UNIVERSITÀ DEGLI STUDI DI TORINO

Laurea Honoris Causa

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Fisica e cosmologa

LAUDATIO

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Aula Magna Rettorato
10 Aprile 2017

“L’unica gioia al mondo è cominciare”

Laudatio
of
Margaret J. Geller
for her honorary degree in Physics at the University of Torino
April 10, 2017

Magnifico Rettore, Colleagues, Ladies and Gentlemen, dr. Geller,

Good afternoon to you all.

I thank the Magnifico Rettore, prof. Ferrari, and prof. Massaglia for introducing this ceremony so exquisitely and have already illustrated many of the outstanding achievements of dr. Geller.

And I very much thank you all, for being with me here today to celebrate this extraordinary scientist.

Introducing the figure of dr. Geller and declaiming her *Laudatio* really is a great honor for me. I am not sure I am up to accomplish this task properly, but I will try to do my best.

The speeches of my respectable colleagues have already convinced those of you who might not know dr. Geller, that she is a brilliant scientist with a brilliant career.

It is apparent from the list of her numerous fundamental contributions to Astrophysics, the numerous prizes she was awarded, the numerous students she trained, who also have had a brilliant career, and not only in science.

However, dr. Geller’s contribution to human knowledge goes beyond the standard. On top of her countless scientific achievements, in 1986, dr. Geller made an outstanding scientific discovery, that - no doubt - made her scientific stature paramount in the path of human knowledge.

Dr. Geller discovered the largest pattern a human being has ever seen, the largest coherent structures in the distribution of the galaxies in the Universe.

In her *Lectio Magistralis*, dr. Geller will explain how she did so and how she is still doing so with her most recent projects.

I wish my task here to be different. I wish to provide you with the proper context of this impressive discovery.

First slide

I will bring you along a journey that starts with this quote from Cesare Pavese, one of the many remarkable alumni of our University: *L’unica gioia al mondo è cominciare* (in *Il mestiere di vivere*)– *The only joy in the world is to begin*.

I chose to use this quote as the title of my *Laudatio*, because, as I said, I will talk about a discovery and each discovery is a beginning, the beginning of a new adventure of humanity.

And when you make a discovery, the joy really is immense.

Slide

There is another remarkable alumnus of our University, Umberto Eco, whose thoughts are relevant for us today.

In 1985, almost contemporarily to dr. Geller’s discovery, he started a popular column on a well-known Italian weekly magazine, a column that lasted for 21 years. The name of the column was *Bustina di Minerva*. I'm sure most of you know this column. Minerva, as you know, is the Roman goodness of wisdom. More originally, *Bustina* stays for the small box of matches where people used to note, with a pencil, some thoughts. Reading those notes afterwards gave the writer the time to distinguish between deep and less deep thoughts. This habit has disappeared: nowadays, most people write their thoughts on the social networks as soon as they conceive them, and so they share them before considering whether they are deep or less deep thoughts.

At any rate, the first piece of this column, that, as I said, appeared in 1985, is, rather interestingly, about discoveries, actually serendipitous discoveries. This topic explains the title: *Che bell'errore! - What a beautiful mistake!* Eco had in mind mistakes that led to revolutionary discoveries, like the mistakes that led to the discovery of a new continent by Cristoforo Colombo [Christopher Columbus], a remarkable man that I will mention again later.

Here, I simply notice that Colombo contributed to change the map of the Earth.

Dr. Geller contributed to change the map of the Universe.

In fact, dr. Geller is a physicist and a cosmologist. But she might define herself differently…

Slide

When people on airplanes ask me what I do, I used to say I was a physicist, which ended the discussion.
I once said I was a cosmologist, but they started asking me about make up,
and the title 'astronomer' gets confused with astrologer.
Now I say I make maps.

What kind of maps does dr. Geller make?

