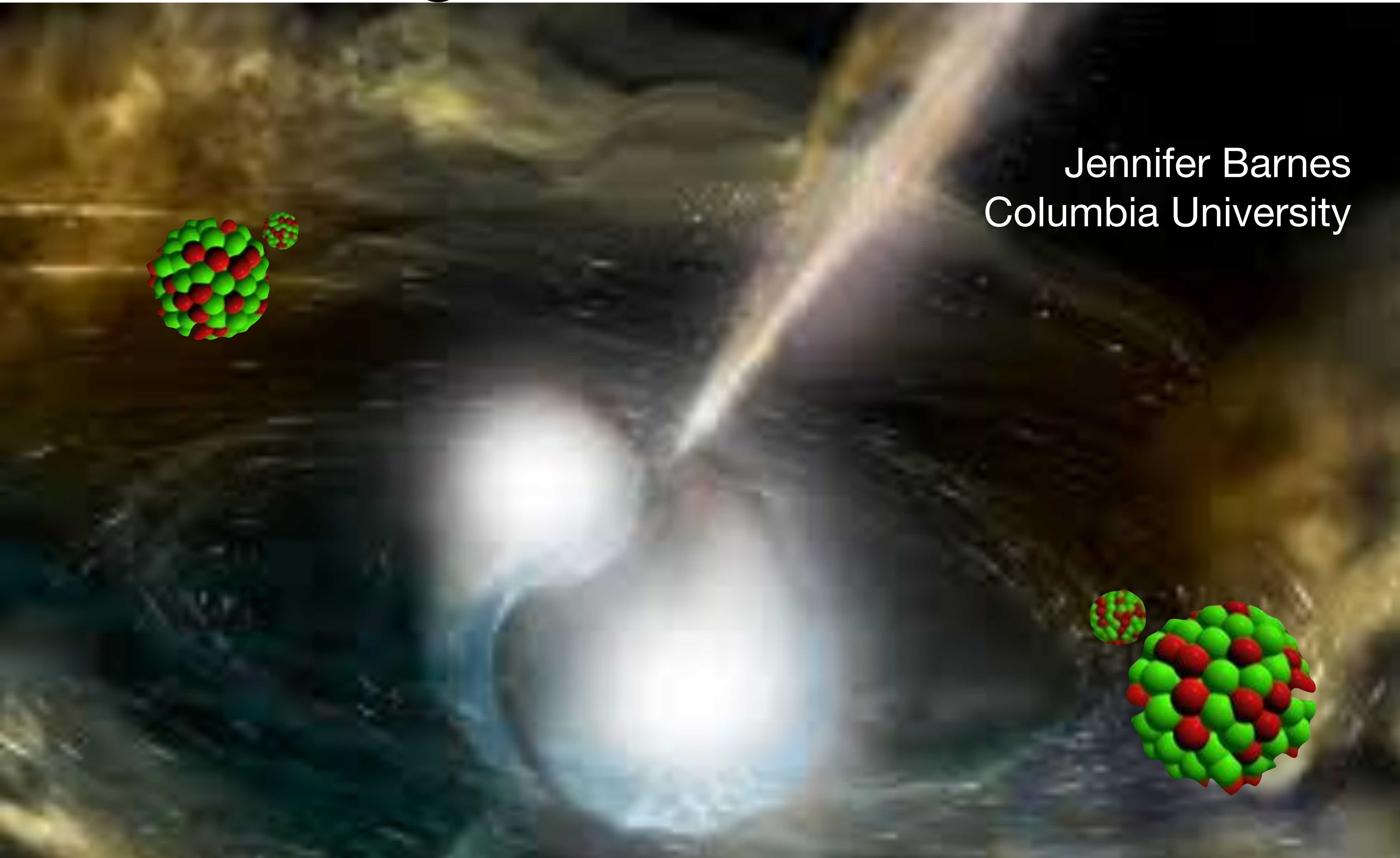
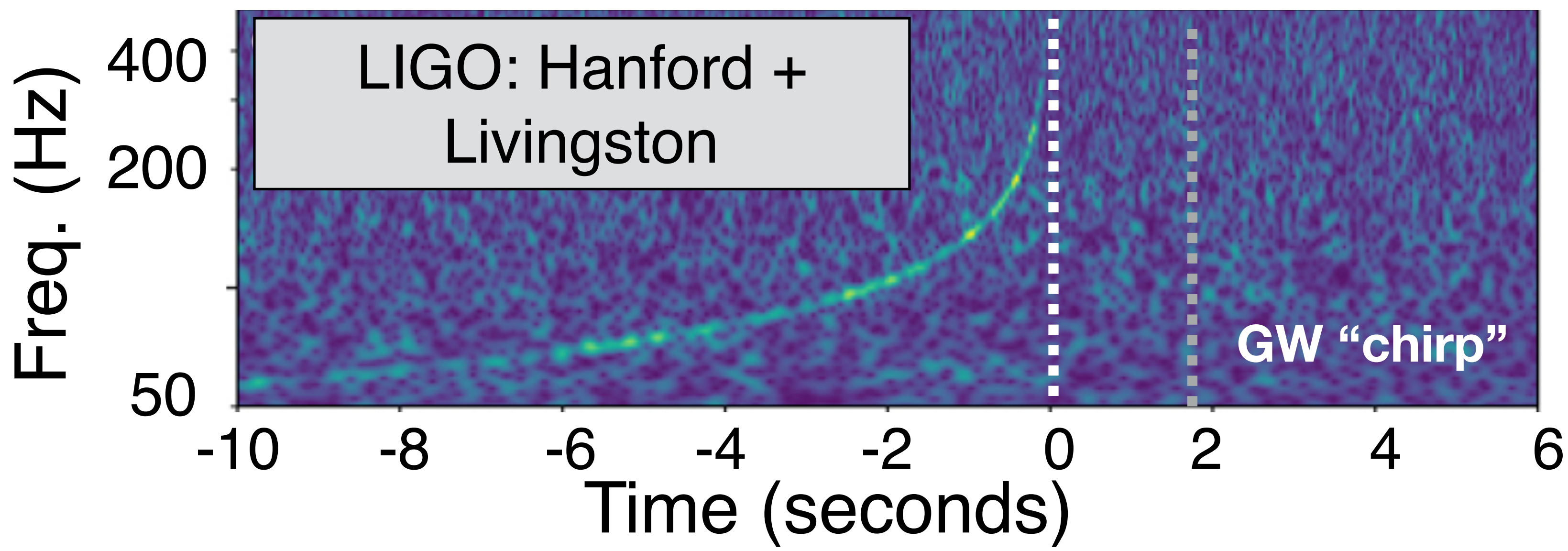
Diagnosing Nuclear Synthesis from Kilonova Light Curves

