Local stellar death rate

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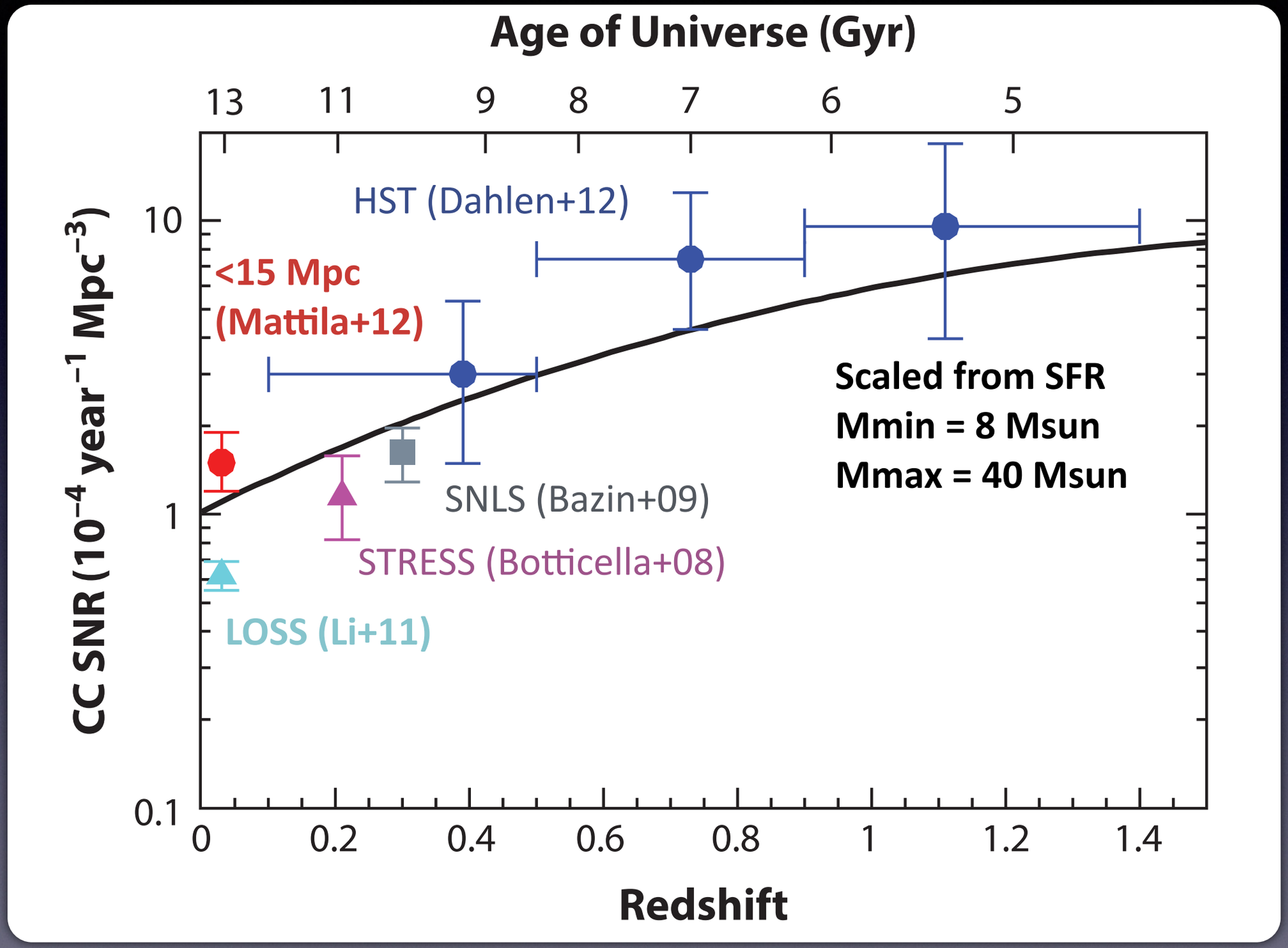
Key questions related to local stellar death rate

- **What is the mass range for core-collapse SNe?**
- **How often do SNe succeed or fail?**
  - How often do SNe form NS or BH?
  - What is the mass function of NSs and BHs?
- **What is the luminosity function of SNe?**
  - What physics/mechanism sets it?

