Direct observations of the r-process

Radioactive decay powered electromagnetic transients

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Transients from r-process ejecta

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Californium-254 and Supernovae*

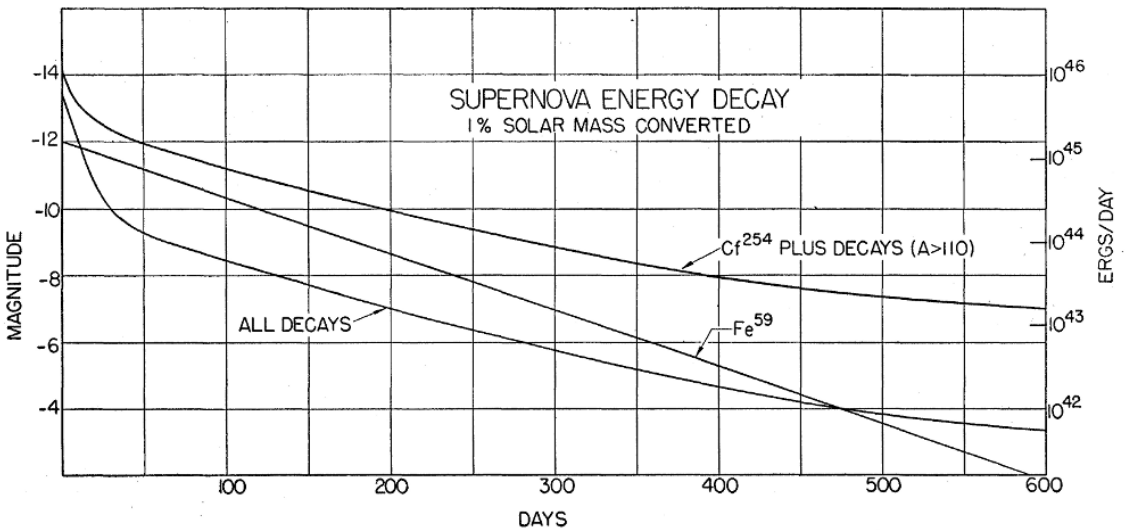
G. R. BURBIDGE AND F. HOYLE,† *Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California*

AND

E. M. BURBIDGE, R. F. CHRISTY, AND W. A. FOWLER, *Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California*

(Received May 17, 1956)

It is suggested that the spontaneous fission of Cf^{254} with a half-life of 55 days is responsible for the form of the decay light-curves of supernovae of Type I which have an exponential form with a half-life of 55 nights. The way in which Cf^{254} may be synthesized in a supernova outburst, and reasons why the energy released by its decay may dominate all others are discussed. The presence of Tc in red giant stars and of Cf in Type I supernovae appears to be observational evidence that neutron capture processes on both a slow and a fast time-scale have been necessary to synthesize the heavy elements in their observed cosmic abundances.



