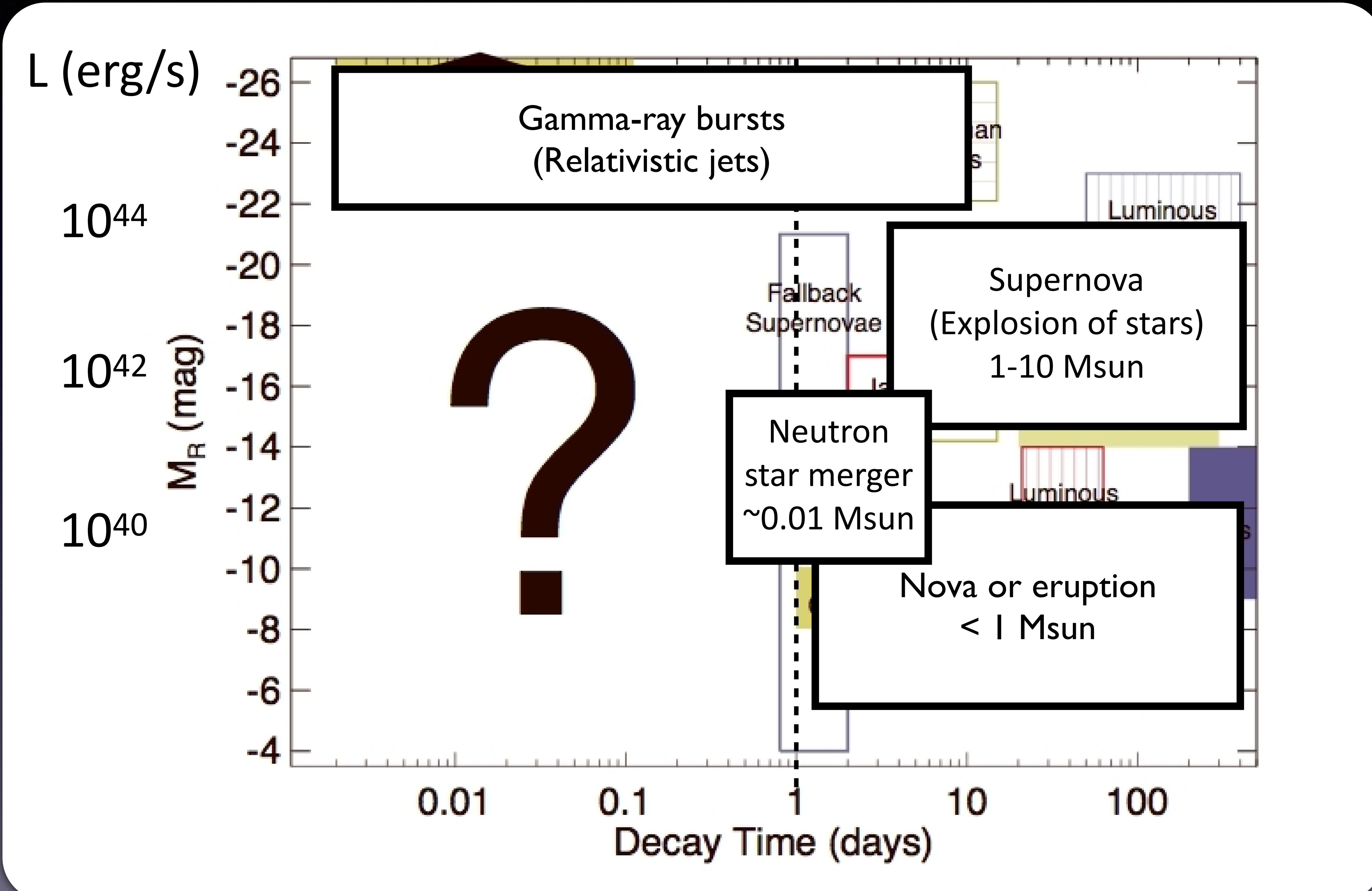
突発天体と可視光・赤外線観測

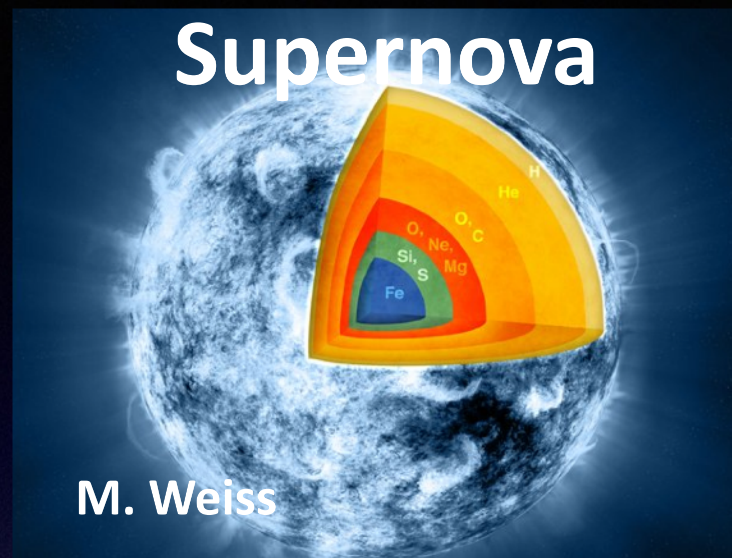
田中 雅臣 (東北大学)

Transient sky (optical/infrared)



LSST Science Book (after Rau+09, Kasliwal+,Kulkarni+)

Multimessenger from transients

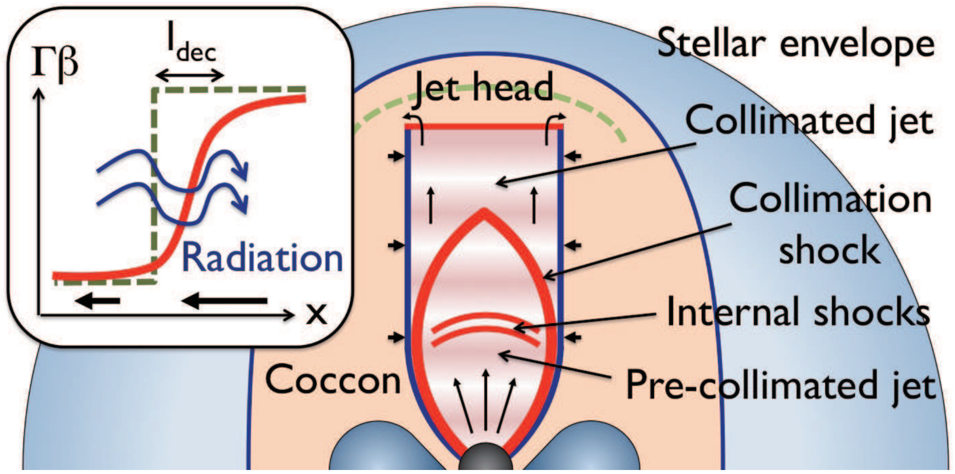


	Supernova	Neutron star merger
GW	Asymmetric motion d ~ 10 kpc	Inspiral + merger d ~ 200 Mpc
Low E neutrino	Neutron star d ~ 100 kpc	Neutron star + disk d ~ 100 kpc
High E neutrino	Jet/failed jet??	Jet?? 木村さん講演
EM (opt/IR)	Decay of 56Ni + shock heating d > 1 Gpc	Decay of r-process d ~ 200 Mpc

