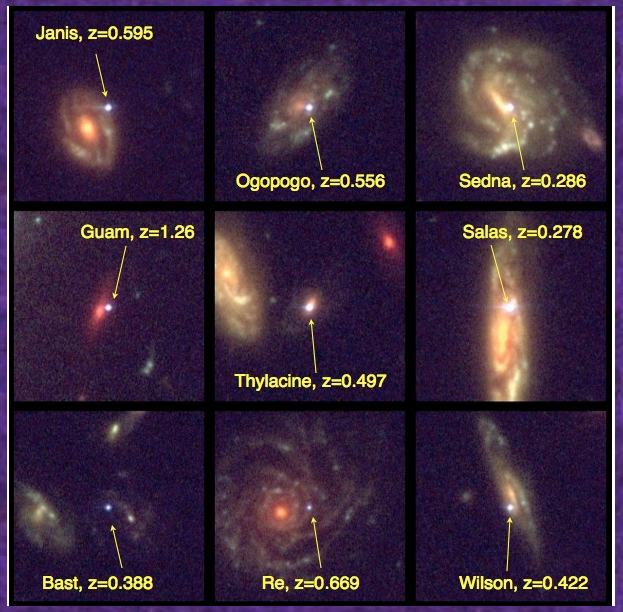
Supernovae in the Universe

(how many are there out there – what is the rate?)

Tomas Dahlen (STScI)

Thanks to my collaborators:
Lou Strolger (Western Kentucky)
Adam Riess (Johns Hopkins)
Steve Rodney (Johns Hopkins)
Jens Melinder (Stockholm)
Seppo Mattila (Turku)
Erkki Kankare (Turku)
Bahram Mobasher(UCR)
The GOODS Team
The CANDELS Team
The SVISS Team



HST detected CC SNe at 0.4<z<1.2.
Lou Strolger

Ia

Redshift	$N_{\rm Ia}$	Rate [10^{-4} yr^{-1} Mpc^{-3}]	Reference
$< 0.0066^a$	37	$0.36^{+0.07}_{-0.06}$	Smartt et al. (2009)
0.01	70	0.183 ± 0.046	Cappellaro et al. (1999)^b
$< 0.019^a$	274	$0.265^{+0.034+0.043}_{-0.033-0.043}$	Li et al. (2010a)
0.0375	516^c	$0.278^{+0.112+0.015}_{-0.083-0.000}$	Dilday et al. (2010a)
0.09	17	$0.29^{+0.09}_{-0.07}$	Dilday et al. (2008)
0.098	19	$0.24^{+0.12}_{-0.12}$	Madgwick et al. (2003)^b
0.1	516^c	$0.259^{+0.052+0.018}_{-0.044-0.001}$	Dilday et al. (2010a)
0.13	14	$0.158^{+0.056+0.035}_{-0.043-0.035}$	Blanc et al. (2004)^b
0.14	4	$0.28^{+0.22+0.07}_{-0.13-0.04}$	Hardin et al. (2000)^b
0.15	516^c	$0.307^{+0.038+0.035}_{-0.034-0.095}$	Dilday et al. (2010a)
0.15	1.95	$0.32^{+0.23+0.07}_{-0.23-0.06}$	Rodney & Tonry (2010)
0.2	17	$0.189^{+0.042+0.018}_{-0.034-0.015} \pm 0.42$	Horesh et al. (2008)
0.2	516^c	$0.348^{+0.032+0.082}_{-0.030-0.007}$	Dilday et al. (2010a)
0.25	1	0.17 ± 0.17	Barris & Tonry (2006)
0.25	516^c	$0.365^{+0.031+0.182}_{-0.028-0.012}$	Dilday et al. (2010a)
0.3	31.05^d	$0.34^{+0.16+0.21}_{-0.15-0.22}$	Botticella et al. (2008)
0.3	516^c	$0.434^{+0.037+0.396}_{-0.034-0.016}$	Dilday et al. (2010a)
0.35	5	0.530 ± 0.024	Barris & Tonry (2006)
0.35	4.01	$0.34^{+0.19+0.07}_{-0.19-0.03}$	Rodney & Tonry (2010)
0.368	17	$0.31^{+0.05+0.08}_{-0.05-0.03}$	Neill et al. (2007)
0.40	5.44	$0.53^{+0.39}_{-0.17}$	Kuznetsova et al. (2008)
0.45	9	0.73 ± 0.24	Barris & Tonry (2006)
0.45	5.11	$0.31^{+0.15+0.12}_{-0.15-0.04}$	Rodney & Tonry (2010)
0.46	8	0.48 ± 0.17	Tonry et al. (2003)
0.467	73	$0.42^{+0.06+0.13}_{-0.06-0.09}$	Neill et al. (2006)
0.47	8	$0.80^{+0.37+1.66}_{-0.27-0.26}$	Dahlen et al. (2008)
0.55	38	$0.568^{+0.098+0.098}_{-0.088-0.088}$	Pain et al. (2002)^a
0.55	29	2.04 ± 0.38	Barris & Tonry (2006)
0.55	6.49	$0.32^{+0.14+0.07}_{-0.14-0.07}$	Rodney & Tonry (2010)
0.552	41	$0.63^{+0.10+0.26}_{-0.10-0.27}$	Neill et al. (2007)
0.65	23	1.49 ± 0.31	Barris & Tonry (2006)
0.65	10.09	$0.49^{+0.17+0.14}_{-0.17-0.08}$	Rodney & Tonry (2010)
0.714	42	$1.13^{+0.19+0.54}_{-0.19-0.70}$	Neill et al. (2007)
0.74	5.5	$0.43^{+0.36}_{-0.32}$	Poznanski et al. (2007b)
0.74	**23.5**	$\mathbf{0.77^{+0.22}_{-0.27}}$	**SDF (this work)**
0.75	28	1.78 ± 0.34	Barris & Tonry (2006)
0.75	14.29	$0.68^{+0.21+0.23}_{-0.21-0.14}$	Rodney & Tonry (2010)
0.80	18.33	$0.93^{+0.25}_{-0.25}$	Kuznetsova et al. (2008)
0.83	25	$1.30^{+0.33+0.73}_{-0.27-0.51}$	Dahlen et al. (2008)
0.85	15.43	$0.78^{+0.22+0.31}_{-0.22-0.16}$	Rodney & Tonry (2010)
0.95	13.21	$0.76^{+0.25+0.32}_{-0.25-0.26}$	Rodney & Tonry (2010)
1.05	11.01	$0.79^{0.28+0.36}_{-0.28-0.41}$	Rodney & Tonry (2010)
1.20	8.87	$0.75^{+0.35}_{-0.30}$	Kuznetsova et al. (2008)
1.21	20	$1.32^{+0.36+0.38}_{-0.29-0.32}$	Dahlen et al. (2008)
1.23	10.0	$1.05^{+0.45}_{-0.56}$	Poznanski et al. (2007b)
1.23	**26.0**	$\mathbf{0.67^{+0.16}_{-0.16}}$	**SDF (this work)**
1.55	0.35	$0.12^{+0.58}_{-0.12}$	Kuznetsova et al. (2008)
1.61	3	$0.42^{+0.39+0.19}_{-0.23-0.14}$	Dahlen et al. (2008)
1.67	3.0	$0.81^{+0.79}_{-0.60}$	Poznanski et al. (2007b)
1.69	**10.0**	$\mathbf{0.64^{+0.27}_{-0.25}}$	**SDF (this work)**

Note – Redshifts are means over the redshift intervals probed by each survey. $N_{\rm Ia}$ is the number of SNe Ia used to derive the rate. Where necessary, rates have been converted to $h = 0.7$.
^{a}Smartt et al. (2009) and Li et al. (2010a) consider SNe Ia within 28 and 80 Mpc, respectively.
^{b}Rates have been converted to volumetric rates using Equation 6.
^{c}Dilday et al. (2010a) compute their rates using 516 SNe Ia in the redshift range $z < 0.5$.
^{d}Botticella et al. (2008) found a total of 86 SN candidates of all types. See their section 5.2 for details on their various subsamples and classification techniques.

CC

Redshift	$N_{\rm CC}$	Rate [10^{-4} yr^{-1} Mpc^{-3}]	Reference
$< 0.0066^a$	92	$0.89^{+0.07+0.11}_{-0.07-0.09}$	Smartt et al. (2009)
0.01	67	0.43 ± 0.17	Cappellaro et al. (1999)^b
$< 0.014^a$	440	$0.62^{+0.07+0.17}_{-0.07-0.15}$	Li et al. (2010a)
0.21	44.95^c	$1.15^{+0.43+0.42}_{-0.33-0.36}$	Botticella et al. (2008)
0.26	31.2	$1.88^{+0.71}_{-0.58}$	Cappellaro et al. (2005)^b
0.3	17	$2.51^{+0.88+0.75}_{-0.75-1.86}$	Dahlen et al. (2004)
0.3	117	$1.63^{+0.34+0.37}_{-0.34-0.28}$	Bazin et al. (2009)
0.66	**5.5**	$\mathbf{3.3^{+4.0}_{-2.7}}$	**SDF (this work)**
0.7	17	$3.96^{+1.03+1.92}_{-1.06-2.60}$	Dahlen et al. (2004)

^{a}Smartt et al. (2009) and Li et al. (2010a) consider CC SNe within 28 and 60 Mpc, respectively.
Note – ^{b,c}Same as in Table 4.

Compilation of rates from Graur et al. (2011, arXiv1102.0005)

Why study CC rates?

- Direct link to star formation

The cosmic SNe can also give clues about

- Metal enrichment of ISM/galactic chemical evolution
- Triggering of star formation
- Feed-back, affecting galaxy formation/evolution
- Dust production in the universe

Redshift	N_{CC}	Rate [10^{-4} yr^{-1} Mpc^{-3}]	Reference
$< 0.0066^a$	92	$0.89^{+0.07+0.11}_{-0.07-0.09}$	Smartt et al. (2009)
0.01	67	0.43 ± 0.17	Cappellaro et al. (1999)^b
$< 0.014^a$	440	$0.62^{+0.07+0.17}_{-0.07-0.15}$	Li et al. (2010a)
0.21	44.95^c	$1.15^{+0.43+0.42}_{-0.33-0.36}$	Botticella et al. (2008)
0.26	31.2	$1.88^{+0.71}_{-0.58}$	Cappellaro et al. (2005)^b
0.3	17	$2.51^{+0.88+0.75}_{-0.75-1.86}$	Dahlen et al. (2004)
0.3	117	$1.63^{+0.34+0.37}_{-0.34-0.28}$	Bazin et al. (2009)
0.66	**5.5**	$\mathbf{3.3^{+4.0}_{-2.7}}$	**SDF (this work)**
0.7	17	$3.96^{+1.03+1.92}_{-1.06-2.60}$	Dahlen et al. (2004)

CC

^{a}Smartt et al. (2009) and Li et al. (2010a) consider CC SNe within 28 and 60 Mpc, respectively.
Note – ^{b,c}Same as in Table 4.

