WELCOME
Cosmology at Chicago: Past, Present, and Future
Edwin Hubble
S.B. ’10, Ph.D. ‘17

Hubble constant
Hubble law
Hubble diagram
Hubble age
Hubble classification
Hubble radius
Hubble sequence
Hubble flow
Hubble volume

....
Pretty much invented observational cosmology & branding & ushered in long, glorious era of Chicago athletic prowess
University of Chicago 1909 Track and Field Team
Edwin Hubble
“Pretty sure I could take John in one-on-one”
David Schramm, founds Fermilab Astrophysics Center, leads development of early universe theory and particle cosmology, continues Hubble tradition of combining cosmology with championship sports (wrestling)

Big Bang Nucleosynthesis
Baryogenesis
Inflation & Structure Formation
Particle Dark Matter
Dark Energy
Astrophysics as Particle Physics Laboratory
.....
Inner Space/Outer Space
Early 1980’s

David Schramm, founds Fermilab Astrophysics Center, leads development of early universe theory and particle cosmology, brings two young cosmology theorists to Chicago/Fermilab,

“Click”

“Clack”

Not so good at branding: WIMPs, dark energy. Why not Chicago WIMPs?
If I have seen further, it is by sitting on the shoulders...
Sloan Digital Sky Survey
1990’s

Return of observational cosmology to Chicago
Dark Energy Survey

The tradition continues…

Dark Energy Camera on the CTIO Blanco Telescope
Golden age of Chicago CMB Experiments

- COBE, MSAM-TOPHAT, DASI, EDGE, TPX, WMAP, Planck, SZA, Quad, SPT, CARMA-SZ, SPT-POL, SPT-3G, BICEP/Keck,…
Cosmology Theory Blossoms
Observational Cosmology Blossoms
Kavli Institute for Cosmological Physics

Thanks Bruce!
Cosmology at Chicago: 2042

- First light for GMT! (reconstructed after mag 9 quake)
- JWST launches!
- WFIRST only 2 years from launch!
- LSST confirms DES discovery that \( w < -1 \)
- CMB S-8 improves constraint on tensors: \( r < 10^{-6} \); KICP hosts “Cyclic Universe ’42” conference
- 10\(^{th}\) generation Dark Matter experiments begin (detector=RI)
- Holometer discovers “it’s turtles all the way down to the Planck scale”
- LHC celebrates 30\(^{th}\) anniversary of Higgs, 10\(^{th}\) anniversary of extra dimensions, still no SUSY
- KICP PFC-10 funded: “Pushing Cosmology way over the Edge”
- Astro2040 recommends SKA; UC considers 21cm
- Astrobotany classes begin at UChicago-Mars campus
- A&A and KICP share 5\(^{th}\) floor broom closet unused by IME
- Mid-term election setback for President Malia Obama
Cosmology at Chicago: 2042

- Climate change causes mount problems for SPT-9G, but eases access to ICECUBE PMTs
# Cosmology at Chicago: 2015

