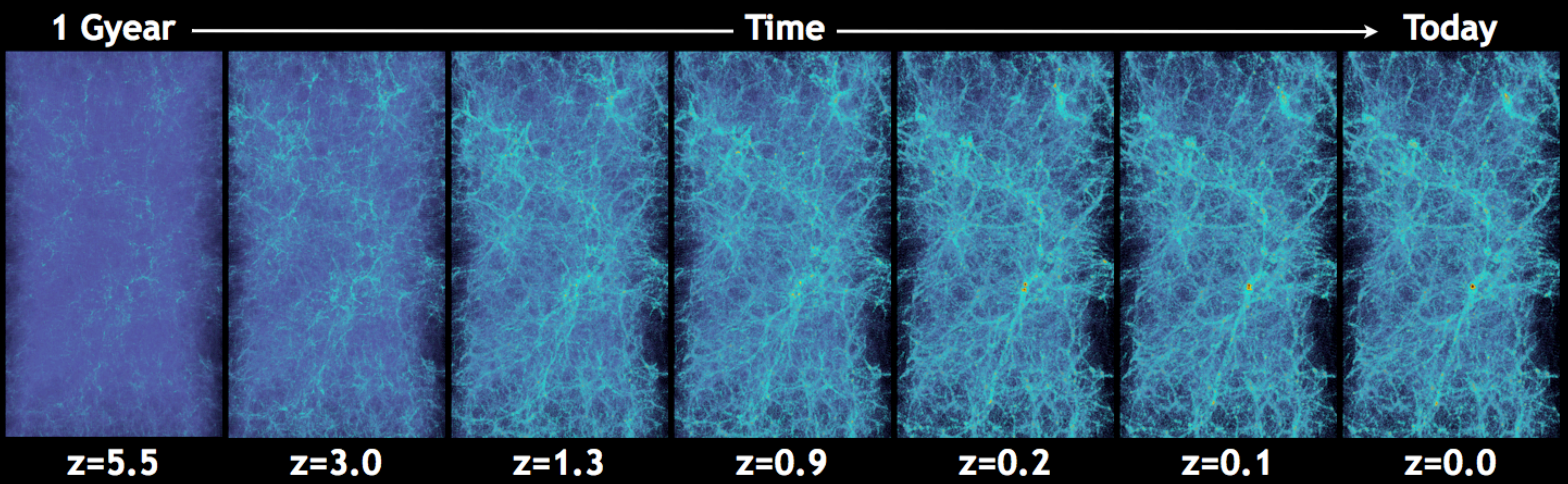
Cosmological Simulations and Modeling Report



