TMT and Gravitational Wave Astronomy

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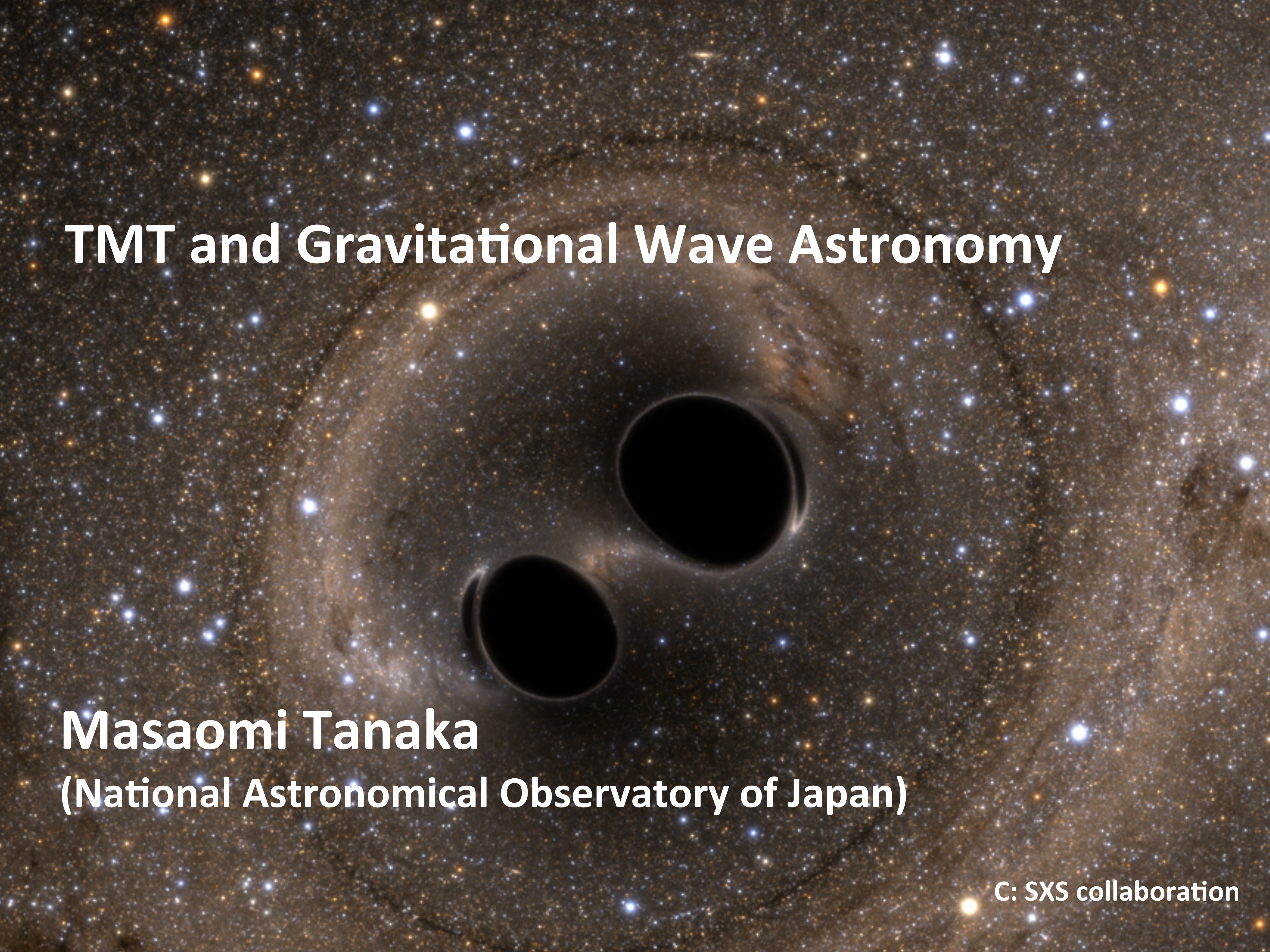
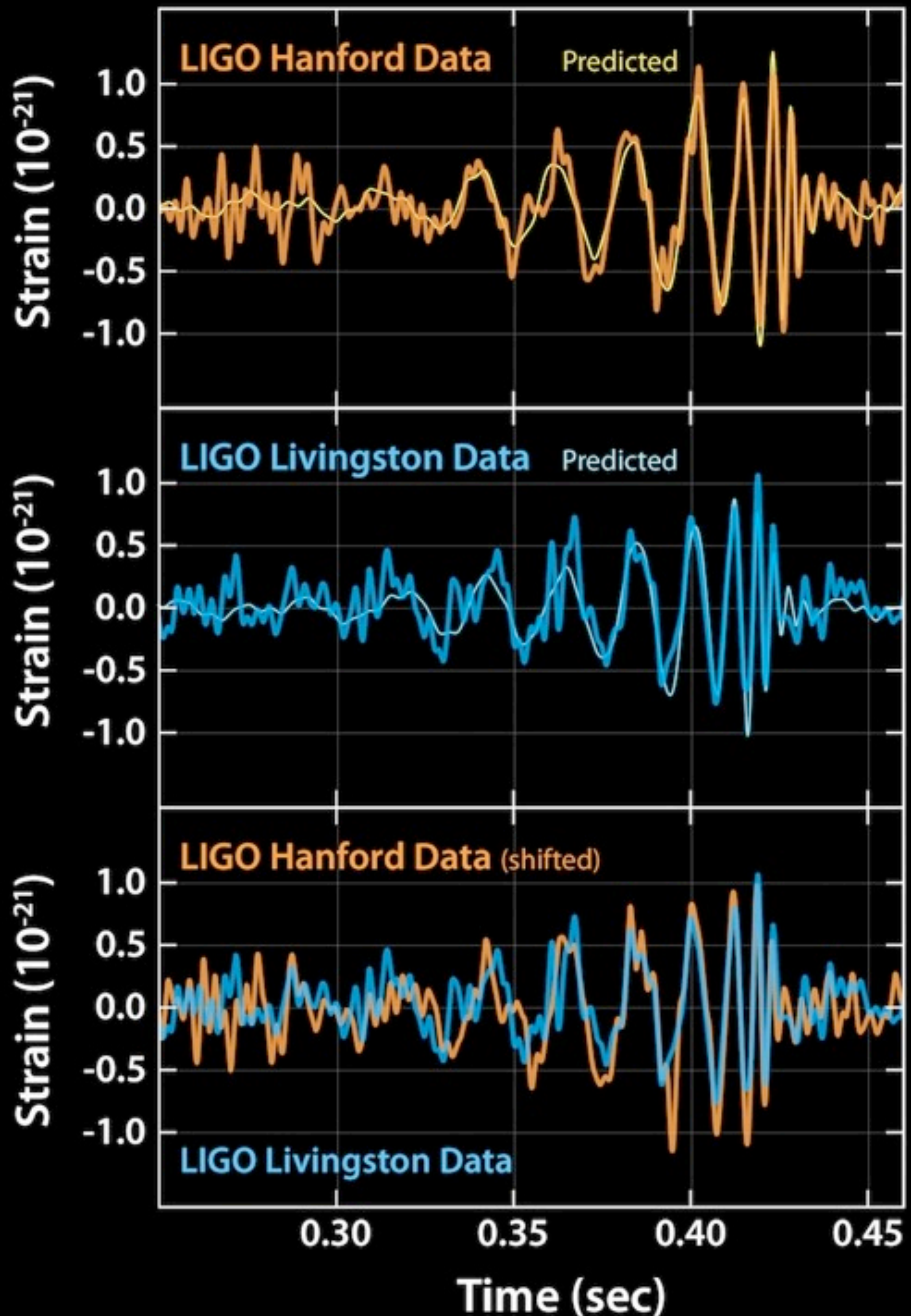


C: SXS collaboration

- GW astronomy => “multi-messenger” astronomy
- EM signals from GW sources
- “Multi-messenger” astronomy with TMT



