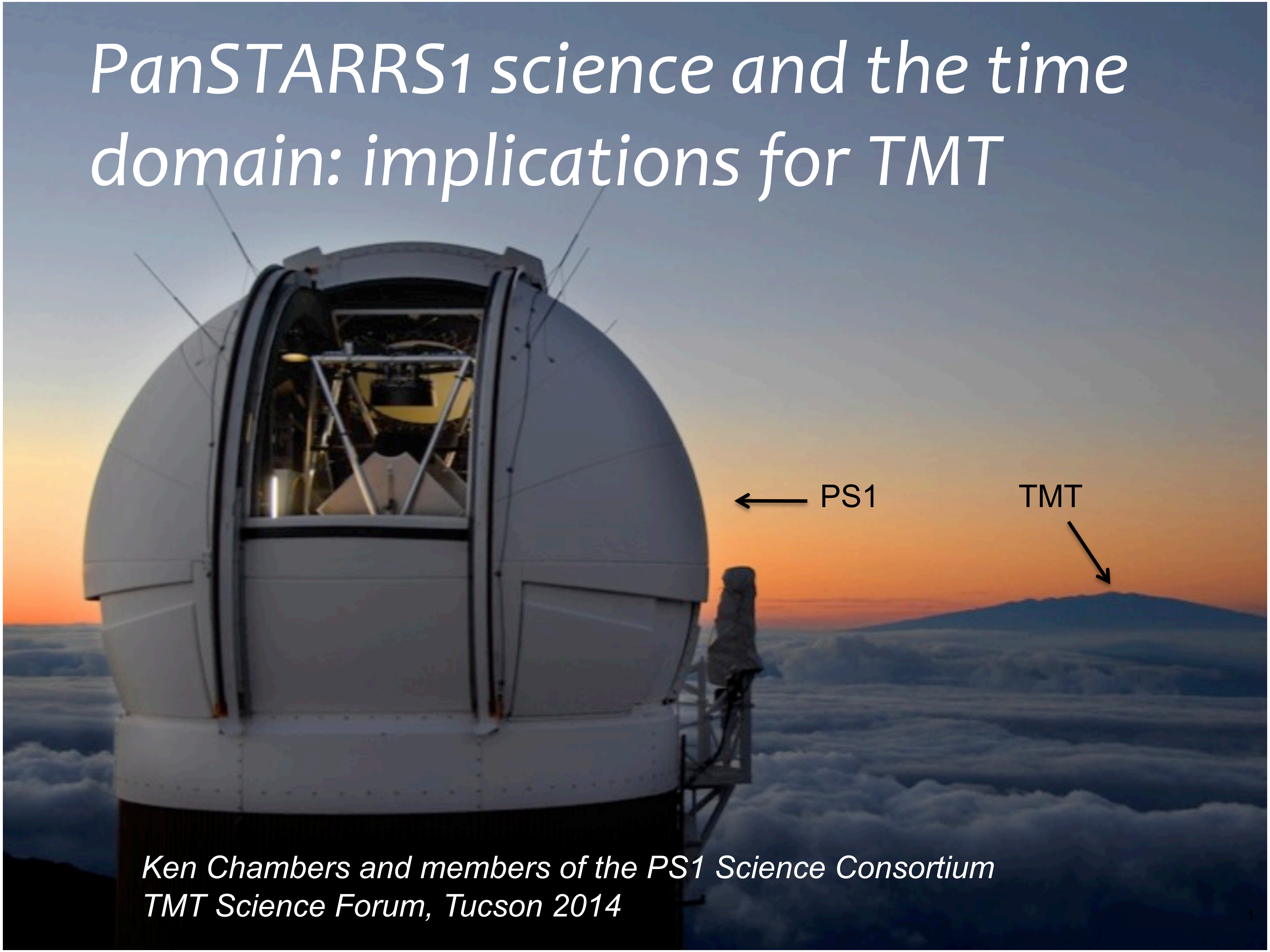
PanSTARRS1 science and the time domain: implications for TMT

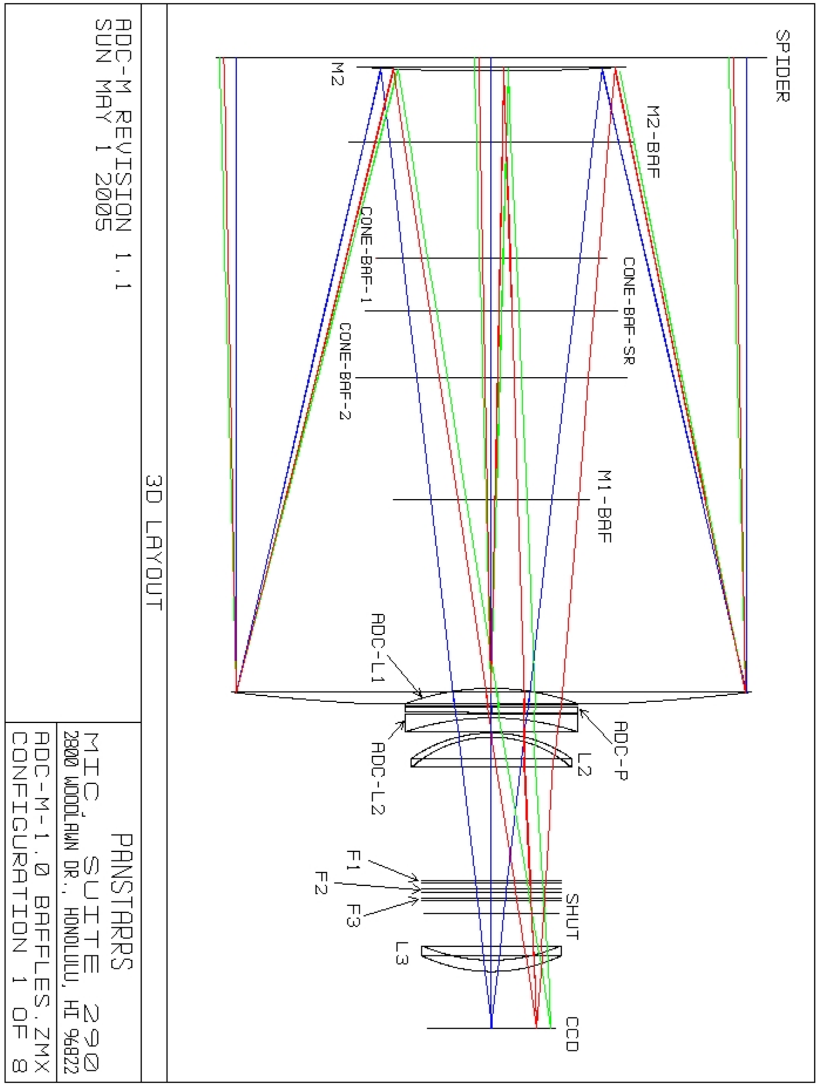


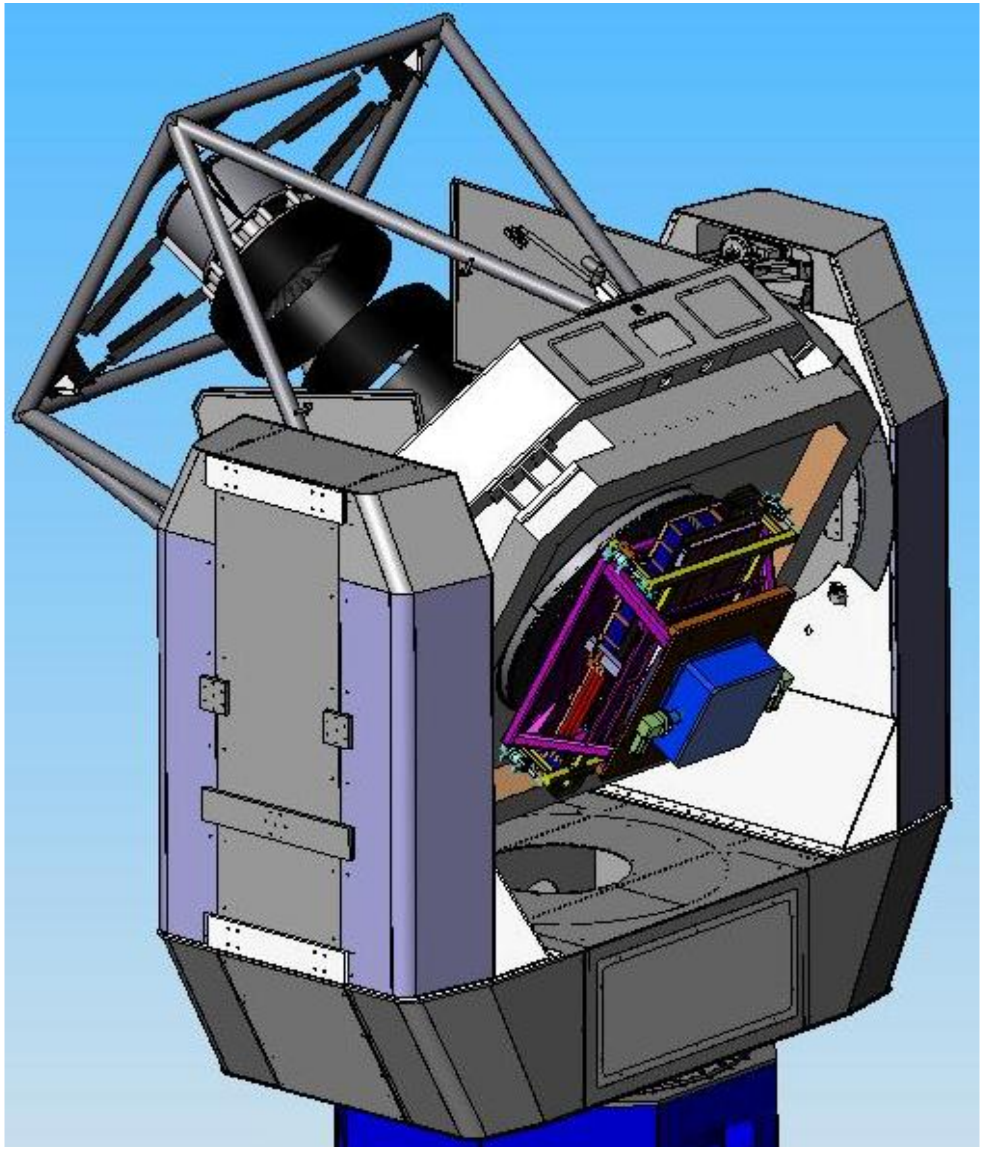
Ken Chambers and members of the PS1 Science Consortium
TMT Science Forum, Tucson 2014

WHAT IS PS1 ?

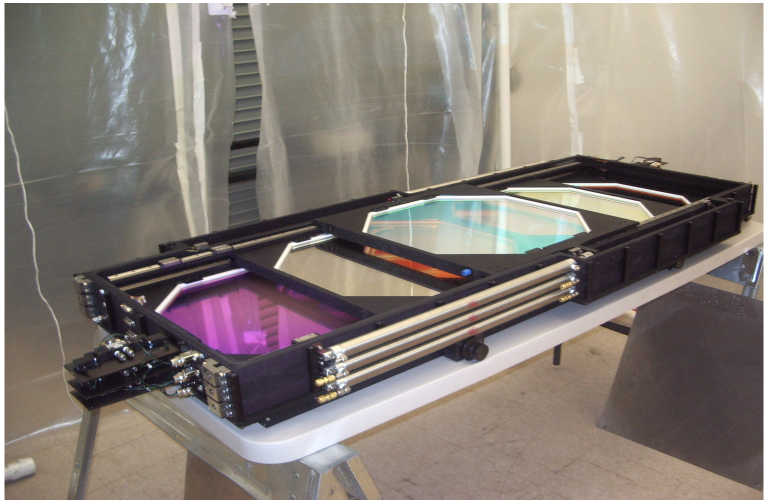
- PS1 wide field survey telescope
- 1.8 meter aperture at f/4.4
- Ritchey-Chretien with 3-element corrector
- 3.3 degree field-of-view
- 1.4 Gigapixel Camera

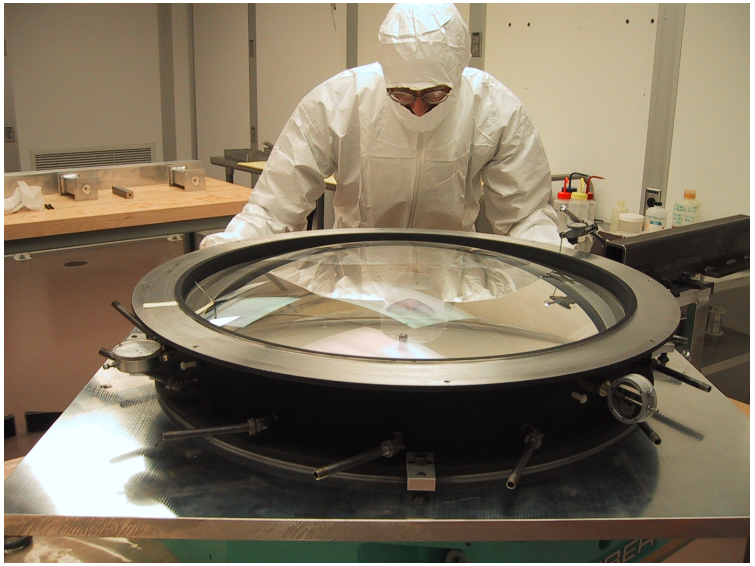
- 1.4 Gigapixel Camera
- 10 sec overhead (read write slew)

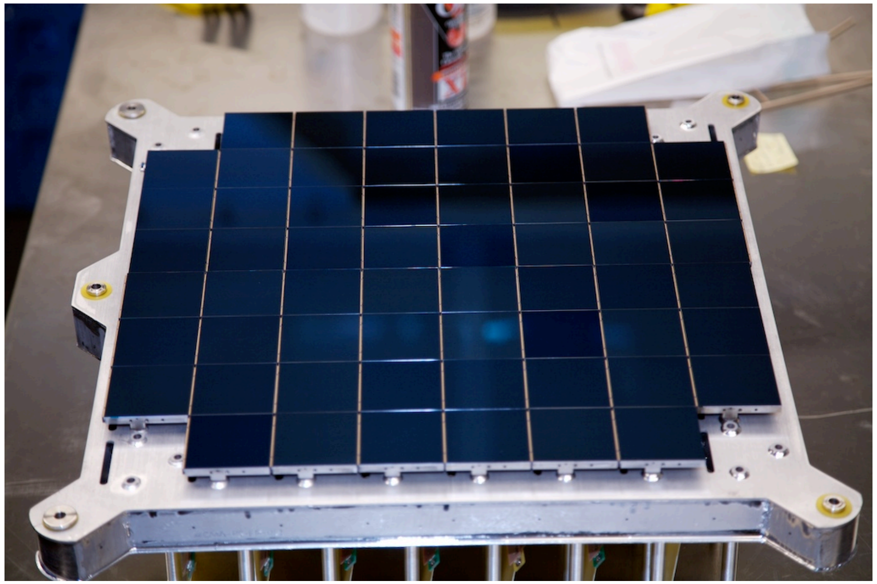


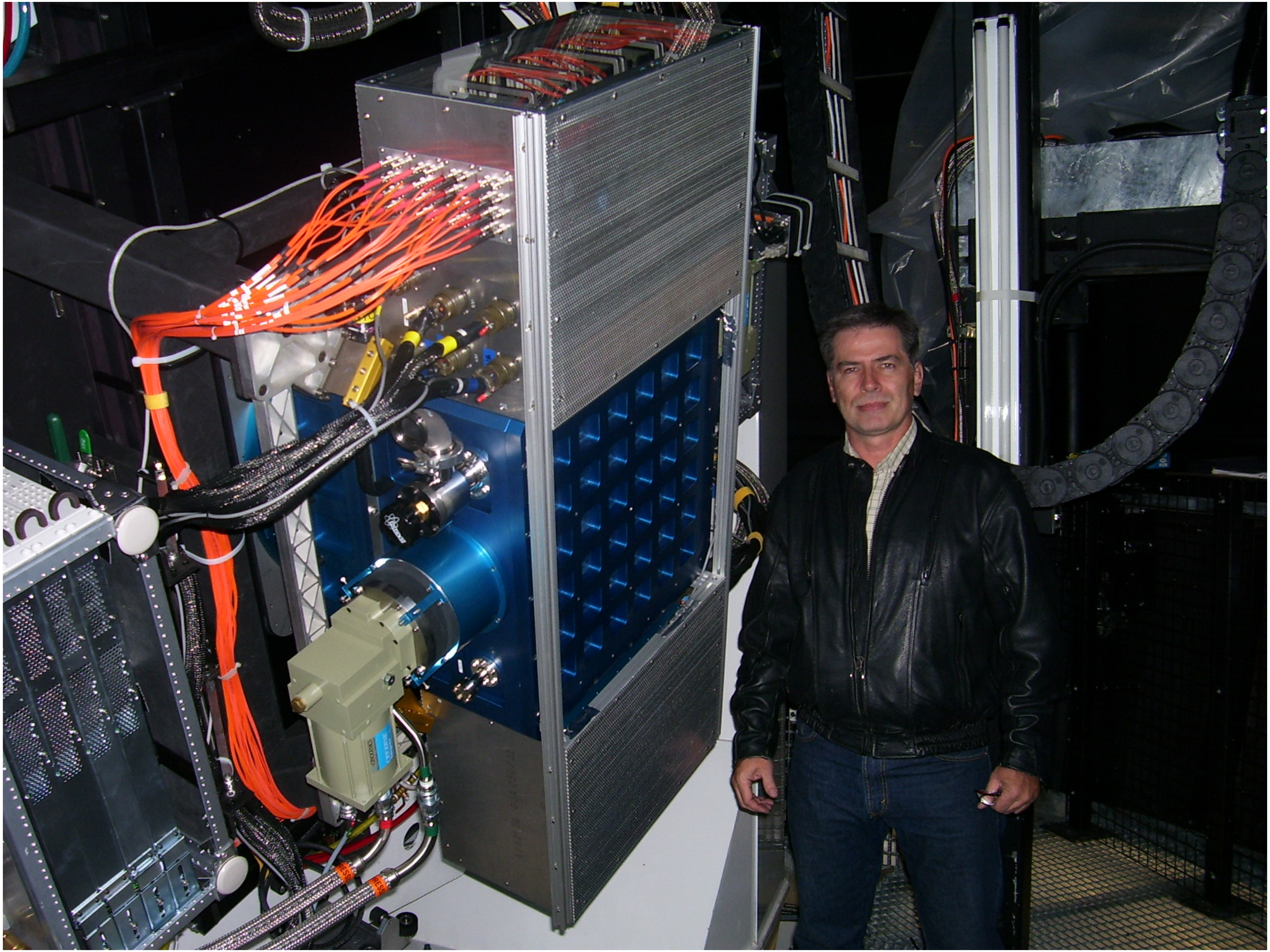


PS1 Filters, Optics, Shutter, 1.4 Gigapixel Focal Plane









Lots of Cyber-Infrastructure

Image processing occupies unique location in cyberspace: need lots of cpu cycles on lots and lots of data.

Different from supercomputers that maximize n-flops, also different from the "cloud" because i/o demands require local storage.

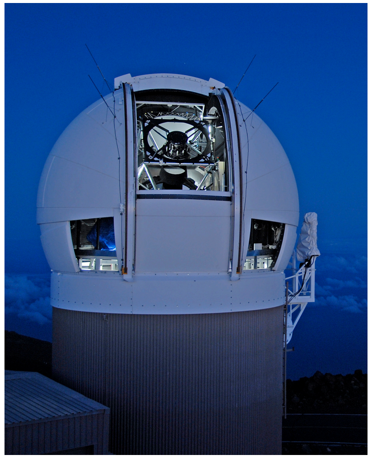
Database: Big Data scans

and People!

PS1 Remote Operations Center, ATRC, Maui

PS1 Operations

The PS1 System consists of:



Images are obtained by the PS1 Observatory and 1.4 Gigapixel Camera, at Summit of Haleakala.

The observatory is operated from the PS1 Remote Operations Center at IfA’s ATRC in Pukalani, Maui

Data is transmitted from the summit to the Image Processing Pipeline located at the Maui Research Technolgy Center in Kihei for data reduction.

Data Reduction and Processing is overseen from IfA Manoa on Oahu.

Los Alamos
NATIONAL LABORATORY

The raw data is transmitted to LANL where the most computationally intensive part of the final data re-processing is done. The reduced data products are then sent back to IPP.

Pan-STARRS
PS1 Science Consortium

Data products available by internet to Scientists of PS1SC

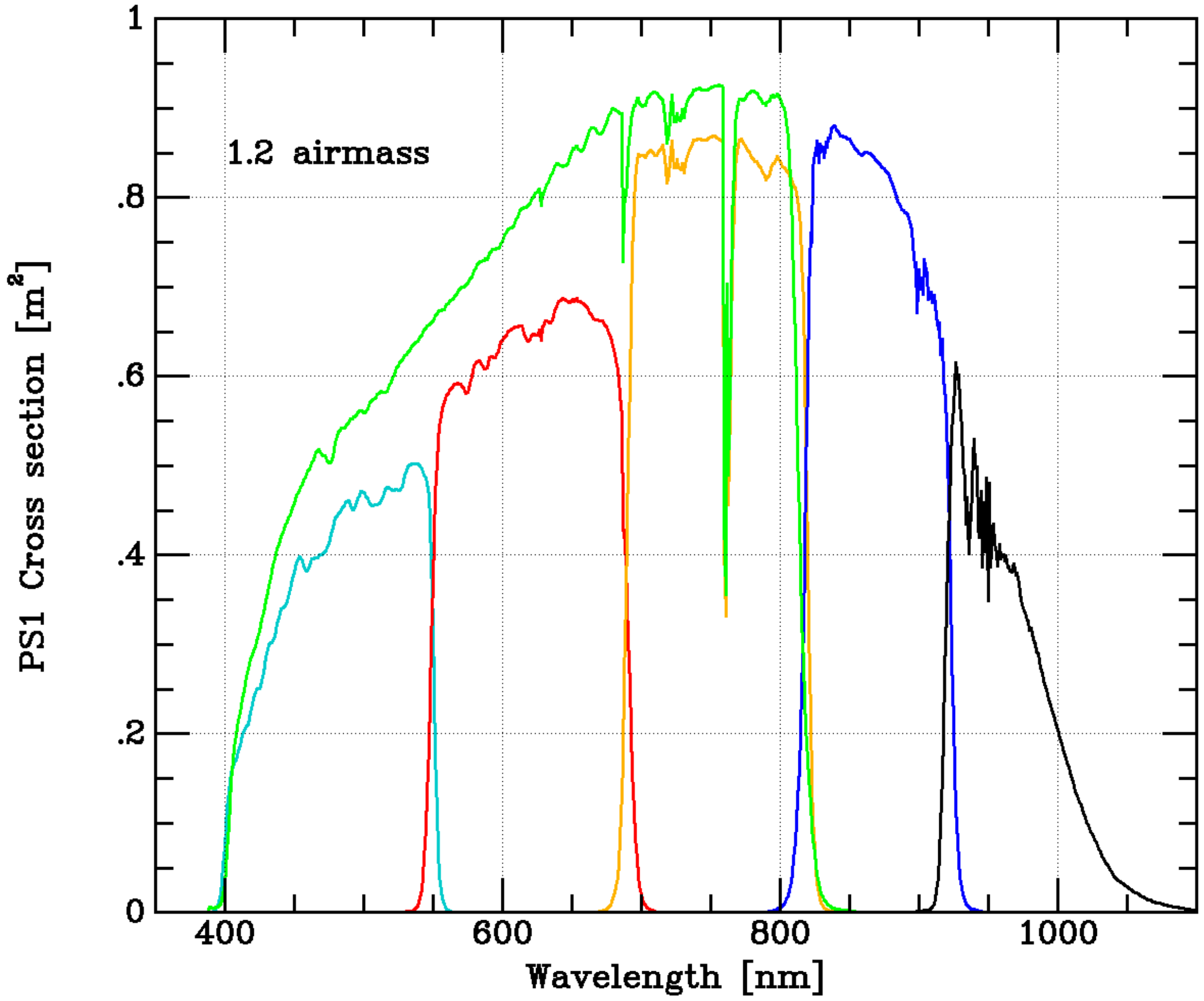
SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

Data products shipped on STScI machines to STScI MAST archive.

All reduced and derived data products available to the world community from STScI April 1, 2015.

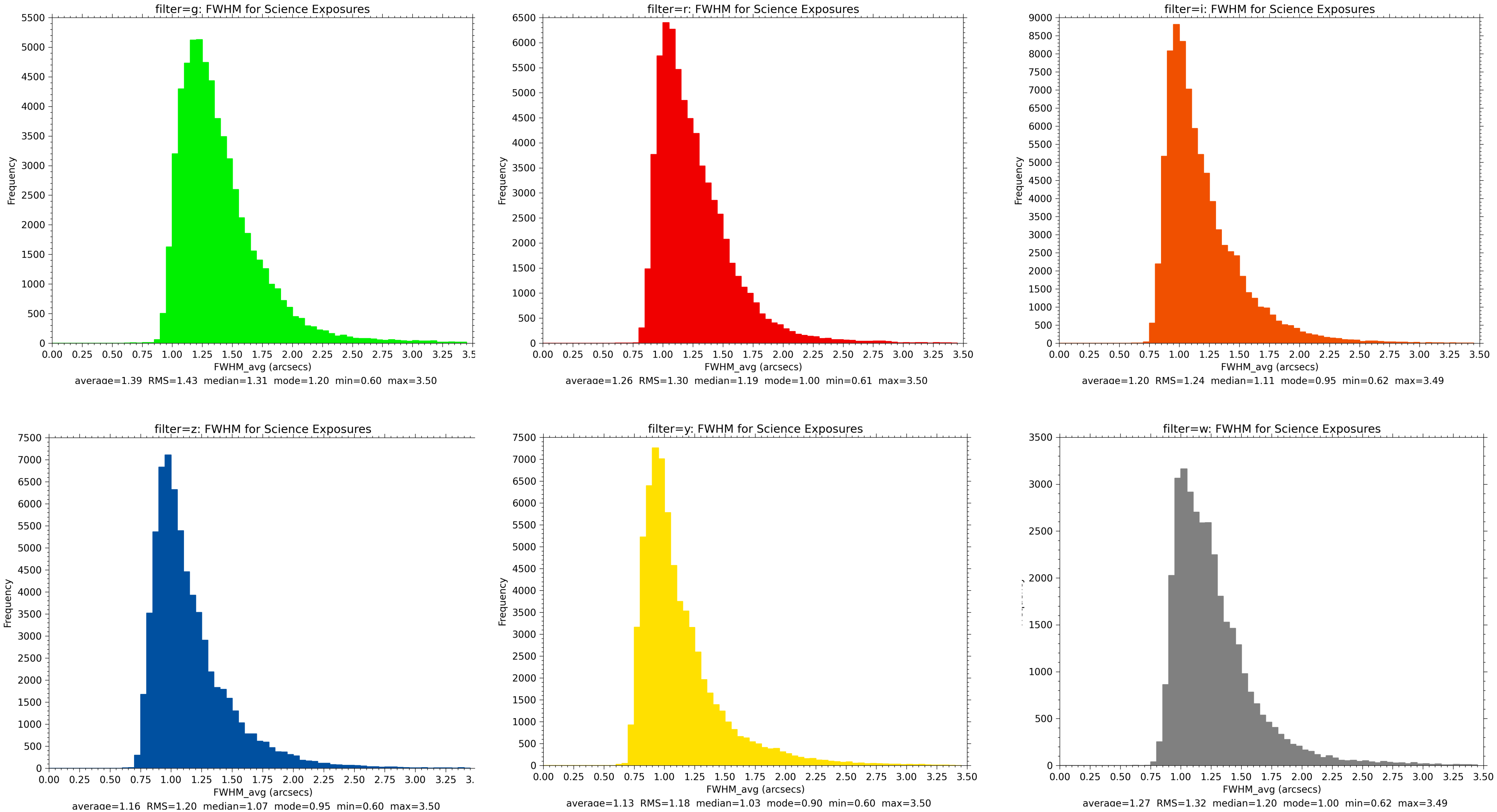
PS1 Filter System

g r i z y,   w (=wide)



The Pan-STARRS1 Photometric System
Tonry et al. 2012, ApJ 750, 99

PS1 has 1 arcsec image quality



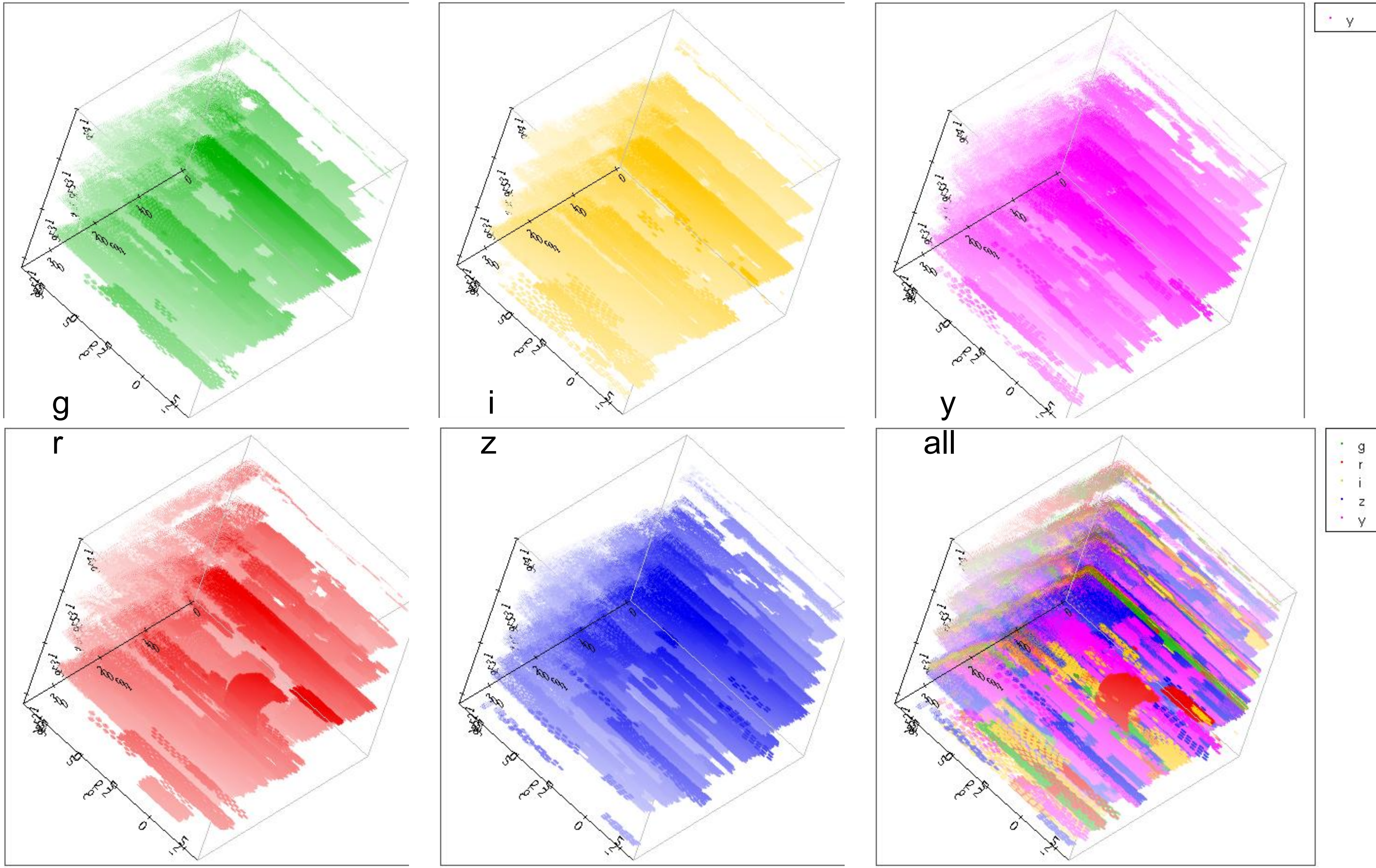
	g	**r**	**i**	**z**	**y**	**w**
FWHM Average	1.39	1.26	1.20	1.16	1.13	1.27
FWHM Median	1.31	1.19	1.11	1.07	1.03	1.20
FWHM Mode	1.18	1.02	0.96	0.96	0.96	1.02

WHAT DATA HAS PS1 PRODUCED ?

