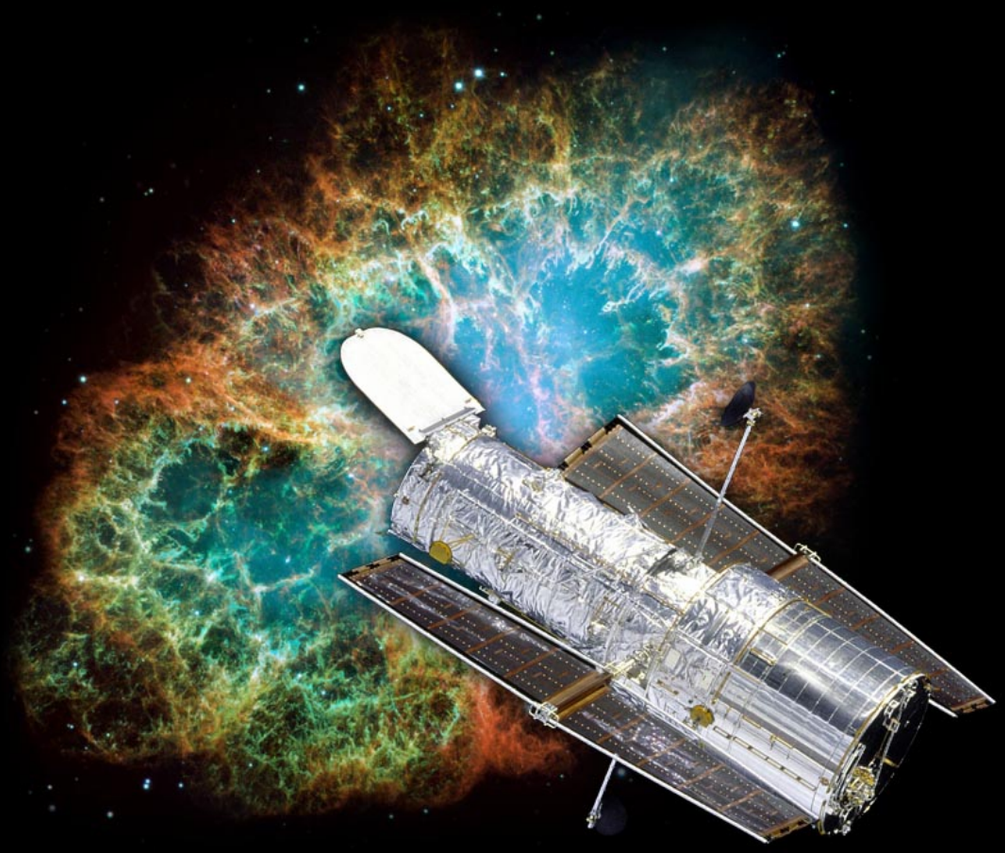
New Hubble Space Telescope Discoveries of Type Ia Supernovae at $z \geq 1$: Narrowing Constraints on the Early Behavior of Dark Energy

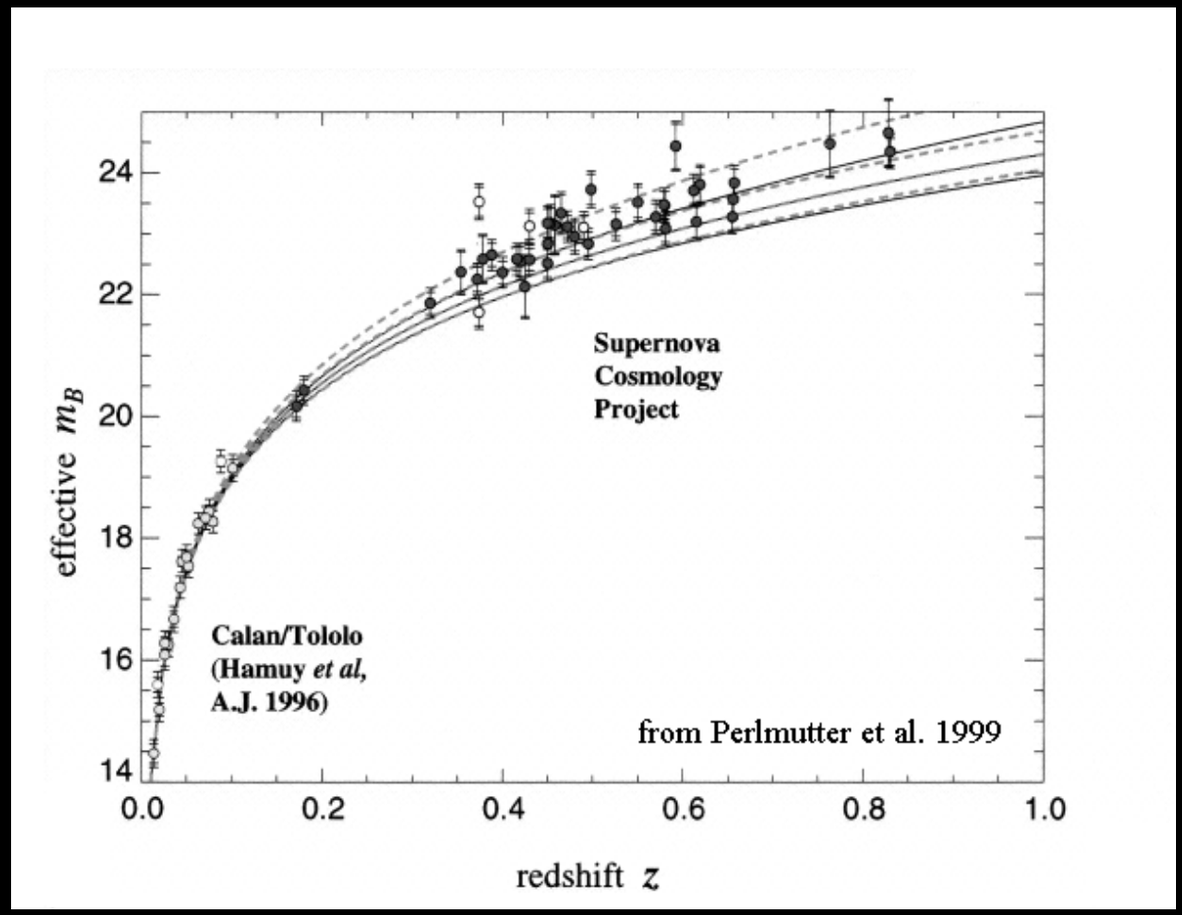


Riess et al.

