Spectral synthesis modelling of kilonovae

Anders Jerkstrand, with Quentin Pognan, Jon Grumer, Smaranika Banerjee, Eliot Ayache    

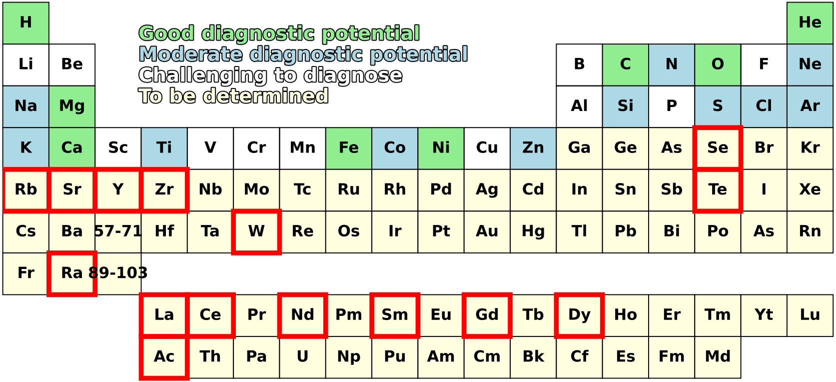
Stockholm University

Stockholm University

European Research Council

Swedish Research Council

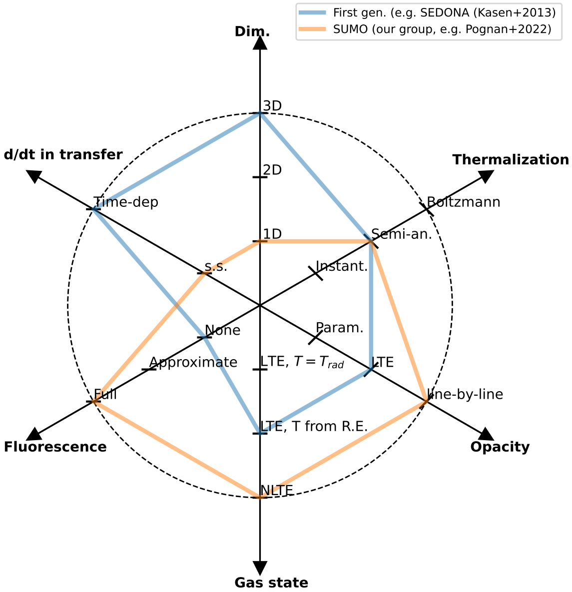
Decoding KN spectra



Claimed (possible) detection in 2017gfo, or potential for detection

Watson+2019,Domoto+2021,2022,Hotokezaka+2022,2023
Sneppen+2023,Pognan+2023,Gillanders+2024

KN spectral synthesis modelling



- Can we reach the circle? Each step out increases compute time by orders of magnitude.
- Atomic data still a major bottleneck.

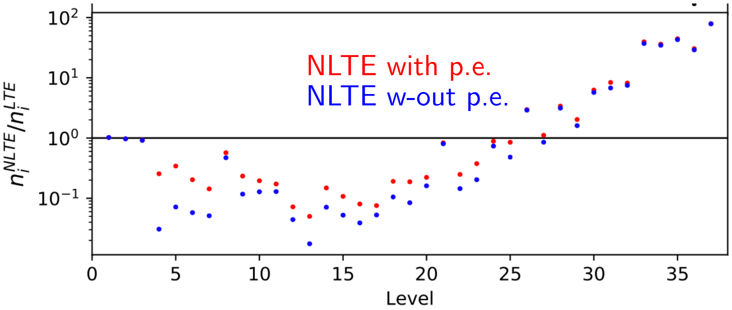
Why NLTE?

The density evolves as

$$\rho \approx 10^{-13} \left(\frac{M}{0.05\ M_\odot}\right) \left(\frac{V}{0.1c}\right)^{-3} t_d^{-3} \text{ g cm}^{-3} \tag{1}$$

Compare to a stellar atmosphere: $\sim 10^{-9}$ g cm^{-3}.

