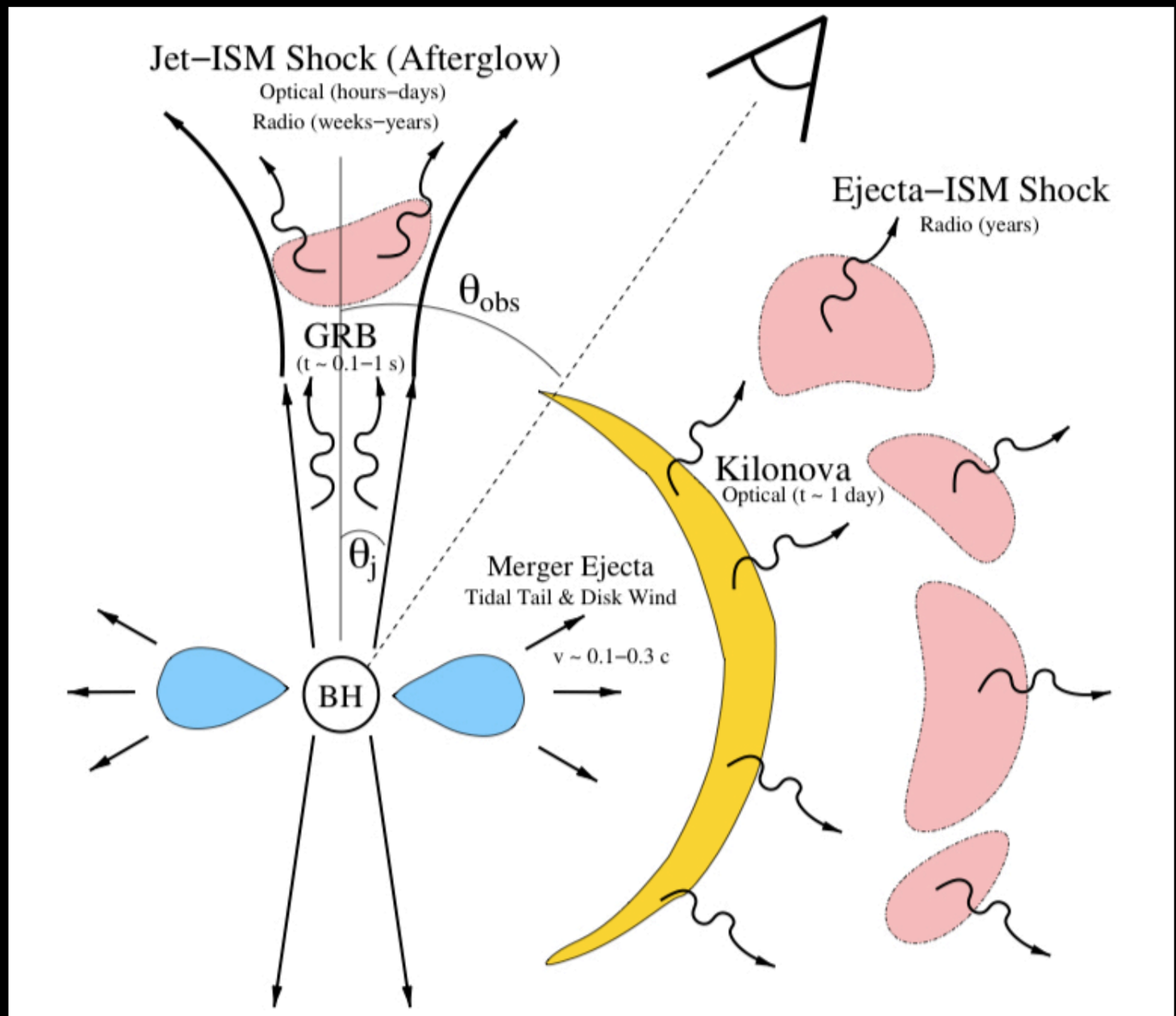
Opt / NIR follow-up observations of GW events

Tominaga, N; Tanaka, M; Morokuma, T; **Utsumi, Y**; et al.; 2018, PASJ, in press
Utsumi, Y; et al., 2017, PASJ, in press
Tanaka, M; **Utsumi, Y**; et al., 2017, PASJ, 69, 102
Utsumi, Y; et al., 2017, PASJ, 69, 101
Yoshida, M; **Utsumi, Y**; et al., 2017, PASJ, 69L, 9
Morokuma, T; Tanaka, M; Asakura, Y; Abe, F; Tristram, P. J.; **Utsumi, Y**; et al., 2016, PASJ, 68L, 9