The Astrophysical Journal, 2007

Context

- Why we need supernovae with $z \geq 1$
  - Dark energy dominates for $z < 2$
  - Expansion models are increasingly disparate for large z
  - Equation of state for dark energy may change with time
- Hubble is critical for these observations



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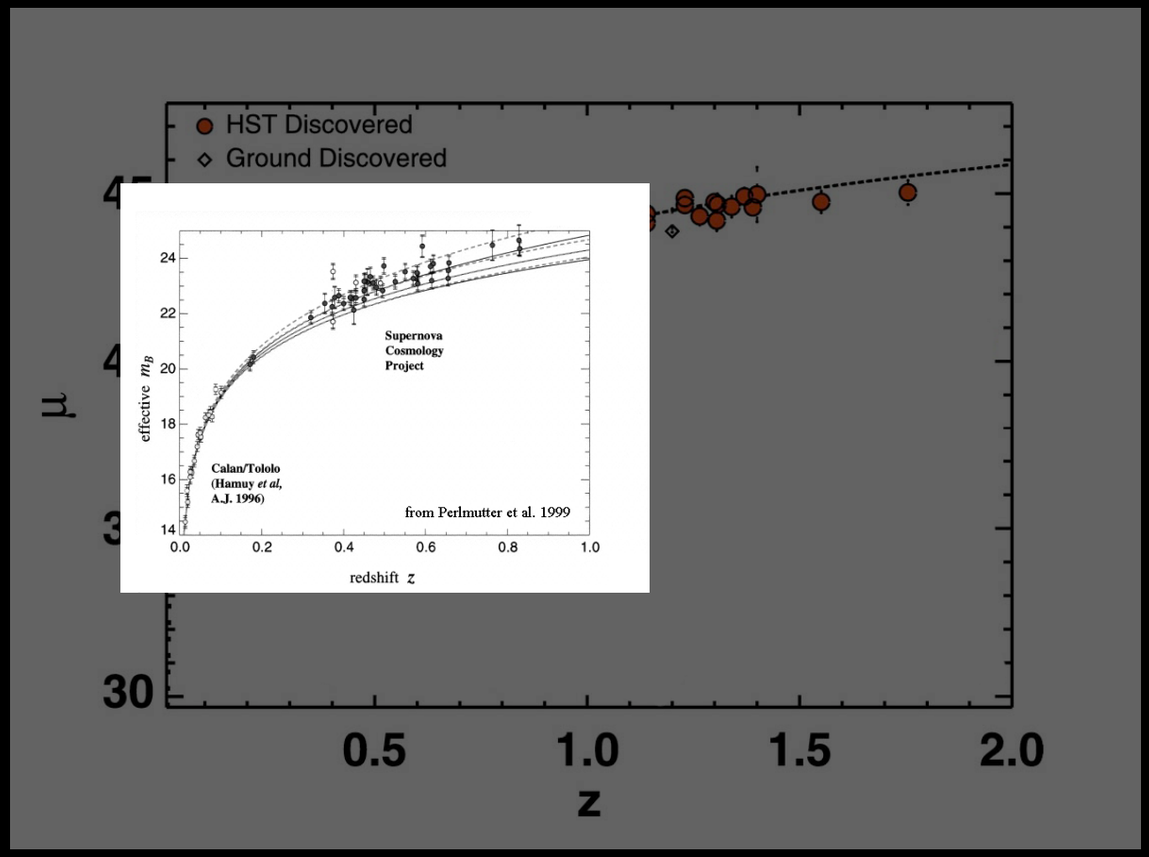

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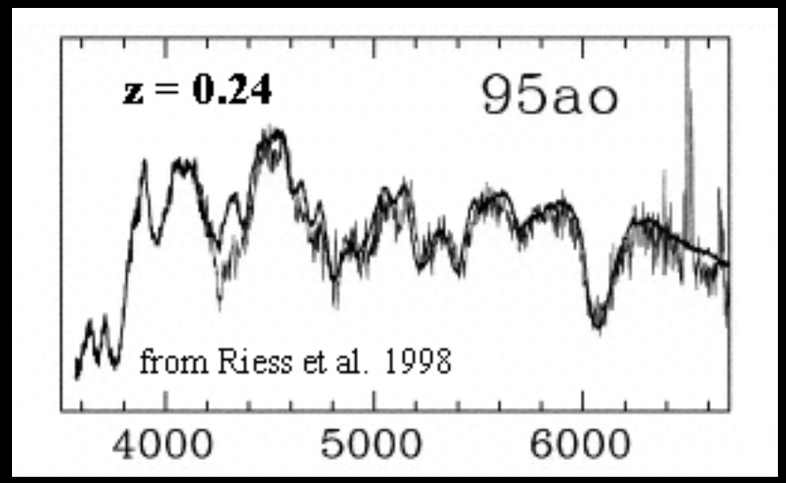

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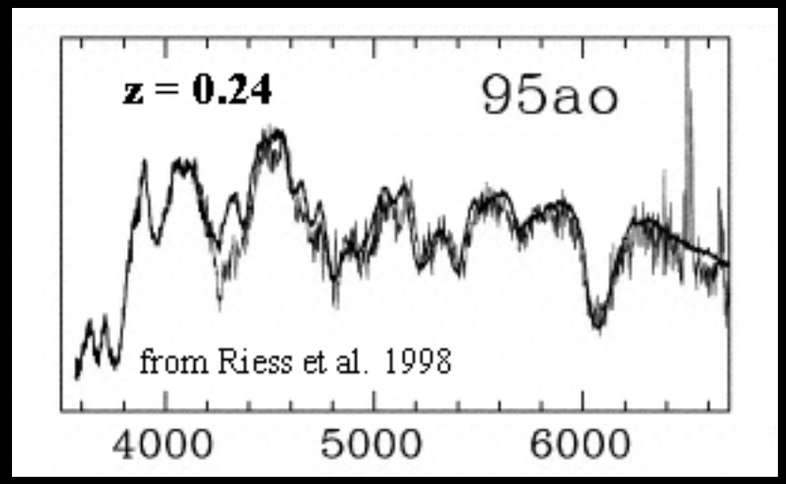

