Supernova cosmology and physics from large surveys

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SNe Ia from three large surveys

➜ Dark energy

- Understanding (measuring) the accelerating universe

➜ Supernova physics

- SN Ia progenitors
- Understanding SN Ia explosions
- Ultimately understanding limitations of the SN Ia method

➜ Supernova Legacy Survey

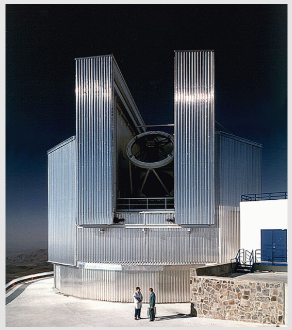
- z>0.1, mostly Type Ia Supernovae
- Dark energy

➜ Palomar Transient Factory

- Local universe
- All transient types
- SN Ia physics

➜ PESSTO

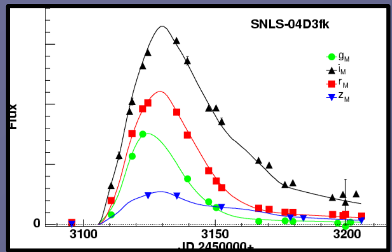
- New ESO public survey
- Spectroscopy of all transients



Supernova Legacy Survey: 2003—2008

Imaging

Distances from light-curves

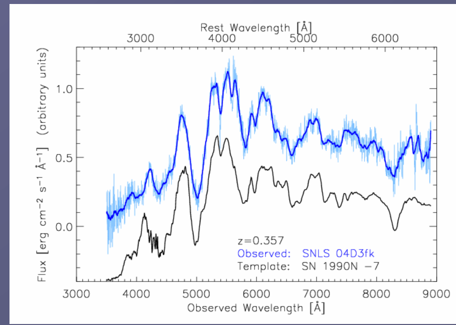


Discoveries   Lightcurves

g′r′i′z′ every 4 days during dark time

Spectroscopy

Redshifts → Distances from cosmological model



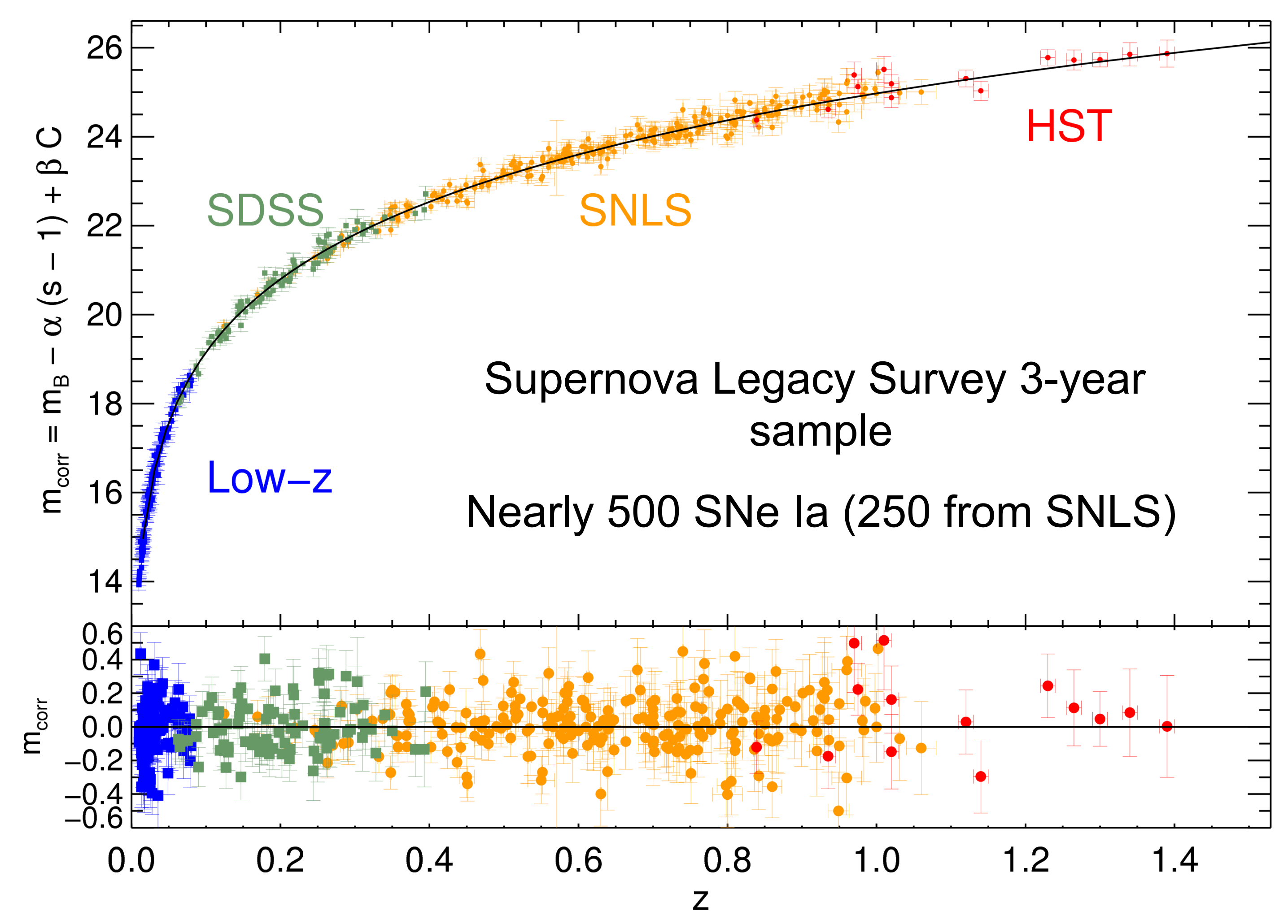
Gemini N & S (120 hr/yr)

VLT (120 hr/yr)

Keck (8 n/yr)

More 8m-class time than CFHT time – implications for planning of future surveys… see DES talk!

The cosmological power of SNe Ia: SNLS3



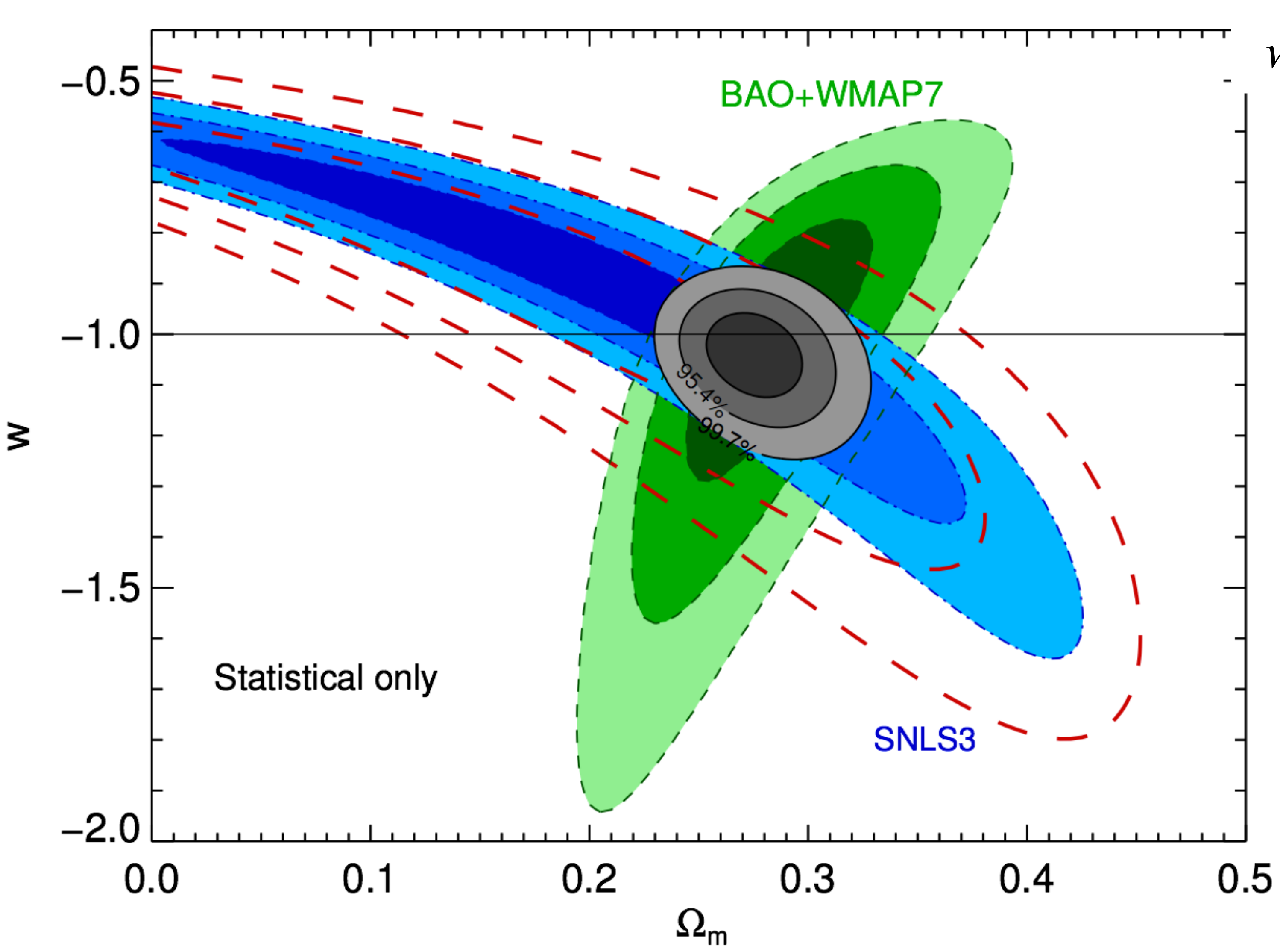
No survey can provide SNe across the entire redshift range

Combining data from different surveys presents significant calibration challenges

Guy et al. 2010

Conley et al. 2011

Sullivan et al. 2011



$w = -1.061 \pm 0.069$

SNLS3: Systematic uncertainties were approximately half the total error budget

Most of this was "photometric calibration"

