM                                 |   |   |   |   |   |   |   |   |   |    |    |    |
| WP 3.1 MAORY                                 |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.1.1 Instrument preliminary design        |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.1.2 R & D                                |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.1.3 Lab preparation                      |   |   |   |   |   |   |   |   |   |    |    |    |
| WP 3.2 MICADO                                |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.2.1 Stellar populations                  |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.2.2 Properties of high redshift galaxies |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.2.3 Observation simulations              |   |   |   |   |   |   |   |   |   |    |    |    |
| WP 3.3 Atmospheric parameters                |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.3.1 Model validation                     |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.3.2 Project system forecast              |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.3.3 Measure and Meteo forecast []        |   |   |   |   |   |   |   |   |   |    |    |    |
| WP 3.4 Technology development []             |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.4.1 Conceptual study                     |   |   |   |   |   |   |   |   |   |    |    |    |
| WP3.4.2 Prototype implementation             |   |   |   |   |   |   |   |   |   |    |    |    |
| OU 4 ELT-HIRES                               |   |   |   |   |   |   |   |   |   |    |    |    |
| OU 5 ELT-MOS                                 |   |   |   |   |   |   |   |   |   |    |    |    |
| OU 6 ELT-PCS                                 |   |   |   |   |   |   |   |   |   |    |    |    |
| WP 6.1 Scientific design                     |   |   | ] | ] |   |   |   |   |   |    |    |    |
| WP 6.2 IFS Design                            |   |   |   |   |   |   |   |   |   |    |    |    |

The following table shows the timeframe of the activities of each OU and their WPs:

Table – Temporal breakdown of the activities of the various OUs e WPs

## 7.1 OU1: Coordination Unit and Project Management.

The Coordination Unit (OU1) is in charge of the general management of the T-REX project. OU1 is chaired and coordinated by the national PI (Tosi). Members of OU1 are the coordinators of the other Operating Units (Diolaiti, Garilli, Gratton, Pareschi, and Oliva in place of Origlia for a better geographical balancing), and experts selected because of their national or international roles: B. Marano (outgoing Italian delegate in the ESO Council, Faculty member at the Bologna University and responsible for the education activity in T-REX), A. Marconi (Chair of the Science and Technology Committee of ESO and Faculty member at UniFi), R. Ragazzoni (member of the ESO Project Science Team and leader of the Italian experts in Adaptive Optics), F. Zerbi (chair of the Office for Ground-based Infrastructures of the INAF Science Directorate).

OU1's task is to coordinate all the activities of T-REX, financial requests and distribution, verification of their proper use and of the outcome of the investments. In case the Ministry considers it appropriate, we can propose an independent and external evaluation committee. An additional task of OU1 is the relation with the major Institutions of interest for T-REX: first of all INAF and its Science Directorate, ESO, and the Universities involved in the formation activity of our project. OU1 is also in charge of coordinating the education and formation of undergraduate and graduate students in the various Universities collaborating with T-REX.

The Coordinator of each Operating Unit is responsible for its management. He/she presents to OU1 the needs of the various WPs of his/her Unit, participates to their discussion and evaluation, and is in charge of justifying to OU1 the use of the financial and human resources allocated to his/her Unit. We point out that 50% of the OU coordinators are women (Tosi, Origlia, Garilli).

This T-REX project plans conspicuous investments to purchase facilities and instrumentation for the development and the integration of the E-ELT instruments. This may represent a risk, since the ESO

instrumentation plan and the role of INAF in the E-ELT instrumental projects are not finalized yet. To mitigate this potential risk, we have decided to primarily invest in long lasting facilities, that can have more general exploitation, and can be useful also for other projects aiming at instrument development. Similarly, for the recruitment of postdocs and young personnel, we require skills and expertise that can be exploited in a flexible manner in a number of projects for the construction of astrophysical instruments.

One of the primary goals of T-REX is to favour the consolidation of INAF's role within the consortia created for the construction of the E-ELT instruments. For the first light instruments, MAORY and MICADO, part of E-ELT CAM, the situation is absolutely positive. Negotiations are well advanced and premises are excellent, as testified by the (attached) letter from Dr. Mark Casali, Head of the ESO Instrument Division. As for the instruments that will be implemented after first light (HIRES, MOS, PCS) INAF researchers and technologists, and INAF itself, are taking all the necessary actions to achieve the desired results. Negotiations and technical/scientific discussions are taking place with other European partners, with ESO, and within INAF. To ensure a high level position of INAF in these projects, we are strategically concentrating our efforts on the areas of INAF recognized excellences.

Another strategic goal of T-REX is to assess and consolidate the unique technological expertise existing in Italy, both in the framework of institutional research and of private enterprises. Our planned investments in R&D, both within INAF and in collaboration with highly specialized companies, may represent a risk, if there was no adequate budget return in terms of ESO contracts to Italian industries. Also in this case, the strategy we adopt to mitigate the risk is to concentrate on the Italian excellences. A good example is the contract for the design of the E-ELT adaptive mirror M4, recently assigned by ESO to an Italian industrial consortium (ADS & Microgate), as a result of the effort made in the last years by these companies in collaboration with INAF in a frontier area of astrophysical technologies.

|  | Total amount | Source | COFIN      | Incidence |
|--|--------------|--------|------------|-----------|
|  | foreseen     | FOE 7% | Other      | %         |
|  |              |        | Sources    |           |
| Staff                                  | 118.000      | 0      | 118.000(1) | 70,2%     |
| Stages and travels in Italy and abroad | 25.000       | 25.000 |            | 14,9%     |
| Publicity costs                        | 25.000       | 25.000 |            | 14,9%     |
| TOTAL                                  | 168.000      | 50.000 | 118.000    | 100%      |

Table – Cost breakdown for OU1 in the first year.

(1): 58.000 euro INAF staff and 60.000 euro University staff.

## 7.2 OU2: E-ELT MIRRORS

Coordinator: Giovanni Pareschi

Affiliation: INAF – Brera Astronomical Observatory

OU2 points at the development and consolidation of innovative technologies for the realization of the E-ELT Telescope. Innovative concepts and methods will be studied, with the participation of young researchers that are expected to bring enthusiasm and new ideas. The project aims to train PhD students and PostDoc researchers in the field of polishing technologies and innovative metrology. For this purpose the Brera Astronomical Observatory will provide to young researchers its present facilities (ion-figuring, metrological instrumentations, polishing machineries) and its laboratories and workshops with the support of expert technicians and engineers. In particular, OU2 requests the support for 2 PhD grants - to get started at the University of Insubria Astronomy and Astrophysics School of Doctorate (to which the Brera Astronomical Observatory is associated/*in consortium*) - devoted to the development of the MAORY prototype mirrors, and a PostDoc fellowship (Assegno di Ricerca).