Matter ejection in mergers

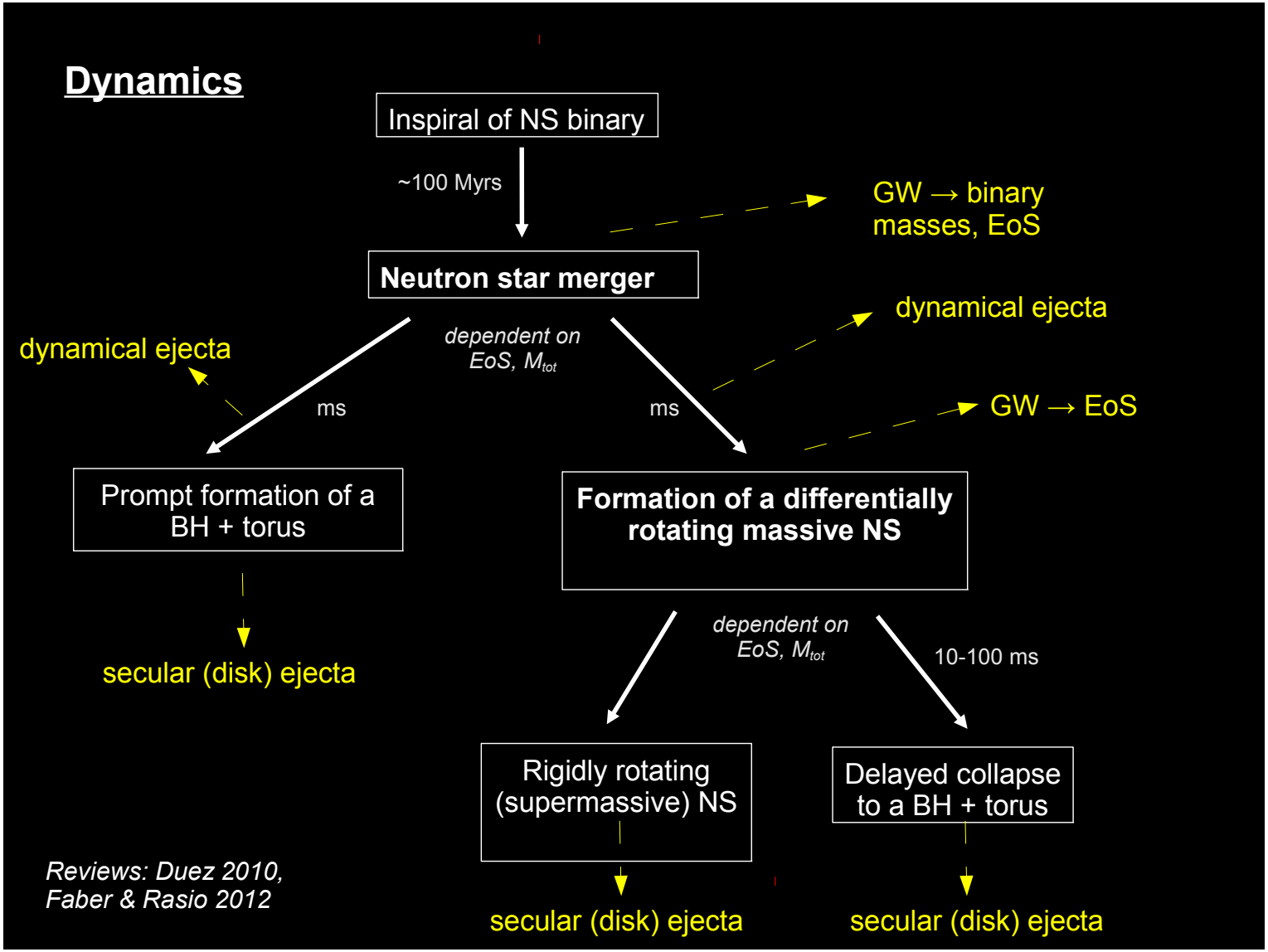
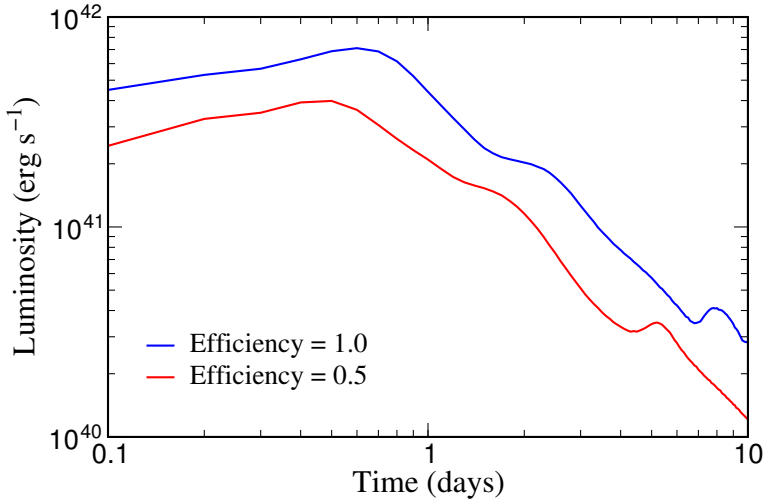


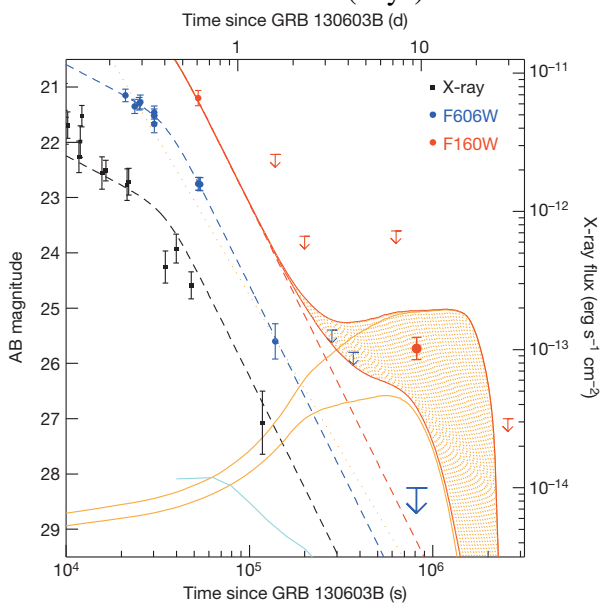
Figure from A. Bauswein.

Observing the r process in mergers

- Large amount of ejected radioactive r-process material can produce an electromagnetic transient [Li & Paczyński 1998]
- "Kilonova" transient: Typical luminosities 1000 times those of a Nova.
- Large opacities of Lanthanides delay the peak to timescales of a week (Kasen *et al*, 2013).
- Probably observed in GRB 130603B.