Stellar death rate: current status



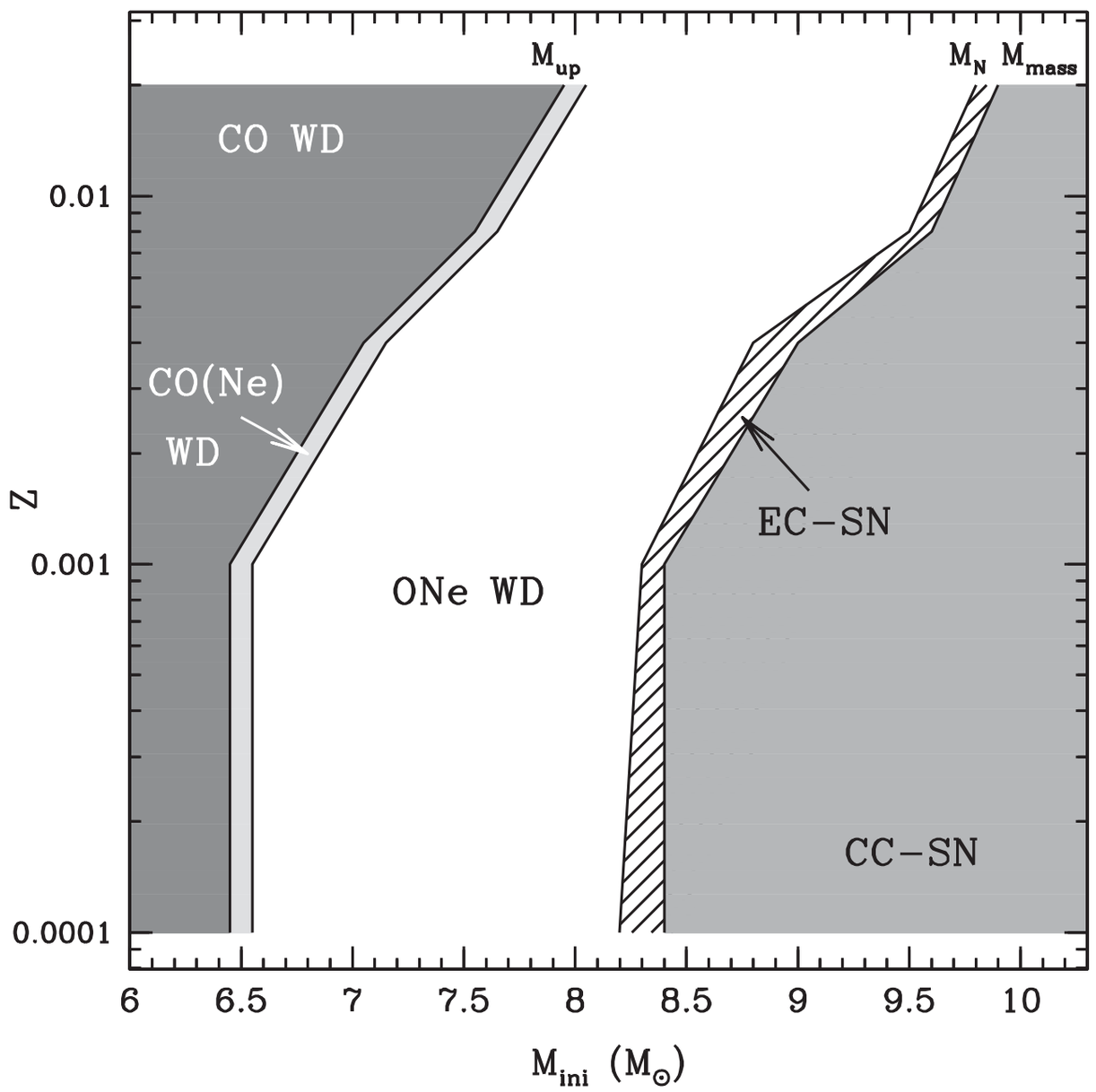
Madau & Dickinson 2014

NOTE: Possible effects of local over-density in Mattila+12

Minimum mass of core-collapse SNe

$$R_{\rm CC}(z) = \psi(z) \times \frac{\int_{m_{\rm min}}^{m_{\rm max}} \phi(m){\rm d}m}{\int_{m_l}^{m_u} m\phi(m){\rm d}m}$$

SFR



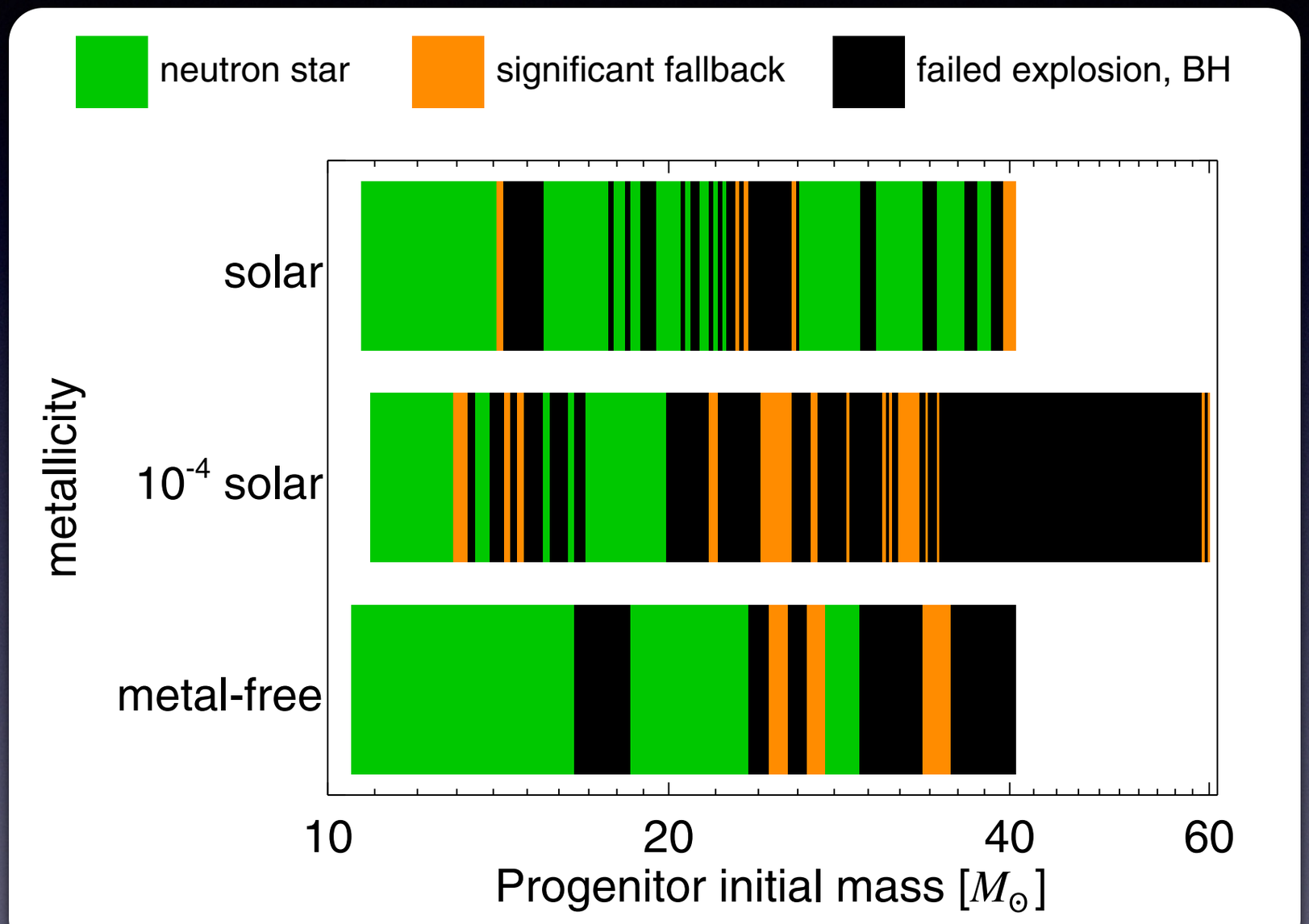
Electron capture SNe only from 9.7-9.8 Msun ?

Doherty+15

ex) SN rate (> 10 Msun) = 0.8 x SN rate (> 8 Msun)

