Supernova Cosmology: Successes, Challenges, & Prospects

Ryan Foley
University of Illinois

Supernova Cosmology: Past, Present, & Future

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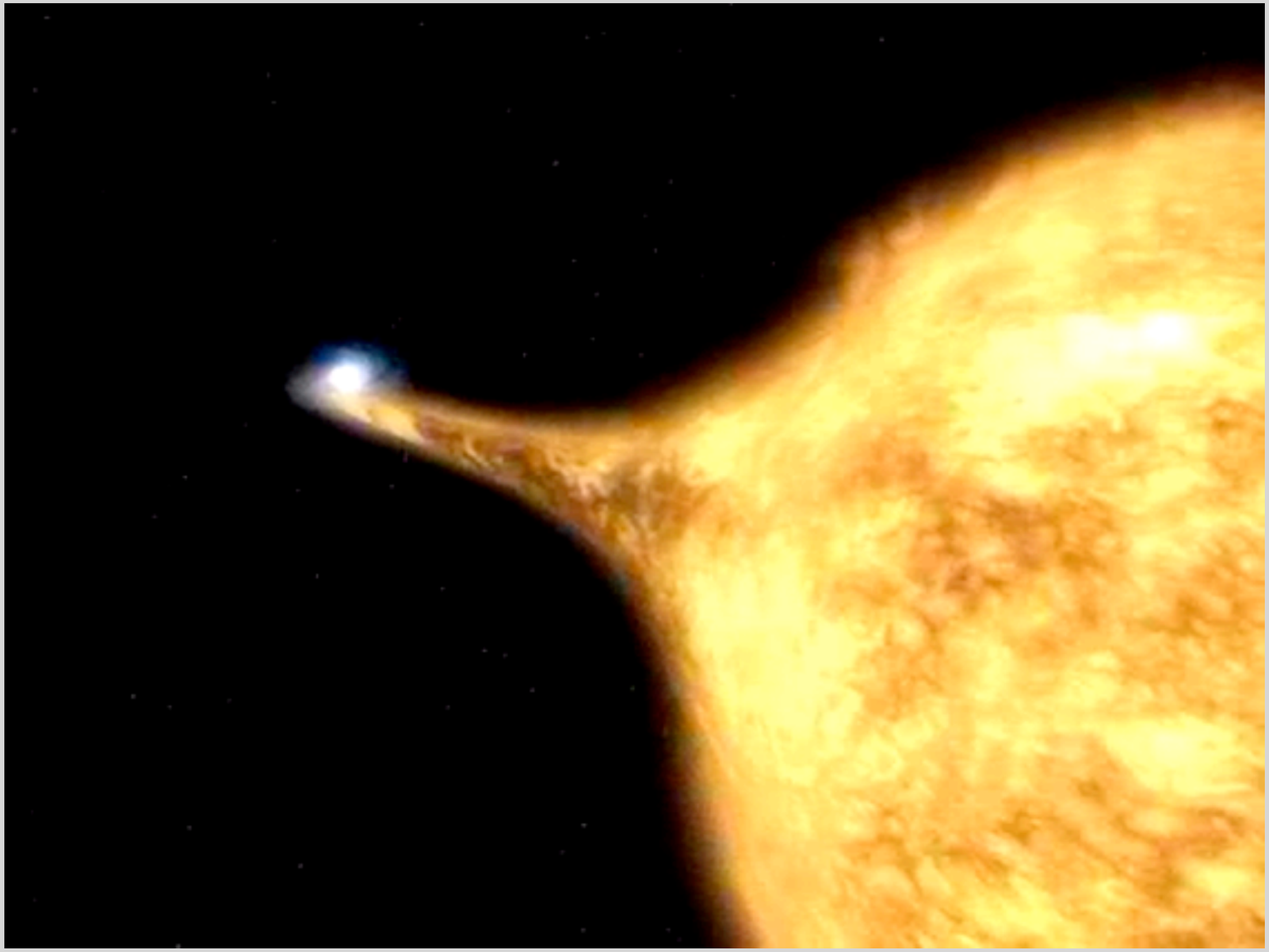
Part 1: Successes (The Past)

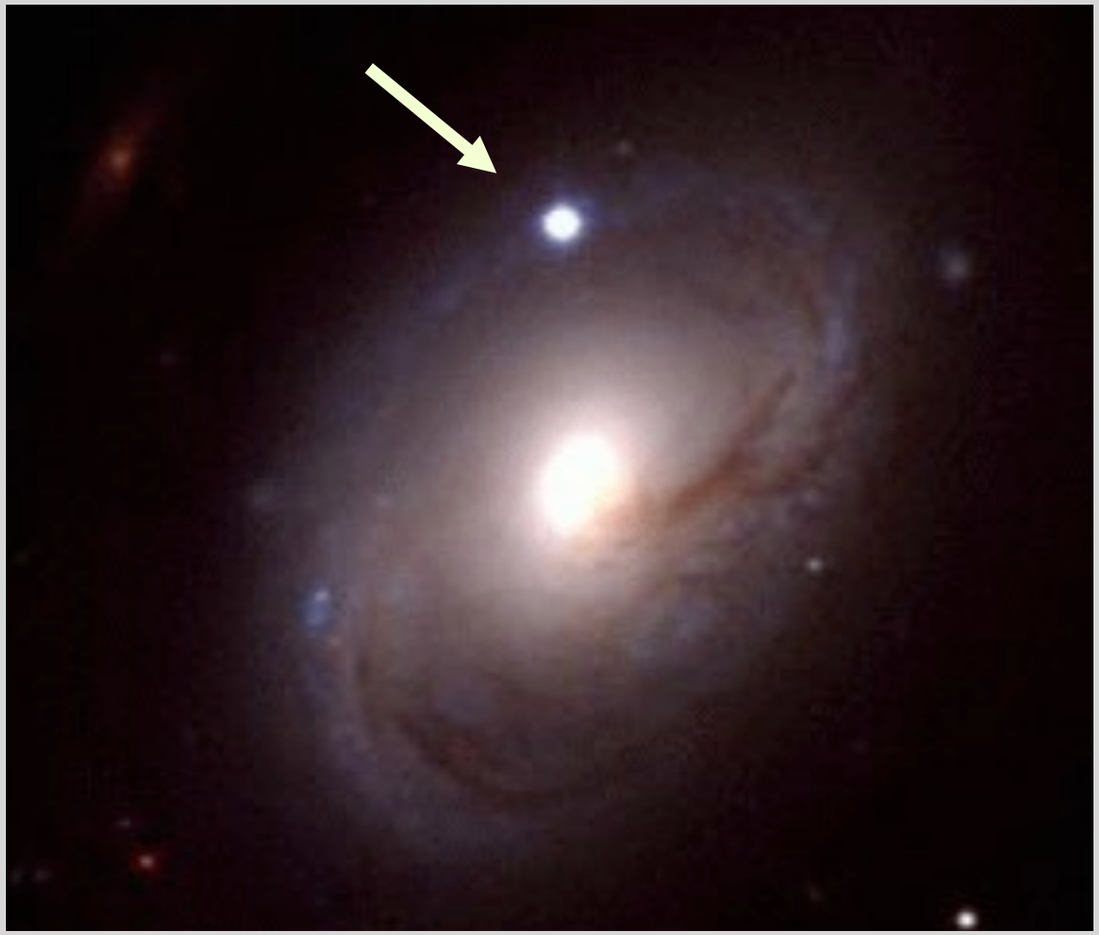
SNe Ia Are Exploding White Dwarfs

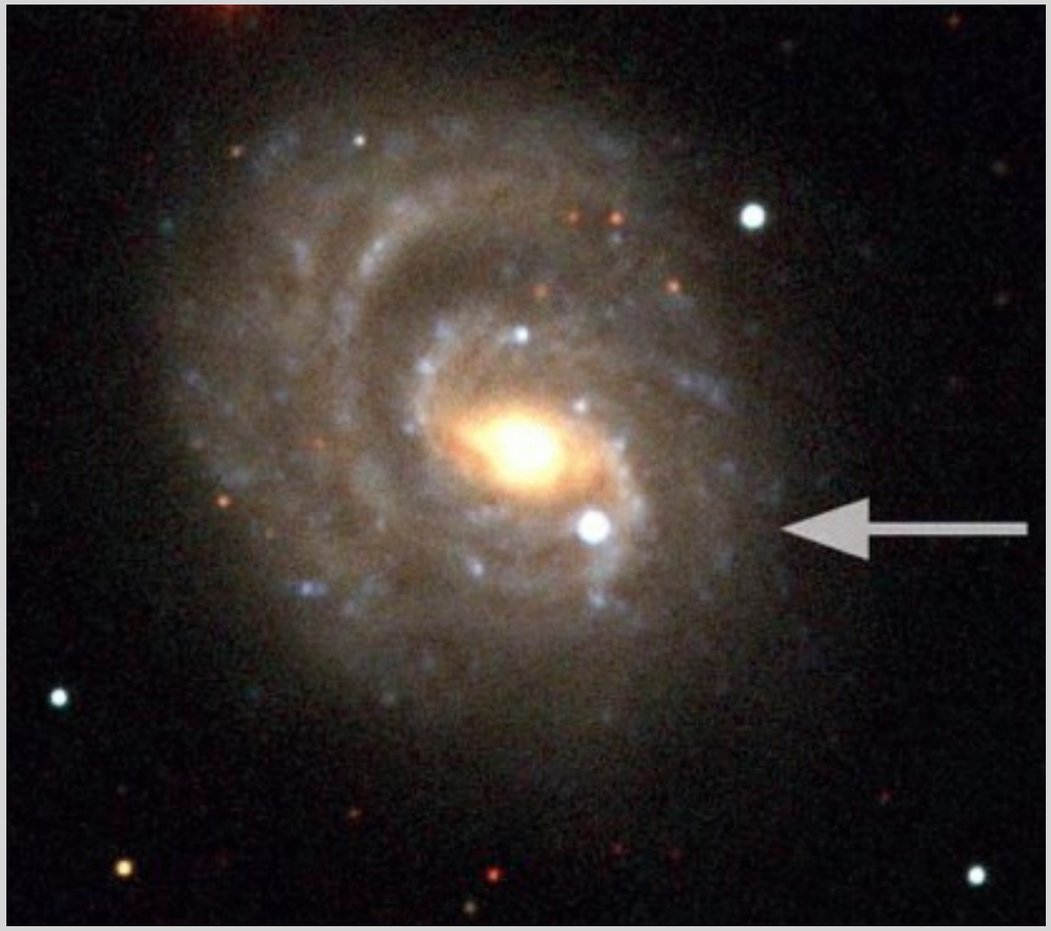


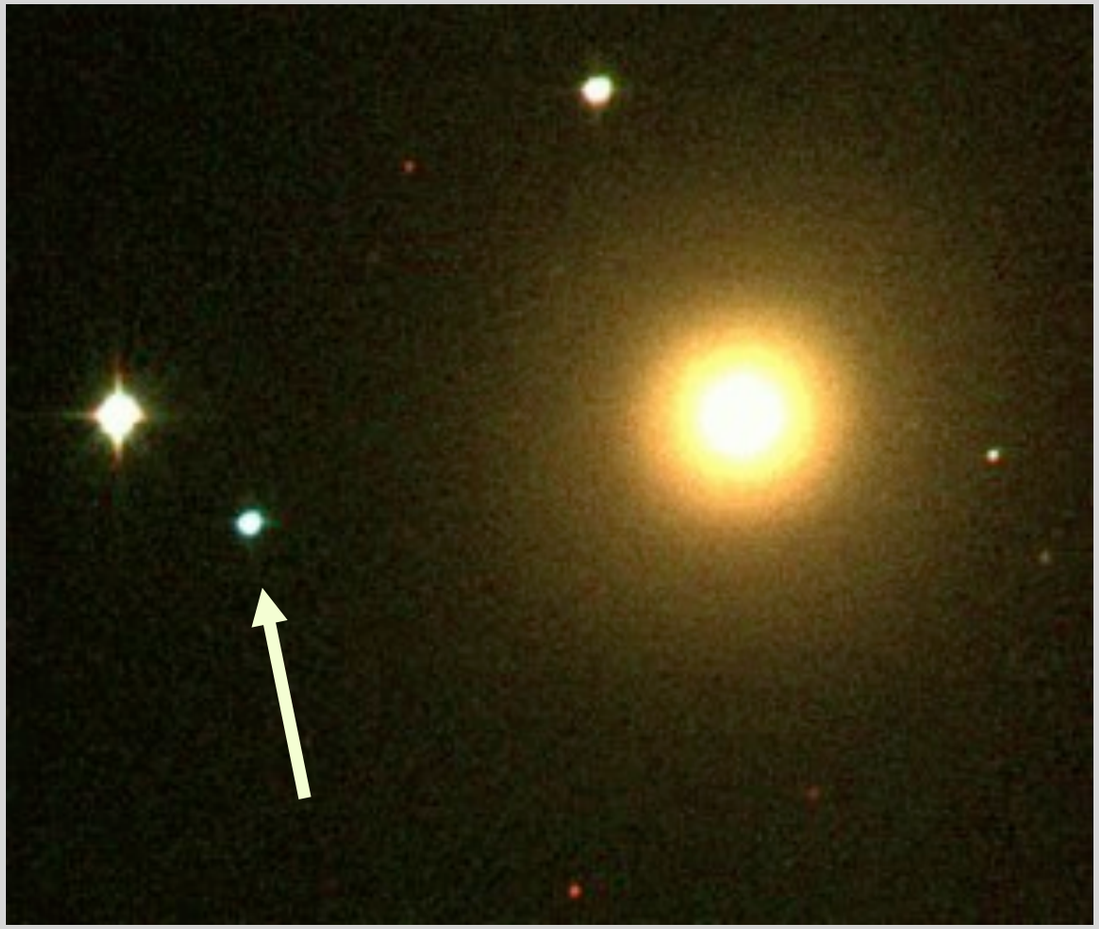
White Dwarf in Binary System

Accretes Matter Until ~1.4 times the Mass of the Sun

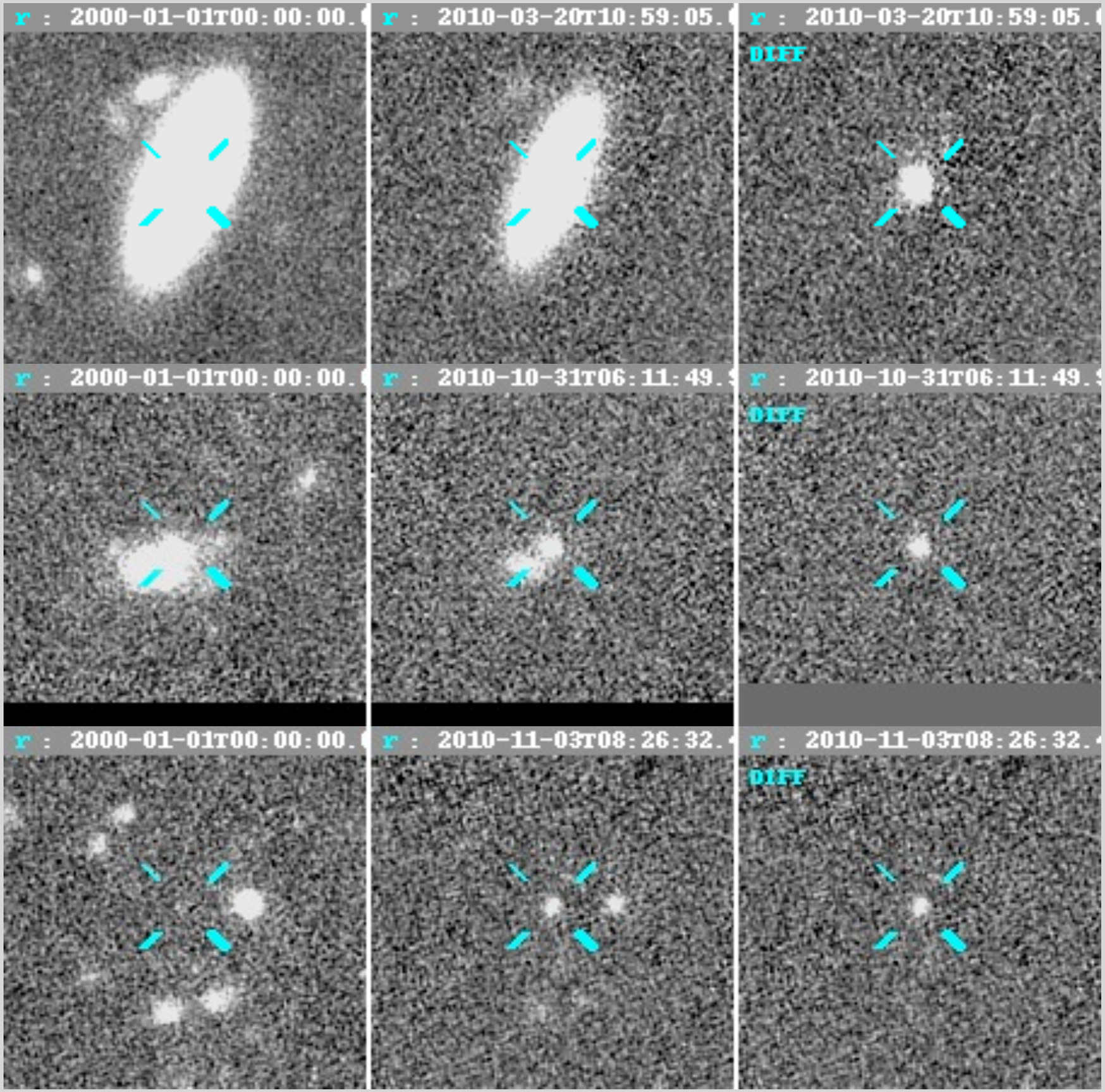
Explodes and is Very, Very Luminous







Before **After** **Difference**

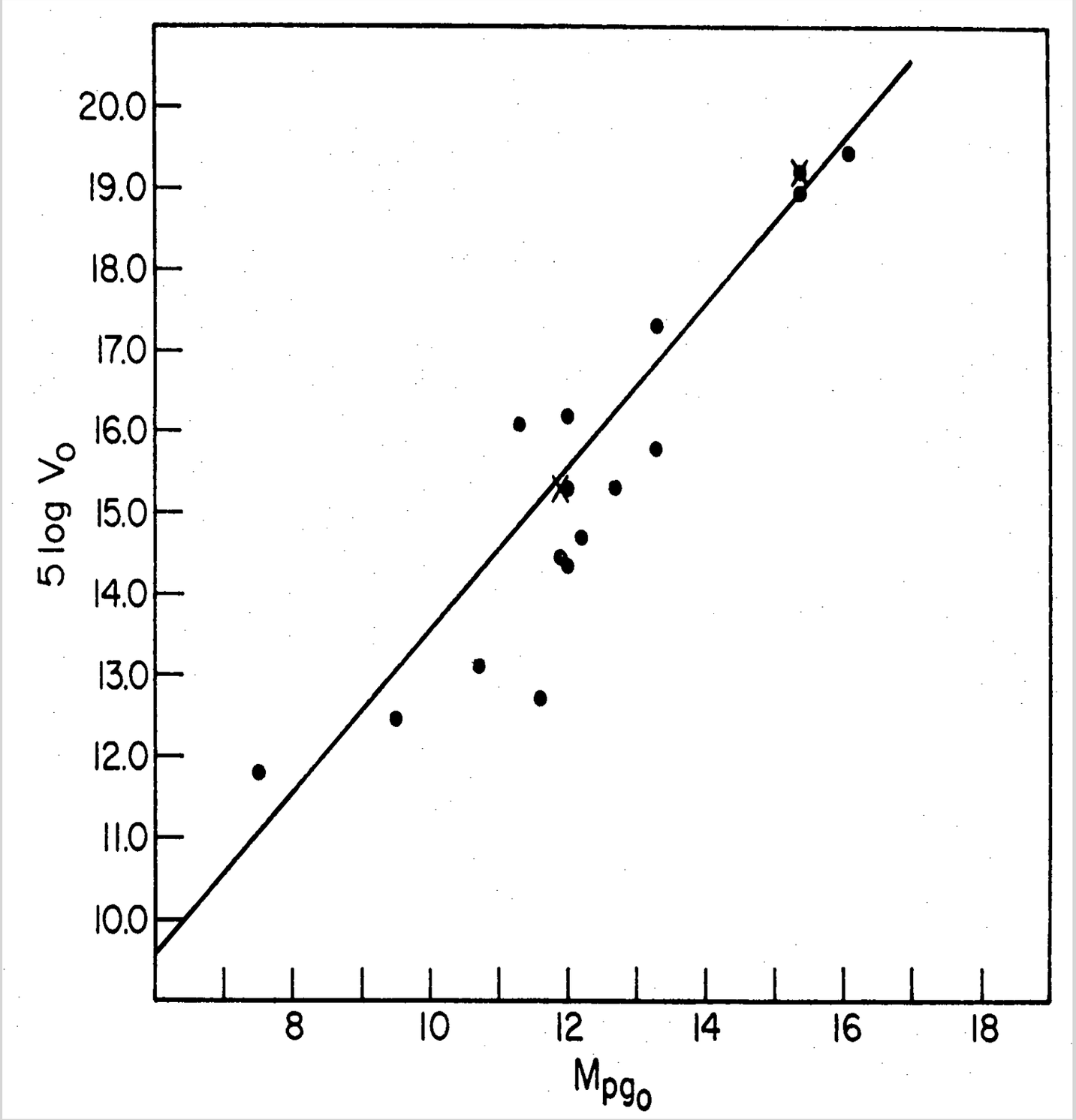


SNe Ia Are Luminous Standard Candles

Peak luminosity
σ = 0.6 mag

Peak absolute mag
V ≈ -19.5 mag!

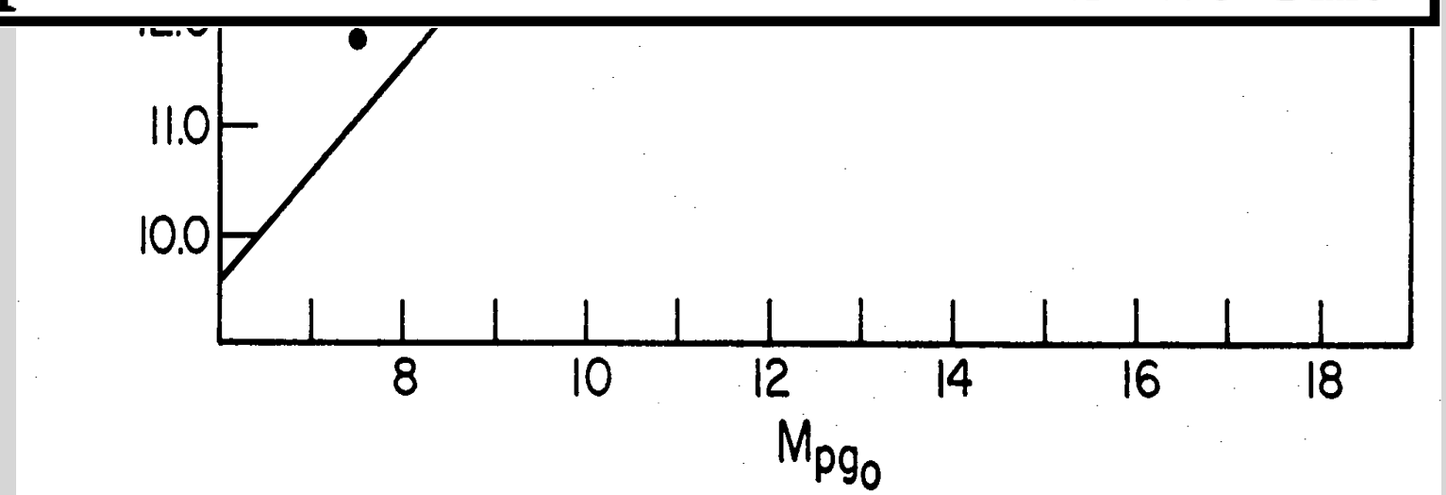
Detectable at high redshifts



Kowal 1968

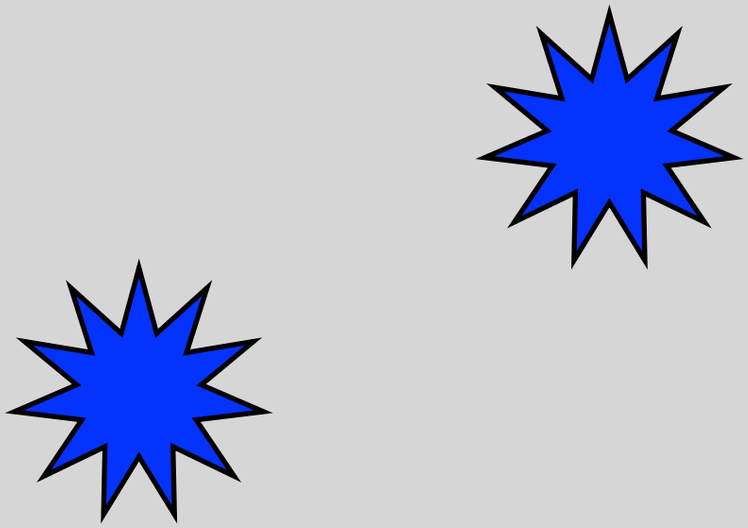
SNe Ia Are Luminous Standard Candles

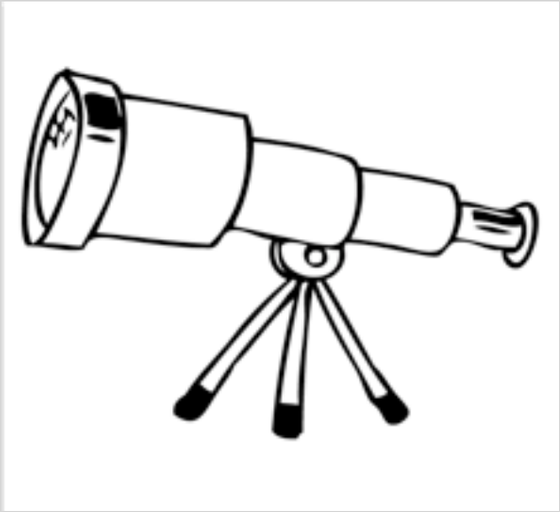
As shown earlier, the observed dispersion in the maximum magnitudes of supernovae of type I is about $0^m.6$, and the intrinsic dispersion should be even smaller. It is obvious, therefore, that these supernovae could be exceedingly useful indicators of distance. It should be possible to obtain average supernova magnitudes in clusters of galaxies to an accuracy of 0.1 or 0.2 mag, which corresponds to accuracies of 5% to 10% in the distances. The main problem now is one of calibration.



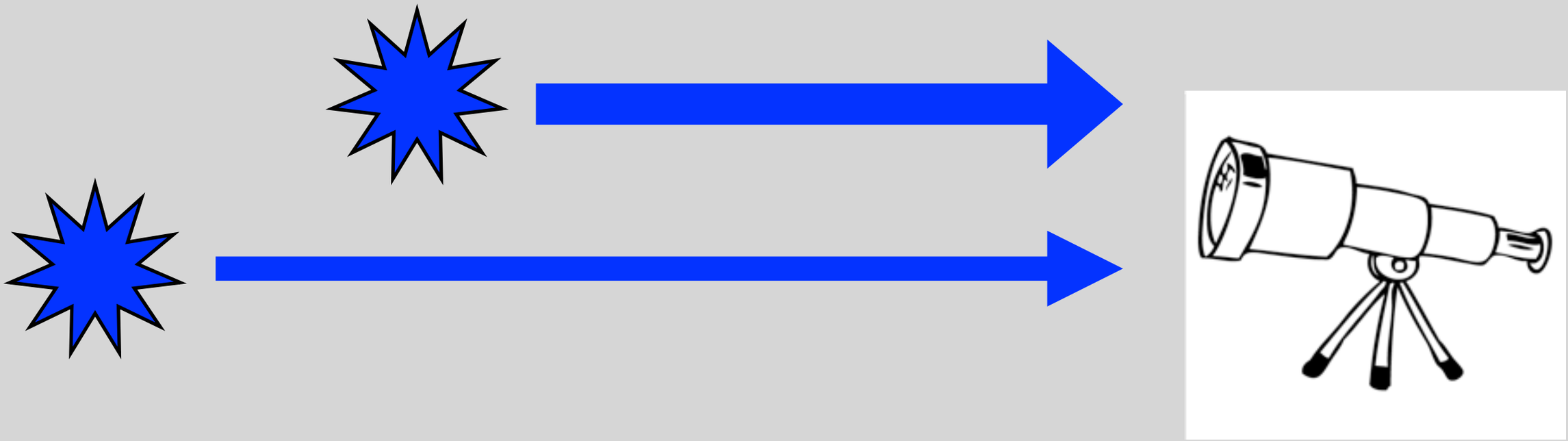
Kowal 1968

Standard Candles And Distances

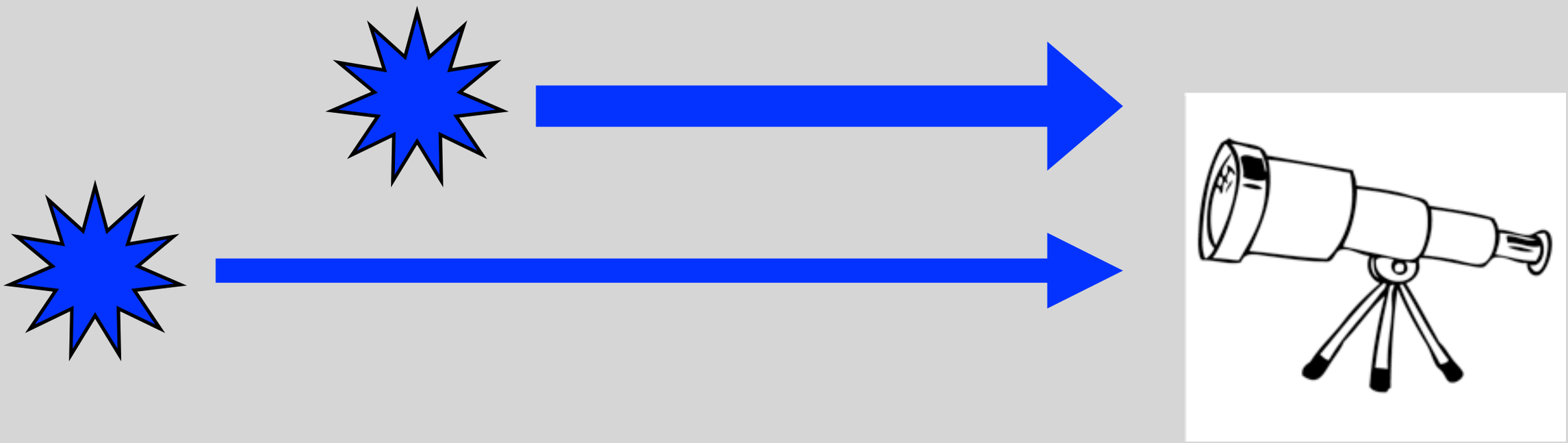




Standard Candles And Distances

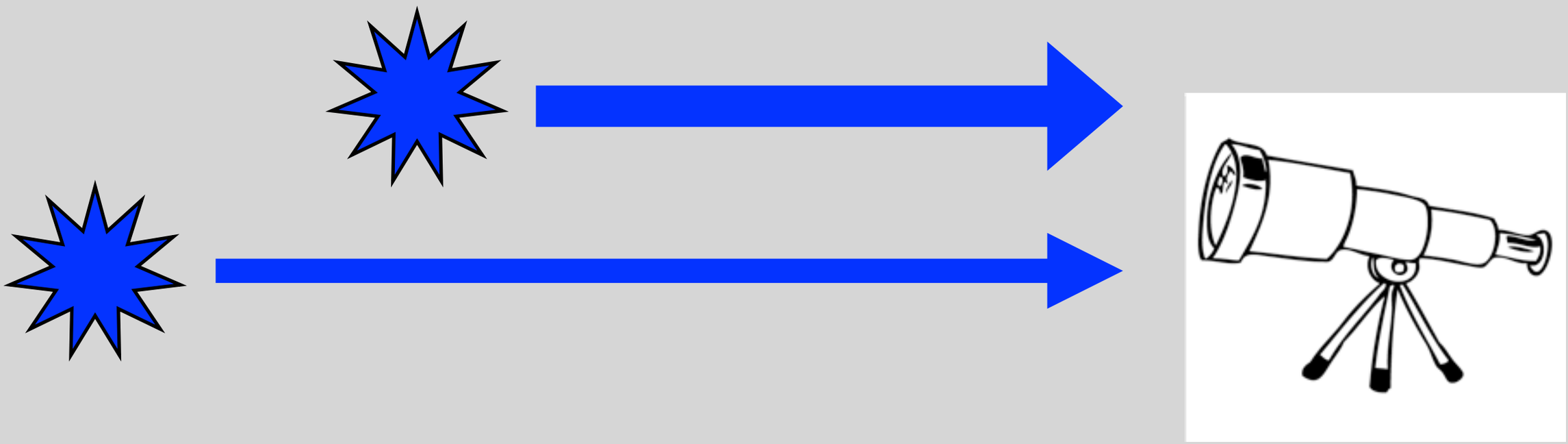


Standard Candles And Distances



Obs: $D = (L/4\pi F)^{1/2}$

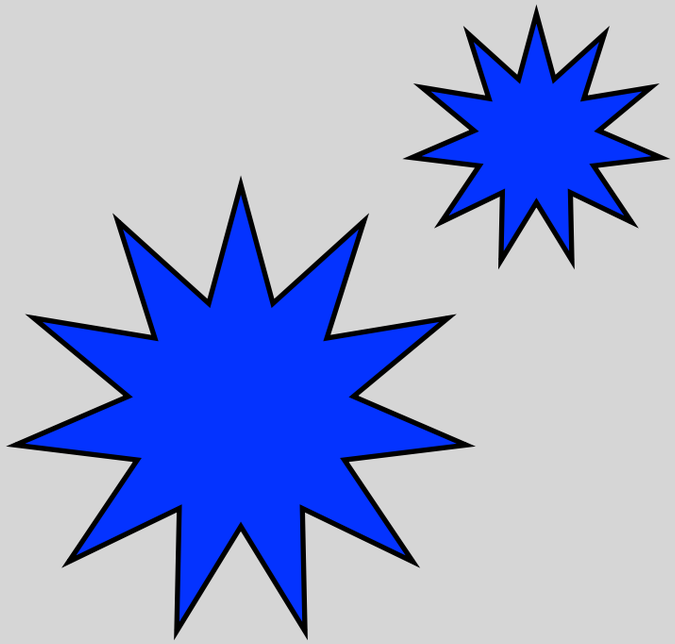
Standard Candles And Distances

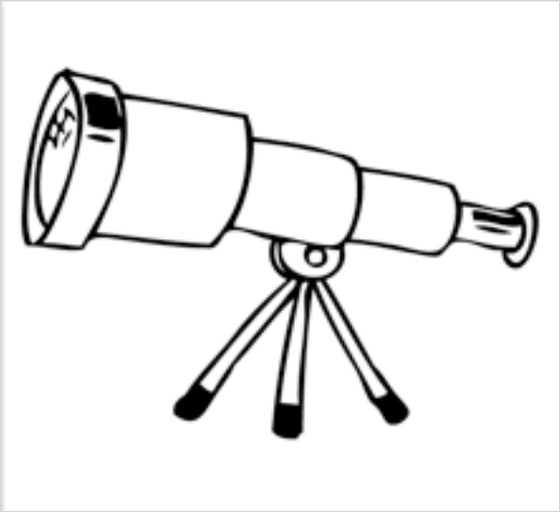


Obs: $D = (L/4\pi F)^{1/2}$

Theory: $D = f(z, \Omega, w(z), \text{etc})$

SNe Ia are NOT Standard Candles!





