Panoramic Survey Telescope and Rapid Response System

Advancing Relativistic Astrophysics with the Pan-STARRS Wide Field High Resolution Optical Survey

William S. Burgett, Pan-STARRS Project Manager (for construction)

Abstract

The advent of wide field high resolution optical surveys has demonstrated the importance of this observing niche for providing critical data to advance our understanding of many relativistic astrophysical phenomena in stellar, galactic, and cosmological physics. From the preceding 15 years through the next 20 years, this type of survey was first represented by the Sloan Digital Sky Survey, then in the last several years by Pan-STARRS and others, and eventually by LSST early in the next decade, In this talk, I shall summarize some recent, forthcoming, and future results from the Pan-STARRS PS1 survey that highlight the richness of results from this type of survey. These include stars being tidally disrupted by super-massive black holes at the centers of galaxies, microlensing in M31, a sample of super-luminous supernovae (SLSN) of ever-increasing diversity, the characterization of a large sample of Type Ia SNe to map out the expansion history of the Universe, weak lensing, and cross-correlating large scale structure with the CMB to search for ISW signatures. I will also present a brief status update for the second Pan-STARRS telescope (PS2), and how future possibilities for a PS1+PS2 survey can continue building on the success of the initial PS1 survey – if only the community will support it.

The Role and Potential of Survey Astronomy

The Renaissance of Wide-Field Imaging

- Wide-field imaging (e.g., Palomar sky surveys) fell into decline with advent of CCDs (high QE but tiny FOV),
  - But the largest most powerful telescopes need a new generation of powerful survey systems to identify targets
- Subsequent decades have seen
  - Exponential growth in area of detectors
  - Matching growth (Moore's law) of computer hardware
  - Major investment in image reduction and database software
- State of the art as of 2000-2008
  - CFHT/Megacam (3.6m/300Mpix), Subaru/Suprime (8m/100Mpix)
  - Advent of dedicated survey instruments (SDSS, 2MASS …)
- The next step - the 2000 NAS Decadal Review LST concept
  - ~ 6m telescope with ~ 7 square deg FOV
  - Scan entire sky to ~24th mag in <~ 1 week
  - Repeated scans → "time domain astronomy"
  - Stacked images → "static sky" science

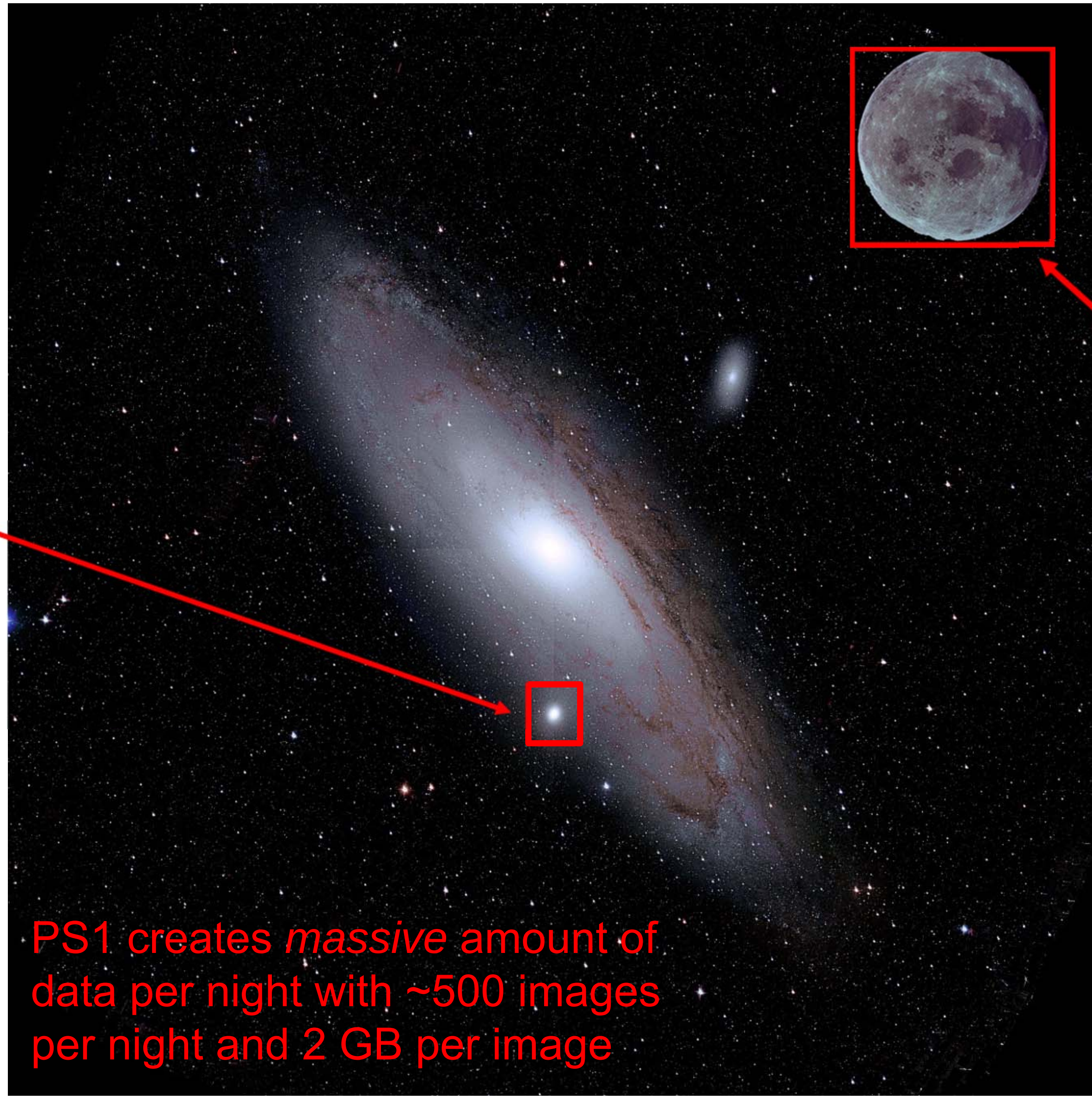
∴ ***Pan-STARRS and e.g., PTF, SkyMapper, VISTA, DES, and LSST***

Pan-STARRS Overview

- Pan-STARRS quick facts
  - Credit for original concept to N. Kaiser, J. Tonry, and G. Luppino
  - Each independent telescope 1.8m R-C + corrector lenses
  - Distributed aperture concept yields 3.5m capability for 4 telescopes
    - Easier/Faster to build, cheaper → less risk (wide field optics already difficult enough!)
  - 7 square degree FOV, 1.4Gpixel cameras
  - R ~ 22.5 from one telescope in 30 s integration → 7000 square deg/night
  - All sky + deep field surveys in g, r, i, z, y and w filters
    - Comprehensive and self-consistent photometric and astrometric catalogs
      - Including parallaxes and proper motions
- Time domain astronomy → "Rapid Response" needed for follow-up
  - Transient objects, e.g., Supernovae and Gamma Ray Bursts
  - Moving objects
  - Variable objects
- Static sky science
  - Enabled by stacking repeated scans to form ultra-deep static sky images

Pan-STARRS: Wide Field Survey Capability

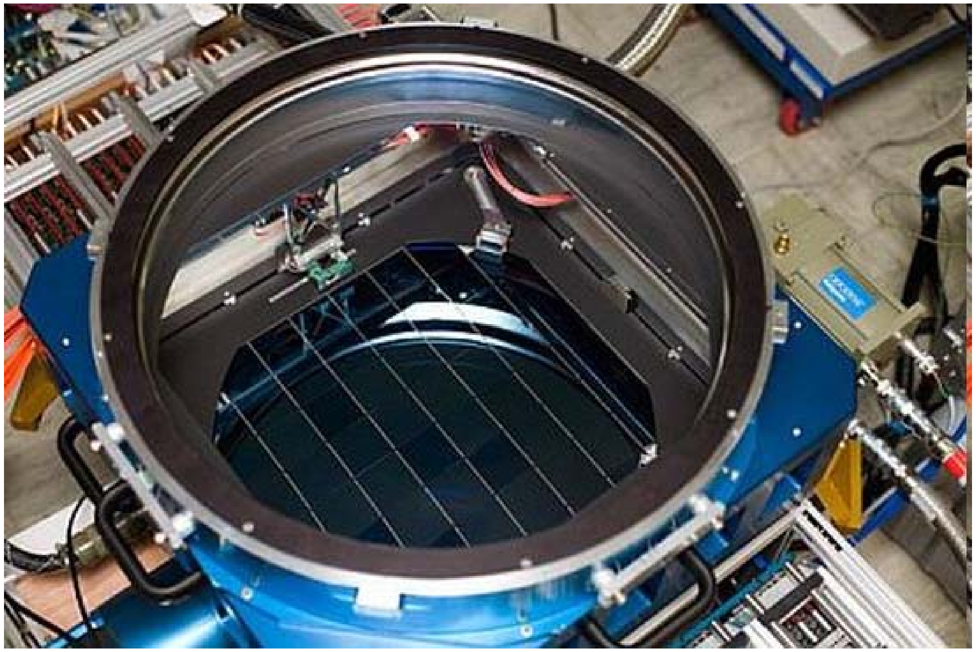
FoV of standard world class research telescope



0.5º diameter of Moon only small fraction of 3º diameter PS GPC FoV ($7\ deg^2$)

The 1.4 billion pixel Pan-STARRS camera is one of the *20 Marvels of Modern Engineering of 2008** !

18. *"Built at Manoa's Institute for Astronomy in Honolulu at the University of Hawaii, the largest digital camera has been installed on the* ***Pan-STARRS PS1*** *telescope on Haleakala, Maui. This digital wonder along with the telescope will form one of the most powerful observatories on the planet and will monitor the cosmos constantly."*



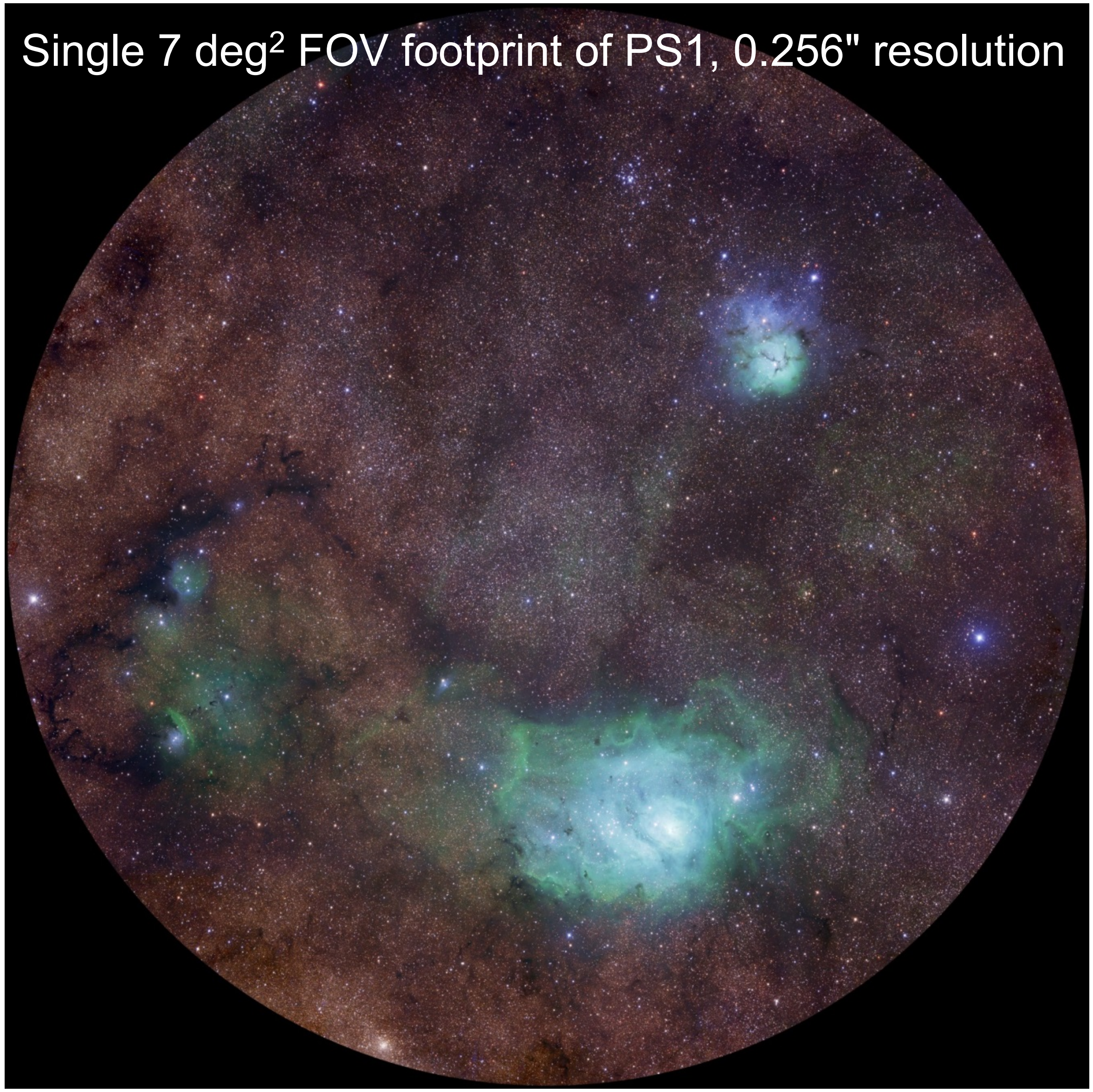
* Reference:

http://www.gizmowatch.com/entry/20-marvels-of-modern-engineering/

The top 5 are as follows:

1. The Large Hadron Collider;
2. The International Space Station;
3. Three Gorges Dam;
4. Petronas Twin Towers;
5. The Chandra space-based X-ray telescope

Astronomy Picture of the Day, Oct. 12, 2012



Pan-STARRS PS1 Survey Results

and

Relativistic Astrophysics and Cosmology

PS1 Science Consortium Key Projects

PS1 Science Mission Director: Kenneth C. Chambers

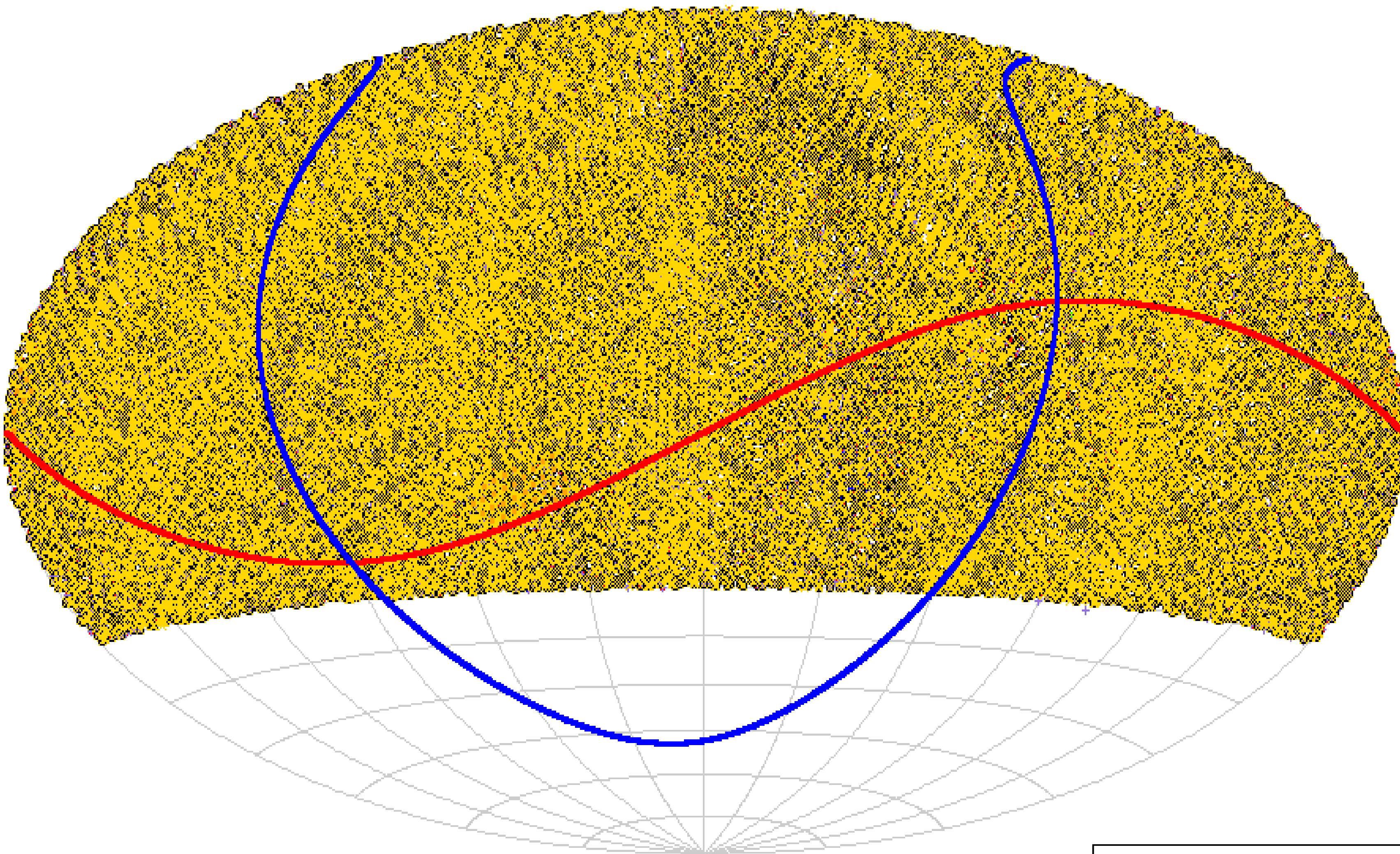
1. Populations of Objects in the Inner Solar System
2. Populations of objects in the Outer Solar System
3. Low-Mass Stars, Brown Dwarfs, and Young Stellar Objects
4. Search for Exoplanets by Dedicated Stellar Transit Surveys
5. Structure of the Milky Way and the Local Group
6. A Dedicated Deep Survey of M31
7. Massive Stars and Supernova Progenitors
8. Cosmology Investigations with Variables and Explosive Transients
9. Galaxy Properties
10. Active Galactic Nuclei and High-Redshift Quasars
11. Cosmological Lensing
12. Large Scale Structure

PS1 Early Science Results

- Time constraints preclude describing these results including, but not limited to:
  - NEOs, comets, TNO discoveries in Solar System
  - Brown dwarf discoveries in local solar neighborhood
  - White dwarfs, variables of all types in MW and M31
  - Distinct stellar streams in Milky Way including bifurcation in the Sagittarius stream
  - Updated, better than ever before, dust/extinction maps and 3D structure of Milky Way disk, better distances to molecular clouds
  - Newly discovered dwarf galaxies orbiting M31
  - SNe pushing envelope of SN physics, especially SLSN
  - TDEs (cf. talks by R. Chornock and J. Guillochon)
  - Large scale structure from galaxies and clusters of galaxies
  - Weak lensing
  - High-z quasars

PS1 Survey is a gold mine of data at all scales, MUCH left to be mined, could be even better with PS1 + PS2! (But is the community interested?)

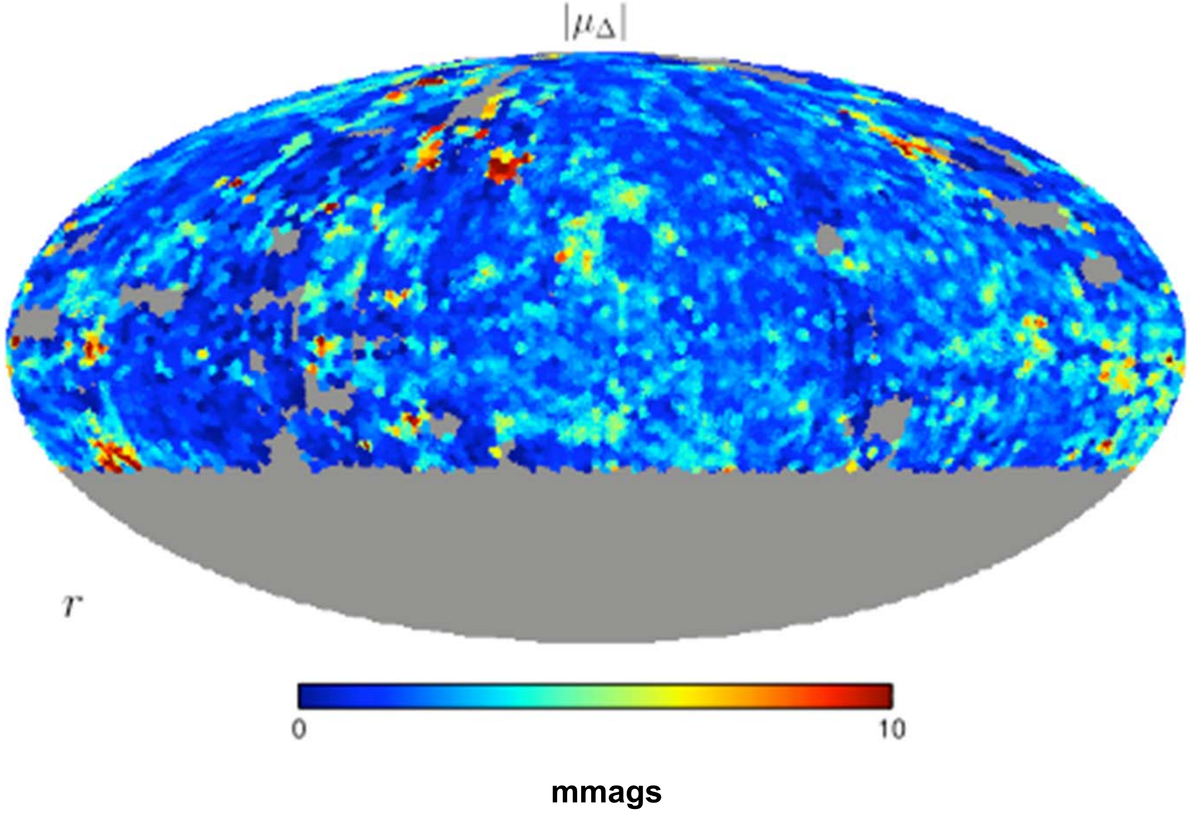
3π Sky Coverage as of Nov 2, 2013
grizy bands

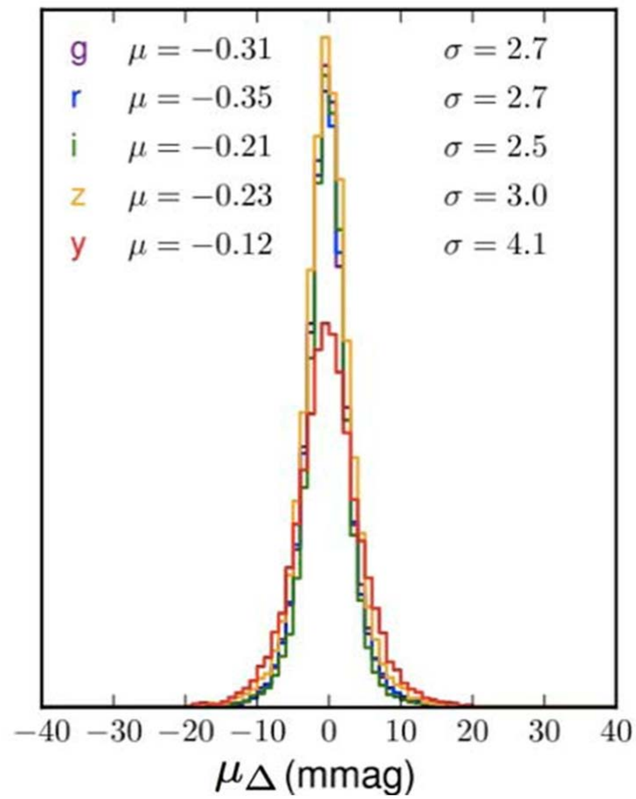


Courtesy K. Chambers

PS1 ZP rms (mmags) from Jan 2012 "Uber-Calibration"

(Schafly, Finkbiener, Magnier, et al. 2012)





- Zero point residuals of ~ 3 mmags (4 mmags in y-band)
- Using results from PS1, can re-calibrate SDSS to have a greater photometric precision and accuracy
- This is *amazing*, and it continues to improve with time!

PAndromeda: A Dedicated Deep Survey of M31 with PS1

- PIs: S. Seitz, R. Bender, M. Kodric, C.-H. Lee, A. Riffeser, J. Koppenhoefer, U. Hopp, C. Goessl, J. Snigula

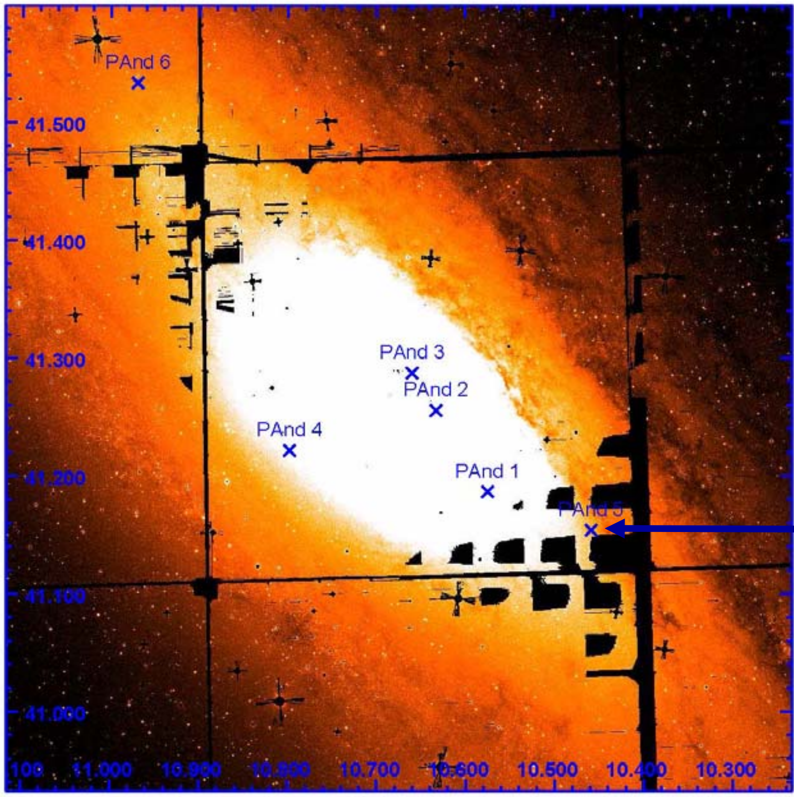
- Special observing cadence yields large sample sizes in relative terms of variable stars
  - Cepheids
  - Eclipsing Binaries
  - Luminous Blue Variables (LVBs)
  - M31 microlensing