In today's talk I'll:

- Present CC rates measured to date
- Discuss how rates are derived: difficulties/systematics
- Discuss the supernova rate – star formation rate connection
- (Mention future surveys)

A few notes:

SNR = ~~Signal-to-Noise Ratio~~

SNR = ~~Supernova Remnant~~

SNR = Supernova Rate

A few notes:

SNR = ~~Signal-to-Noise Ratio~~

SNR = ~~Supernova Remnant~~

SNR = Supernova Rate

Rates, what rates?

Volumetric rates – SNR_{VOL}

SNR_{VOL} = number of SNe per year per Mpc^3

Normalized rates – SNuX

SNuX = number of SNe normalized to quantity X

X=B-luminosity, K-luminosity, or Mass

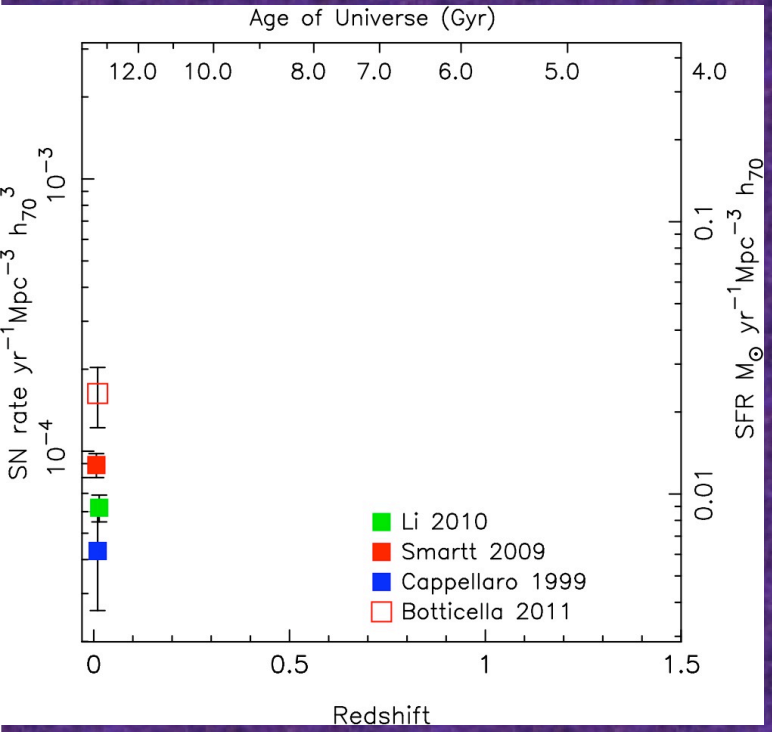
e.g.,: 1 SNuB = 1 SN per 100 year per $10^{10} L_{BSUN}$

In this presentation, normalized rates are converted to volumetric rates

SNR_{VOL} = SNuB * $j_{B,}$ where j_B is the B-band luminosity density

---

Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011

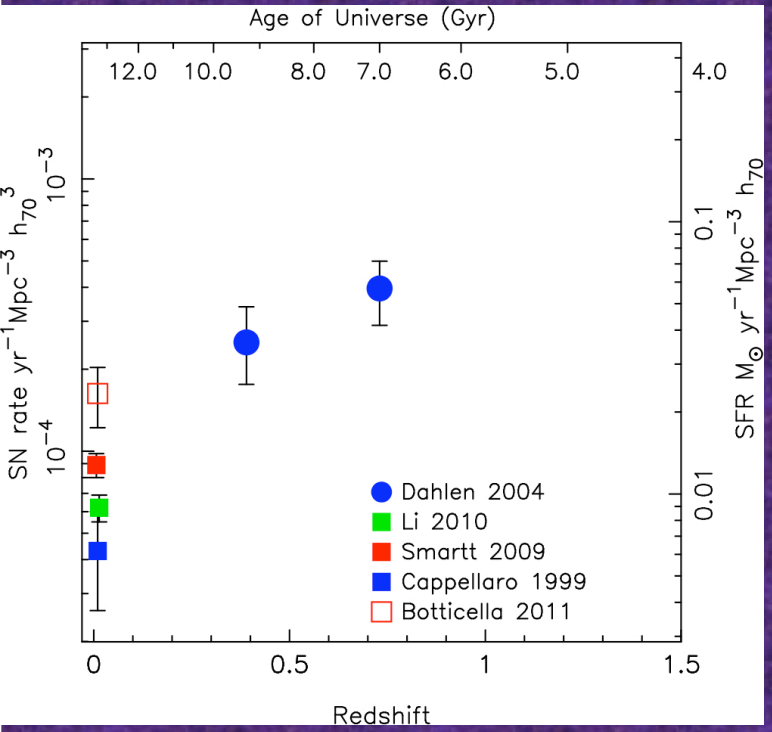
Cappellaro et al. 1999, A&A, 351, 459
Based on photographic plates and visual search
Volumetric rate from rate in SNuB

Smartt et al. 2009, MNRAS, 395, 1409
Sample consists of all detected CC 1998-2008 within 28 Mpc (from IAU Circulars)

Li et al. 2011, MNRAS, 412, 1473
Lick Observatory Supernova Search (LOSS) 1998-2008
Volumetric rate from rate in SNuK

Botticella et al. 2011, unpublished.
All detected CC within 11 Mpc during 13 years

Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004

Dahlen et al. 2004, ApJ, 613, 189
HST/ACS GOODS "unbiased" SN search 2002-03

THE ASTROPHYSICAL JOURNAL, 613:189–199, 2004 September 20
© 2004. The American Astronomical Society. All rights reserved. Printed in U.S.A.

HIGH-REDSHIFT SUPERNOVA RATES

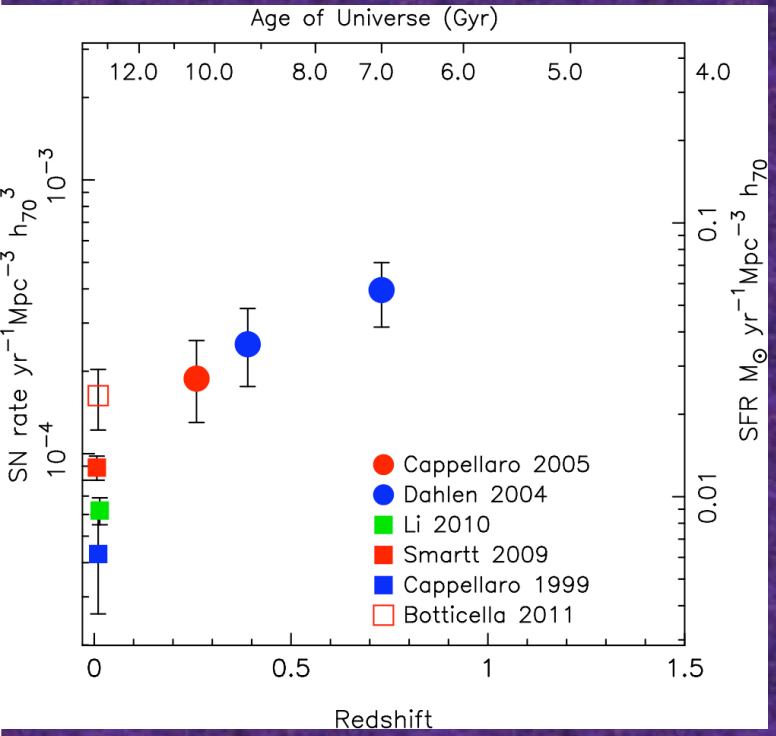
TOMAS DAHLEN,[1] LOUIS-GREGORY STROLGER,[1] ADAM G. RIESS,[1] BAHRAM MOBASHER,[1,2] RANGA-RAM CHARY,[3] CHRISTOPHER J. CONSELICE,[4] HENRY C. FERGUSON,[1] ANDREW S. FRUCHTER,[1] MAURO GIAVALISCO,[1] MARIO LIVIO,[1] PIERO MADAU,[5] NINO PANAGIA,[1,2] AND JOHN L. TONRY[6]

Received 2004 January 30; accepted 2004 May 26

ABSTRACT

We use a sample of 42 supernovae detected with the Advanced Camera for Surveys on board the *Hubble Space Telescope* as part of the Great Observatories Origins Deep Survey to measure the rate of core-collapse supernovae to $z \sim 0.7$ and Type Ia supernovae to $z \sim 1.6$. This significantly increases the redshift range at which

Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005

Cappellaro et al. 2005, A&A, 430, 83

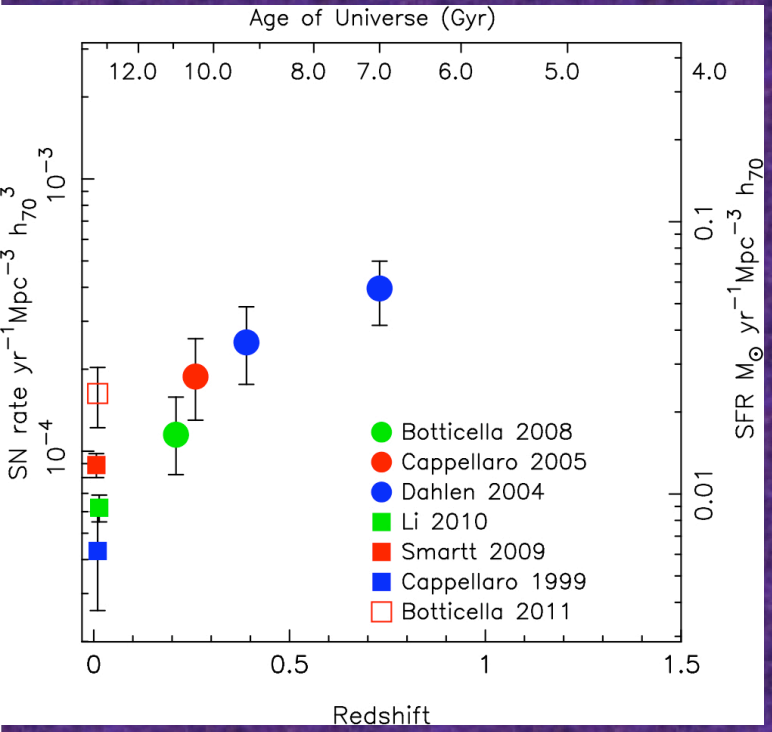
STRESS (Southern inTermediate Redshift ESO SN Survey)