The PS1 Science Consortium Surveys 2010-2014

PS1 Survey	Filter bands	Fraction of time
3pi Steradian Sky Survey (30,000 sq deg)	g r I z y	58 %
Calibration - Photometric standards Celestial North Pole CNP	g, r, i, z, y, w, open g,r,i,z,y	1 %
Medium Deep Survey (10 x 7 sq deg)	g r i z y	25 %
Solar System Survey	w band = g+r+i	5% ->11% Nov 2012
Pan-Planets: high cadence Stellar Transit Survey (50 sq deg)	i	4% thru 2012
PAndromeda: M31 time domain survey	r i	2% thru 2012

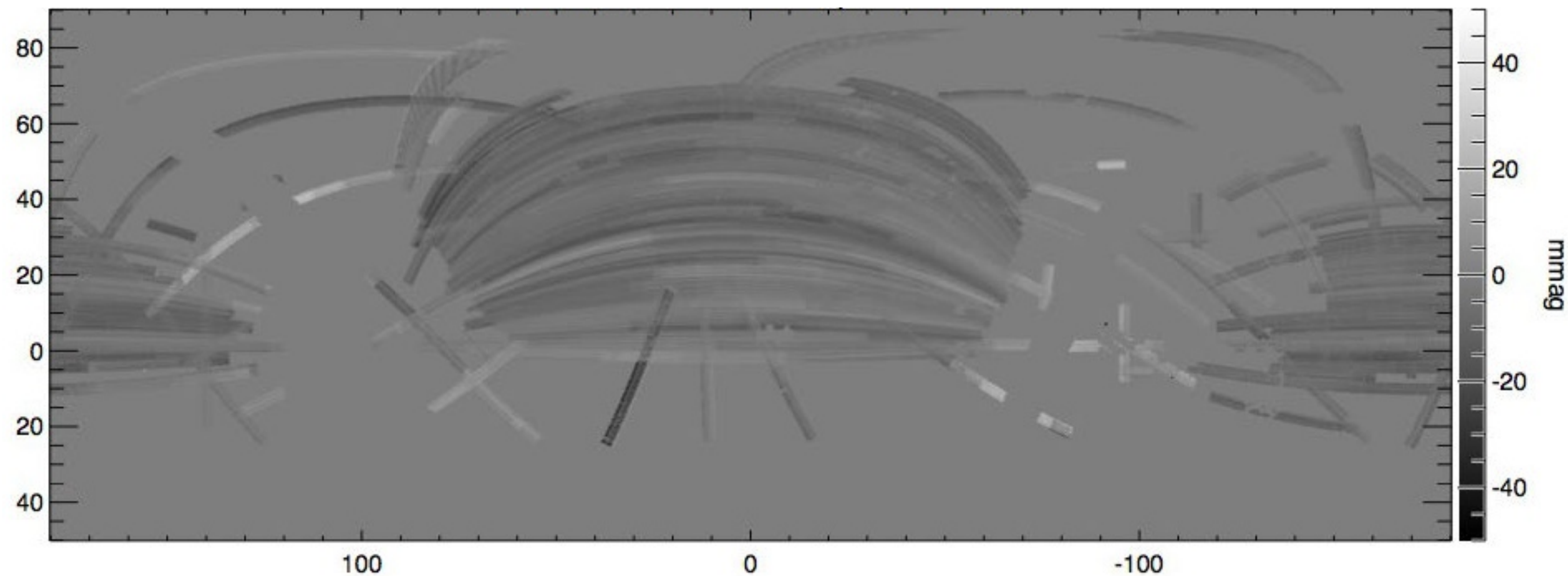
3pi Steradian Survey time domain cubes: ra, dec, time per filter



PS1 is the best-calibrated optical survey: <1%

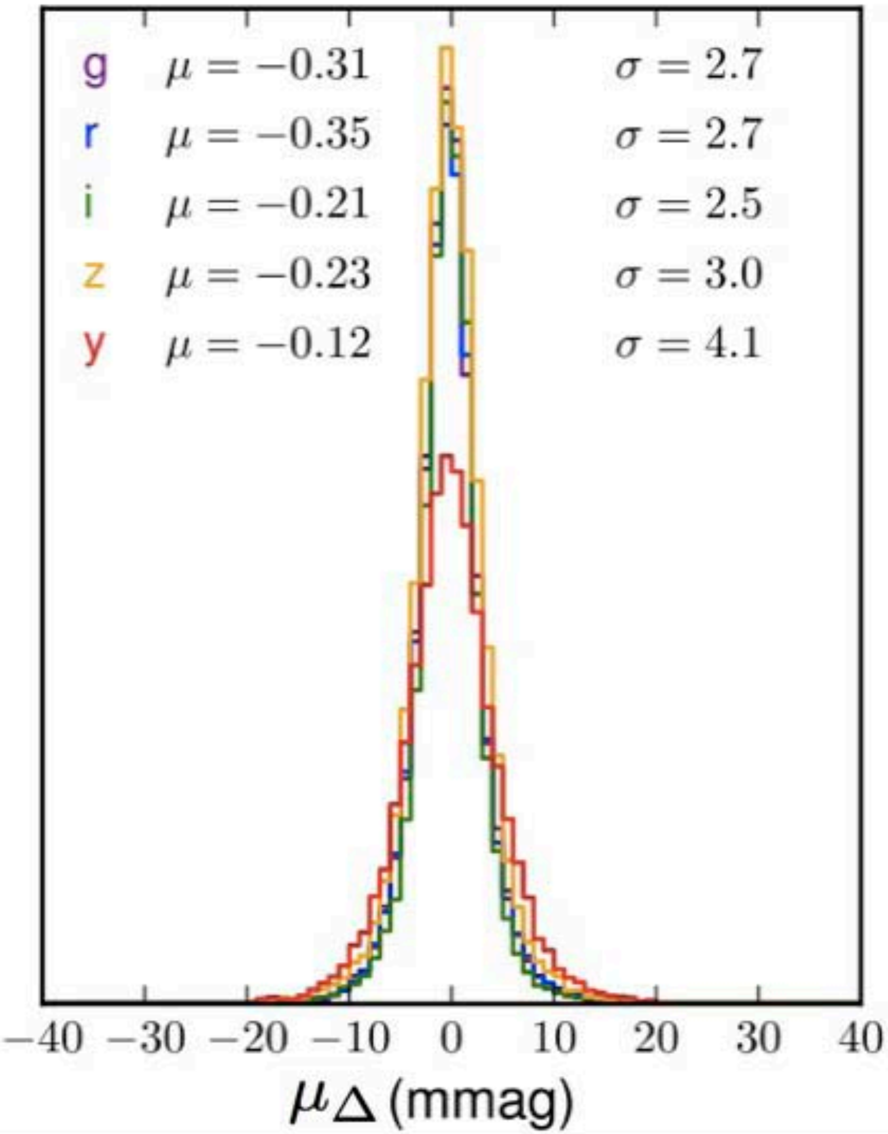
Overlap- and repeat observations enable accurate self-calibration ("übercal")
Based on minimizing the variance of repeat observations

D.Finkbeiner, E. Schlafly, G. Magnier

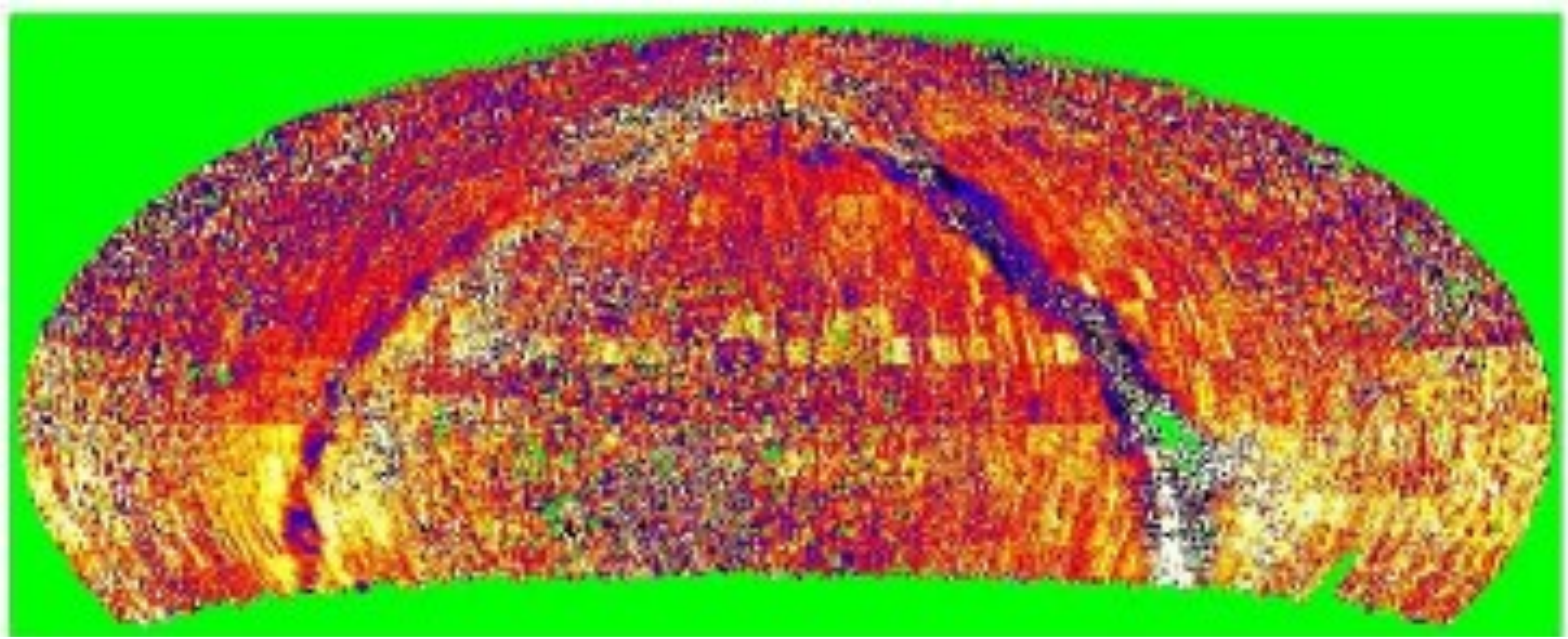


e.g. r-band photom. zero-point PS1 vs SDSS: 0.004 mag variance

ZP residuals are ~ 3 mmag (4 mmag in y-band)

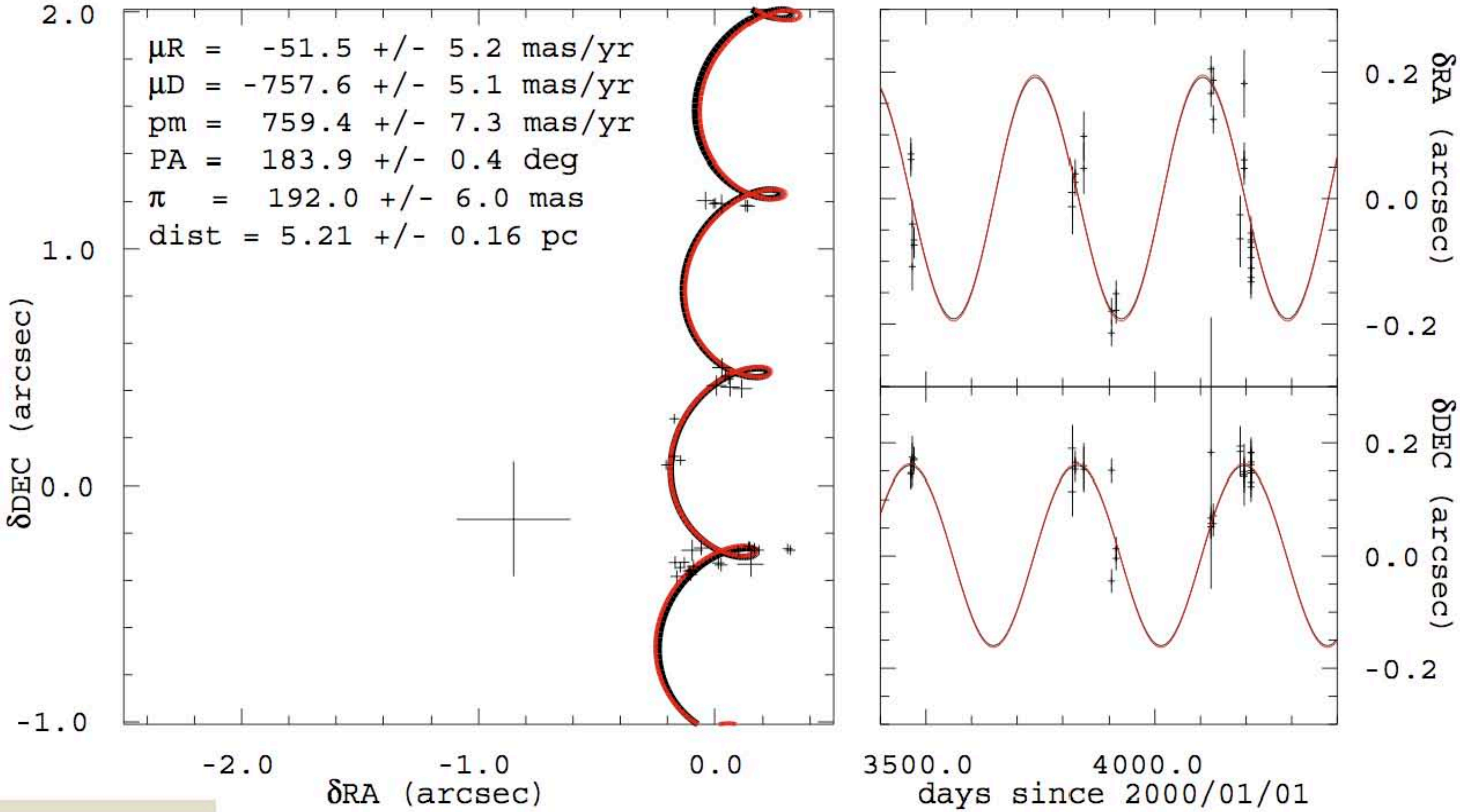


2MASS Comparison with PS1 uber-calibration
Magnier et al , in prep



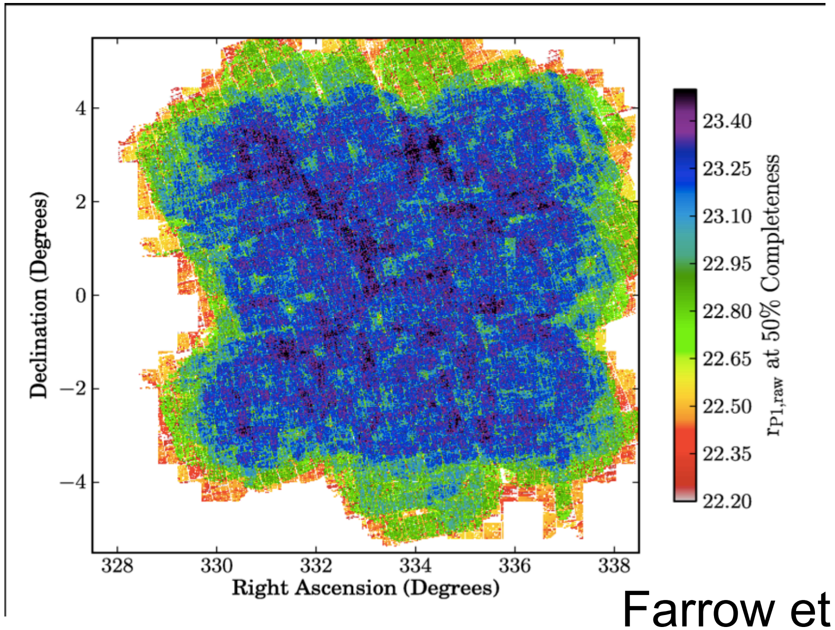
3π Comparison of PS1 and 2MASS photometry.
The color represents the mean *H-K color from* 2MASS at a fixed *g-i color from* PS1 for early-type stars. Extinction from the Galactic Plane dominates, while bands with Dec height 6 degrees are caused by systematic errors in 2MASS *H and K at the 2*-3% level.

Survey completion will enable all-sky parallaxes for faint (i.e. non-GAIA) objects. This will be a unique legacy from the PS1 survey for studying low-mass stars & brown dwarfs.

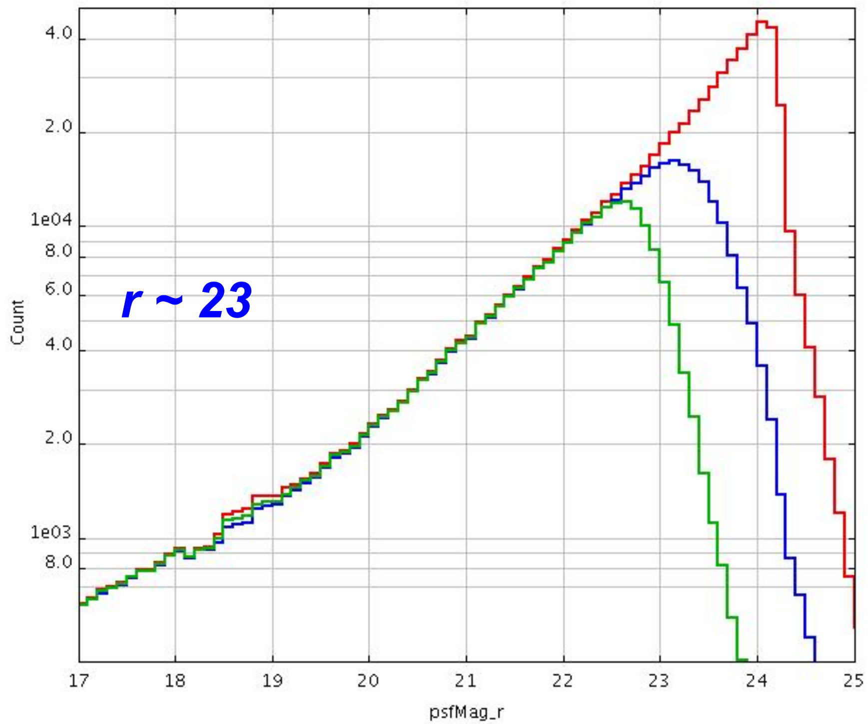


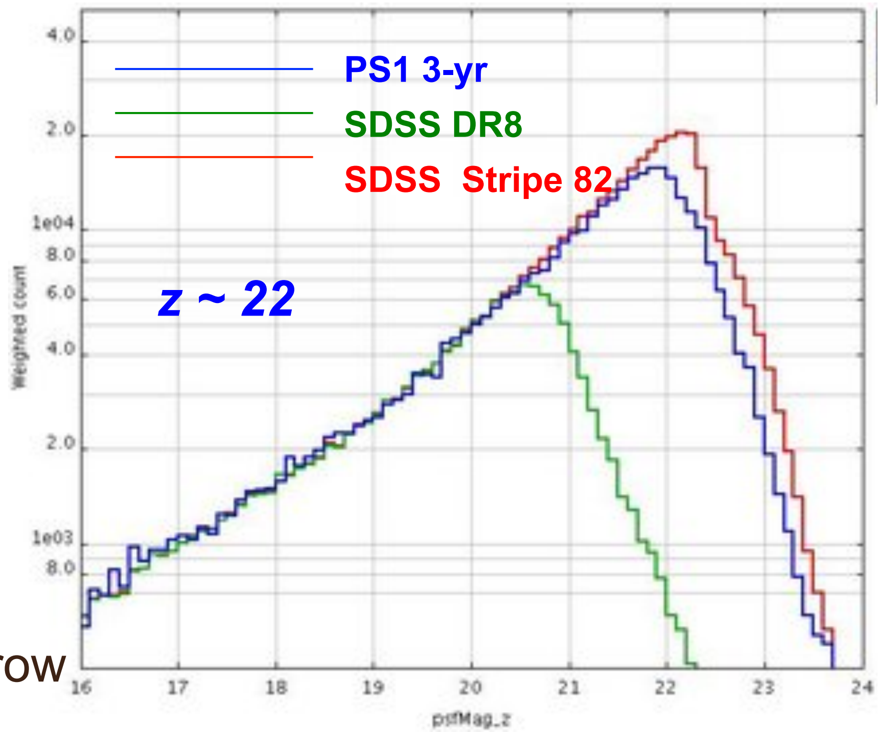
from E. Magnier

3π Survey depth from Small Area Survey



Farrow et al 2014





Comparison of point sources in SDSS DR8 and PS1 3π, 3yr stack

Deeper than SDSS by

g ~ 0.4^{m}

r ~ 0.6^{m}

i ~ 0.8^{m}

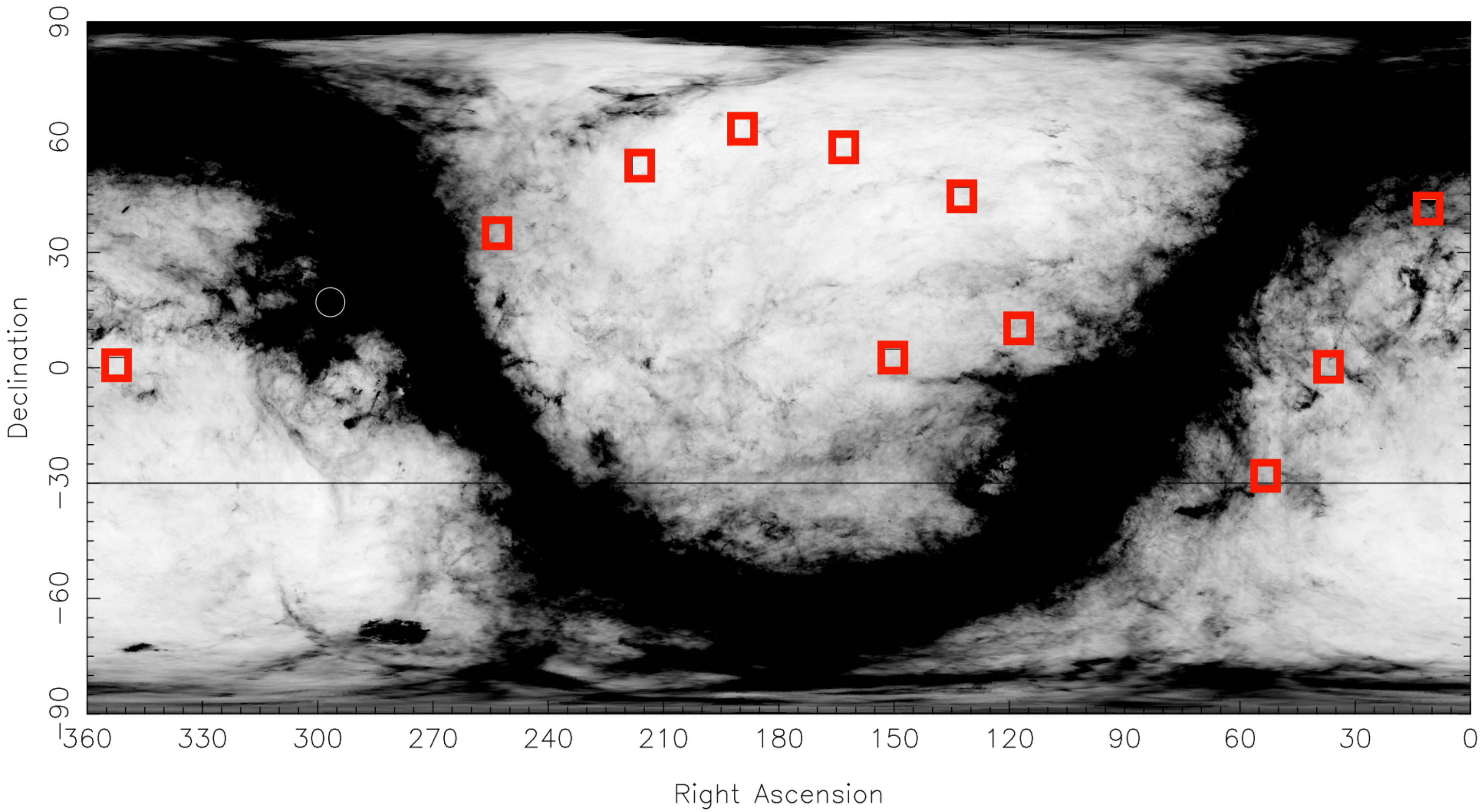
z ~ 1.4^{m}

+ y

From G. Magnier, N. Metcalfe, D. Farrow
PS1 IPP and DRAVG teams

Medium Deep Survey (MDS) fields

10 fields, 7 square degrees each

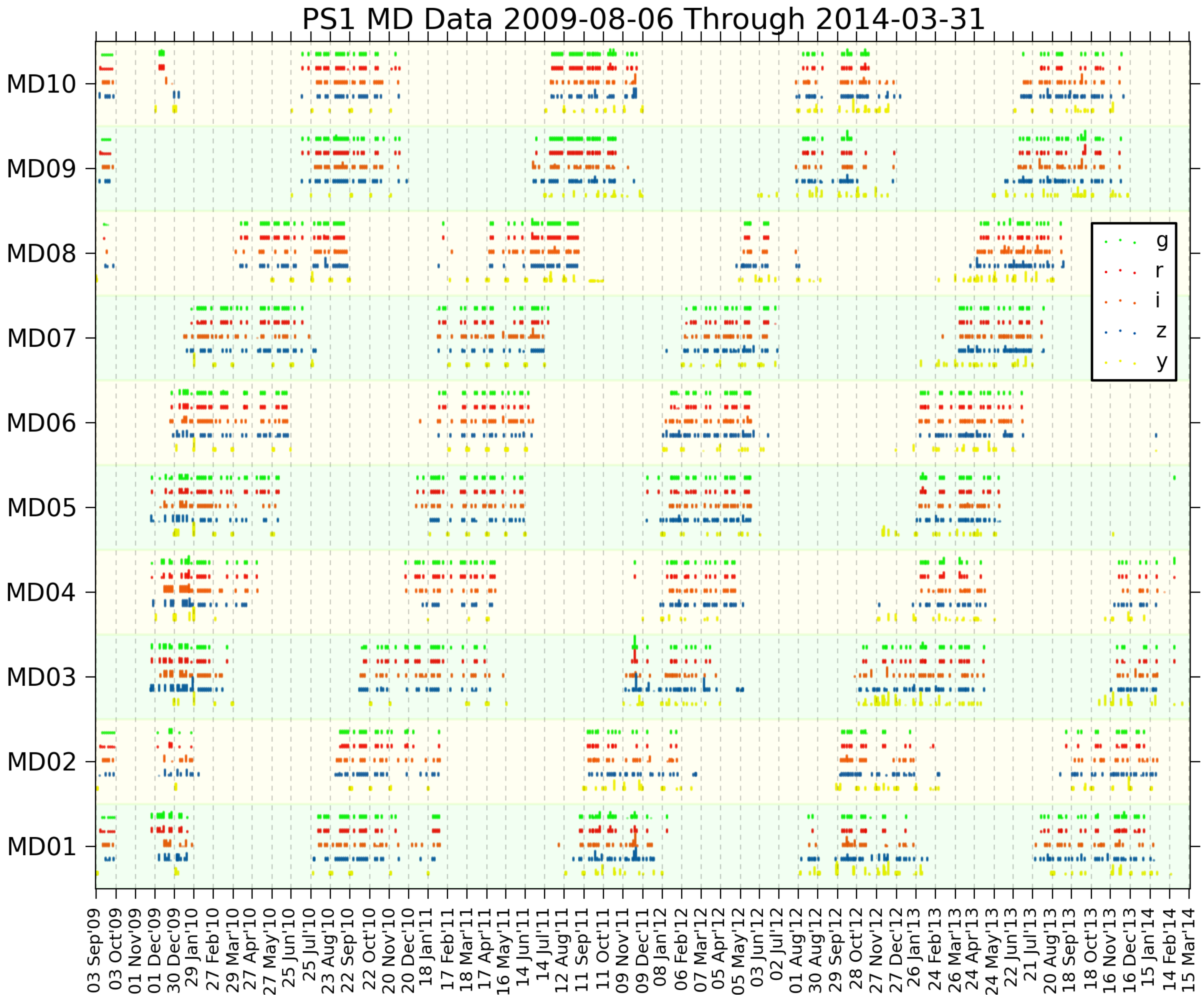


Nearly nightly observations in at least one band, "when field is up"

+ Pandromeda: monitoring M31

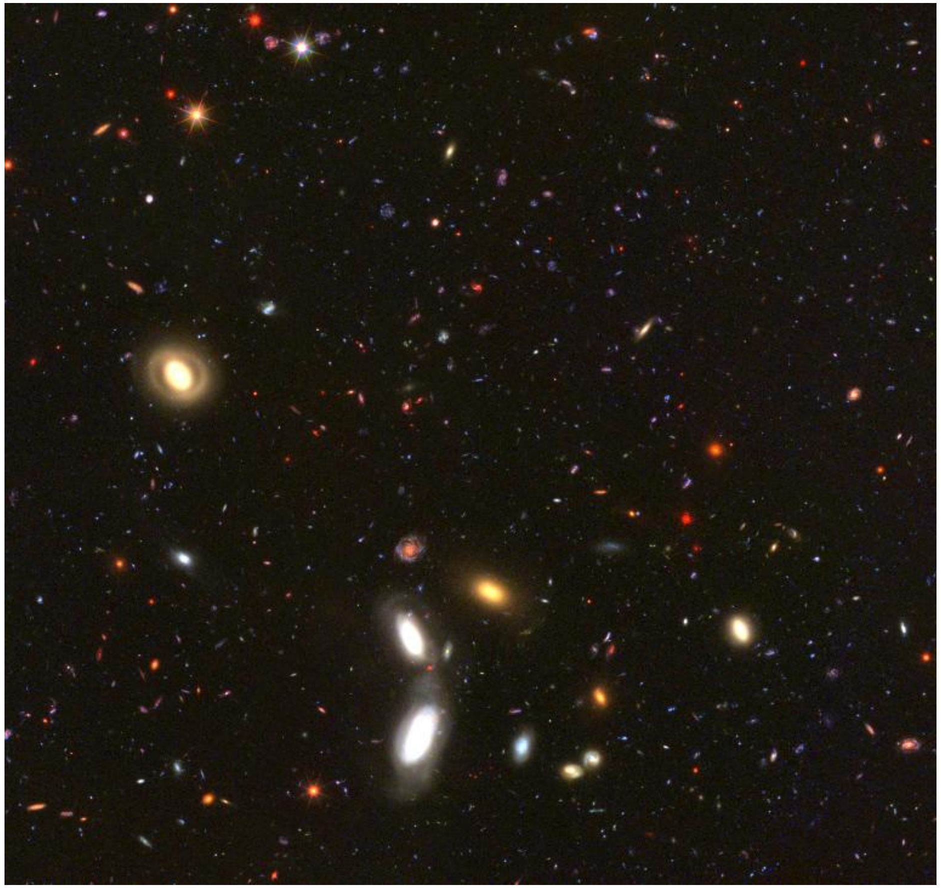
+ Pan-Planets: transit monitoring

PS1 Medium Deep Fields - Observing Cadence



- 4 ± 1 fields observed every night.
- Filter cycle in 3 night pattern: g+r … ..i… ..z (repeats every 3 nights, y-band in full moon)
- Nightly depth : g,r ~ 23.5^{m}

Comparison of PS1 MD fields and GOODS Survey



HST GOOD-S z/r/g
< 0.1 square degree

PS1 Medium Deep Survey
> 70 square degrees

Comparison courtesy Rick White

Initial takeaways:
PS1 has done an enormous amount of brick and mortar astronomy:

- Photometry:
  30,000 square degrees with better photometry than Landolt standards. You don't need to spend time calibrating anymore, everything in your field of view is calibrated

- Astrometry:
  PS1 has 3-4 milliarcsec relative astrometry
  Absolute astrometry is research in progress but unprecedented prior to Gaia, and wi Gaia frame can be extended > 3 magnitudes deeper.

