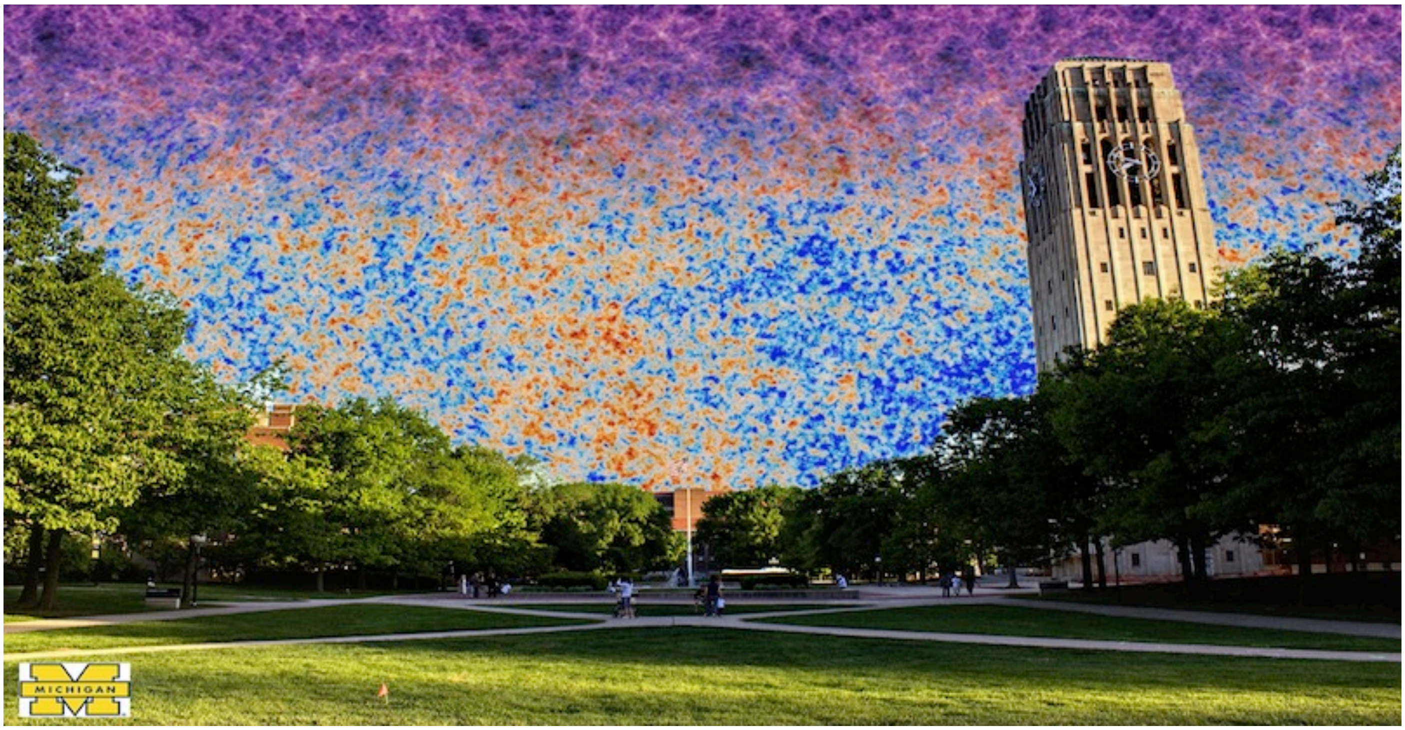
International Conference on Particle Physics and Cosmology, 2016 Ann Arbor, MI



CONFERENCE PROGRAM

Plenary Speakers

- ⋆ **Elena Aprile**
  Columbia University
- ⋆ **Celine Boehm**
  Durham University
- ⋆ **Alessandra Buonanno**
  MPG, Potsdam
- ⋆ **Marcela Carena**
  Fermilab
- ⋆ **John Carlstrom**
  University of Chicago
- ⋆ **Kiwoon Choi**
  Inst. for Basic Sci., Korea
- ⋆ **Cora Dvorkin**
  Harvard University
- ⋆ **Carlos Frenk**
  Durham University
- ⋆ **Joshua Frieman**
  University of Chicago
- ⋆ **Takaaki Kajita**
  University of Tokyo
- ⋆ **Eiichiro Komatsu**
  MPA, Garching
- ⋆ **Andrei Linde**
  Stanford University
- ⋆ **Joe Lykken**
  Fermilab
- ⋆ **Rachel Mandelbaum**
  Carnegie-Mellon University
- ⋆ **Vuk Mandić**
  University of Minnesota
- ⋆ **Malcolm Perry**
  Cambridge University
- ⋆ **Adam Riess**
  Johns Hopkins University
- ⋆ **Rachel Rosen**
  Columbia University
- ⋆ **Enrico Sessolo**
  Nat. Centre for Nuclear Res., Warsaw
- ⋆ **Pierre Sikivie**
  University of Florida
- ⋆ **Douglas Spolyar**
  Stockholm University
- ⋆ **Monica Valluri**
  University of Michigan

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- ⋆ **David Cinabro**
  Wayne State University
- ⋆ **Gus Evrard**
  University of Michigan
- ⋆ **Katherine Freese**
  University of Michigan
- ⋆ **David Gerdes**
  University of Michigan
- ⋆ **Dragan Huterer**
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- ⋆ **Gordy Kane**
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- ⋆ **Wolfgang Lorenzon**
  University of Michigan
- ⋆ **Tim McKay**
  University of Michigan
- ⋆ **Jeffrey McMahon**
  University of Michigan
- ⋆ **Chris Miller**
  University of Michigan
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  Wayne State University
- ⋆ **Keren Sharon**
  University of Michigan
- ⋆ **Greg Tarle**
  University of Michigan

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  Lancaster University
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- **Hans-Peter Nilles**
  Physikalisches Institut der Universität Bonn
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  University of Massachusetts Amherst
- **Antonio Riotto**
  University of Geneva
- **Matts Roos**
  University of Helinski
- **Leszek Roszkowski**
  University of Sheffield
- **Goran Senjanovic**
  International Centre for Theoretical Physics
- **Jun'ichi Yokoyama**
  RESCEU, The University of Tokyo
- **Hu Zhan**
  National Astronomical Observatories, Chinese Academy of Sciences

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8:00 am **Registration and Continental Breakfast**, Michigan League – Ballroom.

9:00 am **Welcome**, Mendelssohn Theatre.

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9:15 am **Eiichiro Komatsu**, MPA, Garching.
From initial conditions to structure formation, and back

10:00 am **Rachel Rosen**, Columbia University.
A Massive Gravity Status Report

10:35 am **COFFEE BREAK**, Michigan League – Ballroom.

11:10 am **Enrico Sessolo**, Nat. Centre for Nuclear Res., Warsaw.
Dark matter — What it is and how to determine its properties

11:45 am **Carlos Frenk**, Durham University.
Searching for the identity of the dark matter in our cosmic backyard

12:20 am **Leszek Roszkowski**, NCBJ, Warsaw.
History of COSMOs

12:30 pm **LUNCH BREAK**.

2:00 pm **PARALLEL SESSIONS**.

CMB/Large Scale Structure, Mendelssohn Theatre.
Chairs: Brad Benson, Rachel Mandelbaum

Dark Energy, Michigan League – Hussey Room.
Chairs: Anne Davis, Roland de Putter

Primordial/Inflation, Michigan League – Vandenberg Room.
Chairs: Andrei Linde

3:30 pm **COFFEE BREAK**, Michigan League – Ballroom.

4:00 pm **PARALLEL SESSIONS**.

CMB/Large Scale Structure, Mendelssohn Theatre.
Chairs: Brad Benson, Rachel Mandelbaum

Dark Energy, Michigan League – Hussey Room.
Chairs: Anne Davis, Roland de Putter

Primordial/Inflation, Michigan League – Vandenberg Room.
Chairs: Andrei Linde

5:30 pm **END OF SESSIONS**.

5:30-6:00 pm **Poster Presentations**, Michigan League – Ballroom and Room 6.

6:00-9:00 pm **Reception and Dinner**, UM Museum of Art.

Tuesday, August 9, 2016

8:00 am **Continental Breakfast**, Michigan League – Ballroom.

PLENARY SESSION, Mendelssohn Theatre.

9:00 am **Celine Boehm**, Durham University.
Dark Matter: the past and future of the field.

9:35 am **Joe Lykken**, Fermilab.
Whatever happened to BSM physics?

10:10 am **COFFEE BREAK**, Michigan League – Ballroom.

10:45 am **Monica Valluri**, University of Michigan.
The orbital structure of dark matter halos and implications for dark matter detection

11:20 am **Rachel Mandelbaum**, Carnegie-Mellon University.
Weak gravitational lensing cosmology: status and future prospects

11:55 am **Elena Aprile**, Columbia University.
Present and Future Prospects for WIMPs Direct Detection

12:30 pm **LUNCH BREAK**.

2:00 pm **PARALLEL SESSIONS**.

Future Probes, Mendelssohn Theatre.
Chairs: Tim Eifler, Elisabeth Krause

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Chairs: Anne Davis, Roland de Putter

LIGO and Black Holes, Michigan League – Vandenberg Room.
Chair: Dejan Stojkovic

Dark Matter Experiment, Michigan League – Michigan Room.
Chairs: Mariangela Lisanti, Leszek Roszkowski

3:30 pm **COFFEE BREAK and Poster Presentations**, Michigan League – Ballroom.

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CMB/Large Scale Structure, Mendelssohn Theatre.
Chairs: Brad Benson, Rachel Mandelbaum

Dark Energy/Dark Matter, Michigan League – Hussey Room.
Chairs: Mariangela Lisanti, Leszek Roszkowski, Anne Davis, Roland de Putter

LIGO and Black Holes/Primordial/Inflation, Michigan League – Vandenberg Room.
Chairs: Dejan Stojkovic, Andrei Linde

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8:00 am	**Continental Breakfast**, Michigan League – Ballroom.
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9:00 am	**Joshua Frieman**, University of Chicago. *Early Results from the Dark Energy Survey*
9:35 am	**Vuk Mandić**, University of Minnesota. *First Direct Detections of Gravitational Waves*
10:10 am	**COFFEE BREAK**, Michigan League – Ballroom.
10:45 am	**Martina Gerbino**, NORDITA. *Neutrinos in cosmology: an overview*
11:20 am	**Roland de Putter**, Caltech. *Probing Inflation with Future Galaxy Surveys*
11:55 am	**Adam Riess**, Johns Hopkins University. *A New Measurement of the Expansion Rate of the Universe*
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Thursday, August 11, 2016

8:00 am **Continental Breakfast**, Michigan League – Ballroom.

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9:00 am **Kiwoon Choi**, Inst. for Basic Science, Korea.
Natural inflation and relaxion with multiple axions

9:35 am **COFFEE BREAK**, Michigan League – Ballroom.

10:10 am **Takaaki Kajita**, University of Tokyo.
Neutrino oscillation experiments — Discovery, status and prospects

10:45 am **John Carlstrom**, University of Chicago.
Cosmology with the Cosmic Microwave Background

11:30 am **Depart for activities (box lunch provided)**.

6:30 pm **PUBLIC TALK: Astronaut Mario Runco**, Mendelssohn Theatre.

Friday, August 12, 2016

8:00 am **Continental Breakfast**, Michigan League – Ballroom.

9:00 am **PARALLEL SESSIONS**.

CMB/Large Scale Structure, Mendelssohn Theatre.
Chairs: Brad Benson, Rachel Mandelbaum

Dark Matter, Michigan League – Hussey Room.
Chairs: Mariangela Lisanti, Leszek Roszkowski

Primordial/Inflation, Michigan League – Vandenberg Room.
Chairs: Andrei Linde

10:30 am **COFFEE BREAK**, Michigan League – Ballroom.

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11:35 am **Malcolm Perry**, Cambridge University.
The Black Hole Paradox Revisited: Soft Black Hole Hair

12:10 pm **LUNCH BREAK**.

2:00 pm **Pierre Sikivie**, University of Florida.
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2:35 pm **Cora Dvorkin**, Harvard University.
Traces of the Early Universe in the CMB and the Large-Scale Structure

3:10 pm **Andrei Linde**, Stanford University.
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3:45 pm **END OF CONFERENCE**.

Monday, August 8, 2016

CMB/LARGE SCALE STRUCTURE, Mendelssohn Theatre.
Chairs: Brad Benson and Rachel Mandelbaum

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The Growth of Cosmic Structure Measured with Galaxy Clusters in the South Pole Telescope SPT-SZ Survey

Carles Sánchez.
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Masato Shirasaki.
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Stefano Anselmi.
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Tuesday, August 9, 2016

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Probing Inflation with Galaxy Clustering on Ultra-Large Scales

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Probing Reionization: Cross-correlation of 21-cm and Lyman-alpha fluctuations

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Mock LSS Surveys with the Peak Patch Approach

Joel Meyers.
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KiDS+2dFLenS: Testing Gravity on Cosmic Scales with Weak Lensing and Redshift Space Distortions

Eva-Maria Mueller.
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Sebastian Cespedes.
Modifications of the speed of gravitational waves at early times

Chi-Ting Chiang.
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Did LIGO Detect Dark Matter?

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Wolfgang Lorenzon.
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Eric Dahl.
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Quantifying discordance in the 2015 Planck CMB spectrum

Marius Millea.
Features in the Planck power spectrum and shifts in cosmological parameters

Melanie Simet.
Weak Lensing Measurement of the Mass-Richness Relation of SDSS redMaPPer Clusters

Jonathan Blazer.
Streaming velocities and baryonacoustic oscillations

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Tim Linden.
Dark Matter, Pulsar, and Diffuse Emission Models for the Galactic Center GeV Excess

Annika Peter.
How self-interacting dark matter shapes the Milky Way satellite population

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Cosmological constraints to dark matter with two- and many-body decays

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Sam Cormack.
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James Mertens.
Deviations from Homogeneity in an Inhomogeneous Universe

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Aditya Rotti, *Florida State University*.
Aditya Rotti

Keir Rogers, *University College London*.
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Xinyi Chen, *University of Michigan*.
Galaxy Cluster Counts: Comparing Multi-wavelength Samples and Simulations

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Maxim Eingorn, *North Carolina Central University, CREST and NASA Research Centers*.
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Eugene Tatum, *Independent Researcher*.
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Testing Lambda-CDM at the lowest redshifts with SN Ia and galaxy peculiar velocities

Dark Matter and Other Relics

Ben Broerman, *Queen's University*.
Status of the DEAP-3600 Dark Matter Search Experiment

Mohammadreza Zakeri, *University of California, Riverside*.
Asymmetric Reheating of the Dark and Visible Sectors

Jennings Deskins, *Case Western Reserve University*.
Numerical Simulations of Binary Pulsars in Galileon Theories

Jong-Chul Park, *Chungnam National University*.
Electro-Weak Dark Matter: Non-perturbative effect on its indirect detections

Hyerim Noh, *Korea Astronomy and Space Science Institute*.
Axion as a cold dark matter candidate: fully relativistic and nonlinear analysis

Alexandra Davis, *the Ohio State University*.
Effects of suppressed power spectra due to early Universe baryon-dark matter scattering on the subhalo statistic of Milky Way-like galaxies.

Isaac Waldstein, *The University of North Carolina at Chapel Hill*.
A Quasi-Decoupled State for Dark Matter during an Early Matter-Dominated Era

Kayla Redmond, *University of North Carolina Chapel Hill*.
New Constraints on Kination Domination

Alex Kavner, *University of Michigan*.
Search for Low-Mass WIMPs Using CCDs at SNOLAB

Shoaib Munir, *KIAS, Seoul*.
Exploring the Higgs boson production in heavy chargino decays for dark matter searches at the LHC

Cosmic Probes and Future Experiments

Traci Johnson, *University of Michigan*.
Resolving star formation in a lensed galaxy at z=2.5

Wang Kei Wong, *Carnegie Mellon University*.
FILTERING INTERLOPERS FROM GALAXY SURVEYS

LIGO/Black Holes

Yukio Tomozawa, *University of Michigan*.
Masses of black hole merger of gravitational waves, GW150914

Abstracts for Plenary Talks

Monday, August 8, 2016

9:25 am **Eiichiro Komatsu**, *MPA, Garching*.

From initial conditions to structure formation, and back

Precise measurements of temperature and polarisation anisotropies of the cosmic microwave background (CMB) taught us a remarkable story. We now think that all the structures in our observable universe, such as galaxies, stars, planets, and eventually ourselves, originated from tiny quantum fluctuations generated during cosmic inflation. This remarkable hypothesis has passed all the observational tests to date, and we have learned a great deal about the physics of inflation. The current model for the subsequent evolution of initial fluctuations due to gravity and baryonic physics on large scales also agrees with the observational data. Turning this around, we can learn more about inflation and the late-time evolution of the universe using the large-scale structure of the universe. In this presentation I review the recent progress in this area of cosmology, and present three new results from our group over the last few years: testing symmetry of space-time during inflation, state-of-the-art calculation of the thermal gas pressure distribution in the universe and comparison to observations, and a new way to look at the large-scale structure of the universe using the âĂIJposition-dependent power spectrumâĂİ. But, are we totally convinced that inflation did occur? Not yet, because extraordinary claims require extraordinary evidence. The CMB community agrees that the next big step is to find a signature of primordial gravitational waves (GW) from inflation in the so-called B-mode polarisation of the CMB. Unlike the GW detected by LIGO recently, which has a wavelength of thousands of kilometres, the wavelength of the primordial GW from inflation affecting CMB is on the order of billions of light years. To this end, I will describe our proposal for the next-generation CMB polarisation mission called "LiteBIRD", a proposed JAXA mission with a target launch date in mid 2020.

10:10 am **Rachel Rosen**, *Columbia University*.

