Supernova follow-up strategy for IceCube neutrino events

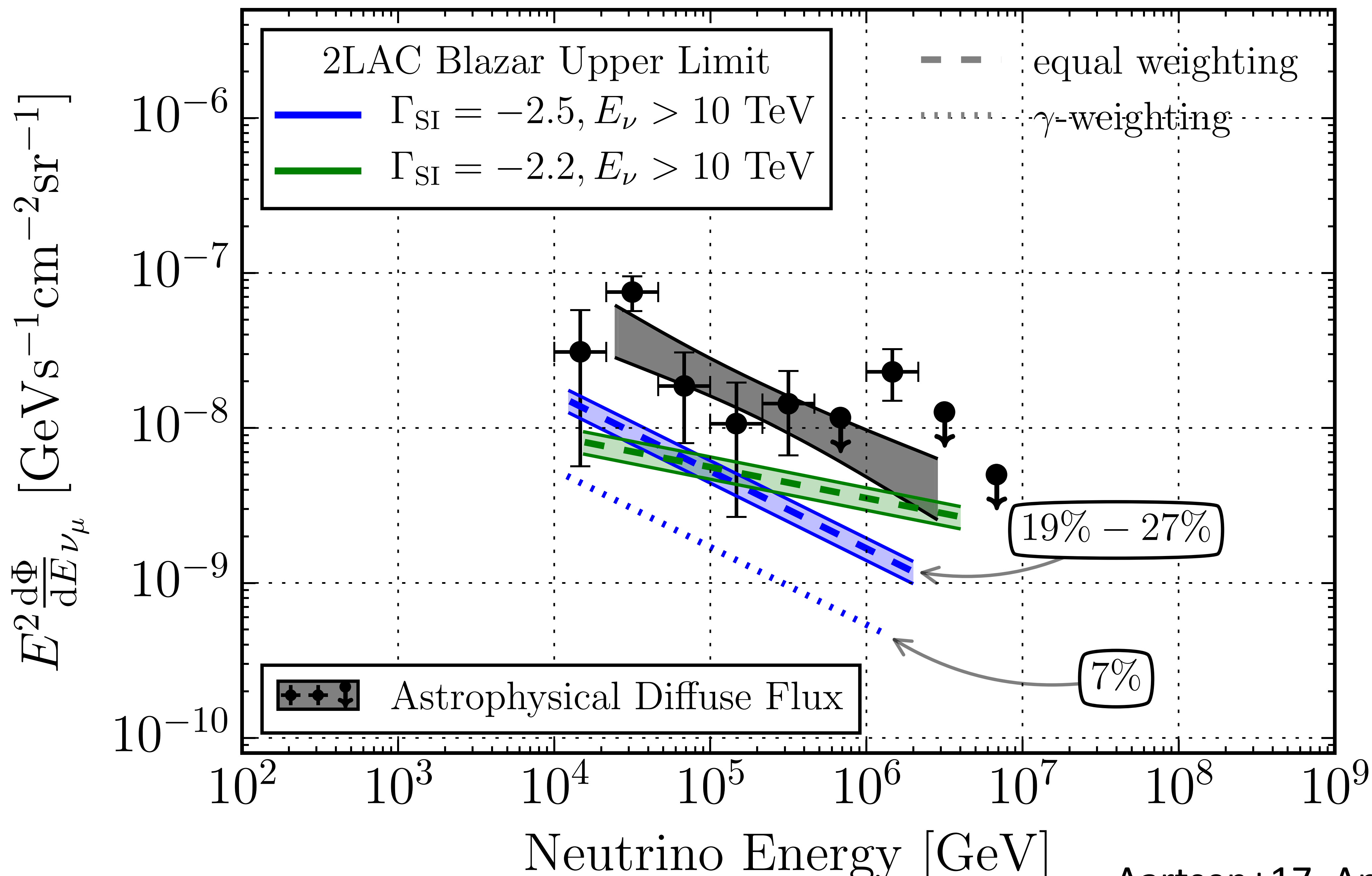
Masaomi Tanaka (Tohoku University)
on behalf of Subaru/HSC transient WG

Yasuda, MT, Tominaga+19, arXiv:1904.09697

Why supernovae (SNe)?

See talks by Xiang-Yu Wang and Zhuo Li

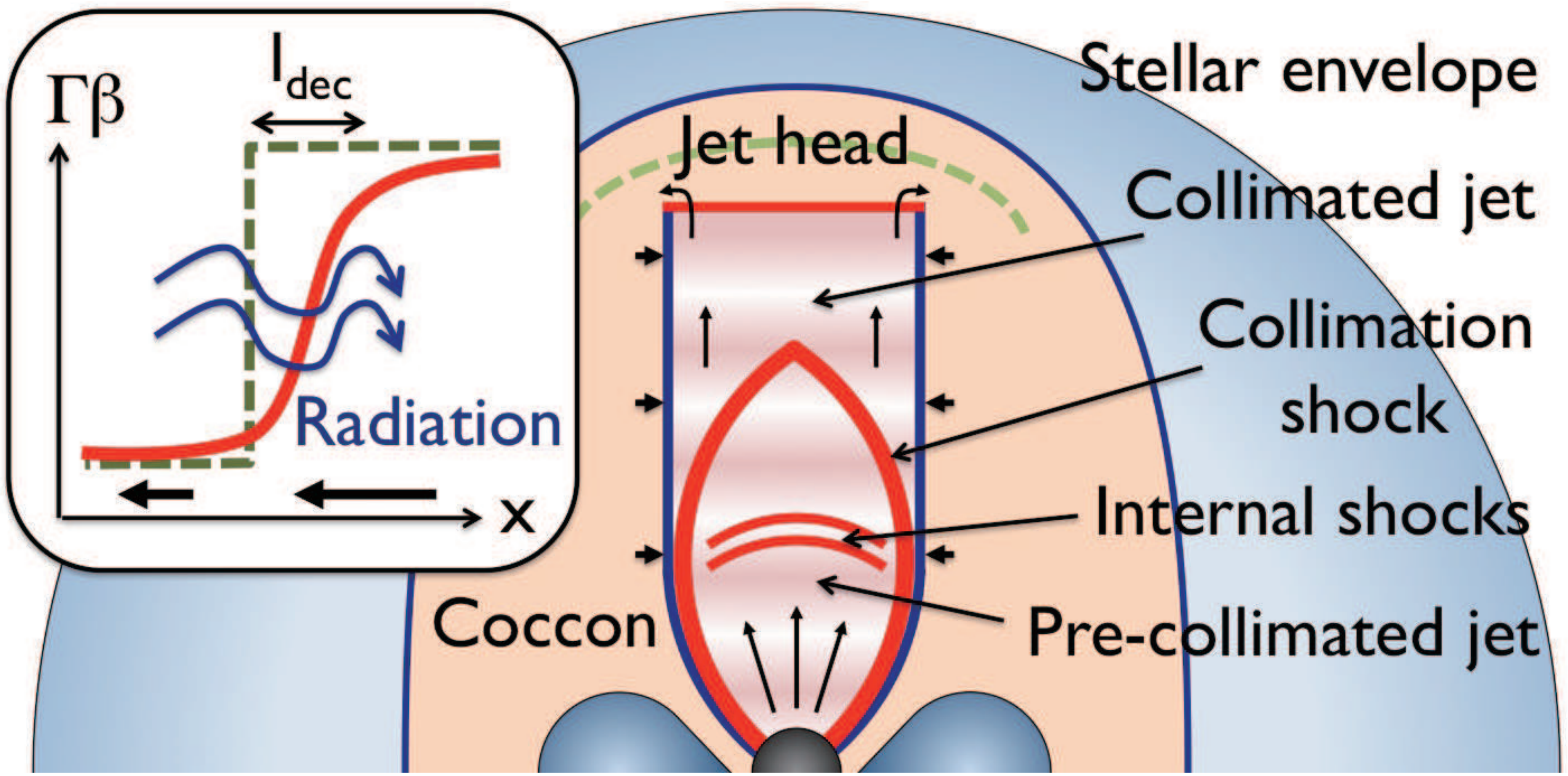
Blazars' contribution to the diffuse neutrino flux



