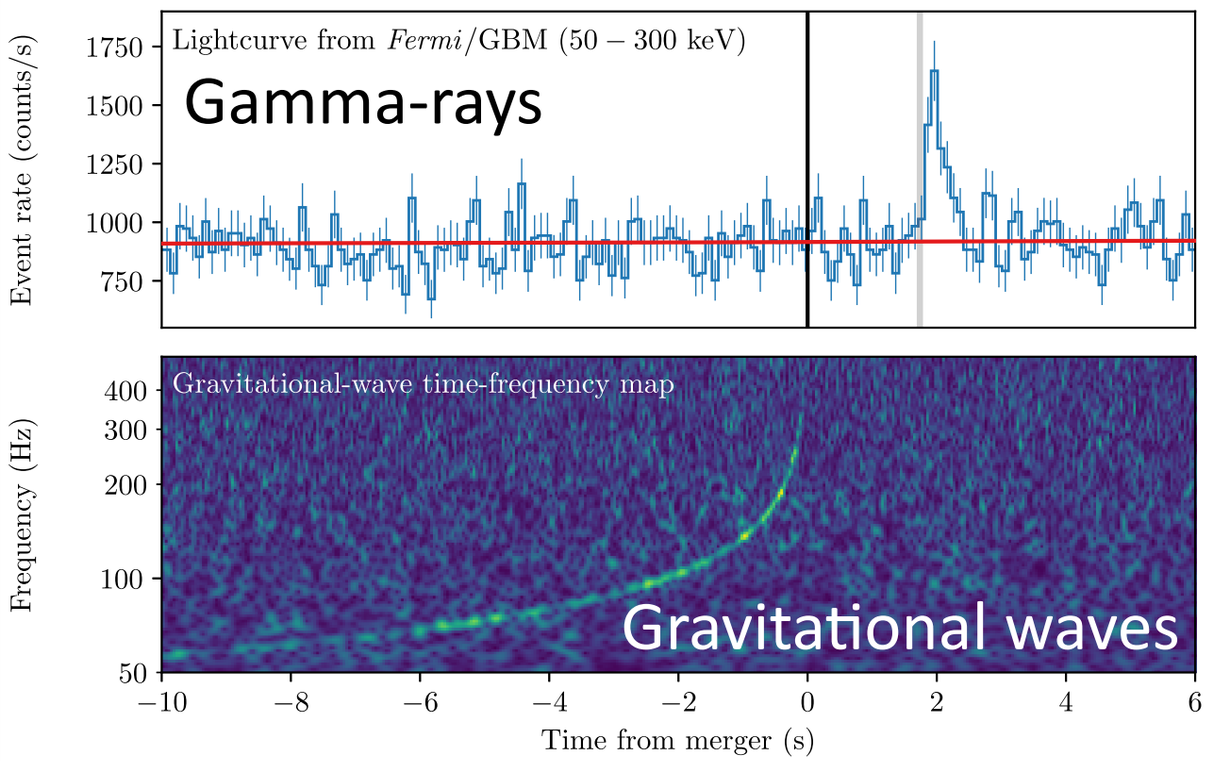
Observations of Gravitational Wave Sources with Tomo-e Gozen

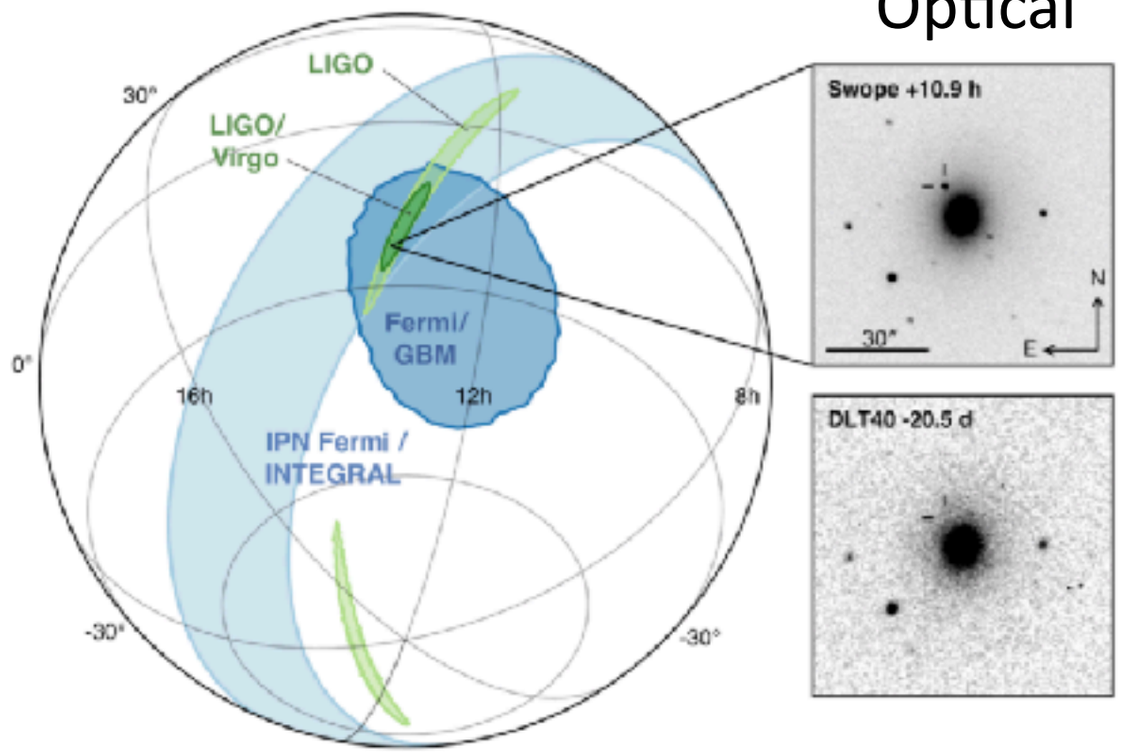
Masaomi Tanaka
(Tohoku University)

GW170817

The first detection of GWs from neutron star merger

The first detection of light from GW sources





http://www.ligo.org

New era of “multi-messenger” astronomy

Observations of Gravitational Wave Sources with Tomo-e Gozen

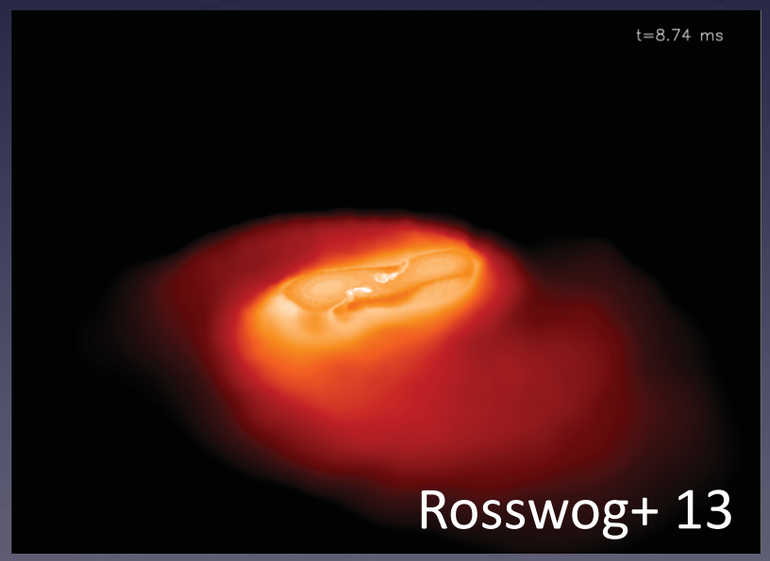
- What we have learned from GW170817
- Survey with Tomo-e Gozen