A Massive Gravity Status Report

The predictions of General Relativity (GR) have been confirmed to a remarkable precision in a wide variety of tests. From the theoretical viewpoint, consistent and well-motivated modifications of GR have been notoriously difficult to obtain. However, in recent years a conceptually simple modification has been shown to be free of the traditional pathologies. This is the theory of massive gravity, in which the graviton has a small mass. In this talk I will give a general review of massive gravity, discuss potential observational signatures and present the current challenges facing this theory.

11:20 am **Enrico Sessolo**, *Nat. Centre for Nuclear Res., Warsaw*.

Dark matter — What it is and how to determine its properties

I will review the present status of particle dark matter, with some attention to the case of supersymmetry. I will focus on the interplay of collider, direct, and indirect detection searches, with prospects and challenges for detection in a reasonable time scale.

11:55 am **Carlos Frenk**, *Durham University*.

Searching for the identity of the dark matter in our cosmic backyard

There are competing claims that the dark matter may have already been discovered through the annihilation of cold dark matter or the decay of warm dark matter. Both hypotheses result in indistinguishable model universes on the large scales probed by temperature anisotropies in the microwave background radiation and the clustering of galaxies. The identity of the dark matter, however, manifests itself in the properties of small, dwarf galaxies. I will discuss predictions from cosmological simulations for the properties of these galaxies for different types of dark matter and discuss whether astronomical observations can, in principle, distinguish amongst them.

9:00 am **Celine Boehm**, *Durham University*.
Dark Matter: the past and future of the field.
In the last decade, particle physics models of Dark Matter have evolved considerably. Much more attention is given to cosmology. Many of the previous assumptions are being questioned and challenged. I will review the new directions that the field has taken.

9:35 am **Joe Lykken**, *Fermilab*.
Whatever happened to BSM physics?

10:45 am **Monica Valluri**, *University of Michigan*.
The orbital structure of dark matter halos and implications for dark matter detection
Collisionless simulations of cosmological structure formation in the Lambda CDM paradigm result in dark matter halos that are strongly triaxial with significant velocity anisotropy. In contrast, simulations which include the dissipative processes and feedback associated with baryons, are significantly more spherical/oblate and isotropic at small radii (although the halos remain triaxial at large radii). I will review our efforts to understand why halo shapes change in response to baryonic condensation, and how the orbital structure of halos is affected. Since the evolution of halo shape occurs rapidly, the orbits of both dark matter particles and halo stars reflect the formation and accretion history of the halo rather than their current shape. The detailed orbital structure of dark matter halos with baryons has implications for two possible observable signatures of WIMP dark matter: (a) the formation of supermassive dark stars, which could be detectable in future JWST surveys; and (b) the ability of direct detection experiments to detect WIMP dark matter through annual modulation. I will also briefly describe ongoing efforts to measure the shape of the Milky WayâĂŹs dark matter halo from the kinematics of field stars in the stellar halo.

11:20 am **Rachel Mandelbaum**, *Carnegie-Mellon University*.
Weak gravitational lensing cosmology: status and future prospects
First, I will review the current state of the field of weak lensing, including the beginnings of science results from ongoing surveys: Hyper-SuprimeCam (HSC), Dark Energy Survey (DES), and the Kilo-Degree Survey (KIDS). I will then discuss some of the challenges for science with even larger future surveys, and the prospects for overcoming them to enable weak lensing to achieve its full power as a probe of our cosmological model.

11:55 am **Elena Aprile**, *Columbia University*.
Present and Future Prospects for WIMPs Direct Detection
I will review the status of the field and discuss the experiments which are likely to have the largest impact on WIMPs direct detection before the end of this decade.

9:00 am **Joshua Frieman**, *University of Chicago*.
Early Results from the Dark Energy Survey

9:35 am **Vuk Mandić**, *University of Minnesota*.
First Direct Detections of Gravitational Waves
During their first observation run the Advanced LIGO gravitational-wave detectors recorded signatures of mergers of binary black hole systems. These events mark the beginning of gravitational-wave astrophysics, enabling a new approach to studying various astrophysical phenomena. I will describe the LIGO detectors that enabled such break-through discoveries. I will also discuss the events they recorded, focusing on the implications of these observations and on expectations for future observations.

10:45 am **Martina Gerbino**, *NORDITA*.
Neutrinos in cosmology: an overview
The existence of a cosmic neutrino background (CNB) is nowadays well established. Even though we still cannot detect it directly, we can infer its properties by investigating the impact that the CNB has on cosmological observables, such as the cosmic microwave background (CMB) and large scale structures (LSS). In this talk, I will present what cosmology can tell us about neutrinos, focusing in particular on the number of relativistic species and neutrino masses. Finally, I will discuss the effect that uncertainties on neutrino parameters could have on constraining inflationary models.

11:20 am **Roland de Putter**, *Caltech*.
Probing Inflation with Future Galaxy Surveys
The large-scale distribution of galaxies is a powerful probe of the physics of inflation. In particular, scale-dependent halo bias presents a unique opportunity for galaxy surveys to study primordial non-Gaussianity with clustering on ultra-large scales. In this talk, I will discuss how near-future galaxy surveys may be able to use this signal to distinguish between single- and multifield inflation and to study other fundamental properties of inflation. I will discuss both general requirements on galaxy surveys for them to take optimal advantage of the signal, and opportunities with specific future surveys, including the recently proposed SPHEREx mission. While the focus will be on scale-dependent bias due to local non-Gaussianity, I will also comment on other inflationary signals in the clustering of galaxies.

11:55 am **Adam Riess**, *Johns Hopkins University*.

A New Measurement of the Expansion Rate of the Universe

The Hubble constant remains one of the most important parameters in the cosmological model, setting the size and age scales of the Universe. Present uncertainties in the cosmological model including the nature of dark energy, the properties of neutrinos and the scale of departures from flat geometry can be constrained by measurements of the Hubble constant made to higher precision than was possible with the first generations of Hubble Telescope instruments. A streamlined distance ladder constructed from infrared observations of Cepheids and type Ia supernovae with ruthless attention paid to systematics now provide 2.4% precision and offer the means to do much better. By steadily improving the precision and accuracy of the Hubble constant, we now see evidence for significant deviations from the standard model, referred to as LambdaCDM, and thus the exciting chance, if true, of discovering new fundamental physics such as exotic dark energy, a new relativistic particle, or a small curvature to name a few possibilities. I will review recent and expected progress.

9:00 am **Kiwoon Choi**, *Inst. for Basic Science, Korea*.
Natural inflation and relaxion with multiple axions
Two applications of axion-like field for cosmology and particle physics, i.e. natural inflation and the relaxion solution of the weak scale hierarchy problem, both require hierarchical axion scales in the effective theory of inflaton or relaxion. We propose a scheme (clockwork mechanism) to generate exponentially big hierarchy among the effective axion scales, which can be realized in underlying theory involving multiple axions.

10:10 am **Takaaki Kajita**, *University of Tokyo*.
Neutrino oscillation experiments — Discovery, status and prospects
Discovery of neutrino oscillations and the small neutrino masses have been the first experimental hint toward our deeper understanding of elementary particles and their interactions beyond the Standard Model of particle physics. In this talk, I will review the discovery of neutrino oscillations and the status of the neutrino oscillation studies. Finally, the future directions of neutrino oscillation experiments will be discussed.

10:45 am **John Carlstrom**, *University of Chicago*.
Cosmology with the Cosmic Microwave Background
Cosmic Microwave Background (CMB) measurements have driven our understanding of the Universe, from the primordial quantum fluctuations to its present state. The CMB provides the foundation for the ΛCDM cosmological model, which fits all cosmological data (with some interesting tensions). There is still a lot to learn from the CMB measurements. We are searching for the unique B-mode polarization that would be induced on the CMB by inflationary gravitational waves. We are able to detect the impact of the neutrino background on the CMB, which can be used to provide precise constraints on the number and masses of the neutrinos, as well as constrain other light relics. We are untangling the correlations in the CMB induced by gravitational lensing to make maps of all the mass in the universe. We are measuring the scattering of the CMB by ionized structures, the Sunyaev-ZelâĂŹdovich effects, to detect clusters of galaxies and soon to map the momentum of the universe in addition to its density. This talk will review the present status and the ambitious advances planned for the next decade, including in particular those with the next generation ground-based experiment, CMB-S4.

11:00 am **Alessandra Buonanno**, *Max Planck Inst.of Grav. Physics*.
What did we learn from LIGO first black holes?
The detection by LIGO of GW150914 and GW151226 mark the beginning of a new era in physics and astrophysics. I will review theoretical work that paved the way to observe such gravitational-wave signals and discuss the results of the discovery focusing on its gravitational, astrophysical and fundamental physics aspects.

11:35 am **Malcolm Perry**, *Cambridge University*.
The Black Hole Paradox Revisited: Soft Black Hole Hair
I discuss the black hole paradox and show how soft black hole hair provides some insight into black hole physics. Whilst not a solution to the information paradox, we will show that soft hair provides a means to escape the usual reasoning that leads to the paradox without the introduction of new physics. We speculate on how the paradox might be resolved.

2:00 pm **Pierre Sikivie**, *University of Florida*.
Axion Dark Matter
The axion provides a solution to the Strong CP Problem of the Standard Model of elementary particles and is a cold dark matter candidate as well. I'll briefly review the limits on the axion from particle physics, stellar evolution and cosmology. I'll describe the ongoing axion searches and recently proposed methods that make possible the search for axion dark matter over most of the plausible axion mass range. Finally, I'll discuss the Bose-Einstein condensation of dark matter axions and the implications thereof for observation.

2:35 pm **Cora Dvorkin**, *Harvard University*.
Traces of the Early Universe in the CMB and the Large-Scale Structure
Cosmological observations have provided us with answers to age-old questions, involving the age, geometry, and composition of the universe. However, there are profound questions that still remain unanswered. In this talk, I will describe ongoing efforts to shed light on some of these questions. The origin of the small anisotropies that later grew into the stars and galaxies that we see today is still unknown. However, the nature of the anisotropies in the Cosmic Microwave Background (CMB) provides strong evidence that they were generated long before the CMB radiation had its last interaction with ordinary matter. In this talk, I will explain how we can use measurements of the CMB and the large-scale structure of the universe to reconstruct the detailed physics of much earlier epochs, when the universe was only a tiny fraction of a second old.

3:10 pm **Andrei Linde**, *Stanford University*.
Inflation, dark energy, and SUSY breaking
I will give an overview of the present status of inflationary cosmology, and describe a solution of the problem of initial conditions for the models favored by Planck. Then I will concentrate on the recent generation of inflationary models in supergravity which can simultaneously describe inflation, dark energy, and supersymmetry breaking.

Monday, August 8, 2016

CMB/LARGE SCALE STRUCTURE.

2-3:30 pm **Bjoern Soergel**, *Institute of Astronomy, University of Cambridge*.
Detection of the kinematic Sunyaev-Zeldovich effect with DES Year 1 and SPT
The kinematic Sunyaev-Zel'dovich effect (kSZ) is a Doppler shift to the CMB signal imparted by the bulk motion of the hot gas in clusters of galaxies. Despite its small amplitude, the kSZ signal can be isolated using a differential statistic which probes the mean pairwise velocity of galaxy clusters. This pairwise kSZ signal is sensitive to a combination of cosmology and the baryonic physics of galaxy clusters, and may eventually be used to probe gravity at 100 Mpc scales. In this talk I will present a statistically significant (4 sigma) detection of the pairwise kSZ signal by combining a cluster catalogue from the first year of Dark Energy Survey (DES) data with CMB temperature maps from the South Pole Telescope (SPT). This measurement is the first evidence of the kSZ using cluster redshifts derived from photometric data, and one of the first science results from the first year of DES data.

Sebastian Bocquet, *Argonne National Laboratory*.
The Growth of Cosmic Structure Measured with Galaxy Clusters in the South Pole Telescope SPT-SZ Survey
We discuss constraints on the growth rate of cosmic structure obtained using galaxy clusters from the 2500 deg2 SPT-SZ survey. The sample contains 377 uniformly selected cluster candidates with Sunyaev-Zeldovich effect detection significance greater than five and redshift z $>$ 0.25. Of these, 82 also have Chandra X-ray data, and 101 have galaxy velocity dispersions measurements that are used for calibrating the mass-observable relation.
We assume a flat CDM background cosmology with the additional degree of freedom , describing the growth rate. Using our cluster data set with H0 and BBN priors we constrain and obtain results that are in agreement with the prediction by General Relativity. At this point, I will discuss the impact of the choice of the different mass calibrators on cosmological and astrophysical results. Adding cosmic microwave background anisotropy data further improves these constraints by precise measurements of the background cosmology, and through the impact of on the integrated Sachs-Wolfe-effect. Additionally allowing for the dark energy equation of state parameter to vary, we simultaneously constrain the growth and expansion histories of the Universe. We find not evidence for departure from the CDM model.
Measuring the amplitude of the matter power spectrum at four redshifts in the range $0.25 < z < 1.7$ further confirms the agreement with the concordance model. i will conclude this talk outlying the path forward for measuring cosmic growth with current and future cluster data sets.

Carles Sánchez, *IFAE Barcelona*.

Weak Gravitational Lensing in the Dark Energy Survey

During fall 2012 the Dark Energy Survey (DES) collaboration installed and commissioned DECam, a 570 mega-pixel optical and near-infrared camera with a large 3 sq. deg. field of view, set at the prime focus of the 4-meter Blanco telescope in CTIO, Chile. Since then, DES has completed 3 of its 5 years of observations, mapping more than 2000 sq. deg. of the southern sky to unprecedented depth.

In this talk, the current status of weak lensing results from DES will be presented. I will review the latest and most important results from the Science Verification period of observations, including cosmological constraints from cosmic shear, shear peaks and from the combination of galaxy clustering and galaxy-galaxy lensing, and other recent analyses like the detection of void lensing or the weak lensing mass calibration of galaxy clusters. Afterwards, the production and validation of weak lensing shear catalogs with DES-Year1 observations will be summarized, and I will describe the outlook of the key science analyses to be performed with this unique data set, namely the full exploitation of large-scale structure and weak lensing probes through the combination of the three possible two-point correlation functions and the advantages of including yet another two additional measurements coming from CMB cross-correlations with the overlapping SPT and Planck data sets. Finally, additional Y1 science cases will be described, like the first DES study of the so-called splashback radius around galaxy clusters, using galaxy profiles as well as weak lensing, or the potential constraints on modified gravity theories using void lensing with this data set.

Siddharth Satpathy, *Carnegie Mellon University*.

Measurement of the growth rate of structure using galaxy correlation functions

We worked with the measurement of the linear growth rate of structure, f from the Sloan Digital Sky Survey III (SDSS III) Baryon Oscillation Spectroscopic Survey (BOSS) Data Release 12 (DR12). The analysis draws on the use of the Convolution Lagrangian Perturbation Theory (CLPT) with Gaussian Streaming Redshift-Space Distortions (GSRSD) to model the two point statistics of BOSS galaxies in DR12. The BOSS-DR12 dataset includes 1,198,006 galaxies spread over the redshift range $0.2 < z < 0.75$. these galaxy samples are categorized in three redshift bins. using clpt-gsrsd, our group was able to report one of the first measurements of $f\sigma_8$ from the combined sample of the three redshift bins. we find $f\sigma_8 = 0.430 \pm 0.054$ at $z_{eff} = 0.38$, $f\sigma_8 = 0.452 \pm 0.057$ at $z_{eff} = 0.51$ and $f\sigma_8 = 0.457 \pm 0.052$ at $z_{eff} = 0.61$. our results are consistent with the predictions of planck λcdm-gr. also, our results are combined with bao only results to provide constraints on the growth rates of structure in the universe at different redshifts and thereby serve as a useful probe which can help to distinguish between a model of the universe based on dark energy and models based on modified theories of gravity.

Juliana Kwan, *The University of Pennsylvania*.

Cosmology from large scale galaxy clustering and galaxy-galaxy lensing with Dark Energy Survey Science Verification data

We present cosmological constraints from the Dark Energy Survey (DES) using a combined analysis of angular clustering of red galaxies and their cross-correlation with weak gravitational lensing of background galaxies. We use a 139 square degree contiguous patch of DES data from the Science Verification (SV) period of observations. Using large scale measurements, we constrain the matter density of the Universe as $\Omega_m = 0.31 \pm 0.09$ and the clustering amplitude of the matter power spectrum as $\sigma_8 = 0.74 \pm 0.13$ after marginalizing over seven nuisance parameters and three additional cosmological parameters. This translates into $S_8 = \sigma_8(\Omega_m/0.3)^{0.16} = 0.74 \pm 0.12$ for our fiducial lens redshift bin at 0.35 < z < 0.5, while $s_8 = 0.78 \pm 0.09$ using two bins over the range 0.2 < z < 0.5. we study the robustness of the results under changes in the data vectors, modelling and systematics treatment, including photometric redshift and shear calibration uncertainties, and find consistency in the derived cosmological parameters. we show that our results are consistent with previous cosmological analyses from des and other data sets and conclude with a joint analysis of des angular clustering and galaxy-galaxy lensing with planck cmb data, baryon accoustic oscillations and supernova type ia measurements.

Ema Dimastrogiovanni, *ASU*.

Testing early Universe physics with upcoming observations

Cosmology has seen tremendous progress thanks to precision measurements and is bound to greatly benefit from upcoming Large Scale Structure and Cosmic Microwave Background data. I will point out a number of interesting directions. In particular, I discuss how the microphysics of inflation may be tested in galaxy surveys through fossil signatures originating from squeezed primordial correlations. I further elaborate on the constraining power of CMB spectral distortions on small-scale cosmological fluctuations and on particle decays in the very early Universe in relation to reheating.

4-5:30 pm **Kevin Huffenberger**, *Florida State University*.

Are there localized B-mode dust foregrounds in the BICEP/Keck field?