- Assorted implications for TMT
  - TMT guide star catalog, positions for faint multi-slit spectroscopy, transient alerts
  - Headline:
    LSST survey is a southern hemisphere survey.
    TMT is in the northern hemisphere.
    Aside from HSC, there is no facility in the construction pipeline that can provide quality sky survey data TMT needs other than Pan-STARRs…
  - The TMT Community has an interest in the survival and potential enhancement of the Pan-STARRs Observatory. That isn't going to happen without community and agency involvement and support.

WHAT SCIENCE HAS PS1 PRODUCED ?

PS1 Science Consortium founded to carry out and exploit the PS1 Sky Surveys

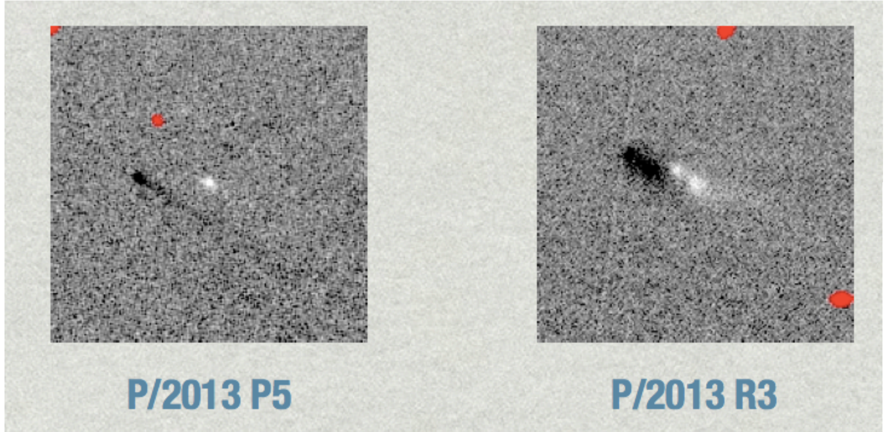
Pan-STARRS
PS1 Science Consortium

Ps1 - discovery machine in the solar system

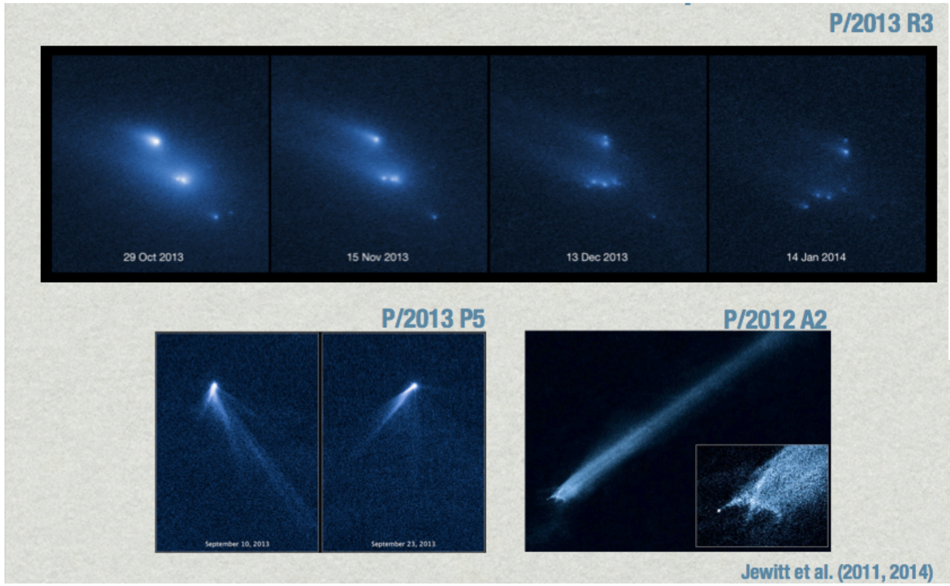
- 2013/14 : now the leading telescope for NEOs and Potentially Hazardous Asteroids (PHAs)
- Discovering ~40% of new comets – image quality is key
- 90% of 1km objects were thought to be known
- But discoveries are continuing … solar system model tension ?
- Thousands of KBO’s / TNO’s in final release – many of interest for TMT studies.

Wainscoat, Denneau, Jedicke, Fitzsimmons et al.

Catastrophic disruptions of solar system bodies

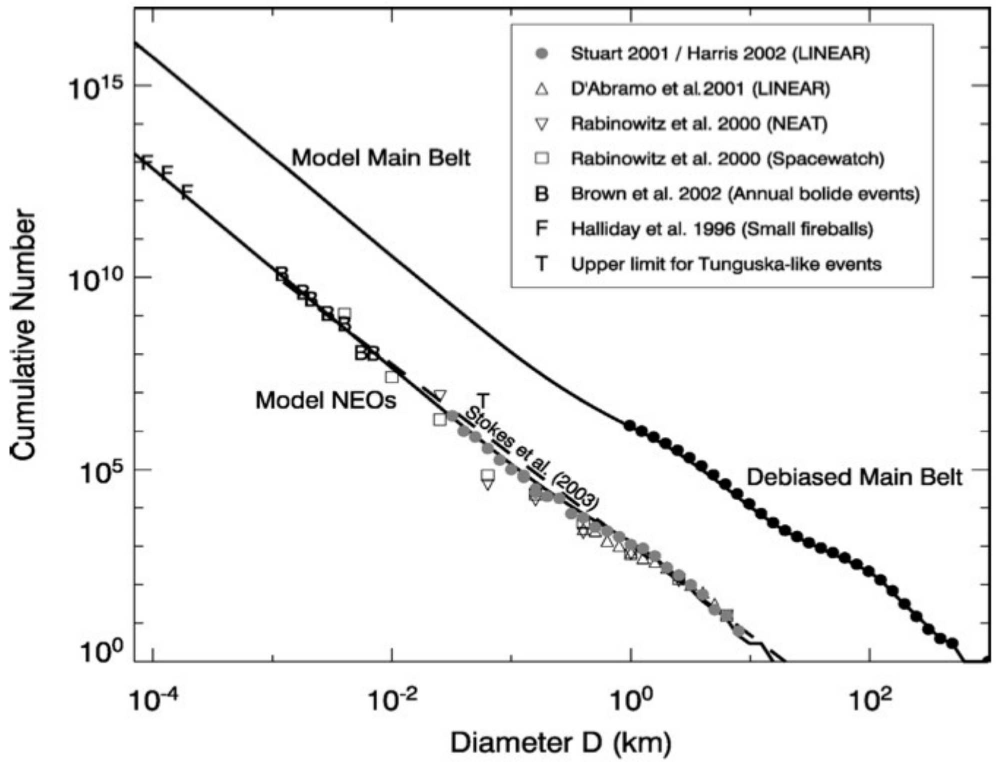


PS1 discoveries
Denneau, Wainscoat, Jedicke et al.



HST imaging follow-up

Rotational vs impact disruption ratio



Time domain surveys like Pan-STARRS can find a steady stream of catastrophically disrupted solar system bodies for TMT studies of freshly surfaces and material.

Liu, Magnier + 2013

PSO 318-22:
The “lonely Planet”

PSO J318.5−22 is the first free-floating object with the colors, spectra, magnitudes, luminosity, and mass that overlap the young dusty planets around HR 8799 and 2MASS J1207−39.

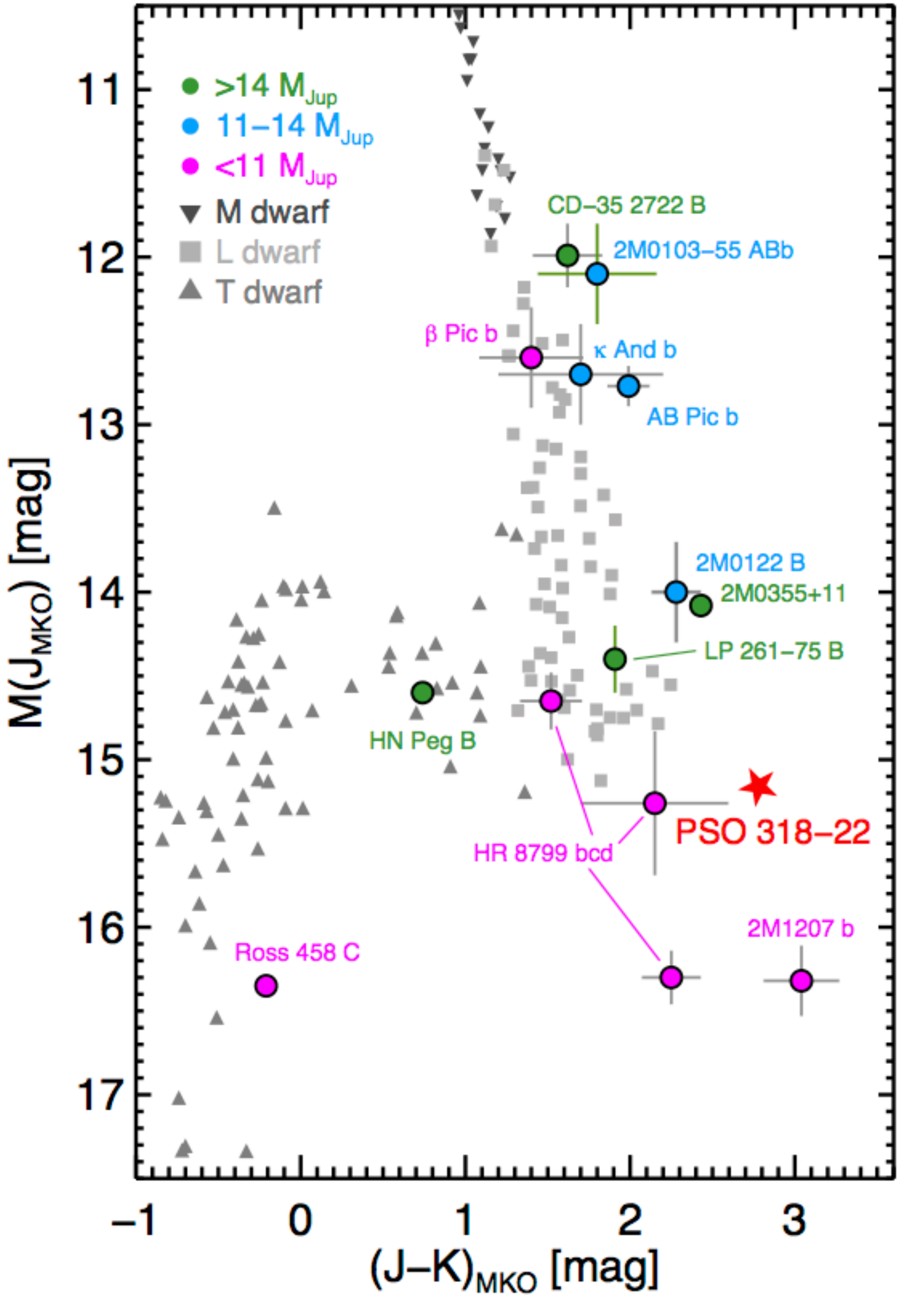


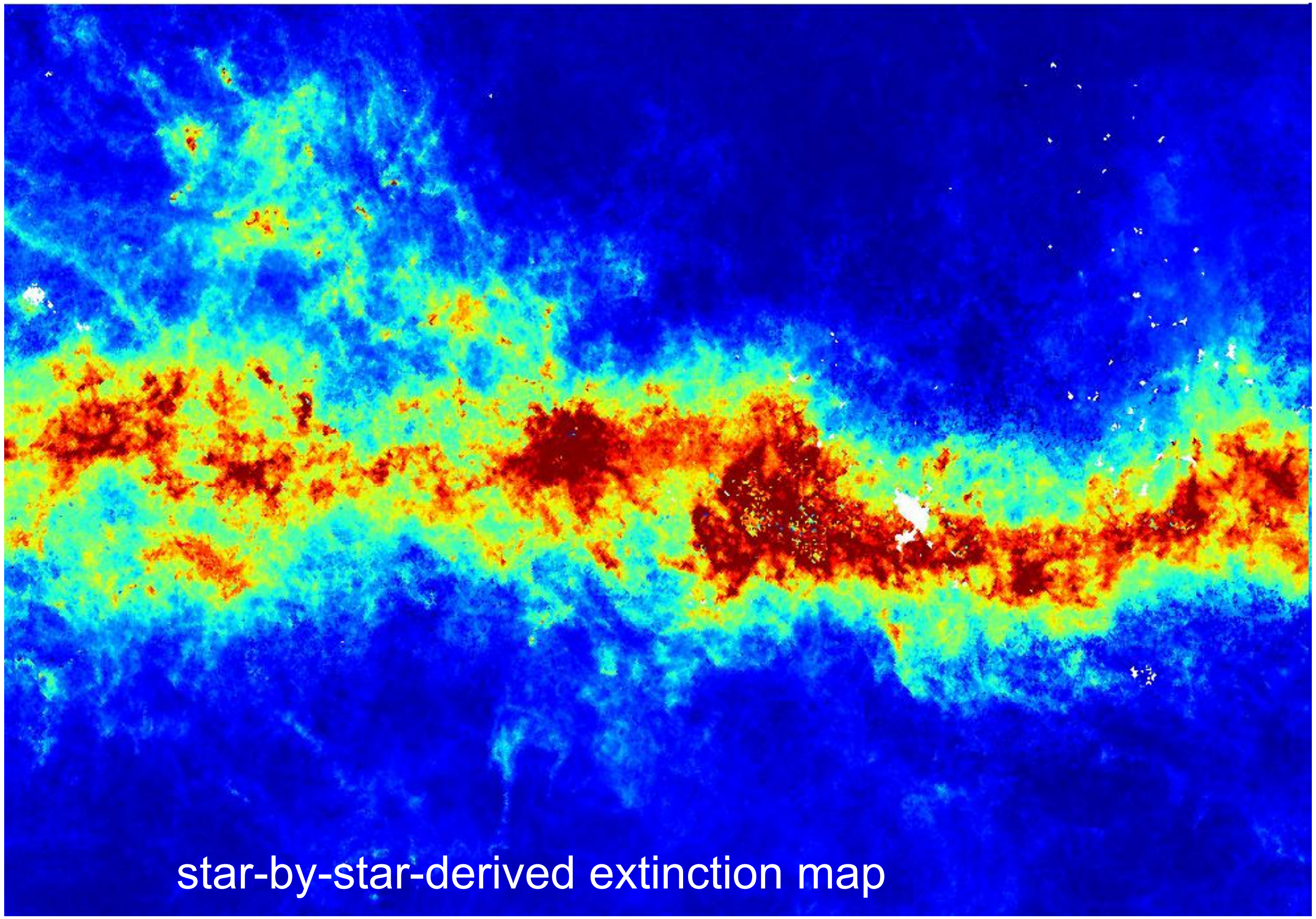
Image Credit :N. Deacon

A high-resolution 3D dust map of the Galaxy

Schlafly, Green, Finkbeiner et (2014) : A MAP OF DUST REDDENING TO 4.5 KPC FROM PAN-STARRS1

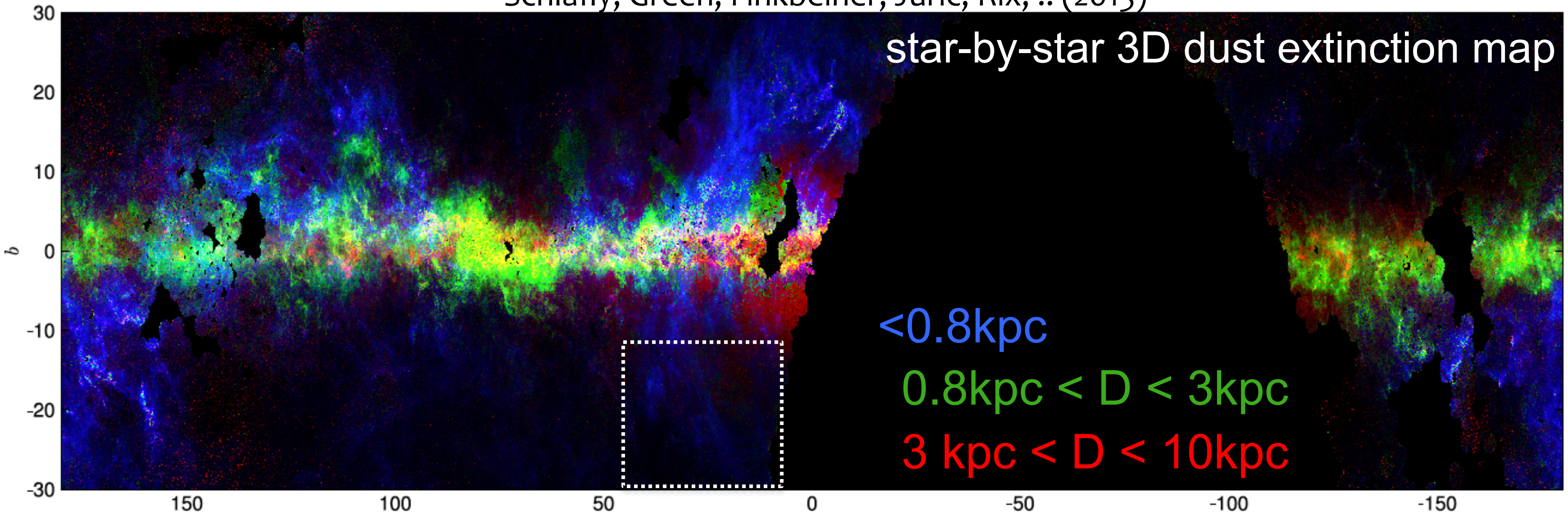
Green , Schlafly, Finkbeiner et al. (2014) : MEASURING DISTANCES AND REDDENINGS FOR A BILLION STARS: TOWARDS A 3D DUST MAP FROM PAN-STARRS 1

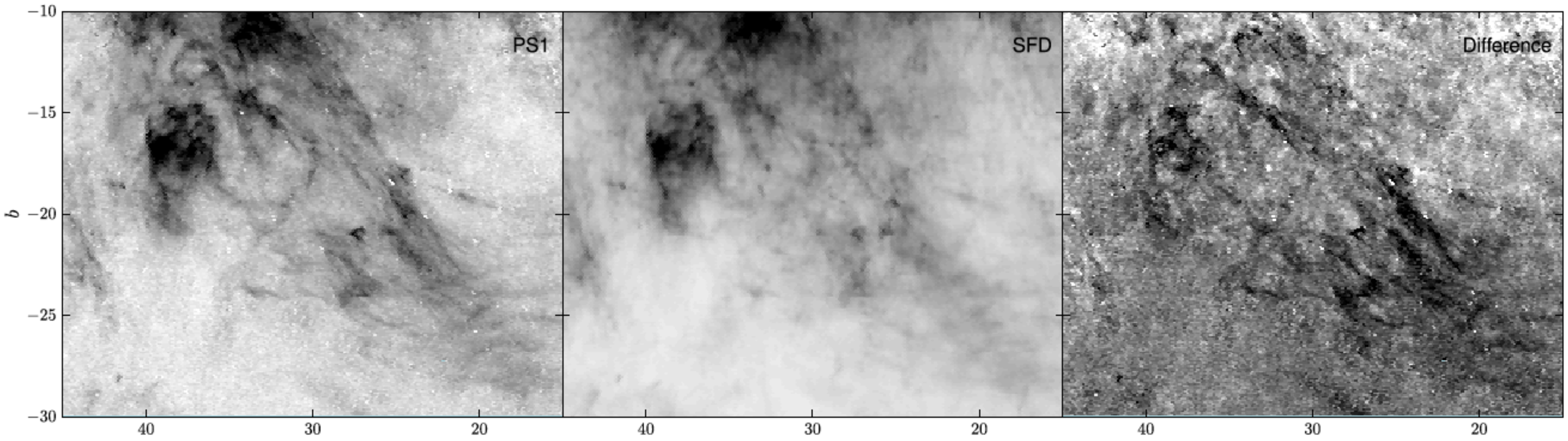
- Joint distance $\mathcal{D}$ and A_v estimate for a billion stars from PS1 photometry
- Combine adjacent stars to get $A_v(\mathcal{D})$ → 3D extinction map



A high-resolution 3D dust map of the Galaxy

Schlafly, Green, Finkbeiner, Juric, Rix, .. (2013)





Star-by-star extinction (PS1)

Dust emission (Schlegel, Finkbeiner, Davis) FIR emission

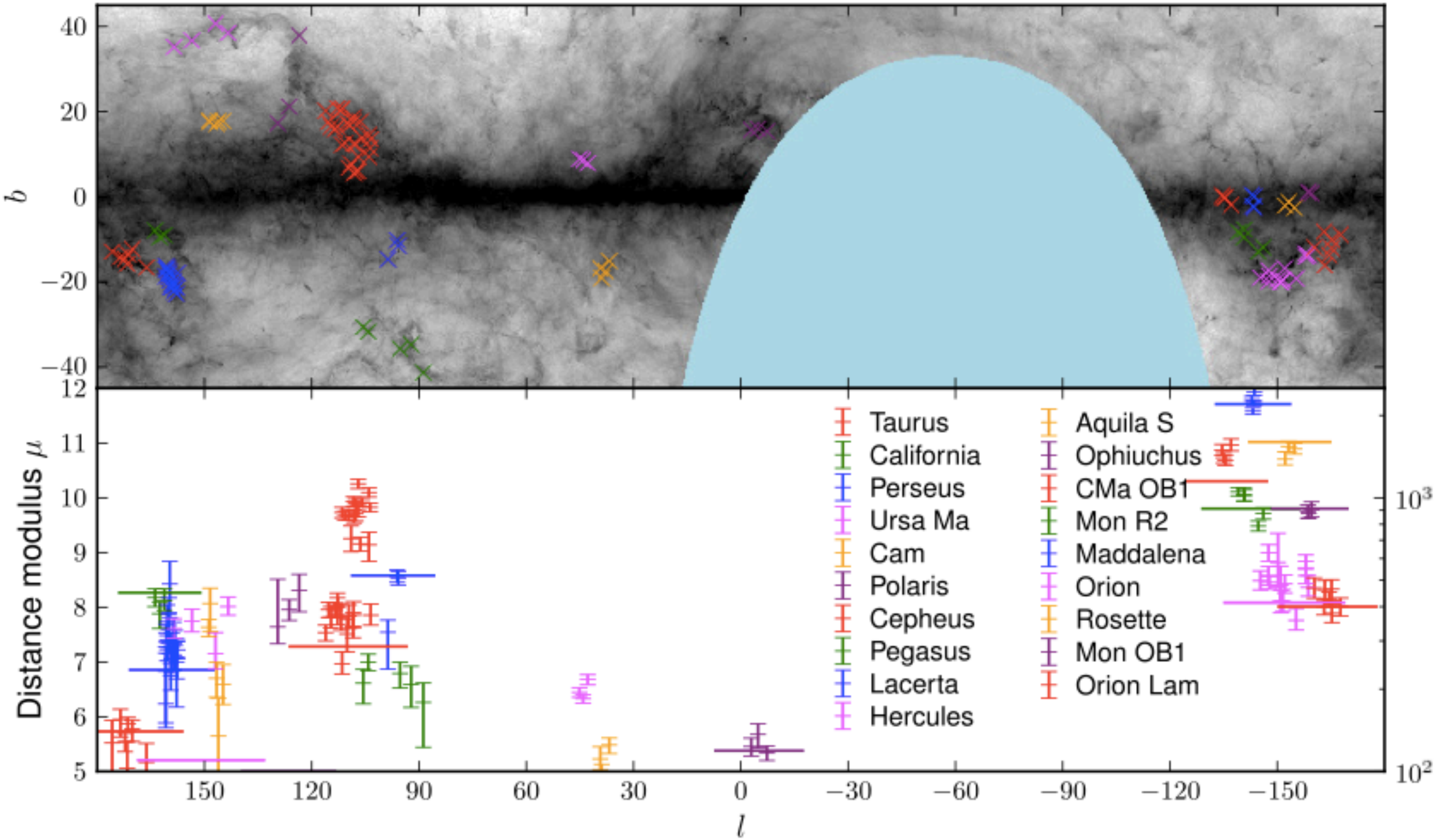
Difference

Cold dust only in extinction?

February 13, 2013

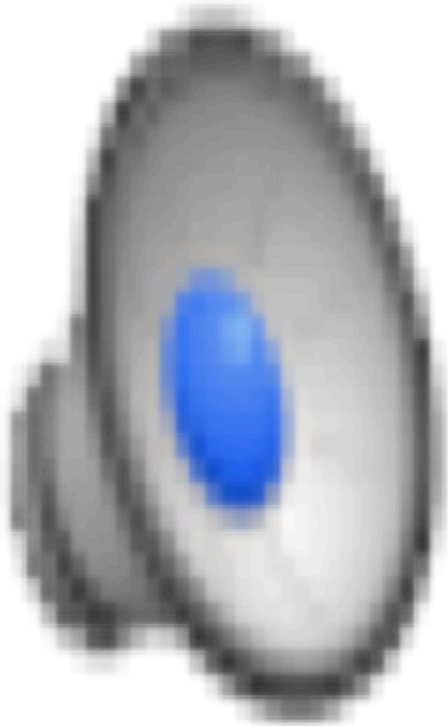
What can we do with this?

