Large Synoptic Survey Telescope Galaxies, Dark-Matter and Black Holes: Extragalactic Roadmap

Borne, Kirk[1] Brandt, William[2] Connolly, Andrew[3], Cooper, Michael[4] Ferguson, Henry C.[5] Gawiser, Eric[6], Ho, Shirley[7], Ivezić, Željko[3], Juric, Mario[3] Kahn, Steven M.[28,29], Lupton, Robert[10], Mandelbaum, Rachel[7], Marshall, Philip. J[8,9], Newman, Jeffrey A.[11], Ptak, Andrew[12] Richards, Gordon[13] Robertson, Brant[14] Strauss, Michael A.[10], Tyson, J. Anthony[15], ... And Many Others, TBD....

[1]George Mason University
[2]Penn State University
[3]University of Washington
[4]University of California, Irvine
[5]Space Telescope Science Institute
[6]Rutgers University
[7]Carnegie Mellon University
[8]SLAC National Accelerator Laboratory
[9]Stanford University
[10]Princeton University
[11]University of Pittsburgh
[12]The Johns Hopkins University
[13]Drexel University
[14]University of Arizona
[14]University of California, Davis

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Abstract.

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Contents

1 Introduction

The Large Synoptic Survey Telescope (LSST) is a wide-field, ground-based telescope, designed to image a substantial fraction of the sky in six optical bands every few nights. It is planned to operate for a decade allowing the stacked images to detect galaxies to redshifts well beyond unity. The LSST and the survey are designed to meet the requirements (Ivezic & the LSST Science Collaboration 2011) of a broad range of science goals in astronomy, astrophysics and cosmology. The LSST was the top-ranked large ground-based initiative in the 2010 National Academy of Sciences decadal survey in astronomy and astrophysics, and is on track to begin the survey early in the next decade.

In 2008, eleven separate quasi-independent science collaborations were formed to focus on a broad range of topics in astronomy and cosmology that the LSST could address. Members of these collaborations have been instrumental in helping to develop the science case for LSST (encapsulated in the LSST Science Book), to refine the concepts for the survey and for the data processing, and to educate other scientists and the public about the promise of this unique observatory.

The Dark Energy Science Collaboration (DESC) has taken the next logical step beyond the science book. They identified they most critical challenges that will need to be overcome to realize LSSTs potential for measuring the effects of Dark Energy. They looked at five complementary techniques for tackling dark energy, and outlined high-priority tasks for the science collaboration during construction. They designated sixteen working groups (some of which already existed) to coordinate the work. This roadmap has been documented in a 133-page white paper (arxiv.org/abs/1211.0310). The white paper provides a guide for investigators looking for ways to contribute to the overall investigation. It may help in efforts to obtain funding, because it provides clear indication of the importance of the advance work and how the pieces fit together.

The investigation of Dark Energy is only one topic for LSST. It is important to develop similarly concrete roadmaps for work in other areas. After some discussion among the collaborations, it appears useful in some cases for different science collaborations to join forces on a single whitepaper. This is particularly true for topics that involve observations of distant galaxies. With the advent of the DESC, some of the science goals of the large-scale-structure, weak-lensing, and strong-lensing collaborations have found a new home. The remaining science goals of those collaborations tend to be focused on galaxy evolution and dark matter. Two other collaborations: AGN and Galaxies, also have those topics as major themes. This roadmap identifies the major high-level science themes of these investigations, outlines how complementary techniques will contribute, and identifies areas where advance work is essential. For this advance work, the emphasis is on areas that are not adequately covered in the DESC roadmap. As convenient shorthand, we use the acronym GALLA (Galaxies, AGN, Lensing Large-scale Structure and Astro-informatics) joint roadmap of the overlapping science collaborations.

Chapter 2 gives a brief summary of the science background. Many of the themes and projects are already set out in the Science Book, where more detail is provided for many of the science investigations. Chapter 3 sets out the highest priority preparatory work to enable these investigations. These tasks are laid out on the assumption that the work plan of the DESC will be carried out and that software and data products resulting from that work will be available to other science collaborations. The Appendix 4 organizes the tasks by science topic and desribes them in more detail.

