Cover Page for Proposal Submitted to the National Aeronautics and Space Administration	NASA Proposal Number **10-EPOESS10-0039**

NASA PROCEDURE FOR HANDLING PROPOSALS

This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
Joel Primack	**joel@scipp.ucsc.edu**	**831-459-2580**

Street Address (1)	Street Address (2)
1156 High St	**Physics Department**

City	State / Province	Postal Code	Country Code
Santa Cruz	**CA**	**95064-1077**	**US**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget	Year 4 Budget
01 / 01 / 2011	**12 / 31 / 2013**	**774,113.00**	**243,326.00**	**249,203.00**	**281,584.00**	**0.00**

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH10ZDA001N-EPOESS	**Opportunities in Education and Public Outreach for Earth and Space Sciences**

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*
Cross Division

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
06 / 03 / 2010	**Electronic Submission Only**		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
125084723	**1CV82**	**941539563**	**2A**

Organization Name (Standard/Legal Name)	Company Division
University Of California, Santa Cruz	

Organization DBA Name	Division Number
CHANCELLOR'S OFFICE	

Street Address (1)	Street Address (2)
1156 HIGH ST	

City	State / Province	Postal Code	Country Code
SANTA CRUZ	**CA**	**950641077**	**USA**

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
Joel Primack	**joel@scipp.ucsc.edu**	**831-459-2580**

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in the two Certifications and one Assurance contained in this NRA (namely, (i) the Assurance of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, and Assurances Regarding Lobbying and Debarment and Suspension.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number
Riley Jordan	**riajorda@ucsc.edu**	**831-459-2639**

AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)*	**Date**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION VI - Team Members

Team Member Role	Team Member Name	Contact Phone	E-mail Address
PI	**Joel Primack**	**831-459-2580**	**joel@scipp.ucsc.edu**
Organization/Business Relationship **University Of California, Santa Cruz**		Cage Code **1CV82**	DUNS# **125084723**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Co-I	**Doris Ash**	**831-459-5549**	**dash5@ucsc.edu**
Organization/Business Relationship **University Of California, Santa Cruz**		Cage Code **1CV82**	DUNS# **125084723**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Co-I	**Mark SubbaRao**	**312-294-0348**	**msubbarao@adlerplanetarium.org**
Organization/Business Relationship **Adler Planetarium**		Cage Code **33EH9**	DUNS# **083081802**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Co-I	**Ryan Wyatt**	**415-379-5183**	**rwyatt@calacademy.org**
Organization/Business Relationship **California Academy of Sciences**		Cage Code **3S8L1**	DUNS# **074632456**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Collaborator	**Thomas Cox**	**626-304-0284**	**tcox@obs.carnegiescience.edu**
Organization/Business Relationship **Carnegie Institution Of Washington**		Cage Code **4B564**	DUNS# **072641707**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Collaborator	**Chris Henze**	**650-604-3959**	**Chris.Henze@nasa.gov**
Organization/Business Relationship **NASA Ames Research Center**		Cage Code **35SG8**	DUNS# **009231648**
International Participation **No**	U.S. Government Agency **NASA Ames Research Center**		Total Funds Requested **0.00**
Collaborator	**Patrik Jonsson**	**775-572-8745**	**pjonsson@cfa.harvard.edu**
Organization/Business Relationship **Smithsonian Institution/Smithsonian Astrophysical Observatory**		Cage Code **1PPP1**	DUNS# **003261823**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Collaborator	**Anatoly Klypin**	**505-646-1400**	**aklypin@nmsu.edu**
Organization/Business Relationship **NEW MEXICO STATE UNIVERSITY**		Cage Code **3X352**	DUNS# **173851965**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**

Team Member Role **Collaborator**	Team Member Name **Francisco Prada**	Contact Phone **34-958-230626**	E-mail Address **fprada@iaa.es**
Organization/Business Relationship **Self**		Cage Code **N/A**	DUNS# **N/A**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **rachel somerville**	Contact Phone **410-338-4893**	E-mail Address **somerville@stsci.edu**
Organization/Business Relationship **Space Telescope Science Institute**		Cage Code **4X357**	DUNS# **101460871**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **Karl von Ahnen**	Contact Phone **408-864-8282**	E-mail Address **vonahnenkarl@deanza.edu**
Organization/Business Relationship **FOOTHILL-DE ANZA COMMUNITY COLLEGE DISTRICT**		Cage Code **3BFX2**	DUNS# **076322296**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**
Team Member Role **Collaborator**	Team Member Name **Risa Wechsler**	Contact Phone **650-704-6932**	E-mail Address **rwechsler@stanford.edu**
Organization/Business Relationship **Stanford University**		Cage Code **1KN27**	DUNS# **009214214**
International Participation **No**	U.S. Government Agency		Total Funds Requested **0.00**

PI Name : **Joel Primack**	**NASA Proposal Number**
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION VII - Project Summary

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 visible material in the universe -- stars, gas, dust, planets, etc. -- accounts for only about 0.5% of the cosmic density. The remaining 99.5% of the universe is invisible. Most of it is non-baryonic dark matter (~23%) and dark energy (~72%), with non-luminous baryons making up ~4%. We propose to visualize state-of-the-art simulations of cosmology and galaxy formation, showing both luminous matter and dark matter, in leading planetariums and other education and outreach venues, and we have already begun working together on this.

Astronomical observations represent snapshots of particular moments in time; it is the role of astrophysical theory and simulations to produce conceptual movies that link these snapshots together into a coherent physical theory. Our cosmological simulations are the best currently available; they show the evolution of the dark matter cosmic web that forms the backbone along which galaxies and clusters form, and how invisible dark matter and dark energy shape the visible universe. 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 as we plan and create planetarium shows for domes and theaters, including 3D. A crucial part of the proposed work is to develop new methods to show the multicomponent universe, to try the visualizations out on public audiences, and to conduct formative and summative evaluations of their successes and needs for improvement. We propose to make the resulting visualizations 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 enrich the materials available to show how astrophysicists are calculating the physical processes that result in observed properties of galaxies and of the large scale structure of the universe, and confronting theory with the latest observations.

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION VIII - Other Project Information

Proprietary Information

Is proprietary/privileged information included in this application?
Yes

International Collaboration

Does this project involve activities outside the U.S. or partnership with International Collaborators?
No

Principal Investigator	Co-Investigator	Collaborator	Equipment	Facilities
No	**No**	**No**	**No**	**No**

Explanation :

NASA Civil Servant Project Personnel

Are NASA civil servant personnel participating as team members on this project (include funded and unfunded)?
Yes

Fiscal Year	Fiscal Year	Fiscal Year	
2011	**2012**	**2013**	
Number of FTEs	Number of FTEs	Number of FTEs	
0.1	**0.1**	**0.1**	

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION VIII - Other Project Information

Environmental Impact

Does this project have an actual or potential impact on the environment?	Has an exemption been authorized or an environmental assessment (EA) or an environmental impact statement (EIS) been performed?
No	**No**

Environmental Impact Explanation:

Exemption/EA/EIS Explanation:

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION VIII - Other Project Information

Historical Site/Object Impact

Does this project have the potential to affect historic, archeological, or traditional cultural sites (such as Native American burial or ceremonial grounds) or historic objects (such as an historic aircraft or spacecraft)?

Explanation:

PI Name : **Joel Primack**	**NASA Proposal Number**
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: EPO via Cosmological Simulation Visualizations

Question 2 : Type of institution:

Answer: Educational Organization

Question 3 : Will any funding be provided to a federal government organization including NASA Centers, JPL, other Federal agencies, government laboratories, or Federally Funded Research and Development Centers (FFRDCs)?

Answer: No

Question 4 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: N/A

Question 5 : Does this proposal include the use of NASA-provided high end computing?

Answer: Yes

Question 6 : Research Category:

Answer: 1) Theory/computer modeling

Question 7 : Team Members Missing From Cover Page:

Answer:

Question 8 : This proposal contains information and/or data that are subject to U.S. export control laws and regulations including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR).

Answer: No

Question 9 : I have identified the export-controlled material in this proposal.

Answer: N/A

Question 10 : I acknowledge that the inclusion of such material in this proposal may complicate the government's ability to evaluate the proposal.

Answer: N/A

Question 11 : Portfolio Area:

Answers :

Informal Education

Outreach

Question 12 : Science Focus:

Answers :

Astrophysics

Question 13 : Does the proposal include any funds that would be used to support civil servant or contract personnel at any NASA Center, or federal agency, or Federally Funded Research and Development Centers such as JPL or Los Alamos?

Answer: No

Question 14 : If the lead institution is a for-profit organization, is there any fee or other cost, that would preclude use of a grant as an award funding mechanism.

Answer: No

Question 15 : Has the proposer reviewed and complied with the Explanatory Guide to Proposal Evaluation Factors for ROSES Program Element: Opportunities in Education & Public Outreach for Earth and Space Science (EPOESS), February 2010?

Answer: Yes

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Cumulative Budget

Budget Cost Category	Funds Requested ($)				
	Year 1 ($)	Year 2 ($)	Year 3 ($)	Year 4 ($)	Total Project ($)
A. Direct Labor - Key Personnel	12,004.00	12,366.00	12,737.00	0.00	37,107.00
B. Direct Labor - Other Personnel	73,085.00	75,087.00	77,152.00	0.00	225,324.00
Total Number Other Personnel	4	4	4	0	12
Total Direct Labor Costs (A+B)	85,089.00	87,453.00	89,889.00	0.00	262,431.00
C. Direct Costs - Equipment	0.00	0.00	0.00	0.00	0.00
D. Direct Costs - Travel	9,500.00	9,500.00	9,500.00	0.00	28,500.00
Domestic Travel	9,500.00	9,500.00	9,500.00	0.00	28,500.00
Foreign Travel	0.00	0.00	0.00	0.00	0.00
E. Direct Costs - Participant/Trainee Support Costs	0.00	0.00	0.00	0.00	0.00
Tuition/Fees/Health Insurance	0.00	0.00	0.00	0.00	0.00
Stipends	0.00	0.00	0.00	0.00	0.00
Travel	0.00	0.00	0.00	0.00	0.00
Subsistence	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00
Number of Participants/Trainees					0
F. Other Direct Costs	74,274.00	102,319.00	125,860.00	0.00	302,453.00
Materials and Supplies	0.00	0.00	0.00	0.00	0.00
Publication Costs	0.00	0.00	0.00	0.00	0.00
Consultant Services	0.00	0.00	0.00	0.00	0.00
ADP/Computer Services	0.00	0.00	0.00	0.00	0.00
Subawards/Consortium/Contractual Costs	70,020.00	97,688.00	110,816.00	0.00	278,524.00
Equipment or Facility Rental/User Fees	0.00	0.00	0.00	0.00	0.00
Alterations and Renovations	0.00	0.00	0.00	0.00	0.00
Other	4,254.00	4,631.00	15,044.00	0.00	23,929.00
G. Total Direct Costs (A+B+C+D+E+F)	168,863.00	199,272.00	225,249.00	0.00	593,384.00
H. Indirect Costs	74,463.00	49,931.00	56,335.00	0.00	180,729.00
I. Total Direct and Indirect Costs (G+H)	243,326.00	249,203.00	281,584.00	0.00	774,113.00
J. Fee	0.00	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	243,326.00	249,203.00	281,584.00	0.00	774,113.00
Total Cumulative Budget					774,113.00

