550 Years of the Copernican Universe: our Place in the Cosmos

WE-Heraeus-Symposium

10 November 2023

Humboldt Carré in Berlin

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the WE-Heraeus-Symposium:

550 Years of the Copernican Universe: our Place in the Cosmos

Copernicus changed Astronomy, the world and humanity when he demoted Earth's otherwise privileged position at the center of the universe. With this simple empirically evidenced idea, Copernicus forever changed the human experience, relegating us to mere bystanders in a universe where no place nor no thing is special: a universe of bystanders. Further demotions followed (the galaxy is not special, nor the solar system nor even the matter we are made of) and the largest demotion (we are not alone) may be ahead of us. By questioning our place in the universe Copernicus's gesture had a unifying effect on humanity, forcing us to appreciate that, as Buckminster Fuller said, "we are all astronauts on space ship earth".

In the spirit of Copernicus's revolutionary idea and in honor of his 550th anniversary this one day symposium focuses on our place in the universe, galaxy and solar system. With a wide variety of world leading astronomers giving lectures on the state of the art in their respective fields, we will celebrate Copernicus's Idea that our place in the universe, although not special, is nevertheless unique. From exoplanets to the search for extra terrestrial life, from dark matter particle physics to black holes across the cosmos, from how galaxies form to how they die, this meeting will honor a European who united the world in appreciation for our special place in the universe.

Scientific Organizers:

Prof. Dr. Matthias Steinmetz	Leibniz-Institut für Astrophysik Potsdam (AIP) Germany
Dr. Noam Libeskind	Leibniz-Institut für Astrophysik Potsdam (AIP) Germany

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Registration:

08:00 – 09:00 a.m.
Humboldt Carré (Kassenhalle)

Program

Friday, 10 November 2023

08:00 – 09:00	*ARRIVAL AND REGISTRATION*	
09:00 – 09:30	Scientific organizers	**Welcome Words**
09:30 – 10:15	Lisa Kaltenegger	**Finding other Earths - the 2nd Copernican revolution**
10:15 – 11:00	Laura Kreidberg	**Copernicus Revisited: Is the Earth Special?**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:15	Amina Helmi	**Unraveling the history of our home galaxy, the Milky Way**
12:15 – 13:00	Roelof de Jong	**Our place amongst others: the quest for the siblings of the Sun and the Milky Way**
13:00 – 14:15	*LUNCH BREAK*	

Program

Friday, 10 November 2023

14:15 – 15:00	Carlos Frenk	**The emergence and future prospects of the standard model of cosmology**
15:00 – 15:45	Laura Baudis	**All the dark we can not see - direct searches for dark matter in the Milky Way**
15:45 – 16:30	Michael Kramer	**Unveiling the Universe: The impact of Radio Astronomy's transformative discoveries**
16:30 – 17:00	*COFFEE BREAK*	
17:00 – 17:45	David Blaschke	**The Copernican Revolution as a change of frames**
17:45 – 18 :30	Eiichiro Komatsu	**Parity Violation in Cosmology: Does the Universe distinguish between left and right?**
18:30 – 19:30	*RECEPTION*	
19:30	*END OF SYMPOSIUM*	

All the dark we can not see - direct searches for dark matter in the Milky Way

Laura Baudis

University of Zurich, Switzerland

The fundamental nature of dark or invisible matter remains one of the great mysteries of our time. A leading hypothesis is that dark matter is made of new elementary particles, with proposed masses and interaction cross sections spanning an enormous range. Among these, particles with masses in the MeV-TeV range could be directly observed via scatters with atomic nuclei or electrons in ultra-low background detectors operated deep underground. After an introduction to the dark matter problem, I will discuss the most promising direct detection techniques, addressing their current and future science reach, as well as their complementarity.

The copernican revolution as a change of frames

D. Blaschke[1,2,3]

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[3] Helmholtz-Zentrum Dresden-Rossendorf (HZDR), 01328 Dresden,Germany

The copernican revolution consisted in the change from the ptolemaic geocentric model of the cosmos to a heliocentric one. It paved the way for Keplers formulation of his laws of planetary motion which found their dynamical explanation as solutions of Newtons law of motion with his universal gravitational force. After this change of frames the ptolemaic epicycles became obsolete.
A big question appeared in the standard (ΛCDM) big-bang cosmology after the discovery of the accelerated expansion [1,2] which requires that the Universe should consist of 75% dark energy aka a positive cosmological constant Λ in the Einstein equations, the origin of which is not known, therefore called "dark". In my talk, I will discuss the question: Could this cosmological constant be considered a modern epicycle which could become obsolete with a change from the Einstein frame to the conformally related Jordan frame, where instead off length scales the Planck mass and all particle masses change with time [3]? The answer was positive [3] and the approach has subsequently been worked out more in detail [4-6]. It has also been shown that such a "Universe without expansion" fulfills all modern observational constraints [5] and is free of a cosmological big-bang singularity. When there exists one frame in which a singularity is absent, one can argue that this singularity is not a physical one.
On this basis, Rubakov and Wetterich [6] have developed the concept of "generalised geodesic completeness" or "time completeness" that does not depend on the choice of the metric frame. Given the ongoing discussion about the nature of dark energy as well as the age of the Universe, in the light of recent observations of the James Webb Space Telescope (JWST) [9], we may presently witness the dawn of another copernican revolution.

