Visualization, Sonification, and Virtual Immersive Spaces in Science Education and Research

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Arizona State University
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Outline of this talk:

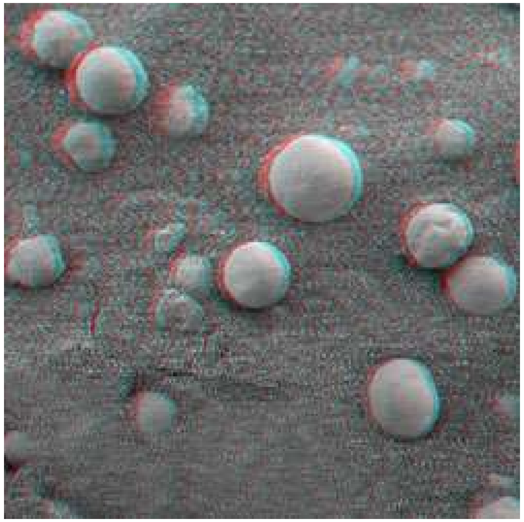
1. Virtual Reality: A very brief overview
   Collaborators: VisLab at Purdue University Calumet
   Project: The Planck Mission as a Multiplatform Immersive Virtual Environment

2. Media Arts Technology : A very brief description
   Collaborators: AlloSphere Group at U.C. Santa Barbara
   Project: Visualization and Sonification of the CMB

3. New Visions in Science Education
   1. Interactive multilingual touch screen for Planck E/PO
   2. Aesthetic Science Education – Symmetry-based curriculum for introductory physics which utilizes multimodal learning strategies to teach concepts from contemporary physics

VR: very brief overview

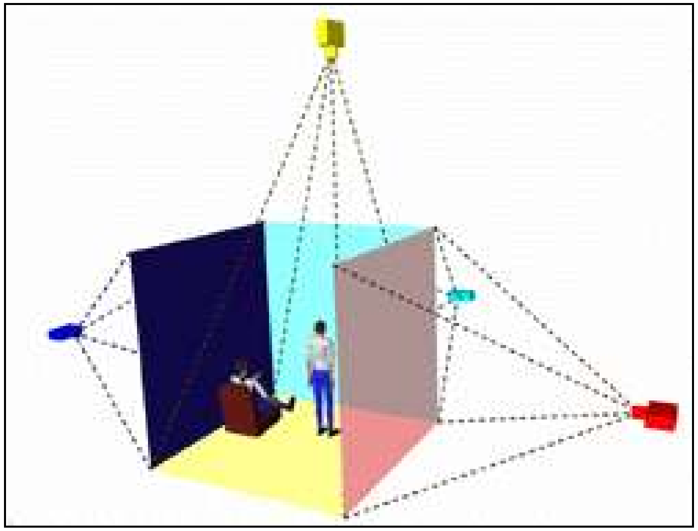
The attempts to create 3D immersive experiences date back to the mid-1800's – early 1900's. What we call VR today began in the 1960's with Ivan Sutherland's "Ultimate Display."



R-L: Stereoscopic photo being taken, ca. 1850; Sutherland's head set, ca. 1965 (both courtesy of J. Moreland, Purdue Univ.); Anaglyph photo of Mars surface (JPL); child's view master toy from the 1950's (image from Google).

VR: very brief overview

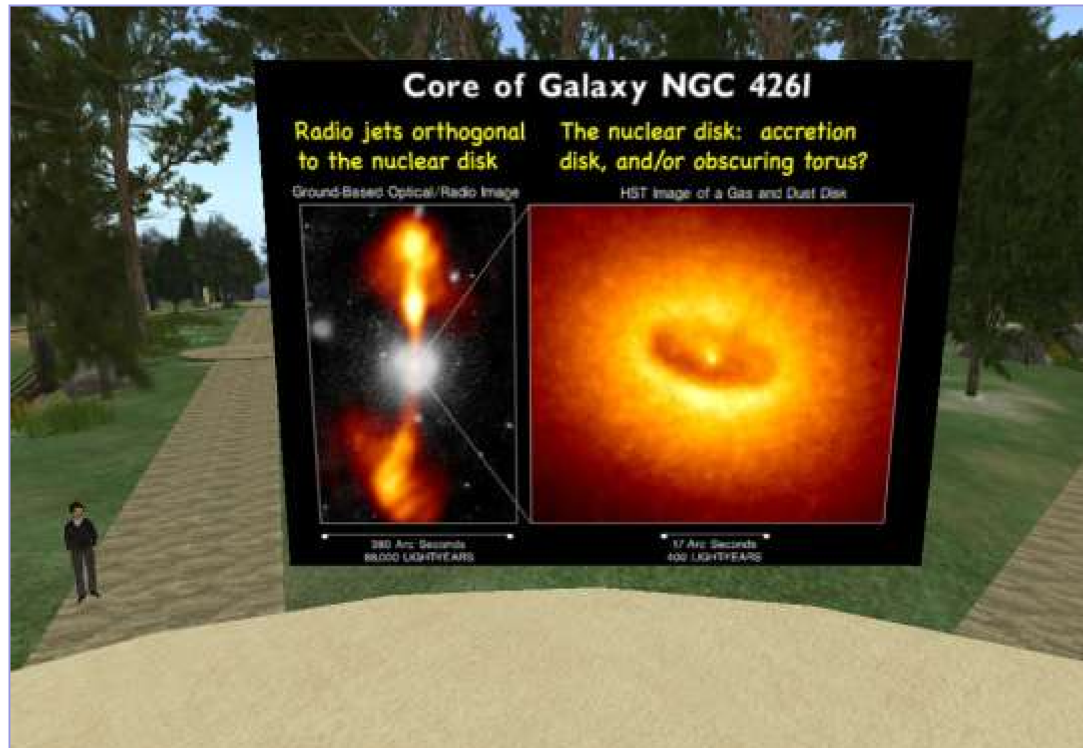
1992 the first CAVE (Cave Automatic Virtual Environment) was demonstrated at Siggraph. UIC/EVL: Cruz-Neira, deFanti, and others.



The term CAVE comes from the simile of the cave in Plato’s Republic. Plato explores the concepts of perception, reality, and illusion using the analogy of a person facing the back of a cave. The wall of the cave is alive with shadows, which are the person's only basis for surmising what real objects are.

VR: very brief overview

Today what we think of as VR encompasses a range of augmented reality environments, from true immersive spaces in which multiple users stand inside a VR environment, to on-line virtual worlds, 3D theater, and virtual worlds that exist within a wall. The viewing technology encompasses inexpensive red-cyan glasses to high-tech active shuttered glasses.

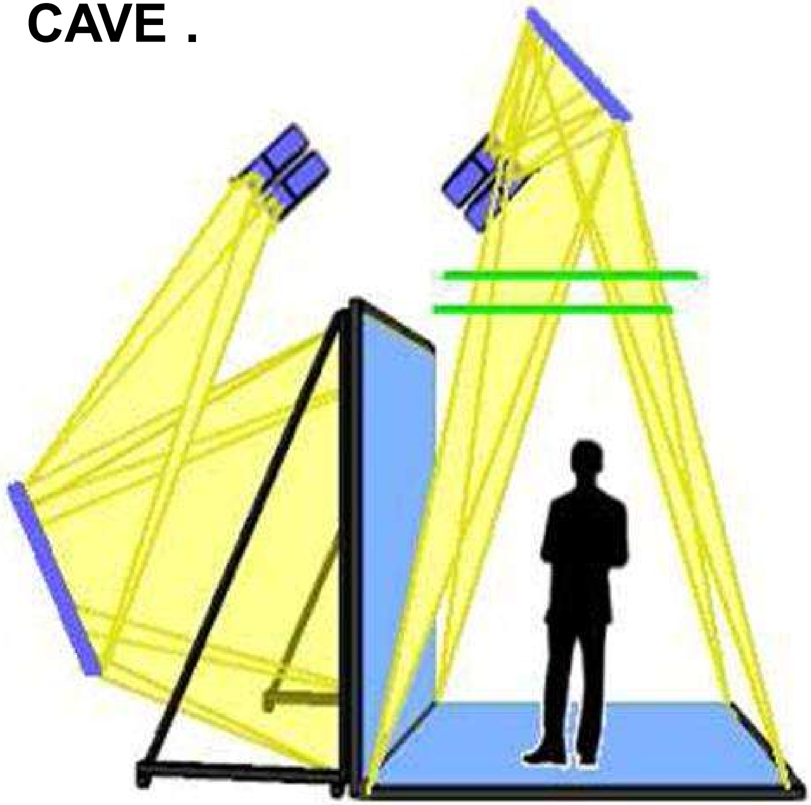


L –R: EVL Hiperwall; Avatar characters (J. Moreland); Scene from SLURL “Stella Nova”

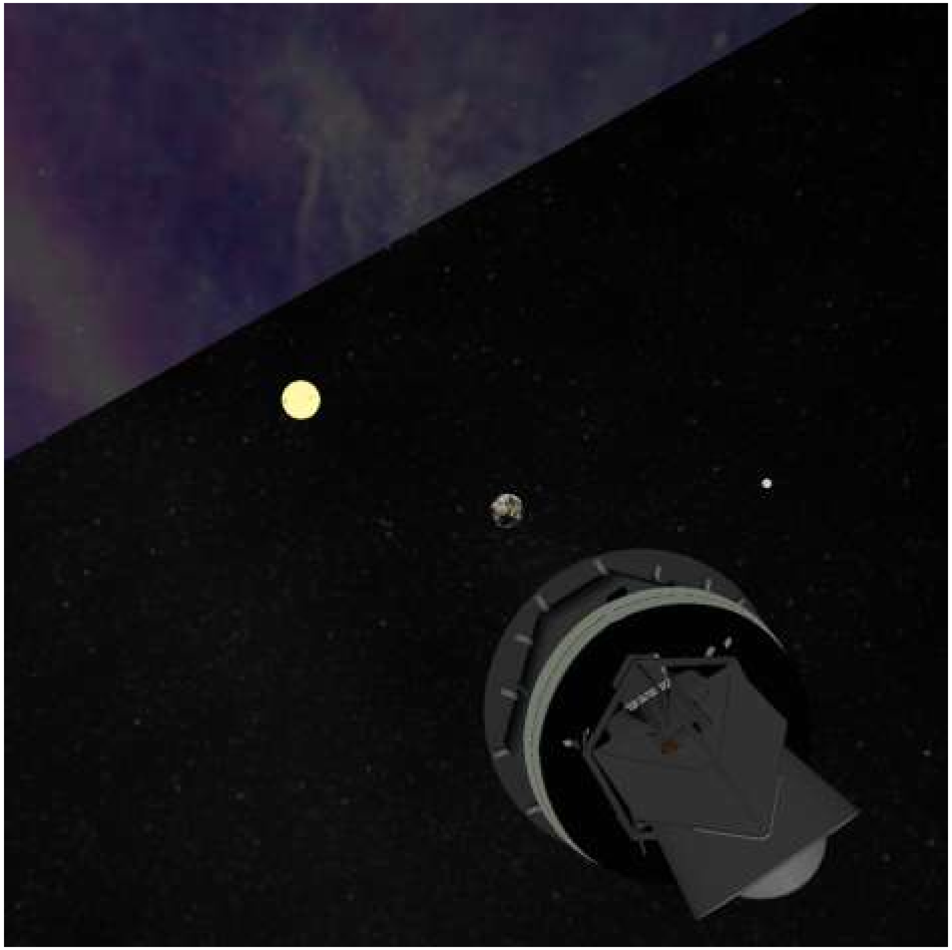
The VisLab at Purdue University Calumet

The "VisBox" - a multi-user immersive 3D VR environment consisting of a wall and floor in the Visualization Lab at Purdue University Calumet – a modified version of the CAVE .

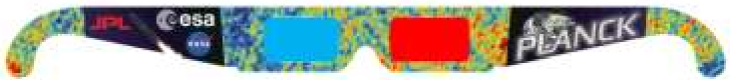
Users wear Infotec glasses; 4 projectors create 3D images on the wall and floor; controlled with 6-dof wand and tracker. Programmed in Open GL and VR Juggler, simulations created in the VisBox can be displayed on a PC in Windows or Linux.



