University of California
High-Performance
AstroComputing Center
(UC-HiPACC)

The High-Resolution Galaxy Simulation Comparison Project

Joel R. Primack, UCSC
(Director, UC-HiPACC)

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The simulations to be discussed will all have resolution better than ~100 parsecs, which we hope will be enough to begin to resolve star formation in galactic disks. This project is motivated by recent improvements in hydrodynamical simulation codes, the availability of millions of cpu−hours for such simulations on high−performance computer systems, and the increasingly rapid acquisition of observational data on galaxies both nearby and out to very high redshifts. The discussions today and over the weekend will consider the current results and performance of various simulation approaches. We want to compare simulations of the same cosmological initial conditions by different codes to each other and to relevant observations. This will help to advance the state of the art of galaxy simulations and the understanding of the key astrophysical processes that control galaxy formation and evolution, including the flows of baryons into and out of galaxies, feedback from stars, supernovae, and massive black holes, and the impact of baryons on dark matter structure and substructure. We will try to model consistently similar recipes across codes, rather than allowing complete freedom in implementation. We will also discuss initial conditions for a range of galaxy masses, not just the Milky-Way-mass simulations that much earlier work has focused on.

Outline of this talk

A word from our sponsor: UC-HiPACC

High-Res Galaxy Simulation Comparison Goals

2013 Galaxy Workshop and HRGS Followup Mtg

HRGS Comparison: Choices To Be Made Here

UNIVERSITY OF CALIFORNIA
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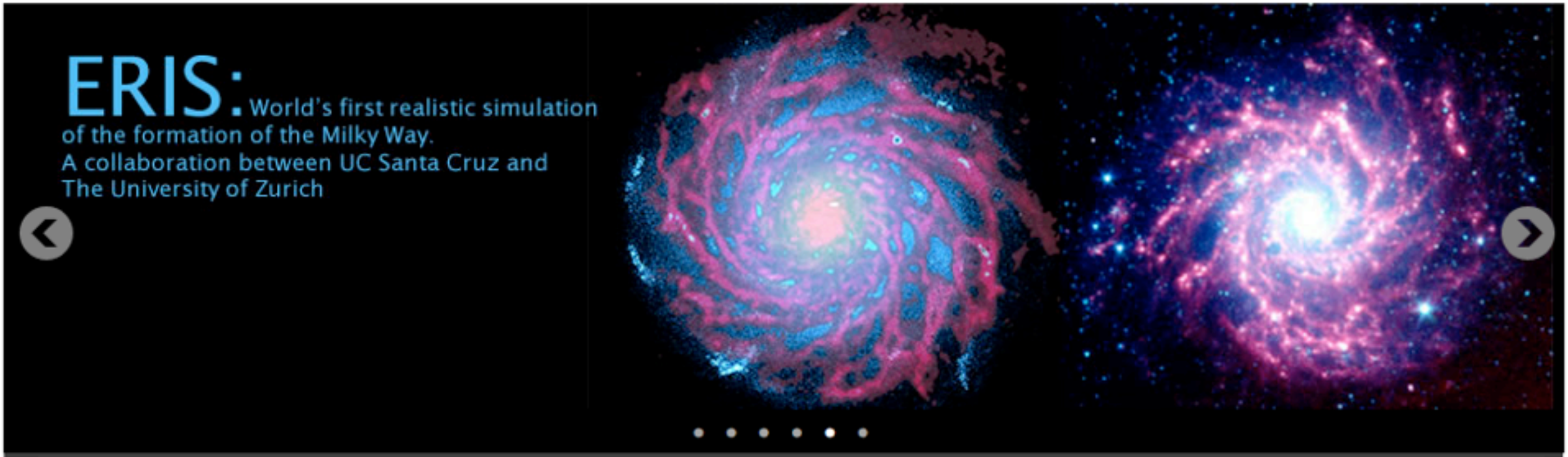
http://hipacc.ucsc.edu/



Home | About the Center | Conferences | Summer School | Education & Outreach | Support | HiPACC Lectures | HiPACC Speakers | Gallery

The purpose of the University of California High-Performance AstroComputing Center (UC-HiPACC) is to realize the full potential of the University of California world class resources in computational astronomy. Read the letter from the Director

Special Topic at San Diego, July 2012: AstroInformatics!

