

# **THE SIXTEENTH MARCEL GROSSMANN MEETING**

**On Recent Developments in Theoretical and Experimental  
General Relativity, Astrophysics and Relativistic Field Theories**

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Proceedings of the MG16 Meeting  
on General Relativity  
Online, 5–10 July 2021

Editors

**Remo Ruffini**

University of Rome “La Sapienza”, Rome, Italy  
International Center for Relativistic Astrophysics Network (ICRANet), Pescara, Italy

**Gregory Vereshchagin**

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World Scientific, 2015

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World Scientific, 1989

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World Scientific, 1986

Proceedings of the Third Marcel Grossmann Meeting on General Relativity  
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Science Press – Beijing and North-Holland Publishing Company, 1983

Proceedings of the Second Marcel Grossmann Meeting on General Relativity  
(Trieste, Italy, 1979)

Edited by R. Ruffini

North-Holland Publishing Company, 1982

Proceedings of the First Marcel Grossmann Meeting on General Relativity  
(Trieste, Italy, 1975)

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North-Holland Publishing Company, 1977

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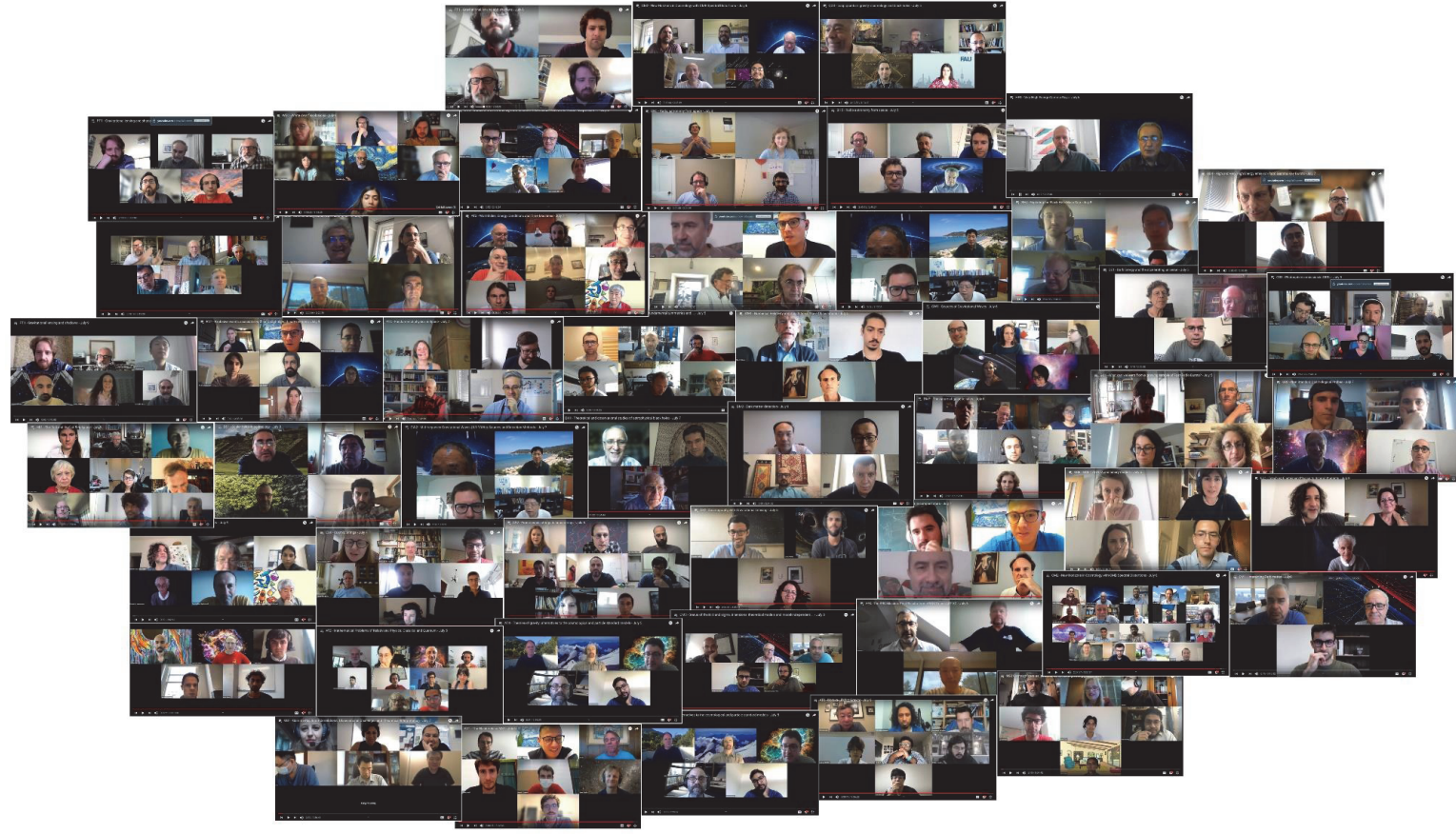
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International Center for Relativistic Astrophysics (ICRA)

## FREEDOM OF MOVEMENT FOR SCIENTISTS

The Marcel Grossmann Meetings were founded with the premise that scientists of all nations have a right to meet to exchange knowledge independent of national borders.

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## MARCEL GROSSMANN AWARDS

### Sixteenth Marcel Grossmann Meeting

#### *Institutional Awards*

*“for the creation of the world’s best X-ray map of the entire sky, for the discovery of millions of previously unknown accreting supermassive black holes at cosmological redshifts, for the detection of X-rays from tens of thousands of galaxy clusters, filled mainly with dark matter, and for permitting the detailed investigation of the growth of the large-scale structure of the universe during the era of dark energy dominance”.*

#### **S.A. LAVOCHKIN ASSOCIATION**

- presented to its Designer General **Alexander Shirshakov**

#### **MAX PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS (MPE)**

- presented to Professor **Peter Predehl**, Principal Investigator of eROSITA

#### **SPACE RESEARCH INSTITUTE (IKI) OF THE RUSSIAN ACADEMY OF SCIENCES**

- presented to Professor **Rashid Sunyaev**, Principal Investigator of SRG Observatory in Russia

#### *Individual Awards*

#### **DEMETRIOS CHRISTODOULOU**

*“For his many lasting contributions to the foundation of mathematical physics including the dynamics of relativistic gravitational fields. Notably for: contributing in 1971, at the age of 19, to derive with Remo Ruffini the mass-energy formula of black holes as a function of their angular momentum, charge and irreducible mass. Christodoulou turned then to the study of partial differential equations and mathematical physics, to which he remained dedicated for the rest of his career. Highlights in this area include the theoretical discovery of the nonlinear memory effect of gravitational waves (Phys. Rev. Letters 1991), the monograph (1993) in collaboration with Sergiu Klainerman on the global nonlinear stability of the Minkowski spacetime, the monograph (2009) on the formation of black holes in pure general relativity by imploding gravitational waves, and the monographs (2007 and 2019) on the formation and further development of shocks in fluids.”*

#### **GERARD ’t HOOFT**

*“for his persistent devotion to the study of the quantum field theory boundary conditions at the black hole horizon”.*

#### **TSVI PIRAN**

*“for extending Relativistic astrophysics across international frontiers, a true companion in the search for the deeper meaning of Einstein’s great theory”.*

**STEVEN WEINBERG**

*“for unwavering support for the MG meetings since their inception, a true companion in the search for the deeper meaning of Einstein’s great theory”.*

Each recipient is presented with a silver casting of the TEST sculpture by the artist A. Pierelli. The original casting was presented to His Holiness Pope John Paul II on the first occasion of the Marcel Grossmann Awards.