Monitoring of selected galaxy sample, 1999-2002

Measured rate in SNuB converted to volume rate

Preliminary results based on 5 of 21 search fields

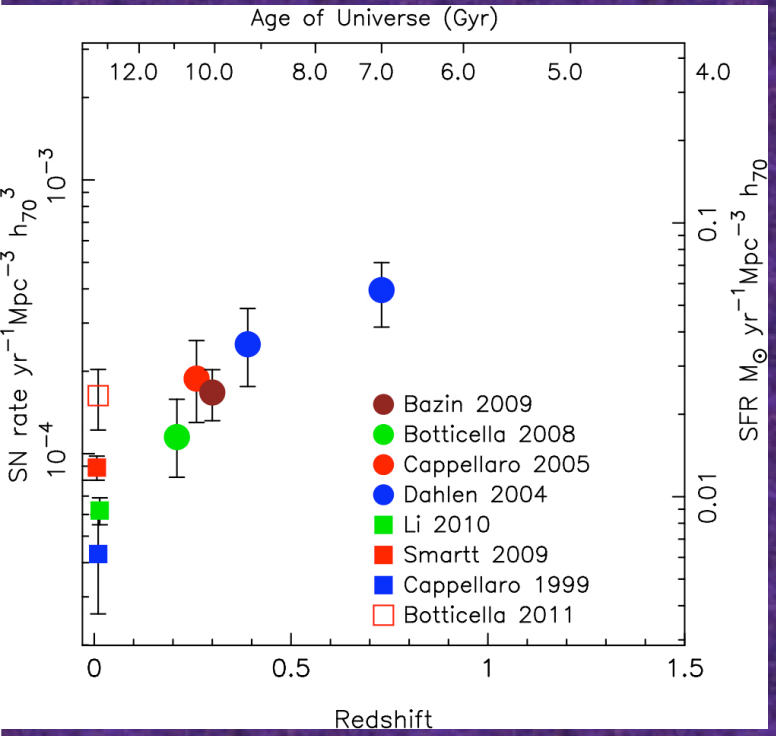
Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005
0.21	$1.15^{+0.43}_{-0.33}$	~46	Botticella	2008

Botticella et al. 2008, A&A, 479, 49
STRESS (Southern inTermediate Redshift ESO SN Survey)
Monitoring of selected galaxy sample, 1999-2005
Measured rate in SNuB converted to volume rate.
"Supersede the preliminary results published in Cappellaro et al. (2005)"

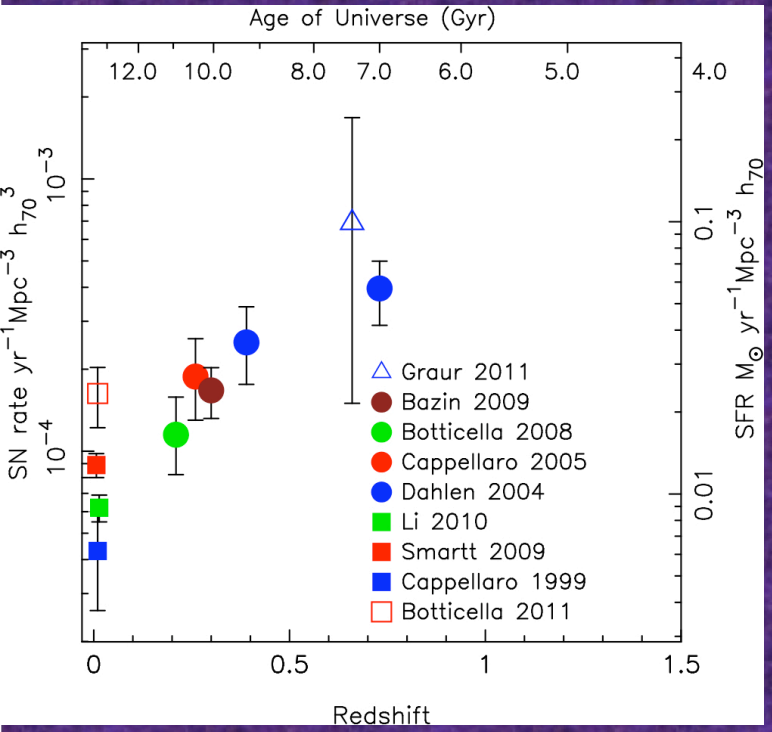
Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005
0.21	$1.15^{+0.43}_{-0.33}$	46	Botticella	2008
0.30	$1.67^{+0.35}_{-0.35}$	117	Bazin	2009

Bazin et al. 2009, A&A, 499, 653
SNLS (Supernova Legacy Survey) 2003-2006

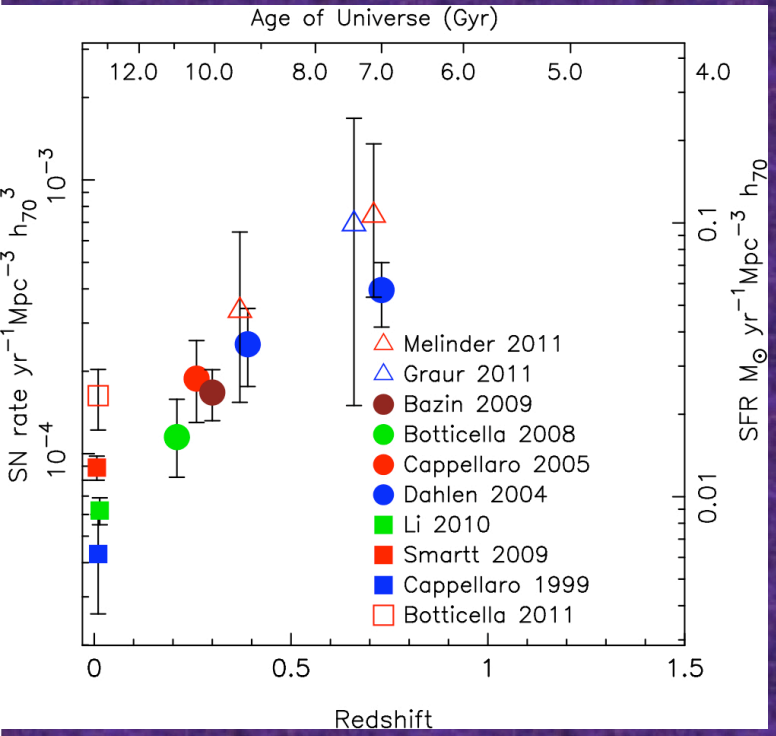
Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005
0.21	$1.15^{+0.43}_{-0.33}$	46	Botticella	2008
0.30	$1.67^{+0.35}_{-0.35}$	117	Bazin	2009
0.66	$6.9^{+9.9}_{-5.4}$	8.7	Graur	2011

Graur et al. 2011, arXiv:1102.0005
Subaru Deep Field 2005-2008

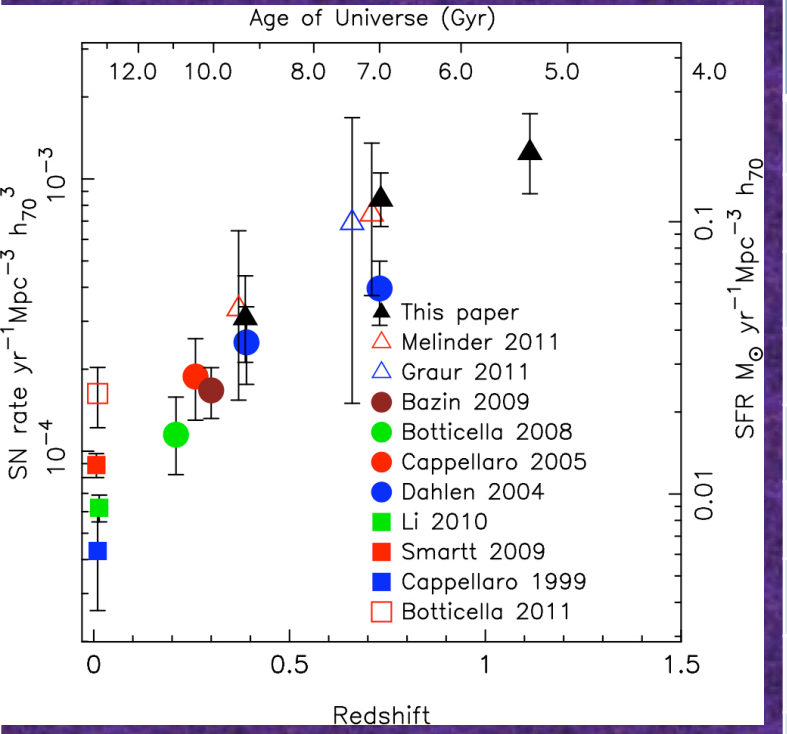
Core collapse rates measured to date



Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005
0.21	$1.15^{+0.43}_{-0.33}$	46	Botticella	2008
0.30	$1.67^{+0.35}_{-0.35}$	117	Bazin	2009
0.66	$6.9^{+9.9}_{-5.4}$	8.7	Graur	2011
0.39	$3.33^{+3.12}_{-1.79}$	3	Melinder	2011
0.73	$7.41^{+6.13}_{-3.68}$	4	Melinder	2011

Jens Melinder, TD, et al. 2011, in prep.
Stockholm Vimos Supernova Survey (SVISS)