OU2 aims to develop the technologies, to be validated with the realization of prototypes and demonstrators, for the production of the mirrors for the E-ELT telescope. Therefore, it is necessary to acquire the know-how for the polishing and figuring of precision mirrors, as well as the metrology needed for the high precision characterization of the reflecting surfaces. One of the main goals is then to transfer the developed know-how to Italian Industries and to support them in the production phase, in particular for the calibration activities. To this end we will study and further develop few technologies on which we are already working but that are not yet completely developed:

- Computer Generated Holograms (CGH) for interferometric measurement of large aspherical mirrors. CGH can be conceived as a binary representation of an interferogram or a hologram, that will be registered if the perfect aspheric wavefront interferes with the reference beam. CGH are therefore used as null sensor in the interferometric measurements and smartly substitute the optical systems based on lenses. INAF is not only acquiring the capability to design and realize standard CGH– aiming particularly to the calibration of the adaptive thin mirror M4 to be realized in Italy for E-ELT, but it is also fine-tuning innovative techniques based on photosensitive polymeric materials in order to "rewrite" the CGH in a simple and efficient way.
- At the same time INAF is studying and implementing high precision profilometry techniques, complementary to the interferometric techniques for the characterization of the mirror surfaces. These characterizations will provide additional measurements and more information compared to those obtainable from the usual/simple profilometer. Moreover, they will be essential in those cases for which the interferometry measurements are difficult perform (e.g. because of air turbulence).
- INAF is re-fining the use of high precision polishing and figuring techniques on surfaces of large dimensions, also aspheric, using the bonnet polishing and the Ion figuring with facilities installed at the Brera Observatory.

More specifically, the activities will concern:

- Calibration and Characterization of the 2.5 meters adaptive mirror M4/EELT, equipped with "voice coil" actuators, with system based on the technology developed and implemented in the last years by INAF and collaborating industries (ADS International e Microgate). ESO already started the contractual activities with the Italian industries. Meanwhile INAF will perform the characterizations and calibration of the system. For this reason the use of CGH technology (in particular the "Rewriteble" CGH) with INAF know-how will be of fundamental importance.
- Development of a 1.4 m mirror prototype fully representative of the elements (about 800) that will compose the E-ELT 39 m primary mirror M1. This activity is carried out in collaboration with Media Lario Technologies (Lecco) and Glyndwr University (UK). In particular INAF will perform the ion beam figuring operations on the mirror, previously developed by the other two partners, and also the final metrology. The results will be presented to ESO to demonstrate the technological readiness for an Italian production chain able to procure the M1/EELT mirrors.
- Development of prototypes and breadboards of the non-adaptive mirrors to be implemented in the optic chain of the multi-conjugate adaptive system MAORY/EELT. The realization of these mirrors presents some critical aspects that have to be overcome at a pre-industrial level. INAF will take the responsibility for the polishing with the bonnet and for the high precision figuring with the Ion beam, using the facilities installed at the Brera Observatory.

The activity will be carried out in collaboration with the involved industries that are interested to the developments connected to the E-ELT.



Figure 2. Left: view of the E-ELT with the laser beams projected to the mesospheric sodium layer, producing artificial sources for the measurement and correction of the atmospheric turbulence. (© ESO/L. Calçada). Right: view of the telescope optics. Note the primary mirror, the support of the secondary mirror and the tower in the centre of the primary that holds the M4 (adaptive) and M5 (used for the image stabilization) mirrors. (© ESO).

|   | Total amount | Source  | COFIN      | Incidence |
|---|--------------|---------|------------|-----------|
|   | foreseen     | FOE 7%  | Other      | %         |
|   |              |         | Sources    |           |
| Staff                                   | 350.000      | 200.000 | 150.000(1) | 36,6%     |
| Fellowships and grants                  | 170.000      | 100.000 | 70.000(2)  | 17,8%     |
| Other services                          | 80.000       | 80.000  |            | 8,4%      |
| Equipment, instrumentation and software | 50.000       |         | 50.000(3)  | 5,2%      |
| Materials                               | 50.000       | 50.000  |            | 20,9%     |
| Infrastructures                         | 200.000      | 100.000 | 100.000(3) | 3,1%      |
| General expenses                        | 30.000       |         | 30.000(3)  | 3,1%      |
| Stages & travels                        | 15.000       | 15.000  |            | 1,6%      |
| POE expenses                            | 10.000       | 5.000   | 5.000(3)   | 1,1%      |
| TOTAL                                   | 955.000      | 550.000 | 405.000    | 100%      |

#### Table – Cost breakdown for OU2 in the first year.

- (1) 150,000.00 euro: staff salaries at their Institution
- (2) 70,000.00 euro: personnel already trained with other projects
- (3) OABr's FOE

Man-power: OU2 includes 8 INAF scientists, all at OABr.

### 7.3 OU3: E-ELT CAMERA

Coordinator: Emiliano Diolaiti

Affiliation: INAF Osservatorio Astronomico di Bologna

ELT-CAM is one of the approved first light instruments for the E-ELT. It is formed by two sub-systems: the MAORY adaptive optics module and the infrared imaging camera MICADO. MAORY is a multi-conjugated adaptive optics module designed for the real-time compensation of the image degradation effects due to the

atmospheric turbulence and the wind action on the telescope. The compensation is achieved by three deformable mirrors: the telescope's M4 adaptive mirror (complemented by the image stabilisation mirror M5) and two adaptive mirrors integrated in the MAORY module itself. The measurement of the atmospheric turbulence effects is performed by a wavefront sensing system based on up to six artificial sources ("Laser Guide Stars") and three natural sources. MICADO, thanks to the turbulence correction provided by MAORY, will be able to acquire images with exceptional angular resolution, achieving excellent astrometric and photometric precision. ELT-CAM will allow to study the proper motions of the stars close to the Black Hole in the center of the Milky Way, orbiting with estimated speed of 0.1c (c: speed of light), the dynamical effects produced by black holes and dark matter haloes, the features of resolved stellar populations in conditions and galaxies never achieved so far.

INAF has given a crucial contribution to the preliminary studies of the E-ELT instrumentation, funded by ESO: it has led the phase A of the MAORY project and has been involved in the MICADO project studying the science cases to provide the requirements for the instrument design. INAF researchers are currently conducting studies funded by ESO devoted to the characterization and forecast of the atmospheric parameters which have a fundamental impact on astronomical observations and adaptive optics in particular (MOSE project), and to the study of high performance techniques for wavefront sensing in adaptive optics with natural stars only. INAF is currently consolidating its position in the context of the next phases of construction of the E-ELT instrumentation. As recalled in the letter by Dr. Mark Casali of ESO attached to this proposal, advanced negotiations are in place to define the international Consortium and the management plan for the MAORY project. At the end of the negotiations, INAF will be the lead institute of the project and will receive from ESO an overall funding of about 19 M€ over about 10 years to cover the cost for the purchase of the various parts of the instrument and the project capital costs. The effort put in the project by INAF in terms of personnel will be compensated by ESO with guaranteed observation time at the telescope.

The first year of the proposed T-REX project overlaps with the first year of the phase B of the projects for the construction of the ELT-CAM sub-systems MAORY and MICADO. This is a crucial phase, in which the design choices adopted in phase A have to be consolidated or re-considered and ambitious 10-years projects start. The primary goal of T-REX is to support this phase, allowing INAF to acquire the necessary equipments for the instrument construction, to consolidate the positions of the non-staff personnel involved in the project, to start the design and research and development activities in preparation for these instrument projects.