15th Marcel Grossmann Meeting  
July 2018, Rome, Italy

*Institutional Awards*

PLANCK SCIENTIFIC COLLABORATION (ESA)

“for obtaining important constraints on the models of inflationary stage of the Universe and level of primordial non-Gaussianity; measuring with unprecedented sensitivity gravitational lensing of Cosmic Microwave Background fluctuations by large-scale structure of the Universe and corresponding B-polarization of CMB, the imprint on the CMB of hot gas in galaxy clusters; getting unique information about the time of reionization of our Universe and distribution and properties of the dust and magnetic fields in our Galaxy”

- presented to Jean-Loup Puget, the Principal Investigator of the High Frequency Instrument (HFI)

HANSEN EXPERIMENTAL PHYSICS LABORATORY AT STANFORD UNIVERSITY

“to HEPL for having developed interdepartmental activities at Stanford University at the frontier of fundamental physics, astrophysics and technology”

- presented to Research Professor Leo Hollberg, HEPL Assistant Director

*Individual Awards*

LYMAN PAGE

“for his collaboration with David Wilkinson in realizing the NASA Explorer WMAP mission and as founding director of the Atacama Cosmology Telescope”

RASHID ALIEVICH SUNYAEV

“for the development of theoretical tools in the scrutinising, through the CMB, of the first observable electromagnetic appearance of our Universe”

SHING-TUNG YAU

“for the proof of the positivity of total mass in the theory of general relativity and perfecting as well the concept of quasi-local mass, for his proof of the Calabi conjecture, for his continuous inspiring role in the study of black holes physics”



14th Marcel Grossmann Meeting  
July 2015, Rome, Italy

*Institutional Award*

EUROPEAN SPACE AGENCY (ESA)

“for the tremendous success of its scientific space missions in astronomy, astrophysics, cosmology and fundamental physics which have revolutionized our knowledge of the Universe and hugely benefited science and mankind”

- presented to its Director General Johann-Dietrich Woerner

*Individual Awards*

KEN'ICHI NOMOTO

“for heralding the role of binary systems in the evolution of massive stars”

MARTIN REES

“for fostering Research in black holes, gravitational waves and cosmology”

YAKOV G. SINAI

“for applying the mathematics of chaotic systems to physics and cosmology”

SACHIKO TSURUTA

“for pioneering the physics of hot neutron stars and their cooling”

FRANK C.N. YANG

“for deepening Einstein’s geometrical approach to physics in the best tradition of Paul Dirac and Hermann Weyl”

T.D. LEE (award received by Yu-Qing Lou on behalf of Prof. T.D. Lee)

“for his work on white dwarfs motivating Enrico Fermi’s return to astrophysics and guiding the basic understanding of neutron star matter and fields”

13th Marcel Grossmann Meeting  
July 2012, Stockholm, Sweden

*Institutional Award*

ALBANOVA

for its innovative status as a joint institute established by Stockholm University and the Royal Institute of Technology and for fostering contributions to cosmology and astrophysics in the profound scientific tradition established by Oskar Klein.

- presented to the Rector of Stockholm University, Prof. Kåre Bremer.

*Individual Awards*

DAVID ARNETT

for exploring the nuclear physics and yet unsolved problems of the endpoint of thermonuclear evolution of stars, leading to new avenues of research in physics and astrophysics.

VLADIMIR BELINSKI and I.M. KHALATNIKOV

for the discovery of a general solution of the Einstein equations with a cosmological singularity of an oscillatory chaotic character known as the BKL singularity.

FILIPPO FRONTERA

for guiding the Gamma-ray Burst Monitor Project on board the BeppoSAX satellite, which led to the discovery of GRB X-ray afterglows, and to their optical identification.

12th Marcel Grossmann Meeting  
July 2009, Paris, France

*Institutional Award*

INSTITUT DES HAUTES ÉTUDES SCIENTIFIQUE (IHÉS)

for its outstanding contributions to mathematics and theoretical physics, and notably for having renewed basic geometrical concepts, and having developed new mathematical and physical aspects of spacetime.

- presented to Prof. Jean-Pierre Bourguignon

*Individual Awards*

JAAN EINASTO

for pioneering contributions in the discovery of dark matter and cosmic web and fostering research in the historical Tartu Observatory.

CHRISTINE JONES

for her fundamental contributions to the X-ray studies of galaxies and clusters tracing their formation and evolution and for her role in collaborations using clusters to study dark matter and in analyzing the effects of outbursts from supermassive black holes on the intracluster gas.

MICHAEL KRAMER

for his fundamental contributions to pulsar astrophysics, and notably for having first confirmed the existence of spin-orbit precession in binary pulsars.

11th Marcel Grossmann Meeting  
July 2006, Berlin, Germany

*Institutional Award*

FREIE UNIVERSITÄT BERLIN

for the successful endeavor of re-establishing — in the spirit of the Humboldt tradition — freedom of thinking and teaching within a democratic society in a rapidly evolving cosmos

- presented to Dr. Dieter Lenzen, President of FUB

*Individual Awards*

ROY KERR

for his fundamental contribution to Einstein's theory of general relativity: "The gravitational field of a spinning mass as an example of algebraically special metrics."

GEORGE COYNE

for his committed support for the international development of relativistic astrophysics and for his dedication to fostering an enlightened relationship between science and religion.

JOACHIM TRUMPER

for his outstanding scientific contributions to the physics of compact astrophysical objects and for leading the highly successful ROSAT mission which discovered more than 200,000 galactic and extragalactic X-ray sources: a major step in the observational capabilities of X-ray astronomy and in the knowledge of our universe.

10th Marcel Grossmann Meeting  
July 2003, Rio de Janeiro, Brazil

*Institutional Award*

CBPF (Brazilian Center for Research in Physics)  
for its role as a teaching and research institution and as a place originating fundamental physics ideas in the exploration of the universe.

- presented to its founders Cesar Lattes, José Leite Lopez and Jayme Tiomno

*Individual Awards*

YVONNE CHOQUET-BRUHAT AND JAMES W. YORK, JR.

for separate as well as joint work in establishing the mathematical framework for proving the existence and uniqueness of solutions to Einstein's gravitational field equations.

YUVAL NE'EMAN

for his contributions to science, epistemology, mathematics and physics from sub-nuclear to space sciences.

9th Marcel Grossmann Meeting  
July 2000, Rome, Italy

*Institutional Award*

SOLVAY INSTITUTES

for identifying and recording in discussions by the protagonists the crucial developments of physics and astrophysics in the twentieth century.