Rotti & Huffenberger (2016) demonstrated that isotropy violation tests can be used to assess the level of foreground contamination to the Cosmic Microwave Background polarization. The first application of this method to Planck 353 GHz B-mode polarization data indicated a potential foreground source in the BICEP/Keck survey field. Here we look closer, optimally combining maps derived from auto- and cross-correlations to make a foreground power map with higher signal to noise, and discuss the significance of of foregrounds in light of these refinements. We explore similar analysis at other frequencies.

Jessica Muir, *University of Michigan*.

Integrated Sachs-Wolfe signal reconstruction using galaxy surveys

The Integrated Sachs-Wolfe (ISW) effect is a large-angle modulation of the cosmic microwave background (CMB), generated when CMB photons traverse evolving potential wells associated with large scale structure (LSS). Recent efforts have been made to reconstruct maps of the ISW signal using galaxy distributions, but there has been only limited investigation into how survey systematics affect their reliability. Using simulated maps, we study the impact of galaxy survey properties and uncertainties on the accuracy of reconstructed ISW signal. We find that systematics associated with modeling the distribution of galaxies along the line of sight have a relatively minor impact on reconstruction quality, but that direction-dependent calibration errors can be very harmful. Specifically, we find that in order to avoid significant degradation of our quality statistics, direction-dependent number density fluctuations due to systematics must be controlled so that their variance is smaller than 1e6 (which corresponds to a 0.1% calibration). Additionally, we explore the implications of our results for attempts to use reconstructed ISW maps to comment on the origins of large-angle CMB alignments.

Arya Farahi, *University of Michigan*.

Forward modeling of galaxy clusters

Relating observations of cluster galaxies or the gas component to the total mass of the system is a key challenge in the current cluster cosmology community. In Evrard et al. (2014), we develop a convenient and powerful mathematical framework for modeling counts and conditional statistics in a space of multiple observable properties and total mass. The model make explicit how counts and scaling relations are sensitive to covariance between pairs of observable properties. In the first part of this talk, I discuss a forward likelihood model to constrain the scaling relation properties, including covariance, of a cluster sample using a cosmological mass function prior. I then present results of this method applied to multi-wavelength data from the LoCuSS survey sample. A related challenge for cosmological analysis of cluster counts, is good understanding of the systematics and the selection function of survey. Cosmological N-body simulations can be thought of as a way to characterise systematics and the selection of given survey. We have developed a flexible simulation method designed to enable testing of X-ray survey selection, and are applying this approach to 10,000 deg^2 synthetic sky simulations (Farahi et al. (in prep)). For the second part, we discuss lessons we learned so far and the potential prospects for future analysis, like the interesting and observationally unconfirmed strong anti-correlation between galaxies and hot gas inside clusters (Wu et al. 2015).

Joyce Byun, *University of Sussex*.

Recovering information beyond the power spectrum of large-scale structure

Future large-scale structure surveys will provide a wealth of new data and make higher-order statistics beyond the power spectrum, such as the bispectrum, more competitive for constraining galaxy clustering and bias, the standard LCDM cosmology, and many of its possible extensions, including non-Gaussianity from inflation. However, given the complexity of measuring the full bispectrum, it may be possible to use recently devised alternative statistics, such as the line correlation function and position-dependent power spectrum, to recover information encoded in the bispectrum while avoiding a full bispectrum analysis. We use Fisher forecasts to quantify how much of the information encoded in the matter power spectrum and bispectrum can be recovered using these alternate statistics to constrain the concordance cosmology, and we also compare Fisher constraints using analytic (diagonal) covariance matrices vs covariance matrices from N-body simulations to assess the impact of non-linear clustering on the resulting degradation of constraints. Weighing the relative constraining power of these competing bispectrum measures will shed more light on the complementarity of these observables and inform more efficient, robust ways of analyzing future data sets.

Masato Shirasaki, *National Astrnomical Observatory of Japan*.

Covariance of galaxy-galaxy lensing: Jackknife vs. Mock

Galaxy-galaxy lensing (GGL) provides a statistical method to probe the cross correlation between matter and a given foreground object such as galaxy and cluster of galaxies. The signal of GGL on large scale would be determined by clustering of neighboring halos, which contains rich cosmological information. In practice, the error of GGL signal on large scale is evaluated with an internal method so-called jackknife method. In this talk, we focus on how accurate GGL covariances jackknife method would provide. We utilize a set of full-sky simulations to create realistic mock catalogs of foreground/background galaxies found in Sloan Digital Sky Survey (SDSS). Then, we perform GGL analysis in the same way as the real data set, and compare of GGL signals and jackknife covariance with mock and real data. Our mock catalog can reproduce both signals and jackknife covariances measured in the case of SDSS. We also find that jackknife covariance tends to overestimate the underlying covariance of GGL on large scale of 10 Mpc. We will discuss the reason why jackknife estimates would be invalid on large scale. Some applications of our mock catalogs to estimate GGL covariances willbe presented.

Jonathan Braden, *University College London*.

Constraining cosmological ultra-large scale structure using numerical relativity

Although the local universe is well described by a homogeneous and isotropic cosmological model with an early stage of inflation, theoretical considerations suggest that our observable universe may be embedded within a much larger landscape of ultra-large scale superhorizon density fluctuations. If present, this superhorizon complexity encodes information on both the initial conditions for and dynamics of inflation, which themselves depend on the microphysical laws governing our universe. This provides an interesting framework to investigate "anomalies" in cosmological data, as well as to constrain models of fundamental physics. It is therefore of great interest to investigate the effects of this superhorizon structure on local observables. Using planar symmetric numerical relativity simulations, we investigate the ultra-large scale structure arising from superhorizon fluctuations present at the beginning of inflation. We focus specifically on the signature in the CMB quadrupole, the Grischuk-Zel'dovich effect, although our framework is easily generalised to include additional correlated anomalies. Due to the gravitational nonlinearities, we find the contribution of the superhorizon fluctuations to the local quadrupole becomes increasingly non-Gaussian as the amplitude of the initial fluctuations is increased. This superhorizon contribution is combined with the usual Gaussian contribution generated by the inflationary phase to produce the observed quadrupole. We find the non-Gaussianity induced by the gravitational nonlinearities significantly alters the predictions of the observed CMB quadrupole power relative to the case of Gaussian superhorizon fluctuations. In a wide range of inflationary models, this in turn significantly alters inferences about the scale of approximate homogeneity and our ability to constrain the initial fluctuation amplitude.

DARK ENERGY.

2-3:30 pm **Elise Jennings**, *Fermilab*.

Cosmological constraints from Supernovae using Approximate Bayesian Analysis

Approximate Bayesian Analysis is a new sampling method where cosmological parameter inference is done without any likelihood assumptions by full forward modeling of the data. This sampling procedure requires a complete simulation to be run at every proposed point in parameter space and then compared with the data using a suitable metric.

This method allows us to avoid assuming anything about the likelihood which is important in cases where the distribution for the data is intractable e.g. multimodal or non-Gaussian. Covariances between parameters and systematics are naturally included in the simulation, and marginalized over, which avoids the need to estimate the covariance matrix with the same precision as demanded by standard MCMC methods.

We shall present our new method as applied to a mock DES supernovae sample using the SNANA simulation code and present some preliminary results showing the impact of systematics on dark energy parameter constraints.

Takahiro Hayashinaka, *RESCEU, university of Tokyo*.
Fermionic Schwinger Effect and Induced Current in de Sitter spacetime
We explore a response of inflationary universe to background electric field using spinor QED in 1+3 dimensional de Sitter spacetime. We analytically calculate the vacuum expectation value of the spinor current which is induced by the produced particles in the electric field. The renormalization is performed with the adiabatic subtraction scheme. We find that the current becomes negative, namely it flows in the direction opposite to the electric field, if the electric field is weaker than a certain threshold value depending on the fermion mass, which is also known to happen in the case of scalar charged particles in 1+3 de Sitter spacetime. Contrary to the scalar case, however, the IR hyperconductivity is absent in the spinor case.

Sebastian Zell, *Max Planck Institute for Physics, Fhringer Ring 6, 80805 Munich, Germany*.
On the substructure of the cosmological constant
We investigate if we can equip the cosmological constant with a substructure by viewing de Sitter spacetime as the classical expectation value of a multi-graviton state. For small times, we are able to define the notion of a bound-state graviton, as opposed to an asymptotically free one. Subsequently, we construct a quantum state with the classical metric as expectation value. The rest energy of the bound state gravitons matches the classical energy associated with the cosmological constant.
In this fully-quantum picture, we calculate redshift as the stimulated emission of a graviton. An external particle loses energy because it deposits gravitons in the bound state. Similarly, particle production in a de Sitter background no longer happens in vacuum, but arises as a scattering process. It is caused by the decay of bound-state gravitons.
In contrast to the semi-classical treatment, a crucial novelty of this approach is that it naturally predicts the back-reaction of these processes on the metric. Since the number of gravitons changes during scattering, the bound state starts to evolve. This leads to quantum corrections of the corresponding rates. More importantly, we conclude that the classical metric ceases to be valid after a finite time.
This point of view fundamentally changes the question about the naturalness of the cosmological constant. Its smallness is required to ensure that the description by a classical metric does not break down on any observable time scale.
Based on G. Dvali, C. Gomez and S. Zell, in preparation

Janina Renk, *Stockholm Unversity*.
Gravity at the horizon: testing gravity with relativistic effects in large scale structure observables
Upcoming galaxy surveys will map out new regimes of our universe in the next decades. With these data we can test gravity on scales near the horizon by studying the signatures of modified gravity models on large scale structure observables. I will address the impact of consistent modifications of gravity on the largest observable scales, focusing on relativistic effects in galaxy number counts and the cross-correlation between the matter LSS distribution and the CMB. As an example for scalar-tensor theories encoded in the Horndeski Lagrangian, self-accelerating Covariant Galileons and parameterizations based on the effective field theory of dark energy are considered. Especially effects which involve integrals along the line of sight (lensing convergence, time delay and the ISW effect) can be considerably modified, and even lead to deviations of order 1000% from General Relativity. The ISW effect is isolated using the cross-correlation between LSS and CMB temperature anisotropies to constrain the considered models with current data. Forthcoming large-volume galaxy surveys using multiple-tracers will search for all these effects, opening a new window to probe gravity and cosmic acceleration at the largest scales available in our universe.

Jounghun Lee, *Seoul National University*.

A Bound Violation on the Galaxy Group Scale: The Turn Around Radius of NGC 5353/4 as a Test of Gravity

The following abstract is extracted from Lee et al. (2015, Astrophys.J. 815, 43): The first observational evidence for the violation of the maximum turn-around radius on the galaxy group scale is presented. The NGC 5353/4 group is chosen as an ideal target for our investigation of the bound-violation because of its proximity, low-density environment, optimal mass scale, and existence of a nearby thin straight filament. Using the observational data on the line-of-sight velocities and three-dimensional distances of the filament galaxies located in the bound zone of the NGC 5353/4 group, we construct their radial velocity profile as a function of separation distance from the group center and then compare it to the analytic formula obtained empirically by Falco et al. (2014) to find the best-fit value of an adjustable parameter with the help of the maximum likelihood method. The turn-around radius of NGC 5353/4 is determined to be the separation distance where the adjusted analytic formula for the radial velocity profile yields zero. The estimated turn-around radius of NGC 5353/4 turns out to substantially exceed the upper limit predicted by the spherical model based on the LambdaCDM cosmology. Even when the restrictive condition of spherical symmetry is released, the estimated value is found to be only marginally consistent with the LambdaCDM expectation.

Shuntaro Mizuno, *Waseda University*.

Vainshtein mechanism in massive gravity nonlinear sigma models

We study the stability of the Vainshtein screening of the bigravity based on the effective action inside the Vainshtein radius. The effective action is obtained by taking the Λ_2 decoupling limit around a curved spacetime. First we show that the Vainshtein screening solution is generally unstable when the vector graviton is not excited. Then we explicitly show that the static and spherically symmetric solution suffers from a ghost and/or a gradient instability for any parameters of the theory. This instability suggests that the nonlinear excitation of the scalar graviton is not sufficient to obtain a successful Vainshtein screening in bigravity.

4-5:30 pm **Amol Upadhye**, *UW-Madison*.

Redshift-space distortions constrain massive neutrinos and evolving dark energy

The amplitude and shape of the redshift-space matter power spectrum contain a wealth of information about fundamental physics and the cosmological parameters. I begin by developing a non-linear perturbative model of the redshift-space power spectrum using the Time-Renormalization Group (Time-RG) approach, designed to accommodate the scale-dependent growth in massive neutrino cosmologies. Through comparison with a suite of high-resolution N-body simulations, I show that redshift-space Time-RG perturbation theory accurately predicts the power spectrum over a large range of scales and for a diverse set of cosmological models, including those with massive neutrinos and rapidly-varying dark energy equations of state. Finally, I apply Time-RG to the redshift-space power spectrum from BOSS Data Release 11 in conjunction with Planck cosmic microwave background data. I present constraints on the cosmological parameters and discuss their dependence on the modeling of scale-dependent bias.

Frank Koennig, *ITP, University of Heidelberg*.

A spectre is haunting the cosmos: Quantum stability of massive gravity with ghosts

Many theories of modified gravity with higher order derivatives are usually ignored because of serious problems that appear due to an additional ghost degree of freedom. Most dangerously, it causes an immediate decay of the vacuum. However, breaking Lorentz invariance can cure such abominable behavior. By analyzing a model that describes a massive graviton together with a remaining Boulware-Deser ghost mode we show that even ghostly theories of modified gravity can yield models that are viable at both classical and quantum levels and, therefore, they should not generally be ruled out. Furthermore, we identify the most dangerous quantum scattering process that has the main impact on the decay time and find differences to simple theories that only describe an ordinary scalar field and a ghost. Additionally, constraints on the parameters of the theory including some upper bounds on the Lorentz-breaking cutoff scale are presented. In particular, for a simple theory of massive gravity we find that a Lorentz violation needs to occur below 200 eV, which still agrees with observations. Finally, we discuss the relevance to other theories of modified gravity.

Mark Hertzberg, *Tufts University*.

Gravitation, Quantum Consistency, and Causality

General relativity was historically introduced as arising from various principles, such as equivalence principle and general co-ordinate invariance. From the modern point of view, we view it as simply a theory of massless spin 2 particles. Modifications of general relativity are often motivated by dark energy, inflation, etc. In this talk, I begin by reviewing this modern perspective. I then point out quantum mechanical inconsistencies in some of the most popular ways to modify general relativity, namely the F(R) scalar-tensor theories. Then I consider a new class of spin 2 theories that involve higher derivatives, and explain that they fail due to causality violation. This goes towards deriving general relativity from very fundamental principles.

Stefano Anselmi, *Case Western Reserve University*.

Quasidilaton massive gravity faces cosmological constraints

The mysterious acceleration of the Universe may be successfully explained by a modification of the standard gravity paradigm. In this regard theories that give mass to the graviton result being very promising candidates. It is thus mandatory to study the cosmological phenomenology of them to allow an accurate comparison with present and future observational data. In this context I will focus on the cosmology of quasidilaton massive gravity, a theory with three additional parameters w.r.t LCDM. Interestingly, already at the background level, it shows a non-trivial behavior, enforcing a fine-tuning of the fundamental parameters of the theory. The evolution of gravity waves reveals that the mass of the graviton may be negative in the past while today is always larger than the Hubble parameter. An effect that may be observed by future surveys. The analysis I will present is a first step toward the investigation of the more stable extended quasidilaton massive gravity.

Matteo Fasiello, *Stanford University*.

LSS probes for Dark Energy & Modified Gravity

The perturbative treatment of LSS dynamics, especially in its effective theory realization, can well describe the quasi-linear regime. I will elaborate on recent progress towards including a dynamical dark energy or a modified gravity component in this framework.

Shuang-Yong Zhou, *Case Western Reserve University*.

The Λ_2 limit of dRGT massive gravity

dRGT massive gravity is a candidate for dark energy. From the EFT point of view, the model is usually associated with a strong coupling scale at Λ_3 $(10^{-13}$eV). With de Rham and Tolley, we show that, by including non-trivial effects from the Stueckelberg modes, one can push the strong coupling scale to much higher values, close to Λ_2 (meV). About these non-trivial vacua, the peculiar linear vDVZ-discontinuity is also absent. For generic parameters of the theory and generic vacua for the Stueckelberg fields, the Λ_2-decoupling limit of the theory is well-behaved and free of any ghost or gradient-like instabilities. This means that these Λ_2 backgrounds are theoretically well-controlled, can easily recover the phenomenological successes of General Relativity and are well suited to explain the dark energy problem.

PRIMORDIAL/INFLATION.

2-3:30 pm **Peter Adshead**, *University of Illinois at Urbana-Champaign*.

Asymmetric reheating and chilly dark sectors

In a broad class of theories, the relic abundance of dark matter is determined by interactions internal to a thermalized dark sector, with no direct involvement of the Standard Model. These theories raise an immediate cosmological question: how was the dark sector initially populated in the early universe? I will discuss one possibility, asymmetric reheating, which can populate a thermal dark sector that never reaches thermal equilibrium with the SM.

Mustafa Amin, *Rice University*.

From Wires to Cosmology: A statistical approach to particle production during inflation and reheating

Current observations provide precise but limited information about inflation and reheating. Theoretical considerations, however, suggest that the early universe might be filled with a large number of interacting fields with unknown interactions. How can we quantitatively understand particle production and the dynamics of perturbations during inflation and reheating in such scenarios and when only limited constraints are available from observations? Based on a precise mapping between particle production in cosmology to resistivity in disordered, quasi one-dimensional wires, I will provide a statistical framework to resolve such seemingly intractable calculations. A number of phenomenon in disordered wires find an analogue in particle production. For example, Anderson localization in quasi one-dimensional wires can be directly mapped to exponential particle production in the early universe. In this talk, I will present our general framework (arXiv: 1512.02637), and discuss ongoing calculations of observables from inflation and reheating.

