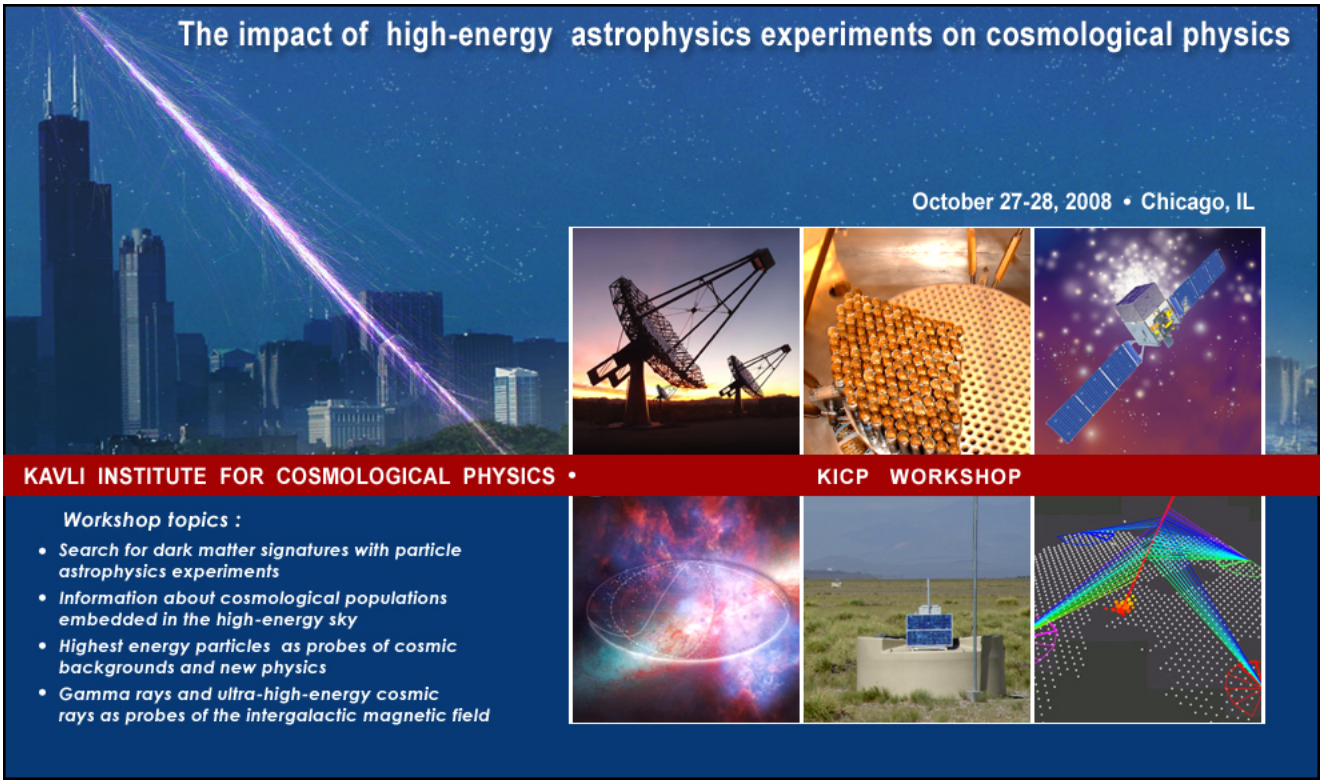
Workshop "The impact of high-energy astrophysics experiments on cosmological physics"

October 27 - 28, 2008 **Chicago, IL**



http://kicp-workshops.uchicago.edu/impact-2008/

WORKSHOP ABSTRACTS

1. **Shin'ichiro Ando** (California Institute of Technology)
   Invited Talk: ***Cosmic Supernova Neutrino Background***
   Session: **Information about cosmological populations embedded in the high-energy sky**
   October 28, 2008 (9:50 AM - 10:15 AM)

   Since the beginning of star formation, explosions of massive stars, supernovae, continued injecting neutrinos to the Universe. These supernova neutrinos now form diffuse neutrino background. Experimentally detecting them is very important, telling us information on cosmic stellar death rate, neutrino generation mechanism in supernova, as well as fundamental properties of the neutrino itself. I will introduce basic physics argument, review the recent updates, and argue implications that we can obtain from the future observations of cosmic supernova neutrino background.