Aartsen+17, ApJ

See talks by Xiang-Yu Wang and Zhuo Li

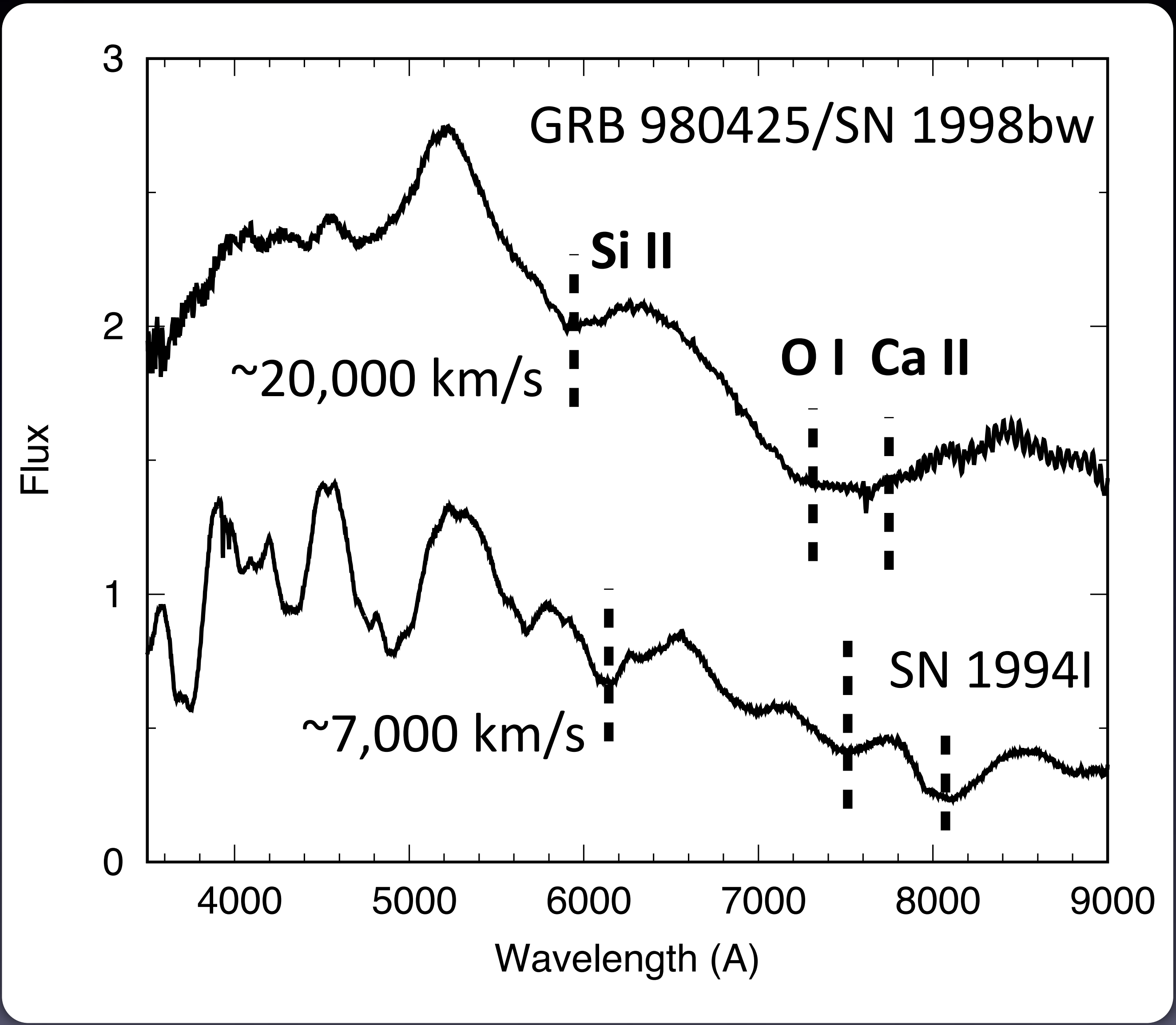
Supernova with chocked jet?

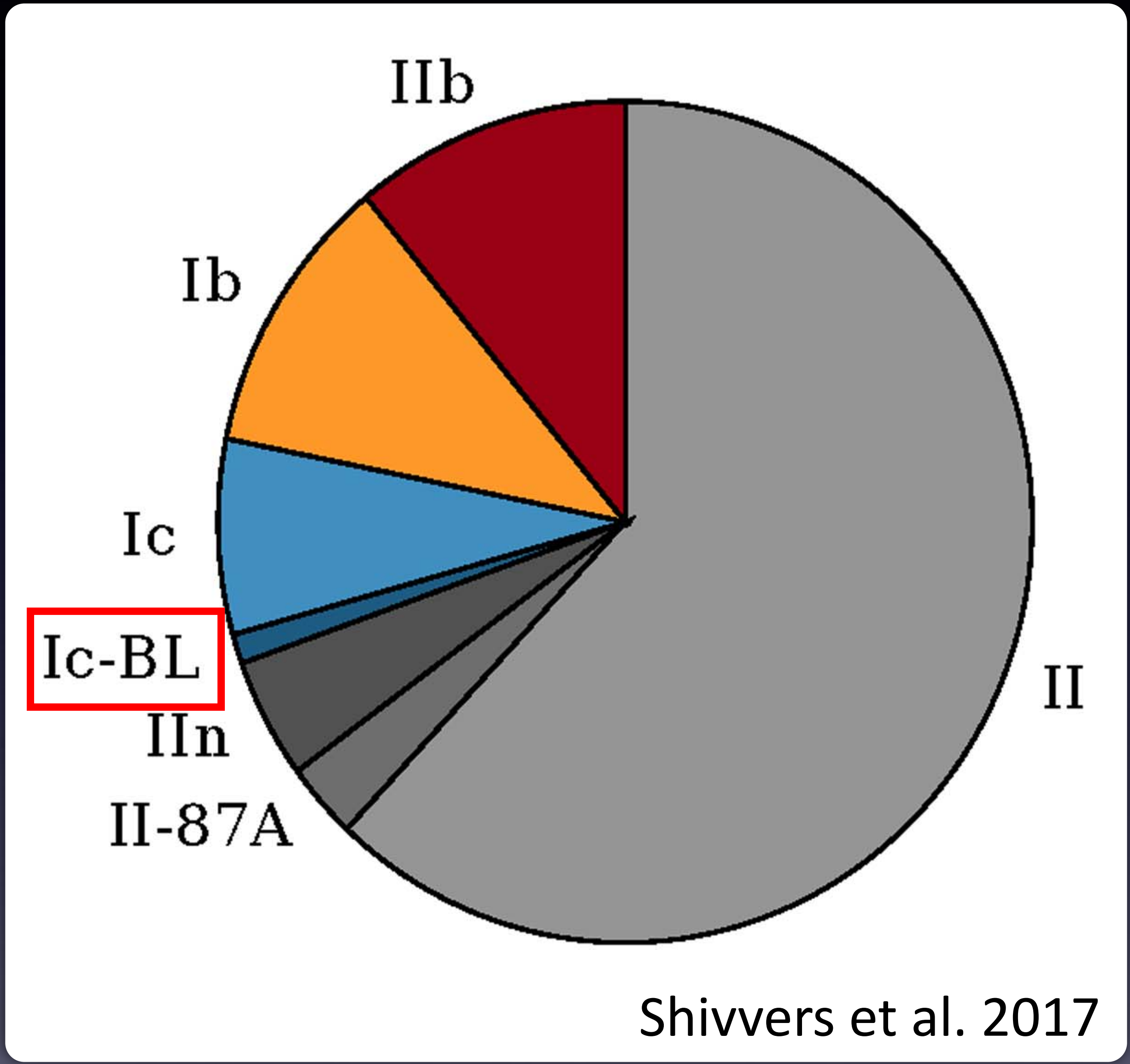


Murase & Ioka 2013

=> Observed as low-luminosity gamma-ray bursts (GRBs)?
=> Special type of supernovae?

“Broad-line” supernovae





~1% of core-collapse SNe

c.f. Long GRBs (~0.1 % of core-collapse SNe)

Can we conclude that such SNe are the origin of IceCube neutrinos?

