2020年代の恒星研究

田中 雅臣
（国立天文台）

頂いたお題

- 初期世代星
- ガンマ線バースト
- 超新星爆発
- 晩期型星　（ごめんなさい）
- 装置ありきではなく、サイエンスから

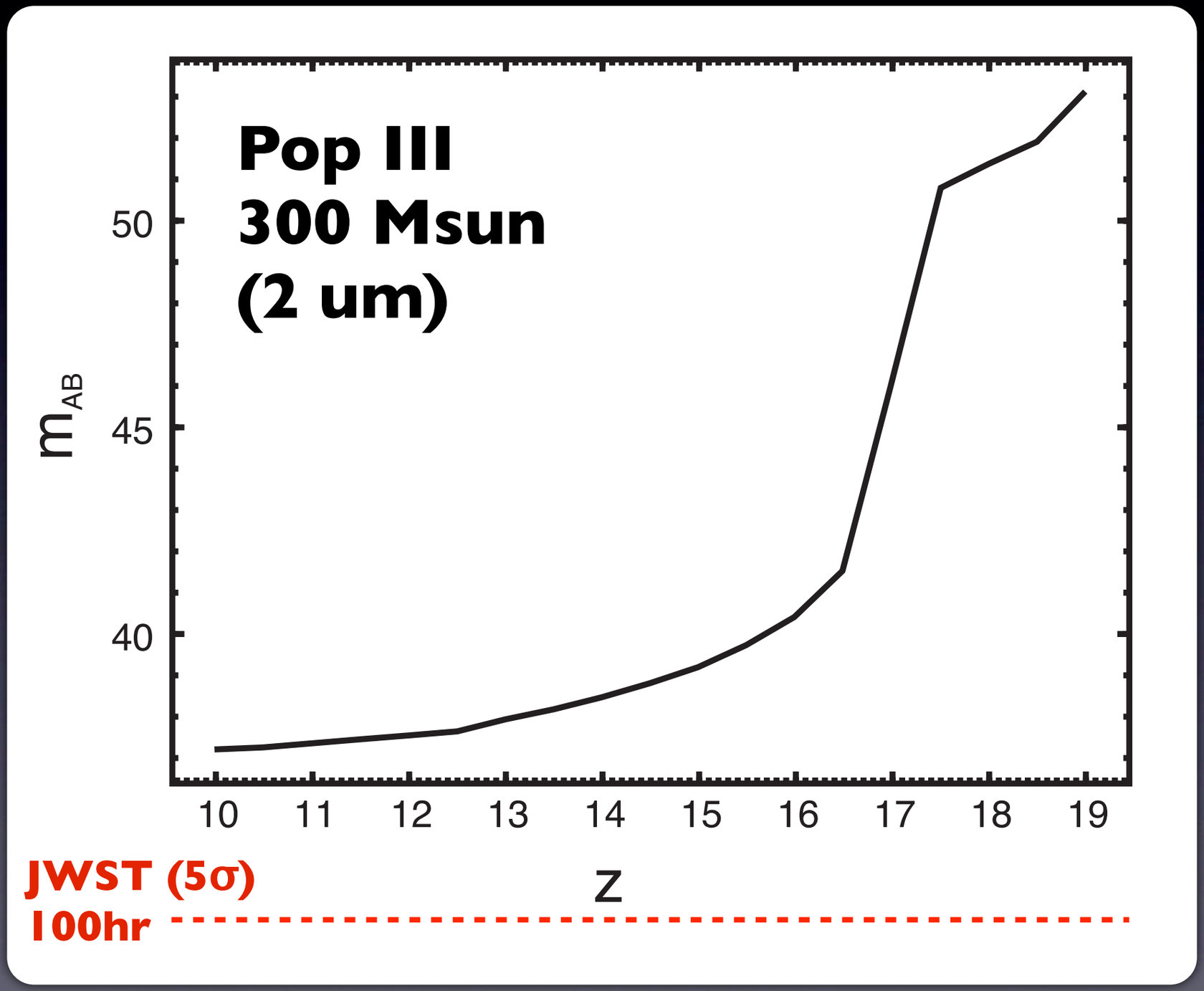
装置 => サイエンス

TMTサイエンス検討会報告書 / SPICA proposal

初代星を見たい

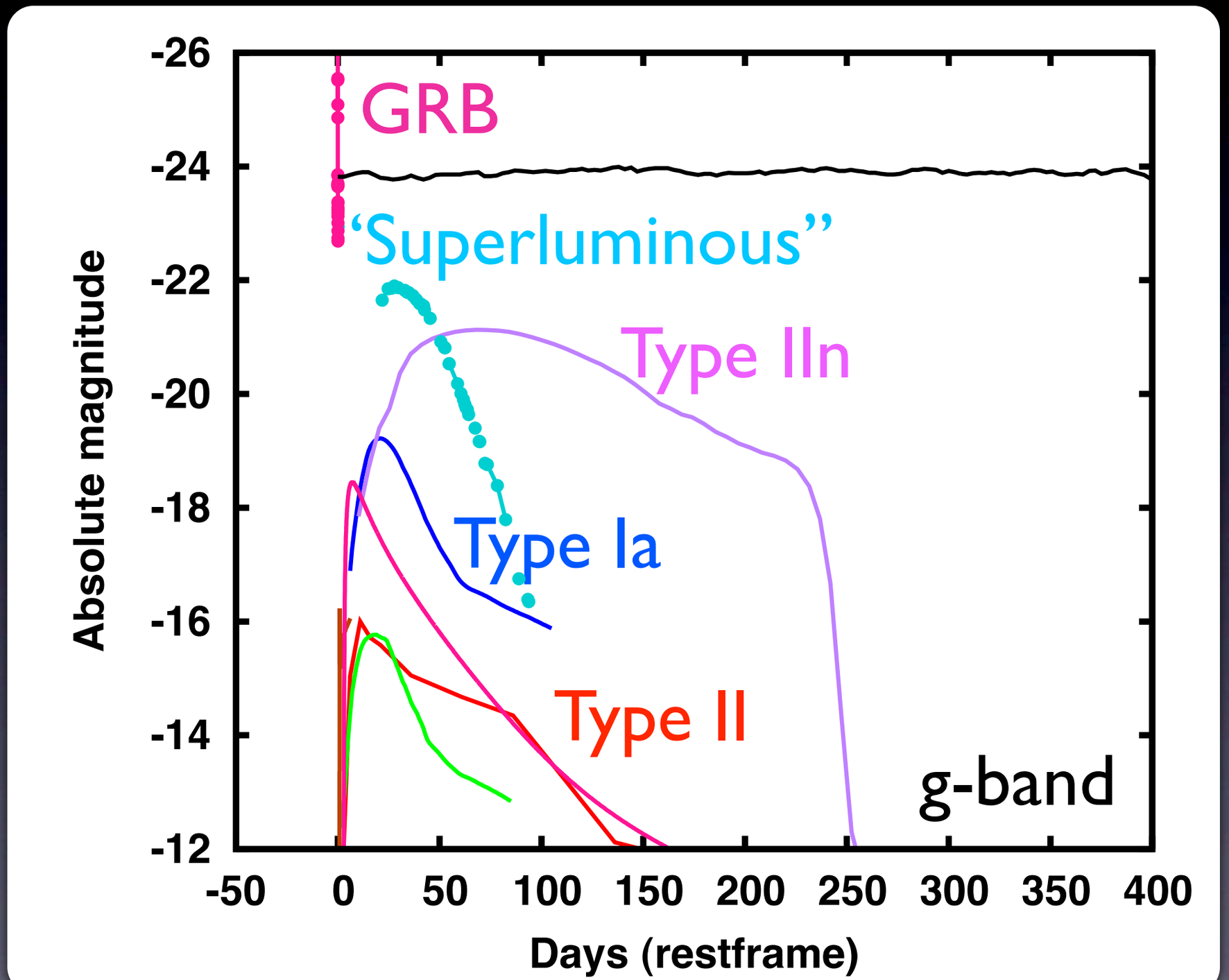
First Star

L ~ 10^6 - $10^{7.5}$ Lsun
(for 100-1000 Msun)



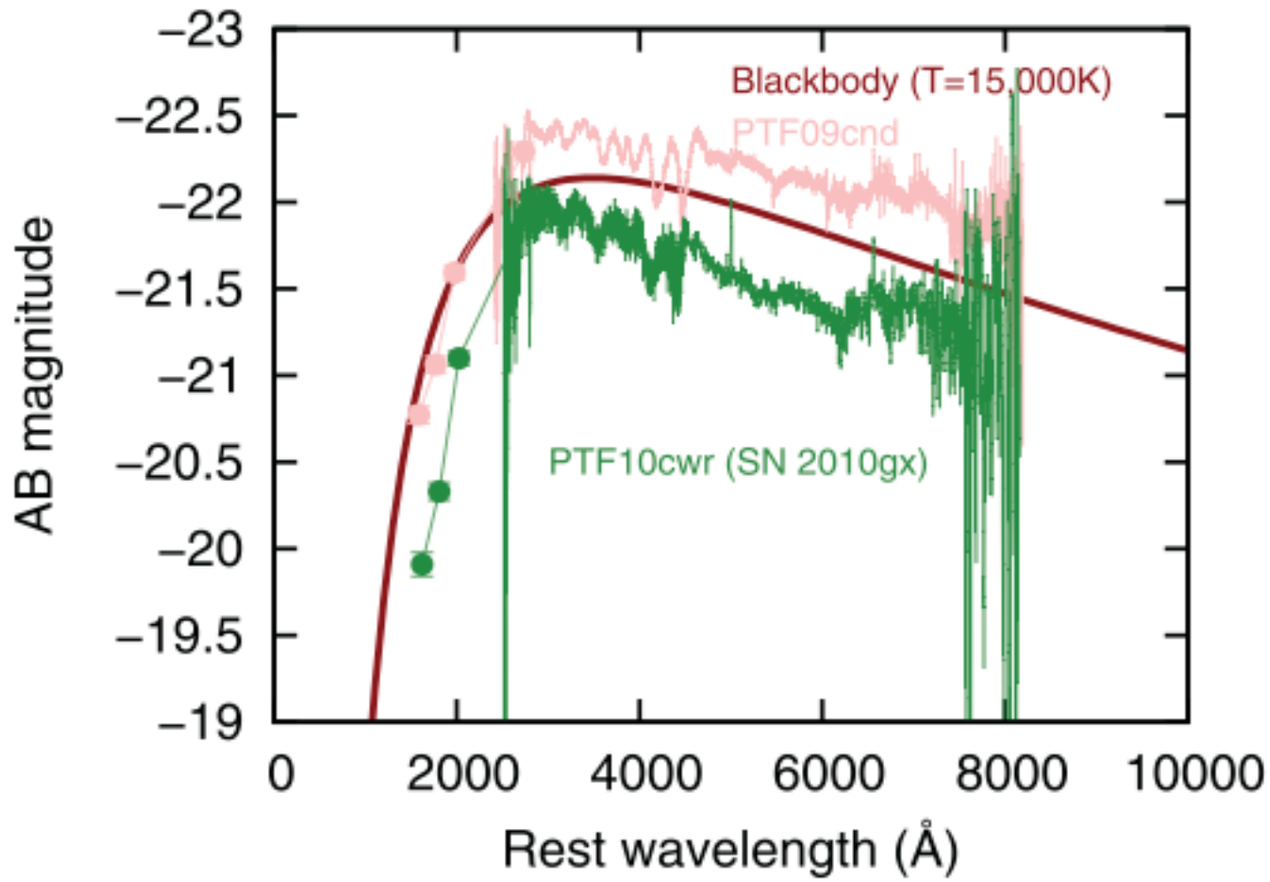
(e.g., Bromm+01, Stiavelli+09, Bromm & Yoshida 11, Rydberg+11)