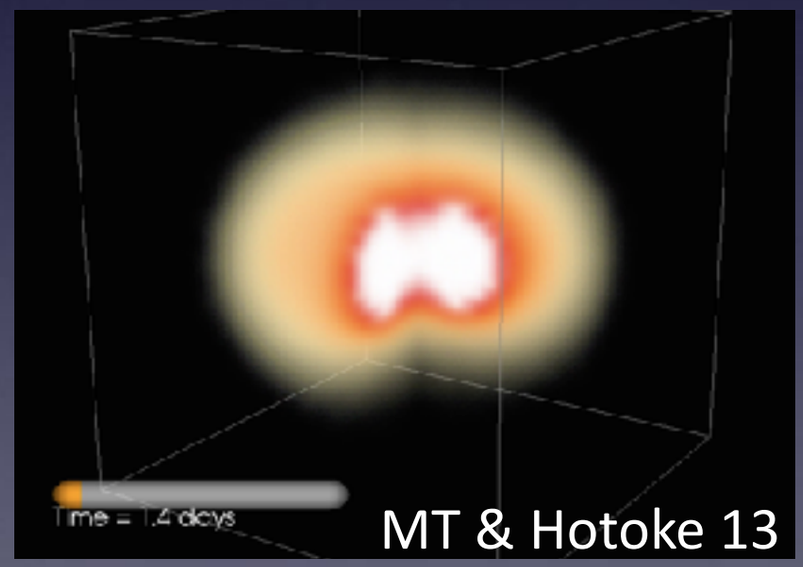
Merger → r-process nucleosynthesis → Radioactive decay => kilonova

Mass ejection

dynamical | disk/viscous

< 10 ms | ~< 100 ms | < 1 sec | ~> days





M ~ 0.01 Msun

v ~ 0.1-0.2 c

Expected light curves of kilonova

$L \sim 10^{40}$-10^{41} erg s^{-1}

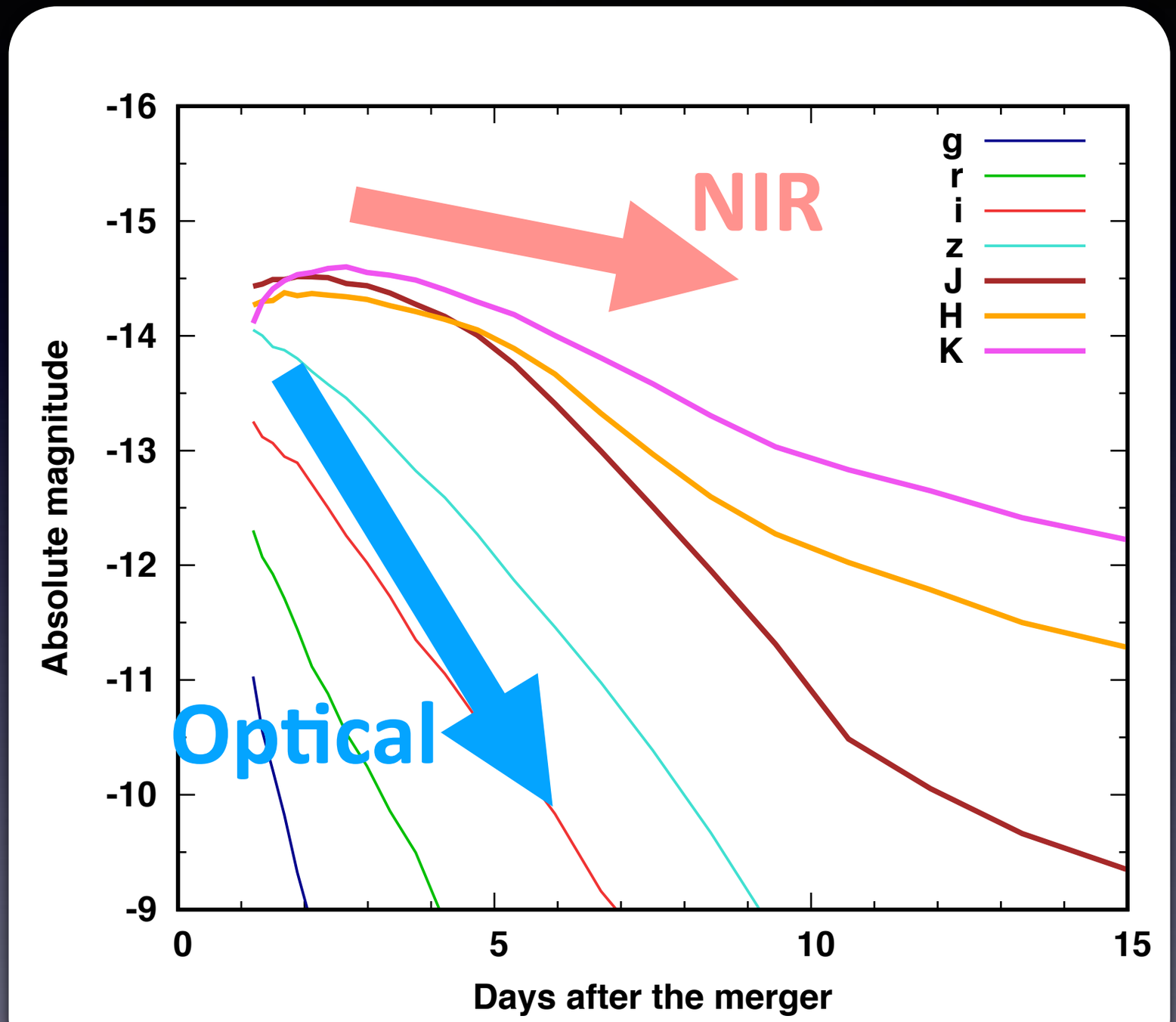
t ~ weeks

NIR > Optical

Smooth spectra (high velocity)

