The Supernova Legacy Survey: Dark Energy and SNe Ia

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NSERC CRSNG

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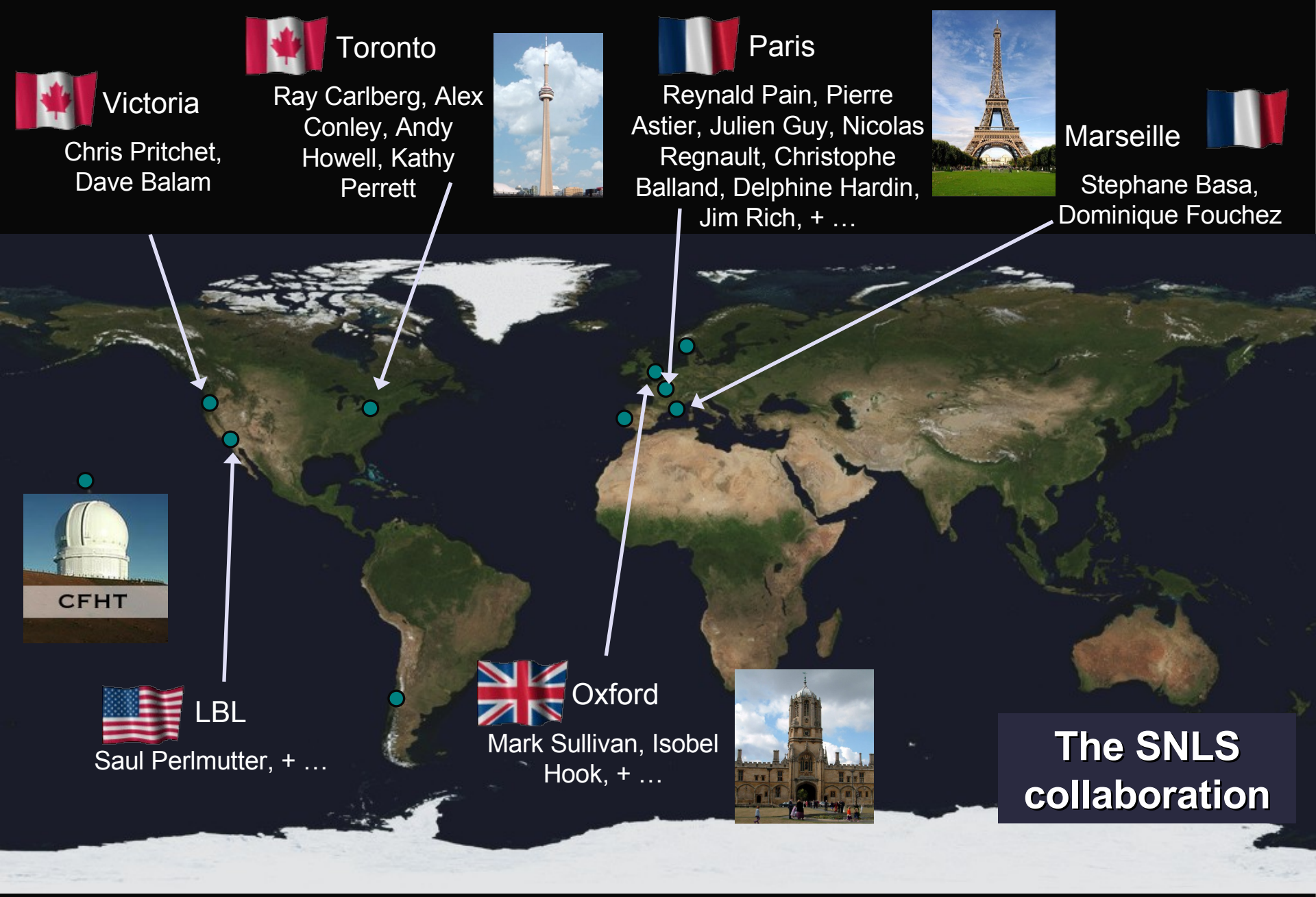
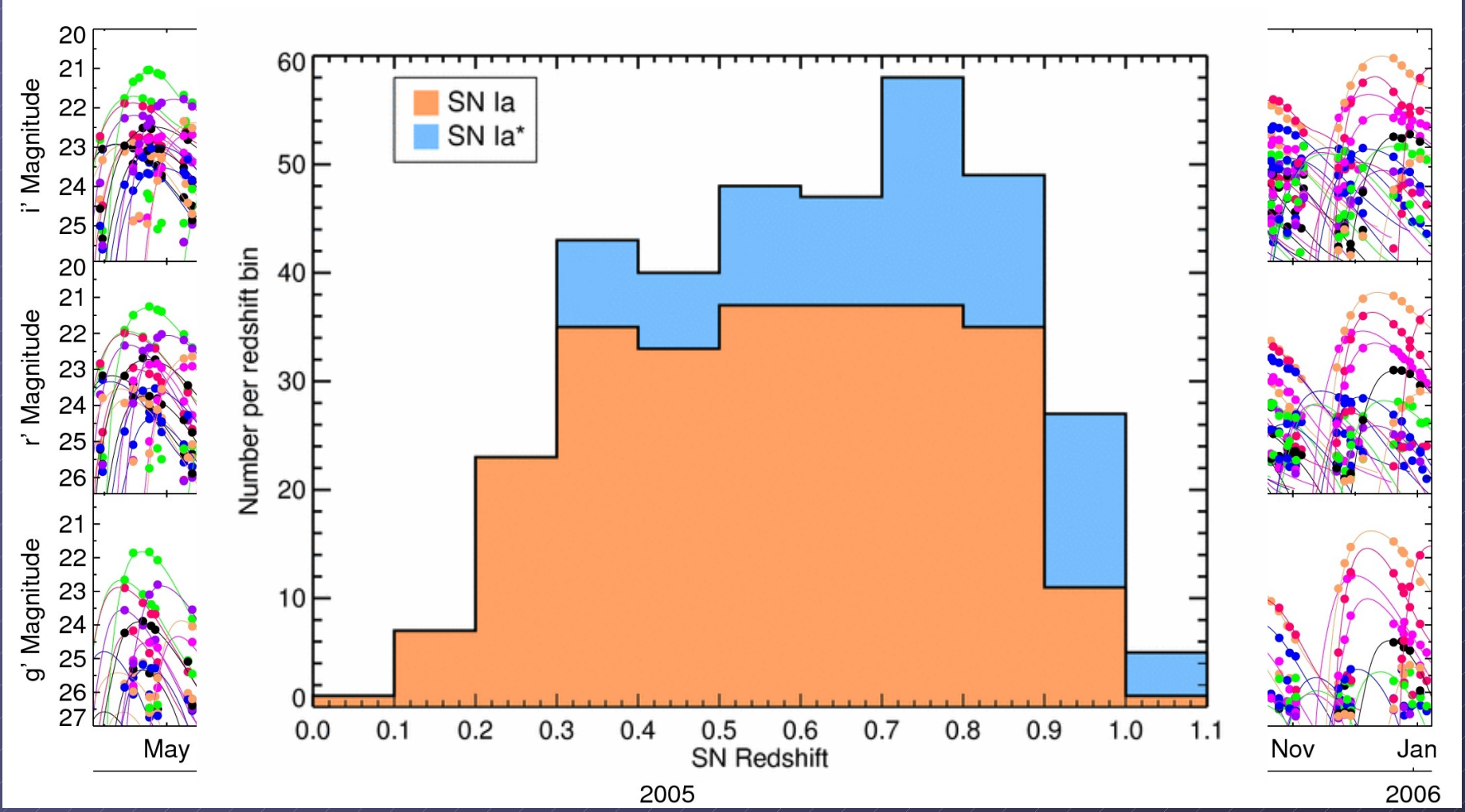
THE ROYAL SOCIETY CELEBRATING 350 YEARS



Full list of collaborators at: http://cfht.hawaii.edu/SNLS/

SNLS: Vital Statistics

- 2003-2008 SN survey with “MegaCam” on CFHT
- griz every 4 nights in queue mode, densely sampled SN light curves
- 400 high-z confirmed SNe Ia to measure “w”
- 2000 SN detections in total



Cosmology with SNe Ia

"Measured" magnitude

Absolute magnitude

$$m_B^{obs} = m_B - M_B$$

Scatter: 0.5mag

s: "stretch"; light-curve width

$$m_B^{obs} = m_B - M_B + a(s-1) - bc$$

Scatter: 0.15mag

c: colour; extinction/intrinsic variation

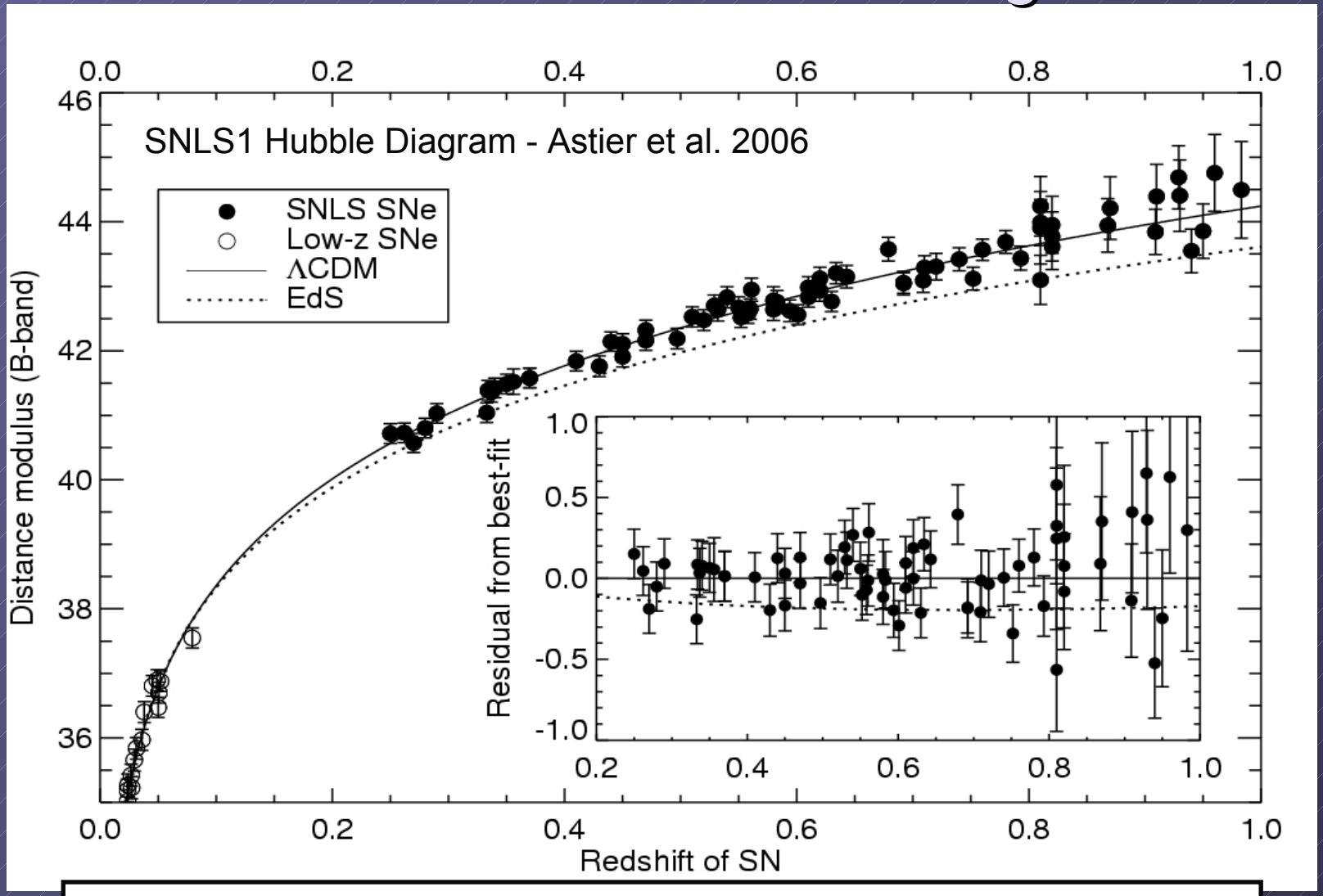
$$m_B^{mod} \; 4 \; D_L(z, w, W_M, W_{DE})$$

QuickTime and a
Cinepak decompressor
are needed to see this picture.

$$c^2 = 4 \frac{(m_B^{obs} - m_B^{mod})^2}{s_{stat}^2 + s_{int}^2}$$

χ^2/DOF is >>1 unless "intrinsic dispersion" σ_{int} is added – parameterises our lack of knowledge about SNe Ia

SNLS1 – SN Ia Hubble Diagram



$\Omega_M = 0.263 \pm 0.042$ (stat) ± 0.032 (sys)

