重力波天体からの電磁波放射

Electromagnetic Emission from Gravitational Wave Source

田中 雅臣

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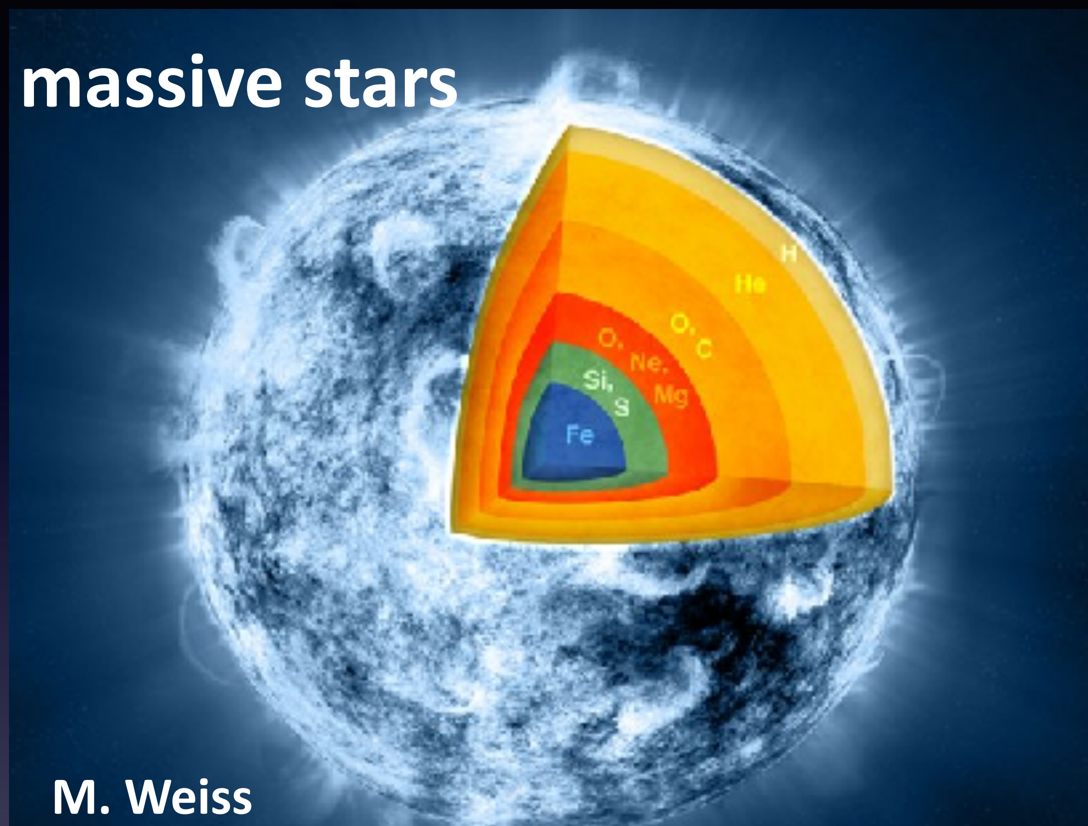
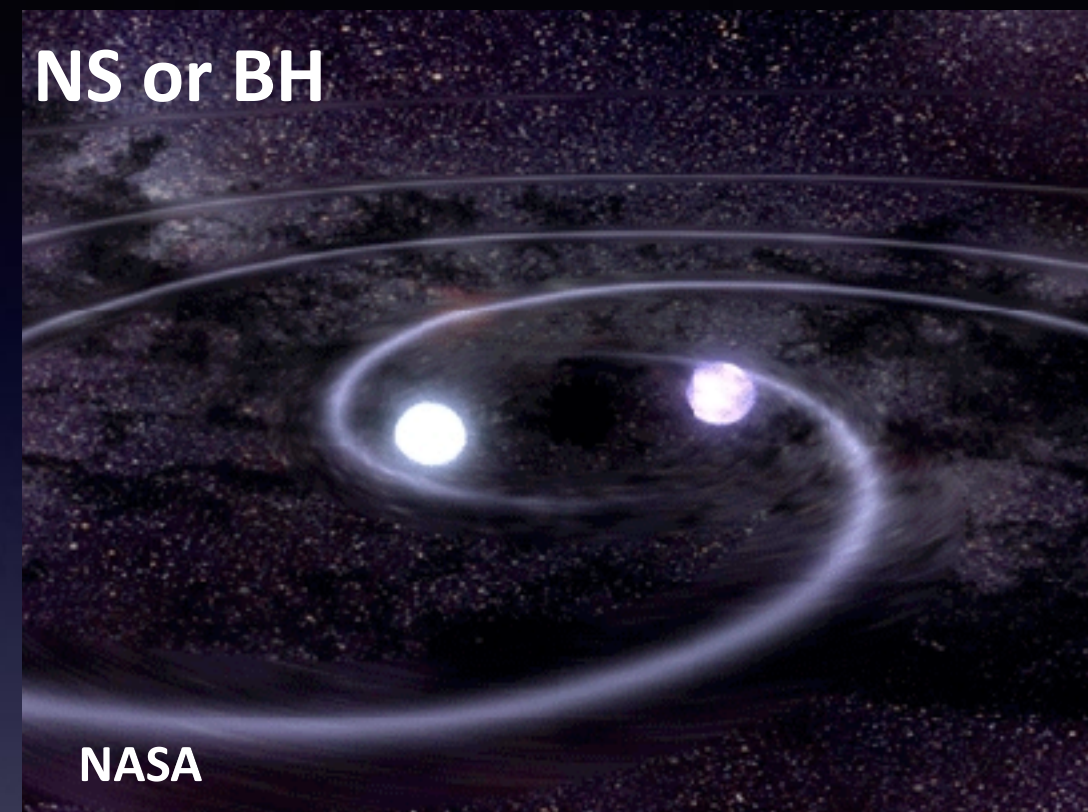
(National Astronomical Observatory of Japan)

GW sources

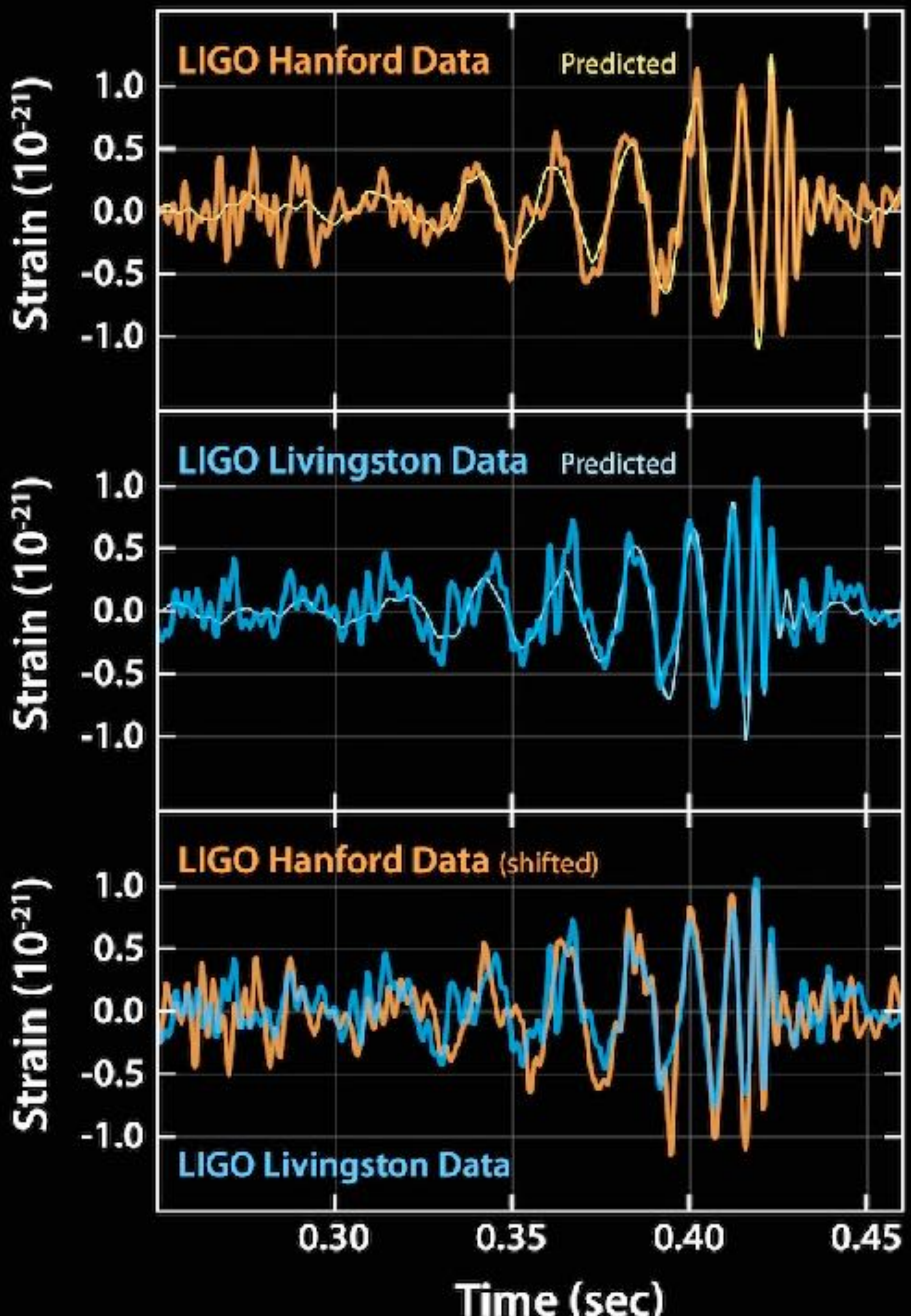
Supernova



Compact binary merger



	Supernova	Compact binary merger
Rate	~ 0.01-0.02 yr^{-1} Gal^{-1}	NS-NS: ~ 10^{-4} yr^{-1} Gal^{-1} BH-NS/BH-BH: ~ 10^{-6} yr^{-1} Gal^{-1}
Distance	Galactic	Extragalactic d ~100 Mpc - 1Gpc z~ 0.02-0.2
Expected number	~ 0.01-0.02 events yr^{-1}	~ 0.1-100 events yr^{-1}

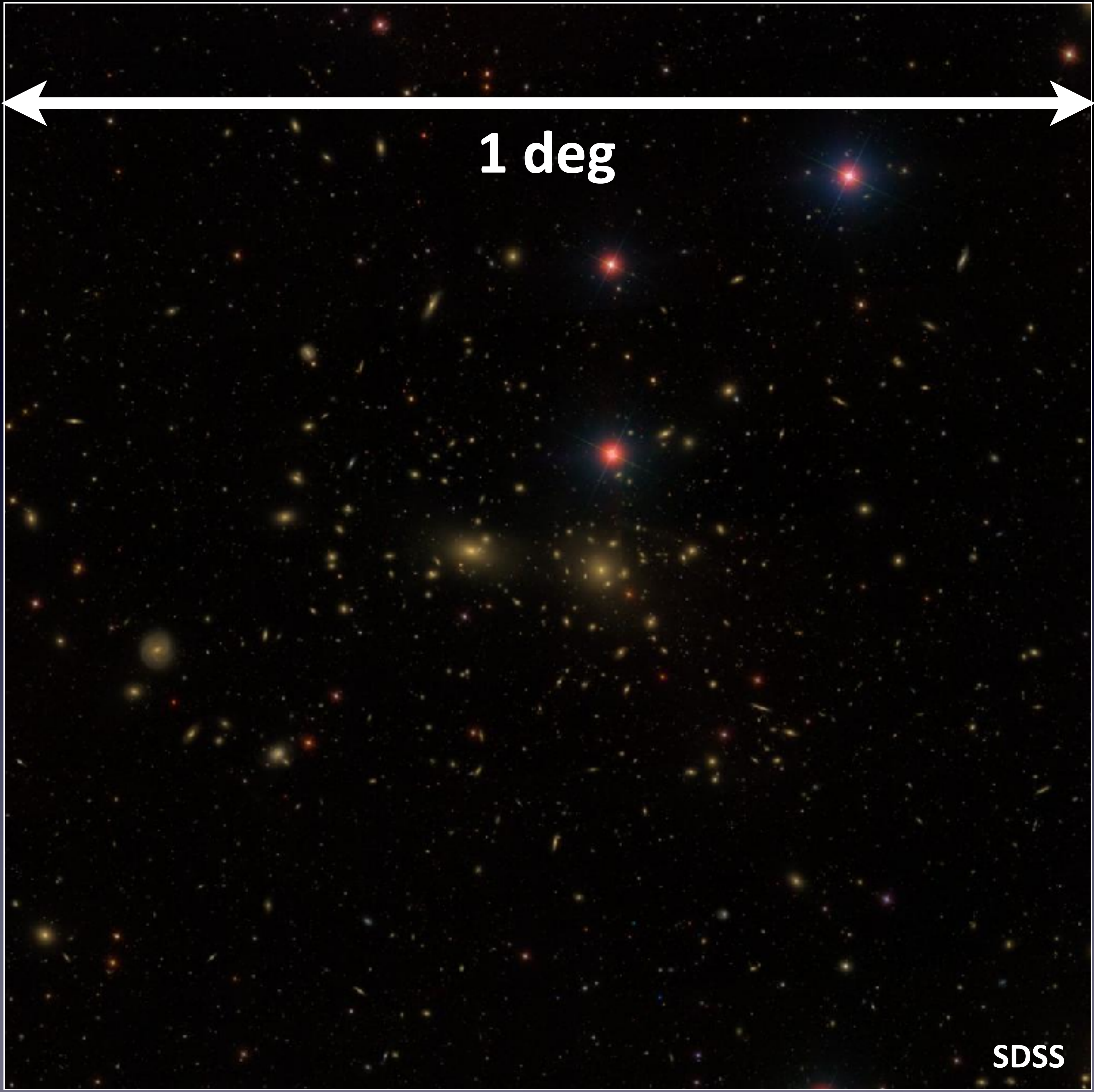


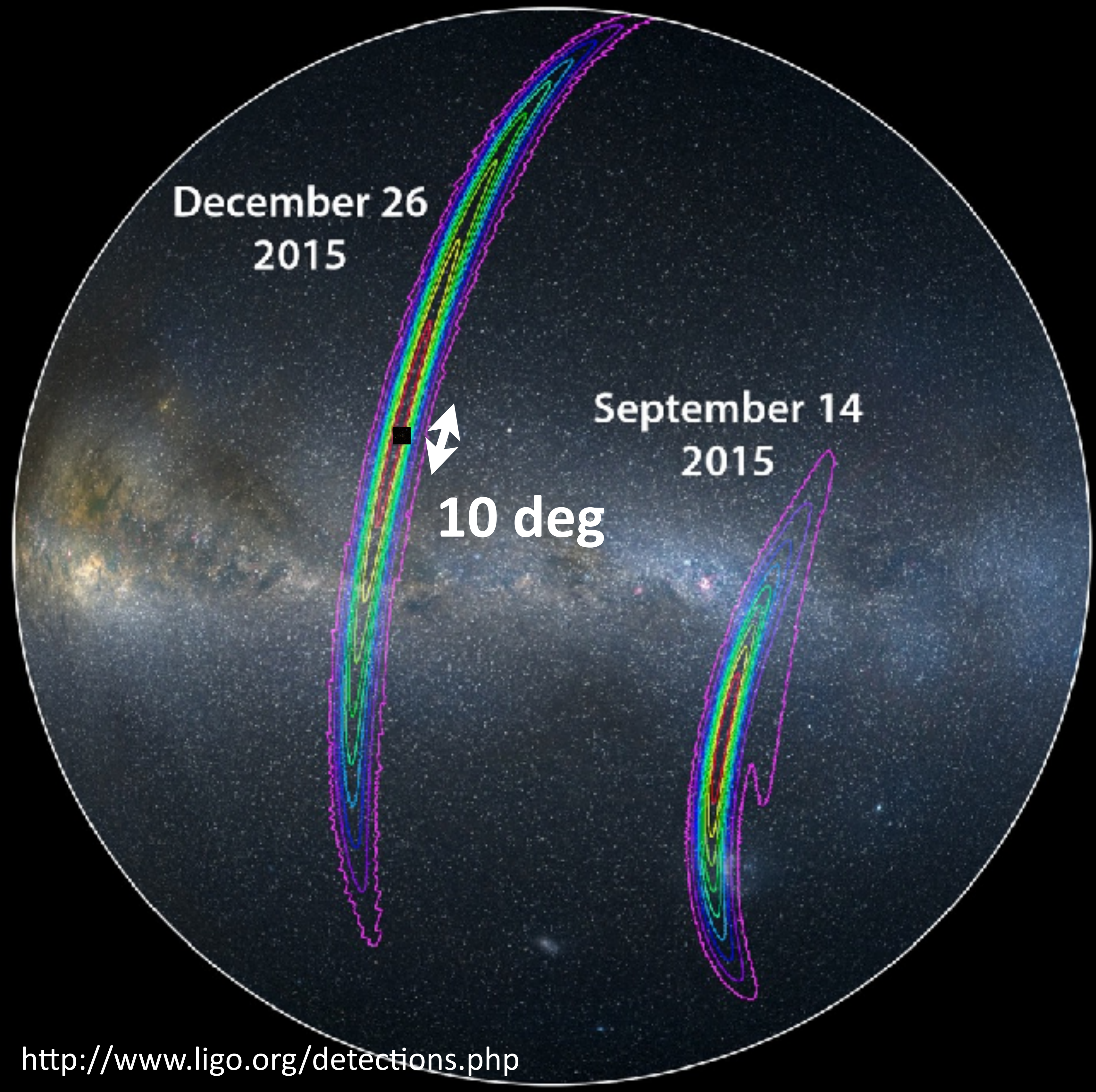
The first detection!!

