Status and Early Science Results of the PS1 Science Mission

1 Introduction

Pan-STARRS[1] is an innovative wide-field imaging facility developed at the University of Hawaii's Institute for Astronomy. Pan-STARRS1 (PS1), the first of four planned telescope, has been scanning the sky since May 2010 from the summit of Haleakala, Maui, Hawaii. With the largest digital camera ever built – 1.4 billion pixels – spanning an unprecedented field of view of 7 square degrees (Onaka et al, 2008), the system is repeatedly surveying 75% of the sky visible from Northern latitudes in the 5 pass-bands g, r, i, z and y.

PS1 is performing a 3.5 year science survey mission organized by the international PS1 Science Consortium (PS1SC), which was set up to fund the operations and to extract the intial science results from the PS1 data. The centerpiece of the PS1 Surveys (Chambers et al. 2012) is the 3π survey, covering the full observable sky and slated to obtain 12 visits in each of the 5 filters by the end of the mission. With so many repeated observations over this large area, PS1 represents an order of magnitude increase in survey richness over SDSS, with unprecedented photometric and astrometric accuracy as well as unique temporal information.

While a major goal of Pan-STARRS is to search for asteroids and comets that might pose a danger to our planet, the full dataset offers vast research possibilities in many other astronomical areas. The PS1 solar system discoveries so far include a number of potentially hazardous asteroids as well as a new comet (C/2011 L4 Pan-STARRS, Wells et al 2011), which should become very bright in 2013. PS1 has also yielded hundreds of supernovae, including a new class of very luminous supernova explosions (e.g. Chomiunk et al 2011, Narayan et al 2011), and dozens of brown dwarfs (e.g. Deacon et al 2011).

To fully exploit the scientific potential of the PS1 survey data we are committed to make the PS1 data available to the general astronomical community as soon as possible. To this end, we have joined forces with the Space Telescope Science Institute (STScI), which has many years of experience with the Hubble Space Telescope and Multi-Mission data archive (MAST). STScI committed itself to Pan-STARRS in part to gain early access to the science of Pan-STARRS and in part to gain experience with hosting Petabyte-scale archives, which reflect the future of astronomy. The PS1 Archive and Server will make all PS1 data products available to the world at the same time as the fully calibrated data becomes available to the members of consortium. The members of the PS1 Science Consortium will barely scratch the surface of the science possible - the full explotation will require the astronomical community.

2 The Science From a Full PS1 Survey

With the combination of large-area coverage in 5 bands, precision astrometry and photometry, depth, and temporal cadence, the PS1 surveys offer the community a gold mine for future science discoveries. While PS1SC research to date has been focused on a small number of key science areas, examples of this work can be used to illustrate the potential of the PS1 survey data. The experience from previous similar surveys (SDSS, 2MASS, POSS) implies that opening the PS1 data to the general astronomical community will drive a much larger outpouring of science results, making the PS1 science archive an essential community asset and engine of discovery for many years to come. It will form a natural bridge between the historical success of the SDSS and the future promise of the LSST. Exemplars of PS1 science below illustrate a small sample of the kinds of science that the community can purse with public access to he PS1 data products, and provides particular examples of the "non-linear" gains to be made by completing the PS1 surveys as requested.

[1]The Panoramic Survey Telescope & Rapid Response System (Kaiser et al. 2010)