Planck Visualization Project in the PUC VisLab

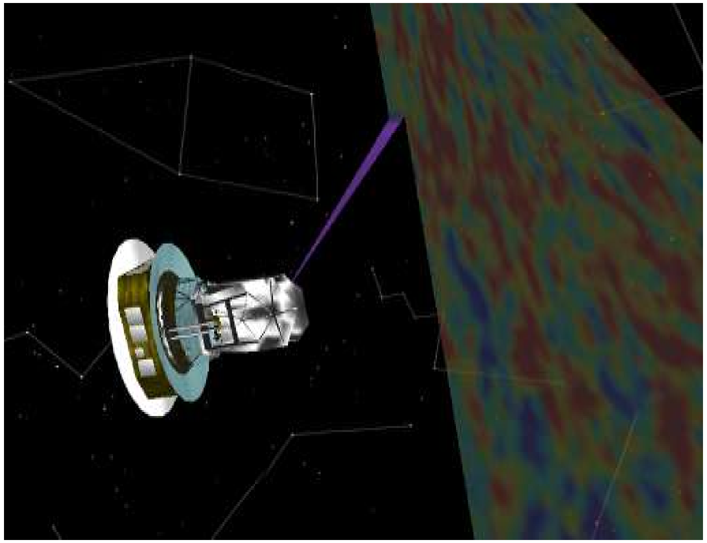


By creating an immersive virtual solar system, the Planck Mission Simulation allows users to observe Planck from space, to zoom into the satellite and explore the instruments, visualize distances in the solar system, follow Planck into its orbit around L2, and watch it "paint" the CMB on the starry background.



PI: van der Veen (UC Santa Barbara); Graduate students John ("Jack") Moreland and Gerald Dekker (Purdue University Calumet)

(See Dekker, Moreland, and van der Veen, *in prep*.)

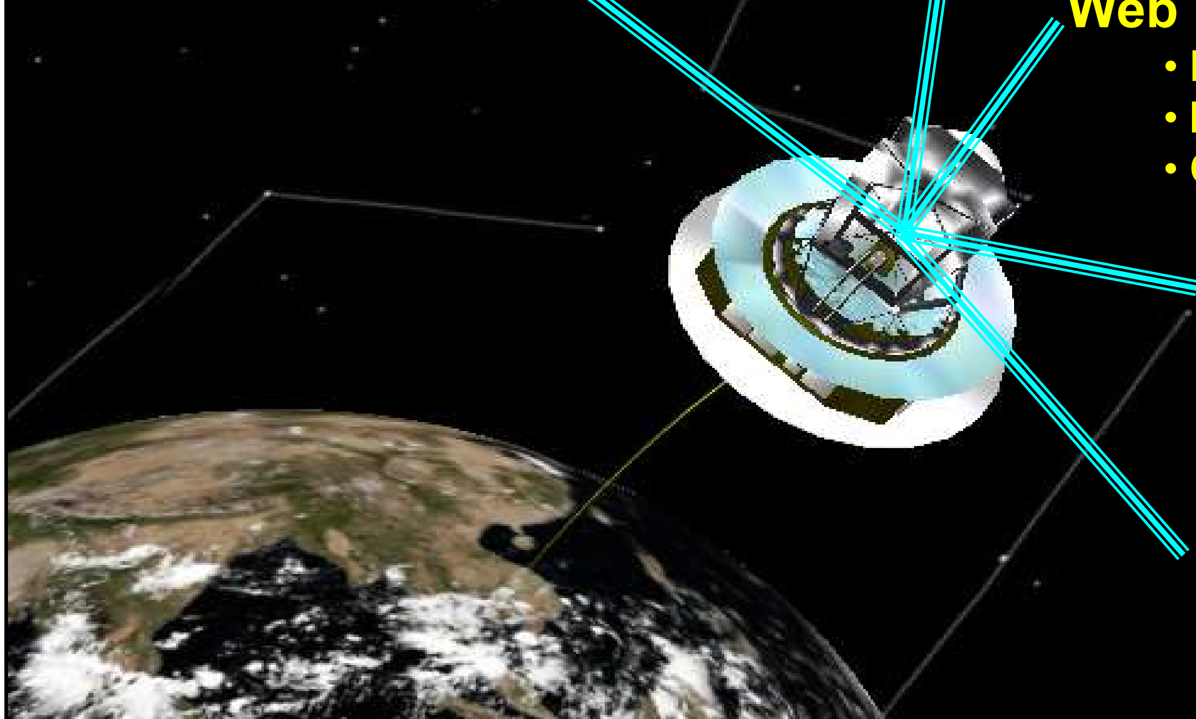


Distribution goals:

Hi-tech visualization facilities:
- VR facilities
- Planetaria
- Virtual Classrooms

Museums and Science Centers
- Thousands of potential sites!
- DVDs for Museums and mass dist.
- Kiosk interactive display
- Passive viewing as movie

Web Distribution
- Download, single computer
- Interactive served application
- Computers in classrooms



Popular Culture
- iPhone application
- Google Universe
- Screen savers

Available in a variety of 3-D technologies, from simple anaglyph to high-tech varieties.

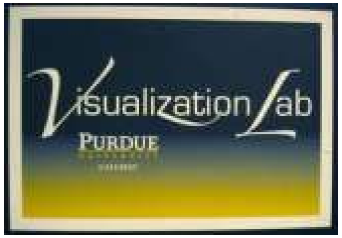
Plans for testing and evaluation:

This June: Deployment in Santa Barbara Planetarium using large 3D screen with active shutter glasses. Screen and glasses donated by TrueVision Systems of Santa Barbara

46 inch 3D 1080p display

March 24th: Testing in the 3D theater at Adler Planetarium

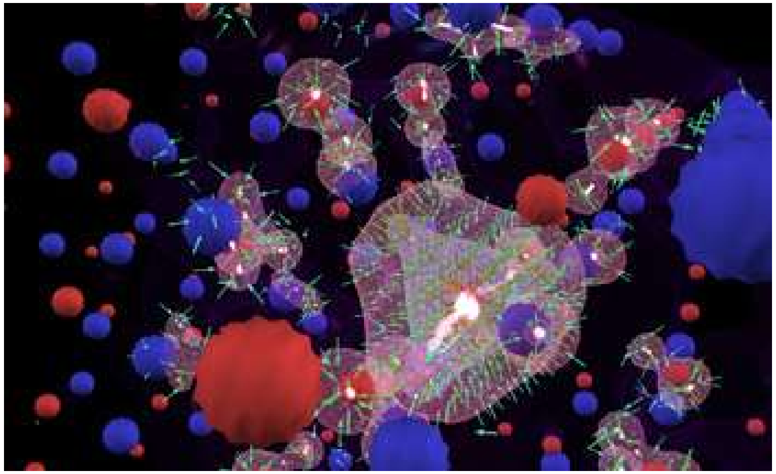
Fall, 2011: Plans to test with astronomy students at Purdue University Calumet in the VisLab (currently undergoing upgrade to a complete virtual immersive classroom)



Future plans: Dissemination via NASA database and Planck web pages at Caltech, UC Santa Barbara, and others

Media Arts Technology: Arts Infusion into VR

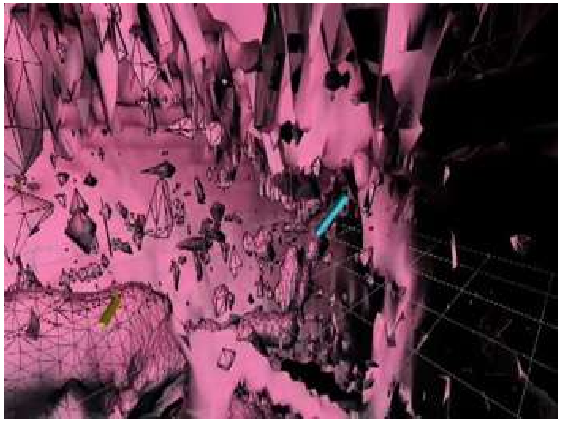
Media Arts Technology (MAT) fuses the technology of VR, computer science, engineering, electronic music and digital art research in the development of aesthetically pleasing, scientifically accurate, multimodal representations of multidimensional data sets.



GOALS:

1) To provide a new methodology for basic research through artistic renderings of complex, multidimensional mathematical data using immersive visualization and sonification

2) To create artistic installations based on mathematically accurate models of scientific data, thus raising public awareness of fundamental research.

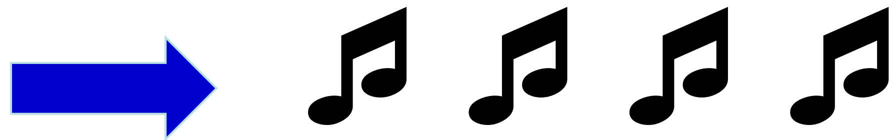


By-product: New types of simulations for science and math education in formal and informal settings

Sonification

Sonification - ***the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation*** **– is an important part of designing multimodal representations of data in MAT.**

numerical data



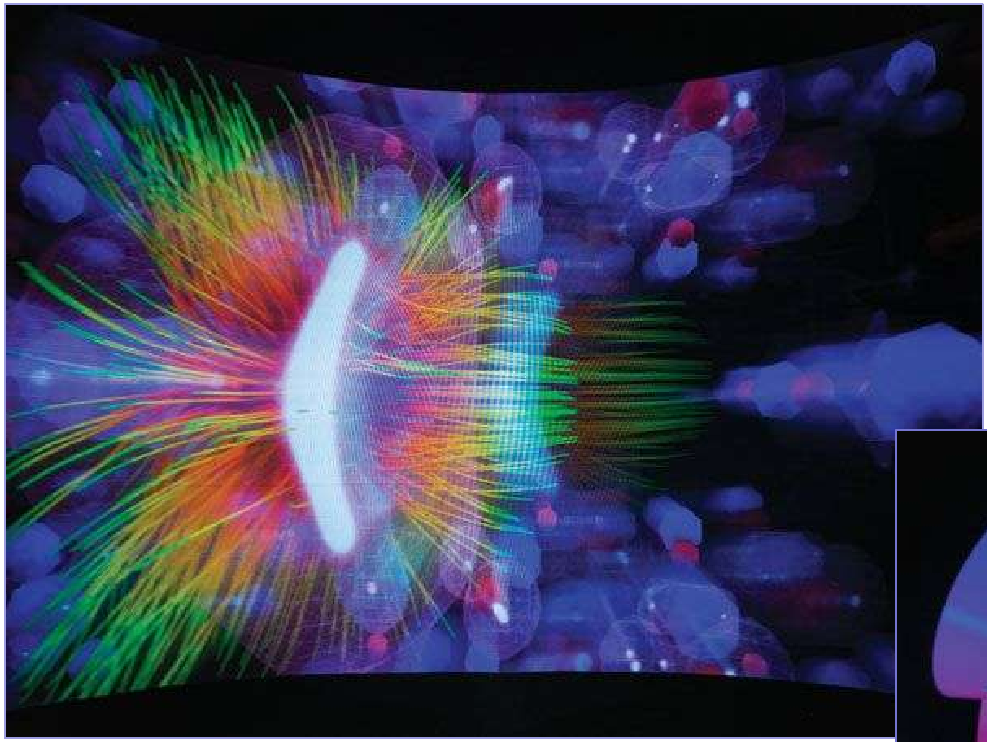
Direct sonification: e.g., Sounds of the Sun (http://bison.ph.bham.ac.uk/sounds/solarsounds.html)

Iconic sonification: e.g., Mapping rain density over time to sounds (http://www.quinnarts.com/srl/tour/3rain.html)

Musical sonification: e.g. Mapping earthquake data to musical sounds (http://www.quinnarts.com/srl/tour/12seismic.html)

Media Arts Technology: Arts Infusion into VR

MAT thus presents new opportunities to interact with data immersively, in real time, using visual simulations, and spatially distributed sounds.



Images from the AlloSphere at UCSB.