On a three years time span we foresee the completion of the design of MAORY and MICADO (phases B and C), the completion of the necessary research and development activities and the purchase of the long-lead hardware components. In the following 5-6 years we foresee the construction and integration of the instruments (phase D), that in the case of MAORY will be performed in Italy with a deep involvement of Italian industries. The last step towards the realization of MAORY and MICADO (phase E) will be the installation at the telescope and the integration of the two sub-systems together in the ELT-CAM instrumental facility in view of the E-ELT first light.

The realisation of a complex instrument such as ELT-CAM and its sub-systems requires a multi-disciplinary approach comprising: 1) design and integration of instrumentation including optical, mechanical and electronics parts, opto-electronics devices, advanced control systems; 2) study of science cases to derive the design requirements; 3) characterisation of the properties of the atmosphere and the related disturbances which have an enormous impact on ground-based astronomical observations; 4) research and development of technological solutions allowing the mitigation of the intrinsic risks of such a complex project. The ELT-CAM OU3 is subdivided into four WPs, devoted respectively to MAORY (WP 3.1), MICADO (WP 3.2), characterisation and forecast of atmospheric parameters (WP 3.3) and development of innovative technologies for adaptive optics (WP 3.4).



Figure 3. Layout of the science instruments on the E-ELT Nasmyth platform. On the right, one can see the MAORY multi-conjugate adaptive optics module and, underneath, the cryostat of the MICADO imaging camera, shown open for maintenance operations. On the upper right part of the picture, behind the support structure, the "tower" holding the M4 adaptive mirror can be seen (© ESO).

## 7.3.1 WP 3.1 MAORY

Responsible: Emiliano Diolaiti Affiliation: OABo Involved institutes: OABo, IASBo, OAA, OABr, OACN, OAPd, University of Bologna

WP 3.1 is devoted to the preliminary design of the MAORY multi-conjugate adaptive optics module, sub-system of ELT-CAM, and to the performance of important preparatory activities such as research and development and set up of the laboratory that will be used for the instrument integration and test. The activities of WP 3.1 are described in detail in the following.

#### WP 3.1.1 Instrument preliminary design

The multi-conjugate adaptive optics module MAORY has been designed at conceptual level in the framework of a two-years phase A study. The objective of WP 3.1.1 is to consolidate the conceptual design considering possible new technical and scientific high-level requirements. The design consolidation implies the verification and, if necessary, the modification of the previously adopted technical solutions, and the identification of the areas requiring dedicated research and development. The activities of WP 3.1.1 comprise project management, systems engineering, including the analysis and optimisation of the adaptive optics system integrated in MAORY, optical engineering, mechanical engineering, electronics engineering, thermal engineering, software engineering.

#### WP 3.1.2 Research and development

The adaptive optics system integrated in MAORY is based on artificial (laser) and natural sources for the realtime measurement of the atmospheric turbulence affecting the optical wavefront. We intend to develop a laboratory activity devoted to the experimental study of the interactions between the two channels (laser and natural sources). For the wavefront compensation, the MAORY module also uses, in addition to the telescope's M4 adaptive mirror, two local deformable mirrors that represent crucial sub-systems. The mirrors of the current baseline design are based on piezo-electric actuators. We intend to start a research and development activity in collaboration with Italian firms specialized in this field to investigate alternative solutions and mitigate the risks of the baseline design.

#### WP 3.1.3 Laboratories set-up

Part of the T-REX project funds will be devoted to the refurbishment of the already existing INAF laboratories that will be used in the integration phase of MAORY and of its sub-systems. The investments concern the purchase of instrumentation that cannot be reimbursed by ESO as a project capital cost. The objective of WP 3.1.3 is to define the requirements of these equipments on the basis of design choices defined by WP 3.1.1 and carry out the procurement.

## 7.3.2 WP 3.2 MICADO

Responsible: Renato Falomo Affiliation: OAPd Involved institutes: OAPd, IASFMi, University of Padova

WP 3.2 is devoted to the study of science cases and the evaluation of the performances of MICADO, subsystem of ELT-CAM, in the framework of the instrument design consolidation. The activities of WP 3.2 are detailed in the following.

#### WP 3.2.1 Study of stellar populations in galaxies

The analysis of Colour-Magnitude Diagrams (CMD) of resolved stars is one of the E-ELT key projects. We plan to study in detail with end-to-end simulations the feasibility of some specific science programs:

1. Measurement of metallicity distribution from the photometric analysis of Giant Branch stars in the central regions of elliptical galaxies, up to and beyond the Virgo cluster.

2. Derivation of the star formation history from the analysis of CMDs sampling bright stars down to the horizontal branch.

3. Investigation of the possibility to detect multiple stellar populations in CMDs of extragalactic globular cluster.

#### WP 3.2.2 Properties of high redshift galaxies

Study of the evolution of the properties of galaxies as a function of cosmic epoch: the angular resolution and sensitivity of ELT-CAM allow the investigation of the morphology and structural features of galaxies as far as redshift 2-3.

#### WP 3.2.3 Simulation of ELT-CAM

Evaluation of the performance of the combination of E-ELT, MAORY and MICADO in various configurations and simulation of images obtained for different science cases. Implementation of specific software for the simulation of instrument effects that can affect image quality.

#### 7.3.3 WP 3.3 Atmospheric parameters

Responsible: Elena Masciadri (affiliation: OAA) for WP 3.3.1 and WP 3.3.2, and Valentina Zitelli (affiliation: OABo) for WP 3.3.3

Planning scientific observations is crucial to guarantee the efficient use of a future generation telescope such as the E-ELT. The evaluation and forecast of atmospheric conditions are essential elements for planning the observations. The objective of WP 3.3 is the study of methods for the forecast of atmospheric parameters based on a) "meso-scale" atmospheric model and hydrodynamic codes already developed in the framework of the MOSE project funded by ESO (WP 3.3.1 and 3.3.2) and b) infrared observations of the Earth atmosphere (WP 3.3.3). The final goal is the implementation of an automatic forecast system to be installed at the E-ELT site. In the meantime WP 3.3 encloses all the necessary competences to interpret the properties of the atmosphere that affect the design of ELT-CAM. The activities are detailed in the following.

#### WP 3.3.1 Model validation

Validation and calibration of the atmospheric model by comparison with measurements of different atmospheric parameters (temperature, pressure, wind speed and direction, optical turbulence).

#### WP 3.3.2 Operational forecast system design

Conceptual definition of an automatic system for the forecast of the optical turbulence, including retrieval of input data, forecast process architecture, algorithms for optical turbulence parameterization on relevant scales for an astronomical telescope, retrieval of output products and final distribution.

#### WP 3.3.3 Evaluation and forecast of weather conditions from ground-based and satellite data

The measurements of the Earth atmosphere emission obtained from satellites at different infrared wavelengths have been successfully used to evaluate critical weather parameters such as presence of clouds, dust and fog. The same methods can be applied to the forecast of these parameters. The objective of this WP is to define the conceptual design of an automatic forecast system, developing the necessary algorithms.