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**Project**	**1**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Primack, Joel	**PI_TYPE**	**153,800.00**			**.5**	**8,544.00**	**1,153.00**	**9,697.00**
Ash, Doris	**CO-I**	**73,200.00**			**.3**	**2,033.00**	**274.00**	**2,307.00**
							Total Key Personnel Costs	**12,004.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
2	**Graduate Students**				**25,745.00**	**747.00**	**26,492.00**
1	**Assistant Specialist**	**9**			**33,300.00**	**6,993.00**	**40,293.00**
1	**Visiting Researcher**	**1**			**5,000.00**	**1,300.00**	**6,300.00**
4	**Total Number Other Personnel**					**Total Other Personnel Costs**	**73,085.00**

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**85,089.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**Project**	**1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**9,500.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**9,500.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Joel Primack**	**NASA Proposal Number**
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**Project**	**1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	0.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	0.00
5. Subawards/Consortium/Contractual Costs	70,020.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
8 . Other: **Gship and fees**	4,254.00
Total Other Direct Costs	74,274.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	168,863.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC	51.50	144,589.00	74,463.00
Cognizant Federal Agency: Wallace Chan on behalf of the Federal Government 415-437-7820		**Total Indirect Costs**	74,463.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	243,326.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	243,326.00

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**
Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**	

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**Project**	**2**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Primack, Joel	PI_TYPE	153,800.00			.5	8,801.00	1,188.00	9,989.00
Ash, Doris	CO-I	73,200.00			.3	2,094.00	283.00	2,377.00
							Total Key Personnel Costs	12,366.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
2	Graduate Students				26,516.00	769.00	27,285.00
1	Assistant Specialist	9			34,299.00	7,203.00	41,502.00
1	Visiting Researcher	1			5,000.00	1,300.00	6,300.00
4	Total Number Other Personnel					Total Other Personnel Costs	75,087.00
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	87,453.00

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**Project**	**2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**9,500.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**9,500.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**Project**	**2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	0.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	0.00
5. Subawards/Consortium/Contractual Costs	97,688.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
8 . Other: **Gship and fees**	4,631.00
Total Other Direct Costs	102,319.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	199,272.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC	51.50	96,953.00	49,931.00
Cognizant Federal Agency: **Wallace Chan on behalf of the Federal Government 415-437-7820**		**Total Indirect Costs**	49,931.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	249,203.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	249,203.00

PI Name : **Joel Primack**	**NASA Proposal Number**
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2013	**12 / 31 / 2013**	**Project**	**3**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Primack, Joel	PI_TYPE	153,800.00			.5	9,065.00	1,224.00	10,289.00
Ash, Doris	CO-I	73,200.00			.3	2,157.00	291.00	2,448.00
							Total Key Personnel Costs	12,737.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
2	Graduate Students				27,312.00	793.00	28,105.00
1	Assistant Specialist	9			35,328.00	7,419.00	42,747.00
1	Visiting Researcher	1			5,000.00	1,300.00	6,300.00
4	Total Number Other Personnel					Total Other Personnel Costs	77,152.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	89,889.00

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2013	**12 / 31 / 2013**	**Project**	**3**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**9,500.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**9,500.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2013	**12 / 31 / 2013**	**Project**	**3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**0.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**110,816.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8 . Other: **Gship and fees**	**5,044.00**
9 . Other: **travel awards**	**10,000.00**
Total Other Direct Costs	**125,860.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**225,249.00**

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC	**51.50**	**109,389.00**	**56,335.00**
Cognizant Federal Agency: **Wallace Chan on behalf of the Federal Government 415-437-7820**	Total Indirect Costs		**56,335.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**281,584.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**281,584.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**4**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Primack, Joel	**PI_TYPE**	**0.00**				**0.00**	**0.00**	**0.00**
Ash, Doris	**CO-I**	**0.00**				**0.00**	**0.00**	**0.00**
							Total Key Personnel Costs	**0.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	**Graduate Students**				**0.00**	**0.00**	**0.00**
0	**Total Number Other Personnel**					**Total Other Personnel Costs**	**0.00**

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**0.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **4**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**0.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Joel Primack**	NASA Proposal Number
Organization Name : **University Of California, Santa Cruz**	**10-EPOESS10-0039**

Proposal Title : **Public Education and Outreach via Cosmological Simulation Visualizations**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **4**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	0.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	0.00
5. Subawards/Consortium/Contractual Costs	0.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
Total Other Direct Costs	0.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	0.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
Cognizant Federal Agency: Wallace Chan on behalf of the Federal Government 415-437-7820		**Total Indirect Costs**	0.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	0.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	0.00

Public Outreach via Cosmological Simulation Visualizations

Table of Contents

Public Education and Outreach via Cosmological Simulation Visualizations

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 & Sutherland'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, science centers, and museums have also begun to install 3D theaters. The things shown, however, are mainly luminous objects, which represent just a tiny fraction of the cosmic density. Planetariums have yet to show how dark matter and dark energy shape the evolution and structure of the universe on both large scales and galaxy scales.

Thirty one 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 the CDM theory and run simulations of CDM with different cosmological parameters. The 1992 NASA *Cosmic Background Explorer* (*COBE*) discovery of the fluctuations in the cosmic background radiation temperature in different directions confirmed a key CDM prediction.

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 WMAP team concluded that 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; Komatsu et al. 2010, Table 1). 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, employing appropriate methods of evaluation to determine how well diverse audiences understand visualizations incorporating alternative 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 3-4 minute modules or "vignettes" 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 have an Advisory Committee composed of astronomers, astronomical visualizers, and planetarium experts to advise us on all these projects, with annual meetings. We propose to organize workshops and other activities to explain the new material to interested planetarium staff. 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 and Proposed Planetarium Shows

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) state-of-the-art high-resolution hydrodynamic simulations of galaxy formation including galaxy mergers; and (3) constrained simulations of the Local Universe. All of these visualizations will be used for digital planetarium dome shows and high definition 2D and 3D theater presentations.

2.1 Bolshoi Simulation. Bolshoi is a cosmological ΛCDM simulation using 8 billion particles in a volume 250 h^{-1} Mpc (about one billion light years) on a side (bolshoi means "big" or "grand" in Russian). The Bolshoi simulation (Klypin, Trujillo, & Primack 2010) used about 6 million cpu-hours in 2009 on the new Pleiades supercomputer at NASA Ames Research Center (then the third fastest supercomputer on the top 500 list). We saved 180 complete timesteps, which required ~75 Tb compressed. All dark matter halos that could host even galaxies as faint as the Magellanic Cloud satellites of the Milky Way have been found in all these timesteps, and merger trees link the halos to show their merger history. Detailed dynamical comparisons between the Bolshoi simulation and galaxy observations show remarkable concurrence (Trujillo, Klypin, Primack, & Romanowsky 2010). Semi-analytic models (SAMs) are now being run on the Bolshoi merger trees, which will show how ~10 million galaxies have evolved. PI Primack has received a 2010-2011 allocation of more than 6.6 million cpu-hours of Pleiades time to simulate Bolshoi subvolumes at 64x better mass resolution, and these new simulations will aid in visualizing cosmic evolution on small as well as large scales. (Key collaborators – simulation: Anatoly Klypin, New Mexico State University; visualization: Chris Henze, NASA Ames.)

Our new Bolshoi simulation has nearly an order of magnitude better mass and force resolution than the Millennium Run simulation (Springel et al. 2006), which has been the leading large cosmological simulation for the past several years and the basis for many cosmological studies. The Millennium simulation was based on the imprecise WMAP1 cosmological parameters (Spergel et al. 2003), while the Bolshoi simulation is based on the WMAP5 parameters (Hinshaw et al. 2009), consistent with WMAP7 (Jarosik et al. 2010), and a much better match to the best available cosmological data. Figure 1 shows the density distribution of dark matter in the final timestep of the Bolshoi Simulation.

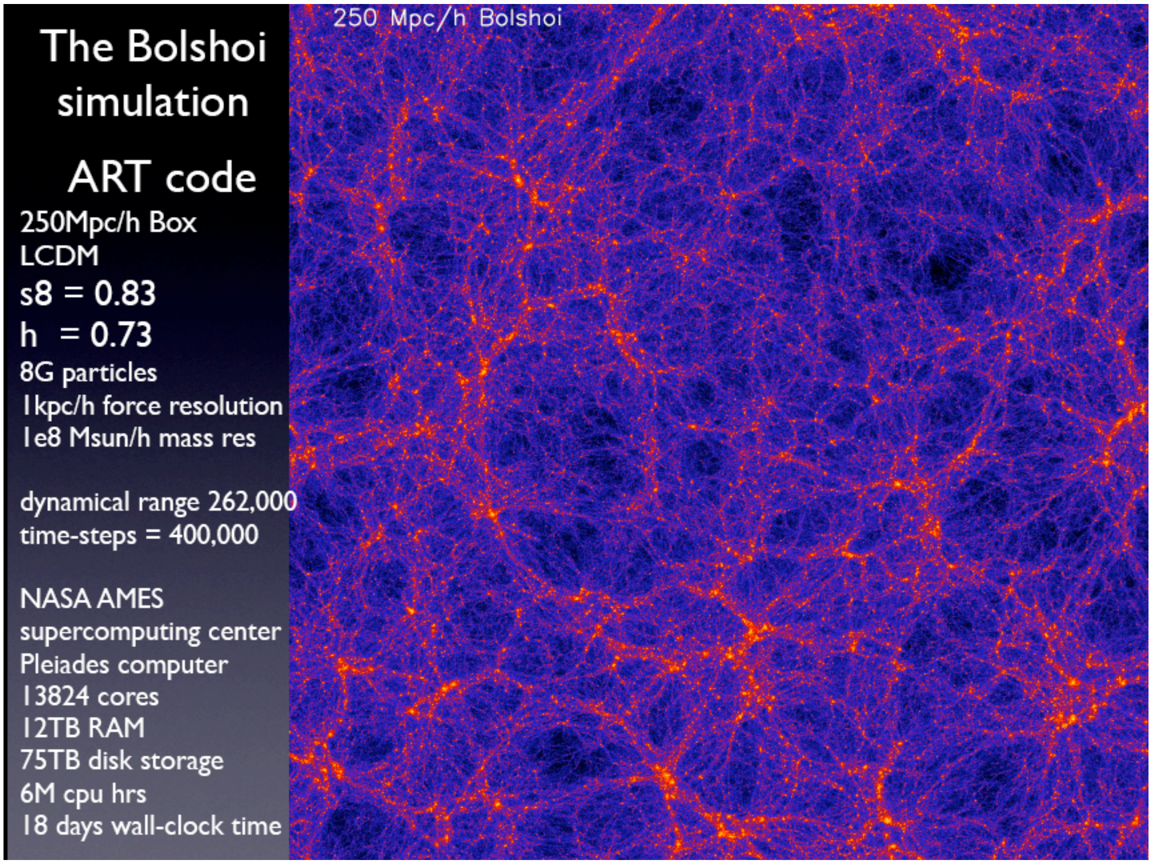

Figure 1. Slice 10 h^{-1} Mpc thick by 250 h^{-1} Mpc square of the Bolshoi Simulation final ($z = 0$) timestep.