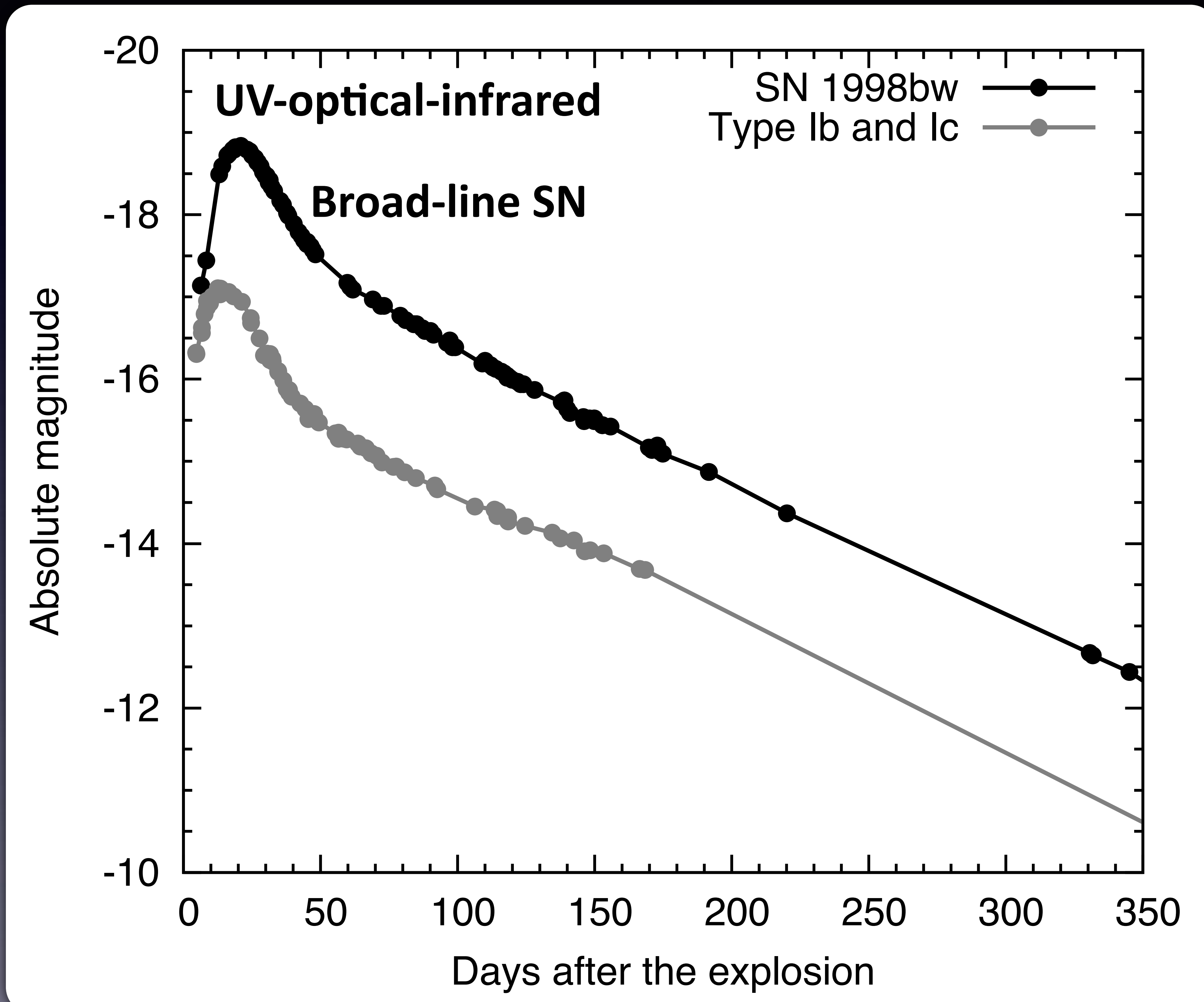
We need to
- identify certain types of SNe in the localization area
- exclude a chance coincidence

Electromagnetic emission from supernovae

10^{43} erg s^{-1}

10^{42} erg s^{-1}

10^{41} erg s^{-1}



Magnitude

$$
\begin{aligned}
m &= -2.5\log_{10}(F_\nu) - 48.6 \\
&= -2.5\log_{10}\left(\frac{F_\nu}{3631\times10^{-23}\ \mathrm{erg\ s^{-1}\ Hz^{-1}\ cm^{-2}}}\right)
\end{aligned}
$$

*Absolute magnitude: magnitude at 10 pc distance

Required size (diameter) of telescopes

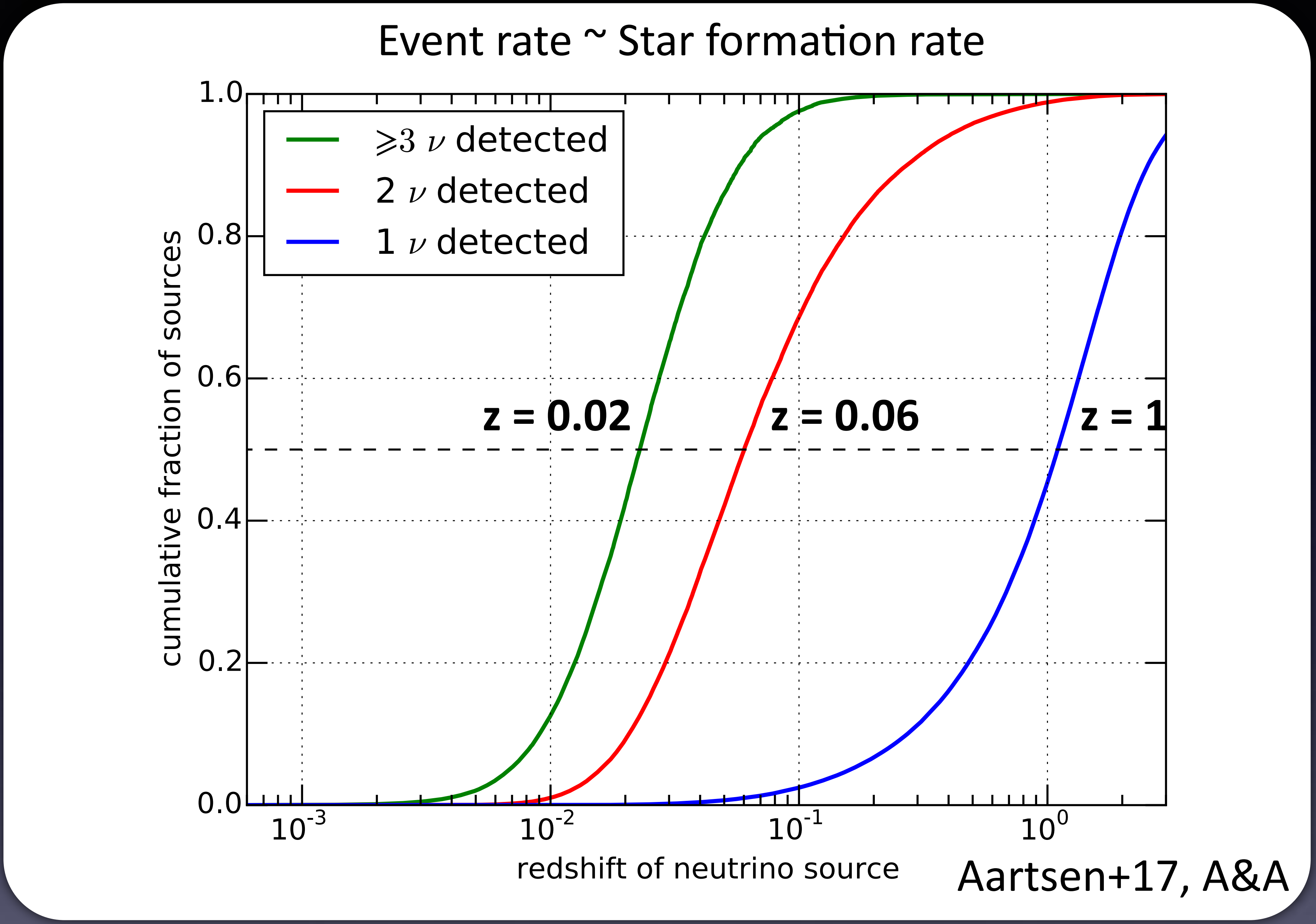
5 10 15 20 25 30 mag

Imaging eye 1m 2m 8m 30m

Spectroscopy 1m 2m 8m 30m

TXS 0506+056

Challenges in identifying SNe as neutrino sources



	Redshift	Distance	SN brightness
Singlet	z ~ 1	7 Gpc	26 mag
Doublet	z ~ 0.06	280 Mpc	19 mag
Triplet	z ~ 0.02	90 Mpc	17 mag

