Cosmophysics workshop participants gather in front of the conference room during a coffee break for group photo.

Cosmic conference at KEK

[Cosmophysics, Dark Matter, PAMELA]

This is part-two of the two-part series on KEK's cosmic connection, featuring the international workshop on high energy astrophysics held on November 10-12, 2009. Read on to learn how a small group of theoretical comophysicists at KEK is taking steps to tackle the frontline of scientists' cosmic endeavors.

Perhaps you have sat on a dark mountaintop, surrounded by imponderable numbers of shimmering stars and galaxies glued on the penetrating darkness of the sky, and listened to the silence of the cosmos. Perhaps you have felt the commanding forces of the cosmos urge you to ponder the deep cosmic processes yet unfathomable to human beings.

Cosmologists and astrophysicists have made it their life's work to study these things, and have already found many wonders. The dark soundless spaces beyond the stars we see contain many luminous objects. Applying science, technology, and mathematics has revealed previously unseen truths, and there is still more to explore. A group of theoretical physicists at KEK is joining these cosmic endeavors under the group name 'Cosmophysics'.

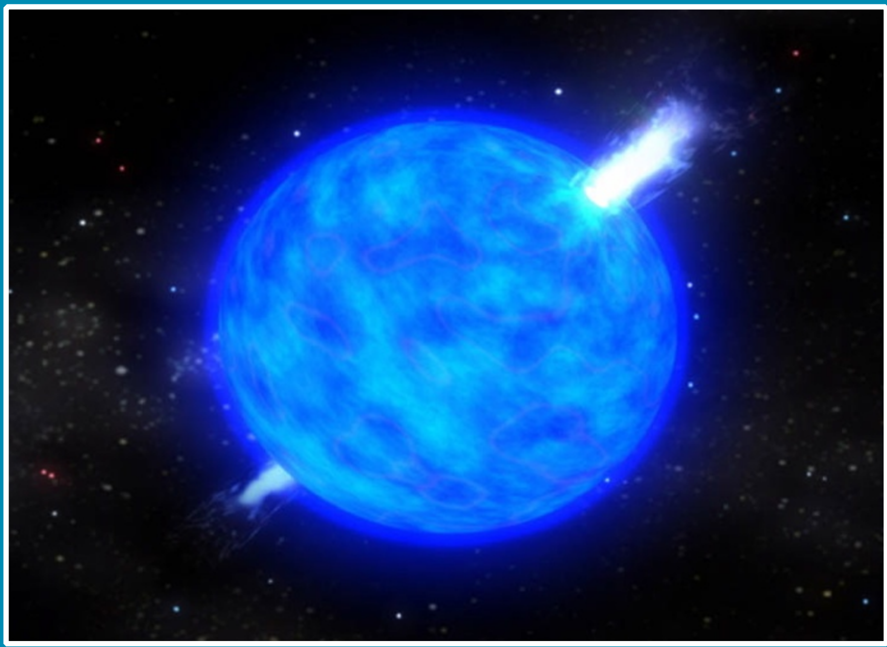
Cosmophysics is not an everyday word. When Prof. Hideo Kodama of KEK named the new theory group at KEK two years ago, he hoped to integrate the fields of high energy astrophysics, gravitational physics, and cosmology. He was then a newly appointed theoretician specializing in general relativity, and the only member of the cosmophysics group at KEK. Now, the group has grown to include nine additional researchers and students.

Luminous explosions in far away galaxies

One recent addition to the cosmophysics group is Dr. Kunihito Ioka, an associate professor of astrophysics. Ioka's cosmic pursuit is in extremely energetic astronomical objects. As he describes it, our universe is a wondrous place. It contains gamma-ray bursts (GRBs), explosions so luminous that they can radiate as much energy as the Sun emit over its entire life span in just a few seconds, as well as black holes a billion times heavier than our Sun. The universe also contains ultra high energy cosmic rays which have as much as 10 million times the energy of particles produced by the most powerful man-made accelerator, the Large Hadron Collider (LHC).

The mechanism of particle acceleration in these high energy sources—Gamma-ray bursts, active galactic nuclei, pulsars etc—is not well understood. It is believed that black holes or neutron stars sit at the center of these energetic sources. The relativistic shock waves flowing out from the extremely dense center is rendered responsible for particle acceleration, but just how those outflows are generated remains mystery.

