

Sky Simulations update

Darren Reed (UZH)

What are “Sky Simulations”?:

Simulations of galaxies, cosmic web, (usually) cosmological volumes

-- span the observable SKA epochs and scales

-- include effects of large scale structures, cosmology

Identify what types of simulations needed by SKACH/SKAO

Plan, run, analyze simulations

Develop code/software required to run and analyze simulations

Provide simulations and analysis products to SKACH

Cosmological simulation:

- Start with a uniform cube (particles)
 - can also do “zoom” volumes, isolated galaxies, etc.
- Apply random perturbations
(high redshift, cosmology)
- Evolve with gravity (+ hydro) solver on supercomputer

Cosmological simulation

redshift 22

redshift 15

redshift 13.7



PhoebosMR
Gas density:

Gas collects into self-bound dark matter halos → star formation → galaxies

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2Mpc

Match simulation properties to observations

Hubble Ultra Deep Field

HST • ACS

- Examples:

- Galaxy and dark matter halo properties
 - Statistical: e.g. luminosity function, clustering
 - Individual: e.g. morphologies
- (HI) Gas distribution:
 - Large scale: cosmic web
 - Small scale: within galaxies



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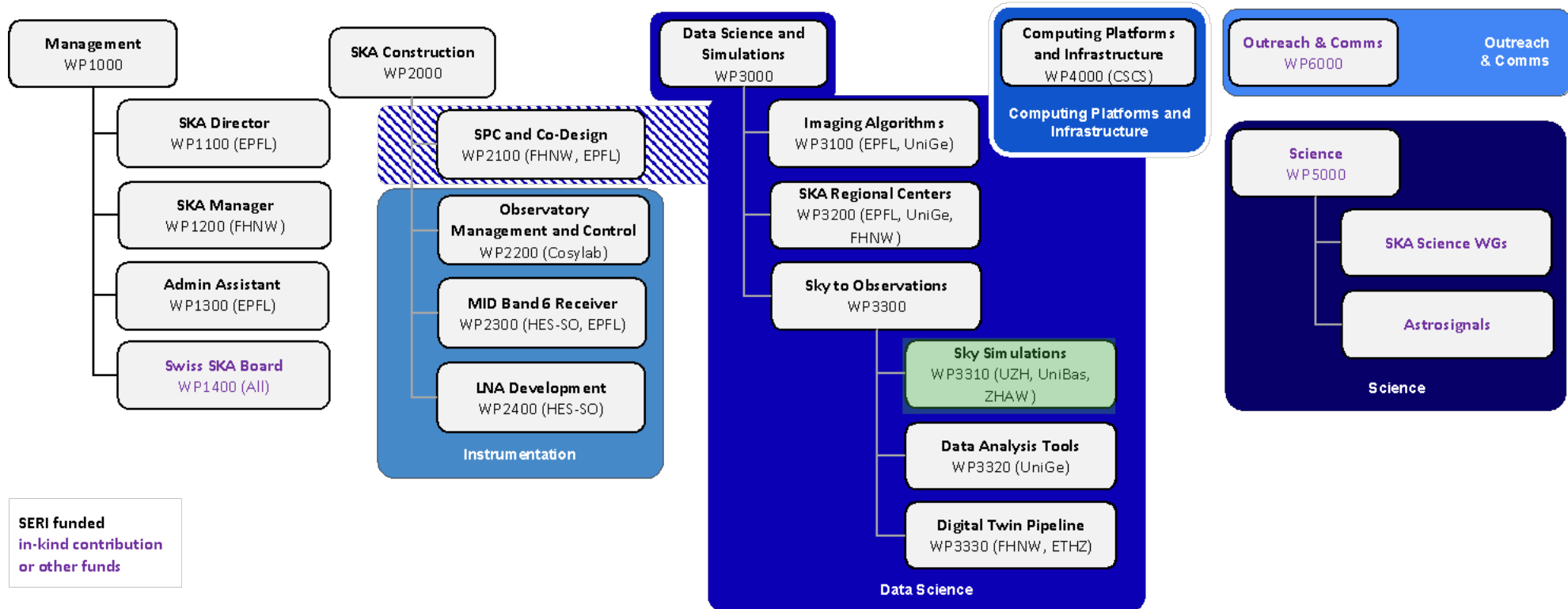
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Provide simulations and analysis products to SKACH