2. **Brian Baughman** (Ohio State University / Center for Cosmology and Astro-Particle Physics)
   Talk: ***Limiting Galactic and Extragalactic Magnetic Field Models with UHECRs***
   Session: **Gamma rays and ultra-high-energy cosmic rays as probes of the intergalactic magnetic field**
   October 28, 2008 (2:55 PM - 3:10 PM)

   Current models of the uniform component of the Galactic magnetic field are not well constrained by rotation measure or synchrotron observations. With the completion of the southern site of the Pierre Auger Cosmic Ray Observatory and its observation of anisotropies in the arrival directions of UHECRs we are being giving another observational tool to probe both Galactic and Extragalactic magnetic fields. Monte Carlo simulations of the traversal of UHECRs through proposed magnetic field models can be used to place limits on these models. We present our methods and tools for performing such an analysis with a focus on the effects of Galactic magnetic field models.

3. **James Braun** (University of Wisconsin - Madison)
   Talk: ***Searches for Neutrino Point Sources with AMANDA and IceCube***
   Session: **Information about cosmological populations embedded in the high-energy sky**
   October 28, 2008 (11:55 AM - 12:10 PM)

   Neutrino astronomy offers the ability to pinpoint high energy hadronic processes in the universe including locations of cosmic ray acceleration. We present the most recent searches for high energy neutrino point sources with AMANDA-II and IceCube, including search methodology and calculated flux limits for several candidate neutrino sources within the context of model predictions. IceCube improves with each season of construction and is expected to surpass current point source sensitivity by a large factor in the next few years.

4. **Jim Buckley** (Washington University, St Louis)
   Invited Talk: ***Prospects for detecting dark matter with VERITAS and future gamma-ray instruments***
   Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
   October 27, 2008 (1:55 PM - 2:20 PM)

5. **Luigi Costamante** (Stanford University)
   Invited Talk: ***Probing the Extragalactic Background Light (EBL) with gamma-ray blazars***
   Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
   October 27, 2008 (9:15 AM - 9:40 AM)

   Gamma ray beams from blazars provide a powerful tool to probe the diffuse Extragalactic Background Light (EBL) independently from direct measurements and theoretical modelling. However they are far from being "standard candles". I will discuss the diagnostic and connection between features in blazars spectra and EBL spectrum in different bands, clarifying some common misconceptions on this topic. While the main progress obtained in recent years (i.e. the exclusion of a high density of the EBL) continues to be confirmed by new observations, further advances on EBL constraints appear more tricky, and depend on a better understanding of the blazar physics.

6. **Corbin E. Covault** (Case Western Reserve University)
   Poster: ***Using Cherenkov light to study the highest energy cosmic ray air showers***

   October 28, 2008 (3:10 PM - 5:00 PM)

   We consider the scientific motivation and the experimental prospects for direct measurement of the lateral distribution of Cherenkov light from the highest energy cosmic ray air showers. In principle, Cherenkov light can provide a means for cross-checking both composition and energy as measured using other techniques.

7. **Charles D. Dermer** (Naval Research Laboratory)
   Invited Talk: ***Cosmological Evolution of Blazars***
   Session: **Information about cosmological populations embedded in the high-energy sky**
   October 28, 2008 (9:00 AM - 9:25 AM)

   Statistical analysis of gamma-ray blazars gives information about the growth, fueling, and evolution of supermassive black holes through cosmic time. A recent study of EGRET blazars, which shows that luminous flat spectrum radio quasars evolve into less luminous BL Lac objects, is summarized. This analysis implies the intensity of the unresolved gamma-ray background from gamma-ray loud AGN, and makes predictions for the number of blazar and radio galaxies expected from the Fermi Gamma ray Space Telescope.