## 7.3.4 WP 3.4 Technology developments for adaptive optics

Responsible: Roberto Ragazzoni Affiliation: OAPd

WP 3.4 is devoted to the development of wave-front sensing and compensation technologies for a possible application to the MAORY module: static modulation of a "pyramid" wave-front sensor and utilization of a stationary wave cavity for wave-front correction. The pyramid wave-front sensor, invented by the responsible of WP 3.4, is a well-known and demonstrated technology: the possibility to extend its dynamic range by means of simple modulation methods would make it an excellent technical solution for MAORY. The demonstration of stationary wave cavities as a technology for wave-front compensation could be the starting point for interesting future technology developments. The activities of WP 3.4 are subdivided as follows.

#### WP 3.4.1 Conceptual study

Conceptual definition of the prototypes for the demonstration of the pyramid wave-front sensor with static modulation and of the stationary wave cavity for wave-front compensation. Development of a simplified model for the working principle of the resonant cavity.

#### WP 3.4.2 Prototypes implementation

Integration of the pyramid wave-front sensor prototype with static modulation; performance of the tests concerning sensitivity, dynamic range and linearity of the wave-front measurements for different levels of modulation. A simple resonant cavity prototype is built and used for experiments concerning wave-front perturbation and control.

|  | Total amount | Source    | COFIN         | Incidence |
|--|--------------|-----------|---------------|-----------|
|  | foreseen     | FOE 7%    | Other Sources | %         |
| Staff                                    | 1.142.000    | 100.000   | (*) 1.042.000 | 3         |
| Senior postdoocs                         | 440.000      | 440.000   | 0             | 20,2%     |
| Education and Formation                  | 120.000      | 120.000   | 0             | 4,2%      |
| Other services from third parties        | 243.000      | 243.000   | 0             | 8,5%      |
| Instrumentation, facilities and software | 776.000      | 746.000   | (**) 30.000   | 28,0%     |
| Stages and travels in Italy and abroad   | 118.000      | 108.000   | (+) 10.000    | 4,1%      |
| Publicity costs                          | 3.000        | 3.000     | 0             | 0,01%     |
| TOTAL                                    | 2.842.000    | 1.760.000 | 1.077.000     | 100%      |

The following table shows the cost breakdown of OU3 ELT-CAM.

#### Table - Cost breakdown of OU3 in the first year.

(\*) Including 50 k€ FP7 OPTICON funds

(+) ESO funds for the MAORY project

<sup>(\*\*)</sup> FP7 OPTICON funds

Man-power: OU3 includes 42 people, distributed over the following institutes: OAA, OABo, OABr, OACN, OAPd, IASFBo, IASFMi, UniBo, UniPd.

#### International collaborations.

The E-ELT CAMERA OU has international collaborations with institutes based in the following countries: Finland (Finnish Meteorological Institute), France (Observatoire de Paris – LESIA; Observatoire de Paris – GEPI; Office National d'Etudes et de Recherches Aerospatiales; Centre National des Recherches Meteorologiques, Toulouse; Laboratoire Lagrange, Observatoire de la Cote d'Azur, Nice), Germany (European Southern Observatory; Max-Planck Institute for Extraterrestrial Physics; Max-Planck Institute for Astronomy; Universitaets-Sternwarte Munich), Netherlands (Nederlandse Onderzoekschool Voor Astronomie), United Kingdom (Durham University), Spain (Istituto Astrofisico de Canarias).

## 7.4 OU4: E-ELT HIRES.

Coordinator: Livia Origlia Affiliation: INAF – Osservatorio Astronomico di Bologna

The Operating Unit E-ELT-HIRES develops the scientific cases and the instrumental concepts for a high-resolution spectrograph. This is one of the first generation instruments foreseen in the ESO roadmap for the E-ELT. The high-resolution spectrograph will be fiber-fed and will simultaneously cover a very broad spectral range, from visual to near-infrared wavelengths (0.37-2.4 microns). Within the Astrophysical context foreseen for the next decade, HIRES will be a powerful and unique instrument in the following fields of research

- Physical and chemical characterization of the atmospheres of extra-solar planets
- Chemistry and kinematics of the intergalactic medium and stellar populations
- Evolution of galaxies
- The Universe at high red-shifts and the possible evolution of physical constants

Since many years, the Italian astronomical community has been remarkably active in high-resolution spectroscopy at visual and near infrared wavelengths, both scientifically and technologically. They participated and leaded the projects for the construction of the spectrographs for the TNG (SARG, GIANO) and for the ESO-VLT (UVES-FLAMES, XSHOOTER, ESPRESSO, CRIRES). They have been deeply involved in the phase-A studies of the first-generation spectrographs for E-ELT. INAF has been the leading institute of the international consortium of SIMPLE, the infrared high-resolution spectrograph, and participated to CODEX, the visual high-resolution spectrometer.

The Operating Unit E-ELT-HIRES analyzes and evaluates possible synergies with other E-ELT instruments. It organizes the necessary work to properly respond to the ESO calls for proposals. It operates for strengthening the position of INAF in the international framework.

The main R&D activities are as follows

- 1. Development of software for the simulation and reduction of echelle spectroscopic data
- 2. Design and tests of diffraction gratings of large sizes (construction and mosaicing)
- 3. Design and tests of optical, mechanical and cryogenic systems to optimize the stability of the spectrographs
- 4. Development of opto-mechanical systems to optimize the coupling between optical fibers and spectrographs
- 5. Tests of special optical fibers, with high transmission in the infrared (including fluoride polymers, which could be used in telecommunication)
- 6. Design and development of single conjugate adaptive optics (SCAO) systems based on natural stars wavefront sensing systems
- 7. Feasibility study of a polarimetric module
- 8. Feasibility study of new architectures for instrument control systems

|  | Total Amount | Source  | COFIN         | Incidence |
|--|--------------|---------|---------------|-----------|
|  | foreseen     | FOE 7%  | Other sources | %         |
|  |              |         |               |           |
| Staff personnel                        | 555.000      | 52.000  | 503.000       | 38,9%     |
| Education and Formation                | 144.000      | 144.000 |               | 10,0%     |
| Contracts                              | 173.000      | 160.000 | 13.000        | 12,1%     |
| Other services from third parties      | 132.000      |         | 132.000       | 9,2%      |
| Instrumentation, facilities and        | 364.000      | 364.000 |               | 25,4%     |
| software products                      |              |         |               |           |
| Stages and travels in Italy and abroad | 60.000       | 60.000  |               | 4,2%      |
| TOTAL                                  | 1.428.000    | 780.000 | 648.000       | 100%      |

Table – Cost breakdown for OU4 in the first year.

Man-power: OU5 includes 39 staff scientists, distributed over the following institutes: OAA, OABo, OABr, OACN, OACt, OARm, OATs, UniCt and UniPd.

International collaborations: The E-ELT-HIRES Unit actively collaborates with the following Countries and Institutes: Chile (Pontificia Universidad Catolica de Chile), Germany (ESO, Thuringer Landessternwarte Tautenburg, Institute fuer Astrophysik Goettingen, Leibniz Institute for Astrophysics Postdam), UK (Institute of Astronomy, University of Cambridge), Spain (Instituto de Astrofisica de Canarias), Sweden (Uppsala Astronomical Observatory), Switzerland (Observatoire Astronomique de l'Universite de Geneve).

