**PARTICIPANTS BIG BAND & BEYOND (2005 SHORT COURSE)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeanne E. Bishop</td>
<td><a href="mailto:jeanbishop@aol.com">jeanbishop@aol.com</a></td>
<td>Westlake Schools Planetarium</td>
</tr>
<tr>
<td>Stephen S Fentress</td>
<td><a href="mailto:steve_fentress@rmsc.org">steve_fentress@rmsc.org</a></td>
<td>Strasenburgh Planetarium (Rochester Museum &amp; Science Center)</td>
</tr>
<tr>
<td>Robert A. Gardner</td>
<td><a href="mailto:rgardner@atlanta.k12.ga.us">rgardner@atlanta.k12.ga.us</a></td>
<td>North Atlanta Planetarium</td>
</tr>
<tr>
<td>James G. Hill</td>
<td><a href="mailto:jhill@rainwaterobservatory.org">jhill@rainwaterobservatory.org</a></td>
<td>Rainwater Observatory &amp; Planetarium</td>
</tr>
<tr>
<td>Bill R. Huston</td>
<td><a href="mailto:whuston@nlci.com">whuston@nlci.com</a></td>
<td>Jefferson High School Planetarium</td>
</tr>
<tr>
<td>Shoichi Itoh</td>
<td><a href="mailto:itoh@science.suginami-ku.ed.jp">itoh@science.suginami-ku.ed.jp</a></td>
<td>Suginami Science Center</td>
</tr>
<tr>
<td>Lisa-Anne D. Kelly</td>
<td><a href="mailto:lisa@alum.wustl.edu">lisa@alum.wustl.edu</a></td>
<td>Washington University</td>
</tr>
<tr>
<td>William B Kelly II</td>
<td><a href="mailto:mrgarabaldi68@yahoo.com">mrgarabaldi68@yahoo.com</a></td>
<td>St. Louis Science Center</td>
</tr>
<tr>
<td>Dimitri I Klebe</td>
<td><a href="mailto:dklebe@dmns.org">dklebe@dmns.org</a></td>
<td>Denver Museum of Nature and Science</td>
</tr>
<tr>
<td>Donald O Knapp</td>
<td><a href="mailto:knapdo@centennialsd.org">knapdo@centennialsd.org</a></td>
<td>Centennial School District</td>
</tr>
<tr>
<td>Elizabeth A Kruesi</td>
<td><a href="mailto:lkruesi@astronomy.com">lkruesi@astronomy.com</a></td>
<td>Astronomy magazine</td>
</tr>
<tr>
<td>(Peggy) K Motes</td>
<td><a href="mailto:pmotes@comcast.net">pmotes@comcast.net</a></td>
<td>Muncie Community Schools Planetarium</td>
</tr>
<tr>
<td>Amera B. Platt</td>
<td><a href="mailto:johnamera@aol.com">johnamera@aol.com</a></td>
<td>Wayne High School</td>
</tr>
<tr>
<td>Nicholas P Rae</td>
<td><a href="mailto:nick.rae@lakeview-museum.org">nick.rae@lakeview-museum.org</a></td>
<td>Lakeview Museum of Arts and Sciences</td>
</tr>
<tr>
<td>Martin Ratcliffe</td>
<td><a href="mailto:mratcliffe@exploration.org">mratcliffe@exploration.org</a></td>
<td>Exploration Place</td>
</tr>
<tr>
<td>Daniela Rosner</td>
<td><a href="mailto:drosner@adlerplanetarium.org">drosner@adlerplanetarium.org</a></td>
<td>Adler Planetarium &amp; Astronomy Museum</td>
</tr>
<tr>
<td>Stephen Schaffer</td>
<td><a href="mailto:schaffer@aaps.k12.mi.us">schaffer@aaps.k12.mi.us</a></td>
<td>Argus Planetarium</td>
</tr>
<tr>
<td>John A Schroer, IV</td>
<td><a href="mailto:ka8grh@sbcglobal.net">ka8grh@sbcglobal.net</a></td>
<td>The New Detroit Science Center</td>
</tr>
<tr>
<td>Steve E Skutnik</td>
<td><a href="mailto:sskutnik@adlerplanetarium.m.org">sskutnik@adlerplanetarium.m.org</a></td>
<td>Adler Planetarium &amp; Astronomy Museum</td>
</tr>
<tr>
<td>Clyde Simpson</td>
<td><a href="mailto:csimpson@cmnh.org">csimpson@cmnh.org</a></td>
<td>The Cleveland Museum of Natural History</td>
</tr>
<tr>
<td>Michael M Smail</td>
<td><a href="mailto:msmail@lasm.org">msmail@lasm.org</a></td>
<td>LASM - Pennington Planetarium</td>
</tr>
<tr>
<td>David L. Weinrich</td>
<td><a href="mailto:weinrich@mnstate.edu">weinrich@mnstate.edu</a></td>
<td>Minnesota State University Moorhead</td>
</tr>
<tr>
<td>Jack White</td>
<td><a href="mailto:white@skyskan-australia.com">white@skyskan-australia.com</a></td>
<td>Sky-Skan (full dome Producer)</td>
</tr>
<tr>
<td>Kenneth D Wilson</td>
<td><a href="mailto:kwilson@smv.org">kwilson@smv.org</a></td>
<td>Science Museum of Virginia</td>
</tr>
<tr>
<td>Ryan J Wyatt</td>
<td><a href="mailto:wyatt@amnh.org">wyatt@amnh.org</a></td>
<td>American Museum of Natural History</td>
</tr>
<tr>
<td>Carrie J Zaitz</td>
<td><a href="mailto:czaitz@csmk12.mi.us">czaitz@csmk12.mi.us</a></td>
<td>Ensign Planetarium</td>
</tr>
<tr>
<td>Gene S Zajac</td>
<td><a href="mailto:pgzajac@adelphia.net">pgzajac@adelphia.net</a></td>
<td>Shaker Heights High School</td>
</tr>
</tbody>
</table>
**Original Assignment:**

**********Pre-course Assignments and Reading List.**********

Written assignments 1 & 2 are due on or before 9/15 and should be submitted via email to randy@oddjob.uchicago.edu and Dragan Huterer dhuterer@cfcp.uchicago.edu.

KICP will try to post all readings on a special password protected course web-site, and will notify people when this happens.

1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.  [due on or before 9/15]

2) Read the “Overview” section of the National Research Council’s (NRC's) “Cosmology A Research Briefing” (available at .http://www.nap.edu/readingroom/books/cosmology/). Note: this summary was written in 1995.

Compile a brief list that, to the best of your present knowledge, answers the following:
* Which problems listed in the summary have been solved since 1995?
* Which have turned out to be less relevant since the summary was written? &
* Which questions remain top priorities in year 2005 and beyond?

Are there any problems now recognized as important that are missing from the 1995 NRC list?
[due on or before 9/15]

**Reading list:**

**Overview:**
- Cosmology primer (by Sean Carroll)  
  [http://pancake.uchicago.edu/~carroll/cfcp/primer/]
- Executive Summary of “Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century” (2003), Board on Physics and Astronomy (BPA)  
  [http://www.nap.edu/execsumm/0309074061.html#sum]

**Cosmic Microwave Background:**

**Dark Energy:**
  (also see several other articles in this edition: esp. Peebles; Ostriker & Steinhardt; Arkani-Hamed, Dimopoulos & Dvali)

**Supernovae (in the context of dark energy):**
- S. Perlmutter, "Supernovae, Dark Energy and the Accelerating Universe",  
  Physics Today, April 2004, p. 53  
  (also available at http://supernova.lbl.gov/PhysicsTodayArticle.pdf)

***************************************************************************
Big Bang and Beyond Pre-Course Assignments General MISCONCEPTIONS: (and instructor to address them) – by Dragan

- "Exploring the relics of the Big Bang is now less relevant" (it's not - it's just very hard to probe, so not too much progress has been made since 1995). (For Scott to address I think.)

- "CMB and WMAP measured the age of the universe accurately" (true, but it also provided the wealth of other information, most notably established flatness of the universe). (For Wayne.)

- emphasize that dark energy is an overriding concept for the thing that makes the universe accelerate, and that the cosmological constant and quintessence are just some of the candidates (Sean's talk).

- should probably say (in Sean's lecture on dark energy) how type Ia supernovae are used to detect DE and measure its properties.

- (also for Sean): emphasize what we do and do not know about the fate of the universe.

- emphasize not just observation of large-scale structure and galaxies, but also their computer modeling and the progress made (Andrey’s talk)

- Inflation: is it finally proven? Or can it ever be proven? What we do and do not know? (for Scott)
Big Bang and Beyond Pre-Course Assignments Individual Comments by Dragan:

Jeanne Bishop:
Show: we were very impressed with your show. It is very carefully thought out and presented. We only suggest that it is too long (certainly for ~1 hr show) - you probably wouldn't have time to talk about the various forces or Moon and the planets. Dark matter and dark energy are big, important topics and would be hard to cover them at the very end of the show. Very nice job overall.

Problems: We couldn't find your thoughts about the cosmological problems listed in the NRC report.

Steve Fentress:
Show: looks excellent. It does not cover all of the modern cosmology, but it is obviously tuned and optimized a specific audience that would get the most of it. Nevertheless, we would like to see at least the mention of dark matter and dark energy - in our opinion, discussion of cosmology without those is incomplete. The Horizons discussion sounds great; the CMB part needs more detail (but that's what this course is about!).

Problems: your understanding of these is excellent. Small corrections and additions: WMAP resolution is about 1/4 of a degree. Measurements of the neutrino mass are also a major development since 1995.

Robert Gardner:
Show: Looks good, but this is an enormous of stuff. You are trying to relate the (sub)atomic physics to the universe, and those to the history of cosmic models, and this is hard. This might still work, but the story needs to be streamlined and some stuff taken out. For example, you could talk about our understanding of the universe at largest scales and how it relates to atomic and particle physics. Or you could "look at" the universe in different wavelengths and talk about what we see and what we learn from this. It would be very hard to tie stars and constellations into this.

Problems: You are right about 1) (amount of DM and DE). As for 2), we disagree that identification of DM is less relevant - if anything it is more relevant, since we *know* it exists and there is much more of it than luminous matter. It is hoped we will detect it directly in the lab in the near future. This will have enormously important implications for understanding the fundamental physics in the universe. Under 3) we agree with everything except steady-state theory that has been ruled out long time ago. You are missing the main conundrum - dark energy (discovered in late 1980s)!

James Hill:
Show: we are very impressed with it. It is dead on target, being true to modern cosmology yet seems feasible. We especially like explaining how extrapolating expansion back in time implies a hot dense beginning.

Problems: Your understanding of them is excellent. Very small tweaks and
additions: that WMAP bumps correlate with galaxy walls and voids is not true strictly speaking since the latter have formed much later than the CMB and there is no way to "find" any given object in the CMB (except of course those that are not coming from the primordial CMB but rather contaminate its observations - e.g. the Galaxy or the Magellanic Clouds). Also add measurement of neutrino masses that happened since 1995. Superb job!

**Bill Houston:**

Show: Your show is well thought out. We fear, however, that is is too ambitious since it is very difficult to start from "old" astronomy, starting from the ancients through Galileo, continuing with Hubble and arriving at modern cosmology, *and* to cover the latter in any significant detail. Maybe start with the universe on its largest scales (or the big-bang picture) instead?

Problems: In addition to age of the universe, we now have much better observations of the distant universe (via Hubble Telescope for example) and measurement of the neutrino masses. We agree with your opinion of the less relevant problems. The top priority, in addition to dark matter, is the origin and nature of dark energy. And you recognized that dark energy is also new as it has only been discovered around 1998.

**Shoichi Itoh:**

Show: good job! We like your journey through space and time, and it covers all important aspects of the history of the universe. The down side is, you do not allow an opportunity to stop the travel and talk about the cosmic microwave background experiments for example, or the nature of dark matter and dark energy. While the latter two can be incorporated in your time travel, understanding them might require separate movies, pictures or demonstrations. Also another comment: we would suggest not talking about the true and false vacuum since their existence and effects are somewhat speculative, and in any case extremely difficult to understand for a general audience.

Problems: you understanding of them is excellent. To things that have been done since 1995 we would like to add mapping of the cosmic microwave background and measurements of the neutrino masses.