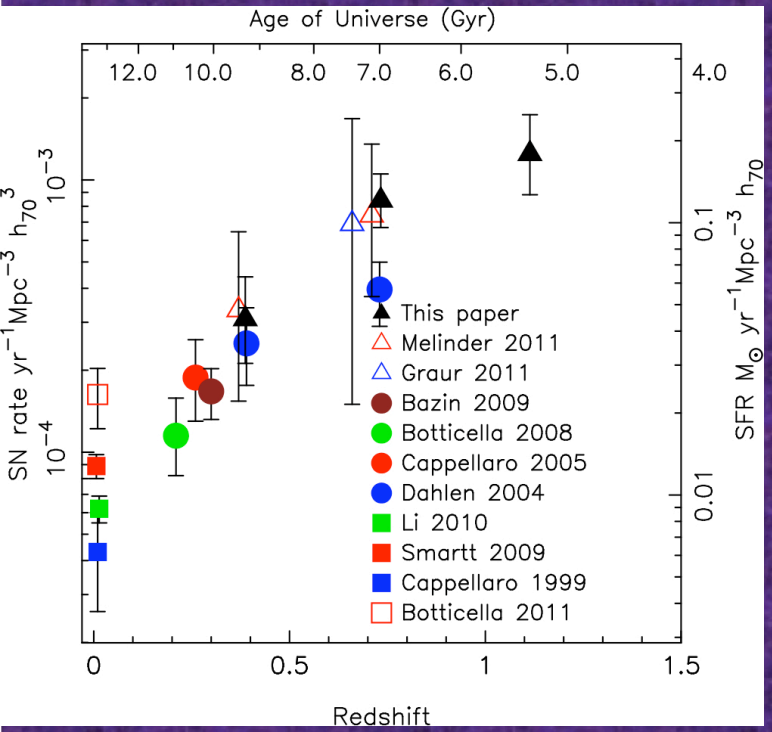
Core collapse rates measured to date

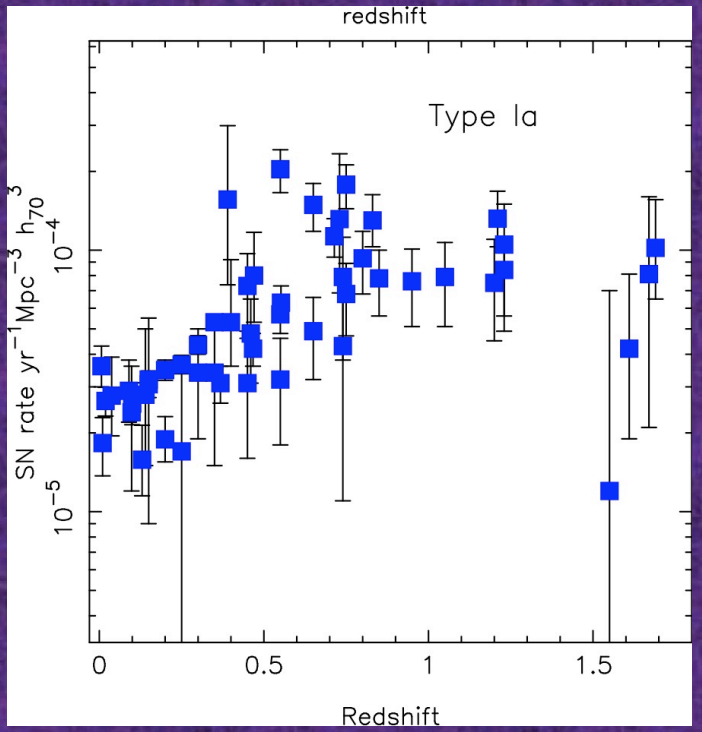


Dahlen, et al. 2011, in prep.
HST GOODS/PANS supernova search 2002-2005.

Redshift	Rate (10^{-4}yr^{-1}Mpc^{-3})	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
local	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
local	$0.62^{+0.07}_{-0.07}$	440	Li	2011
local	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011
0.39	$2.51^{+0.88}_{-0.75}$	6	Dahlen	2004
0.73	$3.96^{+1.03}_{-1.06}$	10	Dahlen	2004
0.26	$1.88^{+0.71}_{-0.58}$	~19	Cappellaro	2005
0.21	$1.15^{+0.43}_{-0.33}$	46	Botticella	2008
0.30	$1.67^{+0.35}_{-0.35}$	117	Bazin	2009
0.66	$6.9^{+9.9}_{-5.4}$	8.7	Graur	2011
0.39	$3.33^{+3.12}_{-1.79}$	3	Melinder	2011
0.73	$7.41^{+6.13}_{-3.68}$	4	Melinder	2011
0.39	$3.08^{+1.32}_{-0.96}$	9	Dahlen	2011
0.73	$8.41^{+2.12}_{-1.72}$	25	Dahlen	2011
1.14	$12.47^{+4.90}_{-3.65}$	11	Dahlen	2011

Core collapse rates measured to date



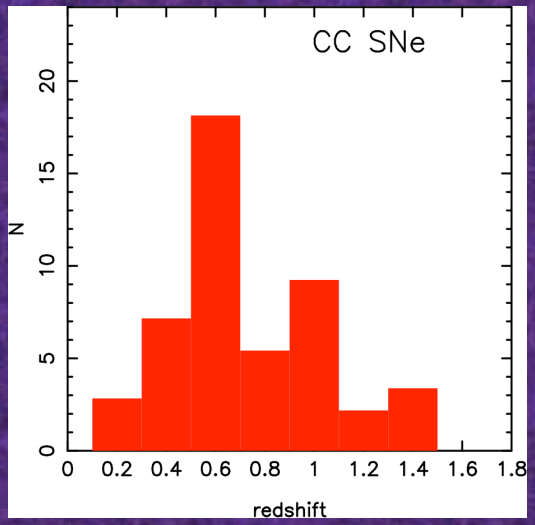


Core collapse vs Type Ia

GOODS/PANS HST Supernova Search

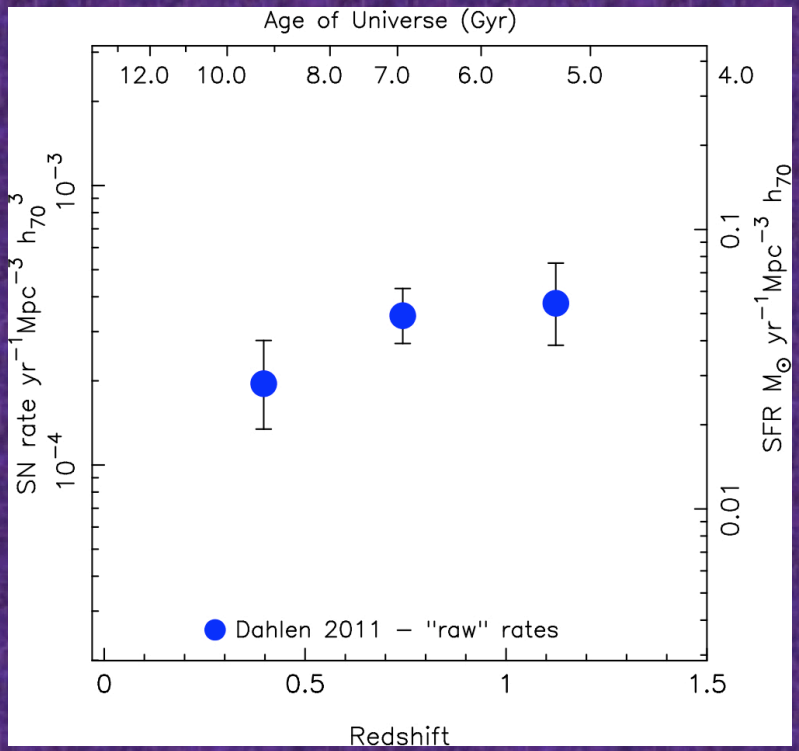
- ✓ This survey is based on data taken with the HST 2002-2005 and includes GOODS (PI: Giavalisco) and PANS (PI: Riess) data.
- ✓ In total: 1000 orbits ~ comparable to the ongoing MCTs.
- ✓ GOODS-S and -N were monitored every ~45 days
- ✓ In total: 22 search epochs x 15 ACS pointings x ~10 sq arcmin = 1 sq degree
- ✓ In addition: follow up photometry and spectroscopy using HST/VLT/KECK

In total 120 SNe discovered
62 Core Collapse SNe
45 used for rates 0.1<z<1.3
Multiple points on lightcurve and colors to determine type
2 spectra of SNe
50 spectra of host
7 photo-z of host
3 hostless SNe
Median redshift: z~0.6



Calculating Rates

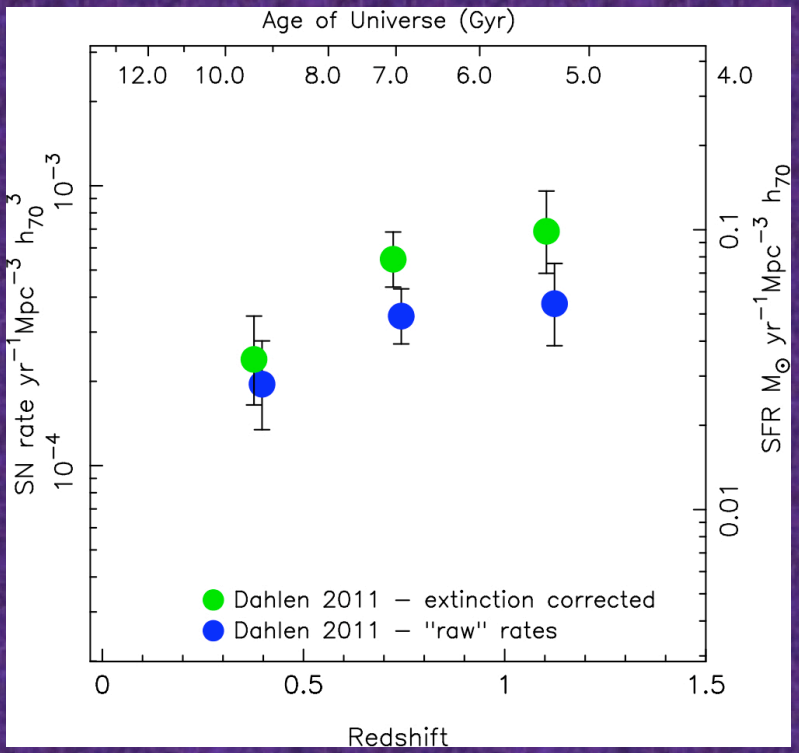
..is tricky. Calculating rates based on an observed sample of SNe includes specifying:
1a) Observational set up (detection efficiency limiting magnitude, area, cadence).
1b) SN statistics (peak magnitudes, subtype fraction, light curve, SED).

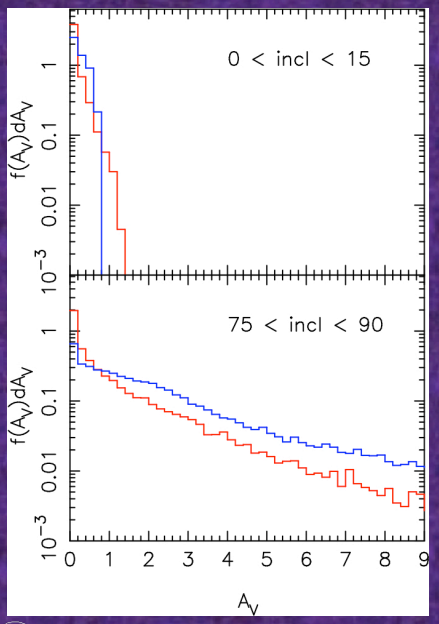


Calculating Rates

..is tricky. Calculating rates based on an observed sample of SNe includes specifying:
1a) Observational set up (detection efficiency limiting magnitude, filter, area, cadence).
1b) SN statistics (peak magnitudes, subtype fraction, light curve, SED).

2) Extinction and inclination corrections (Hatano et al. 1998; Riello & Patat 2005).





