THE PONTIFICAL
ACADEMY
OF SCIENCES

PLENARY SESSION ON

PATHS OF DISCOVERY

5-8 November 2004

VATICAN CITY
2004

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Galileo feels in his scientific research the presence of the Creator, who stimulates him, inspires and helps his intuitions, acting in the deepest recesses of his spirit. In connection with the invention of the telescope, he writes at the beginning of *Sidereus Nuncius*, recalling some of his astronomical discoveries: '*Quae omnia ope Perspicilli a me excogitati divina prius illuminante gratia, paucis abhinc diebus reperta, atque observata fuerunt*'. 'All that has been discovered and observed in the last few days thanks to the telescope that I have invented, after having been enlightened by divine grace'. Galileo's confession of divine illumination in the mind of the scientist finds an echo in the text of the conciliar constitution on the Church in the modern world: 'The humble and persevering investigator of the secrets of nature is being led, as it were, by the hand of God in spite of himself'

John Paul II, *Address to the Pontifical Academy of Sciences*, 22 November 1979

INTRODUCTION

The Council of the Pontifical Academy of Sciences suggests devoting the November 2004 Plenary Session to the following topic: 'Paths of Discovery'. This topic is of interest not only to scientists but also to many other people, including political and economic leaders. The Council is therefore asking for feedback, especially from those members of the Academy who are considering presenting a paper. A tentative title of the proposed paper would be appreciated and any critical or constructive suggestions would be welcome.

Discoveries are at the basis of new knowledge. There is no single recipe leading to discovery; there are a multitude of paths. Some discoveries are made upon verification or falsification of a theory. The discovery can then also give rise to a refinement of the theory, paving the way for further experimental approaches. Quite frequently, a discovery is made while the researcher is looking for something else. His scientific mind and intuition may thereby direct his attention to the unexpected. This source of discovery is generally called *serendipity*. Novel methodology and research strategies can open the doors to many new discoveries, which can then have an impact on individual researchers or, in other cases, on wider research programmes involving many researchers. Think of major scientific endeavours such as CERN depending on a large experimental set-up. However, in this case too progress will depend in part on the activities of individual scientists and their aptitude to design and interpret experiments. The same is true for almost any research, whether it is carried out by a single person or in the context of a larger research programme. More generally, the debate may also address the role played by dogma and widely anchored textbook knowledge in scientific progress, given their frequent influence on the interpretation of observations and experimental data.

The aim of a debate on 'Paths of Discovery' would be to collect a number of case studies largely based on the personal experience of the participants and their scientific environments. However, the debate may also refer to some cases of discovery that have already been documented by the history of science. The resulting documentation is expected to illustrate the range of paths leading to discovery. Such documentation may be useful in political planning for scientific investigations and may represent a welcome contribution to the literature on the principles of the scientific approach.

WERNER ARBER
Member and Councillor of the Pontifical Academy of Sciences
Nobel Prize in Physiology or Medicine (1978)

PROGRAMME

THURSDAY 4 NOVEMBER 2004

16.00-19.00	***Council Meeting***

FRIDAY 5 NOVEMBER 2004

9.00	***Word of Welcome*****:** Prof. Nicola CABIBBO, President of the Academy
9.05	***The Subject of the Meeting*****:** Prof. Werner ARBER, Coordinator of the Meeting
9.15	***Commemorations of Deceased Academicians*** Sune BERGSTRÖM (15.VIII.04) by Prof. N.M. LE DOUARIN Renato DARDOZZI (3.VI.03) by Prof. N. CABIBBO Nicola DALLAPORTA (23.X.03) by Prof. N. CABIBBO Paul A.J. JANSSEN (11.XI.03) by Prof. C. de Duve Stanisław ŁOJASIEWICZ (13.XI.02) by Prof. P. GERMAIN Manuel LORA TAMAYO (22.VIII.02) by Prof. A. GARCÍA BELLIDO Thomas R. Odhiambo (27.V.03) by Prof. M.G.K. MENON George PORTER (31.VIII.02) by Prof. R. HIDE Marcel ROCHE (3.V.03) by Prof. C. PAVAN
10.00	***Self-Presentation of the New Members*** Prof. Suzanne CORY Prof. William D. PHILLIPS Prof. Veerabhadran RAMANATHAN
10.20	***Presentation of the Pius XI Medal*** awarded to Dr. Laure SAINT-RAYMOND
10.30	***Coffee Break***
11.00	***Possible Papal Audience and Photograph with the Holy Father***
13.00	***Lunch at the Academy***
15.00	***Session One*** ***Chairperson*****:** Prof. ***Speaker*****:** ◆ Prof. J. MITTELSTRASS*: Different Types of Discovery – Lessons from the History of Science*
15.15	***Discussion***