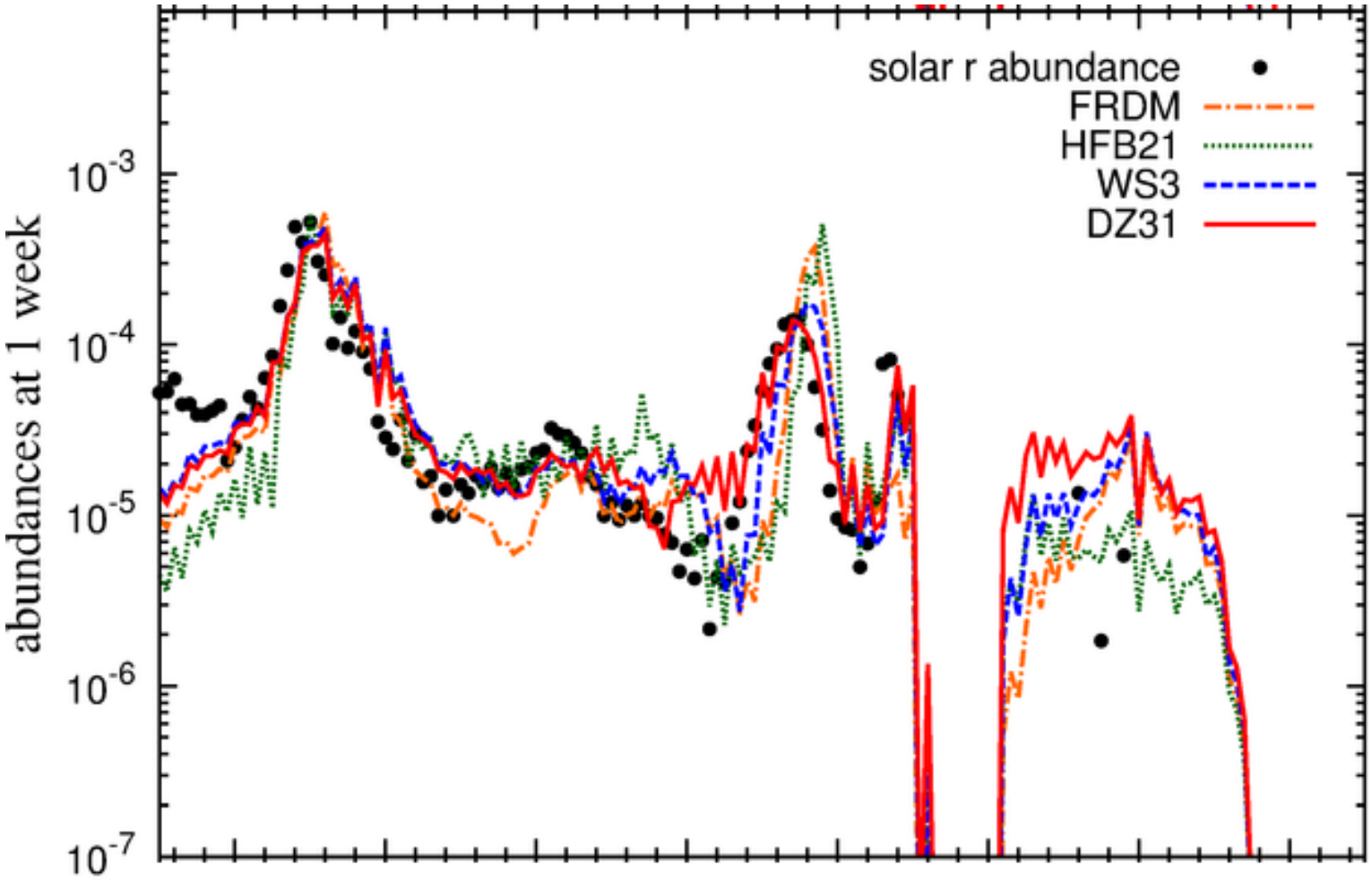
Metzger, GMP, Darbha, Quataert, Arcones *et al*, MNRAS **406**, 2650 (2010)





Tanvir et al, Nature **500**, 457 (2013)

Actinides affect opacities and energy production



Actinides can be an important opacity source at timescales of weeks.

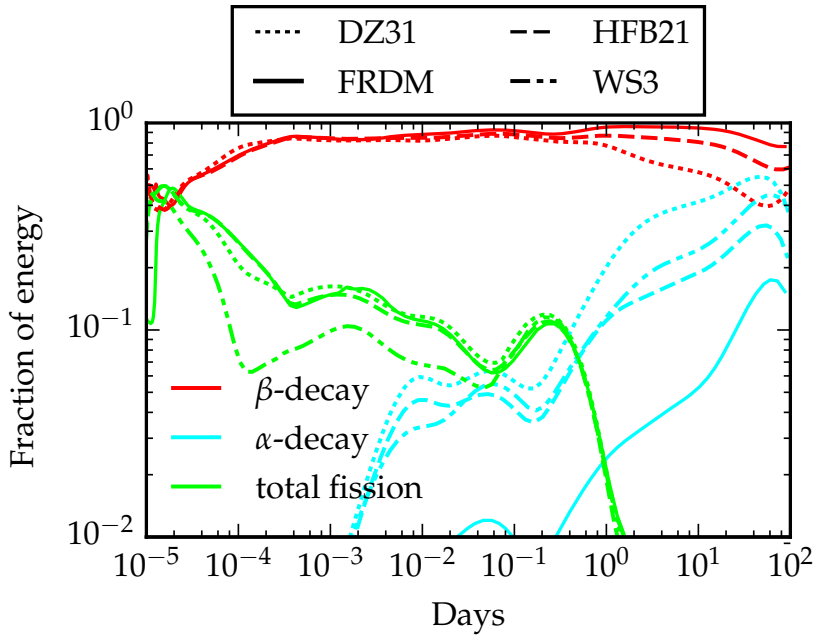
Mendoza-Temis, Wu, Langanke, GMP, Bauswein, Janka, PRC **92**, 055805 (2015)

