SUDARE@VST

SUpernova Diversity And Rate Evolution

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Sharp Eyes on European Skies

OUTLINES

AIMS

- probing different progenitor scenarios
- investigating the SN diversity

METHOD

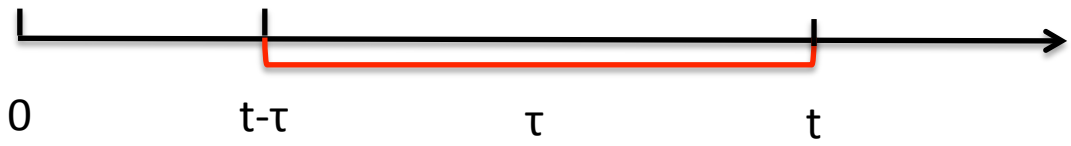
Analysis of the dependence of SN rates on the age distribution of parent stellar population averaging-out over in both a large galaxy sample and a cosmic volume

SUDARE SURVEY

- SN search
- Galaxy sample analysis

RESULTS AND CONCLUSIONS

SN PROGENITORS AND RATE OF OCCURRENCE



$\forall\ \tau$ the time elapsed from the birth of progenitor to the SN explosion

number of SN progenitors born at epoch t-τ x fraction of SN progenitors that explode after a time τ

$$r_{SN}(t) = \int_{\tau_i}^{\min(t,\tau_x)} \psi(t-\tau)k(t-\tau)A_{SN}(t-\tau)f(\tau)d\tau$$

τ_i min delay time
τ_x max delay time

SFR

number of stars per unit mass born at epoch t-τ

fraction of stars that end up as SN

distribution function of delay times

SNe Ia

- ✓ wide range of delay times (τ_{min} few tens of Myr - τ_{max} ~ 14 Gyr)
- ✓ the fraction of stars that end up as a SN Ia is constant over this timescale

$$r_{Ia}(t) = K_{Ia} \int_{\tau_i}^{\min(t,\tau_x)} f_{Ia}(\tau)\, \psi(t-\tau)\, d\tau$$

2 key factors

K_{Ia} number of SN Ia progenitors per unit mass

f_{Ia} delay time distribution

CC SNe

- ✓ all stars with mass between $m_u^{cc} - m_l^{cc}$ produce CC SNe
- ✓ negligible delay time ($\tau < 50$ Myr)
- ✓ constant SFR over this timescale

$$r_{CC}(t) = K_{CC}\psi(t)$$

$$K_{\rm CC} = \frac{\int_{m_{\rm L,CC}}^{m_{\rm U,CC}} \phi(m)dm}{\int_{m_L}^{m_U} m\phi(m)dm}$$

$\phi(m)$	initial mass function
$m_U^{cc} - m_L^{cc}$	mass range CCSN progenitors
$m_U - m_L$	mass range stellar population

METHOD

SFH and SN rates

- immediate environment
- each individual galaxy

averaging out over

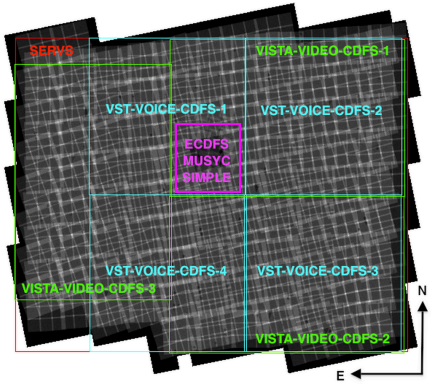
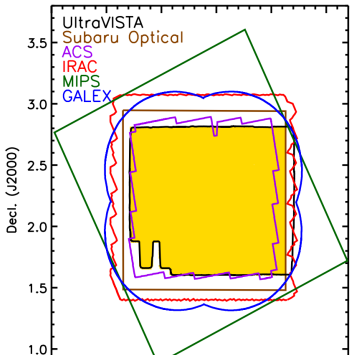
in a galaxy sample
(rest frame colours, sSFR)
via SED fitting

in a cosmic volume
assuming a cosmic SFH

Simultaneous analysis of SN rates as function

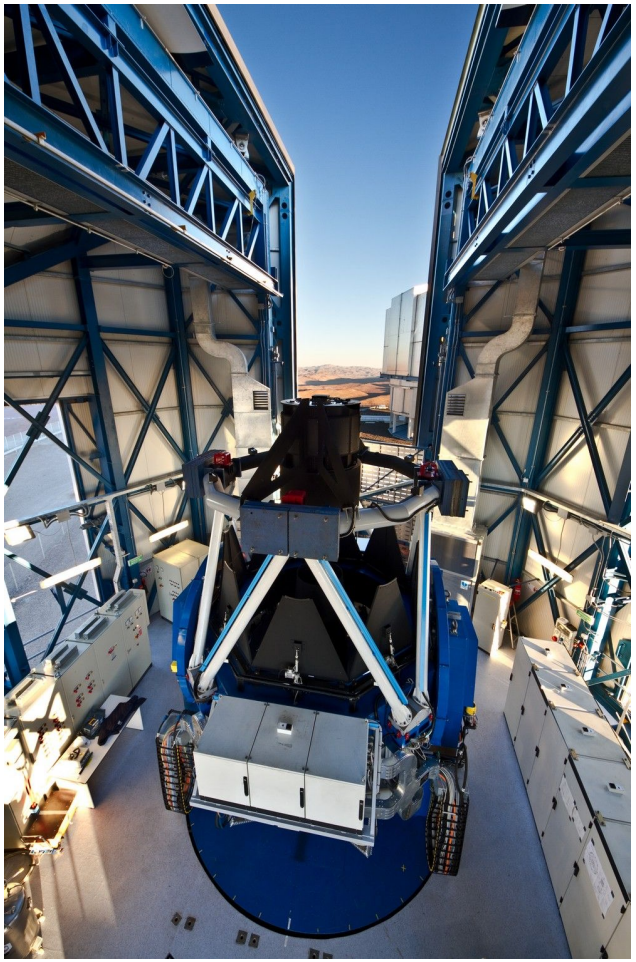
SUDARE SURVEY

4 years programme (2011-2015)

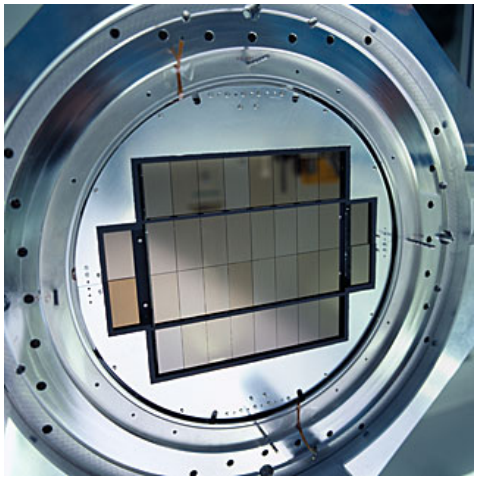
	SN SEARCH	GALAXY SAMPLE ANALYSIS
	multi epoch images r $m_{lim} \approx 25$	deep stacked images r $m_{lim} \approx 26$
CDFS (4 deg^2) 	r every 3 days g,i every 7 days P.I. Cappellaro INAF GTO	g, r, i SUDARE P.I. Cappellaro - INAF GTO u VOICE P.I. Covone Vaccari - INAF GTO J, H, K VIDEO P.I. Jarvis FUV, NUV Galex IRAC ch1,2 Spitzer
COSMOS (1 deg^2) 	r, every 3 days g,i every 7 days P.I. Pignata Chilean Time	**UltraVISTA survey** Muzzin et al 2013

SN SEARCH

INSTRUMENTS

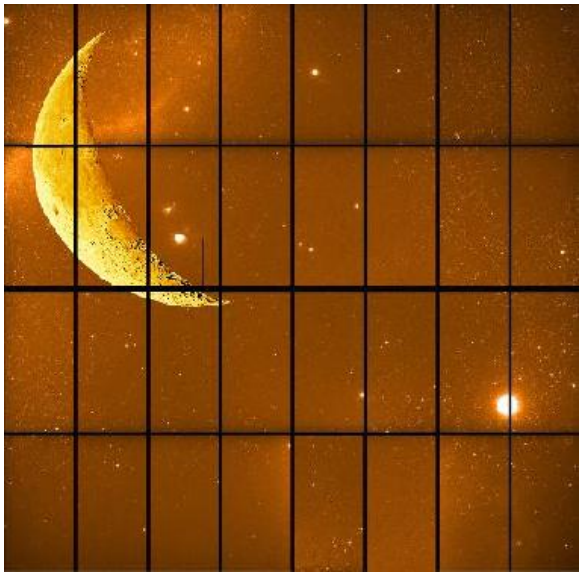


VST 2.6 m



OmegaCAM

0.21 arcsec/pix



1 deg^2

SN SEARCH

Raw Images

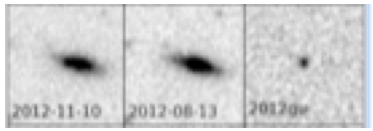
Co-add Images

VSTTube

su_diff

Difference Image

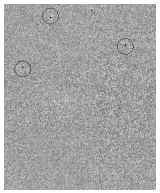
SUDARE PIPELINE

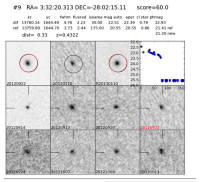


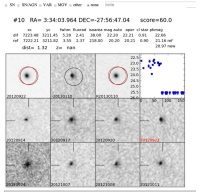
Search Image | Reference Image | Difference Image

