Studying Dark Energy with the Union Supernova data

Marek Kowalski[1], Eric Linder[2]
Saul Perlmutter[2], David Rubin[2]
[1]*Humboldt-Universität zu Berlin*
[2]*Lawrence Berkeley Laboratory*

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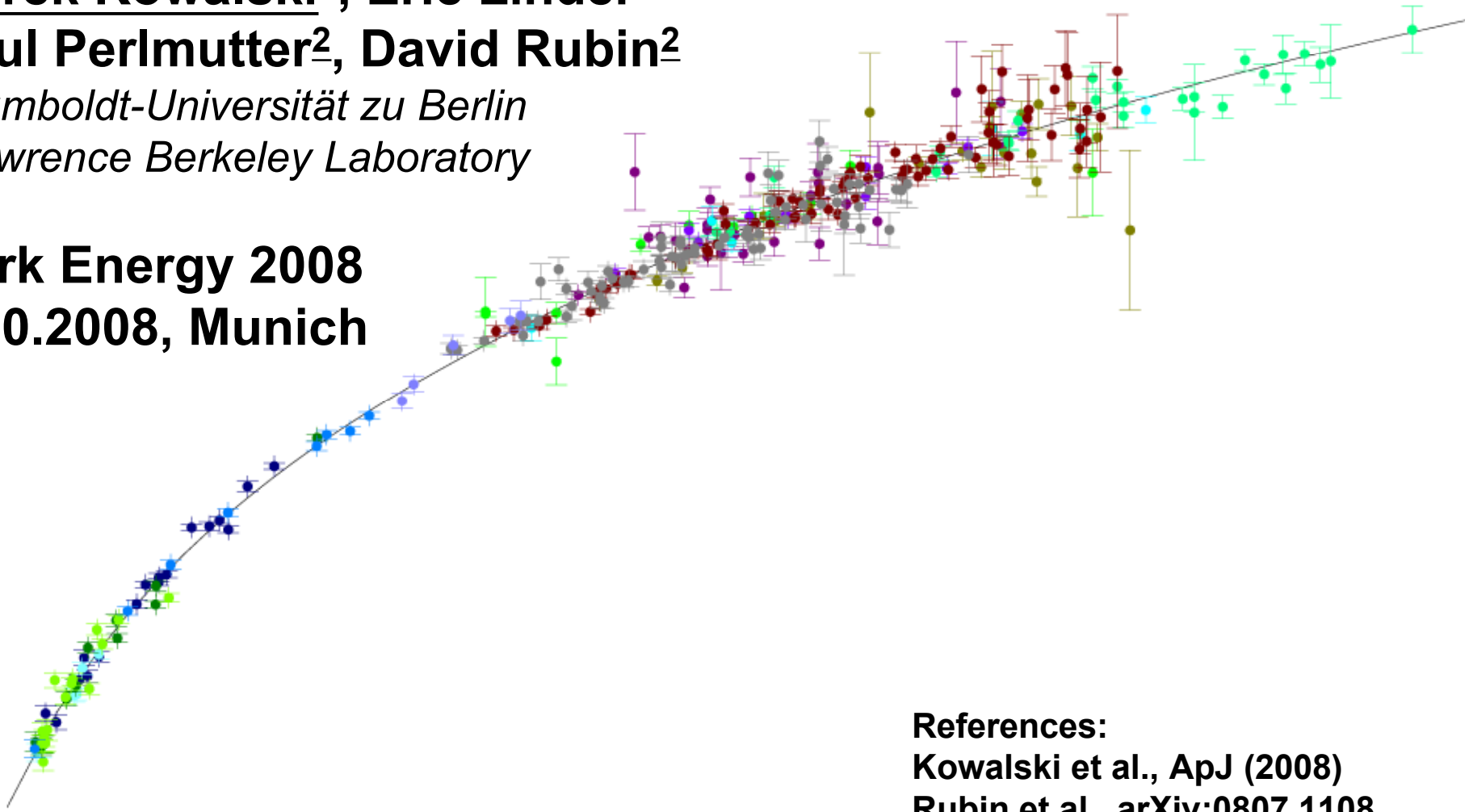
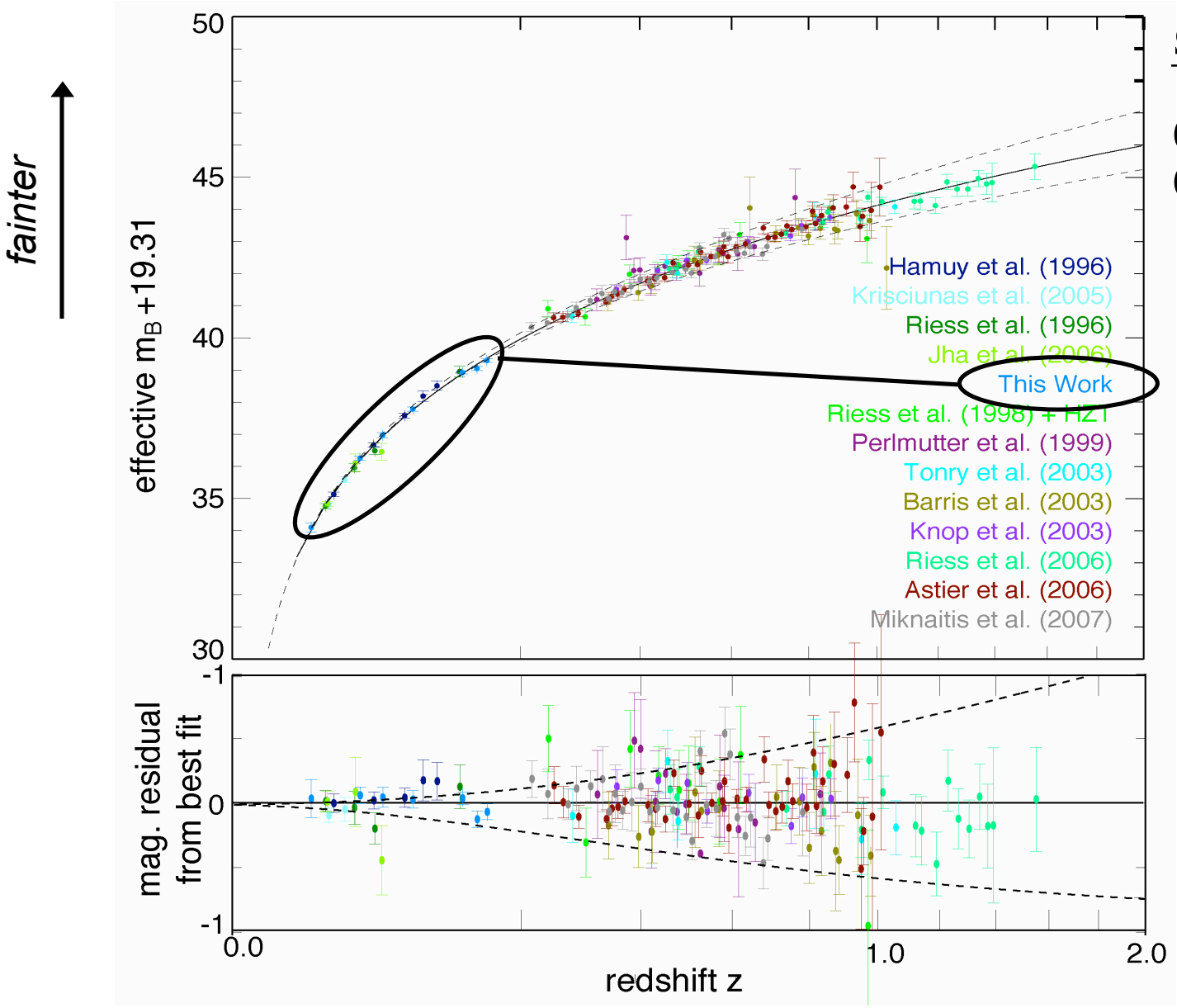