8. **Klaus Dolag** (MPA, Garching)
   Invited Talk: ***Simulating magnetic fields within large scale structures and the propagation of UHECRs***
   Session: **Gamma rays and ultra-high-energy cosmic rays as probes of the intergalactic magnetic field**
   October 28, 2008 (1:55 PM - 2:20 PM)

   In galaxy clusters, non-thermal components such as magnetic field and high energy particles keep a record of the processes acting since early times till now. These components play key roles by controlling transport processes inside the cluster atmosphere and therefore have to be understood in detail. However including them in simulations is extremely challenging as the structures in and around clusters are quite complex and span a very large dynamic range in scales. I will report the status of what can be achieved in numerical simulations of the formation of galaxy clusters in cosmological context and our predictions for the magnetic field structure. Such simulations can be used to constrain the transport and the deflection of UHECRs within clusters and large scale structures.

9. **Brian Fields** (University of Illinois at Urbana-Champaign)
   Invited Talk: ***Physics of starforming galaxies and the gamma-ray background***
   Session: **Information about cosmological populations embedded in the high-energy sky**
   October 28, 2008 (9:25 AM - 9:50 AM)

10. **Stefano Gabici** (DIAS, Dublin)
    Invited Talk: ***Gamma Ray Emission associated with UHECR sources***
    Session: **Gamma rays and ultra-high-energy cosmic rays as probes of the intergalactic magnetic field**
    October 28, 2008 (2:20 PM - 2:55 PM)

11. **Rudy C. Gilmore** (UC Santa Cruz)
Talk: ***The Extragalactic Background Light and Gamma-ray Attenuation***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (9:40 AM - 9:55 AM)

Attenuation of high-energy gamma rays by pair-production with UV, optical and IR background photons provides a link between the history of galaxy formation and high-energy astrophysics. I will present results from our latest semi-analytic models (SAMs), based upon a Lambda-CDM hierarchical structural formation scenario and employing all ingredients thought to be important to galaxy formation and evolution, as well as reprocessing of starlight by dust to mid- and far-IR wavelengths. These latest SAMs are successful in reproducing a large variety of observational constraints such as number counts, luminosity and mass functions, and color bi-modality. I will show 2 models which bracket the possible ranges of galaxy emissivities, and for each of these show how the optical depth from pair-production is affected by redshift and gamma energy. Our work also incorporates the use of a radiative transfer code which is used in conjunction with estimates of the quasar luminosity function and escape fraction from star-forming galaxies to calculate the background into the extreme-UV. The implication of this work for Fermi observations in the 10-300 GeV range will be discussed.

12. **Darren R. Grant** (Pennsylvania State University)
Talk: ***Indirect Dark Matter Searches with the IceCube Neutrino Observatory***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (4:10 PM - 4:25 PM)

If the non-baryonic dark matter is the SUSY LSP, or neutralino, such particles should collect inside massive celestial bodies and ultimately annihilate, producing a measurable neutrino flux. Large scale neutrino telescopes with energy sensitivity in the GeV to TeV range, such as the IceCube observatory under construction at the geographic South Pole, are capable of searching for this potential neutrino source from the Sun and Earth's centre. South Pole neutrino observatories have actively performed competitive indirect dark matter searches for a number of years, beginning with the data-taking of the AMANDA-B10 detector in 1997. This talk will discuss the latest search results from AMANDA Sun and Earth indirect WIMP searches from data taken between 2001 and 2003. Preliminary results with 2007 data using the first 22 strings of the IceCube detector, which completely enclosed AMANDA, will also be discussed. Finally, a new dense inner core, called the DeepCore, has been designed and will start to be installed this coming season within the IceCube detector. The DeepCore will have significantly improved sensitivity to events with energies less than 100 GeV over the standard IceCube detector and the expected improvements in dark matter searches will be presented.