AstroInformatics—data mining for computational astronomy—is the special topic to be featured at the 2012 International Summer School on AstroComputing, to be held on the campus of the University of California, San Diego (UCSD), July 9–20. Hosted by the San Diego Supercomputer Center (SDSC) and the University of California High-Performance AstroComputing Center (UC-HiPACC), the two-week summer school is open to graduate students and post-doctoral fellows.

"Today's telescopes are generating huge amounts of new information about the universe – in some cases by the second," said Michael Norman, director of SDSC and a world-renowned astrophysicist. "Astronomers will need to know how to leverage the capabilities of data-intensive supercomputers to analyze all this data efficiently

Homepage Stories

2012 Summer School

2011 Summer School

View Archive >>

Press Room

Recent press releases about computational astronomy across the HiPACC consortium

- March 1, 2012 - SDSC, UC HiPACC to Host Summer School on Astroinformatics...

Upcoming Events

- 2012 Summer School
- Computational Astronomy Journalism Boot Camp

In the News

- "A Box of Universe: Watch the cosmos evolve in a cube one billion light-years wide" about the Bolshoi simulation; by Brian Hayes, American Scientist (January-February 2012).....view article

- A dwarf galaxy that collided twice with our own Milky Way galaxy may have triggered formation of the Milky Way's spiral arms; by Chris Purcell et al., Nature (September 15, 2011).....view article

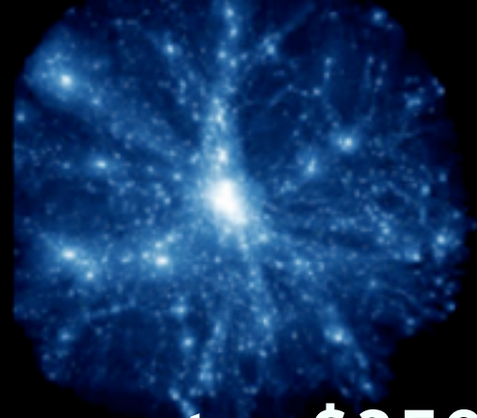
The University of California
High-Performance AstroComputing Center

A consortium of nine UC campuses and three DOE laboratories

As computing and observational power continue to increase rapidly, the most difficult problems in astrophysics are now coming within reach of simulations based on solid physics, including the formation and evolution of stars, planets, and supermassive black holes, and their interactions with their galactic environments.

The purpose of HIPACC is to realize the full potential of the University of California's worldleading computational astrophysicists, including those at the affiliated national laboratories. HIPACC will do this by fostering their interaction with each other and with the rapidly increasing observational data, and by empowering them to utilize efficiently the new supercomputers with hundreds of thousands of processors both to understand astrophysical processes through simulation and to analyze the petabytes and soon exabytes of data that will flow from the new telescopes and supercomputers. This multidisciplinary effort links theoretical and observational astrophysicists, physicists, earth and planetary scientists, applied mathematicians, and computer scientists on all nine UC academic campuses and three national labs, and exploits California's leadership in computers and related fields.

HIPACC's outreach activities will include developing educational materials, publicity, and websites, and distribution of simulation outputs including visualizations that are beautiful as well as educational.



The University of California
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UC-HiPACC Support: ~$350,000/yr from the University of California

UC-HiPACC Executive Committee

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Funding Opportunities

Calls for proposals scheduled twice annually for Fall/Winter & Spring/Summer funding Cycles.

UC-HIPACC will support focused working groups of UC scientists from multiple campuses to pursue joint projects in computational astrophysics and related areas by providing funds for travel and lodging. At the heart of UC-HIPACC are working groups.

1. Small travel grants enable scientists, graduate students, and post-doctoral students to travel easily and spontaneously between Center nodes. UC-HIPACC will fund travel grant proposals submitted by faculty members, senior scientists, postdocs or graduate students up to $1000 on a first-come-first-served basis with a simple application describing the plan and purpose of the travel.