See:
arXiv:2203.07347

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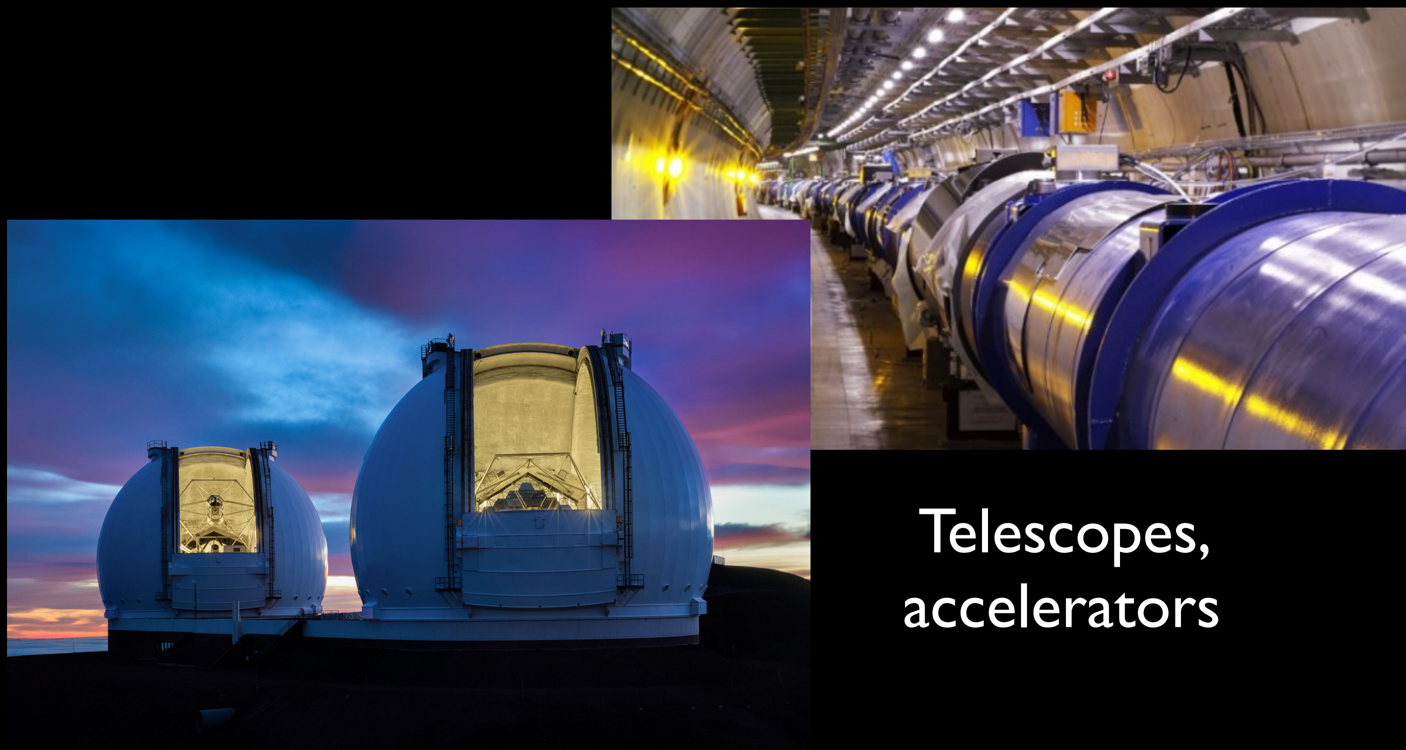
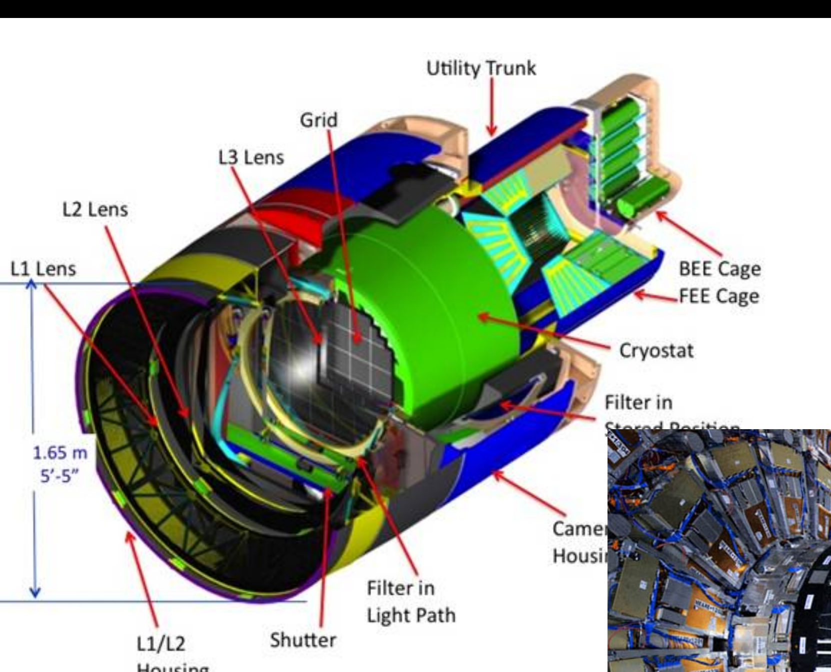
Governing analogies



