

OLivES 2026, August 28th 2026

Nearby supernova rates

Shunsaku Horiuchi

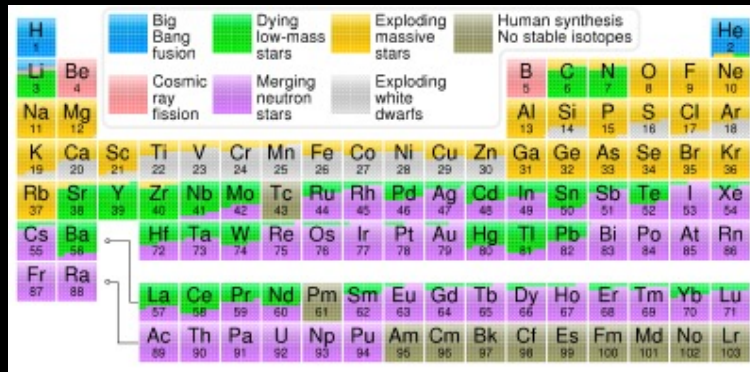
Institute of Science Tokyo
Virginia Tech
Kavli IPMU



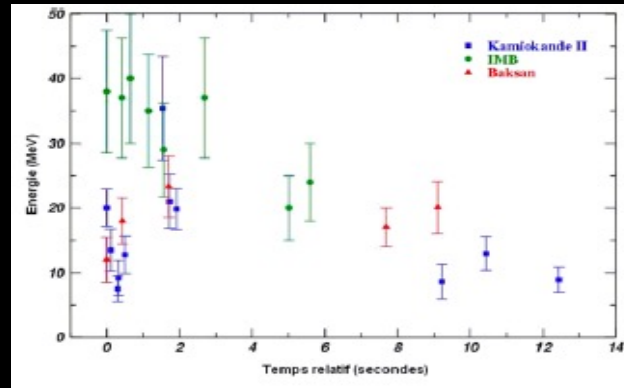
Topics

- Finding supernovae
- Estimating supernova rates
 - Nearby
 - Cosmological
- Estimating star formation rates
- Comparing supernova to star formation rates
 - Cosmological
 - Nearby
- Which stars undergo supernovae?

Broad importance of supernovae



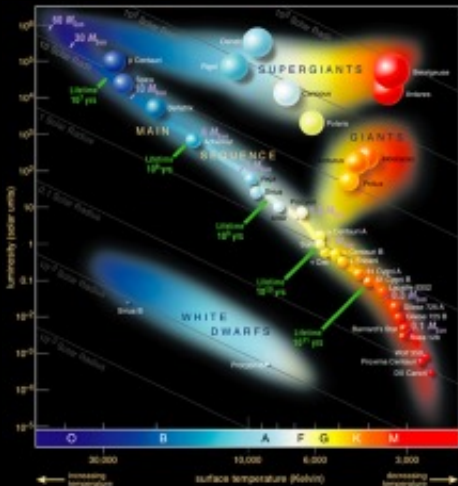
Nucleosynthesis



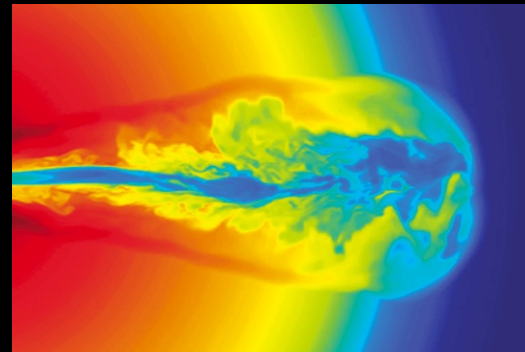
Neutrinos



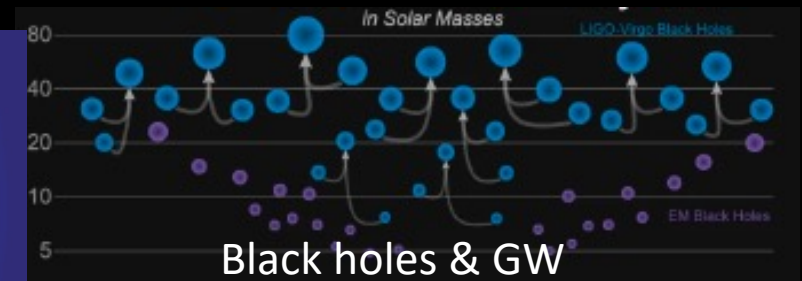
Nuclear matter



Stellar evolution



Relativistic phenomena



Black holes & GW

+ many more



Galaxy evolution, cosmic rays



BSM physics

Core-collapse Supernovae



Typical supernova, $L \sim 10^{35-36}$ watts

Shines for a few months

→ $\sim 10^{50}$ erg total*

(*still only tip of the iceberg)

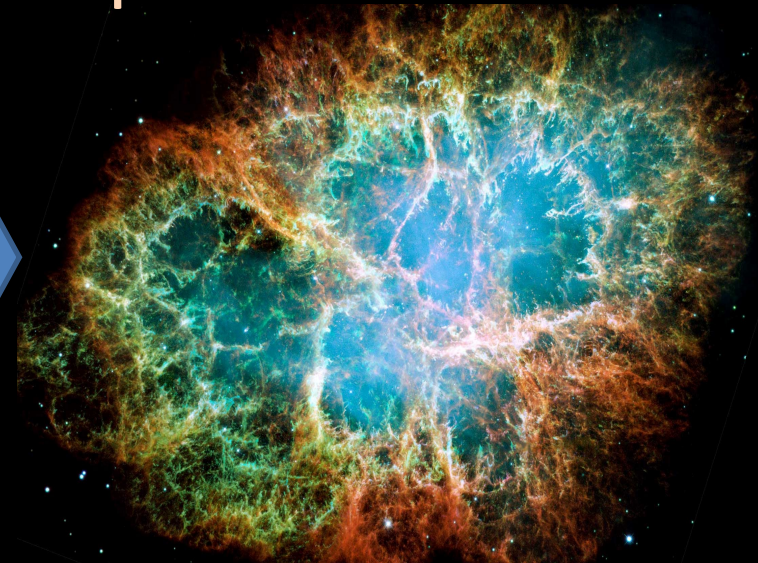
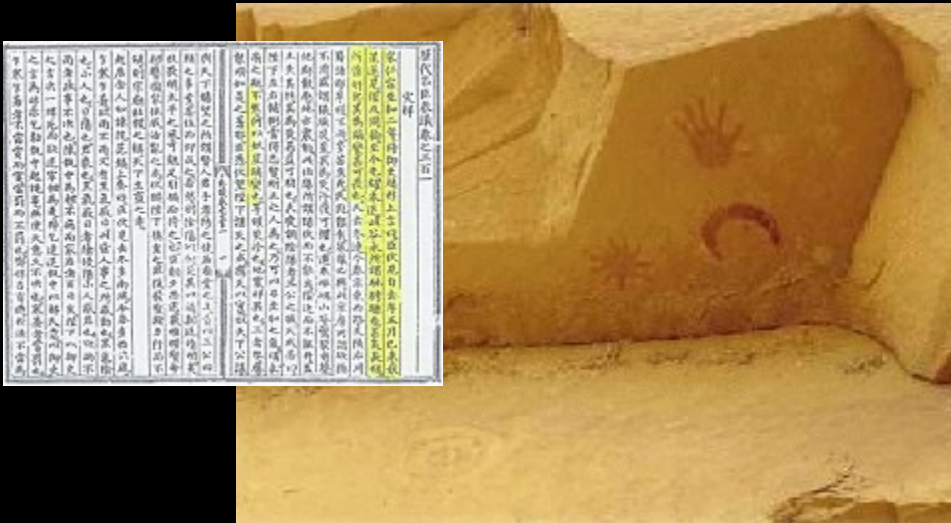
Our sun, $L \sim 10^{26}$ watts

Over 1 billion years old

→ $\sim 10^{50}$ erg total

SN1054

Crab pulsar



What most supernovae really look like

SN 2013cu (iPTF13ast)



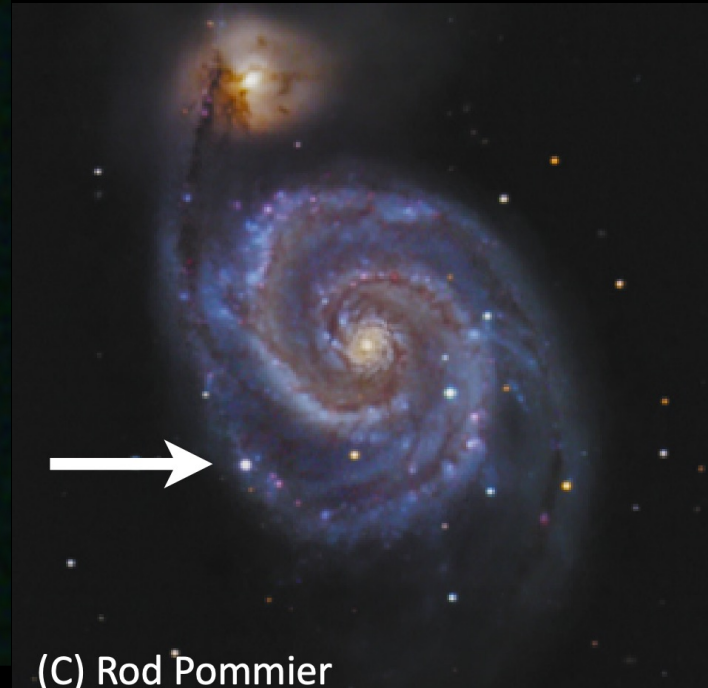
SDSS, prior to supernova explosion

Gal-Yam et al. 2014; Nature, May 22, 2014



Palomar

(distance ~ 108 Mpc)



(C) Rod Pommier

→ use spectra, light curve, to confirm supernovae

Supernovae occur *EVERYDAY*

↓ This (close) is rare

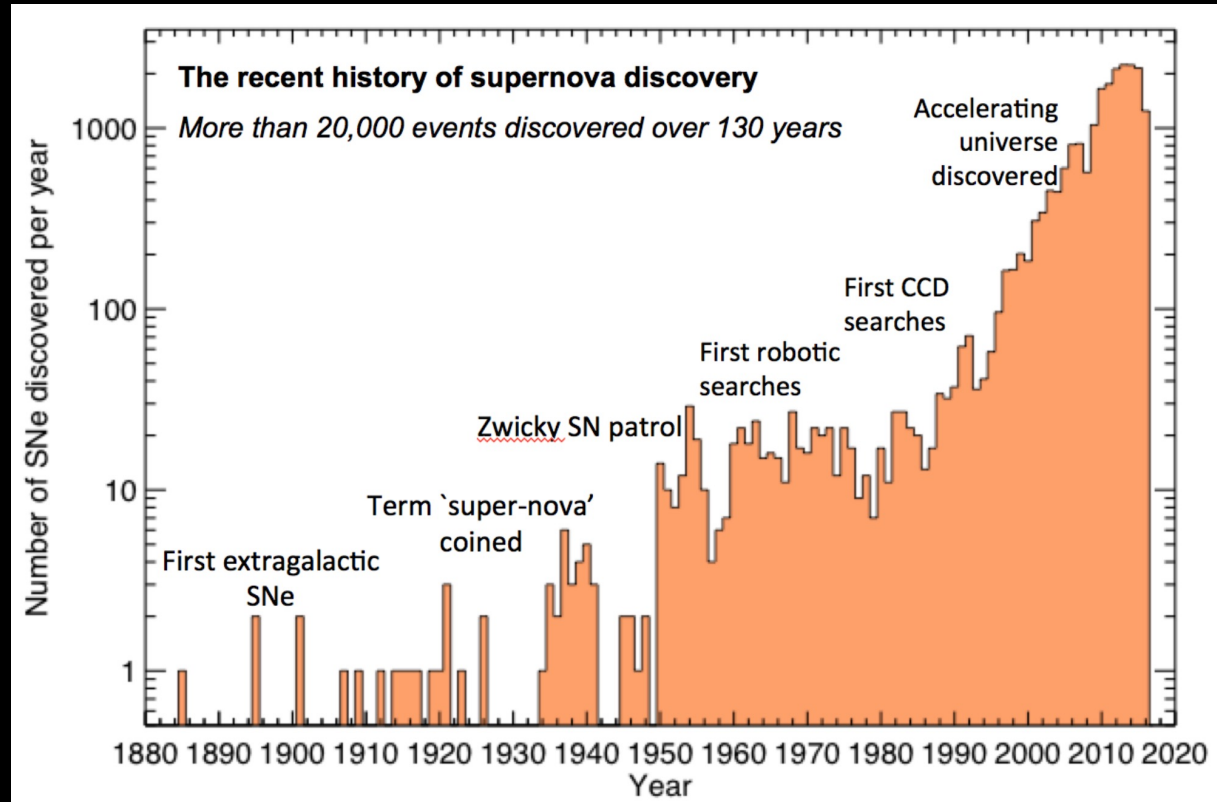


SN 1987A

Occurred in the Large Magellanic Cloud (LMC)

↓ But supernovae are not rare

1801.06643



In fact, there are estimated to be ~ 1 – 10 per *second* in the universe

Recently: supernova @M101 (~ 7 Mpc away)

SUPERNOVA RATE

Supernova rates by simple counting

Supernovae are discovered by both professionals and amateurs, and each discovery is catalogued in online databases

→ incomplete coverage, many systematics

http://www.cfa.harvard.edu/iau/lists
SPIRES arxiv Search astro-ph/new AstroCoffee

Lost lists of thousands of supernovae to date

List of Recent Supernovae

This page gives details on supernovae that have occurred since the start of 2010 . All coordinates given in the table below are J2000.0 positions. Date refers to the date of discovery, Mag. to the magnitude at discovery and offset to the offset from the nucleus of the host galaxy as reported at time of discovery. Disc. Ref. is the reference to the discovery report, Posn. Ref. is the source of the accurate position and Type is the supernova's type (as reported at or near the time of discovery). Note that the preferred hierarchy for host-galaxy catalogue designations is M/NGC/IC, UGC, MCG; all other catalogues are considered "Anon" below.

Links are provided to the references, but access to recent circulars requires a [subscription](#).

This list may be freely pointed-to from your own Web site, but must not be copied to your own site or otherwise redistributed. If you use information from this list in the preparation of any publication, please acknowledge this URL and [CBAT](#).

A larger list of [all supernovae](#) is also available.

SN	Host Galaxy	Date	R.A.	Decl.	Offset	Mag.	Disc. Ref.	SN Position	Posn. Ref.	Type	SN	Discoverer
2011W	UGC 323	2011 01 16	00 32.9 +11 44	12E 5S	18.6	CBET 2651	00 32 51.24 +11 44 07.5	CBET 2651	II?	2011W	Cenko et al	
2011V	MCG +05-22-48	2011 01 28	09 27.6 +28 47	35E 27S	16.0	CBET 2650	09 27 38.76 +28 47 27.5	CBET 2650	IIb	2011V	Drake et al	
2011U	UGC 2985	2011 01 28	04 13.6 +27 33	5E 7N	17.6	CBET 2649	04 13 33.94 +27 32 36.7	CBET 2649	Ia	2011U	Cenko et al	
2011T	UGC 10733	2011 01 28	17 10.1 +32 30	23W 1N	16.3	CBET 2646	17 10 03.62 +32 30 01.2	CBET 2646	Ia	2011T	Peoples, N	
2011S	Anon.	2011 01 14	09 13.9 -17 01	0E 2S	17.6	CBET 2645	09 13 54.05 -17 00 39.3	CBET 2645	IIIn	2011S	Drake et al	
2011R	Anon.	2011 01 14	09 58.5 -10 53	15E 2S	18.8	CBET 2645	09 58 30.13 -10 53 15.4	CBET 2645	IIp	2011R	Drake et al	
2011Q	Anon.	2011 01 05	09 19.2 +39 42	1W 1N	19.0	CBET 2645	09 19 11.45 +39 42 29.2	CBET 2645	Ia	2011Q	Drake et al	
2011P	Anon.	2011 01 05	02 25.7 +16 13		18.6	CBET 2645	02 25 44.80 +16 12 56.0	CBET 2645	IIIn	2011P	Drake et al	
2011O	UGC 8829	2011 01 18	13 54.3 +32 56	1E 8S	18.1	CBET 2643	13 54 19.96 +32 55 39.4	CBET 2643	II	2011O	Cenko et al	
2011N	ESO 120-16	2011 01 20	05 51.6 -59 03	1W 7S	17.8	CBET 2641	05 51 35.18 -59 02 51.3	CBET 2641	Ic	2011N	Pignata et al	
2011M	UGC 3218	2011 01 19	05 00.7 +62 15	15W 1S	18.2	CBET 2640	05 00 41.55 +62 14 38.6	CBET 2640	Ia	2011M	Cenko et al	
2011L	Anon.	2011 01 14	23 40.2 +27 26	6E 2S	17.0	CBET 2638	23 40 11.52 +27 25 42.2	CBET 2638	Ia	2011L	Pandey et al	
2011K	Anon.	2011 01 13	04 45.5 -07 21	2S 15.1	CBET 2636	04 45 30.38 -07 20 52.7	CBET 2636	Ia	2011K	Drake et al		
2011J	Anon.	2011 01 08	10 50.7 +28 01	1N 18.8	CBET 2635	10 50 44.20 +28 00 49.0	CBET 2635	Ia	2011J	Drake et al		

Galactic supernova rate

- The simplest – what's been observed?
- Directly observed are mostly nearby Ia

Strom 1994

Year of SN	Land*	Duration (d)	Remnant	d (kpc)	D (pc)	b (°)	z (pc)	Age (yr)	Basis for young [†]
1604 AD	C,K	330	Kepler	4.4	4.1	+6.8	525	375	v, D
386 AD	C	90	G 11.2–0.3	5	5.8	–0.3	26	1595	D
§	—	—	Cas A	2.8	4.1	–2.1	103	315	v, D
1572 AD	C,K	480	Tycho	2.3	5.6	+1.4	56	410	v, D
1181 AD	C,J	185	3C 58	2.6	6.8	+3.1	141	800	v, D
1054 AD	C,J	540	Crab	2	4.1	–5.8	203	930	v, D, P
—	—	—	G 292.0+1.8	3.6	12.6	+1.8	113	—	v, D
185 AD	C	≥ 140	MSH 14–63	0.95	12.4	–2.3	38	1795	v, D
1006 AD	C,J,K?	240	PKS 1459–41	1.4	12.2	+14.6	365	975	v, D
—	—	—	RCW 103	3.3	8.6	–0.4	23	—	$v, D, (P)$
393 AD	C	210	—	—	—	≈ 5	—	—	—

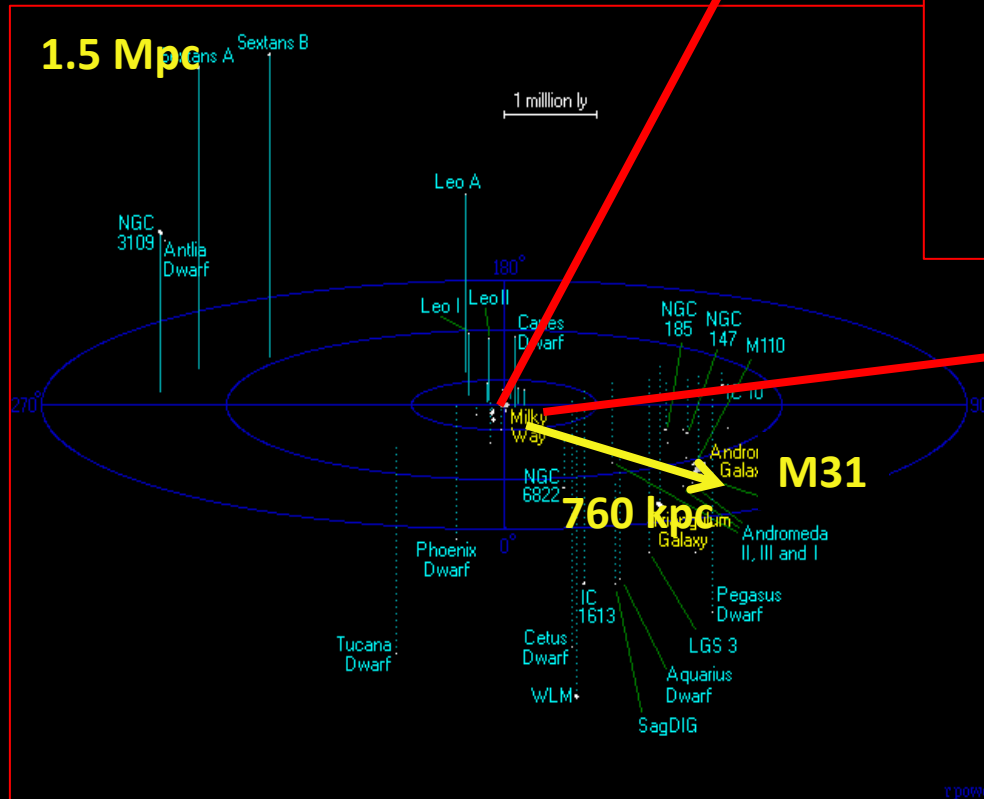
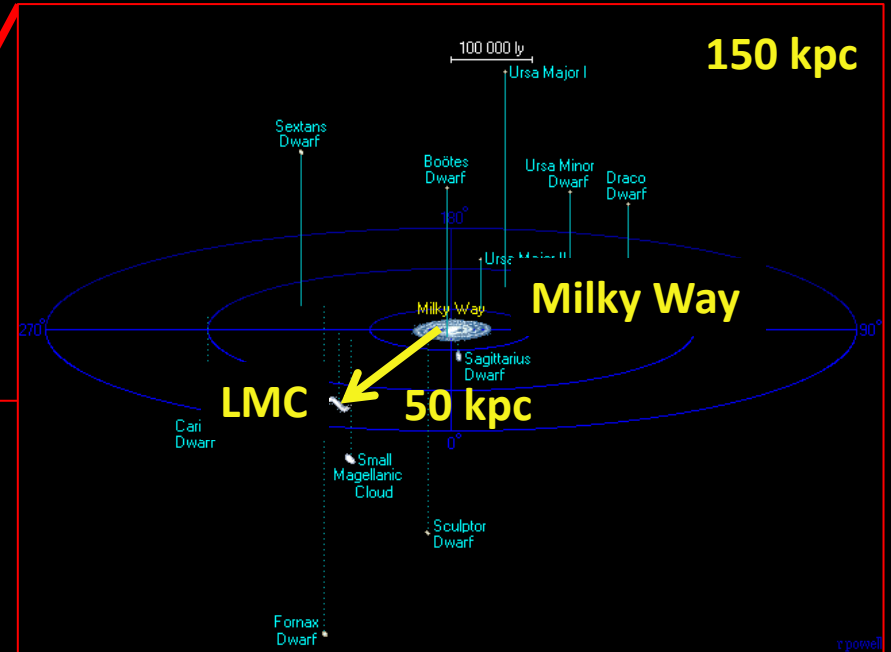
- Several past SNe have been identified via their remnants.
 - E.g. CasA, G1.9+0.3 in ~1868 *Green & Gull (1984), Reynolds et al. (2008)*
- Highly unreliable. There are other, 'better' methods, e.g. Al γ -rays
- **Total SN rate: 1.63 +/- 0.46 / century**

(Rozwadowska et al 2020)

Reach to our neighbors

With Super-K (32 kton):

- $\sim 10^4$ events from Gal center
- ~ 400 events from LMC
- ~ 1 event from M 31