- Direct proof of GWs
- Existence of ~30 Msun BH
- Existence of 30 Msun BH binary

=> Kanda-san's talk

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


1 deg
SDSS



GW150914

Localization ~ 600 deg^2

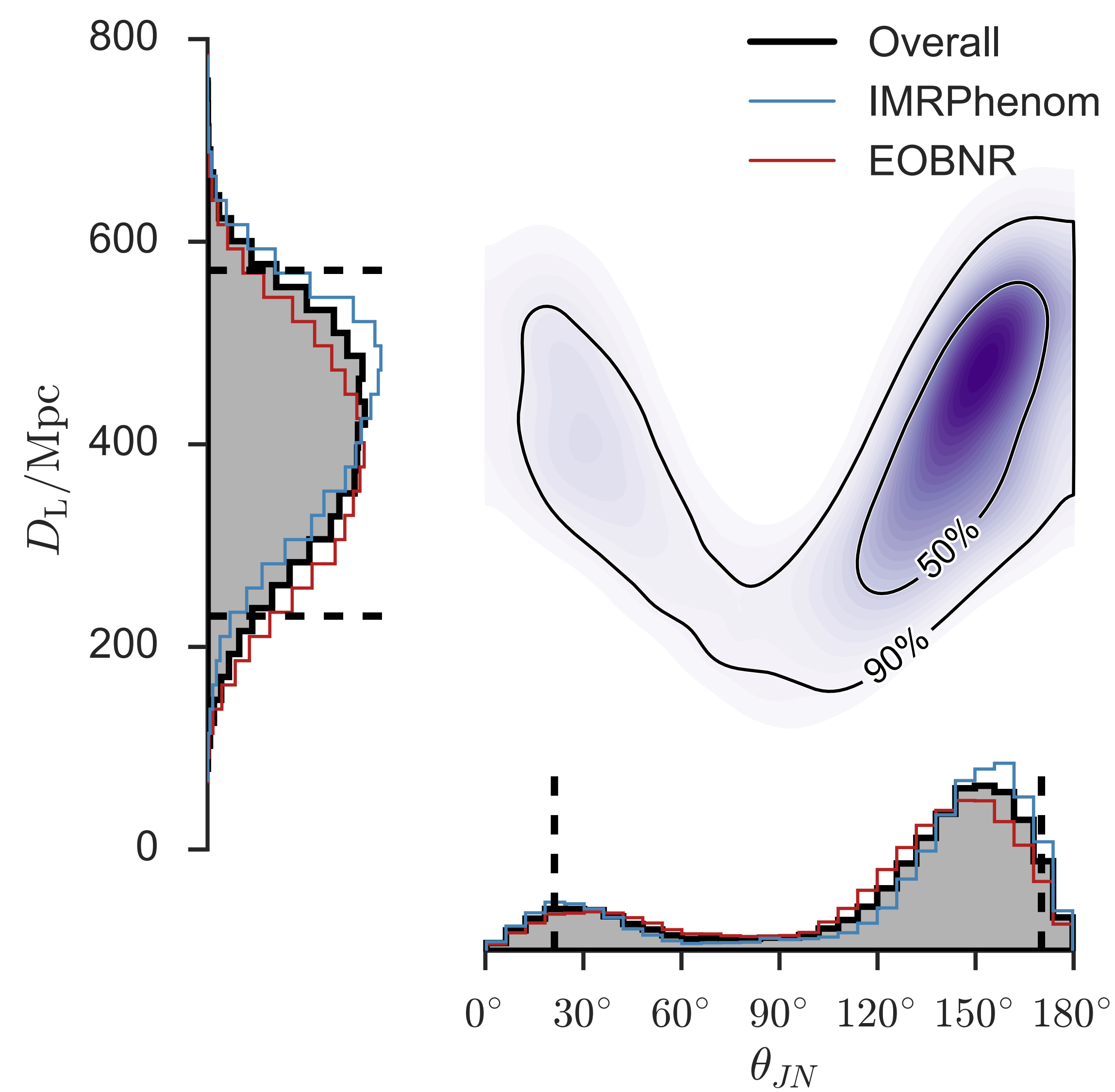
(~< 10 deg^2 with Advanced Virgo and KAGRA)

Electromagnetic (EM) counterparts

- Redshift (distance)
- Host galaxy
- Local environment

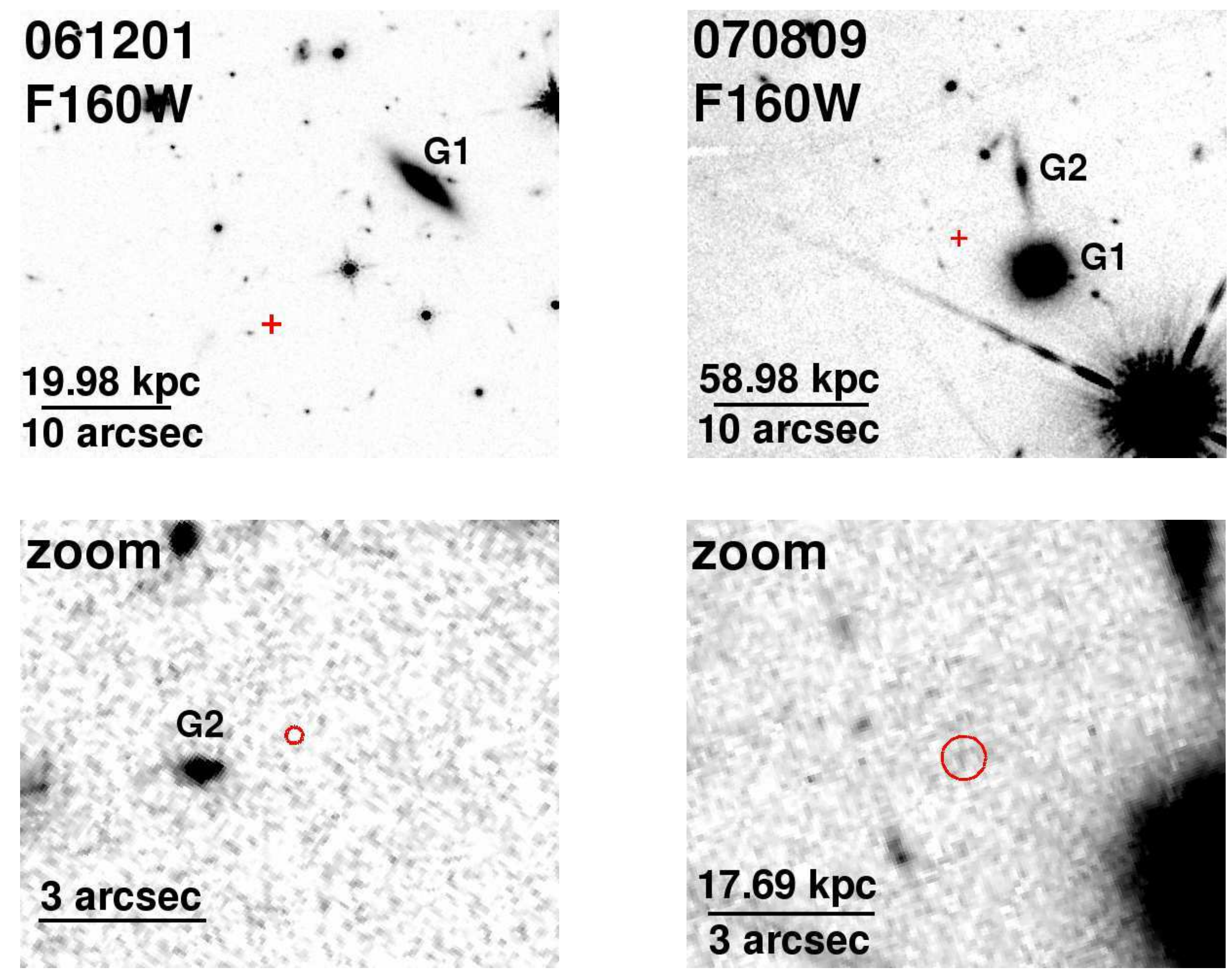
Talks by Kanda-san and Yoshida-san

Degeneracy between inclination and distance



Abbott et al. 2016

Local environments



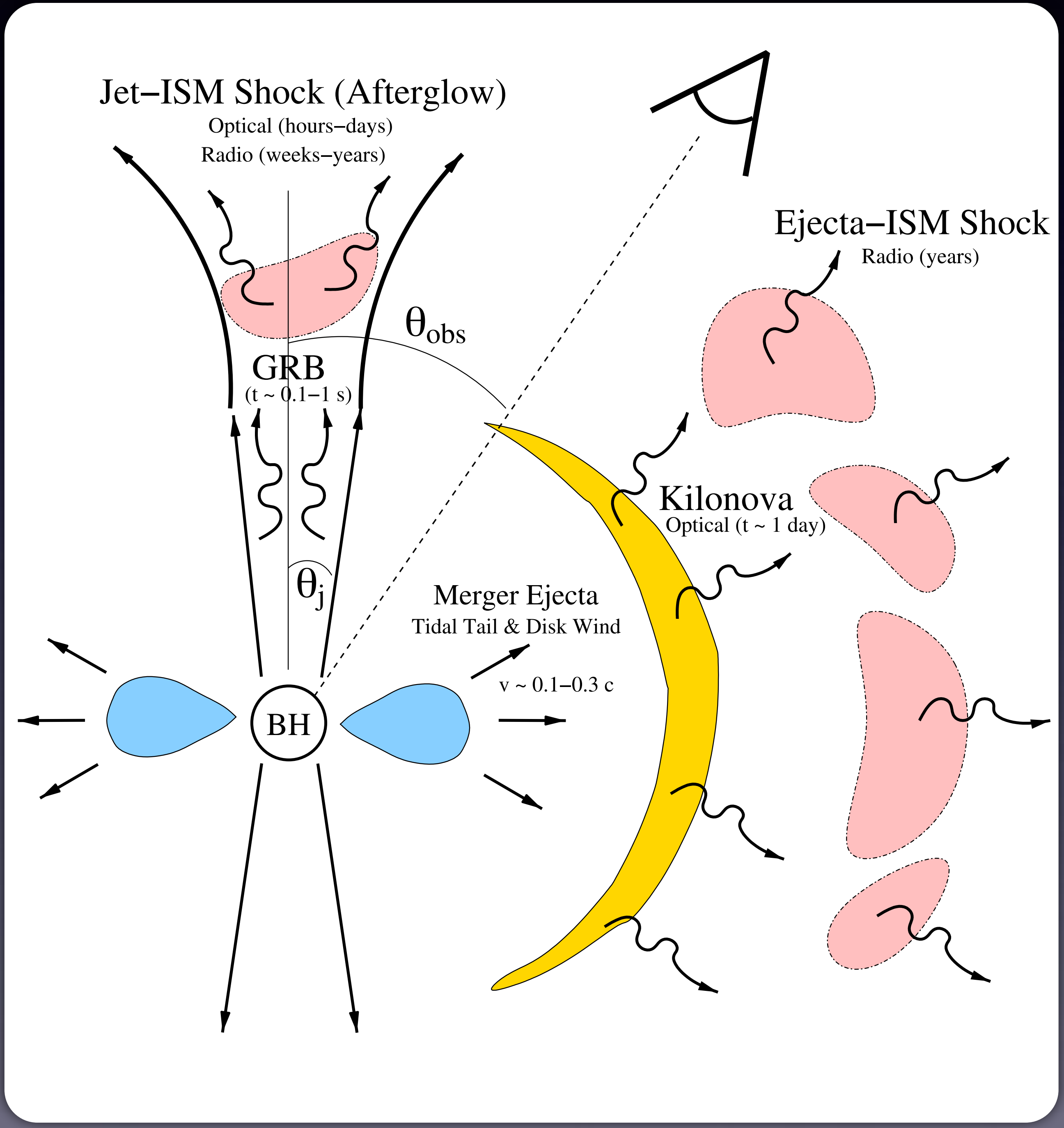
Berger 2014 (for short GRBs)

Electromagnetic Emission from Gravitational Wave Source

- EM emission from compact binary mergers
- Kilonova/macronova emission and the origin of r-process elements

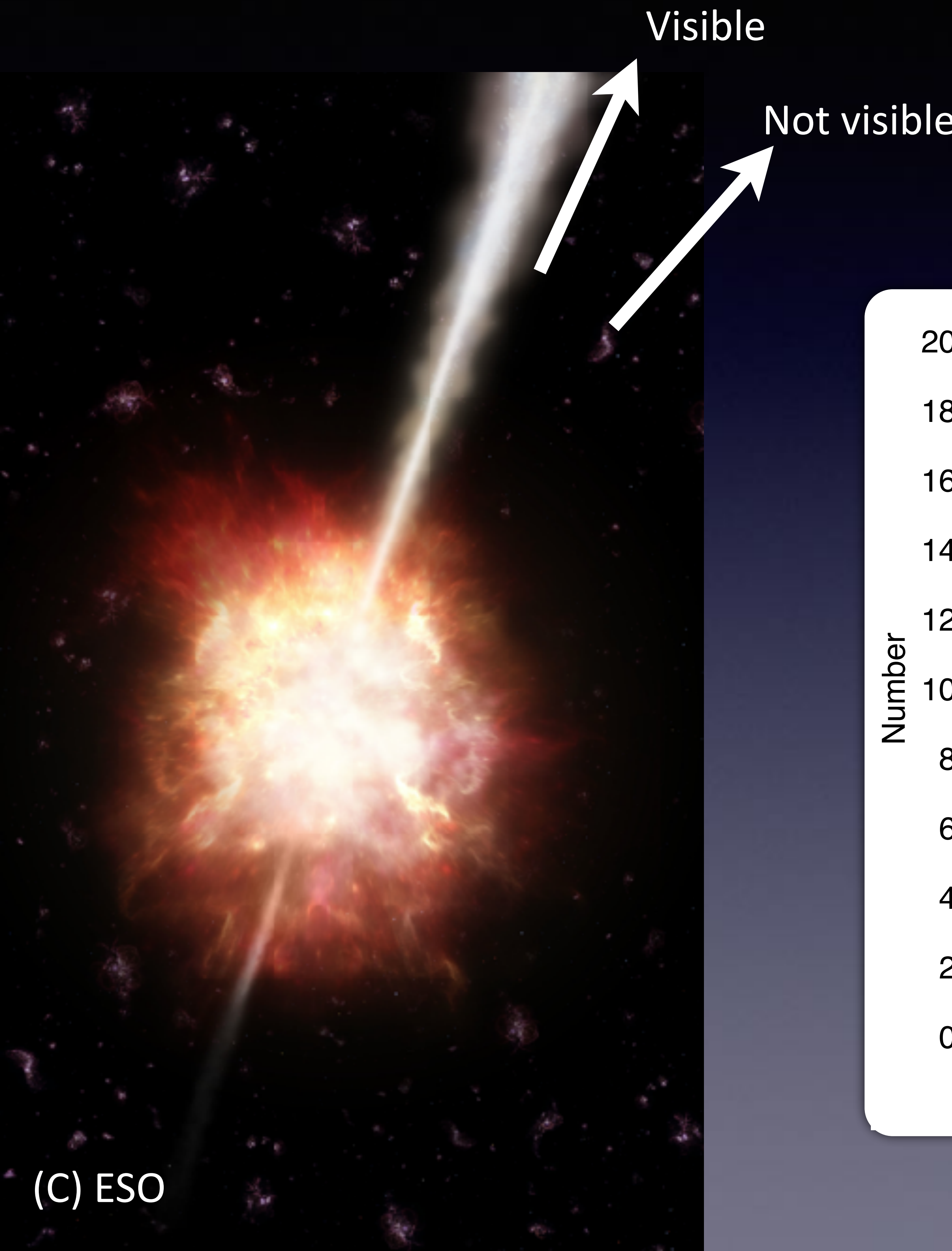
Electromagnetic signature from compact binary merger (NS-NS or BH-NS)