## 7.5 OU5: E-ELT MOS

Coordinator: Bianca Garilli Affiliation: INAF-IASF Milano

Multi-Object Spectrographs (MOS), either slit or fiber fed, are the most fundamental instruments in the domain of observational cosmology: they are the only instruments capable of carrying out large spectroscopic surveys, which are the starting point for any research on the origin and evolution of the luminous matter in the Universe. In fact, this activity requires observations of extremely weak objects having a surface density of the order of  $\sim 1$ per square arc-minute to build samples representative (i.e. a few hundreds of thousand galaxies and AGNs) of the whole Universe at less than one tenth its present age. For this reason, observational cosmology needs a large field spectrograph, covering the near infrared wavelength range, with high multiplexing capabilities. A high throughput is crucial, while a moderate ( $R \sim 3000$ ) spectral resolution is sufficient. Among the various instruments proposed for E-ELT, OPTIMOS DIORAMAS (slit based spectrograph) together with OPTIMOS EVE (fiber based spectrograph) is the one which best meets these requirements. IASF-Milano and OA-Roma were both active participants to the phase A study of OPTIMOS Dioramas, and are currently partners of the MOONS phase A study, a NIR spectrograph for the VLT. Both structures have a long standing experience in observational cosmology: IASF Milano was one of the partners in the consortium which built VIMOS@VLT, which is still the MOS with the highest multiplexing at the VLT, and is internationally known for its expertise in developing software dedicated to this kind of instruments: from the observation preparation tools up to reduction and analysis software packages. OA-Roma has built the large field cameras for LBT, and in the last years the technological group has further advanced and has excellent expertise in the domain of electronics, control systems and cryogenics. From the scientific point of view, both institutes are involved in the largest extragalactic spectroscopic surveys: from VVDS and GOODS, to zCosmos and CANDELS.

The activity of OU5 MOS can be divided into 3 sub-packages:

#### WP 5.1: Scientific design

Responsibility: Laura Pentericci Affiliation: OARm

A spectroscopic survey conceived to investigate evolution of galaxies between redshift 3 and the re-ionization epoch (redshift between 6 and 10), as well as the re-ionization processes themselves, must be based on a reliable and effective selection method. Classical selection techniques, like the *drop-out technique* can and should be refined by making use of all the possible photometry nowadays available from the ground (from visible to NIR bands). This WP has the goal of 1) ameliorating the currently available selection techniques through improvement of the Spectral Energy Distribution (SED) templates required, both using the latest available observations and improving the theoretical models involved; 2) finding the best combination between catalogue extension and limiting magnitude (in the different bands) in order to obtain statistically meaningful samples for the different diagnostics (e.g. luminosity or mass function); 3) set up a full set of scientific requirements for an E-ELT MOS; 4) verify the precision with which the galaxy formation epoch and the mass building can be measured.

#### WP 5.2: Optimisation algorithms

Responsibility: Bianca Garilli Affiliation: IASF-Mi

Given a scientific goal, and consequently a catalogue of potential targets, the first step is to devise a survey strategy and prepare the observations in order to maximize the number of observed sources, taking into account the instrumental hardware characteristics. When the number of observable targets is of the order of some hundreds over few thousand potential targets per pointing, the manual approach is not viable. At the time of VIMOS, we have already shown that the design and development challenge lies in the extremely high number of possibilities (on the order of some hundreds of billions). The case of MOONS is even more extreme since it has a higher number of degrees of freedom. The approach will be the same used in the case of VIMOS (salesman algorithm) adapting it to the circular geometry of the field of view of the instrument. It will be possible to use the final software program either for fiber or slit based instruments, thus it is of immediate use for the MOS that will be chosen for E-ELT.

#### WP5.3: Cryogenic positioners for spectroscopy

Responsibility: Fernando Pedichini Affiliation: OARm

The technological issues of the T-REX project are partially similar to what OARoma is already developing for the MOONS project with ESO and therefore their financing guarantees a strong synergy between both projects. Here is a short list of such research lines and the Italian companies with which we will interact: 1) metrology of the opto-mechanical components and of the optical fiber positioners. 2) Development of micro-actuators and micro-encoders to position opto-mechanical components and optical fibers in a cryogenic environment, in collaboration with Esacrom srl, Imola, Hiperteach srl and Forestal srl, Rome. 3) Study of the local correction for seeing through MEMS actuators: realization of a local adaptive optics in subfields of a few arcsecs for the E-ELT telescope, where a GLAO correction is already present; in collaboration with Astrel srl Rome. 4) Realization of the whole control and of the drivers of what proposed above; in collaboration with National Instruments Italia.

|  | Total amount | Source  | COFIN         | Incidence |
|--|--------------|---------|---------------|-----------|
|  | foreseen     | FOE 7%  | Other Sources | %         |
| Staff                                    | 176.500      | 50.000  | 126.500       | 54,1%     |
| Senior postdocs                          | 70.000       | 70.000  |               | 21,4%     |
| Instrumentation, facilities and software | 70.000       | 70.000  |               | 21,4%     |
| Stages and travels in Italy and abroad   | 10.000       | 10.000  |               | 3,1%      |
| TOTAL                                    | 326.500      | 200.000 | 126.500       | 100%      |

Table – Costs breakdown for OU5 in the first year.

Man Power: OU5 includes 13 participants, distributed over the following institutes: IASFMi and OARm.

#### International collaborations

The ELT-MOS Operating Unit has international collaborations with Institutes in the following countries: France (Laboratoire d'Astrophysique de Marseille, Observatoire de Paris), Germany (ESO, University Observatory Munich), UK (University of Cambridge, UK ATC Edimburgh), Portugal (CAAUL Lisbona), Switzerland (ETH Zurich).

## 7.6 OU6. E-ELT PCS

Coordinator: Raffaele Gratton Affiliation: INAF – Osservatorio Astronomico of Padova

PCS is one of the instruments included in the ESO road-map for E-ELT. It is designed to detect and study extra-solar planets, and in particular terrestrial planets in the habitability zone. This is a primary science goal of E-ELT. In order to achieve the extremely high required contrast (up to  $10^9$  at <0.1 arcsec from the star), PCS uses an extreme adaptive optics system integrated within the instrument, to complement the telescope adaptive optics. This system will be able to achieve extremely high compensation of the atmospheric turbulence in the spectral range 0.6-1.65 µm, within a restricted field of view, using as reference the star around which the planet is orbiting. In addition, PCS includes a diffraction suppression module (either a coronagraph or an apodizer) and two scientific instruments: an integral field spectrograph (IFS) for the near IR (0.95-1.65 µm) and an imager/polarization analyzer for the optical range (0.6-0.95 µm). These two instruments will not only provide scientific information, but also allow reaching the photon noise limit by suppressing the residual speckle noise using differential imaging techniques.

PCS stems from the experience acquired in the construction of SPHERE at VLT (first light expected during autumn 2013) and from the feasibility study EPICS, done during the period 2007-2009. INAF has important responsibilities in SPHERE (scientific design, IFS construction and implementation, instrument control software). Within EPICS, INAF had responsibility of the scientific design (R. Gratton, Instrument Scientist) and of the design of an IFS based on a micro-lenses scheme, analogous to the one INAF has built for SPHERE at VLT. EPICS study revealed the need of a further research and development phase prior to instrument construction. PCS is in this phase. Within this picture, INAF still has the same responsibilities hold for EPICS, with an extension to an image slicer based design for the IFS, to be done at Osservatorio Astrofisico di Catania, in collaboration with the University of Oxford (which leaded this area for EPICS).

