SUDARE
The supernova search with
OMEGACAM @ VST

Enrico Cappellaro

credit

Maria Teresa Botticella & Laura Greggio

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SN rates
contest and history

SN rates basics

Greggio 2005, 2010

SN rate

Initial mass function

SN progenitor scenarios

Star formation rate

core collapse

$$\dot{n}_{cc}(t) = k_{cc}\,\psi(t)$$

mass range

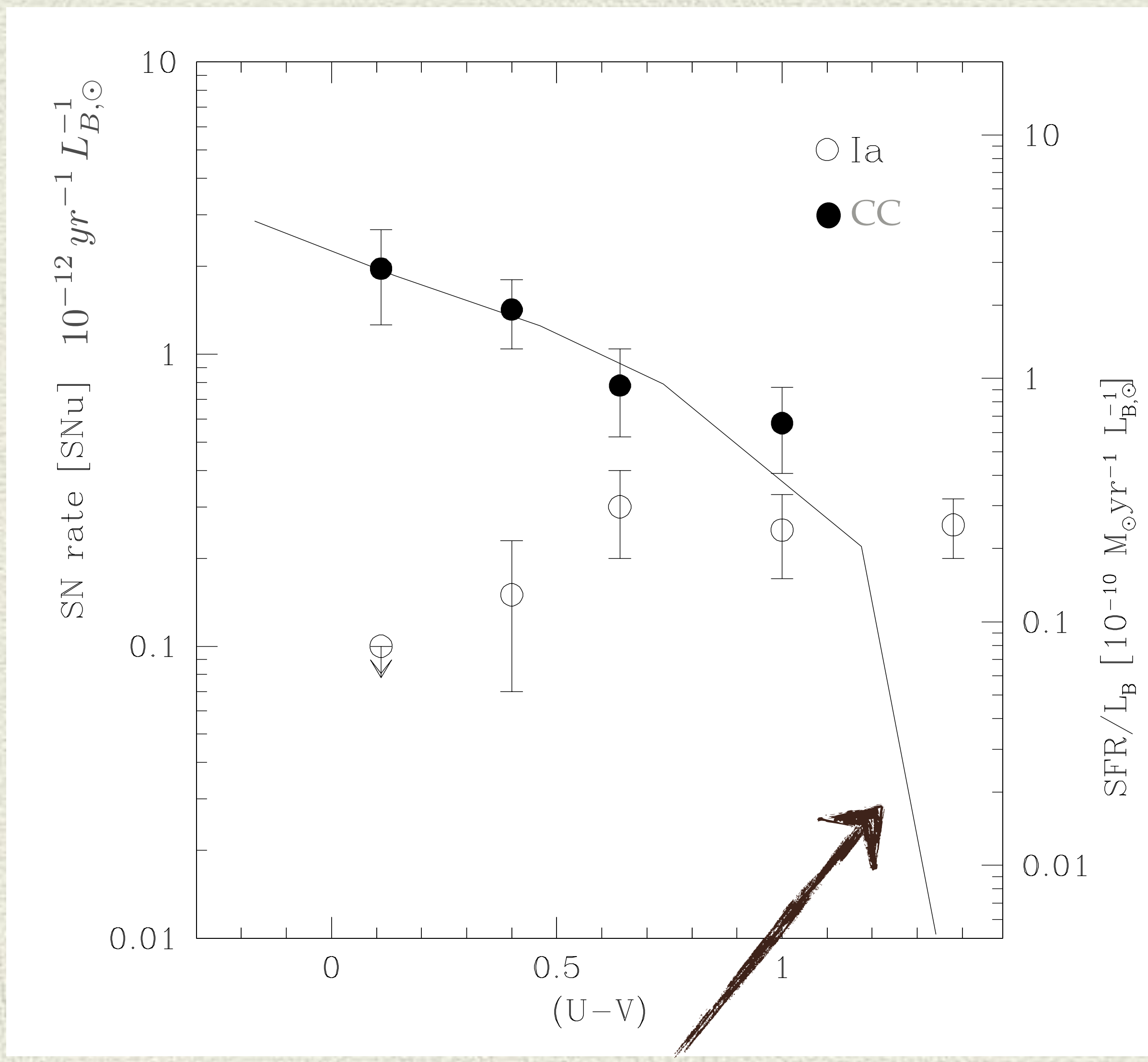
thermo nuclear

$$\dot{n}_{Ia}(t) = k_{Ia} \int_0^t \mathrm{DTD}_{Ia}(t_d)\,\psi(t - t_d)\,\mathrm{d}t_d$$

delay time distribution

Core collapse SNe & SF rates

Cappellaro et al. 1999



Kennicutt 1998
SFR vs. galaxy color from evolutionary synthesis model fitting present day late spirals

The shape of IMF is not important

for Salpeter IMF

$\mathbf{k_{cc}= 6.7x10^{-3}}$

$8 < M_{CC} < 40\ M_\odot$

upper limit 40 ➡100 $M_\odot$ +10%

lower limit 8 ➡ 10 $M_\odot$ -40%

SN Ia delay time distribution & rate

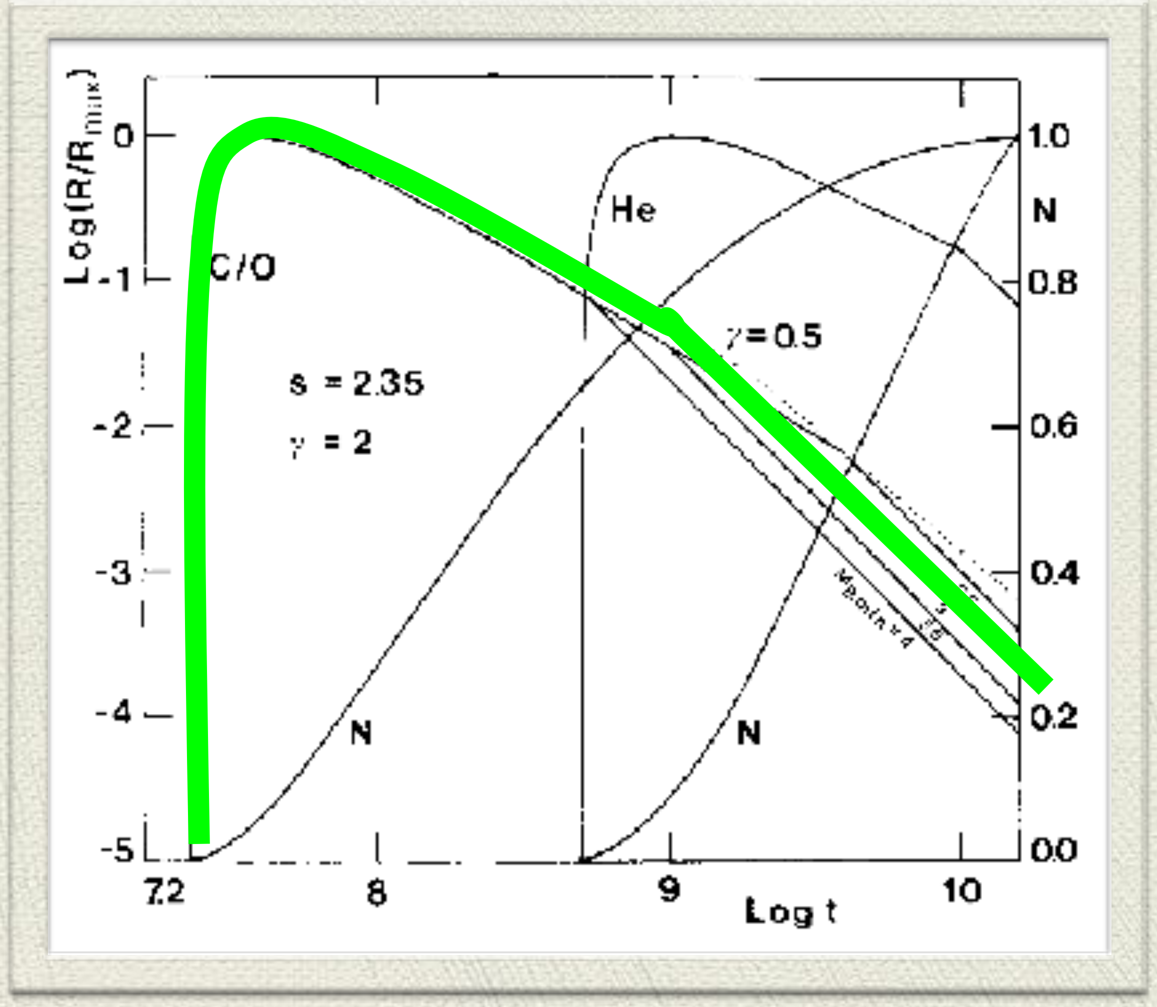
Greggio and Renzini (1983)

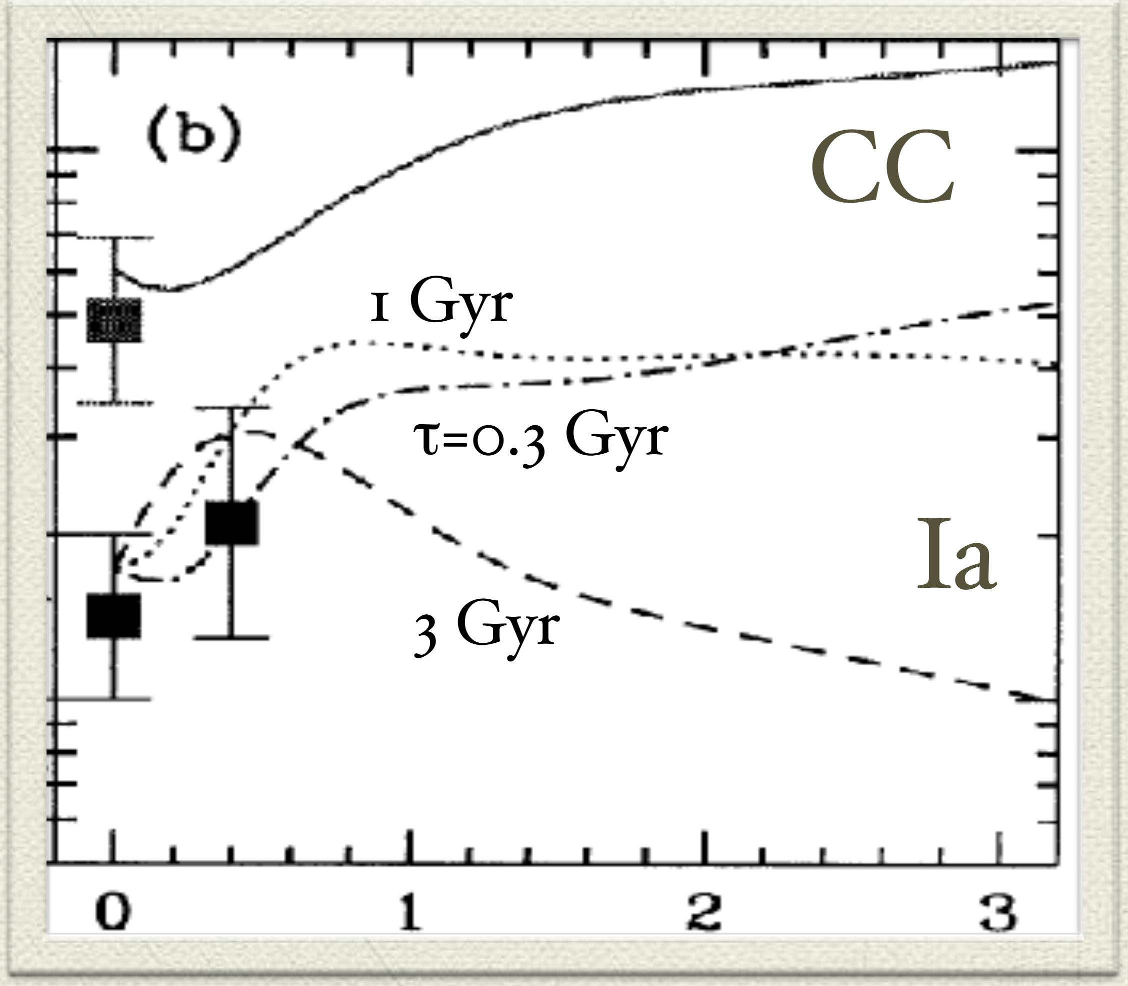
Binary models … naturally account for the occurrence of these events in elliptical and for their higher rate in late-type galaxies

Madau, Della Valle & Renzini (1998)

.. accurate measurements of the frequency of SN events in the range 0<z<1 will be valuable probes of the nature of type Ia progenitors and the evolution of the stellar birth in the universe