- X-ray/gamma-ray
- Radio
- Optical/NIR

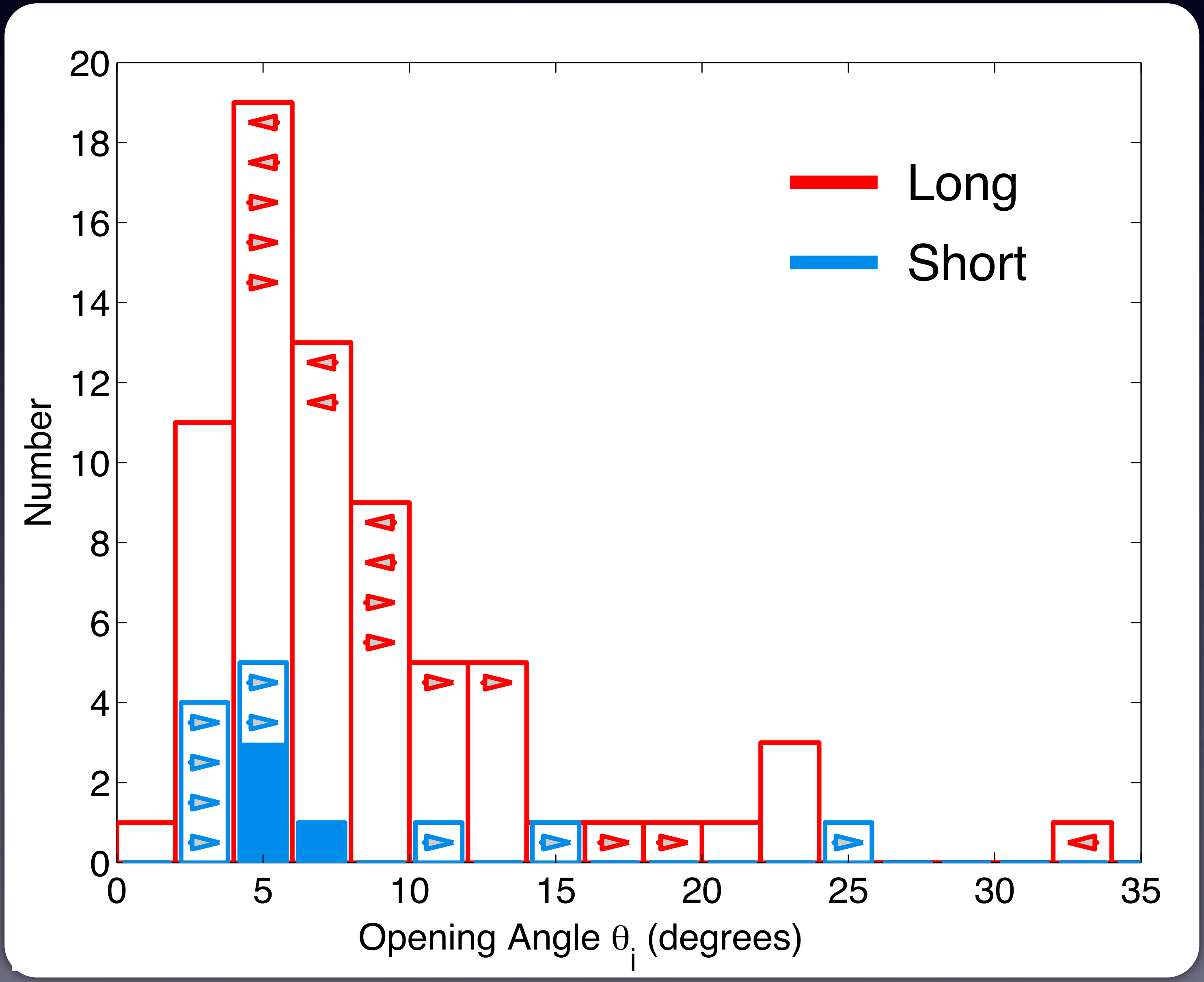


Metzger & Berger 2012

Short gamma-ray burst (GRBs)

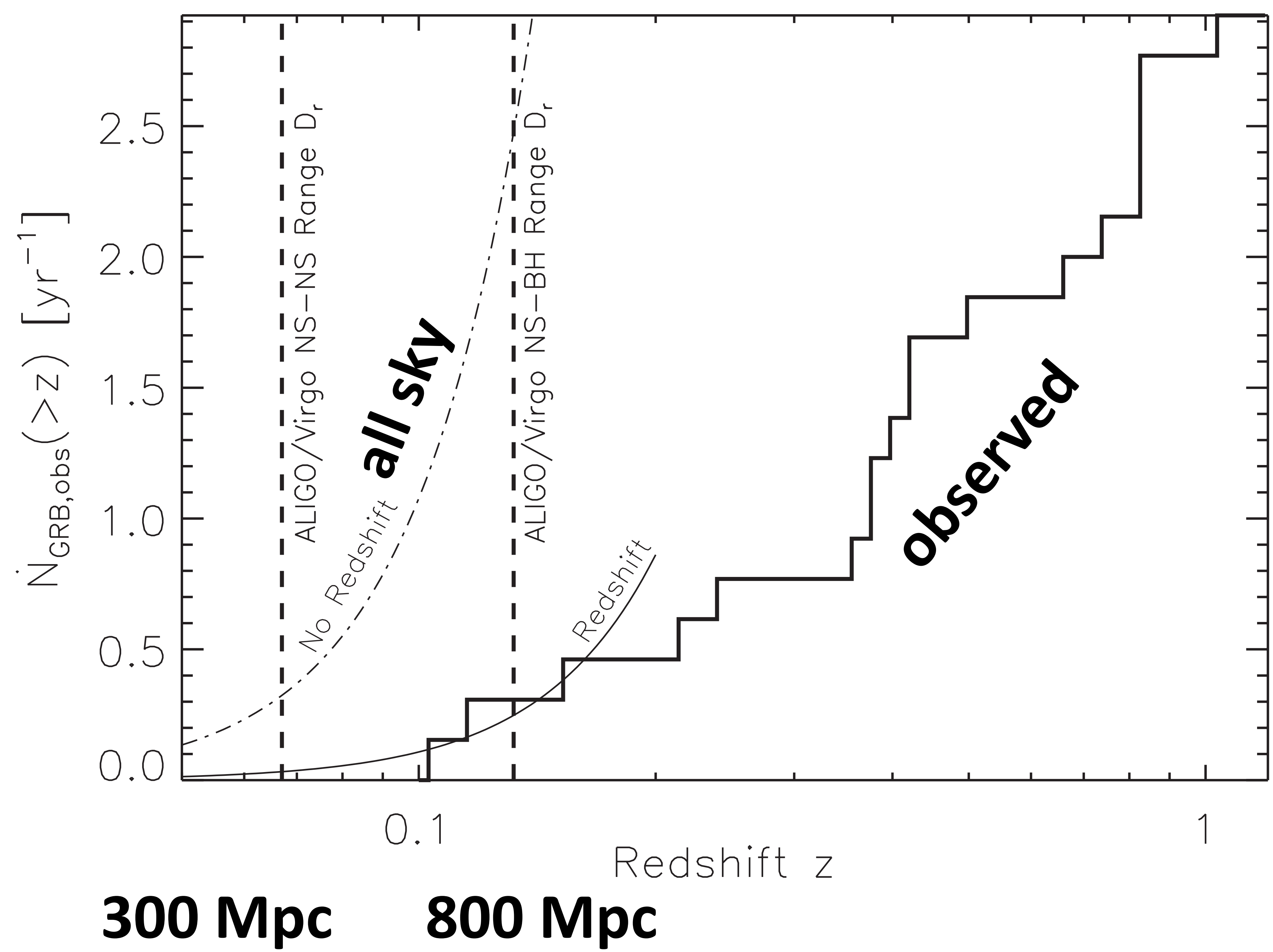


Opening angle ~ 10 deg
=> probability ~ a few %



Fong+14

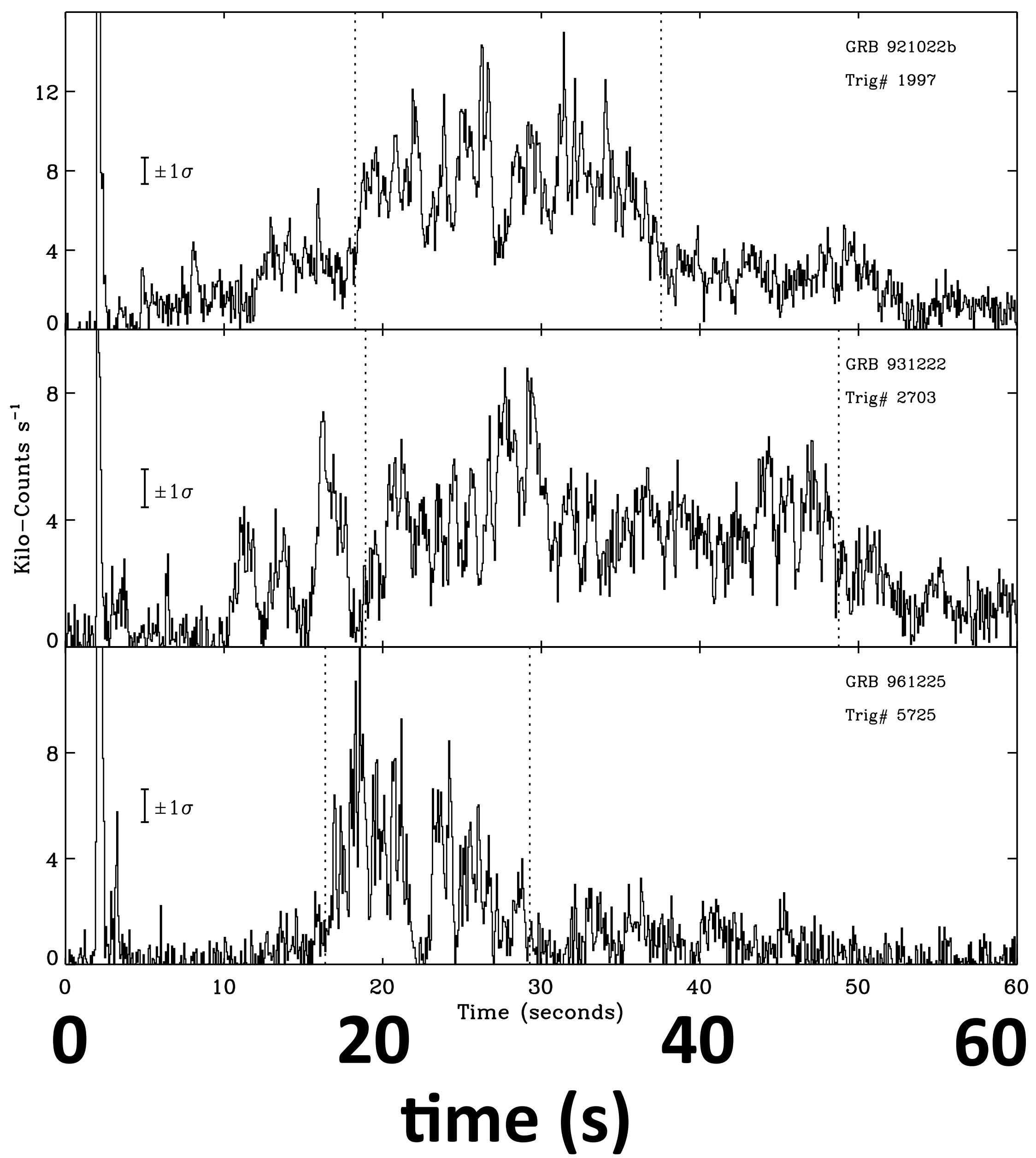
Cumulative redshift distribution of short GRBs



Metzger & Berger 2012

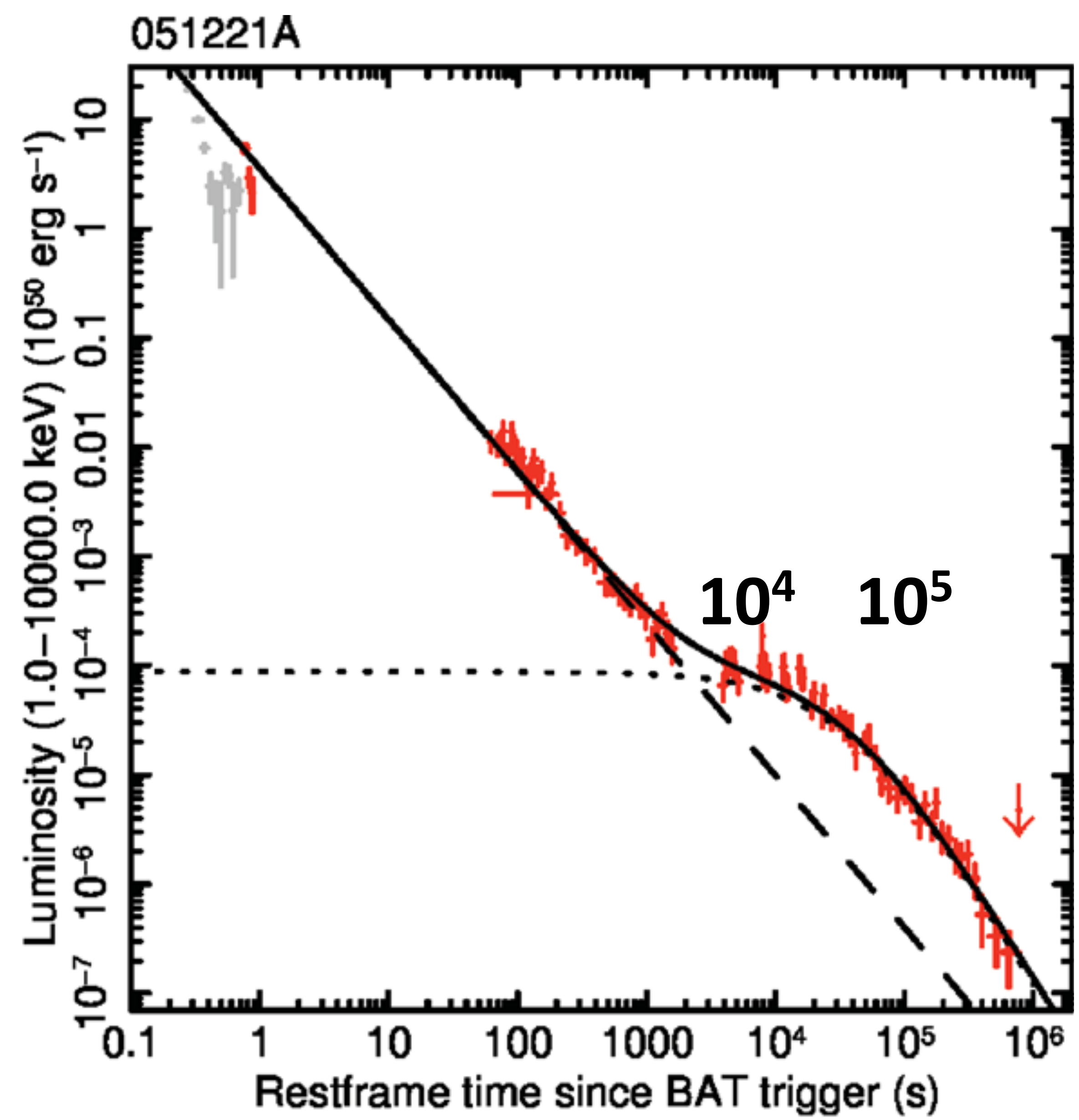
Late-phase activities?

