Radioactively Powered Emission from Neutron Star Mergers

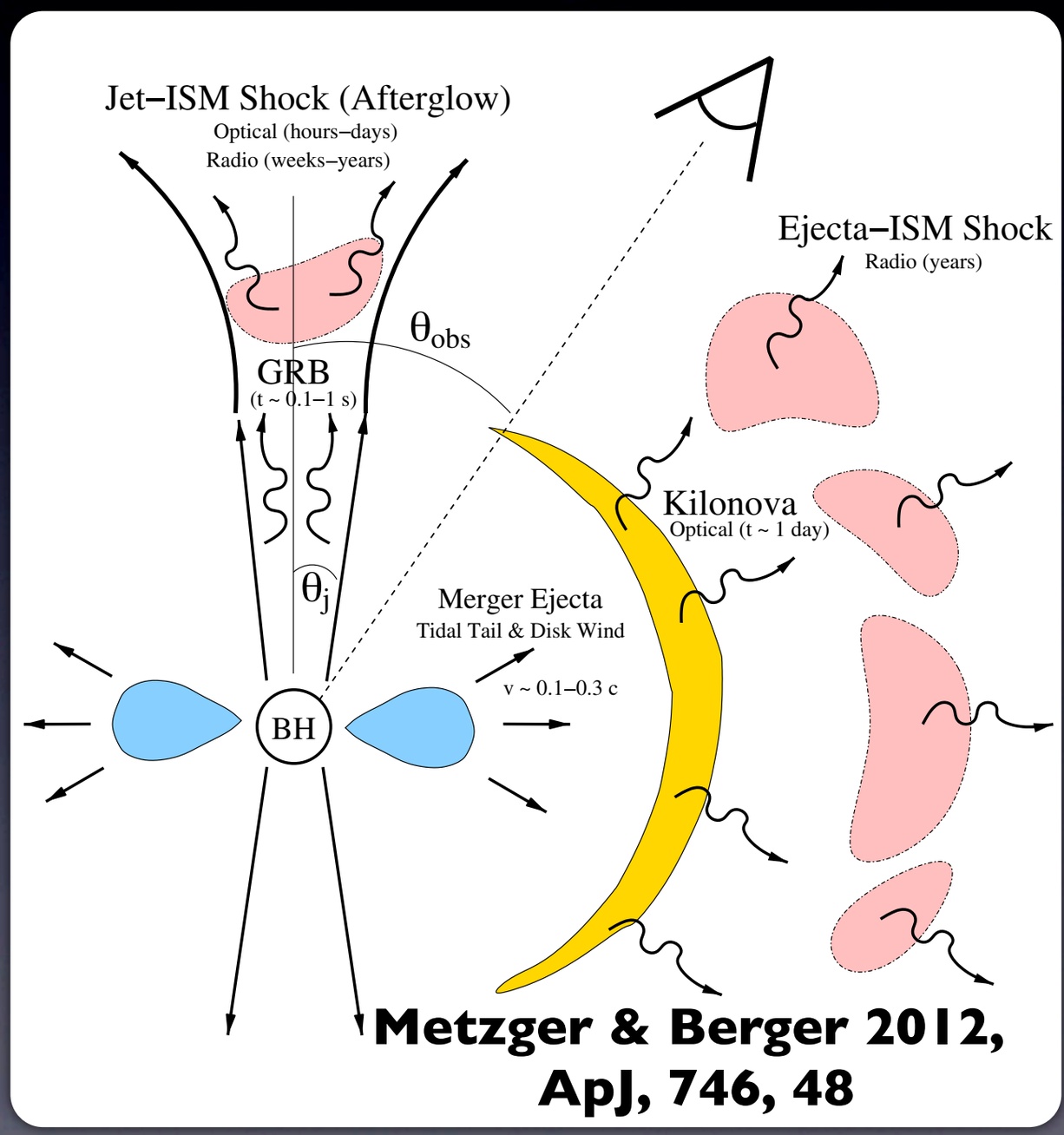
(kilonova, macronova, r-process nova, goldnova, ...)

Masaomi Tanaka (NAOJ)

- MT & Hotokezaka 2013, ApJ, 775, 113
- MT, Hotokezaka, Kyutoku, Wanajo, Kiuchi, Sekiguchi, Shibata 2013, ApJ, in press (arXiv:1310.2774)
- Hotokezaka, Kyutoku, MT, Kiuchi, Sekiguchi, Shibata, Wanajo 2013, ApJ, 778, L16

EM emission from NS-NS merger = EM counterparts of GW sources

- On-axis short GRB
- Off-axis radio/optical afterglow
- Radioactive emission (r-process nuclei)



N. Gehrels's, A. Fruchter's, S. Wanajo's, S. Rosswog's, and B. Metzger's talks

2 deg

Kiso Supernova Survey (KISS)
Kiso 1m Schmidt telescope

~ 200 galaxies / 4deg^2
(< 200 Mpc)

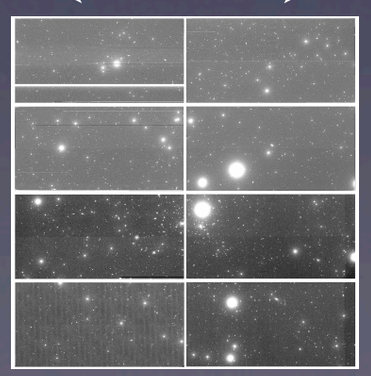
GW alert error box

e.g. 10 deg x 10 deg

~ 5000 galaxies

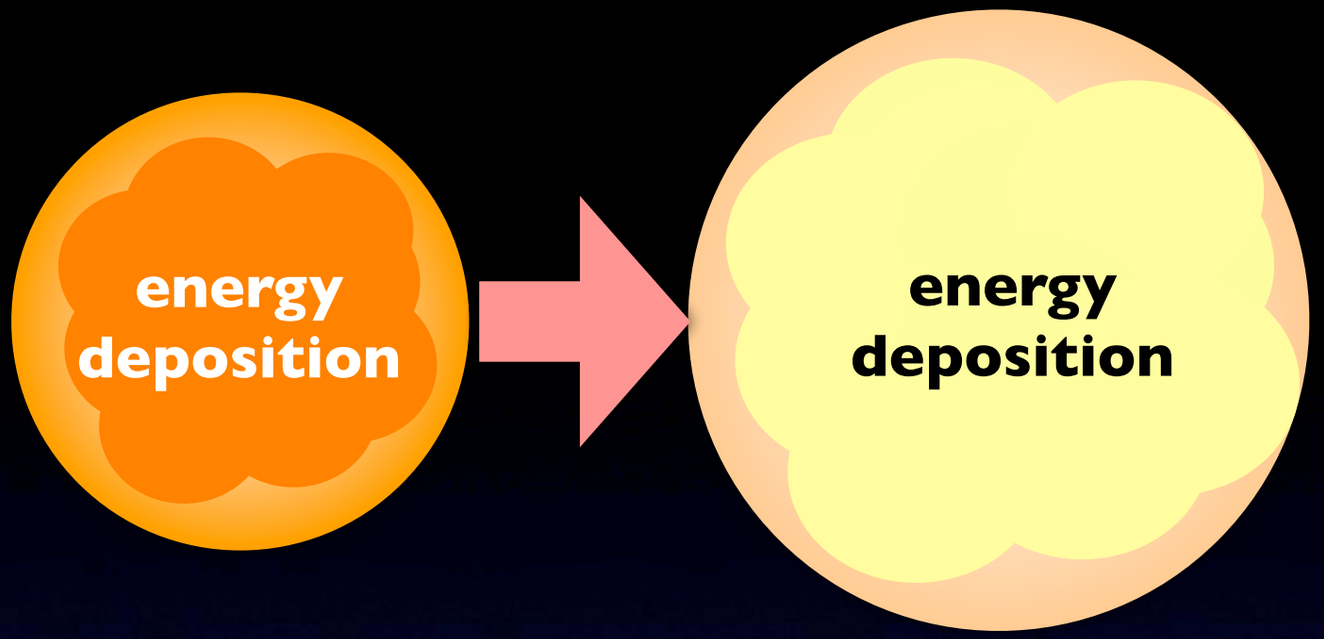
(< 200 Mpc)

2 deg



Expected emission

Li & Paczynski 98
Kulkarni 05
Metzger+10
A. Bauswein's and B. Metzger's talks



Timescale

$$t_p \sim 1 \text{ day} \left(\frac{M}{0.01 M_\odot}\right)^{1/2} \left(\frac{v}{0.2c}\right)^{-1/2} \left(\frac{\kappa}{0.1 \text{ cm}^2 \text{ g}^{-1}}\right)^{1/2}$$

Luminosity

$$L \sim 10^{42} \text{ erg s}^{-1} \left(\frac{M}{0.01 M_\odot}\right)^{1/2} \left(\frac{v}{0.2c}\right)^{1/2} \left(\frac{\kappa}{0.1 \text{ cm}^2 \text{ g}^{-1}}\right)^{-1/2}$$