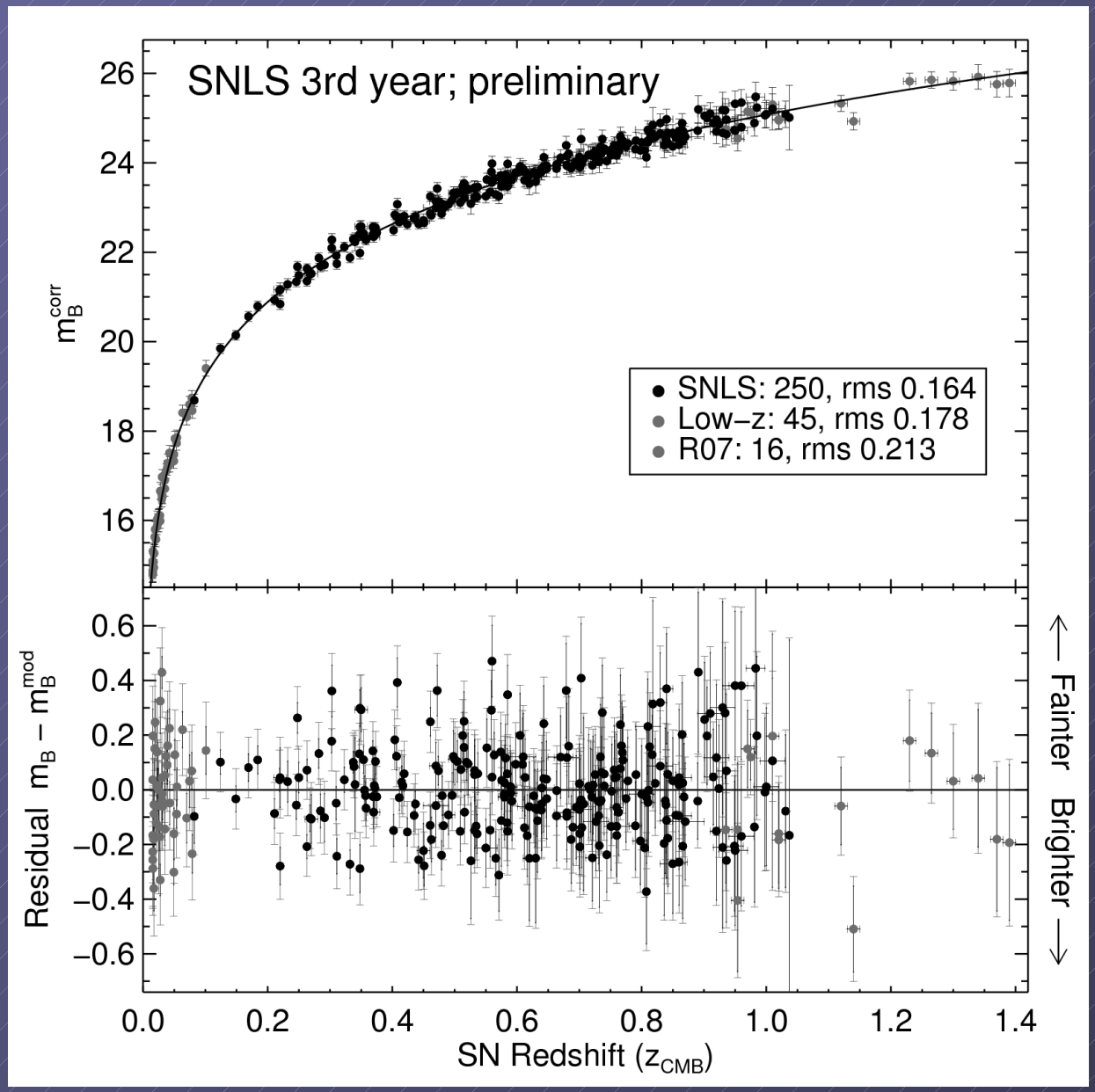
$\langle w \rangle = -1.02 \pm 0.09$ (stat) ± 0.054 (sys) (with BAO + Flat Universe)

SNLS3 versus SNLS1: Highlights

- *More SNe! 71 to 250:* sub-samples & “astrophysical systematics”
  - Represents about 60-70% of final SNLS5 sample
- *Optimised survey calibration and understanding of selection*
  - 3-year monitoring of fields; better calibration of MegaCam
  - Malmquist corrections understood and applied to data
- *Improved understanding of SN Ia properties*
  - New “k-correction” templates; UV spectra,
  - New techniques exploit SN data at λ<4000A
- *Independent analyses (“French” and “Canadian”)*
  - All aspects of analysis cross-checked independently
- *Systematics included directly in cosmological fits*

rms: 0.19
0.16mag

SNLS3 Hubble Diagram (**preliminary**)



~250 distant SNLS SNe Ia

311 SNe total

SNLS+flatness+w=-1:

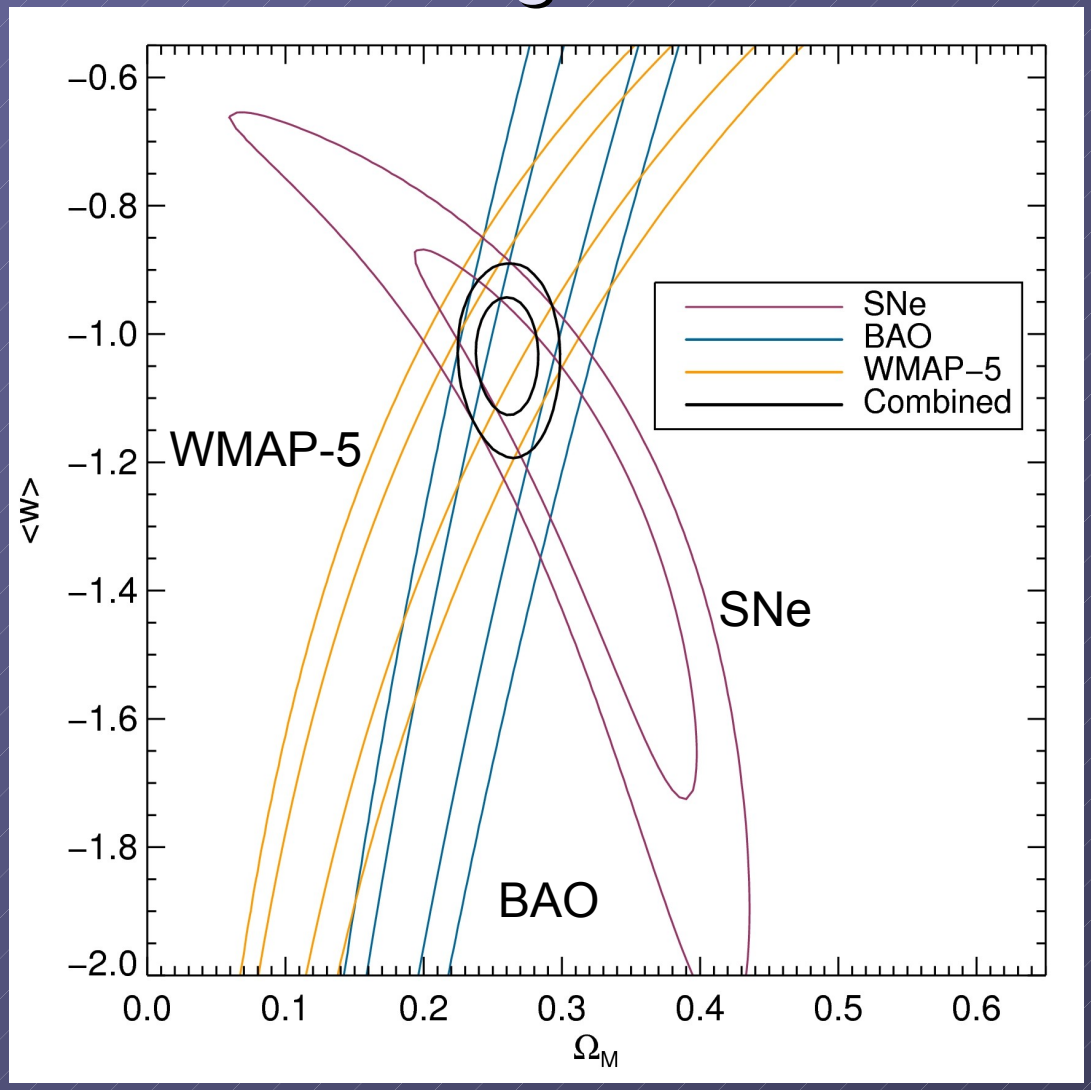
Ω_M 0.25 9.9% error

error is 15.7% for SNLS1 sample

Improvement just a little worse than SQRT(N)

(comparison uses new light curve fits and calibration improvements)

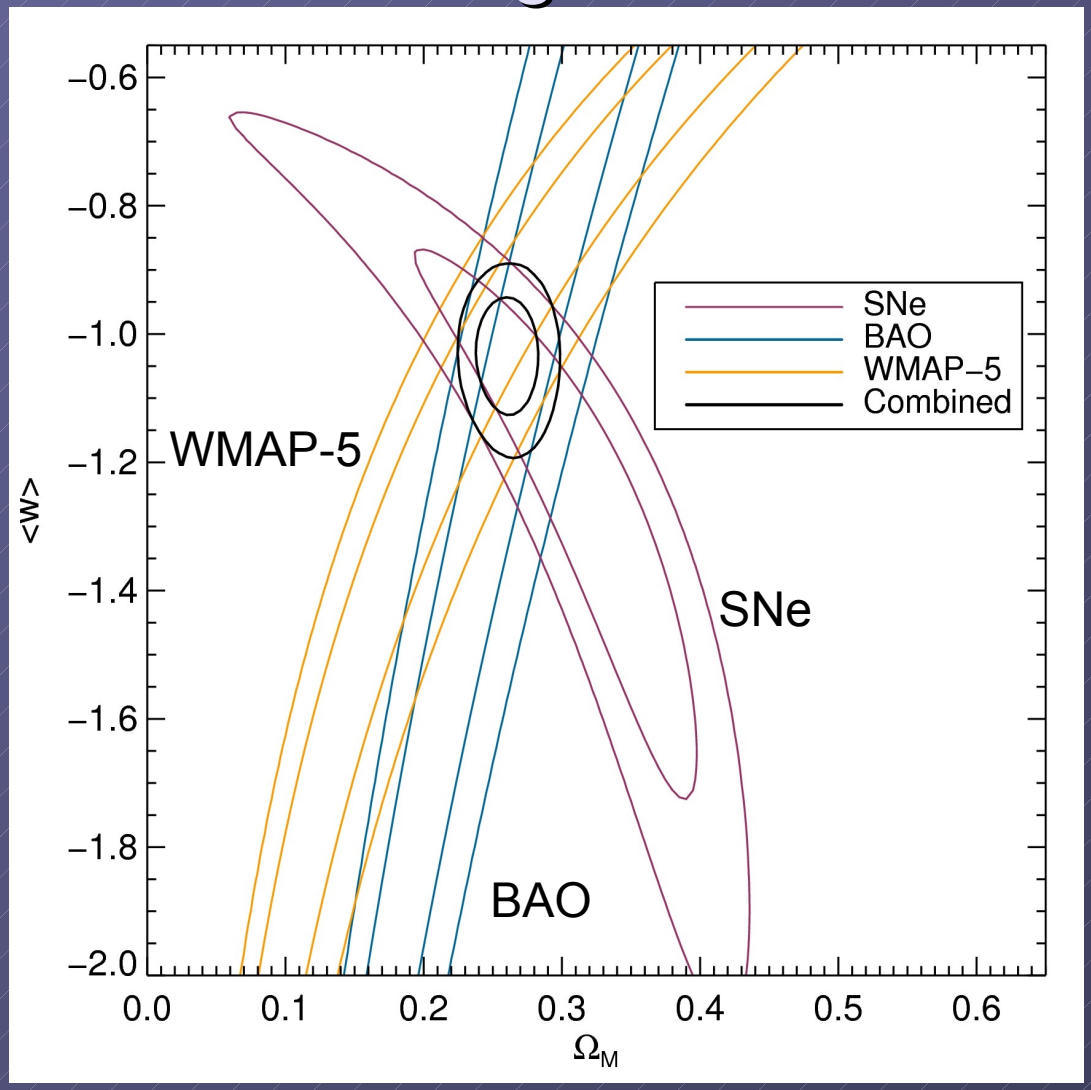
Cosmological Constraints (**Preliminary**)



5.9% statistical measure of <w>

SNLS + BAO + WMAP5 “shifts” + **Flat**

Cosmological Constraints (**Preliminary**)



How fast are SN constraints improving?