2. Grants ranging between $1000 - $5,000 to support larger working groups or participation in scientific meetings.

3. Mini Conference grants of up to $5,000 to support collaborations of multiple UC campuses and DOE labs.

4. Grants to faculty to support astrocomputing summer research projects by undergraduates.

5. Matching grants of up to $10,000 for astrocomputing equipment.

6. Innovative initiative proposals for other purposes that are consistent with the goals of UC-HIPACC. Such purposes could include meetings or workshops, software development, or education and outreach.

Annual Conferences in Northern and Southern California

HIPACC will sponsor two large meetings each year especially (but not exclusively) for scientists working on computational astrophysics and related topics at the UC campuses and labs. Unlike the more specialized meetings of working groups, we expect that these larger meetings will be broad, with the purpose of bringing theoretical astrophysicists together with computer science specialists, computer hardware experts, and observational astronomers. One meeting will be in northern California and the other in southern California to promote maximum participation. In addition to sharing new information, these meetings will highlight problems needing attention to advance the state-of-the-art and introduce participants to potential colleagues and begin collaborations.

Annual International AstroComputing Summer Schools

HIPACC will support an annual school aimed at graduate students and postdocs who are currently working in, or actively interested in doing research in, AstroComputing. Topics and locations of the annual school will rotate, and Caltech and Stanford are also welcome to participate.

The 2010 school was at UCSC, on the topic of Hydrodynamic Galaxy Simulations. Lectures were presented by experts on the leading codes (AMR codes ART, Enzo, and RAMSES, and SPH codes Arepo, GADGET, and Gasoline) and the Sunrise code for making realistic visualizations including stellar SED evolution and dust reprocessing. There were 60 students, including 20 from outside the USA. Lecture slides and videos, codes, inputs and outputs are on the UC-HIPACC website http://hipacc.ucsc.edu. Funding from NSF helped to support non-UC participant expenses.

The 2011 school was July 11-23 at UC Berkeley/LBNL/NERSC, on the topic of Computational Explosive Astrophysics: novae, SNe, GRB, and binary mergers. The scientific organizers were Daniel Kasen (LBNL/UCB) and Peter Nugent (LBNL). There was additional funding from DOE.

The 2012 school was at UC San Diego/SDSC, on AstroInformatics and Astrophysical Data Mining. The scientific director was Alex Szalay (Johns Hopkins) and the host was Michael Norman, director, SDSC. We had funding from DOE as well as HiPACC.

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The 2010 school was at UCSC, on the topic of Hydrodynamic Galaxy Simulations

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Announcing the 2011 UC-HIPACC International AstroComputing Summer School on Computational Explosive Astrophysics

Topics Include: supernovae, gamma-ray bursts, compact object mergers, energetic transients

Location: University of California, Berkeley/ Lawrence Berkeley National Lab/ National Energy Research Scientific Computing Center

Dates: July 18 – July 29, 2011

Organizers: Daniel Kasen & Peter Nugent (UCB/LBNL)

Description: The University of California High-Performance Astro-Computing Center (UC-HIPACC) is pleased to announce the continuation of its international summer school, to be held this year by UC Berkeley and LBNL from July 18-29, 2011. This year's summer school will focus on computational explosive astrophysics, including the modeling of core collapse and thermonuclear supernovae, gamma-ray bursts, neutron star mergers, and other energetic transients. Lectures will include instruction in the physics and numerical modeling of multi-dimensional hydrodynamics, general relativity, radiation transport, nuclear reaction networks, neutrino physics, and equations of state. Afternoon workshops will guide students in running and visualizing simulations on supercomputers using codes such as FLASH, CASTRO, GR1D and modules for nuclear burning and radiation transport. All students will be given accounts and computing time at NERSC and have access to the codes and test problems in order to gain hands on experience running simulations at a leading supercomputing facility.

http://hipacc.ucsc.edu/

UC-HiPACC 2012 International Summer School on AstroComputing students all got accounts on the new Flash Gordon supercomputer at SDSC with 300 Tb of FLASH memory

Director: Alex Szaley, JHU
Host: Mike Norman, SDSC
HiPACC Director: Joel Primack

We had 37 students, 8 from UC, 19 from other US universities, and 10 from abroad.