Supernova theory

- Compactness of the core (M/R)
- Easier to explode for smaller compactness

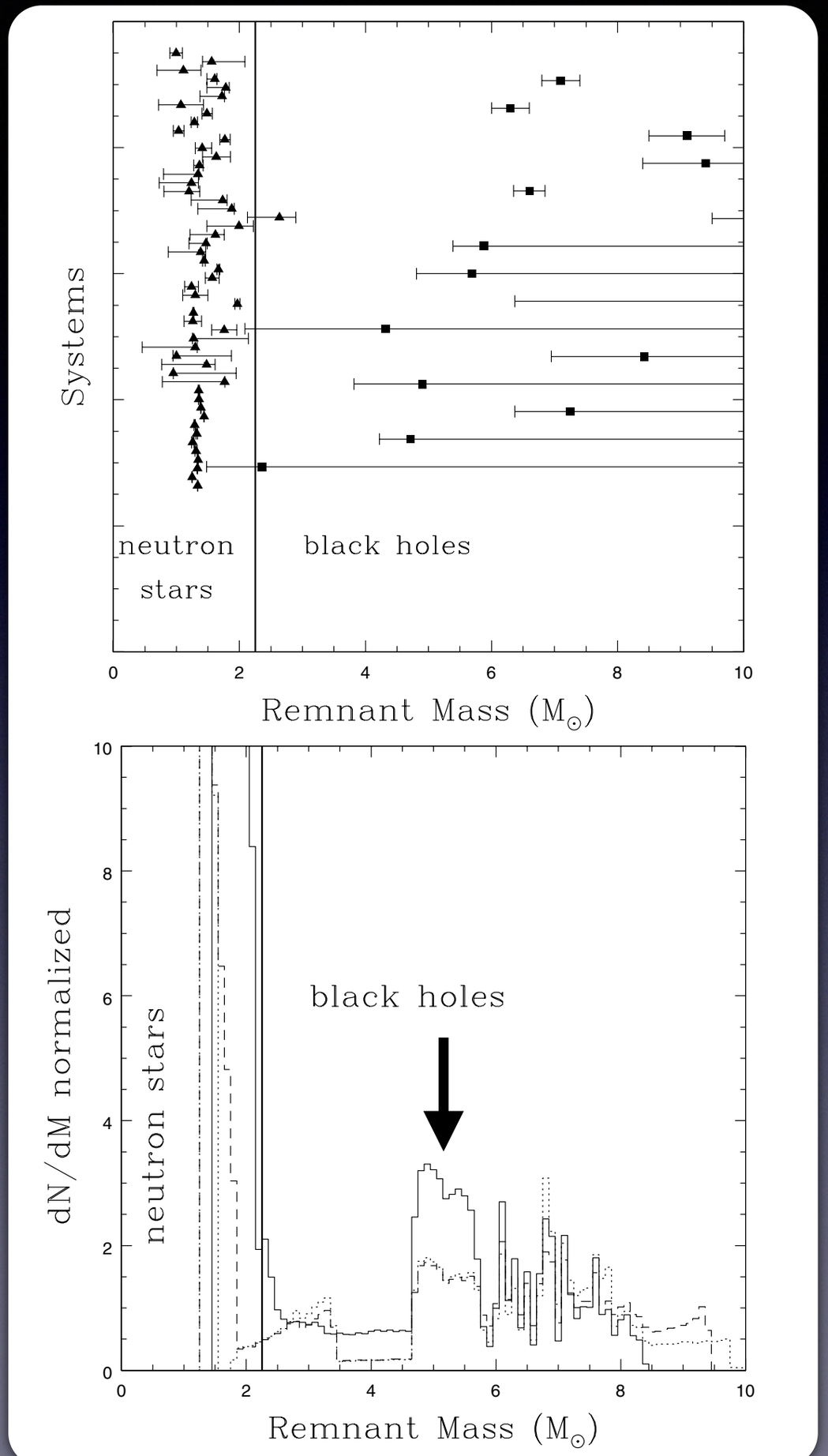


Pecha & Thompson 15

See also O'Connor & Ott 11, Ugliano+12, Etrl+15, Nakamura+15

NOTE: Neutrino luminosity is parameterized to have successful explosion

Impact to the remnant mass function

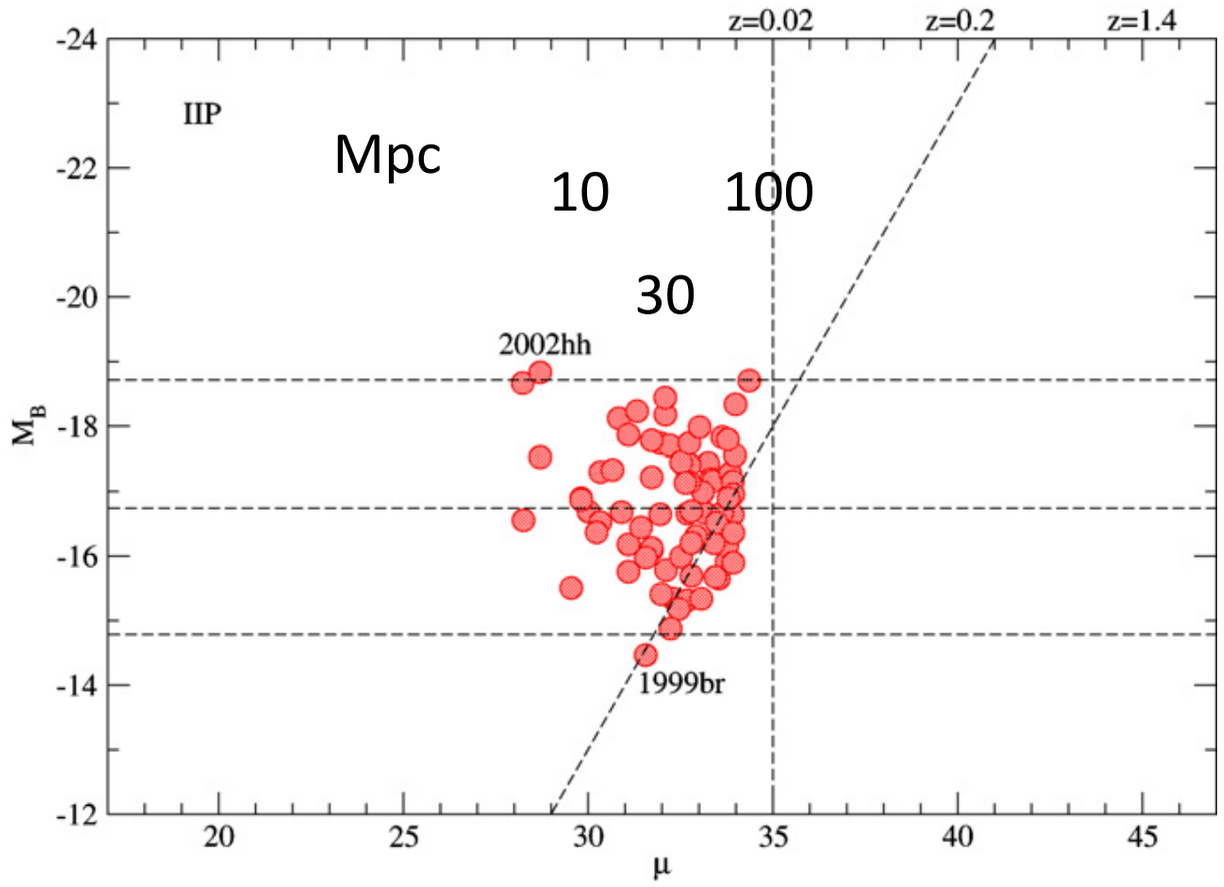


Assuming 16-25 Msun stars do not explode and form BH

Kochanek+14

Luminosity function

SN physics:
Variety in E, Mej, R(preSN), and 56Ni mass



Richardson+14

Heterogenous sample
(most from targeted survey, 100 Mpc)