SKACH Work Breakdown



SKACH WBS



SERI funded
in-kind contribution
or other funds

Sky Simulations Activities: Defining Goals

- What are the science goals?
 - e.g. early stages of galaxy formation
- What are the technical goals?
 - e.g. Pipeline development

What does SKACH need from us?

Survey results highlights

- 12 respondents -- **more input is welcome!**
- Variety of planned uses for simulations
 - Comparison with observations
 - Pipeline development
 - Science from theoretical modeling
- What data products potentially useful?
 - raw particles; halos; **galaxy properties; lightcone** data
 - **HI gas**/phases in and between galaxies (cosmic web)
 - Wide range for output epochs: dark ages, reionization era, present days
- What simulations are desired?
 - Series of varying mass resolutions, box sizes; volume; realizations of same box
 - Varying cosmological parameters, including “beyond standard model”
 - Simulations with advanced/different star formation/feedback, black holes, magnetic fields (for galaxy synchrotron emission)
- Most willing to share analysis results and code, or other info

What does SKACH need?

What simulations?

- Cosmological volumes. Cube: Box Size. Mass resolution. Redshift range (stop $z > 0$)
- Physics to be included: Gravity (dark matter + gas) + (usually) hydrodynamic forces
 - Galaxy formation: star formation + stellar feedback (minimum requirements)
 - Variations: other/better “subgrid” physics
 - e.g. star formation “recipes”; blackhole/AGN feedback
- Simulation Volumes: Use as many particles as practical.
 - *Tradeoffs*
 - *Larger volume for **statistics and accurate large scale structures***
 - Cosmic web, voids, reionization
 - *Small volume for mass **resolution**.*
 - accurate galaxy properties, smaller galaxies resolved.

What does SKACH need?

What data products?

- Raw particles
 - Dark matter; gas; stars (aggregate)
 - positions, velocities, gas temperature, metallicity, + ...
 - available for visualization, analysis, etc.
- Halos: Galaxies, dark matter halos, (self-bound dense groups of particles)
 - Position, velocity, size, mass profile (concentration), shape, angular momentum, orientation
 - Environment (e.g. filament; void; group; close neighbors; satellites)
 - Galaxy properties
 - Direct: stellar mass, gas mass, dark mass, metallicity, velocity profile
 - Indirect: luminosity/magnitude, color
 - Statistical properties: Luminosity function, Mass function, Clustering strength (bias), + ...
 - Time information – galaxy/halo growth history, merger trees, gas infall, star formation history, + ...
 - Currently using Amiga Halo Finder (halos and satellites).
 - Do we need other halo finders? Other structure finders, e.g. filaments, groups, voids?
- Other data products needed?

Halo (galaxy) finding

Halo is a self-bound clump of dark matter.
Galaxies form in halos

HALO CENTRES

AHF - AMIGA's HALO FINDER



what about the adaptive meshes?