15.30	***Speaker*:** ◆ Prof. G.V. COYNE: *Discovery in the New Cosmology of Copernicus, Kepler and Galileo*
15.45	***Discussion***
16.00	***General Discussion***
16.45	***Session Two*** ***Chairperson*:** Prof. ***Speaker*:** ◆ Prof. P.J. LÉNA: *The Case of the Extrasolar Planets*
17.15	***Discussion***
17.30	***Speaker*:** ◆ Prof. R. MURADIAN: *Going from Quarks to Galaxies: Two Findings*
17.45	***Discussion***
18.00	***Coffee Break***
18.30	***Speaker*:** ◆ Prof. C. RUBBIA: *(Title to be submitted)*
18.45	***Discussion***
19.00	***Speaker*:** ◆ Prof. S.L. JAKI: *On a Discovery about Godel's Incompleteness Theorem*
19.15	***Discussion***
19.30	***General Discussion***
20.00	***Dinner at Domus Sanctae Marthae***

SATURDAY 6 NOVEMBER 2004

9.00	***Session Three*** ***Chairperson*:** Prof. ***Speaker*:** ◆ Prof. M. MOSHINSKY*: Diffraction in Time (Tentative Title)*
9.15	***Discussion***
9.30	***Speaker*:** ◆ Prof. C. COHEN-TANNOUDJI: *Optical Methods – A Simple Way to Interrogate and to Manipulate Atoms*
9.45	***Discussion***
10.00	***Speaker*:** ◆ Prof. M.G.K. MENON: *The Role of Innovation, Interdisciplinarity and Phenomenology as Components of Creativity in Opening New Windows*
10.30	***Discussion***
10.45	***Speaker*:** ◆ Prof. M.J. REES: *From Confusion towards Consensus in Cosmology*
11.00	***Discussion***
11.15	***Coffee Break***
11.30	***Session Four*** ***Chairperson:*** Prof. ***Speaker:*** ◆ Prof. W.E. THIRRING: *Instabilities of Gravitation Dominated Systems*
12.00	***Discussion***
12.15	***Speaker*:** ◆ Prof. A. ZICHICHI: *A Personal Experience of Unexpected Discoveries*
12.45	***Discussion***
13.00	***Lunch at the Academy***
15.00	***Speaker*:** ◆ Prof. M. HELLER: *Discovering the World Structure as a Goal of Physics*
15.30	***Discussion***
15.45	***General Discussion***
16.00	***Session Five*** ***Chairperson*:** Prof. ***Speaker*:** ◆ Prof. J.-M. MALDAMÉ: *Comment la réflexion sur l'inspiration de la Bible éclaire l'invention en matière de science*
16.15	***Discussion***
16.30	***Speaker*:** ◆ Prof. M. SELA: *Paths of Discovery of a Therapeutic Vaccine*

16.45	***Discussion***
17.00	***Coffee Break***
17.15	***Speaker*:** ◆ Prof. A. SZCZEKLIK: *Aspirin and Eicosanoid Pathways: The Discoveries that Changed Contemporary Medicine*
17.45	***Discussion***
18.00	***Session Six*** ***Chairperson*:** Prof. ***Speaker:*** ◆ Prof. A.M. BATTRO: *Microdiscoveries: A Case Study of Creative Paths and Academic Networks in Science*
18.30	***Discussion***
18.45	***Speaker*:** ◆ Prof. W.J. SINGER: *The Discovery of Synchronous Oscillations in the Brain: The Role of Chance and Fortunate Coincidences*
19.00	***Discussion***
19.15	***Speaker*:** ◆ Prof. R.J. WHITE: *Discovering Pathways to Brain Cooling*
19.30	***Discussion***
19.45	***General Discussion***
20.00	***Dinner at Domus Sanctae Marthae***