2 Science Background

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2.1 Overview

TBD

2.2 XXX

2.3 Science Background: Galaxies

Galaxies represent fundamental astronomical objects outside our own Milky Way. The large luminosities of galaxies enable their detection to extreme distances, providing abundant and far-reaching probes into the depths of the universe. At each epoch in cosmological history, the color and brightness distributions of the galaxy population reveal how stellar populations form with time and as a function of galaxy mass. The progressive mix of disk and spheroidal morphological components of galaxies communicate the relative importance of energy dissipation and collisionless processes for their formation. Correlations between internal galaxy properties and cosmic environments indicate the ways the universe nurtures galaxies as they form. The evolution of the detailed characteristics of galaxies over cosmic time reflects how fundamental astrophysics operates to generate the rich variety of astronomical structures observed today.

Study of the astrophysics of galaxy formation represents a vital science of its own, but the ready observability of galaxies critically enables a host of astronomical experiments in other fields. Galaxies act as the semaphores of the universe, encoding information about the development of large scale structures and the mass-energy budget of the universe in their spatial distribution. The mass distribution and clustering of galaxies reflect essential properties of dark matter, including potential constraints on the velocity and mass of particle candidates. Galaxies famously host supermassive black holes, and observations of active galactic nuclei provide a window into the high-energy astrophysics of black hole accretion processes. The porous interface between the astrophysics of black holes, galaxies, and dark matter structures allows for astronomers to achieve gains in each field using the same datasets.

The Large Synoptic Survey Telescope (LSST) will provide a digital image of the southern sky in six bands ($ugrizy$). The area ($\sim 18,000$ deg^2) and depth ($r \sim 24.5$ for a single visit, $r \sim 27.5$ coadded) of the survey will enable research of such breadth that LSST may influence essentially all extragalactic science programs that rely primarily on photometric data. For studies of galaxies, LSST provide both an unequaled catalogue of billions of extragalactic sources and high-quality multiband imaging of individual objects. This section of the *Extragalactic Roadmap* presents scientific background for studies of these galaxies with LSST to provide a context for considering how the astronomical community can best leverage the catalogue and imaging datasets and for identifying any required preparatory science tasks.

LSST will begin science operations during the next decade, more than twenty years after the start of the Sloan Digital Sky Survey (**?**) and subsequent precursor surveys including PanSTARRS (**?**), the Subaru survey with Hyper Suprime-Cam (**?**), and the Dark Energy Survey (**?**). Relative to these prior efforts, extragalactic science breakthroughs generated by LSST will likely benefit from its increased area, source counts, and statistical samples, the constraining power of the six-band imaging, and the survey depth and image quality. The following discussion of LSST efforts focusing on the astrophysics of galaxies will highlight how these features of the survey enable new science programs.

2.3.1 Star Formation and Stellar Populations in Galaxies

Light emitted by stellar populations will provide all the direct measurements made by LSST. This information will be filtered through the six passbands utilized by the survey ($ugrizy$), providing constraints on the rest-frame ultraviolet SEDs of galaxies to redshift $z \sim 6$ and a probe of rest-frame optical spectral breaks to $z \sim 1.5$. By using stellar population synthesis modeling, these measures of galaxy SEDS will enable estimates of the redshifts, star formation rates, stellar masses, dust content, and population ages for potentially billions of galaxies. In the context of previous extragalactic surveys, LSST will enable new advances in our understanding of stellar populations in galaxies by contributing previously unachievable statistical power and an areal coverage that samples the rarest cosmic environments.

A variety of ground- and space-based observations have constrained the star formation history of the universe over the redshift range that LSST will likely probe (for a recent review, see **?**). The statistical power of LSST will improve our knowledge of the evolving UV luminosity function, luminosity density, and cosmic star formation rate. The LSST observations can constrain how the astrophysics of gas cooling within dark matter halos, the efficiency of molecular cloud formation and the star formation within them, and regulatory mechanisms like supernova and radiative heating give rise to these statistical features of the galaxy population. While measurement of the evolving UV luminosity function can help quantify the role of these astrophysical processes, the ability of LSST to probe vastly different cosmic environments will also allow for the robust quantification of any changes in the UV luminosity function with environmental density, and an examination of connections between environment and the fueling of star formation.

