Supernova Type Ia and Cosmology

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THE RESEARCH SCHOOL OF ASTRONOMY & ASTROPHYSICS
MOUNT STROMLO AND SIDING SPRING OBSERVATORIES

First use of Supernovae to Measure Distances

Fritz Zwicky

18in Schmidt Telescope

Charlie Kowal 1968

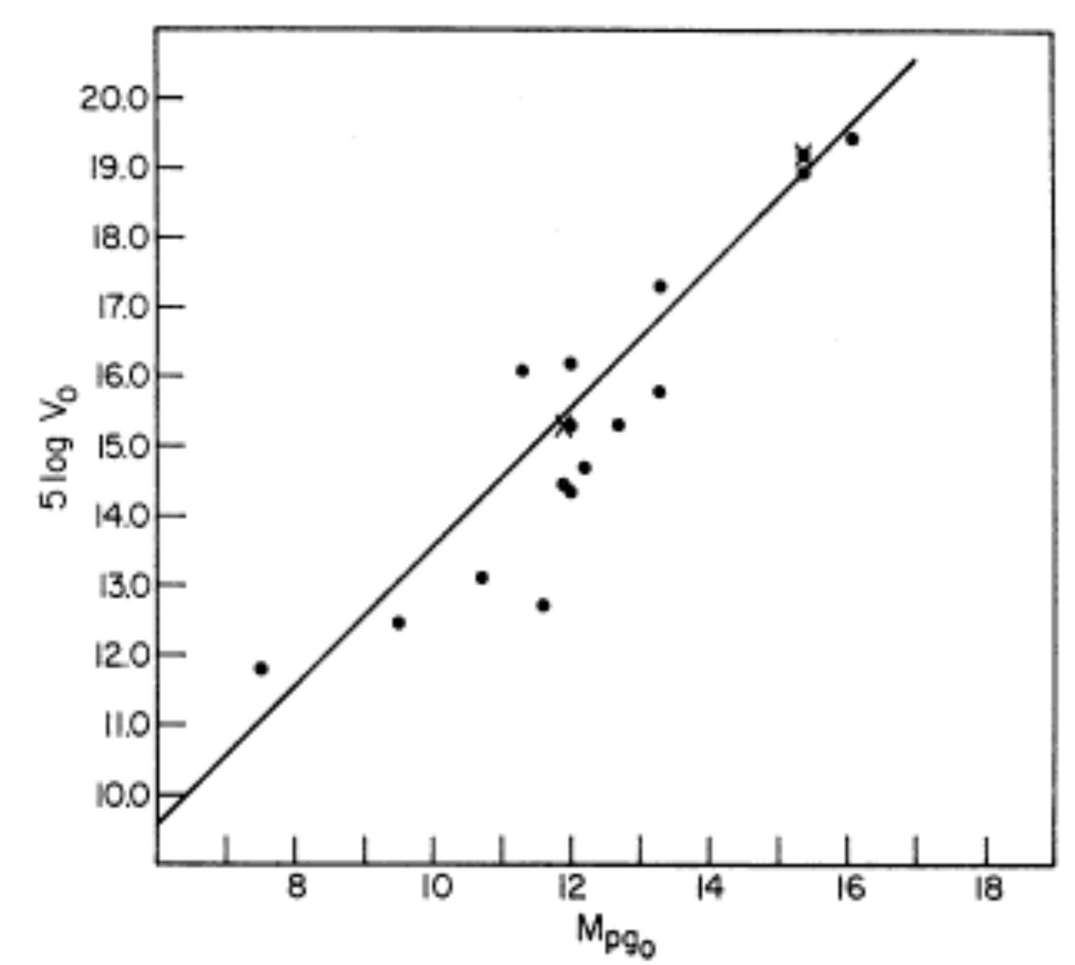
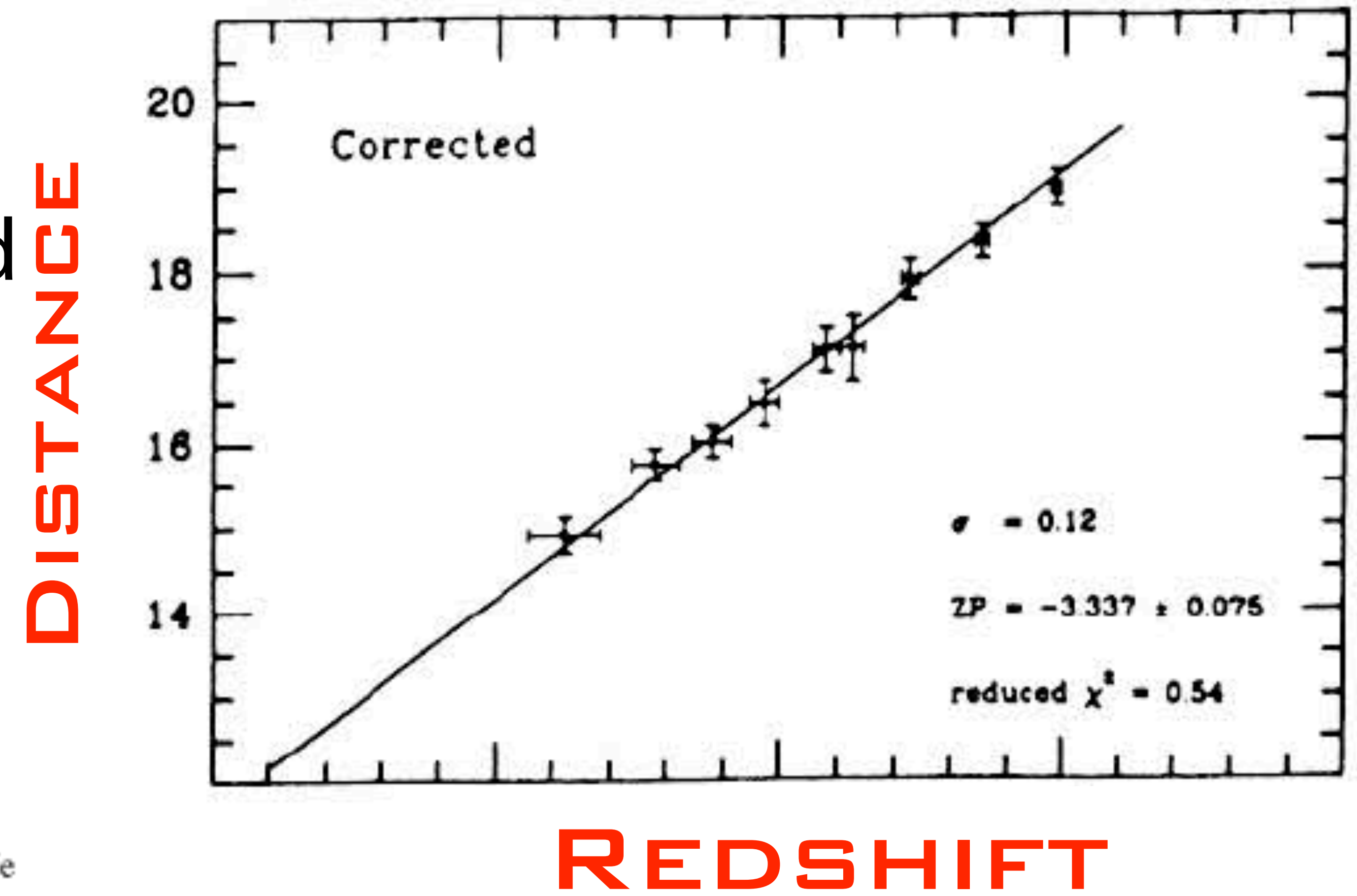


Fig. 1. The redshift–magnitude relation for supernovae of type I. The dots refer to individual supernovae, and the crosses represent averages for the Virgo and Coma clusters, as explained in the text.

Calan-Tololo SN Search

1994 Visit to Harvard
Mario Hamuy showed us this Diagram.

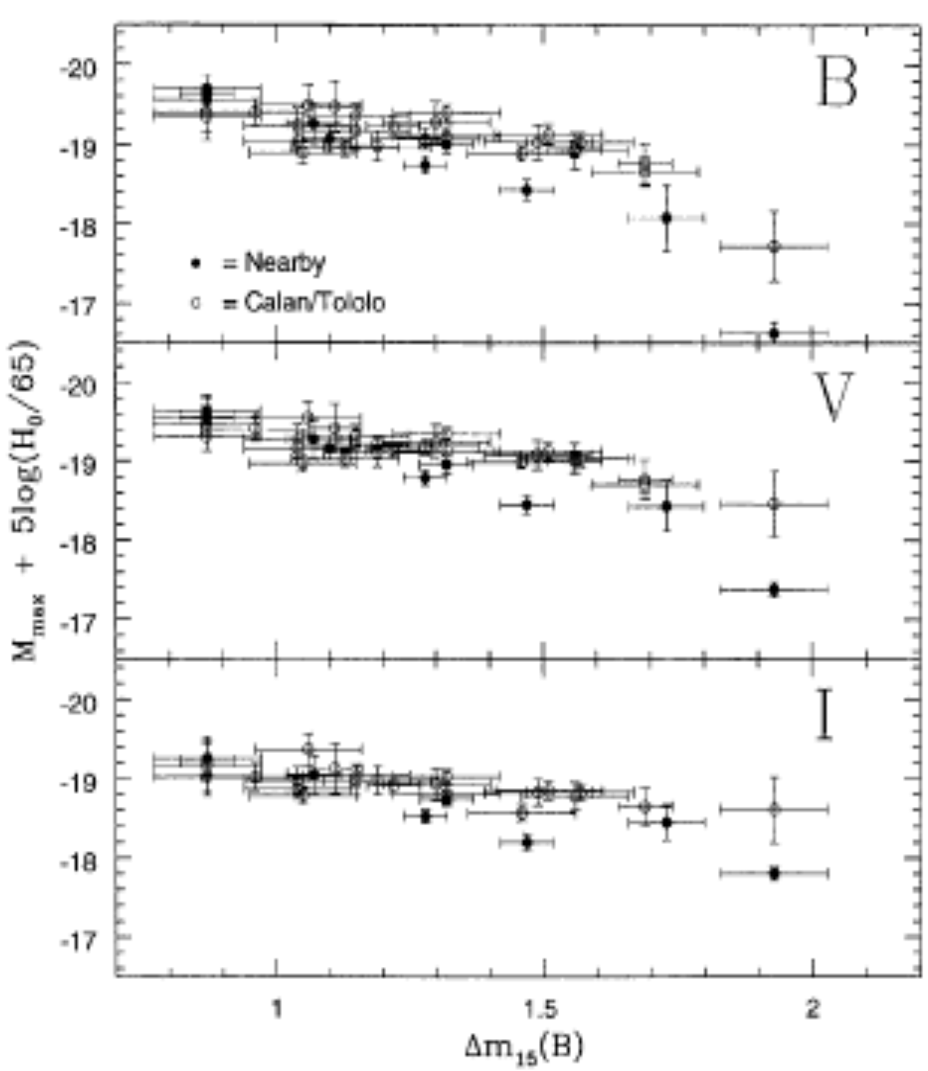
SN Ia are Precision Distance Indicators!



ıre 1: Hubble diagram of SNe Ia in the Calán/Tololo SN survey.

