Title: Cosmology Results from the Pan-STARRs Supernova Survey

Date: Mar 04, 2014 11:00 AM

URL: http://pirsa.org/14030095

Abstract: The Pan-STARRs supernova survey has discovered one of the largest samples of Type Ia supernovae. Measurements of the distances to these supernovae allow us to probe some of the most fundamental questions about the properties of the universe like what is dark energy. When combining measurements from various astrophysical probes, we find hints of interesting tension with the Lambda-CDM model. I discuss the various combinations of astrophysical probes and the source of this tension. It is possible that this tension is due to systematic uncertainties in the various measurements, and I show how we analyze these uncertainties in the Pan-STARRs sample.

Dark Energy and First Pan-STARRs Results

Dan Scolnic. March 4, 2014

Dark Energy is one of the most perplexing problems in Physics and Astronomy

-There are multiple lines of evidence that show the universe is accelerating in its expansion.

-But we don't know why it is accelerating.

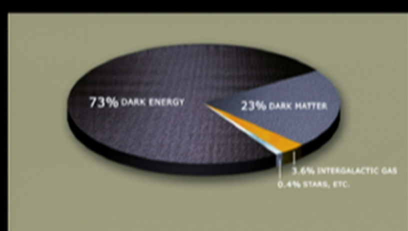
-So observers have to keep learning more about the acceleration to give insight into its source.

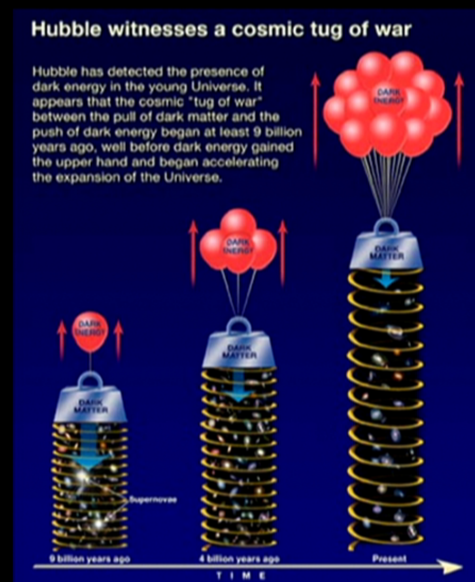
Outline

- Primer on Dark Energy and Type Ia Supernovae
- Analyzing the PS1 data set and first results
- Combining measurements with other probes
- Understanding systematics
- Conclusions and Future Work

We have a basic picture of the universe

- Dark Energy makes up around 73% of the universe
- Matter makes up to 27%
- Neutrinos ~ 0.1 %
- Spatial curvature is near 0.





Credit, NASA

These are the cosmological parameters we measure

-H is the Hubble expansion parameter

-$\Omega_M = \rho_M / \rho_c$ is the fraction of the matter energy density in the critical density $\rho_c = 3H^2/8\pi$

-$\Omega_{DE} = \rho_{DE} / \rho_c$ is the fraction of the Dark Energy density (here a cosmological constant) in the critical density

-$w = P/\rho c^2$ is the equation of state parameter of dark energy

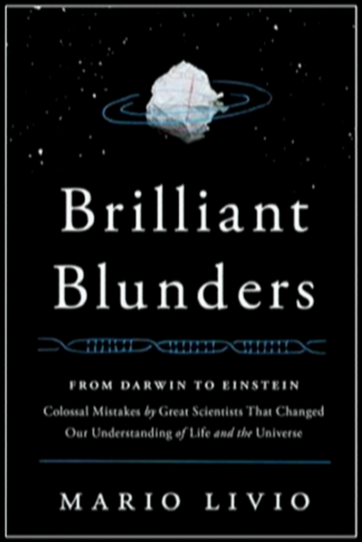
We know that the universe is accelerating, but we don’t know why

-Cosmological Constant (e.g., “nothing weighs something” – w=-1)

-Quintessence

-We don’t understand gravity (especially at long range)

-Insert new ideas <here>



So what are Type Ia Supernovae?

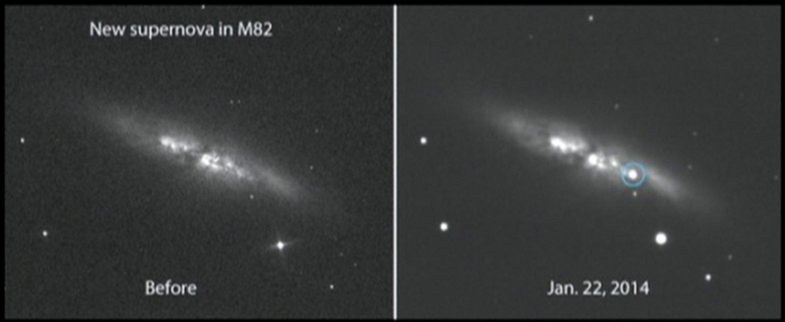
-White dwarf accretes matter from companion, reaches near Chandrasekhar limit, explodes

-Don’t know what companion was.

-Correct brightness for decline-rate and color, all SN luminosities similar to ~10%

-1 SN per galaxy per century

Credit: E. Guido, N. Howes, M. Nicolini



!!! SN 2014J in M82 !!!

-11.4 million light-years away
-Closest SNIa in 20 years
-Can see with binoculars
-Highly reddened

Type Ia Supernovae provide some of the best evidence for dark energy

-St~~andard can~~dles. Standardizable candles

-Their intrinsic luminosity is known (to 10%) – and apparent luminosity can be measured

-The ratio of the two can provide the luminosity-distance (d_L) of the supernova

-The redshift z can be measured independently from spectroscopy

-Each SNIa can be used for a single d_L (z) on a Hubble diagram (d_L versus z)

We can’t fully explain how Type Ia Supernovae come to be.

This talk.

We don’t have a good theory for what dark energy could be.

Today I will mostly talk about two papers

Cosmological Constraints from Measurements of Type Ia Supernovae discovered during the first 1.5 years of the Pan-STARRS1 Survey

A. Rest, D. Scolnic, R. J. Foley, M. E. Huber, R. Chornock, G. Narayan, J. L. Tonry, E. Berger, A. M. Soderberg, C. W. Stubbs, A. Riess, R. P. Kirshner, S. J. Smartt, E. Schlafly, S. Rodney, M. T. Botticella, D. Brout, P. Challis, I. Czekala, M. Drout, M. J. Hudson, R. Kotak, C. Leibler, R. Lunnan, G. H. Marion, M. McCrum, D. Milisavljevic, A. Pastorello, N. E. Sanders, K. Smith, E. Stafford, D. Thilker, S. Valenti, W. M. Wood-Vasey, Z. Zheng, W. S. Burgett, K. C. Chambers, L. Denneau, P. W. Draper, H. Flewelling, K. W. Hodapp, N. Kaiser, R. P. Kudritzki, E. A. Magnier, N. Metcalfe, P. A. Price, W. Sweeney, R. Wainscoat, C. Waters

(Submitted on 14 Oct 2013)