Damien Easson, *Arizona State University*.
Stability of cosmological models with unusual scalar fluids
I will discuss cosmological solutions in standard Einstein gravity sourced by non-standard, non-canonical scalar field fluids. Examples of such fluids include k-essence, DBI, Galileon fields, Horndeski models and the new oscillatory models recently proposed by Nobel Laureate Wilczek et al. I will focus on the stability of these fluids emphasizing the common occurrence of negative kinetic energy degrees of freedom (ghosts),gradient instabilities (imaginary sound speed), superluminal propagating modes and singularities and the physical conditions required for such pathologies to be avoided. The analysis is relevant for a variety of popular cosmological scenarios including K-inflation, Galilean Genesis super-inflation, and the G-bounce models.

Tommi Tenkanen, *University of Helsinki*.
A Strong Electroweak Phase Transition from the Inflaton Field
We study a singlet scalar extension of the Standard Model. The singlet scalar is coupled non-minimally to gravity and assumed to drive inflation, and also couple sufficiently strongly with the SM Higgs field in order to provide for a strong first order electroweak phase transition. Requiring the model to describe inflation successfully, be compatible with the LHC data and yield a strong first order electroweak phase transition, we identify for the first time the regions of the parameter space where the model is viable. We also include a singlet fermion with scalar coupling to the singlet scalar to probe the sensitivity of the constraints on the additional degrees of freedom and their couplings in the singlet sector.

Scott Watson, *Syracuse University*.
The End of Inflation
It is typically assumed that inflation will end providing a "hot Big Bang", where (at least) Standard Model fields and dark matter will eventually be populated. However, little is known about the end of inflation, and prior to BBN direct probes on the cosmic history are elusive. Yet, collider probes and dark matter detection experiments continue to search for physics Beyond the Standard Model at precisely these scales. Moreover, the process by which the inflationary sector transfers its energy to the Standard Model and other hidden sectors can be quite involved. This process can be non-perturbative, chaotic, can exhibit turbulence, and significantly alter the expansion history – presenting a number of theoretical challenges. I will review recent progress in both theory and observations.

Gonzalo Palma, *Departamento de Fsica, FCFM, Universidad de Chile*.
On the role of light fields during inflation
A large coupling between curvature perturbations and light fields can enhance the super-horizon growth of curvature perturbations, alleviating the tension that exists a priori between multi-field models of inflation and the statistical properties of the CMB. In this paper we study this situation for the case where the additional light fields stay exactly massless during inflation, which is possible thanks a non-trivial shift symmetry that may appear at quadratic order in the Lagrangian of fluctuations, involving the simultaneous transformation of curvature perturbations and the massless field. The spectra that result from this situation is such that the power spectrum of isocurvature modes is suppressed in comparison to the power spectrum of curvature perturbations. In addition, the tensor to scalar ratio is predicted to be generically very suppressed. We offer concrete multi-field scenarios where this class of dynamics is realized and in which the coupling between the inflaton and the massless fields are purely determined by the geometry of the field-space manifold. Interestingly, these effects are predicted to be large only in the region where the effective field theory for fluctuations can be trusted.

4-5:30 pm **Ivonne Zavala**, *Swansea University*.

Axion Inflation in String Theory and Primordial Gravitational Waves

An attractive candidate for the inflaton is an axion slowly rolling down a flat potential protected by a perturbative shift symmetry. Realisations of this idea within large field, natural and monomial inflation have been disfavoured by observations and are difficult to embed in string theory. I will discuss the implications and prospects of these type of models for primordial gravity waves in string inflation. I will then show how subleading, but significant non-perturbative corrections to the axion potential can help bringing single-field natural and monomial inflation in UV complete theories like string theory, back into the favour of current observations, with distinctive signatures.

Shuichiro Yokoyama, *Department of Physics, Rikkyo University, Japan*.

Revisiting matter isocurvature fluctuations in the curvaton scenario

We investigate dark matter isocurvature perturbations in the curvaton scenario in detail, analytically and also numerically. In analytic estimation, we employ the delta-N formalism, and use the approximation that dark matter, which is initially in thermal equilibrium, is instantaneously decoupled from the thermal equilibrium. By comparing such approximation with numerical results, we find that we need to take into account the effect of the dilute gas produced from the decay of the curvaton. We explicitly show that even if the freeze-out of the dark matter occurs before the complete decay of the curvaton, dark matter isocurvature perturbations could be much suppressed when the freeze-out occurs deep in the curvaton-dominated Universe. We also discuss the implication of the above result on the constraint on model parameters in the scenario where the dark matter was produced in the curvaton scenario, and find that the allowed region in the parameter space is significantly enlarged by taking the dilute gas effect into account.

Mohammad Hossein Namjoo, *Center for Astrophysics, Harvard*.

Probing the Primordial Universe using Massive Fields

Inflation is the leading paradigm of the early universe cosmology. There are however several alternative-to-inflation scenarios which are consistent with currently available observational data, making them indistinguishable from inflation. In this talk I will discuss how one can probe the physics (i.e. mass spectroscopy of the particles) of the early universe by studying specific features on cosmological observables. Furthermore, I will show that the fingerprints of the presence of massive fields during early universe (i.e. the so called standard clocks) can reveal the time evolution of the universe at that era, thus discriminating between different scenarios. Future theoretical and observational prospects of the primordial standard clocks will also be discussed.

Jinn-Ouk Gong, *Asia Pacific Center for Theoretical Physics*.

Consistency relation and inflaton redefinition in the delta-N formalism

We compute for general single-field inflation the intrinsic non-Gaussianity due to the self-interactions of the inflaton field in the squeezed limit. We recover the consistency relation in the context of the delta-N formalism, and argue that there is a particular field redefinition that makes the intrinsic non-Gaussianity vanishing, thus improving the estimate of the local non-Gaussianity using the delta-N formalism.

Kaloian Lozanov, *Institute of Astronomy, University of Cambridge, UK*.

The Equation of State and Duration to Radiation Domination After Inflation

We calculate particle production during inflation and in the early stages of reheating after inflation in models with a charged scalar field coupled to Abelian and non-Abelian gauge fields. A detailed analysis of the power spectra of primordial electric fields, magnetic fields and charge fluctuations at the end of inflation and preheating is provided. We carefully account for the Gauss constraints during inflation and preheating, and clarify the role of the longitudinal components of the electric field. We calculate the timescale for the back-reaction of the produced gauge fields on the inflaton condensate, marking the onset of non-linear evolution of the fields. We provide a prescription for initial conditions for lattice simulations necessary to capture the subsequent nonlinear dynamics. On the observational side, we find that the primordial magnetic fields generated are too small to explain the origin of magnetic fields on galactic scales and the charge fluctuations are well within observational bounds for the models considered in this paper.

Jason Evans, *Korea Institute for Advanced Study*.

Naturalizing Supersymmetry with a Two-Field Relaxion Mechanism

We present a supersymmetric version of a two-field relaxion model that naturalizes tuned versions of supersymmetry. This arises from a relaxion mechanism that does not depend on QCD dynamics and where the relaxion potential barrier height is controlled by a second axion-like field. During the cosmological evolution, the relaxion rolls with a nonzero value that breaks supersymmetry and scans the soft supersymmetric mass terms. Electroweak symmetry is broken after the soft masses become of order the supersymmetric Higgs mass term and causes the relaxion to stop rolling for superpartner masses up to 10^9 GeV. This can explain the tuning in supersymmetric models, including split-SUSY models, while preserving the QCD axion solution to the strong CP problem. Furthermore, we show that the second field, of this two-field model, can be the inflaton.

FUTURE PROBES.

2-3:30 **Benjamin Saliwanchik**, *University of KwaZulu-Natal*.
Design and Scientific Forecast of the Hydrogen Intensity and Real-time Analysis eXpermiment (HIRAX)
The Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX) is a planned radio telescope array that will consist of 1000 close packed 6 m dishes that will be deployed in South Africa. HIRAX will survey the majority of the southern sky to measure baryon acoustic oscillations (BAO) using the 21 cm hyperfine transition of neutral hydrogen. The telescope is optimized to measure the 100 $h^{-}1$ Mpc BAO scale by measuring integrated emission from many neutral hydrogen sources (intensity mapping). It will operate between 400-800 MHz in 1024 frequency bins, corresponding to a redshift range of $0.8 < z < 2.5$ and a minimum deltaz/z of 0.003. by measuring the bao length scale as a function of redshift, hirax will chart the expansion history of the universe and place constraints on the dark energy equation of state. in addition to bao cosmology, the large survey area and real-time analysis capabilities of the hirax array will make it a powerful tool for identifying pulsars and astrophysical transients such as fast radio bursts. hirax will additionally provide an excellent platform for studying neutral hydrogen absorbers, and the extensive overlap with the large synoptic survey telescope (lsst) will enable cross-correlation studies of radio and optical tracers of large scale structure. the testing of the first prototype hirax dish has begun in durban, and an eight-element prototype array is scheduled for construction and deployment at the hartebeesthoek radio astronomy observatory (hartrao) in early 2016. this presentation describes the telescope design, current plans for deployment and calibration, and preliminary forecasts of scientific constraints.

Seth Siegel, *McGill University*.

CHIME: A Stage IV Dark Energy Experiment

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a radio interferometer that is currently being deployed at the Dominion Radio Astrophysical Observatory (DRAO) near Penticton, British Columbia and is expected to begin observations in late 2016. It consists of four adjacent cylindrical dishes, each 100 x 20 meters, populated with a total of 1024 dual-polarization antenna feeds sensitive to 400-800 MHz. The cylinders are stationary and oriented in the north-south direction, forming a transit telescope that maps approximately half of the sky each day with a synthesized beam resolution of 20-40 arcminutes. CHIME will make a three-dimensional intensity map of the 21 cm radiation from neutral hydrogen over a 600 cubic Gpc volume. This will enable a measurement of the scale of the Baryon Acoustic Oscillations (BAO) in both the angular and line-of-sight direction across the redshift range z=0.8-2.5, which will probe the angular diameter distance versus redshift relation and time evolution of the expansion rate during the epoch when dark energy starts to dominate the energy density of the Universe. CHIME will carry out a five year survey that is expected to yield Stage IV constraints on the dark energy equation of state. One of the primary challenges facing CHIME and 21 cm intensity mapping experiments in general is that the cosmological signal must be separated from foregrounds that are five orders of magnitude brighter. We employ the m-mode analysis formalism combined with the Karhunen-Loeve transform to efficiently separate the 21 cm signal from the contaminating foregrounds using their respective spectral and spatial statistics. This method requires a detailed understanding of the instrument, including precise knowledge of the antenna primary beam patterns and time-variable complex receiver gains. We have developed a number of calibration techniques to address these requirements and are testing them on a smaller scale Pathfinder instrument that consists of two cylinders, each 36 x 20 meters, populated with a total of 128 dual-polarization antenna feeds. In this talk I will give an update on the status of CHIME, discuss calibration strategies, and present an initial look at data from the Pathfinder, which began a two-year survey in December 2015.

Jon Gudmundsson, *Oskar Klein Centre for Cosmoparticle Physics, Stockholm University*.

Lessons learned from SPIDER's first flight and implications for future ballooning and satellite missions

SPIDER is a balloon-borne experiment designed to image the polarization of the cosmic microwave background with the aim of constraining models of the early universe, including the inflationary paradigm. I will examine the detector performance from SPIDER's first flight and discuss the implications for future ballooning and satellite missions. I will review emerging ballooning technology and show how ballooning missions provide essential complementary to ground based experiments.

Roland de Putter, *Caltech*.

Probing Inflation with Galaxy Clustering on Ultra-Large Scales

The large-scale distribution of galaxies is a powerful probe of the physics of Inflation. In this talk, I will explain what it would take for a future galaxy survey to use galaxies as a probe of primordial non-Gaussianity in order to distinguish between single-field and multi-field Inflation, and I will introduce a specific proposal for such a survey, called SPHEREx. I will also revisit the prediction for the exact level of non-Gaussianity and scale-dependent bias in single-field Inflation.

Caroline Heneka, *NBI, University of Copenhagen*.
Probing Reionization: Cross-correlation of 21-cm and Lyman-alpha fluctuations
Line intensity mapping opens up a new and exciting window for probing cosmology during the Epoch of Reionization and at higher redshifts than previously tested by galaxy surveys. The cross-correlation of line fluctuations like 21-cm, Lyman-alpha and H-alpha is a promising tool to probe the IGM during the Epoch of Reionization. It enables us to track the evolution of the ionisation fraction and is a measure of the average size of ionised bubbles. We simulate Lyman-alpha, 21-cm and H-alpha line fluctuations, in order to calculate their respective power and cross-power spectra. The impact of foreground induced anisotropies on the power spectra is investigated by separating perpendicular and parallel Fourier modes and we test dependencies of the cross-correlation on reionization parameters like the escape fraction, on cosmological parameters and on the modelling of Lyman-alpha emitters. We furthermore forecast the ability of probes of the Epoch of Reionization such as SPHEREx, a proposed all-sky spectroscopic survey satellite that will also perform intensity mapping of the Lyman-alpha line, to measure the cross-correlation of 21-cm and Lyman-alpha jointly with upcoming 21-cm surveys like SKA.

Inh Jee, *Max-Planck Institute for Astrophysics*.
Strong Lensing Cosmography : method, predictions and measurements
One of the major ongoing efforts in cosmology is the measurement of the distance-redshift relation and constraining cosmological models from it. The most popular approaches are to use Supernovae type Ia as standard candles, and Baryon Acoustic Oscillation as a standard ruler. I will present a new standard ruler, strong gravitational lenses with time delay measurements, to calculate the angular diameter distances at the cosmological scale. This is a measurement of distances which is independent to other probes, and also an efficient way to populate the Hubble diagram, as individual objects give a distance to the corresponding redshift. I first introduce the basic idea behind the method and discuss the systematics. Then I introduce the constraining power of the method using the simulated observations based on predictions for Large Synoptic Survey Telescope, highlighting where the constraints are coming from. Finally, I present actual measurements applied to real data.

CMB/LARGE SCALE STRUCTURE.

4-5:30 pm **Paul Shapiro**, *The University of Texas at Austin*.

Simulating Cosmic Reionization and Its Observable Consequences

I will summarize recent progress in modelling the epoch of reionization by large- scale simulations of cosmic structure formation, radiative transfer and their interplay, which trace the ionization fronts that swept across the IGM and ionized it, to predict observable signatures of this process. Cosmic reionization by starlight from early galaxies affected their evolution, thereby impacting reionization, itself, and imprinting the galaxies with a memory of reionization. Star formation suppression, for example, may explain the observed underabundance of Local Group dwarfs relative to N-body predictions for Cold Dark Matter. With this in mind, I will describe the first fully-coupled radiation-hydrodynamical simulation of reionization and galaxy formation in the Local Universe, in a volume large enough to model the global history of cosmic reionization and with enough resolving power to follow the formation and evolution of all the atomic-cooling galactic halos in that volume. A representative comoving box 90 Mpc on a side was simulated from a constrained realization of the primordial fluctuations, chosen to reproduce the present-day features of the Local Group, including the Milky Way and M31, and the local universe beyond, including the Fornax and Virgo clusters. The new RAMSES-CUDATON hybrid CPU-GPU code took 11 days to perform this simulation on the Titan supercomputer at Oak Ridge National Laboratory, with 4096-cubed N-body particles for the dark matter and 4096-cubed cells for the atomic gas and ionizing radiation. The simulation is called CoDa, for "Cosmic Dawn".

Anson D'Aloisio, *University of Washington*.

Probing Cosmological Reionization with the High-redshift Lyman-alpha Forest

When the first galaxies emerged, 100 - 500 million years after the Big Bang, their starlight likely reionized and heated the intergalactic hydrogen that had existed since cosmological recombination. Much is currently unknown about this process, including what spatial structure it had, when it started and completed, and even which sources drove it. Recent observations of high-redshift quasars show large-scale spatial variations in the opacity of the z 5.5 intergalactic medium to Lyman-alpha photons. These spatial variations grow rapidly with redshift, far in excess of expectations from previous empirically motivated models. I will discuss possible explanations for the excess, as well as what they imply about the reionization process.

Hao-Yi Wu, *California Institute of Technology*.

A physical model for the anisotropies of cosmic far-infrared background

Cosmic far-infrared background (CFIRB) originates from unresolved dusty star-forming galaxies across cosmic time. It is a powerful probe for the star formation rate (SFR) history and the connection between dark matter and baryons. In this talk, I will interpret the measurements of CFIRB by Planck using a physical model based on continuity equations for baryons. This model simultaneously provides good descriptions for the CFIRB power spectra, correlation between CMB lensing potential and CFIRB, FIR flux functions, and IR luminosity functions. I will then present constraints on SFR-halo mass relation, galaxy bias, SFR history, and dust properties. Base on the physical model, I will also discuss how to optimize future experiments for CFIRB as part of the CMB Stage-IV experiments.

Marcelo Alvarez, *Canadian Institute for Theoretical Astrophysics*.
Mock LSS Surveys with the Peak Patch Approach
Large scale structure surveys contain information on the initial conditions and properties of the universe not otherwise available. In order to optimize the methods to extract this information, we have developed an approach based on the peak patch picture, in which primordial fluctuations are connected explicitly with the formation of bound objects to create mock observations. First applications, to Sunyaev-Zel'dovich and HI intensity mapping surveys, will be presented.

Joel Meyers, *CITA*.
Light Relics and Next Generation CMB Observations
Ongoing and future cosmic microwave background observations will greatly improve our measurement of the temperature and polarization power spectra at small angular scales. These improvements will allow for fundamentally new insights into physics beyond the standard model and the very early universe. I will discuss theoretical targets for CMB constraints on light relics and the path toward reaching those goals.