SN contour area decrease since Astier et al. 2006 again just worse than SQRT(N)

SNLS + BAO + WMAP5 “shifts” + **Flat**

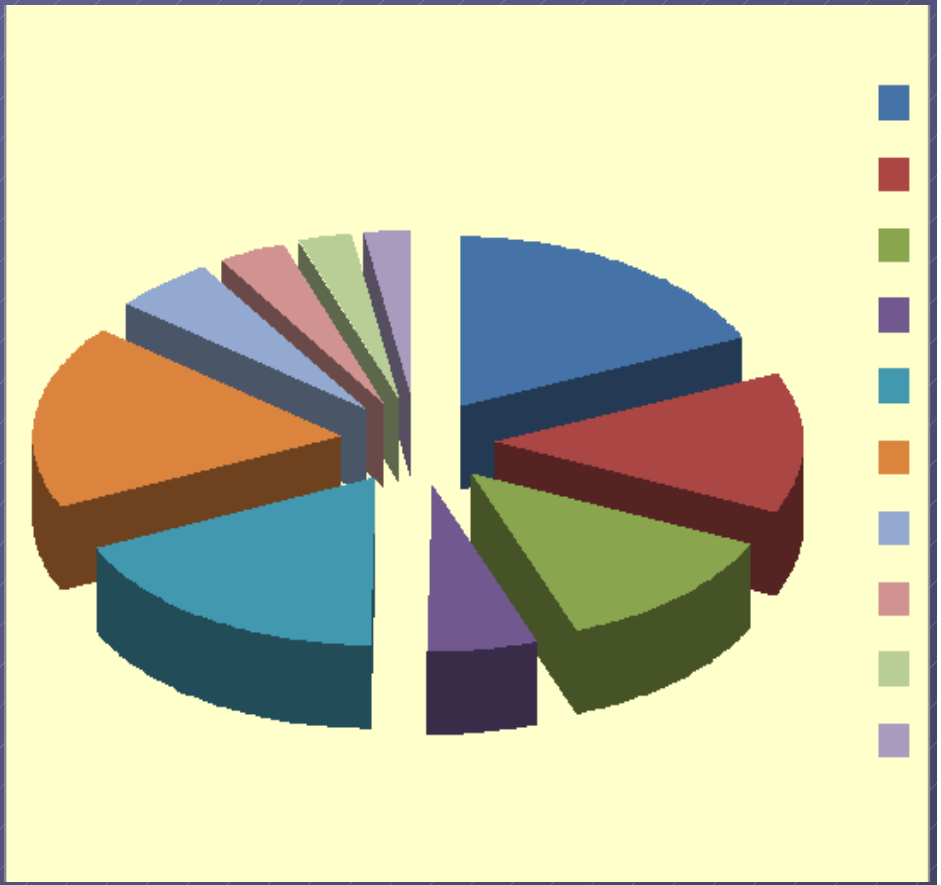
SNe Ia: Systematics

- "Experimental Systematics"
  - *Calibration; photometric system; Malmquist effects*
- Non-SN systematics
  - *Peculiar velocities; Weak lensing*
- SN model and K-corrections
  - *SED uncertainties; colour relations; light curve fitters*
- Extinction/Colour
  - *Effective R_V; Mix of intrinsic colour and dust*
- Redshift evolution in the mix of SNe
  - *"Population drift" – environment?*
- Evolution in SN properties
  - *Light-curves/Colours/Luminosities*

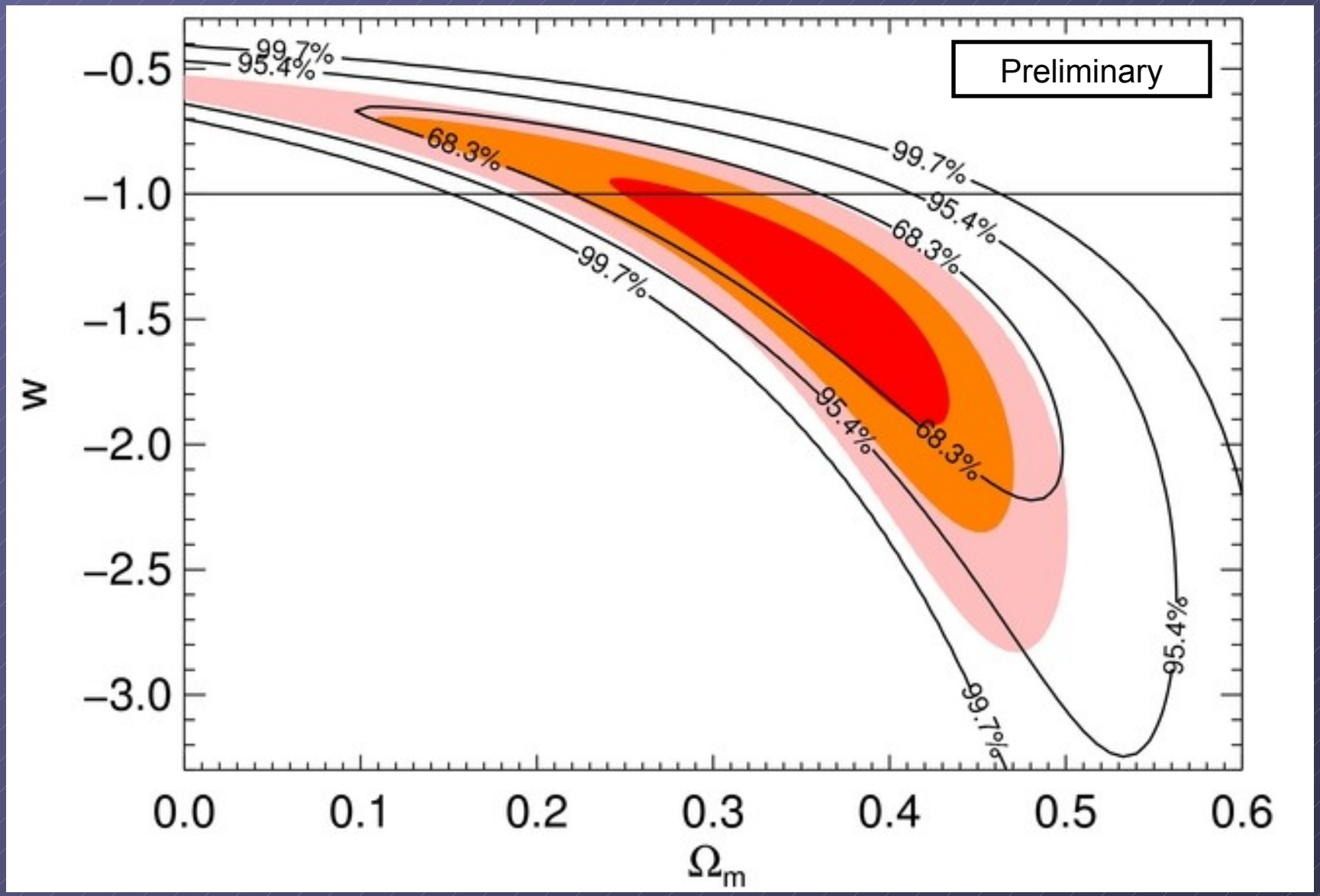
Tractable, can be modelled

Identified systematics in SNLS3 (preliminary)

Conley et al., in prep

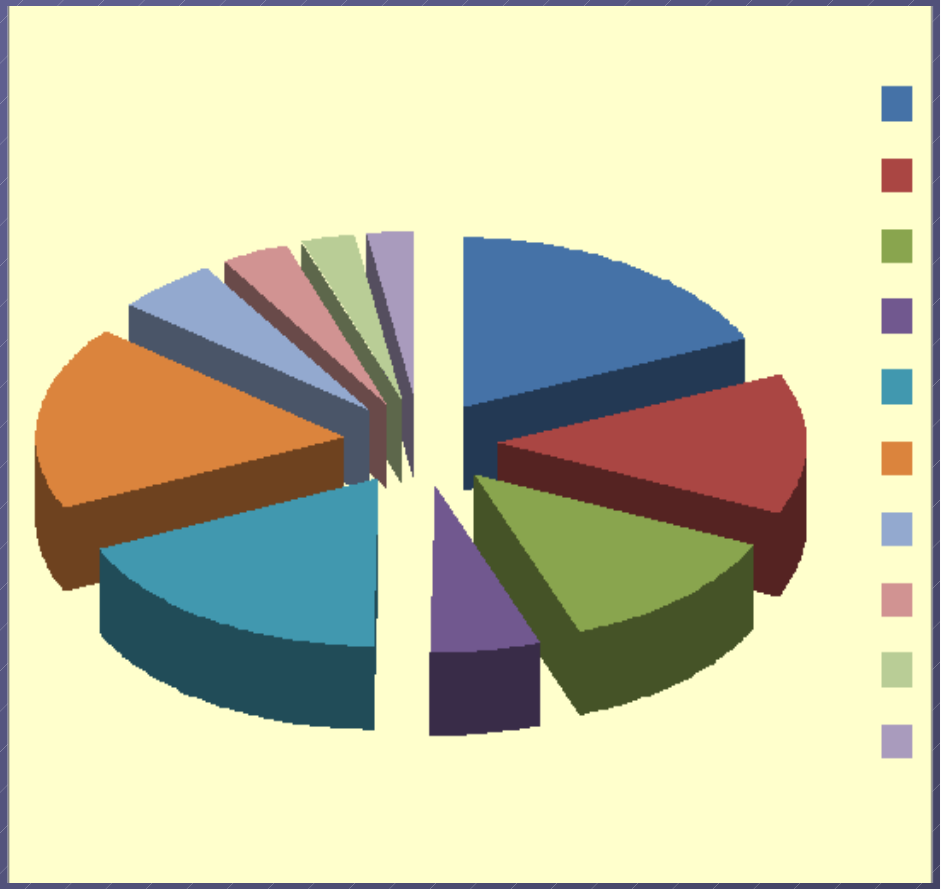


Systematic	% <w> error	Extra
Statistical only	0.060	…
SNLS zero points	0.069	0.031
SNLS filters	0.065	0.023
External zero points	0.064	0.021
External filters	0.061	0.010
SN colour relation	0.067	0.027
Vega colours	0.068	0.030
Vega SED	0.061	0.009
Peculiar velocities	0.061	0.006
Malmquist bias	0.061	0.005
Nicmos non-linearity	0.060	0.004
All systematics	**≈0.09**	**0.068**



Systematic errors included in the error contours. Filled are statistical only.

Identified systematics in SNLS3 (preliminary)



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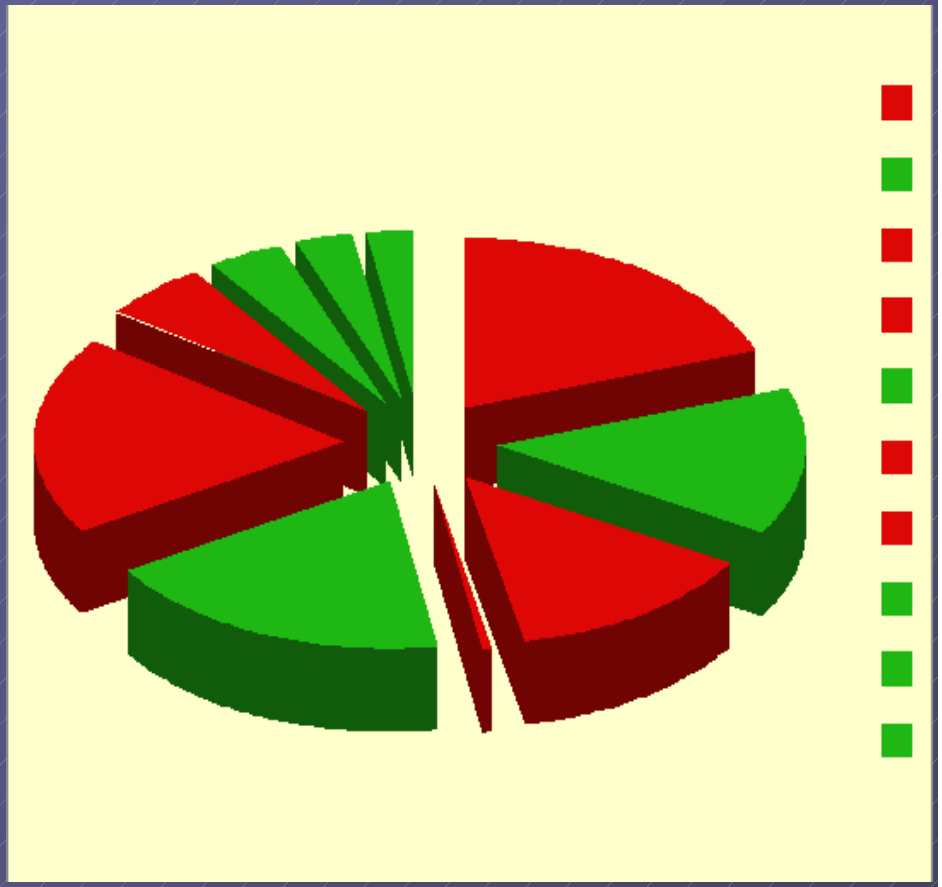
Nicmos non-linearity	0.060	0.004
All systematics	**≈0.09**	**0.068**

Most uncertainties arise from combining different SN samples

Calibration

- **The single greatest challenge in SNLS3**
  (and probably every current SN Ia survey!)
- All SNe must be placed on the same photometric system
- Different SN samples are calibrated to different systems:
  - Historical low-redshift samples: Observed in U,B,V,R (Landolt)
  - High-z: Observed in g,r,i,z- calibrate to SDSS or Landolt?
- Challenges:
  - Zeropoints (colour terms)
  - “Landolt” filter responses
- Goal: Replace low-z sample & remove dependence on Landolt system

Identified systematics in SNLS3 (preliminary)



Guideline numbers

Systematic	% <w> error	Extra
Statistical only	0.059	…
SNLS zero points	**0.069**	**0.031**
SNLS filters	0.065	0.023
External zero points	**0.064**	**0.021**
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Peculiar velocities	0.061	0.006
Malmquist bias	0.061	0.005
Nicmos non-linearity	0.060	0.004
All systematics	**≈0.09**	**0.068**
All systematics	**≈0.07**	**0.042**

When low-redshift sample is replaced, systematics should drop to 4-5%

Need for a "rolling" low-z survey (e.g. CSP, Skymapper/PTF, SDSS?)