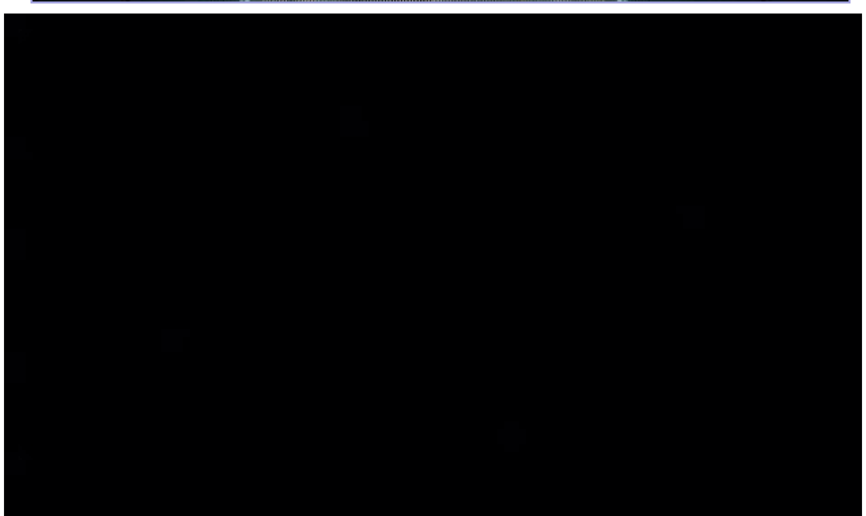
Left: Multicenter hydrogen bond for alternative fuel cells. PI’s: Professor Chris Van de Walle, Materials Research Lab and Professor JoAnn Kuchera-Morin

Right: Manipulating the probability distribution of the electron in a hydrogen atom with interactive gloves. PI’s: Professor Luca Peliti, Università di Napoli, KITP and Professor JoAnn Kuchera-Morin

The AlloSphere at U.C. Santa Barbara

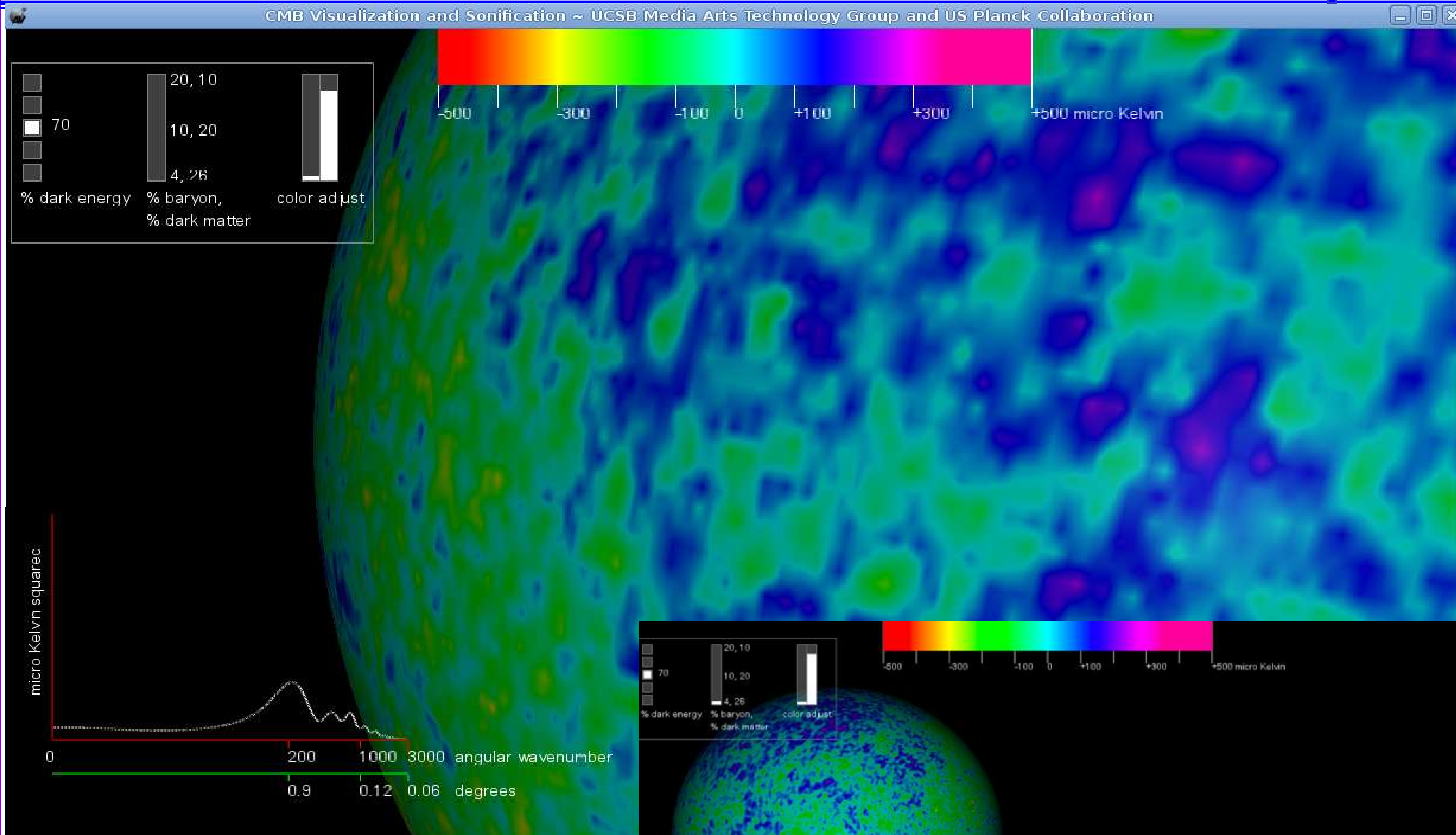
… a total immersion laboratory / microscope for multimodal representations of multidimensional data sets.

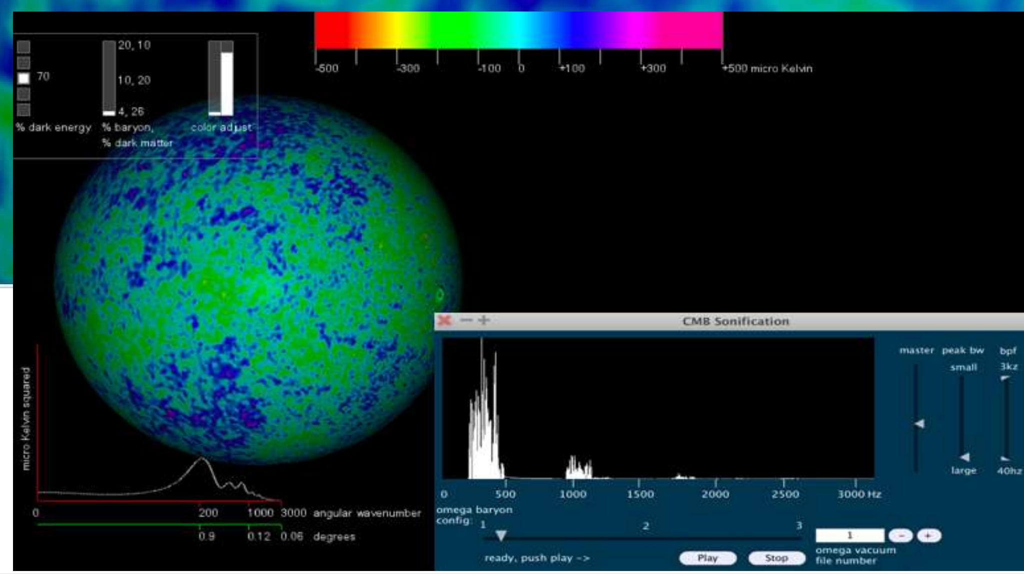
Founder / director / inventor:
Professor JoAnn Kuchera-Morin



See www.allosphere.ucsb.edu

Visualization and Sonification of the CMB in the AlloSphere





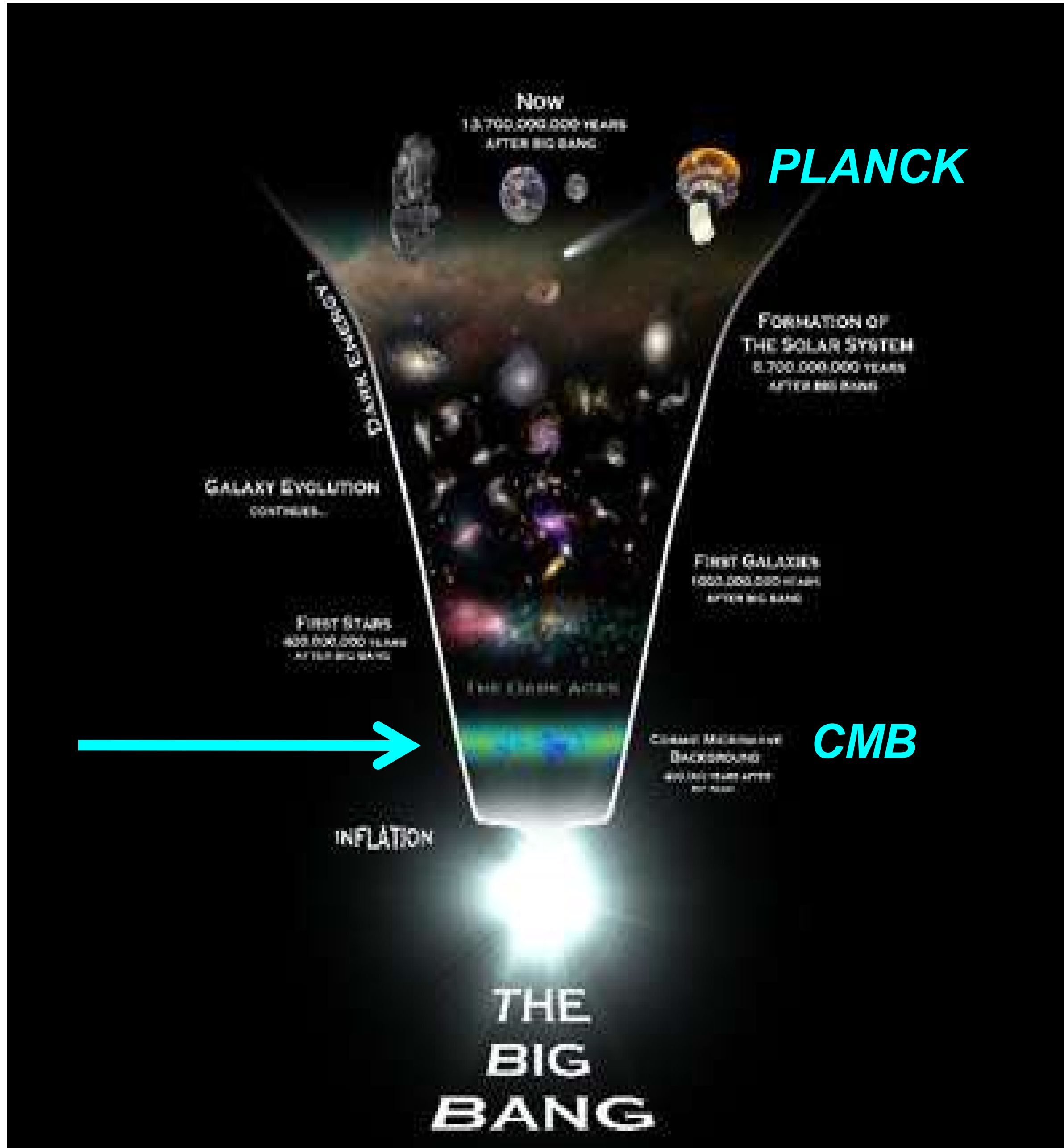
PI: van der Veen; Collaborators: Lubin, Kuchera-Morin; Graduate students Ryan McGee, Basak Alper, Wesley Smith, all at UC Santa Barbara

Visualization and Sonification of the CMB in the AlloSphere

The Cosmic Microwave Background (CMB) is the oldest light we can detect.