Chen Heinrich, *University of Chicago*.
Lensing Bias to Compensated Isocurvature Perturbations
Compensated isocurvature perturbations (CIPs) are modes in which the baryon and dark matter density fluctuations cancel. They arise in the curvaton scenario as well as some models of baryogenesis. While they leave no observable effects on the cosmic microwave background (CMB) at linear order, they do spatially modulate two-point CMB statistics and can be reconstructed in a manner similar to gravitational lensing. Due to the similarity between the effects of CMB lensing and CIPs, lensing contributes nearly Gaussian random noise to the CIP estimator that approximately doubles the reconstruction noise power. Additionally, the cross correlation between lensing and the integrated Sachs-Wolfe (ISW) effect generates a correlation between the CIP estimator and the temperature field even in the absence of a correlated CIP signal. For cosmic-variance limited temperature measurements out to multipoles l2500, subtracting a fixed lensing bias degrades the detection threshold for CIPs by a factor of 1.3, whether or not they are correlated with the adiabatic mode.

DARK ENERGY.

2-3:30 pm **Miguel Zumalacarregui**, *Nordita*.
New probes of gravity and cosmic acceleration
Recent advances in cosmology provide both the motivation and the data to probe gravity on the largest scales available to observation. I will revise the landscape of gravitational theories, focusing on modern scalar-tensor theories and their cosmological implications. Then I will present the ongoing effort to test gravity in novel regimes such as the early universe, non-linear effects and ultra-large scales. I will also introduce the hi_class code (www.hiclass-code.net), which is central to this program.

Lucas Lombriser, *University of Edinburgh*.

Challenges to Self-Acceleration in Modified Gravity from Gravitational Waves and Large-Scale Structure

Scalar-tensor modifications of gravity have long been considered as an alternative explanation for the late-time accelerated expansion of our Universe. I will first show that a rigorous discrimination between acceleration from modified gravity and from a cosmological constant or dark energy is not possible with observations of the large-scale structure alone. I will then demonstrate how gravitational-wave observations break this dark degeneracy and how the combination of the two challenges the concept of cosmic acceleration from a genuine scalar-tensor modification of gravity.

Shahab Joudaki, *Swinburne University*.

KiDS+2dFLenS: Testing Gravity on Cosmic Scales with Weak Lensing and Redshift Space Distortions

The apparent existence of "dark energy" compels us to test the laws of gravity across the scale of the universe in multiple ways. Only a powerful combination of two observables, gravitational lensing and galaxy velocities, will pin down the physics of gravity. In this talk I will present new tomographic weak lensing measurements from one of the largest existing cosmic shear surveys, the Kilo Degree Survey (KiDS), accounting for key astrophysical systematics from intrinsic alignments, baryons, and photometric redshifts. I will discuss the sensitivity of the cosmological constraints to the astrophysical systematics, provide new bounds on extensions to the standard cosmological model, and assess the level of concordance between KiDS and Planck. I will then examine standard cosmology and modified gravity constraints from KiDS in combination with overlapping spectroscopic surveys, given by the 2-degree Field Lensing Survey (2dFLenS) and the Baryon Oscillation Spectroscopic Survey (BOSS), including the full covariance between the RSD monopole and quadrupole spectra, shear-galaxy correlation function, and shear-shear correlation functions.

Eva-Maria Mueller, *Institute for Cosmology and Gravity*.

BOSS DR12 Combined Sample Analysis constraints on modified gravity

I will present updated constraints on modified gravity models using the newest/upcoming BOSS DR12 Combined Sample Analysis results in combination with other data sets. The focus is on phenomenological models that alter the Einstein equations, introducing G_M(k,z) and G_L(k,z) in bins as additional parameters, as well as tensor-scalar theory inspired unifying approaches (BZ-parameterization) and f(R) models. Additionally, I will discuss forecasts for LSST and DESI for these modified gravity models, particularly pointing out challenges due to systematic effects.

Sebastian Cespedes, *DAMTP, University of Cambridge*.

Modifications of the speed of gravitational waves at early times.

A speed different from one for tensor modes can arise in several contexts, such as Galileons theories or massive gravity, nevertheless the speed is very constrained to be one by observations of gravitational wave emission. It has been shown that in inflation a disformal transformation allows to set the speed for tensor modes to one without making changes to the curvature power spectrum. Here we show that this invariance does not hold when considering the CMB anisotropy power spectrum. It turns out that the after doing the transformation there is an imprint on the acoustic peaks and the diffusion damping. This has interesting consequences; and we explore which others observational constraint could be imposed by employing cosmology.

Chi-Ting Chiang, *C. N. Yang Institute for Theoretical Physics, Stony Brook University*.
Fake Separate Universe: A new trick for simulating clustered quintessence cosmologies
The separate universe technique provides a way to absorb the long-wavelength matter fluctuation into the change of background cosmology. The cosmological N-body simulations can thus be performed in the separate universes to study how the small-scale structure formation (such as power spectrum and halo mass function) responds to the long-wavelength perturbation. In the presence of an additional fluid, its density fluctuation may cluster with the matter. Depending on whether the long-wavelength matter fluctuation is below or above the sound horizon of the fluid, the evolution of the long-wavelength matter fluctuation would be affected differently. This thus produces two distinct separate universes, and so as the responses of the small-scale structure formation. We use the separate universe simulations with clustered dark energy to show that there will be a new scale (sound horizon of dark energy) dependence of the matter squeezed-limit bispectrum and the halo bias. This novel feature could potentially be useful to probe the extra fluid such as dynamic dark energy or massive neutrinos.

DARK ENERGY/DARK MATTER.

4-5:30 pm **Brian Nord**, *Fermilab*.
DeepLensing: The Use of Deep Learning to Find Strong Lenses in the Dark Energy Survey
Strong gravitational lenses have potential to be very powerful probes of dark energy and cosmic structure. However, efficiently finding lenses poses a significant challenge—especially in the era of large-scale surveys cosmological surveys. I will present the strong lens discovery program for the Dark Energy Survey (DES), as well as a new application of deep learning to finding lenses.
Over five observing seasons, which started in August 2013, DES will carry out a wide-field survey of 5000 square degrees of the Southern Galactic Cap. DES has identified nearly 200 strong lensing candidates in the first two seasons of data. We have performed spectroscopic follow-up on a subsample of these candidates at Gemini South, confirming over a dozen new strong lenses.
I will first present the DES program, including searches and spectroscopic follow-up of galaxy-scale, cluster-scale and time-delay lensing systems. Then, I will discuss the successful search for lenses using deep learning methods: in particular, we show that convolutional neural nets present a new set of tools for efficiently finding lenses, including the types of configurations that will be critical for cosmological studies.

Joseph DeRose, *Stanford University*.
Simulating the Dark Energy Survey Sky
The challenges associated with simulating wide field galaxy surveys, especially those intending to use weak lensing as a primary cosmological probe, have become pressing issues for ongoing and future cosmological studies. In this talk, I will describe the 100 mock skies, including galaxies, gravitational lensing, and realistic observational errors, that have been created for the analysis of the first year of Dark Energy Survey data. These mocks use a novel algorithm, ADDGALS, to create large volume galaxy catalogs to depths that are beyond the reach of typical HOD/SHAM/SAM methods. I will describe the use of these mocks for covariance matrix estimation, modeling of observables and systematic error analysis. To conclude I will discuss the challenges that will be faced in upcoming years of the Dark Energy Survey as well as for future surveys such as LSST, Euclid and WFIRST.

Evan Grohs, *University of Michigan*.

Precision big bang nucleosynthesis and neutrino cosmology

We present detailed numerical calculations related to big bang nucleosynthesis and cosmological neutrino physics. Specifically, we investigate how increased precision on the primordial deuterium and helium abundances supply new constraints on the neutrino-antineutrino asymmetry, characterized as a lepton number. At previous levels of precision, the observationally-inferred helium abundance placed an upper limit of 0.1 on the lepton number. Future precision of the helium and deuterium measurements will lower the upper limit by an order of magnitude. To quantitatively determine the leverage the abundances have on lepton numbers, our calculations utilize a model consistent with the standard cosmology except for the presence of nonzero lepton numbers. The anticipated level of precision in the abundances requires the integration of a nuclear reaction network to determine the abundances, and the integration of a series of Boltzmann equations to follow the out-of-equilibrium neutrino spectra. In this manner, we obtain precise values of the abundances and other cosmological quantities such as the effective number of neutrinos. Our work has implications for nuclear and beyond standard model physics. Such physics could manifest itself with measurements using next generation cosmic microwave background and thirty-meter-class telescopes.

Tanja Rindler-Daller, *University of Vienna*.

Dark stars as progenitors of supermassive black holes in the early Universe?

Over the past years, observations of high-redshift galaxies have shown that supermassive black holes (SMBHs) with billions of solar masses have already existed a few hundred million years after the Big Bang. Since the timescale for traditional mechanisms of accretion onto stellar BHs is too long, other models have been considered. These include the monolithic collapse of giant gas clouds, or the collapse of early supermassive stars. In this talk, I will elaborate how another proposal, namely early dark-matter-powered stars ("dark stars"), could explain SMBHs. Early dark stars have primordial composition, but they are powered by the energy release of dark matter self-annihilation. I will contrast previous results on the evolution of supermassive stars with our models of supermassive dark stars, where we compute the latter using the state-of-the-art stellar evolution code MESA. By following the evolution of these stars in atomic-cooling halos, using different dark matter particle parameters, we can investigate when supermassive dark stars might become the progenitors of SMBHs. In this talk, I will report on these and other forecasts of supermassive dark stars.

Jayden Newstead, *Arizona State University*.

Neutrino floors for non-standard direct dark matter detection scenarios

The next generation of direct dark matter detection experiments will be sensitive to coherent scattering of solar neutrinos, providing an irreducible background to dark matter searches. While technology may eventually be able to mitigate the effect of this background, non-standard dark matter interactions do not necessarily exhibit a neutrino floor. In this talk I will survey examples of non-standard dark matter interactions and demonstrate the how their discovery potential is effected by the neutrino background.

LIGO AND BLACK HOLES.

2-3:30 pm **Dejan Stojkovic**, *SUNY at Buffalo*.

Quantum aspects of gravitational collapse: non-singularity and non-locality

Singularities in classical general relativity are unavoidable, but perhaps only represent the fact that we are extrapolating our theory beyond its region of validity. We study the end stages of gravitational collapse using the functional Schrodinger formalism to capture quantum effects in the near singularity limit. We find that that the equations of motion which govern the behavior of the collapsing object near the classical singularity become strongly non-local. We managed to solve the non-local equations, and found an explicit form of the wavefunction describing the collapsing object. This wavefunction and the corresponding probability density are non-singular at the origin, thus indicating that quantization should be able to rid gravity of singularities, just as it was the case with the singular Coulomb potential.

Liang Dai, *Institute for Advanced Study*.

Lensing magnification bias on the apparent distribution of black hole mergers

The recent detection of gravitational waves indicates that stellar-mass black hole binaries are likely to be a key population of sources for forthcoming observations. With future upgrades, ground-based detectors could detect merging black hole binaries out to cosmological distances. Gravitational wave bursts from cosmological redshifts can be strongly magnified by intervening galaxies along the line of sight. In the absence of electromagnetic counterparts, the mergers' intrinsic mass scale and redshift are degenerate with the unknown magnification factor. Hence, strongly magnified low-mass mergers from high redshifts appear as higher-mass mergers from lower redshifts. We assess the impact of this degeneracy on the mass-redshift distribution of observable events in generic models of binary black hole formation. We find that strong magnification generally creates a heavy tail of apparently massive mergers. For LIGO and its future upgrades, this tail may dominate the population of intrinsically massive, but unlensed mergers in some binary black hole formation models. Modeling the statistics of lensing magnification can help account for this magnification bias when testing astrophysical scenarios of black hole binary formation and evolution.

Ruth Gregory, *Durham University*.

Screened Scalars and Black Holes

I will discuss screened scalar hair around black holes, first explaining why "no hair" theorems do not work in this case, then deriving the scalar profile around the accretion disc of a Kerr black hole. I will also discuss astrophysical implications and model constraints.

Alexandre Dolgov, *Novosibirsk State University, ITEP, University of Ferrara*.

LIGO-observed gravitational waves: problems and solution.

The direct registration of gravitational waves (GW) by LIGO created several problems related to their possible source: the origin of 30 solar mass black holes (BH), the probability of BH binary formation, the too low value of the primary black hole spins. The model of primordial BH formation is presented which naturally solves the observed problems and predicts some properties the future events of GW observations. The model also explains the observed rich astrophysical population of the universe at redshifts 6-10.

Tomohiro Nakama, *Johns Hopkins University*.
New primordial black hole constraints to primordial gravitational waves
Recently we have proposed a novel method to probe primordial gravitational waves from upper bounds on the abundance of primordial black holes (PBHs). When the amplitude of primordial tensor perturbations generated in the early universe is very large, they induce large scalar perturbations due to their second-order effects. If the amplitude of resultant scalar perturbations is too large at the moment of their horizon reenty, then PBHs are overproduced to a level that is inconsistent with a variety of existing observations constraining the abundance of PBHs. This consideration leads to upper bounds on the amplitude of primordial tensor perturbations on super-horizon scales. In contrast to our recent paper in which we only present simple estimations of the upper bounds from PBHs, in this paper, we present detailed derivations, by solving the Einstein equations for scalar perturbations induced at second order in tensor perturbations. We also derive an approximate formula for the probability density function of induced density perturbations, necessary to relate the abundance of PBHs to the primordial tensor power spectrum, assuming primordial tensor perturbations follow Gaussian distributions. Comparison is presented of the upper bounds from PBHs with other existing bounds obtained from Big Bang Nucleosynthesis, Cosmic Microwave Background, LIGO/Virgo and pulsar timing arrays.

David Weir, *University of Stavanger*.
Simulating a first-order electroweak phase transition
In various extensions of the Standard Model it is possible that the electroweak phase transition was first order. This would have been a violent process, involving the formation of bubbles and associated shock waves. The collision of these bubbles and shock waves could be a detectable source of gravitational waves. I will summarise recent work to model such a phase transition using large-scale hydrodynamical simulations. In addition, I will demonstrate some generic features of the resulting gravitational wave power spectrum, and the implications for detectability of specific scenarios at future gravitational wave observatories.

LIGO AND BLACK HOLES/PRIMORDIAL/INFLATION.

4-5:30 pm **Simeon Bird**, *Johns Hopkins University*.
Did LIGO Detect Dark Matter?
There is a possibility that the recent LIGO detection of gravitational waves originated from the merger of two primordial black holes, making up the dark matter. Thirty solar mass black holes, as detected by LIGO, lie within an allowed mass window for primordial black hole dark matter. Interestingly, our best estimates of the number of observable mergers fall within the range implied by current LIGO data. I will explain these estimates, discuss the (considerable!) theoretical uncertainties, and finish with prospects for testing the model.

Florian Kuhnel, *Stockholm University*.
Primordial Black Holes
Primordial black holes are black holes that may have formed in the early Universe. Their masses span potentially a range from as low as the Planck mass up to many orders of magnitude above the solar mass. Besides their conceptual importance regarding our understanding of quantum effects and gravity, they may provide the dark matter. In order to constrain this possibility, a proper understanding of their formation mechanism is crucial. In my talk, after a general introduction on primordial black holes, I will discuss recent investigations on this issue, including so-called critical collapse, non-sphericity and non-Gaussianity. Furthermore, I will discuss how to properly compare extended primordial black-hole mass spectra to observational constraints, such as those deriving from recent microlensing surveys.

Riccardo Penco, *Columbia University*.
Effective Field Theory of Inflation with Broken Spatial Diffeomorphisms
The vast majority of inflationary models in the literature are based on the premise that one or more fields evolve in time while their total energy density remains approximately constant. This time evolution leads to the spontaneous breaking of time diffeomorphisms. The behavior of cosmological perturbations in these models is captured by the well-known EFT of Inflation (and its multi-field generalization). It is perhaps less well-known that inflation can also be generated by time-independent field configurations with a non-trivial spatial profile. This is much less studied scenario, which is realized for instance if inflation is driven by a solid. In this talk, I will first review the peculiarities of solid inflation, and then discuss the analog of the EFT of inflation for models that break spatial rather than time diffeomorphisms.

Emil Mottola, *Los Alamos National Laboratory*.
Scalar Gravitational Waves in the Effective Theory of Gravity
Classical General Relativity as a Low Energy Effective Theory receives an infrared relevant modification from the conformal trace anomaly of the energy-momentum tensor of massless, or nearly massless, quantum fields. The local form of the effective action associated with the trace anomaly is expressed in terms of a dynamical scalar field that couples to the conformal factor of the spacetime metric, allowing it to propagate over macroscopic distances. Linearized around flat spacetime, this semi-classical EFT admits scalar gravitational wave solutions in addition to the transversely polarized tensor waves of the classical Einstein theory. Astrophysical sources for scalar gravitational waves are considered, with the excited gluonic condensates in the interiors of neutron stars in merger events with other compact objects likely to provide the strongest burst signals. The QCD phase transition is a possible source of a cosmological stochastic background of scalar gravitational radiation, also potentially detectable by the next generation of gravitational wave detectors.

Tomohiro Fujita, *Stanford University*.
Inflationary Gravitational Waves - beyond vacuum fluctuation
It is well known that the amplitude of the gravitational wave (GW) produced from the vacuum fluctuation during inflation is proportional to the energy scale of inflation. Thus the observation of the inflationary GW by CMB B-mode is expected to reveal the energy scale of new physics as well as pin down the inflation model. However, alternative production mechanisms of GW during inflation has been discussed recently. We consider a coupled system between an axion and SU(2) gauge fields whose energy density is subdominant. We found the GW generated by the spectator fields can be much larger than the GW from vacuum fluctuation without a fine-tuning. The produced GW is chiral, its tilt is arbitrary and the production of additional scalar perturbation is suppressed. Therefore, with our spectator fields, a low energy inflation model can produce detectable GW.