Top: Face-on

Bottom: Edge-on

Simulations by Erkki Kankare, TD, et al, in prep

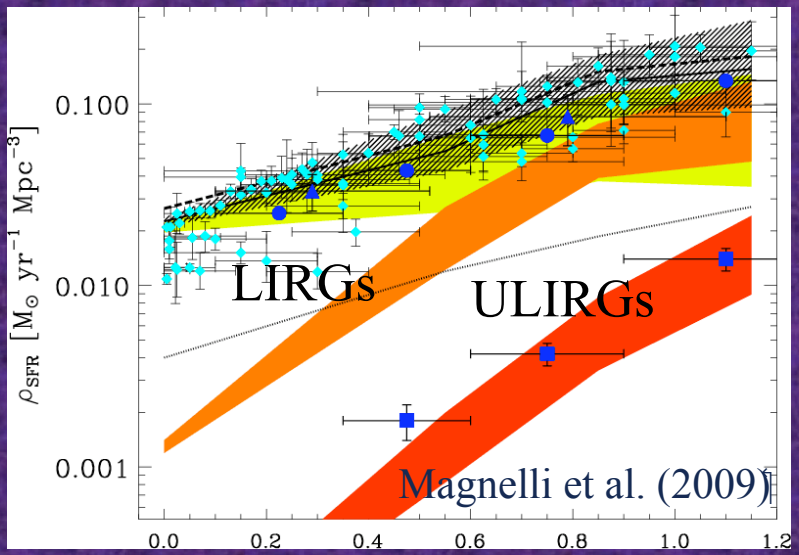
Calculating Rates

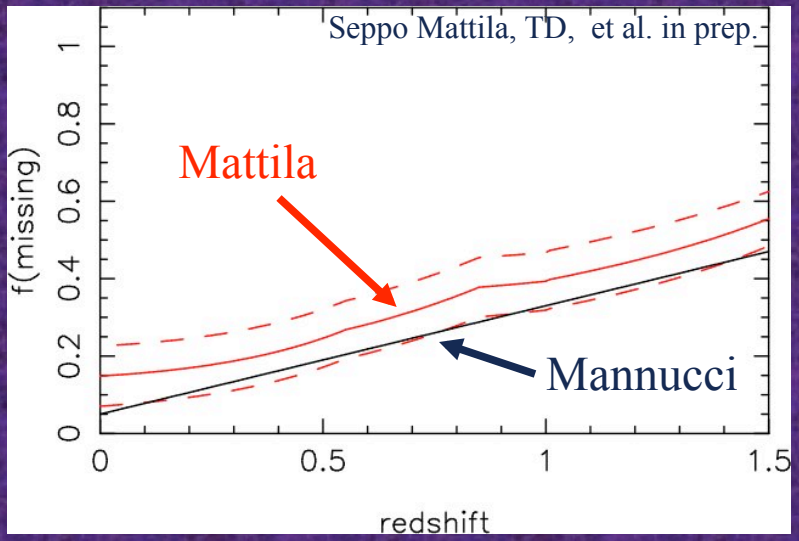
..is tricky. Calculating rates based on an observed sample of SNe includes specifying:
1a) Observational set up (detection efficiency limiting magnitude, filter, area, cadence).
1b) SN statistics (peak magnitudes, subtype fraction, light curve, SED)

2) Extinction and inclination corrections (Hatano et al. 1998; Riello & Patat 2005).

3) Corrections for "missing fraction" in dust enshrouded environments (LIRG/ULIRG) (Mannucci et al. 2007).

Starformation rate





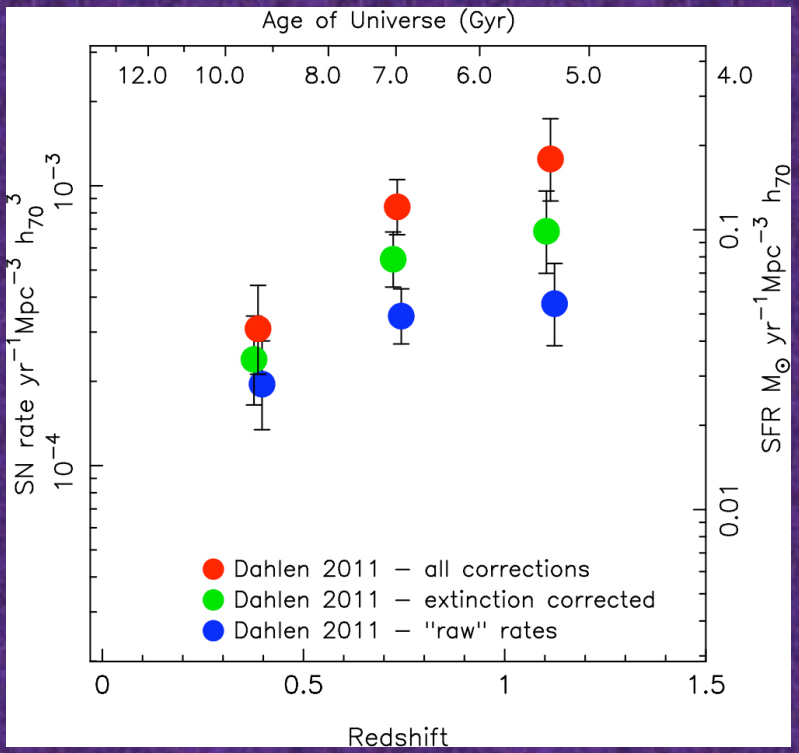
Missing fraction

Calculating Rates

..is tricky. Calculating rates based on an observed sample of SNe includes specifying:
1a) Observational set up (detection efficiency limiting magnitude, filter, area, cadence).
1b) SN statistics (peak magnitudes, subtype fraction, light curve, SED)

2) Extinction corrections (Hatano et al. (1998), Riello & Patat (2005)).

3) Corrections for "missing fraction" in dust enshrouded environments (LIRG/ULIRG) (Mannucci et al. 2007).



Calculating Rates

..is tricky (II). There are many sources for systematic errors.
For example, what is the fraction of different SN subtypes?

	Li	Smartt	Combined
IIP	52.0%	58.7%	54.8%
IIL	7.4%	2.7%	6.1%
IIn	6.7%	3.8%	5.1%
SE (Ib/c,IIb)	33.9%	34.8%	34.0%

Li et al (2011) 137 SNe within <60 Mpc
Smartt et al. (2009) 92 SNe within <28 Mpc

Introduces errors:
~1% at low redshift
~15% at high redshift

Calculating Rates – systematic uncertainties

Table 3. Error sources

	Redshift	Redshift	Redshift
	$0.1< z <0.5$	$0.5< z <0.9$	$0.9< z <1.3$
Subtype fraction	$^{+1.1\%}_{-1.4\%}$	$^{+4.3\%}_{-4.9\%}$	$^{+17.9\%}_{-16.5\%}$
Faint (M> -15) fraction	$^{+17.2\%}_{-10.9\%}$	$^{+18.4\%}_{-13.5\%}$	$^{+20.4\%}_{-13.8\%}$
Peak magnitudes	$^{+4.7\%}_{-4.0\%}$	$^{+9.2\%}_{-8.2\%}$	$^{+9.9\%}_{-9.3\%}$
Redshift uncertainty	$^{+4.1\%}_{-2.7\%}$	$^{+1.1\%}_{-1.8\%}$	$^{+2.5\%}_{-1.7\%}$
Type determination	$^{+7.5\%}_{-9.2\%}$	$^{+7.8\%}_{-6.4\%}$	$^{+6.1\%}_{-13.2\%}$
Extinction model	$^{+4.3\%}_{-3.8\%}$	$^{+9.0\%}_{-7.2\%}$	$^{+9.0\%}_{-7.6\%}$
Extinction laws	$^{+6.5\%}_{-6.3\%}$	$^{+8.8\%}_{-4.0\%}$	$^{+11.8\%}_{-0.2\%}$
Missing fraction	$^{+11.8\%}_{-9.5\%}$	$^{+14.5\%}_{-11.2\%}$	$^{+16.9\%}_{-12.6\%}$
Systematic summed	$^{+24.3\%}_{-19.3\%}$	$^{+29.5\%}_{-22.6\%}$	$^{+37.2\%}_{-30.7\%}$
Statistical errors	$^{+42.8\%}_{-31.2\%}$	$^{+25.2\%}_{-20.5\%}$	$^{+39.3\%}_{-29.2\%}$

Systematic errors 20-40% at high–z, comparable to statistical errors in our z>0.5 bins.

The Starformation Rate Connection

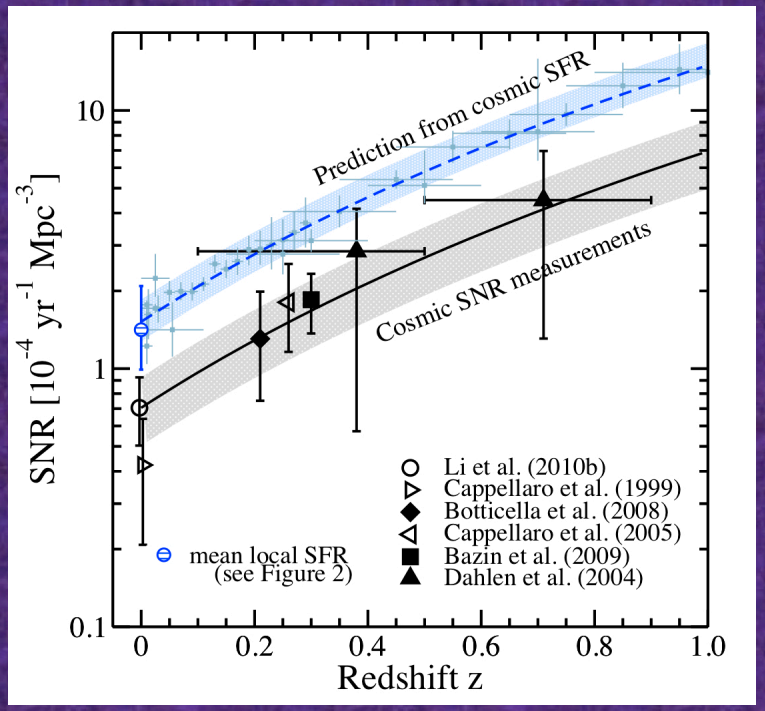
SNR(z) = k * h^2 * SFR(z)