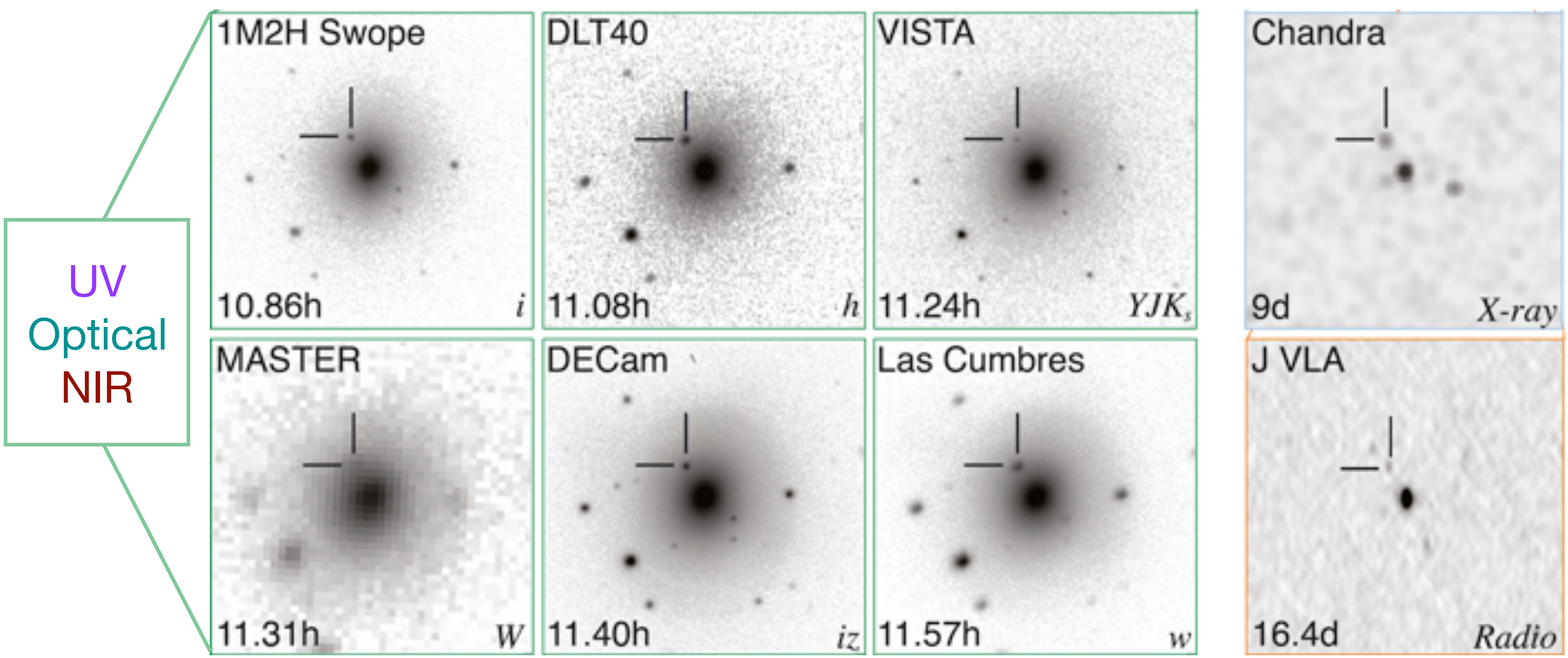


Jennifer Barnes
Columbia University

GW170817: the first neutron star merger



A gravitational wave signal with an electromagnetic counterpart detected from γ-ray to radio waves



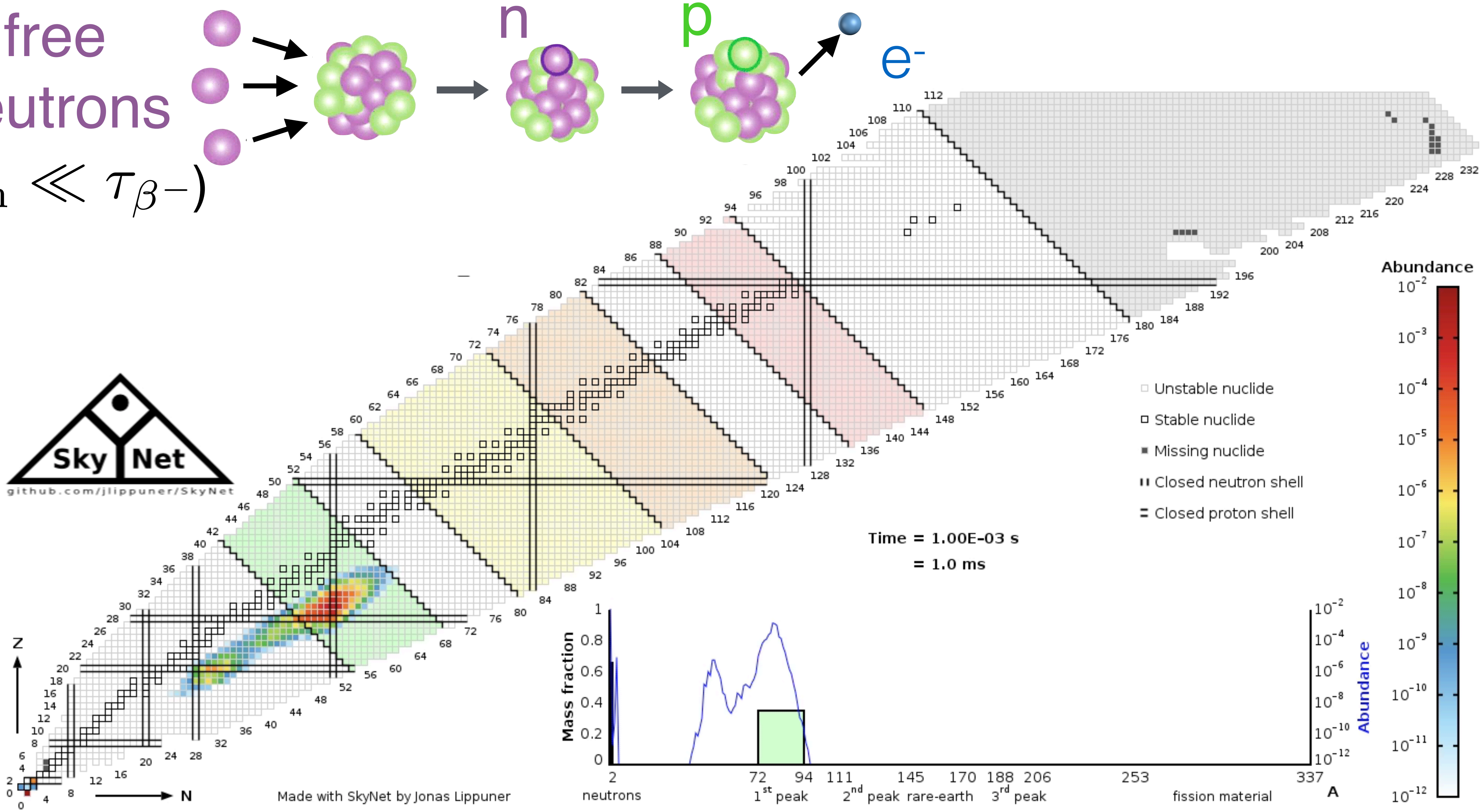
ad. from ALV + EM Partners 17

The thermal (UVOIR) emission* is powered by radioactivity

* "kilonova"