Yousuke Utsumi (KIPAC/SLAC/Stanford)
on behalf of the J-GEM collaboration

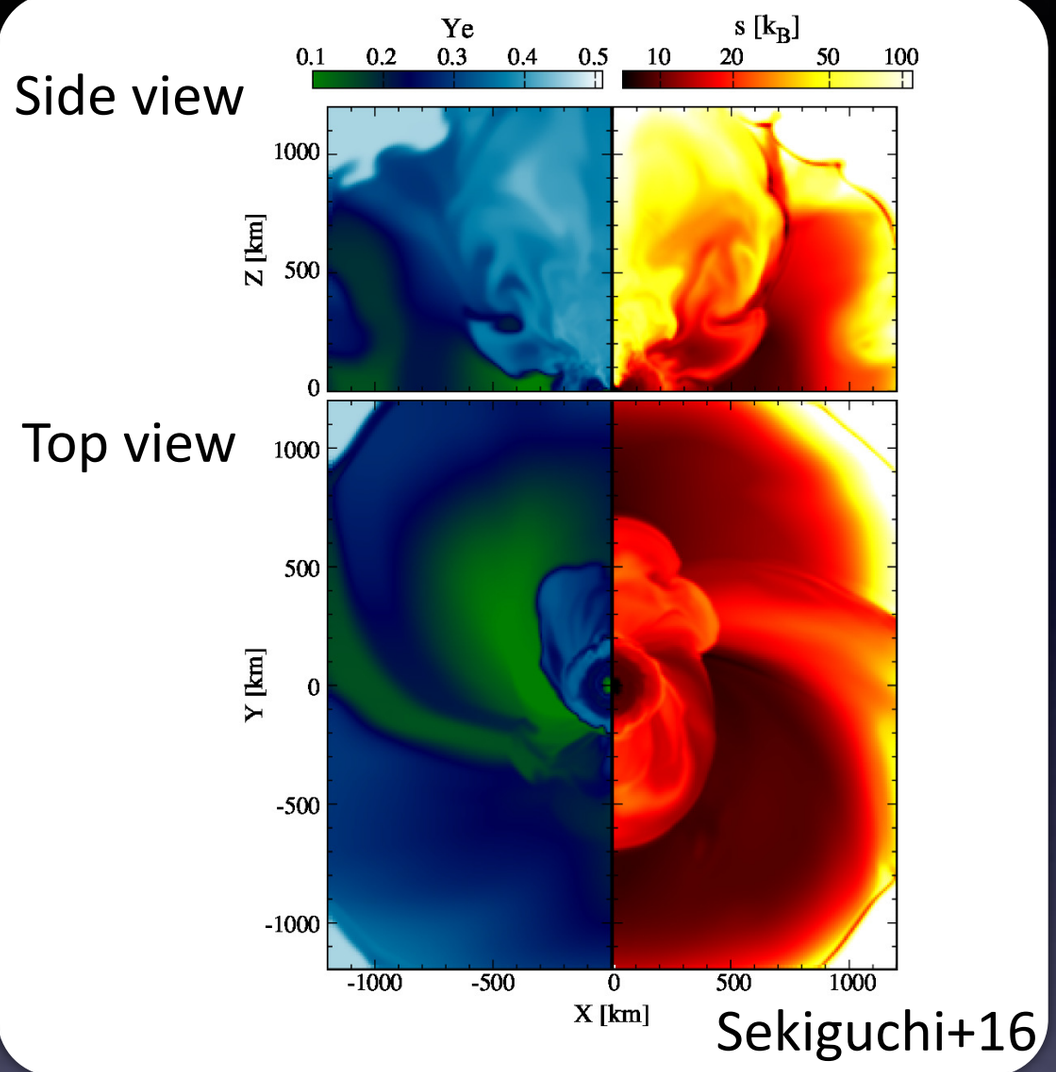
GWs detected

- Compact binary coalescence
- **~1000deg²** localizations
  - GW150914 — The first detection
  - LVT151012 — less significance
  - GW151226
  - GW170104
  - GW170608
- **~50deg²** localizations by three LIGO and Virgo detectors
  - GW170814 — The first detection by three detectors
- **EM emission**
  - GW170817 — The first detection of a system incl. NS



Metzger & Berger (2012) ApJ, 746, 48

Dynamical ejecta (~< 10 ms)

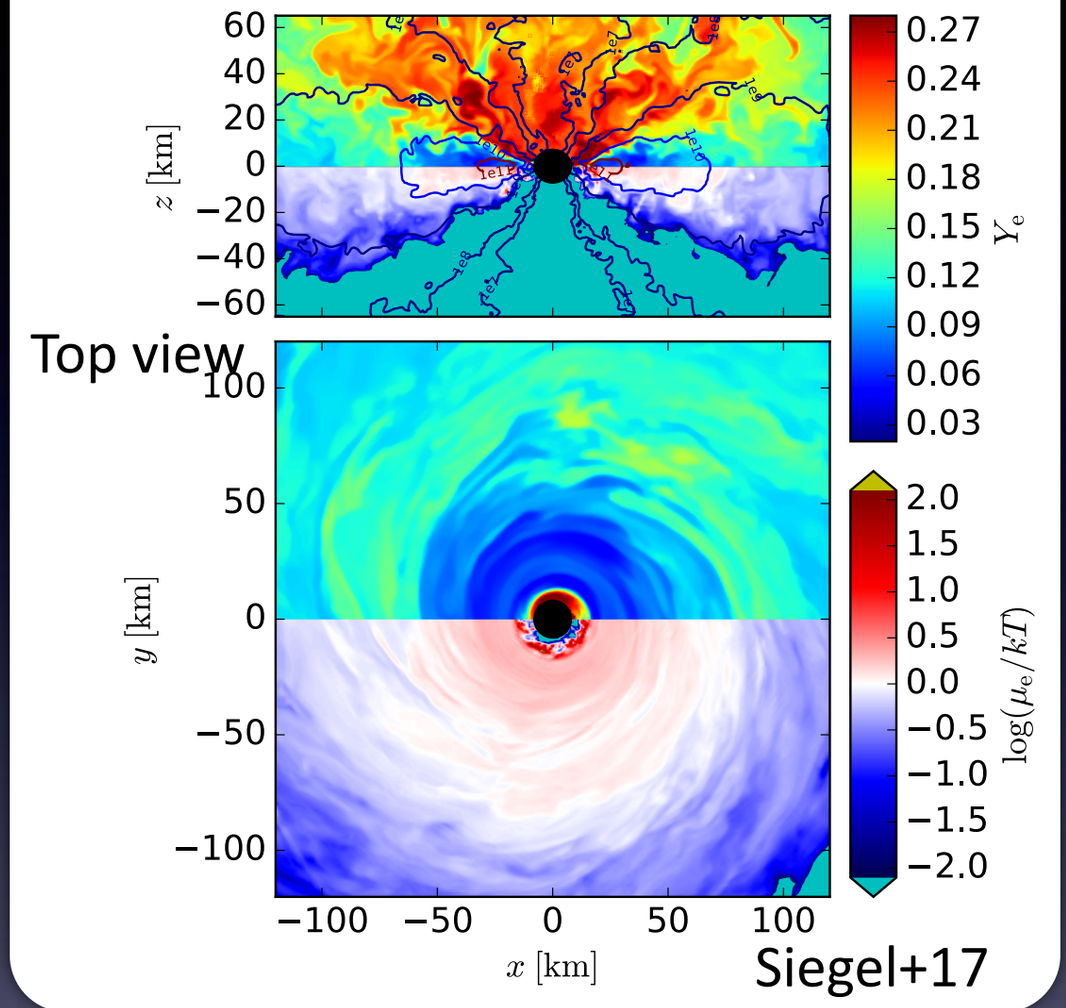


Sekiguchi+16

Rosswog+99, Lee+07, Goriely+11,
Hotokezaka+13, Bauswein+13, Radice+16…

- Mej ~ 10^{-3} - 10^{-2} Msun
- v ~ 0.1-0.2 c
- wide Ye

Post-merger ejecta (~< 100 ms)



Siegel+17

Fernandez+13,15, Perego+14, Kiuchi+14,15,
Martin+15, Just+15, Wu+16, Siegel & Metzger 17…

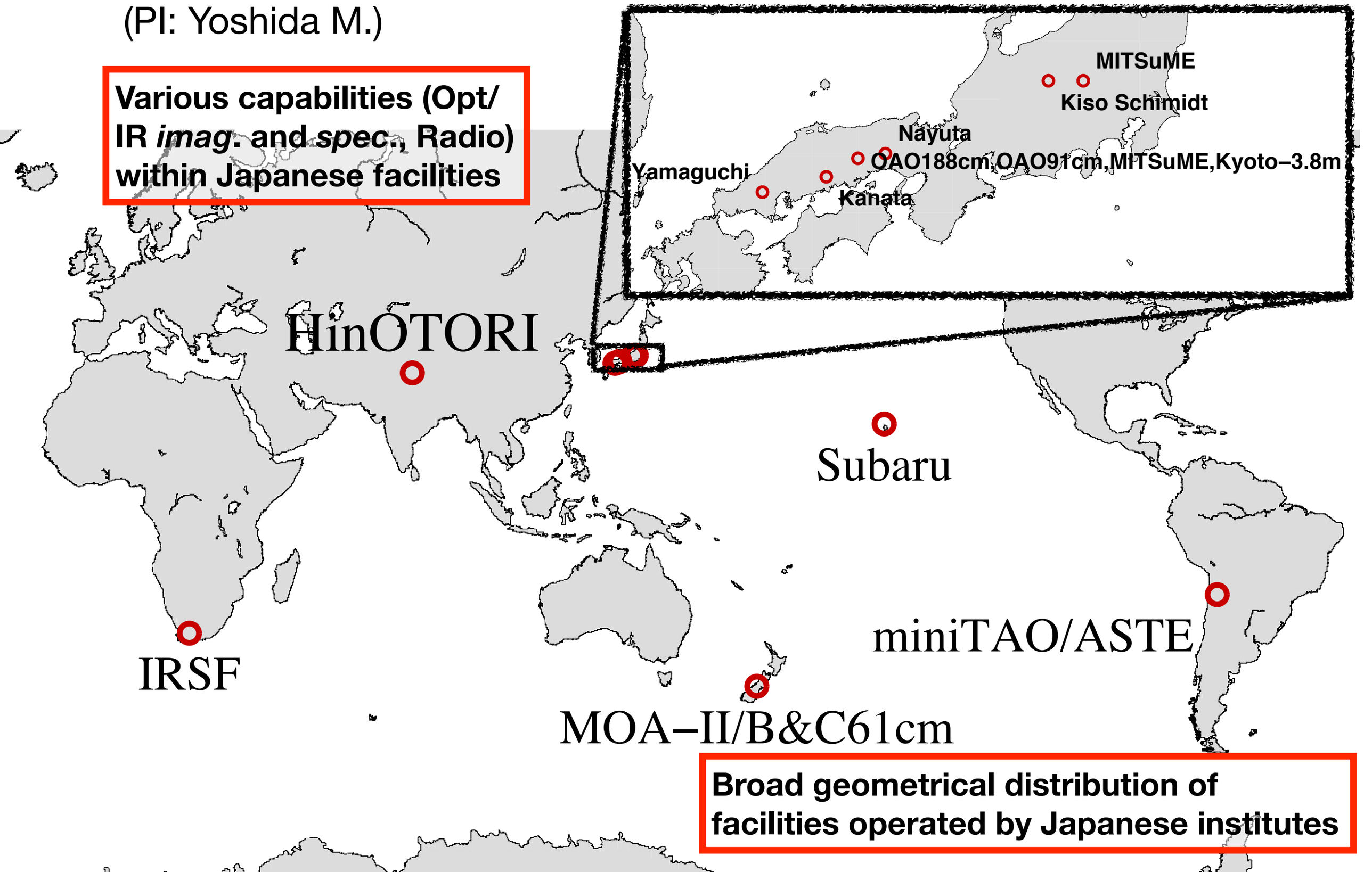
- Mej >~ 10^{-3} Msun
- v ~ 0.05 c
- can be higher Ye