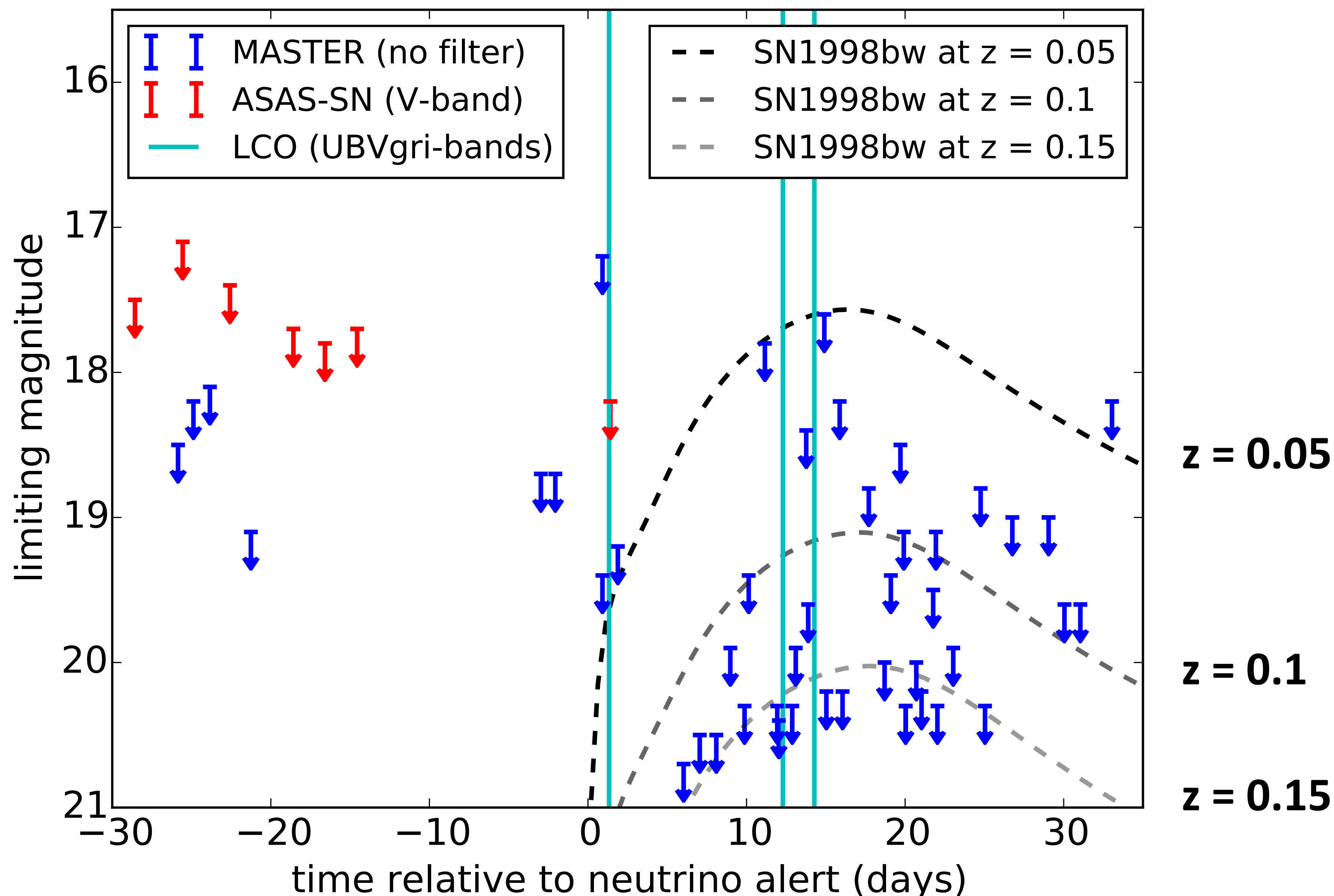
8m telescope!!

1m telescope

Strategy for multiplet event is straightforward

IceCube-160217 (triplet, z ~< 0.05)

*32% probability of a chance alignment of background

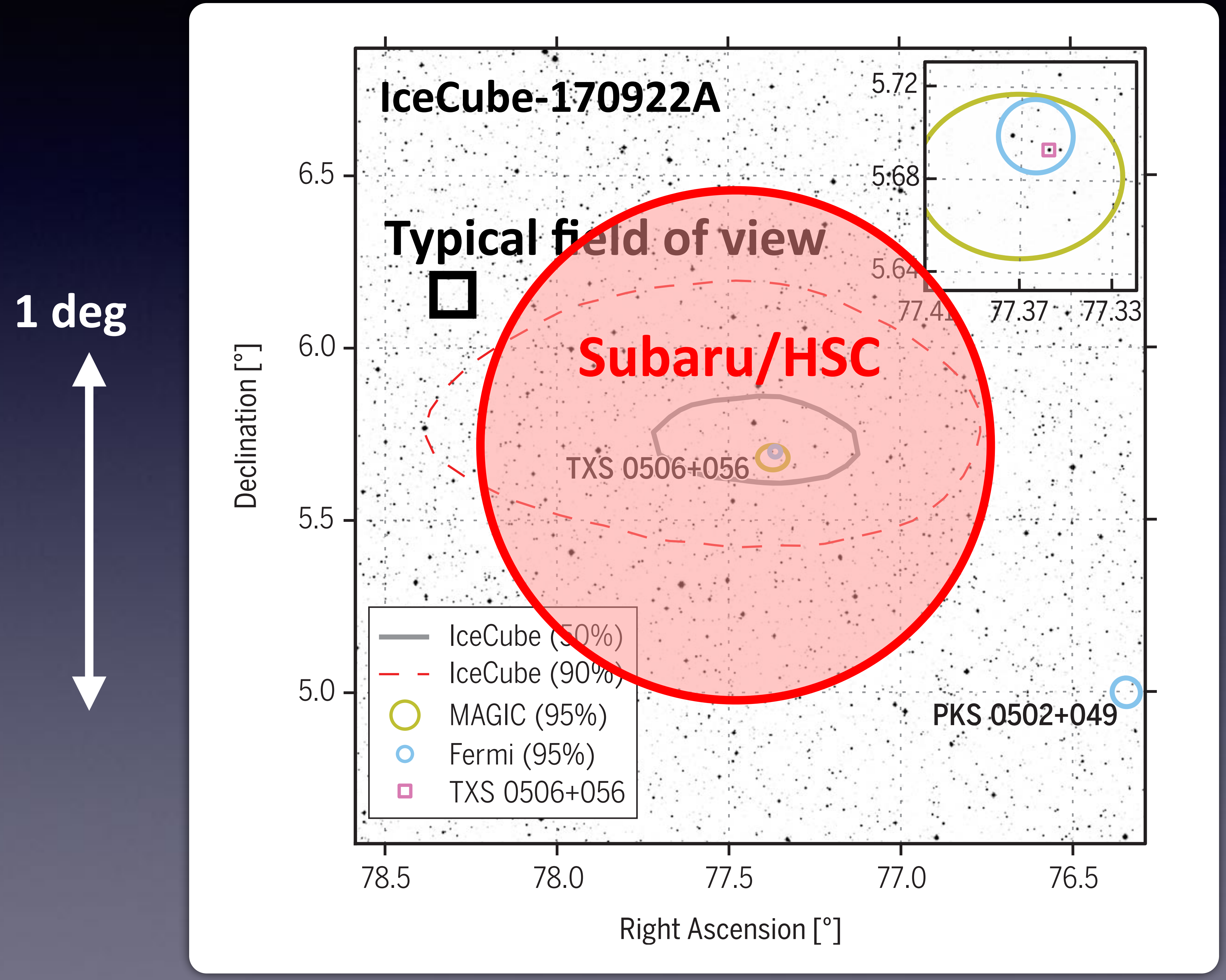


Aartsen+17, A&A

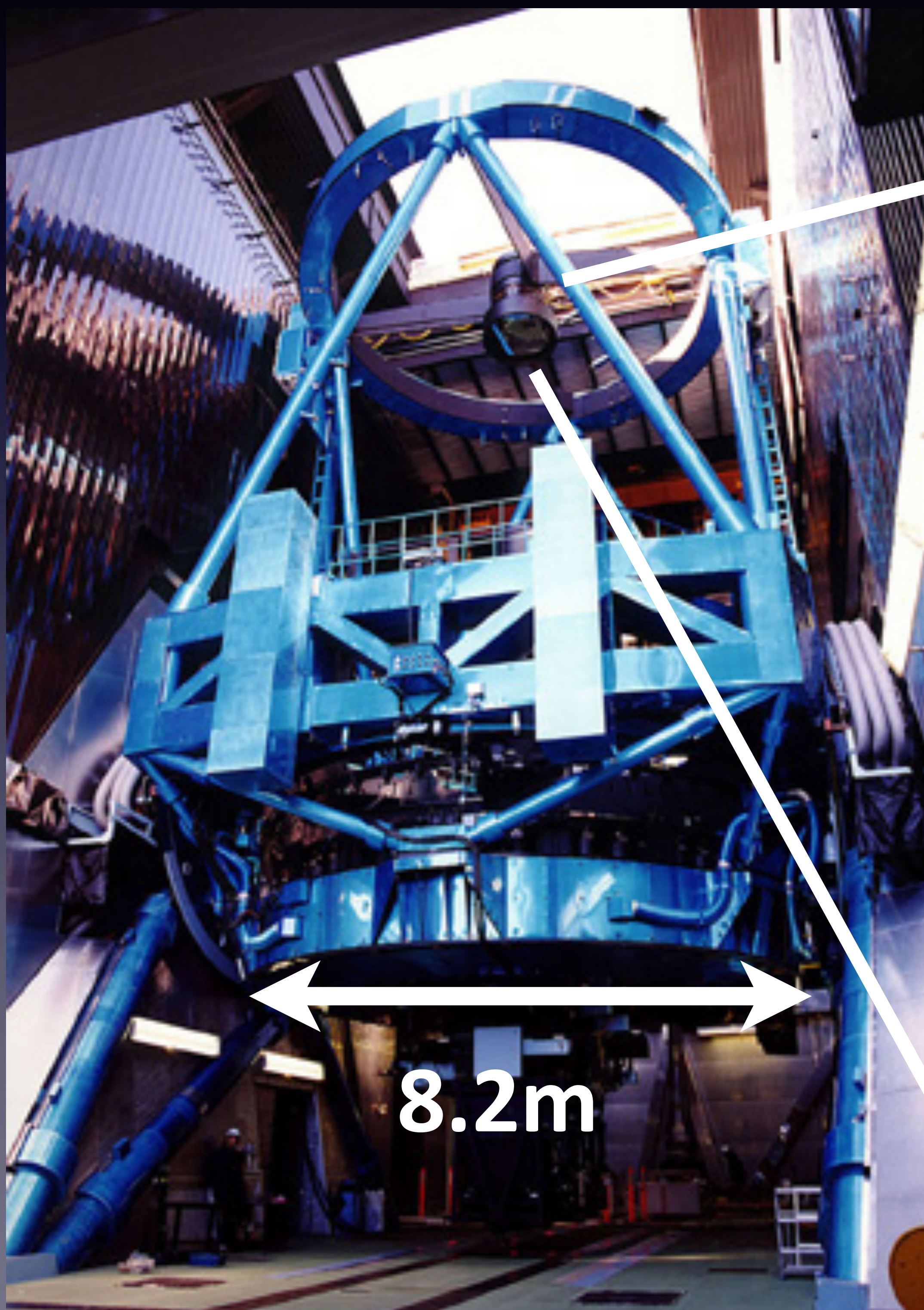
Number of unrelated SNe in 1 degree at 100 Mpc ~ 0.05