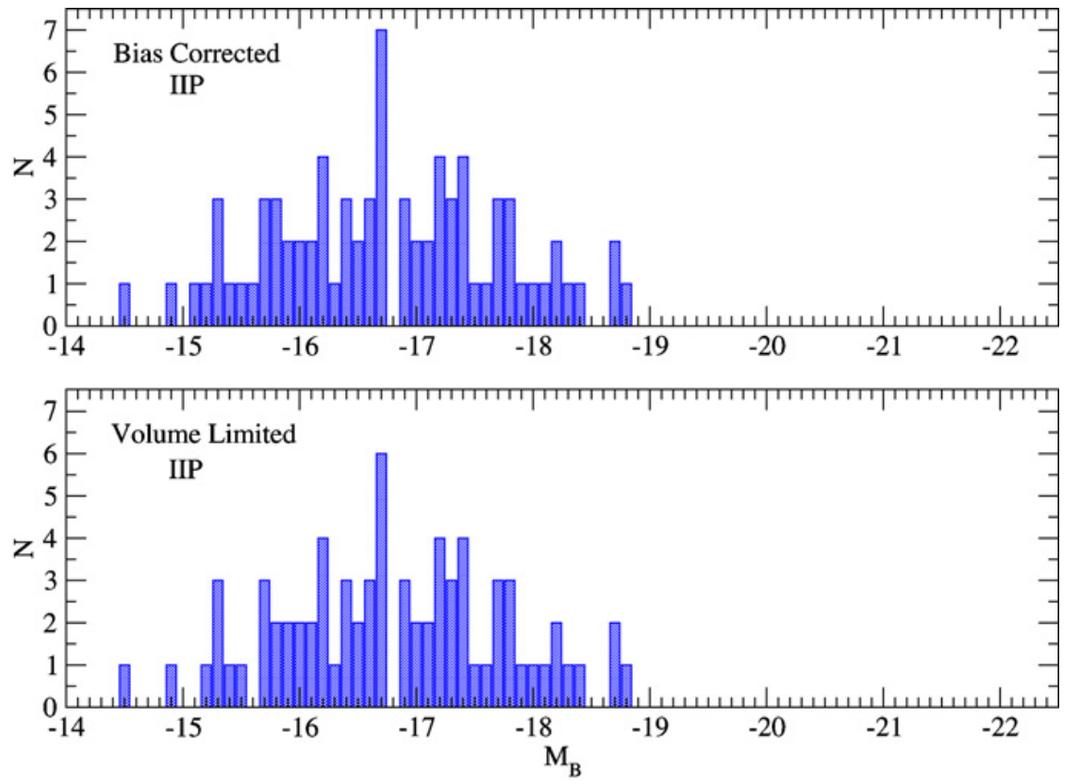


Table 2
Volume-limit Distributions

SN Type	$\overline{M}_B$ [a]	σ [b]	N
Ia	-19.26 ± 0.20	0.51	171
Ib	-17.54 ± 0.33	0.94	18
Ic	-17.67 ± 0.40	1.04	36
IIb	-17.03 ± 0.45	0.93	15
IIL	-17.98 ± 0.34	0.90	17
IIP	-16.80 ± 0.37	0.97	74
IIn	-18.62 ± 0.32	1.48	21

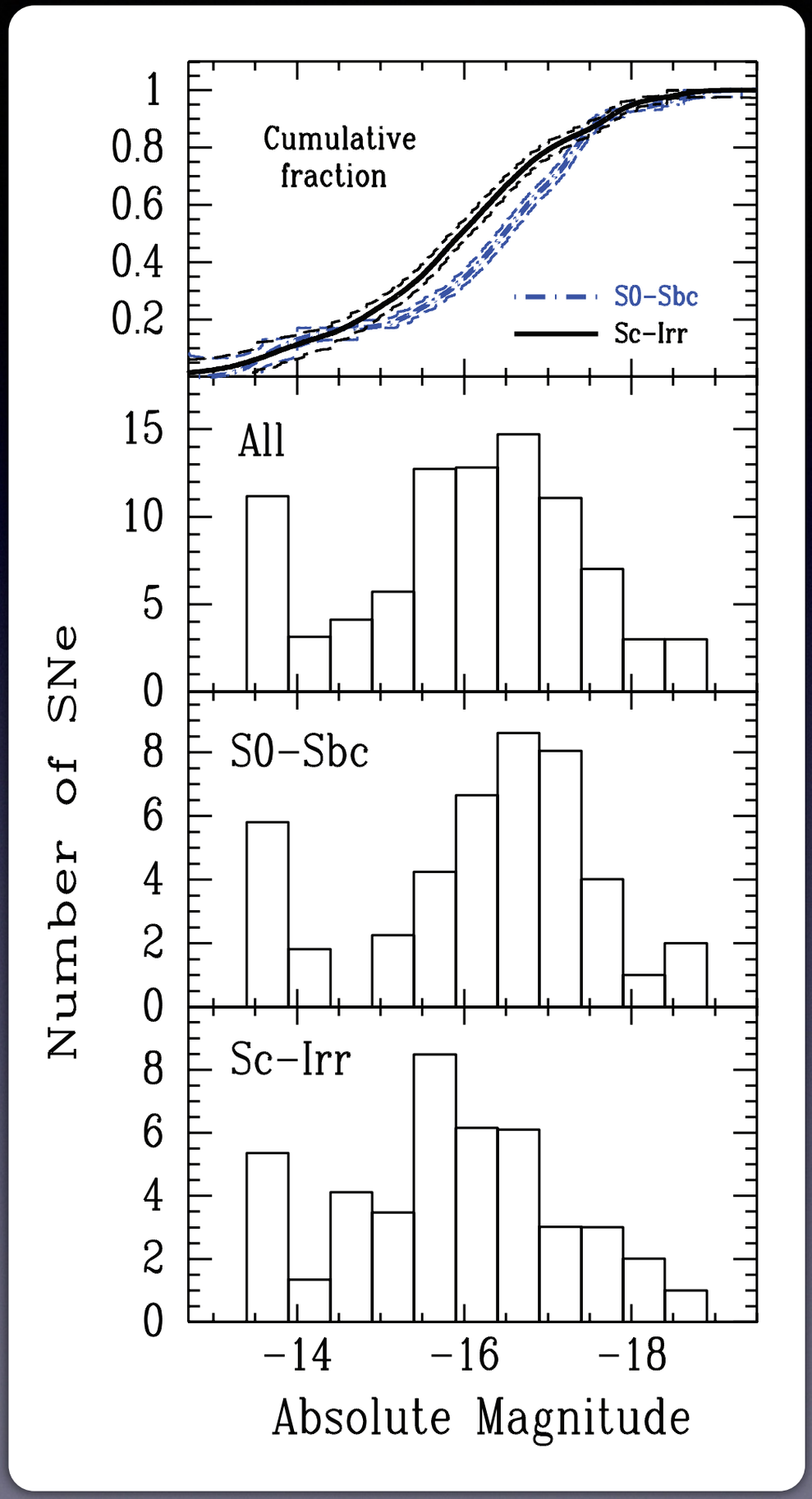
Luminosity function

LOSS (galaxy targeted)