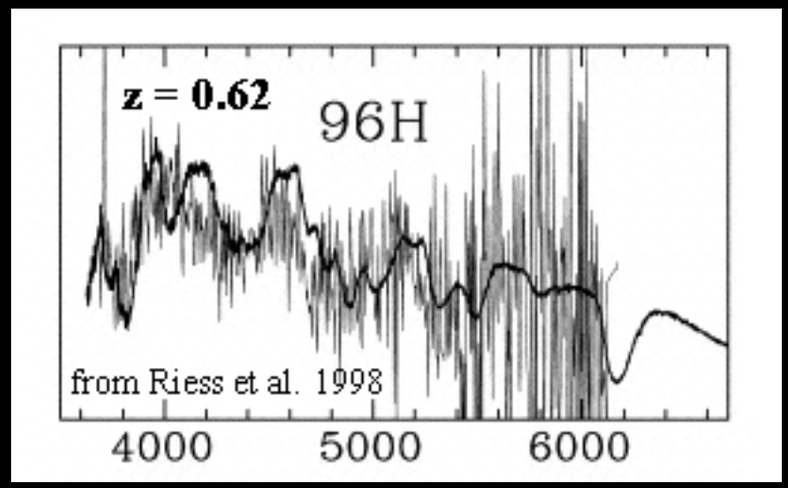

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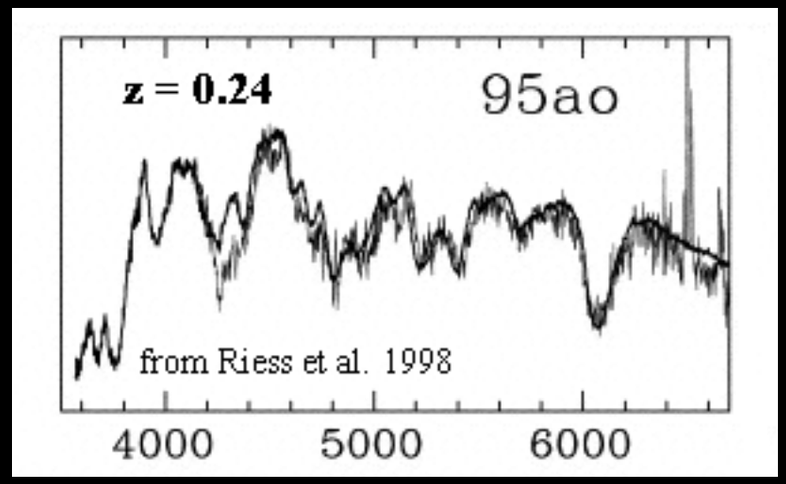
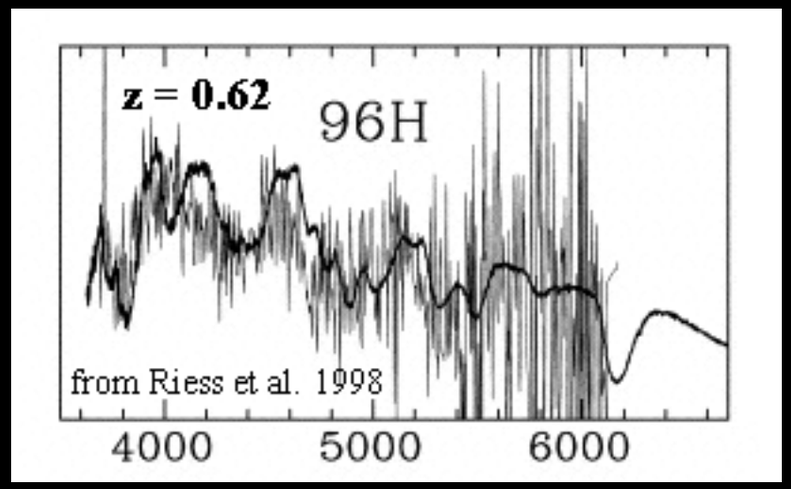
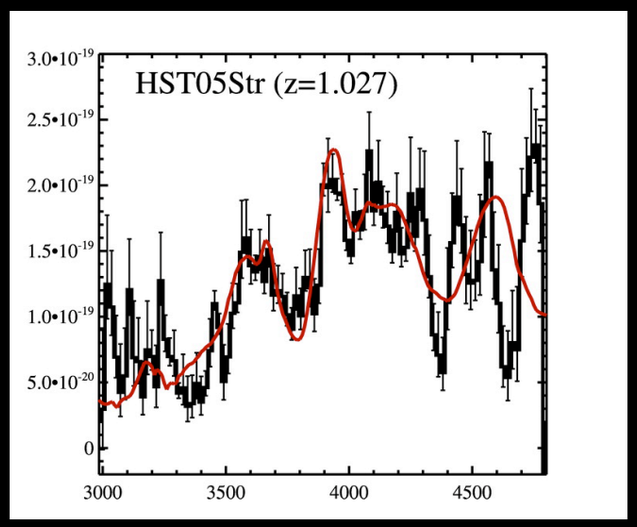
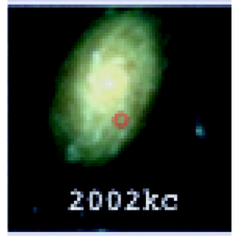