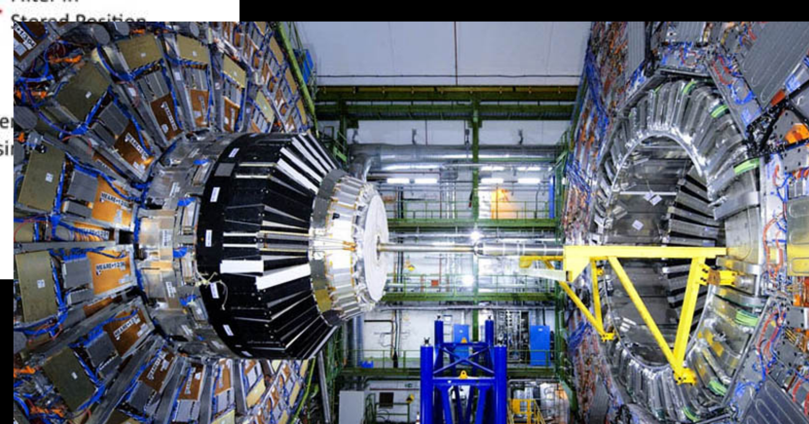
Telescopes, accelerators

Simulation codes, super-computers

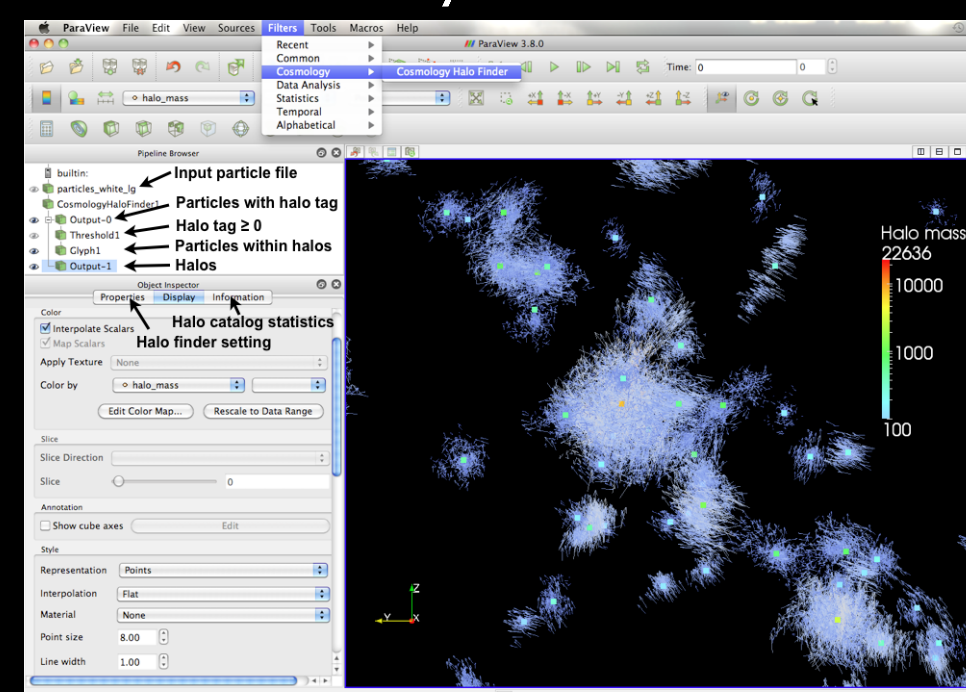
```
int
main (int argc, char* argv[])
{
    BoxLib::Initialize(argc, argv);


    // save the inputs file name for later
    if (argc > 1) {
      if (!strchr(argv[1], '=')) {
        inputs_name = argv[1];
      }
    }
    BL_PROFILE_REGION_START("main()");
    BL_PROFILE_VAR("main()", pmain);

    //
    // Don't start timing until all CPUs are ready to go.
    //
    ParallelDescriptor::Barrier("Starting main.");

    BL_COMM_PROFILE_NAMETAG("main TOP");

#ifdef BL_USE_MPI
    const int MPI_IntraGroup_Broadcast_Rank = ParallelDescriptor::IOProcessor() ? MPI_ROOT : MPI_PROC_NULL;
    int nSidecarProcsFromParmParse(-3);
    Nyx::nSidecarProcs = 0;
    int prevSidecarProcs(0);
    int sidecarSignal(NyxHaloFinderSignal);
    int resizeSidecars(false);  // ---- instead of bool for bcast
#endif
```