First Supernova L ~ 10^{10} Lsun



“Superluminous” Supernovae

(Quimby+10, Pastorello+10)



MT, Moriya, Yoshida+12

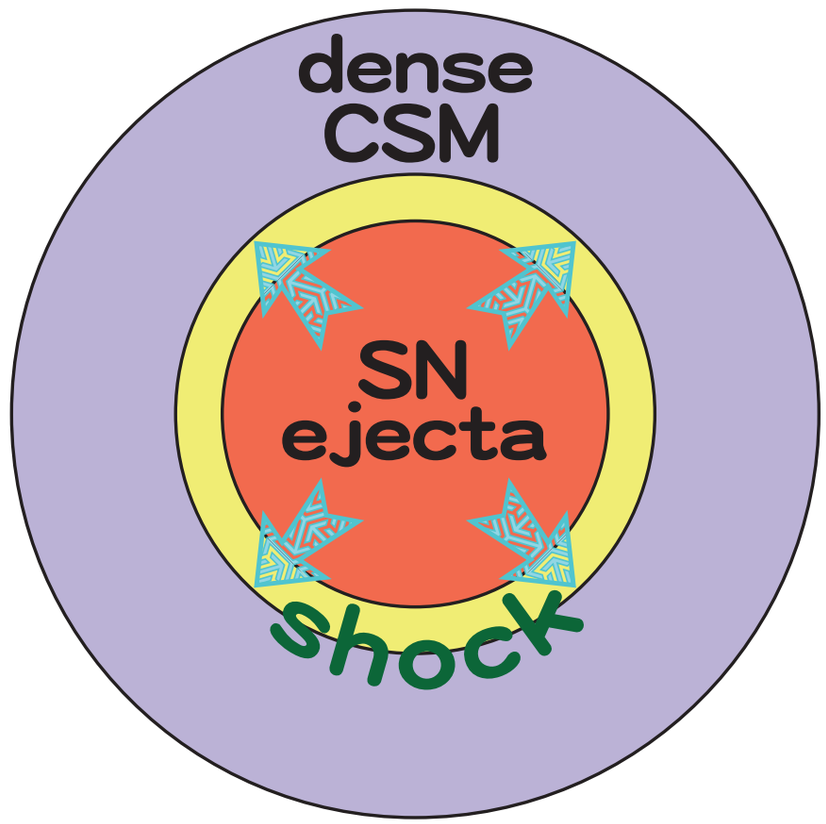
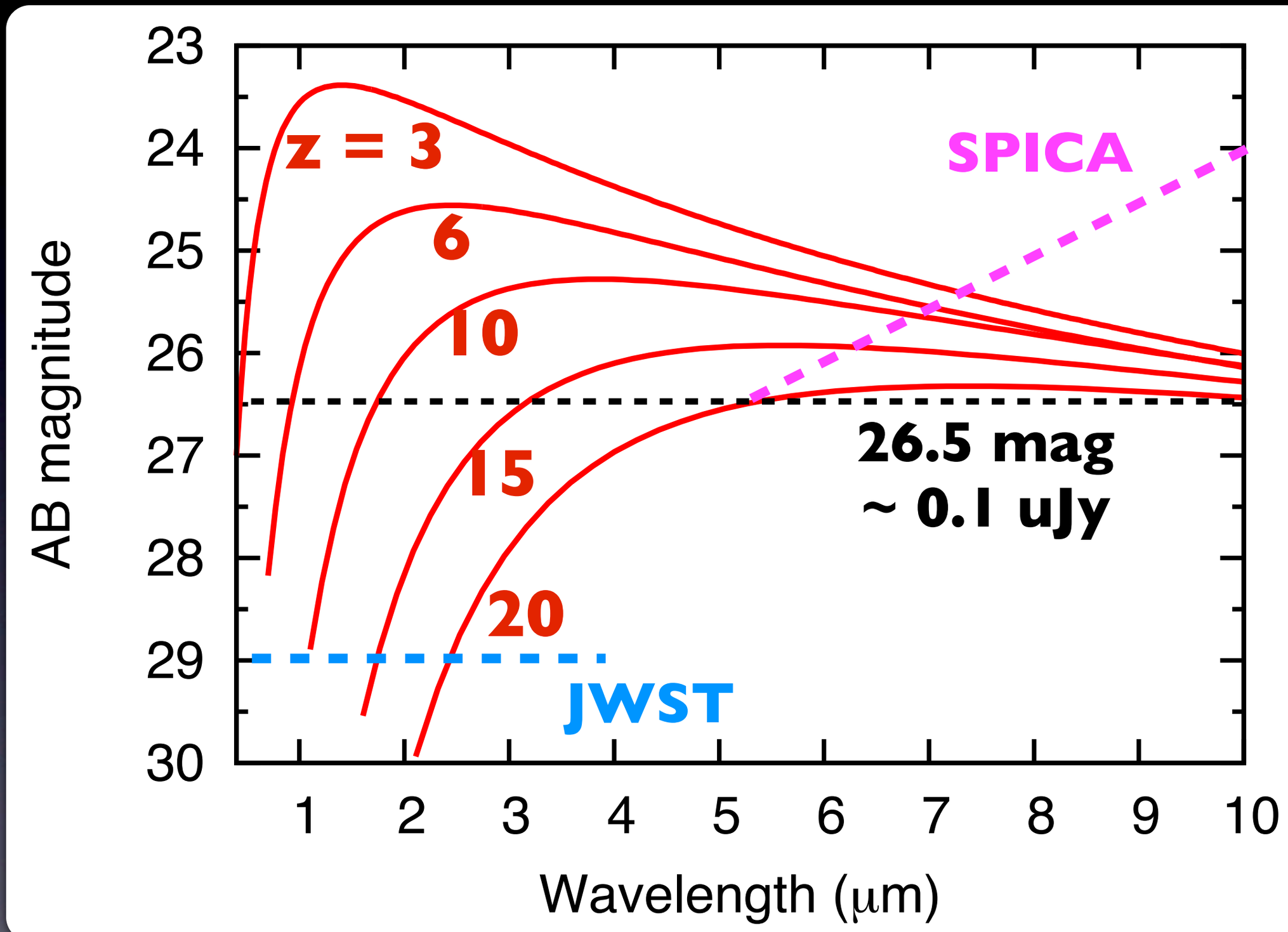
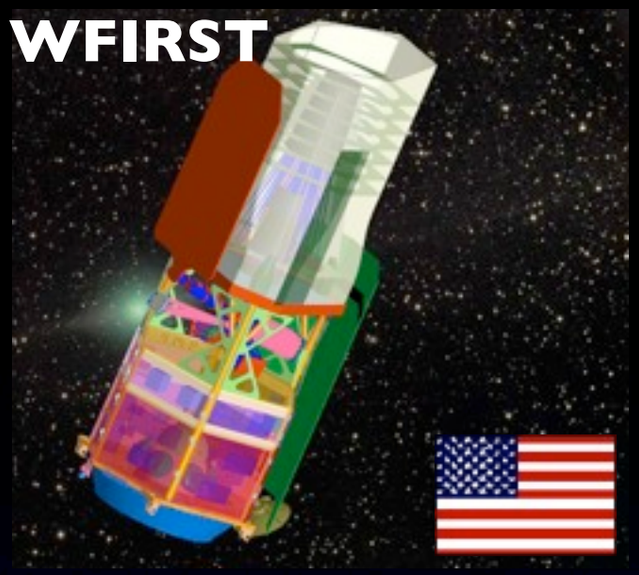
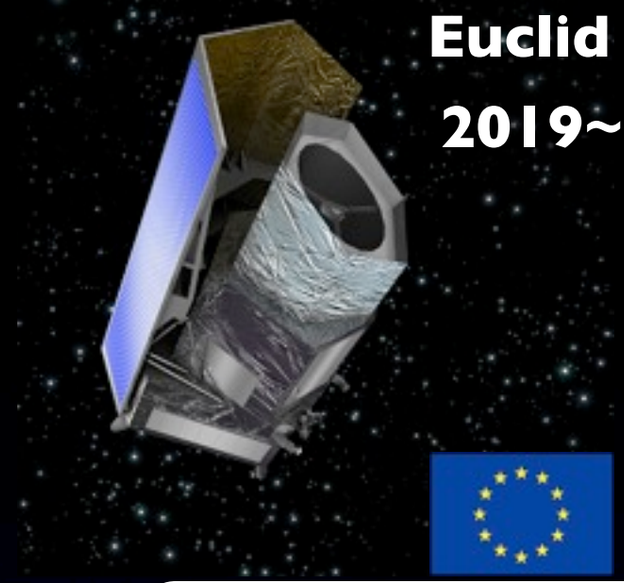


