Macronovae and r-process production sites

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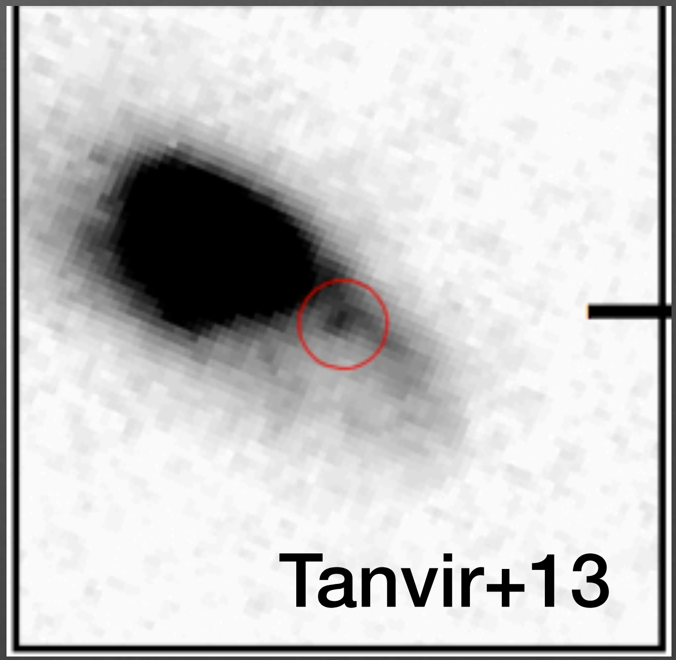
Are macronovae ubiquitous phenomena?

The discovery of the first candidate after the short GRB 130603B:

Evidence for NS mergers
=> short GRB & r-process

HST image in nIR



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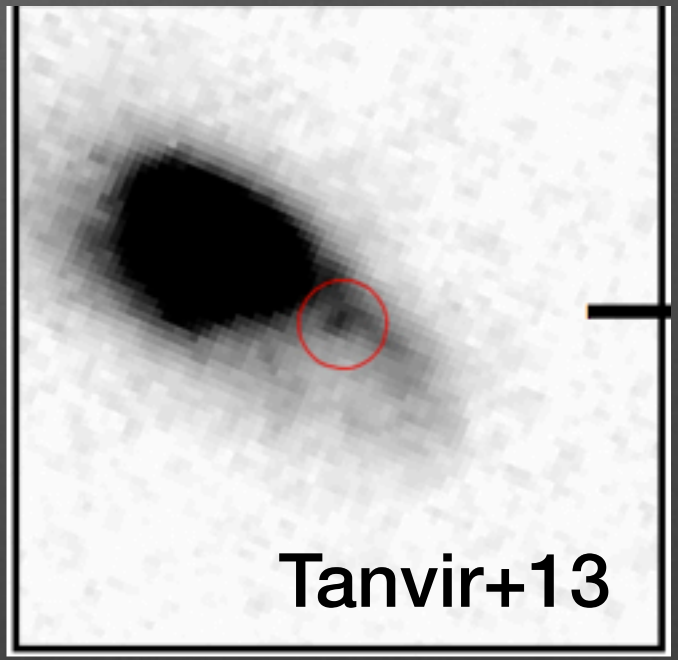


Question: How about other GRBs?

There are 12 possibly non-collapsar GRBs with $z<0.4$.

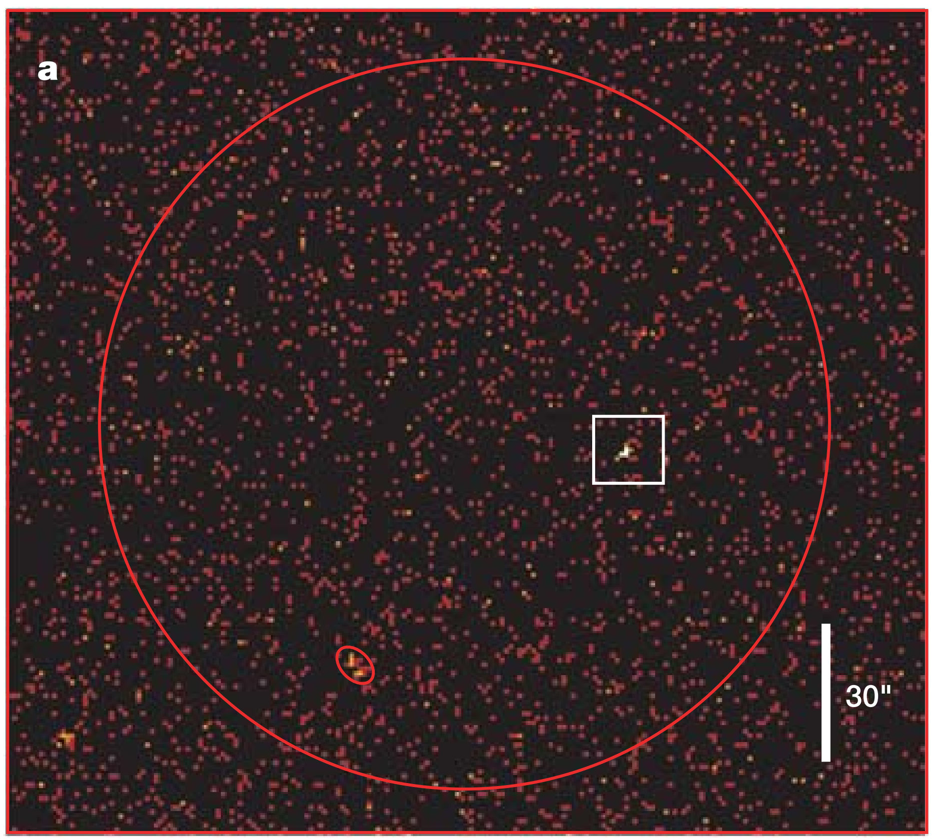
Late-time observations suitable for the macronova search are available.

=> We have 7 samples => 3 macronova candidates.

Short GRB 050709

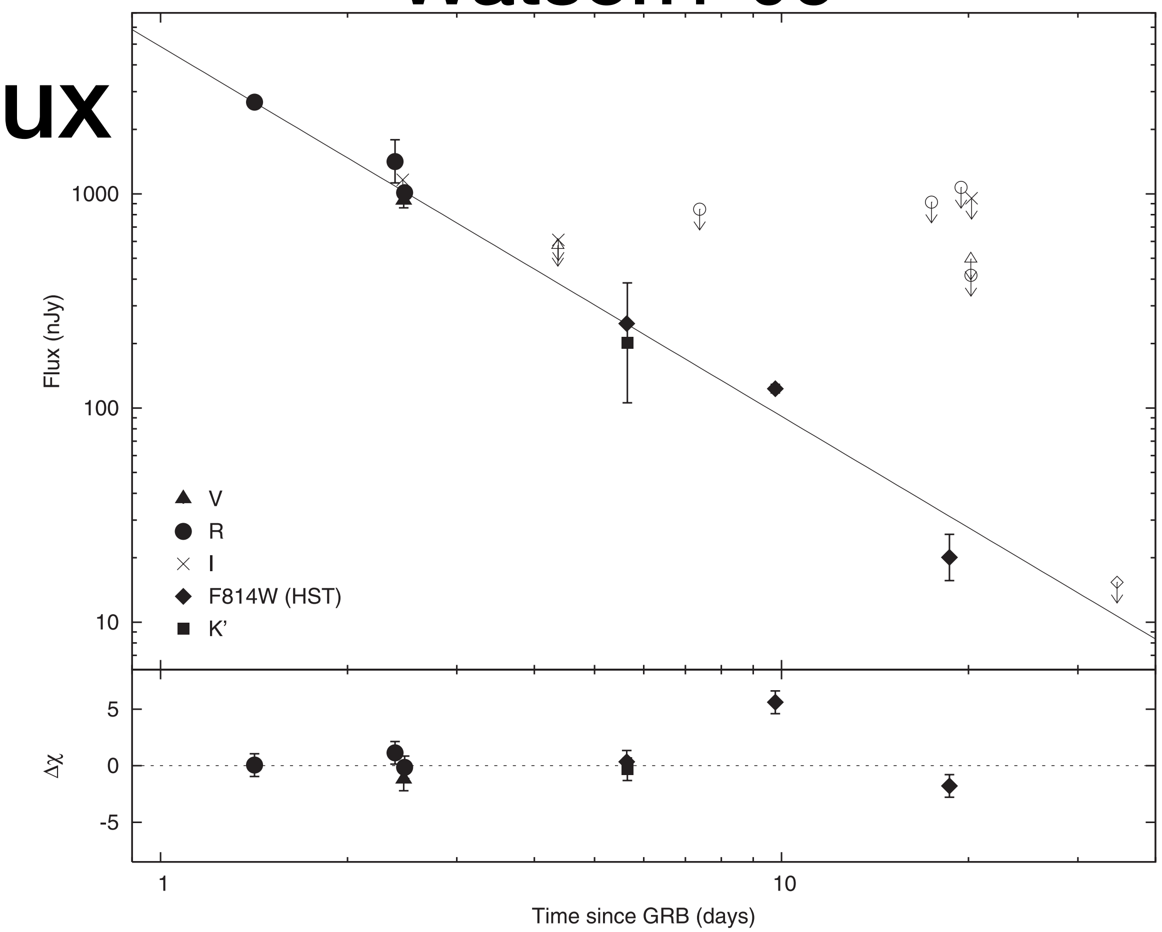
The first short GRB of which the optical afterglow is detected.