**Lisa Kelly:**

Show: It is an interesting idea to have a group discussion, and your program has been prepared very carefully. However most of it seems to center around questioning the audience and focusing on their misconceptions and paradigm changes in the field etc. Instead, we would like to know what materials directly from the subject of cosmology you would teach.

Problems: very good job here. As for the solved problems, even though perhaps nothing was truly solved, we have made significant progress with several of them (e.g. measuring the neutrino masses, mapping out the cosmic microwave background). Your list of missing problems from the NRC list is very complete, but note that you are repeating some of them: dark energy problem is the same
as that of cosmic acceleration, is the same as that of the cosmological constant, and is very closely related to the geometry of the universe. Similarly, the existence of extra dimensions and behavior of gravity on short scales are essentially one and the same problem. Note that the SZ effect and nature of gravitational lensing and not problems - these phenomena have been extremely well understood for decades!

**Bill Kelly:**

Show: very well thought out. However we worry that it relates somewhat disparate areas of astronomy; you are first talking about the expansion of the universe and Hubble, then about the CMB, and then again about the expansion and galaxies. What you'd need instead (for this purpose) is to concentrate on modern cosmology. Probably would have no time to cover ancient history and the middle ages, same with Steady State theory. Instead the important concepts (other than the big bang and expansion of the universe) are modern measurements of the CMB, dark matter and dark energy.

Problems: Excellent job. On top of the problems solved since 1995, add mapping of the CMB, measurement of the neutrino masses, and both observing and simulating the large-scale structure of the universe (e.g. the distribution of galaxies). Your understanding of the status of inflation is right on target.

**Dimitri Klebe:**

Show: We are very impressed with your plan. It is one of the rare cases where the proposal was ambitious in that it covers "real" cosmology, yet seems feasible. Each item is dead on target. Please talk to us if you think we can help you with some of these ideas.

Problems: you have an excellent understanding of them. Small tweaks and corrections: mapping of the cosmic microwave background is one of major developments since 1995 (age of the universe is just one of many things we got out of that). Also, we now have measurements of the neutrino masses. Superb job!

**Donald Knapp:**

Show: Sounds interesting, but you have not provided enough information for us to judge it.

Problems: Looks good. We wish you had explained some of the items in a bit more detail though, since their description in the NRC report was somewhat generic (but that's OK). As the the last item (problems missing from the 1995 NRC list) all of those you listed *except* dark energy and additional space-time dimensions were known for a very long time (some for close to 100 years!). The rest of it looks very good.

**Liz Kruesi:**

Problems: Very good job. Some comments: the physical processes just after the Big bang are still very important and relevant area of research, it's just that such early
times are very hard to probe. As for large-scale structure, we are pretty certain (and have been in 1995) that smaller structures combined into larger ones, not the other way around. Regarding the dark energy, evidence for it comes mainly from type Ia supernovae (see the Perlmutter article) and not WMAP.

Show: your outline is very complete and covers all important stages. We are only worried that it is too ambitious - there is a lot there to be covered as each of the items is a big topic in its own right (and you could very easily lose the reader). You'd need to cover these in a clever way in order to make a coherent story and yet not miss anything important. (We have the same problem with organizing our Course, hehe).

Peggy Motes:

Show: looks very complete; however it is hard to judge because you did not supply details of what exactly you would show for each of the items. Also, we worry that the program is too long: each of the items is a big topic in its own right and the listener can get lost. To that effect, we would take out the Cosmic Velocity Flows, the Role of Technology and the Gravitational Lenses perhaps.

Problems: What we had in mind here is that you answer which problems identified by the report were solved since 1995, which are still relevant, and what are the new problems that emerged after 1995. Still, it is useful that you read through and digested the NRC report.

Amera B. Platt

Show: Good job. Since the show is about cosmology, perhaps a better place to start is what are the big questions and the big picture. E.g. start not with what astronomers first discovered, but what is out there and what is the universe made of? Also too many things - each of them might be a separate show e.g. how about, starting with the idea of looking at Hubble diagram and expansion of the universe, say how modern measurements fill in that picture and how CMB complements it.

Problems: Very nice. The first three were already well known in 1995 (expansion in 1930s, CMB anisotropy in 1992, dark matter in 1930-1960s). Same for the nonuniform distribution of galaxies. The other items are correct. However you are missing the main conundrum - dark energy (discovered in late 1980s)!

Nick Rae:

Show: The concept of nothing for the show is intriguing even though your description is a bit vague (i.e. how do we know about these measurements)?

Problems: great job - your understanding of the current state of cosmology is in good shape.

Daniela Rosner:
Show: sounds excellent. Our only gripe about it is that it doesn't cover some of the main pillars of modern cosmology, namely the CMB, dark matter and dark energy (or does it? dark matter in particular might be mentioned in your show). But we really like the modern and accurate coverage of the large-scale structure.

Problems: looks good. There are a few unclear answers though. For example, the "stuff beyond the horizon" is not really a major conundrum simply because we cannot observe it directly. "What did galaxies look after formation" is also a somewhat unclear question - perhaps you meant how galaxies form. Measurements of CMB are not relevant now even though we have good measurements from WMAP - if anything, we want even better measurements. But you are essentially the only person who noted the topological defects and hot dark matter as being disfavored as being important - great job!

Steve Schaffer:

Show: it sounds excellent. Given that you are working with fairly young kinds teaching of cosmology is challenging, and we understand your dilemma - but this is what the Short Course is for! Perhaps you'd want to convey what the main questions that the scientists are trying to answer about the universe as a whole (how old it is, what it's made of etc).

Problems: correct and very good except the following. That anisotropy is real was known in 1992, 3 years before the NRC report. Curvature in the universe should be in the "solved" category (it's very close or equal to zero). One of the top priorities is finding out the nature of dark matter (what IS it). Good job!

Steven Skutnik:

Show: we were impressed by your proposal - it makes sense and would cover important concepts. We do think it is challenging to cover all topics - you building the show around the timeline, but you need to integrate somewhat difficult concepts such as redshift, lensing, phase transitions.

Problems: your coverage and understanding is excellent. Comments: cold dark matter is really the same as the dark matter problem. Dark energy really belongs to the last category since it wasn't present in 1995. You are "in tune" with the developments!

Clyde Simpson:

Show: Very carefully thought out. We like the emphasis on dark matter and dark energy (cosmic microwave background, as a relic of the Big Bang, probably also deserves attention). The only potential problem we see is the jump you make from human exploration of space to Big bang to dark matter (if we understand this correctly). It might be easier to skip the human centrality, and/or perhaps start with the universe as observed on its largest scales (or perhaps earliest times).

Problems: your understanding of them is superb. Essentially nothing to add; perhaps the fact that the neutrino masses have also been measured since 1995. And we just cannot understand how the NRC report failed to mention the Indians vs. the White Sox.
Mike Smail:

Show: it sounds excellent - it covers most of modern cosmology. It would be a bit challenging though to combine all the topics you mentioned in a smooth story (in particular, connect the early work of Einstein etc to the CMB).

Problems: adding to the list of solved problems, we have evidence for a flat universe from CMB experiments. Also, much better measurements of the large-scale structure (i.e. distribution of galaxies) and also sophisticated methods of simulating them. I agree with your top priorities, but perhaps the very top one is missing: the nature of dark energy. Similarly, dark energy was missing from the overview (that was written in 1995).

Dave Weinrich:

Show: very well thought out. We fear, however, that there is not enough time to show both the night sky and the history of the observations, and cover modern cosmology. Instead, perhaps one could start with universe on large scales as observed today. Also, Steady State theory is long obsolete and could be taken out in favor of more discussion of the CMB, dark matter and dark energy.

Problems: your understanding is very good. Some additions and corrections: string theory was not discredited in the 90s (though perhaps it was not favored either). Neutrino mass meas measured since 1995.

Ken Wilson:

Show: we like your idea of the Cosmic Time Machine. The devil is in the details though, and we would like to know what exactly one would see whole going traveling space and time.

Problems: your answers are a little too terse. Inflation is not really much better understood than it was in 1995. Similarly, the large-scale structure evolution is not less relevant. In addition to dark matter, the current top question is the origin and nature of dark energy.

Ryan Wyatt:

Show: we are very impressed with it. It is dead on target, being true to modern cosmology yet seems feasible. You are doing the tricky navigation through space and time, which sounds like it would work. You still have to be careful that, for example, when you zoom into Milky Way in the WMAP map you need to point out that Milky Way was perhaps a slightly overdense blob in the soup at that time. Great job.

Problems: unfortunately you did not send your thoughts on the 1995 NRC review.

Carrie Zaitz:
Show: very carefully thought out. We worry, however, that there is too much material. It is very challenging to start with the night sky and the local universe, cover the cosmology, and in the process talk about the early history of astronomy. How about starting with the universe on its largest scales and/or the Big Bang?

Problems: very good job. As for the ones solved, you are one of the few who mentions the Hubble Deep Field etc observations of the distant galaxies. However, you missed to mention accurate mapping of the cosmic microwave background which is probably the most important development. Also, neutrino masses have been measured. Less relevant: the physical laws of Big Bang are still important, they are just very hard to probe. Finally, in the missed questions by far the most important one is dark energy and acceleration of the universe which were first discovered around 1998 (see the Perlmutter article).

Gene Zajac:

Show: this is a very clever idea, to compare aging of the universe to aging of a person etc, and we like it. But just asking what the age of the universe is does not necessarily the universe's past and future. And the past and future of the universe are related to what is the universe made of, which of course is mostly dark energy and dark matter. PS. The universe most likely does not end in a big crunch! :)

Problems: your understanding of them is impressive. Small corrections: Spitzer will not help COBE since the former provides infrared measurements (and on small chunks on the sky) while the latter is microwave (and all sky). COBE data have already been improved with WMAP and other experiments. Things you're unsure about we'll talk about during the Course.
Randy,
Here are my assignments for the course:

1. Cosmology program outline: Attached to this E-mail.

2. Overview section of the NRC's "Cosmology: A Research Briefing"
   Lists. Below.

   a. Problems in summary solved since 1995:
      - When did the universe start?
      - How did the large-scale structure of matter form and how large is it?
      - Did the universe undergo inflation at a very early stage?

   b. Problems that have turned out to be less relevant since summary was written—What can we
      learn about physical laws from relics of the Big Bang?
      I judge this to be less relevant now because the findings about actual and critical density are so
      widely known and accepted that there seem to be no new questions or fresh interest. This could
      also be labeled an unsolved problem area—we still wonder why the two are so very close—the
      flatness problem, although inflation seems to have solved much of this.

   c. Which questions remain top priorities in the year 2005 and beyond?
      - How will the universe end? (The fate of the universe may not be controlled by geometry. The
        universe could expand forever depending on the way acceleration changes with time.)
      - What is the dark matter and what is its cosmological role?
      - What can we learn about physical laws from relics of the Big Bang?—Not a top priority, but still a
        concern for why the actual and critical density values are almost congruent, even with inflation.

   d. Are there any problems now recognized as important that are missing from the 1995 NRC list?
      - What is the role of the cosmological constant?
      - Can we discover a Grand unified theory of how gravity separated from the set of four forces in the
        earliest moments of the universe?
      - Does acceleration of the universe change with time, and if so, how?
        - Are there new ways to show, with good data resolution, that the universe is flat?
I. Introduction to the present universe and our position in it
a. Current evening sky—the view from Earth: evening constellations, Moon, planets.
b. “Powers of Ten” video presentation; jumping from Earth to the realm of supergalaxies
c. Explanation and demonstration of different wavelengths: Use a glow-painted wire (and portable UV light), and compress and stretch it to convey the idea of different wavelengths
c. Hubble, Chandra, and Spitzer photographs of distant and younger objects of the universe in different wavelengths.

II. The Expanding Universe
a. Demonstrate how the Universe is expanding with a Hoberman sphere.
b. Show a spectrum with stationary absorption lines and one with red-shifted lines. Explain that we measure the shift to tall how fast each galaxy is receding. All galaxies show red-shifted light. Show lines with different amounts of red shift.
c. Use a balloon analogy to explain how the farther away a galaxy is, the faster it is retreating: Mark the balloon with galaxies and blow it up. Designate the place one blows as the Milky Way with our home. See how the marks farther from the opening go farther with each blow. Velocity is proportional to distance. Discuss Hubble’s discovery (1929) of this
d. Note that the balloon model contains no galaxies inside. The inside of the balloon represents time, a 4th dimension—not space. The universe is finite because there is only the surface of the balloon. But it has no edge and no center. There is no center to the universe. The balloon illustrates space-time curvature.