“Extended” emission



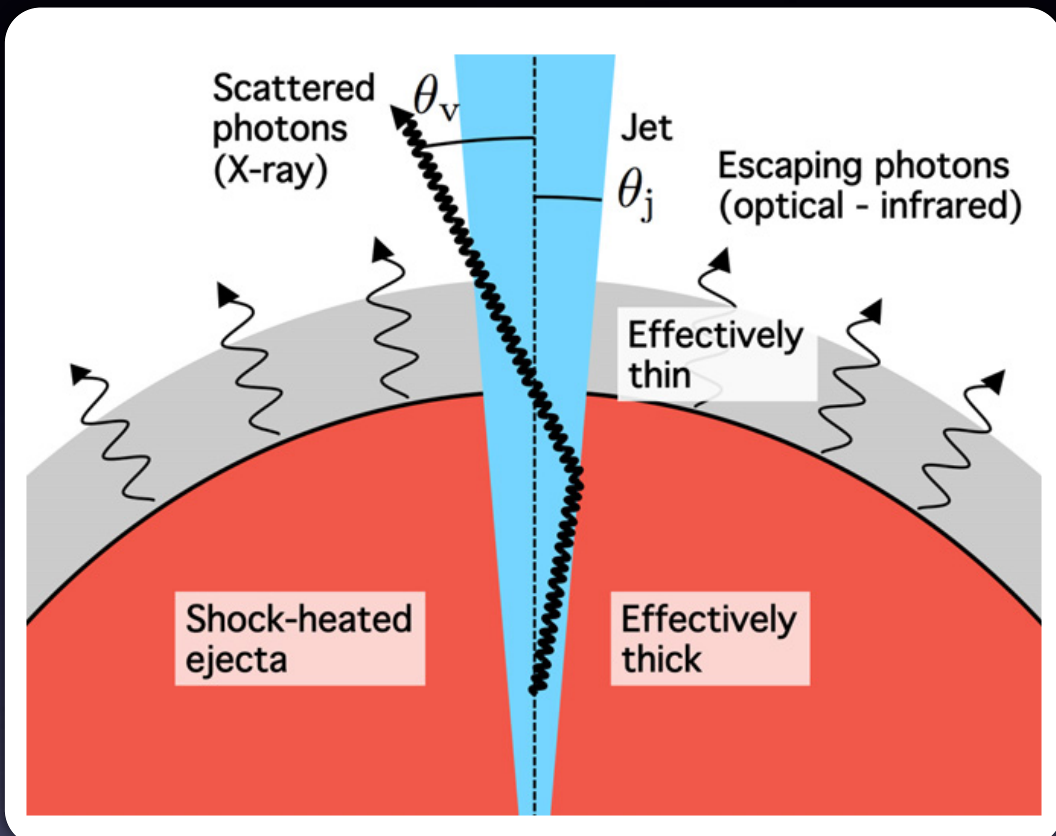
Norris & Bonnell 06

“Plateau” emission

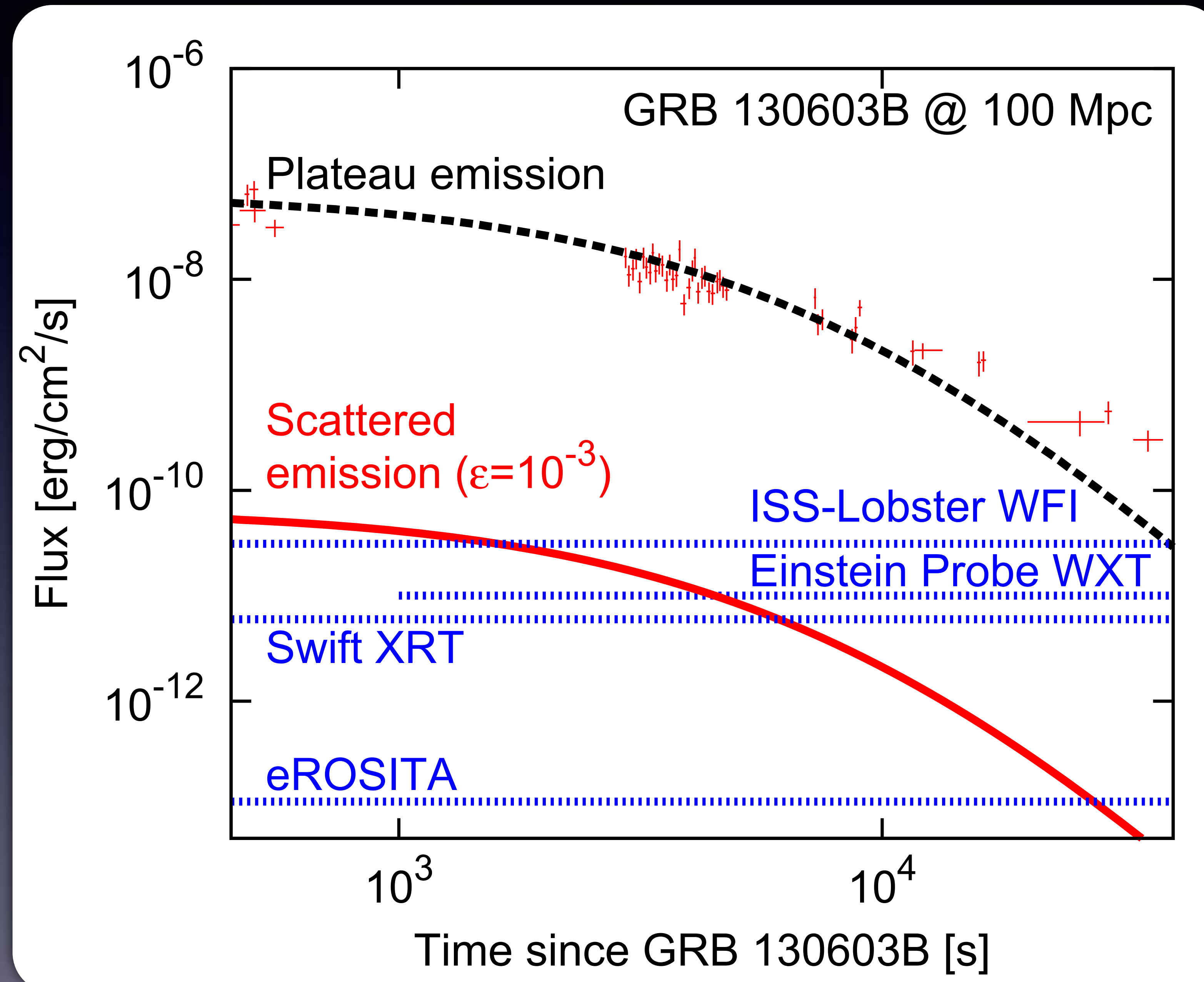


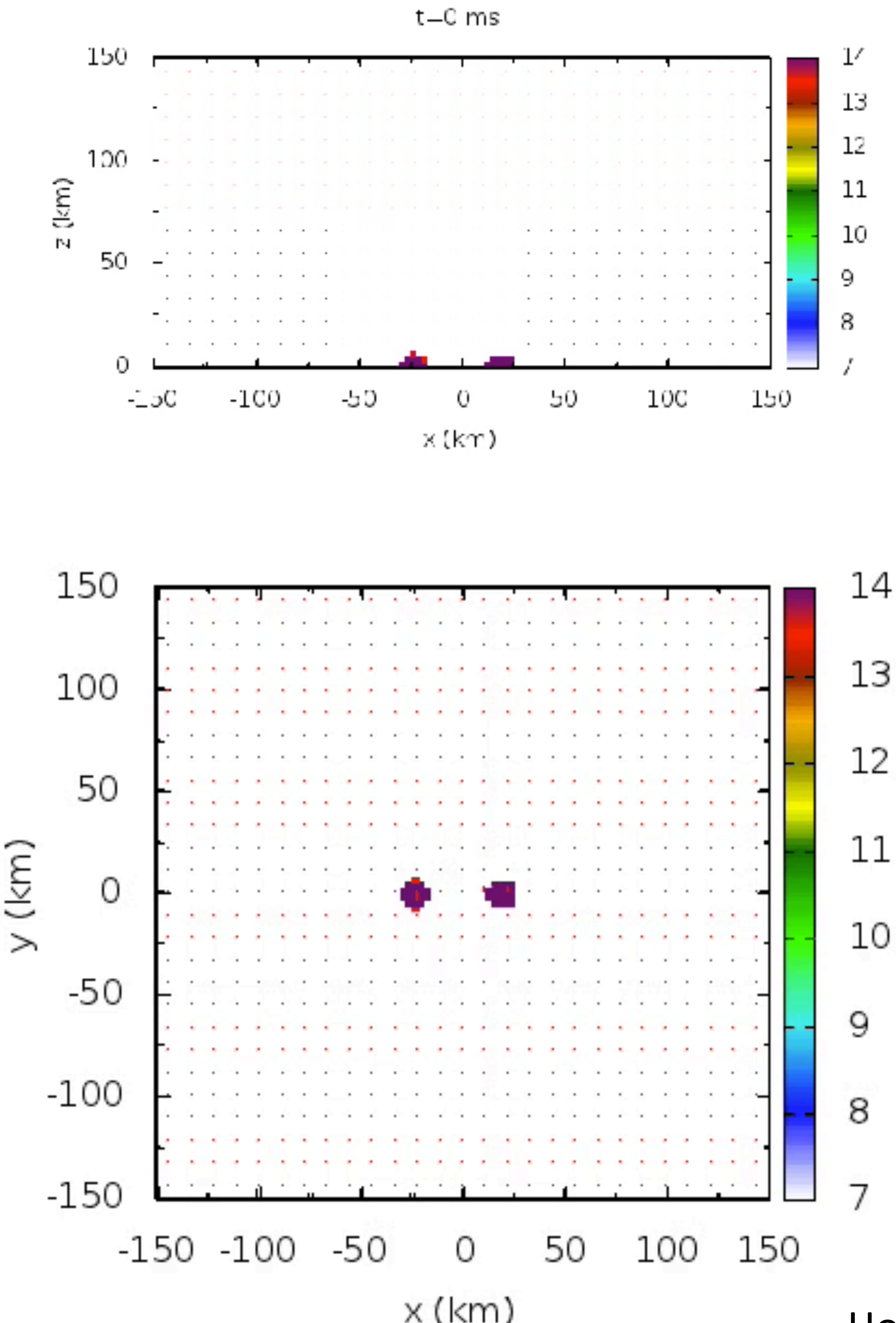
Rowlinson+13

X-ray emission to wider solid angle?



Kisaka+15





Hotokezaka+13

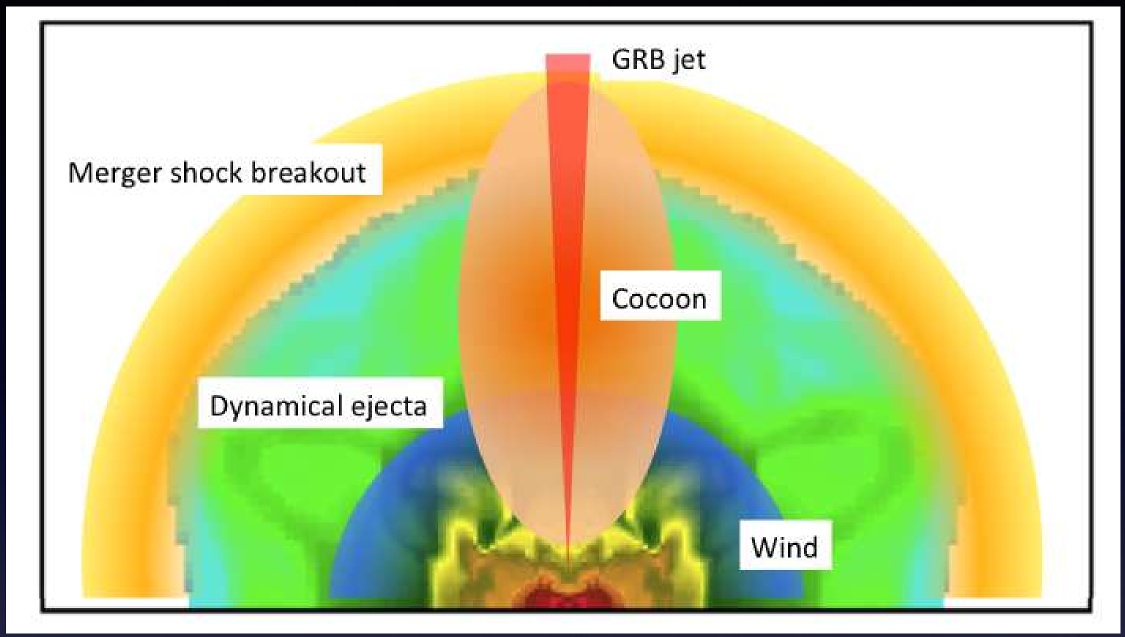
Mass ejection from NS mergers

- tidal disruption
- shock heating

M ~ 10^{-3} - 10^{-2} Msun
v ~ 0.1 - 0.2 c

Rosswog 99, 00, Ruffert & Janka 01
Hotokezaka+13, Bauswein+13

Radio emission (afterglow)