Visualizing the Bolshoi Simulation for Planetariums. As we prepare this proposal, the UCSC team is working with Collaborator Henze and the California Academy of Sciences team to visualize the distribution of dark matter and the dark matter halos where the first stars in the universe form in an early timestep (redshift $z = 20$) of the Bolshoi simulation. This will be part of the opening sequence of the fall 2010 planetarium dome show "Origins" at Morrison Planetarium.

This experience is helping us prepare the major opening segment of the dome show (working title: "The Searcher") that will open the newly renovated Adler Planetarium Sky Theater, a 50-megapixel digital planetarium, in 2011. This segment is planned to include Bolshoi visualizations of the evolution of cosmic structure on both large and smaller scales, showing the three-dimensional structure of the cosmic web via fly-throughs and zoom-ins. Morrison Planetarium will also make a dome vignette based on the Bolshoi visualizations. The 2013 Adler Sky Theater show will continue the cosmology theme, and show how evolving galaxies fill the merging dark matter halos as the universe itself evolves, based on the Bolshoi semi-analytic models.

Bolshoi Semi-Analytic Models. We have determined the Bolshoi halo merger tree, in collaboration with Collaborator Anatoly Klypin and with Primack's former PhD student Collaborator Risa Wechsler and her group at Stanford University. The merger tree is the basis for state-of-the-art Semi-Analytic Models (SAMs) of the evolution of the galaxy population that are now being run. These SAMs will 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 current grad students and 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.) It will also be possible to zoom-in on individual galaxies and mergers based on our high-resolution hydrodynamic simulations (§**2.2**).

2.2 High Resolution Hydrodynamic Simulations of Galaxy Formation

Using Galaxy Simulations for Planetarium Shows. We plan to develop short fulldome and 3D vignettes at Morrison Planetarium featuring our galaxy formation and merger visualizations, as described below. These vignettes will also help us prepare to use the galaxy simulations for the 2013 Adler Planetarium Sky Theater dome show mentioned above, and also for a show on cosmology that Adler will produce for its high-definition, stereoscopic Universe Theater in 2012. This 3D show will tell the story of how advanced telescopes and surveys are building the observational basis of current theories of cosmology, and will connect telescopes to the topics they are investigating. Our galaxy merger simulations will be especially appropriate for shows at the Adler and Morrison 3D theaters, since galaxy mergers are spectacular events and the galaxies are recognizable at most merger stages. Also, viewers will be interested to learn that the Milky Way and Andromeda galaxies will merge in a few billion years, with the solar system likely scattered to the outer halo of the resulting elliptical galaxy (Cox & Loeb 2008).

Galaxy Merger Simulations. Galaxy mergers are thought to be the main way that disk galaxies are transformed into galactic spheroids, which host supermassive black holes and most of the stellar mass in the universe (Fukugita & Peebles 2004). Primack's group has run hundreds 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), with most of these simulations carried out by Primack's former grad student Collaborator T. J. Cox. The calculated visual appearance of the major merger shown in Figure 2 includes stellar evolution and dust absorption and re-radiation treated by the state-of-the-art Sunrise code (Jonsson 2006; Jonsson et al. 2006, 2010; Jonsson & Primack 2010).

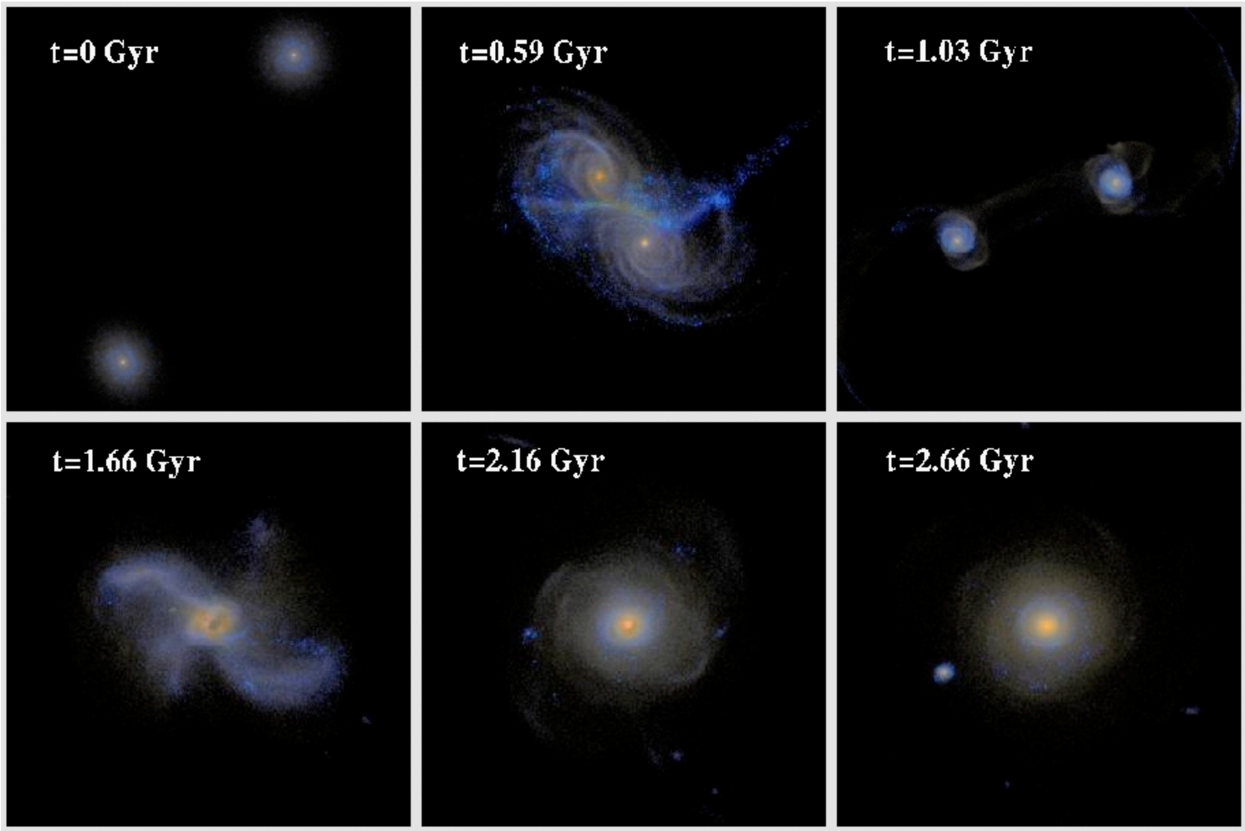

Figure 2. Composite color images including dust extinction for a high-resolution hydrodynamic galaxy major merger simulation. Time since the start of the simulation in given in the upper left corner of each image. (Top row) Initial pre-merger galaxies, first pass, maximal separation after the first pass. (Bottom row) Coalescence of the nuclei, remnant 0.5 Gyr after the merger, remnant elliptical galaxy 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 orange. (From Lotz, Jonsson, Cox, & Primack 2008.)

Sunrise uses a Monte Carlo method to trace the radiation field through the galaxies by shooting millions of simulated multiwavelength "photon packets" that 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 that emerge from the simulation volume in the direction of the observer form a realistic image of what the object would look like from far ultraviolet to submillimeter wavelengths.

We plan to continue this simulation program supported by other grants, and to do new simulations 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 is challenging to visualize all the components: old and newly formed stars, gas density and temperature, metallicity, and dark matter density; and also stellar and gas kinematics. In the galaxy merger video by Patrik Jonsson, Greg Novak, and Joel Primack selected as a semifinalist 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 multiple components. As discussed in §**3.3** below, we propose to try various visualization methods out on audiences and evaluate how well each method succeeds in conveying the key content. (Key collaborators: Primack's former grad students Collaborators Patrik Jonsson (Harvard-Smithsonian Center for Astrophysics), T. J. Cox (Carnegie Observatories), and Greg Novak (now a postdoc at Princeton), Collaborator Jennifer Lotz (NOAO), and Primack's current grad students.)

High Resolution Simulations of Forming Galaxies. Daniel Ceverino started these adaptive mesh hydrodynamic simulations (Ceverino & Klypin 2009) as a PhD student with Collaborator Anatoly Klypin (using PI Primack's NERSC supercomputer time with Klypin's ART-hydro code). Ceverino is running even more ambitious simulations (now using Primack's allocations on the Schirra and Pleiades supercomputers at NASA Ames) as a postdoc with Primack's long-term collaborator Avishai Dekel. Visualizations will be crucial to help us understand the formation and evolution of these galaxies in cosmological simulations, and compare the simulations to observations.

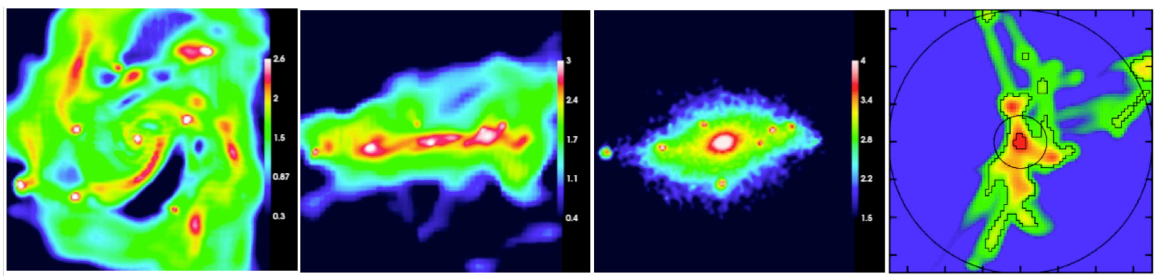

Figure 3. Gas surface density of a galaxy at z = 2.3 from a high-resolution cosmological simulation (Ceverino et al. 2009). The first three images are 10×10 kpc; the color code is log surface density in units of M☉ pc^{-2}. The face-on view (a) shows an extended disk broken into several giant clumps. The edge-on view (b) demonstrates that this is a well-defined gas disk, and the young stars in the giant clumps resemble observed "chain" galaxies (Elmegreen & Elmegreen 2006). The edge-on view of surface density of all stars (c) shows a large bulge formed by merging clumps that comprises about half of the stars. (d) Lyα "observed" surface brightness (contours mark 10^{-18} and 10^{-17} erg s^{-1} cm^{-2} arcsec^{-2}) from the simulation at z = 2.3 (Goerdt et al.), which resembles observations. The outer circle shows the virial radius Rvir = 70 kpc; the inner circle is 0.2 Rvir.

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 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 grants. 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.)