SNe Ia: Systematics

- "Experimental Systematics"
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  - *"Population drift" – environment?*
- Evolution in SN properties
  - *Light-curves/Colours/Luminosities*

Tractable, can be modelled

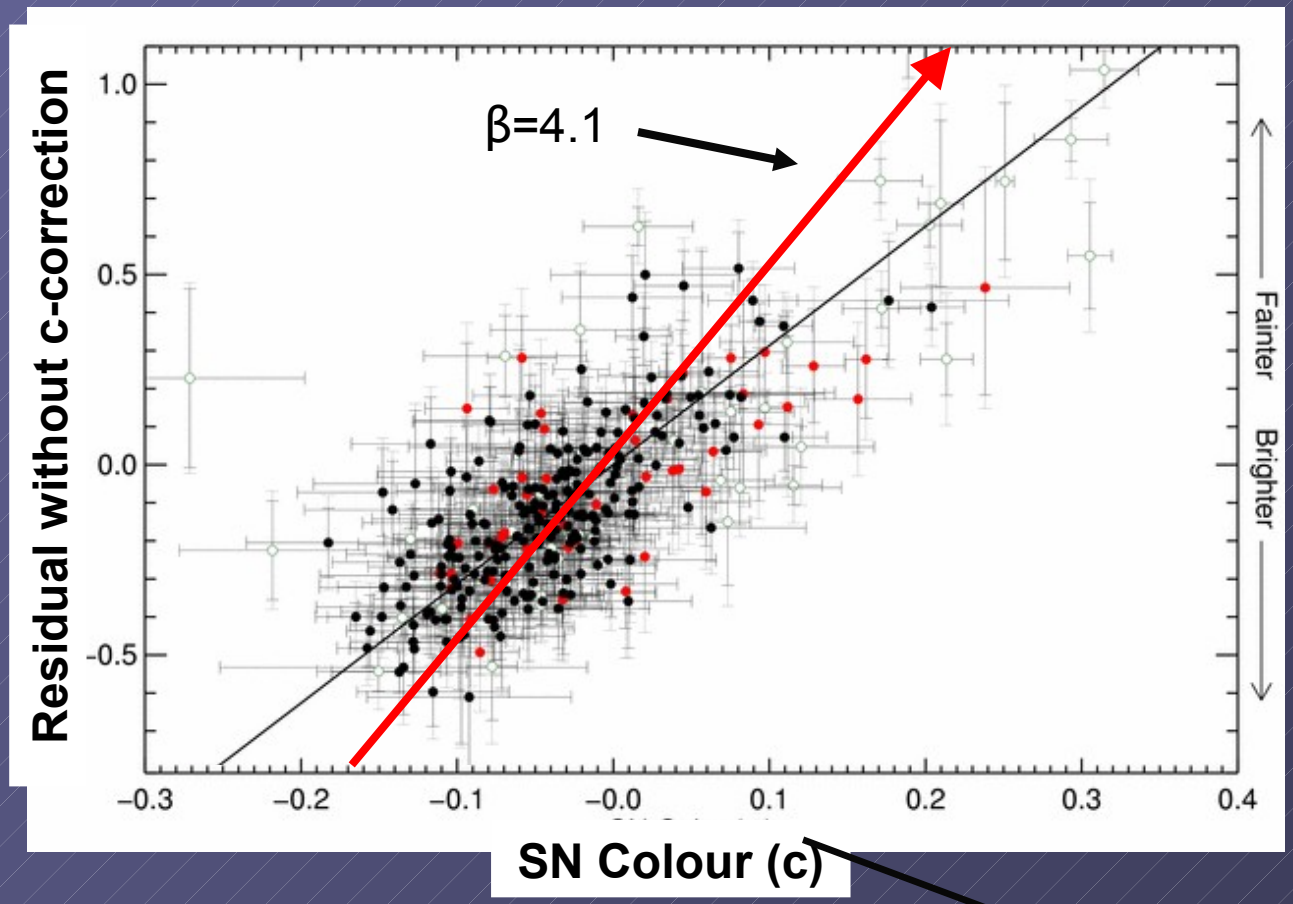
"Extinction"

Increasing knowledge of SN physics

Population Evolution"

How "Standard" is the standard candle?

Concern: Colour/dust systematics?



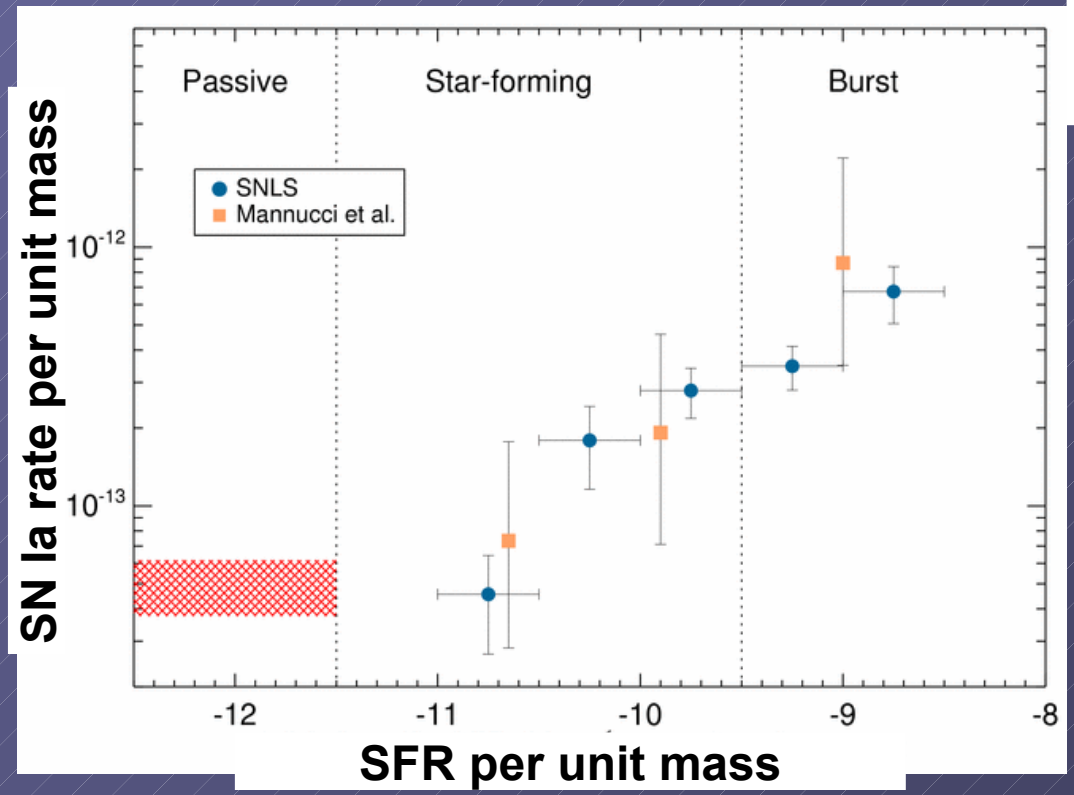
Colour—luminosity relationship inconsistent with MW-type dust

Best-fit: β~3

MW-dust: $\beta \equiv R_B = 4.1$

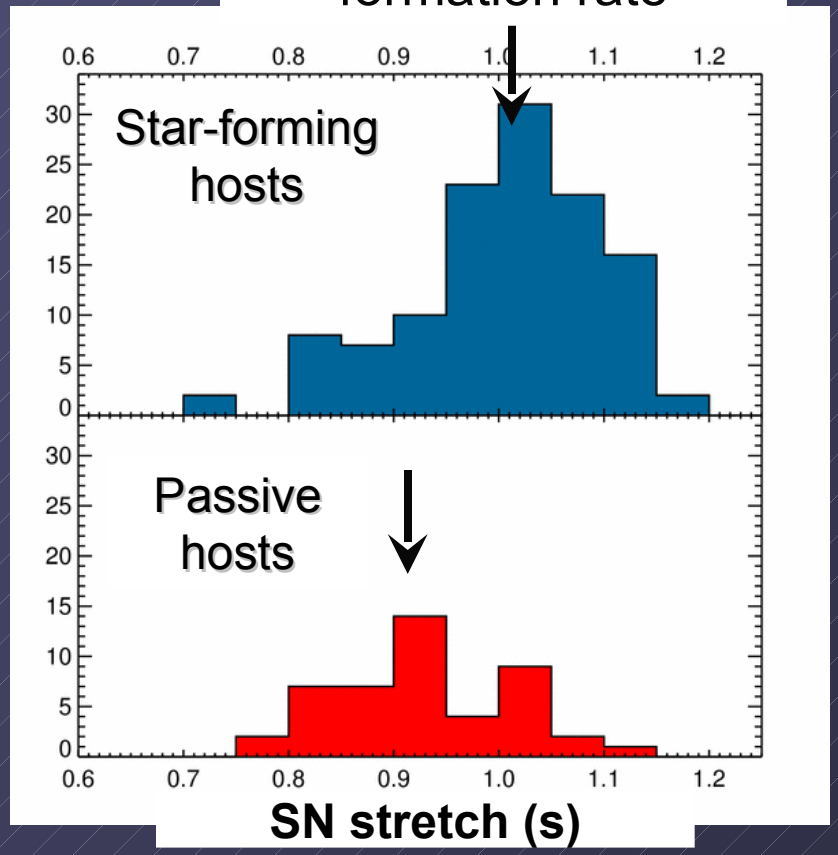
$$m_B = m_B - M_B + a(s-1) - bc$$

Concern: SN evolution?



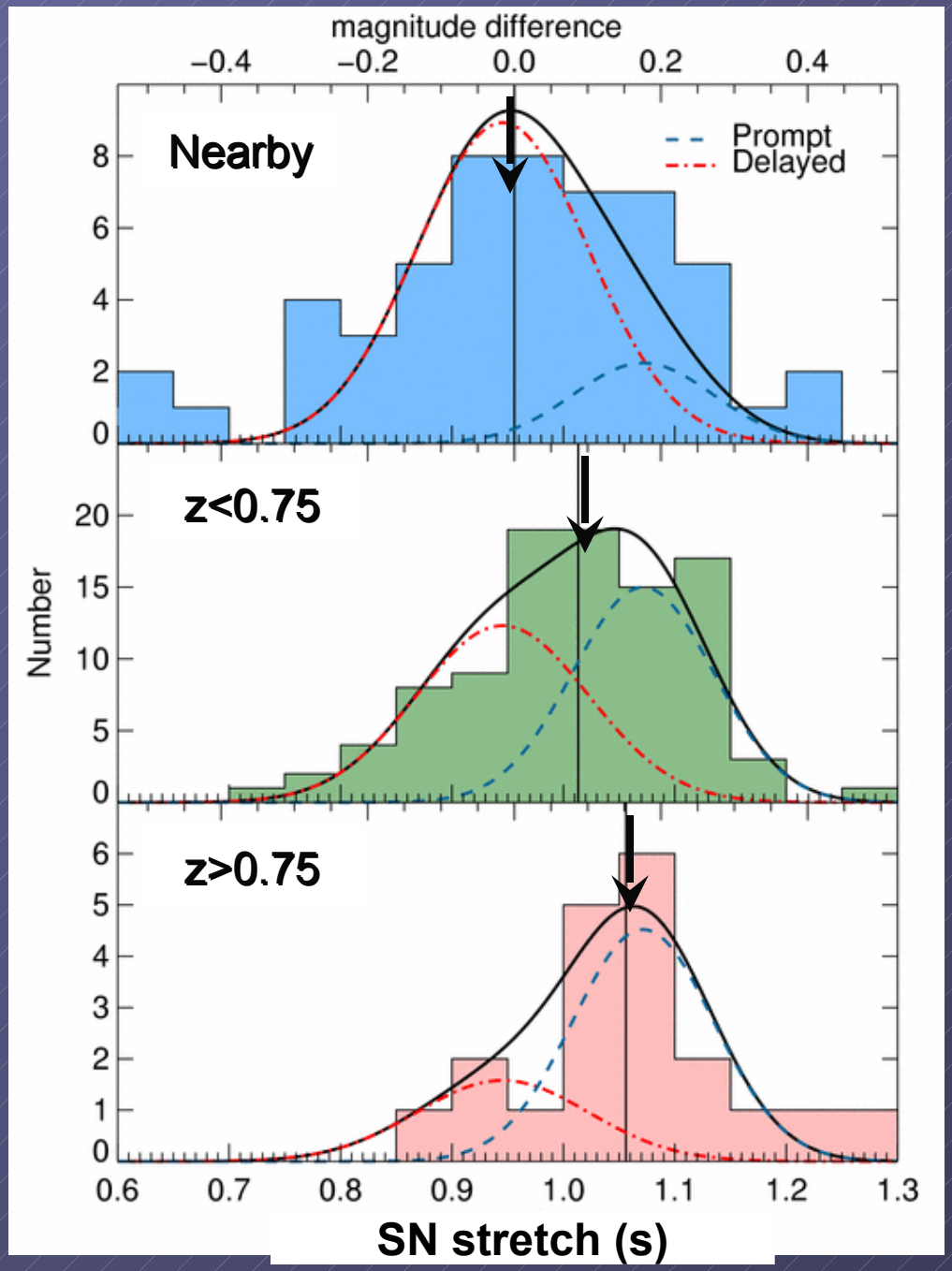
SN rate versus host SFR

SN stretch distributions split by galaxy star-formation rate



Evidence for multiple SN Ia components, or just a wide-range of delay-times with one channel?

