Public Outreach via Cosmological Simulation Visualizations

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Proposal Summary

The visible material in the universe – stars, gas, dust, planets – accounts for only about 0.5% of the cosmic density. The remaining 99.5% of the universe is invisible. Most of it is dark matter (~23%) and dark energy (~72%), with non-luminous baryons making up ~4%. In order to describe the evolution and structure of the universe, it is essential to show the distribution of dark matter and the relationship of dark matter to visible structures. We propose to make visualizations of state-of-the-art simulations of cosmology and galaxy formation, and distribute them to planetariums and other outreach venues. Our cosmological simulations show the evolution of the dark matter cosmic web that forms the backbone along which galaxies and clusters form. Our galaxy formation and galaxy merger simulations show galaxies realistically, using our Sunrise code to simulate both stellar evolution and reprocessing of light by dust. We propose to work with the NASA Ames Research Center visualization team to visualize the simulations, and with the Adler and Morrison Planetariums to adapt the visualizations including developing methods to show the multicomponent universe, to try the visualizations out on public audiences and evaluate their successes and needs for improvement, and to make them available to digital planetariums worldwide. We will also make videos based on these visualizations available to other venues, including on the web. These new visualizations will show how invisible dark matter shapes the visible universe. They will show how astrophysicists are calculating the physical processes that result in observed properties of galaxies and the large scale structure of the universe. Astronomical observations represent snapshots of particular moments in time; it is the role of astrophysical theory to produce movies that link these snapshots together into a coherent physical theory.

1. Introduction

In the 1920's the Carl Zeiss optical works developed the first planetarium star projectors and Max Adler funded the construction of the first planetarium in the western hemisphere, known today as Chicago's Adler Planetarium. The Adler Planetarium, consisting of a Zeiss optical projector showing stars and constellations on a dome overhead, opened its doors on May 12, 1930. This was a year after Edwin P. Hubble reported the relationship between the speed and distance of galaxies moving away from the Milky Way, and three years before Fritz Zwicky pointed out that the high line-of-sight velocities of galaxies in the Coma cluster implied that most of the gravitating material in the cluster is nonluminous "dark matter." Starting with Evans & Southerland's vector graphics planetarium projectors in the 1980's, planetariums have installed increasingly advanced digital projectors, which permit high-resolution dome-filling displays of data including the 2dF and SDSS galaxy distributions and R. Brent Tully's collection of data and images of nearby galaxies. Planetariums have also begun to install 3D theaters. Material shown on these venues however, is comprised solely of luminous objects and represents just a tiny fraction of the cosmic density. Planetariums have yet to project dark matter simulations onto their domes, and to show how dark matter and dark energy shape the evolution and structure of the universe on both large scales and galaxy scales.

Thirty years ago, the review by Faber & Gallagher (1979) convinced most astronomers that dark matter is the dominant form of mass in the universe, and soon after that Blumenthal, Faber, Primack & Rees (1984) proposed the Cold Dark Matter (CDM) theory. Since then many astrophysicists have developed CDM theory and run simulations of versions of CDM with different cosmological parameters. The NASA *Cosmic Background Explorer* (*COBE*) discovery in 1992 of the cosmic background radiation fluctuation amplitude confirmed a key prediction of CDM.

By 1998, multiple lines of observational evidence pointed to a universe dominated by dark energy and dark matter. The cosmological parameters have become known with increasing precision as a result of NASA *Wilkinson Microwave Anisotropy Probe* (*WMAP*) data and the large 2dF and SDSS redshift surveys along with other ground and space-based observations. The cosmic background radiation and the large-scale distribution of galaxies are both consistent with the predictions of the ΛCDM theory (i.e., CDM with a large cosmological constant Λ or other form of dark energy); indeed the standard ΛCDM model with the simplest cosmic inflation models is a better fit to the data than a variety of extended models (Dunkley et al. 2009). The visible material in the universe – stars, luminous gas, light-absorbing dust, planets, etc. – accounts for only about 0.5% of the cosmic density. The remaining 99.5% of the universe is invisible, mostly dark matter (~23%) and dark energy (~72%), with non-luminous baryons making up ~4% (Hinshaw et al. 2009, Table 6). Even though we do not yet know the true nature of the dark matter or the dark energy, we now know enough about their effects to be able to work out in detail the history of structure formation in the universe. And computer simulations are not just playing an essential role in developing scientific understanding, they can also be used to create visualizations that are as beautiful as they are educational.

In order to describe the evolution and structure of the universe, it is essential to show the distribution of dark matter and the relationship of dark matter to visible structures. The aim of the present proposal is to bring this invisible universe to the astronomy-interested public through planetariums and other venues. This involves several aspects, including developing a visual language to show several dark and luminous components, along with evaluations to determine how well diverse audiences understand visualizations incorporating various visual conventions; and developing a digital pipeline to translate outputs from high-resolution simulations into software for planetarium presentations. Our three key visualization projects are described in the next section. Once all of these have been translated into digital planetarium software, it will be relatively easy to produce not only dome shows including preprogrammed 5-7 minute modules with supporting documentation, but also flat-screen 2D and 3D presentations. These projects and the digital pipeline that we will develop to create them will open the door for a wider range of astronomical visualizations in the future. We propose to create an advisory committee of astronomers and planetarium experts to advise us on all these projects, with annual meetings; and in years two and three of the project we propose to organize workshops and other activities to explain the new material to potential users. We also propose to make much of this new visualization, outreach, and background material available to astronomers, educators, and the public via a new website.

2. Key Visualization Projects

Our three key visualization projects are (1) the Bolshoi Simulation, the latest and most ambitious large cosmological simulation, including associated semi-analytic models of the evolving galaxy population; (2) constrained simulations of the Local Universe; and (3) high-resolution hydrodynamic simulations of galaxy formation including galaxy mergers. All of these visualizations can be used for digital planetarium shows, 2D and 3D theater presentations, and videos. (Our main collaborators on each project are listed.)

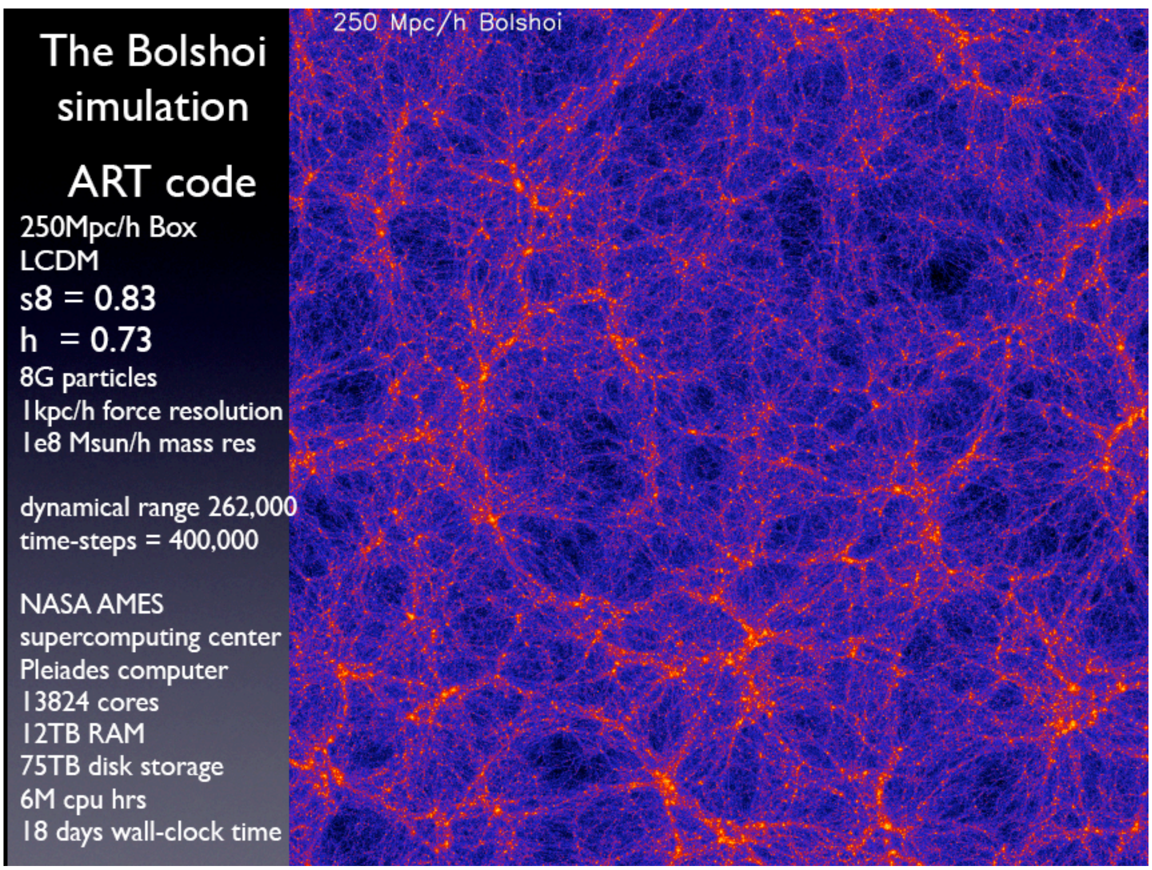

Figure 1. Final (z = 0) timestep of the Bolshoi Simulation, showing a slice 10 h^{-1} Mpc thick by 250 h^{-1} Mpc square.