Optical observations teach us about the established stellar content of galaxies. For stellar populations older than ~ 100 million years, optical observations provide sensitivity to the spectral breaks near a wavelength of $\lambda \approx 4000\AA$ in the rest-frame related to absorption in the atmospheres of mature stars. Such observations help constrain the amount of stellar mass in galaxies. For passive galaxies that lack vigorous star formation, these optical observations reveal the well-defined "red sequence" of galaxies in the color-magnitude plane that traces the succession of galaxies from recently-merged spheroids to the most massive systems at the centers of galaxy clusters. For blue, star-forming galaxies, optical light can help quantify the relative contribution of evolved stars to total galaxy luminosity, and indeed has led to the identification of a well-defined locus of galaxies in the parameter space of star formation rate and stellar mass (e.g., **?**). This relation, often called the "star-forming main sequence" of galaxies, indicates that galaxies of the same stellar mass typically sustain a similar star-formation rate. Determining the physical or possibly statistical origin of the relation remains an active line of inquiry, guided by recently improved data from Hubble Space Telescope over the $\sim 0.2\ \mathrm{deg}^{-2}$ Cosmic Assembly Near-Infrared Deep Extragalactic Survey (**??**). While LSST will be comparably limited in redshift selection, its 30,000 times larger area will enable a much fuller sampling of the star formation–stellar mass plane, allowing for a characterization of the distribution of galaxies that lie off the main sequence that can help discriminate between phenomenological explanations of the sequence.

2.3.2 Galaxies as Cosmic Structures

The structural properties of galaxies arise from an intricate combination of important astrophysical processes. The gaseous disks of galaxies require substantial energy dissipation while depositing angular momentum into a rotating structure. These gaseous disks form stars with a surface density that declines exponentially with galactic radius, populating stellar orbits that differentially rotate about the galactic center and somehow organize into spiral features. Many disk galaxies contain (pseduo-)bulges that form through a combination of violent relaxation and orbital dynamics. These disk galaxy features contrast with systems where spheroidal stellar distributions dominate the galactic structure. Massive ellipticals form through galaxy mergers and accretions, and manage to forge a regular sequence of surface density, size, and stellar velocity dispersion from the chaos of strong gravitational encounters. Since these astrophysical processes may operate with great variety as a function of galaxy mass and cosmic environment, LSST will revolutionize studies of evolving galaxy morphologies by providing enormous samples with deep imaging of exquisite quality.

The huge sample of galaxies provided by LSST will provide a definitive view of how the sizes and structural parameters of disk and spheroidal systems vary with color, stellar mass, and luminosity. Morphological studies will employ at least two complementary techniques for quantifying the structural properties of galaxies. Bayesian methods can yield multi-component parameterized models for all the galaxies in the LSST sample, including the quantified contribution of bulge, disk, and spheroid structures to the observed galaxy surface brightness profiles. The parameterized models will supplement non-parametric measures of the light distribution including the Gini and M20 metrics that quantify the surface brightness uniformity and spatial moment of dominant pixels in a galaxy image (**??**). Collectively, these morphological measures provided by analyzing the LSST imaging data will enable a consummate determination of the relation between structural properties and other features of galaxies over a range of galaxy mass and luminosity previously unattainable.

While the size of the LSST sample supplies the statistical power for definitive morphological studies, the sample size also enables the identification of rare objects. This capability will benefit our efforts for connecting the distribution of galaxy morphologies to their evolutionary origin during the structure formation process, including the formation of disk galaxies. The emergence of ordered disk galaxies remains a hallmark event in cosmic history, with so-called "grand design" spirals like the Milky Way forming dynamically cold, thin disks in the last ~ 10 Gyr. Before thin disks emerged, rotating systems featured "clumpy" mass distributions with density enhancements that may originate from large scale gravitational instability. Whether the ground-based LSST can effectively probe the exact timing and duration of the transition from clumpy to well-ordered disks remains unknown, but LSST can undoubtedly contribute studying the variation in forming disk structures at the present day. Unusual objects, such as the UV luminous local galaxies identified by **?** that display physical features analogous to Lyman break galaxies at higher redshifts, may provide a means to study the formation of disks in the present day under rare conditions only well-probed by the sheer size of the LSST survey.