- presented to Jacques Solvay

*Individual Awards*

CECILLE AND BRYCE DEWITT

for promoting General Relativity and Mathematics research and inventing the “summer school” concept.

RICCARDO GIACCONI

for opening, five successive times, new highways for exploring the Universe.

ROGER PENROSE

for extending the mathematical and geometrical foundations of General Relativity.

8th Marcel Grossmann Meeting  
June 1997, Jerusalem

*Institutional Award*

HEBREW UNIVERSITY

for its role as a cradle of Science and Humanities and for hosting the manuscripts of Albert Einstein.

- presented to M. Magidor, President of the Hebrew University of Jerusalem

*Individual Awards*

TULLIO REGGE

for his contributions to the interface between mathematics and physics leading to new fields of research of paramount importance in relativistic astrophysics and particle physics.

FRANCIS EVERITT

for leading the development of extremely precise space experiments utilizing superconducting technology to test General Relativity and the Equivalence Principle.

7th Marcel Grossmann Meeting  
June 1994, Stanford, USA

*Institutional Award*

SPACE TELESCOPE SCIENCE INSTITUTE

for its critical role in the direction and operation of the Hubble Space Telescope, a truly unique international laboratory for the investigation and testing of general relativity in the context of modern astrophysics and cosmology.

- presented to Peter Stockman

*Individual Awards*

SUBRAHMANYAN CHANDRASEKHAR

for his contributions to the analysis of gravitational phenomena from Newton to Einstein and especially for leading the way to relativistic astrophysics with the concept of critical mass for gravitational collapse.

JIM WILSON

for having built on his experience in nuclear physics, thermonuclear reactions, and extensive numerical simulation to create a new testing ground for the novel concepts of relativistic astrophysics.



6th Marcel Grossmann Meeting  
June 1991, Kyoto, Japan

*Institutional Award*

RITP

for keeping alive first in Hiroshima and then in Kyoto research in relativity, cosmology, and relativistic field theory and the development of a school of international acclaim.

- presented to Professor K. Tomita

*Individual Awards*

MINORU ODA

for participating in the pioneering work of the early sixties in X-ray astronomy and for his subsequent molding of an agile and diversified Japanese scientific space program investigating the deepest aspects of relativistic astrophysics.

STEPHEN HAWKING

for his contributions to the understanding of spacetime singularities and of the large scale structure of the Universe and of its quantum origins.

5th Marcel Grossmann Meeting  
August 1988, Perth, Australia

*Institutional Award*

THE UNIVERSITY OF WESTERN AUSTRALIA  
for its contributions to relativistic astrophysics.

- presented to the Vice Chancellor, Professor Robert Smith

*Individual Awards*

SATIO HAYAKAWA

for his contributions to research in gamma, X-ray and infrared radiation as well as cosmic rays.

JOHN ARCHIBALD WHEELER

for his contributions to geometrodynamics and Einstein's visions.

4th Marcel Grossmann Meeting  
July 1985, Rome, Italy

*Institutional Award*

THE VATICAN OBSERVATORY

for its contributions to the origin and development of astrophysics.

- presented to His Holiness Pope John Paul II

*Individual Awards*

WILLIAM FAIRBANK

for his work in gravitation and low temperature physics.

ABDUS SALAM

for his work in unifying fundamental interactions.

## Institutional Awards for the Spektrum-Roentgen-Gamma (SRG) mission

*“for the creation of the world’s best X-ray map of the entire sky, for the discovery of millions of previously unknown accreting supermassive black holes at cosmological redshifts, for the detection of X-rays from tens of thousands of galaxy clusters, filled mainly with dark matter, and for permitting the detailed investigation of the growth of the large-scale structure of the universe during the era of dark energy dominance”.*

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- presented to its Designer General **Alexander Shirshakov**

### MAX PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS (MPE)

- presented to Professor **Peter Predehl**, Principal Investigator of eROSITA

### SPACE RESEARCH INSTITUTE (IKI) OF THE RUSSIAN ACADEMY OF SCIENCES

- presented to Professor **Rashid Sunyaev**, Principal Investigator of SRG Observatory in Russia

On Tuesday June 29, 2021, the following 31 astro-ph appeared:

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|---|---|
| 1. <a href="https://arxiv.org/abs/2106.14517">https://arxiv.org/abs/2106.14517</a>  | 17. <a href="https://arxiv.org/abs/2106.14533">https://arxiv.org/abs/2106.14533</a> |
| 2. <a href="https://arxiv.org/abs/2106.14518">https://arxiv.org/abs/2106.14518</a>  | 18. <a href="https://arxiv.org/abs/2106.14534">https://arxiv.org/abs/2106.14534</a> |
| 3. <a href="https://arxiv.org/abs/2106.14519">https://arxiv.org/abs/2106.14519</a>  | 19. <a href="https://arxiv.org/abs/2106.14535">https://arxiv.org/abs/2106.14535</a> |
| 4. <a href="https://arxiv.org/abs/2106.14520">https://arxiv.org/abs/2106.14520</a>  | 20. <a href="https://arxiv.org/abs/2106.14536">https://arxiv.org/abs/2106.14536</a> |
| 5. <a href="https://arxiv.org/abs/2106.14521">https://arxiv.org/abs/2106.14521</a>  | 21. <a href="https://arxiv.org/abs/2106.14537">https://arxiv.org/abs/2106.14537</a> |
| 6. <a href="https://arxiv.org/abs/2106.14522">https://arxiv.org/abs/2106.14522</a>  | 22. <a href="https://arxiv.org/abs/2106.14541">https://arxiv.org/abs/2106.14541</a> |
| 7. <a href="https://arxiv.org/abs/2106.14523">https://arxiv.org/abs/2106.14523</a>  | 23. <a href="https://arxiv.org/abs/2106.14542">https://arxiv.org/abs/2106.14542</a> |
| 8. <a href="https://arxiv.org/abs/2106.14524">https://arxiv.org/abs/2106.14524</a>  | 24. <a href="https://arxiv.org/abs/2106.14543">https://arxiv.org/abs/2106.14543</a> |
| 9. <a href="https://arxiv.org/abs/2106.14525">https://arxiv.org/abs/2106.14525</a>  | 25. <a href="https://arxiv.org/abs/2106.14544">https://arxiv.org/abs/2106.14544</a> |
| 10. <a href="https://arxiv.org/abs/2106.14526">https://arxiv.org/abs/2106.14526</a> | 26. <a href="https://arxiv.org/abs/2106.14545">https://arxiv.org/abs/2106.14545</a> |
| 11. <a href="https://arxiv.org/abs/2106.14527">https://arxiv.org/abs/2106.14527</a> | 27. <a href="https://arxiv.org/abs/2106.14546">https://arxiv.org/abs/2106.14546</a> |
| 12. <a href="https://arxiv.org/abs/2106.14528">https://arxiv.org/abs/2106.14528</a> | 28. <a href="https://arxiv.org/abs/2106.14547">https://arxiv.org/abs/2106.14547</a> |
| 13. <a href="https://arxiv.org/abs/2106.14529">https://arxiv.org/abs/2106.14529</a> | 29. <a href="https://arxiv.org/abs/2106.14548">https://arxiv.org/abs/2106.14548</a> |
| 14. <a href="https://arxiv.org/abs/2106.14530">https://arxiv.org/abs/2106.14530</a> | 30. <a href="https://arxiv.org/abs/2106.14549">https://arxiv.org/abs/2106.14549</a> |
| 15. <a href="https://arxiv.org/abs/2106.14531">https://arxiv.org/abs/2106.14531</a> | 31. <a href="https://arxiv.org/abs/2106.14550">https://arxiv.org/abs/2106.14550</a> |
| 16. <a href="https://arxiv.org/abs/2106.14532">https://arxiv.org/abs/2106.14532</a> |   |