## November 18, 2015 - Wednesday

**ERC Main Auditorium, ground level**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Organizers</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 AM - 9:30 AM</td>
<td>Cosmology at Chicago in 2042&lt;br&gt;Organizers: John Carlstrom &amp; Hsiao-Wen Chen</td>
<td></td>
</tr>
<tr>
<td>9:30 AM - 10:30 AM</td>
<td>Astronomy &amp; Astrophysics Outreach &amp; Teaching in 2042&lt;br&gt;Organizers: Julia Brazas &amp; Randy Landsberg</td>
<td></td>
</tr>
<tr>
<td>10:30 AM - 11:00 AM</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>11:00 AM - 12:00 PM</td>
<td><strong>A&amp;Ph Questions that leading Telescopes and Instruments will answer by 2042</strong>&lt;br&gt;Organizers: Jacob Bean &amp; Erik Shirokoff</td>
<td></td>
</tr>
<tr>
<td>12:00 PM - 1:30 PM</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:30 PM - 2:30 PM</td>
<td>Astroparticle Physics in 2042&lt;br&gt;Organizers: Daniel Holz &amp; Daniel Hooper</td>
<td></td>
</tr>
<tr>
<td>2:30 PM - 3:30 PM</td>
<td><strong>A&amp;Ph Questions that leading computations will answer by 2042</strong>&lt;br&gt;Organizers: Andrey Kravtsov &amp; Don Lamb</td>
<td></td>
</tr>
<tr>
<td>3:30 PM - 4:00 PM</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>4:00 PM - 5:00 PM</td>
<td>Exoplanets at Chicago in 2042&lt;br&gt;Organizers: Daniel Fabrycky &amp; Leslie Rogers</td>
<td></td>
</tr>
<tr>
<td>5:00 PM - 7:30 PM</td>
<td>Reception at the Astro Lounge&lt;br&gt;ERC 5th floor</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>9:30 AM – 10:30 AM</td>
<td><strong>Cosmology at Chicago in 2042</strong>&lt;br&gt;Organizers: John Carlstrom &amp; Hsiao-Wen Chen</td>
<td></td>
</tr>
<tr>
<td>9:30 AM - 10:30 AM</td>
<td><strong>Astronomy &amp; Astrophysics Outreach &amp; Teaching in 2042</strong>&lt;br&gt;Organizers: Julia Brazas &amp; Randy Landsberg</td>
<td></td>
</tr>
<tr>
<td>10:30 AM - 11:00 AM</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>11:00 AM - 12:00 PM</td>
<td><strong>A&amp;Aph Questions that leading Telescopes and Instruments will answer by 2042</strong>&lt;br&gt;Organizers: Jacob Bean &amp; Erik Shirokoff</td>
<td></td>
</tr>
<tr>
<td>12:00 PM - 1:30 PM</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:30 PM - 2:30 PM</td>
<td><strong>Astroparticle Physics in 2042</strong>&lt;br&gt;Organizers: Daniel Holz &amp; Daniel Hooper</td>
<td></td>
</tr>
<tr>
<td>2:30 PM - 3:30 PM</td>
<td><strong>A&amp;Aph Questions that leading computations will answer by 2042</strong>&lt;br&gt;Organizers: Andrey Kravtsov &amp; Don Lamb</td>
<td></td>
</tr>
<tr>
<td>3:30 PM - 4:00 PM</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>4:00 PM - 5:00 PM</td>
<td><strong>Exoplanets at Chicago in 2042</strong>&lt;br&gt;Organizers: Daniel Fabrycky &amp; Leslie Rogers</td>
<td></td>
</tr>
<tr>
<td>5:00 PM - 7:30 PM</td>
<td><strong>Reception at the Astro Lounge</strong>&lt;br&gt;ERC 5th floor</td>
<td></td>
</tr>
</tbody>
</table>
Panel

- Abby Vieregg - Asst Professor Physics
- Wendy Freedman - The John & Marion Sullivan University Professor of A&A
- Josh Frieman - Professor of A&A; Director of Dark Energy Survey
- Craig Hogan - Professor of A&A; Director of the Fermilab Center for AstroParticle Physics
- Hsiao-Wen Chen - Associate Professor A&A

- Moderator: John Carlstrom, Professor of A&A; Director of South Pole Telescope.
"We know our immediate neighborhood rather intimately. With increasing distance, our knowledge fades, and fades rapidly..... The search will continue. Not until the empirical resources are exhausted, need we pass on to the dreamy realms of speculations."

— Edwin Hubble 1936
Cosmology in 2042?

“That is an interesting time frame forward, imagine asking that same question in 1988: no COBE, no dark energy, barely any galaxy clustering studies (no IRAS galaxy clustering, CfA2 just finished), wild frontier of inflation models and early universe particle physics that are now basically all ruled out.

So, where could we be in 2042?

No idea, …”

— Gil Holder PhD 2001
Cosmology in 2042?

“…that’s too far from now.

Good theorists don’t know what they will be doing 3 years from now, let alone 30”

— Wayne Hu
Cosmology in 2042?

“It's tough to make predictions, especially about the future.”

— Yogi Berra  PhD 19??
State of Cosmology in 2042?

“The state of cosmology will be Illinois, just as it is now!”

— Marc Kamionkowski PhD 1991
“…the language we will be using in 2042 to describe the universe and its cosmology will likely be qualitatively different from what we use now. I don't have a clue about what that language will be, however.”

— Andrey Kravtsov
“B modes will be mapped in the CMB, and we will find that while Stephen Hawking’s initials are written in the temperature map, “Bulls rule” will be written in the B modes. (Finally!….that’s what the “B” in “B modes” stands for!).”

— Marc Kamionkowski PhD 1991
“The landscape scenario will be pushing up daisies.”

