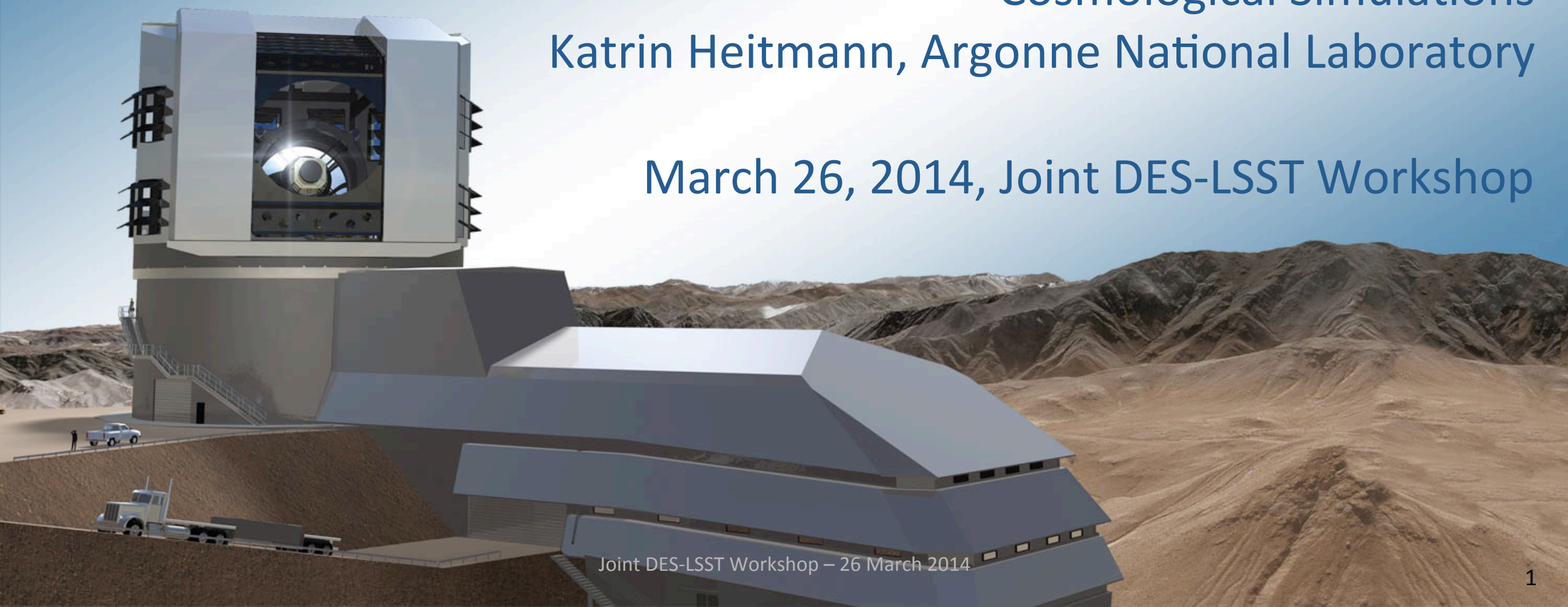
- Role of Cosmological Simulations
- Current Activities
- Future Plans