13. **John D. Hague** (University of New Mexico)
Talk: ***Study of Two Metrics for Anisotropy in the Highest Energy Cosmic Rays***
Session: **Information about cosmological populations embedded in the high-energy sky**
October 28, 2008 (12:10 PM - 12:25 PM)

A two-point and a three-point metric for detecting high energy cosmic ray anisotropy are described and applied to Monte Carlo simulated samples containing known mixtures of (simulated) signal and isotropic background. Several "candidate" anisotropic signals are considered. With an eye for future experiments, the sensitivities of these metrics to detect deviations from isotropy are studied versus sample size and versus the fraction of anisotropically distributed cosmic rays.

14. **Dan Hooper** (Fermilab)
Invited Talk: ***High Energy Positrons and Electrons in the Milky Way - Are We Seeing Dark Matter?***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (3:30 PM - 3:55 PM)

Recent preliminary results from the PAMELA experiment indicate a surprisingly large flux of high energy (>10 GeV) positrons in the cosmic ray spectrum. This appears to require the existence of primary sources of energetic electron-positron pairs in the surrounding few kiloparsecs. I will discuss this signal and possibilities for its origin, including both dark matter annihilations and pulsars.

15. **John Kelley** (University of Wisconsin, Madison)
Talk: ***Searching for Quantum Gravity with AMANDA and IceCube***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (11:35 AM - 11:50 AM)

    The AMANDA-II detector, operating in the deep ice at the geographic South Pole since 2000, has accumulated a large sample of atmospheric muon neutrinos in the 100 GeV to 10 TeV energy range. The zenith angle and energy distribution of these events can be used to search for various phenomenological signatures of quantum gravity in the neutrino sector, such as violation of Lorentz invariance or quantum decoherence. We present the results of such a search using a likelihood method on data from 2000 to 2006. The next-generation IceCube detector, now 50% complete, will provide even more sensitive tests of physics beyond the Standard Model.

16. **Uri Keshet** (Center for Astrophysics)
Invited Talk: ***Physics of galaxy clusters and intergalactic shocks imprinted on the nonthermal sky***
Session: **Information about cosmological populations embedded in the high-energy sky**
October 28, 2008 (10:45 AM - 11:10 AM)

    Galaxy clusters are known to harbor significant populations of nonthermal particles. Physical processes involving these particles play an important role in cluster evolution and should be taken into account in cluster-based cosmology. I will briefly review the observations and theory of non-thermal processes in the intergalactic medium, focusing on the imprint of large-scale shocks.

17. **David C. Latimer** (University of Kentucky)
Talk: ***Dark-matter constraints from a cosmic index of refraction***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (2:45 PM - 3:00 PM)

    The dark-matter candidates of particle physics invariably possess electromagnetic interactions, if only via quantum fluctuations. Taken en masse, dark matter can thus engender an index of refraction which deviates from its vacuum value. Its presence is signalled through frequency-dependent effects: the real part yields dispersive effects in propagation, and the imaginary part yields such in attenuation. Observational limits on these effects can in turn be used to limit its particle properties; this, with the advent of new opportunities to view GRBs at cosmological distance scales, gives us a new probe of dark matter. General considerations inform the expansion of the index of refraction with frequency. We discuss these, the physical interpretation of the terms, and the particular observations needed to isolate its coefficients. We also offer a summary of their current status. This work is a collaborative effort with Susan Gardner of the University of Kentucky.

18. **Amy Y. Lien** (University of Illinois at Urbana-Champaign)
Talk: ***Cosmic Core-Collapse Supernovae and Neutrino Background in Upcoming Sky Surveys***
Session: **Information about cosmological populations embedded in the high-energy sky**
October 28, 2008 (11:10 AM - 11:25 AM)