Hamuy et al. 1994

2395 HAMUY *ET AL.*: CALAN TOLOLO Ia SNe



Hamuy et al. 1996

A Standard Candle With a Difference

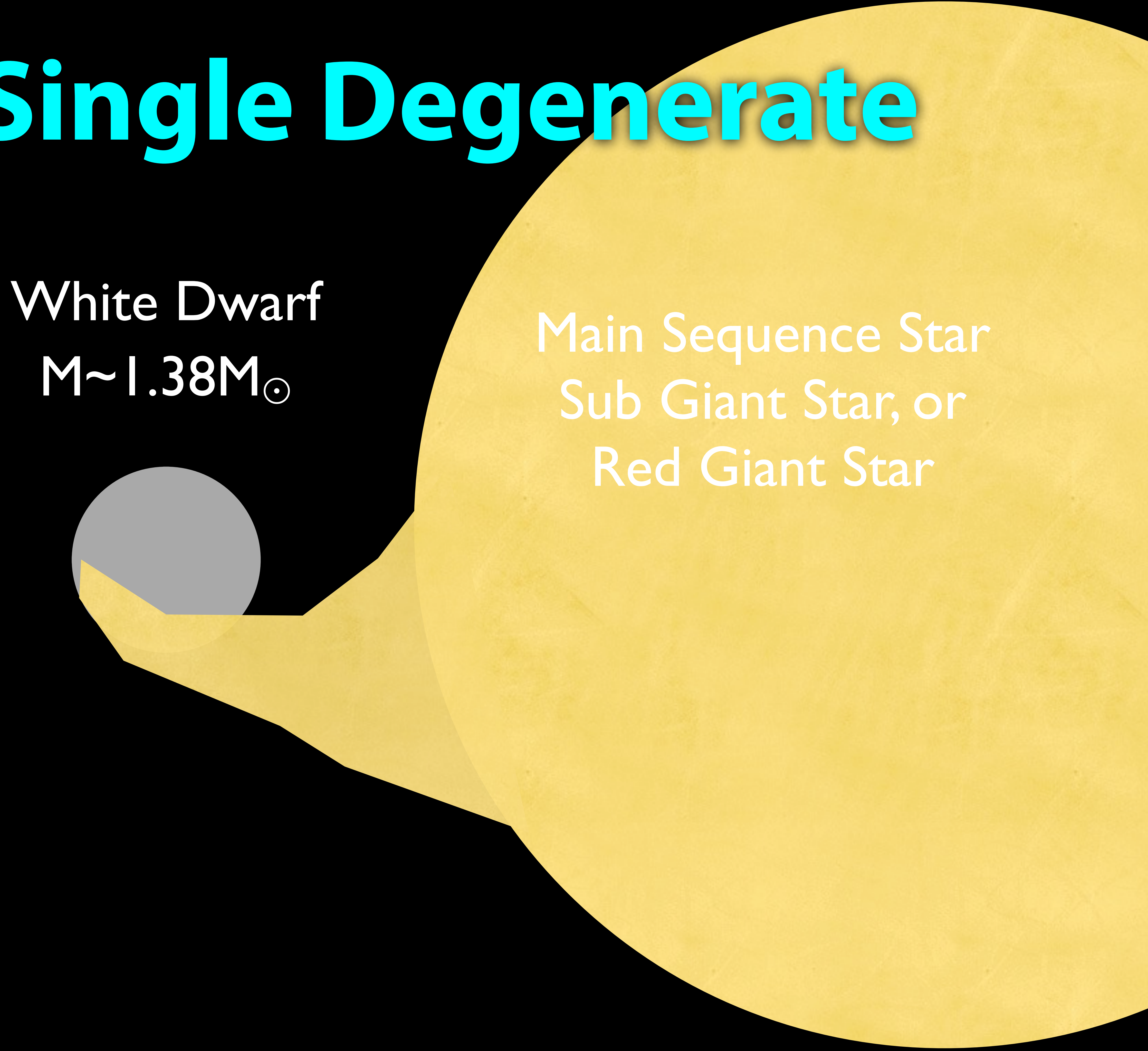
- Very Bright - $L=5x10^9 L_\odot$
- Point Source
- calibratable to 6% in Flux (3% in distance)
- possible to build up samples of thousands of objects
- Provides measure of D_L from z=0 to z>=2

What is a SN Ia?

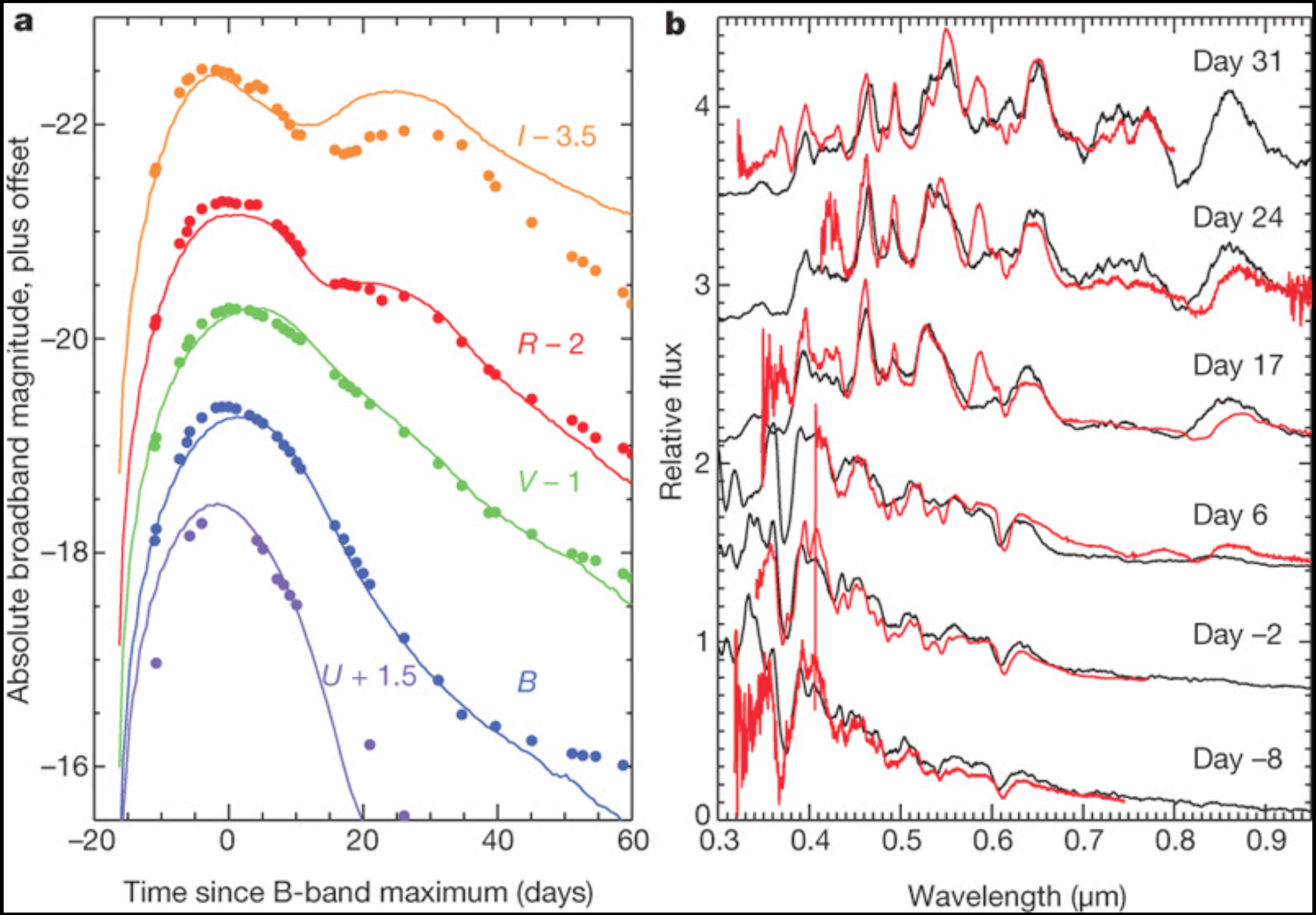
Thermonuclear Detonations of White Dwarfs, but... details are still under question

- Single Degenerate Explosions of ~Chandrasekhar Mass White Dwarfs
- Sub-Chandra Explosions of White Dwarfs
- Double Degenerate Mergers resulting in a detonation