from Tanaka M.'s talk

J-GEM = Japanese collaboration for Gravitational wave ElectroMagnetic follow-up

(PI: Yoshida M.)

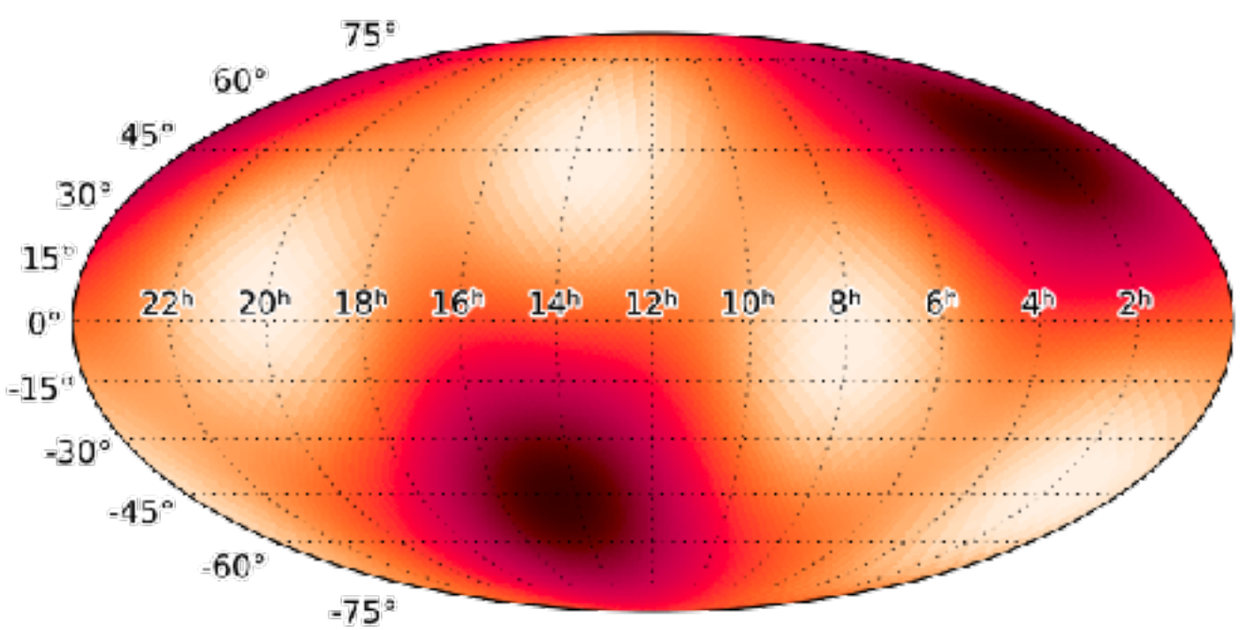
Various capabilities (Opt/IR *imag*. and *spec*., Radio) within Japanese facilities