The observational and theoretical developments in cosmophysics are products of worldwide efforts in the quest to unlock the outstanding mysteries of the universe. For example, modeling astronomical objects in distant galaxies involves complex tasks of incorporating every bit of physics known to humanity from relativity theory to quantum mechanics.



Credit: NASA/SkyWorks Digital

Take GRBs, the most energetic explosions in the universe. It was only in the early 1990s that astrophysicists were able to tell if the sources were just on the edge of the solar system or in the very distant galaxies. Several satellites were launched worldwide, and this resulted in the discovery that these energetic explosions occurred in far away galaxies. Subsequent satellites have brought a wealth of GRB data that allowed researchers to narrow down a broad field of hundreds of theoretical GRB models down to just a few beautifully explained models, though the results have thrown up new challenges.

Workshop on cosmophysics

One event that illustrates the active involvement of the KEK cosmophysics group in the worldwide community is the recent international workshop on cosmophysics held at KEK on November 10-12 of this year. The workshop, attended by 56 astrophysicists and cosmologists from 32 institutions in 5 nations, provided an opportunity for interdisciplinary exploration of the present and future of cosmophysics from both the theoretical and experimental sides.

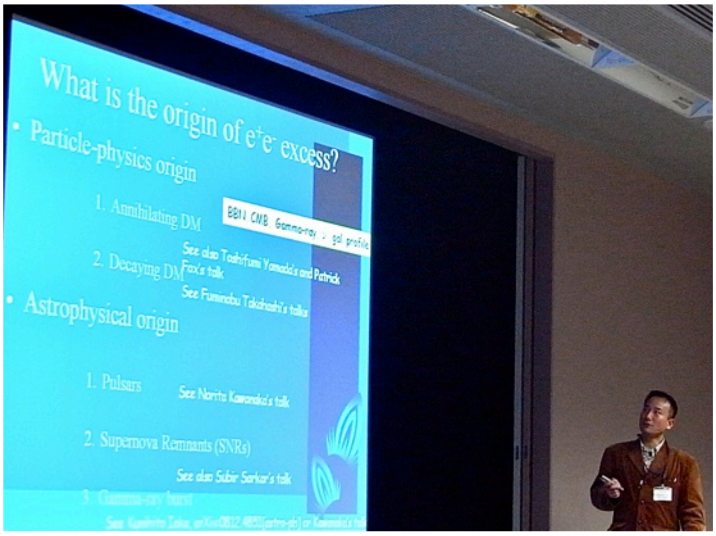
"The aim of this workshop is to exchange ideas on some of the most fundamental problems in cosmophysics, by sharing both observational and theoretical developments," says Ioka, the convener of the cosmophysics workshop.

Prof. Hideo Kodama (left) of KEK, the head of KEK Cosmophysics group, and Dr. Kunihito Ioka of KEK, the convener of the international workshop on cosmophysics.

Fundamental problems in cosmophysics include the origin of cosmic ray particles, the nature of dark matter, the evolution of the universe, the nature of gravity, and the ultimate theory of physics—the grand unified theory. One way to explore these problems is by observing various messages from the cosmos: high energy radiation such as gamma rays, high energy particles known as cosmic rays, cosmic neutrinos, and gravitational waves.

By far the most active discussions presented by the workshop speakers were on the new results from PAMELA and Fermi, two satellite-based telescopes which look for clues to these puzzles by observing cosmic rays and gamma rays.

The Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics, or PAMELA, is a cosmic ray detector module attached to Resurs-DKI satellite.



Dr. Kazunori Kohri of Tohoku University giving a talk on positron excess. He will join the KEK Cosmophysics group in April next year.

Launched in 2006, the Italian satellite aims to observe antimatters in our universe by detecting positrons and antiprotons of cosmic origin. The Fermi Gamma-ray Space Telescope, or Fermi, on the other hand, is a gamma ray telescope launched in 2008, designed to perform an all-sky survey of high energy astronomical objects and dark matter.

New results found by PAMELA in 2008 have excited the entire astrophysics community, and as the result, hint at the nature of dark matter. The results showed an unexpectedly large positron-to-electron ratio (known as 'positron excess') in the energy region of 10 to 60 GeV. While the ratio was theoretically predicted to go down with increasing energy, the PAMELA data showed a ratio that rises with increasing energy (see image).