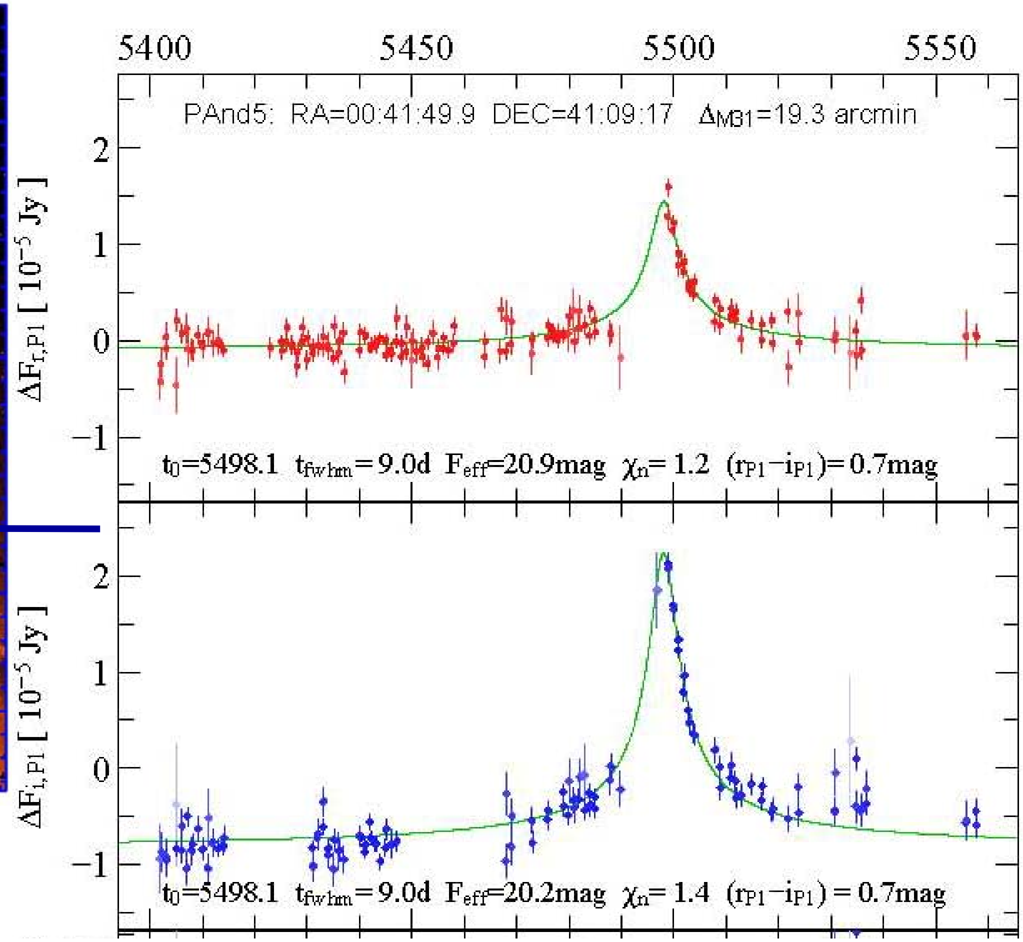
- Pandromeda "Data Release 2" will contain light curves for more than 2 million resolved sources

Microlensing Events in M31

- Gravitational microlensing is due to the gravitational lens effect of General Relativity
- Used to detect objects ranging from the mass of a planet to the mass of a star
- When a distant star or quasar gets sufficiently aligned with a massive compact foreground object, the bending of light due to its gravitational field leads to two distorted unresolved images resulting in an observable magnification **manifested as a transient brightening**
  - The time-scale of the transient brightening depends on the mass of the foreground object as well as on the relative proper motion between the background 'source' and the foreground 'lens' object
- The Pan-STARRS 1 (PS1) survey of M31 (PAndromeda) is designed to identify gravitational microlensing events caused by bulge and disk stars (self-lensing) and by compact matter in the halos of M31 and the Milky Way (halo lensing, or lensing by MACHOs)

Microlensing Events in M31





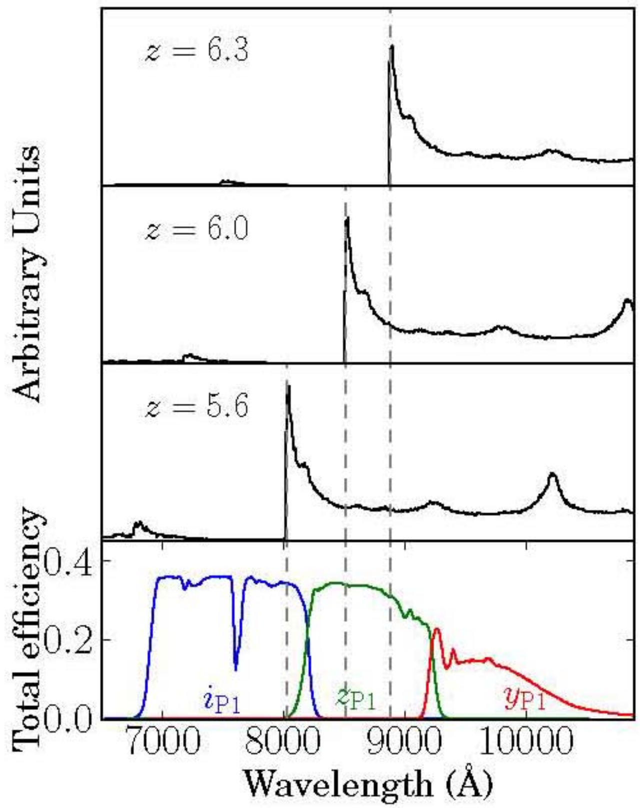
High-z Quasars

E. Bañados et al.

- High-z quasars are currently the only probe of SMH growth and evolution as well as unique tracers of the IGM at early times (z > ~5)
  - Shows the existence of SMBHs less than a gigayear after the Big Bang
  - Shows the presence of near complete Gunn-Peterson absorption, indicating a rapid increase in the IGM neutral fraction and the end of the reionization at z ~ 6-11 (so IGM rapidly changing during this period)
- Quasars with z > 6 and above are rare so a wide field optical survey with sufficient depth and multi-color imaging is ideal for identifying potential candidates for follow-up spectroscopy
  - In the last decade, ~60 quasars with 5.5 < z < 7 have been discovered by surveys such as SDSS and CFHQS
- Lower redshift quasars of z > ~2.5 (!) continue to also be of interest and PS1 survey ideal for increasing catalog and characterizing properties such as variability
- High-z Quasar PS1 team includes E. Bañados, E. Morganson, B. Venemans, F. Walter, R. Decarli, X. Fan, H-W. Rix, E. Farina, L. Jiang, K. Chambers

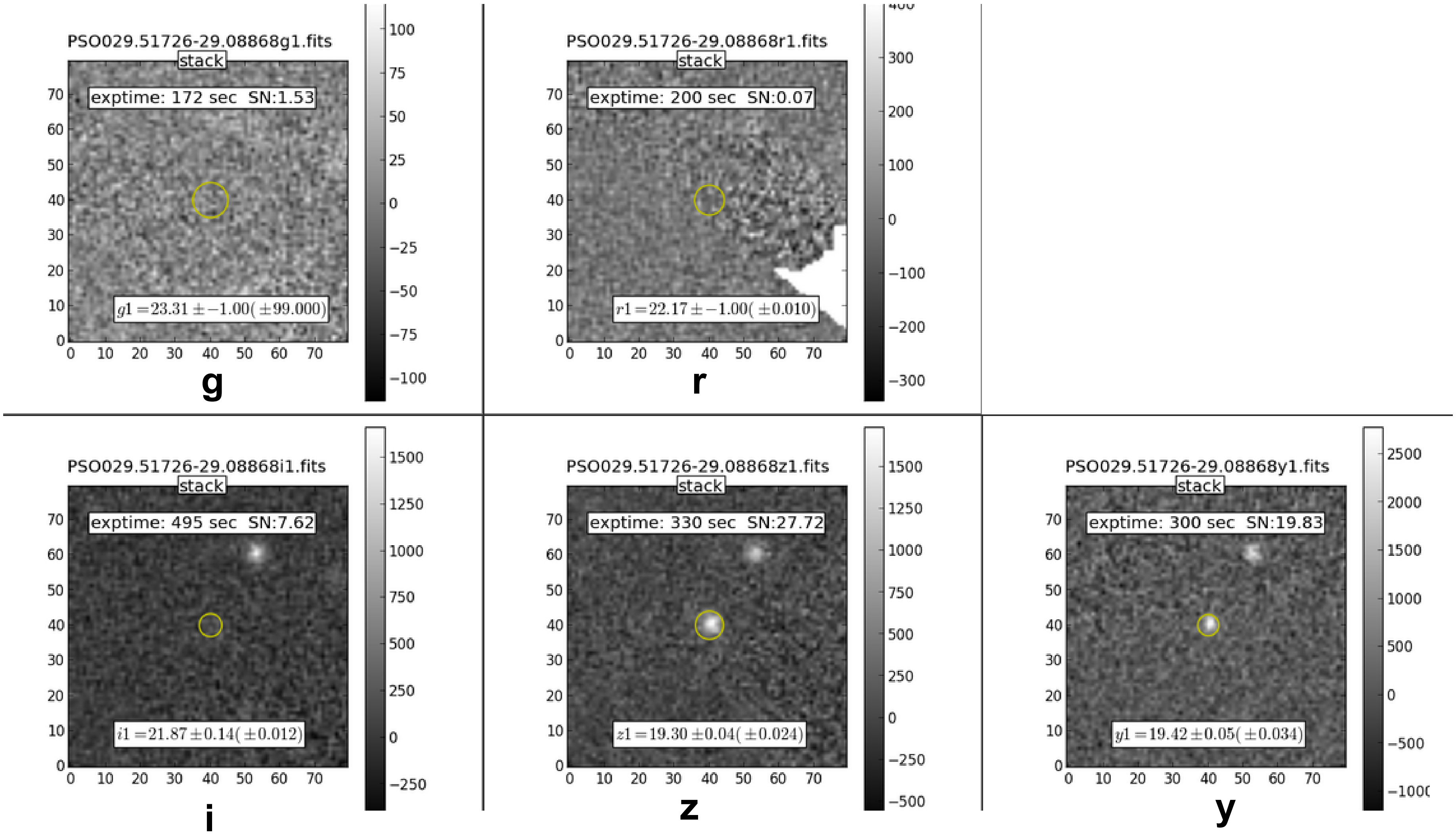
High-z Quasars

E. Bañados et al.



- Shift of Ly-α break with increasing z provides opportunity to select candidates photometrically from optical imaging
  - Of course, must understand precisely system response, atmospherics, etc.
- Inspect PS1 stacked and single epoch images, identify candidates, conduct follow-up photometry and spectroscopy

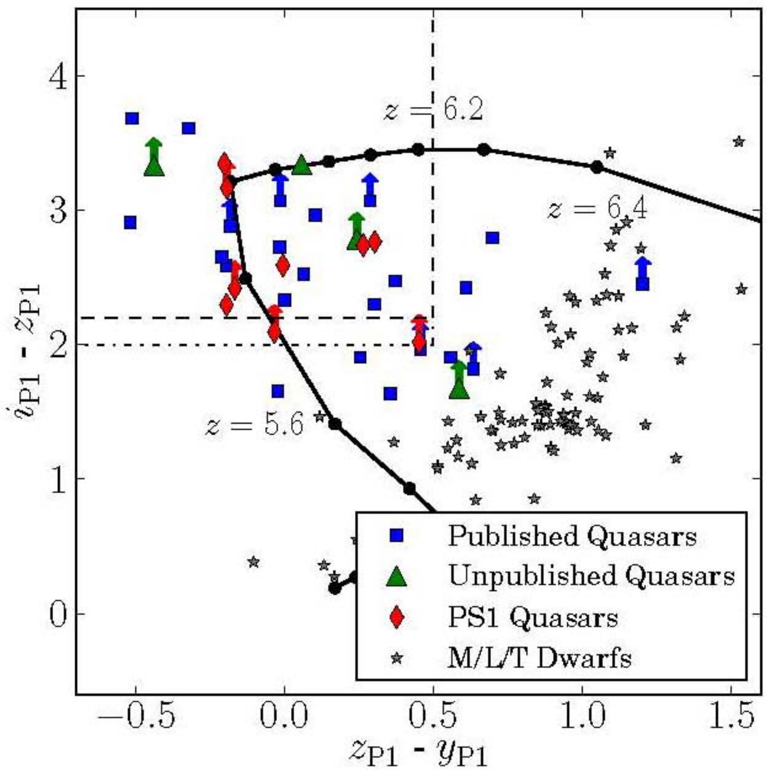
High-z Quasar Selection via Photometric Dropouts