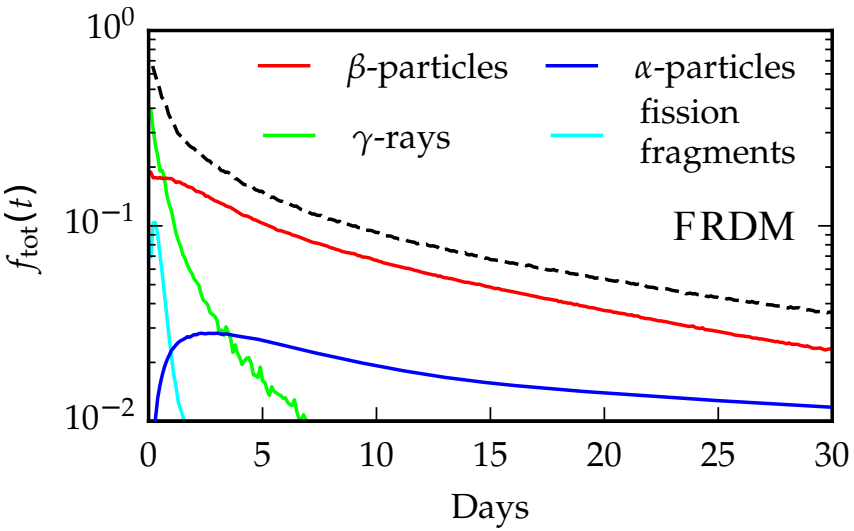
Electromagnetic transient (Kilonova)

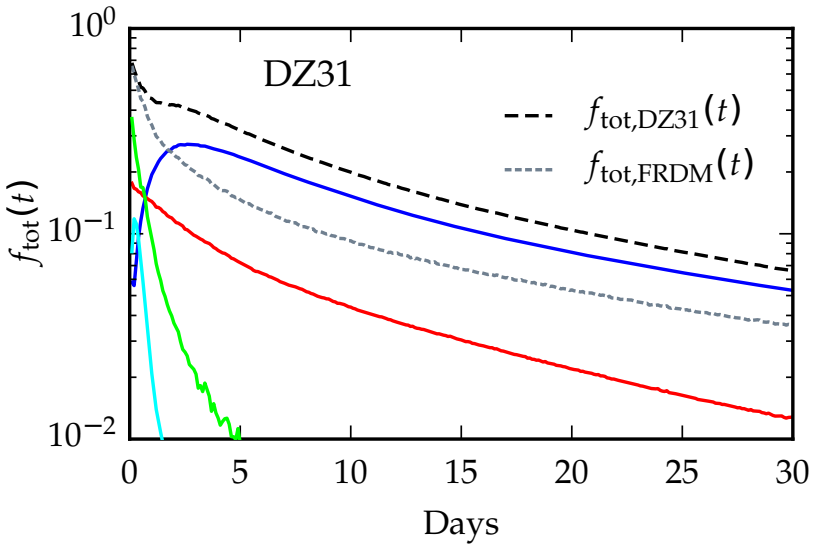
Kinolova models must address:

- Total amount of radioactive energy released ($\dot{q} \sim t^{-\alpha}, \alpha = 1.1$–$1.4$)
- Dominating decay channels at different phases
- Efficiency of decay products thermalization

Important differences abudances α-decaying nuclei between Pb and U.