2.1 Bolshoi Simulation (cosmological ΛCDM simulation using 8 billion particles with WMAP5 parameters in a volume 250 h^{-1} Mpc on a side; bolshoi means "big" in Russian). This simulation finished in April 2009. It used about 6 million cpu-hours of early-user time on the new Pleiades supercomputer at NASA Ames Research Center, the fourth fastest supercomputer in the world on the June 2009 list of the top 500 supercomputers. We saved about 150 timesteps, which required ~75 Tb of storage. PI Primack has received a 2009-2010 allocation of more than 3 million cpu-hours of Pleiades time to simulate subvolumes at 64x better mass resolution, and we will visualize evolution of some of these subvolumes. (Key collaborators: Anatoly Klypin, New Mexico State University; Chris Henze, NASA Ames.)

The Millennium Run simulation (Springel et al. 2006) has been the leading large cosmological simulation for the past several years, and it has been the basis for many cosmological studies. Our new Bolshoi simulation has nearly an order of magnitude better mass and force resolution than Millennium. Moreover, the Millennium simulation was based on the WMAP1 cosmological parameters (Spergel et al. 2003) while the Bolshoi simulation is based on the WMAP5 parameters (Hinshaw et al. 2009), which are a much better match to the best available cosmological data. Figure 1 shows the density distribution of dark matter in a slice of the final timestep of the Bolshoi Simulation.

Visualizing the Bolshoi Simulation. Proposed Bolshoi visualizations for public outreach include both fly-throughs and zoom-ins of the final (redshift $z = 0$) timestep, showing the cosmic web and its substructure. We are now finding the dark matter halos in each timestep using both spherical and friends-of-friends halo finders. It will also be illuminating to visualize the evolution of the merger tree, showing how dark matter halos merge and coalesce, and we are working with Collaborator Henze to develop new methods to do this.

Bolshoi Semi-Analytic Models. We are now calculating the halo merger tree from the Bolshoi halo catalog, in collaboration with Collaborator Anatoly Klypin and his group and with Primack's former PhD student Prof. Risa Wechsler and her group at Stanford University. The merger tree will be the basis for state-of-the-art Semi-Analytic Models (SAMs) of the evolution of the galaxy population. This would allow us to paste appropriate pictures of galaxies on the evolving dark matter simulation, and we plan to show the evolution of structure in the universe by visualizing and flying though regions of the simulated universe including these galaxy images both at earlier epochs and at the present epoch. (Key SAM collaborators: Primack's former students Rachel Somerville, Space Telescope Science Institute, and Darren Croton, Swinburne University, Melbourne, Australia. The SAM based on the Millennium Run simulation is Croton et al. 2006.)

2.2 Local Universe Simulations. These are cosmological dissipationless and hydrodynamical ΛCDM simulations using ~1 billion particles in a volume 64 h^{-1} Mpc on a side or larger, constrained so that a "Local Group" and "Virgo Cluster" and other nearby structures are near the middle. Thousands of timesteps can be stored as the

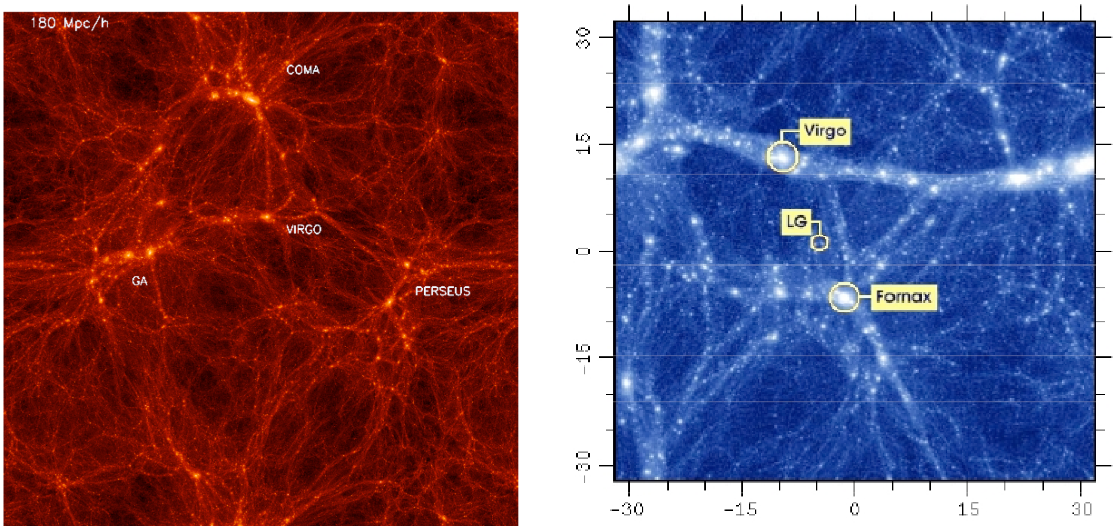

Figure 2. Local Universe Simulations: (left) 160 h^{-1} Mpc volume, showing prominent nearby large structures including the Great Attractor and the Virgo, Coma, and Perseus clusters; (right) 64 h^{-1} Mpc volume, showing the Local Group and the Virgo and Fornax clusters (horizontal axis SGX, vertical SGY). (These constrained simulations are described in Tikhonov & Klypin 2009; the right-hand figure is from Martinez-Vaquero, Yepes, & Hoffman 2008.)

simulations run on the NASA Ames supercomputers so that we can visualize the evolution of structure from the Big Bang to the present. We can also do fly-throughs and zoom-ins, both as the simulation evolves and at the present epoch. Although the constrained simulation method (e.g., Klypin et al. 2003) doesn't exactly reproduce the local universe, the new constrained simulations should be close enough to reality – especially for the Local Group and its neighborhood – that it would be illuminating to overplot in 3D the local galaxies (e.g., from the Tully Catalog) and isodensity contours representing high and low densities. The moderately high density regions are the filamentary "cosmic web" and the bright nearby galaxies should lie in the filaments. The large scale structure also influences the galaxies in other ways; for example, in both the observed and simulated universe, angular momenta of galaxies near voids are perpendicular to the direction that joins the galaxy and the center of the void (Cuesta et al. 2008), a phenomenon that we can visualize. In addition, we plan to fly through 3D maps of simulated gamma ray production by WIMP dark matter annihilation (proportional to dark matter density squared). (Key collaborators: Anatoly Klypin and his group; Francisco Prada and his group, including his student Antonio Cuesta; and Chris Henze and the NASA Ames visualization group.)

Future of the Local Universe. This is the same Local Universe simulations, continued into the far future assuming that the dark energy is a cosmological constant. This can be visualized both in co-moving coordinates (overall appearance of the volume doesn't change much, but on small scales structures fall together) and in physical coordinates (the local region becomes increasingly empty, and in ~100 billion years even the Virgo Cluster leaves the horizon of the Local Group). The main recent papers on this are Nagamine & Loeb (2003) and Busha et al. (2003, 2007). (Key collaborators: same as Local Universe Simulation, plus Michael Busha.)

How Structures Form in the Expanding Universe – visualizing how higher-than-average density fluctuations reach a maximum radius, then stop expanding and undergo gravitational collapse, while the rest of the universe continues to expand around them. This is the basis of our modern understanding of the evolution of the universe, and the goal of this project is to devise visualizations that will help both students and the general public to understand this key process. For example, particles that will be bound into a particular halo at $z = 0$ can be color coded and followed from early times until the present, and regions between bound structures can be color coded to represent the ratio of dark energy to dark matter densities. This will show that bound regions ("tame space") don't expand, while regions between them ("wild space") expand exponentially. (Key personnel: Nina McCurdy, UCSC.)

2.3. High Resolution Hydrodynamic Simulations of Galaxy Formation.

Galaxy Merger Simulations. Galaxy mergers are thought to be the main way that disk galaxies are transformed into galactic spheroids, which now host supermassive black holes and most of the stellar mass in the universe (Fukugita & Peebles 2004). Primack's group has run a wide range of high-resolution GADGET hydrodynamical simulations of major and minor galaxy mergers, including gas cooling and heating, star formation, supernova feedback, and the effects of dust (Cox et al. 2006, 2008; Novak et al. 2006, Novak 2008). Hernquist's group at Harvard has run many similar simulations including the accretion by and feedback from supermassive black holes (reviewed in Hopkins et al. 2008). Most of these simulations were carried out by Primack's former grad student Collaborator T. J. Cox. The calculated visual appearance of a major merger shown in Figure 3 includes stellar evolution and dust absorption and reradiation treated by the state-of-the-art Sunrise code (Jonsson 2006, Jonsson et al. 2006, 2009). Sunrise uses the Monte Carlo method to trace the radiation field through the galaxies by shooting millions of simulated "photon packets," which are scattered and absorbed by interstellar dust grains. As these photon packets traverse the medium, they contribute to heating the dust grains, which subsequently emit this energy as thermal far-infrared radiation. The photon packets emerging from the simulation volume in the direction of the observer form a realistic image of what the object would look like if observed with a telescope, at any wavelength from far-ultraviolet to submillimeter wavelengths.