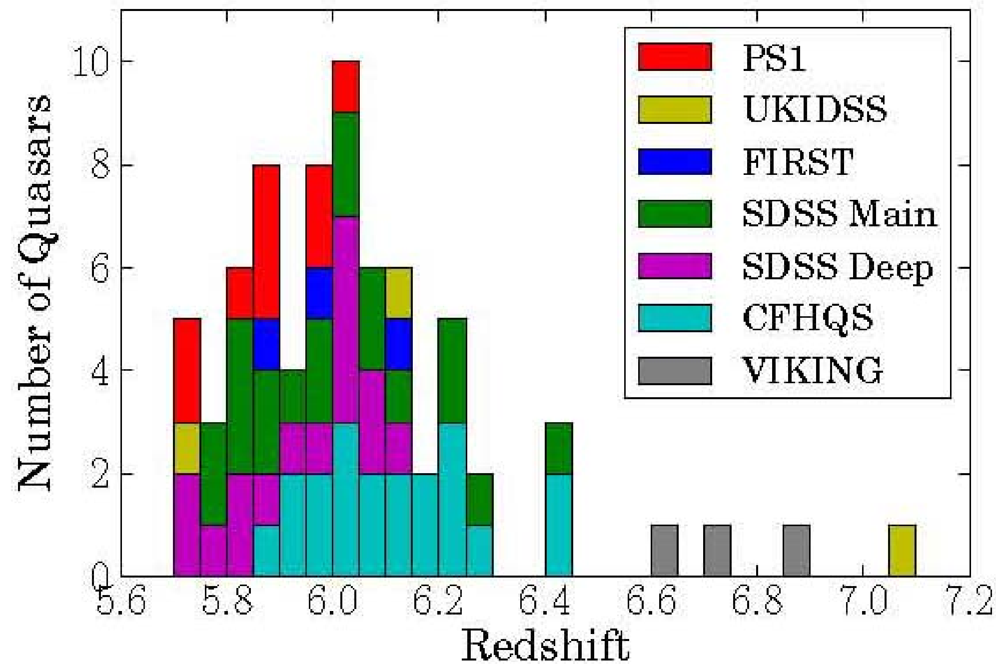


- i-band dropout good to z ~ 6
- z-band dropout for z ~ 7 (so use Pan-STARRS y-band)

High-z Quasars

E. Bañados et al. 2013





- Most recent PS1 results (Bañados et al., submitted to AJ Nov. 2013) present 8 newly discovered quasars with 5.7 < z < 6.0, representing ~10% of all known
- By end of PS1 survey, reasonable to expect an additional ~20, and hope for at least 1-2 at z~7

PS1 and Supernovae

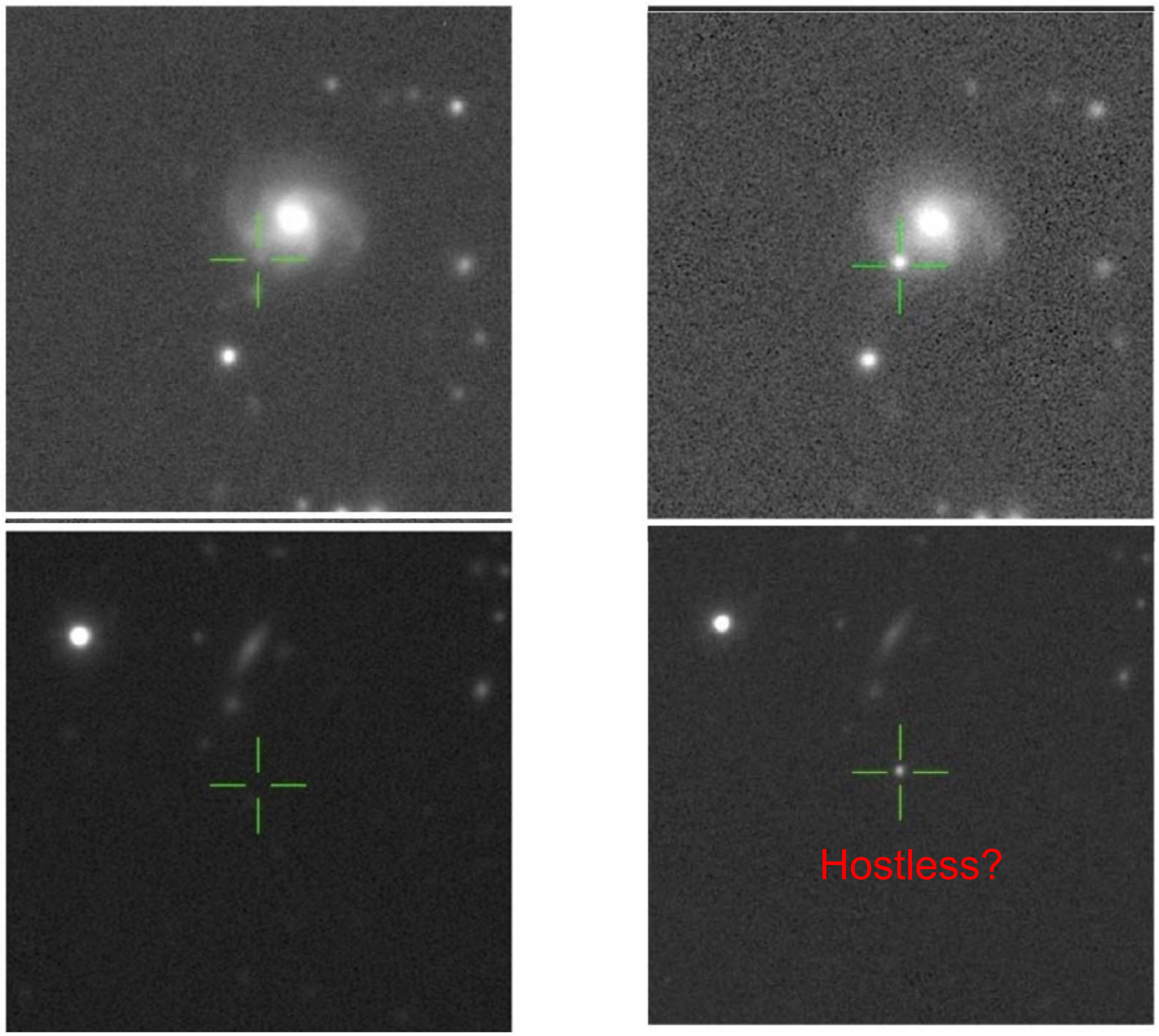
- PS1 has demonstrated high SNe detection rates out to moderate redshifts
  - Current rate of ~100-150 total transients per month
  - Many of these are rare objects of high interest to community
  - Follow-up resources around the world for spectra saturated by PS1 + PTF making it difficult to maximize potential science

- SNe samples increasing to extent that morphological studies of different types can be conducted with very interesting results already
  - Type Ia (especially important for cosmology)
  - Core collapse
    - Type Ib/Ic
    - Type IIp, IIn
  - SLSN

- After initial image processing with UH-IfA IPP, detection and photometric characterization using independent transient pipelines at CfA and at QUB
  - Team of many excellent scientists including R. Chornock, R. Foley, S. Gezari, L. Chomiuk, R. Kirshner, A. Rest, D. Scolnic, C. Stubbs, J. Tonry, E. Schlafly, D. Finkbeiner, M. McCrum, A. Pastorello, S. Smartt, S. Rodney, G. Narayan, A. Riess, E. Berger, R. Lunnan, N. Sanders, M. Huber, A. Soderberg, D. Thilker, M.-T. Botticella

SN in PS1 Images

Pre-supernova | Post-supernova



PS1 and SLSNe

"Typical" or "Normal" SNe

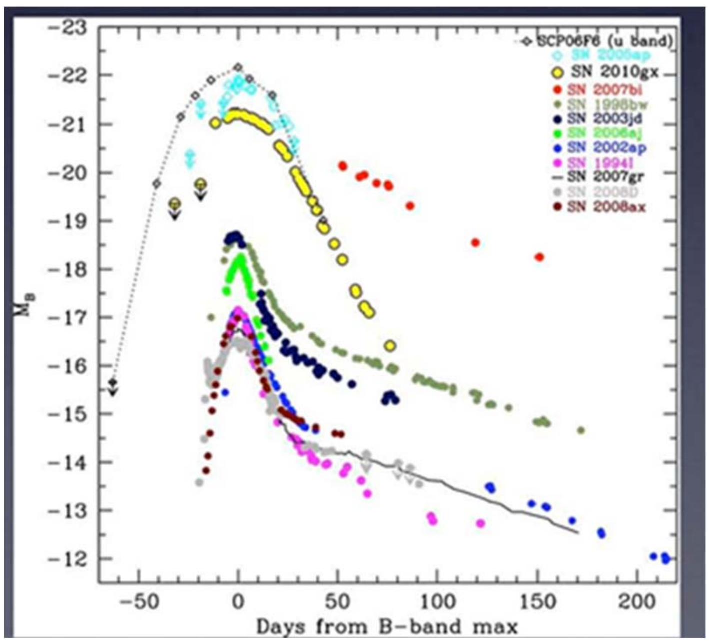
- L_{peak} ~ few x 10^{43} erg/s
- E_{rad} ~ few x 10^{49} erg
- E_{kin} ~ few x 10^{51} erg ?

"Superluminous" or "Ultraluminous" SNe

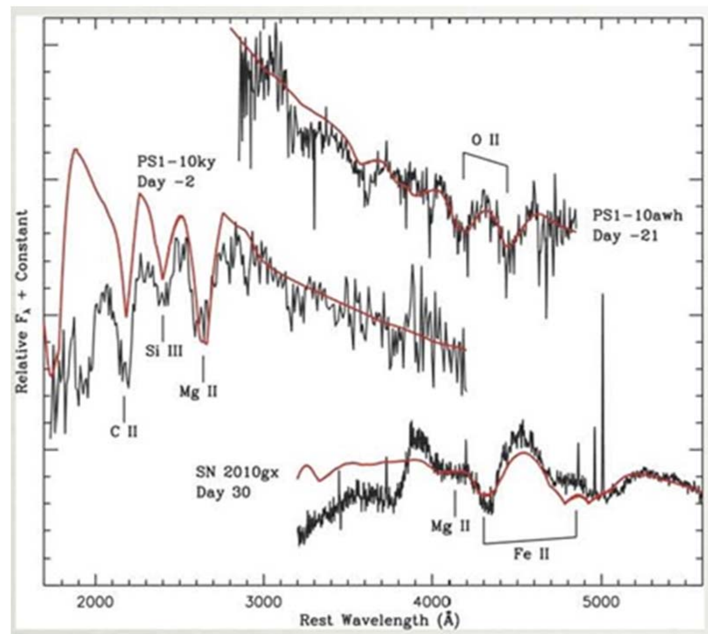
- L_{peak} ~ few x 10^{44} erg/s
- E_{rad} ~ few x 10^{51} erg
- E_{kin} ~ few x 10^{52} erg ?

SLSN Examples

Pastorello et al. 2010



Chomiuk et al. 2011



M_{bol} ~ -22.5, no H or He in spectra

PS1 and SLSNe

- Currently, 17 published PS1 SLSNe events
  - Most of these belong to the SLSNe-I sub class.
  - PS1-11ap is an exception, it's of the slowly evolving type a Ia SN2007bi
  - PS1-10afx is an oddball one that doesn't have a satisfactory typing
  - PS1-11bam is the object with highest *published* redshift of z=1.565)
    - However, PS1-12bmy is at z=1.572
  - At least 3 additional strong candidates

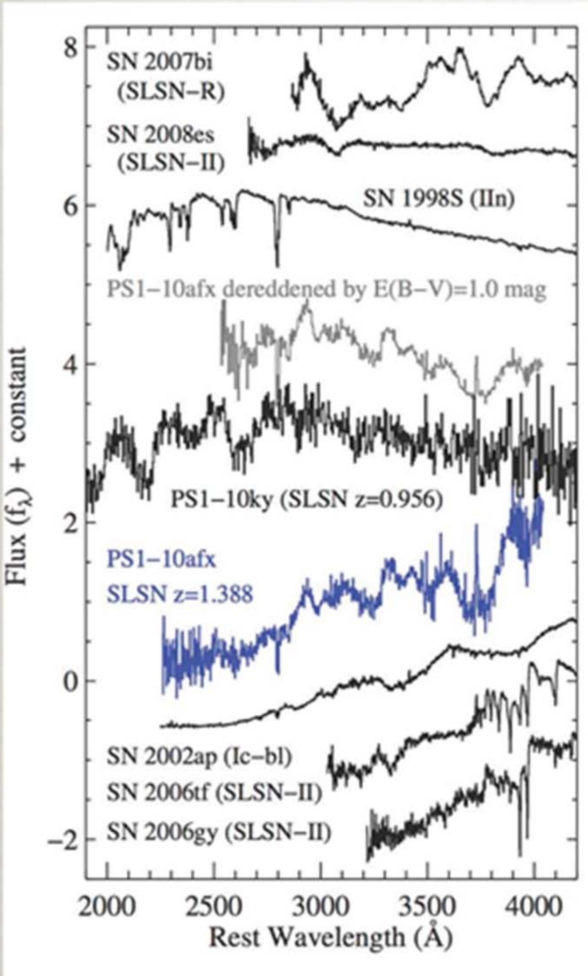
- What the heck are these anyway? Magnetar progenitors? Relationship to long-duration GRBs? Relationship to host environment? Detection strategies leveraging “hostless transients” (see upcoming paper by M. McCrum)

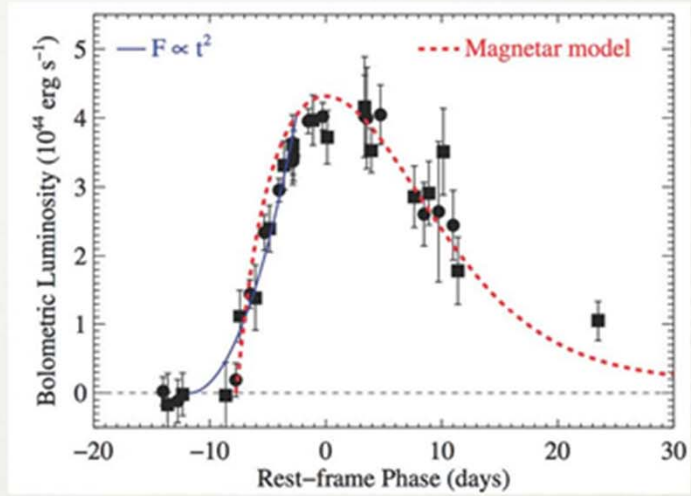
- Papers

PS1-10ky	Chomiuk et al. (2011)
PS1-10awh	"
PS1-11bam	Berger et al. (2012)
PS1-10afx	Chornock et al. (2013)
PS1-11ap	McCrum et al. (2013)
PS1-10pm	McCrum et al. (2014, in prep.)
PS1-10bzj	Lunnan et al. (2013)
PS1-11xk	Inserra et al. (2013)
PS1-12fo	"

PS1-11tt , PS1-11aib , PS1-11afv , PS1-11bdn , PS1-12bmy, PS1-12zn, PS1-12bqf , PS1-13gt
All in prep.