Bohua Li, *The University of Texas at Austin*.
Complex Scalar Field Dark Matter and its Imprint on the Gravitational Wave Background from Inflation
Coauthor: Paul Shapiro, Tanja Rindler-Daller We consider an alternative dark matter candidate to WIMP cold dark matter (CDM), ultralight bosonic dark matter (m $>$ 10^{-22} eV) described by a complex scalar field (SFDM), of which the comoving particle number density, or charge density, is conserved after particle production during standard reheating (w=0). In a Lambda-SFDM universe, SFDM starts relativistic, evolving from stiff (w=1) to radiationlike (w=1/3), before becoming nonrelativistic at late times (w=0). Thus, before the familiar radiation-dominated phase, there is an earlier phase of stiff-matter-domination, and the expansion rate in the early Lambda-SFDM universe is increased compared with that in Lambda-CDM. The transitions between these phases, determined by SFDM particle mass and self-interaction coupling strength, are therefore constrained by cosmological observables, particularly N_{eff}, the effective number of neutrino species during BBN, and z_{eq}, the redshift of matter-radiation equality. Furthermore, primordial tensor fluctuations that reenter the horizon during or before the stiff phase are amplified by the stiff phase and contribute a homogeneous energy density as a stochastic gravitational wave (GW) background. Hence, detection of GWs from inflation is then made possible at high frequencies by current laser interferometer experiments, e.g., aLIGO/Virgo and eLISA. In fact, our calculation for a few fiducial cases shows that for a broad range of reasonable reheat temperature T_{reheat}, the amplified GW background within the sensitive frequency band of aLIGO can reach a signal-to-noise ratio of 3 by the end of the final stage of aLIGO/Virgo experiment should it exist, for currently allowed values of tensor-to-scalar ratio r according to CMB polarization measurements.

DARK MATTER EXPERIMENT.

2-3:30 pm **Evan Pease**, *Yale University*.
Current Status of the LUX Dark Matter Experiment
The LUX experiment searches for direct evidence of galactic dark matter. Located roughly 1.5 km underground at the Sanford Underground Research Facility in Lead, South Dakota (USA), the detector contains a 350-kg active liquid xenon target. LUX operates as a dual-phase (liquid/gas) time projection chamber with 122 photomultiplier tubes, and it is capable of three-dimensional position reconstruction and discrimination of electronic and nuclear recoils. The initial 95 live-days exposure reached a record-setting sensitivity to Weakly Interacting Massive Particles (WIMPs), excluding WIMP-nucleon couplings greater than 5.6e-46 cm^2 for WIMPs of mass 33 GeV. Following this result, LUX has performed detailed calibrations and has recently completed accumulating a new exposure in excess of 300 live days. I discuss implications of the LUX results and present the current status of this search.

Kaixuan Ni, *University of California, San Diego*.

Recent Results from the XENON Dark Matter Experiments

The XENON program carries out dark matter searches with unprecedented sensitivity using the pioneering two-phase xenon technology at the Gran Sasso Underground Laboratory in Italy. We have performed searches for various dark matter candidates using the one-hundred-kg scale XENON100 detector. Recent results on the searches for dark matter elastic scattering signals, low-mass dark matter signals, dark matter induced electron recoil signals, and the annual modulation signals in XENON100 will be presented. We will also present the recent operational results from XENON1T, the largest running dark matter detector with a 2-ton sensitive liquid xenon target.

Wolfgang Lorenzon, *University of Michigan*.

The LZ Dark Matter experiment

The LUX-Zeplin (LZ) experiment is the most advanced next-generation direct detection experiment under construction to search for Dark Matter in the Universe. It contains a dual-phase liquid xenon time projection chamber with a total active mass of 7 tons. LZ is implementing various low background techniques to significantly reduce radioactive background and reach an unprecedented level of sensitivity to spin-independent WIMPs. For a WIMP mass of 50 GeV, an ultimate sensitivity of 2 10-48 cm2 is expected in three years of operation. LZ will be located at the Sanford Underground Research Facility (SURF) in South Dakota, at the same location as the currently running LUX experiment. In this presentation, an overview of the experimental techniques and science reach will be presented.

Anthony Villano, *University of Minnesota*.

Pushing the limits of low-energy calorimetry in SuperCDMS

The SuperCDMS SNOLAB experiment aims for world-leading sensitivity to low-mass WIMPs. This goal underscores the need for an excellent understanding of the energy scale for extremely low energy recoils, especially nuclear recoils less than 1keV. Such an understanding is difficult to obtain because of complicated energy-loss mechanisms in crystalline solid-state matter. I will discuss the experimental and theoretical subtleties of these mechanisms and the future of precision calibrations in this energy regime. I will also present the current analysis status of SuperCDMS detector nuclear-recoil energy calibration with monoenergetic neutrons.

Eric Dahl, *Northwestern University*.

Recent Results from PICO

The PICO collaboration has set the world-leading direct-detection limits on the spin-dependent WIMP-proton cross section with the PICO-60 and PICO-2L bubble chambers at SNOLAB. The PICO-60 result, with a 37-kg CF3I target and 3,415 kg-day exposure, represents the largest bubble-chamber dark matter search to date, while the most recent run of PICO-2L (3-kg C3F8 target and 129 kg-day exposure) successfully eliminates the particulate-induced events that have been the chief background in past PICO experiments. I will cover both of these results, give an update on the next physics run of PICO-60 which is set to begin at the end of summer 2016, and will describe our progress on new zero-buffer-fluid chambers that aim to further reduce particulate- and droplet backgrounds, including our first prototype scintillating xenon bubble chamber.

Phillip Urquijo, *The University of Melbourne*.

The SABRE Dark Matter Experiment: A pair of sodium iodide detectors located in Italy and Australia

The interaction rate of hypothesised dark matter particles in Earth bound detectors is expected to undergo annual modulation due to the planets orbital motion. The DAMA/LIBRA experiment has observed such a modulation with high significance in an array of scintillating NaI(Tl) crystals, however this result remains to be confirmed by independent experiments using the same detection method.

SABRE aims to test the DAMA/LIBRA results by performing a higher sensitivity measurement with NaI(Tl) crystals, and to investigate the nature of dark matter interactions. The key innovations in the detector setup will be the use of high purity NaI(Tl) crystals, improving upon that of DAMA/LIBRA, an active background rejection system using a liquid scintillator, and improved photomultiplier tubes with lower background and a higher quantum efficiency.

The most unique aspect of the experiment will to operate a pair of such detectors, located at LNGS (Laboratori Nazionali del Gran Sasso, Italy) and the new deep underground laboratory in Stawell, Australia (SUPL, Stawell Underground Physics Laboratory). The combined analysis of data sets from the two hemispheres will provide critical information on any terrestrial contribution to the modulation signal.

In this presentation we will present the progress on crystal development, the status of a proof of principle detector currently being installed at LNGS, and the design and physics potential of the ultimate detector configuration.

CMB/LARGE SCALE STRUCTURE.

2-3:30 pm **Martina Gerbino**, *OKC and Nordita, Stockholm University*.

The hunt for neutrino hierarchy

Neutrino physics is one of the most exciting arena for a combined research in cosmology and particle physics. Even though we know from oscillation experiments that neutrinos do have masses, we still fail in assessing the neutrino mass scale. Cosmological probes such as the cosmic microwave background radiation and large scale structures currently provide the tightest constraints on the sum of neutrino masses, though in the form of upper bounds. In this talk, I will discuss the sensitivity of current cosmological probes to the neutrino mass splitting, in light of the results from neutrino oscillation measurements. Even if the differences in the bounds for possible neutrino mass schemes are tiny, there is indeed a difference, implying that present cosmological measurements are mildly sensitive to the distribution of hot dark matter and radiation at late times. This should be regarded as an example of how close we are to the limit at which analyses involving an accurate inclusion of information from oscillation measurements, along with a statistical model comparison able to assess the preference for a hierarchy, become pressing.

Thomas Tram, *Institute of Cosmology and Gravitation (ICG), University of Portsmouth*.

The Intrinsic Matter Bispectrum

Upcoming large scale structure surveys will map the structure of the Universe on very large scales where General Relativistic (GR) effects become important. In order to extract information from these surveys, we must have a fast and accurate analytic model. This is well known on small scales where the precision of Newtonian N-body codes is constantly being pushed but it is equally true at large scales. In this talk I will present numerical and analytic computations of the matter bispectrum generated from Gaussian initial conditions, i.e. the intrinsic matter bispectrum. From the point of view of inflationary non-Gaussianity, this intrinsic matter bispectrum acts as a foreground which must be subtracted in order to extract the primordial signal.

Jerome Gleyzes, *Jet Propulsion Laboratory*.

Non Gaussianity in two-field inflation

Thanks to the fantastic results of the Planck mission, we now have a better understanding of the very early Universe. The evidence points towards a phase of inflation, where the Universe underwent exponential expansion, leaving it very smooth. Moreover, inflation predicts the distribution of initial fluctuations that lead to the galaxies we observe today. In the simplest model, those fluctuations are Gaussian. However, in some models where multiple fields cause inflation, non Gaussianity can arise. Therefore, measuring the non-Gaussianity can allow to distinguish between models. I will show that contrarily to what is sometimes claimed, non-Gaussianity is not a generic feature in multi-field inflation. Through example, I will identify when large non-Gaussianity arise. The bottom line is that, if measuring large non-Gaussianity would clearly means that our simplest picture of inflation is wrong, a non detection would not rule out more complicated scenarios

Christian Fidler, *CP3 - UCL*.

A Relativistic Interpretation of Newtonian Large Scale Structure Simulations

General relativistic effects in structure formation have to be taken into account for the next generation of large-scale structure surveys such as the SKA and the EUCLID mission. In contrast, simplified Newtonian N-body simulations are often employed to solve the gravitational clustering of matter. While this is accurate on the small scales, important corrections are expected on the large scales. We present how unmodified Newtonian simulations can be interpreted in agreement with general relativity, obtaining a consistent relativistic large scale result. The idea is to define a specific gauge in which the dark matter particles move on Newtonian trajectories and employ CLASS to compute the metric potentials in this particular gauge. A relativistic interpretation of the Newtonian simulation is then obtained by interpreting the particle positions on this space-time instead of the Newtonian flat space. We present an analysis in a Universe filled with dark energy, dark matter, baryons and radiation, which a special focus on radiation which is typically neglected in ordinary Newtonian simulations. The advantage of our method is creating a split between the non-linear Newtonian gravitational collapse, solved in a N-body simulation, and the computation of the typically linear metric potentials in an Einstein-Boltzmann code. In addition, the method provides a framework for the inclusion of new physics into relativistic simulations, such as for example theories of modified gravity.

Grant Mathews, *University of Notre Dame*.

Possible Evidence for Resonant Superstring Excitations during Inflation

We show that both the suppression of the l=2 moment of the power spectrum cosmic microwave background temperature fluctuations and the possible dip in the power spectrum for l= 10-30 can be explained as the result of the resonant creation of successive excitations of a single fermionic (or bosonic) open superstring that couples to the inflaton field. For our best-fit models, we can deduce the number of oscillations on the string during inflation. From the deduced degeneracy of the string we can infer the coupling constant between the string and the inflaton field along with the masses of these states. Although the evidence of the dip at l=10-30 is of marginal statistical significance, and there are other possible interpretations of these features, this could constitute the first observational evidence of the existence of a superstring in Nature.

Neil Barrie, *University of Sydney*.

Gravitational Wave Instabilities in the Cosmic Neutrino Background

We investigate the propagation of gravitational waves through the cosmic neutrino background, assuming it carries a non-zero lepton asymmetry. In this background, the graviton dispersion relation is found to exhibit birefringent behaviour leading to an enhancement/suppression of the gravitational wave amplitudes depending on the polarisation, where the magnitude of this effect is related to the size of the lepton asymmetry. The heralding of the new era of gravitational wave astronomy may allow the investigation of this behaviour and provide an indirect way to learn about the properties of the cosmic neutrino background and the neutrino sector.

4-5:30 pm **Craig Copi**, *Case Western Reserve University*.

CMB Anomalies: Status and Future Directions

A number of anomalies in the observed CMB temperature anisotropies were first identified in the WMAP data and subsequently confirmed by Planck, greatly reducing the likelihood that they were just systematic effects. These anomalies typically are rare – at the 2 to 3 sigma level. Though many have been discovered, it is unclear how to combine them, that is, which of the anomalies are independent of the others. Further, all have been discovered a posteriori by looking at the data and seeing something strange. The simplest explanation for them is that our Universe is just a rare realization (the fluke hypothesis). Since we only have one Universe, new observations of the temperature anisotropies will not provide new tests of these anomalies. Even so, future measurements of other correlated observables, such as polarization, can provide new insights and help identify whether our Universe is a rare fluke or if new physics is required. In this talk we will briefly review the status of the anomalies, categorize them, and discuss on-going work to make a priori predictions for future observations.

Graeme Addison, *Johns Hopkins University*.

Quantifying discordance in the 2015 Planck CMB spectrum

I will discuss the internal consistency of the Planck 2015 CMB temperature anisotropy power spectrum and show that tension exists between the determination of some cosmological parameters from multipoles $l < 1000$ (roughly the scales accessible to wmap) and $l \geq 1000$. I will show that the $l \geq 1000$ constraints are also in tension with low-redshift data sets, including Plancks own measurement of the CMB lensing power spectrum (2.4 sigma), the most precise determination of the baryon acoustic oscillation scale (2.5 sigma), and the local Hubble constant (3.8 sigma). Disagreement between parameters inferred from the Planck and South Pole Telescope measurements of the CMB damping tail disfavors a cosmological explanation and suggests the Planck values result from an unusual statistical fluctuation or remaining systematic errors in the Planck data.

Marius Millea, *Intitut Lagrange de Paris*.

Features in the Planck power spectrum and shifts in cosmological parameters

One of the legacies of the results from the Planck satellite is the continued success of the standard six-parameter ΛCDM model. Along with this are a tightening of constraints and a set of shifts in the best-fit values of these six parameters as compared to previous estimates from CMB data. For example, the Planck data prefer a LCDM model with a lower Hubble constant than previously thought, and a higher amplitude of matter fluctuations, σ_8. These shifts have attracted much attention, particularly since some of them serve to drive tensions with other cosmological probes. These tensions are at the forefront of our search for evidence of new physics or of systematic errors in one or more of these probes. In this talk we will take a critical look at these parameter shifts. Are they at the level one should have expected given the increase in precision of the Planck data over its predecessors? What features in the data are driving them, and are these features robust? And what is the physical explanation for why these features impacted the parameters in the way that they have? While some of these questions have been partially addressed, others have never been at all, and we will do so in this talk.

Melanie Simet, *Carnegie Mellon University*.

Weak Lensing Measurement of the Mass-Richness Relation of SDSS redMaPPer Clusters

I will describe a measurement of the mass–richness relation of the redMaPPer galaxy cluster catalogue using weak lensing data from the Sloan Digital Sky Survey. My collaborators and I used an updated forward-modeling approach to better match the expected signal, allowing us to measure rather than assume some features of the model. We also carefully characterized a broad range of systematic uncertainties in our measurement and our signal modeling. Finally, we compared measurements of the lensing signal from two independently-produced shear and photometric redshift catalogues to demonstrate the reliability of both the measurement and the associated systematic and statistical errors.

Jonathan Blazek, *CCAPP - Ohio State University*.

Streaming velocities and baryon-acoustic oscillations

At the epoch of decoupling, cosmic baryons had supersonic velocities relative to the dark matter that were coherent on large scales. These velocities subsequently slow the growth of small-scale structure and, via feedback processes, can influence the formation of larger galaxies. I will discuss the potential impact of these streaming velocities on the baryon acoustic oscillation (BAO) feature. In particular, the combination of galaxy advection and gradients in these streaming velocities yields a significant contribution which must be considered in the analysis of upcoming BAO measurements. This effect also opens a new window to the astrophysics of galaxy formation.

Sukhdeep Singh, *Carnegie Mellon University*.

Galaxy-galaxy and galaxy-CMB Lensing with SDSS-III BOSS galaxies

Weak lensing has emerged as an important cosmological probe for our understanding of dark matter and dark energy. The low redshift spectroscopic sample of SDSS-III BOSS survey, with a well-understood galaxy population is ideal to probe cosmology using galaxy-galaxy lensing and galaxy-CMB lensing. I will present results from two methods that combine information from lensing and galaxy clustering.

The first involves combining lensing and galaxy clustering to directly measure galaxy bias and thus recover the matter correlation function, which is directly predicted from theory. Using scales where linear perturbation theory is valid, we carry out a joint analysis of galaxy-galaxy clustering, galaxy-galaxy lensing, and CMB-galaxy lensing, and constrain linear galaxy bias $b = 1.80 \pm 0.06$, $\Omega_m = 0.284 \pm 0.024$, and relative calibration bias between CMB and galaxy lensing, $b_l = 0.82 \pm 0.15$.

The second method involves including information about redshift-space distortions to measure the E_G statistic and test gravitational physics at cosmological scales. This statistic is independent of galaxy bias and the amplitude of the matter power spectrum. Different theories of gravity predict a different E_G value, making it a clean and stringent test of GR at cosmological scales. Using the BOSS low redshift sample, we have measured E_G at $z = 0.27$ with 10% (22%) accuracy using galaxy (CMB) lensing, with results consistent with LCDM predictions.

DARK MATTER.

2-3:30 pm **Francesc Ferrer**, *Washington University in St Louis*.

A robust halo-independent upper limit on the dark matter cross section

I will describe a method that allows to place an upper limit on the dark matter elastic scattering cross section with nucleons which is independent of the velocity distribution. This approach combines null results from direct detection experiments with indirect searches at neutrino telescopes, and goes beyond previous attempts to remove astrophysical uncertainties in that it directly constrains the particle physics properties of the dark matter. The resulting halo-independent upper limits on the scattering cross section of dark matter are remarkably strong, within a factor of a few of limits that assume a Standard Halo Model.