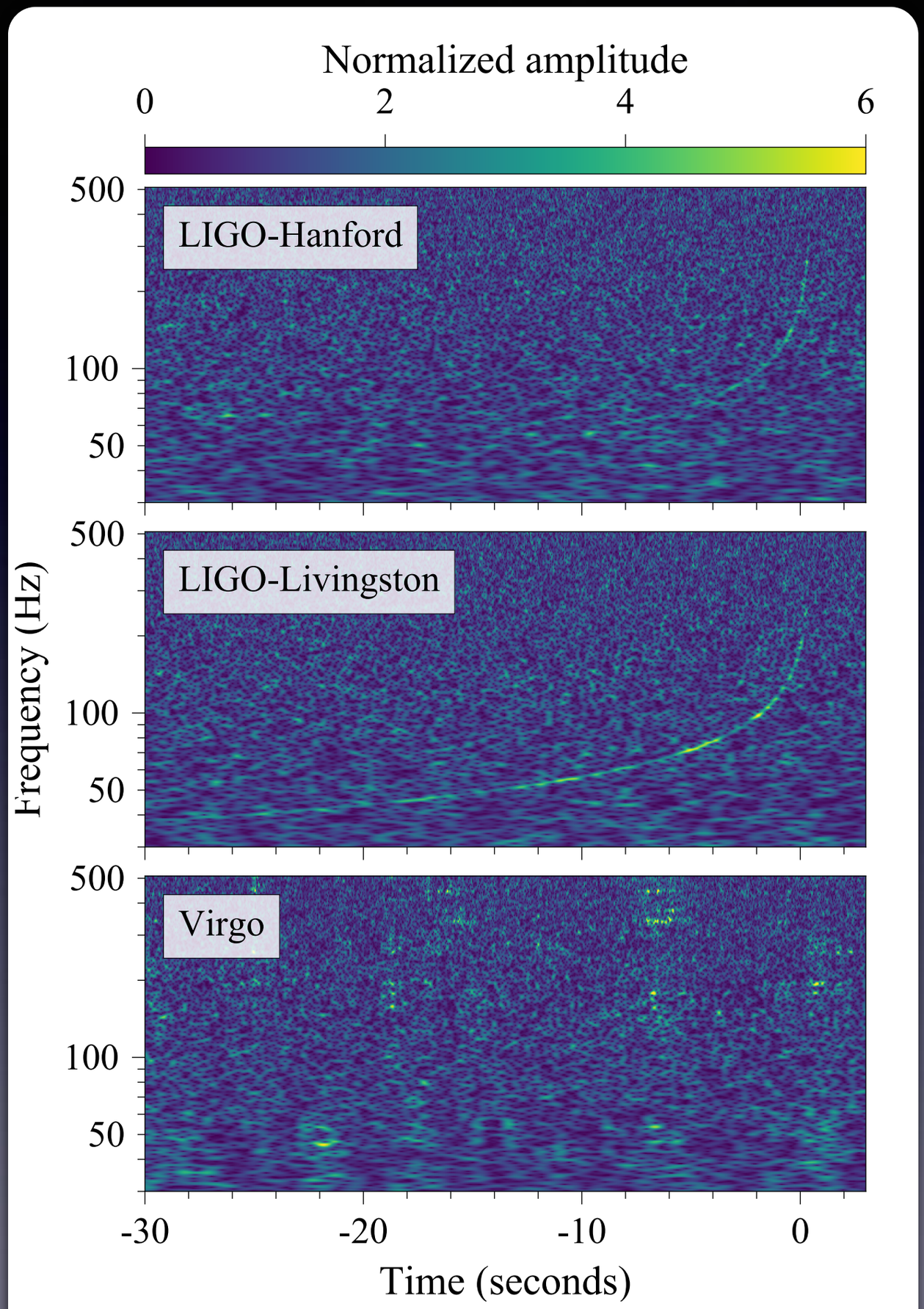
Kasen+13, Barnes & Kasen 13

MT & Hotokezaka 13, MT+14,



2017 Aug 17

GW170817:
The first detection of GWs from a NS merger



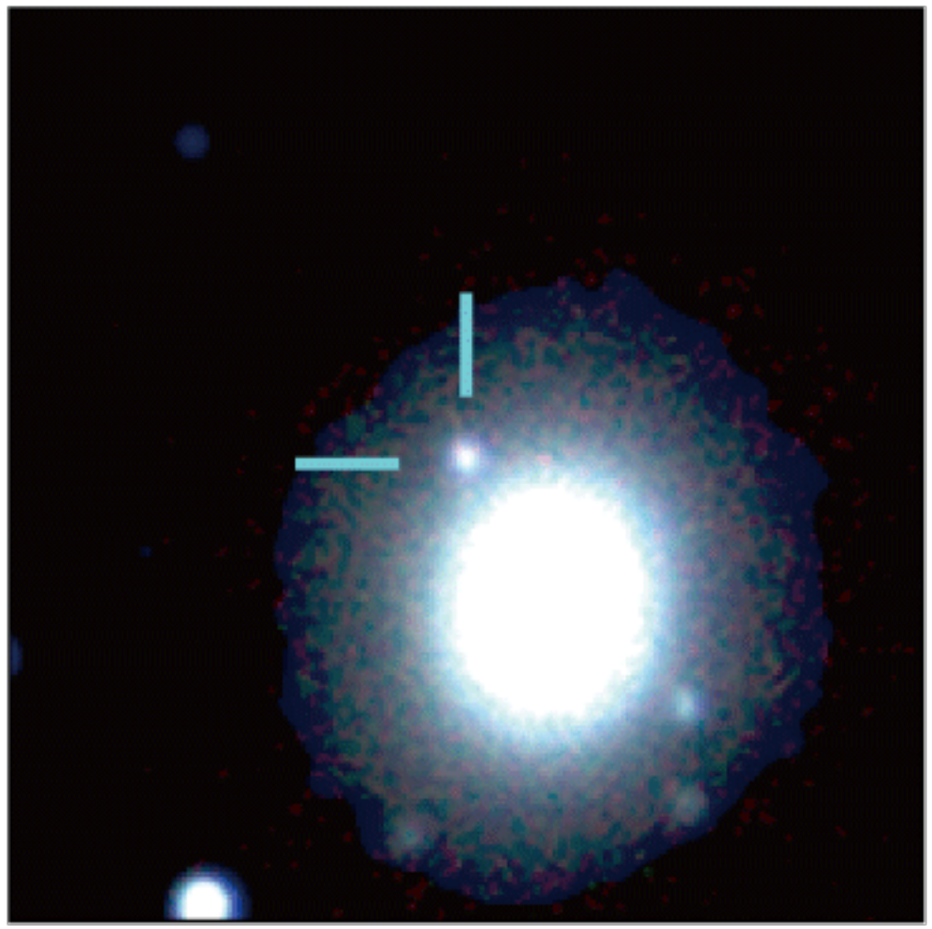
LIGO Scientific Collaboration
and Virgo Collaboration, 2017, PRL

(C) Michitaro Koike (NAOJ/HSC)

