Cosmology: The Origin, Evolution & Ultimate Fate of the Universe

An Introductory Resource Guide
For College Instructors

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Produced by the NASA Astrophysics Forum,
with input from the NASA Astrophysics E/PO community
and the astronomy higher education community.

NASA missions, educational programs, and cosmologists themselves have produced a wide range of materials that astronomy instructors (and their students) can use to learn about the latest developments in modern cosmology. Too often, however, these materials go unused because instructors are not familiar with them or don’t have them accessible at the time they need them. This annotated guide, the first in a series, is designed to highlight useful materials on the web and in print. It was produced in consultation with a selection of Astronomy 101 instructors, who were interviewed about their teaching, and NASA education specialists, who suggested resources that may not have been well known.

Cosmology is an enormous field, and the number of introductory resources is a bit overwhelming. Here we include only a sampling of non-technical materials that instructors around the U.S. have been using and are likely to have access to. Additions to and comments about the usefulness of this list are more than welcome and can be directed to Andrew Fraknoi (fraknoi@fhda.edu) and Greg Schultz (gschultz@astrosociety.org).

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WEB SITES

Selected Web Sites on Modern Cosmology

NASA Resources

NASA Universe Forum Big Bang Pages (Harvard-Smithsonian Center for Astrophysics):
http://www.cfa.harvard.edu/seuforum/bigbanglanding.htm (brief, basic introduction to some of the key ideas)

Planck Mission Education and Outreach Materials (Caltech): http://planck.caltech.edu/epo/epo-intro.html (some basic, some more advanced, information, focusing on the cosmic microwave background radiation)

Universe 101: WMAP Mission Introduction to the Universe (NASA): http://map.gsfc.nasa.gov/universe/ (Concise primer on cosmological ideas from the WMAP mission team)

Dark Energy (Part of the Hubble Discoveries Series): http://hubblesite.org/hubble_discoveries/dark_energy/ (Flash-based multimedia tutorial on the discovery and meaning of dark energy; includes information on the origin and fate of universe)

Resources from Other Sources

Sean Carroll’s Cosmology Primer (Caltech):
http://preposterousuniverse.com/writings/cosmologyprimer/index.html (Astrophysicists Carroll offers a non-technical site with brief overviews of many key topics in modern cosmology.)

Ned Wright’s Cosmology Tutorial (UCLA): http://www.astro.ucla.edu/~wright/cosmology.htm (Astronomer Wright keeps a rich web site where he explains many ideas in cosmology using basic algebra and geometry.)

The Universe Adventure (Lawrence Berkeley Labs): http://www.universeadventure.org/index.html (A flashy introduction to cosmology, designed for the public, but probably best read by those who already know a bit.)

Everyday Cosmology: http://cosmology.carnegiescience.edu/ (An educational website from the Carnegie Observatories with a timeline of cosmological discovery, background materials, and activities.)

Great Debates in Astronomy: http://apod.nasa.gov/diamond_jubilee/debate.html (Between 1995 and 1998, astronomers Robert Nemiroff & Jerry Bonnell put together some cosmological debates in the same hall at the Smithsonian’s Museum of Natural History (and along the same lines) as the Shapley-Curtis debate, with some of the leading cosmologists of our day; sometimes technical)

Runaway Universe (2000 NOVA TV series episode web site): http://www.pbs.org/wgbh/nova/universe/ (Focuses on the discovery of the acceleration of the expansion of the universe, using supernovae as distance indicators)

Brent Tully’s “How Big is the Universe?”: http://www.pbs.org/wgbh/nova/space/how-big-universe.html (This clear essay by a noted astronomer summarizes some key ideas in cosmology and introduces the notion of the acceleration of the universe; it was written for the Runaway Universe program)

Animations and Simulations on the Web

NASA Resources

Jellybean Visual Analogy for the Fraction of Ordinary Matter in the Universe (Chandra animation):
http://chandra.harvard.edu/resources/flash/univ_pie.html

The Chemical Universe (NASA's Chandra X-ray Observatory page with an "astronomer's version" of the periodic table, showing the cosmic abundances of elements):
http://chandra.harvard.edu/resources/flash/periodic_tables.html (Click on "Periodic table for astronomy")
Cosmology Visualizations from the NASA Universe Forum:

http://www.cfa.harvard.edu/seuforum/einstein/resources_visual.htm#featcos (A series of computer visualizations of the evolution and structure of the universe, available in a number of formats.)