III. The Universe Had a Beginning
a. Reuse the Hoberman sphere and balloon to show that the matter that expanded was once in a tight spot.
b. Explain that one way to interpret the observed red-shift (expansion) of distant galaxies is that a Big Bang took place 13.7 billion years ago. Note that it was just a possibility until another observation was made.
c. (Audiences are fascinated by “stories,” both true and mythical.) With illustrations, tell the story of the discovery of the microwave background radiation (MBR). Note the contributions of different individuals and satellites: George Gamow, Robert Dickie, Arno Penzias and Robert Wilson, COBE, WMAP. The accuracy of the recorded data was within 1 percent of what was predicted—providing very strong support of the Big Bang theory.
d. Explain how radiating gas at 3000 K from a hot big bang would lead to the discovery of 2.7 K degrees microwave radiation, how the original photon wavelengths cooled and became about 1000 times longer (1000 nanometers to 1 mm). The radiation changed from orange-red visible light to microwaves, which emit microwaves.

IV. Early Stages of the Universe
a. Use the Analogy of Timothy Ferris Widows in the stairs of a lighthouse to “view” the universe (slides or video) at earlier and earlier times.
   1a. Forces of gravity, electromagnetism, weak nuclear force, and strong nuclear force separated when universe was 10^{-35} second old. Energy released caused rapid expansion, so the universe went from size of an atom to a size of a cherry pit (10 billion times larger).
   1. 0.000 001 (Ten millions of 1 second) old: high energy photons with a temperature way over 1 trillion K and a density over 5 x 10^{13} g/cm^3. Was a dynamic soup changing from photons into particles and back again. The particles were protons, antiprotons, and neutrons.
   2. 0.0001 second old: Mostly photons (gamma rays) were made by collisions of particles and antiparticles. No more protons and neutrons could be made. A small amount of normal matter was left over, and we are made of it. Gamma rays made electrons and positrons, 1800 times less massive than protons and neutrons. Universe was now 1 trillion K.
   3. 4 seconds old: No more protons, neutrons, and electrons were made.
4. 2 minutes old: proton and neutron combined to form deuterium (heavy hydrogen). Single protons are normal hydrogen nuclei. Then two protons combined to make helium.

5. 30 minutes old: Nuclear fusions stopped to freeze the amount of hydrogen and helium in the universe, about 25% helium and the rest hydrogen. All the hydrogen and helium were ionized, meaning they had no electrons surrounding them. The free electrons made the gas very opaque—a photon could not travel far before it collided with an electron. Radiation could not leave.

6. 300,000 year old: Photons were cool enough, 3000 K, that free electrons were captured and H and He became normal atoms. The gas became transparent and the radiation left to be detected today as the 2.7 K radiation

7. Stars and galaxies then formed

V. Recent Discoveries
a. Dark Matter
b. Universe expansion is speeding up and Dark Energy

Wrap-Up and Question
KICP Cosmology Course 2005 written assignment

Steve Fentress

Program outline:
"Cosmology with Rusty Calculus" - a four-session mini-course for lifelong learners. Target audience: lifelong learners 50ish and up who remember a bit about derivatives and vectors and are looking for intellectual stimulation.

The mini-course would consist of four talks using mathematics at about the level of the mathematical supplement at the end of Weinberg's _First Three Minutes_ -- a few key equations.

Session 1: the Hubble parameter
The redshift-distance relation. \( H \) as a parameter, but not constant in time. Getting physical intuition for the idea that \( 1/H \) gives a characteristic expansion time for the universe.

Session 2: Horizons
The adult learners I have talked to are fascinated by the cosmic horizon, asking, for example, if galaxies that were once close to us have since flown beyond our horizon and are just now becoming visible a second time. We will try to provide motivation for the idea that (if the expansion is not accelerating) the distance to a typical galaxy increases as the two-thirds power of the time, while the distance to the horizon increases as the first power of the time, so the horizon will eventually overtake every galaxy. Next, this may be the right place to introduce the detection of acceleration using supernovae. At the KICP course I'd like to get better physical intuition of how the relation between a supernova's brightness and redshift can indicate acceleration.

Session 3: Elements
We look at the abundances of helium and deuterium as independent evidence for the Big Bang. Blackbody radiation and how it changes in an expanding universe - the trends in temperature and predominant wavelength with expansion - threshold energies for particle creation and recombination. (To prepare for this I'd like to learn more about the observational data on helium and deuterium abundances.)

Session 4: Cosmic Microwave Background
We grapple with the meanings of the peaks in the spectrum of fluctuations in the CBR, following the approach on Wayne Hu's web site

=================================================================
Lists based on the NRC "Overview"

Which problems in the summary have been solved since 1995?
- Age of the universe was refined to 13.7 billion years by WMAP
- Distant galaxies were not used as the ultimate standard candle for discovering the acceleration of the expansion; type Ia supernovas were
- WMAP confirmed the acceleration by measuring cosmic mass density
- WMAP has angular resolution down to one degree
- Galaxy surveys have now gone much farther out than the 1995 map

Which have turned out to be less relevant since the summary was written?
I'm not sure I have a good answer to this one beyond the

Which questions remain top priorities in year 2005 and beyond?
- The nature of dark matter
- The formation of the first stars and galaxies. The pie-slice illustration in the 1995 report shows the first stars and galaxies appearing between 15 million and 1 billion years; the WMAP web page puts the first stars at 200 million years

Are there any problems now recognized as important that are missing from the 1995 summary?
- What is the nature of dark energy (the agent responsible for accelerating the cosmic expansion)?

Program outline:
"Cosmology with Rusty Calculus" - a four-session mini-course for lifelong learners. Target audience: lifelong learners 50ish and up who remember a bit about derivatives and vectors and are looking for intellectual stimulation.

The mini-course would consist of four talks using mathematics at about the level of the mathematical supplement at the end of Weinberg's _First Three Minutes_ -- a few key equations.

Session 1: the Hubble parameter
The redshift-distance relation. H as a parameter, but not constant in time. Getting physical intuition for the idea that 1/H gives a characteristic expansion time for the universe.

Session 2: Horizons
The adult learners I have talked to are fascinated by the cosmic horizon, asking, for example, if galaxies that were once close to us have since flown beyond our horizon and are just now becoming visible a second time. We will try to provide motivation for the idea that (if the expansion is not accelerating) the distance to a typical galaxy increases as the two-thirds power of the time, while the distance to the horizon increases as the first power of the time, so the horizon will eventually overtake every galaxy. Next, this may be the right place to introduce the detection of acceleration using supernovae.

Session 3: Elements
We look at the abundances of helium and deuterium as independent evidence for the Big Bang. Blackbody radiation and how it changes in an expanding universe - the trends in temperature and predominant wavelength with expansion - threshold energies for particle creation and recombination.

Session 4: Cosmic Microwave Background
We grapple with the meanings of the peaks in the spectrum of fluctuations in the CBR, following the approach on Wayne Hu's web site
Purpose: This show will use constellations and key stars in the planetarium to focus student attention and participation on the location and instrumentation of recent discoveries that model our cosmos.

1. Derivation of early cosmic models
   a. Earth centered visual detection
   b. Lower energy astronomy
   c. Atomic structure basics

2. Present day model of our cosmos.

3. How did we get to our present day cosmic picture?
   a. Electromagnetic spectrum (high energy detection)
   b. Atomic structure (today)
   c. Galaxy and star formation
   d. Black holes
   e. Dark matter

4. The Big Bang and high energy detection.
   a. Atomic structure (new particle physics.)
   b. High energy physics.
   c. Inflation

5. Summary: review the cosmic picture from big bang back to naked eye earth.

Randy, these are pretty general ideas of my show. The show will be clued together by the placement and methods of detecting these new discoveries among the stars and constellations.

I plan to use components of extreme astronomy from last year and the new big bang session next week.

Part 2 Big Bang and Beyond

1. Which problems have been solved……..
   • The amount of dark matter and dark energy in the universe.

2. Which has been less relevant since the summary……..
   • The identification of dark matter. How can there be any relevance in something that you can not detect. Why is dark matter just accepted as a universal constant?
   • The exact age of the universe.
   • The average density of universe.

3. Are there any problems now recognized as important…..
   • The increased role of neutrinos in understanding our present model of the big bang.
   • New inflation theories
   • Increase research of the steady state theory
   • Gravitational wave detection techniques

Robert Gardner
North Atlanta Planetarium
OUTLINE OF A PRESENTATION ON COSMOLOGY

A. Begin with a personal statement of my own fascination with cosmology in the 1950s when cosmology was as much philosophy as science.

B. Take a historical approach to the development of evidence that would eventually lead to the current "standard" "big bang model.
   a. Show how the understanding of light and the spectrum led to an understanding that physical laws can describe the distant universe. Explain the basic structure of atoms and how they make light. (Use a diffraction grating to demonstrate the spectrum and use discharge tubes with bits of grating film to show various spectral “fingerprints”). Without this background much of the following will seem like a fairy tale to non science listeners.
   b. Detail how the study of absorption lines and the Doppler Effect led to the hypothesis that the universe was expanding. (Use a whirling buzzer to demonstrate the Doppler effect) Here would fit the contributions of Hubble and the idea of the Hubble “law” (Show spectra of various galaxies and show how galactic velocity and distance are correlated. Graphs of speed and distance would go in here.)
   c. Explain how the expansion if run backwards in time implies a hot dense beginning.
   d. Explain how the cosmological red shift is not really a Doppler shift but really a consequence of space time itself expanding and stretching the light waves as implied by Einstein’s theories.
   e. The discovery of the CBR in the 1960s gave confirmation of predictions of the big bang model and made cosmology a scientific theory backed by evidence.

C. Modern data have combined astronomy with theoretical physics to make some bizarre predictions and experiments have confirmed many of them.
   a. COBE and WMAP have confirmed predictions of unevenness in the early universe that led to latter large scale structure and implied the age and history of the early universe to an amazing degree.
   b. Zwicky and Rubin confirm exotic “dark matter” stuff.
   c. Supernova studies imply a force that is accelerating the expansion of the universe.

D. Conclusion: It appears that we now can give a time line to the history of the universe from birth till now and possibly the future of the universe as well. (Here would go a graphic showing the eras from the creation instant through the radiation era, to recombination, the “dark ages”, the birth of stars and galaxies, the current universe, and possible future scenarios.

As we look further out with our new instrumentation, we also are looking back in time. Amazing!

COMMENTS ON “COSMOLOGY: A RESEARCH BRIEFING” NRC 1995

1. The briefing says the creation event was between 8 and 15 billion years ago. New data implies a much more precise 13.7 billion years for the age of the universe.
2. The “dark matter” problem is still not in sight of a solution.
3. The apparent acceleration of the expansion rate revealed in 1998 is a new twist whose effect is still being debated.
4. There has been some progress on the fundamental question of the nature of matter and how it causes the effect we call gravity.
5. WMAP results seem to have given backing to how the seeds of large scale structures grew out of what was thought to be too smooth an early universe. The “bumps” seem to correlate with walls and voids of galaxy clusters.
6. Inflation of some sort seems to have happened. How and why are still a great puzzle.
7. There is some progress since the report on character of the first so-called population III stars that formed, but the details are vague.
8. The formation process of the first galaxies seems to be gaining a consensus.
Finally, the idea that science can make a contribution to the culture by answering, even in part, questions about creation, has caused a backlash among right wing evangelical Christians. Fundamentalism through intelligent design and other well financed anti-science movements has had an impact that the scientific community has ignored to its peril. Polls seem to show that about a large percentage distrust science being as anti-religious. A decade ago this was not deemed a significant problem.
KICP Short Course Pre-course Assignment
By Bill Huston

1. Which problems listed have been solved since 1995?

As far as I have heard, none of the questions have been solved, with the possible exception of “When did the universe start and how will it end?” I understand it is believed to be now from 12 to 13 billion years ago for the Big Bang; and the universe will “peter out” into elementary particles since its expansion is accelerating, not slowing down (as I had hoped), and will expand forever. Of course, these aren’t completely “solved” but certainly better understood than in 1995.