free neutrons

$(\tau_{\rm n} \ll \tau_{\beta-})$

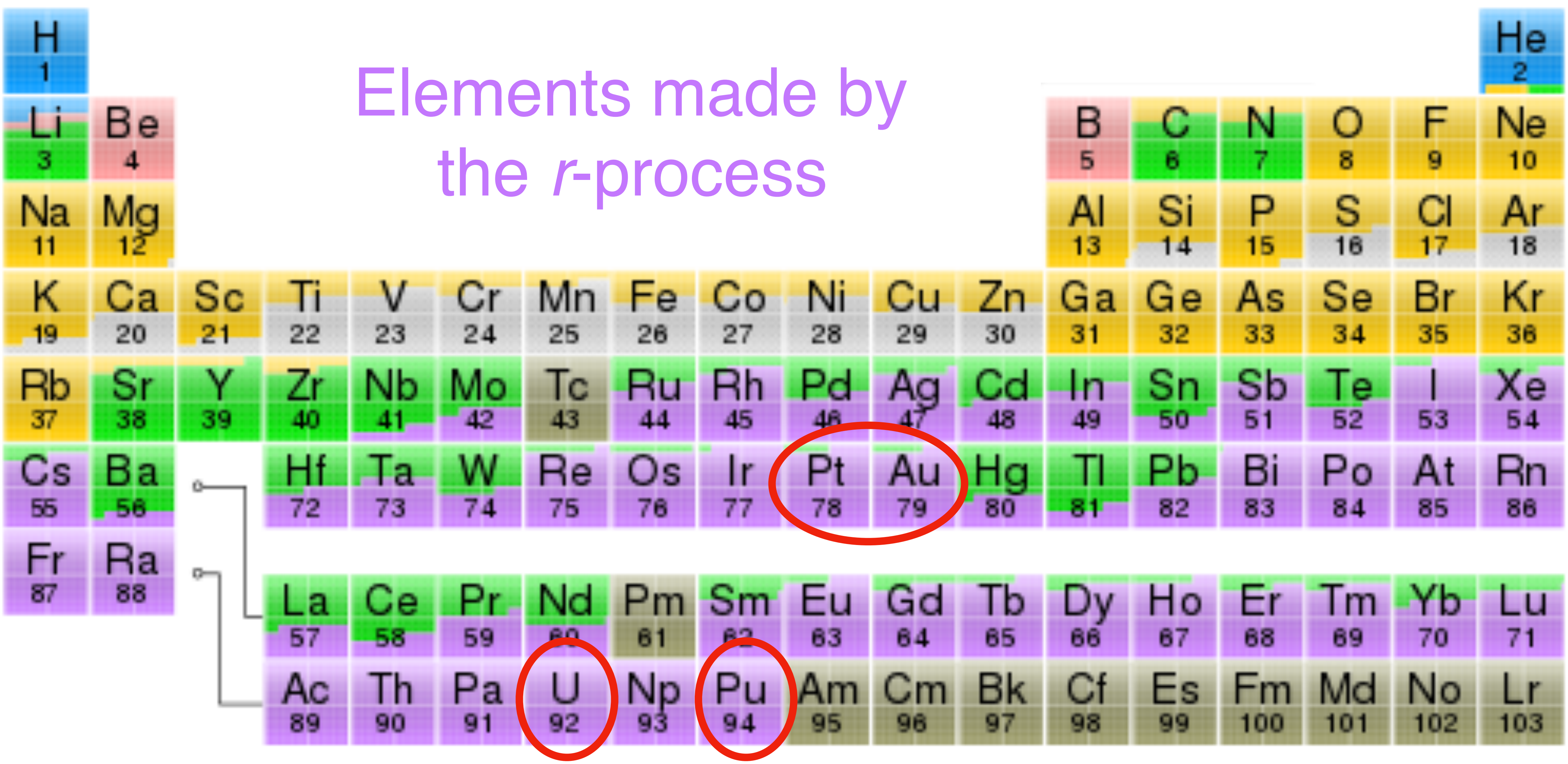


More protons

More neutrons

courtesy J. Lippuner

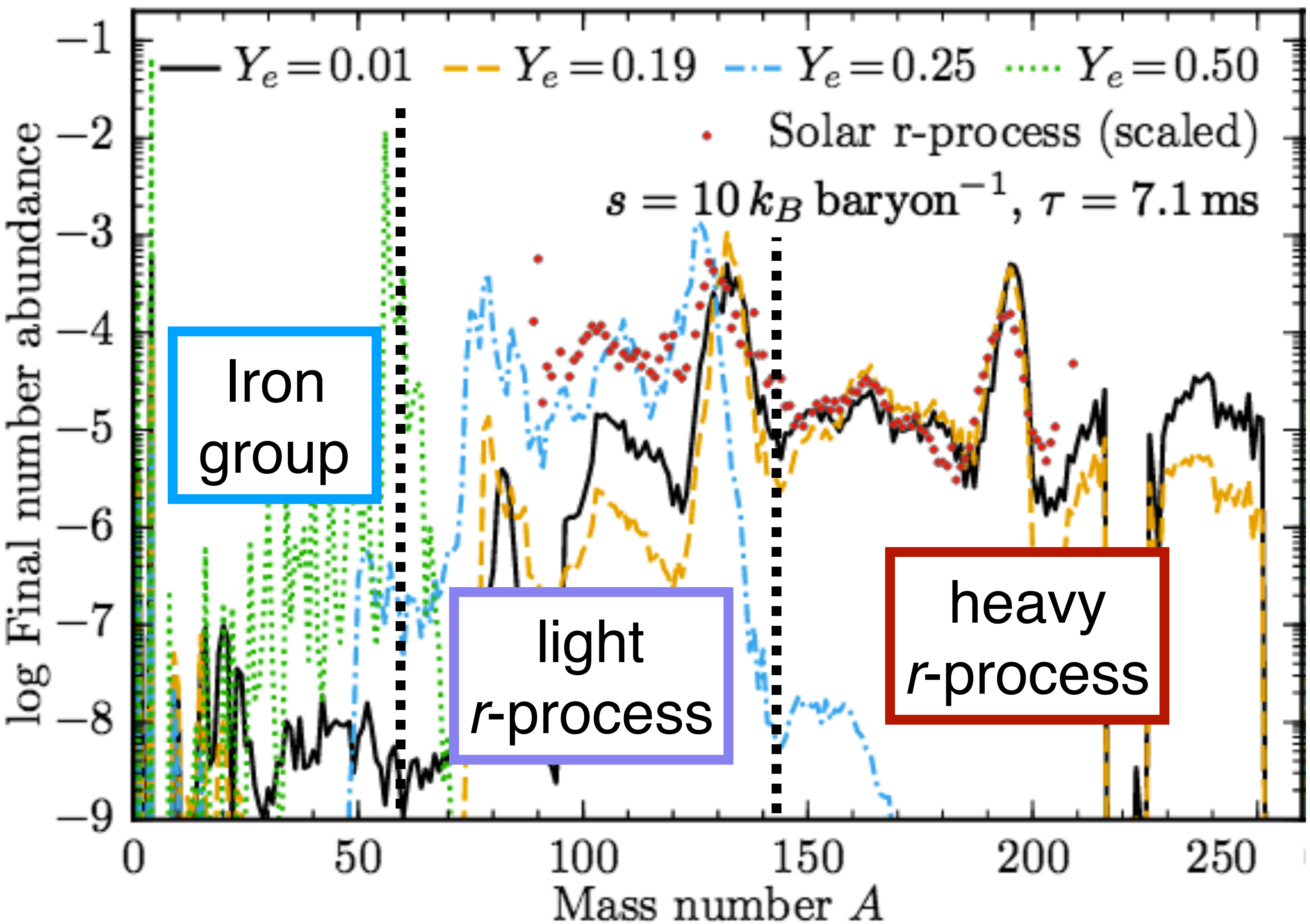
R-process nucleosynthesis can produce ~50% of nuclei heavier than Fe



Can…but doesn't have to

The outcome of the *r*-process is highly variable, and we (currently) have only crude diagnostics for the composition