Sullivan et al. (2006)



Redshift drift in stretch

Average stretch, and thus average *intrinsic* brightness of SNe Ia evolves with redshift

If stretch "works", this will not affect cosmology –but it must work equally well at all s

e.g. Sarkar et al. 2008

This is a demographic change, **not** evolution in SN properties

Howell et al. (2007)

Demographic shifts in SN spectra

SN Ia spectra stretch dependence

Ellis et al. (2008)

SN light curves powered entirely by decay of ^{56}Ni

Higher stretch implies:

➔ Higher luminosity

➔ More ^{56}Ni synthesised

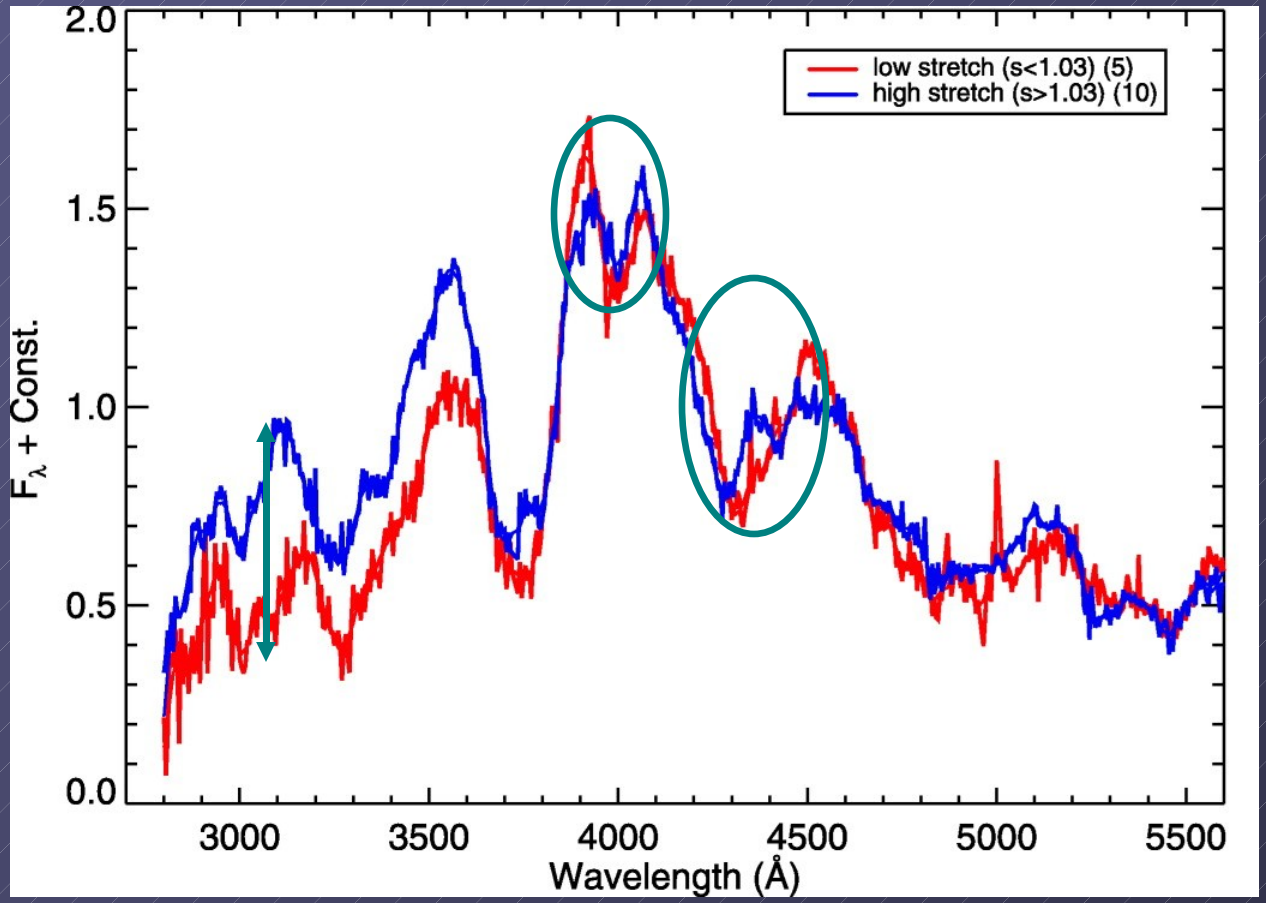
➔ Less intermediate mass elements (and hotter ejecta)

High-s SNe show weaker:

Mg 4400A

Si 4000A

as well as a bluer UV continuum



See also Ryan Foley's talk

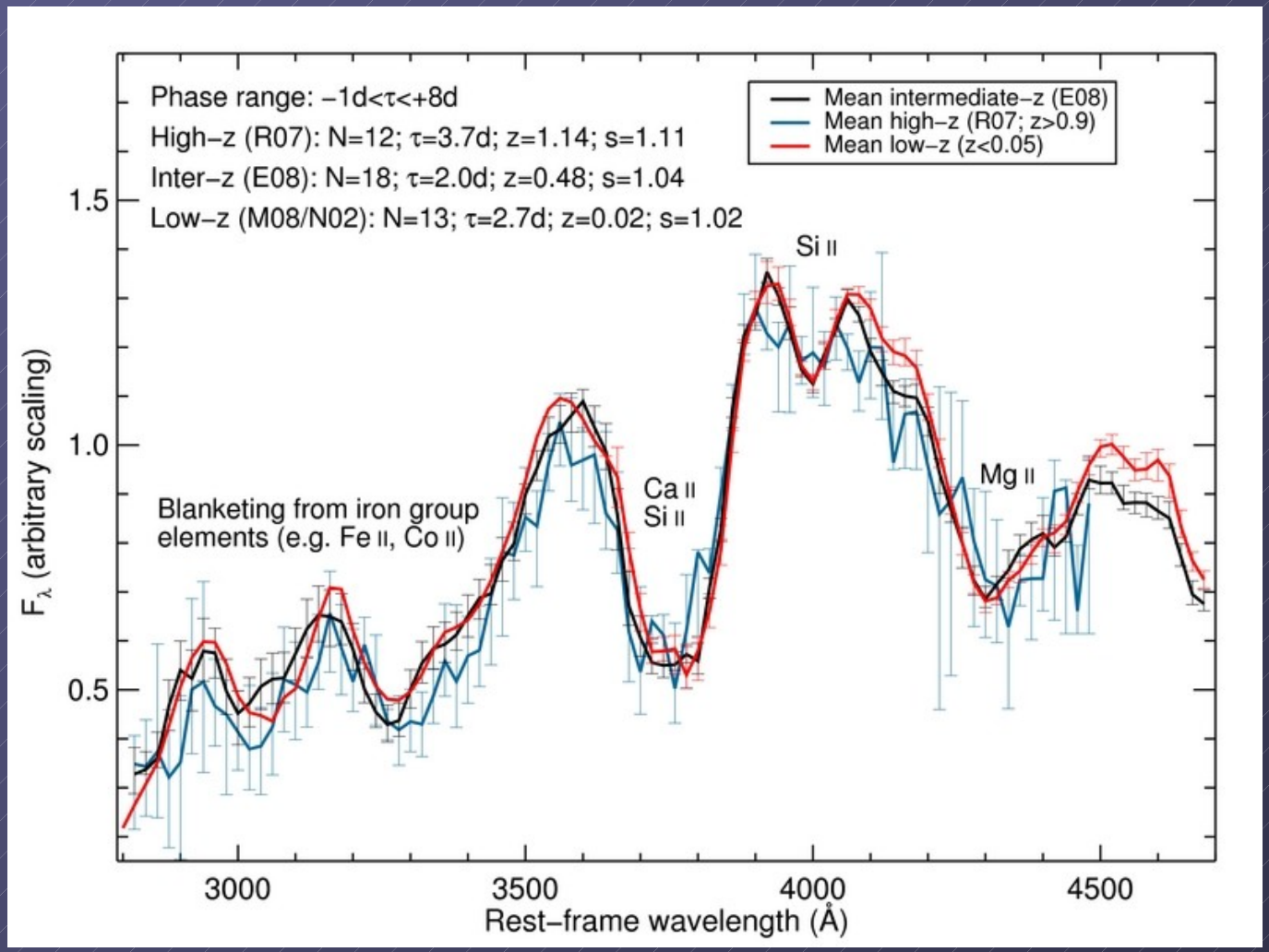
Demographic shifts in SN spectra

Spectra matched in phase

Highest-z spectrum has highest mean stretch

As expect, less Si and Ca in this spectrum

But, note the *redder* continuum



Sullivan et al. (2008); spectra from Ellis et al. (2008), Matheson et al. (2008), Riess et al. (2007)

See also Ryan Foley's talk

Demographic shifts and cosmology

- Are □ and □ “universal” coefficients? An age or metallicity (environmental) dependence might imply “drifts” with redshift
- Test with SNLS sample where host information is available; hosts span full range of stellar mass and SFR
- Each SN host has stellar mass / mean age / SFR estimates
- Split into young/old, passive/star-forming, metal-rich/metal-poor samples

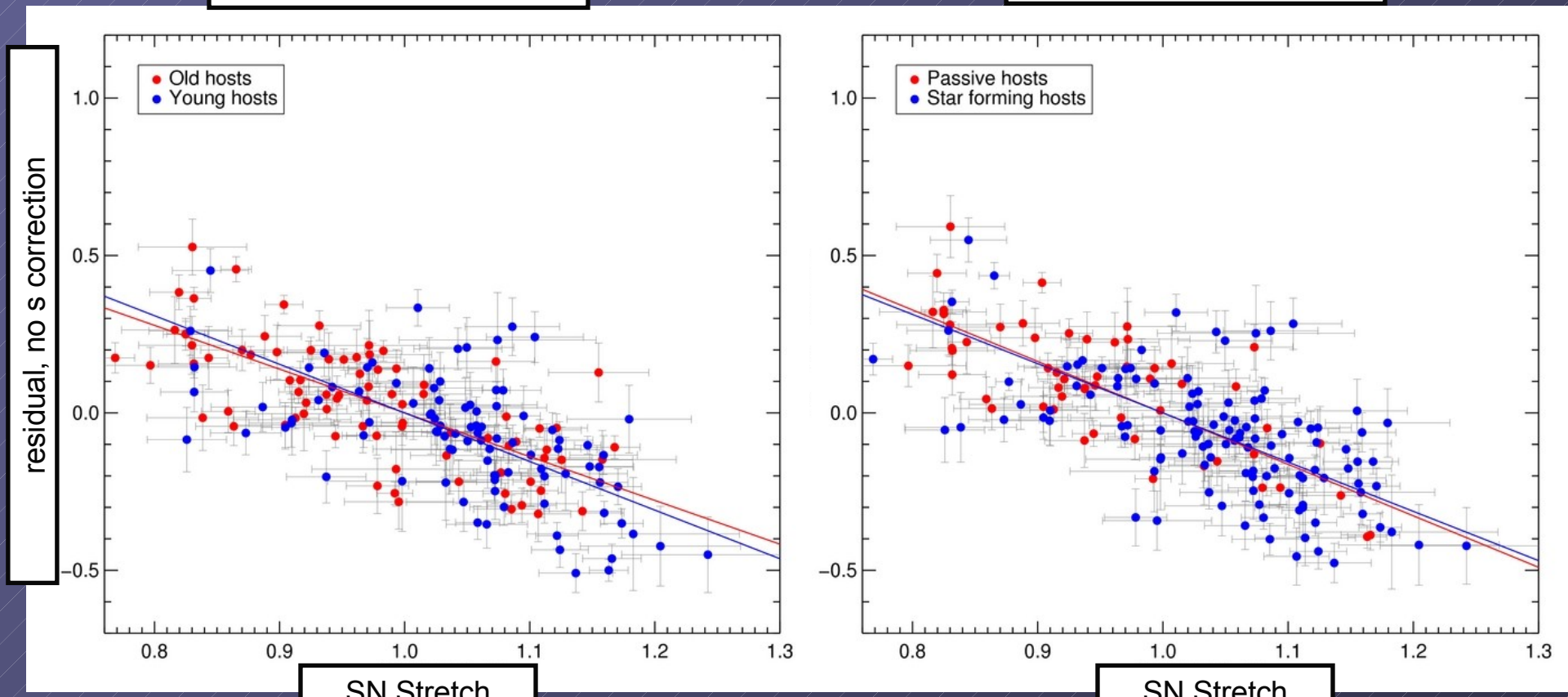
Stretch (□) correction by age/environment

