Applications of NIR stellar spectra toward understanding kilonova spectra

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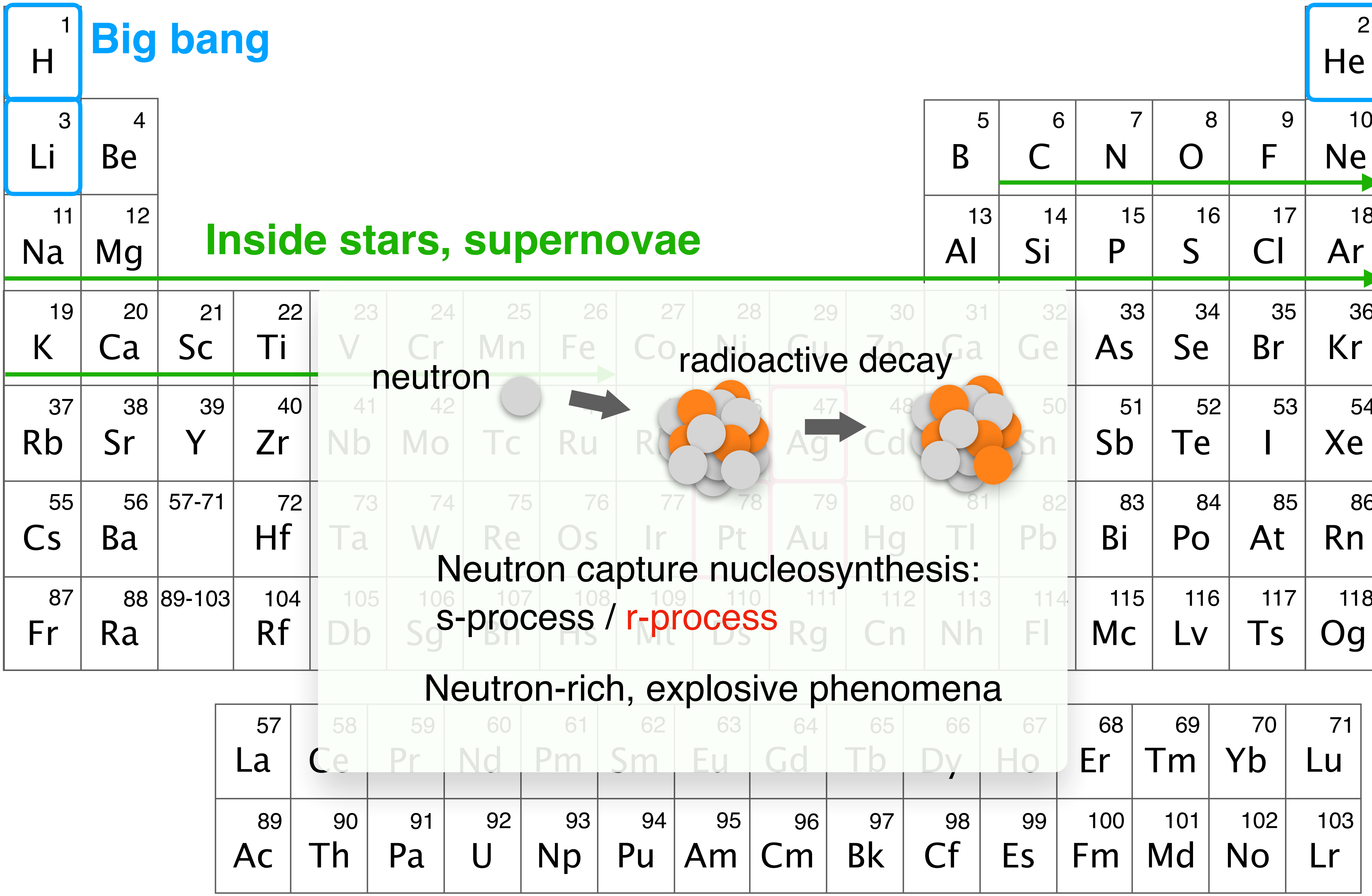
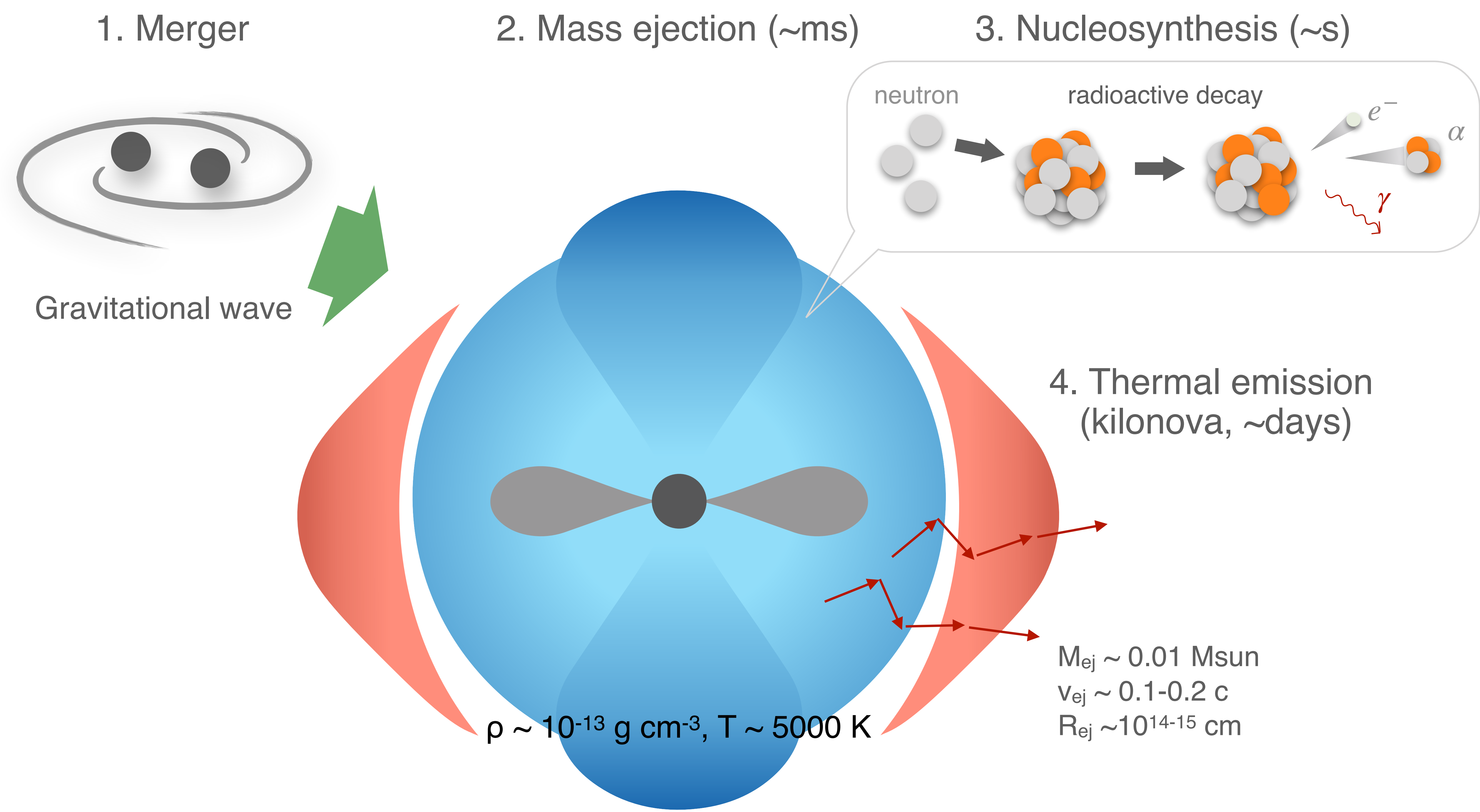
Origin of elements