Cameras, detectors

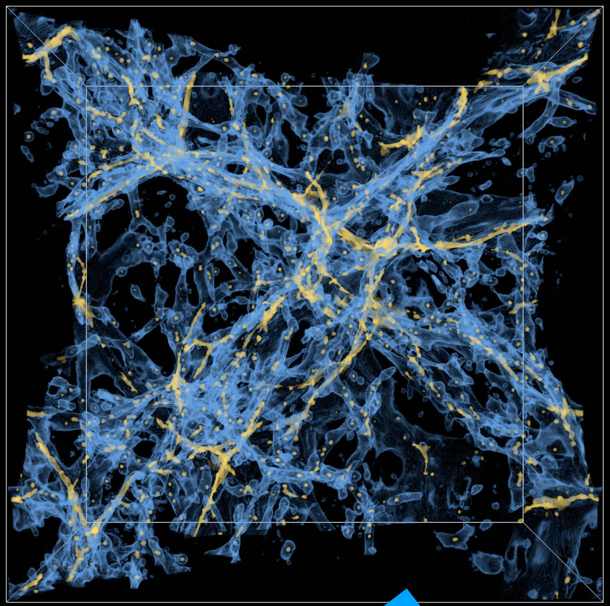


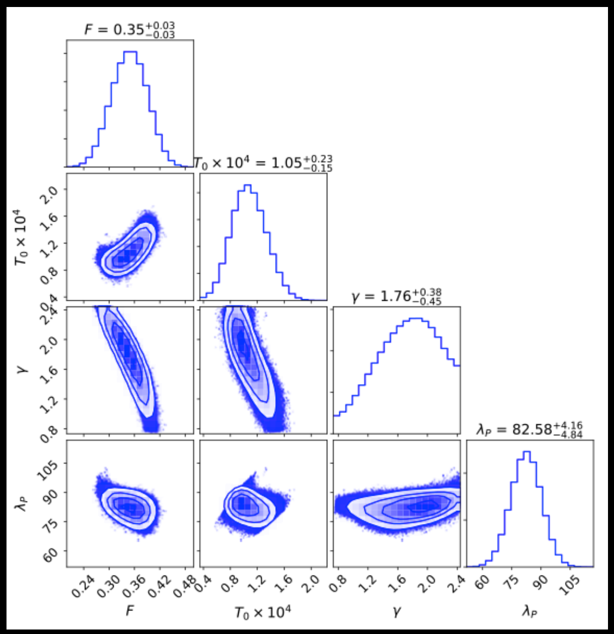
Analysis software



Requirements for the next decade

- Scientifically rich and broadly-scoped simulations which capture relevant physics and cross-correlations between probes
- Precise translation of simulation outputs into realistic observables
- Emulators and data-driven methods serving as surrogates for expensive simulations, constructed from a small set of high-fidelity simulations
- Performance on next-gen architectures and transparent verification and validation programs for simulation as well as analysis tools



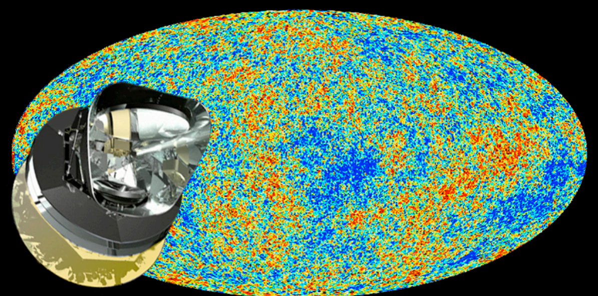


Simulation challenges

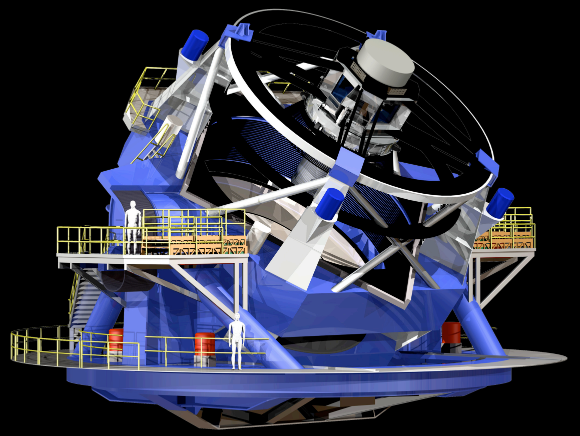
- N-body: computationally efficient way to cover wide dynamic range (Gpc to kpc) accurately describing matter fluctuations down to non-linear regime. However, usually no direct access to observables, thus additional modeling like HOD, SAM, SHAM…
- Hydro: needed to model distribution of baryons; expensive and very dependent on choice of sub grid models. Exascale systems will be of substantially help for this, but V&V will be critical.
- Beyond LCDM: modified gravity and certain dark matter models require substantial departure from solvers used in LCDM case. Again, V&V is necessary to establish accuracy and robustness of predictions.
- Radiative transport: especially important for high-z probes where reionization details matter. Also, the ionizing radiation from galaxies affects their own evolution, creating a complex feedback loop.

Cross-correlated observables

- Probes/observables: galaxy clustering/lensing/counts, spectroscopic galaxies, CMB lensing, Lyman alpha forest, tSZ/kSZ, cosmic infrared background (CIB), X-ray, line intensity mapping, 21cm…