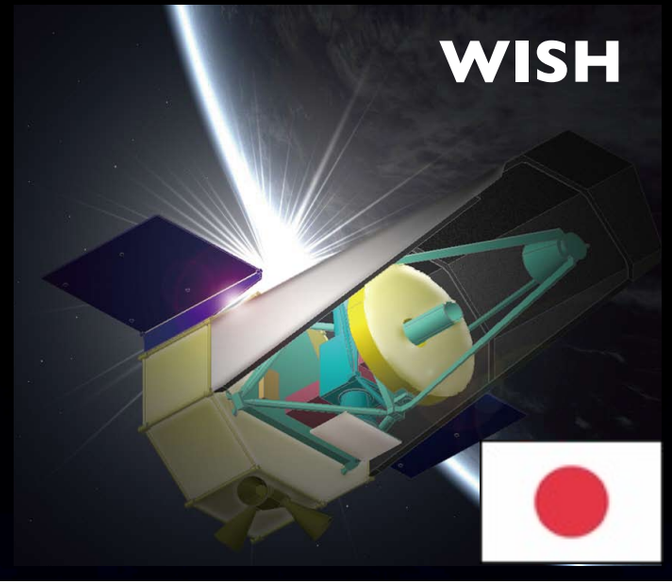
Figure courtesy of Takashi Moriya



MT, Moriya, Yoshida+12

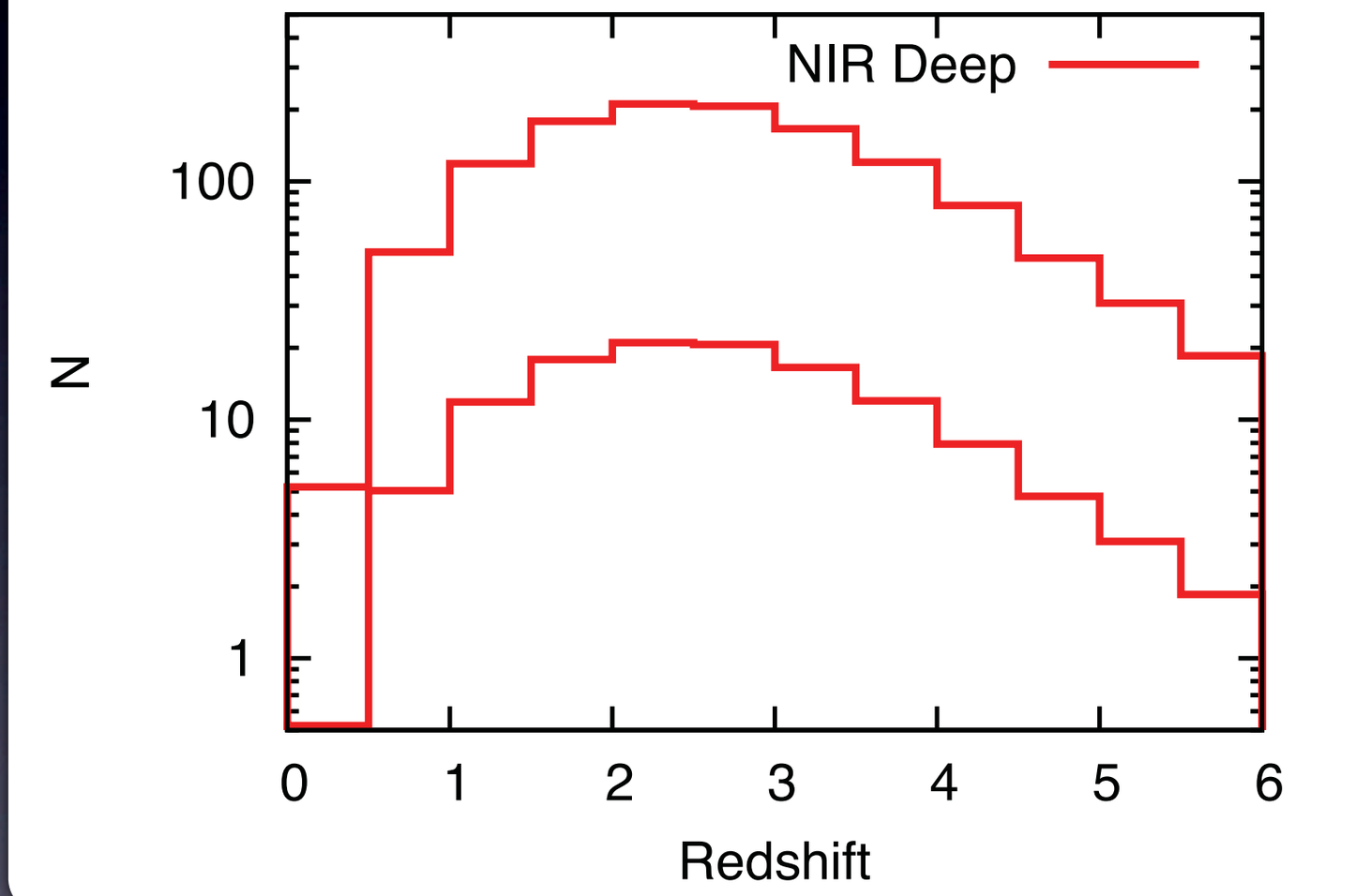






AB = 26.5 mag
(@ 1-4 um)
100 deg^2
6 visits in 0.5 yr

10^{-4} - 10^{-3}

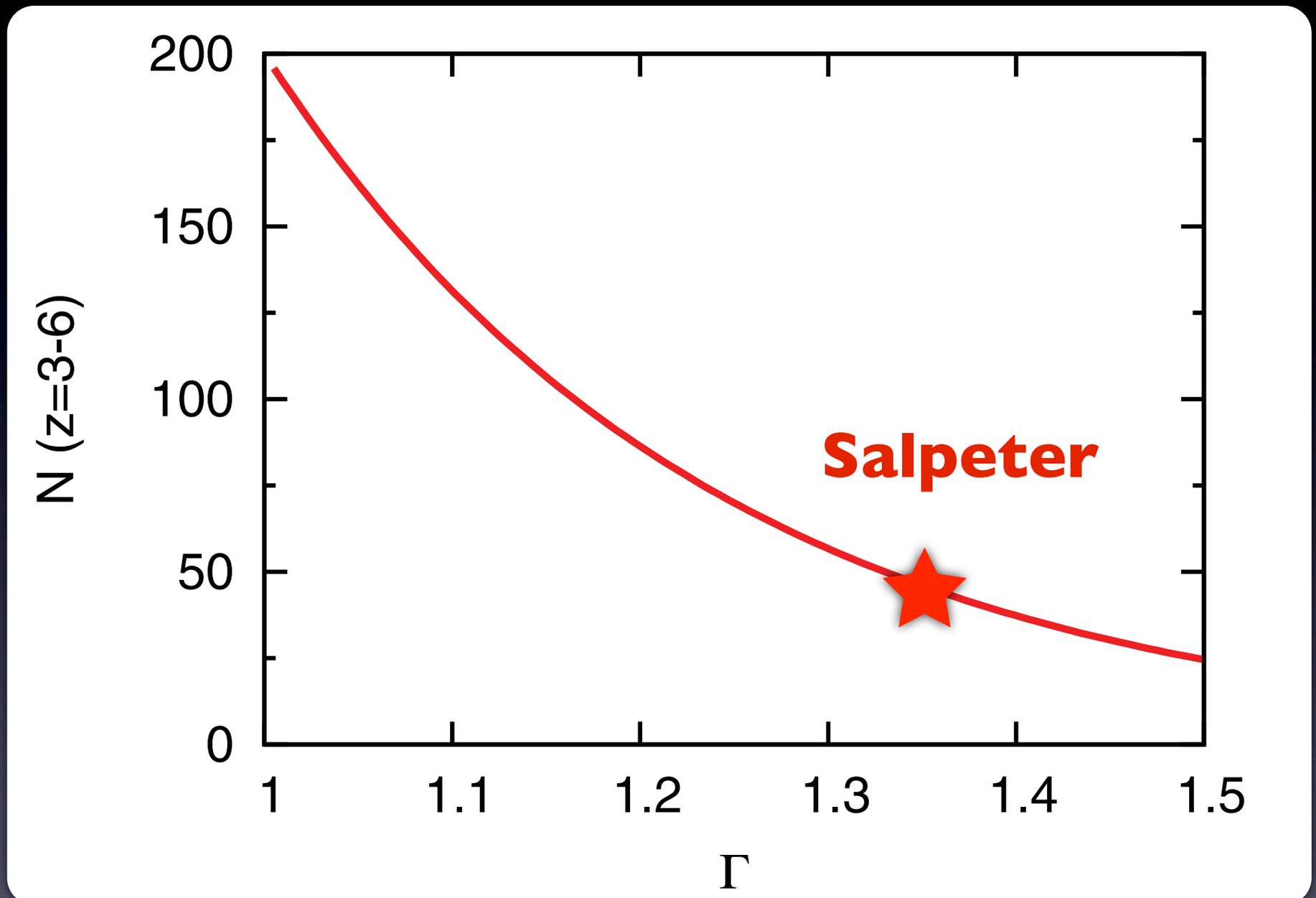


$$R_{\rm SLSN}(z) = f_{\rm SLSN}\,\rho_*(z)\,\frac{\int_{M_{\rm min,SN}}^{M_{\rm max,SN}}\psi(M){\rm d}M}{\int_{M_{\rm min}}^{M_{\rm max}}M\psi(M){\rm d}M}$$