Fox + 05, HST image



Watson+ 06

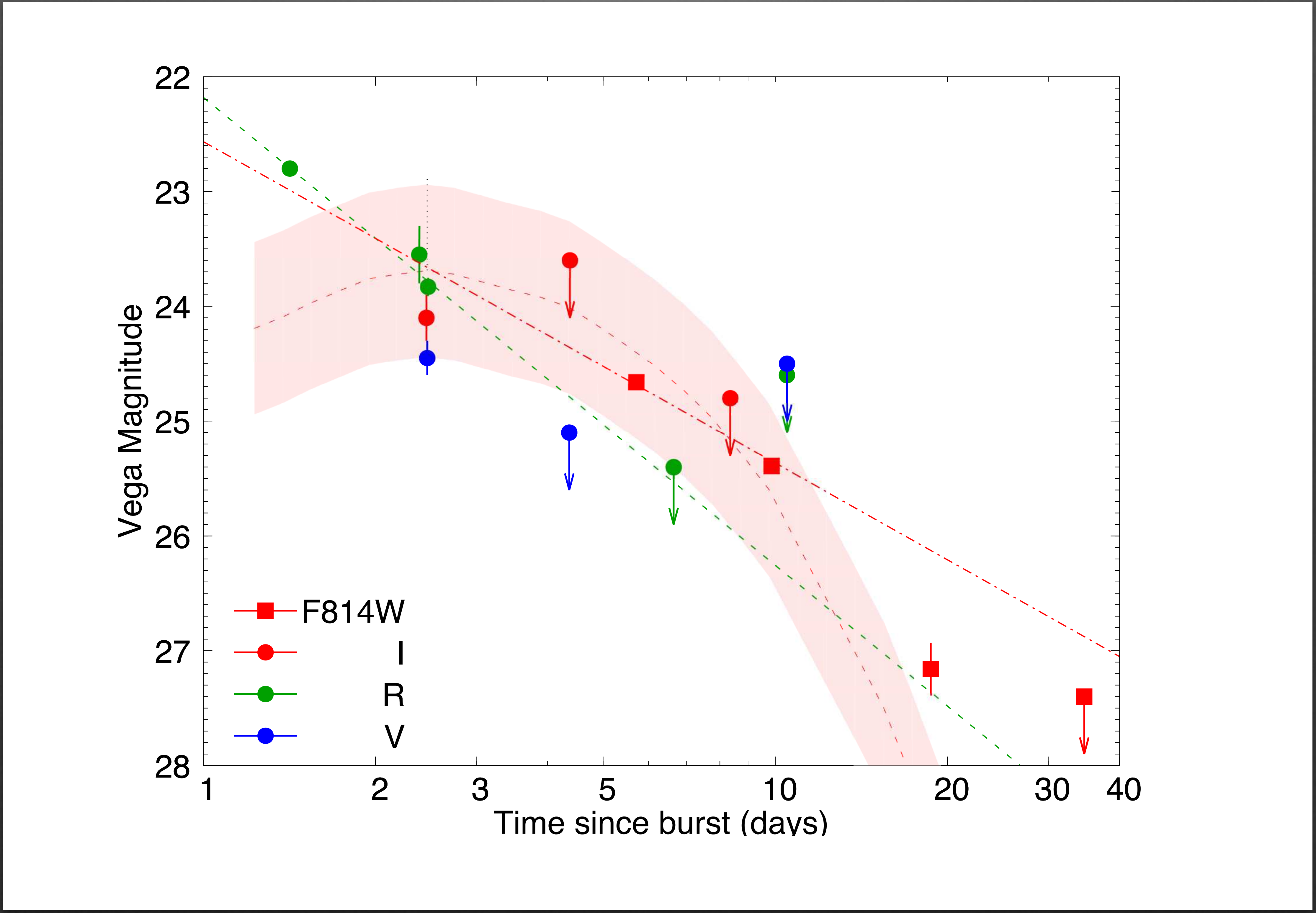
Flux



Time [days]

Watson + 06 show that the optical data are not consistent with the simple afterglow model => an optical flare?

Macronova interpretation of GRB 050709



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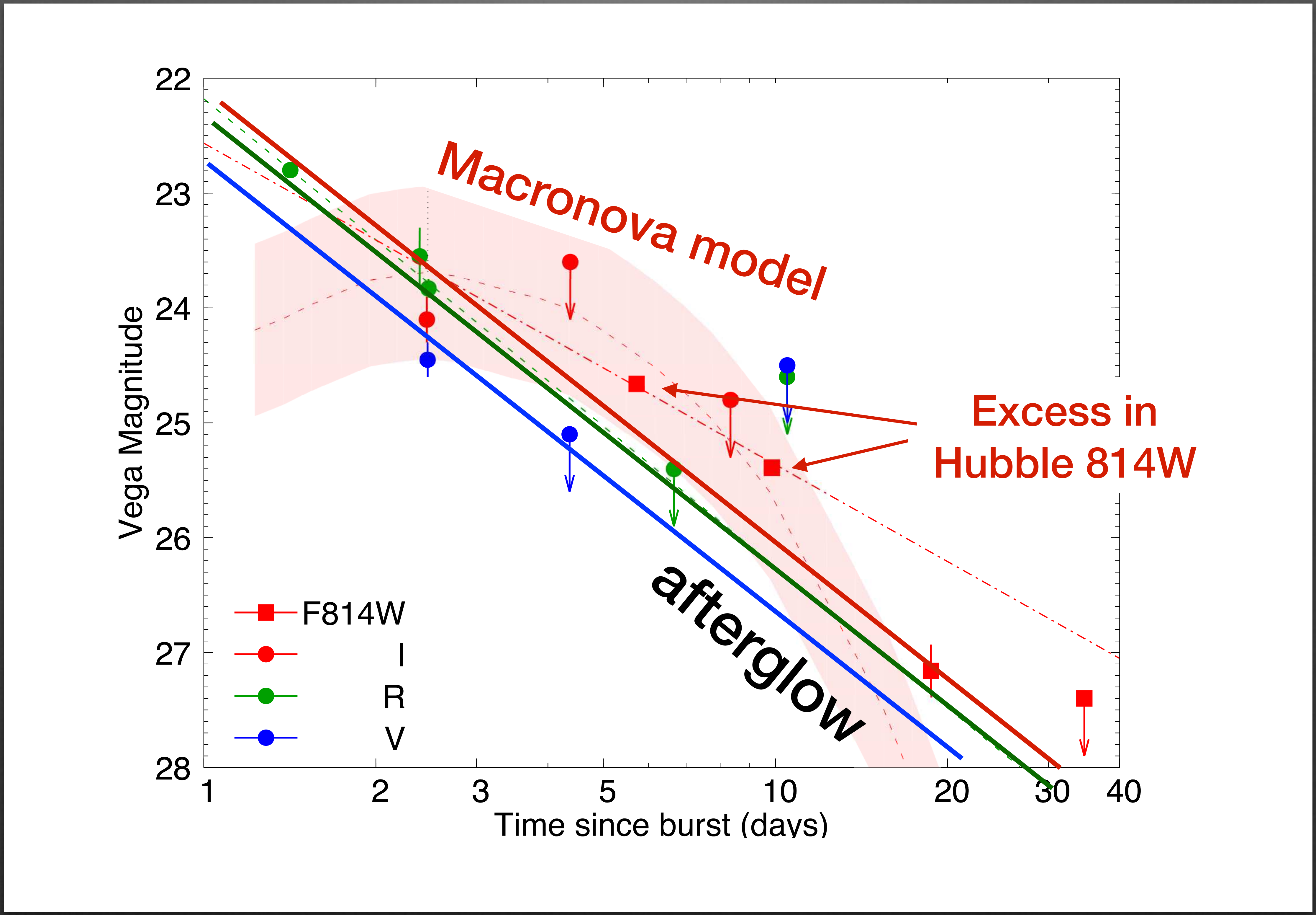
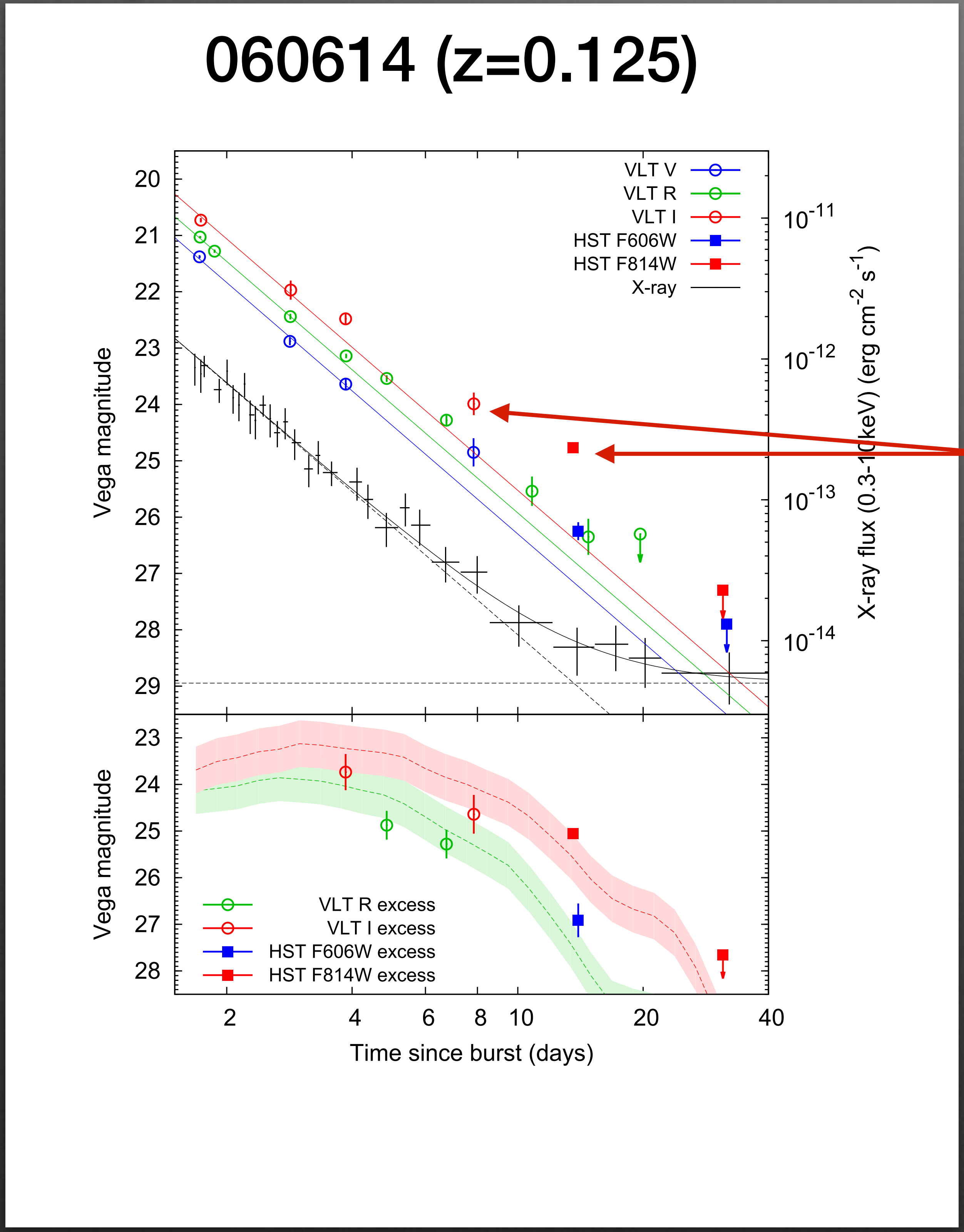