More specifically, the WP PCS activities will be:

#### WP 6.1 Scientific design

Responsibility: R. Gratton Affiliation: OAPd

We will update the scientific design of PCS taking into account new developments in extra-solar planet field (distribution of planets as a function of stellar properties; mass, radius and separation of the planets from the star; planetary systems architecture; planets structure and atmospheres) and of the expected performances of PCS. This analysis will be done using Monte Carlo techniques and will be used to set the scientific specifications for PCS. What is actually feasible in a reasonable time horizon for PCS (mid of next decade) will be considered. In particular, we will explore the impact of methodologies that allow reduction of the extremely challenging specification for the deformable mirror, at the expenses of a reduction of the area around the star where adaptive optics will achieve an extremely good correction. In addition, we intend to study limiting performances for different algorithms for speckle noise calibration (such as spectral, angular and polarimetric differential imaging) and what can be achieved using techniques like the Principal Component Analysis, widely used in the treatment of medical images but still not common in astronomy.

#### WP 6.2 IFS Design

Responsibility: S. Scuderi Affiliation: OACt

In this work-package, the existing design for IFS developed within EPICS – both based on micro-lenses and on image slicers – will be re-examined and optimized for PCS. To this purpose, we will build on the experience we are acquiring using IFS on SPHERE. Namely, we will construct an extensive noise model which will allow

setting the technical specifications for the instrument. We will evaluate the pro's and con's of either a completely cryogenic IFS, such as that adopted in the American GPI project, or an instrument where only detector and a cold filter are cool, as in the case of SPHERE. Speckle calibration will be considered carefully. Finally, complete opto-mechanics design will be prepared for the two schemes, with a comparison of performances and costs.

|                                       | Total amount | Source  | COFIN         | Incidence |
|---------------------------------------|--------------|---------|---------------|-----------|
|                                       | foreseen     | FOE 7%  | Other sources | %         |
| Staff                                 | 94.000       |         | 94.000        | 37,0%     |
| Education and Formation               | 140.000      | 140.000 |               | 55,1%     |
| Instrumentation and software products | 5.000        | 5.000   |               | 1,9%      |
| Stages e travels in Italy and abroad  | 15.000       | 15.000  |               | 6,0%      |
| TOTAL                                 | 254.000      | 160.000 | 94.000        | 100%      |

#### Table – detailed costs for OU6 in the first year.

Man-power: OU6 includes 8 participants, distributed over the following institutes: OACt, OAPd, and UniCt.

#### International collaborations

The ELT-PCS Operating Unit has international collaborations with Institutes in the following countries: France (Laboratoire d'Astrophysique de l'Observatoire de Grenoble, d'Astrophysique de Marseille, Observatoire de Paris - LESIA), Germany (ESO), United Kingdom (University of Oxford), Netherlands (NOVA, Universities of Amsterdam and Utrecht), Switzerland (ETH Zurich).

# 8 Project Costs

The project timeline is 3 years (besides the year already funded in response to the 2011 call) and its total cost is 22 Meuro, temporally distributed as reported in the table below.

|                       | 2013     | 2014  | 2015  |
|-----------------------|----------|-------|-------|
| INAF                  | 1.473    | 1.500 | 1.500 |
| MIUR                  | 3.500    | 3.500 | 3.500 |
| Other funding sources | 1.000(*) | 3.000 | 3.000 |
| TOTAL                 | 5.973    | 8.000 | 8.000 |

(\*) contribution of external participants (Universities and industries)

#### Table – Summary of the project total cost.

For the first year, according to the present proposal, costs including the requests from the various Operative Units (OU) can be summarized as follows.

|                               | Total amount | Source    | COFIN         | Incidence |
|-------------------------------|--------------|-----------|---------------|-----------|
|                               | foreseen     | FOE 7%    | Other sources | %         |
| Staff                         | 2.280.000    | 302.000   | 1.978.500     | 38,17%    |
| Contracts                     | 988.000      | 850.000   | 138.000       | 16,54%    |
| Education and formation       | 404.000      | 404.000   | 0.000         | 6,76%     |
| Scientific consultancy        |              |           |               |           |
| External partners             | 455.000      | 323.000   | 132.000       | 7,62%     |
| Hardware, supply and software | 1.285.000    | 1.205.000 | 80.000        | 21,51%    |
| Materials                     | 50.000       | 50.000    | 0.000         | 0,84%     |
| Infrastructures               | 200.000      | 100.000   | 100.000       | 3,35%     |
| Consumables                   | 30.000       | 0.000     | 30.000        | 0,50%     |
| Travels and meetings          | 243.000      | 233.000   | 10.000        | 4,07%     |
| Publicity costs               | 38.000       | 33.000    | 5.000         | 0,64%     |
| TOTAL                         | 5.973.000    | 3.500.000 | 2.473.500     | 100%      |

Table – Summary of the costs for the first year.

#### 8.1 Financial return

The T-REX financial return is twofold: a) an immediate return in the form of ESO contracts and other European sources of funding (e.g. the UE, international consortia) to INAF and to the Italian industries, and b) a more general return in terms of education and know-how (less quantifiable but of primary importance) of new generations of scientists and engineers who will participate first to the construction and then to the exploitation of the largest telescope in the word, contributing to diffuse the *Made in Italy* in Europe and worldwide.

The high chances of type a) return can be evaluated taking into account that, during the design phase of the E-ELT, ESO already invested 48 Meuro for industrial contracts, of which 8.3 Meuro went to Italian companies. In the last few months Italy obtained a contract to AdOptica (Attachment 1) of 3.183.400 euro (399.800 to INAF) for the design of the M4 mirror and a contribution of 198.000 euro to INAF from the European Consortium Opticon for the study of Maory (Attachments 4 e 5). When Maory is finally approved by ESO, a 10 years contract of 19 Meuro will become a reality. This budget will be spent within Italian companies and INAF. The final decision will be taken in a few months and T-REX represents a crucial element for a successful negotiation with ESO. Similarly, if Italy obtains the PI-ship of the international consortium that will build the HIRES spectrograph, it will get a few tens Meuro funding from ESO.

Together with these likely funding sources, one can expect that the investments and the activities within the T-REX project will bring new commitments and contracts from other international institutions that may need the top-level quality of our advanced technology For example, the interest of the American astronomical consortia for our adaptive optics technology and the overall INAF know-how in the field is matter of fact.

Regarding the more general return of type b), it is worth noticing how important is investing in education and excellence not only for the scientific and technological but also for the social and economical advancements of a Nation. Modern and advanced countries like France, UK, The Netherlands have been investing in education and research since many years, and they are obtaining a huge economic pay-back in terms of European grants and overall social advancement. In this respect, T-REX can significantly contribute to reverse the tendency of brain drain and attract young talents. We also note that with the new rules for the PhD courses, the T-REX project can play a major role to maintain alive PhD courses in Astronomy, by funding 7 positions in 4 Universities.

