Observing the Unobservable: a Multi-messenger View of Black Holes

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We have come a surprisingly long way in the ~century since the concept of black holes first emerged as a potential byproduct of the General Relativistic framework. The idea that physical objects could exist, cloaked behind their own event horizons, was originally met with something of the same discomfort as was quantum mechanics. However the discovery of a dark stellar-mass object orbiting (and consuming) its companion star in the X-ray binary system Cygnus X-1 was enough evidence to convince the majority of skeptics, most famously Stephen Hawking and Kip Thorne. Cyg X-1 also illustrates the necessity of using both space- and ground-based instrumentation to discover, observe, and ultimately understand, accreting black holes. These systems unleash energy across the entire electromagnetic spectrum and thus to fully characterise them we need the broadband picture, also to constrain the host system parameters. Nothing illustrates this synergy better than the recent results from the Event Horizon Telescope, where a global, ground-based submillimeter radio interferometry experiment directly imaged two supermassive black hole event horizons, simultaneously with facilities operating from the radio through TeV gamma-ray bands. Such observations enable new tests of General Relativity in the strong regime, but only if the mass and distance of the black holes can be pinned down via studies in other wavebands.

Furthermore, we now suspect black holes of all scales to be sources of accelerated particles (cosmic rays), adding the multi-messenger element as we seek to also understand how matter at its extremes behaves both under strong gravity as well as when expelled to great distances via outflows. Via such outflows, black holes manage to greatly influence their environments, and unlocking the relationship between what goes in to what comes out is a critical step towards assessing the impact of black holes in the Universe at large. I will give an overview of some recent highlights for black hole studies, including the key questions we have about them, and the challenges moving forward, such as combining photon and particle signatures. In particular I will mention the prospects for combining multi-wavelength observations from space and ground with upcoming astroparticle facilities such as the Cherenkov Telescope Array (very-high-energy gamma-rays) and IceCube-GEN2/KM3NET (neutrinos), as well as more longterm ideas such as space-based X-ray interferometry.

Planetary Atmospheric Evolution : Earth and its nearby neighbors

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In spite of their common origin in the neighborhood of the Sun, the three telluric planets surrounded with an atmosphere (Venus, the Earth and Mars) exhibit drastic differences in their atmospheric conditions. At the surface of Venus, the pressure is almost a hundred times higher than on Earth, and its temperature is close to 460°C; in contrast, the surface pressure of Mars is less than ten millibars, and its mean temperature is around - 50°C, with strong local and seasonal variations. Between these two extremes, the Earth stands as an intermediate state, where the surface conditions appeared favorable for water to stay in liquid form, which made possible the development of life. Why did these three planets, born under fairly comparable conditions, evolve to the conditions we observe today?

In this talk, we will discuss the main atmospheric properties of the three planets, with their analogies and differences. We will try to rebuild the relative evolution scenarios of the three planets, and we will address the question of their habitability, past and present. In conclusion, we will address the question of the habitability of rocky extrasolar planets.

The SmallSat Revolution.

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Abstract

The number of satellites that are planned to be in Low Earth Orbit (LEO) by the end of the decade is more than 25,000. The trend towards mega constellations of small satellite for communication and Earth imaging, the introduction of the Cubesat standard in 1999 along with miniaturization in sensor technologies and increased access to space through frequent launches, rideshare opportunities and the emergence of dedicated small satellite launch companies have all contributed to this unprecedented growth in the number of small satellites being built. Spacecraft production is rapidly changing from traditional one-off builds to mass production lines similar to the automotive industry in the last century. The emergence of cubesats with lower entry point costs have allowed a large number of national agencies, Universities and commercial entities into the space industry. Over the last decade and a half, about 45 countries have built and operated their first satellite. In the next five to ten years another 50 are poised to do so. Scaling of cubesat technologies with an increased acceptance of risks for lower duration missions in LEO have paved the way for mega constellations to move from cubesats to more capable small spacecrafts. Small Satellites offer countries a means to start space science research programs, which didn't exist before. Satellite technologies can help immensely in disaster management, crop monitoring, resource utilization, etc. To create sustainable space programs at universities and for these new actors, capacity building is required that goes beyond space engineering. Collaboration in the area of fundamental research, Earth sciences, climate monitoring, etc. will help to advance these studies both for newcomers, as well as established spacefaring nations and universities. It is important to share knowledge of such technologies, so that new players in this field can apply lessons learned to their own design and development processes.