References:
Kowalski et al., ApJ (2008)
Rubin et al., arXiv:0807.1108

The Union SNe Compilation



Ω_Λ	Ω_M
1	0
0.72	0.28
0	1

Analysis aspects

Consistent Lightcurve Fits
SALT fitter used for all SNe using mostly original band-passes (Guy et al 2005/2007).

Blind analysis
The analysis (i.g. cuts) were developed on a blinded data set, all luminosities were offset by a hidden redshift-dependent amount.

Robust analysis
✓Initial cosmological fit using median statistics.
✓3-sigma outliers removed.
✓Assignment of sample dependent dispersion.

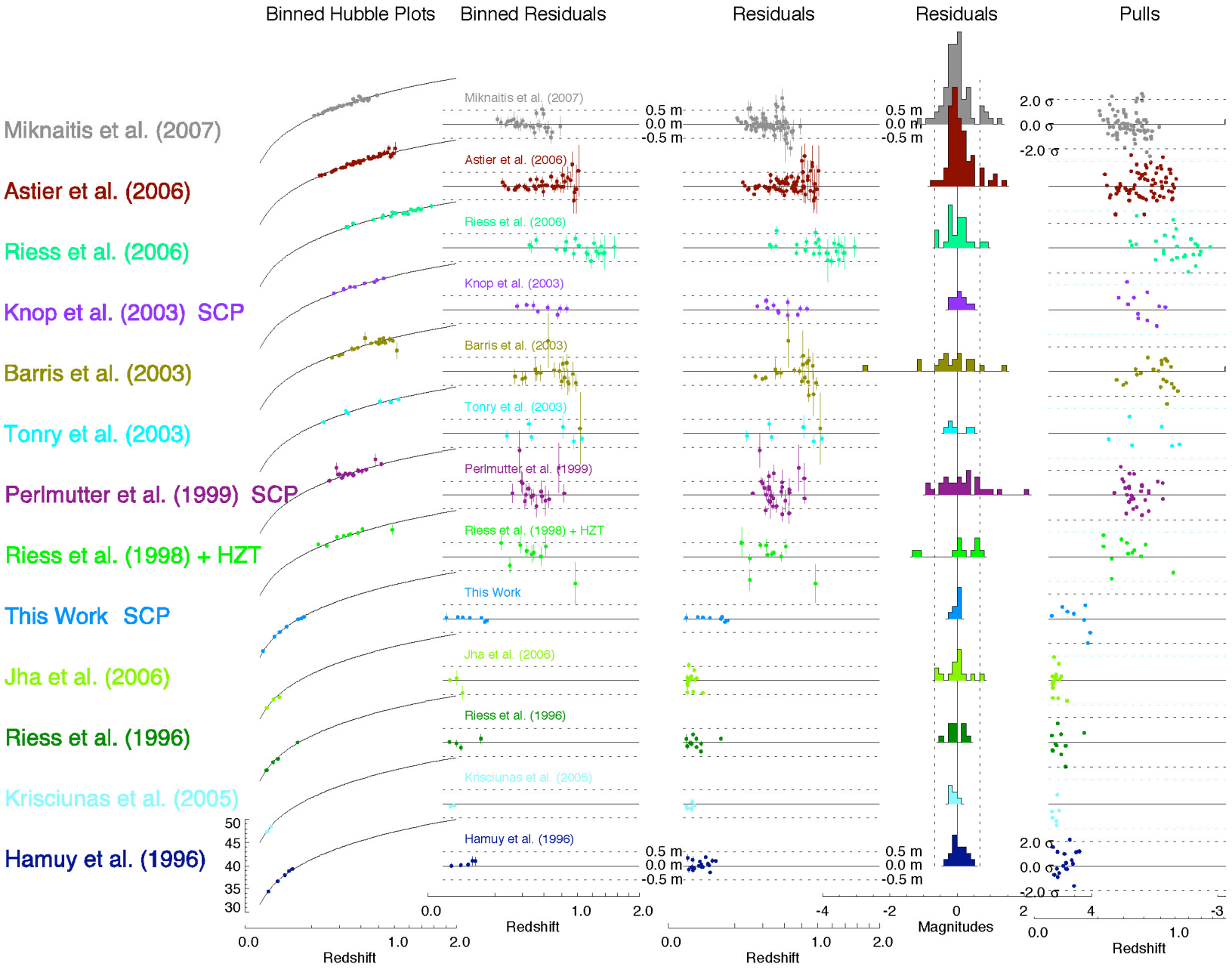
Stretch and color corrected luminosity:

$$\mu_B = m_B^{\max} - M + \alpha(s-1) - \beta c$$

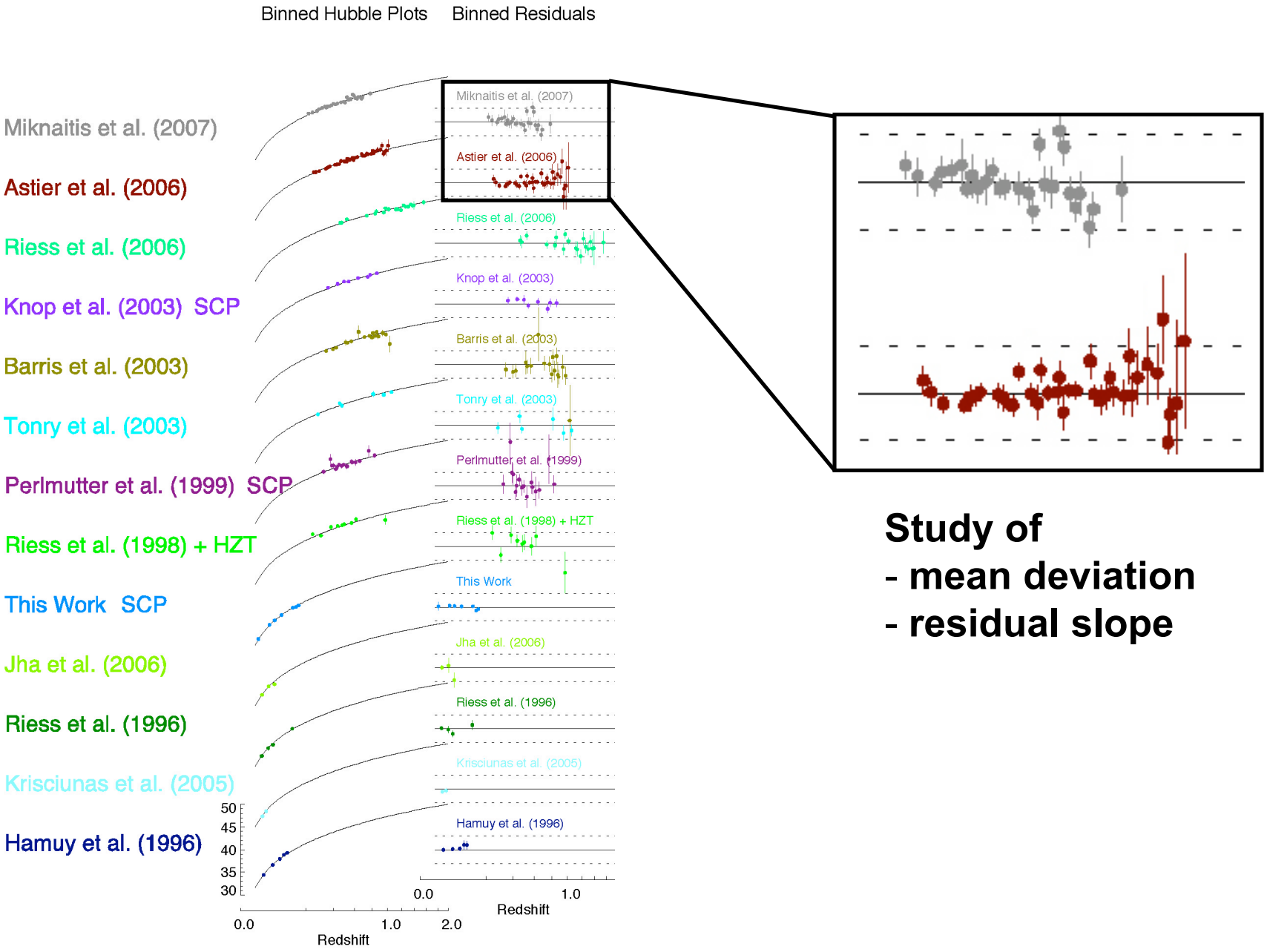
Requirement	$N_{\rm SN}$
all	414
$z > 0.015$	382
Fit successful	366
Color available	351
First phase < 6 d	320
$N_{\rm photo} \geq 6$	315
Outlier rejection	307