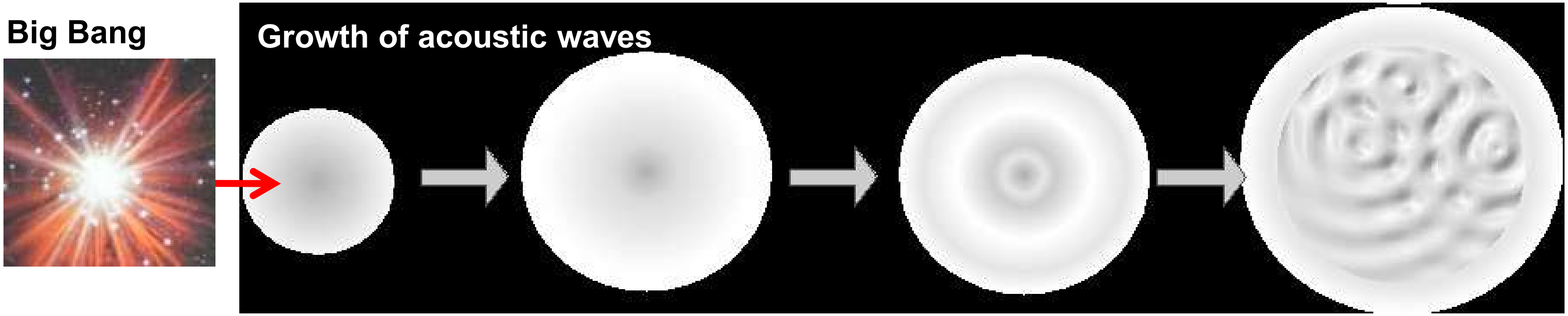
It comes from a time around 380,000 years after the Big Bang – around 13.7 billion years ago.

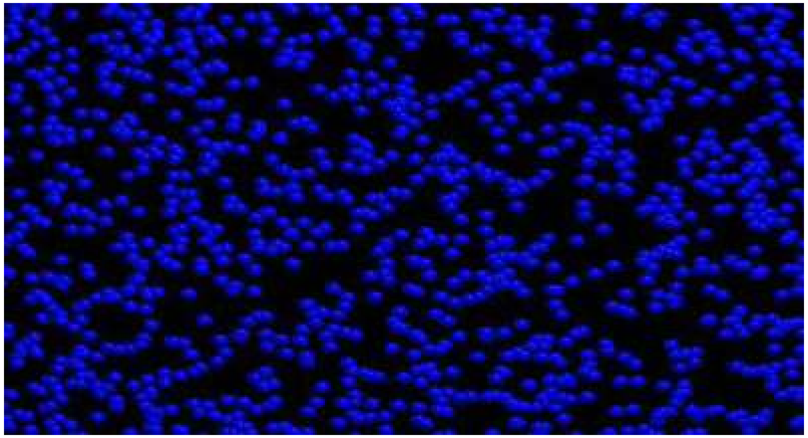
Image credit: Rhys Taylor, Cardiff University, Planck Collaboration



Visualization and Sonification of the CMB in the AlloSphere

The first 380,000 years of the universe were dominated by a tightly coupled plasma of baryons and photons, which was permeated by gravity-driven pressure oscillations - sound waves.

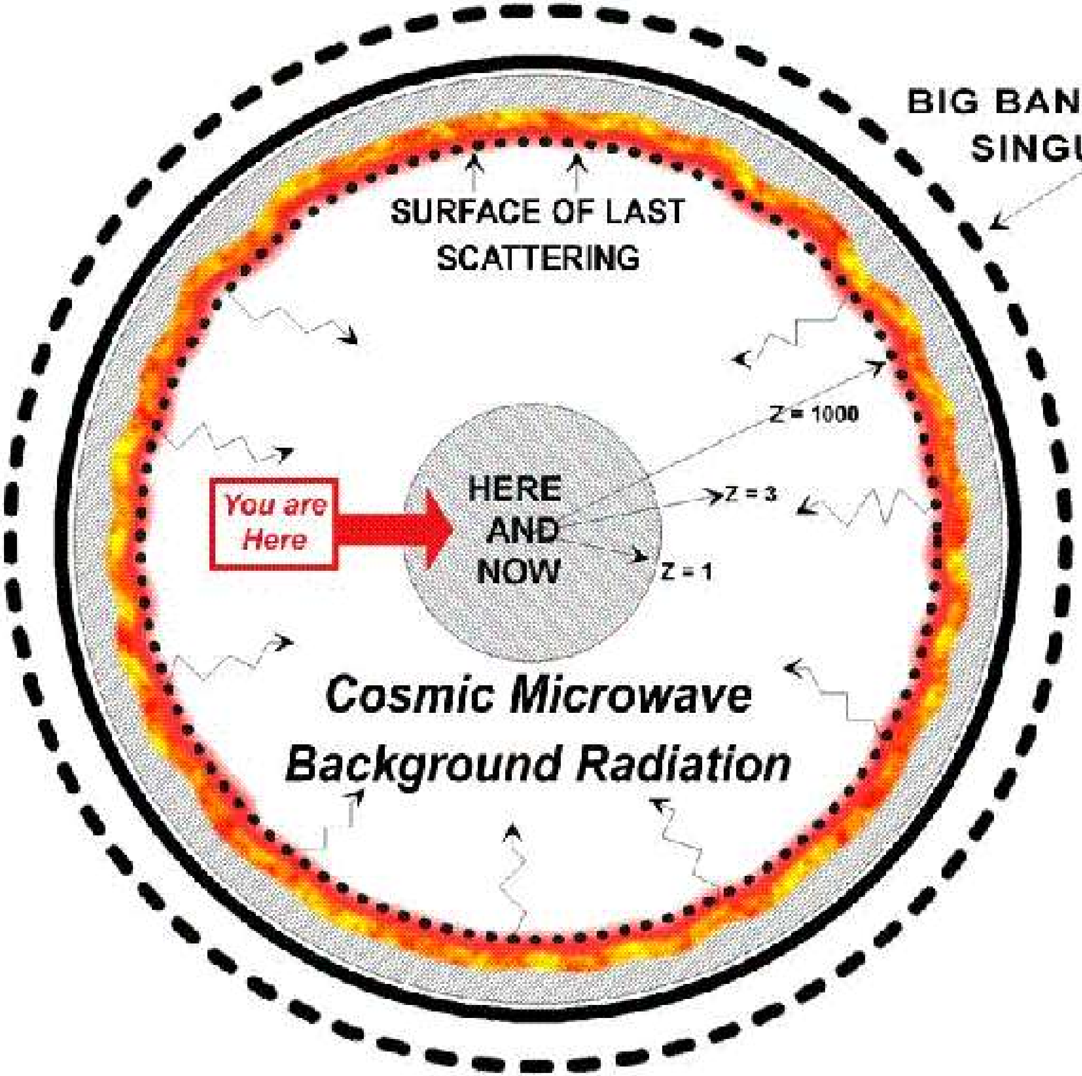




Animation: Lloyd Knox and Damien Martin, UC Davis, Planck Collaboration

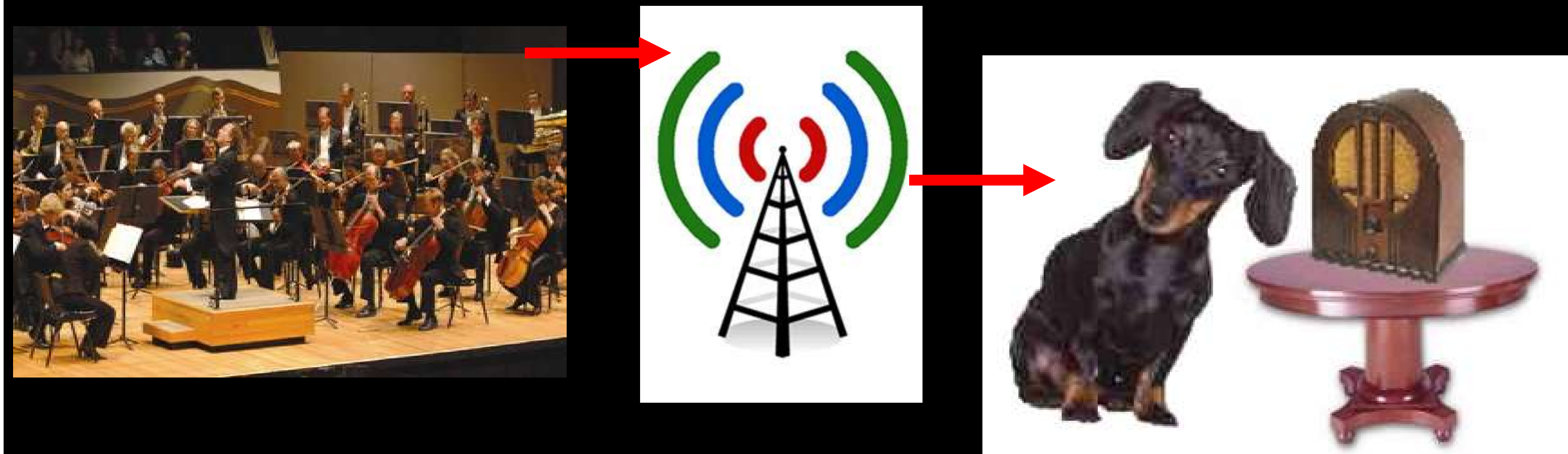
Visualization and Sonification of the CMB in the AlloSphere

We detect the imprint of these primordial sound waves as “light echoes” – small amplitude red and blue shifts in the black body radiation of the universe, having originated at the time when the universe cooled sufficiently for neutral hydrogen to form, and photons scattered off charged particles for the last time.

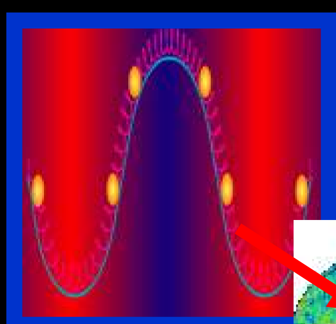


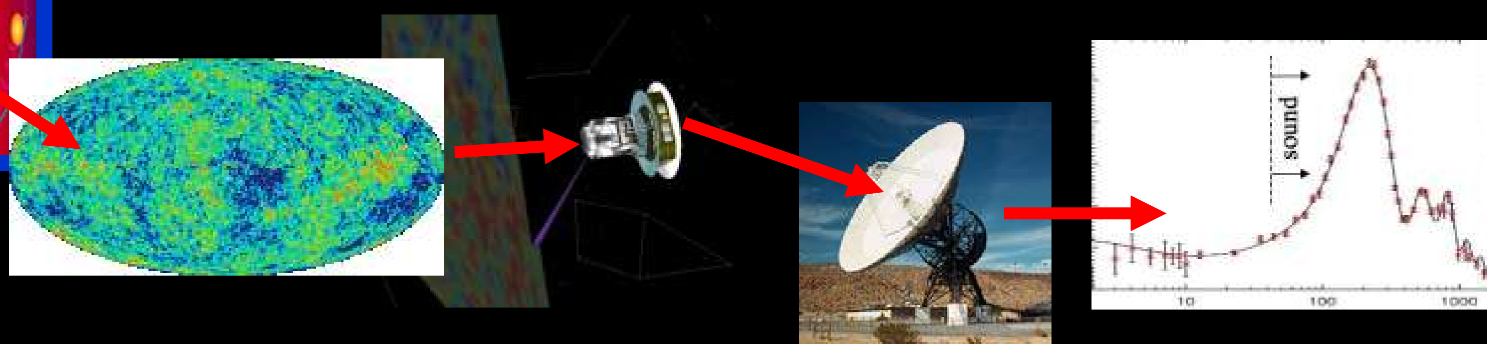
Visualization and Sonification of the CMB in the AlloSphere

a few seconds of time delay

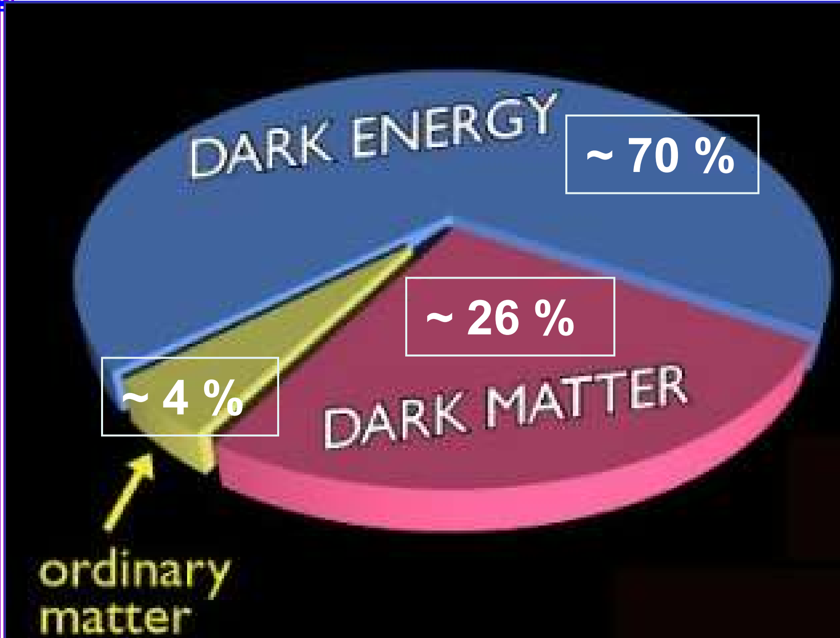


13.7 billion years of time delay!