We have stored thousands of timesteps for some of these simulations and we plan to continue this simulation program supported by other grants, so that we can visualize the entire process from any vantage point including the view from a star in one of the merging galaxies. It will be challenging to visualize all the components: old and newly formed stars, gas density and temperature, metallicity, and dark matter density; and also kinematics. In the galaxy merger video by Patrik Jonsson, Greg Novak, and Joel Primack selected as a finalist in the 2008 Science Magazine – NSF Visualization Challenge, we alternated between showing the optical appearance and the gas distribution during a galaxy merger, but we will seek to discover more accessible methods of showing the

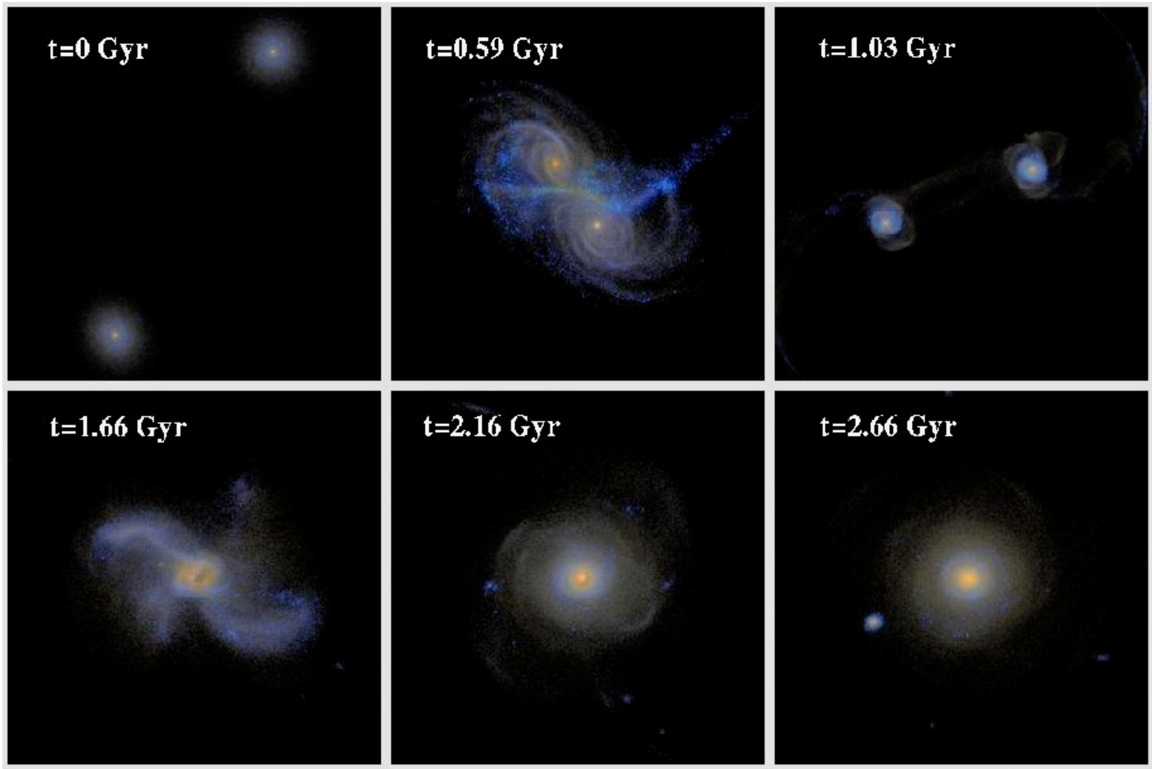

Figure 3. Composite color images including dust extinction for a high-resolution hydrodynamic galaxy major merger simulation. Time since the start of the simulation in given in the upper left corner of each image. (Top row) Initial pre-merger galaxies, first pass, maximal separation after the first pass. (Bottom row) Merger of the nuclei, 0.5 Gyr after the merger, remnant at 1 Gyr after the merger. The field of view at 0 Gyr and 1.03 Gyr is 200 kpc, while the field of view for the other images is 100 kpc. Star-forming regions appear blue, while the dust-enshrouded star-forming nuclei appear red. (From Lotz et al. 2008.)

multiple components. Galaxy merger simulations may be especially appropriate for 3D theater displays, since the galaxies are recognizable at most merger stages. (Key collaborators: Primack's former grad students Patrik Jonsson (now a postdoc with Primack at UCSC, moving to Harvard in September 2009), T. J. Cox (now working with Lars Hernquist at Harvard, moving in September 2009 to Carnegie Observatories), and Greg Novak (now a postdoc with Jeremiah Ostriker at Princeton), and Primack's current grad students).)

Very High Resolution Simulations of Forming Galaxies. Daniel Ceverino started these high-resolution adaptive mesh hydrodynamic simulations (Ceverino & Klypin 2009) as a PhD student with Collaborator Anatoly Klypin (using PI Primack's supercomputer time with Klypin's Open MP ART-hydro code). Ceverino is running even more ambitious simulations as a postdoc with Primack's long-term collaborator Avishai Dekel, now using Primack's allocations on the Schirra and Columbia computers at NASA Ames. Visualizations will be crucial to help us understand the formation and evolution of these galaxies in cosmological simulations, and compare the simulations to observations. These are among the highest resolution and most realistic galaxy formation simulations now being done, and they suggest that the process of star-forming clump

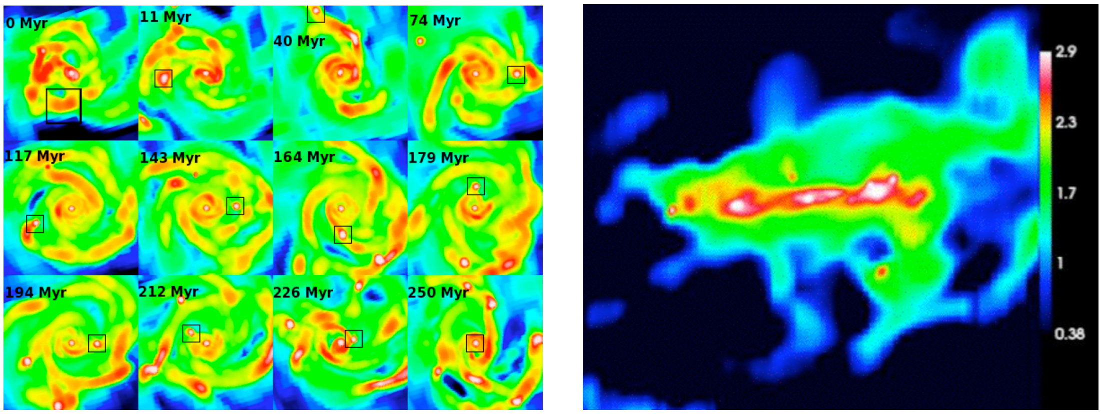

Figure 4. (Left) Evolution of gas disk at $z \sim 2$, showing a clump (boxed) merging onto central spheroid. (Right) Side view of a timestep of the same simulation. The region shown is 15 kpc across. Color code is log surface density in $M_{\odot}/pc^2$.

formation in gaseous galactic disks fed by cold streams at high redshift $z > 2$ followed by clump merging onto central spheroids may be the main formation mechanism of massive galactic spheroids (Dekel et al. 2008; Dekel, Sari, & Ceverino 2009). We will also visualize new simulations of the same systems, but now with seed supermassive black holes (SMBHs), led by Primack's grad student Priya Kollipara working with Ceverino. We will also run ART-hydro galaxy merger simulations with and without SMBHs. This research is funded by PI Primack's current NASA ATP grant. Adaptive-mesh hydrodynamic galaxy merger simulations have been pioneered by Advisory Committee member Tom Abel (Kim, Wise, & Abel 2009). (Key collaborators: Daniel Ceverino, Avishai Dekel, Anatoly Klypin, Priya Kollipara.)

2.4 Additional Visualization Projects. Once we have established a pipeline to translate simulations into digital planetarium software formats and determined what sorts of visual metaphors work best, it will be relatively easy to translate other cosmological simulations into the planetarium formats. Many such simulations will be produced by astrophysicists affiliated with the University of California systemwide AstroComputation Institute, led by Primack. The following are two other examples of such simulations.

Evolution and Substructure of a Milky Way Size Dark Matter Halo. Via Lactea I was the first billion particle simulation of a dark matter halo of the size that hosts our own galaxy was run by Piero Madau's UCSC group (Diemand et al. 2007), and their more recent 4 billion particle Via Lactea II simulation (Diemand et al. 2008) is competitive with the European Aquarius simulation (Springel et al. 2008).

Massive Star Formation. Mark Krumholz (UCSC) is doing state-of-the-art hydrodynamical simulations that are answering the question of how stars ~100 times the mass of the sun form, and why most are in binary systems with similar-mass stars (Krumholz et al. 2009).

2.5 Spinoffs. The following two projects are direct spinoffs of the proposed project.

Education Resources. A secondary goal of this proposal is to prepare and disseminate cosmological visualizations that will be useful in education at all levels, including formal K-12 and undergraduate science education, and informal science education through film, TV, and the web. Production of such visualizations will be relatively easy once the content has been transferred to digital planetarium software, which includes the ability to generate 2D and 3D outputs as well as dome shows. This proposal therefore is also relevant to SMD education portfolio by developing SMD-related course resources for both primary and secondary education and higher education. The related proposal submitted by Tara Firenzi on which Primack is a Co-I will develop grades 7-12 content and ancillary resources using visualizations produced by the activities we are proposing.

Cold Dark Matter Explorers computer interactive. We are currently collaborating with the computer game design program at UCSC to visualize our cosmological simulations for the purposes of game-based learning. The ultimate goal of this project is to create a computer game that encourages the exploration of the "cosmic web" (from the Bolshoi or Local Universe simulations), and from which the user will gain a richer picture of our universe and a deeper understanding of our cosmology. (Key personnel: Nina McCurdy will be working with one of the graduate students from the UCSC's Computer Game Design program, a new joint degree program of the Departments of Computer Science and Film and Digital Media.)

3. Role of Planetariums

3.1 Why Planetariums? With scientific advancement comes the responsibility to include the general public by integrating new discoveries into the story of the cosmos. Planetariums provide the perfect venue to do just that, since they have both the best equipment and the most interested audience. The fact that the audience is self-selected means that viewers are personally invested in the material. By conveying the excitement within the scientific community, beautiful simulation visualizations will undoubtedly inspire future scientists, and in particular future astronomers and physicists. Digital planetariums are also the most ambitious venue, since digital planetarium software makes extending our productions to 3D theaters, flat screens, and the internet comparatively easy.