Opacity of Fe

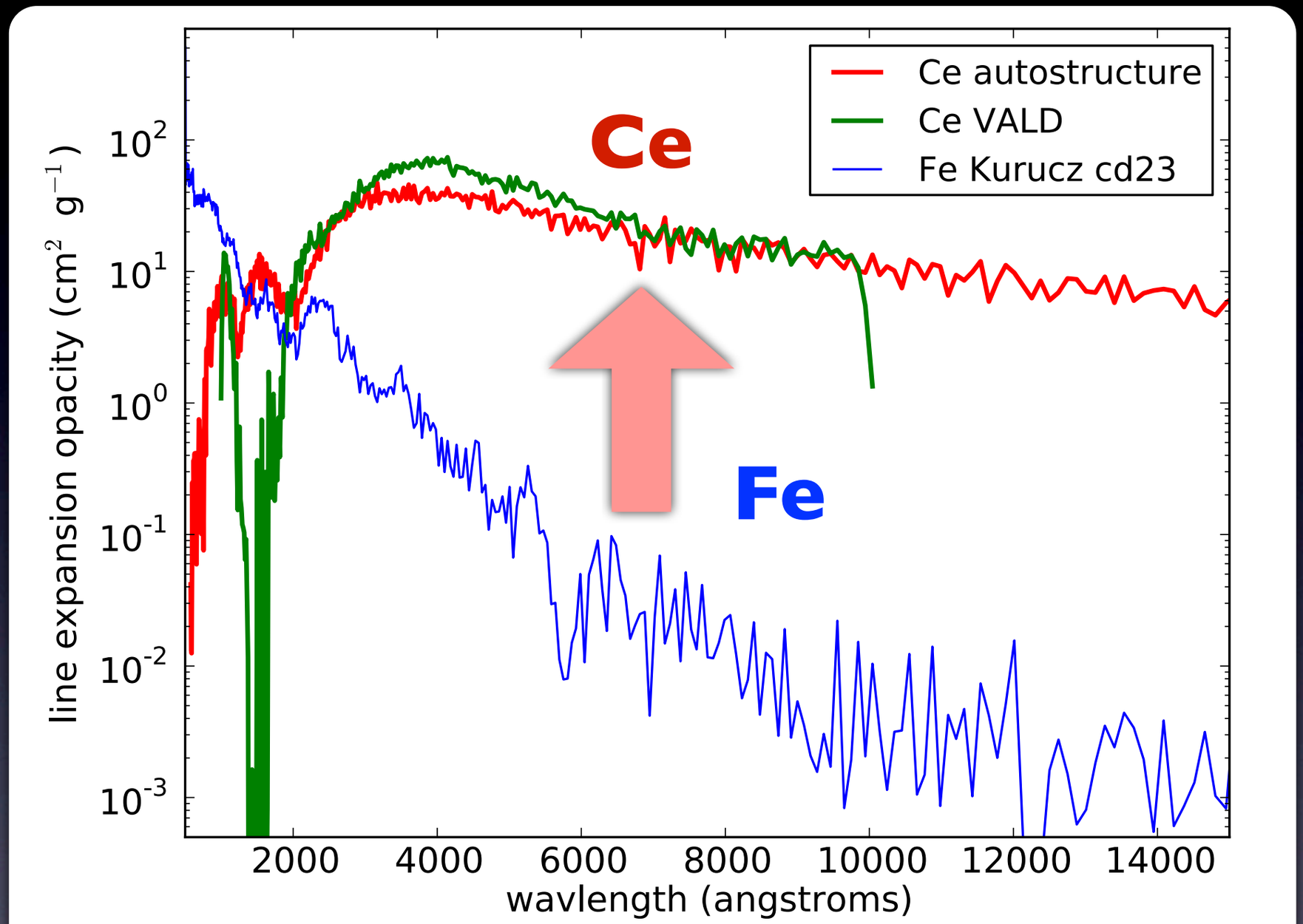
~ 20 mag at 200 Mpc
(1m-class telescopes)

Opacity of Lanthanoid Ce

$\kappa \equiv 10\ cm^2\ g^{-1}$

$\kappa \equiv 1\ cm^2\ g^{-1}$

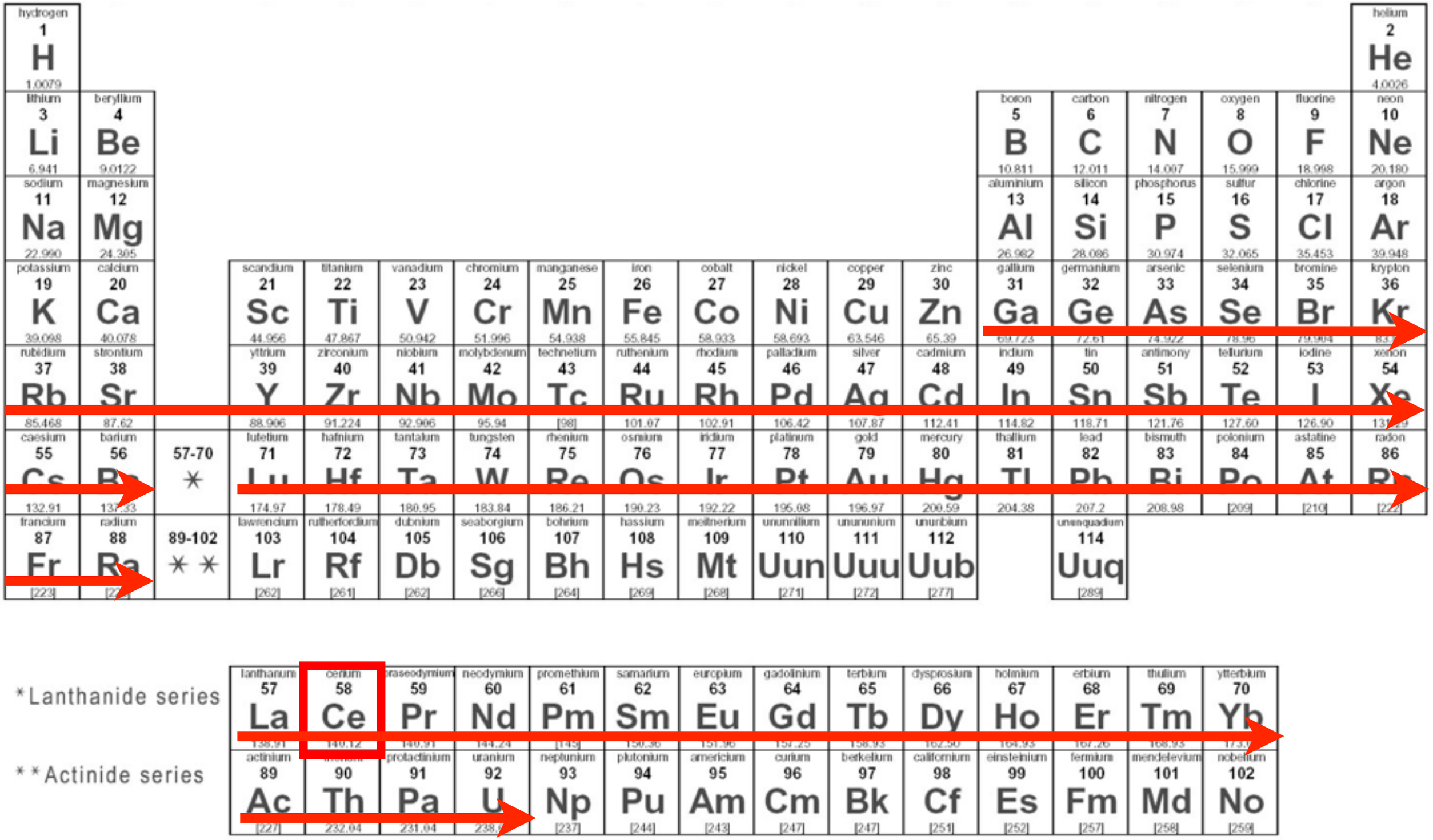
$\kappa \equiv 0.1\ cm^2\ g^{-1}$



High opacity (x 100) => Lower luminosity (x 1/10)