Volume limited LF
(60 Mpc for Type II and Ibc)

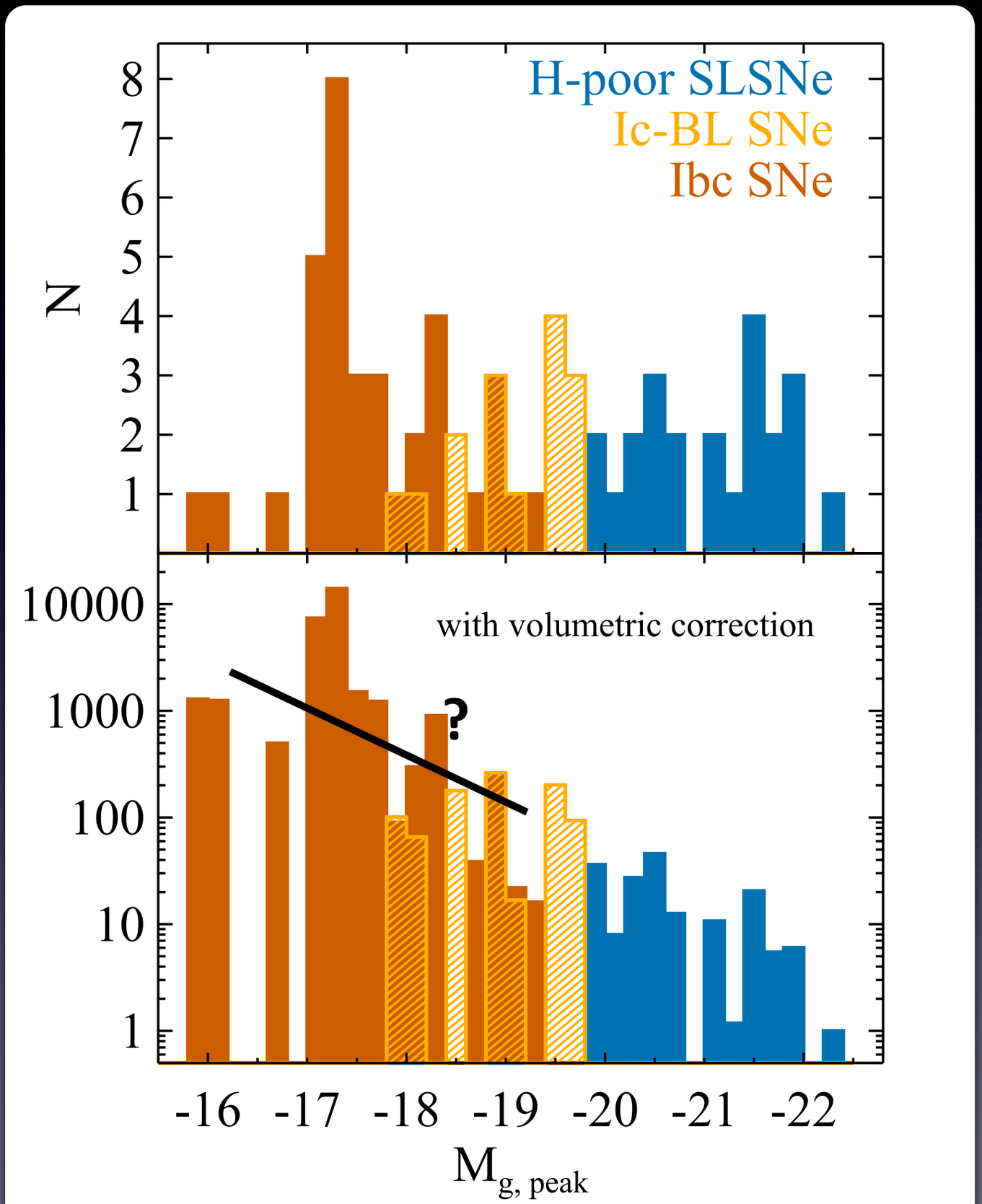
Bin	Mean	II σ	SDOM
all			
E–Sab			
Sb–Irr			
all	−16.05	1.37	0.15
S0–Sbc	−16.22	1.39	0.21
Sc–Irr	−15.88	1.34	0.20

Li+11



Luminosity function

PTF (unbiased survey)



De Cia+18

Local stellar death rate: observational goals

- **Derive accurate luminosity function (+ light curve shape)**
  - SN physics (+ progenitor)
- **Derive accurate SN rate**
  - Lowest mass of core-collapse SNe (8-10 Msun is ~20-30 % of all massive stars)
  - Success/failure rate => SN physics & remnant mass distribution

Observational program

Why is the SN rate so uncertain?

1. **Poor understanding of the LF and light curves of SNe**

   A. LF at the faintest end
      Down to which mag? Gaussian? Power law?

   B. Some SNe only show SBO signal?
      Missed due to too rapid light curves

   (C. Some SNe even do not produce EM signals)

2. **Completeness of the survey**

   A. Dust extinction (both ISM and CSM)

Survey design

- **Complete down to M(max) = -15 mag**
  - Light curves from -13 mag
- **100% completeness of spectroscopy**
- **Sensitive to “rapid” objects**
  - < 3 days cadence
- **Need >~ 100 objects**

Some numbers

*** Numbers for all sky**

Distance (Mpc)	Volume (Mpc^3)	# of galaxies	# of SNe (yr^{-1})	mag (abs mag -15 mag)	mag (abs mag -13 mag)
10	4×10^3	40	0.4	15.0	17.0
30	1×10^5	10^3	10	17.4	19.4
50	5×10^5	5×10^3	50	18.5	20.5
70	1×10^6	1×10^4	100	19.2	21.2
100	4×10^6	4×10^4	400	20.0	22.0
200	3×10^7	3×10^5	3,000	21.5	23.5
500	5×10^8	5×10^6	50,000	23.5	25.5