Neutron star merger/Kilonova

Radioactively-powered UV-optical-IR emission from neutron star merger: signatures of r-process

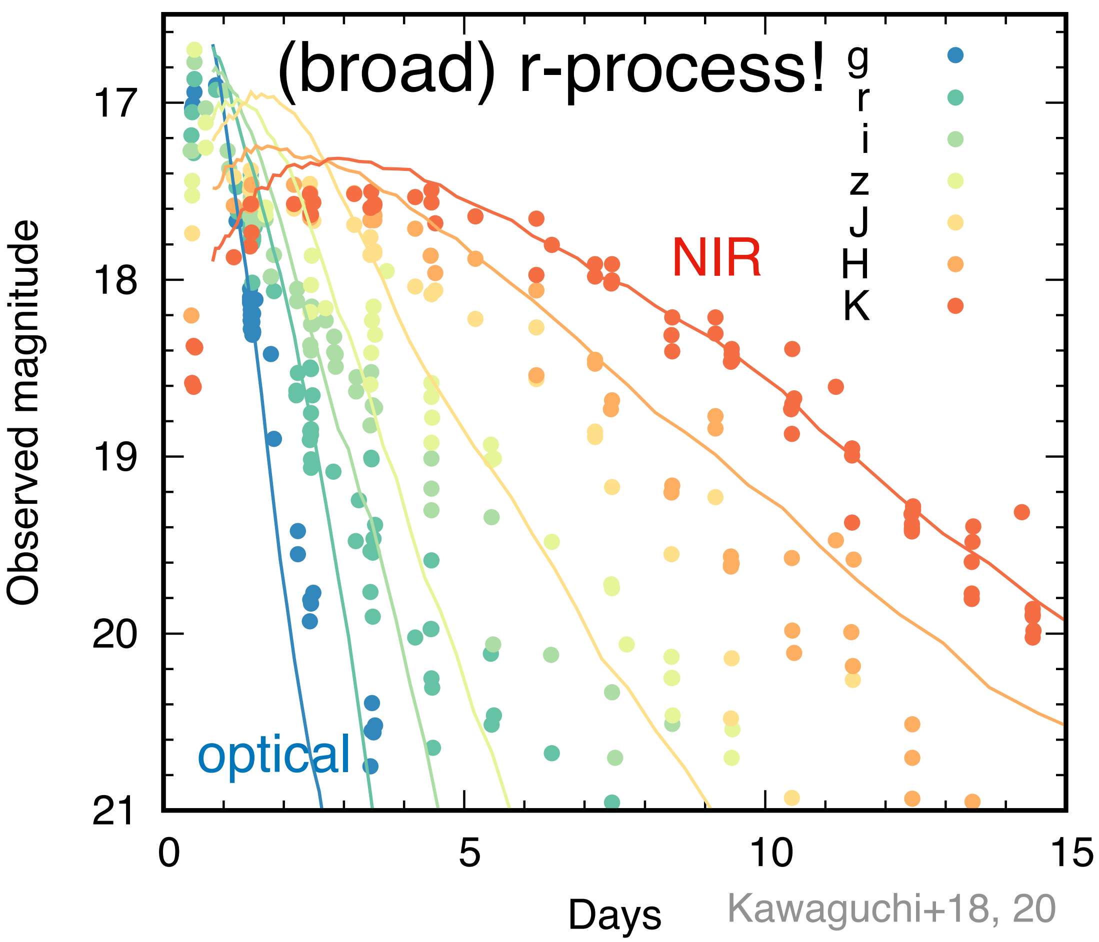


e.g., Lattimer & Schramm 74, Eichler+89, Li & Paczynski 98, Freiburghaus+99, Metzger+10, Goriely+11, Roberts+11, Tanaka & Hotokezaka 13…

Kilonova in GW170817

e.g., Arcavi+17, Smartt+17, Kasen+17, Kilpatrick+17, Perego+17, Rosswog+17, Shibata+17, Tanaka+17, Toroja+17, …