Kasen et al. 2013

Barnes & Kasen 2013

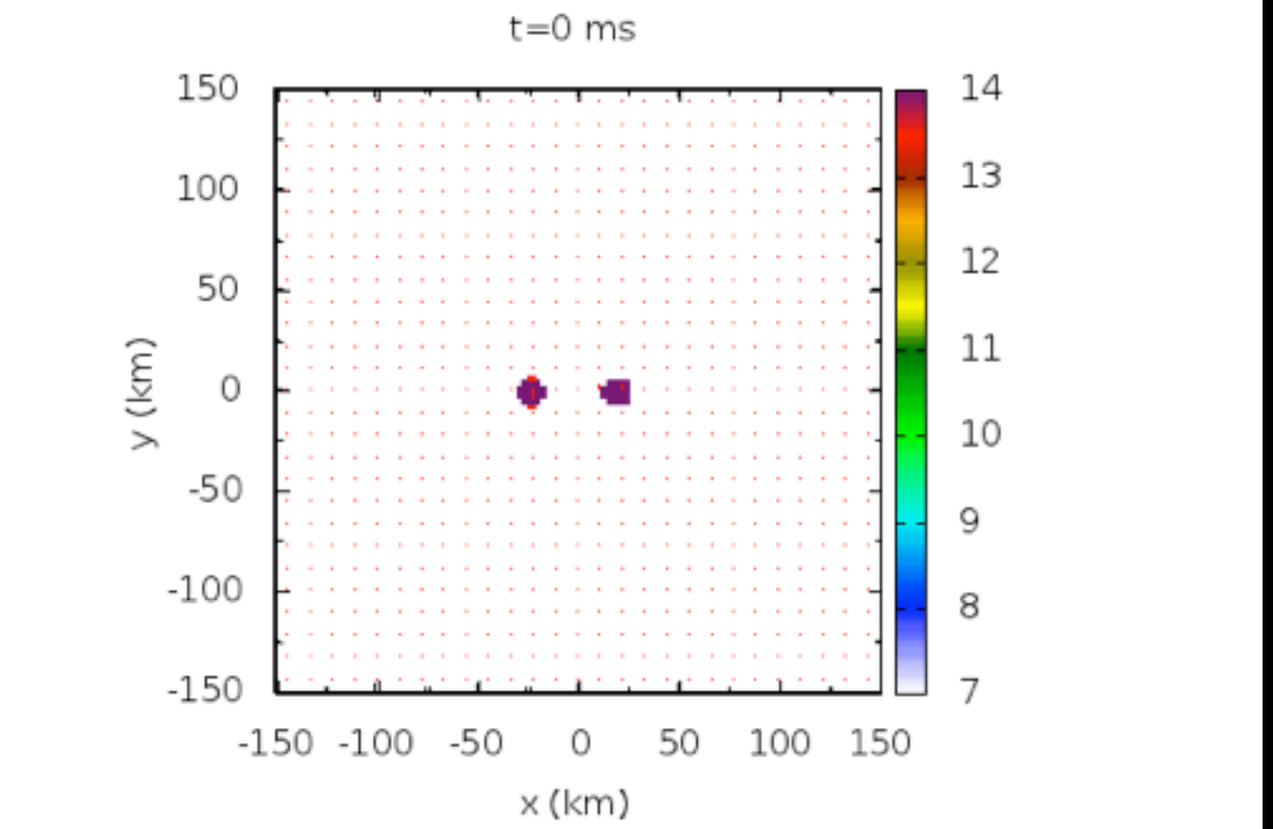


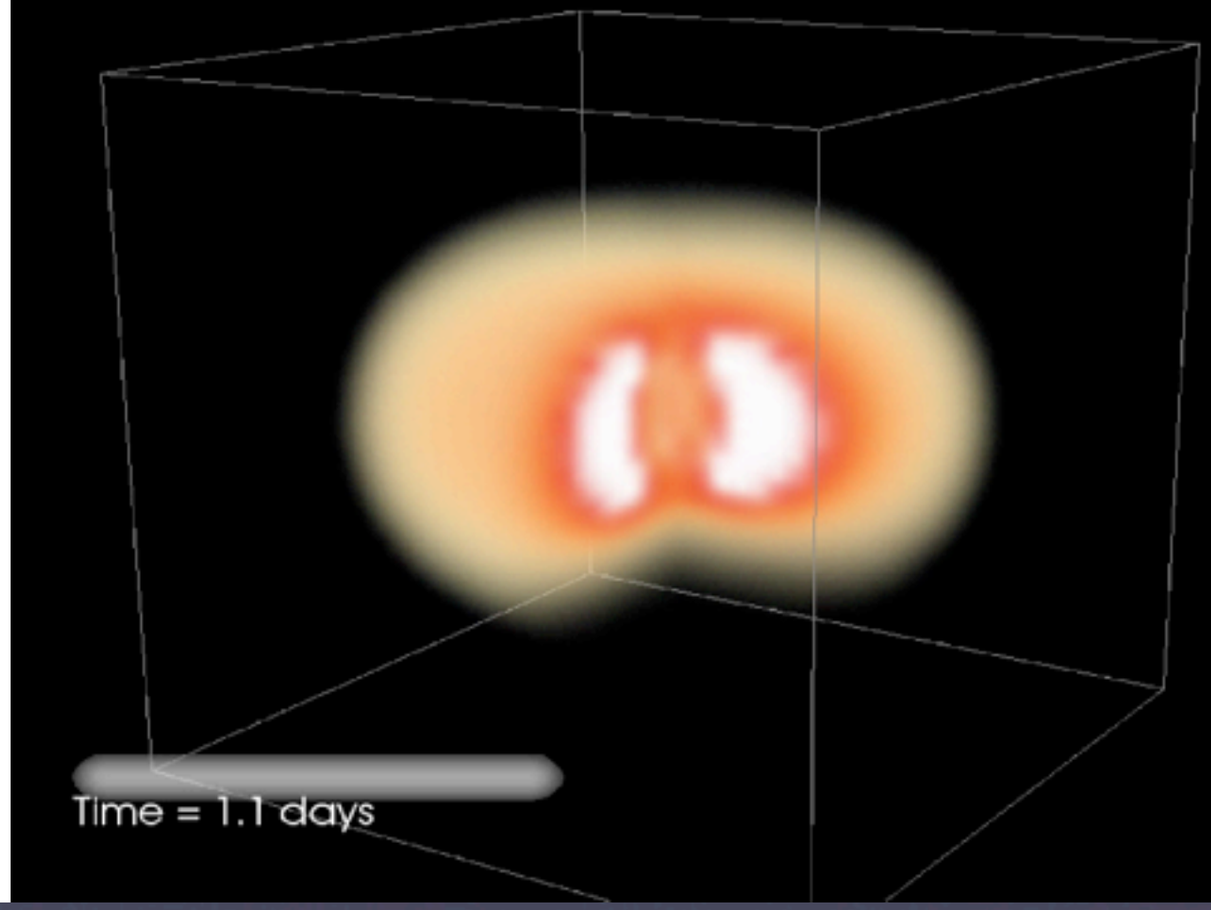
Radiative transfer in NS merger ejecta

with all the r-process elements

Numerical relativity

3D, time-dependent, multi-frequency radiative transfer

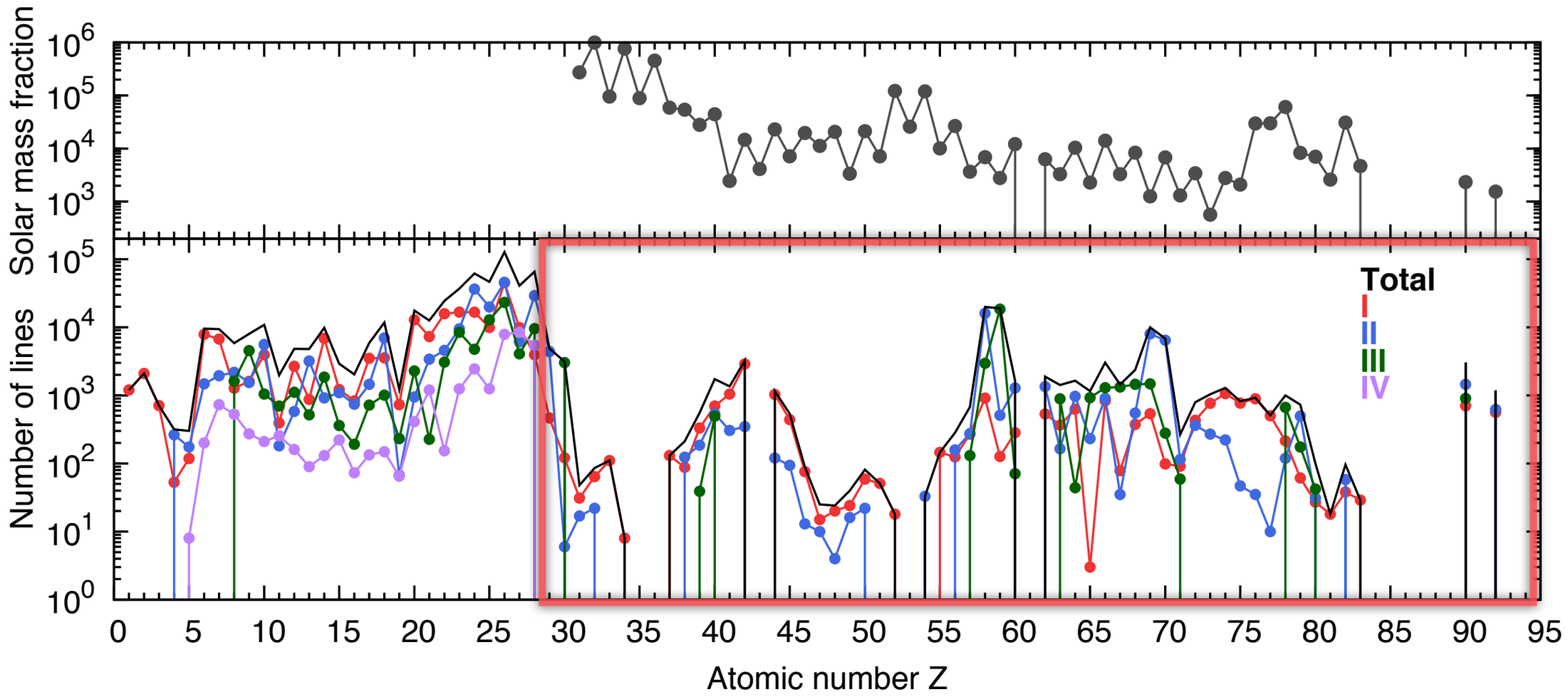




Hotokezaka et al. 2013