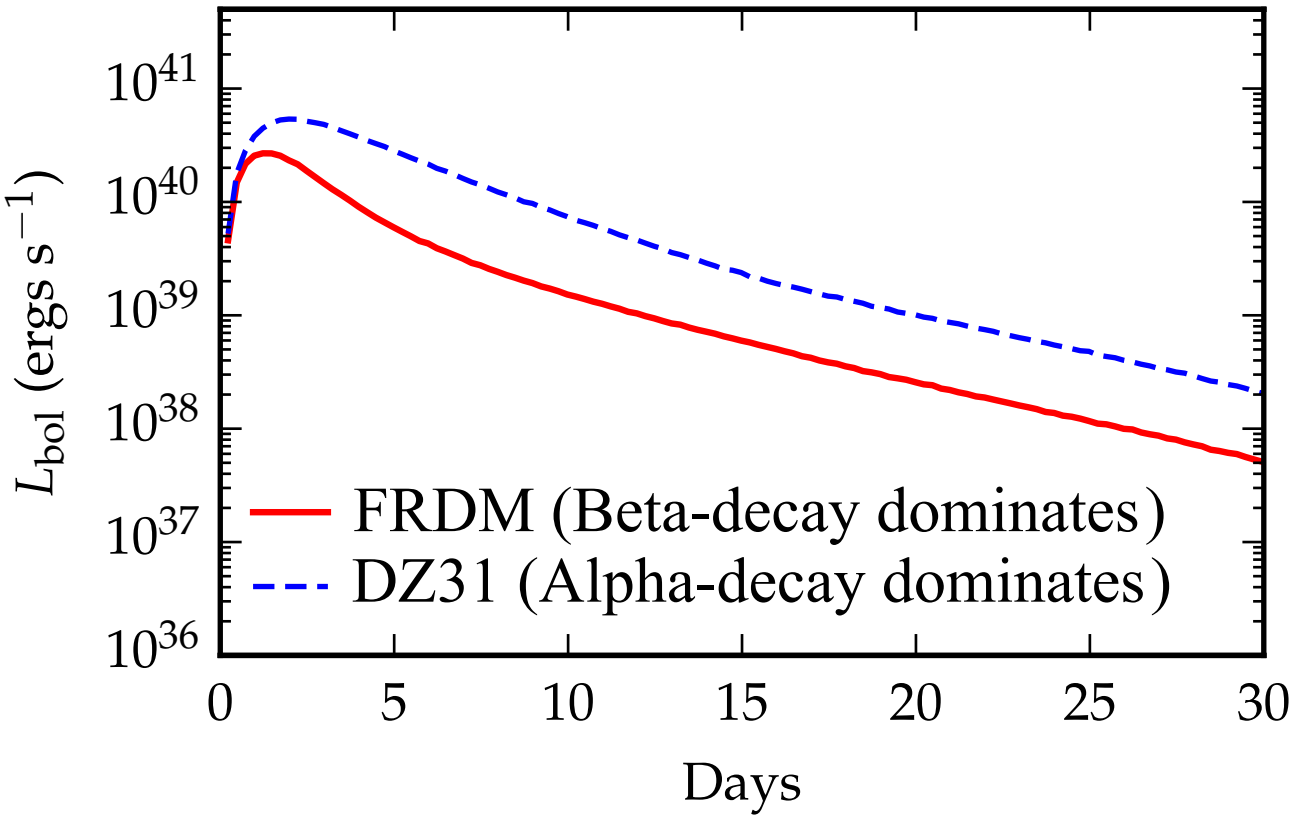




Barnes, Kasen, Wu, GMP, arXiv:1605.07218, ApJ in press

Kilonova light curve

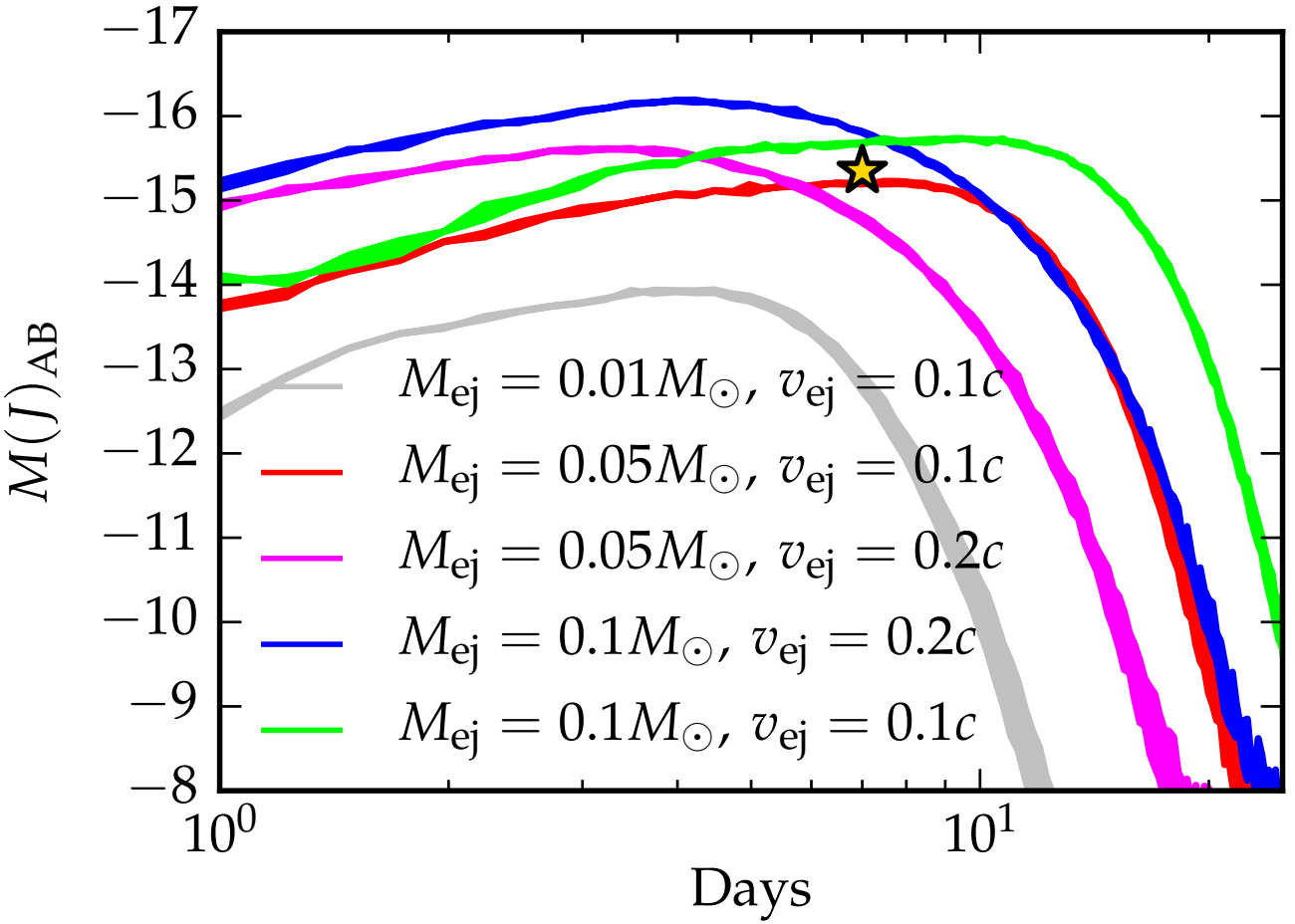
Light curve contains nuclear physics signatures.



Ratio of luminosities at peak value and at late times can be used to constrain the produced amount of nuclei between Pb and U.