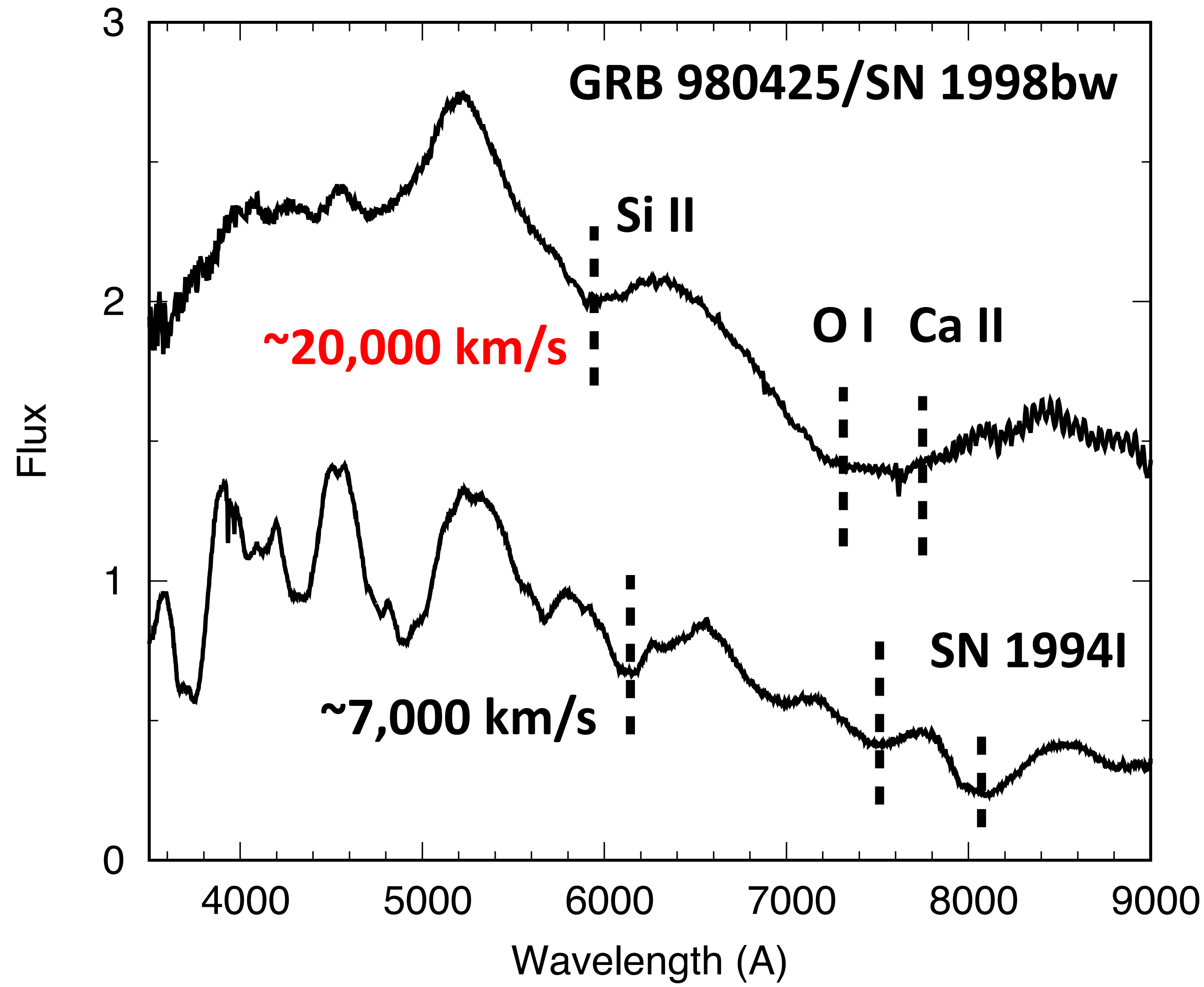
Expectation Observed

- Supernovae as high-E neutrino sources
- Neutron star mergers as gravitational wave sources

Supernova with chocked jet as high-E neutrino source?



Murase & Ioka 2013



木村さん講演 (for NS merger)

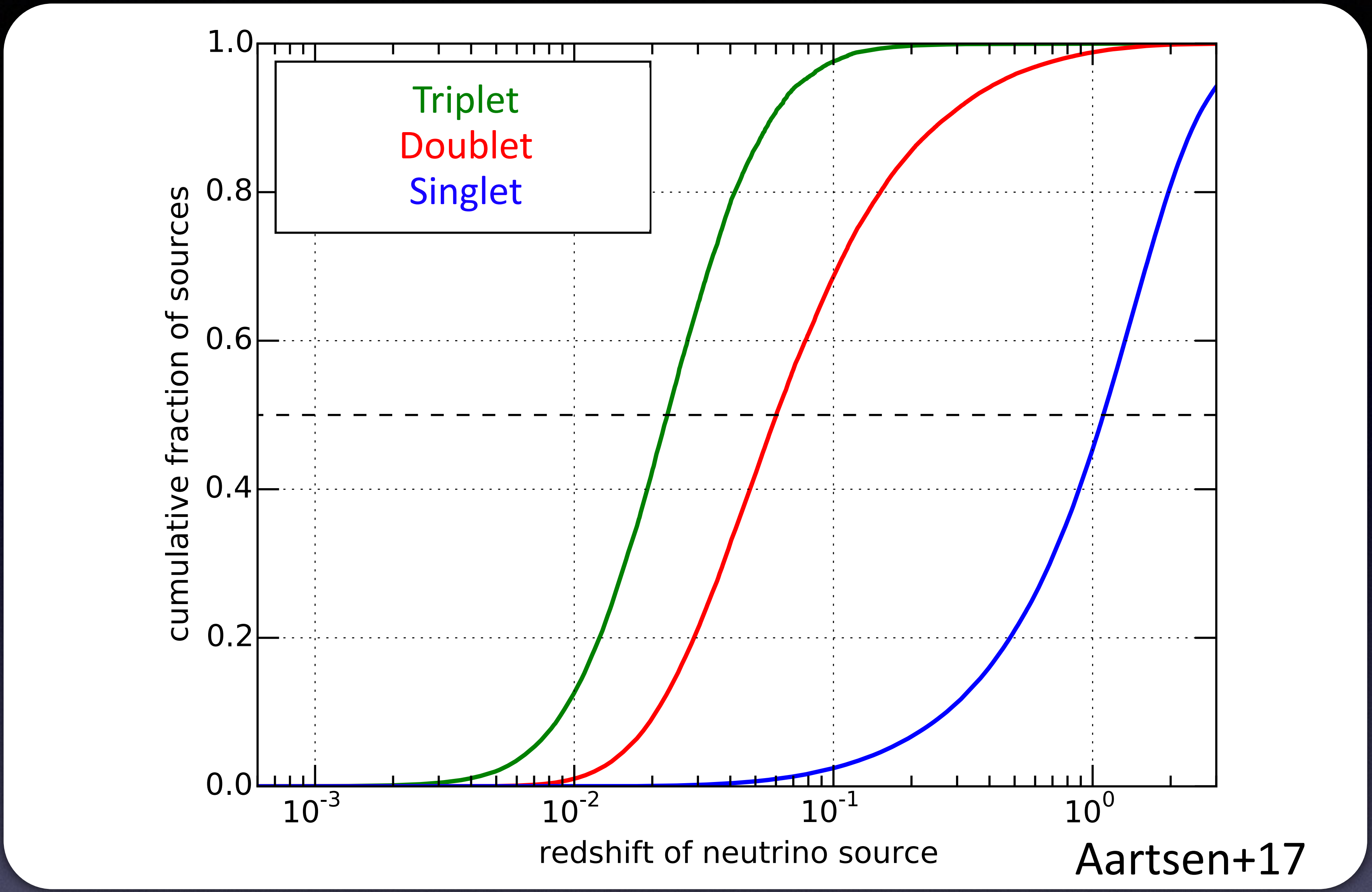
Observed as "broad-line" SNe?

(~1 % of core-collapse SNe)

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

Can we detect SNe as a counterpart of high-E neutrino?

清水さん講演



Redshift	0.02	0.2	1.0
Lum distance	100 Mpc	1 Gpc	7 Gpc
SN brightness	17 mag	22 mag	26 mag
Telescope size (optical imaging)	1m	4m	8m

Detectable with existing telescopes!

Magnitude…

天文学辞典 > 観測天文学 > 共通基礎 > 等級

(C) 天文学辞典

等級

学習レベル
小 中 高

観測天文学
共通基礎

よみ方　とうきゅう

英 語　magnitude

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

説 明

天体の明るさを測る単位で、「級」を省いて単に1等、2.3等、-0.4等などともいう。古代ギリシアのヒッパルコスは、1000個あまりの恒星を記載したヒッパルコス星表で、星を明るさに従って6つの光度階級に分類した。最も明るい星を1等、肉眼でやっと見える星を6等としたこの光度階級が現在の星の等級の起源となった。18世紀末のイギリスの天文学者ウィリアム・ハーシェルは星の明るさと等級の関係を調べ、彼の息子のジョン・ハーシェルは1等星は6等星のほぼ100倍の明るさであることを発見した。1856年にイギリスのポグソン（N. Pogson）がポグソンの式により等級差の定量的な定義を定めたが、最も明るい星を1等星、肉眼で見える最も暗い星を6等星とした伝統的な尺度を踏襲した。