References: F. Ferrer. A. Ibarra and S. Wild, JCAP 1509 (2015) no.09, 052 [arXiv: 1506.03386]

Francis-Yan Cyr-Racine, *Harvard University*.

From dark particle physics to the matter distribution of the Universe

The effective theory of structure formation (ETHOS) allows the classification of dark matter theories according to their structure formation properties rather than their intrinsic particle properties. This makes ETHOS a particularly useful framework for comparing theoretical predictions of extended dark matter scenarios to actual cosmological and astrophysical observations. Using this effective theory, we describe how the details of the dark matter physics actually affect the shape of the linear matter power spectrum, hence clarifying the link between dark matter microphysics and structure formation. We then use the ETHOS framework to put cosmological and astrophysical constraints on broad classes of dark matter microphysics. We finally discuss how nonminimal dark matter theories can be used to remove apparent tension between various cosmological probes.

Tim Linden, *The Ohio State University*.

Dark Matter, Pulsar, and Diffuse Emission Models for the Galactic Center GeV Excess

Fermi-LAT observations have discovered a gamma-ray excess emanating from the Galactic center of the Milky Way. While the existence of this excess is now certain, its origin is not. Three distinct classes of models have been posited to explain its key features: dark matter annihilation, a population of sub-threshold gamma-ray pulsars, and diffuse emission from the intense Galactic center environment. In this talk, I will describe the successes and failures of each model as an explanation for the Galactic center excess outlining several significant advances in modeling pulsars and diffuse emission properties near the Galactic center. Finally, I will describe smoking gun tests of each scenario which may rule out, or lend credence to each model within the next five years.

Annika Peter, *The Ohio State University*.

How self-interacting dark matter shapes the Milky Way satellite population

Using a suite of high-resolution dark-matter-only simulations tagged with star, we investigate the effects of self-interacting dark matter (SIDM) on the tidal stripping and evaporation of satellite galaxies in a Milky Way-like host. We find that stars are stripped at a higher rate in SIDM than in cold dark matter cosmologies. We show that this enhanced stripping is almost entirely due to the enhanced tidal stripping resulting from the SIDM-induced shallow gravitational potentials of the satellites. This leads to a suppression in the abundance of ultra-faint dwarf galaxies and growth in the satellite's half-light radius after infall. Ultra-faint dwarfs are thus prime targets for constraining SIDM models.

Savvas Koushiappas, *Brown University*.
Gamma-ray emission and the dark matter content of the dwarf galaxy Reticulum II
I will present results on the analysis of gamma-ray emission from the recently discovered dwarf galaxy Reticulum II. Using Fermi-LAT data and a suite of background models we quantify the probability that the observed gamma-ray emission is due to background. Reticulum II is found to have the most significant gamma-ray emission from any other known dwarf galaxy. I will also discuss the dark matter content of Reticulum II as derived from kinematic studies of its member stellar population and show that Reticulum II has a dark matter halo similar to other nearby dwarf galaxies. If the gamma ray emission is due to dark matter annihilation, the annihilation cross section is consistent with the s-wave relic abundance cross section. I will conclude by discussing further tests that are needed in order to ascertain the likelihood of this emission to be due to a conventional astrophysical interpretation.

Mei-Yu Wang, *Texas A&M University*.
Revealing the nature of dark matter with Milky Way dwarf satellite galaxies
The dwarf galaxies surrounding the Milky Way provide a unique and powerful way to explore the nature of dark matter. They are the most extreme dark matter dominated objects known to us with central mass to light ratios typically of the order of tens to hundreds. Through measurements of their stellar kinematics, we can study their dark matter content in exquisite precision. This allows us to probes their halo structure that is sensitive to different dark matter physics such as warm dark matter, self-interaction, and decay instabilities. In this talk, I present frameworks that address these questions by combining high-precision stellar kinematic measurements with state-of-art cosmological N-body simulations and detailed kinematic modeling. I will demonstrate that the properties of the dark matter are linked to the mechanisms that drive satellite galaxy and halo evolution such as infall time and the effects of tides. In the CDM scenario some dwarf galaxies explicitly require to be shaped under significant gravitational tidal forces, which will leave imprints on their stellar distribution and kinematics. I also show how to determine the optimized kinematic observational strategies for achieving precision measurement of dark matter contents in newly discovered faint dwarf galaxies with current and future spectroscopic follow-up facilities, and forecast their constraining power on WIMP dark matter models. I will discuss how these results are driving advances in both astronomy and particle physics, and having the potential to shed lights on the nature of dark matter.

4-5:30 pm **Haipeng An**, *Caltech*.
Dark matter annihilation via dark bound state formation
We study the impact of bound state formation on dark matter annihilation rates in models where dark matter interacts via a light mediator. For indirect detection, our result shows that dark matter annihilation inside bound states can play an important role in enhancing signal rates over the rate for direct dark matter annihilation with Sommerfeld enhancement.

Hongwan Liu, *Massachusetts Institute of Technology*.

The Darkest Hour Before Dawn: Contributions to Cosmic Reionization from Dark Matter Annihilation and Decay

Dark matter annihilation or decay could have a significant impact on the ionization and thermal history of the universe. We have studied the potential contribution of dark matter annihilation (s-wave- or p-wave-dominated) or decay to cosmic reionization, via the production of electrons, positrons and photons. We map out the possible perturbations to the ionization and thermal histories of the universe due to dark matter processes, over a broad range of velocity-averaged annihilation cross-sections/decay lifetimes and dark matter masses. We have employed recent numerical studies of the efficiency with which annihilation/decay products induce heating and ionization in the intergalactic medium, and in this work extended them down to a redshift of $1 + z = 4$ for two different reionization scenarios. We also improve on earlier studies by using the results of detailed structure formation models of dark matter haloes and subhaloes that are consistent with up-to-date N-body simulations, with estimates on the uncertainties that originate from the smallest scales. We find that for dark matter models that are consistent with experimental constraints, a contribution of more than 10% to the ionization fraction at reionization is disallowed for all annihilation scenarios. Such a contribution is possible only for decays into electron/positron pairs, for light dark matter with a mass of about 100 MeV within a limited range of decay lifetimes.

Sebastian Trojanowski, *National Center for Nuclear Research, Poland / UC Irvine*.

Reconstructing WIMP properties through an interplay of signal measurements in direct detection, Fermi-LAT, and CTA searches for dark matter

In the presentation I will examine the projected ability to reconstruct the mass, scattering, and annihilation cross section of dark matter in the new generation of large underground detectors, e.g., XENON-1T, in combination with diffuse gamma radiation from expected 15 years of data from Fermi-LAT observation of 46 local spiral dwarf galaxies and projected CTA sensitivity to a signal from the Galactic Center. To this end I will consider several benchmark points spanning a wide range of WIMP mass, different annihilation final states, and large enough event rates to warrant detection in one or more experiments. As previously shown, below some 100 GeV only direct detection experiments will in principle be able to reconstruct the WIMP mass well. This may, in case a signal at Fermi-LAT is also detected, additionally help restricting σ v and the allowed decay branching rates. On the other hand at large WIMP mass, 1 TeV, CTA will have the ability to reconstruct mass, annihilation cross section, and the allowed decay branching rates to very good precision for the or purely leptonic final state, good for the WW case, and rather poor for bb. A substantial improvement can potentially be achieved by reducing the systematic uncertainties, increasing exposure, or by an additional measurement at Fermi-LAT that would help reconstruct the annihilation cross section and the allowed branching fractions to different final states. The presentation will be based on astro-ph.CO/1603.06519

Isabel M. Oldengott, *Bielefeld University*.

Reionization and dark matter decay

Cosmic reionization and dark matter decay can impact observations of the cosmic microwave sky in a similar way. A simultaneous study of both effects is required to constrain unstable dark matter from cosmic microwave background observations. We compare two reionization models with and without dark matter decay. We find that a reionization model that fits also data from quasars and star forming galaxies results in tighter constraints on the reionization optical depth τ_{reio}, but weaker constraints on the spectral index n_s than the conventional parametrization. We use the Planck 2015 data to constrain the effective decay rate of dark matter to $\Gamma_{eff} < 2.9 \times 10^{-25}$/s at 95% c.l. this limit is robust and model independent. it holds for any type of decaying dark matter and it depends only weakly on the chosen parametrization of astrophysical reionization. for light dark matter particles that decay exclusively into electromagnetic components this implies a limit of $\gamma < 5.3 \times 10^{-26}$/s at 95% c.l. specifying the decay channels, we apply our result to the case of kev-mass sterile neutrinos as dark matter candidates and obtain constraints on their mixing angle and mass, which are comparable to the ones from the diffuse x-ray background.

Keisuke Harigaya, *UC Berkeley/LBNL*.

Light Chiral Dark Sector

An interesting possibility for dark matter is a scalar particle of mass of order 10 MeV - 1 GeV, interacting with a U(1) gauge boson (dark photon) which mixes with the photon. We present a simple and natural model realizing this possibility. The dark matter arises as a composite pseudo Nambu-Goldstone boson (dark pion) in a non-Abelian gauge sector, which also gives a mass to the dark photon. The gauge symmetry of the model does not allow any mass term for the dark quarks, and stability of the dark pion is understood as a result of an accidental global symmetry. The model has a significant parameter space in which thermal relic dark pions comprise all of the dark matter, consistently with all experimental and cosmological constraints. In a corner of the parameter space, the discrepancy of the muon g-2 between experiments and the standard model prediction can also be ameliorated due to a loop contribution of the dark photon. Smoking-gun signatures of the model include a monophoton signal from the e+ e- collision into a photon and a "dark rho meson." Observation of two processes in e+ e- collision, the mode into the dark photon and that into the dark rho meson, would provide strong evidence for the model.

Sam Cormack, *Dartmouth College*.

Superfluid fermion dark matter

There has recently been significant interest in the idea that dark matter could form a many body quantum state. Previous work has focused on Bose-Einstein condensates and degenerate Fermi matter. We investigate the possibility that fermionic dark matter becomes a superfluid via a BCS transition. This requires an attractive interaction which alters the density profile of the halo and we consider whether this interaction could be torsion-induced. If the halo is indeed a superfluid it may contain interesting features such as vortices.

DARK ENERGY.

2-3:30 pm **David Cinabro**, *Wayne State University*.

No Evidence for Type Ia Supernova NUV-Optical Subclasses

In response to a recent reported observation by Milne and collaborators, we search for evidence of two classes of Type Ia supernovas (SNIa) distinguished by their brightness in the rest-frame near ultra-violet. Using the SNANA supernova analysis package, we develop a model of two classes of SNIa that reproduce the features described by Milne et al. We simulate the appearance of the light curves of these objects in the Sloan Digital Sky Survey Supernova Search (SDSS) and the Supernova Legacy Survey (SNLS) showing that we could easily observe the two classes as compared to the more conventional explanation for the diversity of SNIa ultraviolet brightnesses with the SALT-II SNIa model. We compare the simulation of the two models to 158 observed SNIa light curves in the SDSS and SNLS data sets. We see no evidence of two classes of SNIa and find good agreement between the observed data and the predictions of the SALT-II model of SNIa light curves.

Dan Scolnic, *KICP at University of Chicago*.

New Cosmology Results with Type Ia Supernovae

I will describe recent progress to measure the equation-of-state of dark energy and the Hubble constant using Type Ia Supernovae. I will primarily focus on new measurements of w with the Pan-STARRs spectroscopic SN sample and discuss new techniques to remove biases in the supernova distances and recalibrate the full compilation of SN lightcurves. I also will show how these improvements impact the latest measurement of the Hubble constant.

Tom Giblin, *Kenyon College/CWRU*.

Toward Full General Relativity in Cosmology

The principles of homogeneity and isotropy have been the cornerstones of cosmology since the birth of our field. Nonetheless, these approximations are just that and must be tested, especially in light of cosmological scenarios where a density contrast may lead to meaningful departures from homogeneity – for example, the creation of compact objects or the generation of structure in the Universe. I will discuss exciting new advances in infrastructure that allow full, non-linear General Relativity to be applied to cosmological models that will pave the way for precision tests of cosmology.

James Mertens, *Case Western Reserve University*.

Deviations from Homogeneity in an Inhomogeneous Universe

It has long been wondered to what extent the observable properties of an inhomogeneous universe will be measurably different from a corresponding FLRW model. Here, we use tools from numerical relativity to study the properties of photons traversing an inhomogeneous universe. We evolve the full, unconstrained Einstein field equations for a spacetime containing dust and vacuum energy in proportions similar to our Universe, with a spectrum of long-wavelength density perturbations similar to the observed one. We then integrate the optical scalar equations along paths through this numerical spacetime, with all paths terminating at an observer situated similarly to ourselves, and construct the resulting Hubble diagrams.

Tony Padilla, *University of Nottingham*.

The "sequestering" approach to the cosmological constant problem.

I will discuss recent developments in the sequestering approach to the cosmological constant problem. Sequestering is a mechanism for eliminating the contributions to vacuum energy from matter loops. It represents an extremely conservative modification of gravity, only deviating from GR at the global level, while exploiting the fact that vacuum energy is the unique source of energy-momentum that is locally constant and spacetime filling. I will show how the mechanism can be rendered manifestly local, how it can be adapted to include graviton loops, and other new developments.

Christoph Schmid, *ETH Zurich*.

Einstein's equations from Einstein's inertial motion and Newton's laws

With Einstein's concept of inertial motion as freefalling-nonrotating, Newton's law for relative acceleration of freefalling neighbouring test-particles, spherically averaged, gives the exact $R^{\hat{0}\hat{0}}$ equation of general relativity for non-relativistic matter and for arbitrarily strong gravitational fields. This equation of Newton for relative acceleration and Einstein's $R^{\hat{0}\hat{0}}$ field-equation for space-time curvature are explicitely identical, if one uses our adapted space-time slicing (by the observer's radial 4-geodesics), our adapted Local Ortho-Normal Bases, LONBs (radially parallel with the observer's LONBs), and Riemann normal 3-coordinates. Hats on indices denote LONB components.— With Einstein's principle of equivalence between fictitious forces and gravitational forces, the gravitational field equation of 19th-century Newtonian physics and Einstein's field equation for $R^{\hat{0}\hat{0}}$ are both linear for inertial observers, but both bilinear for non-inertial observers. — Full general relativity follows by using Lorentz covariance and the Bianchi identity. $R^{\hat{0}\hat{0}} = -\text{div}\vec{E}_g$ and $R^{\hat{i}\hat{0}} = -(\text{curl}\vec{B}_g/2)^{\hat{i}}$ hold exactly in general relativity for inertial observers. The gravitoelectric $\vec{E}_g$ and the gravitomagnetic $\vec{B}_g$ fields are defined and measured exactly with nonrelativistic test-particles via $(d/dt)(p_{\hat{i}})$ and $(d/dt)(S_{\hat{i}})$ in direct correspondence with the electromagnetic $(\vec{E}, \vec{B})$ fields. — The $(\vec{E}_g, \vec{B}_g)$ fields are identical with the Ricci connection for LONBs for displacements along the observer's worldline, $(\omega_{\hat{a}\hat{b}})_{\hat{0}}$. $R^{\hat{0}\hat{0}}$ and $R^{\hat{0}\hat{i}}$ can be measured exactly with non-relativistic test particles. For inertial observers, $(R^{\hat{0}\hat{0}}, R^{\hat{i}\hat{0}})$ are linear in the gravitational fields. For non-inertial observers, and with the equivalence of fictitious and gravitational forces, the gravitational field equations of 19th-century Newtonian physics and Einstein's field equations for $R^{\hat{0}\hat{0}}$ and $R^{\hat{0}\hat{i}}$ are all bilinear in the gravitational fields, i.e. in $\vec{E}_g$ and $\vec{B}_g$. Einstein's $R^{\hat{0}\hat{0}}$ equation for non-relativistic matter and for inertial observers gives the Gauss law, $\text{div}\vec{E}_g = -4\pi G_N \rho_{mass}$, and Einstein's $R^{\hat{0}\hat{i}}$ equation gives the gravito-magnetic Ampère law, $\text{curl}\vec{B}_g = -16\pi G_N \vec{J}_{mass}$. — For relativistic matter and inertial observers, Einstein's $R^{\hat{0}\hat{0}}$ equation gives $\text{div}\,\vec{E}_g = -4\pi G_N(\rho_\varepsilon + 3\tilde{p})$, where ρ_ε is the energy density, and $(3\tilde{p})$ is the trace of the momentum-flow 3-tensor, and Einstein's $R^{\hat{0}\hat{i}}$ equation gives the relativistic gravitomagnetic Ampère law, $\text{curl}\vec{B}_g = -16\pi G_N J^{\hat{i}}_{\varepsilon}$. The remaining six Ricci components, $R^{\hat{i}\hat{j}}$, involve the curvature of space-space plaquettes, which are unmeasurable with non-relativistic particles in quasi-local experiments.

PRIMORDIAL/INFLATION.

4-5:30 pm **Sonia Paban**, *University of Texas at Austin*.
On primordial equation of state transitions
We revisit the physics of transitions from a general equation of state pa- rameter to the final stage of slow-roll inflation. We show that it is unlikely for the modes comprising the cosmic microwave background to contain imprints from a pre- inflationary equation of state transition and still be consistent with observations. We accomplish this by considering observational consistency bounds on the amplitude of excitations resulting from such a transition. As a result, the physics which initially led to inflation likely cannot be probed with observations of the cosmic microwave background. Furthermore, we show that it is unlikely that equation of state transitions may explain the observed low multipole power suppression anomaly.