Core-collapse supernovae are important sources of neutrinos. About 99% of the energy released from supernovae is in the form of neutrinos and antineutrinos of all species with energy from ~10 MeV to ~30 MeV. Our observational understanding of core-collapse supernova will soon experience a revolution due to the flood of new data from scanning (synoptic) sky surveys. In the coming decade, many such surveys are coming up, including DES, Pan-STARRS, LSST; indeed SDSS-II is already ongoing. The number and redshift depth of the supernovae discovered strongly depend on the survey limiting magnitude. With the limiting magnitude suggested by these surveys, from ~10^3 to eventually ~10^5 supernovae will be discovered per year, out to redshift z~1. We will present detailed forecasts for the huge supernova harvest which will result from these surveys. The enormous detections of core-collapse supernovae will have dramatic impacts on supernova and neutrino science as well as cosmology. Statistical analysis can be applied and greatly improve our understanding of the observable properties of the core-collapse supernovae and their evolution with environment and redshift out to z~1. The cosmic core-collapse supernova rate and star formation rate can be estimated to high precision. Core-collapse supernovae are potential distance indicators via the expanding photosphere method and can provide an independent cross-check on the distance measurements from type Ia supernovae. Furthermore, a lower bound on the diffuse cosmic supernova neutrino background (DSNB) can be estimated and help us understand the missing fraction of the core-collapse supernova either due to dust or "failed" explosions.

19. **Kalliopi Petraki** (UCLA)
Talk: ***Sterile Neutrinos in Cosmology and Astrophysics***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (11:50 AM - 12:05 PM)

The discovery of neutrino masses implies the existence of new particles, called sterile neutrinos, whose number and mass scale are still undetermined. If one of these fermions has mass of several keV, it can account for the cosmological dark matter. Different mechanisms can be responsible for the production of its relic population, resulting to "warmer" or "colder" dark matter that can explain the small scale structure of the universe. The same particle can give rise to the observed velocities of pulsars. The X-ray photons produced in its radiative decay can speed up the formation of the first stars and constitute a potentially observable signal that can ultimately lead to its discovery. Heavier sterile neutrinos can be produced in supernova cores and decay inside the envelope, changing greatly the thermal evolution of the star. Their production and decay facilitate the energy transport from the core to the vicinity of the shock, enhancing the probability for a successful shock. This scenario would give rise to a high energy neutrino signature, detectable by galactic supernova neutrino observations.

20. **Stefano Profumo** (University of California, Santa Cruz)
Invited Talk: ***Fundamental Physics with GeV Gamma Rays***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (1:30 PM - 1:55 PM)

We discuss the implications of gamma-ray data for the identification of the fundamental nature of particle dark matter. We present recent results on 1/v WIMP models, and show that there are very stringent constriaints on those models from annihilations in the first collapsed structures. We then discuss the potential for the Fermi gamma-ray space telescope to unveil aspects of the particle dark matter model such as its dominant pair annihilation mode, and how the extraction of information on the nature of dark matter with gamma-ray spectra can be biased by background models. Finally, we discuss the role of multi-wavelength observations in the Fermi era of precision gamma-ray astronomy and its impact for indirect dark matter searches.

21. **Luis C Reyes** (KICP - University of Chicago)
Talk: ***EBL Studies with the Fermi Gamma-ray Telescope***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (9:55 AM - 10:10 AM)

The Large Area Telescope (LAT) on board the Fermi Gamma-ray Space Telescope will study the gamma-ray sky in the energy range 20 MeV to >300 GeV. Fermi-LAT's improved sensitivity with respect to previous missions will increase the number of known gamma-ray blazars from about 100 to thousands, with redshifts up to z~3-5. Since gamma rays with energy above 10 GeV interact via pair-production with photons from the Extragalactic Background Light (EBL), the systematic attenuation of Fermi-detected blazars as a function of redshift would constitute and effective and unique probe to the optical-UV EBL density and its evolution over cosmic history, which is particularly sensitive to the history of star formation and the effects of dust extinction in star forming regions.