We present griz light curves of 146 spectroscopically confirmed Type Ia Supernovae (0.03<z<0.65) discovered during the first 1.5 years of the Pan-STARRS1 Medium Deep Survey. The Pan-STARRS1 natural photometric system is determined by a combination of on-site measurements of the instrument response function and observations of spectrophotometric standard stars. We have investigated spatial and time variations in the photometry, and we find that the systematic uncertainties in the photometric system are currently 1.2% without accounting for the uncertainty in the HST Calspec definition of the AB system. We discuss our efforts to minimize the systematic uncertainties in the photometry. A Hubble diagram is constructed with a subset of 112 SNe Ia (out of the 146) that pass our light curve quality cuts. The cosmological fit to 313 SNe Ia (112 PS1 SNe Ia + 201 low-z SNe Ia), using only SNe and assuming a constant dark energy equation of state and flatness, yields w = -1.015^{+0.319}_{-0.201}(Stat)+{0.164}_{-0.122}(Sys). When combined with BAO+CMB(Planck)+H0, the analysis yields \Omega_M = 0.277^{+0.010}_{-0.012} and w = -1.186^{+0.076}_{-0.065} including all identified systematics, as spelled out in the companion paper by Scolnic et al. (2013a). The value of w is inconsistent with the cosmological constant value of -1 at the 2.4 sigma level. This tension has been seen in other high-z SN surveys and endures after removing either the BAO or the H0 constraint. If we include WMAP9 CMB constraints instead of those from Planck, we find w = -1.142^{+0.076}_{-0.087}, which diminishes the discord to <2 sigma. We cannot conclude whether the tension with flat CDM is a feature of dark energy, new physics, or a combination of chance and systematic errors. The full Pan-STARRS1 supernova sample will be 3 times as large as this initial sample, which should provide more conclusive results.

Systematic Uncertainties Associated with the Cosmological Analysis of the First Pan-STARRS1 Type Ia Supernova Sample

D. Scolnic, A. Rest, A. Riess, M.E. Huber, R.J. Foley, D. Brout, R. Chornock, G. Narayan, J.L. Tonry, E. Berger, A.M. Soderberg, C.W. Stubbs, R.P. Kirshner, S. Rodney, S.J. Smartt, E. Schlafly, M.T. Botticella, P. Challis, I. Czekal, M. Drout, M.J. Hudson, R. Kotak, C. Leibler, R. Lunnan, G.H. Marion, M. McCrum, D. Milisavljevic, A. Pastorello, N.E. Sanders, K. Smith, E. Stafford, D. Thilker, S. Valenti, W.M. Wood-Vasey, Z. Zheng, W.S. Burgett, K.C. Chambers, L. Denneau, P.W. Draper, H. Flewelling, K.W. Hodapp, N. Kaiser, R.P. Kudritzki, E.A. Magnier, N. Metcalfe, P.A. Price, W. Sweeney, R. Wainscoat, C. Waters

(Submitted on 14 Oct 2013)

We probe the systematic uncertainties from 112 Type Ia supernovae (SNIa) in the Pan-STARRS1 (PS1) sample along with 201 SN Ia from a combination of low-redshift surveys. The companion paper by Rest et al. (2013) describes the photometric measurements and cosmological inferences from the PS1 sample. The largest systematic uncertainty stems from the photometric calibration of the PS1 and low-z samples. We increase the sample of observed Calspec standards from 7 to 10 used to define the PS1 calibration system. The PS1 and SDSS-II calibration systems are compared and discrepancies up to

This is the past/current/future status of SNIa surveys

	Past/Current	Current/Future	More Future
Low-z: $z<0.1$	CfA1-4, SNF, CSP	PTF	LSST?
Mid-z: $.1<z<1.0$	SDSS,SNLS	PS1,DES	LSST
High-z: $1.0<z$	HST	HST-Candels	Euclid/ WFIRST
#s:	~1000	~10,000	>100,000

PS1 is in many ways a precursor to DES

	PS1	DES
V	7 square degrees	3 square degrees
ters	grizy	ugrizy
ission	SNIa, transients,Weak lensing, asteroids...	SNIa, BAO, Weak lensing, Galaxy cluster
survey	10 fields– r~23.5 mag (z up to 0.65)	2 deep, 8 shallow fields (z up to 1.0)
erage seeing	~1.1 ″	~1.1″
cebook page	No	Yes

PS1 covers more area, DES goes deeper

PS1 telescope

This is the order of operations for doing cosmology with supernovae

1. Discover SNe and spectroscopically identify them.
2. Do photometry and calibration.
3. Fit the light curves with light curve fitter.
4. Determine distances.
5. Solve for cosmology.
6. Think about everything that could have gone wrong.

We spectroscopically follow-up ~10% of our likely SNIa candidates

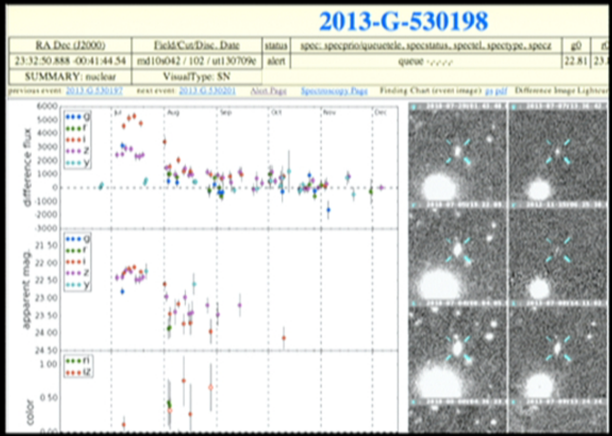
-We have found ~4000 likely SNIa

-We have spectroscopically identified ~400 SNIa

-First paper is first 1.5 years, 150 spec. confirmed SNIa, 112 of which are cosmologically useful

-Spectroscopy time mostly from MMT

-Beginning large-scale host galaxy follow-up



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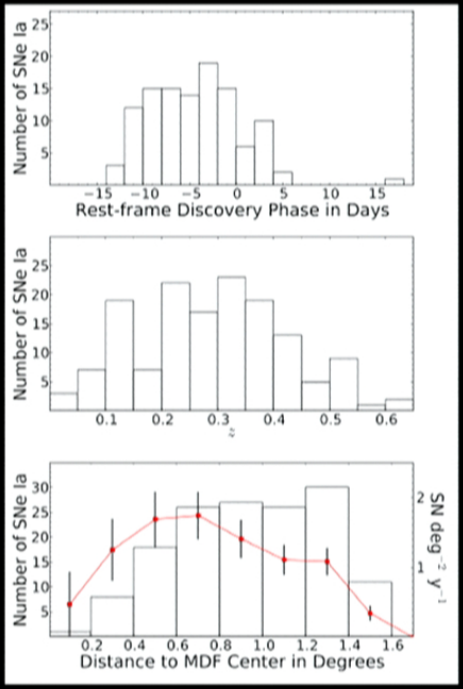