— Marc Kamionkowski PhD 1991
“More seriously, are we going to see in 2042 $w=-1$, no B modes, $N_{\text{eff}}=3.046$ and no new physics at accelerators beyond the Standard Model? — i.e., no new physics beyond what we see now? It’s a possibility, although one that I don’t hope for. What else will this whole cosmological/particle-physical endeavor provide in that case?”

— Marc Kamionkowski (JHU) PhD 1991
“Thanks to Euclid, WFIRST, LSST etc we will confirm $w = -1$ to some $x\%$, but that wouldn't say anything about what dark energy is so we'll be designing experiments to look for $10^{-2} - 10^{-3}$ departures from $w = -1$. In parallel, we will be looking for experiments capable of detecting $10^{-5}$ departures from curvature. Still we wouldn't be solving the dark energy problem.”

— Asantha Cooray (UCI) PhD 2001
“There is still no appealing/convincing/consistent theory for dark energy and the accelerating universe leading cosmologists to increasingly rely on astrophysical observations for guidance as to the nature of both dark components. The current data include that from WFIRST, which has been launched in the mid 2030s!”

— Dragan Huterer (U. Mich) PhD 200?
“A future version of CMBpol will measure the amplitude of tensors by 2040s via CMB B-modes cleaned for lensing but we will still be arguing about physics of inflation. ”

— Asantha Cooray (UCI) PhD 2001
“Will inflation ultimately lead to a new fine tuning problem? I could imagine a world where we have ~4 sigma evidence that \( r > 0 \), but it’s too small to agree with simple single field models. Where do we go from there?

I predict we will have an \( r > 0 \) detection (because why not?), which will lead us to fly eLISA to learn about inflation.”

— Eduardo Rozo (U. Arizona) PhD 2006
“The scalar-to-tensor ratio \( r \) will have been limited to immeasurably small values, and we won't care anymore. But that will be OK, because we will have figured out that inflation is not actually due to a new scalar field, but instead is due to the quantum nature of gravity, and we will have new ways to test the new theory.”

— Kyle Story (KIPAC Fellow) PhD 2014
“The phrase "quantum cosmology" will actually mean something, and it will be theoretical, observational, and experimental”

— Gil Holder (McGill) PhD 2001
“…between now and 2042, we will have a breakthrough on the theory side that explains / ties together dark energy and inflation. Could be a viable theory of quantum gravity, could be something utterly unexpected, but as soon as it is written down, everyone will say "ohhhhh, that's what we were missing." It will be aesthetically pleasing and in no way involve anthropic reasoning.”

— Tom Crawford (UC) PhD 2003
“We will have a quantum theory of gravity that will explain the origin and exact value of the cosmological constant, and its relationship to a new and deeper Standard Model of matter and forces. The theory will agree with a set of precise laboratory experimental results to many significant digits.”

— Craig Hogan
“There will be several determinations of (separately) the primordial Helium abundance and the Hubble constant, none of which will agree within their stated error bars”

— Gil Holder (McGill) PhD 2001
“Ooooohhhh…. Just to be contrarian.

Cosmology manages to put an upper limit on the neutrino mass that is in violation of the neutrino oscillation experiments. What’s the solution?”

— Eduardo Rozo (U. Arizona) PhD 2006
“Precision measurements of the anomalies seen in reactor neutrino and accelerator neutrino experiments confirm the existence of sterile neutrinos suggested by measurements of the sum of the neutrino masses from cosmology that are in conflict with the known Δm2 from accelerator/reactor/atmospheric/solar experiments.”

— Abby Vieregg
“Euclid, WFIRST, LSST, CMB-S4 etc will all be successful and cosmology will measure the sum of the neutrino masses and neutrino hierarchy. Some members in the audience will have received the next Nobel prize for neutrinos by 2040s for exactly that. 2040s neutrino community will be looking for its next science goal, a clever experiment with a technology breakthrough to directly detect the 1.95K cosmic neutrino background.”

— Asantha Cooray (UCI) PhD 2001
“Cosmic neutrino background: after the CvB is discovered, we figure out how to build a directional tritium endpoint detector with a volume big enough to see the tiny fluctuations and make maps”

— Abby Vieregg
“In 2042 we will directly detect the cosmic neutrino background.

In 2067 will have a map of the CNB anisotropies at a range of energies. Scott Dodelson was the first to point out to me that due to their non-relativistic speeds today, these neutrinos are actually arriving here from *closer* than the last-scattering surface, which is kind of cool.