brighter　5　10　15　20　25　30　fainter

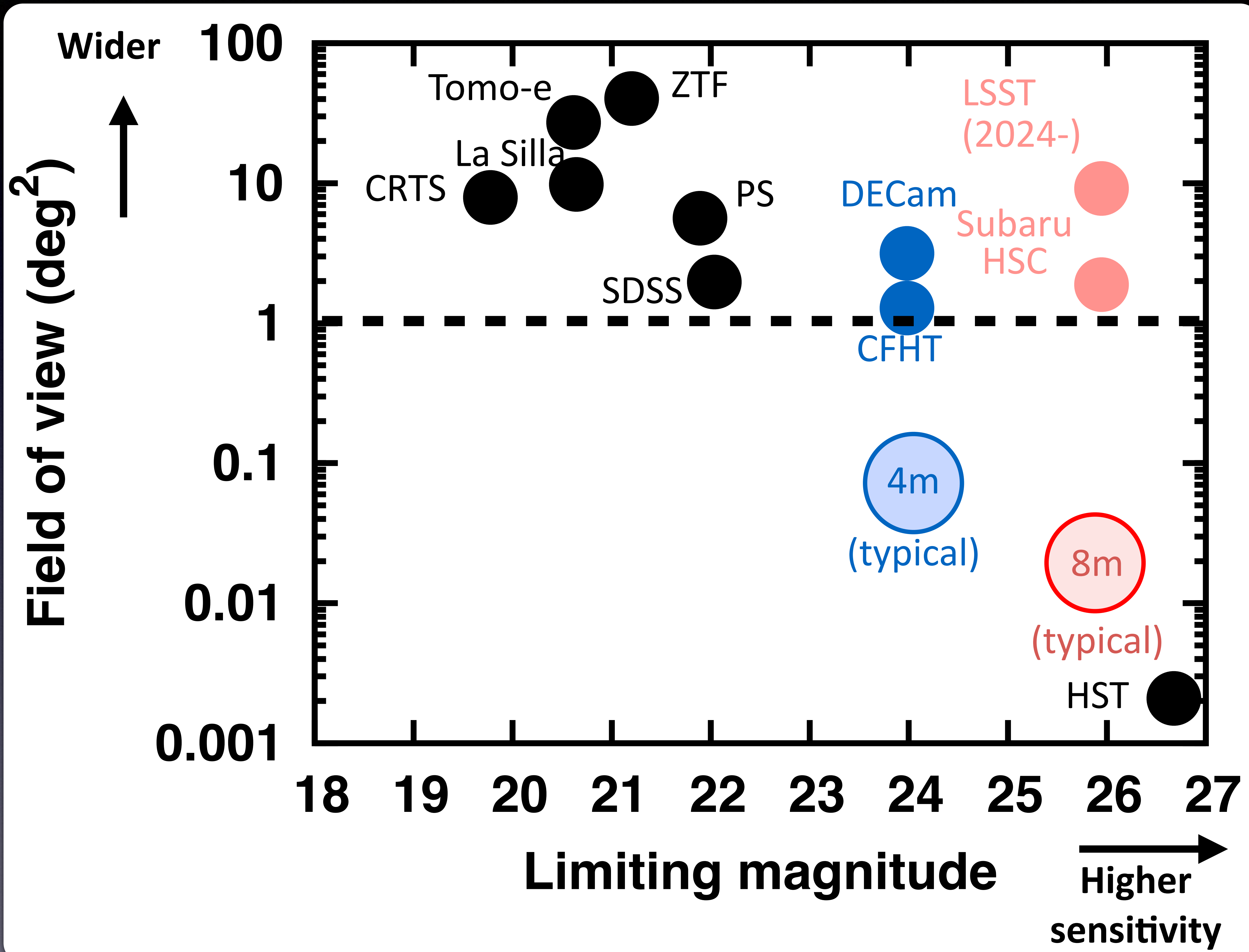
→ mag

Required size (diameter) of telescopes

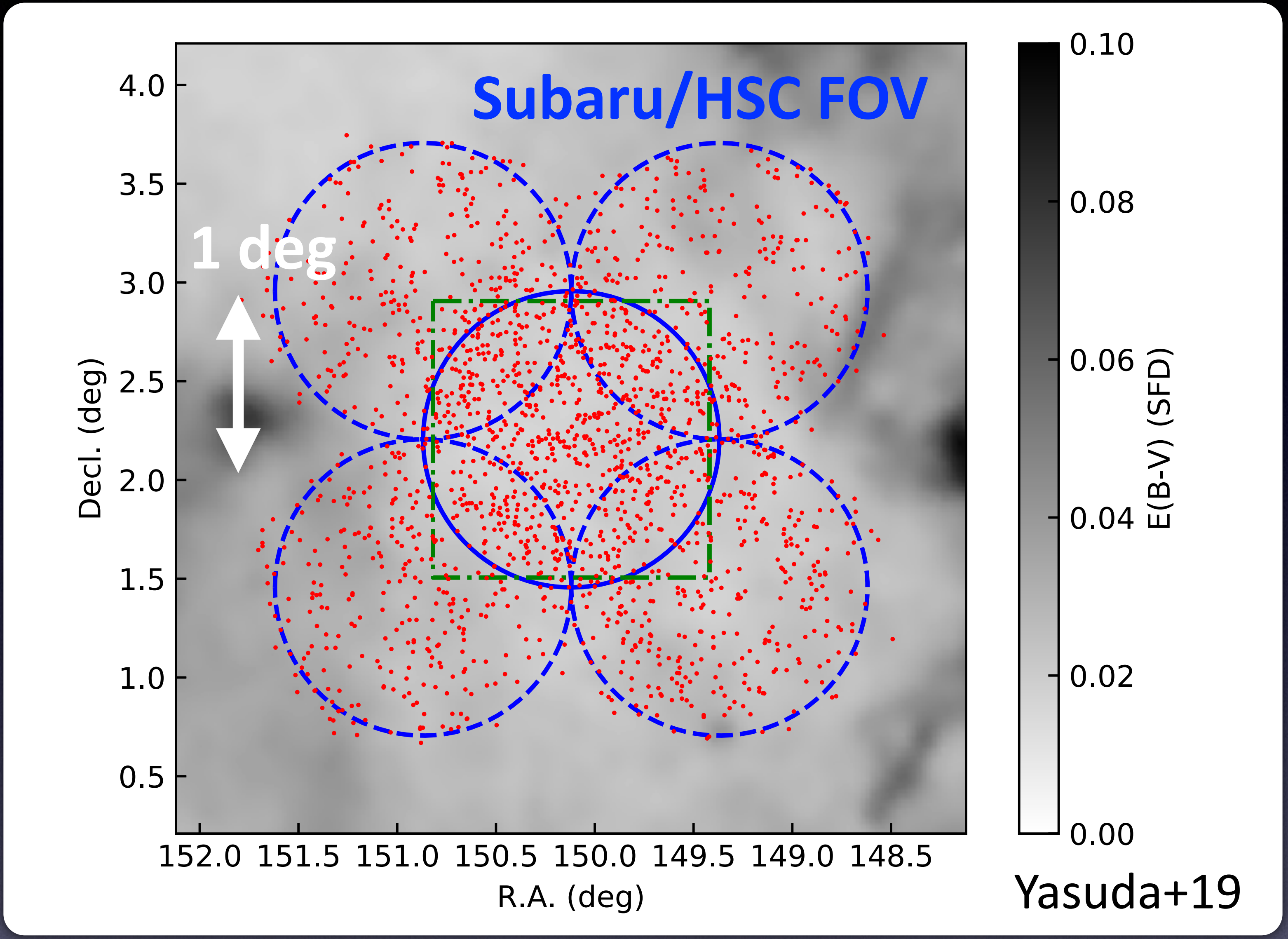
Imaging	eye	1m 木曽	2m かなた	8m すばる	(30m) TMT
Spectroscopy		1m	2m	8m	(30m)

Can we search SNe in the localization area?

内海さん講演



Can we identify the counterpart?
(contamination of unrelated objects)



清水さん講演

Doublet (z~0.2, 22 mag)
~ 1 SNe / deg2 / 1 vist

- Feasible with current instruments

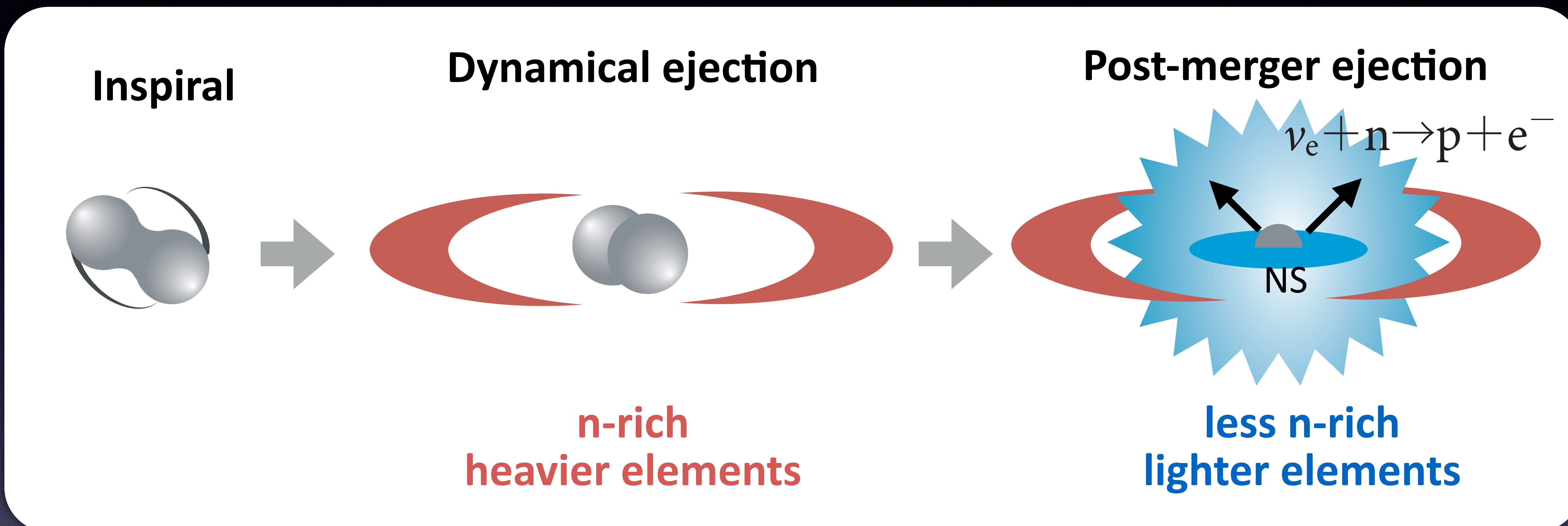
石原さん、清水さん講演

Singlet (z ~ 1, 26 mag)
~50 SNe / deg^2 / 1 visit

- Better localization with IceCube-Gen2 (< 1 deg)
- Spectroscopy with 30m-class telescopes (e.g., TMT)

- Supernovae as high-E neutrino sources
- Neutron star mergers as gravitational wave sources