Dawn of GW astronomy

GW 150914

BH-BH merger

M1 = 36^{+5}_{-4} Msun

M2 = 29^{+4}_{-4} Msun

d = 410 Mpc $^{+160}_{-180}$ Mpc

LIGO Scientific Collaboration
and Virgo Collaboration, 2016, PRL, 061102

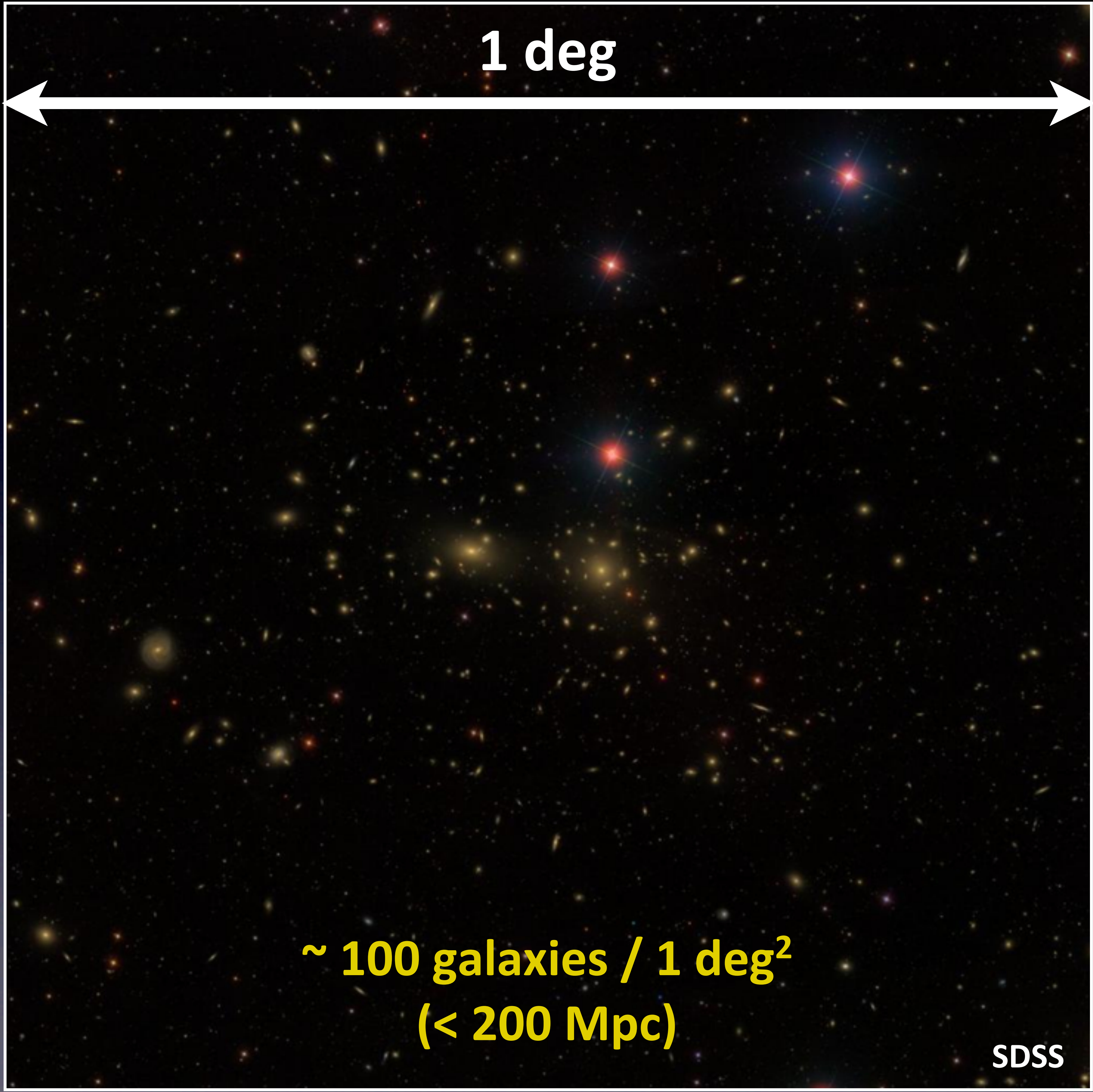
Astrophysical impact of GW150914

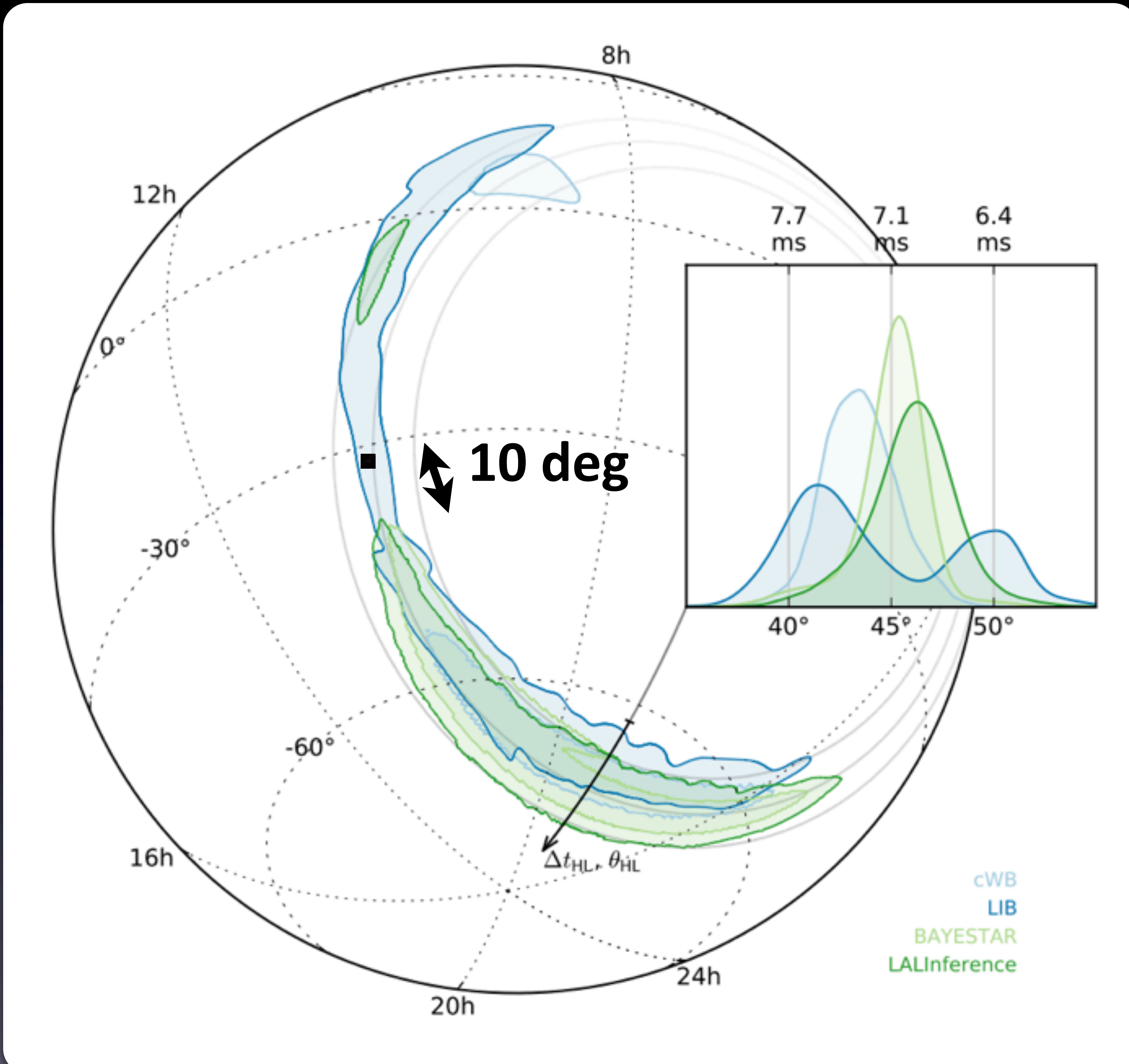
LIGO Scientific Collaboration and Virgo Collaboration, 2016, ApJ, 818, L22

- BH with > 25 Msun does exist
  - Need low metallicity (preventing strong wind)
- BH-BH binary does exist, and
  such binary merges within the Hubble time
  - Progenitor: isolated system? stellar cluster? Pop III?
- Relatively high event rate
  - 2-53 Gpc^3 yr^{-1} (10^{-4} of supernova rate, ~10^5 Gpc^3 yr^{-1})

Environment of such binary?