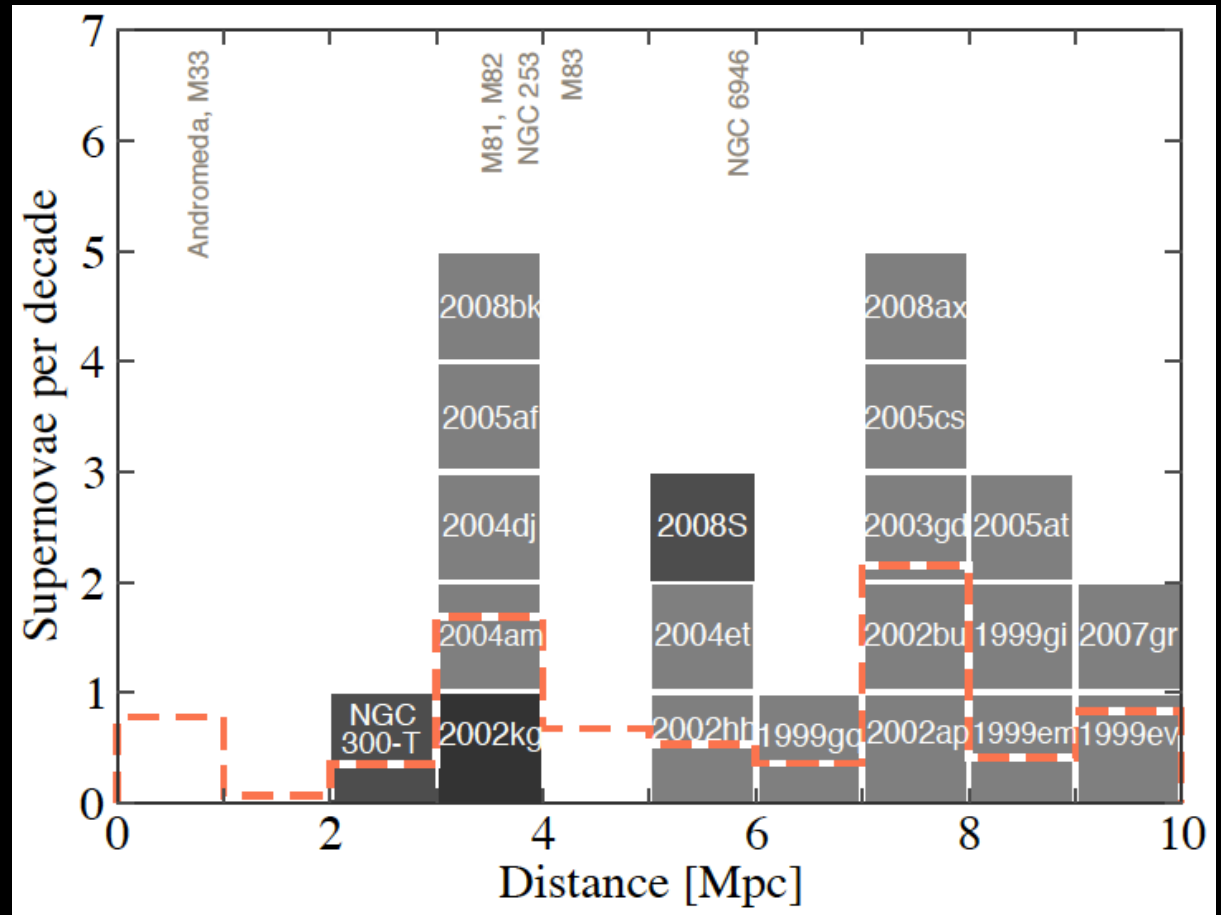
With Hyper-K ($\sim x10$ SK):

- $\sim 10^5$ events from GC
- ~ 4000 events from LMC
- ~ 10 event from M 31
- ~ 1 event from few Mpc away

Supernova rate in nearby galaxies

- Counting the supernovae discovered
- Uncertainties to watch out for:
 - Distance
 - Poisson
 - The sky is not systematically surveyed
 - Highly star forming galaxies, dim supernovae

→ SN rate (<10Mpc)
 $\sim 3 \times 10^{-4} \text{ yr}^{-1} \text{ Mpc}^{-3}$



Kistler et al. (2008)

Ando et al. (2005), Horiuchi et al. (2011)

Supernova rate within 100 Mpc

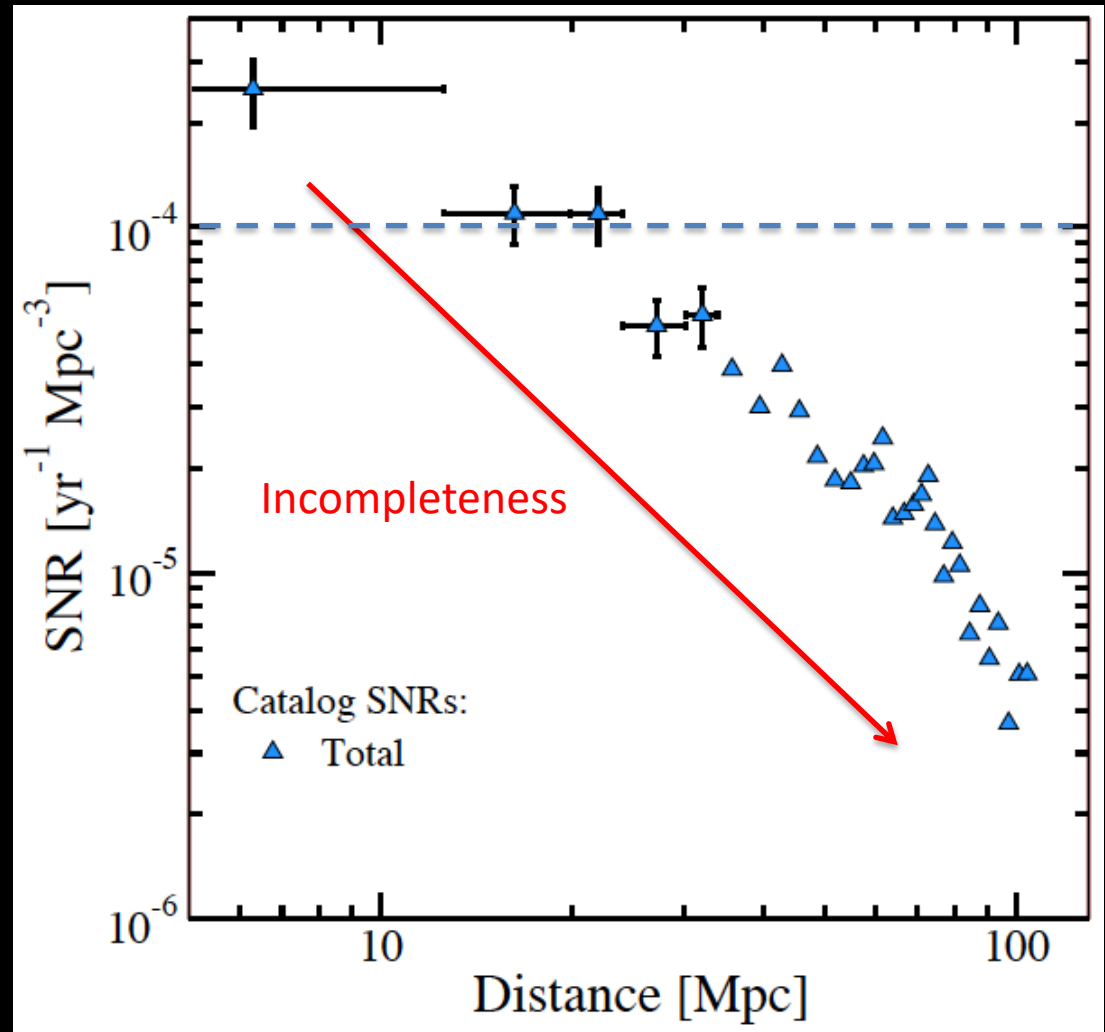
From simple counting

- Within 10 Mpc should be higher than mean
- Beyond local enhancement, rate should be approx flat in distance.

→ decline with distance is due to incompleteness??

- Simplest estimate from galaxy density

$$10^{-2} \text{ (SN/yr)} \times 10^{-2} \text{ (/Mpc}^3\text{)} \\ \sim 10^{-4} \text{ SN/yr/Mpc}^3$$



Horiuchi et al. (2011)

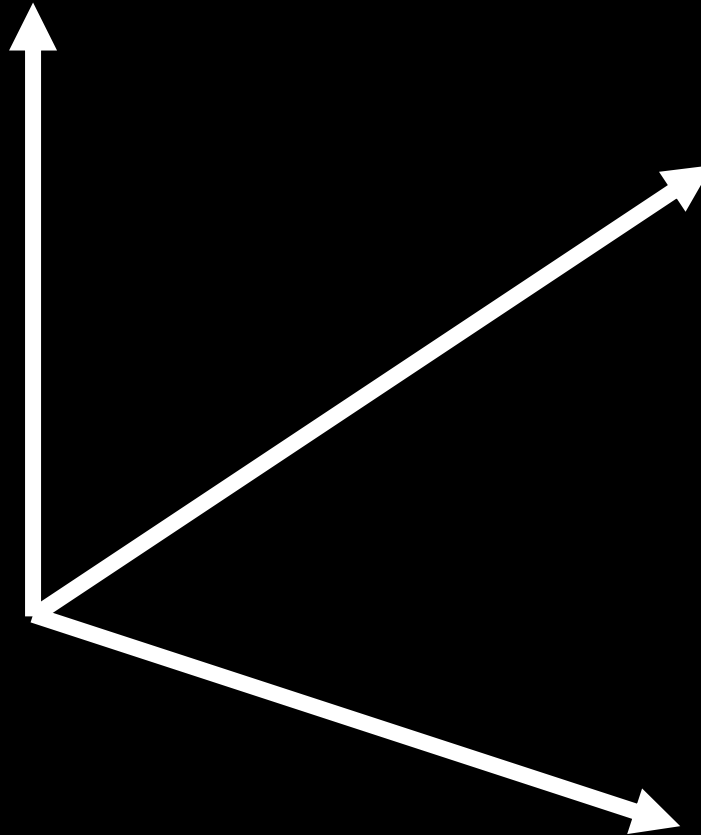
Transient search parameters

How to quantify incompleteness of supernovae?

Cadence (faster is better)
Decay time

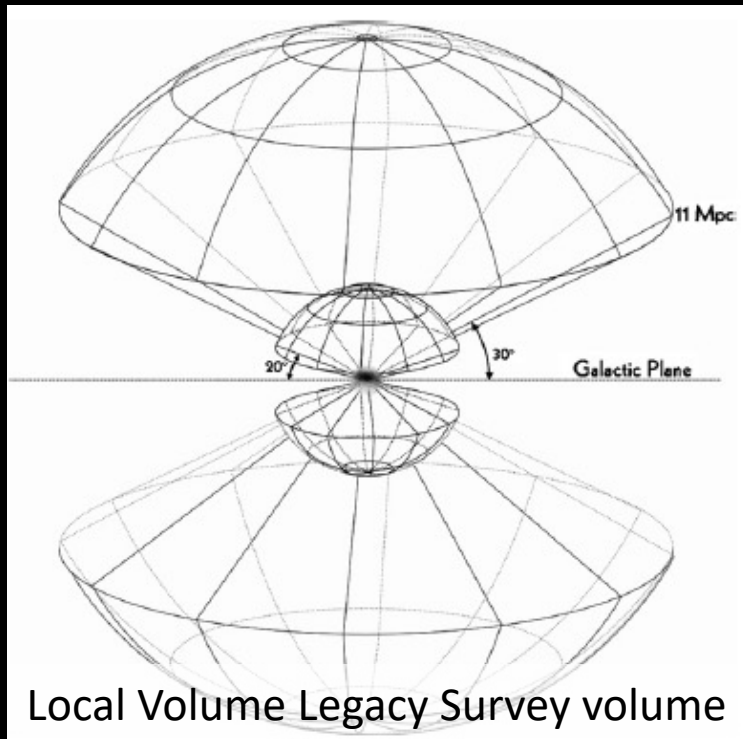
Depth (deeper is better)
Sensitivity

Area (wider is better)
Sky coverage



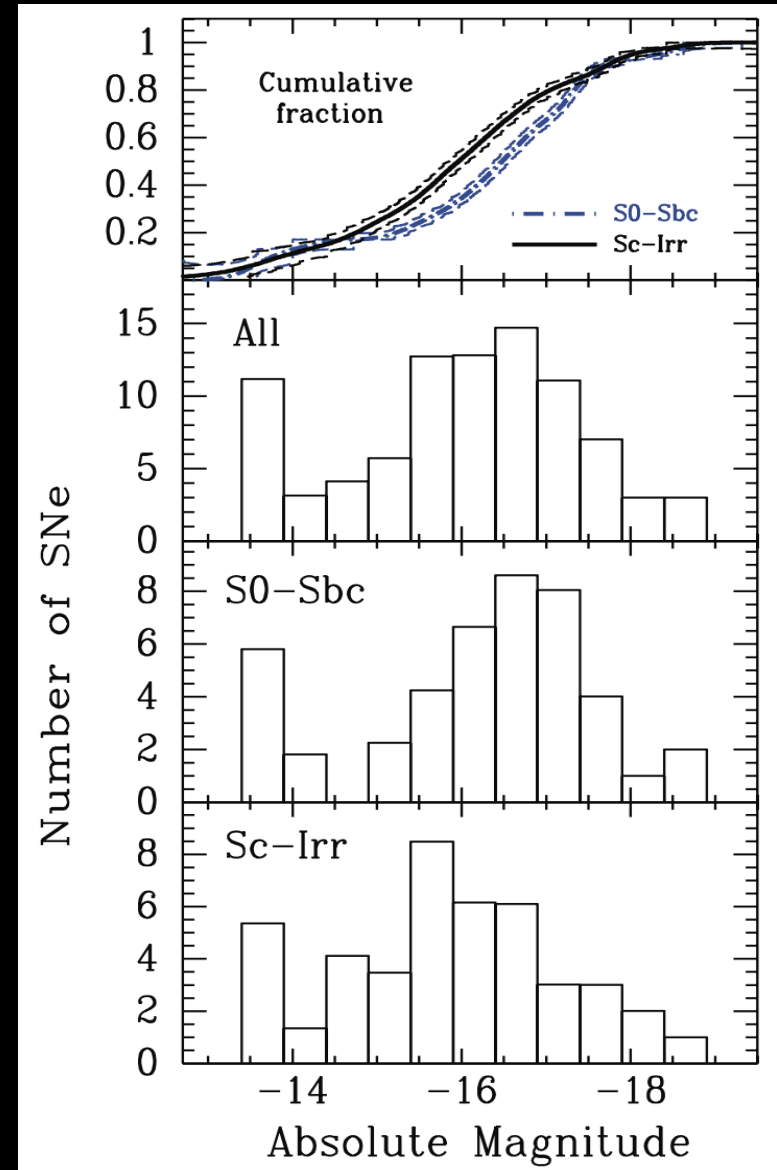
Various corrections are needed

- Sky / depth coverage
 - North-South (raw: 1.9 : 1)
- Faint supernovae (luminosity function)
- (Short duration transients)



Dale et al 2009

➔ Easier to apply to systematic collections



LOSS (Li et al 2011)

Cosmic core-collapse rate

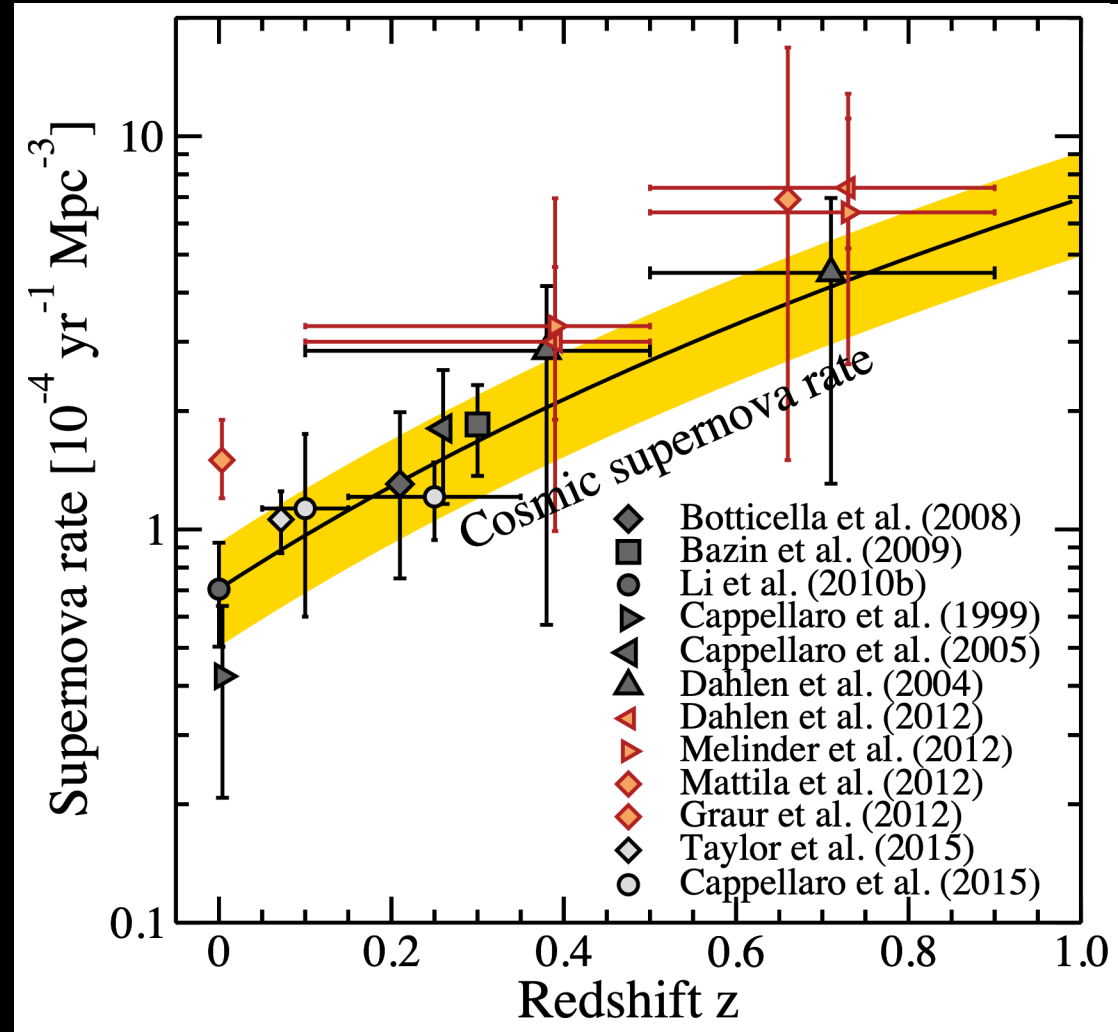
Direct measurements

Find supernovae and apply various corrections.

Broadly, 2 strategies:

1. Efficient but Biased: target pre-selected galaxies, e.g., LOSS, STRESS
2. Unbiased but harder: target pre-selected fields, e.g., SNLS, HST-ACS, DES, ...

→ **Good measurements by many groups**



Updated from Horiuchi et al (2011)

Similarities

Missing supernovae is deliberate

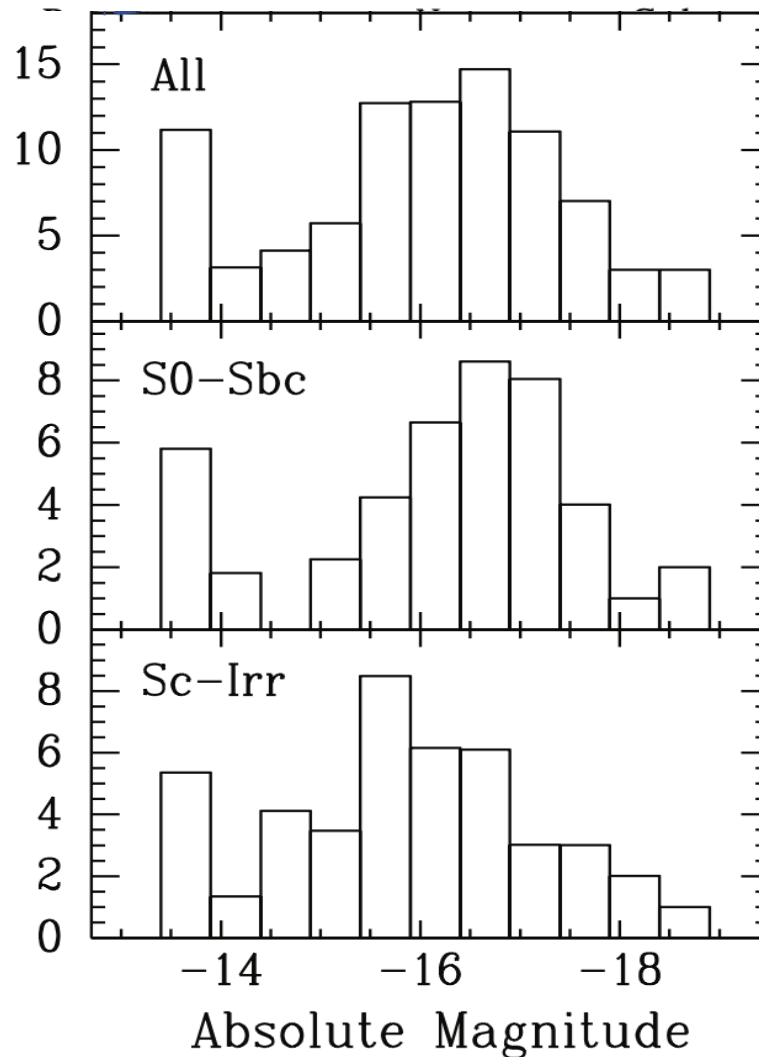
Horiuchi et al (2011)

Redshift

0
0
0.21
0.26
0.3
0.1–0.5
0.5–0.9

Various re

Number of SNe



N_{CCSN}

m_{lim}
(mag)

M_{lim}
(mag)

67	$m_R \sim 16$	...
440	$m_R \sim 19$	$M_R \sim -15.0$
46.1 ^b	$m_R \sim 23$	$M_R \sim -16.7$
19.5	$m_V \sim 23$	$M_V \sim -17.1$
117	$m_i \sim 24$	$M_V \sim -16.4$
6	$m_z \sim 26$	$M_R \sim -14.8$
10	$m_z \sim 26$	$M_V \sim -16.0$

ar limiting luminosity sensitivity

→ Searches are barely observing the peak

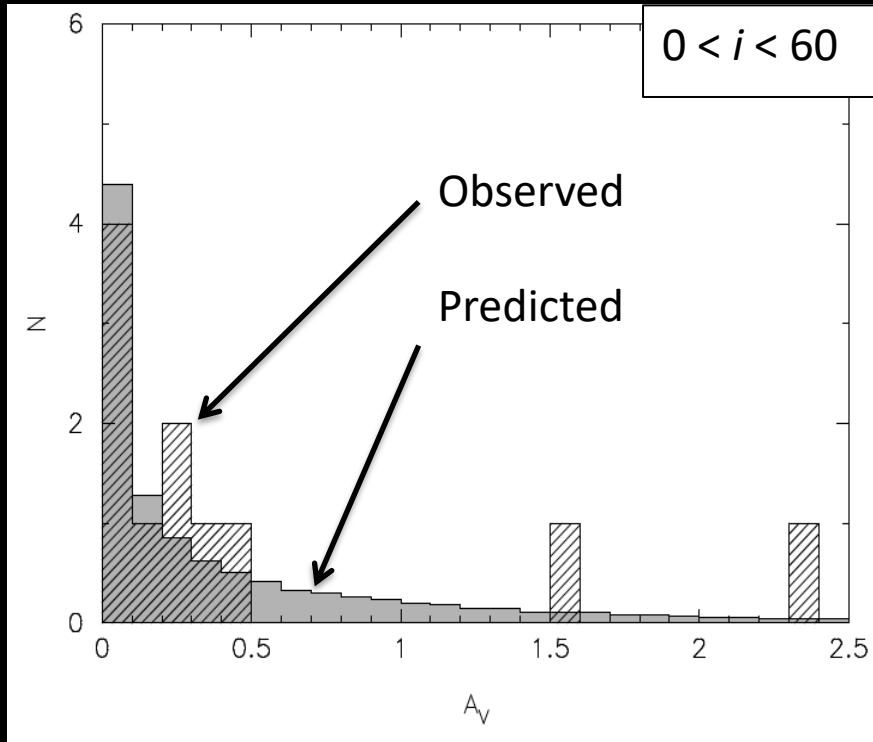
Li et al (2011)