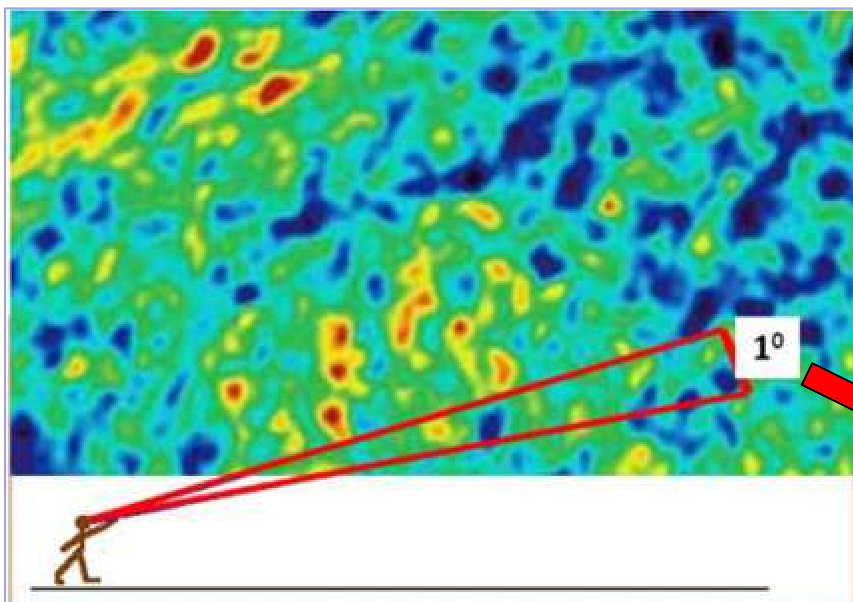


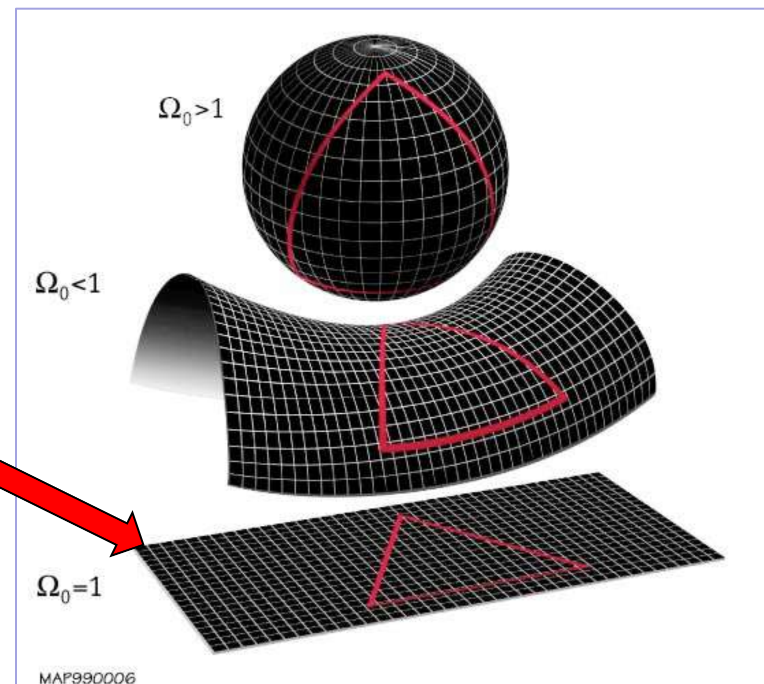
Visualization and Sonification of the CMB in the AlloSphere



Observations indicate that we live in an overall 'Minkowski' universe, but we have no idea what ~96% of the mass/energy of the universe is made of.

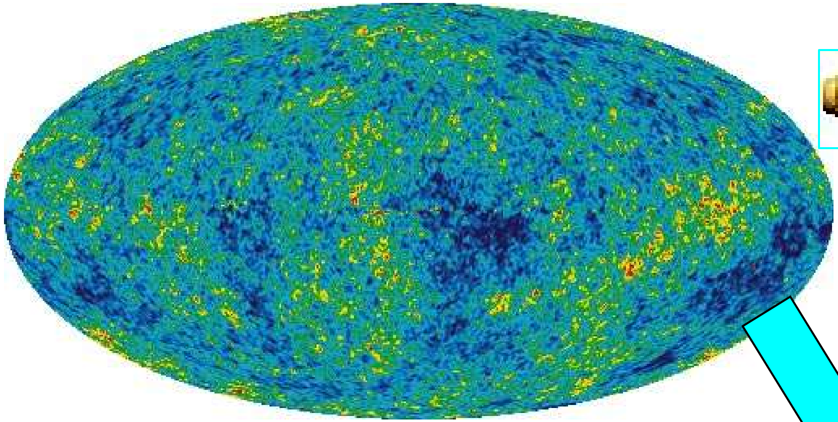
The first three harmonics of the power spectrum of temperature anisotropies in the CMB are largely controlled by the relative proportions of baryons, dark matter, and dark energy.

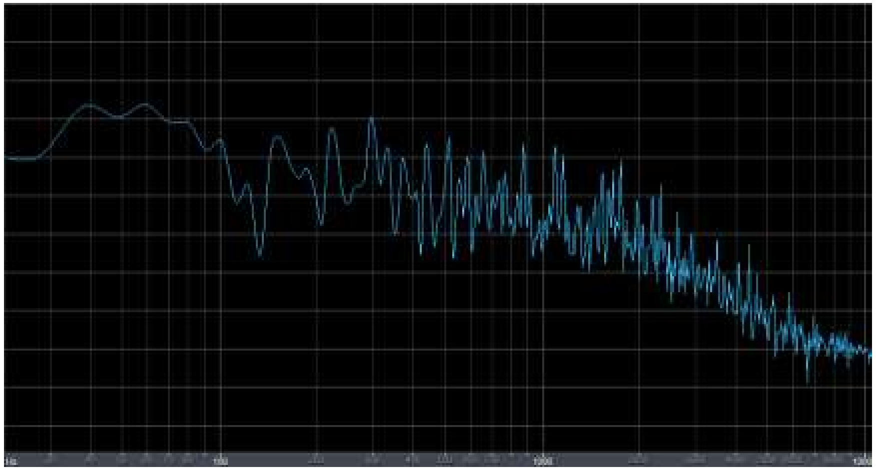


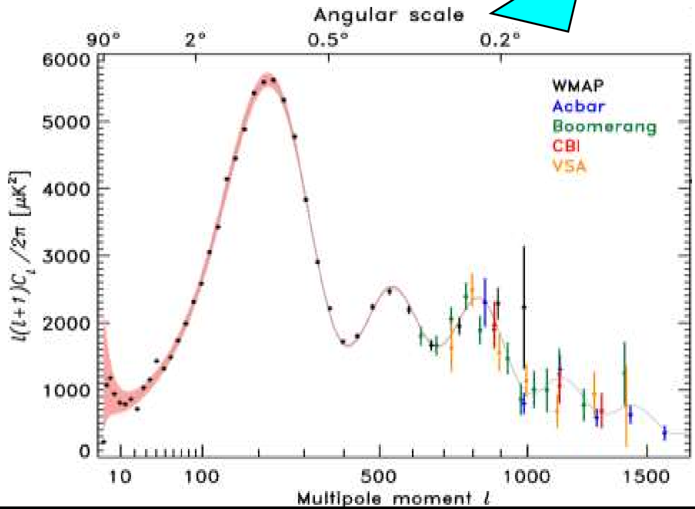


Visualization and Sonification of the CMB in the AlloSphere

Just as the power spectrum of the tones produced by a musical instrument is determined by the characteristic properties of that instrument, similarly the angular power spectrum of the CMB is controlled by the properties of the universe, characterized by ~30 cosmological parameters.

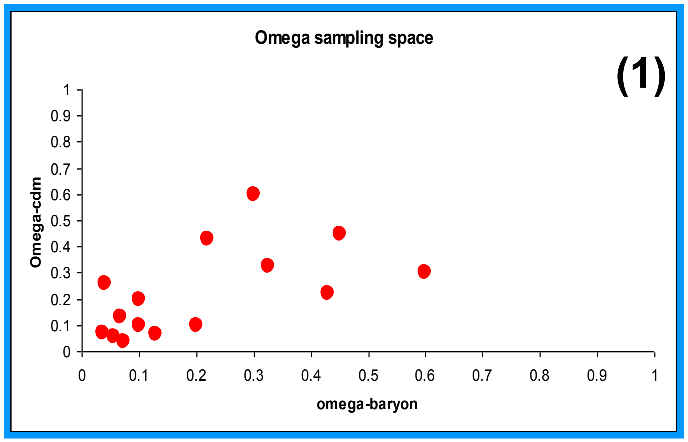


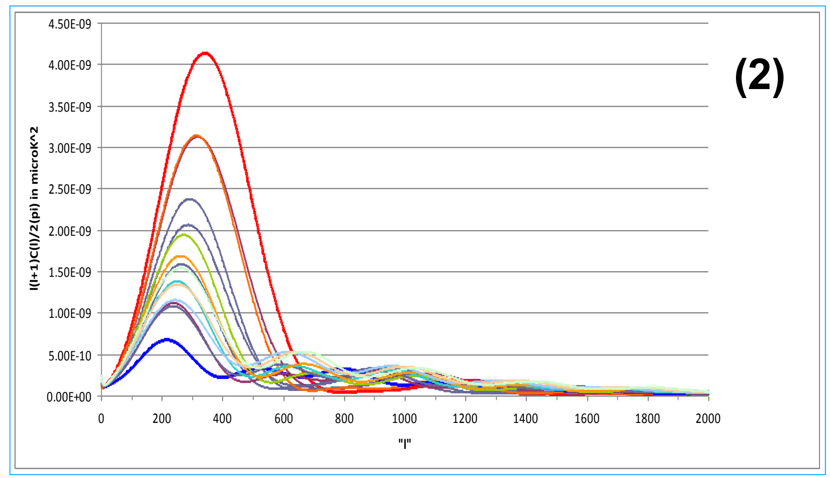




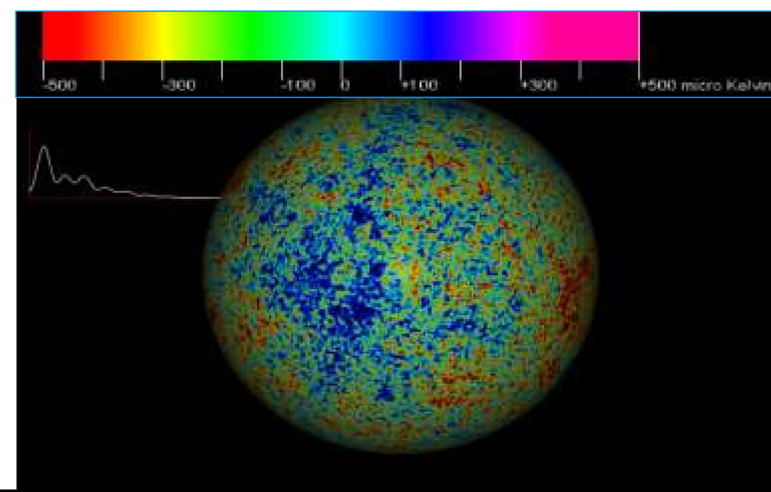
Creating the Interactive Visualization

We used the software package CAMB to create 15 model universes, keeping the total density parameter Ω = 1 for a flat universe, varying the relative proportions of baryons, dark matter, and dark energy, and keeping the other cosmological parameters at the current best estimates. We used the HEALPIX algorithm to create the maps.