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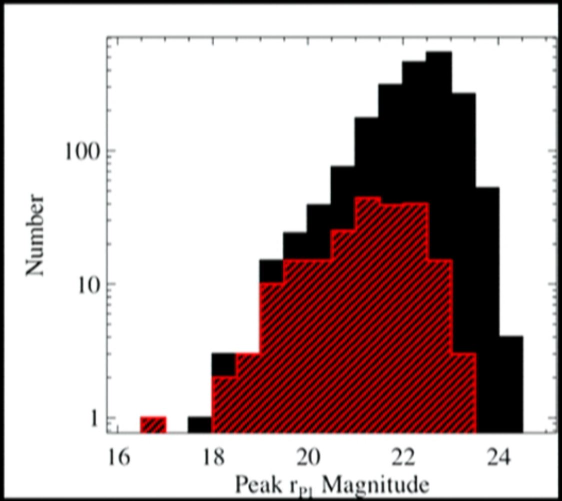
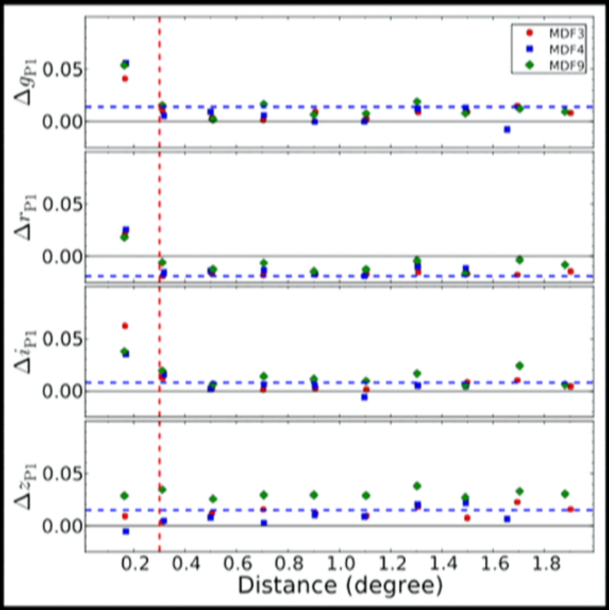


This leads to a selection bias that we can simulate

The step with the most impact on cosmology is calibration and photometry

-Calibration based on very precise filter measurements and tied to Calspec system



Here we are comparing SDSS and PS1 observations (mags) for different fields across focal plane

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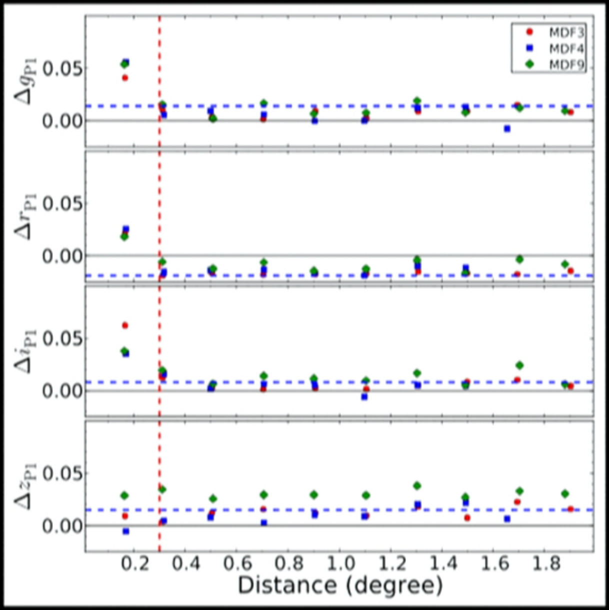

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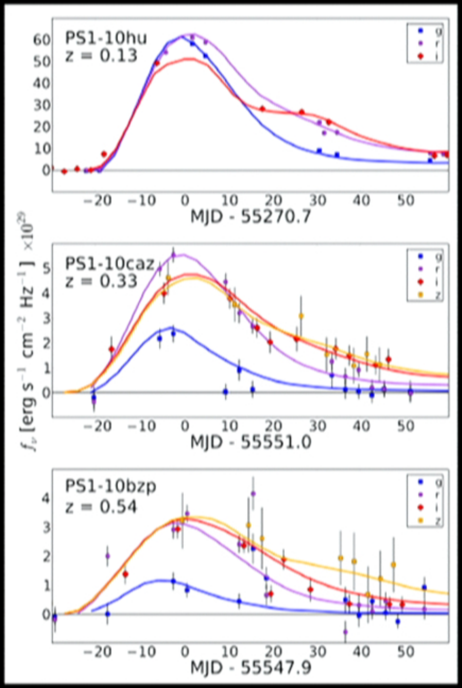
The step with the most impact on cosmology is calibration and photometry

-Calibration based on very precise filter measurements and tied to Calspec system

-Photometry done on subtracted images, non-gaussian PSF

-Fit light curves with SALT2 light curve fitter



If everything goes right, light curves come out that can be fit to find light curve parameters

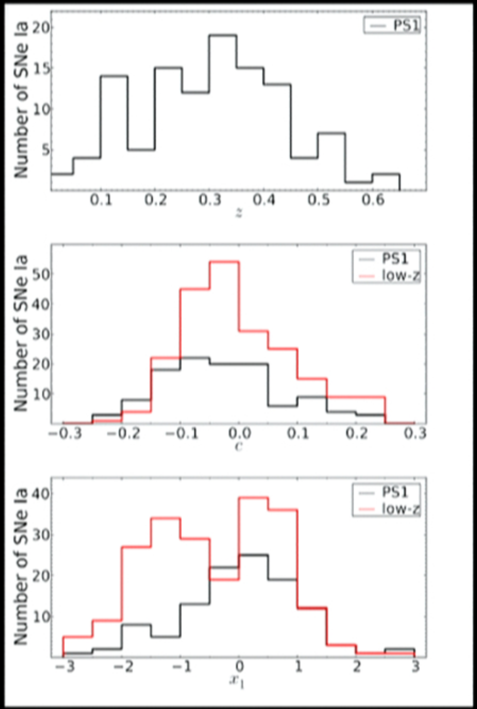
The step with the most impact on cosmology is calibration and photometry

-Calibration based on very precise filter measurements and tied to Calspec system

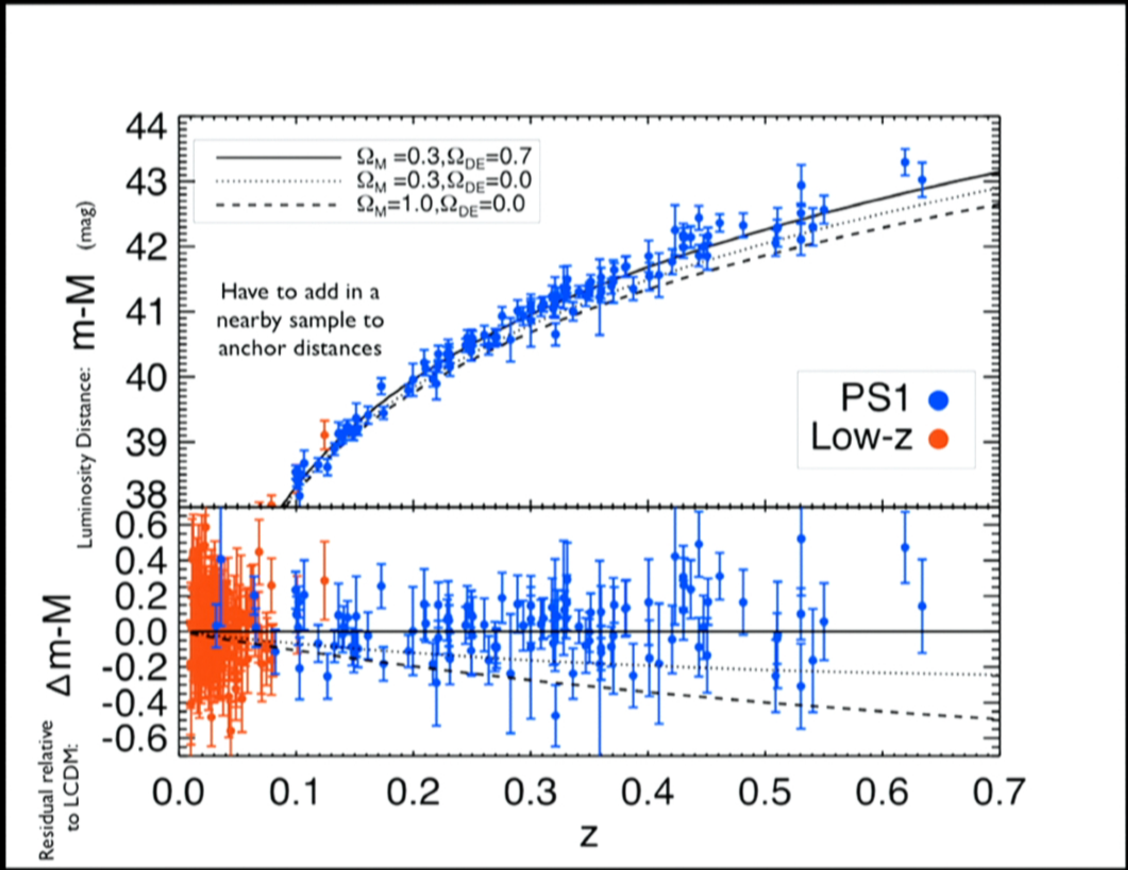
-Photometry done on subtracted images, non-gaussian PSF