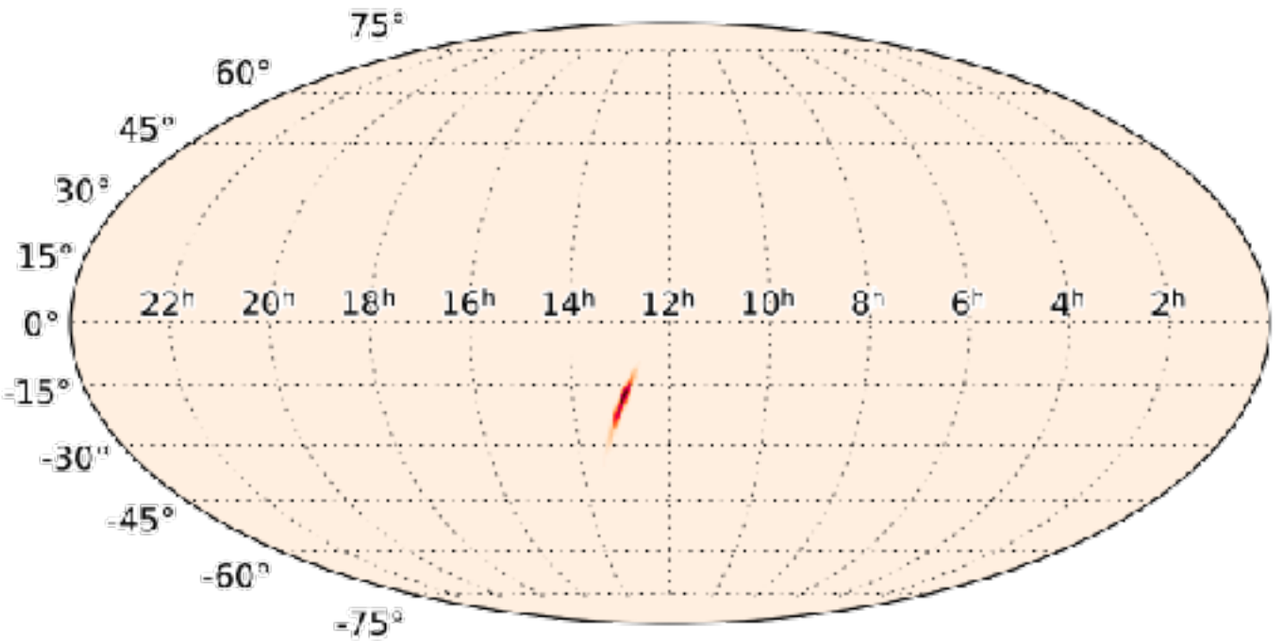


Broad geometrical distribution of facilities operated by Japanese institutes

GW170817

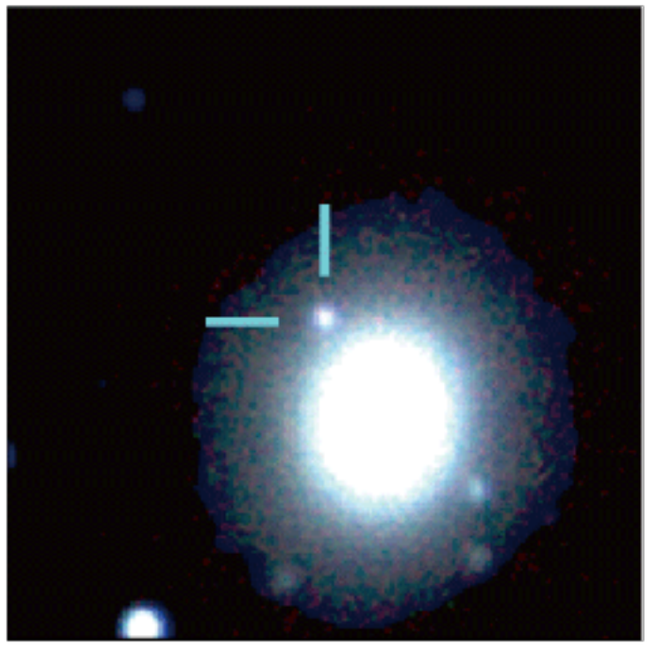
- On Aug 17, 2017, received an initial poor localization map
- Subsequently, GRB170817 is reported
- IRSF at South Africa tried to image a couple of galaxies
- 5 hours later, an improved map was distributed, ~30deg^2
- Coulter+2017 reported a candidate, SSS17a nearby NGC4993 at 40Mpc
- Many groups performed follow-up observations (Andreoni+2017; Arcavi+2017; Coulter+2017; Cowperthwaite+2017; Díaz+2017; Drout+2017; Evans+2017; Hu+2017; Kasliwal+2017; Lipunov+2017; Pian+2017; Pozanenko+2017; Shappee+2017; Smartt+2017; Tanvir+2017; Troja+2017; **Utsumi+2017**; Valenti+ 2017)