Finally, we like to recall the possible economic impact of T-REX in fields other than astronomical technology, (see the paragraph on Potential Applications, below). As already mentioned, astronomy is providing tools that have a wide application and commercial value, like lenses and CCD cameras. INAF promoted several activities for the technological innovation that lead to projects and patents also proposed to the Ministry of Economic Development, like cryogenic systems, digital devices for neural networks, devices to quickly localize tumor sentinel lymph nodes as traced with radio-nuclides etc.. Within T-REX we foresee to contribute to ophthalmology with our advanced optical systems, to renewable energy applications with high performance solar concentrators and to the study of climate variation with our measurements and modeling of the Earth atmosphere (see WP 3.3).

## 9 State of the art and expected results

#### 9.1 State of the art

The European Roadmap for Research Infrastructures (ESFRI) 2008 identified as one of the top priorities the construction of the largest telescope in the world (E-ELT) that will revolutionize our understanding of the Universe and its constituents, from primordial galaxies to extrasolar planets with habitable conditions. E-ELT is an ESO project. Italy is an ESO member since 1982 and it has been always very active in the scientific exploitation of the existing instruments as well as in the development of new facilities. Italy has been crucial to the approval of the E-ELT project by the ESO Council, and INAF is significantly contributing to the Italian

fraction of the participation costs. It is thus strategically critical for INAF and the Italian industries to obtain contracts and commitments from ESO that exceed the costs of participation to the E-ELT project.

E-ELT will be located on the top of Cerro Armazones, in the Atacama desert in Northern Chile, near the already existing ESO Observatory of Paranal with the Very Large Telescope. The construction phase of the E-ELT is expected to last 9 years. The telescope will have an aperture of 39m and will provide images of cosmic sources with a superb resolution and sensitivity, thanks to the advanced adaptive optics technology, which will allow to exploit many fundamental scientific programs.

The main science goals of the E-ELT projects are: 1) Study of the epoch of re-ionization and of the first stars, 2) Study of the first galaxies formed after the Big Bang and of the formation of galaxies, stars and planets, 3) detection and characterization of extrasolar planets with habitable conditions and possible life signatures.

E-ELT requires top-level implementation of the most advanced techniques in optical/infrared astronomy already in use or under development. The technical and financial effort requested to build E-ELT implies an international coordination which is led by ESO and involves many institutes from the participating countries. The preliminary studies of E-ELT and its scientific instruments have already involved about 40 European research institutes, among which several INAF institutes and Italian universities. The contribution of these institutes has been very important since the beginning.

Italy can significantly influence the technical and scientific decisions for E-ELT and thus define the future of optical astronomy. Italy is in a strategic position in many respects. As for science and infrastructures, Italy has a strong, highly prepared community, actively involved in all fields that will most benefit from E-ELT's ability of seeing deeper and with the best achievable spatial and spectral resolution (habitable planets, young forming galaxies, clustering of dark matter, global dynamics of the Universe, and dark energy). As for technology, Italy is world leader in the field of wave-front sensors, high-frequency deformable mirrors, building and characterization of mirrors and, in general, of adaptive optics. Our industries have already achieved great successes and secured important jobs in building telescopes and adaptive optics modules (for instance, working for ESO: the rotating dome and the telescope for the New Technology Telescope in 1986-89; 4 telescopes, construction works and the Coudé laboratory for the Very Large Telescope in 1991-2001; the prototype, the production of 25 radiotelescopes and 150 construction works for the Atacama Large Millimeter Array in 1999-2003). Regarding space science, we recall the manufacturing of the X-rays optics for the telescopes XMM and e-Rosita by Italian industries supported by INAF, under contracts by ESA and the German space agency DLR. Italy is also partner (25% share) of the Consortium which has built and is operating LBT in Arizona (USA); this telescope has two mirrors, each one of more than 8 meter in diameter, leading to a resolution similar to that of a 23 meter telescope. LBT represents the link between present-day large telescopes (8-10m class) and the future giants, like E-ELT (30-40m class). The conceptual designs and prototypes being developed for E-ELT can be efficiently tested and used on LBT, to validate both technological and scientific advances.

INAF and some Astronomical Departments of Italian Universities (Bologna and Padova) actively participated, in some cases in a leadership position, to the definition of the proposals for the focal-plane instruments of E-ELT, a task of paramount importance to reach its highest priority science goals. In 2007 ESO asked for conceptual projects (phase A) for scientific instruments and for two "post-focal" adaptive optics modules. The selected first-light instruments chosen by ESO include the infrared camera MICADO, with its multi-conjugate adaptive optics module MAORY, and the spectrograph HARMONI. Other projects should be re-submitted and there will be implementation of new instruments every two years. INAF institutes participated to 7 such studies, in 4 of which INAF personnel had high-level responsibilities (principal investigator, project manager, system engineer, or project/instrument scientist).

With the present proposal we intend to work on all fronts (technological, industrial, and scientific) in order to actively participate to the technological development of E-ELT and orient ESO's final decisions towards Italian industry and science. We will also educate industries and scientists to properly answer calls for proposals of instrumental and observational projects.

#### Instruments for E-ELT and Innovation: The Italian contribution

E-ELT has adaptive optics directly integrated in the telescope structure. This requires a mirror (M4) of 2.5m in diameter, deformable in a controlled way in 6000 points, with a duty cycle of 1 millisecond. Thanks to the experience gained in high success projects (like LBT in Arizona) and to the distinctiveness of the Italian expertise, the Italian companies ADS and Microgate, in collaboration with INAF-OABr, obtained from ESO the

contract for the M4 design (see attachments 1, 2 and 3), a 3.2 Meuro contract. These companies will continue the collaboration with T-REX also in the future.

Building the many (about 800) concave mirrors that will constitute the primary mirror M1 is a highlycompetitive, high-cost project. The Italian company Media Lario, an INAF spin-off established for the X-ray optics of SAX in the early 90's, is highly qualified in the manufacturing of components made of special materials, and mirrors in particular, for space and ground-based telescopes (projects SAX, Swift, XMM, e-Rosita, MMT, ALMA, MAGIC e CTA). They have developed a new technology to build mirrors, thanks to the exchange of know-how with INAF (OABr). T-REX proposes to proceed in these activities and evaluate the possibility of orders from ESO.

## 9.2 Expected Results

#### Strategic results

The proposed project gives INAF the possibility of contributing to a strategic infrastructure considered of highest priority by the European and world-wide scientific community. INAF international role will be strengthened and its leadership position in the consortia building the E-ELT instrumentation will be enhanced. ESO will compensate INAF contribution to the building of instruments in the form of guaranteed observing time, thus giving the national scientific community the possibility of being first in using this exceptional telescope and in obtaining high impact scientific results. Furthermore, the proposed project allows INAF to give Italian companies the opportunity to participate in the design and construction of E-ELT instruments, enhancing the country excellences. Finally, the project will give new formation and employment opportunities to young researchers and engineers.