“There are various explanations for this excess,” says Dr. Kazunori Kohri of Tohoku University. “It could have dark matter origin, but it could also have other astrophysical origin such as pulsars, supernova remnants, or gamma-ray bursts.” So far more than 300 theoretical papers have been written on the positron excess, and the issue is yet to be settled.

Searching for dark matter

Dark matter is matter that doesn’t interact with electromagnetic forces. Because of this fact, dark matter cannot be seen directly with any wavelength of light. Its presence has so far only been inferred through its gravitational interaction with the visible contents of observable universe. Unlike the disk-shaped arrangement of visible matter in spiral galaxies, dark matter is thought to have a spherical distribution around galactic centers.

Scientists have built colliders and launched satellites to search for dark matter signature. The LHC is one such collider, in which dark matter particles might appear as a “missing particles”. PAMELA and Fermi, on the other hand, look for evidence of dark matter in cosmic ray and gamma ray signals.

There are direct and indirect ways for physicists to probe dark matter in observational astrophysics. The direct detection involves processes in which dark matter particle scatters ordinary matter particle. PAMELA and Fermi are designed to detect dark matter particles indirectly. Astrophysicists believe that exploring dark matter particles may occasionally collide with each other and annihilate, producing ordinary particles. They may also simply decay into ordinary particles over time. A whole host of dark matter models are currently under investigation to explain the positron excess discovered by PAMELA.

Dark matter particles are an area of new physics. Plausible dark matter particles, such as weekly interacting massive particles (WIMPs) only appear in physics theories beyond the Standard Model.

Nearby cosmic accelerators

The dark matter theories are not without problems. For one thing, the standard WIMP models cannot be easily fitted to the positron excess curve and need a bit of twisting to push the positron fraction upward at high energies. The expected decay processes also appear unlikely, considering the fact that typical dark matter particles’ predicted decay time being 10^9 times longer than the age of the universe.

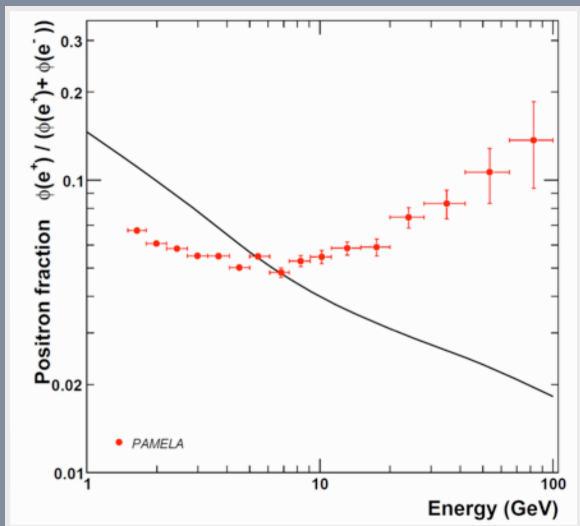
Astrophysicists have worked out possible solutions from pulsars, supernova remnants, micro quasars and GRBs as well. Nearby accelerators of particles could produce the observed positron excess in a variety of ways. “What PAMELA has seen is consistent with our current model of galactic cosmic rays,” says Prof. Subir Sarkar of Oxford University. "A refined calculation of the 'background' due to nearby sources removes the need to invoke dark matter."

The future observatories

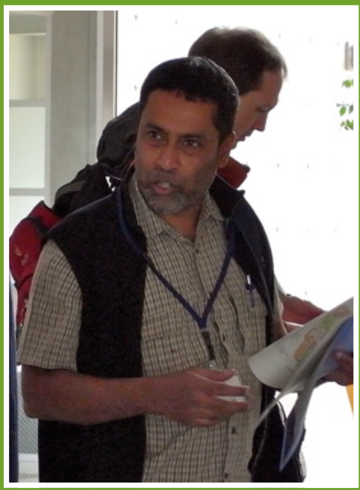
“The exciting thing about this debate over dark matter is that it should be finalized soon when the next generation of satellites is launched and data taking starts in a few years time,” smiles Kodama. “I am particularly excited to hear about the series of future experiments under development.”

Many of the acronyms heard at the workshops, such as CTA, CALET and AMS, are the future experiments making solid progresses towards launch by 2015. The Cherenkov Telescope Array, or CTA, is the next-generation European ground-based gamma ray telescope, employing optical arrays in two locations in northern and southern hemisphere. CALET, the CALorimetric Electron Telescope onboard the Japan Experiment Module on the international Space Station (ISS) is the next-generation high energy electrons and gamma ray telescope. The Alpha Magnetic Spectrometer, AMS, is another cosmic ray search module which will be mounted on the ISS next year.