Distances to nearby molecular clouds (Schlafly et al. 2014 ApJ 786 29)



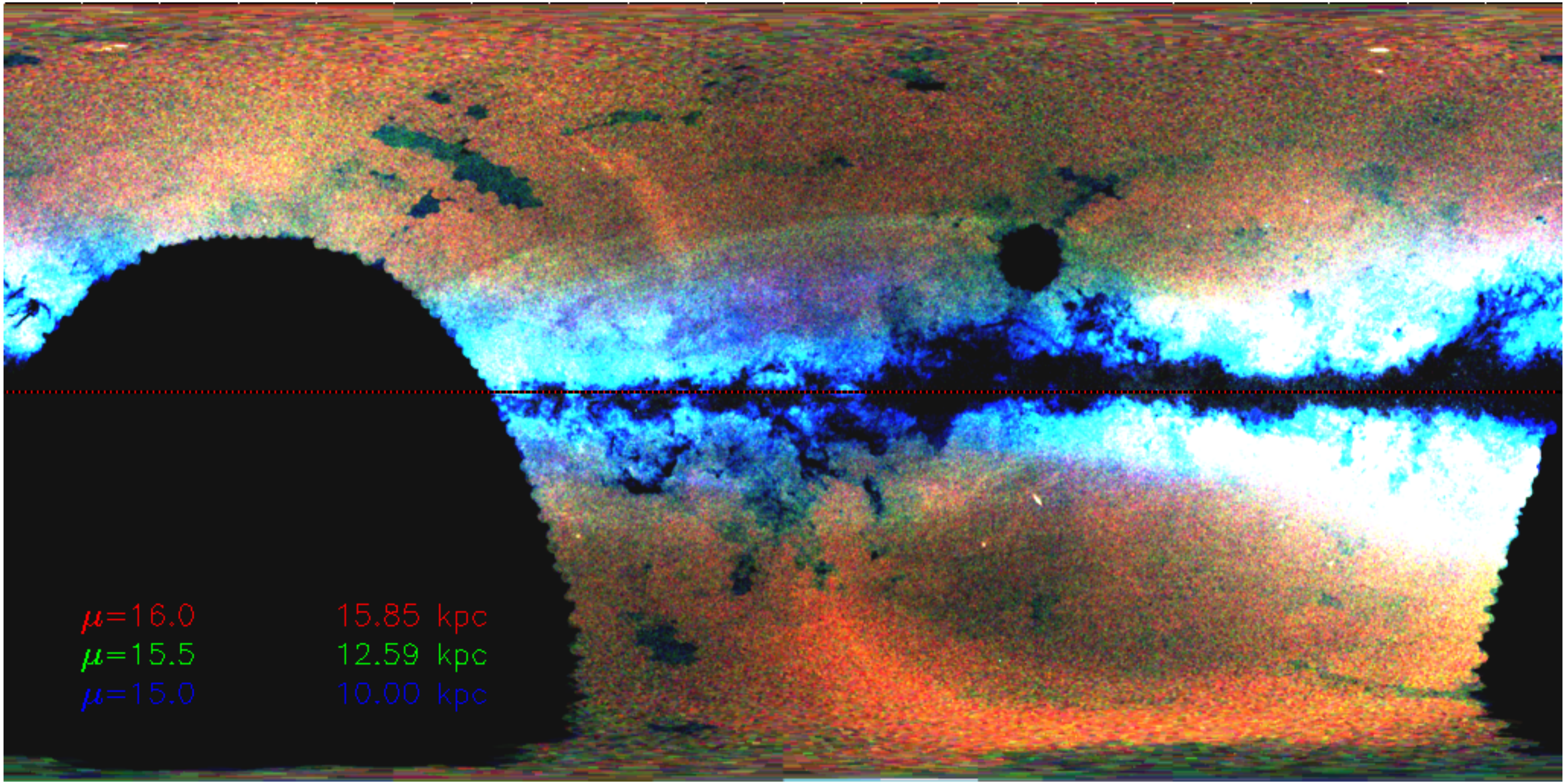
e.g. Cepheus resolved into two
distinct systems in projection

Movie



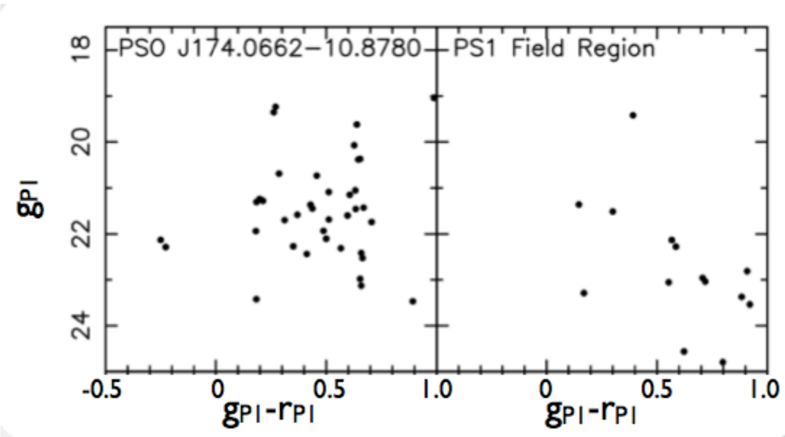
G. Green, D. Finkbeiner, E. Schlafly et al. in prep.

PS1 Field of Streams
Dynamical structure in the Milky Way

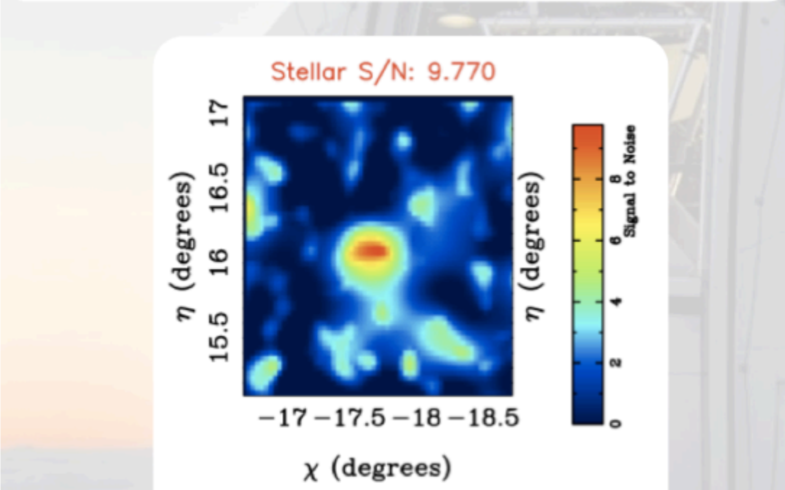


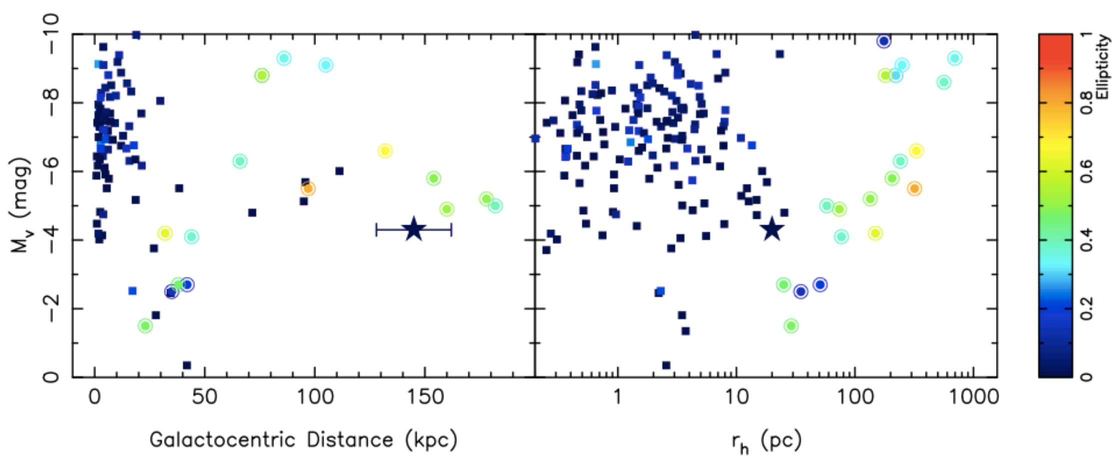
3-D map of Stellar streams in the Milky Way
Stellar distances from de-reddened tip of the giant branch
From 3yr PS1 data by Finkbienner, Green, Schlafly in prep.

Most distant globular or dwarf galaxy ?



Laevens et al. 2014

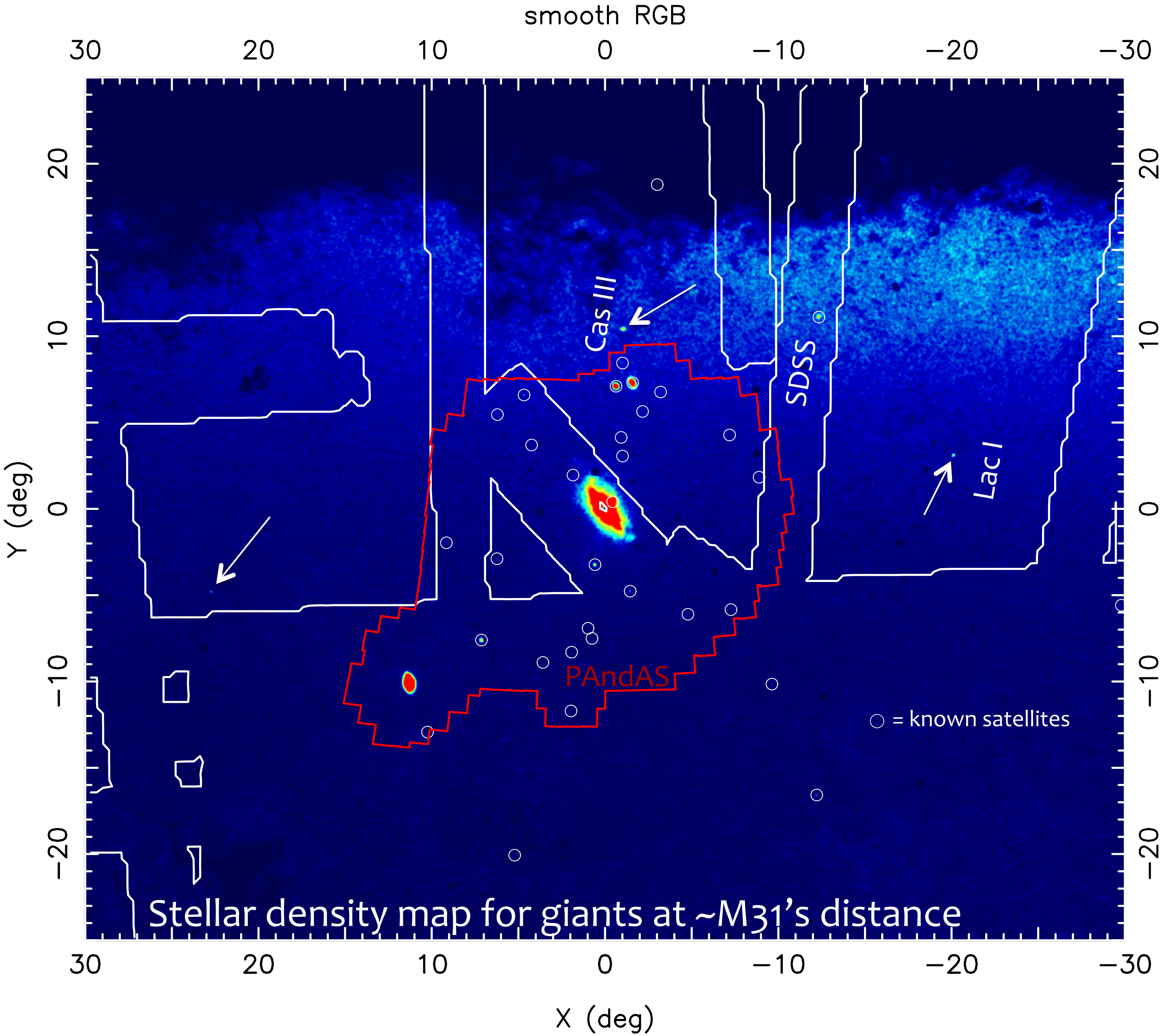




Co-discovery with ATLAS : Belokurov et al. 2014 (proposed a dwarf galaxy“Crater”)
Spectra of stellar components being pursued – velocities, dispersion, metallicities

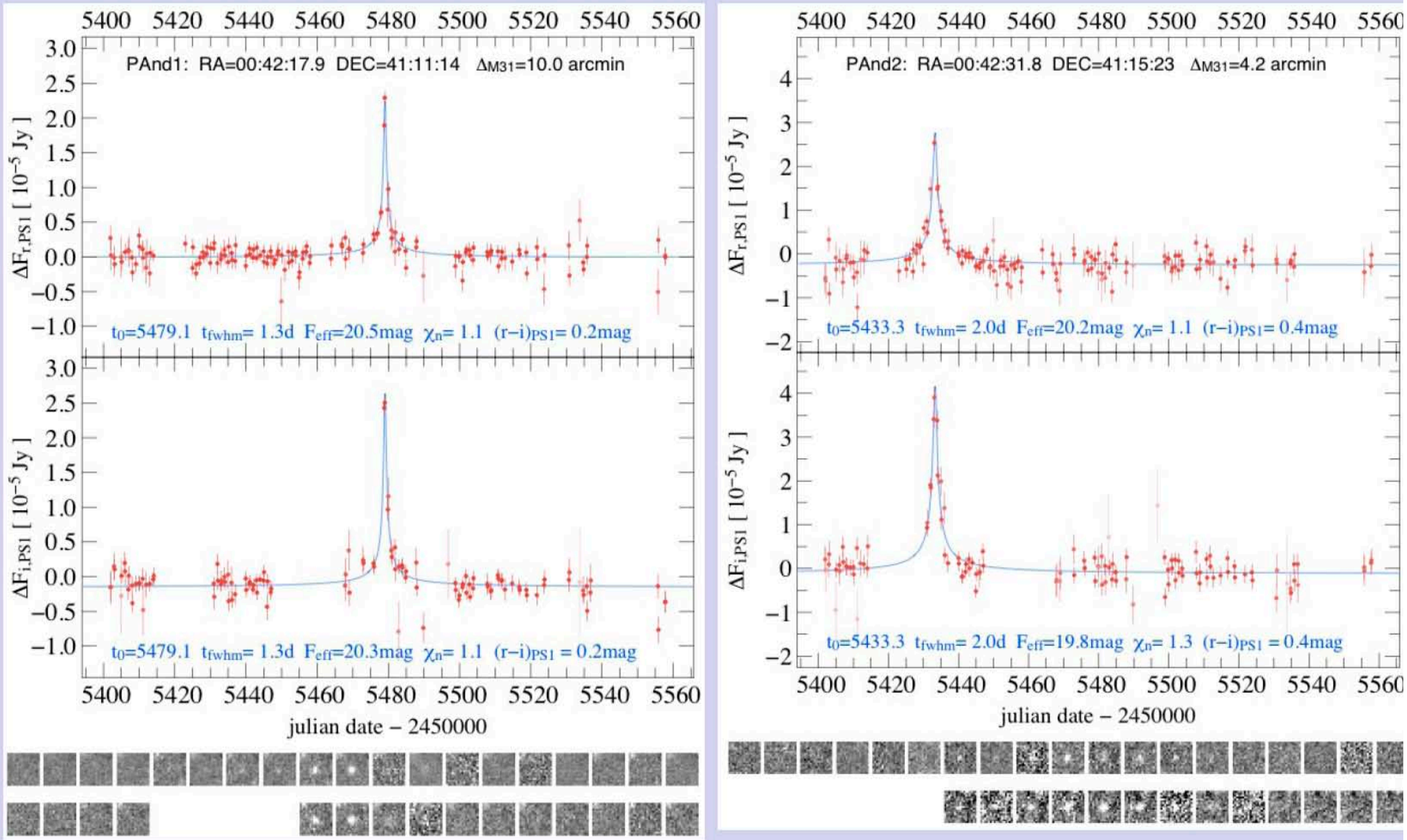
The most distant satellite galaxies to M31

Martin et al 2013 + Martin et al. 2013



Observatoire astronomique de Strasbourg

microlensing candidate PAnd 1 + 2

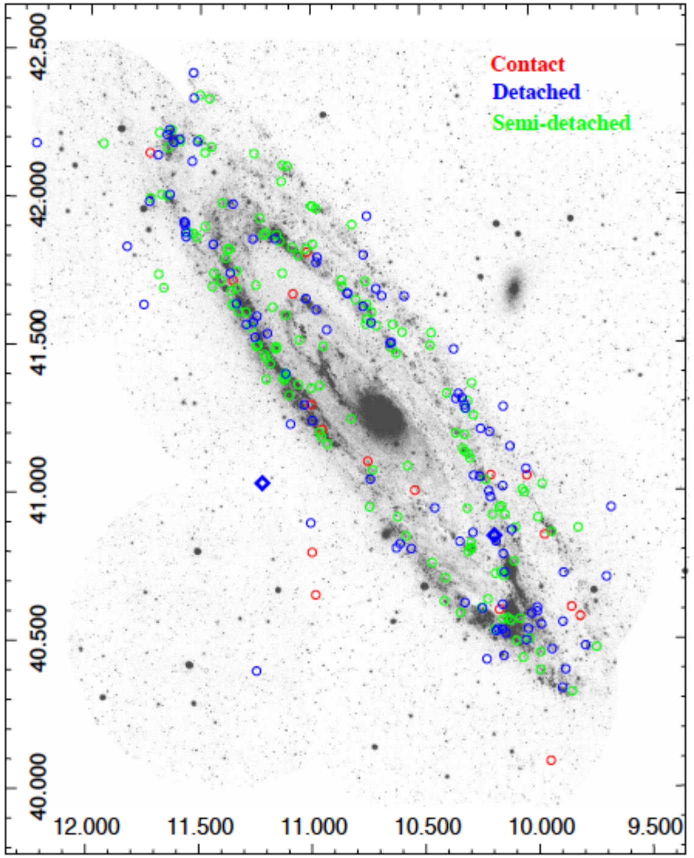


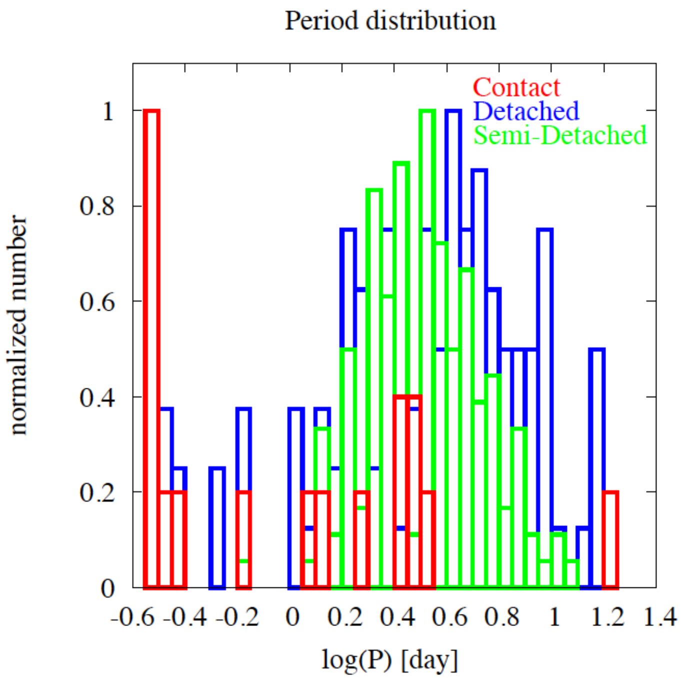
Lee et al., 2012 : 6 events from first year

Full systematic analysis to come with final reprocessed events (many more identified)

M31 eclipsing binaries!

- 300 eclipsing binaries, 11 could be followed spectroscopically with 10m telescopes for distance indicators.





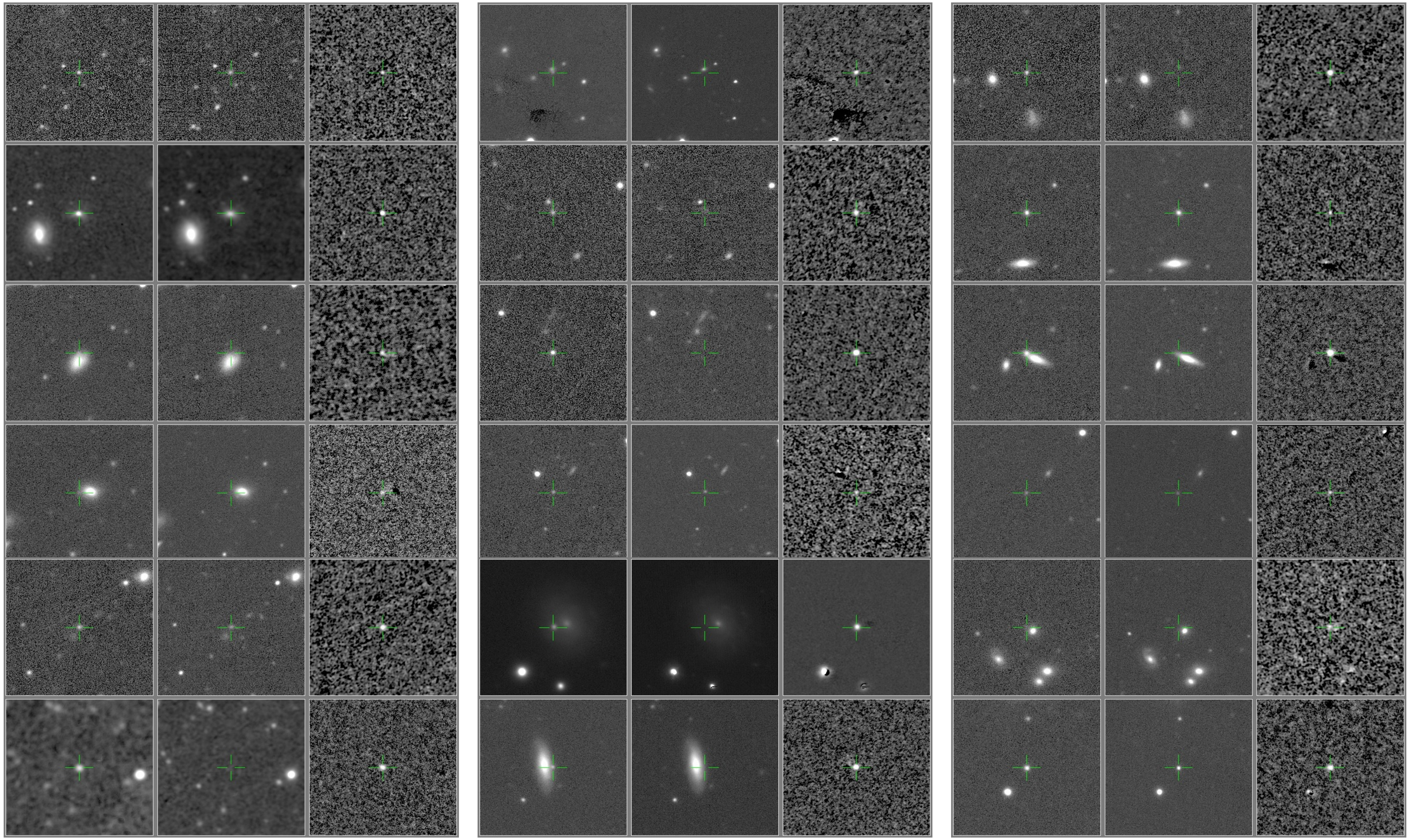
TMT spectra of M31 eclipsing binaries would eliminate the Anchor distance as a significant contribution to the error budget.

Target Goal – absolute distances to M31,

The Anchor distance contributes 1.3% of the 3.1% uncertainty in H_0 (MW Cepheids, LMC and NGC4258 maser - NGC4258 is in PS1 MD07 field)

PS1 time domain haul from MD field survey

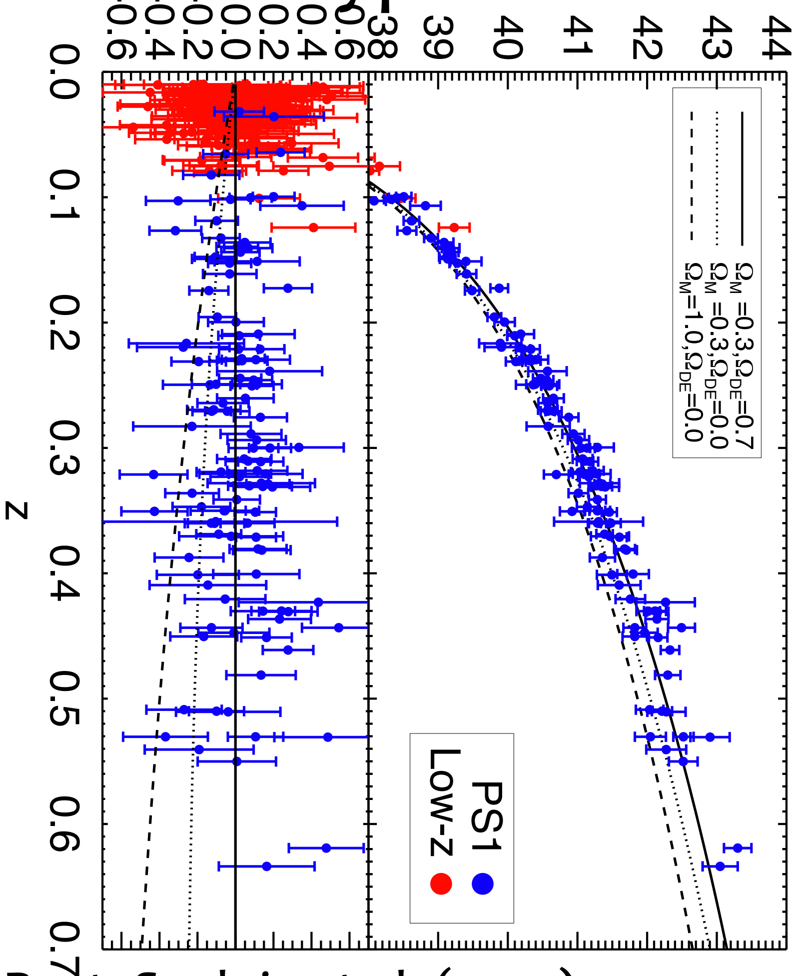
~7000 explosive transients, ~600 spectroscopically confirmed

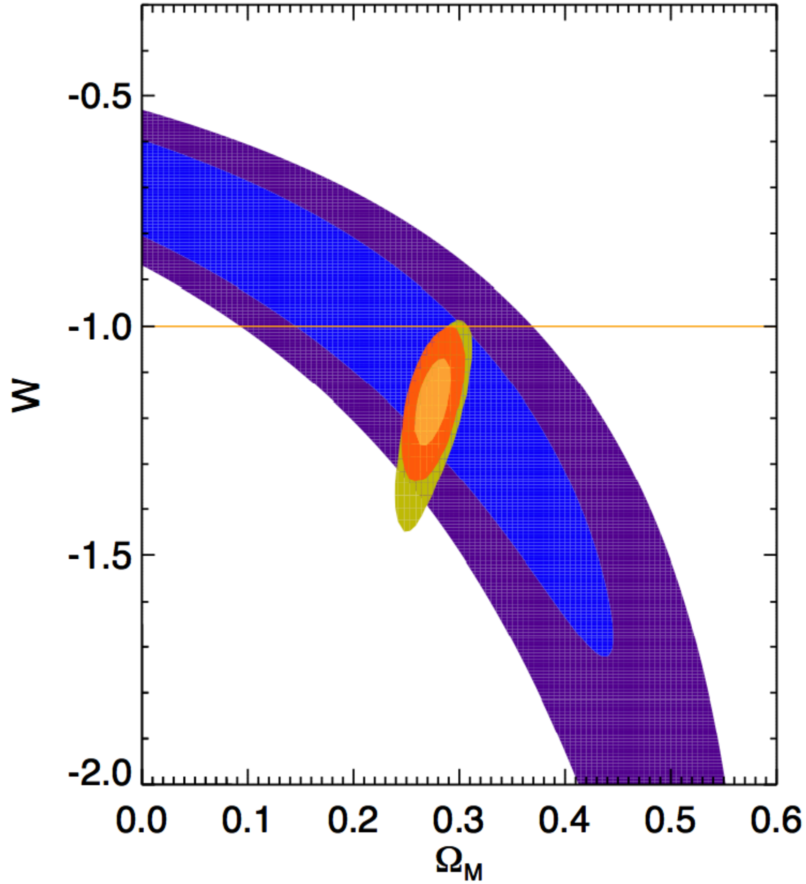


CfA : Berger, Rest, Narayan, Stubbs Chornock, Foley, Lunnan, Kirshner, Soderberg et al.
JHU : Riess, Scolnic, Rodney, Gezari (Maryland)

QUB : Smartt, Smith, Kotak, McCrum, Fraser,Wright, Nicholl, Inserra, Gall
IfA : Tonry, Huber, Bresolin, Kudritzki
LCOGT: Valenti, Howell

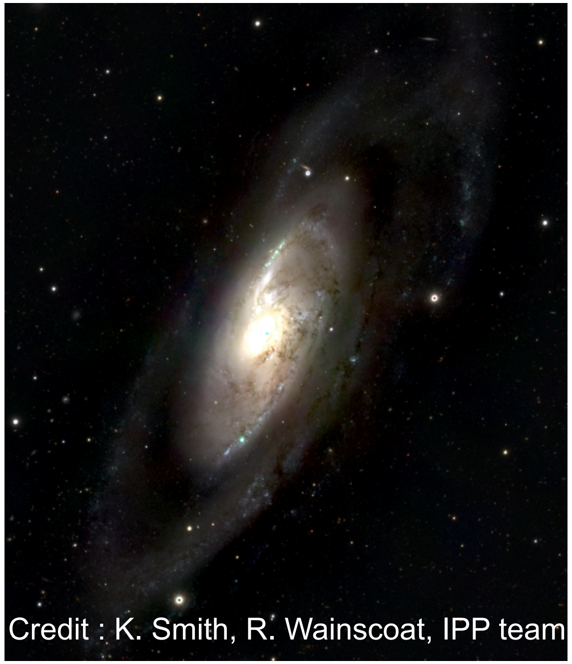
Type Ia SN and cosmology

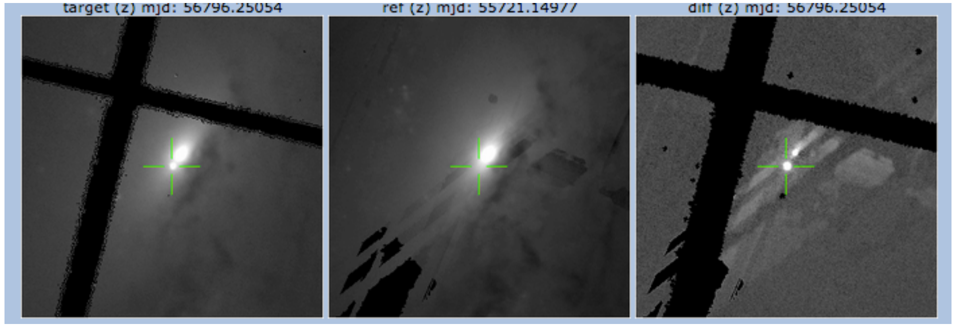


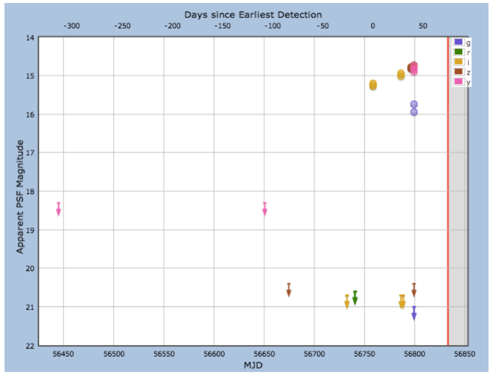


- Rest, Scolnic et al. (2014)
- 146 SNe from Year 1 sample
- PS1+low-z, Planck, BAO, H_0
- w = -1.166 +-0.07
- Tension with w = -1 at 2.3 sigma level
- Totals : ~350 in total spectroscopic sample, ~2000 photometric sample

Transients in 3π



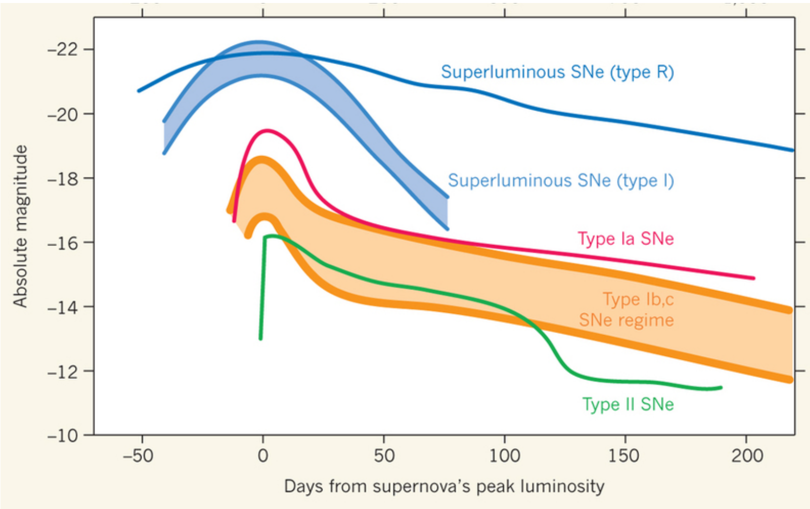




Type II-P SN in NGC4258,
Caught after we finished the
MD Fields !
While NEO survey running and
holes being covered

- Since mid-June 2013, <u>all images</u> differenced with respect to stacked sky
- Transients identified and publicly released (1193)
- http://star.pst.qub.ac.uk/ps1threepi/psdb/public/

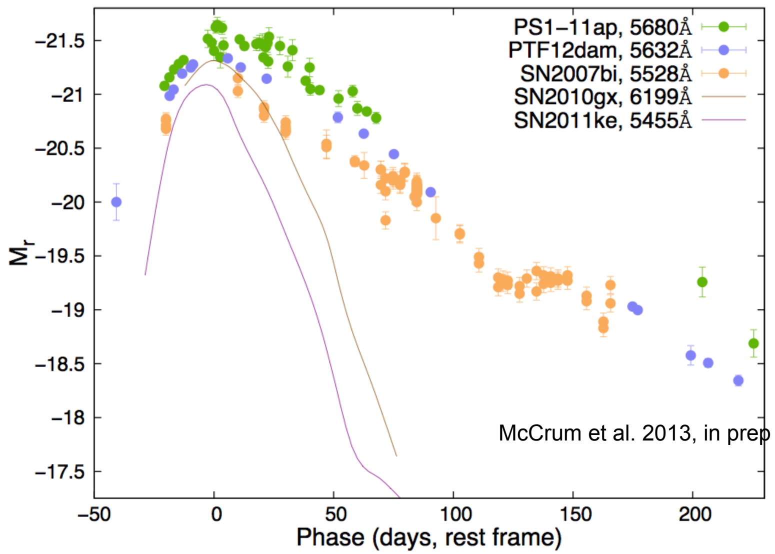
Superluminous stellar explosions



Stellar Explosions 100 times more luminous than core-collapse SNe.