Dust attenuated supernovae

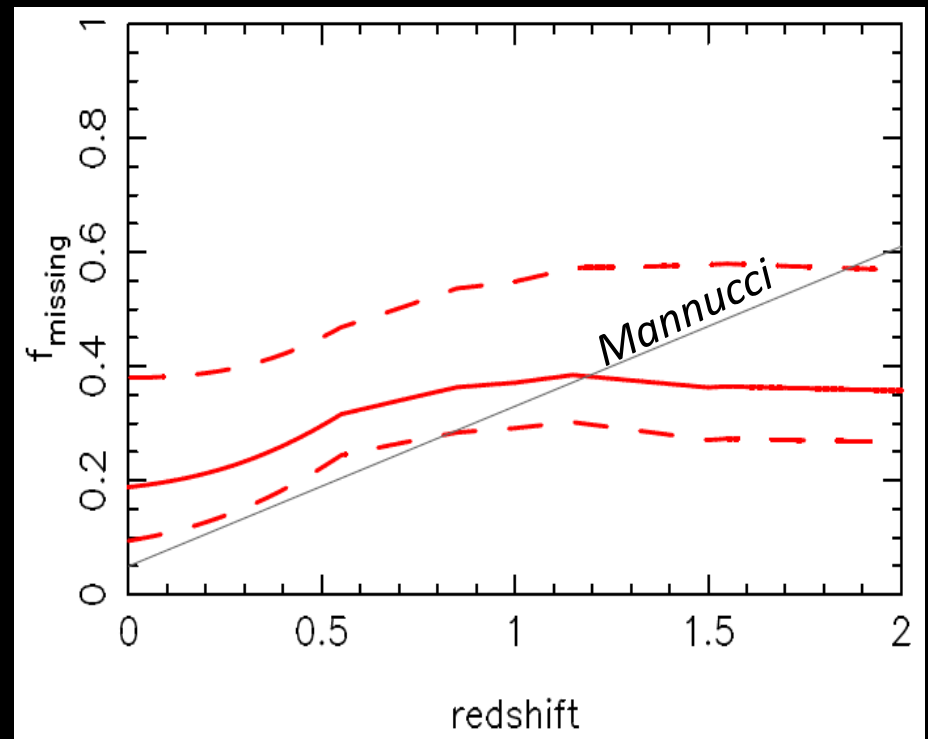
What are these dim supernovae? Mostly dust (probably)

Most of the locally dim supernovae are heavily dust attenuated objects.

Combined with a missing fraction in starbursts of 83% (using Arp 299 study).



Plus outliers (02hh & 09hd with $A_V = 3.7$ & 4.1)



Mattila et al (2012), see also Mannucci et al (2007)

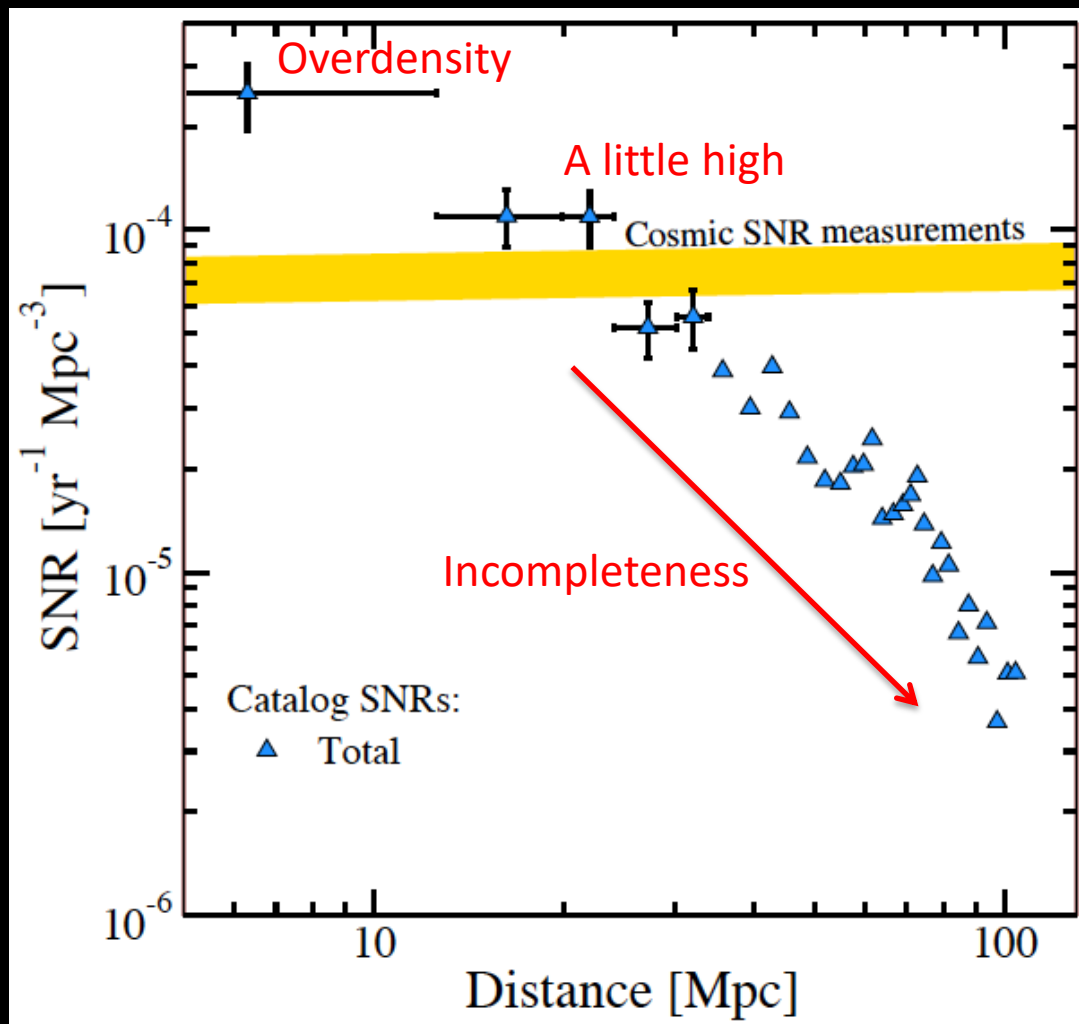
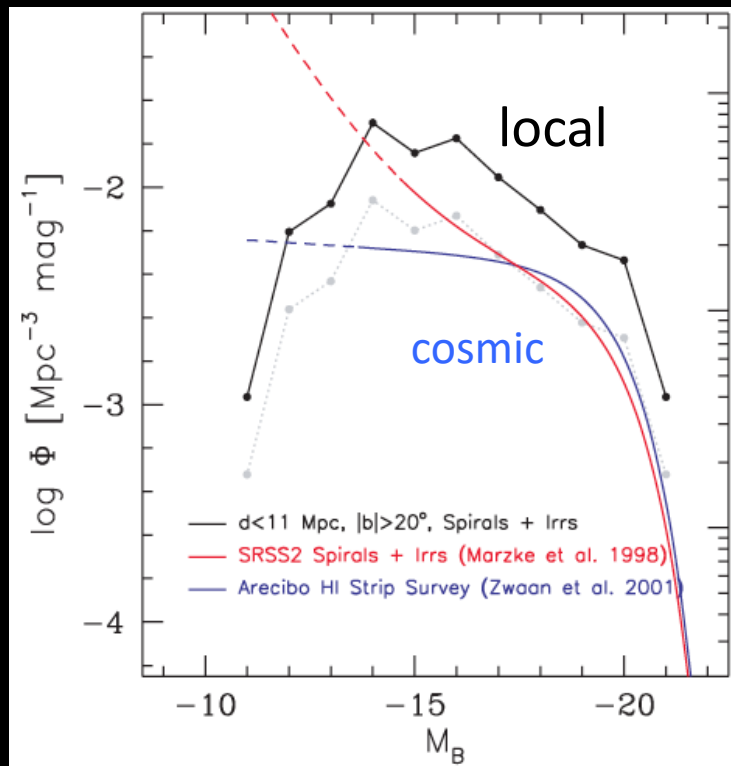
➔ **Missing fraction ($z=0$) is 10-40% (but could be much higher)**

Comparing supernova rates

Use the $z = 0$ cosmic SN rate as a bench mark

→ A high ($\sim \times 3$) rate within $O(10)$ Mpc

compare: B-band luminosity overdensity is $\times 1.7 - 2.0$



← Lee et al (2009)

Horiuchi et al. (2011)

Comparing supernova rates

Use the $z = 0$ cosmic SN rate as a bench mark

→ Around 30 Mpc,
supernova rates are higher
than cosmic by ~50%

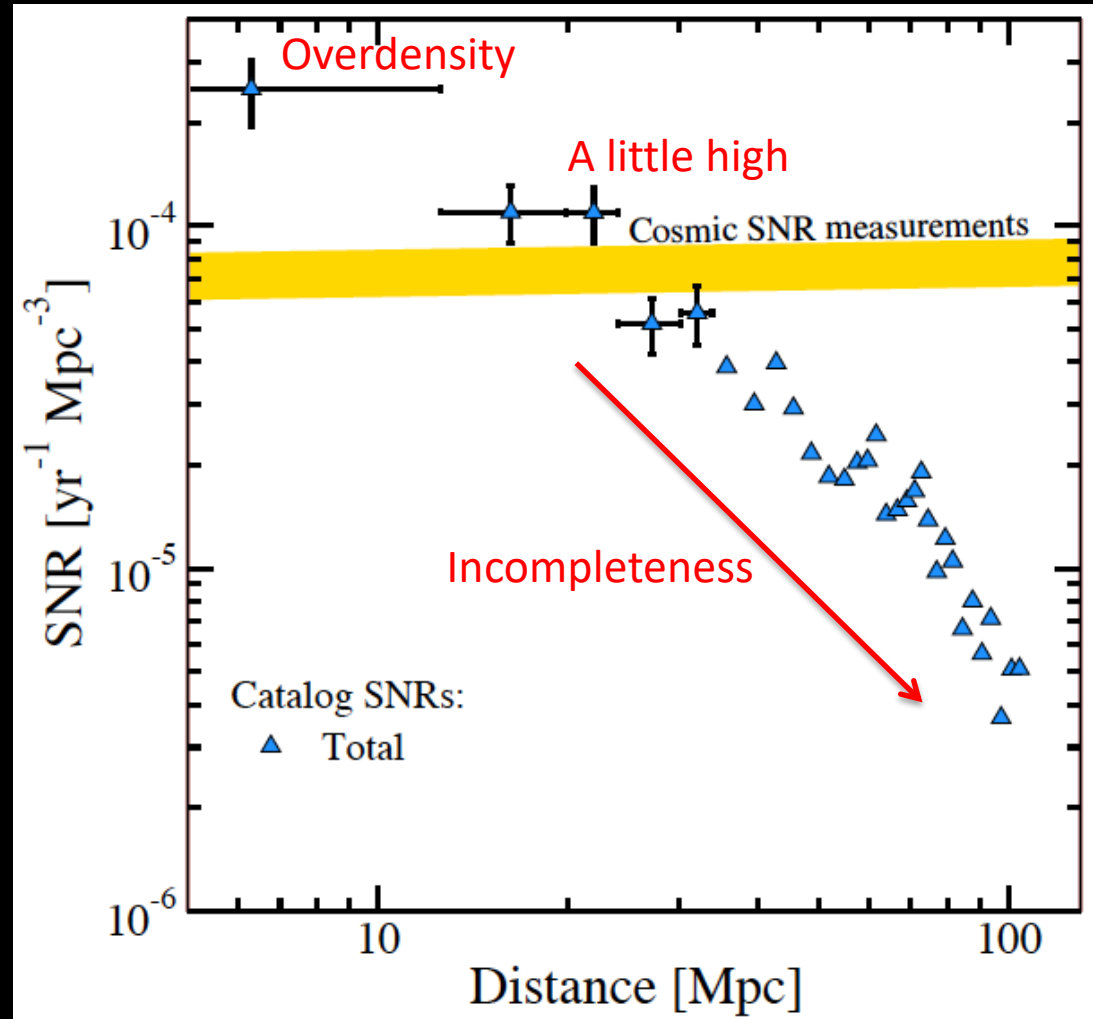
By 30 Mpc, cosmic variance
should be tiny (few percent)

Simply fluctuation?

Or, what can this be?

Supernova counting and
supernova rate don't yield a
full picture.

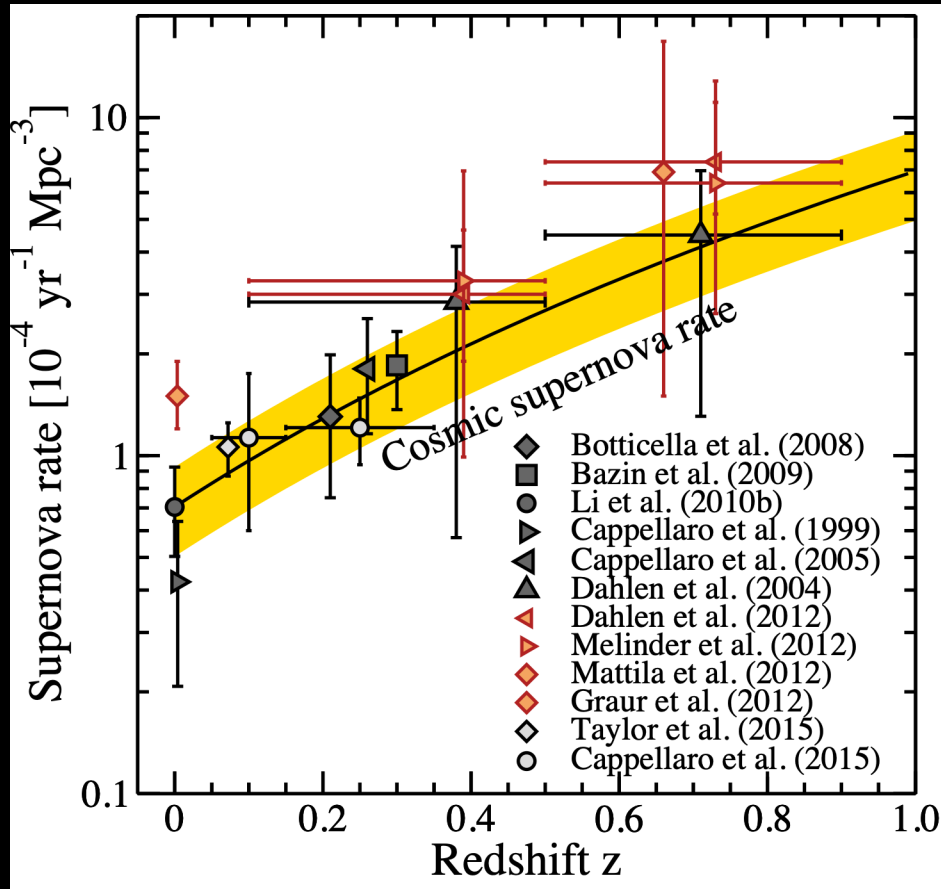
Let's obtain other estimates



Horiuchi et al. (2011)

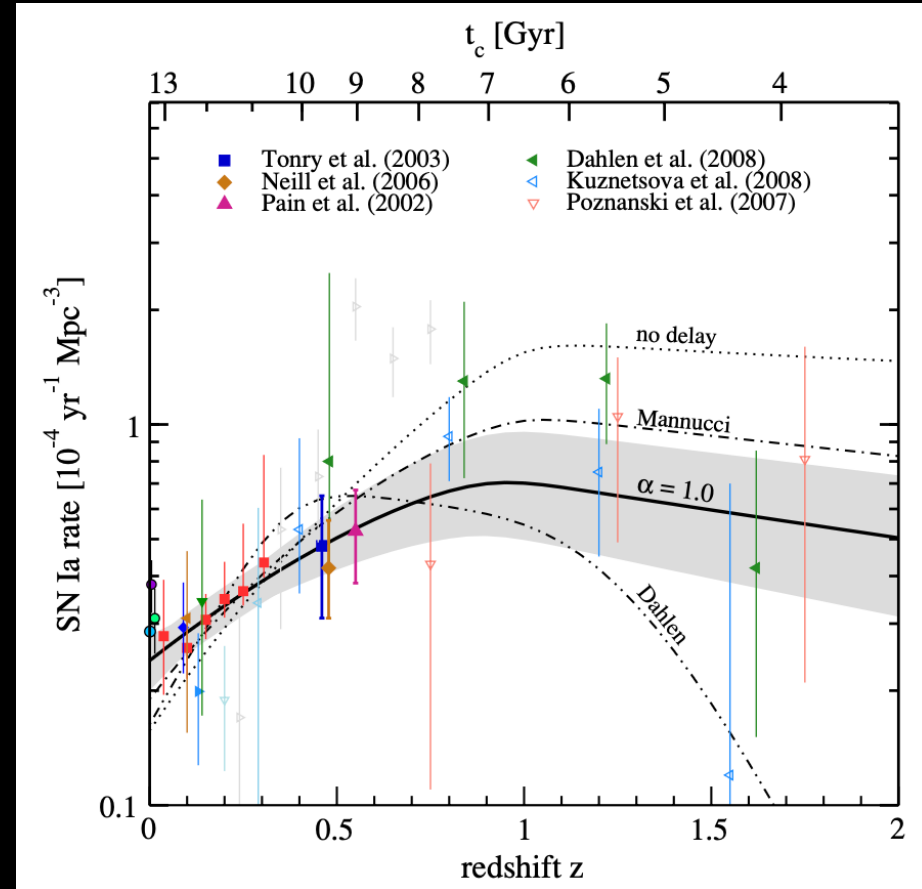
Redshift evolutions

Core-collapse supernovae:



Updated from Horiuchi et al (2011)

Thermonuclear supernovae (Type Ia):



Horiuchi & Beacom (2010)

➔ Slower redshift evolution of Type Ia is due to longer delay wrt progenitor formation

Star formation rates

To measure the star formation rate, we need to track the number of stars with short lifetimes

1. SFR are measured by indicators of the most massive stars
 - e.g., UV, H α , FIR, radio
 - Each has merits & cons
2. Observed luminosities must be corrected for dust attenuation
 - Complicated dust
 - Needs distances
3. Luminosities are then converted to SFR (i.e., all stars including low mass ones)
 - Calibration factors (f_x) needed

H α : hydrogen electron drops from n=3 to n=2

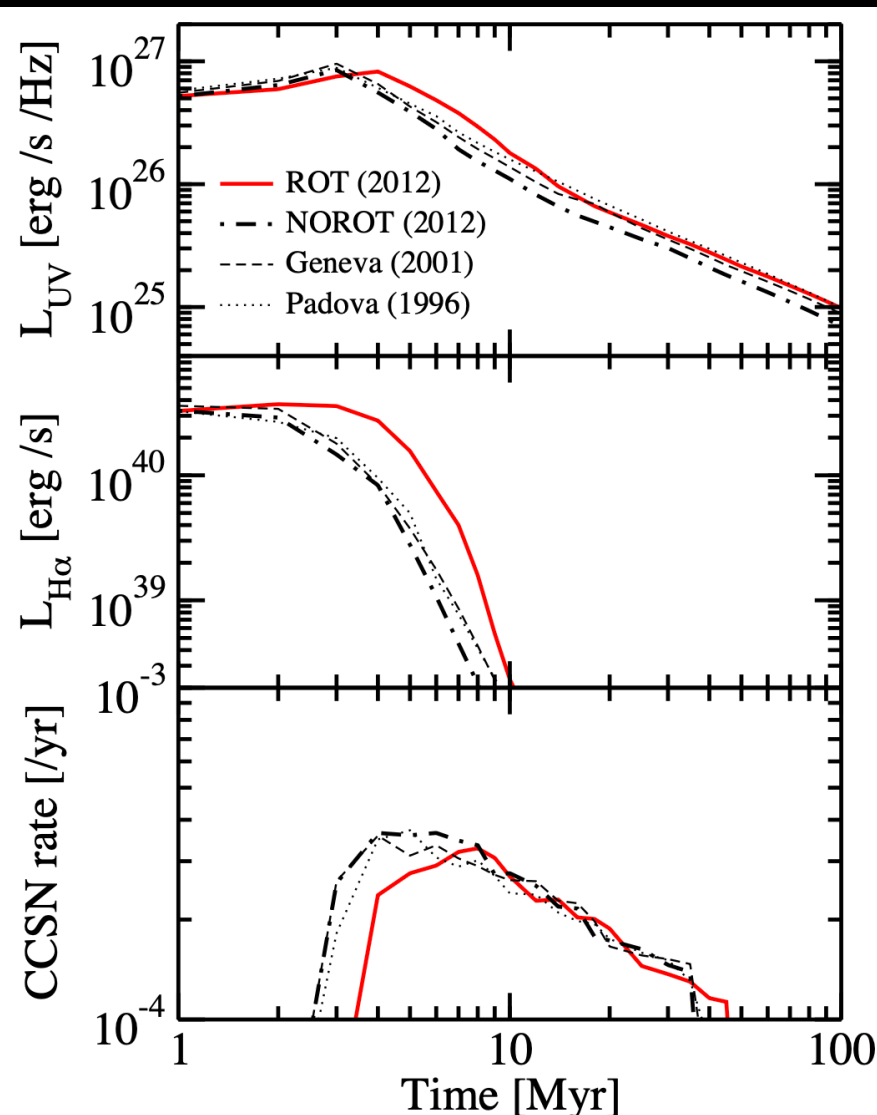
➔ **Many steps...**

$$\text{SFR} = f_x L_x$$

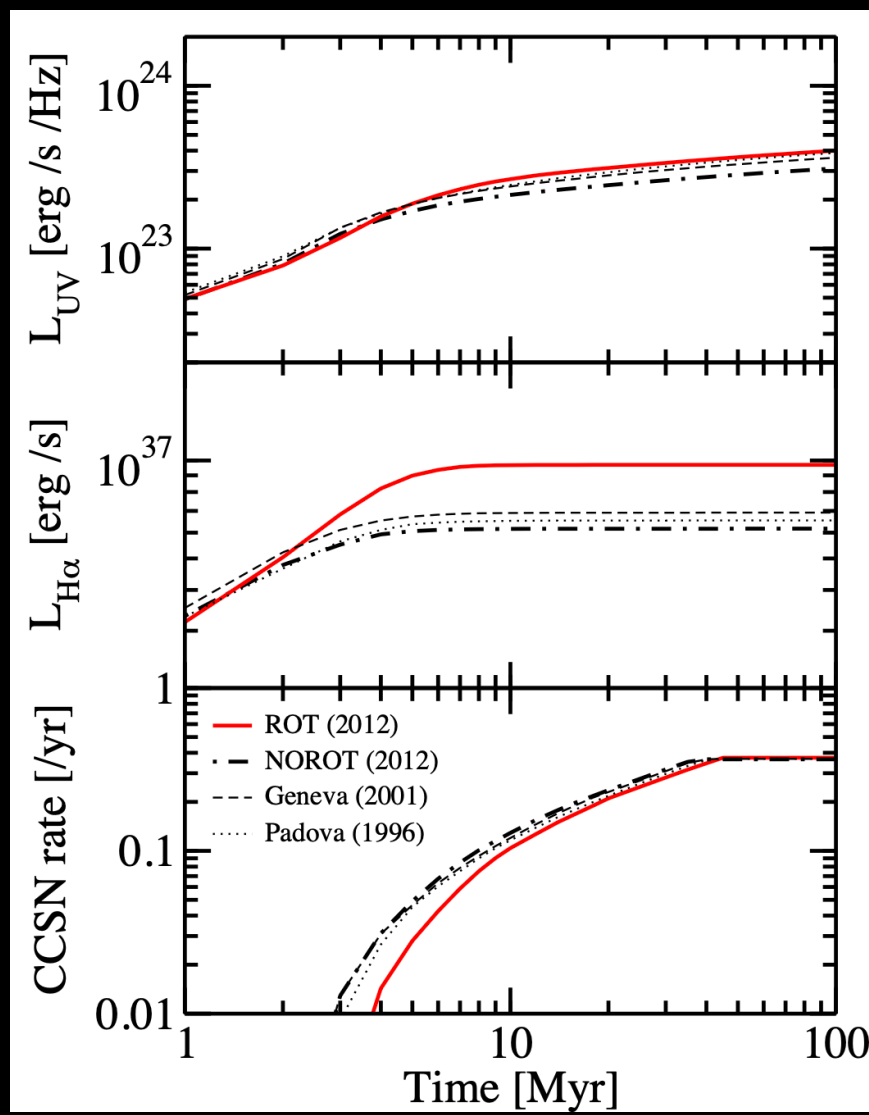
x = UV, H α , FIR, etc,,,

Calibration factors

After a burst of star formation:



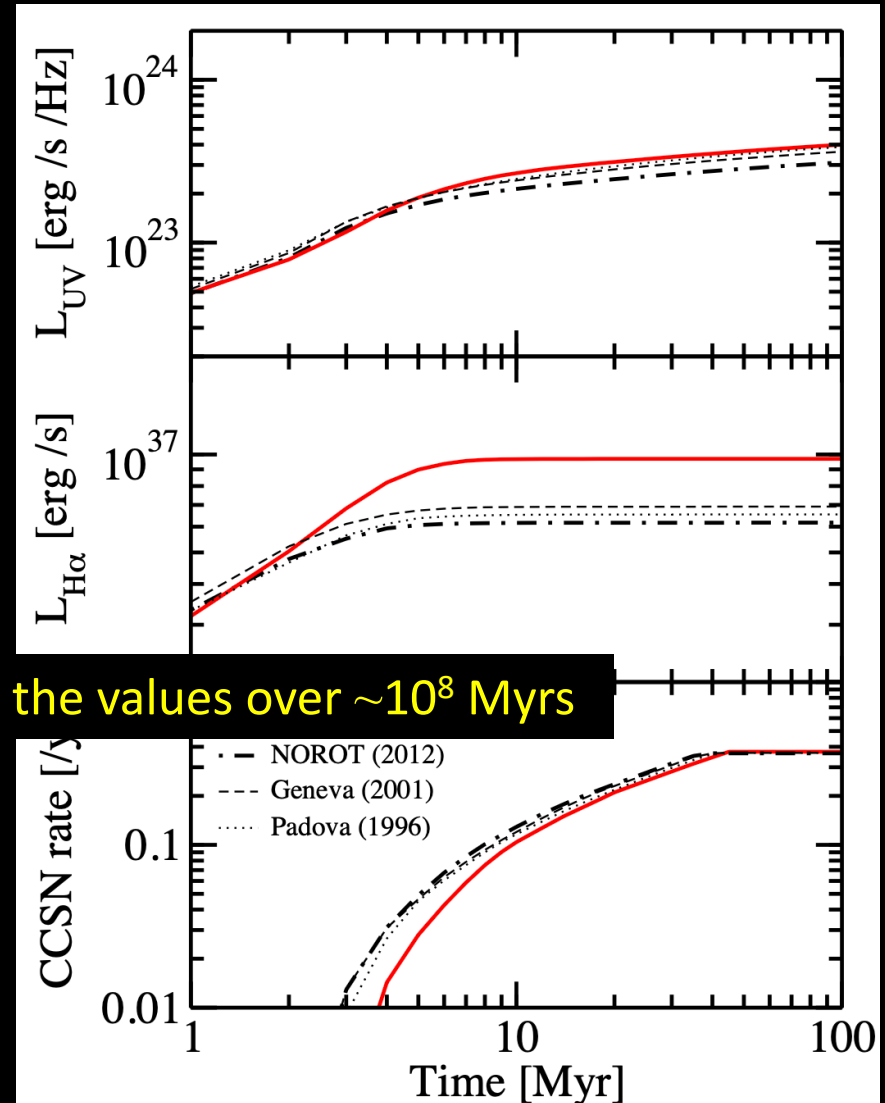
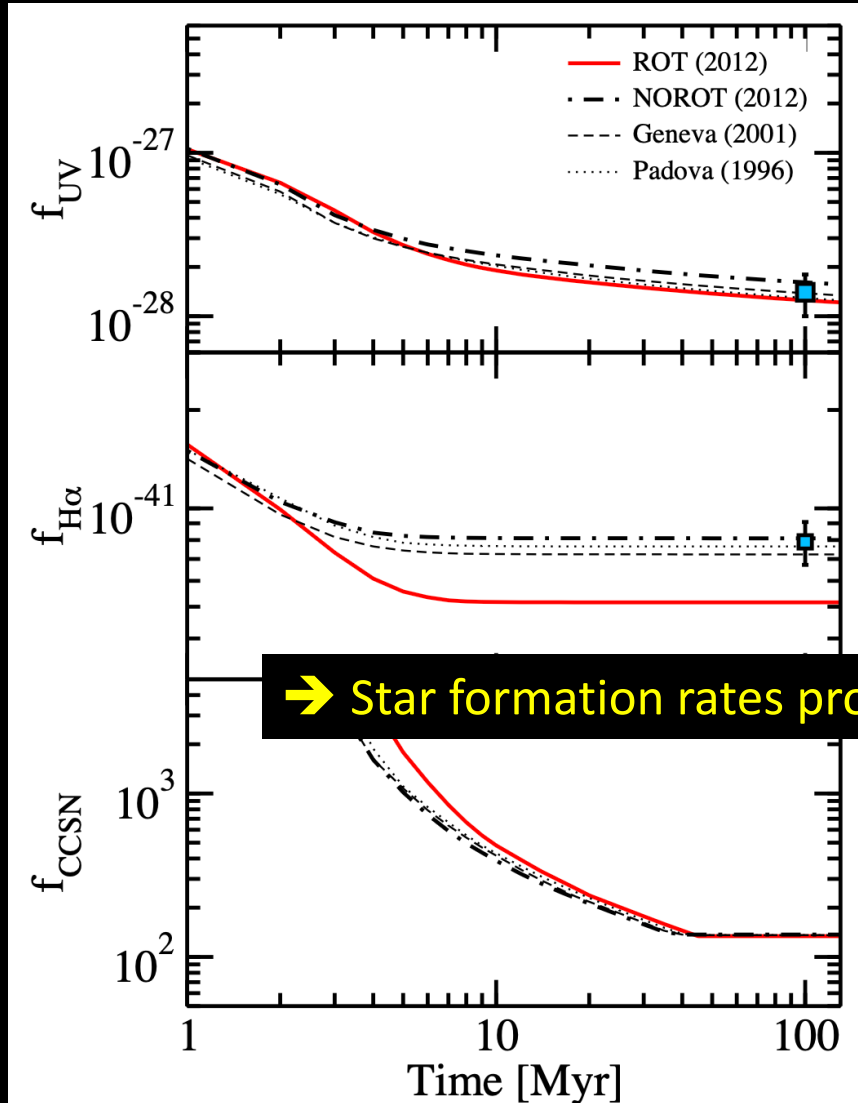
Constant continuous star formation:



Calibration factors

$$\text{SFR} = f_x L_{x_{\text{ion}}}$$

Constant continuous star formation:



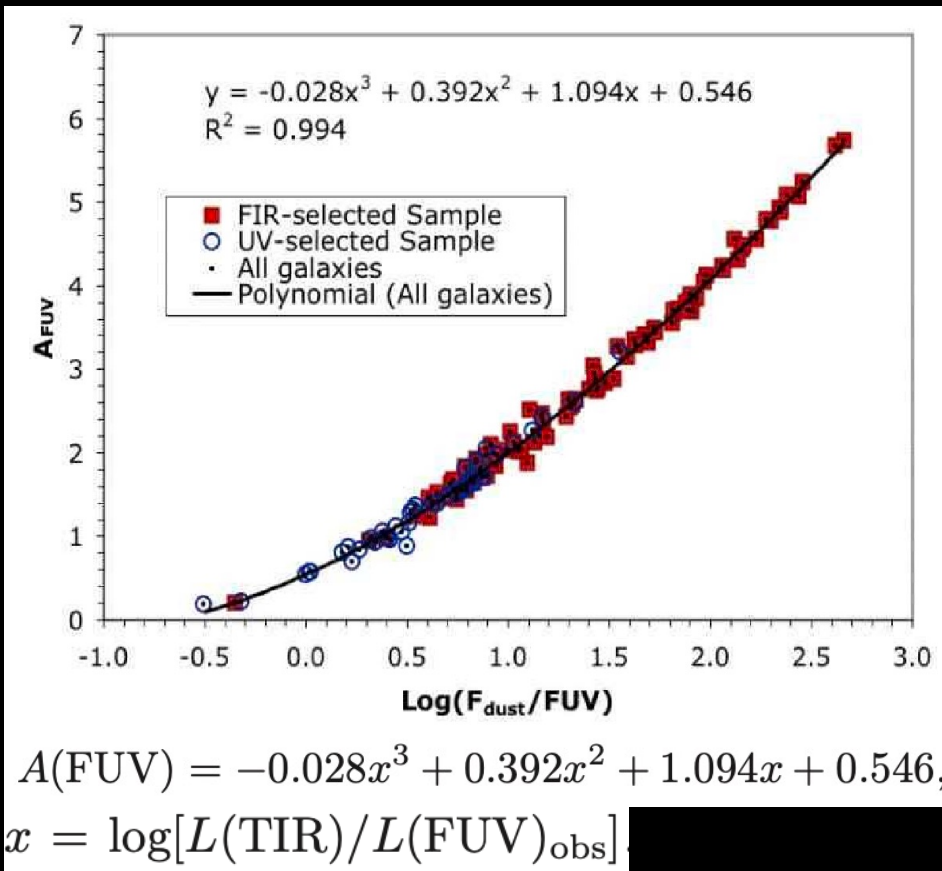
→ Star formation rates probe the values over $\sim 10^8$ Myrs

Dust correction

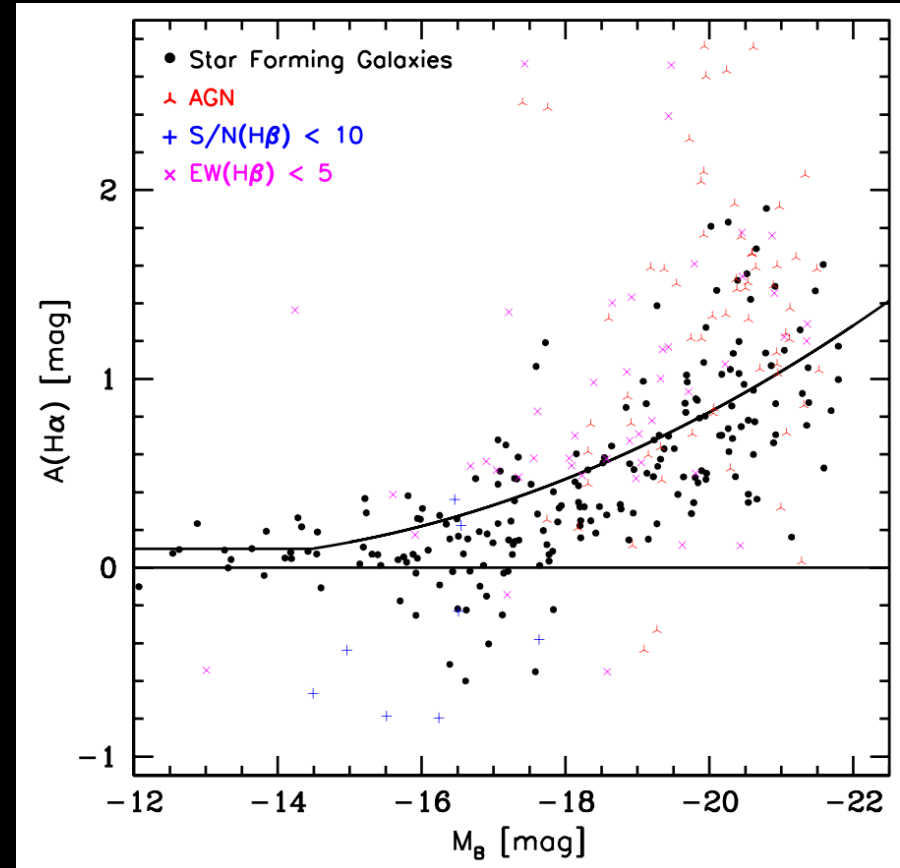
Star formation tracers must be correct for dust attenuation:

UV: about 180 galaxies over 50 – 165 Mpc

H α : About 300 galaxies over 11 Mpc



Burgarella et al (2009)



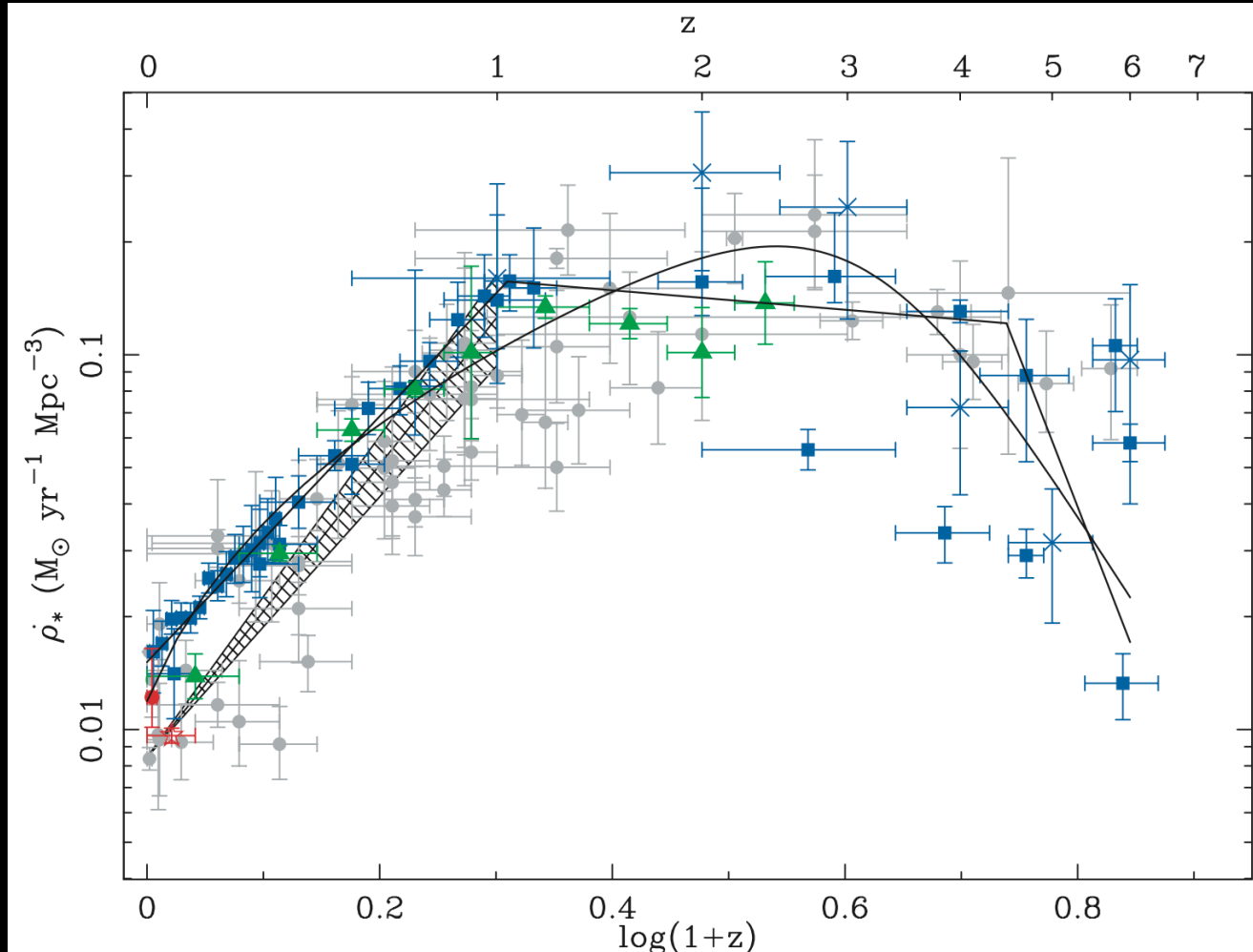
Lee et al (2009)

➔ Dust correction can be large & uncertain

Dust correction

“common” correction scheme: IR star formation is added to the UV star formation

- Compares well to luminosity-dependent schemes (Hopkins 2004)



➔ Simplified dust correction schemes are also common

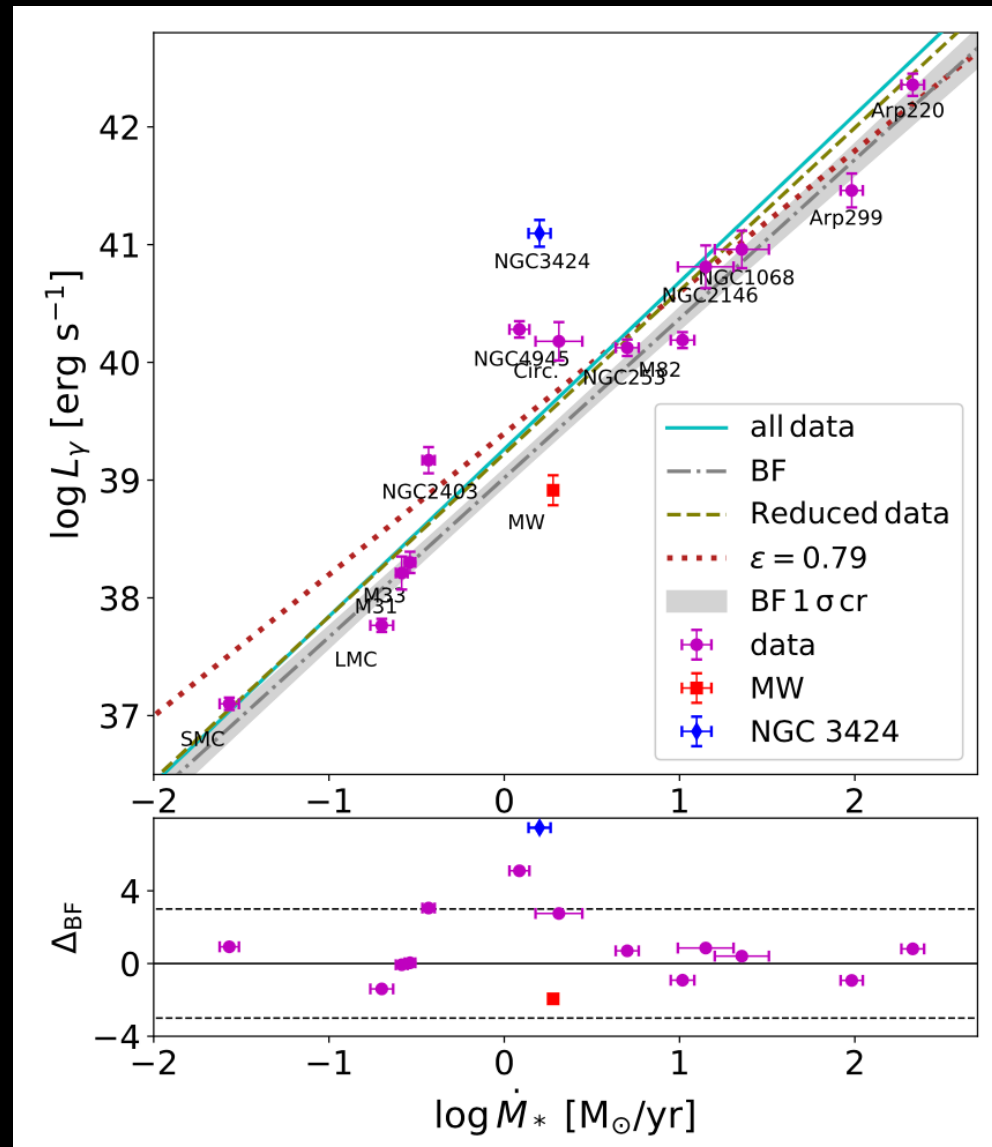
Hopkins & Beacom (2006)