Also, Inflation appears to be commonly accepted as the mechanism for early rapid expansion of the universe.

2. Which have turned out to be less relevant since the summary was written?

(Sounds like an opinion question, so…) I would choose “Do physics and cosmology offer a plausible description of creation?” I believe this question is important, but it almost sounds like cosmology wishes to appease the religious community. I know science shouldn’t “wage war” against the naysayers in religion, but I believe we should not bend to their level, either. Of course this question would be addressed solely by scientific means, but I still feel a little uneasy with it, as far as how the generally non-scientific society will view this attempt. However, I would agree that is important, but it is, perhaps, a little less relevant.

3. Which questions remain top priorities in year 2005 and beyond?

Certainly, the start and end issue will always be adjusted with new discoveries, so it remains near the top. The role of Dark Matter will continue to be a priority, since it’s so daggone hard to see. And what we can learn from physical laws from the relics of the Big Bang has the potential to change the face of physics.

4. Are there any problems now recognized as important that are missing from the 1995 NRC list?

The one about which I have heard much, read little, and understand less, is this stuff called “Dark Energy.” Is this a new word for Dark Matter? Also, what discovery or explanation is missing from all of this that will convince “non-believers” that the universe is very old, very large, follows neat rules, and started from nothing in a big ol’ kablammy?
Cosmology Planetarium Show outline (rough)
By Bill Huston

Statement:
I would like to develop a show that demonstrates the “evolution” of humanity’s concept of the Universe. That is, examine the beginnings of how humans view their universe, how ideas changed (sometimes radically), and where cosmologists are now. I would like this show to be somewhere between 30 and 45 minutes in length, allowing discussion afterwards (even conflict; yikes!).

<table>
<thead>
<tr>
<th>Visual</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open with a video clip of a “big bang.”</td>
<td>The “bang” then narrator: We’ve all heard about the Big Bang but how did scientists come to such a fantastic idea for the origin of the Universe? Today we’ll explore how the human imagination has propelled us from the simplest and sometimes silliest ideas to grand and deep explanations for the beginning, life, and end to the Cosmos.</td>
</tr>
<tr>
<td>2. Then slides of Hubble Deep Field and Ultra Deep Field, Andromeda galaxy, et al., the Sun, and planets fading in and out neatly.</td>
<td>Baroque or older music in background, then narrator: harrumpff, harrumpff, harrumpff…</td>
</tr>
<tr>
<td>3. Slides of early models of Earth, such as Flat Earth, Earth on back of Atlas on Turtle, etc.</td>
<td>Why this was acceptable for the time.</td>
</tr>
<tr>
<td>5. Galileo slides, such as w/telescope, Helio-centric SS, phases of Venus, sunspots, on trial, etc.</td>
<td>Explanation of his “radical” view of Universe and how he proved Ptolemaic wrong.</td>
</tr>
<tr>
<td>6. Advancement in Astronomy slides, such as larger and larger telescopes, discoveries: Uranus, Neptune, Pluto, concept of galaxies.</td>
<td>Blah blah blah. Progressively more modern music coming and going (perhaps some good American music for Pluto and stuff in the early 20th century, like Copeland and Gershwin).</td>
</tr>
<tr>
<td>7. Hubble and Humason discovering red shift on distant galaxies.</td>
<td>How this extrapolated nicely into the Big Bang.</td>
</tr>
<tr>
<td>8. 20th Century advances and scientists.</td>
<td>Refinement of Big Bang.</td>
</tr>
<tr>
<td>10. Art work of Flat, Closed, and Open universes.</td>
<td></td>
</tr>
<tr>
<td>11. Latest discoveries and…</td>
<td>…what they mean.</td>
</tr>
</tbody>
</table>
1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution. [due on or before 9/15]

And so, we Came to Be.

Shoichi Itoh
Suginami Science Center

<Planetarium screen is completely dark. Suddenly it becomes brilliant-so bright that it hurts the eyes>
In the beginning there was nothing, no space… and no time…. there was only a state called false vacuum. Bubbles of new phase, the true vacuum, continuously formed and then disappeared. Eventually one of the bubbles expanded and the false vacuum phase disappears--. In this way our universe was born. The bubble expanded rapidly--powered by vacuum energy. It doubled and doubled in size – resulting in an exponential expansion. This doubling happened to begin only $10^{-35}$ seconds since the universe was born. In those early instants, the universe we know today was arisen from a volume $10^{-30}$ times smaller than it is today! This period of expansion, called the inflationary epoch, finished when the universe was only $10^{-33}$ seconds old! It was also extremely hot back then, some $10^{32}$ Kelvin! At that temperature the force of gravitation first became distinct.

<The planetarium sky is now seen to be full of rapidly flickering gluons.>
When time passed 6 more powers of ten a quark-gluon phase transition occurred. Quarks and gluons became bound into the protons and neutrons we see today. When the universe was passed one second mark, it became clear or transparent to neutrinos. When the universe was 10 seconds old, primordial nucleosynthesis started. This is because the universe had finally cooled to a point where protons and neutrons could combine to form light atomic nuclei, primarily Helium, Deuterium, and Lithium. The nucleosynthesis last about three minutes since universe was born!

<The planetarium sky is now filled with high-speed electrons, as well as atomic nuclei of Helium, Deuterium and Lithium.>
Now significant changes in the universe would take very long periods of time. 370 thousand years would pass until we entered-the final stages of Big Bang. By that time the expanding universe finally cooled to a point where electrons could combine with nuclei to form complete atoms. At that point space became transparent. Electromagnetic radiation called the Cosmic Microwave Background is a snapshot of that era. We call it the recombination stage of our universe. The temperature then was about 3000 Kelvin.

<Planetarium all-sky shows a cross-fade of atoms capturing electrons>
The temperature of the universe was very uniform then with very tiny, fluctuations of temperature only about one part in $10^{5}$. These tiny fluctuations were the seeds of stars and galaxies.

<Planetarium all-sky: cross-fades to the WMAP sky. It then reddens in color and fades-out>
Throughout this initial dark age, the tiny ripples in the density of matter gradually assembled into stars and galaxies. Everywhere countless bright areas flashed excitedly with new born stars and their clusters. These clusters in turn would form galaxies and finally clusters of galaxies. Many interacted and merged into huge galaxies with active nuclei containing black holes.

<In the planetarium all-sky. Bright clouds with new born stars appears and many proto-galaxies born. Gradually they form clusters of galaxies and make the structure of the universe>
Heavy elements were produced in the cores of massive stars. These stars exploded in the last stage of their life and releasing these precious elements deep into space. In this way every places of the universe were sprinkled with heavy elements. They would become the seeds of planets and the seeds of life.

<On the dome we see now the hot Jupiters of extra-solar systems and then our solar system. In the very end we zoom-up to our home planet, the Earth.>
And so, we came to be..

2) Read the "Overview" section of the National Research Council's (NRC's) "Cosmology A Research Briefing" (available at http://www.nap.edu/readingroom/books/cosmology/).
Compile a brief list that, to the best of your present knowledge, answers the following:
* Which problems listed in the summary have been solved since 1995?

1) Universe is 13.7 billion years old, with a margin of error of close to 1%.
2) First stars ignited 200 million years after the Big Bang.
3) Content of the Universe (from CMB fluctuation analysis): 4% Atoms, 23% Cold Dark Matter, 73% Dark Energy.
4) First moving neutrinos do not play major role in the evolution of structure the universe.
5) Expansion rate value: \( H_0 = 71 \text{(km/sec)/Mpc} \) (with a margin of error of about 5%).
6) New evidence of Inflation (CMB polarization).
7) Universe will expand forever. (Super Novae type Ia observation)

* Which have turned out to be less relevant since the summary was written? &

Neutrinos as the dark matter candidate

* Which questions remain top priorities in year 2005 and beyond?
  Why Inflation happened and stopped? And why again? (Vacuum Energy)
  What is Dark Energy? (Vacuum Energy)
  What is Dark Matter,

Are there any problems now recognized as important that are missing from the 1995 NRC list?

**Omega values**

**Carvature of the universe: \( W = 1 \) flat universe**

\[
\begin{array}{ll}
WL &= 0.73 \quad 0.04 \quad \text{:Dark Energy} \\
Wm &= 0.27 \quad 0.04 \quad \text{:Dark Matter} \\
Wb &= 0.044 \quad 0.004 \quad \text{:Baryon} \\
W\nu &= 0.015 \\
\end{array}
\]
Pre-course Assignment for KICP's Big Bang & Beyond
Lisa Kelly
September 15, 2005

1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

Outline of Cosmology Presentation

NOTE: I am a doctoral student in science education. Therefore, my intended audience for this presentation is members of the university community including, professors, research-staff, graduate students, and undergraduate students.

I. Introduction
   a. Questioning the audience:
      i. In groups of 3 or 4, discuss what comes to mind when you hear the term, “cosmology?”
      ii. Report back to the larger group
      iii. What challenges have you faced in teaching cosmology and related topics to students (of all ages – children to adults -- and in all settings – K-12 schools, universities, planetariums, museums)?
      iv. What successes have you had in teaching cosmology and related topics to students?
      v. What ideas do you have regarding expanding on these successes?
      vi. What ideas do you have regarding overcoming these challenges?

II. Conceptual change
   a. Introduce theories of conceptual change
      i. e.g., Dewey; Vygotsky; Posner, Strike, Hewson, & Gertzog (1982)

III. Misconceptions and alternate conceptions in physics, astronomy, and cosmology
   a. Review of the educational literature
      i. e.g., Minstrell (1982); Halloun & Hestenes (1985); Baxter (1991); Zeilik, Schau, & Mattern (1998).

IV. Wrap-up – small and large group discussion
   a. Bringing together research and practice
      i. In small groups discuss how the literature on conceptual change and misconceptions might inform your work in teaching and learning cosmology?
      ii. Share with the larger group
      iii. How might what we discussed here today connect with the successes and challenges we identified in the Introductory section?
   b. Other comments and questions?

Acknowledgment: Special thanks to Ji Shen, Science Education Doctoral Student, Washington University, for assistance in providing bibliographical resources
2) Read the "Overview" section of the National Research Council's (NRC's) "Cosmology A Research Briefing" (available at http://www.nap.edu/readingroom/books/cosmology/). Compile a brief list that, to the best of your present knowledge, answers the following:

*Which problems listed in the summary have been solved since 1995?*
  - None of the problems listed in the summary have been solved. However, the answer to the question “When did the universe start?” now seems to have converged on around 14 billion years ago.

*Which have turned out to be less relevant since the summary was written?*
  - None of the problems listed in the summary have turned out to be less relevant since the summary was written. However, the question “Do physics and cosmology offer a plausible description of creation?” does not seem to be addressed in the articles published after 1995, possibly indicating a declined focus on this question.

*Which questions remain top priorities in year 2005 and beyond?*
  - “What is the dark matter and what is its cosmological role?”
  - “Did the universe undergo inflation at a very early stage?”
  - “What can we learn about physical laws from relics of the Big Bang?”

*Are there any problems now recognized as important that are missing from the 1995 NRC list?*
  - What is dark energy and what is its cosmological role? (Perlmutter, 2003)
  - What is the physical nature of dark energy? (Kraus, 2002)
  - Is the time-averaged behavior of the dark energy consistent with a cosmological constant? (Perlmutter, 2003)
  - Are there large extra dimensions? (Arkanik-Hamed, Dimopoulous, & Dvali, 2002)
  - Are there small extra dimensions? (Arkanik-Hamed, Dimopoulous, & Dvali, 2002)
  - Why is gravity so weak? (Arkanik-Hamed, Dimopoulous, & Dvali, 2002)
  - If there was inflation, what caused it? (Caldwell & Kamionkowski, 2002)
  - What drives cosmic acceleration? (Krauss & Turner, 2004)
  - How can we solve the “horizon problem” if the theory of inflation does not hold true? (Kraus, 2002)
  - What are the properties and nature of the Sunyaev-Zel’dovich effect? (Kraus, 2002)
  - What are the properties and nature of gravitational lensing? (Kraus, 2002)
  - How can the lack of large-angle correlations (C) be resolved? (Starkman & Schwarz, 2005)
  - Is there a cosmological constant? (Krauss & Turner, 2004)
  - What is the geometry of the universe? (Krauss & Turner, 2004)
  - How might cosmological observations illuminate the relation between gravity and quantum mechanics? (Krauss & Turner, 2004)
  - Where should we look for differences between general relativity and its successor theory – short distances or cosmic differences? (Krauss & Turner, 2004)
Cosmology Presentation Outline
by
Bill Kelly
for
Planetarium and Classroom Demonstrations

I. Background Information about Hubble and Humason including powerpoint slides with pictures of scientists.
   A. 1920. Hubble saw galaxies moving away from each other.