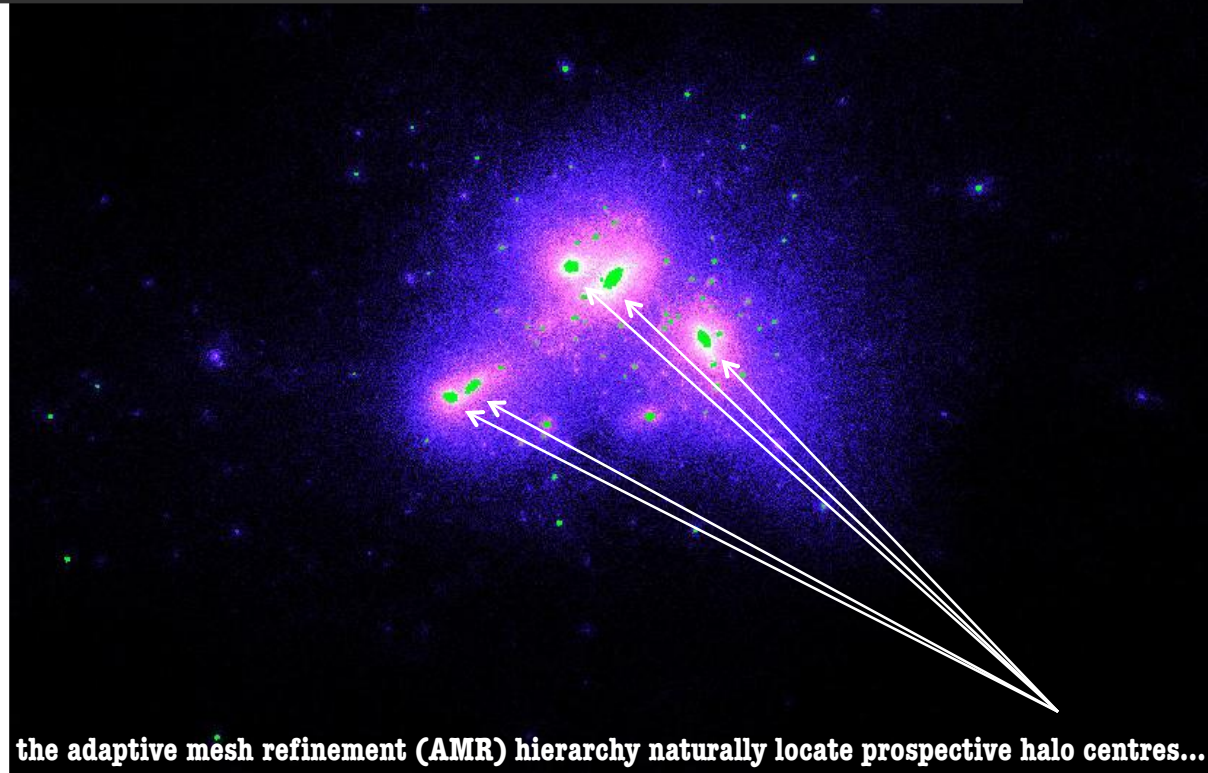
Knebe et al.

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Knebe et al.

What does the Sky Simulations group need to meet goals?

- Run simulations; analyze; distribute results
 - Simulation codes able to utilize Exa-scale systems:
 - Support for development of SPH-EXA (PIs: Ciorba, Mayer, Cabezon)
 - astrophysics modules; performance improvements
 - Computational resources
 - Running simulations – e.g. SKACH computing calls at **CSCS** through Computing Platforms/Infrastructure
 - Data storage and distribution – currently no large dedicated resources
 - Coordination of simulation analysis
 - Development of analysis tools/pipelines for large SPH simulations
 - Collaborative analysis
 - Your help/feedback/requests

Sky Simulations Activities

- Sky Simulations Forum -- 1st Friday each month (next meet June 9), 2pm, zoom (everyone is welcome)
 - Send me message to be added to email list
- Phoebos series
- SPH-EXA development and testing (astrophysics modules)
- Identify needs of SKACH for cosmological simulations
 - Science
 - Pipeline development
 - Mock catalogs (see talk by Philip Denzel)
 - Visualization of big simulations – (Florian Cabot, VIRUP)
- Plan Future simulations
- Simulations
 - Run
 - Analyze (e.g. create galaxy catalogs)
 - Provide simulations ((raw or processed)

Sky Simulations Activities +

- Sky Simulations Forum -- 1st Friday each month (next meet June 9), 2pm, zoom (everyone is welcome).
- Other simulations (e.g.: see talk by Andrej Obuljen)
- Additional simulation codes:
 - **PKDGRAV** (developed by Potter, Stadel, +);
 - ChaNGa (Menon+) -- porting ChaNGa astrophysics modules into SPH-EXA; verification of SPH-EXA
 - Gizmo (Hopkins+)
- Various SKA related work on cosmology and galaxy formation