Plot cosmological residual *without* (s-1) correction

SNLS z<0.8

Hosts split by age

Hosts split by SFR



$$m_B^{obs} = m_B - M_B + \cancel{a(s-1)} - bc$$

Cosmology fixed -- fit for and only

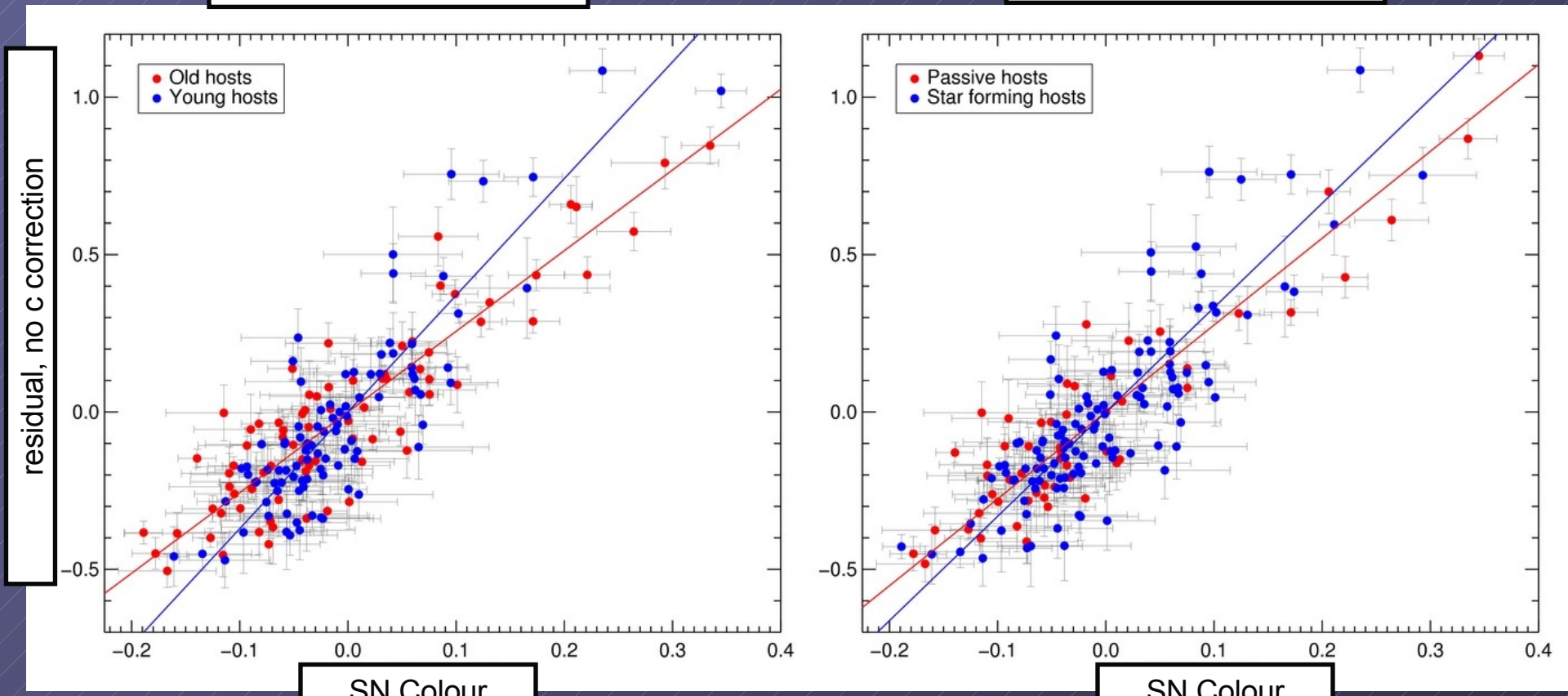
Colour (□) correction by age/environment

Plot cosmological residual *without* □colour correction

SNLS z<0.8

Hosts split by age

Hosts split by SFR

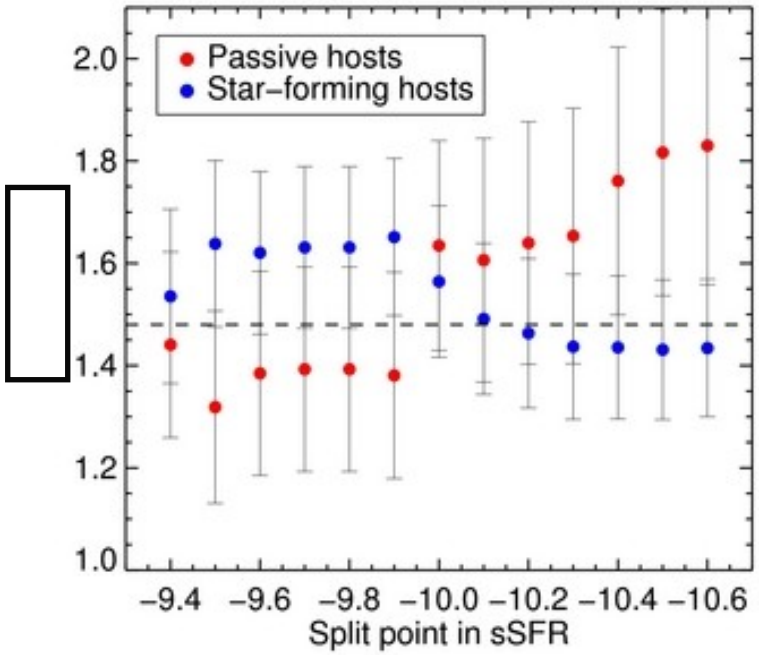


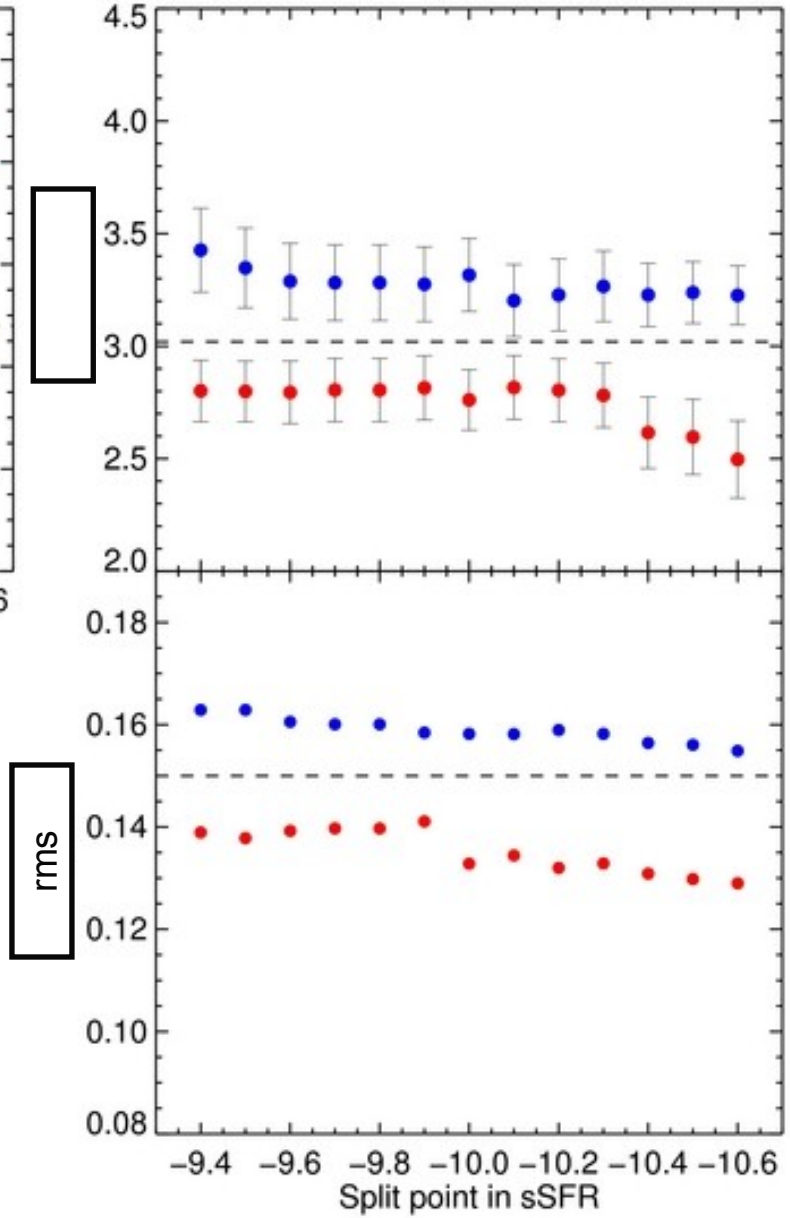
$$m_B^{obs} = m_B - M_B + a(s-1) - \cancel{bc}$$

Cosmology fixed -- fit for and only

Sensitivity to SFR split

SNLS z<0.8





rms is smaller in passive galaxies

is smaller in passive galaxies

H is consistent

Approaching limit of current c method? But no better alternative!

CNO Cycle

See Timmes, Brown & Truran (2003) for full story, including role of ^{56}Fe

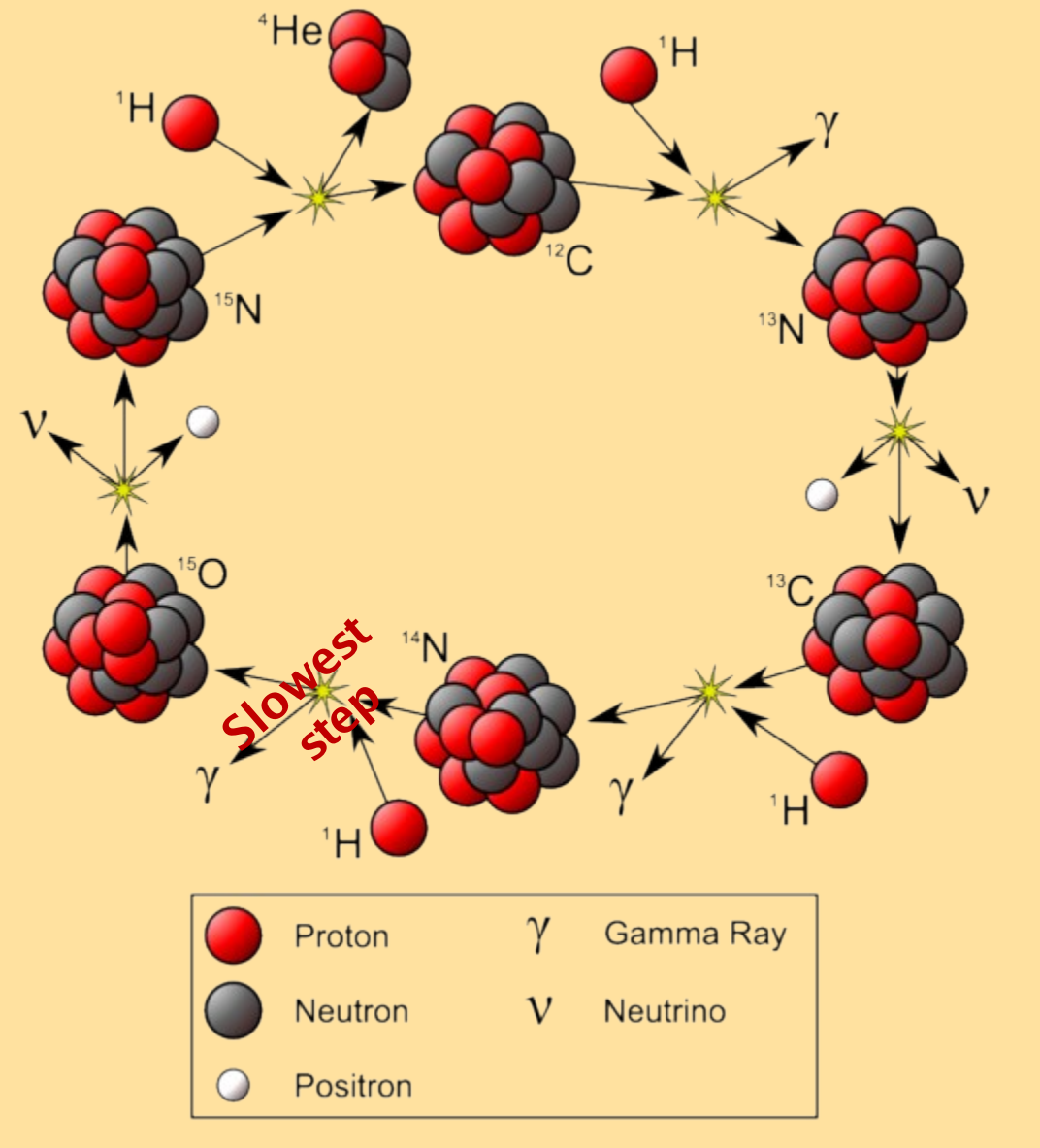
All CNO catalysts pile up into ^{14}N when H-burning is completed.