SFR

MT, Moriya, Yoshida+12

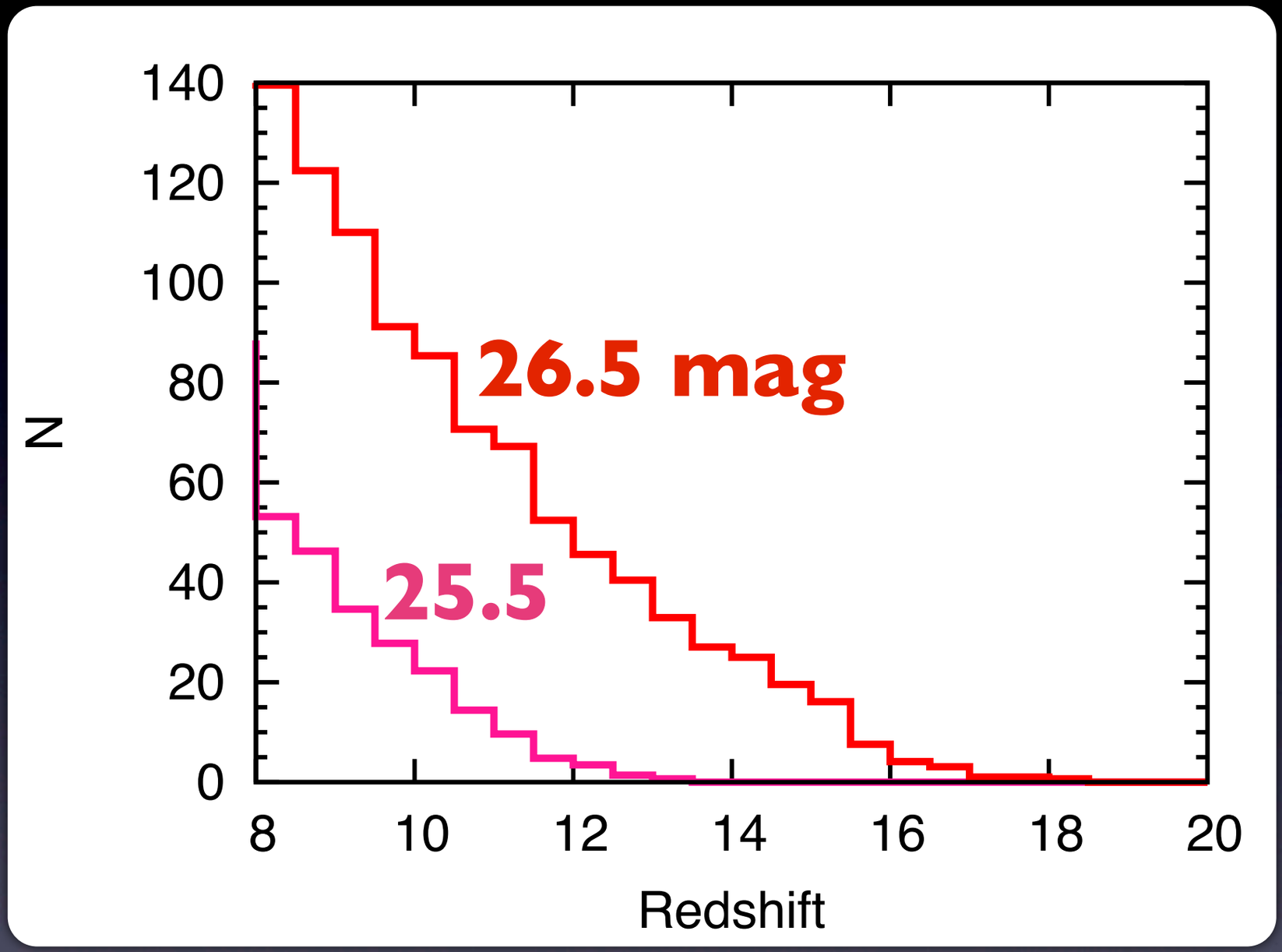
IMF by Number Count of Supernovae



* Completeness
* SN rate

Transient survey with Subaru/HSC

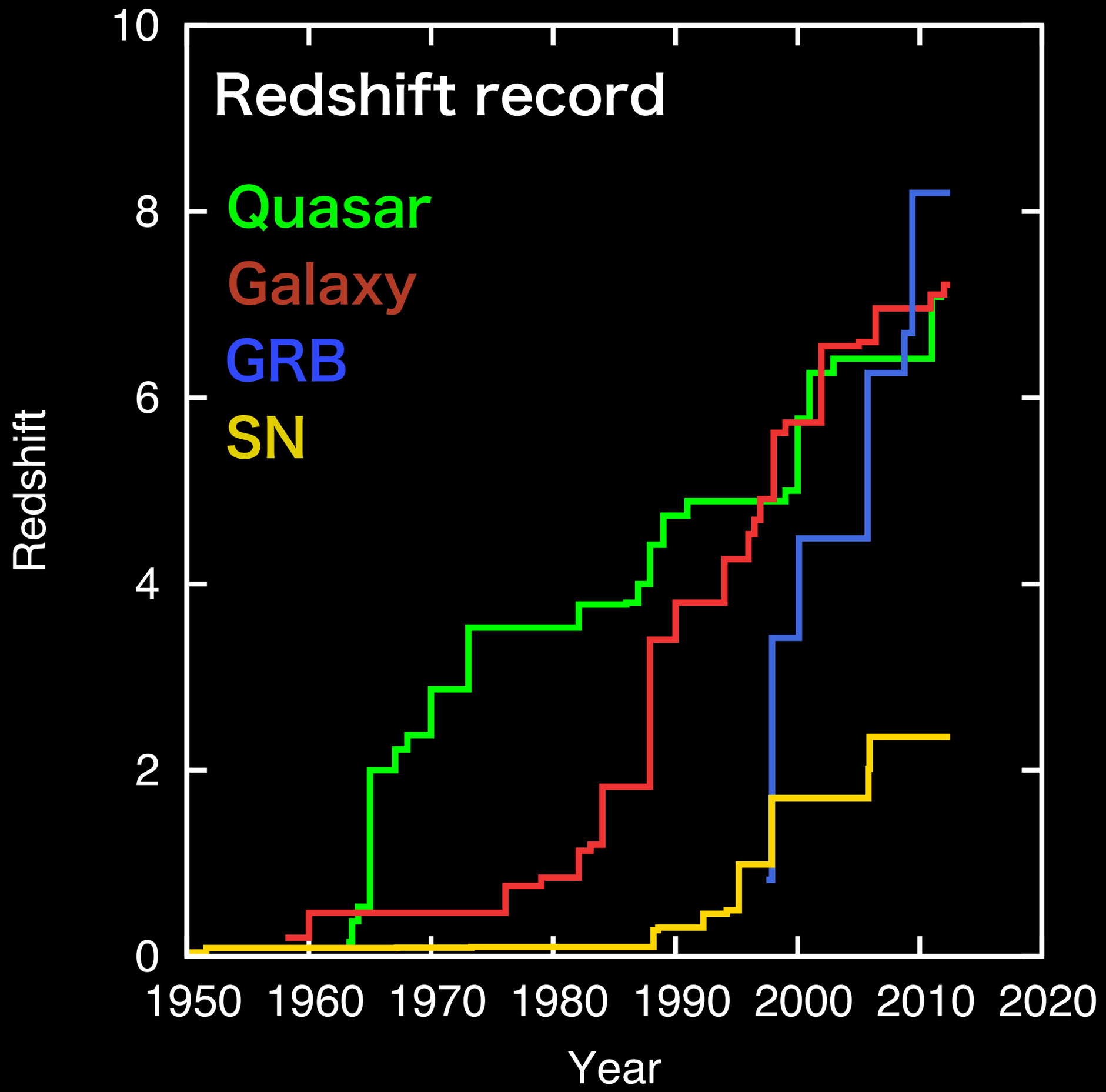
Detecting First Supernovae

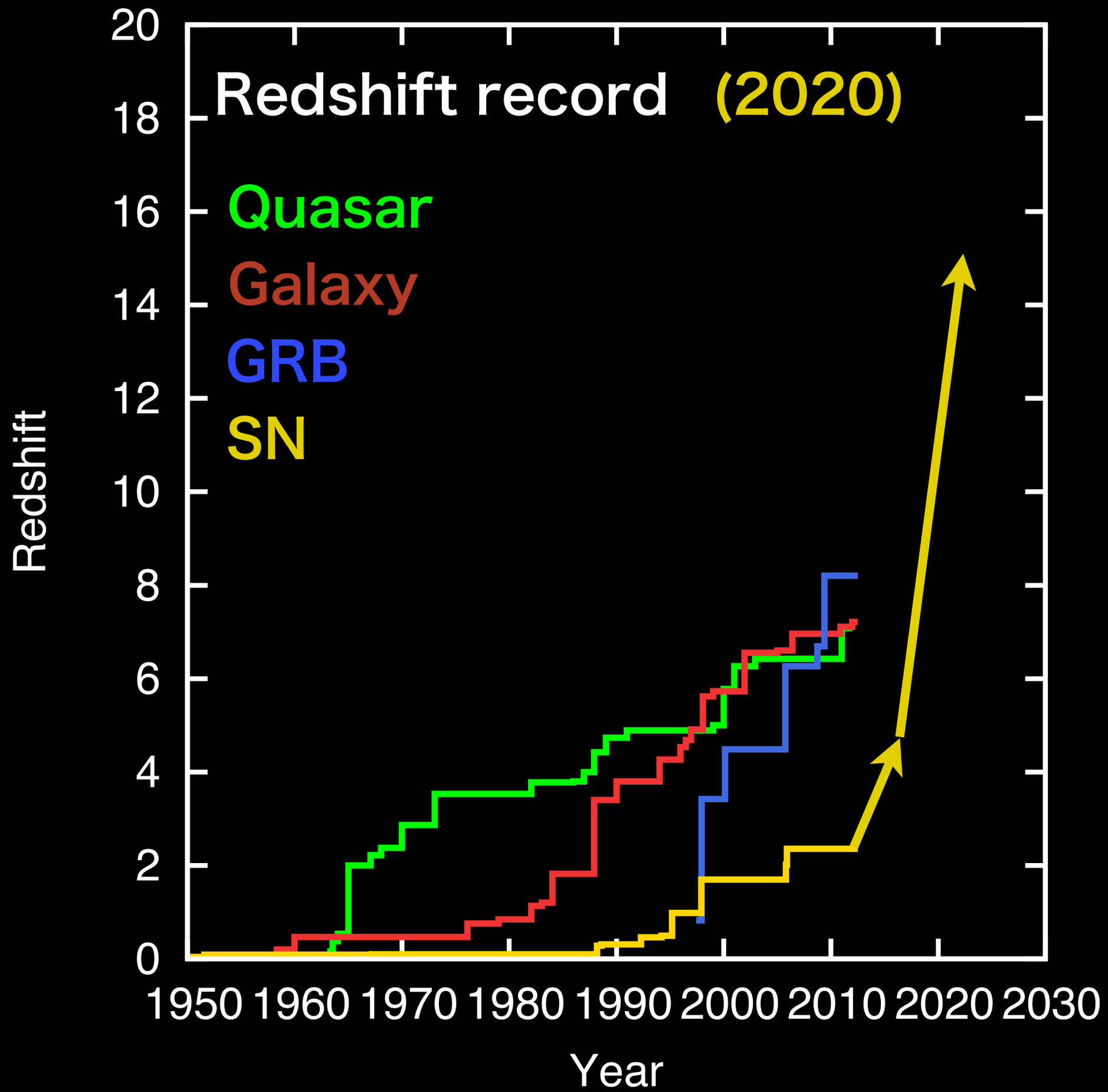


AB = 26.5/25.5 mag (@ 1-4 um)

2000 deg^2

6 visits in 0.5 yr


Redshift record
Quasar
Galaxy
GRB
SN
Redshift
Year
0
2
4
6
8
10
1950
1960
1970
1980
1990
2000
2010
2020


Redshift record (2020)
Quasar
Galaxy