-Fit light curves with SALT2 light curve fitter

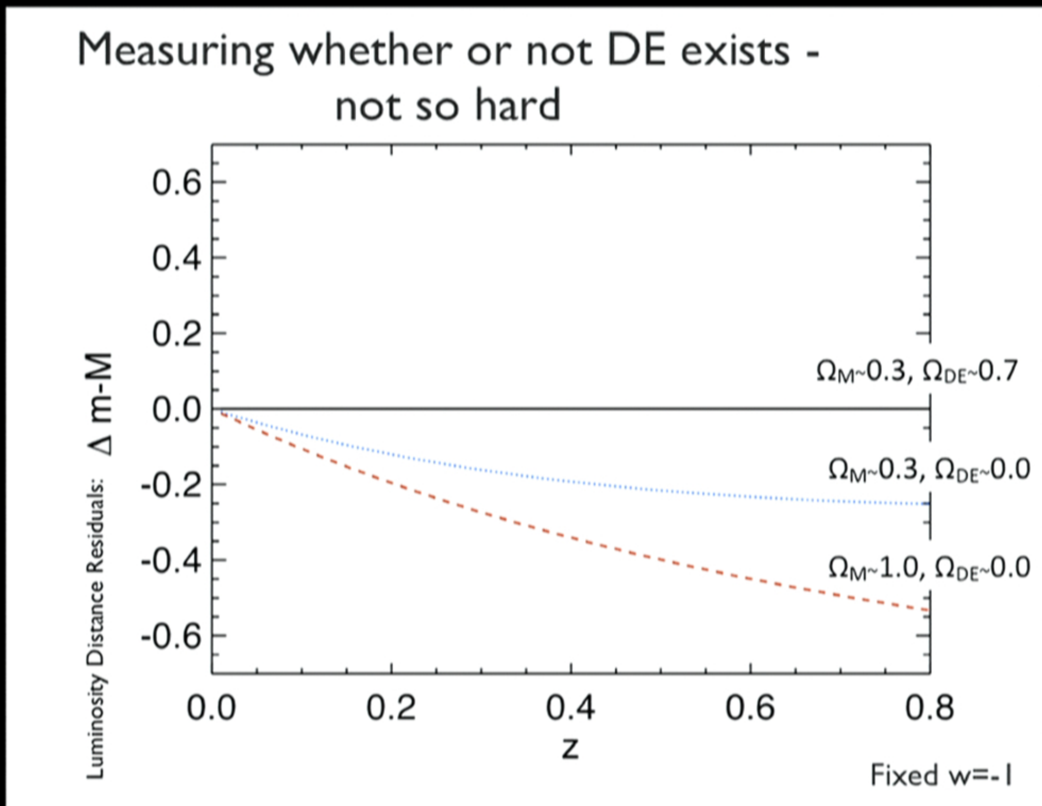
-From light curves, we measure a peak brightness, color (c) and stretch (x_1) - to determine distance. Then we find relations between luminosity and c and x_1 to minimize distance scatter.



Finally, we can analyze luminosity distances versus redshift



Let's take a close look at cosmology



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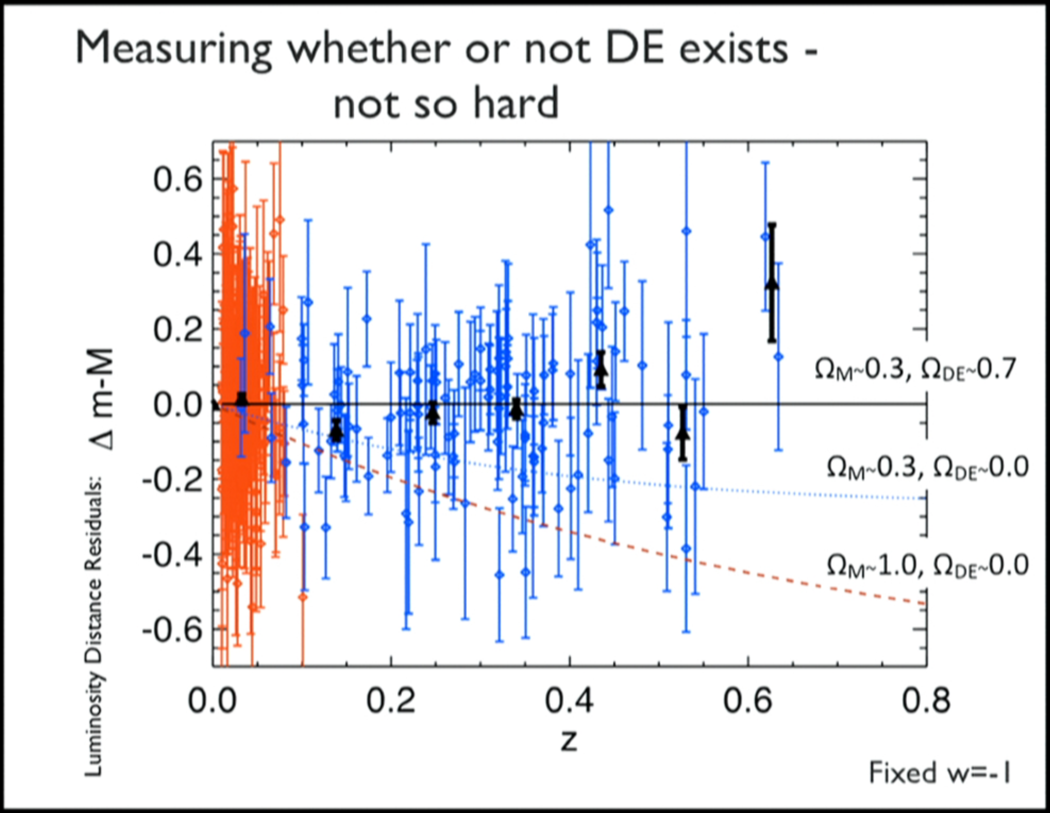