Similarly, the characterizing the extremes of the massive spheroid population can critically inform theoretical models for their formation. For instance, the most massive galaxies at the centers of galaxy clusters contain vast numbers of stars within enormous stellar envelopes. The definitive LSST sample can capture enough of the most massive, rare clusters to quantify the spatial extent of these galaxies at low surface brightnesses, where the bound stellar structures blend with the intracluster light of their hosts. Another research area the LSST data can help address regards the central densities of local ellipticals that have seemingly decreased compared with field ellipticals at higher redshifts. The transformation of these dense, early ellipticals to the spheroids in the present day may involve galaxy mergers and environmental effects, two astrophysical processes that LSST can characterize through unparalleled statistics and environmental probes. By measuring the surface brightness profiles of billions of ellipticals LSST can determine whether any such dense early ellipticals survive to the present day, whatever their rarity.

Beyond the statistical advances enabled by LSST and the wide variation in environments probed by a survey of half the sky, the image quality of LSST will permit studies of galaxy structures in the very low surface brightness regime. Observational measures of the outer most regions of thin disks can constrain how such disks "end", how dynamical effects might truncate disks, and whether some disks smoothly transition into stellar halos. LSST will provide such measures and help quantify the relative importance the physical effects that influence the low surface brightness regions in disks. Other galaxies have low surface brightnesses throughout their stellar structures, and the image quality and sensitivity of LSST will enable the most complete census of low surface brightness galaxies to date. LSST will provide the best available constraints on the extremes of disk surface brightness, which relates to the extremes of star formation in low surface density environments.

The ability of LSST to probe low surface brightnesses also allows for characterization of stellar halos that surround nearby galaxies. Structures in stellar halos, from streams to density inhomogeneities, originate from the hierarchical formation process and their morphology provides clues to the formation history on a galaxy-by-galaxy basis (**??**). Observations with small telescopes (**??**) have already demonstrated that stellar halo structures display interesting variety (e.g., **?**). LSST, with its unrivaled entendue, can help build a statistical sample of stellar halos and cross-reference their morphologies with the observed properties of their central galaxies. Such studies may determine whether the formation histories reflected in the structures of halos also influence galaxy colors or morphological type. The examination of stellar halos around external galaxies may also result in the identification of small mass satellites whose sizes, luminosities, and abundances can constrain models of the galaxy formation process on the extreme low-mass end of the mass function.

2.3.3 Probing the Extremes of Galaxy Formation

The deep, multiband imaging LSST provides over an enormous area will enable the search for galaxies that form in the rarest environments, under the most unusual conditions, and at very early times. By probing the extremes of galaxy formation, the LSST data will push our theoretical understanding of the structure formation process.

The rarest, most massive early galaxies may form in conjunction with the supermassive black holes that power distant quasars. LSST can use the same types of color-color selections to identify extremely luminosity galaxies out to redshift $z \sim 6$, and monitor whether the stellar mass build-up in these galaxies tracks the accretion history of the most massive supermassive black holes. If stellar mass builds proportionally to black hole mass in quasars, then very rare luminous star forming galaxies at early times may immediately proceed the formation of bright quasars. LSST has all the requisite survey properties (area, mutliband imaging, and depth) to investigate this long-standing problem.

The creation of LSST Deep Drilling fields will enable a measurement of the very bright end of the high-redshift galaxy luminosity function. Independent determinations of the distribution of galaxy luminosities at $z \sim 6$ show substantial variations at the bright end. The origin of the discrepancies between various groups remains unclear, but the substantial cosmic variance expected for the limited volumes probed and the intrinsic rarity of the bright objects may conspire to introduce large potential differences between the abundance of massive galaxies in different areas of the sky. Reducing this uncertainty requires deep imaging over a wide area, and the LSST Deep Drilling fields satisfy this need by achieving sensitivities beyond the rest of the survey.