=> Need to pin down the accurate position


1 deg
~ 100 galaxies / 1 deg^2
(< 200 Mpc)
SDSS



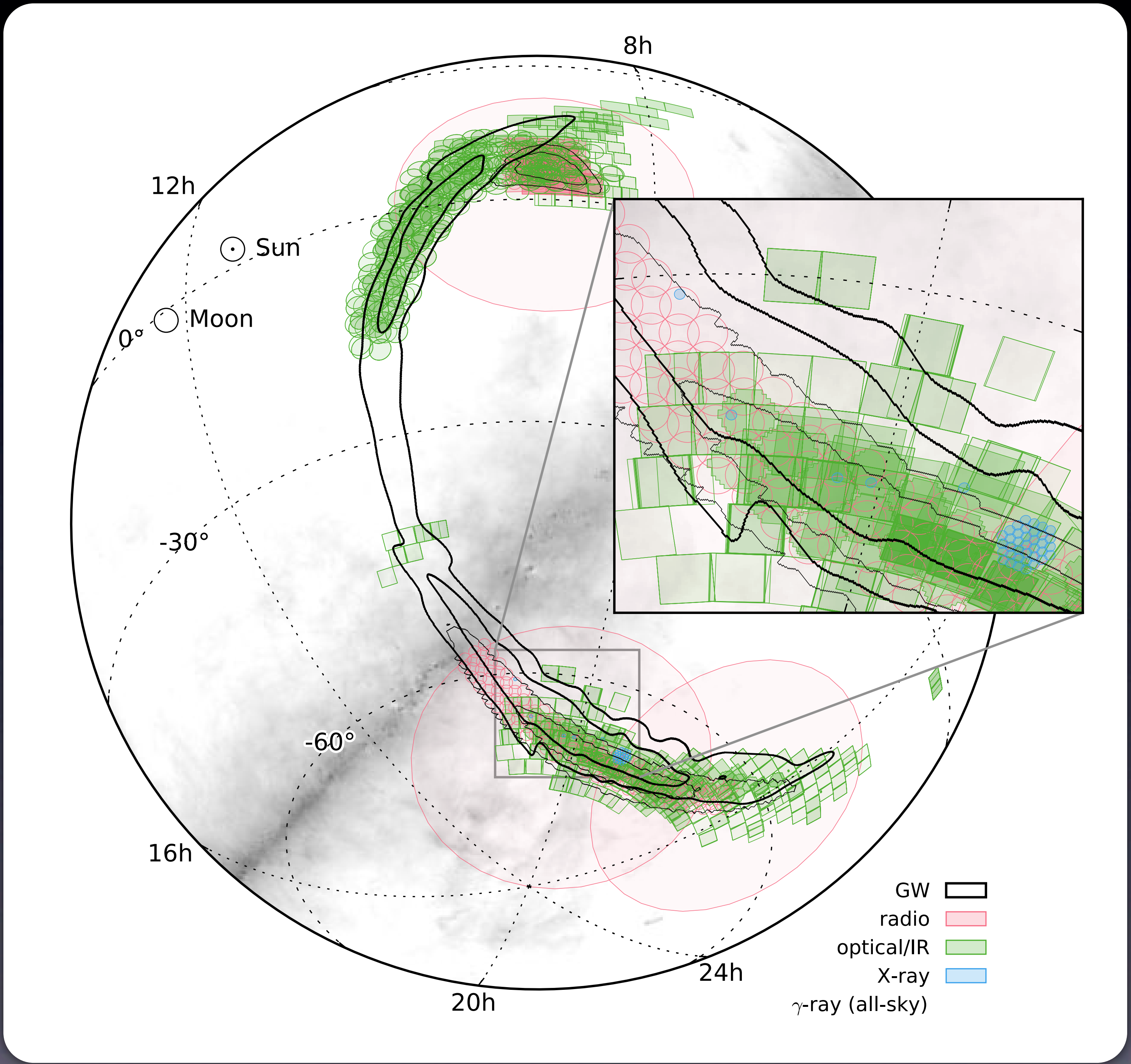
Localization ~ 600 deg^2

Detection of electromagnetic (EM) counterparts is essential

- **Redshift (distance)**
- **Host galaxy**
- **Local environment**

LVC collaboration and EM follow-up groups, 2016, in press, arXiv:1602.08492

GW150914: Electromagnetic follow-up
"multi-messenger" astronomy!



- **No plausible EM counterpart**

Except for possible Fermi/GBM detection (arXiv:1602.03920), but non detection w/ INTEGRAL (arXiv:1602.04180)

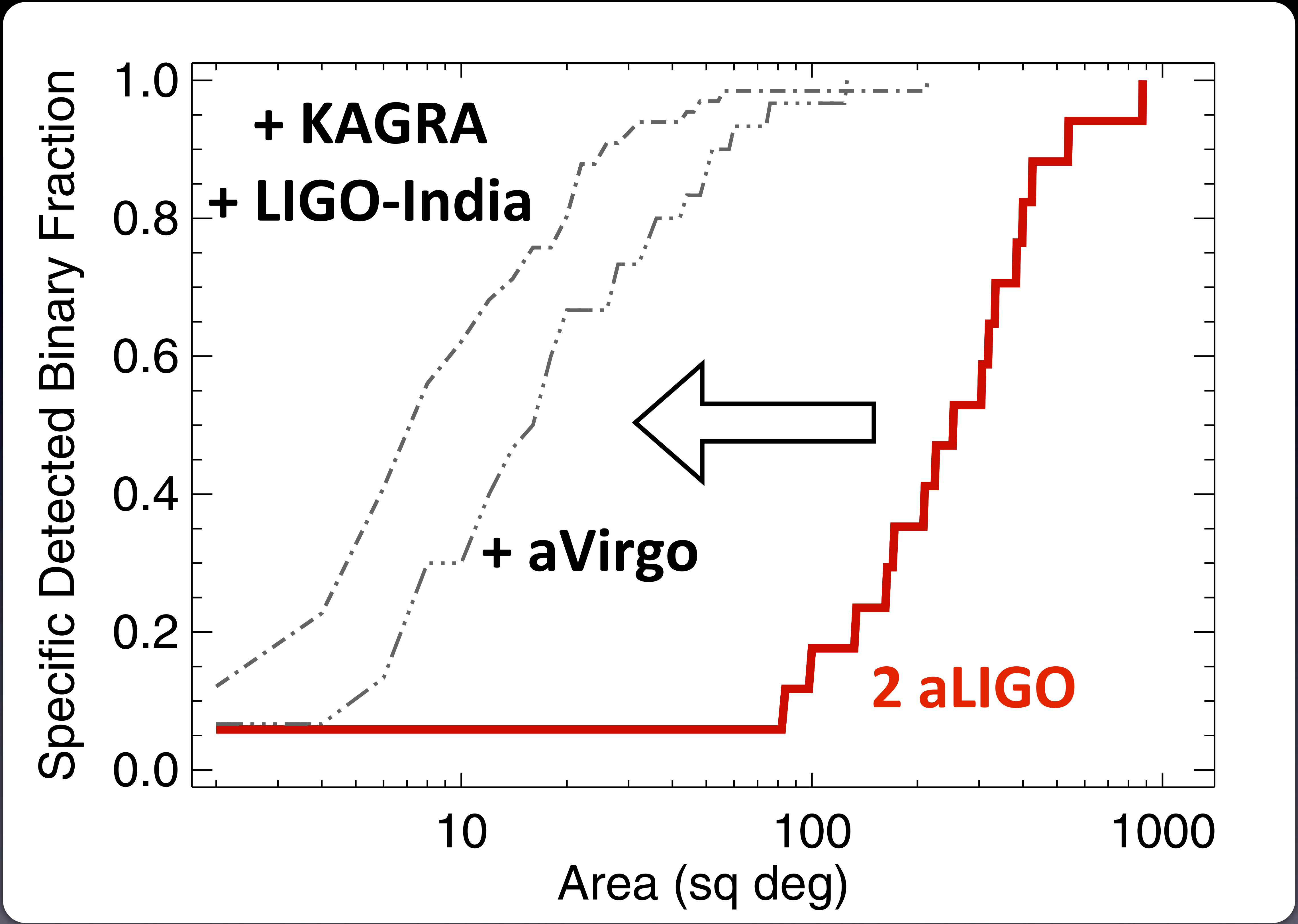
- **EM emission from BH-BH merger??**

(e.g., Nakamura+2016)