Aerosols, Clouds, and Climate – The Details that Matter: Those We Know, and Those We Don't

Anthopogenic activities profoundly alter the composition of the atmosphere, leading to a cascade of effects on the Earth System and climate. Atmospheric particulate matter, or aerosols, that are produced from these activities play a central role in all these changes. Apart from directly scattering/absorbing incoming solar radiation, anthropogenic aerosols can modulate global clouds – and their ability to reflect sunlight and intercept terrestrial heat - by affecting their concentration of droplets and ice crystals (and this, because aerosols act as the "seeds" upon which cloud particles form). These aerosol variations may also affect the development of precipitation, storm systems and the hydrological cycle at large. Much of the predictive uncertainty surrounding human impacts on the Earth System is related to poorly understood processes involving the emission, transformation and related impacts of atmospheric aerosol, and their complex and multi-scale coupling of aerosols and clouds. Added to this complexity is the large variability and range of aerosol types, each of which is characterized by its own ability to form droplets and ice crystals.

This lecture will present an overview of aerosol-cloud-climate interactions, and the advances that have taken place to understand and describe them in state-of-the art climate models. We will show how the combination of observations, theory and modeling have helped shape our understanding of aerosol-cloud-climate interactions but also lead to representations and models that, to this day, insufficiently capture the full range of interactions and scales involved. We then provide perspectives on important challenges that lie ahead, first pointing to the regions and cloud types that we least understand but need to know, then pointing to modeling and observational strategies that will help bridge the scales, leading to reduced model uncertainty and improved climate sensitivity predictions.

Environment Near the Sun: Advances, Challenges, and Prospects

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Human curiosity and interest in the near-Sun environment date back millennia, as shown by numerous historical records. The confluence of these motives results from our existence and life depending upon Sun. Life on Earth (and maybe elsewhere in the solar system and on other habitable stellar worlds) might never have commenced if not for solar magnetic activity in conjunction with the Sun's light and heat. Whatever happens in the solar atmosphere can affect us in many ways, and sometimes adversely. Over the past few decades, we made significant strides in understanding the near-Sun environment and how it affects our planetary system. We owe these insights to targeted space missions, ground observations, and great improvements in numerical modeling. Cutting-edge technology allows exploring this complex system in ways thought nearly impossible not long ago. Parker Solar Probe is now venturing closer to the Sun than ever —8.5 million kilometers [0.057 AU] from the Sun's surface by July 2022— providing unparalleled insights into phenomena known for decades but still not understood, such as the heating and acceleration of the young and pristine solar wind. Solar Orbiter will image the solar poles from latitudes higher than 30 degrees, which may hold the secrets of the solar dynamo, among other things. The Daniel K. Inouye Solar Telescope (DKIST) will enable high-resolution observations of features on the Sun as small as 20 km, shedding light on the inner workings of solar magnetism. With these opportunities, we may be living in one of the golden ages of heliophysics. There are, however, challenges still to be addressed. Solar magnetic field generation, the solar cycle, and the trigger(s), effects, and forecasting of solar activity are examples of what needs to be explored to understand how the Sun works and how it shapes its – and our – environment. The talk will overview the advances made through the fascinating observations from the recent space-borne missions and ground-based observatories and novel ways of observing the Sun and its environment, which remain a pressing scientific imperative.

Astrobiology – challenges and opportunities for research on Earth and in space

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Astrobiology is the study of the origin, evolution and distribution of life in the universe. Since millennia, humans have thought about how and when life on Earth began, whether life might be found elsewhere in our solar system and beyond and how this hypothetical life forms might look like. However, only recently we can address these questions on a scientific basis with research on Earth and in space. Many different scientific disciplines contribute to astrobiology by working from their points of view on these questions. The challenge lies in the integration of all these different perspectives to form a common picture. In the field of biology our knowledge about life on Earth and its physical and chemical limits has increased substantially. Life has been found in extreme environments where nobody did expect any living organisms a few decades ago. Examples are hydrothermal vents, deep subsurface areas, hot springs, permafrost, deep sea brines, hot and cold deserts. In parallel, the investigation of single organisms in a laboratory environment was complemented by extensive research on natural communities and the complex interactions of their members in the context of the local environment and climate. This increase in knowledge was supported by a remarkable technology development in form of high-throughput analysis methods, bioinformatics, and miniaturization. Our knowledge about the planets and moons in our solar system and the identification of habitable environmental conditions, e.g. on Mars and in the subsurface oceans of Europa and Enceladus, are the result of a series of successful space missions performed by different nations. From missions like MSL, Insight, ExoMars, Mars2020, and MSR we have received and will receive detailed informations about the geology, the climate and the radiation field on Mars. Missions to the outer solar system's planets and moons, e.g. Europa Clipper and JUICE, are expected to produce exciting new data about the potential habitability of the icy moons. Examples from investigations in analogue environments, laboratories, simulation facilities, and in space are clearly demonstrating the diversity of astrobiological research activites and illustrate important steps towards a deeper understanding of habitability and the origin and evolution of life.