The PHOEBOS simulations roadmap:

Large cosmological volume (100 comoving Mpc)

Run:	# DM	# gas	# tot	$m_{\text{DM}} [M_{\odot}]$	$m_{\text{gas}} [M_{\odot}]$	ϵ [kpc]	memory [kB]	# nodes
Sph EXA PhoebosHR	5808^3	3888^3	2.547×10^{11}	1.699×10^5	1.059×10^5	0.15	3.135×10^{11}	
PhoebosMR	2904^3	1944^3	3.184×10^{10}	1.360×10^6	8.473×10^5	0.30	3.918×10^{10}	2048
ChaNGa { ✓ PhoebosLR	1452^3	972^3	3.980×10^9	1.088×10^7	6.778×10^6	0.60	4.898×10^9	
✓ PhoebosULR	726^3	486^3	4.974×10^8	8.701×10^7	5.423×10^7	1.20	6.122×10^8	

→ **Eventual Goal:** EXA-PHOEBOS simulation **1 trillion** particles

PhoebosMR

redshift 22

redshift 15

redshift 13.7

- Phoebos MR (“medium resolution”) simulation using ChNGa
 - See talk by Floor van Dokelaar
 - Science goal: formation & evolution of 1st generations of galaxies + cosmic web (to redshift < 5)
- Running on Piz Daint
 - SKACH Computing Platforms & Resources allocation (July2022-June2023)

2Mpc

SPH-EXA

SPH-EXA

- SPH for astrophysics +
- designed for ExaScale platforms
- to allow better simulations (more particles → accurate astrophysics + large volumes)
- UniBasel, UZH, CSCS/ETHZ



SERI; PASC <https://hpc.dmi.unibas.ch/en/research/skach/> <https://www.pasc-ch.org/projects/2021-2024/sph-exa2/>

Turbulence simulations completed

Proposals submitted in May:

Gas turbulence -- EuroHPC

Galactic disk fragmentation – CSCS production (user lab)

PhoebosMR continuation (ChaNGa → SPH-EXA, verification) SKACH long call (CSCS)

EXASCALE SKY SIMULATIONS FOR SQUARE KILOMETER ARRAY OBSERVATORY

PIs in SKACH and > PASC SPH-EXA:

- > [Florina Ciorba](#) (University of Basel)
- > [Lucio Mayer](#) (University of Zurich)
- > [Rubén Cabezón](#) (University of Basel)



Project members:

- > [Osman Seckin Simsek](#) (University of Basel)
- > [Lukas Schmidt](#) (University of Basel)
- Yiqing Zhu (University of Basel)

Collaborators:

- > [Noah Kubli](#) (University of Zürich)
- > [Darren Reed](#) (University of Zurich)
- > [Sebastian Keller](#) (ETH Zurich/CSCS, Switzerland)
- > [Jean-Guillaume Piccinali](#) (ETH Zurich/CSCS, Switzerland)
- > [Jean M. Favre](#) (CSCS/ETHZ)
- > [Benjamin Cumming](#) (CSCS/ETHZ)
- > [John Biddiscombe](#) (CSCS/ETHZ)

External collaborators:

- José Escartin (European Southern Observatory)
- Axel Sanz (Universitat Politècnica de Catalunya, Spain)
- Joseph Touzet (Université Paris-Saclay)

Funding agency: The State Secretariat for Education, Research and Innovation (SERI) > <https://www.sbfi.admin.ch/sbfi/en/home/seri/seri.html>

Duration: 01.09.2021-31.12.2024

Software: The SPH-EXA simulation framework is publicly available > [here](#).

Swiss SKA Consortium (SKACH): > <https://skach.org>



Summary: Sky Simulations update

- Plan & run cosmological simulations for SKACH
 - Based on collaboration needs
 - Phoebos series
 - SPH-EXA development
- Analyze simulations & distribute within collaboration
 - Develop software/analysis pipelines
- SKACH Sky Simulations Forum (monthly meeting)
 - anyone welcome to join