DTD



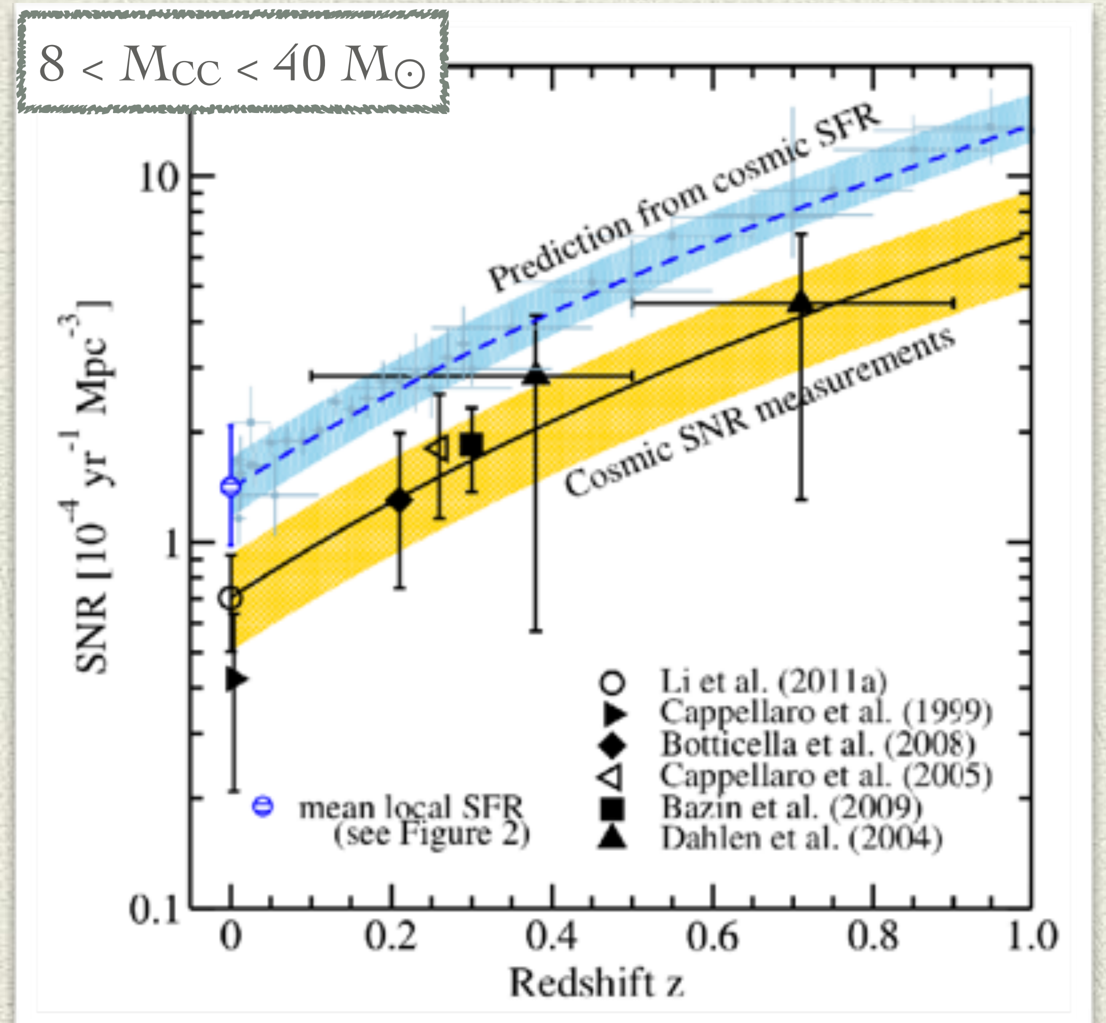


SN-CC and star formation rates evolution

Horiuchi et al 2011

… if the mass range is 8-40 $M_\odot$ …

We identify a "supernova rate problem:" the measured cosmic core-collapse supernova rate is a factor of ~2 smaller (with significance ~2σ) than that predicted from the measured cosmic massive-star formation rate



Botticella et al. 2012

…. Hα, FUV and TIR luminosities … for a complete galaxy sample within the ***local 11 Mpc volume*** *and the number of discovered supernovae in this sample within the last 13 years*

the core-collapse supernova rate matches the SFR from the FUV luminosity. However, the SFR based on Hα luminosity is lower than these two estimates by a factor of nearly 2.

CC progenitor lower limit 6-8 $M_\odot$

SN-Ia rate evolution

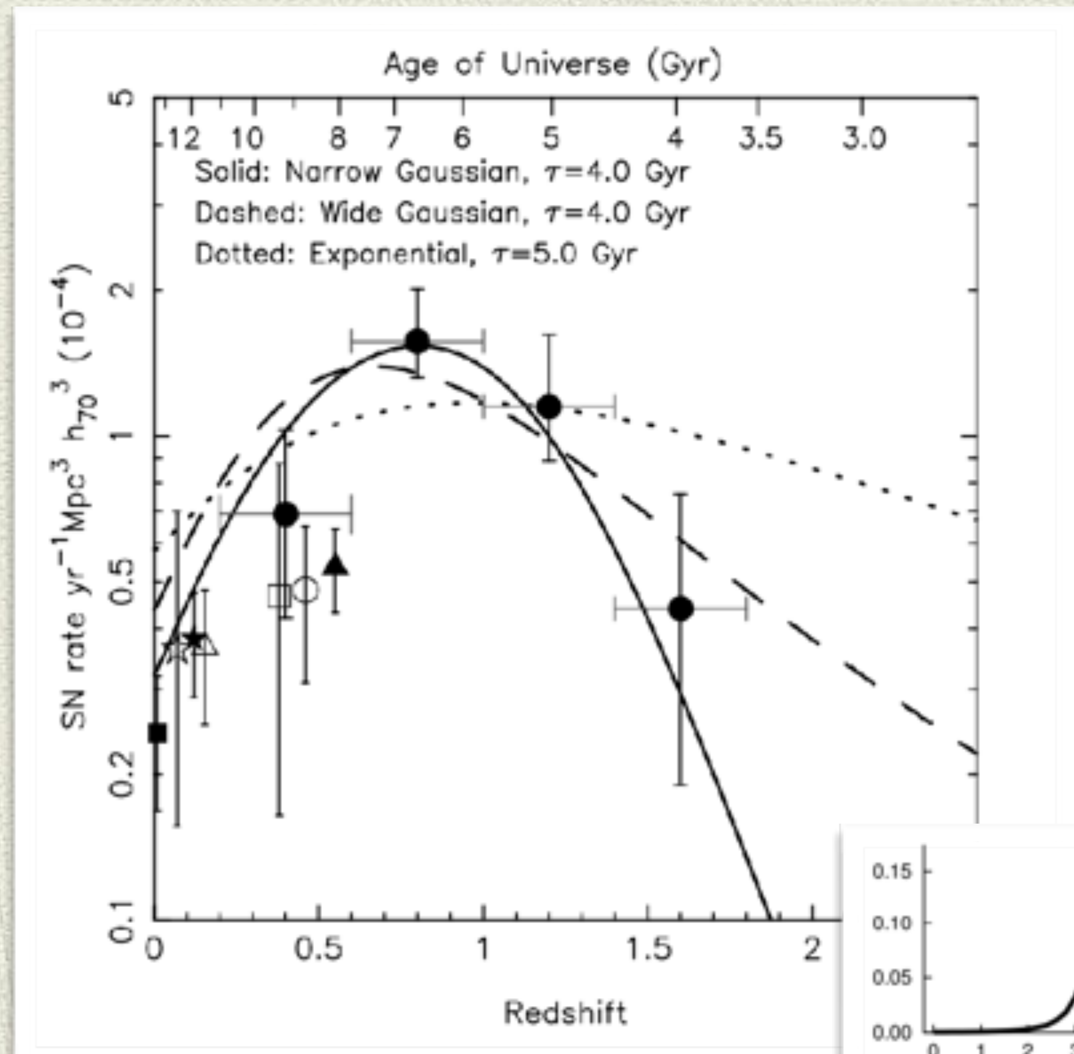
Strolger et al. 2004 (2010)

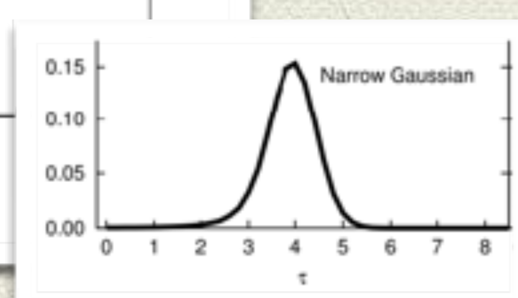
SN Ia rate history from the GOODS/ HST SN survey, reveals a SN Ia delay-time distribution that is tightly confined to 3–4 Gyr (to >95% confidence)

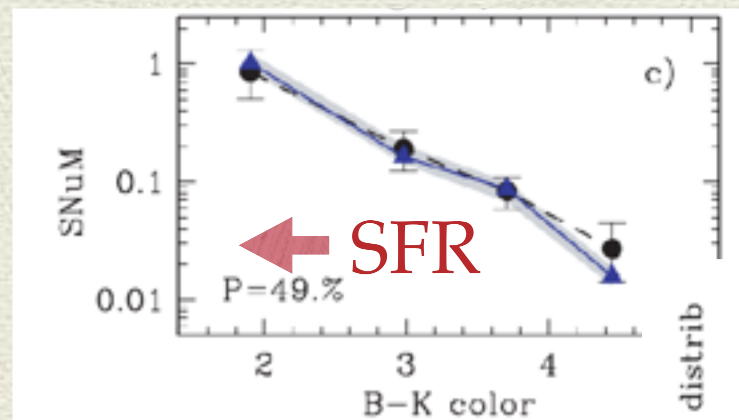
Mannucci et al 2006

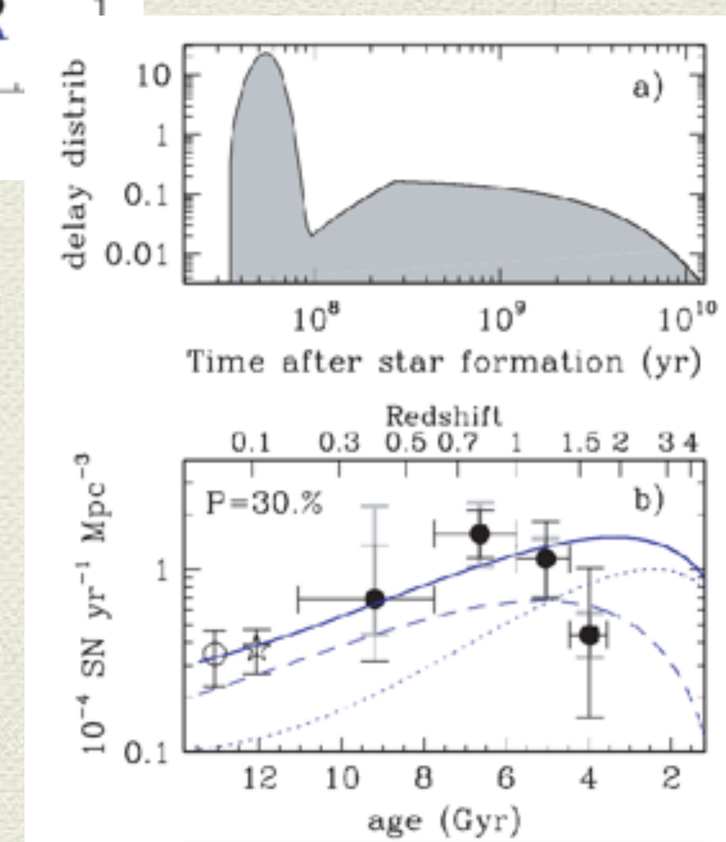
Local rates need a dominant population of young SNIa progenitors

Two distinct SN~Ia progenitors









Two (inconsistent ?) complementary approaches

SN rate per unit volume	cosmic SFH from integrated luminosity
SN rate in galaxies as function of mass, color star	galaxy SFH from SED fitting

core collapse	progenitor mass range
Ia	empirical or astrophysical motivated DTD

SUDARE
The VST SN search

SUDARE@VST

Two pointing:

CDFS 03 32 13 -27 50 00
COSMOS 10 00 28 +02 12 21

Three programs:

Cappellaro: VST+Omegacam GTO
Pignata: Chilean time
Covone: synergy with VOICE

Strategy: r-band exposure every 3 day
g,i band colors once 10 days

exposure 30-40 min

CDFS 2x2 pointings, one per season
COSMOS 1 same pointing for 3 seasons

Follow-up:

VOICE and public surveys for host galaxy characterisation
Live spectroscopy: VLT / GEMINI/MAGELLAN