PS1-10afx: A New Type of SLSN



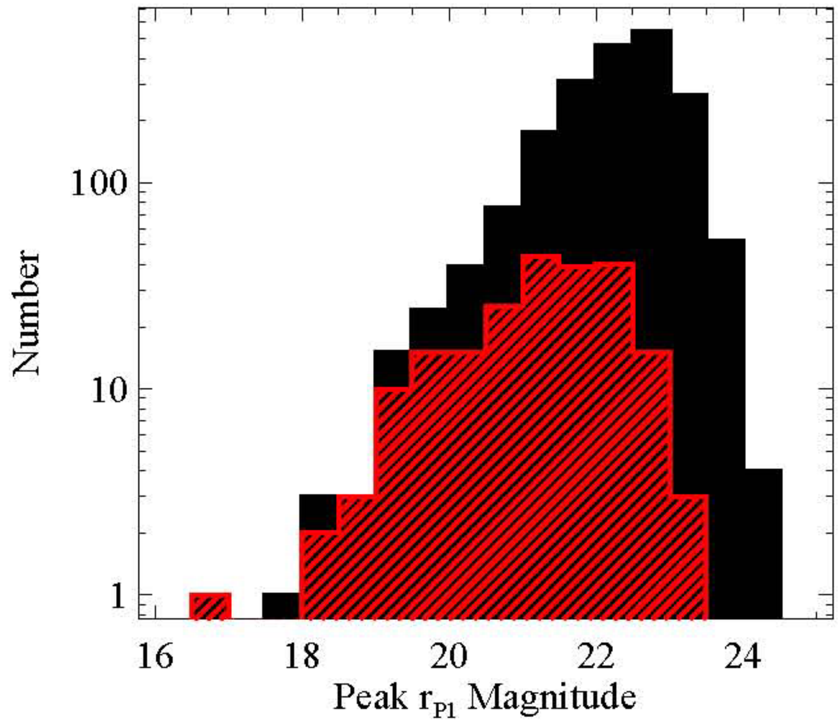


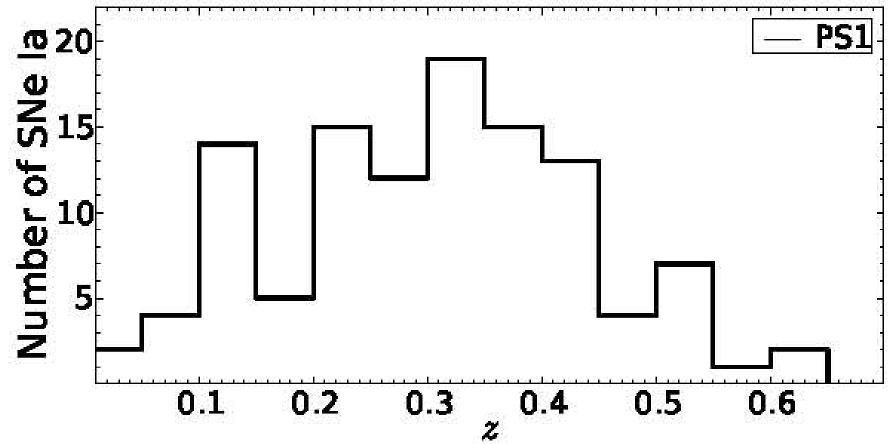
- Peak L_{bol} ~ 4.1 × 10^{44} erg/s
- Spectra unlike any other SLSN
- Very fast rise time (<12 d)
- No existing model works

Chornock et al., 2013

PS1 Cosmology Constraints from First 1.5 Years

A. Rest et al. (arXiv 1310.3828v1), D. Scolnic et al. 2013 (arXiv 1310.3824v1)





- 112 PS1 Type Ia SNe conservatively selected from 146 spec. confirmed
- Add 201 previously known low-z Type Ia Sne as robust anchor

Black: From ~1700 good candidates here, 400+ very likely Type Ia

Red: 146 spectroscopically confirmed

- Observed Sep 2009 – May 2011
- 5σ detection limit to m < 24 (*g, r, i, z*)
- ~1.2% absolute photometry

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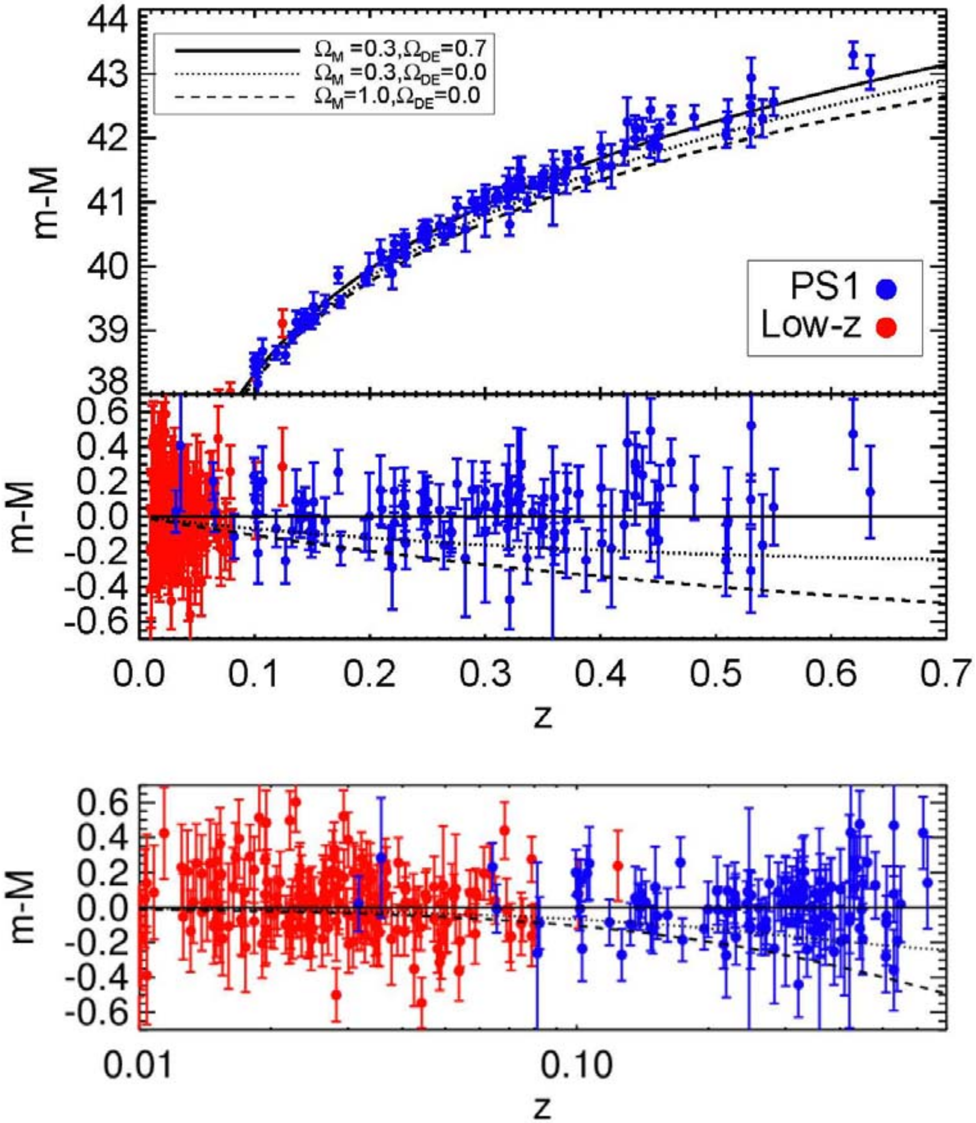

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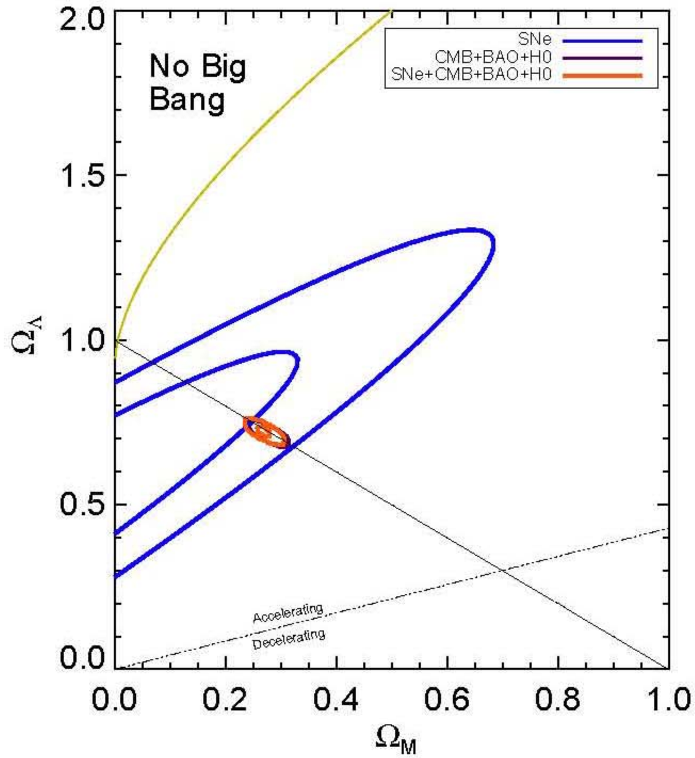
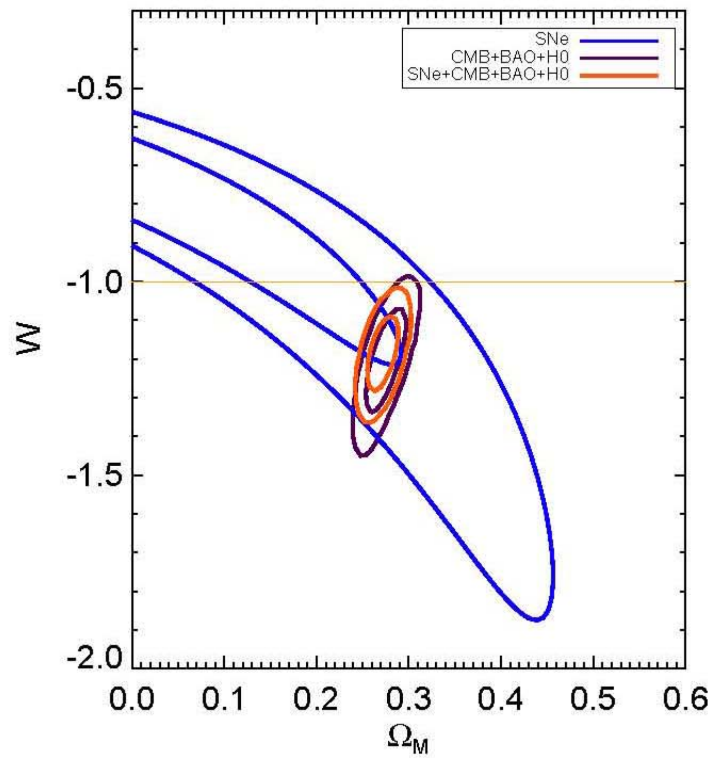
Constraints on Ω_M and Ω_Λ assuming a cosmological constant ($w = -1$)



Constraints on Ω_M and w assuming a constant DE EOS and flatness



- The 1σ and 2σ cosmological constraints using PS1/low-z, Planck, BAO and H_0 measurements with both the statistical and systematic uncertainties are propagated.
- These confidence contours will shrink significantly as PS sample size grows and systematics are further reduced, especially from benefits of combining with NIR (cf. R. Kirshner's talk)

PS1 Cosmology Constraints from First 1.5 Years

A. Rest et al. (arXiv 1310.3828v1), D. Scolnic et al. 2013 (arXiv 1310.3824v1)

- Using PS1/low-z sample only, and assuming Ω = 1,

  $w = -1.015 \ +0.319/-0.201(\text{Stat}) \ +0.164/-0.122\ (\text{Sys})$

- Cosmological parameter constraints using combinations from different probes/experiments:
  PL (Planck Collaboration 2013), BAO (Blake et al., 2011), H_0 (Riess et al., 2011)

Sample	Without PS1/Low-z		With PS1/Low-z (Stat+Sys)	
	Ω_M	w	Ω_M	w
PL	**0.218** $+0.023/-0.079$	**−1.485** $+0.253/-0.426$	**0.272** $+0.020/-0.023$	**−1.173** $+0.084/-0.080$
PL + BAO	**0.287** $+0.021/-0.020$	**−1.133** $+0.138/-0.104$	**0.284** $+0.013/-0.014$	**−1.149** $+0.078/-0.072$
PL + H_0	**0.258** $+0.016/-0.021$	**−1.240** $+0.095/-0.093$	**0.264** $+0.013/-0.015$	**−1.195** $+0.069/-0.066$
PL + BAO + H_0	**0.275** $+0.014/-0.014$	**−1.205** $+0.102/-0.087$	**0.277** $+0.010/-0.012$	**−1.186** $+0.0076/-0.065$

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PL + BAO + H_0	**0.275** $+0.014/-0.014$	**−1.205** $+0.102/-0.087$	**0.277** $+0.010/-0.012$	**−1.186** $+0.0076/-0.065$

PS1 Cosmology Constraints from First 1.5 Years

A. Rest et al. (arXiv 1310.3828v1), D. Scolnic et al. 2013 (arXiv 1310.3824v1)

- When combining PS1/low-z SNe with CMB only, using WMAP9 CMB constraints instead of those from Planck yields

  $w = -1.142 \ +0.076/-0.087$

  which reduces the discord to $< 2\sigma$

- When combined with (Planck + BAO + H_0), the value of w is inconsistent with the cosmological constant $w = -1$ at the 2.4σ level
  - This tension has been seen in other high-z SN surveys and persists after removing either the BAO or H0 constraint

- Cannot yet decide whether the tension with ΛCDM is a feature of dark energy, new physics, or a combination of random and statistical errors
  - The full PS1 survey sample will be ~3 times larger as the sample here (so, ~400 robust Type Ia), and should provide more conclusive indications

N.B. : While these two papers have been submitted for publication and posted on the arXiv, the final numbers to be published are still a bit in flux (will be re-submitted). Now looks a bit more like 1.5σ tension with ΛCDM when combining with only Planck rather than the 2σ in the table above, but remains ~2.5σ with ΛCDM when combined with (Planck+BAO+H_0)

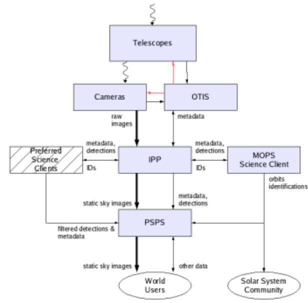
PS1: What's Coming?