Macronova interpretation of GRB 060614

Yang+ 2015, Jin+2015



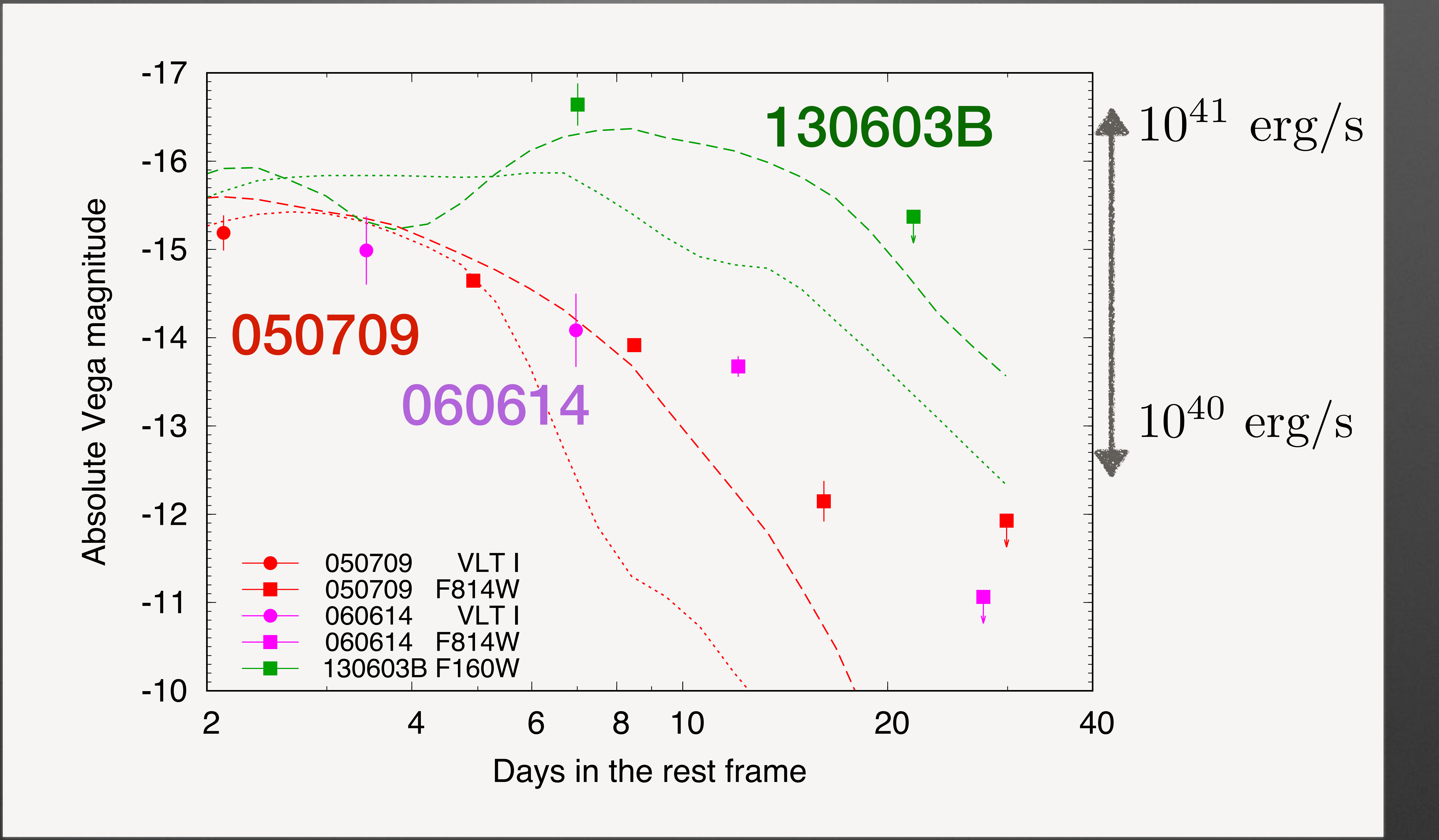
This is a strange GRB.
it can be either a long or short GRB.

VLT I-band and HST 814W excesses.

The late time HST observation can be consistent with a macronova model.

We need ~0.1 Msun.
=> black-hole neutron star merger?