II. Presenter will talk about how Hubbles' ideas about galaxies supported the "Big Bang Theory"
    A. Show Hubble Space Telescope images and discuss how they improve our understanding of our universe.

III. Brief overview of some of the other theories and developments that evolved from Hubbles' work.
    A. 1948 Hermon/Alpher- Predicted CMBR
       "Big Bang Theory" VS "Steady State Theory"
    B. Robert Wilson and Arno Penzias (Bell Labs) 1965 saw background radiation.
    C. 1965 the MAP showed no Fluctuations in density
       Einstein “Space time has curvature.”

IV. Cosmology Activities
    A. Simulate Hubbles' view of Galaxies moving apart.
       1. Draw two Galaxies on an overhead projector and tape drawing paper to a wall.
       2. Shine the galaxies on the paper.
       3. Students will trace the galaxies on the paper in a blue marker
       4. Move the projector away from paper.
       5. Have the students draw the galaxies new location on the paper in green marker.
       6. Ask the students what is happening to the galaxies.
    B. Make a Model of the expanding Universe
       1. Tape dots to a balloon.
       2. Students or visitors will use a ruler to measure the distances between dots.
       3. The students or visitors will blow up the balloon half way and measure the distances between the dots.
       4. The teacher or gallery staff will ask the student if there is a difference in the distance between galaxies.
       5. The student will blow up the balloon more and measure the distance between galaxies.
6. The teacher or gallery staff will again ask the student if there is a difference in the distance between galaxies.

William KELLY

Cosmology Questions

Write a brief outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

Read the “overview” section of the National Research Council’s (NRC’s) “Cosmology A Research Briefing” Compile a brief list that, to the best of your knowledge, answers the following:

a. Which Problems listed in the summary have been solved since 1995?

To my knowledge and after reading some of the suggested articles it seems that cosmologists have a rough idea when the universe started based on the CMBR. This answers the first part of question one, when did the universe start. I believe cosmologists are still trying to determine how the universe will end.

b. Which have turned out to be less relevant since the summary was written?

Based on what I have read and currently understand, it doesn’t seem as though there is only one question posited in the 1995 article that is less relevant today than when they were written. The question of whether physics and cosmology offer a plausible description of creation seems to be less relevant because current research seems to be using both disciplines to solve the problems which have risen from current cosmological models. The rest of the questions presented in the 1995 article relate to current research in cosmology.

c. Which questions remain top priorities in the year 2005 and beyond?

Cosmologists still seem to be working on the question of what can we learn about physical laws from relics of the Big Bang. Many questions about the physical laws in relation to cosmology are examined in the article, “Eleven Science Questions for the New Century.

Another question that seems to be a top priority for investigation is if the universe underwent inflation at an early age. Even though inflation fits the model of the formation of the universe, it still lacks conclusive proof that cosmologists need. For this reason it seems a problem that will be a top priority for cosmologists to solve.

The article from 1995 examined the concept of dark matter however I did not read any discussion of dark energy until I read literature from a later date. After attending a presentation by Michael Lemmonick I learned that this is concept that is currently under investigations by cosmologists. Several of the articles from the suggested reading including, “Eleven Science questions for the New Century explore the concept of dark energy.

d. Are there any problems now recognized as important that are missing?

It seems that dark energy has become a topic for investigation that was not present in the 1995 article. The article, “eleven science questions for the new century” presents this as a problem cosmologists will examine. In particular cosmologists will look for the properties of dark energy.
Another problem presented in the article, “supernovae, dark energy, and the accelerating universe” by Saul Perlmutter is the problem of the search for a cosmological constant.
1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

My intention is to develop a show for the Galaxy Stage within DMNS’s (Denver Museum of Nature and Science’s) permanent exhibit Space Odyssey (SO). Currently we do a number of shows there, our most recent one being “Operation Super-Chill”, a show using liquid nitrogen to demonstrate what it might be like to visit Neptune’s moon Triton.

The show would deal with explaining the key elements of Big Bang cosmology. I would be working with SO’s team of educators to produce the show but one of my reasons for attending the cosmology short course will be to solicit ideas on how best to demonstrate Big Bang concepts. Concepts I’d like to demonstrate include the following:

- Uniform expansion: This will answer such questions like how we can know the age of the universe by running the movie backwards and why does the universe look the same from all points of few.
- Understanding the CMBR: I’m not sure what the best way to do this is, but I’d really like to give people a real sense of what they are looking at when we view the CMBR.
- Galaxy Building: This will answer questions in regards to how the structures in the universe can evolve from the tiny fluctuation in the CMBR. I’ve been thinking of ideas along the line of seeing macroscopic features grow out of microscopic ones. Again I’m looking for ideas on how to portray this.
- Why Inflation: Demonstrate the “horizon” and the “flatness” problems to standard Big Bang cosmology and why inflation solves them.
- Dark Matter and Dark Energy: Clearly separate in the visitors minds the difference in these two concepts. The choice of Dark Energy is somewhat unfortunate in my mind but I’m afraid it is here to stay.

The galaxy stage has several projection screens so that the show can be accompanied by digital media as well. There is also small hand held video camera that can show live video on these screens.
2) Read the "Overview" section of the National Research Council's (NRC's) "Cosmology A Research Briefing"

Which problems listed in the summary have been solved since 1995?

The age of the universe has been tightly constrained at 13.8 (plus or minus 0.2) billion years old. The epoch in which decoupling occurred seems to be revised to 370,000 years rather than 150,000 years after the Big Bang.

Though not completely solved, computer modeling of the evolution of the large scale structure of the universe seems to fit the initial fluctuations of the CMBR data provided by COBE and now WMAP. These models, however, seem to require the existence of primarily cold dark matter.

With several galaxy surveys now under our belts, it seems that we have a pretty good idea about the homogeneity scale of the universe.

Which have turned out to be less relevant since the summary was written?

The question of whether or not the universe will expand forever or someday collapse seems to be less relevant. The discovery of an accelerating universe seems to indicate that the universe will expand forever.

Which questions remain top priorities in year 2005 and beyond?

The nature of dark matter continues to be a top priority with an emphasis on finding cold dark matter.

The nature of what may have driven inflation continues to be a major question. Theories that inflation is a result of a phase transition related to the unification of the strong and electro-weak force still seem to be the front runners.

Are there any problems now recognized as important that are missing from the 1995 NRC list?

The big one is of course the discovery that the expansion of the universe is not slowing down but is in fact speeding up. This has led to the postulate of dark energy.

The problem of the unification of general relativity and quantum mechanics seems to be getting more press. This seems to be the realm of the string theorists.
1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

**Title:** The Expanding Universe

**Audience:** High School Science Students

**Summary:** After a brief survey of the night sky, the concept of an expanding universe will be introduced. The ramifications of this expansion will then be considered. The model of the hot Big Bang as an explanation of the observed universe will be thoroughly investigated. Many of the modern techniques used to refine this model will be included in the discussion. Problems remaining to be answered will be outlined at the conclusion of the presentation.

2) Read the "Overview" section of the National Research Council's (NRC's) "Cosmology: A Research Briefing." Note: this summary was written in 1995. Compile a brief list that, to the best of your present knowledge, answers the following:

- **Which problems listed in the summary have been solved since 1995?**
  
  *How did the large-scale structure of matter form, and how large is it?*

- **Which have turned out to be less relevant since the summary was written?**
  
  *Do physics and cosmology offer a plausible description of creation?*

- **Which questions remain top priorities in year 2005 and beyond?**
  
  *When did the universe start and how will it end?*
  
  *Did the universe undergo inflation at a very early stage?*
  
  *What is the dark matter and what is its cosmological role?*
  
  *What can we learn about physical laws from relics of the Big Bang?*

- **Are there any problems now recognized as important that are missing from the 1995 NRC list?**
  
  *What are the properties of dark energy?*
  
  *What are the masses of the neutrinos, and how have they shaped the evolution of the universe?*
  
  *Are protons unstable?*
  
  *Do new states of matter exist at exceedingly high density and temperature?*
Are there additional space-time dimensions?

How were the elements from iron to uranium made?

What is the origin of the highest-energy gamma rays, neutrino, and cosmic rays?
List concerning Cosmology Overview

Questions that have been solved (at least fairly well):

• The age of the universe. The overview states an age between 8 and 15 billion years old, but WMAP pinpointed the universe’s age to 13.7 billion years with a 1-percent uncertainty — plus or minus 200 million.
  ○ We also now know the CMBR isn’t an echo from 150,000 years after the Big Bang, as the document states, but 379,000 years after.
• How the universe will end is another area that has greatly advanced since 1995. Cosmologists have found the universe is expanding at an accelerated rate. This discovery came as quite a surprise.
• Cosmologists are fairly certain the universe underwent a period of inflation in its early times. WMAP helped prove this theory.

Less relevant:

• What the physical laws from the Big Bang can tell us seems to be not as important in research today. This surprises me; I would think, because this governs so much, the area would be more important?

Still priorities:

• What is dark matter? Even though cosmologists have a better understanding of what it may be (neutrinos or a new particle — WIMPs), they still don’t know.
• Large-scale structure: did smaller structures clump together to form larger ones? Or did larger structures fragment into smaller? SDSS and 2dF have allowed scientists to observe the structure, where computer simulations have helped with theory.
New questions:

- The finding of the “end” — the universe’s accelerating expansion — brings the question of what is causing this? Enter “dark energy.” Cosmologists are fairly certain (from WMAP) the universe is composed of about 73 percent dark energy, 23 percent dark matter, and 4 percent ordinary matter. We understand about 4 percent of the universe ... that leaves 96 percent to still learn about.
Instead of writing an outline of a cosmology exhibit, I thought I’d come up with an article idea for *Astronomy* magazine:

A cosmology “primer” would be extremely helpful to our readers. This would cover the basics of all different aspects of the field. Included would be thorough definitions and diagrams. This would probably be a compact 4 or 6 page article.

Would cover:

- A timeline of events (probably serving as the order and outline)
- The initial explosion, the Big Bang
- Formation of particles — Big Bang nucleosynthesis
- CMBR, steps leading up to it, decoupling, recombination
  - What the map tells us
- Large-scale structure
- Dark energy
- Dark matter
- Redshift, cosmological distances
- “Dark ages” and “first light”
- Formation of the first stars and protogalaxies (bottom up versus top down)
- Recent findings and where we go from here
I. What is Cosmology?

II. What Is Known About Cosmology?

III. Who Made Early Discoveries?

IV. What is the Hubble Constant?

V. Role of Technology
   a. Early Discoveries
   b. Recent Discoveries
   c. Satellites
   d. Computers

VI. What is Dark Matter?

VII. What is Cosmic Microwave Background Radiation?

VIII. What is Large Scale Structure of the Universe?

IX. What are Cosmic Velocity Flows?

X. What are Redshift Maps?

XI. What are Gravitational Lenses?

XII. What is the Role of Particle Theory?

Comments on NRC 1995 Research Briefing

Overview

Cosmology – Make observations,
Seek basis of scientific understanding of how the universe
Use the tools of modern physics to develop theories and test models of the evolution of
the universe from the creation to the present and into the future

Inflation and Dark Matter have revolutionized modern cosmology

Hubble Expansion – The more distant a galaxy is from the Milky Way, the faster it appears to be
moving away from the Milky Way. Working backward the universe was created during a definite
time between 8 and 15 billion years ago.

Hot Big Bang Model
Early Universe – enormously dense and hot consisting mostly of radiation. The universe cooled as it expanded. Best Description of evolution

Bell Laboratories 1964 – Scientists studying radio antenna noise discovered the cooled-down remnant that we now know as the Cosmic Microwave Background Radiation from the Big Bang Model

1990 COBE (Cosmic Background Explorer) satellite
1. Data confirms original existence of the CMBR & irregular data
2. Galaxies are not uniformly distributed. Huge areas of the universe in a bulk mass are moving at high speed relative to the CMBR.