LSST DESC
Dark Energy Science Collaboration

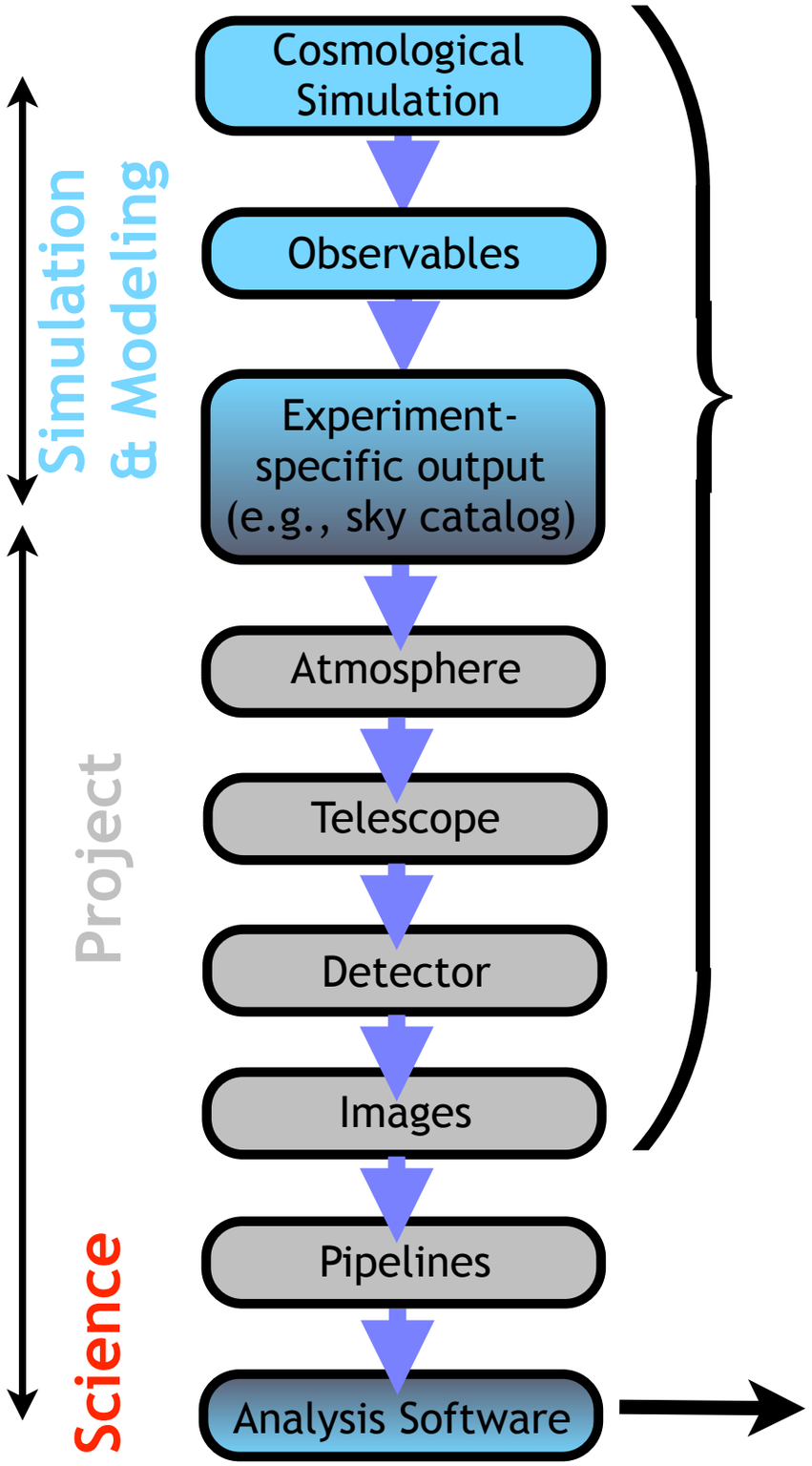
Cosmological Simulations

Katrin Heitmann, Argonne National Laboratory

March 26, 2014, Joint DES-LSST Workshop

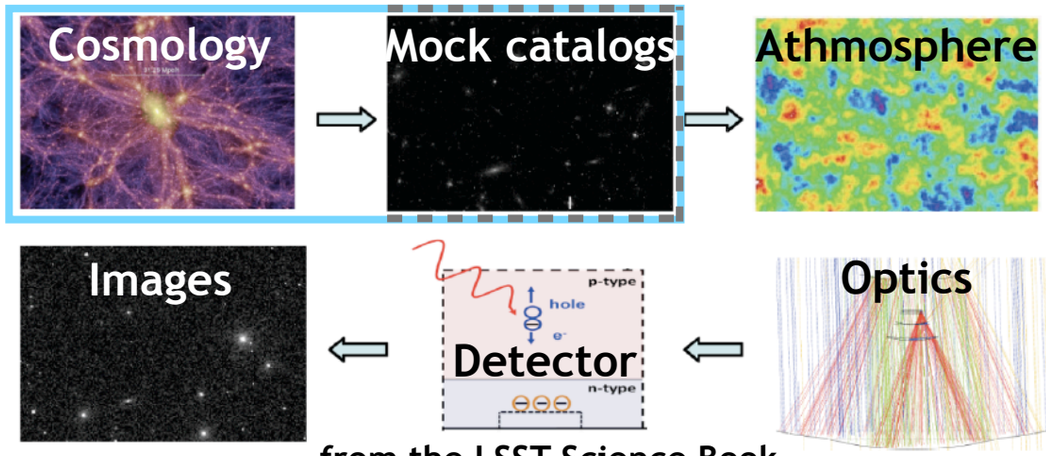


Roles of Cosmological Simulations in DE Survey Science



(1) CosmoSim as Input to CatSim/PhoSim

- First part of end-to-end simulation
- Control of systematics



from the LSST Science Book

Task 5.9.1, H1
Task 5.9.2, H1-H3

(2) Solving the Inverse Problem, Extracting Dark Energy Science

- Fast, very accurate predictions tools (emulators) for physics and observables of interest
- Astrophysical systematics, e.g. baryonic effects
- Predictions for covariances

Task 5.9.1, H2-H3

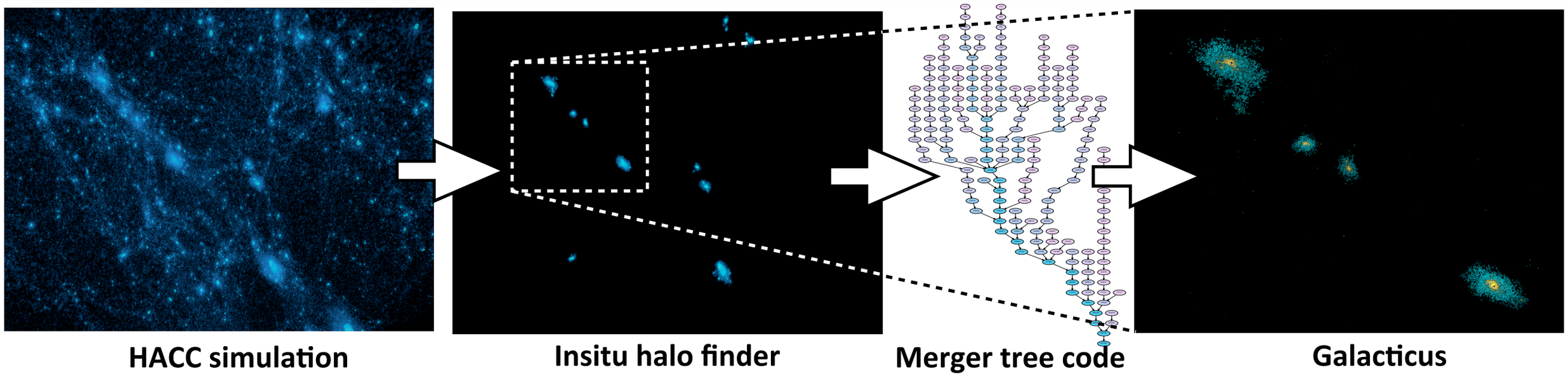
Mock Catalog Generation Efforts within LSST-DESC