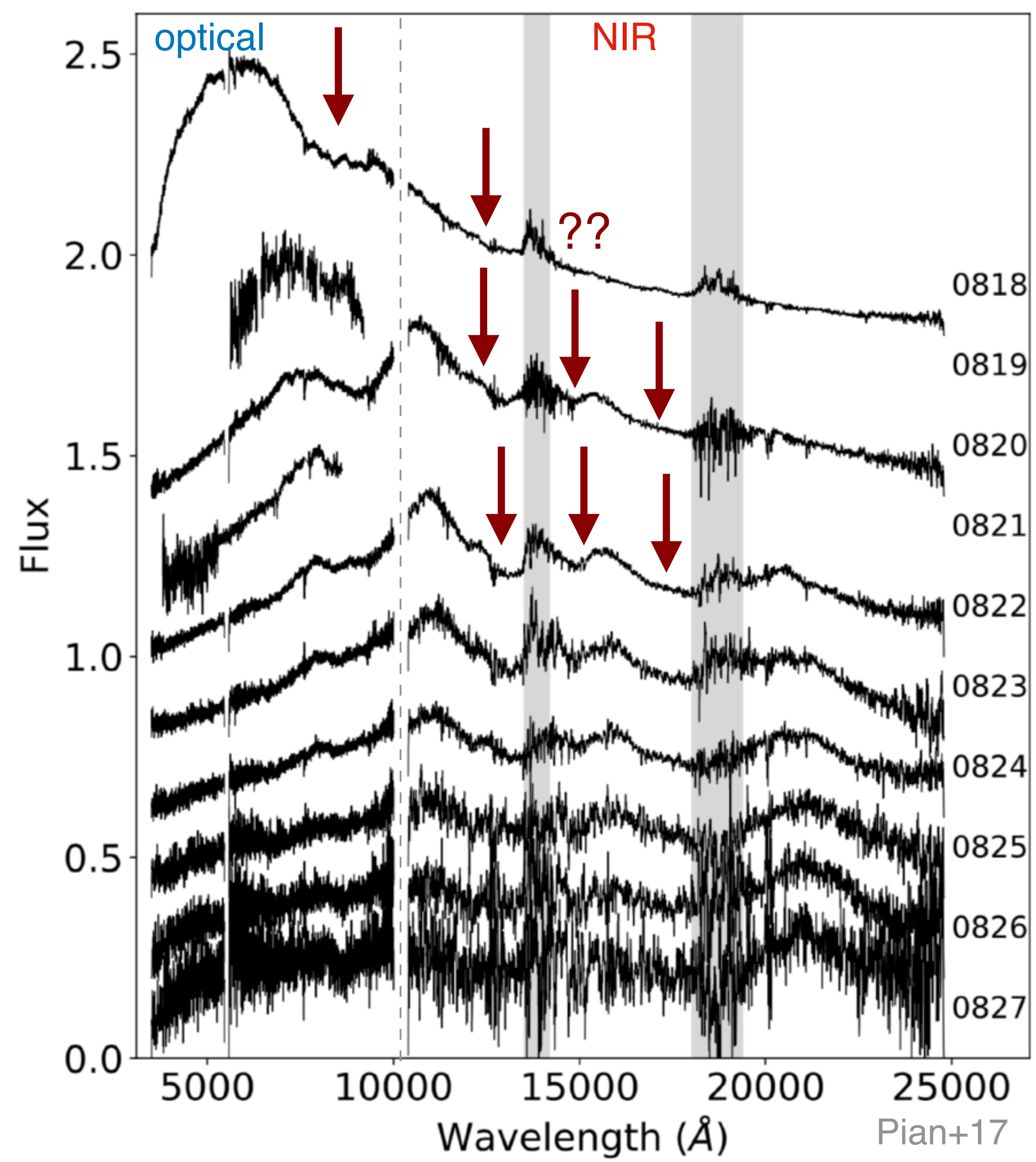
Utsumi+17 (Subaru/HSC, IRSF/SIRIUS)



Kawaguchi+18, 20

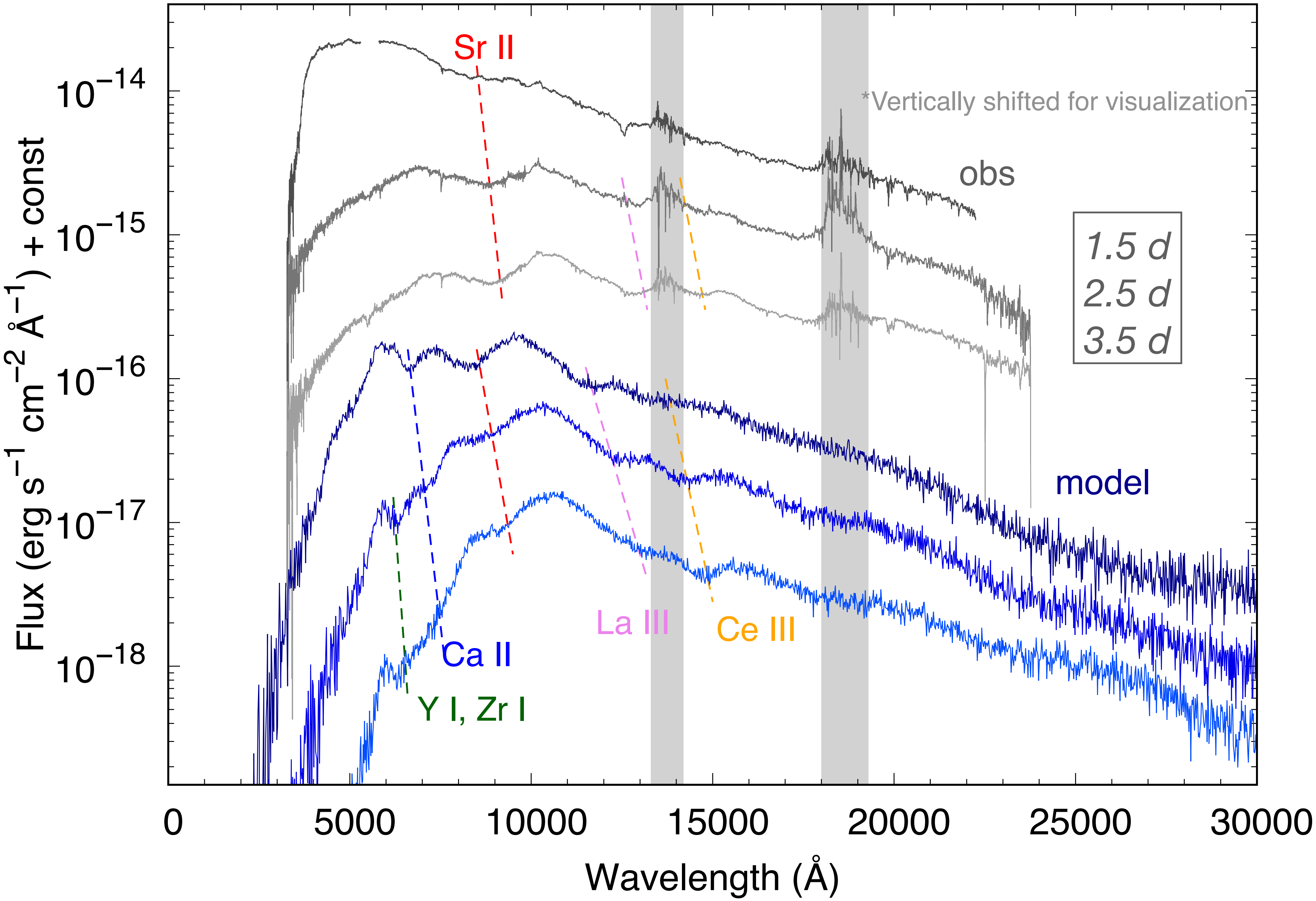
Which and how much elements?
Abundance pattern?