2.3 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. Although the constrained simulation method

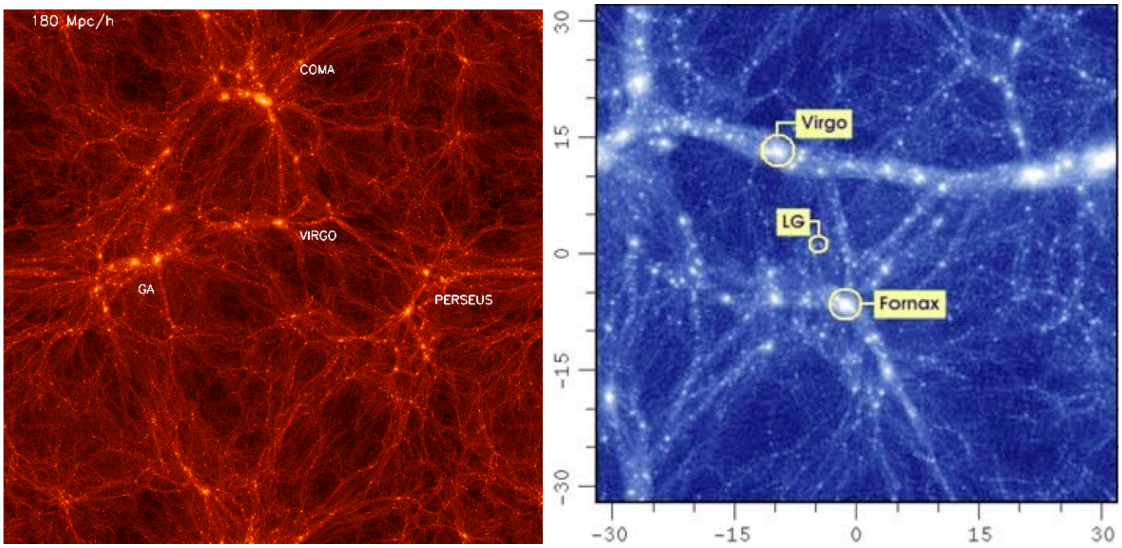

Figure 4. Local Universe Simulations: (left) 180 h^{-1} Mpc volume, showing prominent nearby large structures including the Great Attractor and the Virgo, Coma, and Perseus clusters; (right) 64 h^{-1} Mpc volume, showing the Local Group and the Virgo and Fornax clusters (horizontal axis SGX, vertical SGY). (These constrained simulations are described in Tikhonov & Klypin 2009; the right-hand figure is from Martinez-Vaquero et al. 2008.)

(e.g., Klypin et al. 2003, Lavaux 2010) 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 show simultaneously in 3D the local galaxies (e.g., from the Tully Catalog) and dark matter isodensity contours. 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. (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 simulation, continued into the far future assuming that the dark energy is a cosmological constant. These simulations 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). Recent papers on this are Nagamine & Loeb (2003) and Busha et al. (2003, 2007).

Using Local Universe Visualizations for Planetarium Shows. The second cosmology dome show at Adler's Sky Theater will most likely open in 2013, in conjunction with Adler's new 5000 square foot gallery on Cosmology called "Deep Space Adventure" (DSA). This new show will continue the theme of "The Searcher" and include a fly-through of a visualization of a "Local Universe Simulation" as described above. Based on testing and evaluation throughout 2011-12 (see section 3.4), the Academy and Adler teams will explore and test methods to juxtapose the dark matter distribution and the Tully catalog of nearby galaxies, to provide a richer picture of our cosmic neighborhood. This show will also include a visualization of the future of the local universe simulation, in which the local region becomes increasingly empty and eventually all galaxies outside the local group disappear. Following the show, the audience will be directed to learn more of the physics behind the visuals in presentations on the topic of cosmology in Adler's DSA gallery, including kiosks that allow interaction with the datasets.

2.4 Additional Visualization Projects. Once we have established the pipeline at Morrison Planetarium to translate simulations into digital planetarium software formats and determined what sorts of visual metaphors work best to show the dark matter and visible matter simultaneously (§**3.3**), 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 new University of California systemwide High-Performance Astro-Computing Center (UC-HIPACC, http://hipacc.ucsc.edu), led by Primack. The following are just two examples of such simulations.

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 a fundamental part of the basis of our modern understanding of cosmology, 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 once the universe is dominated by dark energy. (Key personnel: Nina McCurdy, UCSC.)

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 4 billion particle Via Lactea II simulation (Diemand et al. 2008) and even larger current simulations are competitive with the European Aquarius simulations (Springel et al. 2008).

2.5 Spinoffs. The following two projects are direct spinoffs of the proposed project. Funds have been and will be sought for them in separate proposals.

Cold Dark Matter Explorers computer interactive. We would like to use visualizations of our cosmological simulations for the purposes of game-based learning, via computer games that encourage the exploration of the "cosmic web" and from which the user will gain a richer picture of our universe and a deeper understanding of modern cosmology. These could be the basis for interactive exhibits at Adler Planetarium's Deep Space Adventure cosmology gallery. Adler submitted a 2009 NASA proposal for this on which Primack was a Co-I; it was unsuccessful, but we plan to try again. (Key personnel: Primack and Nina McCurdy working with Prof. Noah Wardrip-Fruin of UCSC's Computer Game Design program, a new joint degree program of the Departments of Computer Science and Film and Digital Media.)

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 also supports the NASA Science Mission Directorate education portfolio by enabling SMD-related course resources for primary and secondary education and higher education.

3. Roles of Adler and Morrison Planetariums, NASA Ames, and UCSC

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. 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 2D and 3D theaters and the internet comparatively easy.

Planetariums used to show mainly the nearby planets and stars in the night sky. With the advent of digital projectors they have greatly expanded their content by including various sky surveys (Tully nearby galaxy data, Sloan digital sky survey, etc.). However, as we mentioned above, planetariums have only scratched the surface showing dark matter. 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 and of the galaxies it contains.

3.2 Roles of Adler and Morrison Planetariums. The resources of these planetariums are crucial to our goal of developing a visual language for displaying dark matter as well as visible matter (stars, gas, and dust) in order to make compelling visualizations of multicomponent simulations. In addition to their domes, both Adler and Morrison Planetariums have 3D theaters and other venues in which we can evaluate visualizations with various audiences.

In particular, in the Adler Space Visualization Laboratory the visualizations will be shown on multi-screen and stereoscopic display walls 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 Adler Universe Theater, a high definition (1080p) stereoscopic theater seating 200, and in a similar 3D theater at the California Academy of Sciences. The Adler definiti Dome Theater (also seating 200) will use the real-time visualizations in an updated version of the Night Sky Live show, a presenter-led tour of the Universe. The definiti Theater show will prepare visitors for their experiences in the Deep Space Adventure gallery.

The California Academy of Sciences proposes to collaborate with the Adler Planetarium and adapt simulations for use in real-time programming at the Academy. Since reopening to the public in September 2008 in Golden Gate Park, the Academy has welcomed more than three million visitors, and is anticipated to reach 1.6 million visitors annually. The Academy's Visualization Studio creates content for the Morrison Planetarium and other digital venues in the Academy, so cosmology visualizations can extend well beyond the planetarium dome. The Academy proposes to highlight cosmology simulations during the planetarium's monthly Benjamin Dean Astronomy Lecture Series, as well as through our "Science in Action" and "NightLife" venues.

The Academy's "Science in Action" exhibit provides a forum dedicated to conveying the latest scientific news and research. Short HD stories (which are also distributed online) run continuously throughout the day, and the exhibit also allows for informal presentations to small audiences. Evaluation and refinement of the cosmology visualizations will support three five-minute "Science in Action" stories that will play in the exhibit and online.

The Academy will additionally target adult learners during the Academy's NightLife programs, which attracts an average of more than 2,000 visitors weekly, ages 21 and up, with those aged 25 to 34 constituting the majority of attendees. Visualizations will be integrated into the Academy's monthly "Universe Update," a 35- to 45-minute program geared toward NightLife audiences that currently reaches more than 7,000 visitors annually. The NightLife age cohort avidly utilizes social media, and the Academy currently has more than 16,000 fans on Facebook, and 14,000 Facebook users have separately become fans of NightLife. The Academy will leverage this audience to attract attention to programs making use of simulation data, but the social media audience will also be connected to HD versions of the vignettes and "Science in Action" stories.

Based on experiences at the Academy, as well as formative work at the Adler, the visualization studio will develop three 2-to-4-minute dome "vignettes" that distill critical concepts into short-form pieces that can play at a variety of fulldome planetariums. Such vignettes will include a soundtrack of a researcher or educator describing the data, with pre-rendered visuals designed for a variety of fulldome video configurations. HD versions of the vignettes will also be made publicly available.

3.3 Making Visualizations. It will be necessary to create (or re-run) a number of simulations especially in order to make possible the visualizations proposed here. In some cases this will be necessary in order to capture thousands of timesteps for smooth videos. In other cases it will be necessary to tune the simulations, for example in order to create a better match between the constrained simulations of the Local Universe and the actual locations of nearby galaxies and galaxy groups. Primack's grad students will do most of this work, sometimes aided by visiting Collaborators and other visiting researchers.

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 Sunrise outputs are snapshots of the radiation emerging from the simulated object in one specific direction, and (as for visualization of any real 3D object) another computation is needed to show the object from another viewpoint. Sunrise can easily generate 3D images – i.e., two nearby views. But the outputs 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.

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 and textures convey information without confusion? What we discover should improve both our outputs and also future astronomical and computational visualization and outreach efforts.

NASA Ames has developed concurrent visualization capabilities (Ellsworth et al. 2006), enabling vast quantities of data to be captured without seriously impacting runtime performance of simulations. 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. Therefore part of the preliminary process will be determining how best to sub-sample the current data in such a way that maintains the most interesting and valuable characteristics of the simulation. Part of the work in preparing visualizations will also be interpolating between the saved timesteps.

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.

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 2 to 4 minute blocks designed to explore the most illuminating aspect/components of the simulations. Morrison Planetarium will make versions of these for both dome and 2D and 3D theater shows.

Aside from SCISS and SkySkan, which together constitute more than a quarter of all installed fulldome planetariums, other vendors have come into the market to provide digital solutions that create the ability to explore the universe in 3D. 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 eventually to make our Pre-Rendered and Real-Time materials accessible to all planetariums.

3.4 Plans and Methodology for Evaluation of Visualizations. Visualizations have the potential to move and educate audiences. However, it is unlikely that a visualization of content that is unfamiliar to any given audience will be meaningful to that audience, especially without appropriate guidance. The general public does not have extensive background knowledge or understanding of cosmology, and people often have pervasive misconceptions. We include in this proposal extensive evaluation of our products.

The proposed evaluation is both formative and summative. The overarching concern of both aspects is tracking, refining, and documenting the appreciation and understanding of the proposed visualizations and programs by the general public. Content topics for evaluation include the evolution of the universe, dark matter, and galaxies. Formative evaluation, by design, is meant to be somewhat flexible as project goals shift: its aim is to provide rapid feedback to the leadership team in order to make changes to designs or adjust goals as needed. Summative evaluation provides a reflective summary of the project's match of goals to outcomes, particularly how transformation of complex astronomical data to visual forms recognizable and understandable by the general public was accomplished.

Formative evaluation includes attending key project meetings, interviewing key partners, conducting baseline surveys, and observing activities at multiple levels (PIs, visualizers, public). Rapid feedback based on these data assists the leadership team make decisions as the project progresses. Evaluators act as 'reflective partners' providing real-time feedback and reality checks, while also communicating with the leadership team regarding areas needing attention, additional time, and/or resources. Survey instruments will be developed to test how different representations of the data impact the effectiveness of the visualizations with the general public. The Adler SVL is an excellent environment for acquiring open-ended responses in a small-group setting. In the Adler's definiti Theater, we will show short clips as a preview to an upcoming show and collect statistically significant numbers of responses. The Academy will take a grassroots approach to evaluating a range of audiences across a variety of venues, from small, informal settings to larger lectures and dome presentations.