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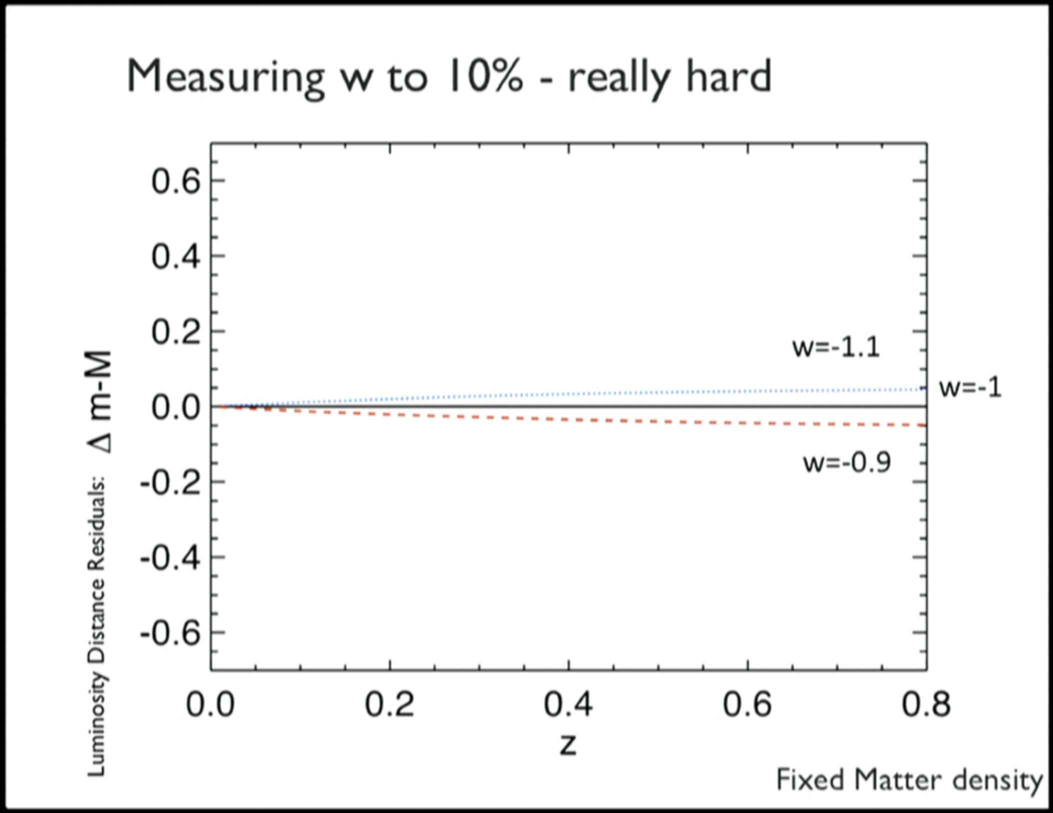
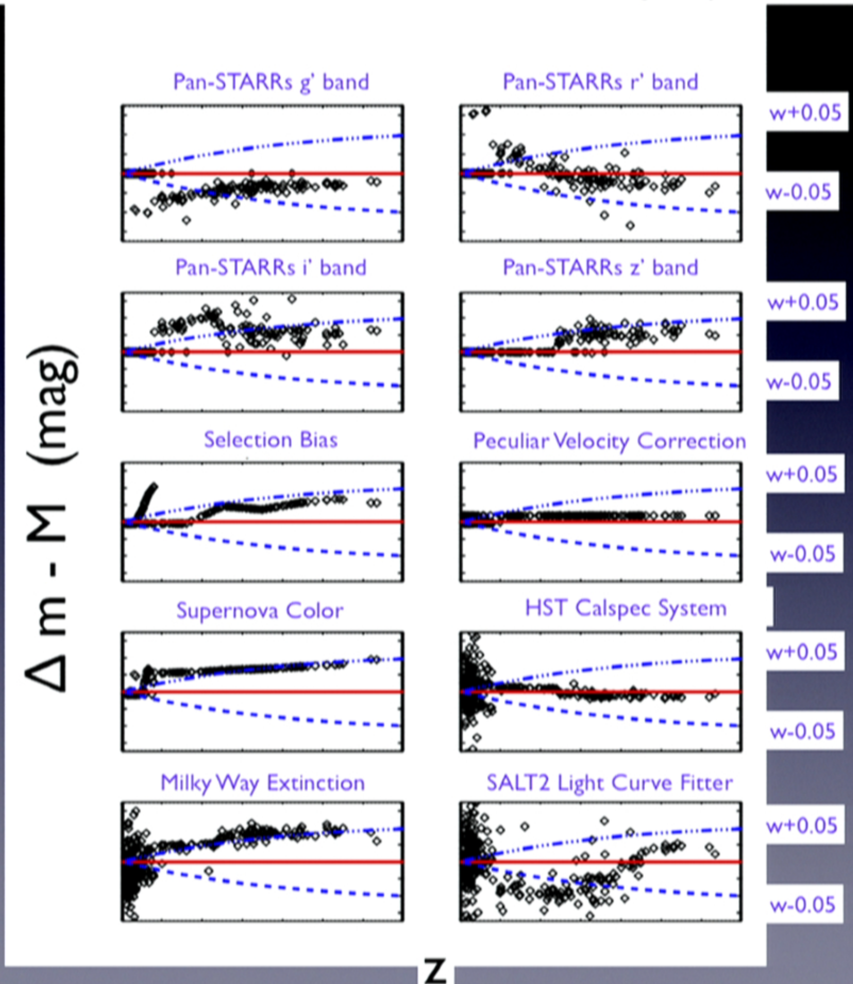


To measure w to 10%, we need careful accounting of systematics

Here we show Hubble diagram differences when we change our biggest systematics by 1σ