References

[1] A. G. Riess et al., Astron.J. **116**, 1009 (1998)
[2] S. Perlmutter et al., ApJ 517, 565 (1999)
[3] J. V. Narlikar, Ann. Phys. 107, 325 (1977)
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[5] M. Dabrowski, J. Garecki and D. Blaschke, Annal. Phys. **100**, 101101 (2009)
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[7] C. Wetterich, Phys. Rev. D 89, 024005 (2014)
[8] V. A. Rubakov and C. Wetterich, Symmetry **14**, 2557 (2022)
[9] R. P. Naidu et al., ApJ **940**, L14 (2022)

Our place amongst others: the quest for the siblings of the Sun and the Milky Way

R.S. de Jong[1]

[1] *Leibniz-Institut für Astrophysik Potsdam (AIP), Potsdam, Germany*

Our Sun is just one of the hundreds of billions of stars in our Milky Way and the Milky Way is just one galaxy out of the hundreds of billions of galaxies in the observable Universe. To understand our place and history in the Universe, it turns out that it is very useful to understand how the properties of our Sun and our Milky Way relate to the properties of other stars and other galaxies. In particular, it is especially interesting to find other stars and other galaxies that have very similar properties to our own, which could be called stellar and galactic twins. But what does it mean to be similar? I will explore a number of dimensions that we can use to compare stars and galaxies and call them similar. In particular I will highlight how the new 4MOST instrument will be taking part in this ongoing quest for twins by obtaining high quality spectra of tens of millions of star and galaxies in the coming five years.

The emergence and prospects of the standard model of cosmology

Carlos S. Frenk

Institute for Computational Cosmology
Durham University
UK

The ``Lambda cold dark matter'' (LCDM) cosmological model is one of the great achievements in Physics of the past thirty years. Theoretical predictions formulated in the 1980s turned out to agree remarkably well with measurements, performed decades later, of the galaxy distribution and the temperature structure of the cosmic microwave background radiation. Yet, these successes do not inform us directly about the nature of the dark matter. This manifests itself most clearly on subgalactic scales, including the dwarf satellite galaxies of the Milky Way and especially less massive dark matter halos, too small to have made a galaxy. Apparent contradictions between the predictions from cosmological simulations and observations have led to the perception of a ``small-scale crisis'' for LCDM. I will argue that this perception stems from an inappropriate application of the simulations and that, in a very Copernican sense, the simplest version of the theory is consistent with available data. I will contrast the predictions of LCDM with those of the interesting alternative of warm dark matter and show how forthcoming gravitational lensing and gamma-ray data can conclusively distinguish between the two.

Unraveling the history of our home galaxy, the Milky Way

A. Helmi [1]

[1] *Kapteyn Astronomical Institute, University of Groningen, The Netherlands*

The Milky Way is one of many billions of galaxies in the Universe and the one we know best. Our Galaxy turns out to be fairly average and therefore it can be used to understand in general terms how galaxies form and evolve and also to learn about what the Universe is made of. At the same time, the Milky Way is also our home galaxy, and hence a big motivation to unravel how it has formed stems from human's innate curiosity to understand our origin. In this talk I will describe the ongoing revolution in our view of the Galaxy which is driven primarily by ESA's Gaia space mission combined with ground-based datasets. The vast amounts of information that are becoming available are allowing us to conduct ‘archaeology' with stars and to reveal the evolutionary history of the Milky Way.