- Many more transients
- Static Sky
  - Clustering and correlation papers now beginning to appear with additional ones in work
    - Interesting results vs. color and SFR/sSFR
    - Hoping for a cluster catalog before data becomes public
  - Possible new ISW result
    - Effort led by I. Szapudi
    - As a serendipitous result, possible discovery of new void behind the Cold Spot (but *very* preliminary and being rigorously checked)
  - Weak lensing
  - Really need good photo-z, lots of progress has been made, but still more needed
    - Started at $\delta z/(1+z) \approx 0.06 - 0.07$ (not acceptable)
    - Now achieving $\delta z/(1+z) \approx 0.03 - 0.05$, consistency/uniformity should improve further

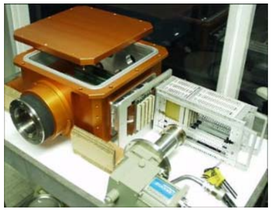
Pan-STARRS Roadmap

Pan-STARRS Development and Evolution

- Design, development, infrastructure, and testing (2003-2006)

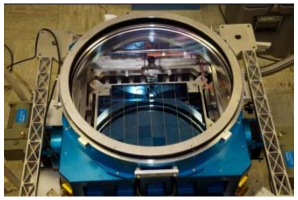


TC 3
360 Mpix

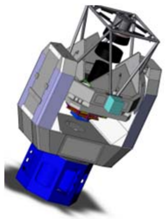


- PS1 (2010 – 2014)
  - Integration and Commissioning (2006 – 2008, 2009)
  - 3.5 year mission (2010 – 2013)

GPC 1
1.4 Gpix

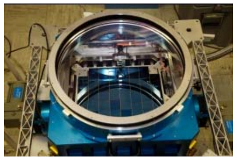
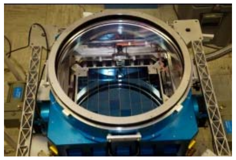


- PS1+2 Survey (2014 – ???)
  - Improved telescope/optics
  - Improved camera/CCDs
  - Multiple tel/cam control

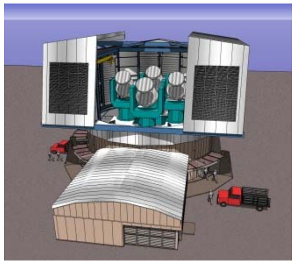



PS1 + PS2

GPC 1 & 2
2.8 Gpix

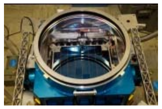



- PS-4
  - Development and Construction (???)
  - PS4 10-yr Mission (???)



GPC 1, 2, 3, 4
5.6 Gpix

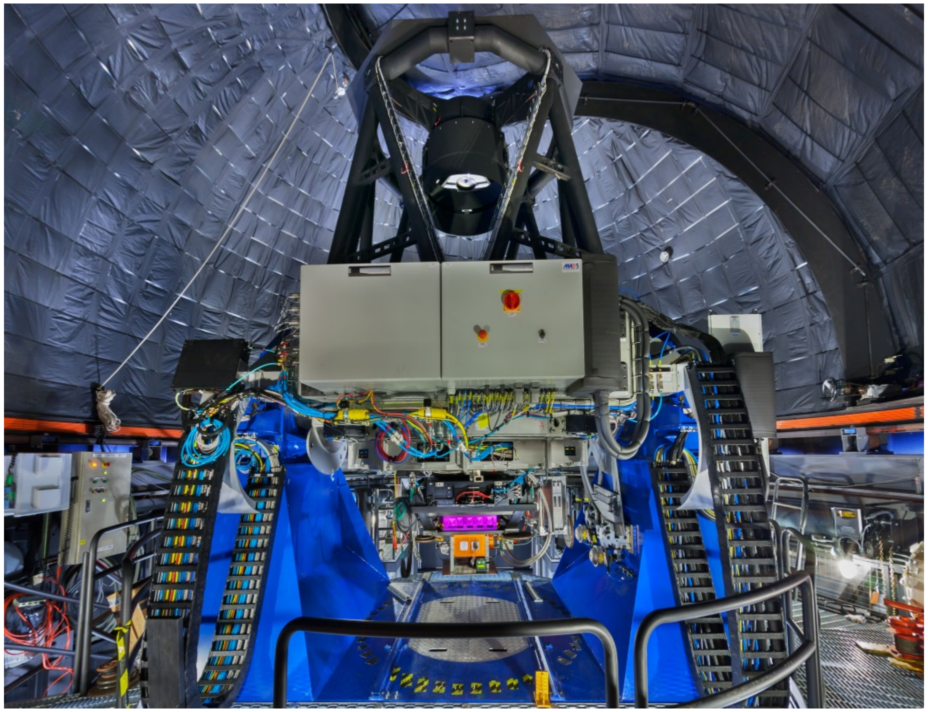





Pan-STARRS Status as of December 2013

- PS1 has achieved most of its initial performance and science goals
  - Currently the world's most comprehensive optical survey system
  - World leader in discovering extragalactic optical transients
  - Static sky results just now emerging to provide significant tests of ΛCDM (e.g., correlation functions, weak lensing, ISW, etc.)
  - ***Public database hosted by STScI available by early 2015***

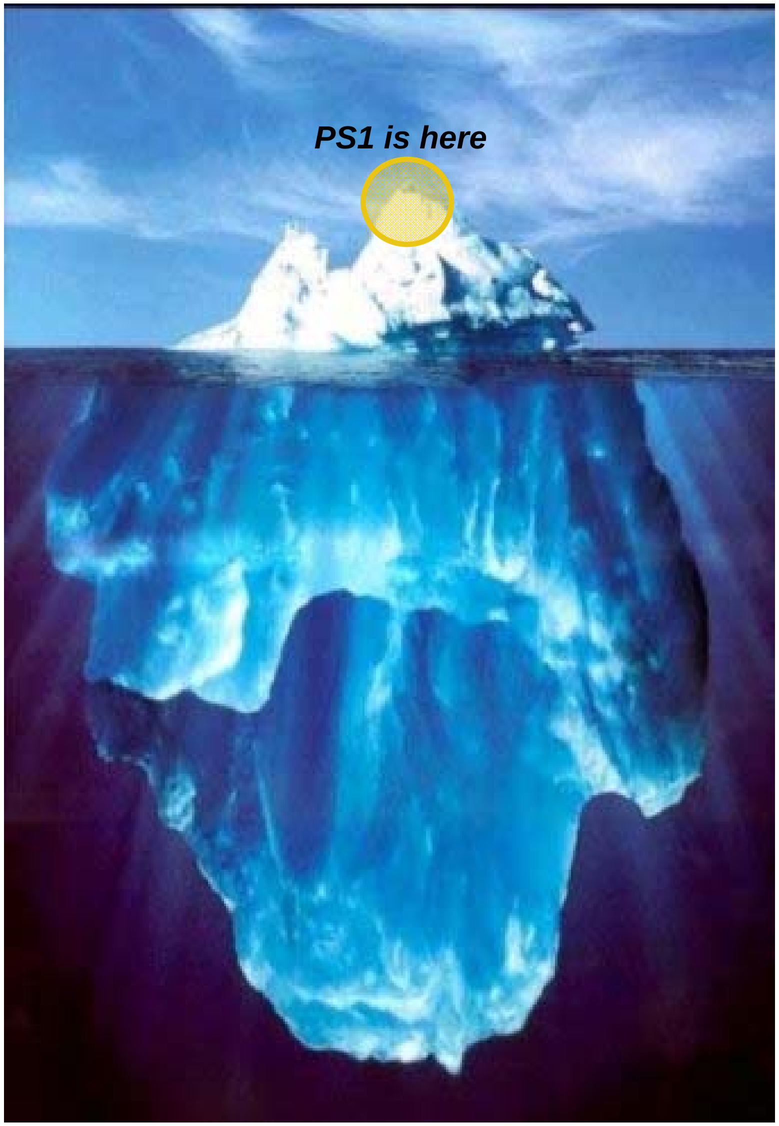
- PS1+PS2
  - PS2 integration and testing in 2013
  - PS2 operational readiness in 2014
  - PS1+PS2 potentially world's work horse survey system pre-LSST
  - Similar AΩ to DES, high res, rapid readout

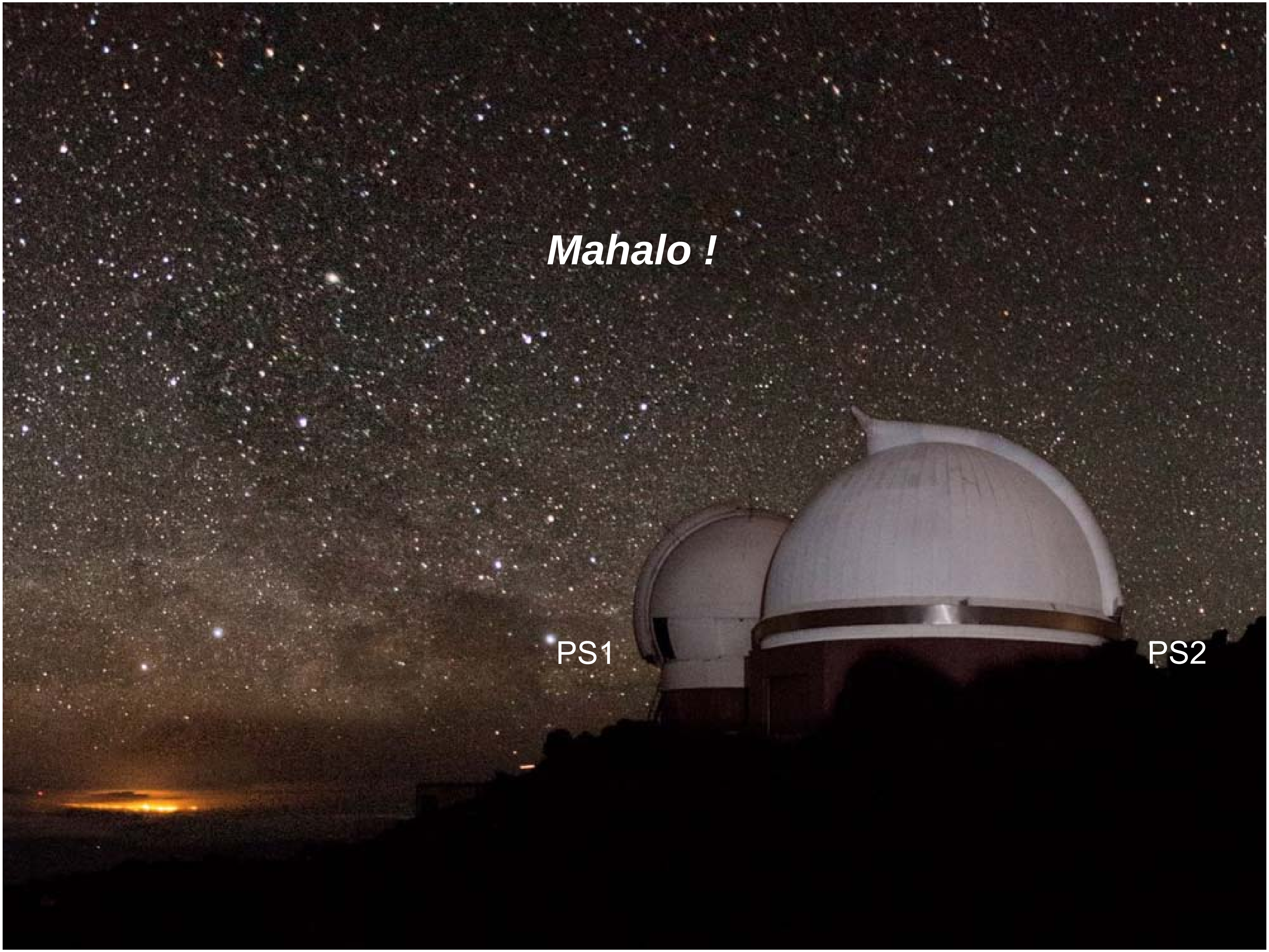


PS2 Commissioning Image of Crab Nebula in g-band

Early PS1 Results: The Tip of the Tip of the PS1+PS2 Iceberg!