Planetariums used to show mainly the nearby stars in the night sky. With the advent of digital projectors they have greatly expanded their content by including various sky surveys (Sloan digital sky survey, Tully galaxy data set, etc.). However, planetariums have yet to project dark matter simulations onto the dome for a public audience. Also, while flying around static environments can provide a wealth of information about the current shape of the Universe, a static environment represents only a snapshot of a moment in cosmic evolution. Cosmological simulations can tell a more complete story by visualizing the evolution of the cosmic web.

3.2 Roles of Adler and Morrison Planetariums. These planetariums will be crucial in developing a visual language for displaying dark matter as well as visible matter (stars, gas, and dust), and working with PI Primack and his scientific collaborators and with Collaborator Chris Henze and the NASA Ames visualization group to make compelling visualizations of our multicomponent simulations. In addition to their domes, both Adler and Morrison Planetariums have 3D theaters and other venues where we can try visualizations on various audiences.

For example, in the Adler Space Visualizations Laboratory (SVL) the visualizations will be shown on the stereoscopic display wall during the Astronomy Conversations program. In this program, visitors interact with an astronomer who makes use of the SVL's displays and visualizations to describe their research or recent discoveries in space science, and respond to visitor questions. This venue provides a controlled environment where we can gauge visitor reactions to the visualizations and hone our descriptions of them. Over the course of a year approximately 25,000 Adler visitors attend an Astronomy Conversations program. We will also deploy the visualizations in the Universe Theater, a high definition (1080p) stereoscopic theater seating 200. There they will be used as previews before the ticketed show. In out Definiti Dome Theater (also seating 200) we will use the real-time visualizations in an updated version of our Night Sky Live show, a presenter-led tour of the Universe. Our pre-rendered visualizations will also be used as an introduction to the Deep Space Adventure gallery, a new 5,000 square foot gallery opening in 2011 that features modern cosmology. The introduction will take place in the Definiti Theater and prepare visitors for their experience in the gallery. We also plan to make use of the visualizations in the Deep Space Adventure gallery itself.

The California Academy of Sciences proposes to collaborate with the Adler Planetarium and adapt simulations for use in real-time programming at the Academy. Numerous opportunities for engaging diverse audiences exist at the Academy: of 1.7 million visitors in the first ten months since its reopening in September 2008, approximately a third have seen the planetarium's debut program, "Fragile Planet." We propose to host several cosmology-oriented events at the Academy's popular "NightLife" program targeting young adults. We also propose to include simulations in the planetarium's monthly Benjamin Dean Lecture Series, which remains sold out during its first year in the new Morrison Planetarium. The Academy's 3D stereoscopic theater and "Science in Action" exhibit and video podcast provide additional venues for presenting cosmological content. The visualization studio will refine a pipeline for simulation data to be incorporated into rendering software for use in content for the planetarium community.

The International Planetarium Society's Fulldome Video Committee, which Co-I Wyatt chairs, has proposed initiatives to improve professional development among planetarium educators, and cosmology is a key topic area opened up by new technology. The simulations developed by this project could prove a significant resource for the more than 700 fulldome theaters worldwide.

3.3 Making Visualizations. NASA Ames has developed concurrent visualization capabilities (Ellsworth et al. 2006), enabling vast quantities of data to be visualized without seriously impacting runtime performance of simulations. The first part of this project will be devoted to translating such outputs into formats compatible with systems used for video, digital planetarium and 3D theater systems. Simulation visualizations were originally created for research purposes and they can easily be too large for planetarium display systems, where the number of dynamic objects is currently limited to about 10^5. The number of dynamic particles displayed thus must be greatly reduced. Therefore a large part of the preliminary process will be determining how to best sub-sample the current data in such a way that maintains the most interested and valuable characteristics of the simulation. Part of the work in preparing visualizations will also be interpolating between the saved timesteps.

The outputs from the Sunrise simulations are very realistic depictions of what the simulated galaxies would look like to an observer, but they are different from the particle-based galaxy simulations in the sense that they do not contain "objects" (particles) that can be subsequently visualized from any viewpoint. The outputs are a snapshot of the radiation emerging from the simulated object in one specific direction, and (as for visualization any real 3D object) another computation is needed to show the object from another viewpoint. The outputs thus cannot be used directly by planetarium software such as PartiView, and part of our proposed project will be to determine how to adapt these simulation outputs for use in planetariums and 3D theaters. Sunrise can easily generate 3D images – i.e., two nearby views.

We need to see what visualizations work best in 3D. The merging of two galaxies looks very different from various vantage points. Merger simulation visualizations often show the event several times from different perspectives but fail to present the entire three-dimensional experience in a single animation. Adapting the current merger simulations to 3D theater will allow for a more complete and powerful experience. More critical will be deciding what material to present and how to present it so that it will be understood by diverse audiences. How can we show the dark matter and visible matter simultaneously without confusing the audience? How can we show motion? What sorts of color codes convey information without confusion? What we discover should improve our outputs and also future astronomical and computational visualization and outreach efforts.

Real-Time vs. Pre-Rendered shows. We plan on producing both Real-Time and Pre-Rendered shows to be distributed to planetariums. The Pre-Rendered material will also be useful in video form for other applications including education and science museums. Real-Time shows would require providing a data set that can be used both to create shows and to hold live (exploration) sessions. Pre-rendered shows would demand less compatibility and would therefore be compatible with a larger variety of systems. These shows would be in 5 to 7 minute blocks designed to explore the most illuminating aspect/components of the simulations.

3.4 Plans and Methodology for Evaluation of Visualizations. Visualizations have the potential to move and educate audiences. However, it is an open question as to whether a visualization of content that is unfamiliar to any given audience will be meaningful to this audience, especially without appropriate guidance. Studies show, particularly in the area of cosmology, that the general public does not have extensive background knowledge or understanding, and that people often have pervasive misconceptions. Absent appropriate foundational understandings, audiences may not be able to relate to the visualizations or may misinterpret them.

Evaluation work undertaken at the Adler Planetarium and the Morrison Planetarium will be formative in nature. Evaluator Michelle Nichols, using her experience in visitor evaluation in the museum setting and taking advantage of the facilities at the Adler's Space Visualization Laboratory and at the California Academy of Sciences, will work with small groups of visitors to ascertain how they interpret portions of visualizations or entire visualizations. This will be done first without, and then with some guidance from museum staff about what these visualizations represent, and help with any difficult concepts. Audiences' initial reactions, impressions and questions about visualizations given without guidance will inform what guidance is offered. When guidance is offered, again audience reactions will be recorded to see if their understanding of the visualizations is enhanced.

This data about what guidance is appropriate to facilitate understanding will be available to partners to use in several ways: first it can inform subsequent iterations of visualizations, possibly suggesting additional content or different approaches to the visualization. Second, it will be available to be included in accompanying materials for end users of these visualizations. As such it can inform voiceover scripts for planetarium shows, or notes for lectures or other educational programs that use these visualizations.

In order to present an accurate picture of the known universe and to depict the relationship of dark matter to visual structures, it will be necessary to develop the appropriate visual language to describe both dark and luminous components. A large part of the visualizing process will be devoted to developing and perfecting this visual language, and will require effective and meaningful evaluation.

3.5 Dissemination. The next part of the proposed project will be devoted to creating a dissemination process and continuing to evaluate the success of the productions.
Other possibilities include producing DVDs or Blu-Ray disks and distributing them to both formal and informal science education institutions.

We also intend to create 5-10 minute tutorials, giving background on the content of the materials and tips on the most appropriate ways to fully exploit them. These tutorials will either be taken directly from the training sessions planned for the third year of our project, or will be produced from scratch. These short films will be distributed with the visualizations as well as being made available on various websites (including the site we intend to create).

4. Management Plan, Division of Labor, Timeline, and Advisory Committee

Management: The PI and Co-Is will constitute a management committee to consider all major issues. PI Joel Primack will act as program manager and will supervise all collaborations, activities, workshops and events. While Primack will ultimately be responsible for the overall planning, management and coordination of all formal and informal education activities, it will be staff person Nina McCurdy who carries out much of the efforts. Primack and McCurdy will meet on a weekly basis to discuss planning, progress, issues and concerns. Most importantly, Nina will develop and maintain clear lines of communication between UCSC, the Adler Planetarium and the Morrison Planetarium, and will work with the three institutions to see that key milestones are being met and that all activity is aligned with the goals and objectives of the present proposal.

Timeline: 2010 – create initial planetarium versions of key projects, begin trials and evaluations, first meeting of advisory committee. 2011 – finish first versions of key projects for evaluation and limited distribution, first presentations to planetariums at relevant conferences. 2012 – finish final versions of projects including supplementary materials, launch major distribution effort, workshops for planetarium staff, and outreach to other venues.

Staff: Nina McCurdy will play a crucial role in various aspects of this proposed project. Nina's academic background in physics and astrophysics, combined with the knowledge and vocabulary she has gained through her personal explorations of the visual arts, makes her a valuable liaison between the scientific, artistic, and planetarium communities. Nina has worked at Adler Planetarium in 2008 and 2009 and been trained there to run digital planetarium shows, and she will work closely with the Adler and the Morrison Planetariums, as well as any other institutions/sites that this project extends to. She will be deeply familiar with the scientific concepts of the simulations and will help the planetarium teams design the most meaningful and effective explorations of them. Nina will also be responsible for creating simulation visualizations and interactive learning software. In addition, Nina will create a website to make our productions publicly available, and thereby extene our outreach to a much wider audience. We propose to have Nina supported 75% by the present proposal and 25% by the new University of California systemwide Institute on AstroComputation, directed by PI Primack, for which she will be performing similar functions.

Evaluator: Michelle Nichols, Master Educator, Adler Planetarium is the professional evaluator on our team. She has developed and conducted evaluation projects for a variety of Adler Planetarium programs, including exhibit galleries, educational programs, and planetarium shows. She will workwith both Adler and Morrison Planetariums to do formative evaluations and to assess the effectiveness of the visualizations (section 3.4).