LVC collaboration and EM follow-up groups, 2016, in press, arXiv:1602.08492

Advanced GW detectors

More opportunities for EM observations



Kasliwal & Nissanke 2014

- GW astronomy => “multi-messenger” astronomy
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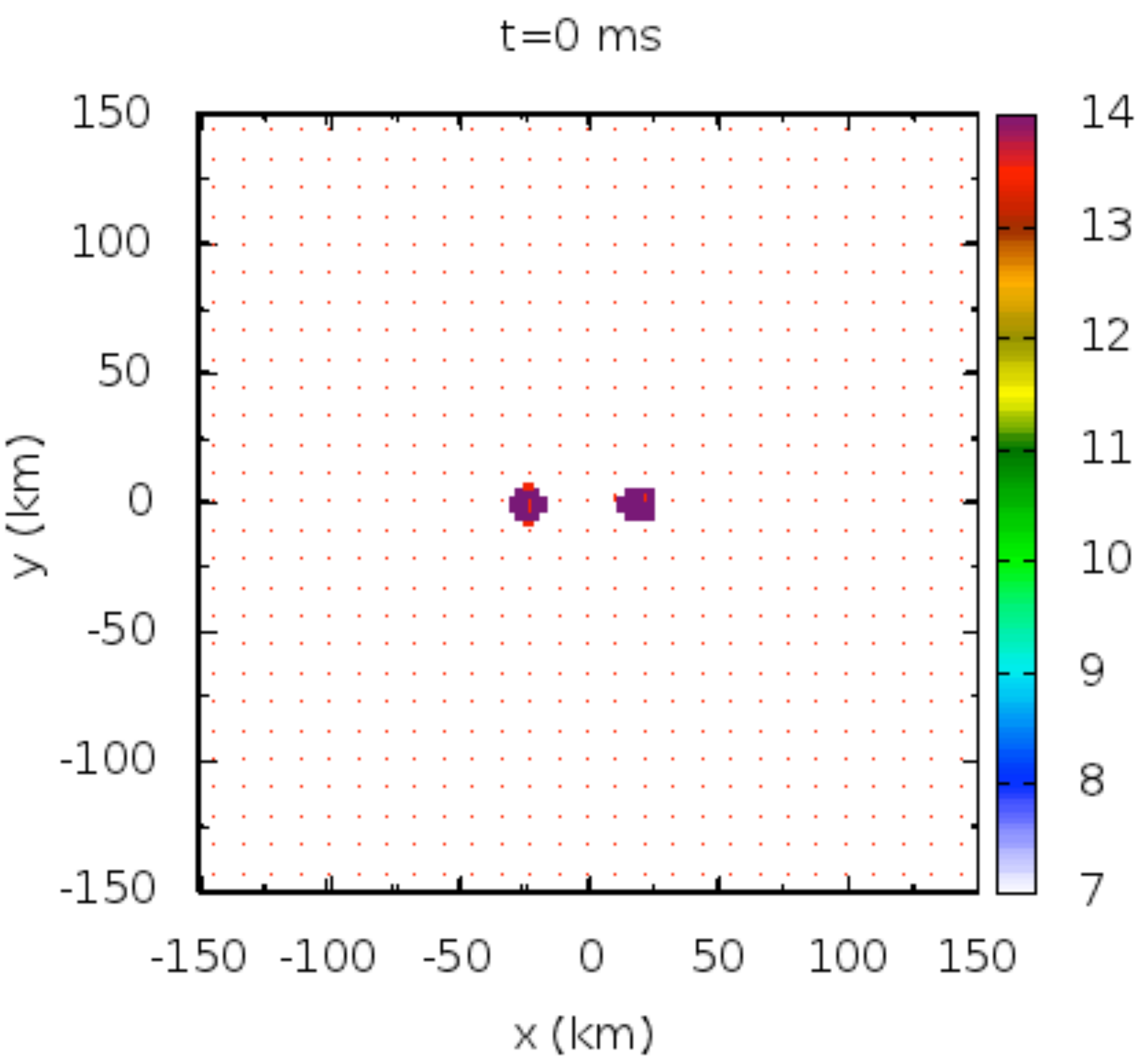
NS-NS merger
(or NS-BH merger)