Single Degenerate

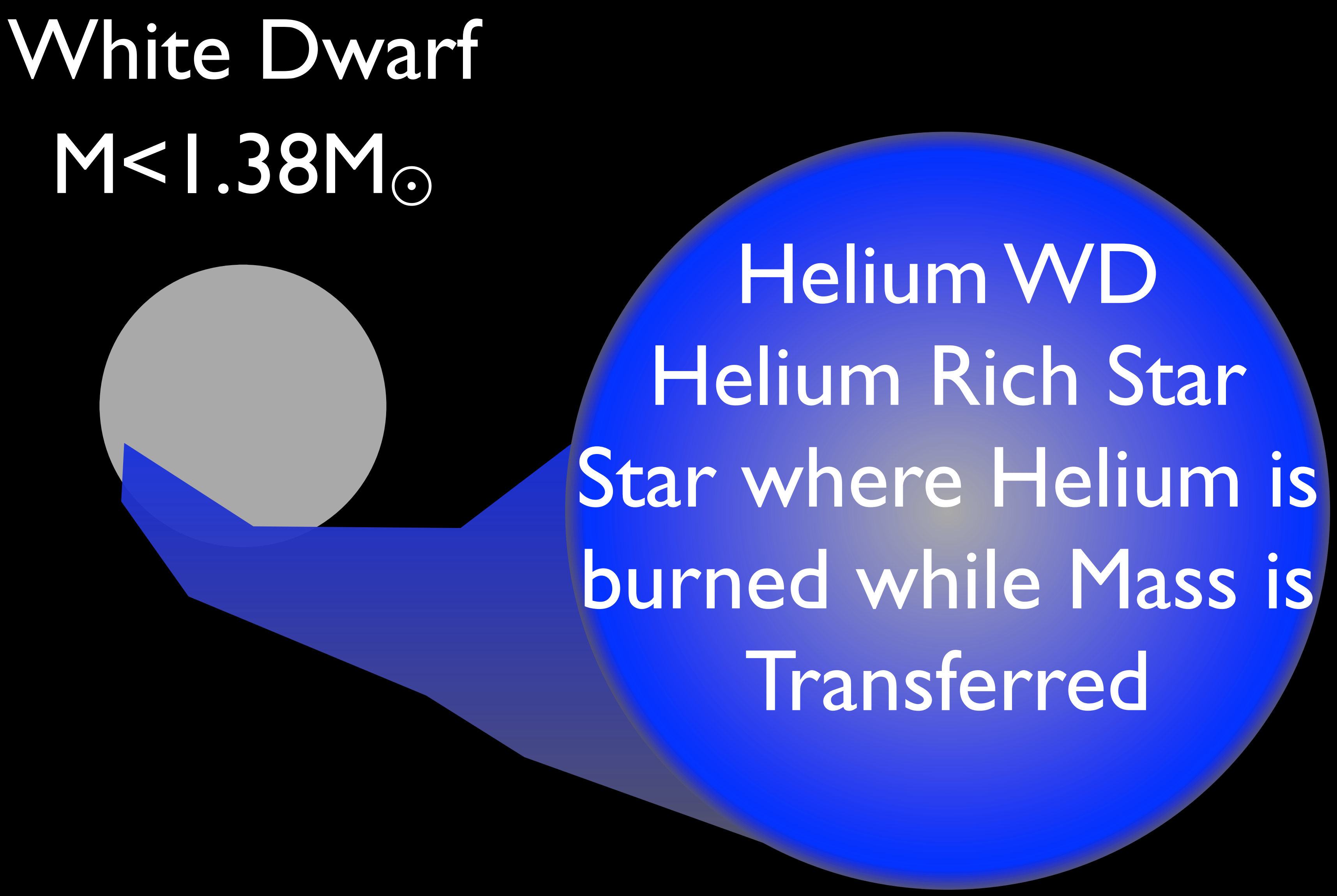


Single Degenerate

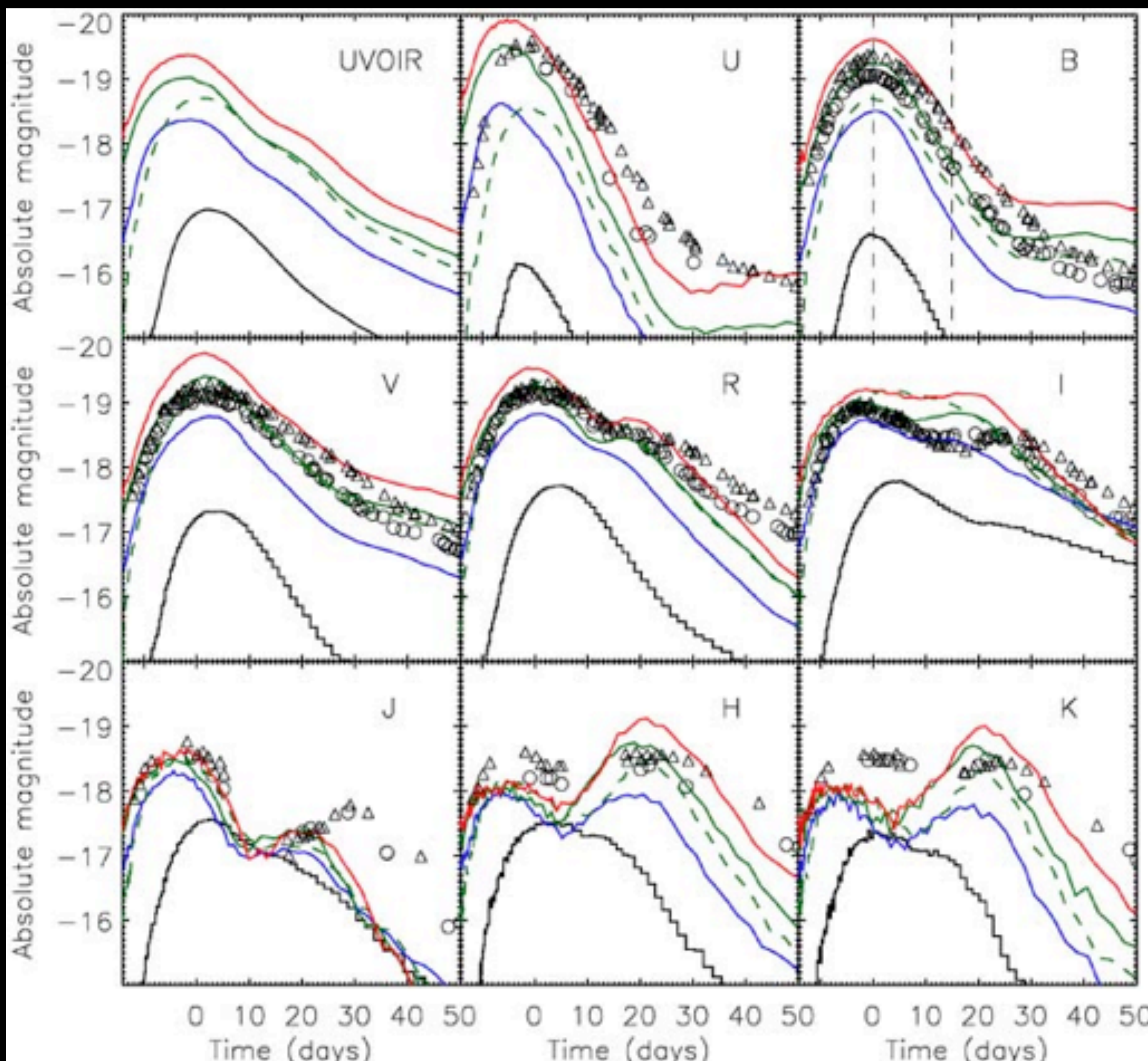


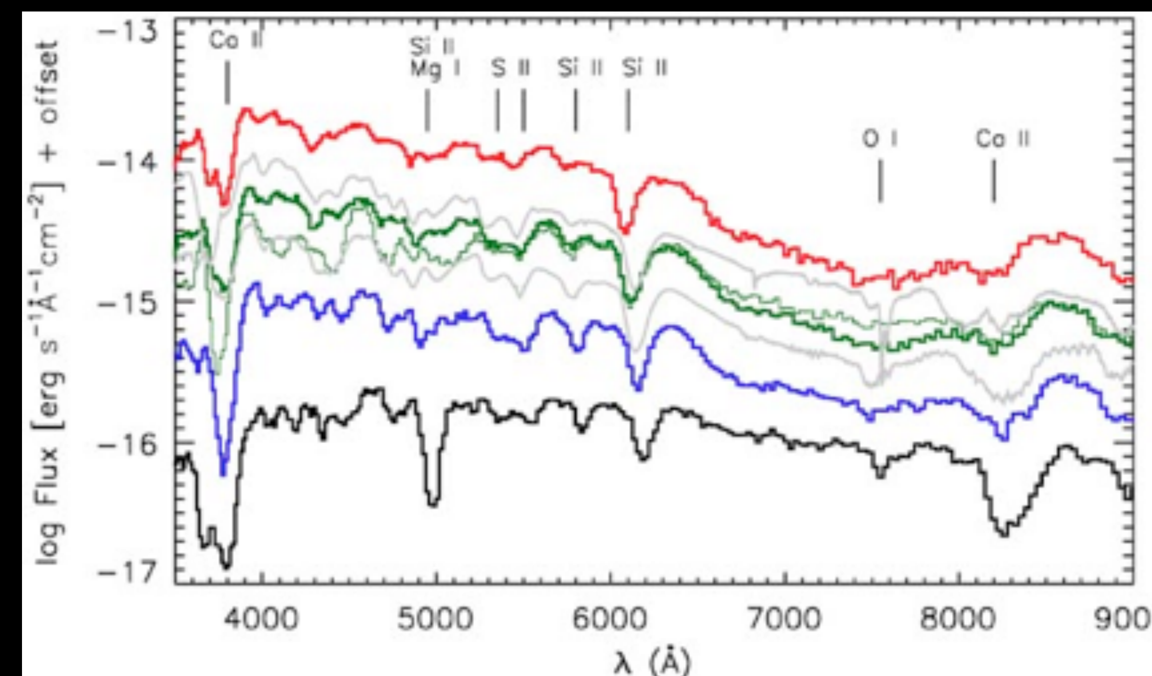
Kasen, Roepke, & Woosley 2009

Sub-Chandra


White Dwarf
M<1.38M⊙
Helium WD
Helium Rich Star
Star where Helium is burned while Mass is Transferred

Sub-Chandra



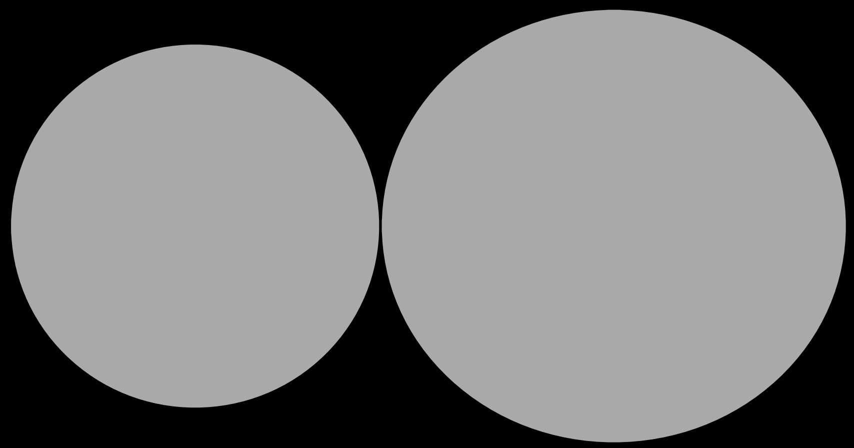


Sim et al 2009

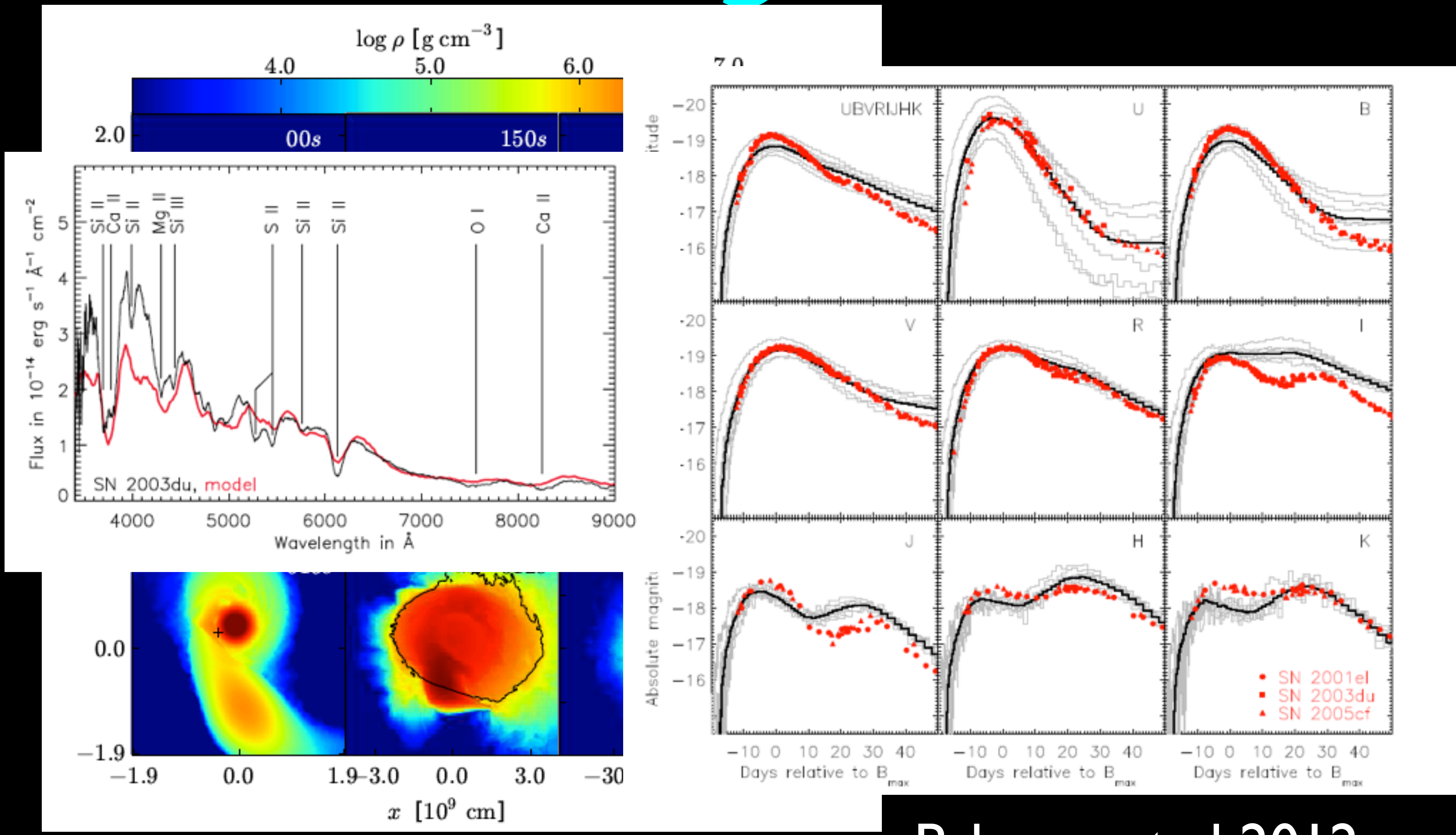
Mergers

White Dwarfs

$M_1 + M_2 > 1.38 M_{\odot}$



Mergers



Pakmor et al 2012

Progenitors

- No obvious donor stars in historical remnants (although a claim star for Tycho)
- No sign of donor star in early observations
- But some signs of ISM in some events

Delay in Single Degenerate Channel or Sub-Chandra or Mergers? Or maybe a mix?

Measuring Distances from SN Ia

- Nature has been kind -
- if you blow up a 1-1.5 $M_\odot$ ball of nearly electron-degenerate gas - no matter how you do it - you get a bomb that looks like a SN Ia
- More ^{56}Ni means more Energy and more Opacity -
  Brighter & Slower SN Ia

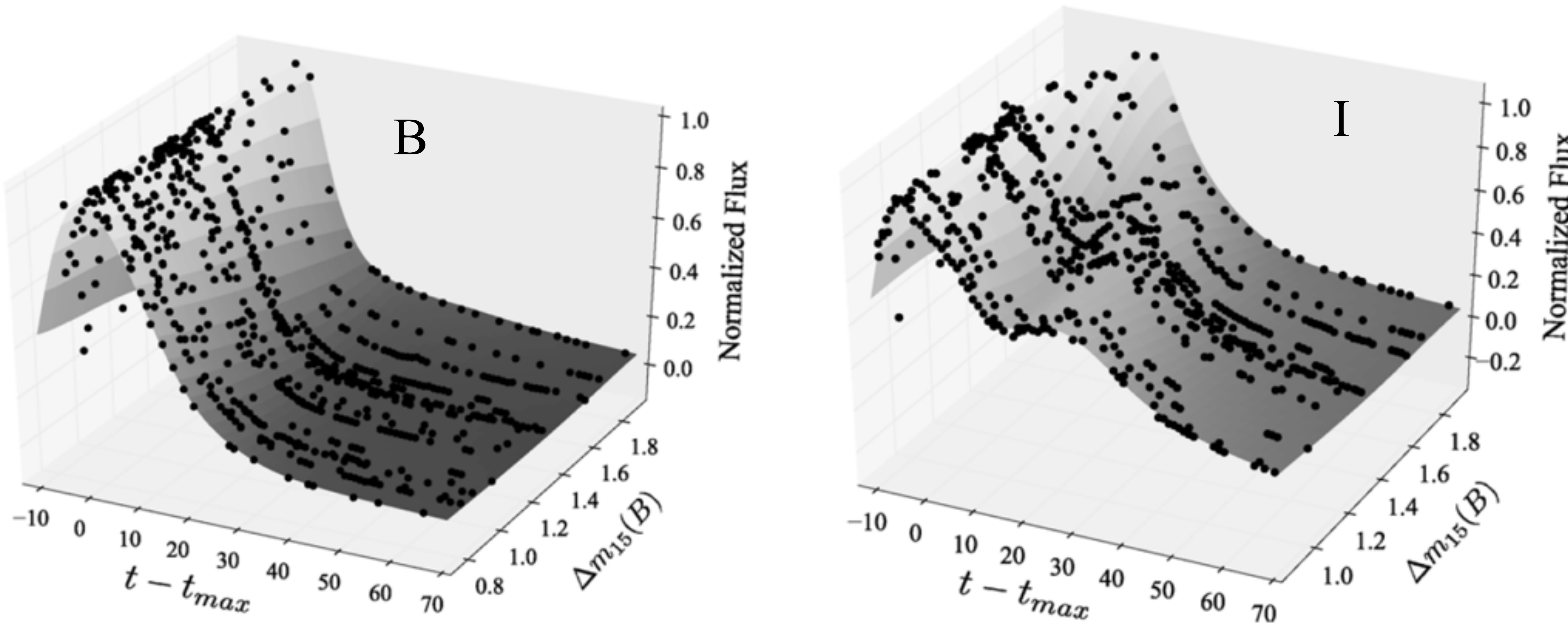
Measuring Distances from SN Ia

- But Nature has also not been so kind
- We know stars will be affected by dust
- But the dust properties of SN Ia are NOT the same as the dust properties of normal stars in the Milky Way