## S.A. LAVOCHKIN ASSOCIATION

presented to its Designer General **Alexander Shirshakov**



*Dr Alexander Shirshakov*

S.A. Lavochkin Association created the Navigator space platform carrying German eRosita and Russian ART-XC X-Ray Telescopes, organized the launch of SRG Orbital X-Ray Observatory to the second Lagrangian point of the Sun-Earth system at a distance of 1.5 million km from the Earth and managed the observatory flight and the daily reception of its scientific data on Earth for 23.5 months.

Dr Alexander Shirshakov, Designer General of the S.A. Lavochkin Association, is specialized in design, manufacture, testing, launch and control of S/C for scientific purposes. Among those S/C launched, there are the «Radiostron» Astrophysical Observatory (2011) and the «Spektr-RG» space observatory (2019), while the planned S/C launches are «Luna-25» and «Exomars».

Dr Shirshakov started his career in 1973, working as an engineer of the State Unitary Enterprise «NPO named by S.A. Lavochkin» in Khimki (Russian Federation). Starting from 1989 he has played multiple roles within the Lavochkin Association, been appointed head of the group, head of the sector, head of department, deputy head of the complex, head of the branch, director of the center, deputy head of the Design Bureau, deputy General Designer and deputy General Director.

Dr Shirshakov is an editorial board Member of the reviewed edition of «Vestnik of Lavochkin Association». Since 2017, he is also member of the General Designer council. He has been awarded Honored Mechanical engineer of the Russian Federation as well as Agency-level award of the Russian Federal Space Agency.

## MAX PLANCK INSTITUTE FOR EXTRATERRESTRIAL PHYSICS (MPE)

presented to Professor **Peter Predehl**, Principal Investigator of eROSITA



*Professor Peter Predehl*

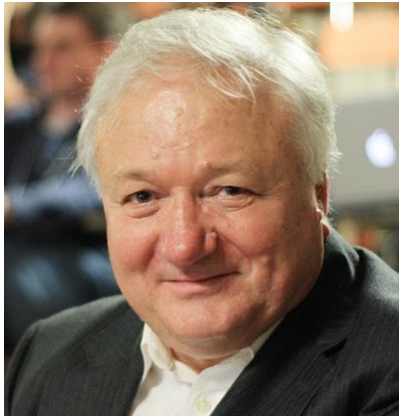
eROSITA is the soft X-ray telescope on-board the Russian-German Spektr-RG mission which was successfully launched from Baikonur on July 13, 2019 and placed in a halo orbit around the L2 point. 30 years after ROSAT, eROSITA performs an all-sky survey with an unprecedented sensitivity, spectral and angular resolution. Clusters of galaxies are the largest collapsed objects in the Universe. Their formation and evolution is dominated by gravity, i.e. Dark Matter, while their large scale distribution and number density depends on the geometry of the Universe, i.e. Dark Energy. X-ray observations of clusters of galaxies provide information on the rate of expansion of the Universe, the fraction of mass in visible matter, and the amplitude of primordial fluctuations which are the origin of clusters of galaxies and the whole structure of the universe. eROSITA has

been designed to detect at least 100.000 clusters of galaxies and to detect systematically more than 3 million obscured accreting Black Holes. eROSITA will also allow to study the physics of galactic X-ray source

populations, like pre-main sequence stars, supernova remnants and X-ray binaries. The eROSITA telescope consists of seven identical Wolter-1 mirror modules. A novel detector system has been developed by MPE on the basis of the successful XMM-Newton pn-CCD technology. MPE is the scientific lead institute of eROSITA, responsible for the development of the instrument, the operation, the analysis software and data archive. Peter Predehl led this development as Principal Investigator of eROSITA and German lead scientist of the SRG mission for more than 15 years until the completion of the first of eight surveys in 2020. At this time eROSITA has already discovered more than 1 million X-ray sources, more than all X-ray observatories of the last 50 years together. This demonstrates that the design goals of the mission will easily be fulfilled.

## SPACE RESEARCH INSTITUTE (IKI) OF THE RUSSIAN ACADEMY OF SCIENCES

presented to Professor **Rashid Sunyaev**



*Professor Rashid Sunyaev*

Space Research Institute (IKI) of the Russian Academy of Sciences was responsible for developing the overall concept and scientific program of the SRG Orbital observatory and played a leading role in developing the ART-XC telescope and the entire SRG observatory as part of the Russian space science program carried out by Roskosmos Corporation in the interests of the Russian Academy of Sciences.

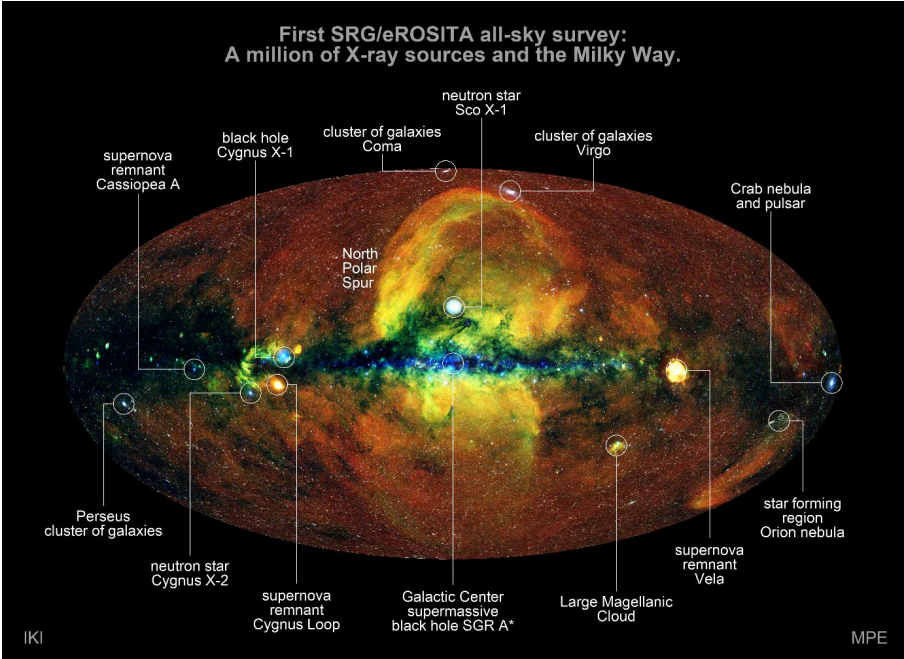
During the flight to the L2 point of the Sun-Earth system, SRG with German (eRosita) and Russian (ART-XC named after Mikhail Pavlinsky) X-ray Telescopes aboard performed calibrations and long duration Performance Verification observations of a dozen of targets and deep fields. Starting in the middle of December 2019, the SRG scanned the whole sky three times. During these scans, SRG discovered two million point X-ray sources: mainly quasars, stars with hot and bright coronae, and more than 30 thousand clusters of galaxies. There is a competition and synergy in the search for

clusters of galaxies between SRG and the ground-based Atacama Cosmology and South Pole Telescopes, which are searching for clusters of galaxies in microwave spectral band using Sunyaev-Zeldovich effect.