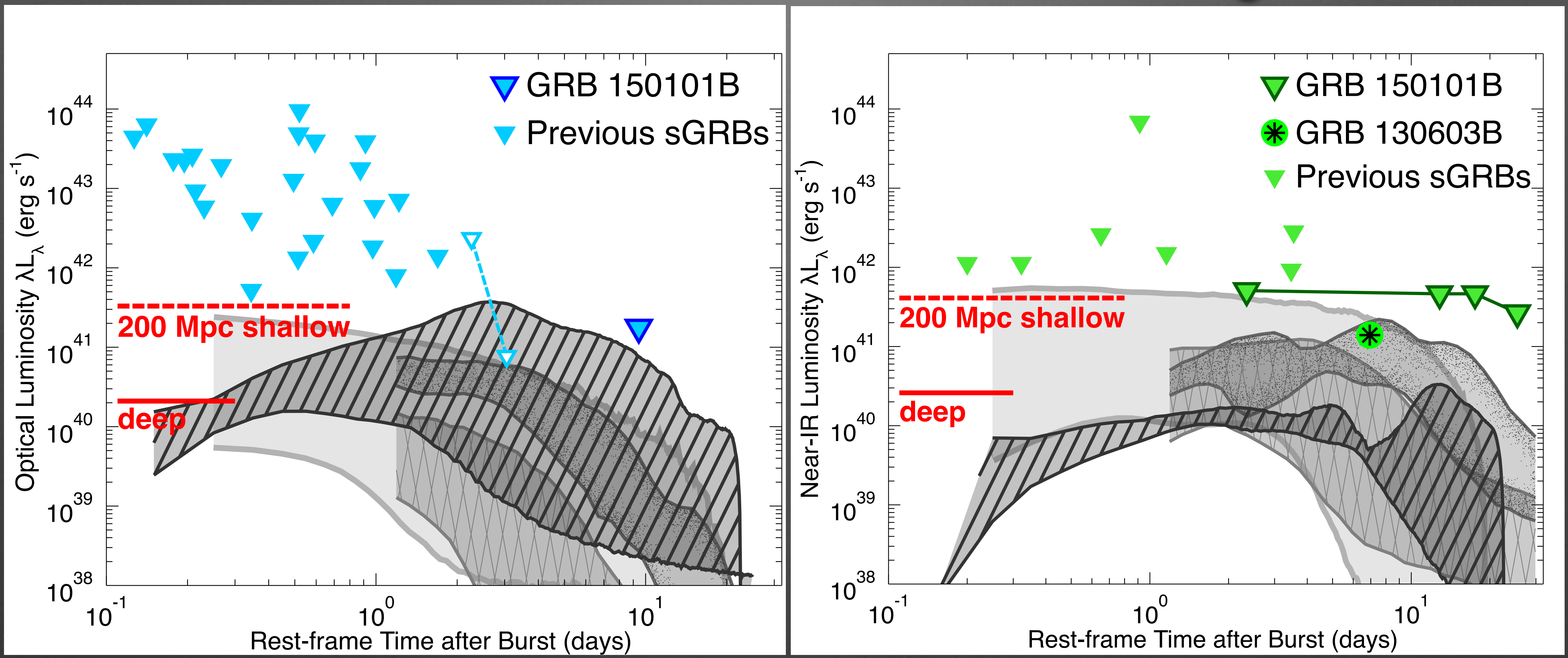
Three macronova candidates



- Peak luminosity ~ 10^41 erg/s.
- The I-band light curves of 050709 and 060614 are quite similar.

short GRB 150101B: macronova limits

Fong et al 2016



A nearby short GRB, z = 0.134

Limits on opt-IR macronova L < 10^41 erg/s (r),

10^42 erg/s (IR)

No HST observation at the macronova peak time,

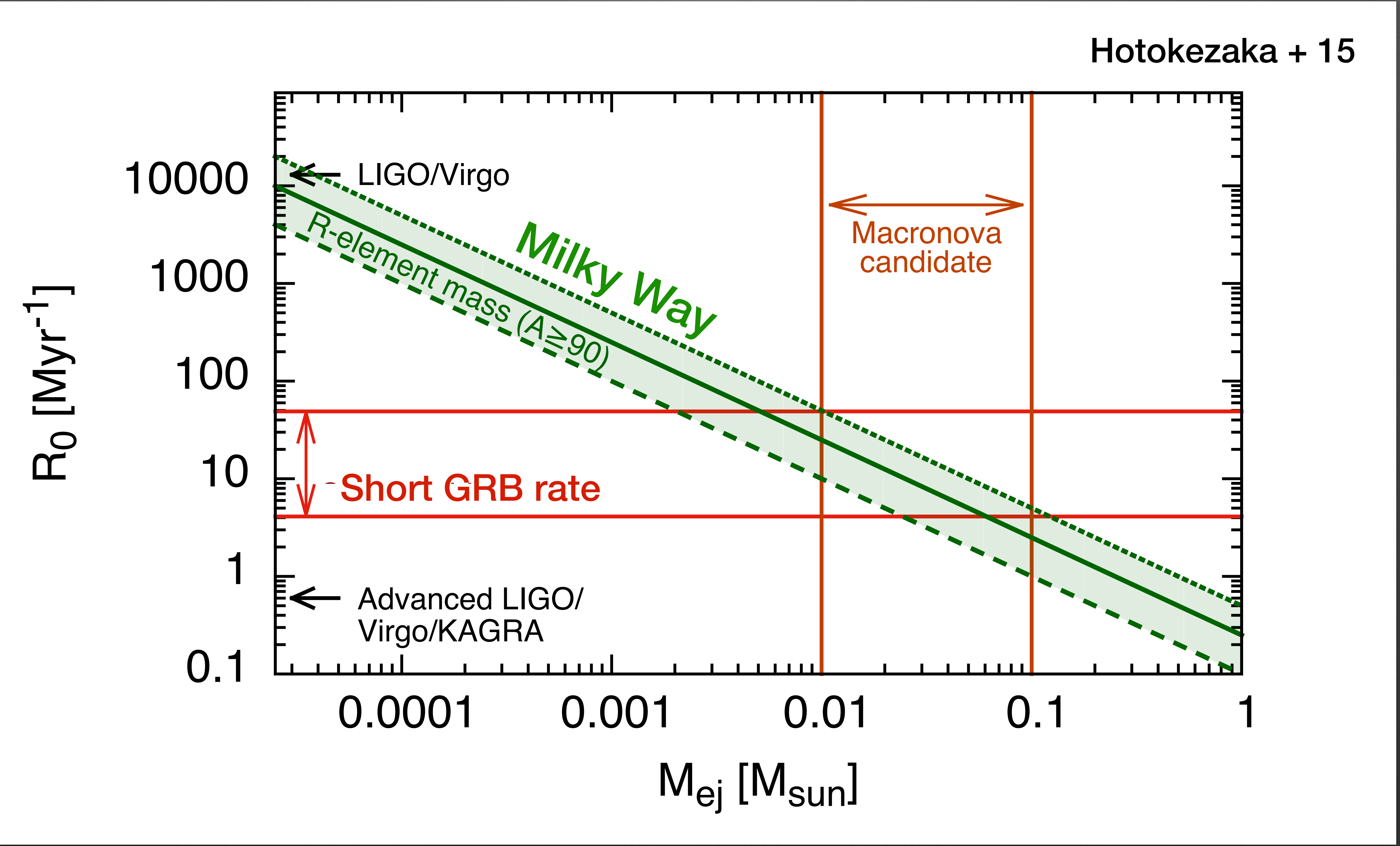
the limits are not strong enough to reject a macronova.

Macronovae may be ubiquitous

	Redshift	T90 (s)	Eiso (10^51 erg)	Macronova (erg/s)	Host
GRB 050709	0.16	0.1 (+130)	0.07	10^41 (I-band)	star forming (small)
GRB 060614	0.125	5 (+97)	2.5	10^41 (I-band)	weakly star foming
GRB 130603B	0.356	0.18	2.1	10^41 (H-band)	star forming
GRB 150101B no detection	0.134	0.012	0.013	<10^42 (H-band)	Early type

Association of macronovae with sGRBs may be > 50%.

Rate vs Mass/event



Heating Issue in the mass estimates

Given a specific heating rate, we can estimate the ejecta mass from the observed bolometric luminosities.