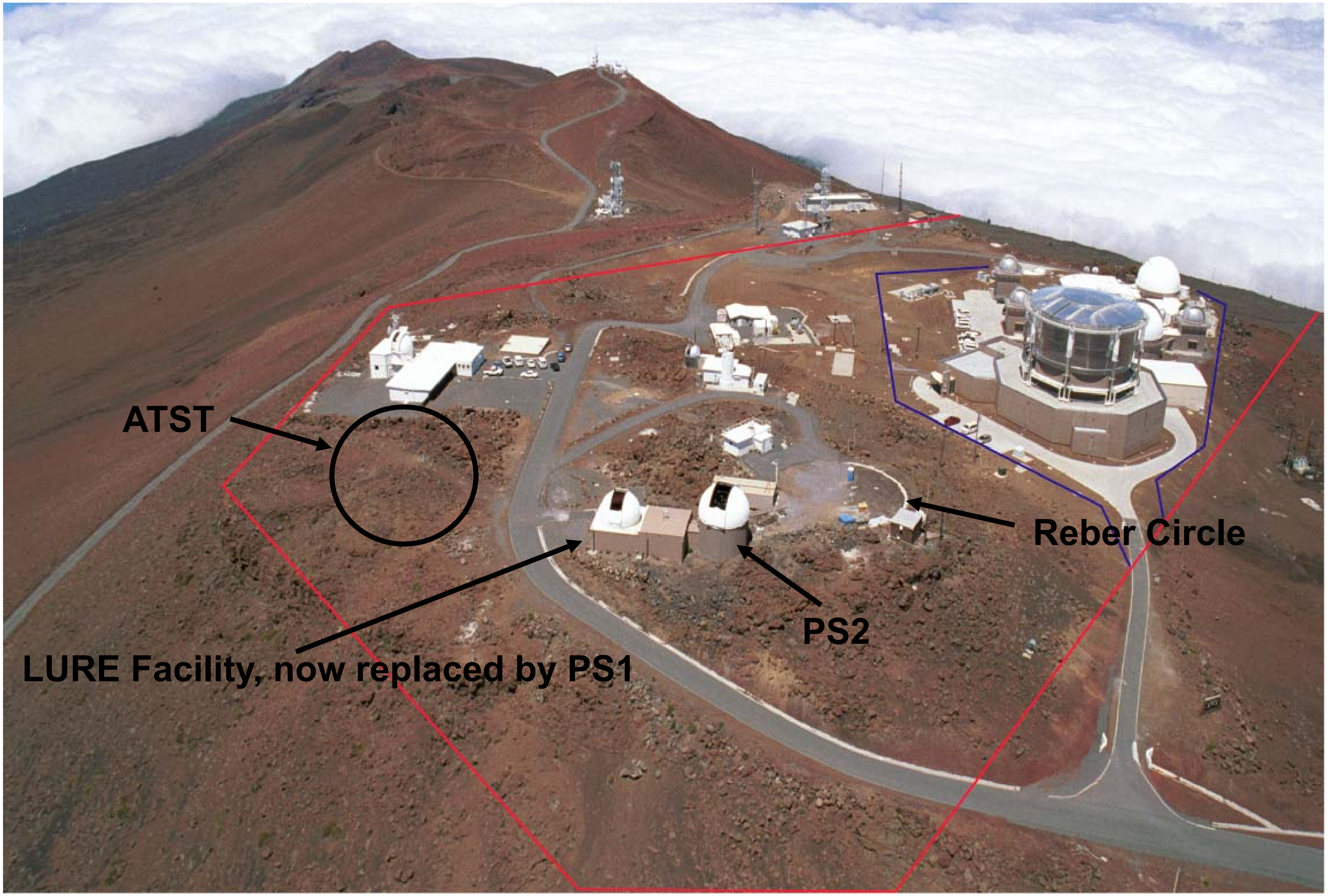
(Please do not let this wonderful asset be wasted)



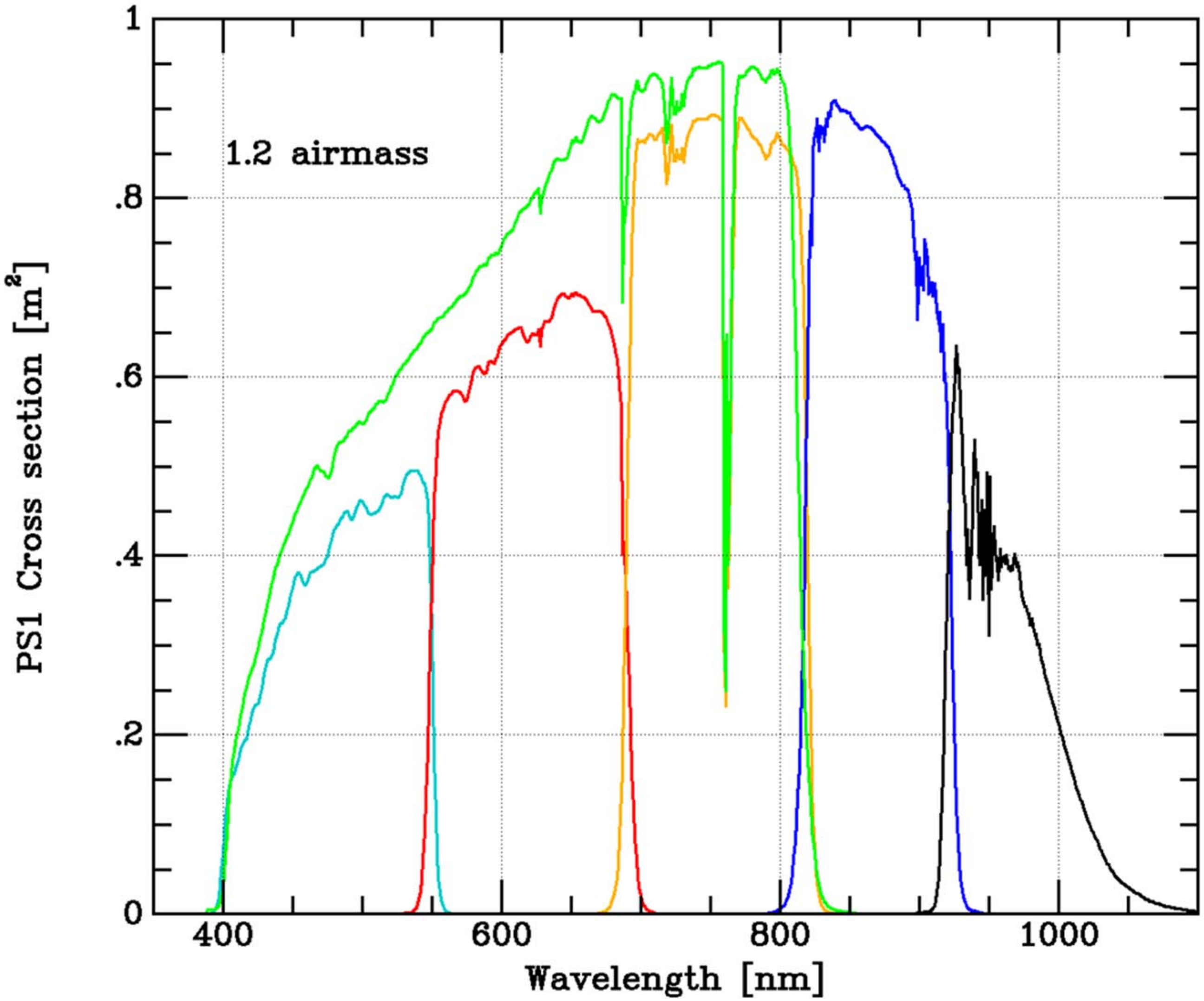

Mahalo !
PS1
PS2

Supplemental Material

Haleakala High Altitude Observatory Site
(before PS1)