SRG provided the X-Ray map of the whole sky in hard and soft bands, the last is now the best among existing. The huge samples of the X-ray selected quasars at the redshifts up to  $z = 6.2$  and clusters of galaxies will be used for well-known cosmological tests and detailed study of the growth of the large scale structure of the Universe during and after reionization. SRG/eRosita is discovering every day several extragalactic objects which increased or decreased their brightness more than 10 times during half of the year after the previous scan of the same one-degree wide strip on the sky. A significant part of these objects has observational properties similar to the Events of Tidal Disruption of a star orbiting in the vicinity of the supermassive black hole. ART-XC discovered a lot of bright galactic and extragalactic transients.



Rashid Sunyaev is the Principal Investigator of SRG mission in Russia, director-emeritus of the Max-Planck Institute for Astrophysics and Maureen and John Hendricks distinguished visiting professor of the Institute for Advanced Study, Princeton.



## Individual Awards

### Professor DEMETRIOS CHRISTODOULOU

*“For his many lasting contributions to the foundation of mathematical physics including the dynamics of relativistic gravitational fields. Notably for: contributing in 1971, at the age of 19, to derive with Remo Ruffini the mass-energy formula of black holes as a function of their angular momentum, charge and irreducible mass. Christodoulou turned then to the study of partial differential equations and mathematical physics, to which he remained dedicated for the rest of his career. Highlights in this area include the theoretical discovery of the nonlinear memory effect of gravitational waves (Phys. Rev. Letters 1991), the monograph (1993) in collaboration with Sergiu Klainerman on the global nonlinear stability of the Minkowski spacetime, the monograph (2009) on the formation of black holes in pure general relativity by imploding gravitational waves, and the monographs (2007 and 2019) on the formation and further development of shocks in fluids.”*



Professor Demetrios Christodoulou

It was back in 1967 that [Achille Papapetrou](#) mentioned the case of the 16-year-old [Demetrios Christodoulou](#) to [John Archibald Wheeler](#). Wheeler interviewed Demetrios in Paris and brought him immediately to Princeton where he was registered as an undergraduate at the university. After one year he entered the graduate school and started collaborating with me. At the time I was working with Wheeler on the effective potential approach to geodesics co-rotating and counter-rotating (see e.g. reference in [The Classical Theory of Fields \(Landau and Lifshitz, 1980\)](#) in the Kerr metric (later renamed as ISCO; see e.g. [\(Gravitation Misner, Thorne, Wheeler, 1973\)](#)). In parallel, [Frank Zerilli](#) was working on the gravitational radiation emitted by the fall of a test particle in a Schwarzschild black hole ([Zerilli 1970](#)). From these limited conceptual arena [Charles Misner](#) and later [Kip Thorne](#) launched a program for the detection of gravitational waves on the Earth; see e.g. [Misner 1974](#), [Abbott et al. 2016](#), [Abbott et al. 2017](#). See however [Davis et al. 1972](#), [Rodriguez et al. 2018](#) and [J.A. Rueda et al. 2018](#).

A new approach started with the arrival of Demetrios: he was just creating mathematics following his needs. We identified the reversible and irreversible transformations of a Kerr black hole. Wheeler advanced a thermodynamic analogy. I addressed the need of identifying the concept of irreducible mass (from the Italian “irriducibile”), and was Demetrios’s contribution to integrate, overnight, the differential equation for infinitesimal reversible transformations which led to the finite mass-energy formula of a Kerr black hole. That evening, while walking back home through [IAS](#) woods, I expressed to Wheeler the great relevance of the newly found formula by Demetrios and proposed to let Demetrios be the single author of this article, admiring his great mathematical talent. Wheeler agreed. The Editor of PRL objected since in that two pages article the Fig. 2 by Wheeler and myself was still unpublished. Actually that Fig. 2 followed a discussion I previously had with Penrose in Florence ([Penrose 1961](#)) which allowed us to present there, for the first time, a “Penrose Process”. Some difficulties in achieving this process were obvious from the example in Fig. 2, which Roger later recognized himself ([Penrose & Floyd 1971](#)). The Editor finally agreed on our written request and the paper appeared on September 17, 1970 ([Christodoulou, 1970](#)). On January 1971 appeared my article with Johnny introducing the Black Hole ([Ruffini & Wheeler, 1971](#)), with the new physics we were developing in Princeton, including the concept of the “ergosphere”. On march 1 1971 we submitted the mass formula of the Kerr Newmann metric, including the relation between the surface area of the horizon and the irreducible ([Christodoulou & Ruffini, 1971](#)). On March 11, 1971 the same results were independently confirmed by Steven Hawking, extending further the applicability of our equation ([Hawking 1971](#)).

The thesis was successfully discussed by a committee including Eugene Wigner (see Fig. 1), one of the closest collaborators of [Albert Einstein](#) and [David Wilkinson](#) (see Fig. 2), the head of the [NASA WMAP mission](#), and Johnny and myself as supervisors. The new message was clear: Black Holes, far from being a sink of energy, were energy sources emitting “in principle” 50% of their mass energy, being extractable ([Christodoulou & Ruffini, 1971](#)).



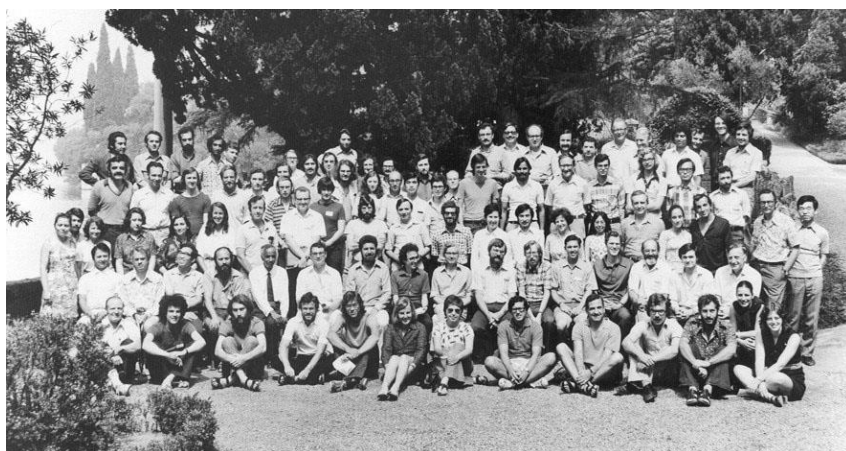


*Fig. 1 and Fig. 2: Demetrios during his thesis presentation with Eugene Wigner (Fig. 1) and David Wilkinson (Fig.2). Johnny and I were supervisors, ready to intervene in case of need, but no need of intervention was necessary! Wigner elaborated the aphorism of Niels Bohr "Interesting = wrong" in the most definite "very interesting if true = totally wrong".*

Demetrios turned soon to the study of partial differential equations and mathematical physics, to which he dedicated for the rest of his career and results were published in four monographs: ([Christodoulou and Klainerman 1994](#), [Christodoulou 2007](#), [Christodoulou 2009](#), [Christodoulou 2019](#)). In 1968, Johnny proposed to Demetrios the collapse of a "geon" composed of massless scalar field as a second topic for his thesis. It took almost forty years for him to solve this problem, extended by Demetrios to the focusing of gravitational waves leading to black hole formation ([Christodoulou 2009](#)).