Finding other Earths - the 2nd Copernican revolution

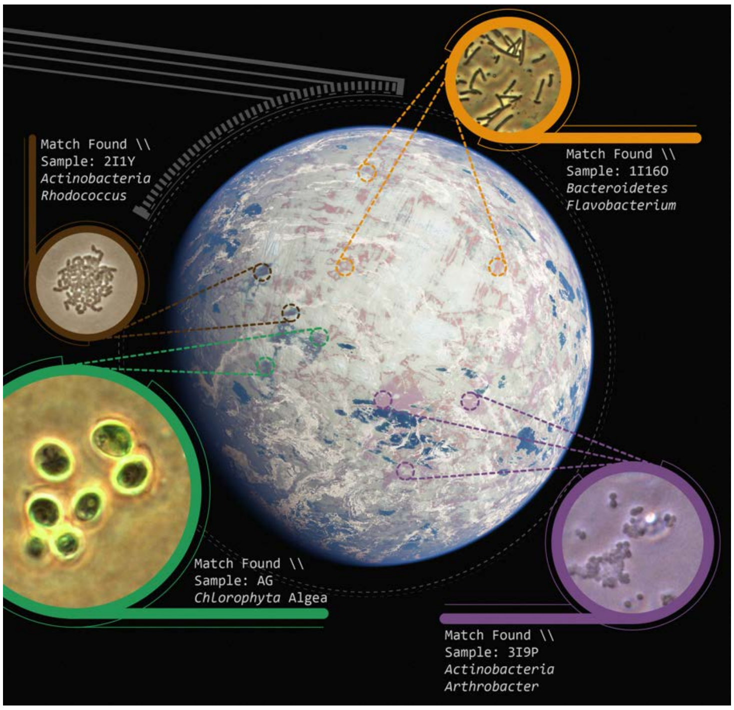
L. Kaltenegger

Carl Sagan Institute & Astronomy Dep., Cornell University, Ithaca, USA

The detection of exoplanets orbiting other stars has revolutionized our view of the cosmos. First results suggest that it is teeming with a fascinating diversity of rocky planets, including those in the habitable zone. Even our closest star, Proxima Centauri, harbors a small planet in its habitable zone. With the James Webb Space Telescope we have started to peer into the atmospheres of rocky planets and get a glimpse into other rocky worlds.

Our own planet and its wide range of biota is the Rosetta stone to explore how to detect habitability and signs of life on other rocky worlds over interstellar distances.

The discussion on what makes a planet a habitat and how to detect signs of life is lively. My talk will highlight some of the latest results and address the opportunities and challenges of how to identify and characterize such habitable worlds.



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Parity Violation in Cosmology: Does the Universe distinguish between left and right?

E. Komatsu

Max Planck Institute for Astrophysics, Garching, Germany

Copernicus showed that there is no special place in the Universe. Taking this further, we ask, “Is there a special handedness in the Universe?”, the question of parity symmetry. Parity symmetry is known to be violated in the weak interaction. Do the physical laws behind the unsolved problems of modern cosmology - cosmic inflation, dark matter, and dark energy - also violate parity symmetry? In this talk, we will discuss theoretical and observational possibilities of parity violation in cosmology, a topic that has received much attention in recent years.

References

[1] E. Komatsu, Nature Reviews Physics **4**, 452 (2022)

Unveiling the Universe: The impact of Radio Astronomy's transformative discoveries

M. Kramer

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During the 1930s, the field of radio astronomy emerged as a new ground-breaking window into the cosmos. Over time, it facilitated observations of the universe's most abundant element, hydrogen, spanning cosmic history. This discipline not only confirmed the presence of large-scale magnetic fields in galaxies beyond our own, but also unveiled complex molecules in space. Furthermore, it discovered the reality of previously theoretical objects known as neutron stars - remarkable for showcasing quantum mechanics at macroscopic scales and in space. Radio astronomy also provided the first evidence for gravitational waves and allows us to conduct the most precise tests of Einstein's theory of gravity in strong-field conditions. Imaging black holes is also only possible with radio astronomy. This talk aims to capture the transformative impact of radio astronomy on our cosmic understanding, while also spotlighting the latest findings, inducing the utilization of pulsars in constructing a gravitational wave detector spanning the entirety of our galaxy to conduct gravitational wave astronomy at ultra-low frequencies that are inaccessible by other means.

Copernicus Revisited: Is the Earth Special?

L. Kreidberg[1]

[1]*Max Planck Institute for Astronomy, Heidelberg, Germany*

Nearly 500 years ago, Nicolas Copernicus published his disruptive theory that Earth is not the center of the universe. This "Copernican demotion" has held fast over the centuries, as astronomers have learned that there is nothing particularly remarkable about Earth or even the Milky Way. In the last two decades, however, a new test of the Copernican Principle has emerged -- the discovery of an abundance of planets orbiting other stars. These discoveries allow us to put Earth in context and evaluate whether the formation, architecture, and present-day characteristics of our Solar System are in fact typical. One of the biggest open questions is whether Earth-like exoplanets have water, a key ingredient for life. Thanks to the revolutionary new observing capabilities of the James Webb Space Telescope (JWST), it is possible to characterize the atmospheres of Earth-sized worlds for the first time. In this talk, I will share the latest observations of rocky exoplanet atmospheres from JWST, discuss the implications for their water abundances in comparison to the Earth, and answer the question: was Copernicus wrong?