SUNDAY 7 NOVEMBER 2004

Trip to Montecassino Abbey ***60th Anniversary of the Abbey's Destruction and Reconstruction***	
7.00	***Bus leaves Domus Sanctae Marthae***
10.15	***Arrival in Montecassino and Greeting by Abbot Monsignor Bernardo D'Onorio***
10.30	***Abbey Mass with Gregorian Chants, celebrated by His Eminence Cardinal Joseph Ratzinger***
11.30	***Guided Visit to the Abbey***
12.30	***Social Lunch at the Abbey***
15.00	***Bus leaves for Domus Sanctae Marthae***

MONDAY 8 NOVEMBER 2004

9.00	***Session Seven*** ***Chairperson*:** Prof. ***Speaker*:** ◆ Prof. W. ARBER: *The Impact of Microbial Genetics on the Development of Genomics and Biotechnology*
9.30	***Discussion***
9.45	***Speaker*:** ◆ Prof. C. PAVAN: *Endosymbiotic Bacteria Associated with Plant Seeds and Birds' Eggs*
10.00	***Discussion***
10.15	***Speaker*:** ◆ Prof. R. VICUÑA: *Microbial Biodiversity: A New Voyage of Discovery*
10.45	***Discussion***
11.00	***Coffee Break***
11.30	***Session Eight*** ***Chairperson*:** Prof. ***Speaker*:** ◆ Prof. R. HIDE: *Geomagnetism, 'Vacillation', Atmospheric Predictabilit and 'Deterministic Chaos'*
11.45	***Discussion***
12.00	***Speaker*:** ◆ Prof. B.M. COLOMBO: *Paths to Discovery: Personal Experiences in a Social Science*
12.15	***Discussion***
12.45	***Speaker*:** ◆ Prof. P.J. CRUTZEN: *The 'Anthropocene', the Present Era Influenced by Human Activity*
13.00	***Discussion***
13.15	***Lunch at the Academy***
15.00	***Speaker*:** ◆ Prof. M.J. MOLINA: (*Title to be submitted*)
15.15	***Discussion***
15.30	***General Discussion***
16.00	***Closed Session for Academicians***
19.00	***Dinner at Domus Sanctae Marthae***

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Pius XI Medal

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ABSTRACTS

MICRODISCOVERIES: A CASE STUDY OF CREATIVE PATHS AND ACADEMIC NETWORKS IN SCIENCE

ANTONIO M. BATTRO

My thesis is that several cognitive processes engaged in any 'microdiscovery' are common to every scientific task up to major discoveries or breakthroughs, like the double helix. I analyze the paths of discovery of the 'fractal character of saccadic eye movements' as a case study where I have recorded in detail many of the different steps of the new idea from the point of view of the cognitive sciences. In particular, I discuss the importance of 'analogies' in my research, the role of 'chance' encounters with relevant information, meetings with people and findings of experimental data. Finally, I analyze the concepts of innovation, confrontation, modelisation and parsimony in scientific discoveries.

Reference: http://www.byd.com.ar/fractalstory.htm

DISCOVERING THE WORLD STRUCTURE AS A GOAL OF PHYSICS

MICHAEL HELLER

The structuralist view on mathematics, claiming that mathematics is 'about structures and their morphology', is well founded in both mathematical practice and metatheoretical investigation, although it is difficult to formulate in a rigorous manner. Assuming the structuralist view on mathematics, we look for its consequences for interpreting physical theories.

Empirical successes of physical theories support their realistic interpretation, but discontinuities in the world image, often caused by replacing a successful physical theory by another even more successful theory, support their anti-realistic interpretation. However, if we remember that the mathematical structure of the old theory can be obtained, as a limiting case, from the mathematical structure of the new theory, we recover a continuity at the level of structures (even if there is no continuity at the level of respective world images). This supports the view that physical theories are 'about the structure of the world' or, more precisely, that the method of physics catches only the world structure. From the philosophical point of view, two possibilities can be envisaged: either (1) structures discovered by physical theories are structures of something, i.e., there is a 'structured stuff', but this stuff is transparent for the physical method (epistemic structuralism), or (2) such a stuff does not exist (ontic structuralism). To decide between these two possibilities one should go beyond the analysis of the physical method and appeal to metaphysical or logical reasons.