J-GEM observations

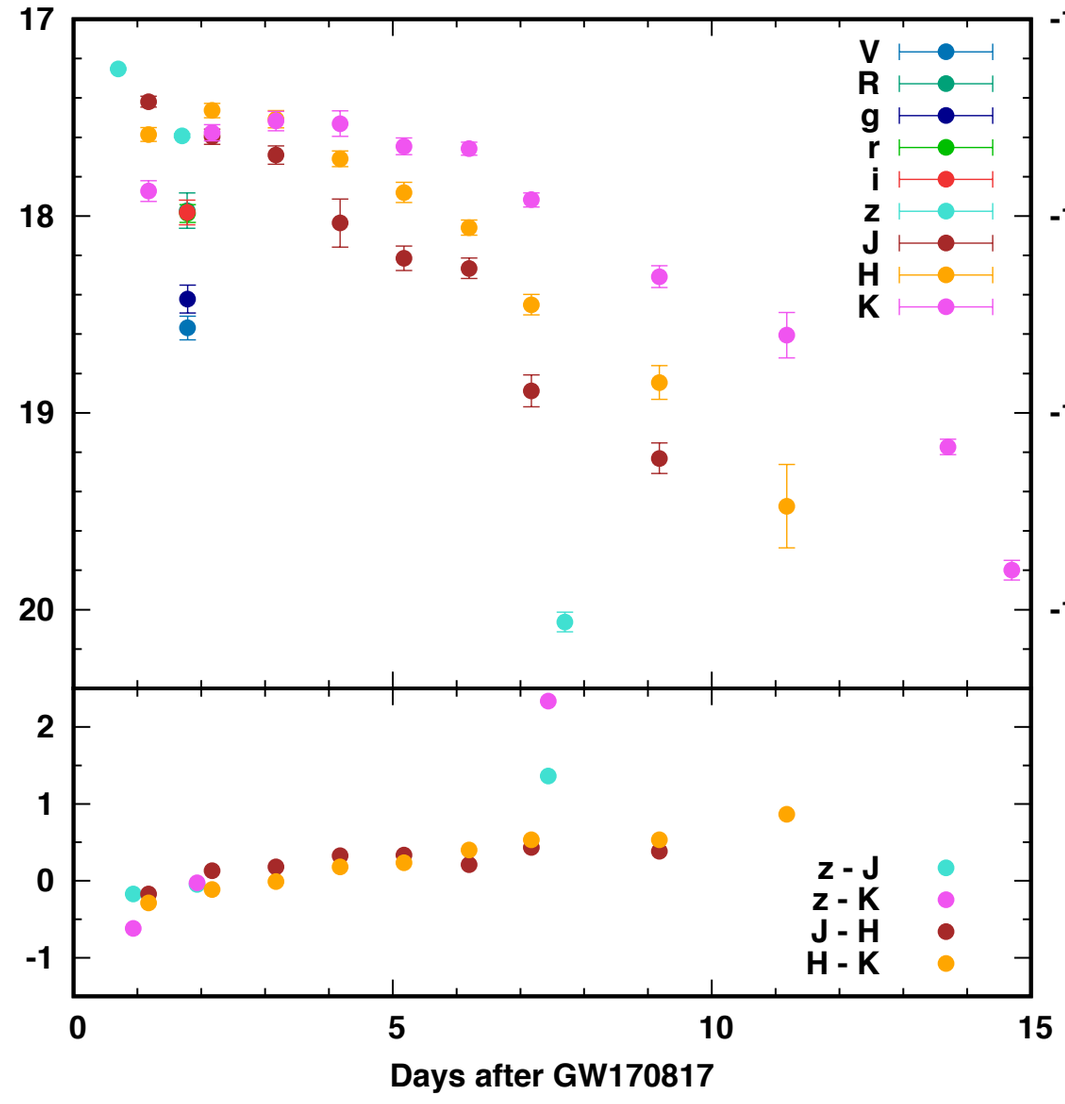
2017.08.18-19



2017.08.24-25

HSC z & IRSF HKs

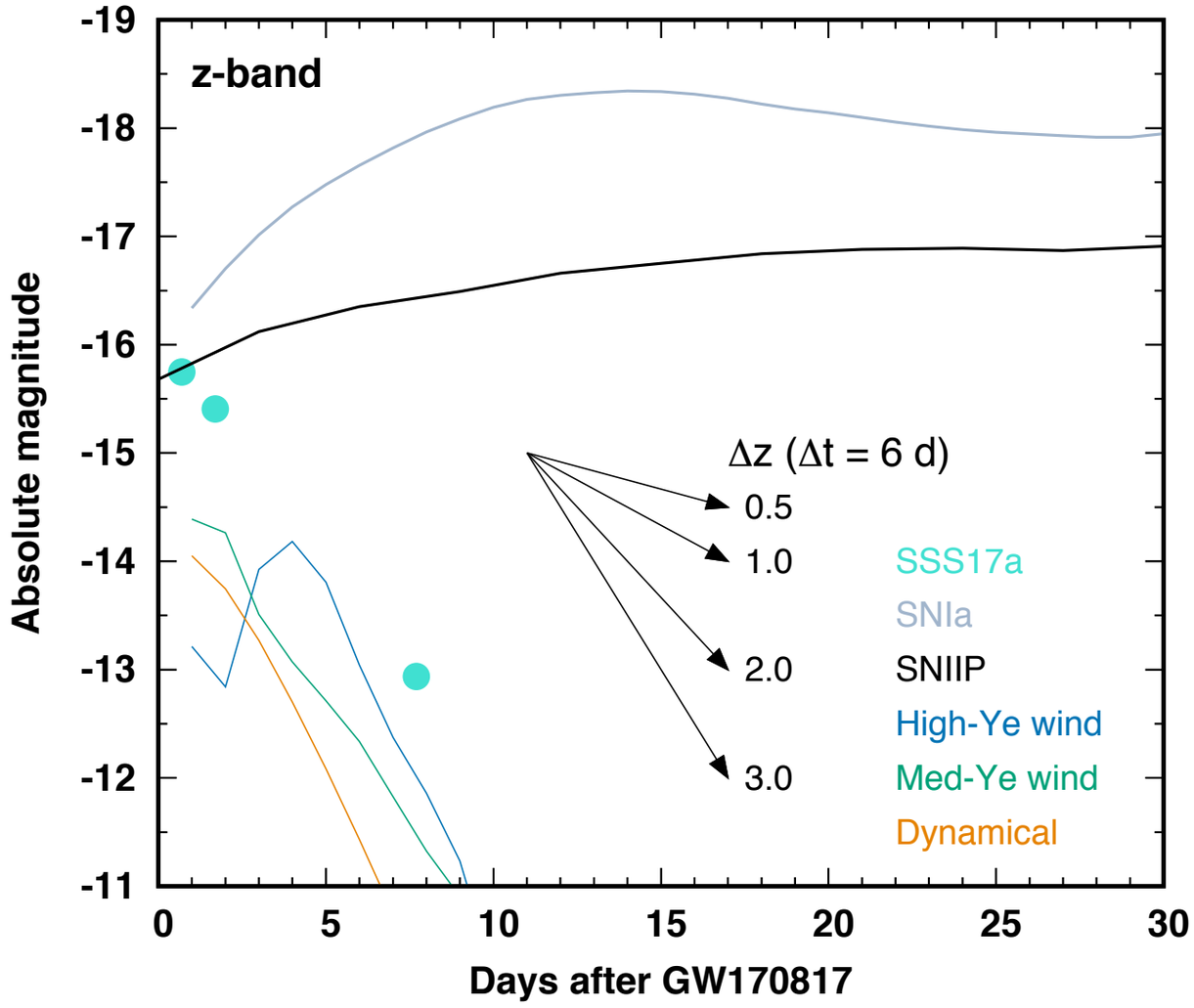
Subaru / HSC, MOIRCS @ MK
IRSF / SIRIUS @ South Africa
MOA-II / MOA-cam3 @ NZ
B&C / tripol3 @ NZ

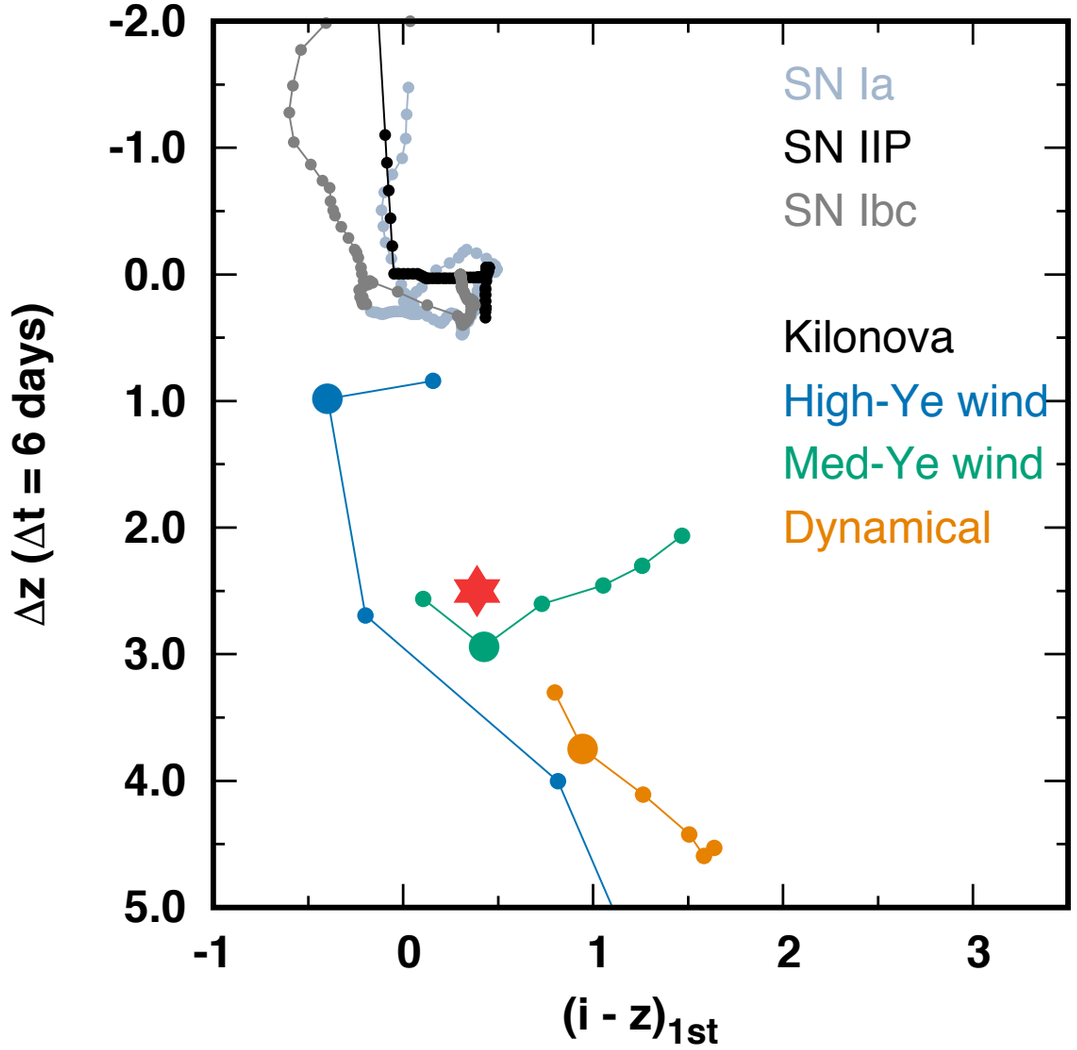


- Apply same photometry technique
  - Host galaxy subtraction, PSF photometry
- Obtained light curve in Opt/NIR
- A transient becomes faint and red

(Utsumi et al. 2017a, PASJ)

Origin of SSS17a





- Brighter than the standard scenario
- Color and decline agree with Kilonova

- Higher mass ejection or cocoon??