Sweet spots

Easy spectroscopy

Survey with m ~ 21 mag (d ~ 70 Mpc), 20,000 deg2 => 50 SNe/yr

Large number

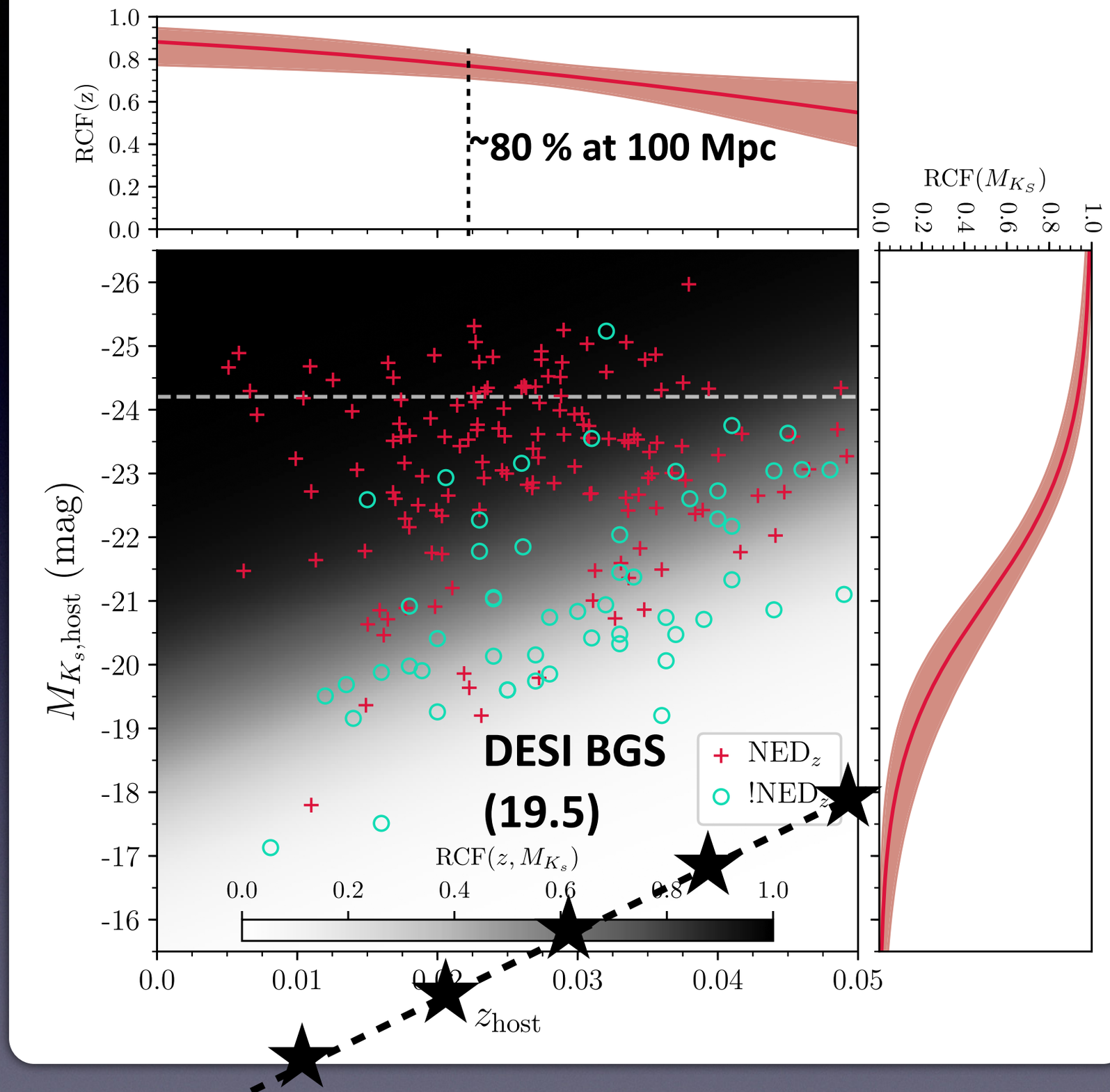
Survey with m ~ 22 mag (d ~ 100 Mpc), 20,000 deg2 => 200 SNe/yr

Feasibility with ongoing transient surveys (optical)

Survey	Depth (mag)	Area (deg^2)	Cadence	Distance (Mpc)	# of SNe (yr^{-1})
BlackGEM	21.5	10,000	2 weeks	70	25
DES	23.5	5,000	1 week	200	300
KMTNet	~21	~6,000	1 day	70	~15
MOA	~21	~1,000	1 day	70	~3
TNTS	20.0	2,000	?	40	~2
PTSS	20.5	4,000	1 day	50	~5
HSC	25	800	1 day	500	1000
Tomo-e	18/19	7,000	2 hr/1 day	20/30	0.5/2
ZTF	**21**	**23,000**	**3 days**	**70**	**50**
	21	2,000	1 day	70	5
	21	6,000	2 hr	70	15
ASAS-SN	17	40,000	1 day	10	0.4
DLT40	20	600 gal	1 dat	40	6

Toward complete spectroscopy

- **The number of objects (< 100 Mpc) is not huge and they are brighter than 21 mag**
- **Issue: galaxy information is NOT perfect**
  = we do not know if SNe are local before spectroscopy
  = Need spectroscopy of ALL the objects?
- **Synergy with massive multiplex spectroscopy**
  - Local SNe: ~ 100 (yr^{-1}) in 20,000 deg^2
    = 0.005 in 1 deg^2 in total
    ~ 0.001 in 1 deg2 (assuming SN is visible for 2 month)
  - All SNe: $O(10^4)$ yr^{-1} in 20,000 deg^2
    = 2.5 in 1 deg^2 in total
    ~ 0.5 in 1 deg^2 (assuming SN is visible for 2 month)