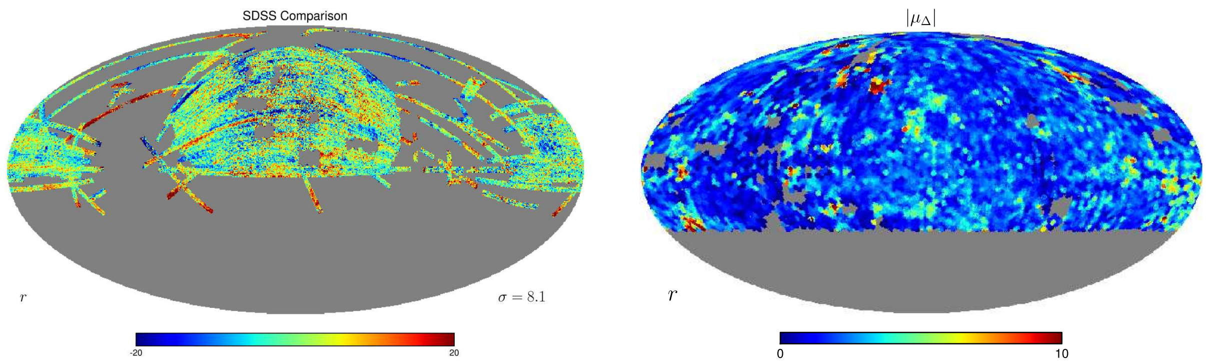

Figure 1: **Left:** The consistency of the zero-points (r band) across the survey for SDSS. The color range is in mmag. Errors in SDSS calibration are evident from striping along SDSS observing pattern. **Right:** Current consistency of zeropoints in 3π Survey. Increasing the length of the survey will ensure 3 mmag rms. See Schlafly et al. 2012 for details.

Table 1: PS1 Surveys and Comparison Surveys

survey	**area sq deg**	**region**	**pixel size arcsec**	**image quality median FWHM**	**filters**	**cadence**	**lim mag per dwell**	**lim mag per sum**
PS1							g,r,i,z,y	g,r,i,z,y
3π	30000	$\delta > -30$	0.256	1.1”	$grizy$	25 min, 1 mth	22.2, 22.0, 21.5, 20.8, 19.8	23.4, 23.2, 22.7, 22.0, 21.1
MD	70	std fields	0.256	1.1”	$grizy$	3 min, 1 day		25.0, 25.0, 25.1, 24.4, 23.5
SS	5000	ecliptic	0.256	1.1”	w	25 min	22.5(w)	...
STS	49	bulge	0.256	1.1”	i	8 min	21.7(i)	...
M31	7	M31	0.256	1.1”	r, i	2hrs	22.2(r), 21.7(i)	...
								u, g,r,i,z
SDSS	8000	galactic cap	0.396	1.3”	$ugriz$	one epoch	...	22.5, 23.2, 22.6, 21.9, 20.8
PTF	...	available	1.100	2.0”	g', R	1 min, 5 days	21.3(g), 20.6(R)	...
DES	5000	s. gal. cap	0.270	0.9”	$grizy$	one epoch	...	24 (predicted in i band)
HSC	2000	...	0.170	0.5”	$grizy$	...	...	26.2

2.1 The Solar System

The study of small bodies in the solar system provides unique clues about how planetary systems form and evolve. The PS1 3π survey has an observing cadence that is well suited to the detection of the full range of solar system bodies, from fast-moving Near-Earth Objects (NEOs) to slow-moving Trans-Neptunian Objects (TNOs).

Over the course of a 3.5 year science mission, this unprecedented survey will discover nearly every asteroid, comet, and other small solar system object brighter than $r \sim 22$ that passes through the survey region. We will be able to characterize the orbits and sizes of these objects. This census will provide major new information about the physical and dynamical properties of these various small-body populations, yielding major new clues about the formation and evolution of our own solar system. We have already discovered a major new comet (C/2011 L4 - on track to becoming the second brightest naked eye comet in more than a decade early in 2013). There is a chance we will discover new collisional asteroid debris, a new impacting Near Earth Object, and even new planet-sized bodies at great distances from the sun.

The Near Earth Objects (NEO) are arguably the most interesting population of minor planets in the inner solar system due to their potential impacts with the Earth. The difference between PS1 and the other NEO surveys is that KP1 will convert the raw discoveries into a de-biased population model that improves upon previous work by providing much better statistics, more source populations, and better input residence time distributions. We are certain that the PS1 data will lead to papers that will set the standard for the NEO population for at least the next decade. Much of this is made possible by the Moving Object Processing System or MOPS (Jedicke et al. 2009). It is recognized as the most sophisticated software in the world for the purpose of identifying moving object detections and linking them together within and across nights. Soon PS1 will claim first place in the total number of minor planets reported to the Minor Planet Center (Spar, 2011). We also note that astrometry of moving objects detected by PS1 is far superior to astrometry from the other major asteroid surveys. Further afield, PS1 will determine the key properties of the population of small-planet-sized objects at great distances in the outer solar system. PS1 will also permit a systematic dynamical classification of every detected body in the outer solar system. Each object will be identified as a resonant, classical, scattered, detached, or inner Oort cloud body, for example. Using the detection efficiencies and observational biases of the PS1 survey, we will determine the intrinsic abundance of each of the dynamical subclasses of Tran-Neptunian Objects (TNOs). Indeed, we expect to detect $\sim 2,000$ new and $\sim$ 450 previously known TNOs. Each of these will have an exquisitely well determined orbit. We expect this new census and dynamical classification to form the observational backbone of a number of theoretical investigations of formation and evolution of the outer solar system.