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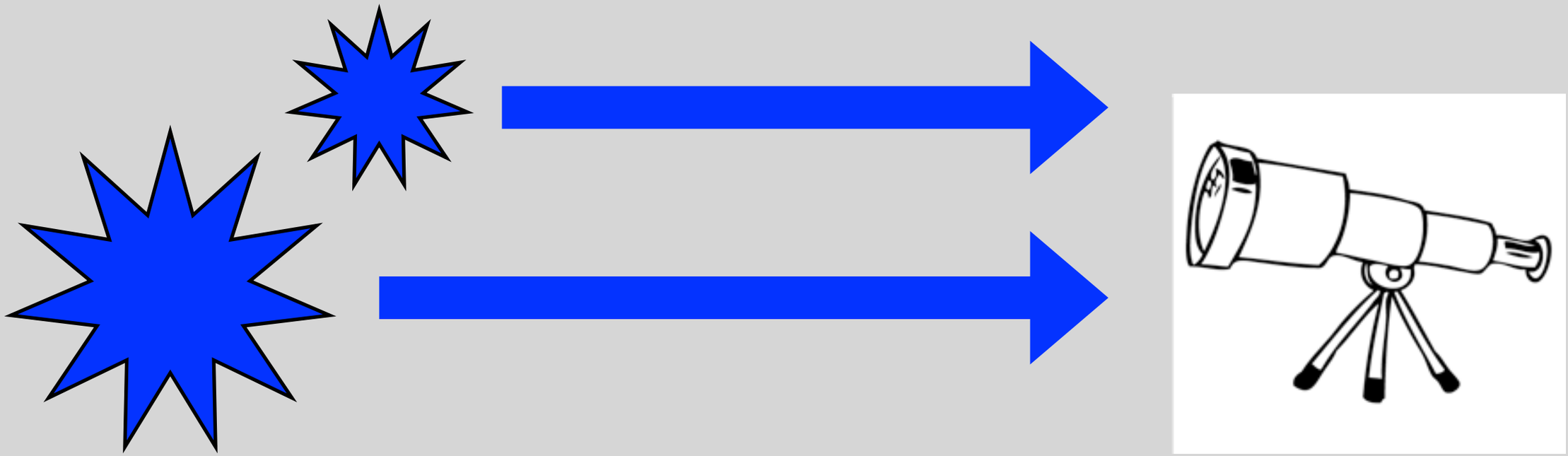
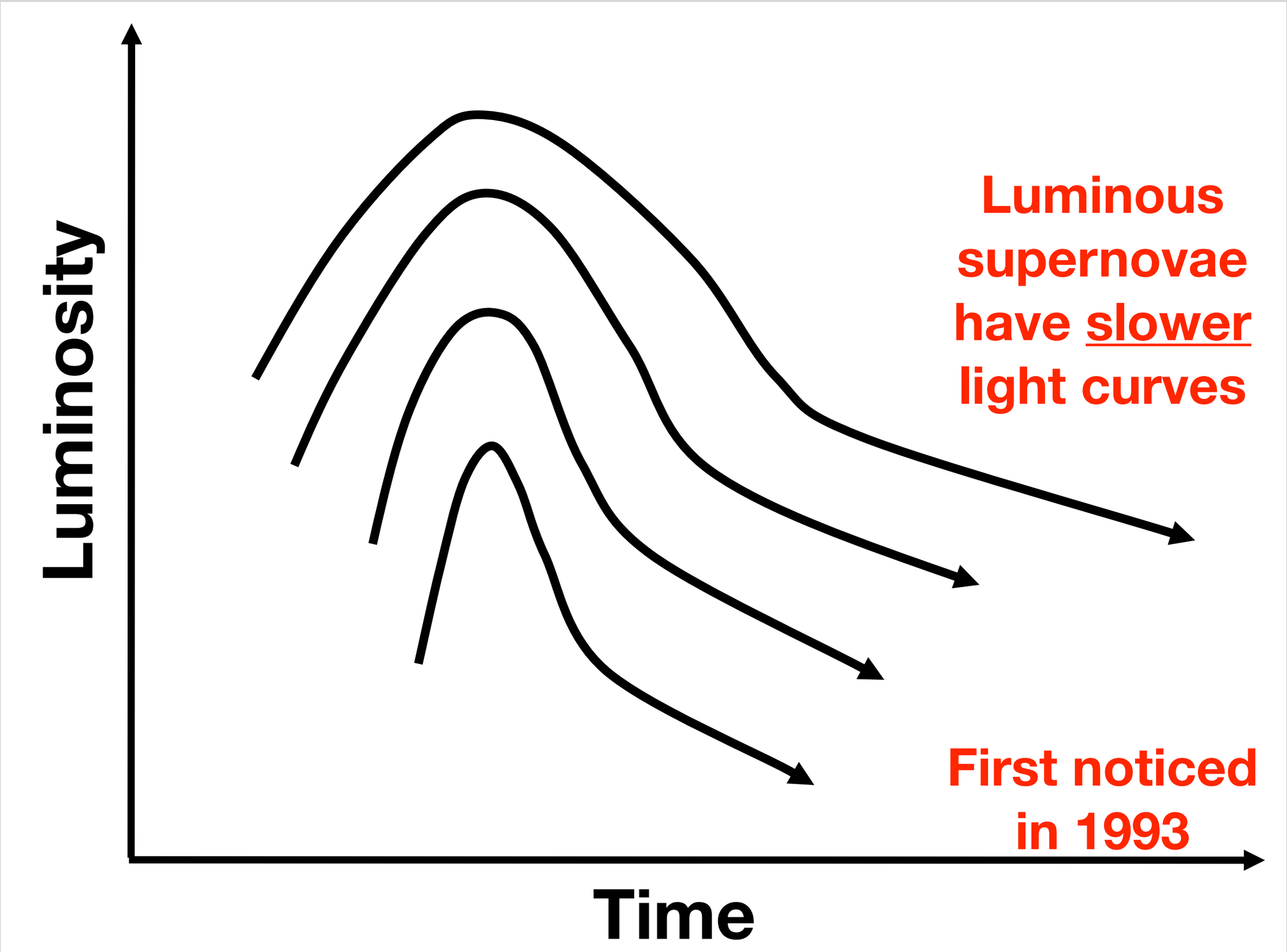


Calibrating the Nearly Standard Candle



Dust Makes Things Fainter/Redder

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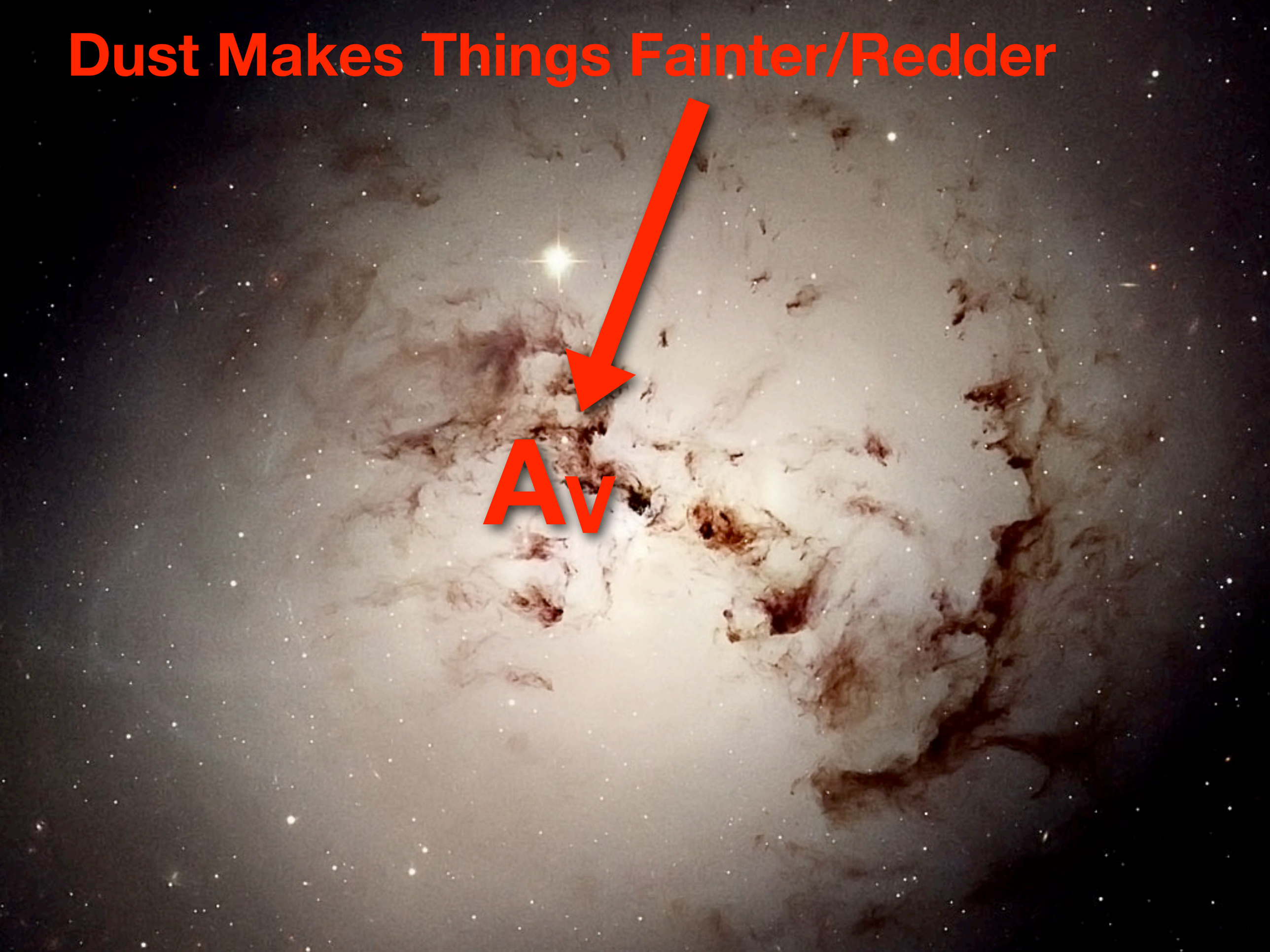
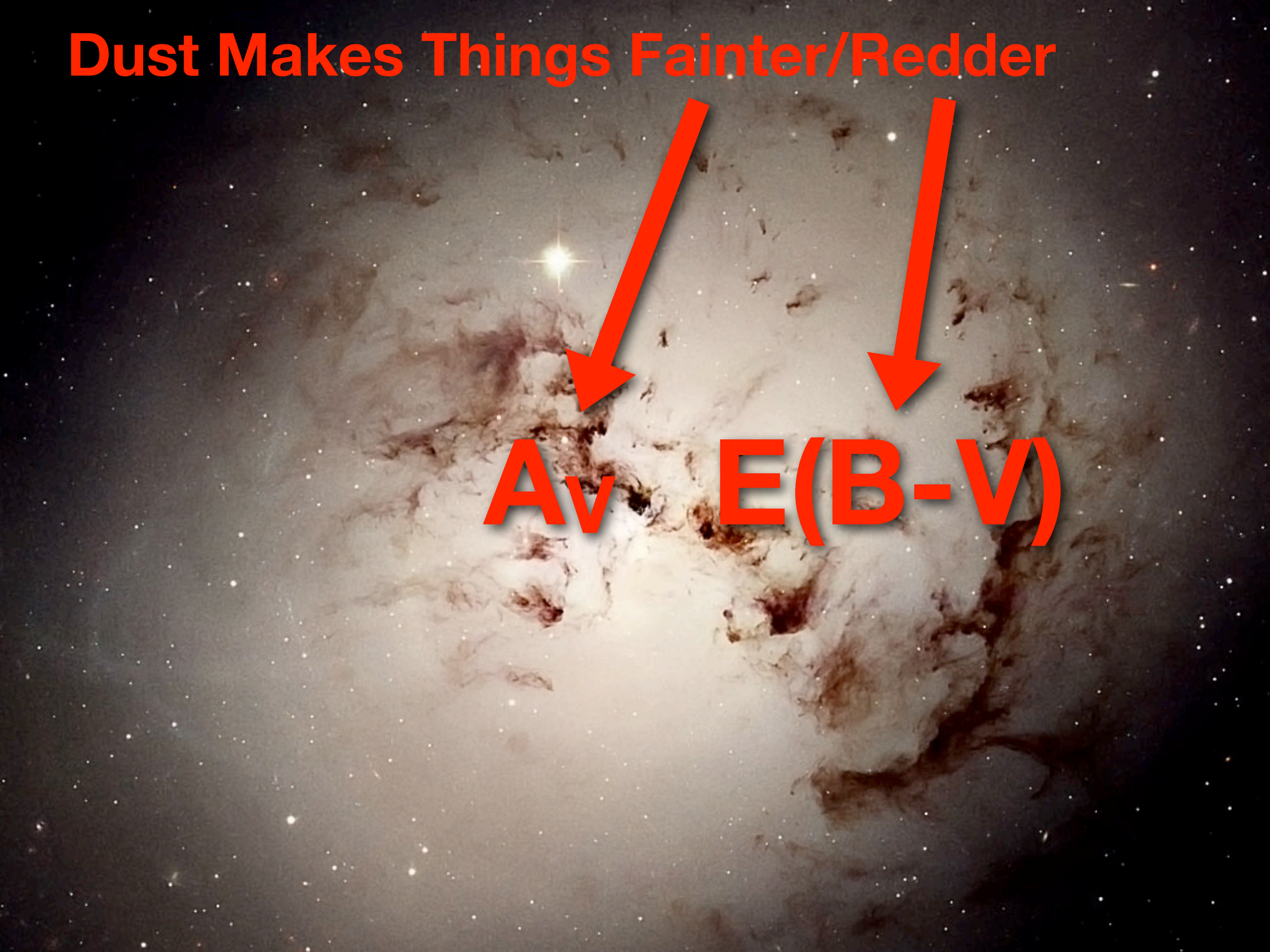
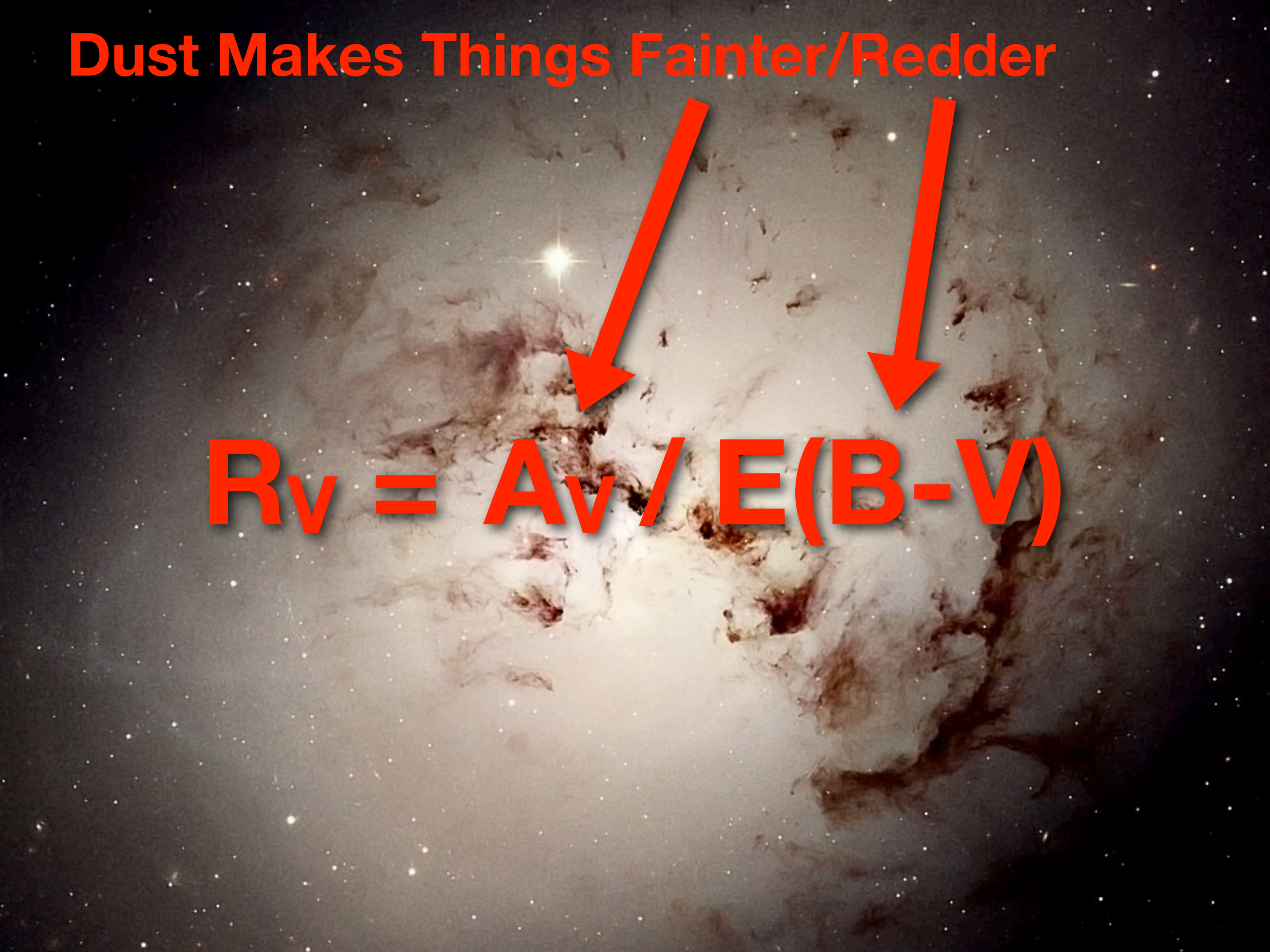
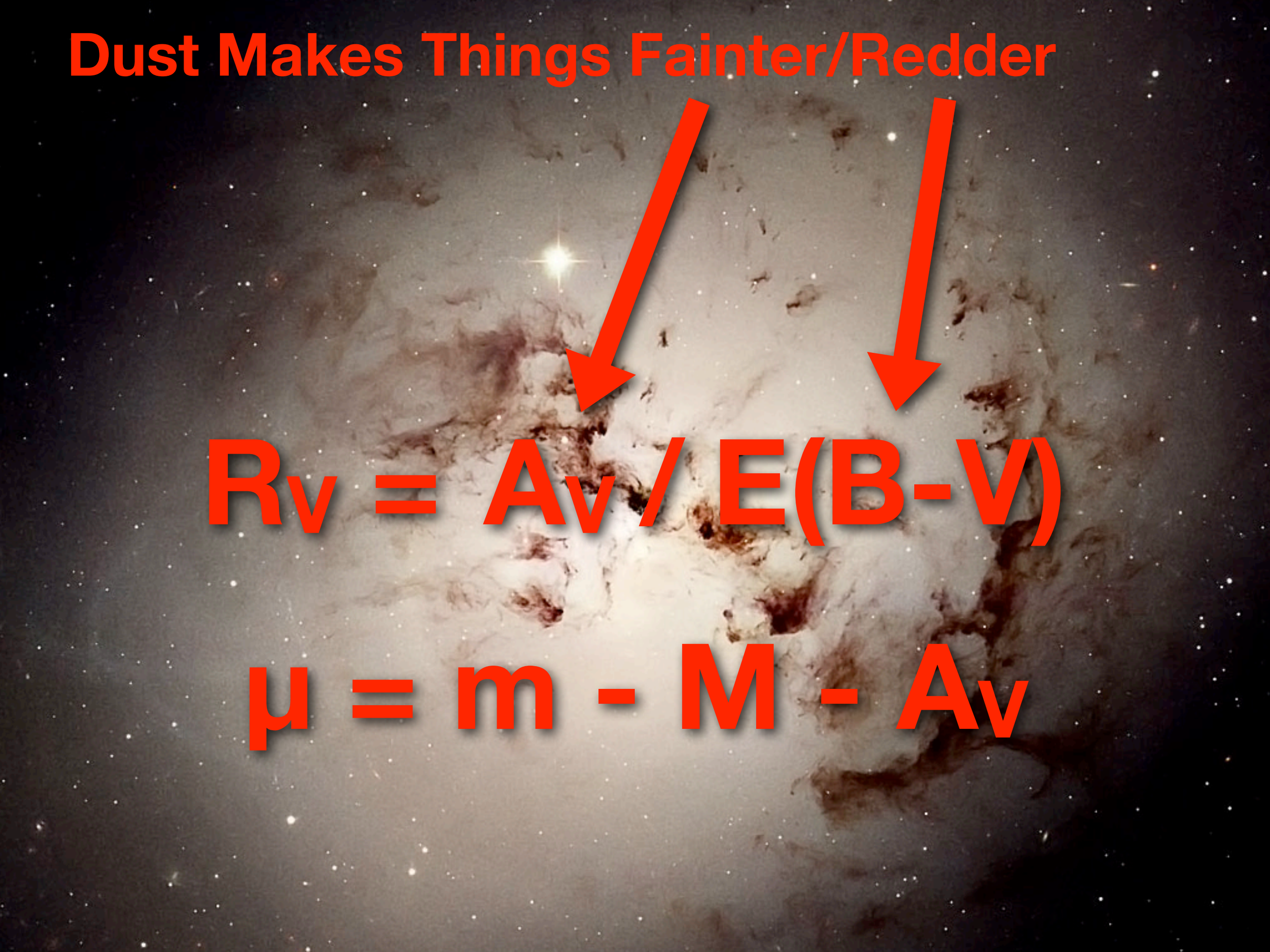



Dust Makes Things Fainter/Redder
A_V
E(B-V)


Dust Makes Things Fainter/Redder
Rv = Av / E(B-V)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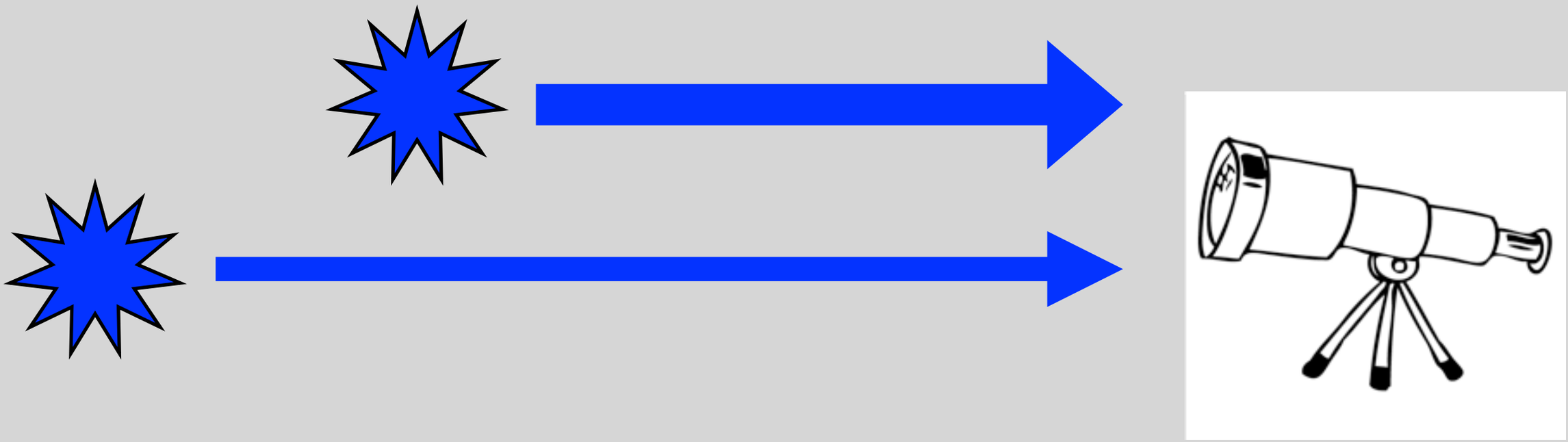
$R_V = A_V / E(B-V)$
$\mu = m - M - A_V$

Dust Makes Things Fainter/Redder



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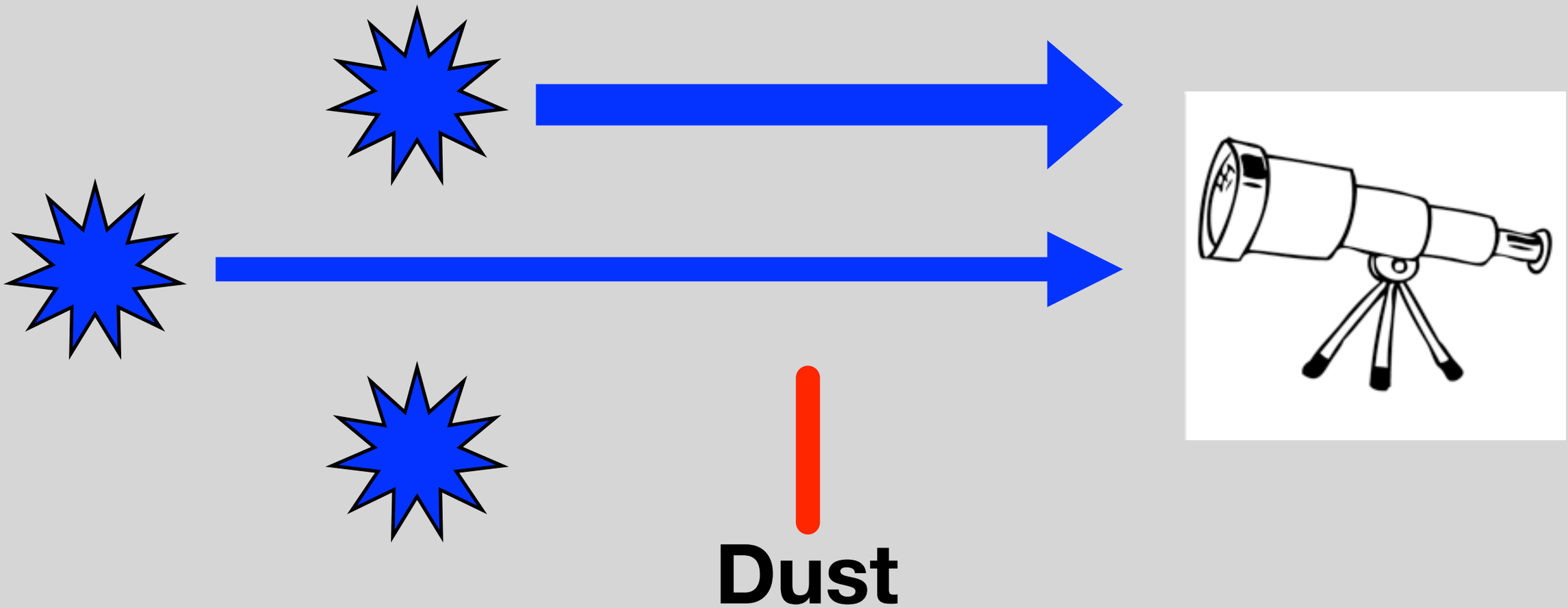

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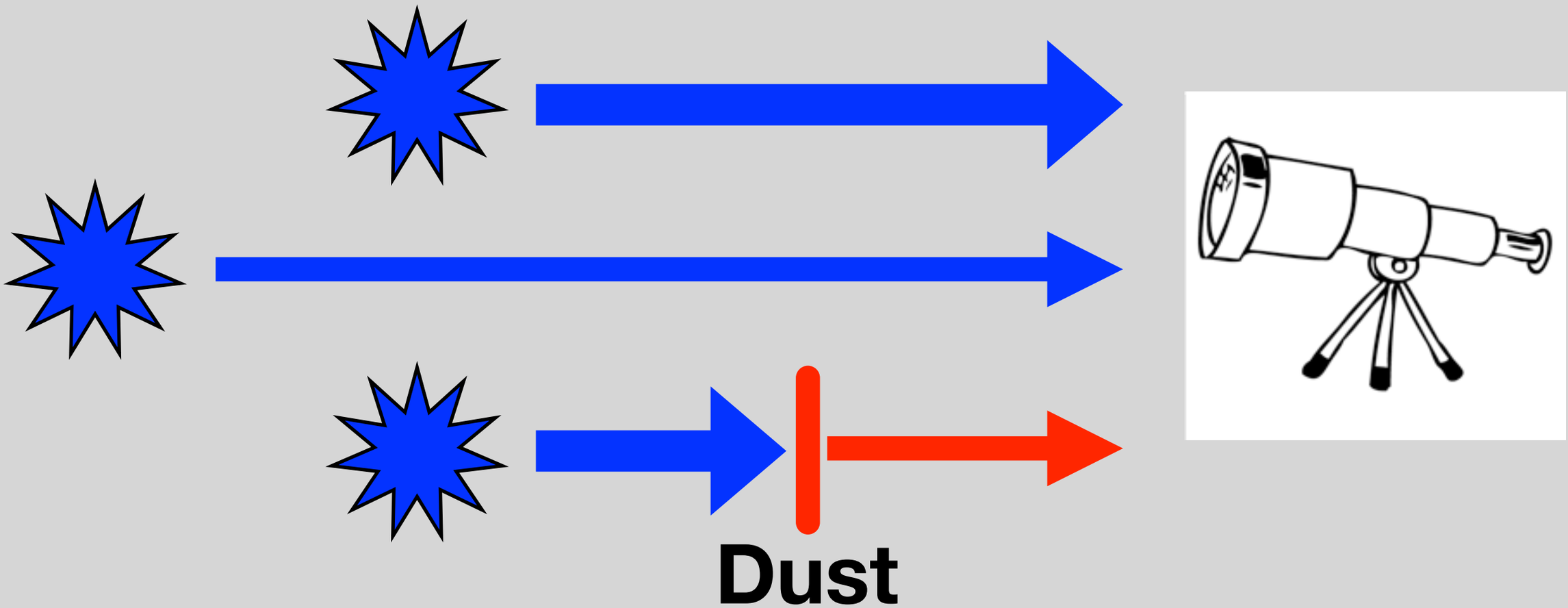


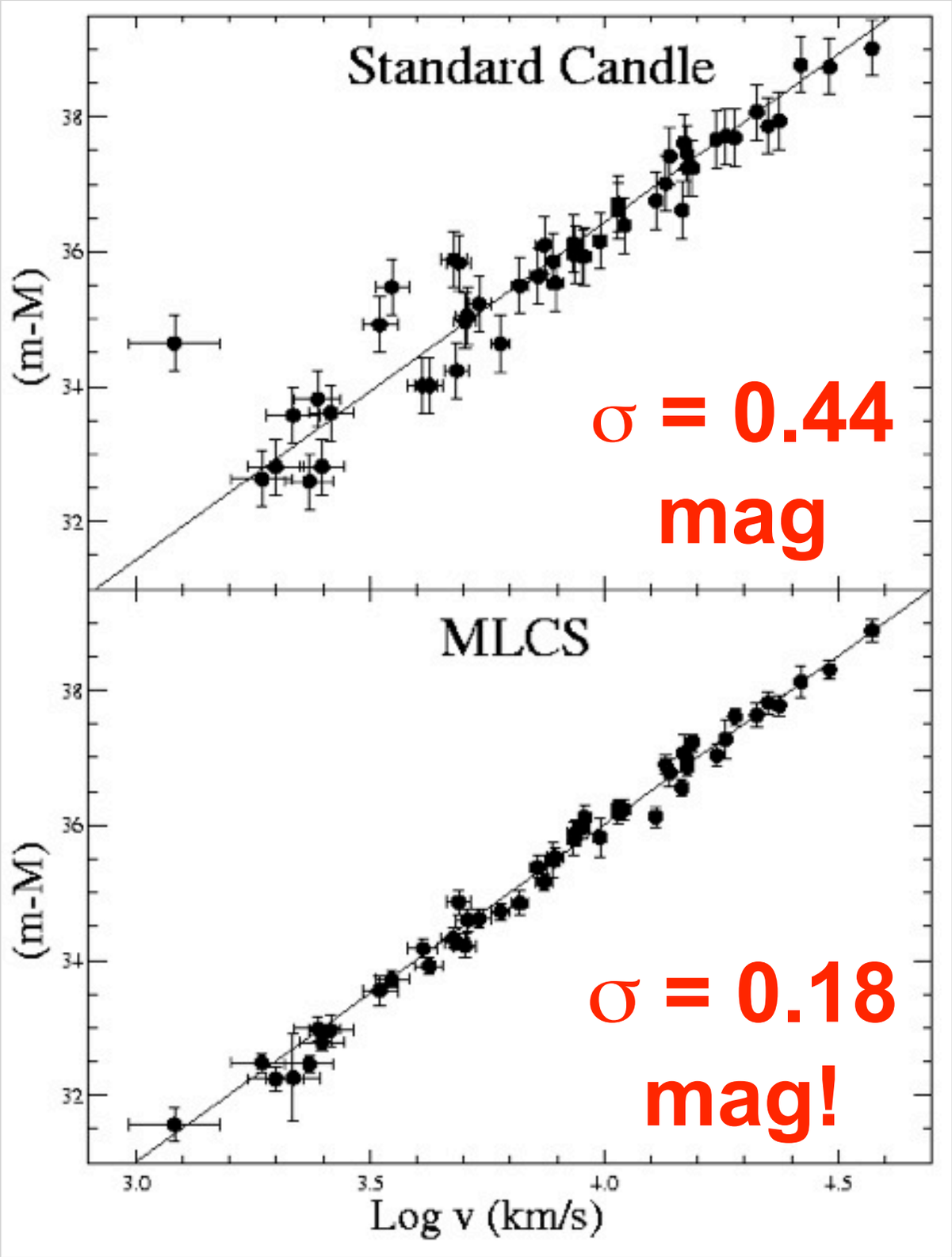
Dust Makes Things Fainter/Redder

$$R_V = A_V / E(B-V)$$

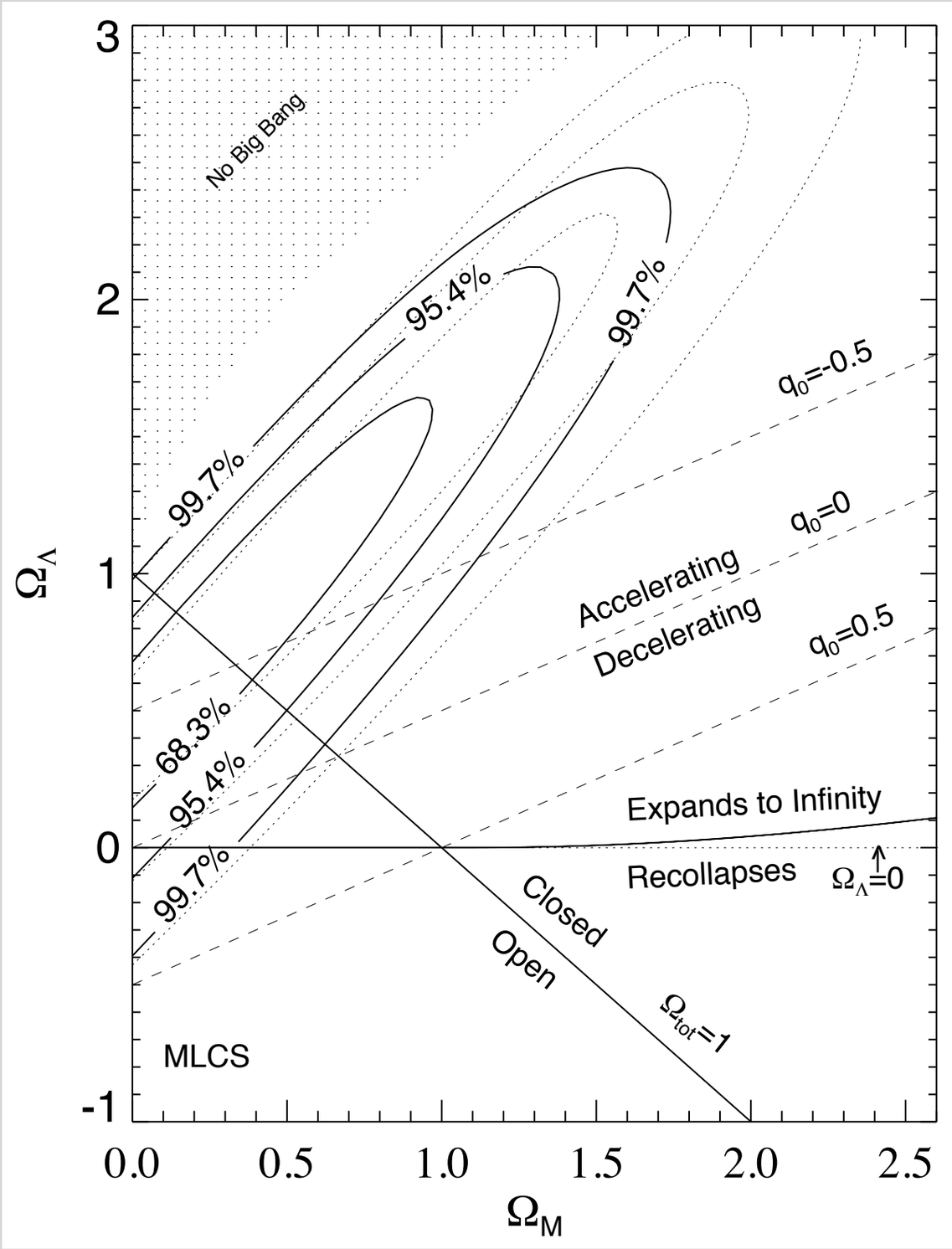
$$\mu = m - M - A_V$$

$$= m - M - E(B-V)\, R_V$$

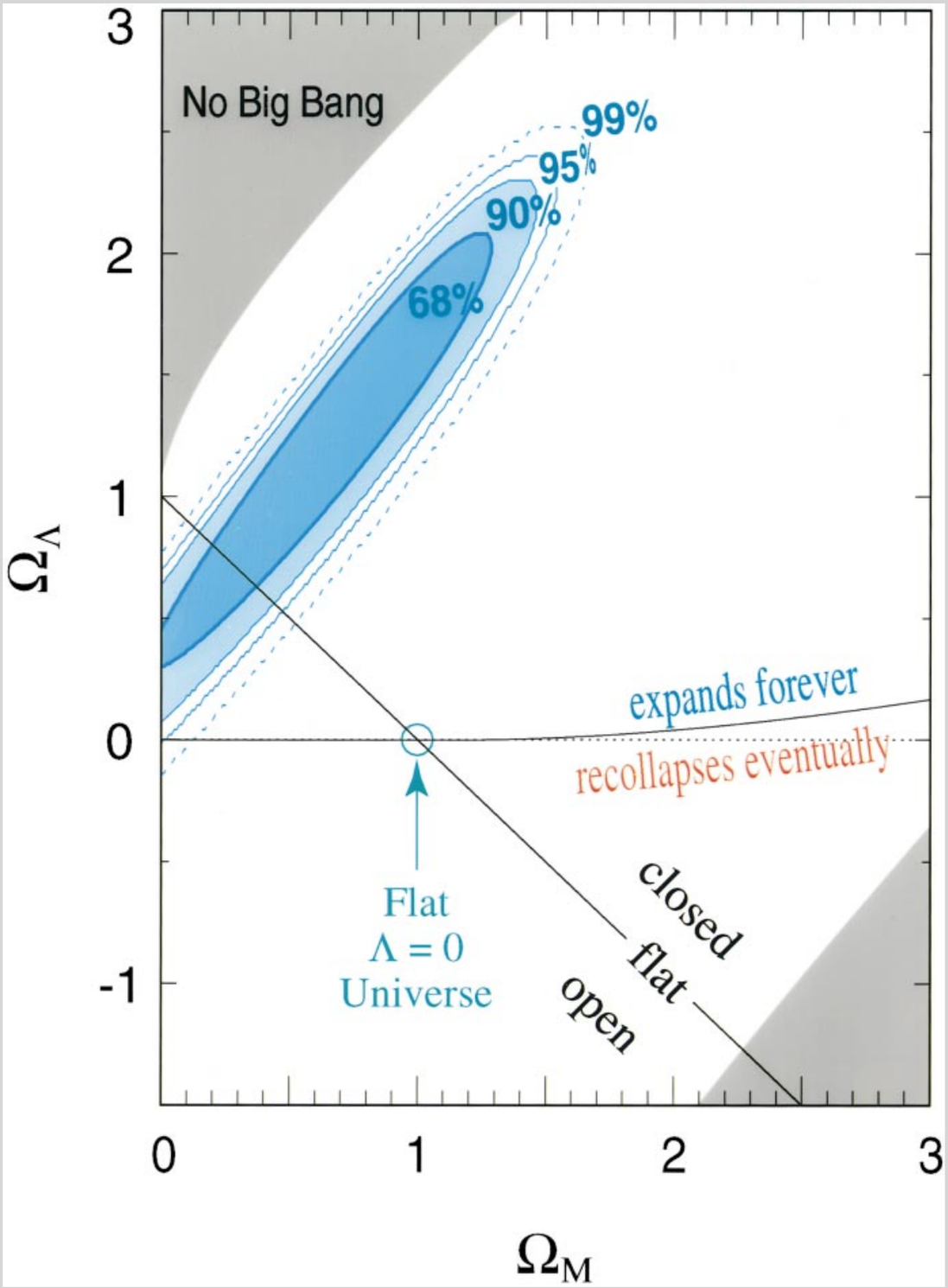
Calibrating SNe Ia



Accelerating Universe!



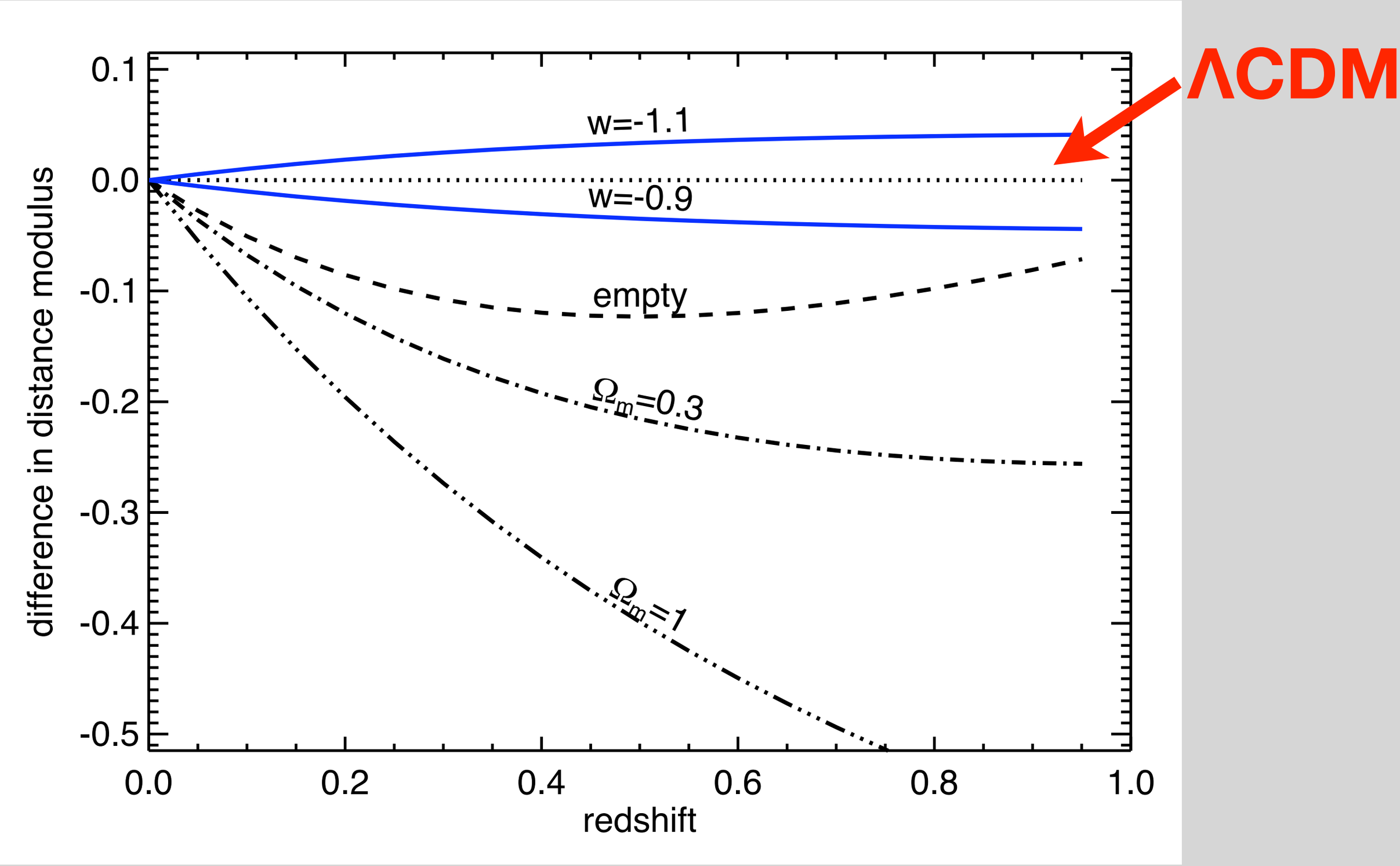
Riess et al. 1998



Perlmutter et al. 1999



Measuring w is Hard



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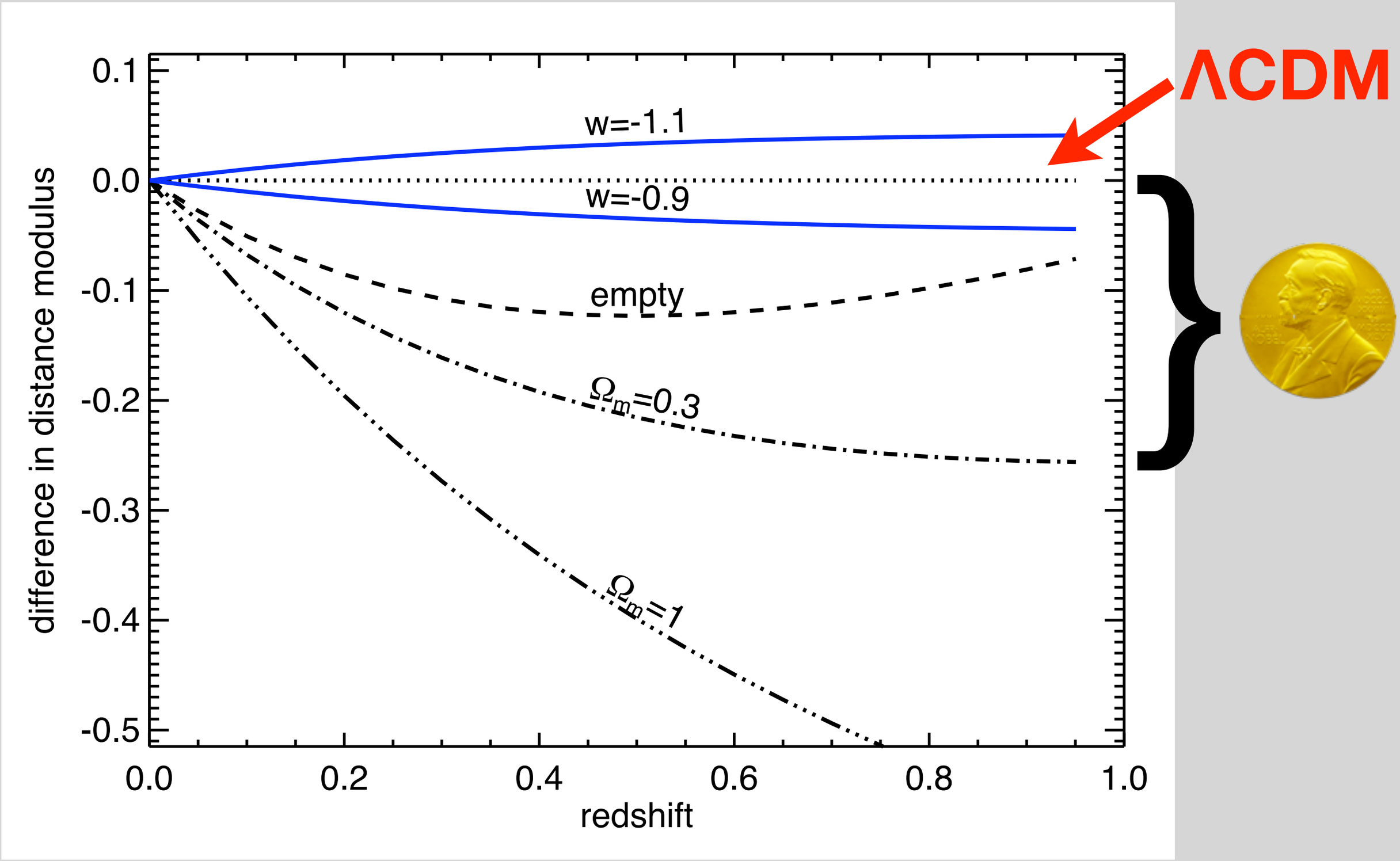
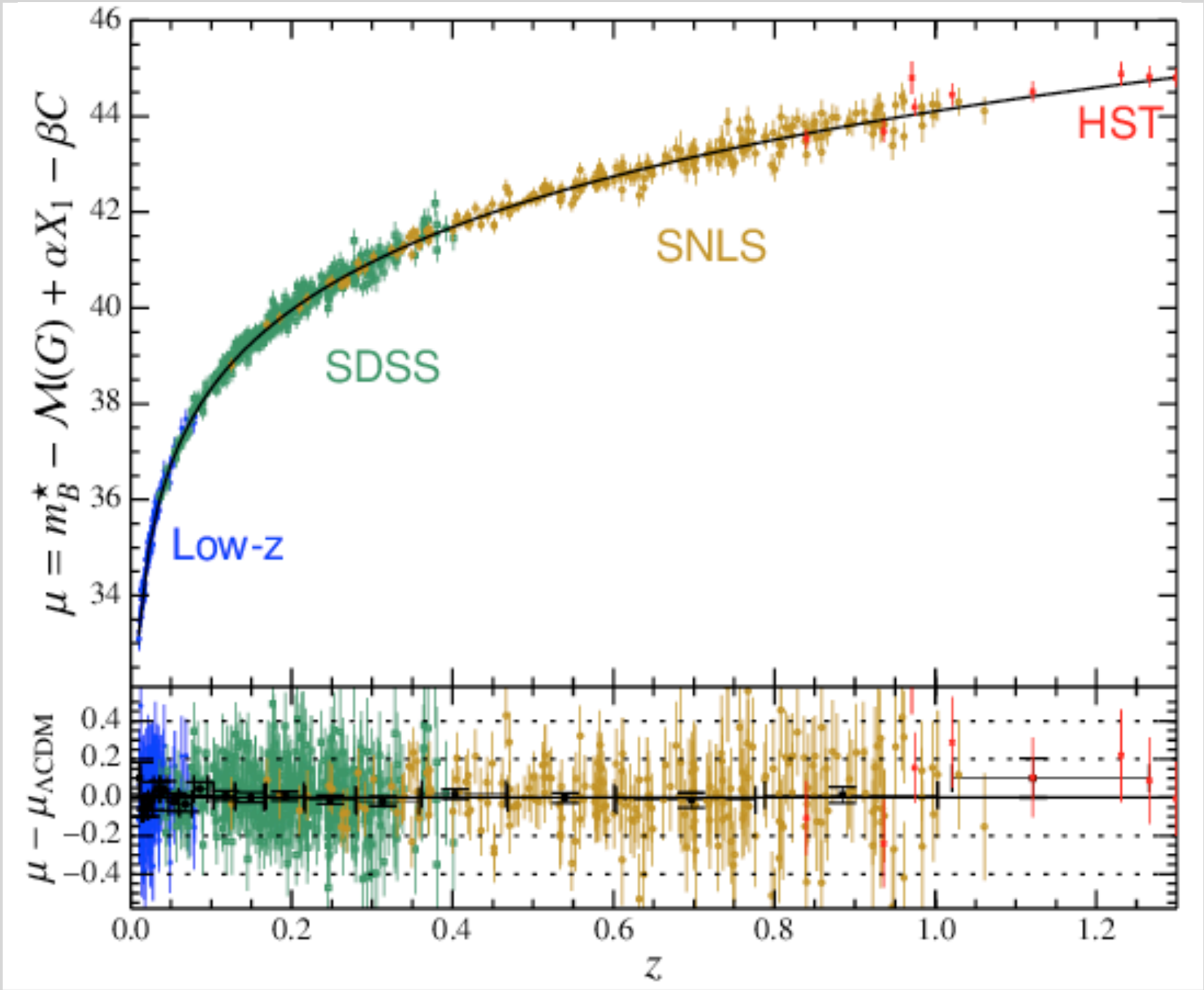


Recent Hubble Diagram (740 SNe Ia)



Betoule et al. 2014

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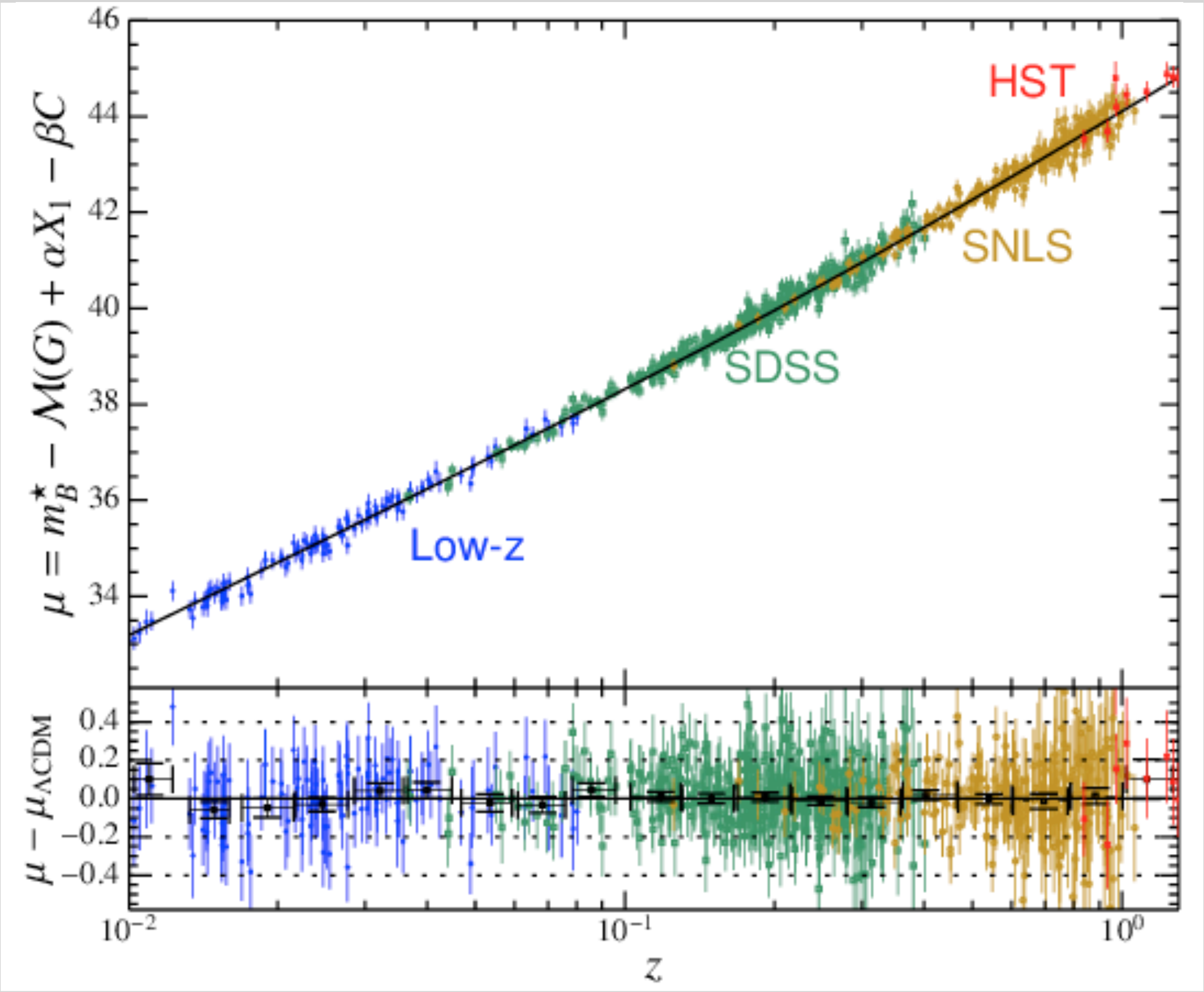
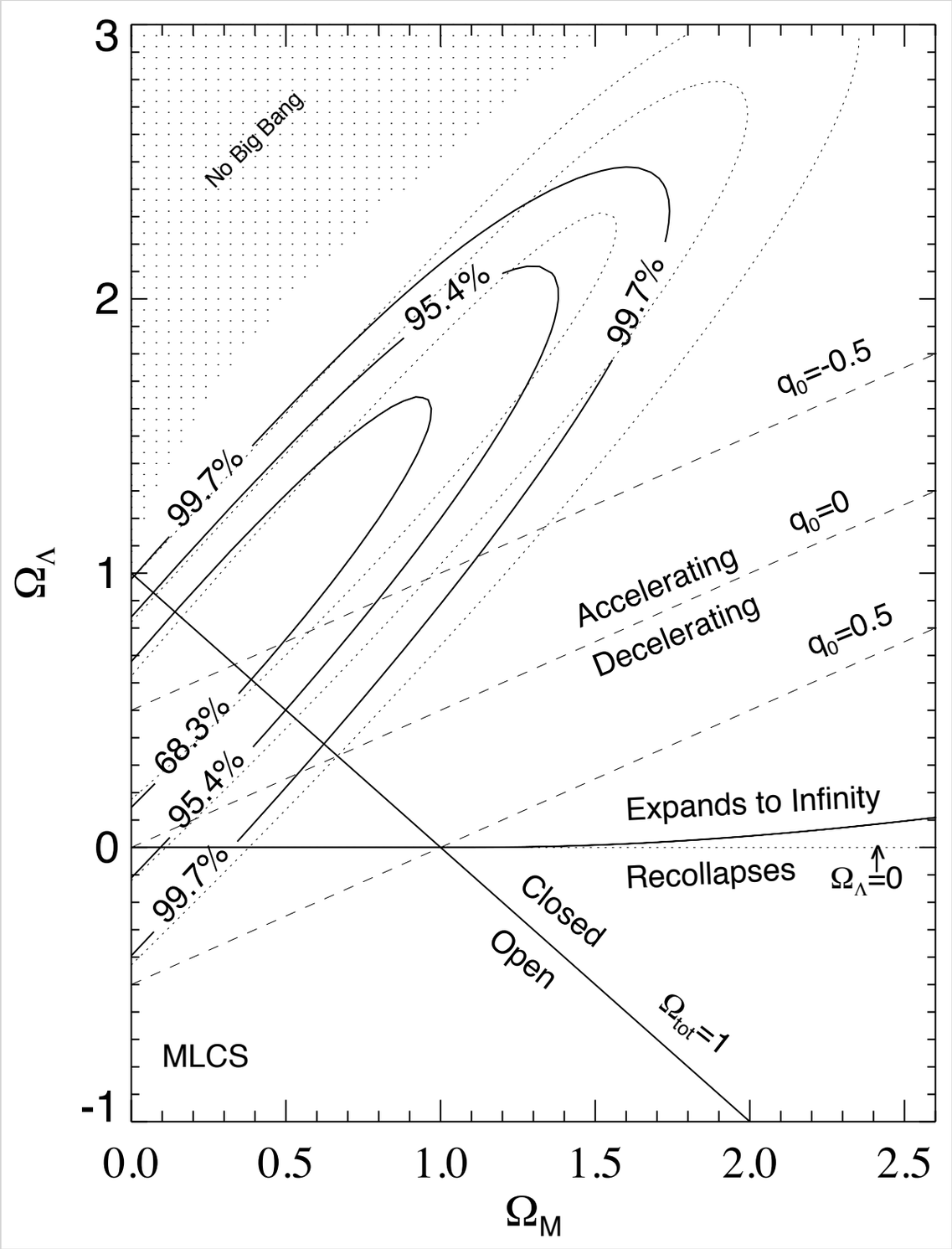
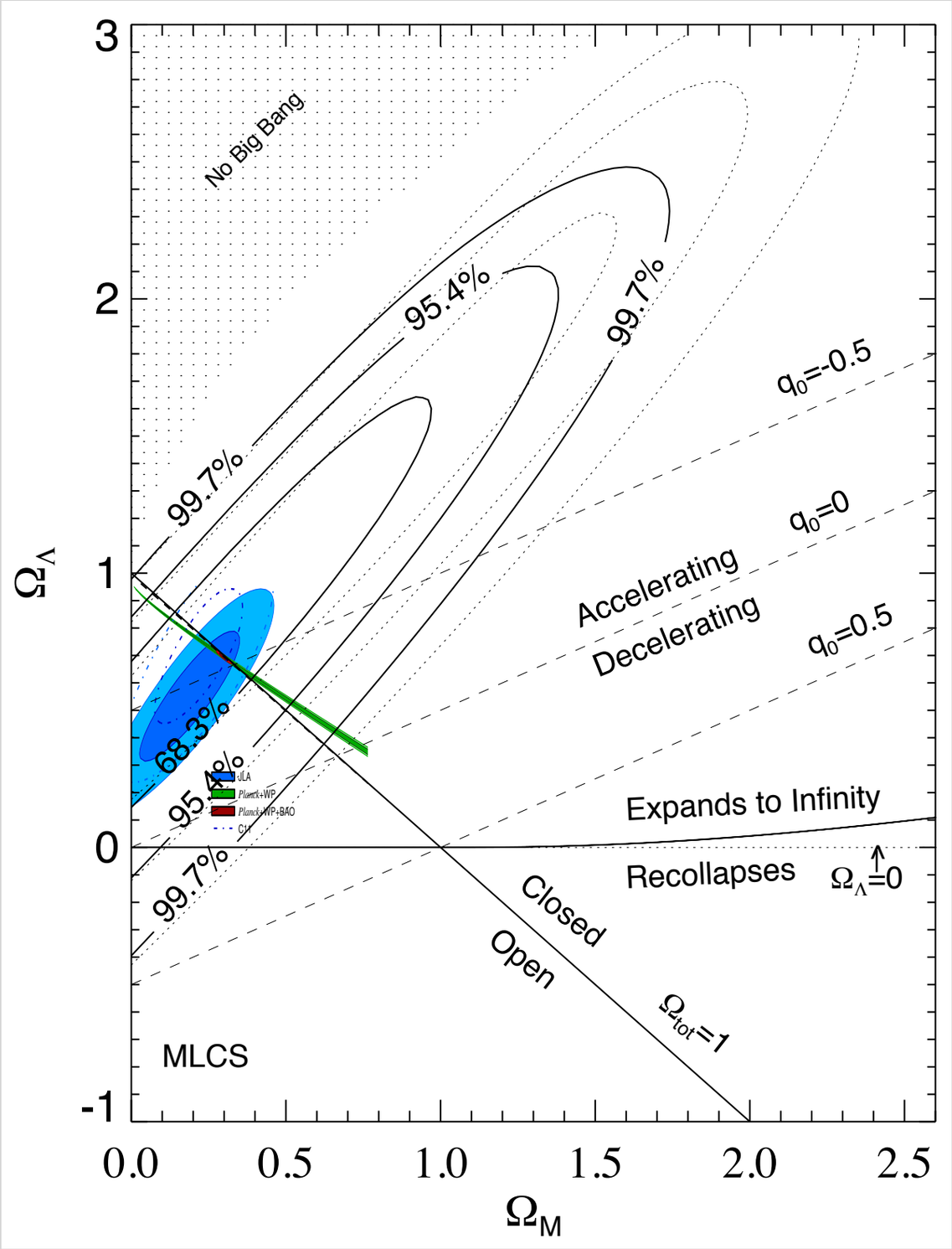


Betoule et al. 2014

Accelerating Universe! (Today)



Accelerating Universe! (Today)



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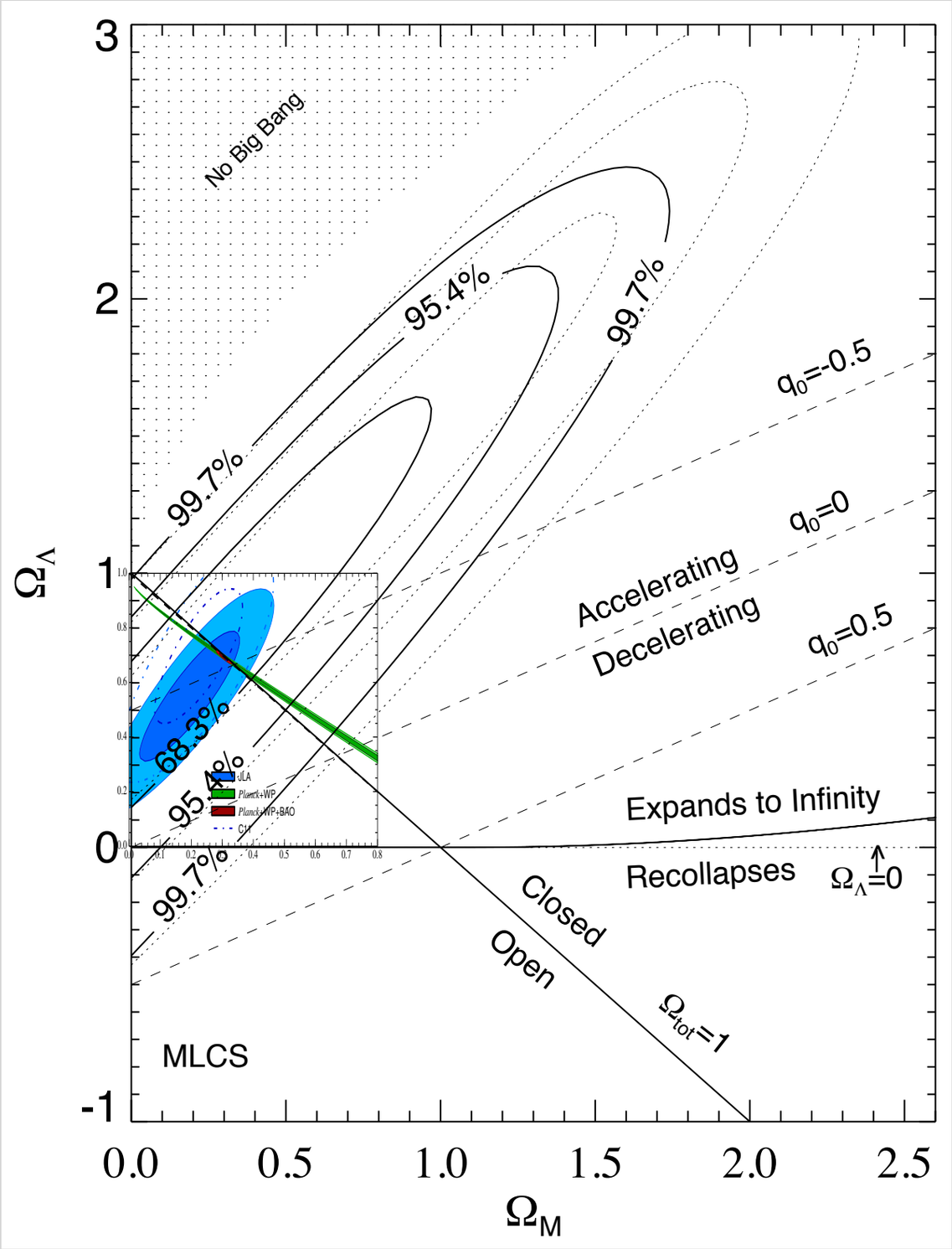
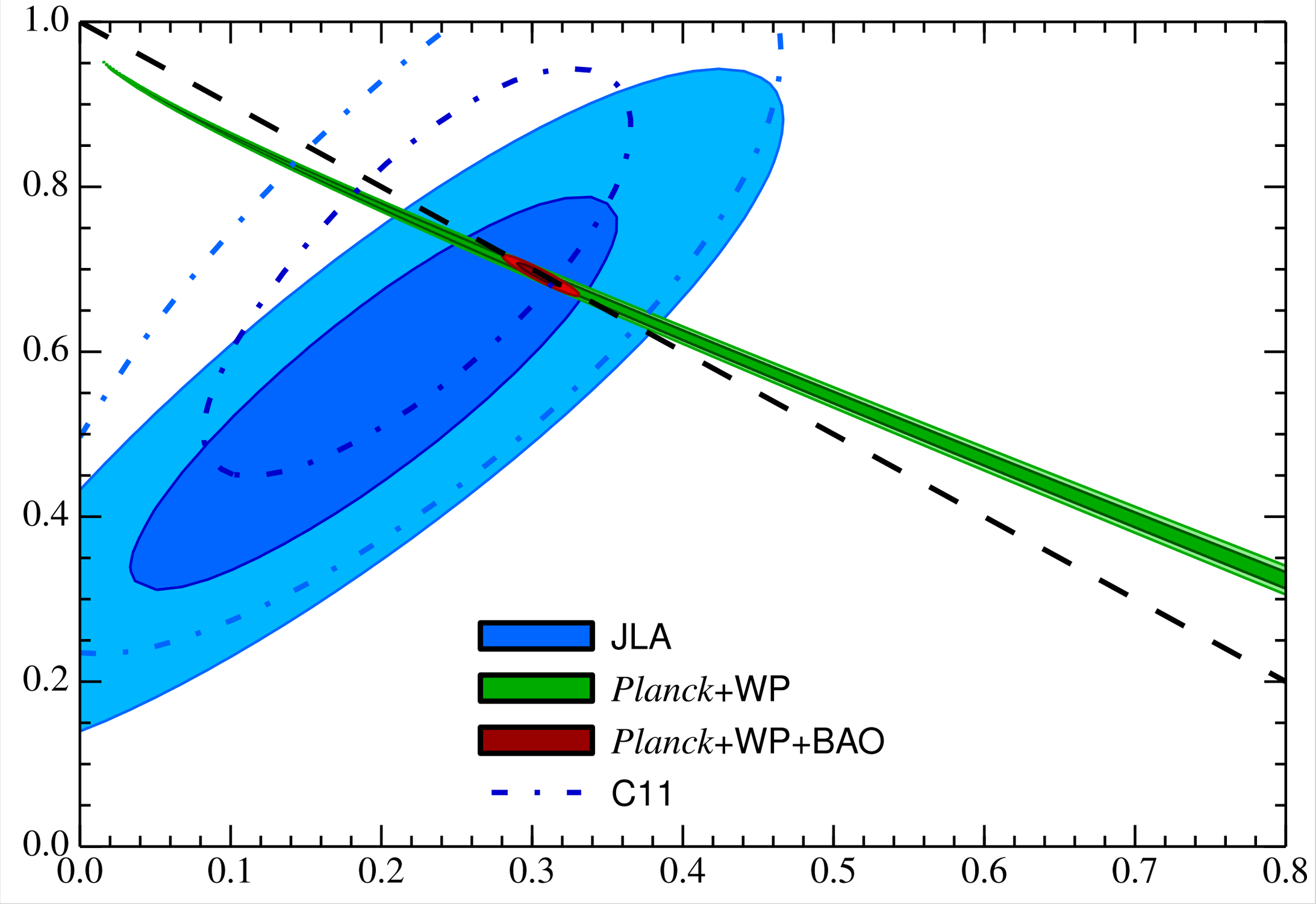
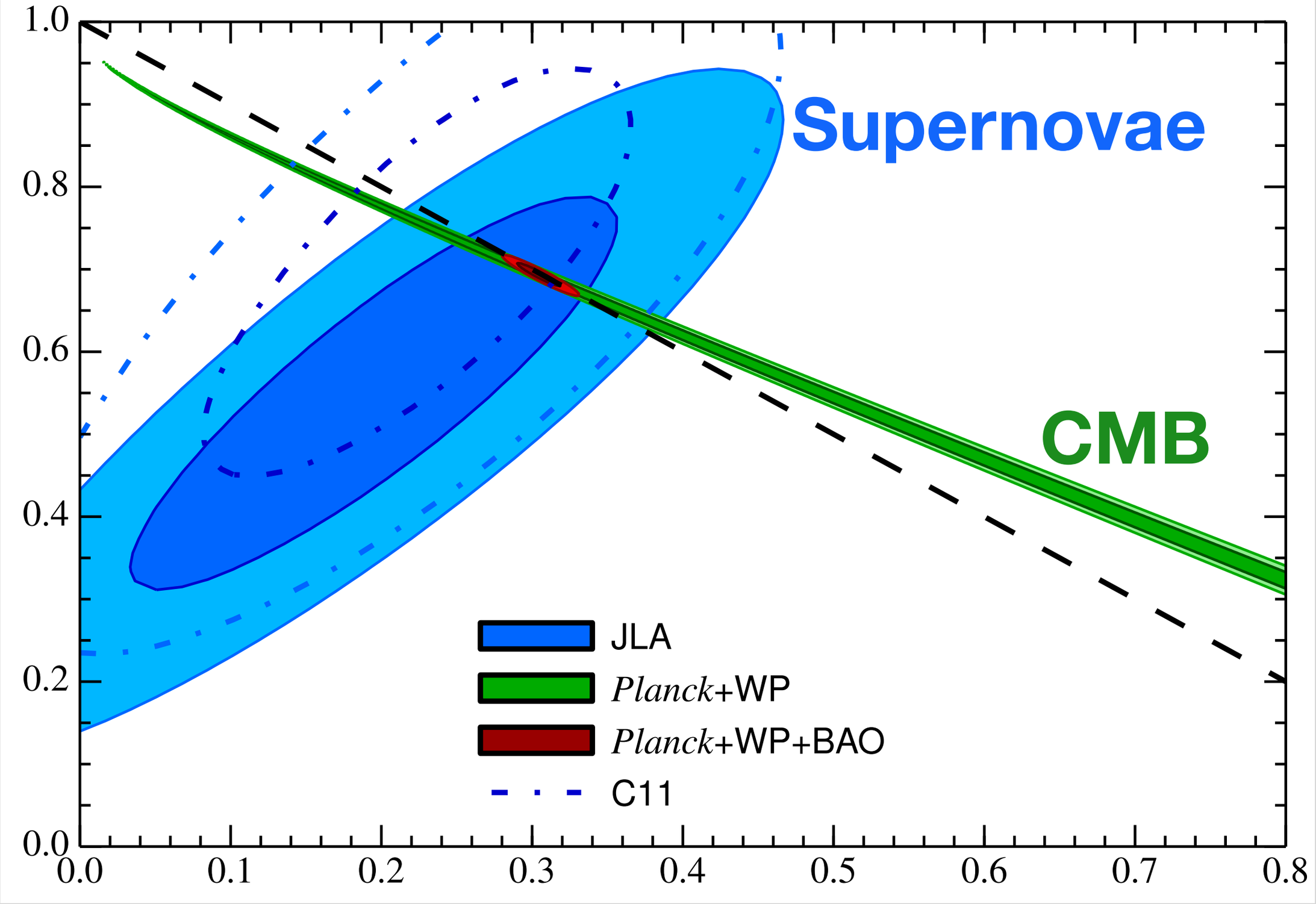


Accelerating Universe! (Today)



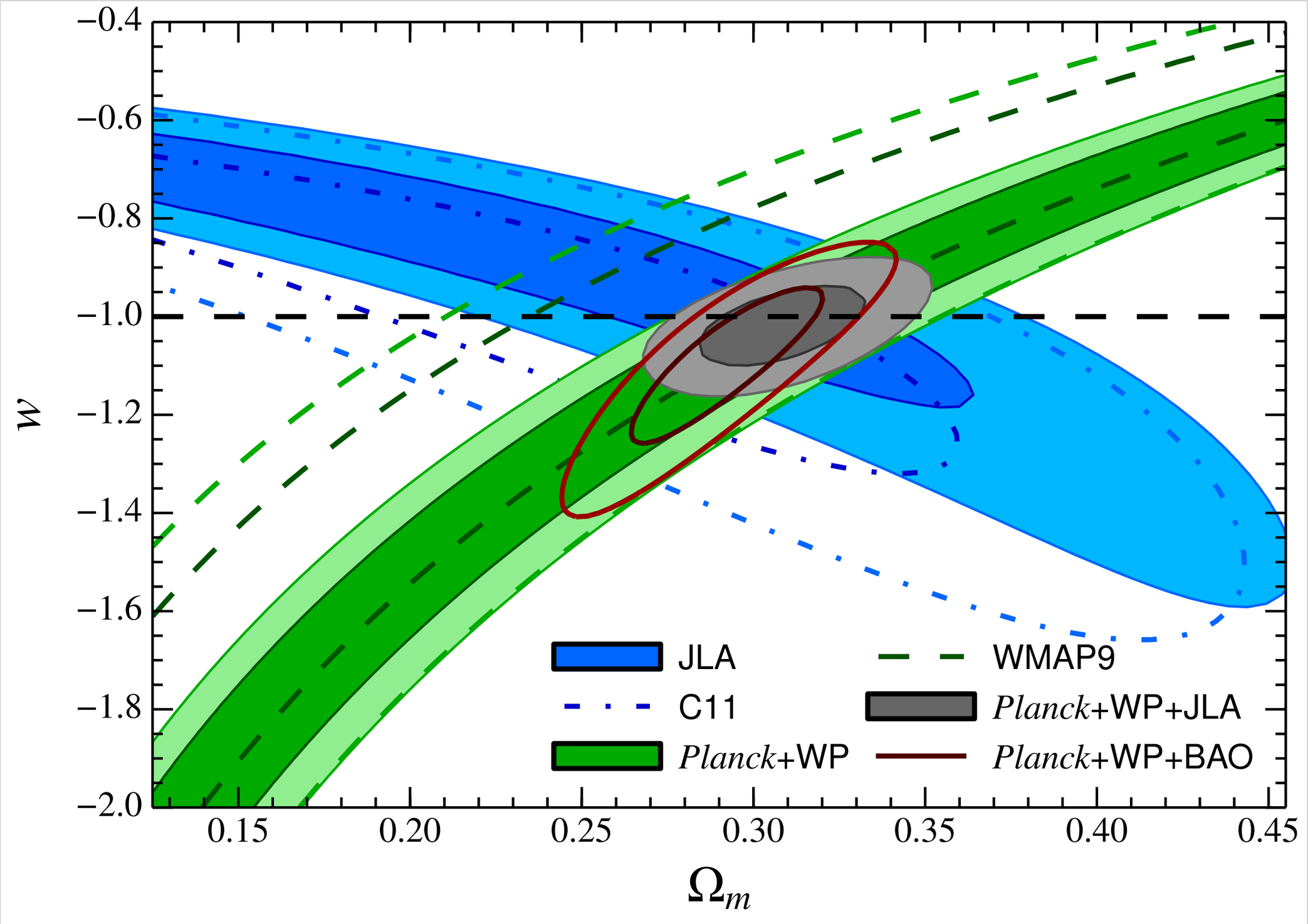
Betoule et al. 2014

Accelerating Universe! (Today)



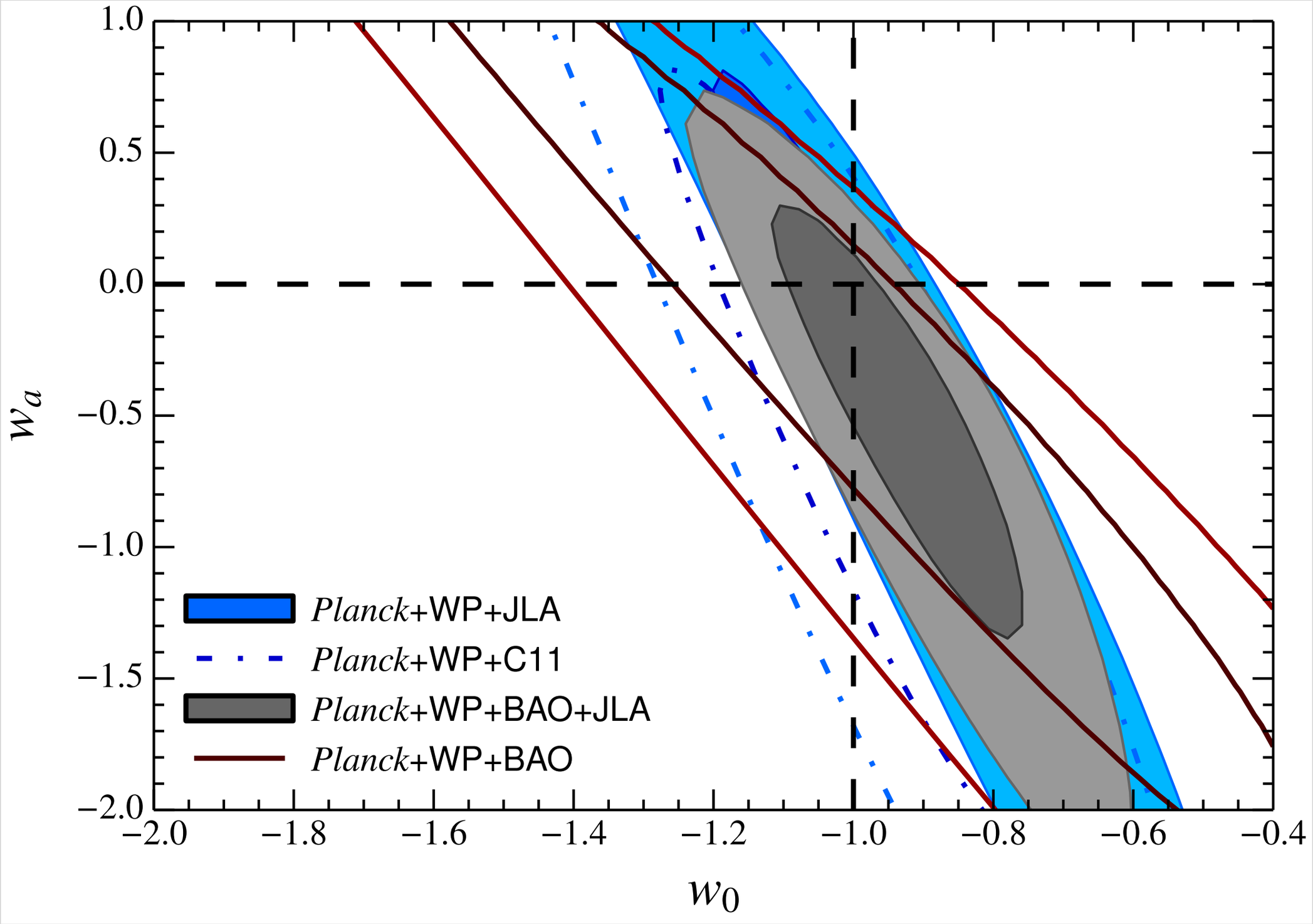
Betoule et al. 2014

w = -1.027 ± 0.055 (stat + sys)



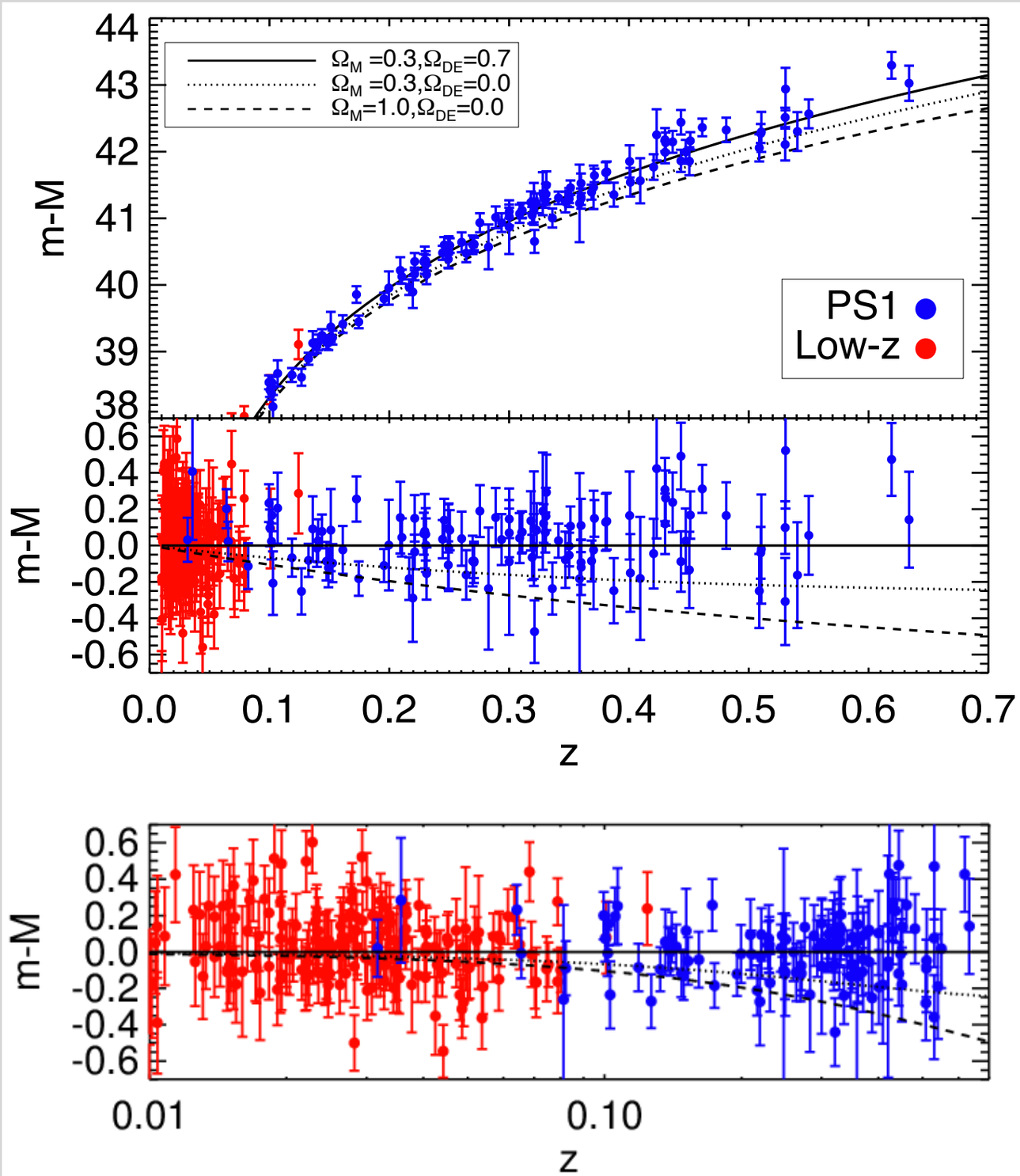
Betoule et al. 2014

$w_0 = -0.96 \pm 0.12$; $w_a = -0.34 \pm 0.55$



Betoule et al. 2014

Pan-STARRS Adds 146 SNe Ia



Rest et al. 2014; Scolnic et al. 2014

Only first 1.5 years in plot

~500 spectroscopically confirmed SNe Ia in 5 years

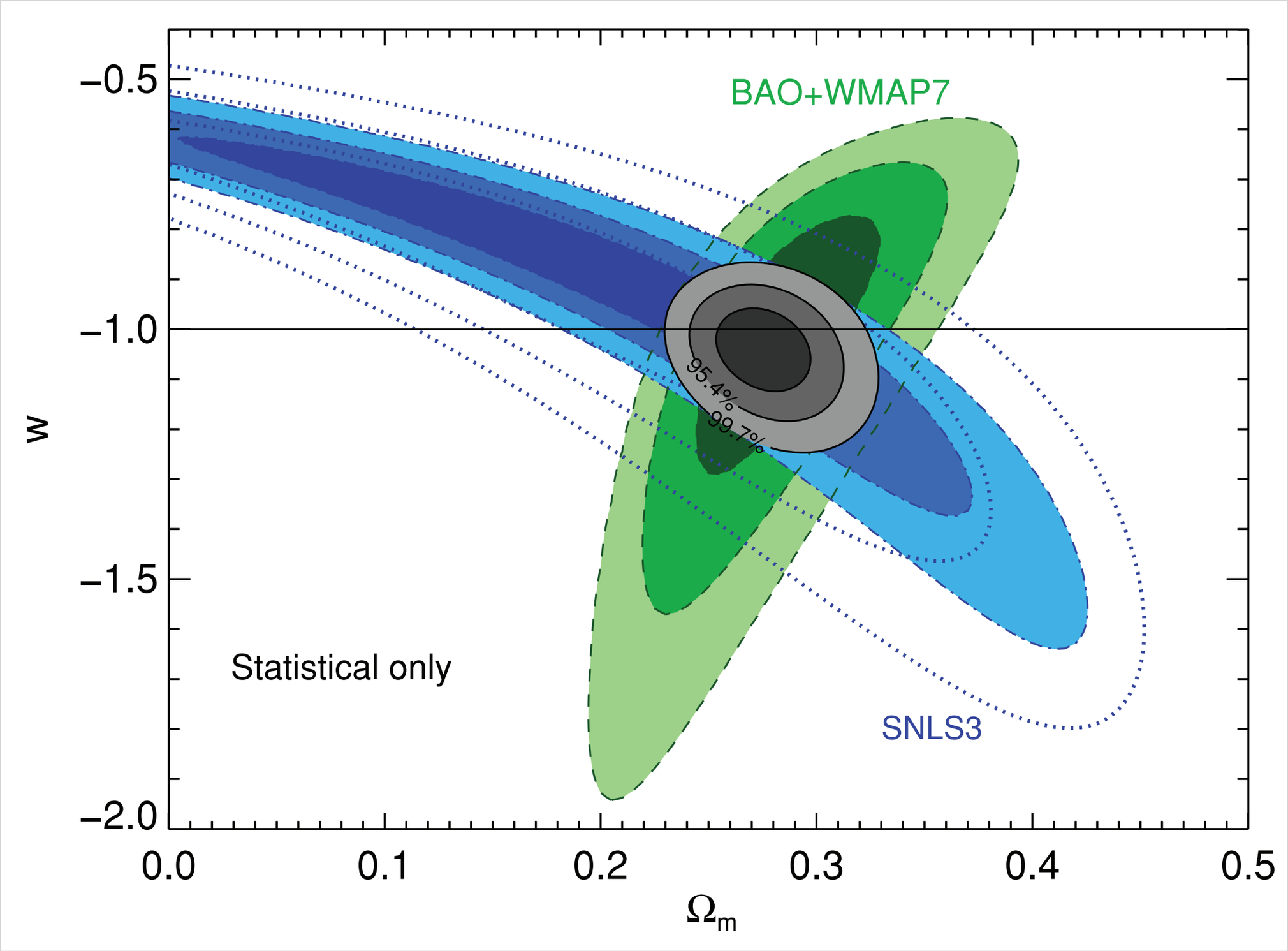
Large redshift range

Better than SDSS calibration

~3000 photometrically classified SNe Ia

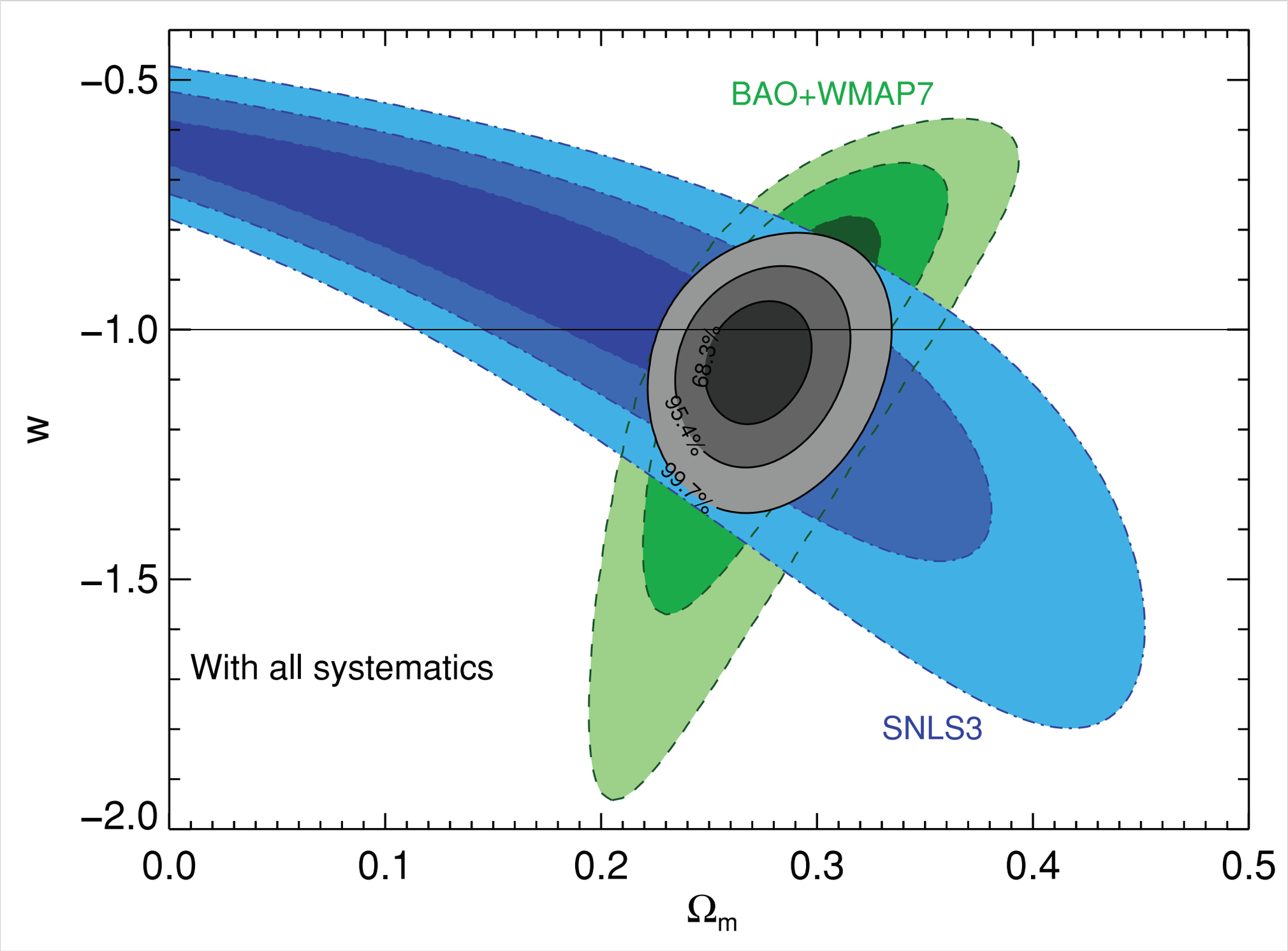
Part 2: Challenges (The Present)

Systematics Dominate



Sullivan et al. 2011

Systematics Dominate



Sullivan et al. 2011

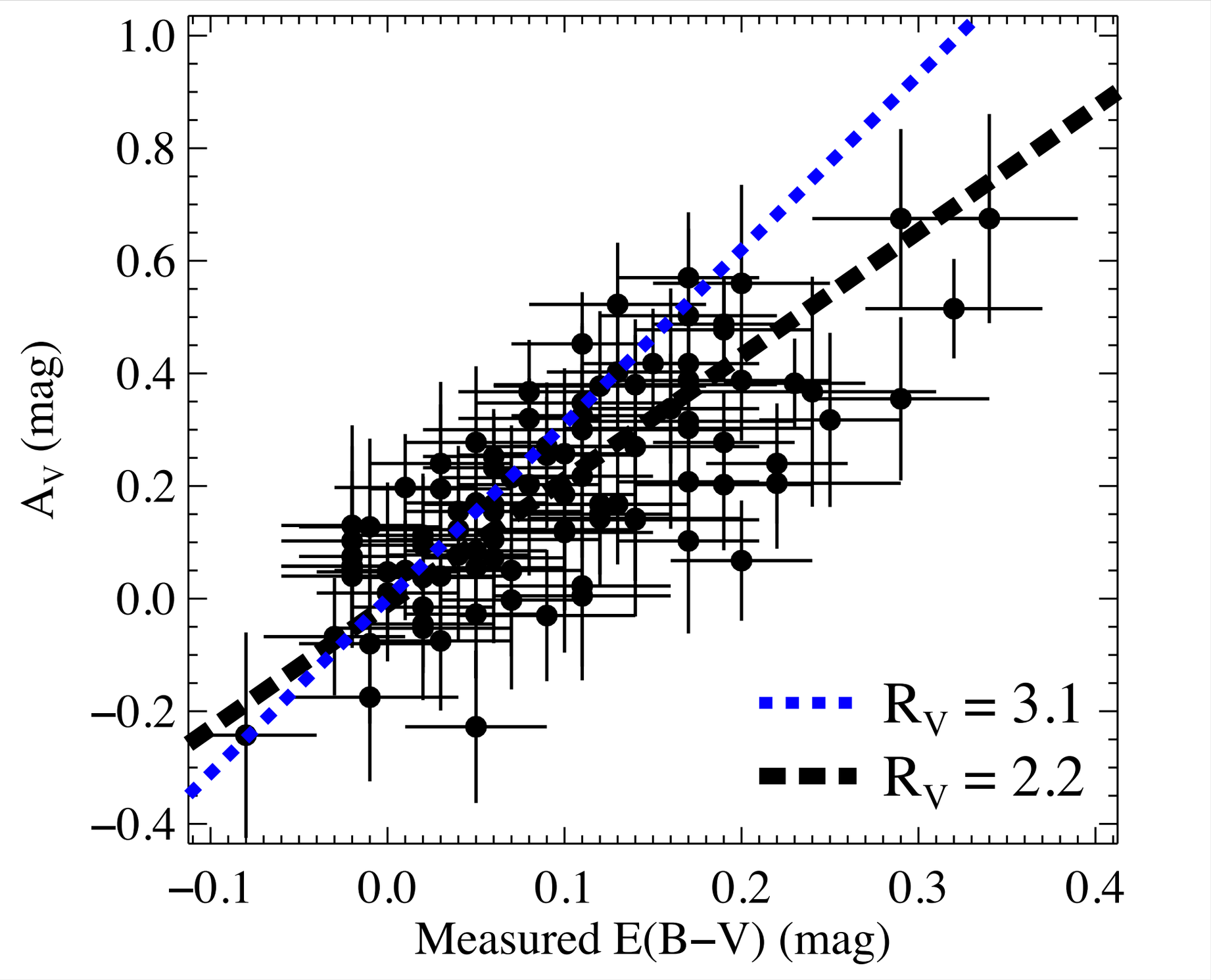
Dust Makes Things Fainter/Redder

$$R_V = A_V / E(B-V)$$

$$\mu = m - M - A_V$$

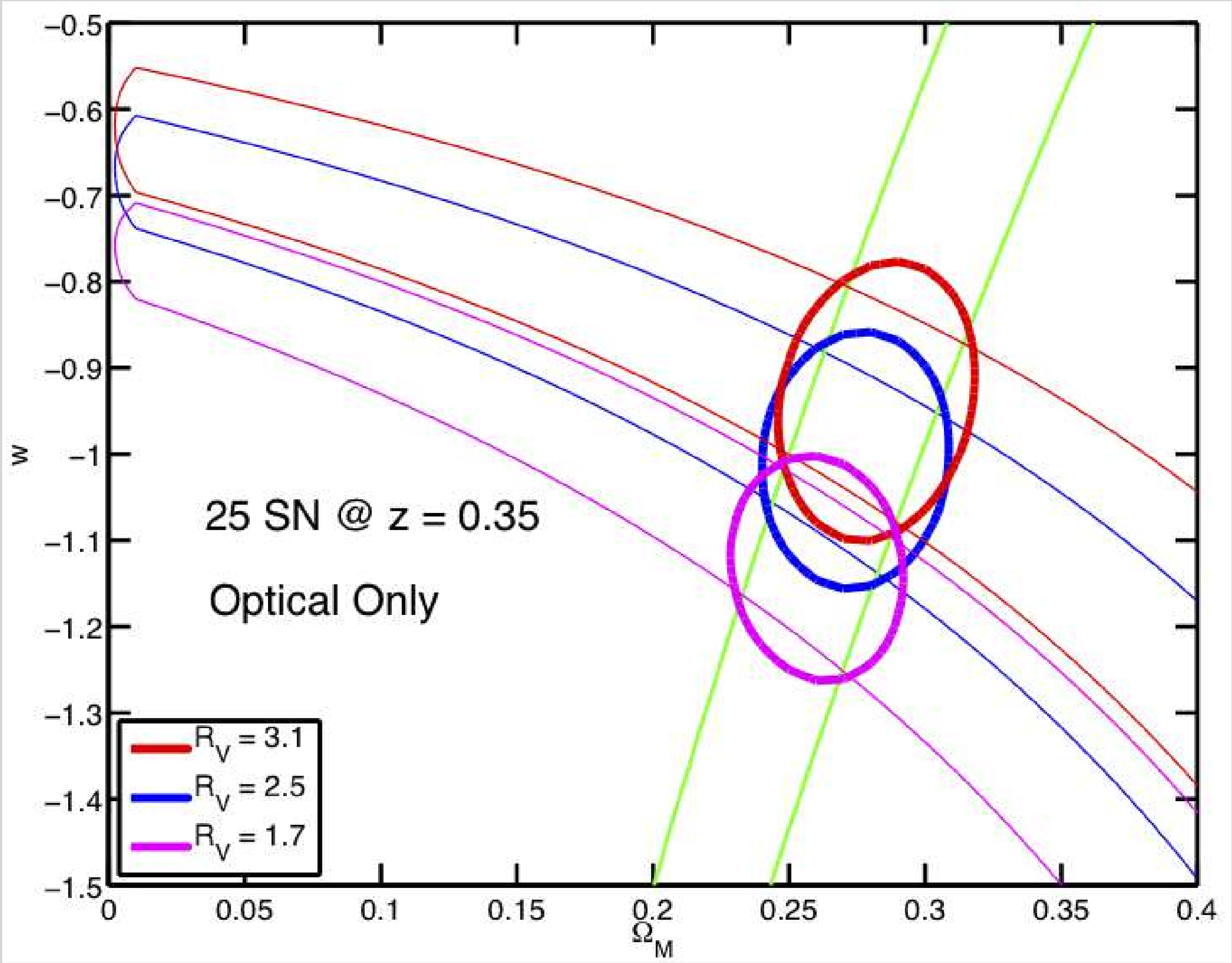
$$= m - M - E(B-V)\, R_V$$

Samples of SNe Ia have Low R_V



$R_V = A_V/E(B-V)$

R_V Is A Significant Systematic



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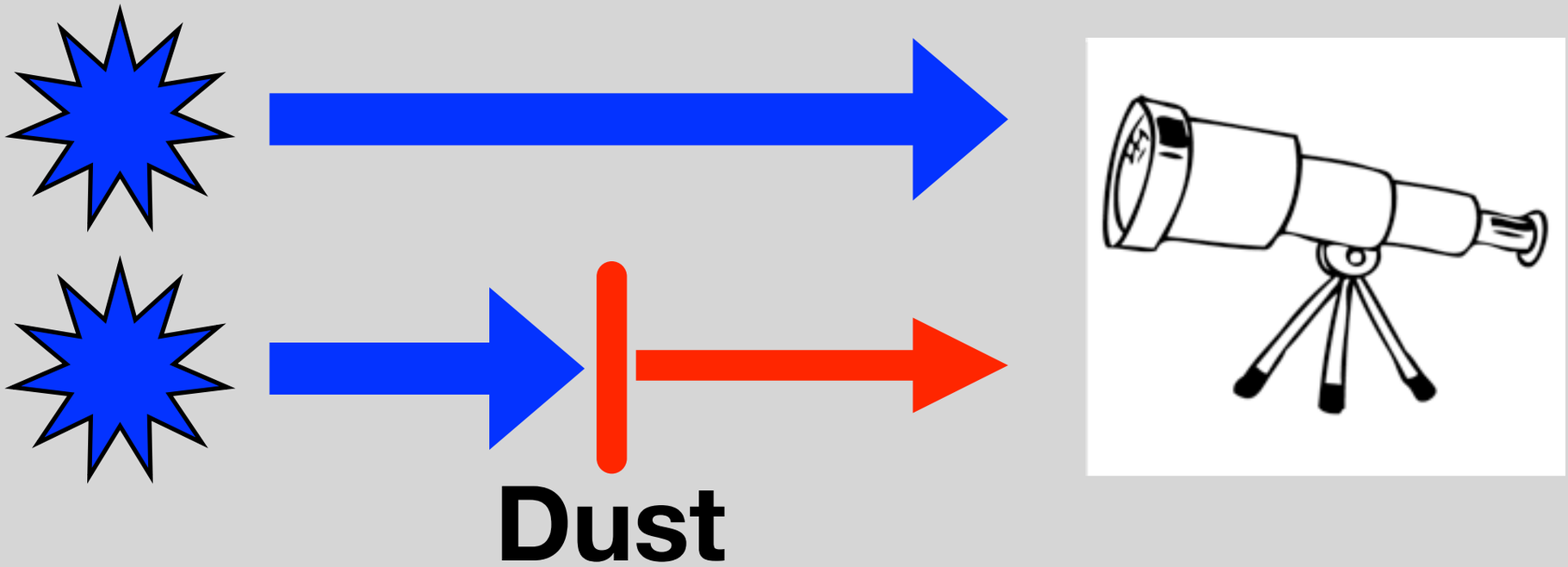

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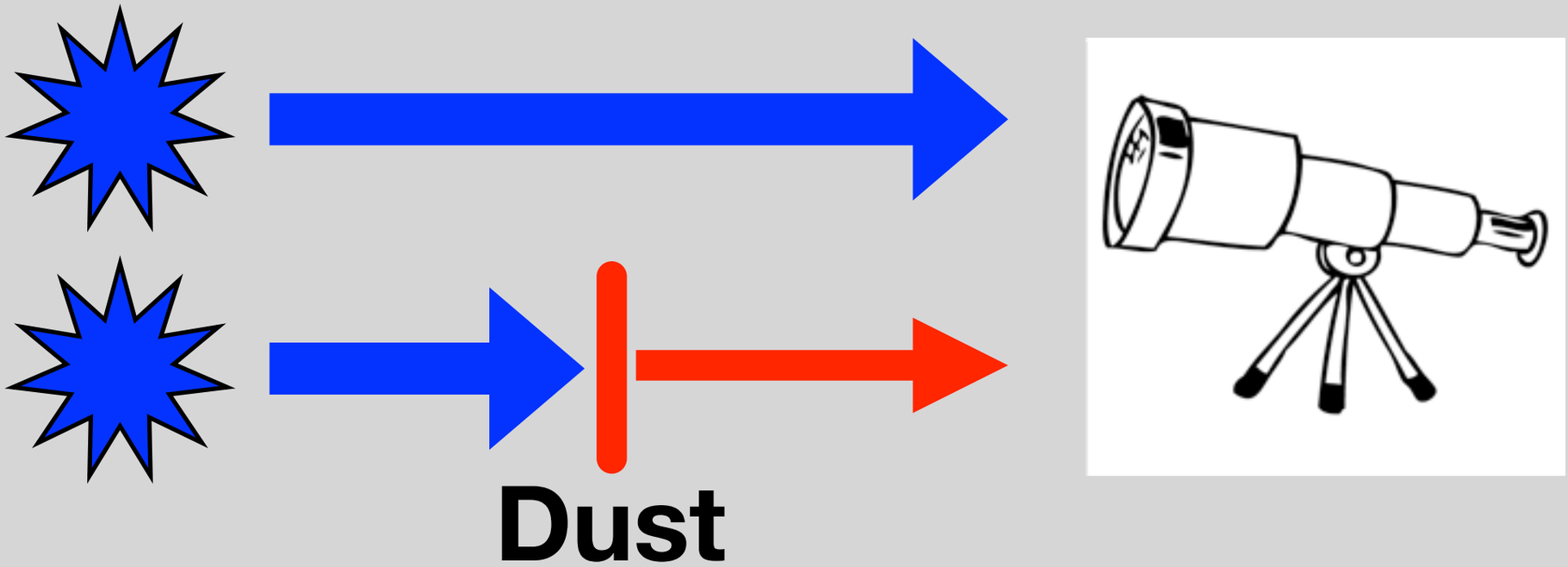
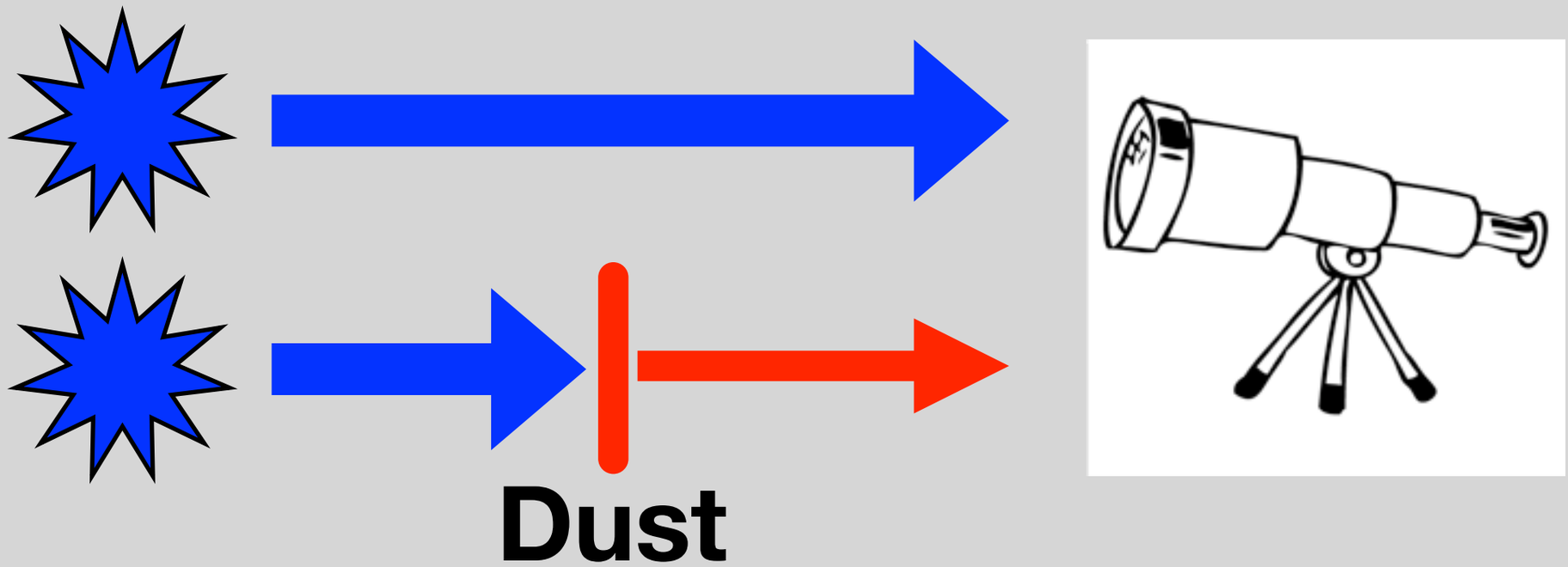
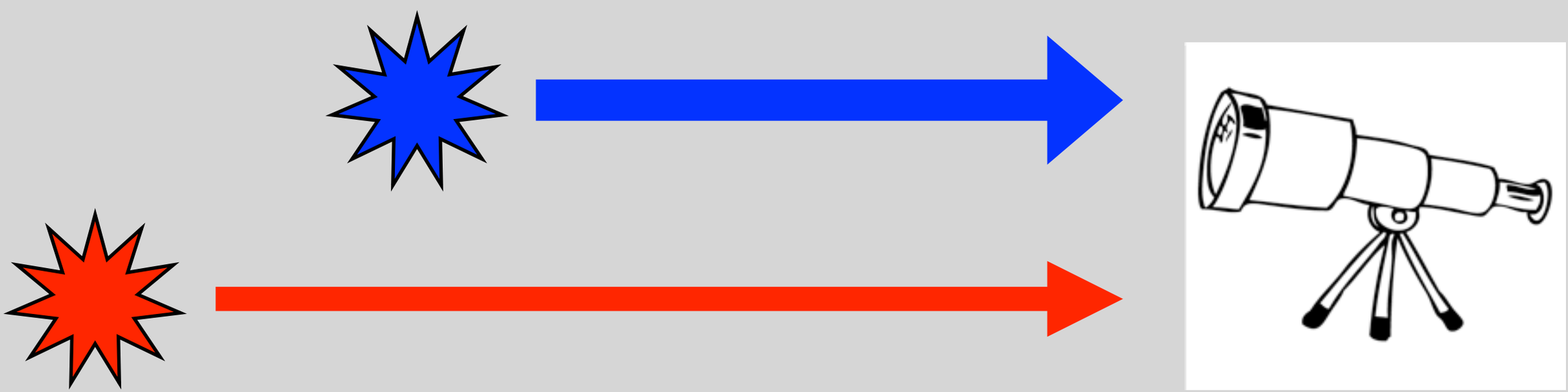


Different Intrinsic Colors

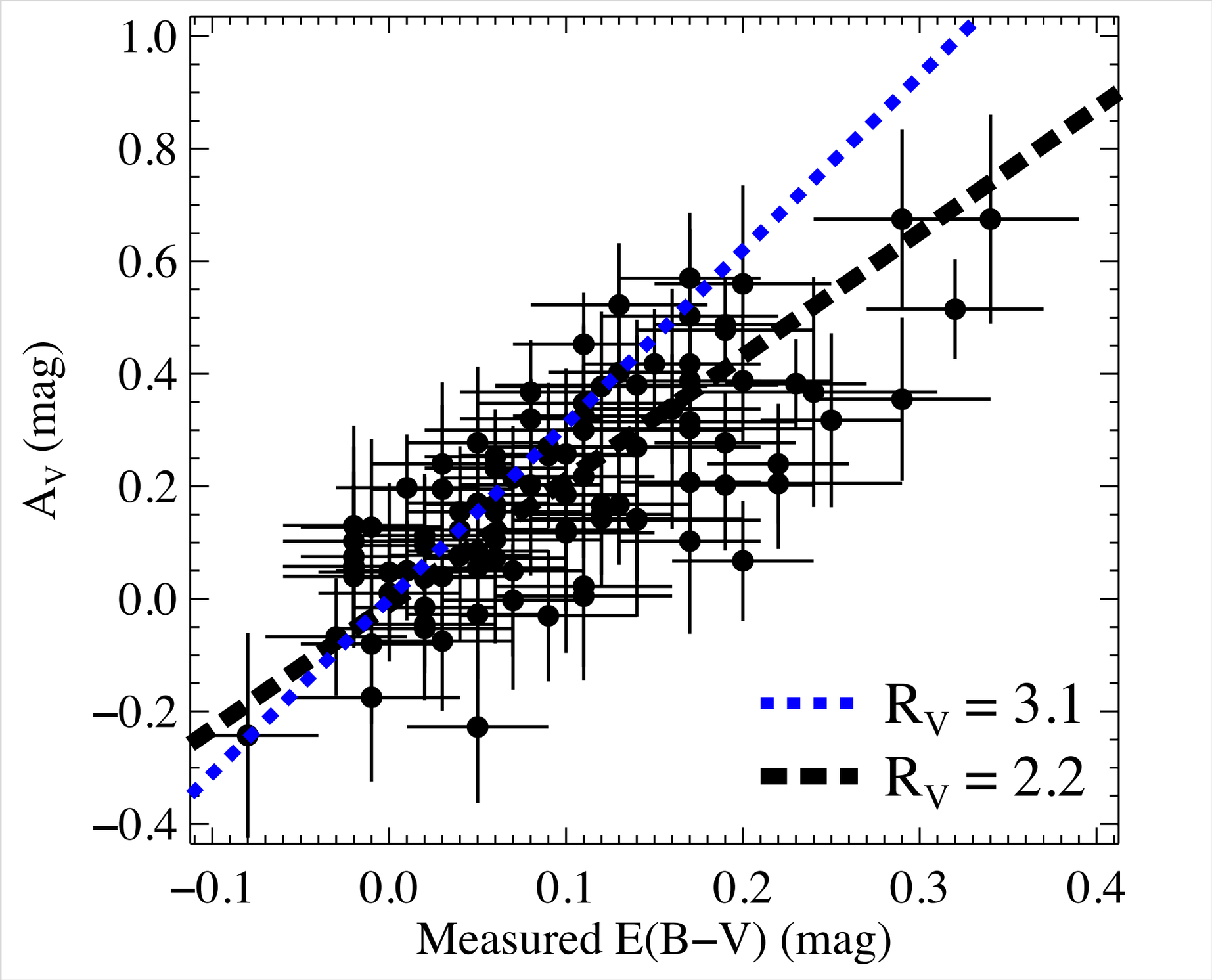
Dust Makes Things Fainter/Redder



Different Intrinsic Colors



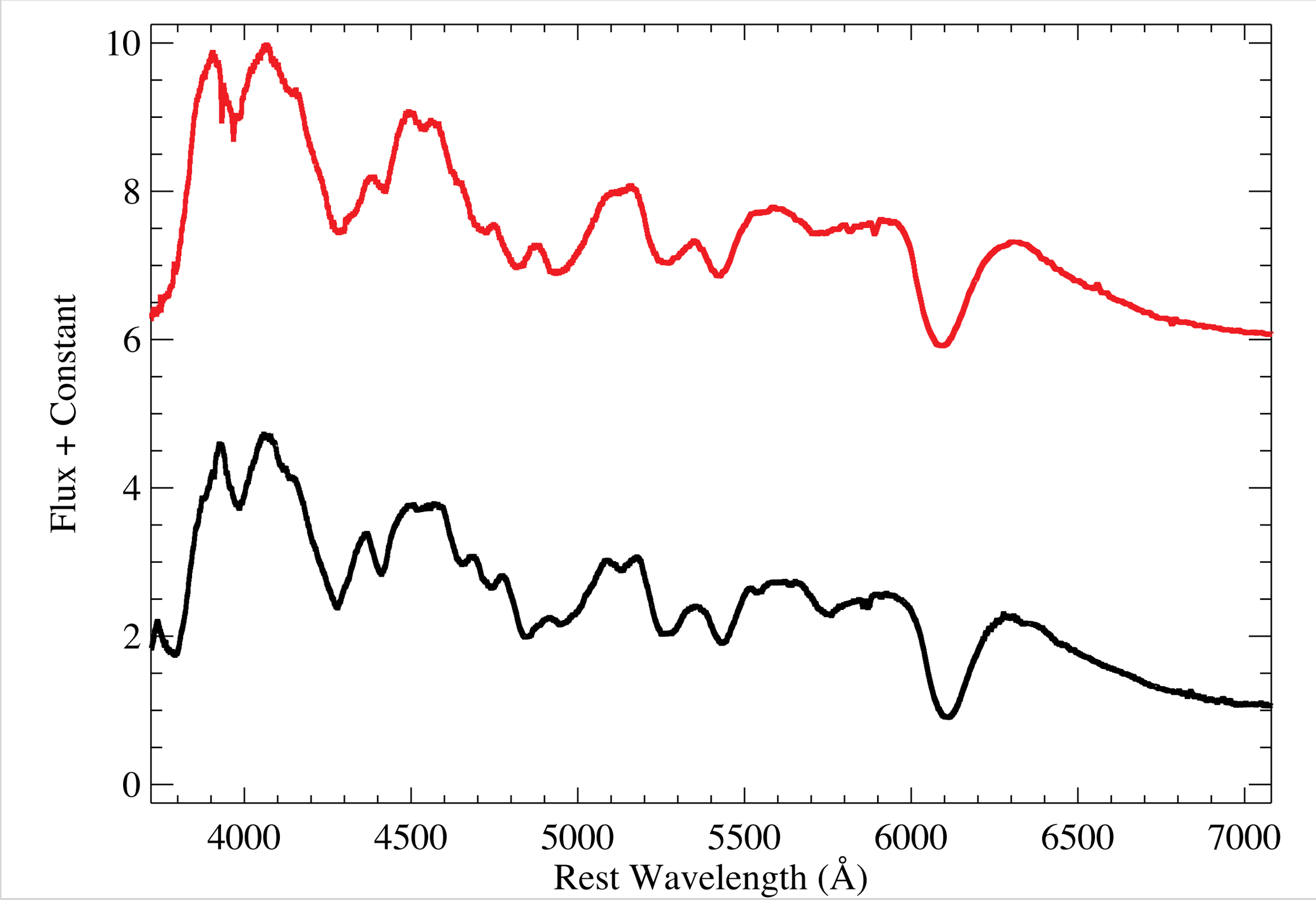
Samples of SNe Ia have Low R_V



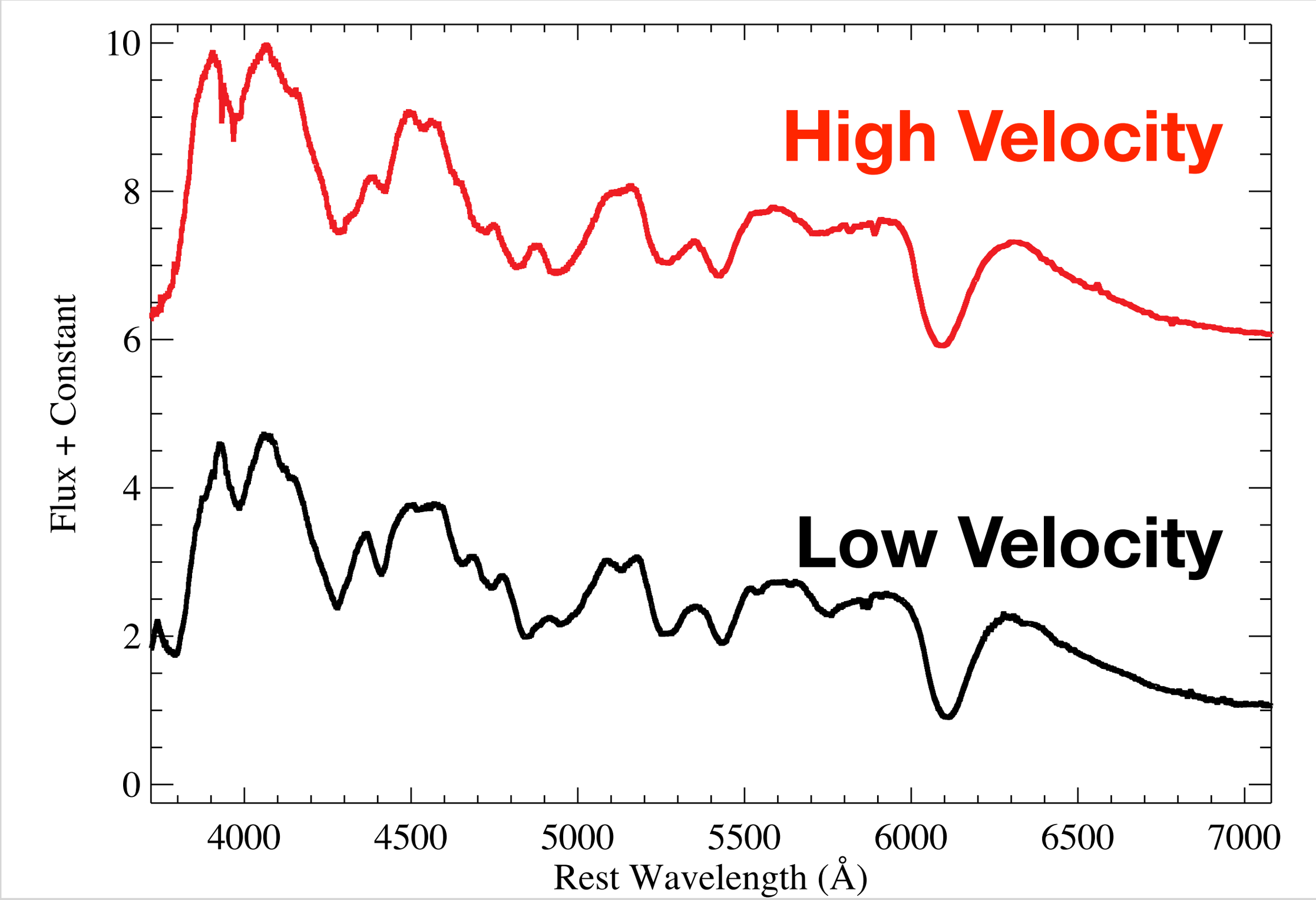
R_V = A_V/E(B-V)

Foley & Kasen 2011

Optical Spectrum to Measure Velocity



Optical Spectrum to Measure Velocity



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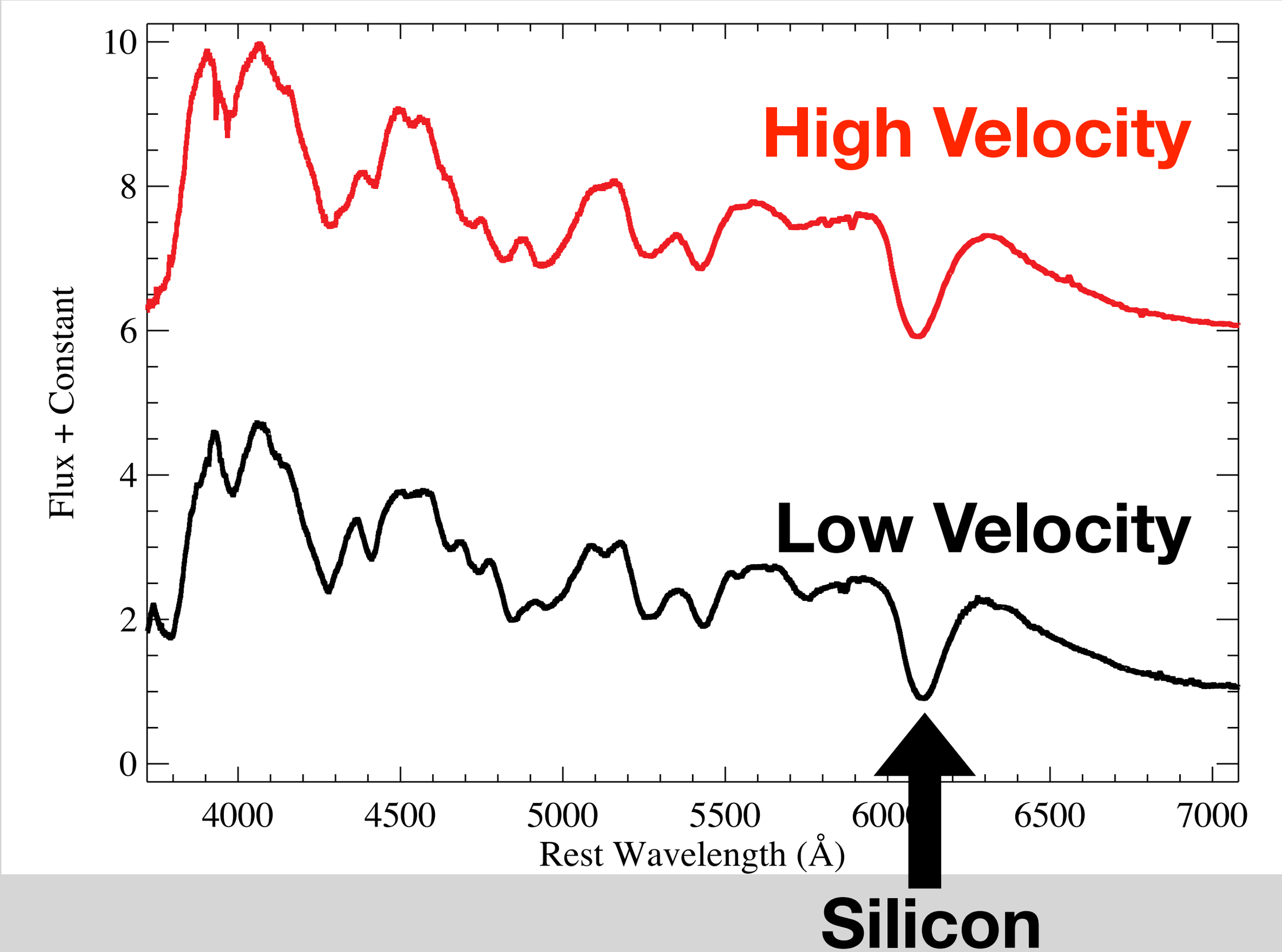
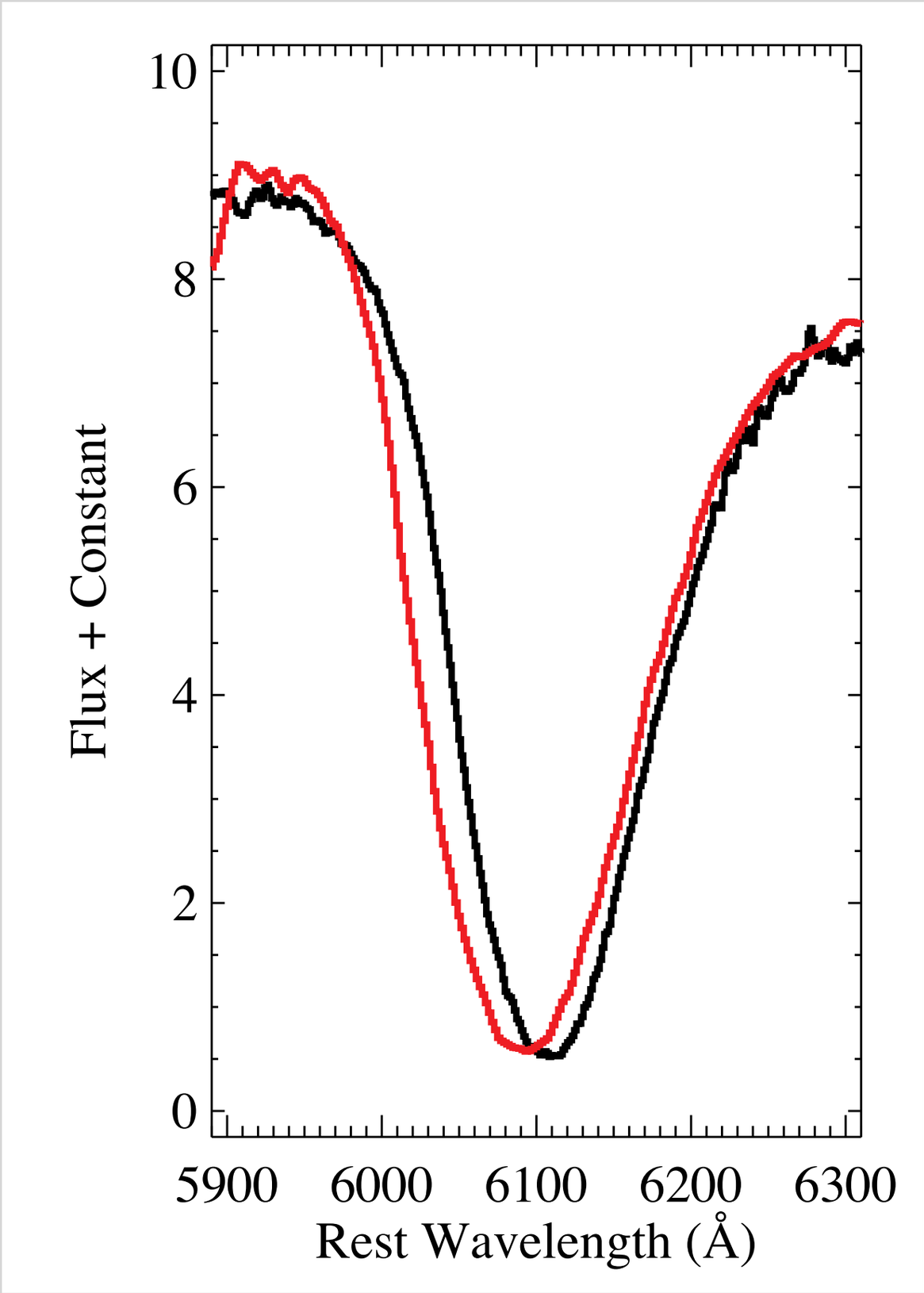


Measure Silicon Velocity

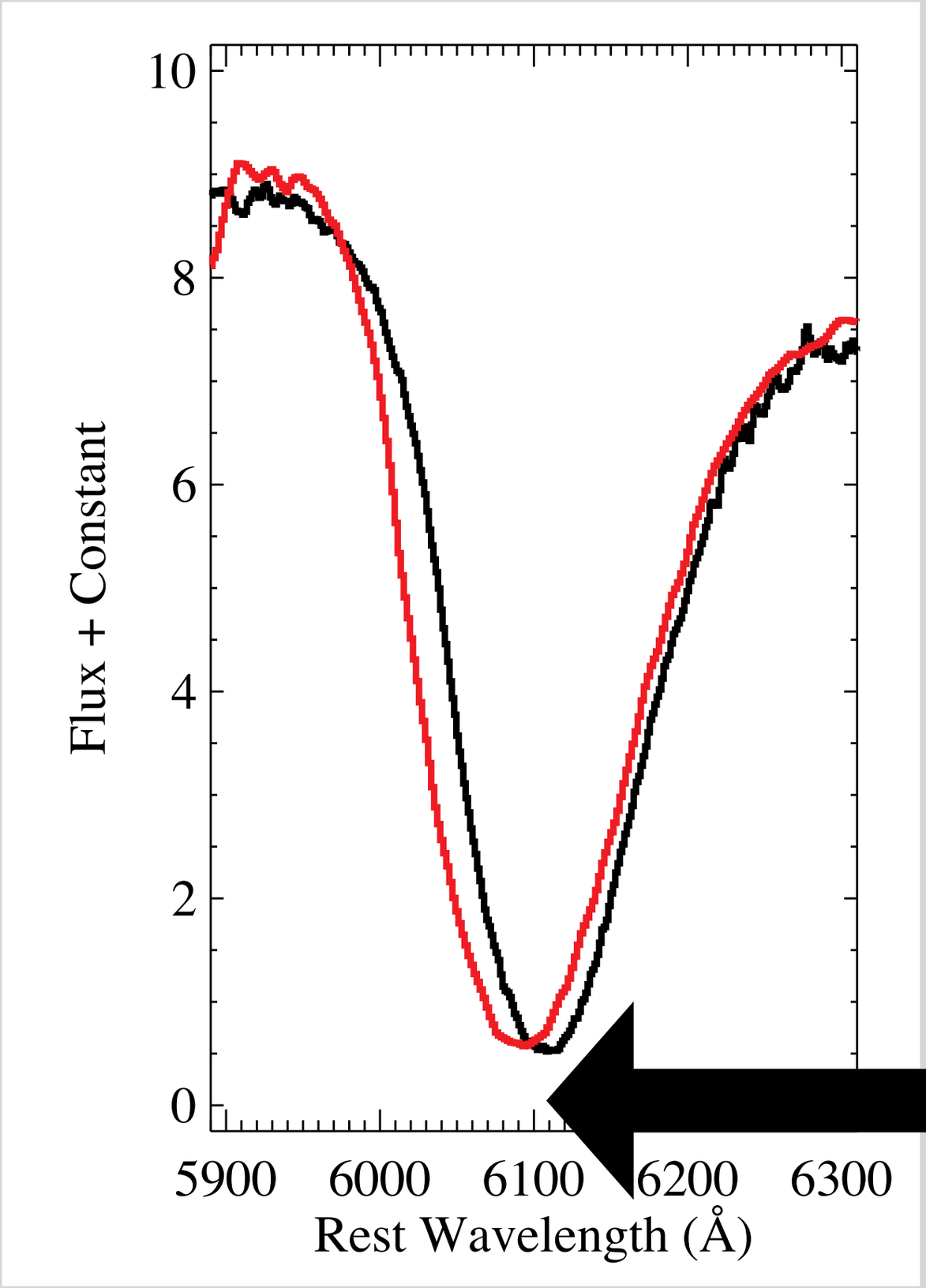


High Velocity:
~ -13,000 km s^{-1}

Low Velocity:
~ -10,000 km s^{-1}

Wider Lines With Higher Velocity

Measure Silicon Velocity

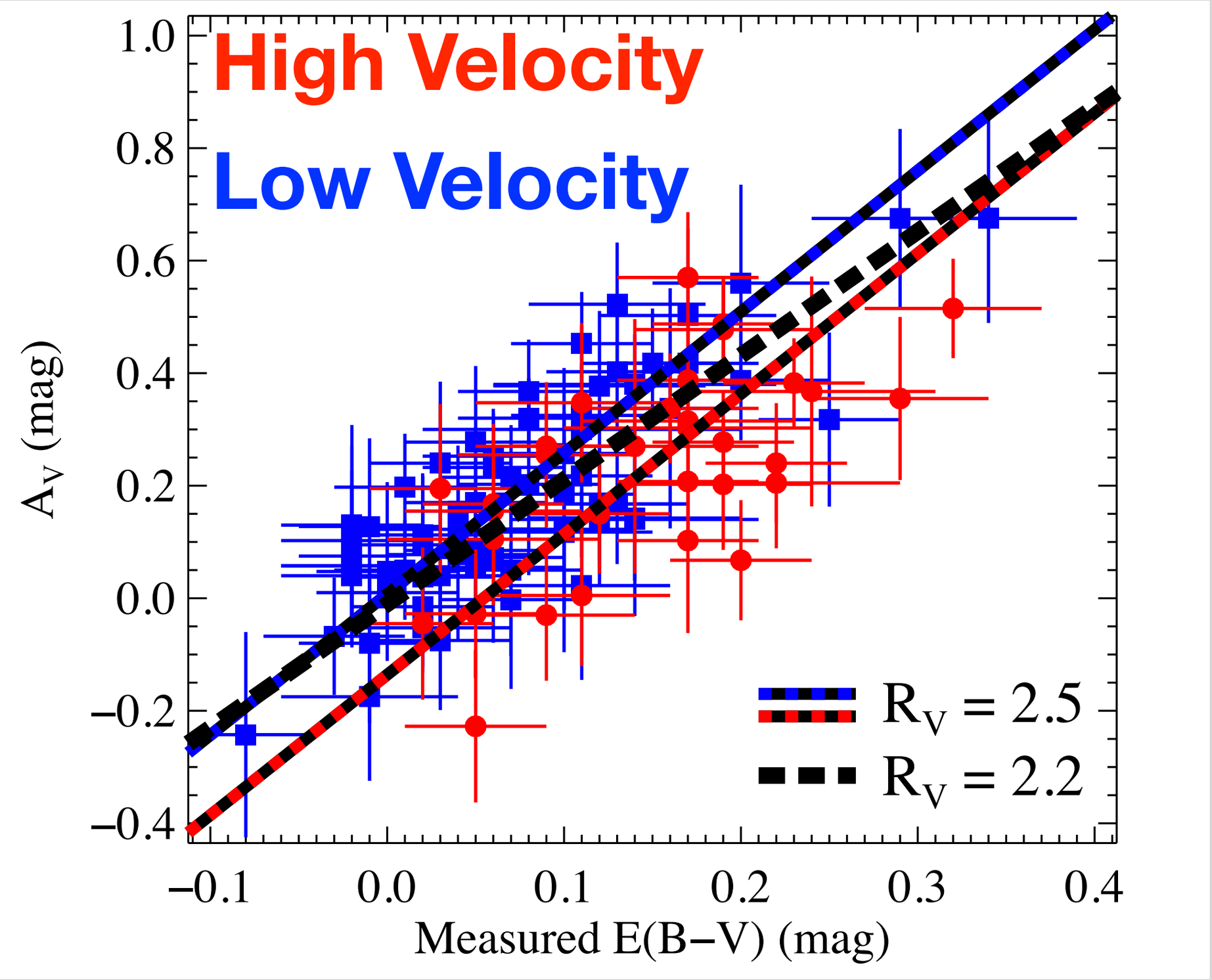


High Velocity:
~ -13,000 km s^{-1}

Low Velocity:
~ -10,000 km s^{-1}

Wider Lines With Higher Velocity

Intrinsic Color Depends on SN Velocity



$R_V = A_V/E(B-V)$

Foley & Kasen 2011

Ejecta Velocity is the "Next Parameter"

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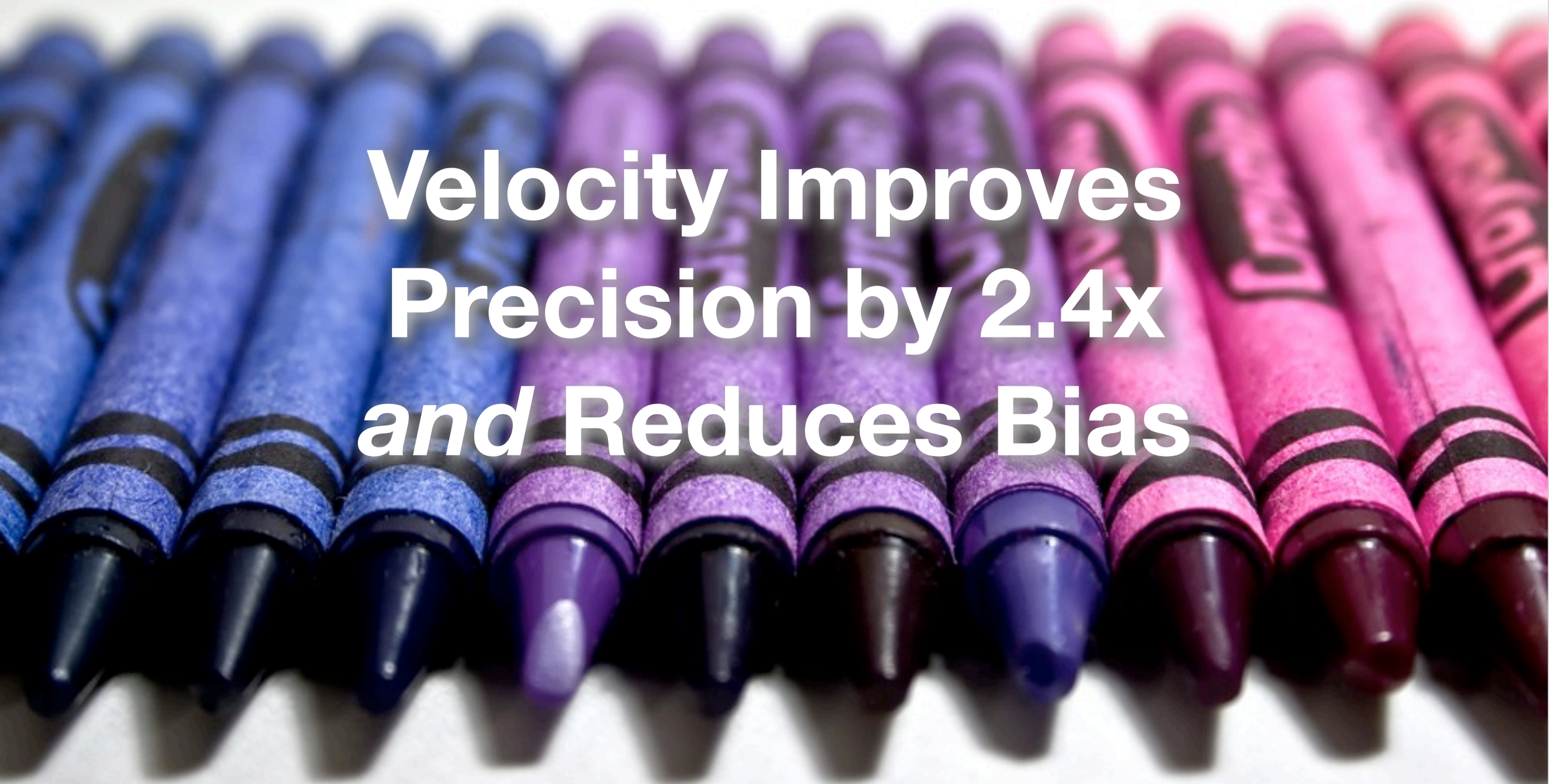
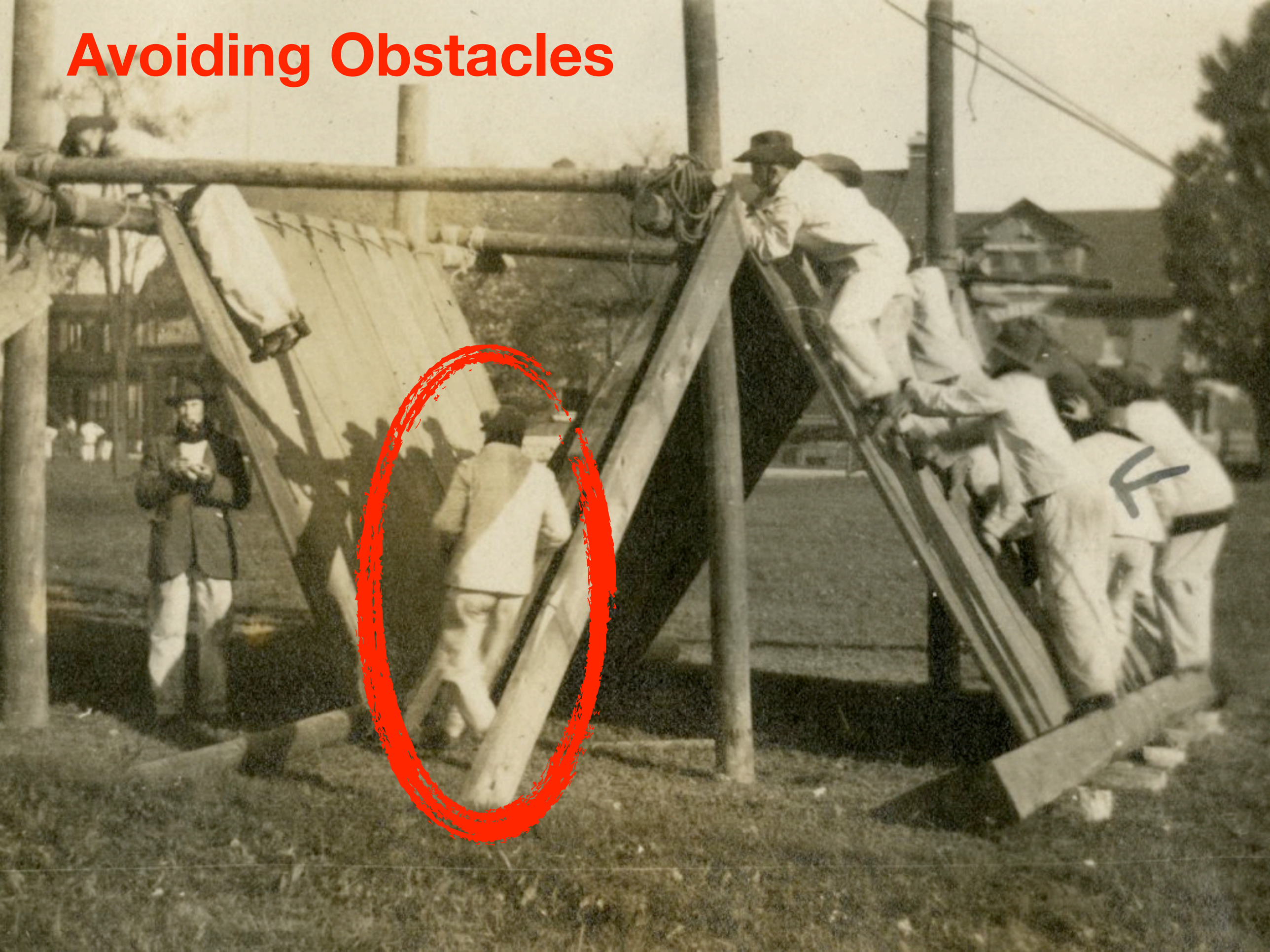


Velocity Improves Precision by 2.4x *and* Reduces Bias

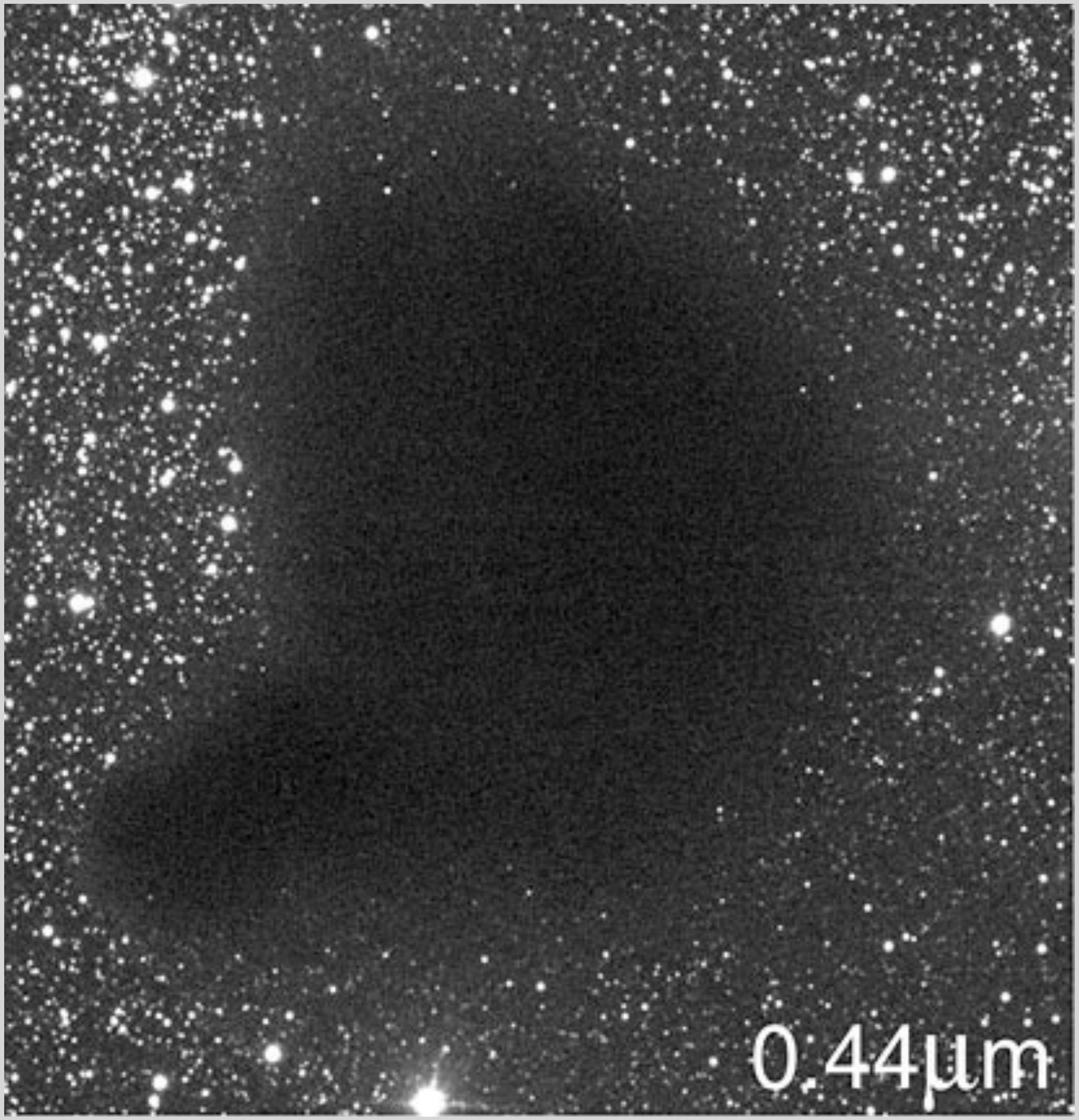
Low Velocity **High Velocity**

Avoiding Obstacles

Avoiding Obstacles

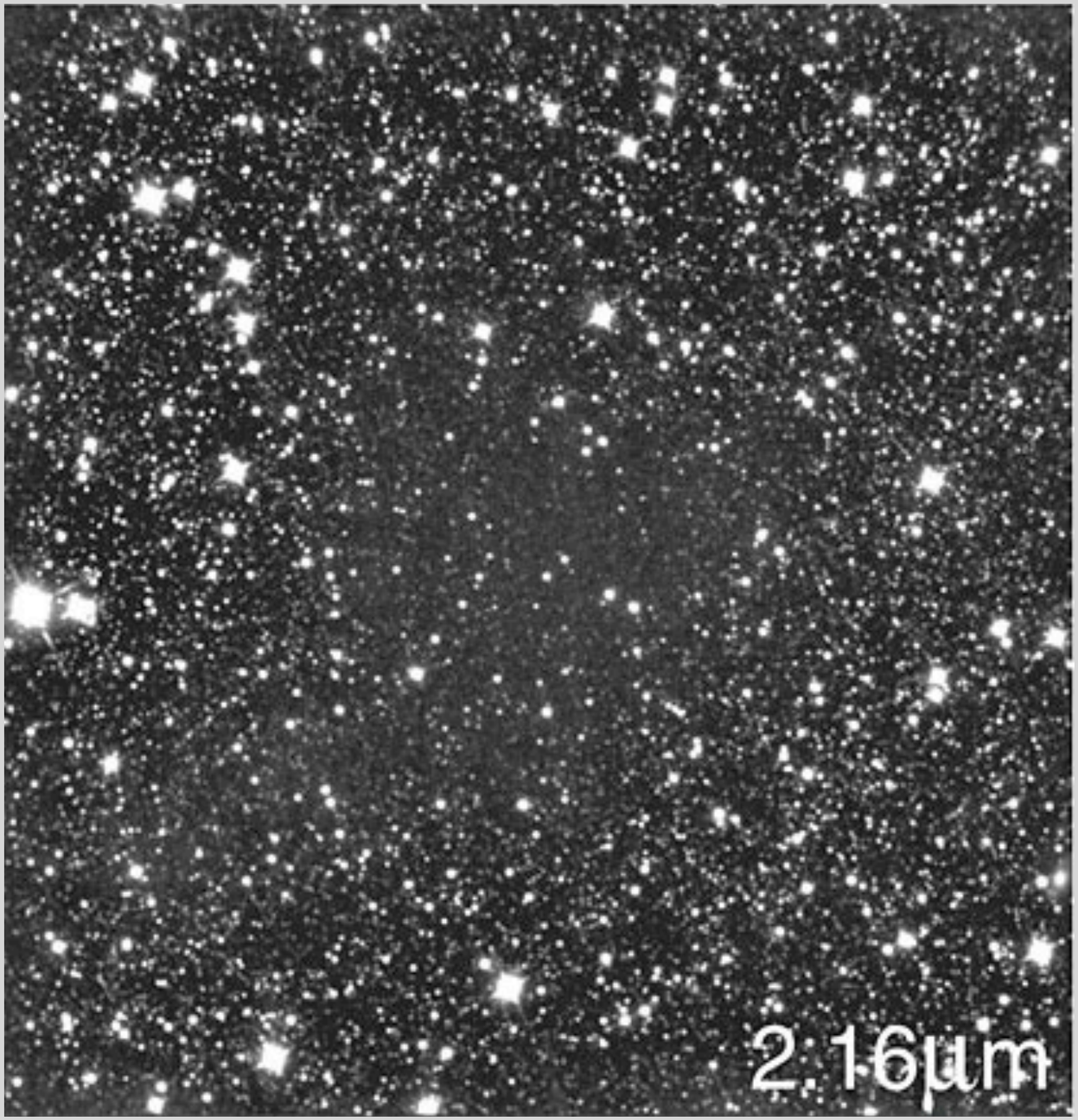


Seeing Through The Dirt in the NIR



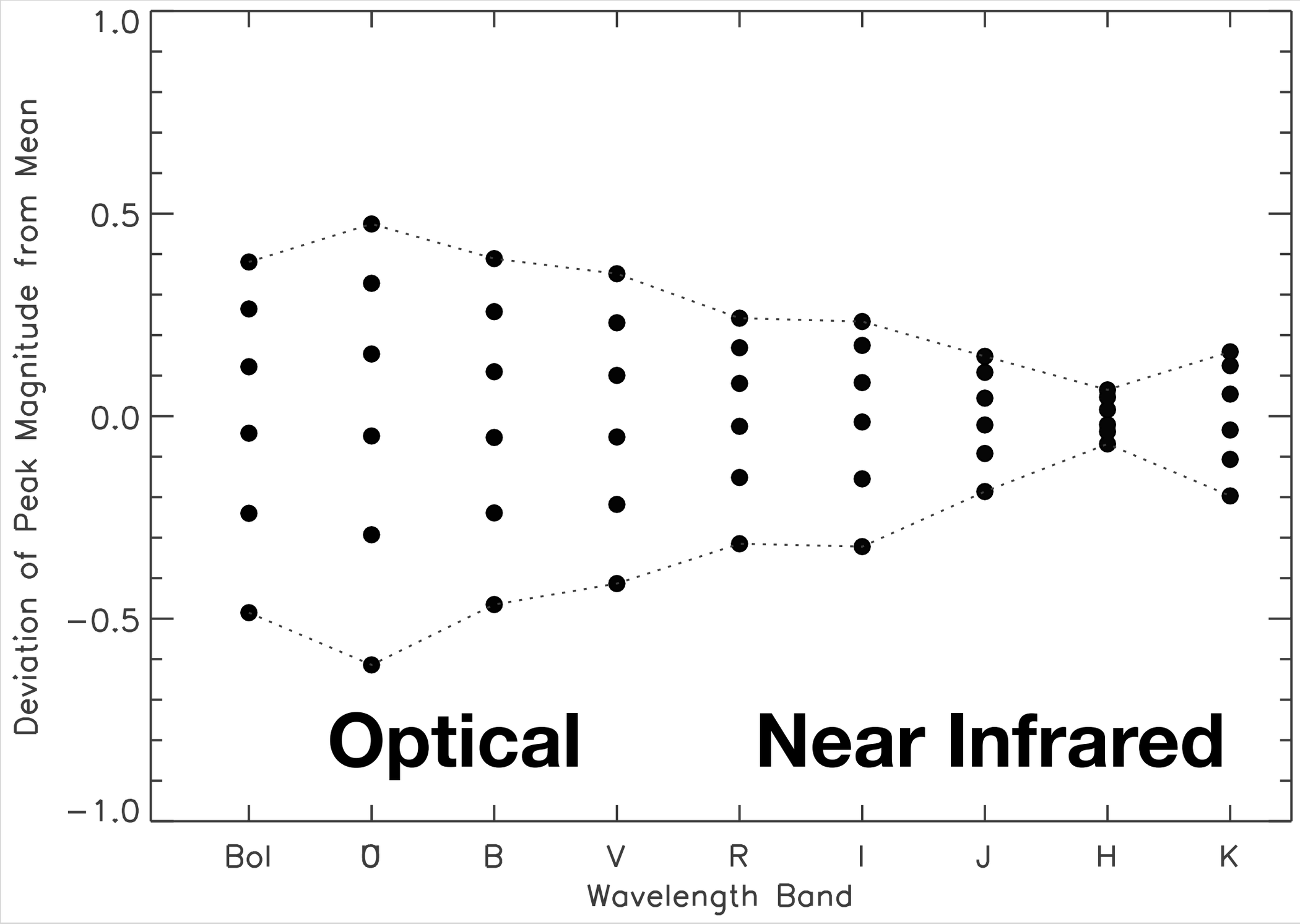
Optical

Seeing Through The Dirt in the NIR



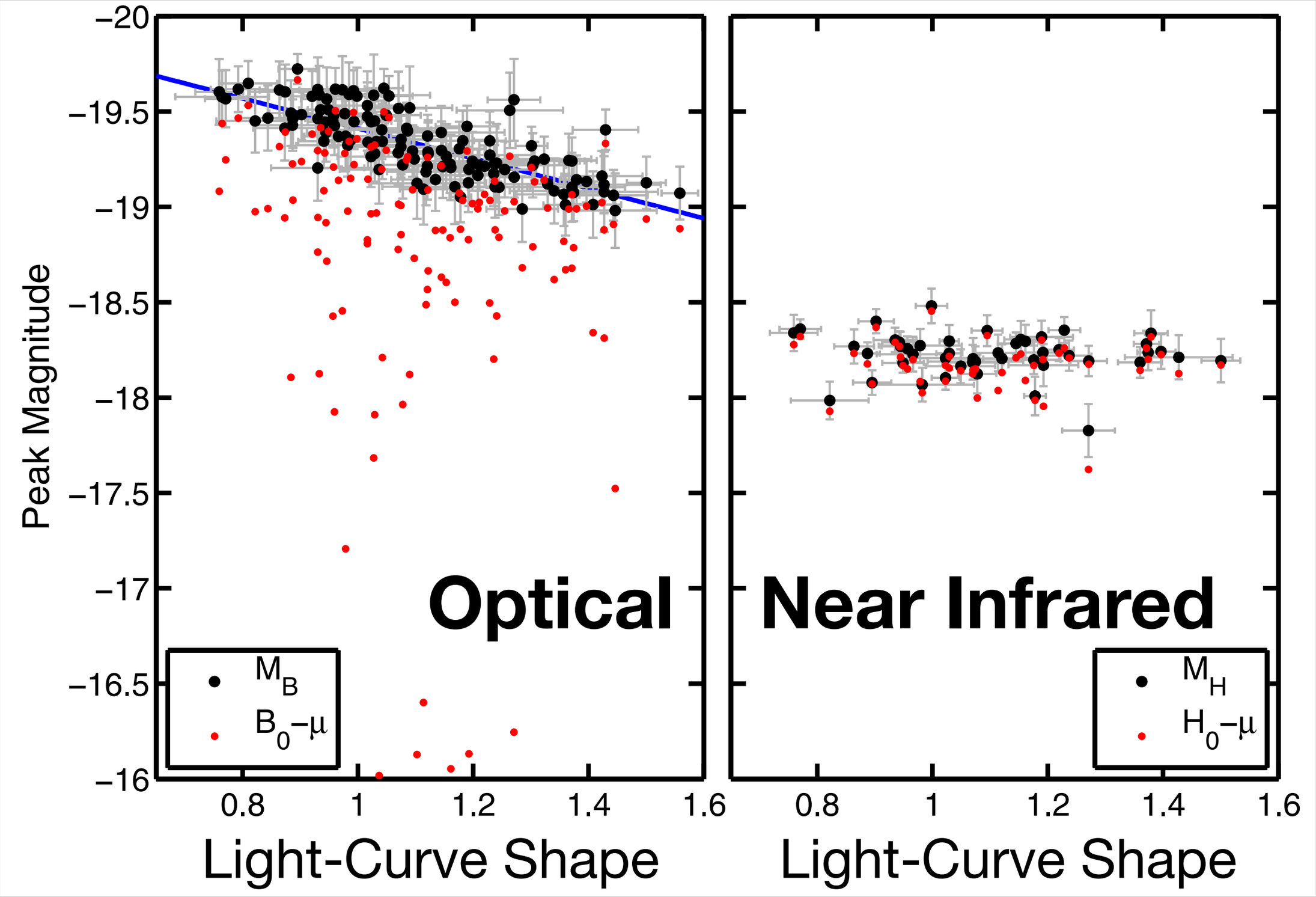
Near Infrared

Theory Points to the IR for Cosmology



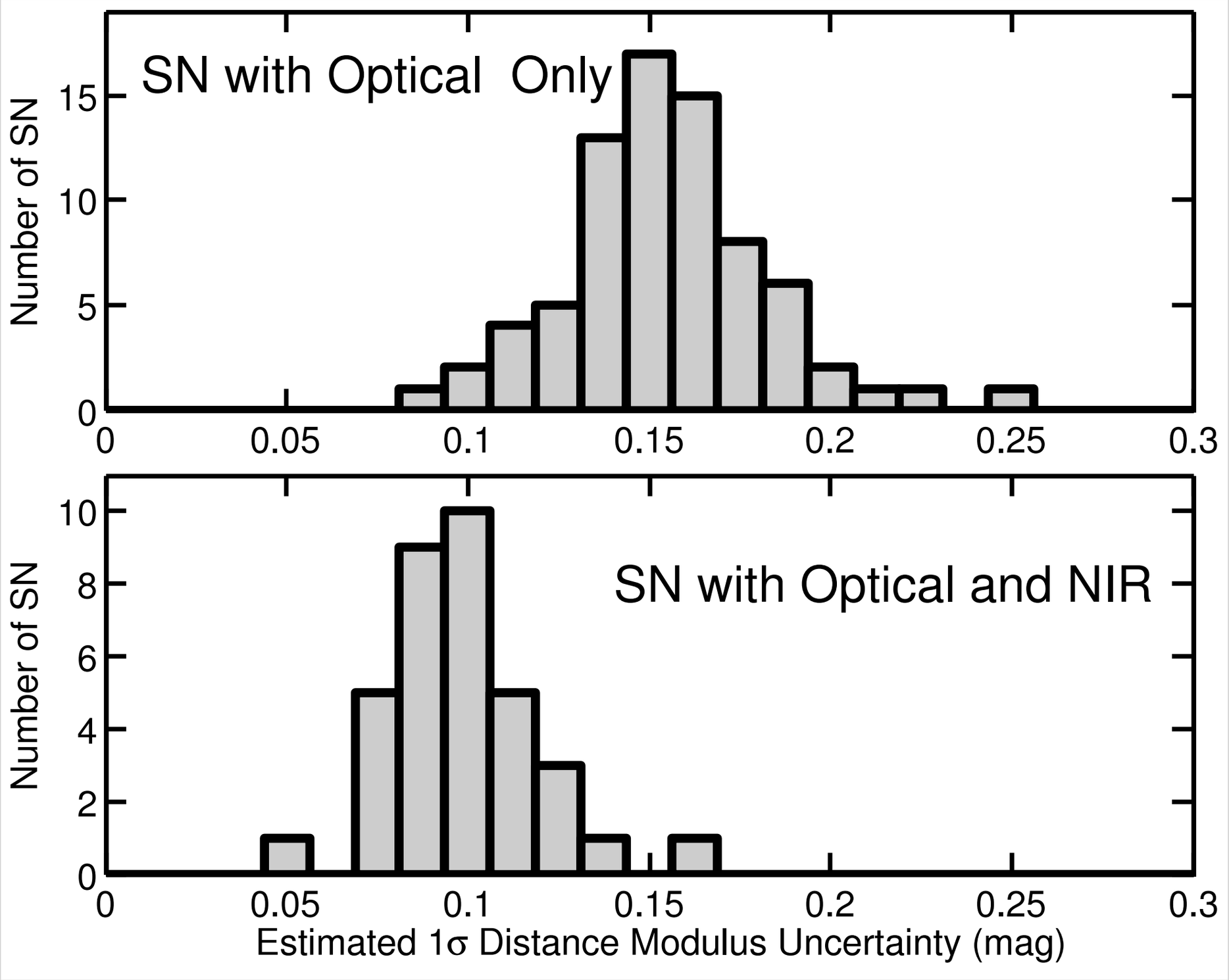
Kasen 2006

Smaller Light Curve Corrections in IR



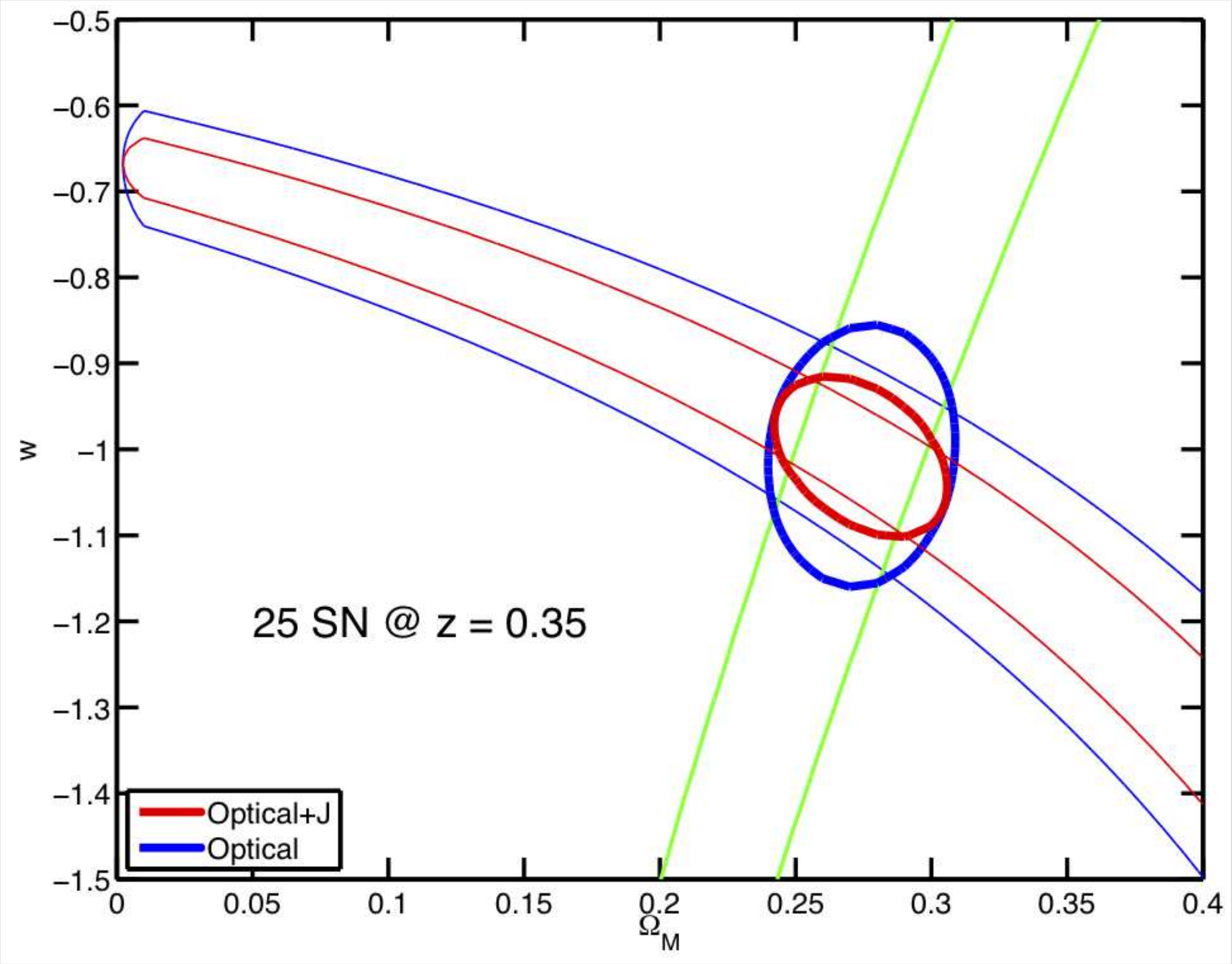
Mandel et al., 2011

Smaller Total Errors in IR



Mandel et al., 2011

Adding NIR Improves Constraints



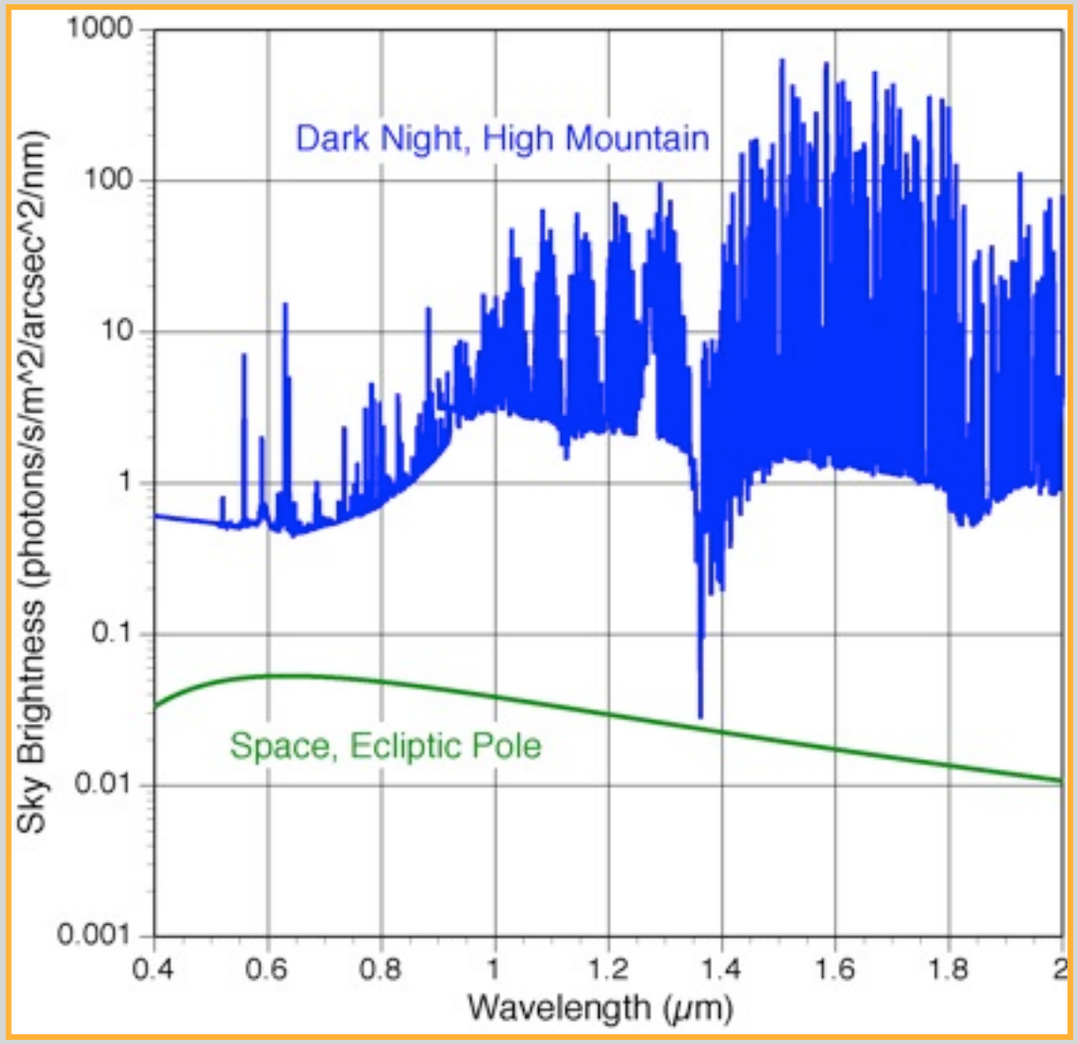
IR is Hard! (From the Ground)

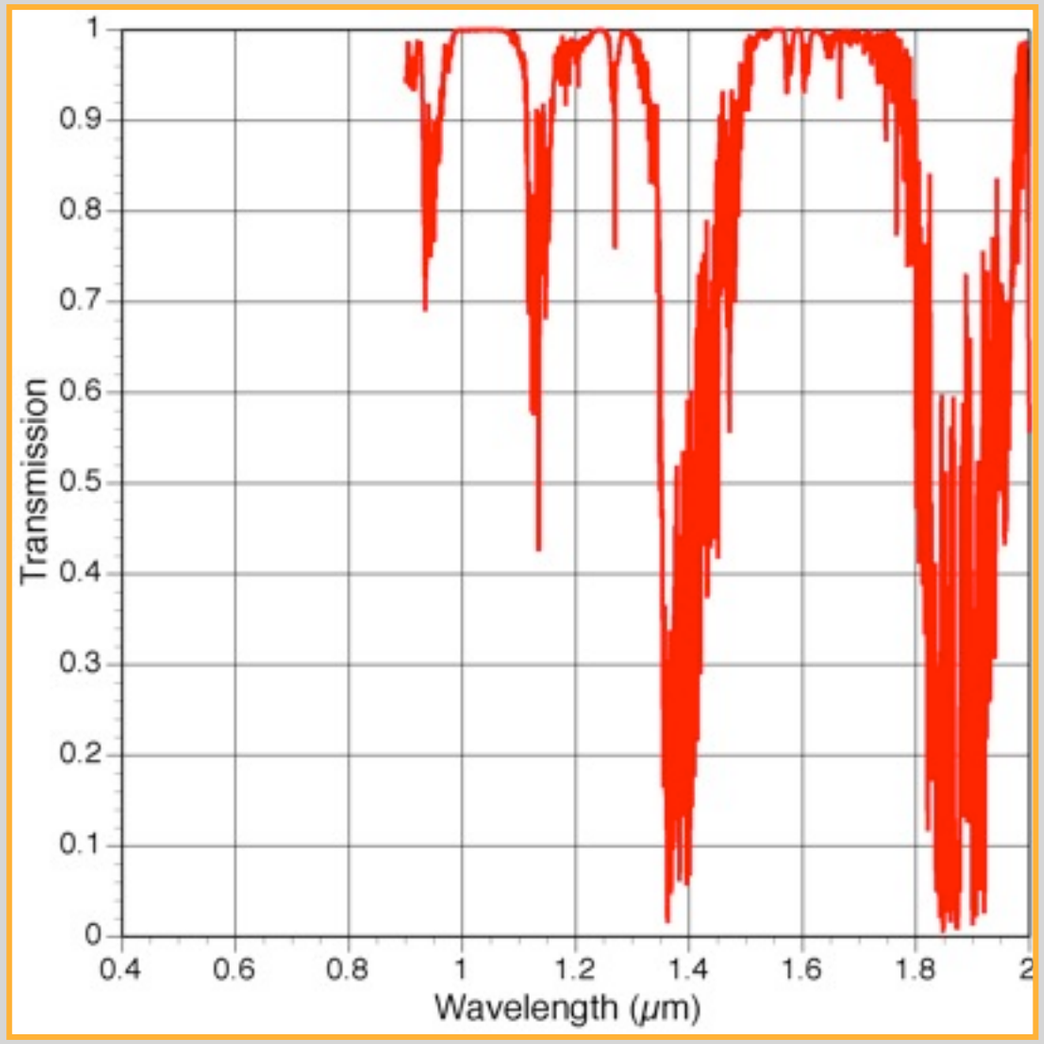
Rest frame IR measurements of z~1 supernovae are not possible from the ground

Go as far into the IR as technically feasible!

Sky is very bright in NIR: >100x brighter than in space

Sky is not transparent in NIR: absorption due to water is very strong and extremely variable

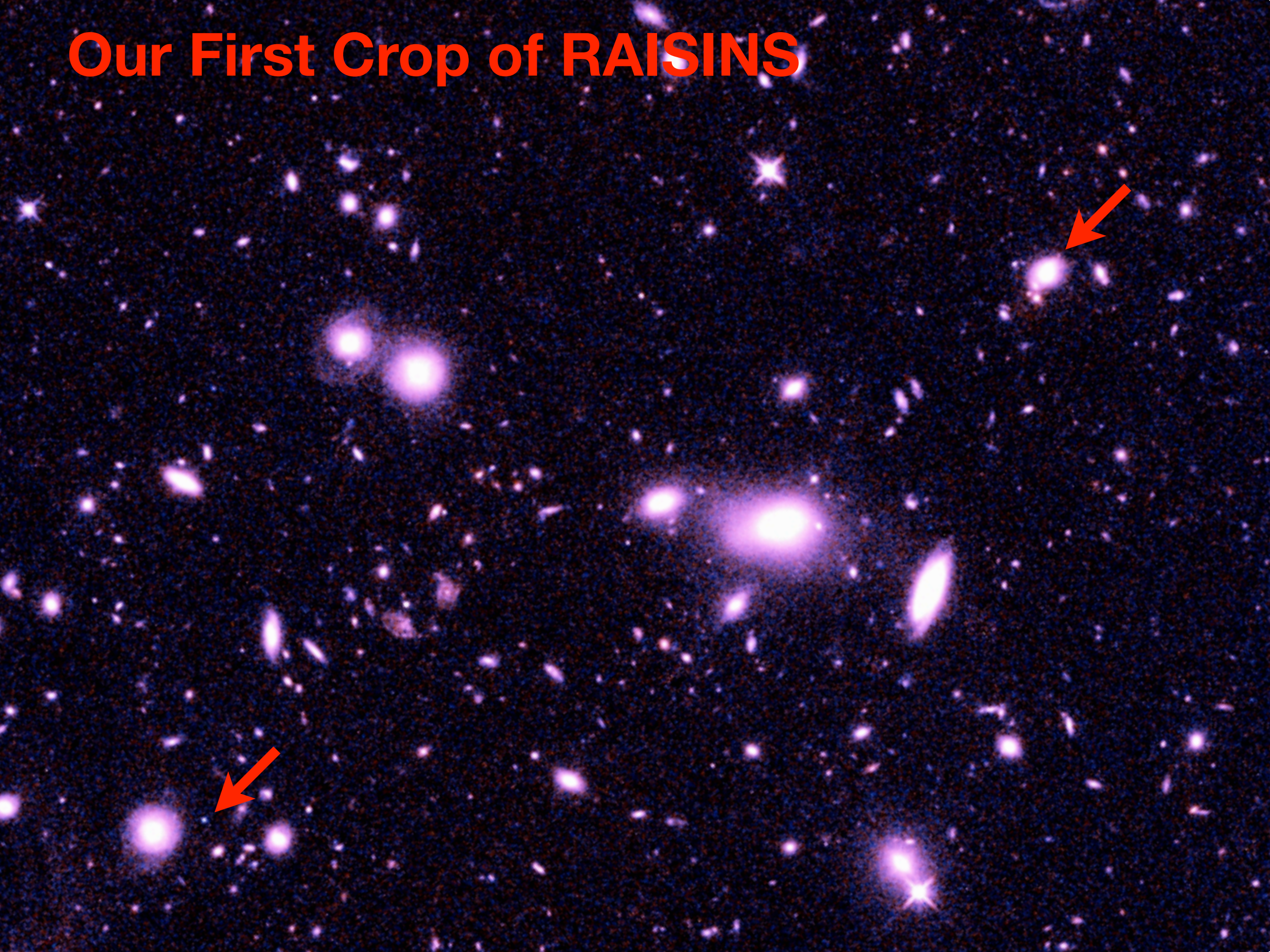




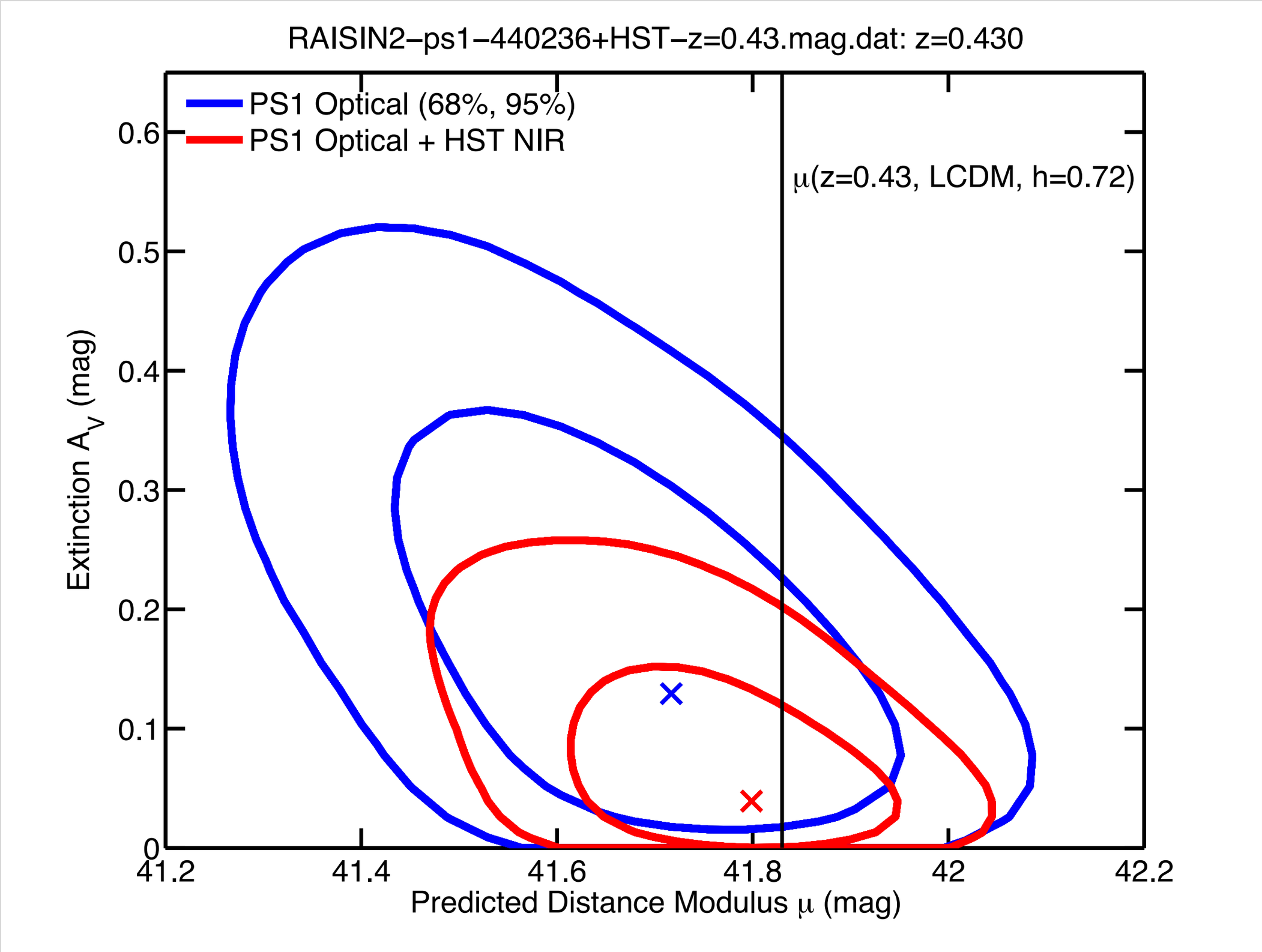
Use WFC3 to get rest frame IR of moderate redshift SN Ia!

RAISIN
100 orbits

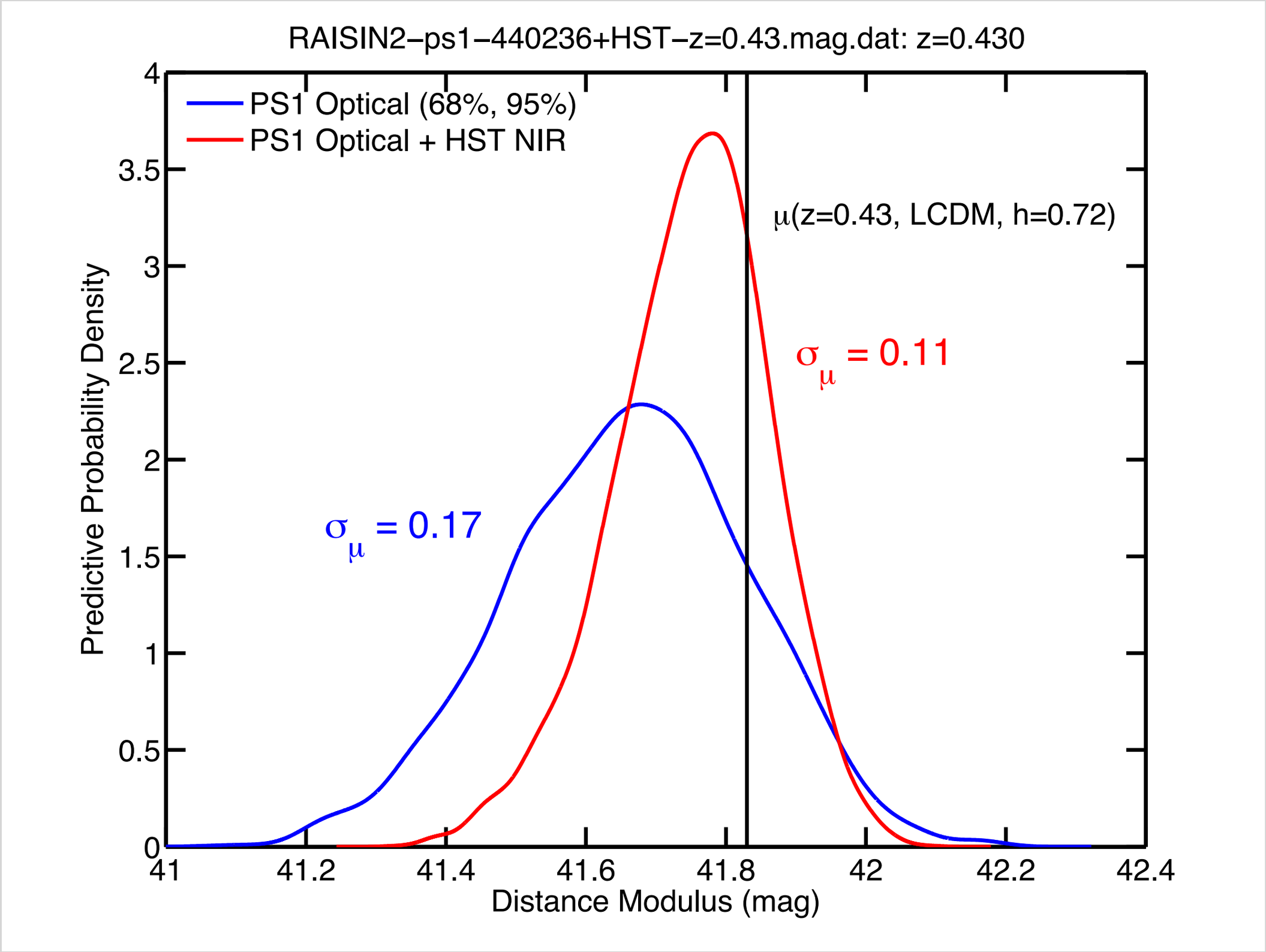
Our First Crop of RAISINS



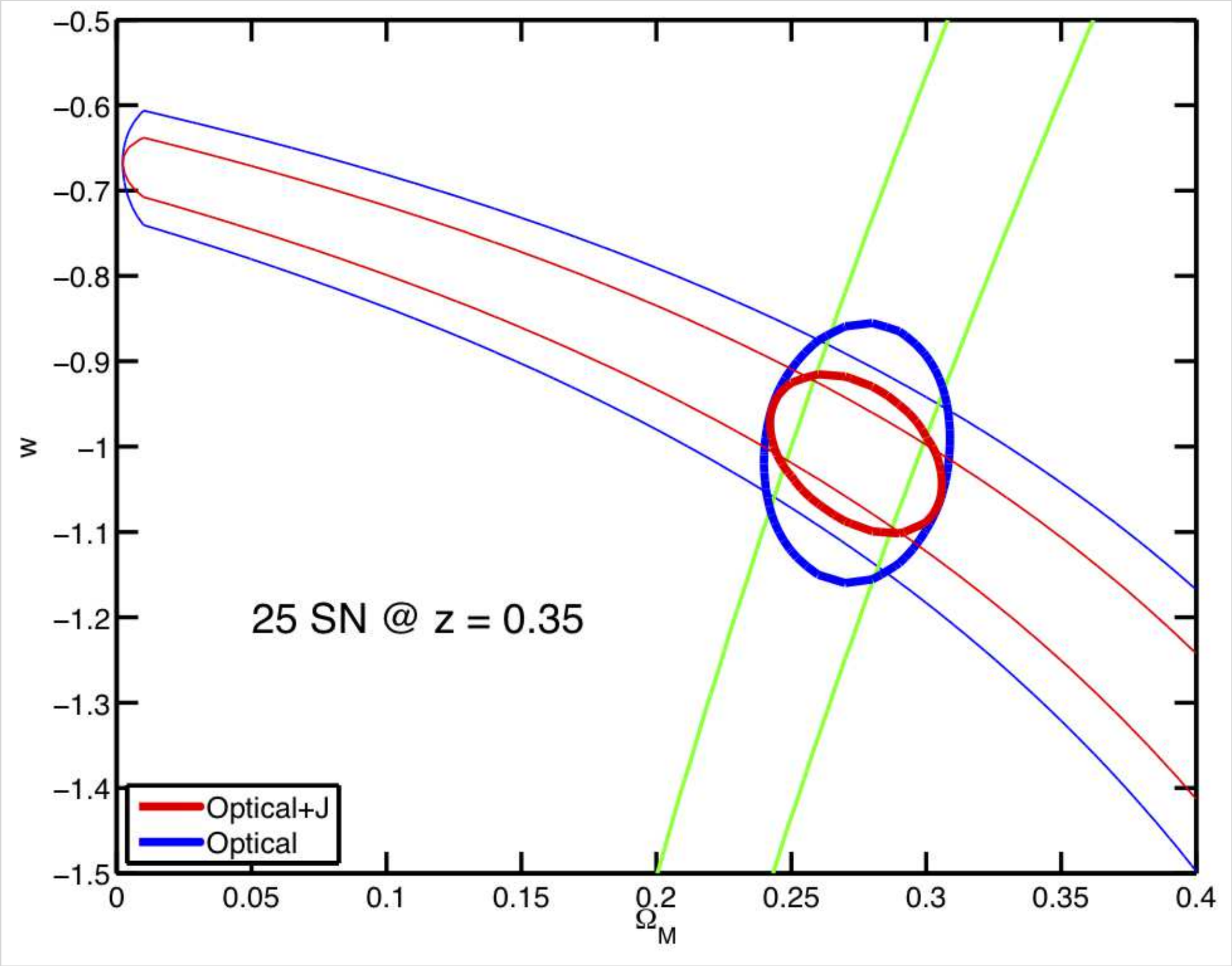
RAISIN is Working!



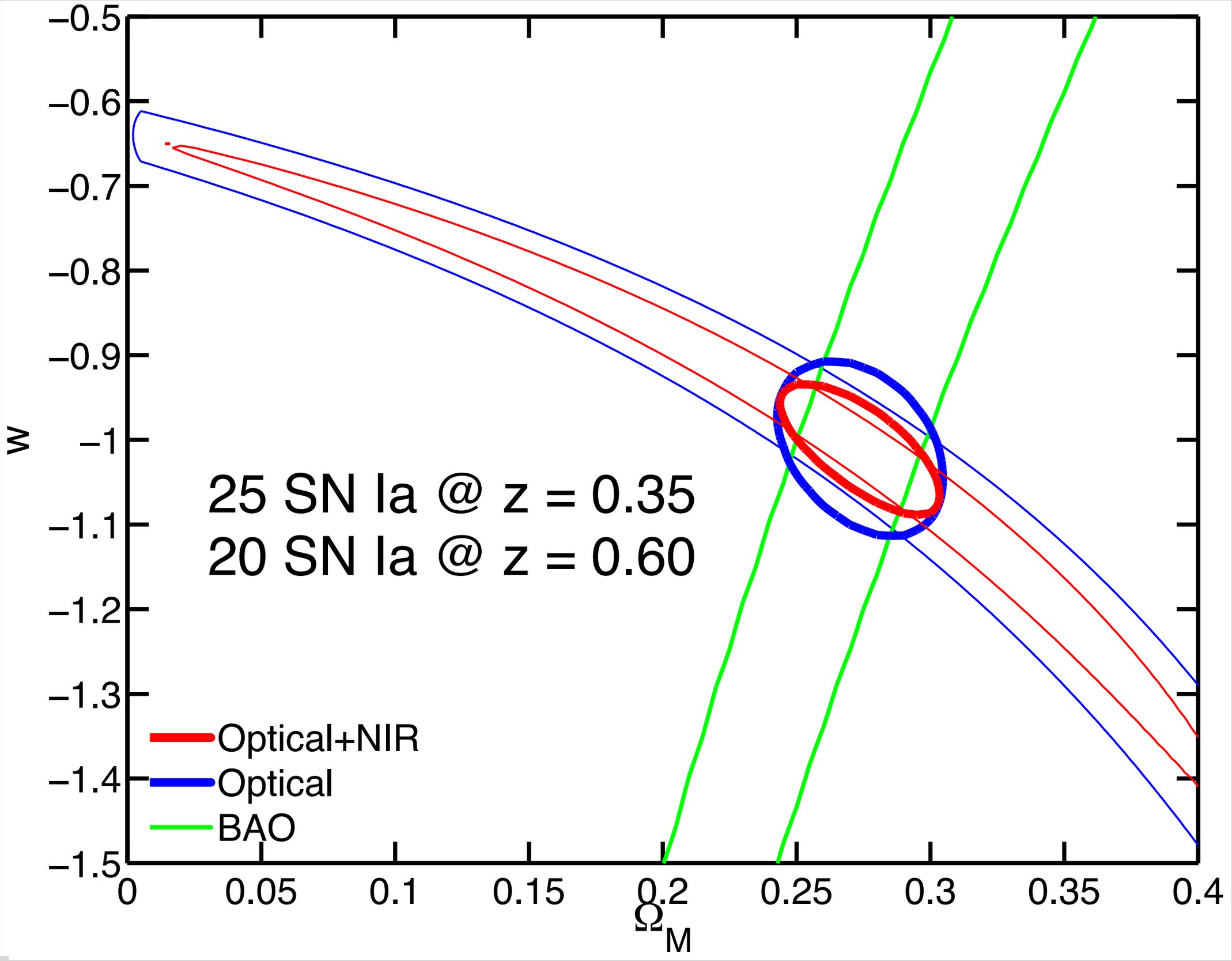
Better than Expected!



RAISIN 2

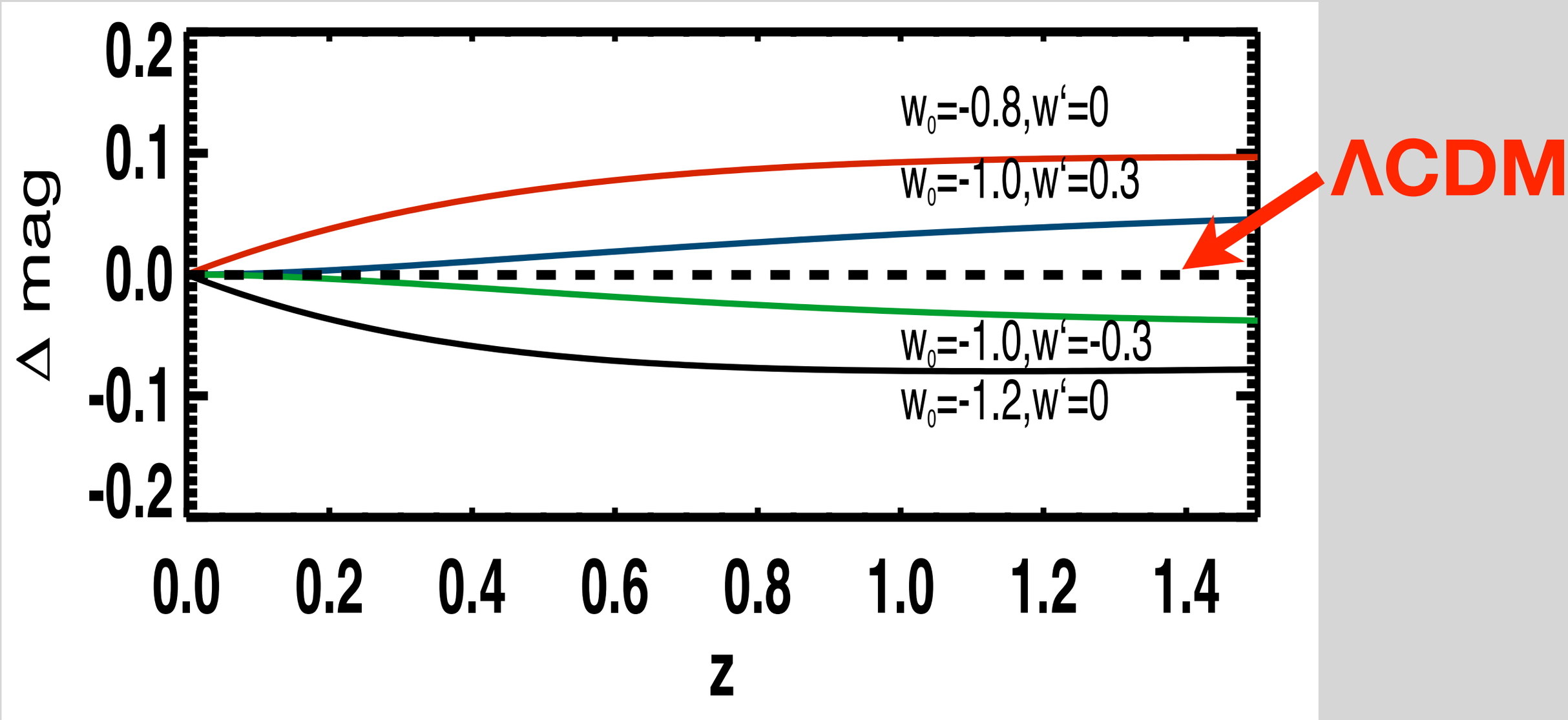

25 SN @ z = 0.35
Optical+J
Optical
w
Ω_M
−0.5
−0.6
−0.7
−0.8
−0.9
−1
−1.1
−1.2
−1.3
−1.4
−1.5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

RAISIN 2

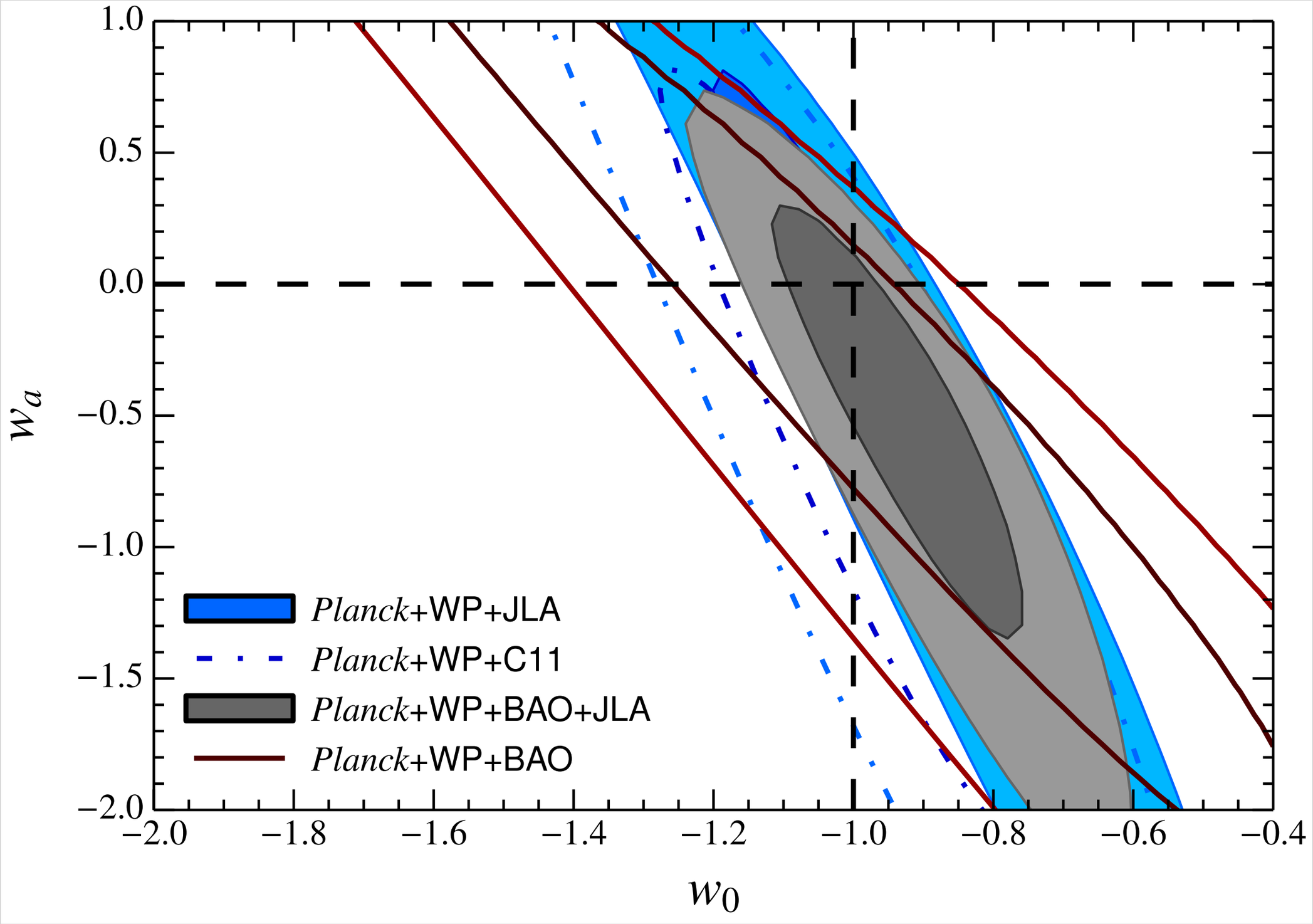

25 SN Ia @ z = 0.35
20 SN Ia @ z = 0.60
Optical+NIR
Optical
BAO
w
Ω_M
−0.5
−0.6
−0.7
−0.8
−0.9
−1
−1.1
−1.2
−1.3
−1.4
−1.5
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

Part 3: Prospects (The Future)

Measuring w′ is Really Hard

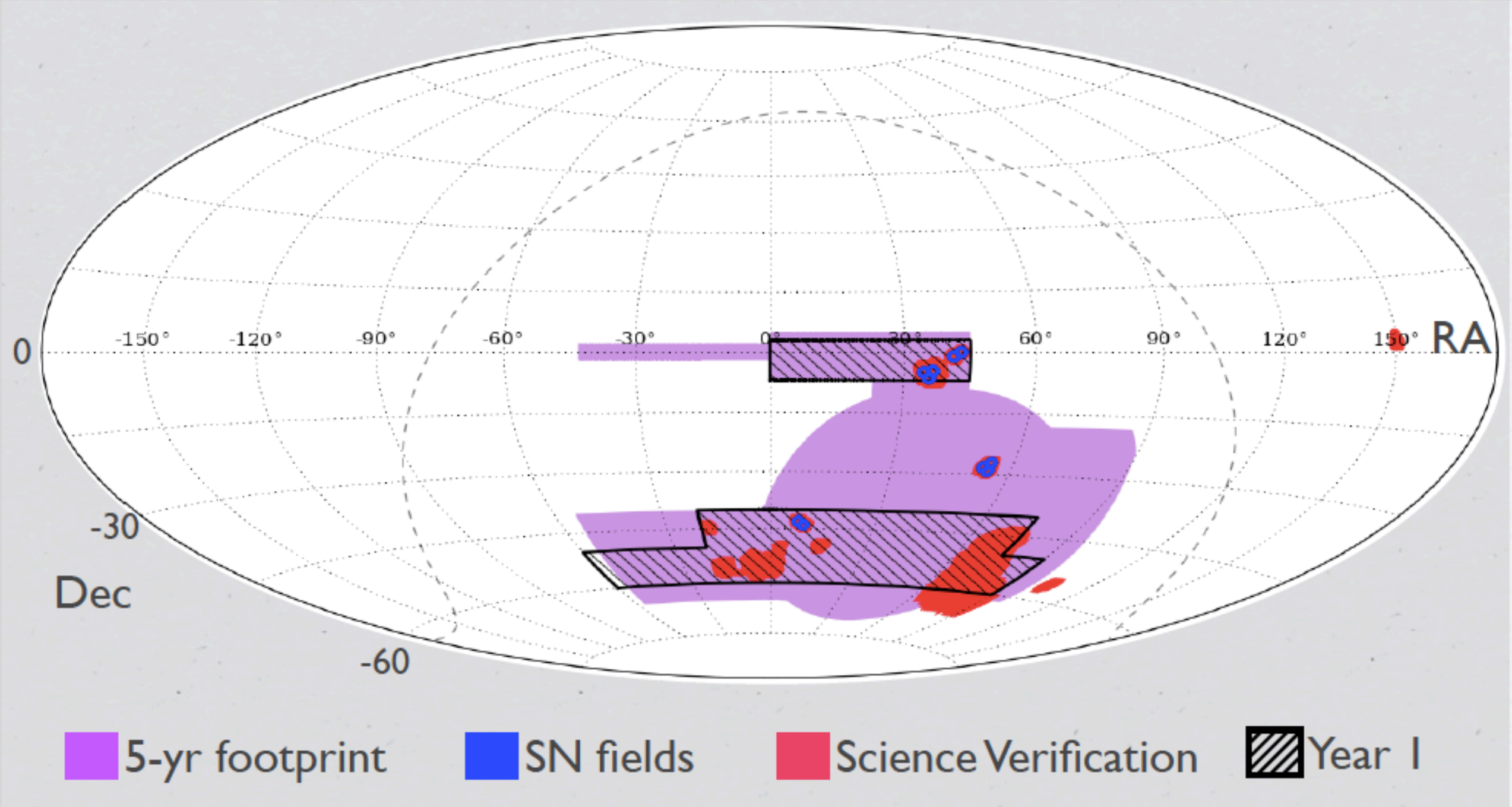


$w_0 = -0.96 \pm 0.12$; $w_a = -0.34 \pm 0.55$

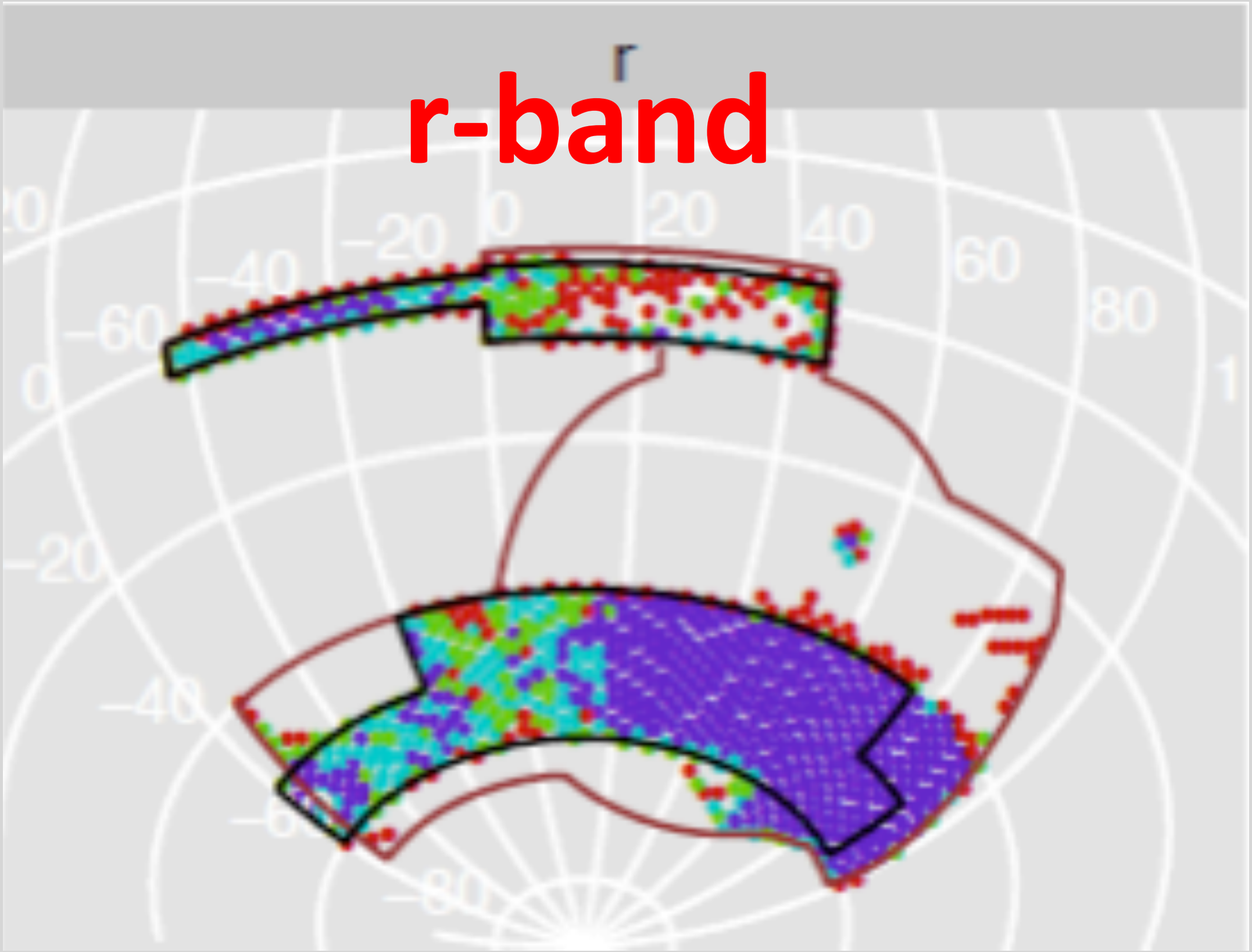


Betoule et al. 2014

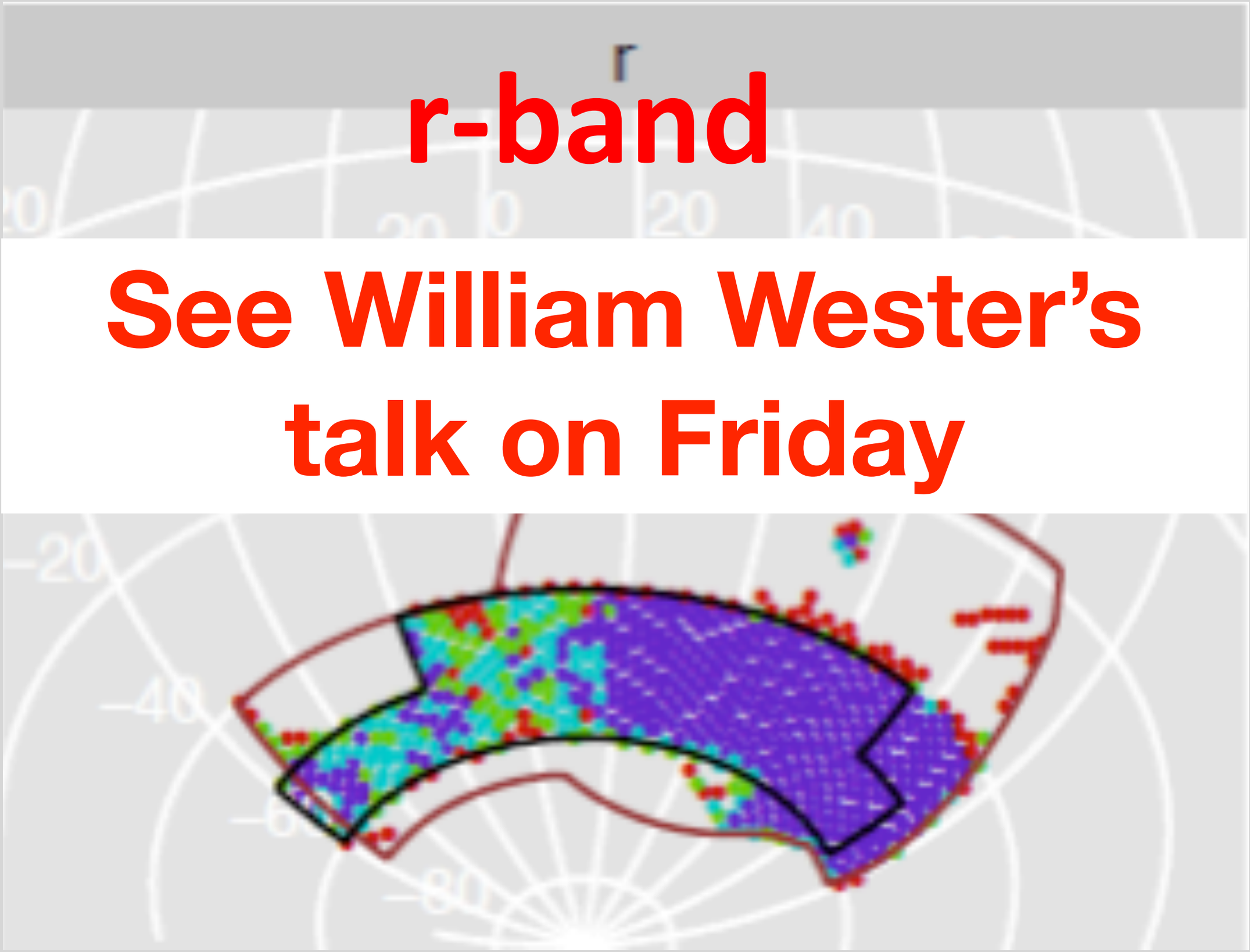
Dark Energy Survey



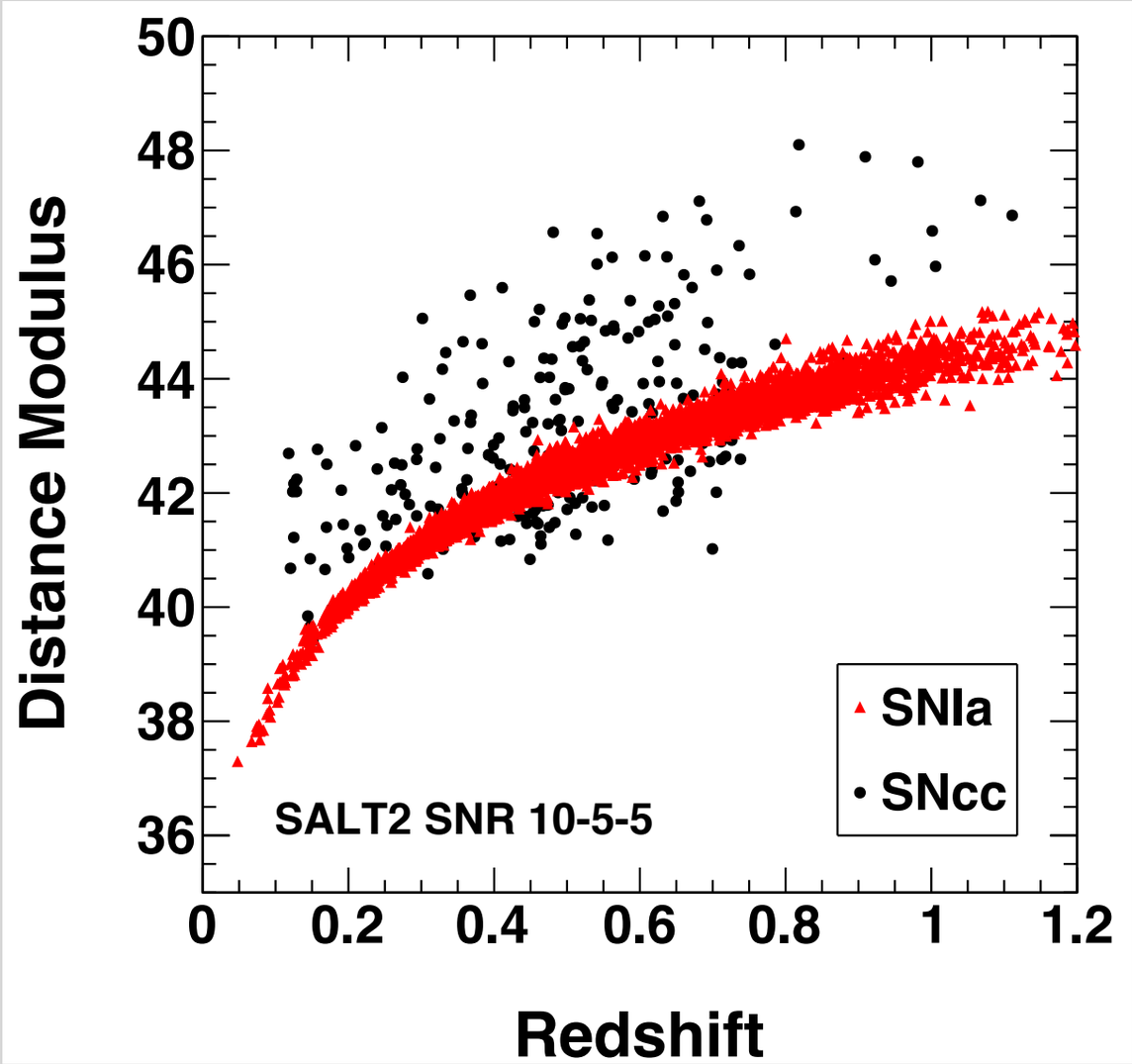
Dark Energy Survey



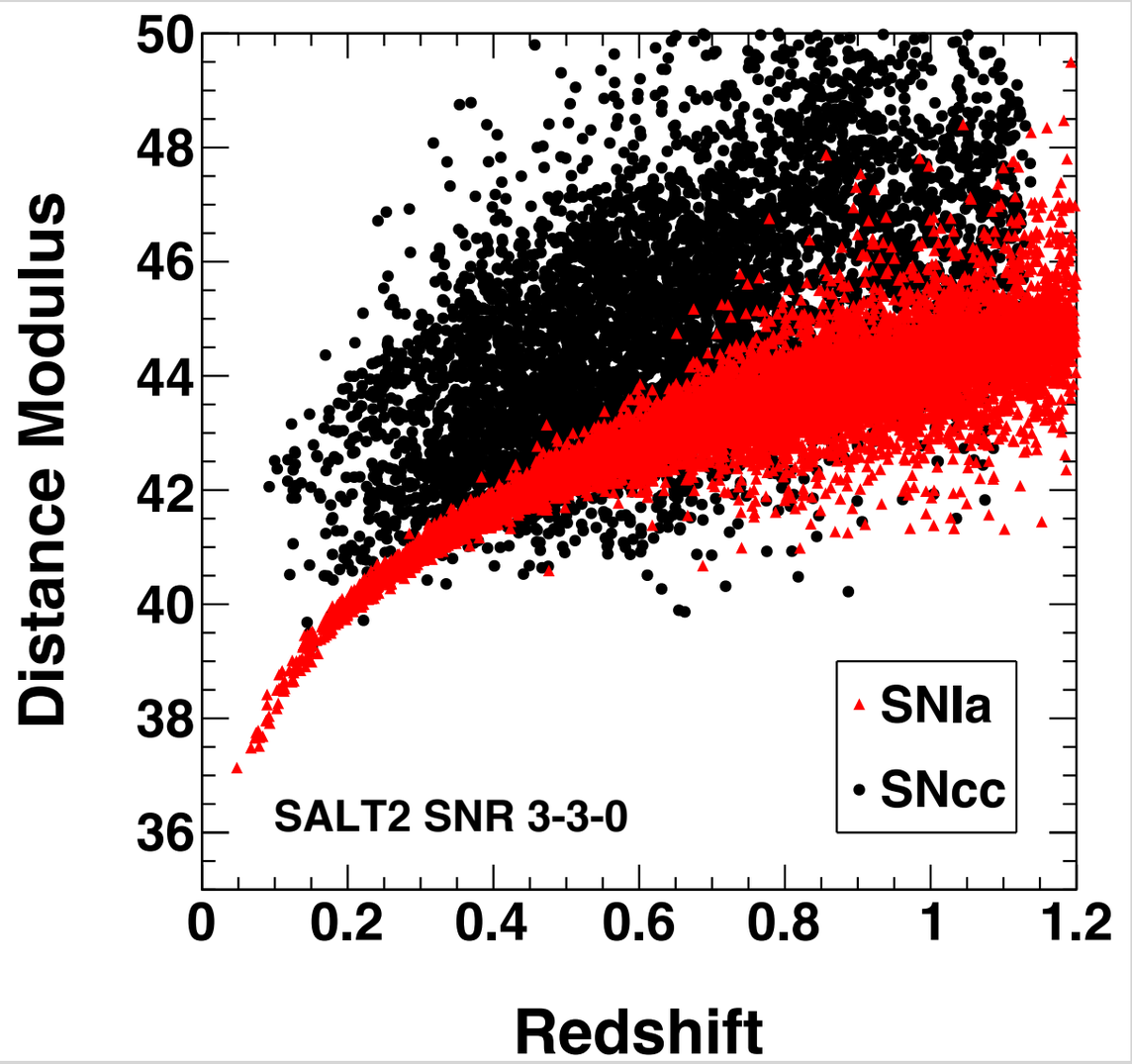
Dark Energy Survey



Contamination from Lack of Spectra



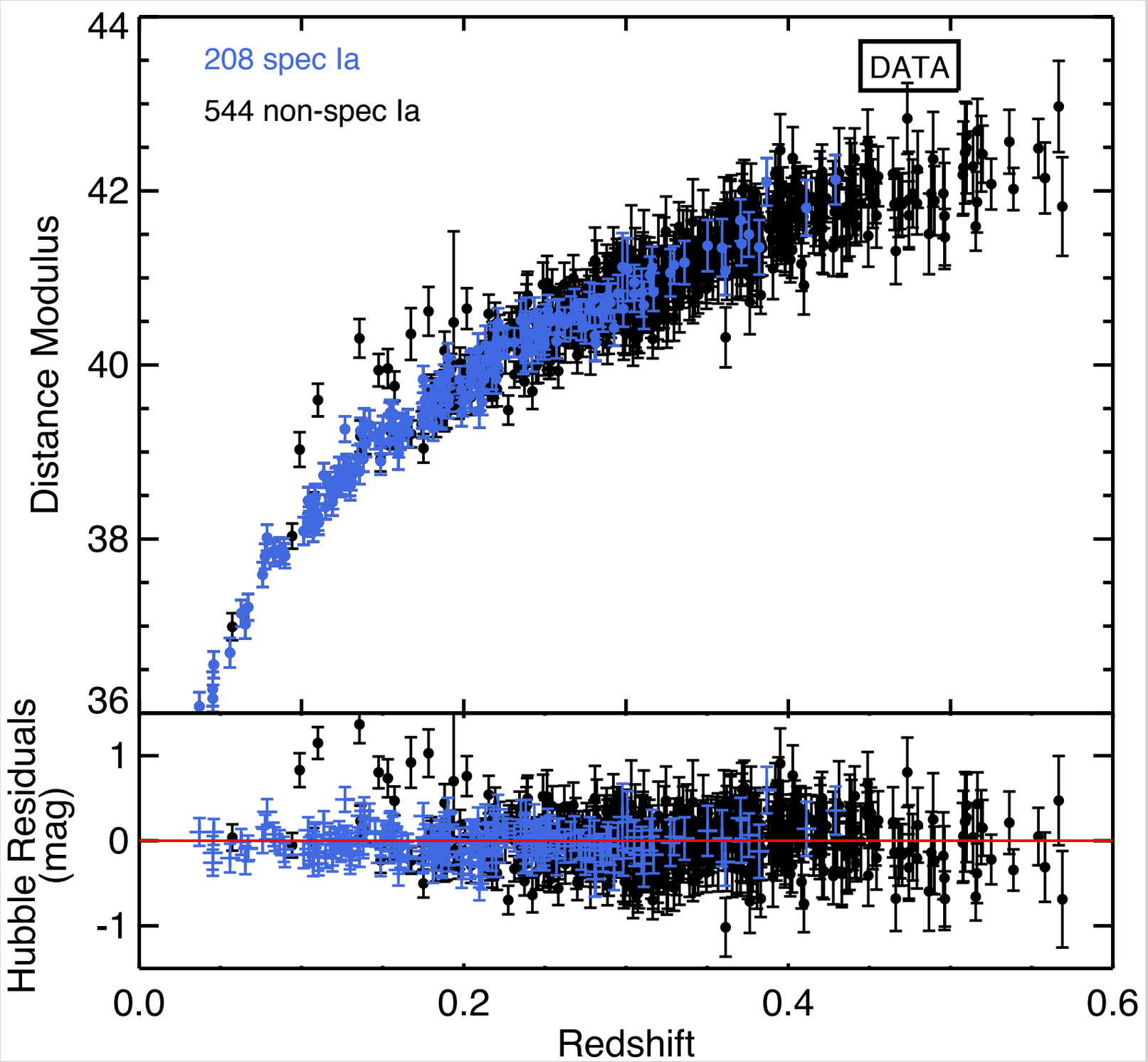
Strict Cuts FoM=196



Loose Cuts FoM=104

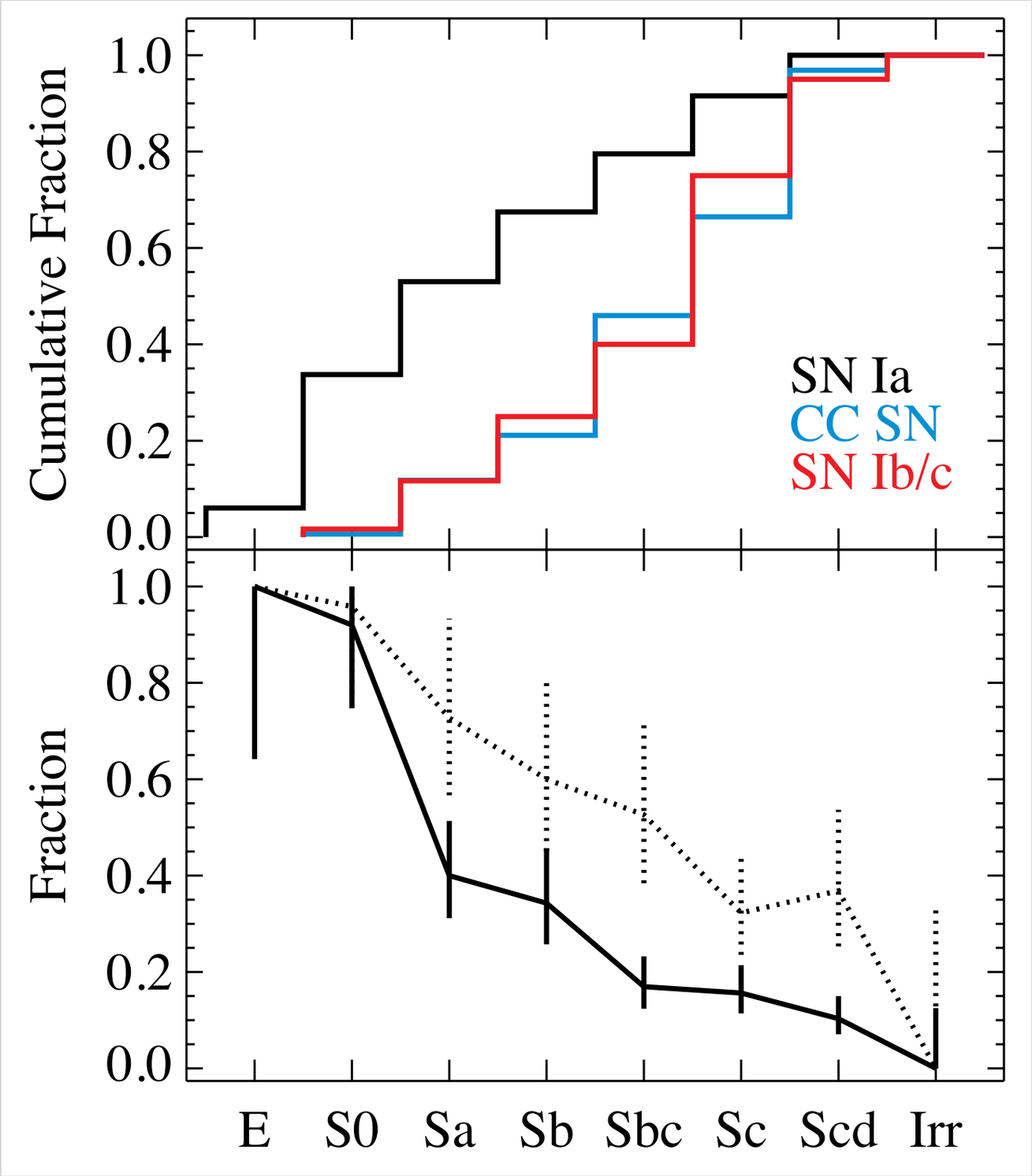
Gjergo et al. 2013

Contamination from Lack of Spectra



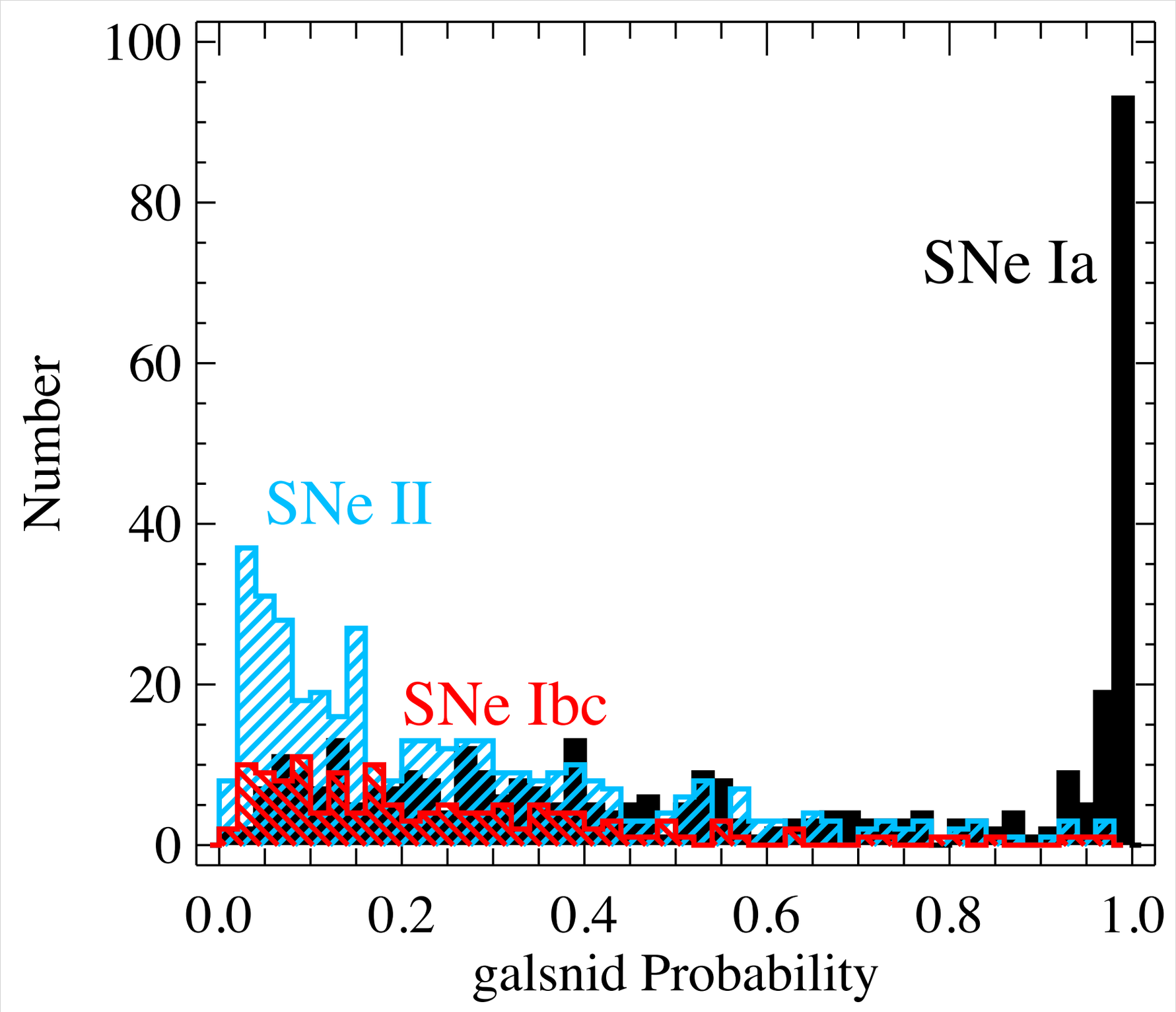
Campbell et al. 2013

Use Host Properties to Find SNe Ia



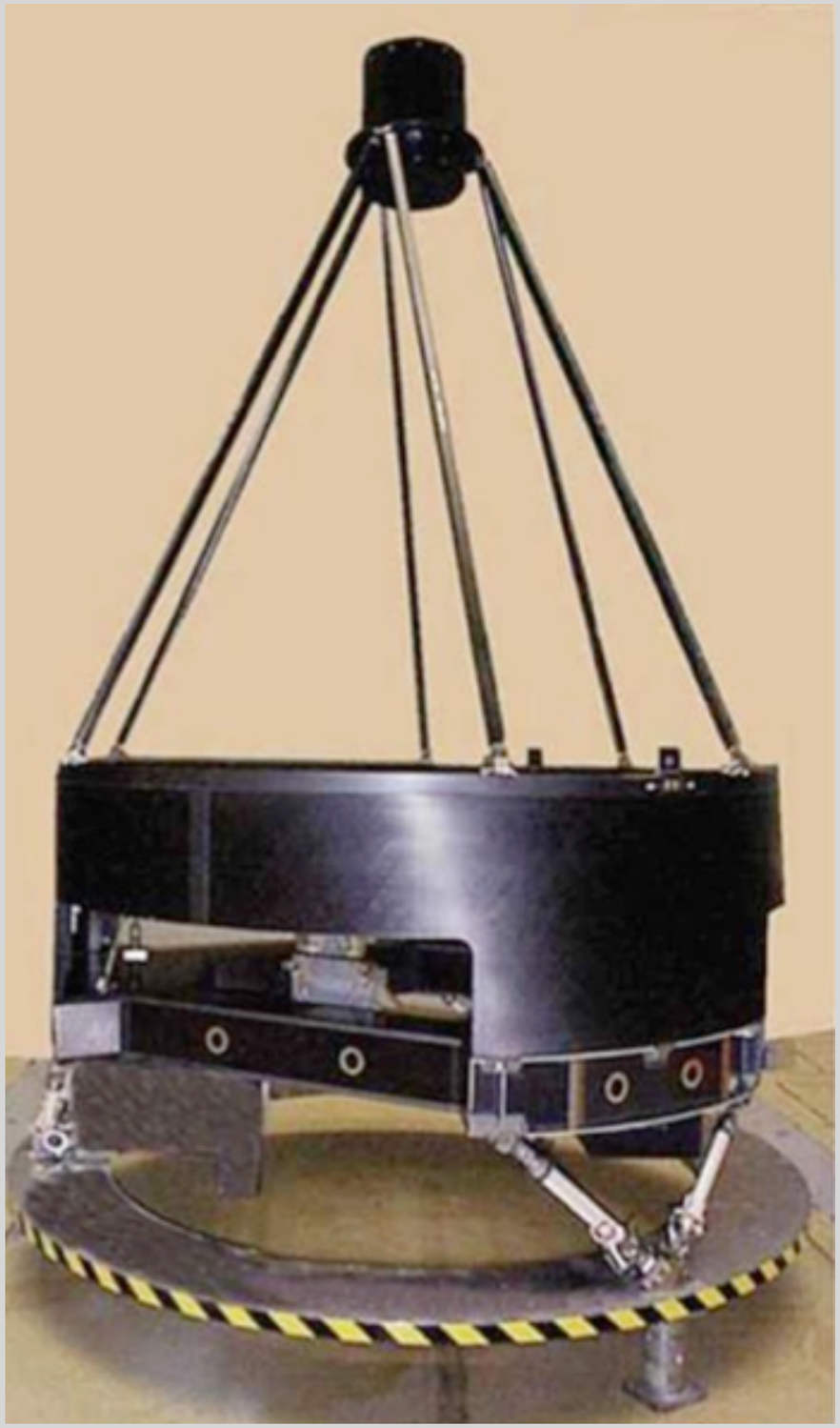
Foley & Mandel 2013

Use Host Properties to Find SNe Ia



Foley & Mandel 2013

Two NRO Satellites Transferred to NASA

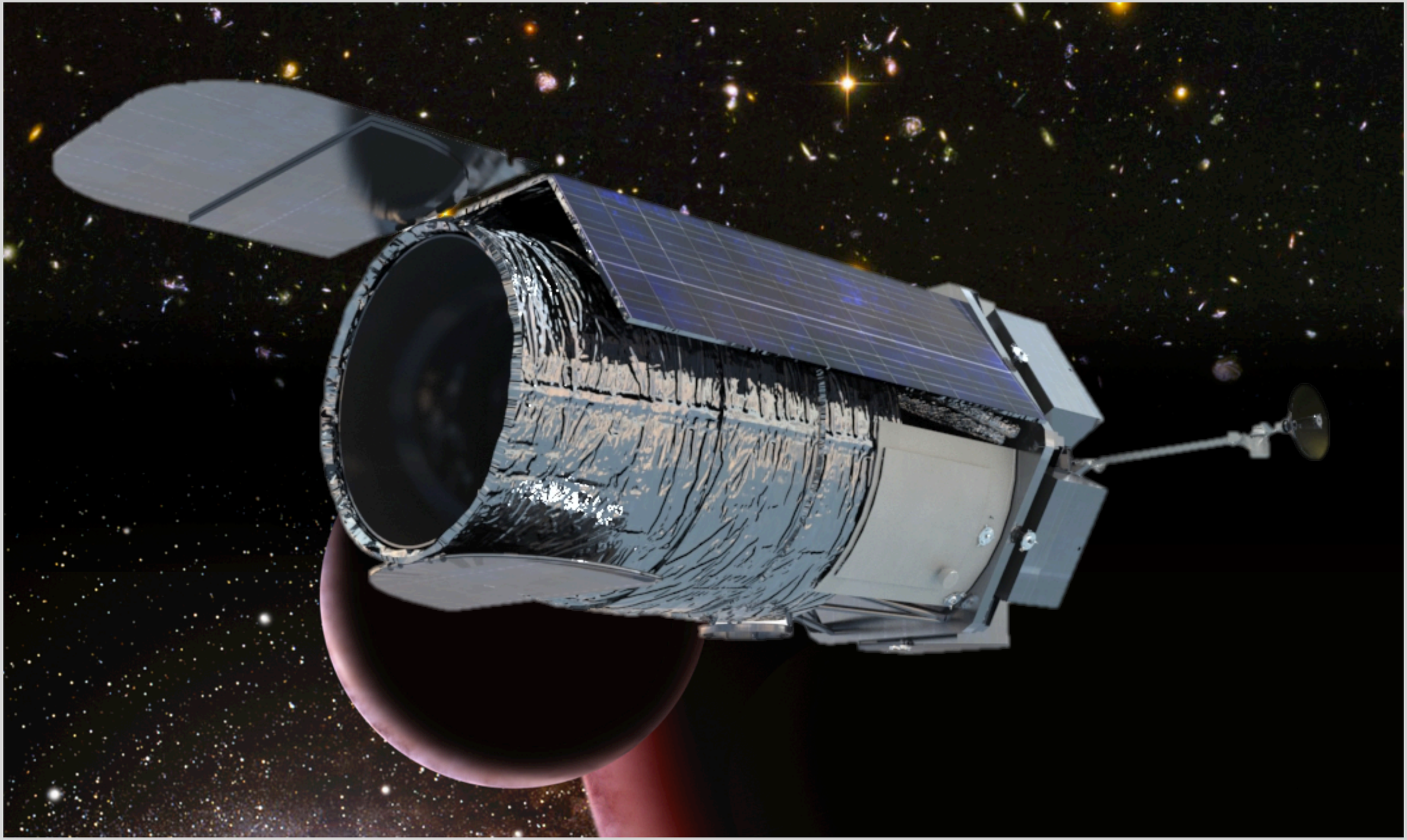


2.4 m, like Hubble

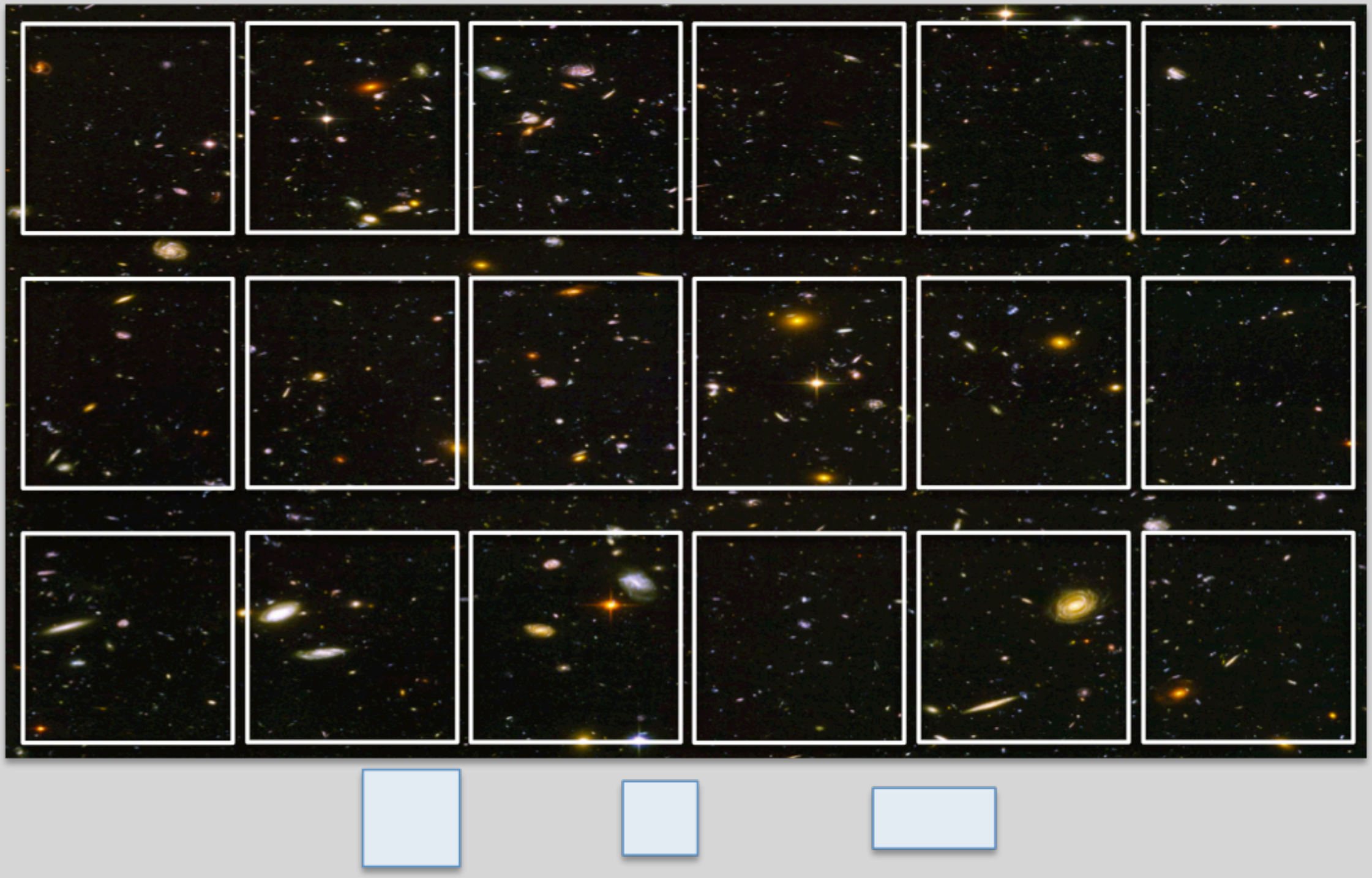
Much wider FOV than Hubble

“Free”

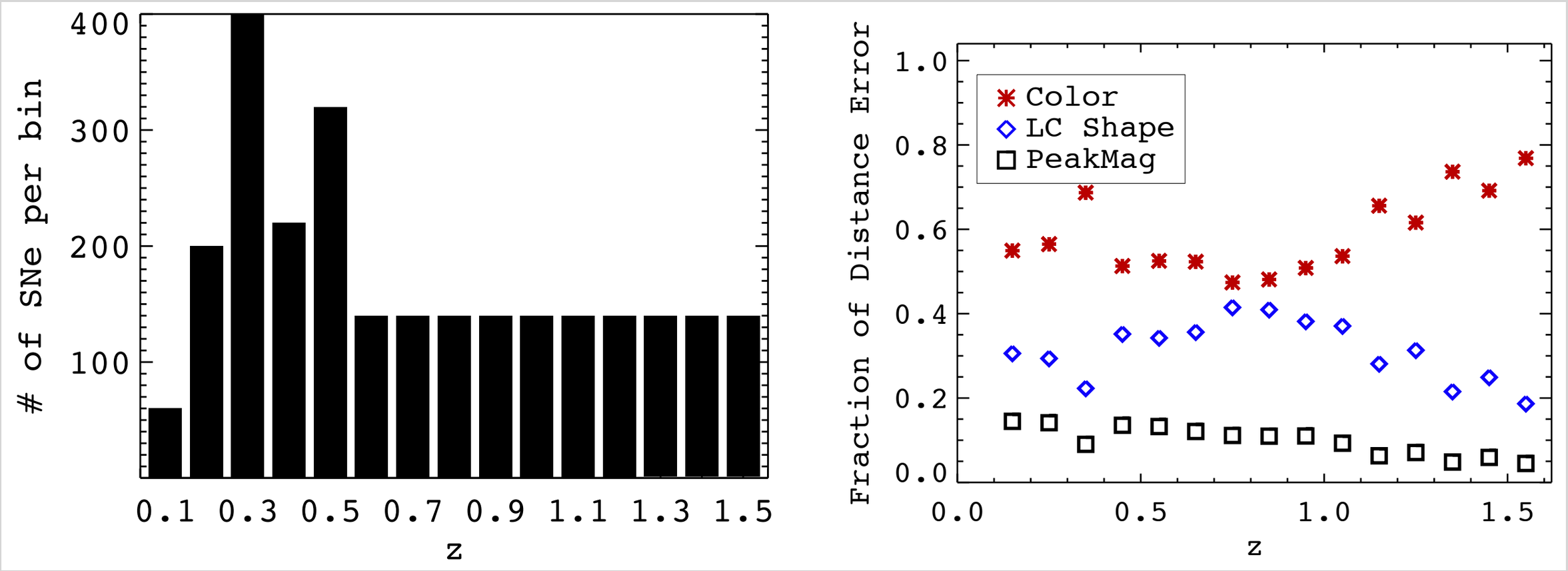
WFIRST-AFTA



WFIRST-AFTA: 0.79 x 0.43 degrees



WFIRST-AFTA: SN Survey

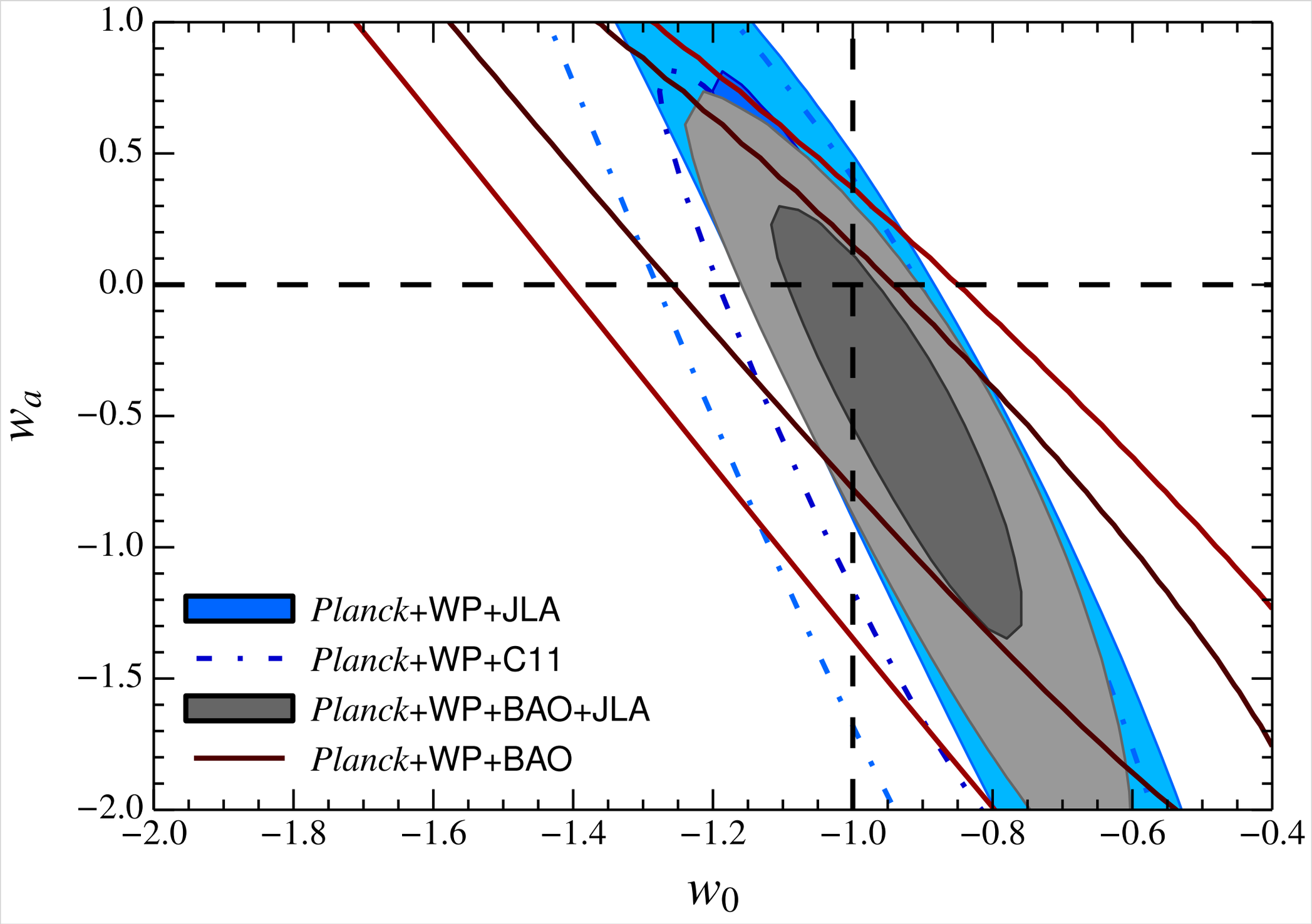


Foley & Scolnic

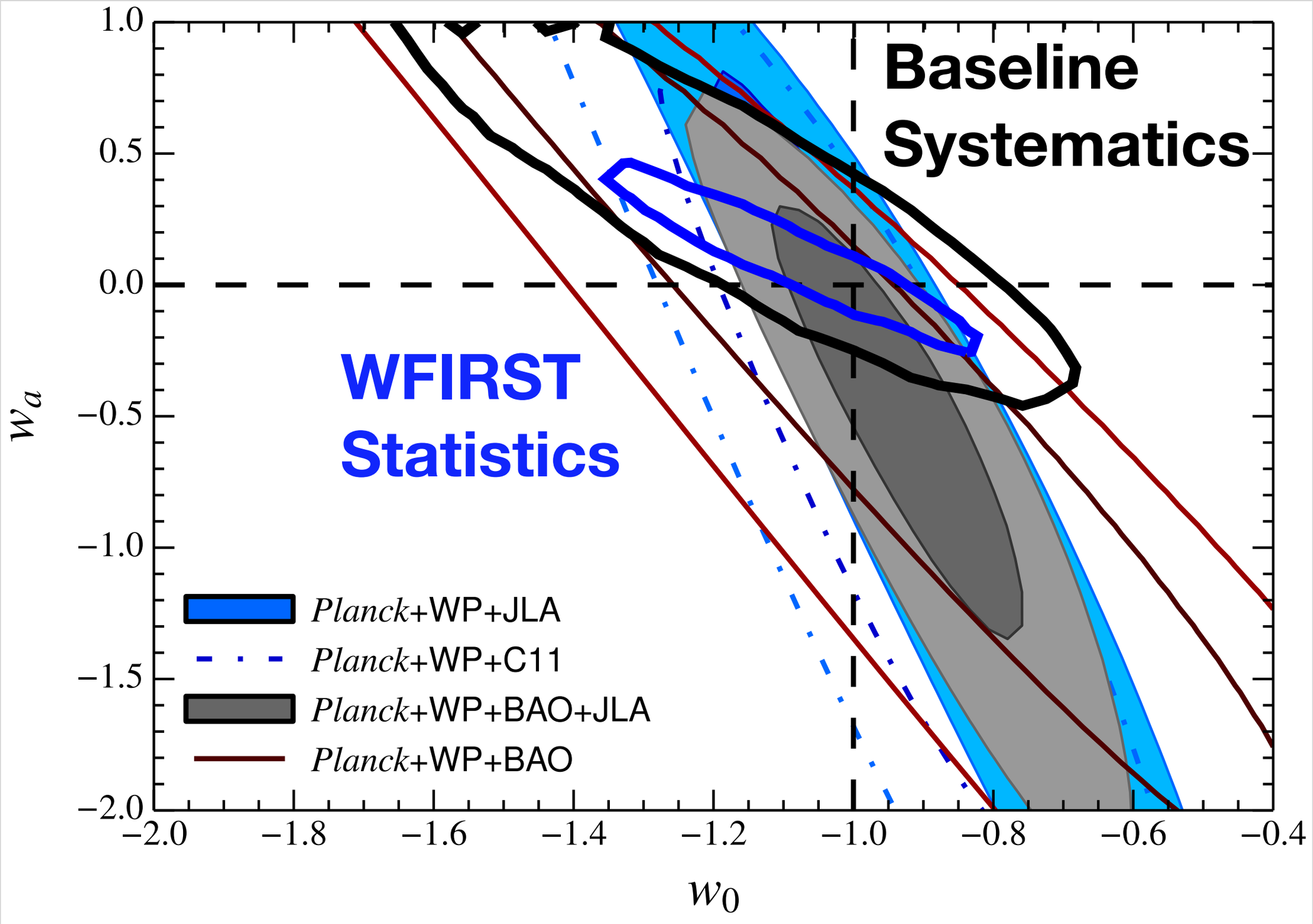
2700 SNe to z ≈ 1.7 *with spectra*

Color/Dust still biggest systematic

WFIRST-AFTA SN Constraints

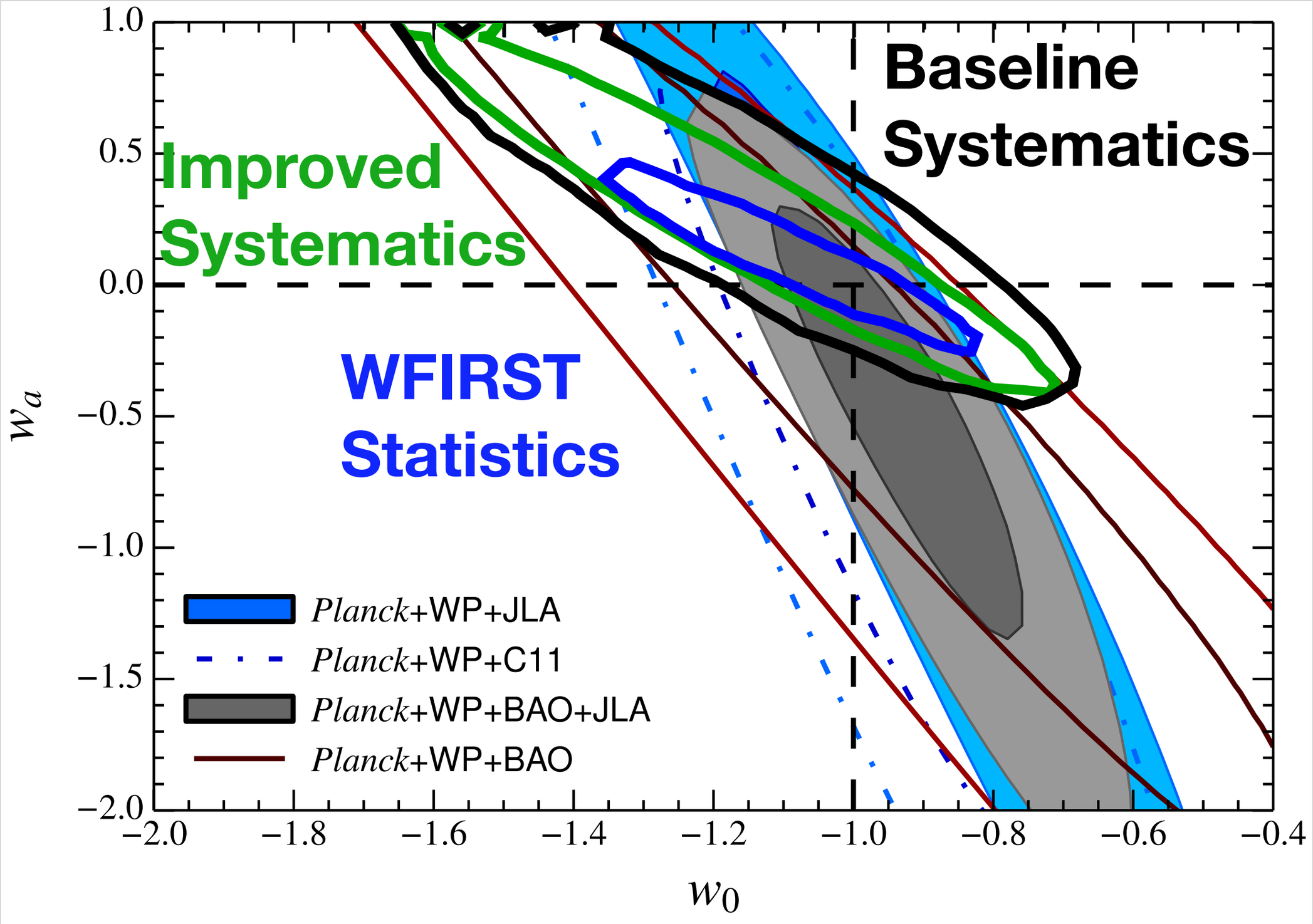


WFIRST-AFTA SN Constraints



Foley & Scolnic

WFIRST-AFTA SN Constraints



Foley & Scolnic

Type Ia Supernovae are extremely excellent cosmological distance indicators

SNe Ia were used to discover the Universe's acceleration

We have overcome previous hurdles, *but*

We are currently limited by systematics

Correcting for dust is arguably the largest systematic

Color used to determine amount of dust and distance

Higher velocity supernovae are redder

Measuring velocity (standardizing the crayon) reduces bias and scatter ➡ <u>more accurate and precise distances</u>

RAISIN follows the physics and avoids dust

RAISIN is a precursor to JWST and WFIRST

WFIRST and DES (and JWST and LSST) will be tranformational

Cosmology measurements will improve with more observations / understanding