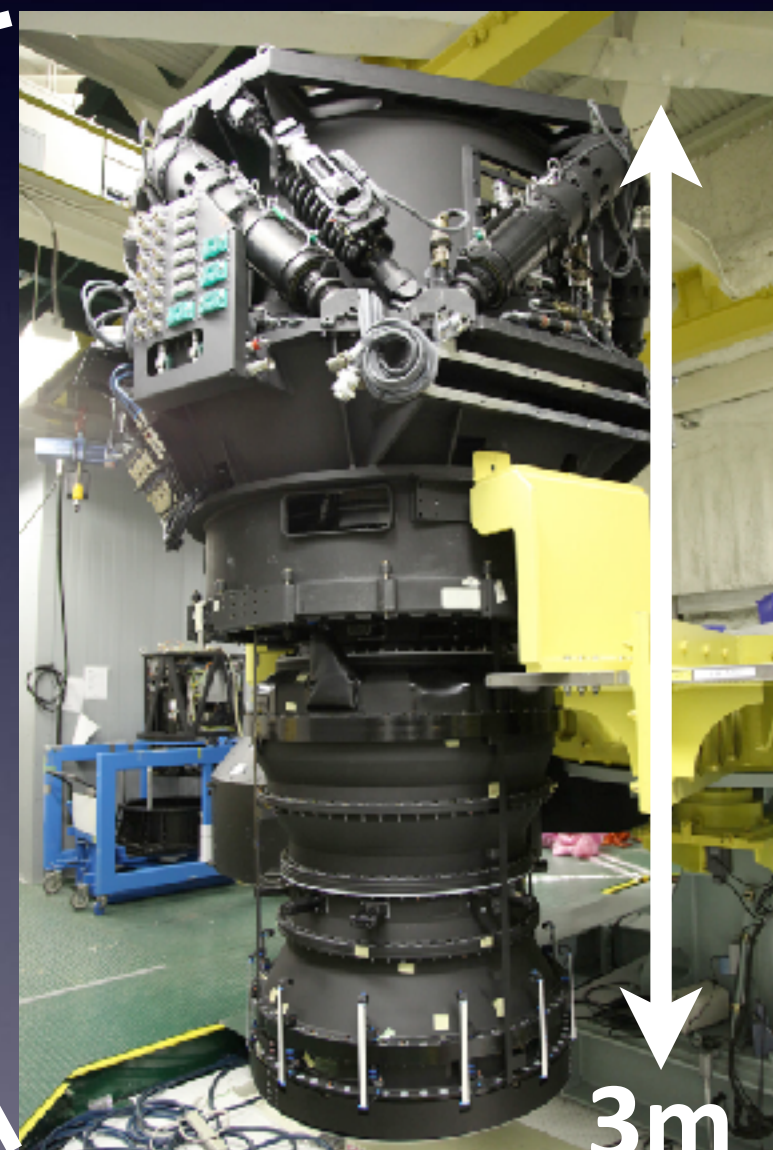
Strategy for singlet event

~ 26 mag if SN is the counterpart => need 8m class telescope

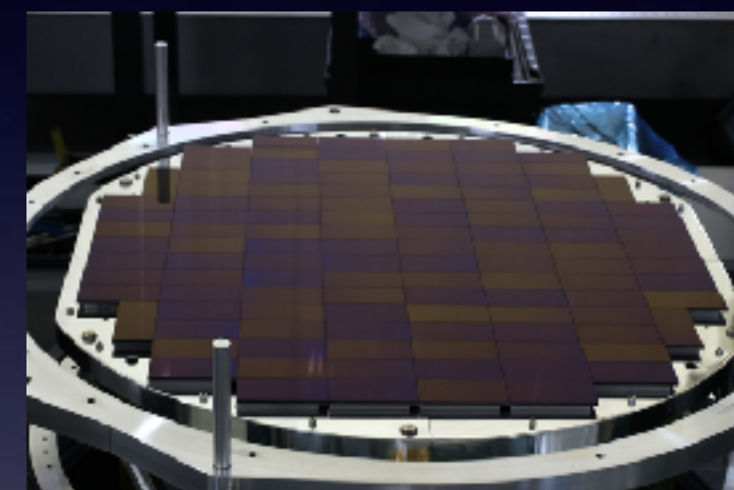


Subaru/Hyper Suprime-Cam





3t !