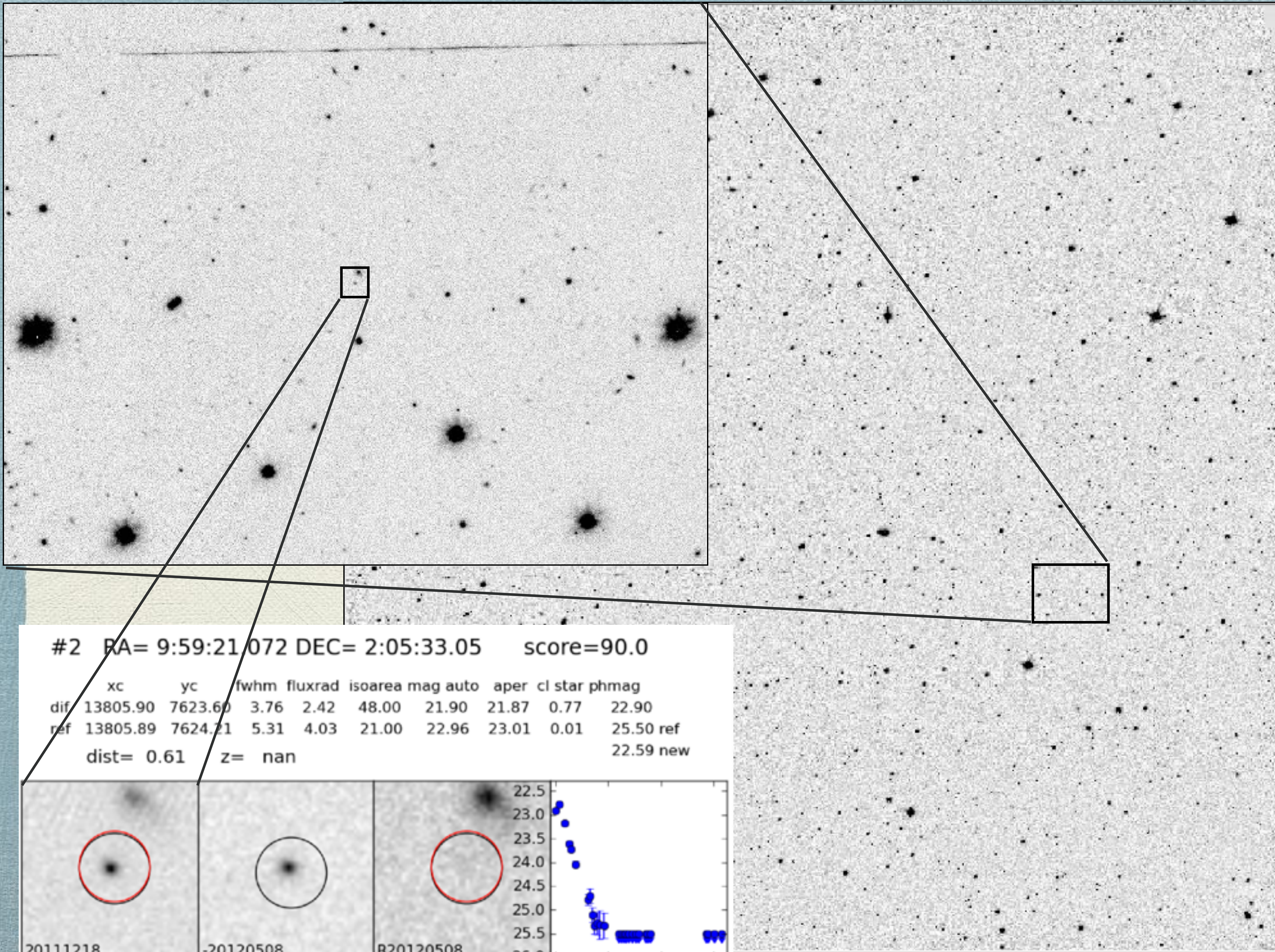
total exposure time ~150h

Start Oct 2011
End Jan 2015
Last Mar 2018

Processing steps

Data acquisition	Service observing
Data delivery	via ESO archive
Calibration	VSTtube (Capodimonte)
Search	Sudare pipeline (Padova)
Validation	visual inspection (web)
Follow-up	Photometry (built-in) spectroscopy
Classification	host galaxy redshift multi-band light curve fit comparison with template spectra

VST search image 14 Sept 2012
VLT classification 15 Sept 2012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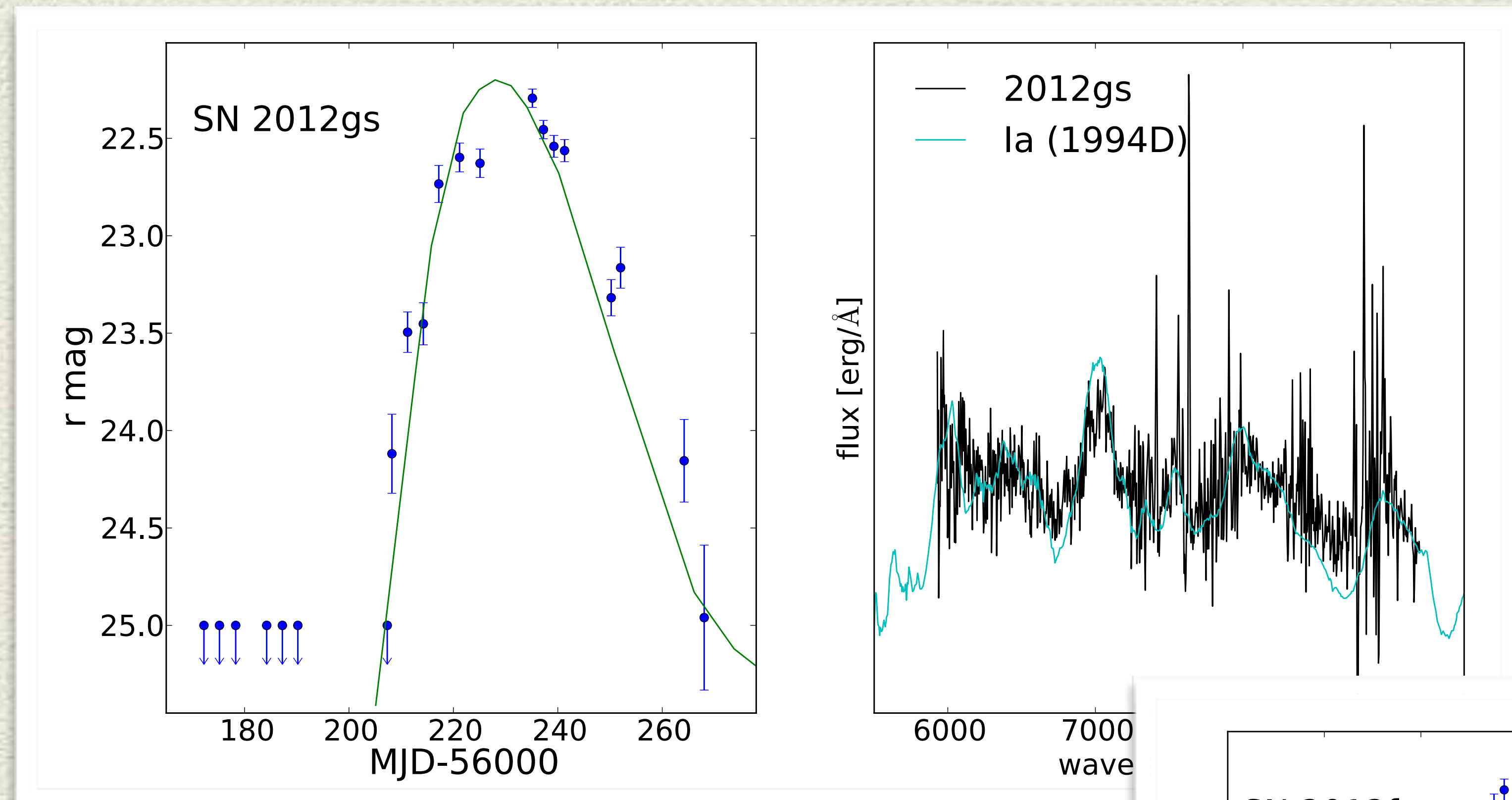
xc yc fwhm fluxrad isoarea mag auto aper cl star phmag
dif 13805.90 7623.60 3.76 2.42 48.00 21.90 21.87 0.77 22.90
ref 13805.89 7624.21 5.31 4.03 21.00 22.96 23.01 0.01 25.50 ref
22.59 new
dist= 0.61 z= nan
20111218
-20120508
R20120508
22.5
23.0
23.5
24.0
24.5
25.0
25.5
26.0