Measuring Distances from SN Ia

- Brightness of Supernova depends on
  - Shape of Light Curve
  - Amount and nature of Dust
    - 2nd order effects
      - Colour of Light Curve
      - Metallicity

Measuring Distances from SN Ia



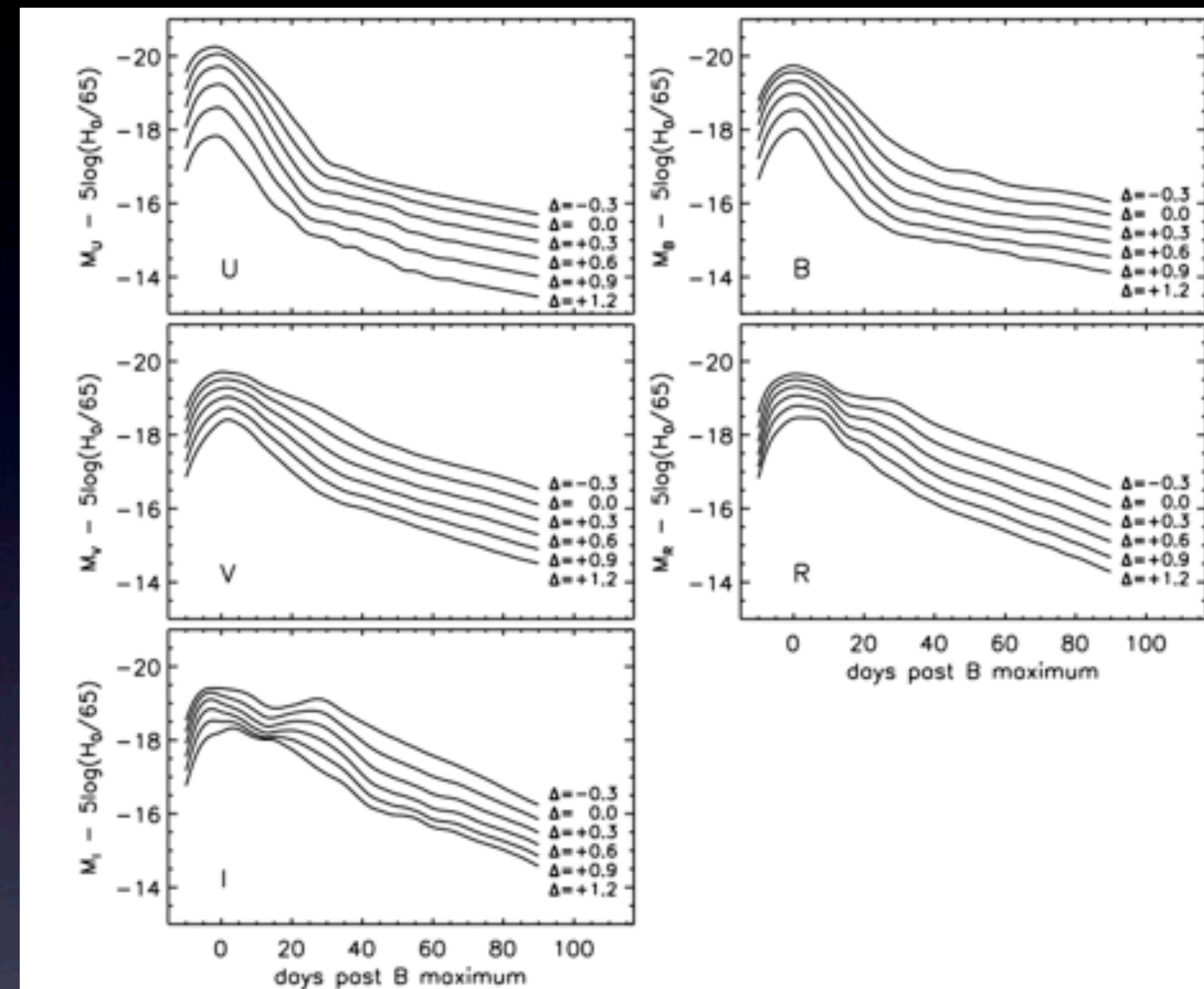
Burns et al 2011 Dust Free Sample

Measuring Distances with SN Ia

Everyone agrees that SN Ia brightnesses depends on their light curve shape, extinction, and possibly colour
L(t)=f(shape,colour,t)

MLCS/dm15 explicitly attribute colour to extinction - but allows colour to correlate with light curve shape - does not allow colour to also correlate with luminosity. Many parameter non-linear model. Applies prior $A_V>0$

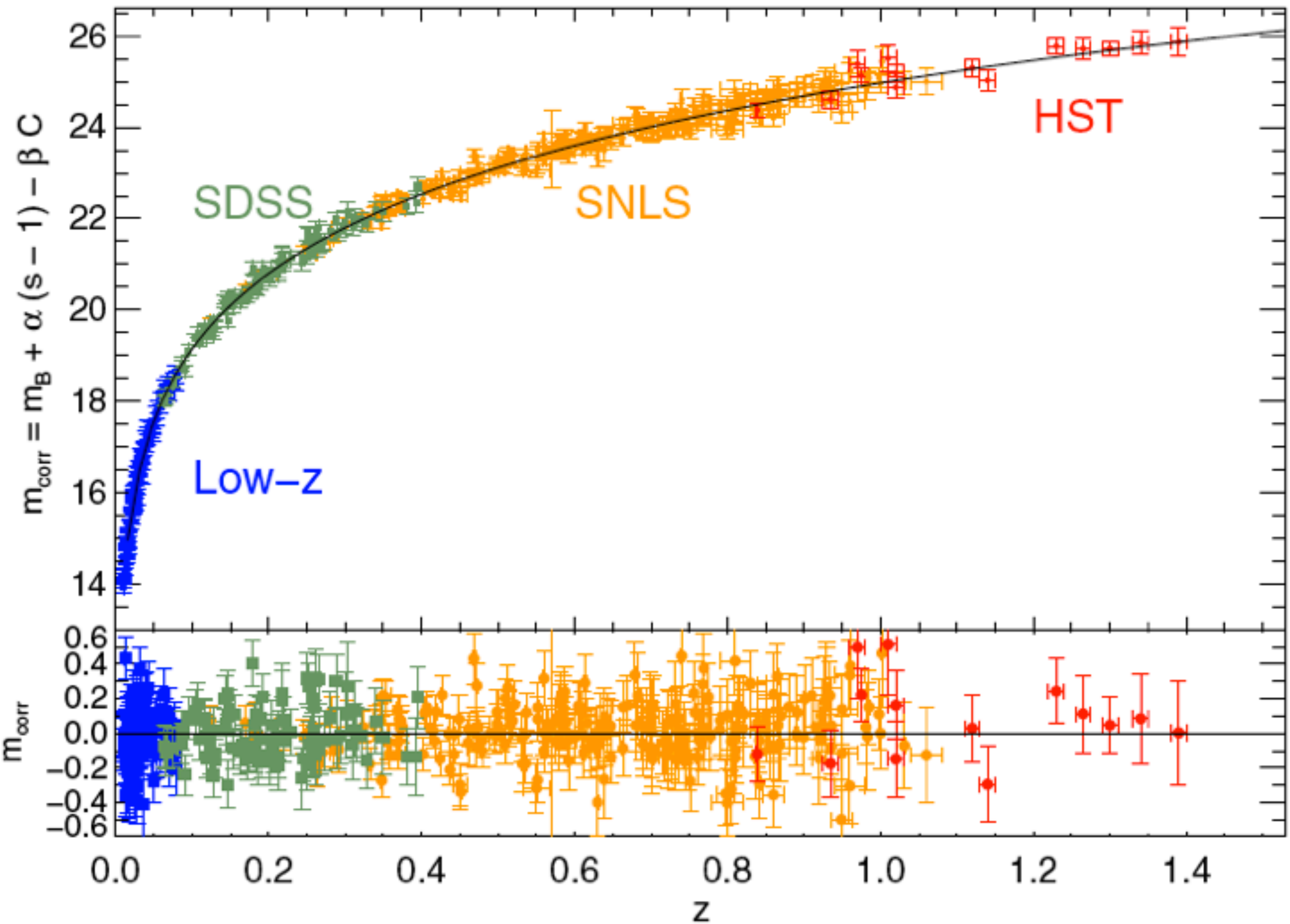
SALT/SiFTO empirically derives colour-luminosity dependence from data using many fewer parameters and linear model.



- M_B – absolute magnitude
- α – parameterises the stretch—luminosity relation
- β – parameterises the colour—luminosity relation

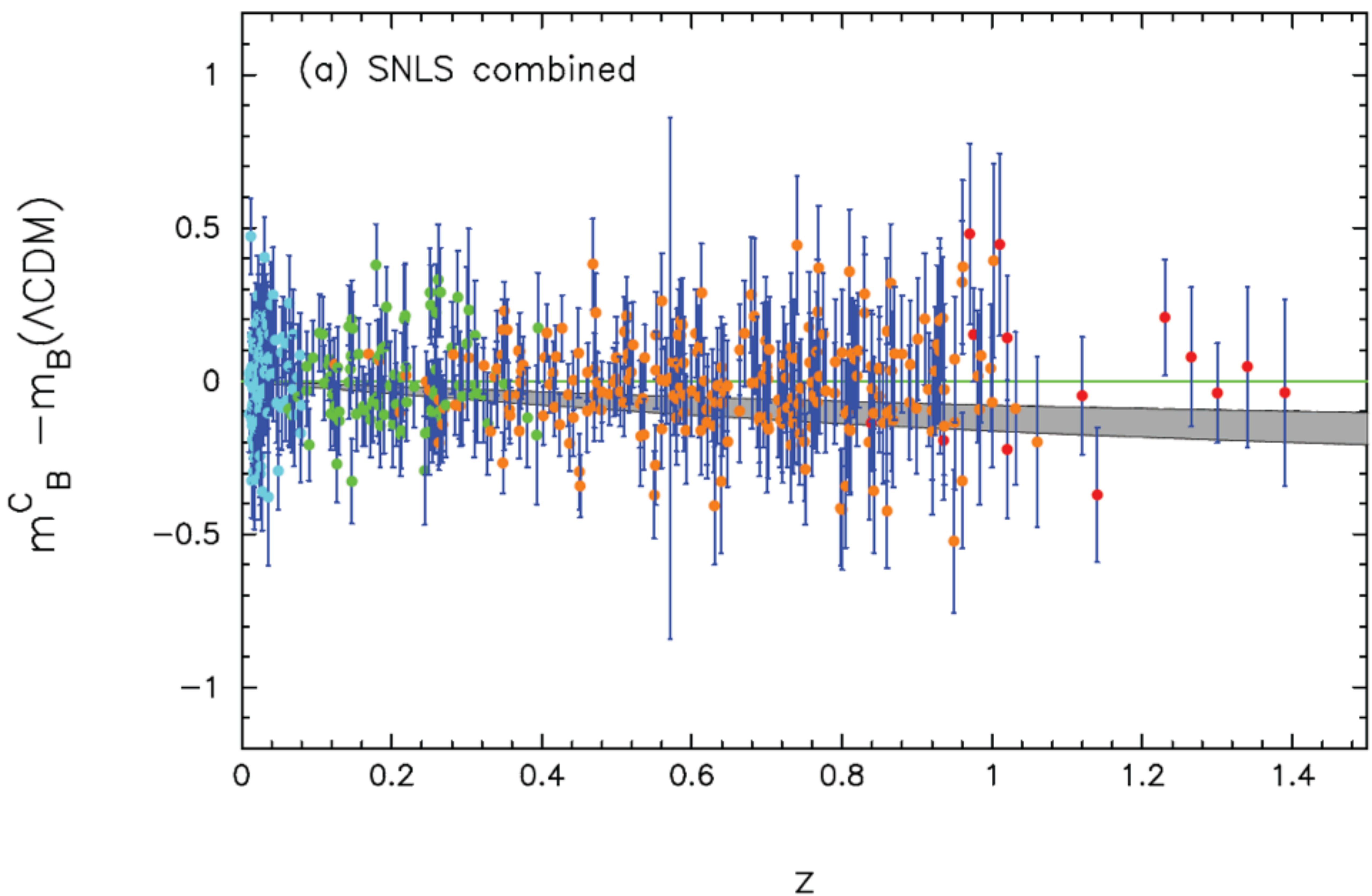
$$\mu_B = m_B - M_B + \alpha(s-1) - \beta c$$