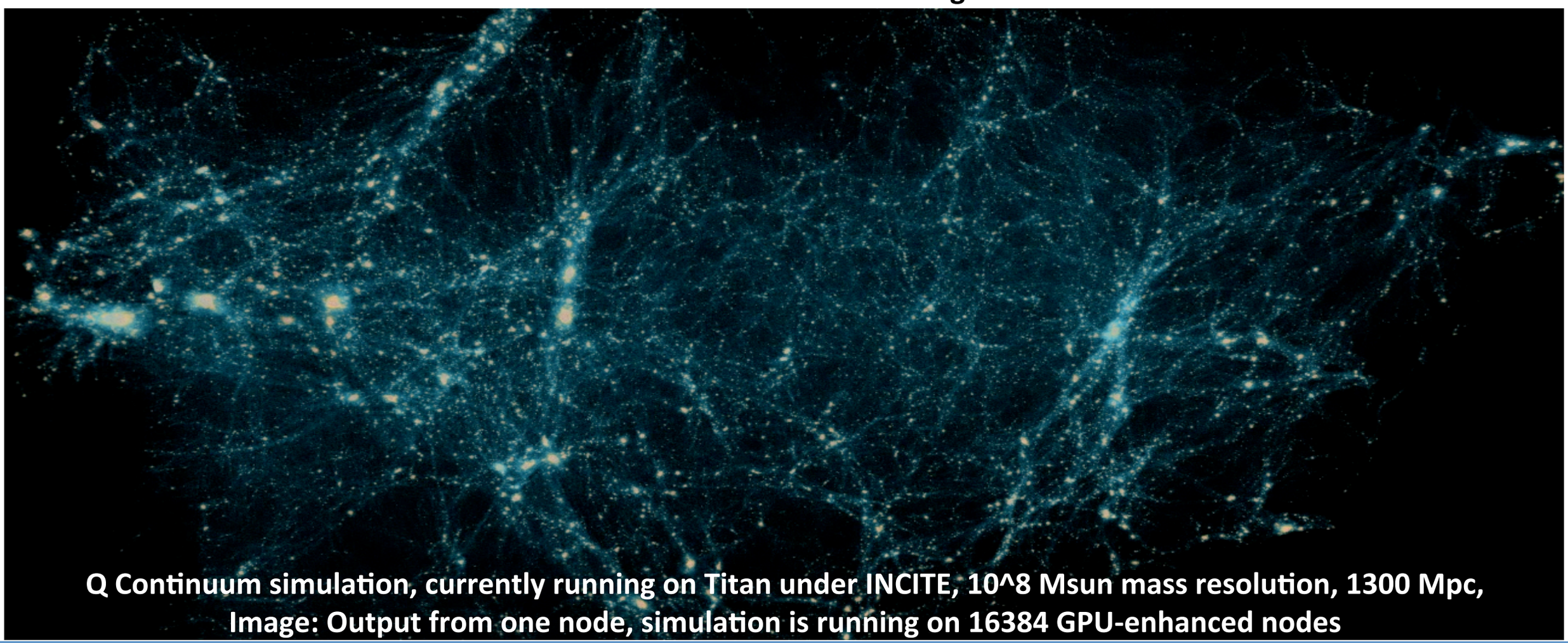
- **CMU Effort:**
  - S. Ho, A. Klein, Z. Liu, R. Mandelbaum, J. Oliver, B. Pozcos, J. Schneider, H. Trac, X. Xu et al.
  - Machine learning techniques used to populate dark matter simulations with galaxies, use halo information beyond mass
  - Machine learning techniques used to generate nonlinear density fields from initial conditions, ``train'' 2LPT on high-res N-body simulations, promising method to generate many mocks very fast, covariances!
- **JPL Effort:**
  - A. Kiessling et al.
  - SUNGLASS: Simulated UNiverses for Gravitational Lensing Analysis and Shear Surveys
  - Medium resolution simulations, focus on topics such as covariance matrices for weak lensing
  - Next: realistic galaxy properties via Galacticus, intrinsic alignment modeling

Mock Catalog Generation Efforts

- **Stanford/SLAC/Michigan/Chicago Effort (talk yesterday):**
  - R. Wechsler, M. Busha, M. Becker, Y. Lu, R. Reddick, E. Rykoff, G. Evrard, A. Kravtsov et al.
  - Three different approaches: (i) ADDGALS, based on medium resolution simulations, large volumes, (ii) Subhalo abundance matching, based on high resolution simulations, smaller volumes, (iii) semi-analytic modeling (SAM)
  - Many different uses of mocks across all working groups
- **ABC Effort (Argonne/Berkeley/Carnegie):**
  - A. Benson, R. Biswas, J. Cohn, N. Frontiere, B. Gutierrez, S. Habib, K. Heitmann, E. Kovacs, E. Lawrence, T. Malik, A. Pope, E. Rangel, M. White
  - Two approaches: (i) HODs on large volume simulations, (ii) SAM on high resolution simulations using Galacticus
  - For SAMs two major efforts: (i) Emulator approach to explore parameter settings; (ii) Connection to CatSim/PhoSim, e.g database development, required galaxy properties etc.

Mock Catalog Generation ABC Effort





Q Continuum simulation, currently running on Titan under INCITE, 10^8 Msun mass resolution, 1300 Mpc, Image: Output from one node, simulation is running on 16384 GPU-enhanced nodes

Mocks and Simulations Currently Available or in Progress

- **Current LSST project mock: Based on Millennium simulations, 16 sq deg**
- **SUNGLASS lightcone mocks, 0<z<2, contain shear, convergence, and positions, 7 different cosmologies, 450 realizations (Kiessling)**
- **2 cosmologies, 5,000 sq deg for each mock, current focus on DES, more cosmologies are currently being processed (Wechsler et al)**
- **Many large N-body simulations available:**
  - Trac et al: 2 Gpc/h, 4096^3 particles, halo catalogs, merger trees, lightcone out to z=6, currently running
  - Argonne: **1.5 Gpc/h**, 3200^3 particles, halo catalogs, 6 cosmologies (LCDM, w0-wa, neutrinos), 100 snapshots starting at z=10; **4 Gpc/h**, 4096^3 particles, 6 cosmologies (Planck, WMAP-7, and variants around those), snapshots starting at z=4; **Outer Rim Simulation: 3 Gpc/h**, 10240^3 particles, currently at z=0.4, ~85 snapshots, **Q Continuum Simulation:** 923 Mpc/h, 8192^3 particles, currently at z=0.8

