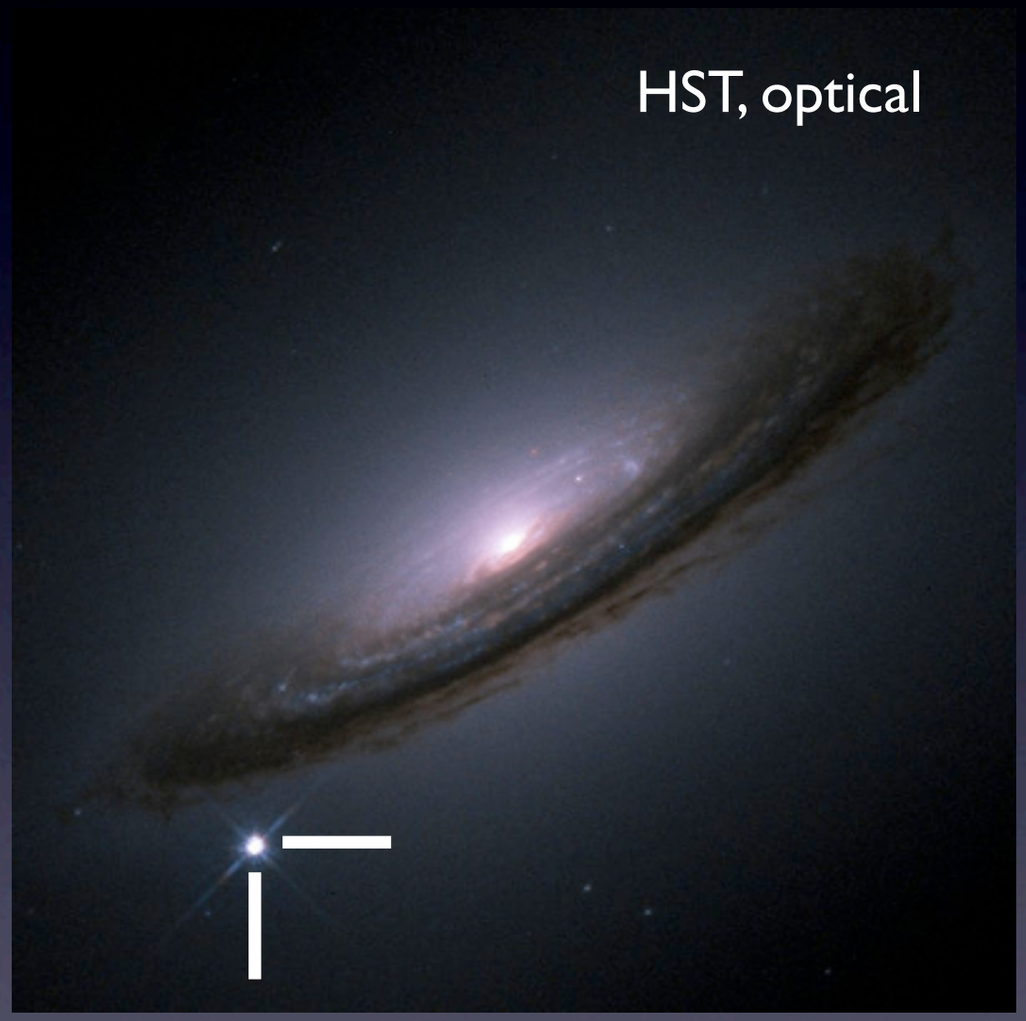
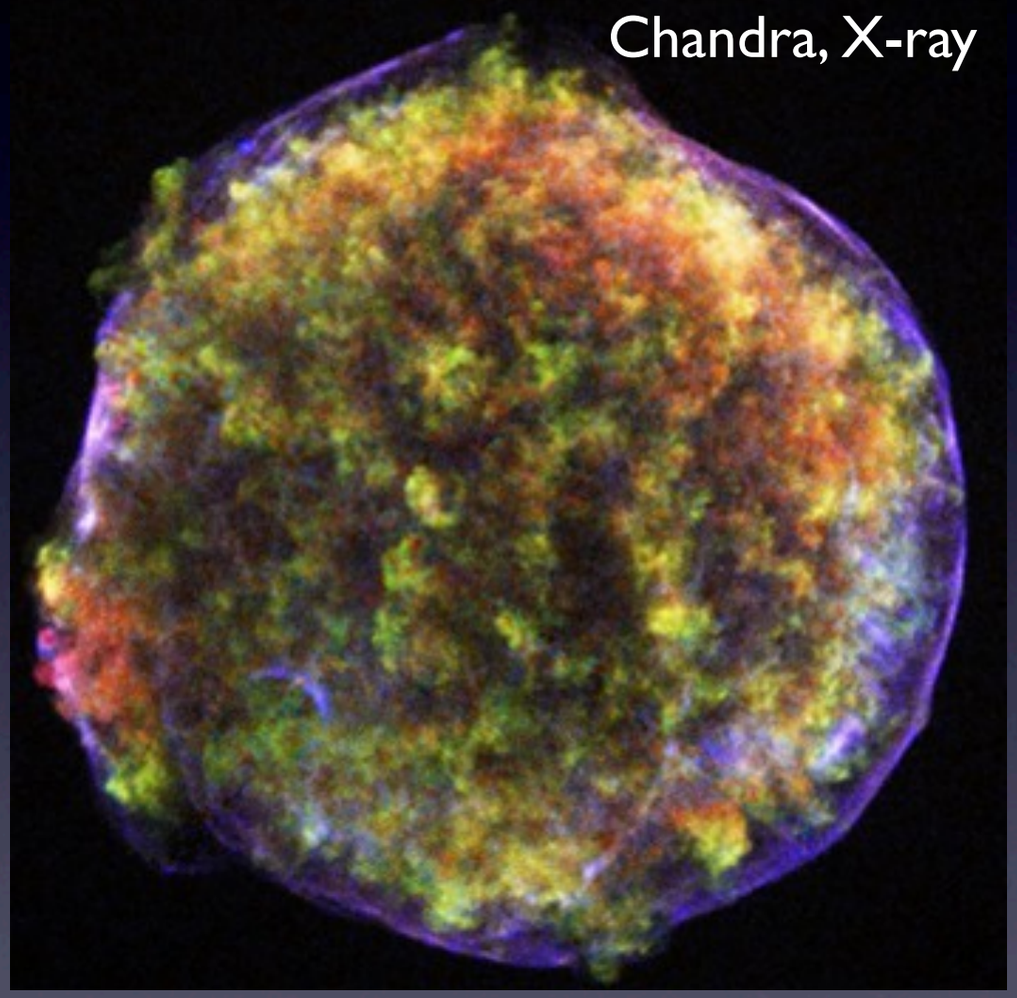
Optical Observations of Supernovae
Current Status and Future

超新星爆発：可視光観測の現状とこれから



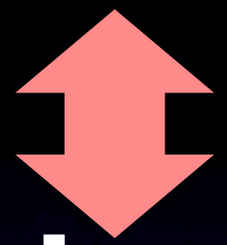


Masaomi Tanaka

田中 雅臣

（国立天文台）

Science with CTA
Cosmic ray acceleration by SNR



Optical observations

Gamma-ray signatures of cosmic ray acceleration, propagation, and confinement in the era of CTA

F. Acero[e], A. Bamba[h], S. Casanova[a,b,c,**], E. de Cea[f], E. de Oña Wilhelmi[b], S. Gabici[a,*], Y. Gallant[e], D. Hadasch[f], A. Marcowith[e], G. Pedaletti[f], O. Reimer[d,**], M. Renaud[e], D. F. Torres[f,g], F. Volpe[b], for the CTA collaboration.

If SNRs indeed are the sources of CRs, they have to convert $\sim 10\%$ of their explosion energy into accelerated particles. Since the explosion energy of a supernova is a remarkably constant quantity close to 10^{51} erg, a rough estimate of the expected gamma-ray flux from a given SNR can be obtained if one knows the density of the ambient medium, and the SNR distance.

Acero et al. Astroparticle Physics (arXiv:1209.0582)

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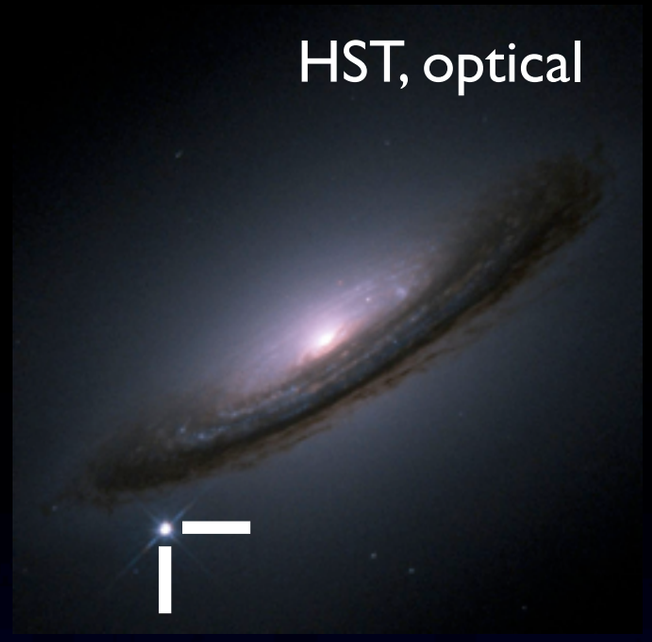
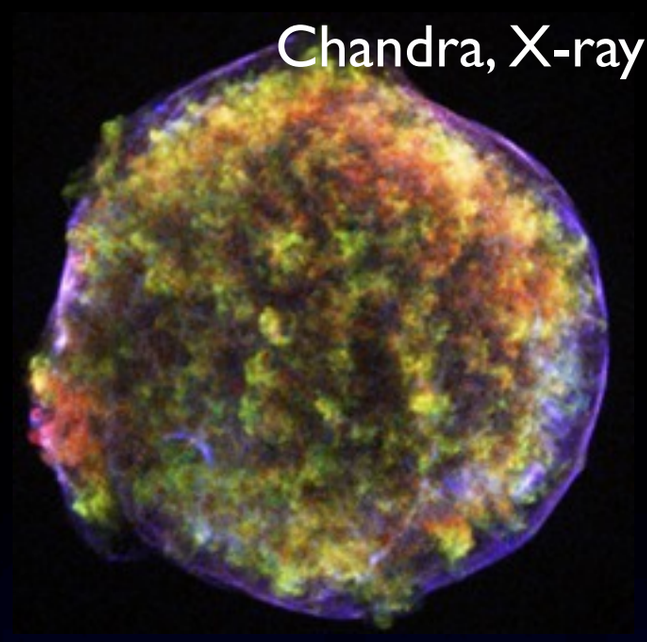
- **Supernova rate and kinetic energy**
- **SNR type and distance**
- **Future opportunities**

Thanks to many of you!
(@ banquet)





- Extra-galactic (point source)
  - ~300-500 / yr
- R ~ 10^{15} cm, v ~ 10,000 km/s
- Luminosity <= radioactivity
- Optical
  - Lopt ~ 10^{42} erg/s
- absorption-line spectrum
  => emission-line spectrum
  (thick => thin)

- Galactic and LMC/SMC
  - ~200 in our Galaxy
- R >~ pc, v < 3,000 km/s
- Luminosity <= shock
- Radio-Opt-X-Gamma
  - Lx ~ 10^{37} erg/s
- Synchrotron
  + brems + emission line