**Fig. 3: Prof. Remo Ruffini receiving the Cressy Morrison Award of the New York Academy of Sciences, 1972 for the discovery of the first Black Hole in our galaxy Cygnus X1.**



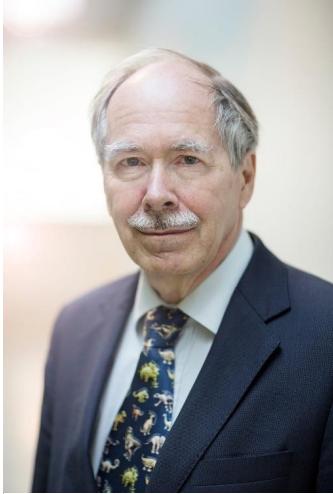
**Fig. 4: In the second row, from left to right, there are, among others: E. T. Newman, S. Chandrasekhar (Nobel 1983), R. Giacconi (Nobel 2002), R. Ruffini, A. Treves, A. Hewish (Nobel 1974), D. Arnett, J.H. Taylor (Nobel 1993), J. Wilson, R. Penrose (Nobel 2020), as well as J. Bahcall, T. Damour, T. Piran et al.**

Today, after fifty years, this “long march” has reached a definite result: through the grandest observational multi-wavelength effort in the history of mankind, from space, ground and underground observatories, we are finally finding evidence that black holes are “alive” and their “extractable energy” in our mass formula ([Christodoulou & Ruffini, 1971](#)), is the energy source of the most energetic cosmological sources: gamma ray bursts (GRBs), the active galactic nuclei (AGNs) as well as the ultra-high energy cosmic rays (UHECRs) ([Ruffini et al. 2021 and references therein](#)). Their “inner engine”, has three independent components: 1) a Kerr black hole which is neither in a stationary state nor in vacuum, 2) a background magnetic field aligned with the black hole rotation axis, and 3) an extremely diluted fully ionized plasma ([Moradi et al. 2021](#)). There is no role in this inner engine for ISCO. Indeed a new electro dynamical field equations describe the synchrotron radiation emitted close to the black hole horizon, they point to a discrete and repetitive emission of “blackholc quanta” in the MeV and in the GeV. The magnitudes and the emission time scales of these quanta, for M87 and GRB 130427A, are expressed as a function of the above three parameters ([Rueda & Ruffini, 2021](#)). A long lasting GeV emission with a luminosity decreasing as a temporal power law, allows for the first time in GRBs, the determination of the black hole mass and spin as well as their time evolution perfectly fulfilling our mass energy formula ([Christodoulou & Ruffini, 1971](#)): a long lasting emission process profoundly different from the traditional process of continued gravitational contraction.

*Remo Ruffini*

Professor **GERARD 't HOOFT**

*"for his persistent devotion to the study of the quantum field theory boundary conditions at the black hole horizon".*



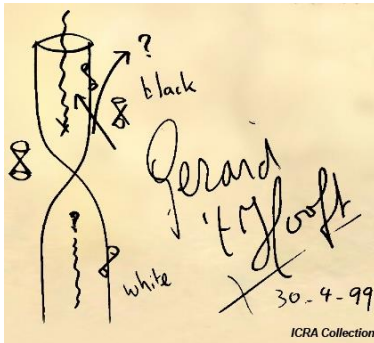
**Professor Gerard 't Hooft**

Prof. Gerard 't Hooft has been a full Professor at the Utrecht University (the Netherlands), since 1977. Nowadays, he is an Emeritus Professor at that University. During his career, he has paid extended scientific visits to CERN (Geneva), Harvard, Stanford, Princeton and Duke University, NC. In 1999, together with M. Veltman, he received the Nobel Prize in Physics, awarded by The Royal Swedish Academy of Sciences, *"For elucidating the quantum structure of electroweak interactions in physics"*.

Prof. 't Hooft's main subjects of research includes:

- Gauge Theories for the sub-atomic particles and forces, various aspects and ingredients of what is now called "The Standard Model of the sub-atomic particles: renormalizability, topological features such as magnetic monopoles and instantons,  $1/N$  expansions.
- Theories for the quantization of the gravitational force and black holes: producing models for the quantum properties of a black hole, as derived from Standard Model and General Relativity alone; its topological features such as antipodal identification.
- Fundamental theories underlying quantum mechanics, in particular returning determinism and reality to the dynamics of the tiniest material entities in his universe.

Prof. 't Hooft has been awarded the Wolf Prize of the State of Israel (1982), the Pius XI Medal (Vatican City, 1983), the Lorentz Medal (KNAW Amsterdam, 1986) as well as the Spinoza Premium (Netherlands Organization for Scientific Research NWO, 1995).



**Fig. 2: The signature of Gerard 't Hooft on the wall of ICRA Room 301 (April 4, 1999).**

A special event took place at ICRA on April 30, 1999. Prof. Ruffini invited Gerard 't Hooft to Rome to discuss a boundary condition for a quantum field on the black hole horizon, a topic Prof. Ruffini discussed in a previous article "Black-hole evaporation in the Klein-Sauter-Heisenberg-Euler formalism" with Thibault Damour (Phys. Rev. D 14, 332, 1976), but which needed to be examined in more detail. Prof. Ruffini planned to direct Gerard's attention to some specific aspects of this problem. Because we have traditionally been very attentive in spending ICRA travel funds, ICRA offered Gerard to come to Rome on a reduced fare weekend ticket arriving Friday and departing Monday. He had a great relaxing weekend together with Prof. Ruffini following his seminar, which among other things allowed Gerard to sign the wall in our ICRA Room (see Fig. 2), and during this splendid Rome spring weekend he also was able to find a missing factor of 2 in a formula in Prof. Ruffini's 1971 paper with Demetri Christodoulou on the black

hole mass formula. The following October, Gerard received the Nobel prize, which meant that we could no longer get away with bringing him to Rome on a cheap ticket! Ever since Gerard has been in our MG IOC helping us with the preparation of the meetings. We are very happy to announce this MG16 Award to Gerard 't Hooft with the motivating phrase *"for his persistent devotion to the study of the quantum field theory boundary conditions at the black hole horizon"*.