su_search

Transient detection



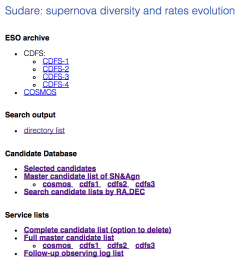




su_rank & su_look

Visual confirmation of candidates

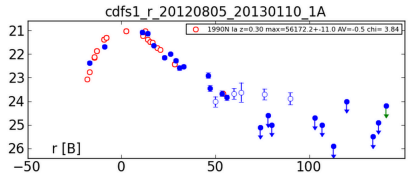
Archive



su_lightcurve

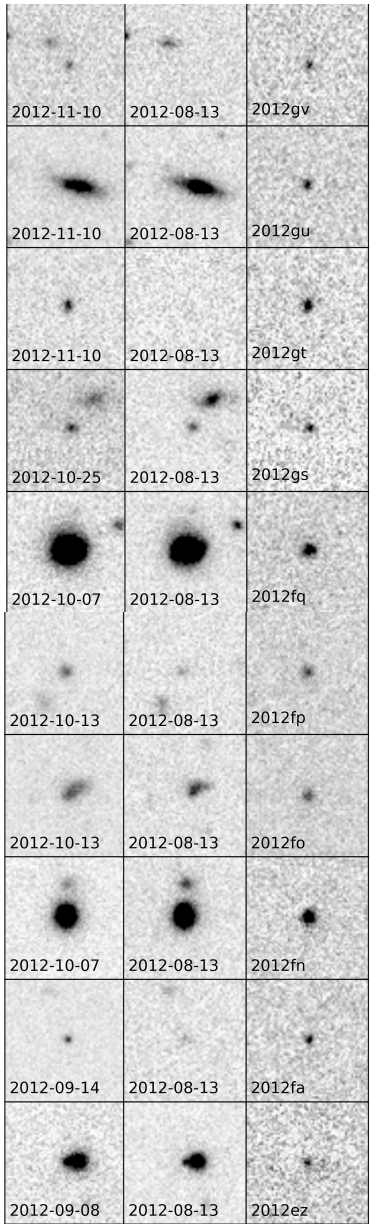
PSF and aperture photometry

Photometric Classification

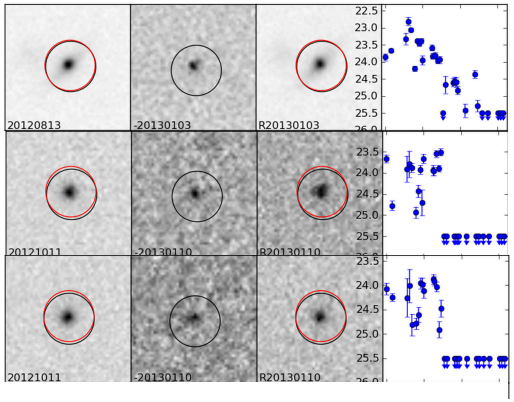


SN SEARCH

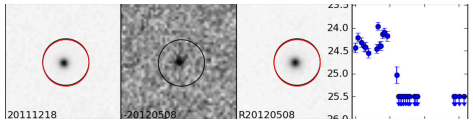
TRANSIENT DETECTION



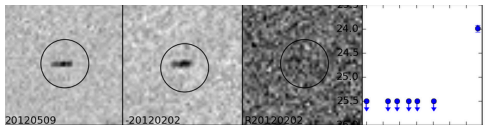
SNe



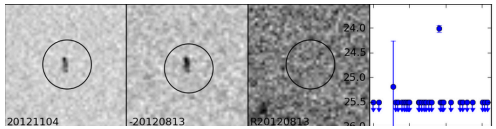
AGNs



Variable Stars



Moving objects

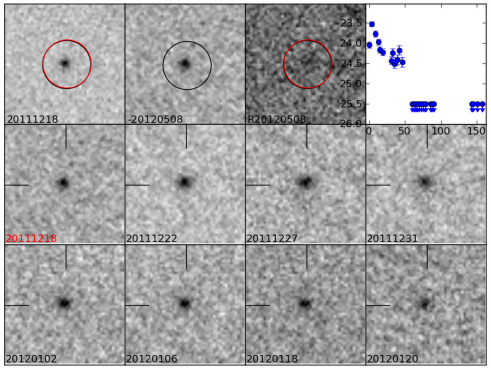


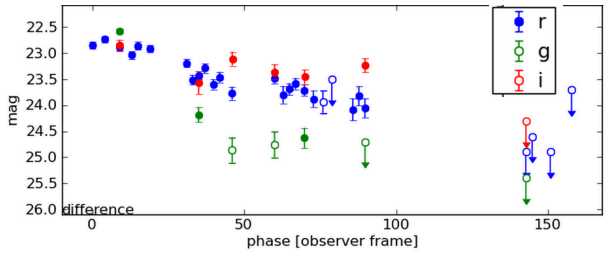
Spurious detection

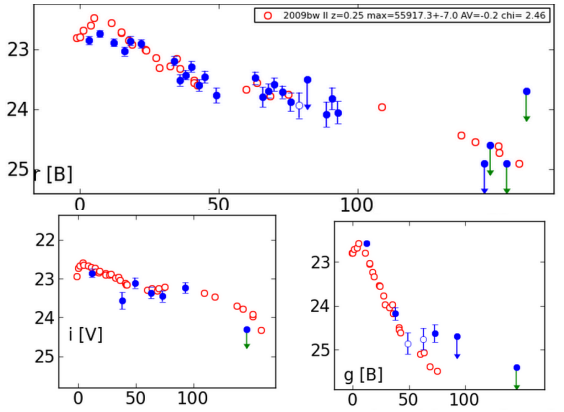
Sharp Eyes on European Skies

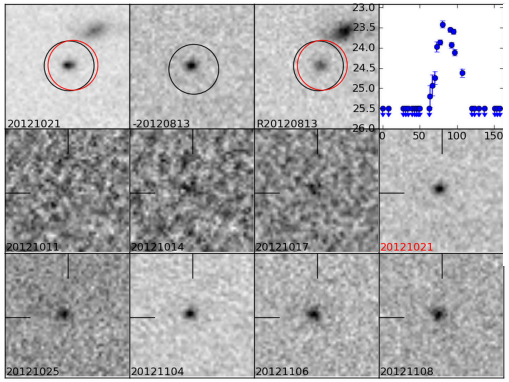
SN SEARCH

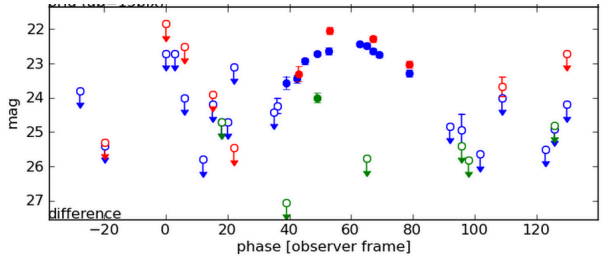
PHOTOMETRIC TYPING

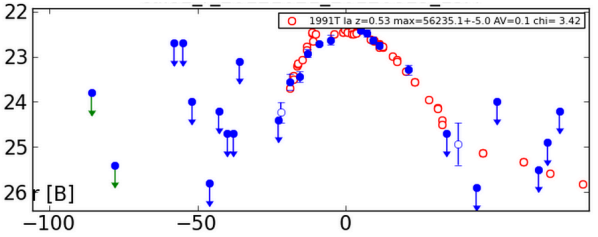


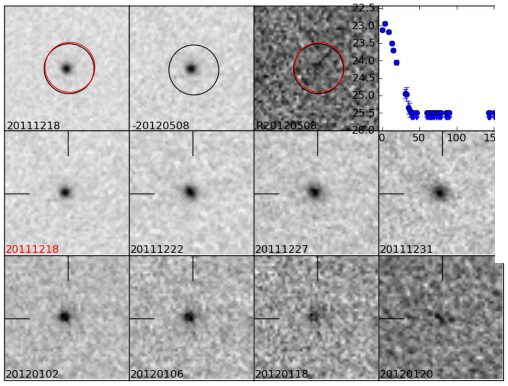


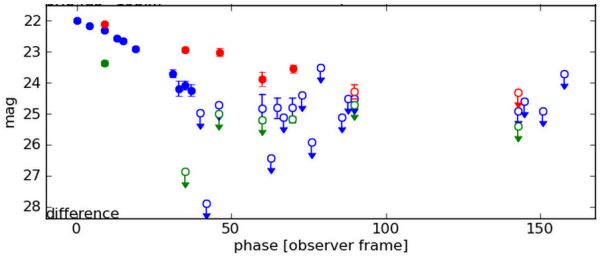


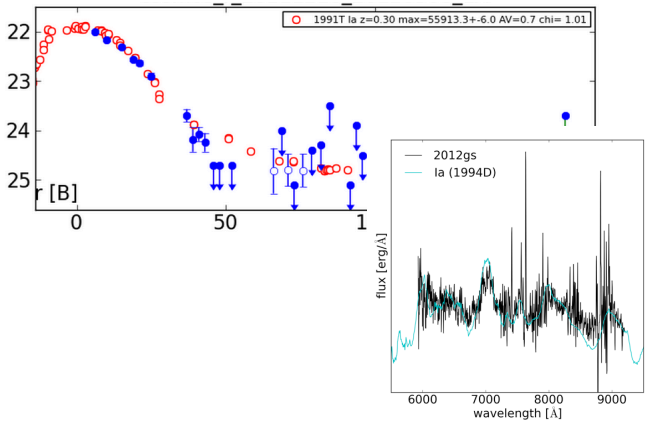












Sharp Eyes on European Skies

SN SEARCH

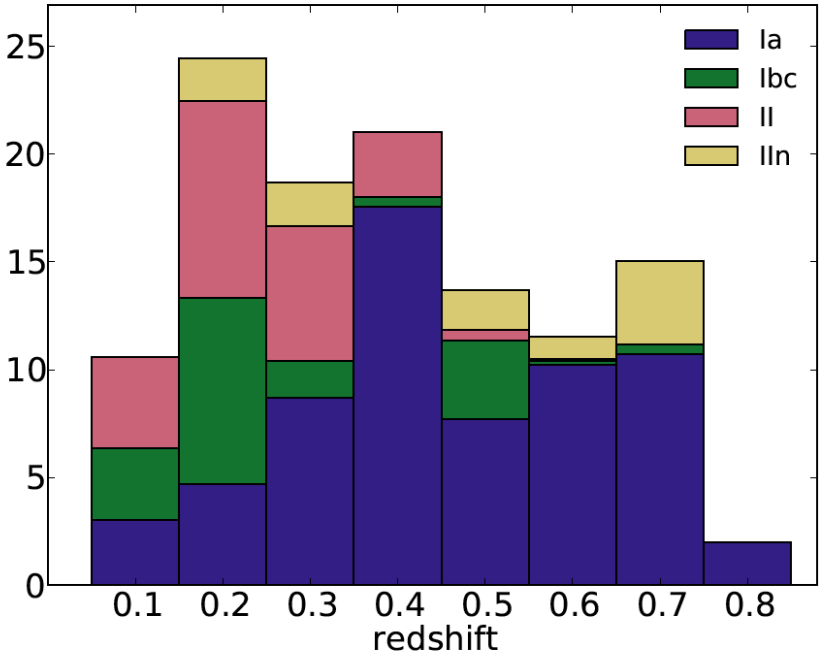
SN SAMPLE

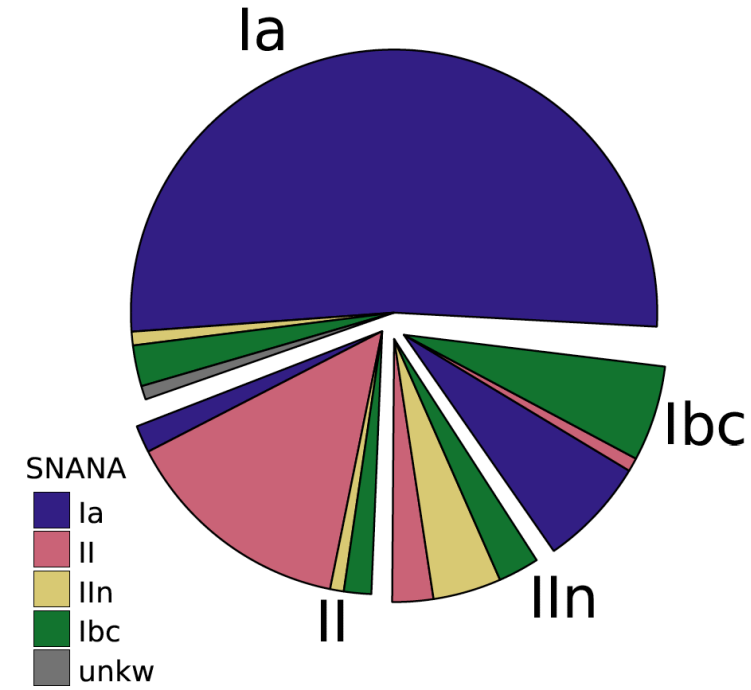
117 SNe

57% Ia
19% II 9% IIn 15% Ib/c

27 PSNe

weight =0.5

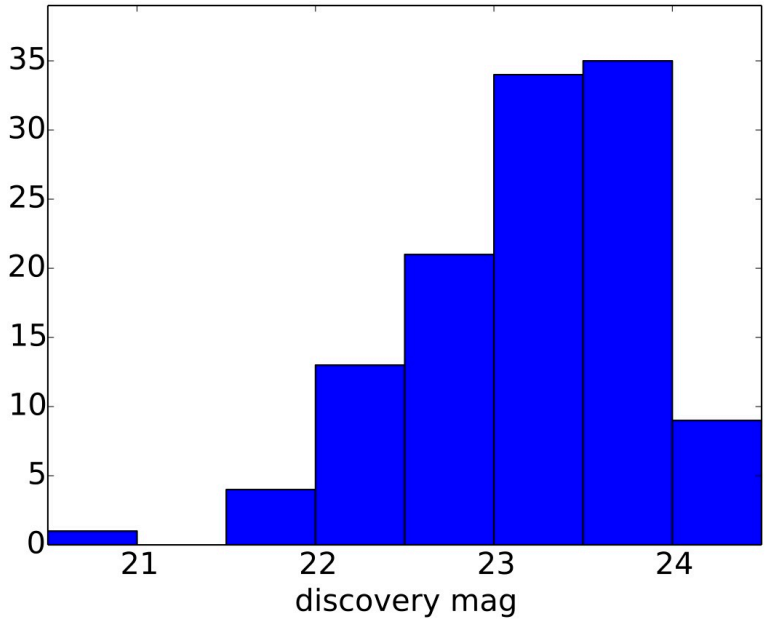


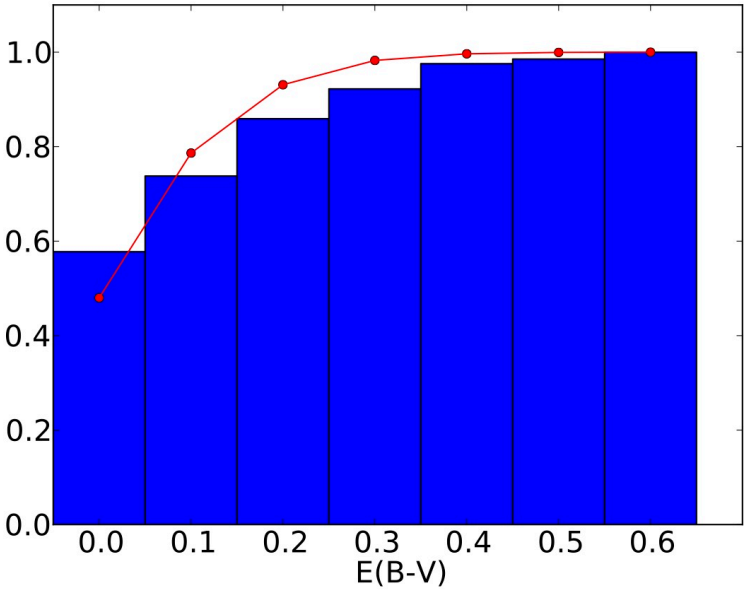


Cappellaro et al 2015

SN SEARCH

SN SAMPLE

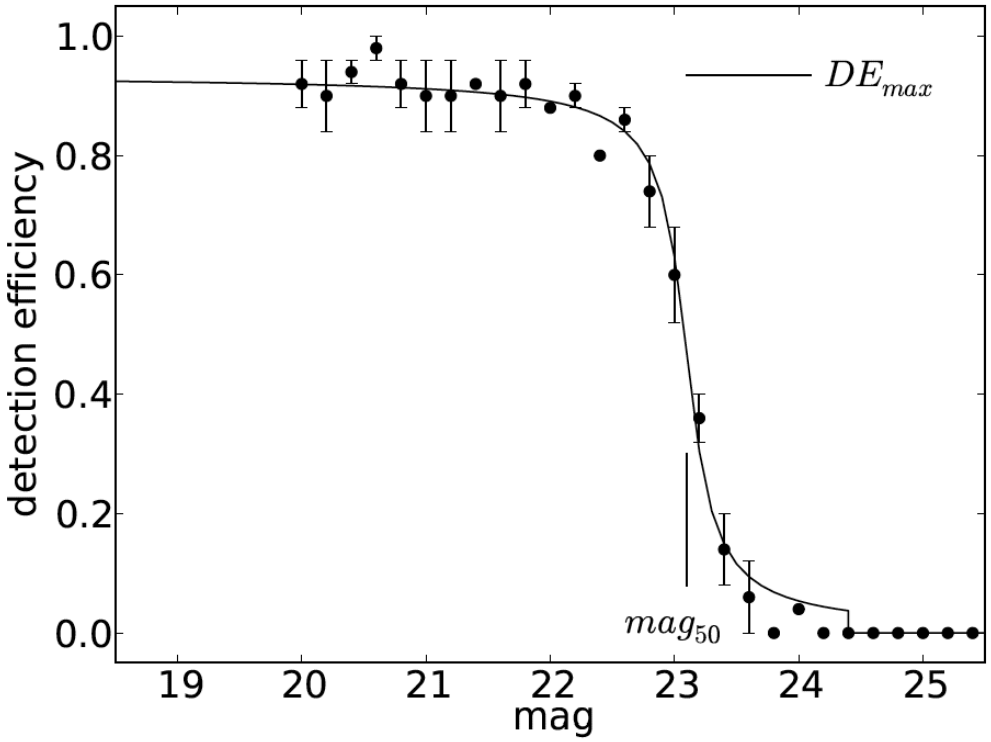




Cappellaro et al 2015

SN SEARCH

DETECTION EFFICIENCY



$$DE = DE_{max}\left(\frac{\arctan\beta\,(mag_{50} - mag)}{\pi} + \frac{1}{2}\right)$$