Lastly, the spatial rarity of extreme objects discovered in the wide LSST area may reflect an intrinsically small volumetric density of objects or the short duration of an event that gives rise to the observed properties of the rare objects. Mergers represent a critical class of short-lived epochs in the formation histories of individual galaxies. Current determinations of the evolving numbers of close galaxy pairs or morphological indicators of mergers provide varying estimates for the redshift dependence of the galaxy merger rate (e.g., **?????**). The identification of merging galaxy pairs as a function of separation, merger mass ratio, and environment in the LSST data will enable a full accounting of how galaxy mergers influence the observed properties of galaxies as a function of cosmic time.

2.3.4 Science Book

The contents of the Galaxies Chapter 9 of the Science Book (**?**).

1. Measurements, Detection, Photometry, Morphology
2. Demographics of Galaxy Populations
    - Passively evolving galaxies
    - High-redshift star forming galaxies
    - Dwarf galaxies

   - Mergers and interactions
3. Distribution Functions and Scaling Relations
   - Luminosity and size evolution
   - Relations between observables
   - Quantifying the Biases and Uncertainties
4. Galaxies in their Dark-Matter Context
   - Measuring Galaxy Environments with LSST
   - The Galaxy-Halo Connection
   - Clusters and Cluster Galaxy Evolution
   - Probing Galaxy Evolution with Clustering Measurements
   - Measuring Angular Correlations with LSST, Cross-correlations
5. Galaxies at Extremely Low Surface Brightness
   - Spiral Galaxies with LSB Disks
   - Dwarf Galaxies
   - Tidal Tails and Streams
   - Intracluster Light
6. Wide Area, Multiband Searches for High-Redshift Galaxies
7. Deep Drilling Fields
8. Galaxy Mergers and Merger Rates
9. Special Populations of Galaxies
10. Public Involvement

2.4 XXX

2.5 XXX

2.6 XXX

2.7 XXX

3 The Roadmap

4 Task Lists by Science Area

In this Appendix, we identify specific areas where effort is needed to prepare for LSST science. Tasks are categorized as (1) *techniques algorithms, techniques, or software*, (2) *precursor observations or synergy with other facilities*, (3) *LSST-targeted theory or simulations* and (4) *Databases, science queries and data services.* For convenience in preparing the Appendix, these are divided by science topic along the science collaboration boundaries. The lists in this Appendix were synthesised and consolidated in the roadmap in chapter 3.

4.1 XXX

4.2 Galaxy Evolution Task Lists

The LSST design, and to a certain extent the design of the data-management system, is optimized to carry out the core science mission. For measurements of dark-energy, that generally means treating galaxies as "tracer particles" – using statistical measures of ellipticity and position provide statistical constraints on large-scale structure and cosmic geometry. While many of the DESC tasks are directly relevant to studying galaxy evolution, they are incomplete. In particular, studies of galaxy evolution require more attention to optimizing multi-wavelength supporting data, different kinds of spectroscopy, different kinds of simulations and theoretical support, and greater attention to detection and characterization of low-surface brightness features or unusual morphologies.

The task list presented here highlights the preparation work needed in the next 3-4 years. Of primary importance are tasks that might influence the detailed survey design or the algorithms used in the DM to construct catalogs. These are the most urgent. Also included are activities that can be reasonably independent of the LSST survey design and DM optimization, but which will ensure good support for LSST galaxy studies.

4.2.1 Techniques, Algorithms, or Software Development

T-1. Techniques for finding low-surface-brightness features or galaxies

Motivation: A huge benefit of LSST relative to prior large-area surveys will be its ability to detect low-surface-brightness (LSB) features associated with galaxies. This includes tidal streams and other features associated with past and ongoing mergers, it includes intra-cluster and intra-group light, and it includes relatively nearby, extended low-surface-brightness galaxies. Prior to LSST, typical studies of the low-surface-brightness universe have focused on relatively small samples, often selected by criteria that are difficult to quantify or reproduce in theoretical models. Measurements of the LSB features themselves themselves are challenging, often requiring hand-tuning and interactive scientific judgment. This is important for accurately quantifying what we observe, but such interactive tuning of the measurements (a) is not something that can be applied on the LSST scale and (b) is difficult to apply to theoretical models. For LSST it is crucial that we automate the detection and characterization of LSB features, at least to the point where samples for further study can be selected via database queries, and where the completeness of samples returned from such queries can be quantified.