Other tracers

Tracer: anything that traces massive stars

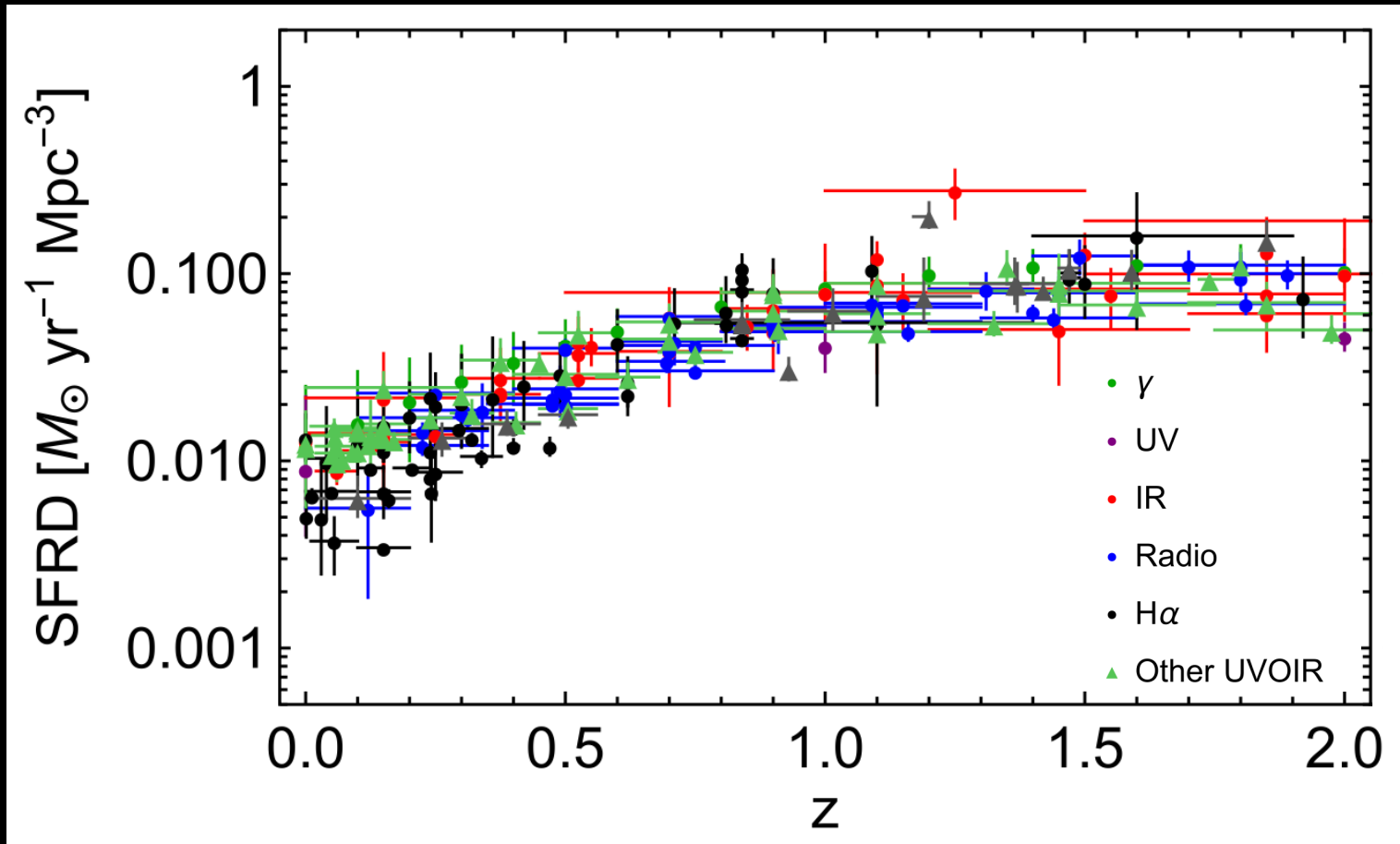
- UV: most direct
- H α : most massive stars
- FIR: indirect (dust reprocessing)
- Radio: indirect (particle acceleration)
- Gamma: indirect (particle acceleration)
- Supernova as well

Differences: dust correction, contamination correction, time scales, sky coverage, sensitivity



Cosmic star formation rates

- Multiple indicators, sample galaxies, dust assumptions, etc
 - **Measurements agree reasonably well (but note the scatter)**
- (Note: these are total star formation rate, not only massive stars)



Massive star formation rates

- The supernova rate can also be predicted. The most accurate and precise prediction comes from the measured star formation rate (SFR)

Core collapse
rate



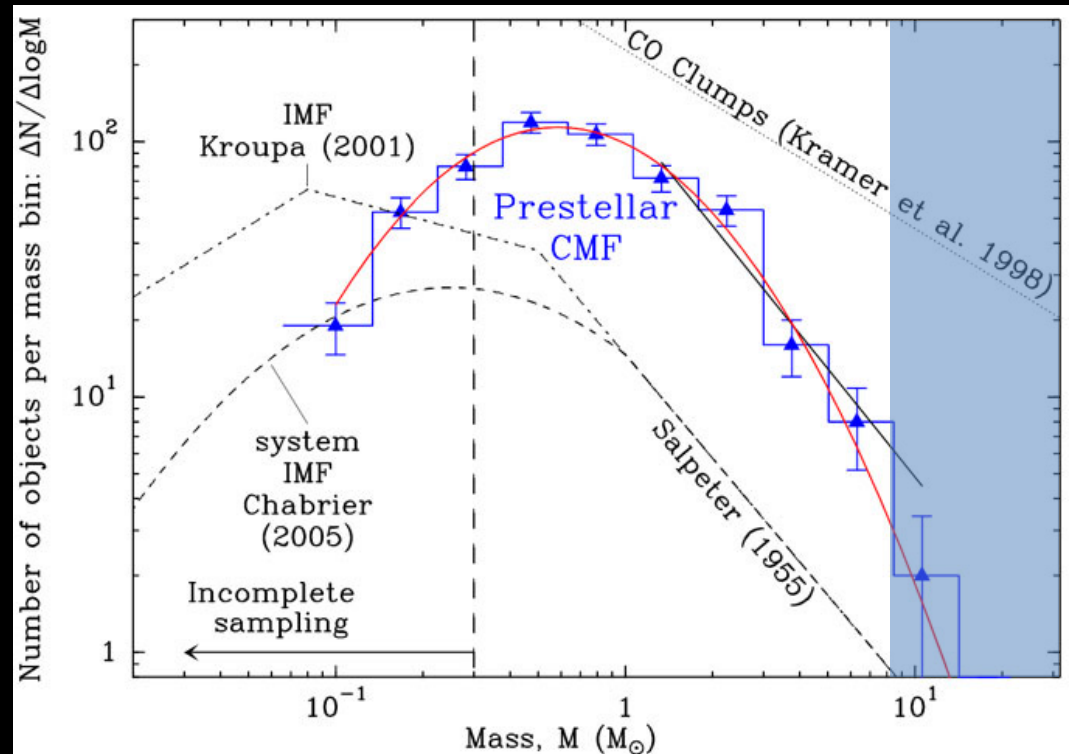
Birth rate of
massive stars

*because lifetime of
massive stars are
cosmologically short

Not all stars are relevant. We
will select only stars that
become supernovae:

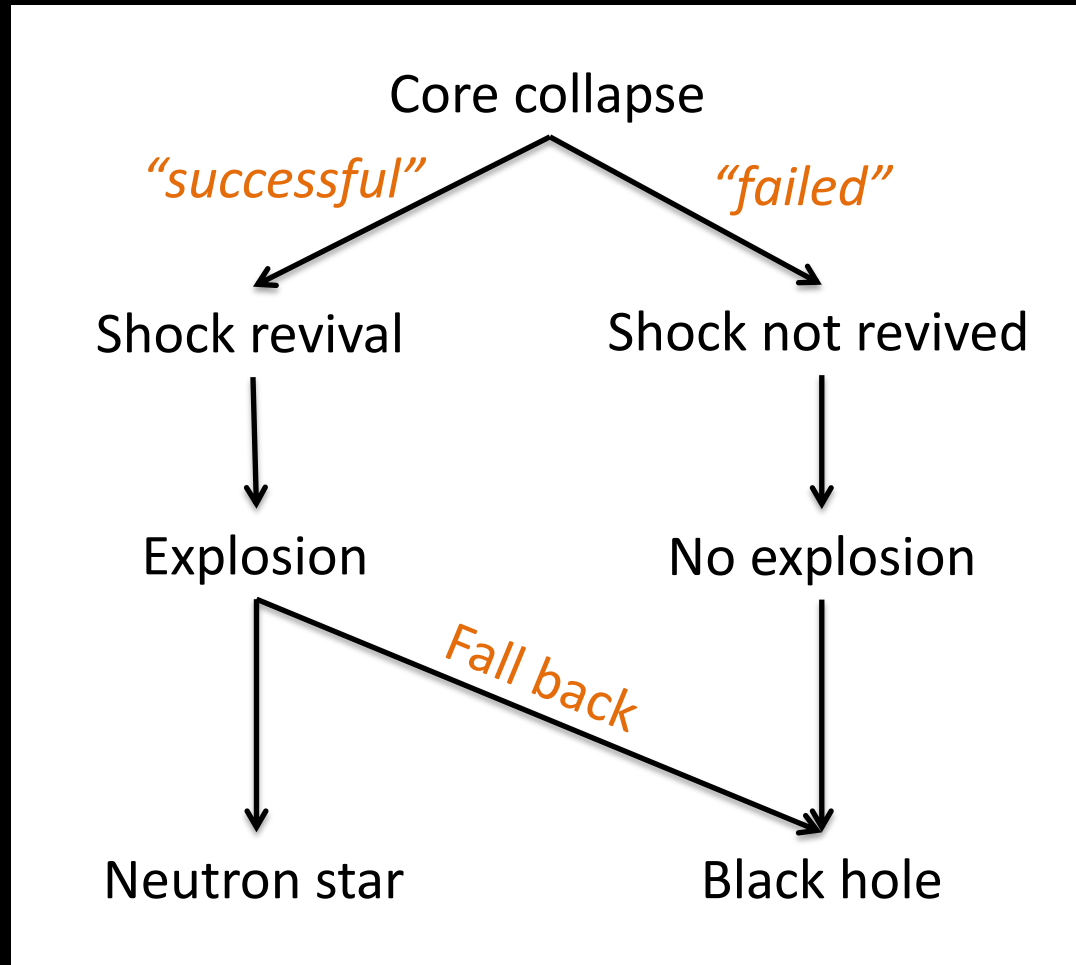
use initial mass function

(approximately 1 out of every
100 Msun of stars formed)



Which stars undergo supernovae?

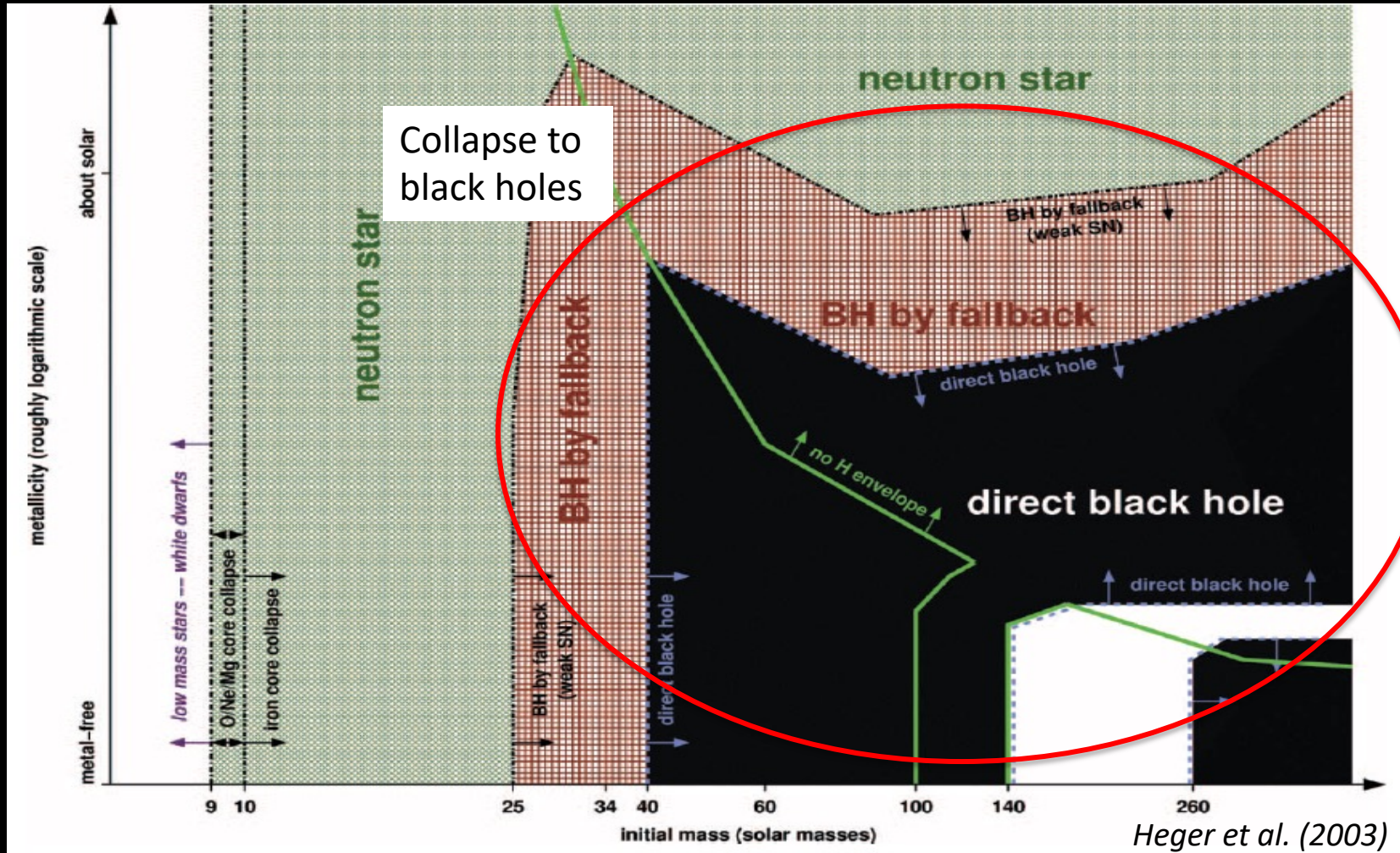
Simple picture



Simple picture

The expectation circa 2000:

Qualitative expectations, no binaries, no rotation, metal-driven mass loss only



Massive star formation rates

- The supernova rate can also be predicted. The most accurate and precise prediction comes from the measured star formation rate (SFR)

Core collapse
rate



Birth rate of
massive stars

*because lifetime of
massive stars are
cosmologically short

Not all stars are relevant. We
will select only stars that
become supernovae:

use initial mass function

$$R_{\text{CCSN}}(z) = \dot{\rho}_*(z) \frac{\int_8^{50} \psi(M) dM}{\int_{0.1}^{100} M \psi(M) dM},$$

ρ : star formation rate density

ψ : initial mass function

cf for Type Ia supernovae

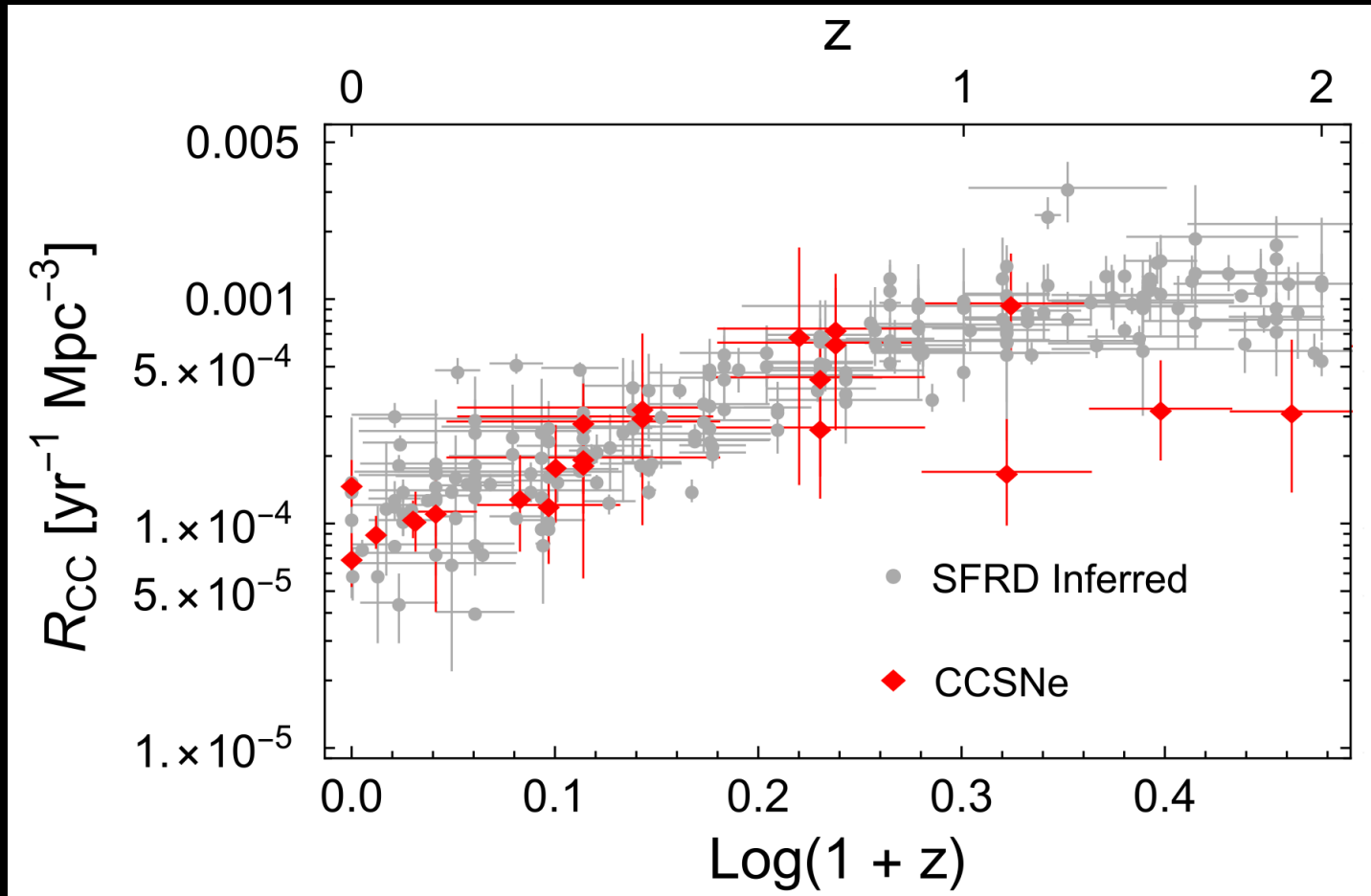
$$R_{\text{Ia}} [z(t_c)] = \eta \int_{t_{10}}^{t_c} \Phi(t_c - t'_c) \dot{\rho}_*[z(t'_c)] dt'_c,$$

Φ : delay time distribution

Cosmic comparison

Compare the star formation rate of massive stars to the supernova rate

- Shape match $\rightarrow$ *implies short delays*
- Normalization match $\rightarrow$ *implies most explode as supernovae*



Nearby star formation rates

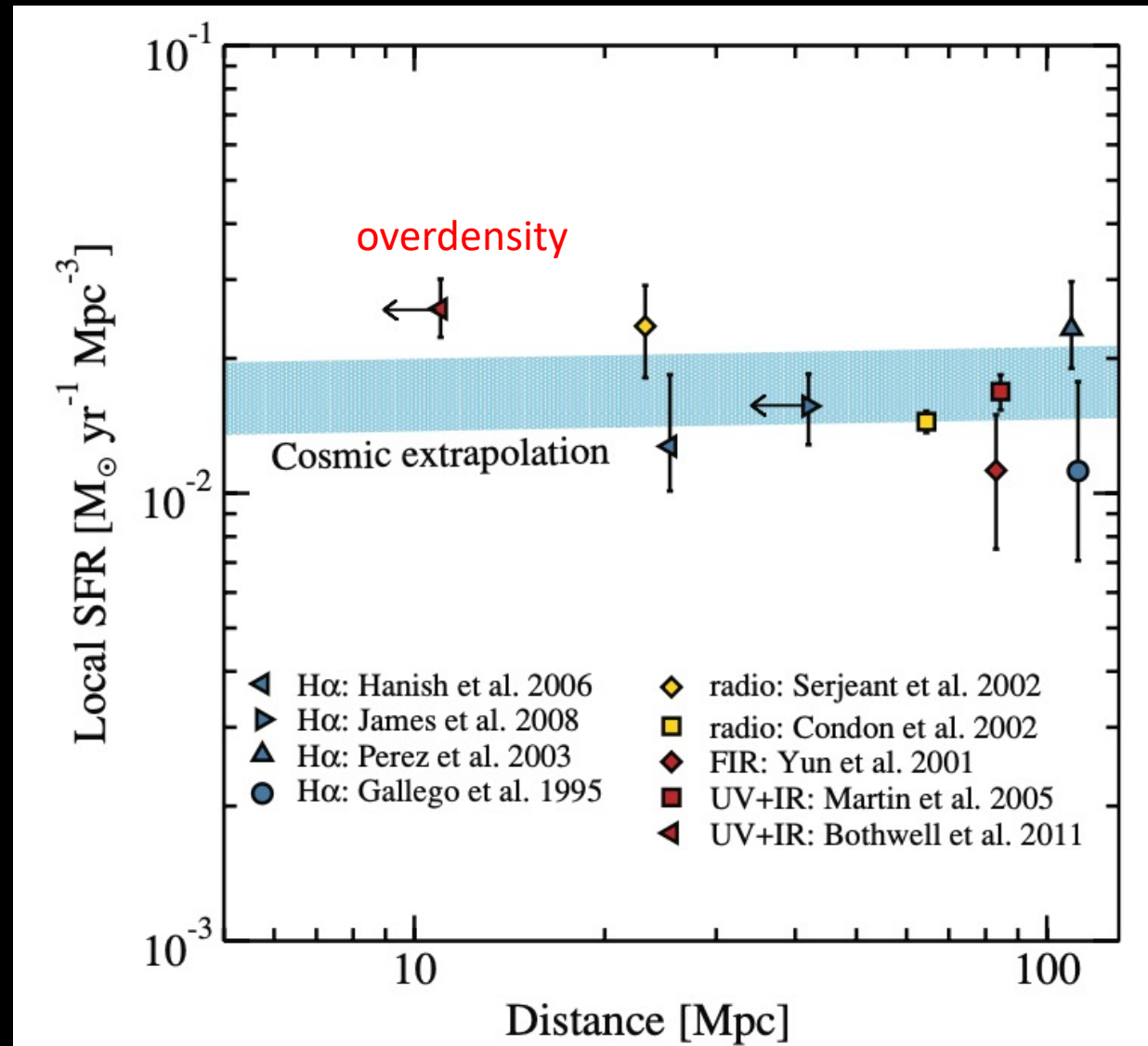
Use knowledge of star formation rate and check with supernova rate for nearby galaxies

1. Catalogues (there are many, these are only the most closest ones)
 - 11 Mpc H α and UV Galaxy Survey (11HUGS, Kennicutt et al 2008)
 - GALEX Nearby Galaxy Survey (Gil de Paz et al 2007)
 - Local Volume Legacy (LVL, Dale et al 2009)
 - Catalog of Neighboring Galaxies (Karachentsev et al., 2004)
→ Nearby Galaxy Catalog (UNGCG) (Karachentsev et al., 2013)
 - 50 Mpc Galaxy Catalog (50 MGC, Ohlson et al 2024)
2. Indicators:
e.g., UV, H α , FIR, radio → 11HUGS is a suitable collection