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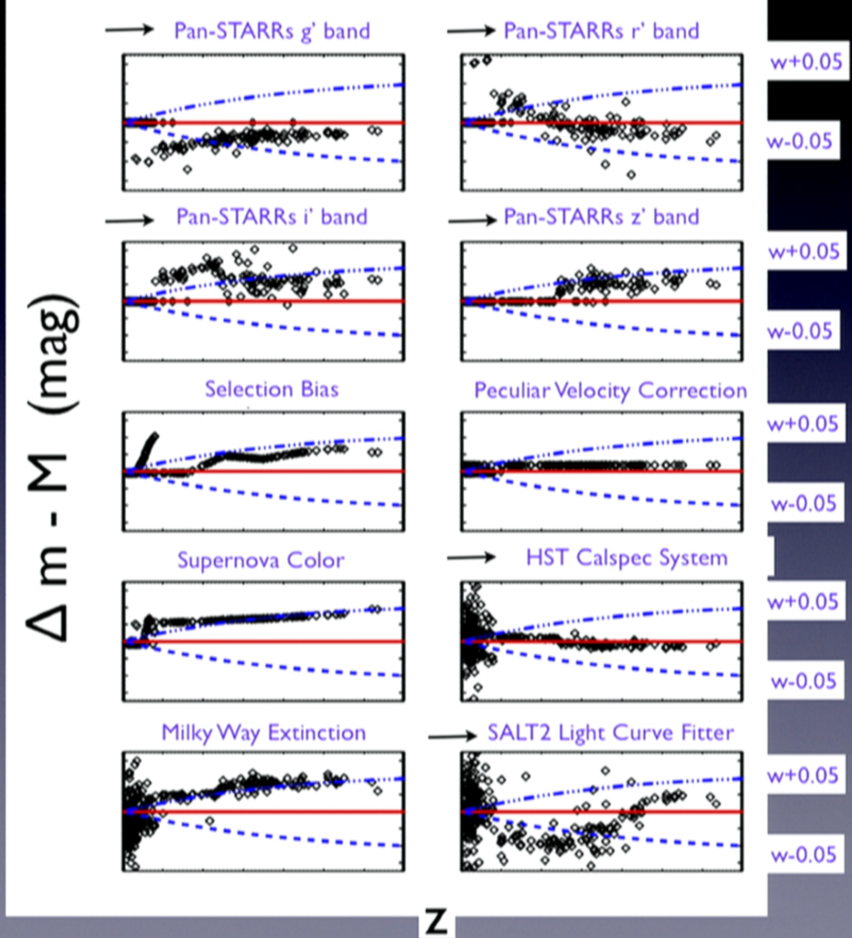
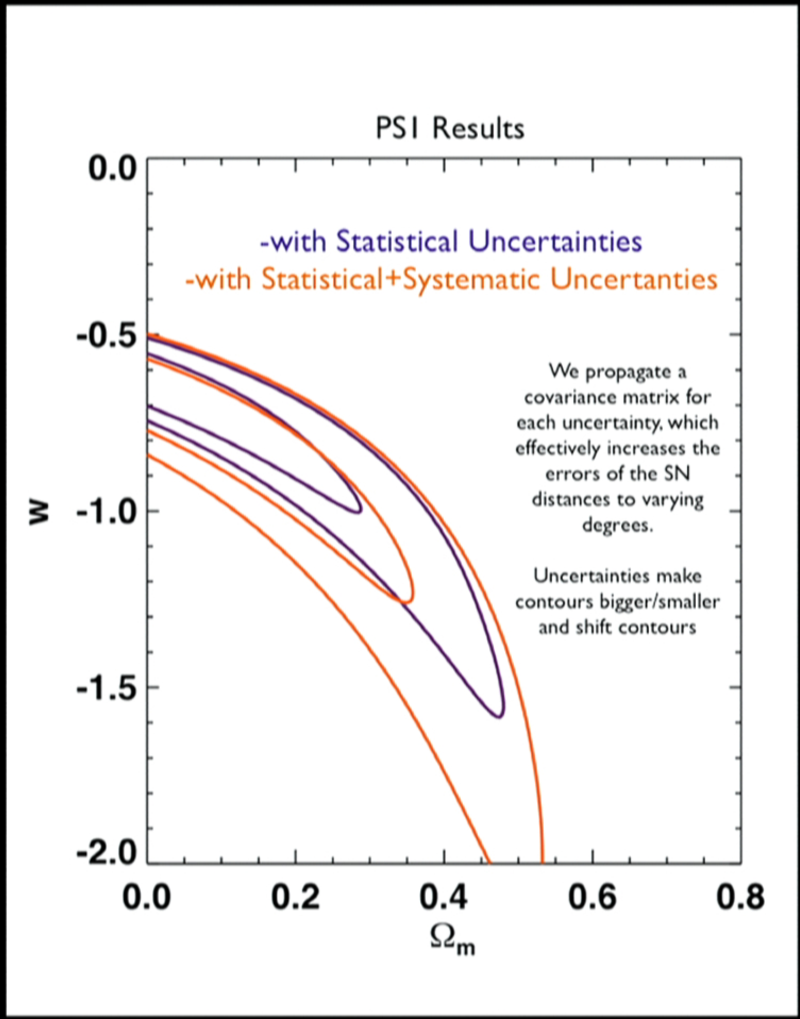