Neutron star mergers



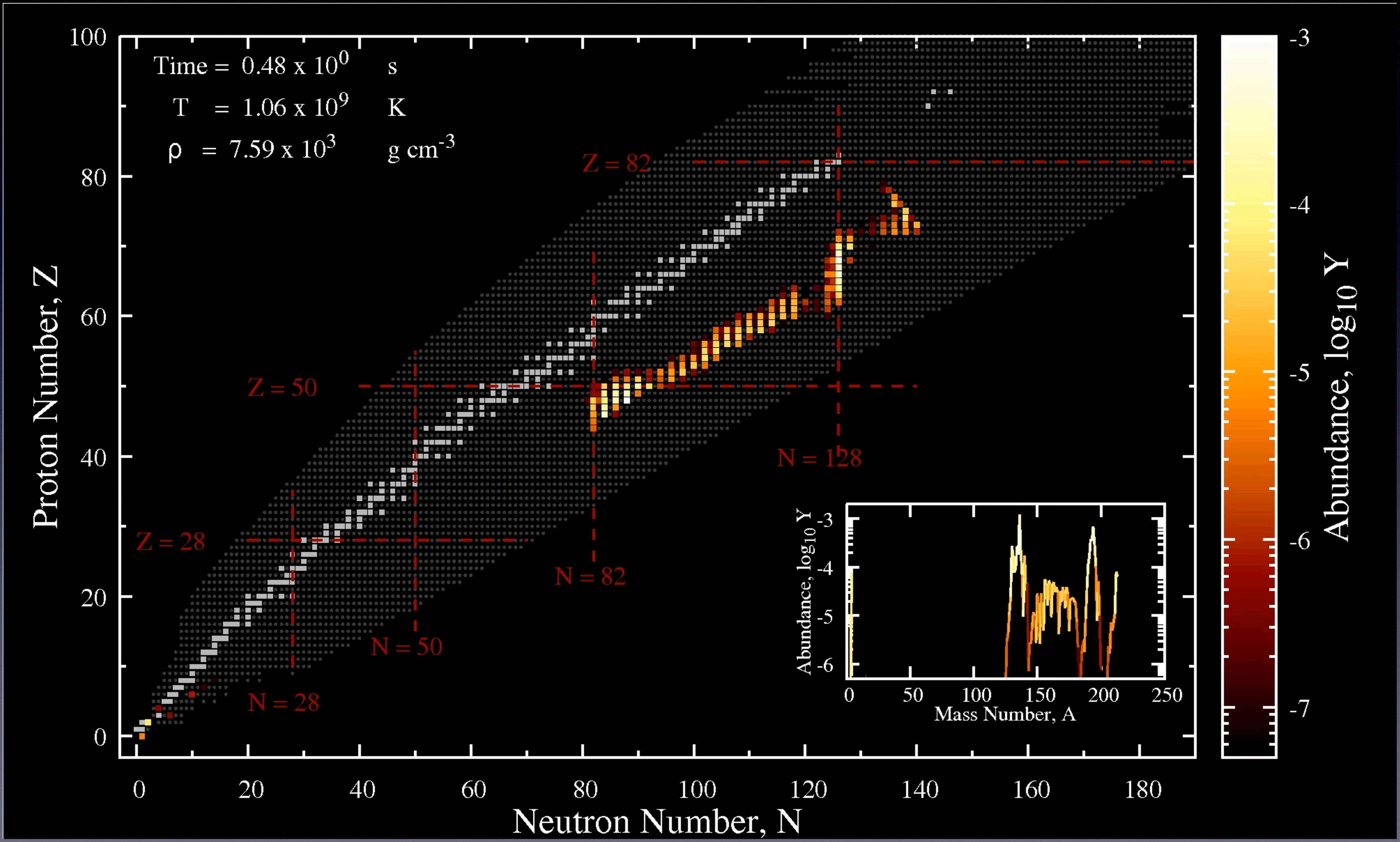
Gravitational wave

Time

~ 10 msec

~ 1 sec

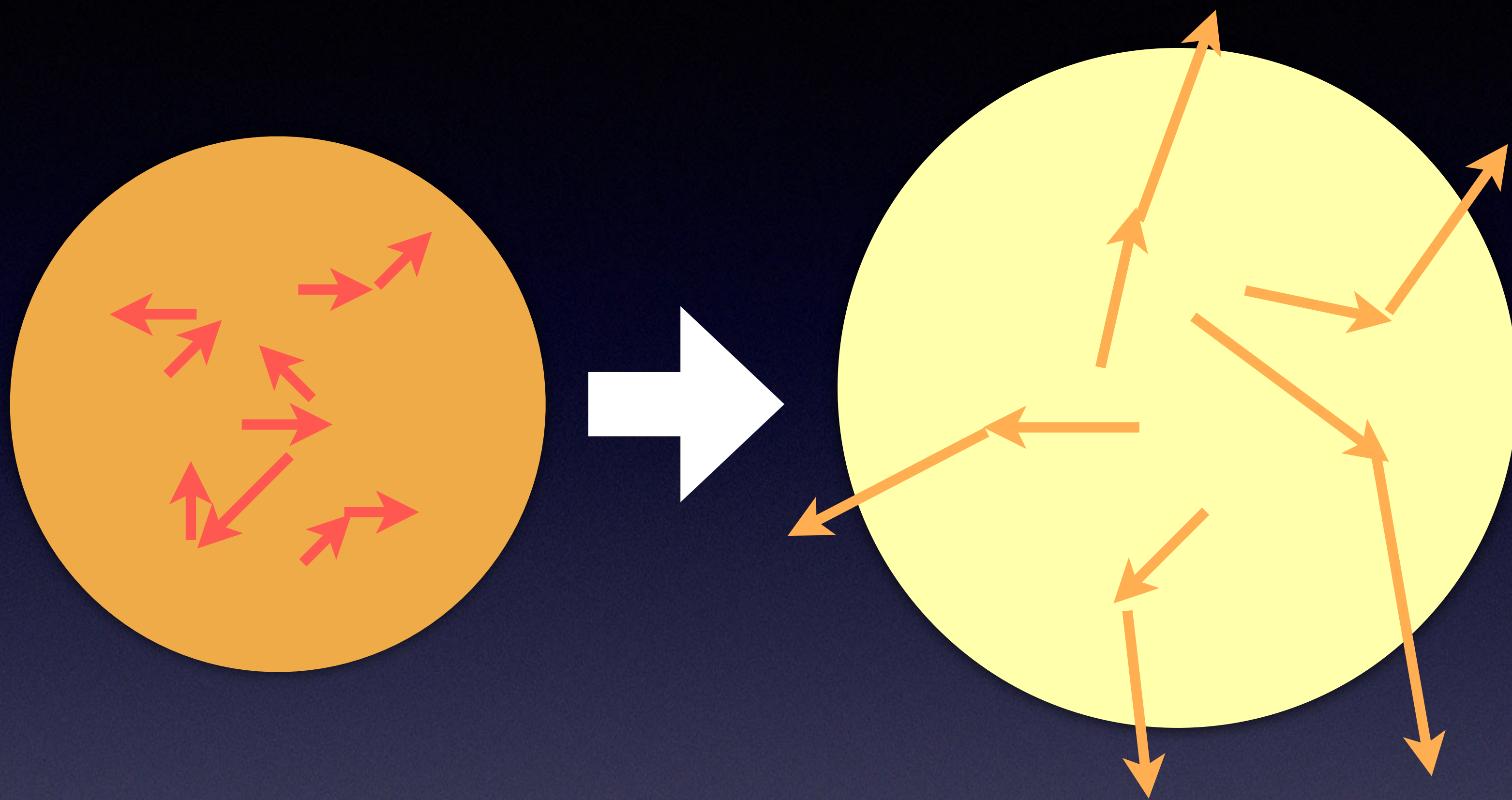
rapid neutron capture (r-process) t ~ 1 sec **Nuclear physics**