Mock Catalog Validation

- **Long list of possible observational measurements that can be compared to observations compiled by Joanne Cohn**
- **Use of catalogs determines which observations are most useful for validation**
- **Working group agreed that it will be very useful to have a common set of observational data that can be used by each group for validation**
- **Data format question for exchanging data: dictated by input format to CatSim (sql database)**

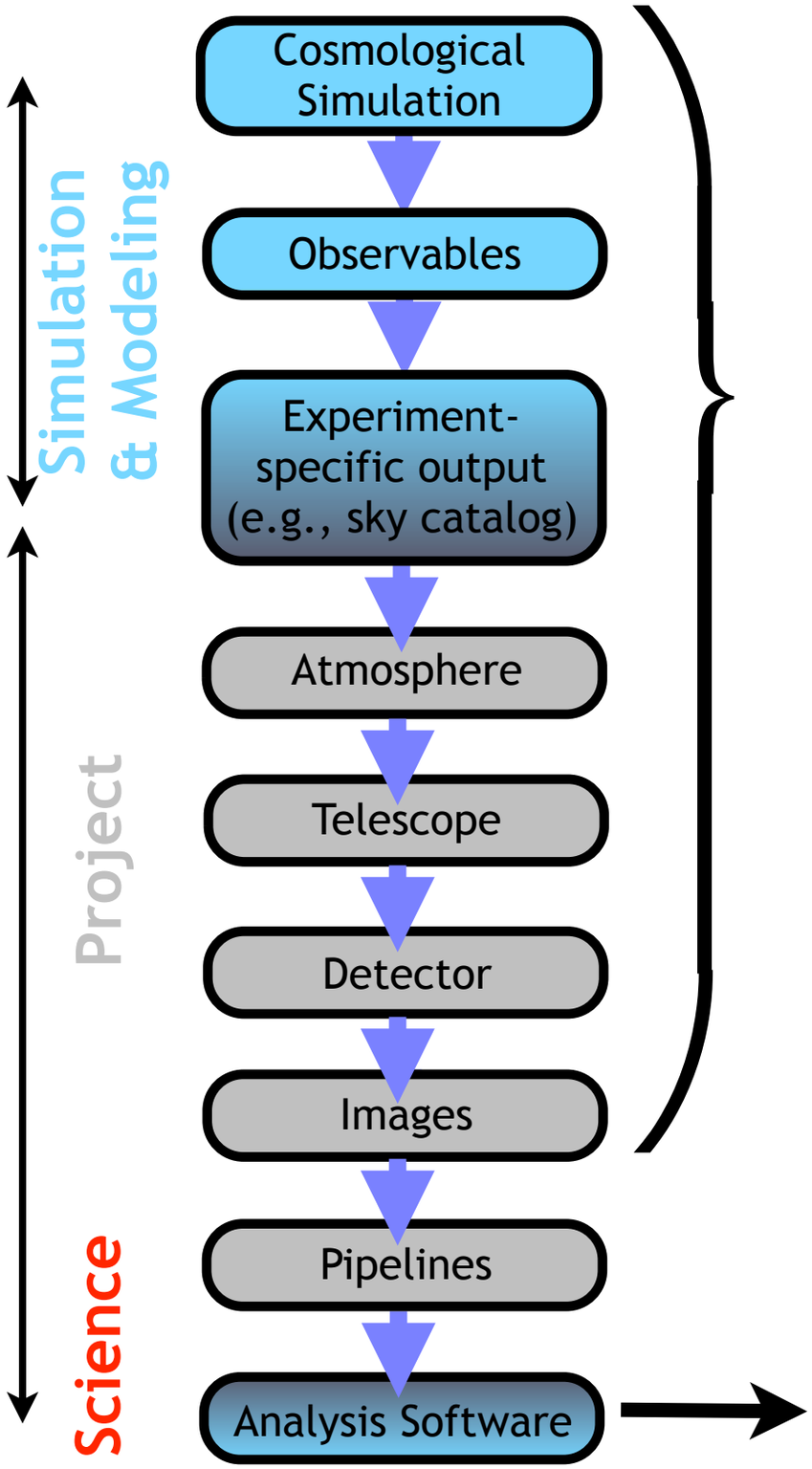
Working Group Requirements

- **Lots of information collected by Debbie Bard**
- **Questions asked:**
  - What quantities do you care about most in simulation mocks?
  - What (if any) range of cosmologies would be useful?
  - What is the time scale by when those mocks are needed?
- **Answers from: LSS, WL, Clusters, Strong Lensing, SN, Photo-z**
- **Most useful in short term: small (~10 sq deg) volumes with great details (several cosmologies), and larger (~100 sq deg) volumes with less detail, one cosmology**
- **Very large volumes (~10,000 sq deg) with ~no galaxy properties beyond position and shear, with a range of cosmologies**

Mock Catalog and Requirements Document

- **Started write-up that covers three topics:**
- **Mock catalog generation efforts**
  - Currently four efforts listed, complementary approaches
  - For each effort: approach, status, possible shortcomings and planned mitigations
- **Requirements from the Working Groups and as Input to CatSim/PhoSim**
- **Validation: Comparison of mocks with sky observations, collaboration with IPAC**