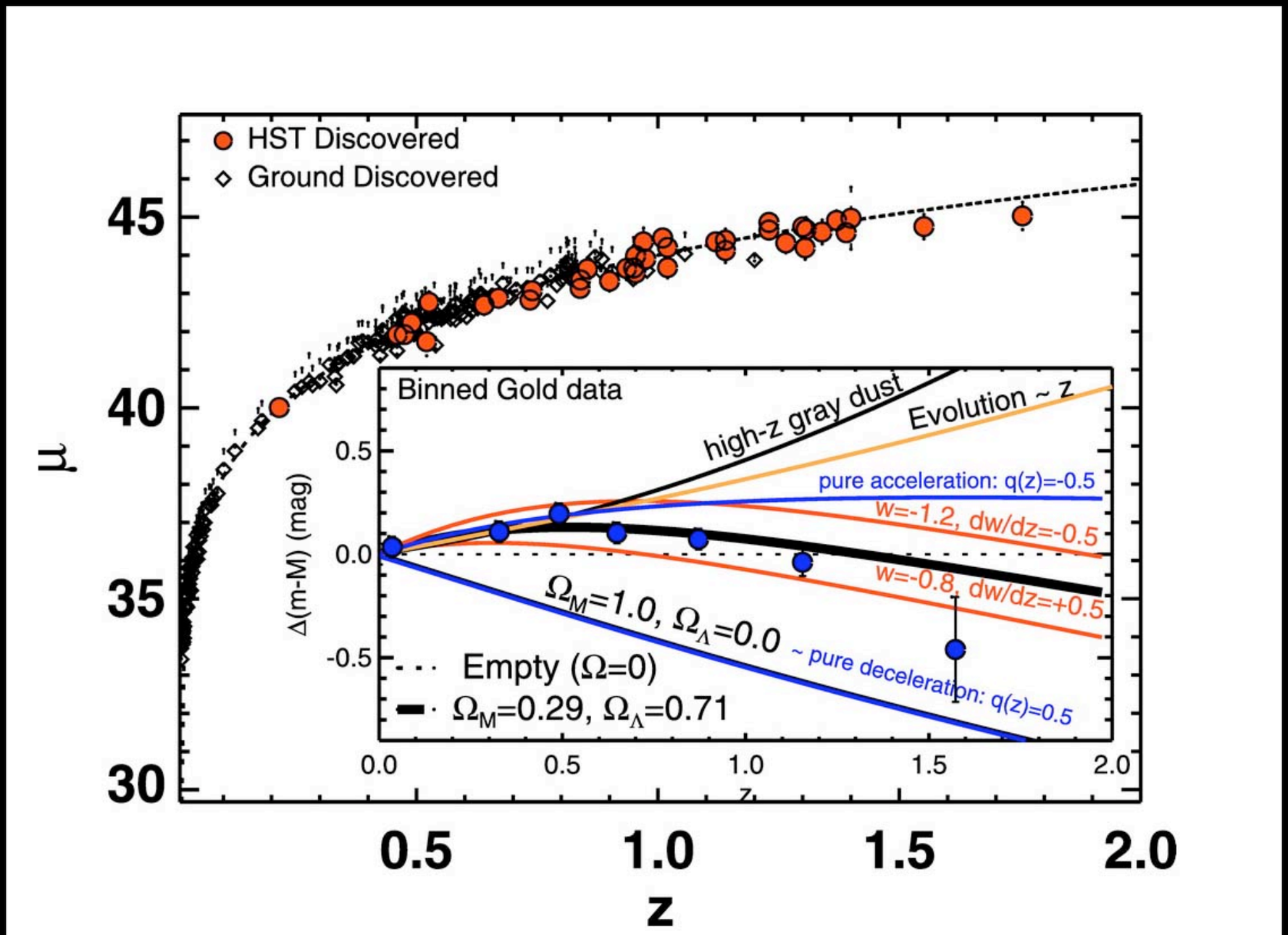




The Data

- Hubble (ACS and NICMOS)
- Hubble Deep Field-North & Chandra Deep Field-South
- Combined 23 supernovae at $z \geq 1$
- Light curves and spectroscopy for each candidate