Activities: Several activities are of crucial importance: (1) simulating realistic LSB features, (2) using the simulations to optimize detection and measurement, (3) ensuring that LSST level-2 processing strategies and observing strategies are at least cognizant of needs of LSB science and (4) developing a strategy for finding and measuring LSB features through some combination of level 2 measurements, database queries, and level 3 processing.

It is important to insert realistic low-surface-brightness features into LSST simulated images and try to extract and measure them, exploring different techniques or algorithms for doing the detection and measurement. Because the LSB objects are sparse on the sky, making realistic LSST sky images is probably not the most efficient way to accomplish this; more targeted simulations with a higher density of LSB objects are needed. The simulated observations need to be realistic in their treatment of scattered light, particularly scattering from bright stars which may or may not be in the actual field of view of the telescope. Scattering from bright stars is likely to be the primary source of contamination when searching for extended LSB features. Ideally, the LSST scattered-light model, tuned by repeated observations, will be sufficiently good that these contaminants can be removed or at least flagged at level 2. Defining the metrics for "sufficiently good," based on analysis of simulations, is an important activity that needs early work to help inform LSST development. Including Galactic cirrus in the simulations is important for very large-scale LSB features. Including a cirrus model as part of the LSST background estimation is worth considering, but it is unclear yet whether the science benefit can justify the extra effort.

Because the LSST source extraction is primarily optimized for finding faint, barely-resolved galaxies, it is going to be challenging to optimize simultaneously for finding large LSB structures and cataloging them as one entity in the database. For very large structures, analysis of the LSST "sky background" map, might be the most productive approach. We need to work with the LSST project to make sure the background map is stored in a useful form, and that background measurements from repeated observations can be combined to separate the fluctuating foreground and scattered light from the astrophysically interesting signal from extended LSB structures. Then, we need strategies for measuring these background maps, characterizing structures, and developing value-added catalogs to supplement the level 2 database.

For smaller structures, it is likely that the database will contain pieces of the structure, either as portions of a hierachical family of deblended objects, or cataloged as separate objects. Therefore, we need to develop strategies for querying the database to find such structures and either extract the appropriate data for customized processing, or develop ways to put back together the separate entries in the database. A possible value-added catalog, for example, from the galaxies collaboration might be an extra set of fields for the database to indicate which separate objects are probably part of the same physical entity. This would be sparsely populated in the first year or two of LSST, but by the end of the survey could be a useful resource for a wide variety of investigations.

Deliverables: Deliverables over the next several years from the activities described above include the following:

a) realistic inputs of LSB galaxies or LSB features for the LSST image simulations;

b) custom simulations;

c) algorithms for finding and measuring LSB features;

d) input to the Project on scattered-light mitigation and modeling strategies;

e) input to the project on photometric and morphological parameters to measure/store at level 2;

f) query strategies and sample queries for finding LSB structures; and

g) a baseline concept for a value-added database of LSB structures

T-2. Techniques for identifying and deblending overlapping galaxies

Motivation: The Level 2 data products are the most relevant starting point for galaxy-evolution science. In the LSST nomenclature, `Objects` represent astrophysical entities (stars, galaxies, quasars, etc.), while `Sources` represent their single-epoch observations. The master list of Objects in Level 2 will be generated by associating and deblending the list of single-epoch source detections and the lists of sources detected on coadds. The exact strategies for doing this are still under active development by the LSST project, and engagement with the science community is essential. While each data release will have unique object IDs, it will be a huge impediment for LSST science if the first few generations of catalogs turn out severely the limit the science that can be done via database queries.