Sr II Watson+19, Domoto+21, Gillanders+22



Pian+17

“Identified” elements so far



9000 A → Sr II Watson+19, Domoto+21, Gillanders+22

12500 A → La III, 14500 A → Ce III Domoto+22

Road to the line identification

"Candidate"

for Ce III…

Wavelengths are consistent
(w/ reasonable Doppler shift)
=> Need transition wavelengths ✓

Domoto et al. 2022

Strong lines are expected
(in terms of abundances, ionization, excitation, …)
=> Need transition probabilities ✓

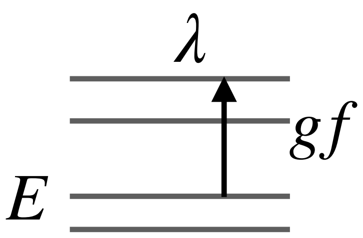
Domoto et al. 2023

No other line can produce the feature
=> Need complete data for strong transitions

Tanaka, Domoto, Aoki, et al. 2023

Line identification

Incomplete experimental atomic data

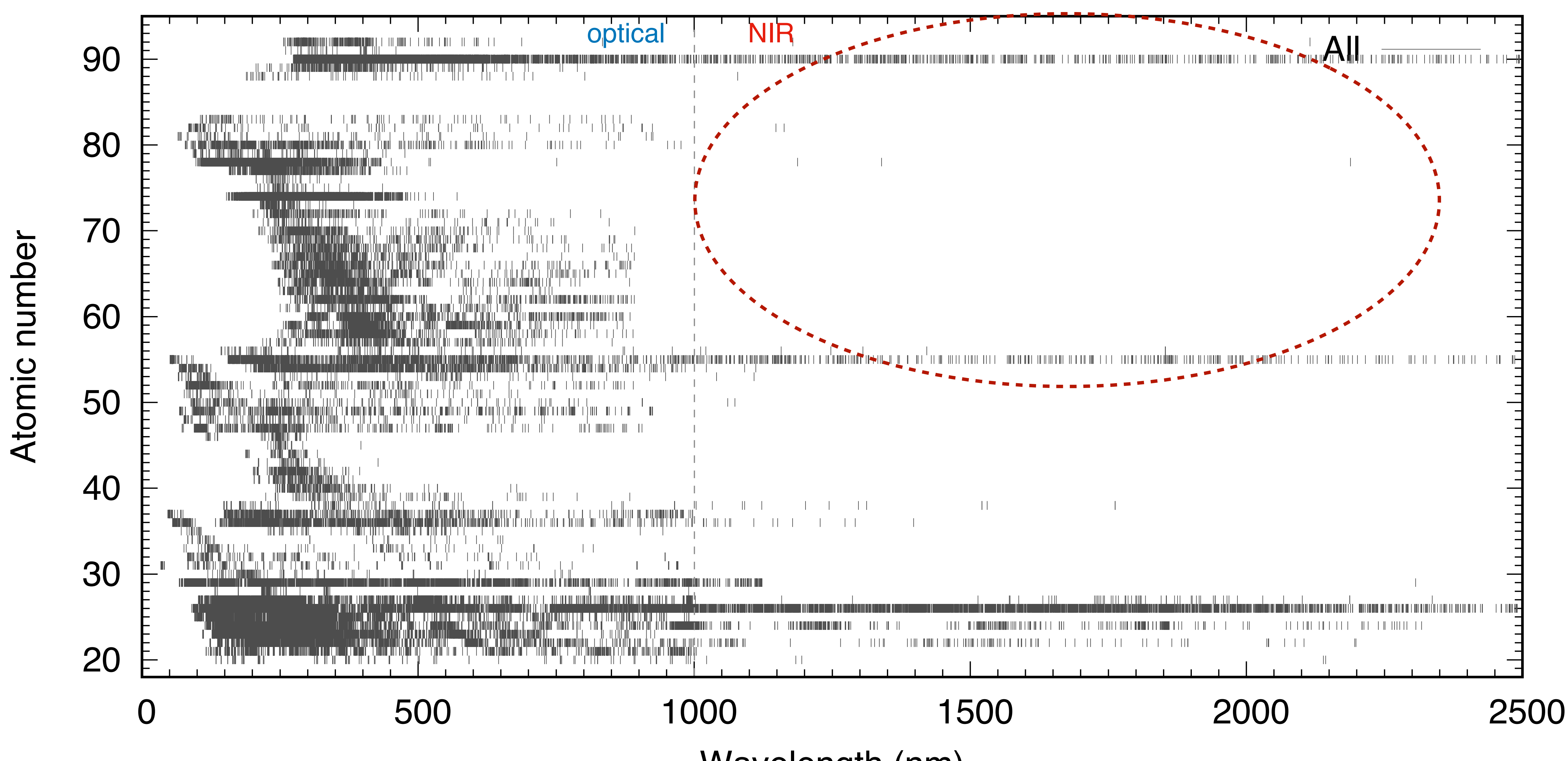


Essential, but highly incomplete

<u>How to exclude the possibility that unknown lines produce the feature</u>

※Domoto et al. (2022) used theoretical atomic data to ensure completeness

Measured transition wavelengths



from NIST ADS

Tanaka, Domoto, Aoki et al. 2023

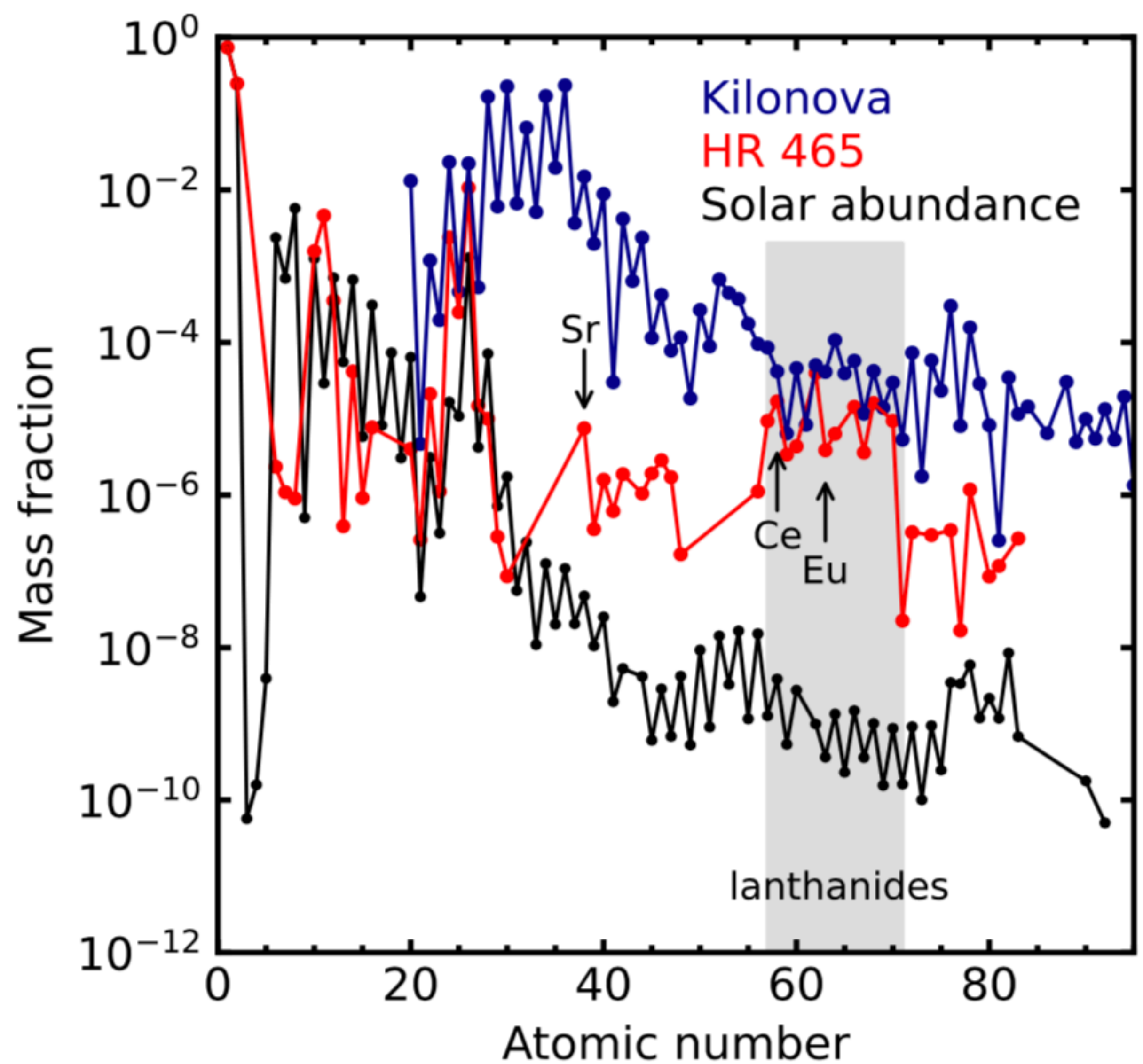