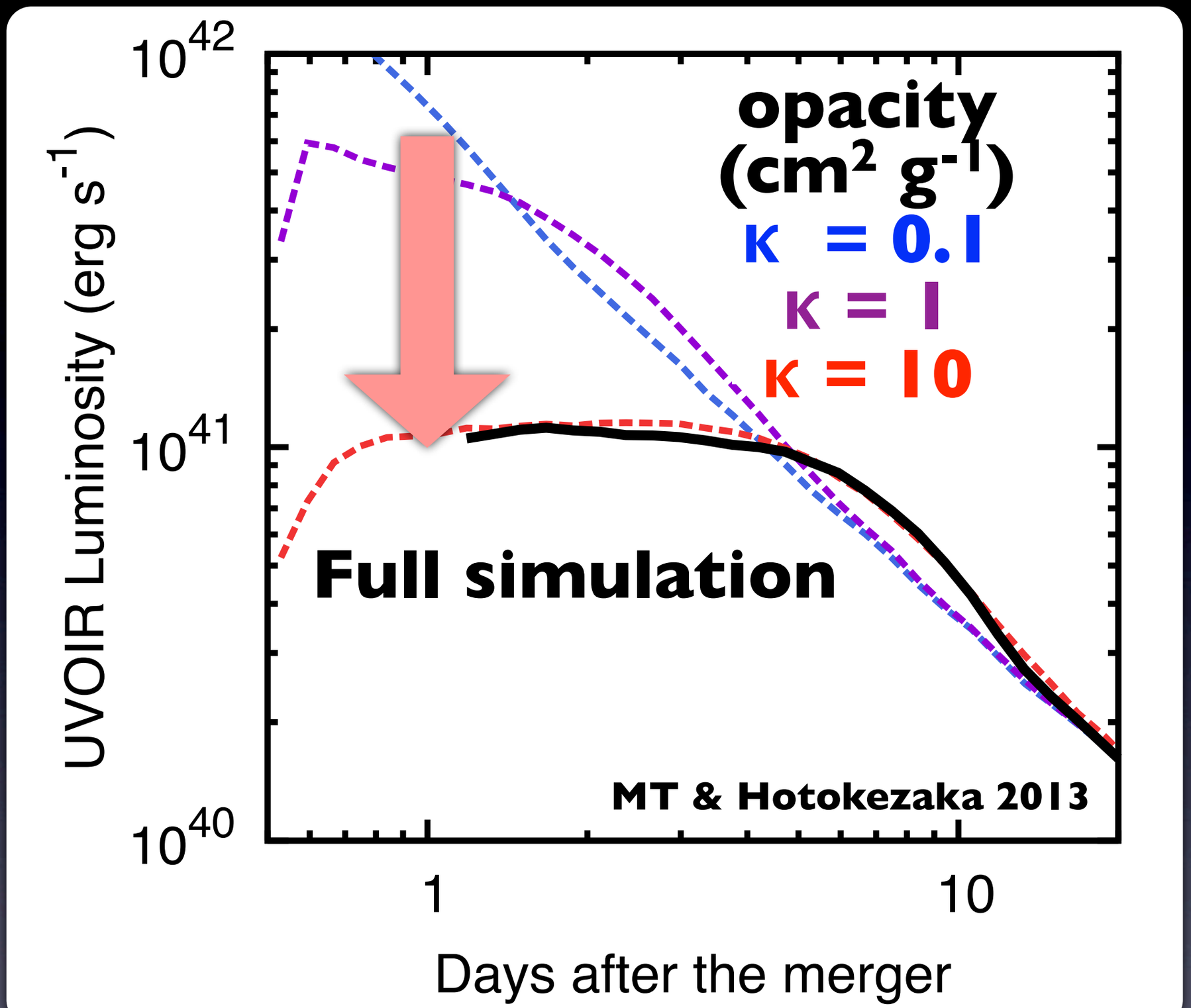
MT & Hotokezaka 2013

1. Opacity of r-process-dominated ejecta?
2. Characteristic feature of NS merger?
3. Dependence on EOSs and progenitors?



~500,000 transitions (up to Fe)
+100,000 transitions (r-process)

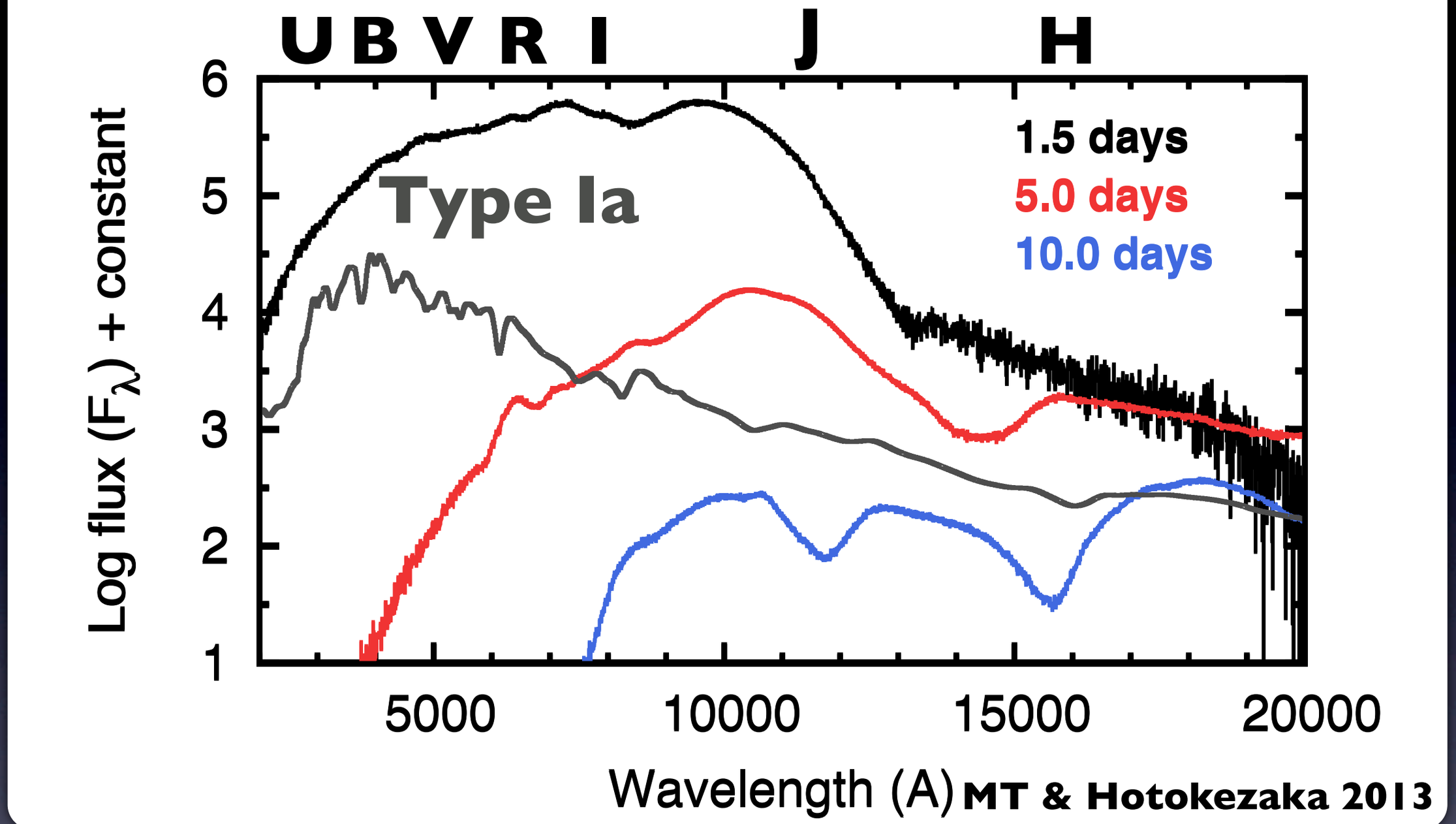
Evaluate bound-bound opacity
(in each time step)