#### **Scientific Results**

When E-ELT becomes operational it will be possible to reach revolutionary scientific results. The whole ESO project is based on the technical requirements necessary to detect and investigate the first cosmic structures formed in the very early Universe, the regions of star formation in close-by and distant galaxies, the formation of planetary systems around newly born stars, Earth-like planets in habitable zones around stars, i.e. in physical conditions allowing the development of at least simple life forms. A particular attention is given to the development of instrumentation allowing to characterize the atmosphere of rocky planets orbiting around Sunlike stars, in order to establish whether life has developed on them. As all conceptually revolutionary enterprises, from Galileo's to the Hubble Space telescope, there are good chances that E-ELT will unveil totally unknown phenomena that could drastically change our understanding of the Universe and of fundamental physics.

#### Interesting results for technology advancement

The development of astronomical instrumentation for a high-tech telescope like E-ELT implies huge advancements in several technological fields: system engineering, optics, mechanics, software engineering, automation, electronic components and systems, micro- and nano-electronics, etc. In the specific case of E-ELT and its instrumentation, the heavy use of active and adaptive optics techniques will certainly allow progress in the field of automatic controls, of sensing devices and of actuators.

In the timeframe of this project, the results will concern the technological innovation and the know-how needed to reach the technical specifications given by the scientific goals mentioned above. It is thus necessary to develop extremely innovative designs and techniques to optimize adaptive optics systems, the angular resolution and the efficiency of the cameras and the spectrographs, the mechanics, the electronics and the building techniques. The result must be a product giving the best techno-scientific performances, minimizing costs and management complexities, guaranteeing our companies success in the international competition for the assignment of E-ELT contracts, and the possibility of applying it to different production domains. In other words, a product confirming the *esprit de génie* which made the *Made in Italy* unique in the world.

#### The role of Italian companies

Italian industry significantly contributed to the VLT construction (Ansaldo, EIE) and to the construction of ALMA, now being completed (EIE, Media Lario, Thales-Alenia Italia and sub-contractors). During the design phase of E-ELT, ESO invested 48 M€ in industrial contracts. 8.3 M€ went to Italian companies. The contracts

concerned the overall design of the E-ELT structure and building, and the design of M4, the adaptive mirror which is the key of the new telescope technique.

The Italian companies which are more involved are:

- ADS & Microgate (Lecco, Bolzano): development of adaptive M4 mirror, activity in which these companies have acquired a unique competence the result of which has been a new ESO contract for 3,183,400 € (see attachment 1), 399,800 of which will be Microgate contribution to INAF (see attachments 2 and 3).
- EIE (Mestre): structure and building design. This is a company with a high level international experience in designing and realizing large scientific infrastructures.
- Media Lario (Lecco): production of segments of the main mirror with the new deterministic optical figuring techniques like bonnet figuring and ion figuring with advanced surface metrology. In these operations, especially in the pre-industrial assessment phase of the production methods, Media Lario will be flanked by INAF (OABr).

Highly specialized Italian companies have also been involved in the phase A studies of E-ELT instruments. In particular

- Tomelleri s.r.l. (Villafranca, VR), specialized in designing and building mechanical systems for telescope and astronomical instrumentation;
- CRIOTEC Impianti s.r.l. (Chivasso, TO), specialized in cryogenic systems for scientific applications like nuclear physics (CERN, INFN) and astronomy (ESO VLT, INAF TNG). See the CRIOTEC letter of interest to collaborate to T-REX in attachment.

Several national companies could be assigned "minor" contracts, as it occurred with VLT, LBT, ALMA and other telescopes: power supplies, high stability electronics, precision mechanics, control systems, "local" electrical power generators, piping, simulation and modelling (wind tunnel) of the structure aero-dynamical behaviour, optical components (Gestione Silo). Other industries can be involved in "major" contracts, depending on their industrial policy, on the technical and economical competitiveness in specific subsystems, on the need of a reasonable "geographical distribution" of the contracts among the member states. Examples are companies like EIE, Ansaldo-Camozzi or Thales-Alenia Italia for the building of the structure (past experiences are VLT, LBT, ALMA) or industrial consortia such as Technosud.

#### Potential applications

Research in the field of active and adaptive optics is central in the proposed project and has remarkable potential applications. We can cite three examples. The first concerns the technologies for ophthalmic diagnostics and surgery. Observations of the retina are limited by the optical aberrations of the crystalline lens and by the viscous nature of the vitreous body: an adaptive corrections allows sharper images of the retina, to the diffraction limit of the instrument. Wavefront sensing techniques are also used in surgery to correct eyesight defects. A clear example in this field is the Waterfall project, which saw INAF, Catania University and SIFI spa (a company leader in Europe in the field of ophthalmology) working together. Other applications are possible in this field.

The second example concerns solar concentrators in the field of renewable energy. In thermal solar plants the concentrated solar energy is essentially used to produce water vapour and propel turbines. In this field OAA has recently conducted a project (Solare Termodinamico ad Alto Rendimento) to optimize the concentrator performances by using innovative geometries. Furthermore, systems producing electrical energy by concentrating photovoltaic cells look very promising. Other interesting applications are the use of concentrated solar radiation to test materials or - an even more futuristic application - to reach extreme temperatures useful in the production processes of a non fossil fuel, such as hydrogen. At present OABo and IASF-Bo in collaboration with the University of Bologna have assigned a Ph. D. thesis to systematically analyze the gain that can be obtained by applying active optics techniques to the solar concentrators used in the above mentioned applications.

The third example concerns the nano-lithographic techniques to manufacture some nano-processors for the next generation computers. Regarding this, the main companies like INTEL and PHILIPS are striving to move from the present techniques for manufacturing microprocessors, based on UV transmission lithography (i.e. with optical benches made of lenses), to chip production with nanometric tracks through extreme UV transmission lithography needing high precision profile mirrors. The know-how developed to manufacture the E-ELT mirrors with fast & precise polishing can be exploited to manufacture the reflecting collectors needed for the nano-

lithography optical benches. In this activity Media Lario and the main companies in the field are already collaborating.

## 10 Elements and criteria to verify achievement of project goals

As described above, the National Coordinator is responsible for the project and funds management; she is helped by OU1 in order to coordinate and control the activities of the whole project and verify the achieved results. A completely independent evaluation panel can be set up, if required by MIUR.

Achievement of project goals will be evaluated taking into account:

- a) Documentation: scientific reports prepared to define instrument requirements, designs and technical reports of individual components, prototypes and E-ELT instrumentation sub-systems.
- b) Documented investments for the implementation and development of prototypes and to strengthen laboratories and integration facilities for E-ELT instrumentation.
- c) Strengthening research teams involved in the design and construction of E-ELT instrumentation by recruitment of young researchers and technologists
- d) Role of INAF in the international consortia for the construction of MAORY and MICADO, subsystems of the ELT-CAM first light instrument.
- e) Role of INAF in the proposals for ELT-HIRES and ELT-MOS instruments submitted answering the ESO *call for proposals* foreseen during 2013, and success of these proposals.
- f) Contracts assigned by ESO to Italian industries within the E-ELT project, related to the support by INAF to consolidate design and technologies, as foreseen within this project.
- g) Number and strength of master thesis and doctoral fellowships assigned to participants of T-REX on the relevant topics.

Applicability of criteria from d) to f) to this proposal depends on the schedule of the whole E-ELT project, defined by ESO and submitted for review to the control bodies.

## See also 18 attachments