In the case, when one physical theory admits more than one mathematical formulation (which is not infrequent situation in physics), we should assume that these formulations are but various representations of an abstract structure, and that it is this abstract structure that reflects or approximates the Structure of the World.

GEOMAGNETISM, 'VACILLATION', ATMOSPHERIC PREDICTABILITY AND 'DETERMINISTIC CHAOS'

RAYMOND HIDE

'Discoveries' – as the organisers of this symposium on 'paths of discovery' emphasise – 'are the basis of all new knowledge. [----] Some stem from the direct verification or 'falsification' of theory, but in many cases serendipity plays a key rôle. Then a discovery is made whilst something else is being sought but the scientific mind and intuition of the researcher become directed towards the unexpected'.

Serendipity certainly featured in some of the main events outlined in this contribution to the symposium. They started in 1947 when P.M.S. Blackett, a cosmic ray physicist then at the University of Manchester, proposed a testable new theory of the Earth's magnetism [1], which over the next few years he and colleagues succeeded in 'falsifying' by observation and experiment. The events ended in 1963 when E.N. Lorenz, a dynamical meteorologist at the Massachusetts Institute of Technology (MIT), published an account of his work on deterministic non-periodic fluid flow, motivated by his interest in the predictability of weather patterns. Lorenz's paper [2] was later recognised by scientists in other disciplines and by mathematicians as a seminal contribution to what subsequently became known as 'chaos theory'. This now influences ideas and methodologies in many branches of science and technology.

Linking these studies were quantitative laboratory experiments in which I discovered in spinning fluids subject to steady (thermal) forcing several nonlinear régimes of flow of varying degrees of complexity in their spatial and temporal characteristics, including (multiply-) periodic ('vacillation') and highly aperiodic ('chaotic') régimes. Undertaken from 1950 to 1953 at the University of Cambridge (and later repeated and their findings confirmed by D. Fultz and his colleagues at the University of Chicago), the experiments were motivated in the first instance by my interest in geomagnetism and motions in the metallic core of the Earth. But they were to attract the attention of meteorologists engaged in research on large-scale atmospheric motions and influence Lorenz's mathematical work on atmospheric predictability and nonlinear dynamical systems.

MY SCIENTIFIC LIFE

MARCOS MOSHINSKY

My interest in science started rather late in my life as in my primary and early high school I was just an average student. Though my parents had a great admiration for knowledge they emigrated from Russia to Mexico in 1927 and were to busy making a living to be able to dedicate much time to continue their education beyond high school. Arriving though at the third year of Secundaria (equivalent to the end of Junior High) I had a professor of mathematics who required an entrance examination and to my astonishment I got the highest grade of the class. This of course interested me in the field and I finished the course way ahead of the other students.

The following years of high school in Mexico required a definition of the interest of the student in subject matters with the view that they could enter the appropriate courses in college with some basic preparation. I chose mathematics and physics and was thinking of engineering as my future profession. It turned out that on finishing High School I had some psychosomatic illness that the doctors where not able to diagnose but suggested that I stop study-

ing for a year to diminish the mental strain. Thus I spent a year (1939) in New York as a worker in a knitting factory (on Broadway and 12th street) using part of the time to improve my English. On my return to Mexico, on the eve of the Second World War, I learned that the National University of Mexico (UNAM) had established in 1938 a Faculty of Sciences among whose fields where mathematics and physics. I entered the Faculty in the fields mentioned in 1940 and, still in my second year, I received an appointment as an assistant researcher at the Institute of Physics of UNAM, which was also founded in 1938.

My main job at the time was to attend a cosmic ray counter as that was the field of the Director of the Institute a former student of Dr. Manuel Sandoval Vallarta one of the pioneers in cosmic ray research. My work did not interfere with my studies and in 1944 I received the equivalent of my Bachelors degree.

At the time three distinguished American mathematicians spent long periods in Mexico as most of their students were in the armed forces during the Second World War. They were George Birkhoff, Norbert Wiener and Solomon Lefschetz. It was the latter, working in Princeton University, that suggested that I do my graduate studies in his University with Eugene Wigner then already an outstanding physicist and later a Nobel Prize Winner. He helped me get admitted in late 1945 and also obtain a fellowship, and I got my Ph.D. in 1949.