Scale of structure in Universe is enormous and complex

Theoretical Particle Physics offers explanations.

**Dark Matter**
Dominates the universe, Nature is unknown
Unseen mass binding together galaxies and clusters of galaxies

**Gravitational Lensing**
Ability to bend light from distant stars or galaxies

**Tools of New Era for Observational Cosmology**
Hubble Space Telescope
10 Meter Keck
8 Meter Gemini Twins

**Theoretical Calculations based on Earth Physics**
Nuclear reactions predicted to occur when the universe was one minute old produced the light elements helium, deuterium, and lithium. Predicted abundances agree with measured abundances of these elements.

CMBR lumps that were seeds for the formation of the large-scale structure can be traced back to the quantum fluctuations in the first minute second after the Big Bang.

**Cosmic Questions**

- **When did the universe start and how will it end?**
  Universe is expanding
  Galaxies are moving apart
  Started 8-15 billion year ago
  End of Universe
  Expanding Forever
  Stop expansion, halt, and collapse
  Measure the average mass density of universe and find out if there is enough gravitational force to stop the current expansion OR
  Observe expansion velocities of galaxies at greater distances and in earlier times to measure the rate at which universe is slowing down.
• What is Dark Matter and What is its Cosmological role?
  Cannot be observed directly
  Does not shine like a star
  Cannot see it
  Can observe its effect on other matter
  Dominate form of matter in the universe is unknown to man

• How did the large scale structure of matter form and how large is it?
  Over large scales the Universe is homogeneous
  Over small scale of just 5% of the CMBR distance the universe is clumpy and uneven.
  How did the universe evolve to this point?
  Data from large sky surveys of a million galaxies provide data
  Need to understand the CMBR bumps and large-scale structure

• What can we learn about physical laws from relics of Big Bang?
  Density and temperature was just right to generate most of the helium and all of the deuterium present in the universe today.
  Physics laws work back then and now today
  Elementary-Particle physicists trying to understand the observed ratio of photons from the CMBR to hydrogen atoms in the universe

• Did the universe undergo inflation at a very early stage?
  Problems with the Big Bang Model
  How did regions never in casual contact manage to reach the same temperature as indicated by the all-sky CMBR measurements?
  Why is the density of the universe so close to the critical density required to stop the expansion?
  Extraordinary coincidences must have been present in the values of the cosmological constants in the initial universe

  Problem for Cosmologists – balance the kinetic energy of expansion to the potential energy of gravity

  Inflation
  Based in elementary particle theory
  Supported by COBE satellite
  Predicts particular size distribution for the bumps in the CMBR Universe went through a huge rapidly accelerating expansion extremely early
  Adjusts density to precisely the critical value needed to balance the expansion

• Do physics, cosmology and creation?
  On speculation suggests the universe as the result of a tiny quantum fluctuation in the vacuum under the right circumstances this could expand to larger than the entire observable universe. Should taxpayers fund this?

Benefits of Cosmology Research
1. Technical Spinoffs
Developments in instrumentation for collection, manipulation, and detection of radiation in electromagnetic spectrum
   Radio, Infrared, Visible, Ultraviolet, and X-ray

**Understanding Radiation Improves**
Radar
Remote sensing
Optics
Medical radiology
One-of-a-kind instruments
Models for effective technology transfer
Large scale computing to run modeling programs

**Fermi National Accelerator Laboratory**
Large scale cosmological projects and sky surveys drive innovative hardware and software developments

**Collaborative Teams Drive Research**
Astronomers, physicists and engineers

2. Ability to probe matter under extremes of density and temperature not achieved on Earth laboratories today
   3. Intellectual appeal Excites human imagination
   4. Affects religious beliefs, ethical choices, and human behavior

**Still Unknown**

Accurate age of Universe
Timing of the Epoch of Galaxy formation
Dark Matter
A Brief Planetarium Show

A Perspective of Cosmology

Play selected music & bring up star ball.

As lights dim and music fades define the following terms: A.U., L.Y., Parsec, & Cosmology to start.

Explore planetarium sky. Point out significant areas.

Explain Galaxies. Point out Andromeda

Move to Virgo. Show where Hubble discovered many galaxies

Tell Hubble’s history. etc.

Explain Doppler Effect

Tell about Wilson and Pensias---- CMBR

COBE

Tell about Discoveries & future research

Illustrate the above with a variety of slides, pictures, and overheads.

Problems Solved

1. The Universe is expanding.
2. CMBR Consistant with hot Big Bang model.
3. A major component of the Universe is "dark matter".

Less Relevant

1. Galaxies are not uniformly distributed.
2. Just when the universe under went inflation.

Top Priorities

1. The continued study of "dark matter."
2. Learning from the relics of the Big Bang.
3. Investigate photon decoupling when the universe was stronger, denser, and hotter.
Cosmology: A Research Briefing

- We now know the Universe began 13.7 billion years ago, give or take 100 million years.
- We now know dark matter makes up about 23% of the total matter & energy content of the Universe.
- We have yet to identify the nature of dark matter.
- We now know the CMBR is from a time approximately 379,000 years after the Big Bang.
- We now think the lumps in the CMBR might be from quantum fluctuations.
- We now know stars began forming approximately 200 million years after the Big Bang.
- We don’t yet know when galaxies began forming.
- The Universe appears as though it will expand forever, but we don’t know enough about dark energy to say for sure.
- It turns out that the Universe isn’t slowing down, but is actually speeding up.
- We still don’t know for sure if our Universe began as a tiny quantum fluctuation.
- We still don’t have an explanation for the observed ratio of photons to hydrogen atoms.
- We don’t know what the nature of dark energy is, which is causing the Universe’s expansion to accelerate.

Cosmology Show: *From The Void*

Lakeview Museum has plans for producing an in-house planetarium show related to cosmology, called *From The Void*. It is scheduled to open next spring.

The show deals with the concept of “nothing.”

Much of cosmology is related to the show’s concept, including: dark energy, dark matter, inflation, virtual particles, black holes, and the birth of the Universe.

Mixed in with the scientific concepts pertaining to “nothing” will also be historical and philosophical views on the matter, some of them serious, some of them humorous.

We also plan on interrupting the programmed portion of the show with live presentations and demonstrations to help clarify some of the scientific concepts. Hopefully some of the presentations and discussions in Chicago will provide fruitful ideas for this mode of education.
1. Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

Space Exploration Display Wall

An exhibit that would be relevant to this course for our Cosmology Gallery at the Adler is a Space Exploration Display Wall. The exhibit would allow visitors to investigate and explore data from the National Virtual Observatory (NVO) and the Sloan Digital Sky Survey using the image-cut-out service provided by NVO on a large titled display wall. The display wall would be composed of LCD screens with touch screen capabilities. Visitors would be able to touch a star, galaxy or other object, and get information on that object (its type, distance, brightness, what type of object it is etc.). These objects could then be logged in a database and classified according to their attributes. A single floor mounted display would keep track of these logged objects, allowing the visitor to visualize the information investigated by the larger museum audience. The floor mounted display would also control the region of sky being studied on the large tiled display, and would allow the user to independently explore the sky and explore the sky through other people observations. This exhibit has the potential to highlight the Sloan and NVO web technologies, which offer prime examples of current science research. The exhibit will also show visitors what the sky actually looks like, and what type of data astronomers take, thus offering visitors an authentic exploration data.

2.

a) Which problems listed in the summary have been solved since 1995?

Questions (before 1995)

"As the universe gets older, the horizon moves out, bringing more of the unseen universe into view. What is the nature of the "stuff" beyond the horizon?"

Our understanding of the very early universe: "The cosmological picture gets much fuzzier and more speculative as one tries to understand more distant, earlier conditions and events."

Is "our entire universe as the result of a tiny quantum fluctuation in the vacuum?" "the nature of the dark matter still remains a mystery"

"What did galaxies look like soon after formation?"

"How do [galaxies] evolve? When did they form?"

Did CMBR lumps that act as seeds for the formation of the large-scale structure that can be traced back to quantum fluctuations occurring in the first billion billion billion billionth of a second after the Big Bang?

Answers (after 1995)

Wilkinson Microwave Anisotropy Probe (WMAP): We can now more precisely measure the fluctuations in the cosmic microwave background. Cosmological isotropy was an issue in 1995 but today is no longer relevant, thanks to these WMAP observations. Hubble constant: determining the hubble constant to better...
than 5% has helped to determine the accurate age of the Universe. The universe is expanding at an increasing rate. Neutrino mass was found after 1995.

b) Which have turned out to be less relevant since the summary was written?
Measurements of CMB harmonics have produced a new diagram of sound waves in the dense early universe, which strongly supports the inflationary Big Bang model. Topological defects have become less relevant after 1995. Cold and hot dark matter and mixed-models were a big thing in 1995. Now hot dark matter is synonymous with neutrinos (and yet their mass has been determined to be so little that it makes little impact) and cold dark matter is still a mystery.

c) Which questions remain top priorities in year 2005 and beyond?
Top 2 Questoins: What's the nature of dark matter? and what's the nature of dark energy? sn@er@adlerplanetarium.org
1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution. [due on or before 9/15]

The Argus Planetarium is a school planetarium. Our audience is primarily students from our own district. Each year over 5,000 students in grades 1, 3, and 6 make a required visit to the planetarium. With 4 High Schools, 6 Middle Schools, and 21 Elementary Schools, this adds up to about 300 shows per year. Optionally, about 50 high school classes visit the planetarium, coming from Earth Science, Accelerated Physical Science, and Physics.

Basic cosmology is a part of every visit except the 1st grade. Using our Digistar projector, we slowly work our way out from Earth, until we end up about 12 billion light years from home. By switching visual databases in the Digistar, we view the Earth-Moon system, the solar system, our local stars (the Hipparcos catalog), the Milky Way, and finally the visible universe (a database of about 30,000 of the brightest known galaxies out to a distance of about 12 billion L.Y.)

While we travel outward, my live narration explains what we are seeing, adjusted to the age level of the audience. I may include a discussion of the Big Bang, background microwave radiation, cosmological red shift, the “bubble-like” structure of the universe, time dilation, 11 dimensions, etc.

This last part is where I really need help. I would like to include a lot more cosmological detail. I envision “windows” and/or full-dome visuals that illustrate cosmological red shift, the curved nature of space, microwave background, etc. Unfortunately, I am discovering that my information is very out of date.

My brief introduction to cosmology currently reaches over 4,000 students per year. I do not anticipate that the number of students will change, but I do expect that the depth and accuracy of the introduction will improve considerably.
1) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

Our plans for revamping our cosmology gallery at the Adler include a focus on the “timeline of the universe,” going back in time from the modern era, from the formation of galaxies and clusters, to large-scale structure and cosmic microwave background radiation, to nucleosynthesis, inflation, and finally the Big Bang itself.

The focus of each element of the exhibit will be the on the controlling physical processes of each era, from gravity, relativity, light, chemistry, and finally nuclear physics.

Each element of the exhibit will have different interactives to engage visitors regarding key concepts, such as the red shift of moving galaxies, optical lensing (as an analogue to gravitational lensing), an “adiabatic compressor” (to demonstrate the “heat” remains of the CMB), and a “Big Bang mini-dome” to give visitors a sense of the beginnings of the universe.

Key concepts to be emphasized shall be ideas such as phase transition, attempting to relate ordinary experiences such as the phase transition of water to ice and steam to the phase transition of matter from quark-gluon plasma in the early universe to baryonic matter, and then baryonic matter into the earliest elements.
2) a) Which problems listed in the summary have been solved since 1995?

- Value of the Hubble constant found to be $\sim 72 \pm 8$ (km/s)/Mpc (2001, Hubble Key Project), $71 \pm 4$ (km/s)/Mpc (WMAP satellite, 2003).

- Neutrino mass – found, but not large enough to account for the “missing matter” in the universe

b) Which have turned out to be less relevant since the summary was written?

- Age of the universe: with a more precise measurement of the Hubble Constant, the uncertainty in the age of the universe has been greatly narrowed. While some margin for error still remains, it appears to be far less disputed than before.

- “Hot, dark mater”: neutrino mass isolated but far too small to account for the missing matter in the universe.