Example: Pt III in NLTE at 5d: Pognan, Jerkstrand & Grumer 2022



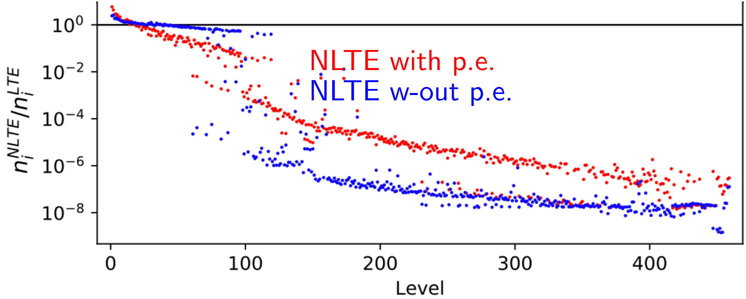
Why NLTE?

The density evolves as

$$\rho \approx 10^{-13} \left(\frac{M}{0.05\ M_\odot}\right) \left(\frac{V}{0.1c}\right)^{-3} t_d^{-3}\ \mathrm{g\ cm}^{-3} \tag{1}$$

Compare to a stellar atmosphere: $\sim 10^{-9}$ g cm^{-3}.

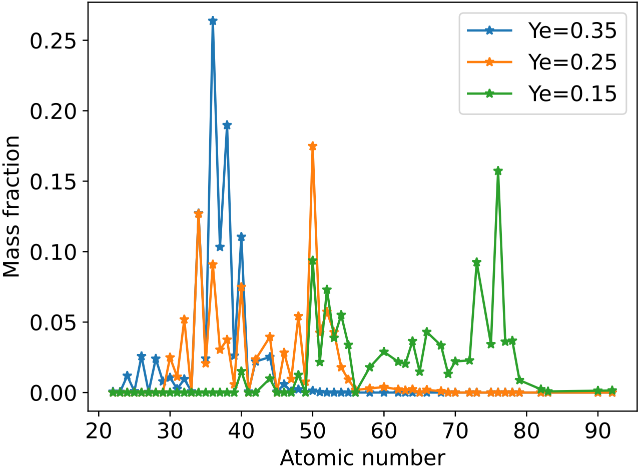
Example: Ce II in NLTE at 3d:



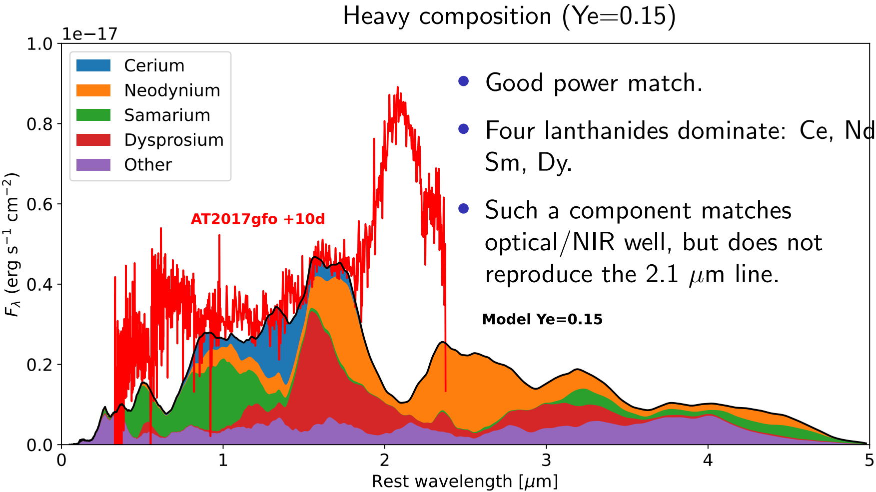
Kilonova models Pognan+2022ab,2023

- 1D models for three different $Y_e = 0.15, 0.25, 0.35$, 5-20d.