No hydrogen and helium seen in spectra

What is the physics powering this extreme luminosity ?



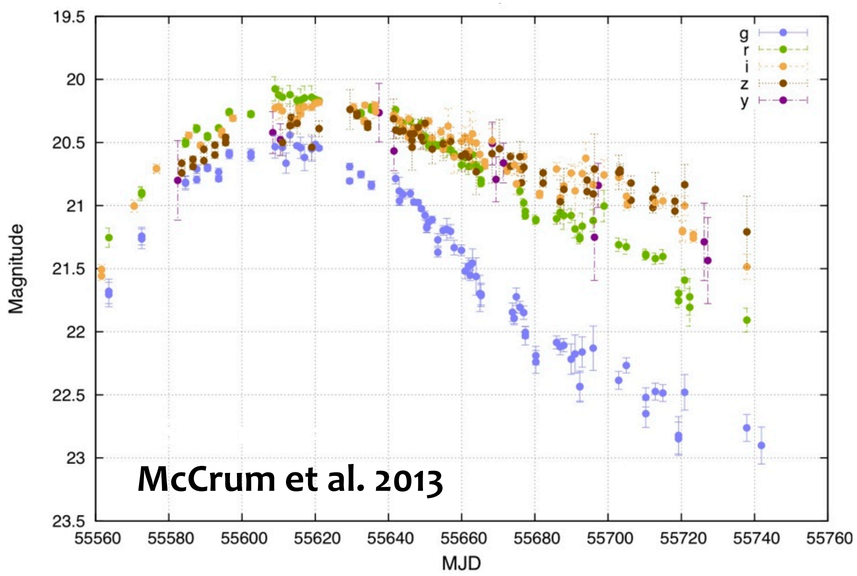
PS1 : has discovered them at redshift ranges z ~ 0.1 – 1.5

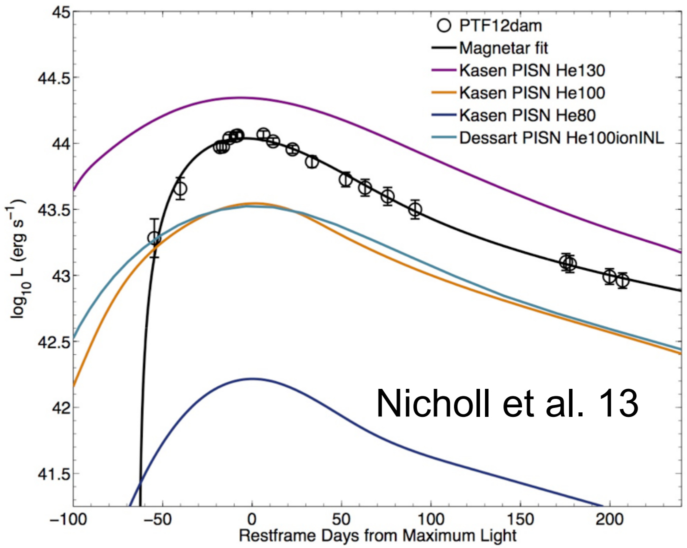
- z = 0.1 – 0.3 in the 3π survey
- z = 0.5 – 1.5 in the MD fields

PTF discoveries : Quimby *et al. Nature* 2011

Chomiuk et al. 2011, Berger et al. 2012, Nicholl et al. 2013, Inserra et al. 2013, Lunnan et al. 2013, Chornock et al. 2013

Are they ***all*** magnetar powered SNe?





PS1 – excellent lightcurves and explosion epochs

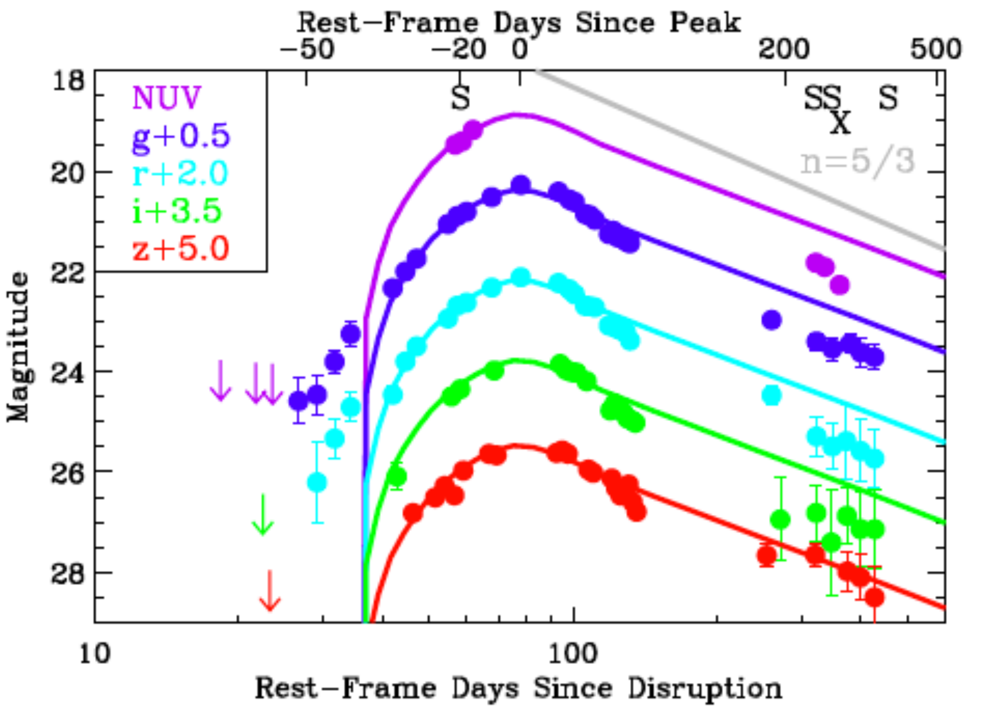
Magnetar powered model fits well :
$M_{ej} = 10\text{-}16 M_{\odot}$ $B \sim 10^{14}$ G
$P \sim 2.6$ ms

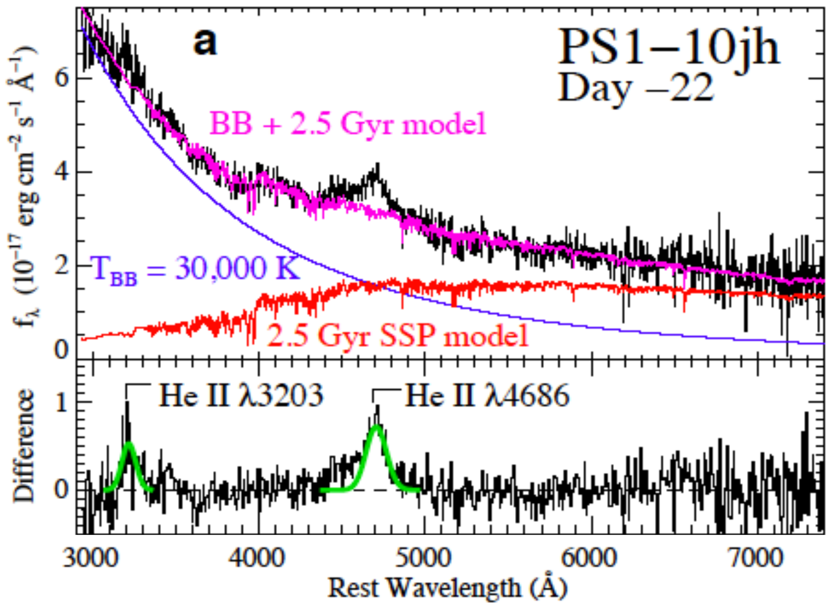
- Major PS1 result : pair-instability SNe do not exist
  or very low rate (< 10^{-5} of all core collapse SNe)

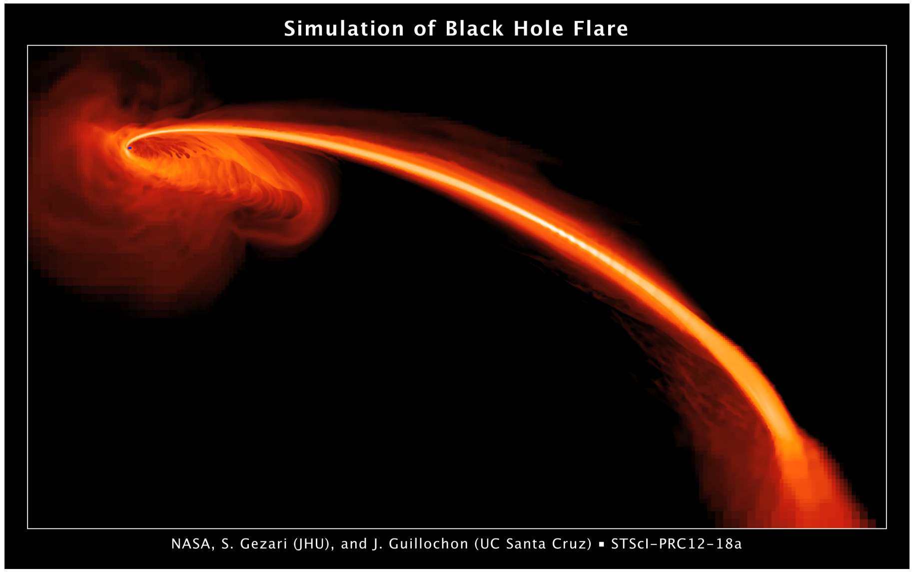
- **All** superluminous SNe could be explained with magnetars
  Nicholl, Smartt et al., 2013, Nature

nature

He-rich star disrupted by central galactic black hole



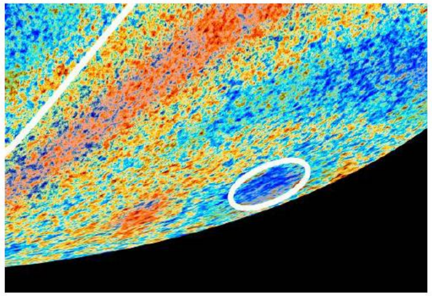


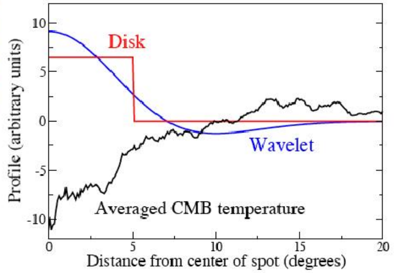


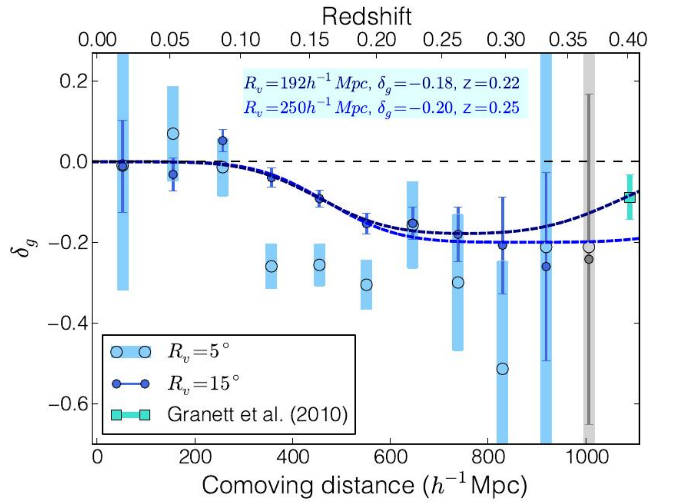
Gezari et al 2012, Nature

nature

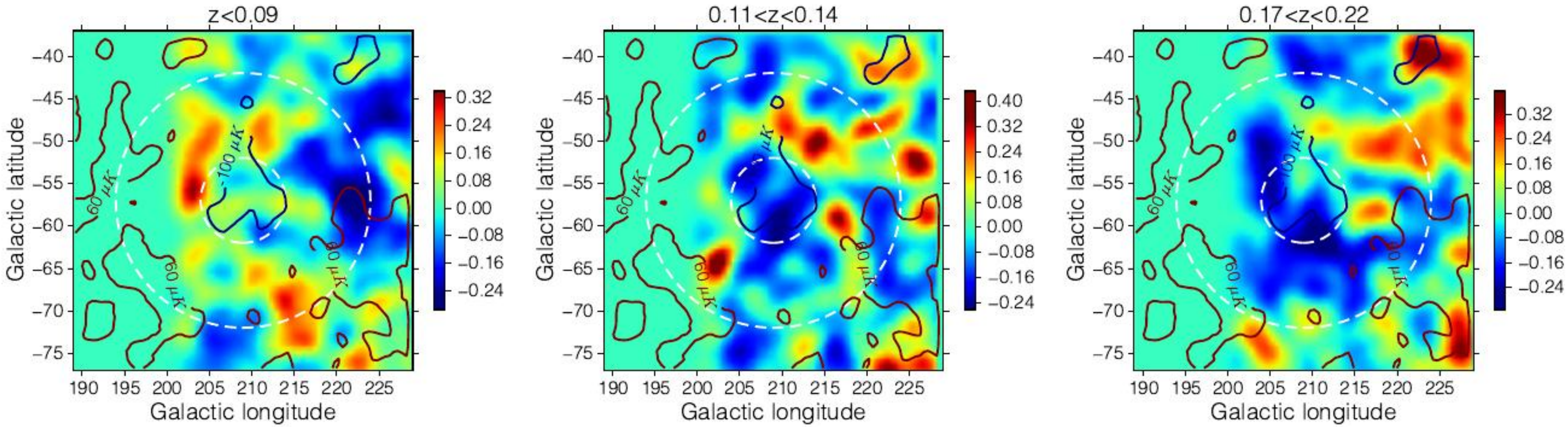
Large scale structure : The CMB cold spot







- Discovered in WMAP data and confirmed by Planck
- Cold Spot 0.5% unlikely (Cruz et al. 2006), $\Delta T \simeq -70\ \mu K$
- extends at least 5°, and up to 15° on the CMB
- explanation ranges from textures to statistical fluke
- Inoue & Silk (2007): $200\mathrm{h}^{-1}\mathrm{Mpc}$ void with $\delta = -0.3$ via linear ISW (at redshift $z \approx 1$)

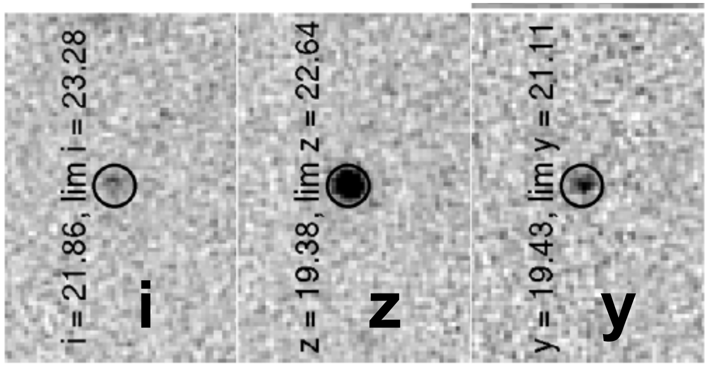


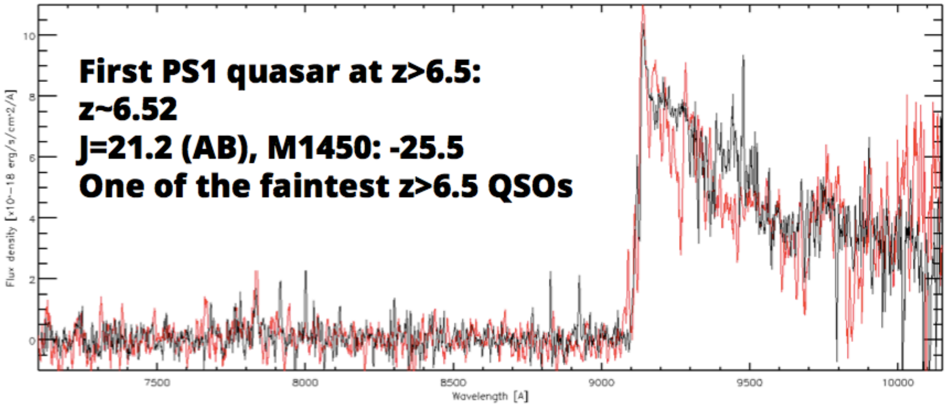
Kovacs, Szapudi et al. 2014

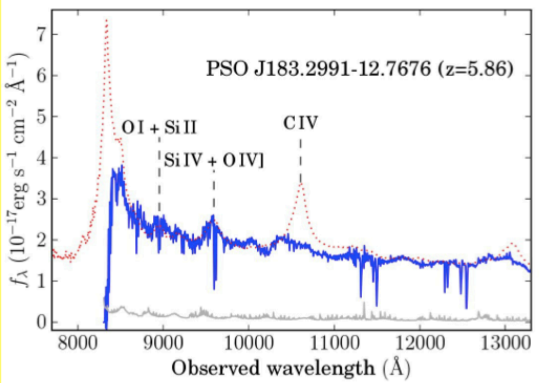
Most PS1 LSS work will come with the final 4 year data stacks and re-processed data.

Z > 5 Quasars

Farina, Banados, Walter, Chambers, Venemans, Morganson et al (MPIA, CfA, U.Hawaii)

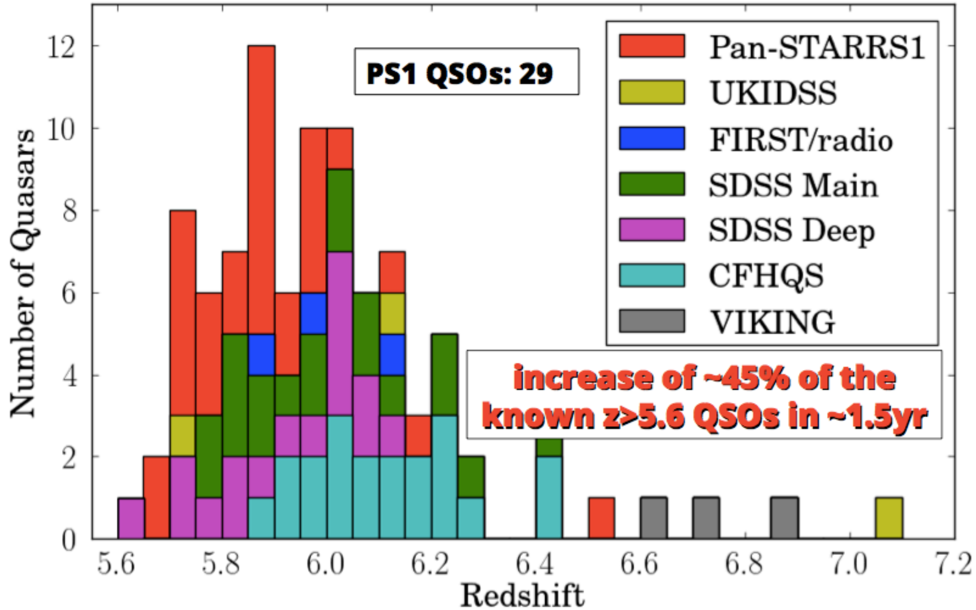






WEL quasars
~25% @z~6
~1% @z<4

Bañados+2014



Quasar evolution at z > 6 ?

WHEN WILL THE PS1 DATA BE RELEASED?

PS1 Public Data Release

All data products, images, and derived data products to be served by STScI Archive (MAST) from April 1, 2015

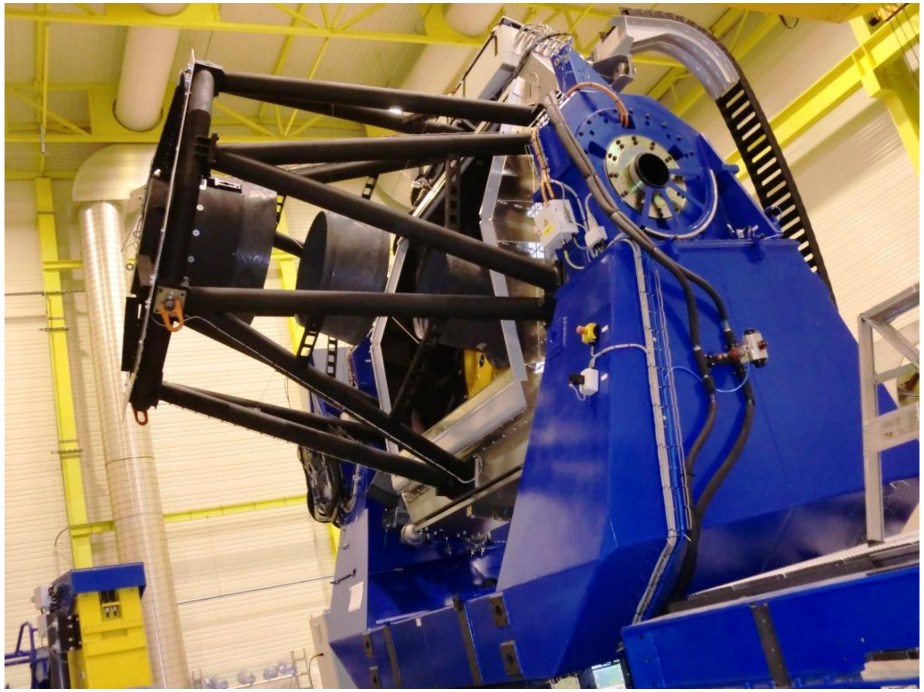
- Data release ~1 year after end of PS1 data taking
  - < 3 months after completion of re-processing virtually no proprietary period for 4-year stacks.
  - 2 Pbyte of imaging data to be shipped back to STScI in Dec. 2014
  - 100TB source catalogue in hierarchical database with image server

- Data products
  - > 100×10^9 single-epoch detections (min 72 epochs, mean 90 epochs, some regions w/ 100's)
  - ~ 5×10^9 objects (associations and stack detections)
  - c.f SDSS DR9 : 4.7×10^6 objects

WHAT IS NEXT?

Status of PS2

- PS2 has the same optics design as PS1, with hopefully superior fabrication of L2 optic
- Aside from optical design, PS2 is a completely different telescope from PS1.
- Construction is done, signifies the completion of the Pan-STARRS Project
- The GPC2 Camera is currently only partially populated, but tnew detectors look good.
- Commissioning including collimation & alignment, observing software, completion of GPC2 and integration is underway by ops team.
- Expect full functionally of PS2 & integrated operations with PS1 by summer 2015.



PS2 telescope w/o optics on the factory floor at AMOS, Belgium.

PS2 telescope w/ optics assembled inside PS2 dome on Haleakala.