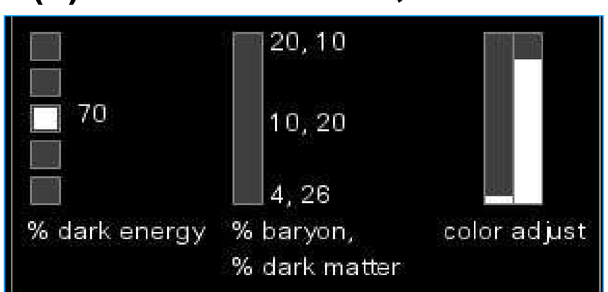




(1): Omega sampling space;
(2): 15 models on one plot;
(3): mapping the CMB on a sphere;
(4): choose model, set color-temp.



(3)



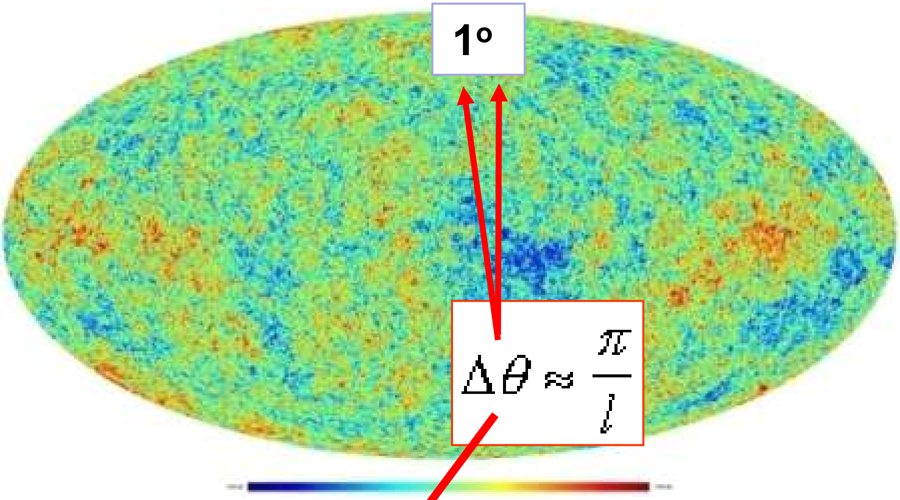
(4)

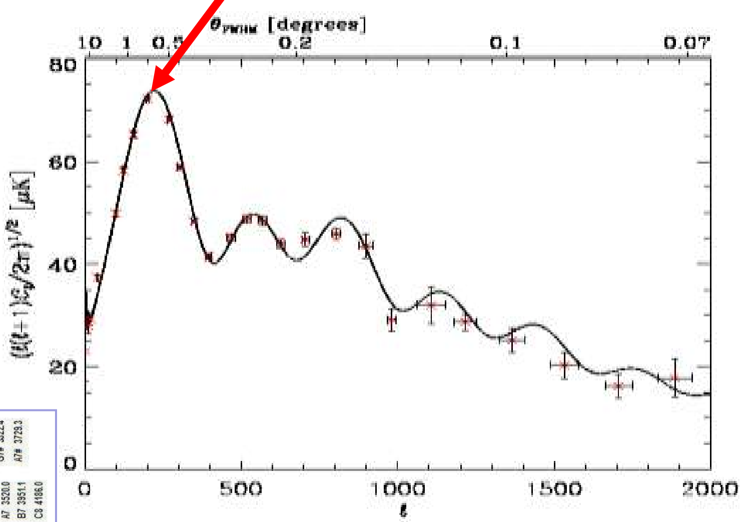
Creating the Interactive Sonification

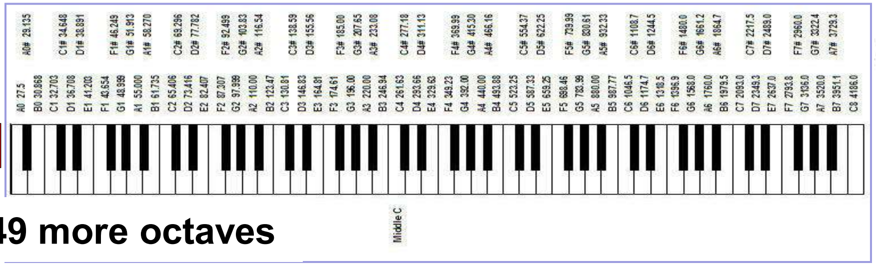
1. Mapping angular wave number on the sky to audible frequency

Calculating the size of the fundamental:
Distance the longest wave could have crossed at recombination = vt = (.6c) (380,000 years) = 2×10^{21} meters, or ~ 228,000 light years = half a wavelength

$\Rightarrow$ Fundamental wavelength was ~ 456,000 light years, which corresponds to a frequency of ~ 7×10^{-14} Hz, or slightly more than 49 octaves below the lowest note on the piano (27 Hz).





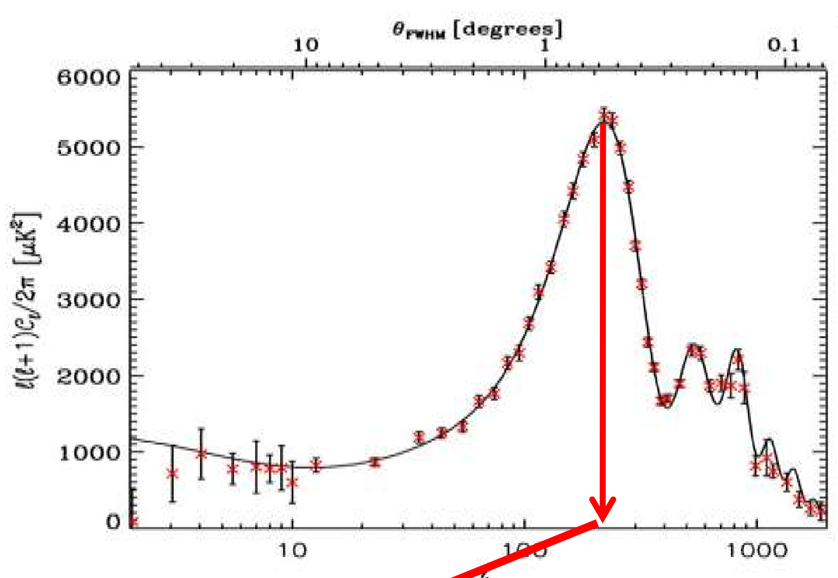


Go down 49 more octaves

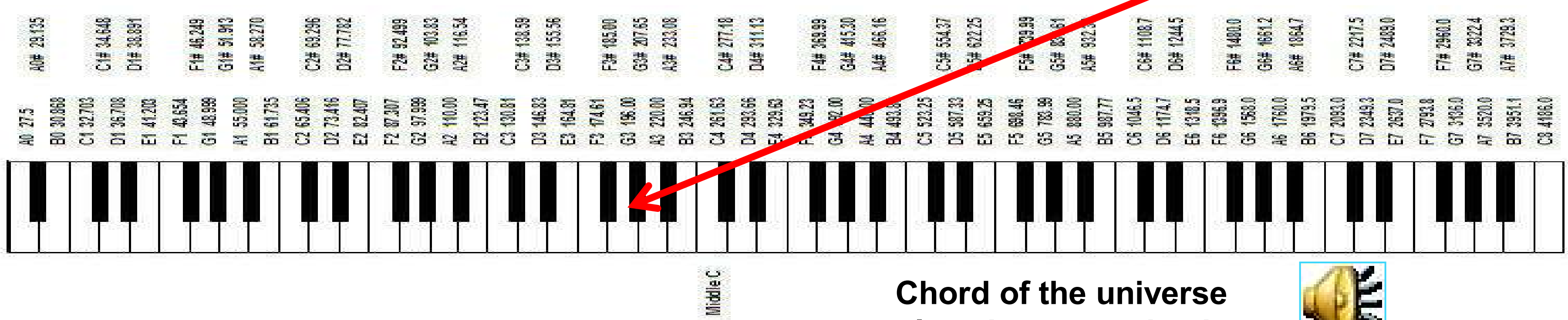
Creating the Interactive Sonification

We map angular wave number to Hertz, so the fundamental at l ~200 maps to a frequency of ~200 Hz. The higher harmonics damp out at approximately 0.08 degree, corresponding to l = 3000, which maps to 3 kHz in our scheme.

Conceptually, this mapping amounts to scaling up the primordial sound waves by approximately 52 octaves.



The fundamental corresponds to somewhere between G and G# on the piano.



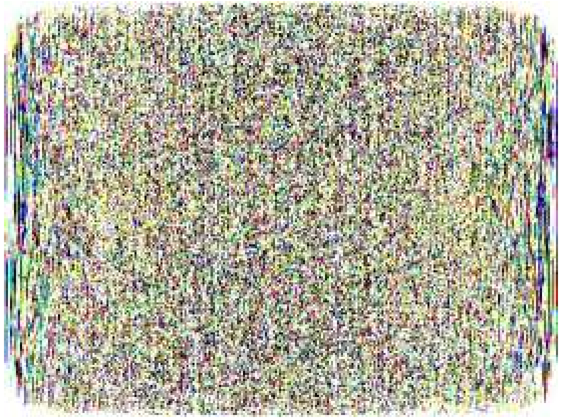
Chord of the universe played on a synthesizer

Creating the Interactive Sonification

2. Creating audible sound from a power spectrum:

A power spectrum contains no phase data, so to create audible sounds we first specify an amplitude and phase for each 1-Hz frequency bin between 40 Hz and 3 kHz, then compute the IFFT, then add random phase between - π and π.

take FFT; Randomize the phases, inverse FFT



This sonification process becomes akin to shaping the amplitude spectrum of band limited white noise between 40 and 3000 Hz.

(See McGee, van der Veen, Wright, Kuchera-Morin, and Lubin *in prep.*)

Both "normal" and randomized signals have the same power spectra.