Higher opacity by factor of 100

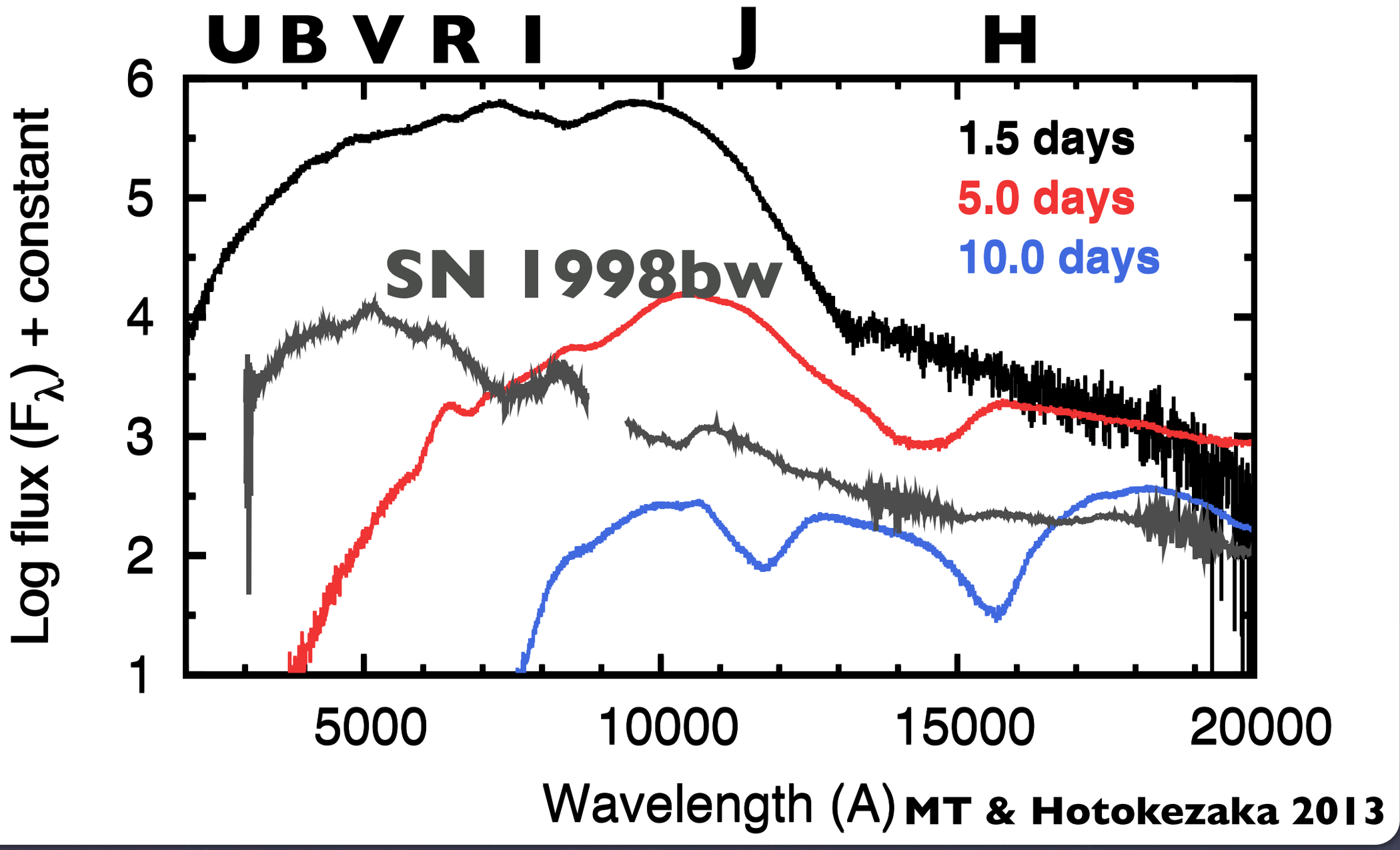
Fainter than previously expected by a factor of 10

(consistent with Kasen+13, Barnes & Kasen 13)



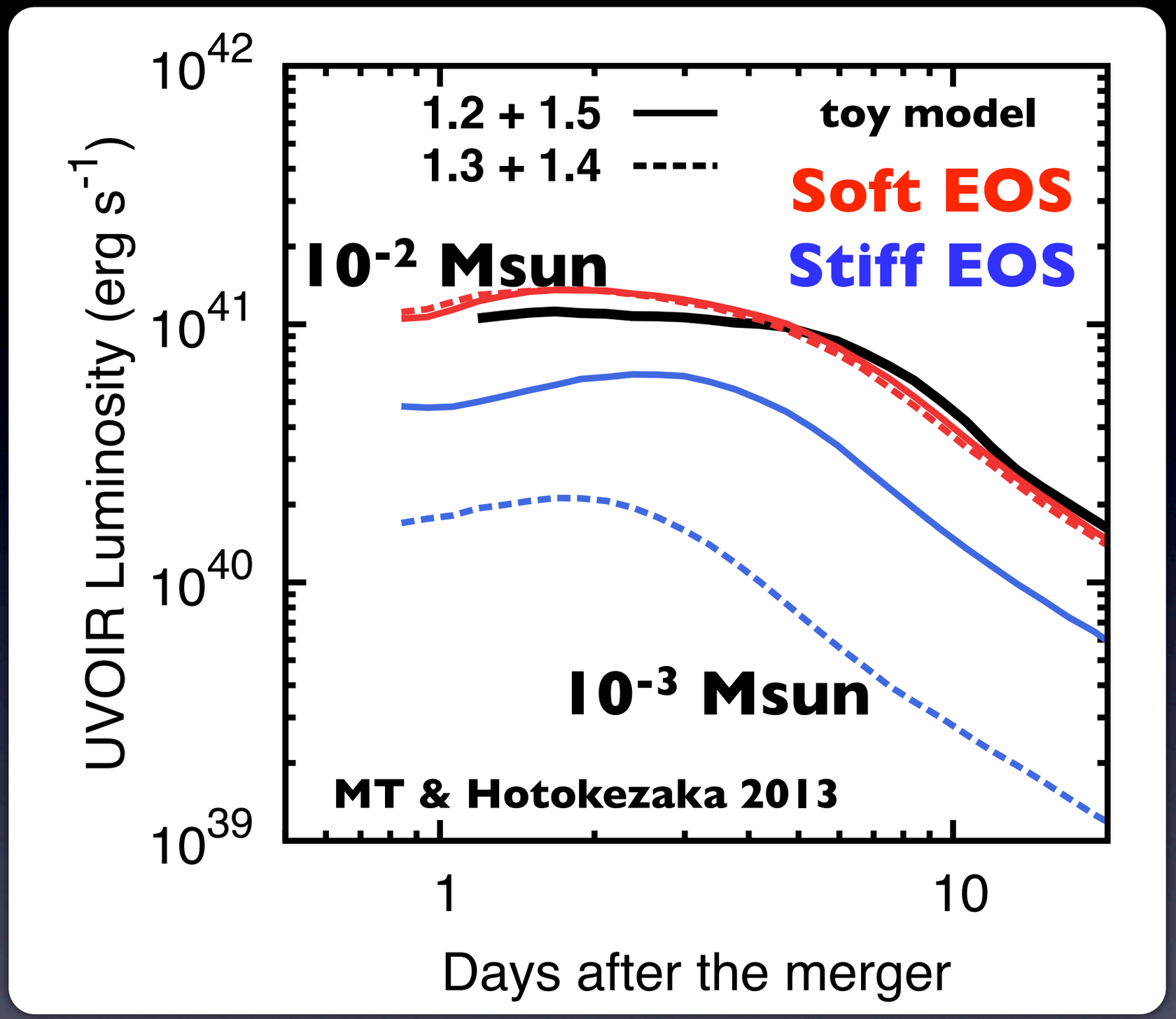
- Very red SED (peak at NIR)
- Extremely broad-line (feature-less) spectra

(Identification of r-process elements seems difficult)



- Very red SED (peak at NIR)
- Extremely broad-line (feature-less) spectra

(Identification of r-process elements seems difficult)