$DE_{max} = 95\% \pm 3$

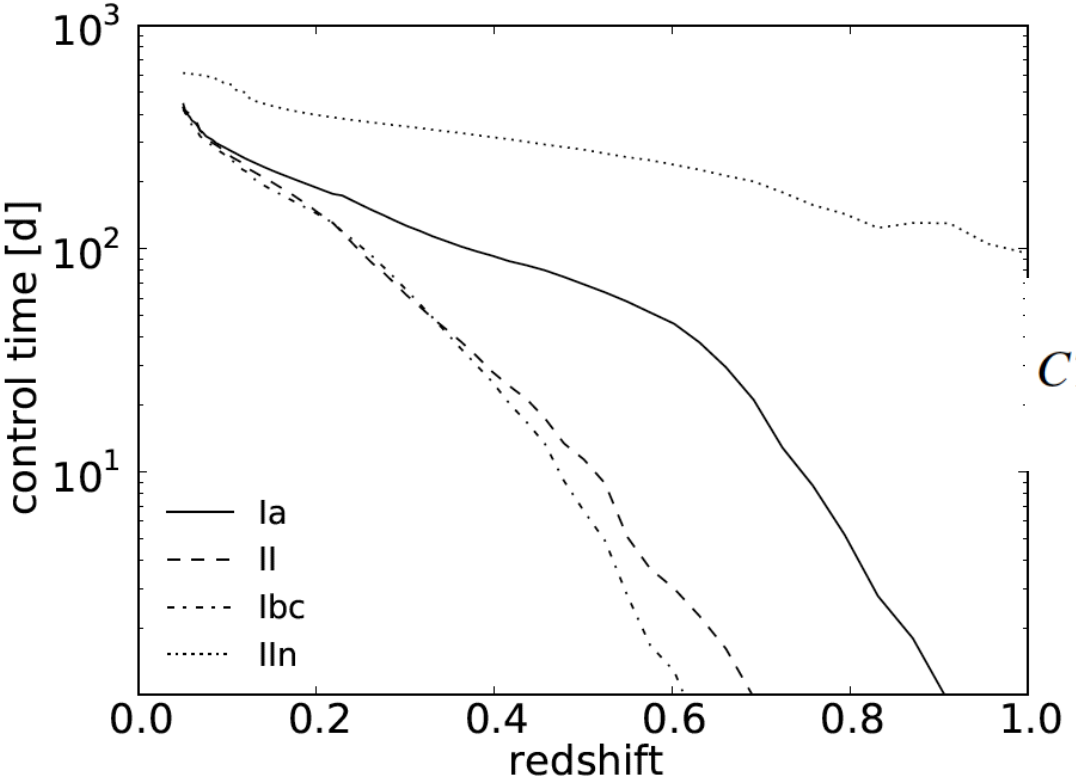
$\beta = 4 \pm 2$

$22 \leq mag_{50} \leq 24$

Cappellaro et al 2015

SN SEARCH

CONTROL TIME



$$CT_{SN}(z) = \sum_{SNi} \sum_{E_{BV}} f_{SNi}\, g_{E_{BV}}\, CT_{SNi,E_{BV}}(z).$$

f_{SNi} subtype distribution

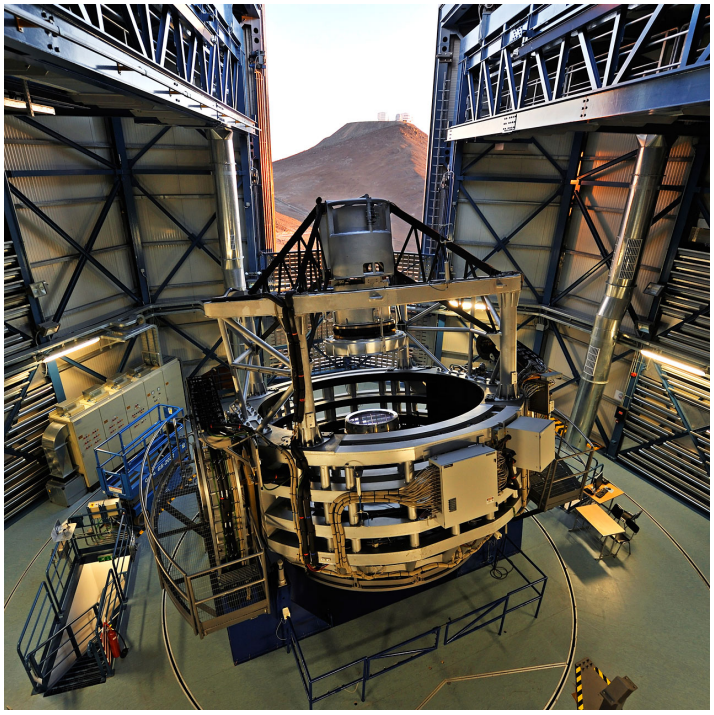
$g_{E(B-V)}$ colour excess distribution

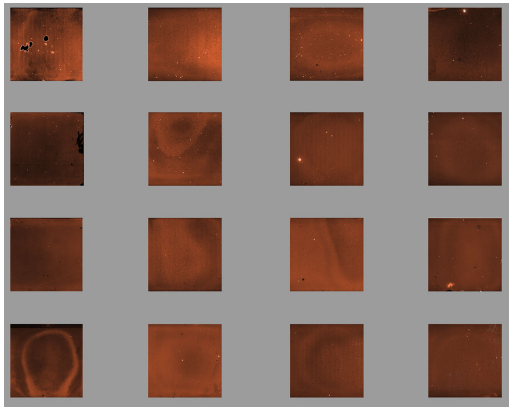
Cappellaro et al 2015

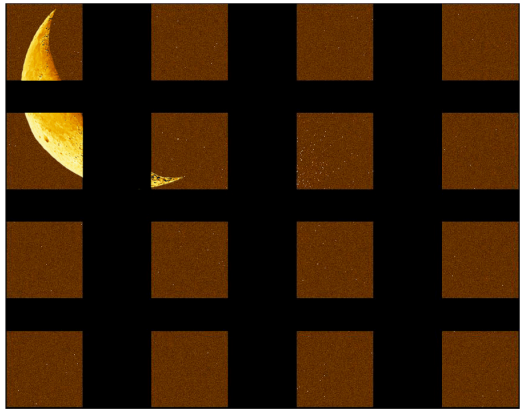
GALAXY SAMPLE ANALYSIS

INSTRUMENTS

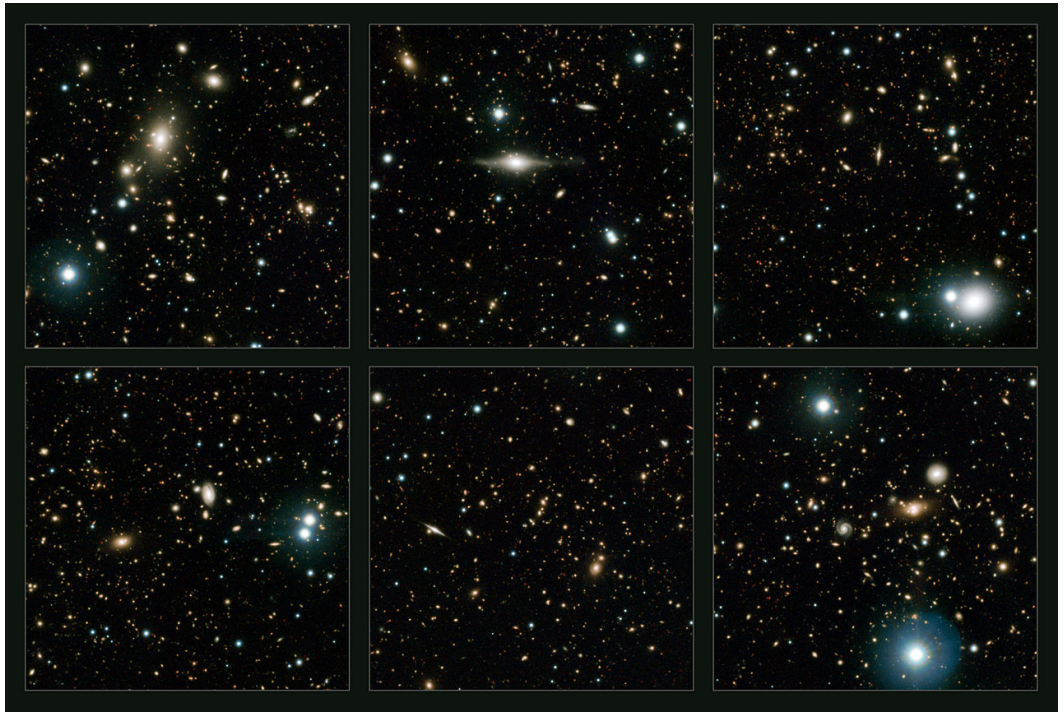
VISTA 4.1 m







VIRCAM



VISTA Deep Extragalactic Observations (VIDEO) Survey

Jarvis et al 2013

GALAXY SAMPLE ANALYSIS

PIPELINE

VSTTube

VIDEO

Raw Images

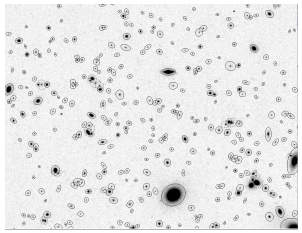
Deep stacks

SWARP

Image resampling

SEXTRACTOR

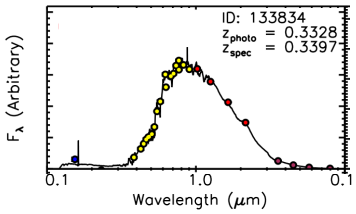
Source detection



EAZY

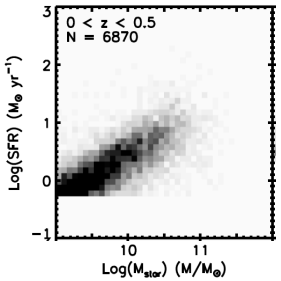
Photometric Redshifts

Rest Frame colors



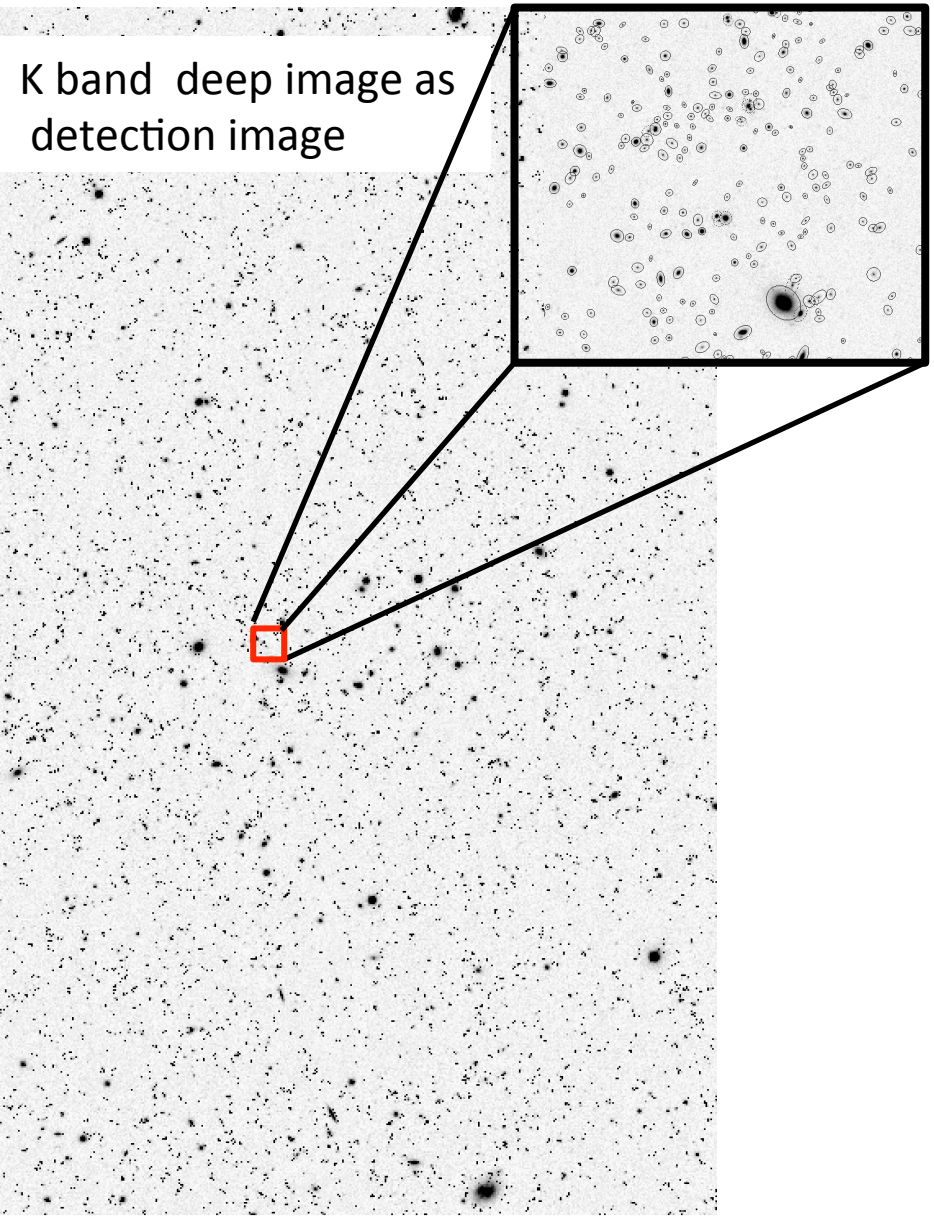
FAST

SFR sSFR mass

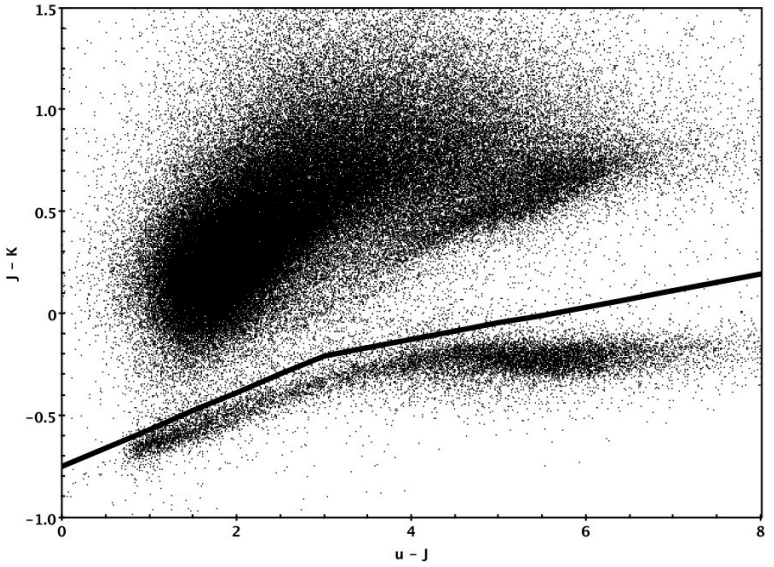


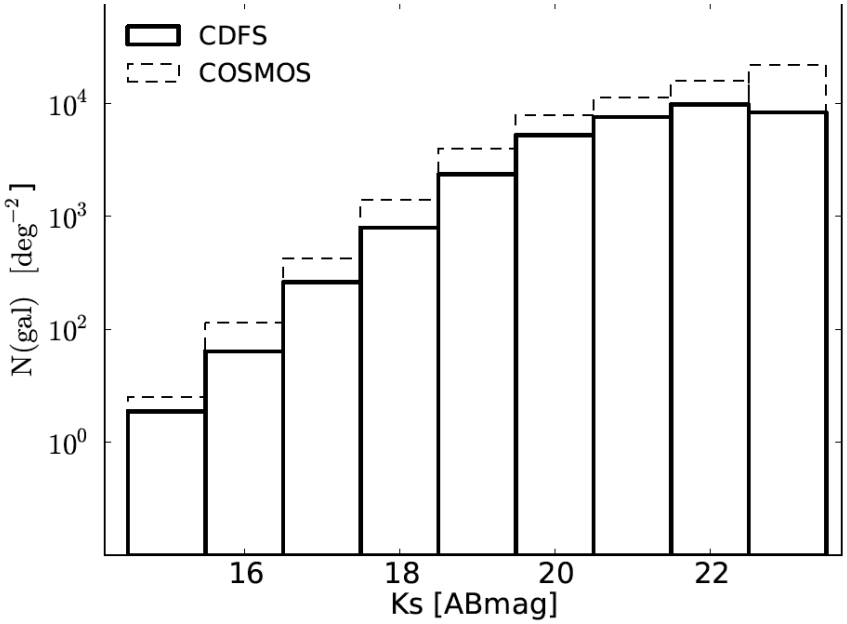
GALAXY SAMPLE ANALYSIS

K band deep image as detection image

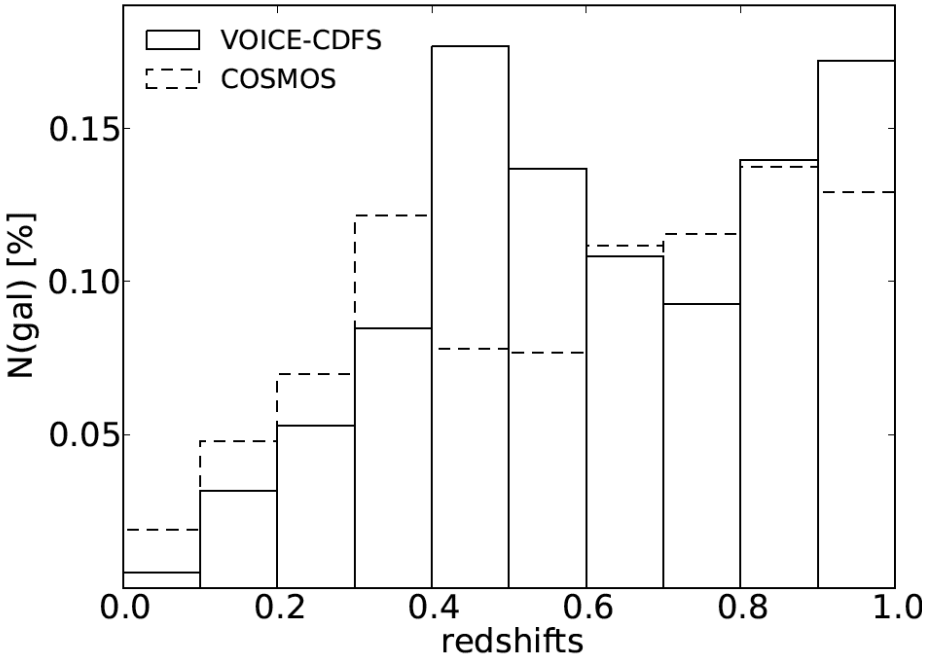


SOURCE DETECTION

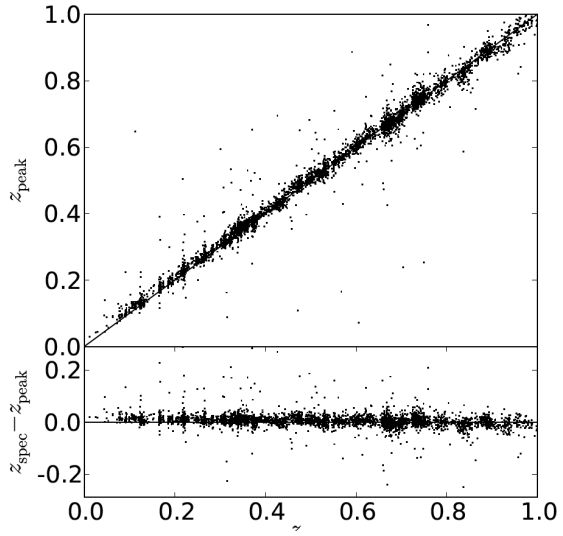




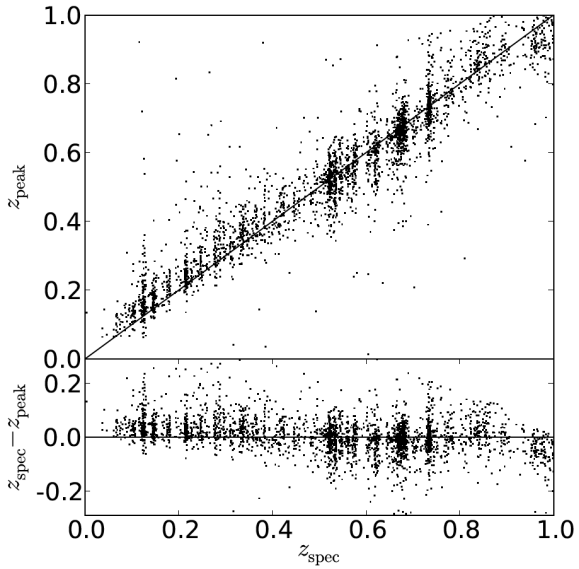
GALAXY SAMPLE ANALYSIS



PHOTOMETRIC REDSHIFTS



COSMOS
σ_{NMAD} =0.005
4% of 5σ outliers



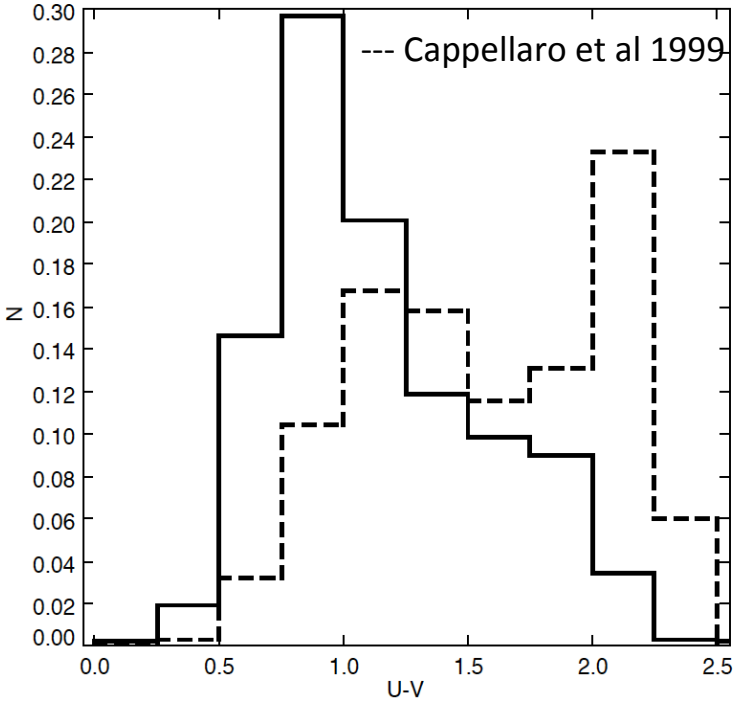
CDFS
σ_{NMAD} =0.02
14% of 5σ outliers

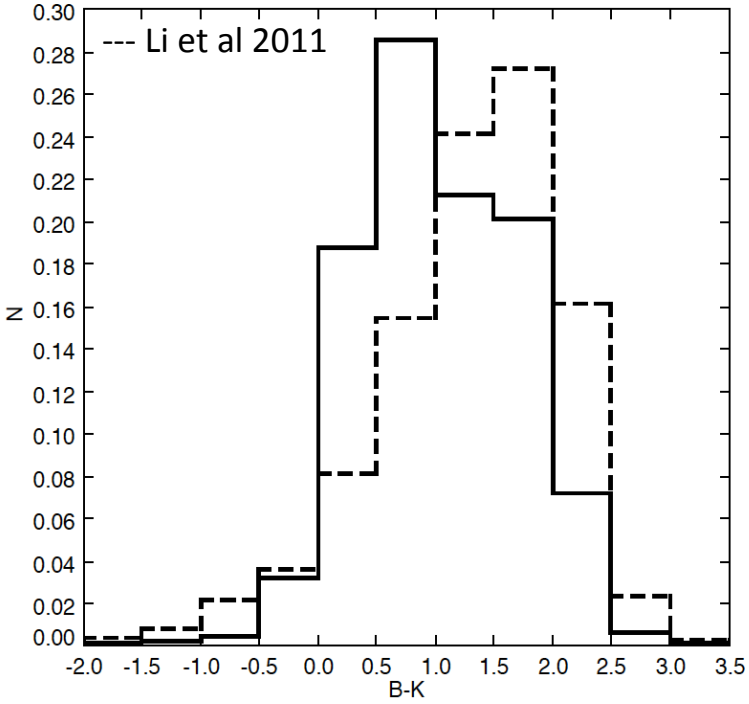
i. K ≤ 23.5 mag
ii. Q_z <1
iii. 0 ≤ z ≤ 1

CDFS 1+2 67224 galaxies
COSMOS 62863 galaxies

GALAXY SAMPLE ANALYSIS

REST FRAME COLOURS

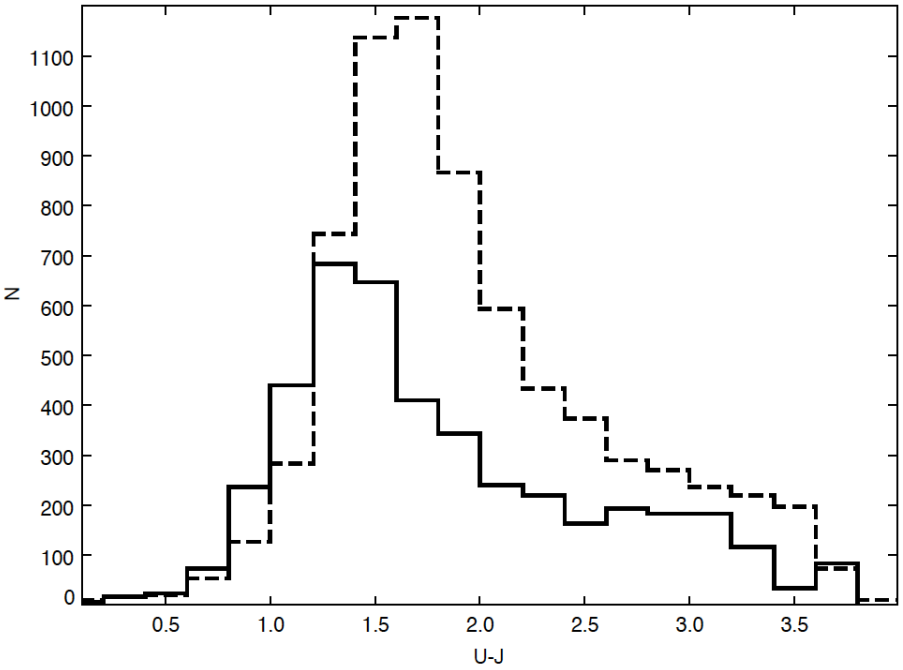




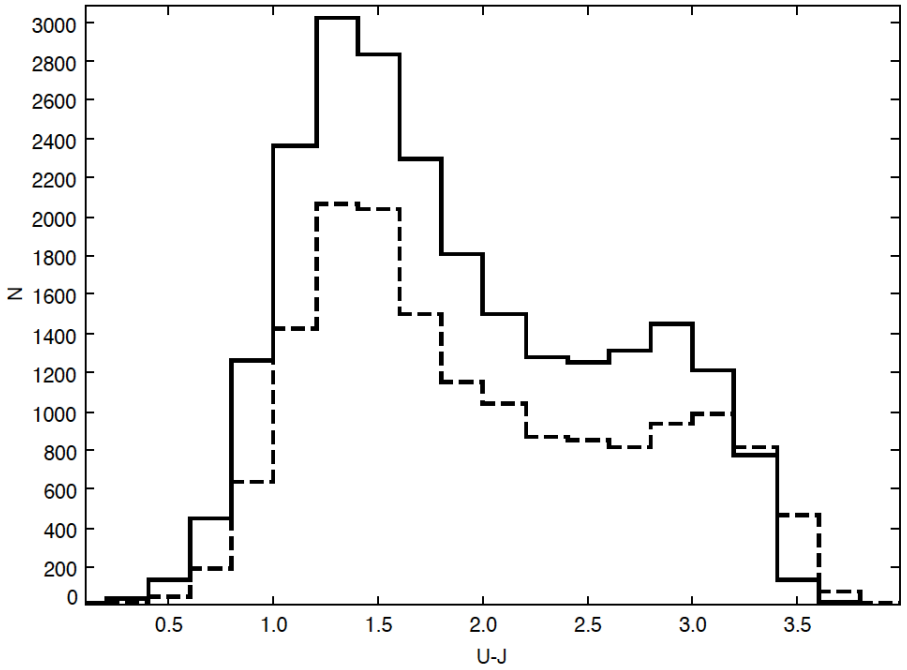
Botticella et al in preparation

GALAXY SAMPLE ANALYSIS

REST FRAME COLOURS



$0.5 \leq z \leq 1$



$0 \leq z < 0.5$

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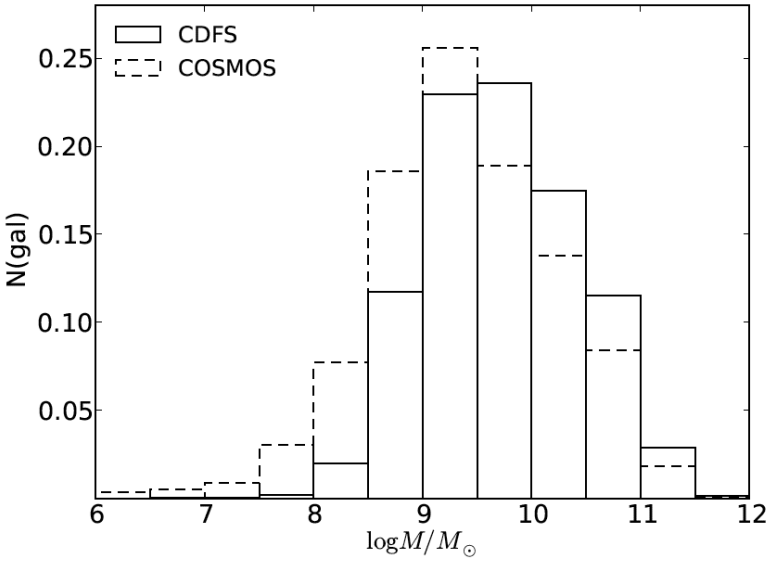
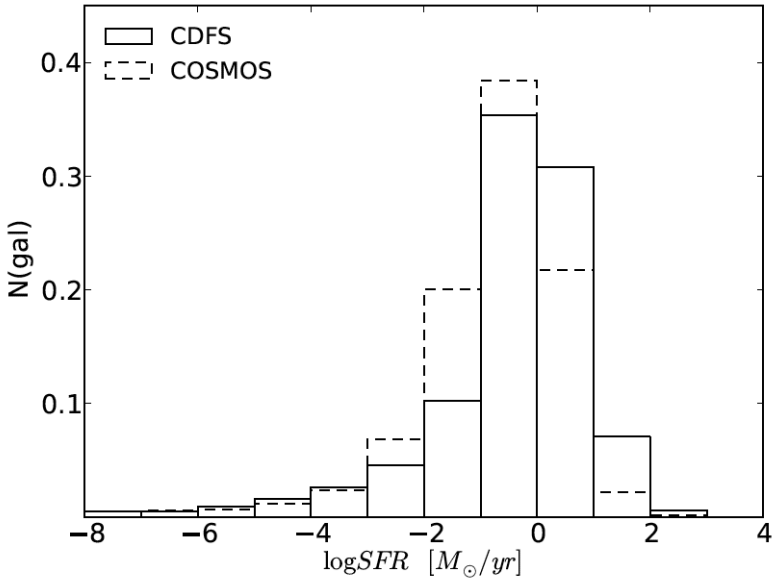
GALAXY SAMPLE ANALYSIS

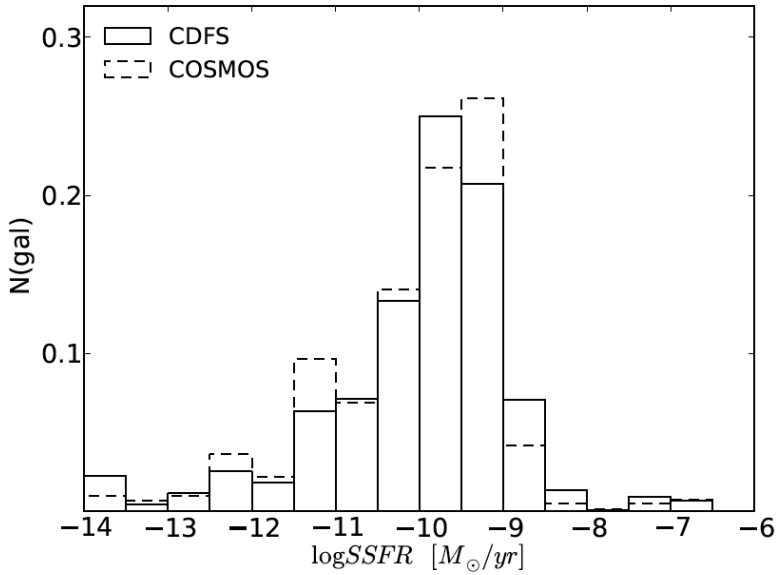


MASS

SFR



sSFR



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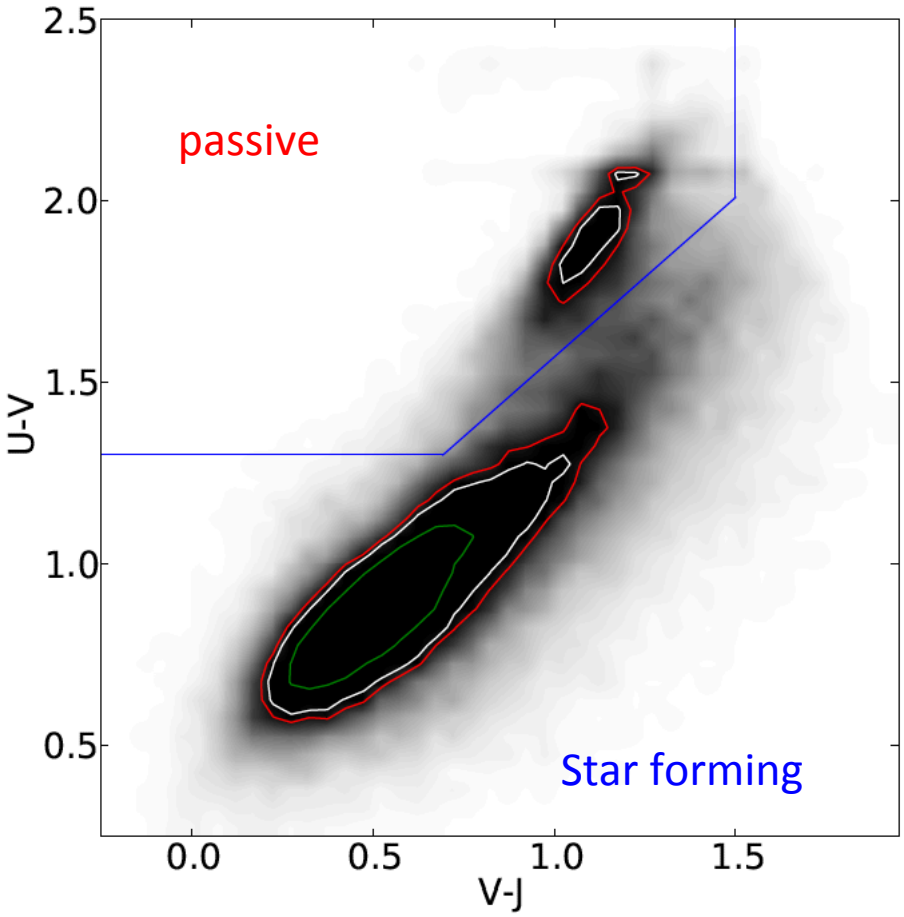
GALAXY SAMPLE ANALYSIS

PASSIVE AND STAR FORMING GALAXIES

$$U - V > 1.3 \qquad V - J < 1.5 \quad \text{at all redshifts}$$
$$U - V > (V - J) \times 0.88 + 0.69 \qquad \text{for } 0 < z < 1$$

Williams et al 2009



Passive galaxies 12% in CDFS
18% in COSMOS

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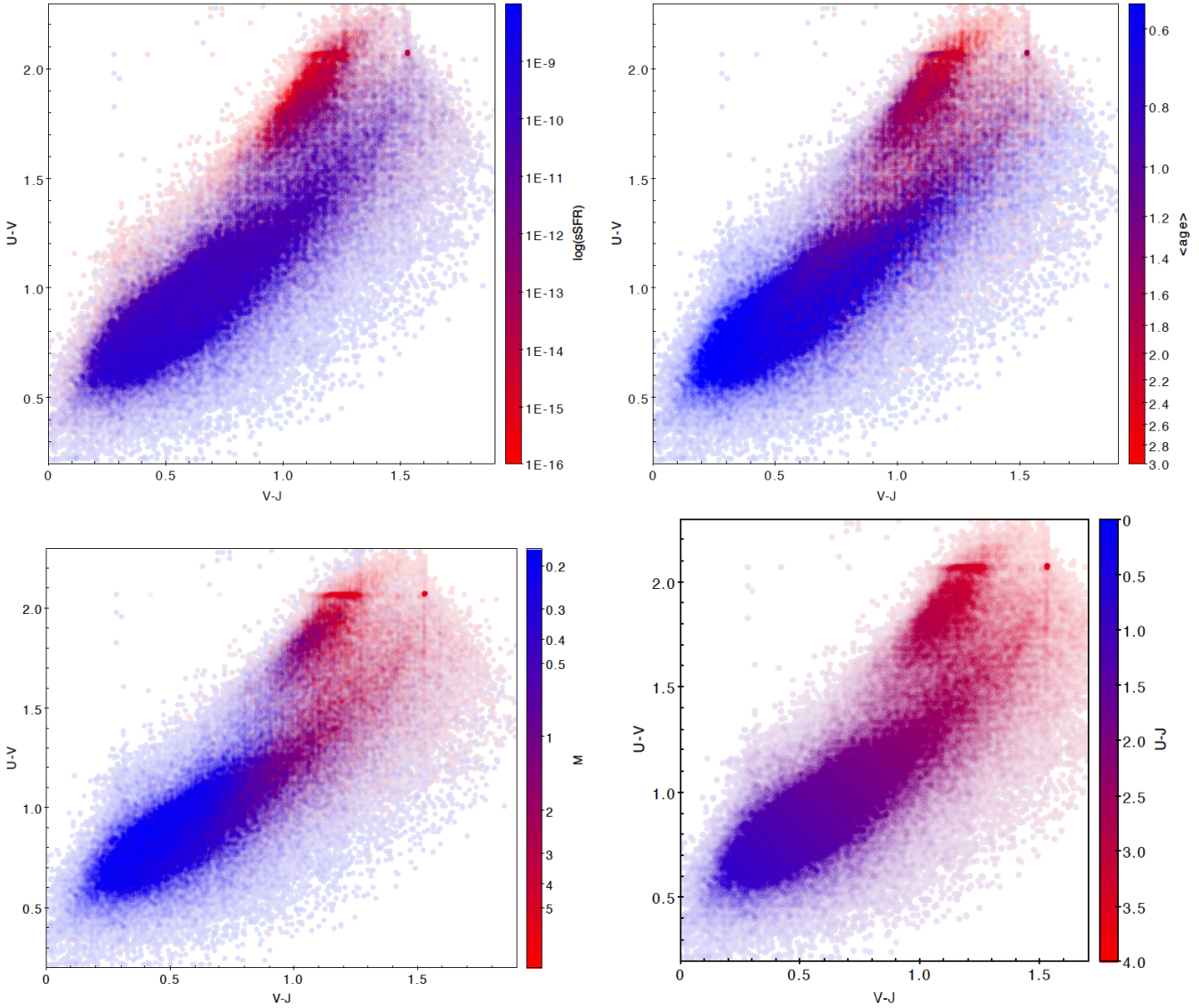
GALAXY SAMPLE ANALYSIS