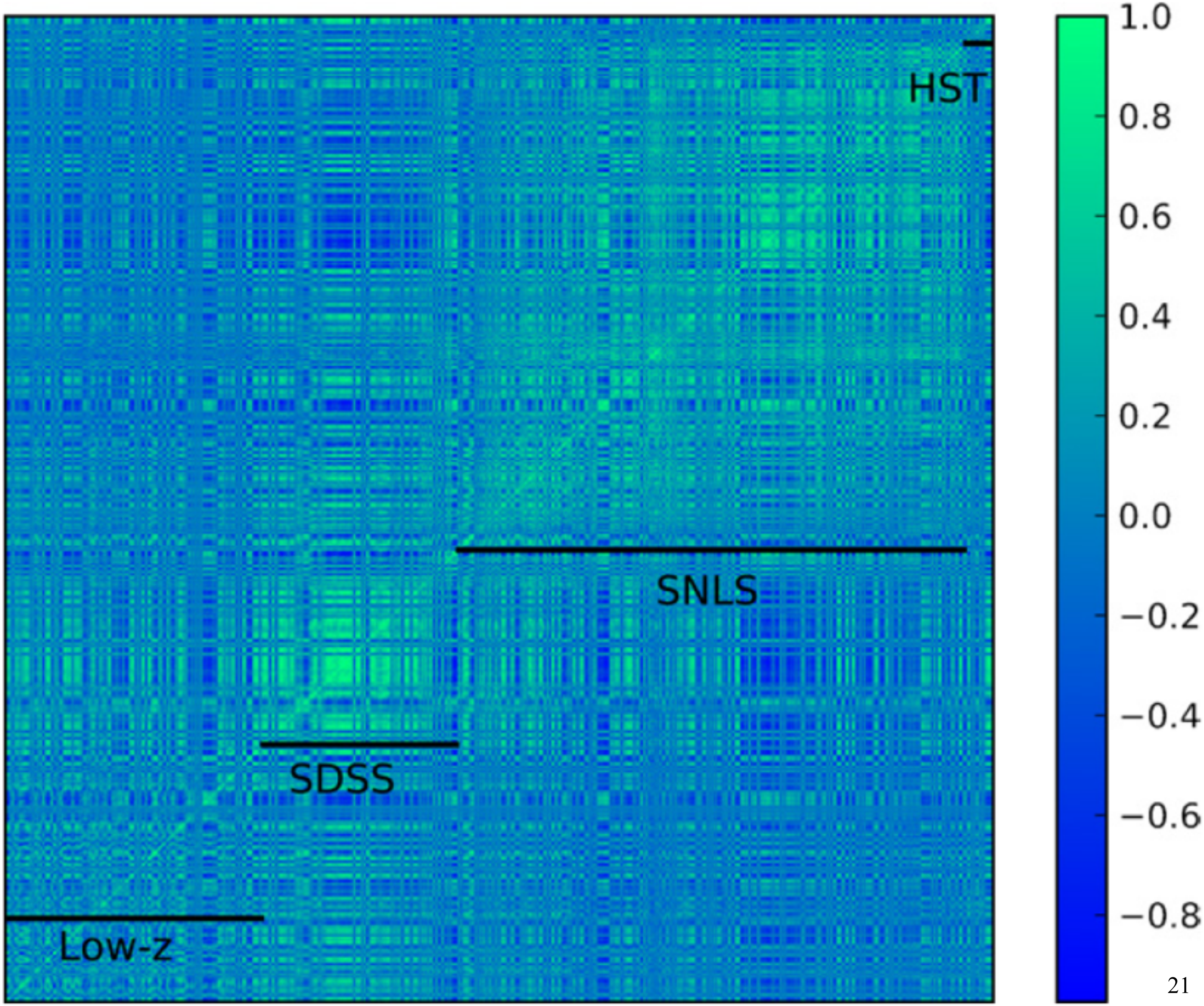
Conley et al

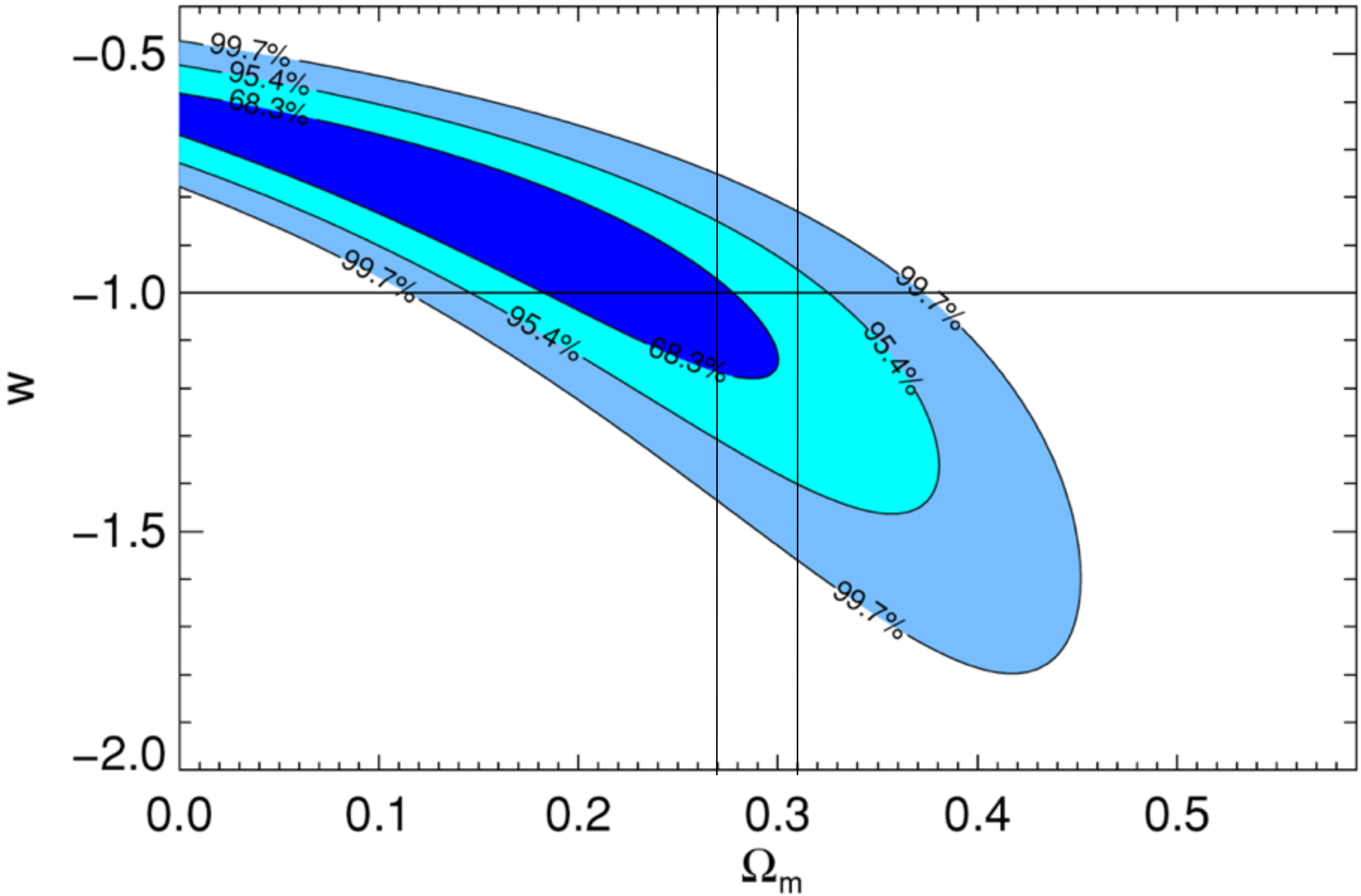


SDSS
SNLS
HST
Low−z
$m_{corr} = m_B + \alpha\,(s-1) - \beta\,C$
m_{corr}
26
24
22
20
18
16
14
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
z

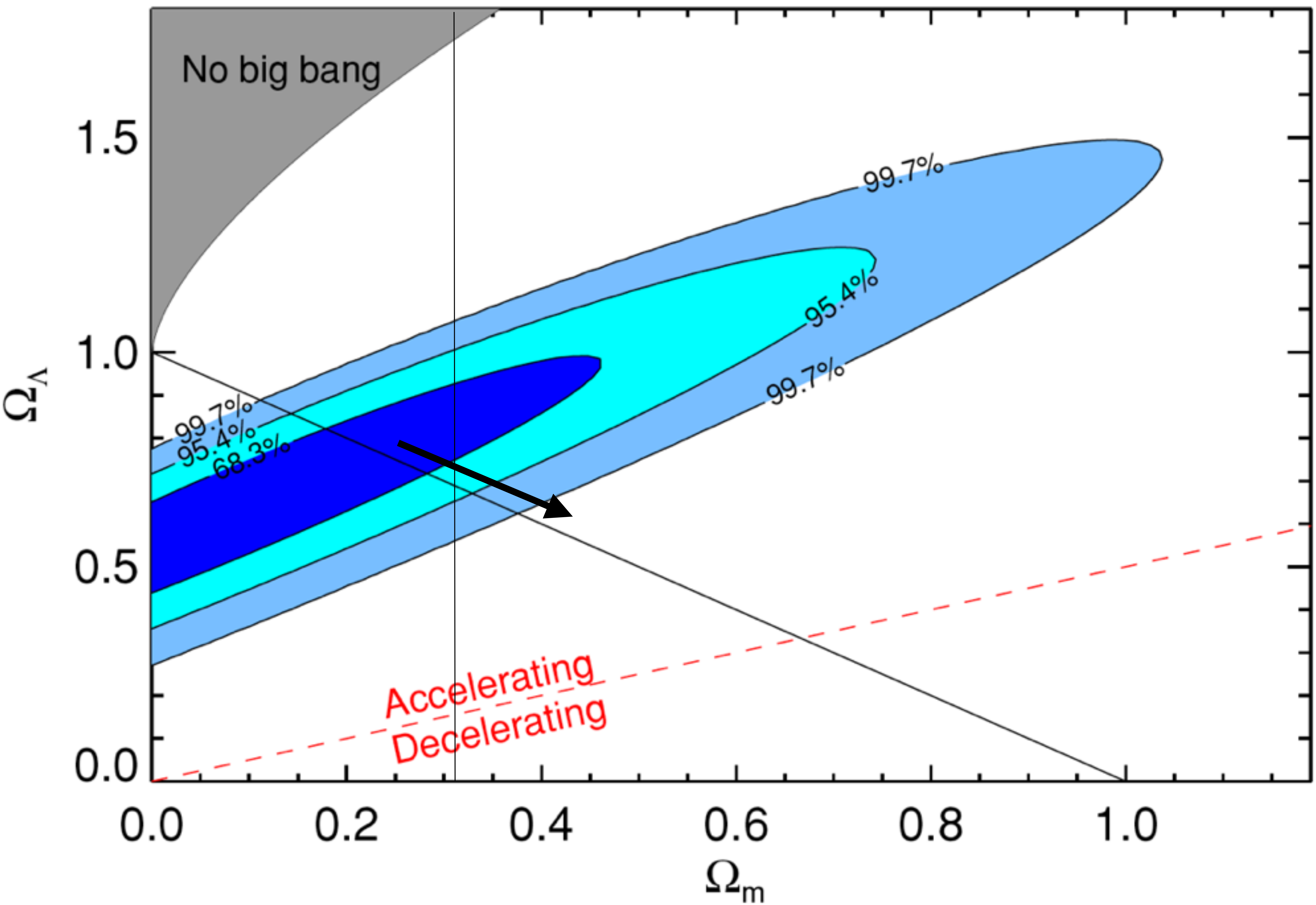
Distance scale comparison: SNe




HST
SNLS
SDSS
Low-z
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8


99.7%
95.4%
68.3%
99.7%
95.4%
68.3%
99.7%
95.4%
99.7%
−0.5
−1.0
−1.5
−2.0
w
0.0
0.1
0.2
0.3
0.4
0.5
Ω_m