22. **Michael Schubnell** (University of Michigan)
Talk: ***Cosmic-Ray Positron and Antiproton Measurements with the HEAT Balloon Experiment***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (3:55 PM - 4:10 PM)

The HEAT-pbar experiment, a balloon borne magnet spectrometer with precise particle identification and rigidity measurement, has produced new antiproton and positron data at energies between 5 and 50 GeV. Both antiparticle species were found to be substantially in agreement with models of secondary antimatter production in interstellar collisions of hadronic cosmic rays. The positron measurements however seem to consistently indicate the possibility of a small primary antimatter component. This positron excess at energies > 5GeV was first reported by the HEAT e+- collaboration and appears to be confirmed by more recent measurements by HEAT-pbar, AMS and Pamela. Such a component could result from the annihilation of dark matter particles in the galactic halo. Alternatively, the positron excess may originate in discrete astrophysical sources such as pulsars. In this talk I will review the HEAT results and discuss those in light of recent measurements by AMS and Pamela.

23. **Floyd W. Stecker** (NASA/GSFC)
Invited Talk: ***Testing Lorentz Invariance Using Ultrahigh Energy Cosmic Rays***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (11:10 AM - 11:35 AM)

There has been much interest in possible violations of Lorentz invariance, particularly motivated by quantum gravity theories. It has been suggested that a small amount of Lorentz invariance violation (LIV) could turn off photomeson interactions of ultrahigh energy cosmic rays (UHECRs) with photons of the cosmic background radiation and thereby eliminate the resulting sharp steepening in the spectrum of the highest energy CRs predicted by Greisen Zatsepin and Kuzmin (GZK). Recent measurements of the UHECR spectrum reported by the HiRes and Auger collaborations, however, indicate the presence of the GZK effect. I will present the results of a detailed calculation of the modification of the UHECR spectrum caused by LIV using the formalism of Coleman and Glashow. I will then compare these results with the experimental UHECR data from Auger and HiRes and thereby place limits on the amount of LIV. I will also discuss how a small amount of LIV that is consistent with the experimental data can still lead to a recovery of the cosmic ray flux at higher energies than presently observed.

24. **Tonia M. Venters** (KICP - University of Chicago)
Talk: ***Cosmological Implications of Studies of the Blazar Contribution to the Extragalactic Gamma-ray Background***
Session: **Information about cosmological populations embedded in the high-energy sky**
October 28, 2008 (11:40 AM - 11:55 AM)

The study of the diffuse Extragalactic Gamma-ray Background (EGRB) provides insight into the high-energy processes of the universe. Though the census of contributors to the EGRB is still quite unclear, collective emission from unresolved gamma-ray emitters, like blazars, certainly plays a role. Theoretical determinations of the blazar contribution to the EGRB predict that emission from blazars constitute as little as a few percent to as much as 100 percent of the overall emission with the uncertainty resulting from the uncertainty in the blazar gamma-ray luminosity function. Additionally, TeV gamma rays from blazars cascade through the Extragalactic Background Light resulting in an enhancement of the EGRB at lower energies and a suppression at higher energies, the prominence of which depends on the redshift distribution of blazars. Thus, the study of the blazar contribution to the EGRB with GLAST and other high-energy astrophysics experiments can provide a better understanding of blazars as a cosmological population.

25. **Stefan J. Wagner** (LSW - Heidelberg University)
Invited Talk: ***Current and future tests of Lorentz Violation***
Session: **Highest energy particles as probes of cosmic backgrounds and new physics**
October 27, 2008 (10:45 AM - 11:10 AM)

One of the signatures predicted in many models of Lorentz Violation is a velocity of electromagnetic radiation that depends on energy. VHE radiation from very distant soures provides the most sensitive tests of such models. We describe the results from first attempts to constrain Lorentz Violation using signals from active galaxies and GRBs and discuss the potential for improving these limits.

26. **Tom Weisgarber** (University of Chicago)
Poster: ***Monte Carlo Simulation of Cosmic Gamma-Ray Propagation: Status and Expectations for VERITAS***

October 28, 2008 (3:10 PM - 5:00 PM)

The universe is not transparent to all photons. At energies above 10 GeV, very high energy photons (gamma rays) begin to interact noticeably with the cosmic photon backgrounds. Understanding the astrophysical processes responsible for creating gamma rays is therefore dependent on understanding gamma-ray propagation in the universe. This work presents the current progress on a robust Monte Carlo simulation of gamma ray propagation, emphasizing effects observable by gamma-ray telescopes that employ the air Cherenkov technique.