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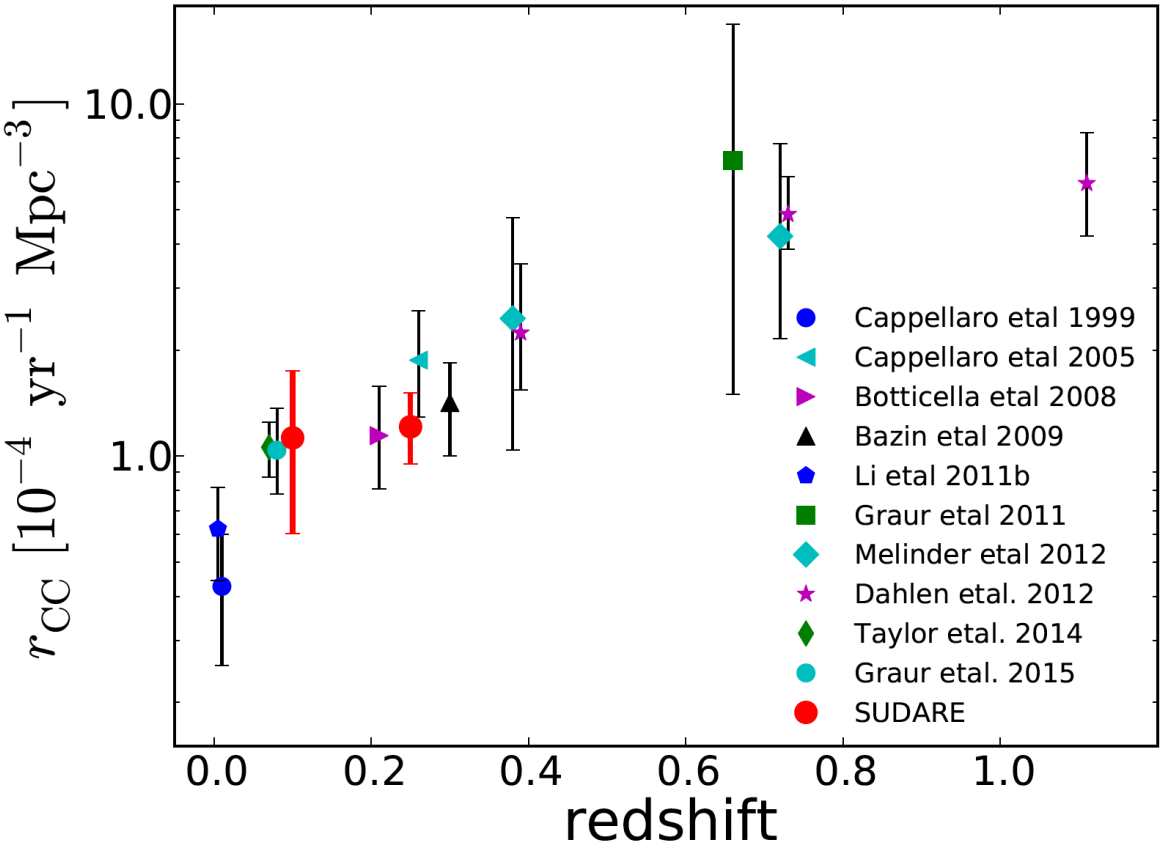
RESULTS

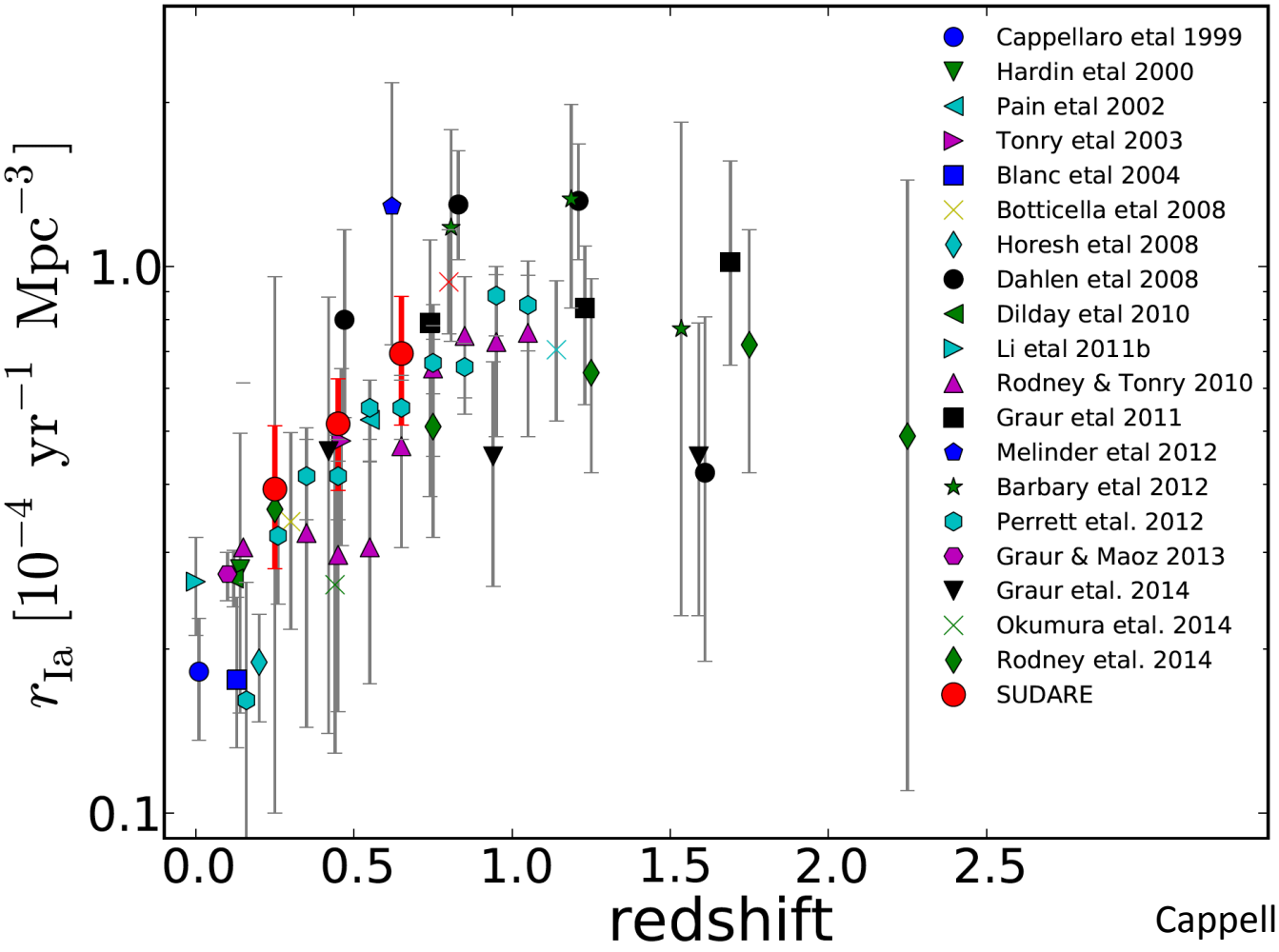
CC SN RATE AS A FUNCTION OF COSMIC TIME



Cappellaro et al 2015

RESULTS

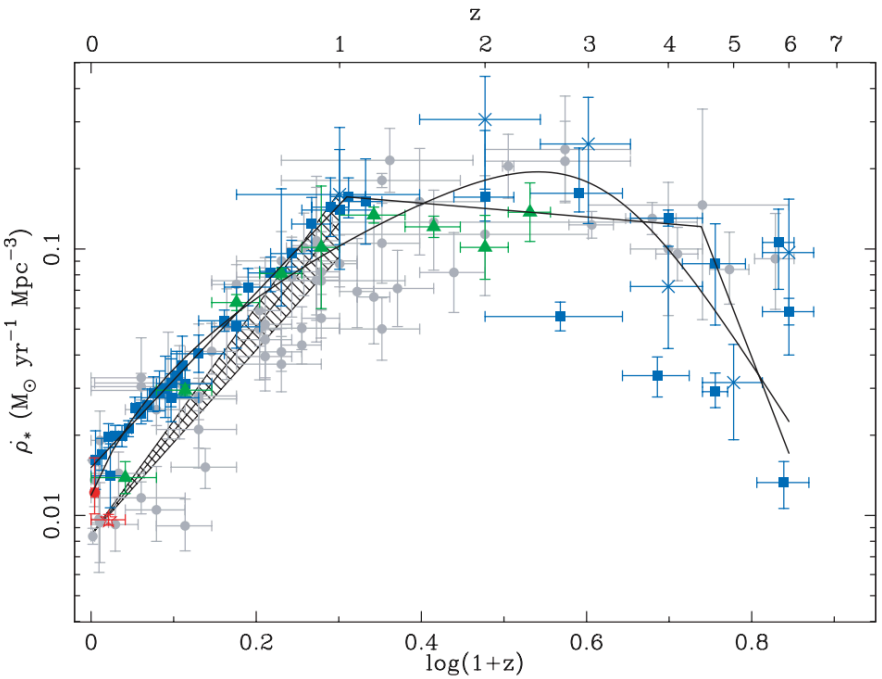
SN Ia RATE AS A FUNCTION OF COSMIC TIME



Cappellaro et al 2015

RESULTS

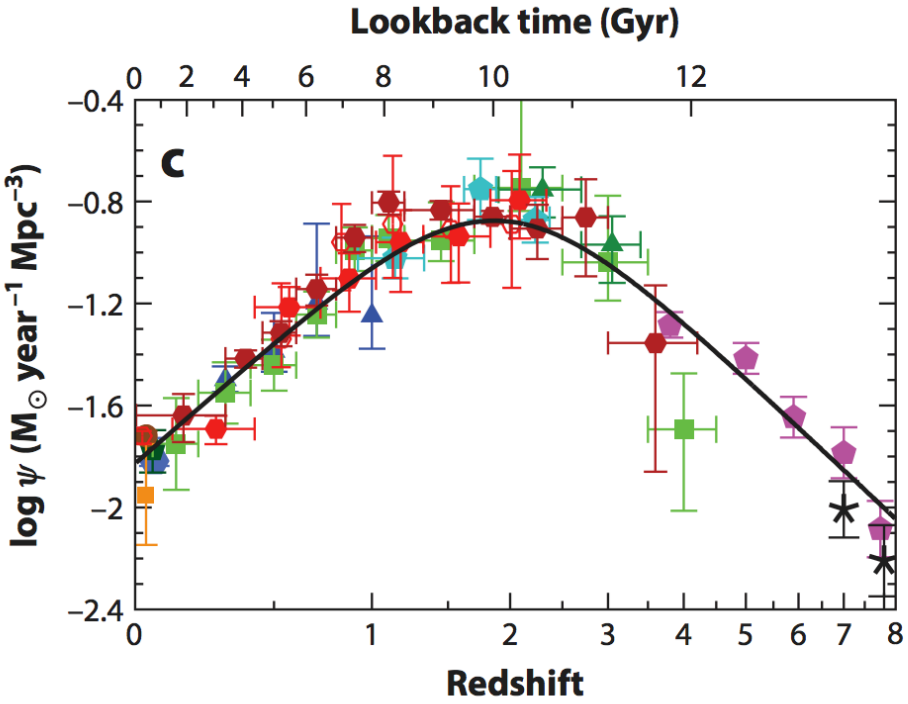
PREDICTED RATES VS OBSERVED RATES



Hopkins & Beacom 2006

Salpeter A IMF

$\alpha = -1.3 \quad m < 0.5\ M_\odot$

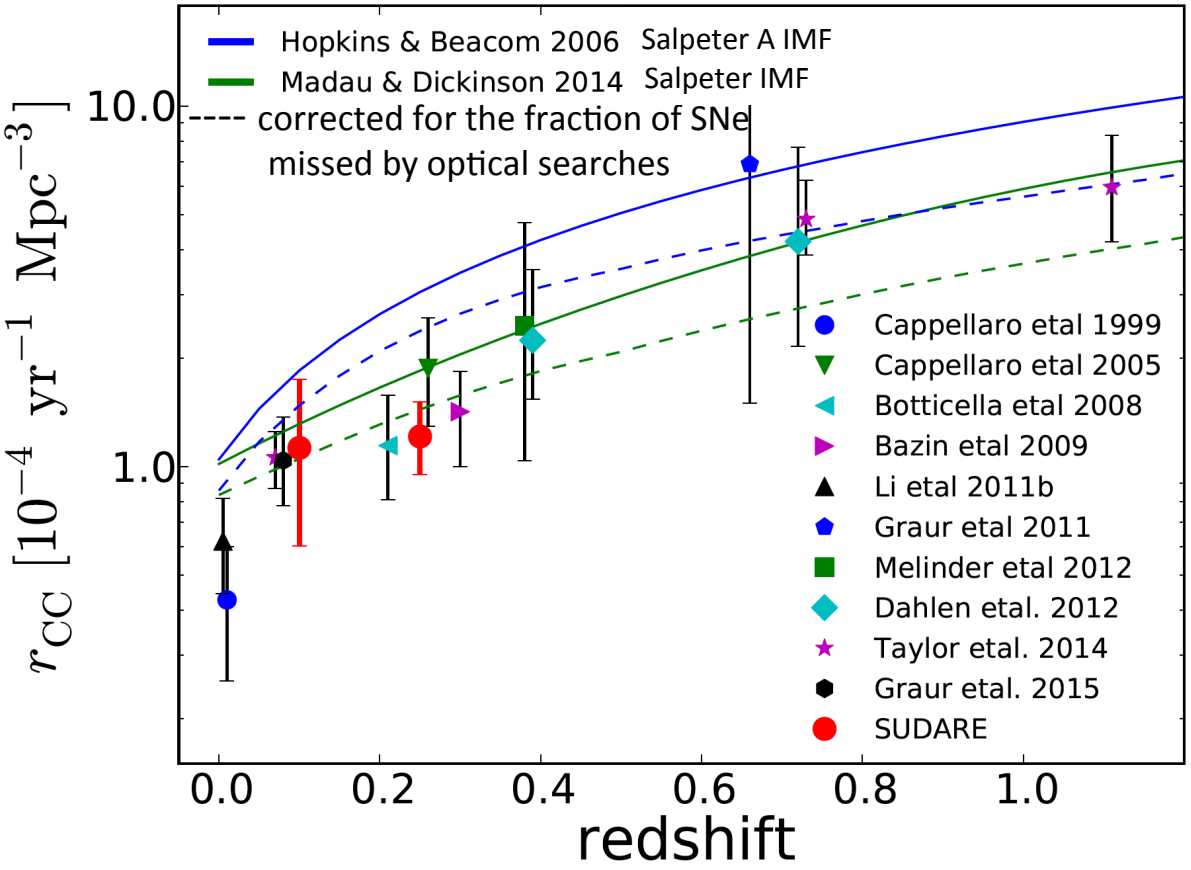


Madau & Dickinson 2014

Salpeter IMF

RESULTS

PREDICTED RATES VS OBSERVED RATES



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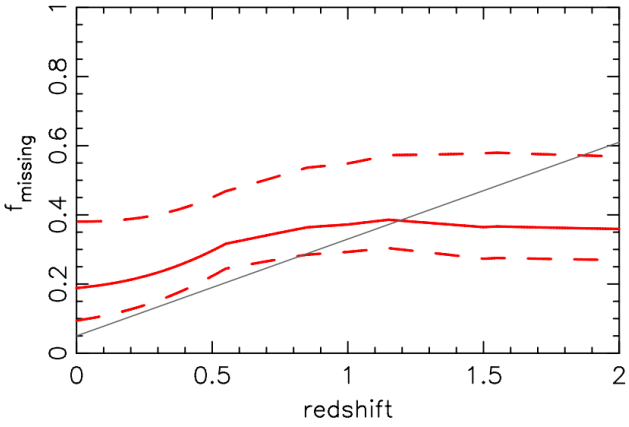
Mass range for CC SN progenitors
8 - 40 $M_\odot$