Robert Caldwell, *Dartmouth College*.
Gravitational Wave – Gauge Field Oscillations
Gravitational waves propagating through a stationary gauge field transform into gauge field waves and back again. When multiple families of flavor-space locked gauge fields are present, the gravitational and gauge field waves exhibit novel dynamics. At high frequencies, the system behaves like coupled oscillators in which the gravitational wave is the central pacemaker. Due to energy conservation and exchange among the oscillators, the wave amplitudes lie on a multi-dimensional sphere, reminiscent of neutrino flavor oscillations. This phenomenon has implications for cosmological scenarios based on flavor-space locked gauge fields.

Martin Winkler, *University of Bonn*.
Modulated Natural Inflation
I discuss natural inflation and its embedding into supergravity / string theory. As a consequence of stringy duality symmetries the pure cosine potentials of natural inflation are replaced by modular functions. This leads to "wiggles" on top of the leading potential which induce deviations of the scalar power spectrum from the standard power law form. The consistency of natural inflation with the latest CMB data is improved. I will also show that the wiggles reconcile trans-Planckian excursions of the axion with the weak gravity conjecture.

Raghavan Rangarajan, *Physical Research Laboratory, Ahmedabad, India*.
Constraints on just enough inflation preceded by a thermal era
If the inflaton was in thermal equilibrium at some time in a radiation dominated era prior to inflation then the CMB data places an upper bound on the comoving temperature of the (decoupled) inflaton quanta.
If one considers models of “just enough" inflation (where the number of e-foldings of inflation is just enough to solve the horizon and flatness problems) then in the above thermal scenario we get a lower bound on the Hubble parameter during inflation, H_inf, which is in severe conflict with the upper bound from tensor perturbations. Alternatively, imposing the tensor upper bound on H_inf implies an extremely large number of relativistic degrees of freedom in the thermal bath in the pre-inflationary Universe (greater than 10^9 or 10^11), which is not feasible in known cosmological scenarios. So a thermal initial state for the inflaton is incompatible with just enough inflation. [Phys. Rev. D93 (2016) 023516]

Nadia Bolis, *UC Davis*.

Observational Consequences of Scalar-Tensor Entanglement during Inflation

We consider the effects of entanglement in the initial quantum state of scalar and tensor fluctuations during inflation. We allow the gauge-invariant scalar and tensor fluctuations to be entangled in the initial state and compute modifications to the various cosmological power spectra. We compute the angular power spectra (C_l's) for some specific cases of our entangled state and discuss what signals one might expect to find in CMB data. This entanglement also can break rotational invariance, allowing for the possibility that some of the large scale anomalies in the CMB power spectrum might be explained by this mechanism.

Krzysztof Turzynski, *University of Warsaw*.

Geometrical destabilization of heavy scalar fields during inflation

We show the existence of a general mechanism by which heavy scalar fields can be destabilized during inflation, relying on the fact that the curvature of the field space manifold can dominate the stabilizing force from the potential and destabilize inflationary trajectories. We describe a simple and rather universal setup in which apparently benign higher-order operators trigger this instability. This phenomenon can prematurely end inflation, thereby leading to important observational consequences and sometimes excluding models that would otherwise perfectly fit the data. More generally, it modifies the interpretation of cosmological constraints in terms of fundamental physics.

CMB/LARGE SCALE STRUCTURE.

9-10:30 am **Pieter Daniel Meerburg**, *CITA*.

The Holiest Grail

I will discuss to what degree the cosmic microwave background (CMB) can be used to constrain primordial non-Gaussianity involving one tensor and two scalar fluctuations, focusing on the correlation of one B-mode polarization fluctuation correlated with two E or T modes, i.e. BTT, BTE and BEE. In the simplest models of inflation, the tensor-scalar-scalar primordial bispectrum is non-vanishing and is of the same order in slow-roll parameters as the scalar-scalar-scalar bispectrum. I will show that constraints from an experiment like CMB-Stage IV using this observable are more than an order of magnitude better than those on the same primordial coupling obtained from temperature measurements alone. I will argue that B-mode non-Gaussianity opens up an as-yet-unexplored window into the early Universe, demonstrating that significant information on primordial physics remains to be harvested from CMB anisotropies. BTT, BTE and BEE present measures of both primordial tensors and primordial non-Gaussianity, two of the most sought after signatures of the inflationary paradigm. A detection would provide profound insight into the workings of the early Universe.

Laura Mocanu, *The University of Chicago*.

Measuring the CMB gravitational lensing potential with SPTpol

Weak gravitational lensing by large-scale structure in the universe causes deflections in the paths of cosmic microwave background (CMB) photons. This effect introduces non-Gaussian correlations in the observed CMB temperature and polarization fields. The signature of lensing can be used to reconstruct the projected gravitational lensing potential with a quadratic estimator technique; this provides a measure of the integrated mass distribution out to the surface of last scattering, sourced primarily from redshifts between 0.1 and 5. The power spectrum of the lensing potential encodes information about the geometry of the universe and the growth of structure and can be used to place constraints on the sum of neutrino masses and dark energy. High signal-to-noise mass maps from CMB lensing are also powerful for cross-correlating with other tracers of large-scale structure and for delensing the CMB in search for primordial gravitational waves. In this talk, I will describe recent progress on measuring the CMB gravitational lensing potential and its power spectrum using data from 500 square degrees of sky observed with the polarization-sensitive receiver installed on the South Pole Telescope, SPTpol.

Alexander van Engelen, *Canadian Institute for Theoretical Astrophysics*.

CMB Lensing with ACTPol and successors

Lensing of the CMB is quickly becoming a precision cosmological tool. I will discuss the ACTPol survey, the recently-begun Advanced ACTPol survey, and successors, focussing on the status of the gravitational lensing measurements and on other, related probes of the growth of structure out to high redshift.

Kyle Story, *Stanford University - KIPAC*.

Delensing CMB B modes with the South Pole Telescope polarimeter

Cosmic inflation in the early universe is expected to have produced a background of primordial gravitational waves (PGW), which induce a curl or "B-mode" component in the polarization of the Cosmic Microwave Background (CMB). In many inflation models, this B-mode signal is predicted to be at a level detectable in the near future. Observed B modes also contain a "lensing B-mode" component that is produced by gravitationally lensing primordial E modes; current searches for PGW are already limited by contamination from these lensing B modes. In order to potentially detect the PGW signal from B-mode measurements, lensing B modes must be characterized and removed in a process referred to as "delensing." This process has been studied extensively theoretically and with simulations, but has not been performed on data. In this talk, we present an analysis to delens the CMB B-mode spectrum using polarization data from the South Pole Telescope polarimeter, SPTpol.

Kimmy Wu, *UC Berkeley*.

BICEP3 performance overview and the BICEP/Keck program

BICEP3 is a 520mm aperture, compact two-lens refractor telescope observing the Cosmic Microwave Background (CMB) at 95 GHz, designed in pursuit of a potential B-mode signal from inflationary gravitational waves. It is the latest addition to the BICEP/Keck Array series inflationary probes located at the South Pole, which has provided the most stringent constraints on the tensor-to-scalar ratio r to date. For the 2016 observing season, the BICEP3 receiver was upgraded to its full focal plane configuration with 2560 TES detectors. In this talk, we will give an overview of the BICEP/Keck program and summarize BICEP3s design and performance.

Alexandra Rahlin, *Princeton University*.

Status report on the first flight of the SPIDER balloon-borne polarimeter

SPIDER is a balloon-borne polarimeter designed to characterize degree-scale microwave emission on the sky. The goals of the SPIDER program are to (1) characterize the anisotropy spectrum of the microwave sky with high fidelity over many angular modes, with a focus on the polarized B-mode signal at degree angular scales, (2) separate the angular and frequency spectrum of intervening galactic foregrounds from that of the primordial microwave background, and (3) verify the statistical isotropy of the primordial signal across the sky. The first instance of the SPIDER payload flew successfully in January 2015, observing for 16 days over 12% of the sky (6% when weighted by integration time), with an instantaneous sensitivity of 6-7 uK-rts at frequencies of 94 and 150 GHz. In parallel with analysis of the flight data, an upgraded payload is under development in preparation for a December 2017 flight, with the addition of a 285 GHz band to improve the characterization of Galactic dust in the SPIDER field. This talk will present an update on the ongoing data analysis, along with build progress and forecasts for the second mission.

DARK MATTER.

9-10:30 am **Julian Munoz**, *Johns Hopkins University*.

Probing compact dark matter with fast radio bursts

The possibility that part of the dark matter is made of massive compact halo objects (MACHOs) remains poorly constrained over a wide range of masses, and especially in the window between 20 and 100 solar masses. It has been recently argued that primordial black holes in this mass window could make up the dark matter, and that they might produce gravitational wave events, such as the one detected by the LIGO collaboration. We show that strong gravitational lensing of extragalactic fast radio bursts (FRBs) by MACHOs (which includes PBHs) of masses larger than $20M_\odot$ would result in repeated FRBs with an observable time delay. Considering the expected FRB detection rate by upcoming experiments, such as CHIME, of tens of thousands of FRBs per year, we should observe from tens to hundreds of repeated bursts yearly, if MACHOs in this window make up all the dark matter. A null search for echoes with just 10^4 FRBs, would constrain the fraction of dark matter in MACHOs to be smaller than 10% for all masses larger than $20M_\odot$.

Adam Christopherson, *University of Florida*.

Astrophysical bounds on ultra light axion-like particles

Motivated by tension between the predictions of ordinary cold dark matter (CDM) and observations at galactic scales, ultra-light axion-like particles (ULALPs), with mass of the order 10^22eV have been proposed as an alternative CDM candidate. The ULALP fluid is ordinarily described by classical field equations. However, we show that, like QCD axions, the ULALPs thermalize by gravitational self-interactions and form a Bose-Einstein condensate, a quantum phenomenon. A lower limit of order 10^23eV on the ULALP mass is obtained from the requirement that the infall of ULALPs onto the galaxy does not excessively heat the galactic disk. A tighter limit of order 10^20eV on the ULALP mass is obtained from the requirement that the wave nature of ULALP dark matter does not excessively smooth the caustic rings of the galaxy.

James Dent, *University of Louisiana at Lafayette*.

Dark Matter, Light Mediators, and the Neutrino Floor

The next generation of direct detection of dark matter experiments will be sensitive to an irreducible background provided by coherent neutrino-nucleus scattering from solar neutrinos which can well mimic low mass dark matter scattering. Within a general effective field theory framework I will discuss which operators describing dark matter-nucleus elastic scattering will have their discovery potential as a function of detector exposure saturated, which is known as the neutrino floor. I will also show that this effect changes in character with the mass of the particle mediating the scattering interaction. The distinguishability of dark matter recoils from backgrounds is vital, and this work addresses this area of importance. This work is based on PRD 93 (2016) 075018, arXiv:1602.05300 and work currently in progress with collaborators Bhaskar Dutta, Jayden Newstead, and Louis Strigari.

Stacy Kim, *The Ohio State University*.

Constraining Self-Interacting Dark Matter through Equal Mass Galaxy Cluster Mergers

While the LCDM model has been wildly successful at explaining structure on large scales, it fails to do so on small scales. Dark matter halos of scales comparable to that of galaxy clusters and smaller are more cored and less numerous than LCDM predicts. One potential solution challenges the canonical assumption that dark matter is collisionless and instead assumes that it is self-interacting. The most stringent upper limits on the dark matter self-interaction cross section have come from observations of merging galaxy clusters. Self-interactions cause the merging dark matter halos to evolve differently from the galaxies, which are effectively collisionless, which leads to a spatial offset between the peaks in the dark matter and galaxy distributions. We show that in equal mass mergers, offsets matching those observed do not develop except under a narrow range of merger conditions that promote extreme dark mass loss during collision. Furthermore, offset formation cannot be described by a drag force nor by tail formation alone, as has previously been claimed. Self-interactions have a significant influence on other aspects of merger evolution, which can be exploited to derive stronger constraints on the self-interaction cross section. In particular, we expect a large fraction of BCGs in relaxed clusters to be miscentered by order 100s of kpc with cross sections greater than 1 cm^2/g; the lack of such large miscenterings implies a cross section no larger than 0.1 cm^2/g.

Patrick Stengel, *Stockholm University*.

Charged Mediators in Dark Matter Scattering

We consider a scenario, within the framework of the MSSM, in which dark matter is bino-like and dark matter-nucleon spin-independent scattering occurs via the exchange of light squarks which exhibit left-right mixing. We show that direct detection experiments such as LUX and SuperCDMS will be sensitive to a wide class of such models through spin-independent scattering. Moreover, these models exhibit properties, such as isospin violation, that are not typically observed for the MSSM LSP if scattering occurs primarily through Higgs exchange. The dominant nuclear physics uncertainty is the quark content of the nucleon, particularly the strangeness content. We also investigate parameter space with nearly degenerate neutralino and squark masses, thus enhancing dark matter annihilation and nucleon scattering event rates.

PRIMORDIAL/INFLATION.

9-10:30 am **Marco Drewes**, *TU Munich*.

Experimental tests of leptogenesis

The extension of the Standard Model by heavy right handed neutrinos can simultaneously explain the observed neutrino masses via the seesaw mechanism and the baryon asymmetry of the universe via leptogenesis. If the mass of the heavy neutrinos is at or below the TeV scale, they can be found in collider or fixed target experiments. We study the generation of the baryon asymmetry of the universe via low scale leptogenesis from first principles of nonequilibrium quantum field theory, including spectator processes and feedback effects. This allows to derive predictions for the properties of heavy neutrinos from the requirement to explain the observed baryon asymmetry of the universe. If any heavy neutral leptons are found in the future, our predictions can be used as a criterion to assess whether these new particles can be responsible for the origin of matter in the universe.

Zachary Kenton, *Queen Mary University of London*.
The Separate Universe Approach to Soft Limits
In this talk I'll calculate soft limits of n-point inflationary correlation functions using separate universe techniques. Our approach naturally allows for multiple fields and leads to an elegant diagrammatic approach. We apply this to the bispectrum and trispectrum, giving explicit formulae for all possible single- and double-soft limits. When compared to previous work on the bispectrum we find a 20% theoretical correction to observable parameters relevant for future cosmological experiments. We also investigate consistency relations and present an infinite tower of inequalities between soft correlation functions which generalise the Suyama-Yamaguchi inequality.

Austin Joyce, *University of Chicago*.
Three-dimensional inflation
There has been considerable recent interest in the soft limits of inflationary correlation functions, and restrictions placed upon them by symmetry considerations. Parallel to this, there has been a resurgence of interest in soft limits of flat-space scattering amplitudes, particularly with respect to asymptotic symmetries. I will describe a connection between these ideas in the context of inflation in three spacetime dimensions. In this case, the asymptotic symmetry transformations of three-dimensional de Sitter space are in one-to-one correspondence with the adiabatic modes familiar from cosmology. Further, these transformations lead to an infinite number of soft theorems for inflationary correlators.

Kohei Kamada, *Arizona State University*.
Large-scale magnetic fields and baryogenesis via chiral anomaly
It is known that time-dependent helical hypermagnetic fields can generate baryon (and lepton) asymmetry through chiral anomaly. In this talk, I will show that if the present magnetic fields indicated by the blazer observations is originated by a mechanism before the electroweak phase transition, it is enough to explain the present baryon asymmetry of the Universe. While this mechanism does not generate B-L asymmetry, the electroweak sphaleron cannot wash out the B and L asymmetry completely due to the source from the helical hypermagnetic fields.

Evangelos Sfakianakis, *University of Illinois at Urbana-Champaign*.
Magnetogenesis from axion inflation
The origin of magnetic fields in galaxies and intergalactic voids remains largely unknown. There have been several attempts to provide a primordial magnetic field seed through inflation. I will discuss magnetogenesis in models of axion inflation coupled to the hypercharge sector of the Standard Model through a Chern-Simons interaction term.
I will describe the use of lattice simulations to calculate the magnetic field strength, helicity and correlation length at the end of inflation. For a small value of the axion-gauge coupling strength the results agree with no-back-reaction calculations and estimates found in the literature. For larger couplings the helicity of the magnetic field differs from the no-back-reaction estimate and depends strongly on the comoving wavenumber.
I will present a mechanism through which the hypercharge gauge bosons that populate the preheated state thermalize and estimate the scattering rate of these particles into Standard Model particles. This scattering rate is efficient enough to allow the formation of a charged primordial plasma with a high temperature within a few e-folds from the end of inflation.
Estimating the evolution of the magnetic fields until the present day, I will show that they can be large enough to have phenomenological consequences (e.g. Blazar observations). This result is insensitive to the exact value of the coupling, as long as the coupling is large enough to allow for instantaneous preheating.

Naritaka Oshita, *University of Tokyo*.

A baby universe from a black hole

We investigate the effect of a black hole as a nucleation cite of a false vacuum bubble based on the Euclidean actions of relevant configurations. As a result we find a wormhole-like configuration may be spontaneously nucleated once the black hole mass falls below a critical value of order of the Hubble parameter corresponding to the false vacuum energy density. As the space beyond the wormhole throat can expand exponentially, this may be interpreted as creation of another inflationary universe in the final stage of the black hole evaporation.

- ⋆ **Graeme Addison** Johns Hopkins University
- ⋆ **Saroj Adhikari** University of Michigan
- ⋆ **Peter Adshead** University of Illinois, Physics
- ⋆ **Zeeshan Ahmed** SLAC National Lab
- ⋆ **Rob Allen** Sam Houston State University
- ⋆ **Natacha Altamirano** Perimeter Institute/University of Waterloo
- ⋆ **Mustafa Amin** Rice University
- ⋆ **Haipeng An** Caltech
- ⋆ **Stefano Anselmi** Case Western Reserve University
- ⋆ **Elena Aprile** Columbia University
- ⋆ **Taketo Ariki** Nagoya University
- ⋆ **Kam Arnold** University of Wisconsin-Madison
- ⋆ **Taylor Baildon** University of Michigan
- ⋆ **Nilanjan Banik** University of Florida
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- ⋆ **Sebastian Baum** OKC Stockholm
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Independent Researcher

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- ⋆ Be kind to others. Do not insult or put down other attendees.

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