I. Variability

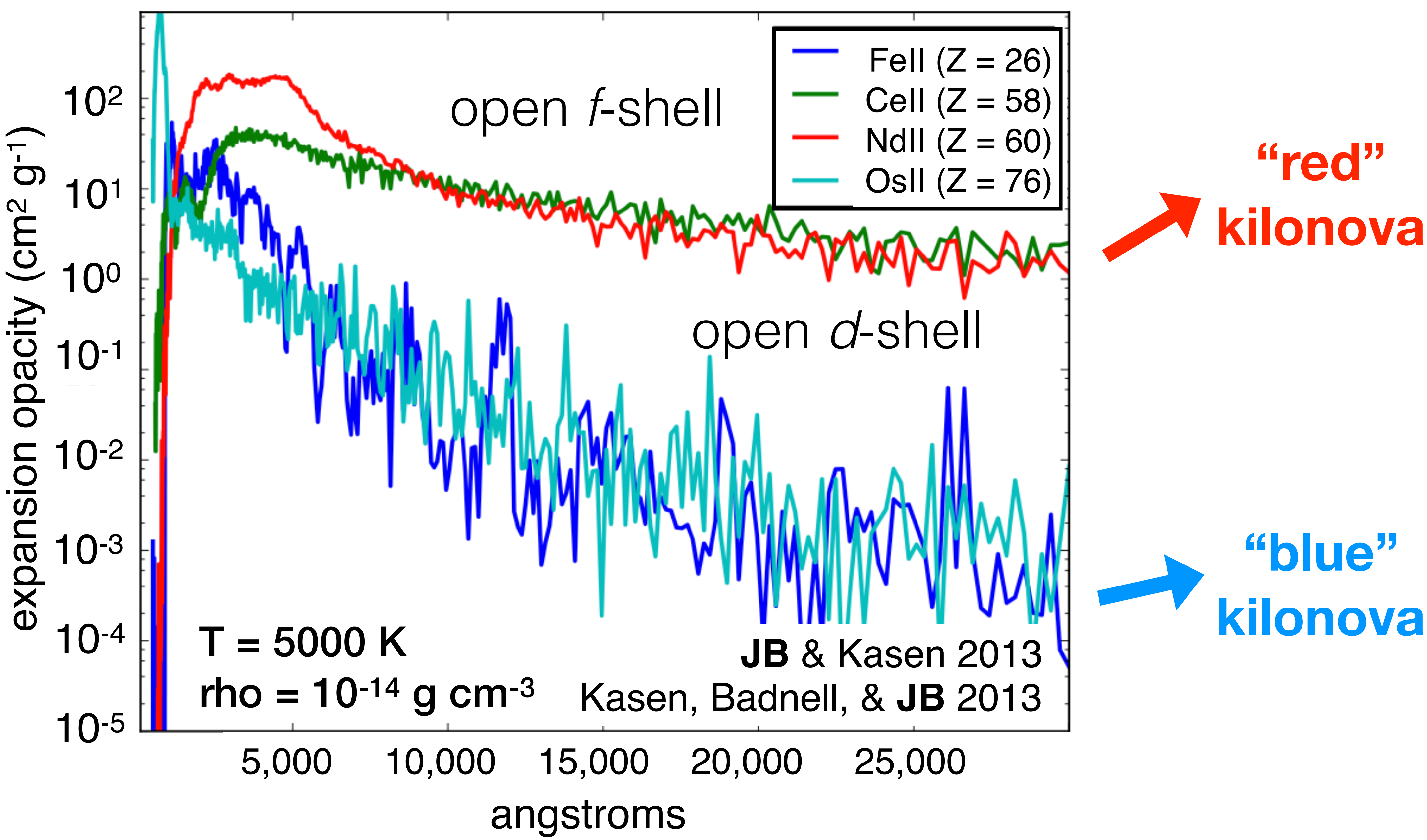


$$Y_\mathrm{e} = \frac{p}{p+n}$$

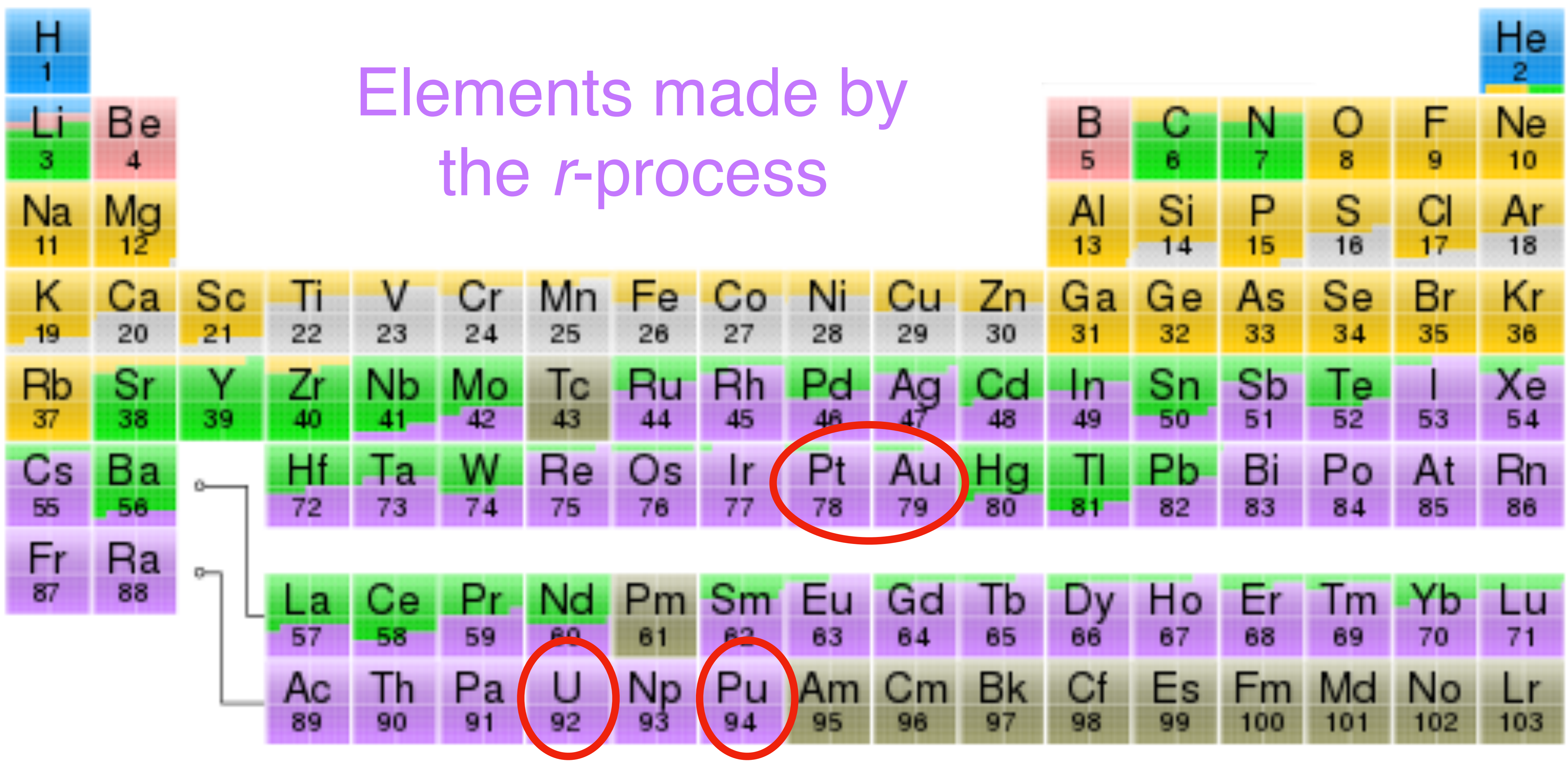
Can…but doesn't have to

The outcome of the *r*-process is highly variable, and we (currently) have only crude diagnostics for the composition