(Utsumi et al. 2017a, PASJ)

Model fitting

Dynamical ejecta

Wind ejecta

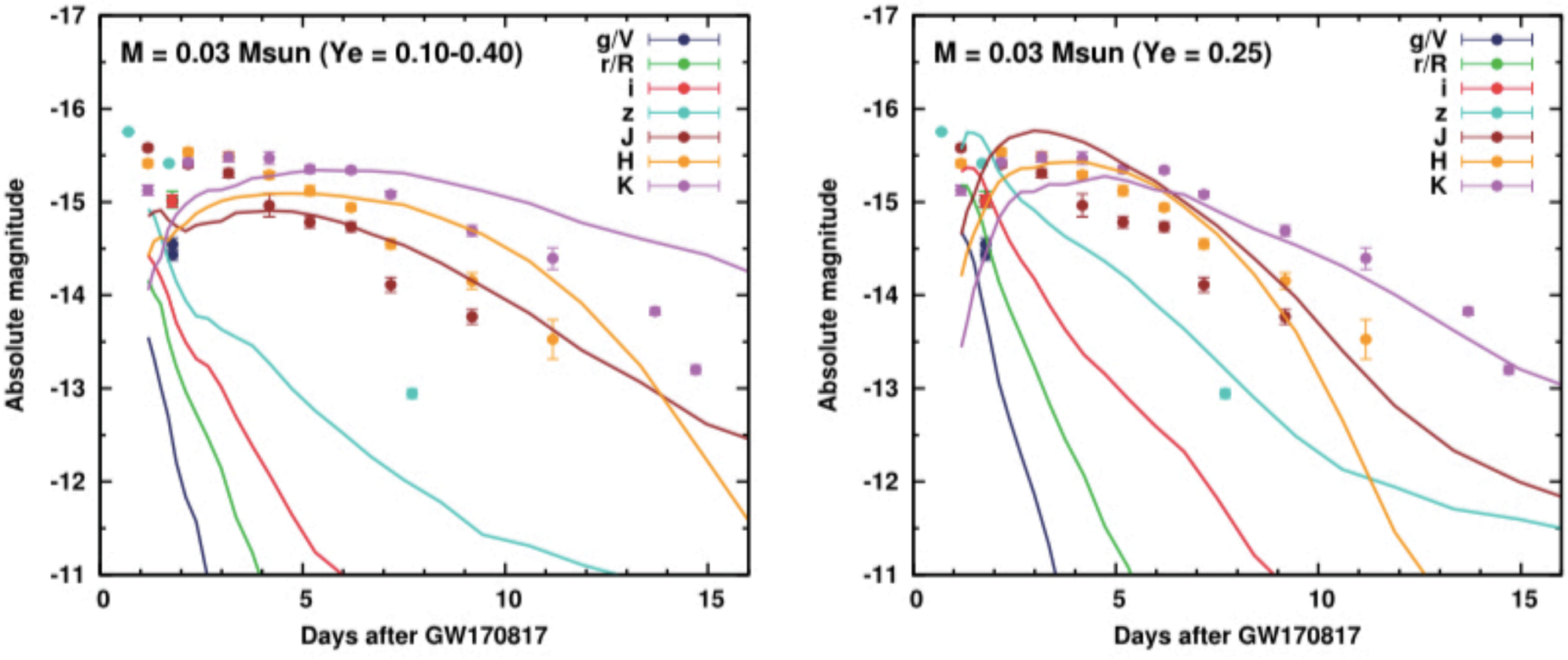
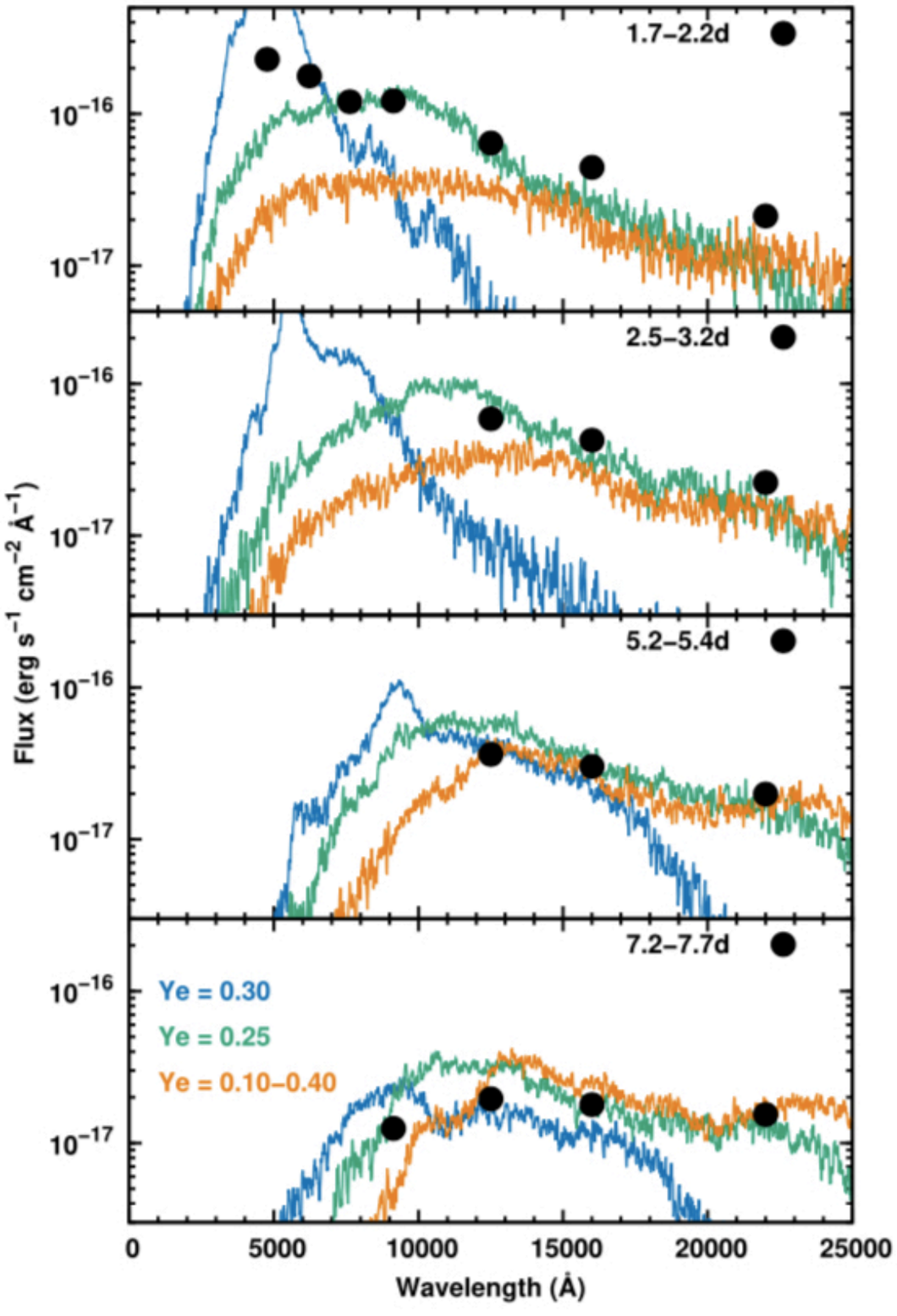


Fig. 2. Optical and near-infrared light curves of SSS17a compared with kilonova models with (left) $Y_e = 0.10–0.40$ and (right) $Y_e = 0.25$. The optical and near-infrared data are taken from Utsumi et al. (2017). For the observed data, the line-of-sight extinction of $E(B - V) = 0.1$ mag has been corrected. All the magnitudes are given in AB magnitudes.