GRB
SN
Redshift
Year
0
2
4
6
8
10
12
14
16
18
20
1950
1960
1970
1980
1990
2000
2010
2020
2030

（個人的）2020年代の恒星研究

衛星観測

赤外サーベイヤー

Euclid/WISH/WFIRST

Deep survey

SPICA

JWST

Follow-up

初代星の超新星爆発

地上観測

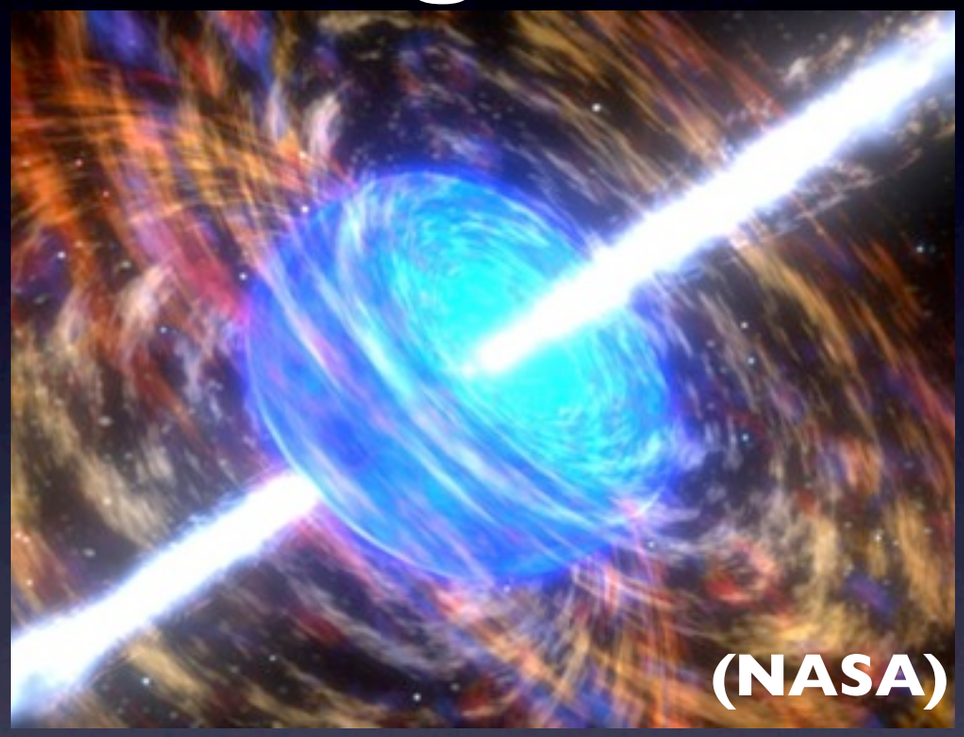
1-2 m望遠鏡

4-10 m望遠鏡

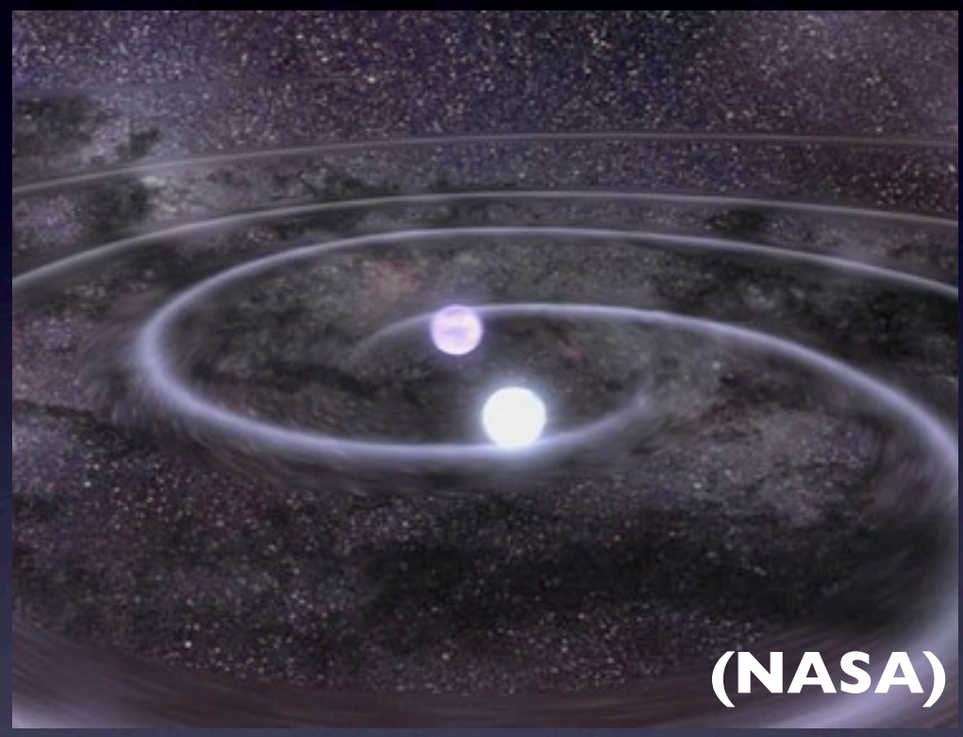
30 m望遠鏡

ガンマ線バースト

Long GRB



Short GRB



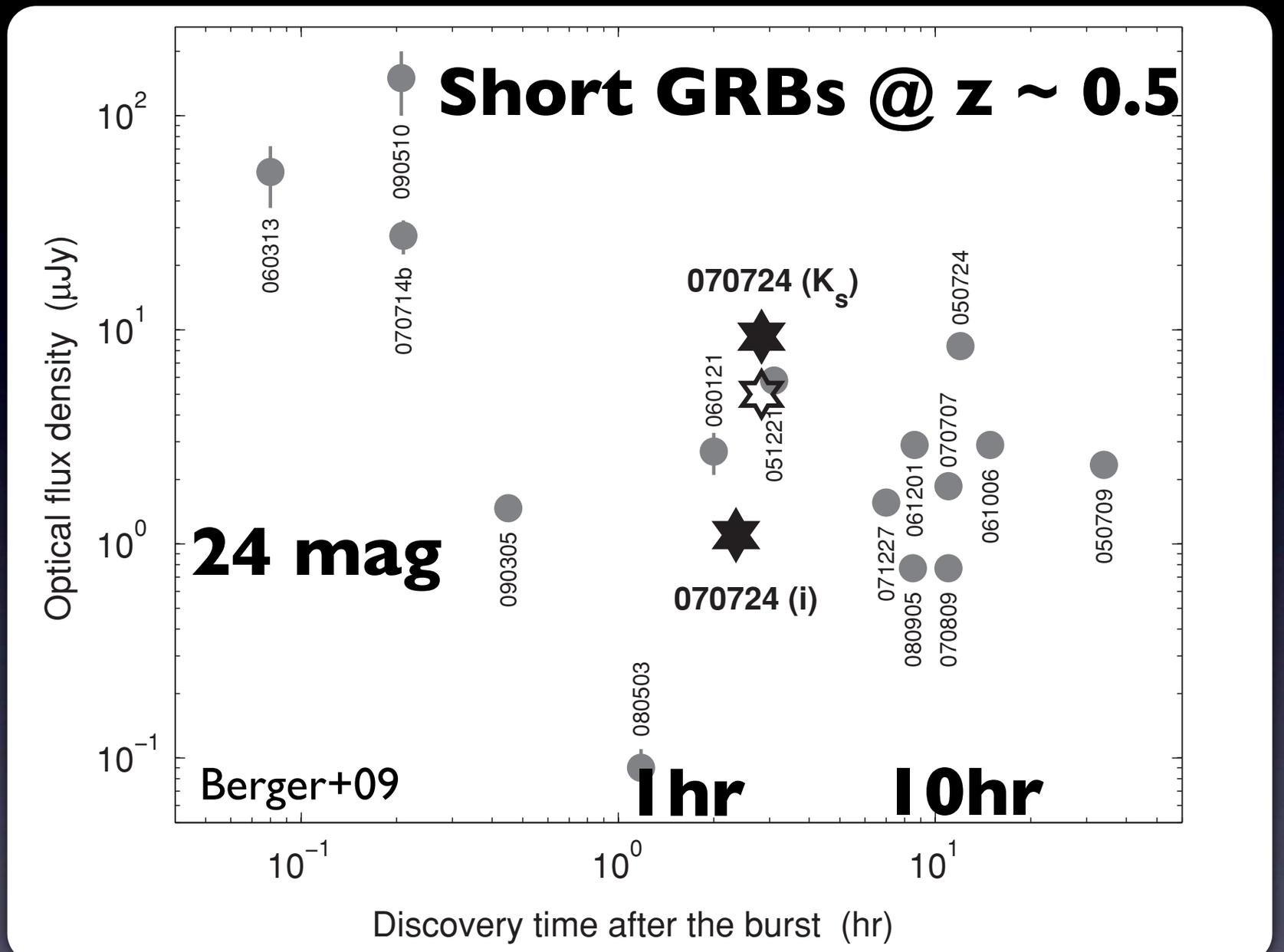
Pop III GRBs Cosmology

Yonetoku-san's poster

重力波天文学

Optical Counterpart of GW Source?