II. Diagnostics

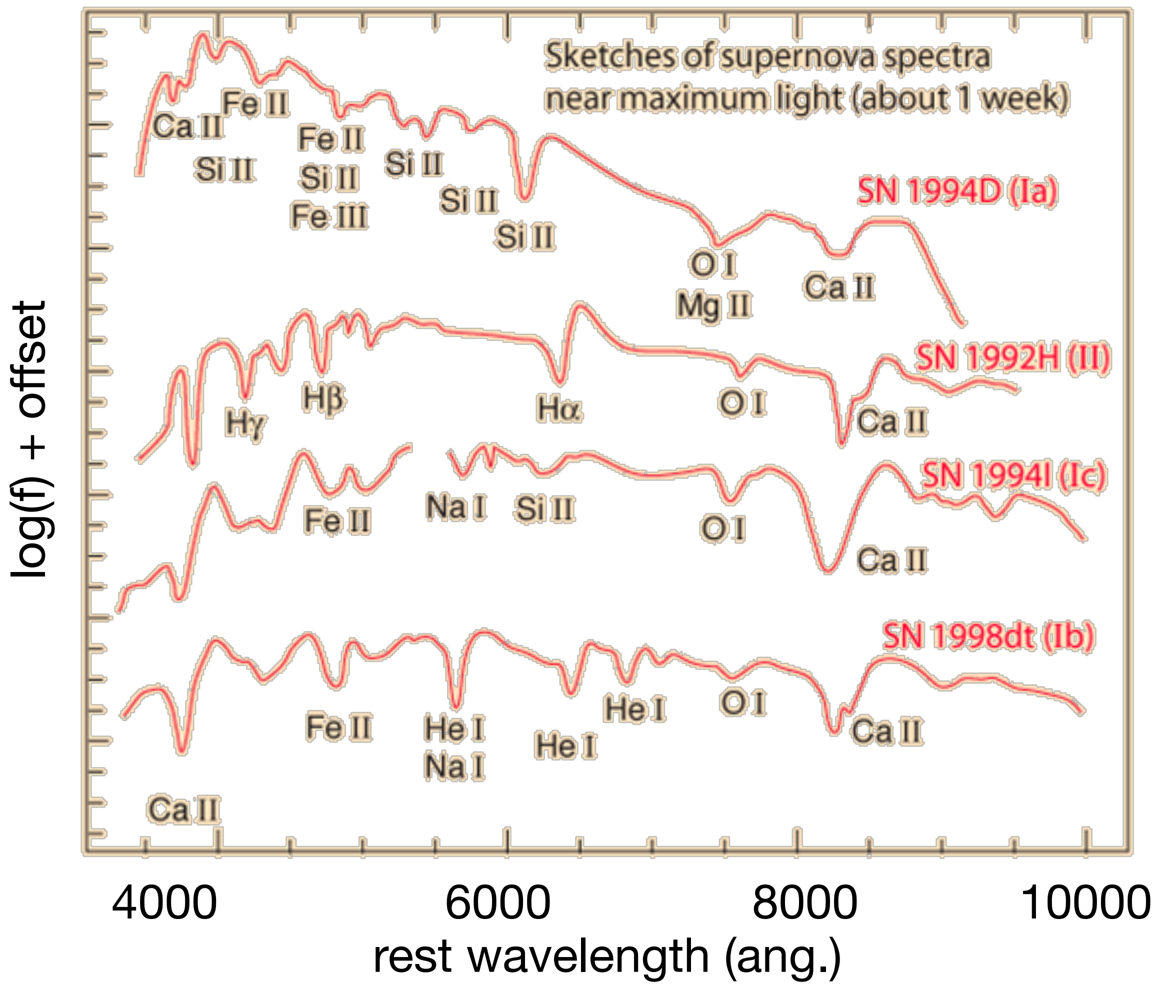


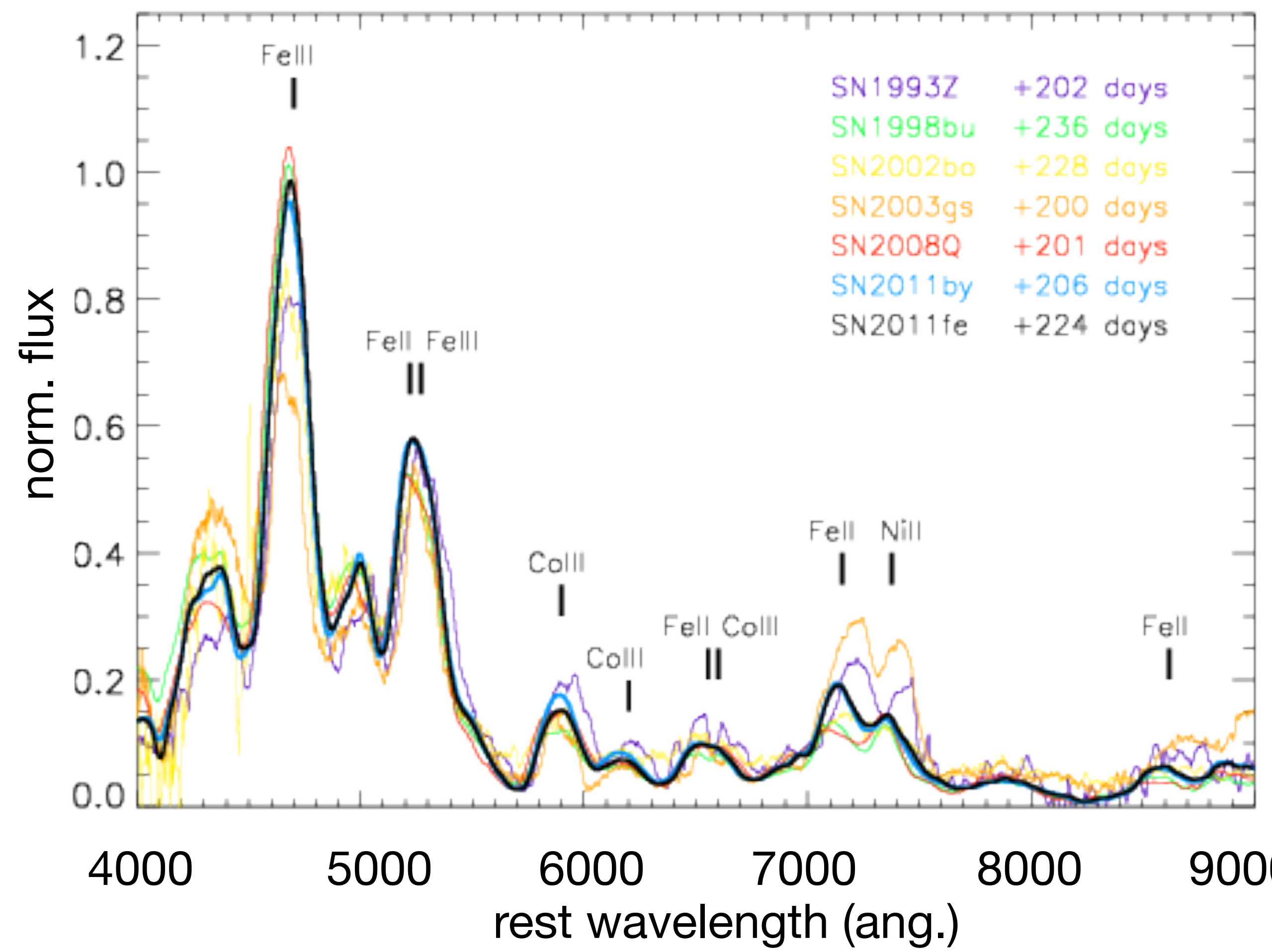
Did the NS merger really synthesize the full range of r-process elements?