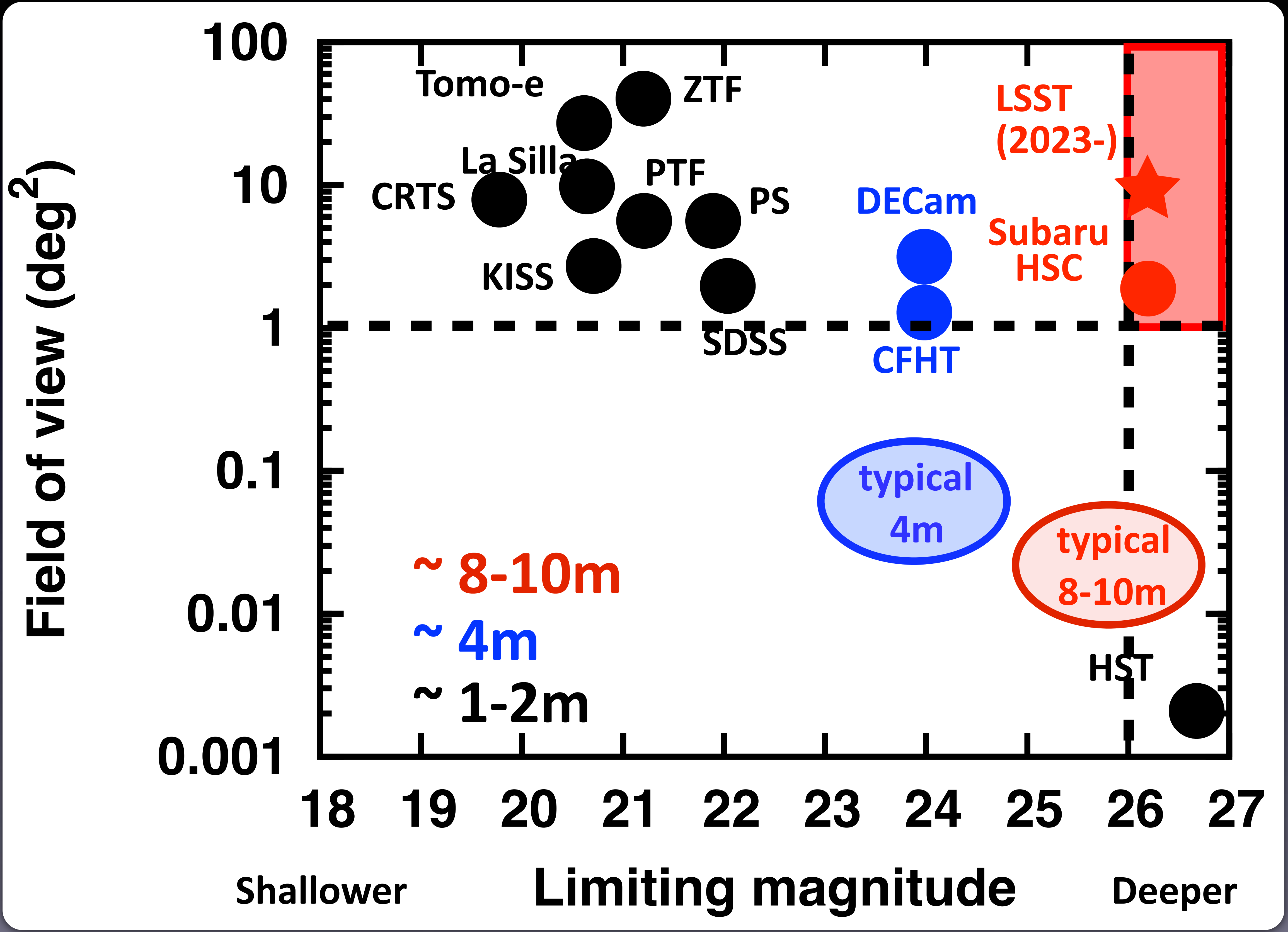
104 CCDs

~ 900 Mpix

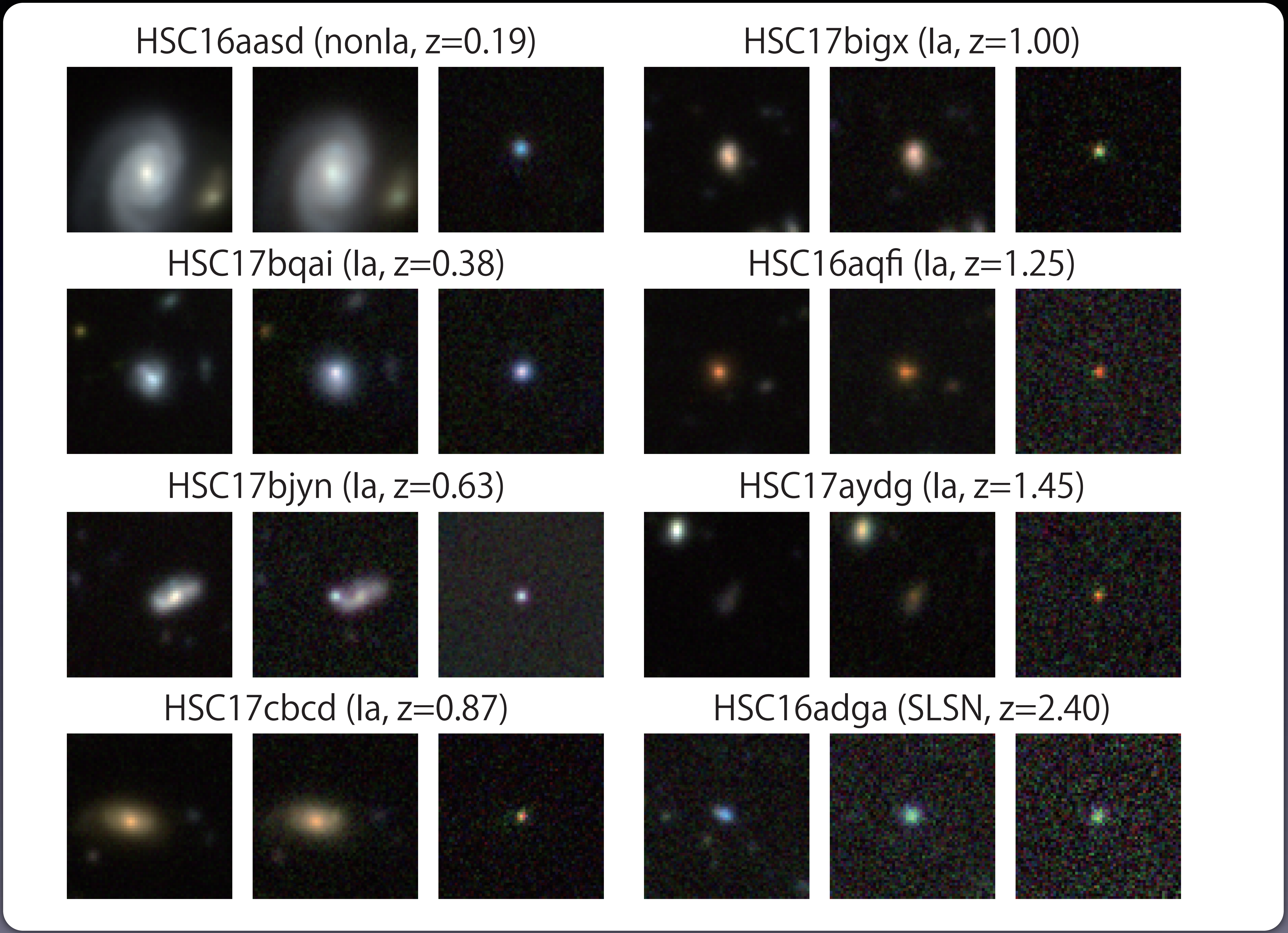
2 GB/image

~300 GB/night

Field of view vs sensitivity



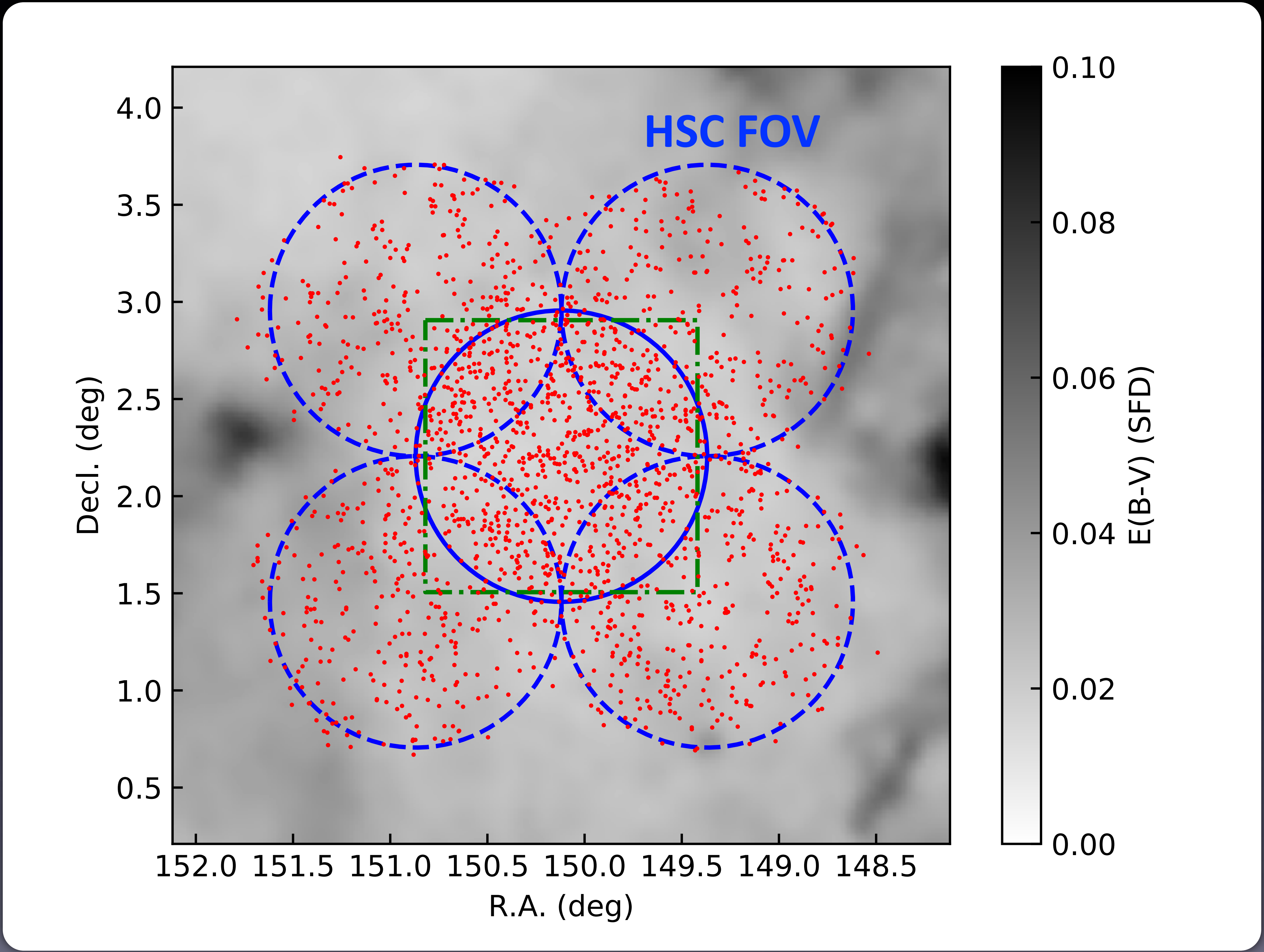
Subaru HSC transient surveys (~26 mag sensitivity)



Yasuda, MT, Tominaga+19, arXiv:1904.09697

~1800 SNe in 0.5 yr (~6 deg²)