… because neutrinos have mass, their time-of-flight from last scattering to us is now energy dependent. … It means by mapping out CNB anisotropies at a range of neutrino energies, we can sample multiple last-scattering surfaces.

So that’s one thing that will be happening when I am 99 years old. I can’t wait to read about it!”

— Lloyd Knox (UCD) PhD 1995
“We have measured fluctuations in the cosmic neutrino background, with different energies corresponding to different distances from us (because they are massive and non-relativistic today) and a different amount of gravitational lensing, allowing a full 3D map of the real initial conditions of our Hubble volume”

— Gil Holder (McGill) PhD 2001
“21 cm cosmology: We’ll have a detailed 3-D map of the history of most of the first billion years. We’ll still be talking about going to the back side of the moon to get away from radio noise.”

— Abby Vieregg
“In 2042, I predict that we will be in the era of precision cluster cosmology. One of the key ingredient for getting there will include precision modeling of the structure and evolution of galaxy clusters that includes dark matter, gas, star, and black holes. Specifically, we will achieve 1% calibration of observable-mass relation, which should enable the use of galaxy clusters as one of the most robust and precise cosmological probes. In the process, we might discover (or at the very least significantly constrain) the nature of dark matter, dark energy, and/or modified gravity using galaxy clusters as a probe. Given the rapid advances in both computations and astronomical observations, I expect that we will attain this goal by the 150th anniversary of the U.Chicago Astronomy Department!”

Paraphrasing: Galaxy Cluster Cosmology will deliver!

— Daisuke Nagai (Yale) PhD 2005
“Will we be able to give a computer a map of the CMB and have it spit out cosmological parameters [without us telling it what we think we know about cosmology]”

— Scott Dodelson
“Now that it’s 2042, we are celebrating 50 years of COBE-DMR, ~30 years of Planck, and 10 years of CMB-S5. They discovered (in order): primordial density fluctuations in the CMB, large-angle anomalies in the CMB, and the signature of a single horizon-sized cosmic string cutting across the anisotropy pattern.”

— Dragan Huterer (U. Mich) PhD 2001
“CMB spectral distortions: after the first successful CMB spectral distortions mission, we’ll build the experiment that can characterize μ and y distortions from the early universe”

— Abby Vieregg
“...here’s something that might be OK for the scrapbook:

25 years ago today: I was at the South Pole on my first trip (grad school at Chicago was still 7 years in the future). The CMB was still isotropic, but expected to be done in 5 years or so. There was no Lambda yet in LCDM (except possibly if you asked Mike Turner?)

Today: I am still at the damn South Pole...thanks to my Chicago education. The CMB drives precision cosmology, but is expected to be done in 5 years or so. The data loves LCDM.

25 years from today: No idea where I will be. Whatever physics the CMB will be teaching us, it'll be expected to be done in 5 years or so. LCDM will break at some point. I hope Mike Turner will have a great name for whatever does it.”

— John Kovac (Harvard) PhD 2004
“We will know what (most of) the dark matter is. In fact I know it already but I am not telling!

We will have a physical model for the dark energy and have some testable predictions.

We will have a replacement theory for “inflation” - to explain the homogeneity and isotropy of the universe and the origin of perturbations.

We will still be scratching our heads about all of the uncanny cosmological coincidences (e.g., comparable amounts of baryons, DM & DE and neutrinos) and the many other coincidences outlined in Martin Rees’ book: Just Six Numbers.

And I have found another six. It is spooky. Can we derive all of these numbers (and the fine structure constant and, and, and…) from string theory??”

— Jeremy Ostriker (Princeton) PhD 1964
“I hope that in 2042, we will have learned completely unexpected new things. Q-theory will be the new quantum gravity theory. It will not involve strings. Dark energy will have turned out to be an epicycle. There will be a rich family of detected dark matter particles. There will be a standard theory of cosmology, but it will not be simple Lambda-CDM. Primordial gravitational wave and neutrino astronomy will have re-written the textbooks on the early universe. But independent 1% measurements of the Hubble constant will still not have overlapping error bars.”

— Wendy Freedman
“I hope that science is a more diverse endeavor by 2042. I hope we are doing education and science in a slightly different way, such that a more diverse group of people are contributing to the body of knowledge about our universe. This might come in the form of more citizen science projects and younger people getting involved in research or a strong push to hire professors and administrators that are from many different backgrounds so that universities and research institutions have a different culture than the one we currently have.”

— Abby Crites (Keck Fellow, Caltech) PhD 2013