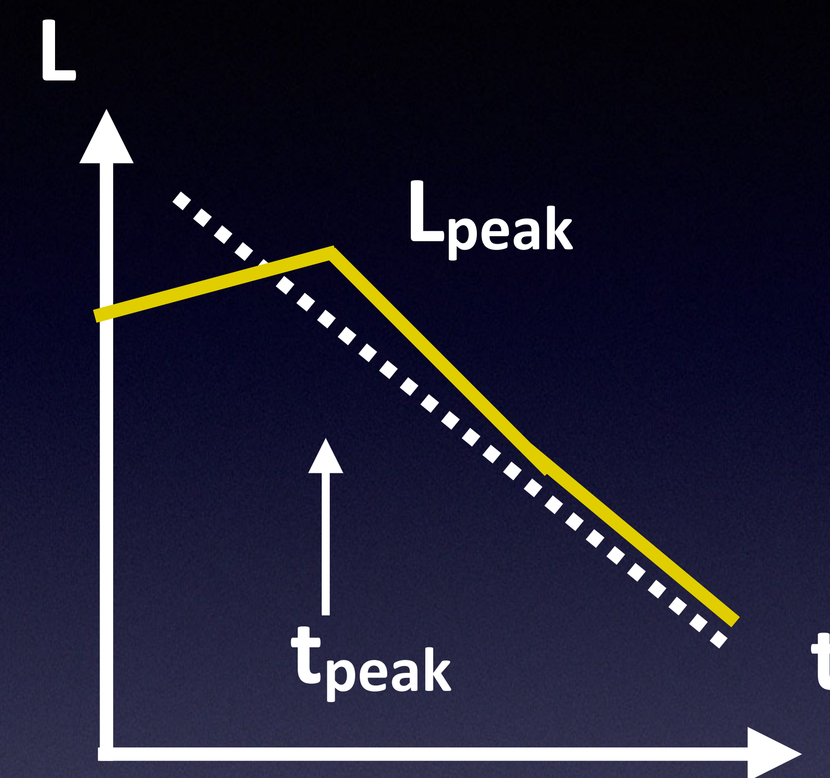


(C) Nobuya Nishimura

“Kilonova” t ~ 1 day-month

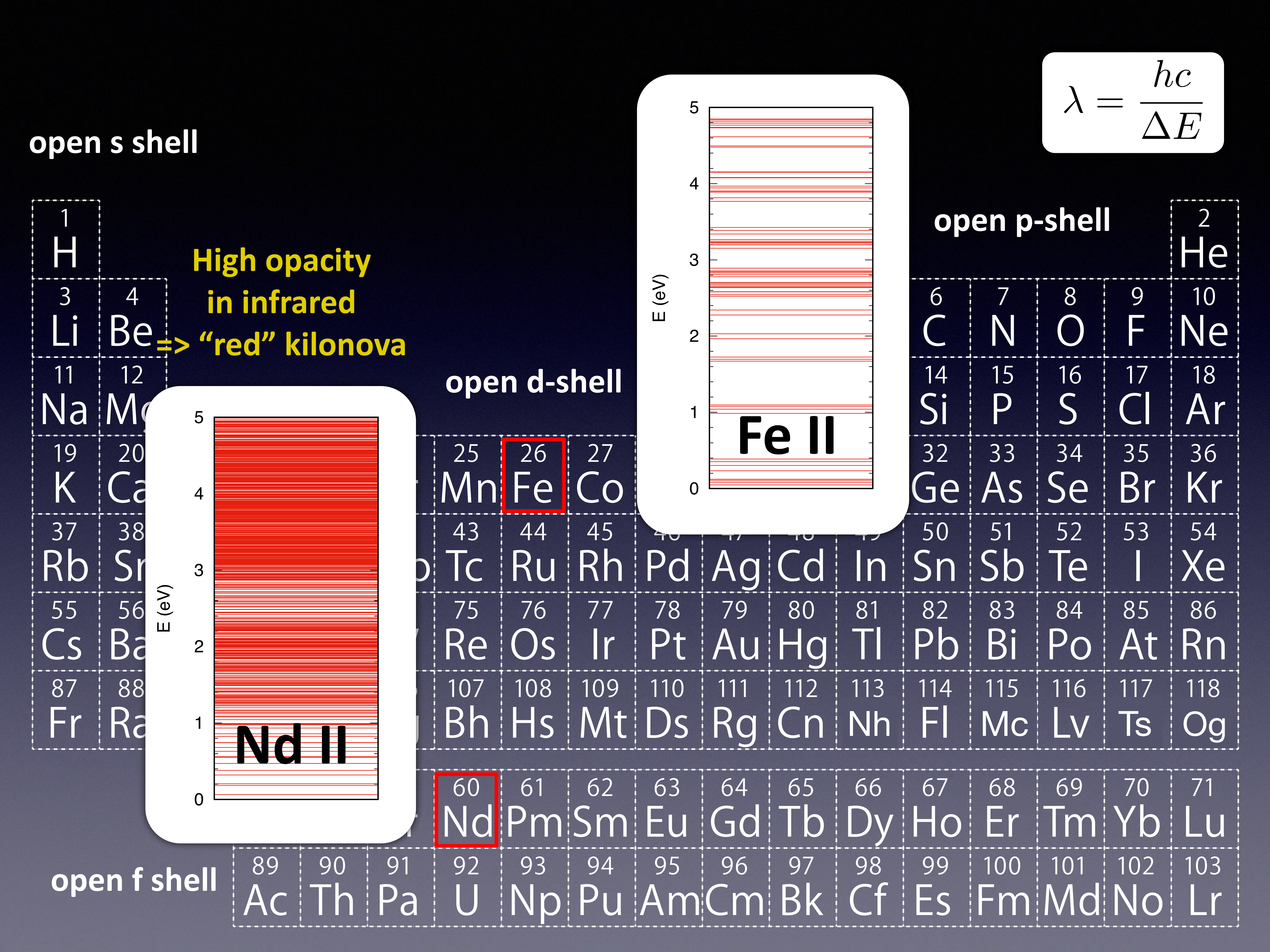
Atomic physics



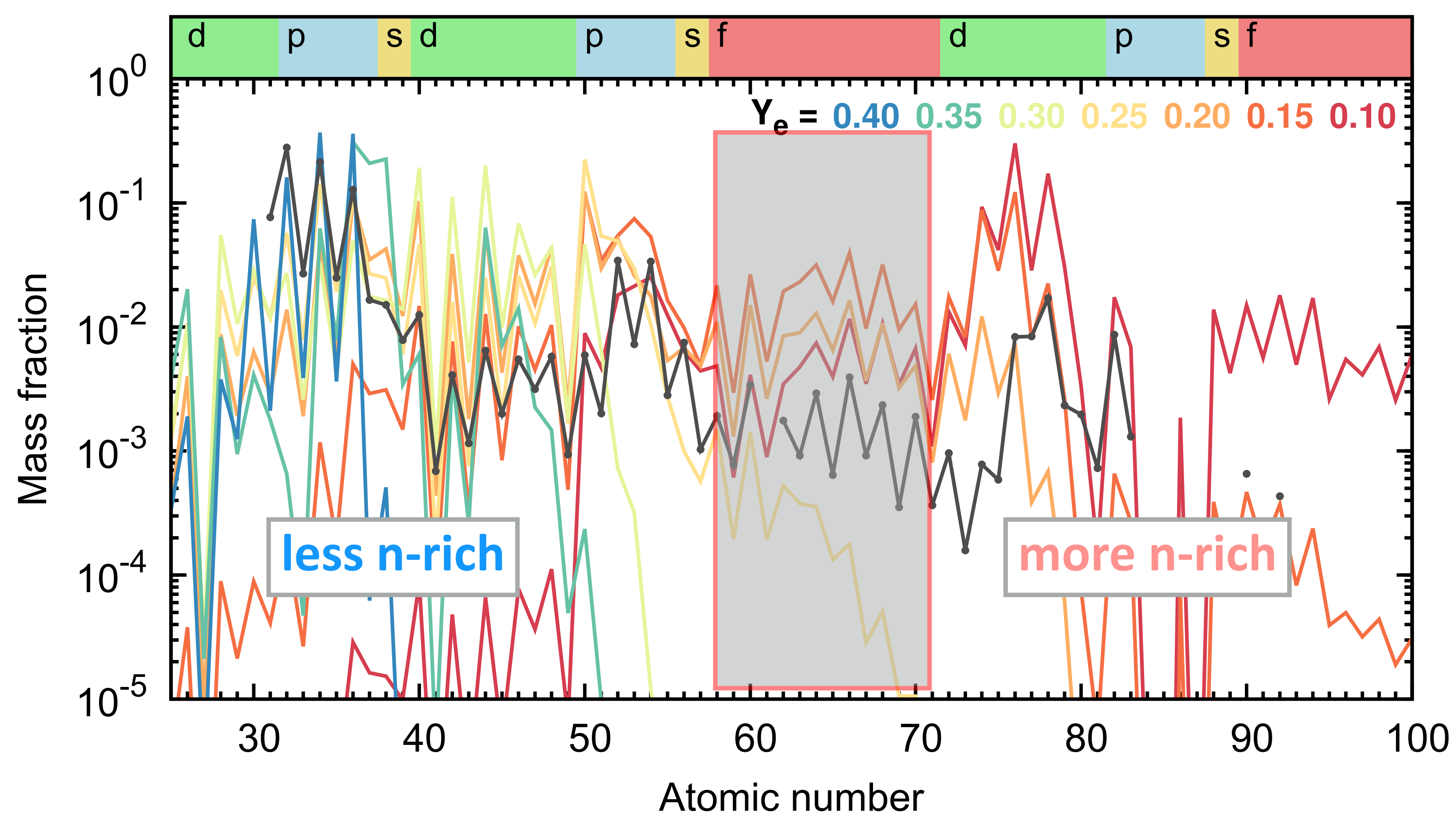


$$
\begin{aligned}
t_{\rm peak} &= \left(\frac{3\kappa M_{\rm ej}}{4\pi c v}\right)^{1/2} \\
&\simeq 8.4 \ {\rm days} \left(\frac{M_{\rm ej}}{0.01 M_\odot}\right)^{1/2} \left(\frac{v}{0.1c}\right)^{-1/2} \left(\frac{\kappa}{10 \ {\rm cm^2 \ g^{-1}}}\right)^{1/2}
\end{aligned}
$$

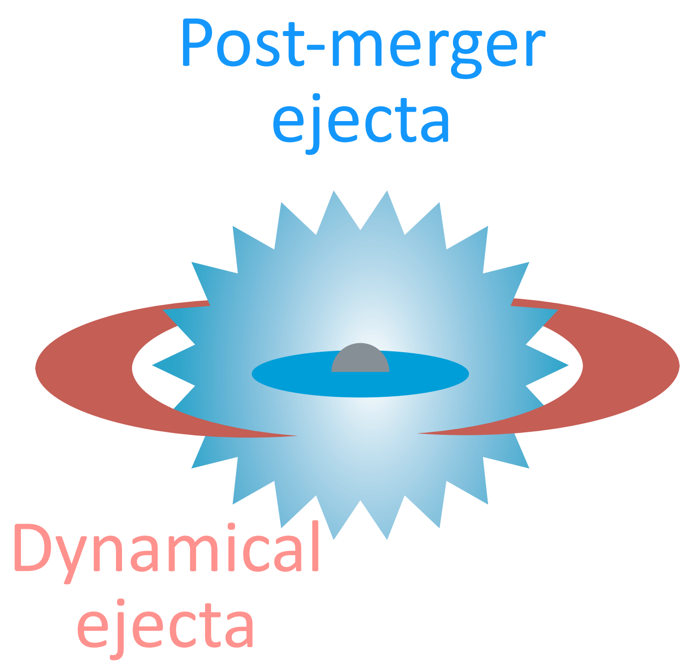
GW+EM observation => Ejected material and composition


open s shell
High opacity
in infrared
=> “red” kilonova
open d-shell
open p-shell
open f shell
Fe II
Nd II
E (eV)
$\lambda = \frac{hc}{\Delta E}$