Discovery of extragalactic SNe

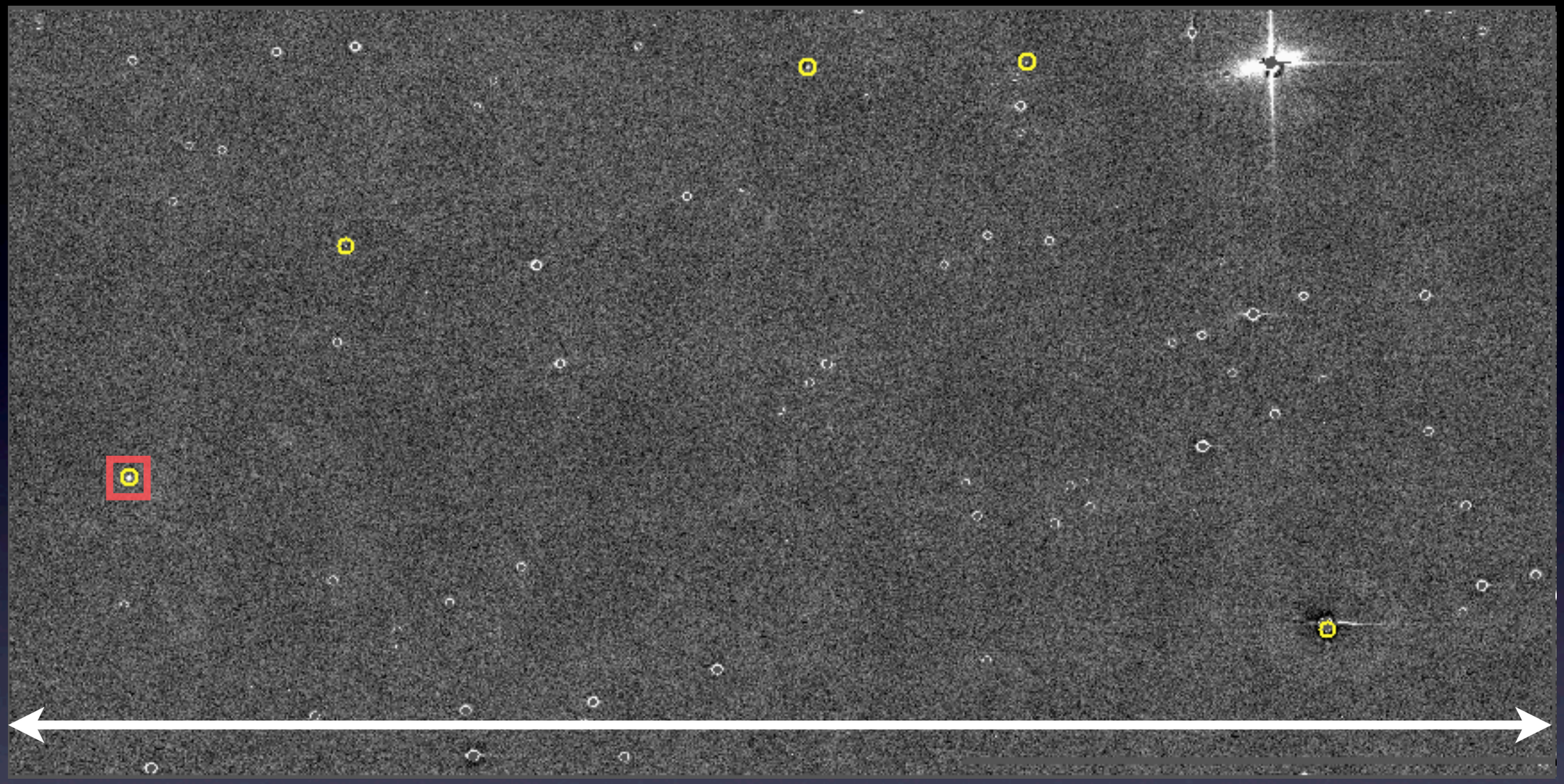
1 deg

Before

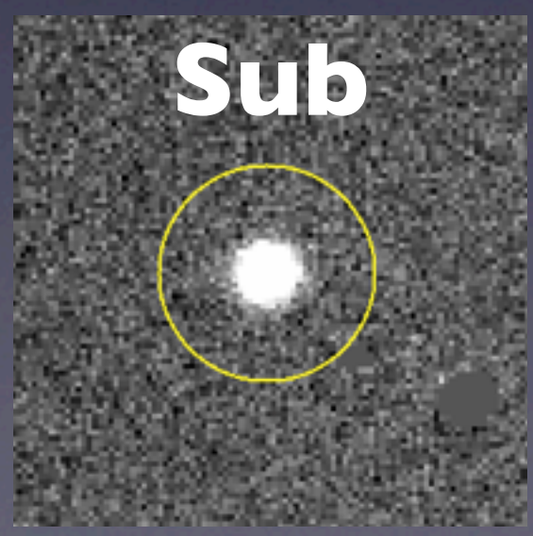
After

KISS:
Kiso supernova survey
東京大学木曽観測所
シュミット望遠鏡

Discovery of extragalactic SNe

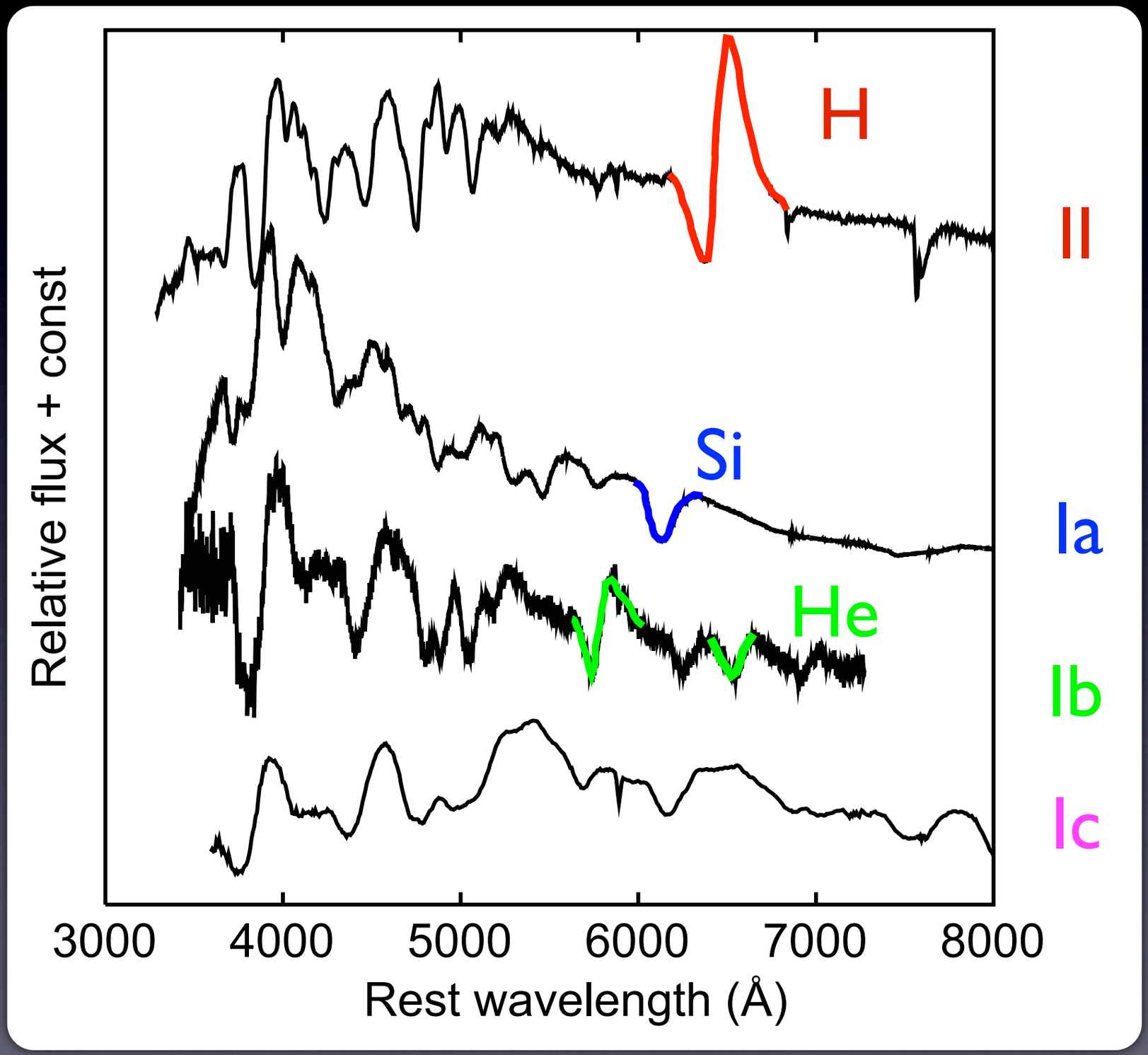


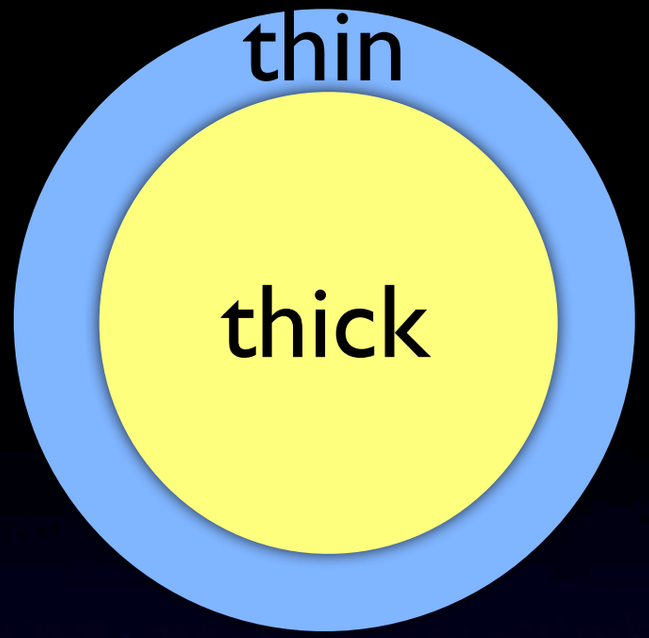
1 deg



KISS:
Kiso supernova survey
東京大学木曽観測所
シュミット望遠鏡

Optical spectra





Type II: Hydrogen

Type I: No hydrogen

Ia: Strong Si

Ib: Strong He

Ic: No strong Si/He

Small Star

Red Giant

Planetary Nebula

Ia

White Dwarf

Large Star

Red Supergiant

II/Ib/Ic

Supernova

Neutron Star

Stellar Cloud
with
Protostars

Black Hole

IMAGES NOT TO SCALE

(C: Essay Web)