Hubble Diagram



Results: Acceleration vs. Others

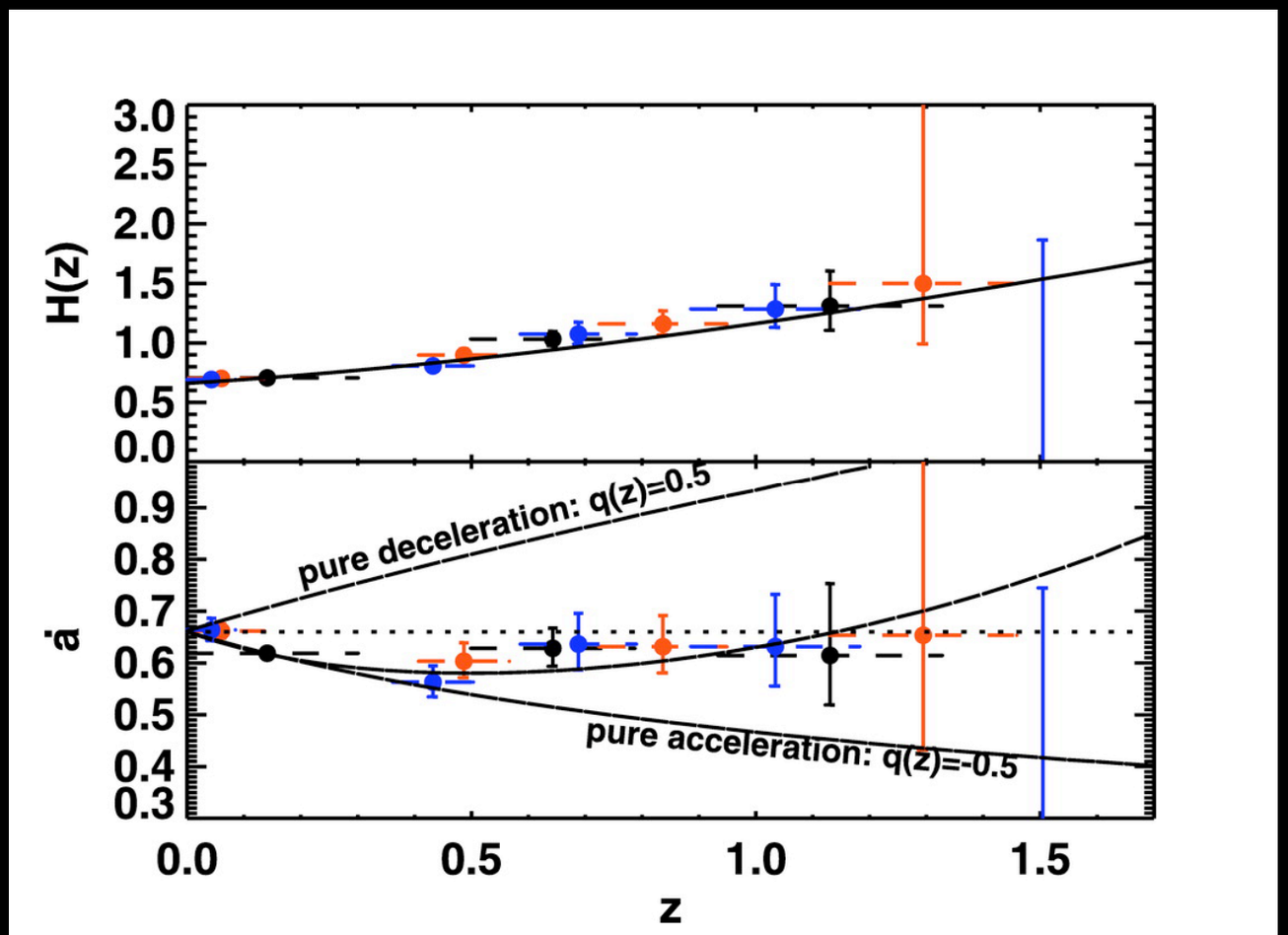


TABLE 5

χ^2 Comparison of Gold Set Data to Models, $cz > 7000$ km s^{-1}

Model	χ^2(for 184 SNe Ia)
$\Omega_M = 0.29$, $\Omega_\Lambda = 0.71$	150[a]
$\Omega_M = 1.00$, $\Omega_\Lambda = 0.00$	285[a]
$\Omega_M = 0.00$, $\Omega_\Lambda = 0.00$	164[a]
High-redshift gray dust (with $\Omega_M = 1.00$, $\Omega_\Lambda = 0.00$)	344[b]
Replenishing dust (with $\Omega_M = 1.00$, $\Omega_\Lambda = 0.00$)	150[b]
Dimming $\propto z$ (with $\Omega_M = 1.00$, $\Omega_\Lambda = 0.00$)	266[b]

[a] Best χ^2 after marginalizing over H_0.
[b] Best χ^2 for best H_0.

Results: Time Dependence of w

- "First order expansion":
  $w(z) = w_0 + w_a z/(1+z)$
  - No strong support for time evolution
- Expand w(z) into orthogonal vectors W_i
  - Bin w(z) and remove dependence on earlier values
  - Consistent with constant w(z)

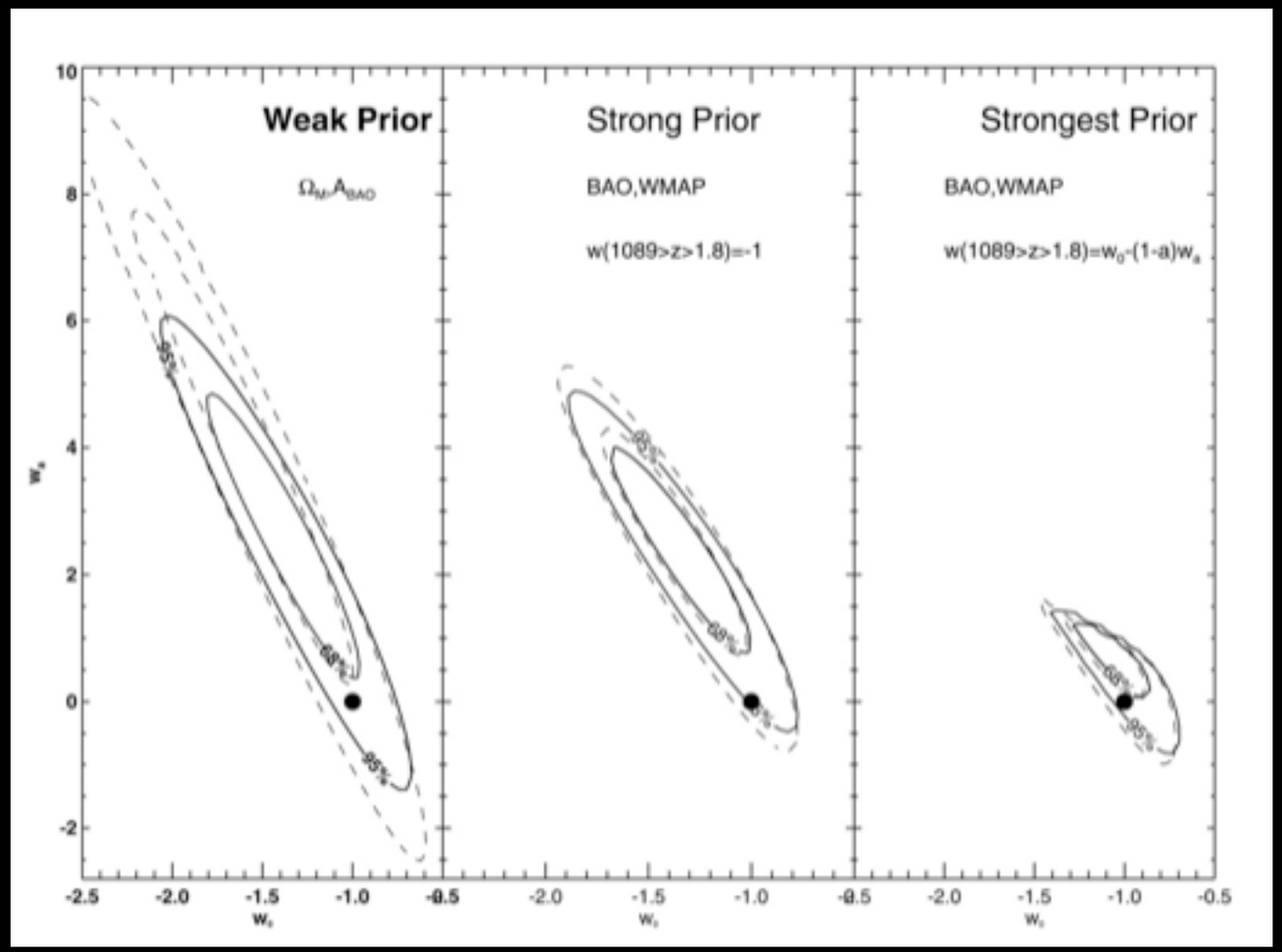


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TABLE 6
LIKELIHOOD REGIONS FOR W_z