The higher mass model with Ye=0.25 agrees with overall trend
BNS generates r-process elements
(Tanaka M., UY et al. 2017, PASJ)

SED analysis



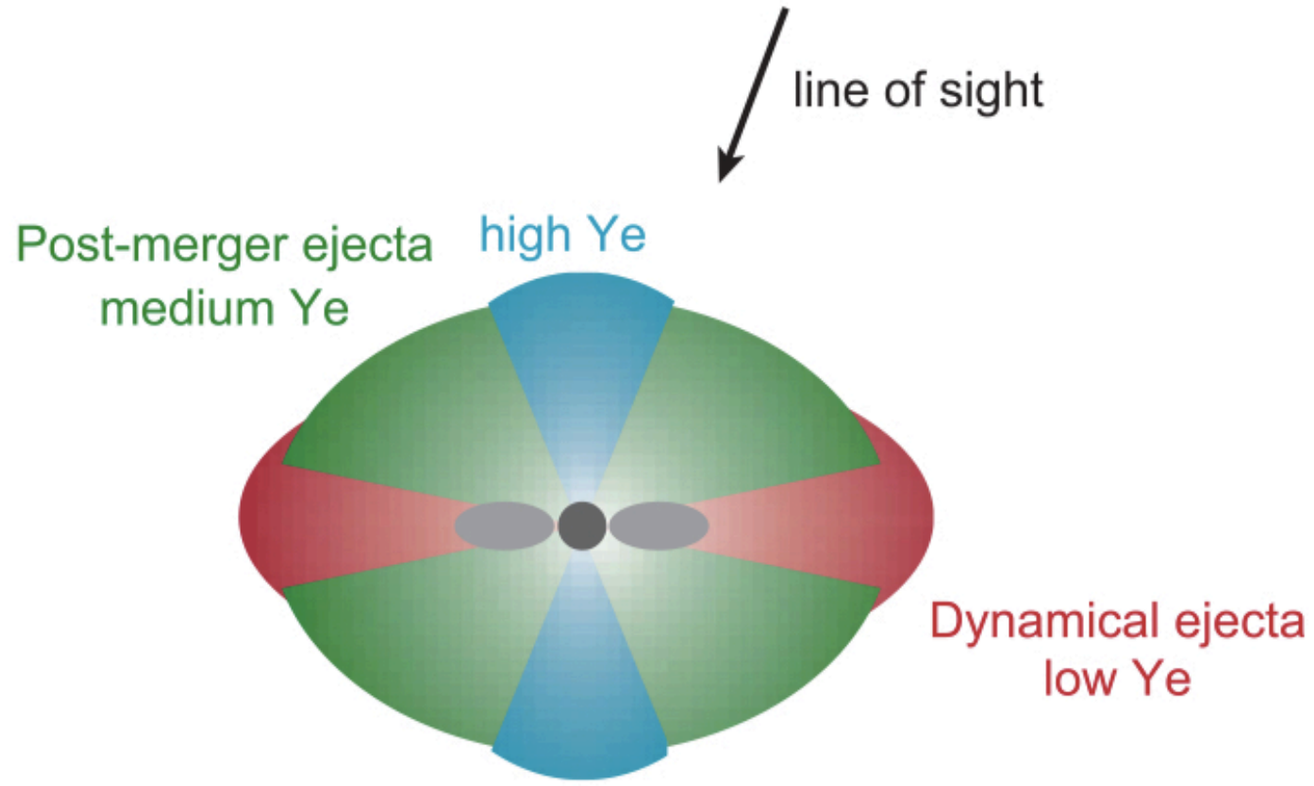
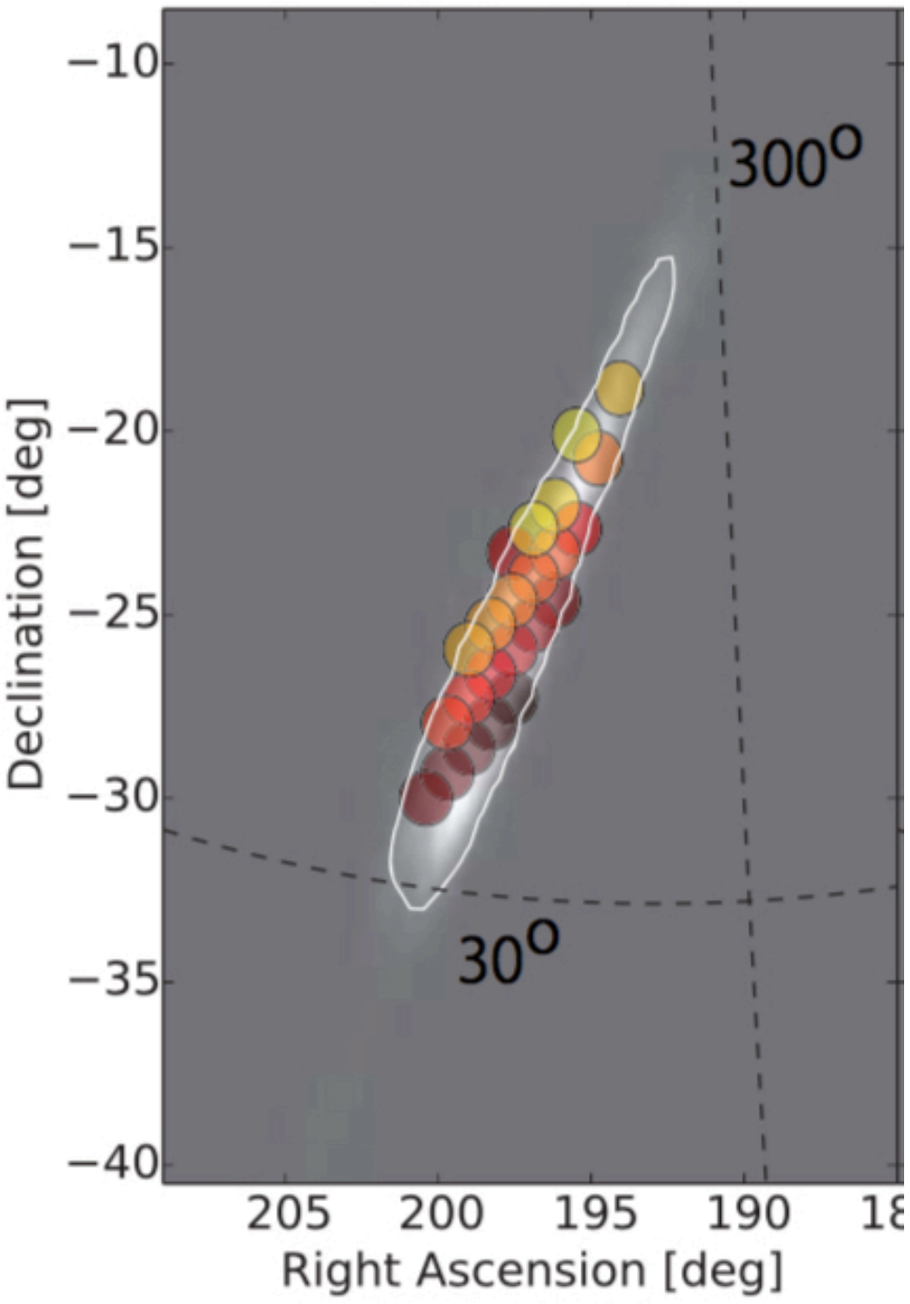