~19 mag (@ 200Mpc)

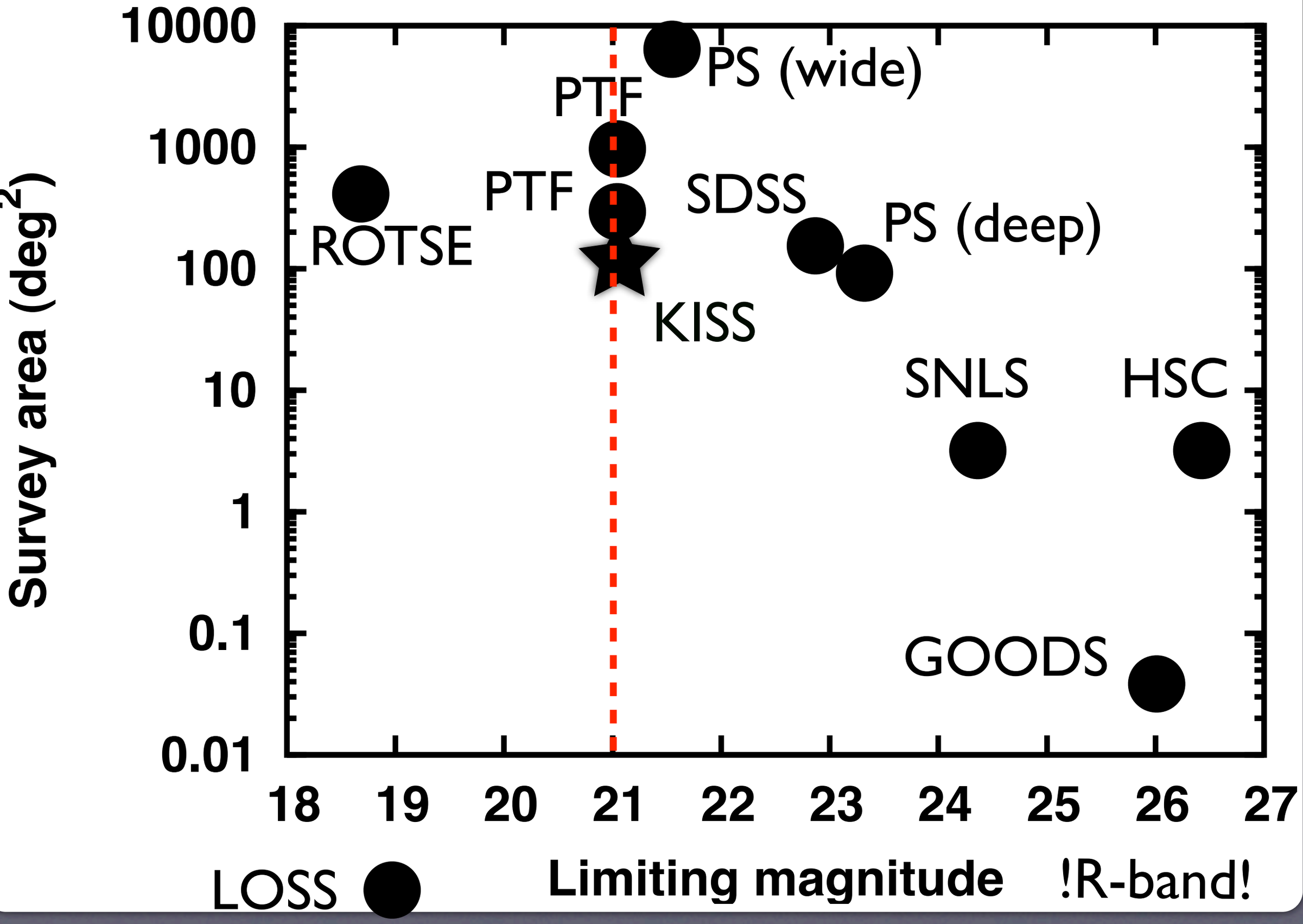


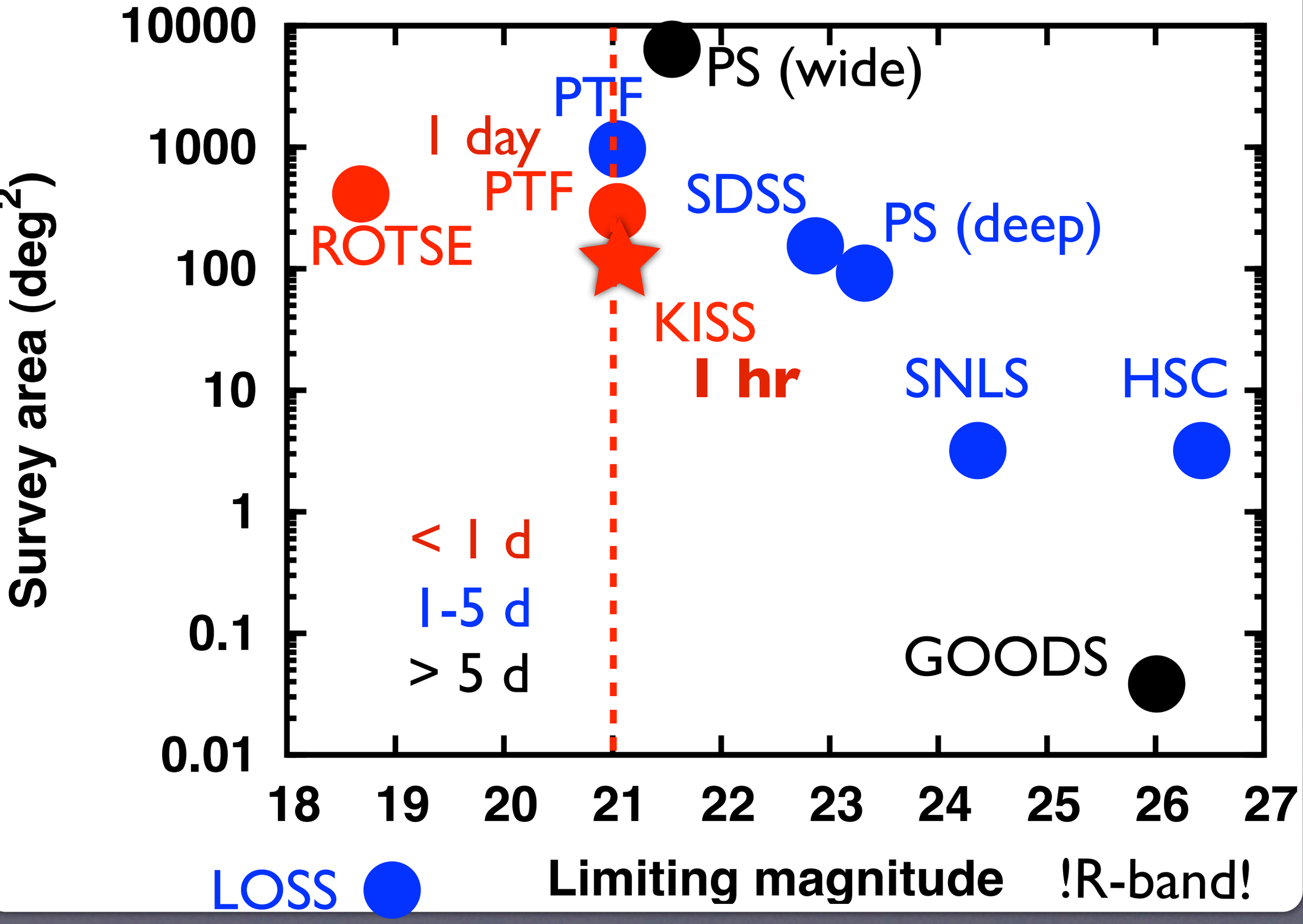
Monitoring nearby Universe with high cadence

Transient Survey

Survey	Diameter (m)	FOV (deg^2)	Depth (R mag)	Area/day (deg^2)
LOSS	0.76	0.01	19	1000 galaxy
ROTSE-III	0.45	3.42	18.5	450
PTF	1.26	7.8	21	1000
Pan-STARRS	1.8	7	21.5	6000
SDSS-II	2.5	1.5	22.6	150
SNLS	3.6	1	24.3	2
GOODS	2.5 (HST)	0.003	26	0.04
HSC	8.2	1.75	26.5	1.75
KISS	1.08	4	21	100

(partly taken from Rau et al. 2009, PASP, 121, 1334)


10000
1000
100
10
1
0.1
0.01
Survey area (deg^2)
PS (wide)
PTF
PTF
SDSS
PS (deep)
ROTSE
KISS
SNLS
HSC
GOODS
LOSS
18
19
20
21
22
23
24
25
26
27
Limiting magnitude
!R-band!