Optical light curve

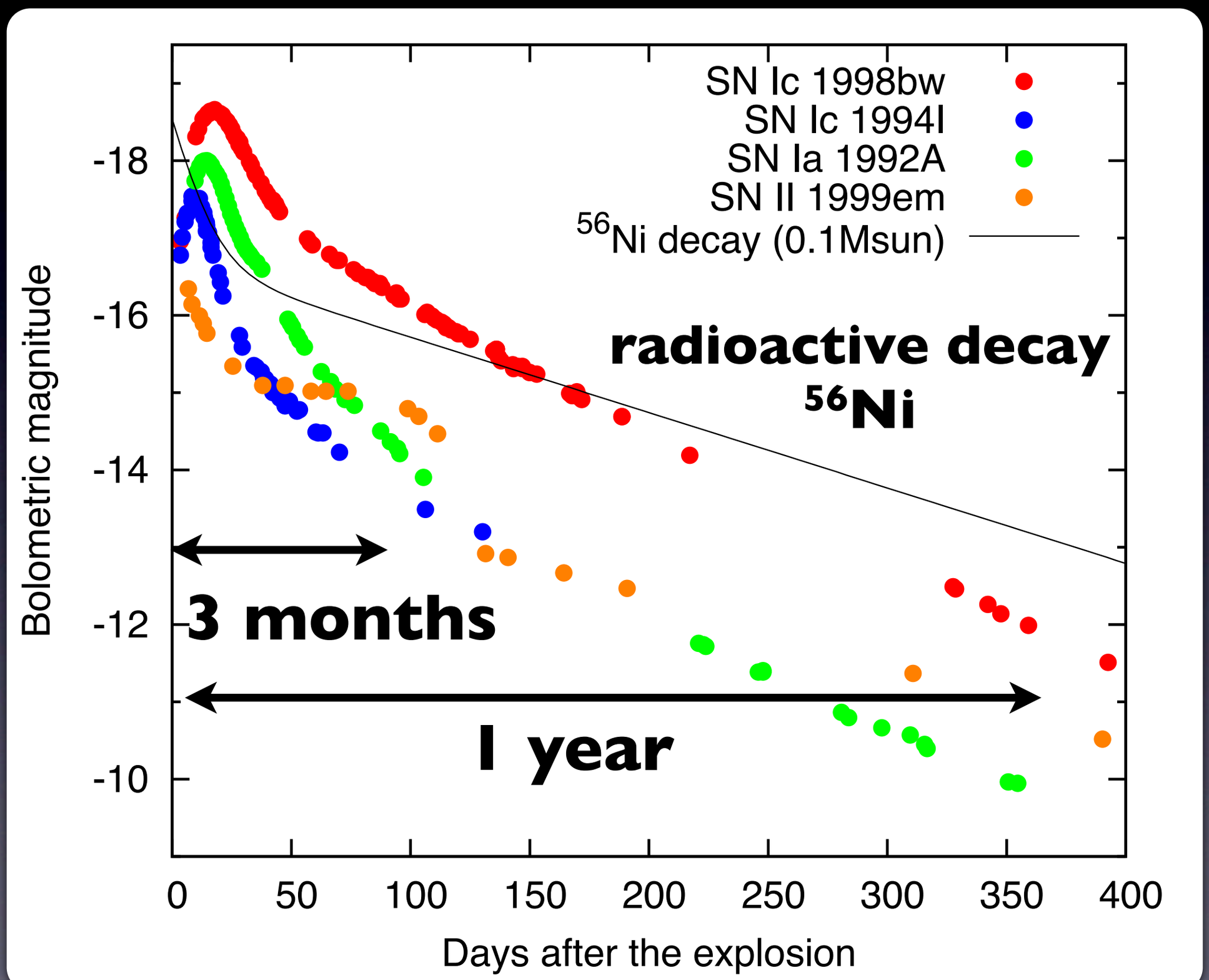
10^9 Lsun

10^8 Lsun

10^7 Lsun

γ-ray

optical



Core-collapse SN rate

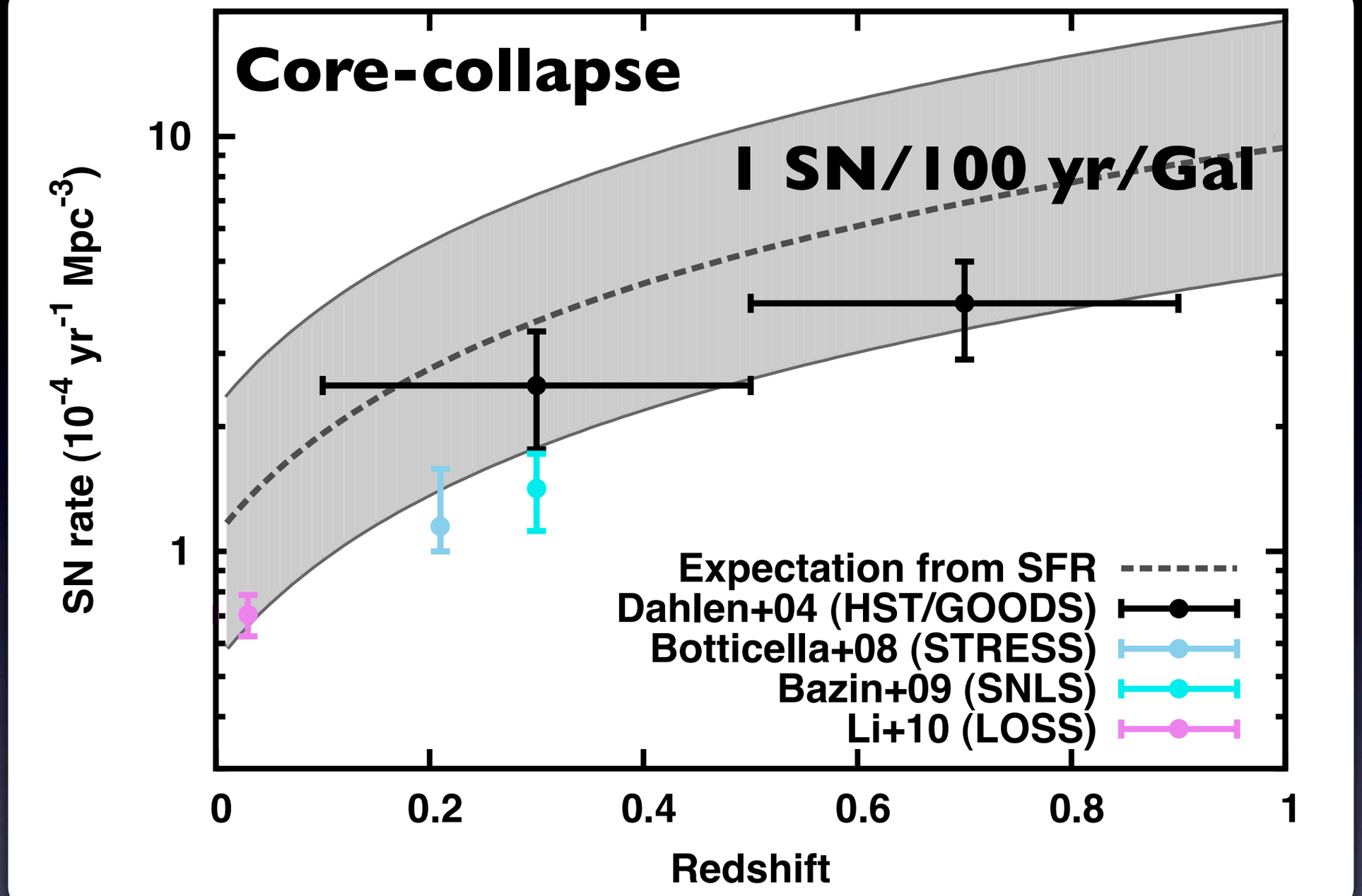
Initial mass function

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

Star formation rate
1 (Msun/yr)

0.01 (/Msun)

Galactic SN rate
~ 0.01 SN/yr (= 1 SN / 100 yr)



SN rate ~ 1/2 x expectation

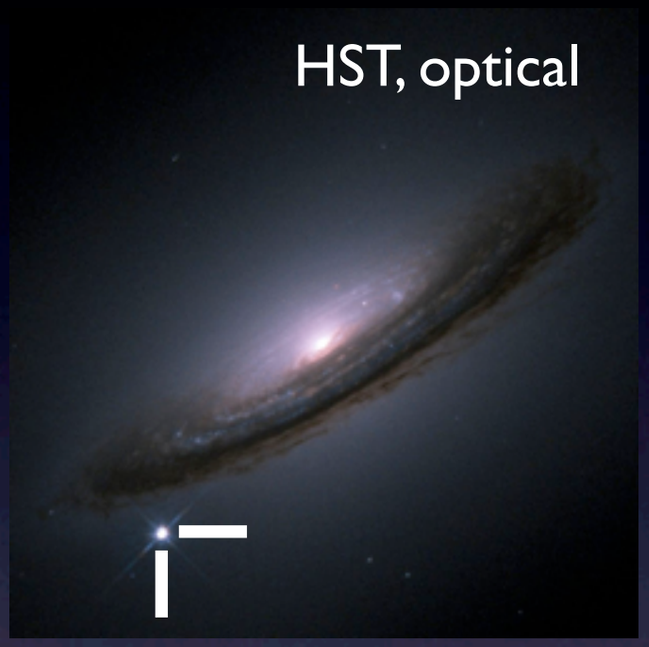
Dust extinction?
Luminosity function?

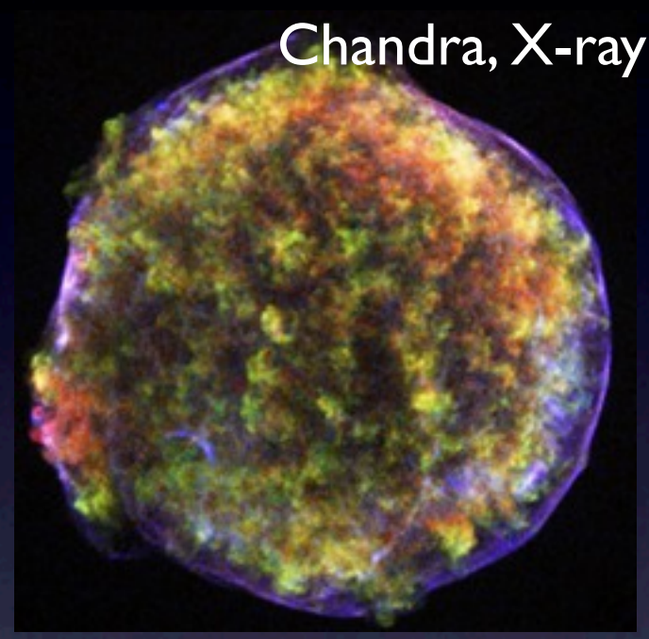
(Type Ia rate ~ 1/3 x core-collapse rate)

Dahlen et al. 2004
Botticella et al. 2008
Bazin et al. 2009
Li et al. 2011
see also Horiuchi et al. 2011

Kinetic energy

$E = (1/2)\, M\, v^2$





Mass

Diffusion time

Intensity

$$\tau_{\rm LC} \propto M_{\rm ej}^{3/4} E_K^{-1/4}$$

Velocity

Doppler v (free expansion)

proper motion
Doppler v (decelerated)

Sedov solution needs n(ISM)