NS-NS merger (~< 200 Mpc)
BH-NS merger (~< 800 Mpc)
~30 (0.3-300) events/ 1 yr



Mass ejection

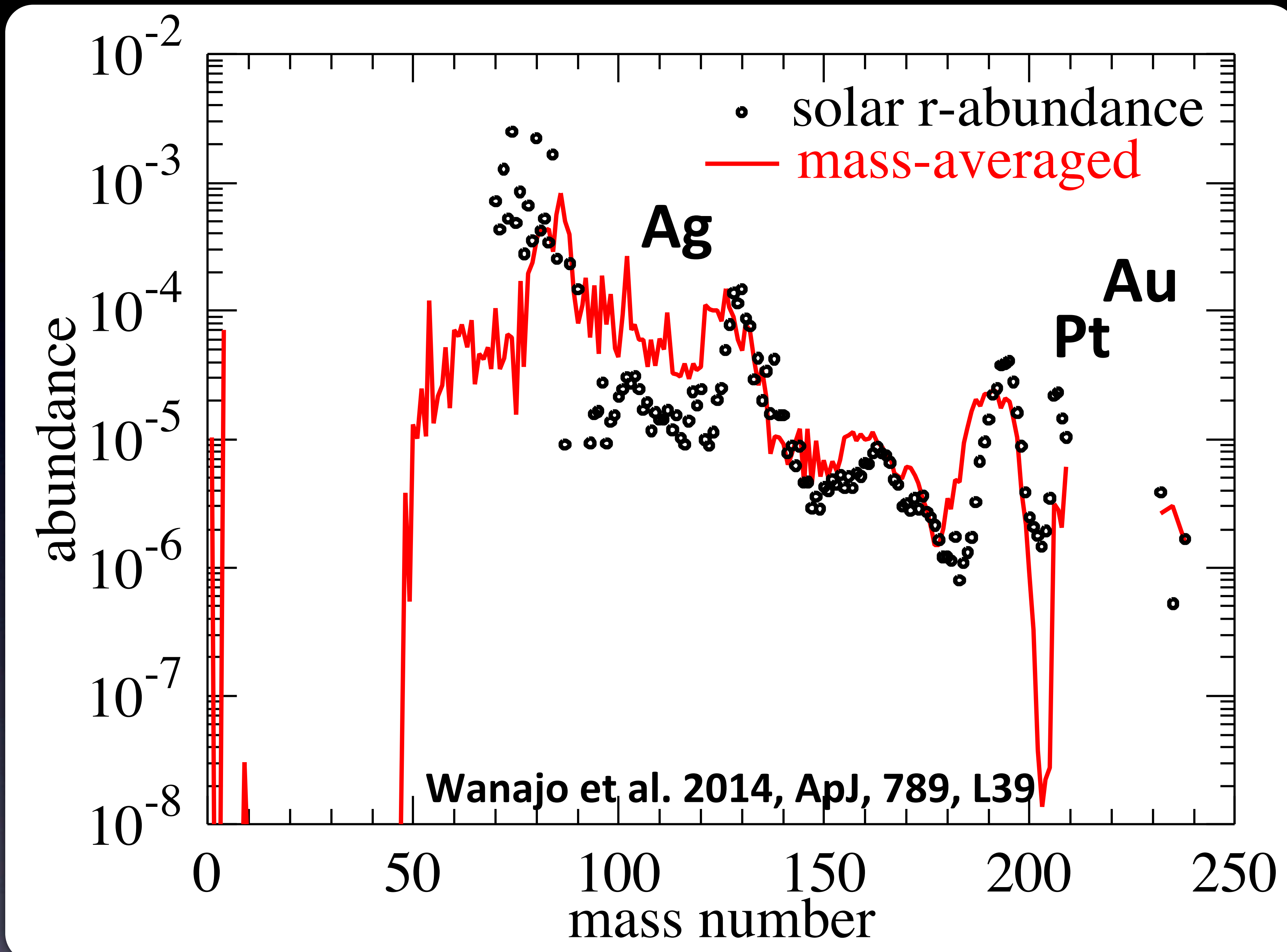
M ~ 10^{-3} - 10^{-2} Msun

v ~ 0.1 - 0.2 c

=> electromagnetic emission

Hotokezaka+13, PRD, 87, 4001
Rosswog+13, MNRAS, 430, 2580

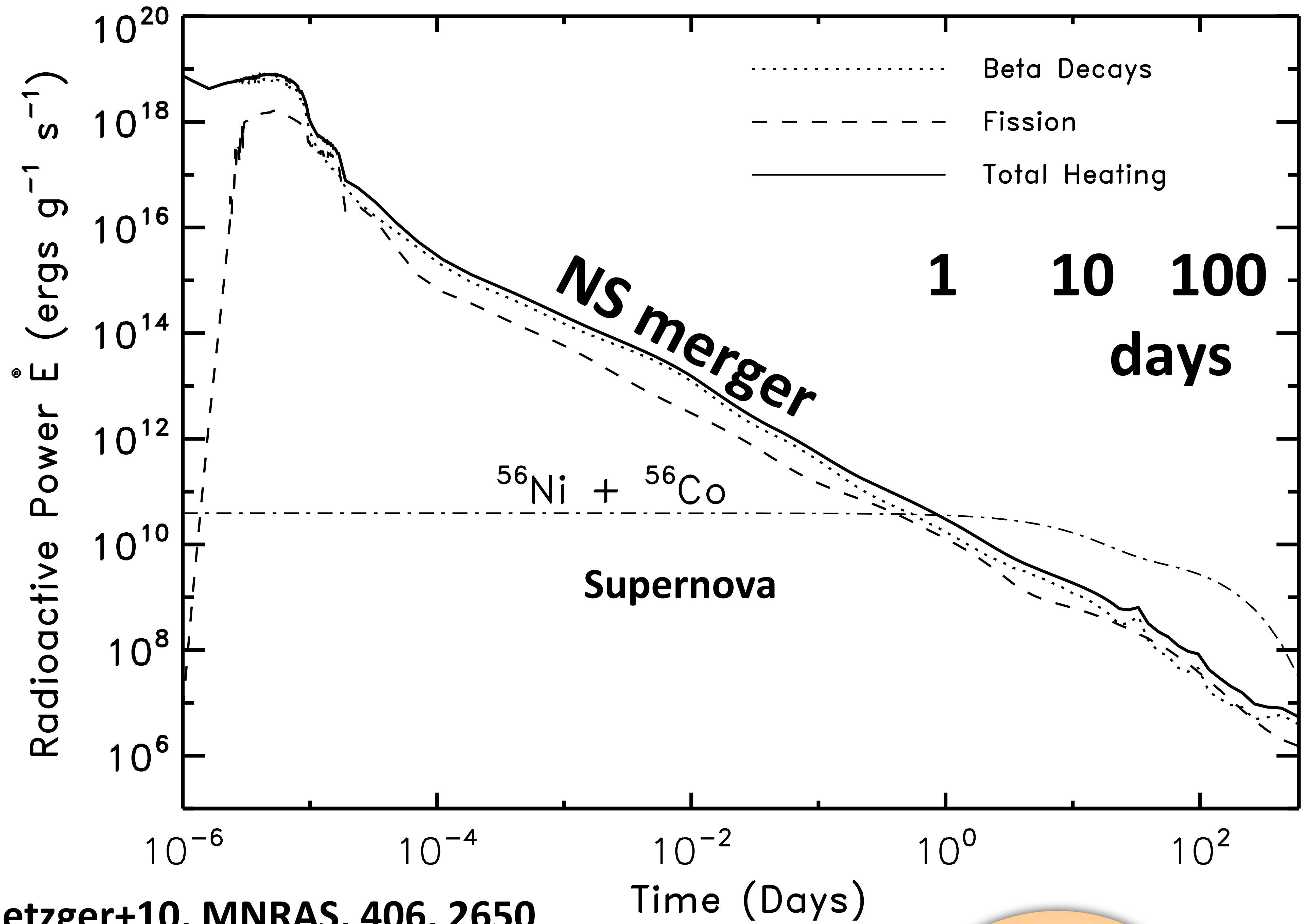
r-process nucleosynthesis



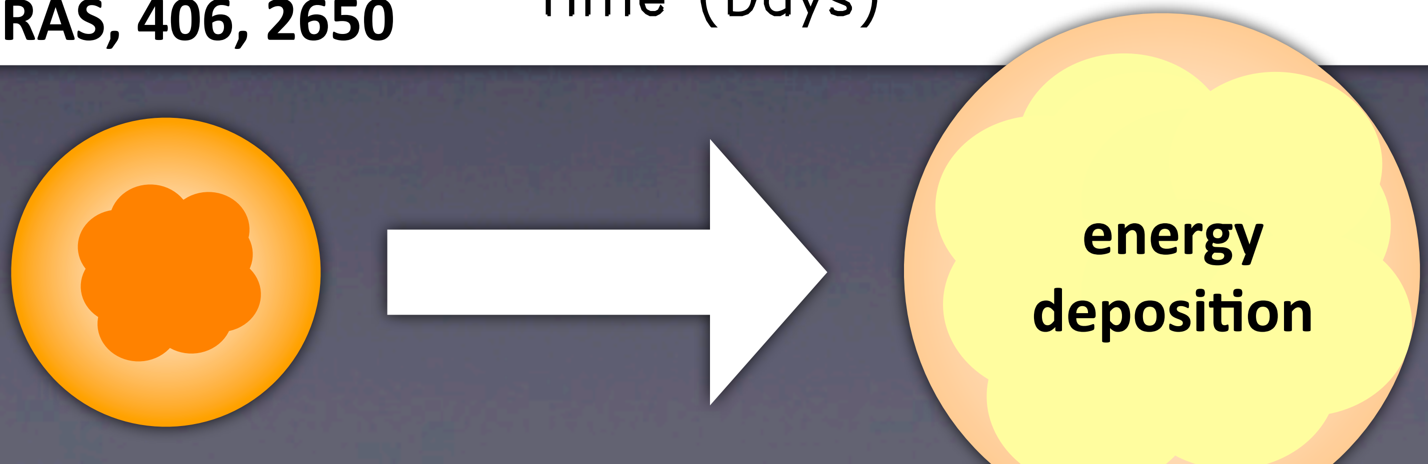
NS merger can be the origin of r-process elements

- Event rate ~ 10^{-4} events/yr/Galaxy (<= GW)
- Mass ejection ~ 10^{-2} Msun/event (<= Opt/IR)

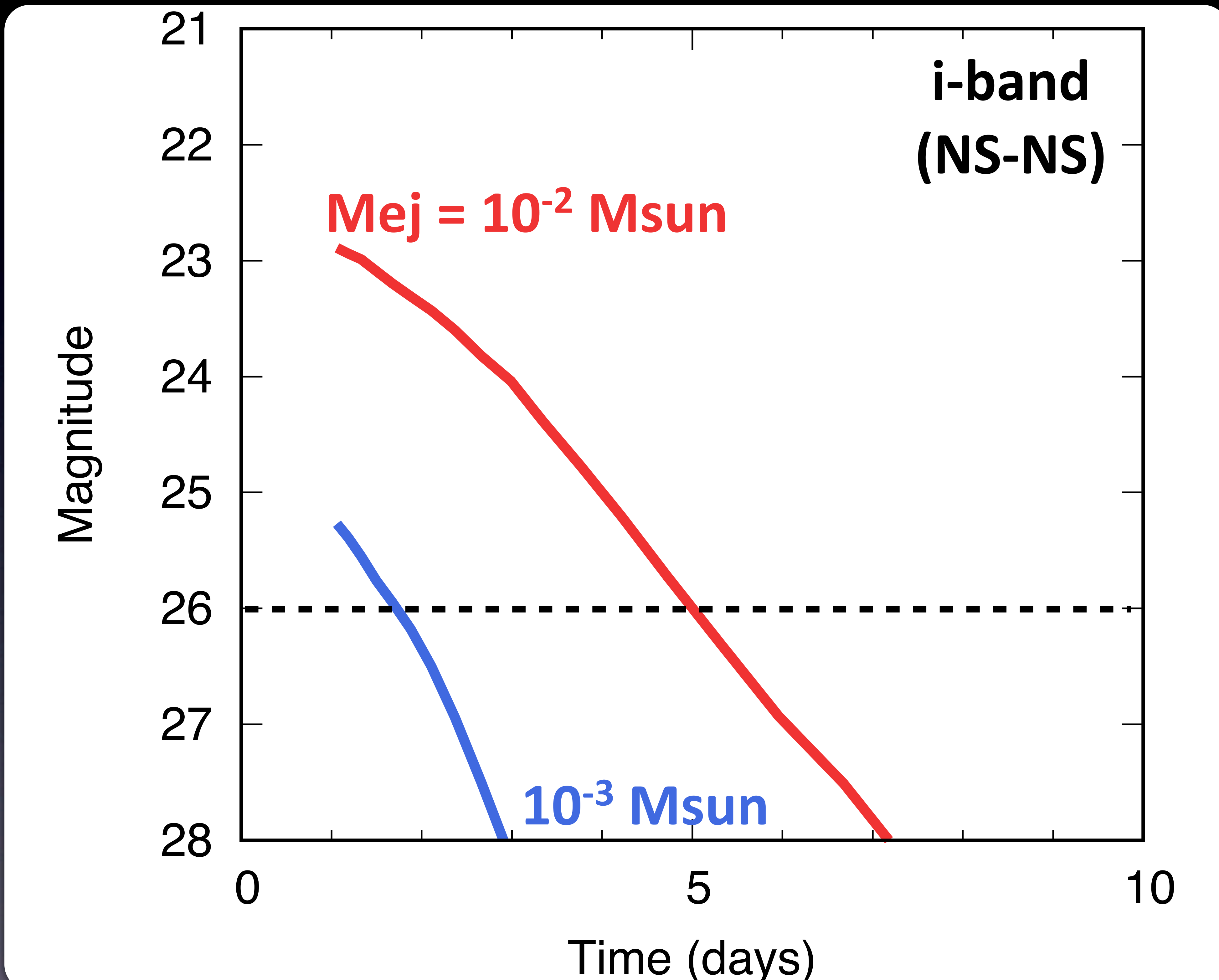
Radioactive energy => optical/IR emission