Tools for probing the composition

I. Spectral features (in the photospheric or nebular phase)



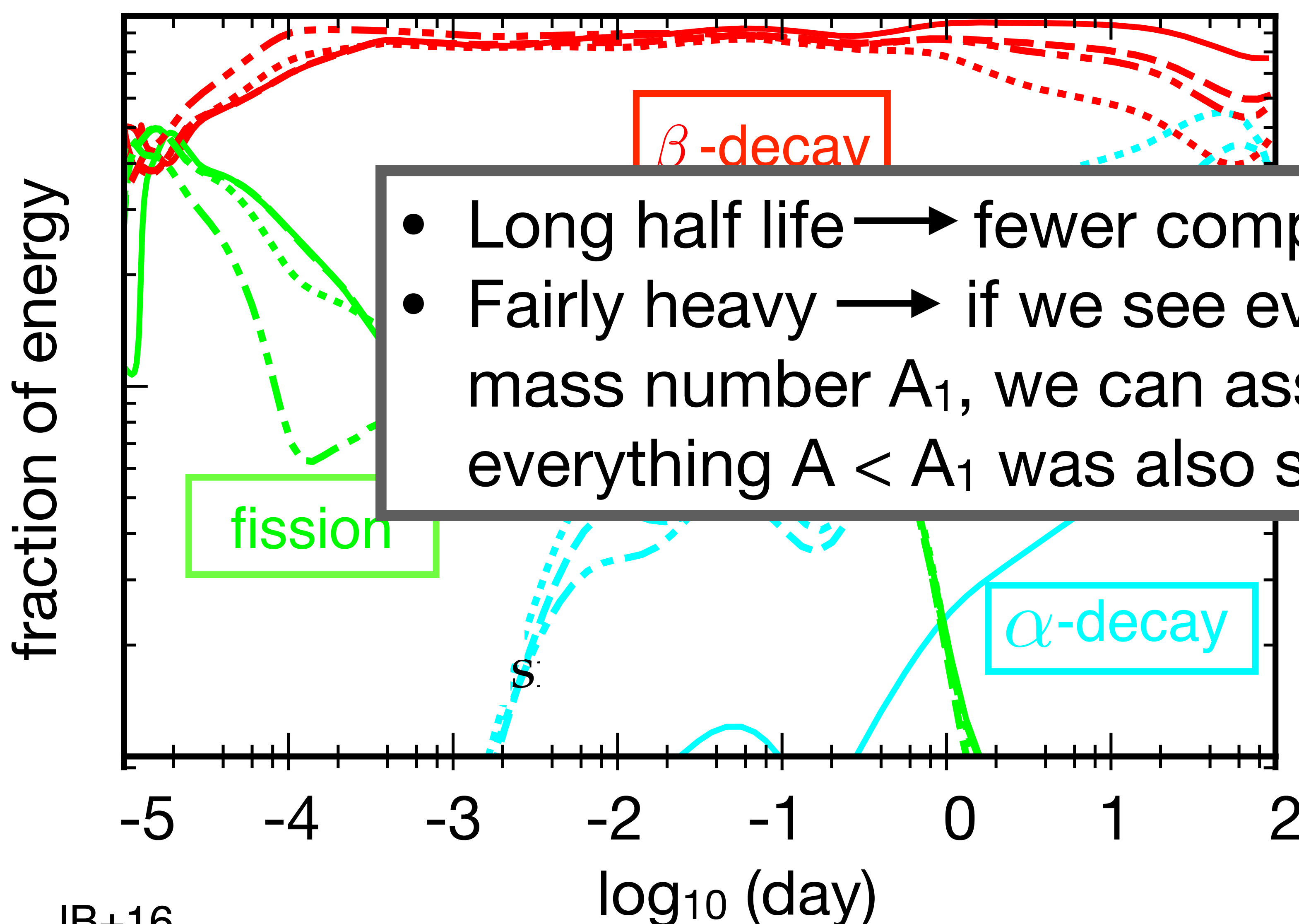


Disclaimer: this plots shows supernova spectra. We don't yet have the tools needed to do a similar analysis for kilonovae

Tools for probing the composition

II. Look for clues in the bolometric luminosity

Basic idea: Kilonovae are powered by the combined effects of many decays. If at some time one of these becomes dominant, it could change the shape of the bolometric light curve.