The surface of Mars and its habitability: the rover's eyes view

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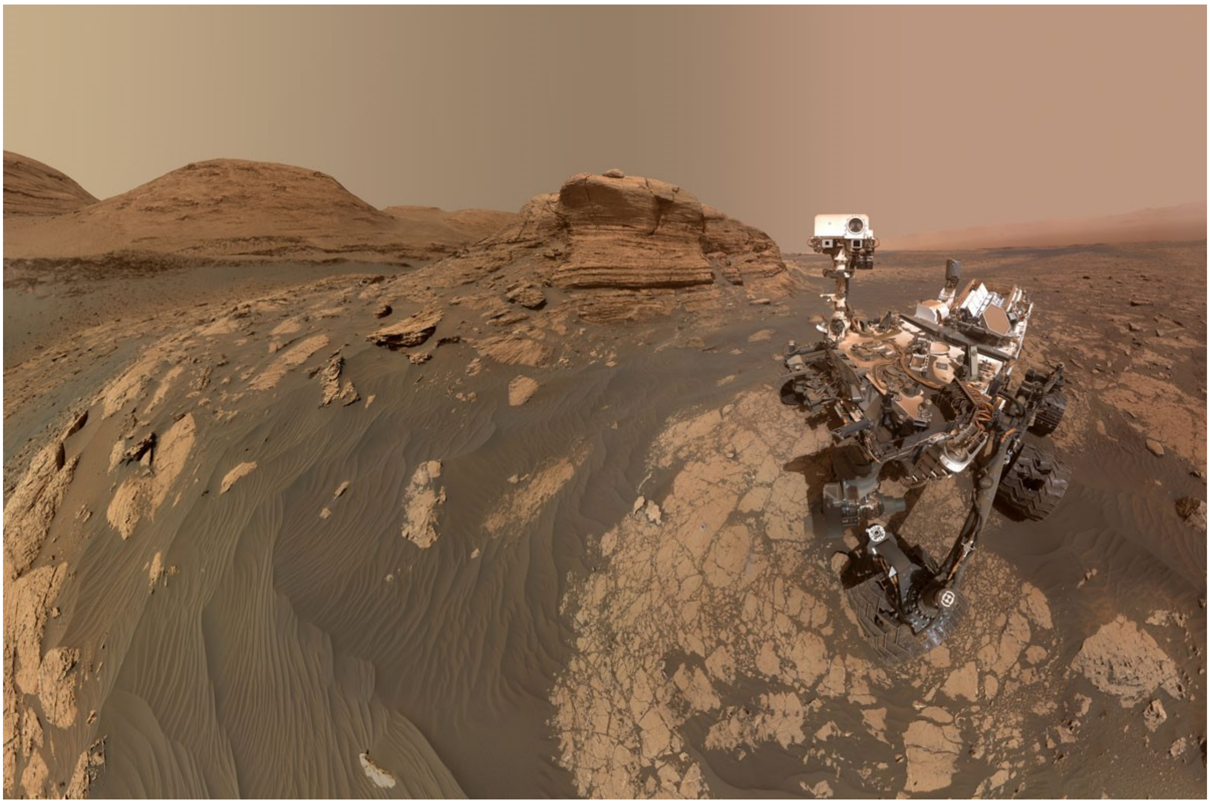
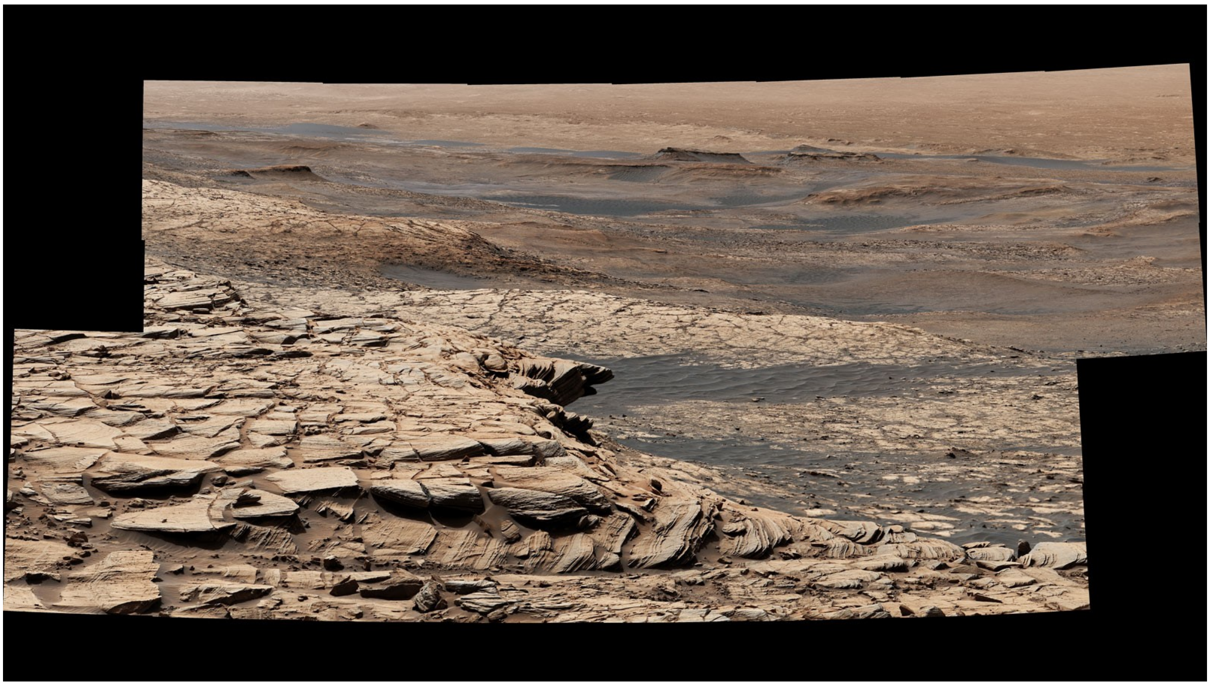