27. **Brian L. Winer** (Ohio State University)
Invited Talk: ***Prospects for detecting dark matter with Fermi***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (2:20 PM - 2:45 PM)

The Fermi Gamma-Ray Space Telescope was launched in June of this year and has started in scientific mission. One component, the Large Area Telescope (LAT), surveys the entire sky for gamma-rays in the energy range of 20 MeV to several hundred GeV. This energy range makes the Fermi LAT an ideal observatory for an indirect search for dark matter. The talk will summarize the different search strategies being carried out by the collaboration and the estimated sensitivities of each approach. These approaches include examining dwarf spheroidal galaxies, the galactic center of the Milky Way, the galactic halo, and searching for gamma-ray lines.

28. **Stephanie Wissel** (KICP - University of Chicago)
Poster: ***The Direct Cerenkov Method for Detecting the Charge Composition of Cosmic Rays***

October 28, 2008 (3:10 PM - 5:00 PM)

By measuring the Cerenkov radiation of the primary particle directly with imaging atmospheric Cerenkov telescopes (IACTs), the Direct Cerenkov technique aims to measure the composition of very-high-energy (VHE) cosmic rays with a large effective area and a reduced dependence on hadronic interaction models. This technique is most effective for massive particles. making it particularly intriguing for studies of exotic new particles, such as magnetic monopoles. Studies of Direct Cerenkov radiation in both VERITAS and TrICE data are presented.

29. **Patrick W. Younk** (Colorado State University)
Talk: ***Extracting information from the way the highest energy events cluster***
Session: **Information about cosmological populations embedded in the high-energy sky**
October 28, 2008 (11:25 AM - 11:40 AM)

Our current understanding of ultra-high energy cosmic rays is that they originate from extragalactic sources, and that the highest energy particles originate from sources close enough (within ~100 Mpc) so that their flux is not significantly attenuated by interactions with the cosmic microwave background (the Greisen-Zatsepin-Kuzmin Effect). The source objects remain unidentified because of low statistics. However, it is possible to infer some general properties of the nearby sources based on how the highest energy events cluster on different angular scales. In this talk, I will show how we can set limits on the number of nearby sources, the particle charge, and the intervening magnetic fields. The technique works well with low statistics, and much progress can be made over the next few years. These measurements may have a significant impact on other branches of astrophysics and cosmology.

30. **Hasan Yuksel** (Bartol / University of Delaware)
Talk: ***Neutrinos as Probes or Candidates of Dark Matter***
Session: **Search for dark matter signatures with upcoming particle astrophysics experiments**
October 27, 2008 (4:25 PM - 4:40 PM)

Dark Matter, an invisible and elusive substance originally proposed by Zwicky to explain the mass to light ratio of the Coma galaxy cluster, still evades revealing its true identity. While weakly interactive massive particles as candidates are studied extensively, many others have also been proposed, spanning many orders of magnitude in mass. I will focus on various possibilities including scenarios in which neutrinos are expected to play a significant part. Sterile neutrinos (which would be a very plausible addition to the Standard Model) can play the role of the Warm Dark Matter and their mass and mixing can be constrained directly through their radiative decays. Alternatively, normal active neutrinos (which are the least detectable Standard Model particles) conservatively bind the total self-annihilation cross section of heavy Cold Dark Matter candidates as their final annihilation products.

31. **Ellen Zweibel** (University of Wisconsin, Madison)
Invited Talk: ***Galactic and Extragalactic Magnetic Fields***
Session: **Gamma rays and ultra-high-energy cosmic rays as probes of the intergalactic magnetic field**
October 28, 2008 (1:30 PM - 1:55 PM)

The origin of astrophysical magnetic fields is an open problem in plasma physics and cosmology. I will review the observational status of galactic and intergalactic magnetic fields and summarize the main theoretical challenges.