Slide

You look at the night sky: unfortunately, many of us cannot see the sky as it was used to be seen in the past. Most of us live in cities where light pollution is tremendous and, if it is not, we are often so busy with our own terrestrial life that we believe that we do not have time to look up at the sky with the wonder of a child.

Slide

But if you look up, you see stars and if you are not as short-sighted as I am (even when I wear eye-glasses), you can see a few extended sources of light, like the one on this image.

Until the beginning of the 20th century, these sources were called *nebulae* and we now call them galaxies.

It took a while to understand that most *nebulae* are ensembles of billions of stars. Immanuel Kant suggested this in 1755 in his [*Allgemeine Naturgeschichte und Theorie des Himmels*] - *Universal Natural History and Theory of the Heavens*, but we could definitely prove it only 170 years later, in 1925.

Slide

We need to thank Henrietta Leavitt, at the Harvard College Observatory, who observed variable stars in the Magellanic Clouds for a few years: in 1908 she discovered the Leavitt relation, that she definitely confirmed in 1912.

This plot shows the Leavitt relation: you can see that the more luminous is a variable star, the longer is the period of its cyclic variability: this relation enables the measurement of large distances in the Universe.

Slide

Thanks to this relation, Hubble made the Universe explode in size! On this plate showing the galaxy in the Andromeda constellation, you can see how Hubble identified this small dot as a nova and subsequently he enthusiastically realized that it was not a nova but a variable star of the Leavitt relation. This identification enabled him to measure the distance to the galaxy.

Leavitt's relation is so important, that Leavitt was considered to be nominated for the Nobel prize in Physics in 1924. A necessary condition for being awarded the prize, however, is to be alive. Unfortunately Leavitt had died in 1921, and we cannot thus list her among the Nobel laureates, as she would have deserved.

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Until 1925, the Universes of very respectable scientists, including Herschel, Kapteyn, Shapley, and even Einstein, was limited to an ensamble of stars who formed our own, albeit large, Milky Way.

Slide

The Universe is actually enormously larger than the conventional wisdom had thought until those days. Here, you can see how many galaxies like our own Milky Way are there in any very tiny square of the sky.

Still, the scientists of the early 1900s had reached revolutionary achievements in our understanding of the structures of the cosmos.

But these achievements were based on an even more revolutionary change of perspective.

Slide

Look at Aristotle’s cosmos. You see a dichotomy between the terrestrial world and the Heavens. The terrestrial world is made of earth, water, air, and fire; the Heavens is made of aether. The Earth and the Heavens are ruled by different laws of physics: on the Earth linear motions are the natural motions; in the Heavens circular motions are the natural motions.

Slide

A critical view, based on every day experience, of the physics of Aristotle's already is present in the Middle Ages: for example, in the 14th century, John Buridan promoted the theory of impetus, completely at odds with Aristotle's principle of the natural motions.

When God created the world, He moved each celestial sphere as He liked, and while initiating their motion, He gave them an impetus such that they kept moving on their own, without any other intervention of His.

And this impetus that He transmitted to the celestial spheres was neither reduced nor altered afterwards, because the celestial spheres had no tendency for other motions. Neither was there a resistance that would have altered or suppressed this impetus.

Buridan applied this same principle to an arrow on the Earth: he thus assumed that the same physical law holds on the Heavens and on the Earth.

Buridan's idea became the principle of inertia of Galileo Galilei, three centuries later, and Newton’s first principle of dynamics.

So scientific revolutions often behaves like waves on the ocean: they start quietly and grow exponentially. Galileo’s scientific revolution did not pop up out of the blue, but it was prepared by a number of philosophers and intellectuals.

Slide

When Galileo observed Kepler’s supernova in 1604 and the moons orbiting Jupiter in 1610, it was definitely clear to him that the Earth and the Heavens are ruled by the same laws: this conclusion was the crown of a long journey that lasted for a few centuries.