HSC survey led by Y. Utsumi and N. Tominaga

Electromagnetic counterpart of GW170817 @ 40 Mpc

2017.08.18–19



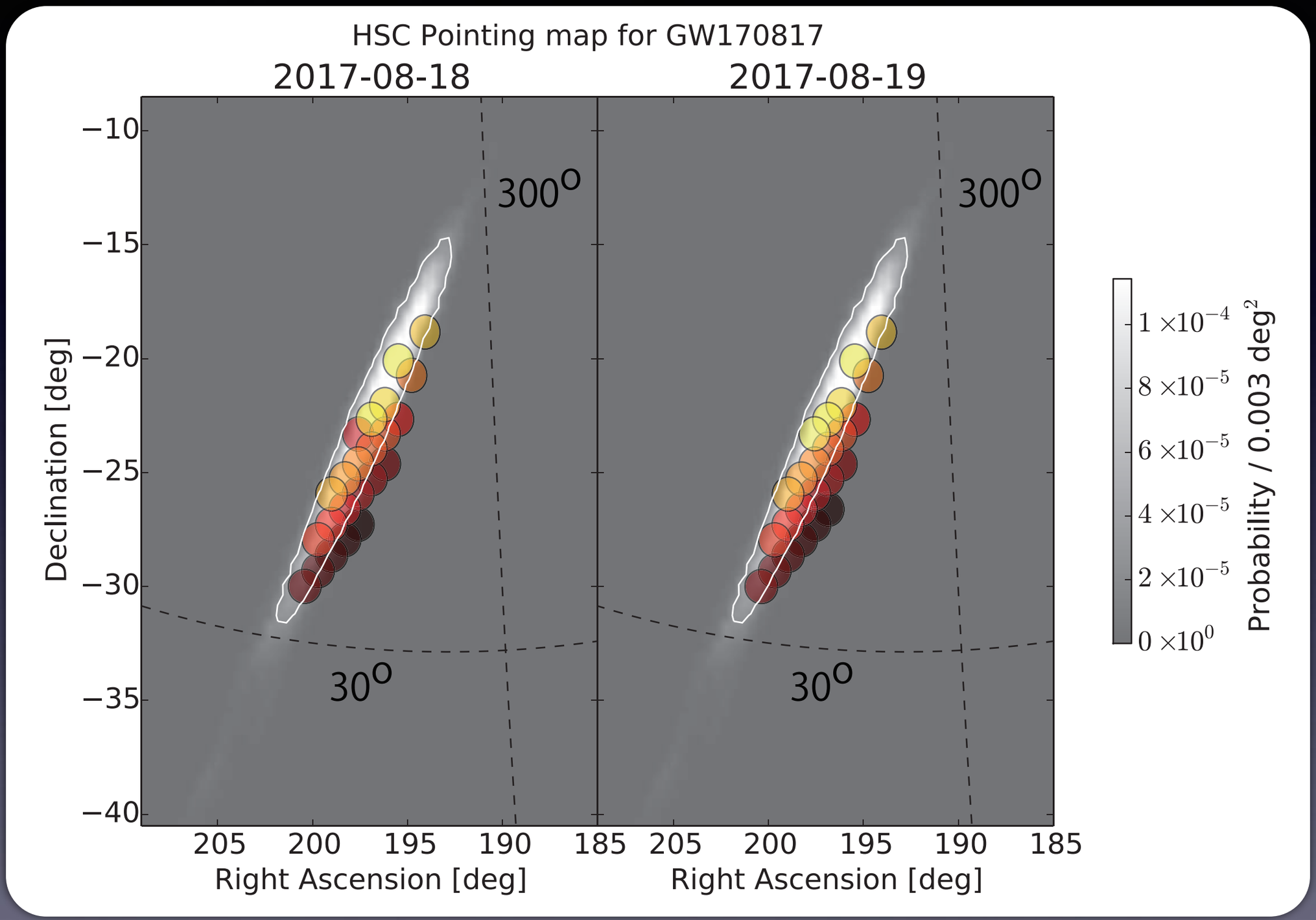
2017.08.24–25

Subaru/HSC z +IRSF/SIRIUS H, Ks

(**Utsumi**, MT, Tominaga et al. 2017, PASJ)

J-GEM: Japanese collaboration for Gravitational-wave Electro-Magnetic follow-up

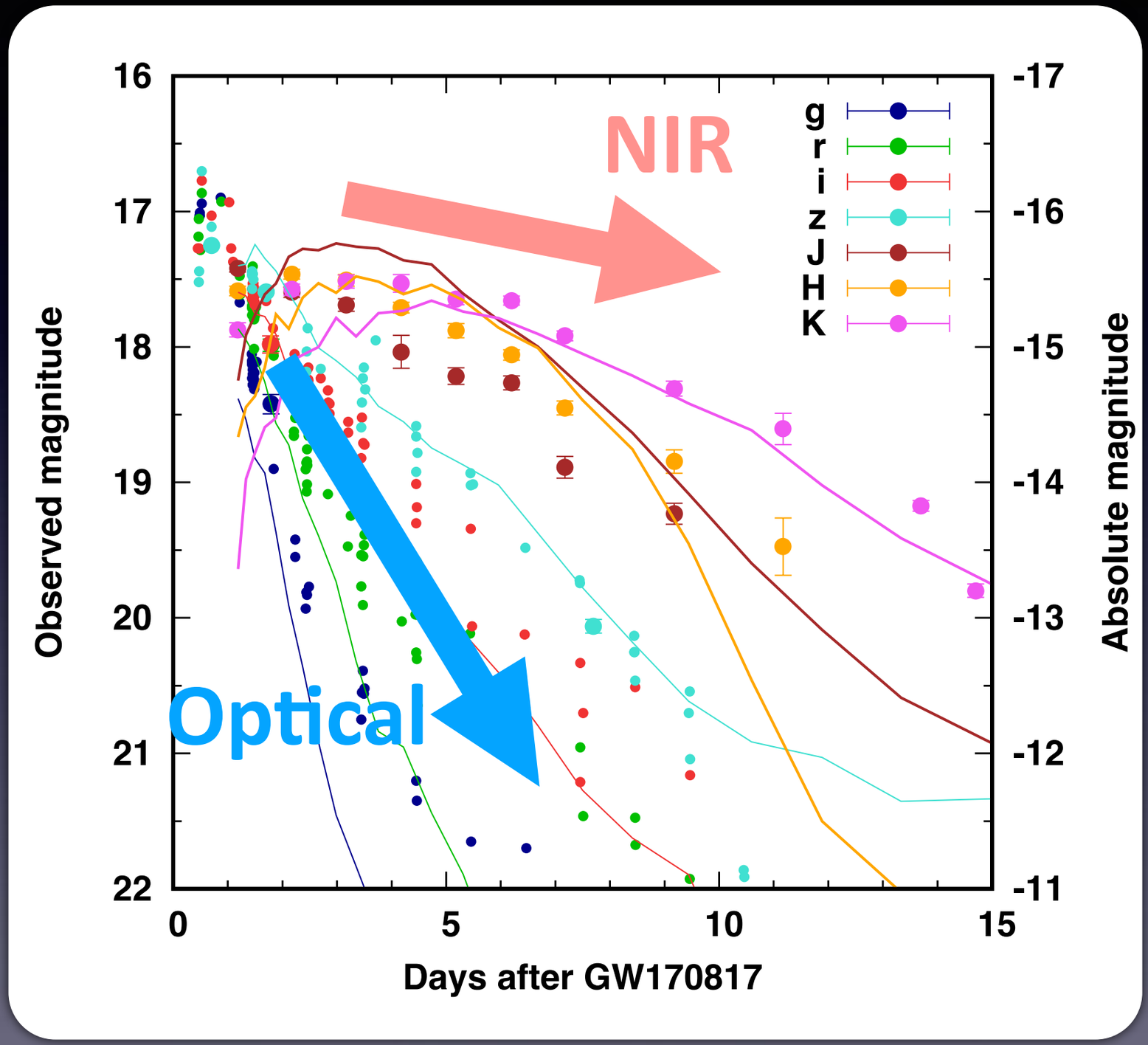
Survey with Subaru/HSC



Tominaga, MT et al. 2018, PASJ

DECam: Soares-Santos et al. 2017

GW170817: light curves



Model: MT+17b

Data: Utsumi, MT+17, Drout+17, Pian+17, Arcavi+17, Evans+17, Smartt+17, Diaz+17, Valenti+17, Cowperthwaite+17, Tanvir+17, Troja+17, Kasliwal+17