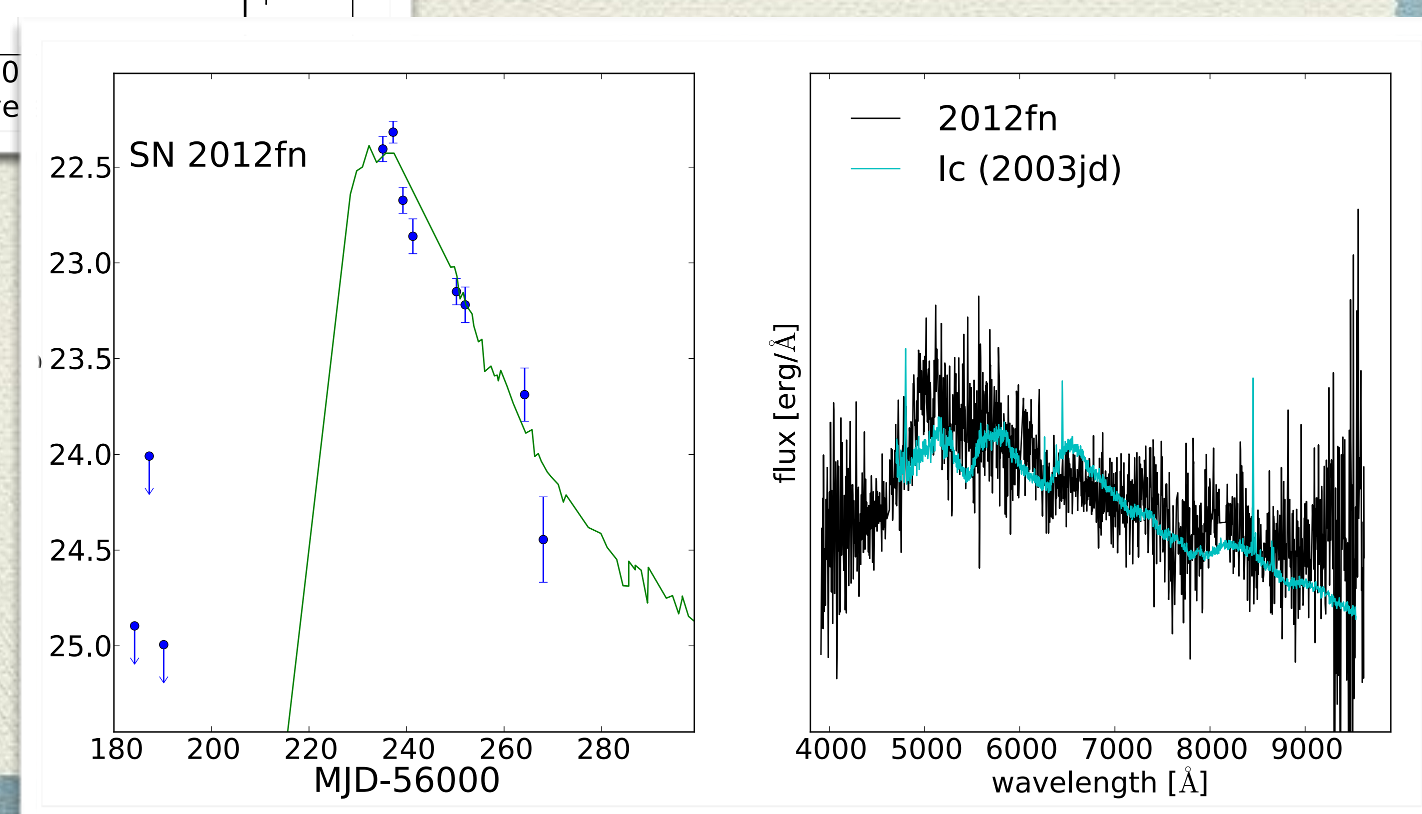
SN candidate classification

Ia z=0.525

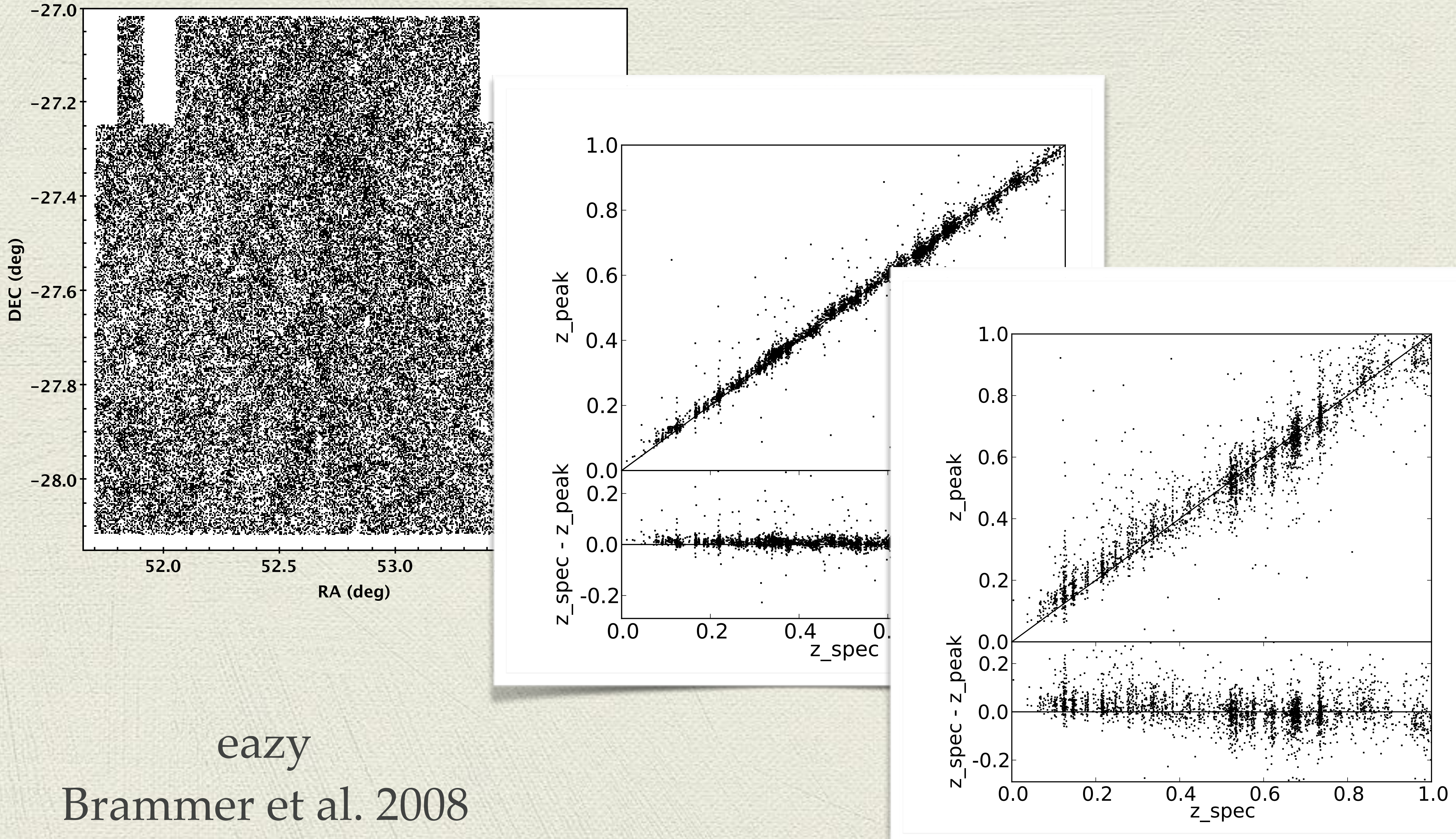


Botticella et al. 2013

Ic z=0.284



Galaxy photometric redshifts

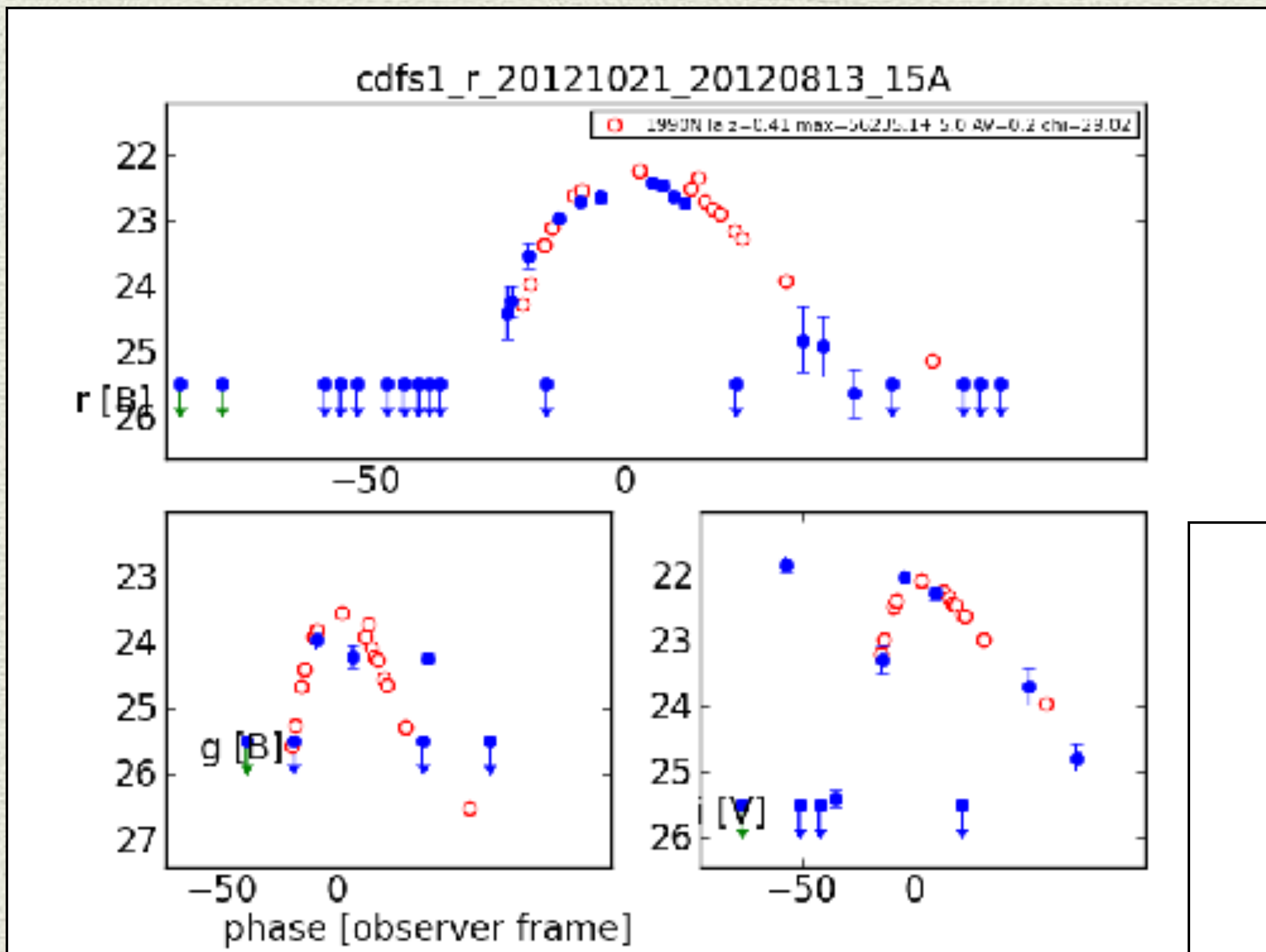


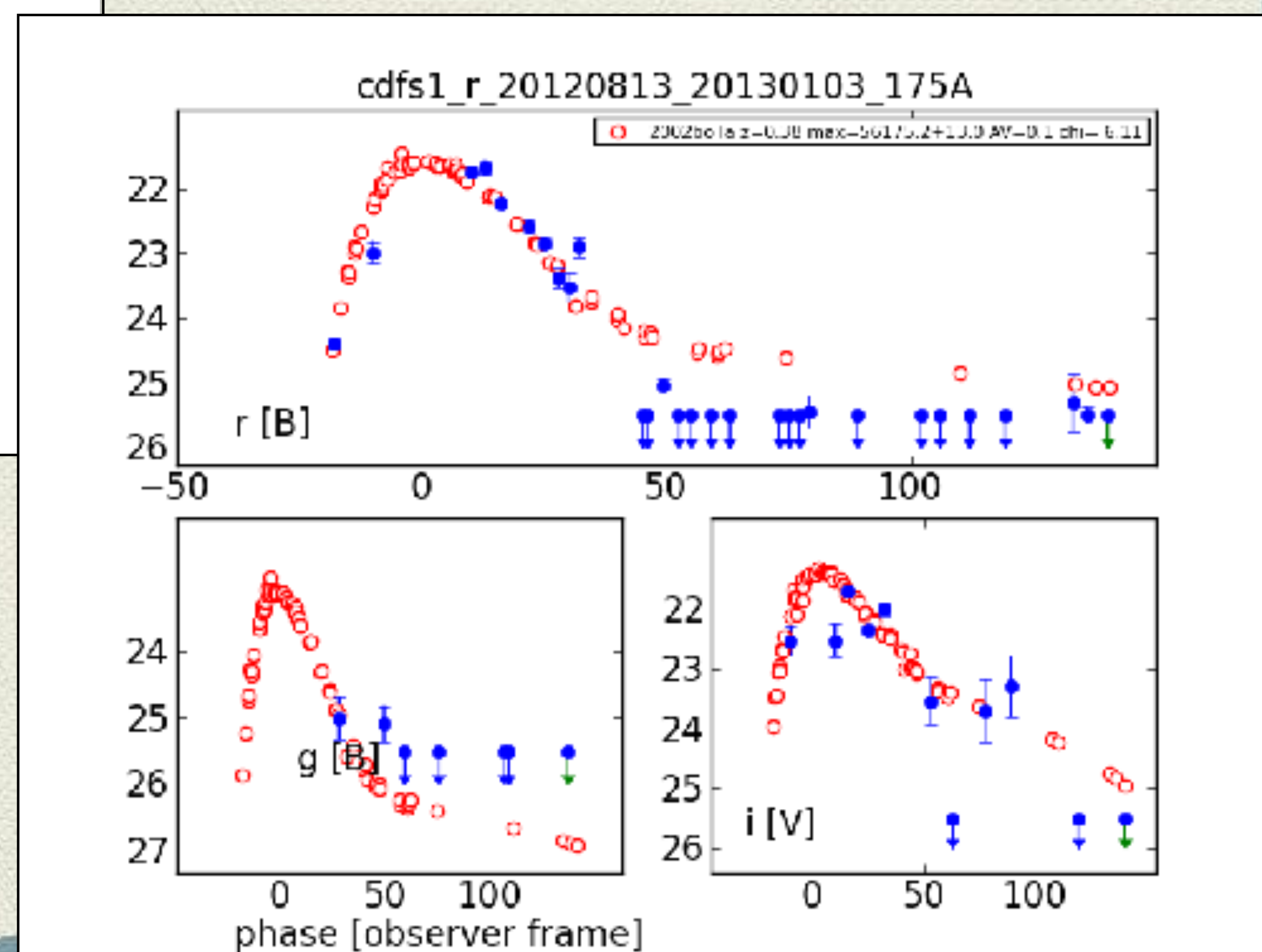
eazy

Brammer et al. 2008

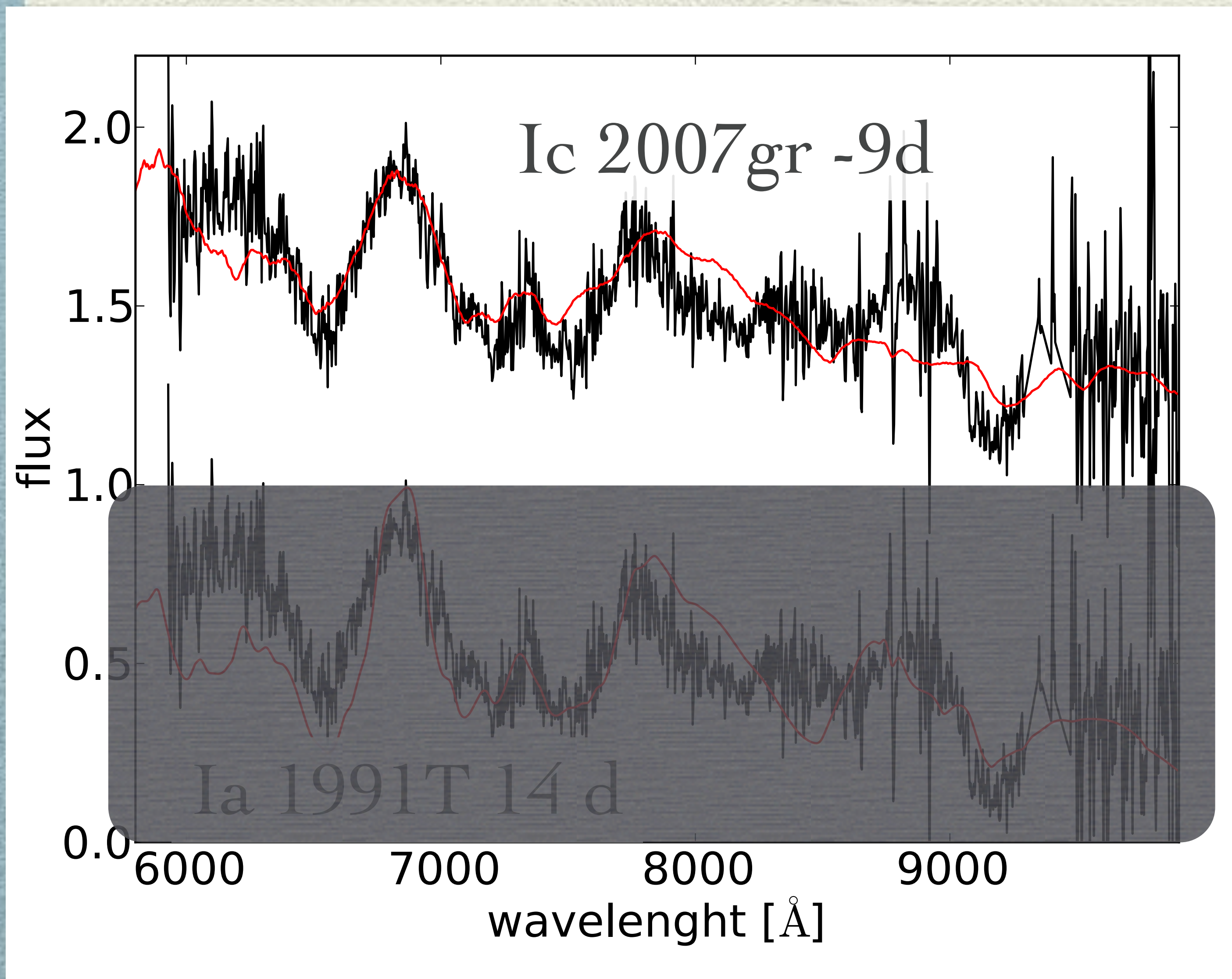