2.2 Low Mass Stars and Brown Dwarfs

One of the major frontiers in stellar astrophysics is understanding the population of the lowest mass stars and of the sub-stellar brown dwarfs. PS1 will provide a complete volume-limited census of such objects in the local solar neighborhood over 75% of the sky. PS1 data are already being used to search for the brown dwarfs in this region. To date, we have focused on brown dwarf searches based on single-epoch PS1 z and y-band data combined with 2MASS JHK detections, using both color and PS1-2MASS proper-motions to guide our searches. The combination allows us to go fainter and to denser regions than prior 2MASS-based searches, and to exclude the contaminating M-dwarfs more efficiently. These searches have proven to be extremely effective: we have already discovered 62 T-dwarfs (with about 15% found independently by others) from the PS1-2MASS search and expect this to grow by another ∼20% as we fill in the holes in the original survey area.

One strength of the PS1 dataset is the ability to discover rare and unusual objects. For example, we have discovered several notable individual objects: a proper-motion companion to a nearby Hipparcos star which can be used as a benchmark and a nearby very late T dwarf. We also have found 6 blue L dwarfs, thought to either have low metallicity or to have an emission spectrum modified by features in the atmosphere such as a relatively thin condensate cloud layer. This is just a hint of the promise of the full exploitation of the PS1 archive over the years to come.

An exciting new opportunity is to conduct a PS1-only proper-motion and parallax based searches, with an eventual goal of producing a volume-limited sample in the full 3π region. We have used the PS1 data to measure the parallax for 2MASS 1835+22, an object with an independently measured distance. This dataset will be unique until LSST is available (as GAIA will not be sensitive to very cool stars and brown dwarfs), and will enable characterization of the low-mass populations without current distance ambiguities. The improved proper motions and parallaxes will also allow for the identification of low-mass members of nearby streams, providing an age indicator for many more nearby sub-stellar objects.

2.3 Galactic Archaeology

The fossil clues to the formation and assembly of our Milky Way galaxy (a very typical galaxy) are imbedded in the structure and stellar content of its various components. The PS1 3π survey will enable decisive steps in the next several years in exploring the “archaeology” of our Milky Way. As such, it will serve as a vital bridge between the SDSS era and that of GAIA and the LSST.

Compared to SDSS, the crucial new elements that PS1 brings are: (i) the much larger area coverage (including the Galactic plane); (ii) an imaging depth of about one magnitude fainter than SDSS in the r, i, z

bands; (iii) time domain data that measure proper motions for a vastly larger region and sample of stars; and (iv) time domain data that produce a large sample of faint stars with high-quality parallaxes for stars within 100 pc; and (v) the y band and red-sensitivity of GPC1 which adds an entire passband further into the near infrared than SDSS.

To achieve this promise, it is essential that PS1 make a full third pass around the sky. This is critical in several ways. First, it will provide a large increase in the astrometric precision (which increases with survey duration at $t^{3/2}$). Second it will provide a dramatic increase in the spatial uniformity of the multi-band 3π data as discussed in section 3.1 below. The resulting uniformity in the depth of the data will lead to a similar uniformity in the selection function, which is the key to identifying galactic sub-structures and quantifying their properties. Finally, the third pass on the sky will increase the depth of the survey and hence in the number of stars that can be used to probe these sub-structures.

One major project that would be enabled by these data would be a comprehensive census of 'ultra-faint' satellite galaxies around the Milky Way. This would provide both more examples of how galaxy formation works at the low-mass end, and unique information about how the Milky Way is embedded in the cosmic web through the anisotropy of the satellite distribution.

The full PS1 data will also yield a far more extensive view of stellar streams around the Milky Way, where SDSS's view of these streams is limited by its sky coverage. Dynamical models of these streams offer the best approach to measuring the 3D shape of the Milky Way's gravitational potential, ultimately enabling tests of gravity itself. The utility of cold stellar streams as dynamical probes grows quadratically with their traced extent, as measuring accelerations is the critical requirement. Current analysis shows that the boost in imaging depth, the increased fidelity of star-galaxy separation (related to the point spread function size) and again the homogeneity and uniformity of the photometric selection function are key here. The tracing of even prominent streams into the PS1 footprint is limited by the large-scale variations in current 3π data quality.