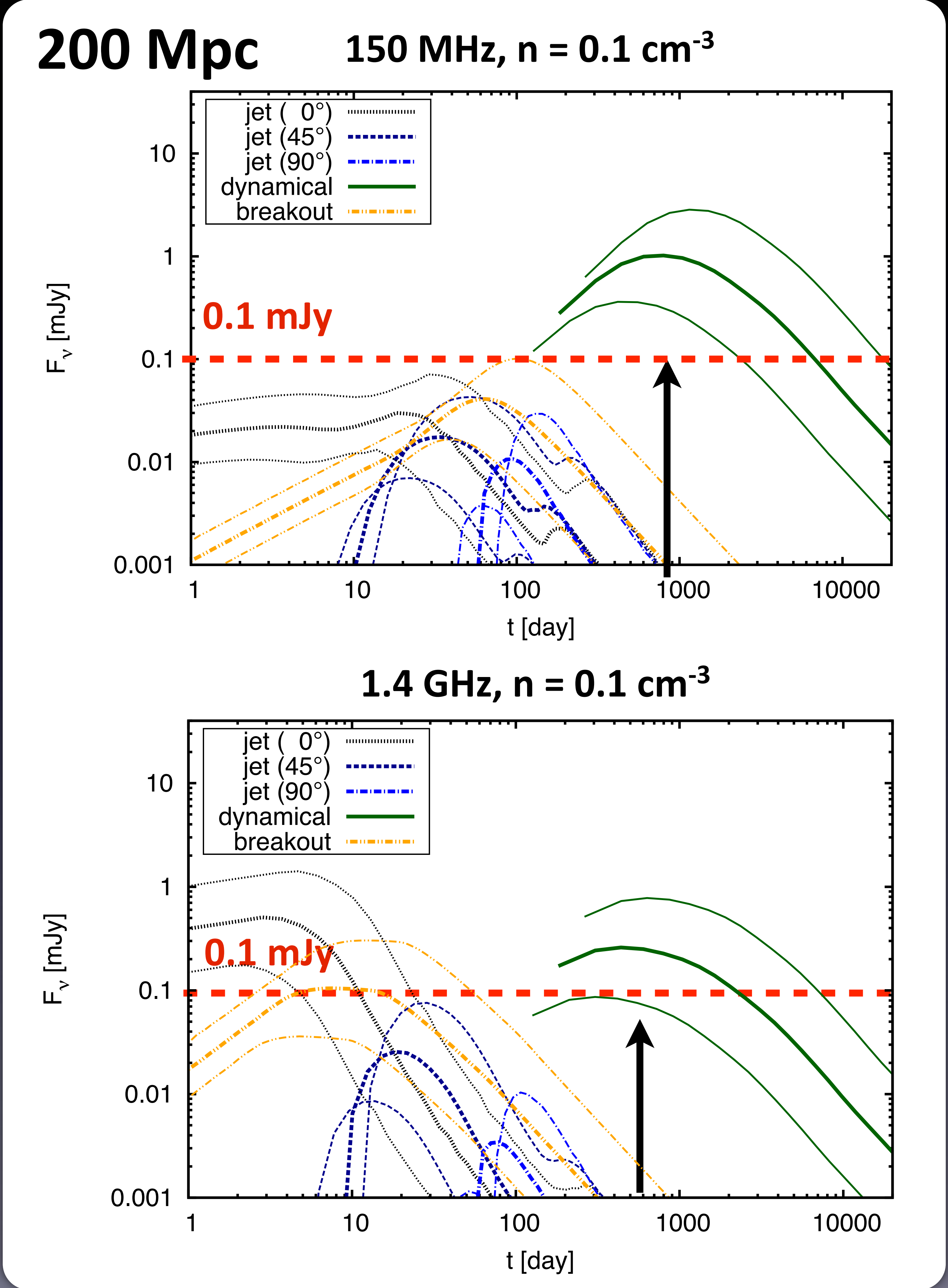


Delayed by ~> years

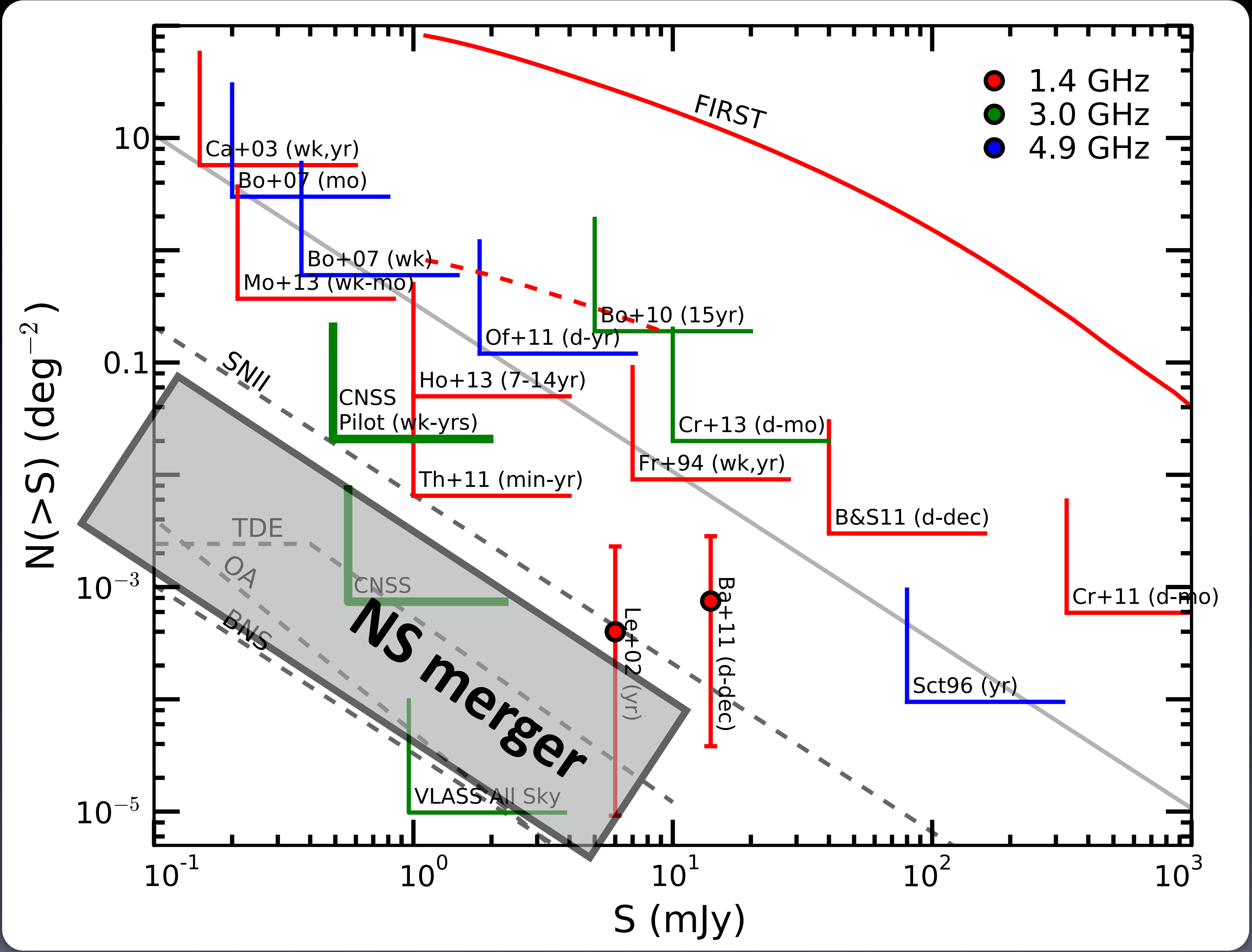
- Not immediate identification
- Good for confirmation
- Not affected by visibility

Depends on ISM density

Nakar & Piran 11
Hotokezaka & Piran 15



Radio transient sky is “quiet”



Mooley+2016

Low contamination rate

* Higher L(radio)/L(optical) than supernova

L(radio) <= v
L (optical) <= M

Electromagnetic signature from compact binary merger (NS-NS or BH-NS)

- X-ray/gamma-ray

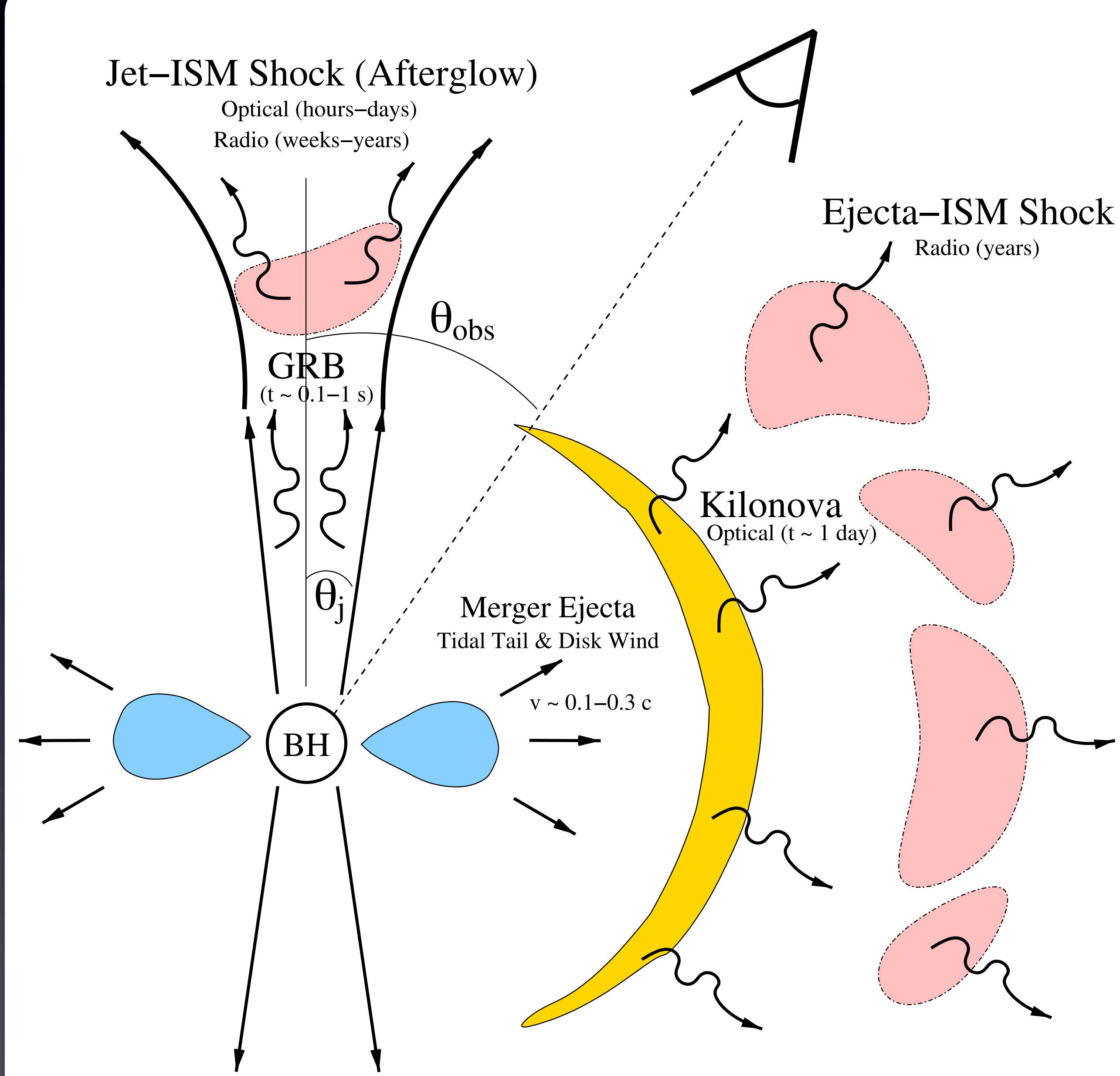
  Short GRB: strongly beamed
  Late activity: isotropic??

- Radio

  Delayed by years
  Low contamination rate

- Optical/NIR

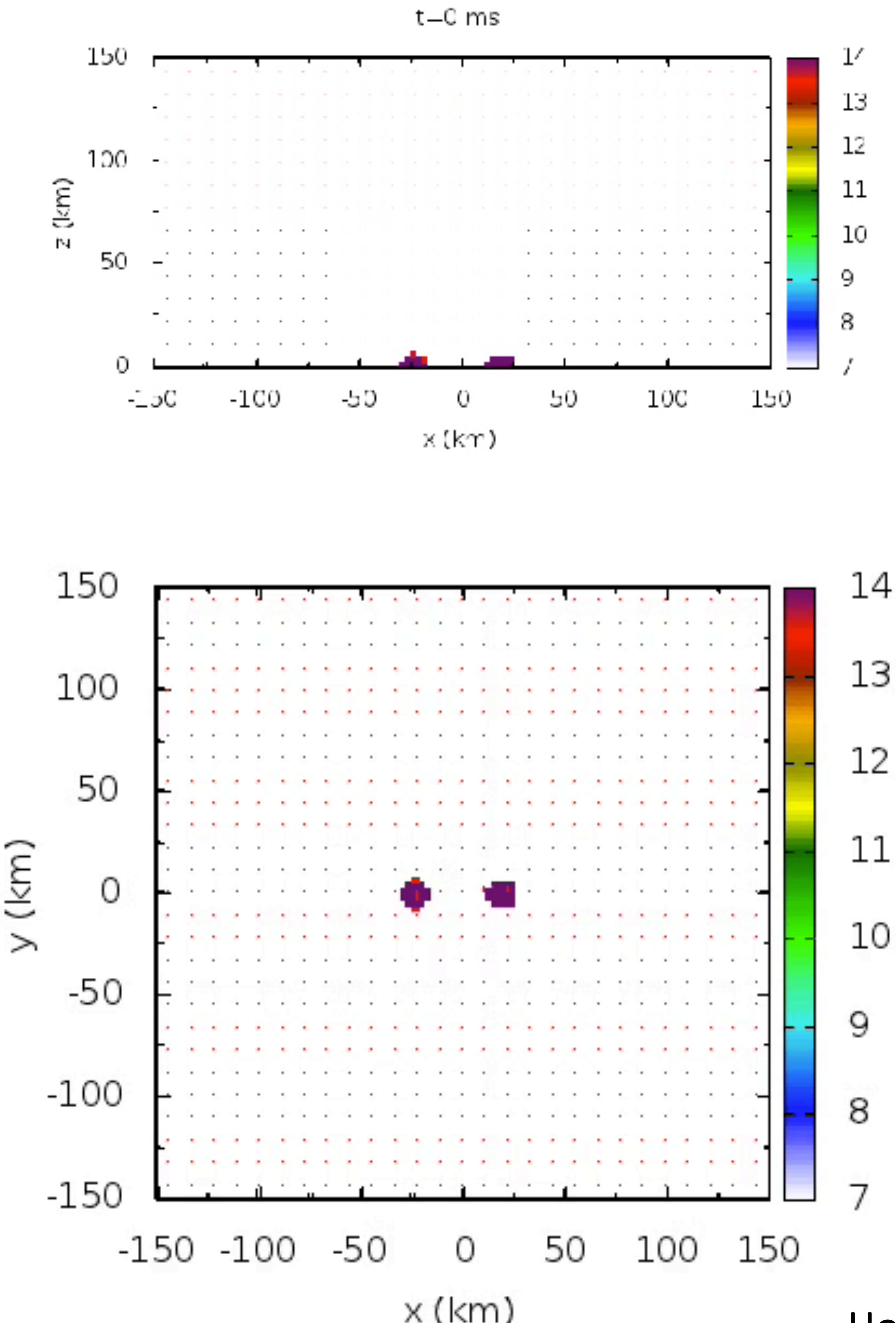
  Delayed by only ~ 1 week
  Isotropic



Metzger & Berger 2012, ApJ 746, 48

Electromagnetic Emission from Gravitational Wave Source

- EM emission from compact binary mergers
- Kilonova/macronova emission and the origin of r-process elements



Hotokezaka+13

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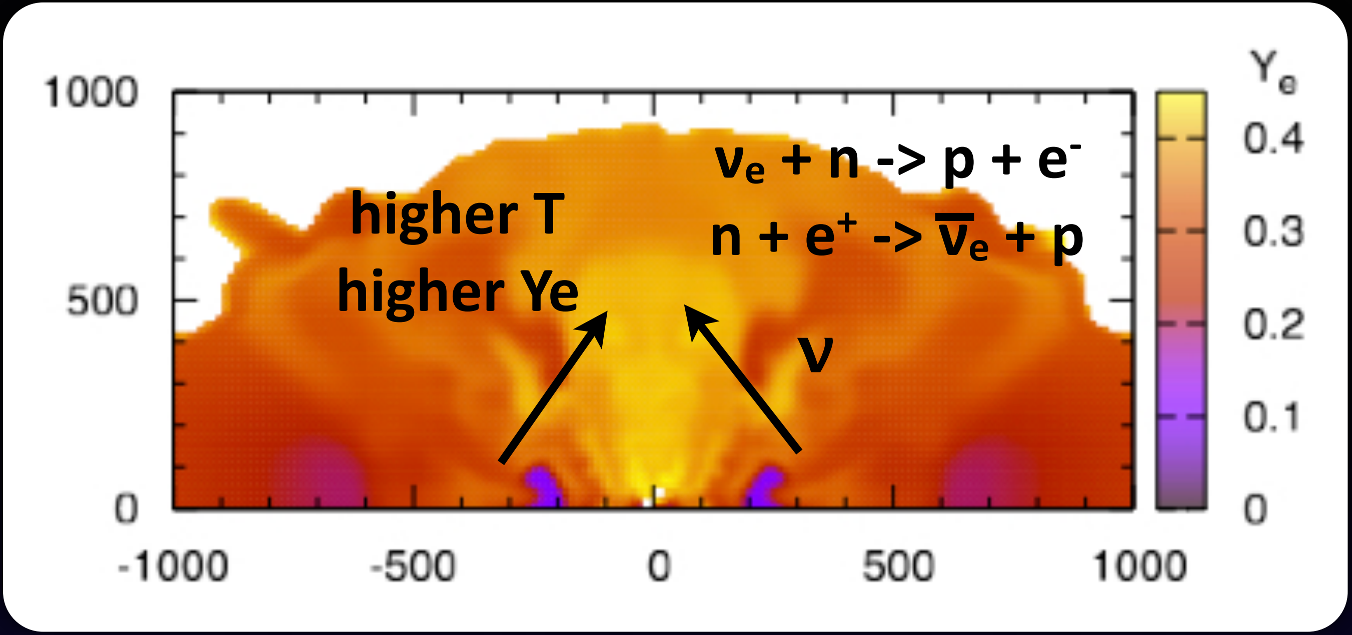
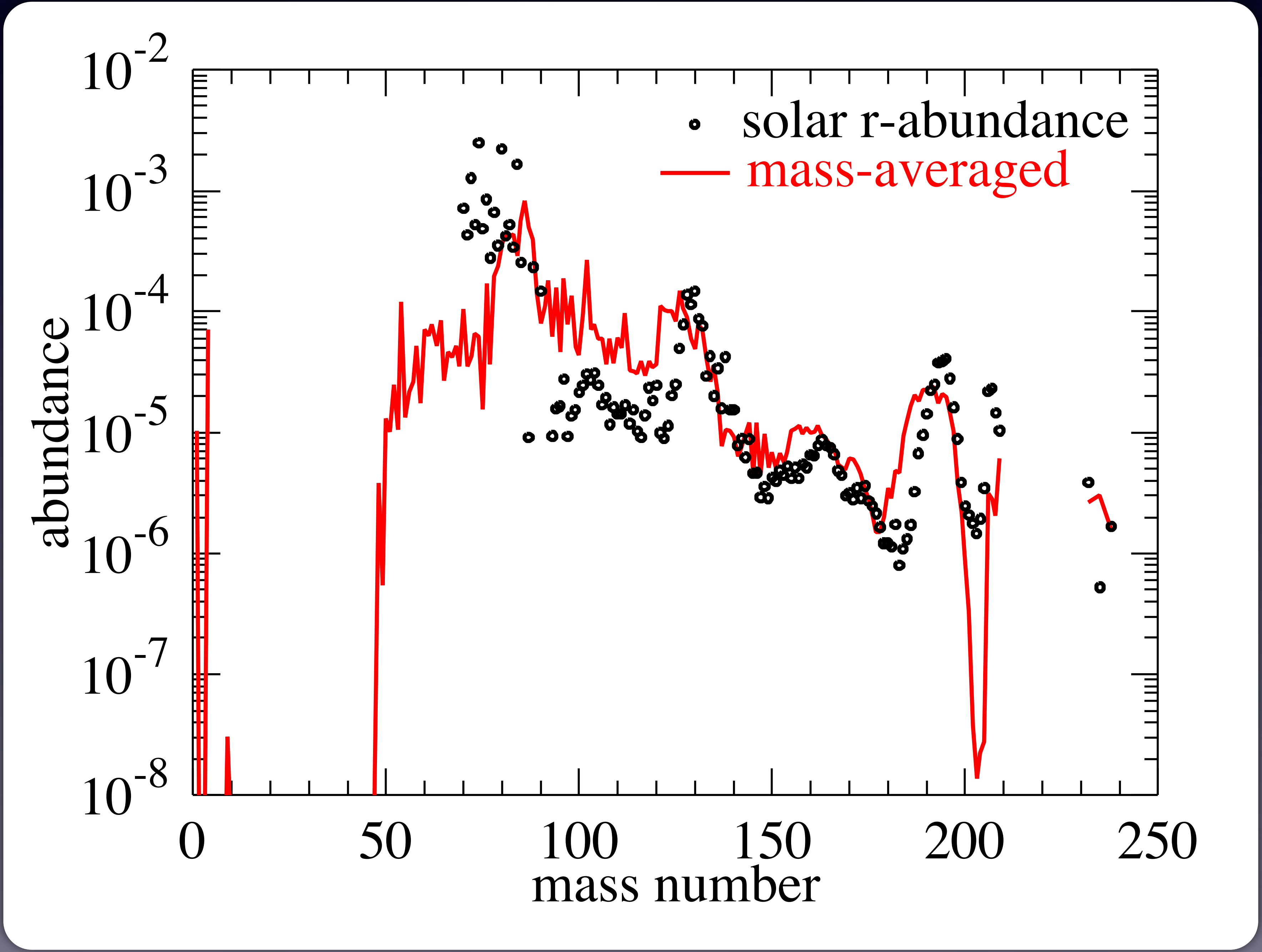
Rosswog 99, 00, Ruffert & Janka 01
Hotokezaka+13, Bauswein+13