Consistent with w=-1 when combined with BAO/ WMAP results

But – nearly 2σ tension with more recent Planck

Guy et al. 2010

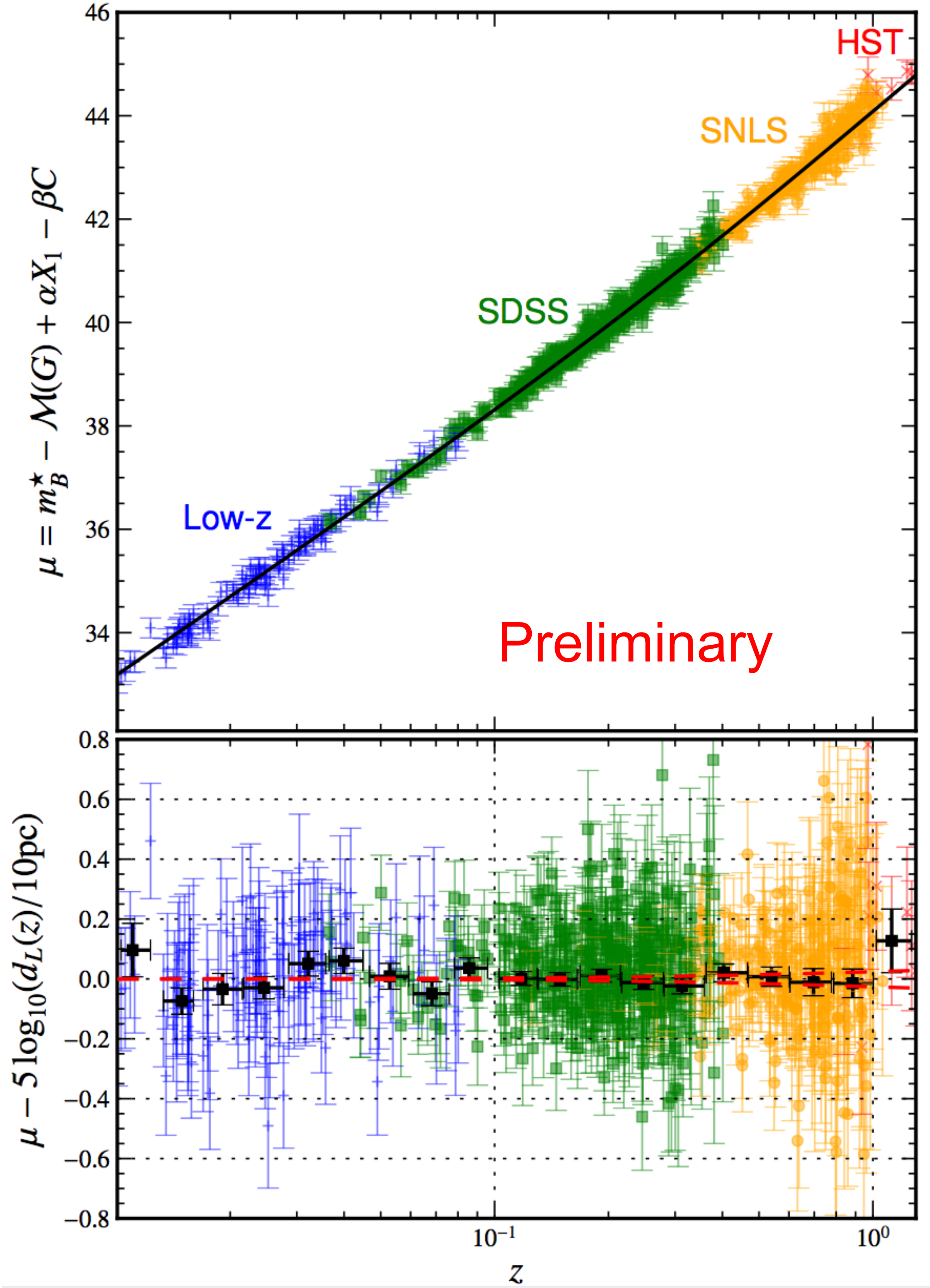
Conley et al. 2011

Sullivan et al. 2011

Which systematics are the most important (SN only)?

Description	Ω_m	w	Rel. Area
Stat only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1
All systematics	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$	1.85
Calibration	$0.191^{+0.095}_{-0.104}$	$-0.92^{+0.17}_{-0.23}$	1.79
SN model	$0.195^{+0.086}_{-0.101}$	$-0.90^{+0.16}_{-0.20}$	1.02
Peculiar velocities	$0.197^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.03
Malmquist bias	$0.198^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.07
Non-Ia contamination	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1
MW extinction correction	$0.196^{+0.084}_{-0.100}$	$-0.90^{+0.16}_{-0.20}$	1.05
SN evolution	$0.185^{+0.088}_{-0.099}$	$-0.88^{+0.15}_{-0.20}$	1.02
Host relation	$0.198^{+0.085}_{-0.102}$	$-0.91^{+0.16}_{-0.21}$	1.08

In the current published results, systematics from photometric calibration completely dominates



Joint SNLS+SDSS sample

Importance of calibration led to a revised calibration effort in 2012

Joint SNLS-SDSS analysis

SNLS/SDSS observe in similar griz filters, and can observe the same calibrating stars

(SNLS SN sample is the same as in the SNLS3 papers)

Betoule et al. in prep

What's changed since SNLS3?

- New calibration to HST spectrophotometric standards ("calspec")
  - Calibrated into this system at 0.4%
- Correction of instrumental effects e.g.
  - Filter aging
  - Improved flat-fielding (precise to 0.003mag)
  - PSF size variation (with colour, flux, etc.)
- Correction of sign error in construction of tertiary standards...

Summary of zeropoint changes since SNLS3 (SNLS3-r):

	Band	g	r	i	z
	Δ_{SNLS} (mag)	-0.0129	-0.0009	0.0013	-0.0179
Guy et al. 2010	SNLS3 uncertainty	±0.006	±0.006	±0.008	±0.019

Betoule et al. 2013

New SNLS/SDSS calibration

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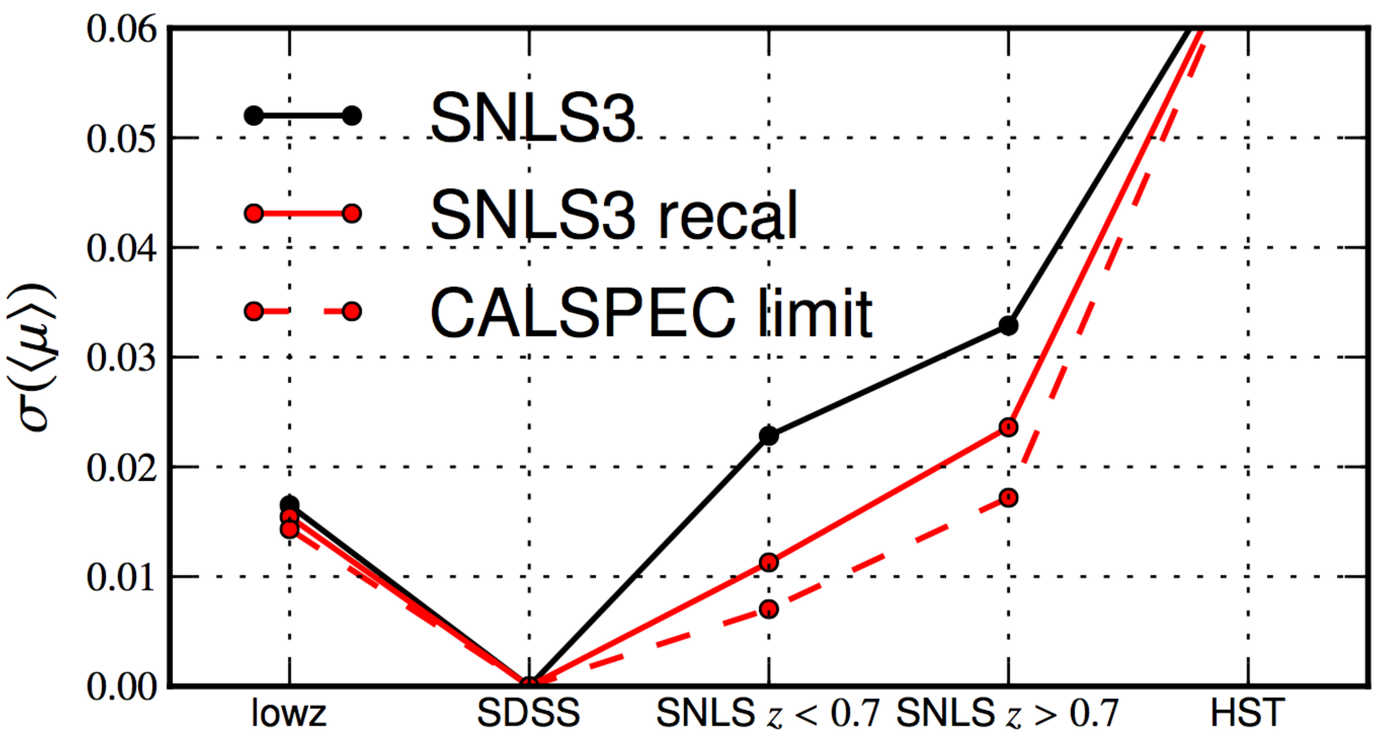
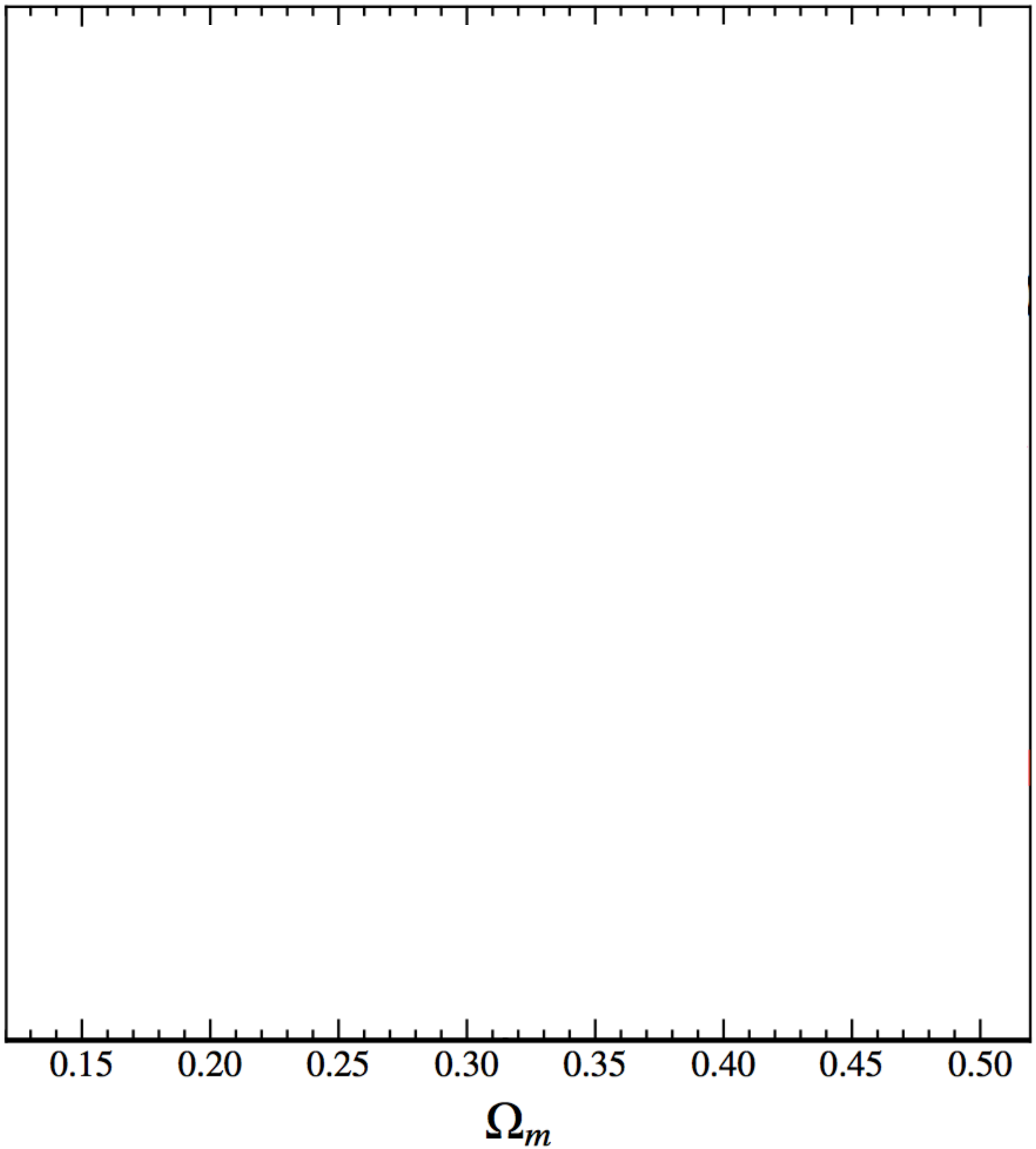