10000
1000
100
10
1
0.1
0.01
Survey area (deg^2)
18
19
20
21
22
23
24
25
26
27
Limiting magnitude
!R-band!
PS (wide)
PTF
1 day
PTF
ROTSE
SDSS
PS (deep)
KISS
1 hr
SNLS
HSC
GOODS
< 1 d
1-5 d
> 5 d
LOSS

KISS:
KIso Supernova Survey

- **Extremely high-cadence SN survey**

Time: 1-hr cadence	→	**OK (?)**
Area: ~50-100 deg^2 /day	→	**all sky?**
Depth: ~ 20-21 mag in g-band (3 min exposure)	→	**galaxy monitor?**
	→	**OK**

2012 Apr -
PI: T. Morokuma (see poster)

Optical-GW Astronomy

- **Dedicated 1m-class telescopes**
- **Survey method**
  - **Blank field survey**
  - **Targeted survey**
- **Time resolution**
  - **CCD => CMOS?**

Blank field survey	Targeted survey
400 deg^2/telescope	40 galaxies/telescope

=> several tens of telescopes!?

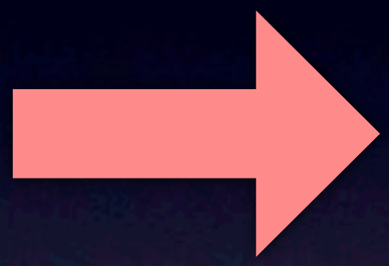
（個人的）2020年代の恒星研究

衛星観測

赤外サーベイヤー

Euclid/WISH/WFIRST

Deep survey



SPICA

JWST

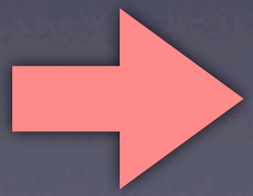
Follow-up

初代星の超新星爆発

地上観測

重力波源

超高頻度モニタリング



Follow-up

1-2 m望遠鏡

4-10 m望遠鏡

30 m望遠鏡

超新星爆発

Multi-messenger Astronomy (EM+GW+Neutrino)

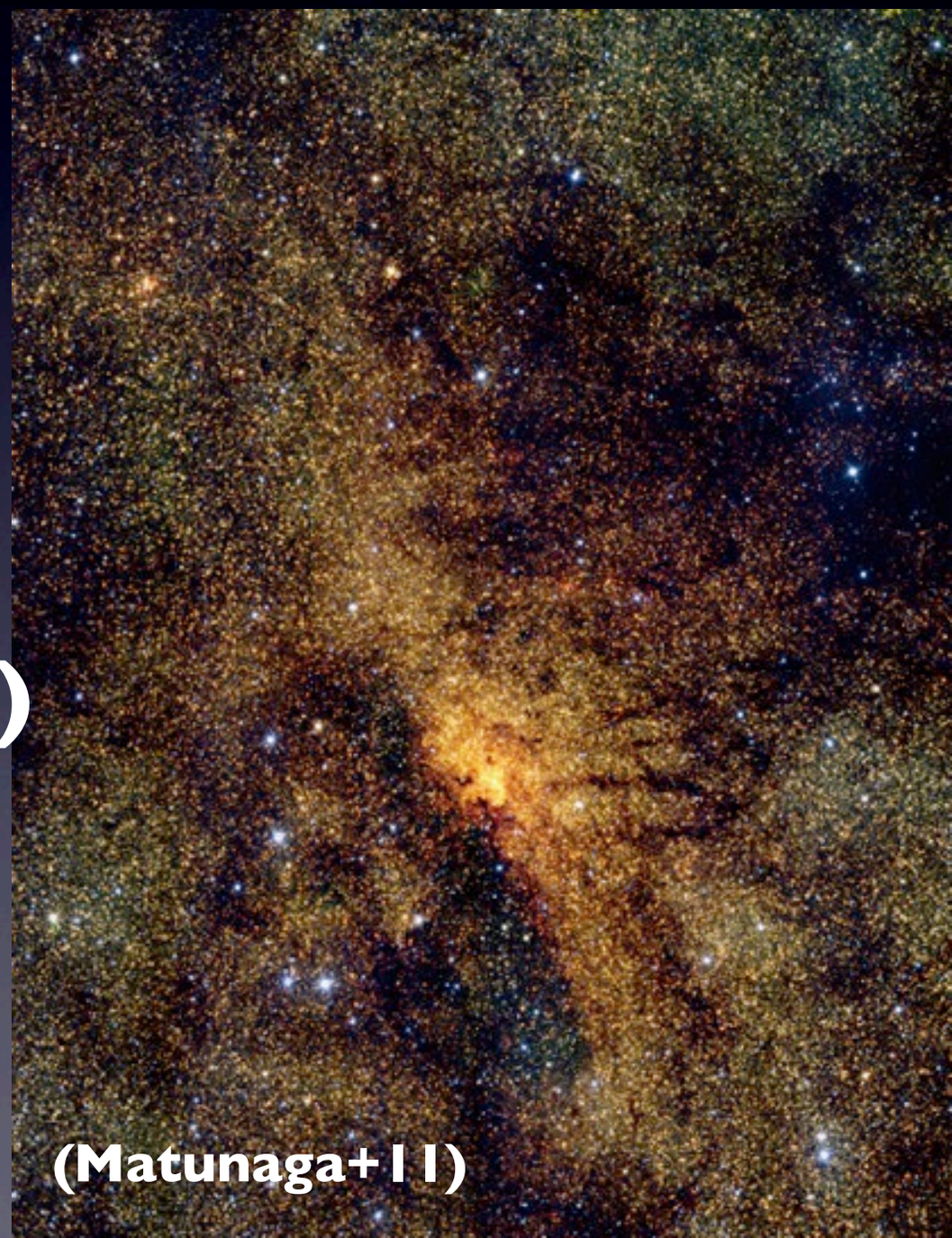
Galactic SN rate ~ 1 SN / 100 yr

$$R_{\rm SN}(z) = \rho_*(z) \frac{\int_{M_{\rm min,SN}}^{M_{\rm max,SN}} \psi(M) {\rm d}M}{\int_{M_{\rm min}}^{M_{\rm max}} M\psi(M) {\rm d}M}$$

1 (Msun/yr)

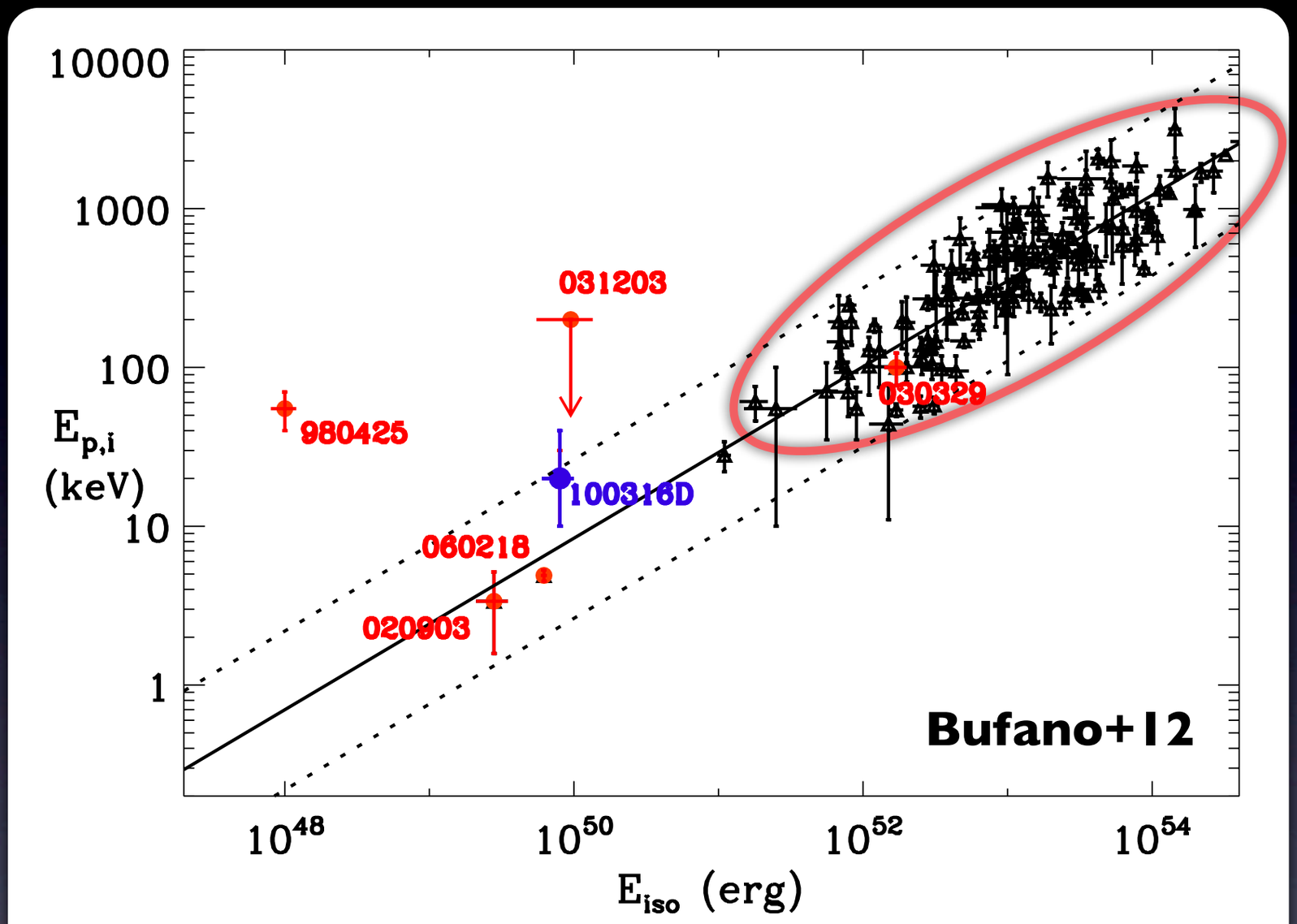
0.01 (/Msun)