The summative evaluation documents and assesses the quality of the project overall, asking the following key questions:

1. Were key goals and timelines clearly identified and met (including learning goals for the public)
2. Was astronomical data effectively translated into effective visualizations?
3. Were visualizations useful for the public: did they appreciate them; did they understand them?

Points 2 and 3 are inter-related, as we will know if shows are useful to public by prototyping them, getting public feedback, and subsequently revising efforts.

In order to present an accurate picture of the 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. This aspect of our proposed work especially will require effective and meaningful evaluation.

3.5 Dissemination. All partners – UCSC, Adler Planetarium, and Morrison Planetarium – agree that all the materials produced will be made freely available to the planetarium community and to educators. We will also produce a rich website with background material to facilitate their use in various settings. This will include both written material and 5-10 minute video tutorials, giving background on the content and tips on the most appropriate ways to fully exploit them. The tutorials will be developed for the training sessions for planetarium staff planned for the third year of our project.

The International Planetarium Society's Fulldome Video Committee, which 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 800 fulldome theaters worldwide, more than half of which are located in the United States. The majority of these domes are 10 meters or less in diameter, and many are portable theaters: these small theaters serve diverse publics, primarily but not exclusively school-aged, over an extensive geographic distribution. Most of these theaters have very limited access to production resources, relying instead on live presentations, "clip lists" of fulldome sequences, and pre-recorded shows from a variety of distributors. Short-form "vignettes" can thus supply much-needed content to a network of avid astronomical interpreters.

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.

Timeline: 2011 – finish "The Searcher" dome show at Adler, begin trials and evaluations of visualizations at Adler SVL and at Morrison, first meeting of advisory committee. 2012 – produce initial Morrison dome vignettes and "Science and Action" pieces for evaluation and limited distribution, prepare dome and 3D visualizations for Adler shows, continue formative evaluations. 2013 – produce remaining Morrison vignettes and "Science in Action" pieces; finish final versions of all projects including supplementary materials and summative evaluations; launch major distribution effort, workshops for planetarium staff, and outreach to other venues. The timeline is such that the testing of content (both at the Adler and the Morrison) in year one, will no doubt support the development of more refined products in years two and three.

Staff: Nina McCurdy will play a crucial role in various aspects of this proposed project. Her academic background in physics and astrophysics combined with her knowledge of the visual arts makes her a valuable liaison between the scientific, artistic, and planetarium communities. McCurdy worked at Adler Planetarium in 2008 and 2009 and was trained there to run digital planetarium shows. She will work closely with the Adler and the Morrison Planetariums, and she will also be responsible for creating simulation visualizations and interactive learning software. In addition, she will create a website to make our productions publicly available, and thereby extend 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 High-Performance Astro-Computing Center, directed by PI Primack, for which she will be performing similar functions.

UCSC Grad Students will be responsible for developing and running special simulations for purposes of generating visualizations (§**3.3**). **Visiting Researchers** will assist with special needs; for example, Dr. Patrik Jonsson, author of the Sunrise code, will help to plan camera movements and interface image data with the planetarium software.

Evaluators: Doris Ash, Associate Professor of Science Education at UCSC, will serve as an external evaluator for this project. Ash has had extensive experience with NSF-funded science education projects, especially cross-disciplinary, geographically distributed, and multiply partnered efforts. She will work closely with Zoe Buck, a graduate student in science education at UCSC with a Princeton undergraduate degree in astronomy. Ash and Buck will also work closely with formative evaluators Paul D'Addario and Ken Walczak at the Adler Planetarium (§**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), Andrey Kravtsov (U Chicago), Shawn Laatsch (Hilo Planetarium), Start Levy (NCSA), Ian McLennan (Vancouver), Derrick Pitts (Franklin Institute and Fels Planetarium), and Frank Summers (STScI). The PI and Co-Is will consult frequently with the Advisory Committee electronically, and aim to meet with members in person annually, perhaps in conjunction with scientific conferences and AstroViz and/or International Planetarium Society meetings. As discussed above, we need 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 and explain this well will probably be the main issue on which we will need the advisory committee's wisdom.

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. A selection is included in the supporting documents for this proposal.

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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 High-Performance Astro-Computing Center, 2010-; Chair, UCSC Committee on Computing and Telecommunications, 2008-2011; Chair, University Committee on Computing and Communications, 2010-11

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)
• 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)

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

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A. Professional Preparation

B.S.	(Science Education)	1965, Cornell University, Ithaca, NY.
M.S.	(Biology)	1968, Cornell University, Ithaca, NY.
Ph.D.	(Science Education)	1995, University of California, Berkeley, CA

B. Appointments Relevant to Grant

2007-present	Associate Professor, University of California, Santa Cruz
2000-2007	Assistant Professor, University of California, Santa Cruz, Research focus on learning and teaching in science education, professional development formative assessment, and cultural diversity
1995-2000	Science Educator, Exploratorium, Institute for Inquiry, Specialist in inquiry, documentation of program efforts, and assessment of inquiry to a national research audience.

C. Publications—Related Research

Ash, D. (2008). Using video data to capture discontinuous science meaning making in non-school settings. In Video Research in the Learning Sciences. Peter Lang Press.

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Ash, D. & Levitt, K. (2002). Working within the zone of proximal development: Formative assessment as professional development. Journal of Science Teacher Education.

D. Relevant Current Grant Experience

- Ash's (NSF ISE # 0515468, end date 11.10, Co -PI) **Successful scaffolding strategies in urban museums: Research and practice on mediated scientific conversations with families and students** grant conducted basic research on best mediation/teaching practices in informal learning contexts. One book is under contract and 2 peer review articles are under review. Research with diverse urban populations currently under-served by informal institutions.
- Ash is PI on a NOYCE planning grant, NSF (0934748, 10/09-9/10) **Silicon Valley Consortium for Mathematics and Science Teachers (SVCMST)** which seeks to re-train science professionals to teach in under-served schools in East San Jose. Professional development emphasizes deep disciplinary knowledge and working with English learners.
- Ash is also PI (NSF GK-12 DGE-0947923, 3/10-2/15) on **SCWIBLES, (Santa Cruz-Watsonville Inquiry-Based Learning in Environmental Sciences)**, a new graduate training program for scientists at the University of California Santa Cruz in partnership with Watsonville High School, a school with a high proportion of English learners to help train graduate students in environmental sciences to effectively communicate with non-scientists about science.

E. Narrative Ash has consulted with informal science institutions (ISIs) in San Francisco, Monterey, Los Angeles, Chicago, Boston and Florida. She has been a key partner in the Center for Informal Learning and Schools (CILS) (02-08), working at UCSC to promote new scholars crossed-trained in both education and in science. Ash is engaged currently in a cross-country NSF-funded collaboration researching and practicing innovative ways to train educators in informal settings (museums, aquaria, planetariums, and zoos, for example) how to mediate learners' experiences with and understanding of science. Ash especially focuses on working with culturally and linguistically diverse and other non-dominant populations.

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

Address: Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA 95064
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: -"A Little Bit of Quantum Mechanics", presenting the first order perturbations of an electron in an infinite square well caused by the absorption of electromagnetic radiation. -VERITAS EPO interactive on gamma ray astronomy.

Awards

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

Published Projects

- University of California High-Performance Astro-Computing Center website: www.hipacc.ucsc.edu
-VERITAS EPO interactive: svl.adlerplanetarium.org/VERITAS/
-Eternal Inflation Visualization included in the 2009 Yale Terry Lectures by Joel Primack and Nancy Abrams (www.youtube.com/watch?v=WRX6GdUz-Yw)

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.
Feb.-Aug. 2008	Scientific Illustrator, UCSC Physics Department,
Jan.-March 2009.	Teacher's Assistant/Reader, UCSC Physics Department, (Course: Conceptual Physics)
May-Dec 2009.	Junior Specialist in Public Outreach, UCSC SCIPP
July-Nov.2009	Scientific Animator, UCSC SCIPP
Sept.-Nov 2009	Graphic Designer, UCSC Astronomy Dept.
Dec. 09-Present	Illustrator & Assistant, Abrams and Primack, Inc.
Jan. 09-Present	Public Outreach Coordinator and Webmaster, UC HIPACC

Internships

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

Programming Skills: Actionscript, HTML, XML, CSS, PHP, MySQL, CGI, MEL, Basic level of C/C++ and Python. **Simulation/Graphic Codes:** Gadget-2, Splash, Splotch, IDL, Partiview, familiarity with LLNL's Visit. **Software Skills:**Fluent in Mathematica, Adobe (Illustrator, Photoshop, Flash, Fireworks, Dreamweaver), Maya 2010, Microsoft office (word, excel, powerpoint), iWork (pages, numbers, Keynote) Certified in DigitalSkyII

ACADEMIC CURRICULUM VITAE

Zoë Elizabeth Buck zbuck@ucsc.edu | 818.395.7435 | 331 Mission St. Apt 5, Santa Cruz, CA 95060

A. Specialization: Astronomy and space science education in formal and informal settings.

B. Research Interests: I am interested in how learners and researchers of different ages and backgrounds organize their knowledge about the scale of the universe and the creation of mental frameworks for enormous distances.

C. Education:

2009-now University of California Santa Cruz
PhD student in Education (Science and Math Concentration)

2004-2008 Princeton University
B.A. cum laude in Astrophysical Sciences

D. Honors, Awards, Grants:

2009-10 Chancellor's Fellowship, UCSC
2008 AAAS Mass Media Fellowship
2008 Sigma Chi Research Society
2004 National Merit Scholar Finalist

E. Related Professional Development

2010 Participant in Institute for Science and Engineering Education Professional Development Program Including a weeklong workshop in Maui, Hawaii on Inquiry in Science and Engineering Learning and Teaching, and the re-design and facilitation of an inquiry activity for an astronomy course at Hartnell Community College in Salinas, CA.