Type Ia: Observational test

A few days

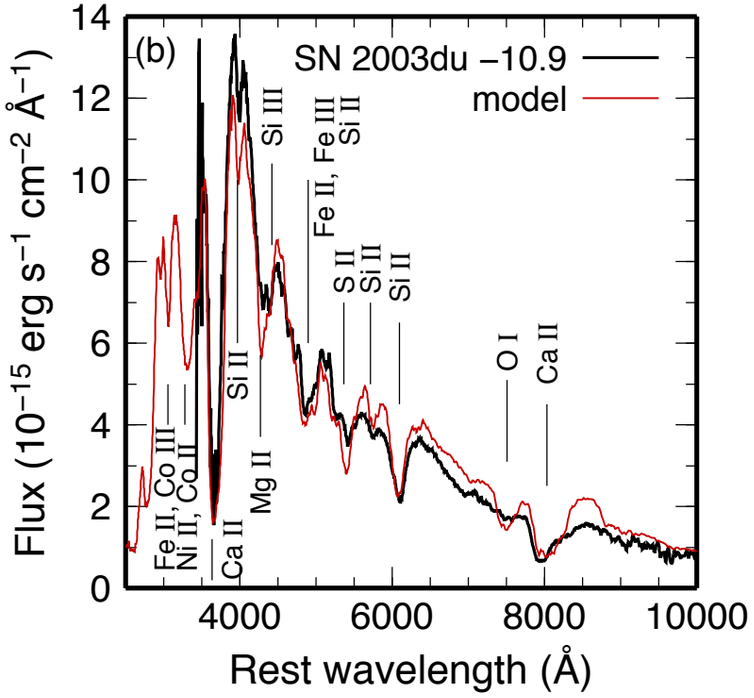
~ 10 AU

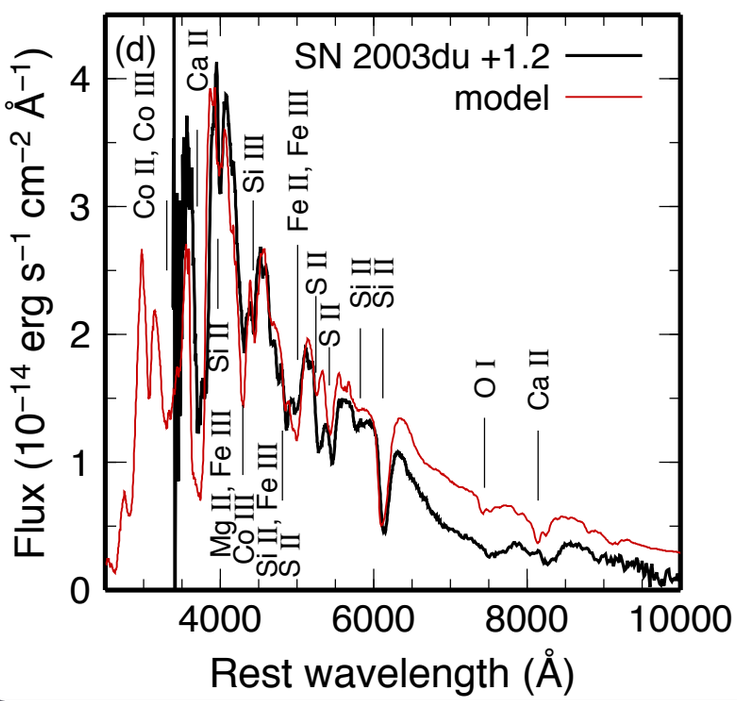
A few tenth days

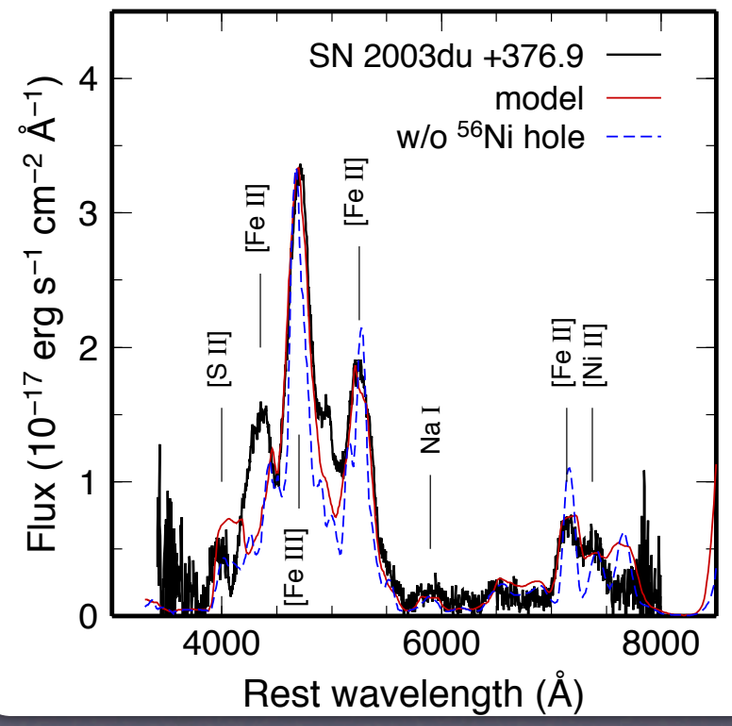
~ 100 AU

1 yr

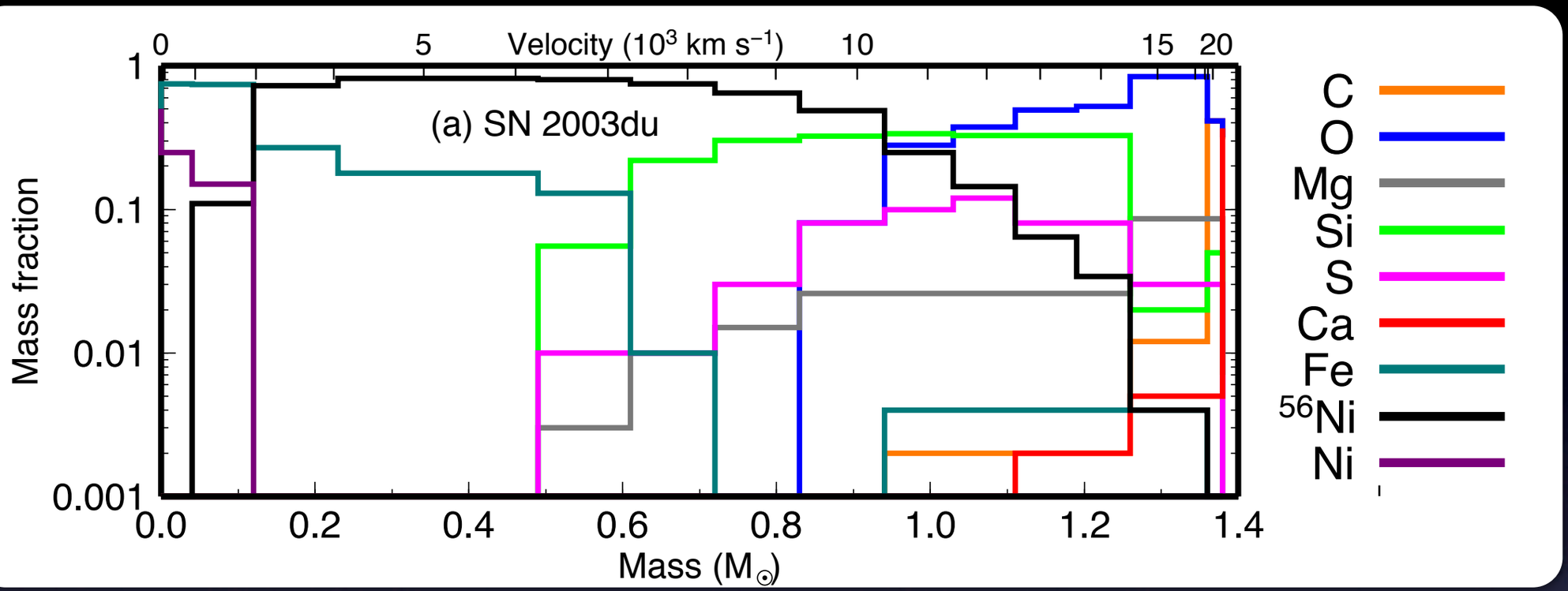
~ 1000 AU ~ 0.01pc







Kinetic energy

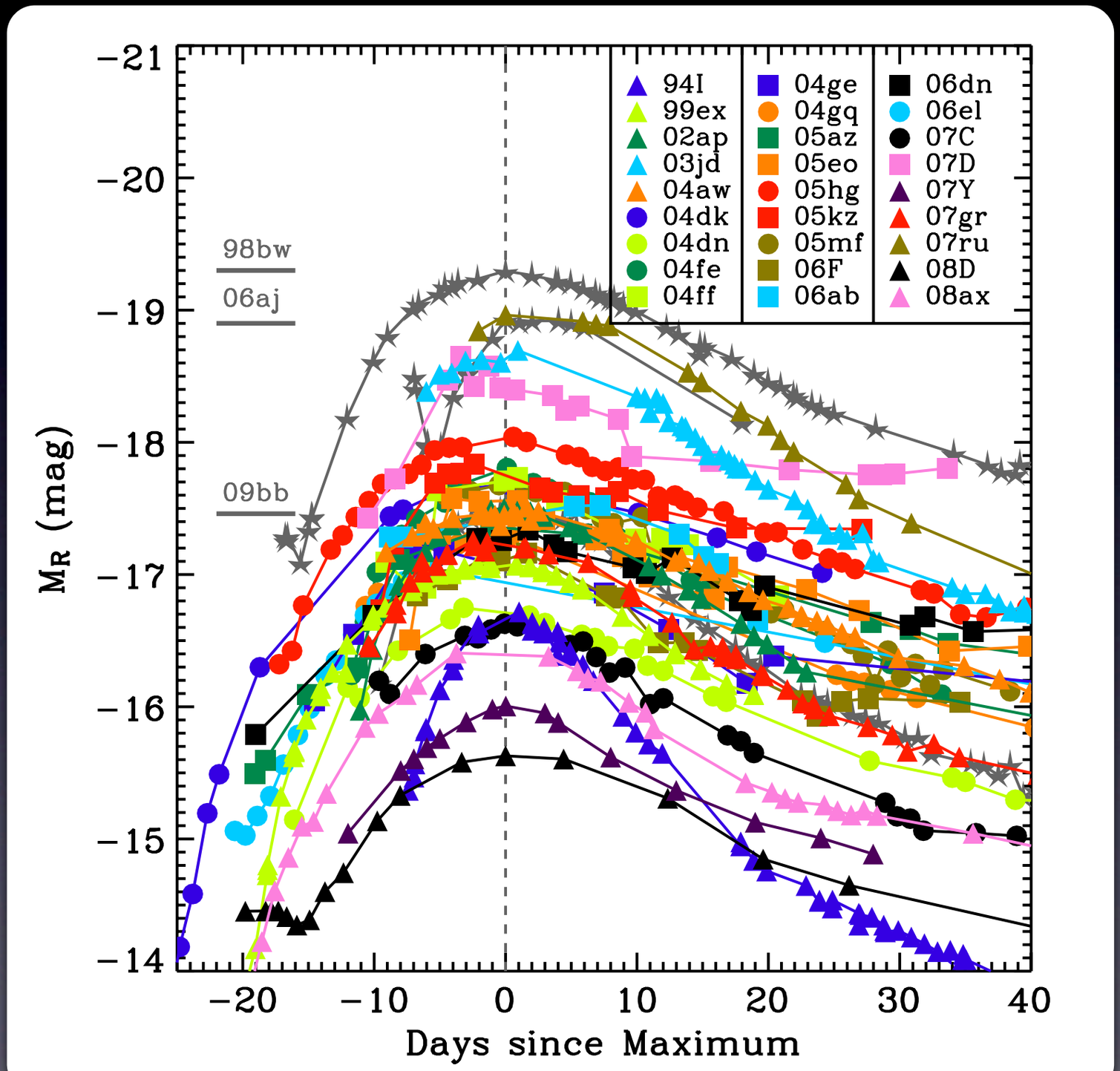


MT+11 MNRAS, 410, 1725

- **Nuclear energy production**
  - E(nuclear) = [1.56M(^{56}Ni) +1.74M(Fe) +1.24M(Si)] x 10^{51}
    ~ (1.56x0.6 + 1.74x0.3 + 1.24x0.3) x 10^{51}
    ~ 1.8 x 10^{51} erg
- **Kinetic energy = Nuclear - binding energy**
  - E(kinetic) = E(nuclear) - E(binding energy of WD)
    ~ 1.8 x 10^{51} - 0.5 x 10^{51} ~ **1.3 x 10^{51} erg**