IR monitoring Galactic center with high cadence



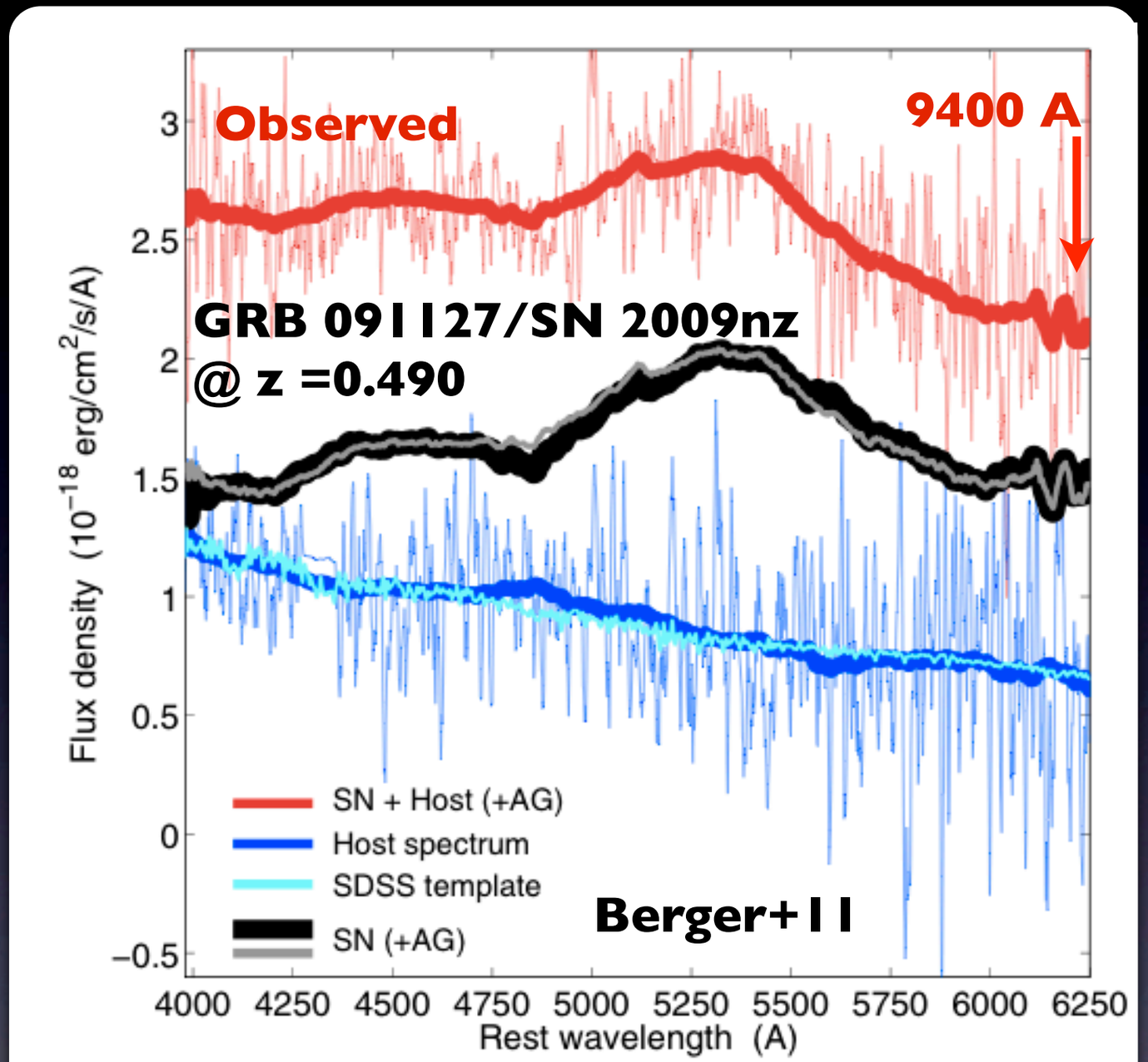
(Matunaga+11)

GRB-SN connection



GRB 980425/SN 1998bw (z=0.0085)
GRB 030329/SN 2003dh (z=0.1685)
GRB 031203/SN 2003lw (z=0.105)
XRF 060218/SN 2006aj (z=0.033)
GRB 100316/SN 2010bh (z=0.0591)
GRB 120422/SN 2012bz (z=0.283)

GRB-SN @ z > 0.5



TMT with ...

- Rapid ToO
- Opt-NIR spectrograph
- Polarization

（個人的）2020年代の恒星研究

衛星観測

赤外サーベイヤー

Euclid/WISH/WFIRST

Deep survey

SPICA

JWST

Follow-up

初代星の超新星爆発

地上観測

“Multi-messenger”

重力波源

超高頻度モニタリング

1-2 m望遠鏡

Follow-up

4-10 m望遠鏡

GRB-SN

@ z > 0.5

即応観測

30 m望遠鏡

（個人的）2020年代の恒星研究

- **初代星の超新星爆発**
  - 近赤外サーベイ
- **光赤外＋重力波天文学**
  - 近傍銀河の高頻度モニタリング
- **“Multi-messenger” 天文学**
  - 銀河中心の赤外線モニタリング
- **ガンマ線バースト+超新星 @ z>0.5**
  - **30m級望遠鏡での即応観測 + 可視赤外同時 + 偏光**

物理学と天文学の
交差点

「広さ」＋「深さ」＋「時間」

Appendix

Supernova and IR Emission

Heavy elements

Kinetic energy

Radiation

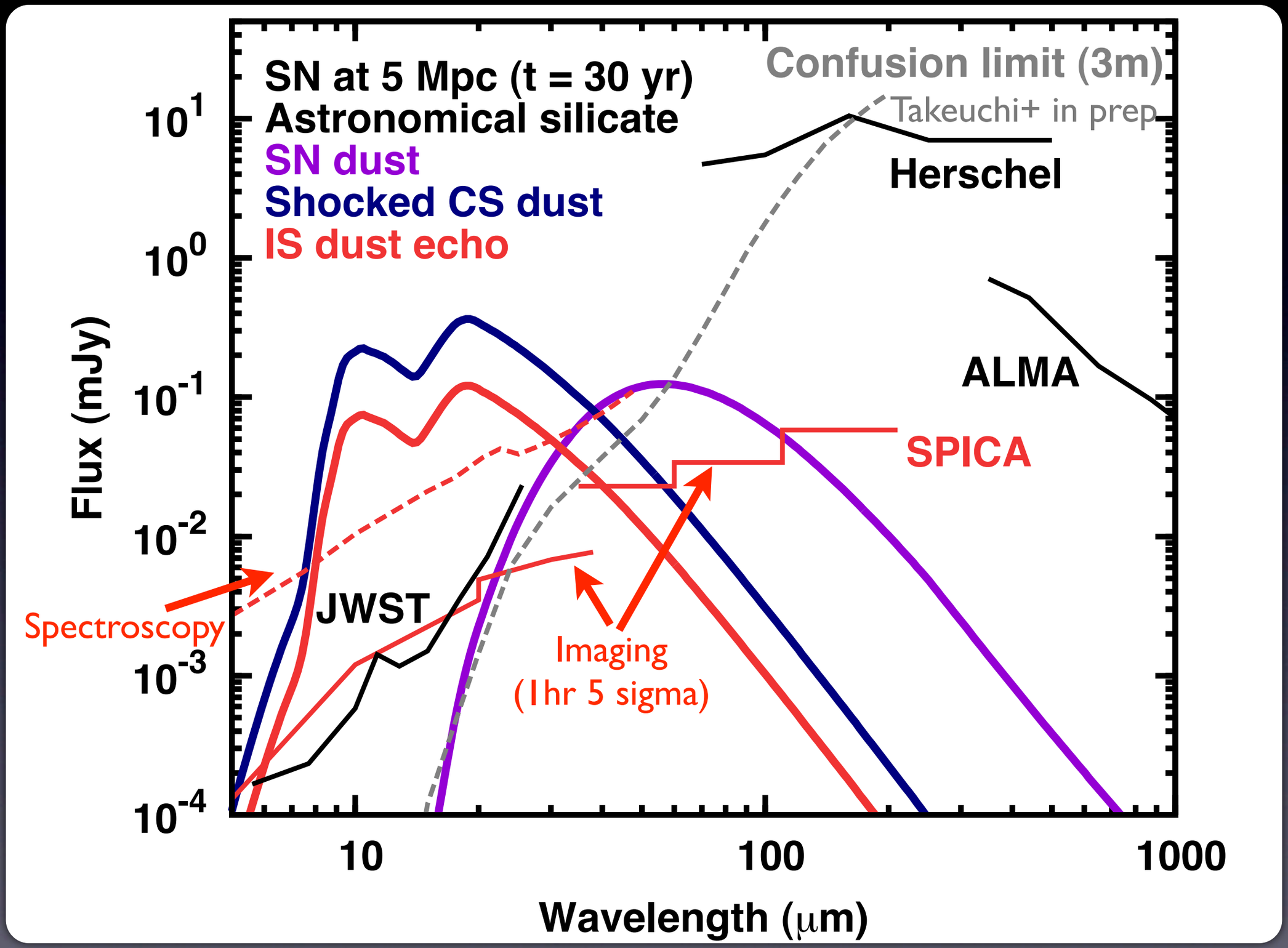
Circumstellar dust

Supernova dust

IR observation

Dust formation by stellar wind / SN

Prospects for SPICA (SN at 5 Mpc)



MT, Nozawa, Sakon, Onaka+12, ApJ, 759, 173

（個人的）2020年代の恒星研究

衛星観測

赤外サーベイヤー

Euclid/WISH/WFIRST

Deep survey

SPICA

ダスト形成

JWST

Follow-up

初代星の超新星爆発

地上観測

“Multi-messenger”

重力波源

超高頻度モニタリング

1-2 m望遠鏡

Follow-up

4-10 m望遠鏡

GRB-SN

@ z > 0.5

即応観測

30 m望遠鏡