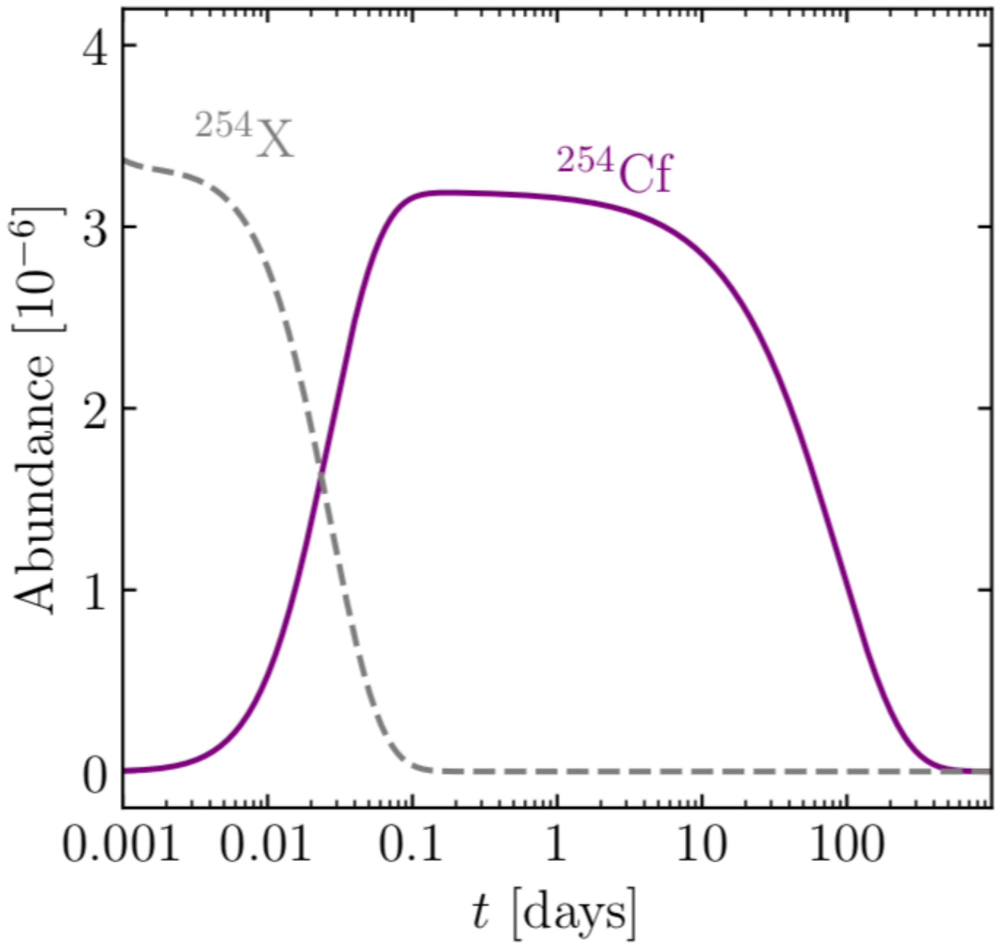
JB+16

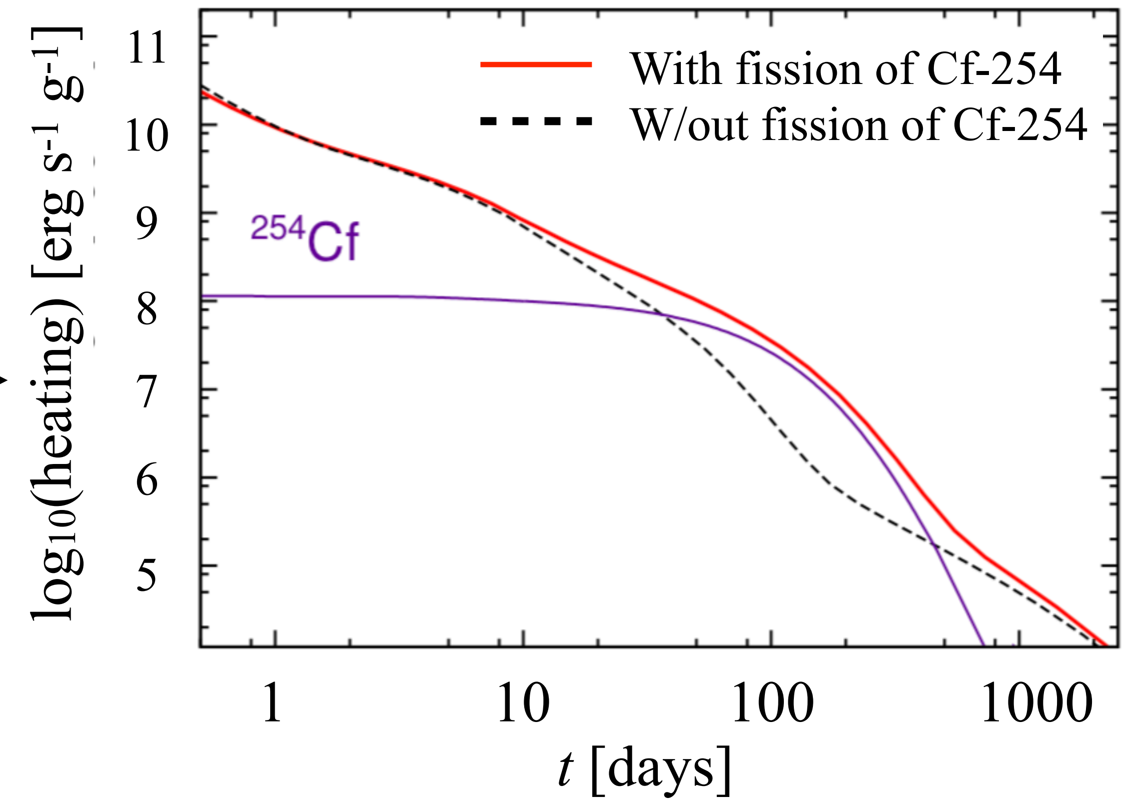
- Long half life ⟶ fewer competing decays
- Fairly heavy ⟶ if we see evidence of mass number A_1, we can assuming that everything $A < A_1$ was also synthesized

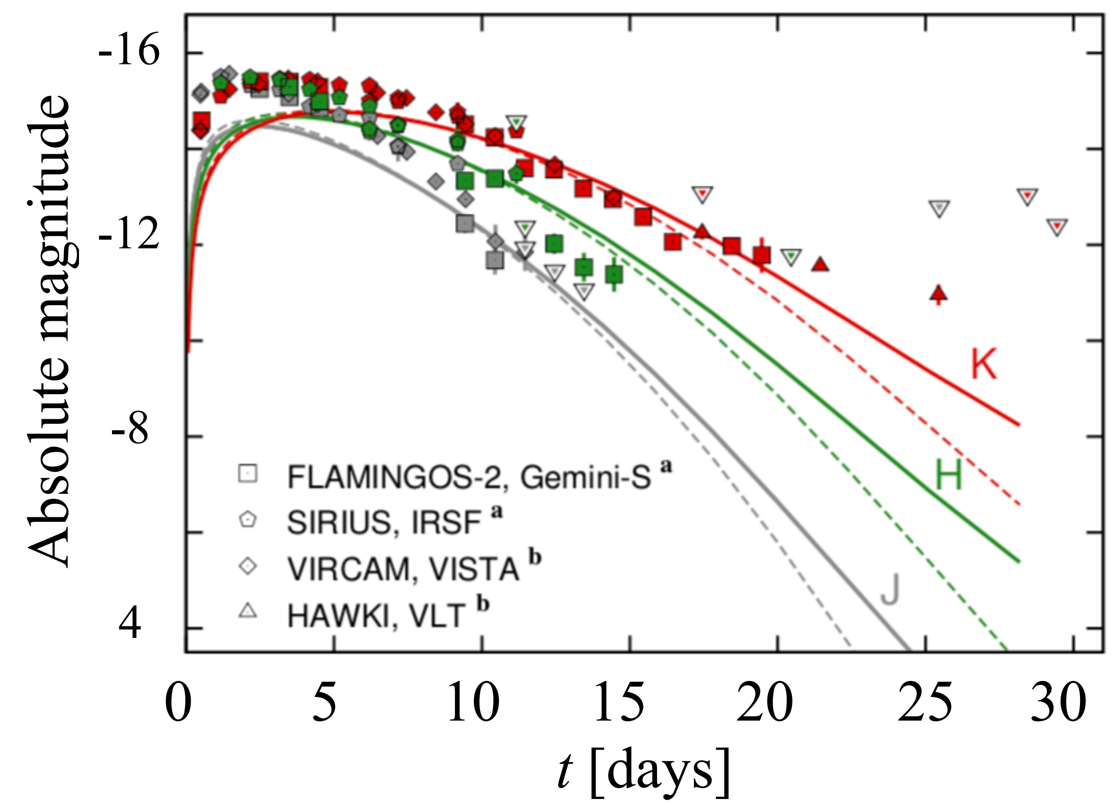
Fission and alpha-decay

- Produce a lot of energy compared to beta-
- … t energy to … fficiently … -decay = higher L_{bol})
- Don't follow power-law energy generation of beta-decay