Dominated by the uncertainty on the HST calibration

Betoule et al. 2013

Cosmological constraints (Ω_M) Preliminary



Betoule et al. in prep

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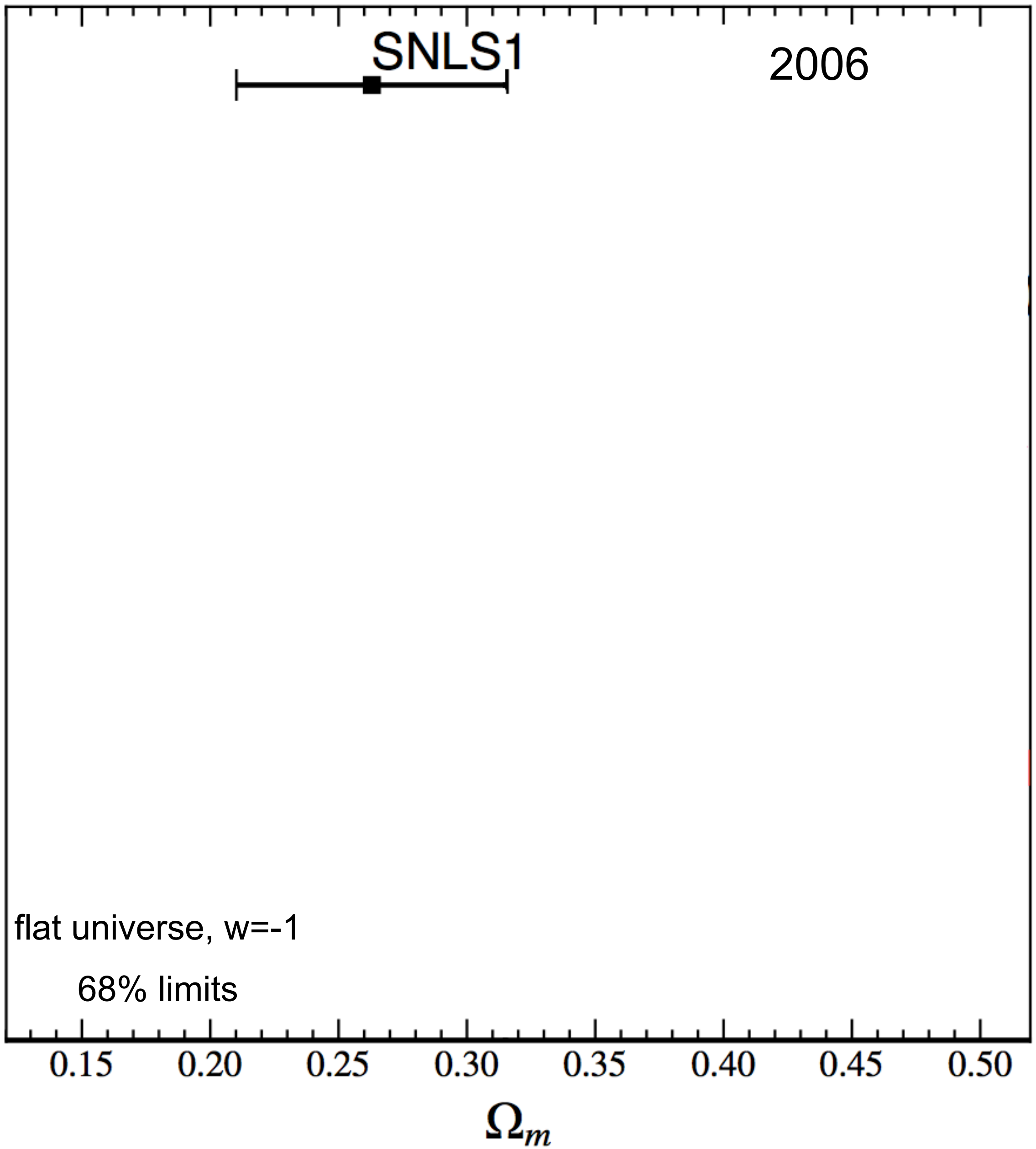

SNLS1 - Astier et al. (2006)
(Not systematics limited)

Betoule et al. in prep

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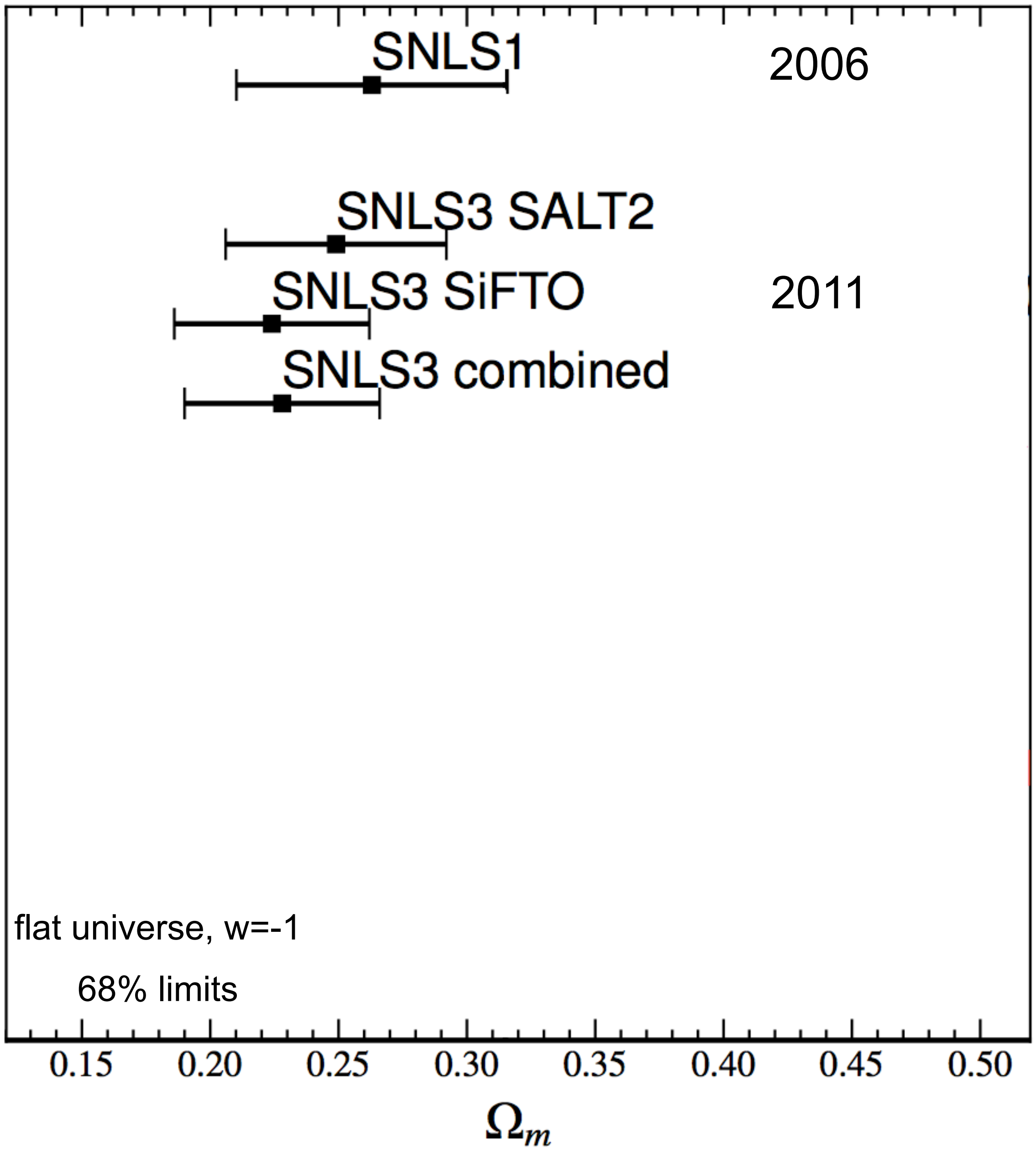

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(Limited by photometric calibration)

Betoule et al. in prep

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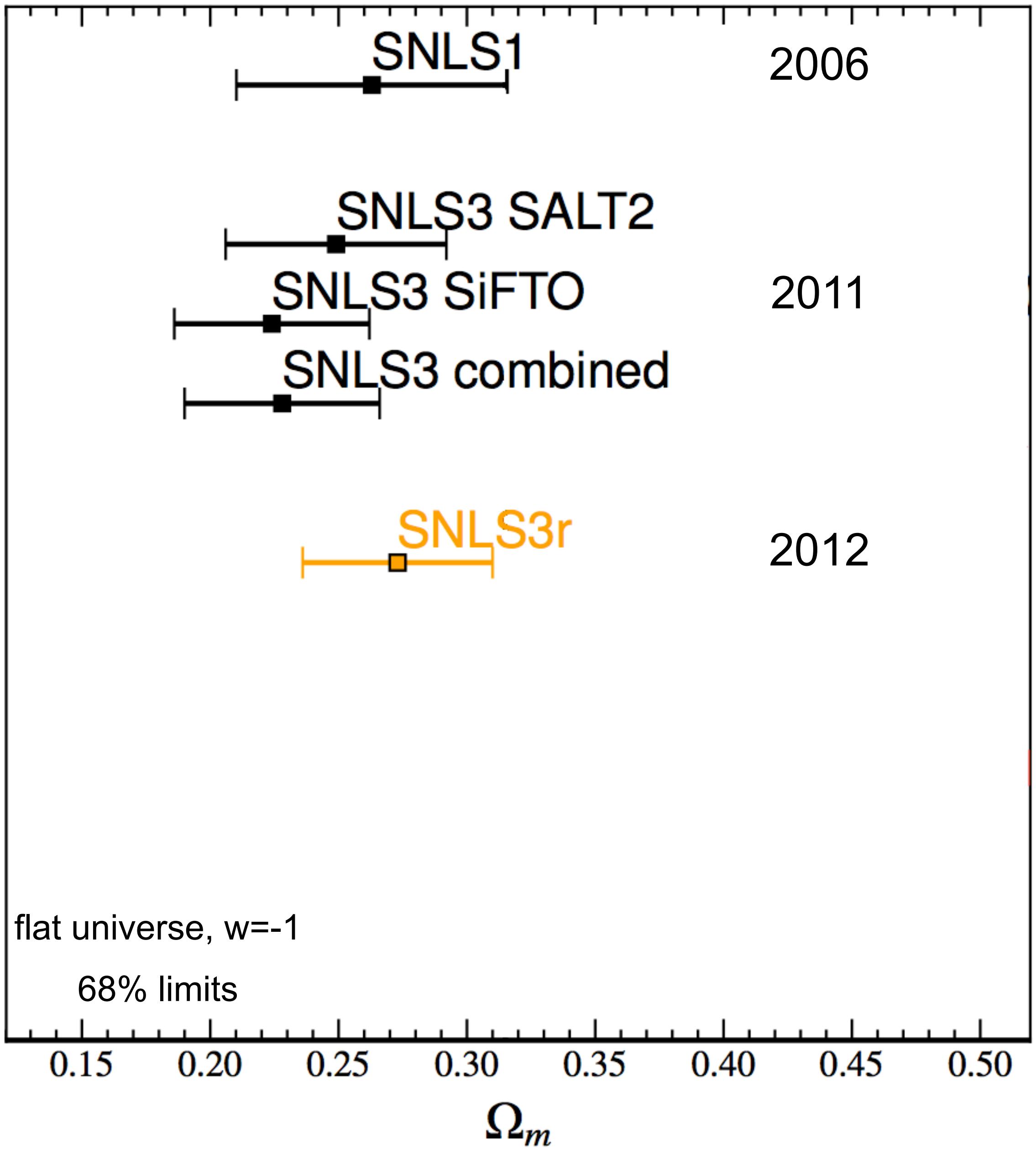