$$L_{\mathrm{bol}}(t) \sim M_{\mathrm{ej}} \cdot \dot{Q}(t)$$

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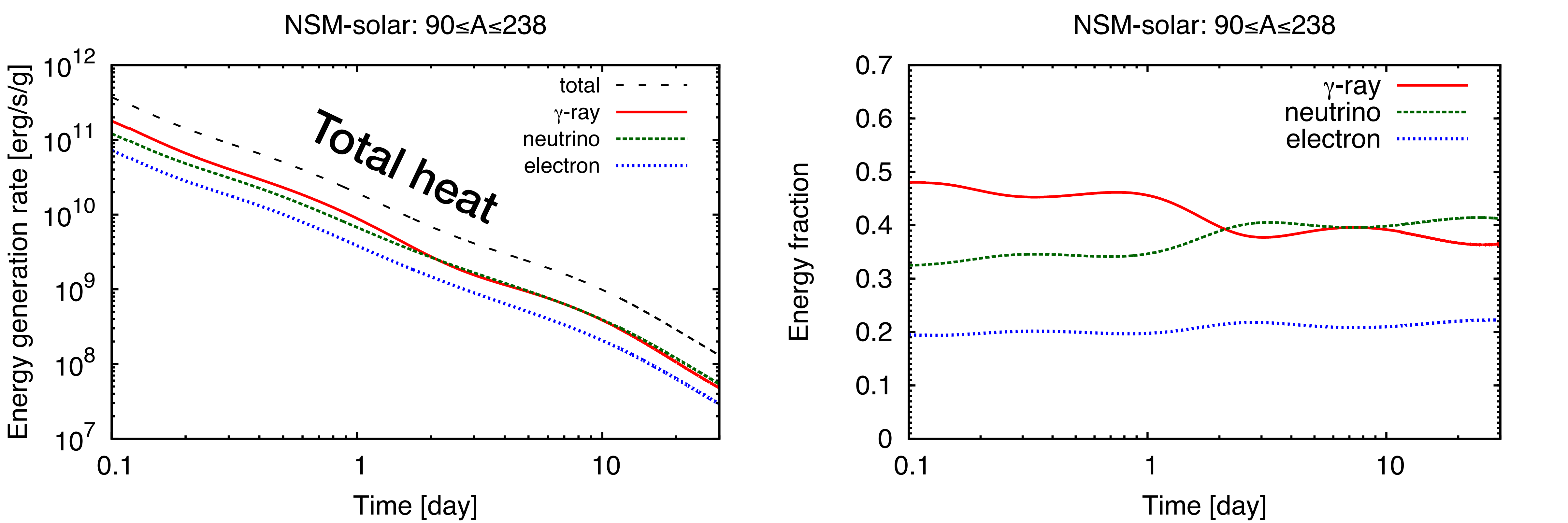
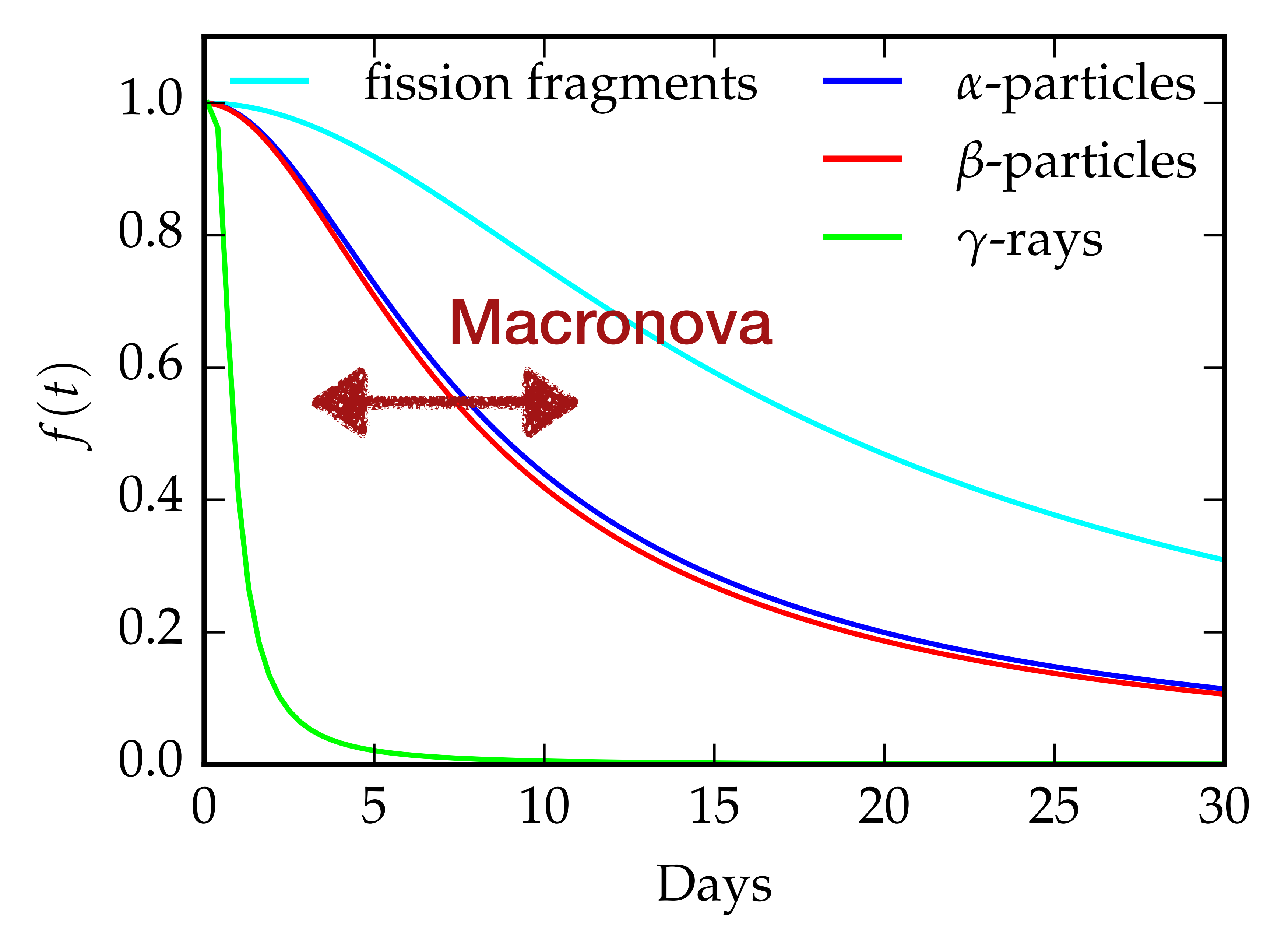


Hotokezaka + 2016

On the mascronova timescale, neutrino and gamma-rays do not contribute to the heating. 20% of decay energy may be heatable.