WMAP Mission Concept Animations: http://map.gsfc.nasa.gov/resources/animconcepts.html (Brief animation showing evolution of the early universe and ideas associated with studying the cosmic microwave background)

The Cosmic Microwave Background on a Beach Ball (An inflatable globe with the full-sky image of the microwave background from the WMAP Mission):
http://map.gsfc.nasa.gov/resources/edactivity1.html

Resources from Other Sources

Origin of the Elements (Flash movie from Don York’s group at the U. of Chicago):
http://ecuip.lib.uchicago.edu/originsoftheelements/

Supercomputer simulations of the formation of structure in the universe by Andrey Kravstov:
http://cosmicweb.uchicago.edu/sims.html

Making Galaxies: http://svl.adlerplanetarium.org/astroviz/makinggalaxies.html (8-min movie on evolution and large-scale structure of galaxies from the Adler Planetarium Visualization Lab)


Selected Web Sites on the History of Cosmology

NASA Resources

Cosmic Times Project (from NASA’s Goddard Space Flight Center): http://cosmictimes.gsfc.nasa.gov/ (James Lochner and Barbara Mattson have compiled a rich resource of 20th-century cosmology history in the form of news reports on key events)


Resources from Other Sources

Cosmic Journey: A History of Scientific Cosmology (from the American Institute of Physics Center for the History of Physics): http://www.aip.org/history/cosmology/ (a web “exhibit” on the history of our thinking, with images and biographies)


Brief Profile of Georges Lemaître:
http://www.amnh.org/education/resources/rfl/web/essaybooks/cosmic/p_lemaitre.html (from the American Museum of Natural History, an excerpt from the book Cosmic Horizons)

Selected Talks on Cosmology Available on the Web

Marcia Bartusiak: “The Day We Found the Universe” (May 21, 2009; the distinguished science writer discusses Hubble’s work and the discovery of the expansion of the cosmos -- one of the Observatory Night lectures at the Harvard-Smithsonian Center for Astrophysics):
http://www.cfa.harvard.edu/events/mon_video_archive09.html

Roger Blandford (Stanford Linear Accelerator Center): “The Runaway Universe” (Oct. 26, 2004; public lecture on the discovery and meaning of cosmic acceleration and dark energy):
http://www2.slac.stanford.edu/lectures/default.asp?id=lecture_detail&eventID=31
Patricia Burchat *(Stanford University)*: "The Dark Side of the Universe: Dark Matter and Dark Energy" (May 20, 2009 in the Silicon Valley Astronomy Lecture Series):
http://www.astrosociety.org/education/podcast/index.html

Sean Carroll *(Caltech)*: “The Origin of the Universe and the Arrow of Time” (Aug. 13, 2010; Google Tech Talk):

Alex Filippenko *(University of California, Berkeley)*: "Dark Energy and the Runaway Universe" (October 4, 2006 in the Silicon Valley Astronomy Lecture Series):
http://www.astrosociety.org/education/podcast/index.html

John Mather *(NASA Goddard)*: "From the Big Bang to the Nobel Prize" (Jan. 16, 2009):
http://svs.gsfc.nasa.gov/vis/a010000/a010300/a010370/index.html

Adam Reiss *(STScI)*: “Dark Energy and the Fate of the Universe” (March 7, 2006 at the Space Telescope Science Institute):
https://webcast.stsci.edu/webcast/detail.xhtml?talkid=1961&parent=1

http://www2.slac.stanford.edu/lectures/default.asp?id=lecture_detail&eventID=14

Ned Wright *(UCLA)*: "Observing the Origins of the Universe: A Century of Progress in Cosmology” (Oct. 28, 2008; UCLA Faculty Research Lecture):
“New Light on Dark Energy” (Apr. 25, 2011 panel on cosmology from the Lawrence Berkeley National Laboratory):
http://www.youtube.com/user/BerkeleyLab?feature=mhum#p/a/u/0/K171B6EvA6c

**Some Cosmology Lab Activities on the Web**

NASA’s Universe Forum developed a series of “Modeling the Universe” activities which could be adapted to be part of a lab session or a class activity sequence. Generally for grades 8 - 12. See:
http://www.cfa.harvard.edu/seuforum/learningresources.htm#lesson

Age of the Universe Activity (U. of Michigan):
http://www.astro.lsa.umich.edu/undergrad/Labs/cosmo/intro-cosmo.html
(This is a college-level lab in which students can see the effect of changing cosmological parameters and can compare the age of the universe in different models.)

Expanding Universe and Balloon Activity (U. of Washington):
(A short college or high school level activity where you blow up a balloon on which you’ve drawn galaxies and derive a “Hubble Law for balloons.”)

Hubble’s Law Lab (shorter) (U. of Washington):
(Derive Hubble’s constant from galaxy data and calculate the Hubble time; for university students.)

Hubble’s Law Lab (longer) (U. of Washington):
(A longer version of the above lab, which includes more discussion of the nature of galaxies.)

The CLEA Project (Gettysburg College) has two college-level cosmology labs, one on the Hubble Law and one on the large-scale structure of the universe. Go to:
http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html and click on the software button.

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**BOOKS**

**Selected Books about Modern Cosmology**

Two astronomers consider the distant past and far future.

Carroll, Sean *From Eternity to Here: The Quest for the Ultimate Theory of Time*. 2010, Plume Books. On modern ideas of time as they relate to cosmology.

Duncan, Todd & Tyler, Craig *Your Cosmic Context: An Introduction to Modern Cosmology*. 2009, Addison-Wesley/Pearson. The first non-majors textbook on cosmology done without a lot of math.