Toward firm identification…

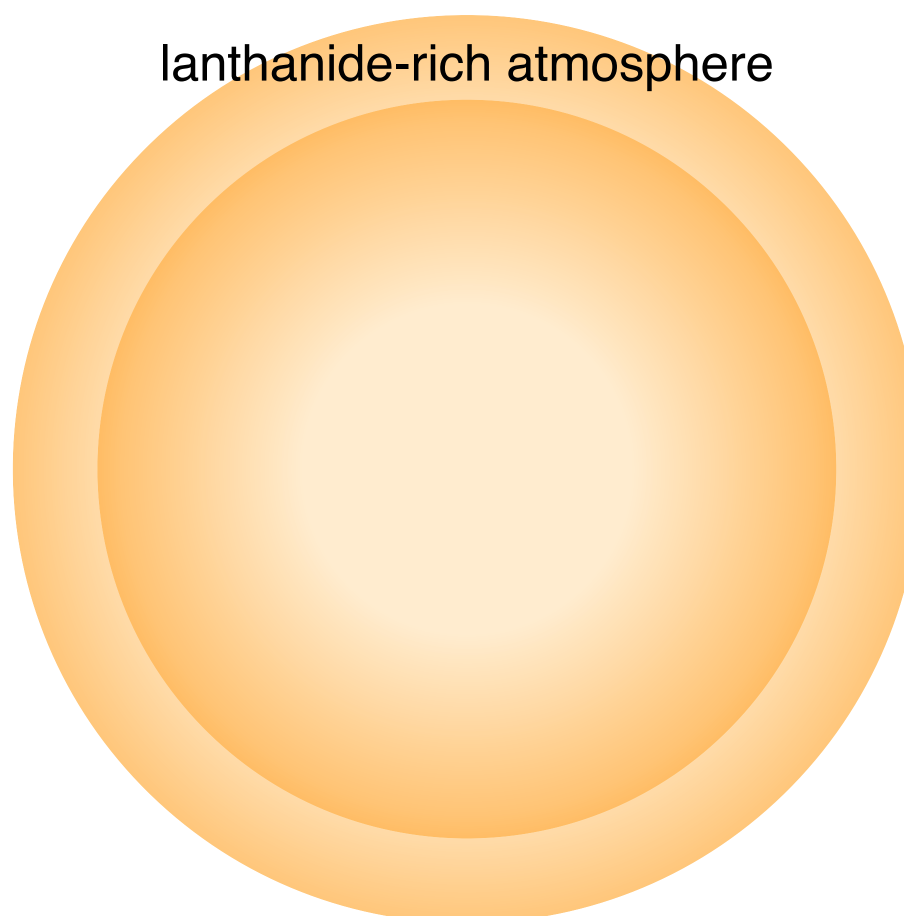
NIR lines are highly incomplete experimentally…

How to assure the completeness of strong transitions?

→ Use chemically peculiar stars

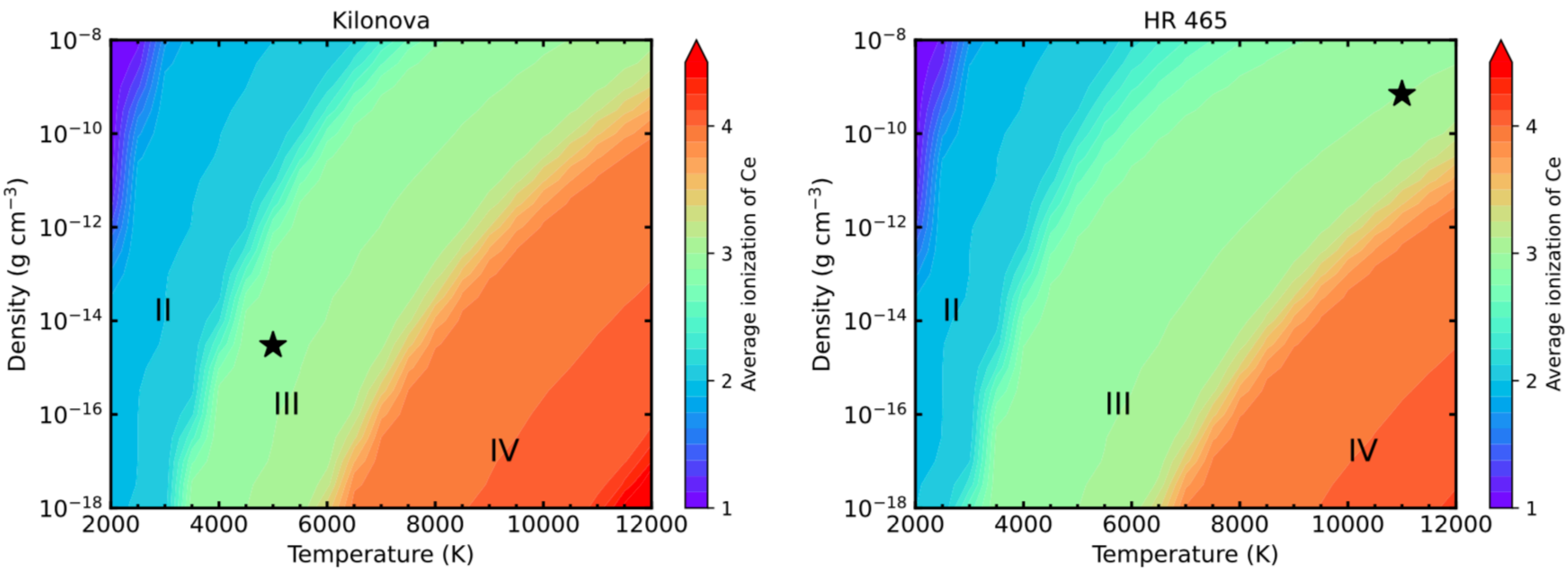
with <u>similar lanthanide abundances</u>





Similarity in ionization degree

In both “atmosphere” of kilonvoa and the star (※LTE)
→ List of strong absorption lines in the stellar spectrum
= “complete” list of strong transitions



※ Temperature is different (i.e., excitation is different)