Barnes, Kasen, Wu, GMP, arXiv:1605.07218, ApJ in press

Light curve for GRB 130603B



Observed flux is consistent with an ejected mass

$5 \times 10^{-2}\ \mathrm{M}_\odot \lesssim \mathrm{M}_{\rm ej} \lesssim 10^{-1}\ \mathrm{M}_\odot$

Barnes, Kasen, Wu, GMP, arXiv:1605.07218, ApJ in press

Delayed outflows from accretion disks

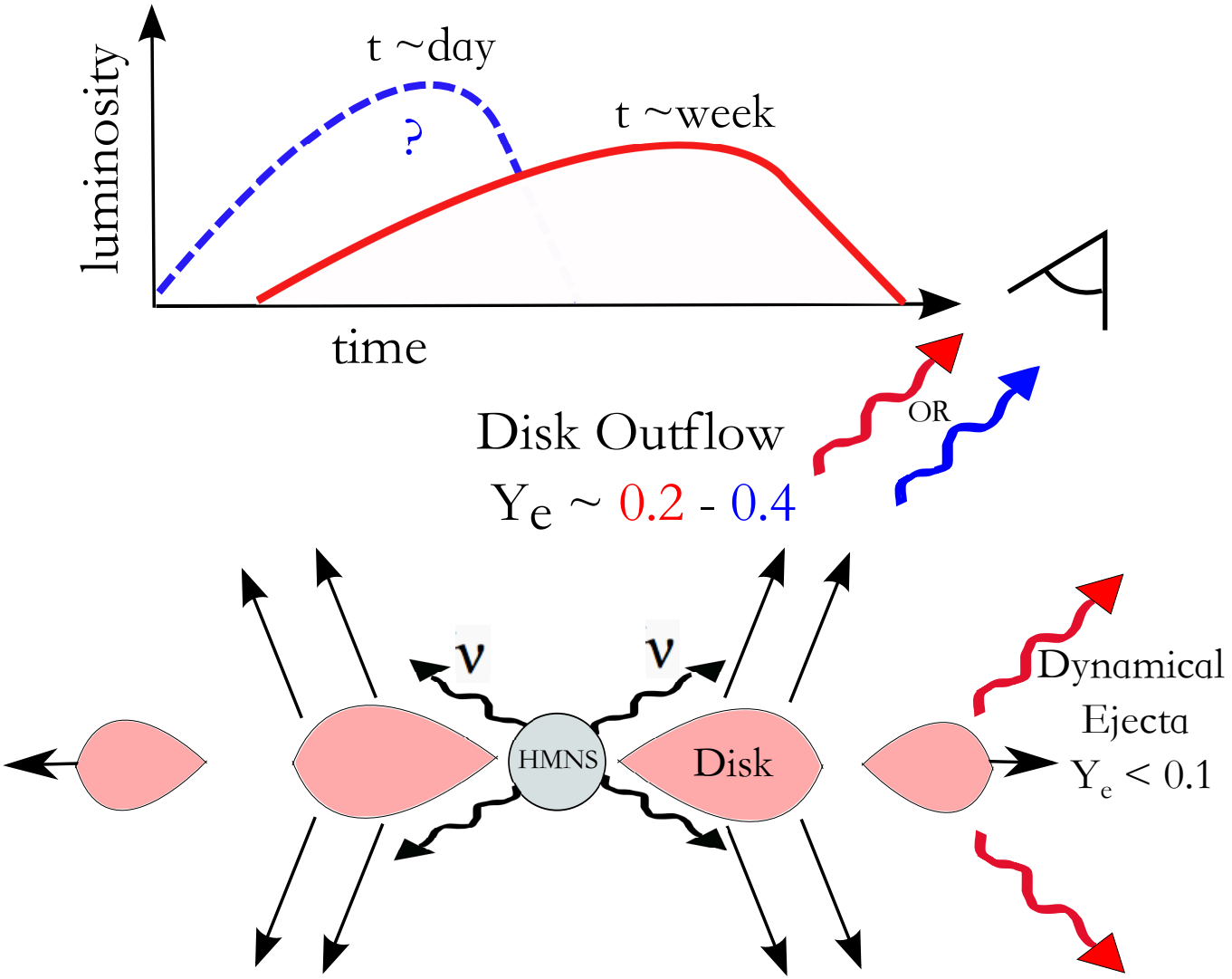
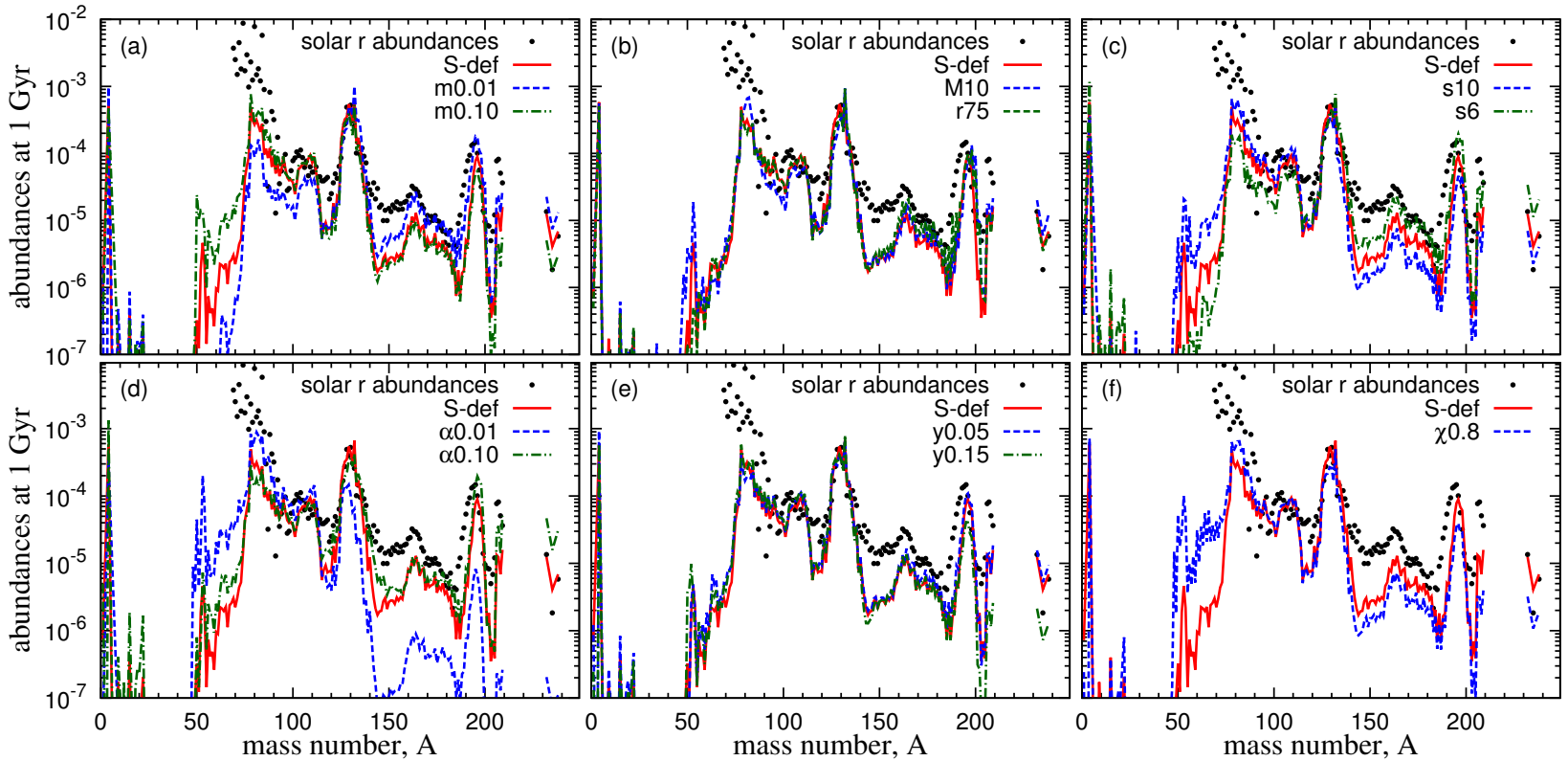