For galaxies science, the issue of deblending is of critical importance. For example, searches for high-redshift galaxies via color selection or photometric redshifts involve model or template spectra that make the prior assumption that the object in question is a single object at one redshift, not a blend of two objects at two different redshifts. Therefore to get a reliable estimate of the evolution of classes of galaxies over redshift, we need to (a) have reasonably clean catalogs to start with and (b) be able to model the effects of blending on the sample selection and derivation of redshift and other parameters. This is critical not just for galaxy-evolution science, but for lensing and large-scale structure studies. This is just one example. Another is the evolution of galaxy morphologies, where the effects of blending and confusion may well be the dominant source of uncertainty.

The plan for the level-2 catalogs is that sources are hierarchically deblended and that this hierarchy is maintained in the catalog. Scientifically important decisions are still to be made about whether and how to use color information in the deblending, and how to divide the flux between overlapping components. Even if the Project is doing the development work, engagement with the community is important for developing tests and figures of merit to optimize the science return.

Activities: Preparations for LSST in this area involve working both with simulations and real data. The current LSST image simulations already have realistic source densities, redshift distributions, sizes, and color distributions. However, the input galaxies do not have realistic morphologies. At least some simulations with realistic morphologies are needed, especially for the Deep Drilling Fields. Inputs should come both from hydrodynamical simulations (where "truth" is known), *Hubble* images, and images from precursor surveys such as CFHTLS, DES and HyperSuprimeCam. The science collaborations should help provide and vet inputs.
More challenging is to come up with techniques and algorithms to improve the deblending. When two galaxies at different redshifts overlap, using observations from all the LSST filters and perhaps even EUCLID and WFIRST might help to disentangle them. Some attempts have been made over the past few years to incorporate color information into the deblending algorithm, but this needs much more attention, not only for developing and testing algorithms, but for deciding on figures-of-merit for their performance.

Deliverables: Deliverables over the next several years from the activities described above include the following:

a) providing realistic galaxy image inputs to the ImSim team;

b) developing tests and figures of meerit to quantify the effects on several science objectives;

c) assessing the current baseline plan for level-2 deblending and for parameter estimation for blended objects; and

d) developing prototype implementations of deblending algorithms that take advantage of the LSST color information

T-3. Optimizing Galaxy Morphology Measurements

Motivation:

Activities:

Deliverables:

T-4. Optimizing Galaxy Photometry

Motivation:

Activities:

Deliverables:

T-5. Optimizing Measurements of Stellar Population Parameters

Motivation:

Activities:

Deliverables:

T-6. Software Integration

Motivation:

Activities:

Deliverables:

4.2.2 Precursor Observations or Synergy with Other Facilities

T-1. Redshift surveys in the Deep Drilling fields

Motivation:

Activities:

Deliverables:

T-2. Spitzer observations of Deep Drilling fields

Motivation:

Activities:

Deliverables:

T-3. VLA observations of Deep Drilling fields

Motivation:

Activities:

Deliverables:

T-4. Photometric redshift training and calibration

Motivation:

Activities:

Deliverables:

T-5. Joint use of spectroscopic and photometric redshifts

Motivation:

Activities:

Deliverables:

4.2.3 LSST-targeted theory or simulations

T-1. Image simulations of galaxies with complex morphologies

Motivation:

Activities:

Deliverables:

T-2. Rare objects

Motivation:

Activities:

Deliverables:

T-3. Cosmic Variance estimators

Motivation:

Activities:

Deliverables:

T-4. Nearby dwarfs: surface brightness fluctuations

Motivation:

Activities:

Deliverables:

T-5. Testing group and void finders

Motivation:

Activities:

Deliverables:

4.2.4 Databases and Data Services

T-1. Data structures to characterize survey biases and completeness

Motivation:

Activities:

Deliverables:

T-2. Queries to find unusual class of objects

Motivation:

Activities:

Deliverables:

T-3. Compact representations of likelihood functions

Motivation:

Activities:

Deliverables:

T-4. Interaction and integration with citizen science

Motivation:

Activities:

Deliverables:

4.3 XXX

4.4 XXX

4.5 XXX

4.6 XXX