http://www.astro.yale.edu/eazy/

SUDARE: light curve fitting

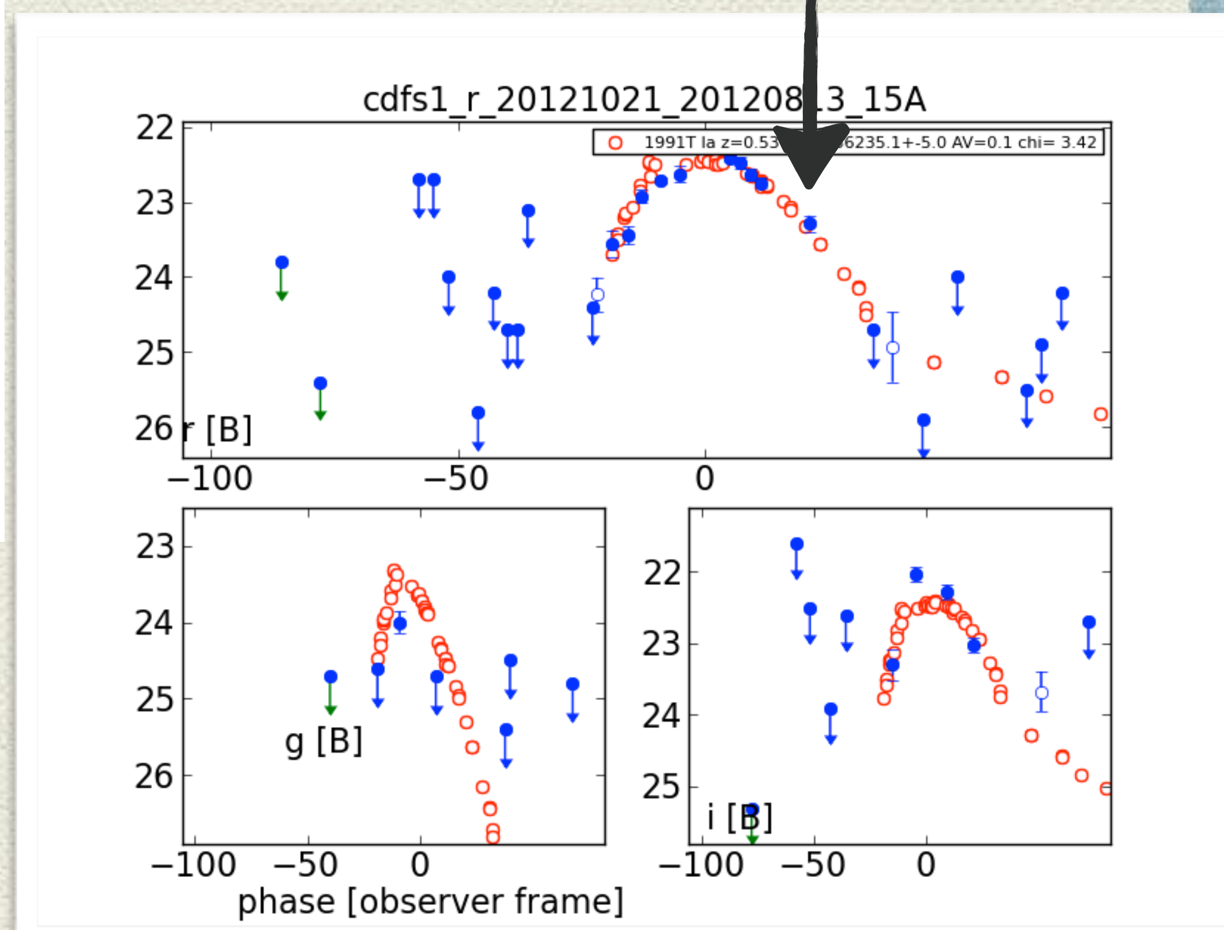




SN candidate classification

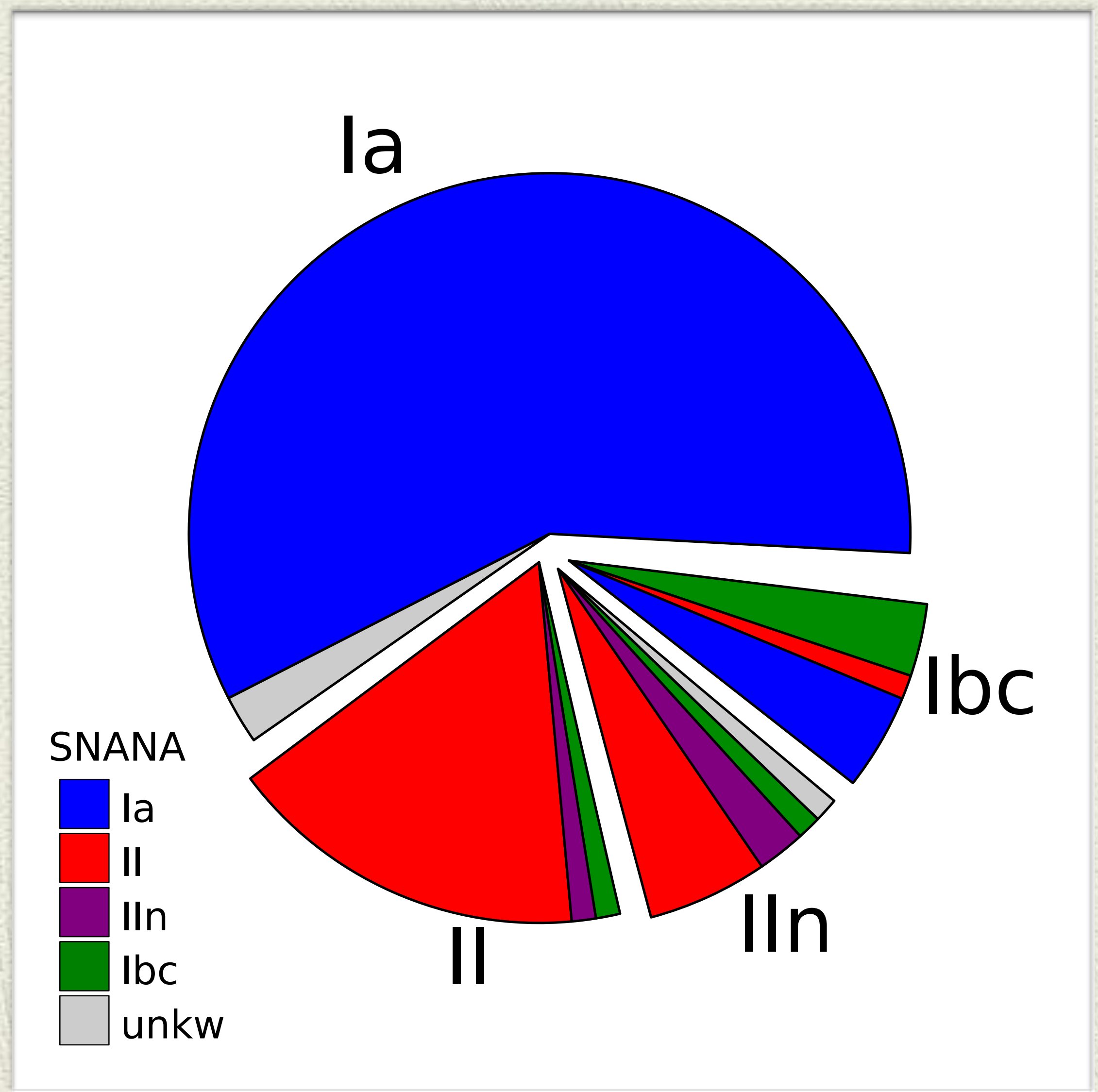


spectrum

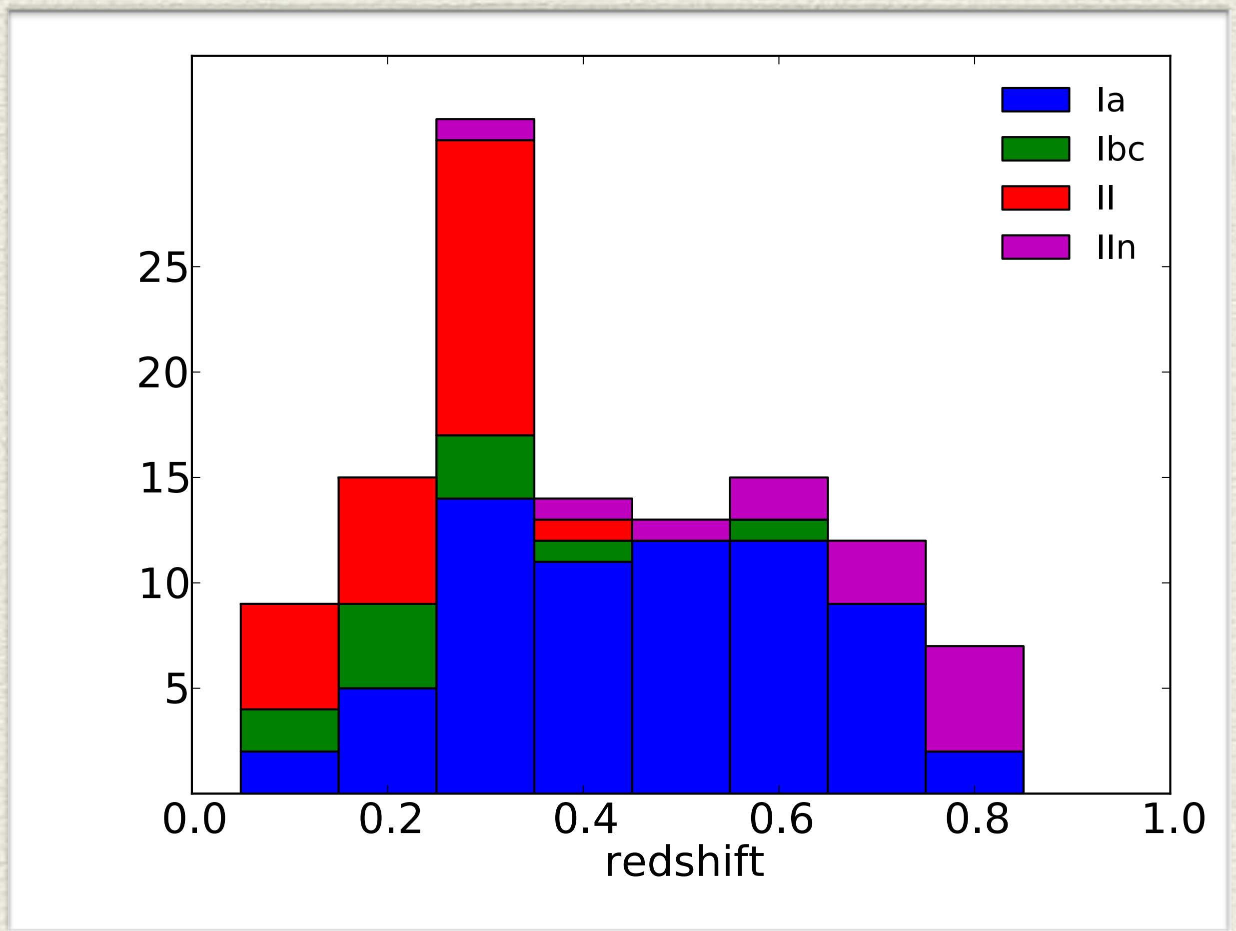


SUDARE SNe sample

SUDARE light curve fitting vs. SNANA (*Kessler 2009*)