Metzger+10, MNRAS, 406, 2650



Brightness of "kilonova" @ 200 Mpc



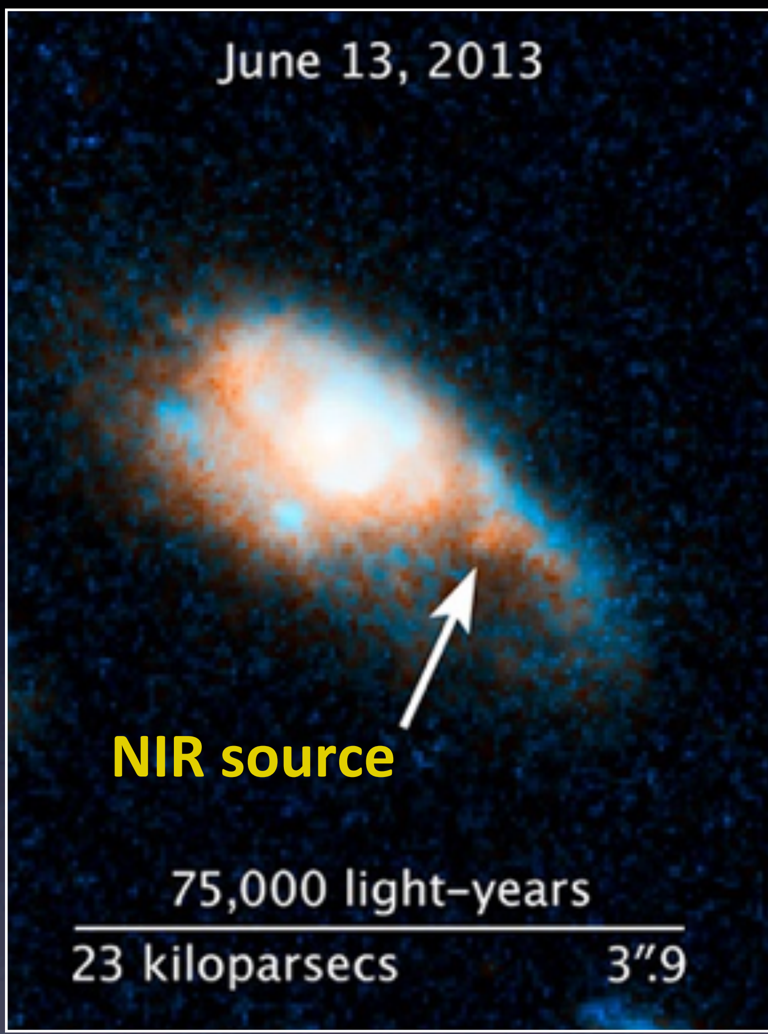
* SED peaks at red optical/NIR (T ~ 3000 K)

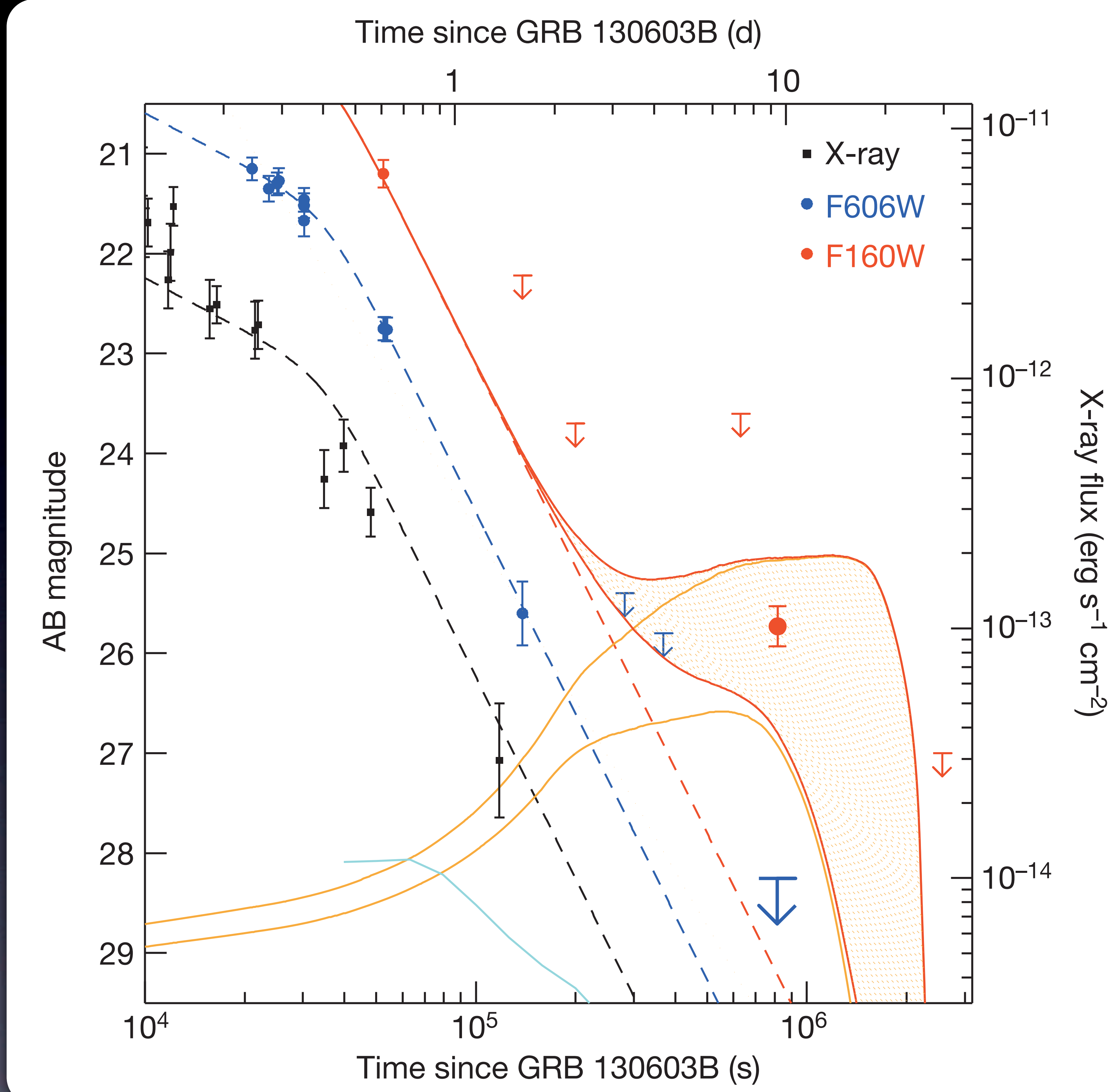
*brighter than 26 mag only for 2-5 days (time-domain!)