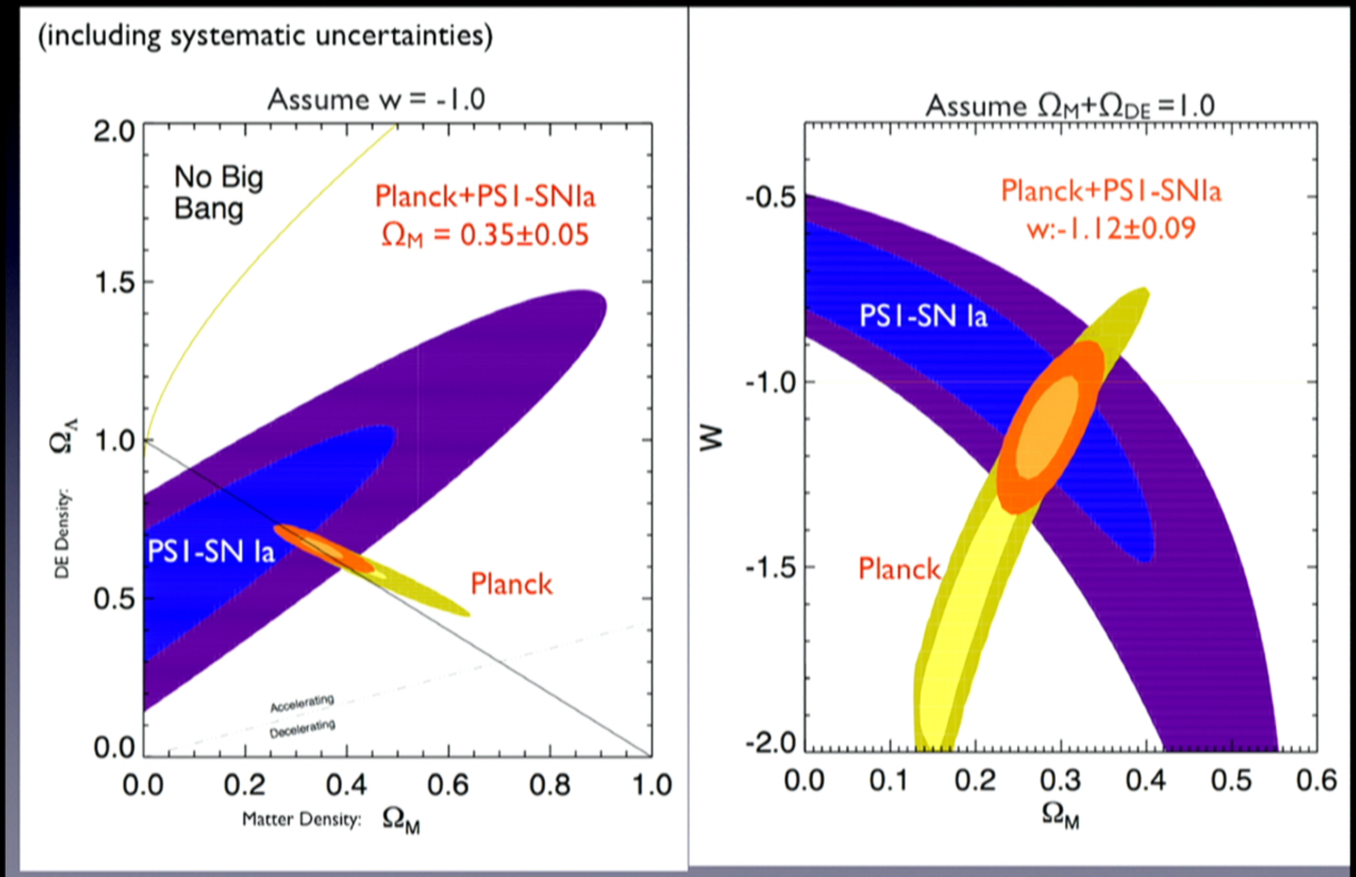
Arrows show calibration uncertainties

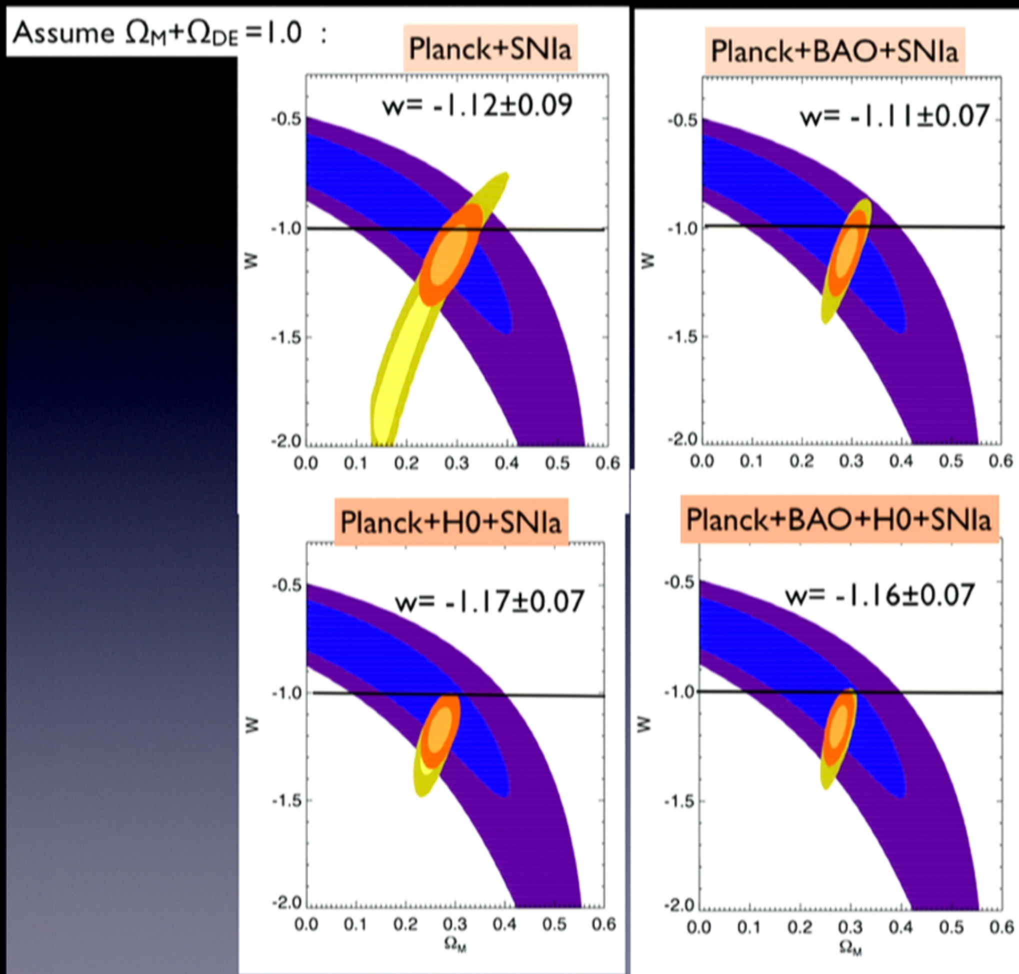
There is significant room for improvement in each of these systematic uncertainties

Systematic uncertainties are of similar size to statistical uncertainties. Propagate systematic uncertainties to covariance matrix.


PS1 Results
-with Statistical Uncertainties
-with Statistical+Systematic Uncertanties
We propagate a covariance matrix for each uncertainty, which effectively increases the errors of the SN distances to varying degrees.
Uncertainties make contours bigger/smaller and shift contours
w
0.0
-0.5
-1.0
-1.5
-2.0
0.0
0.2
0.4
0.6
0.8
Ωm

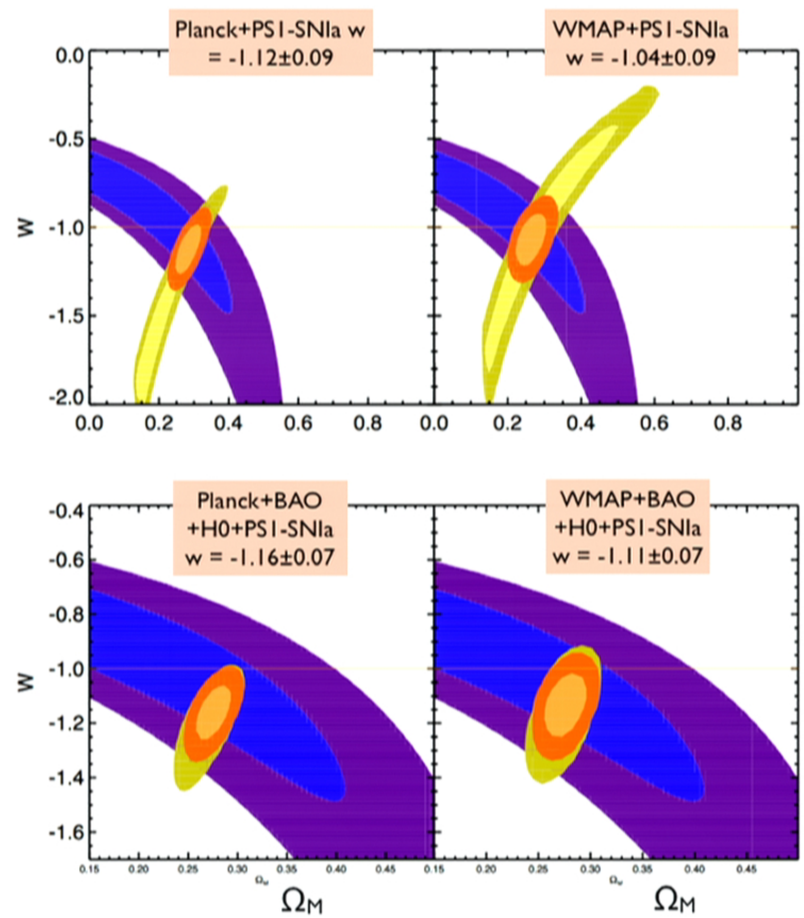
When we combine with other measurements, can get tight constraints on Ω_M and w





We see between $1<x<3\sigma$ tension with w=-1 when combining various probes

Assume $\Omega_M+\Omega_{DE}=1.0$:



Tension with w=-1 is smaller when we use WMAP for CMB measurements instead of Planck.