Figure from Metzger & Fernández, MNRAS **441**, 3444 (2014)

Nucleosynthesis from black-hole accretion disks

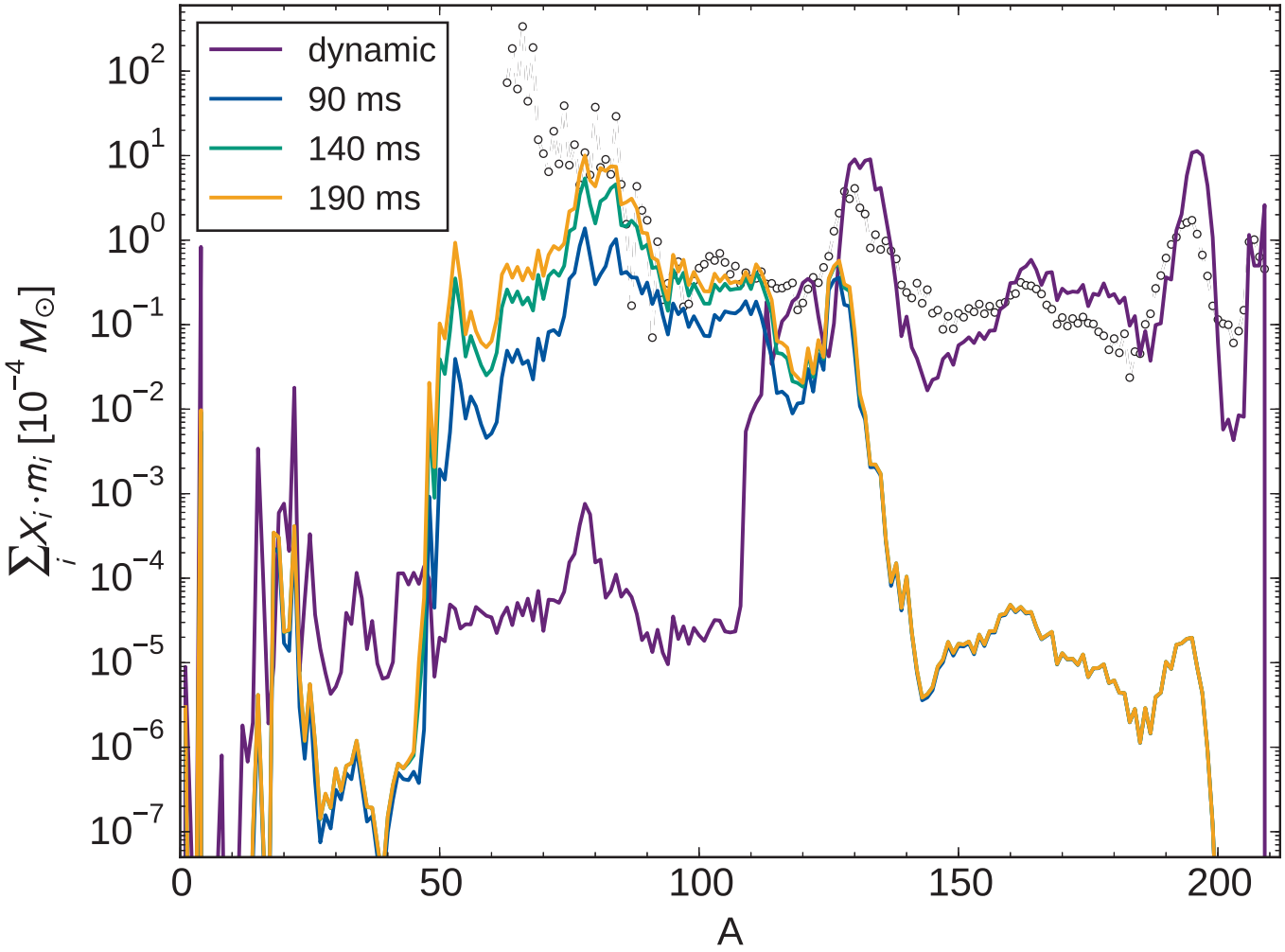
Despite variations in black-hole mass, spin, disk mass, viscosity, entropy and Y_e models produce all r-process nuclides including Lantinides and Actinides.