Nearby star formation rate: < 100 Mpc

1. Excess within ~ 10 Mpc
2. Beyond 20-30 Mpc, the star formation rate connect well to the cosmic rate

→ Star formation rate within 100 Mpc look reasonable



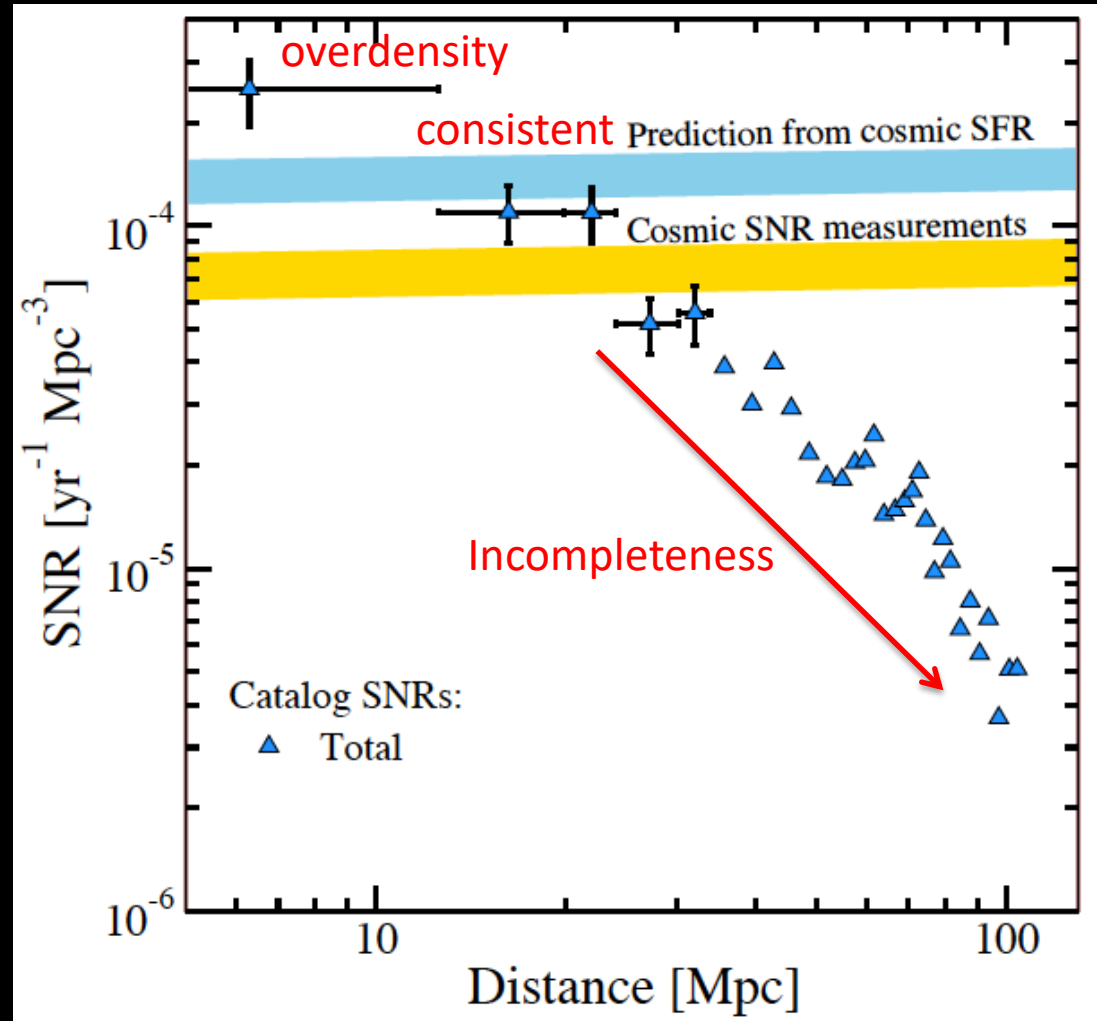
Horiuchi et al (2011)

Compare with supernova rates

Compare star formation rate of massive stars to supernova rates:

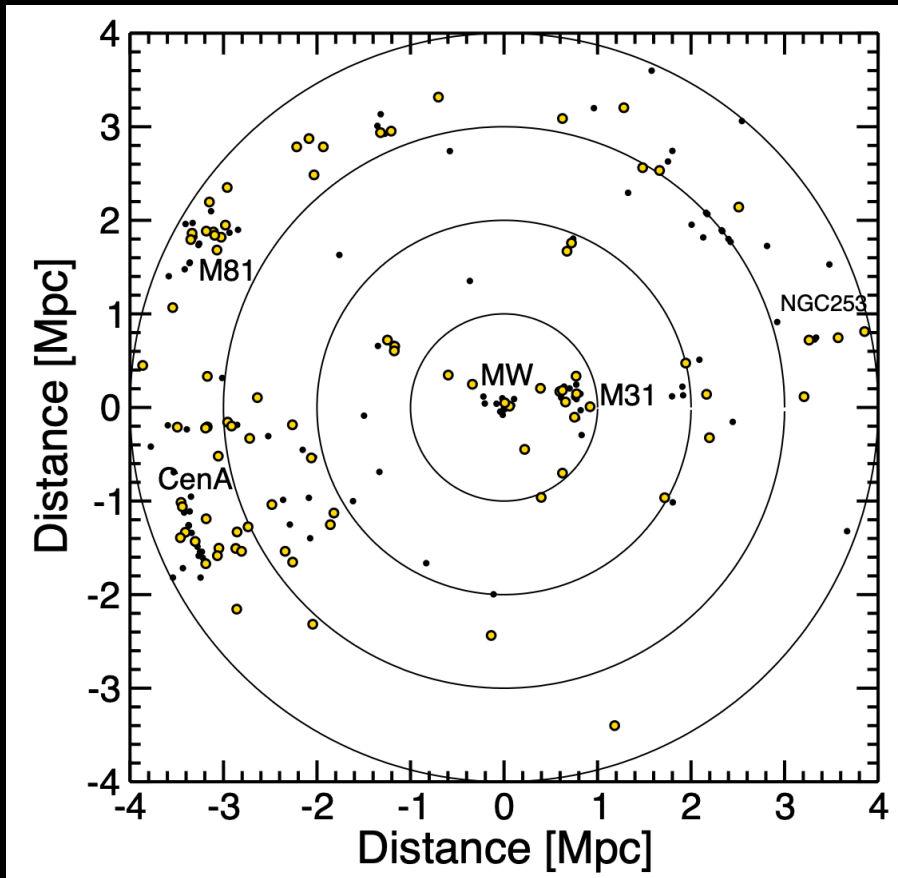
1. The overdensity within 10Mpc looks more reasonable now
2. Beyond, the SFR appears more-or-less compatible with the SN discoveries within ~ 25 Mpc
3. Beyond ~ 25 Mpc still see incompleteness

→ **Completeness divide seems to be around ~ 30 Mpc**

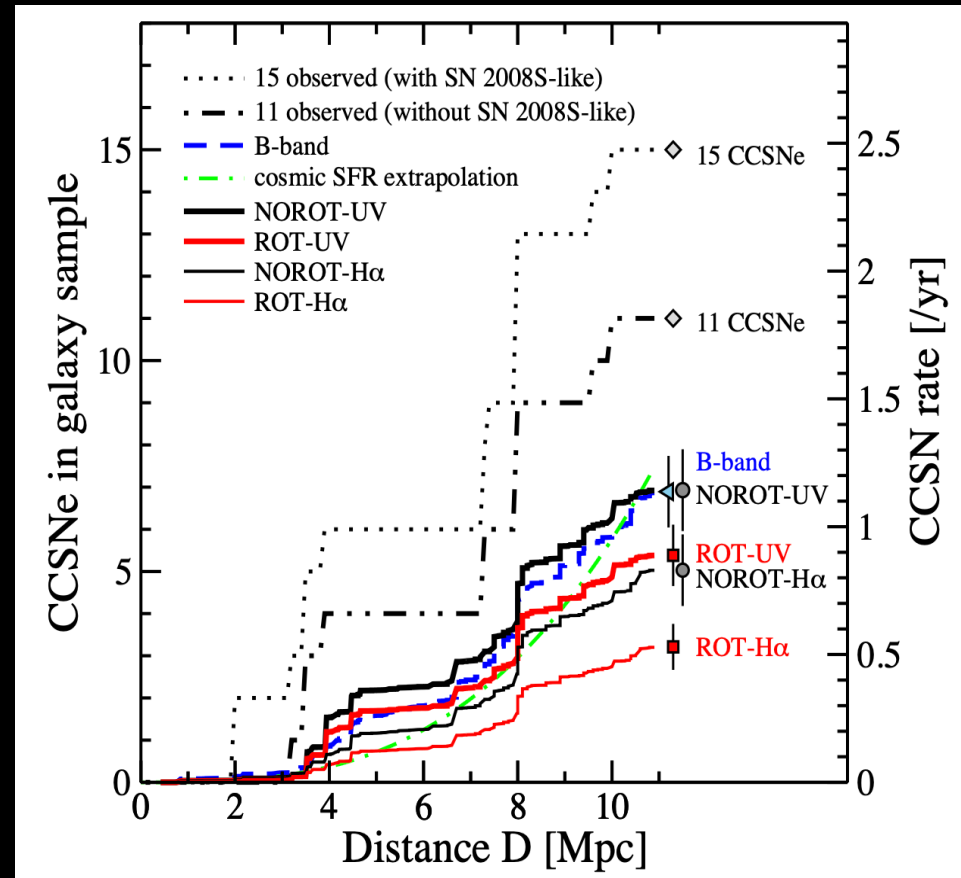


Nearby supernova rates

Galaxy samples $\rightarrow$ tracer luminosities $\rightarrow$ dust correction $\rightarrow$ SFR



Nakamura et al (2016)



Horiuchi et al (2013)

$\rightarrow$ More supernovae found within ~ 11 Mpc than star formation rate

The data base (to ~ 5 Mpc)

Name (1)	RA [°] (2)	dec [°] (3)	Dist [Mpc] (4)	$\log(L_{H\alpha})$ (5)	Abs. B -band (6)	CCSN rate [yr^{-1}] (7)
NGC5236	204.253	-29.866	4.47	41.25	-20.26	0.024
NGC253	011.888	-25.288	3.94	40.99	-20.00	0.013
NGC3034	148.968	+69.680	3.53	41.07	-18.84	0.012
NGC5128	201.365	-43.019	3.66	40.81	-20.47	0.009
NGC3031	148.888	+69.065	3.63	40.77	-20.15	0.008
Maffei2	040.479	+59.604	3.30	40.76	-20.22	0.008
UGC2847	056.704	+68.096	3.03	40.65	-20.58	0.007
NGC4945	196.365	-49.468	3.60	40.75	-19.26	0.006
NGC2403	114.214	+65.603	3.22	40.78	-18.78	0.006
NGC4449	187.047	+44.093	4.21	40.71	-18.17	0.005

Only the first ten rows are shown in this table. The full list is available in online material.

<http://th.nao.ac.jp/MEMBER/nakamura/2016multi/>

The CCSN rates are derived from their B -band magnitudes and the LICK SNUB rates.

The galaxy catalog is based on the compilation of [Karachentsev et al. \(2013\)](#).

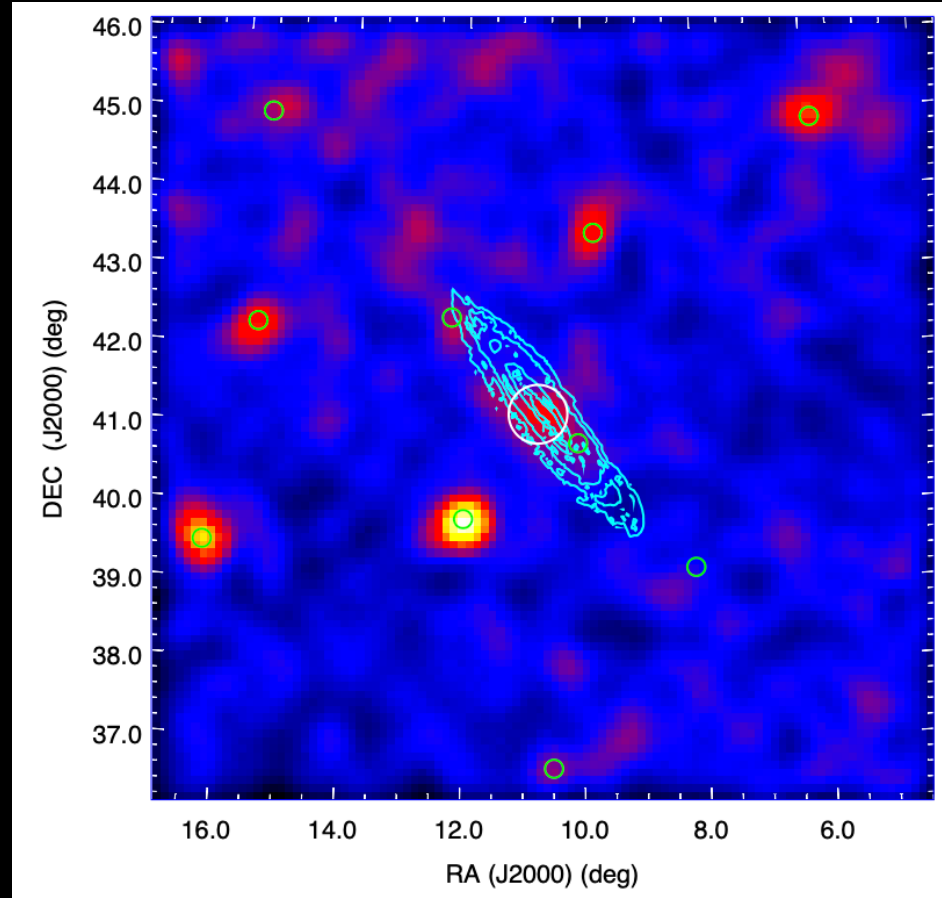
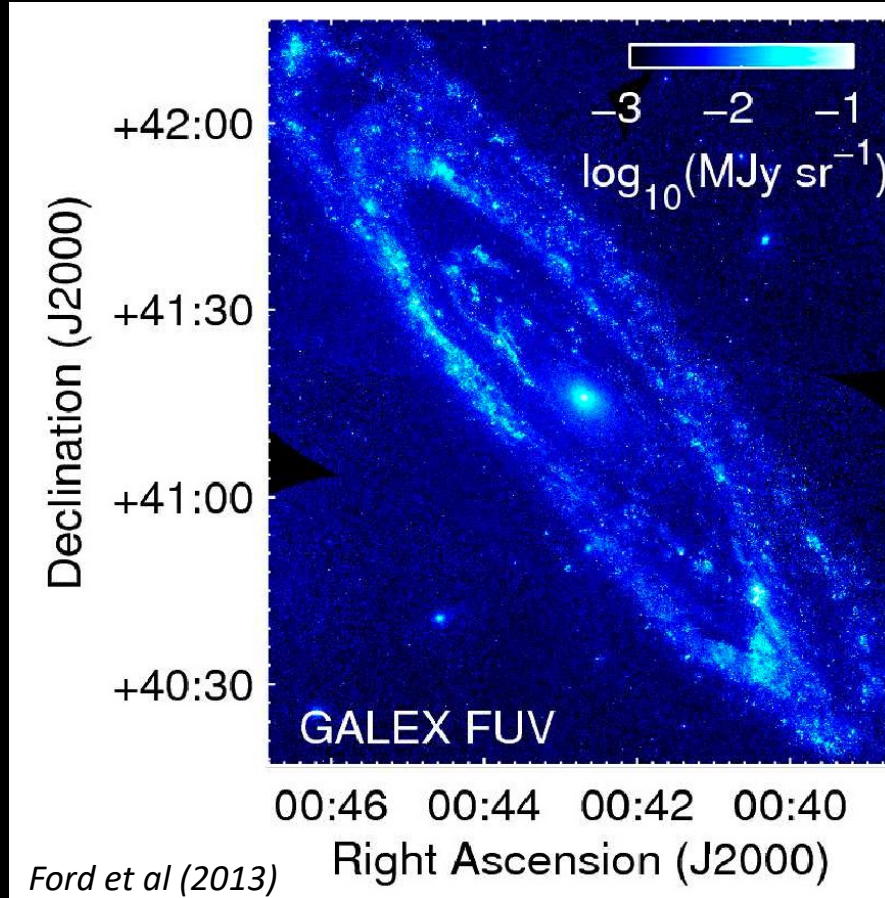
The columns show (1) the galaxy name, (2,3) RA and declination, (4) distance, (5) log of $H\alpha$ luminosity, (6) absolute B -band magnitude, (7) derived CCSN rate.

Nakamura et al (2016)

Focus: Andromeda galaxy

Star formation is in a ring of ~ 10 kpc

...but gamma ray is centrally concentrated.

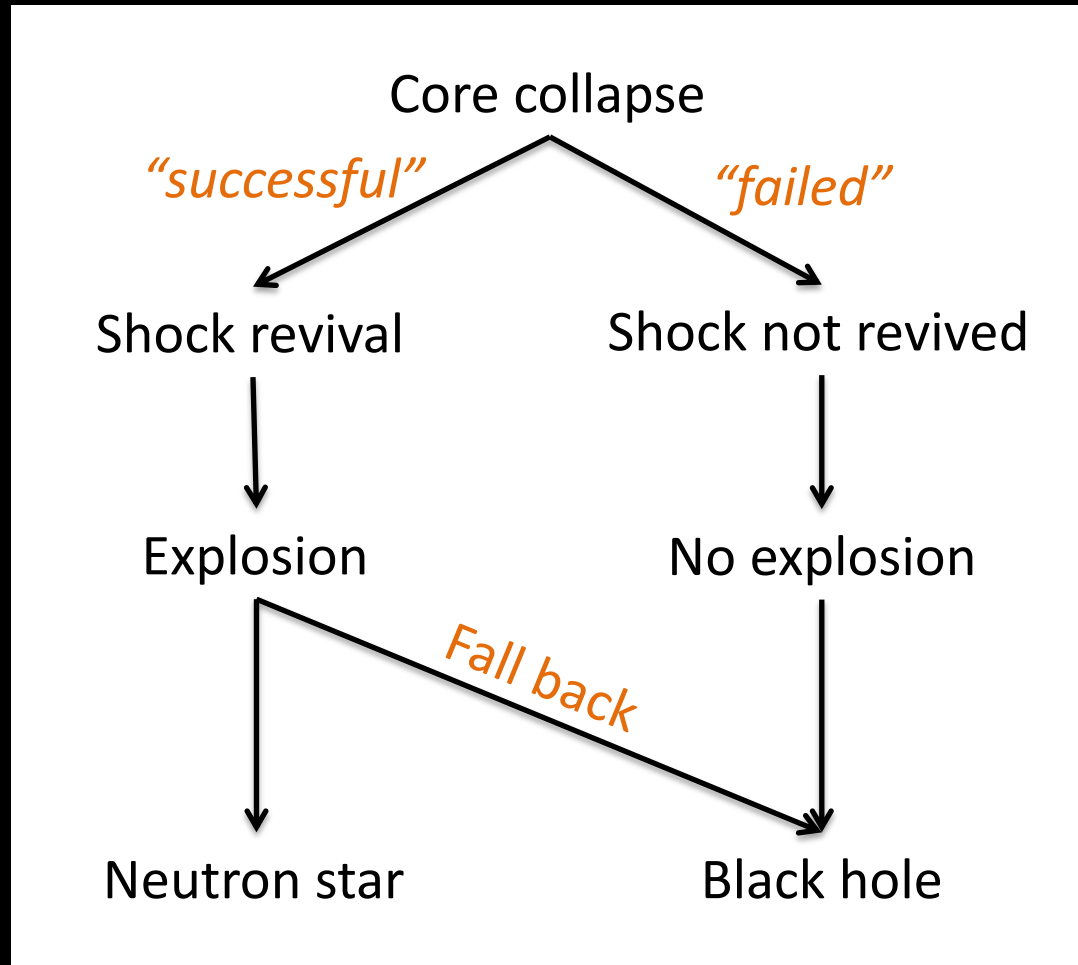


- mass $\sim 1.2 \times 10^{12}$ Msun (about MW)
- distance ~ 780 kpc (closest spiral)
- SFR ~ 0.2 Myr/yr (lower than MW)

➔ Be careful which indicator. Gamma & radio needs cosmic-ray transport

Which stars undergo supernovae?

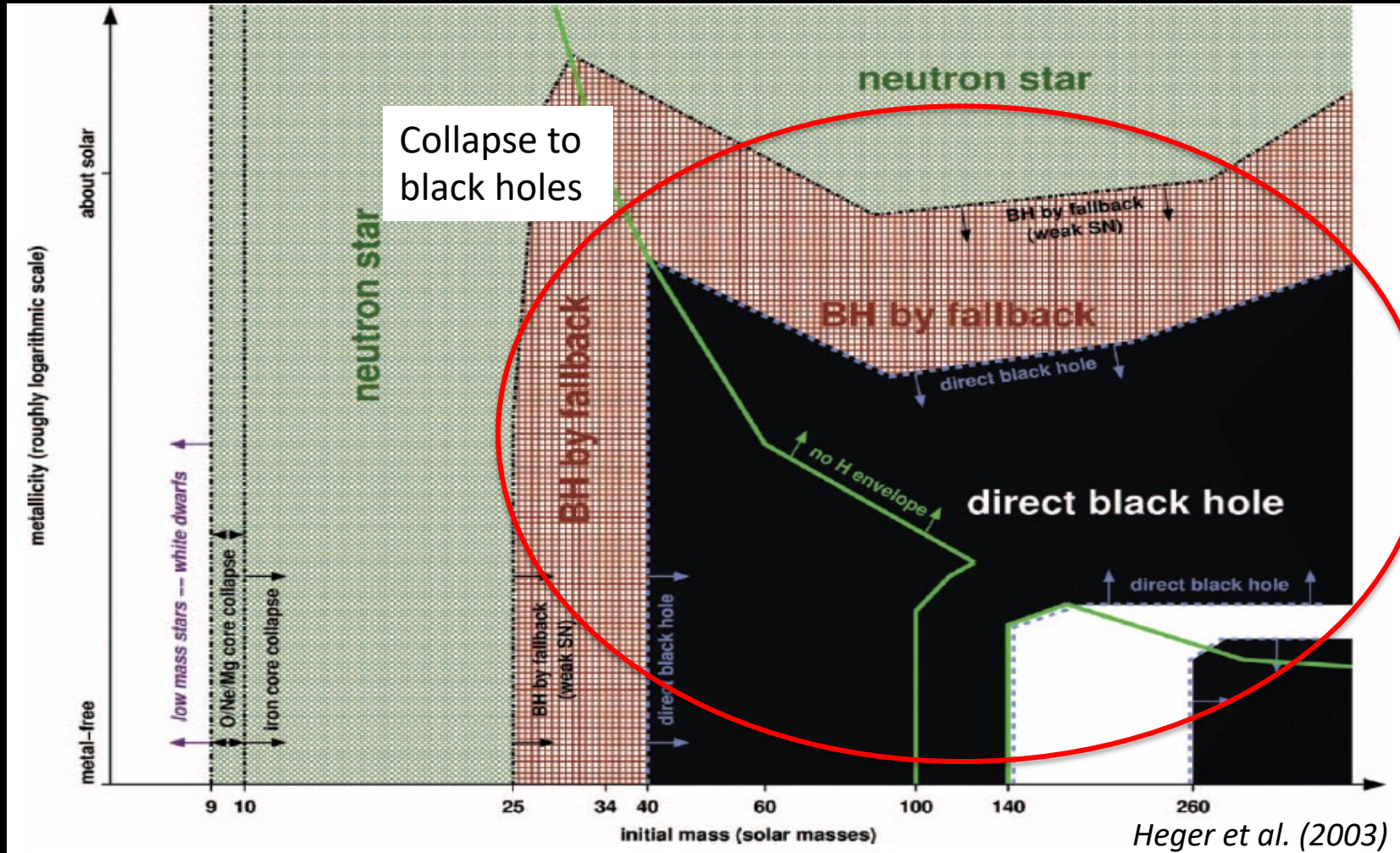
Simple picture



Simple picture

The expectation circa 2000:

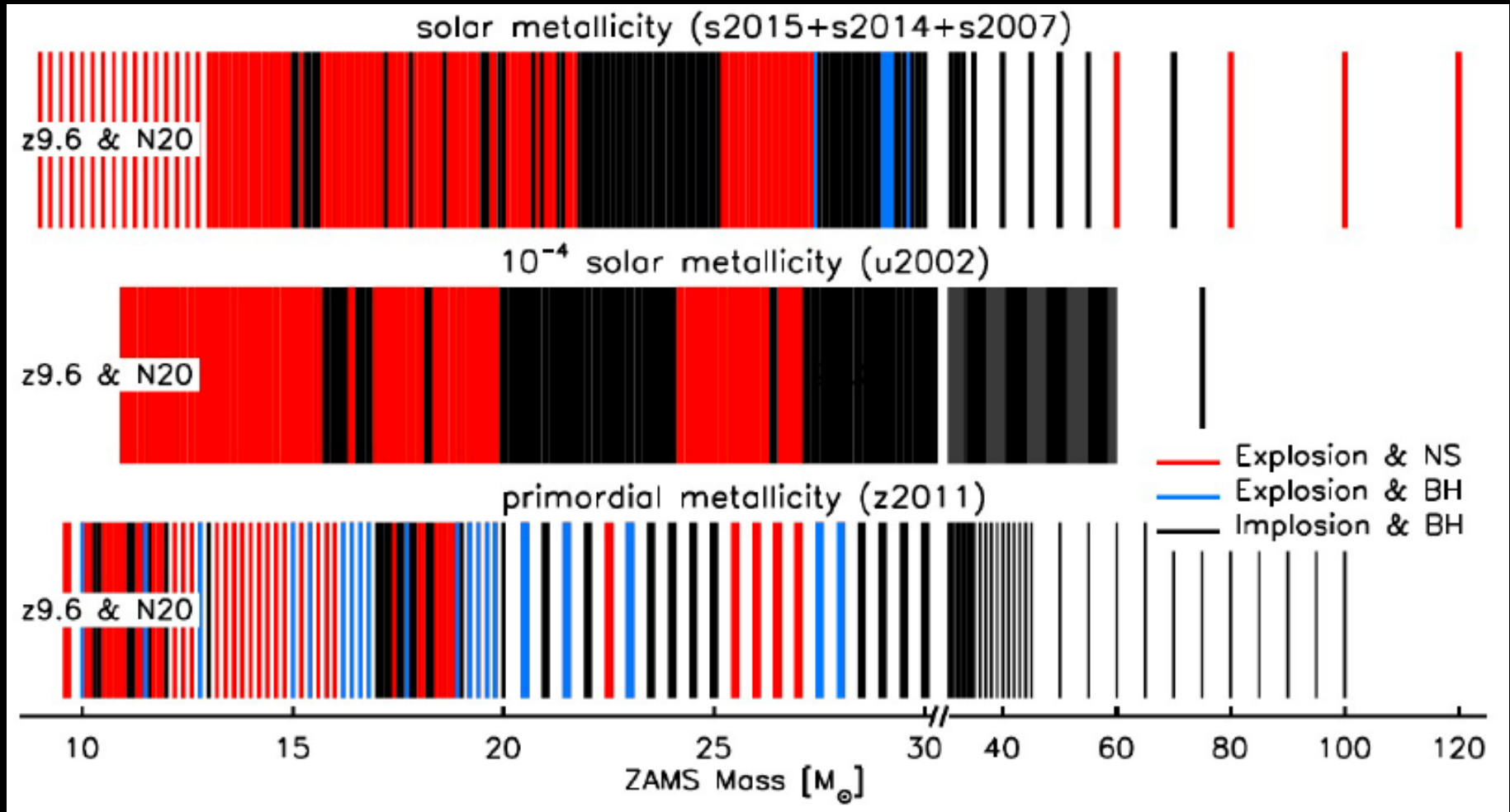
Qualitative expectations, no binaries, no rotation, metal-driven mass loss only



A little more detailed

Emerging picture:

Thinking in mass looks incomplete. Trends are deeply connected to progenitor.