Ejecta mass (w/ lanthanides) ~0.03 Msun

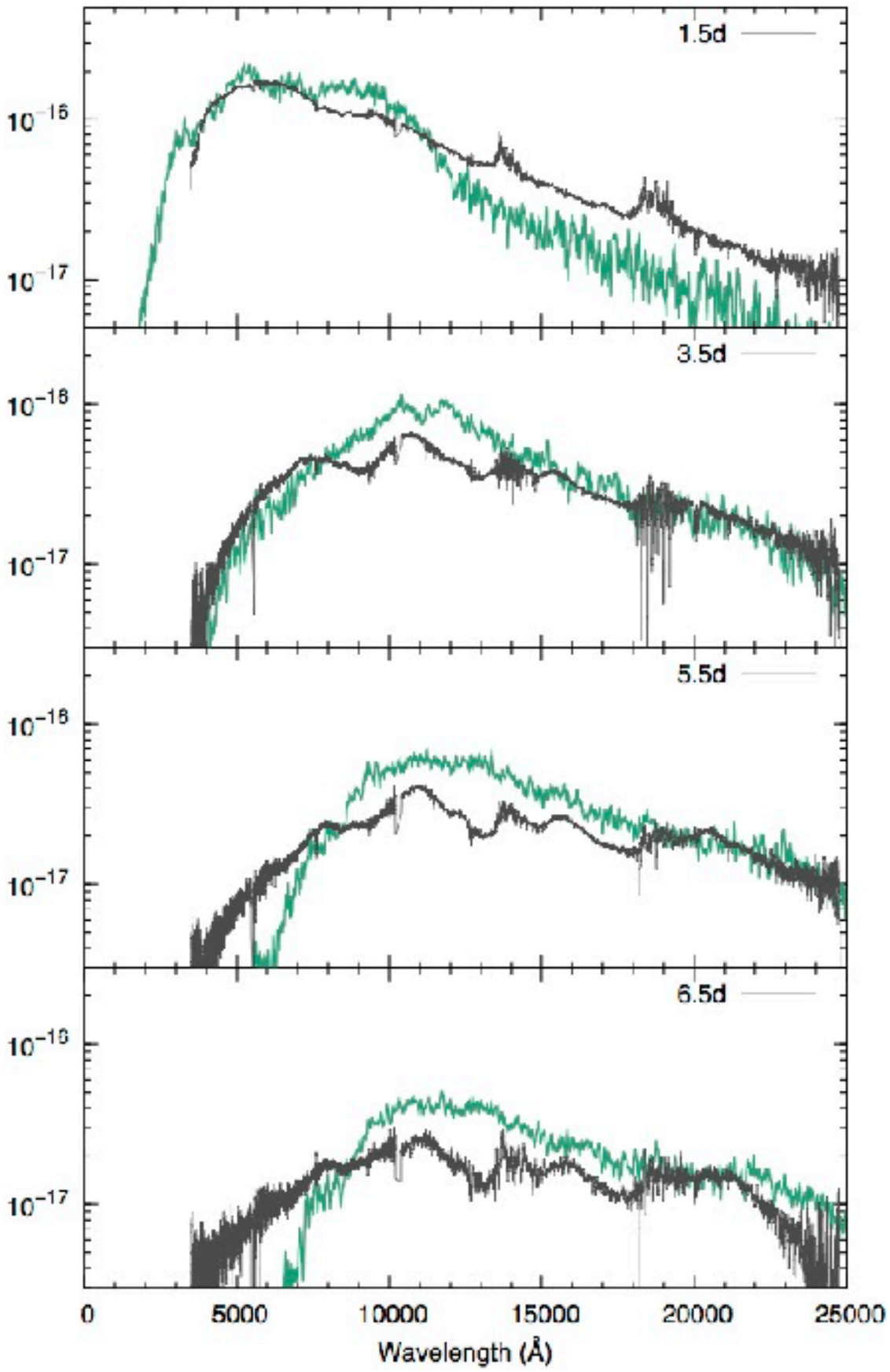
GW170817: Spectra

- Smooth spectra

Smoking gun!!

Spectra taken w/ VLT/X-shooter

Data: Pian+2017
Model: MT+2017



What we have learned from GW170817

- **Kilonova and nucleosynthesis**
  - R-process nucleosynthesis took place
  - R-process produced a wide range of elements
    - Red kilonova => lanthanides
    - Blue kilonova => lighter elements
  - Ejection of ~ 0.03 Msun with v >~ 0.1c
- **Other signals**
  - Host galaxy => “old” environment
  - Redshifts from EM => Hubble constant
  - GRBs and X-ray/radio afterglow => relativistic jets

(Many) open questions

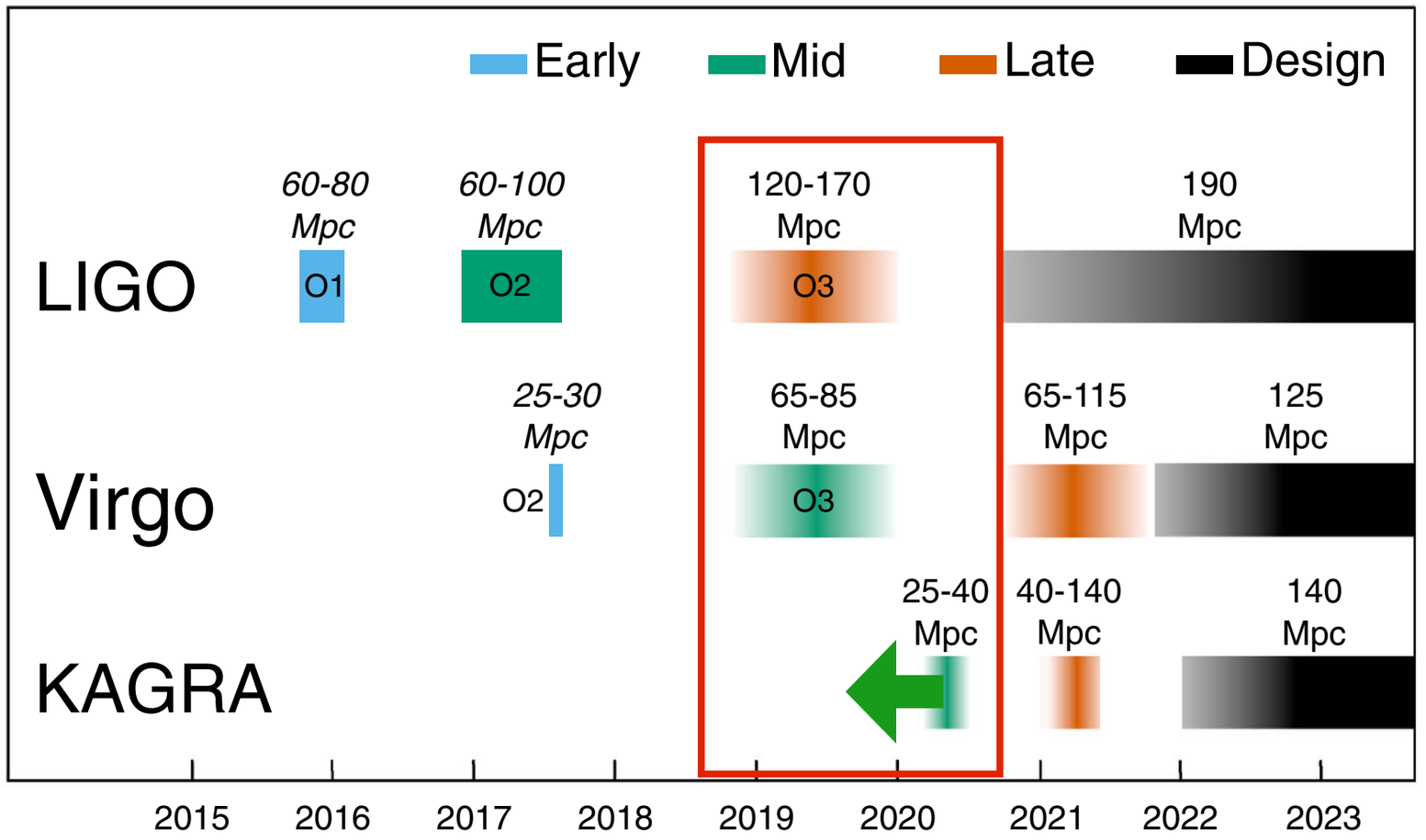
- **Event rate and production rate?**
  - Enough to explain the total amount in the Universe?
- **Abundance pattern? Similar to solar abundances?**
  - Production of 3rd peak?? (Au and Pt!)
- **Delay time?**
  - r-process elements in metal poor stars

Need more observations with
different viewing angles, NS masses, and environments