Thermalization efficiency of beta decay

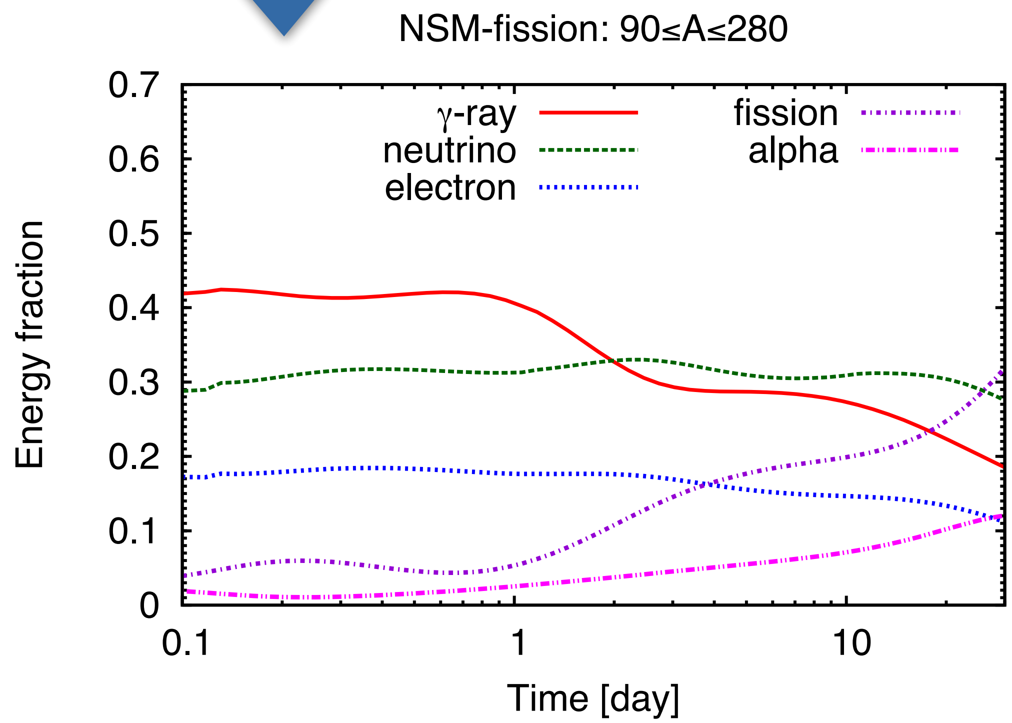
Barnes + 2016

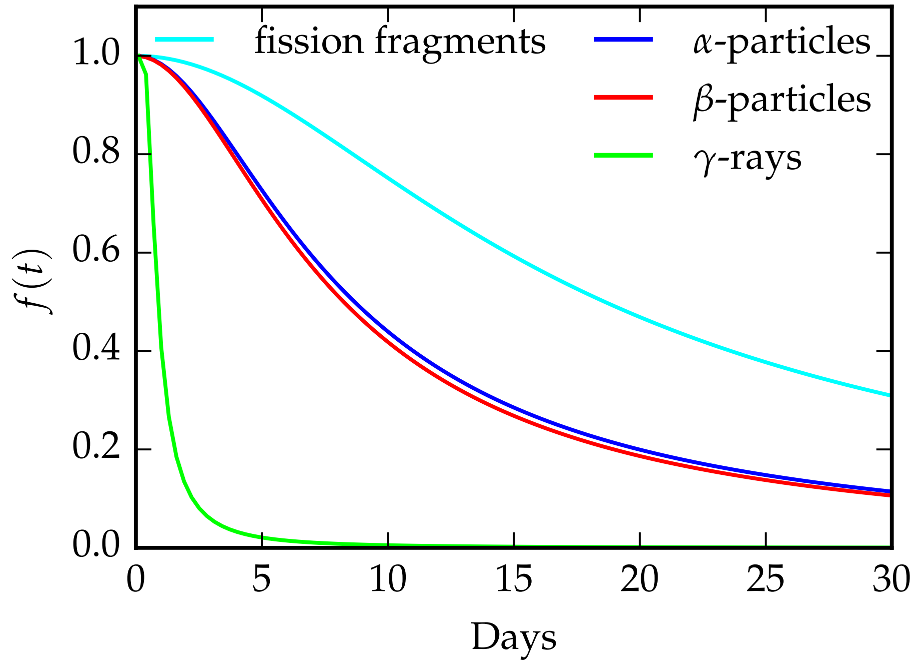


Only about half of the beta electrons' energy is thermalized.
In total, the beta decay heats are less effective by a factor of 5 than what we thought before. => Do we need ~ 0.1 Msun ejecta (much more than that simulations tell, Rosswog 13, KH+13, Bauswein+13, Perego+14,...)

Fission helps?

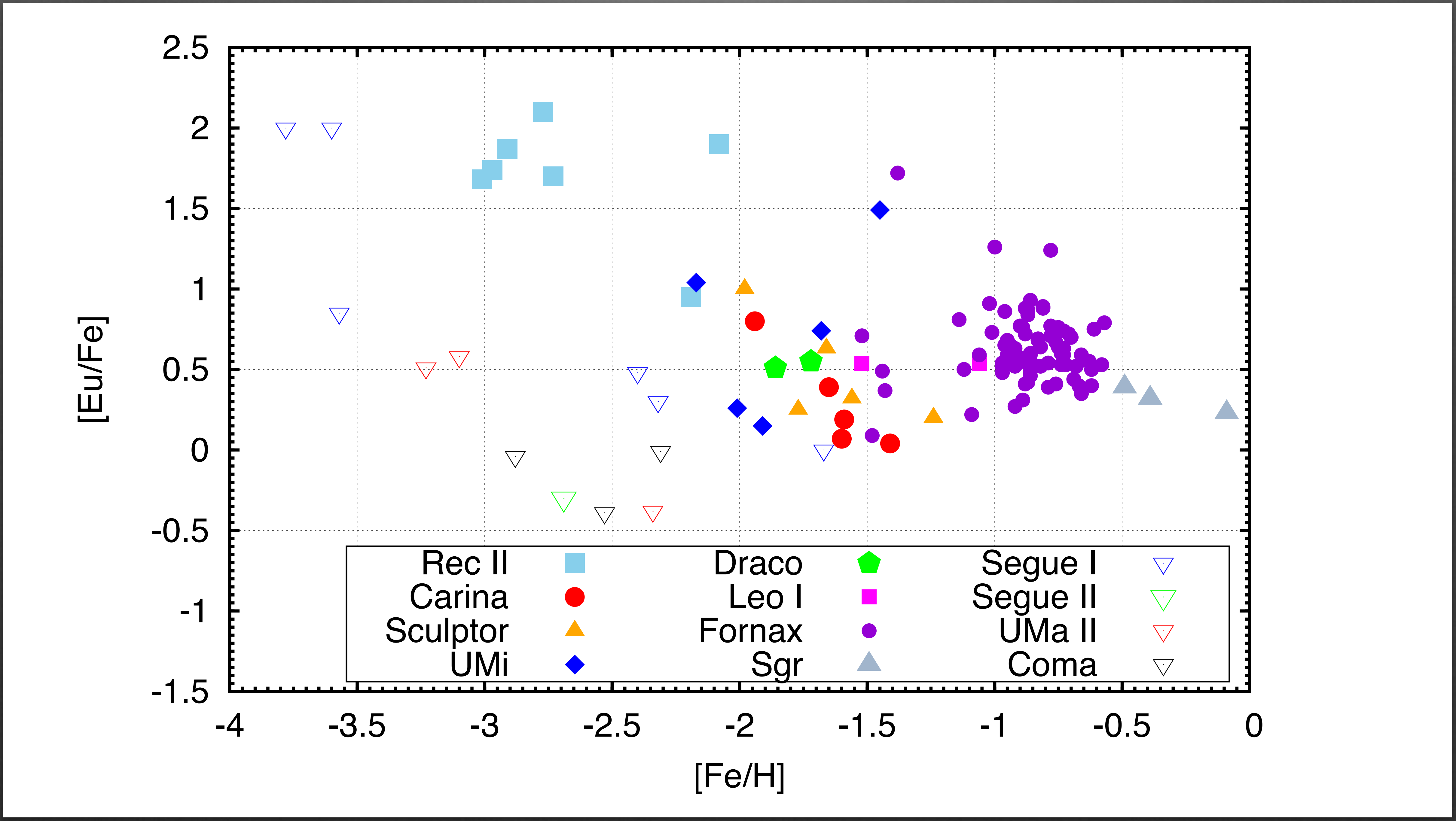
Hypothetical assumption:
2% of the ejecta mass is composed of nuclei with A>250.



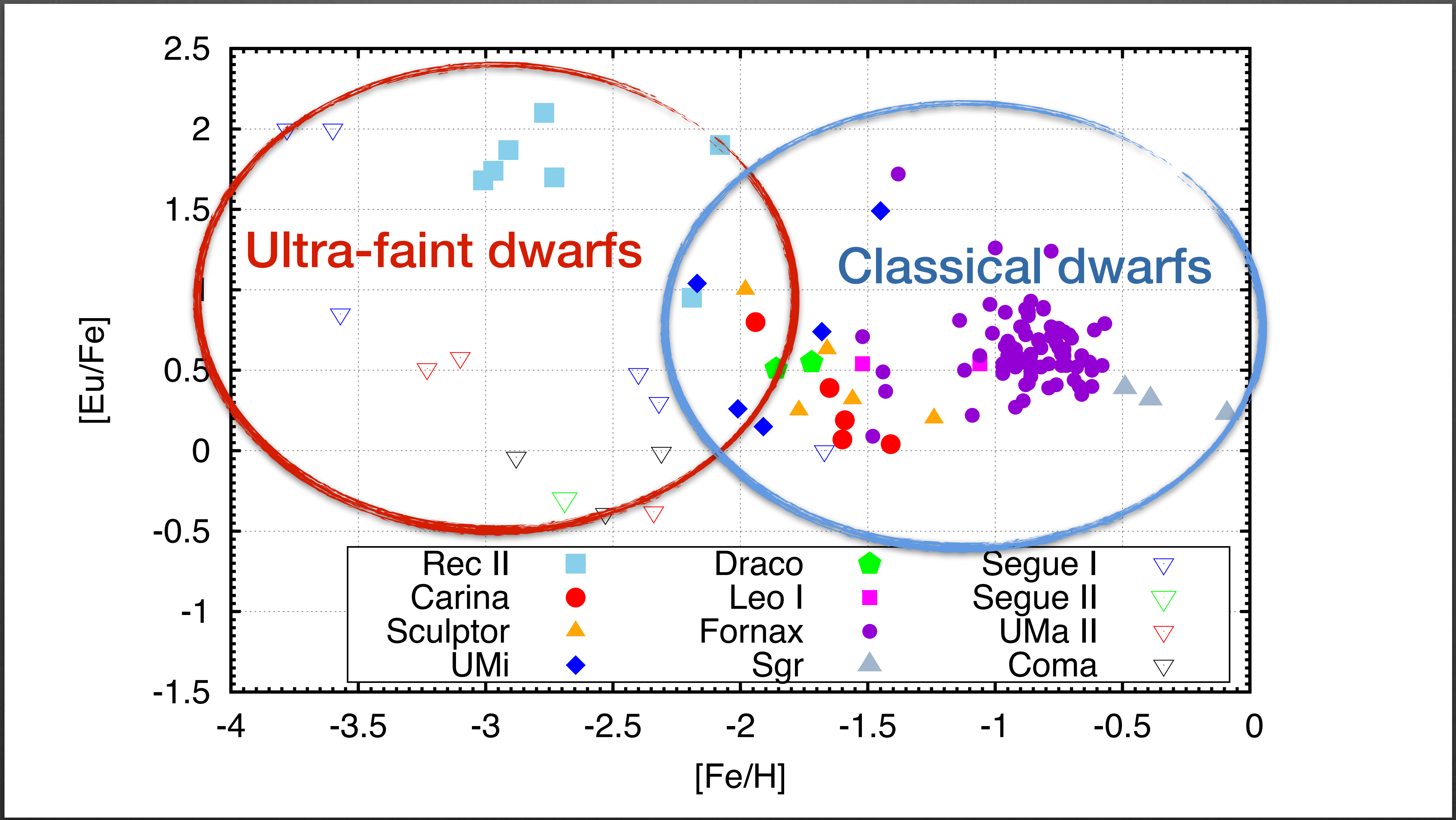


The thermalization efficiency of fission fragments is high.
Fission may dominate the late time heating???