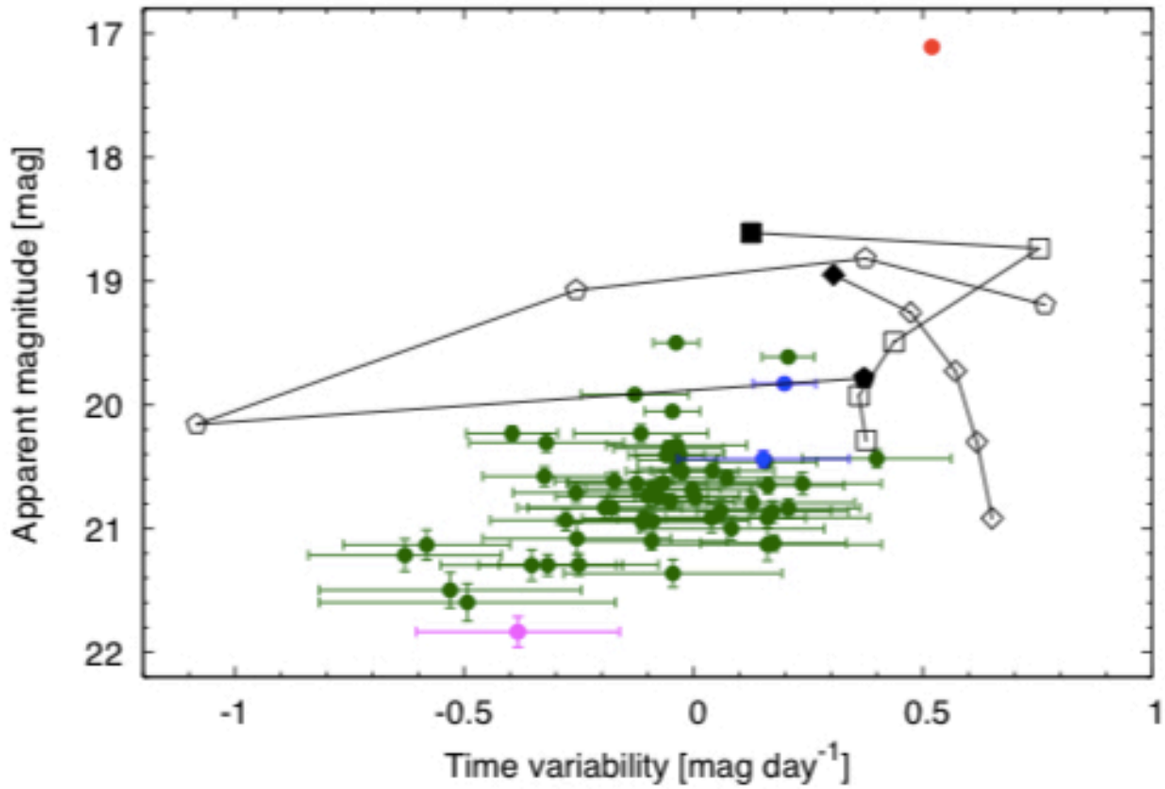
Fig. 4. Schematic picture of the ejecta of the NS merger event GW170817.

- Blue in early phase, becomes red in later phase
- Excess in early phase implies an additional component with high Ye, cocoon?

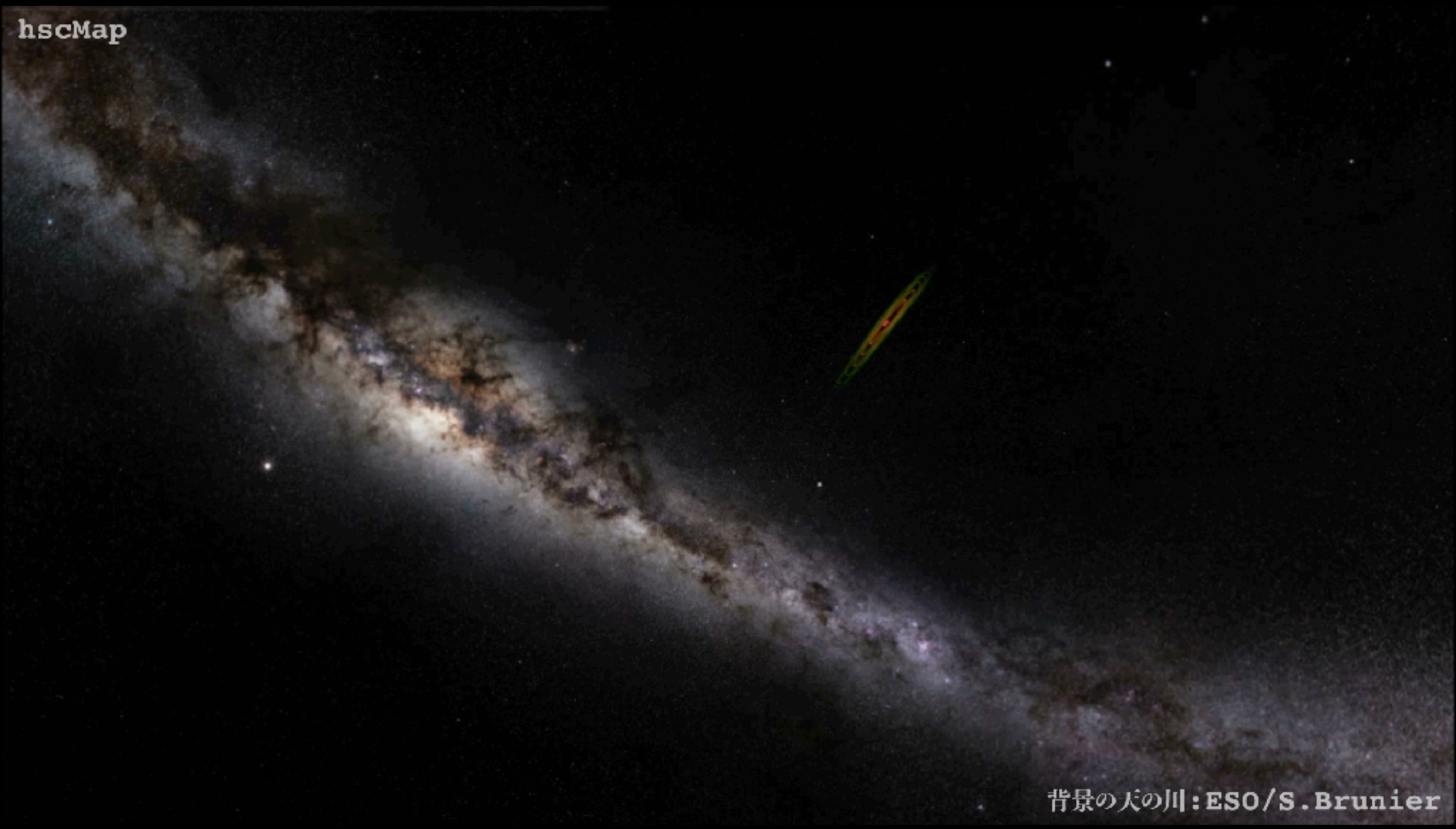
(Tanaka M., UY et al. 2017, PASJ)

HSC survey





- HSC surveyed 23.6deg² (56%) of the localization with depth of z=20.6
- J-GEM17btc(=SSS17a) was distinguished transient
  - rapid decline
  - High probability along with LoS
- Tominaga, N., TM, MT, UY et al. (2018), PASJ



Developed by Koike Michitaro (NAOJ/HSC)

Summary

- J-GEM (Japanese EM community for GW followup)
- SSS17a
  - J-GEM observations reveal SSA17a is a kilonova
    - The first kilonova with GW
  - ~ 2 mag brighter than the standard ejecta model
    - Higher mass ejection? or Cocoon?
  - No other candidate is discovered
- What’s next?
  - **Early phase**: revealing the blue component
  - **Variety**: More events with different masses, mass ratios, viewing angle, also BH-NS mergers
  - **Statistics**: Are BNSs enough to be the origin of r-process elements?

For future

- We appreciate your understanding on the ToO mode, and observatories' flexible supports
  - sudden schedule change
  - software and hardware limit were changed
  - exposure under "twilight flat" condition

- For the coming GW run
  - Minimize dead-time between exposures of the HSC to widen out the localization area
  - Quick reduction and analysis to make a rapid response
    - Computers
    - Network
  - The queue-mode observation software might be helpful