  $Y_e =$ "inverse of neutron richness". Wanajo+2014,2018



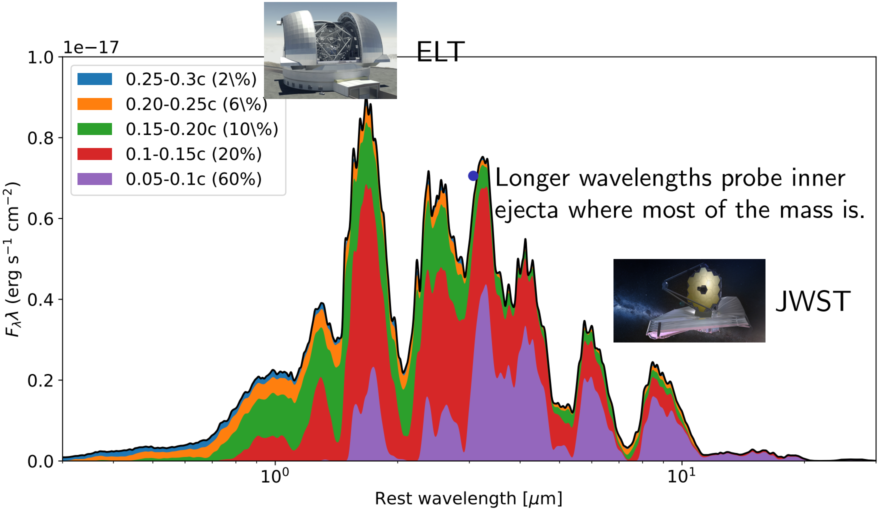
First NLTE KN spectra Pognan+2022ab,2023



- Good power match.
- Four lanthanides dominate: Ce, Nd, Sm, Dy.
- Such a component matches optical/NIR well, but does not reproduce the 2.1 μm line.

Pognan+2023(optical),Jerkstrand+in prep(IR).

First NLTE KN spectra Pognan+2022ab,2023

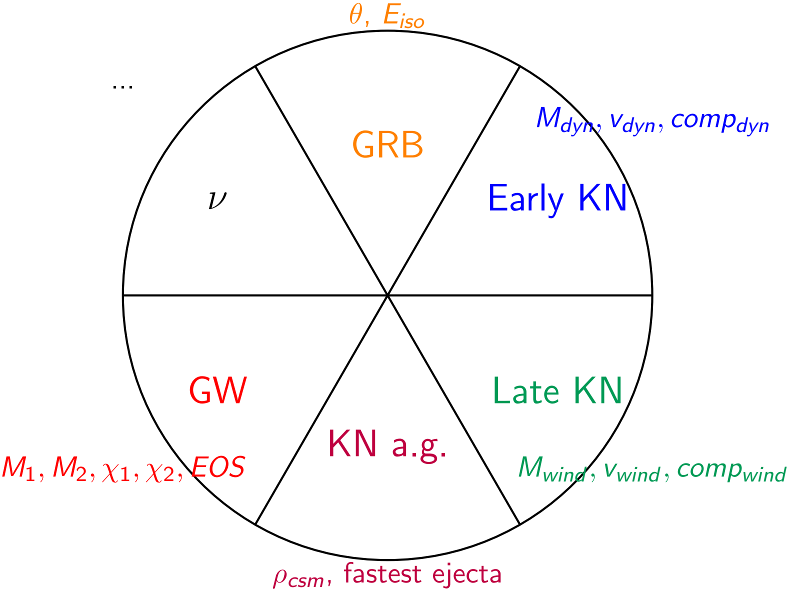


Pognan+2023(optical),Jerkstrand+in prep(IR).

Take-home points

- **A second generation of KN spectral models** are now coming into place considering NLTE and fluorescence. These effects qualitatively change KN spectra from a few days already and are useful for EM follow-up planning and data analysis. Pognan+2023,2023,Shingles+2023
- Post-peak EM gives us information on **slow/inner material** constituting the bulk of the mass of the KN.
- Exploratory 1D models show **which elements hold best diagnostic potential** from post-peak spectra
  - High Y_e : Rb, Sr, Y, Zr
  - Medium Y_e: Lanthanides, in particular Nd, Sm, Dy
  - Low Y_e : Same as medium Ye
- We are happy to discuss which kind of KN models to pursue for in-depth modelling.

The MM cake


θ, E_{iso}
...
GRB
$M_{dyn}, v_{dyn}, comp_{dyn}$
Early KN
ν
GW
Late KN
KN a.g.
$M_1, M_2, \chi_1, \chi_2, EOS$
$M_{wind}, v_{wind}, comp_{wind}$
ρ_{csm}, fastest ejecta