Radius of 1.35 Msun NS

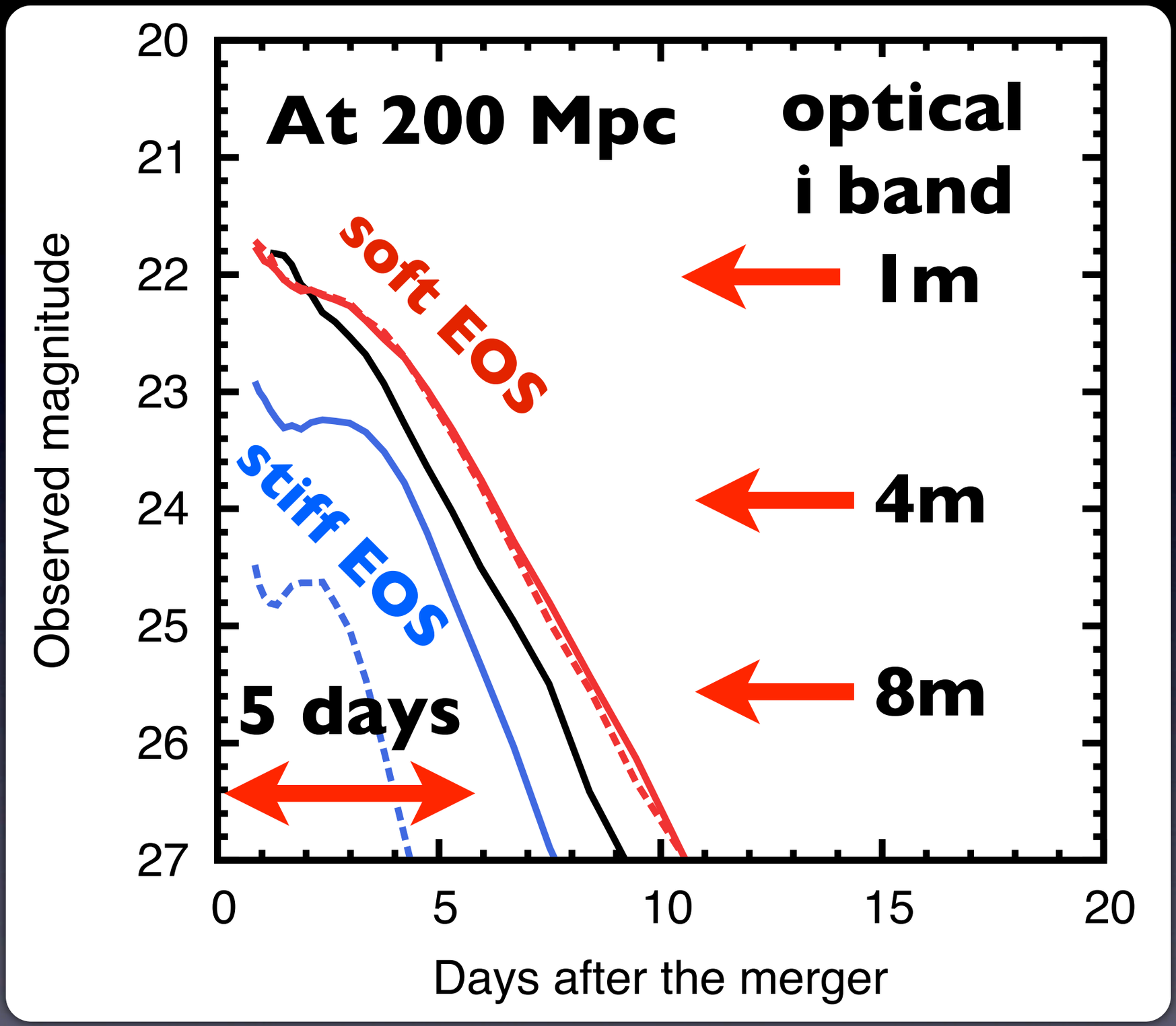
R = 11.1 km
R = 13.6 km

Softer EOS/Higher NS mass ratio

Brighter emission

(Hotokezaka+13; Bauswein+13, M. Shibata's, A. Bauswein's talks)

Observing strategy after GW detection

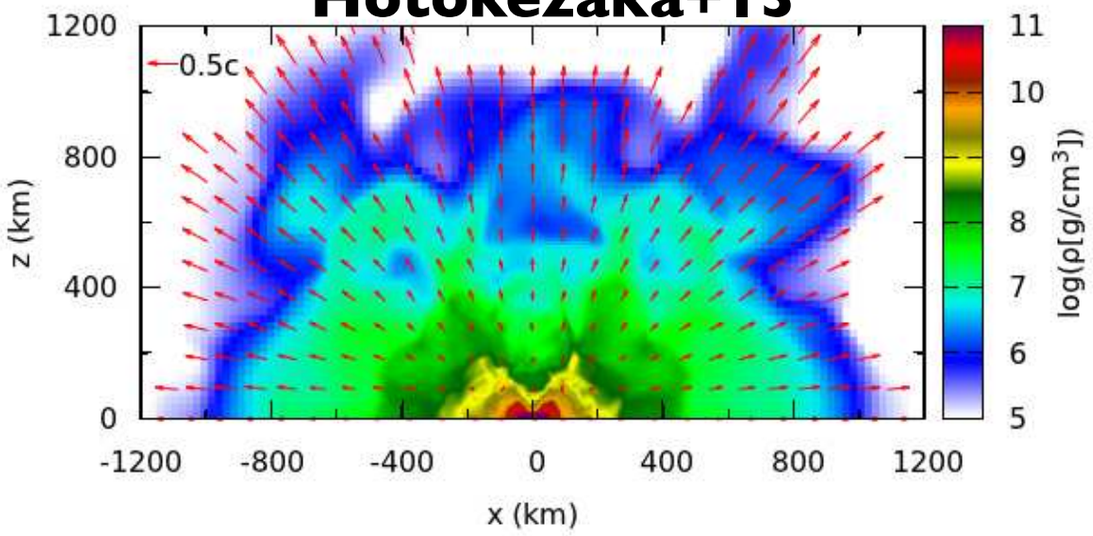


10 min
5 sigma

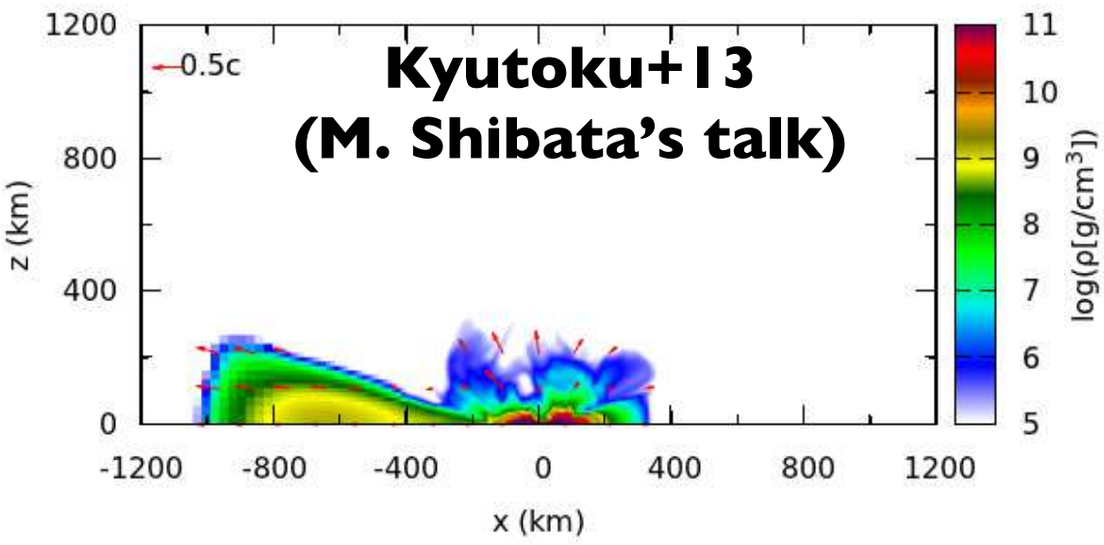
Best with i band (0.8 um)
NIR (~21 AB mag in NIR)