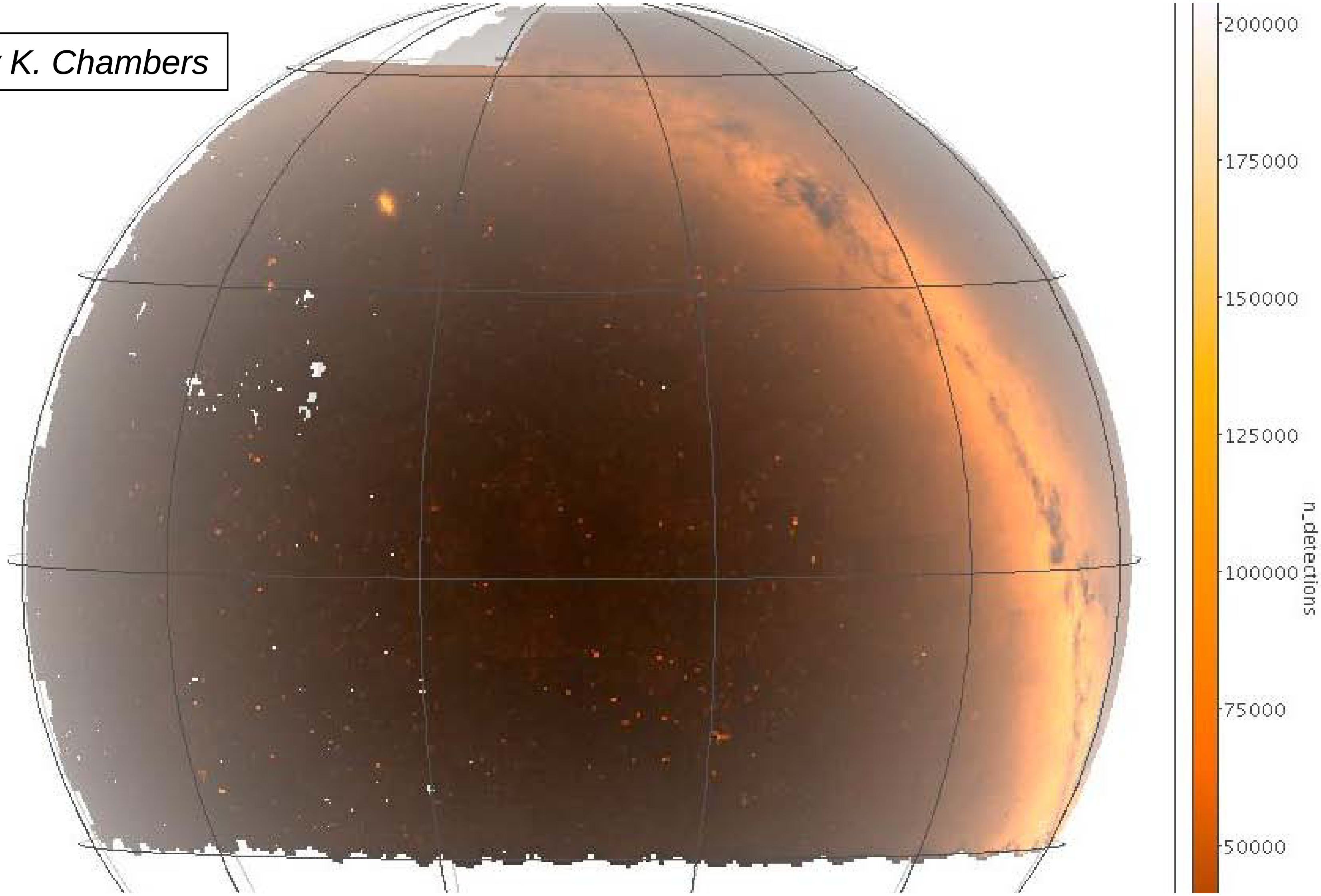


PS1 Filter Bandpasses



PS1 Detections as of March 18, 2013

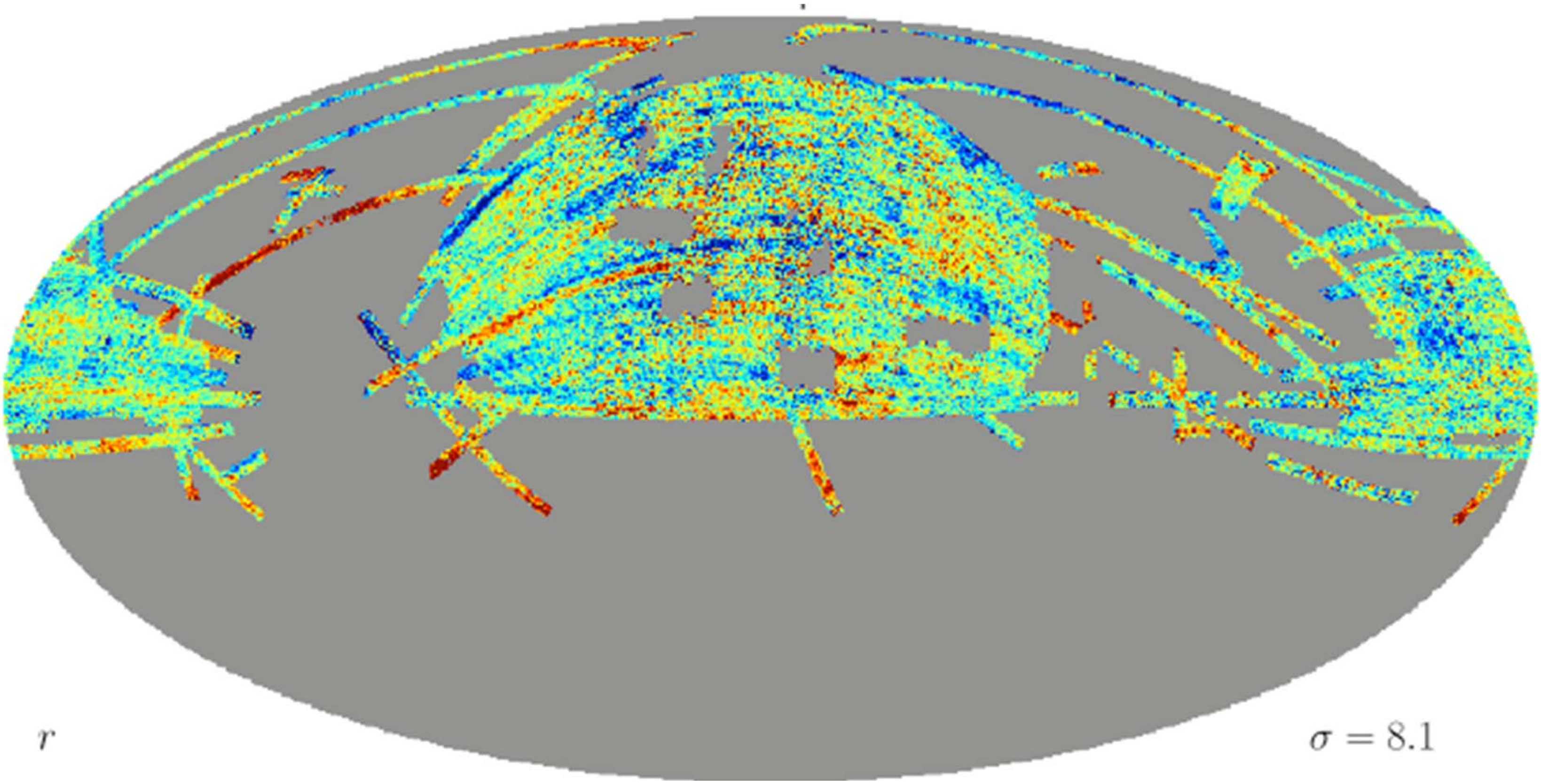
Courtesy K. Chambers



PS1 has collected data for more than 500 million stars in the Milky Way

PS1 Photometry: PS1 vs SDSS

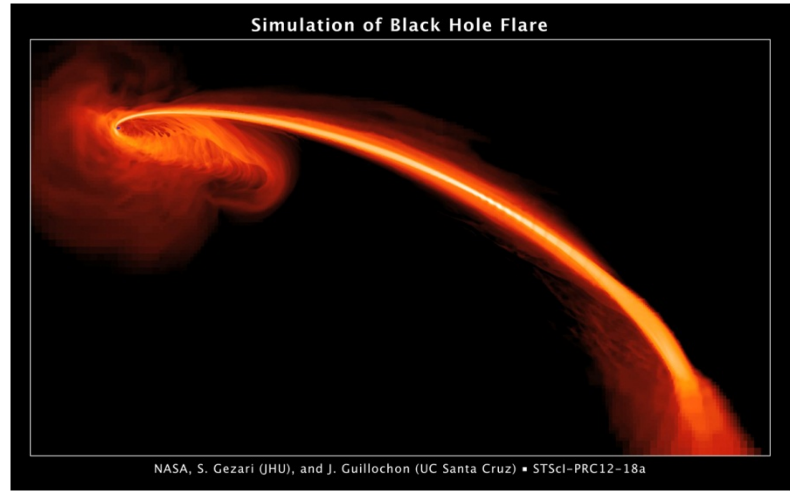
In 2003, photometry state-of-the-art of ~20 mmags from SDSS



- RMS differences of 8 millimags in r –band with the differences…
  - Dominated by the SDSS observing pattern (stripes)
  - Primarily due to systematic errors in SDSS photometry
- Using results from PS1, can re-calibrate SDSS to have a greater photometric precision and accuracy

Black Hole Swallows Star as Seen by PS1 and GALEX

For the first time, scientists have identified a stellar victim of a giant black hole at the center of a galaxy – an unlucky star whose death may ultimately provide more clues on the inner workings of the enigmatic gravitational monster that devoured it. Scientists first caught a supermassive black hole red-handed in a stellar murder last year. Now researchers have determined not only the culprit in a similar cosmic homicide but the casualty as well: a star rich in helium gas.

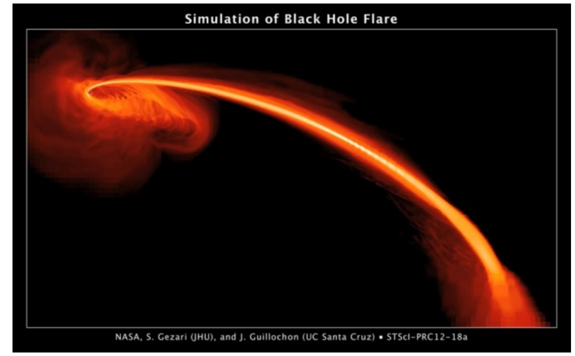


Followed by the Hawaiian Pan-STARRS-1 and NASA GALEX telescopes, the bursts of radiation emitted by the event are so clearly recorded that S. Gezari (JHU) and her co-workers have been able to perform a cosmic post mortem, piecing back together the final months of the doomed star's life. What the data suggest is that the star in the constellation Draco was a red giant when it met its end by getting too close to the black hole.

At a distance equivalent to about the orbit of Pluto from the Sun in our own system, the outer hydrogen layer of the star was stripped away, leaving just the helium core. In this state, roughly a third of its former size and with a quarter of its mass remaining, this stellar cinder continued its deadly approach. At a distance from the black hole of 50 million kilometers, equivalent to the orbit of Mercury from the Sun, and travelling about 32 million kilometres per hour, the huge gravitational tidal forces of the black hole tore the helium core to pieces. Half the material was sent spinning away into space; the rest was consumed. And as it fell into the black hole about two months later, the material was heated, triggering the light show seen by Gezari and her team and reported this week in the May 7 edition of Nature. (Text from Space. Com and Science News Archives)

Black Hole Swallows Star as Seen by PS1 and GALEX

- *Scientists first caught a supermassive black hole red-handed in a stellar murder last year, but could only identify the stellar remains after the deed had been done (check references)*
- *Now, for the first time*, scientists have identified a stellar victim of a giant black hole at the center of a galaxy, identifying both the culprit in a similar cosmic homicide and the casualty as a star rich in helium gas, most probably a red giant



- *Followed by the Hawaiian Pan-STARRS-1 and NASA GALEX telescopes*, the bursts of radiation emitted by the event are so clearly recorded that S. Gezari (JHU) and her co-workers have been able to perform a cosmic post mortem, piecing back together the final months of the doomed star's life.
- The data suggest that the star in the constellation Draco when it met its end by getting too close to the black hole so that the strong tidal forces from the black hole disrupted the star even before the black hole consumed roughly half of the star's material
    - First, at a distance equivalent to about the orbit of Pluto from the Sun in our own system, the outer hydrogen layer of the star was stripped away, leaving just the helium core.
- In this state, roughly a third of its former size and with a quarter of its mass remaining, this stellar cinder continued its deadly approach.
- At a distance from the black hole of 50 million kilometers, equivalent to the orbit of Mercury from the Sun, and travelling about 32 million kilometers per hour, the huge gravitational tidal forces of the black hole tore the helium core to pieces.
    - Half the material was sent spinning away into space; the rest was consumed. And as it fell into the black hole about two months later, the material was heated, triggering the light show seen by Gezari and her team and reported this week in the May 7, 2012 edition of Nature.

PS1 Systematic Error Budget

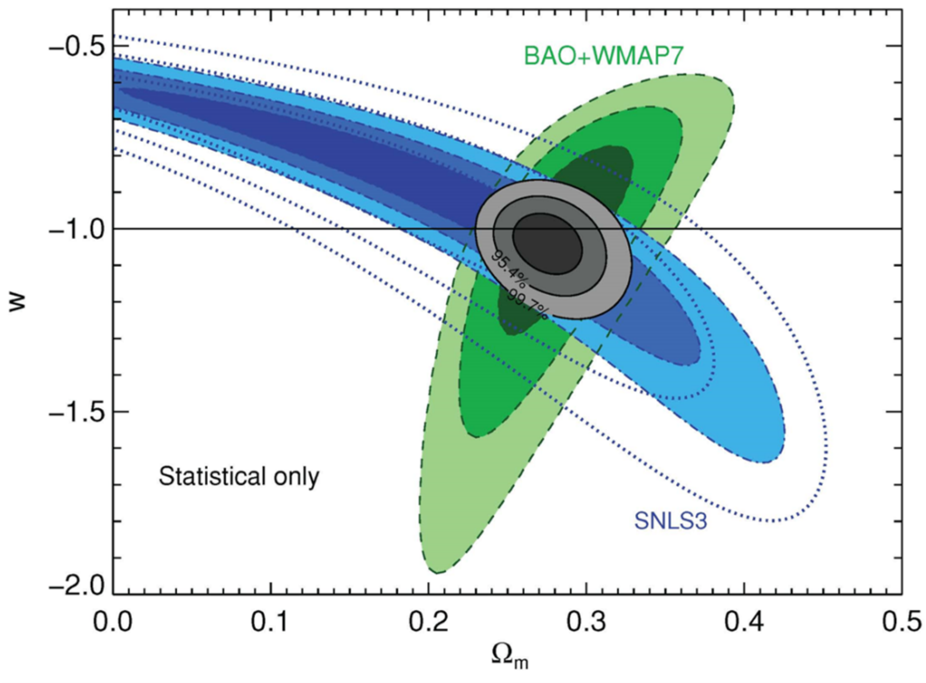
TABLE 3
DOMINANT SYSTEMATIC UNCERTAINTIES FOR PS1 SNIA SAMPLE

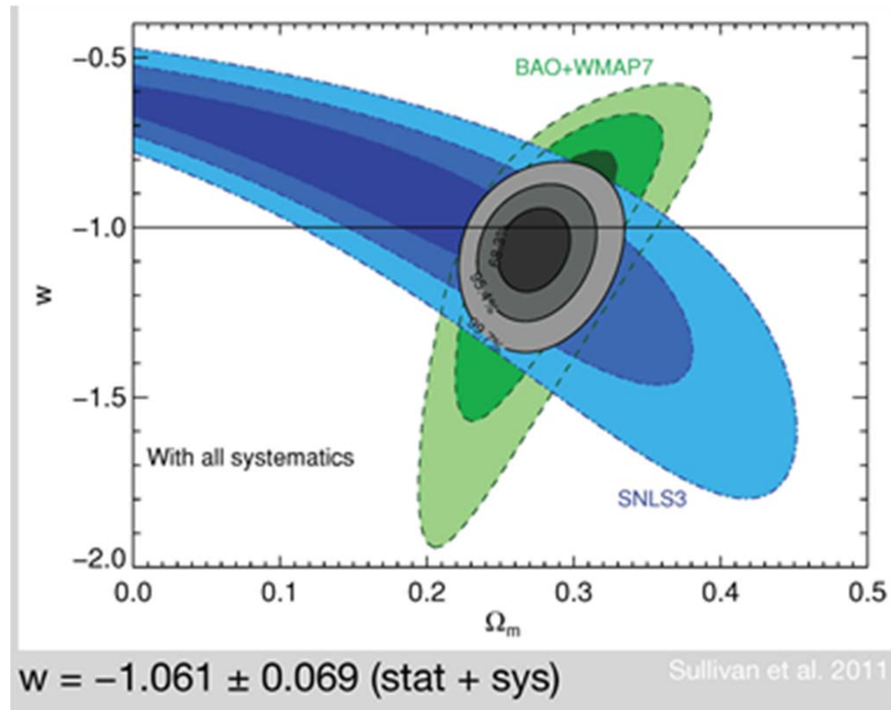
Error	Error Mag.	Ω_m	w	Rel. Area
Statistical	-	$0.284\pm^{-0.036}_{0.034}$	$-0.923\pm^{0.090}_{0.090}$	1.000
Statistical+Systematics	-	$0.276\pm^{-0.034}_{0.036}$	$-0.939\pm^{0.125}_{0.128}$	1.514
+Calibration	-	$0.280\pm^{-0.040}_{0.030}$	$-0.903\pm^{0.116}_{0.117}$	1.329
+Selection Bias	-	$0.284\pm^{-0.036}_{0.034}$	$-0.923\pm^{0.090}_{0.090}$	1.005
+Coherent Flow Correction	-	$0.283\pm^{-0.037}_{0.033}$	$-0.923\pm^{0.090}_{0.090}$	1.026
+Milky Way Extinction	-	$0.284\pm^{-0.036}_{0.034}$	$-0.924\pm^{0.091}_{0.089}$	1.005
+β Bias	-	$0.283\pm^{-0.037}_{0.033}$	$-0.920\pm^{0.094}_{0.093}$	1.081
+Host Galaxy Mass	-	$0.275\pm^{-0.035}_{0.035}$	$-0.954\pm^{0.107}_{0.106}$	1.121

Scolnic et al. 2013

Constraints on w as of 2011

Sullivan et al. 2011





PS1 Survey Data Publicly Available from STSCI

- Will leverage experience from current infrastructure of Mikulski Archive for Space Telescopes (MAST)
  - MAST is very heavily used
    - ~ 5000 users, 18 million searches/month,
    - 16 TB/month of data downloaded
- PS1 Survey requires a new scale of infrastructure, but MAST experience is relevant
  - MAST holdings currently ~ 250 TB
  - PS1will be ~ 2000 TB
- High level schedule
  - Transfer and Ingest complete copy of PSPS DR2 Nov 2013
  - Start shipping (data-loaded) disks from Hawaii to STScI Jul 2014
  - All disks arrive at STScI, hardware+software integration begins Sep – Jan 2014
  - Public PS1 archive opens early 2015