In those years Princeton was the Meca of Theoretical Physics not only because of professors like Wigner, Wheeler, Bargman etc., but also by the fact that in 1947, Robert Oppenheimer became the Director of the Institute of Advanced Study a mile away from the University and brought with him some of the best younger physicists and mathematician of the time. Thus my stay in Princeton was very fruitful and on my return to Mexico I was able to help the development of Theoretical Physics at UNAM.

During my stay in Princeton it became very clear to me that the future standing of nations in the international context would not be given so much by their industries or their arms, as by the knowledge and use of science by its inhabitants. On my return to Mexico I wanted my country to be aware, of this situation and increase the scientific knowledge of its population as well as the use of the same.

Thus during more than 40 years I gave an undergraduate and a graduate course at my University (UNAM), the first one usually on quantum mechanics that I considered the basic one in modern physics, and the second usually related to the research I was carrying out at the moment. In that period I directed close to 30 thesis for Bachelor Degree in Physics, 15 for Ph.D. in the same subject and, as I became more well known internationally, more than 15 foreign postodcs came to Mexico for a year or more to collaborate on research with me.

My physics publications include more than 275 articles in refereed international journals and five books as well as many papers in newspapers mainly on the impact of science and education on society.

My permanent association was always with UNAM though I have traveled widely to many other institutions for periods from a year to a few weeks. I never felt that working in Mexico was a hindrance to my scientific work. In fact it was beneficial as I did not have the pressure to work on subjects that were the rage in advanced countries, but could concentrate on the ones that by myself decided were important.

In fact a few of the subjects that I considered worthwhile became popular after I had written a paper on them such as the role of symmetries of canonical transformations in quantum mechanics; the simplifications of nuclear structure calculations with the help of harmonic oscillator transformation brackets; the relativistic many body problem; the Dirac oscillator, etc. My advice to a young physicist and, also to a young scientist in any field, is not the one of Einstein to work in light-house far from the pressures and distractions of the main institutions of learning, but rather choose a university or research group that is just beginning to be able to contribute to its transformation into a first rate establishment.

STANDING RULES FOR MEETINGS

1. The Academy invites a number of illustrious scholars who have especially studied a given question and have arrived at different conclusions to meet in Rome at its headquarters, the 'Casina Pio IV', situated in the Vatican City, so as to make a joint examination of all the data on the question.

2. The chief aim of these discussions is to endeavour to reach a common view on the subject of the meeting, but when this is not possible to formulate precisely the reasons for this inability. The scholars invited to these meetings undertake in advance to concentrate their efforts on this.

3. A critical examination of these reasons should lead either to agreement on a partial or provisional solution or else to the conclusion that, on the basis of the information presently available, it is impossible to establish unity on the question concerned. In the latter event the scholars involved will be called upon:

a) to define the reasons why agreement appears to be impossible for the present;

b) to specify the kind of research work it would be desirable to undertake in order to solve the problem.

4. The invitation will be addressed by the Academy to only a small number of representatives of each branch of learning: these will be selected from scholars who are not connected with the Academy. These representatives will be joined during the discussions by members of the Academy who are experts in the same discipline. This invitation, moreover, will apply only to the study of one precise question by each branch of learning.

5. The debates will be strictly private and will take the form of papers and talks in the presence only of a few members of the Pontifical Academy of Sciences who have special knowledge of the subject under discussion.

6. The conclusions arrived at will be published in the form of a 'Statement' (to which may be added individual notes) mentioning:

a) the points on which agreement was reached;

b) the points on which it was impossible to reach agreement;

c) the reasons why it was not possible to reach agreement;

d) suggestions about the research work that appears most appropriate in order to arrive at a solution of the difficulties.