Conley et al 2011



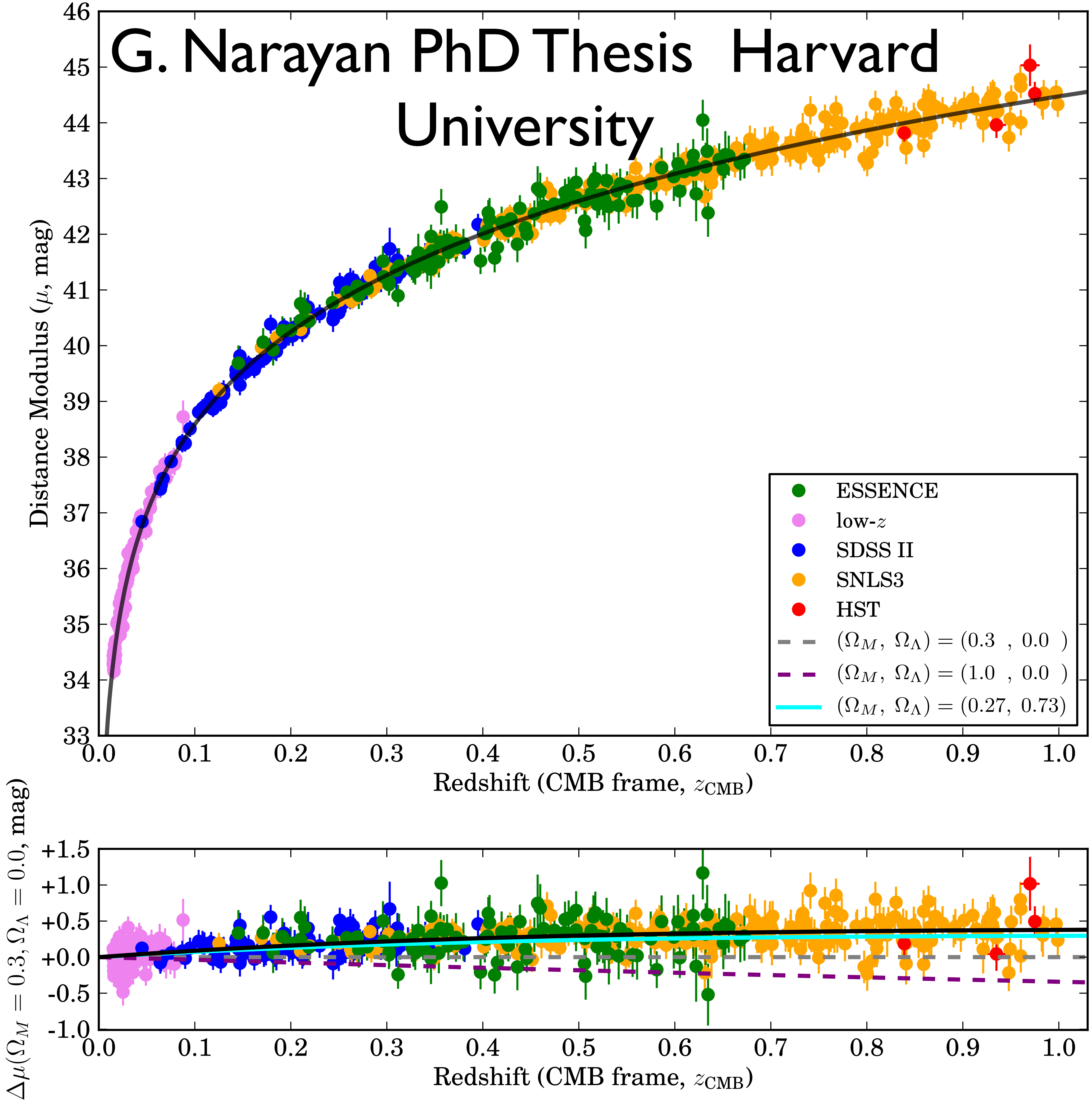
Conley et al 2011

Calibration Systematics

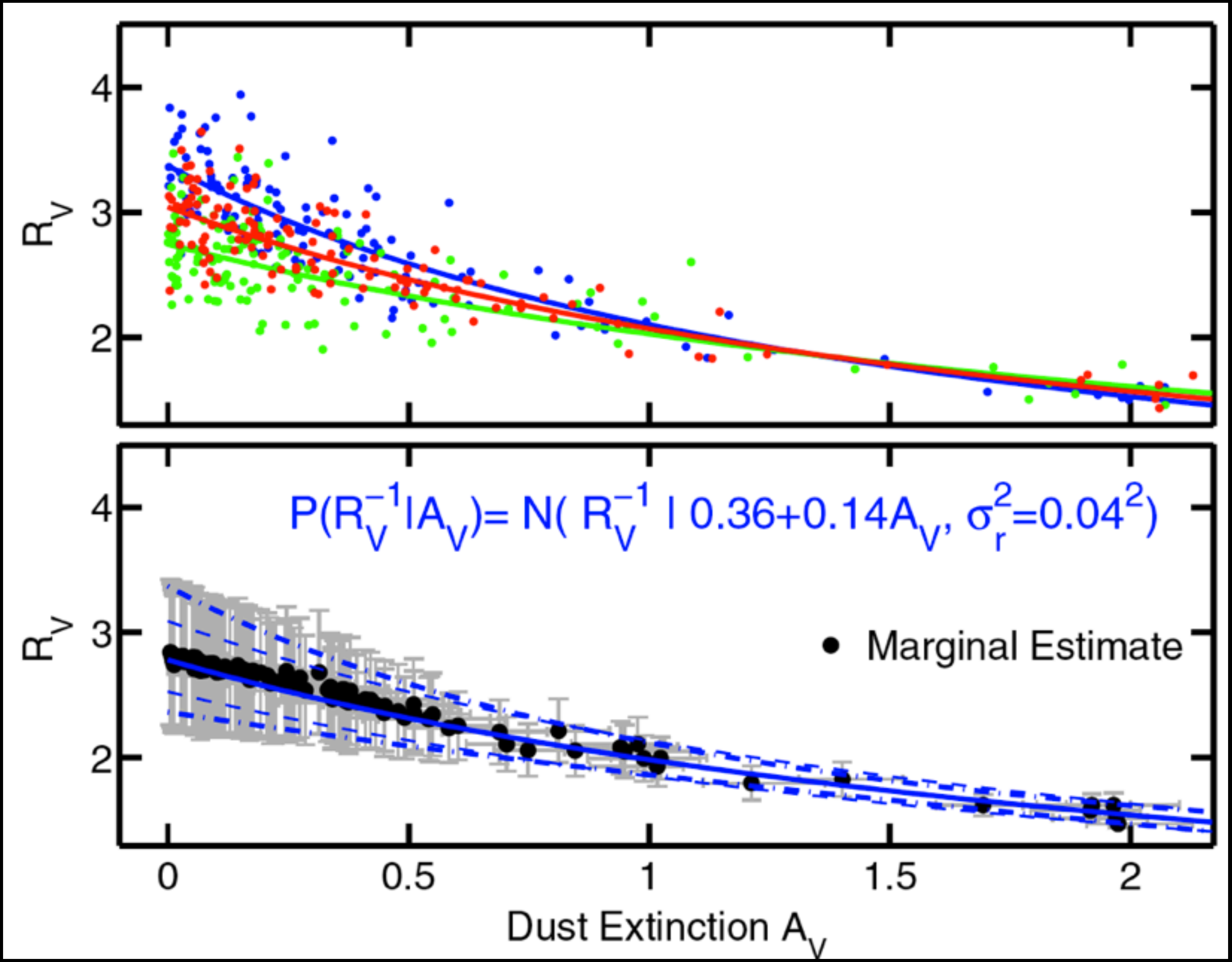
Description	w for $\Omega_m = 0.27$	Rel. Area
Stat only	-1.031 ± 0.058	1
All calibration	-1.06 ± 0.10	1.79
Colors of BD 17° 4708	-1.075 ± 0.075	1.31
SED of BD 17° 4708	-1.026 ± 0.073	1.23
SNLS zero points	-1.030 ± 0.069	1.21
Low-z zero points	-1.044 ± 0.065	1.13
SDSS zero points	-1.028 ± 0.060	1.02
MegaCam bandpasses	-1.017 ± 0.066	1.20
Low-z bandpasses	-1.027 ± 0.059	1.04
SDSS bandpasses	-1.026 ± 0.059	1.02
HST zero points	-1.027 ± 0.058	1.03
NICMOS nonlinearity	-1.029 ± 0.059	1.05

Evolutionary Systematics

Description	dX/dz	w for $\Omega_m = 0.27$	Rel. Area
Stat only	...	-1.031 ± 0.058	1
Combined	...	$-1.028^{+0.059}_{-0.058}$	1.02
α evolution	0.07	-1.030 ± 0.058	1.00
β evolution	1.0	$-1.028^{+0.059}_{-0.058}$	1.02



G. Narayan PhD Thesis Harvard University
Distance Modulus (μ, mag)
Redshift (CMB frame, $z_{\rm CMB}$)
ESSENCE
low-z
SDSS II
SNLS3
HST
$(\Omega_M,\ \Omega_\Lambda) = (0.3\ ,\ 0.0\ )$
$(\Omega_M,\ \Omega_\Lambda) = (1.0\ ,\ 0.0\ )$
$(\Omega_M,\ \Omega_\Lambda) = (0.27,\ 0.73)$
$\Delta\mu(\Omega_M = 0.3, \Omega_\Lambda = 0.0$, mag)
Redshift (CMB frame, $z_{\rm CMB}$)



Mandel, Narayan, & Kirshner 2011

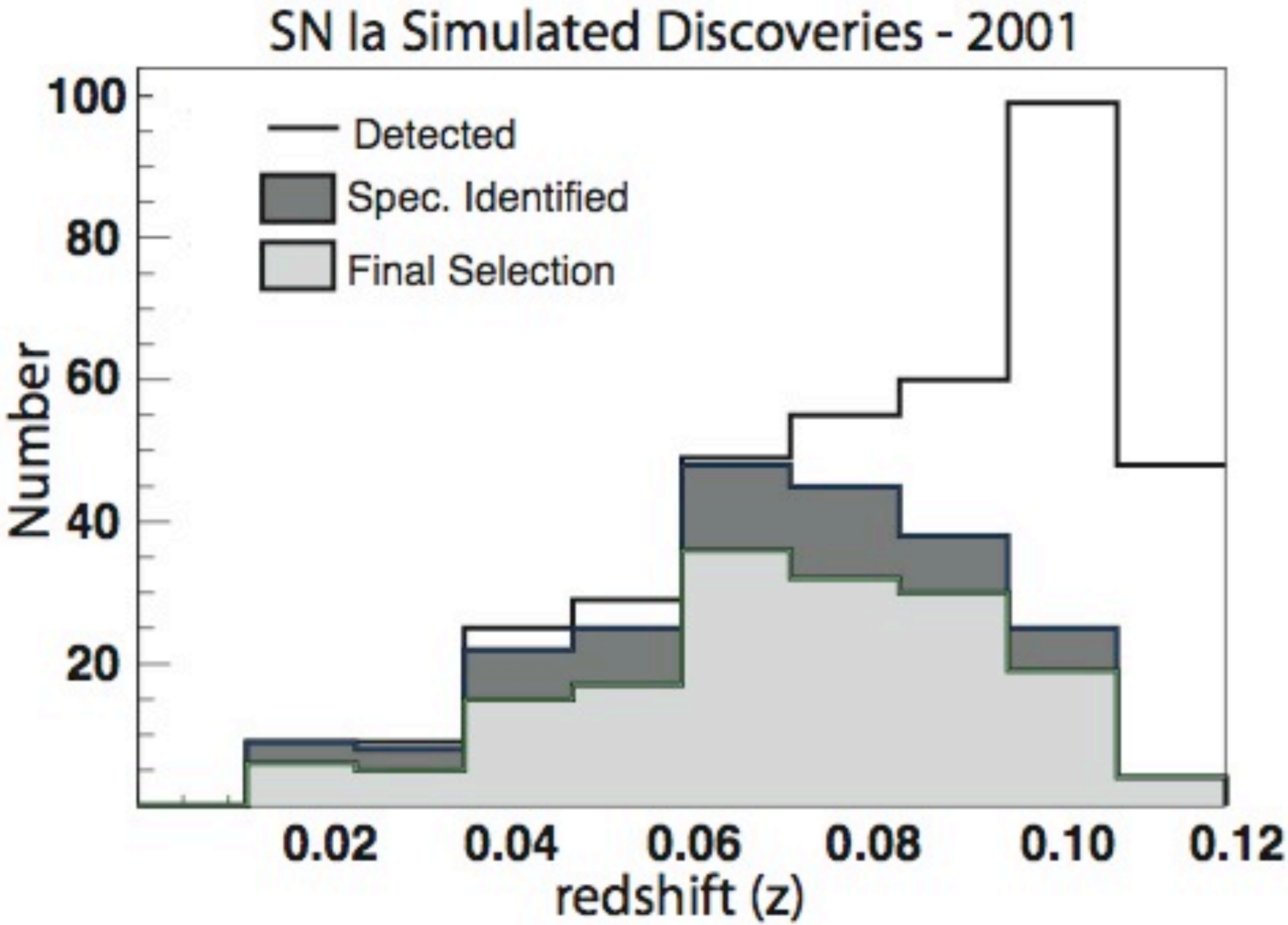
Improvements?