Slide

The most outstanding achievement of this identity between the Earth and the Heavens is the intuition of Isaac Newton in his *Philosophiae Naturalis Principia Mathematica* appeared in 1687: a cannon ball launched at high enough velocity could orbit the Earth like the moon does, as sketched by this Newton's drawing. It was a tremendous achievement of the human mind.

Our current artificial satellites orbit the Earth thanks to this principle, a principle that is now 330 years old. The extreme consequence of this principle is space traveling.

But before traveling in space we need to know how to travel on Earth: this brings us back to maps. The interest of mapping our world starts with the human beings: to be able to move around, you need to map your environment, including the sky above your head. But if you know the map of the sky, you can find your way on the Earth. On turn, if you can travel on the Earth, you can map the Earth.

Slide

In the year 150 AD, the western world already had a rather clear view of its surrounding. This slide shows a reconstruction, made in the 15th century, of a map of the Earth drew by Ptolemy, who was the first to apply mathematics and geometry to geography.

But technological progress often helps you to go beyond the conventional wisdom.

Slide

In fact, we need to reach the 15th century to start to *enlarge* the world. In 1451, Prince Henry the Navigator, in Portugal, promoted the construction of the first caravel. The caravel is a small, highly maneuverable sailing ship that, unlike the more fragile cargo vessels usually adopted in the Mediterranean sea for coastal navigation, can successfully overcome the strong winds, the shoals and the strong currents of the ocean.

Slide

In 1488, with two caravels, the Portuguese Bartolomeu Dias was able to reach the Indian Ocean from the Atlantic Ocean. Ten years later, Vasco da Gama reached India from Europe by sea for the first time in European history.

Slide

We can thus see a new *revolution*, a geographic revolution, that again grows like a wave: the 15th century is a collection of navigators and intellectuals that culminates with Colombo's discovery of the American continent in 1492 and the circumnavigation of the Earth between 1519 and 1522 by Ferdinand Magellan, who actually was killed during the journey; Elcano and Pigafetta, shown here, are among the only 18 survivors who returned to Spain, out of the initial 240 men of this expedition.

En passing, in 2008, dr. Geller was awarded one of the many prizes she received in her career: the Magellanic premium of the American Philosophical Society. To avoid misunderstandings, I say that the name comes from John Hyacinth de Magellan, a Portuguese natural philosopher of the 18th century, and not from Ferdinand Magellan. But the prize motivation is telling.

Slide

I quote from the American Philosophical Society: *Established by a gift of 200 guineas by John Hyacinth de Magellan of London in 1786 "for a gold medal to be awarded from time to time under prescribed terms, to the author of the best discovery or most useful invention relating to navigation, astronomy, or natural philosophy..."*

Dr. Geller's discovery meets all these three fields: astronomy, natural philosophy, and navigation in space, albeit virtual navigation.

Slide

By the mid 16th century, the Earth was a reasonably well known globe. Here you see the oldest known globe: it was probably made in Florence around the year 1500. It was discovered in Belgium in 2013 and it might thus be older than the Hunt-Lenox globe, that you see in the left corner of the slide, in the collections of the New York Public Library, of which dr. Geller is one of the Library Lions. In fact, the Hunt-Lenox globe is dated around 1510. Unlike the Hunt-Lenox globe, that is made from copper, the older globe discovered in Belgium is constructed of two ostrich eggs. It shares almost identical labels and detailed contours with the Hunt-Lenox globe: you can clearly see South America in the bottom right corner, whereas North America only is a collection of islands.

The 16th century brings us back to the heliocentric revolution of Copernicus, who died in 1543, and the scientific revolution of Galileo, who was born in 1564: human curiosity craves to understand the world, the Earth and the sky.

And similarly to the geographic exploration who required the construction of a new ship, the caravel, we need technological progress to enlarge our knowledge of the sky, and, on turn, technological progress is driven by the desire of knowledge.