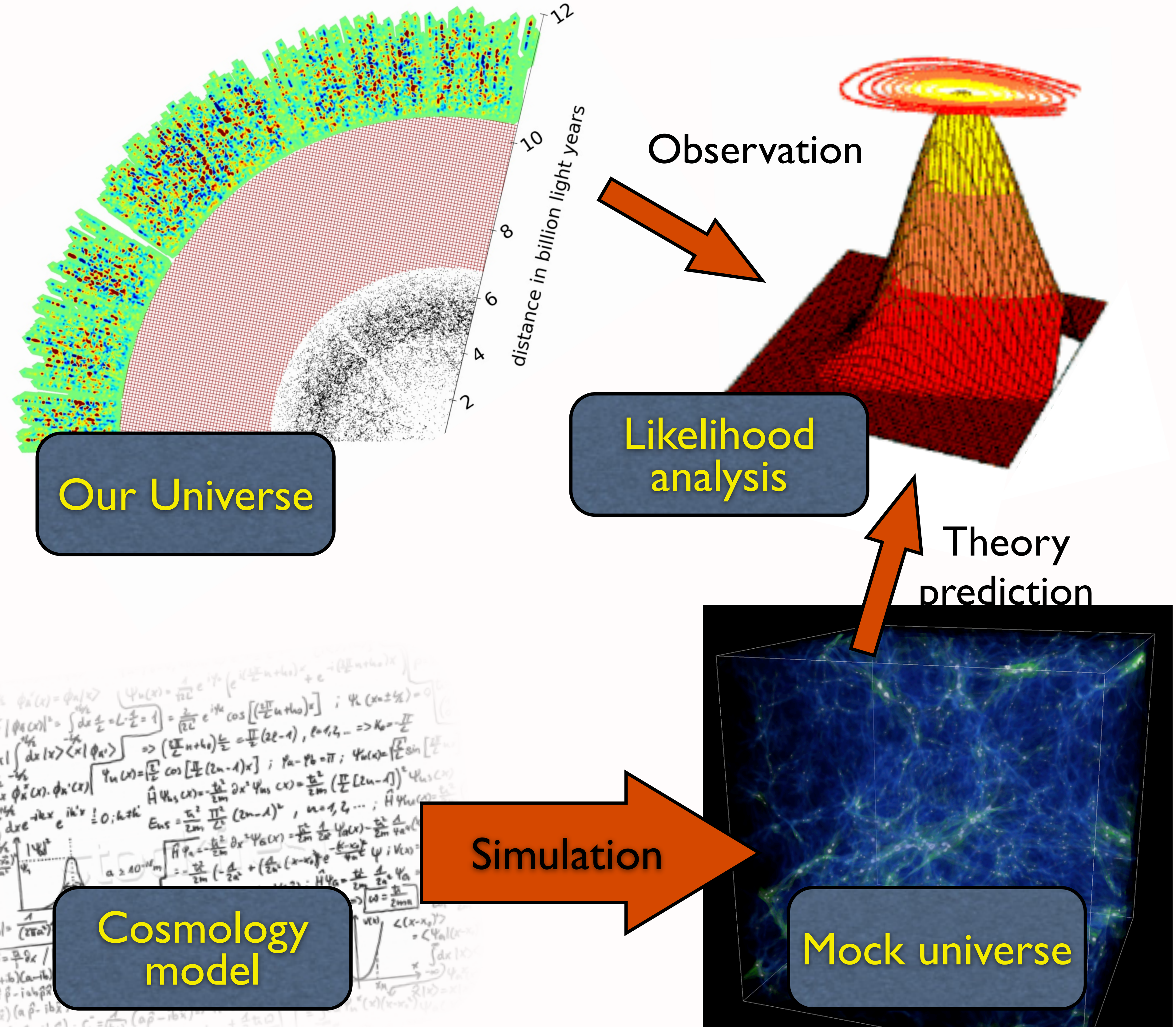


- Simulations geared towards a particular probe satisfying the requirements of a specific survey are common, but simulations capable of describing more than one probe, especially those consisting of more than one experiment, are far less developed.



- Significant cosmological and astrophysical information is expected to be extracted from combinations of observables from different surveys, so the development of such simulations is of increasing interest.

Emulation frameworks and statistical inference



Scientific inference with sky surveys is an inverse problem, where, given a set of measurements, one fits a class of physical models to the data, and infer the values of the model parameters.

We need emulators: (1) Connected directly to survey observables; (2) Which can explore larger number of parameters to support sub grid model parameterizations; (3) Which can utilize multi-fidelity simulation data; (4) which provide better error estimation.

Continuous inclusion of observational data in emulator construction could reduce the volume of parameter space that needs to be explored.

Utilizing the future of HPC

- The Exascale Computing Project (ECP) led by the Office of Advanced Scientific Computing Research (ASCR) has made tremendous impact in preparing scientific applications for the next-gen resources; continuous development is nevertheless needed.
- Scalable analysis (in situ, in transit, data compression) will become critical due to increasing offset between flops and (storage) bytes.
- Disagreements of multi-physics codes are (mostly) larger than projected observational errors. Need for rigorous V&V programs.