- “Cold, dark matter”: some baryonic dark matter found in low-density oxygen clouds surrounding quasars show unique UV-absorption lines, i.e., “backlighting” (FUSE and Chandra findings, 2003).

c) Which questions remain top priorities in the year 2005 and beyond?

- Inflation theory and the nature of “Dark Energy”

- Large-scale anisotropy

- MACHOs, WiMPs, Supersymmetry, Axions, i.e., the “Dark Matter Problem”

d) Are there any problems now recognized as important that are missing from the 1995 NRC list?

- Variances from predicted values in the spherical harmonics of the CMBR – i.e., the “out of tune” universe at low frequencies.
SKUTNIK

2) Read the "Overview" section of the National Research Council's (NRC's) "Cosmology A Research Briefing" (available at http://www.nap.edu/readingroom/books/cosmology/).

Note: this summary was written in 1995. Compile a brief list that, to the best of your present knowledge, answers the following:

* Which problems listed in the summary have been solved since 1995?
* Which have turned out to be less relevant since the summary was written?
* Which questions remain top priorities in year 2005 and beyond?

Are there any problems now recognized as important that are missing from the 1995 NRC list?

i) Problems that have been solved since 1995:
- Anisotropy is unquestionably real.

ii) Problems that are less relevant:
- The existence of dark matter is less controversial.
- Curvature of the universe.

iii) Top priorities:
- Understanding the increasing rate of expansion of the universe.
- Understanding the meaning of the “lumps” in CBGR.

iv) Problems that were not on the 1995 list:
- Increasing rate of expansion of the universe.
SIMPSON

Clyde Simpson <csimpson@cmnh.org>
Subject: Re: Pre-course Assignment for KICP's Big Bang & Beyond (Sept. 23-25)

1) Cosmology planetarium program

"THE WAY WE WERE...ARE...AND MIGHT BE"

Our public planetarium programs are 1/2 hr. in length and include at least 10 minutes of current events and current sky description. The program will be a broad overview of the history of cosmology, with special emphasis on progress made in the past decade. We use slides/powerpoint, several special effects projectors (interacting galaxies, expanding universe, imaginary video fly-through of galaxies in space, etc.)

I. Introduction
Definition of cosmology, description of early Earth-centered models of universe, note persistent historical sense of human/Earth centrality in cosmos and the role astronomy and cosmology has played in displacing that centrality.

II. Big Bang
The history of astronomy has been characterized by humans exploring greater and greater depths of space with increasingly sophisticated technology. It is very appropriate that this expanding awareness of the universe resulted in a model that shows the universe itself is expanding.

III. Dark Matter
The notion of human/Earth centrality to the cosmos is echoed in the relative inattention of astronomers to early evidence that there exists unseen matter in the universe which makes itself known by large scale gravitational effects. Review of historical and current understanding and estimates of relative proportions of matter and dark matter. I'd like to present the ratio to the audience in something other than a standard pie chart. Perhaps the light level of a dimly illuminated planetarium dome could represent the amount of normal matter, and increasing the light level five-fold could represent the amount of dark matter. The two light levels should be kept fairly low in anticipation of similar treatment and addition of dark energy. (The disconnect of using increased light levels to illustrate something dark might be noted, but then again the discovery of dark matter was truly illuminating.) Two levels of a sound tone might also illustrate the example.

IV. Dark Energy
Discussion of discovery and known nature of dark energy. The relative proportions of dark energy, matter and dark matter might again be represented by varying planetarium light levels, with full illumination representing all matter and energy. Ending the program by returning to the fully dark skies of the planetarium will let the audience know that the cosmic panorama witnessed from a dark country site may appear vast, but is only a tiny fraction of a universe wider and more exotic than they had imagined. Within the discussion of dark energy, sound tones and overtones of several octaves might be used to illustrate the temperature ripples remnant from inflationary period.

V. The Future
Where do we stand in trying to discern dark energy and dark matter? What is the "shape" of the universe? Is it finite/wrapped around itself? How can we test? What is the ultimate fate of the universe.

2) LISTS
* Which problems listed in the summary have been solved since 1995?
  - age of universe has been determined
  - relative proportions of matter and dark matter have been resolved
  - confirmed that dark matter is not ordinary matter
  - far more detailed imaging of early galaxies with Deep Field views
  - universe is flat
  - more complete understanding of how galaxies form/evolve
  - finer resolution of biggest structures/scales of universe (WMAP)

* Which problems have turned out to be less relevant than when the summary was written?
  - age of universe at CMB now estimated at 370,000 years instead of 150,000
  - influence of ordinary/dark matter on structure and fate of universe
  - observing distant galaxy velocities to measure rate at which universe is slowing
  - conflict of results from various methods of estimating age of universe
  - ruling out ordinary matter as possible candidate for dark matter

* Which questions remain top priorities in the year 2005 and beyond?
  - how do galaxies form and evolve?
  - when did galaxies first form? stars?
  - what is dark matter? dark energy?
  - at what scales is the universe clumpy? - increasing resolution
  - description of creation of universe
  - what is the ultimate fate of the universe?
  - unification of general relativity and quantum theory

* Are there any problems now recognized as important that are missing from the NRC list?
  - what is dark energy?
  - acceleration rather than slowing of expansion of universe
  - did stars or galaxies come first?
  - "atonality" of temperature fluctuations in CMB
  - measuring polarization of CMB
  - will the Indians catch the White Sox and win the World Series?
3) Write a brief (no more than 1 page) outline of a cosmology show or exhibit you would prepare and present at your planetarium/institution.

Our plans for revamping our cosmology gallery at the Adler include a focus on the “timeline of the universe,” going back in time from the modern era, from the formation of galaxies and clusters, to large-scale structure and cosmic microwave background radiation, to nucleosynthesis, inflation, and finally the Big Bang itself.

The focus of each element of the exhibit will be the on the controlling physical processes of each era, from gravity, relativity, light, chemistry, and finally nuclear physics.

Each element of the exhibit will have different interactives to engage visitors regarding key concepts, such as the red shift of moving galaxies, optical lensing (as an analogue to gravitational lensing), an “adiabatic compressor” (to demonstrate the “heat” remains of the CMB), and a “Big Bang mini-dome” to give visitors a sense of the beginnings of the universe.

Key concepts to be emphasized shall be ideas such as phase transition, attempting to relate ordinary experiences such as the phase transition of water to ice and steam to the phase transition of matter from quark-gluon plasma in the early universe to baryonic matter, and then baryonic matter into the earliest elements.
4) a) Which problems listed in the summary have been solved since 1995?

-Value of the Hubble constant found to be ~ 72±8 (km/s)/Mpc (2001, Hubble Key Project), 71±4 (km/s)/Mpc (WMAP satellite, 2003).

-Neutrino mass – found, but not large enough to account for the “missing matter” in the universe

b) Which have turned out to be less relevant since the summary was written?

-Age of the universe: with a more precise measurement of the Hubble Constant, the uncertainty in the age of the universe has been greatly narrowed. While some margin for error still remains, it appears to be far less disputed than before.

-“Hot, dark mater”: neutrino mass isolated but far too small to account for the missing matter in the universe.

-“Cold, dark matter”: some baryonic dark matter found in low-density oxygen clouds surrounding quasars show unique UV-absorption lines, i.e., “backlighting” (FUSE and Chandra findings, 2003).

c) Which questions remain top priorities in the year 2005 and beyond?

-Inflation theory and the nature of “Dark Energy”

-Large-scale anisotropy

-MACHOs, WiMPs, Supersymmetry, Axions, i.e., the “Dark Matter Problem”

d) Are there any problems now recognized as important that are missing from the 1995 NRC list?

-Variances from predicted values in the spherical harmonics of the CMBR – i.e., the “out of tune” universe at low frequencies.
Earlier this year we ran a show called *Journey to the Edge of Space and Time*, from the Museum of Science in Boston. The show covers some cosmological basics: black holes, dark matter and the CMB. But for me, the show didn’t go into enough detail. I would like to create a show that really expands on the framework of *JEST*. Maybe a sequel, or an updated version.

1. **Introduction**
   1.1 Brief history of cosmology: Overview of the research and studies by Einstein, Lemaitre and Hubble
   1.2 Discovery of the CMB: Penzias and Wilson’s fluke discovery, and how it supported current ideas.

2. **Attempting to peer back in time**
   2.1 COBE: Launch and early measurements from the craft. What new information did it provide?
   2.2 WMAP: Launch and enhancements of COBE detail. How has this advanced and solidified our knowledge of cosmology?

3. **What we have learned**
   3.1 Dark Matter: What is it? Where does it come from? How do we locate it?
   3.2 Large scale structure of the universe: How is everything related? How does what we currently see help us understand the earliest moments of our universe?

4. **Where do we go from here?**
   4.1 Unsolved mysteries: What cosmological aspects are scientists still trying to solve? How is it all going to end? Big crunch, big rip, how can we find out? Which theories are most accurate, and which will fade away.
   4.2 New spacecraft and observatories: How are we figuring out those unsolved mysteries? Planck Surveyor and the Beyond Einstein program.

5. **Conclusion**
   5.1 What is our place in the universe? What can we really expect to discover about humanity and the universe?
SMAIL

What listed problems have been solved:
WMAP put the age of the universe at 13.7 billion years. Not quite solved, but certainly better than “between 8 and 15 billion years old”

Which items are now less relevant:
It really depends on your frame of reference. To John Doe on the street, most of this probably isn’t relevant to his daily life. To a cosmologist, it’s all relevant. I would guess that the problems that have been effectively solved, aren’t as relevant today as they were prior to being solved. The problems that didn’t create new problems upon their completion, that is.

Which items are still top priorities:
Pinpointing the nature of dark matter.
How will the universe end?
Did you the universe undergo inflation at a very early stage? – Since the writing of the article, much more has been proposed and understood regarding the Inflation theory. I’m sure that all the problems haven’t been solved, but now that Inflation is more widely regarded, it’s a bigger priority.

Any current problems missing from overview:
Not that I’m aware of, but certainly some new problems have presented themselves over the past decade.
Outline of Cosmology Show for MSUM Planetarium (40 minutes long)

Audience: High School Science Class

I. Brief look at the current night sky. I think it’s important in a planetarium to always show what the audience can see for themselves outside on a clear night.
   A. Point out the Andromeda Galaxy as the only other galaxy that we in Moorhead can see with naked eye.
   B. Concept of “look-back time” Everything we see in the sky is as it used to look.

II. Cosmology- the study of the origin and the evolution of the universe. Historically people have constructed cosmological models for millennia, but the scientific study of cosmology is a relatively recent phenomenon- a little less than 100 years.

III. Two basic theories were proposed Give brief definition of each
   A. Steady State
   B. Big Bang

IV. To distinguish between theories we must look at
   A. Evidence that we can observe
   B. And even more importantly once a theory is constructed we look for predictions which can be confirmed by observation.

V. Evidence
   A. Einstein’s general theory of relativity leads to birth of modern cosmology.
   B. An expanding universe was discovered by Hubble and Humason. Describe how this was done.
   C. Distribution of galaxies and surveys that have been done.
   D. Olbers’ Paradox
   E. Cosmic Background Radiation
   F. Study of the oldest stars.
   G. Dark Matter

VI Simple Outline of Big Bang

VII. Fate of the Universe
   A. Expand forever
   B. Collapse
   C. Evidence favors the former.
Comments on NRC 1995 Research Briefing

1. Problems that have been solved since 1995.
   a. Age of the universe is between 13 and 14 billion years.
   b. The universe will keep expanding forever.
   c. The universe did undergo inflation at a very early stage.

2. Problems which are less relevant.
   None that I am aware of.

3. Problems which remain top priority.
   a. What is dark matter and what is its cosmological role?
   b. How did the large-scale structure of matter form, and how large is it?
   c. What can we learn about physical laws from relics of the Big Bang?
   d. Do physics and cosmology offer a plausible description of creation?