PS1 & PS2 2014-2017:

A sky survey optimized for NEO detection

- The NASA NEO program is supporting the commissioning of PS2 and the Operations of PS1 & PS2 for 3.5 years for a ~ all sky survey.
- Program will use wide filters for greater instantaneous sensitivity.
  - W filter = g + r + I in dark time
  - Currently i and r band in bright time
  - Transition to x ~ i + y + z filters in bright time.
  - 4 exposures spaced by ~ 30 minutes
- Over the last two months PS1 has "broken" the current international follow up system – many PS1 NEOs candidates are going without followup needed to get an orbit. Need PS2 and self follow-up.
- Shameless Advertisement: Consider having your

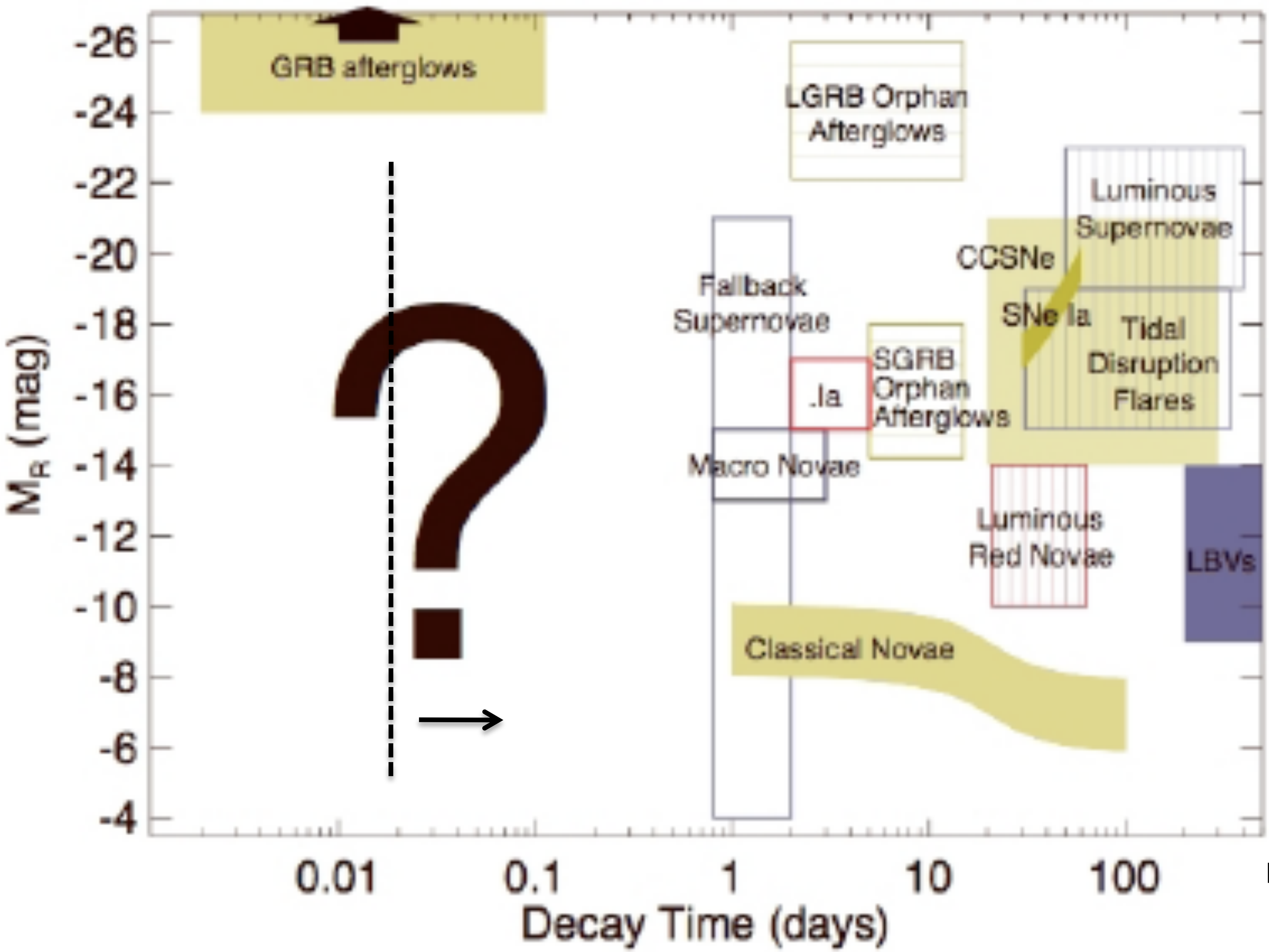
research group / institution / agency / country

join the 2014-2017 PS1&PS2 survey

- Access to deep all sky, high cadence time domain
- Access to new stacked data all sky data in wide filters

  inproved photoz's and stellar parameters by fine tuning of filters
- 10% time is available at cost for your program starting March 1 2015

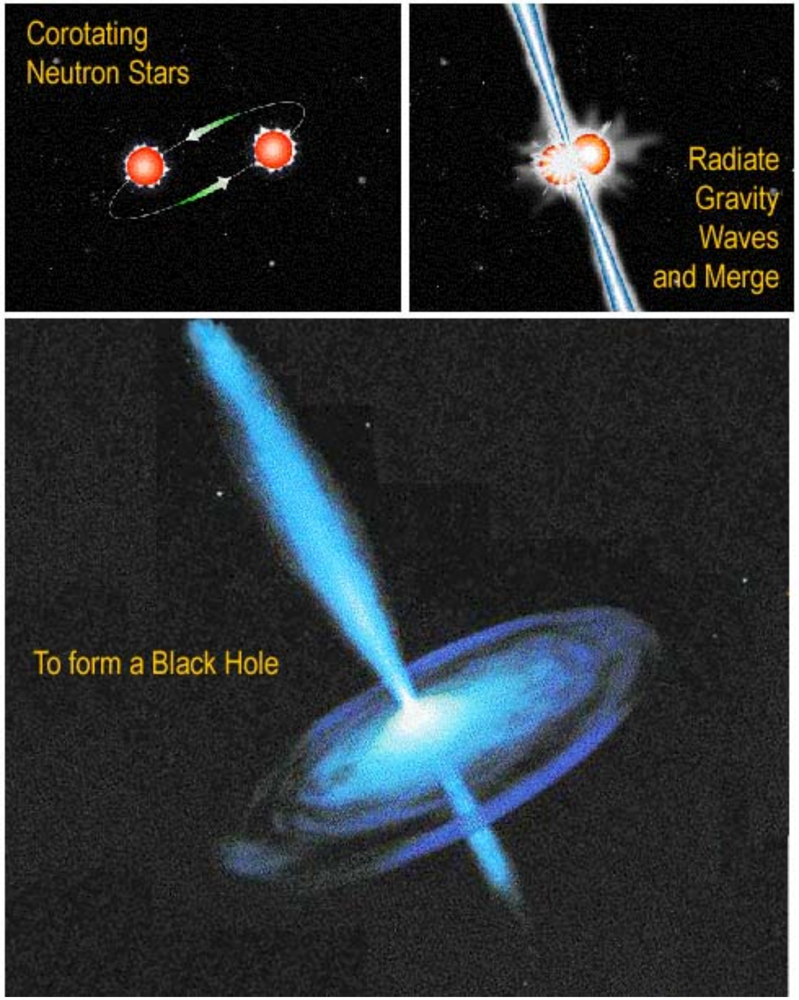
Short timescale is terra incognito

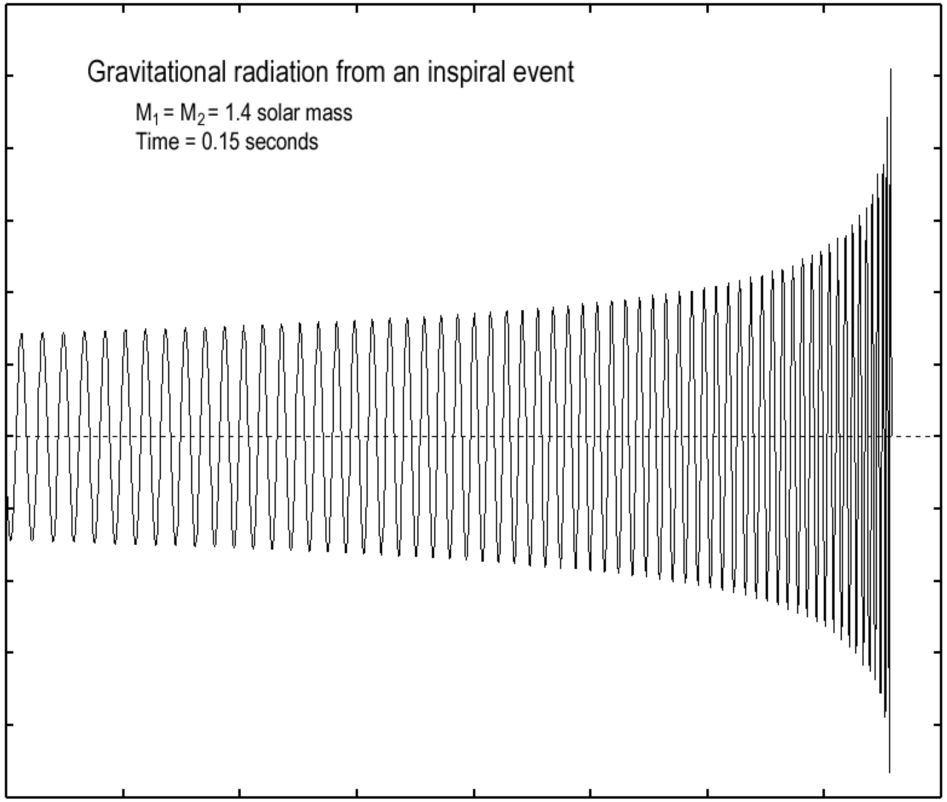


From LSST book

2nd Pan-STARRS Mission 2014-2017 will explore this region extensively to 24 mag

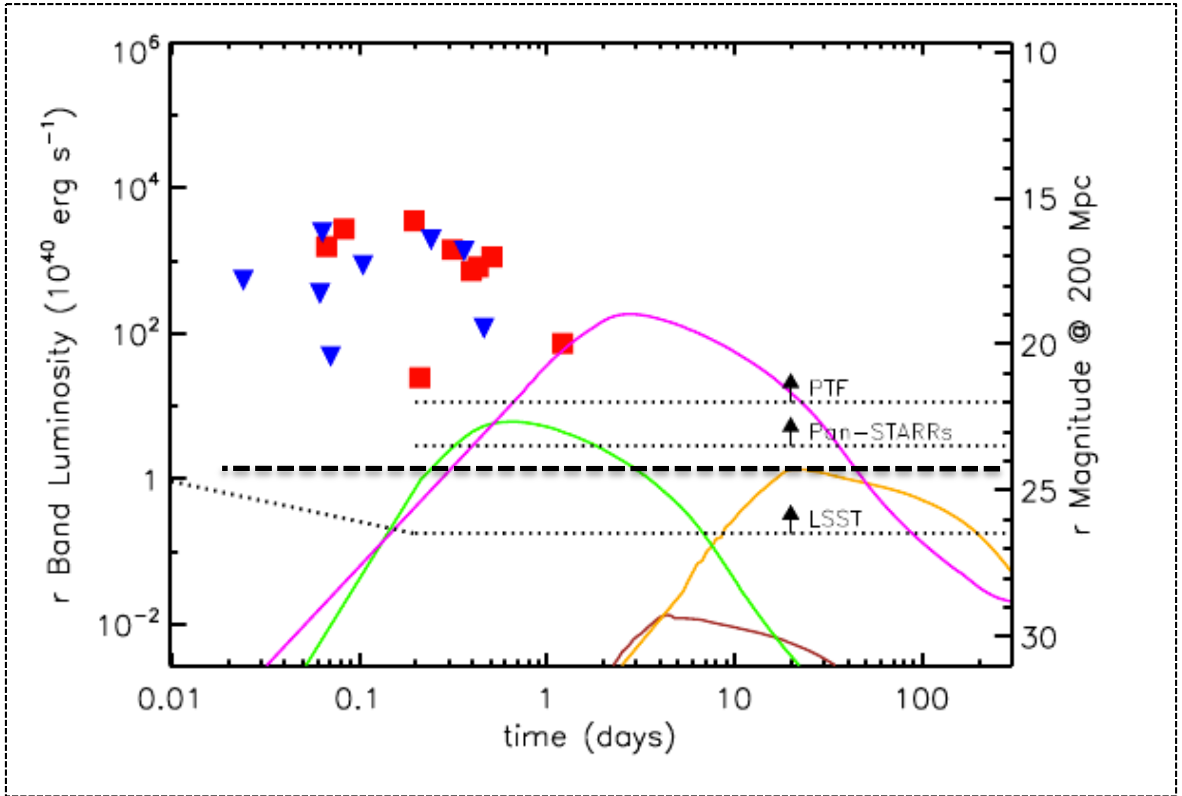
Neutron Star – Neutron Star Mergers
best candidates for producing detectable Gravitational Waves





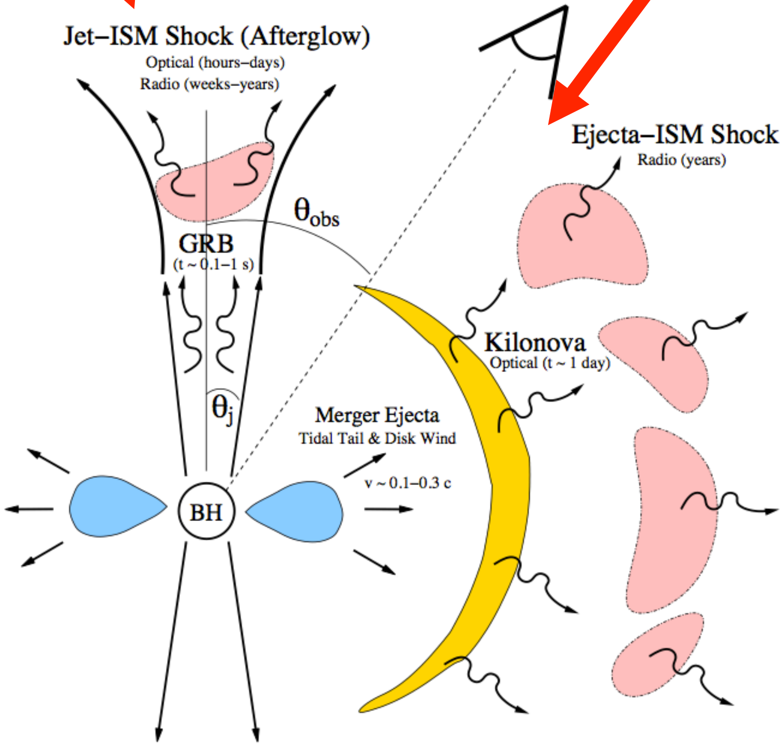
NS-NS merger likely to be seen as off-axis short GRBs or Kilonova

Berger et al 2012



Short GRB

"Kilonova"



PS1 with NEO program filter & cadence. At a minimum PS2 increases nightly survey area ----------------

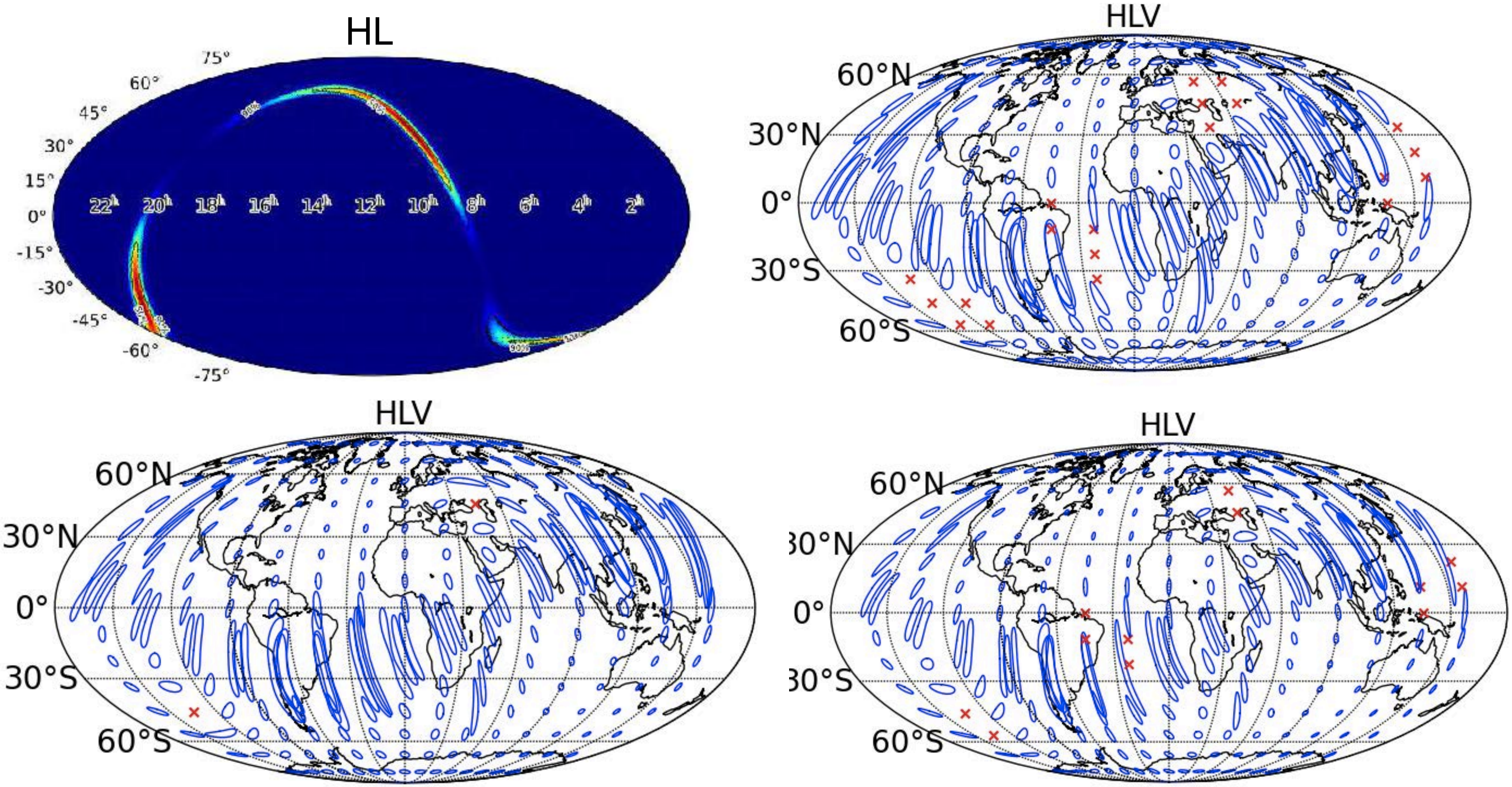
Advanced LIGO and aVirgo GW Observatory

first observing campaigns starting 2015

Advanced LIGO will be able to detect gravitational waves that stretch the length of the 2k arms by a fraction of the size of a proton

Adv LIGO – Hanford, Livingston, aVirgo

2015, 2016, 2017, 2018



aLIGO-Virgo error “bananas” will be 100’s to ~1000 square degrees. Pan-STARRS can map these to ~ 24th mag in a single night, and will have prior visit and upper limit from ongoing NEO survey. Problem will be eliminating the ~ 100 un-related transients.

WHAT IS AFTER THAT? (2017)

Pan-STARRS+ after 2017

- Have ~ 3 years to get a international public/private consortium in place or the Pan-STARRS functionality and the institutional knowledge will be lost.
- Potential to fix PS1 Image Quality floor -> sub-arcsec imaging on both tel.
- Potential for PS1-PS2 -> PS blue-PS red (including u-band)

  Simultaneous bandpasses in a sky survey is a unique capability, many apps.
- Note: a PS4 could survey all the available sky, 20,000 square degrees every night! Two to three times then number of epochs of LSST albeit to the depth of PS1 detections for < 10% of the cost. Need something in the north.
- Consider having your

  research group/institution/agency/country
  - Join the 2014-2017 PS1&PS2 survey
  - Prepare to Organize/Join/Define a Pan-STARRS + UKIRT + MKO + ?

    suite of surveys and integrated science program starting late 2017.

    IfA is planning to host an initial workshop coincident with IAU 2015.
- Prepare for TMT support effort and train for LSST/WFIRST/Euclid type science by organizing and doing science now.


PS1
PS2

PS1 wide field survey telescope

- at Haleakala, Maui

Pan-STARRS1
Observatory,
Haleakala, Maui

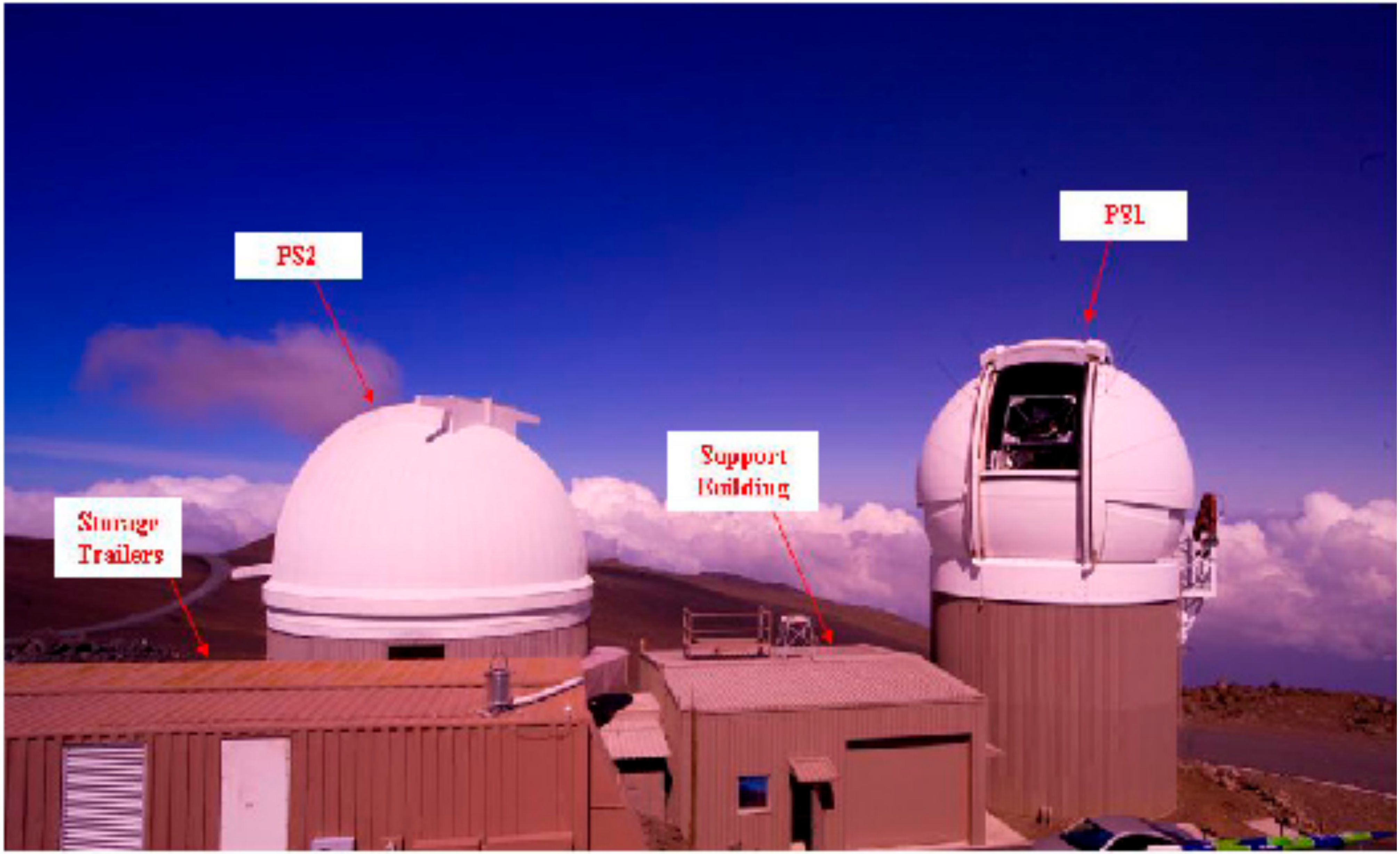
The PS1 Surveys

PS1 Surveys	Filters	Percent Time
3 π Steradian Survey	g, r, i, z, y	56
Calibration Fields	g, r, i, z, y	2
Medium Deep Survey	g, r, i, z, y	25
Solar System Survey	w	(5) 11%
Stellar Transit Survey	i	(4)
Deep Survey of M31	g, r, i, z, y	(2)
Principal Investigator Discretionary Time (NK)		6

- Science survey started Summer 2010; duration ~3.5 years

- ***grizy*** not taken simultaneously:
- Number of of epochs
  - ~30 in 3π
  - Each epoch = 2 exposures (30-43 sec) separated by 15 mins ("TTI pairs")
  - 100s epochs in the other sub-surveys

PS1 + PS2 at the summit of Haleakala



PS1 IS A *RED* CCD SURVEY

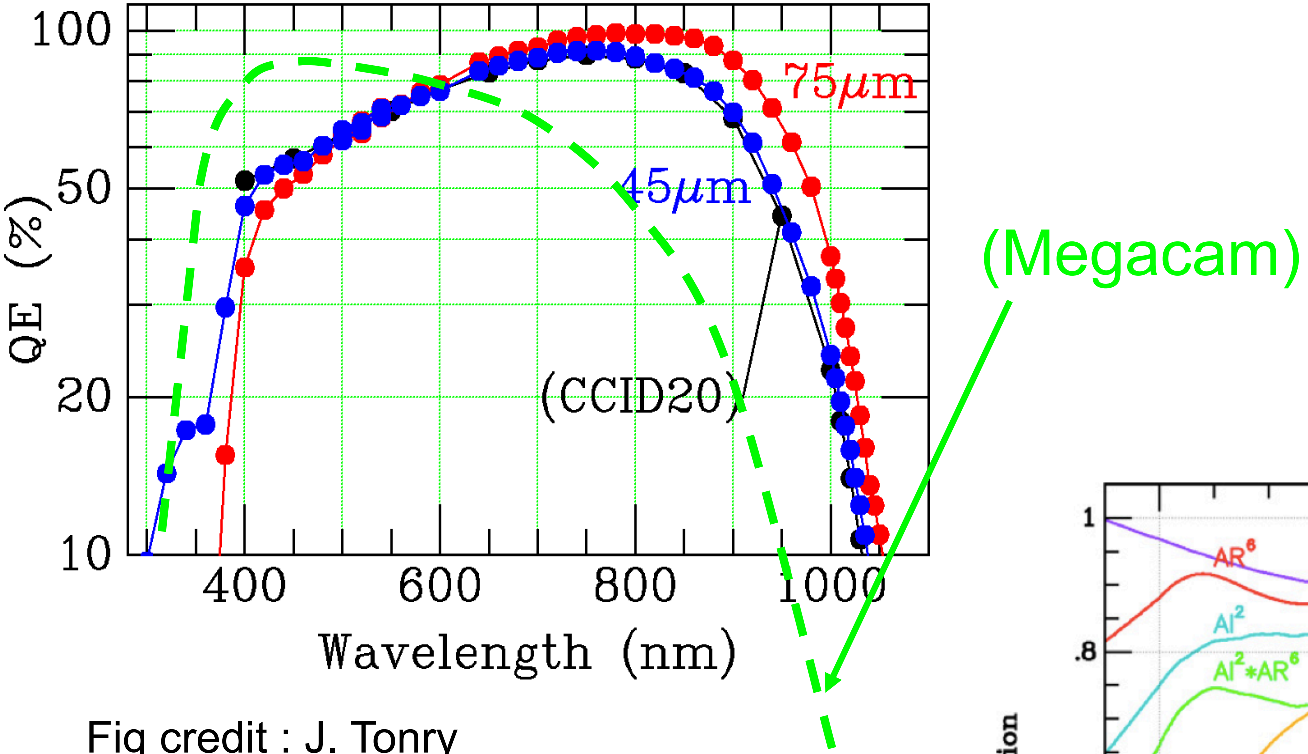
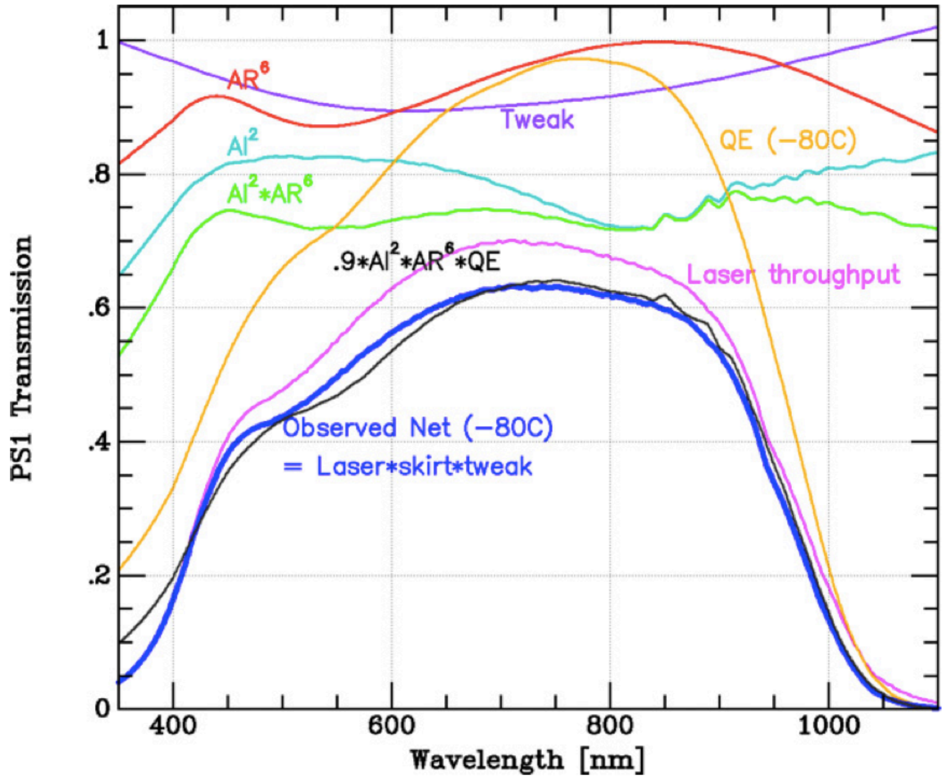
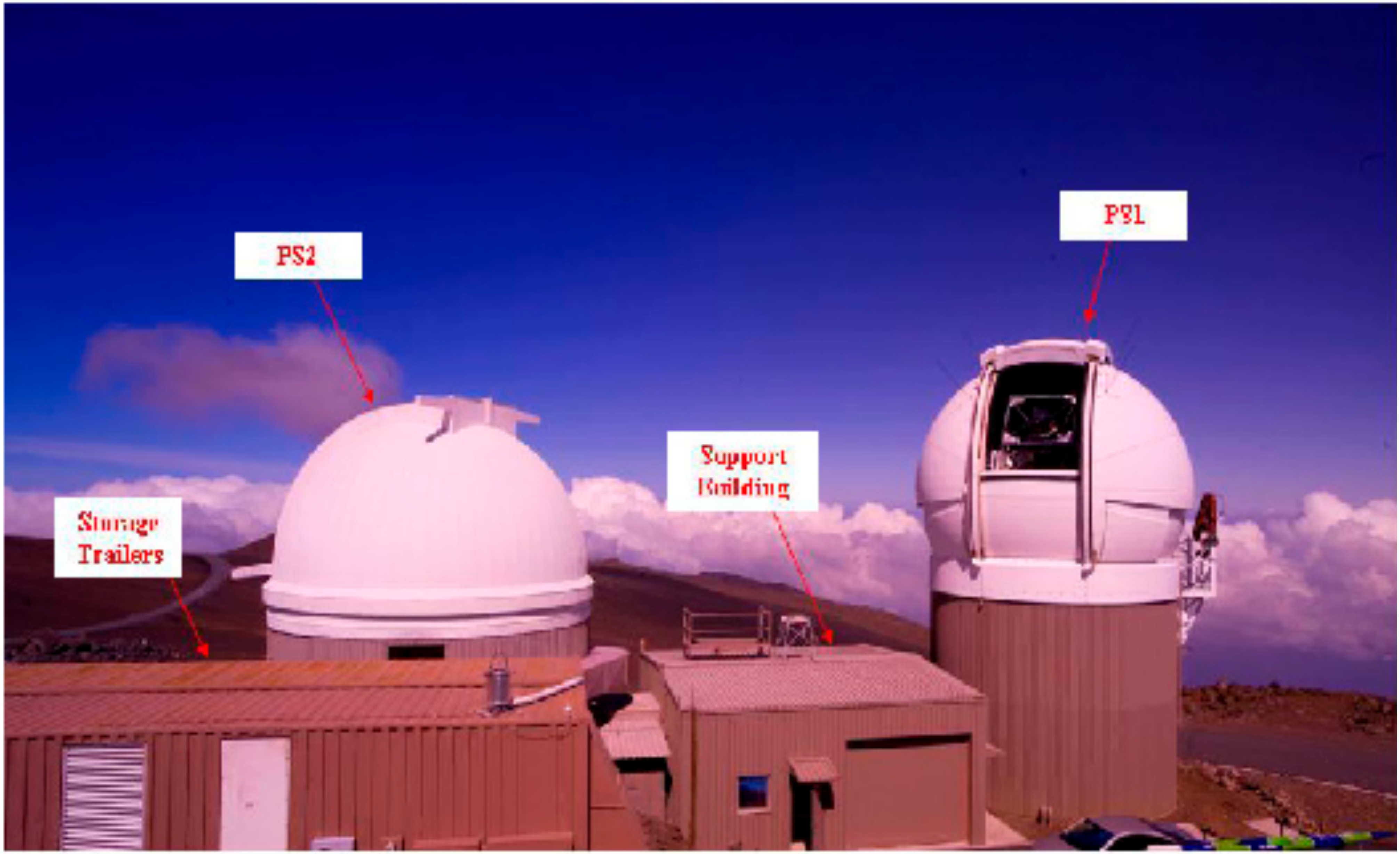