Credit NASA/JPL-Caltech/MSSS

Curiosity at Mont Mercou sat upon ancient lake deposits.

Mars is currently cold and hyper-arid; liquid water is not stable at its surface. Whilst a large body of evidence from orbital data points to an earlier warmer, wetter climate, the character, relative timing and duration of aqueous activity and habitability on early Mars remain poorly constrained. Because the history of water on the surface of Mars is encoded into the planet's sedimentary rocks, detailed on-ground observations of martian sedimentary rocks are needed to deduce the nature of Mars' early environments and climates. In this talk, I will demonstrate how observations from NASA's Mars Science Laboratory the Curiosity rover have revolutionized our understanding of the landscapes of processes that operated on early Mars, and the clues this provides for martian habitability in its distant past. The Curiosity rover has been exploring Gale crater since 2012 with the aim of determining if habitable conditions ever existed at this field site and how they changed through time. Here, I show how using sedimentological techniques, the Curiosity science team have reconstructed an early history in which surface water was abundant at Gale's surface with compelling evidence for water flows transporting sediment by rivers into lakes that may have persisted for hundreds of thousands to millions of years in the Hesperian epoch some 3.6 billion years ago. In particular the discovery of thick successions of lake deposits points to low energy environmental conditions that would have been favourable for life if it ever existed on Mars, a point highlighted by the detection of a diverse assemblage of organic molecules in lake mudstones at Gale. Above the clearly aqueously deposited sediments, we observe a transition to rocks formed in more arid environments, nevertheless there is evidence of transient episodes of water activity suggesting the surface may have been episodically habitable. And there is also abundant evidence for fluid circulation in the subsurface indicating that the subsurface may also have been a viable habitable environment even if surface condition became less favourable for life. Finally in this talk I will touch on recent results from NASA's Mars 2020 Perseverance rover mission that is exploring an ancient delta that built into a crater lake approximately 3.7 billion years ago. Robotic exploration of Mars is providing an exciting and scientifically compelling story of early Mars.



Credit NASA/JPL-Caltech/MSSS

A transition from 'wet' Mars to 'dry' Mars. Rocks in the midground represent ancient lake deposits, whereas sediments in the foreground were deposited by wind-blown dunes.