Tanaka, Domoto, Aoki et al. 2023

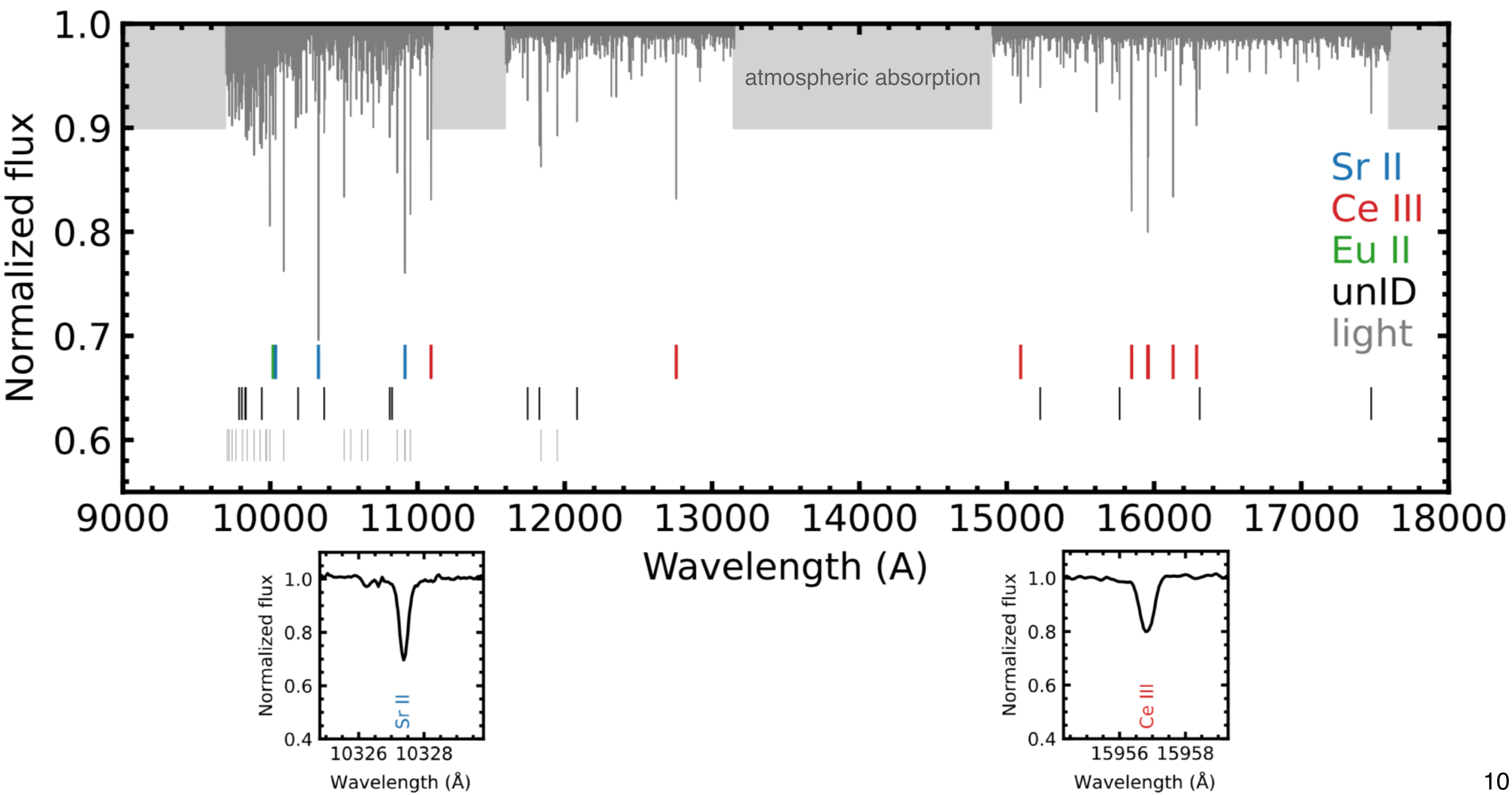
“Complete” list of strong transitions

HR 465 spectrum: Subaru/IRD YJH-bands (R~70000)

2020 July 25 (UT), 300 s exposure

The strongest lines are Ce III and Sr II!