R-process in Dwarf galaxies



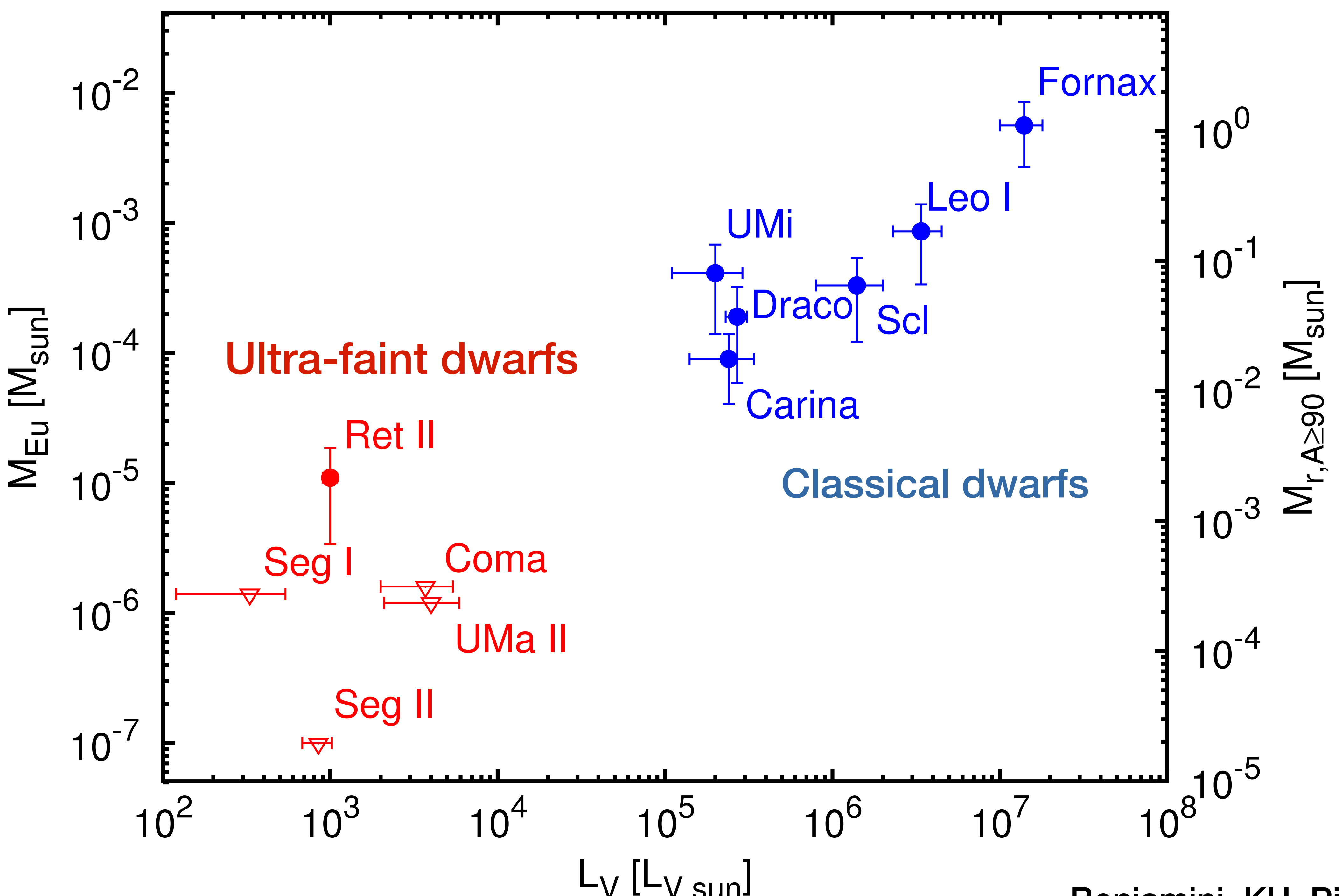
R-process in Satellite Dwarf galaxies



Note a recent progress by Ji + 16 and Roederer + 16 finding an r-process enriched ultra-faint dwarf galaxy.

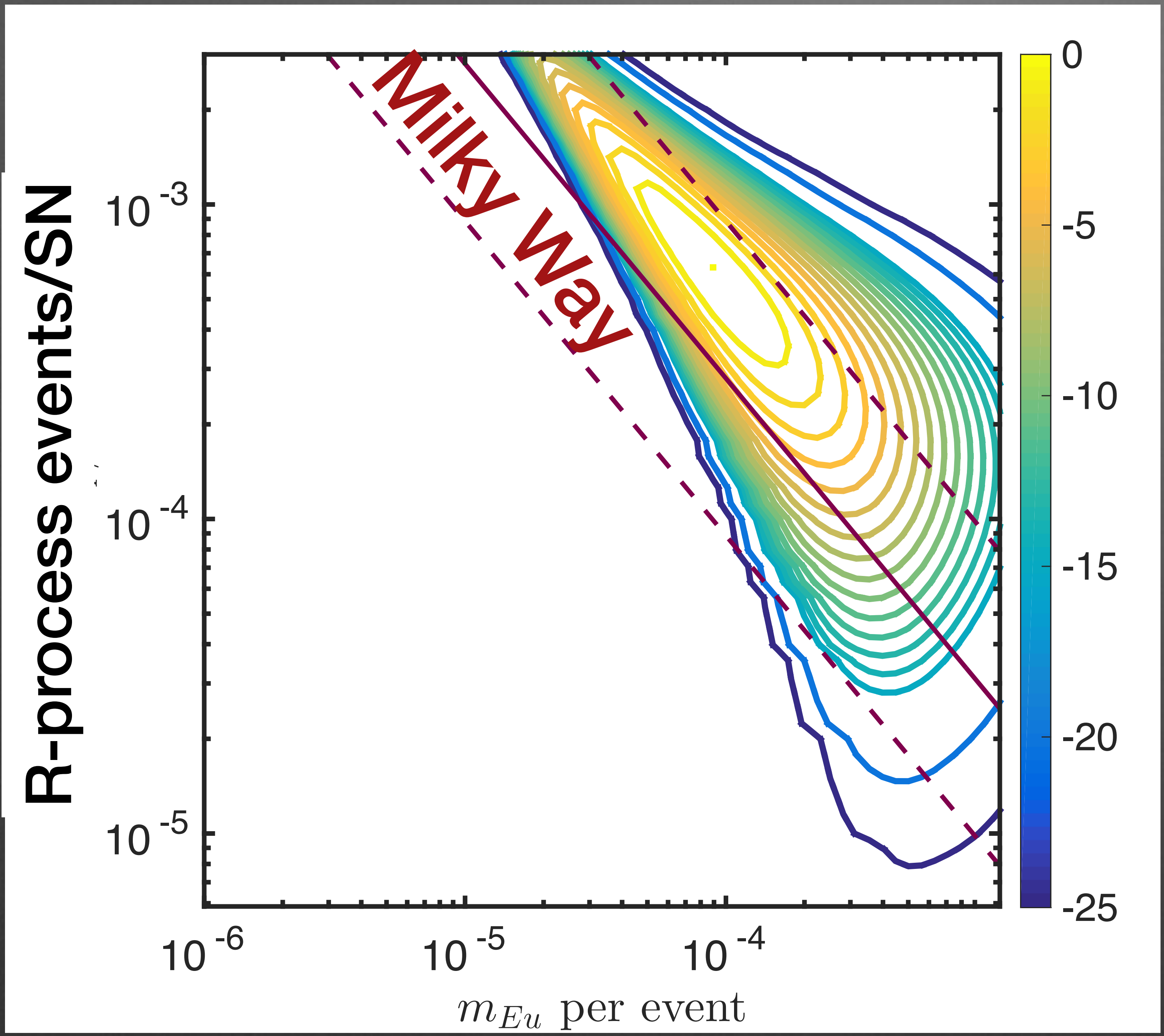
Eu mass in the Dwarfs

$$M_{\mathrm{Eu}} \approx 3.7 \cdot 10^{-5+[\mathrm{Eu/H}]} M_\odot \left(\frac{M_g}{10^5 M_\odot} \right)$$



Beniamini, KH, Piran 16

R-process rate and Eu mass/event



An r-process event every 10^3 - 10^4 SNe.