Looking for Fission with Cf-254



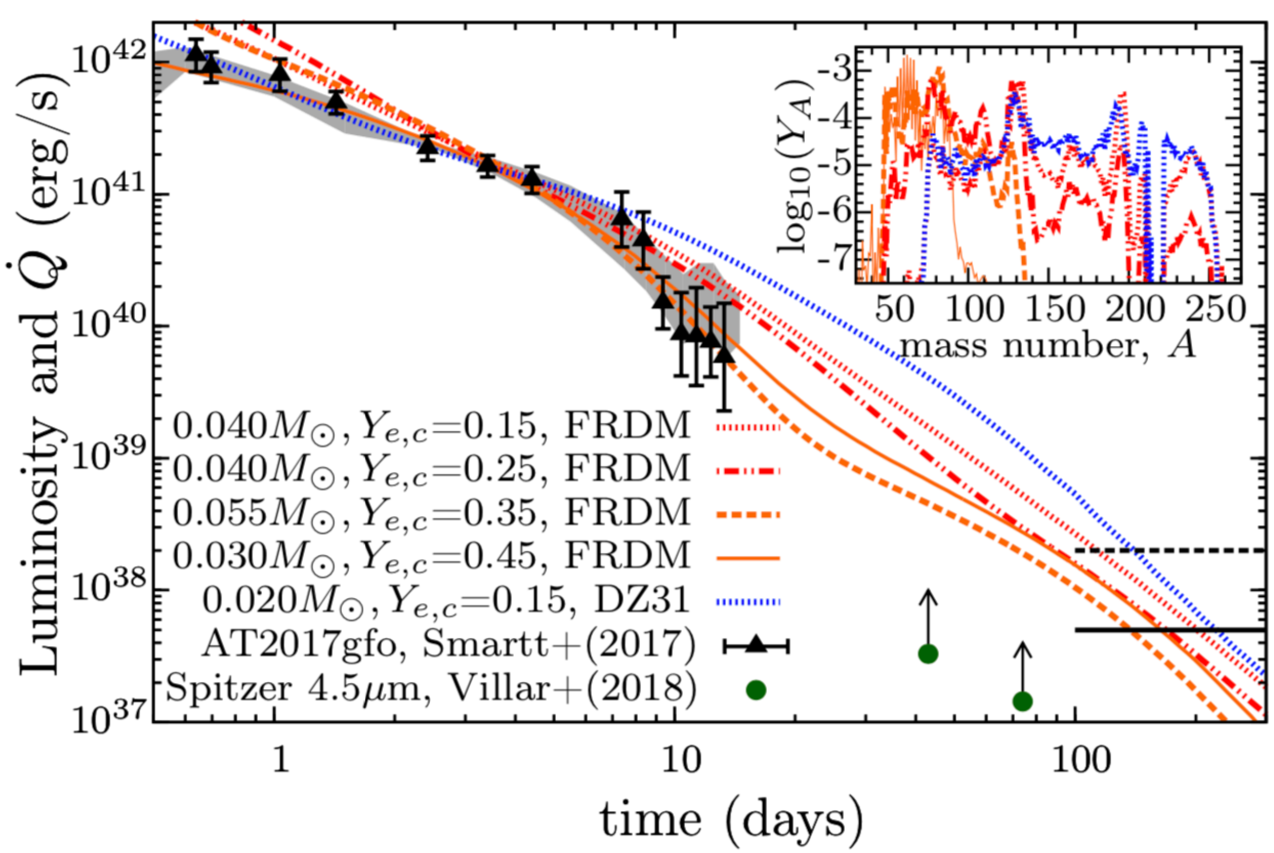


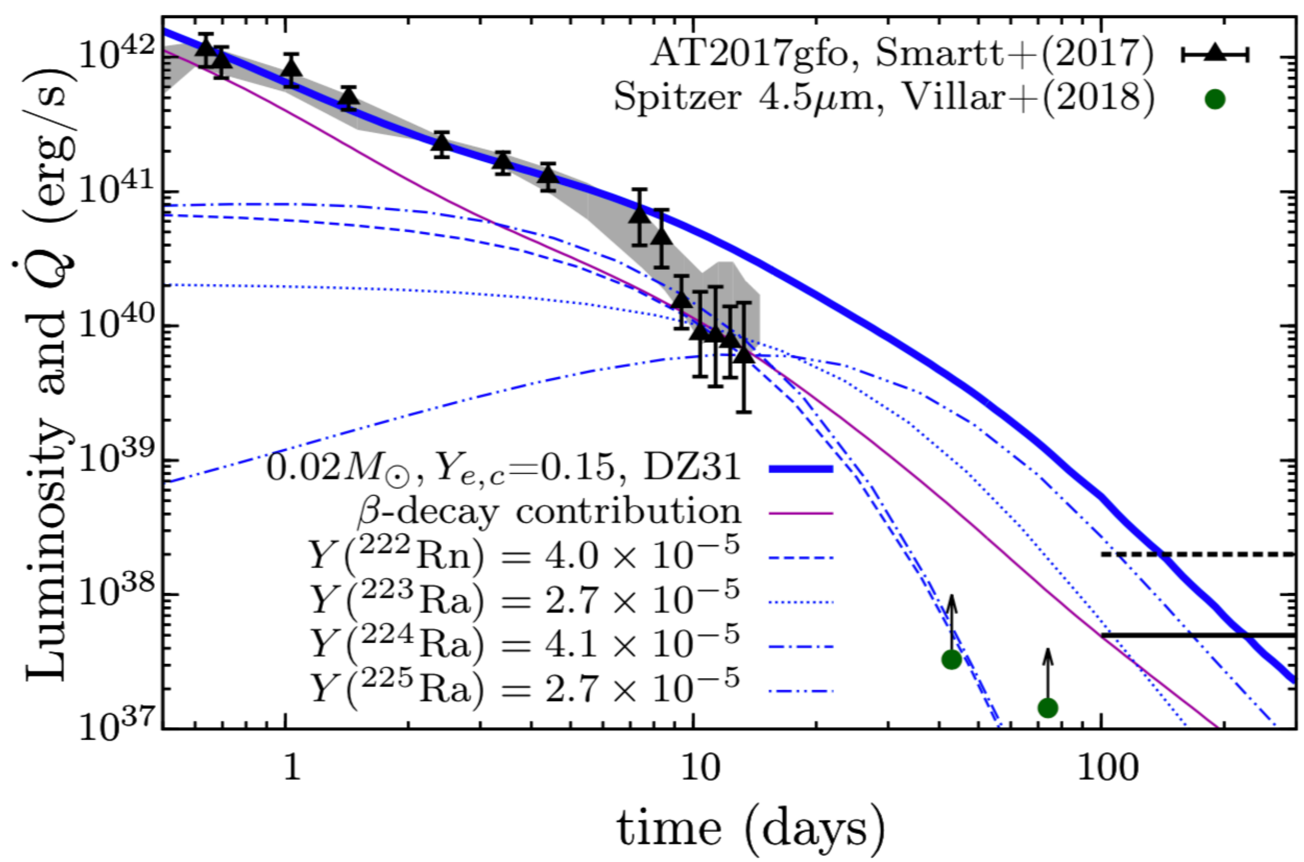


Cf-254 could serve as a late time ($\tau_{1/2} = 60.5$) energy reservoir, brightening the light curve

(see Zhu…**JB** 2018 (ApJL))

Looking for actinide fingerprints with alpha-decay



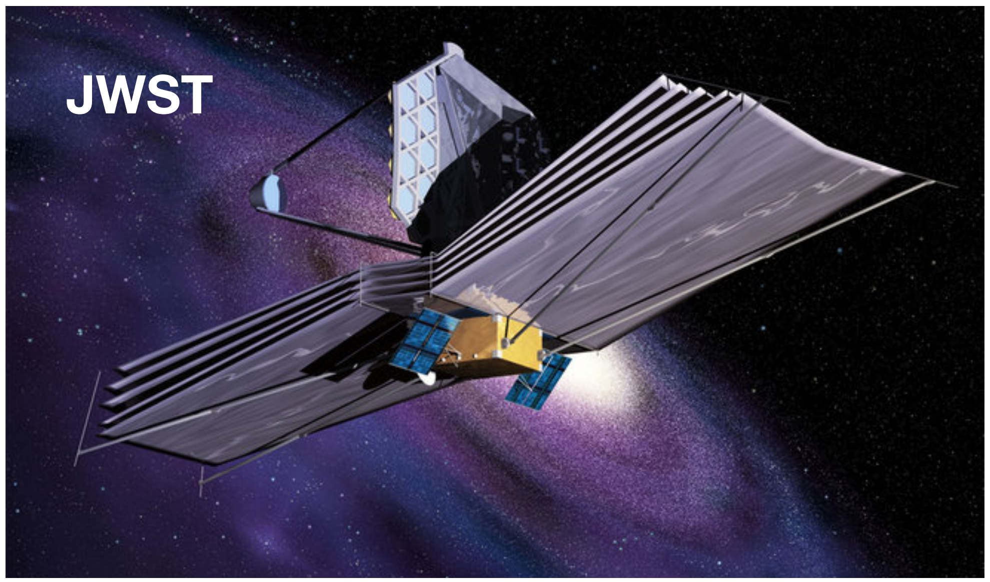


- Determine which sets of nuclear heating rates gives properties the are consistent with observed bolometric luminosities of AT2017gfo
- Perform a detailed study of late time heating, modeling heating by individual alpha-decay chains, to extrapolate bolometric luminosity to late times

(see Wu, **JB**+2018 (ApJL))

Challenges to measuring L_{bol}

Technical: We need to make precision measurements at low luminosities



James Webb Space Telescope:

- *NIR-cam* (0.6—4μm): can detect $L_{NIR} > 5 \times 10^{37}$ erg s^{-1}
- *Mid-Infrared Instrument* (5—14 μm): can detect $L_{MIR} > 1 \times 10^{38}$ erg s^{-1}

Theory/modeling: How can we measure bolometric luminosity in the nebular phase?

- The blackbody assumption eventually breaks down
- We have very limited knowledge of the prominent emission features for *r*-process compositions
- Low densities may lead to inefficiencies in the reradiating of deposited energy (aka “freeze out”)