Harrison, Edward *Cosmology: The Science of the Universe*, 2nd ed. 2000, Cambridge U. Press. This remarkable, literate, thought-provoking introductory textbook, using some math, is one of the best guides to thinking about cosmology.


Livio, Mario *The Accelerating Universe: Infinite Expansion, the Cosmological Constant, and the Beauty of the Cosmos*. 2000, John Wiley. Beautifully written, layperson’s introduction to key cosmological ideas of our day.


Silk, Joseph *The Big Bang*, 3rd ed. 2001, W. H. Freeman. A cogent introduction to the universe and our observations relating to it, for the intelligent layperson.


**Selected Books about the History of Cosmology**


Gleiser, Marcelo *The Dancing Universe: From Creation Myths to the Big Bang*. 1997, Dutton. A physicist chronicles the long history of human thinking about the origin of the universe.

Guth, A. *The Inflationary Universe*. 1997, Addison-Wesley. One of the key scientists responsible for the inflationary hypothesis describes how it came about.


Nussbaumer, Harry & Bieri, Lydia *Discovering the Expanding Universe*. 2009, Cambridge U. Press. Carefully researched, detailed history of both the theory and the observations that led to our modern day view; occasionally a bit technical.

**ARTICLES**

**Overview Articles**

Kruesi, L. “Cosmology: 5 Things You Need to Know” in *Astronomy*, May 2007, p. 28. Five questions students often ask, and how modern cosmologists answer them.

Pendrick, D. “Is the Big Bang in Trouble?” in Astronomy, Apr. 2009, p. 48. This sensationally titled article is really more of a quick review of how modern ideas and observations are fleshing out the big bang hypothesis (and raising questions.)


Wakeley, S. “The Universe is in the Details” in Astronomy, Sep. 2006, p. 42. 5-page overview of how particle physics can assist cosmology.

Articles about Dark Energy and Acceleration

Appell, D. “Dark Forces at Work” in Scientific American, May 2008, p. 100. A profile of Nobel laureate Saul Perlmutter, the leader of one of the teams whose work with supernovae led to the discovery of the universe’s acceleration.

Carroll, S. “Dark Energy & the Preposterous Universe” in Sky & Telescope, Mar. 2005, p. 32. 7-page review; explains the observations and gives candidates for the source of dark energy.

Conselice, C. “The Universe’s Invisible Hand” in Scientific American, Feb. 2007, p. 34. An introduction to dark energy and the effects it has on the structure and evolution of the universe.


Kruesi, L. “Will Dark Energy Tear the Universe Apart?” in Astronomy, Feb. 2009, p. 34. On how acceleration will determine the ultimate fate of the universe.


Articles about Inflation


Articles about the Study of the Cosmic Microwave Background


Dorminey, B. “Europe’s Space Revolution” in Astronomy, Sep. 2008, p. 28. Preview of Herschel and Planck missions and how they will study the CMB.


**Articles about Dark Matter**


Kruesi, L. “What do We Really Know about Dark Matter?” in *Astronomy*, Nov. 2009, p. 28. Focuses on what dark matter could be and experiments to find out.

**Articles about Other Specific Topics in Modern Cosmology**


Dorminey, B. “Where Has All the Lithium Gone?” in *Astronomy*, Feb. 2011, p. 42. What we can learn about the early stages of the universe from the abundance of this light element.


Frank, A. “How the Big Bang Forged the First Elements” in *Astronomy*, Oct. 2007, p. 32. On how the hot phase of the big bang synthesized elements, and what their abundance today can tell us about the properties of the universe.


Strauss, M. “Reading the Blueprints of Creation” in *Scientific American*, Feb. 2004, p. 54. On large-scale surveys of galaxies and what they tell us about the organization of the early universe.

**Articles about New Ideas in Cosmology**


Barrow, J. & Webb, J. “Inconstant Constants: Do the Inner Workings of Nature Change with Time?” in *Scientific American*, June 2005, p. 56. Possible astronomical evidence that the fine-structure constant has changed over cosmic periods.

Bojowald, M. “Follow the Bouncing Universe” in *Scientific American*, Oct. 2008, p. 44. On theories of quantum gravity, and a universe that may have had events before the big bang.


Tegmark, M. “Parallel Universes” in *Scientific American*, May 2003, p. 40. Ideas about a “multiverse”: physical theories that permit or demand other universes.

Veneziano, G. “The Myth of the Beginning of Time” in *Scientific American*, May 2004, p. 54. Ideas from string theory about space, time, and branes that pre-date the big bang.

**Articles about Understanding Cosmological Distances**


**A Few Articles about the History of Cosmology**


**Papers and Articles on Teaching Cosmology**


Miller, E. “The Gender Gap in Cosmology: Results from a Small Case Study of Undergraduates” in *Astronomy Education Review*, vol. 1, no. 2, p. 35: [http://dx.doi.org/10.3847/AER2002004](http://dx.doi.org/10.3847/AER2002004)


(see also a brief summary at: http://www.colorado.edu/istem/pdfs/Wallace1.pdf)