MT & Hotokezaka 2013 (see also Kasen+2013, Barnes & Kasen 2013)

GRB 130603B

(short GRB <= NS merger)

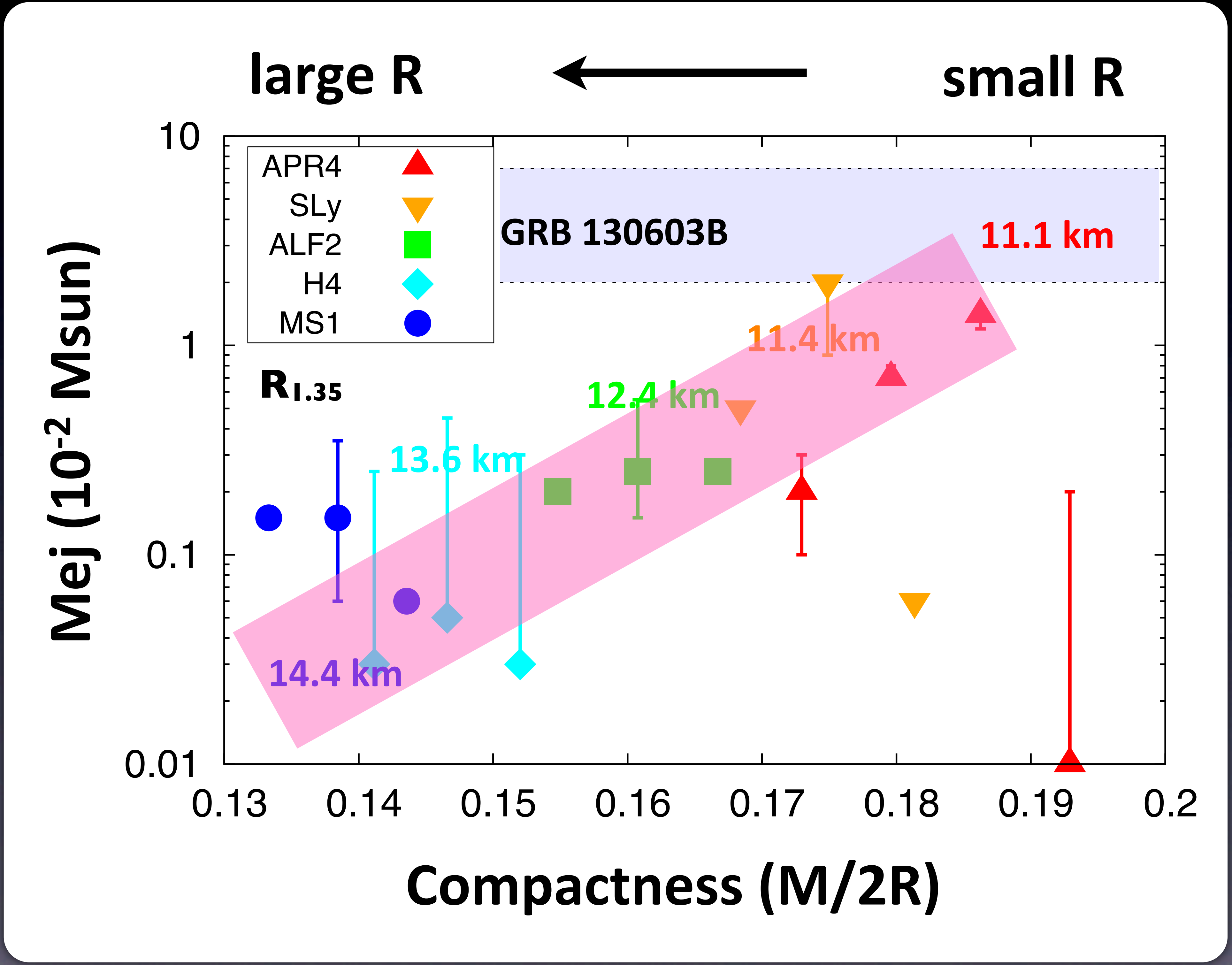




Tanvir+2013, Nature, 500, 547
Berger+2013, ApJ, 774, L23

As expected by theoretical models!
==> ejection of ~0.02 Msun

A new probe for high-density matter (or NS radius)



Hotokezaka, Kyutoku, MT+ 2013

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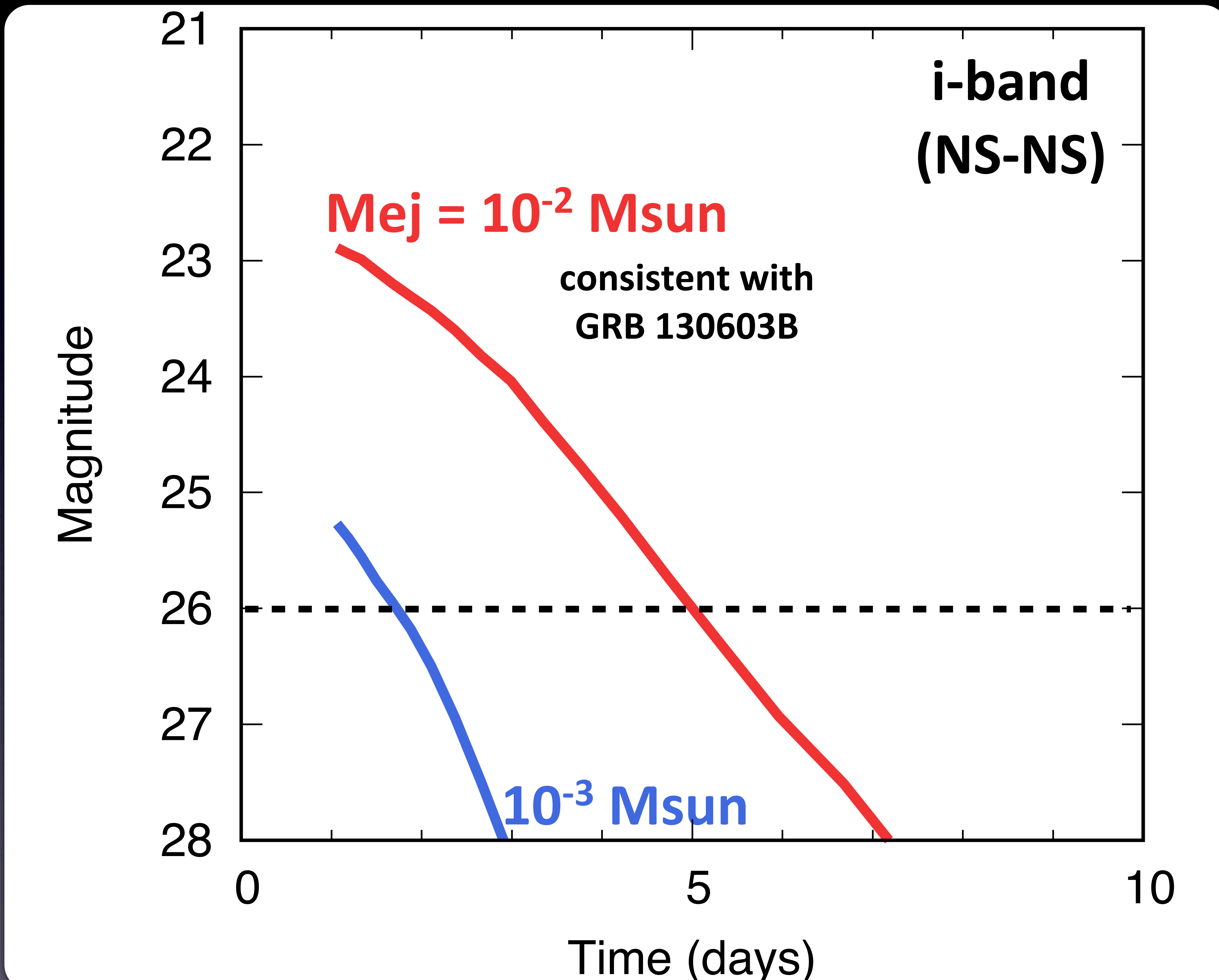
Brightness of “kilonova” @ 200 Mpc



* If the event rate is high, we also have events at ~100 Mpc

MT & Hotokezaka 2013 (see also Kasen+2013, Barnes & Kasen 2013)

GW alert error
e.g. 6 deg x 6 deg
(not box shape in reality)

GW detection

EM transient search
w/ wide-field telescope
(e.g., HSC, LSST and WFIRST)

Source identification
(TMT)