An **Advisory Committee** has been created for this project, consisting of leading experts in cosmological simulations and visualization. The current membership includes Tom Abel (Stanford), Donna Cox (NCSA), Andrey Kravtsov (U Chicago), Shawn Laatsch (Hilo Planetarium), Start Levy (NCSA), Ian McLennan (Vancouver), Derrick Pitts (Franklin Institute Fels Planetarium), and Frank Summers (STScI). (All of these people have confirmed their participation in our Advisory Committee except Donna Cox.) The PI and Co-Is will consult frequently with the Advisory Committee electronically, and meet with members in person at least annually, perhaps in conjunction with scientific conferences and AstroViz and/or International Planetarium Society meetings. W we will need to try various ways to visualize the multicomponent universe in order to find a visual language that accurately conveys the interaction of visible matter with dark matter and dark energy in forming both large scale structure and galaxies. How to do this well will probably be the main issue on which we will need the advisory committee's wisdom.

Capabilities of Digital Planetarium Systems. Working with the Adler and Morrison Planetariums, it is our priority to develop material that is compatible with their systems. The Adler's Definiti Dome and 3D theaters run exclusively on DigitalSky systems (created by SkySkan), whereas the Morrison Planetarium employs both DigitalSky 2 and Uniview (created by SCISS) systems. At their cores, Uniview and DigitalSky 2 are similarly based on the 4D interactive visualization tool, PartiView (written by Stuart Levy at the National Center for Supercomputing Applications, who is a member of our Advisory Committee). Both systems are capable of importing and displaying multi-point data sets (e.g., the Sloan Digital Sky Survey), volumetric visualizations and isosurfaces. These capabilities are critical to the production of the proposed visualizations. In addition, both DigitalSky 2 and Uniview are capable of both Pre-Rendered and Real-Time shows. With DigitalSky 2, the user can move freely through a 3D universe (under 3-axis joystick facilities). Using a similar approach, Uniview's FlightAssist allows for five degrees of freedom including radial motion and orientation. These capabilities will allow for both pre-rendered flight paths and also for operator-controlled navigation through the proposed visualizations of the multicomponent universe.

Aside from SCISS and SkySkan, other vendors have come into the market to provide digital solutions which create the ability to explore the universe in 3D, unlike the earth based view of opto mechanical. Although the Pre-Rendered productions will be compatible with all systems, it will be necessary to work with other vendors to translate the Real-Time materials into the appropriate formats. Although this is not within the scope of the proposed project, we hope to eventually extend our Pre-Rendered and Real-Time materials, making them accessible to all planetariums, regardless of their system.

5. Responsiveness to NASA's Education and Public Outreach Goals

The NASA Science Mission Directorate's (SMD's) vision for Education and Public Outreach is:

To share the story, the science, and the adventure of NASA's scientific explorations of our home planet, the solar system, and the universe beyond, through stimulating and informative activities and experiences created by experts, delivered effectively and efficiently to learners of many backgrounds via proven conduits, thus providing a return on the public's investment in NASA's scientific research.

Planetariums are proven conduits. The goals and objectives of this proposal speak most directly to NASA's strategic subgoal 3D: "Discover the origin, structure, evolution, and density of the universe and search for earthlike planets." The proposed visualizations address two of the subgoal's four primary science questions: "What are the origin, evolution and fate of the universe?" and "How do planets, stars, galaxies, and cosmic structure come into being?" The visualizations also address two of its major research objectives: (3D.1) to "Understand the origin and destiny of the universe, phenomena near black holes, and the nature of gravity" and especially (3D.2) to "Understand how the first stars and galaxies formed, and how they changed over time into the objects recognized in the present universe."

The primary goal of the present proposal is Public Outreach via Cosmological Simulation Visualizations for planetariums. It is thus directly responsive to SMD's Outreach portfolio items "Activities to increase interest in science, engineering, and technology careers relevant to NASA SMD;" and "Activities to increase understanding by the general public of SMD science, engineering, and technologies."

In the Informal Education Outcome, SMD encourages proposals that increase utilization of SMD resources in out-of-school time or after school programs. This proposal is responsive, since many schools bring classes to planetariums. In addition, planetariums make an effort to bring student/schools from underrepresented neighborhoods to their institutions. Six hundred and seventy teachers from all over the Chicago area brought classes to the Adler Planetarium during the 2007-2008 school year for field trips, for whom free admission is provided. More than 20,000 of these visitors are Chicago Public School (CPS) students, the majority of whom (91%) are members of minority populations.

Also, since the proposal includes training for planetarium staff, it is also responsive to SMD's Informal Education goals of developing, supporting, and improving the competency and qualifications of STEM informal educators, enabling informal educators to effectively and accurately communicate information about NASA SMD activities and access NASA SMD data for programs and exhibits.

Customer Needs Focus: In order to get a sense of the level of interest and support within the planetarium community for our proposal, a description of our project was sent out to a number of planetariums. Within a few days, we received statements of interest/support from dozens of institutions scattered across the country. Below are just a few quotes taken from the many positive responses received:

"Your project sounds fantastic! We'd love to be involved and could offer our planetarium for field testing in a variety of settings…" – Laurel Ladwig, Planetarium Developer, New Mexico Museum of Natural History Foundation

"Outstanding. This type of endeavor is exactly what is needed to assist planetariums in bringing real science to the general public…" – Michael J. Narlock, Head of Astronomy/Web Coordinator, Cranbrook Institute of Science, MI

"The concept of dark matter and energy are hard to represent easily and any help with the presentation of these ideas and concepts will be met with open arms by planetariums around the world…" – Kurt Kuechenberg, Manger, Saunders Planetarium, Tampa FL

6. References

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Dekel, A., Sari, R., & Ceverino, D. 2009, Formation of Massive Galaxies at High Redshift: Cold Streams, Clumpy Disks and Compact Spheroids, arXiv0901.2458

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Springel, et al. 2008, The Aquarius Project: the subhaloes of galactic haloes, MNRAS, 391, 1685

Joel R. Primack

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Home phone: (831) 425-1194; Cell phone: (831) 345-8960

Education
Princeton University A.B. 1966 Physics (Summa cum Laude)
Stanford University PhD 1970 Physics

Academic Positions
Junior Fellow, Society of Fellows, Harvard University 1970-73
Assistant Professor of Physics, UCSC 1973-1977; Associate Professor of Physics, UCSC, 1977-1983; Professor of Physics, UCSC 1983-present; Distinguished Professor 2007-

Director, University of California systemwide Institute on AstroComputation, 2010-
Chair, UCSC Committee on Computing and Telecommunications, 2008-2010

Advice (partial list): SAGENAP advisory panel to DOE/NSF 2000-2001; NSF Astronomy Theory Review Panel 2000; DOE Lehman Review of SNAP Proposal 2001; Chair, NASA Cosmology panel on LTSA and ADP 2001; Cosmology Panel, Hubble Space Telescope Time Allocation Committee 2003; Editorial Board, Journal of Cosmology and Astroparticle Physics 2003-06; National Academy Beyond Einstein panel, 2006-07.

American Physical Society activities (partial list): Executive Committee, APS Division of Astrophysics, 2000-2002; APS Panel on Public Affairs (POPA) 2002-2004; Chair, POPA Task Force on Moon-Mars Program and Funding for Astrophysics 2004; Chair, APS Forum on Physics and Society 2005; Chair, APS Sakharov Prize committee 2009

Outreach (partial list): Smithsonian National Air and Space Museum, Advisory Committee on *Cosmic Voyage* IMAX film, 1994-1996. Co-organizer, "Cosmic Questions" Conference, Smithsonian National Museum of Natural History, Washington, DC, April 14-16, 1999. Co-author of popular book *The View from the Center of the Universe* (2006). Over 100 public lectures on cosmology, including Sackler Lecture (UC Berkeley, 2006); J. Robert Oppenheimer Memorial Lecture (Los Alamos, 2007); APS Public Lecture (St. Louis, 2008); Terry Lectures (with Nancy Abrams, Yale, 2009)

Honors (partial list):
A. P. Sloan Foundation Research Fellowship, 1974-1978
American Physical Society Forum on Physics and Society Award, 1977; Fellow, 1988
American Association for the Advancement of Science, Fellow, 1995
Humboldt Senior Award of the Alexander von Humboldt Foundation, 1999-2004

Books
- Joel R. Primack and Frank von Hippel, *Advice and Dissent: Scientists in the Political Arena* (New York: Basic Books, 1974; New American Library, 1976)
- S. Bonometto, J. R. Primack, A. Provenzale, eds., *Dark Matter in the Universe* (Amsterdam: IOS Press, 1996)
- Joel R. Primack and Nancy Ellen Abrams, *The View from the Center of the Universe: Discovering Our Extraordinary Place in the Cosmos* (New York: Riverhead/Penguin, 2006; London: HarperCollins, 2006; Paris: Laffont, 2008; and other foreign editions)

Selected peer-reviewed publications (in chronological order)

Supersymmetry, cosmology, and new physics at teraelectronvolt energies 1982, *Phys. Rev. Letters* **48**, 223. Pagels, Heinz, and **Primack, Joel R.** (348 citations in SPIRES High Energy Physics database, *253 citations in NASA Astrophysics Data System*)

Formation of galaxies and large-scale structure with cold dark matter 1984, *Nature* **311**, 517. Blumenthal, G. R.; Faber, S. M.; **Primack, J. R**.; Rees, M. J. (471 SPIRES cites, *747 ADS cites*)

Contraction of dark matter galactic halos due to baryonic infall 1986, *ApJ* **301**, 27. Blumenthal, G. R.; Faber, S. M.; Flores, R.; **Primack, J. R. (**299 SPIRES, *382 ADS***)**