& SDSC PRESENT:

AstroInformatics

The 2012 International Summer School on AstroComputing

July 9 - 20, 2012

San Diego Supercomputer Center
University of California, San Diego

http://hipacc.ucsc.edu/ISSAC2012.html

The data available to astronomers is growing exponentially. Large new instruments and new surveys are generating ever larger data sets, which are all publicly available. Supercomputer simulations are used by an increasingly wider community of astronomers. Many new observations are compared to and interpreted through the latest simulations. The Virtual Astronomical Observatory is creating a set of data-oriented services available to everyone. In this world, it is increasingly important to know how to deal with this data avalanche effectively, and perform the data analysis efficiently. The summer school will address this analysis challenge. The topics of the lectures will include how to bring observations and simulations to a common framework, how to query largedatabases, how to do new types of on-line analyses and overall, how to deal with the large data challenge. The school will be hosted at the San Diego Supercomputer Center, whose data-intensive computing facilities, Including the new Gordon supercomputer with a third of a petabyte of flash storage, are among the best in the world. Special access to these resources will be provided by SDSC.


SDSC's Gordon Supercomputer. Photo: Alan Decker.

Director: Alex Szalay (Johns Hopkins University)

Speakers will include:

Main lecturers
Tamas Budavari (Johns Hopkins University)
Andy Connolly (University of Washington)
Darren Croton (Swinburne University)
Gerard Lemson (Max Planck Institute for Astrophysics)
Risa Wechsler (Stanford University)
Rick White (Space Telescope Science Institute)

Additional lecturers
Mike Norman (UCSD/SDSC)
Peter Nugent (LBNL / UC Berkeley)
Joel Primack (UCSC)
Alex Szalay (Johns Hopkins University)
Matt Turk (Columbia University)

Other Details

Housing: Students will be staying at Conference Housing near SDSC on the UCSD campus (approximately $50/night).
Registration for the summer school will be $300. Payment will be required at the time of acceptance.
Aid: UC-HiPACC will cover lodging and travel expenses for UC-affiliated students, and some financial assistance may be available for other students.

Apply by March 16, 2012. For more information and to apply:
http://hipacc.ucsc.edu/ISSAC2012.html

Past UC-HiPACC Conferences & Workshops

- **June 14-16, 2012:** The Baryon Cycle, Beckman Center, Irvine, CA
- **August 8 - 12, 2011:** The 2011 Santa Cruz Galaxy Workshop, UC Santa Cruz
- **August 16 - 18, 2010:** The 2010 Santa Cruz Galaxy Workshop, UC Santa Cruz
- **December 16 & 17, 2010:** The Future of AstroComputing Conference, San Diego Supercomputer Center
- **June 24-27, 2012:** The Computational Astronomy Journalism Boot Camp

Current UC-HiPACC Conferences & Workshops

- **August 13-17, 2012:** The 2012 Santa Cruz Galaxy Workshop, UC Santa Cruz
- **August 17-20, 2012:** High-Resolution Galaxy Simulations Workshop


Engineering
2012 Santa Cruz Galaxy Workshop

The High-Resolution Galaxy Simulation Comparison Project: Rationale

Key Earlier Simulation Comparisons

The paper led by Carlos Frenk, “The Santa Barbara Cluster Comparison Project: A Comparison of Hydrodynamics Simulations,” ApJ, 525, 554 (1999), which grew out of a workshop at the KITP in Santa Barbara, has now received 303 citations. Our HRGS program also follows an earlier galaxy simulation comparison project that resulted in the paper led by Cecilia Scannapieco, “The Aquila Comparison Project: The Effects of Feedback and Numerical Methods on Simulations of Galaxy Formation” (MNRAS 2012). The simulations there mostly used the Gadget smooth−particle−hydrodynamics code, and they had typical force resolutions of ~1 kiloparsec, with dark matter particle masses larger than 10^6 $M_\odot$ and gas particle masses mostly larger than 0.4×10^6 $M_\odot$. The one adaptive mesh refinement code used for these simulations, RAMSES, was run with relatively poor force resolution of 260 pc and dark matter particle mass 0.2×10^6 $M_\odot$. At these resolutions, all the key physics of star formation and feedback is sub−grid, and it is therefore not surprising that there were large code−to−code variations in the size, morphology, and stellar and gas masses of the simulated galaxies started from the same initial conditions, and rather poor agreement with observed galaxies. The success of recent higher−resolution simulations such as Eris (Javiera Guedes, Simone Gallegari, Piero Madau, & Lucio Mayer 2011, ApJ, 742, 76) in matching observed galaxies encourages us to hope for progress with the high−resolution simulations that will be discussed here.