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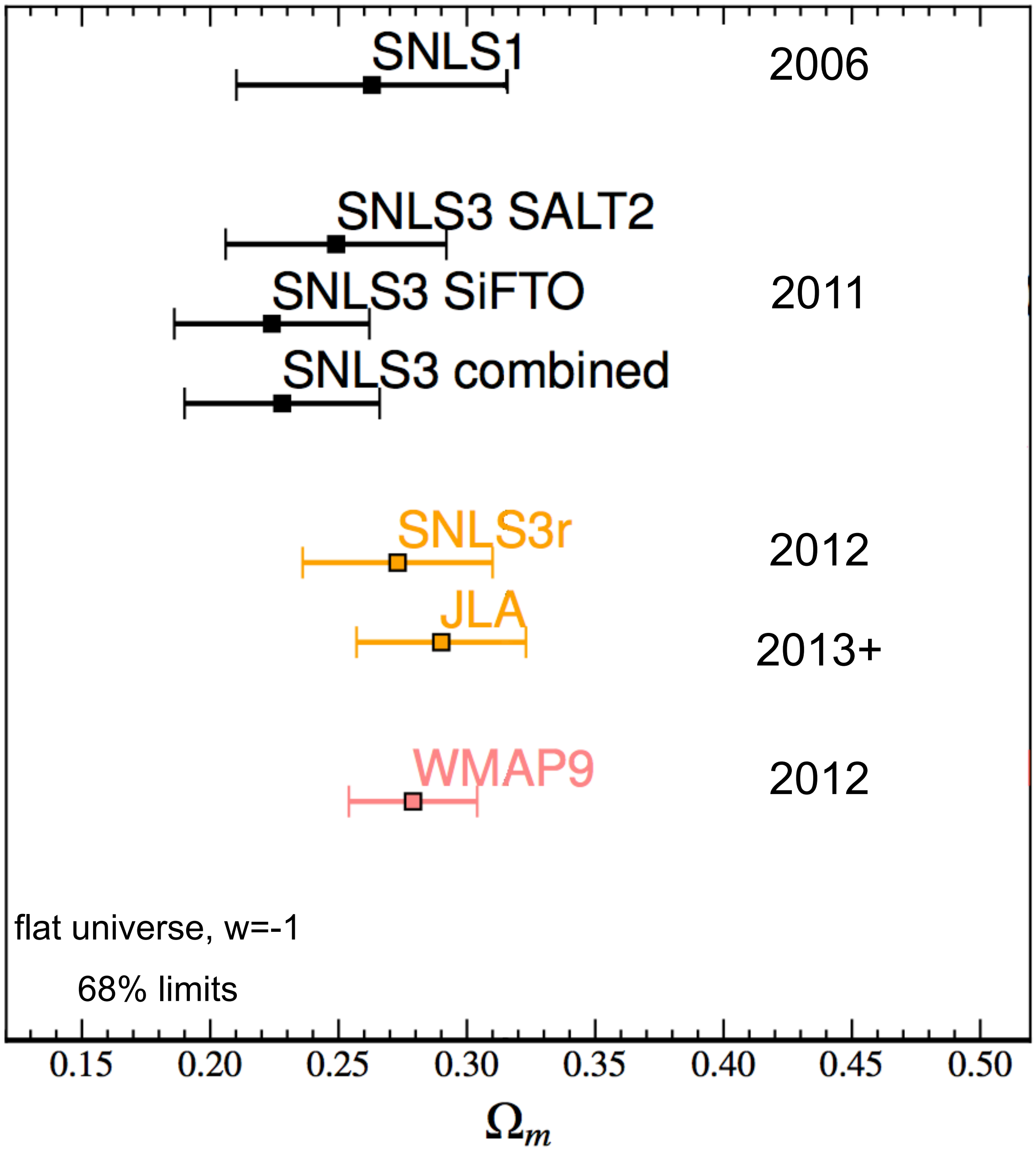

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WMAP9 (2012)

Betoule et al. in prep

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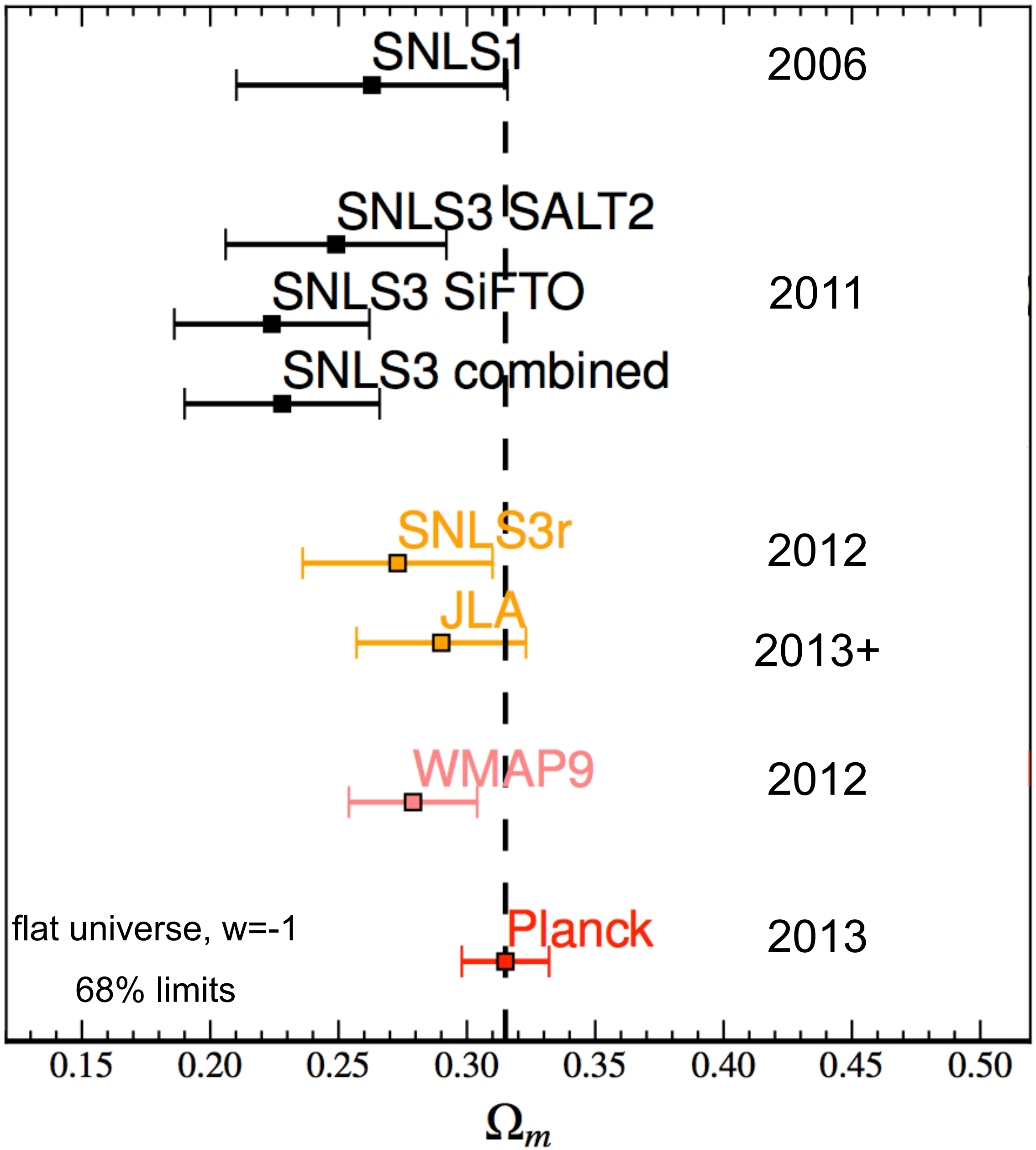

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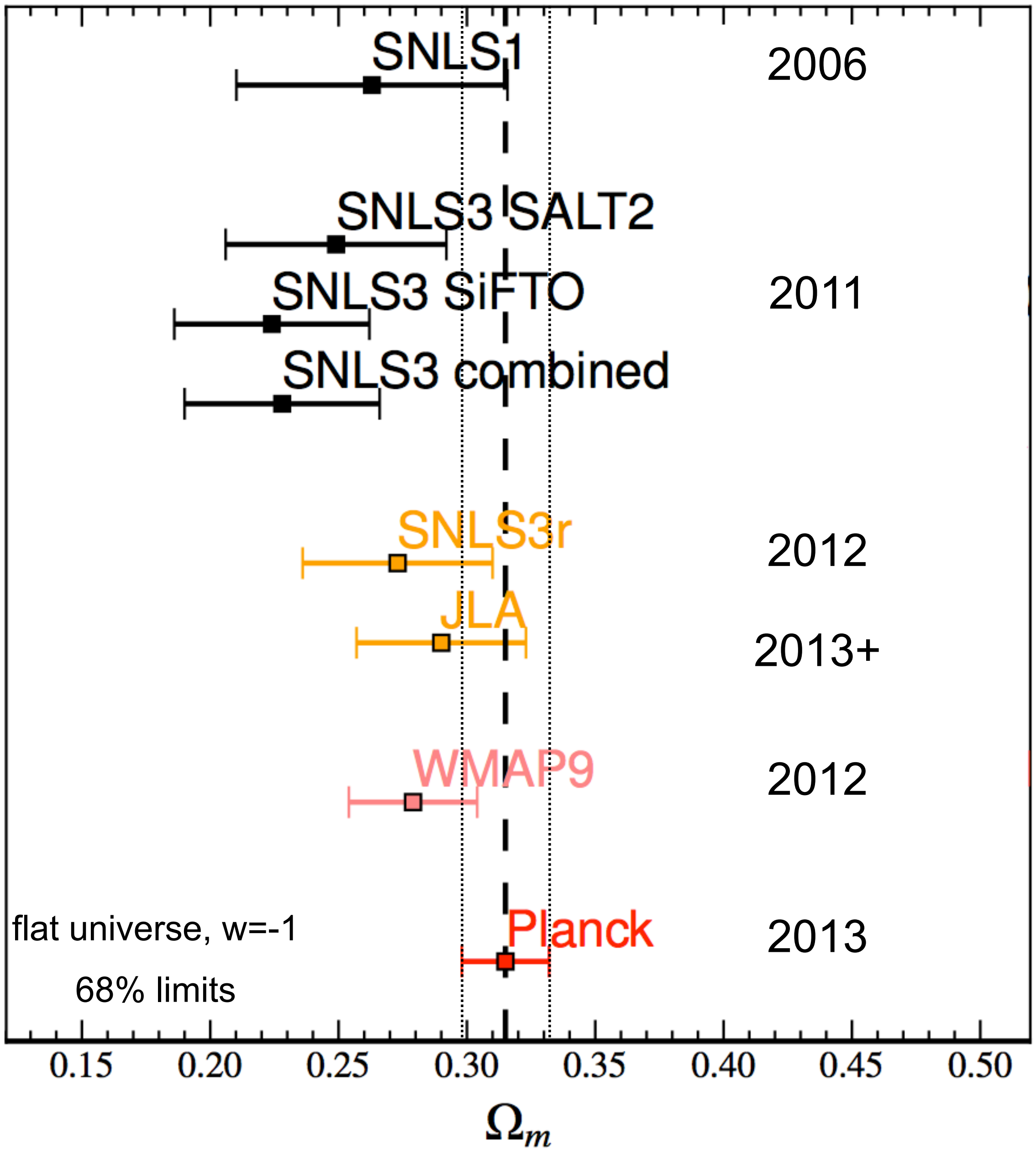

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About H_0

These cosmological results come from a comparison of distant and nearby SN fluxes

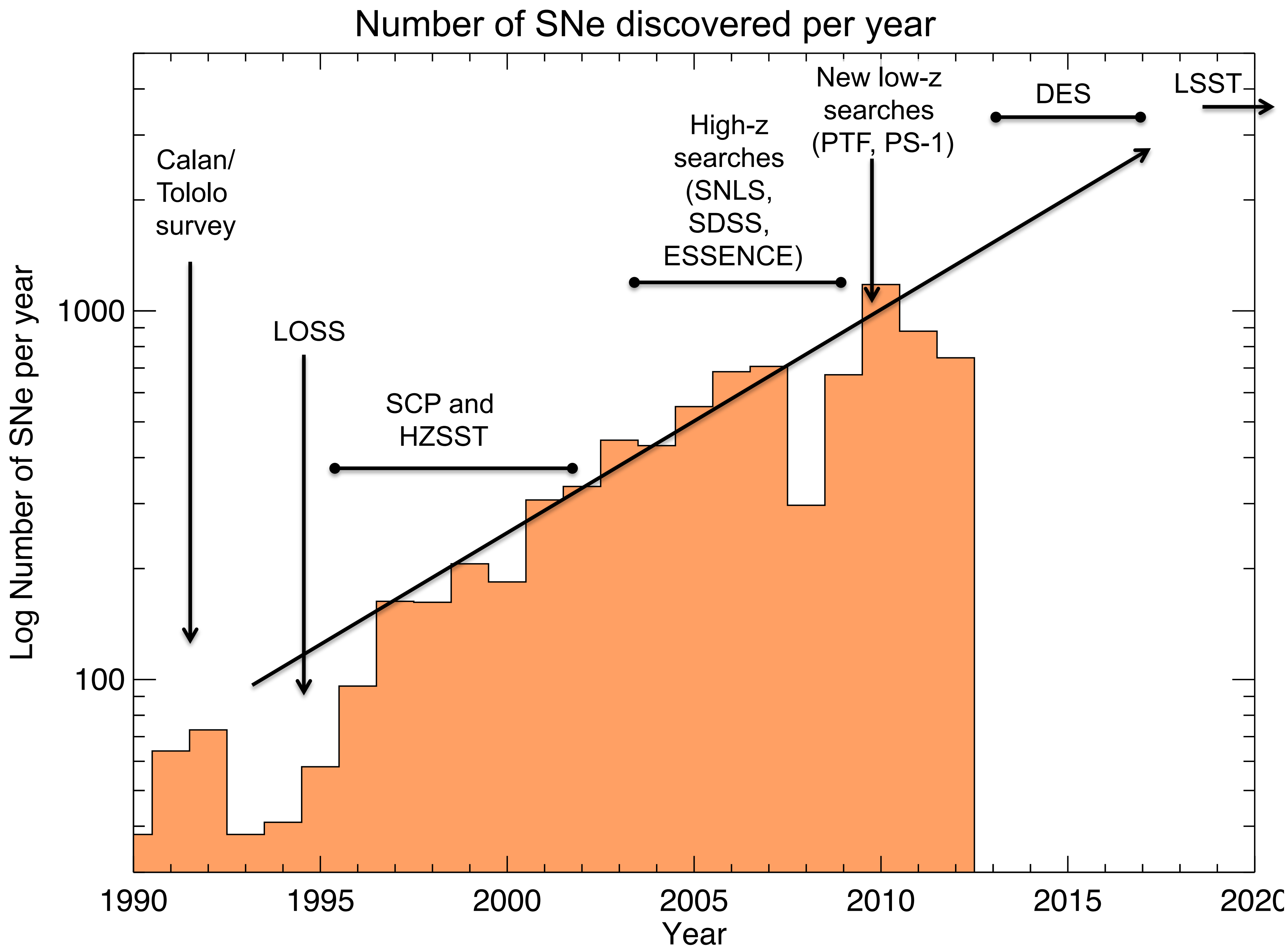
SNe alone do not measure H_0 – an absolute distance scale must first be set

e.g. using MASER distances and propagating to SN hosts using Cepheids. These have their own systematics

None of this SNLS/SDSS recalibration is going to affect the Cepheid+SN Ia H_0 measurement

SN Ia cosmology current summary

- SNLS3+SDSS joint calibration
  - Significant improvement on SNLS3 calibration
  - Differences are within the SNLS3 uncertainties (except g')
  - Shift e.g. Ω_M by 1-σ
  - No tension with Planck
  - No tension with w=-1; total 5.6% uncertainty
- 'SNLS5' to come – 425 versus 250 SNLS3 SNe
- Improved low-redshift samples (PTF, SkyMapper)
- Dark Energy Survey: 3500 SNe Ia should replace SNLS
  - (next talk)



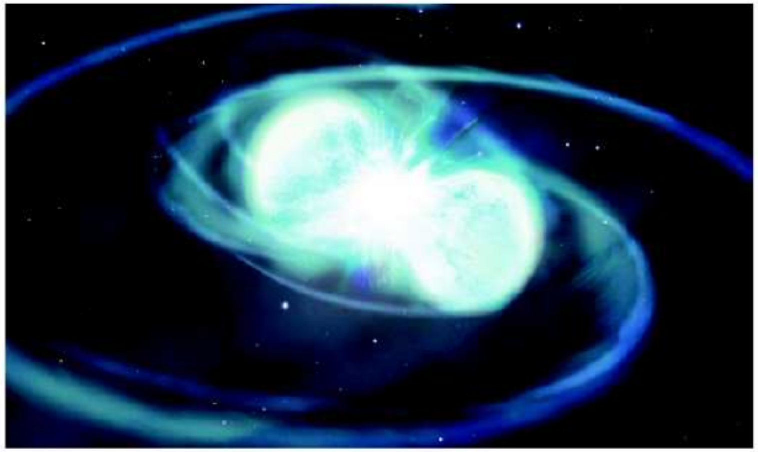
Number of SNe discovered per year
Log Number of SNe per year
Year
1000
100
1990
1995
2000
2005
2010
2015
2020
Calan/
Tololo
survey
LOSS
SCP and
HZSST
High-z
searches
(SNLS,
SDSS,
ESSENCE)
New low-z
searches
(PTF, PS-1)
DES
LSST

Astrophysics of SNe Ia

How does the SN Ia progenitor influence the explosion?

What are the progenitors of SNe Ia and what can we learn from observations?

White-dwarf/white-dwarf
"merger" (double degenerate; DD)

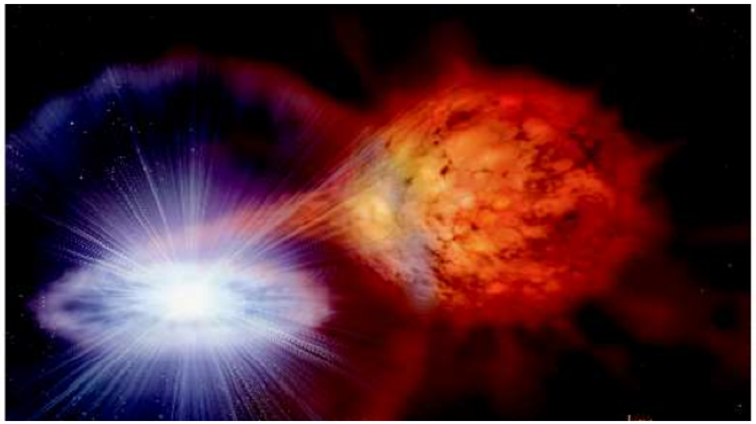


Accretion from a non-degenerate
companion (single degenerate; SD)

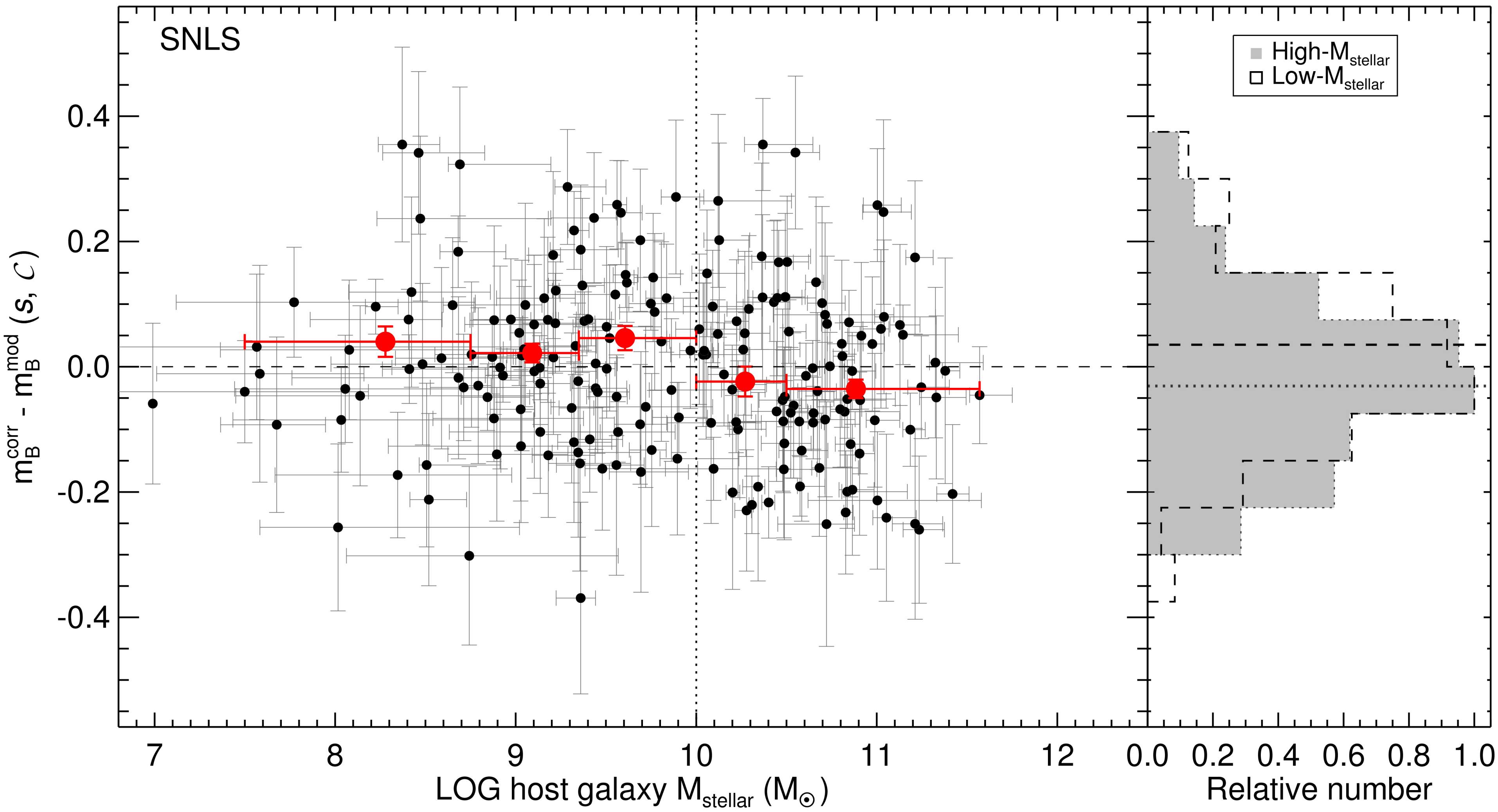
Accretes from a wind (symbiotic channel)?

Roche Lobe over-flow?

Helium star channel?



How does this progenitor diversity map into the cosmology?



Kelly et al., Sullivan et al., Lampeitl et al., etc.

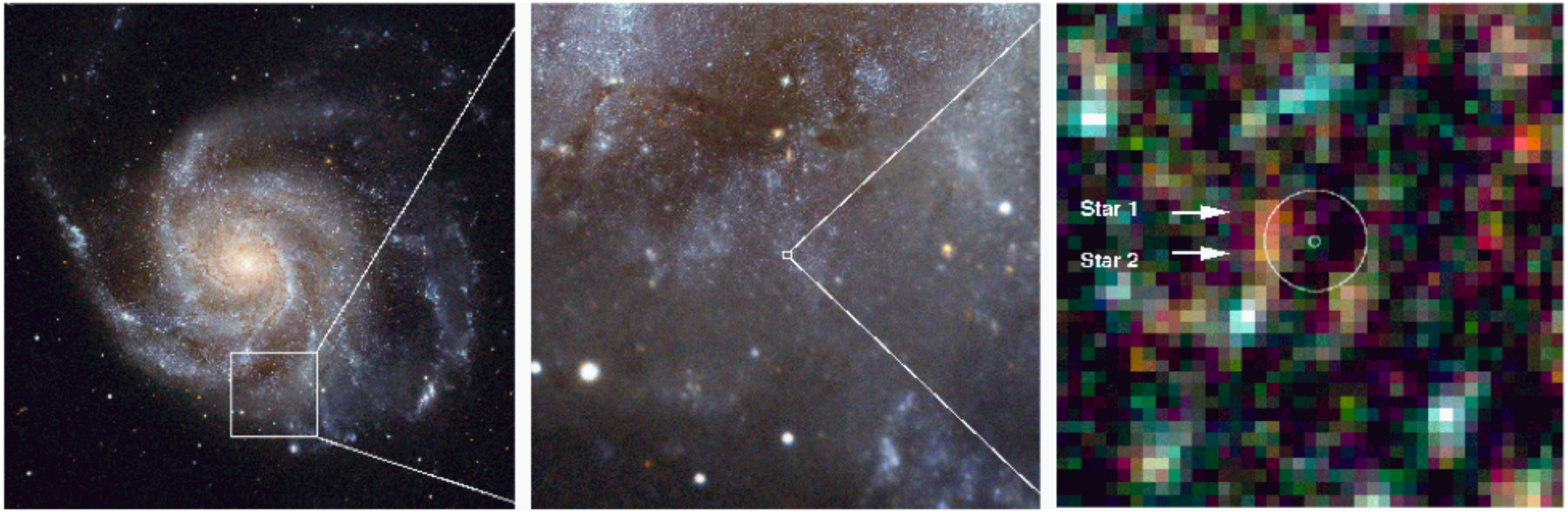
SN 2011fe

Transient located by PTF on night of August 23rd (Palomar)

Found in M101 – ~6Mpc

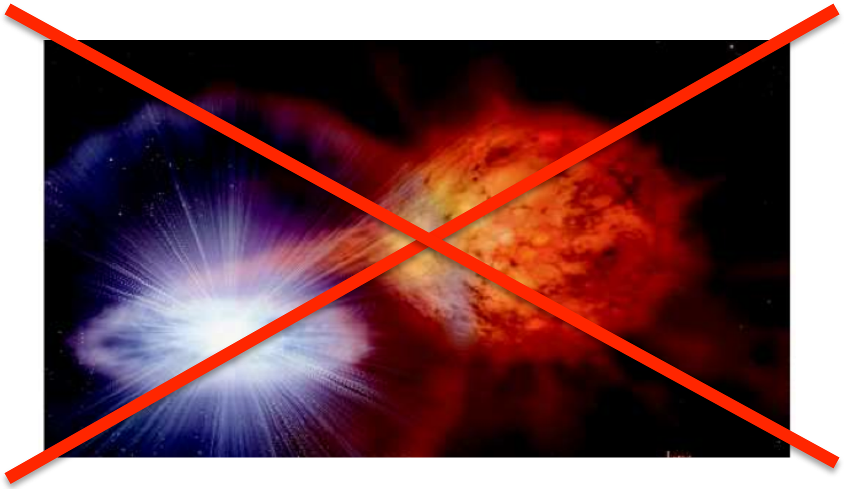
Nugent et al. 2011

Direct progenitor imaging



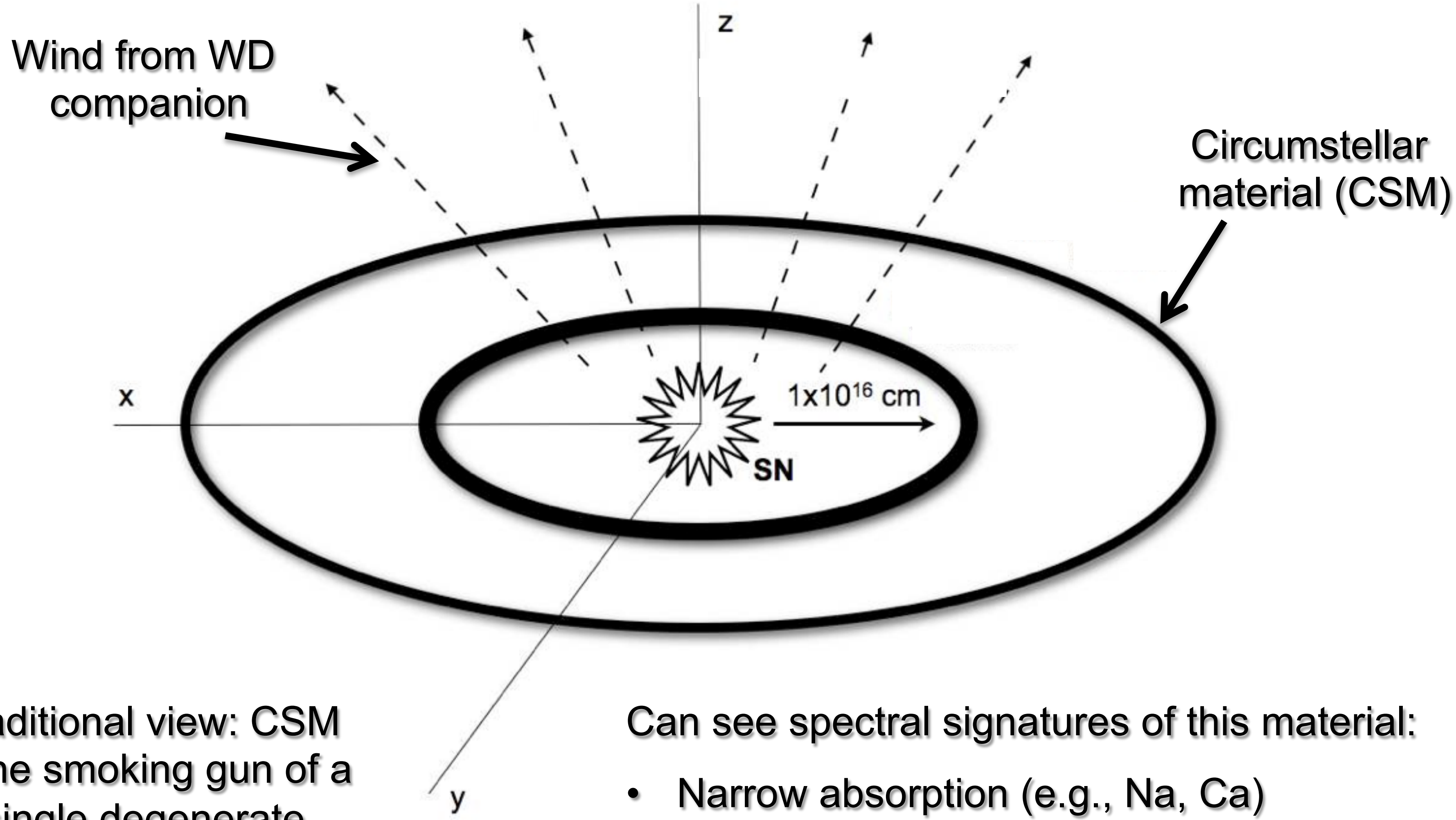
No progenitor (companion) star detected in HST imaging

Other complementary studies also place severe limits on SD scenarios



Li et al. 2011

But some SNe Ia show strong evidence for circumstellar material



Traditional view: CSM is the smoking gun of a single degenerate progenitor system

Can see spectral signatures of this material:

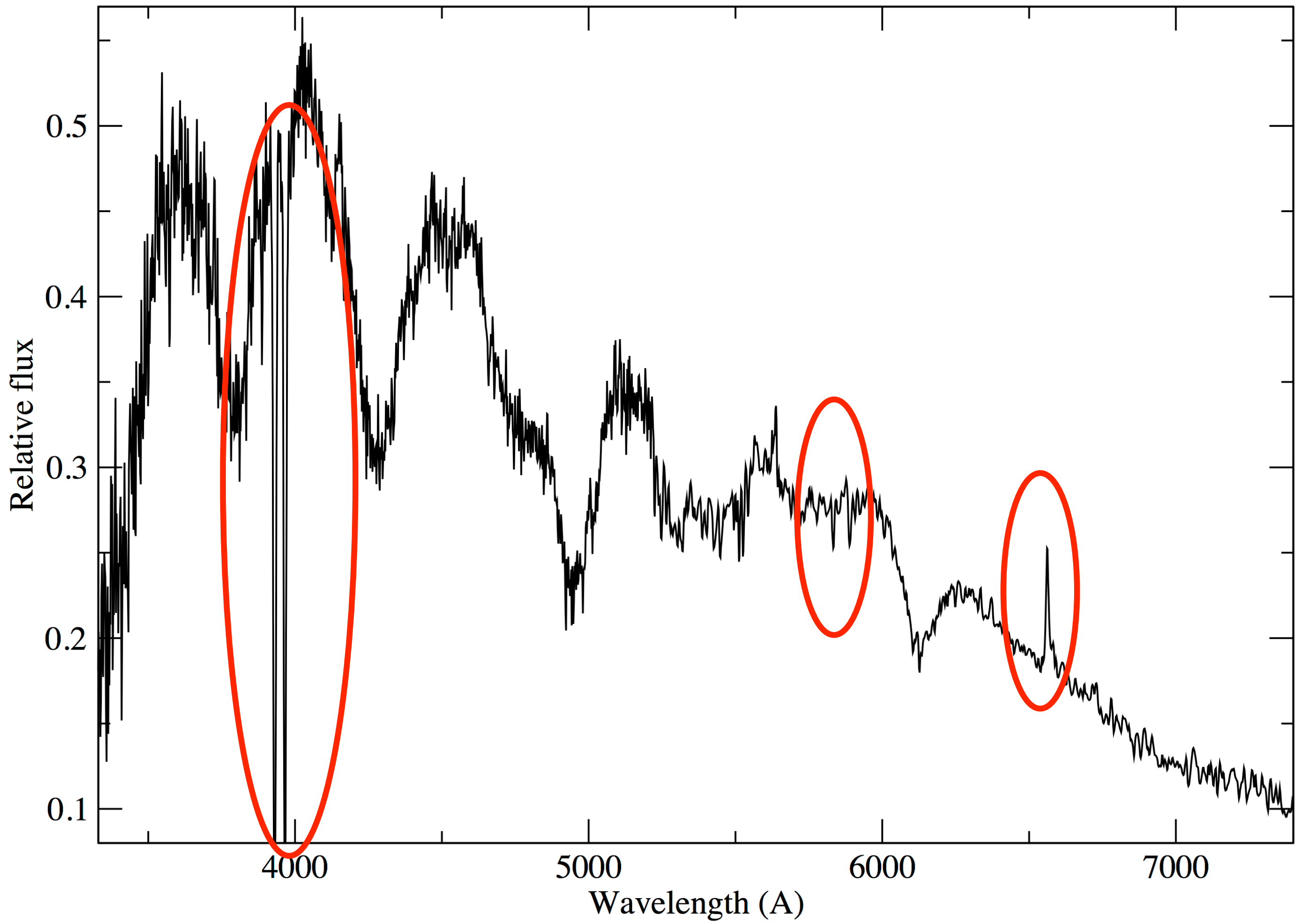
- Narrow absorption (e.g., Na, Ca)
- Narrow emission (e.g., H)

An extreme case: PTF11kx

Normal SN Ia spectrum

Additional, strong signatures of CSM – hydrogen, calcium, sodium, etc.

Hydrogen means a single degenerate progenitor (probably)



Dilday et al. 2012

Strong CSM: “Ia-CSM”

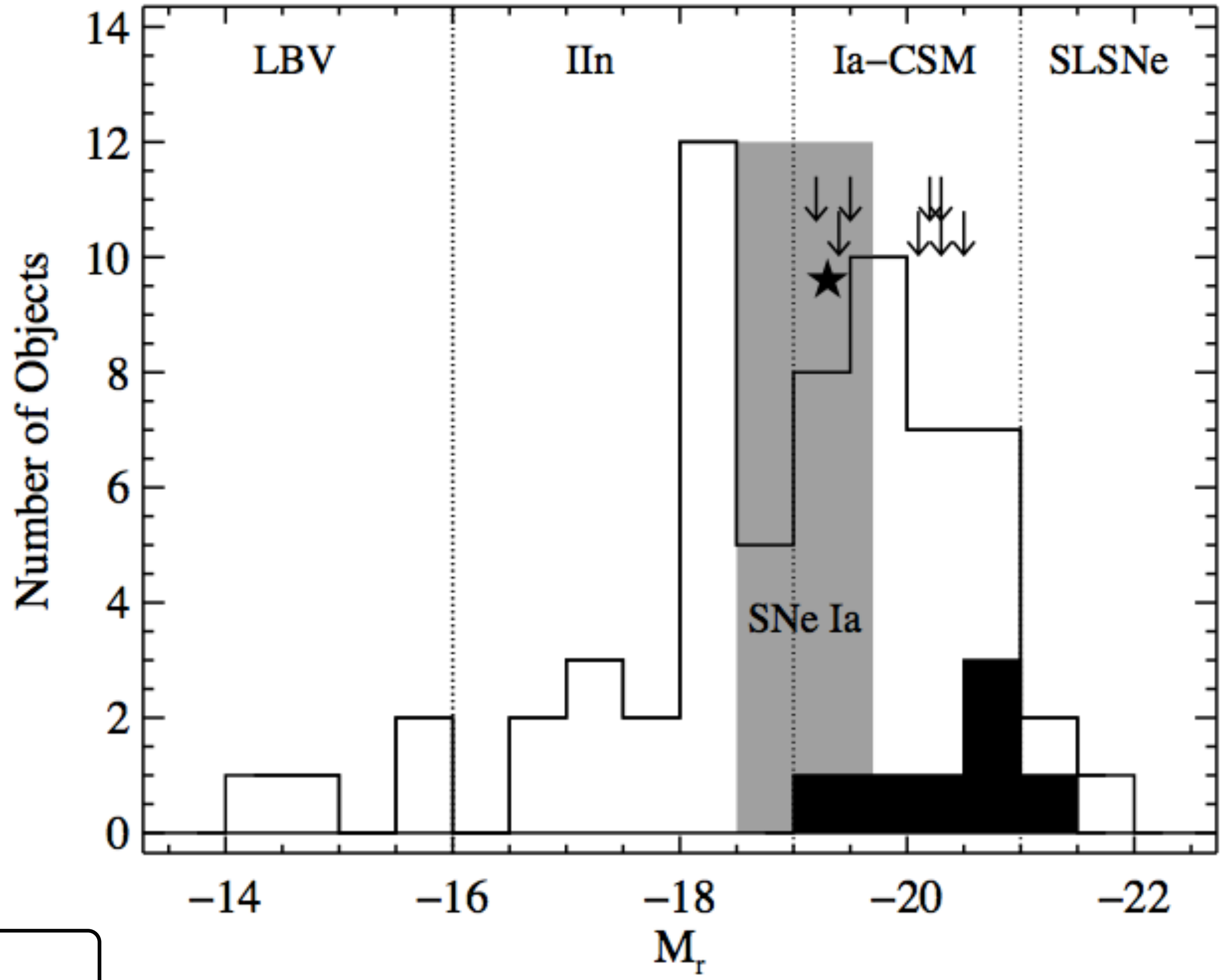
Search of SNe IIn – SNe with narrow hydrogen emission

Search for underlying SN Ia spectra

16 members of the class with strong CSM

All located in star-forming galaxies

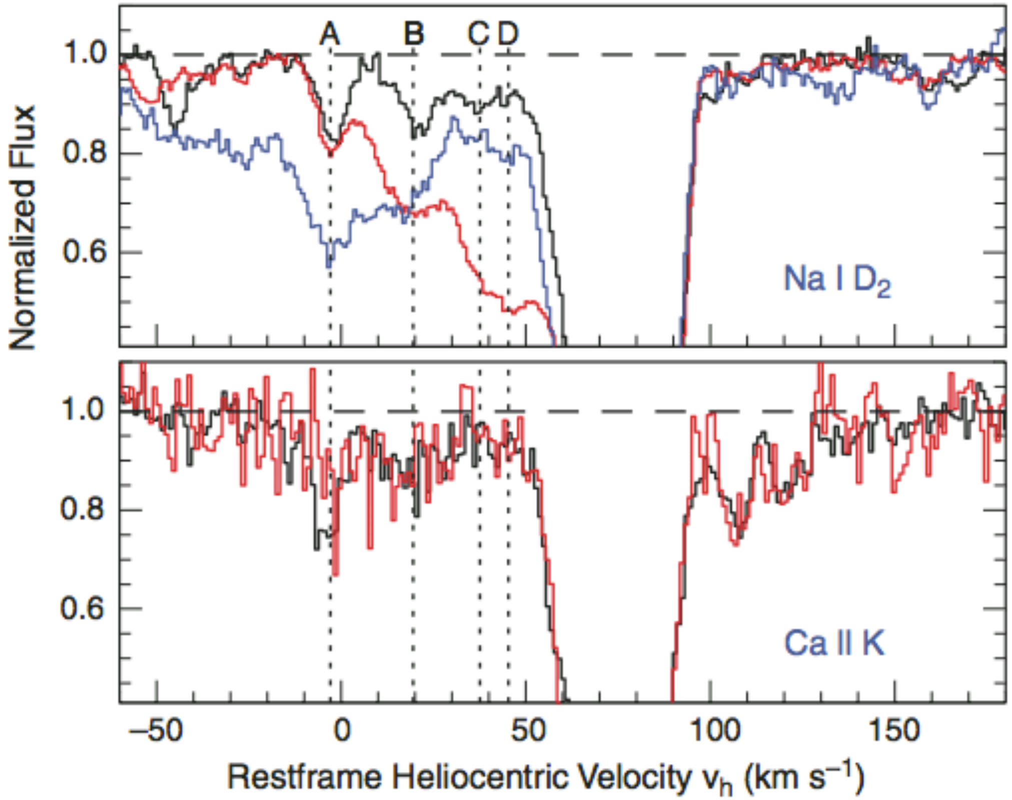
All brighter than normal SNe Ia (presumably interaction)

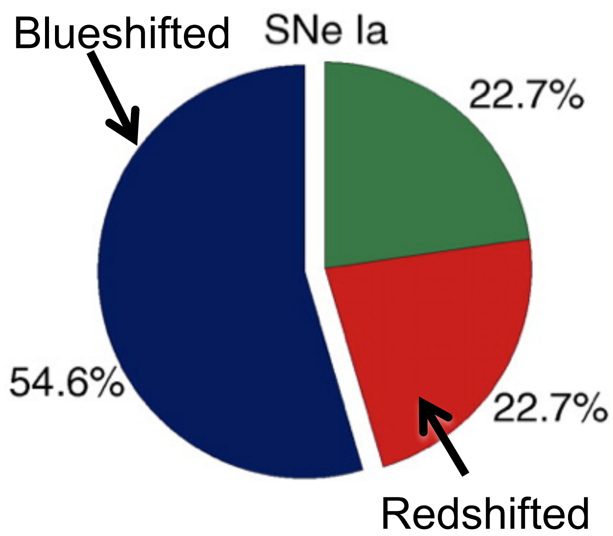


Silverman et al. 2013

Weaker CSM

Patat et al. (2007)