During He-burning all ^{14}N is converted into ^{22}Ne, neutron-rich

→Higher metallicity progenitor means more neutron-rich SN Ia

→More neutrons during SN, more stable ^{58}Ni instead of ^{56}Ni

→Fainter SN



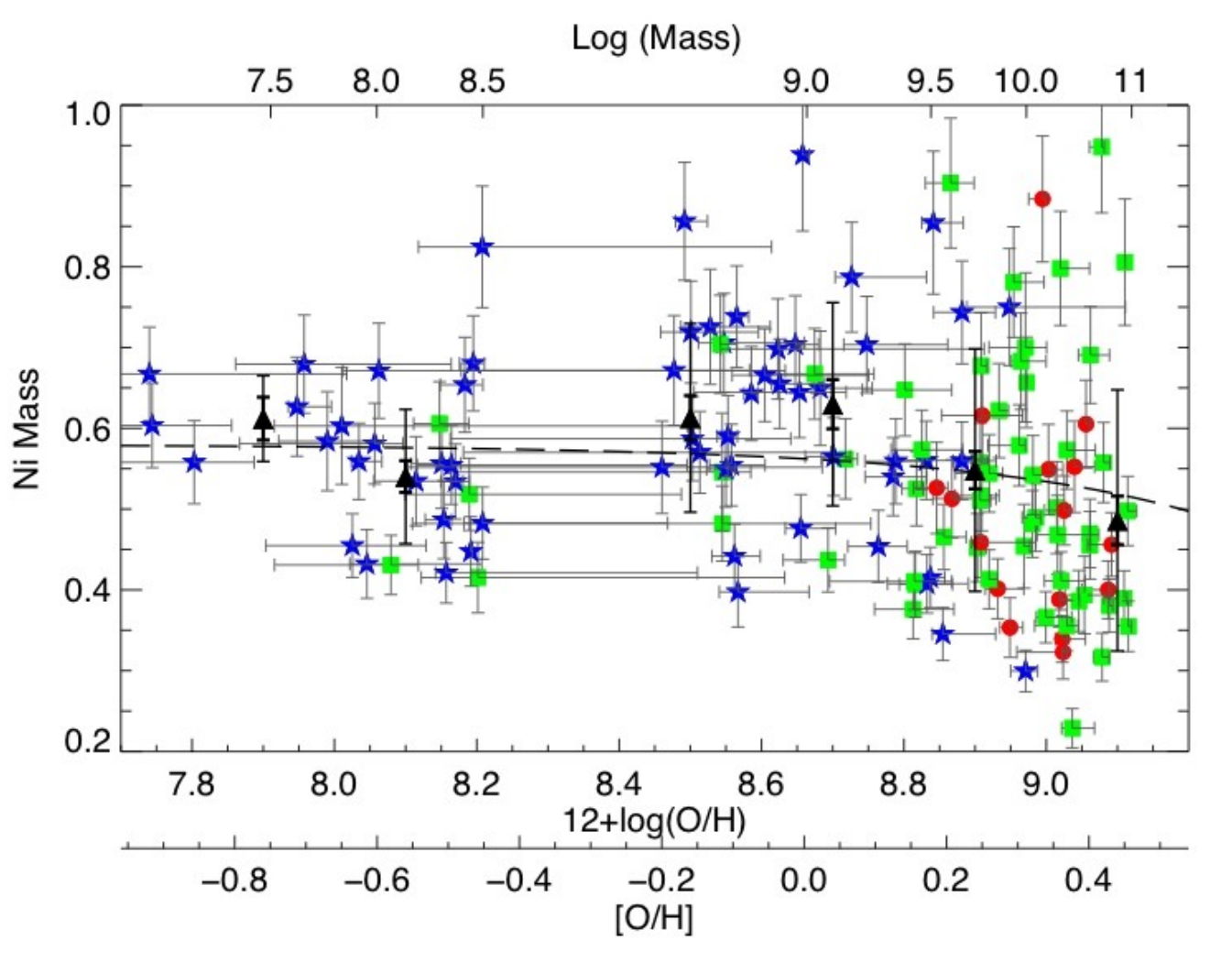
^{56}Ni yield and host properties

Howell et al. (2008)

^{56}Ni decay powers light curve - can be estimated from SN luminosity and rise-time

Galaxies with higher stellar mass and therefore inferred gas phase metallicity tend to host SNe with smaller ^{56}Ni fraction

Same sense as theoretical predictions



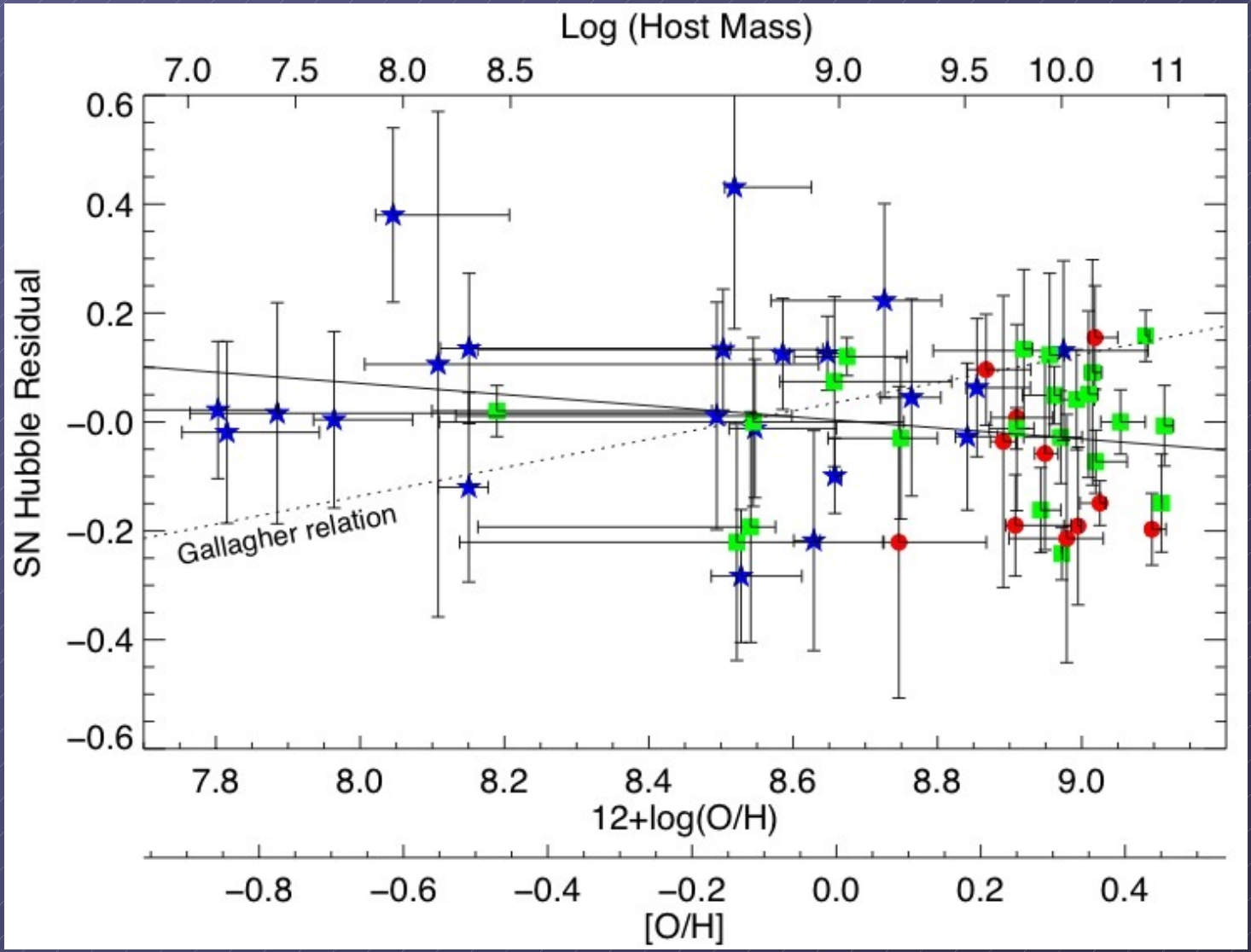
"Metallicity"

Howell et al. (2008)

Uses SNLS1 (Astier et al.) residuals

No trend between HD residual and inferred metallicity

(Note intriguing inconsistency with Gallagher et al. relation)



SN Samples? Light curve fitters? Metallicity diagnostics?

Summary

- Current constraints on <w>: <w> -1 to <6% (stat)
  (inc. flat Universe, BAO+WMAP-5)
- Systematics ~7%; dominated by z<0.1 sample
- SNLS5 survey statistical uncertainty will be 4-5%:
  - 400 SNLS + **200? SDSS** + larger z<0.1 samples, BAO, WL

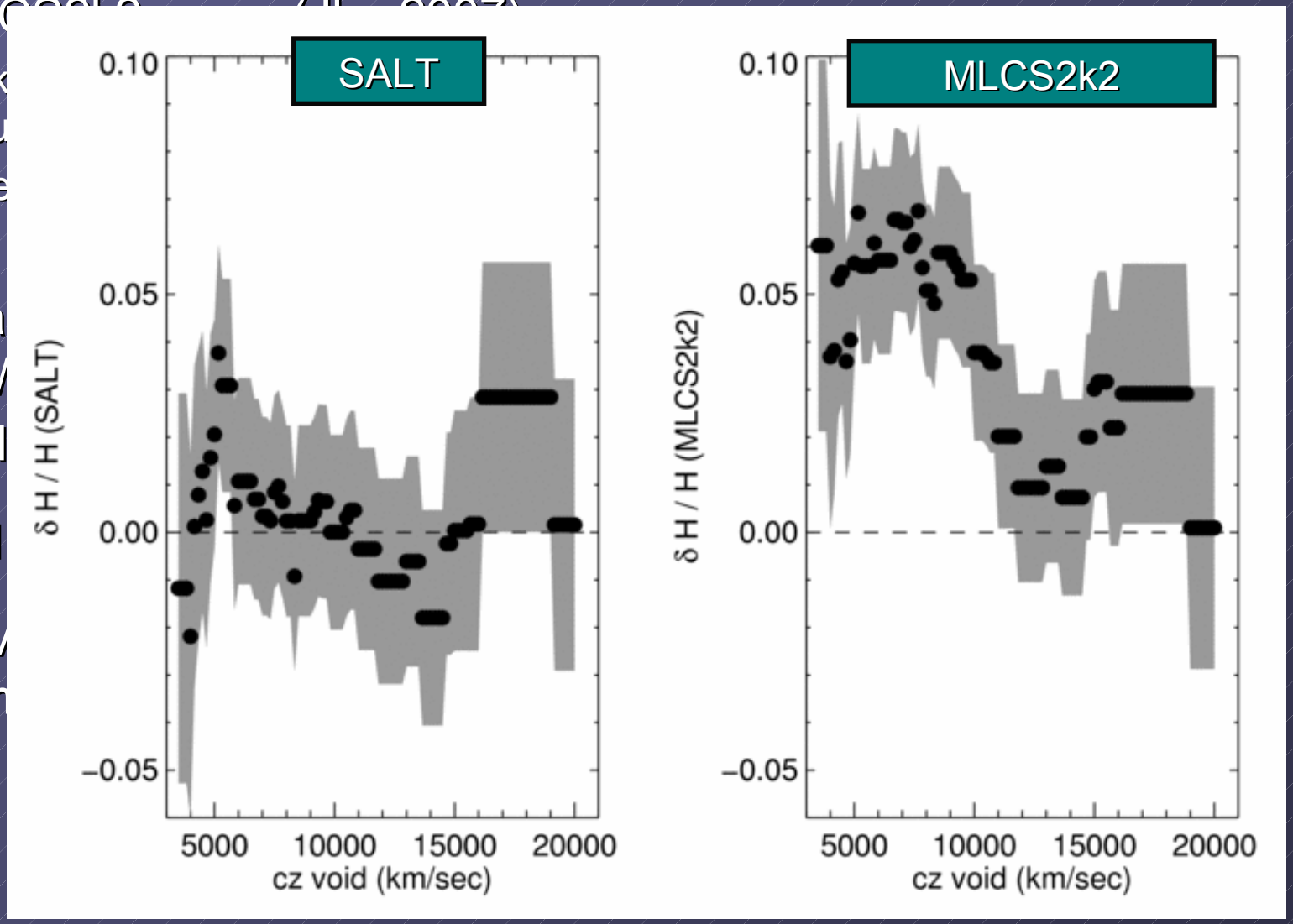
Current issues:

- Photometric calibration limiting factor; will improve dramatically
- *Mean* SN Ia properties evolve with redshift - so far no bias in cosmology detected
- *Colour corrections need to be understood; some evidence for environmental dependence*
- Urgent need for z<0.1 samples with wide wavelength coverage
  - Replace existing sample & disentangle SN Ia colours

Assuming β=4.1 leads to systematic errors – Hubble Bubble

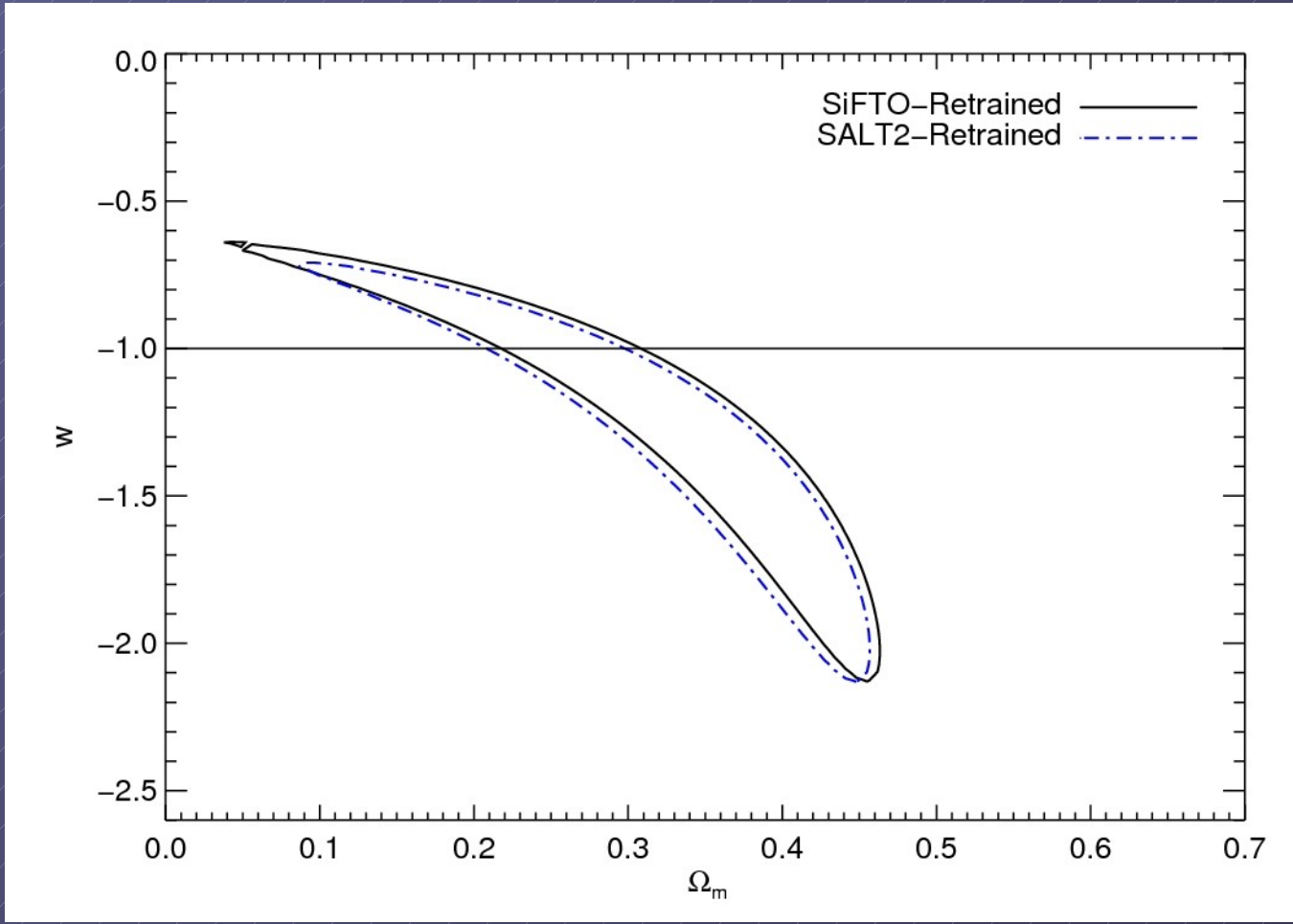
- Latest MLC
  - MLCS2k
    colour-lu
  - The latte
- 3σ decrea
  ≈7400 km/
  distant SN
- Local void
- Would hav
  measurem