<u>No other comparably strong lines as Ce III around 16000 A</u>



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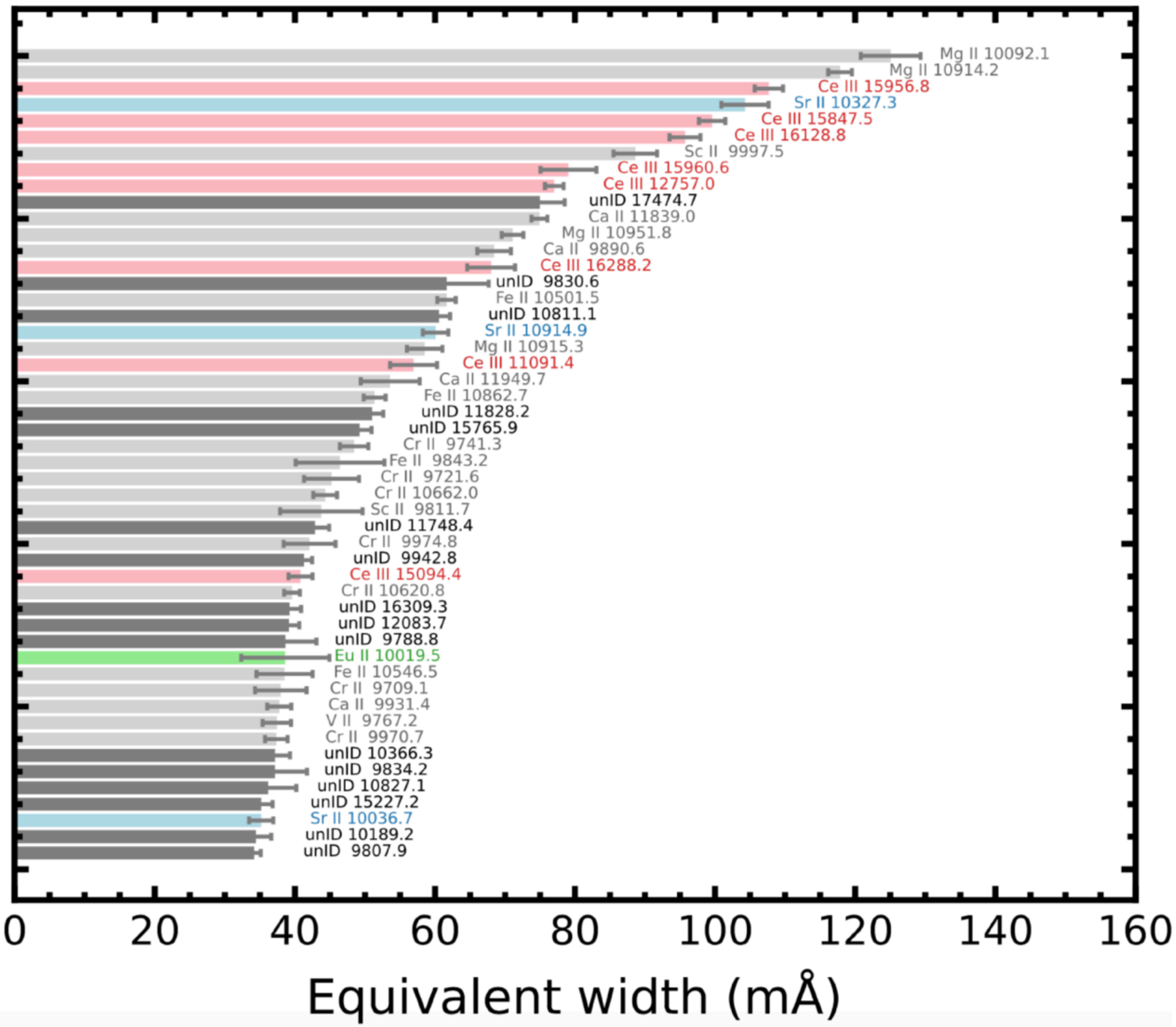
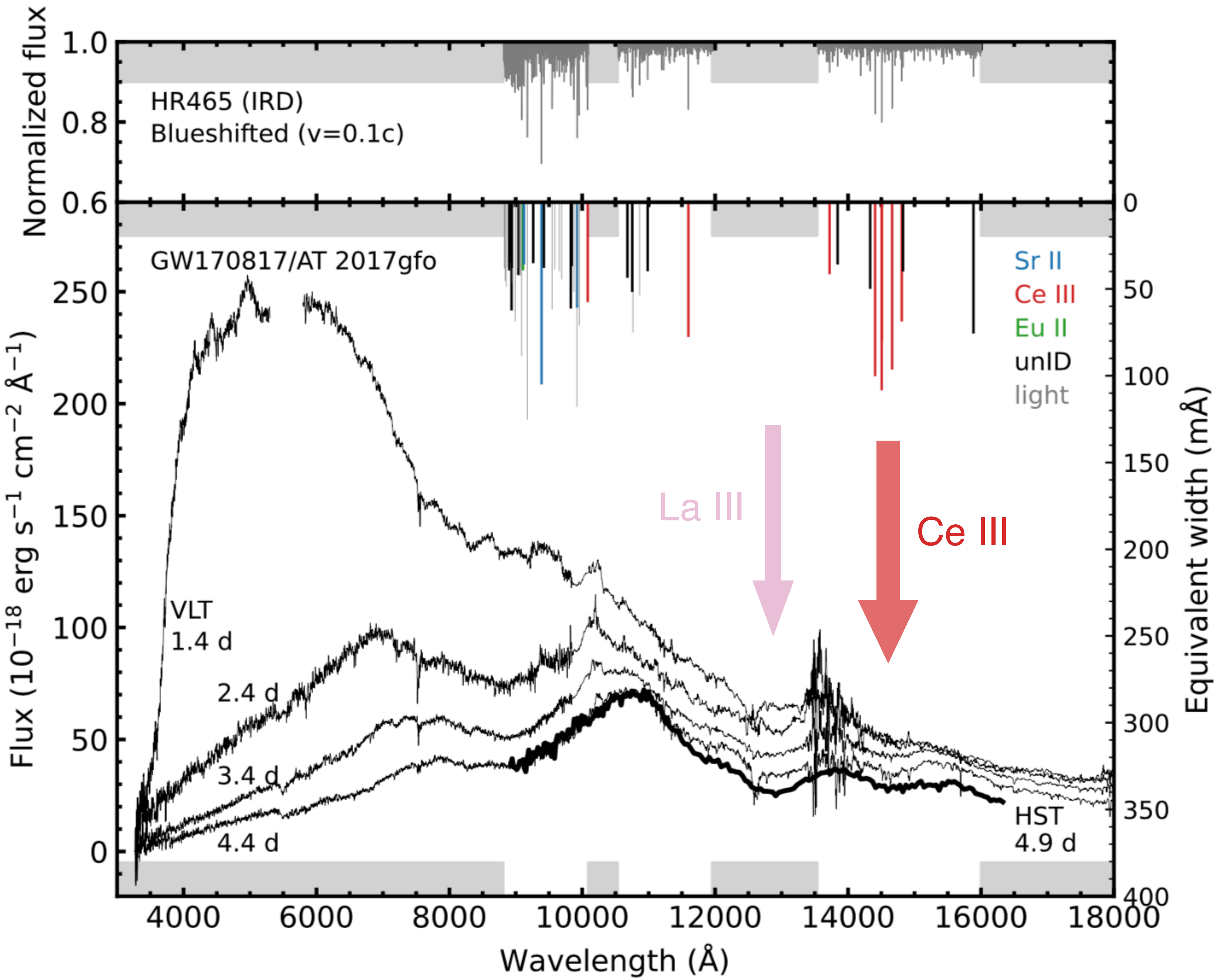


Support identification of Ce



※La III cannot be tested as Ce III due to telluric absorption…

Road to the line identification

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for Ce III…

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(w/ reasonable Doppler shift)
=> Need transition wavelengths ✔

Domoto et al. 2022

Strong lines are expected
(in terms of abundances, ionization, excitation, …)
=> Need transition probabilities ✔

Domoto et al. 2023

No other line can produce the feature
=> Need complete data for strong transitions ✔

Tanaka, Domoto, Aoki, et al. 2023

Line identification

Summary

- Binary neutron star mergers are promising sites for r-process
- R-process has been confirmed by GW170817/AT2017gfo,
  but the detailed abundances synthesized there are not yet
- Want to extract information of elements from the observed spectra
- The observed NIR features in AT2017gfo can be explained by La III and Ce III

- How to make the identification of elements in kilonova firm?
  - List of “complete” strong transitions
    using the Subaru/IRD spectrum of CP star HR 465
    → Sr II, Ce III are the strongest, support identification of Ce in kilonova
  - Want to further confirm it using other CP stars
    having different temperature and abundances (S23B-48N; PI: Domoto → in S24B?)