NS-NS

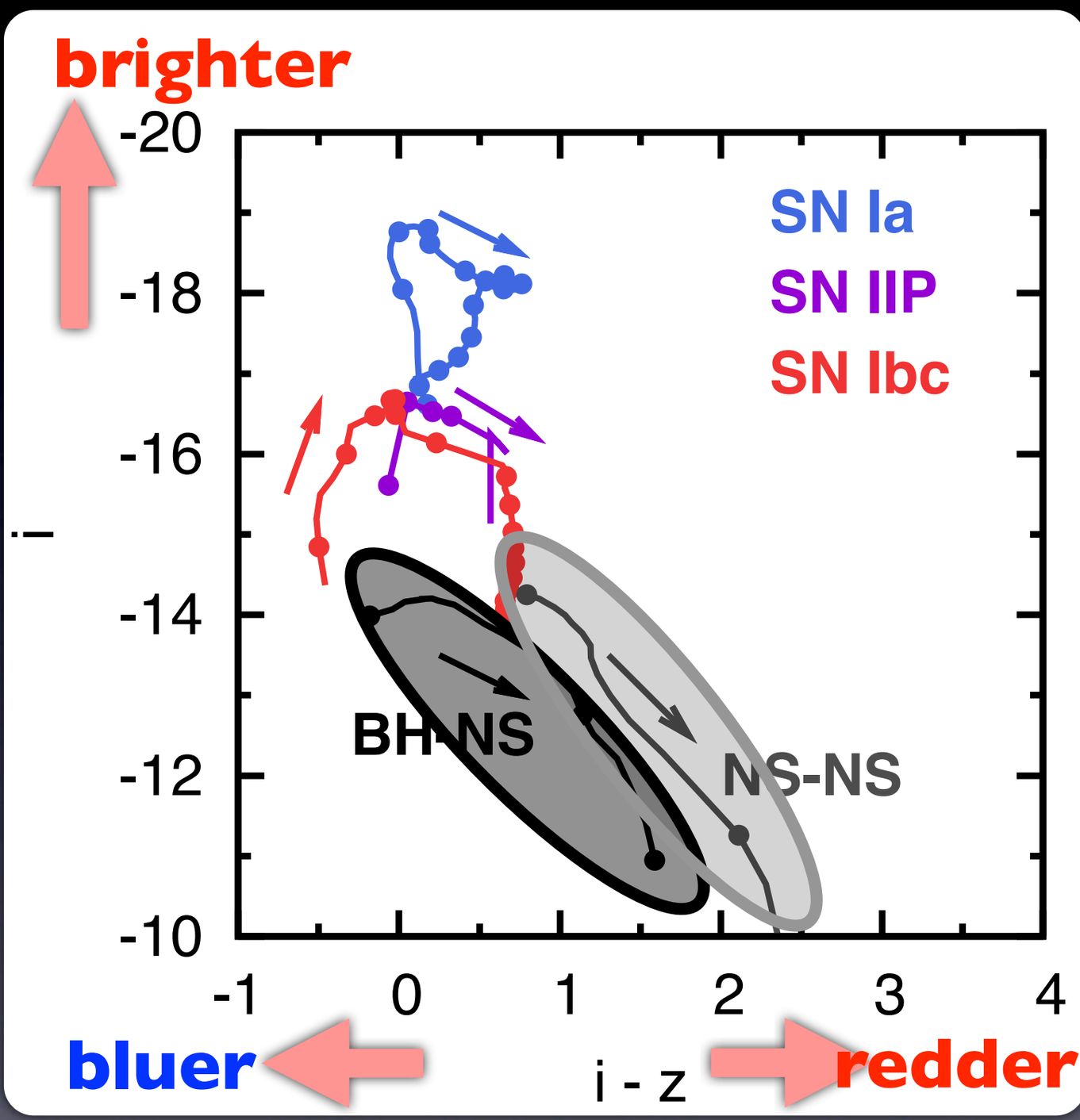
Hotokezaka+13



BH-NS



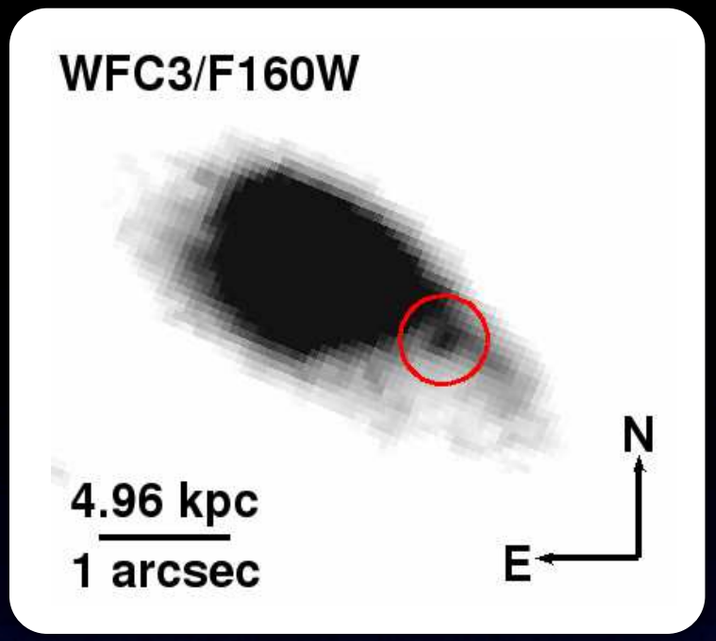
HR diagram



MT, Hotokezaka, Kyutoku, Wanajo, Kiuchi, Sekiguchi, Shibata
2013, ApJ, in press (arXiv:1310.2774)