4. New important problems that were not recognized in 1995.
   a. What is the “dark energy” that is accelerating the expansion of the universe?
   b. Are there multiple universes?
   c. How does string theory, which was discredited in the 90’s but is now re-emerging as an important theory, figure into cosmology?
   d. What powered the Big Bang?
Ken Wilson

The Cosmic Time Machine – a proposed cosmology exhibit

This exhibit would be an interactive, audio-visual exhibit that would graphically show the entire history of the universe, as we currently understand it, from just before the Big Bang to the current era. The exhibit would consist of:

- a large 3-D video screen
- a single pilot’s seat large enough for one adult and child to share
- a couple rows of seats behind the pilot’s seat for other visitors or family members to sit and watch the session.
- A large-handled lever like a ship’s engine telegraph that’s easy but slow to move and labeled “Big Bang” at one extreme and “Now” at the other extreme, with whole billion year division markings.
- Audio system with overhead and surround speakers for recorded narration and sound effects/music.
- Optional: Seats have motion actuators for ‘theme park-like’ bumpy ride effects.

Operation: The visitor at the controls can move the lever to any point in the past along the cosmic time scale and see a narrated 3-D computer generated graphics illustrated description of what the universe was like at that time. An optional button would take you through the whole time range from Big Bang to Now in 10 minutes.

Cosmology: A Research Briefing – Overview

Solved Problems:

What’s the age of the universe?
Did the universe undergo inflation at a very early stage?

Problems Less Relevant Now:

How did the large-scale structure of matter form, and how large is it?

Current Top Questions:

What’s dark matter and its cosmological role?
RYAN WYATT
My program is a live piece based on the American Museum of Natural History's Digital Universe. I delivered a similar show in May 2004.
Sorry if what follows is a tad long.

===

"The Big Bang and Cosmic Construction"

Begin at the beginning, as close as possible to the Big Bang, then travel through space and time. In our visuals, Earth will remain at the center: the "here and now" is a single point that corresponds to the location from which we make our observations. Stepping away from that point takes us through space and time, with the outermost shell of space-time in most the distant past.

Begin outside the WMAP image wrapped on the surface of a sphere.
Describe the scale of the WMAP image, then fly down to the location of the Milky Way (i.e., see WMAP as we observe it), then back out: this is the Observable Universe. We will "fill in" the intervening volume.

WMAP is a snapshot of the earliest universe, from the point in time at which matter and light decoupled. Describe structure in terms of smoothing and "acoustical" time scales, then clarify that these are tiny fluctuations (one part in 100,000) in a very uniform medium.

This picture tells us a lot. WMAP results indicate that the Universe is 13.7 billion years old, with a margin of error of close to 1%. Light in WMAP picture is from 379,000 years after the Big Bang, and the first stars ignited 200 million years after the Big Bang.

Content of the Universe is 4% atoms, 23% Cold Dark Matter, and 73% Dark Energy. Data places new constraints on the Dark Energy, which seems more like a "cosmological constant" than a negative-pressure energy field called "quintessence," but quintessence is not ruled out. Fast-moving neutrinos do not play any major role in the evolution of structure in the Universe: they would have prevented the early clumping of gas in the universe, delaying the emergence of the first stars, in conflict with the WMAP data. WMAP also gives an expansion rate (Hubble constant) value of $H_0 = 71$ (km/sec)/Mpc (with a margin of error of about 5%) and provides new evidence for Inflation (in polarized signal). For the theory that fits our data, the Universe will expand forever (the nature of the dark energy is still a mystery, so if it changes with time, or if other unknown and unexpected things happen in the universe, this conclusion could change).

Travelling in toward Earth's position, we reveal the locations of the Sloan quasars, then the Sloan galaxies. Describe that SDSS one of the largest astronomical surveys undertaken and will eventually cover about 25% of the sky. Numerous terabytes of data have already been released to the public. Describe fan shape (i.e., it's not that there are no galaxies elsewhere, but rather that only a portion of the sky is being covered by the survey. Note that we see more structure in galaxies, less in quasars.

Turn off WMAP so it's no longer a distraction.

Then compare the 2dF survey with Sloan. Note that these are unprecedented surveys: we have automated the tricky process of measuring redshifts, which has enabled a new look at the large-scale structure of the Universe.

Move in to reveal Tully's atlas of approximately 30,000 galaxies.
Now we're looking at the local Universe, a mere 300 million light years on the diagonal, but we can still see the clusters, clumps and voids that are evident in the Sloan and 2dF data. We can also subset structures:
note the dense clusters of galaxies (e.g., Virgo Cluster) and larger structures such as the Great Attractor. Show density isosurfaces and note the resemblance to the WMAP image, albeit on a much smaller scale. Somehow, the density fluctuations of the early Universe evolved into the smaller variations we see nearby. One of the great challenges of modern cosmology is piecing this puzzle together.

Punchline: this is observed data! From a location near Milky Way, turn off the points that represent galaxy positions and show simply the images of the galaxies (appropriately scaled, but slightly brighter than the actual galaxies). This is what the observed universe looks like, with only a few faint patches of light visible. Reinforce the difficulty of cosmological observations. Turn Tully points back on and describe the Zone of Obscuration, where we cannot make observations because the disk of the Milky Way blocks more distant light. Turn 2dF on and show the observational bias and telescope pointings. Pull outside Tully and away from 2dF, then switch to the Sloan galaxies plus quasars. Finally, bring back WMAP.

End where we began: outside the WMAP "sphere." We are now outside the Universe in both space and time. If we reside inside the Observable Universe, what lies outside? Other observers? The reason our map appears inside-out is because it's a map of observed data: we are not the center of the Universe, but we do lie at the center of our observations, plotted in terms of distance (in space *and* time) from us. What you see is a map, one which has even more challenging limitations because it includes both spatial and temporal elements, but nonetheless, simply a map of plotted data.
Intro:
• Regular night sky, stars, planets, SS objects
• Hints at things you cannot see, nebulae, galaxies, (begin by showing the visible clues-the Orion Nebula, the Andromeda Galaxy)
• Looking further out, to clusters of Galaxies, semblance of structure.
• How do we know? Cosmology!

Part I: History
• Quick survey of (western) ancient views of the Cosmos
  Mesopotamian, Sumerian ideas, to Greek, Roman, Enlightenment
• Hubble and the Expanding Universe, Age of the Universe
• Sky Observatories and what They tell us (show us)

Part II: Current Knowledge
• What is the Big Bang? How do we know?
• How did we find out about : String Theory, Dark Matter, Dark Energy?
  And what do we currently know about these topics?
• What Does the Large-Scale Universe Look like (Galactic Super Structures)?
• What was Inflation?
• How did Galaxies form?

Part III: Future: What are the Questions to be answered?
• What is Dark Energy?
• What is Dark Matter?
• What is the Shape of the Universe
• Big Whimper or another Big Bang?

Conclusion:
Why do we care? Why study Cosmology? What might we learn about ourselves?

Assignment 2:
Comparing the Cosmological knowledge of 1995 to that of 2005.
Carrie JE Zaitz

Compile a brief list that, to the best of your present knowledge, answers the following:
* Which problems listed in the summary have been solved since 1995?
* Which have turned out to be less relevant since the summary was written?
* Which questions remain top priorities in year 2005 and beyond?
* Are there any problems now recognized as important that are missing from the 1995 NRC list?

Questions from 1995:
1. When did the universe start and how will it end?

2. What is the dark matter and what is its cosmological role?

3. How did the large-scale structure of matter form, and how large is it?

4. What can we learn about physical laws from relics of the Big Bang?

5. Did the universe undergo inflation at a very early stage?

6. Do physics and cosmology offer a plausible description of creation?

7. What did galaxies look like soon after formation? How do they evolve? When did they form?

Problems solved since 1995: Have any of them been “solved”? We are learning more about galaxies as we look farther and farther back with the Hubble- I’d say the Deep Field and the Ultra Deep Field have given us much of our information, and that wasn’t available back in 1995. In fact, most of the fantastic images and the data we learn from them hadn’t been made yet. We’ve seen that there are basically two types of galaxies (spiral and elliptical), but we still don’t know why or how they formed that way. (As far as I know- which must preface this entire essay...) We’ve also learned more about the large scale structure of the universe as more galaxies have been mapped- the little pie wedge that we used to have has been expanded to a fuller picture of the stringy large scale structure of the galaxies. Our ideas about the inflation era of the Universe are more defined than in 1995, or at least pretty accepted.

Less relevant today: The creation question- with the current political-religious climate, I’m not sure if questions about science explaining creation are in the forefront. I also haven’t heard of research in this area lately- going back to the moment of the big bang and the start of everything. Perhaps, like SETI, it was deemed not important enough a question to study? Again, that’s my perception- maybe I’ve missed the research. Learning about physical laws from the Big Bang: I’m not sure about, “the observed ratio (with a value of 1010) of photons from the CMBR to hydrogen atoms in the universe.” Has that been studied?

Top 2005 questions: Questions about the nature of Dark Matter and Dark Energy are still on the list, questions about galactic formation are pretty hot- especially with the notion that all galaxies contain black holes, and that the size of the BH seems to have a strong relationship to the size of the galaxy itself. I would think string theory would be in the running, though it’s been around for awhile. The question of the fate of the Universe is a perennial favorite topic, and still wide open, AFAIK.

Missed Questions in 1995: There wasn’t mention of the topic of High Energy Astronomy- the high energy rare particles that we are trying to study to find out where they come from and if they can tell us more about events in the early Universe. I think questions about the lack holes in the center of galaxies, especially ours, is missing.

I had my first course in Cosmology in 1985, and back then we were trying to figure out the age of the universe and the value of Omega. Things have come a long way, and I’m looking forward to learning more about what we know in 2005.
Planetarium show
Gene Zajac
Happy Birthday!

I think a good theme leading to the Big Bang cosmology would be to compare it to a person and their birthday event. Each person has experienced a birth and there is observable evidence to determine the age of that individual. Through observations of behavior we can guess at an approximate age. For humans we also have the good fortune to observe many humans at various stages of growth. To my knowledge we cannot observe other universes as they mature. But we could not determine the birth day but could we get close to the year?

I would examine the Earth’s movement to determine what makes the unit of measurement called one year. Mentioning the struggle of cultures to determine the year could be brought into play. I would determine ages of people on other planets using video and PowerPoint as a means to show the orbits of the planets. I am not quite two on Saturn and I have been teaching for a long time in Mercury years. I am entering my 135th teaching year which should equal a very good retirement!

What about the age of the Earth and Moon? Here I would bring in the idea of dating rocks geologically. If there is time in the program, I would discuss cratering counts as a method of determining the age of a celestial object’s age.

The formation of the sun and a typical star would be next. Using Hubble images we can find stars being born and understand its process.

How old is the universe? What evidence do we have that the universe is in fact aging? Stars evolve. Theorists examine the age of stars which will at least tell us how old things should be. One cannot be older than their parents and a star cannot be older than the universe. Does the theory of a Calvin and Hobbs birth (The Great Horrendous Space Kablooey) have supporting evidence? The discovery of Edwin Hubble and the redshift of galaxies would be presented here. Following this evidence I would add the temperature of the background radiation.

What do we know about the universe today? The number of stars is part of our state standards so I mention it here. Surveys and distribution of galaxies is important to looking at the birth of the universe. The audience I am thing about will be multi-aged and thus I will talk about dark energy and dark matter briefly.

In science we want to know about our past and also about our future. I will give a few ideas about the future of the universe. I have a great clip showing the Big Crunch. The program ends with a new beginning. A good sound clip to end would be that of a baby crying or one of a baby in a crib playing with a star mobile. The End

Overview summary
Gene Zajac

Which problems have been solved?

I think the mass density has been more closely examined. The velocity of the expansion view has changed from one that is slowing down to the increase of expansion due to dark energy.
The age of the universe range has become narrower than the 8 to 15 billion years stated in the article. The dominant matter was unknown in the article and I think there are better ideas describing it. Finer details than COBE measurements are now being examined. The role of Spitzer should help. The destiny was a major question and we may be closer to that answer but I am unsure. The timing of galaxy formation and the tiny fluctuations seen early in the universe has probably gained more evidence through improved techniques. This is one of the items I think will be discussed at our time in Chicago.

Which main top priorities in 2005 and beyond?

Dark energy and dark matter are two important ideas that I need to discover and understand. The theory to look at the unification of the four major forces after the instant of the big bang. Are there other universes or a recycling of this universe? Laws of physics seem to be present everywhere. Are we missing any underlying principals of physics, especially with the inflation period? How much farther back in time have we gone? How did the structures of the universe form with these fluctuations? It seems many agree COBE data needed to be improved.