Subaru
HSC
1.5 deg

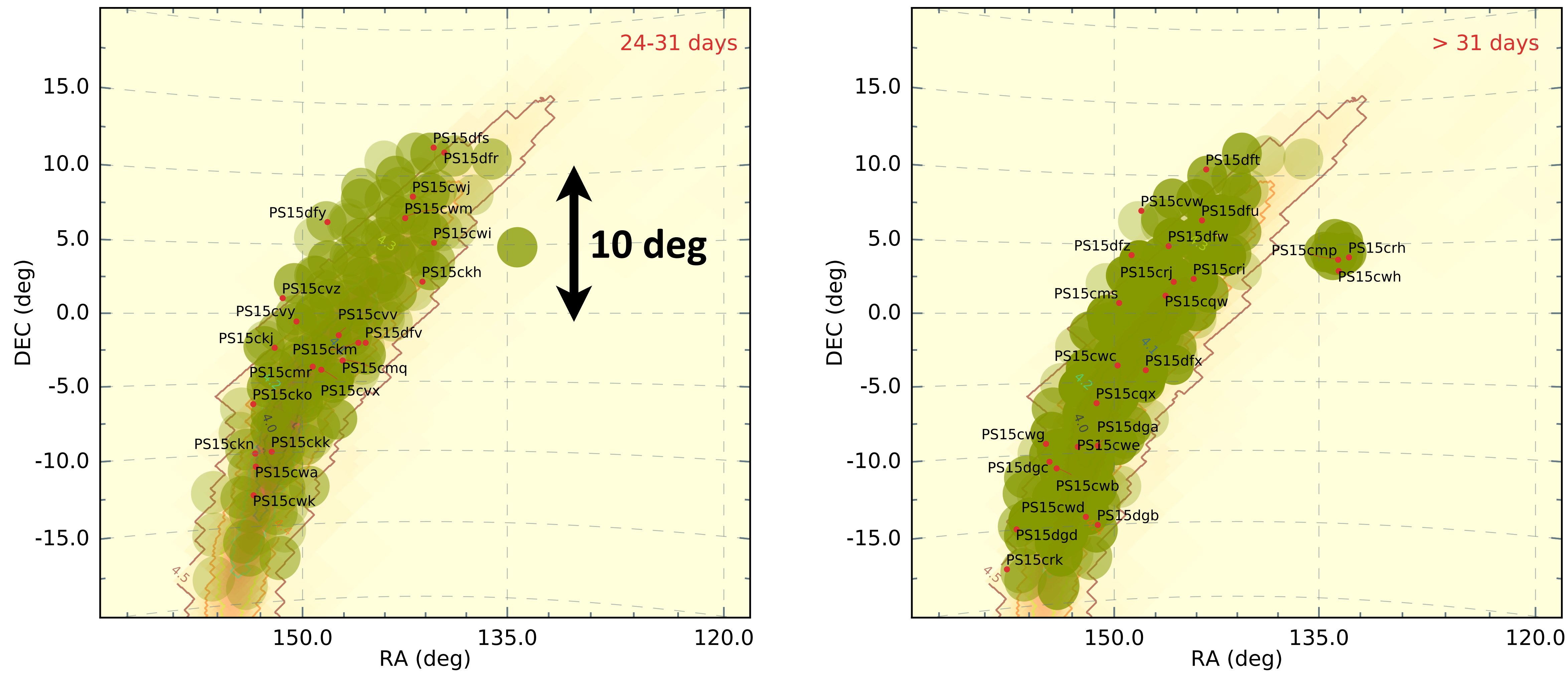
LSST
3.5 deg

Typical FOV size (~8m class)

Spectroscopy is essential

Follow-up for GW150914

Pan-STARRS and PESSTO (i ~20 mag)

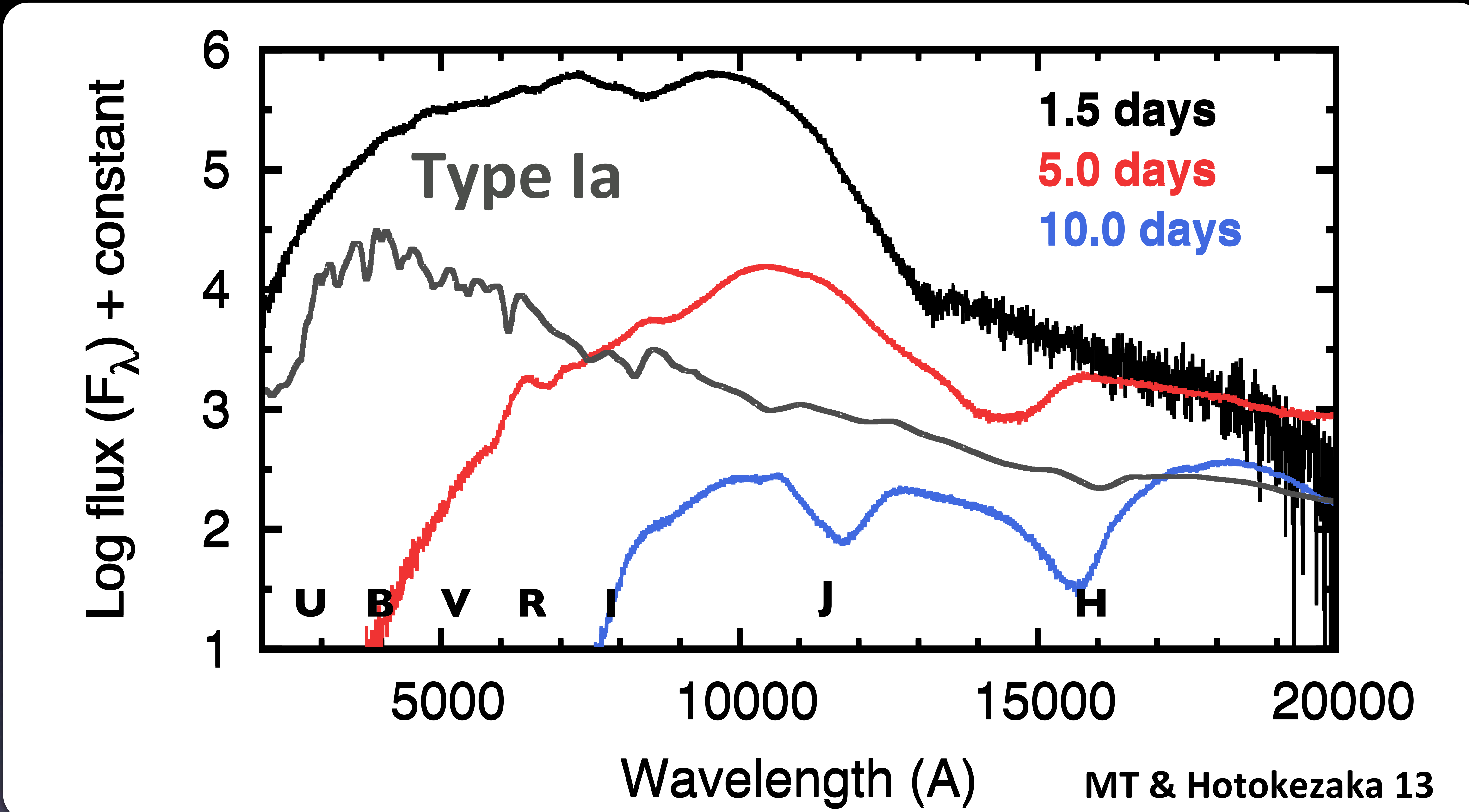


Smartt et al. 2016 (see also Kasliwal et al. 2016; Soares-Santos et al. 2016; Morokuma et al. 2016)

50 deg^2 survey w/ 25 mag depth → >~ 1000 supernovae and 1 GW source!

Selection by timescale, color, brightness, ...

Smoking gun: spectroscopic identification

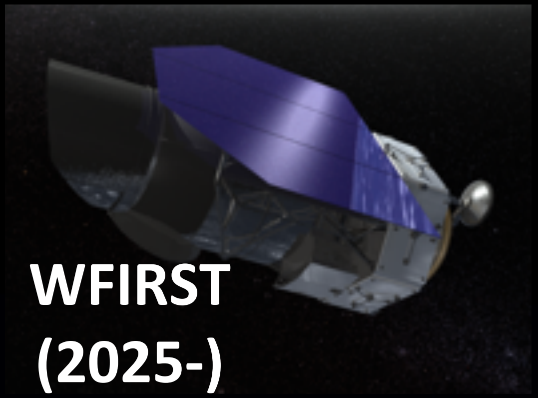


NS merger: extremely broad-line (v ~ 0.1-0.2c), red spectra (lanthanide)

- Optical/NIR spectroscopy with WFOS+IRIS
- Rapid instrument exchange,
  and flexible ToO (< hr)   <= 48 hr for JWST

GW detection

EM search



"Multi-messenger" astronomy

<u>**New opportunities**</u>

- Origin of r-process elements
- High-density matter
- Hubble constant (N. Suzuki's talk)
- ...

Identification

Summary

- GW and “Multi-messenger” astronomy
- EM signals from GW sources
  - Faster and fainter than supernovae
  - 22-26 mag at 200 Mpc for ~5 days
- TMT in the era of “multi-messenger” astronomy
  - Spectroscopic identification is crucial
  - Opens new opportunities to study
    - Origin of r-process elements
    - High-density matter
    - ...