F. Related Employment History

2008-2009 Astronomy instructor and program coordinator at astronomy and outdoor education facility in Idyllwild, CA
2008 AAAS funded Science Reporter at Raleigh News & Observer in Raleigh, NC
2007 Teaching Assistant in Princeton Astrophysics Department
2007 UCO Lick Observatory Staff Research Associate II in Mt. Hamilton, CA
2006 SETI Institute Undergraduate Research Intern in Mountain View, CA

G. Education and Astrophysics Research Experience:

2010-now *A comparative phenomenology of large scale cosmological knowledge*
Advisor: Doris Ash, University of California, Santa Cruz

2009-now *Scaffolding in family interactions at the Museum of Science and Industry in Tampa, FL*
Advisor: Doris Ash, University of California, Santa Cruz

2008 *Distant Quasar Clustering in the SDSS Deep Stripe*
Advisor: Michael Strauss, Princeton University, Princeton, NJ

2007 *Accurately Determining Galaxy Cluster Parameters using a Matched Filter Method*
Advisor: David Spergel, Princeton University, Princeton, NJ

2006 *Identifying Pre-Main-Sequence Stars Using SDSS Spectroscopy*
Advisor: Gillian Knapp, Princeton University, Princeton, NJ

2006-7 *Optical Search for Extraterrestrial Intelligence*
Advisor: Frank Drake, SETI Institute, Mountain View, CA

JOEL R. PRIMACK: CURRENT AND PENDING SUPPORT

JOEL R. PRIMACK: CURRENT AWARDS 2010

AGENCY	TITLE	DATES	AMOUNT	MONTHS FUNDED & COMMITMENT
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 Commitment: 25% all year
NASA ATP NNX10AHH11G	Evolution of Structure and of the Cosmic Population of Galactic Spheroids PI: Primack	6/01/10- 9/30/10	$25,000	0 funding for PI, only grad students
NASA GLAST NNX09AT98G	Modeling Gamma-Ray Attenuation PI: Primack; Co-Is: Madau, Prada	10/1/08- 9/30/09	$65,000	½ summer month 2010
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 funding for PI (just for students)
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	$350,000 per yr for 4 staff, conferences, summer school, etc.	½ month during 2010-2014 Commitment: 10% of Academic Yr

JOEL R. PRIMACK: PENDING AWARDS 2010

AGENCY	TITLE	DATES	AMOUNT	MONTHS FUNDED & COMMITMENT
NSF AST	Collaborative Research: Evolution of Cosmic Structure and of the Population of Galactic Spheroids PI: Primack; Co-I: Dekel; Collaborators: Bullock, Cox, Croton Faber, Jonsson, Klypin, Lotz, Somerville, Wechsler	7/1/10- 6/30/13	$423,456	0 month 2010 ½ month 2011-12 Commitment: 35% Academic Yr + 1½ summer months each year
DOE	UC-HIPACC Astro-Computing Summer School on Galaxy Simulations PI: Primack, Co-I: Klypin	7/01/10- 12/31/10	$20,000	Commitment: PI: ½ month Co-I: ½ month
NSF	UC-HIPACC Astro-Computing Summer School on Galaxy Simulations PI: Primack, Co-I: Klypin	7/01/10- 12/31/10	$20,000	Commitment: PI: ½ month Co-I: 1 month

Current and Pending
Doris Ash
5.10

1. Support: **x Current** Pending Submission Planned in Near Future
Source of Support: NSF DRL 0515468
Project Title : Successful Scaffolding Strategies in Urban Museums: Research and Practice on Mediated Scientific Conversations with Families and Museum Educators
Total Award Amount: $850,000 for UCSC. Total Award Period Covered 11/05-10/10
Location of Project: Tampa Florida, UCSC
Person-months per year committed to the project: Cal: 0.00 Acad: 0.00 Summer: 1.00
PI Lombana, Co PI Ash

2. Support: **X Current** Pending Submission Planned in Near Future
Source of Support: NSF DUE 0934748
Project Title: Silicon Valley Consortium for Mathematics and Science Teachers (SVCMST) Total Award Amount: $74,836.00. Total Award Period Covered 9/09-8/10
Location of Project: Silicon Valley, CA
Person-months per year committed to the project: Cal: 0.00 Acad: 0.00 Summer: 1.00
PI Ash

3. Support: **X Current** Pending Submission Planned in Near Future
Source of Support: NSF GK 12
Project Title: The Santa Cruz-Watsonville Inquiry-Based Learning in Environmental Sciences (SCWIBLES) DGE-0947923
Total Award Amount: $2.1 million Total Award Period Covered 10.09-9/14
Location of Project: UCSC
Person-months per year committed to the project: Cal: 0.00 Acad: 0.00 Summer: .5
PI Gilbert, Co PIs Parker, Ash

4. Support: Current **X Pending** Submission Planned in Near Future
NSF DUE 1043439
Project Title: Breakthroughs in Interpretation of Coastal Climate Change Science (BICCCS)
Total Award Amount: $865,000. Total Award Period Covered 1/11-12/12
Location of Project: UCSC
Person-months per year committed to the project: Cal: 0.00 Acad: 0.00 Summer: 1.0
PI Sloan, Co PI Ash

Current and Pending Support for Mark SubbaRao

Project/Proposal Title	Source of Support	PI	Total Award Amt.	Start Date	End Date	Cal. Mos. Per Year
Current						
Explore the Galaxy	NASA	Paul Knappenberger	$99,877.00	8/1/09	7/31/10	1.00
Astronomy Research	Brinson Foundation	Lucy Fortson	$500,000.00	1/1/08	5/31/12	1.00
Deep Space Adventure	Pritzker Foundation	Paul Knappenberger	$2,000,000.00	12/1/06	12/31/10	2.00
Interactions in Understanding the Universe	NSF	Marjorie Bardeen	$650,000.00	10/1/09	9/30/10	1.00
Dissecting the Virgo Cluster	Space Telescope Science Institute	Hsiao-Wen Chen	$19,585.00	3/1/10	2/29/12	0.50
International Year of Astronomy 2009 in the U.S.: Exhibiting Astronomy with the "From Earth to the Universe" Project	NASA/ASU	Kimberly Arcand	$300,118.00	1/1/09	5/31/10	0.50
CDI Type II: Zooniverse - Conquering the Data Flood with a Transformative Partnership between Citizen Science and Machine	NSF - ARRA	Lucy Fortson	$1,889,993.00	1/1/10	12/31/13	1.20
Total Current			***$3,569,580.00***			***7.20***
Pending						
Total Pending			***$-***			***0.00***
TOTAL Current + Pending			**$3,569,580.00**			**7.20**

Current and Pending Support for Ryan Wyatt

Project/Proposal Title	Source of Support	PI	Total Award Amt.	Start Date	End Date	Cal. Mos. Per Year
Current						
Total Current			***$-***			
Pending						
Initiative for Climate Science Literacy	NOAA Office of Education Environmental Literacy Grant	Ryan Wyatt	$1,000,000.00	10/1/10	9/30/13	3.00
My Satellite, Our Earth: Using Earth System Data and Social Media Gaming to Advance Climate Literacy	NASA Global Climate Change Education	Ryan Wyatt	$397,906.00	1/1/11	3/31/13	1.20
Total Pending			**$1,397,906.00**			***4.20***
TOTAL Current + Pending			**$1,397,906.00**			**4.20**

ADLER
PLANETARIUM

May 27, 2010

Dear Joel:

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled "Public Education and Outreach via Cosmological Simulation Visualizations" that is submitted by Principal Investigator Joel R. Primack to the NASA Research Announcement NNH10ZDA001N-EPOESS: Opportunities in Education and Public Outreach for Earth and Space Sciences, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation.

The Adler Planetarium is very excited about the potential of the project to improve the quality of our shows and exhibits as well as the opportunity to advance the field of informal science as a whole. We strongly believe in the value of presenting contemporary scientific research to our visitors and are deeply committed to the success of the project.

Sincerely

Digitally signed by Mark Subbarao
Date: 2010.05.27 11:21:36 -05'00'

Mark SubbaRao, PhD
Space Visualization Laboratory Director

CALIFORNIA
ACADEMY OF
SCIENCES

55 Concourse Drive
San Francisco, CA 94118
calacademy.org

31 May 2010

Joel R. Primack
University of California, Santa Cruz
1156 High Street
Santa Cruz, CA 95064

Dear Joel:

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled "Public Education and Outreach via Cosmological Simulation Visualizations," submitted by Principal Investigator Joel R. Primack to the NASA Research Announcement NNH10ZDA001N-EPOESS: Opportunities in Education and Public Outreach for Earth and Space Sciences, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation.

Through the work of the Visualization Studio, the California Academy of Sciences demonstrates a deep commitment to present contemporary scientific research to our audiences. Our multiplicity of venues—from the planetarium to the "Science in Action" exhibit, the 3D stereoscopic theater and online video podcasts—all stand to benefit from the proposed work.

I look forward to the opportunity to iterate on the development and evaluation of visualizations, especially as it relates to the visual language and the verbiage used to describe them. I believe that such a considered procedure is very much needed in the field right now, when too much content is produced without taking the audience(s) into account. At the Academy, we plan to contextualize the visualizations differently in a variety of programs, for audiences ranging from our die-hard astronomy buffs to our more casual visitors: internally, we have even discussed combining climate modeling, genome sequencing, and cosmology into a larger discussion about computational science. We hope these experiences can contribute to the proposed evaluation work while deeply enhancing our programs.

I believe this project has the potential to advance the field of informal science as a whole. In particular, the planetarium community has a deep interest in the topic of cosmology while lacking the necessary tools to talk about it. Short-form "vignettes" strike me as an ideal mechanism for empowering planetariums to address challenging topics: the short pieces can be integrated into live programming or presented as a follow-up to longer shows, and they relieve the pressure on planetarians to be experts on every subject.

Thank you for the opportunity to collaborate on this proposal. If you have any questions, please do not hesitate to contact me directly at rwyatt@calacademy.org. Thank you for your consideration.

Ryan J. Wyatt
Director of Morrison Planetarium
Director of Science Visualization
California Academy of Sciences

DENVER MUSEUM OF
NATURE & SCIENCE

May 28, 2010

Joel Primack
UC High-Performance Astro-Computing Center
Physics Department, UCSC
Santa Cruz, CA 95064

Dear Dr. Primack,

I am writing in support of your grant proposal "Public Education and Outreach via Cosmological Simulation Visualizations" to the NASA EPOESS program to create cosmology and galaxy formation simulations for digital planetariums. The visualizations that you will be creating for your fulldome show are highly complementary to and will support our outreach work at the Gates Planetarium at the Denver Museum of Nature & Science (DMNS). I have given many lectures to visitors that have touched upon or focused on the topics of dark matter, dark energy, and the history and evolution of the Universe since the Big Bang. I find that my audiences–ranging in age from teenagers to retirees–are fascinated by these topics, not only because they deal with the frontiers of scientific understanding, but also because they represent concepts that the general public has little to no prior knowledge about.

Yet cosmology remains a challenging subject to teach, because so many of the key ideas are highly abstract to the layperson. Therefore any attempts to help visualize these concepts–whether it's the expansion of the universe, the evolution of large-scale structure, or how galaxies merge and grow over time–will be immensely valuable for public understanding. I can foresee using the animations created by your project in public talks in our fulldome Gates Planetarium as well as in lectures in traditional classroom and auditorium settings. They will also be invaluable in our docent training. Our Space Odyssey exhibit has over three hundred volunteer Museum Galaxy Guides who interact with the public every day. Your simulation visualizations may eventually be part of the daily rotation of visuals that are shown and talked about by our volunteers, potentially impacting a portion of the several hundred thousand people that visit that exhibit each year.

I therefore look forward to seeing the simulations from your group properly visualized for the dome and elsewhere.