PS1 will produce a peerless multi-color survey of the Milky Way's stellar disk, providing a 3D map of the stellar distribution through photometric parallaxes. Current analyses show that kinematics to augment the photometry are key to understand the build-up of the Milky Way disk, e.g. to see whether a 'thick disk' is distinct from a 'thin disk'. This requires velocities to about 10 km/s to distances comparable to the Milky Way's radial scale length and the (thick) disk scale height, i.e. to 1-2 kpc. Proper motions with 2 mas/yr are required for this analysis, and this accuracy can only be delivered by a third year of PS1 observations.

2.4 Explosive Stellar Transients

Supernovae and gamma-ray bursts are explosive events that signal the death or destruction of a star. As such, they are not only ideal laboratories to test our understanding of matter under extreme conditions, they also play a critical role in the heating and chemical enrichment of galaxies and even the intergalactic medium. One of the major goals of the PS1 project is to discover new supernova explosions in locations ranging from nearby to galaxies in the early universe.

The cadence and grasp of the PS1 3π and Medium Deep Surveys enable the discovery and characterization of a vast treasure trove of the various known populations of explosive stellar transients. One of the major products of the PS1 survey will be a large sample of supernovae located in host galaxies that are close enough to allow detailed follow-up observations. These will enable comprehensive statistical investigations of the relationship between the various kinds of supernovae and the properties of their environment (e.g. the mass, metallicity and star-formation rate of their host galaxy and their radial distribution within these galaxies). PS1 is also discovering wholly new types of exotic stellar transients. We are only now seeing these due to the extraordinary discovery power of PS1. PS1 will blaze a trail for future facilities like LSST, JWST, WFIRST, and Euclid.

For example, if stars of initial mass $200 - 400 M_{\odot}$ do exist, then they are expected to end their lives in pair-instability explosions. These have been predicted for four decades, but until recently believed to be found only in the early Universe (in Pop III stars). Two remarkably luminous supernovae, including the PS discovery of PS1-11ap, have been found in SMC-type dwarf galaxies at relatively low redshift ($z = 0.13 - 0.5$), showing all the characteristics of these exotic explosions. PS1 has produced an excellent multi-color and bolometric lightcurve indicating that more than $3M_\odot$ of ^{56}Ni is required to power the luminosity, far larger than seen from typical core-collapse supernovae ($0.07M_\odot$) and type Ia supernovae ($0.7M_\odot$). This huge mass of radioactive Ni can only be viably produced in pair-instability models.

Even more surprisingly, PS1 has discovered the highest redshift SNe known ($z \sim$ 1 - 1.4), which are 100 times brighter than normal core-collapse supernovae but cannot be due to pair-instability as they lack radioactive Ni. We are only now able to discover these populations of exotic explosions, perhaps from the most massive stars, by understanding how to find them among the Ia SNe.

2.5 Galaxies

The multicolor images resulting from the stacked PS1 3π survey will represent a significant improvement both in seeing and depth relative to the SDSS (Figure 3). The greater depth, better spatial resolution, and more complete sky coverage of PS1 will make it possible to dissect unprecedented numbers of galaxies in the present-day ($z < 0.1$) universe. The greater depth and better angular resolution allow us to probe the structures and stellar populations of galaxies over a wider dynamic range in radial/physical scales. The wider sky coverage improves the sample size (which is most important for the nearest galaxies) and maximizes overlap with the highly complementary data from the ESO near-IR VISTA imaging survey.

These data will make it possible to map out the spatially-resolved (2-D) history of star-formation, to convert the multi-band images into maps of the structure of the underlying stellar mass surface density, and to probe the disks and halos beyond the regime accessible with SDSS. For example, compared to SDSS, we will get a better view of the role of mergers/interactions from studying the outer parts of galaxies. These outer parts retain the record of the interaction for longest and are the most fragile. They offer a unique probe of galaxy evolution.

Analyses of the PS1 images will make it possible to better determine the “archaeological record” of galaxy evolution in the local universe and compare this to direct measures of the cosmic star formation rate as a function of redshift and to predictions of numerical simulations and semi-analytic models. Such numerical and semi-analytic models are rapidly becoming more sophisticated and physically realistic. Despite this, their value is realized only when they can be compared to robust observational results that provide empirical diagnostics of the physical processes that are at work in shaping the way galaxies evolve, obtained for a large and well-characterized sample of galaxies.