Observations of Gravitational Wave Sources with Tomo-e Gozen

- What we have learned from GW170817
- Survey with Tomo-e Gozen

Schedule

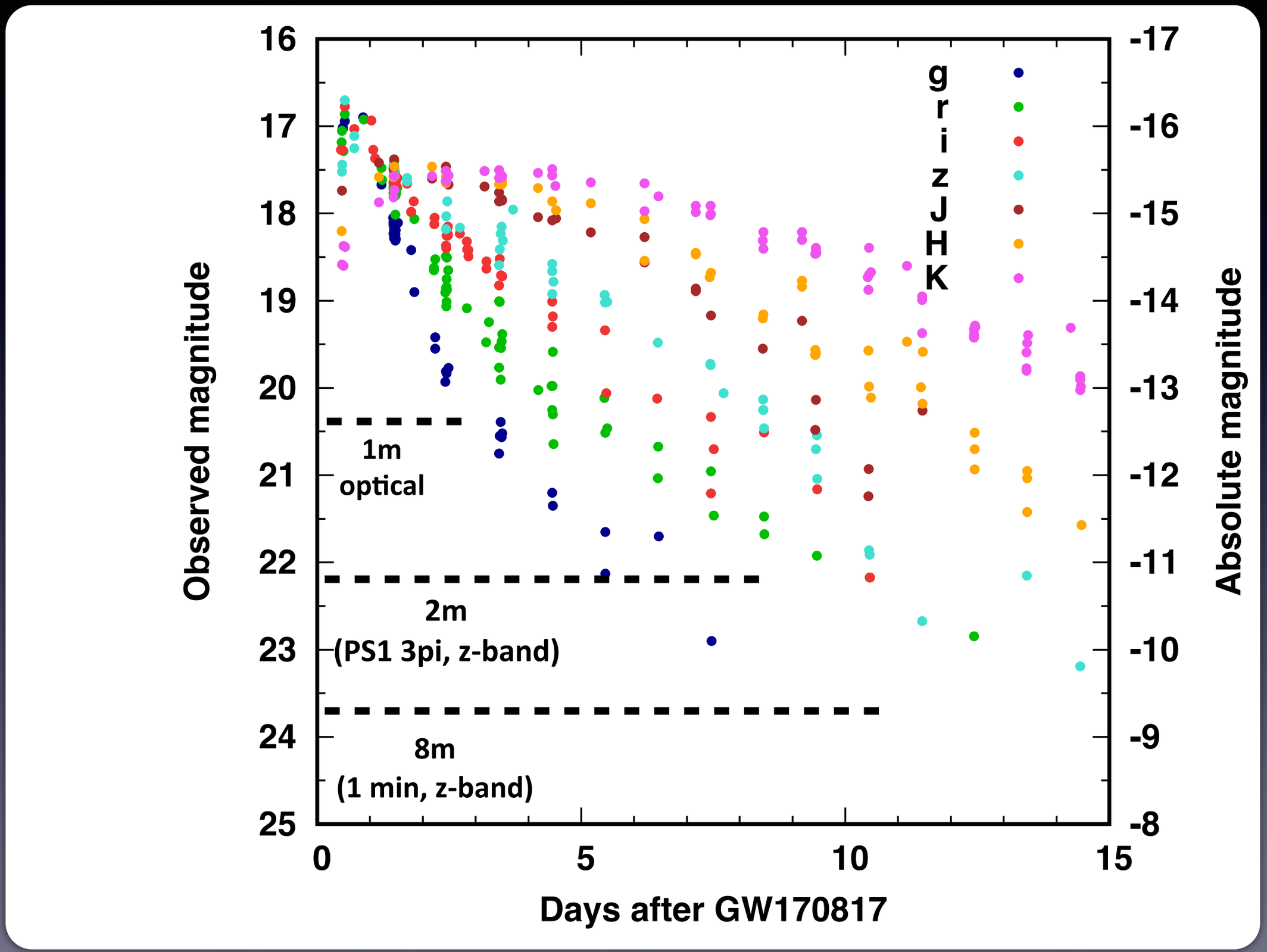


90% region

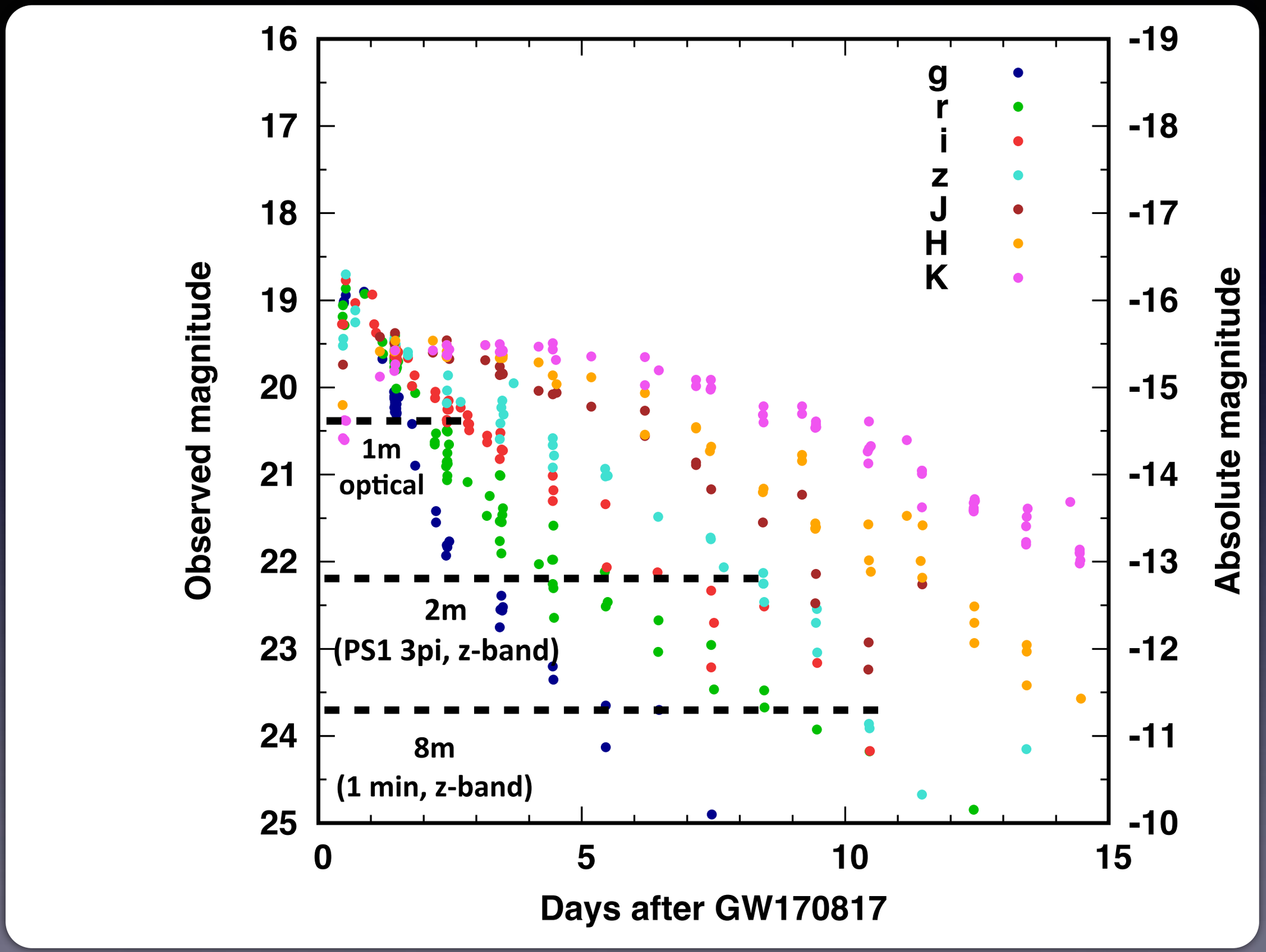
		2015–2016	2016–2017	2018–2019	2020+	2024+
% within	5 deg^2	< 1	1–5	1–4	3–7	23–30
	20 deg^2	< 1	7–14	12–21	14–22	65–73
Median/deg^2		460–530	230–320	120–180	110–180	9–12