Large sample of SNe allows new studies of systematic errors

A heterogenous data sample

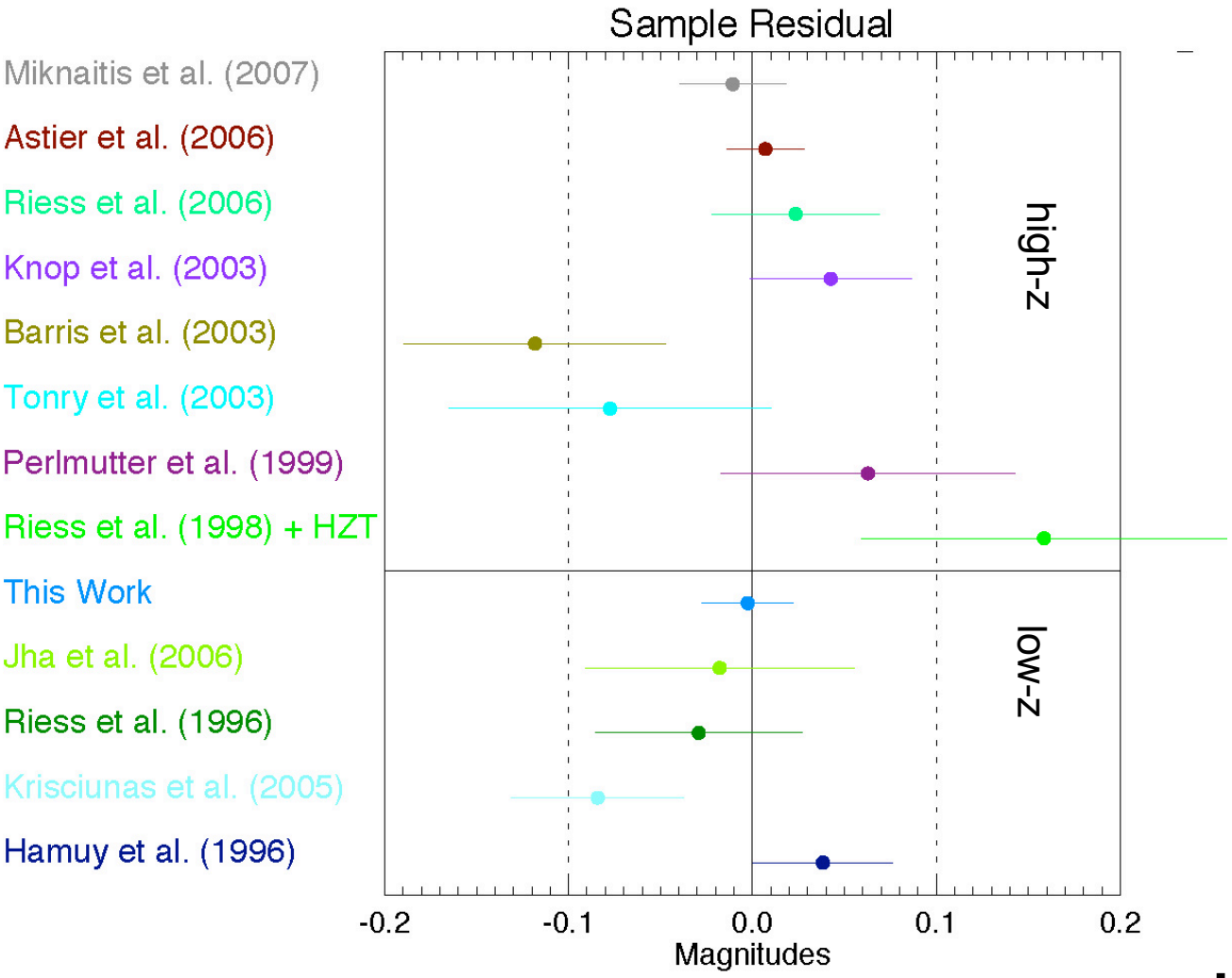


A heterogenous data sample



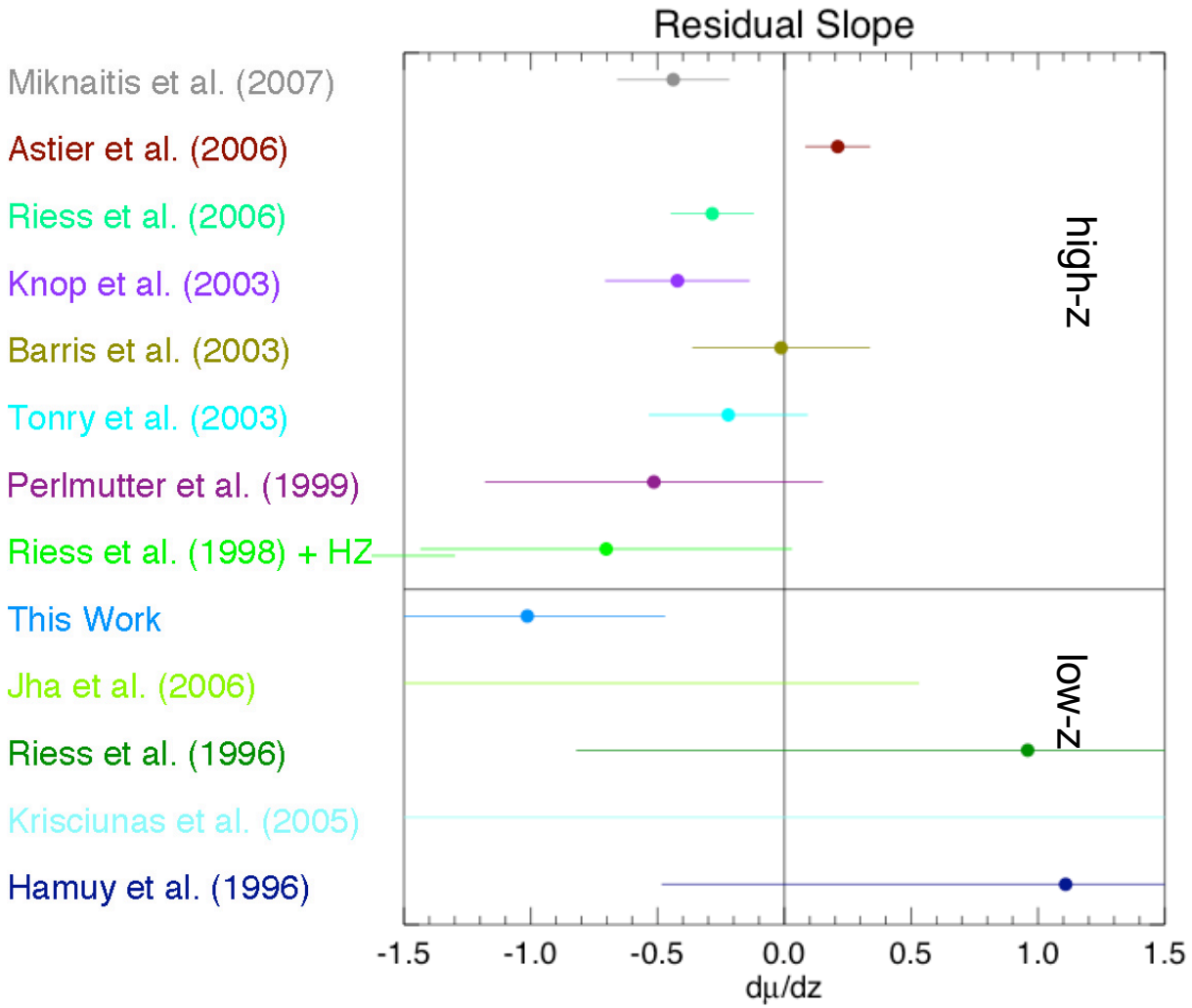
Study of
- mean deviation
- residual slope