The Aquila comparison Project: The Effects of Feedback and Numerical Methods on Simulations of Galaxy Formation

C. Scannapieco,[1] M. Wadepuhl,[2] O.H. Parry,[3,4] J.F. Navarro,[5] A. Jenkins,[3] V. Springel,[6,7] R. Teyssier,[8,9] E. Carlson,[10] H.M.P. Couchman,[11] R.A. Crain,[12,13] C. Dalla Vecchia,[14] C.S. Frenk,[3] C. Kobayashi,[15,16] P. Monaco,[17,18] G. Murante,[17,19] T. Okamoto,[20] T. Quinn,[10] J. Schaye,[13] G. S. Stinson,[21] T. Theuns,[3,22] J. Wadsley,[11] S.D.M. White,[2] R. Woods[11]

2012 MNRAS 423, 1726

ABSTRACT

We compare the results of various cosmological gas-dynamical codes used to simulate the formation of a galaxy in the ΛCDM structure formation paradigm. **The various runs** (thirteen in total) differ in their numerical hydrodynamical treatment (SPH, moving-mesh and AMR) but **share the same initial conditions and adopt in each case their latest published model of gas cooling, star formation and feedback.** Despite the common halo assembly history, **we find large code-to-code variations in the stellar mass, size, morphology and gas content of the galaxy at z = 0, due mainly to the different implementations of star formation and feedback**. Compared with observation, **most codes tend to produce an overly massive galaxy, smaller and less gas-rich than typical spirals, with a massive bulge and a declining rotation curve**. A stellar disk is discernible in most simulations, although its prominence varies widely from code to code. There is a well-defined trend between the effects of feedback and the severity of the disagreement with observed spirals. In general, models that are more effective at limiting the baryonic mass of the galaxy come closer to matching observed galaxy scaling laws, but often to the detriment of the disk component. Although numerical convergence is not particularly good for any of the codes, our conclusions hold at two different numerical resolutions. Some differences can also be traced to the different numerical techniques; for example, more gas seems able to cool and become available for star formation in grid-based codes than in SPH. However, this effect is small compared to the variations induced by different feedback prescriptions. We conclude that state-of-the-art simulations cannot yet uniquely predict the properties of the baryonic component of a galaxy, even when the assembly history of its host halo is fully specified. **Developing feedback algorithms that can effectively regulate the mass of a galaxy without hindering the formation of high-angular momentum stellar disks remains a challenge.**

The Aquila Comparison Project

Code	Reference	Type	UV background (z_{UV})	UV background (spectrum)	Cooling	Feedback
G3 (GADGET3)	[1]	SPH	6	[10]	primordial [13]	SN (thermal)
G3-BH	[1]	SPH	6	[10]	primordial [13]	SN (thermal), BH
G3-CR	[1]	SPH	6	[10]	primordial [13]	SN (thermal), BH, CR
G3-CS	[2]	SPH	6	[10]	metal-dependent [14]	SN (thermal)
G3-TO	[3]	SPH	9	[11]	element-by-element [15]	SN (thermal+kinetic)
G3-GIMIC	[4]	SPH	9	[11]	element-by-element [15]	SN (kinetic)
G3-MM	[5]	SPH	6	[10]	primordial [13]	SN (thermal)
G3-CK	[6]	SPH	6	[10]	metal-dependent [14]	SN (thermal)
GAS (GASOLINE)	[7]	SPH	10	[12]	metal-dependent [16]	SN (thermal)
R (RAMSES)	[8]	AMR	12	[10]	metal-dependent [14]	SN (thermal)
R-LSFE	[8]	AMR	12	[10]	metal-dependent [14]	SN (thermal)
R-AGN	[8]	AMR	12	[10]	metal-dependent [14]	SN (thermal), BH
AREPO	[9]	Moving Mesh	6	[10]	primordial [13]	SN (thermal)