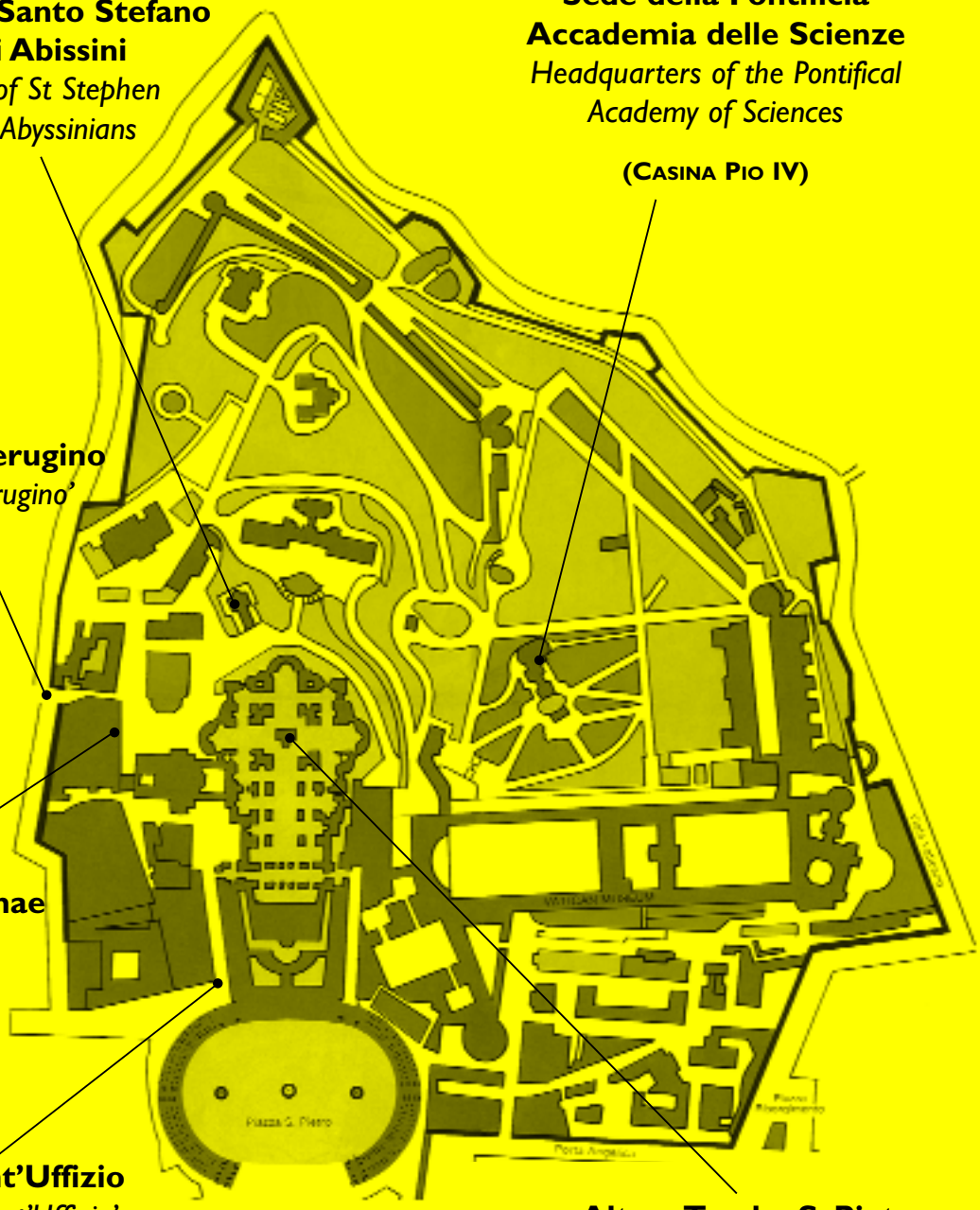
7. The 'Statement' arrived at will be immediately printed and transmitted by the Pontifical Academy of Sciences to all the centres of learning which might be interested in it.

PONTIFICIA ACADEMIA SCIENTIARVM

PLENARY SESSION ON

PATHS OF DISCOVERY

5-8 November 2004



Chiesa di Santo Stefano degli Abissini
Church of St Stephen of the Abyssinians

Sede della Pontificia Accademia delle Scienze
Headquarters of the Pontifical Academy of Sciences

(CASINA PIO IV)

Ingresso del Perugino
Gate of the 'Perugino'

Domus Sanctae Marthae

Ingresso Sant'Uffizio
Gate of the 'Sant'Uffizio'

Altare Tomba S. Pietro
Altar of St Peter's Tomb