*Remo Ruffini*

Professor **TSVI PIRAN**

*“for extending relativistic astrophysics across international frontiers, a true companion in the search for the deeper meaning of Einstein’s great theory”.*



**Professor Tsvi Piran**

Tsvi Piran is the emeritus Schwartzmann professor at the Hebrew University of Jerusalem. He obtained his PhD in Physics, in 1976 from the Hebrew University working on the collisional Penrose process. Piran returned to the Hebrew University at 1981 after being a post doc at Oxford and Texas and a long-term member at the IAS at Princeton. In 1982 he initiated and directed the first ever summer school on Gravitational Waves that took place at Les Houches. Piran was a visiting professor at Harvard, Columbia and New York and a Moore scholar at Caltech.

Piran’s research deals with numerous aspects of relativistic astrophysics, ranging from the foundation of numerical relativity to modeling of observer relativistic phenomena and analytic work on the fate of gravitational collapse. Piran’s research work focuses mostly on black holes and in particular on gamma-ray bursts. He was among the first to point out their cosmological origin and their association with merging neutron stars and heavy r-process nucleosynthesis. Piran’s achievements were recognized in the 2019 EMET prize for Physics.

Professor **STEVEN WEINBERG**

*“for unwavering support for the MG meetings since their inception, a true companion in the search for the deeper meaning of Einstein’s great theory”.*



**Professor Steven Weinberg. Photo courtesy of Matt Valentine.**

Steven Weinberg is a member of the Physics and Astronomy Departments at The University of Texas at Austin. His research has covered a broad range of topics in quantum field theory, elementary particle physics and cosmology. He has been honored with numerous awards, including the Nobel Prize in Physics, the National Medal of Science, the Heinemann Prize in Mathematical Physics and in 2020, the Breakthrough Prize. He is a member of the US National Academy of Sciences, Britain’s Royal Society, and other academies in the USA and abroad. The American Philosophical Society awarded him the Benjamin Franklin Medal, with a citation that said he is “considered by many to be the preeminent theoretical physicist alive in the world today.” His books for physicists include *Gravitation and Cosmology*, the three-volume work *The Quantum Theory of Fields, Cosmology* and published in April of 2021, *Foundations of Modern Physics*. Educated at Cornell, Copenhagen, and Princeton, he also holds honorary degrees from sixteen other universities. He taught at Columbia, Berkeley, M.I.T., and Harvard, where he was Higgins Professor of Physics, before coming to Texas in 1982.





**Fig. 1: Chuo Pei Yuan and Cheng Ning Yang at MG2 in Trieste, Italy (1979).**

the meeting and for China. A multi-millennia “*motto*” in China, which was then proclaimed on banners everywhere, read “*Friends from all over the world are welcomed*”.

We were soon at an impasse over the participation of scientists from Israel, since no diplomatic relations existed between China and Israel at that time and the Israeli scientists were not to be allowed to attend the meeting. A long negotiation began. The boundary conditions were clearly set by Steven Weinberg, a member of the present MG16 IOC: no MG meetings on Einstein’s theory of general relativity could occur without the participation of Israeli scientists.

The intervention of Yuval Ne’emann, also a member of the MG IOC then as well as the Minister of Science of Israel (see Fig.2), proposed a compromise that would admit at least one Israeli scientist. I went to Beijing alone, meeting every morning for a week with 12 Chinese representatives led by Chuo Pei Yuan going over all possible options. I stayed in an isolated villa not far from Tiananmen Square, accompanied by the 3 volumes of Matteo Ricci (RI MA TO) to keep me company. No solution was in sight the entire week. At the last moment, just before my departure, an agreement was finally reached allowing two Israeli scientists into China. The historic compromise would admit Gerard Tauber and Tsvi Piran into China using a special ICRA travel document I had proposed for them to be able to participate in the meeting, accepted by the Chinese Ambassador in Rome. This modified the thousand-year Chinese “*motto*” to read “*Scientists from all over the world are welcomed*”. The event was extremely beneficial for China and signaled the truly international nature of the MG meetings.



**Fig. 2: From right to left: Chaim Weizmann, President of Israel; Yuval Ne’emann, Minister of Science of Israel; R. Ruffini.**

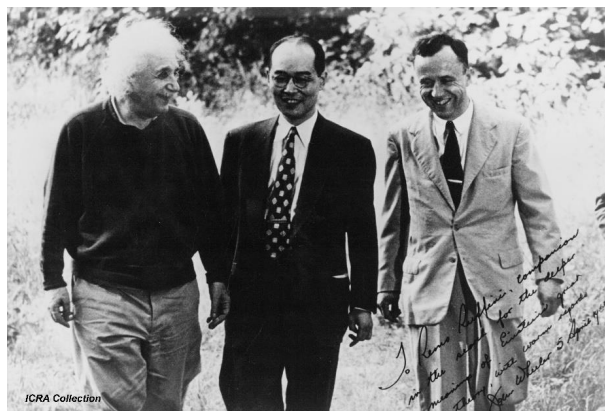
The intervention of Yuval Ne’emann, also a member of the MG IOC then as well as the Minister of Science of Israel (see Fig.2), proposed a compromise that would admit at least one Israeli scientist. I went to Beijing alone, meeting every morning for a week with 12 Chinese representatives led by Chuo Pei Yuan going over all possible options. I stayed in an isolated villa not far from Tiananmen Square, accompanied by the 3 volumes of Matteo Ricci (RI MA TO) to keep me company. No solution was in sight the entire week. At the last moment, just before my departure, an agreement was finally reached allowing two Israeli scientists into China. The historic compromise would admit Gerard Tauber and Tsvi Piran into China using a special ICRA travel document I had proposed for them to be able to participate in the meeting, accepted by the Chinese Ambassador in Rome. This modified the thousand-year Chinese “*motto*” to read “*Scientists from all over the world are welcomed*”. The event was extremely beneficial for China and signaled the truly international nature of the MG meetings.

The Sixteenth Marcel Grossmann Meeting (MG16) is a very special one in many respects: it will take place during a pandemic and in spite of the many difficulties, we have decided not to postpone it but to organize it as a virtual meeting. As described on the MG series webpage, these meetings started in 1975 with the first meeting at the International Centre for Theoretical Physics (ICTP) in Trieste (Italy) that I organized with Nobel Prize winner Abdus Salam. A second meeting followed in 1979, with a significantly larger participation including Nobel Laureate Cheng Ning Yang and a Chinese delegation led by Chuo Pei Yuan (see Fig. 1), including Fang Li-Zhi who had accompanied me during my entire first visit to China in 1979. The first truly international MG meeting followed in 1982 in Shanghai (China): this represented an especially important step forward both for

I kept on meeting Tauber in the years which followed (see Fig. 3). Soon after, Yuval Ne'emann visited China. The development of bilateral relations, including military cooperation and economical ties, grow exponentially until the establishment of normal diplomatic relations between Israel and China in 1992.