Fig credit : J. Tonry



Tonry et al. 2012,
ApJ, 750, 99

PS1 + PS2 at the summit of Haleakala



Pan-STARRS

PS1 Science Consortium

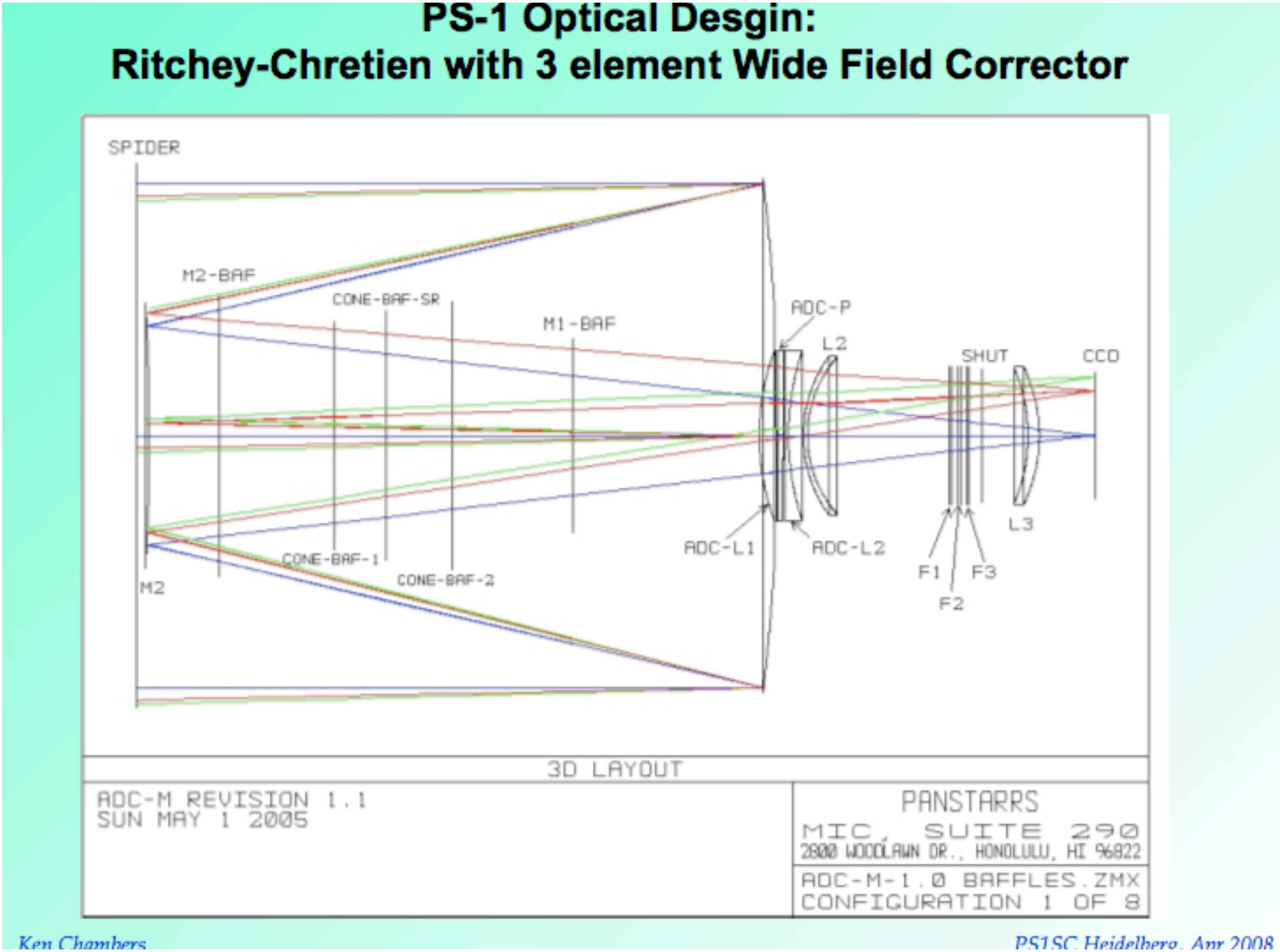
SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

Los Alamos NATIONAL LABORATORY

UNIVERSITY OF MARYLAND

University of Hawai'i
UH Institute for Astronomy
Max Planck Institute for Extraterrestrial Physics
Max Planck Institute for Astronomy
JOHNS HOPKINS UNIVERSITY
Department of Physics and Astronomy
Harvard-Smithsonian Center for Astrophysics
Queen's University, Belfast
University of Edinburgh
Durham University
Durham University Institute for Computational Cosmology
National Central University, Taiwan
Las Cumbres Observatory Global Telescope Network

- PS1 wide field survey telescope
- 1.8 meter aperture at f/4.4
- 3.2 degree field-of-view
- 1.4 Gigapixel Camera



The Pan-STARRS1 Photometric Reference Ladder Release 12.01

E. A. Magnier,[1] E. Schlafly,[2,3] D. Finkbeiner,[2] M. Juric,[2] J. L. Tonry, [1] W. S. Burgett,[1] K. C. Chambers,[1] H. A. Flewelling,[1] R.-P. Kudritzki,[1] J. S. Morgan,[1] P. A. Price,[4] W. E. Sweeney,[1] C. W. Stubbs,[2]

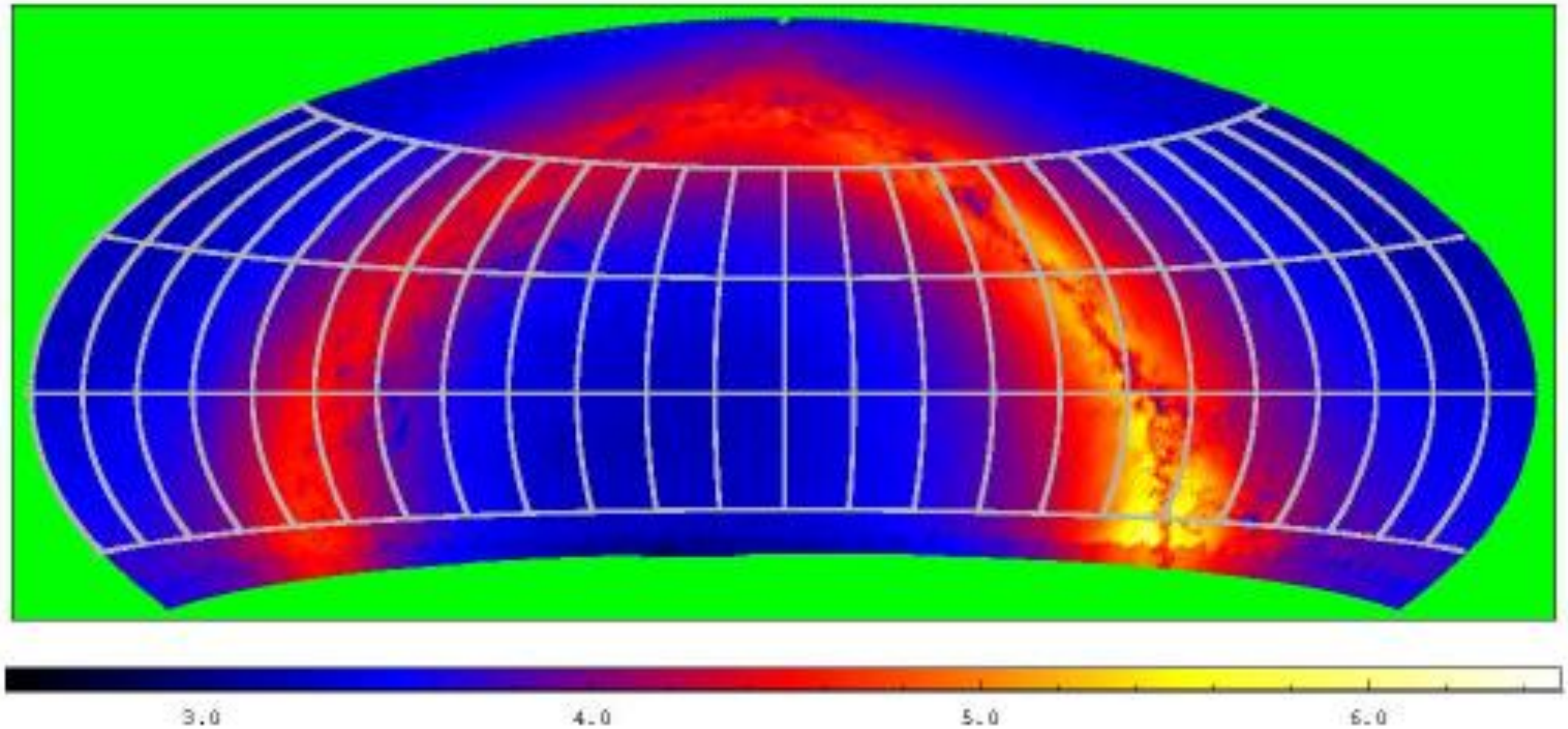
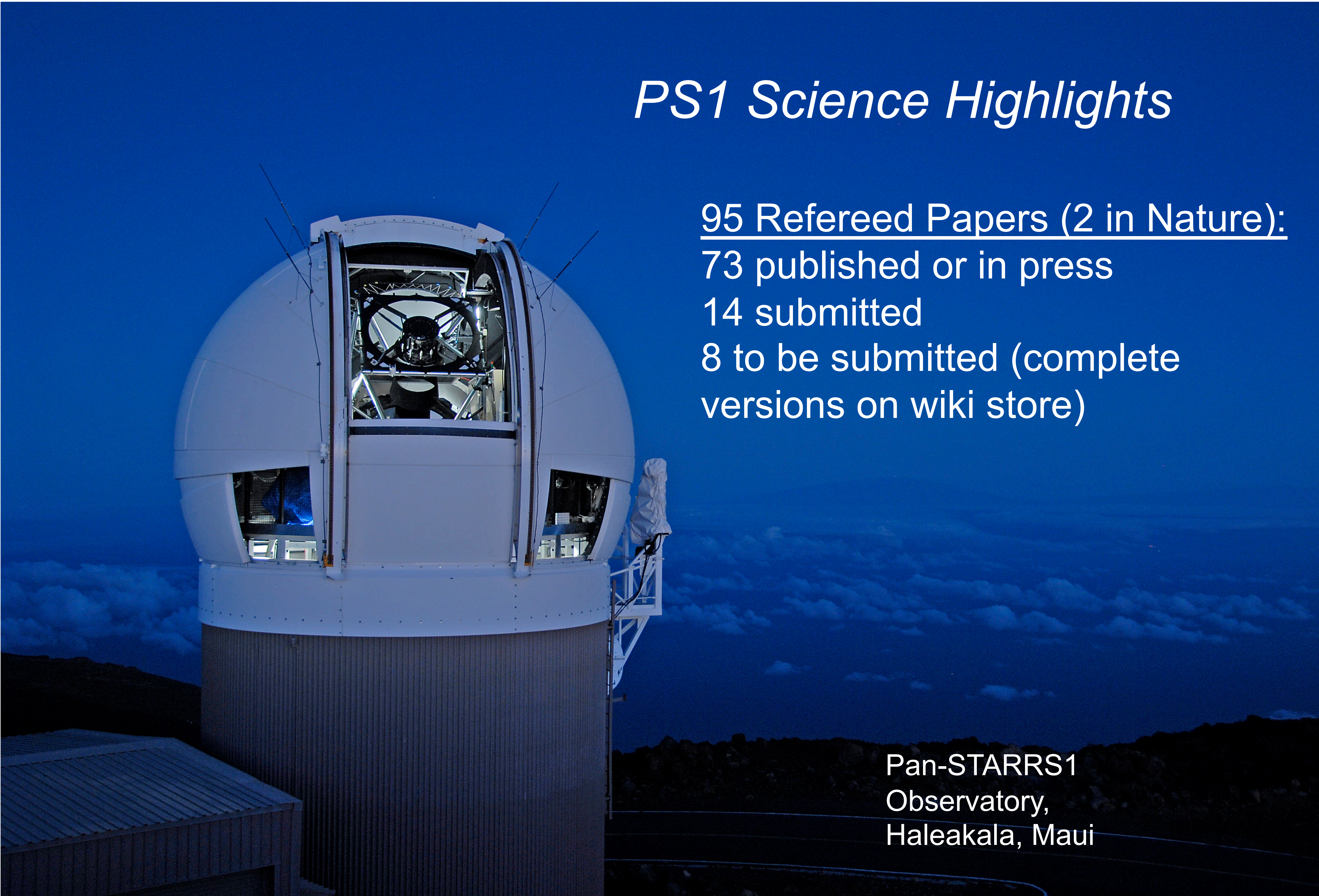


Figure 8. Location of the photometric ladder overlayed on a plot of the spatial density of objects. The color scale gives the logarithm of the number of objects per square degree with at least 3 measurements and $r_{P1} < 19.0$. RA = 0.0 is at the center of the plots and increases to the left.

Precision photometry of stars ~< 19.5 in a 1 degree wide stripes across the sky with a density of ~1000 well measured stars per square degree.

http://ipp.ifa.hawaii.edu/photladder.20130107.subset/

PS1 Science Highlights



95 Refereed Papers (2 in Nature):

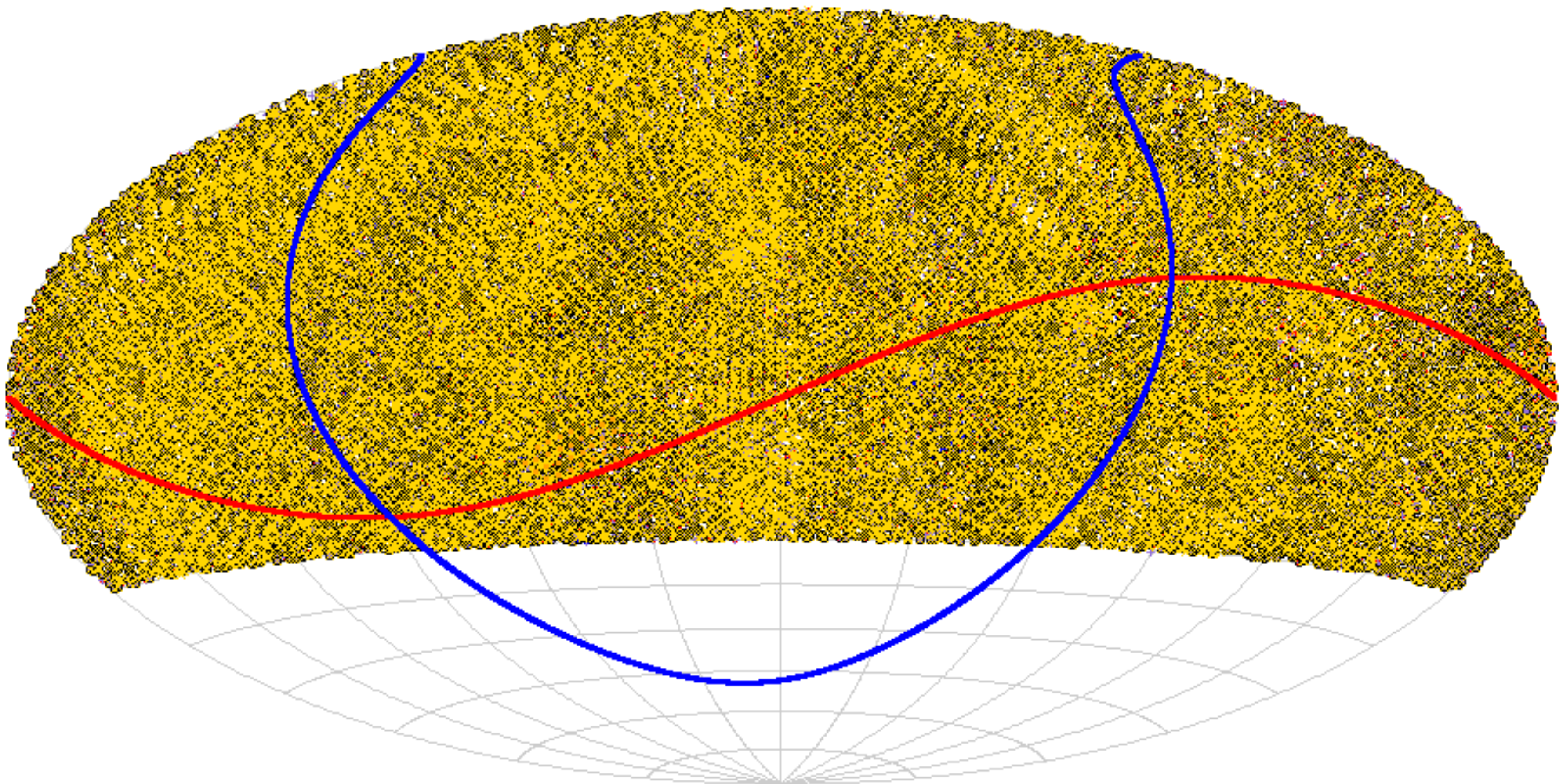
73 published or in press

14 submitted

8 to be submitted (complete versions on wiki store)

Pan-STARRS1 Observatory, Haleakala, Maui

3pi sky coverage to June 12, 2013



Ecliptic Plane
Galactic Plane

grizy bands >300,00 total exposures

Low-Mass stellar objects and free floating planets

Deacon (MPIA), Liu (U. Hawaii)

- Wide (proper motion) ultra-cool companions to main sequence stars
- Age, distance and metallicity determined from primary
- Doubled the number late-M and L companions known already

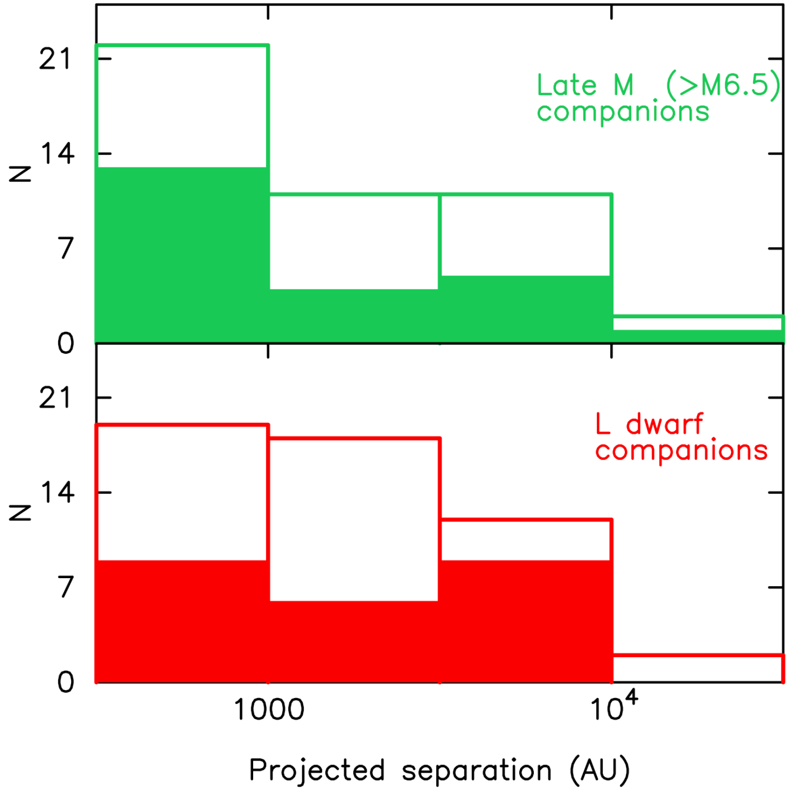
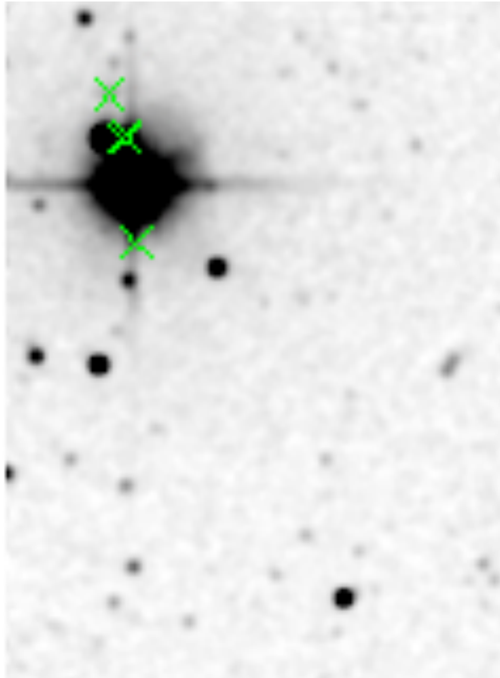


Image Credit :N. Deacon

HIP 38939B



Deacon 2012a

T4.5 companion to a K4.5 at 19pc
Age 300 Myr - 3 Gyr

Atmospheric model fit 1100K
Evolutionary model fit 1090±60K

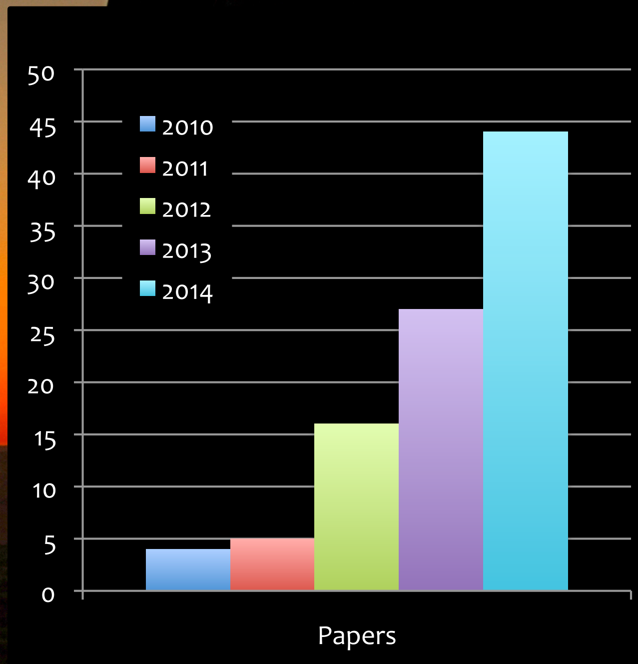
PS1 Science Consortium surveys

PS1 survey

- Complete over 3π & special fields
- time-domain survey: ~30-500 epochs over 3yrs
- g to 1μm; much deeper than SDSS in the red
- unprecedented photometric precision ~0.5 %

Already producing great science on:

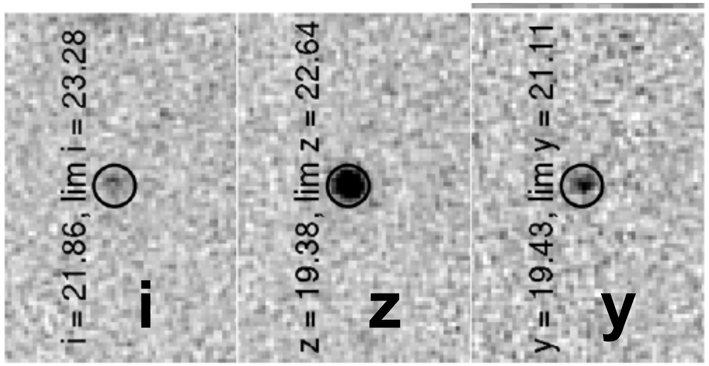
asteroids, BDs, Milky Way structure, supernovae, variable stars, transients, black holes, QSOs

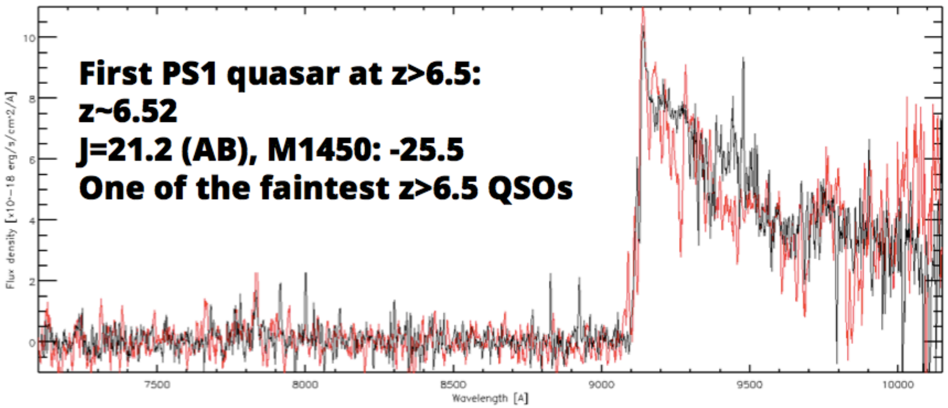


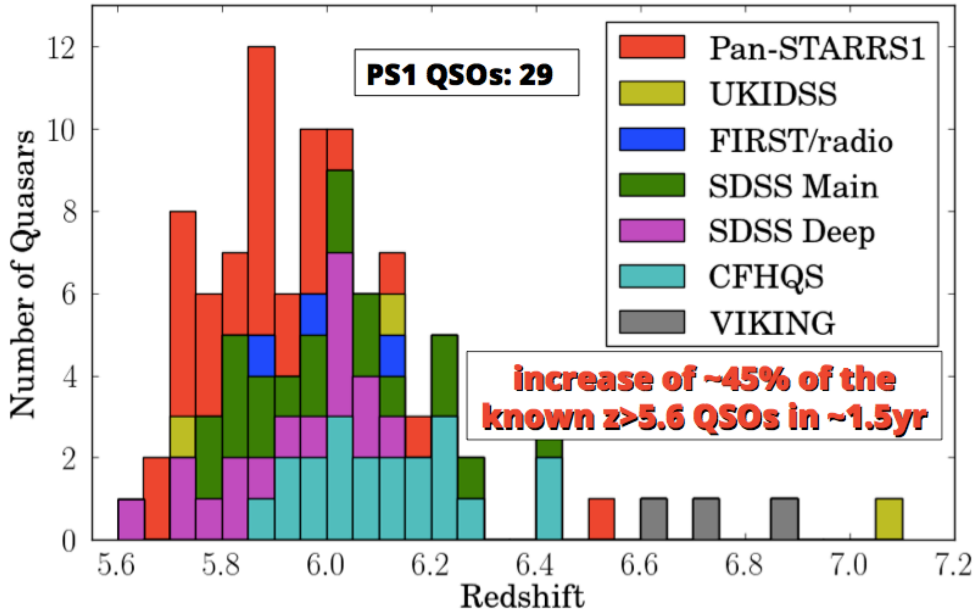
Public Data Legacy in MAST from April 2015
The full, stacked sky not yet exploited

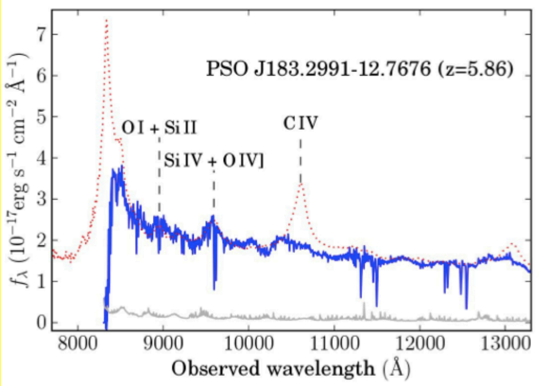
Z > 5 Quasars

Farina, Banados, Walter, Chambers, Venemans, Morganson et al (MPIA, CfA, U.Hawaii)









WEL quasars

~25% @z~6

~1% @z<4

Bañados+2014

Quasar evolution at z > 6 ?