Core-collapse supernovae

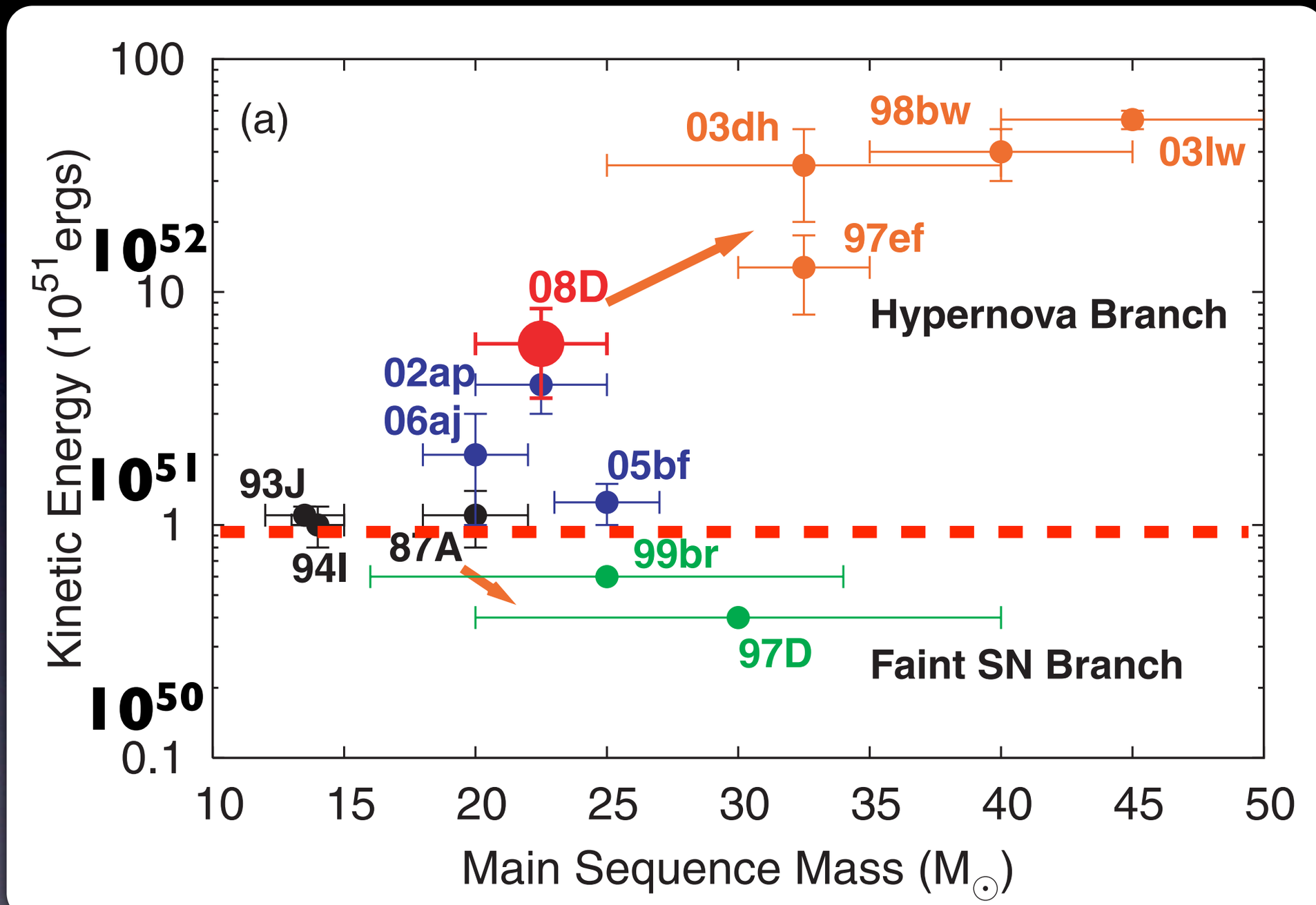
Type Ib/Ic



Drout et al. 2011, ApJ, 741, 97

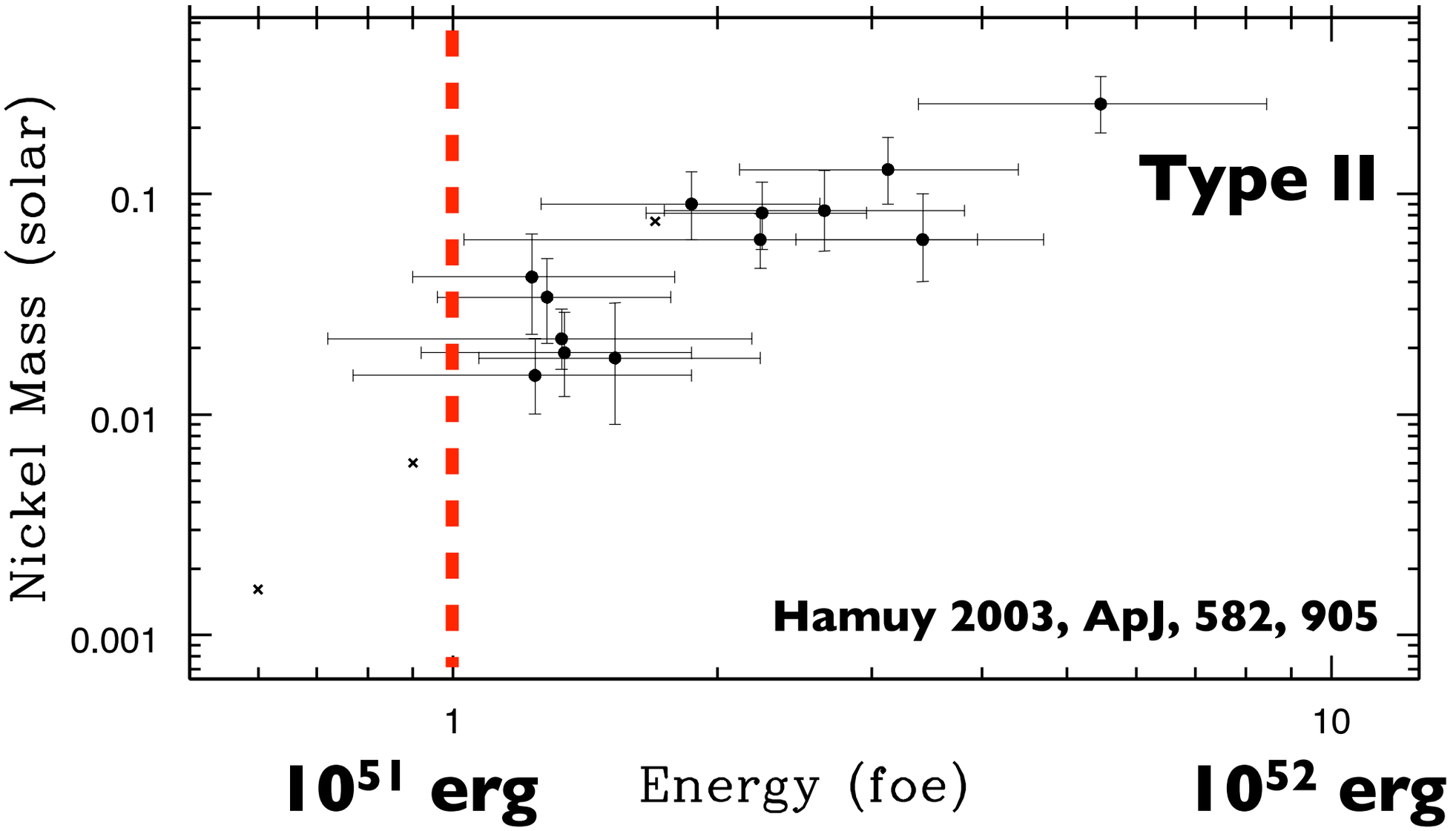
Kinetic energy

Type II/Ib/Ic



!! biased sample !!

see eg., MT+09 ApJ, 692. 1131



Not very biased sample

CAVEAT: luminosity function?

(Li et al. 2011, MNRAS, 412, 1441)

Galactic SN rate
~ 1 SN / 100 yr ??

Type Ia SN
E = 1.0-1.5 x 10^{51} erg

Core-collapse SN
E = 10^{50} - 10^{52} erg
<E> = 10^{51} erg ??

Overall picture of CR acceleration?

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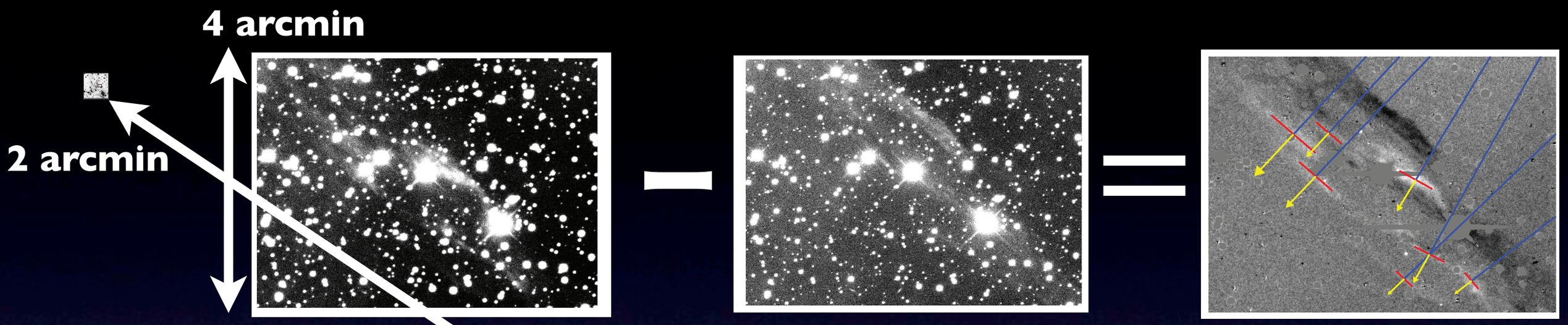
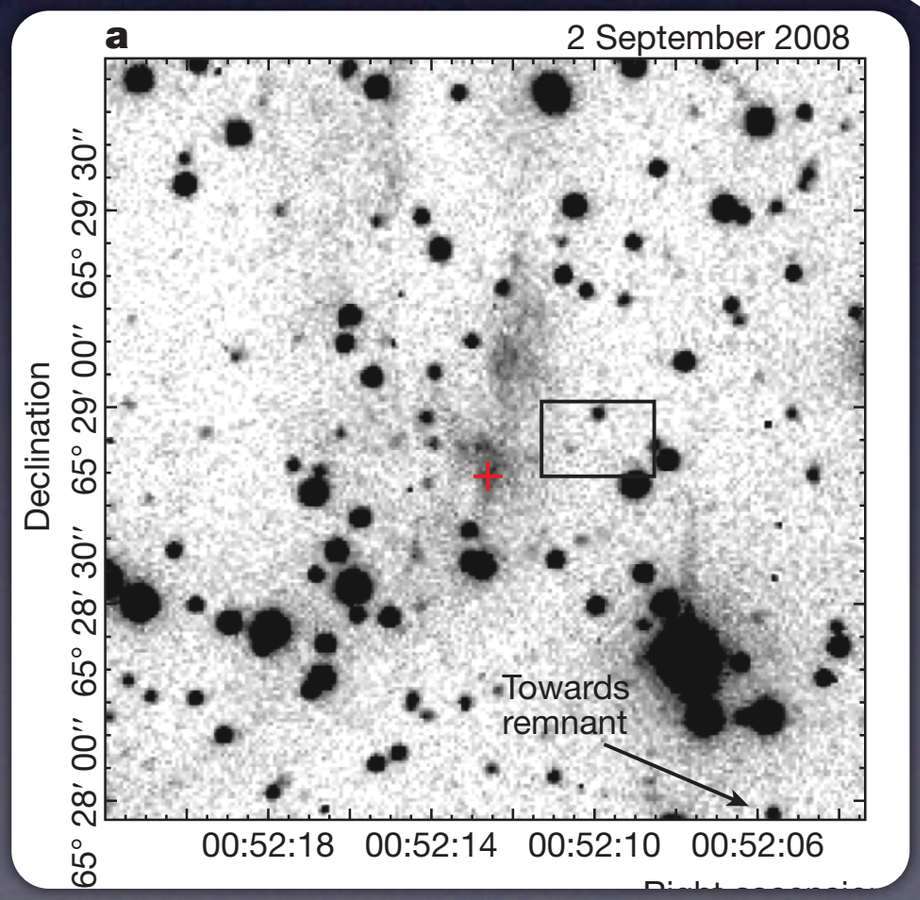
C: MPIA