Kilonova as a probe of nucleosynthesis



$$Y_e = \frac{n_e}{n_p + n_n} = \frac{n_p}{n_p + n_n}$$



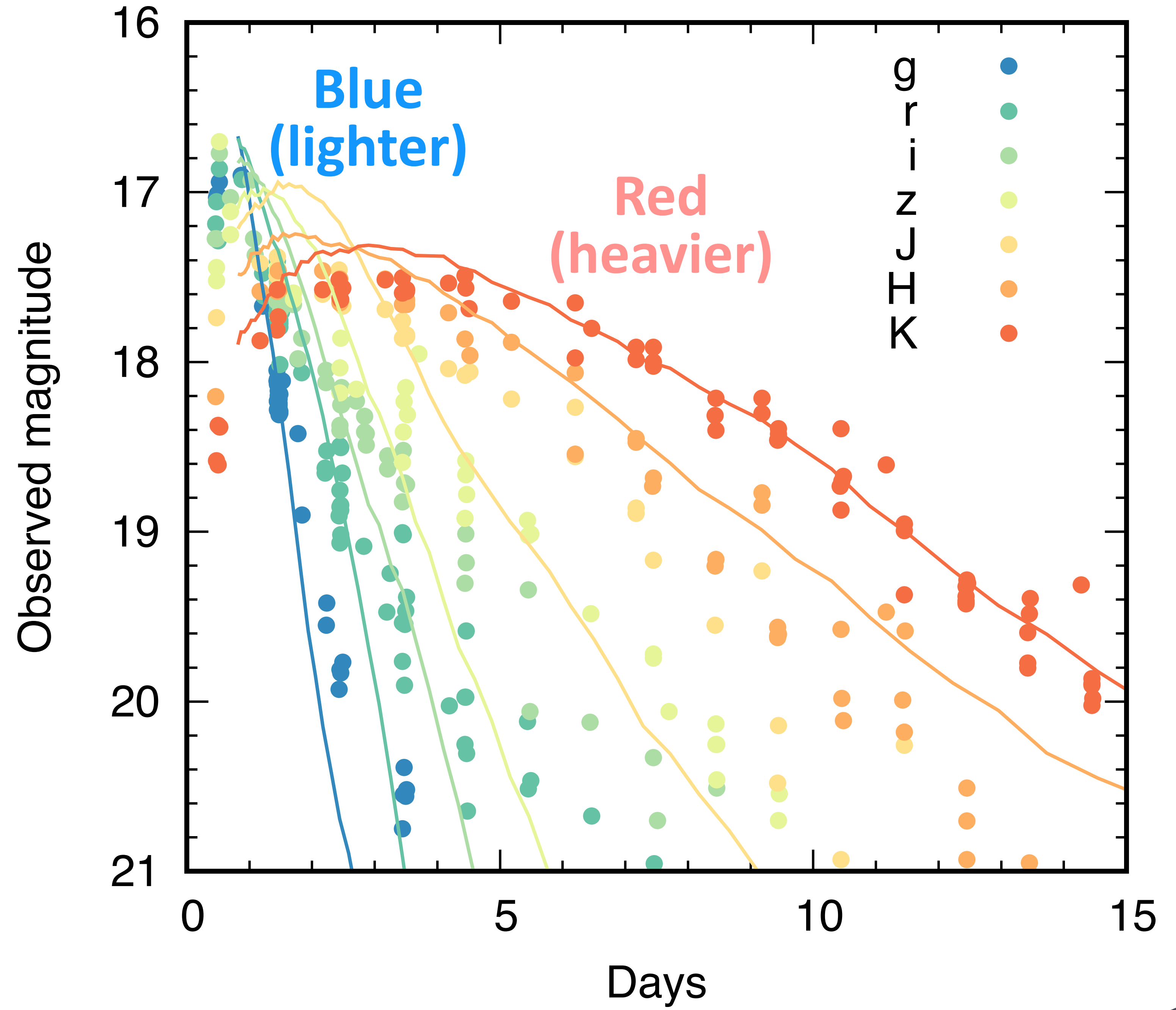
Less n-rich ==> “blue” kilonova

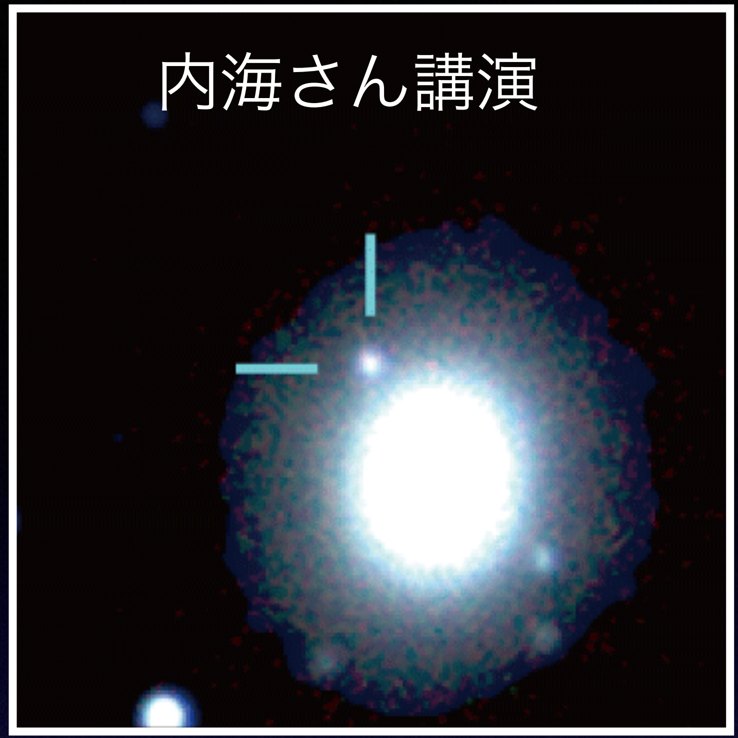
More n-rich ==> “red” kilonova

MT, Kato, Gaigalas, Kawaguchi 2020

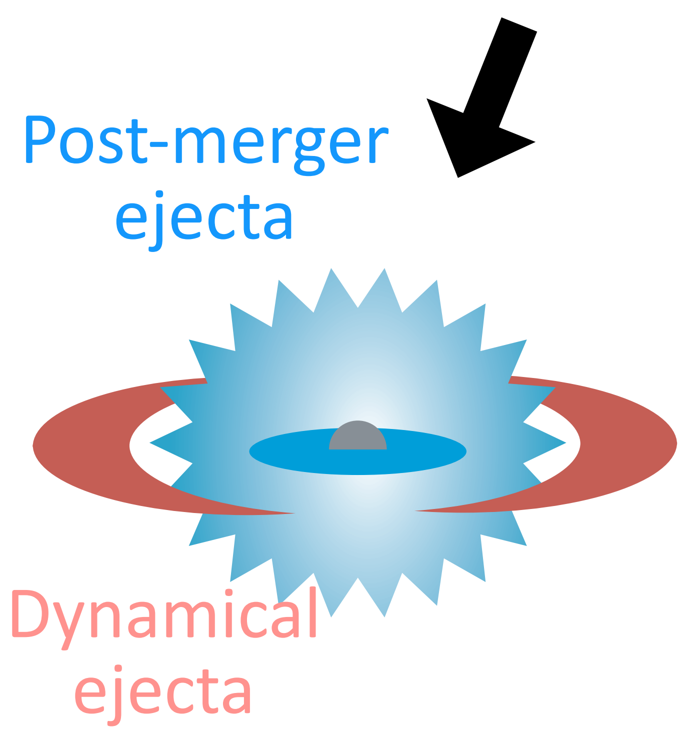
GW170817

Kawaguchi+2018, 2020



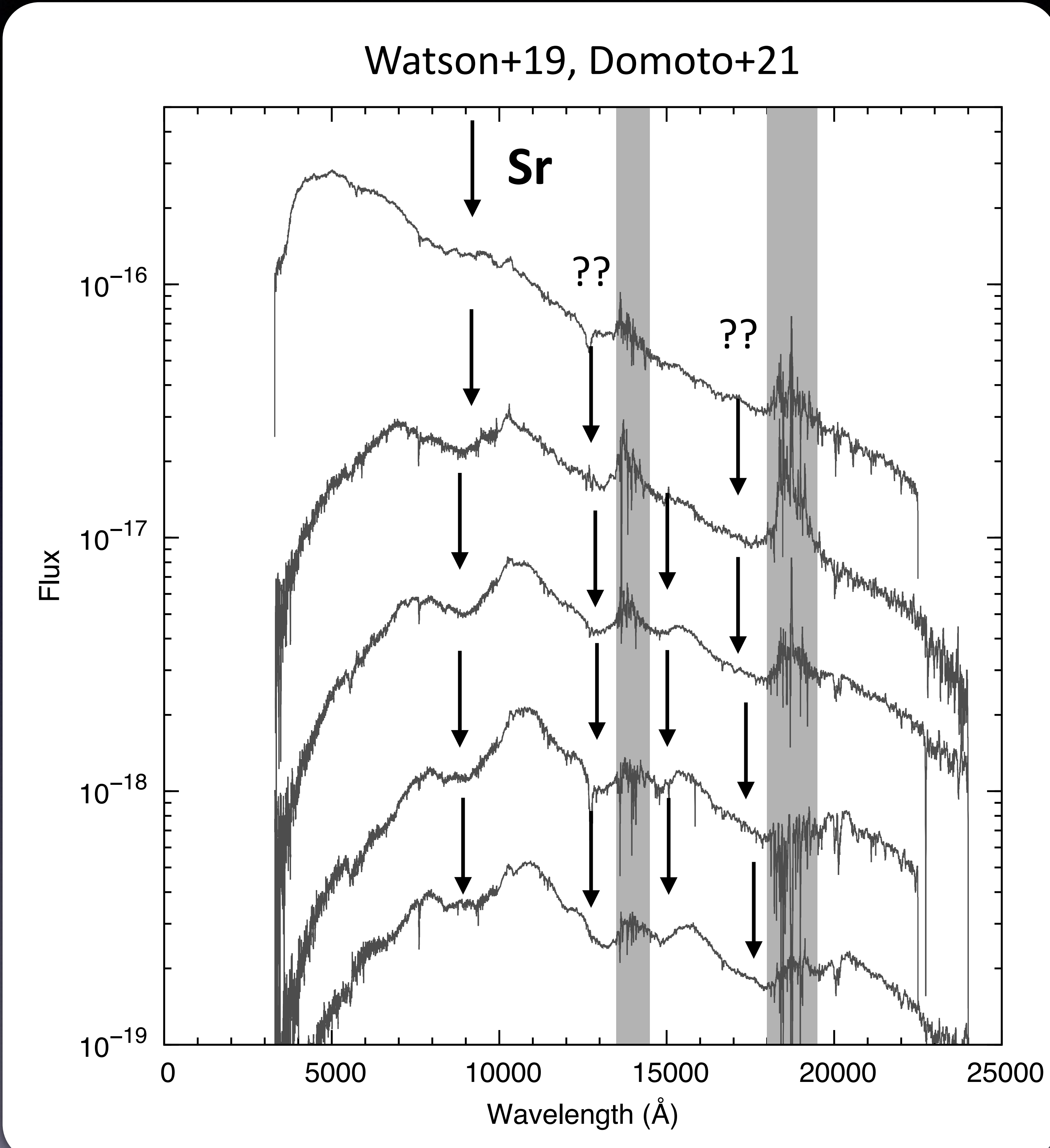


Utsumi+ 2017, Tominaga+18



Smoking gun: r-process nucleosynthesis by the NS merger

Element identification in kilonova spectra



Atomic physics

Lack of atomic data in infrared wavelengths (> 1 um)

- Systematic atomic calculation (MT+2020, Banerjee+20)
- Lab spectroscopy

Plasma modeling

- non LTE model (Hotokezaka+21)