Slide

Allegedly, the first telescope was built by Hans Lippershey in 1608: most likely he had in mind the use of the telescope for navigation. Galileo built his own and more powerful telescope in 1609. Apparently Galileo was the first man to point a telescope to the sky.

And his pointing raised new questions, that encouraged more numerous and deeper astronomical observations.

But this is not the place to tell you the history of Astronomy.

Slide

Let me jump to what was known about the sky in 1784. In this year, William Herschel already knew that the *nebulae* are not homogeneously distributed on the sky.

In my late observations on nebulae I soon found,

that I generally detected them in certain directions rather than in others: that the spaces preceding them were generally quite deprived of their stars, so as often to afford many fields without a single star in it:

that the nebulae generally appeared some time after among stars of a certain considerable size, and but seldom among very small stars,

that when I came to one nebula, I generally found several more in the neighborhood.

Unfortunately, in 1784, there was no way to determine whether these *nebulae* are close or distant, within the Milky Way or beyond it.

Slide

As I mentioned at the beginning, we need to arrive to the year 1912, when Henrietta Leavitt provided the tool to start answering this question. Based on the equations of Einstein's General Relativity, in 1927, Georges Lemaitre suggested that cosmic space is expanding.

In 1929, this suggestion appeared to correspond to reality thanks to Edwin Hubble's discovery of the correlation, shown in the bottom panel, between the distances of the galaxies, measured with Leavitt's relation, and their recession velocity.

In other words, once we measure the galaxy recession velocity from its electromagnetic spectrum, we can infer its distance.

With this relation between distance and a property of the electromagnetic spectrum, a three-dimensional mapping of the Universe is now possible!

Unfortunately, in the 1920s measuring a spectrum of a single bright galaxy took a few nights of observing time at the large telescopes available in those days, and it still took a few hours in the following decades. Again technological progress was required here. Only by the end of the 1970s, the construction of semi-conductor devices enabled the measure of a large number of galaxy spectra, and therefore galaxy distances, within the life time of a human being.

As I mentioned, the fact that the *nebulae* were not homogeneously distributed on the sky was already noticed by Herschel as early as in the 18th century. When Hubble definitely proved that they are not within our Milky Way, but they are galaxies in their own right, like the Milky Way itself, interest grew on understanding the distribution of galaxies on a quantitative basis.

Slide

In 1932, Harlow Shapley and Adelaide Ames at the Harvard College Observatory measured the positions of 1250 galaxies in the sky and derived the existence of a "general unevenness in the distribution" of the galaxies projected onto the plane of the sky.

In 1930s, rudimentary count-in-cell methods were used [by Bart Bok in 1934 and by Albert Mowbray in 1938] to have a measure of the clustering of galaxies on the scale of several millions of light years. This kind of analyses was continued and extended for the following decades, until the Lick survey, that is shown here, that used large field plates from the Lick Observatory and revealed extended clustering and super-clustering of galaxies.

Slide

A notable exception to this common understanding was Fritz Zwicky. Zwicky was an outstandingly brilliant astrophysicist, who had a number of successful intuitions, including, in the 1930s, the first evidence of a discrepancy between Newtonian gravity and the kinematics of galaxies in the Coma cluster, and the suggestion that galaxies should act as gravitational lenses.

I quote from one of his many papers on the subject of the galaxy distribution:

There are no indications whatsoever for the existence of any systematic clustering of clusters of galaxies.

No doubt, we now know that, regarding the distribution of galaxies on large scales, Fritz was eventually simply wrong.

The real break-through in the distribution of the galaxies in the Universe is when you move from two dimensions to three dimensions. As I said, this requires taking galaxy spectra, and we have to wait until the 1970s to see the first large samples of galaxy spectra. In the 1970s and early 1980s, these samples of galaxy spectra focused around clusters of galaxies or were too sparse or covered a too small solid angle to assess the general properties of the large-scale structure.