Test for Tension



mean deviation: OK

Test for Tension



residual slope: (OK)

Testing SN evolution by subdividing the sample

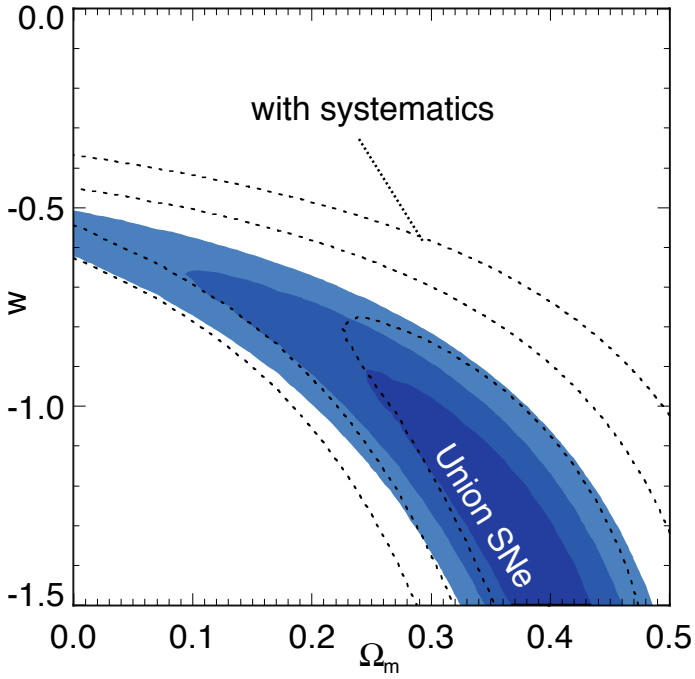
$$\mu_B = m_B^{\max} - M + \alpha(s-1) - \beta c$$

	subset	$N_{\rm SN}$	α	β	$\Omega_{\rm M}^a$	w^b
	all	307	1.26(0.10)	2.28(0.12)	0.28(0.03)	-1.00(0.07)
Evolution test:	$z > 0.2$	250	1.47(0.16)	2.26(0.14)	-	-
Redshift	$z \leq 0.2$	57	1.10(0.12)	2.24(0.21)	-	-
Evolution test:	$s < 0.96$	155	1.56(0.27)	2.18(0.18)	0.27(0.05)	-1.01(0.10)
Population	$s \geq 0.96$	152	1.57(0.34)	2.33(0.17)	0.30(0.04)	-0.96(0.08)

No significant evidence for evolution!

Systematic errors

Source	common (mag)	sample-dependent (mag)
$\alpha\&\beta$ correction	0.015	-
Contamination	-	0.015
Lightcurve model	0.028	-
Zero point	0.021	0.021
Malmquist bias	-	0.020
Gravitational lensing	-	0.008*
Galactic extinction normalization	0.013	-
Total in mag	$\Delta M = 0.040$	$\Delta M_i = 0.033$



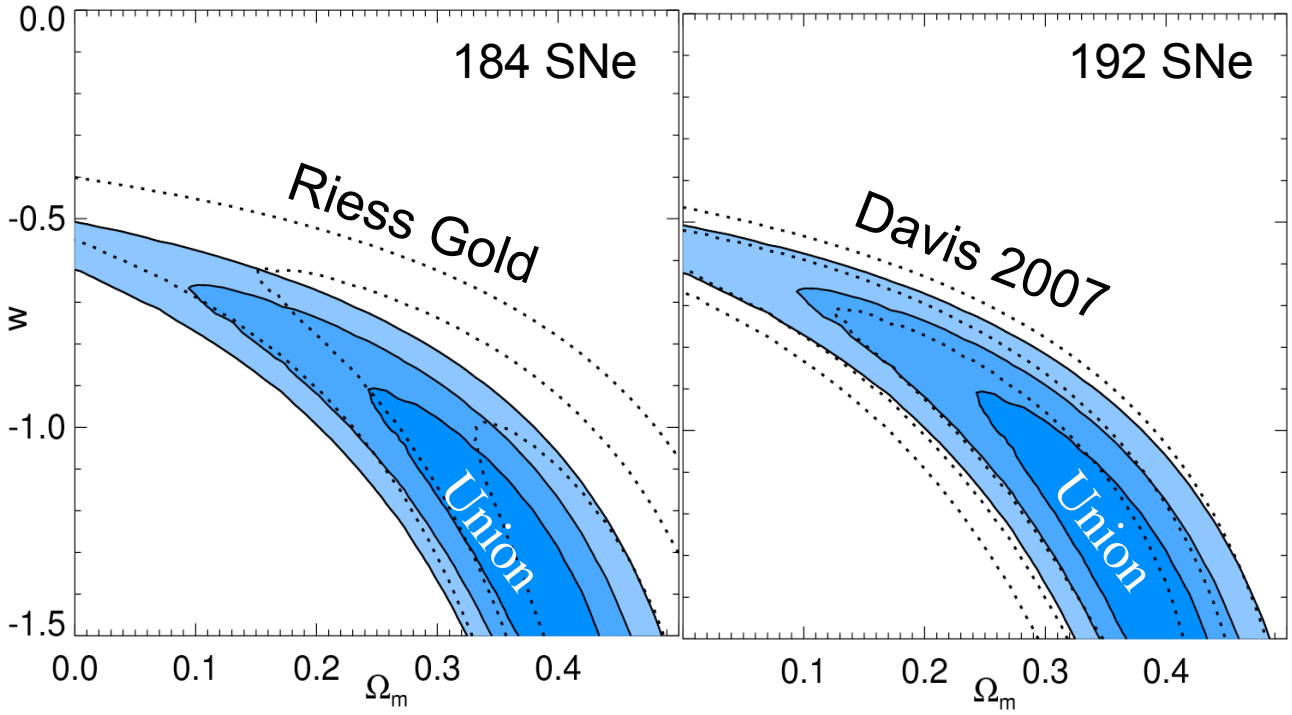
Nuisance parameters for systematic errors:

$$\mu = m^{\max} - M + \alpha(s-1) - \beta c + \Delta M + \Delta M_i$$

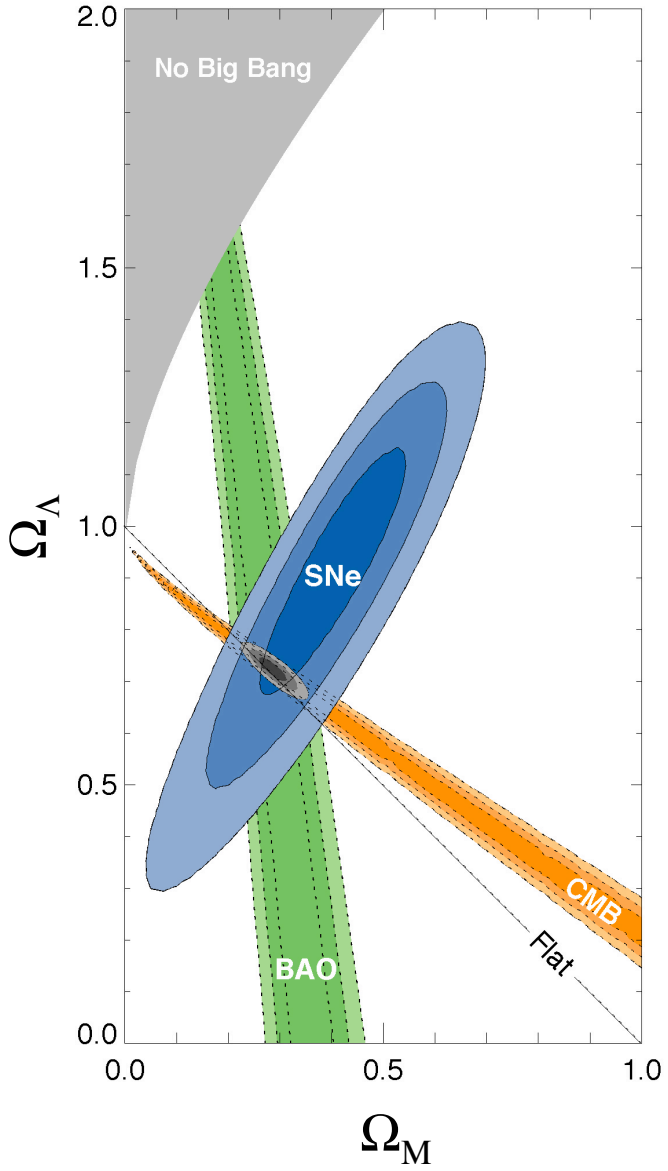
common for all z>0.2 SNe

sample dependent

Comparison with previous compilations



Results: Cosmological fit parameters



Combination of SNe with:
BAO (Eisenstein et. al., 2005)
CMB (WMAP-5 year data, 2008)

For a flat Universe:

$$\Omega_m = 0.274 \pm 0.016(\text{stat}) \pm 0.012(\text{sys})$$

… and with curvature:

$$\Omega_m = 0.285 \pm 0.020(\text{stat}) \pm 0.010(\text{sys})$$

$$\Omega_k = -0.010 \pm 0.010(\text{stat}) \pm 0.005(\text{sys})$$

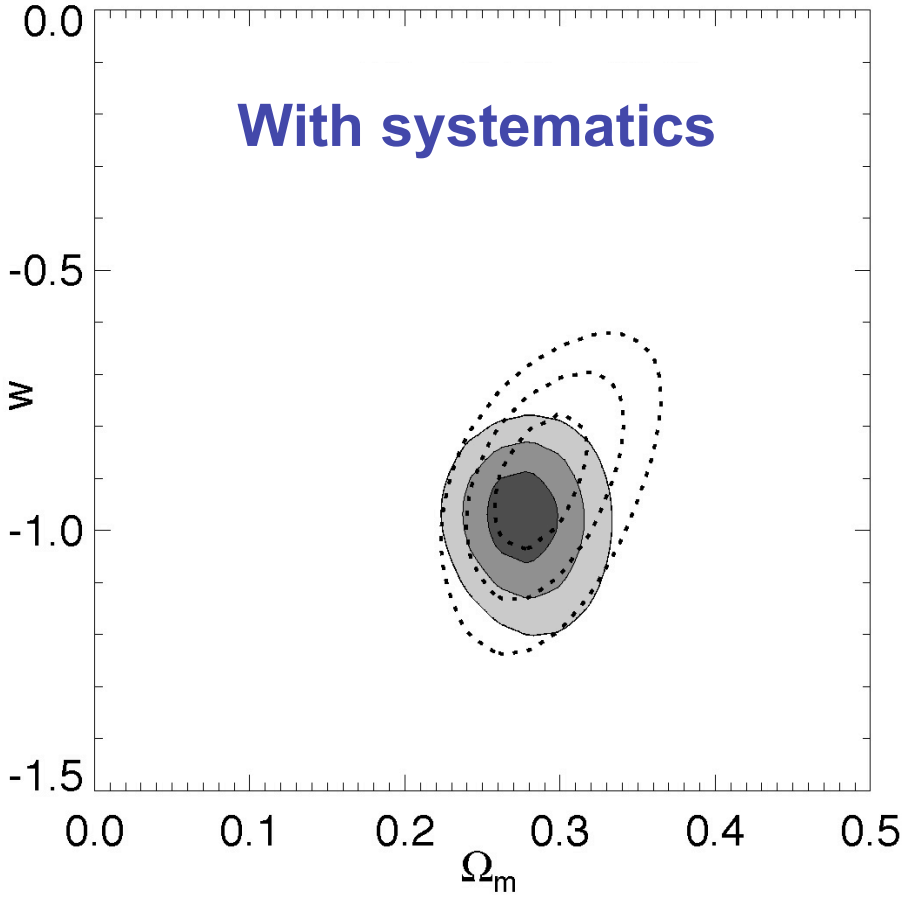
Equation of state: $w = p/\rho$

SNe + BAO + CMB

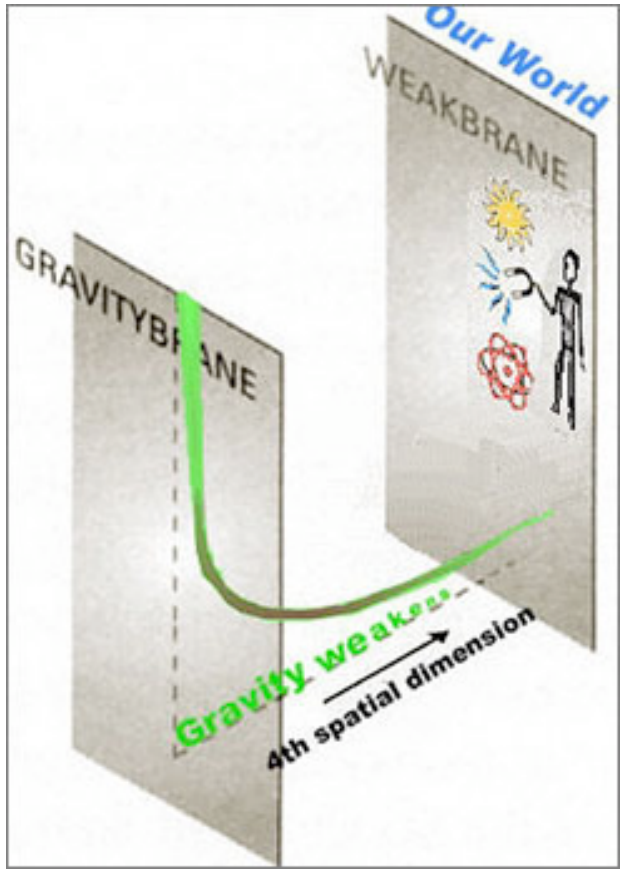
$w = -0.969 \pm 0.061(\text{stat}) \pm 0.065(\text{sys})$

... and allowing for curvature:

$w = -1.001 \pm 0.071(\text{stat}) \pm 0.081(\text{sys})$



Constraining Models (I): Braneworld Gravity

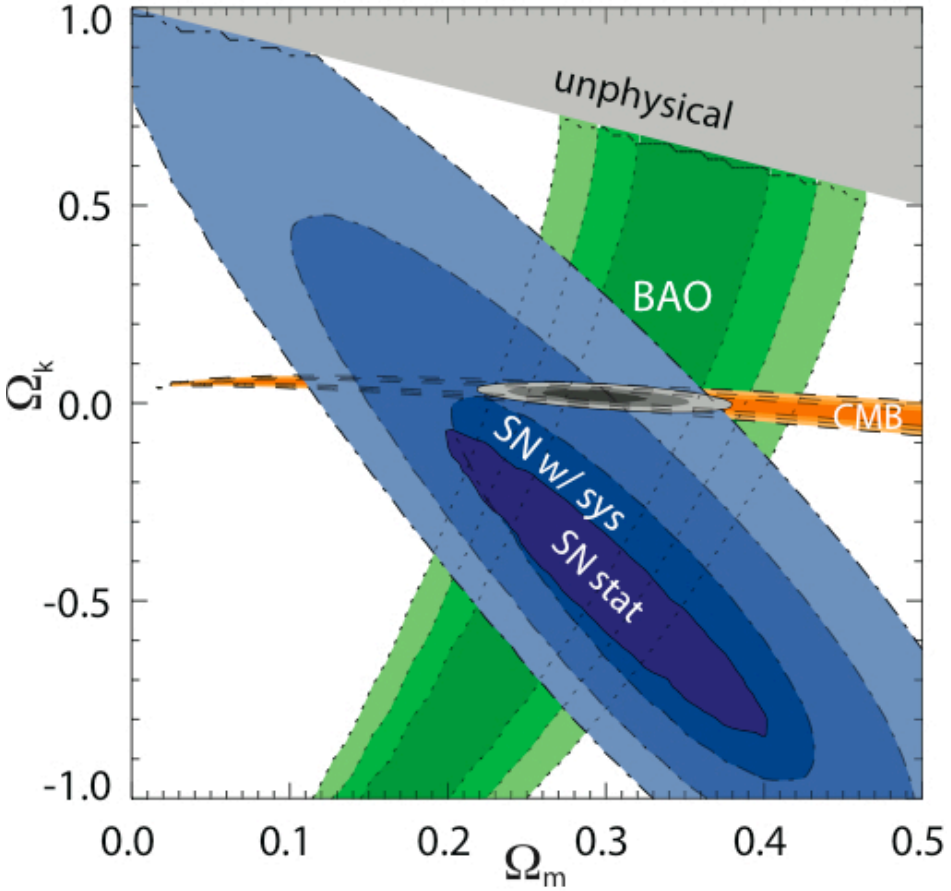


Gravity leaking into extra dimensions on the scales of the Hubble radius can mimic cosmic acceleration.
Dvali, Gabadadze, Porrati (2000) - DGP

We chose dark matter and curvature as DGP parameters to obtain an effective Dark Energy equation of state:

$$w(z) = -\frac{1-\Omega_k(z)}{1+\Omega_m(z)-\Omega_k(z)}$$

Constraining Models (I): Braneworld Gravity



DGP-Model versus ΛCDM:

$\Delta \chi^2_{stat} = 15.0$ (stat error only)

$\Delta \chi^2_{sys} = 2.7$ (with sys. error)

D.Rubin, E. Linder, MK et al., (2008)

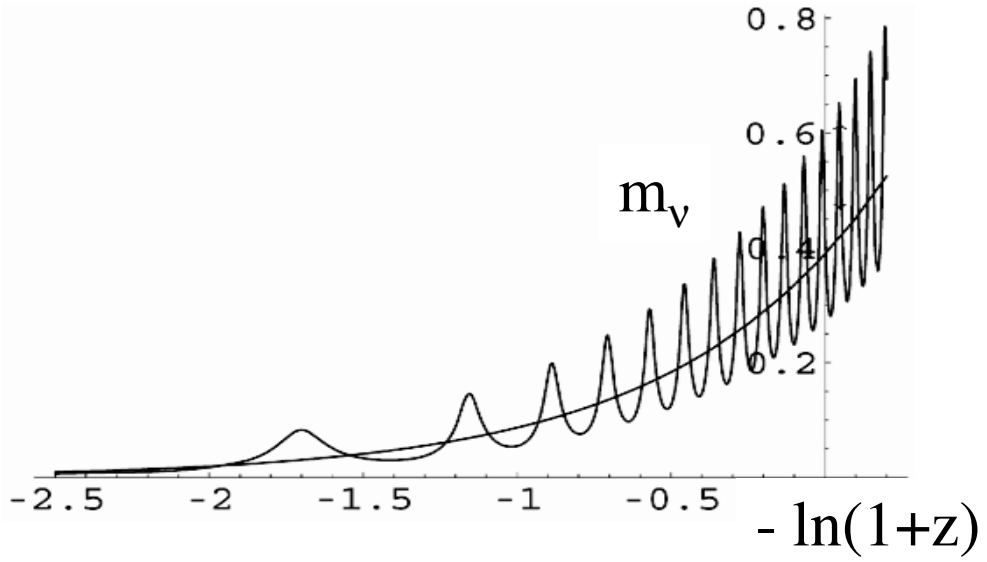
Constraining Models (II): Growing Neutrinos

Scalar-field couples to massive neutrinos.

Once neutrinos become sub-relativistic, one obtains Λ-like behavior.

Today: massive neutrinos and small offset of *w* from -1:

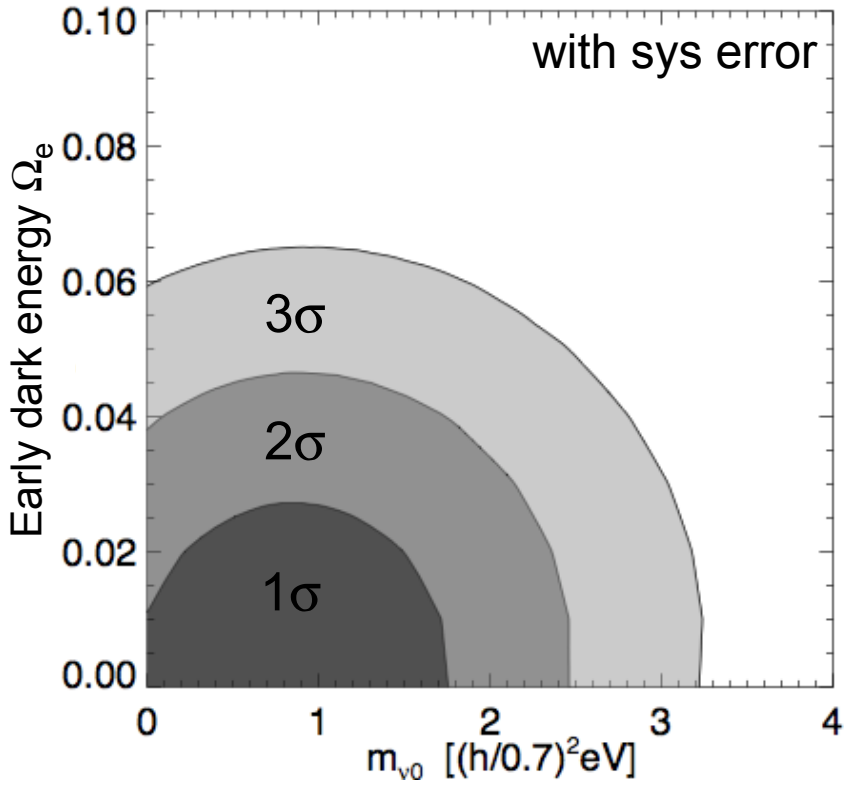
$$w_0 = -1 + \frac{m_{\nu,0}}{12\ \mathrm{eV}}$$



C. Wetterich (2007),
L. Amendola et al. (2007),

Early dark energy (Ω_e) is second parameter and LSS and WMAP constrain Ω_e to be less then a few % (Doran et al. 2007).
We assume a 10% linear growth prior.

Constraining Models (II): Growing Neutrinos



Lab constraints:
$m_\nu \leq 2$ eV
Katrin sensitivity:
$m_\nu \leq 0.2$ eV
ν–oszillations:
$m_\nu \geq 0.05$ eV

$m_\nu < 1.2\ (h/0.7)^2$ eV @ 95 CL stat error only
$m_\nu < 2.1\ (h/0.7)^2$ eV @ 95 CL with sys error

D.Rubin, E. Linder, MK et al., (2008)

Summary

The Union SN compilation provides a consistently analyzed data set, and with new nearby SNe, is the largest available.

Investigations of systematics show no significant tension between the individual samples as well as no evidence for SN evolution.

Combining SNe, BAO, and CMB we (slowly) become able to test individual models for dark energy.

The Union SN compilation is publicly available along with a plug-in for CosmoMC, that handles systematic errors correctly.

See http://supernova.lbl.gov/union for more details