No Bubble with other light-curve fitters

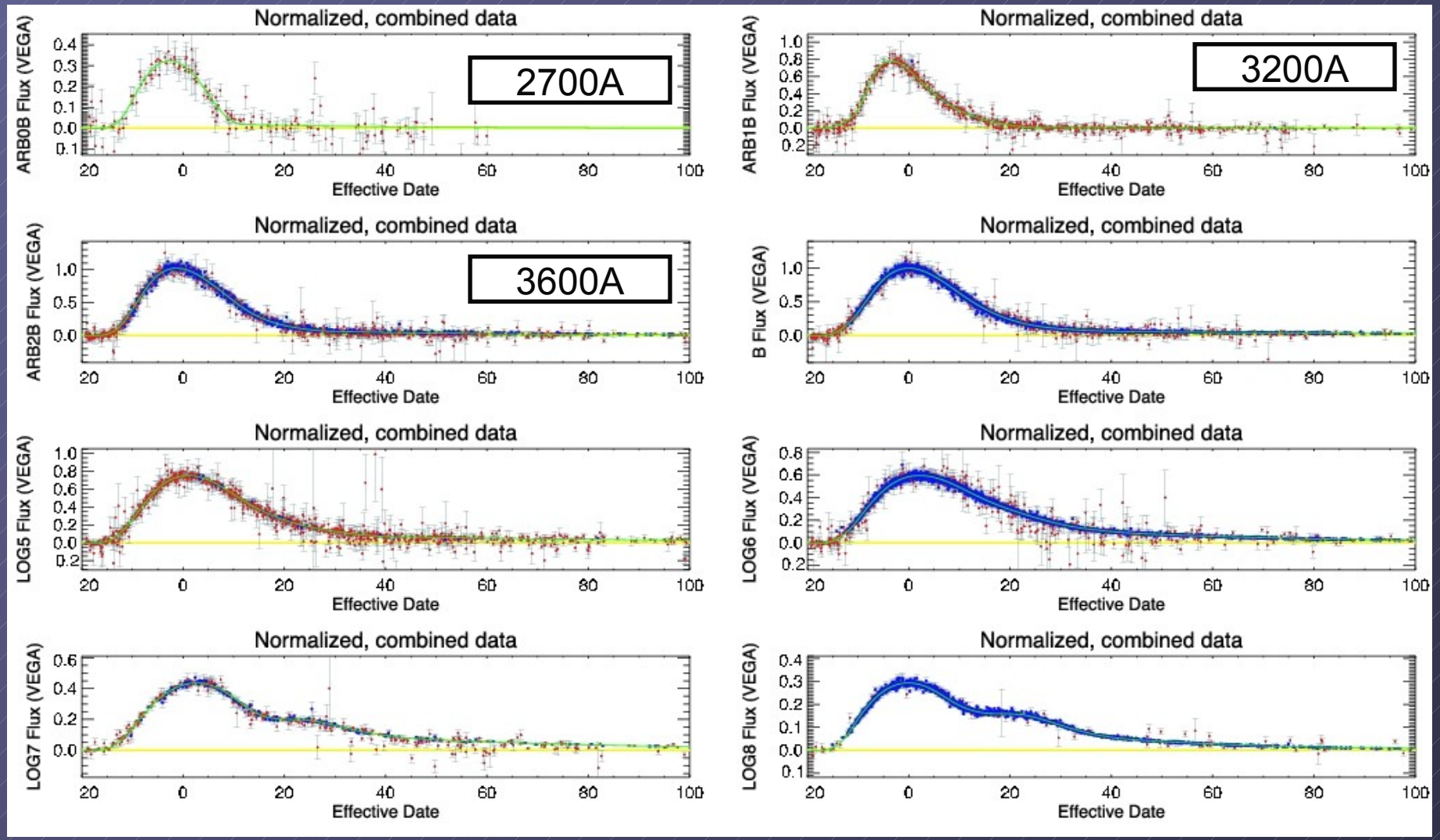


Conley et al. (2007)

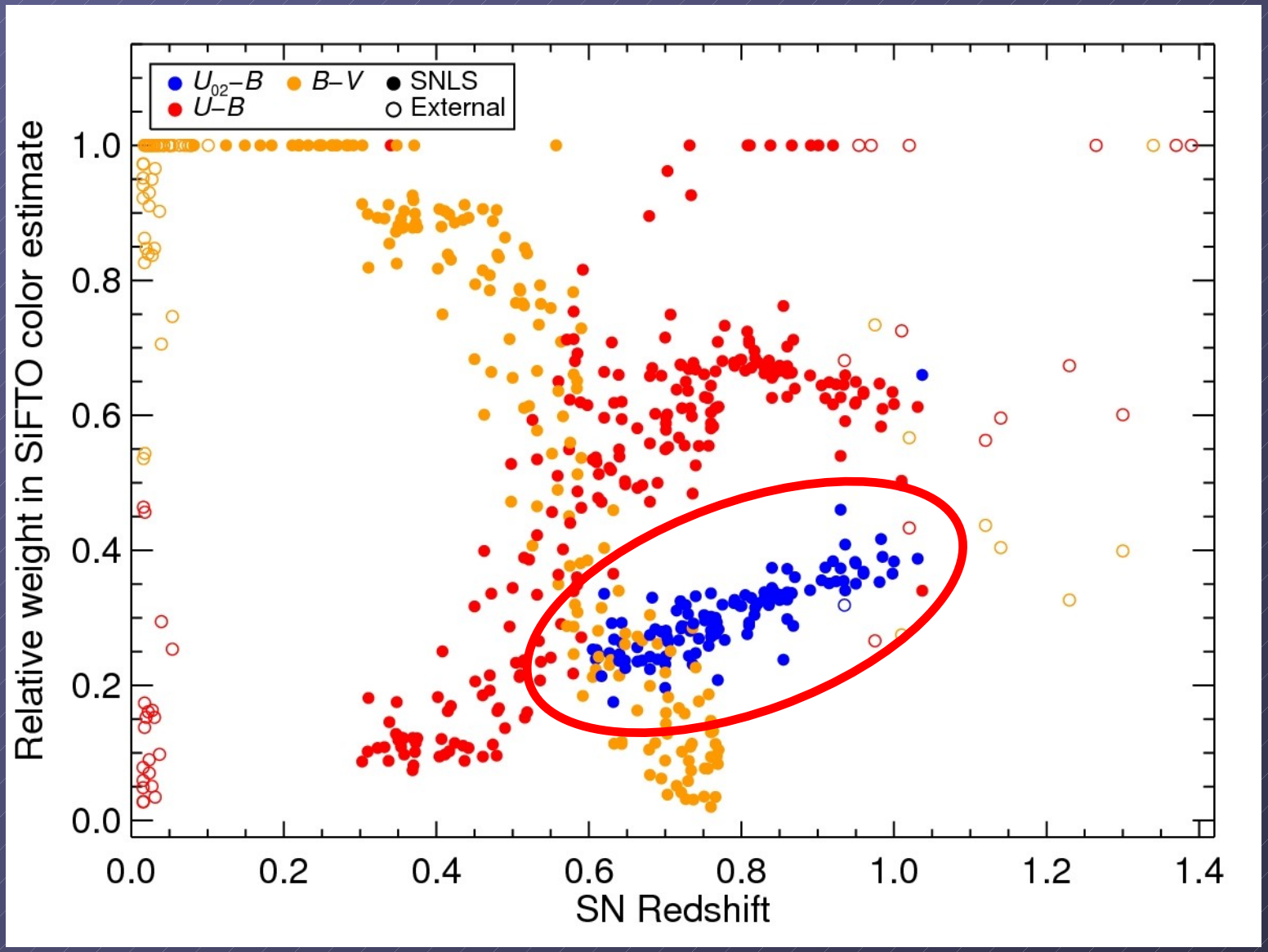
SiFTO versus SALT2



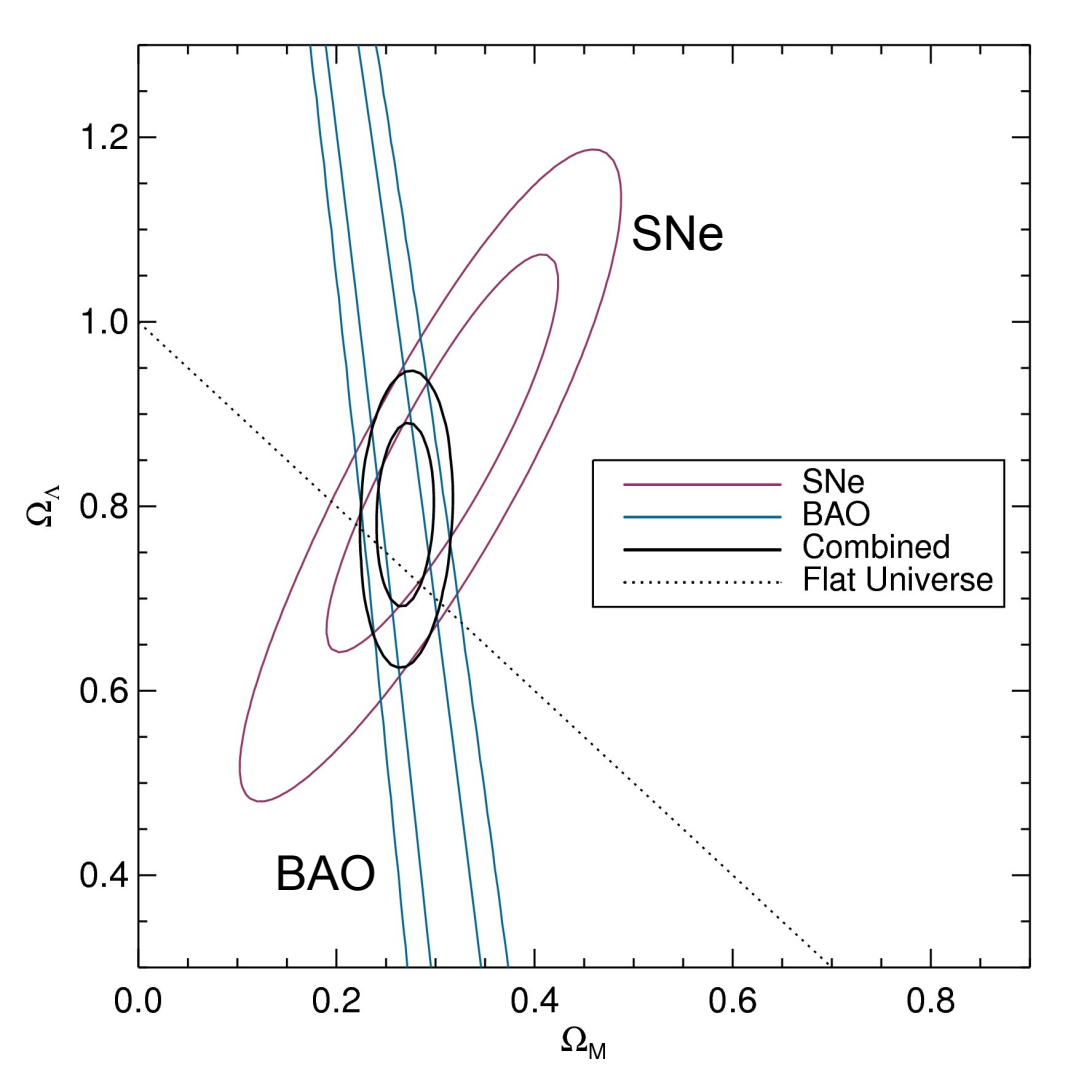
SNLS3 Highlights: Sifto & lightcurve fitters



Weighting of different colours



Cosmological Constraints (**Preliminary**)



SNLS + BAO