How to find echoes



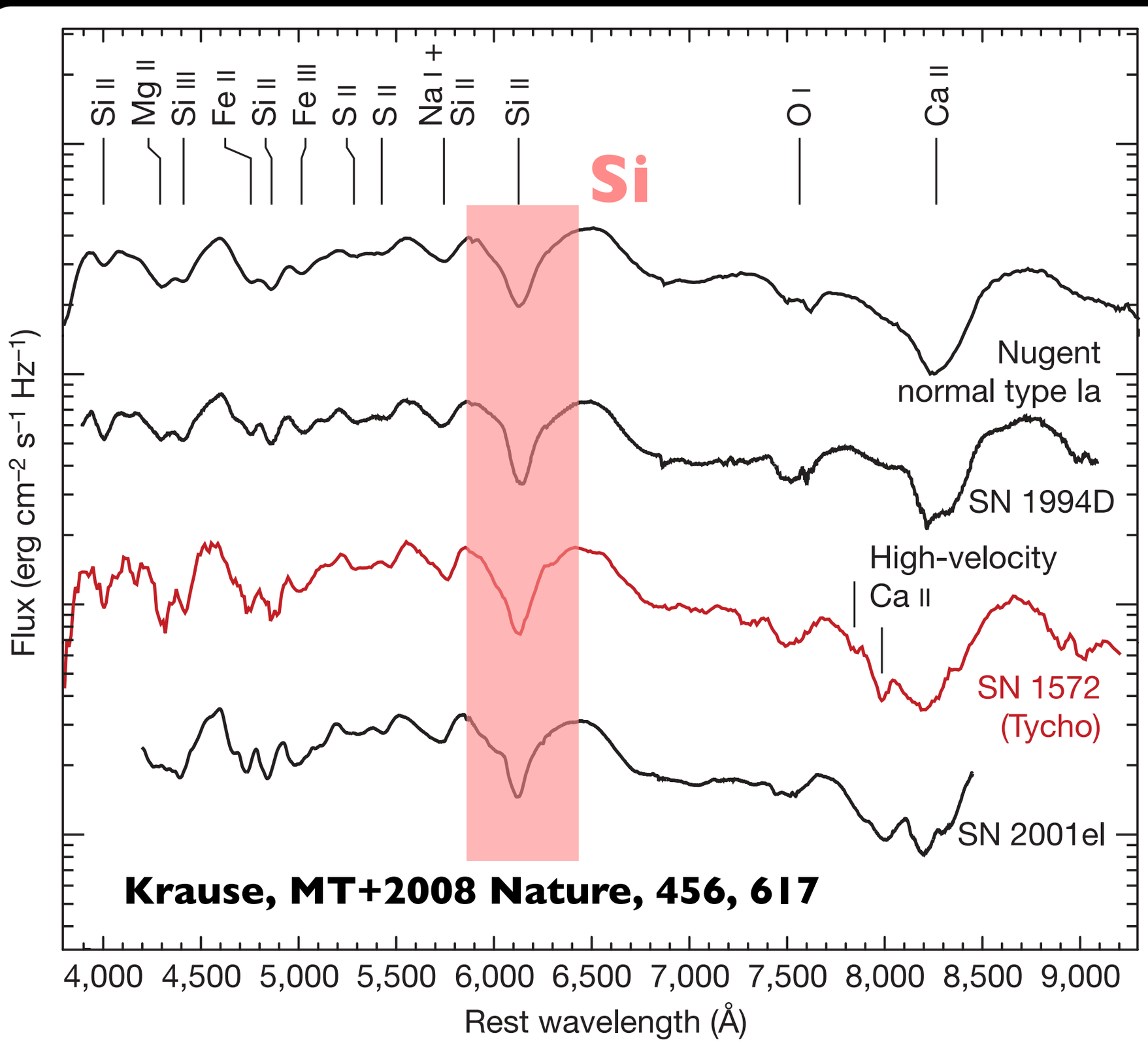
Rest et al. 2008

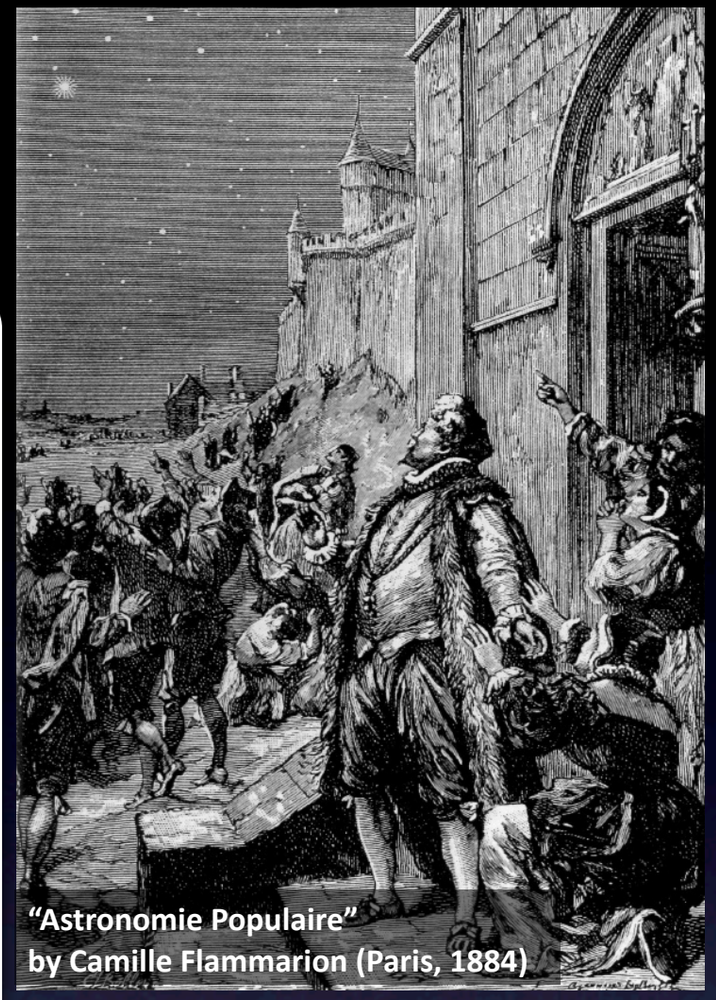


30 arcmin

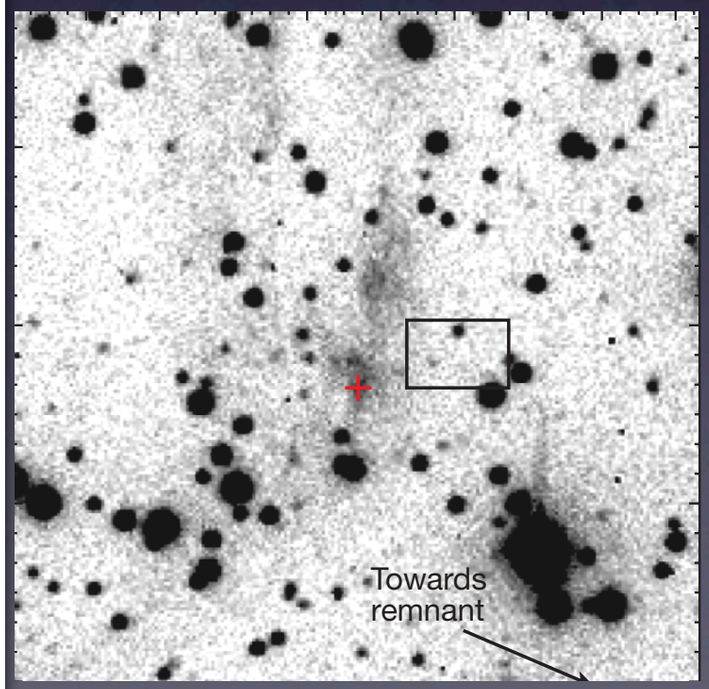
5 arcmin

Tycho's SN = Type Ia

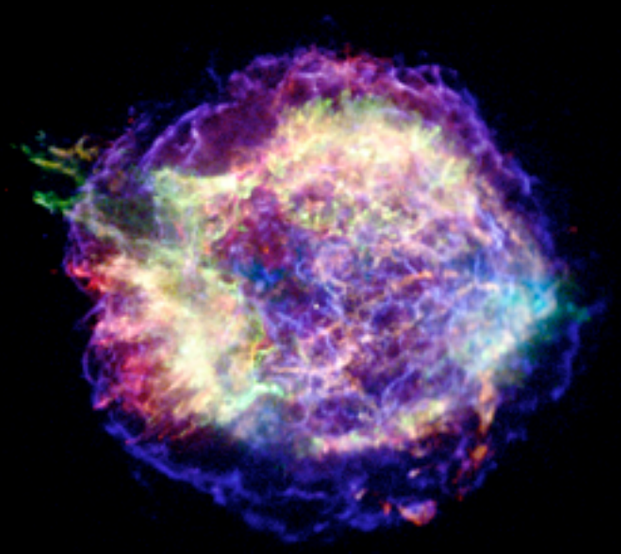




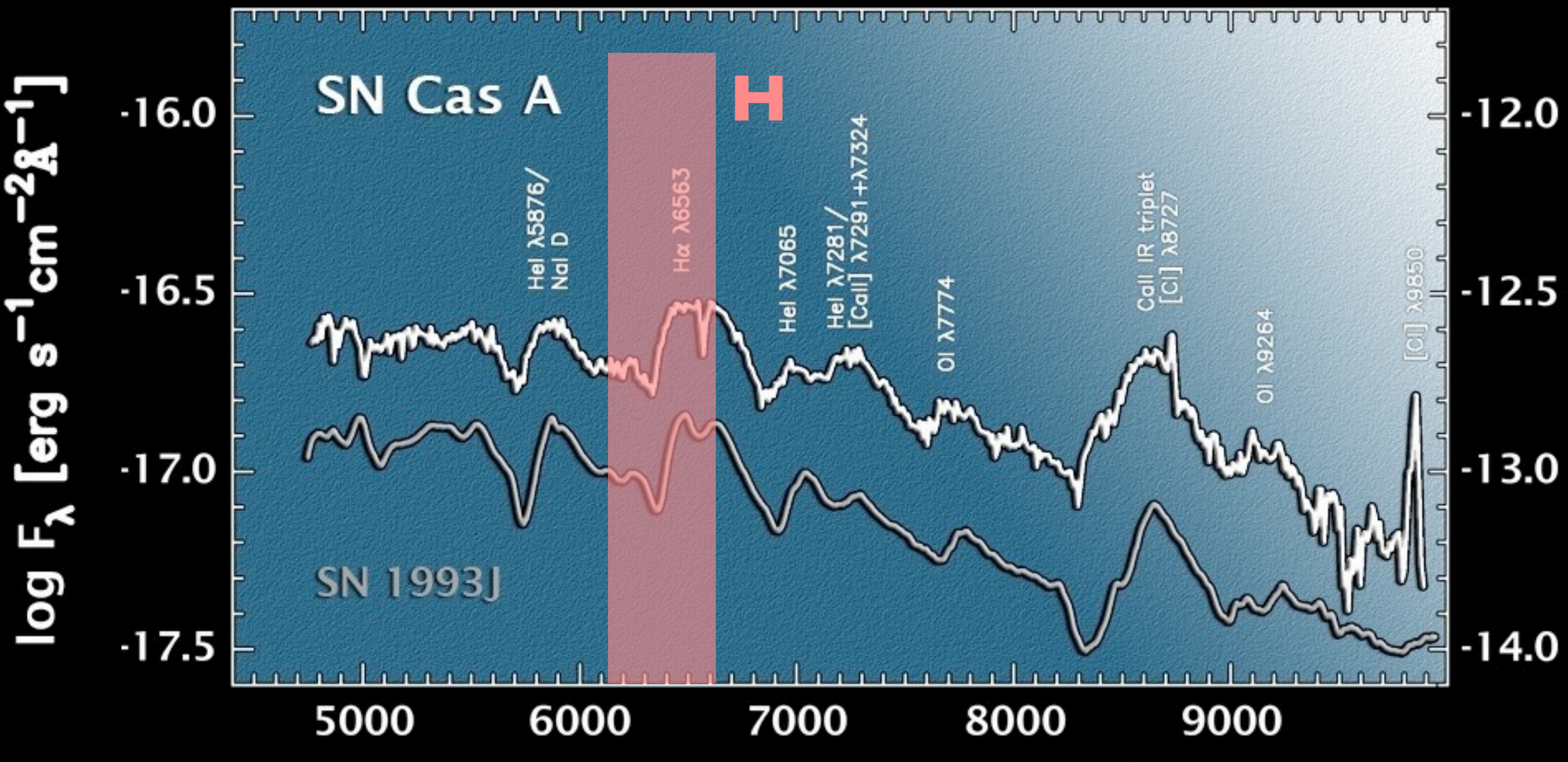
1572



2008

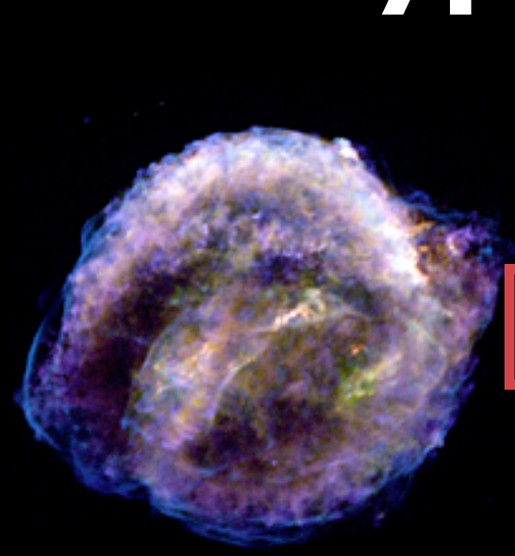


Cas A = Type IIb (thin H layer)

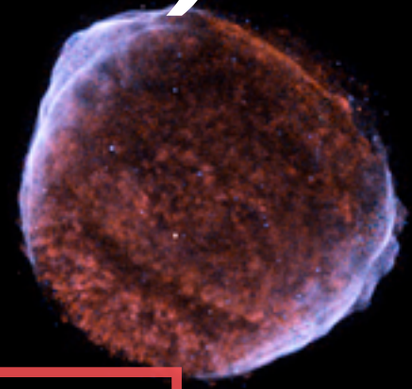


Krause et al. 2008

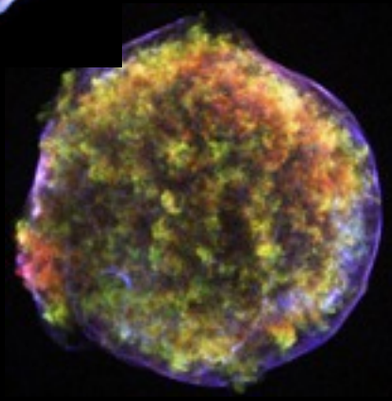
More typing (future)