Creating the Interactive Sonification

3. Mapping temperature intensity to a suitable dB scale

$$dB = 20\log\left(\frac{I}{I_0}\right)$$

$I_0 = 10^{-12}$ Watts/m^2 =threshold of hearing between 1 kHZ and 5 kHz

$$dB = 20\log\left(\frac{\Delta T^2}{\Delta T_0^{\ 2}}\right)$$

ΔT_0 = faintest signal detectable by Planck's HFI at 100 GHz = 2μK so $\Delta T_0^{\ 2} \sim 4\times10^{-12}$ K^2

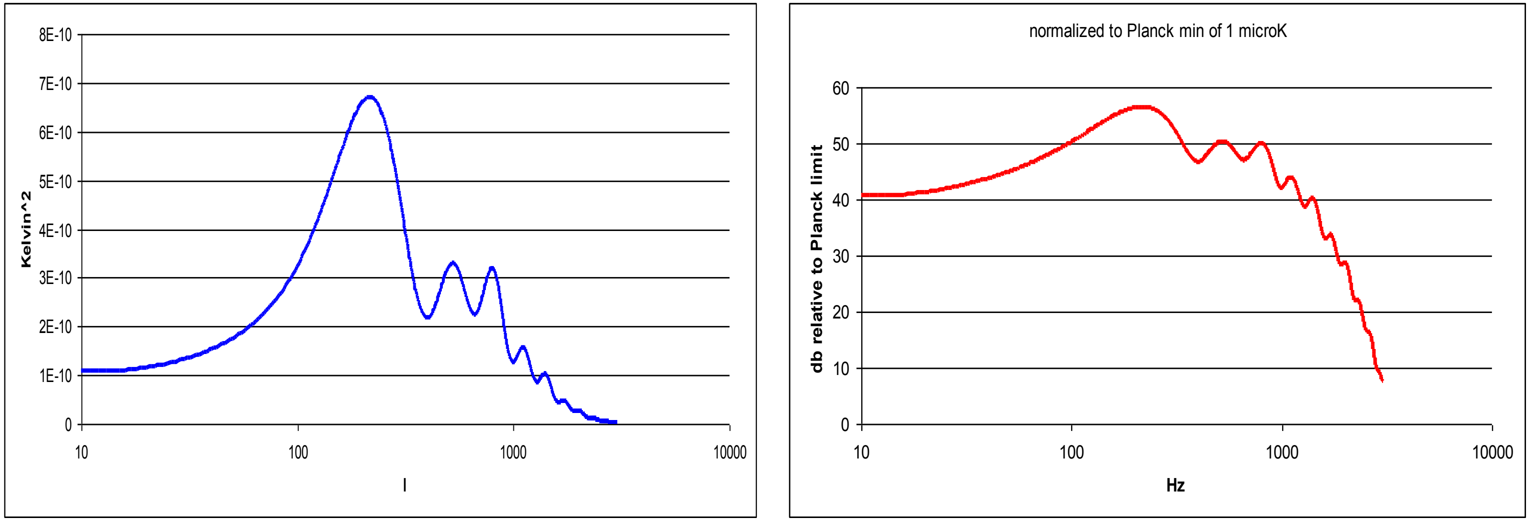
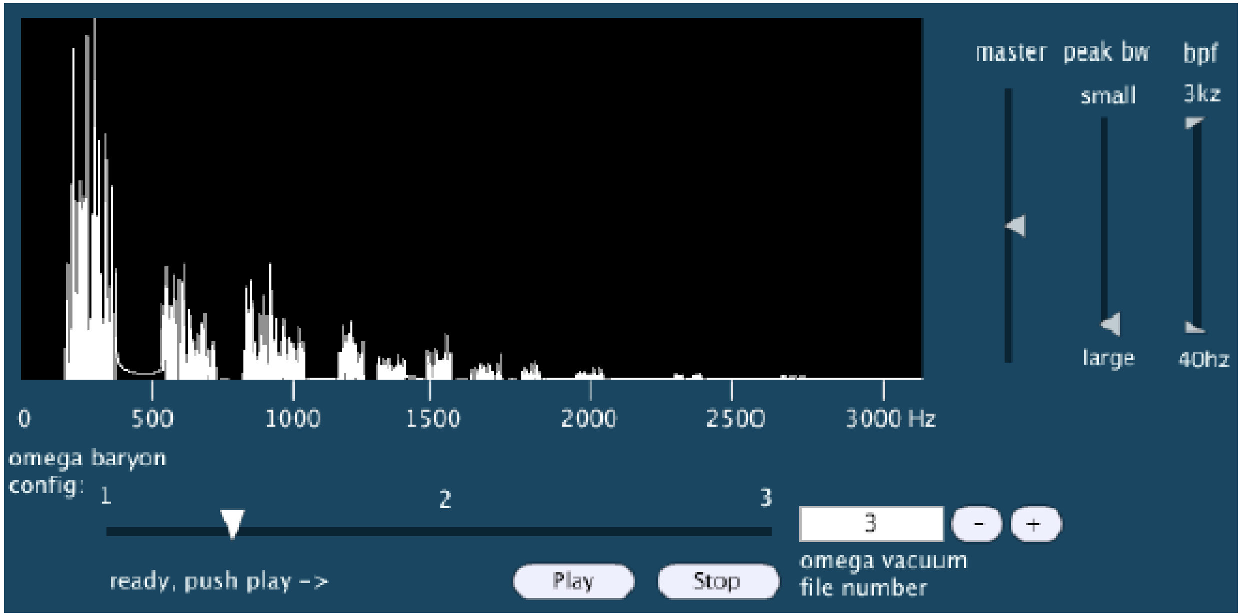


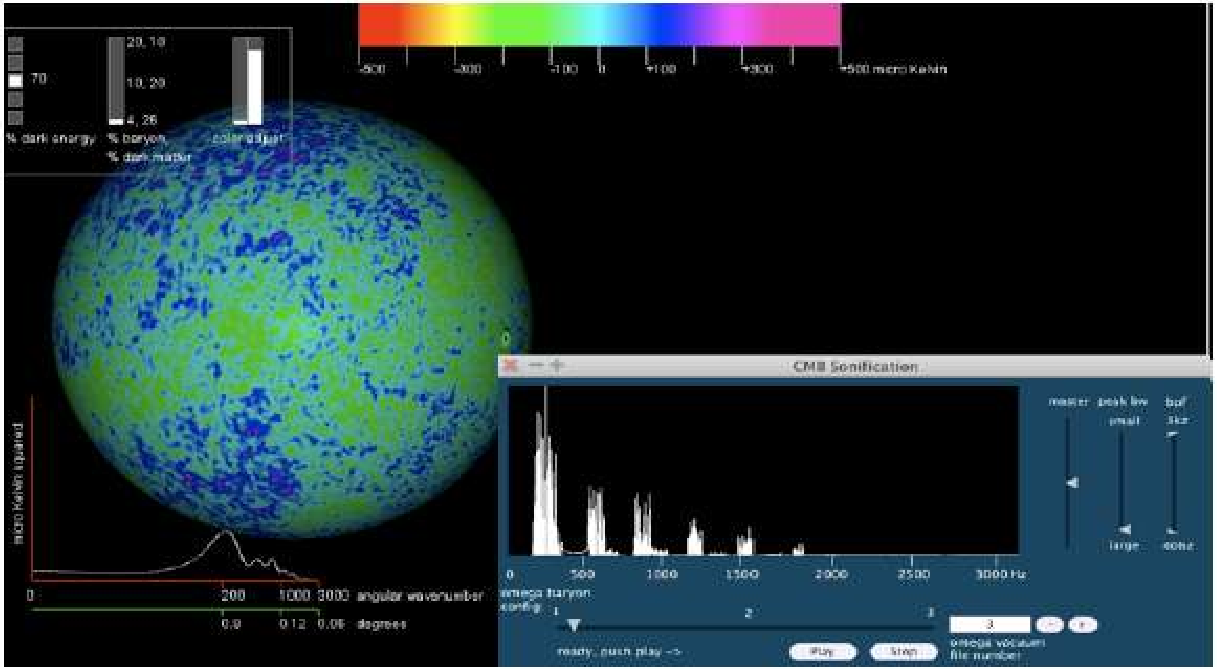
Figure 2. Left: Power spectrum of CMB temperature anomalies in μK^2 vs. angular wave number. Right: Mapping the temperature power spectrum of the CMB to sound space. Vertical axis is dB relative to the limit set by the Planck High Frequency Instrument; horizontal axis is Hertz. (From van der Veen, et. al, *in prep*)

Visualization and Sonification of the CMB in the AlloSphere

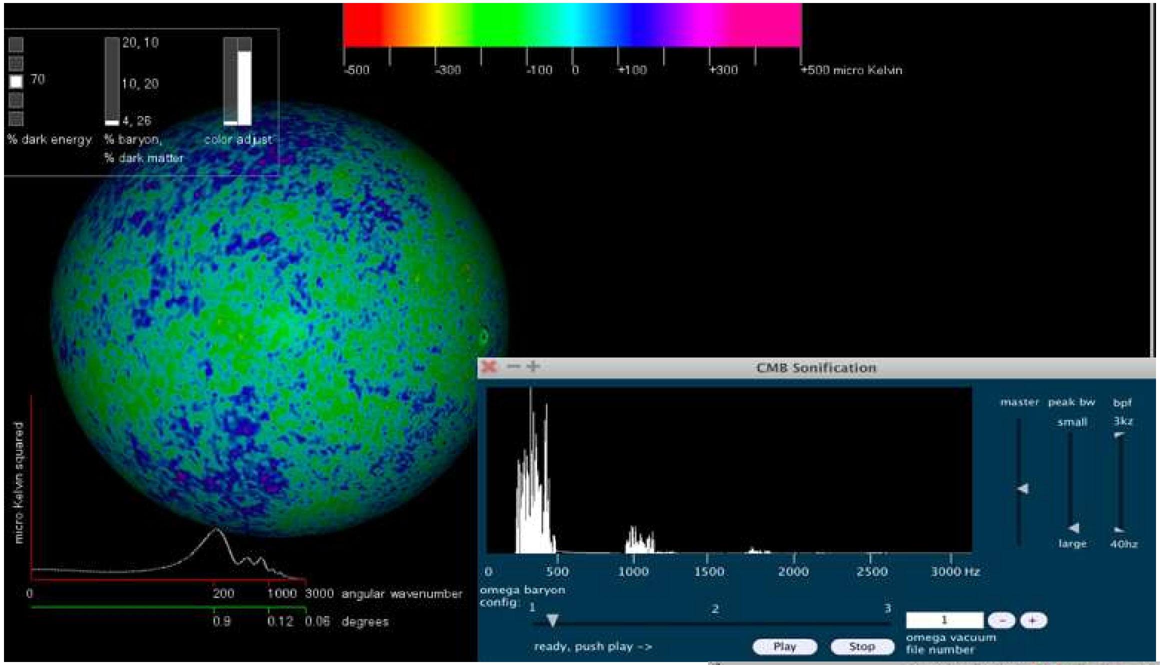


Available for Mac OS and Linux/ubuntu.

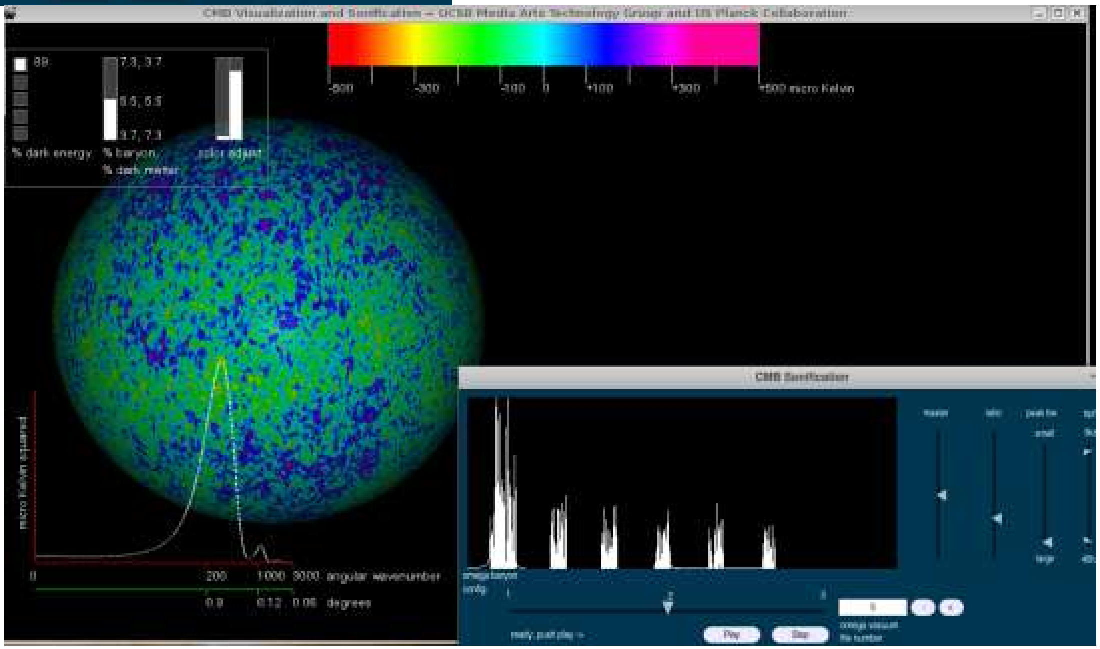
As the user slides between model universes, the power spectrum, map, and sounds change. With the audio controls, you can change the timbre, and zoom in on one or more harmonic.



See and Hear the differences in the models!