PAndromeda

(Andromeda with PANSTARRS)

Stella Seitz, Ralf Bender (PIs)
Team Members:
Chien-Hsiu Lee, Arno Riffeser,
Mihael Kodric, Johannes Koppenhoefer,
Ulrich Hopp,
Jan Snigula, Claus Goessl

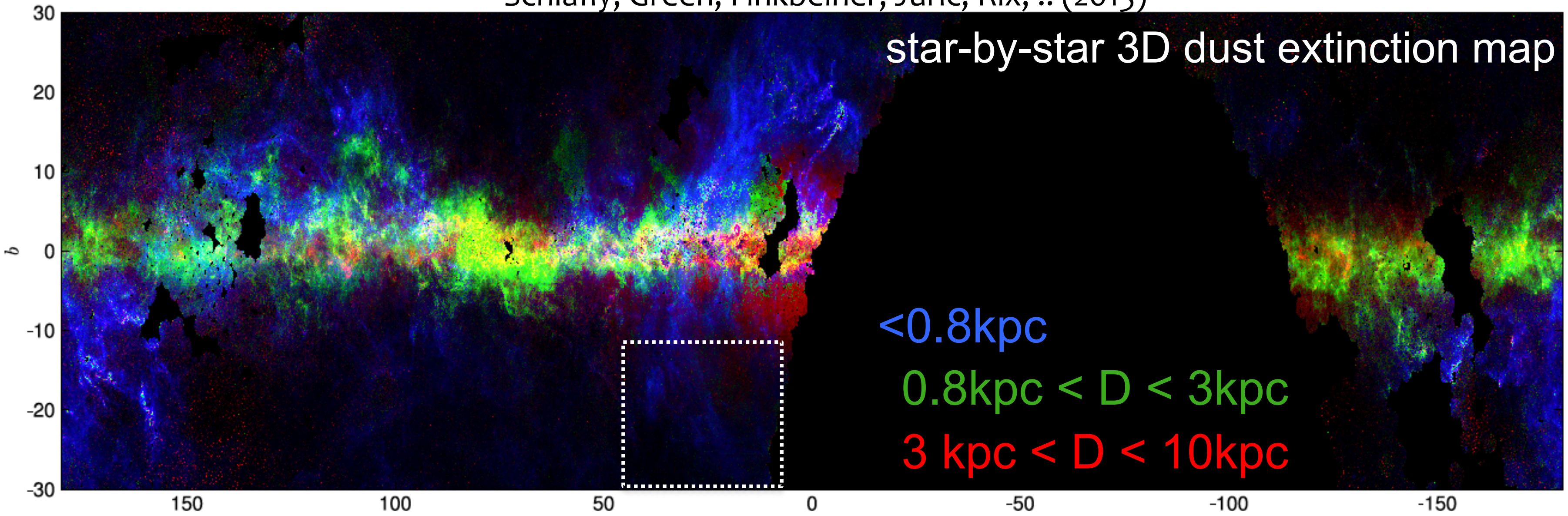
3 Seasons : 2010, 2011, 2012

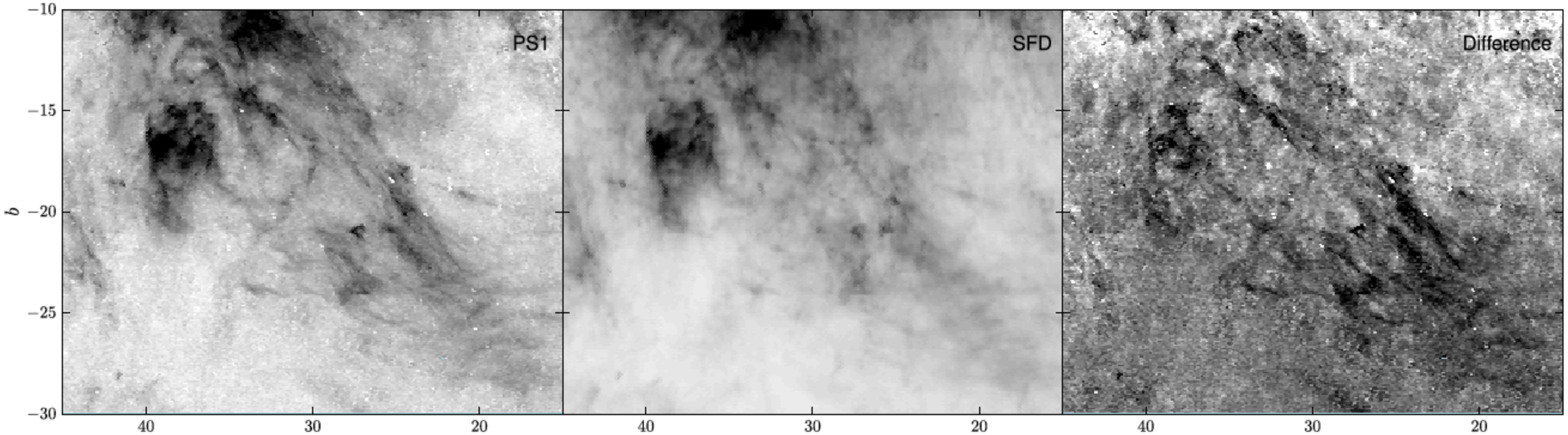
In the 2010 : 90 nights in r_{P1} (70740s) and 66 nights in i_{P1}. (36180s)

Lee et al. (2012)

A high-resolution 3D dust map of the Galaxy

Schlafly, Green, Finkbeiner, Juric, Rix, .. (2013)





Star-by-star extinction (PS1)

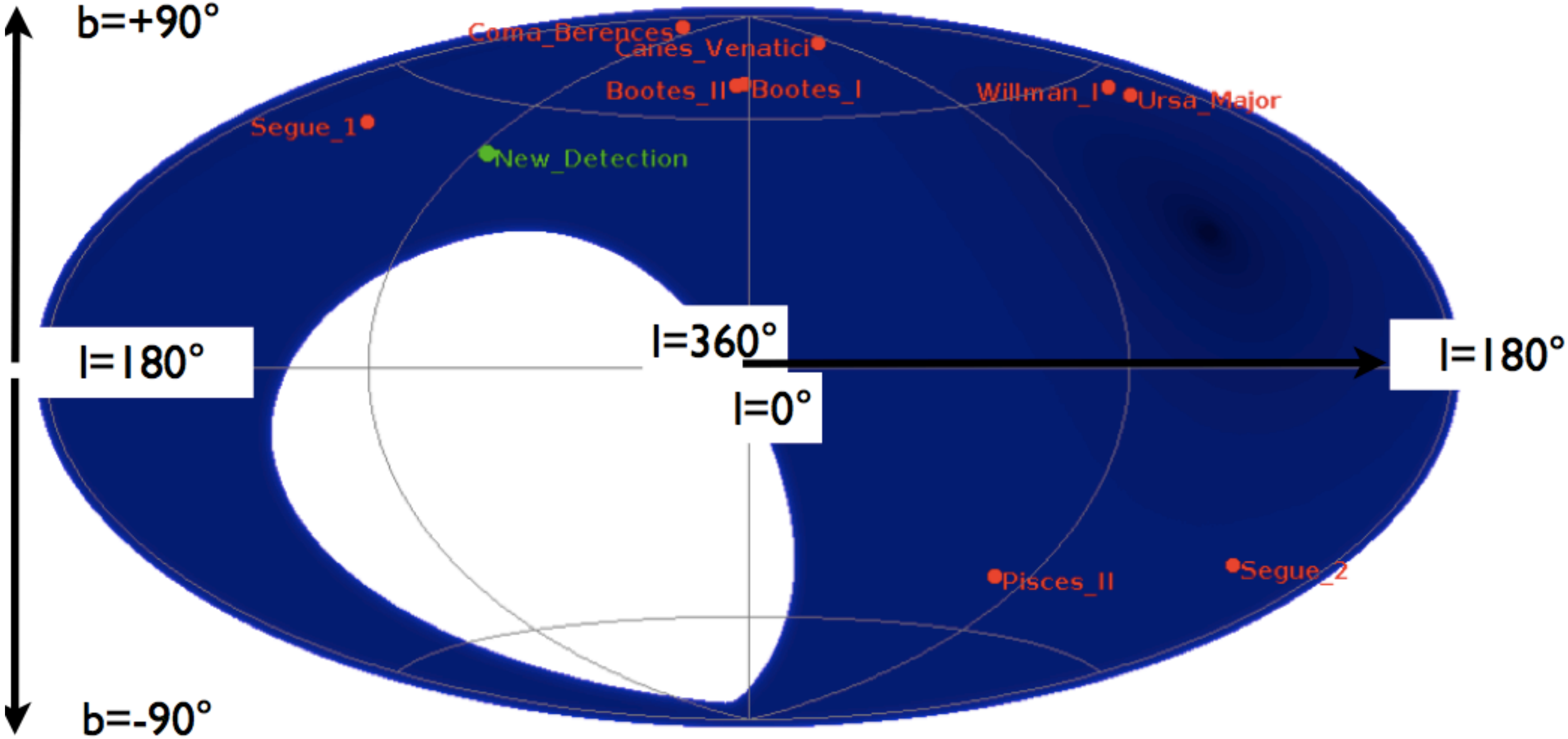
Dust emission (Schlegel, Finkbeiner, Davis) FIR emission

Difference
Cold dust only in extinction?

MW Results (2)

Credit : B. Leavens, N. Martin et al.

Recovery Rate of the SDSS Dwarf Galaxies + Detections

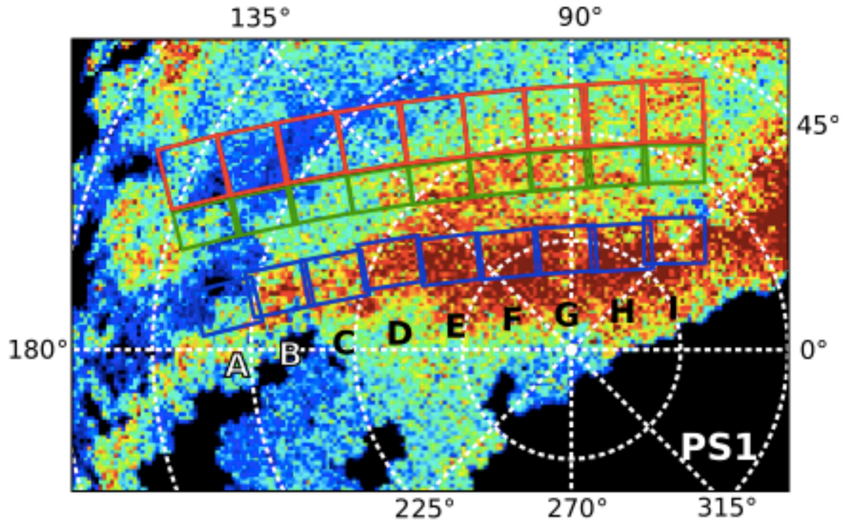


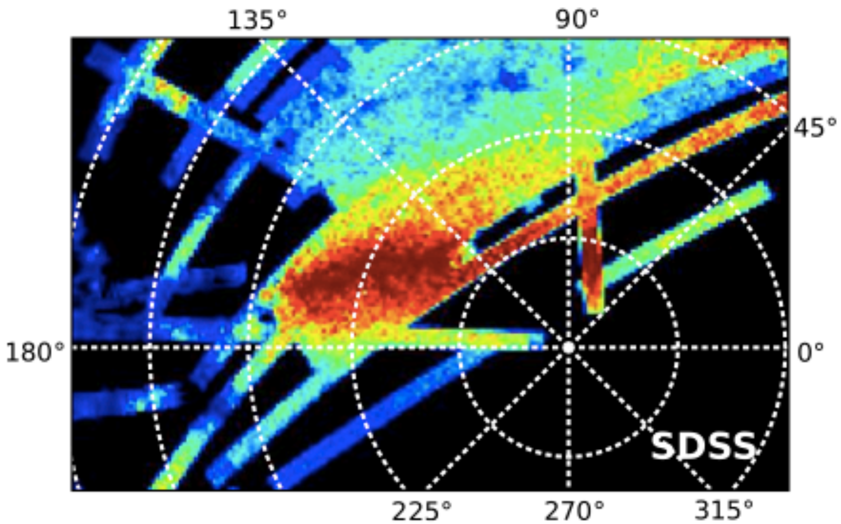
- Recovery Rate SDSS DGs: Good indicator of code efficiency (9/13)
- Investigation of whole sky led to just one obvious detection

Stellar streams in the Milky Way

Slater, Bell, Schlafly, Martin et al 2013

Bernard, Ferguson et al. 2014





PS1 view of the Sagittarius bifurcated stream

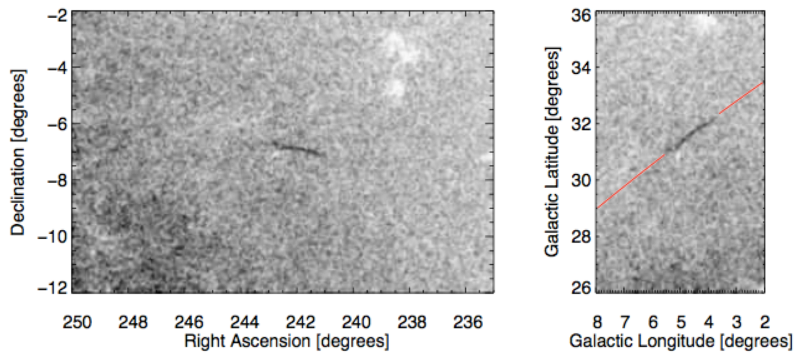
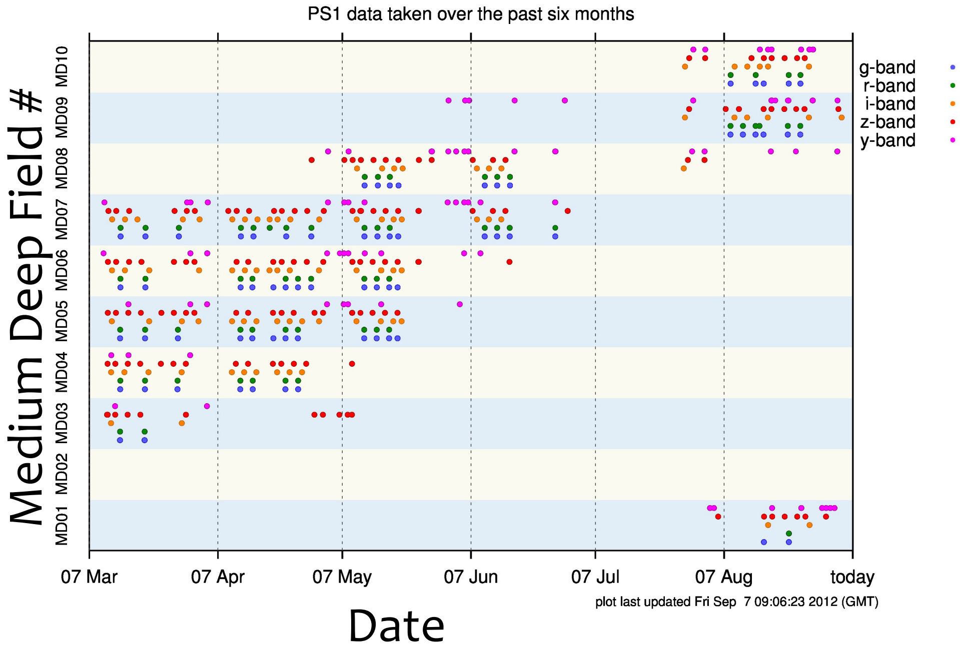


Table 1. Summary of the Stream Properties.

Parameter	Value
R.A. (J2000.0)	16:07:12
Dec. (J2000.0)	−06:55:30
l	$4^{\circ}\!.53$
b	$+31^{\circ}\!.69$
$(m-M)_0$	14.9 ± 0.2
Median E(B−V)	0.23
Heliocentric distance	9.5 ± 0.9 kpc
Galactocentric distance	5.0 ± 1.0 kpc
Width (FWHM)	$7.0' \pm 0.8'$ (19 ± 2 pc)
Length	$\sim 2.5^{\circ}$ (~ 400 pc)
M_V	-3.0 ± 0.5
L_V	$1.4 \pm 0.6 \times 10^3 L_{\odot}$

"Serendipitous Discovery of a Thin Stellar Stream near the Galactic Bulge in the Pan-STARRS1 3Pi Survey"

“Transients” in the PS1 Medium Deep Fields

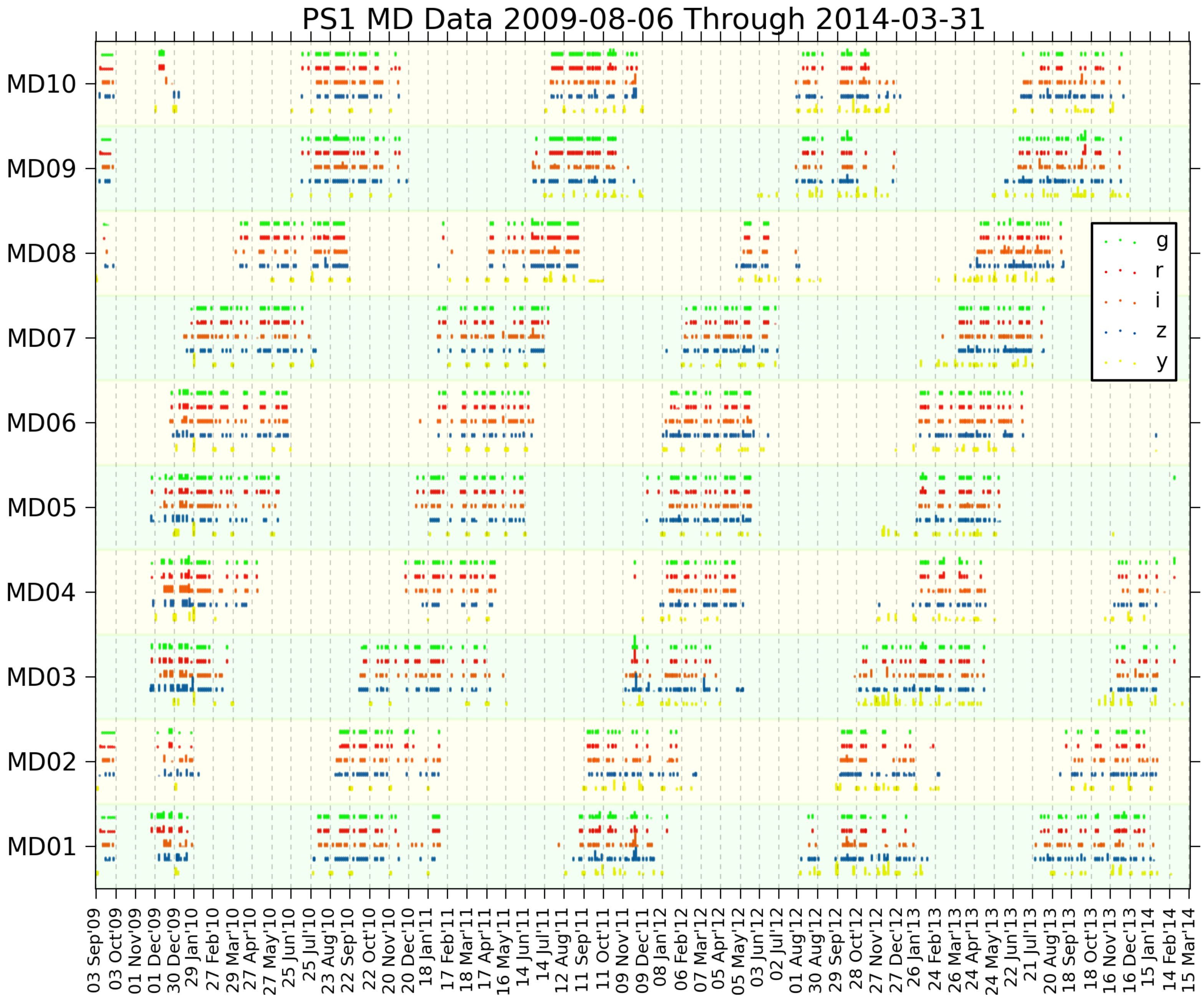


- 4 ± 1 fields observed every night.
- *Filter* cycle in 3 night pattern:

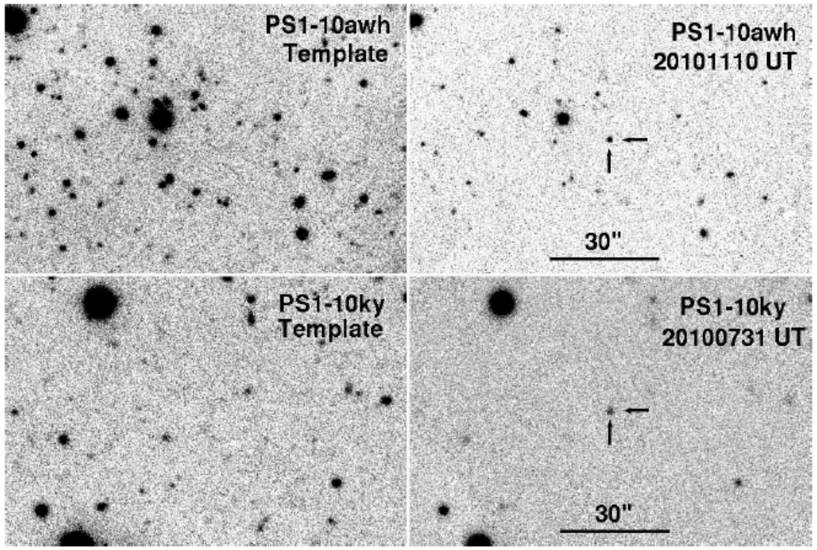
  g+r ……i……z

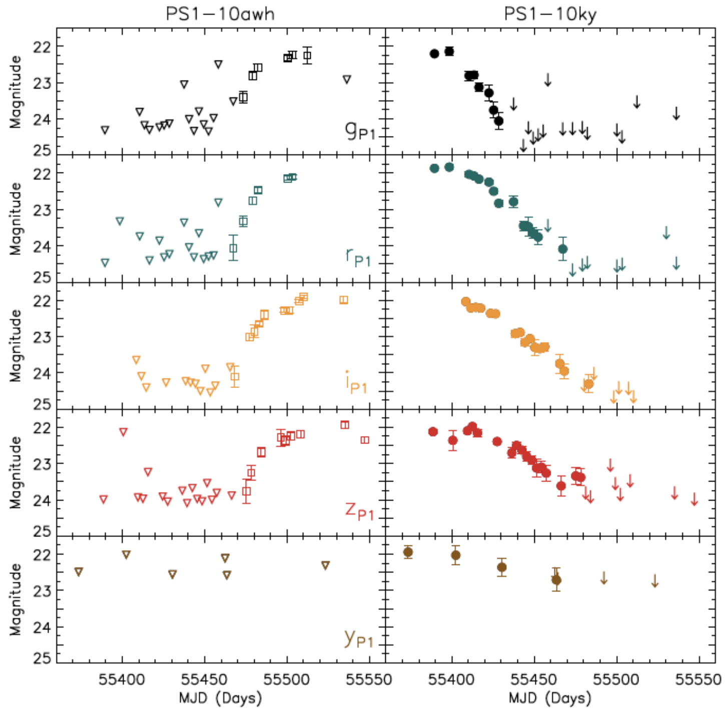
  (repeats every 3 nights, y-band in full moon)
- *Night depth : g,r ~ 23.5^m*

“Transients” in the PS1 Medium Deep Fields

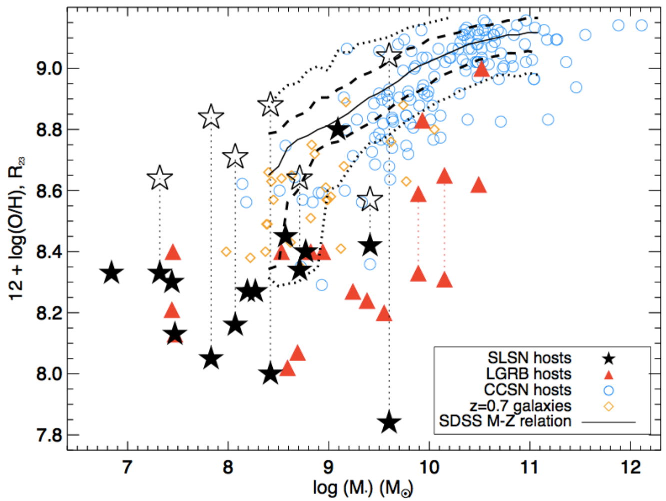


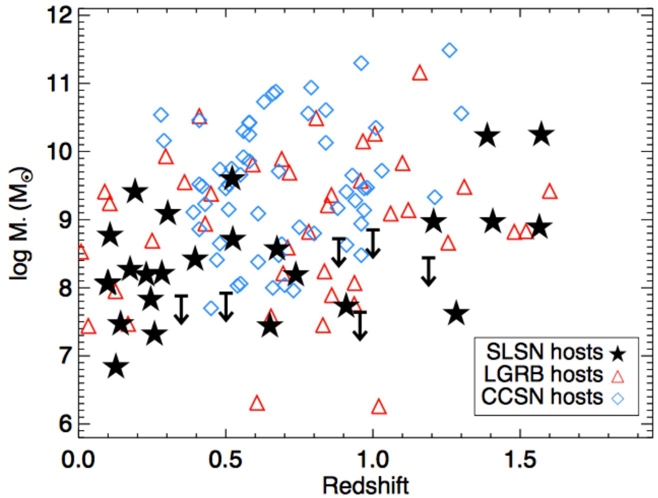
Superluminous SNe : CfA results





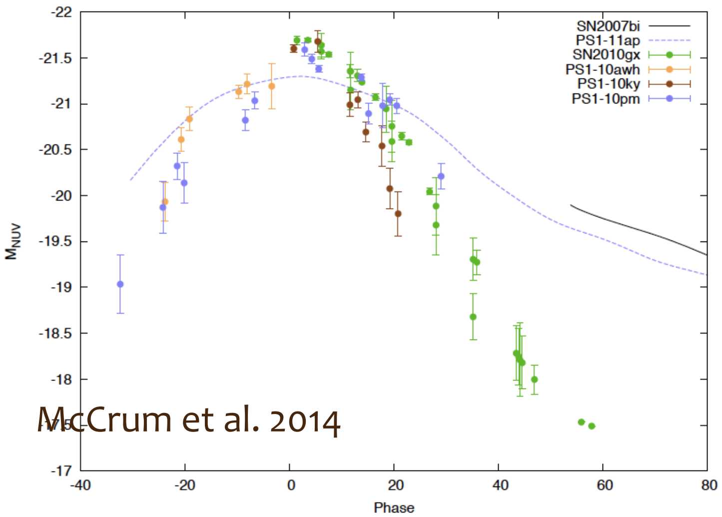
R. Chornock,
R. Lunnan
(E. Berger's
group)

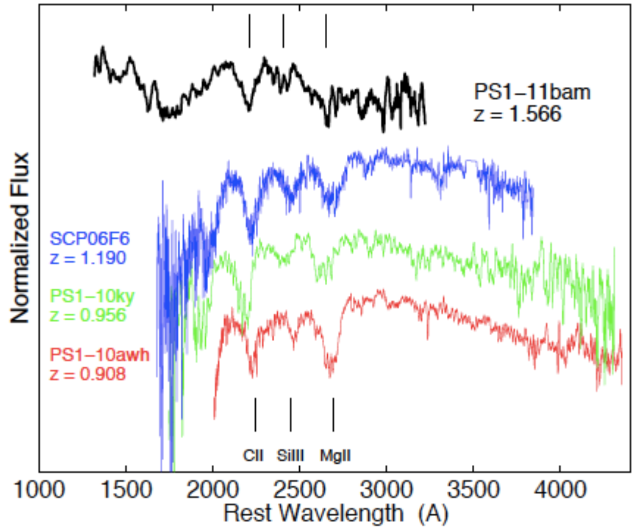


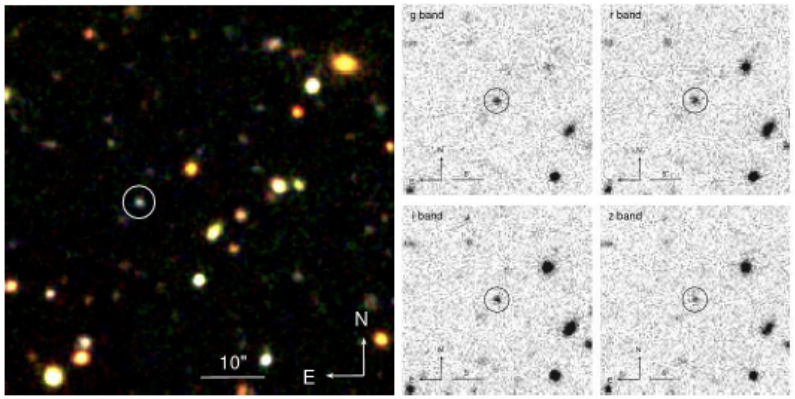


- low luminosity (M_B ~ -17.3 mag
- low mass (~ 2 x $10^8 M_\odot$)
- high-medium specific star formation rate (~ 2 Gyr^{-1})
- low metallicity (< 0.3 $Z_\odot$)
- Similar to long-GRB hosts ?

High redshift SNe with spectra







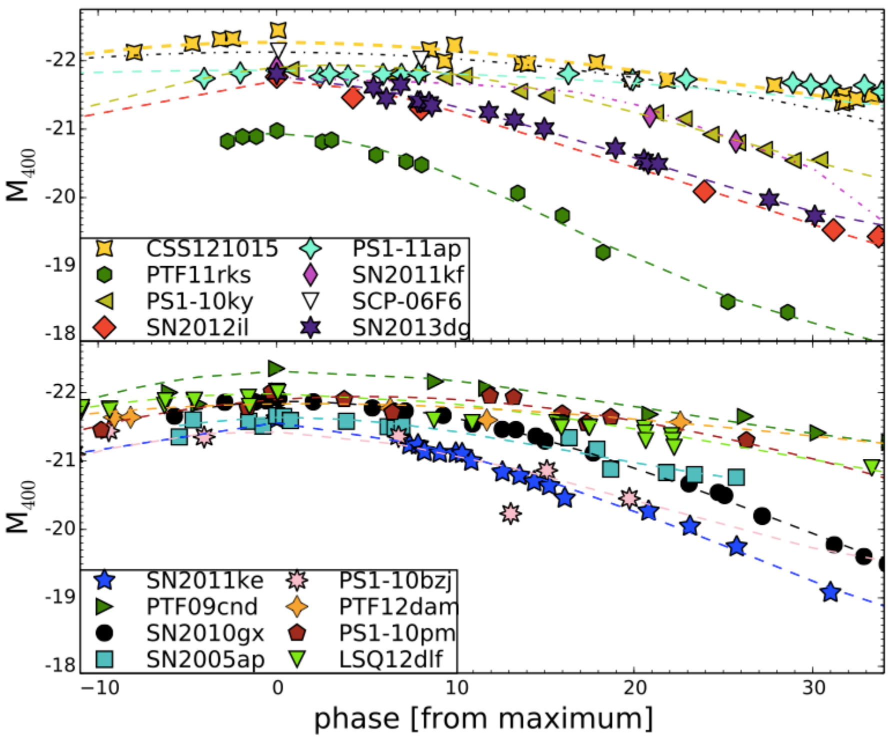
Berger et al. 2012

- PS1 detecting Superluminous SNe z ~1.5
- Chomiuk et al. 2011, Berger et al. 2012, McCrum et al, 2013.
- Physical origin of extreme luminosity ?
  - Magnetar enhanced ?
  - Dense circumstallar shells (pulsational instabilities ?)
  - Pair instability SNe ?

SLSNe as standardizable candles

- Inserra & Smartt 2014 (Apj in prep.)
- 16 objects, z = 0.1 to 1.2

	SLSNe	Type Ia SNe
Raw	M(400) = −21.77 ± 0.44	M_V = −18.7 ± 0.6
Decline rate correction	± 0.23	± 0.28 (Phillips)
Colour decline rate correction	± 0.13	± 0.14 (current best)



Pan-STARRS PS1 Science Consortium

Pessto ESO

PTF