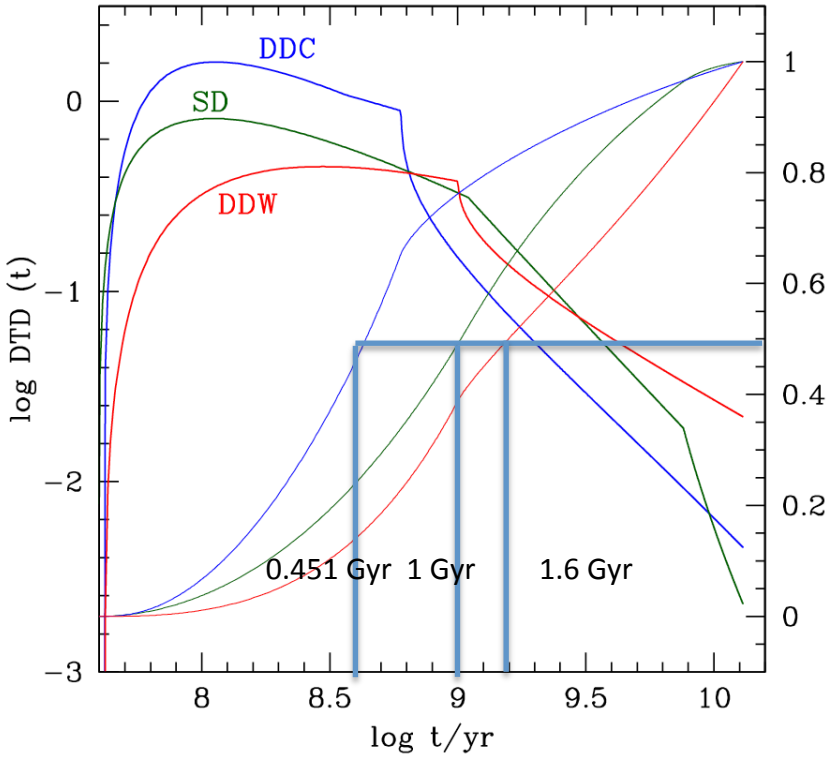
Salpeter IMF $K_{CC} = 6.7 \times 10^{-3}\ M_\odot^{-1}$
Salpeter A $K_{CC} = 8.8 \times 10^{-3}\ M_\odot^{-1}$



Mattila et al 2012

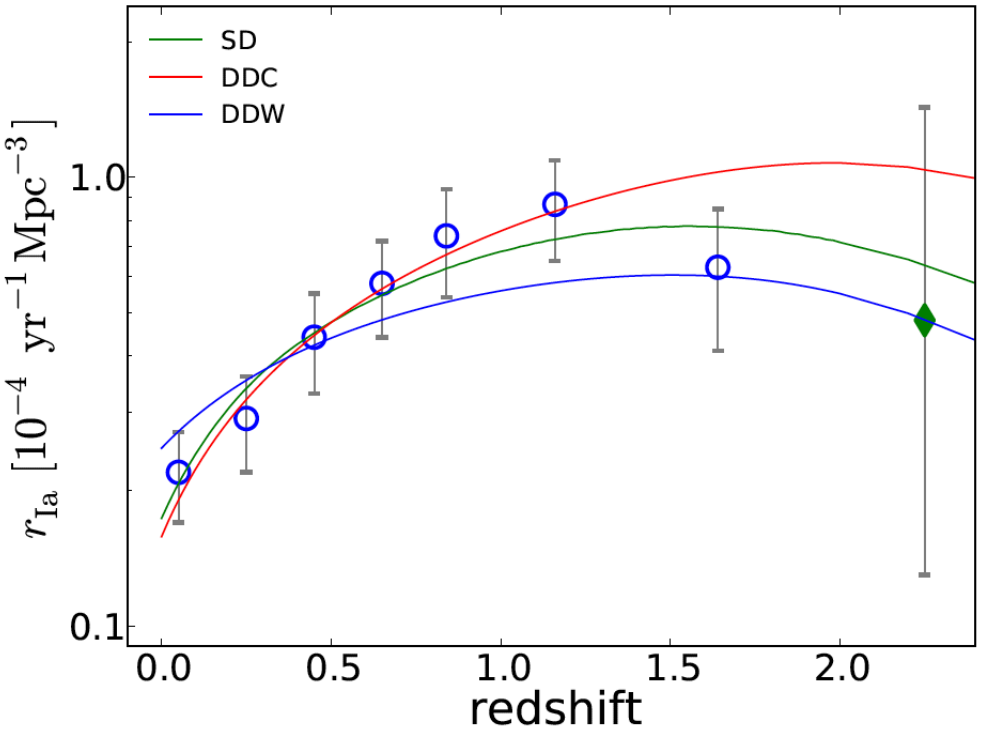
RESULTS

PREDICTED RATES VS OBSERVED RATES



Single Degenerate (SD)
Double Degenerate Close (DDC)
Double Degenerate Wide (DDW)

Greggio 2005



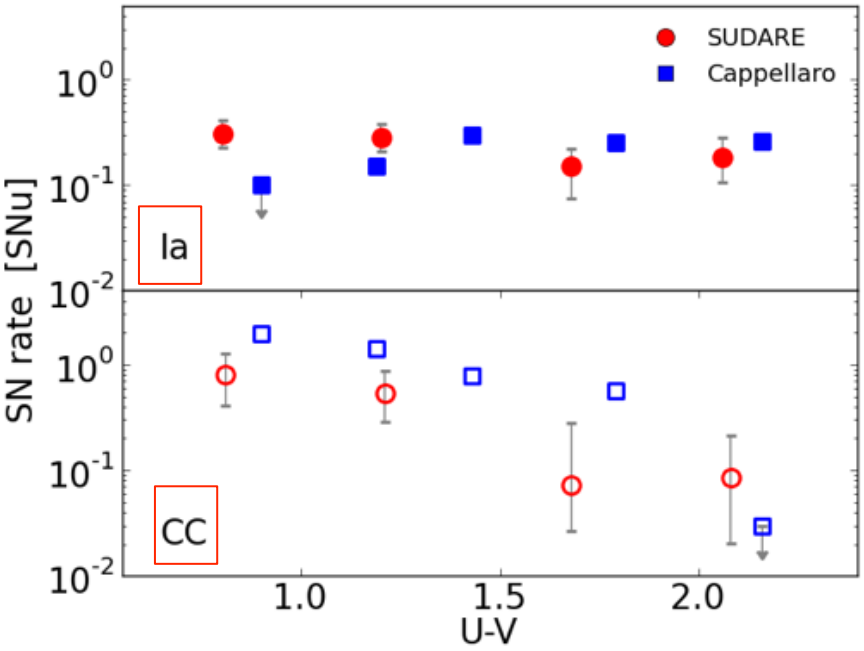
SD and DDW $K_{Ia} = 7.5 \times 10^{-4}\ M_{\odot}^{-1}$

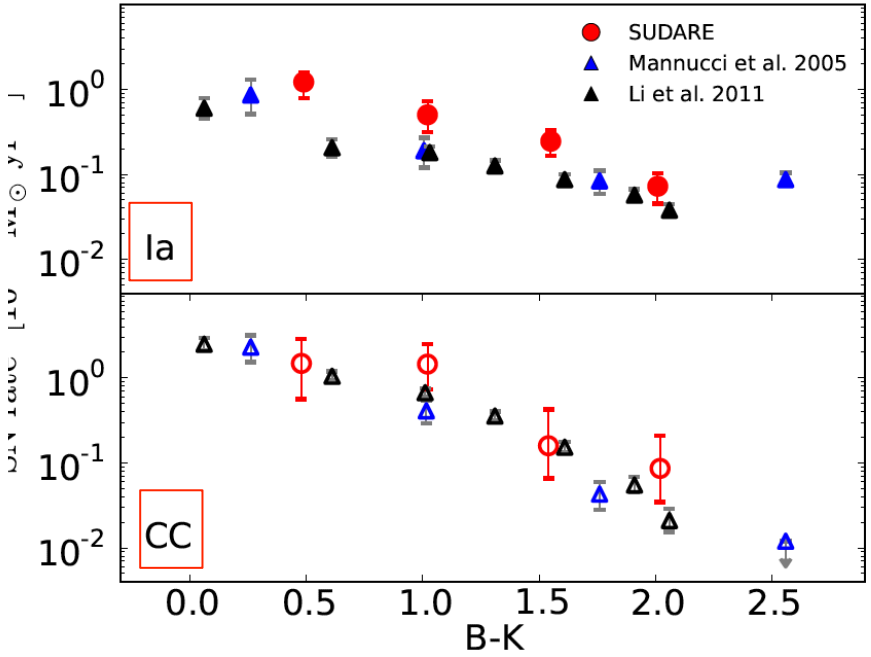
DDC $K_{Ia} = 8.5 \times 10^{-4}\ M_{\odot}^{-1}$

Cappellaro et al 2015

RESULTS

SN RATE AS A FUNCTION OF GALAXY COLOURS





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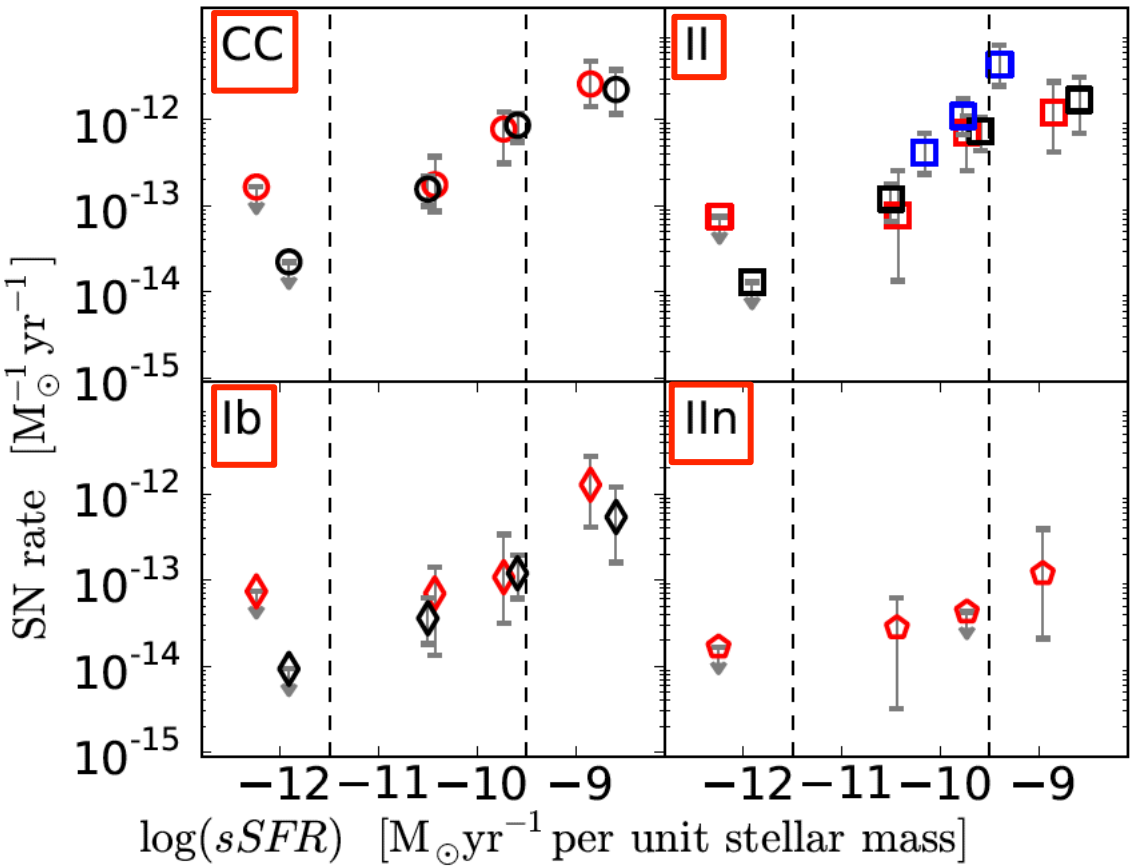
RESULTS