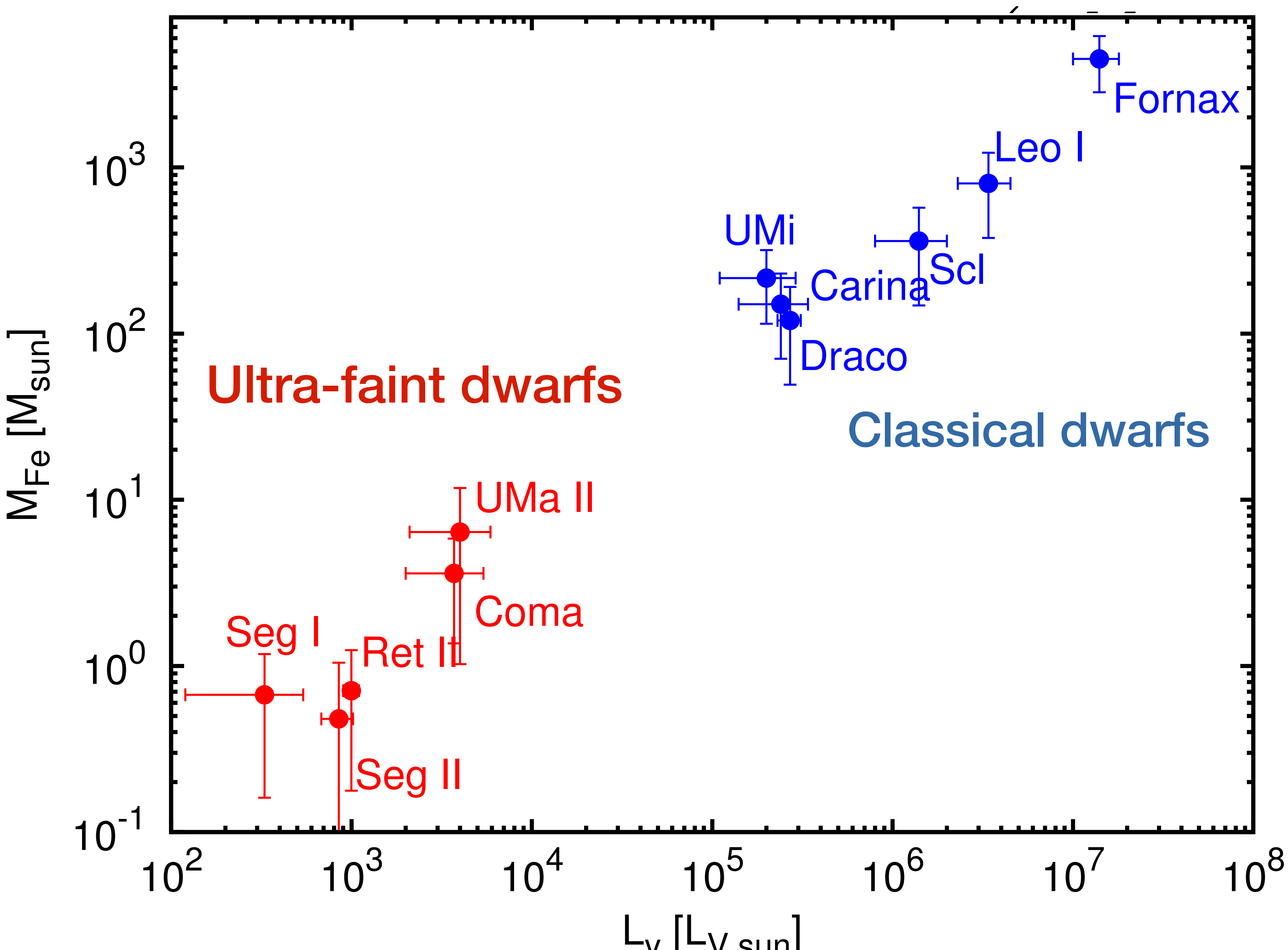
r-process elements ~0.01 Msun.

This is “consistent” with SGRB macronova obs., deep sea Pu measurements (Wallner+ 15, Hotokezaka+15), and Milky Way EMP stars (Macias & Ramirez-Ruiz 16).

More careful studies with the chemical mixing are needed.

Estimates of Iron mass

$$M_{\rm Fe} \approx 120 \cdot 10^{[\rm Fe/H]} M_\odot \left(\frac{M_g}{10^5 M_\odot} \right)$$



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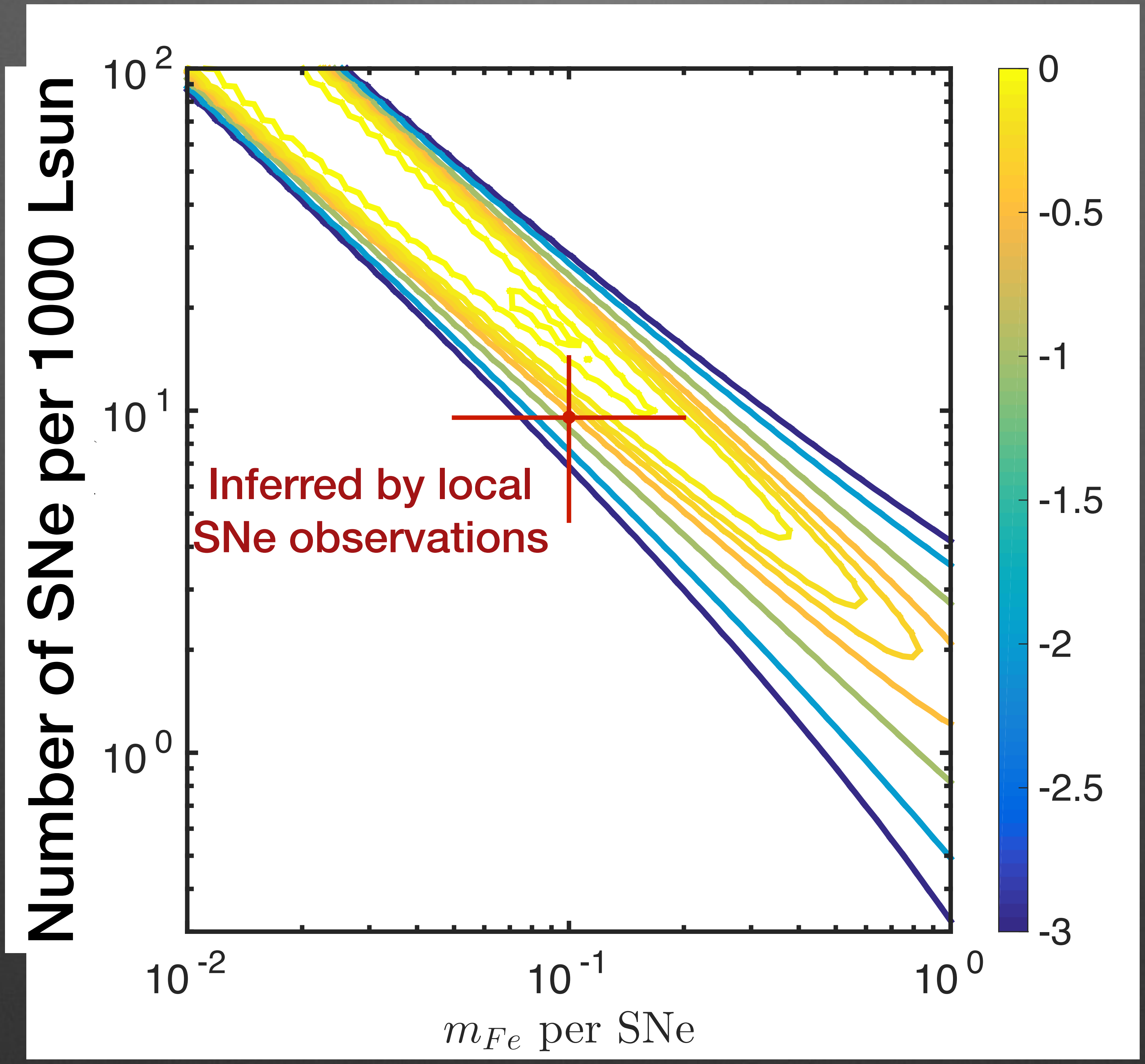
Rate and Iron mass/SN from Dwarfs



The constraint is not strong. It agrees with other observations.

Summary

Macronovae may be ubiquitous.

L_peak ~ 10^41 erg/s is too bright? as beta-decay heating rate is not so high.

Is fission important for macrnovae?

The r-process amounts in dwarf galaxies can be used to constrain the rate and production mass/event.
~ 1 r-process/1000 SNe, 0.01 Msun.

Gravitational-wave & astro observations will be able to confirm or reject the merger scenario.