**Fig. 3:** From right to left: Arrigo Finzi, Remo Ruffini, Gerard Tauber and Konrad Bleuler.



**Fig. 4:** Albert Einstein, Hideki Yukawa and John A. Wheeler with a handwritten dedication to Remo Ruffini "To Remo Ruffini, companion in the search for the deeper meaning of Einstein great theory. With warm regards, John Wheeler 5 April 1968".

Given their key role played in the foundations of the MG meetings, I am very happy to propose on behalf of the MG16 IOC, two special Marcel Grossmann Individual Awards: one to Steven Weinberg for "for unwavering support for the MG meetings since their inception, a true companion in the search for the deeper meaning of Einstein's great theory" and another one to Tsvi Piran, "for extending Relativistic astrophysics across international frontiers, a true companion in the search for the deeper meaning of Einstein's great theory", in the words of John A. Wheeler's photo dedication to me (see Fig. 4).

Remo Ruffini

## PREFACE

Since 1975, the Marcel Grossmann Meetings on Recent Developments in Theoretical and Experimental General Relativity, Gravitation, and Relativistic Field Theories have been organized in order to provide opportunities for discussing recent advances in gravitation, general relativity and relativistic field theories, emphasizing mathematical foundations, physical predictions and experimental tests. The objective of these meetings is to elicit exchange among scientists that may deepen our understanding of spacetime structures as well as to review the status of ongoing experiments aimed at testing Einstein's theory of gravitation either from the ground or from space. Previous meetings have been held in Trieste (MG1: 1975) and (MG2: 1979), Shanghai (MG3: 1982), Rome (MG4: 1985, MG9: 2000), Perth (MG5: 1988), Kyoto (MG6: 1991), Stanford (MG7: 1994), Jerusalem (MG8: 1997), Rio (MG10: 2003), Berlin (MG11: 2006), Paris (MG12: 2009), Stockholm (MG13: 2012), MG14 in 2015 and MG15 in 2018 both in Rome.

Due to the COVID-19 pandemic spreading in the last two years the decision was taken to organize the Sixteenth Marcel Grossmann meeting for the first time in history entirely online. Despite numerous challenges, related to the organization of large worldwide event, MG16 showed the strongest ever interest from the scientific community with a record-breaking number of almost 1200 registered participants and of more than 1000 speakers.

The traditional six-day schedule has been modified to account for different time zones of the speakers and each day the program of the meeting was divided in three blocks with the reference to the Central European Summer Time. The first block was starting at 06:30 in the morning, allowing comfortable time for speakers from Asia and Oceania. The second block was held in the daytime in Europe and Africa. The third block was starting in the afternoon and ending at 19:30 allowing accommodation of the speakers from the Americas. Each day the blocks of plenary sessions were interchanging with the blocks of about 30 parallel sessions each, making this one of the most intense MG meetings ever. All this was possible thanks to recent developments in communication technologies. The Indico open-source software was selected as a web platform for this meeting, while Zoom platform was adopted for the video-conferencing. The meeting was streamed on ICRA Net YouTube channel.

The meeting started on Monday July 5 with the Award ceremony. The individual awards went to Demetrios Christodoulou, Tsvi Piran, Gerard 't Hooft and Steven Weinberg, while the Institutional Awards went to the S.A. Lavochkin Association, to the Max Planck Institute for Extraterrestrial Physics – MPE and to the Space Research Institute IKI of the Russian Academy of Sciences. Overall there were 54 plenary talks, 4 public lectures and 5 roundtables and about 90 parallel sessions. The plenary session “Events in Relativistic Astrophysics” on Monday have seen the contributions from Rashid Sunyaev, Michael Kramer, James Miller-Jones, Felix Mirabel. The public lectures were delivered by Razmik Mirzoyan, Asghar Qadir

and Mohammad Bagheri. Plenary talks on Tuesday session “Black holes and the Quantum” by Juan Maldacena, Ahmed Almheiri, Gerard 't Hooft, Mihalis Dafermos, Sergiu Klainerman, Abhay Ashtekar and Frank Wilczek were bracketed by two roundtables on “New results from SRG/eRosita” with the participation of Andrea Merloni, Prof. Rashid Sunyaev, Alexander Lutovinov, Chandreyee Maitra, Esra Bulbul and “Solar neutrinos and Borexino” with the participation of Gianpaolo Bellini and Wick Haxton. Plenary talks on Wednesday in the session “Lambda CDM tensions” by George Efstathiou, Scolnic Daniel, Marc Kamionkowski, Wendy Freedman, Priya Natarajan and Licia Verde were followed by the roundtable “Precision cosmology” with the participation of Licia Verde, Marc Kamionkowski, Piero Rosati, and the public lecture by Francis Halzen. Two blocks of Thursday plenary sessions “Black holes in GRBs” and “Precision tests” included the talks by Roy Kerr, Yuan Ha, Lorenzo Amati, Elena Pian, Carlos Raúl Argüelles, Di Li, Jianglai Liu, Claus Lämmerzahl, Gerhard Heinzl and Ignazio Ciufolini and were followed by the roundtable “GRB 170817A and GRB 190829A” with the participation of Eleonora Troja, Liang Li, Rahim Moradi, Jorge Armando Rueda Hernandez. Two plenary blocks on Friday “Massive stars” and “Physics behind stellar collapse” included the talks by Selma de Mink, Norbert Langer, Jiri Bicač and Tomáš Ledvinka, Ivan De Mitri, Rahim Moradi and Giancarlo Cella. Finally, two plenary blocks on Saturday “Current and future missions” have seen the talks by Shuang-Nan Zhang, Weimin Yuan, Makoto Tashiro, Ruoyu Liu, Jean-Luc Atteia, Jim Hinton and Nicholas White and were followed by the roundtable “What is in our Galactic center” with the participation of Reinhard Genzel, Carlos Raúl Argüelles, Andreas Krut, Jorge Armando Rueda Hernandez, Eduar Becerra Vergara. The program of the meeting can be found at the official website <http://www.icra.it/mg/mg16> and at ICRANet Indico website <https://indico.icranet.org/event/1/>.

These proceedings include about 400 papers containing the results presented at the Sixteenth Marcel Grossmann meeting. The plenary papers from the meeting have been published in *International Journal of Modern Physics D* as they were submitted. The table of contents includes also the links to YouTube videos with talks given at the meeting and cover plenary talks, public lectures, roundtables and all parallel sessions. The general link to the videos from MG16 is: <https://www.youtube.com/watch?v=QFe1lsSid-o&list=PLr5RLbSWsOnZukBDs0qsNIWM8AvRF>.

As the editors we would like to express our gratitude to all the chairpersons of the parallel sessions at MG16, who peer-reviewed the papers submitted for these proceedings, as well as to the ICRANet secretariat office and in particular to Cinzia di Niccolo, Elisabetta Natale and Yasmina Di Domizio, as well as to ICRANet system manager Gabriele Brandolini for their help in preparation of this publication.

Remo Ruffini and Gregory Vereshchagin  
November 2021



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• **Dark Energy and the Accelerating Universe**

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• **Cosmography with Gravitational Lensing**

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*L. J. Goicoechea and V. N. Shalyapin . . . . .* 1990

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