Sincerely,

Ka Chun Yu
Curator of Space Science
Denver Museum of Nature & Science

2001 Colorado Blvd.
Denver, CO 80205-5798
P 303.322.7009
F 303.331.6492

www.dmns.org

Selected Statements from Letters of Support

"I was very excited to hear of your proposal, and sincerely hope that your proposal will be funded. Here at the new Noble Planetarium in Fort Worth, Texas, we would be most interested in acquiring such simulations. For digital planetariums such as ours, the material you propose to produce for public use would be very valuable. We have been wanting to present a show about dark matter/dark energy, but we have found that illustrative materials for this are very limited. We, like many other planetariums, do not have access to the massive computing power and expertise that it takes to produce this type of material. Also, like most planetariums, we do not have the resources available to fund this kind of endeavor ourselves, although we could certainly make good use of the material. We would be sincerely interested in assisting you in this endeavor in any way that we possibly can."-Linda M. Krouse, Director, The Noble Planetarium, The Fort Worth Museum of Science and History, Fort Worth, TX

"I would be very interested in using your astronomical visualizations in the planetarium here at Tellus. We had over 100,000 visitors last year through our planetarium and I'm always on the look out for new content to excite our visitors about the cosmos. If I can be of any help with your new proposal please let me know."-David A. Dundee, Astronomy Program Manager, Tellus Museum, Cartersville, GA

"Thanks again for contacting the community regarding these wonderful project. Like I mentioned last year we would be more then happy to help you in your proposal, and please sign us as one of the planetariums interested in having the content you plan to create. We are really excited about this project. Its a great idea, wonderful science and goes into the heart of what a digital planetariums really is, a bridge that sustains the flux of scientific knowledge towards the general public presented in the proper context." Antonio Pedrosa - Navegar Foundation, Portugal, Spain

"…this sounds like a great idea. Something of this nature would greatly enhance our offerings. Looking forward to hearing more about this."- Prof. Jim Moravec, Planetarium, Community College, Denver, CO

"This looks like an amazing project. I am at your disposal to lend whatever type of support you fine folks need from me and my institution.Thanks!"-Michael J. Narlock, Head of Astronomy/Web Coordinator, Cranbrook Institute of Science

“This is something that I would be extremely interested in for our planetarium. As a university-based digital planetarium, I see multiple uses for this in both astronomy and science education curriculum as well as in engaging computer science students. I am the director of Strickler Planetarium on the campus of Olivet Nazarene University in Bourbonnais, IL.” - Steve Case, Assistant Professor and Planetarium Director, Department of Physical Sciences, Olivet Nazarene University in Bourbonnaise, IL

“I am a doctoral student in a transdisciplinary research program currently writing my dissertation on how interpretations of visual representations of the cosmos influence psychological perspectives on the world. I am most interested how the outcome of this project as it should provide a premiere example of how findings from observational cosmology are being interpreted for public viewing.” - David McConville, University of Plymouth, Planetary Collegium, Doctoral Candidate & Co-Founder of The Elumenati, immersive projection design

“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, Albuquerque, NM

“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

“It is my sincere hope that this project will come to pass. I believe that these 3D simulations of complex and large scale physical processes enable a level of understanding and insight that cannot be realized or appreciated in any traditional way. This would be a wonderful asset to both educators and researchers.”-Tony DeLia, Physics, Astronomy and Mathematics, North Florida Community College, Madison, FL

Budget Justification: Budget Narrative and Budget Details

This is a proposal for a grant, in response to NASA ROSES10 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 and director of the new University of California High-Performance Astro-Computing Center	0.5 summer months at 100% time + (2)** months in years 1, 2 and 3
Co-I: Mark SubbaRao, Adler Space Visualization Laboratory Director	0.9 months in years 1,2 and 3
Co-I: Ryan Wyatt, Director of Morrison Planetarium and Science Visualization	0.6 months in year 1, 1 month in years 2 and 3
Co-I: Doris Ash, Associate Professor of Education at UCSC	0.3 summer months at 100% time in years 1, 2 and 3
UCSC GSR Academic: Zoe Buck	3.0 months at 50% time and 3.0 summer months at 100% time for years 1, 2 and 3
UCSC Staff: Nina McCurdy	12.0 months at 75% time for years 1, 2 and 3
GSR #2	3 summer months at 100% time for years 1, 2 and 3
Visiting researcher	1.0 month at 65% in year 1, 1.0 month at 64% in year 2, and 1.0 month at 62% in year 3
Adler Staff: Julieta Aguilera	0.9 months in years 1, 2 and 3
Adler Staff: Lu Natalino	0.6 months in years 1, 2 and 3
Adler Staff: Patrick McPike	0.6 months in years 1, 2 and 3
Educator: Paul D'Addario	0.4 months in years 1, 2 and 3
Educator: Ken Walczak	0.9 months in years 1, 2 and 3
Academy Staff: Matthew Blackwell	0.7 months in year 1, 1.0 month (160hrs) in years 2 and 3
Academy Staff: Grant Inouye	0 months in year 1, 0.4 months in year 2, and 0.9 months in year 3
Academy Staff: Michael Garza	0.2 months in year 1, 0.6 months in year 2 and 0.7 months in year three

Academy Staff: Cheryl Vanderbilt	0.7 months in year 1,
Academy Staff: Molly Michelson	0 months in year 1, 0.4 months in year 2, and 0.8 months in year 3
Collaborator: Thomas Cox	(0.2) months in years 1, 2 and 3
Collaborator: Chris Henze	(1) month in years 1, 2 and 3
Collaborator: Patrik Jonsson	(0.2) months in years 1, 2 and 3
Collaborator: Anatoly Klypin	(0.2) months in years 1, 2 and 3
Collaborator: Francisco Prada	(0.2) months in years 1, 2 and 3
Collaborator: Risa Wechsler	(0.2) months in years 1, 2 and 3
Collaborator: Rachel Somerville	(0.2) months in years 1, 2 and 3
Collaborator: Karl von Ahnen	(0.2) months in years 1, 2 and 3
Members of the Advisory committee: Tom Abel, Stephen Case, Andrey Kravtsov, Shawn Laatsch, Stuart Levy, Ian McLennan, Derrick Pitts, Frank Summers.	(0.1) months in years 1, 2 and 3

***Work commitment given in fractions of a month was calculated based on a 167 hour work month. Calculations were rounded to the nearest decimal. Exact time (in hours) may be found in the narrative below. **Unfunded commitments are in parenthesis.**

Direct labor Budget Narrative

PI Joel Primack, Distinguished Professor of Physics, UCSC and director of the new University of California High-Performance Astro-Computing Center
0.5 summer months at 100% time in years 1, 2 and 3 will act as program manager and will supervise all collaborations, activities, workshops and events.

Nina McCurdy, Assistant Specialist, is supported 12 months of the year at 75% time. Nina will be involved in all aspects of the project including planning meetings workshops and conferences. She will work closely with scientists, artists and educators and help to support any collaboration between them. Nina will aid in opening and maintaining clear lines of communication between planetarium show production personnel and scientists/visualizers. Throughout the project Nina will work with collaborator Chris Henze and collaborator Patrik Jonsson to generate the appropriate large scale structure and galaxy merger simulations and then to visualize them and/or format their output in a way that is accessible to the Adler's and the Academy's visualization teams. Nina will create visualizations (e.g "How Structures Form in the Expanding Universe," §**2.4)** that will be made accessible via the web, and which may be featured in the Adler's Space Visualization Lab (SVL) (2011) and the DSA gallery on Cosmology (2013). Nina will also help to create presentations for others (involved in the project) to bring to conferences (e.g. AAS, APS) and to incorporate into talks. These presentations may also be converted to videos and made available on the web. In year 3 (2013), Nina will help in the development of resources created to provide planetarium staff with the appropriate training and background to present our products. She will also be an active participant in the relevant workshops, meetings and conferences throughout the three years. Lastly, Nina will create and manage a website to make our productions publicly available, and thereby extend our outreach to a much wider audience.

Co-I Doris Ash, Associate Professor of Education at UCSC, is supported 0.3 summer months at 100% time in years 1, 2 and 3. Ash will oversee the overall evaluation on the West Coast. Ash will attend meetings on site and in the field as necessary. She will confer with the leadership team bi-weekly, and on an as-needed basis. Ash will consult weekly with Buck on the specific activities listed below.

Zoe Buck, Graduate Student Researcher (GSR) in the UCSC Department of Education, is supported 3.0 months at 50% time and 3.0 summer months at 100% time for years 1, 2 and 3. Buck's time will be compensated in the form of a university Graduate Student Research (GSR) appointment.

Buck's time will be divided into the following:

1. Review astronomy education literature for public understanding of space and time in astronomy, especially dark matter and the formation of galaxies and the large scale structure.
2. Attend meetings (Morrison, Adler, DeAnza) with Ash as necessary to track progress of key questions
3. Consult with Ash weekly, and with leadership team as necessary.
4. Help design, conduct and analyze initial survey of partners' goals and readiness.
5. Help design, conduct and analyze initial survey of public's appreciation and understanding of astronomical 'big ideas' such as dark matter.
6. Help design focus group questions and consult with Adler regarding prior experience with focus groups.
7. Help design and conduct interviews (written, phone and/or in person) with key personnel.
8. Help analyze interviews, survey, and other documents as necessary.
9. Maintain a data-base of all evaluation materials, both paper and electronic.

GSR #2 (TBA) is supported three summer months (at 100%) time. This student will develop and run simulations that will be used to produce special visualizations requested by Adler or the Academy (§**3.3**). This student will be our expert on one or more of the simulations featured in this proposal. To give an example, Lauren Porter, Priya Kallapara and Chris Moody are three graduate students currently working with PI Joel Primack. They are our local experts in Semi-analytic models (filling dark matter halos with galaxies), Simulations of forming galaxies including super massive black holes, and hydro-simulations of galaxy mergers, respectively. It is important to note that in any given year this money is likely to be shared amongst several different students, depending on the visualizations developed during that period.

Visiting Researchers (TBA, will change each year) is supported 1.0 month at 65% in year 1, 1.0 month at 64% in year 2, and 1.0 month at 62% in year 3. He/she will address a particular need/issue regarding a specific visualization. For example, Dr. Patrik Jonsson, author of the Sunrise code, will help to plan camera movements and interface image data with the planetarium software. Prada, who along with Klypin will be our main links with a large program of constrained simulations of the local universe, is another example of a possible visiting researchers. (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.)

Subcontract/Subaward Budget Narrative

Adler Planetarium Budget Narrative

Co-I Mark SubbaRao, Space Visualization Laboratory Director is supported 150hrs each in years 1, 2 and 3. He will guide the grant activities at Adler, working closely with the PI, other Co-I's and advisors. He will also oversee the deployment of the visualizations in the various venues at Adler, namely the Space Visualization Laboratory, the Universe Theater, the definiti Theater, and the Deep Space Adventure cosmology exhibit gallery. His will work with the planetarium vendors to increase the capability of their software to perform real-time visualizations of simulation data. He will also contribute to the production of explanatory materials for the visualizations and develop a plan for their distribution in various formats to the broader planetarium community.

Paul D'Addario, Educator (75 hours in years 1, 2, and 3) and Ken Walczak, Assistant Educator (150 hours in years 1,2 and 3) will collaborate to carry out formative evaluations of the visualizations. They will develop survey instruments, analyze and interpret the data in order to help refine the presentation of the visualizations. In the Space Visualization Laboratory we can systematically test how different representations of the data (e.g. color maps, isocontours) impacts the effectiveness of the visualization with the general public. This controlled setting is an excellent venue for acquiring open-ended responses in a small-group setting. In the Adler's definiti theater we have the opportunity to collect large, statistically significant numbers of responses. Visitors will be shown short clips as a preview to an upcoming sky show and then asked to respond to the clip using the interactive handsets mounted on the armrests.

Julieta Aguilera, Visualization Developer (150 hours in years 1,2 and 3) will act as an art consultant, advising on issues of color and camerapath as well as the specialized issues involved in stereoscopic rendering. She will also create titles, labels and diagrammatic effects to support the visualizations.