Dynamical effects of the cosmological constant 1991, *MNRAS* **251**, 128. Lahav, Ofer; Lilje, Per B.; **Primack, Joel R.**; Rees, Martin J. (268 SPRES, *327 ADS*)

Semi-analytic modeling of galaxy formation: the local Universe 1999, *MNRAS* **310**, 1087. Somerville, Rachel S.; **Primack, Joel R.** (431 SPIRES, *509 ADS*) *

The nature of high-redshift galaxies 2001, *MNRAS* **320**, 504. Somerville, Rachel S.; **Primack, Joel R.**; Faber, S. M. (336 SPIRES, *385 ADS*) *

Profiles of dark haloes: evolution, scatter and environment 2001, *MNRAS* **321**, 559. Bullock, J. S.; Kolatt, T. S.; Sigad, Y.; Somerville, R. S.; Kravtsov, A. V.; Klypin, A. A.; **Primack, J. R.**; Dekel, A. (723 SPIRES, *792 ADS*) *

Generating Hot Gas in Simulations of Disk Galaxy Interactions 2004, ApJ, 607, L87-L90. T.J. Cox, **Joel R. Primack**, Patrik Jonsson, & Rachel Somerville *

A New Non-Parametric Approach to Galaxy Morphological Classification 2004, AJ, 128, 163-182. Jennifer M. Lotz, **Joel Primack**, and Piero Madau *

Dark-Matter Haloes in Elliptical Galaxies: Lost and Found 2005, Nature, 437, 707. A. Dekel, F. Stoehr, G.A. Mamon, T.J. Cox, G.S. Novak, & **J.R. Primack ***

The Effects of Feedback in Simulations of Disk Galaxy Major Mergers 2006, MNRAS, 373, 1013. T. J. Cox, Patrik Jonsson, **Joel R. Primack**, and Rachel S. Somerville *

Simulations of Dust in Interacting Galaxies I: Dust Attenuation 2006, ApJ, 637, 255. Patrik Jonsson, T. J. Cox, **Joel R. Primack**, Rachel S. Somerville *

AEGIS: Host Galaxy Morphologies of X-ray and Infrared-selected AGN at $0.2 < z < 1.2$ 2007, ApJ Letters, 660, L19, C. Pierce, J. M. Lotz, , et al. *

Predicting the Properties of the Remnants of Dissipative Galaxy Mergers 2008, MNRAS, 384, 94. M. Covington, A. Dekel, T. J. Cox, P. Jonsson, and **J. R. Primack** *

The effect of galaxy mass ratio on merger–driven starbursts 2008, MNRAS, 384, 386. T. J. Cox, P. Jonsson, R. S. Somerville, **J. R. Primack**, A. Dekel

Diffuse Extragalactic Background Radiation 2008, AIP Conf. **1085**, 71. **J. R. Primack**, R.C. Gilmore, R. S. Somerville

GeV Gamma-Ray Attenuation and the High-Redshift UV Background 2009, MNRAS, in press, R.C. Gilmore, P. Madau, **J. R. Primack**, R. S. Somerville, F. Haardt *

* These papers are based on PhD dissertation research supervised by **Joel Primack**

JOEL R. PRIMACK: CURRENT AND PENDING SUPPORT

JOEL R. PRIMACK: CURRENT AWARDS 2009

AGENCY	TITLE	DATES	AMOUNT	MONTHS FUNDED
NSF AST-0607712	Structure Formation on Small Scales and the Nature of Dark Matter PI: Kaplinghat; Co-Is: Klypin, Primack	9/1/06- 8/31/09	$43,905	0
NASA ATP NNX07AG94G	Galaxy Interactions and the Formation and Structure of Elliptical Galaxies PI: Primack; Co-I: Dekel; Collaborators: Faber, Jonsson, Lotz, Somerville	2/06/07- 2/05/10	$353,601	1 summer month 2007, 08, 09
NASA GLAST NNX08AW37G	Modeling Gamma-Ray Attenuation PI: Primack; Co-I: Madau	10/1/08- 9/30/09	$63,000	0
UCSC-NASA UARC-ARP NAS2-03144	Simulation and Visualization for Astronomy and Public Education PI: Primack	3/3/09- 9/30/10	$50,000	0
UC MRPI Multi-Campus Research Unit	University of California High Performance AstroComputing Center PI: Primack; Collaborators: Anninos, Bullock, Faber, Furlanetto, Habib, McKee, Norman, Nugent, Oh, Sprague, Wilson	1/1/10- 12/31/14	$400,000 per yr for 4 staff, conferences, summer school, etc.	1/2 summer month

JOEL R. PRIMACK: PENDING AWARDS 2009

AGENCY	TITLE	DATES	AMOUNT	MONTHS FUNDED
NSF AST	Formation and Evolution of Galactic Spheroids: Star Formation, Quenching, and Comparison with Observations PI: Primack; Co-I: Dekel; Collaborators: Cox, Faber, Jonsson, Lotz, Novak, Somerville, Wechsler	8/1/09- 7/31/12	$401,722	1 summer month 2010, 11, 12 Commit 25% acad yr + 1 summer mo
NASA ATP 09-ATP09-0189	Evolution of Structure and of the Cosmic Population of Galactic Spheroids PI: Primack; Co-Is: Dekel, Klypin; Collaborators: Cox, Faber, Jonsson, Krumholz, Lotz, Somerville, Wechsler	1/1/10- 12/31/12	$577,090	1 summer month 2010, 11, 12 Commit 25% acad yr + 1 summer mo

Lucy Frear Fortson
lfortson@adlerplanetarium.org
312-322-0338

Education:

1984 B.A. Physics and Astronomy Smith College, Northampton, MA
1991 Ph.D. Physics University of California, Los Angeles, CA

Recent Appointments:

- October, 2004 - present Vice President for Research, Adler Planetarium and Senior Research Associate, University of Chicago Department of Astronomy and Astrophysics;
- December, 2001 - October, 2004 Director of Astronomy, Adler Planetarium and Senior Research Associate, University of Chicago Department of Astronomy and Astrophysics;
- August, 1997 - December, 2001 Astronomy Faculty Member, Adler Planetarium and Research Scientist, University of Chicago Department of Astronomy and Astrophysics;
- October, 2004 - present PI, VERITAS Collaboration Group, Adler Planetarium;
- 1997 - 2000 Principal Investigator, CASA-BLANCA experiment; University of Chicago

Selected Publications:

- Fortson, L., SubbaRao, M., & Greenberg, G., *Using Collaborative Environments in Research-based Science Education*, Proc. Astro. Soc. Pac., **389** 239-243 (2008).
- Carney, K., Fortson, L., & Nichols, M., *CI-Team: Introducing Quasar Research to High School Science Teachers using the Cyber-infrastructure*, Proc. Astro. Soc. Pac., **389** 91-95 (2008).
- Fortson, L.,*The Importance of Involving Research Scientists in Education and Outreach* NASA OSS Education & Public Outreach Conference; ASP Conf. Series, Vol. 319; Eds. C. Narasimhan, B. Beck-Winchatz, & I. Hawkins (2004).
- Horan, D., et al., *Multiwavelength Observations of Markarian 421 in 2005 - 2006*, Astrophys. J., accepted (2009).
- Acciari, V.A., et al. (VERITAS Collaboration, http://veritas.sao.arizona.edu/), *Discovery of Very High Energy Gamma-ray Radiation from the BL Lac 1ES 0806+524*, Astrophys. J, **690** L126-L129 (2009).

Experience: As VP for Research at the Adler, Dr. Fortson oversees the research and public understanding of research programs conducted by the fifteen researchers in the departments of Astronomy, History of Astronomy and Education. Dr. Fortson is Education Director for the *Zooniverse* Collaboration, an extension of the Galaxy Zoo Project engaging more than 200,000 online volunteers to classify nearly one million galaxies from astronomical databases showing that analysis methods incorporating humans as sophisticated computational algorithms can lead to important scientific results while at the same time engaging the public in the process of science. Dr. Fortson has written content and interactives for three museum galleries covering over 10,000 square feet and has been Project Director for three Planetarium shows in Adler's Virtual Reality theater. Dr. Fortson is also PI of the Adler Planetarium group involved in the VERITAS gamma ray collaboration, focusing on TeV emission from AGN used to understand the underlying emission mechanisms and black hole engine. The Adler group leads the multiwavelength campaign organization on AGN targets. Dr. Fortson serves on many committees including the Human Capital Committee of the NASA Advisory Council, co-chair of the Astro2010 Decadel Survey EPO Study Group, and member of the Citizen Science subcommittee for the International Year of Astronomy.