Code	f_b (Ω_b/Ω_m)	m_{DM} [$10^6 M_\odot$]	m_{gas} [$10^6 M_\odot$]	Softening $\epsilon_g^{z=0}$ [kpc]	z_{fix}
G3 G3-BH G3-CR G3-CS G3-CK Arepo	0.16	2.2 (17)	0.4 (3.3)	0.7 (1.4)	0 (0)
G3-TO G3-GIMIC	0.18	2.1 (17)	0.5 (3.7)	0.5 (1)	3 (3)
G3-MM	0.16	2.2 (17)	0.4 (3.3)	0.7 (1.4)	2 (2)
GAS	0.18	2.1 (17)	0.5 (3.7)	0.46 (0.9)	8 (8)
R R-LSFE R-AGN	0.16	1.4 (11)	0.2 (1.8)	0.26 (0.5)	9 (9)

All simulations share the same initial conditions (ICs), a zoomed-in resimulation of one of the halos of the Aquarius Project (halo “Aq-C”, in the notation of Springel et al. 2008).

Most stars form in galactic disks, so it is essential to resolve disks. The scale height of the MWy disk is about 100 pc.

Softening is 500 pc or worse (fixed in comoving coordinates at $z = z_{fix}$).

Softening is 260 pc (fixed in comoving coordinates at $z_{fix} = 9$)

The High-Resolution Galaxy Simulation Comparison Project: Calendar

This Kickoff Meeting: August 17-18-19, 2012

Roughly every two months: simulation comparison telecon

Roughly January 2013: web conference on HRGS Comparison

Summer 2013:

UC-HiPACC Summer School on Star Formation at UCSC
July 22 - August 9, directed by Mark Krumholz

Santa Cruz Galaxy Workshop - August 12-16

Followup Conference for HRGS Comparison Project
August 19-23 or August 19-30 at UCSC, or during
August 19 - September 6 at KITP Santa Barbara
(KITP will make 20 office spaces available during their Black Hole workshop, in response to proposal by Primack, Madau, Mayer, and Teyssier)

Outline of this talk

√ A word from our sponsor: UC-HiPACC

√ High-Res Galaxy Simulation Comparison Goals

√ 2013 Galaxy Workshop and HRGS Followup Mtg

HRGS Comparison: Choices To Be Made Here

HRGS Comparison: Choices To Be Made Here

Initial Conditions to Simulate?

Galaxy Masses at z~0: ~10^{10}, 10^{11}, 10^{12}, 10^{13} $M_\odot$
with a variety of merging trees

Astrophysics that all groups should try to include?

Optional additional astrophysics to include?

At what redshifts to compare simulations?

How to compare simulations, tools to use (yt, ...)?

2013 Followup HRGS Comparison Meeting:

1, 2, or 3 weeks? At KITP/UCSB or at UCSC?

Codes and People Participating in HRGS Comparison

Codes	People Here, Online*, and Not here (incomplete list)
SPH: AREPO	Hopkins, Keres*
SPH: Gadget	Hopkins, Kashi, Nagamine
SPH: Gasoline	Christensen, Governato, Guedes, Madau, Mayer, Quinn, Shen, Wadsley
SPH: SPHS	Read*
AMR: ART	Ceverino, Dekel, Gnedin, Kravtsov, Primack, Trujillo-Gomez, Zolotov
AMR: ENZO	Abel, Kim, Kuhlen, Madau, Onorbe, O'Shea*, Turk, Wise
AMR: RAMSES	Agertz, Dekel, Hahn, Teyssier
Other Participants	Bullock, Conroy, Goldbaum, Krumholz, Leitner, Robertson,

I apologize for any mistakes! Please tell Ji-hoon Kim and me if you should be listed differently.