CC SN RATE AS A FUNCTION OF sSFR



SUDARE

Mannucci et al 2005

Graur et al 2015

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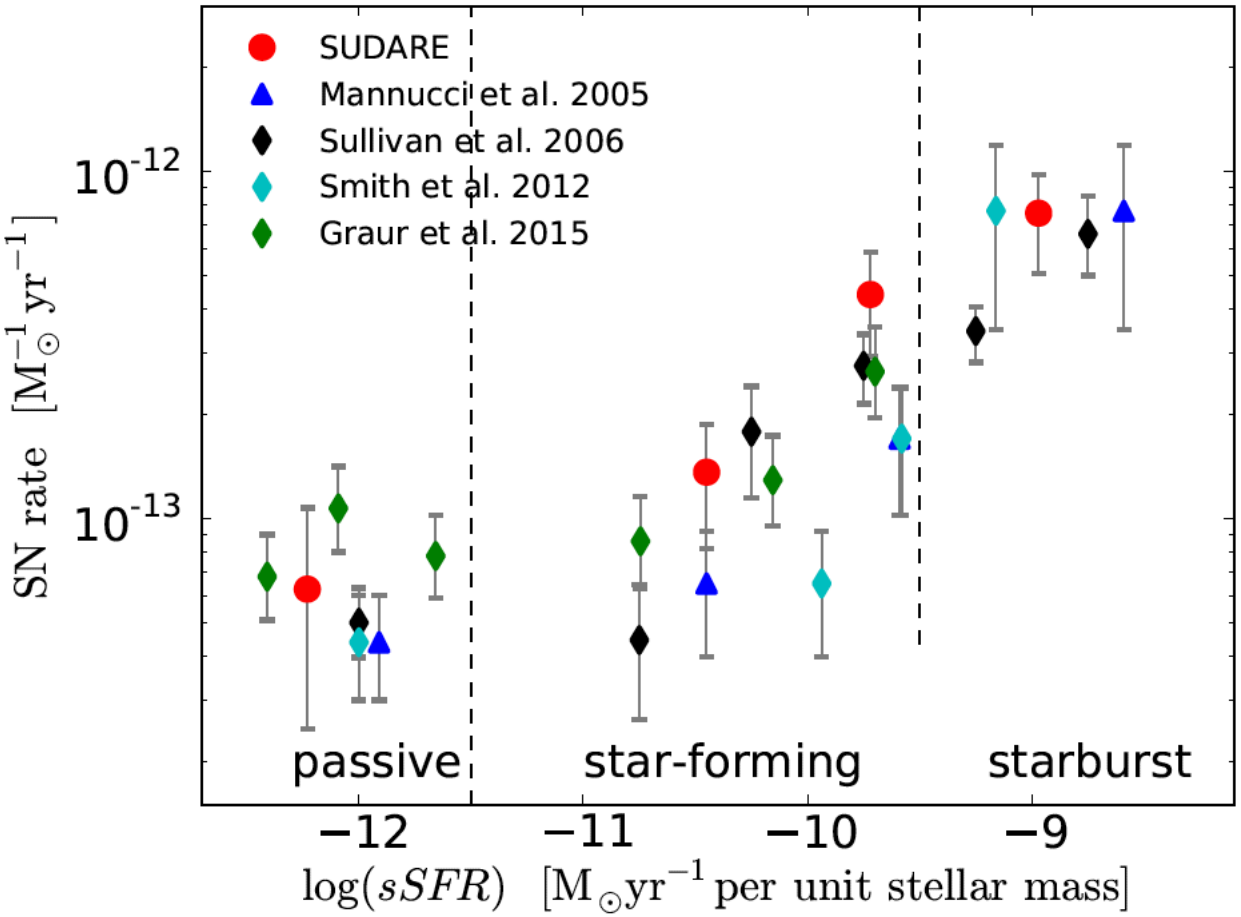
RESULTS

SN Ia RATE AS A FUNCTION OF sSFR



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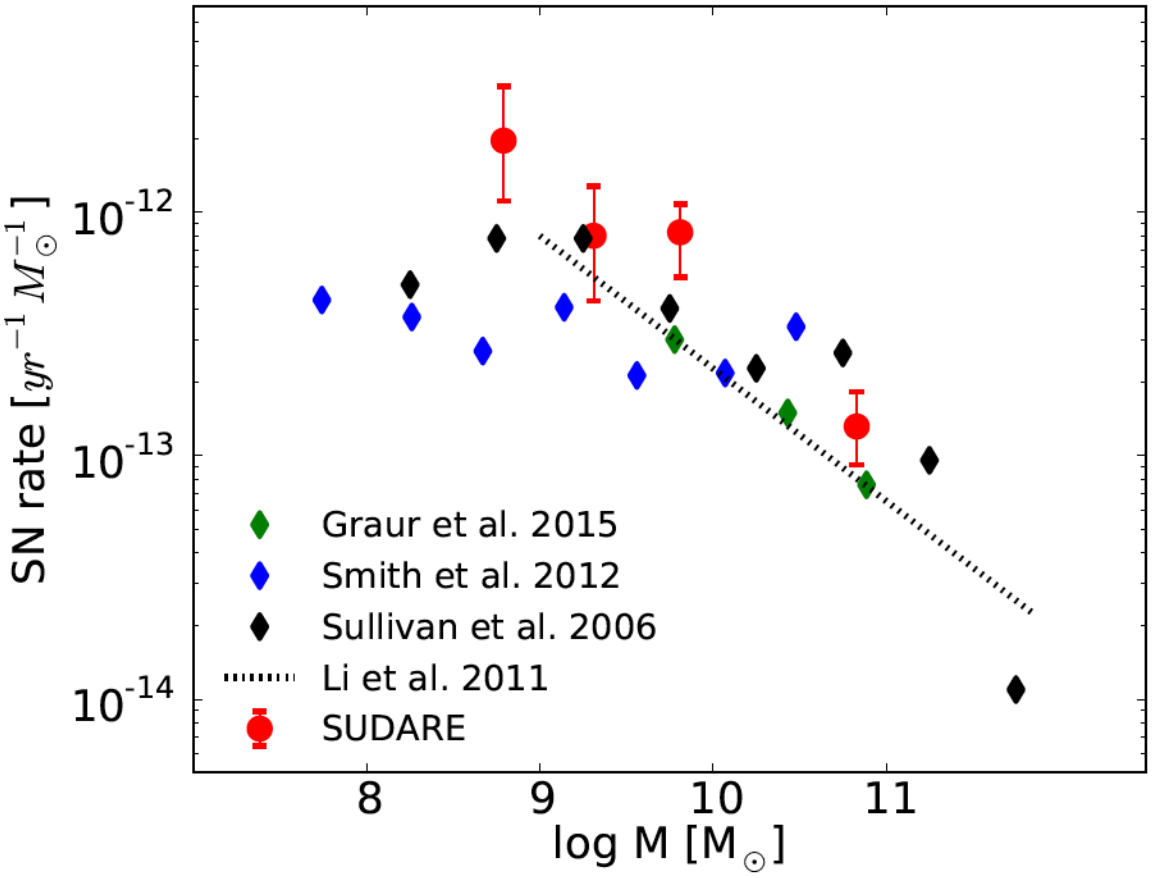
RESULTS

SN Ia RATE AS A FUNCTION OF GALAXY MASS



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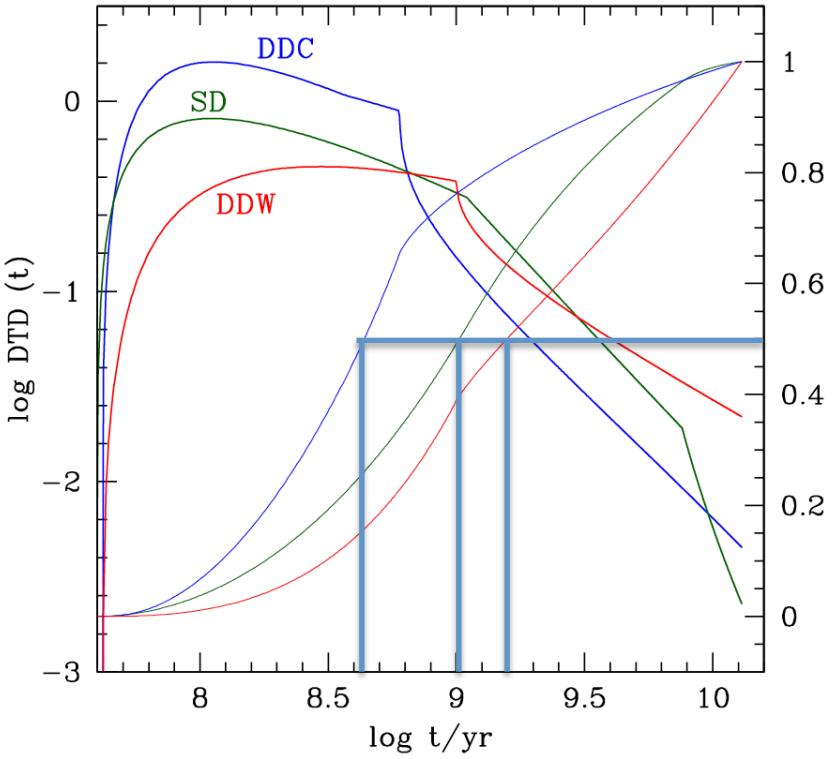
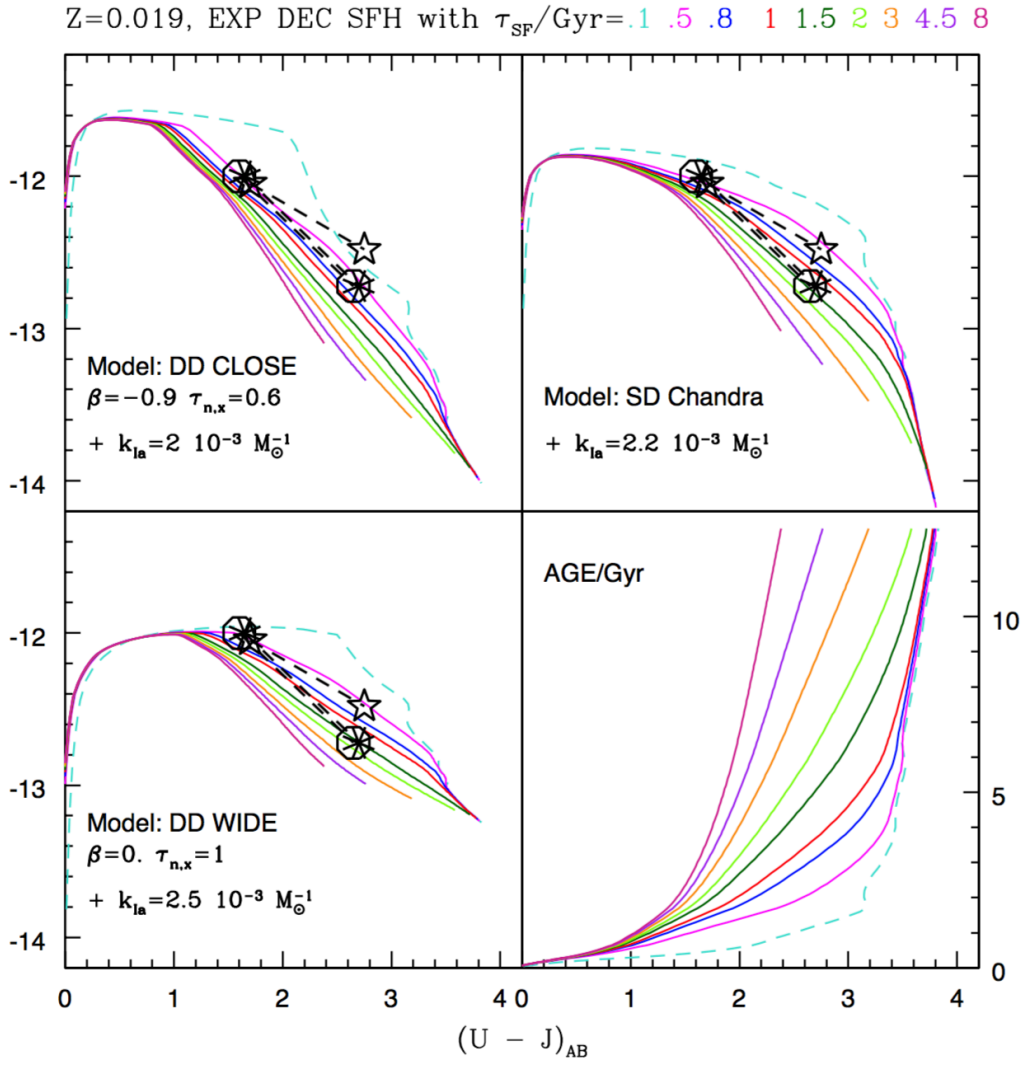
RESULTS

PREDICTED RATES VS OBSERVED RATES



PRELIMINARY RESULT



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CONCLUSIONS

- Our measurements of both SN rates pe unit volume are in agreement within the errors with other measurements in the same redshift range.
- The CC SN rate is consistent with the prediction based on recent SFH's estimate and 8-40 $M_{\odot}$ progenitor mass range
- Errors on SN rate and SFR measurements and the uncertainties on the progenitor mass range are too large to invoke a "SN rate problem" and hence to speculate on possible explanations.
- The dispersion of SN Ia rate measurements does not allow us to discriminate between SD and DD scenarios tough for the DDC scenario seems favoured.
- The SN rates per unit luminosity as a function of U-V and B-K rest frame colours have the same trend in the local Universe and at intermediate redshift
- The clear increase in the SN rates per unit stellar mass with increasing galaxy sSFR has approximately the same trend in the local Universe and at intermediate redshift.
- The SN Ia rate increase from passive to star burst galaxies of about a factor of 13
- The CC SN rate increases from star forming to star burst galaxies of a factor of 15