Mark Upadhyayula SubbaRao

Education:

1989 B.S. Engineering Physics Lehigh University
1991 M.A. Astrophysics The Johns Hopkins University
1996 Ph.D. Astrophysics The Johns Hopkins University

Positions:

• 2008 – Present Space Visualization Laboratory Director, Adler Planetarium and Astronomy Museum
• 2006 -2008 Director of Visualization, Adler Planetarium and Astronomy Museum
• 2003 – 2006 Astronomy Faculty Member, Adler Planetarium and Astronomy Museum
• 2008 –Present Senior Research Associate, University of Chicago
• 2001 – 2008 Research Scientist, University of Chicago
• 1998 - 2001 Research Associate, University of Chicago
• 1996 – 1998 Postdoctoral Fellow, The Johns Hopkins University
• 1993 – 1998 Research Assistant, The Johns Hopkins University
• 1989 – 1993 Teaching Assistant, The Johns Hopkins University

Selected Publications:

• SubbaRao, M., et. al., "Visualization of large scale structure from the Sloan Digital Sky Survey", *New J. Phys. 10* (*2008*) *125015*.
• SubbaRao, M., Aragon-Calvo, M.A., "A Cosmic Map", Physics World, December 2008, 29
SubbaRao, M., Rosner, D., Skutnik, S., "National Virtual Observatory in Museums and Planetaria". BAAS, 57.02, 37, 2006
• Fortson, L.; SubbaRao, M.; Greenberg, G.. "Using Collaborative Environments in Research-Based Science Education", ASP Conference Series, 389 (2008), 239
• Eisenstein, D. et al., "Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies", ApJ, 633 (2005), 560.
• York, D., "The Sloan Digital Sky Survey: Technical Summary", AJ, 120 (2000),1579.
• Gates, E. et al., "Discovery of New Ultracool White Dwarfs in the Sloan Digital Sky Survey, ApJ, 612 (2004), 129.
• SubbaRao, M., Freiman,J.; Bernardi, M., Loveday, J., Nichol, R., Castander, F.;,Meiksin, A., "The Sloan Digital Sky Survey 1-Dimensional Spectroscopic Pipeline", SPIE, 4847 (2002), 452.
• • SubbaRao, M.U., Connolly, A.J., Szalay, A.S., Koo, D.C., "Luminosity Functions from Photometric Redshifts. I. Techniques". AJ, 112 (1996), 929

Ryan Wyatt
Education:

1990 B.A. Astronomy, Cornell University
1993 M.A. Space Physics and Astronomy, Rice University

Positions:

- April 2007–Present Director of Morrison Planetarium and Science Visualization, *California Academy of Sciences, San Francisco, California*
- March 2001–April 2007 Science Visualizer, Rose Center for Earth and Space, *American Museum of Natural History, New York, New York*
- November 1999–February 2001 Director of Theaters, LodeStar Astronomy Center, *LodeStar Project, University of New Mexico, Albuquerque, New Mexico*
- November 1996–November 1999 Manager, Dorrance Planetarium, *Arizona Science Center, Phoenix, Arizona*
- August 1993–November 1996 Manager, Burke Baker Planetarium *Houston Museum of Natural Science, Houston, Texas*
- August 1995–May 1996 Planetarium Instructor, *Houston Independent School District, Houston, Texas*
- March 1991–July 1993 Planetarium Operator / Lecturer, *Houston Museum of Natural Science, Houston, Texas*
- August 1990–July 1993 Research / Teaching Assistant, *Rice University, Houston, Texas*
- October 1986–June 1990 Art Director, *Visions Magazine, Ithaca, New York*
- August 1986–June 1990 Writer / Cartoonist, *Cornell Daily Sun, Ithaca, New York*

Professional Organizations:

- American Astronomical Society; Astronomical Society of the Pacific (2008 Meeting Program Committee); CineGrid (Executive Committee);
- International Planetarium Society (Chair, Fulldome Video Committee); Moderator of Fulldome Mailing List

Selected Publications:

- “Exploring the Invisible Frontier: Why Astronomers Observe in Infrared,” fourth place winner in the 2005 Boeing Writing Contest, appeared in *Griffith Observer* (February 2006), Vol.70, No. 2, pp. 2–9.
- “Virtual Universe,” with Brian Abbott and Carter Emmart, *Natural History* (April 2004), pp. 44–49.
- “The Big Picture: Planetariums, Education, and Space Science,” *NASA Office of Space Science Education and Public Outreach Conference*, A.S.P. Conference Series, No. 319, pp. 169–173.

Nina McCurdy

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Phone: (415) 828-1496 Email: nmccurdy@ucsc.edu

Education

B.S. Applied Physics, University of California, Santa Cruz, 2009
(University Honors, Highest honors in the major)

Thesis: Presenting Fundamental Concepts in Physics to the General Public through Visual Representation.

Associated projects: Wrote and produced "A Little Bit of Quantum Mechanics", an Animation presenting the first order perturbations of an electron in an infinite square well, caused by the absorption of electromagnetic radiation.
-Currently finishing an interactive designed to teach the general public about gamma rays and cosmic rays. To be placed on the Adler Planetarium website, in connection with VERITAS (Very Energetic Radiation Imaging Telescope Array System).

Awards

The Ron Ruby award for great promise in the field of physics, UCSC 2008

Experience (partial list)

June-Aug. 2001, 2002	Camp Counselor/Math & Science Teacher, AIM HIGH Summer Program, San Francisco CA. ,
Sept.-June 2005-2008	Reader/grader, UCSC Physics/Astrophysics Department,
May-Dec. 2007	Lab assistant, UCSC Physics Department. (Lab: Spectroscopy of Novel Materials, Supervisor: Zack Schlesinger)
Feb.-Aug. 2008	Scientific Illustrator, UCSC Physics Department, (Illustrating the lower division, undergraduate lab manuals. Supervisor: George Brown)
Aug.-Sept. 2008	Scientific Illustrator, UCSC Physic Department. (Description: Redrawing several diagrams from *Quantum Enigma*, to be submitted, as part of a paper, to *The Physics Teacher*. Supervisors: Bruce Rosenblum and Fred Kutner)
Jan.-March 2009.	Teacher's Assistant/Reader, UCSC Physics Department, (Course: Conceptual Physics)

Internships

June-Aug. 2005	Receptionist/secretary, McKinsey & Company, San Francisco CA.
Aug. 2008	Visualization lab, Adler Planetarium, Chicago IL.
Feb.-June 2004	Tree Frog Treks, San Francisco CA.

Skills

Fluent in Mathematica, Adobe Flash CS3 (Actionscript), Adobe Illustrator/Photoshop, PowerPoint, iMovie.
Basic training in C/C++, Adobe DreamWeaver, and DigitalSkyII

Michelle Nichols

Address: The Adler Planetarium, 1300 S. Lake Shore Dr., Chicago, IL 60605
Phone: (312) 322-0520 Email: mnichols@adlerplanetarium.org

Education

M. Ed. Curriculum and Instruction, National-Louis University, 2002
B.S. Physics and Astronomy, University of Illinois at Urbana-Champaign, 1995

Experience (partial list)

June 1995 to present Master Educator for Informal Programs, The Adler Planetarium

Responsibilities include the following:
- Develop and conduct evaluation projects for a variety of Adler Planetarium programs, including exhibit galleries, educational programs, and planetarium shows;
- Develop and maintain plans, staffing levels, budgets, evaluation projects, and timelines for all educational Public Outreach Events: organize activities and staffing for onsite and offsite public events on the topics of space exploration, sky observing, current topics in astronomy; and current shuttle, International Space Station, and solar system missions;
- Develop and maintain plans, staffing levels, budgets and timelines, and facilitate activities for the Park Voyagers Chicago Park District community outreach program;
- Serve as educator for NSF and NASA Education and Public Outreach projects; missions and projects have included developing materials and programs for:
  - NASA ARES Scout mission
  - NASA E/PO project on the topic of ultraviolet light
  - Large Synoptic Survey Telescope (LSST)
  - NSF VERITAS gamma ray observatory
  - Interactions in Understanding the Universe (I2U2) cosmic ray program
  - NASA E/PO for the Interstellar Boundary Explorer (IBEX) mission
- Serve as project manager and lead educator for NSF Cyberinfrastructure Demonstration Project on the topic of quasars; and
- Develop and facilitate museum gallery floor activities and demonstrations for Adler visitors on the topics of current astronomy, history of astronomy, and manned & unmanned space exploration.

Publications

Nichols, M. and Carney, K. *Meeting IYA Goals for Diverse Planetarium and Science Center Audiences.* Astronomical Society of the Pacific Annual Conference Proceedings 2008 (upcoming publication).

Nichols, M., Fortson, L. and Carney, K. *CI-Team: Introducing High School Science Teachers to Quasar Research Using the Cyberinfrastructure.* Astronomical Society of the Pacific Annual Conference Proceedings 2007.

Budget Justification: Budget Narrative and Budget Details

This is a proposal for a grant, in response to NASA ROSES09 E.4 OPPORTUNITIES IN EDUCATION AND PUBLIC OUTREACH FOR EARTH AND SPACE SCIENCE (EPOESS).

Personnel and Work Effort Each Year for Three Years

PI: Joel Primack, Distinguished Professor of Physics, UCSC – Responsible for direction and management of cosmological simulations and visualizations	1/2 month summer + 15% academic year
Co-I: Lucy Fortson, Vice President for Research, Adler Planetarium – Direction and management at Adler	5% time all year, participate in all leadership telecons
Co-I: Mark SubbaRao, Director, Space Visualization Laboratory, Adler Planetarium – oversee development, production, and utilization of visualizations at Adler, and distribution to planetariums; supervise SVL intern	1 month each year
Co-I: Ryan Wyatt, Director, Morrison Planetarium, California Academy of Sciences – oversee development, production, and utilization of visualizations at CalAcad, and distribution to planetariums	1 month each year
Staff: Nina McCurdy, Junior Specialist, UCSC – assistant to PI Primack, liason with Adler and Morrison Planetariums, developing visualizations, webmaster	75% time each year (with remaining 25% funded by the new UC AstroComputing Inst. directed by Primack)
Evaluator: Michelle Nichols, Master Educator, Adler Planetarium – formative and summative evaluations at both Adler and Morrison Planetariums	2.25 months each year
Postdoc at UCSC – run simulations and prepare them for visualizations, working with Henze and planetariums	50% time each year
Graduate Student Reseacher at UCSC – run simulations and prepare them for planetarium visualizations	3 summer months each year
Collaborators: Michael Busha, T. J. Cox, Patrik Jonsson, Anatoly Klypin, Francisco Prada, Risa Wechsler – run and analyze simulations, help visualizing them	1/2 month funded each year for visiting collaborator (Prada in 2010)
Collaborator: Chris Henze (NASA Ames Research Center Visualization Lab) – manage simulation visualizations	several weeks each year

The roles of the PI, Co-Is, Staff, and Evaluator are spelled out in more detail in the Scientific/Technical/Management text. We anticipate that the Advisory Committee members will each consult with us 1-2 days each year.