“It is evident from the talk that the Fermi satellite is an enormous success, producing many new results,” says Ioka. “CTA will follow soon with better sensitivity, better angular resolution, and an extended sensible energy. As to the positron excess, we are in a very exciting time as CALET and AMS are expected to give the final answer soon.” Ioka is also the coordinator for the CTA Japan theory group.

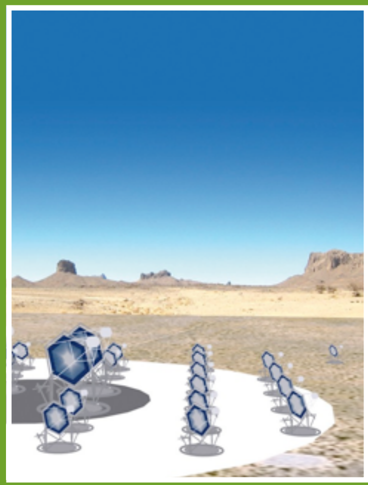


Positron excess in 10-100GeV energy region found by the PAMELA satellite last year has been cited in more than 300 papers. The red is PAMELA data, solid line is the theoretically predicted curve.



Prof. Subir Sarkar of Oxford University gave a talk on PAMELA/Fermi results as well as closing remarks, presenting Europe's new strategic roadmap in astroparticle physics.

Dr. Marco Casolino of the National Institute of Nuclear Physics in Rome presenting new results from the PAMELA experiment.



The Cherenkov Telescope Array (CTA) is a next-generation ground-based gamma ray telescope.

Connecting fields

The workshop also discussed cosmic gamma rays, ultra-high energy cosmic rays, neutrino observatories, gravitational waves, and quark-gluon plasma. The future experiments in these subfields are also making headway. JEM-EUSO, the Extreme Universe Space Observatory on board the Japan Experiment Module on the International Space Station (ISS), will observe ultra high energy cosmic ray particles colliding with the Earth's atmosphere and producing brief flashes of light. In high energy neutrino, IceCube observatory in the Antarctic ice sheet have already employed more than half of full 80 strings of photomultiplier tubes. In gravitational waves, the Large Scale Cryogenic Gravitational Wave Telescope (LCGT) is one of many future gravitational wave projects worldwide.

"It is nice to share our results in an interdisciplinary workshop like this because you learn from experts from other fields," says Dr. Marco Casolino of the National Institute of Nuclear Physics in Rome, who presented new results from the PAMELA experiment.

"The workshop also provided us with a good opportunity to get know how the field of cosmology and astrophysics is strategically promoted in Europe and the US," says Ioka.

In his closing remarks, Prof. Sarkar discussed the recently established Astroparticle Physics European Coordination (ApPEC), the advisory committee whose role is to define a strategic roadmap for this field in Europe.

"Astroparticle physics bridges astronomy and particle physics," said Prof. Sarkar. "The scale and scope of astroparticle experiments are set to grow substantially over the coming decade ... Japan has substantial expertise in many key areas, both in theory and in experiment."

Kodama says that in cosmophysics, theory and experiment go hand-in-hand. KEK has long participated in the Balloon-borne Experiment with a Superconducting Spectrometer, or BESS, which has previously produced antiproton results consistent with PAMELA's new data. The Cosmophysics group also closely collaborates with the new cosmic microwave background (CMB) project launched two years ago at KEK.

In the KEK theory center as well, the Cosmophysics group bridges the fields of physics. "The Cosmophysics group links Hadron physics with particle physics community" says Dr Kazunori Itakura of the KEK Hadron theory group. "The timing is good. Cosmophysics has recently become a new field that hadron physics can contribute to." He says that there are two areas of cosmophysics in which hadron physics plays important roles: the early universe when it was filled with quark-gluon plasma, and the ultra high energy cosmic rays that induce energetic hadronic reactions with nuclei in the Earth's atmosphere.

"Cosmophysics at KEK has just started," says Ioka. "There is much room for diversity in terms of discipline at KEK. Hopefully we will be able to better contribute internationally to both experiment and theory in Cosmophysics."

Related Link:

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