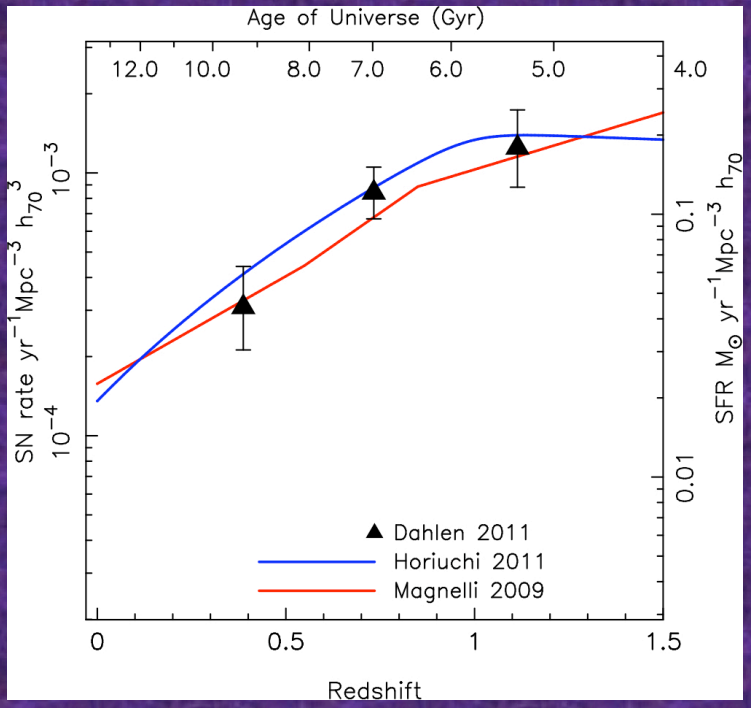
$$k = \frac{\int_{8\,M_\odot}^{50\,M_\odot} \psi(M)dM}{\int_{0.1\,M_\odot}^{125\,M_\odot} M\psi(M)dM}.$$

$$k = 0.007 M_\odot^{-1}$$

The Starformation Rate Connection

$$SNR(z) = k * h^2 * SFR(z)$$



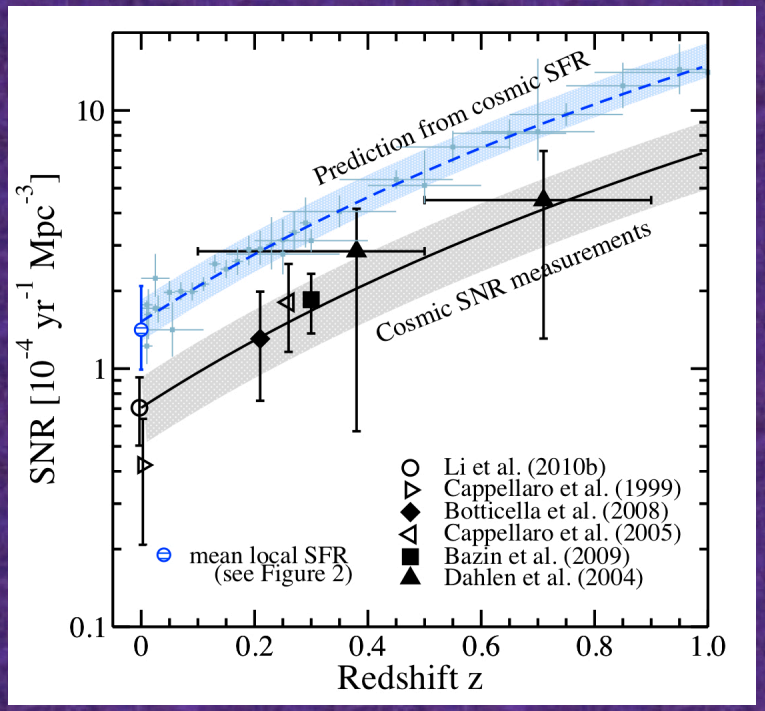


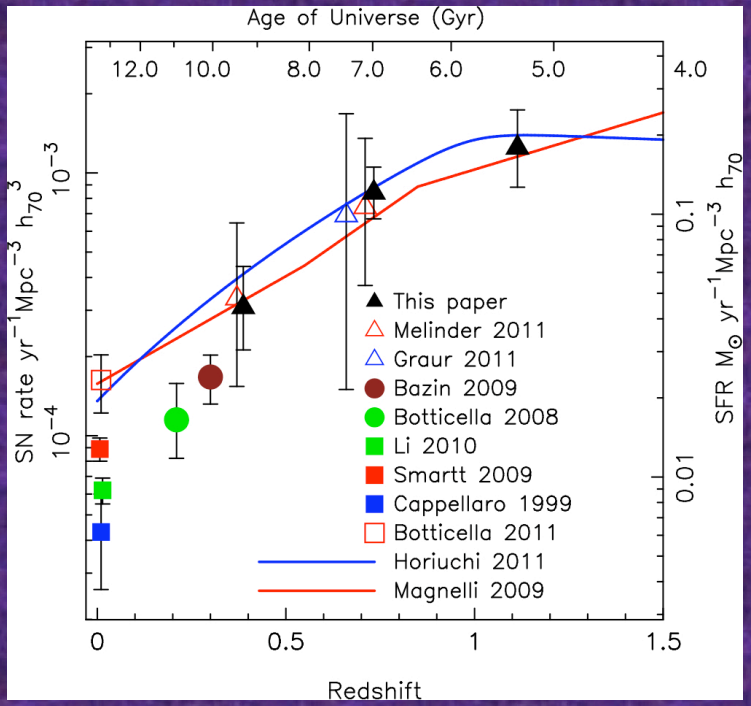
The "supernova rate problem" Horiuchi et al. (2011, arXiv:1102.1977).
The derived SNRs are a factor ~2 lower than the SFR (2σ)
proposed solution: ~50% of CC are faint or dark(?)

The rates from Dahlen et al. (2011) are consistent with SFR.

The Starformation Rate Connection

$$SNR(z) = k * h^2 * SFR(z)$$

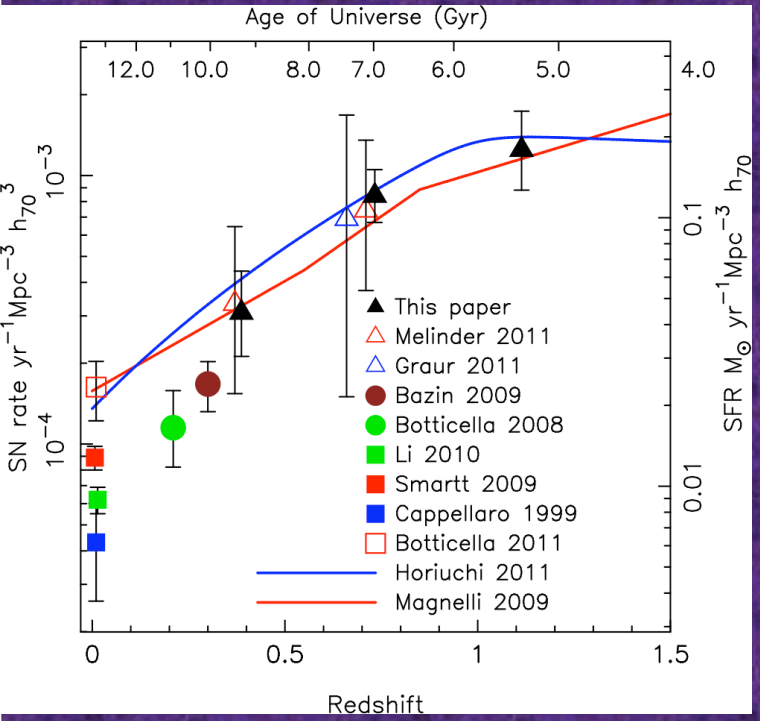




The "supernova rate problem" Horiuchi et al. (2011, arXiv:1102.1977).
The derived SNRs are a factor ~2 lower than the SFR (2σ)

The rates from Dahlen et al. (2011) are consistent with SFR.
Problem: where to normalize…

Local CC SN rates



Redshift	Rate 10^{-4}yr^{-1}Mpc^{-3}	N	Reference	year
local	$0.43^{+0.17}_{-0.17}$	67	Cappellaro	1999
>100 Mpc	$0.62^{+0.07}_{-0.07}$	440	Li	2011
28 Mpc	$0.89^{+0.09}_{-0.09}$	92	Smartt	2009
11 Mpc	$1.6^{+0.4}_{-0.4}$	14	Botticella	2011

Higher local rates at smaller radii.

- *Is this due to detection of more faint SN in nearby sample?*
  Faintest SN in Botticella sample M_B ~ -17.8
  ~5 of 101 CC are faint in Li sample (M~ - 14-15, <60 Mpc)
- *Is this due to detection of SNe with high extinction in the nearby sample?*
  2 of 14 included in sample have high extinction, 02hh, 04am
- *Other explanations: cosmic variance, statistical uncertainties, systematics*

CANDELS + CLASH

PI: S. Faber, H. Ferguson

PI: M. Postman

The HST MCT SN Survey

PI: A. Riess (w. Steve Rodney)

SN discovery and Target of Opportunity follow-up

Search with WFC3 IR channel. Why search in the IR?

Prediction:

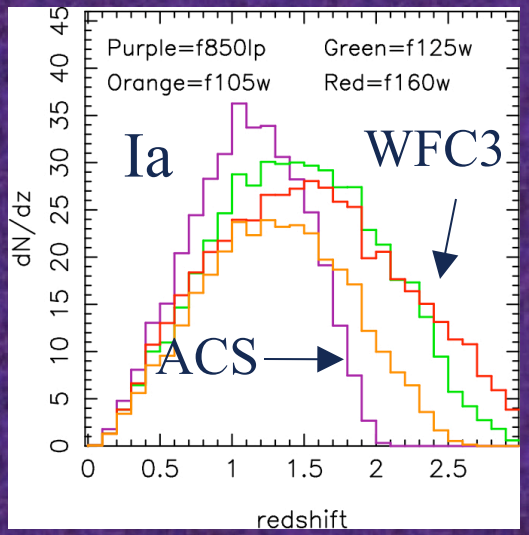
Type Ia

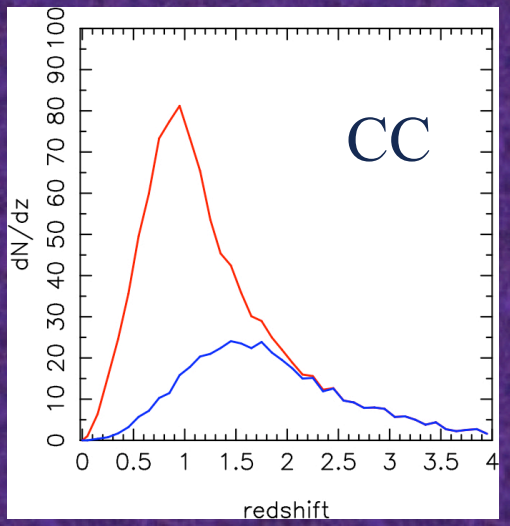
"Gold sample":

~8 at z>1.5

~10 at 1<z<1.5

with SN spectra, LC, host properties



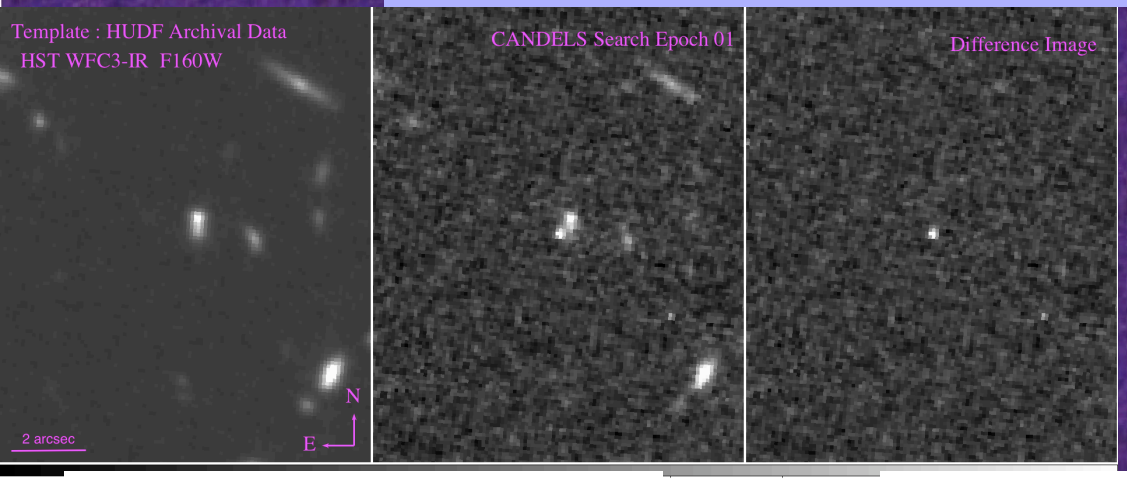


Core collapse:

Similar number to the ACS search expected.