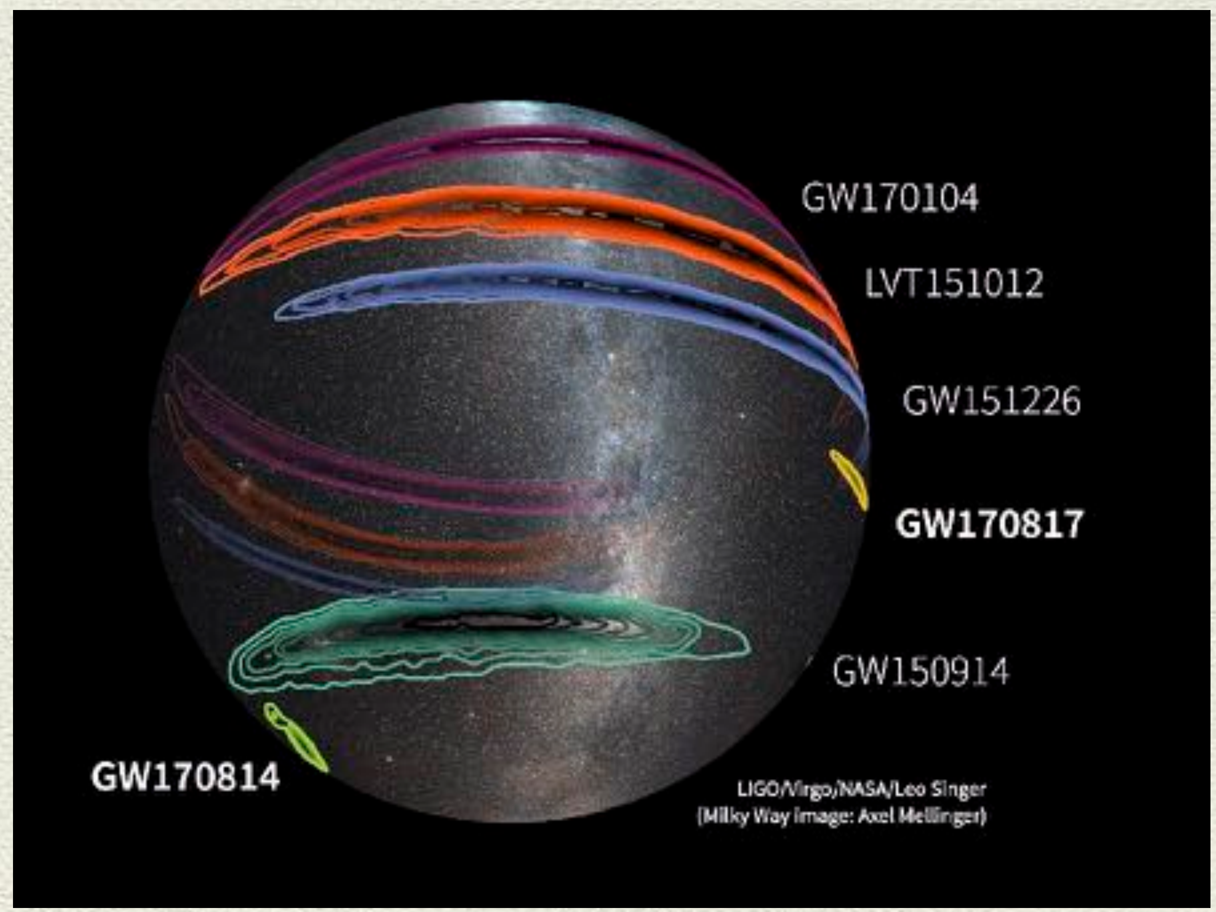


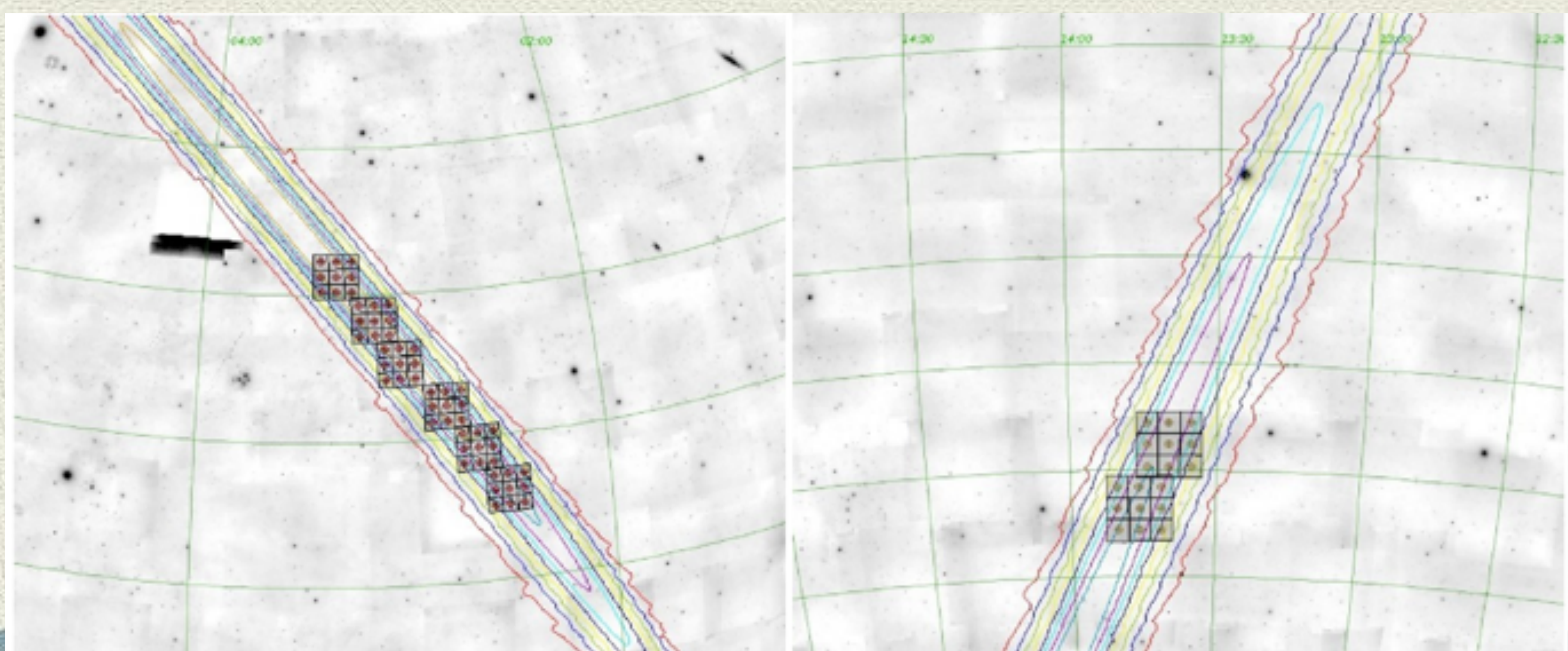
117 SNe

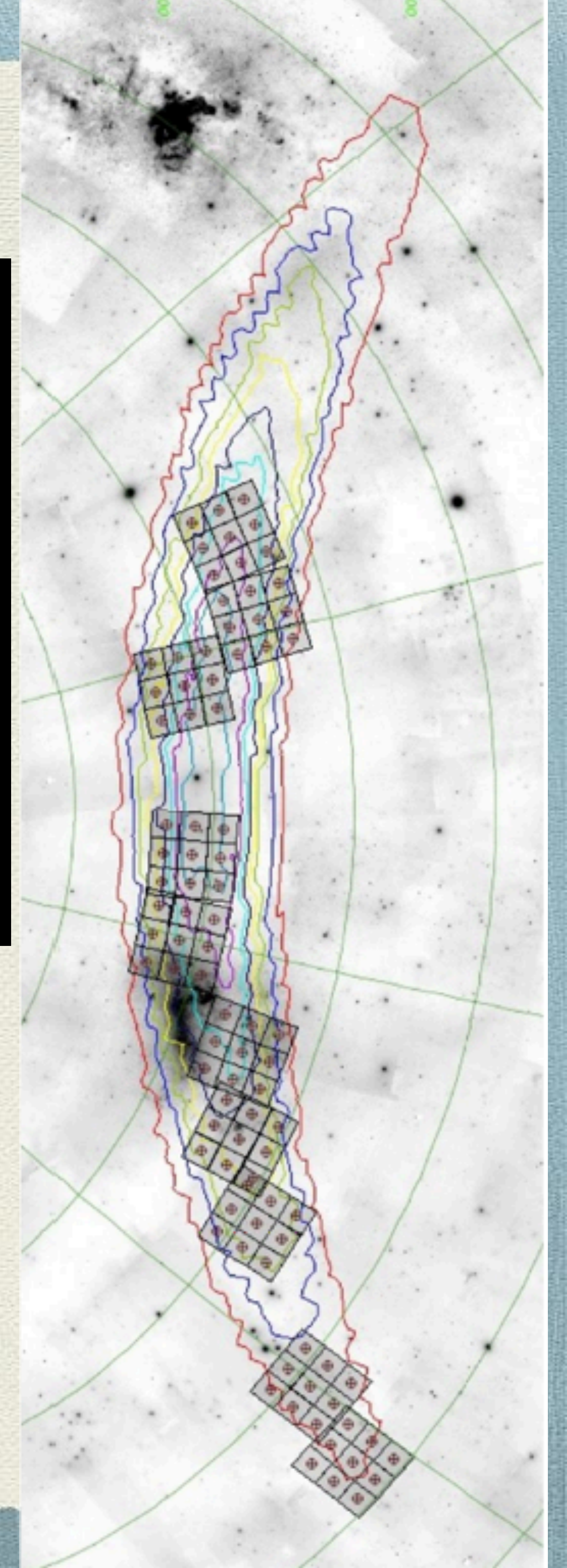


Legacy

GRAWITA: VLT Survey Telescope observations of the gravitational wave sources GW150914 and GW151226
Brocato et al. 2018