KAGRA, LIGO, and Virgo 2018

40 Mpc


16
17
18
19
20
21
22
23
24
25
-17
-16
-15
-14
-13
-12
-11
-10
-9
-8
0
5
10
15
g
r
i
z
J
H
K
1m
optical
2m
(PS1 3pi, z-band)
8m
(1 min, z-band)
Observed magnitude
Absolute magnitude
Days after GW170817

100 Mpc


Observed magnitude
Absolute magnitude
16
17
18
19
20
21
22
23
24
25
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10
0
5
10
15
Days after GW170817
g
r
i
z
J
H
K
1m
optical
2m
(PS1 3pi, z-band)
8m
(1 min, z-band)

GW-EM observations with Tomo-e

ToO: < 3 days after the merger

** Quicker is always better **

Cadence: ~2-4 hr <= 2-3 visits /night

No filter <= faint, colors are uncertain (viewing angle)

Depth: 20-21 mag

15 min (3 min x 5) on-source exposure

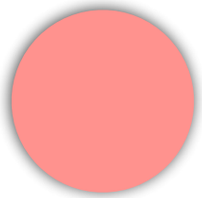
2x2 dithering => **~ 60 deg^2 in ~1 hr!**

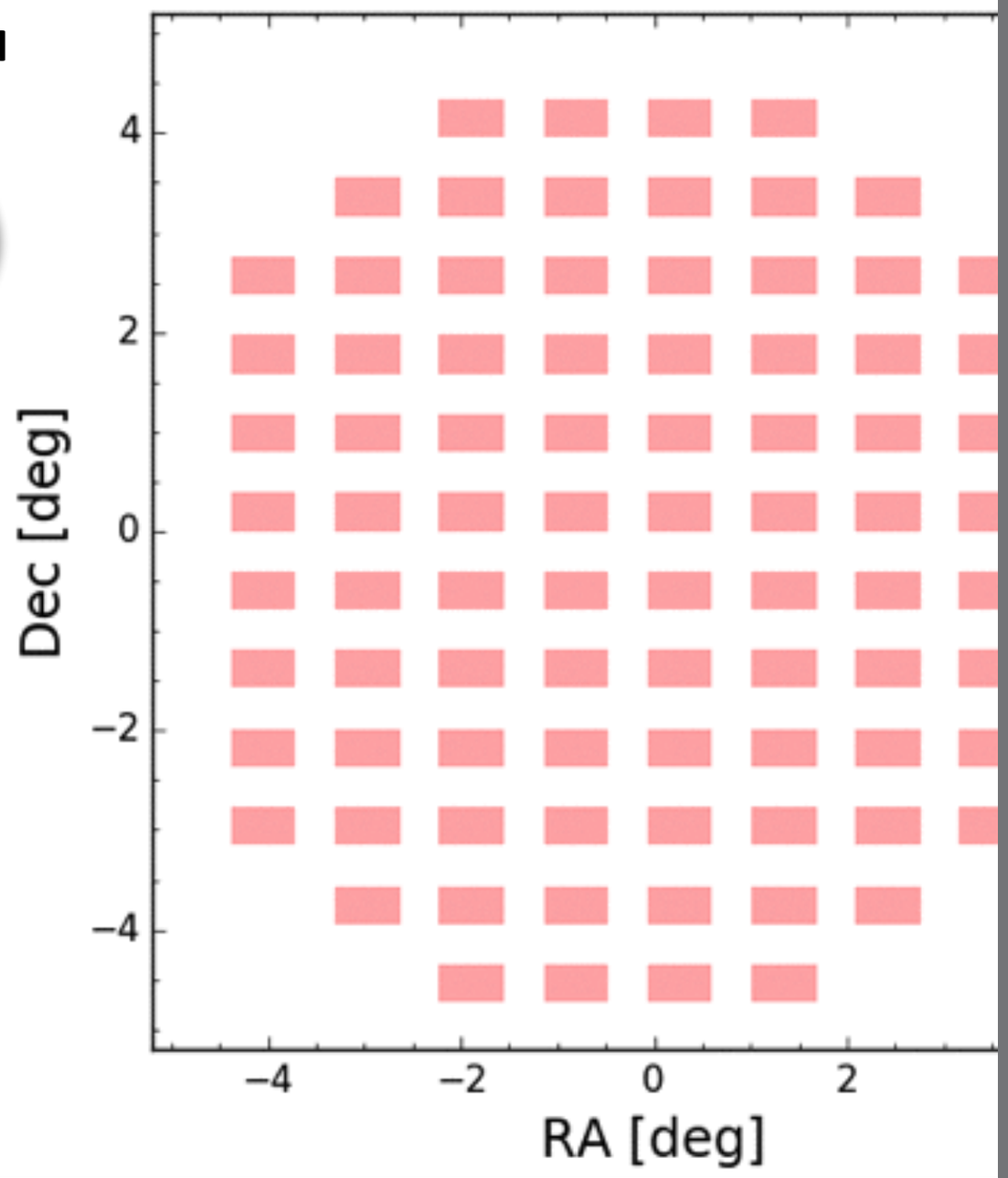
(~500 deg^2 in 1 night!)

2 x 2 dithering => ~60 deg^2

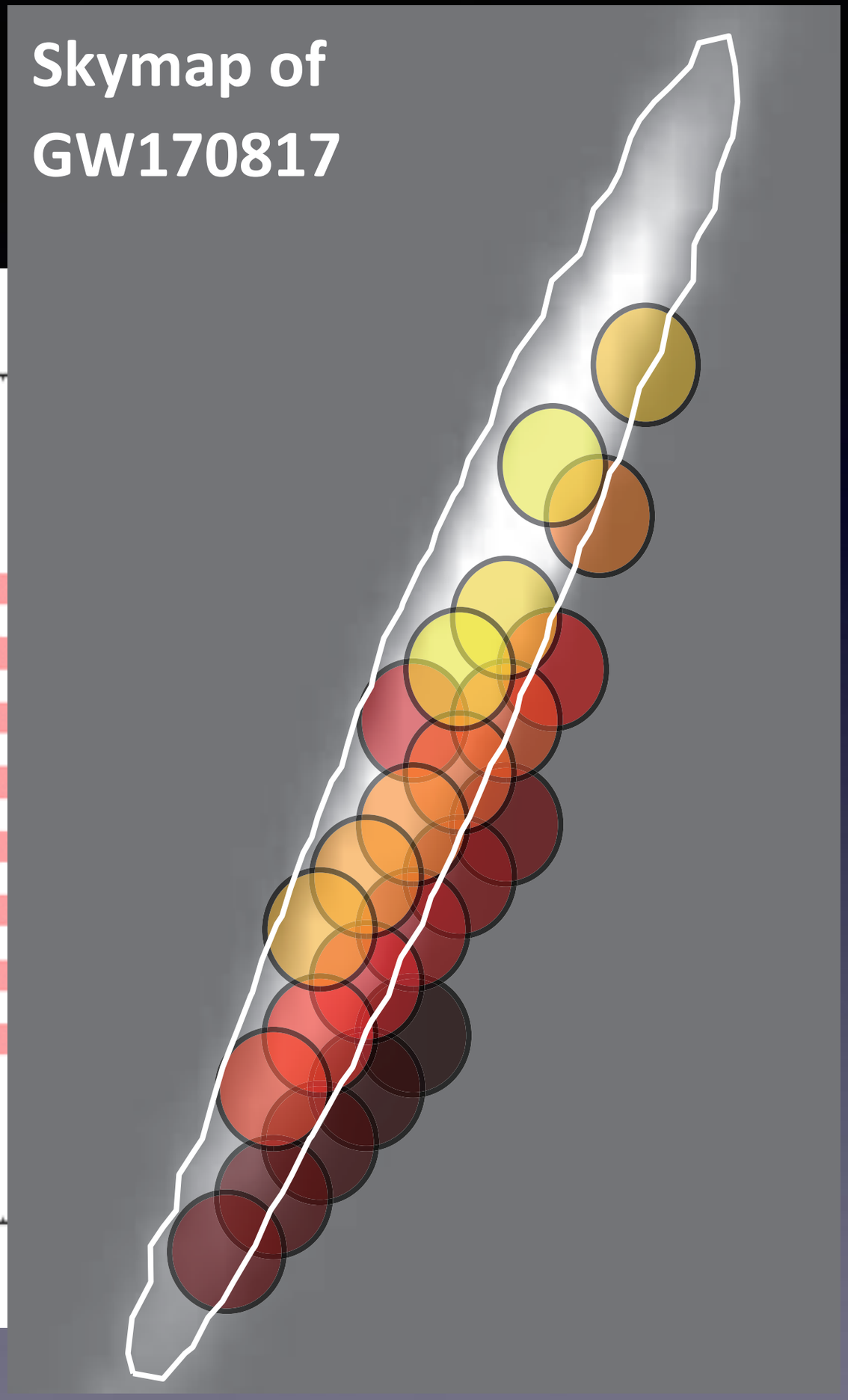
(e.g., 15 min x 4 = 1hr)

