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The NASA Physics of the Cosmos Program

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The NASA Physics of the Cosmos program is a portfolio of space-based investigations for studying fundamental processes in the universe. Areas of focus include: probing the physical process of inflation associated with the birth of the universe, studying the nature of the dark energy that dominates the mass-energy of the modern universe, advancing new ways to observe the universe through gravitational-wave astronomy, studying the universe in X-rays and gamma rays to probe energetic astrophysical processes and to study the formation and behavior of black holes in strong gravity, and determining the energetic origins and history of cosmic rays. The program is supported by an analysis group called the PhysPAG that serves as a forum for community input and analysis. Space offers unique advantages for these exciting investigations, and the program seeks to guide the development of future space missions through observations from current facilities, and by formulating new technologies and capabilities.

The Future of Space-Based Gamma Ray Astronomy

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The gamma-ray sky offers a unique view into broad range of astrophysical phenomena, from nearby solar flares, to galactic pulsars, to gamma-ray bursts at the furthest reaches of the Universe. The Fermi mission has dramatically demonstrated the broad range of topics that can be addressed by gamma-ray observations. The full range of gamma-ray energies is quite broad, covering the electromagnetic spectrum at energies above about 100 keV. The energy range below several hundred GeV is the domain of space-based gamma-ray observatories, a range that is not completely covered by the Fermi LAT instrument. The gamma ray community has recently embarked on an effort to define the next steps for space-based gamma ray astronomy. These discussions are being facilitated through the Gamma-ray Science Interest Group (GammaSIG), which exists to provide community input to NASA in regards to current and future needs of the gamma-ray astrophysics community. The GammaSIG, as a part of the Physics of the Cosmos Program Analysis Group, provides a forum open to all members of the gamma-ray community. The GammaSIG is currently working to bring the community together with a common vision that will be expressed in the form of a community roadmap. This talk will summarize some of the latest results from active gamma ray observatories, including both Fermi and INTEGRAL, and will summarize the status of the community roadmap effort.

Probing the Hot and Energetic Universe: X-rays and Astrophysics

Mark Bautz
MIT

X-ray observations are a cornerstone of our understanding of the formation and evolution of structure in the Universe, from solar-system-sized supermassive black holes (SMBH) to the largest galaxy clusters. At the most basic level, a significant fraction of the energy output in the Universe is in X-rays, and much of this emission traces the response of baryonic matter to the inexorable, gravity-driven growth of cosmic structure. At present, for example, half or more of the baryons in the Universe reside in a hot (>1 MK) X-ray-emitting phase. We discuss some of the remarkable progress that has been made in understanding the broad outlines of these processes with the current generation of X-ray observatories. We summarize the potential of the next large X-ray observatories to track the development of large-scale cosmic structure and to understand the physics linking the growth of SMBH with that of the (many orders of magnitude larger) galaxies and clusters which host them. We briefly review nearer-term prospects for smaller, focussed missions, including one that will soon exploit pulsating X-ray emission from neutron stars to probe the equation of state of matter at nuclear densities.

Unveiling the Origin of Cosmic Rays

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The origin of cosmic rays, relativistic particles that range from below GeVs to hundreds of EeVs, is a century old mystery. Extremely energetic phenomena occurring over a wide range of scales, from the Solar System to distant galaxies, are needed to explain the non-thermal particle spectrum that covers over 12 orders of magnitude. Space Missions are the most effective platforms to study the origin and history of these cosmic particles. Current missions probe particle acceleration and propagation in the Solar System and in our Galaxy. This year ISS-CREAM and CALET join AMS in establishing the International Space Station as the most active site for studying the origin of Galactic cosmic rays. These missions will study astrophysical cosmic ray accelerators as well as other possible sources of energetic particles such as dark matter annihilation or decay. In the future, the ISS may also be the site for studying extremely high-energy extragalactic cosmic rays with JEM-EUSO. We review recent results in the quest for unveiling the sources of energetic particles with balloons and space payloads, and report on activities of the Cosmic ray Science Interest Group (CosmicSIG) under the Physics of the Cosmos Program Analysis Group (PhysPAG).

Cosmic Microwave Background Polarization: Status and Experimental Prospects

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The faint signatures encoded in the cosmic microwave background (CMB) radiation have provided a powerful means to constrain the physical state of the early Universe. Advances in instrumentation, observation, and analysis techniques have led to the recent detections of B-mode polarization associated with gravitational lensing by several groups. A host of experimental efforts – including the Planck satellite, balloon-borne instrument platforms, and ground-based telescopes – have pending results that will undoubtedly provide greater clarity to this rapidly emerging field. Detailed characterization of the cosmic microwave background's subtle B-mode polarization signature provides an exciting prospect to place stringent limits on the properties of light astroparticle species and large scale gravity waves, as well as experimentally confront the inflationary cosmology paradigm. Anticipated near-term research progress will be summarized and followed by highlights from the "Cosmology with the CMB and its Polarization" workshop. Future directions for spaceborne polarimetry missions of interest to the Inflation Probe Science Interest Group (IPSIG) will be discussed.

Dark Energy Research: A Space Odyssey

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Dark energy, the name given to the cause of the accelerating expansion of the Universe, is one of the most tantalizing mystery in modern physics. Current cosmological models hold that dark energy is currently the dominant component of the Universe, but the exact nature of dark energy remains poorly understood. There are ambitious ground-based surveys underway that seek to understand dark energy and NASA is participating in the development of significantly more ambitious space-based surveys planned for the next decade. NASA has provided mission enabling technology to the European Space Agency's (ESA) Euclid mission in exchange for US scientists to participate in the Euclid mission. NASA is also developing the Wide Field Infrared Survey Telescope-Astrophysics Focused Telescope Asset (WFIRST-AFTA) mission for possible launch in ?2023. WFIRST was the highest ranked space mission in the Astro2010 Decadal Survey. Understanding dark energy is one of the primary science goals of WFIRST-AFTA. This talk will review the state of Dark Energy science, the relevant activities of the Physics of the Cosmos Program Analysis Group (PhysPAG), and detail the status and complementarity of Euclid and WFIRST.

LISA in the gravitational wave decade

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With the expected direct detection of gravitational waves in the second half of this decade by Advanced LIGO and pulsar timing arrays, and with the launch of LISA Pathfinder in the summer of this year, this can arguably be called the decade of gravitational waves. Low frequency gravitational waves in the mHz range, which can only be observed from space, provide the richest science and complement high frequency observatories on the ground. A space-based observatory will improve our understanding of the formation and growth of massive black holes, create a census of compact binary systems in the Milky Way, test general relativity in extreme conditions, and enable searches for new physics. LISA, by far the most mature concept for detecting gravitational waves from space, has consistently ranked among the nation's top priority large science missions. In 2013, ESA selected the science theme ``The Gravitational Universe'' for its third large mission, L3, under the Cosmic Visions Program, with a planned launch date of 2034. Recently, NASA has decided to join with ESA on the L3 mission as a junior partner. Both agencies formed a committee to advise them on the scientific and technological approaches for a space based gravitational wave observatory. The leading mission design, Evolved LISA or eLISA, is a slightly de-scoped version of the earlier LISA design. This talk will describe activities of the Gravitational Wave Science Interest Group (GWSIG) under the Physics of the Cosmos Program Analysis Group (PhysPAG), focusing on LISA technology development in both the U.S. and Europe, including the LISA Pathfinder mission.