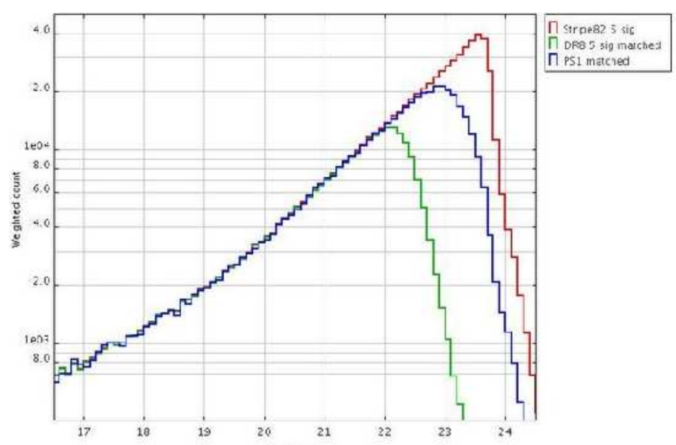

Figure 2: Galaxy counds in i band from SDSS (DR*), PS1-3pi, and Stripe 82 compared. This shows PS1 going a magnitude deeper than SDSS in i band.

Significant progress of this kind has already been made. Thanks to the high quality of SDSS spectra and the combination of SDSS and GALEX imaging and photometry, we now have a wealth of information about the rate at which stars are forming and black holes are accreting in galaxies in the nearby universe. However, we need to go beyond this. This will require measuring important internal properties of a large sample of galaxies. This is difficult to do with the existing SDSS imaging data. Typically there are too few spatial resolution elements across the galaxy, and the images are too shallow to allow robust maps to be constructed of the key parameters that can in principle be derived from mapping the spectral energy distribution from the inner to the outer regions of the galaxies. The Medium Deep Survey images of PS1 extend the study of galaxy formation and evolution to intermediate and high redshifts. Using the 2-point (galaxy-galaxy) correlation functions and galaxy clustering power-spectra (together with photometric redshifts) enables the study of the dependence of the strength and form of galaxy clustering on galaxy properties and redshift. Modelling the dependence of this clustering using halo occupation distributions and similar methods will make it possible to empirically relate the evolution of galaxy properties and the dark matter haloes that they inhabit and hence constrain models of galaxy formation.

2.6 Super-massive Black Holes

Studying accreting super-massive black holes (i.e. quasars) and their relationship to galaxy formation at the earliest cosmic epochs is a prime objective in modern astrophysics. How these first luminous sources formed is one of the most fundamental open questions in cosmology. This "Epoch of Reionization" (the transition of a dark, neutral, universe to a universe that is mostly ionized) constitutes a key phase transition in the universe and is believed to have occurred in the redshift range $z \sim 6$ to 10 (i.e. within the first billion years after the Big Bang). The nature of the population of sources responsible for reionization remains unclear (are they quasars with luminosities below the range probed to date, or star-forming galaxies that are porous to the escape of ionizing radiation, or both?).

Ever since SDSS's detection of a sizable sample of quasars at $z \sim 6$ about a decade ago, it has been imperative to push the detection of quasars to higher redshifts. These data will be needed in order to: (i) understand how super-massive black holes could have grown to their inferred masses, (ii) constrain the black hole masses at even earlier cosmic times (iii) derive the chemical abundances in the centers of galaxies in the early universe (iv) to probe further back into the reionization history of the universe, by studying the absorption lines imprinted on the quasar light by neutral hydrogen along the line of sight.

The recent discovery of a $z = 7.1$ quasar in a small area of the sky covered by UKIDSS demonstrated not only that quasars do exist at these extreme redshifts but that they are indeed unique tools to constrain early black hole growth and the state of the IGM. However, it is also clear that the current sample needs to be extended significantly to derive statistically meaningful conclusions about the earliest quasars.

Significant progress beyond SDSS can be made by means fo PS1's y band. (See Figure 4). The outcome would be the detection and characterization of a sizable sample of distant accreting black holes at $z > 7$ (i.e. at substantially earlier periods in the Universe's history than typically accessible today). The key challenge is that distant quasars are both faint and rare: one expects a sample of 10-100 objects at $z > 7$ over one sky hemisphere at the depth of the final stacked PS1 3π data. These rare "needles" need to be distinguished efficiently from a the "haystack" of 30 billion objects.