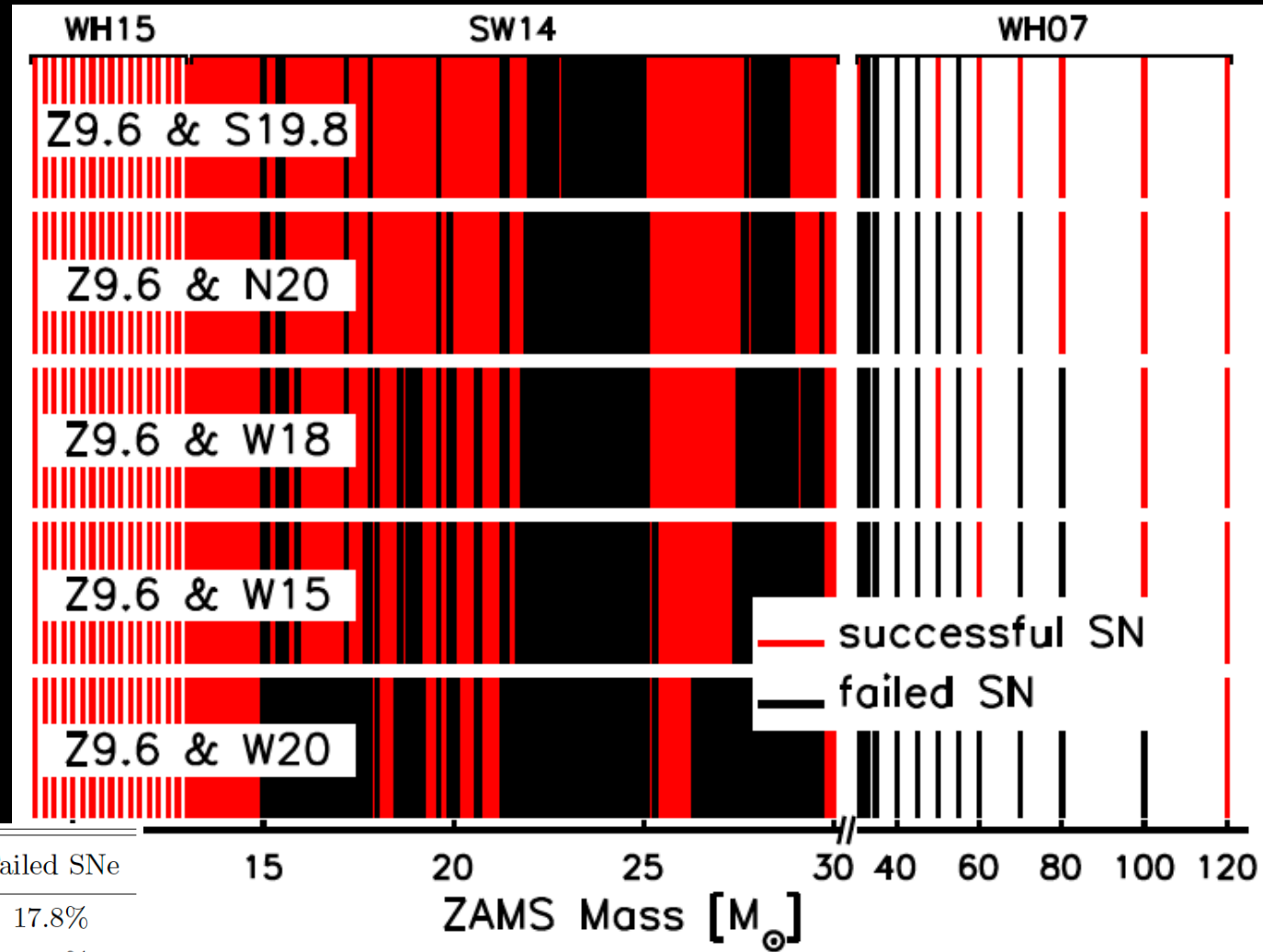


Janka 2017; see also O'Connot & Ott (2011), Ugliano et al (2012), Horiuchi et al (2014), Pejcha & Thompson (2015),

A little more detailed

Details depend
on explosion
mechanism and
stellar models

compare: 50-100Msun
is 5%



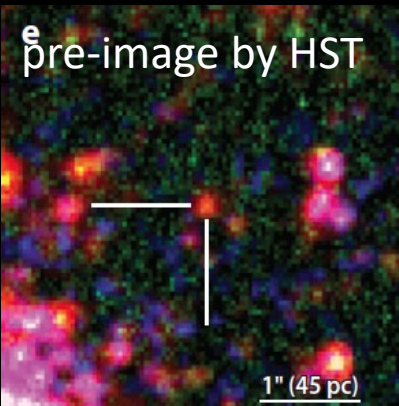
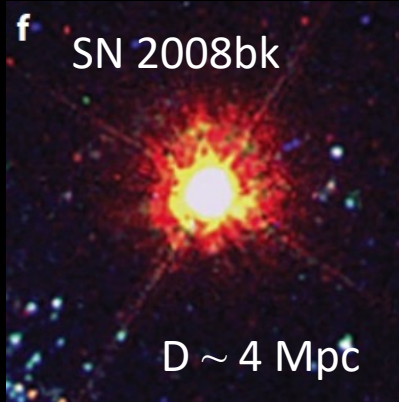
Kresse et al (2021)

➔ Failed fraction can be large

Looking for progenitors

Pre-imaging:

Limited to nearby
SNe, highly
successful



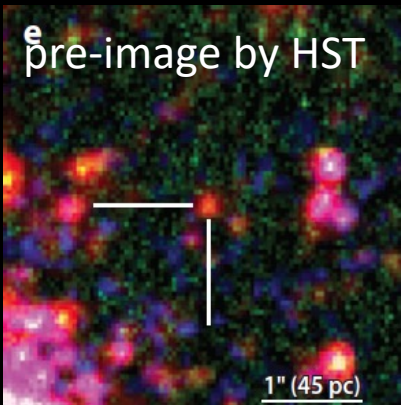
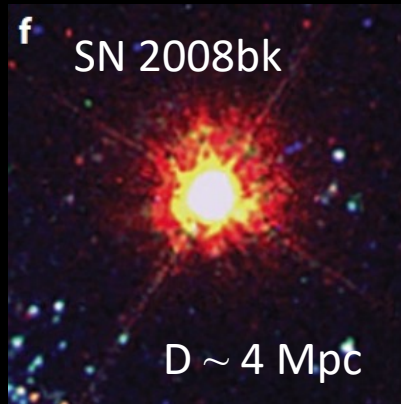
#	SN	dist. mod. (mag)	$E(B - V)$ (mag)	band	BC (mag)	mag (mag)	limmag (mag)	abs. bol. mag (mag)	abs. bol. limmag (mag)	Ref.
1	SN 2017eaw	29.44 ± 0.12	0.3 ± 0.04	F606W	-1.83 ± 0.38	26.4 ± 0.05	28.55 ± 0.1	-5.53 ± 0.41	-3.38 ± 0.42	1, 2
2	SN 2003gd	29.84 ± 0.19	0.14 ± 0.04	F814W	0.1 ± 0.15	24.0 ± 0.04	26.39 ± 0.1	-5.97 ± 0.26	-3.58 ± 0.27	3, 4
3	SN 2008bk	27.96 ± 0.13	0.08 ± 0.03	K	3.0 ± 0.18	18.39 ± 0.03	21.09 ± 0.1	-6.6 ± 0.22	-3.9 ± 0.24	3, 4, 5, 6
4	SN 2020jfo	30.81 ± 0.12	0.02 ± 0.04	F814W	0.0 ± 0.15	25.02 ± 0.07	26.8 ± 0.1	-5.82 ± 0.22	-4.04 ± 0.23	7
5	SN 2005cs	29.62 ± 0.12	0.16 ± 0.02	F814W	0.0 ± 0.15	23.62 ± 0.07	25.4 ± 0.1	-6.27 ± 0.21	-4.49 ± 0.22	3, 4
6	SN 2018aoq	31.3 ± 0.12	0.03 ± 0.04	F814W	0.0 ± 0.15	23.91 ± 0.02	26.81 ± 0.1	-7.44 ± 0.2	-4.54 ± 0.23	1
7	SN 2018zd	30.61 ± 0.12	0.08 ± 0.04	F814W	0.0 ± 0.15	25.13 ± 0.15	26.09 ± 0.1	-5.61 ± 0.25	-4.66 ± 0.23	8, 9
8	SN 2013ej	29.8 ± 0.11	0.14 ± 0.02	F814W	0.4 ± 0.2	22.65 ± 0.05	24.8 ± 0.1	-6.99 ± 0.24	-4.84 ± 0.25	2, 3
9	SN 2022acko	31.74 ± 0.12	0.17 ± 0.04	F814W	0.0 ± 0.15	25.61 ± 0.09	27.12 ± 0.1	-6.41 ± 0.22	-4.9 ± 0.23	10
10	SN 2023ixf	29.18 ± 0.05	0.04 ± 0.04	F814W	-2.28 ± 0.1	24.44 ± 0.06	26.39 ± 0.1	-7.09 ± 0.14	-5.14 ± 0.16	10, 11
11	SN 2012A	29.96 ± 0.15	0.03 ± 0.04	K	3.0 ± 0.18	20.29 ± 0.13	21.4 ± 0.1	-6.68 ± 0.27	-5.57 ± 0.26	3, 8
12	SN 2019mhm	30.81 ± 0.12	0.18 ± 0.04	F814W	0.0 ± 0.15	—	24.97 ± 0.1	—	-6.14 ± 0.23	13
13	SN 2004A	31.54 ± 0.17	0.21 ± 0.06	F814W	0.0 ± 0.15	24.36 ± 0.12	25.56 ± 0.1	-7.52 ± 0.28	-6.32 ± 0.27	3, 4, 14
14	SN 2006ov	30.5 ± 0.19	0.08 ± 0.02	F814W	0.0 ± 0.15	—	24.2 ± 0.1	—	-6.43 ± 0.26	3, 15
15	SN 2008cn	32.61 ± 0.1	0.33 ± 0.04	F814W	0.0 ± 0.15	25.13 ± 0.09	26.64 ± 0.1	-8.02 ± 0.21	-6.51 ± 0.22	3, 16
16	SN 2012ec	31.19 ± 0.1	0.22 ± 0.06	F814W	0.0 ± 0.15	23.39 ± 0.08	25.03 ± 0.1	-8.16 ± 0.22	-6.52 ± 0.23	3
17	SN 2004et	29.43 ± 0.12	0.42 ± 0.03	Ij	0.25 ± 0.15	22.06 ± 0.12	23.26 ± 0.1	-7.78 ± 0.23	-6.58 ± 0.22	1, 3, 5, 15
18	SN 2006my	31.74 ± 0.12	0.49 ± 0.26	F814W	0.0 ± 0.15	24.86 ± 0.13	25.97 ± 0.1	-7.7 ± 0.48	-6.59 ± 0.48	3, 4, 15
19	SN 2006bc	30.84 ± 0.18	0.21 ± 0.04	F814W	0.0 ± 0.15	—	24.45 ± 0.1	—	-6.73 ± 0.26	3
20	SN 2021yja	31.84 ± 0.12	0.10 ± 0.04	F606W	-1.83 ± 0.38	—	27.07 ± 0.1	—	-6.83 ± 0.42	17
21	SN 2004dg	31.51 ± 0.13	0.24 ± 0.03	F814W	0.0 ± 0.15	—	25.0 ± 0.1	—	-6.91 ± 0.23	3
22	SN 2007aa	31.56 ± 0.13	0.03 ± 0.04	F814W	0.0 ± 0.15	—	24.44 ± 0.1	—	-7.17 ± 0.23	3
23	SN 1999gi	30.0 ± 0.08	0.17 ± 0.04	F606W	-1.83 ± 0.38	—	24.9 ± 0.1	—	-7.3 ± 0.41	3, 5
24	SN 2012aw	29.96 ± 0.02	0.43 ± 0.05	K	3.0 ± 0.18	19.56 ± 0.29	19.8 ± 0.1	-7.56 ± 0.34	-7.32 ± 0.21	3, 18
25	SN 2001du	31.31 ± 0.07	0.16 ± 0.08	F814W	0.0 ± 0.15	—	24.25 ± 0.1	—	-7.32 ± 0.24	3, 5
26	SN 2018ivc	30.02 ± 0.12	0.5 ± 0.04	F606W	-1.83 ± 0.38	—	25.4 ± 0.1	—	-7.53 ± 0.42	19
27	SN 1999br	30.75 ± 0.18	0.02 ± 0.02	F606W	-1.83 ± 0.38	—	24.9 ± 0.1	—	-7.71 ± 0.43	3, 5
28	SN 1999em	30.34 ± 0.09	0.09 ± 0.04	Ic	-0.32 ± 0.15	—	23.0 ± 0.1	—	-7.79 ± 0.21	3, 5
29	SN 1999an	31.34 ± 0.08	0.11 ± 0.05	F606W	-1.83 ± 0.38	—	24.7 ± 0.1	—	-8.7 ± 0.41	3, 5
30	SN 2002hh	29.43 ± 0.12	1.36 ± 0.05	i	-0.49 ± 0.15	—	22.8 ± 0.1	—	-9.23 ± 0.23	1, 3, 5, 20
31	SN 2020fqv	31.19 ± 0.12	0.52 ± 0.04	F606W	-1.83 ± 0.38	—	24.88 ± 0.1	—	-9.27 ± 0.42	21

Strotjohann et al. (2024); see also Davies & Beasor (2020), Healy et al (in prep)

Red supergiant problem

Pre-imaging:

Limited to nearby SNe, highly successful

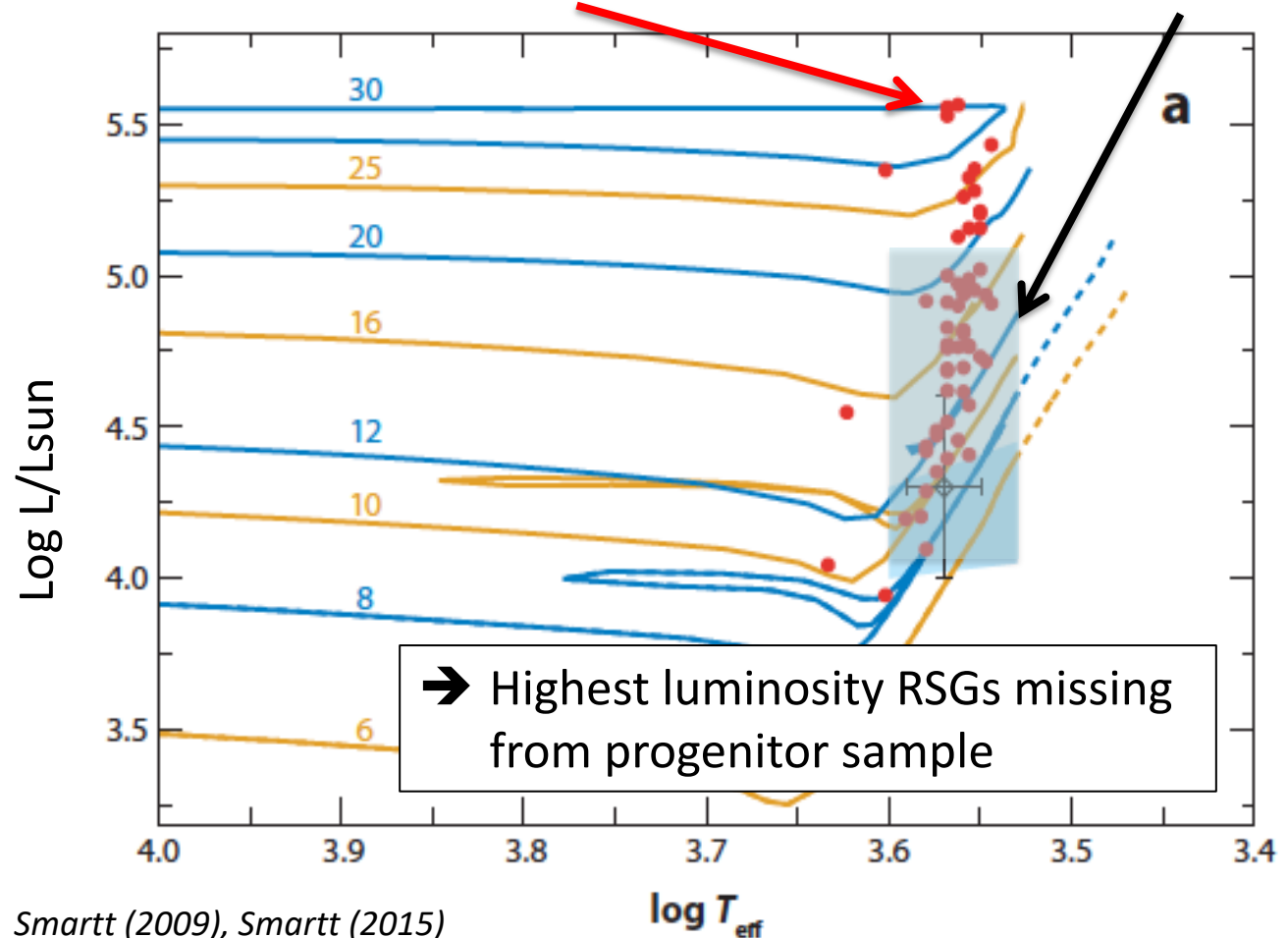


A deficit of high mass supernova progenitors Kochanek et al (2008)

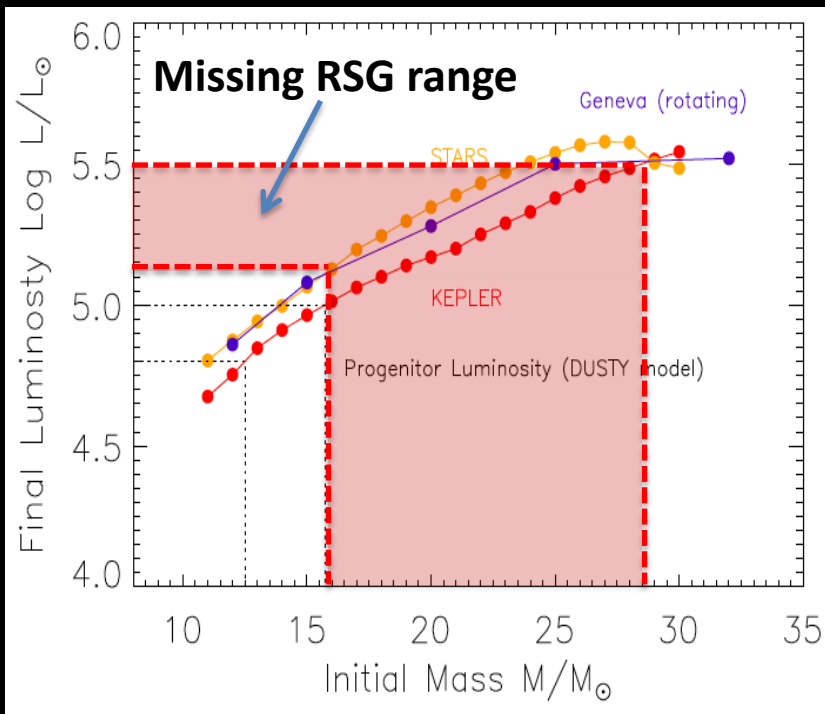
Sample: volume limited to < 28 Mpc ($V < 2000$ km/s)

Known red-supergiants (@MW, LMC)