w_z	Peak	1 σ	2 σ
Prior = Weak, Sample = All Gold			
$W_{0.25}$	−1.05	−1.15 to −0.95	−1.26 to −0.85
$W_{0.70}$	−0.45	−0.86 to −0.06	−1.49 to 0.32
$W_{1.35}$	0.59	−2.62 to 3.03	−16.6 to 6.15
Prior = Weak, Sample = Gold minus *HST*			
$W_{0.25}$	−1.06	−1.16 to −0.95	−1.27 to −0.86
$W_{0.70}$	0.11	−0.43 to 0.61	−1.17 to 1.17
$W_{1.35}$	10.77	1.86 to 18.55	−20.1 to 27.92
Prior = Strong, Sample = All Gold			
$W_{0.25}$	−1.02	−1.12 to −0.93	−1.23 to −0.84
$W_{0.70}$	−0.15	−0.57 to 0.131	−1.05 to 0.46
$W_{1.35}$	−0.76	−1.78 to −0.16	−15.8 to 0.51
Prior = Strong, Sample = Gold minus *HST*			
$W_{0.25}$	−1.03	−1.14 to −0.94	−1.25 to −0.85
$W_{0.70}$	0.151	−0.26 to 0.61	−0.80 to 1.00
$W_{1.35}$	−1.95	−5.89 to −0.70	−17.8 to 0.35
Prior = Strongest, Sample = All Gold			
$W_{0.25}$	−1.02	−1.11 to −0.92	−1.21 to −0.83
$W_{0.70}$	−0.13	−0.47 to 0.17	−0.88 to 0.48
$W_{1.35}$	−0.85	−1.81 to −0.46	−17.0 to −0.30
Prior = Strongest, Sample = Gold minus *HST*			
$W_{0.25}$	−1.03	−1.13 to −0.94	−1.24 to −0.85
$W_{0.70}$	0.24	−0.17 to 0.64	−0.70 to 1.06
$W_{1.35}$	−1.89	−5.50 to −0.80	−18.0 to −0.34
Prior = Strong, Sample = All Gold with MLCS2k2 Fits to SNLS SNe			
$W_{0.25}$	−1.05	−1.14 to −0.94	−1.26 to −0.84
$W_{0.70}$	−0.09	−0.45 to 0.23	−0.91 to 0.56
$W_{1.35}$	−1.01	−2.23 to −0.26	−15.8 to 0.37

A Kinematic Approach to Dark Energy Studies

David Rapetti, Steven W. Allen, Mustafa A. Amin, & Roger D. Blanford

Monthly Notices of the Royal Astronomical Society, 2007

Kinematic Framework

- Allows for characterization of the expansion history without assumptions
- Parameters are the dimensionless time derivatives of the scale factor
  - Deceleration (2nd): $q(t) = -\ddot{a}/(H^2 a)$
  - Jerk (3rd): $j(t) = \dddot{a}/(H^3 a)$
- Evolving jerk model
  - Higher order evolution of j(t) using Chebychev polynomials

Data and Analysis

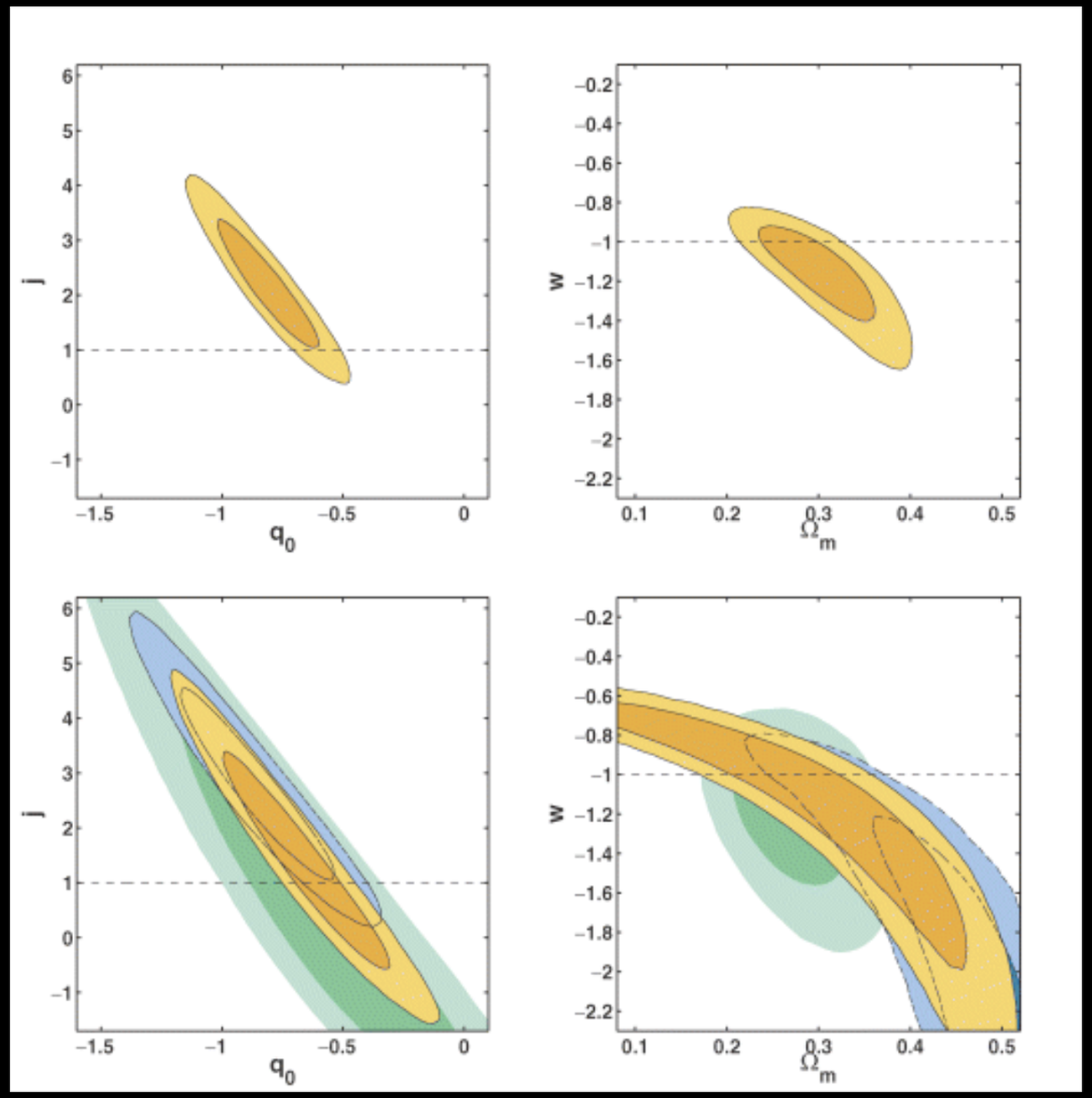
- Combines data from supernovae and x-ray clusters
- Exploring the parameter space
  - MCMC
  - limiting parameter choices

Results

- No support for evolving jerk models
- Highlighted values correspond to:

$\Omega_m = 0.306^{+0.042}_{-0.040}$

$w = -1.15^{+0.14}_{-0.18}$



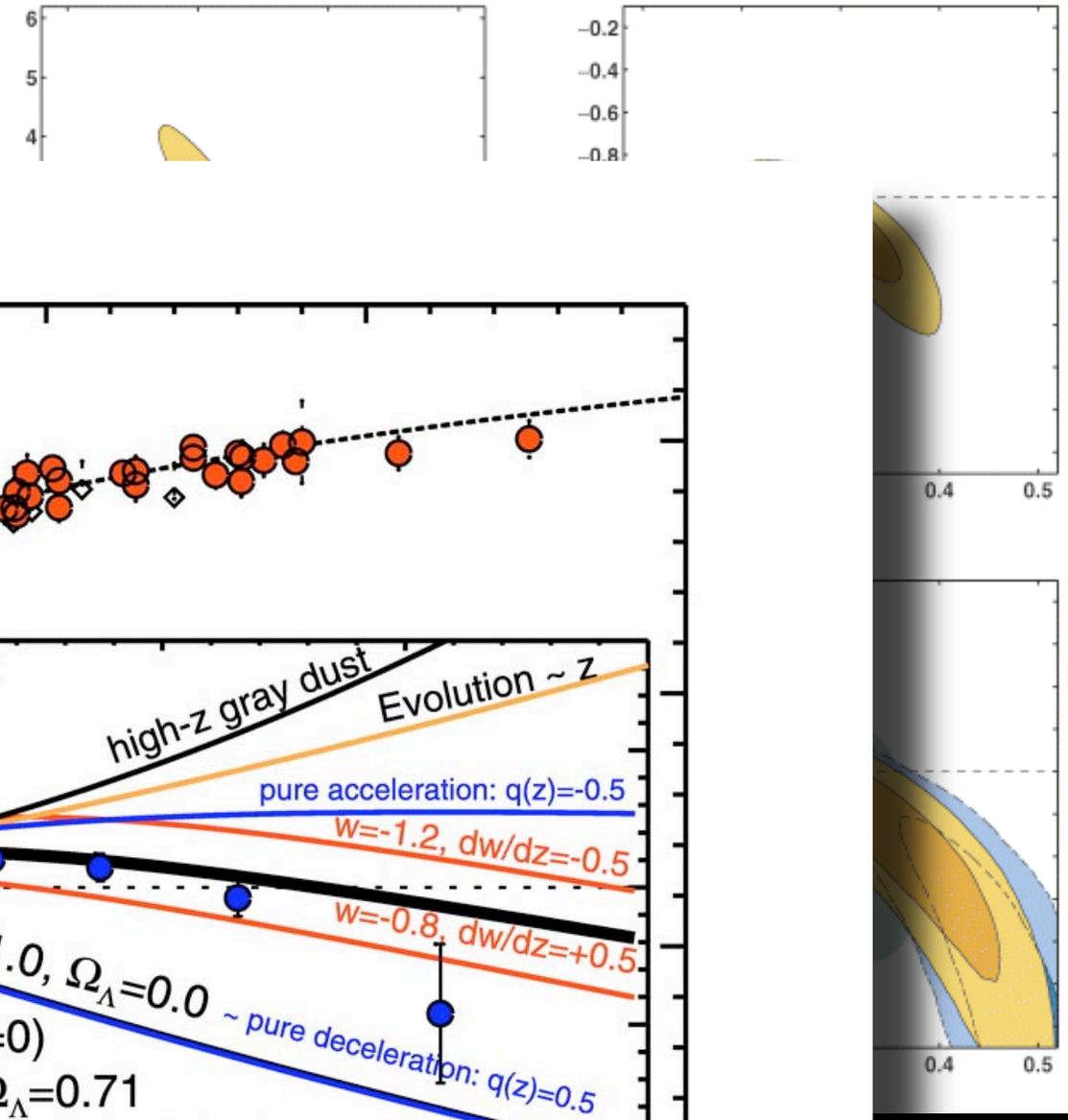
Data set	$\mathcal{Q}$ model		$\mathcal{J}$ model				Improvement		
	q_0	$\chi^2_{\mathcal{Q}}$/d.o.f.	q_0	j	$\chi^2_{\mathcal{J}}$/d.o.f.	$\Delta\chi^2_{\mathcal{JQ}}$	F-test (per cent)	ΔBIC	ln $B_{\mathcal{JQ}}$
Clusters	-0.55 ± 0.14	39.6/39	$-0.61^{+0.38}_{-0.41}$	$0.51^{+2.55}_{-2.00}$	39.6/38	0.01	5.6	-3.7	-3.2
SNLS SNeIa	-0.417 ± 0.062	112.1/113	-0.65 ± 0.23	$1.32^{+1.37}_{-1.21}$	111.0/112	1.1	69.4	-3.6	-2.5
Gold SNeIa	-0.289 ± 0.062	182.8/155	-0.86 ± 0.21	$2.75^{+1.22}_{-1.10}$	174.6/154	8.2	99.1	3.1	1.2
Gold+SNLS+Cl	-0.391 ± 0.045	300.8/272	-0.81 ± 0.14	$2.16^{+0.81}_{-0.75}$	290.1/271	10.7	99.8	5.1	3.0