Still, we really need to be concerned about conformation bias

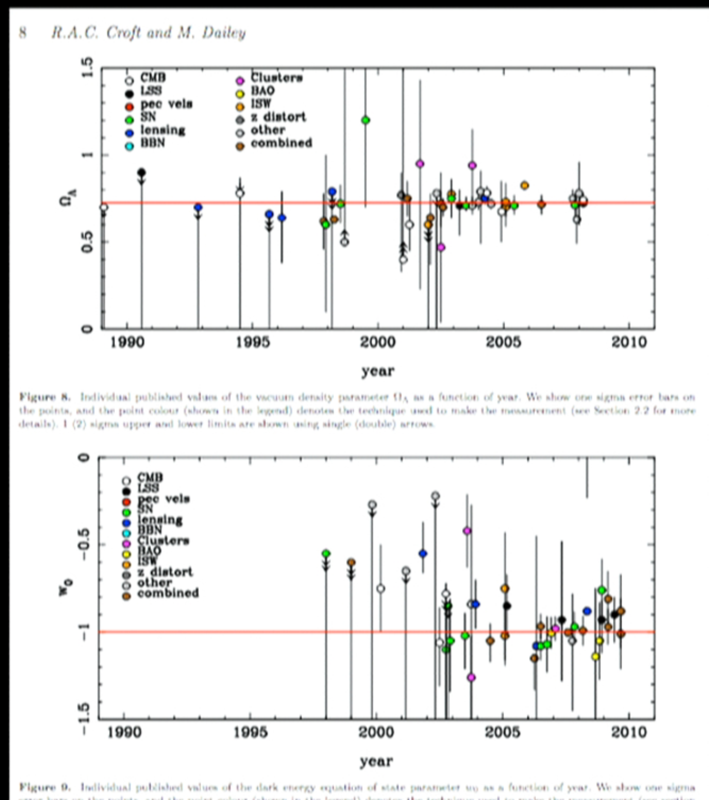

8 R.A.C. Croft and M. Dailey

Figure 8. Individual published values of the vacuum density parameter Ω_Λ as a function of year. We show one sigma error bars on the points, and the point colour (shown in the legend) denotes the technique used to make the measurement (see Section 2.2 for more details). 1 (2) sigma upper and lower limits are shown using single (double) arrows.

Figure 9. Individual published values of the dark energy equation of state parameter w_0 as a function of year. We show one sigma error bars on the points, and the point colour (shown in the legend) denotes the technique used to make the measurement (see section

I'd like to focus on a couple of our largest systematic uncertainties and discuss how to improve them

- Calibration
- Supernova physics

I'd like to focus on a couple of our largest systematic uncertainties and discuss how to improve them

- Calibration
  - Absolute Flux Photometry
  - Relative Photometry
- Supernova physics

Our relative calibration is better than 1%

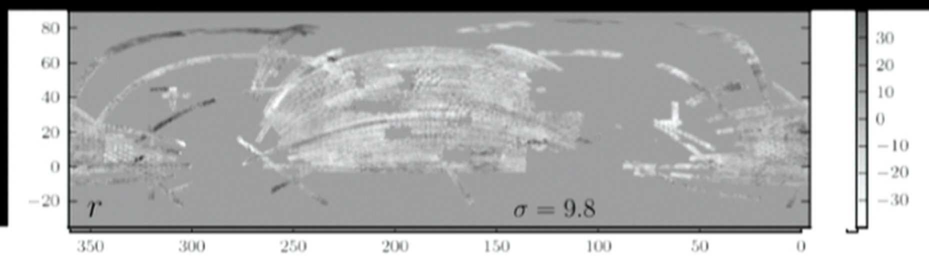
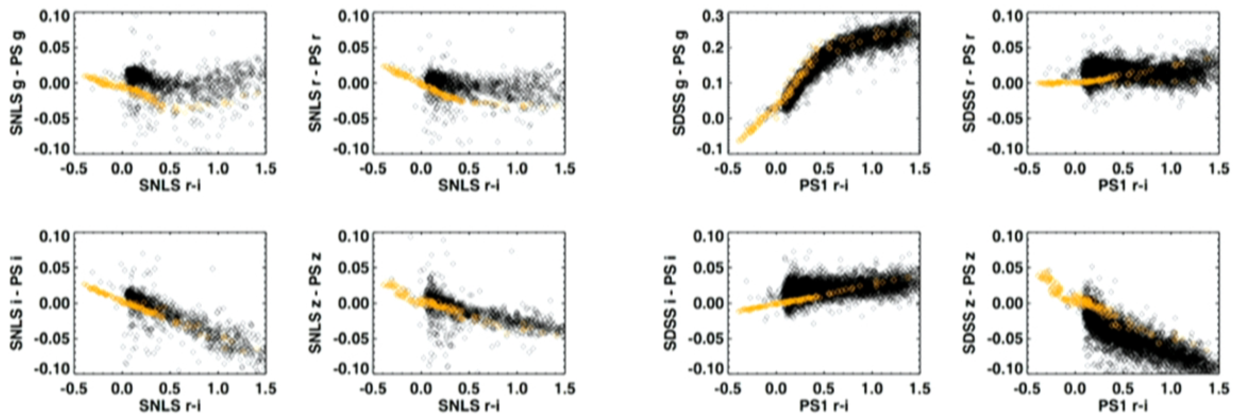


FIG. 5.— Maps of the difference between the color-corrected SDSS magnitudes of stars and the internally-calibrated Pan-STARRS1 magnitudes of the same stars in the filters $grizy_{P1}$ (rows). The x-axes give right ascension and the y-axes give declination. The rms of the maps is about 10 mmag. Narrow stripes in right ascension are symptomatic of problems with the SDSS photometric calibration, while rectangles in right ascension and declination indicate problems with the PS1 calibration. The filter used for each map is indicated in the lower left, while the rms of the map is indicated in the lower right.

Schlafly, Finkbeiner et al, 2012

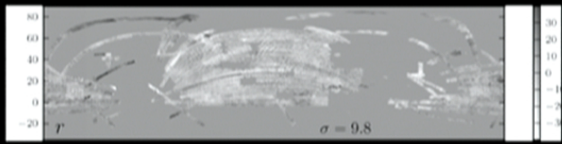
Here we compare PS1 to SDSS. SDSS differences show up as stripes. PS1 differences show up as blocks.

We can use this to cross-calibrate SDSS and SNLS



Orange - synthetic, Black - actual

More work needs to be done to uncover these 1-2% discrepancies!!



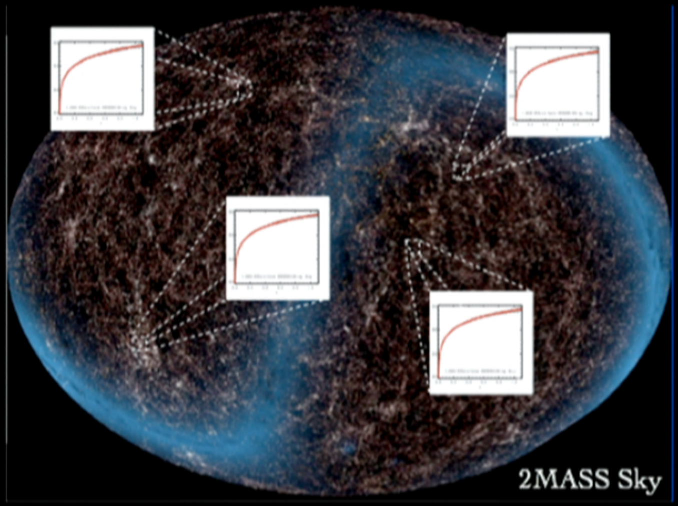
I'd like to focus on a couple of our largest systematic uncertainties and discuss how to improve them

- Calibration

- Supernova physics
  - SN color and dust
  - SN host galaxy - luminosity relation

With greater statistics, there are a number of interesting applications:

e.g. Can build Hubble diagrams for different parts of the sky:



With large statistics, can measure strong lensing in different clusters!

Conclusions

- It's a particularly exciting time to work on cosmology
- Cosmological probes have intersecting measurements - now we can all start cross-checking each other
- There is more Pan-STARRs work to do, and hopefully PS1 and DES can help each other out!