Observed progenitors



Implications: progenitors



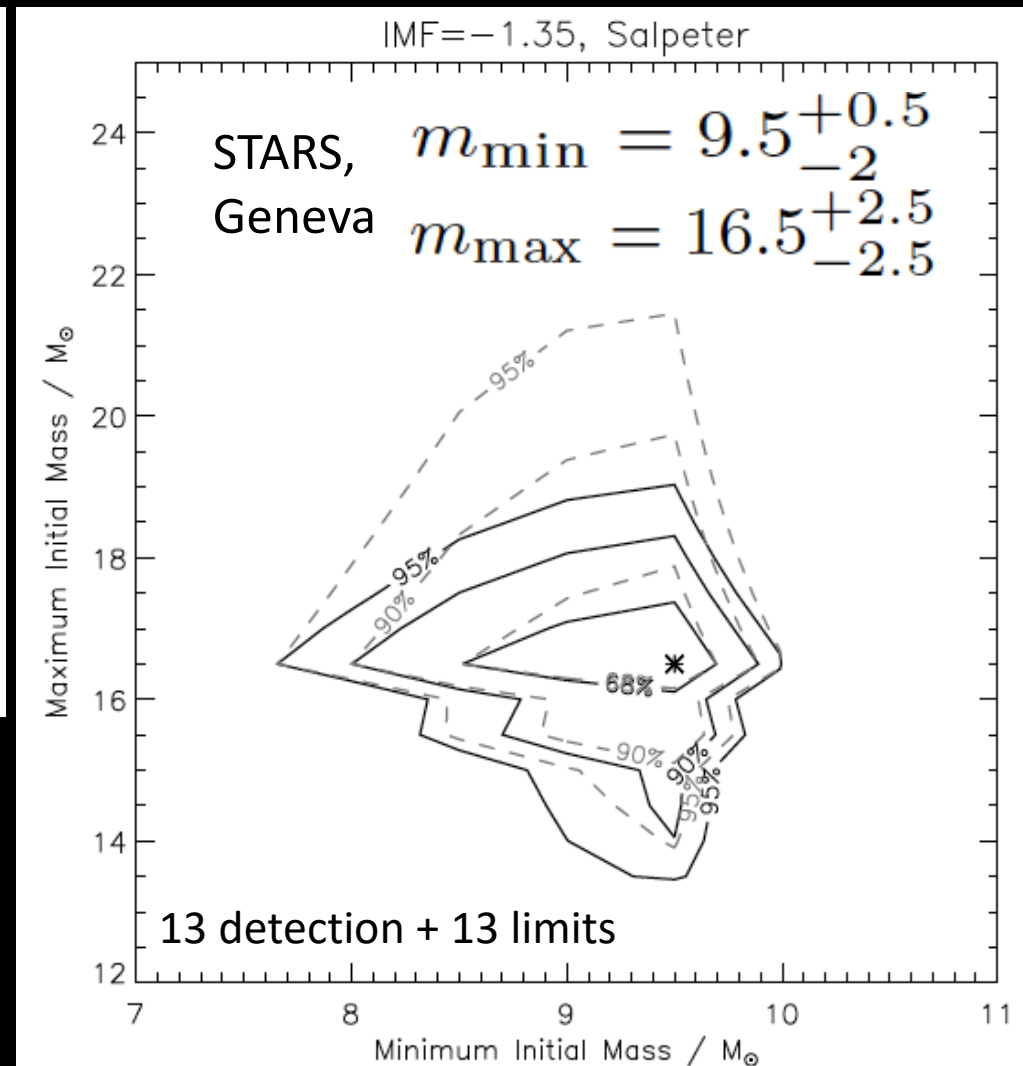
Jerkstrand et al (2014)

Systematic uncertainty in mass
estimating: +2Msun with KEPLER

With
KEPLER:

$$m_{\min} = 10^{+0.5}_{-1.5}$$

$$m_{\max} = 18.5^{+3}_{-4}$$

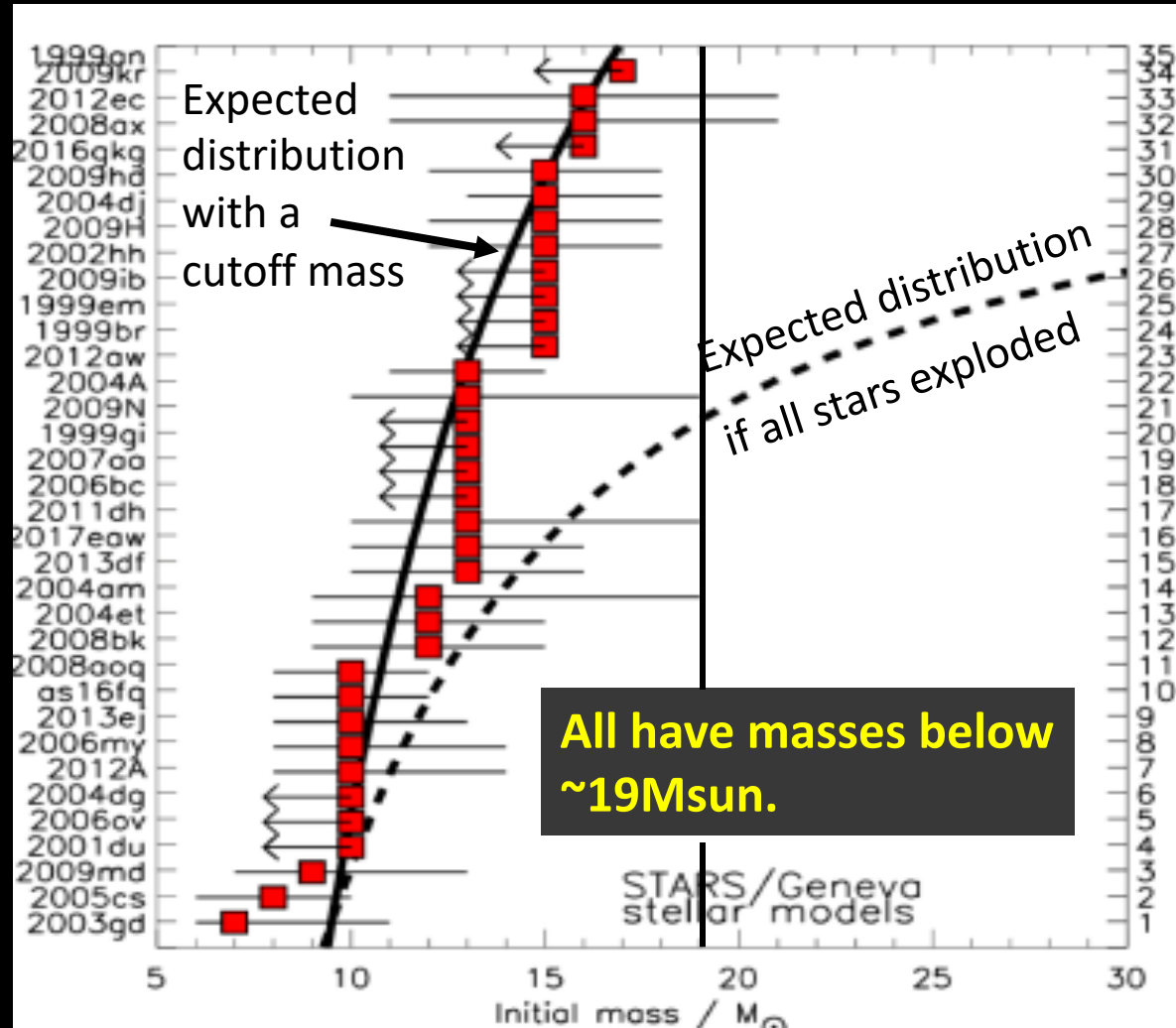
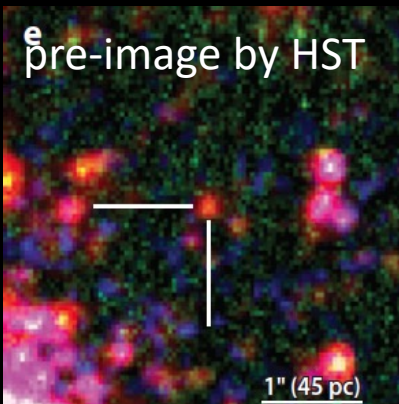
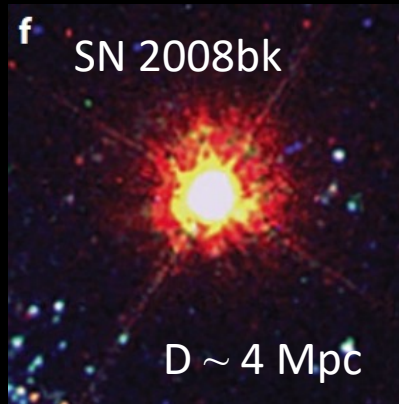


Smartt (2015), updated from Smartt et al (2009)

Implications: progenitors

Pre-imaging:

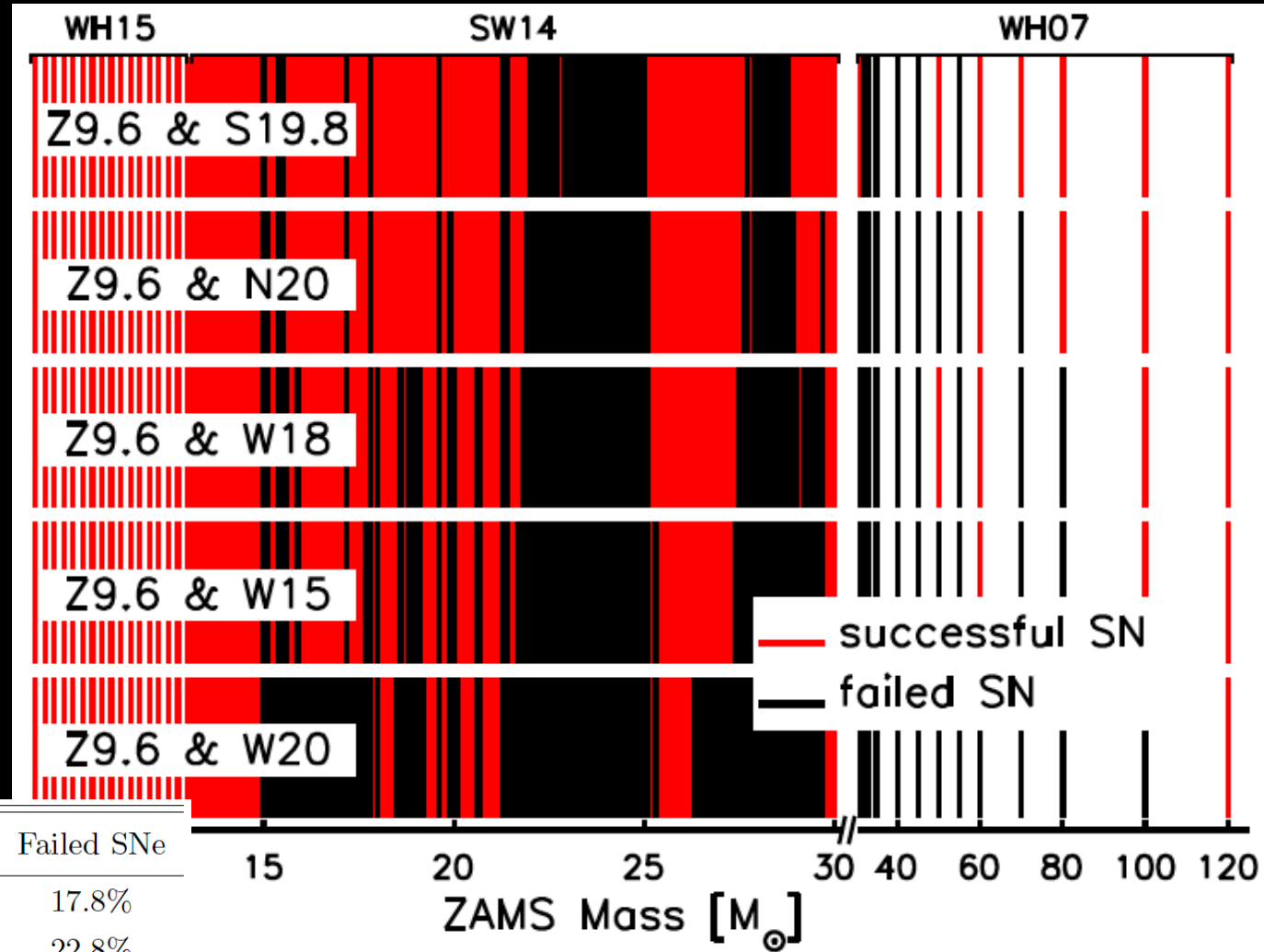
Limited to nearby
SNe, highly
successful



Smartt, STScI Spring Symposium (2019)

Comparison to simulations

Mass boundaries are similar to theoretical models – are stars around 25M_{sun} becoming black holes?



Engine Model	Successful SNe	Failed SNe
Z9.6 & S19.8	82.2%	17.8%
Z9.6 & N20	77.2%	22.8%
Z9.6 & W18	73.1%	26.9%
Z9.6 & W15	70.9%	29.1%
Z9.6 & W20	58.3%	41.7%

Kresse et al (2021)

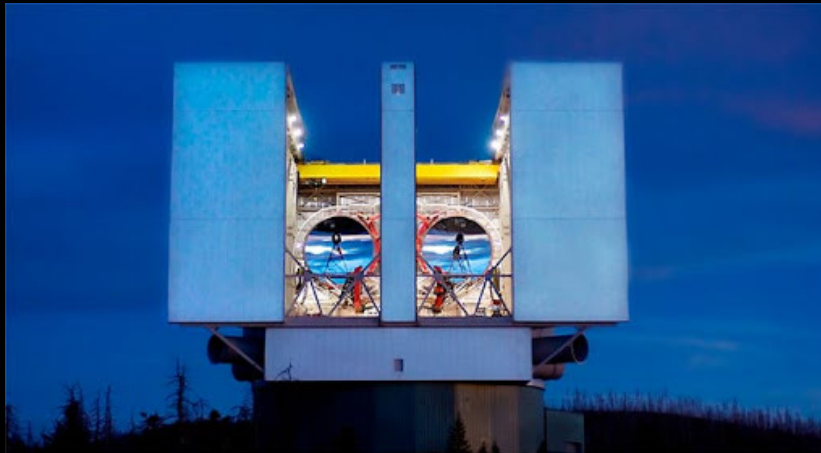
Looking for implosions

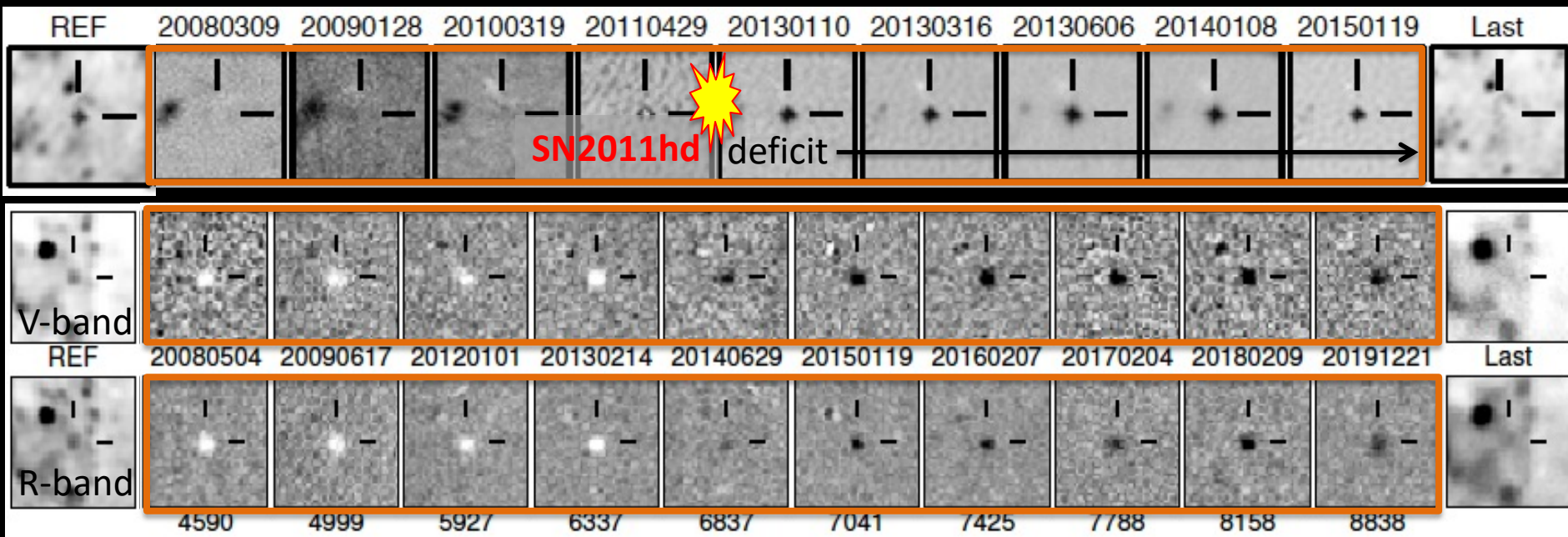
Look for disappearance of stars

Monitor ~ 27 galaxies

- Survey $\sim 10^6$ red supergiants
- Expect ~ 1 core collapse /yr
- In 10 years, sensitive to 20 – 30% failed fraction at 90% CL

Kochanek et al. (2008)



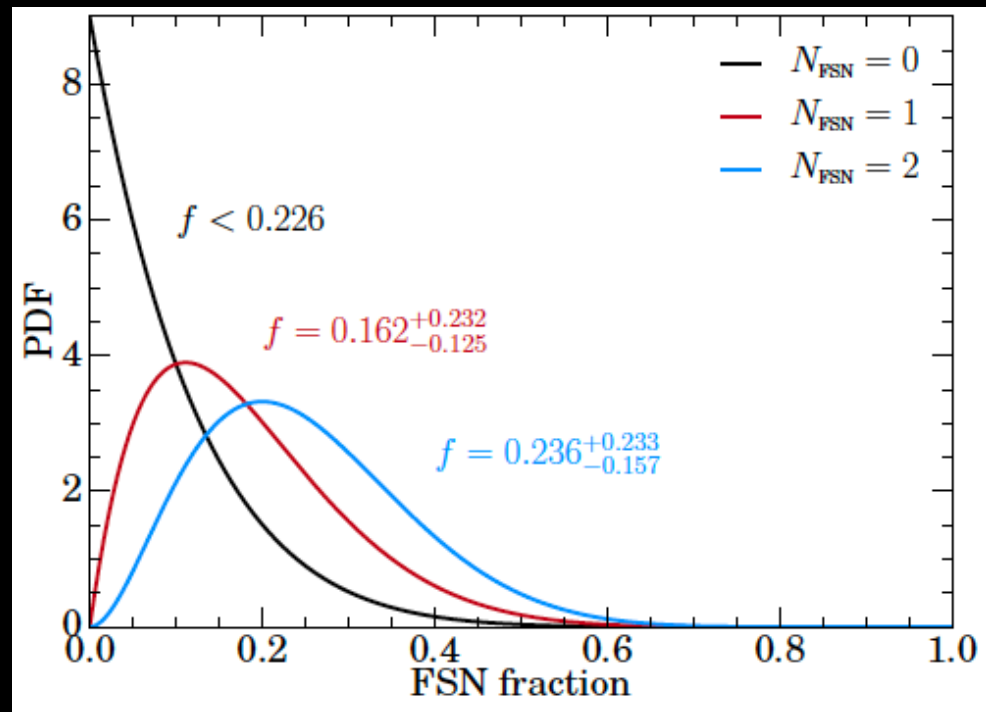


In 11 years running,

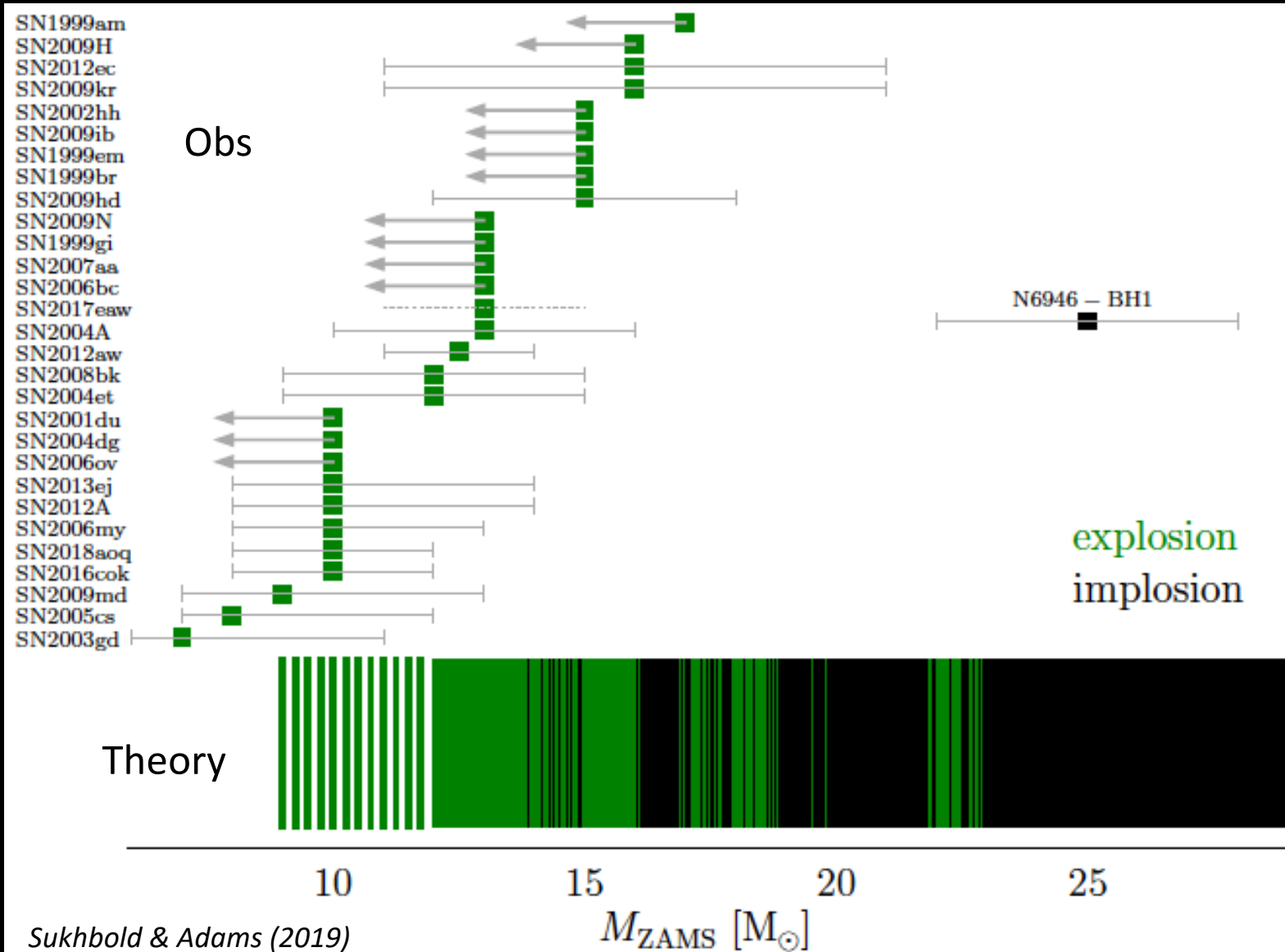
- ✓ 9 luminous CC supernovae
- ✓ 2 implosion candidates
 - NGC6946-BH1: 'fireworks' galaxy at 7-8Mpc distance, SED well fit by ~ 25 Msun RSG
 - M101-OC1: follow-up ongoing

Neustadt et al (2021)

Also: *Gerke et al(2015)*, *Adams et al (2017)*,
Reynolds et al (2016)



The picture we want to test



Final remarks

- Supernova rates impact searches & interpretations
- Supernova rate measurements are improving, but systematic measurements are still limited.
 - Future promises: ASAS-SN, DES, LSST
- Star formation rates have a significantly better systematic coverage
 - Many uncertainties, but supports supernova rates
- Application to nearby distances provides a expectation database
 - Nearby distances also have supernova progenitors,
 1. Nearby galaxies
✓ See slide 32
 2. Nearby supernova progenitors
✓ See slide 42
 3. Nearby galaxy star formation rate, supernova rate
✓ See slide 36

Database: