Observations of Gravitational Wave Sources
重力波天体の観測

Masaomi Tanaka (Tohoku University)

Observations of Gravitational Wave Sources
重力波天体の観測

- 重力波天体のマルチメッセンジャー観測
- 最近の話題
- OISTERによる重力波天体の観測

History of astronomy

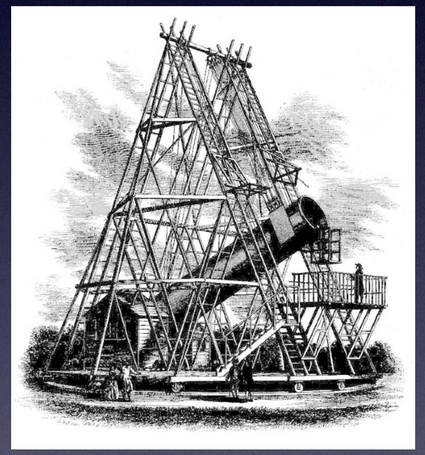
"Visible" light

"Multi-wavelength" astronomy

1610-

(C) Astroarts

1789-



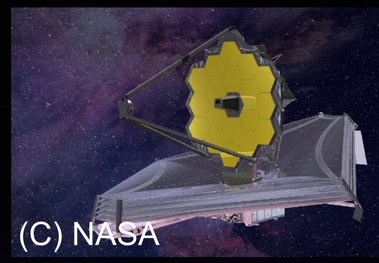
1999-

(C) NAOJ

2013-

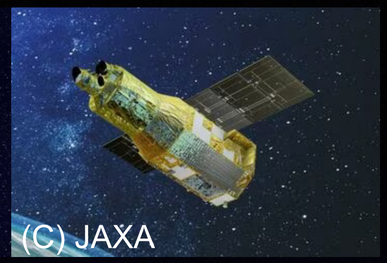
(C) NAOJ

2021-



(C) NASA

2023-



(C) JAXA

1600

1700

1800

1900

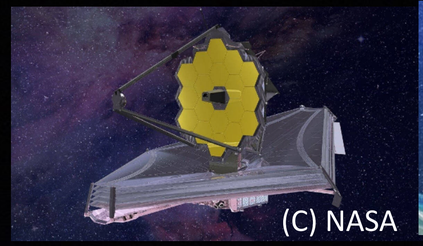
2000

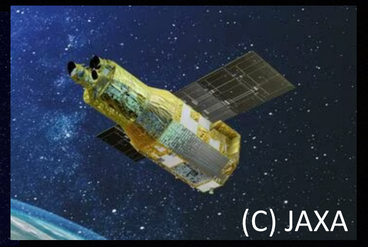
2015-

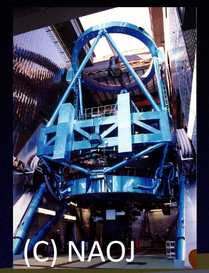
Gravitational wave

1960s-

Neutrino





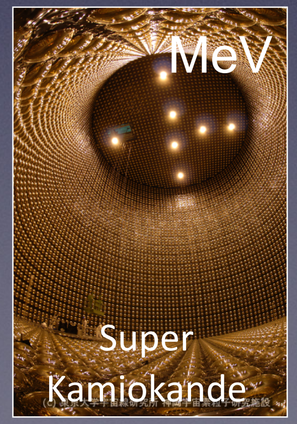


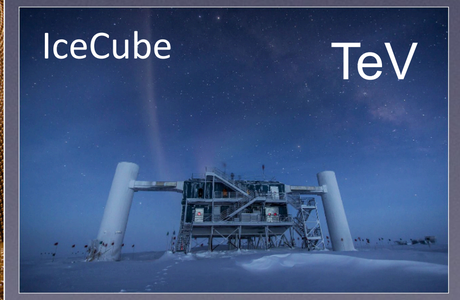
Electromagnetic wave

Multi-messenger astronomy

Neutrino

小汐さん
内田さん
中西さん

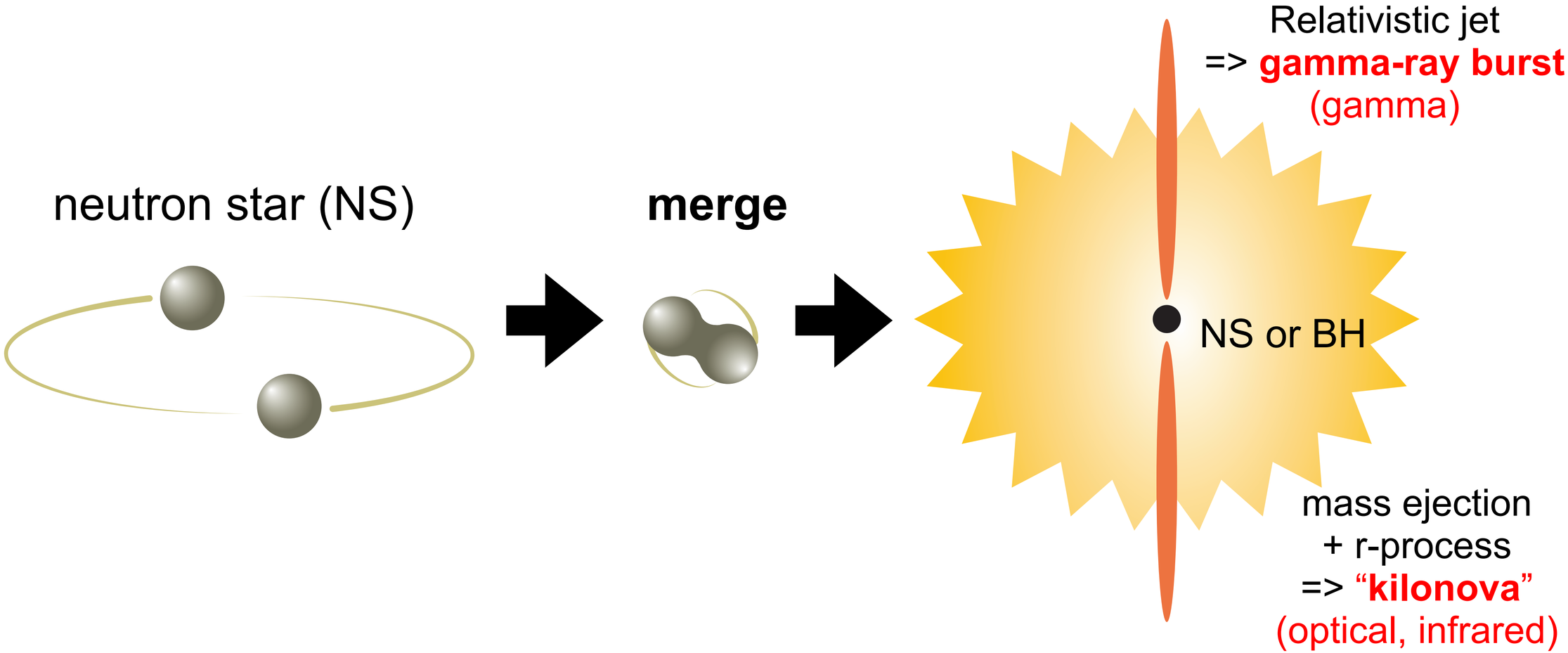




敏蔭さん

Gravitational wave

Multi-messenger from neutron star merger



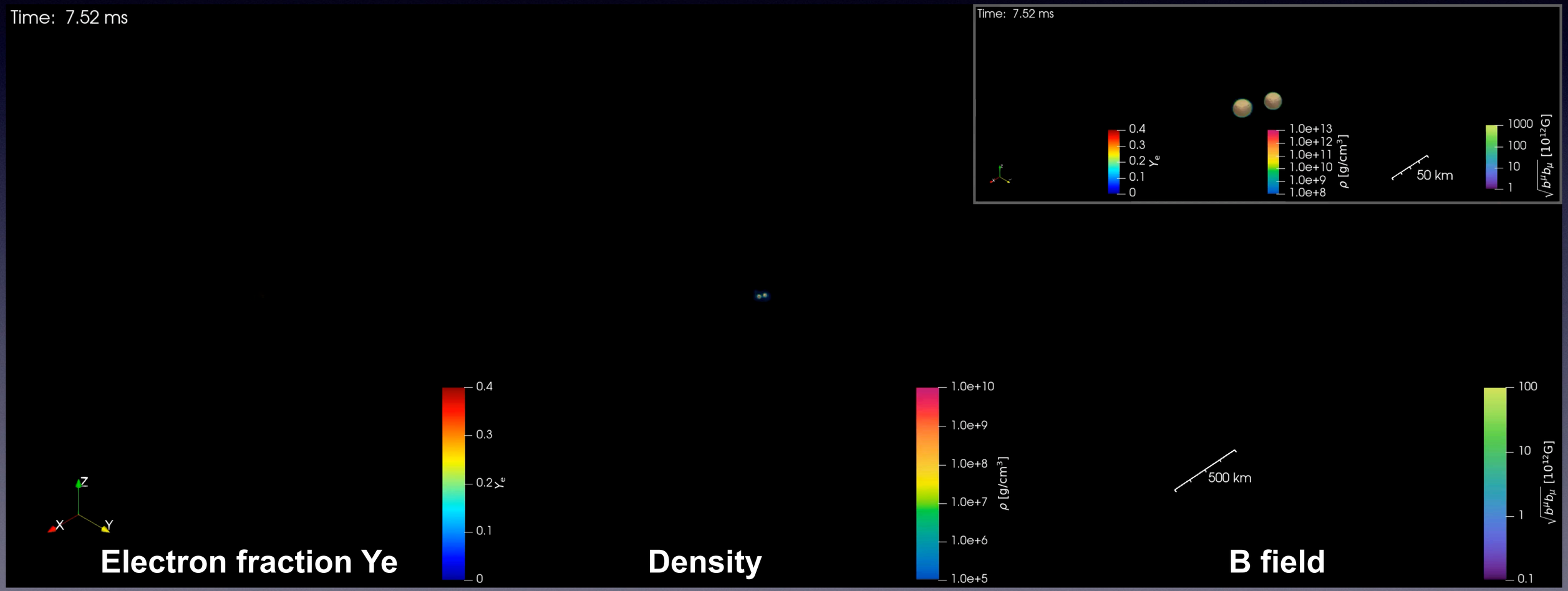
Gravitational wave (GW)

Electromagnetic (EM) wave

NS merger => dynamical mass ejection (< 0.1 sec)

=> “wind” from disk (~ 1 sec)

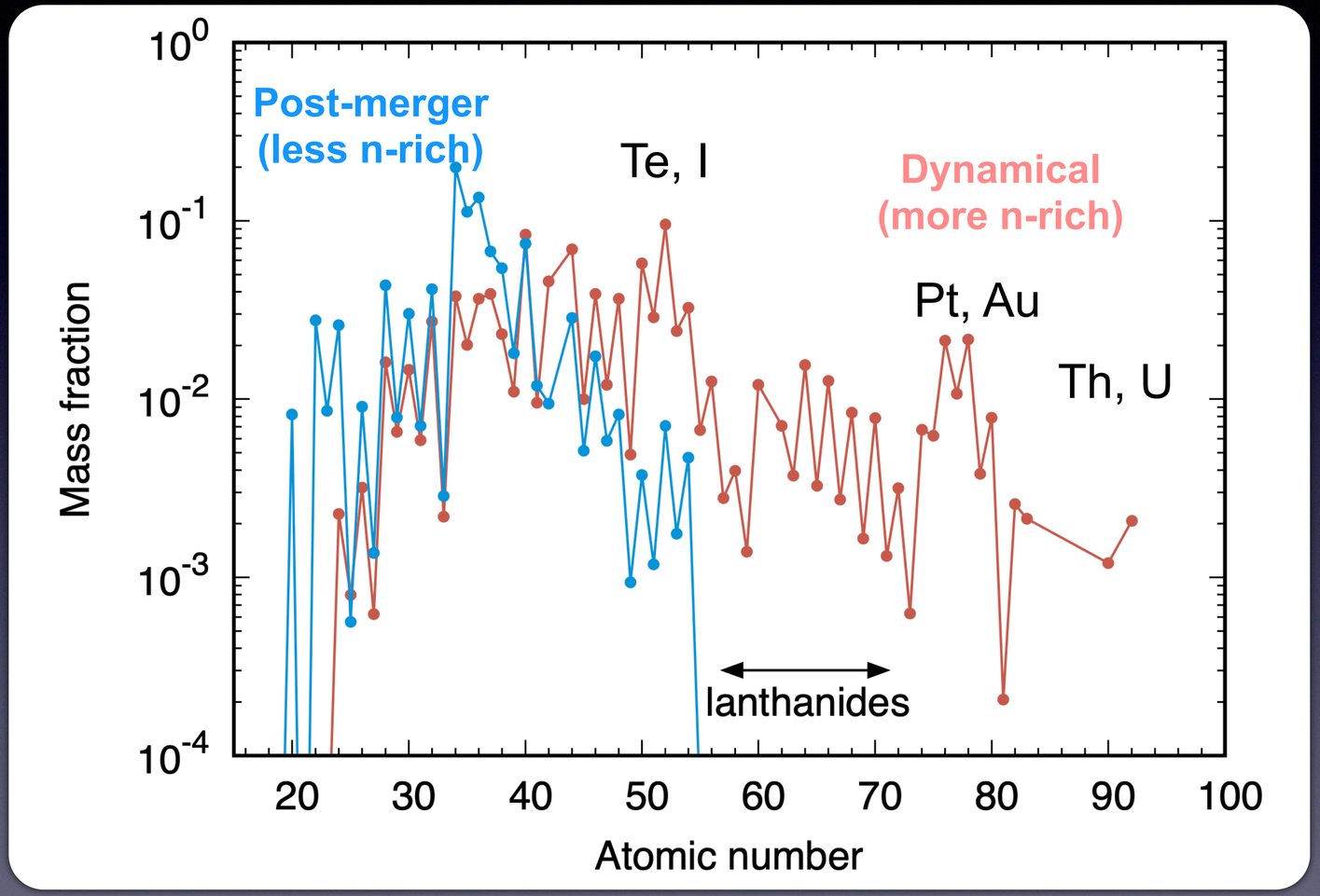
+ relativistic jets (=> gamma-ray burst)



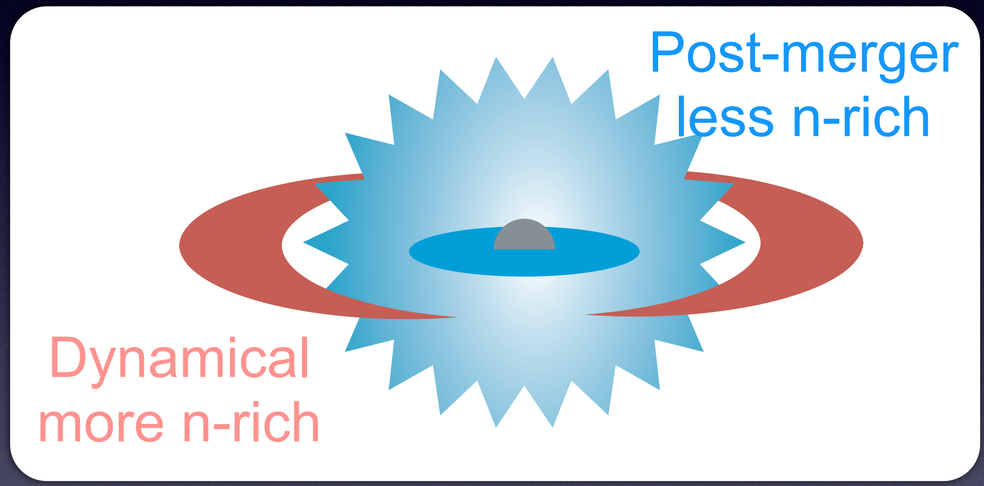
Kiuchi+23

Heavy element production in NS mergers

Lattimer & Schramm 1974, Eichler et al. 1989, Goriely et al. 2011, Korobkin et al. 2012, Bauswein et al. 2013, Wanajo et al. 2014, …



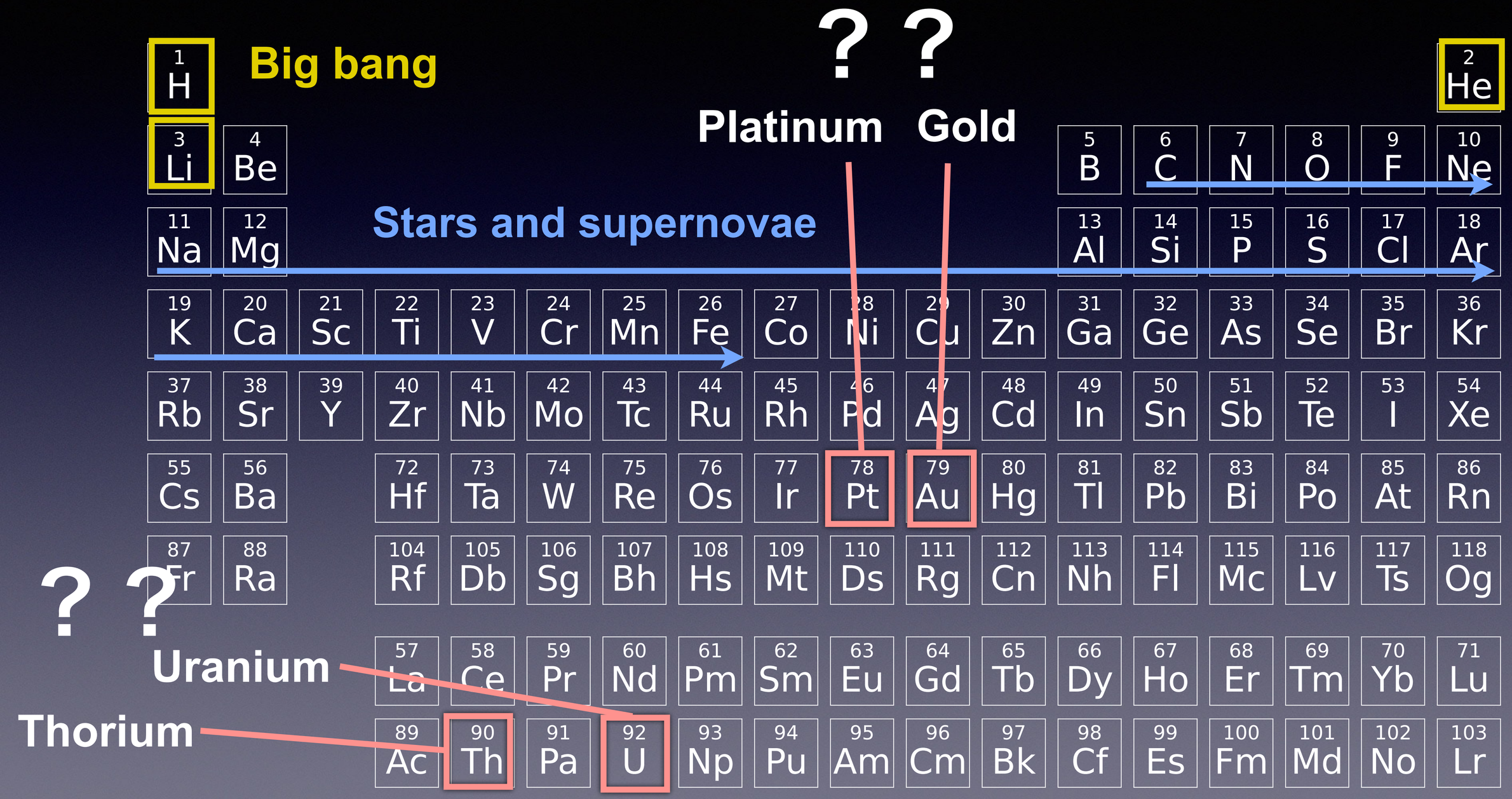
Fujibayashi+23



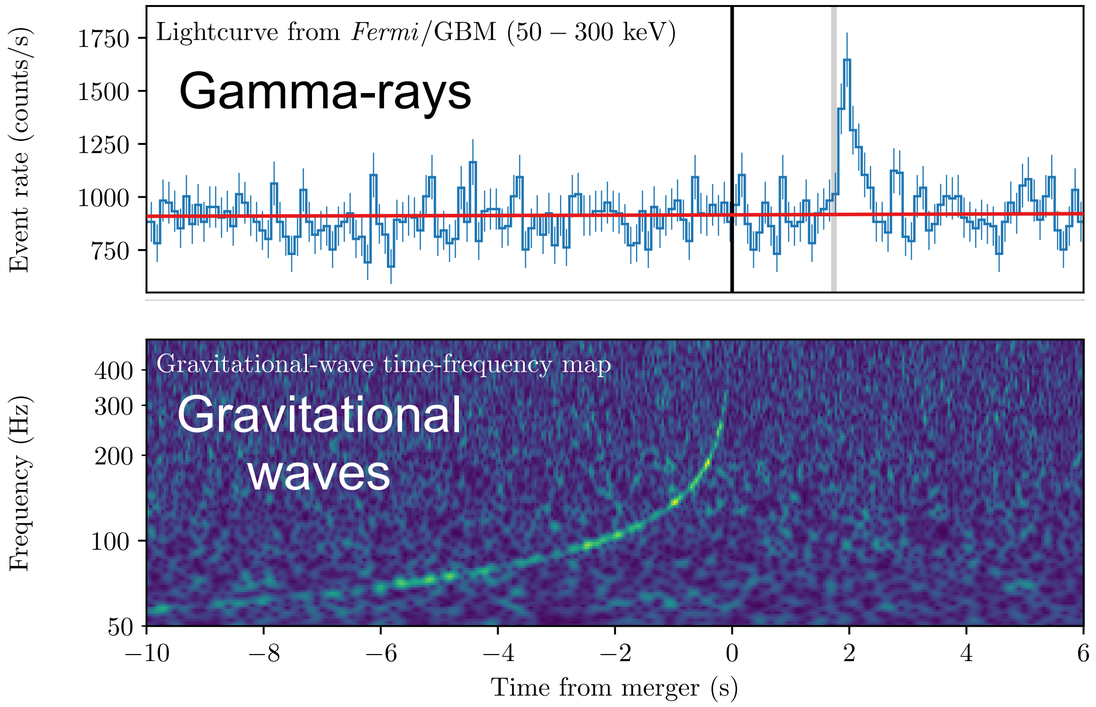
* mass fraction is normalized for each component

Possible origin of heavy elements (r-process elements)

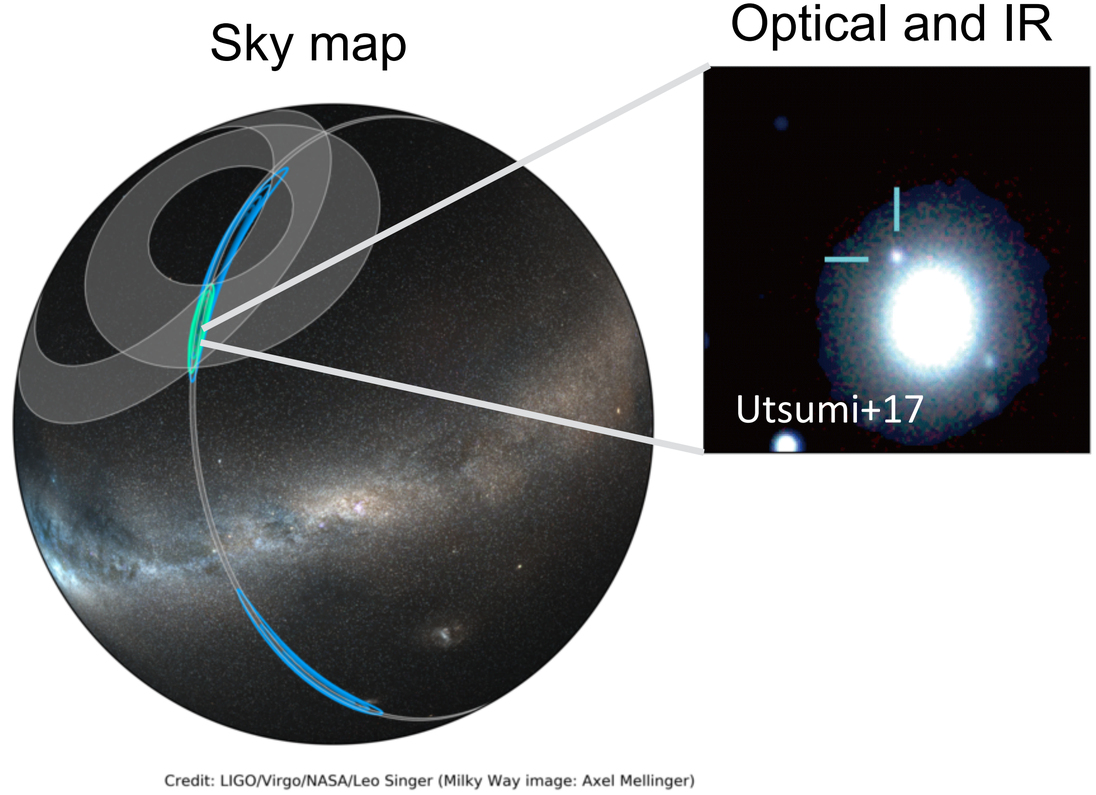
The origin of elements in the Universe



First observations of neutron star merger (2017)



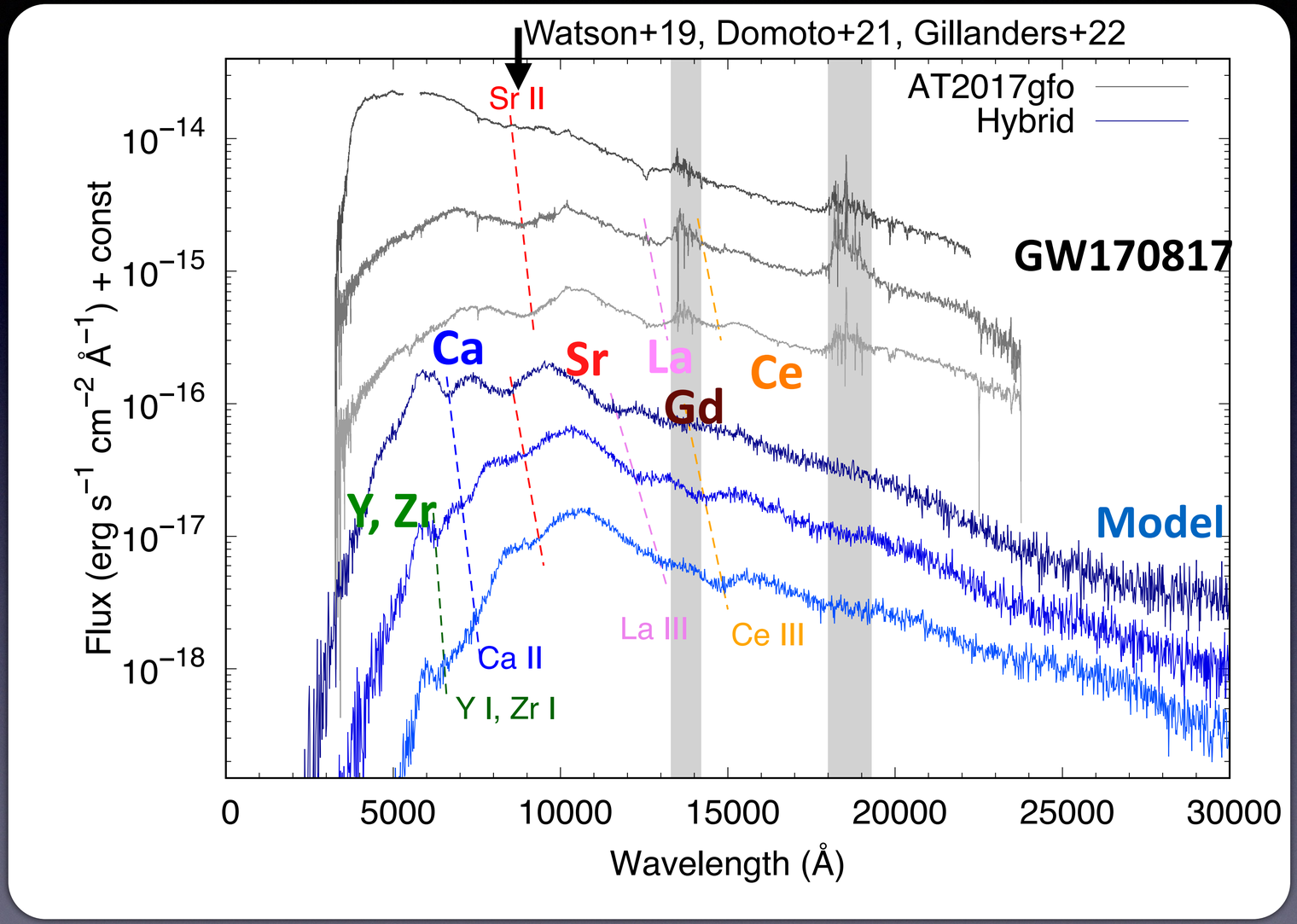
Abbott+2017

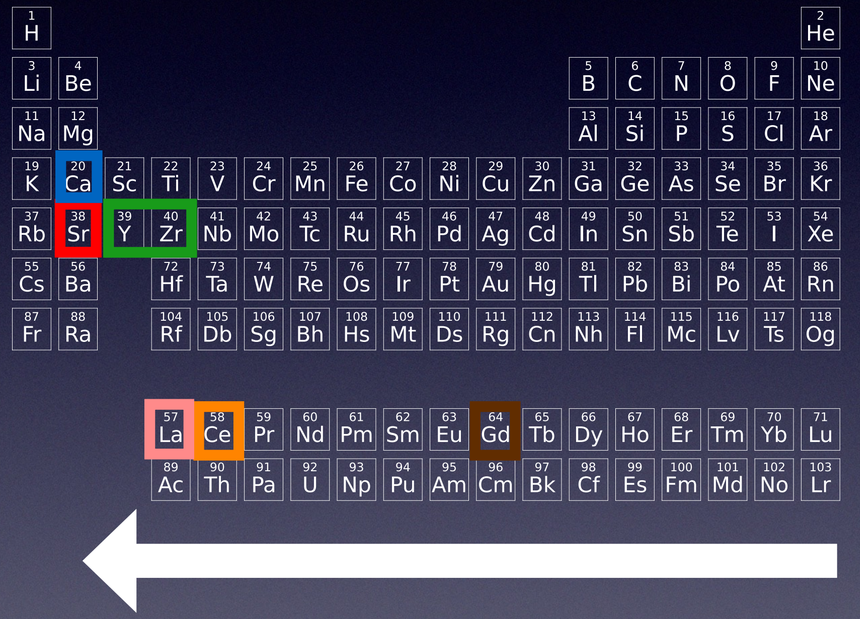


The first “multi-messenger” observations

Spectroscopy => element identification

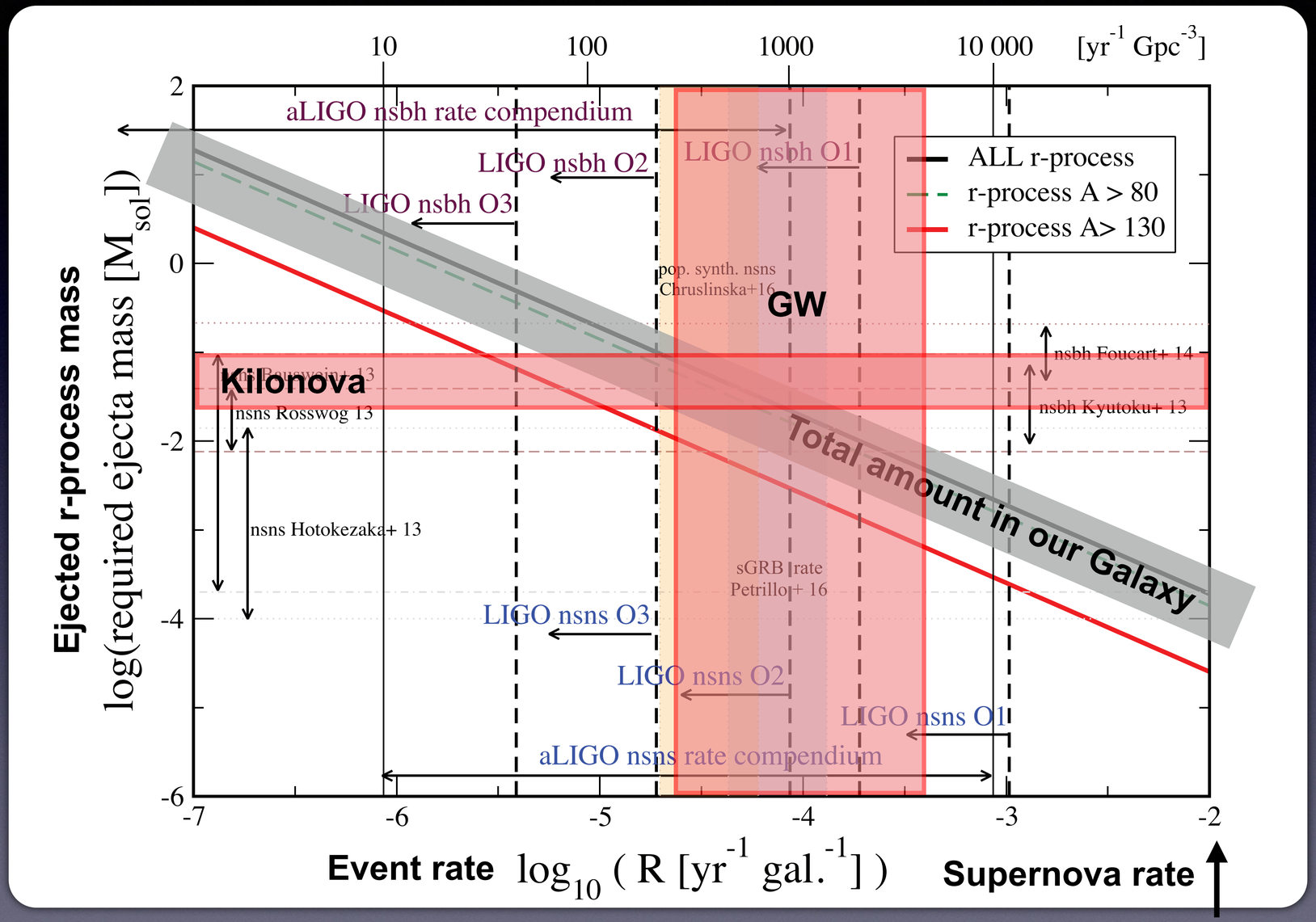
Domoto, MT+22
MT+23, Domoto+23
Rahmouni+25





Direct evidence of heavy element production

Production rate of heavy elements



Rosswog+17
Hotokezaka+15, 18

Neutron star mergers can provide enough amount of heavy elements

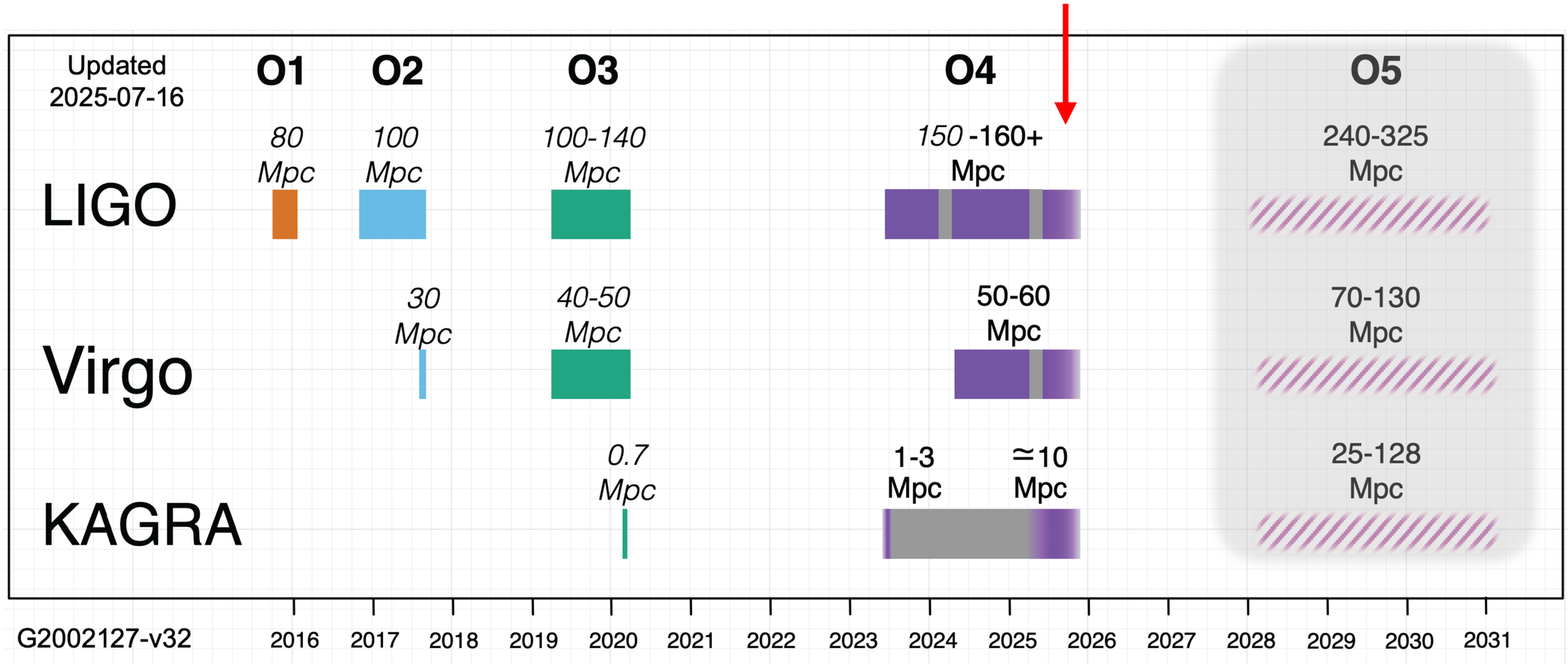
Power of multi-messenger astronomy

	GW	EM
Origin of GRBs	Nature of merging objects	Gamma-ray burst
Origin of elements	Nature of merging objects	Kilonova
Cosmology	Luminosity distance	Redshift
Fundamental physics	Speed of GW	Speed of light

Observations of Gravitational Wave Sources
重力波天体の観測

- 重力波天体のマルチメッセンジャー観測
- 最近の話題
- OISTERによる重力波天体の観測

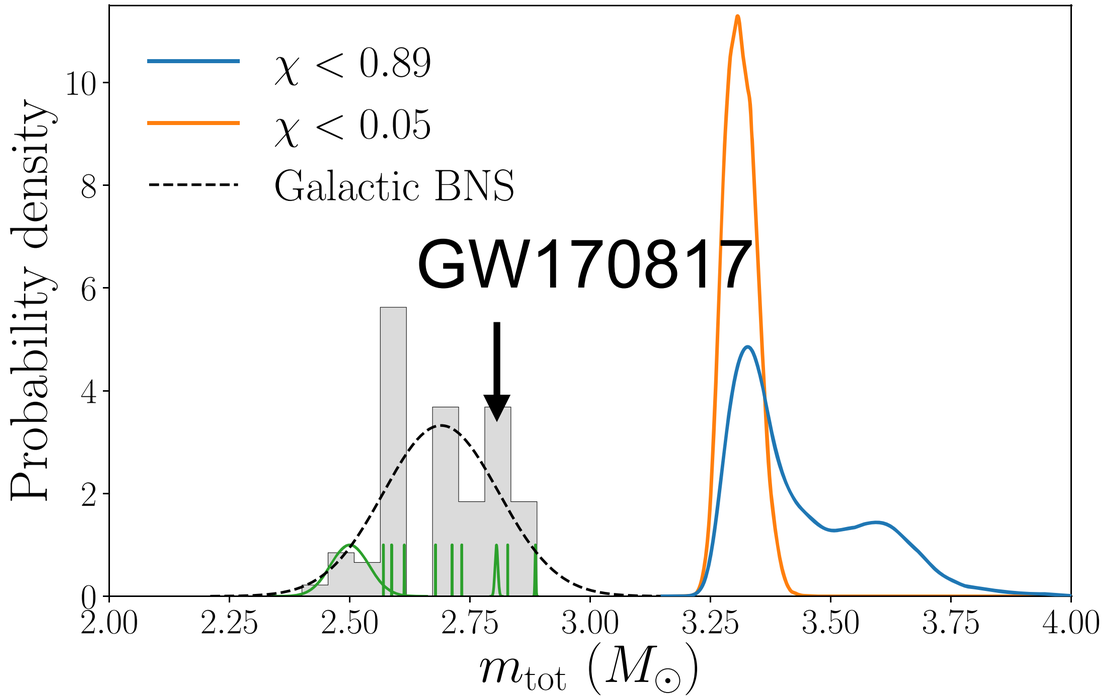
Status of GW observations

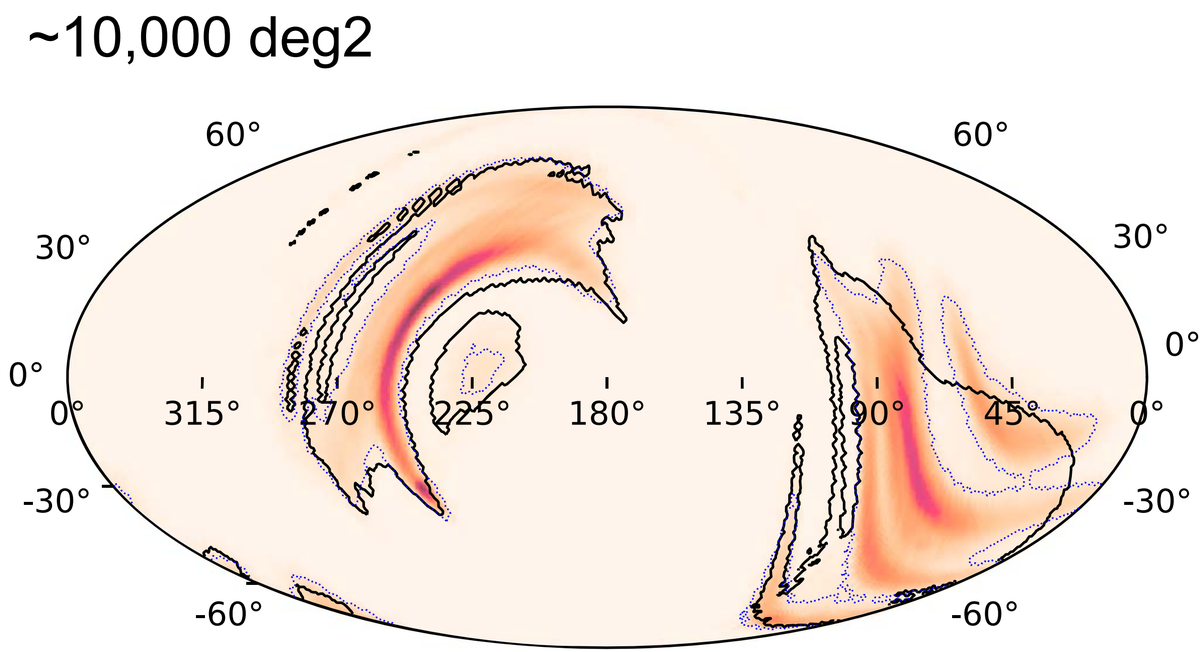


https://observing.docs.ligo.org/plan/

GW190425: 2nd NS merger event in O3

Total NS mass ~ 3.4 Msun



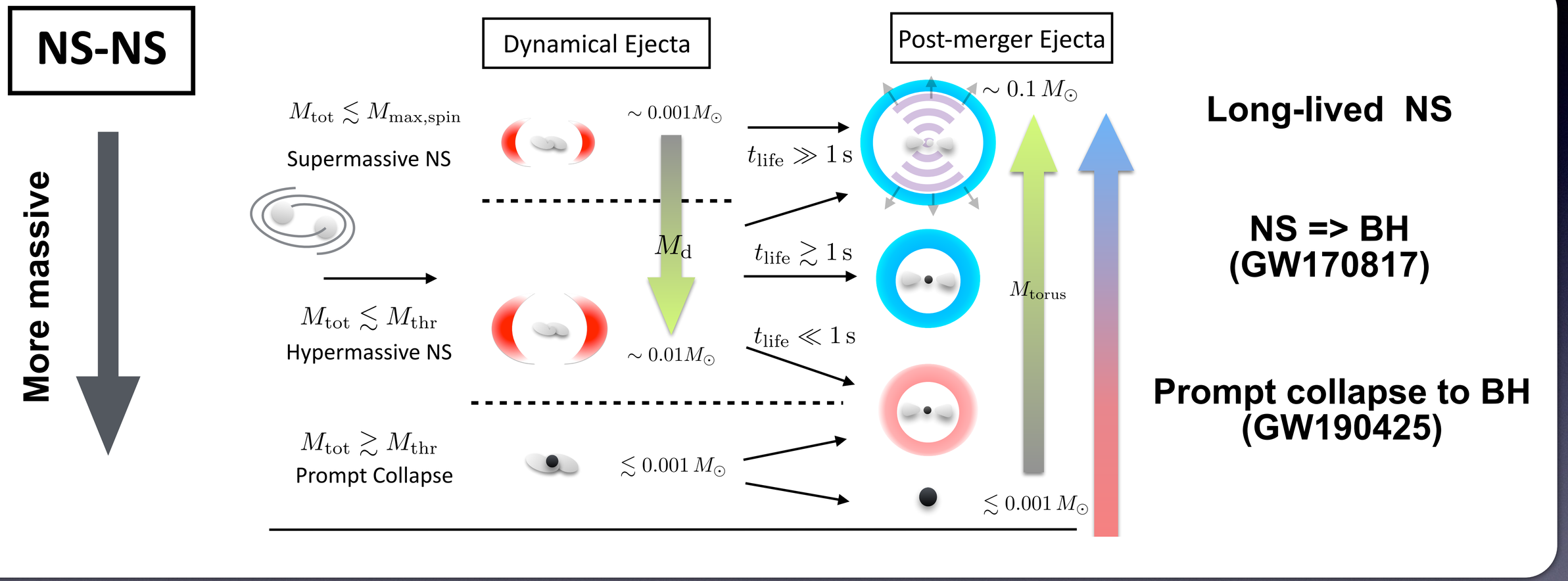


Diversity in neutron star masses
=> diversity in mass ejection, r-process, and kilonova

Abbott+2020

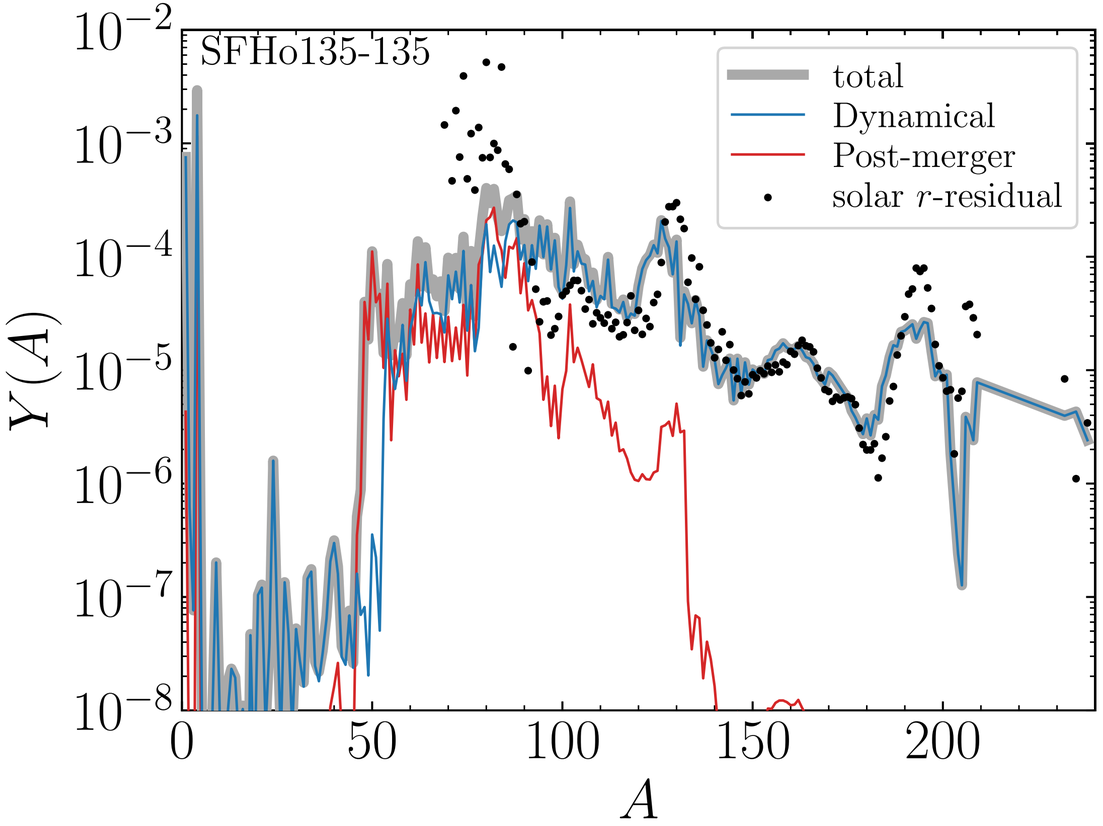
Diversity in NS merger and kilonova

Kawaguchi, Shibata, MT 2020

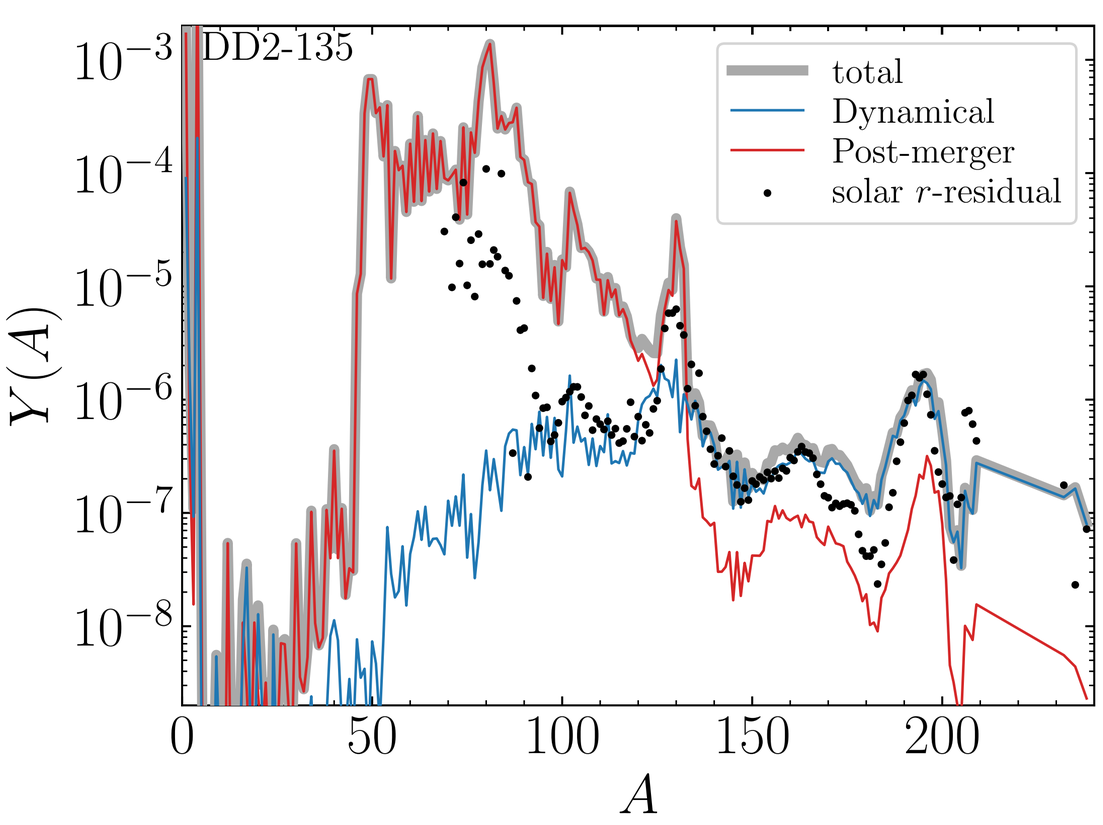


Impact to the nucleosynthesis

Hypermassive NS τ ~ 10 msec



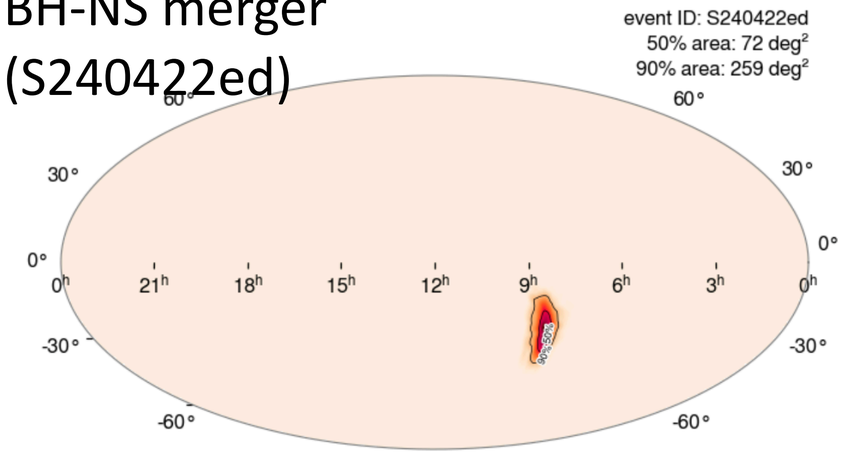
Long-lived NS (> 10 sec)



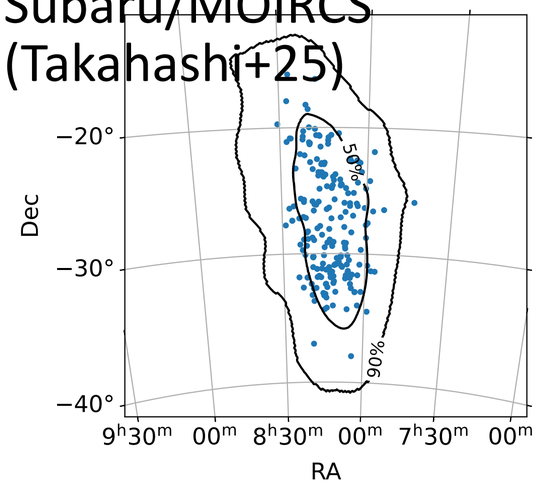
Fujibayashi+23

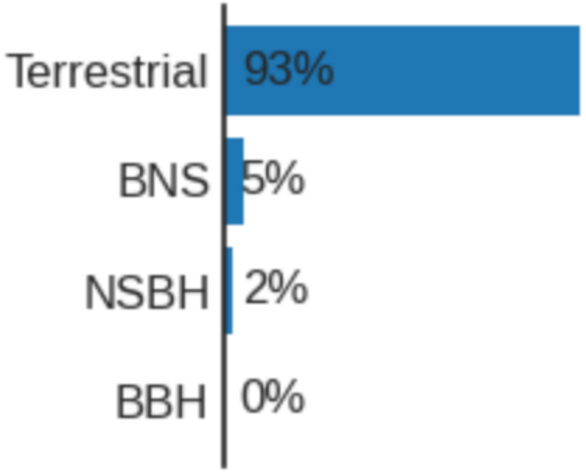
No significant neutron star merger event after 2019…

BH-NS merger
(S240422ed)



Subaru/MOIRCS
(Takahashi+25)





Event rate of neutron star merger

距離d ~ 100 Mpc

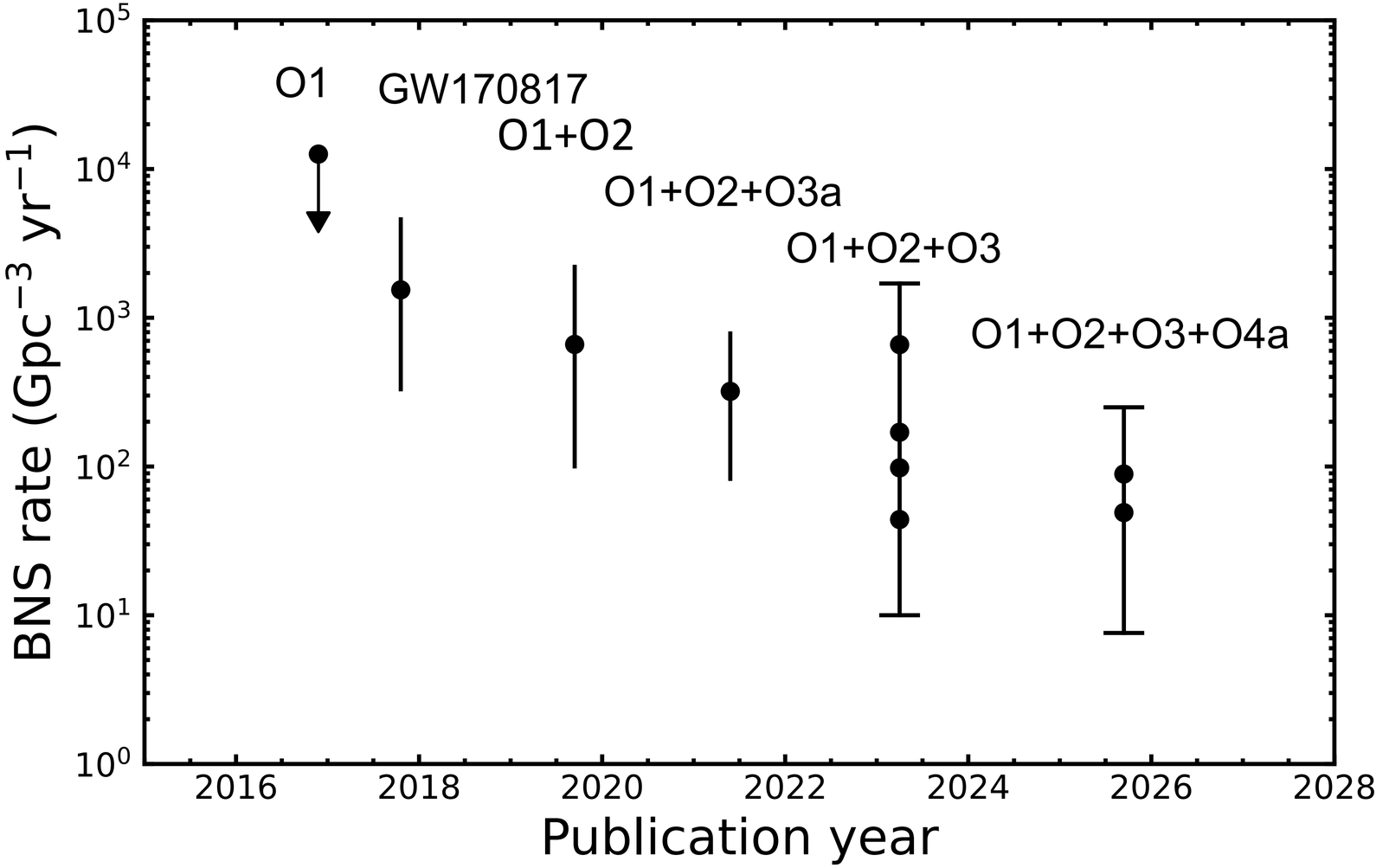
=> 体積V ~ 4 x 10^6 Mpc^3 = 4 x 10^{-3} Gpc^{-3}

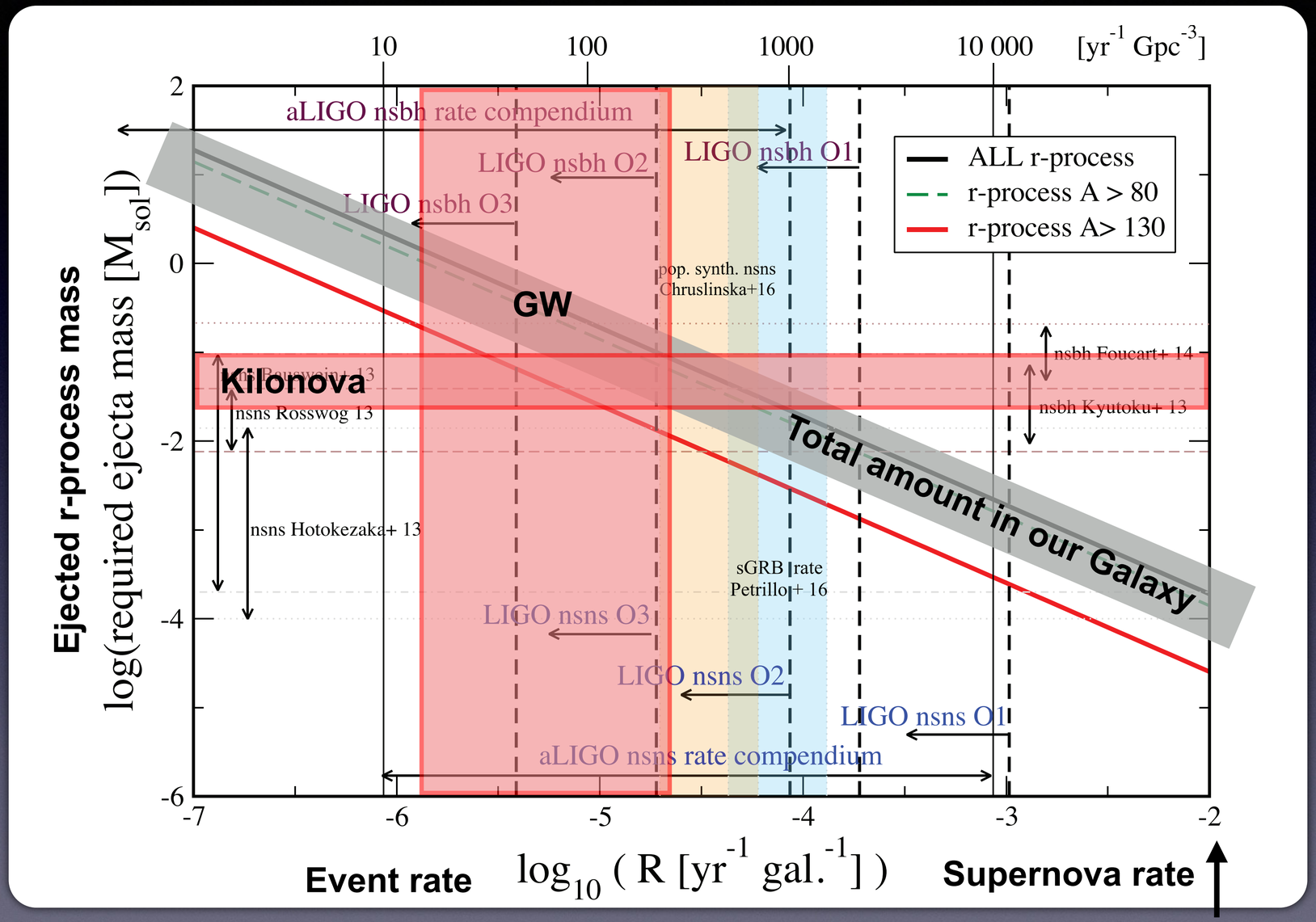
100 Mpc以内の
イベント数 (全天)

1年で4イベント

2-3年で 1イベント

20-30年でイベント





Rosswog+17
Hotokezaka+15, 18

Possible tension??

Observations of Gravitational Wave Sources
重力波天体の観測

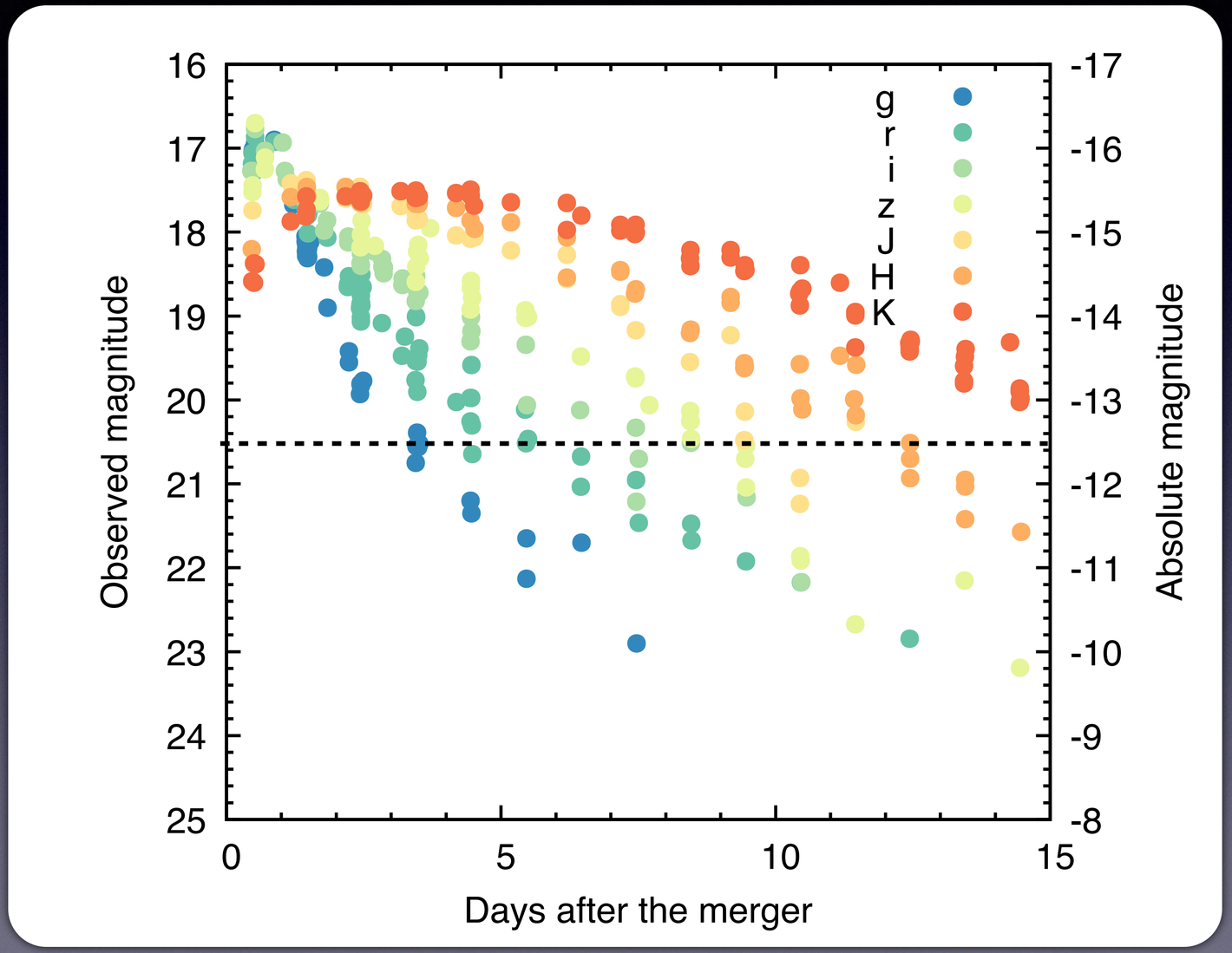
- 重力波天体のマルチメッセンジャー観測
- 最近の話題
- OISTERによる重力波天体の観測

40 Mpc (GW170817)

20-30年に1回

(R ~ 10^2 Gpc^{-3} yr^{-1})

Spectroscopy	Imaging
1m	
4m	1m telescope →
8m	4m telescope →
30m space	8m telescope →

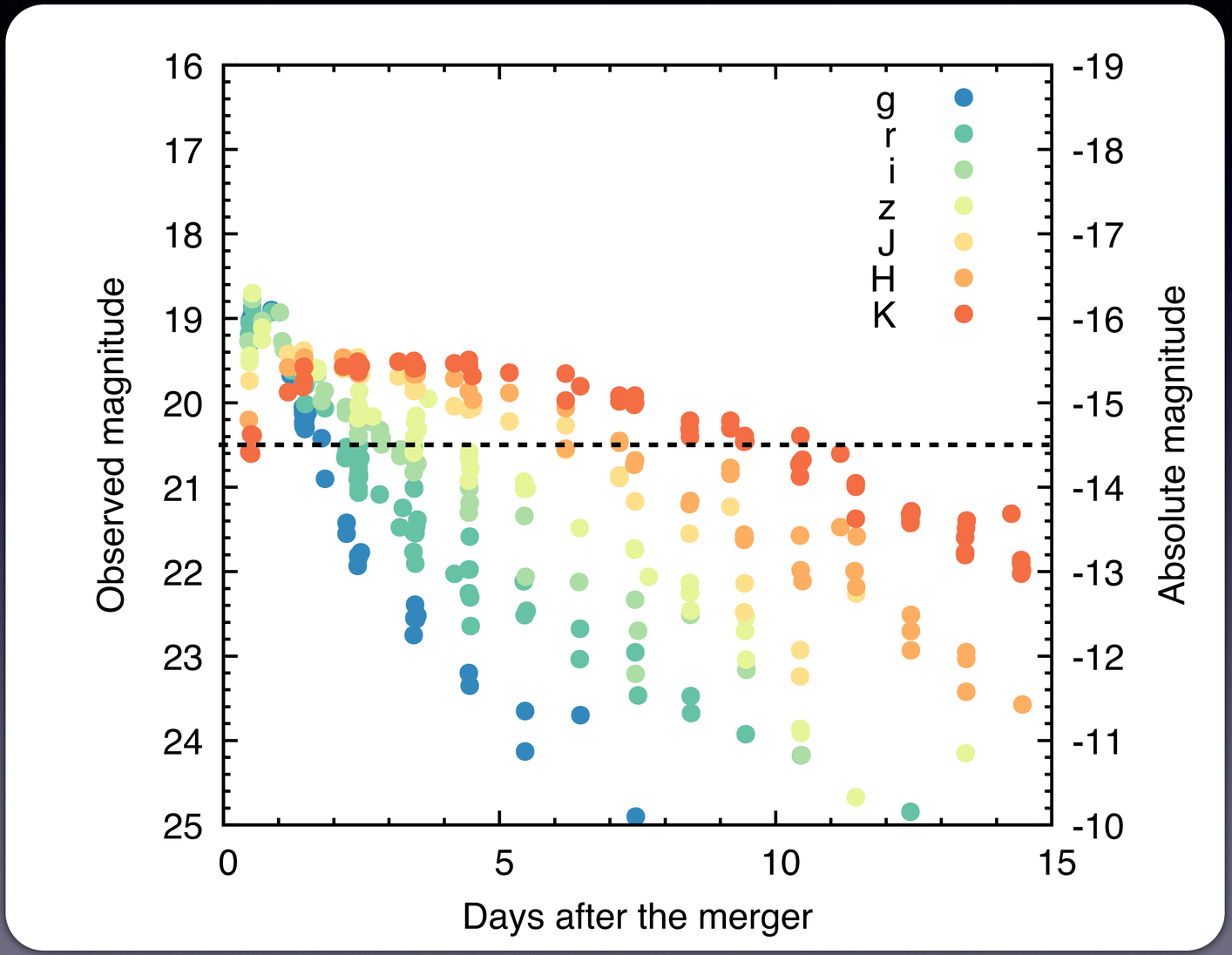


100 Mpc

2-3年に1回

GW170817よりも~2 mag暗い

Spectroscopy	Imaging
1m	
4m	1m telescope →
8m	4m telescope →
30m space	8m telescope →

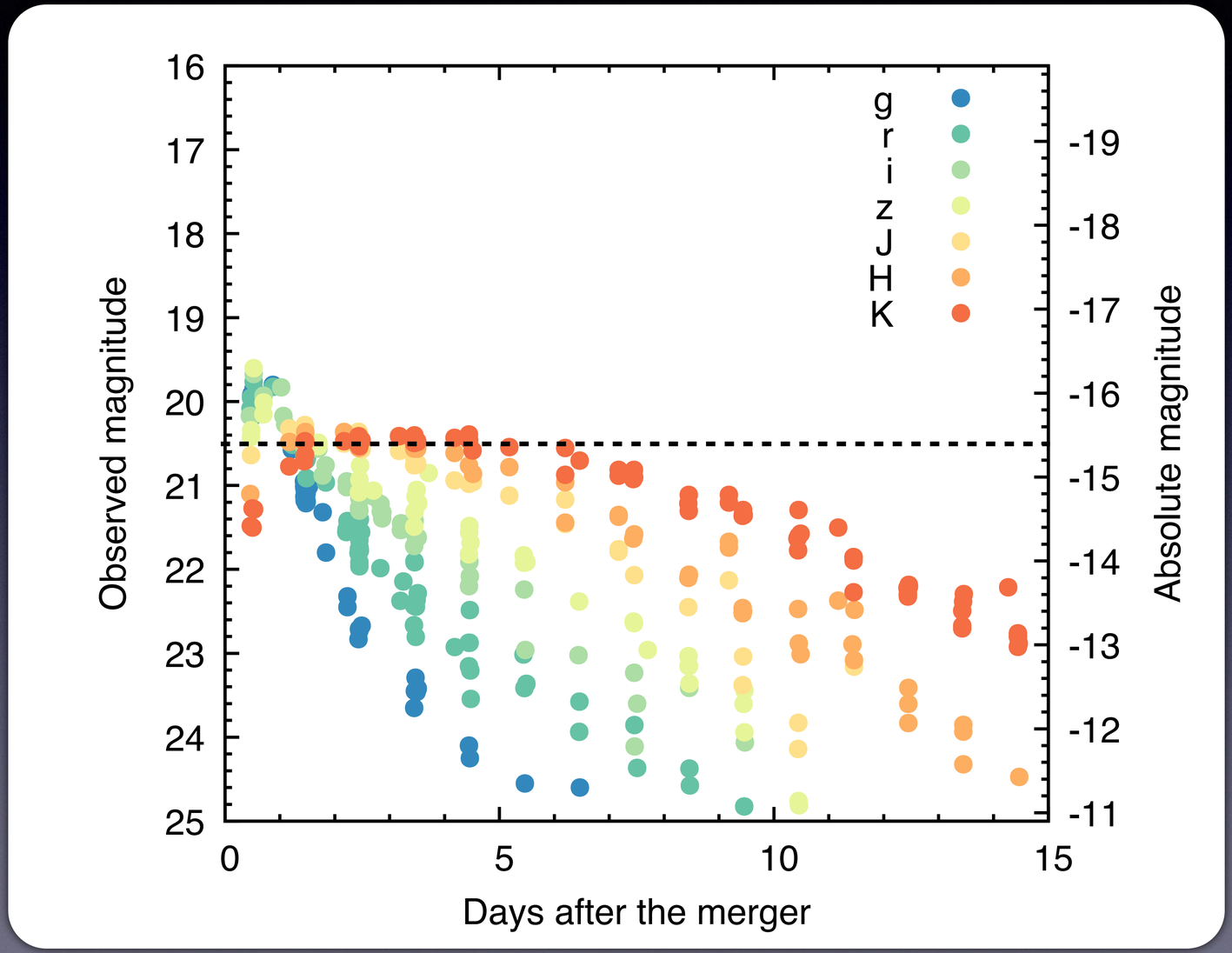


150 Mpc

1年に1回

GW170817よりも~3 mag暗い

Spectroscopy	Imaging
1m	
4m	1m telescope →
8m	4m telescope →
30m space	8m telescope →

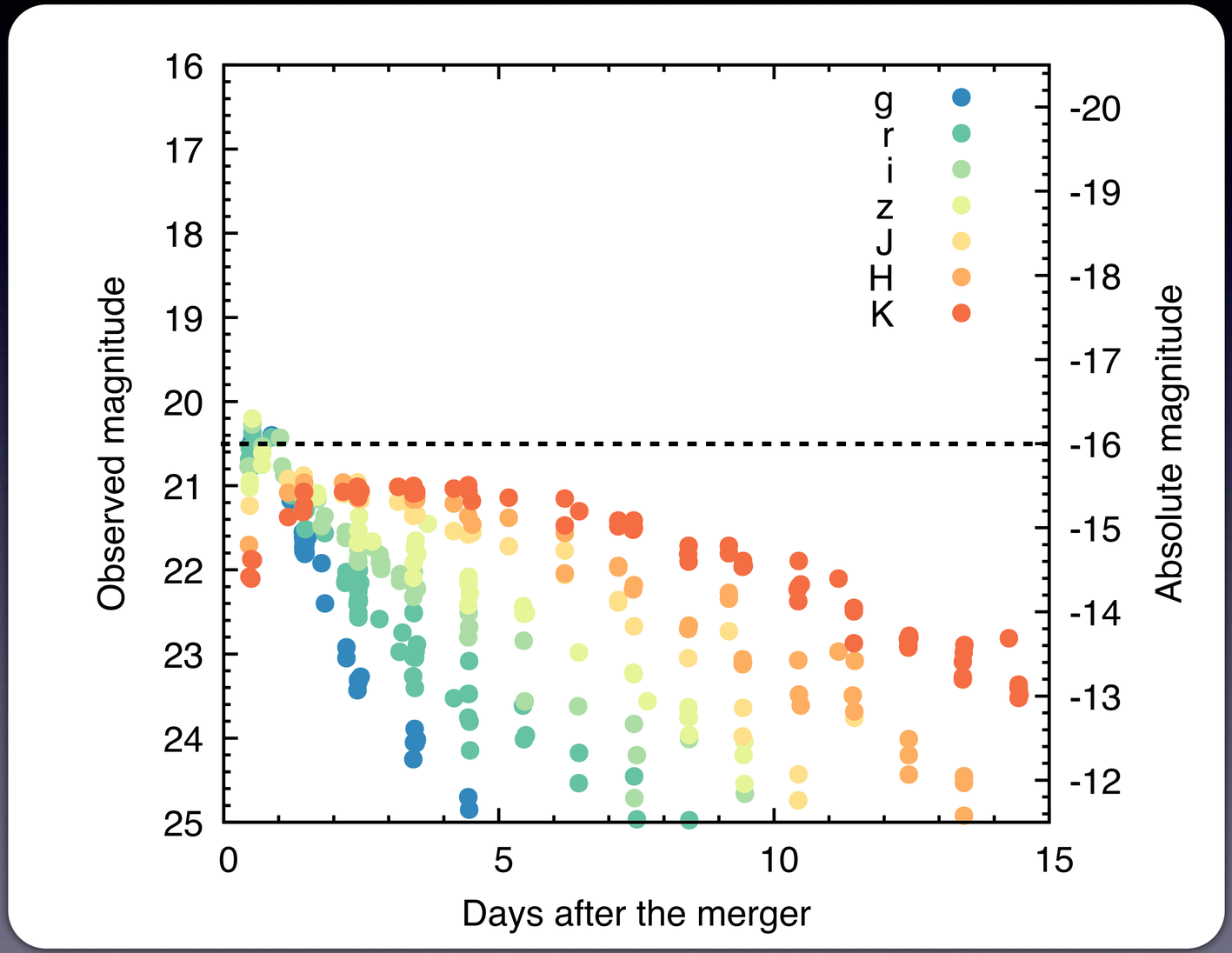


200 Mpc

1年に3回

GW170817よりも~3.5 mag暗い

Spectroscopy	Imaging
1m	
4m	1m telescope →
8m	4m telescope →
30m space	8m telescope →



Required survey for the events at 150 Mpc

Imaging depth

~ 20 mag

Survey area

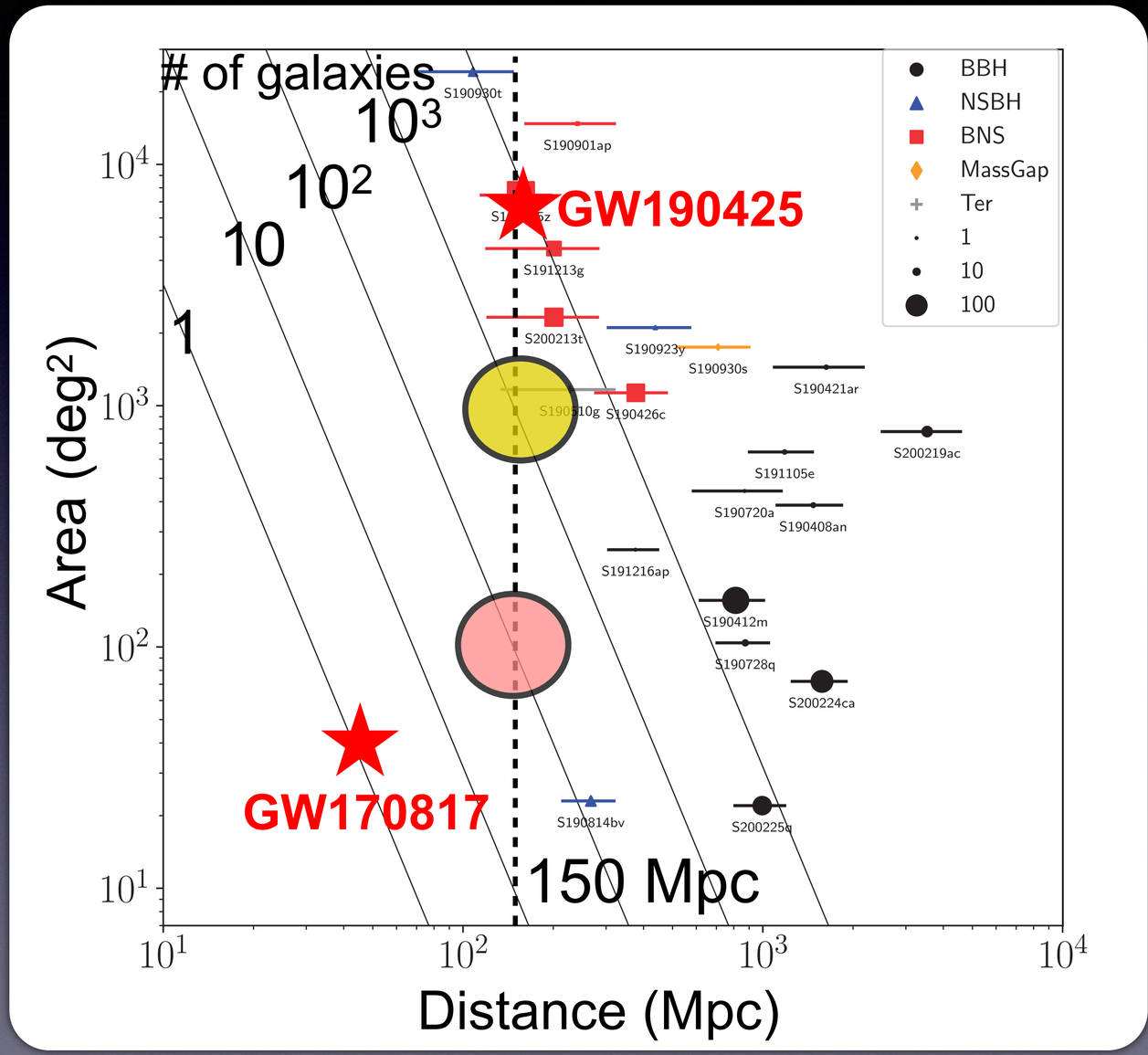
LIGO x 2 : ~ 1000 deg^2

LIGO x 2 + Virgo: ~100 deg^2

Number of galaxies < 150 Mpc

1000 deg^2 => ~1000 galaxies

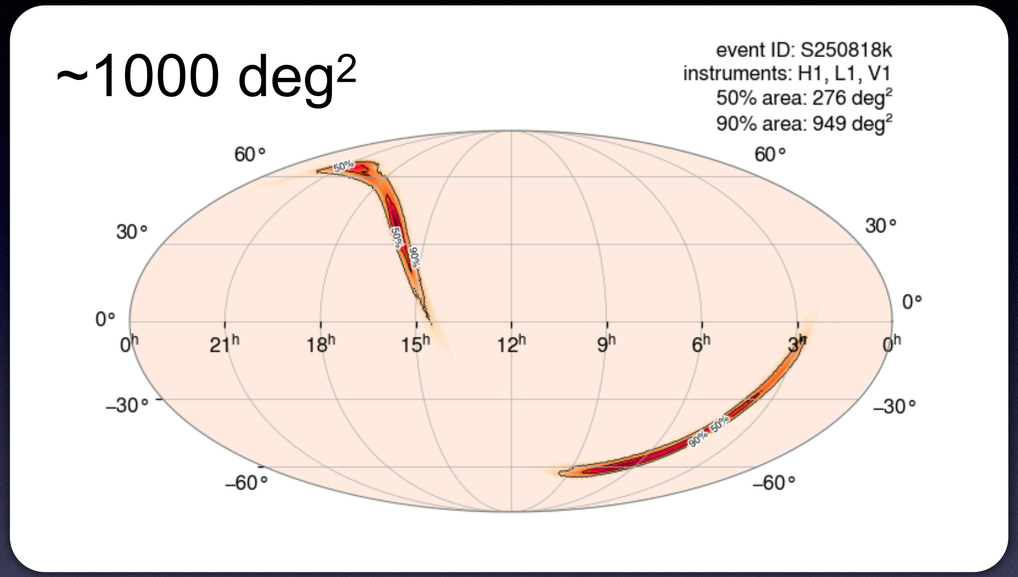
100 deg^2 => ~100 galaxies

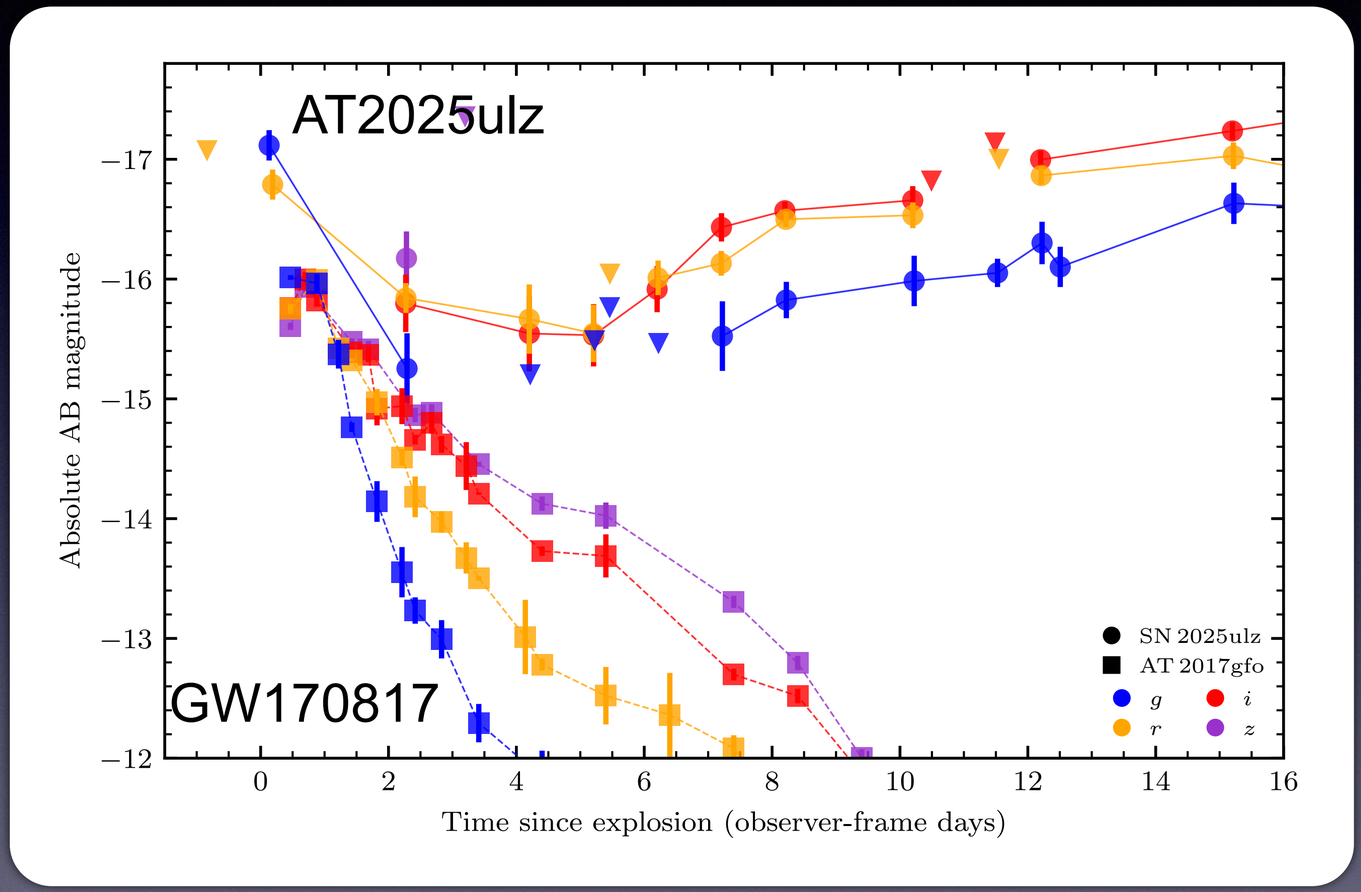


Sasada+21

S250818k: a possible NS merger event (~250 Mpc)

Gillanders+25





Key: Long-term monitoring and spectroscopy

Summary

- **Multi-messenger observations of neutron star mergers**
  - Origin of heavy elements, Formation of relativistic jets
  - No significant event after 2019: an estimated event rate is becoming lower
- **Observational strategy**
  - Observations of the events at **~150 Mpc** distance
  - Survey depth: **~20 mag imaging**
  - Area:
    - LIGO: ~1000 deg^2 (~1000 galaxies)
    - LIGO+Virgo: **~100 deg^2 (~100 galaxies)**
  - Follow-up: **imaging and spectroscopy: down to 25 mag**