- Photometric Zero Points and Bandpasses are by far the largest component of Systematic Error in Current SN Experiments

- Photometric ZPs (HST Program to calibrate 15 Stars across the sky several ways)

SkyMapper

Photo by Jamie Gilbert

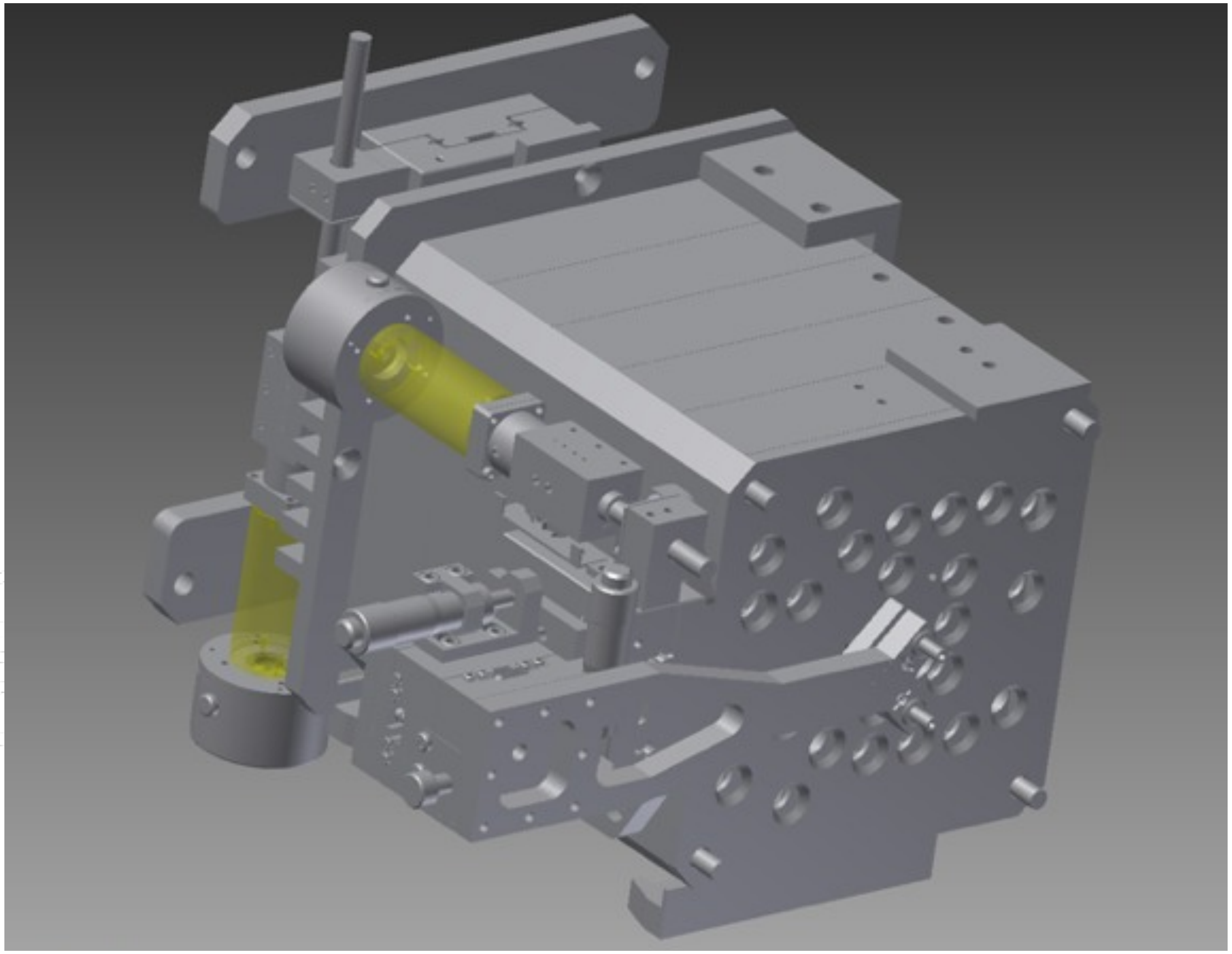


Regnault and Guy (IN2P3)

Calibration Plans

SkyDice - PI Nicolas Regnault - LPNHE

- >20 LEDs covering 0.3-1μ
- observed through telescope with NIS calibrated photo diode
- absolute calibration and monitoring of optics




HATSouth @ SSO 2013-01-13 22:15:30

Improvements?

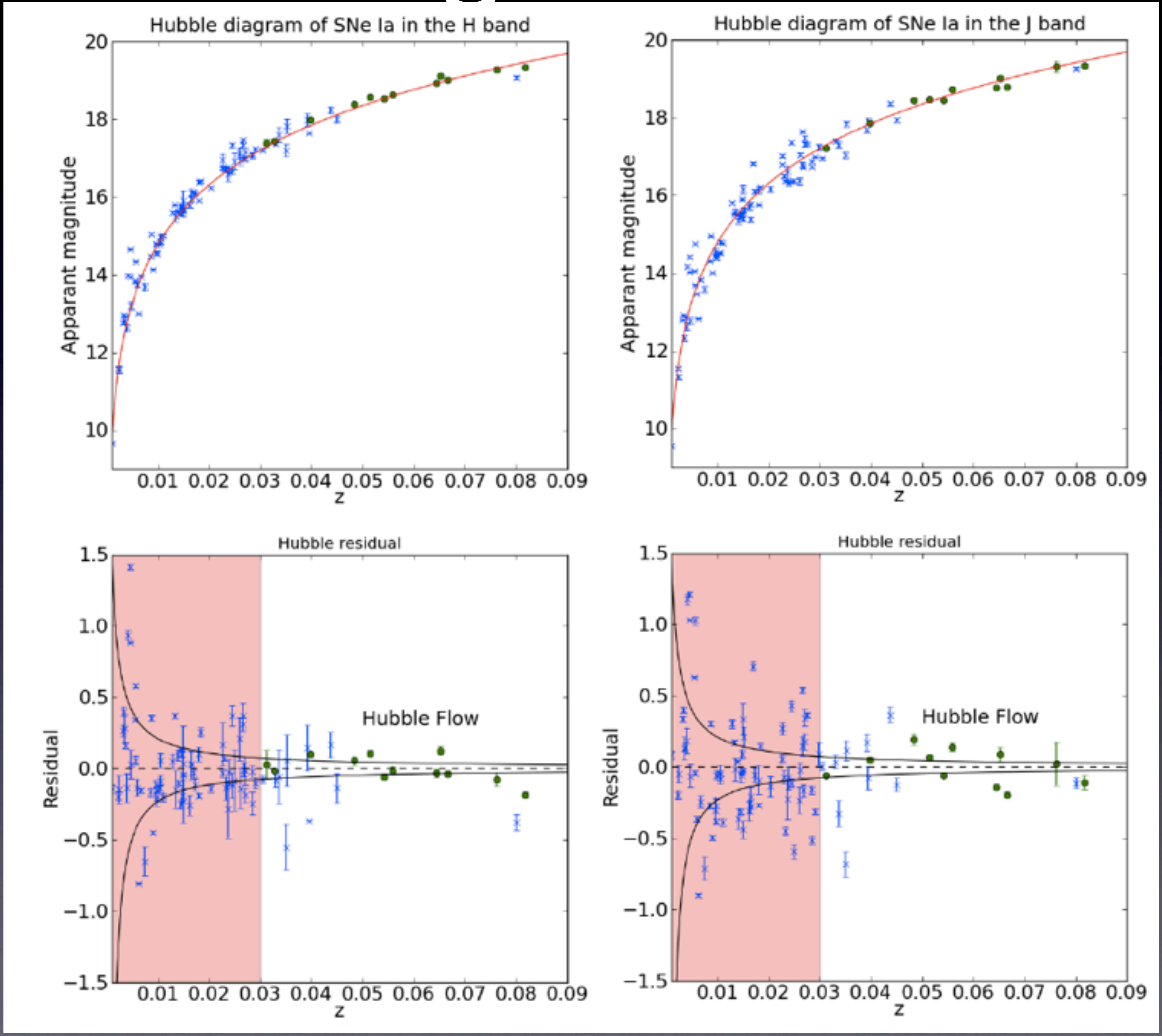
- Possible to improve the accuracy of SN Distances by better treatment of dust
- There is potentially a systematic error due to dust that is not completely accounted for because current methods are not correctly modelling dust and colour

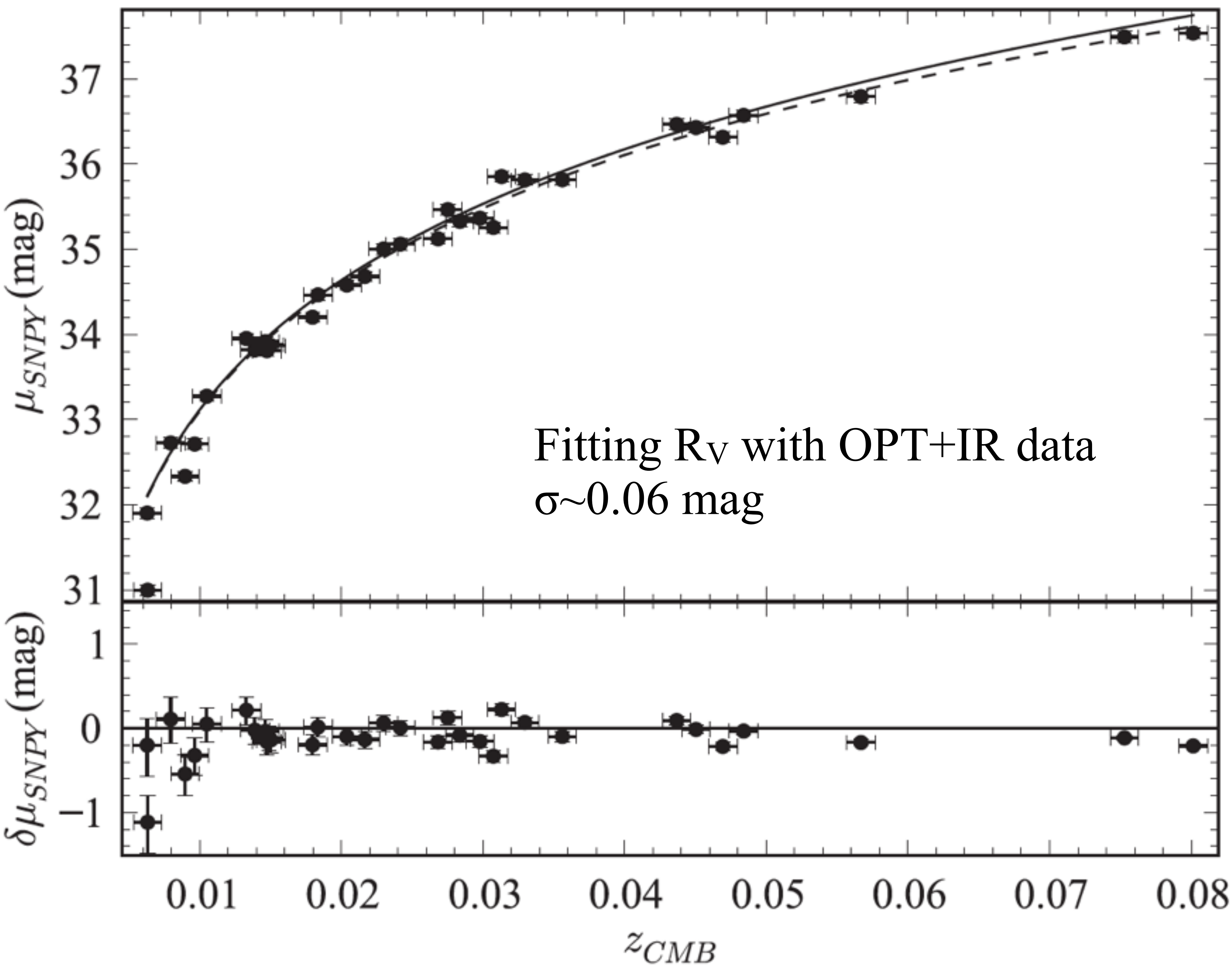
Moving to IR

Baron-Nugent (2012)