And here it comes a very simple strategy, originally conceived and realized by dr. Geller. She will describe the details of this strategy later. Here I show what she found in 1986.

Slide

Here it is!

Each point is a galaxy and we are here, where the Milky Way is. This is the distance from the Milky Way that reaches 315 millions of light years. You can see that galaxies are very unevenly distributed in three dimensions.

Large voids and very large-scale structures are ubiquitous.

These are the largest patterns in Nature a human being has ever seen.

Here we see another epic revolution that grew like a wave: there were redshift surveys before the survey of dr. Geller, and even claims of the existence of large-scale structures. But those data were very poor and the claims were shaky. Dr. Geller aimed to go beyond the standard with an original idea that was as simple as brilliant.

Like Colombo, who was also preceded by a number of brave navigators, she challenged the conventional wisdom, and like Colombo, dr. Geller was rewarded for her courage.

Slide

The impact on the media was enormous: dr. Geller's discovery appeared on the front page of the New York Times, the Encyclopedia Britannica was updated to include her picture of that slice of the Universe, and the number of interviews and popular science articles is countless.

It was appropriate, because it was indeed a major achievement of human knowledge and the beginning of a new, exciting adventure.

Slide

In fact, dr. Geller's discovery started a new field, the field of "cosmography" that is now routinely investigated. Nowadays the number of redshift surveys is countless: LCRS, 2dF, SDSS, VIPERS, to mention a few.

But more importantly, as any other major achievements, her discovery opened new doors and raised new questions.

The question that is, at the same time, most obvious and most relevant is: How did these large structures form?

With the discovery of the large-scale distribution of galaxies in the Universe, we see exactly what happened in geography.

Slide

In 1912, the same year of Henrietta Leavitt's discovery, a really remarkable year for us today, the geophysicist and polar researcher Alfred Wegener, inspired by the shape and the distribution of the continents, proposed the theory of the continental drift. The theory was corroborated by similarities in geological structures and fossil plants between matching sides of the continents, but it was initially opposed by the community.

Eventually, fifty years later, in the 1960s, the intuition of Harry Hess of the sea floor spreading gave Wegener's idea such a solidity that the earth sciences were revolutionized. The modern theory of plate tectonics indeed is based on Wegener's and Hess' ideas and is now widely accepted: it enables us to understand where and why earthquakes are more frequent and more intense.

Slide

Let's take a look at the very abstract of dr. Geller's original paper:

The best available model for generating these structures is the explosive galaxy formation theory of Ostriker and Cowie, published in 1981.

I bet very few of you, if any, know what this model was about. In fact, this model is now fully obsolete.

This sentence from the abstract of dr. Geller's paper tells us how much progress and new ideas the discovery of dr. Geller boosted over the last thirty years.

We now think that the best way to explain the formation of these large cosmic structures is to resort to "quantum fluctuations" on subatomic scales in the early universe during the inflationary period.

The infinitely small is linked to the infinitely large!

But now a new conundrum comes. Explaining the formation of cosmic structures we see in dr. Geller's maps with quantum fluctuations in the early Universe requires large amounts of two unknown components: dark matter and dark energy. What are they? Do dark matter and dark energy really permeate the entire Universe as suggested by the conventional wisdom of the community of astrophysicists and cosmologists?

Slide

To Lev Davidovich Landau, the 1962 Nobel laureate in Physics, is credited a very famous quote

Cosmologists are often in error, but seldom in doubt.

I am a cosmologist and I certainly fall into the first part of Landau's classification: I'm often in error. I don't feel like falling in the second part of his classification, however, because I'm always in doubt.

Slide

When, in 1783, a year before Herschel wrote his notes on the distribution of the galaxies, Antoine Lavoisier read to the Academy of Sciences in Paris his [*Réflexions sur le phlogistique*] - *Reflections on Phlogiston* – it was commonly accepted that combustion was due to the phlogiston, an element contained in combustible bodies and released during combustion: thus, burnt material was thought to be dephlogisticated. However, some material is lighter after burning, so it was proposed that phlogiston had negative mass. So, to save the phlogiston theory, even the concept of negative mass appeared reasonable.