Subaru HSC





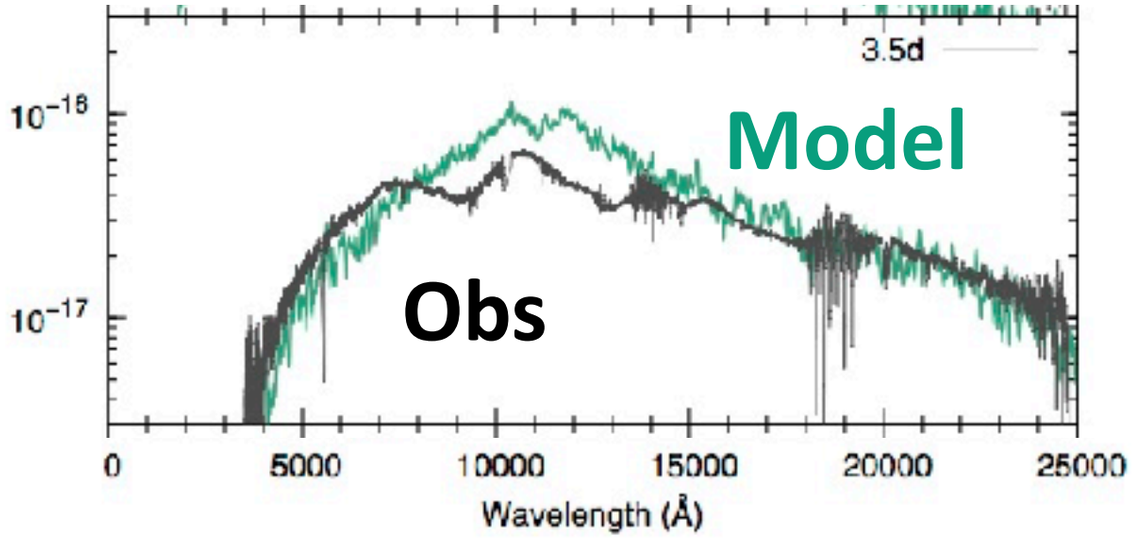
Skymap of GW170817



(C) Tomoki Morokuma

Spectroscopy is a key
- to identify NS mergers
- to identify elements(*)

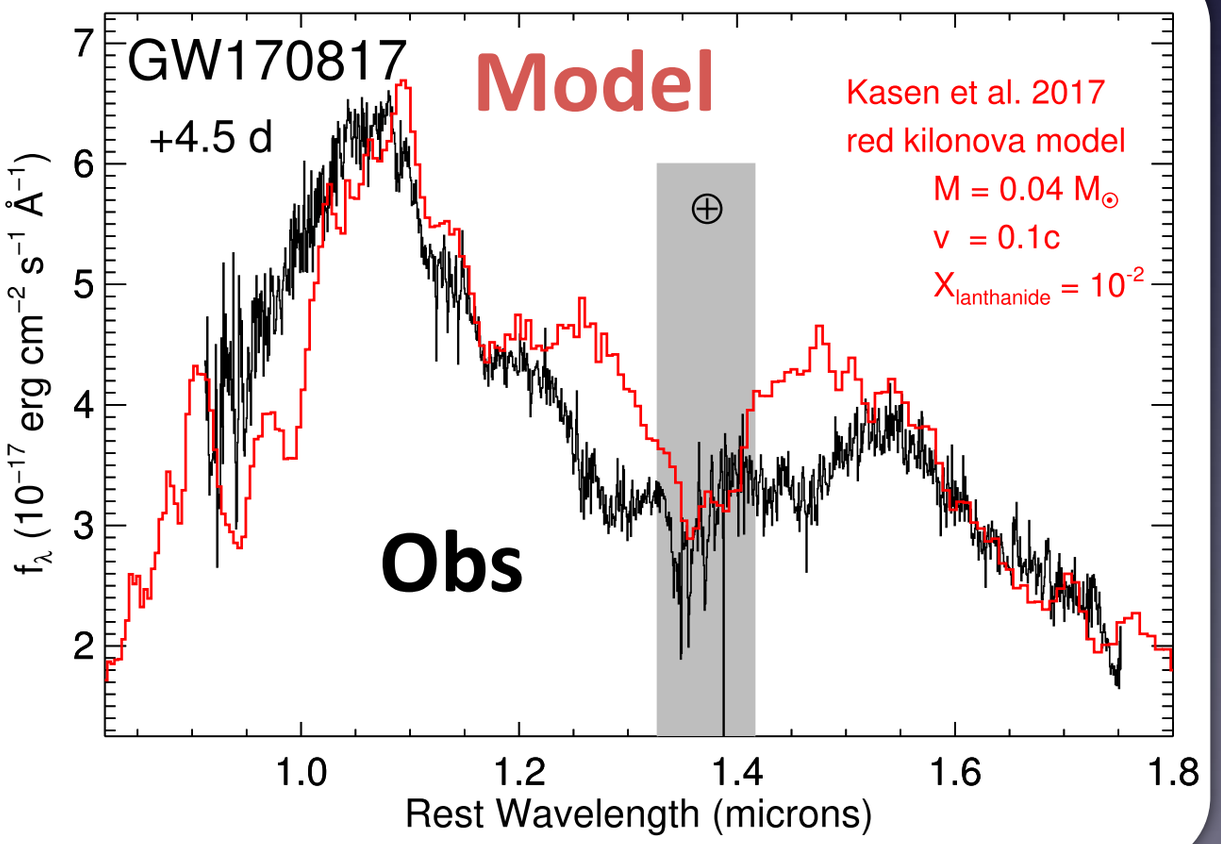
(*) Not conclusive yet,
but improvement in theory is ongoing



MT+17

Follow-up with
3.8m telescope (Seimei)
and TAO

Ohta-san's talk



Chornock+17

Summary

- **GW170817 (NS merger)**
  - Kilonova was observed
  - Signatures of a wide range of elements (red and blue kilonova)
- **Open questions**
  - Event rate and production rate?
  - Abundance pattern? Similar to solar abundances?
  - Delay time?
- **Observations with Tomo-e**
  - ~100-300 deg^2 / 20-21 mag / 2hr cadence / no filter
  - Low-resolution spectroscopy with Seimei telescope

Observations of NS mergers with different viewing angles, NS masses, and environments