Roles of Cosmological Simulations in DE Survey Science



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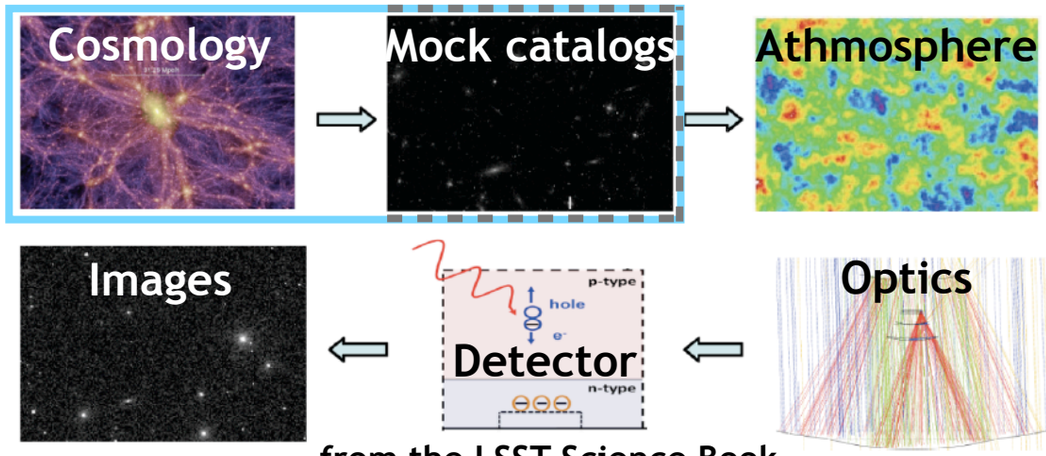

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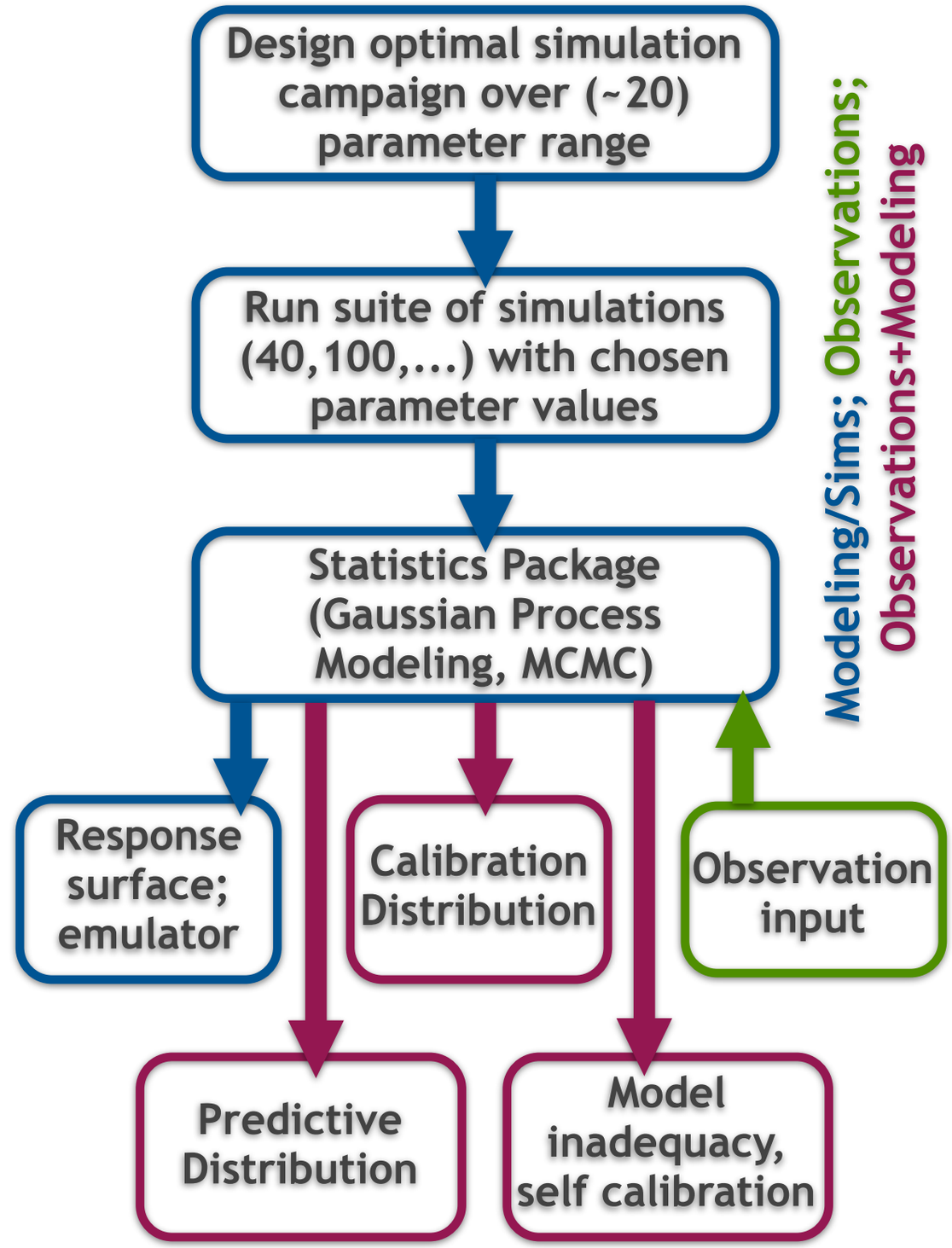
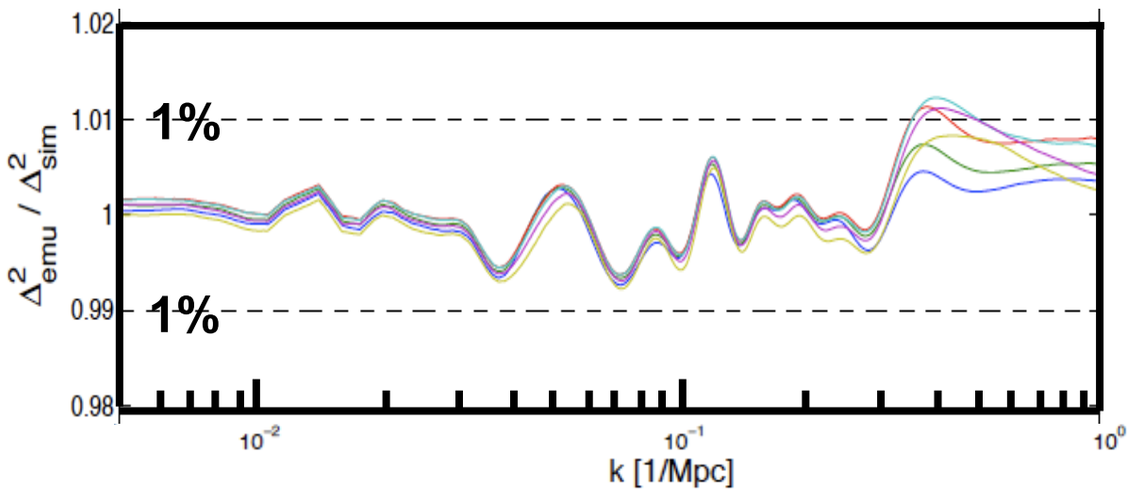
Cosmic Emulators