r-process nucleosynthesis in NS mergers

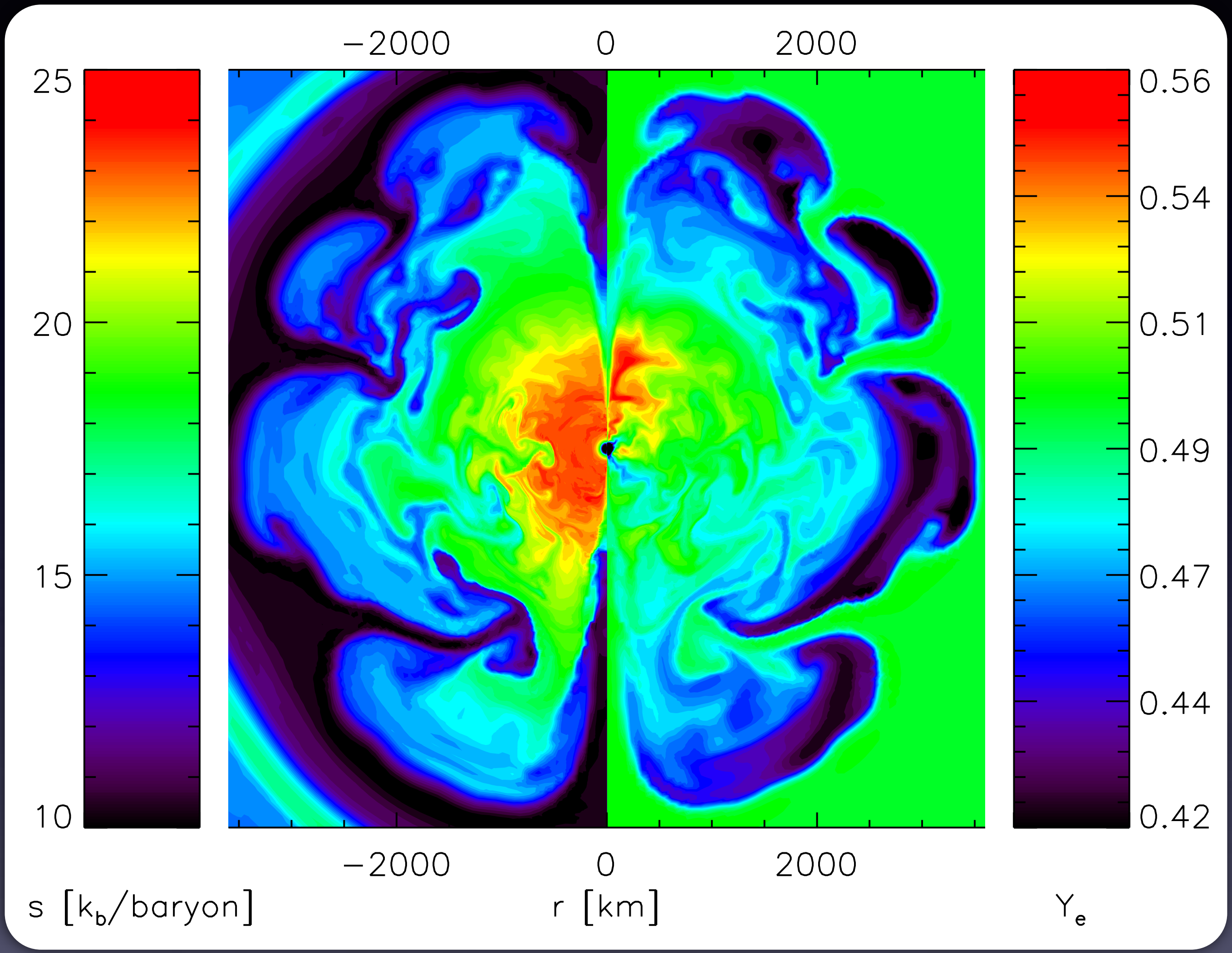
=> solar abundances

(e.g., Wanajo+14, Just+15, Wu+16)





r-process nucleosynthesis in core-collapse supernovae



Wanajo+11, Wanajo 14

$$\nu_e + n \rightarrow p + e^-$$

$$\bar{\nu}_e + p \rightarrow n + e^+$$

Difficult to produce r-process elements in (normal) core-collapse supernovae

NS merger as a possible origin of r-process elements

Event rate

$R_{NSM} \sim 10^3\ Gpc^{-3}\ yr^{-1}$

~ 30 GW events yr^{-1}

(w/ Adv. detectors, < 200 Mpc)

GW

LIGO O1

$R_{NSM} < 10^4\ Gpc^{-3}\ yr^{-1}$

Ejection per event

M_{ej}(r-process) ~ 10^{-2} Msun

EM

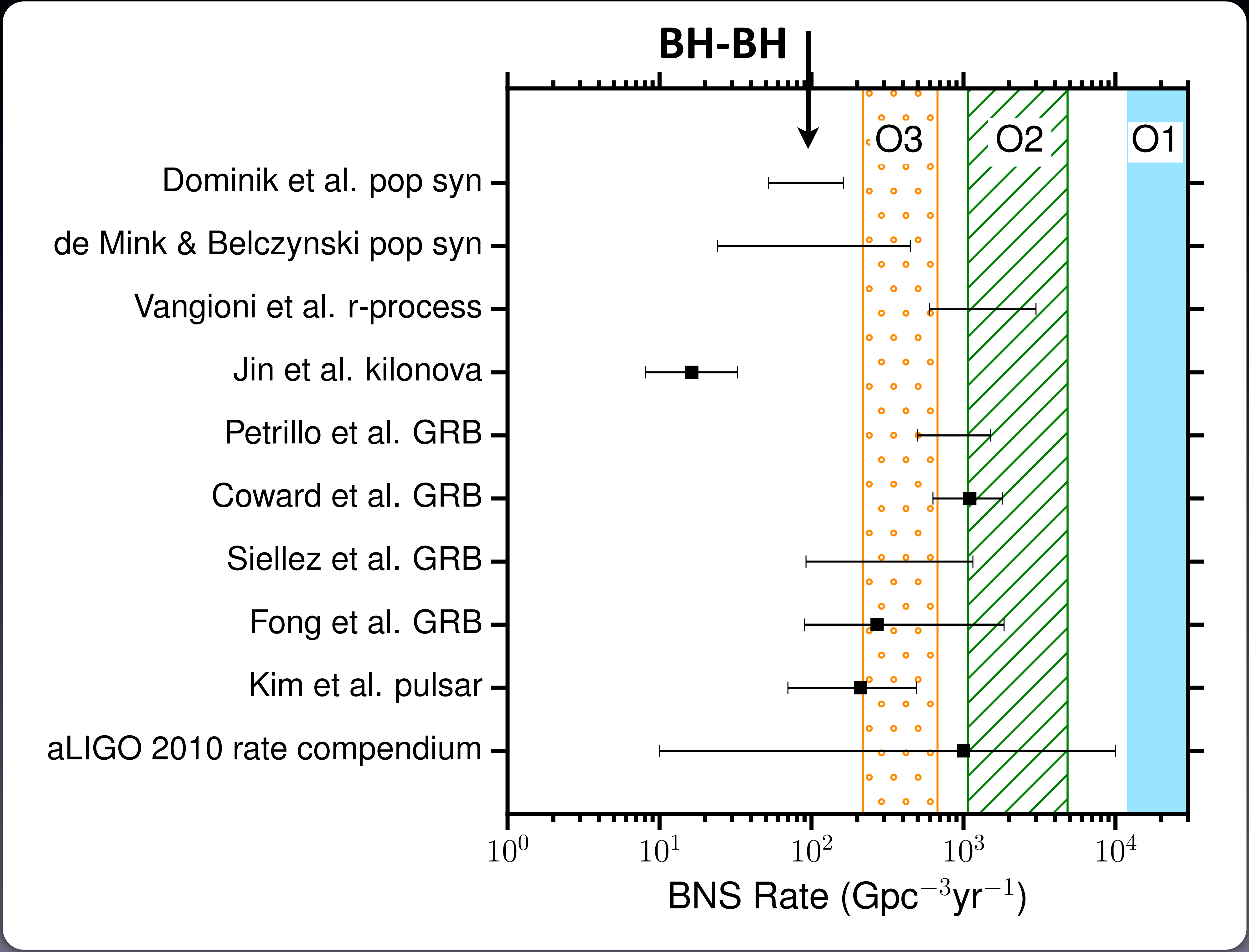
Enough to explain the r-process abundance in our Galaxy