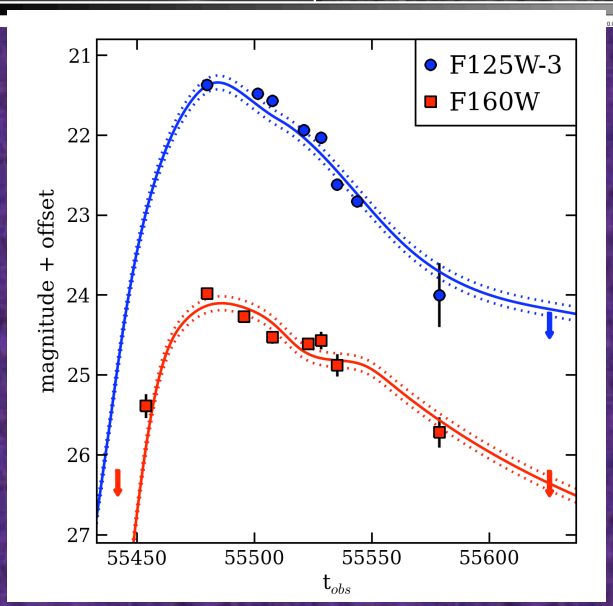
A handfull z>2 should be detected

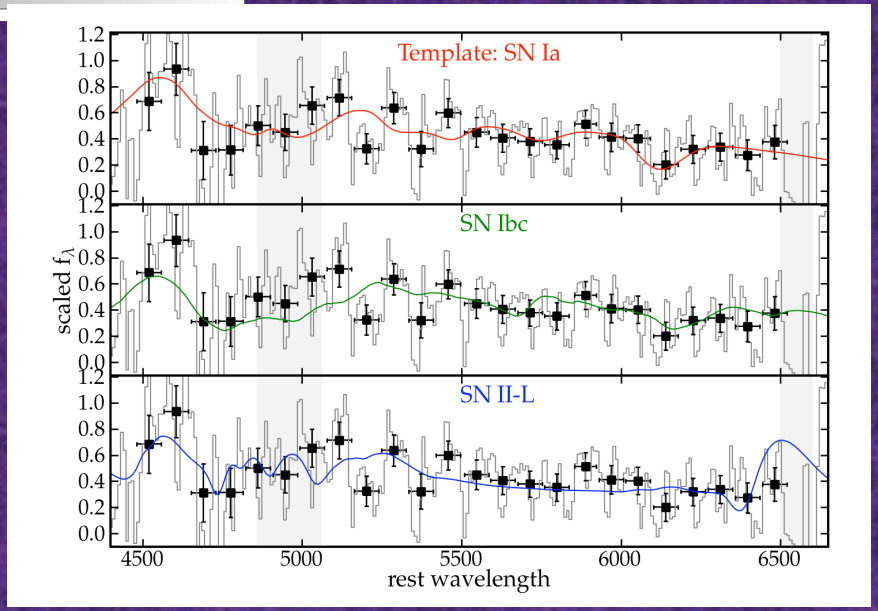
The HST MCT SN Survey



First discovery: SN Primo
Found in UDF
Host redshift: z_{spec}=1.55

WFC3 grism, 8 orbits, ~20,000s



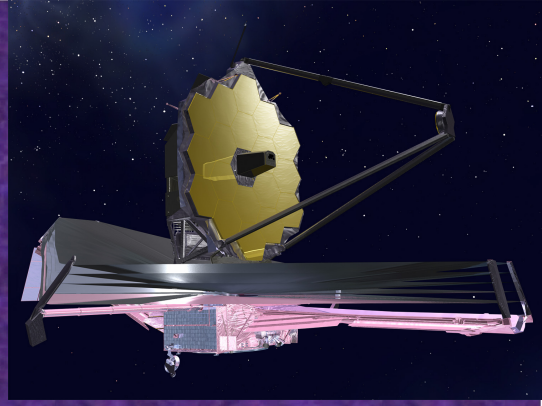


Template : Normal SNIa at z=1.55
Av=0.3, R_V=3.1

Ia: χ^2/ν=1.14
Ibc: χ^2/ν=1.27
IIL: χ^2/ν=1.51

SPACE TELESCOPE SCIENCE INSTITUTE

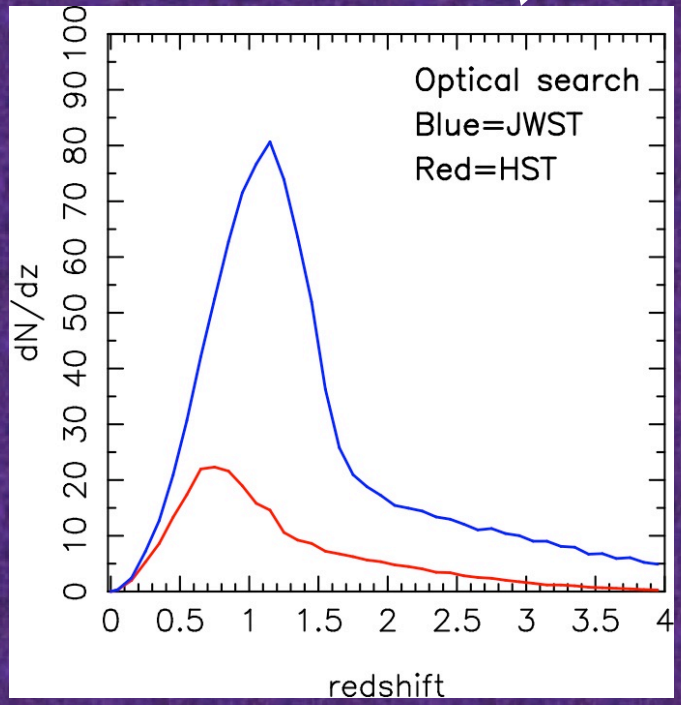
Well beyond: Core Collapse SNe with JWST

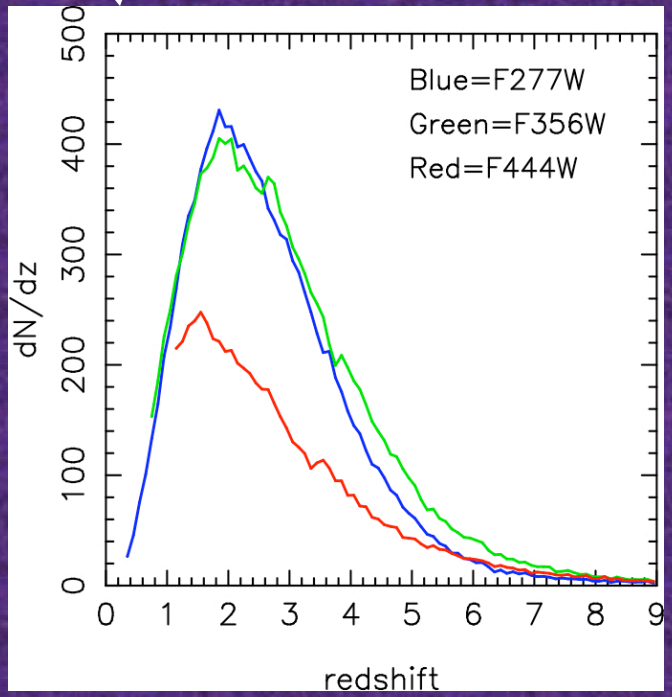


Example: a "GOODS-like" search with JWST/NIRCam:
1 reference + 4 search epochs over 300 sq arcmin
Total exp. time in search filter ~300,000s
gives 1875s per JWST pointing
JWST ETC gives S/N=5 point source limits

m_{AB}(F090W) ~ 28.2
m_{AB}(F277W) ~ 29.5
m_{AB}(F356W) ~ 29.3
m_{AB}(F444W) ~ 28.8

Optical Infrared





~ 5 times the GOODS number
Tail at z > 2

~ 500-1000 CC SNe
30-40% at z > 3
10-20% at z > 4

1998

HIGH z SUPERNOVAE WITH THE NGST

T. Dahlén, C. Fransson

Stockholm Observatory, S-133 36 Saltsjöbaden, Sweden
Phone +46 8 16 44 67/69, fax +46 8 717 47 19
e-mail tomas@astro.su.se, claes@astro.su.se

ABSTRACT

We use different assumptions for the combination of dust extinction and star formation up to redshifts $z \gtrsim 5$, as well as detailed modeling of supernova properties, to estimate the number of supernovae that should be observable with various instruments, in particular the NGST. In the model we use realistic light curves and spectral shapes that evolve with time for the different types supernovae.

We find that the NGST should be able to detect several tens of core collapse SNe in a single detection if the observational limit in the range 1-5 μm is ~ 1

accordingly. We also calculate the counts for different filters and include information about the estimated redshifts of the detected SNe.

Section 2 describes our model. Results are presented in section 3. In section 4 we discuss the influence of dust. Further discussion follows in section 5. Conclusions are given in section 6. We assume a cosmology with $H_0 = 50$ km s^{-1} Mpc^{-3} and q_0=0.5.

2. THE MODEL

A problem when using luminosity densities from high

Astron. Astrophys. 350, 349–367 (1999)

ASTRONOMY AND ASTROPHYSICS

1999

Rates and redshift distributions of high-z supernovae

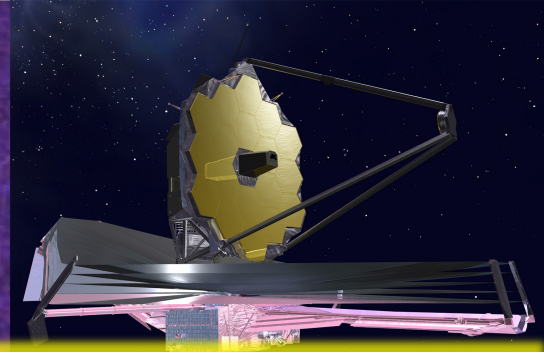
Tomas Dahlén and Claes Fransson

Stockholm Observatory, 133 36 Saltsjöbaden, Sweden

Received 5 February 1999 / Accepted 26 July 1999

VST

ared



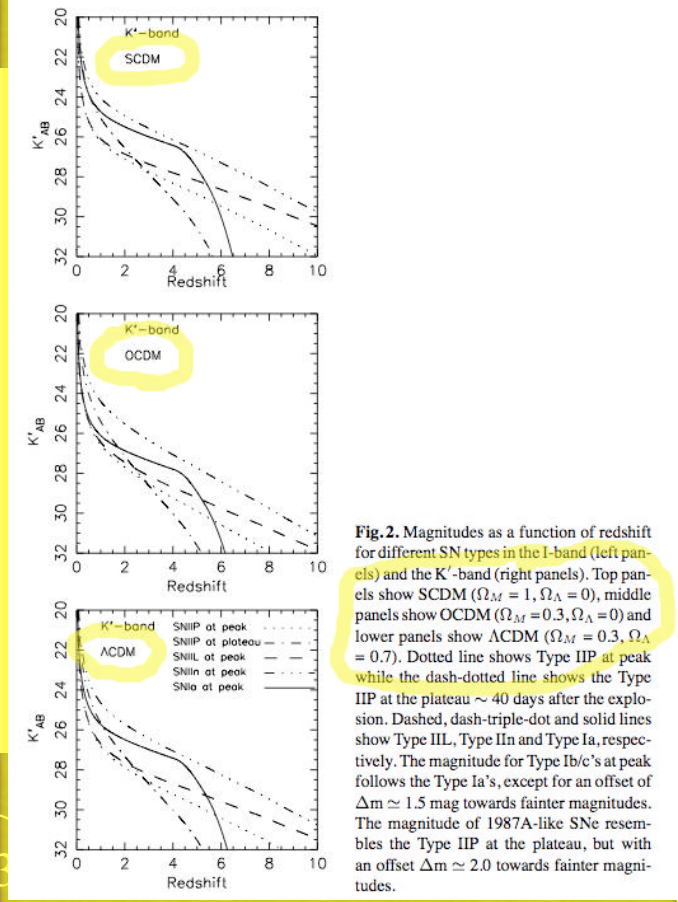
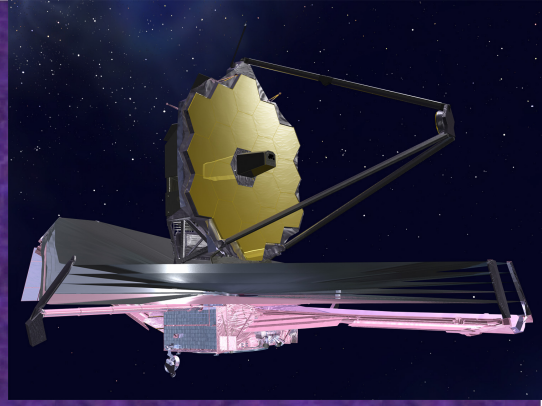


Fig. 2. Magnitudes as a function of redshift for different SN types in the I-band (left panels) and the K′-band (right panels). Top panels show SCDM ($\Omega_M = 1, \Omega_\Lambda = 0$), middle panels show OCDM ($\Omega_M = 0.3, \Omega_\Lambda = 0$) and lower panels show ΛCDM ($\Omega_M = 0.3, \Omega_\Lambda = 0.7$). Dotted line shows Type IIP at peak while the dash-dotted line shows the Type IIP at the plateau ~ 40 days after the explosion. Dashed, dash-triple-dot and solid lines show Type IIL, Type IIn and Type Ia, respectively. The magnitude for Type Ib/c's at peak follows the Type Ia's, except for an offset of $\Delta m \simeq 1.5$ mag towards fainter magnitudes. The magnitude of 1987A-like SNe resembles the Type IIP at the plateau, but with an offset $\Delta m \simeq 2.0$ towards fainter magnitudes.

10-20% at z > 4

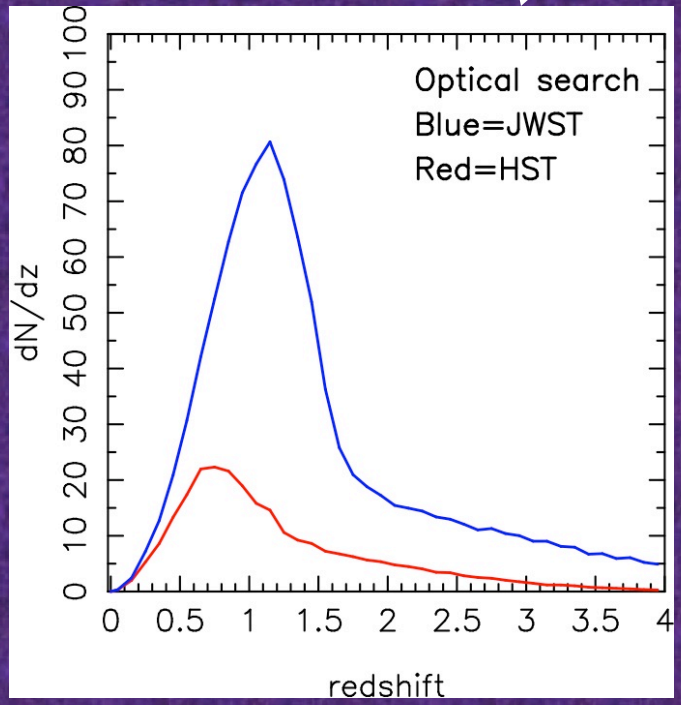
Well beyond: Core Collapse SNe with JWST

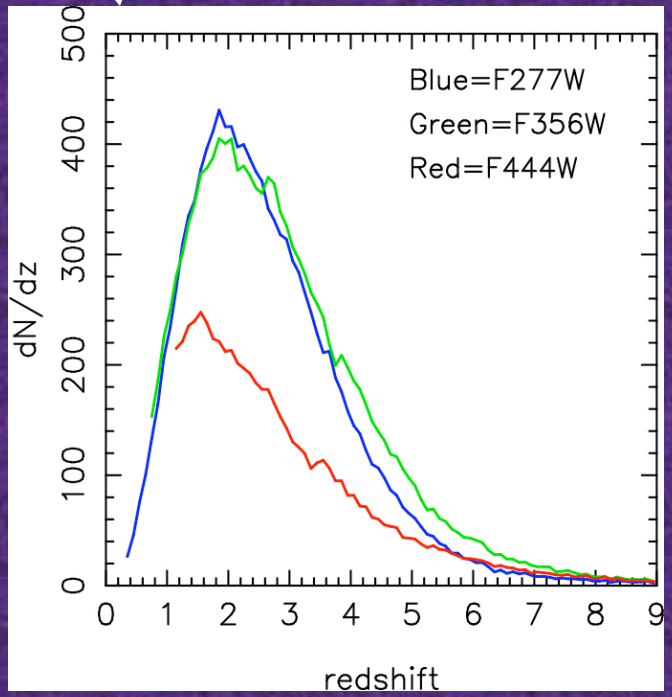


Example: a "GOODS-like" search with JWST/NIRCam:
1 reference + 4 search epochs over 300 sq arcmin
Total exp. time in search filter ~300,000s
gives 1875s per JWST pointing
JWST ETC gives S/N=5 point source limits

m_{AB}(F090W) ~ 28.2
m_{AB}(F277W) ~ 29.5
m_{AB}(F356W) ~ 29.3
m_{AB}(F444W) ~ 28.8

Optical Infrared



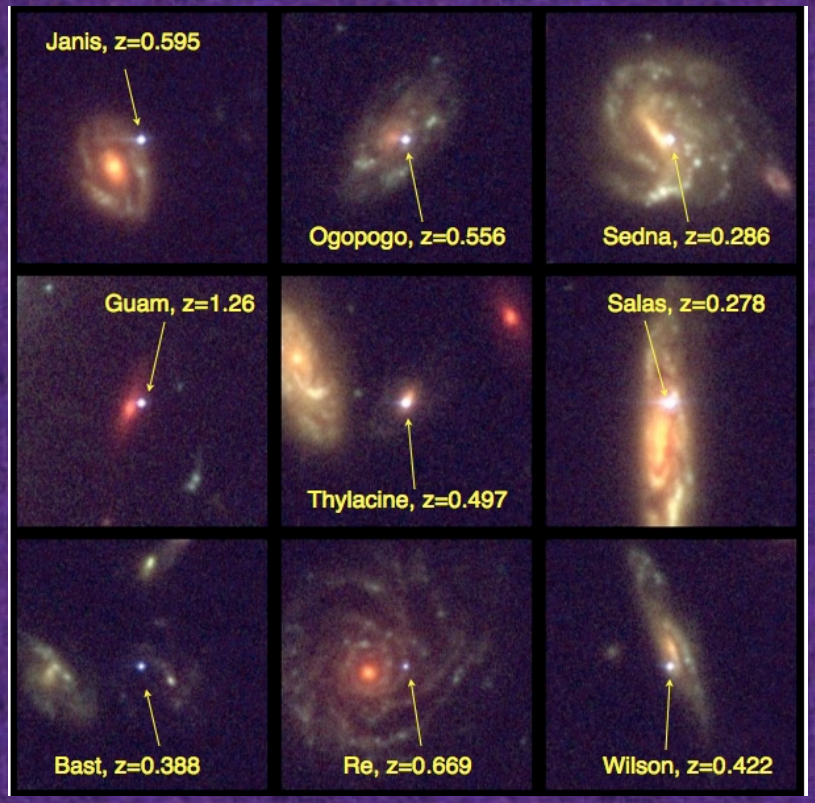


~ 5 times the GOODS number
Tail at z > 2

~ 500-1000 CC SNe
30-40% at z > 3
10-20% at z > 4

Summary

- ✓ Core collapse rates have now been measured beyond redshift z=1
- ✓ The HST sample consists of 62 CC SNe to z~1.3
- ✓ Systematic errors are comparable to or larger than statistical at z>0.5
- ✓ SN rates follow the star formation rate at z>0.3
- ✓ Systematic differences between local SNR measurements
- ✓ JWST will be able to detect CC SNe well beyond z~2-3



HST detected CC SNe
Lou Strolger