- **Challenge:** Extract cosmological constraints from observations in the nonlinear regime, need to run Markov Chain Monte Carloe code, input: 10,000 - 100,000 different models
- **Current Strategy:** Fitting functions for, e.g., P(k), accurate at the 10% level, this is not good enough! This will lead to biases in the dark energy equation of state estimates that could escape notice
- **Our alternative:** Emulators, fast prediction schemes build from a limited set of high-accuracy simulations

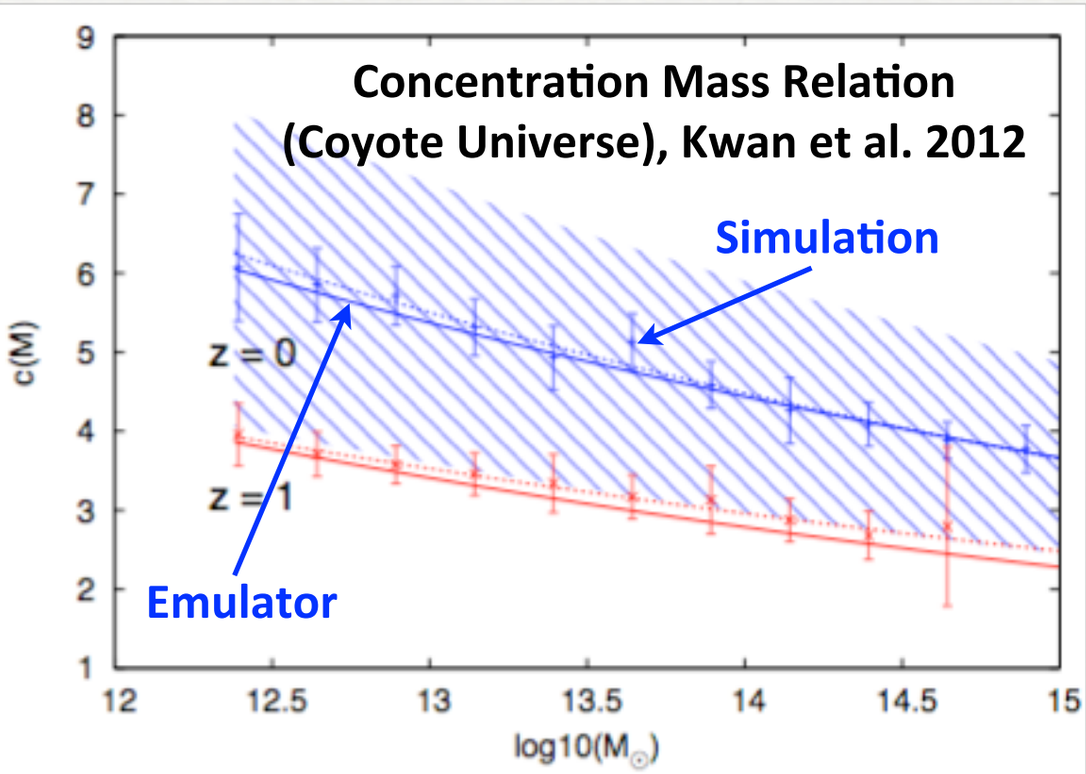


Cosmic Emulator Gallery

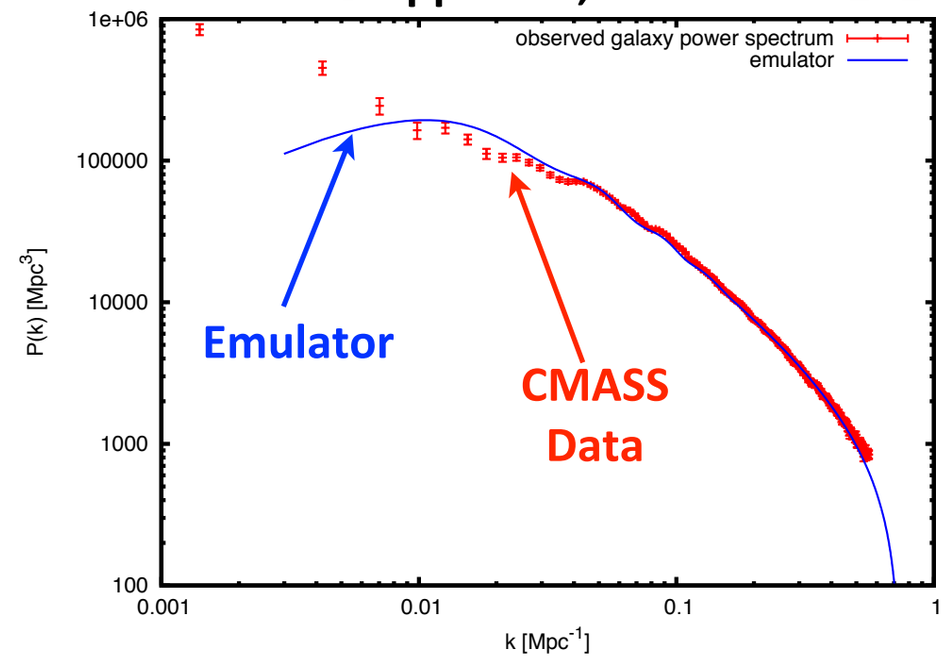
Matter power spectrum (Coyote Universe), Lawrence et al. 2010, Heitmann et al. 2013