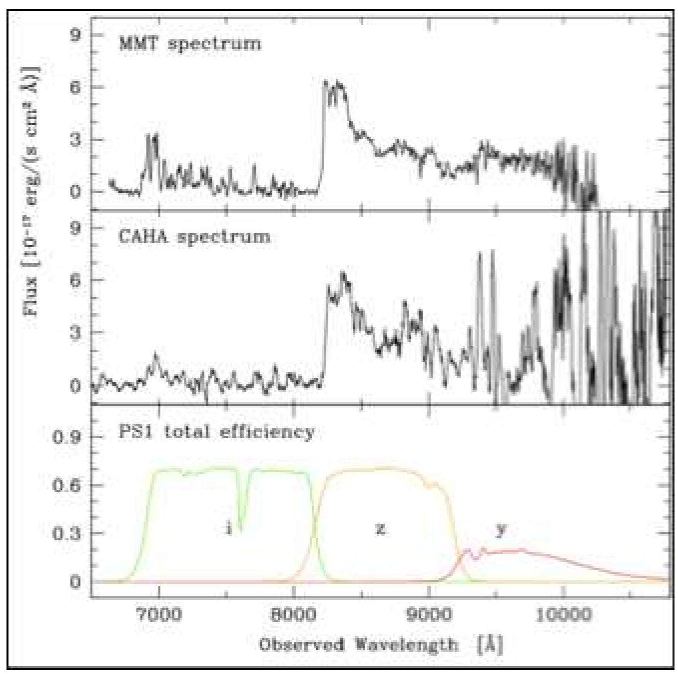

Figure 3: First z 6 quasar discovered by PS1 (Morgansen et al. 2011) PS1's y band will enable to push these studies to $z > 7$

The PS1 opening of the time domain provides an important new probe of the nature of supermassive black holes and their immediate environments: by detecting the flare of radiation from the tidal disruption and accretion of a star that wanders too close to a dormant black hole in a distant galaxy. The PS1 Medium Deep Survey has already yielded the discovery of a luminous flare from the nucleus of an inactive galaxy with a densely sampled multi band light curve that follows the rise and decay of the mass accretion rate expected for the tidal disruption of a star by a several million solar-mass black hole. Scaling from the detection rate of 2 tidal disruption events in the SDSS Stripe 82 survey, we expect PS1 MDS to detect tens of events with well-sampled light-curves, which will be used to provide unique insights into accretion physics and black hole demographics.

2.7 Cosmology

The PS1 science archive will make it possible to undertake several different investigations into the large-scale structure of the universe and its evolution. The first component will significantly improve the constraints on the nature of dark energy eprovided by using Type Ia supernovae as standardize-able candles. These first revealed the presence of dark energy and continue to provide powerful constraints on its properties. PS1 has quickly become the most prolific supernova search engine to date, being particularly adept in finding type Ia supernovae out to z=0.65. To date PS1 has identified approximately 2400 supernovae. Based on spectral confirmations of 187 SNe Ia, we estimate that PS1 has collected light curves for about 1800 SNe Ia. This is already a factor of 2 greater than the SDSS supernova survey, but the PS1 SNe Ia extend to higher redshifts, improving their leverage on dark energy. The multi-band data from PS1, high cadence, and spectroscopic follow-up of host redshifts should yield the best constraints on dark energy to date. The large PS1 sample offers the opportunity to address outstanding systematic uncertainties by selecting preferred subsamples such as SNe Ia in early type hosts, a low-dispersion sample which should approach 300 by the end of the survey and can circumvent systematic uncertainties due to dust and color.

A second major component of these cosmological investigations will come from the analysis of weak gravitational lensing using the 3π survey. The weak lensing analysis directly probes the distribution of the dominant dark matter component of the universe and the of the growth of the structure it defines. Such tests can in principle probe both the nature of dark energy and the validity of general relativity on very large scales. Compared to SDSS, the roughly one magnitude greater depth, 3 times more sky area, and better image quality (both in the size and circularity of the PSF) of the final stacked PS1 3π images will allow a major improvement in all of the weak lensing applications that have been successfully carried out with SDSS imaging. For the 3π survey, the shapes of galaxies can be reliably measured with our 1.1 arcsec typical $i - band$ images.