Kepler



SN 1006



0.6
0.4
0.2
kpc
0
-0.2
-0.4

Galactic center

10
5
0
-5
-10
kpc

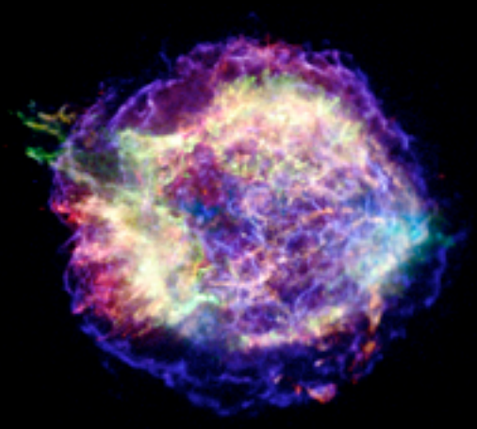
sun

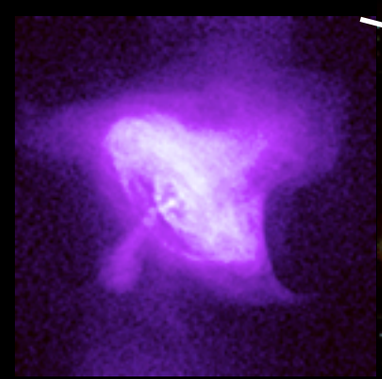
Tycho

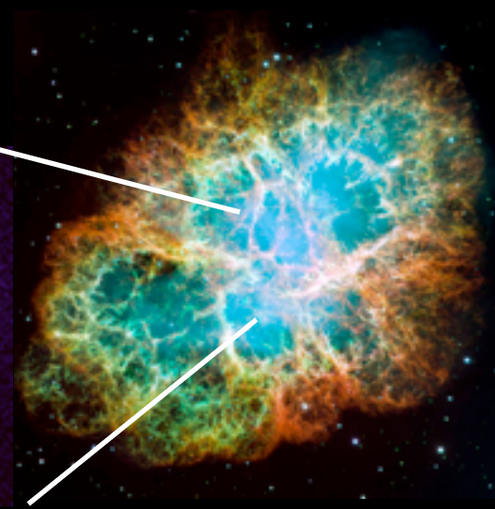
Crab

Cas A

-10
-5
0
5
10
-15
kpc





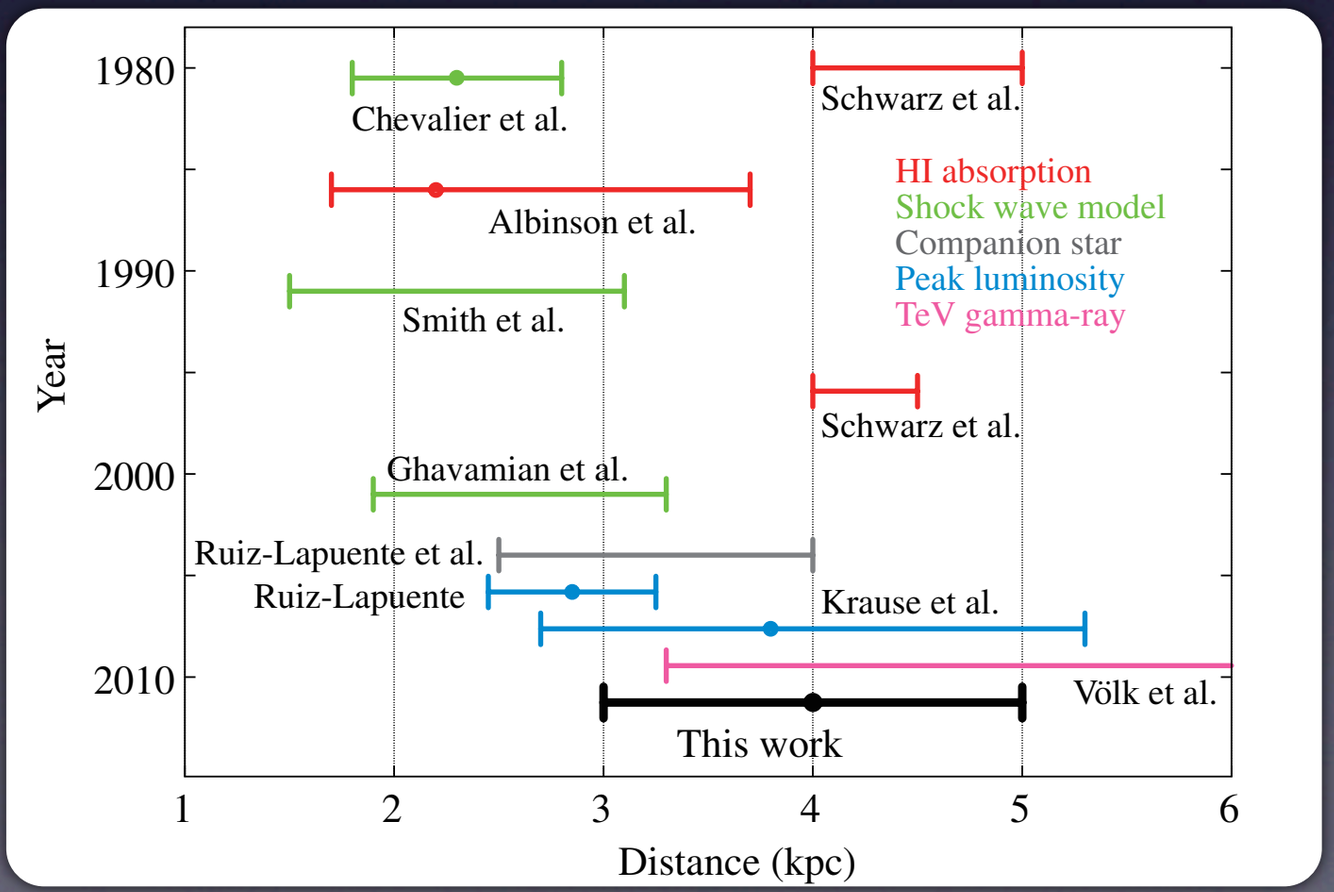


M. Tanaka

Distance to Tycho's SNR

distance modulus
= [m(obs) - extinction] - M(abs)
= (-4.0 ~ -4.5 mag) — Tycho Brahe (1603)
- (1.86 +- 0.2 mag) — Extinction toward SNR
- (-19.0 +- 0.3 mag) — Standard luminosity of Type Ia SNe

d = 3.8 (+1.5 -0.9) kpc



Hayato et al. 2010

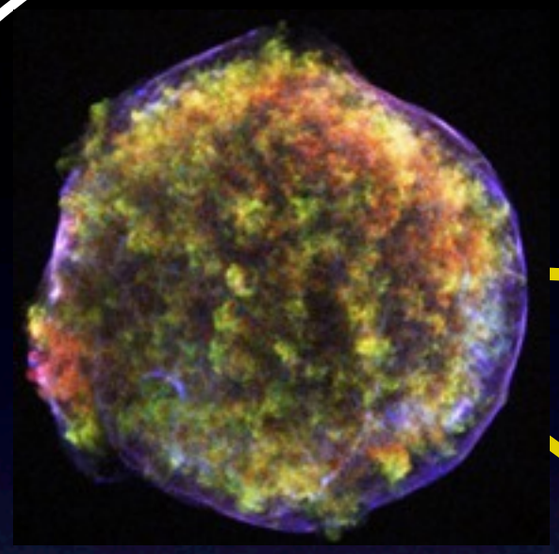
A promising method (future)

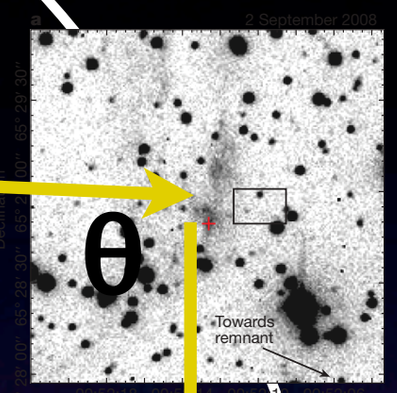
Polarization maximum

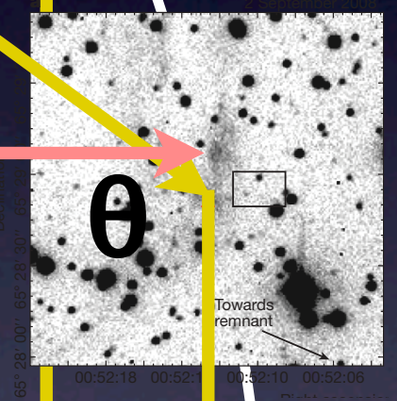
Depth z=0

Distance!

z

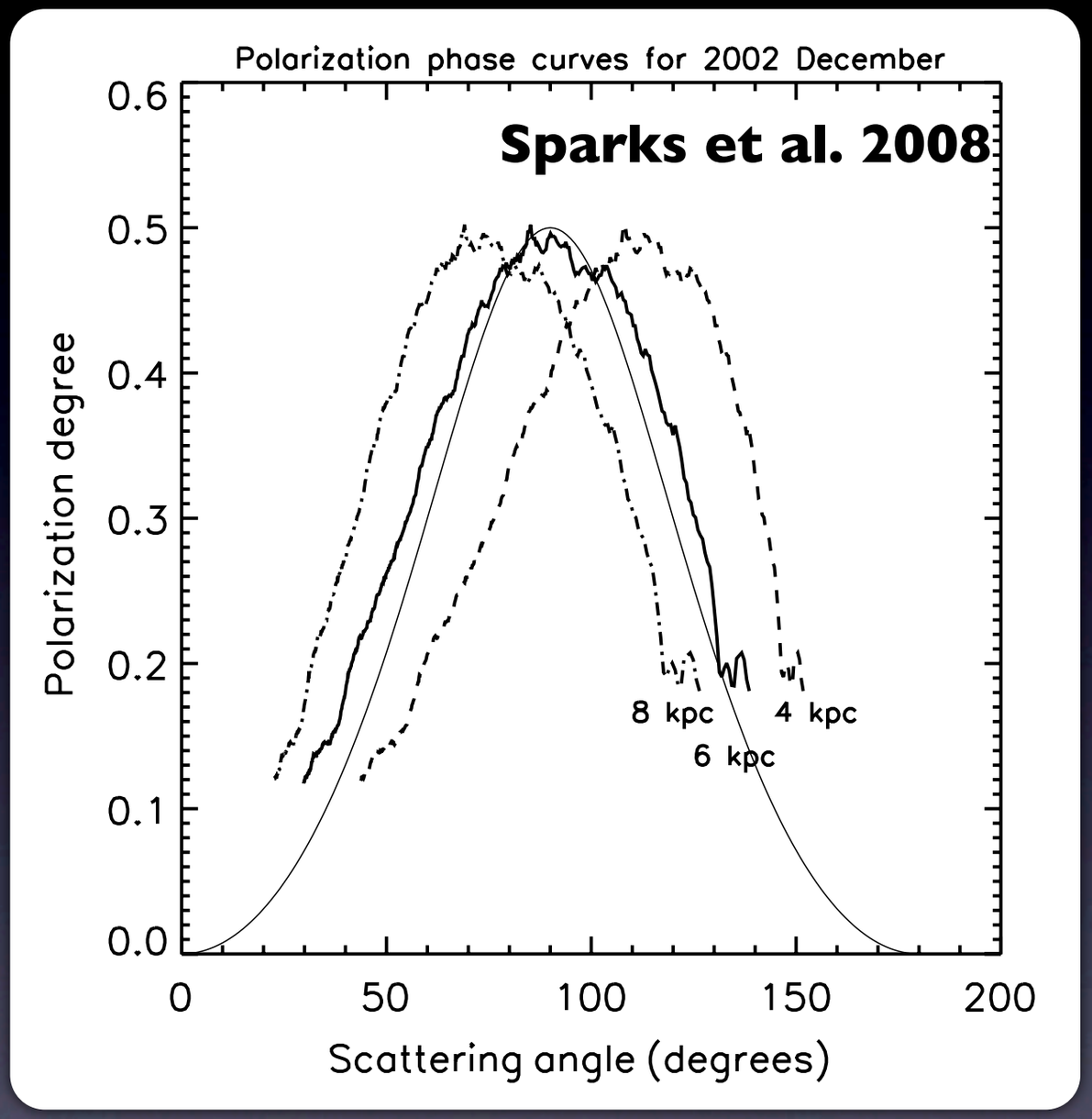




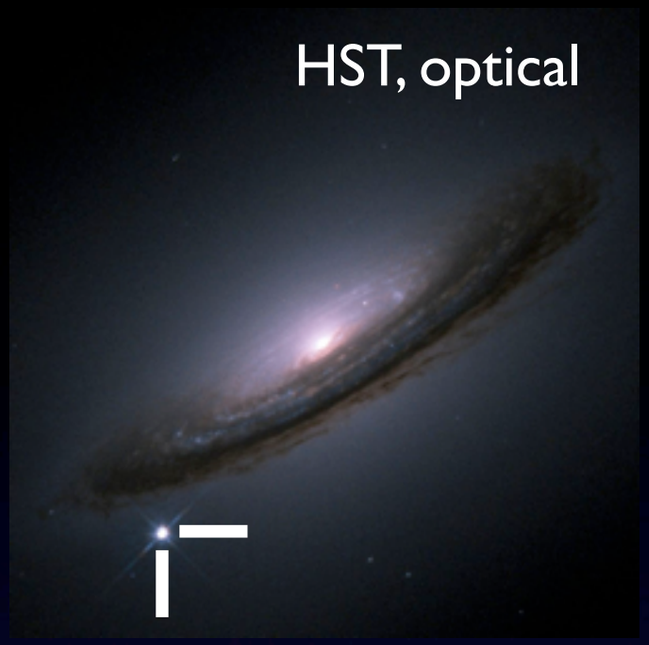


$\rho = D \sin \alpha$

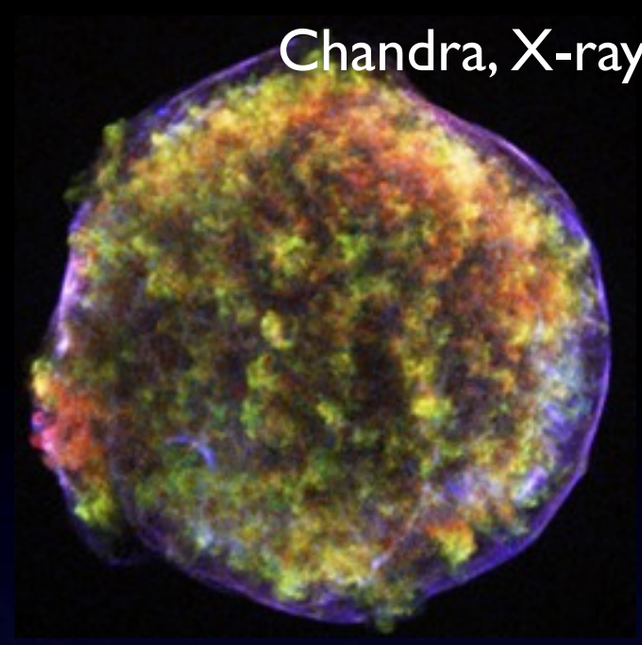
$$z = \frac{\rho^2}{2ct} - \frac{ct}{2}$$



V838 Mon
d = 6.2 +- 1.2 kpc



Light echo



<u>SNR typing</u>

- Tycho

- Cas A

<u>Future</u>

More typing (Kepler, Crab, ...)