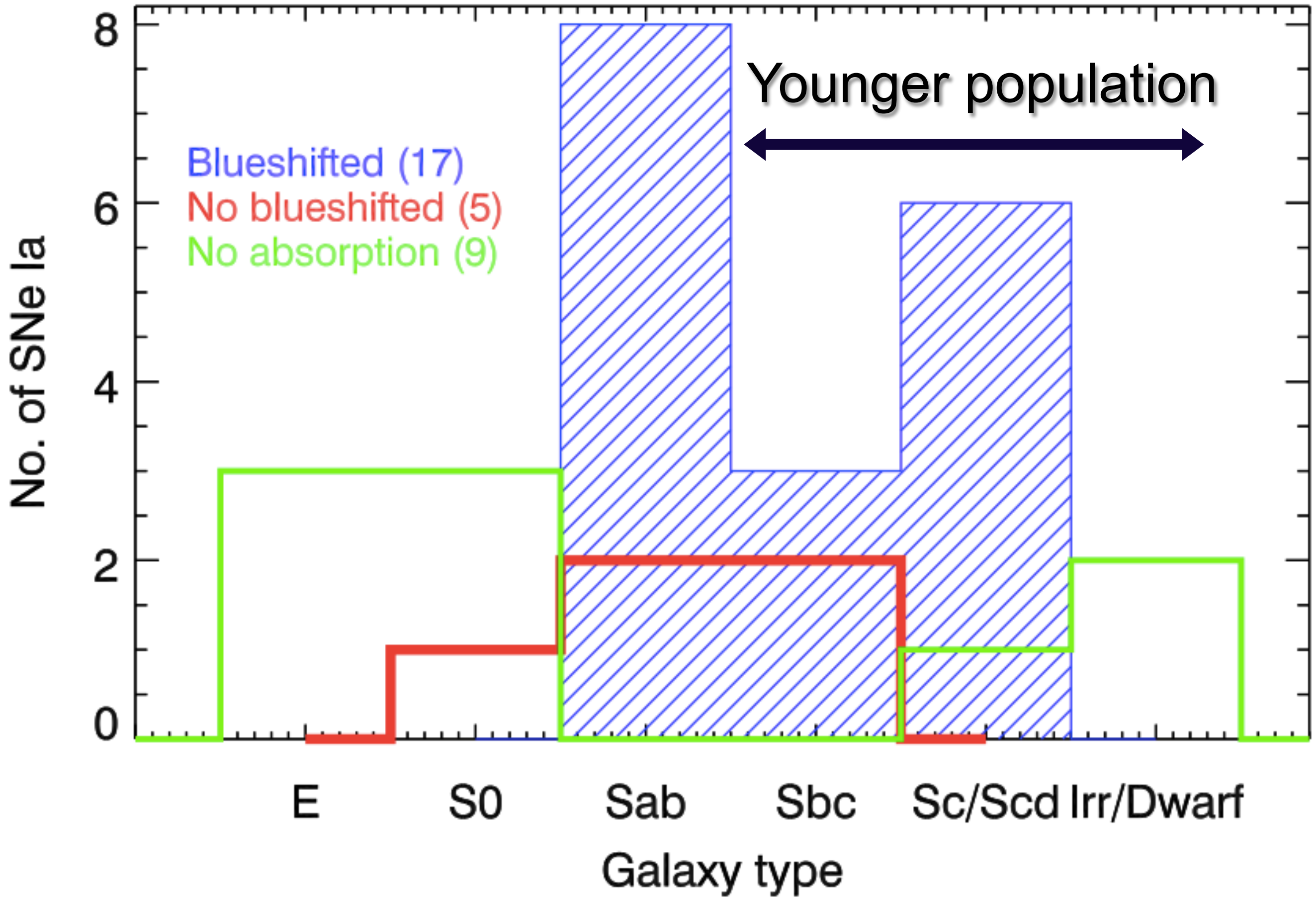




Sternberg et al. (2011)

- Some SNe Ia show variable, blue-shifted CSM (Patat et al 2007)
- Majority of SNe Ia in spirals show blue-shifted Na I D lines: outflow from progenitor system?

Host galaxy properties

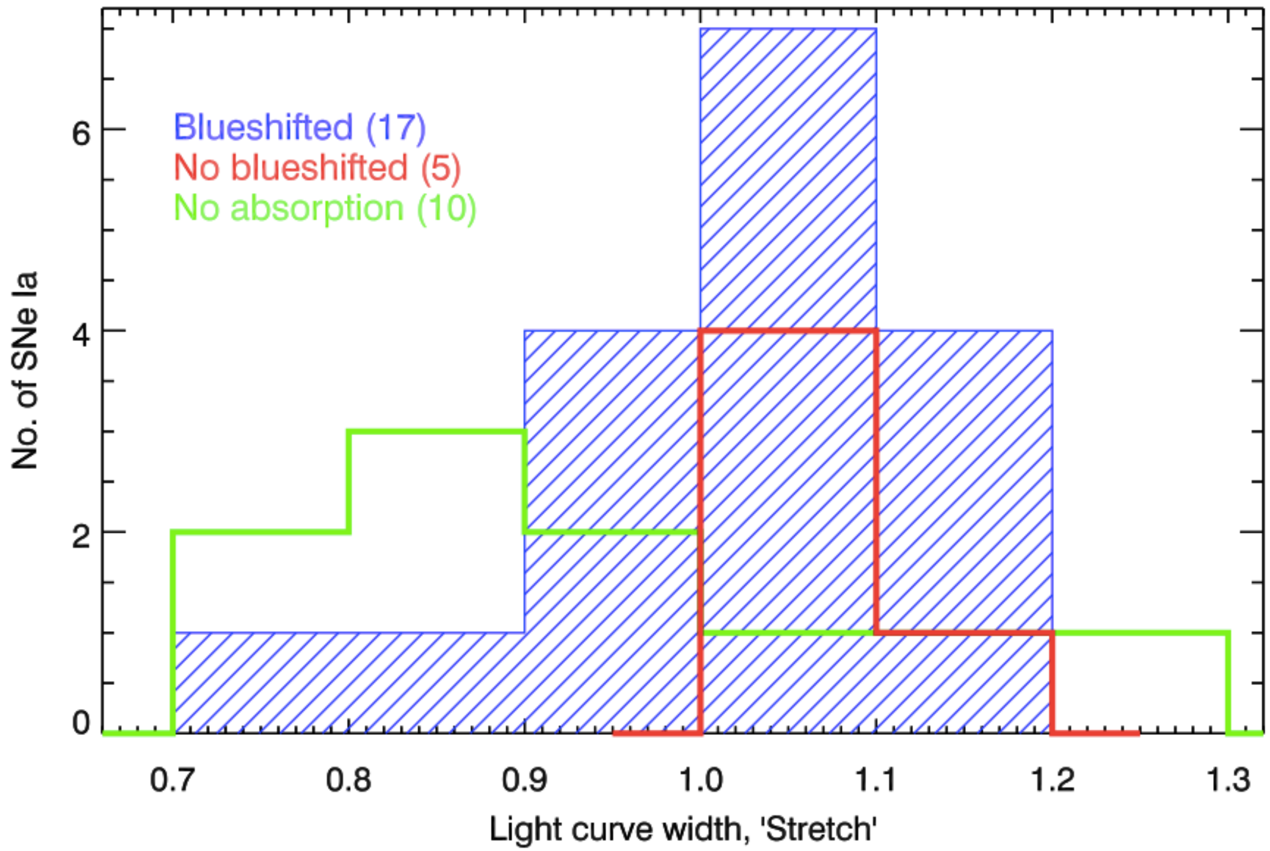


Na I (CSM) features more common in star forming galaxies

Less/No CSM in elliptical galaxies

Maguire, Sullivan et al. 2013

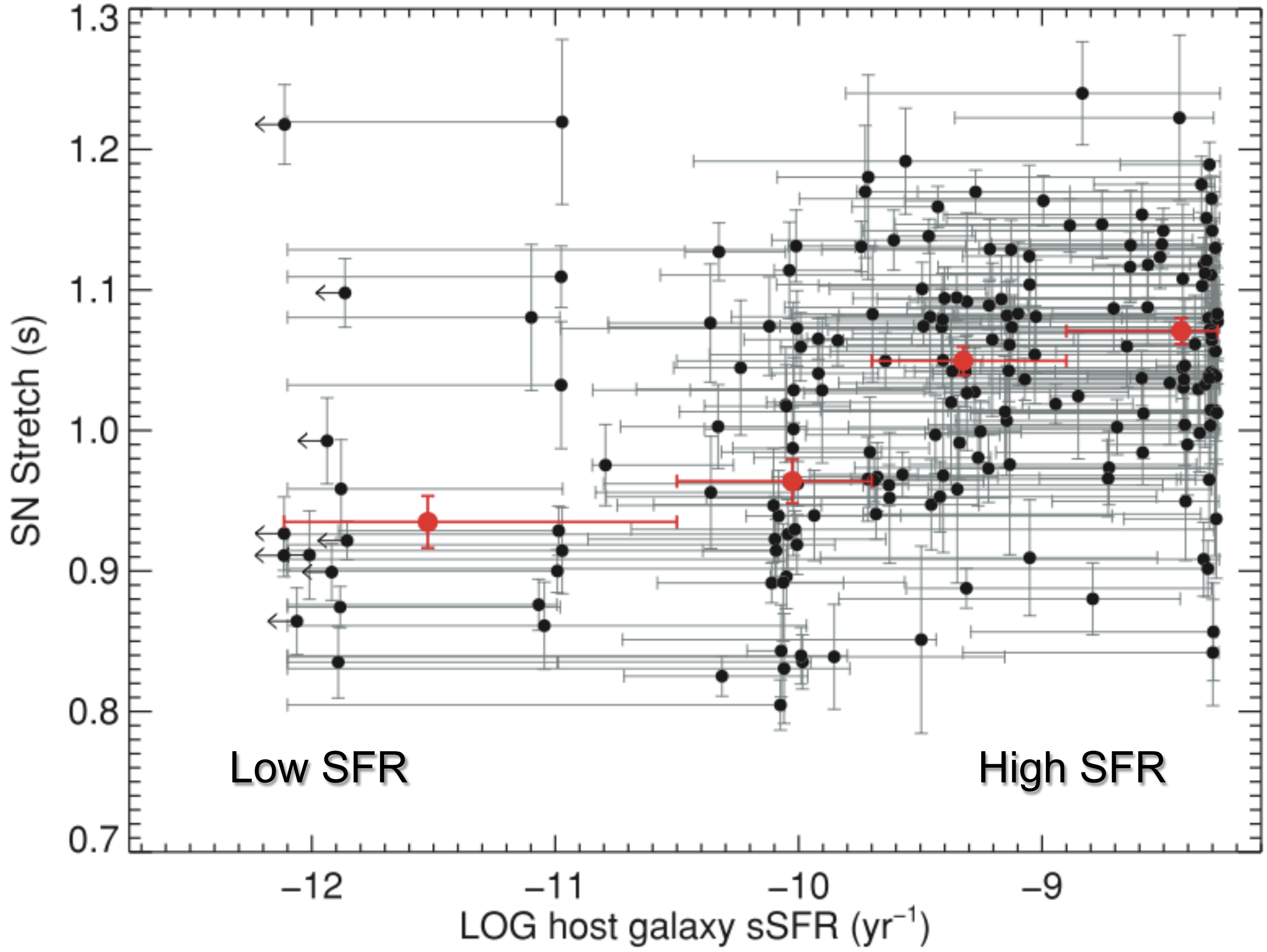
Link to progenitors?



SNe Ia displaying blueshifted CSM have (on average) higher stretches: brighter SNe

Maguire, Sullivan et al. 2013

Higher stretch means younger progenitor



Two families of ‘normal’ SNe Ia?

Family 1	Family 2

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Photometric properties	More luminous Broader light curves (High stretch, low Δm15)	Less luminous Narrower light curves (Low stretch, high Δm15)

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Delay-time Distribution	Younger progenitors	Older progenitors

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Environment	Ia-CSM/Blueshifted CSM?	Less/No CSM?

Different progenitor types?