Wu, Fernández, GMP, Metzger, MNRAS **463**, 2323 (2016)

Nucleosynthesis from neutron star accretion disks

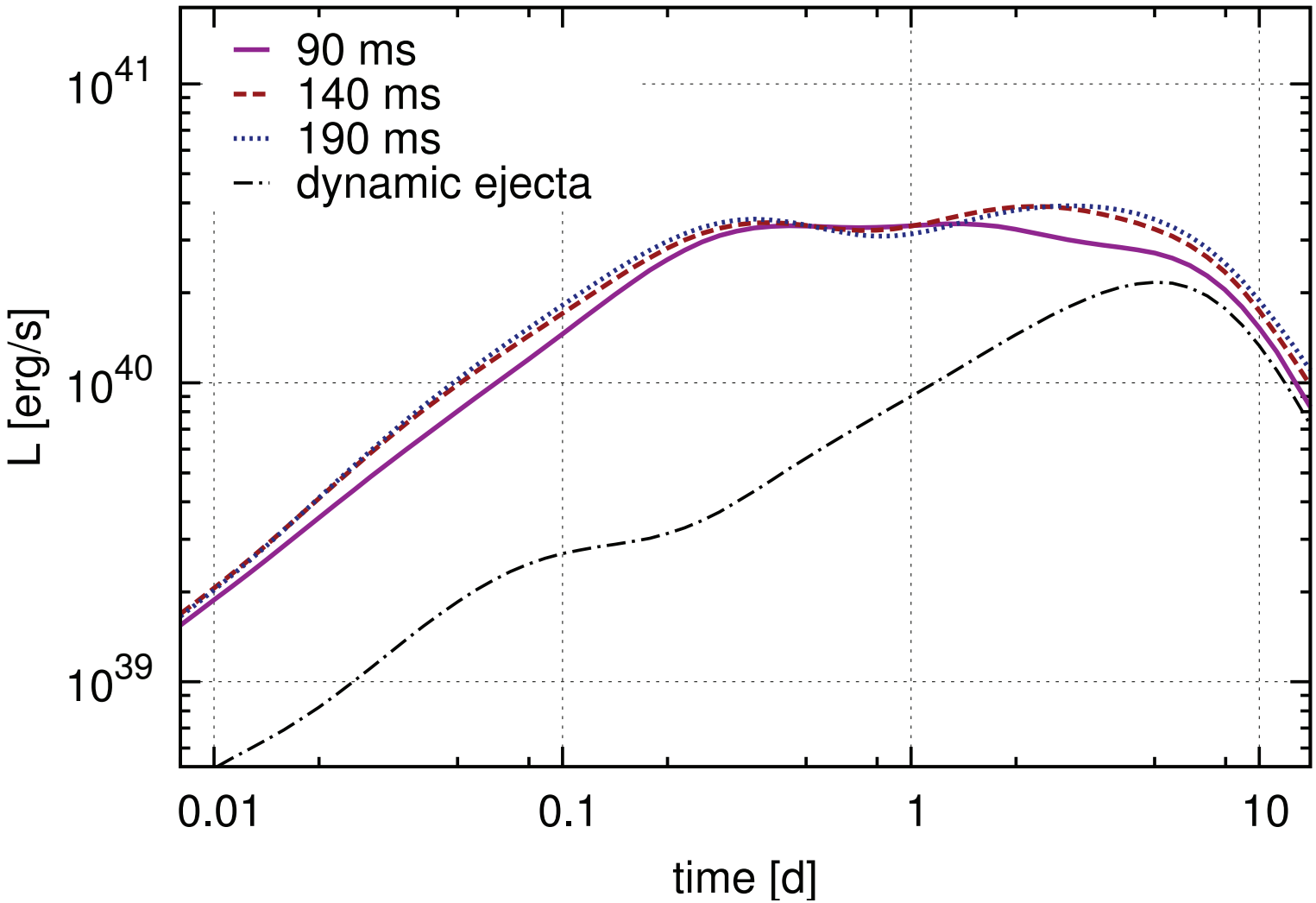
Much less neutron-rich ejecta due to stronger neutrino effects.



Martin, Perego, Arcones, Thielemann, Korobkin, Rosswog, ApJ **813**, 2 (2015)

Light curve

Ejecta allow for an early ($\sim$ 1 day) blue peak in the light curve



Martin, Perego, Arcones, Thielemann, Korobkin, Rosswog, ApJ **813**, 2