Kulkarni+18, SNe Ia from ASAS-SN / NED redshift

Notes on NIR surveys

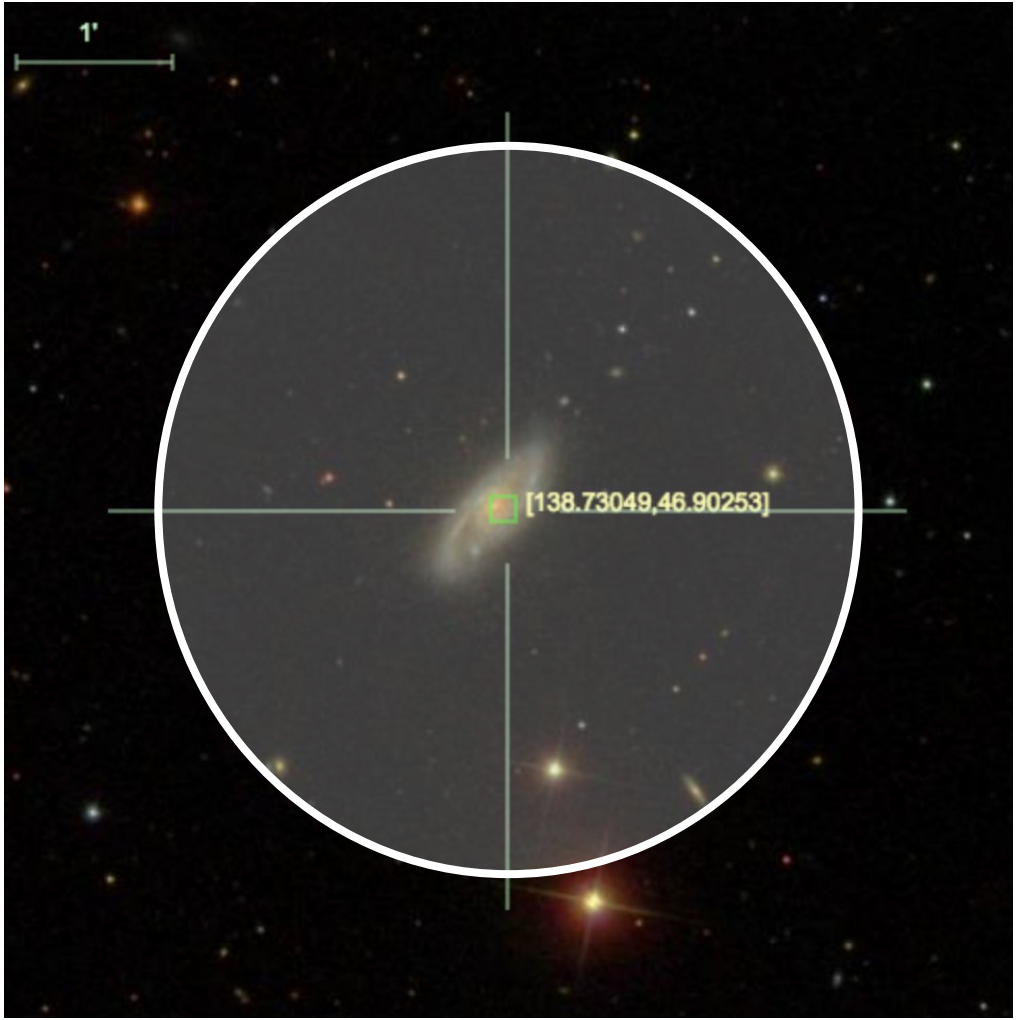
Estimated by Kishalay and Takashi

- **Gattini-IR (J ~16 AB, 25 deg^2 FOV)**
  - 30,000 deg^2 survey => ~ 40 Mpc
  - ~15 SNe/ yr
- **PRIME (H ~ 21 AB, 1.56 deg^2 FOV)**
  - Targeted survey focusing on LIRG/ULIRG at < 50 Mpc (RA = 3h - 10h, visible from PRIME)
  - ~60 galaxies with > 1 Msun/yr => ~300 Msun/yr in total
  - ~1 SN / 3 months

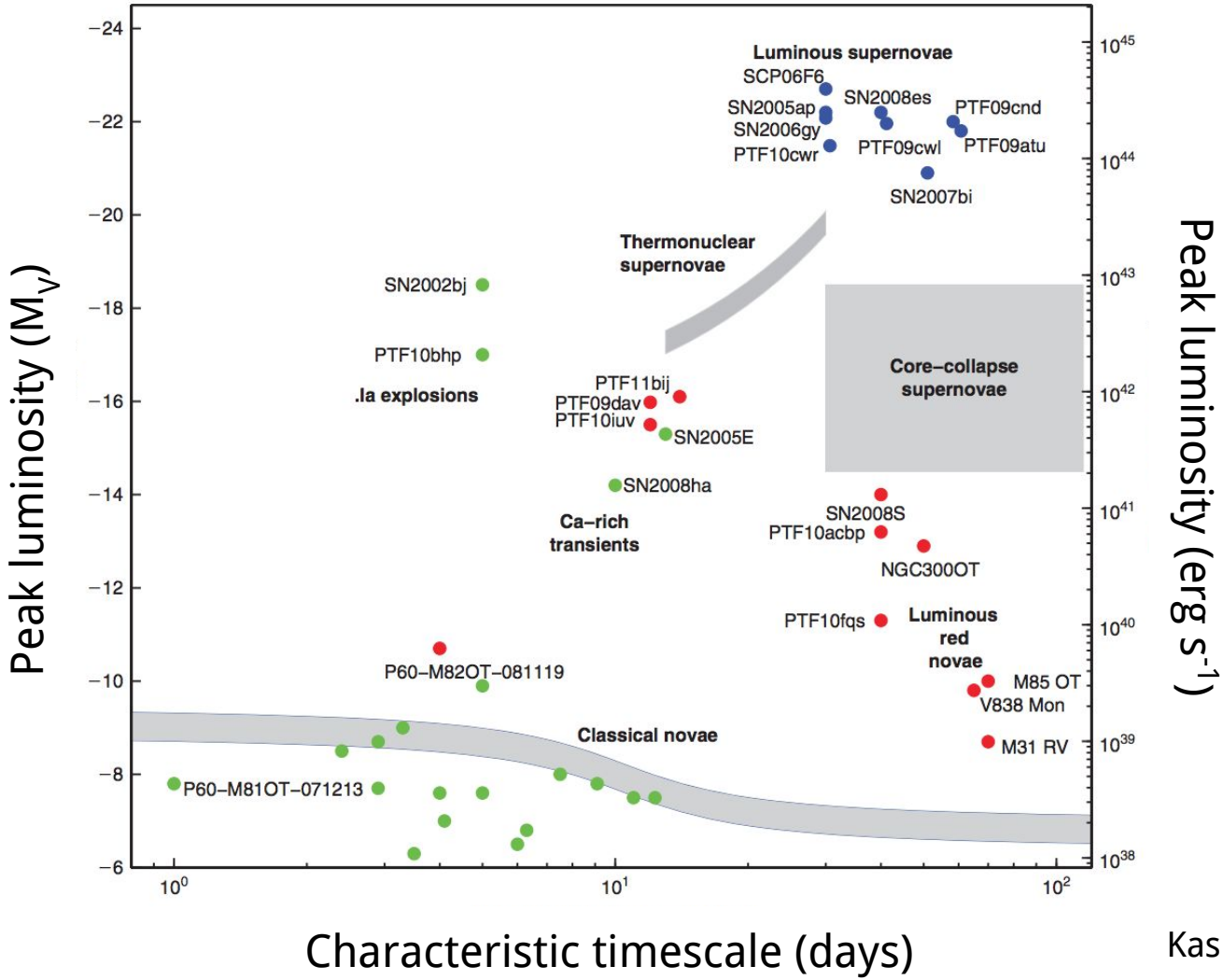
Summary

- **Survey for complete local SN rate**
  - 21 mag - 20,000 deg^2 - 1 day cadence
    => ~50 SNe/yr at < 70 Mpc
  - ZTF public survey: 21 mag - 20,000 deg^2 - 3 days
- **Need spectroscopy of all the objects**
  - Incompleteness of the galaxy catalog
  - Fiber sharing with multi-object spectroscopic survey
- **NIR survey is still challenging**
  - Optical multi-color data helps understanding extinction