Matter power spectrum prediction for wCDM cosmology out to k~1/Mpc at ~1% accuracy, out to k~10/Mpc at ~3% accuracy



Galaxy power spectrum (Mira Universe) based on HOD approach, Kwan et al. 2013



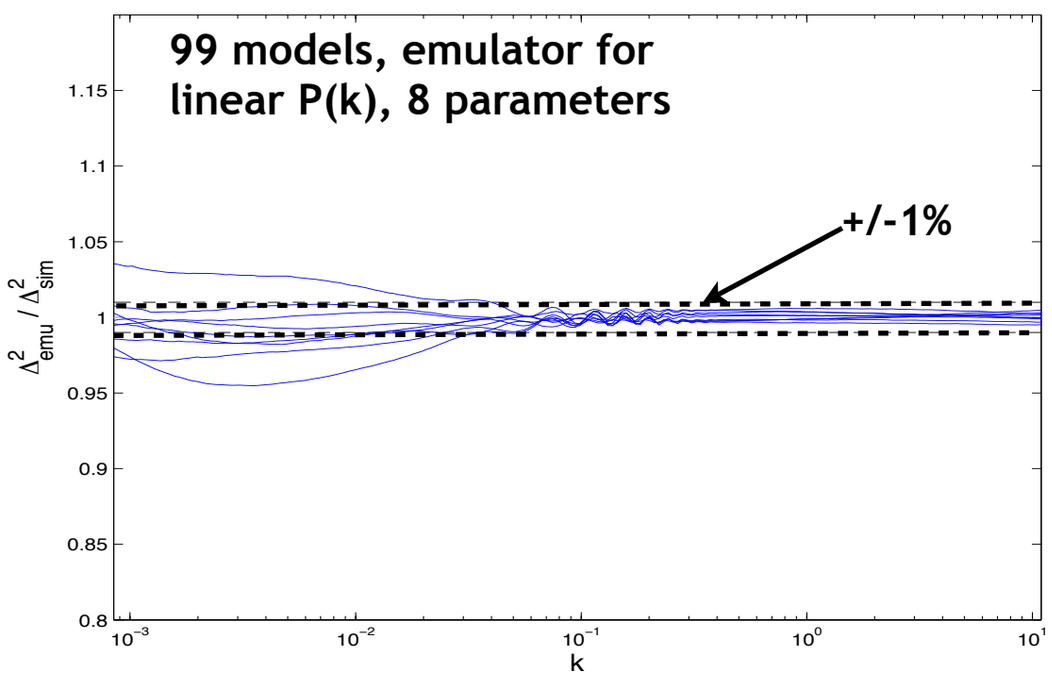
https://hep.anl.gov/cosmology/CosmicEmu

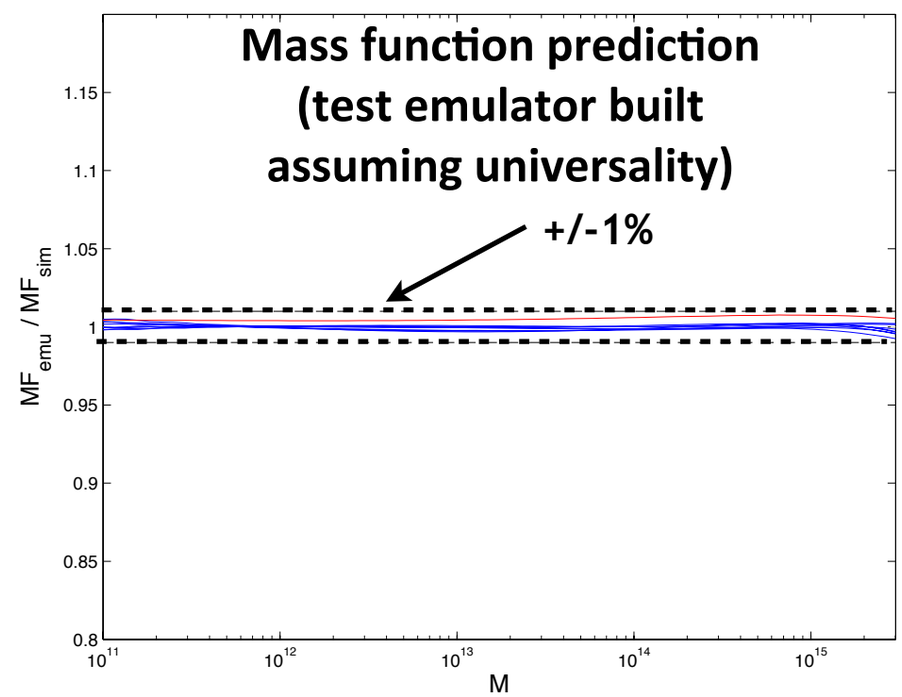
Next Steps in Emulator World

- **Mira Universe:** Extend parameter space to include varying w(z) and massive neutrinos
- Build "nested designs": enable to build emulator from first set of 25 models, improve with additional 27 models, final precision with 99 models overall
- Various emulators for P(k), mass function, c-M relation, derived quantities...
- LCDM done, finalizing set-up based on this run

Parameters

$$0.12 \leq \omega_m \leq 0.155$$
$$0.0215 \leq \omega_b \leq 0.0235$$
$$0.7 \leq \sigma_8 \leq 0.9$$
$$0.55 \leq h \leq 0.85$$
$$0.85 \leq n_s \leq 1.05$$
$$-1.3 \leq w_0 \leq -0.7$$
$$-1.5 \leq w_a \leq 1.15$$
$$0.0 \leq \omega_\nu \leq 0.01.$$



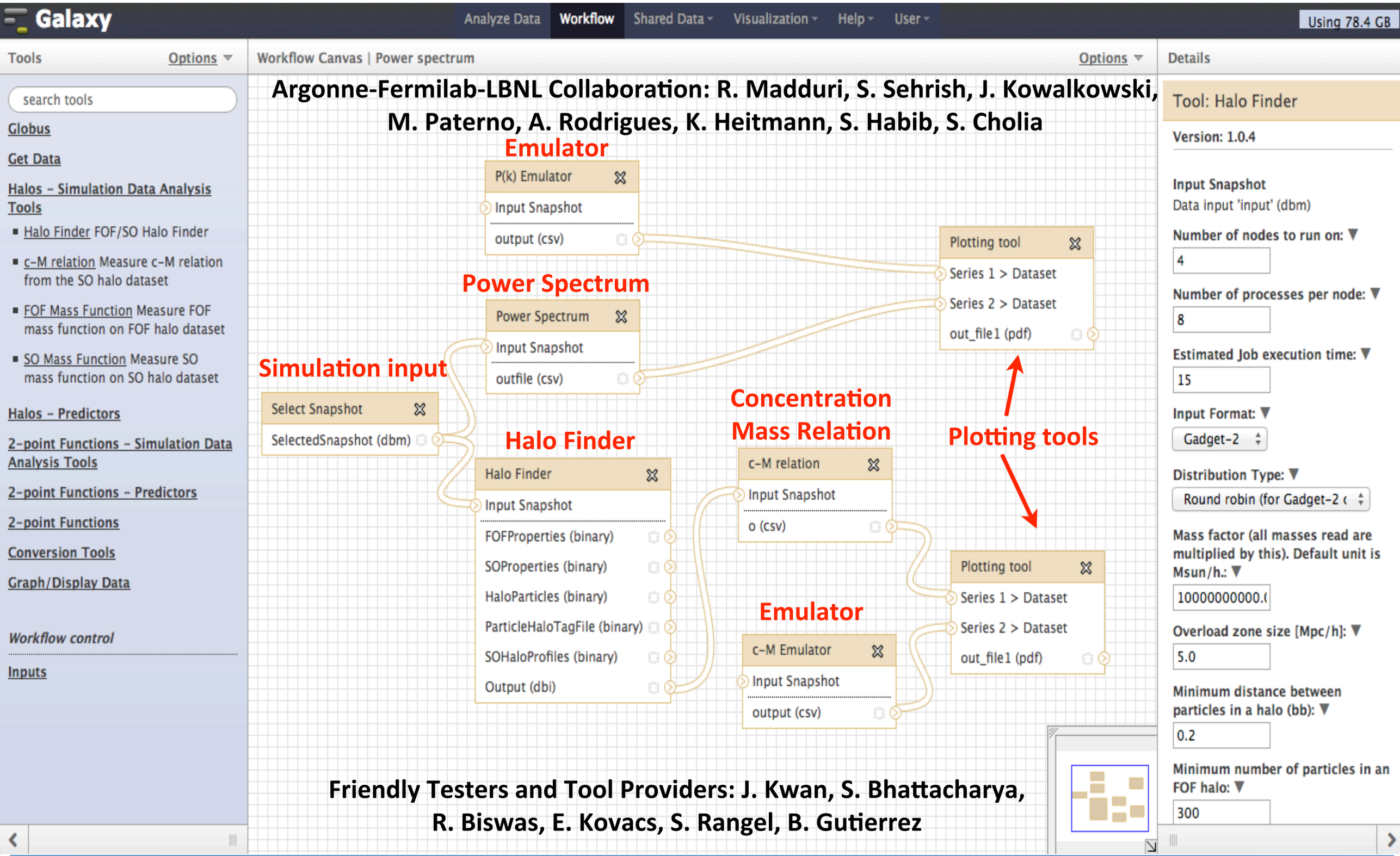


- **Emulator Factory (Eifler, Kwan et al.):** Combine different probes, covariances

Examples for Projects Joint with Other DESC Working Groups

- **Intrinsic Alignments (WL, Theory & Combined Probes)**
  - Study IAs via hydro simulations, compare with gravity only (DiMatteo, Mandelbaum et al.)
  - Study IAs via semi-analytic approach (Kiessling et al.)
- **Covariance Matrices**
  - Emulator approach, cosmology dependence (Schneider, Morrison, Dodelson et al.)
  - Emulator approach (Eifler, Kwan et al.)
- **Baryonic effects on the matter power spectrum (Theory & Combined Probes)**
  - Hydrodynamic simulations, analysis, parameter estimates, mitigation ... by Gnedin, Eifler, Zentner, Dodelson et al.

PDACS: Portal-based Data Analysis for Cosmological Simulations



Summary

- Cosmological simulations play important roles for different aspects of large-scale surveys
- If we want to deliver high-precision measurements for the dark energy equation of state, fitting functions are not an option
- Many investigations that are based on simulations are important in the same way for DES and LSST: IAs, modified gravity, covariances, photo-z, clusters, baryonic effects ....
- "Living" document on mocks and simulation requirements for LSST-DESC started
- Develop easier ways to share simulations and tools
- Continuous improvement of simulations in all aspects ...

Thanks to the Organizers!