M(Galaxy, r-process) ~ $M_{ej}(r) \times (R_{NSM} \times t_G)$

$\sim 10^{-2} \times 10^{-4} \times 10^{10} \sim 10^4$ Msun

Constraints on the NS-NS merger rate

Expected event rates

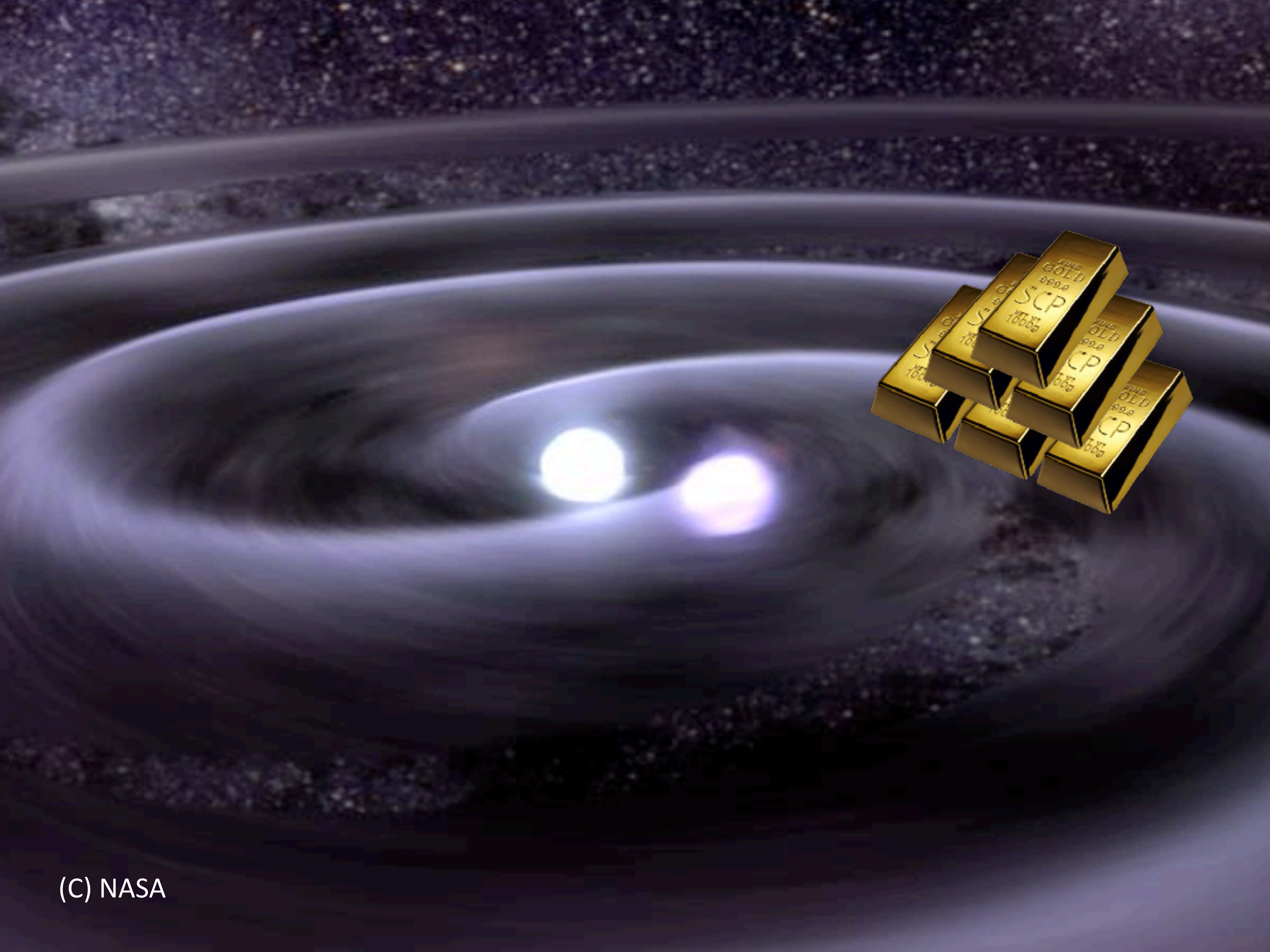


O1: 2015-2016

O2: 2016-2017

O3: 2018

arXiv:1607.07456

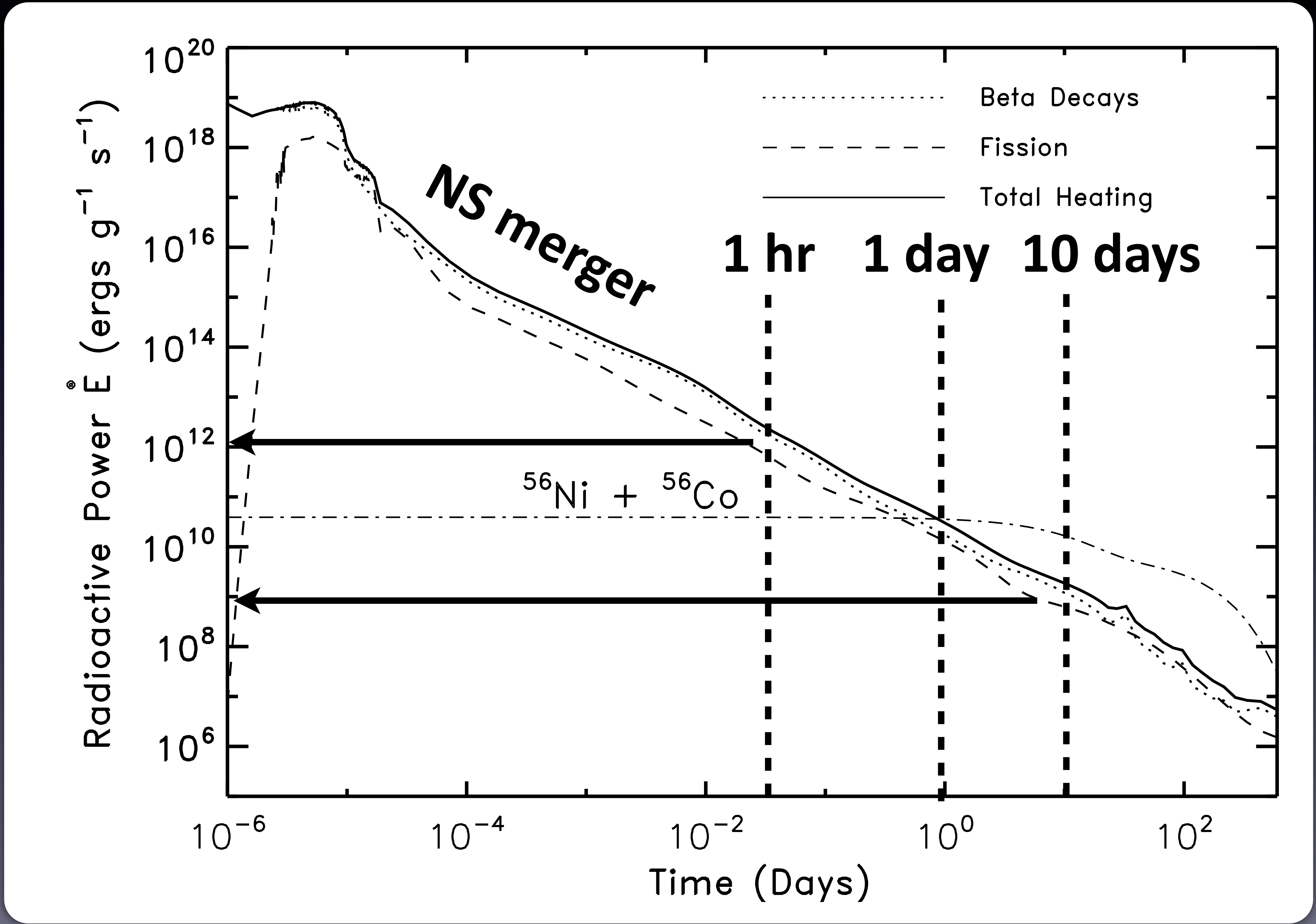


(C) NASA

Heating by radioactive decay of r-process nuclei

10^{43} erg s^{-1}

10^{40} erg s^{-1}



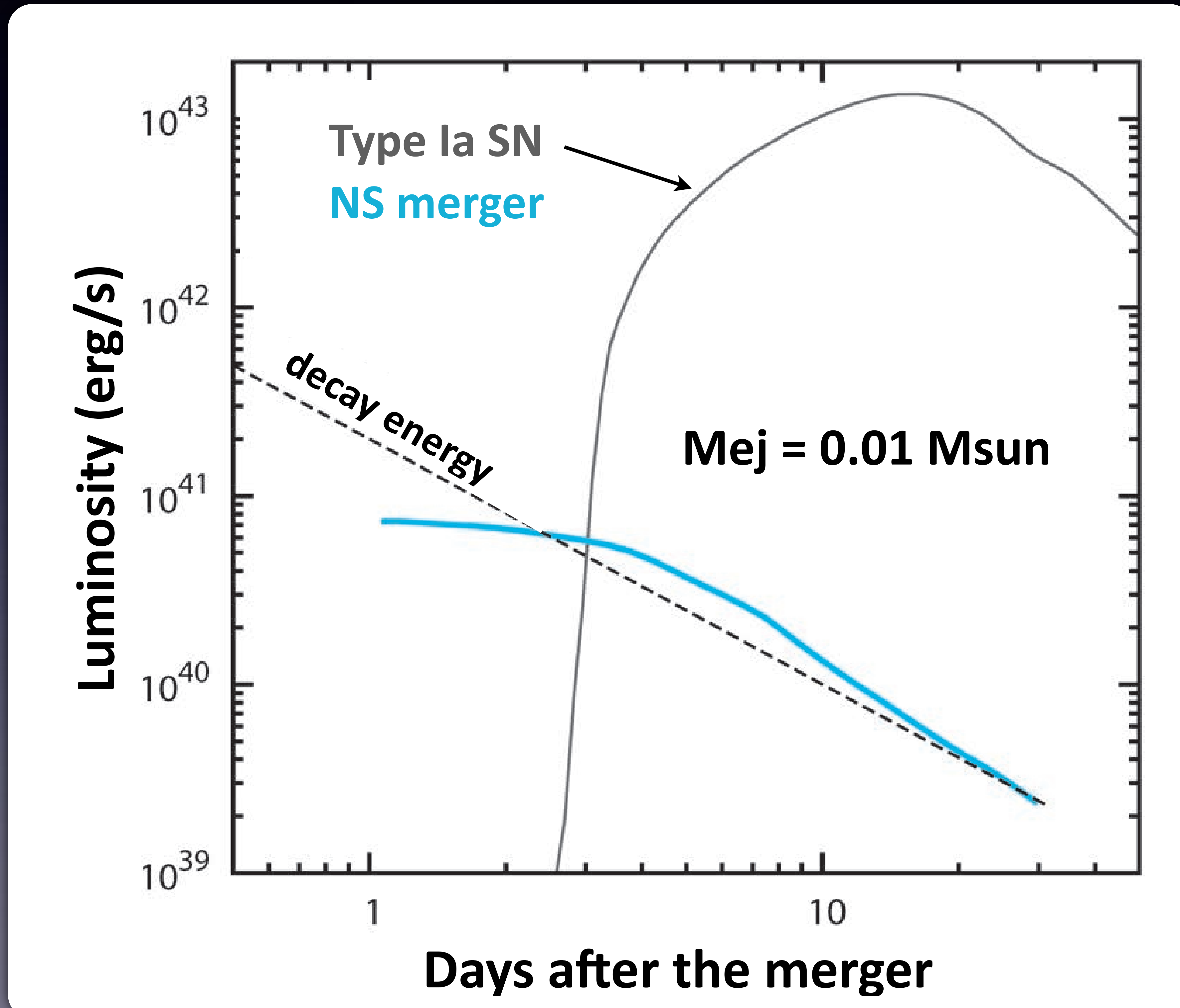
(for M = 0.01 Msun)

Metzger+10

“kilonova/macronova”

Li & Paczynski 98, Metzger+10,
MT & Hotokezaka 13, MT+14,
Kasen+13, Barnes & Kasen 13