ZTF Census of the Local Universe (CLU) survey

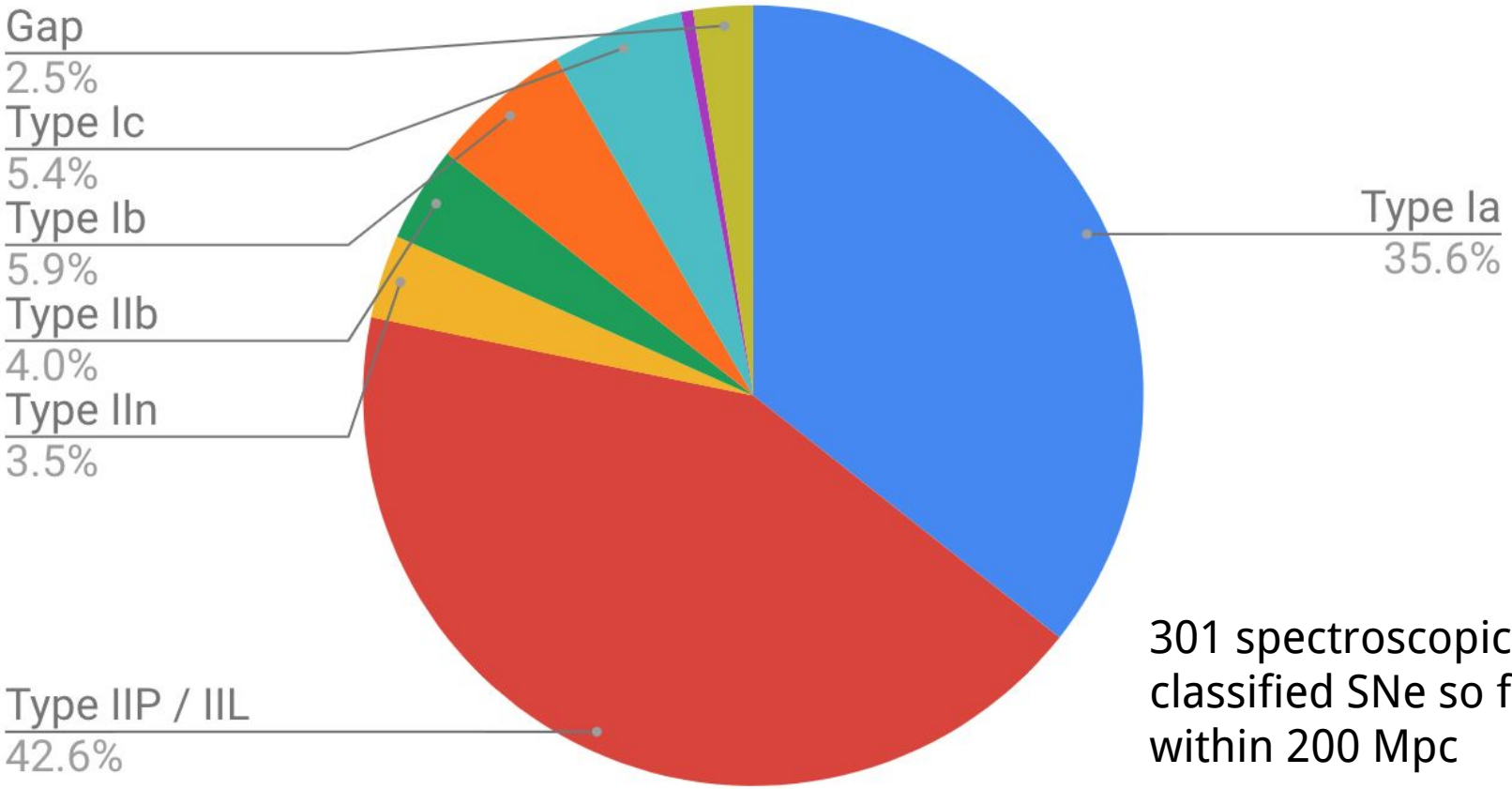


- Spatial cross-match of ZTF alerts to CLU catalog of nearby galaxies (< 200 Mpc; Cook+ 18)
- Spectroscopic follow-up of all transients within 100” or 5 R_{eff} of CLU galaxy
- Aim for volume-complete SN sample within 200 Mpc



Kasliwal 2012

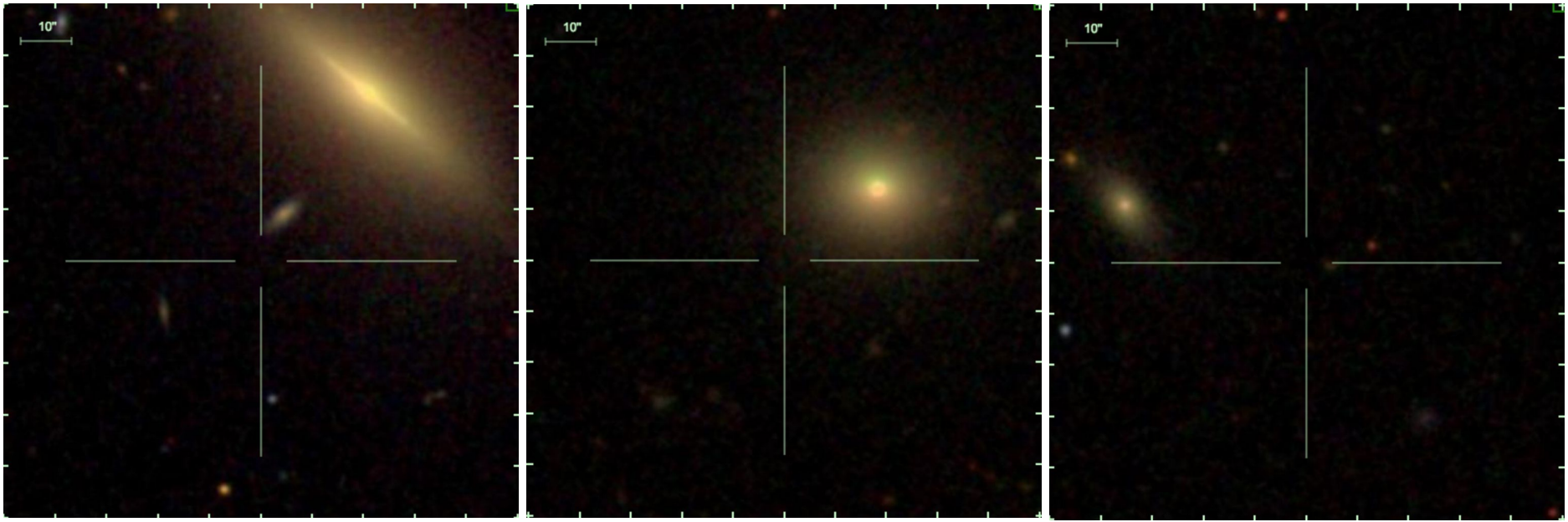
Fraction by SN Type



301 spectroscopically classified SNe so far within 200 Mpc

Rare transients

CLU volume is ripe for rare faint and fast evolving transients



Five new Ca-rich gap transients in outskirts of galaxies
More than half the total known sample of events