$\sigma_J = 0.12^m$

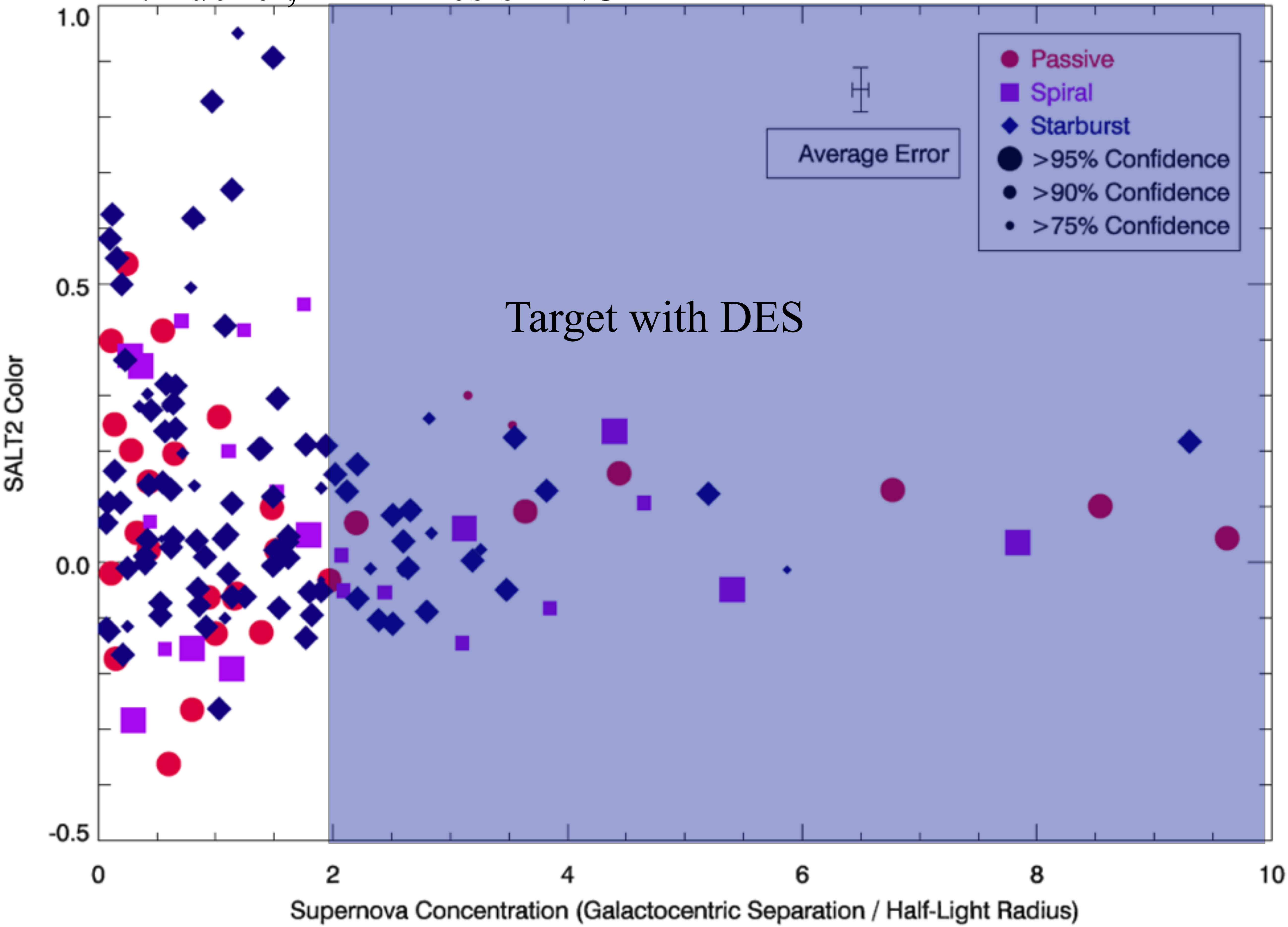
$\sigma_H = 0.09^m$



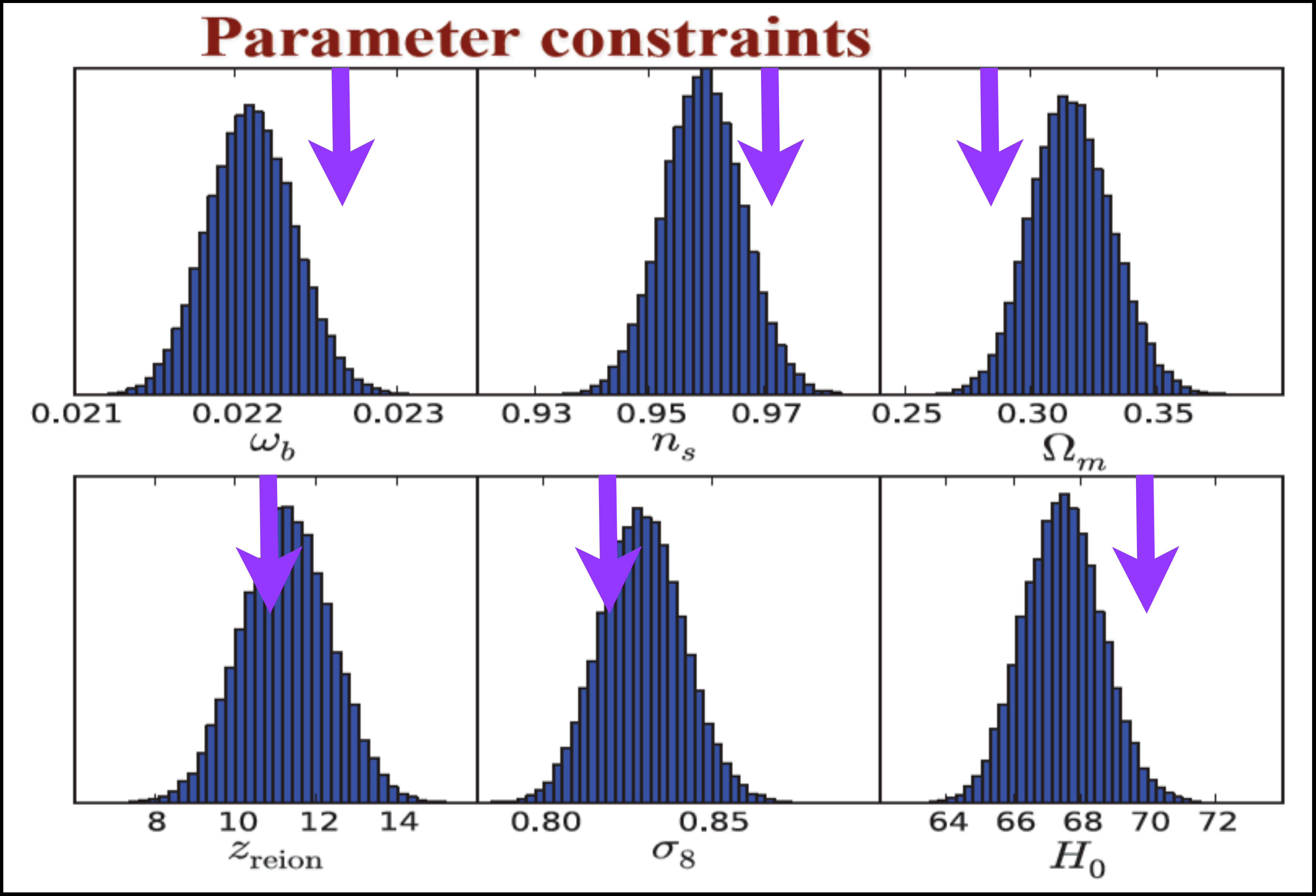


Fitting R_V with OPT+IR data
σ~0.06 mag

B. Tucker, PhD Thesis ANU

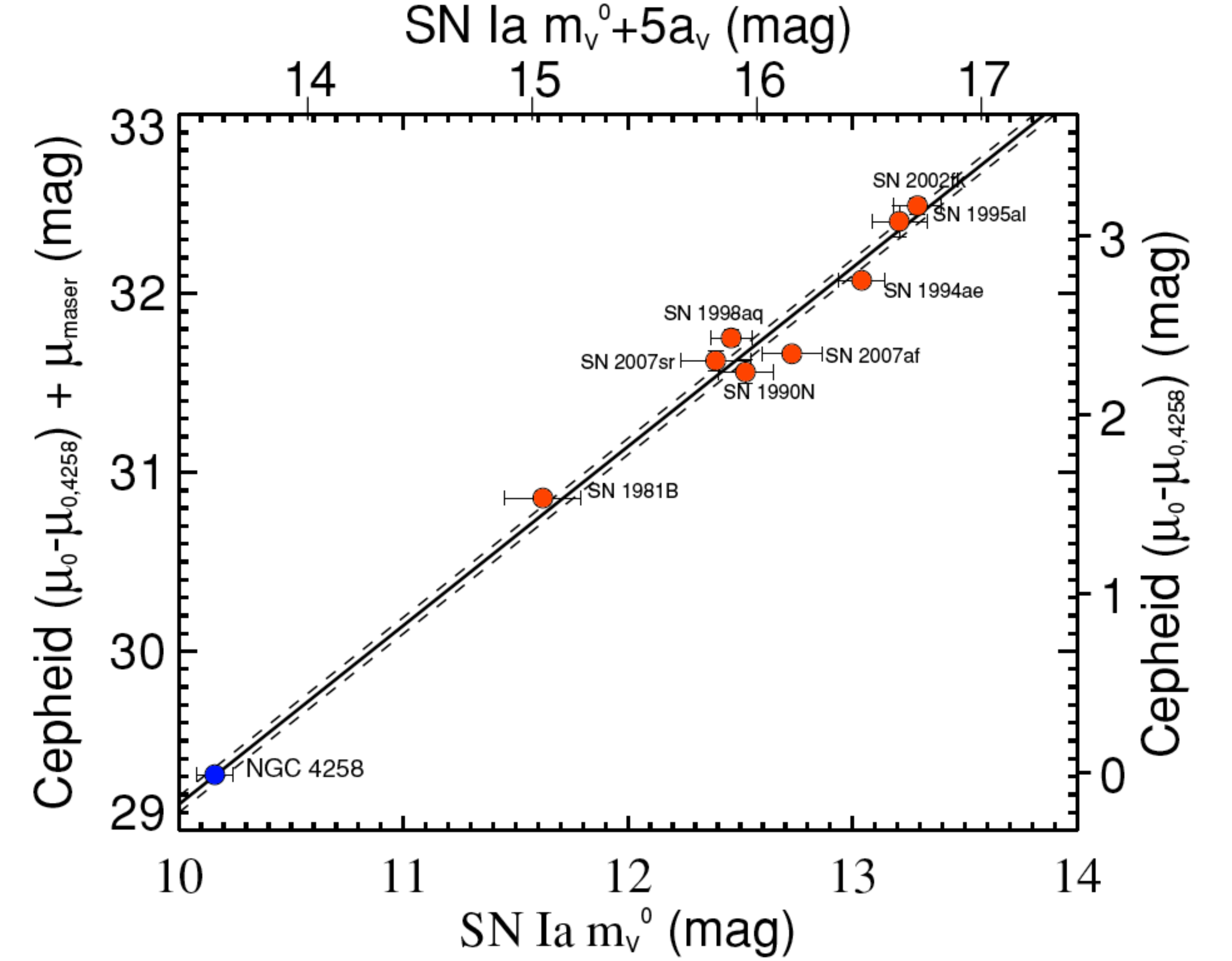


Trouble in Our CDM-Λ Paradise?



Hubble Constant

- Planck
  - 67.8 ± 0.8 km/s/Mpc
- Local Measures $H_0=v/D$ (Riess et al 2011)
  - 73.8 ± 2.4 km/s/Mpc
- Very different measures of the Hubble Constant - one is one of 6 parameters in a flat Λ-CDM model - other is direct measure
- But Local measurement is hard...


SN Ia m_V^0+5a_V (mag)
14
15
16
17
33
32
31
30
29
Cepheid (μ_0-$\mu_{0,4258}$) + μ_{maser} (mag)
3
2
1
0
Cepheid (μ_0-$\mu_{0,4258}$) (mag)
SN 2002fk
SN 1995al
SN 1994ae
SN 1998aq
SN 2007sr
SN 2007af
SN 1990N
SN 1981B
NGC 4258
10
11
12
13
14
SN Ia m_V^0 (mag)

Childress et al. 2013

SN	Host	D[a] (Mpc)	$\Delta m_{15}(B)$
SN1981B	NGC 4536	14.8	1.07 ± 0.09
SN1990N	NGC 4639	21.6	1.00 ± 0.03
SN1994ae	NGC 3370	26.6	0.96 ± 0.04
SN1995al	NGC 3021	30.5	0.87 ± 0.04
SN1998aq	NGC 3982	22.5	1.11 ± 0.04
SN2002fk	NGC 1309	32.5	1.13 ± 0.03
SN2007af	NGC 5584	22.4	1.04 ± 0.01
SN2007sr	NGC 4038	21.7	1.13 ± 0.06
SN1998dh	NGC 7541	36.7	1.17 ± 0.06
SN2001el	NGC 1448	15.9	1.13 ± 0.04
SN2003du	UGC 9391	26.1	1.07 ± 0.06
SN2005cf	MCG -01-39-3[b]	26.4	1.05 ± 0.03
SN2006D	MCG -01-33-34	34.9	1.35 ± 0.05
SN2009ig	NGC 1015	35.9	0.89 ± 0.02
SN2011fe	M101	6.7	1.07 ± 0.06
SN2012fr	NGC 1365	17.9	0.80 ± 0.01

Calibration is almost Everything!

Riess et al. 2011 use

- NGC 4258 Maser Distance (7.3 to 7.6 Mpc)

  (74.8 ± 3.1) ⟶ 71.8 ± 3.1

  Eclipsing Binary Distances to LMC

  (71.3 ± 3.8)

  Parallax Distances to Milky Way Cepheids (75.7 ± 2.6)

- 72.8 ± 2.4 km s^{-1} Mpc^{-1}

So My Take

- Flat Λ-CDM still fits any given set of data - but there are inconsistencies between datasets (resolved if $w \sim -1.1$)
- Unresolved questions over $l > 1000$ & $l < 1000$ cosmological results
- The discrepancies are within the bounds that can be controlled by near-future SN experiments - We are dominated by Experimental Uncertainty!
- BUT EVERYTHING MUST BE BLINDED HERE ON OUT