However, this and other challenges were solved when Lavoisier demonstrated that combustion requires a massive gas that he called oxygen. Requiring the existence of phlogiston was now superflous. Convincing the community, however, took some time.

Slide

In the 1800s, the propagation of electromagnetic waves was explained by the presence of ether: the ether was assumed to be weightless, transparent, frictionless, undetectable chemically or physically, and permeating all matter and space.

When, in 1905, Einstein conceived the special theory of relativity, the concept of ether became superfluous. Again, this concept, in its widest interpretation, did not immediately disappear.

In 1920, in a lecture at the University of Leiden, Einstein himself said: *More careful reflection teaches us, however, that the special theory of relativity does not compel us to deny ether. […] We may say that according to the general theory of relativity space is endowed with physical qualities; in this sense, therefore, there exists an ether. According to the general theory of relativity space without ether is unthinkable.*

Nowadays, a few physicists would share this view, or at least this lexicon.

Today, as I said, explaining the formation and evolution of the cosmic structures discovered by dr. Geller requires the existence of dark matter and dark energy within the framework of the general theory of relativity.

Slide

According to Encyclopedia Britannica, *dark energy, in contrast to other forms of matter, is relatively uniform in time and space and is gravitationally repulsive, not attractive, within the volume it occupies. The nature of dark energy is still not well understood.*

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Last February, David Merritt, a brilliant astrophysicist in Rochester, NY, wrote an enlightening article where he says:

The use of conventionalist stratagems [i.e. dark matter and dark energy] *in response to unexpected observations implies that the field of cosmology is in a state of 'degenerating problemshift' in the language of Imre Lakatos.*

Imre Lakatos was a Hungarian philosopher of science. In his view, *a degenerative research programme indicates that a new and more progressive system of theories should be sought to replace the currently prevailing one.*

In other words, we might be at a time when we need a new Lavoisier who got rid of phlogiston or a new Einstein, whose theory eventually got rid of ether.

Slide

Give light, and the darkness will disappear of itself

is a quote credited to another notable alumnus of our university, Erasmus of Rotterdam.

We indeed still have to give light to the mystery of the large-scale structures in the Universe.

Slide

Let us return to Umberto Eco and his first *Bustina di Minerva.* I suspect that, to solve the mystery of dark matter and dark energy, we need astrophysicists and cosmologists who do not fall into that class of scientists that Eco mentions*:*

Certe volte temo che chi non scopre mai niente sia colui che parla solo quando è sicuro di aver ragione – Sometimes, I fear that those who discover nothing are those who only talk when they are sure to be right.

I thus hope that the same courage that dr. Geller had, and still has, to go beyond the conventional wisdom will inflame the new generation of scientists.

I hope that these young scientists will eventually solve the mystery of the large-scale structures in the Universe.

For this courage of going beyond the most accepted view and the conventional approaches, dr. Geller deserved and received many prizes.

We are very honored that she accepted to be awarded the honorary degree in Physics from our University of Torino.

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But I'm sure that she totally shares a thought of Vera Rubin, the scientist who, in the 1970s, discovered that the kinematics of stars in disk galaxies disagree with what is expected based on the distribution of their luminous matter: this discovery, along with theoretical considerations about the stability of galactic disks, suggested the hypothesis of dark matter on the scales of galaxies.

Slide

Well, Vera Rubin once said: *Don't worry about prizes and fame. The real prize is finding something new out there.*

This very prize, the most important prize in the life of a scientist, was no doubt awarded to dr. Geller.

Thank you, dr. Geller, for being with us today. But especially, thank you so much for opening, to the human kind, the largest possible horizon.

And thank very much to all of you for your attention.