While it will take some time to accumulate the necessary depth, there is little doubt that the lensing analysis of PS1 3π images will produce outstanding results for at least two applications: cluster lensing, and galaxy-galaxy lensing. These are applications where systematics arising from imperfect modelling of the PSF anisotropy has a low impact. The former is of great interest at the moment in relation to the surprisingly low Sunyaev-Zelovich (SZ) detection rate from recent surveys: direct mass determinations from large numbers of clusters from lensing will help better calibrate SZ and also X-ray luminosities as proxies for mass. Another application where we can expect interesting results is intrinsic alignments, which are vital to understand to do cosmic shear science. For cosmic shear the performance for large-angle power spectrum measurements should be much better than for previous surveys, but this is an application where systematics are dangerous and current forecasts should be treated with caution. Here, in order to obtain a good signal, it is necessary to have the greater depth which the extension of the survey by an extra year would allow. Moreover, the resulting large number of images (12 per passband) will be very valuable for control of systematic effects.

A complementary way to investigate large-scale structure and its evolution is to use the galaxies themselves as probes. The galaxy catalogs constructed from the PS1 3π and Medium Deep Surveys will provide a powerful platform for these investigations. One key aspect of such studies will be the characterization of the Integrated Sachs-Wolfe (ISW) effect through the cross-correlation of the galaxy distribution with the with Cosmic Microwave Background (CMB) temperature perturbations. The unprecedented large area of the 3π survey will provide the most accurate measurements to date. The ISW arises due the passage of CMB photons through gravitational potential fluctuations that are decaying due to the accelerating expansion of the universe caused by dark energy. The five band Pan-STARRS photometry will allow photometric redshifts to be estimated for all the catalogued galaxies and provide particularly accurate estimates for red, early-type galaxies. This will enable us to quantify the dependence of the ISW effect on redshift which will, in turn, set important constraints on the evolution and nature of the dark energy.

Galaxy clustering, as characterized by 2-point correlation functions and power-spectra, is also of great intrinsic interest. By quantifying the angular clustering in photometric redshift slices of the 3π survey we expect to measure clustering out to the scales of the baryonic acoustic oscillations. These provide an important yardstick which can be used to set constraints on cosmological parameters including constraints on Dark Energy. Another aspect of large scale structure studies is the identification and exploitation of galaxy clusters. We have developed cluster finding techniques that utilize the multi-color information of the Pan-STARRS surveys to identify the red-sequence in galaxy clusters. While the photometric redshifts of individual galaxies are quite uncertain the cluster redshifts can be determined accurately by averaging over cluster members. Hence the resulting cluster catalogue can be exploited in a variety of ways. These include quantifying their imprint of the cosmic microwave background via the SZ effect, measuring their 3D clustering and quantifying the evolution of the cluster galaxy population.

3 Summary

The impact of making the PS1 data products available to the astronomical community and the public as a whole can not be understated. The impact to astronomy covers nearly every field from the nearest objects in the solar system to cosmology. It will enable scientific studies at all wavelengths and resolutions and open new windows on the time domain. Pan-STARRS builds on the tremendous success of the Sloan Digital Sky Survey (SDSS), which imaged about 1/4 th of the sky, and is a pathfinder for the even more ambitious Large Synoptic Survey Telescope (LSST). In twelve years SDSS has produced nearly 3000 referreed papers with SDSS in the title or abstract according to ADS, and these papers have over 100,000 citations. Like SDSS, PS1 is carrying out a dedicated survey and will generate catalogue and image data products to serve a large community of astronomers pursuing many science goals. With PS1's combination of a 3π steradian survey, the MD fields, and the time domain, together with better spatial resolution and depth than SDSS, we can only guess at the extent of what the broader impact will be. The photometric data alone will provide the equivalent of a Landolt standard in the field of view of any astronomical imaging program on any telescope, and with the y bandpass, extends the coverage further into the near-infrared. Most significantly, the PS1 Surveys add the extra time dimension to dramatically open up the field of time-domain astronomy and enables the discovery of new transient or variable phenomena. Serving the data from the PS1 Science Mission to the astronomical community will enable vast areas of scientific exploration. Furthermore the potential for education and outreach from public distribution of this data is immense.