$L \sim 10^{40\text{-}41}$ erg/s
@ ~1 week



Magnitude

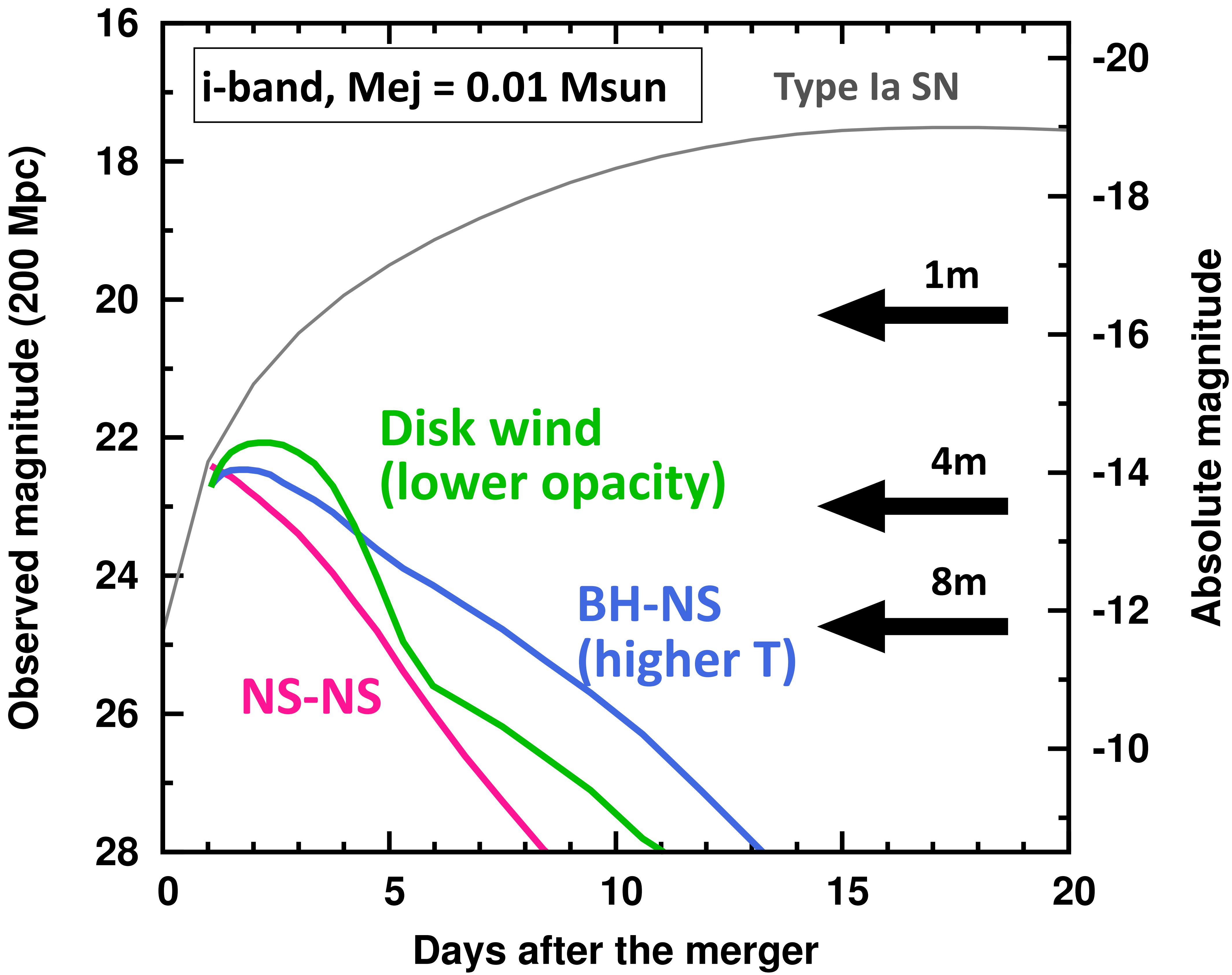
$$m = -2.5\log(F/F_0) + m_0$$

Absolute magnitude

brightness if the object is located at 10 pc

The sun: Observed magnitude = -27 mag

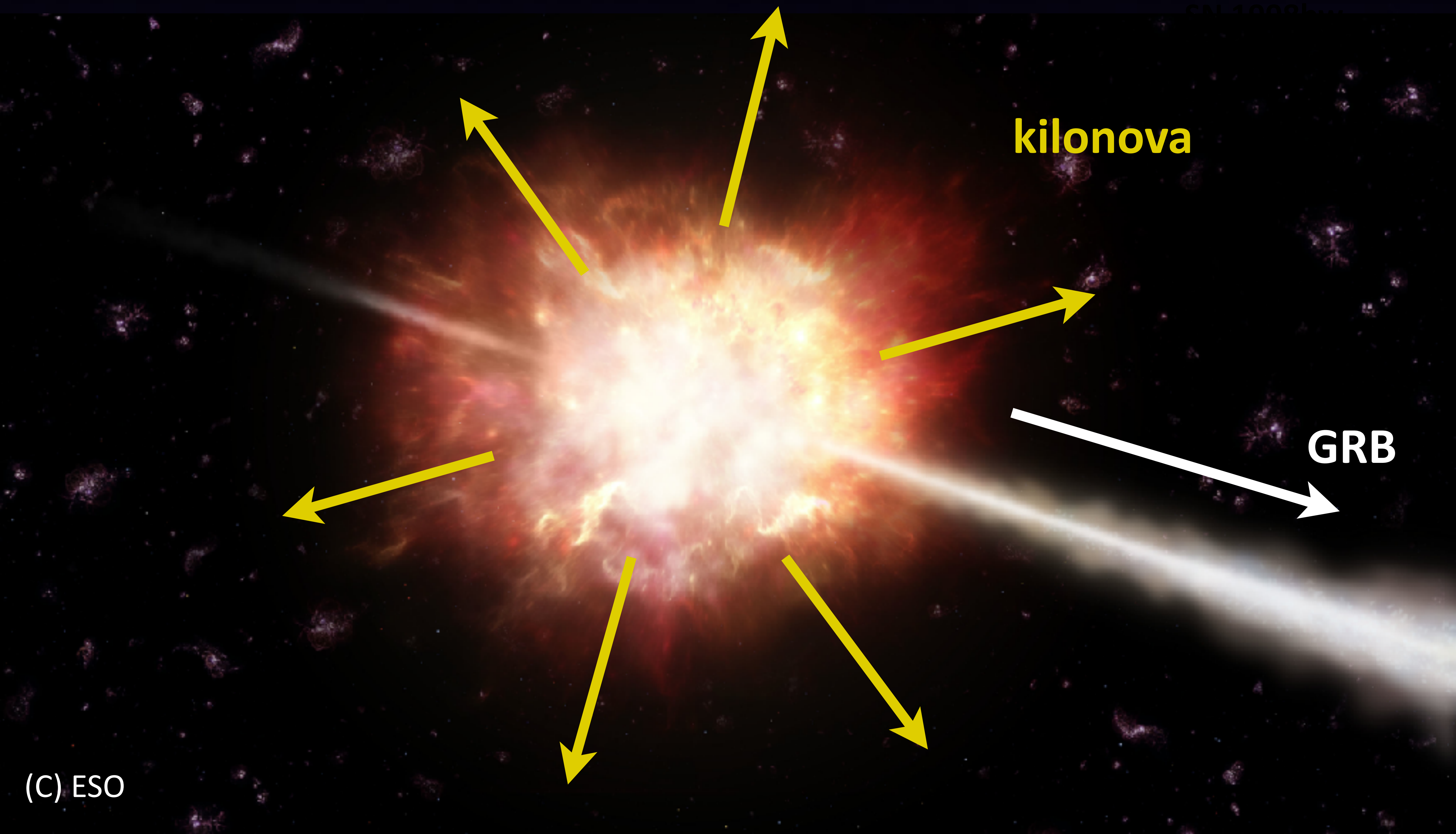
Absolute magnitude = +4.8 mag



MT 2016

Talks by Yoshida-san and Tominaga-san

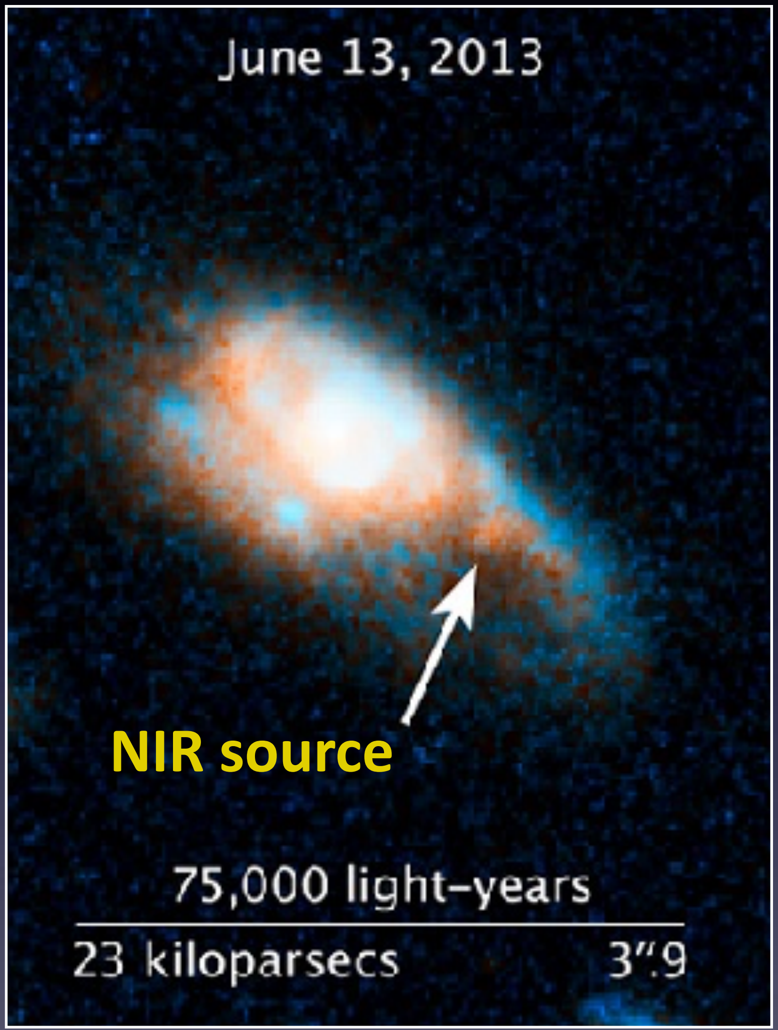
Constraints from short GRBs

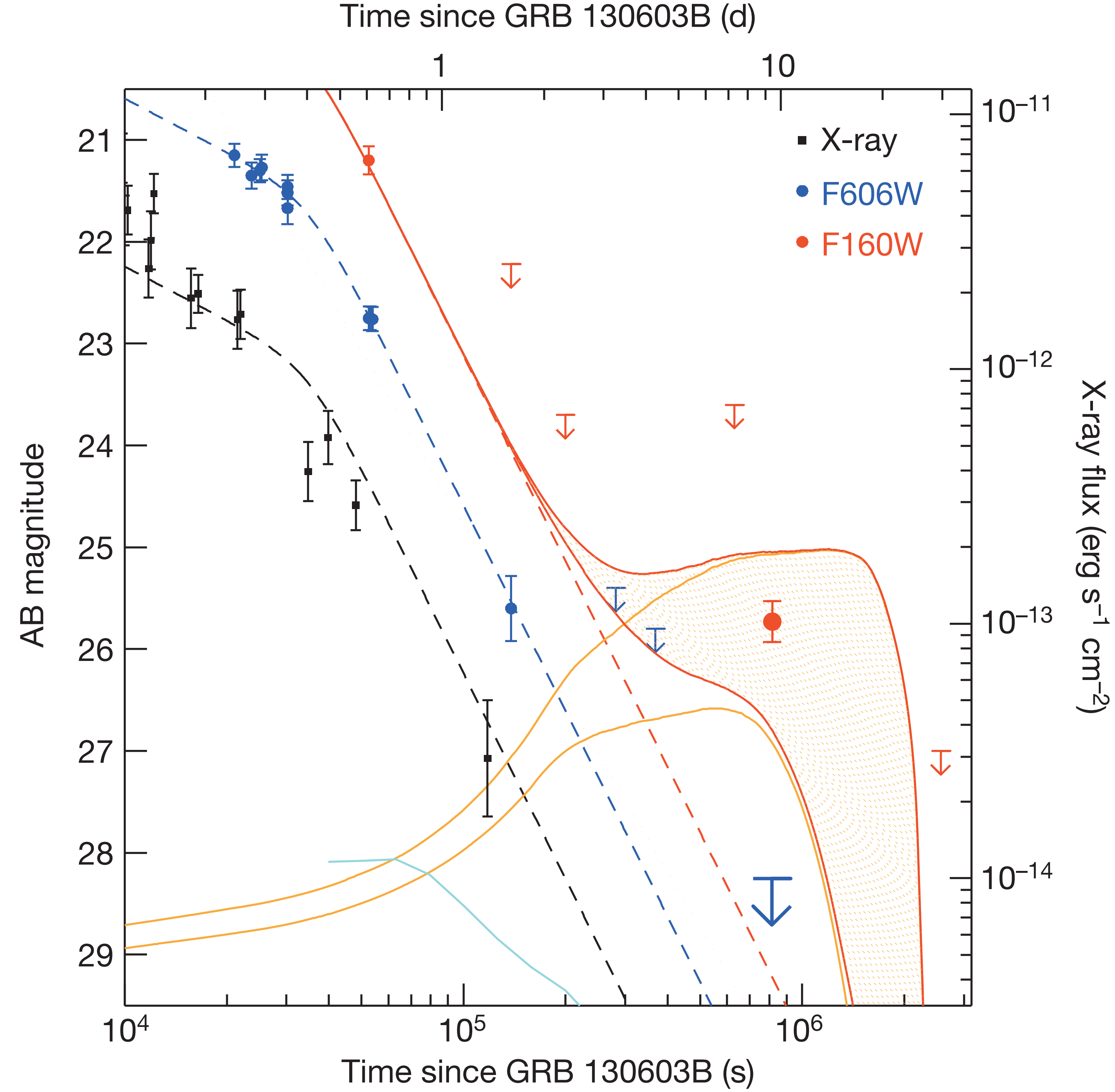


(C) ESO

Constraints from short GRBs (1/3)

GRB 130603B





Tanvir+2013, Berger+2013

Possible detections also in
GRB 060614 (z=0.125) Yang+15, Jin+15
GRB 050709 (z=0.16) Jin+16

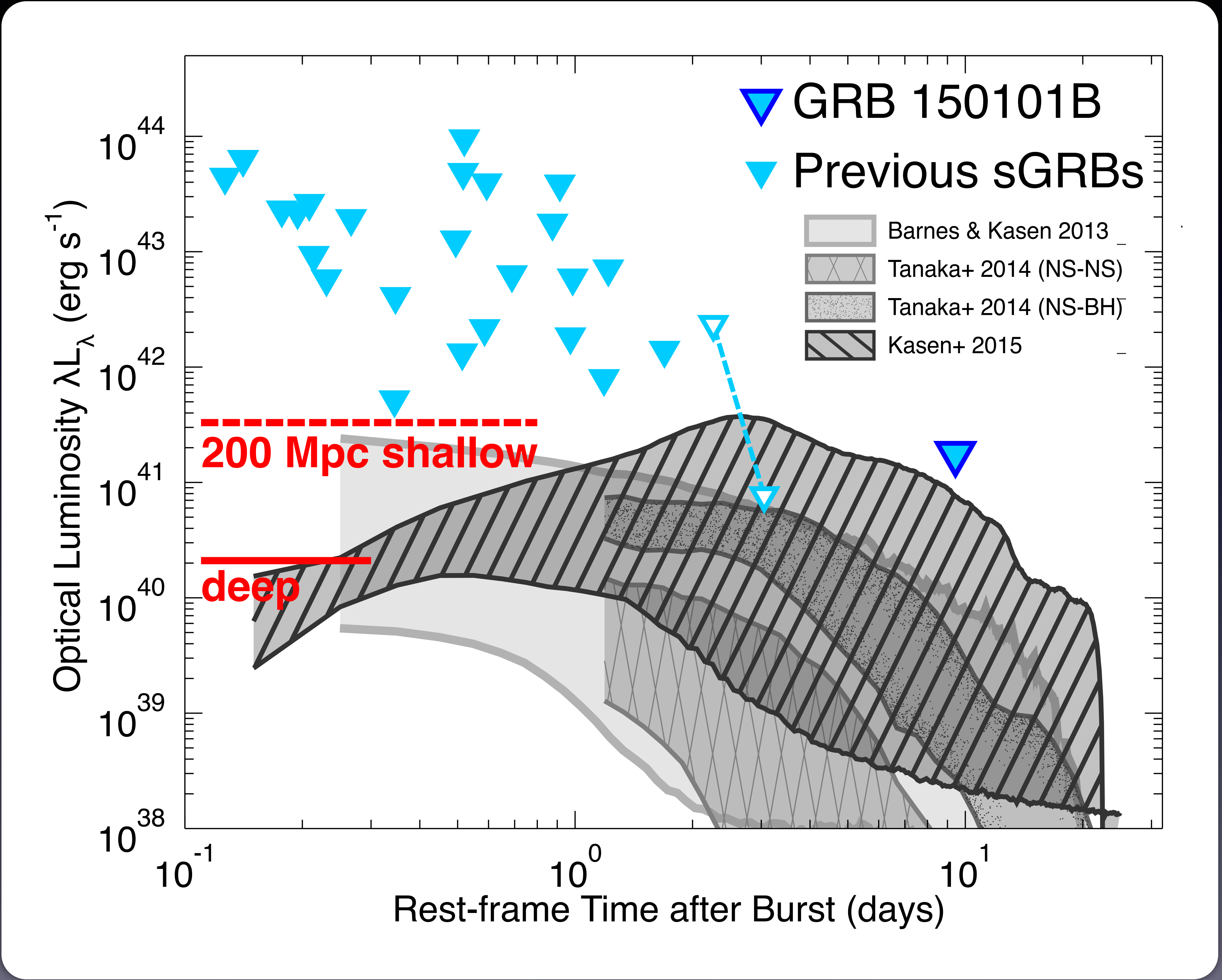
=> ejection of M ~0.02 Msun

Constraints from short GRBs (2/3)

@ 200 Mpc

21 mag

24 mag



Fong+16

M ~< 0.3 Msun

Constraints from short GRBs (3/3)

GRB 160821B (z=0.16)

F606W ~ 25.8 mag @ z=0.16
=> Mabs -14 mag
=> **~22 mag @ 200 Mpc**

M ~ 0.01 Msun

TITLE: GCN CIRCULAR
NUMBER: 20222
SUBJECT: GRB 160821B: HST detection of the optical and IR counterpart
DATE: 16/12/01 02:36:37 GMT
FROM: Eleonora Troja at GSFC <eleonora.troja@nasa.gov>

E. Troja (UMD/GSFC), N. Tanvir (U. Leicester), S. B. Cenko (NASA/GSFC), A. Levan (U. Warwick), J. Barnes (U. Berkeley), A. Castro-Tirado (IAA-CSIC), A. S. Fruchter (STScI), N. Gehrels (NASA/GSFC), J. Greiner (MPE), N. Kawai (Tokyo Tech), R. Hounsell (UCSC), J. Hjorth (DARK/NBI), A. Lien (NASA/GSFC), B. Metzger (Columbia), D. Perley (DARK/NBI), S. Rosswog (U. Stockholm), T. Sakamoto (AGU), C. Thoene (IAA-CSIC), A. de Ugarte Postigo (IAA-CSIC), and D. Watson (DARK/NBI) report:

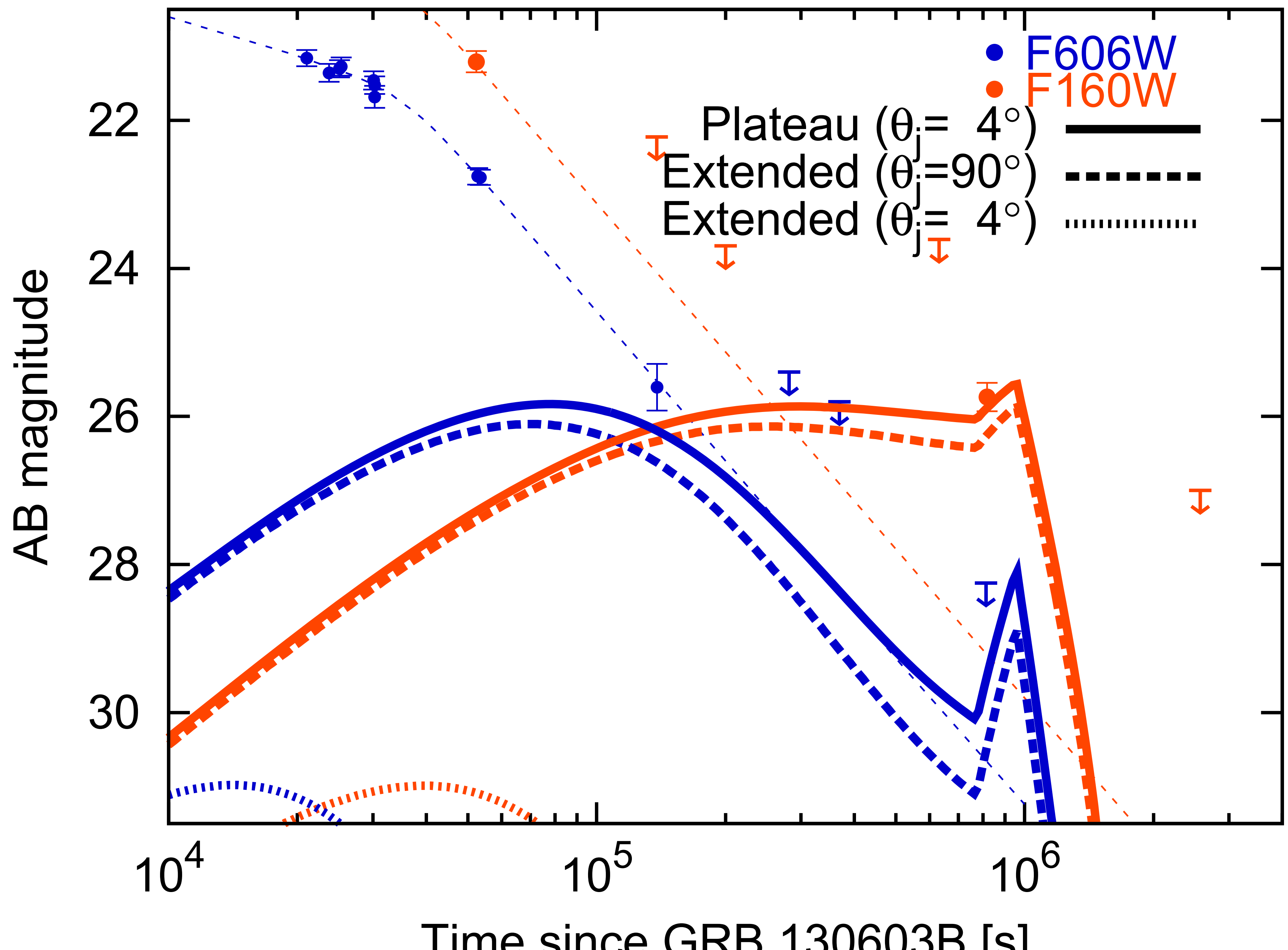
We monitored the location of the short GRB 160821B (Siegel et al. GCN 19833; Xu et al. GCN 19834) with the Hubble Space Telescope under our approved guest observer programs (GO14237 PI: Tanvir; GO14087 PI: Troja). Observations were carried out with the Wide Field Camera (WFC3) in three filters, F606W, F110W and F160W, at epochs 3.6, 10.4 and 23.2 days post-burst. The GRB counterpart is clearly detected in all filters during the first two epochs, and fades from a magnitude of F606W~25.8 (AB) in the first epoch to become undetectable in the third epoch.

Assuming a redshift of z=0.162 from the nearby galaxy identified as the likely host (Levan et al. GCN 19846), our observations rule out the presence of an emerging supernova comparable to SN1998bw or to other SNe associated to long GRBs. The observed fluxes constrain the contribution of any r-process kilonova/macronova component to be at least a factor ~5 fainter in the IR than that seen in GRB 130603B. The lack of a bright supernova and the moderate-to-low ejecta mass implied by our observations are consistent with this event being produced by the merger of two neutron stars.

However, the current dataset cannot firmly exclude the presence of an underlying, higher redshift host galaxy. Deeper HST observations aimed at placing better constraints on the GRB redshift are on-going.

We thank the STScI staff, in particular Tricia Royle, for assistance with rapidly scheduling our observations.

Re-processed emission of extended/plateau emission



Kisaka+15

==> Need detailed follow-up of GW sources

EM emission from GW sources

- X-ray/gamma-ray
  - Short GRBs: promising, but strongly beamed
  - Central engine activity (isotropic??)
- Radio
  - Afterglow: delayed by ~ years
  - Good for confirmation and low contamination rate
- Optical/infrared
  - r-process nucleosynthesis => kilonova/macronova
  - Probably detected in short GRB observations
  - GW + EM => r-process production rate

Multi-messenger astronomy ==> Origin of r-process elements