Patrick McPike, Technical Director (150 hrs in years 1,2 and 3) and Lu Natilino, Senior 3D-Artist-Animator (150 hrs in year 1,2 and 3) will support the production of the visualizations. They will import scientific datasets into commercial 3D modeling packages (Maya, 3DS Max) and choose materials and camerapaths. The will set up specialized renders for both full-dome and the stereoscopic theaters. They will also encode and load the visualizations into the theaters.

California Academy of Sciences Budget Narrative

Co-I Ryan Wyatt, Director of Morrison Planetarium and Science Visualization (100 hours in year 1, 175 hours in years 2 and 3) will guide the grant activities at the

Academy, working closely with the PI, other Co-I's, and advisors. He will also oversee the deployment of the visualizations in the various venues at the Academy, namely the Morrison Planetarium, the stereoscopic theater, and the "Science in Action" presentation space. He will coordinate with the Adler and UCSC team to ensure that content presented at the Academy will build on experience with other audiences. He will supervise production of the "Science in Action" pieces and direct the fulldome vignettes. Wyatt will collaborate with the Adler team to develop and execute a plan for optimal distribution to the broader planetarium community; this work will build on models currently in use and being explored by both Adler and the Academy.

Matthew Blackwell, Technical Director (120 hours in year 1, 160 hours in year 2, and 160 hours in year 3), will support the production of the visualizations. He will import scientific datasets into commercial 3D modeling packages (e.g. Maya) and animate camerapaths. He will create specialized renders for fulldome, HD, and other formats for final production.

Grant Inouye, Audio/Video Editor (60 hours in year 2 and 150 hours in year 3), will edit selected animations, create graphics and titles, produce audio and final video renders to create segments and vignettes for HD and other formats.

Michael Garza, Production Engineer (31 hours in year 1, 105 hours in year 2, and 125 hours in year 3) will provide encoding, setup and audio video support for presentations at Dean lectures, NightLife and any other Academy venues and develop the appropriate codec and provide encoding for each delivery format.

Cheryl Vanderbilt, Production Coordinator (110 hours in year 1, 140 hours in year 2, and 170 hours in year 3), will contact and coordinate with other planetariums to ensure broadest distribution of elements and vignettes. She will provide production support: acquiring datasets, scheduling public events, creating distribution copies, uploading and shipping as required.

Molly Michelson, Producer (60 hours in year 2 and 135 hours in year 3), will research, interview, provide storyline copy, edit narration and oversee the production of "Science in Action" segments.

The Academy will work with an outside contractor during years 2 and 3 to develop music for the fulldome vignettes.

Travel

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 one of the three other Adler staff personnel will visit UCSC and Morrison Planetarium approximately once per year. Co-I Doris Ash and GSR Zoe Buck will visit Adler approximately once per year. Each of these four visits is estimated to be 5 days in duration ($400 airfare + 5 days @145). We have also budgeted two week-long visits by a

Collaborator each year, for example Cox (at Carnegie Observatories, thus Pasadena-SFO) or Klypin (at University of New Mexico, thus Las Cruces NM-SFO). We also budgeted three four-day 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). We have planned an additional four-day trip for a member of our Advisory Committee in year three (e.g Chicago to SFO). It is important to note that due to UCSC's low overhead, a significant portion of the requested travel funds will be used to cover trips by collaborators and members of the advisory committee. During the third year (2013), 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 may be co-organized by the Kavli Institute for Particle Physics (KICP) and held at the University of Chicago. 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.

Facilities & Equipment

No funds are requested for equipment. PI Primack at UCSC already has the necessary workstations, and additional visualization facilities will be purchased using University of California High-Performance Astro-Computing Center (UC-HIPACC) 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 with various audiences 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 Agency Budget

Title Public Outreach via Cosmological Simulation Visualizations

Budget Prepared Date

Preparer Riley Jordan

SC# 20101241

PI Name Primack, Joel **Agency** NASA/Shared Services Center

Start Date 01/01/2011 **End Date** 12/31/2013

Salaries:

Title/Name	SalaryType/Level		Year 1	Year 2	Year 3	Total
PI Summer	PROFFULL	NA	8,544	8,801	9,065	26,410
Joel Primack	Months/Time%		0.5 100%	0.5 100%	0.5 100%	
Co-PI Summer	PROFASSOC	III	2,033	2,094	2,157	6,284
Doris Ash	Months/Time%		0.3 100%	0.3 100%	0.3 100%	
Asst Specialist	SPECASST	III	33,300	34,299	35,328	102,927
Nina McCurdy	Months/Time%		12.0 75%	12.0 75%	12.0 75%	
GSR Academic	GSR-Res	III	4,989	5,138	5,293	15,420
Zoe Buck	Months/Time%		3.0 50%	3.0 50%	3.0 50%	
GSR Summer	GSR-Res	III	9,978	10,277	10,585	30,840
Zoe Buck	Months/Time%		3.0 100%	3.0 100%	3.0 100%	
GSR #2 Summer	GSR-Res	IV	10,778	11,101	11,434	33,313
To be selected	Months/Time%		3.0 100%	3.0 100%	3.0 100%	
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 62%	
	Salaries:		74,622	76,710	78,862	230,194

Fringe:

Title/Name	SalaryType/Fringe Rate		Year 1	Year 2	Year 3	Total
PI Summer	PROFFULL	NA	1,153	1,188	1,224	3,565
Joel Primack	13.5%					
Co-PI Summer	PROFASSOC	III	274	283	291	848
Doris Ash	13.5%					
Asst Specialist	SPECASST	III	6,993	7,203	7,419	21,615
Nina McCurdy	21.0%					
GSR Academic	GSR-Res	III	125	128	132	385
Zoe Buck	2.5%					
GSR Summer	GSR-Res	III	299	308	318	925
Zoe Buck	3.0%					
GSR #2 Summer	GSR-Res	IV	323	333	343	999
To be selected	3.0%					
Visiting Researcher	RESFULL	II	1,300	1,300	1,300	3,900
To be selected	26.0%					
	Fringe:		10,467	10,743	11,027	32,237
	Salaries & Fringe:		85,089	87,453	89,889	262,431

Domestic:

Name	Destination

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SFO to Chicago	3 trips x 400 airfare + 4 nights @ 150 per diem & 2 trips in yr 3	3,000	3,000	2,000			8,000
SFO to Chicago	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000			3,000
Pasadena to SFO	1 trip x 200 airfare + 7 days per diem @ 150	1,250	1,250	1,250			3,750
Las Cruces NM to SFO	1 trip x 200 airfare + 7 days per diem @ 150	1,250	1,250	1,250			3,750
Chicago to SFO	1 trip x 400 airfare + 4 days per diem @ 150	1,000	1,000	1,000			3,000
Philadelphia to SFO	1 trip x 400 airfare + 4 days per diem @150	1,000	1,000	1,000			3,000
Hilo to SFO	1 trip x 400 airfare + 4 days per diem @ 150	1,000	1,000	1,000			3,000
Chicago to SFO	1 trip x 400 airfare + 4 days per diem @ 150	0	0	1,000			1,000
	Domestic:	9,500	9,500	9,500			28,500
	Total Travel:	9,500	9,500	9,500			28,500

Subcontracts:

Type	Description						
Subcontracts	Adler Planetarium	41,727	42,843	43,994			128,564
Subcontracts	Morrison PLanetarium / CA Academy of Sciences	28,293	54,845	66,822			149,960
	Subcontracts:	70,020	97,688	110,816			278,524

Other Direct Costs:

Type	Description						
Other	Travel Awards		0	10,000			10,000
	Other Direct Costs:		0	10,000			10,000

Fees:	Non-resident Tuition:						
	Graduate Student Health Insurance Program:	960	1,008	1,058			3,026
	Graduate Student Registration Fees:	3,294	3,623	3,986			10,903
	Graduate Fee Override:						
	Total Graduate Fees:	4,254	4,631	5,044			13,929
	Total Other Direct Costs:	74,274	102,319	125,860			302,453

Totals:	**Total Direct Costs:**	168,863	199,272	225,249			593,384
	Indirect Cost Base:	144,589	96,953	109,389			350,931
	Indirect Cost Base Override:						
	IC Rate:	51.5%	51.5%	51.5%	51.5%	51.5%	

Total Indirect Costs:	74,463	49,931	56,335	180,729
TOTAL BUDGET:	243,326	249,203	281,584	774,113

ADLER PLANETARIUM SUBCONTRACT BUDGET

	HRS	Year 1	Year 2	Year 3	Project Totals
Mark Subbarao	150	$ 6,181.50	$ 6,366.95	$ 6,557.95	$ 19,106.40
Julieta Aguilera	150	$ 4,714.50	$ 4,855.94	$ 5,001.61	$ 14,572.05
Lu Natalino	100	$ 2,308.00	$ 2,377.24	$ 2,448.56	$ 7,133.80
Patrick McPike	100	$ 2,747.00	$ 2,829.41	$ 2,914.29	$ 8,490.70
Paul D'Addario	75	$ 1,977.75	$ 2,037.08	$ 2,098.19	$ 6,113.03
Ken Walczak	150	$ 1,978.50	$ 2,037.86	$ 2,098.99	$ 6,115.35
Salary Totals		$ 19,907.25	$ 20,504.47	$ 21,119.60	$ 61,531.32
Travel		$ 4,500.00	$ 4,500.00	$ 4,500.00	$ 13,500.00
Fringe @ 22%		$ 4,379.60	$ 4,510.98	$ 4,646.31	$ 13,536.89
Salaries + Fringe		$ 24,286.85	$ 25,015.45	$ 25,765.91	$ 75,068.21
Indirect @ 65% salary		$ 12,939.71	$ 13,327.90	$ 13,727.74	$ 39,995.36
Total by year		**$41,726.56**	**$42,843.35**	**$43,993.65**	**$ 128,563.57**

Salaries increased by 3% each year.
Adler's Indirect Cost rate can be applied to salaries only. Fringe is excluded.

NASA ROSES GRANT: California Academy of Sciences Subaward

					Jan - Dec 2011		Jan - Dec 2012		Jan - Dec 2013		Project Total
	Fringe Benefit Rate:	24%									
Staff	**Base**	**Benefits**	**Weekly**	**Hourly**	**Hours**	**Salary**	**Hours**	**Salary**	**Hours**	**Salary**	**Salary**
Visualization Director	$2,436	$585	$3,021	$76	100	$7,552	175	$13,215	175	$13,215	$33,982
Technical Director	$1,385	$332	$1,717	$43	120	$5,151	160	$6,868	160	$6,868	$18,886
Audio/Video Editor	$904	$217	$1,121	$28	0	$0	60	$1,682	150	$4,205	$5,887
Production Engineer	$1,635	$392	$2,027	$51	31	$1,571	105	$5,321	125	$6,334	$13,226
Production Coordinator	$1,000	$240	$1,240	$31	110	$3,410	140	$4,340	170	$5,270	$13,020
SIA Producer	$1,030	$247	$1,277	$32	0	$0	60	$1,915	135	$4,309	$6,224
Subtotal: Direct Costs						$17,683		$33,341		$40,201	$91,225
Contract (Flat Fee)											
Production Sound								$1,500		$2,500	$4,000
Indirect Costs/Current Approved Rate =		**60%**									
						$10,610		$20,004		$24,121	$54,735
Total Costs											
						$28,293		$54,845		$66,822	**$149,960**