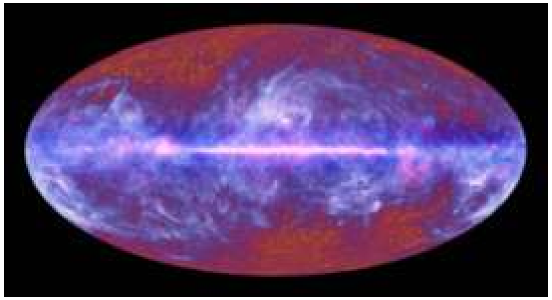
Ω_{lambda} = .70
Ω_{baryon} = .04
$\Omega_{dark\ matter}$ = .26



Ω_{lambda} = .89
Ω_{baryon} = .05
$\Omega_{dark\ matter}$ = .05

Plans for the future:

1. Spring, 2011: Create additional data bases for open ($\Omega < 1$) universes closed ($\Omega > 1$) universes.



2. Fall, 2011: Spatially sonify the Planck All-Sky Map in the AlloSphere

1. May, 2011: Evaluate effectiveness of sonifying the CMB with visually impaired students at the Washington School for the Blind (collaborator: Professor Ana Larson, University of Washington)

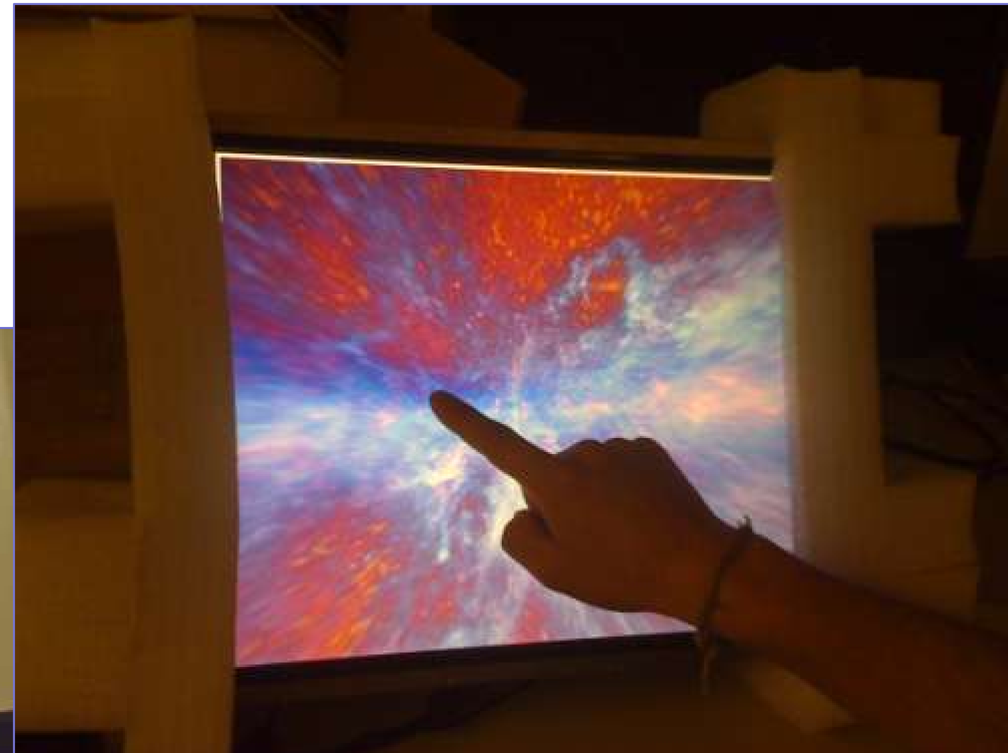
2. Distribute as part of Planck curricula via NASA and ESA websites

Paper and tutorial to be presented at the 17th International Conference on Auditory Display, Budapest , Hungary, June 20-24, 2011

New Visions in Science Education

1. Planck Presents: We are developing interactive applications in cosmology for education and outreach as part of the Planck E/PO program, using a new touch screen monitor.

Current languages: English & Spanish.
Language portals for any language with an html library are built in.



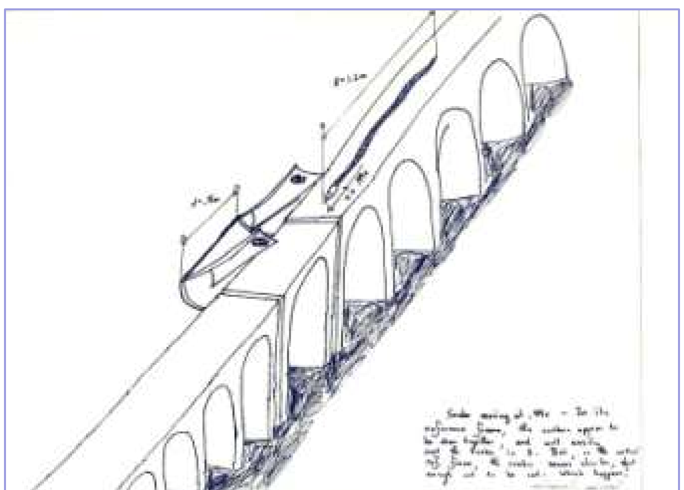
PI: van der Veen; Undergraduate research assistants: Blake Regalia, CS and Geography major and Evelyn Alfago, Physics major.

New Visions in Science Education

SYMMETRY AND AESTHETICS IN CONTEMPORARY PHYSICS

An interdisciplinary course for undergraduates which utilizes visualizations, drawing, and music, along with mathematics, in teaching foundations of contemporary physics, starting from the perspective of symmetry.

www.physics.ucsb.edu/~jatila/ccs-120_w2011.html



Examples of one drawing assignment:
Draw your understanding of the problem of simultaneity in Special Relativity

Students love this approach:

Thank you so much for teaching this class. I don't think I've ever been quite so stimulated by a class here as much as your class has done for me.

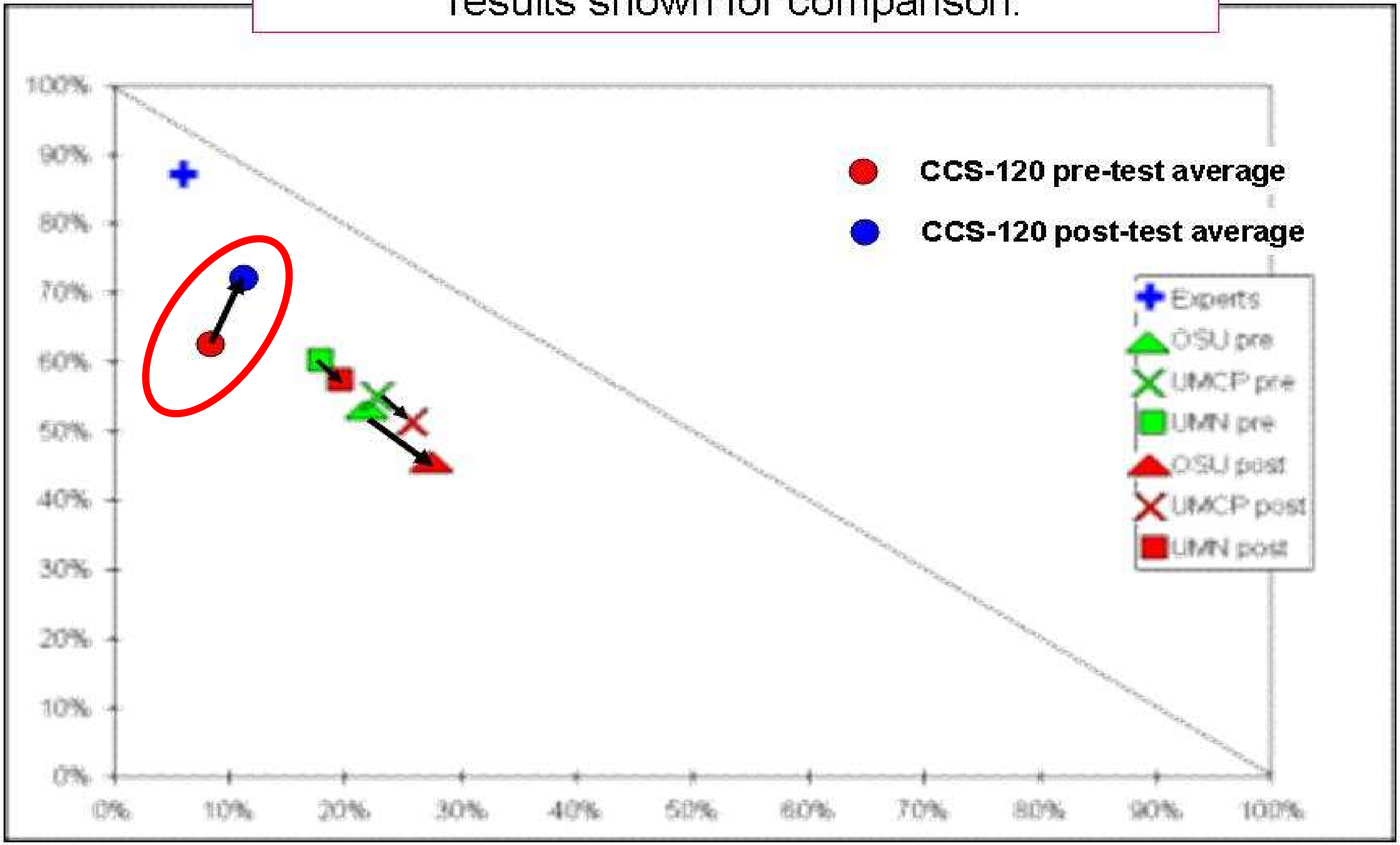
Thank you for one of the craziest (cool) classes I've taken my whole time being here. Not many classes care about what you think but in your class I felt like my understanding was the whole point. I really liked

parts to a whole. Thank you so much! It was My pleasure to take your class.

Thank You for opening my mind to Physics concepts I never thought I would Be aBle to otherwise comprehend. I appreciate the fact

New Visions in Science Education

Results of MPEX for RSS survey, with CCS-120 results shown for comparison.



Attitudes toward physics improved during this course, in contrast with national surveys of students in traditional first-year physics courses.

In Conclusion...

Visualization, Sonification, and Virtual Immersive Spaces have important and increasing roles to play in the future of Science Education and Research

* Provide greater access to complex mathematical concepts through multiple learning modalities
* Potential to improve access to science and math where teacher and student speak different languages
* Sonification has the potential to improve access to math and science for visually impaired students
* Media Arts Technology provides ways of immersing in data which are otherwise only accessible mathematically – such as the world of particles or the primordial universe

End of slides; Now for the demos!

1. Demonstration of Interactive Planck Mission Simulation for Windows

2. Demonstration of Interactive Visualization and Sonification of the CMB

Relevant publications where these projects are discussed more fully:

[1] Dekker, G., Moreland, J., van der Veen, J. (2011) Developing the Planck Mission as a Multi-Platform Immersive Application, Proceedings of the ASME 2011 World Conference on Innovative Virtual Reality WINVR2011, June 27-29, 2011, Milan, Italy

[2] McGee, R., van der Veen, J., Wright, M., Kuchera-Morin, J., Lubin, P. (2011) Sonifying the Cosmic Microwave Background, Proceedings of the 17th International Conference on Auditory Display (ICAD-2011) June 20-24, 2011, Budapest, Hungary

[3] van der Veen, J., McGee, R., Lubin, P., Kuchera-Morin, J., Wright, M., Alper, B., Smith, W. (2011) The Planck Visualization Project: Seeing and Hearing the CMB. Poster presented at AAS-2011, January, 2011, Seattle; *manuscript in prep*.

[4] van der Veen, J. (2010) The Planck Visualization Project: Seeing and Hearing the Cosmic Microwave Background, in Science Education and Outreach: Forging a Path to the Future. ASP Conference Series, Vol. 431, 2010, Eds. Jonathan Barnes, James G. Manning, Michal G. Gibbs, and Denise A. Smith, p. 295-306.

[5] van der Veen, J. (2007). Symmetry and Aesthetics in Contemporary Physics, Doctoral Dissertation