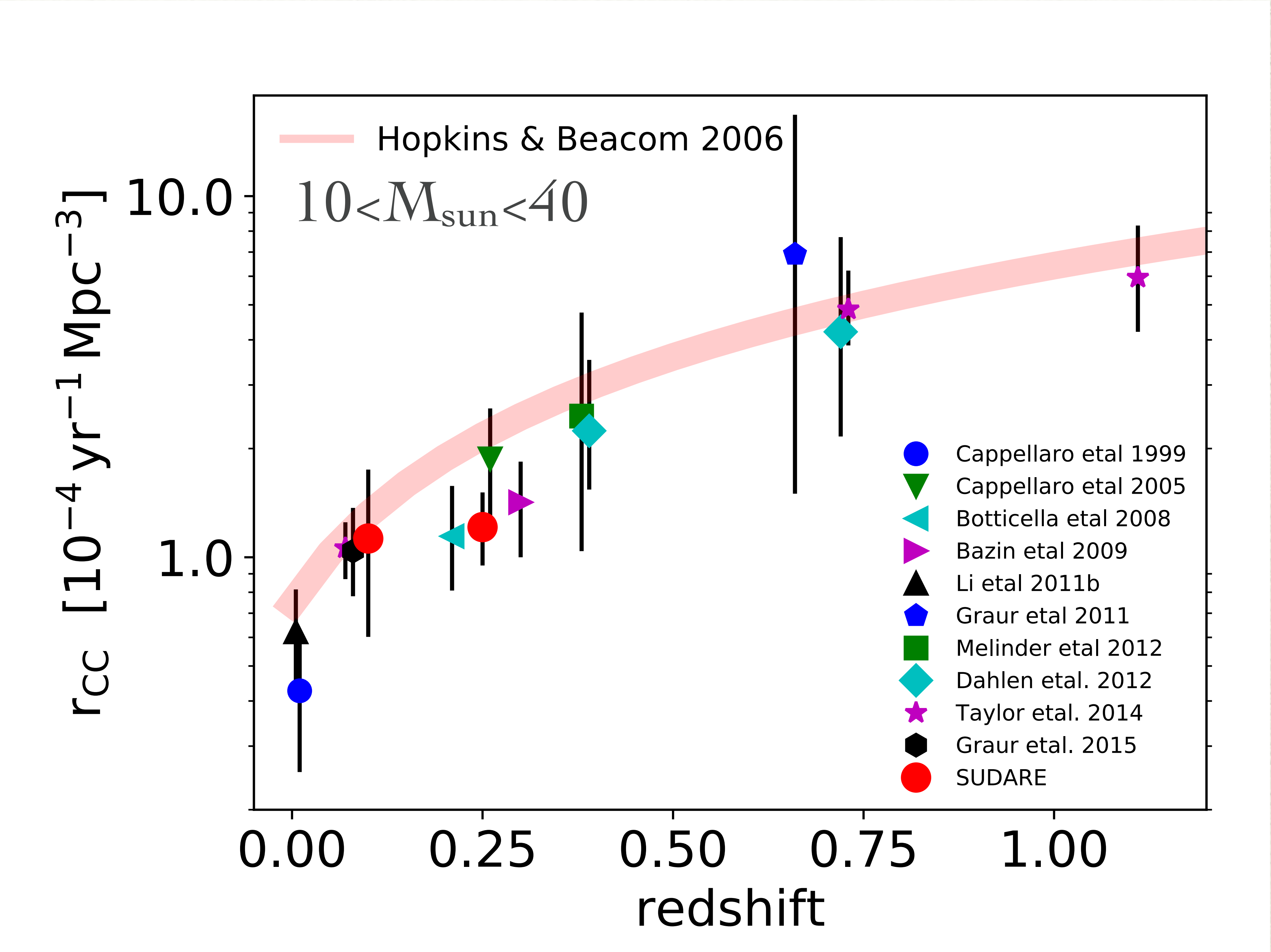




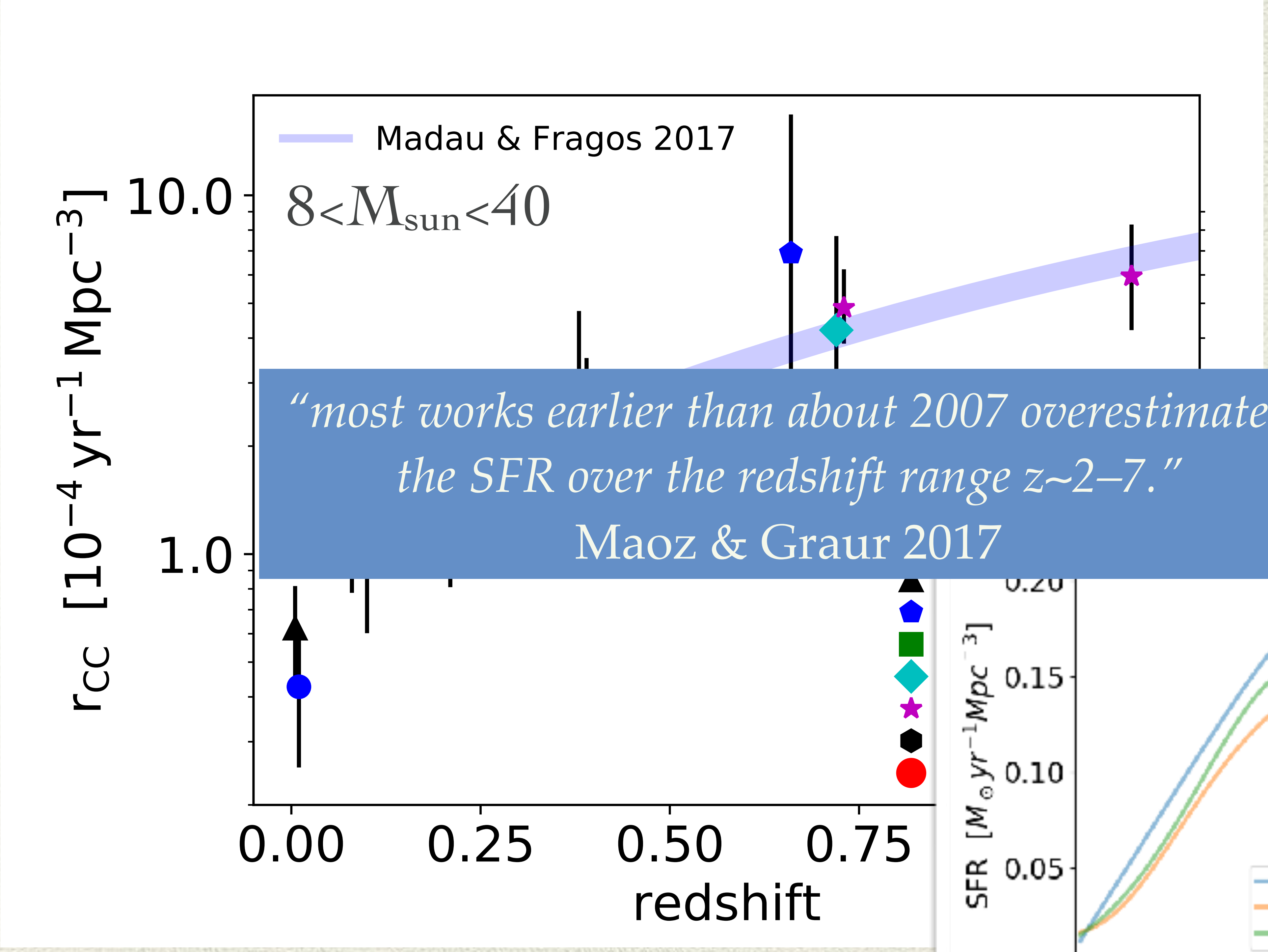


Summary of current results

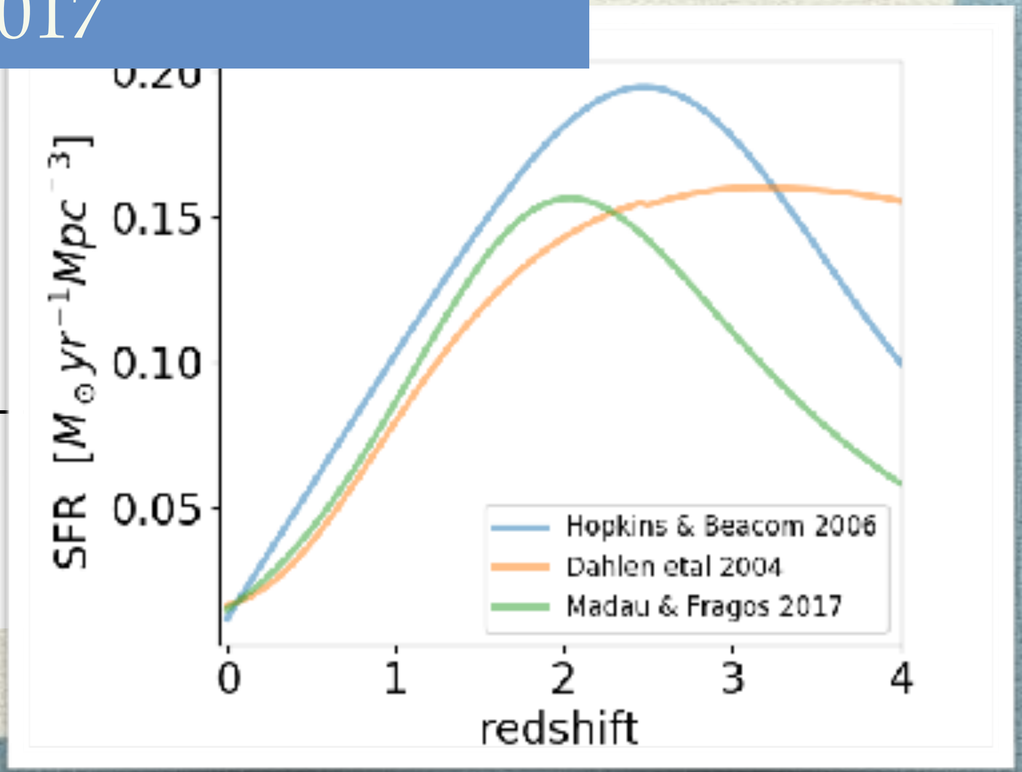
SN-CC rate evolution



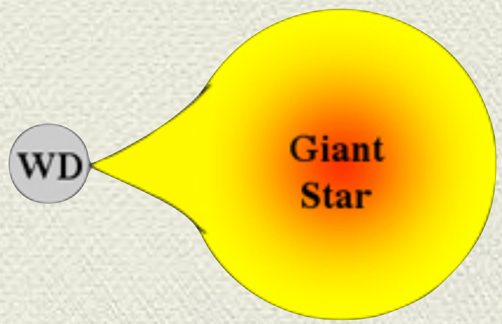
SN-CC rate evolution



"most works earlier than about 2007 overestimated the SFR over the redshift range z~2–7."
Maoz & Graur 2017



What to measure: SNIa



Single degenerate

Double degenerate

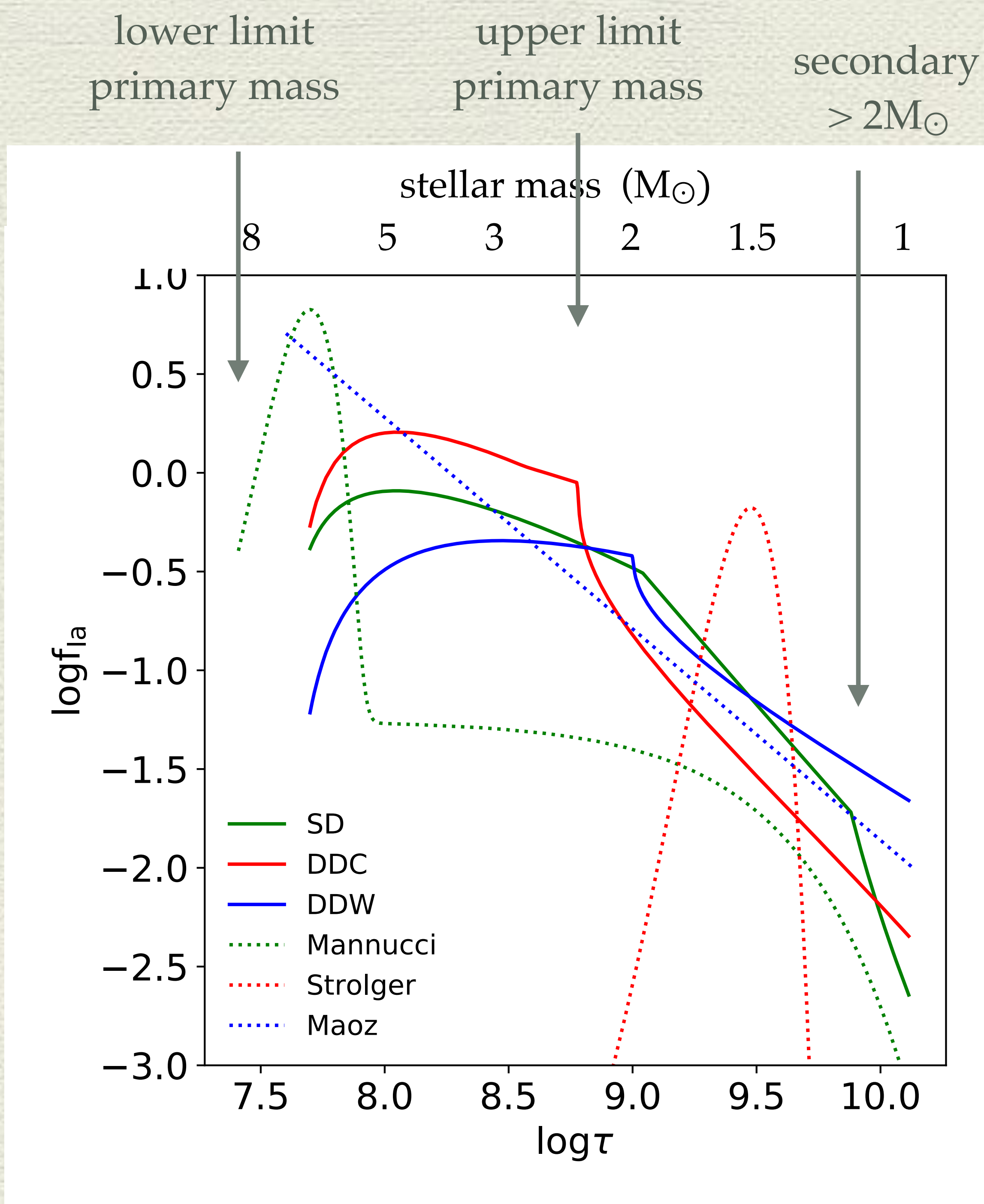
Binary separation

Close Wide

mass range 2 - 8 $M_\odot$

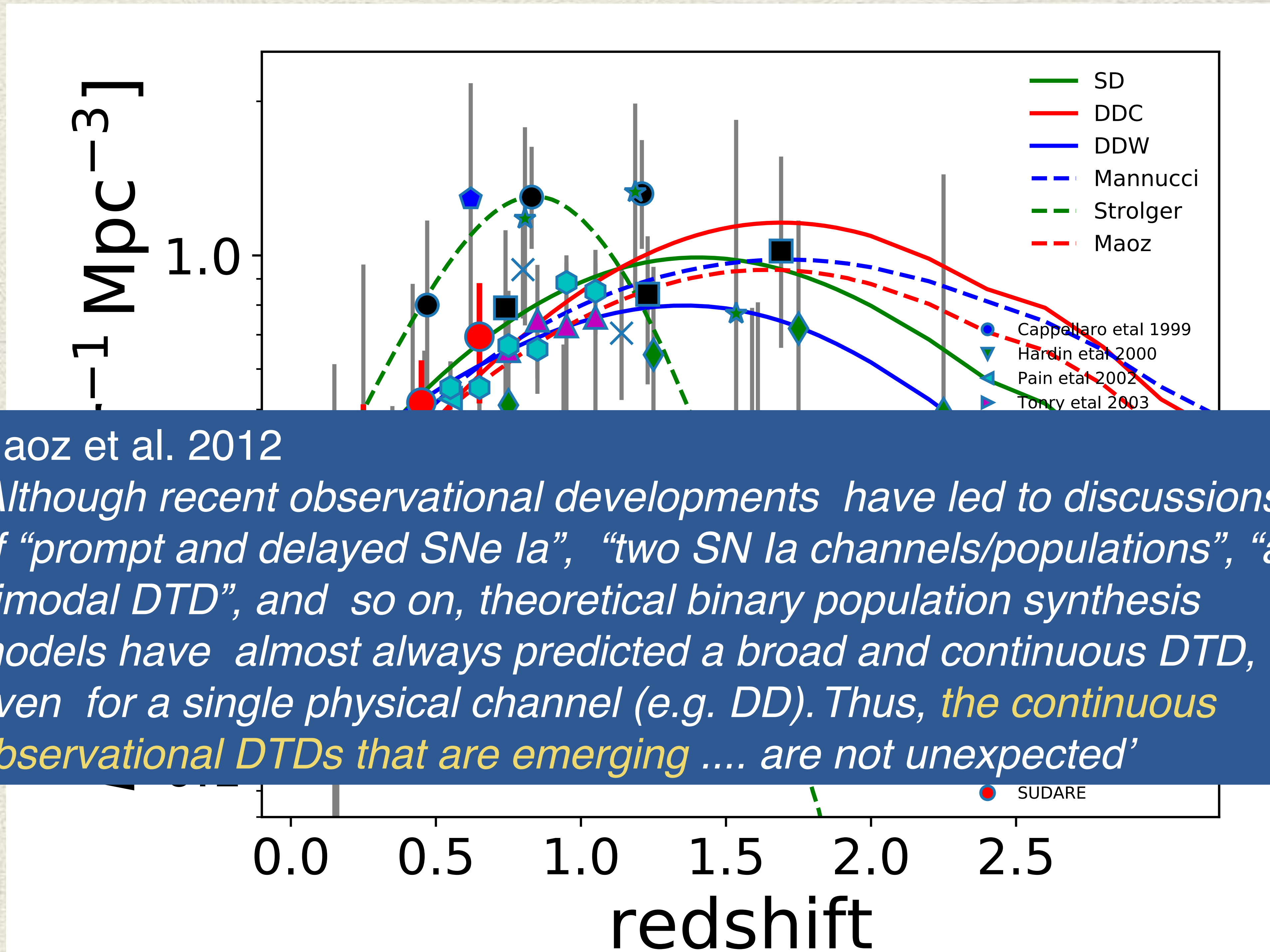
40 WDs x 1000 $M_\odot$

2 (5%) makes Ia



Greggio 2010

SN Ia rate evolution



Maoz et al. 2012

'Although recent observational developments have led to discussions of "prompt and delayed SNe Ia", "two SN Ia channels/populations", "a bimodal DTD", and so on, theoretical binary population synthesis models have almost always predicted a broad and continuous DTD, even for a single physical channel (e.g. DD). Thus, the continuous observational DTDs that are emerging .... are not unexpected'