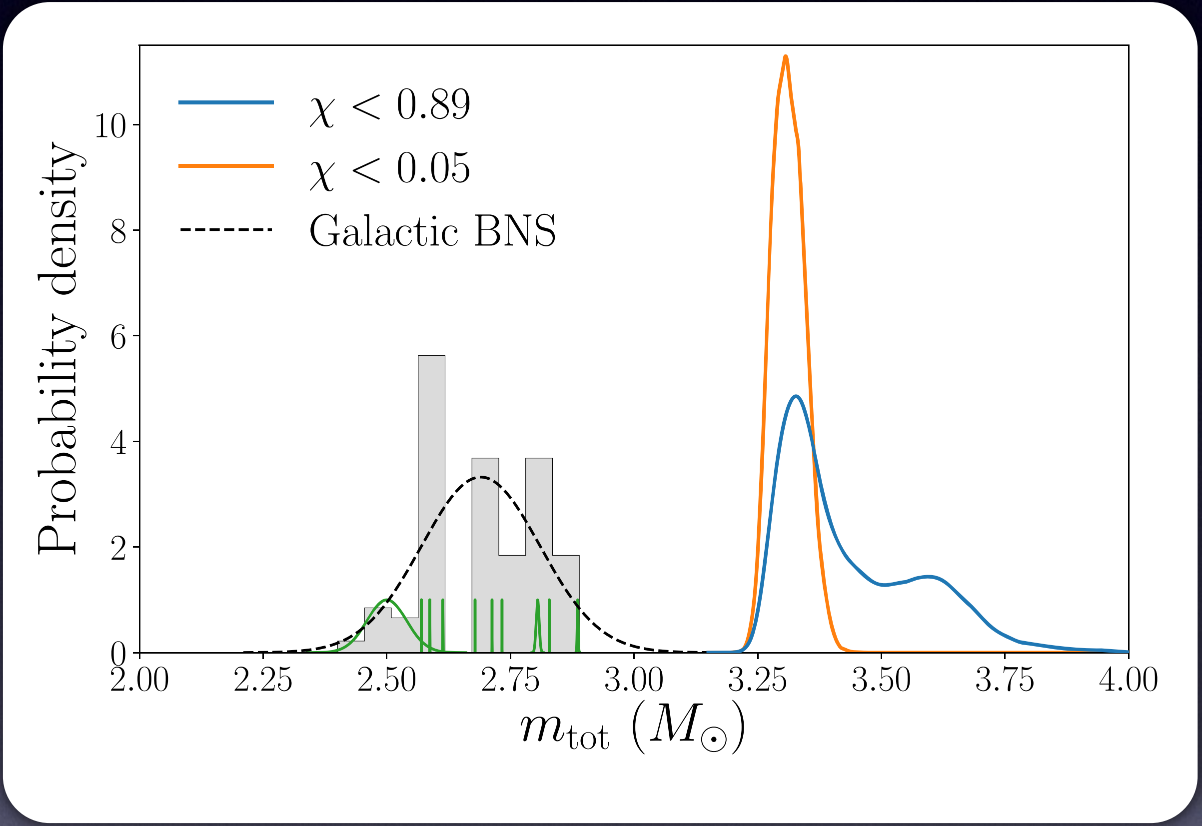
Plasma physics

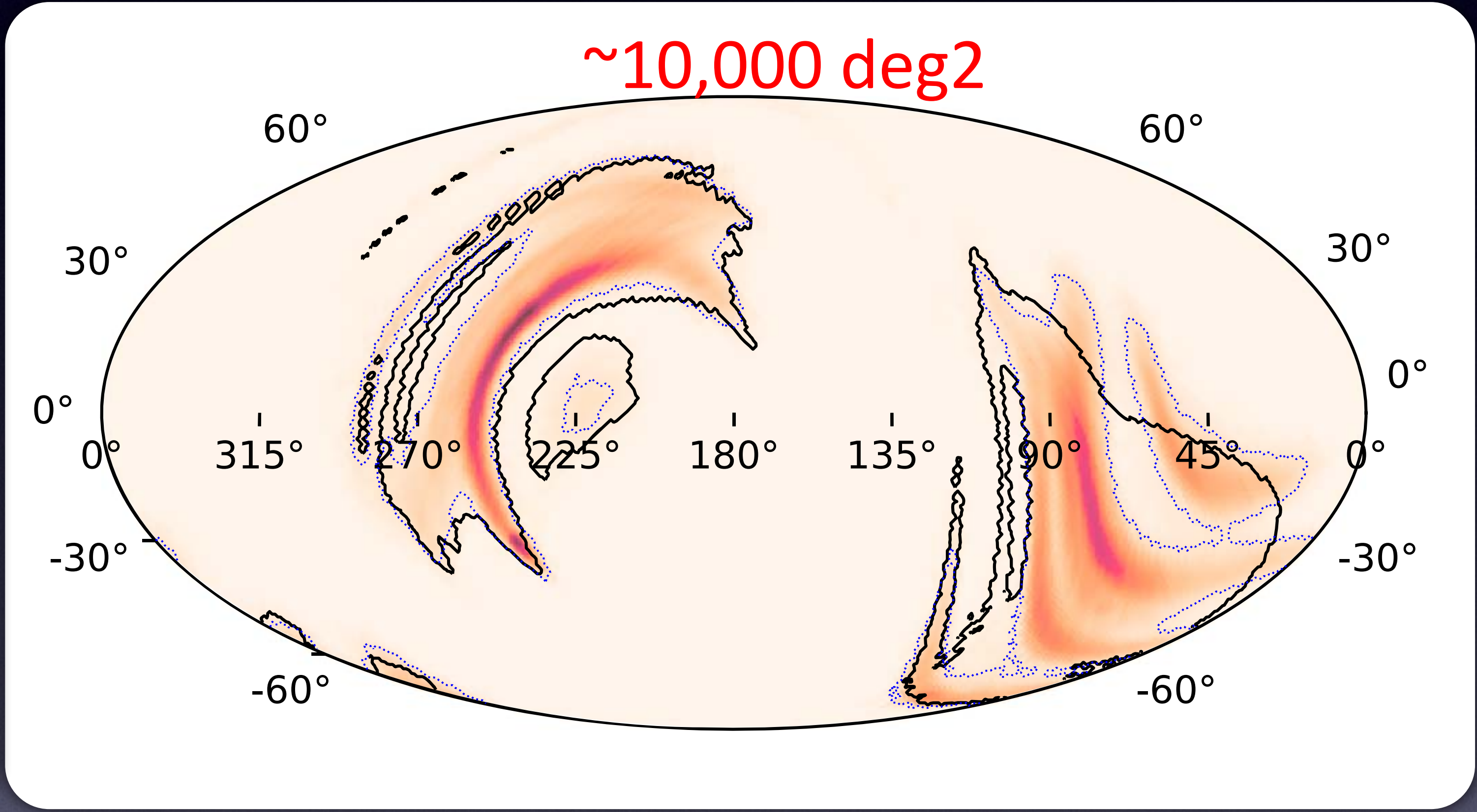
More events, larger variety

森崎さん講演

GW190425 Mtot ~ 3.4 Msun

Abbott+2020



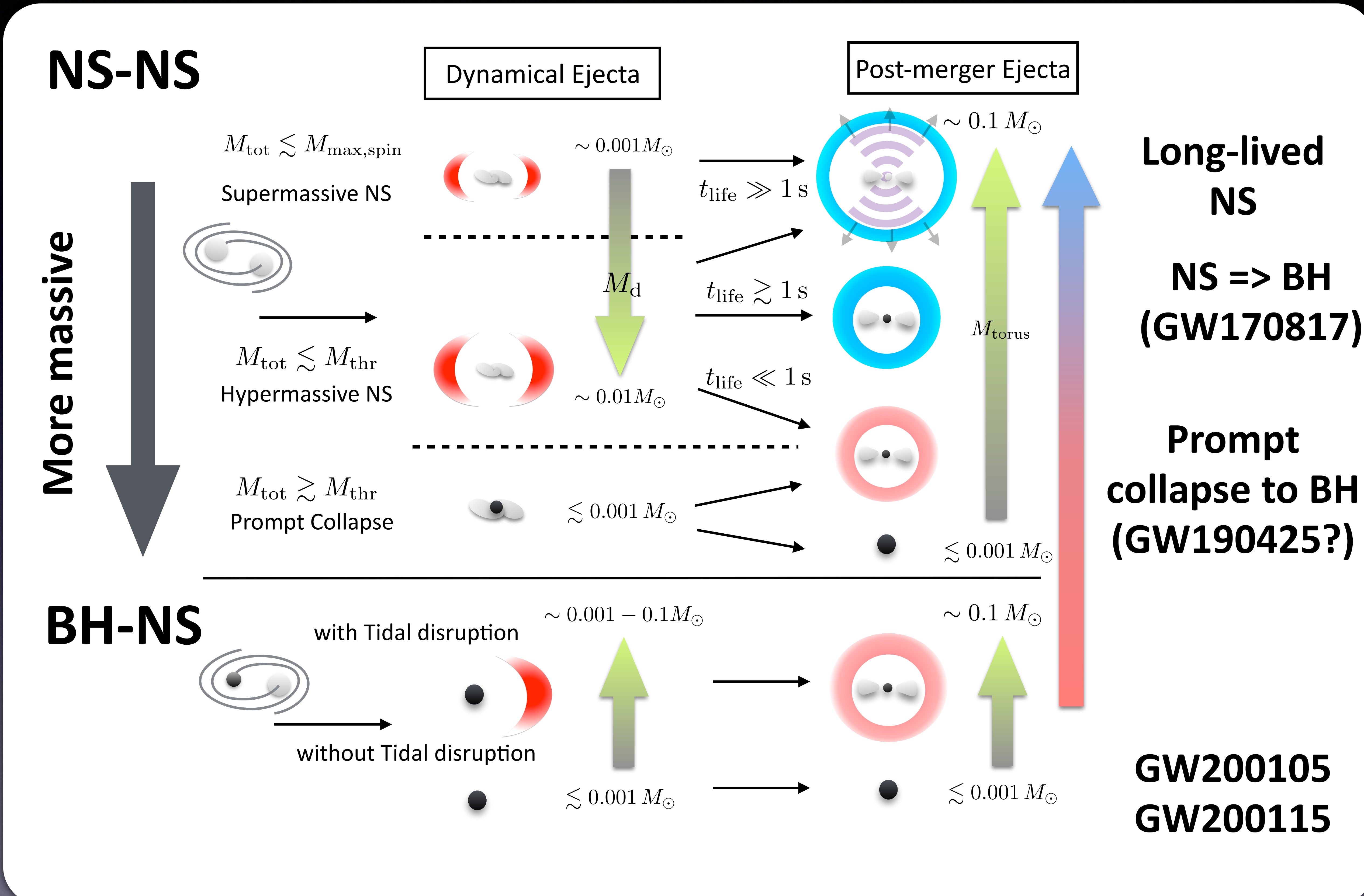


No EM observations covering the entire area…

=> Better localization with KAGRA

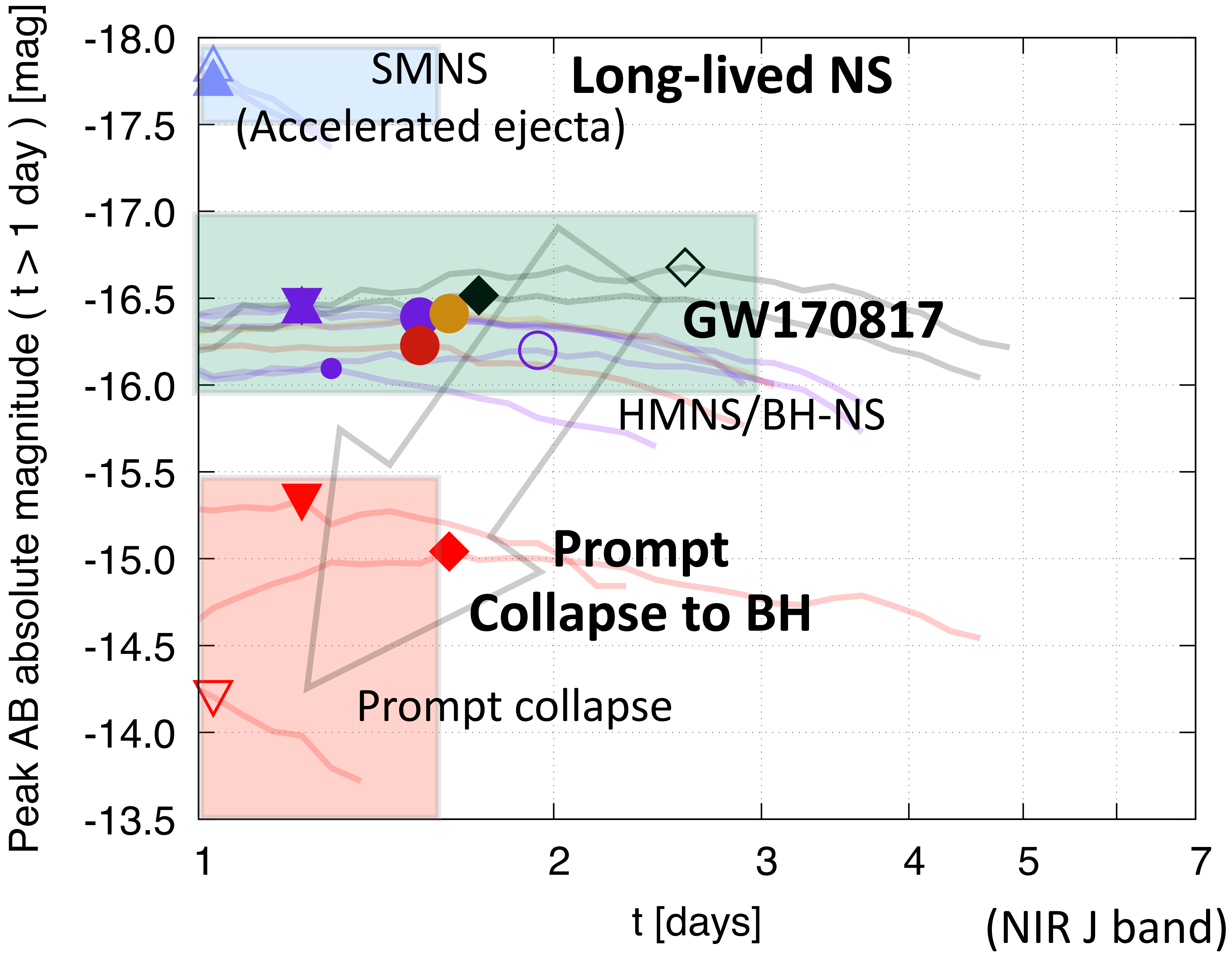
神田さん講演

Diversity of neutron star merger



Kawaguchi, Shibata, MT 2020

Toward complete census of neutron star mergers



GW => Mass (initial condition!)

EM => physics and nucleosynthesis in NS merger

Summary

- **Supernovae as high-E neutrino sources**
  - Doublet events (z ~< 0.2): ideal test for SN scenario
  - Singlet events:
    - Better localization (< 1 deg)   => IceCube-Gen2
    - Higher EM sensitivity => TMT
- **Neutron star mergers as GW sources**
  - GW170817: r-process nucleosynthesis
  - More events, larger variety
    - Better localization => KAGRA
  - Complete understanding of nucleosynthesis