Results

- N
ev
- Hi
co

$\Omega_$

w



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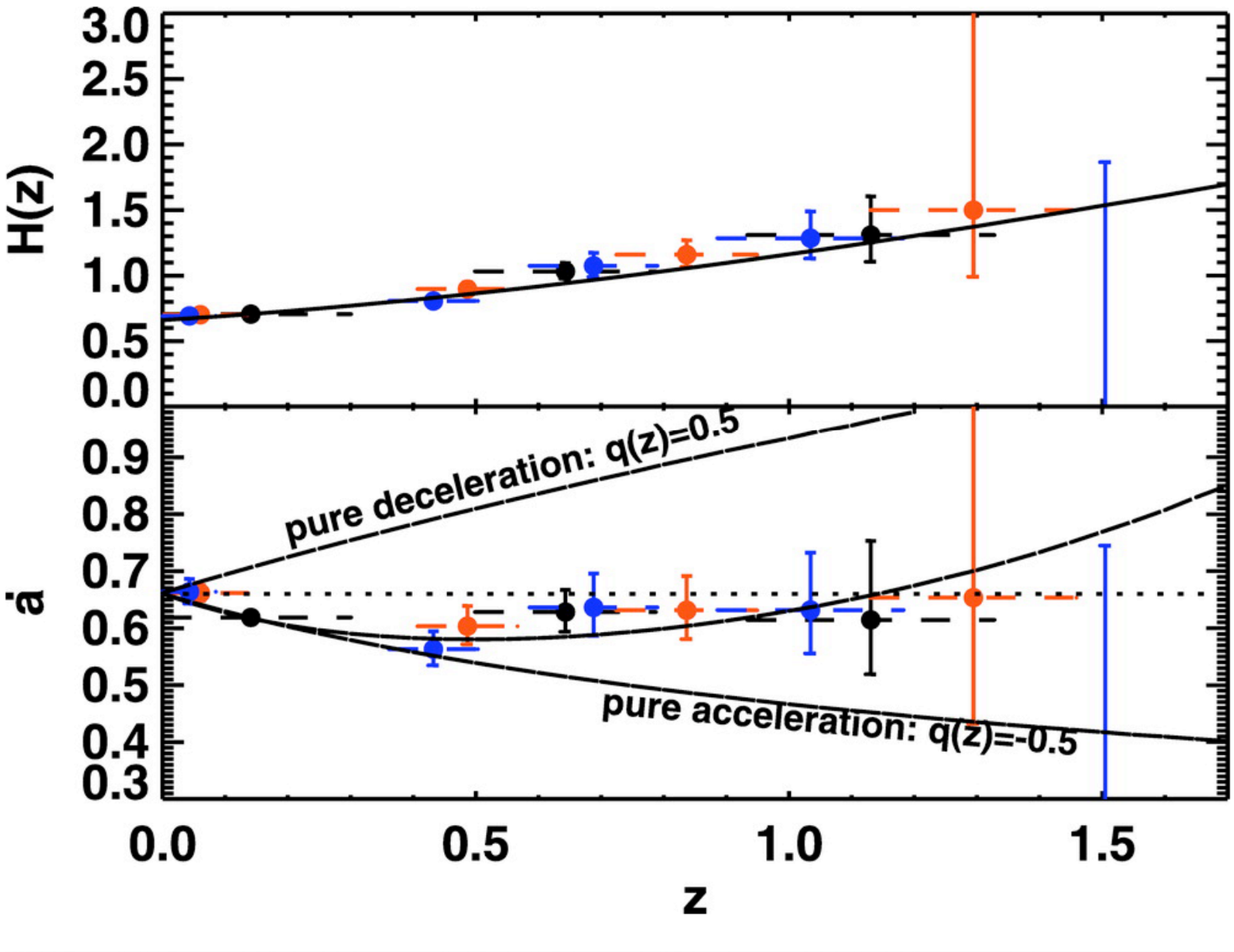

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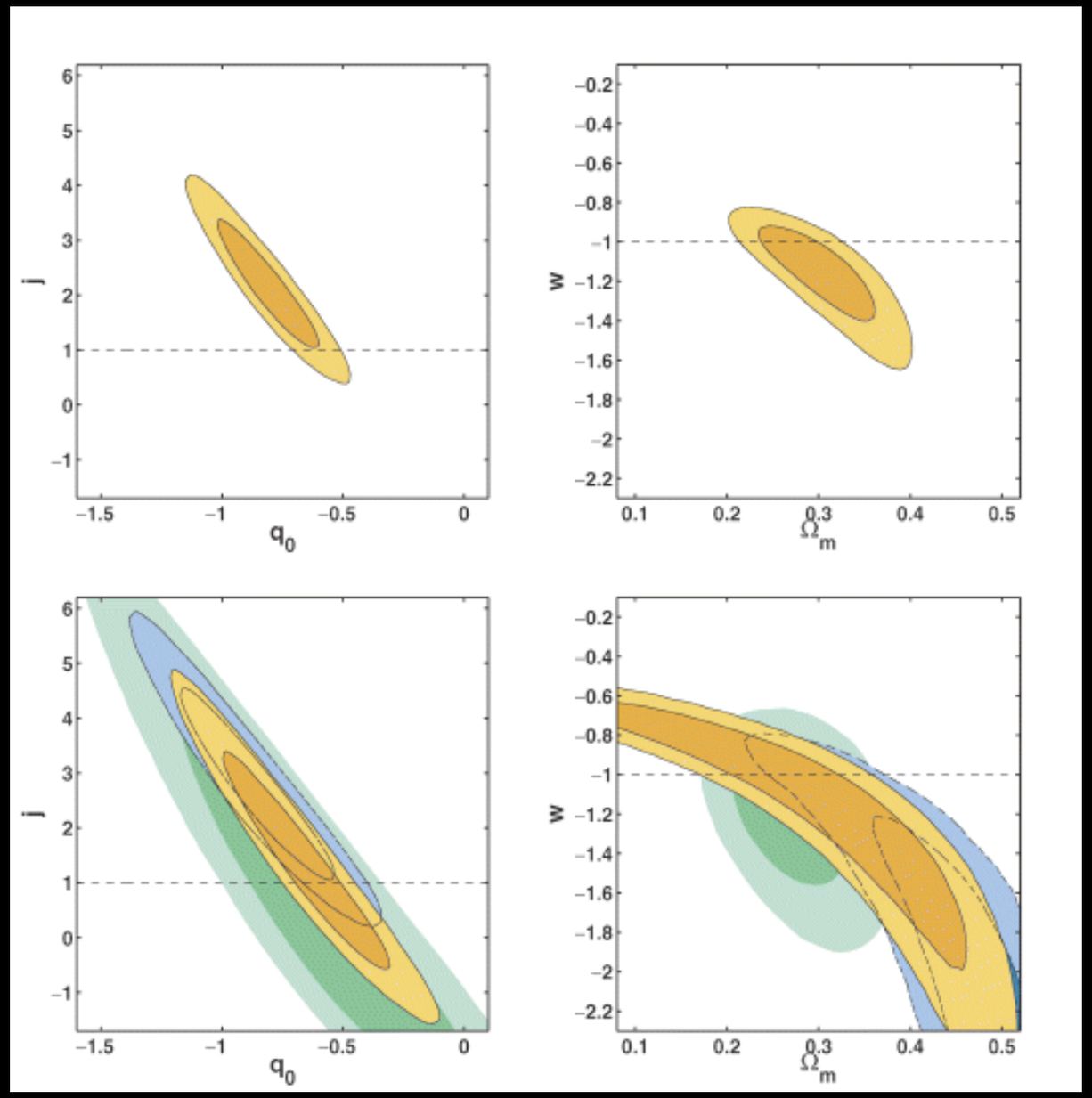

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