SN rate-galaxy mass dependence

Mannucci et al. 2006

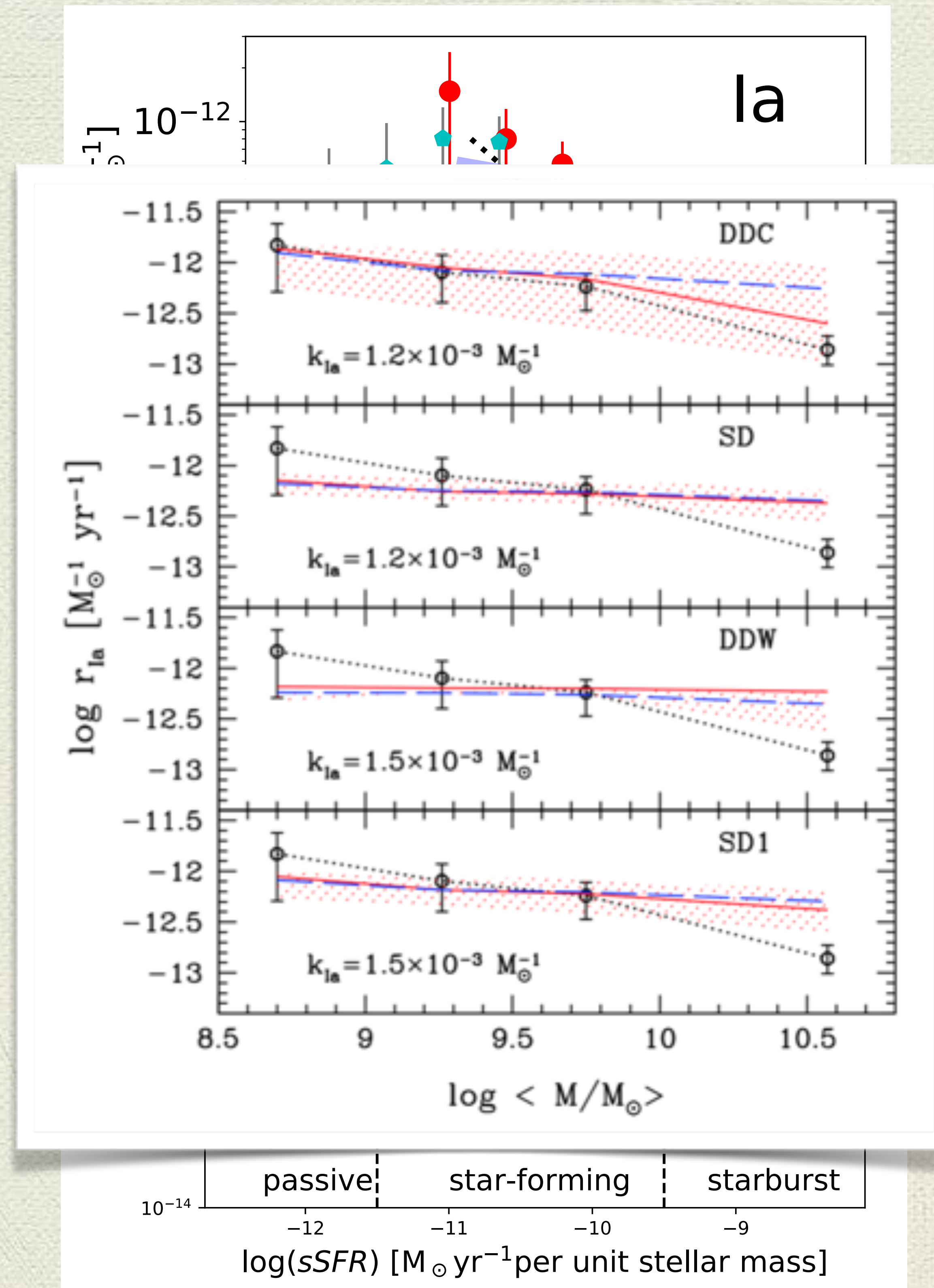
Sullivan et al. 2006

Li et al. 2011

Smith et al. 2012

Graur et al. 2015 using power law DTD and SFH for SDSS galaxy with spectra

Botticella et al. 2017



Graur et al. 2015

'correlations between SN Ia and SN II rates per unit mass and galaxy stellar mass, SFR, and sSFR can be explained by a combination of the respective SN DTD …the ages of the surveyed galaxies, the redshifts at which they are observed, and their star formation histories.'

What next ?

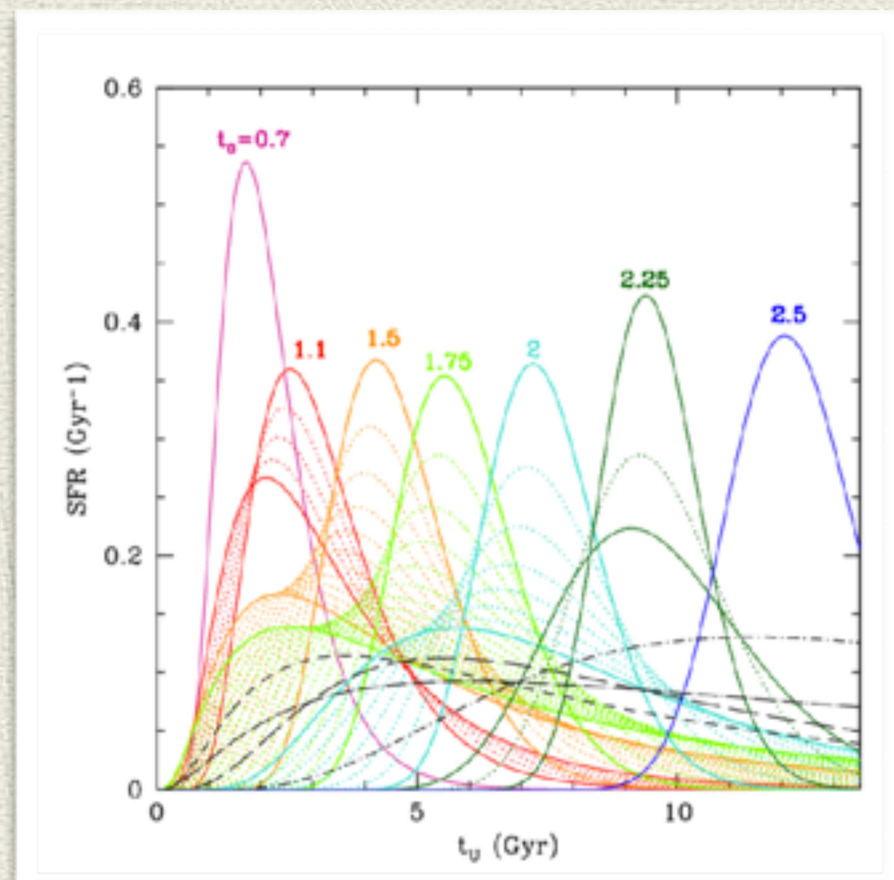
- Complete analysis of SUDARE data: CDFS3/4 + COSMOS new epoch *(Botticella, Ragosta)*
- Explore parameter space for modelling (*Greggio*)
- Get prepared for LSST (*Botticella, Greggio*)

Testing SFH approximation and DTD

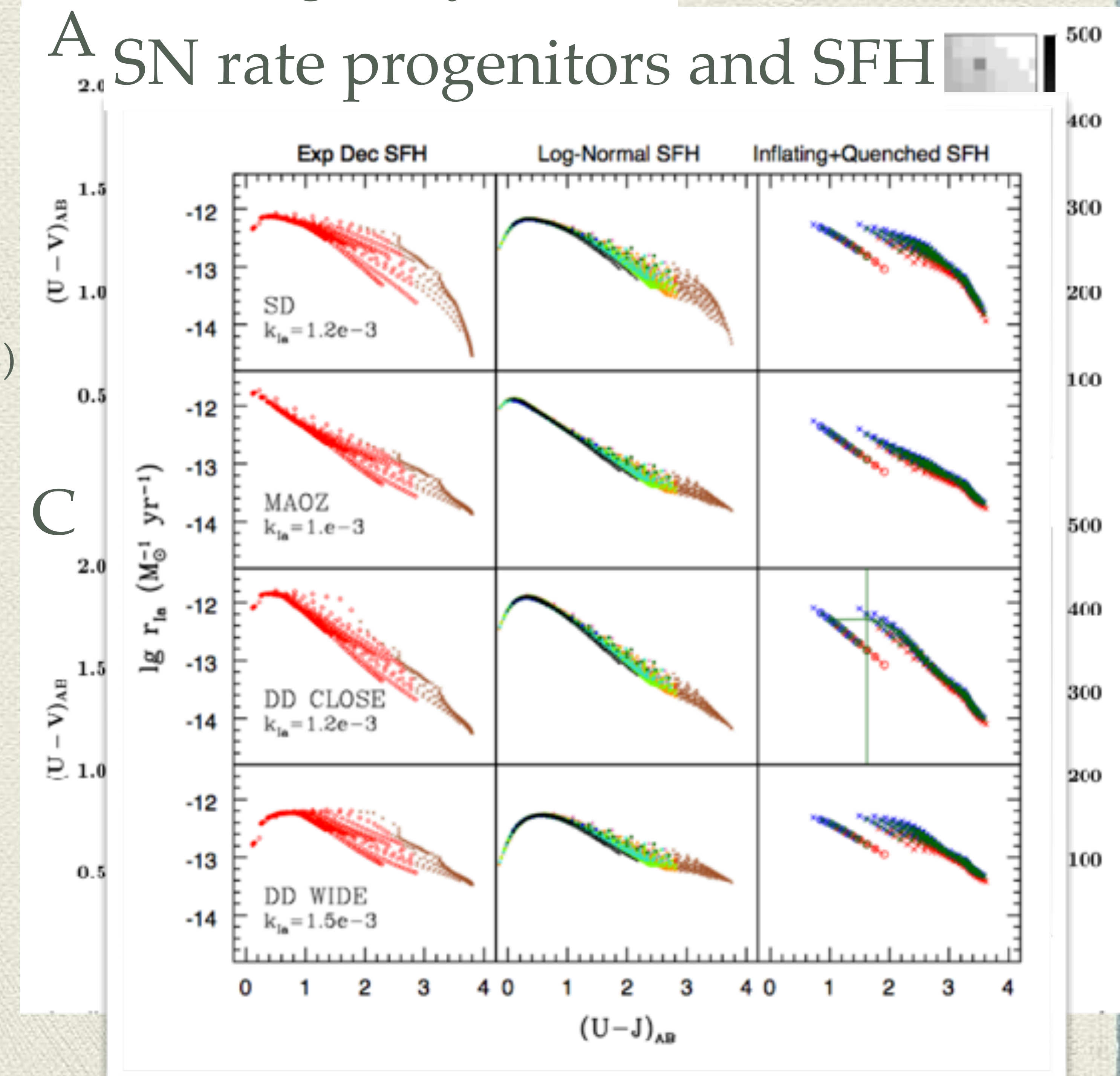
Greggio et al.
in preparation

SFH

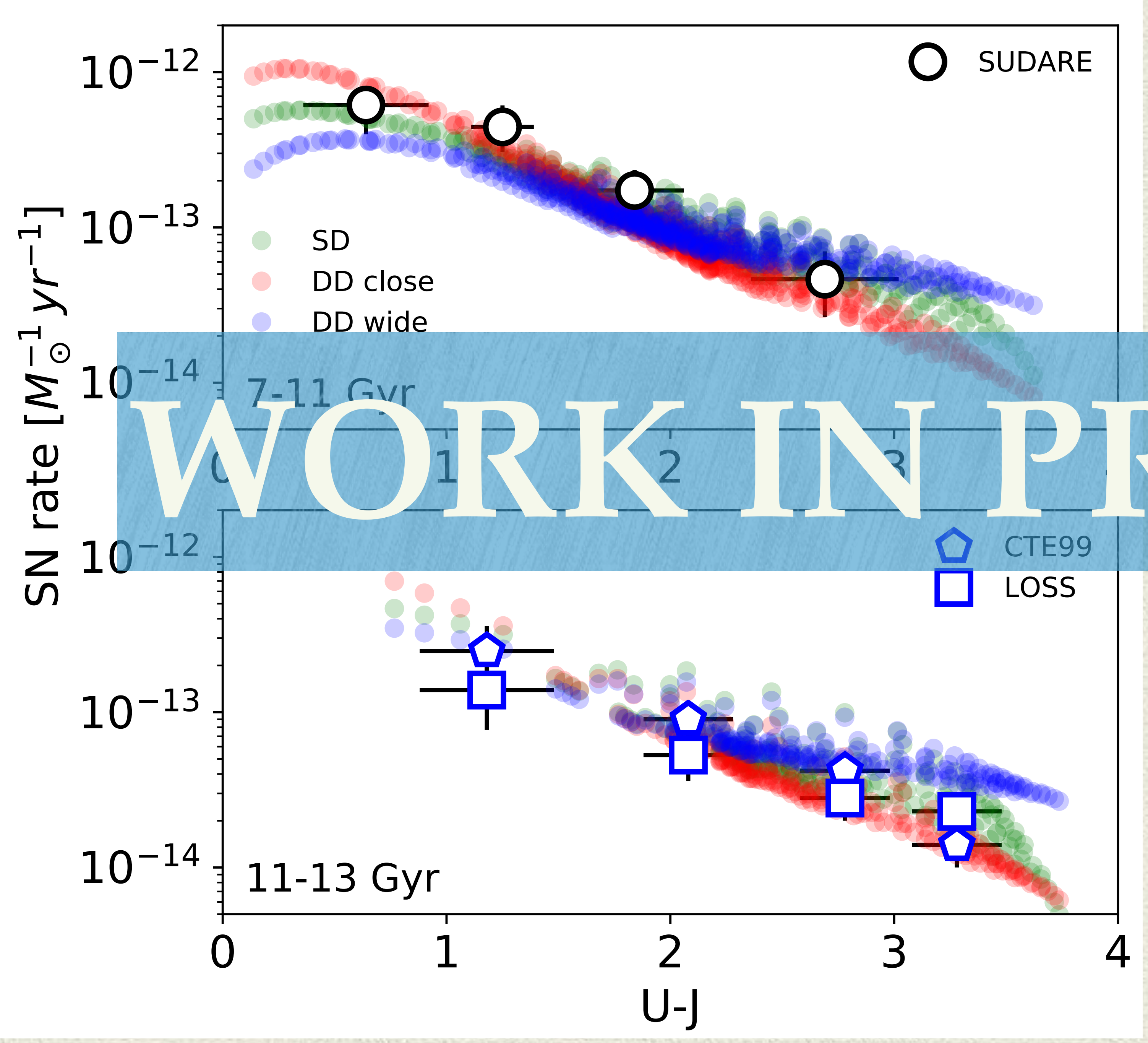
A. exponentially decreasing
B. delayed exponential
C. **log-normal** (Abramson et al 2015)
D. inflating / quenching (Peng et al. 2013)



SFH and galaxy colors



Testing SFH approximation and DTD



Current data cannot discriminate SD/DD.

DD wide are disfavoured

WORK IN PROGRESS

Multi-wavelength constraints of galaxy SFH is crucial

Better statistics is needed to probe very young and very old parent populations