PI Primack will be director of a new University of California systemwide multi-campus research unit (MRU) in AstroComputing and its impact on astronomical observation and theory, funded at $400,000 per year. The relationships between the UC AstroComputing Institute and the work proposed here will be synergistic. A major goal of the AstroComputing Institute is education and outreach. Approximately $150,000 per year is for staff, and Nina McCurdy will be funded at 25% to do outreach and be webmaster, thus leveraging the support we request for her in the present proposal. The remainder of the UC AstroComputing MRU budget is for an international AstroComputing summer school each year, two conferences per year, and travel grants for collaborations between UC campuses and UC-managed DOE laboratories (LANL, LBNL, LLNL).

Travel is budgeted as follows: PI Primack will visit Adler Planetarium once per year, and Staff McCurdy will visit there approximately three times per year. Co-I SubbaRao and Evaluator Nichols will each visit UCSC and Morrison Planetarium approximately once per year. We have also budgeted two week-long visits by Collaborators each year, for example Cox (at Carnegie Observatories, thus Pasadena-SFO) and Klypin (at New Mexico State University, thus Las Cruces-SFO), and salary for a half-month per year visit by a Collaborator, for example Prada, who along with Klypin will be our main links with a large program of constrained simulations of the local universe. (Graduate students working with Prada are also visiting UCSC for up to six months each year to work with Primack; no funding is sought for them since they are supported by Spanish grants.) We also budgeted three trips per year to UCSC and Morrison Planetarium by members of our Advisory Committee, for example Derrick Pitts (Fels Planetarium, Philadelphia), Shawn Laatsch (Imiloa Planetarium, Hilo), and Andrey Kravtsov (University of Chicago).

During the third year (2012) , we plan to have a four-day workshop for planetarium staff, led by PI Primack and the Co-Is and Staff, to explain the materials produced by this grant including the cosmological background, and to show how these materials can be used in various types of planetarium shows. (This might be done just before or after the 2012 meeting of the International Planetarium Society meeting, which is likely to be hosted by the Morrison Planetarium in San Francisco.) We expect to record these lectures and make them available on the web. We are budgeting $10,000 for travel ($400) and lodging ($600) awards for approximately 20 planetarium staff to participate in this workshop.

Equipment: no funds are requested for equipment. PI Primack at UCSC already has the necessary workstations, and additional visualization facilities will be purchased using AstroComputing Institute funds. We will interact with Chris Henze and the NASA Ames visualization team, and with the Adler and Morrison Planetariums, both remotely and by making frequent trips. In addition, the De Anza Planetarium, very close to NASA Ames, will provide a convenient DigitalSky 2 testbed for dome shows when it is not otherwise in use, courtesy of its director, Collaborator Karl von Ahnen.

University of California Santa Cruz
Office of Sponsored Projects
Detailed Budget

Printed on 7/1/2009

SC# **20091332**

Title Public Outreach via Cosmological Simulation Visualizations

Budget Prepared Date 6/22/2009
Budget Revised Date
Preparer Sharon Collum
Not Submitted? ☐

PI Name Primack, Joel
Start Date 1/1/2010
End Date 12/31/2012
Location UCSC
Agency NASA/Shared Services Center
Analyst Sharon Collum
IC Rate 51.50%
IC Type MTDC

Salaries:

Title / Name	Salary	Type/Level		Year 1	Year 2	Year 3	Total
PI-Summer	PROFFULL			8,544	8,801	9,065	26,410
Primack			Months/Time%	0.5 100%	0.5 100%	0.5 100%	
Post Doc	POSTDOC	IV		20,000	20,000	20,000	60,000
To be selected			Months/Time%	12.0 51%	12.0 50%	12.0 48%	
GSR-Summer	GSR-Res	III		9,978	10,277	10,585	30,840
To be selected			Months/Time%	3.0 100%	3.0 100%	3.0 100%	
Jr. Specialist	SPECJR	II		26,928	27,736	28,568	83,232
McCurdy			Months/Time%	12.0 75%	12.0 75%	12.0 75%	
Visiting Researcher	RESFULL	II		5,000	5,000	5,000	15,000
To be selected			Months/Time%	1.0 65%	1.0 63%	1.0 61%	
	Total Salaries:			70,450	71,814	73,218	215,482

Fringe:

Title / Name	Salary / Fringe Rate	Type/Level	Year 1	Year 2	Year 3	Total
PI-Summer	PROFFULL		1,153	1,188	1,224	3,565
Primack	13.5%					
Post Doc	POSTDOC	IV	5,400	5,400	5,400	16,200
To be selected	27.0%					
GSR-Summer	GSR-Res	III	249	257	265	771
To be selected	2.5%					
Jr. Specialist	SPECJR	II	5,655	5,825	5,999	17,479
McCurdy	21.0%					
Visiting Researcher	RESFULL	II	1,050	1,050	1,050	3,150
To be selected	21.0%					
	Total Fringe:		13,507	13,720	13,938	41,165
	Total Salaries & Fringe:		83,957	85,534	87,156	256,647

Travel:

Domestic Travel:

Name	Destination	Year 1	Year 2	Year 3	Total
SFO to Chicago, Il (1)	3 trips x 400 airfare + 4 nights @ 150 per diem & 2 trips in Yr. 3	3,000	3,000	2,000	8,000
Chicago to SFO, (1)	2 trips x 400 airfare + 4 days per diem @150	2,000	2,000	2,000	6,000
SFO- Chicago (1)	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000	3,000
Pasadena to SFO (1)	1 trip x 200 airfare + 7 days per diem @150	1,250	1,250	1,250	3,750
Las Cruces NM to SFO (1)	1 trip x 200 airfare + 7 days per diem @150	1,250	1,250	1,250	3,750
Chicago to SFO (1)	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000	3,000
Philadelphia to SFO (1)	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000	3,000
Hilo to SFO (1)	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000	3,000
Chicago to SFO (1)	1 trip x 400 airfare + 4 days per diem @150	0	0	1,000	1,000
	Total Domestic:	11,500	11,500	11,500	34,500

Foreign Travel:

Name	Destination	Year 1	Year 2	Year 3	Total
	Total Foreign:				
	Total Domestic & Foreign Travel:	11,500	11,500	11,500	34,500

Permanent Equipment (with a value of $1,500 or greater):

Equipment Description	Year 1	Year 2	Year 3	Total
Total Permanent Equipment:				

Participant Support Costs:

Type	Description	Year 1	Year 2	Year 3	Total
	Total Participant Support Costs:				

Subcontracts:

Type	Description	Year 1	Year 2	Year 3	Total

Type	Description	Year 1	Year 2	Year 3			Total
Subcontracts		38,607	39,766	40,959			119,332
Subcontracts		20,000	25,000	10,000			55,000
	Total Subcontracts:	58,607	64,766	50,959			174,332

Other Costs (excl Subcontracts):

Type	Description	Year 1	Year 2	Year 3			Total
Other	Travel Awards		0	10,000			10,000
	Total Other Costs:		0	10,000			10,000

Fees:

Non-Resident Tuition:						
Graduate Student Health Insurance:						
Graduate Student Fees:						
Graduate Fee Override:						
Total Graduate Fees:						
Total Other Direct Costs:	58,607	64,766	60,959			184,332

Totals:

Total Direct Costs:	154,064	161,800	159,615			475,479
Indirect Cost Base:	140,457	102,034	108,656			351,147
Indirect Cost Base Override:						
IC Rate:	51.5%	51.5%	51.5%	51.5%	51.5%	
Total Indirect Costs:	72,335	52,548	55,958			180,841
TOTAL BUDGET:	226,399	214,348	215,573			656,320

Adler Planetarium Subcontract

	Year 1	Year 2	Year 3	Total
Senior Personnel				
Mark SubbaRao	6250	6437.5	6630.625	19318.125
Time (months)	1	1	1	3
Michelle Nichols	10561.5	10878.345	11204.6954	32644.5404
Time(months)	2.25	2.25	2.25	6.75
Other Personnel				
SVL Summer Intern	2275	2343.25	2413.5475	7031.7975
Time(months)	1	1	1	3
Total	19086.5	19659.095	20248.8679	58994.4629
Benefits (22%)	4199.03	4325.0009	4454.75093	12978.7818
Salary plus Benefits	23285.53	23984.0959	24703.6188	71973.2447
Indirect Costs (65.8%)	15321.8787	15781.5351	16254.9812	47358.395
Total	38607.4087	39765.631	40958.5999	119331.64

Outreach via Cosmological Simulation Visualizations – California Academy of Sciences Subcontract

Staff	Base/Wk	Benefits	Total/Wk (28%)	Yr1 - 2010		Yr2 - 2011		Yr3 - 2012	
Visualization Director	$2,403.13	$673	$3,076.01	0.9	$2768.41	1.64	$5044.66	0.6	$1,845.60
Technical Director	$1,386.72	$388	$1775.00	5.0	$8875.00	5.0	$8875.00	2.0	$3,550.00
System Engineer	$1,332.65	$373	$1,705.79	0.5	$852.90	1.0	$1,705.79	0.5	$852.90
			Subtotal Yearly Cost		$12,496.31		$15,625.45		$6,248.50
			60% Indirect Cost or Overhead		$7,497.79		$9,375.27		$3,749.10
			Total Yearly Cost		$19,994.09		$25,000.72		$9,997.60

Note: the higher costs during Yrs 1 & 2 will support creation of a digital pipeline to transfer simulation outputs into digital planetarium software.