Geometric distance

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Space

Opt/IR surveyor
(1-2m class)
Euclid (2017-) 0.5-2 um
WFIRST (?-) 0.7-2.5 um
WISH (?-) 1-5 um

SPICA (2022?-)
5-200 um

JWST (?-)
0.7-25 um

2010

2020

8-10m telescope

>30m telescope

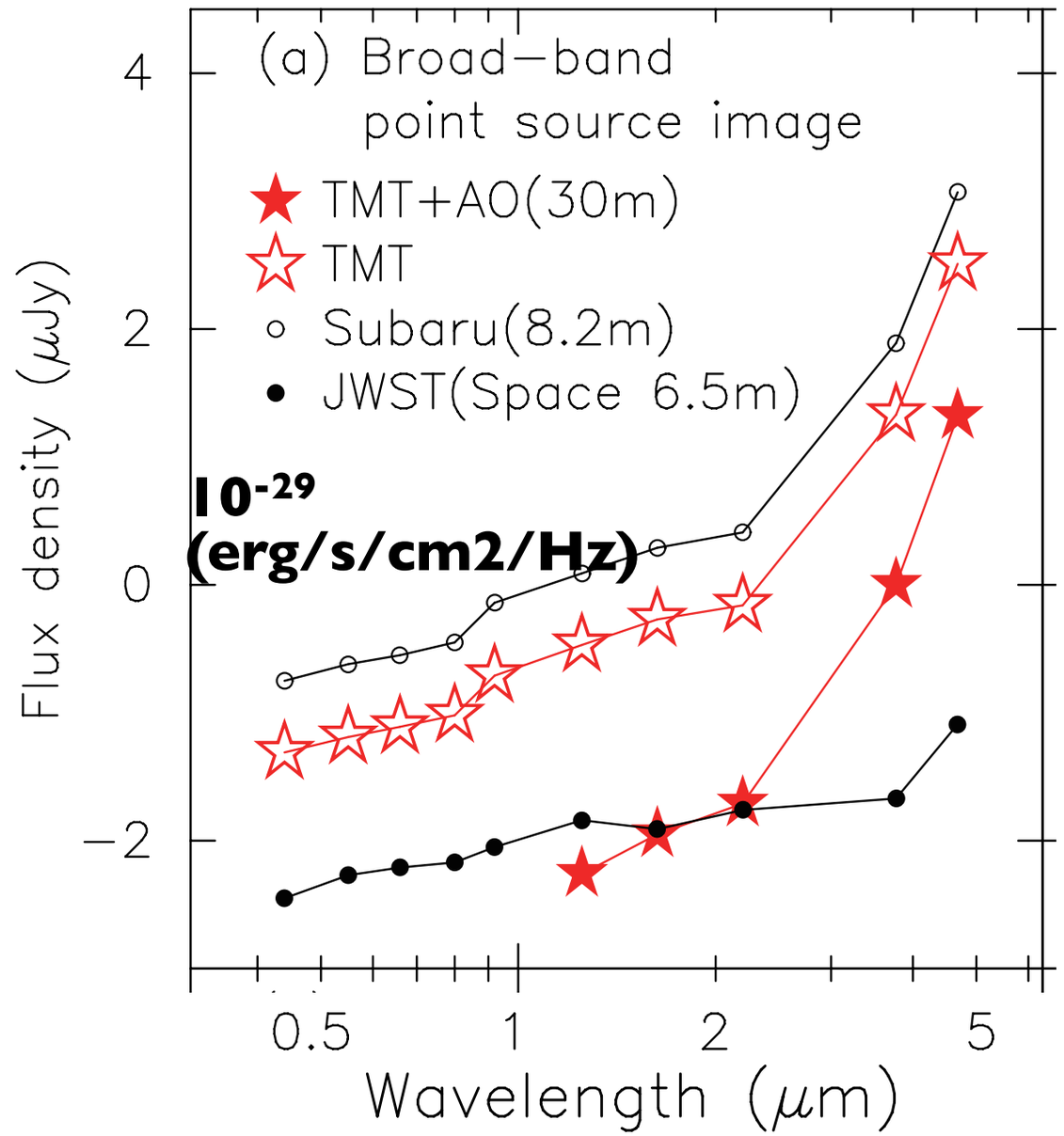
TMT (2021?-)
GMT, E-ELT

Hyper Suprime-Cam
2013- (Urata-san)

Ground

TMT:
Thirty meter telescope

TMT計画説明書より



0.01 arcsec resolution! @ NIR
(better than JWST)

H alpha filament in Tycho's SNR

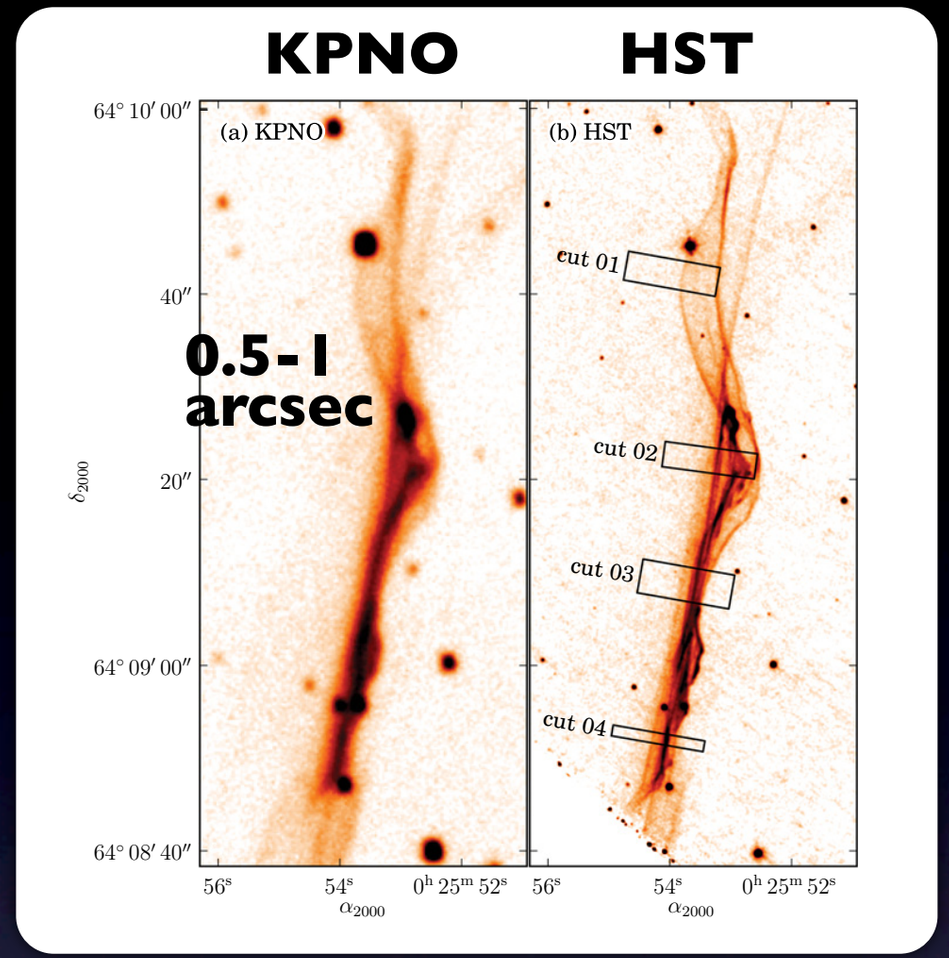
Lee et al. 2010, ApJ, 715, L146

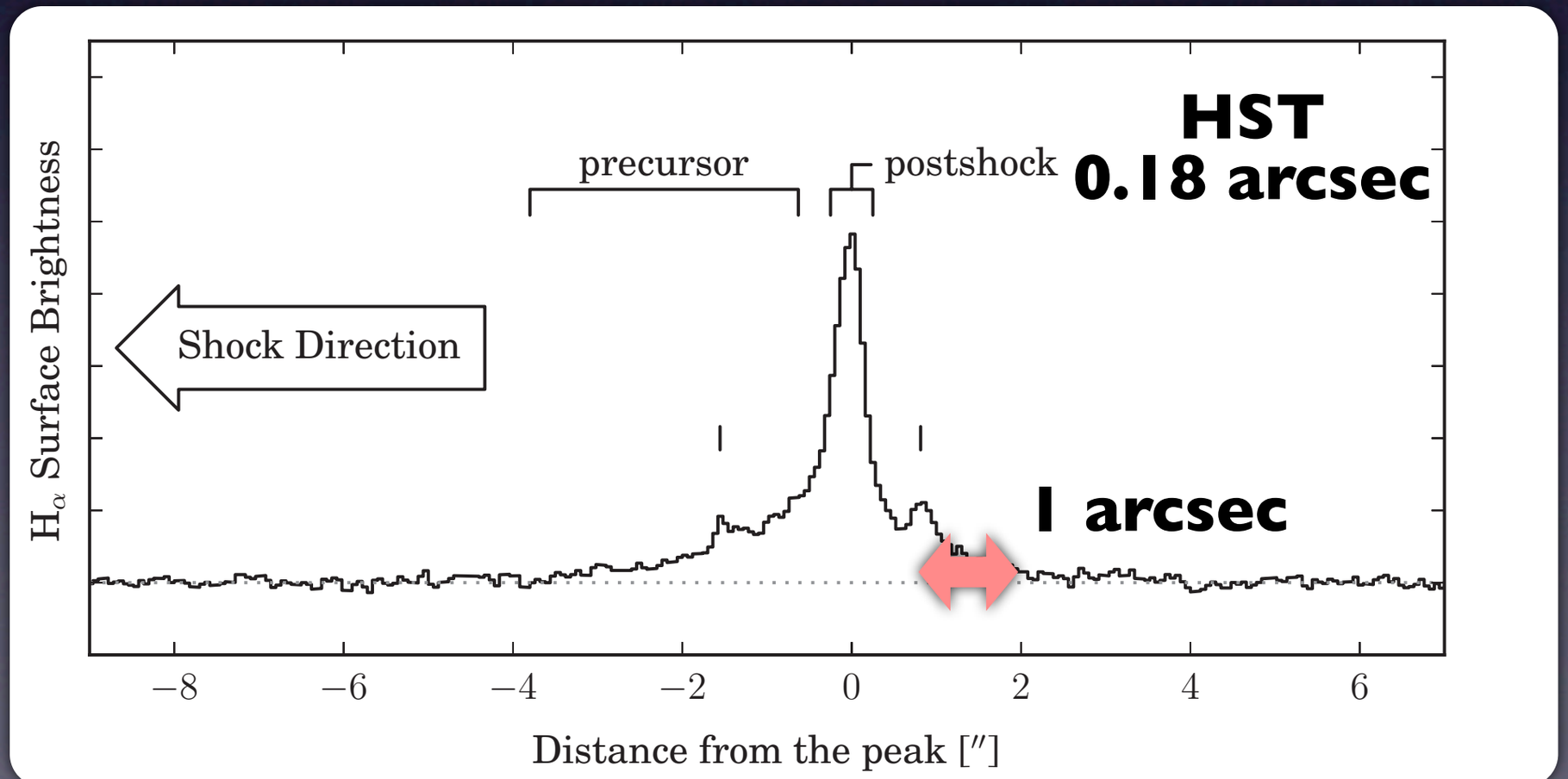
At 4 kpc

1 arcsec = 6 x 10^{16} cm

0.1 arcsec = 6 x 10^{15} cm

0.01 arcsec = 6 x 10^{14} cm





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