1 deg

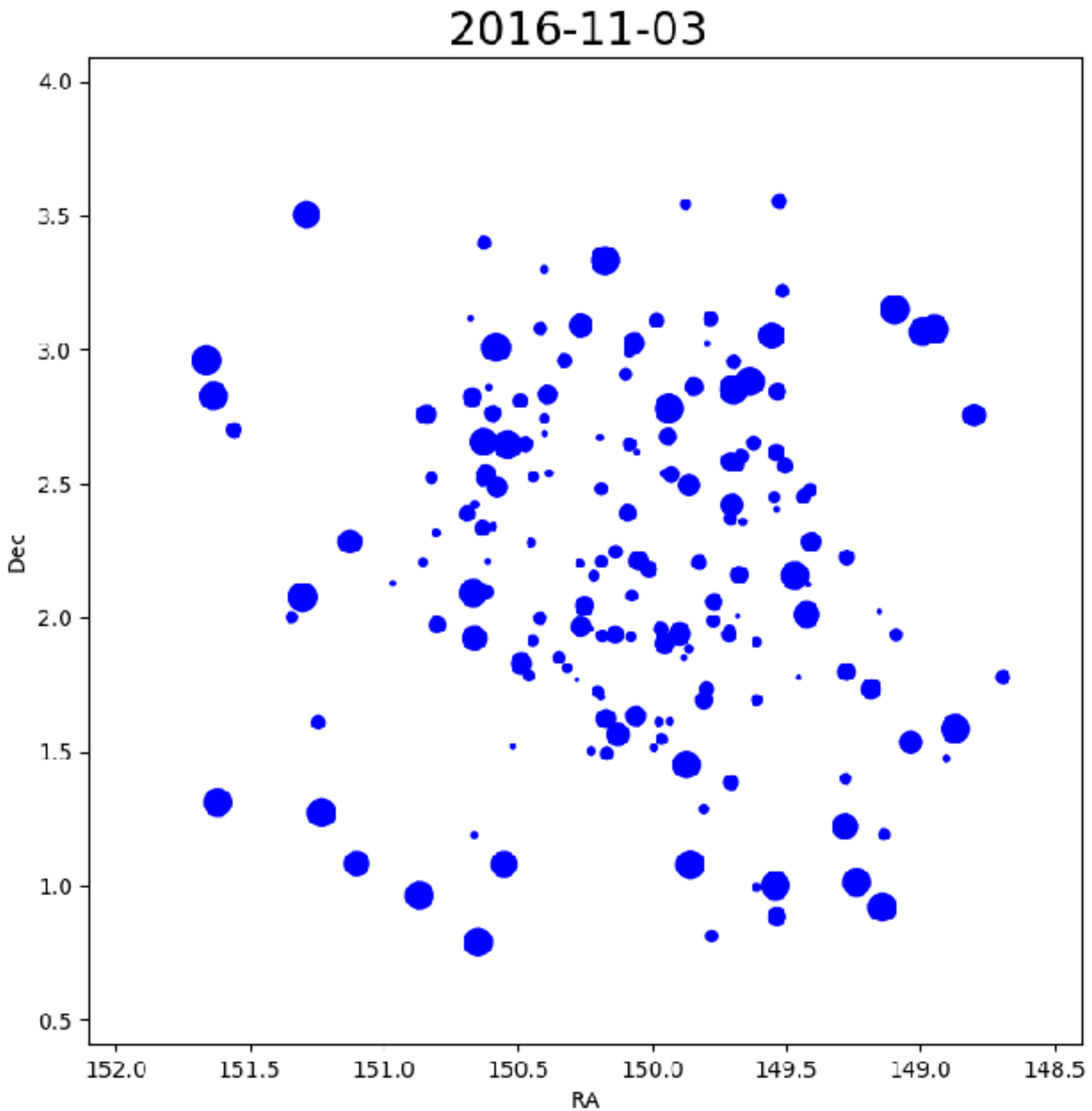


~50 SNe / deg² / 1 visit

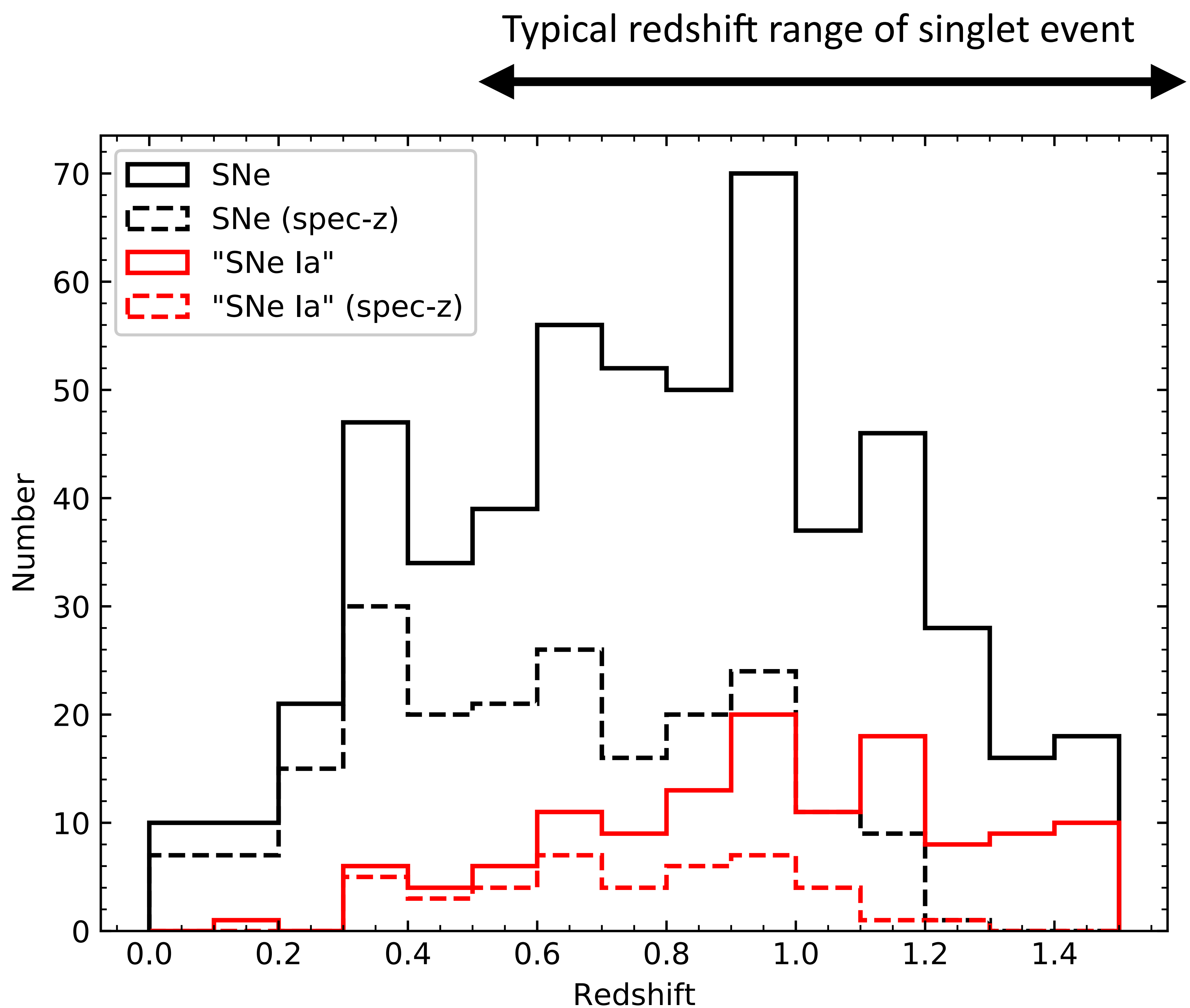
(c.f. ~500,000 objects / deg²)

Yasuda, MT, Tominaga+19

1 deg


2016-11-03
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Dec
152.0
151.5
151.0
150.5
150.0
149.5
149.0
148.5
RA

Redshift distribution



Yasuda, MT, Tominaga+19

How many supernovae in 1 visit (26 mag)?