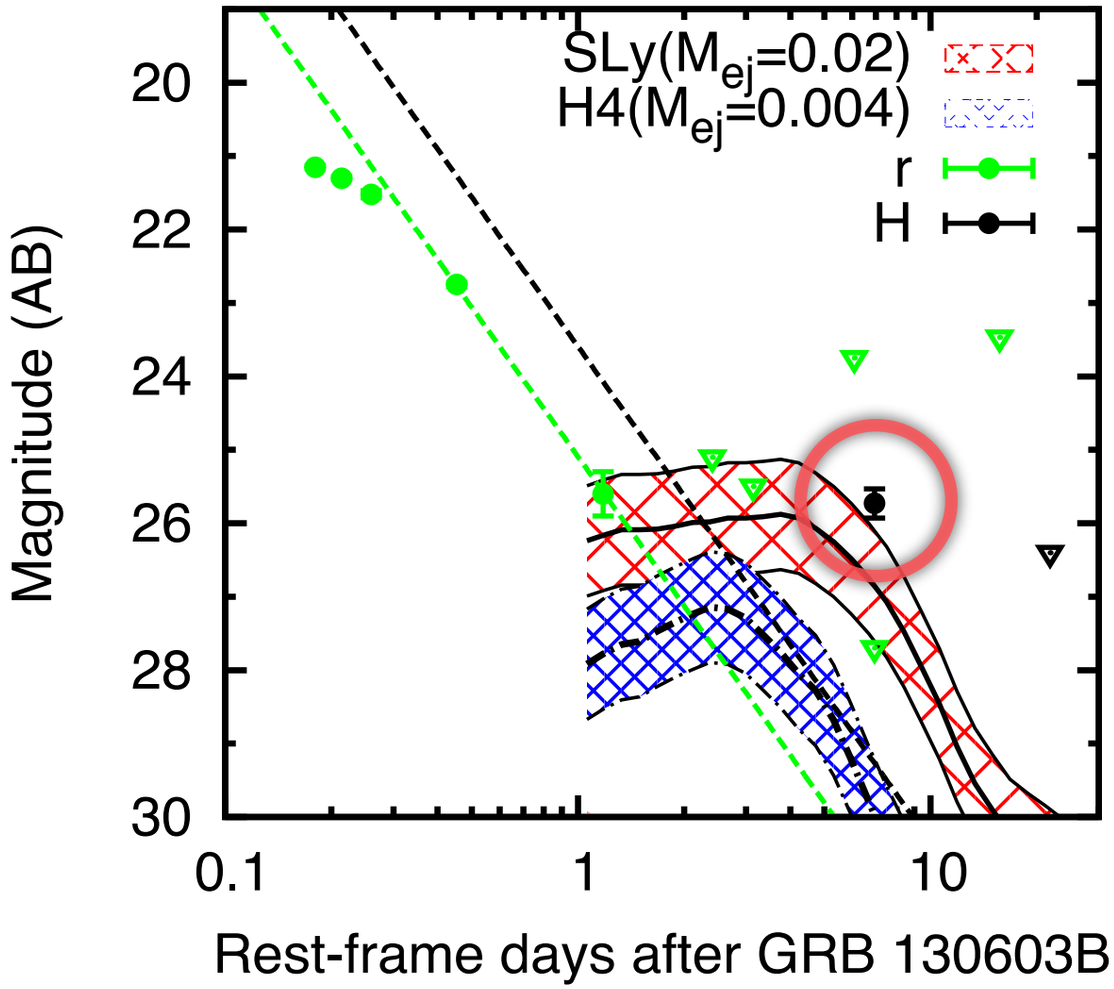
Application to GRB 130603B

Berger+13
Tanvir+13
A. Fruchter's talk

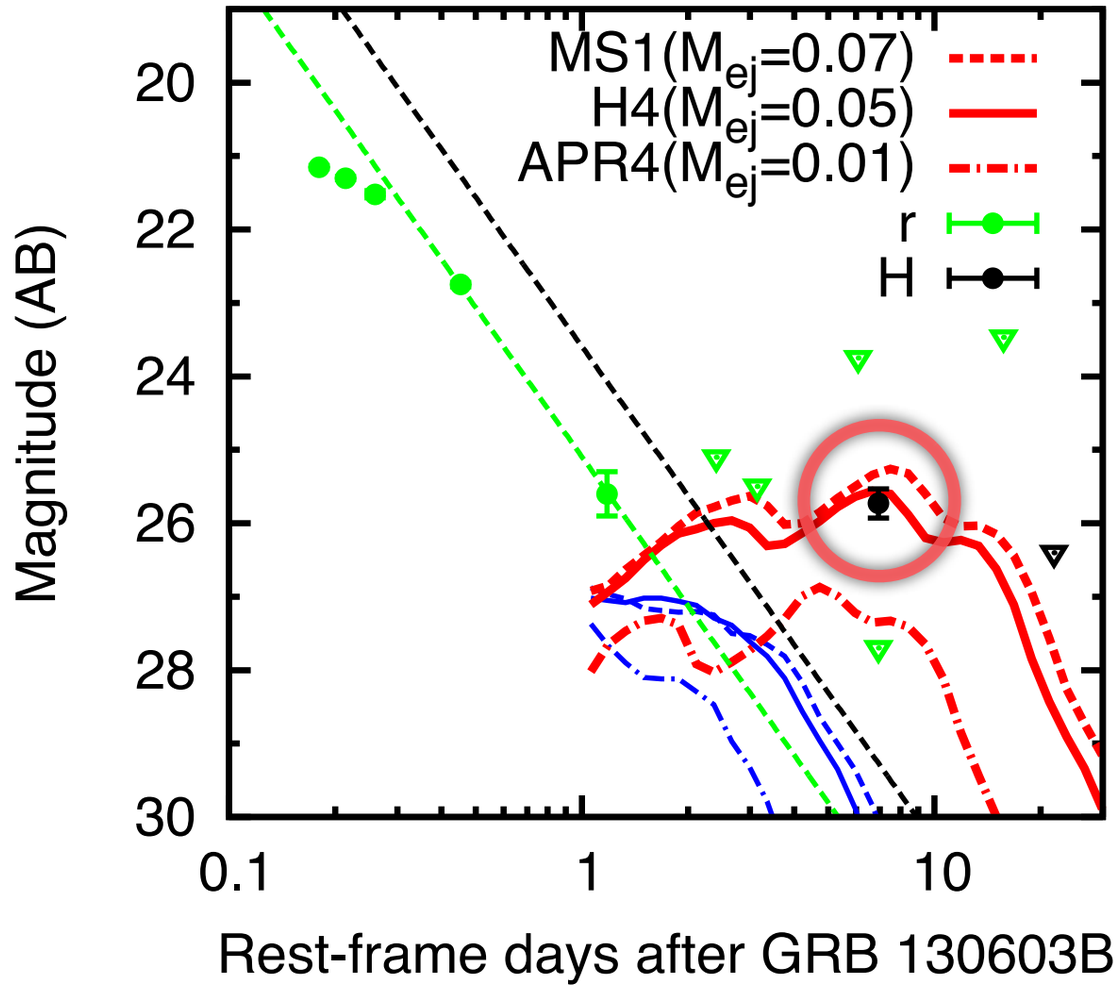


NS-NS

Hotokezaka+13



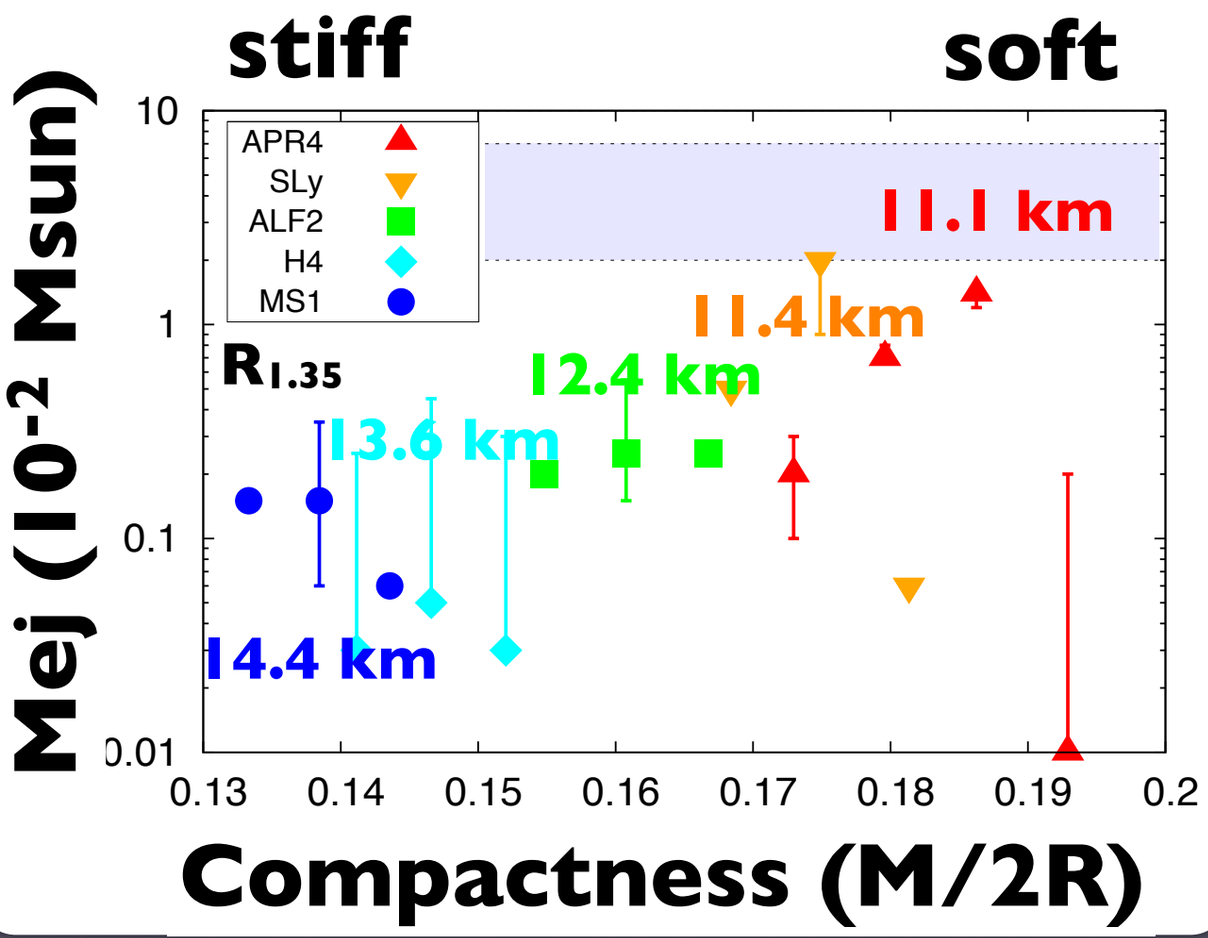
BH-NS



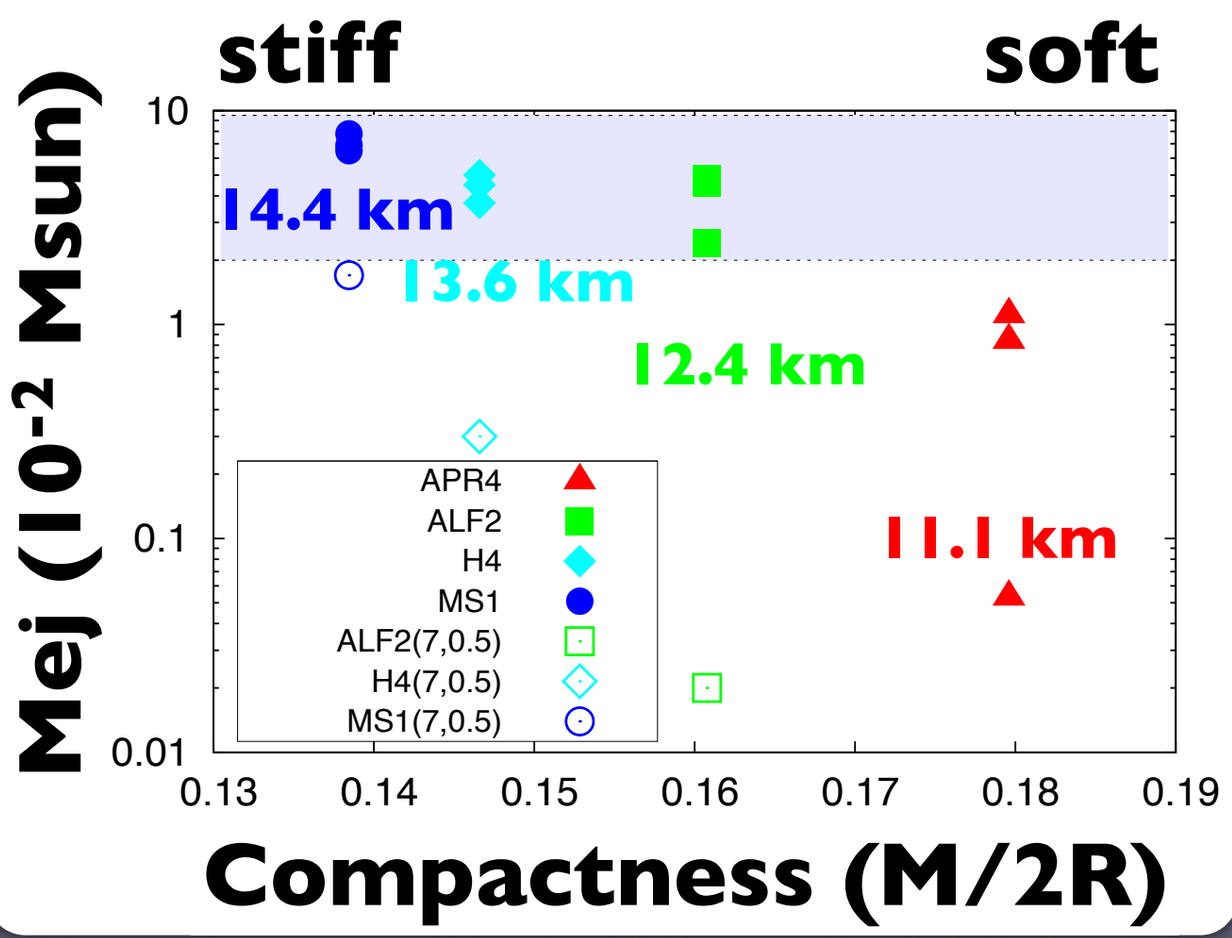
Constraints on Progenitors/EOSs

Efficient mass ejection
Mej ~ 0.02 Msun

NS-NS
=> soft EOS



BH-NS
=> stiff EOS



Hotokezaka, Kyutoku, MT, Kiuchi, Sekiguchi, Shibata, Wanajo
2013, ApJ, 778, L16

Summary

- EM emission from NS-NS/BH-NS mergers
  - Accurate localization of GW sources
- "Full" radiative transfer simulations
  - Higher opacity than Fe by a factor of 100
  - SED peak at near-IR
  - Bluer emission from BH-NS mergers
- Observing strategy
  - 22-25 mag (i band) => 4-8m class telescopes
  - Extremely broad-line spectra
- GRB 130603B
  - Constraints on progenitors and EOSs