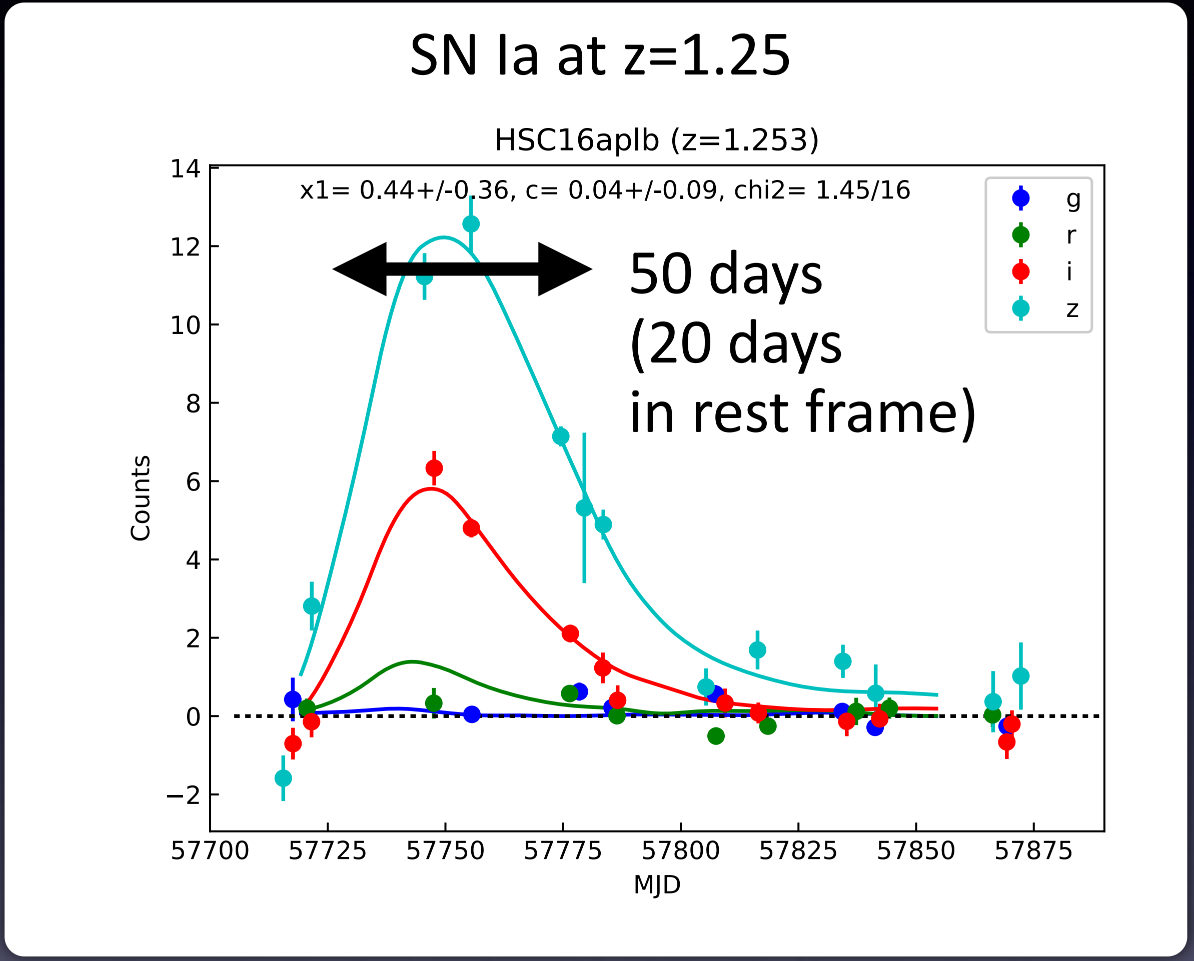
$$N \sim RV\Delta t f_\Omega \sim 10 \left(\frac{R}{10^5 \ \mathrm{Gpc}^{-3} \ \mathrm{yr}^{-1}}\right)\left(\frac{V}{100 \ \mathrm{Gpc}^3}\right)\left(\frac{\Delta t}{20 \ \mathrm{days}}\right)\left(\frac{\Omega}{1 \ \mathrm{deg}^2}\right)$$

Type	M_{abs} (mag)	z_{max}	Δt (days)	Local rate (Gpc^{-3} yr^{-1})	N (deg^{-2})	z< 0.1 N (deg^{-2})
Ia	-19	1.3	20	0.3×10^5	10 - 30	0.01
II (H-rich)	-17	0.7	50	0.7×10^5	10 - 30	0.05
IIn (CSM)	-18	1.0	50	0.1×10^5	4 - 12	0.007
Ibc (H-free)	-17	0.7	20	0.2×10^5	1 - 3	0.006
Broad line (hypernova)	-18	1.0	20	0.01×10^5	0.2 - 0.6	0.0003

Local rate x 3

For IceCube-170922A
0.15 deg² (50 %) and 0.97 deg² (90%)

How to identify broad-line SNe at z ~ 1 ?
(among >10 of Type Ia/II SNe)



(1) Photometric classification

Need good time sampling
cadence of 2-3 days
continuous monitoring for ~50 days

Need color information
>= 3 filters
(no redshift information in advance)

(2) Spectroscopic confirmation

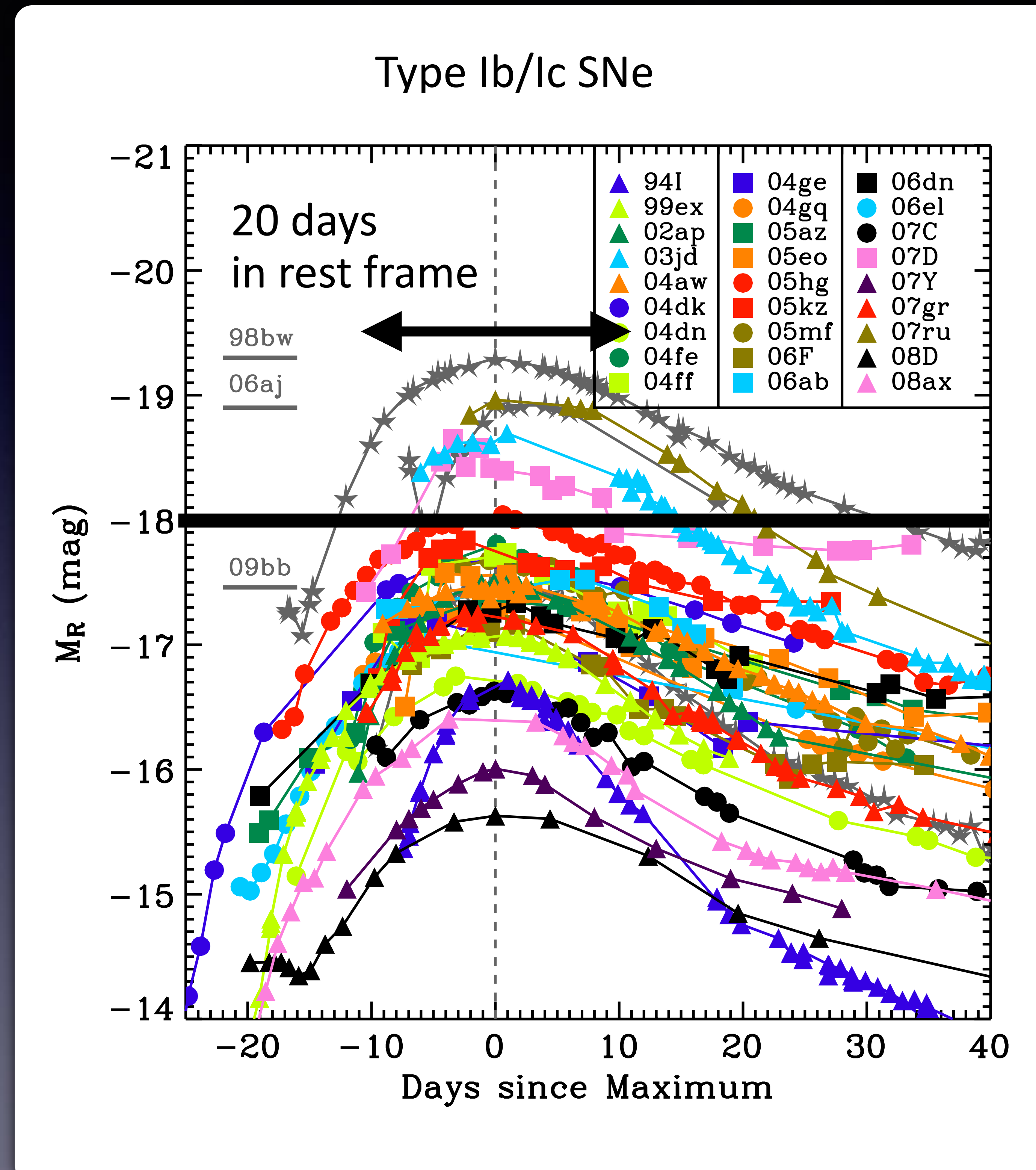
Need realtime spectroscopy
Multi-object spectroscopy? (Subaru/PFS)
30m-class telescope (late 2020?)

How to estimate the explosion date?

~5 days uncertainty should remain for objects at z ~ 1

Number of unrelated broad-line SNe in a window of Δt ~ 5 day ~ 0.05-0.15 / deg²

* **Contamination becomes higher if neutrino emission lasts longer**
(dense material around Type IIn or IIP SNe, see Zhuo Li's talk)



Drout et al. 2011

Summary: strategy to identify SNe as neutrino sources

- **Multiplet events ($z < 0.1$)**
  - Follow-up with 1-2m telescopes => spectroscopy
  - Low contamination
- **Singlet events ($z \sim 1$)**
  - Deep observations (~26 mag w/ Subaru/HSC and LSST)
    - High probability, but high contamination
  - Moderate observations (22-24 mag w/ 2-4m class telescopes)
    - Low probability, but low contamination
- **IceCube-Gen2**
  - Better sensitivity => more multiplet
  - Better localization => lower contamination (needs ~0.1 deg)