

Detectability of r-process signatures in JWST kilonova spectra

Multi-Messenger Astrophysics in the Dynamic Universe
Yukawa Institute for Theoretical Physics, Kyoto University
Wednesday 18/02/2026

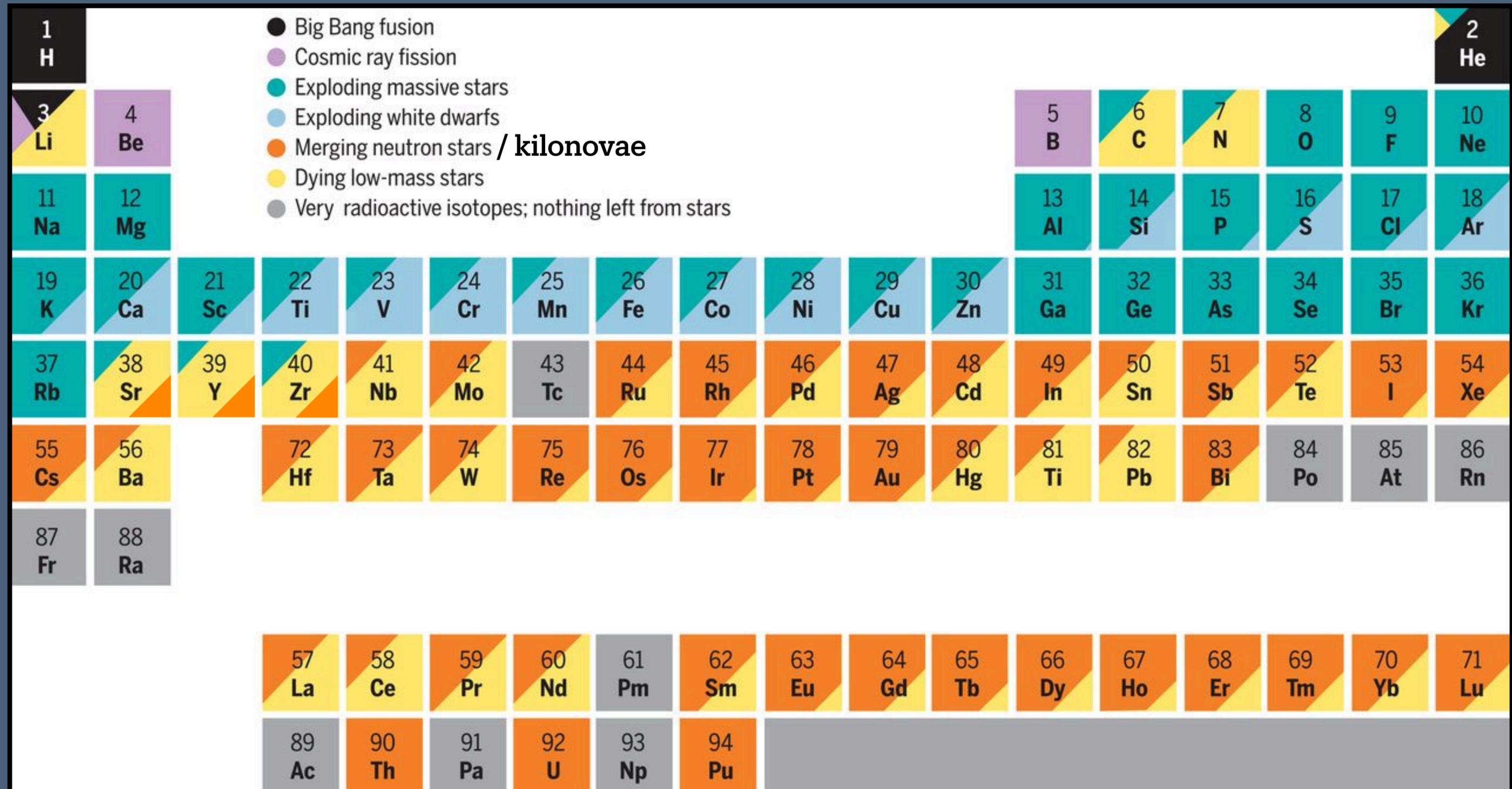
James Gillanders
Postdoctoral Research Assistant
University of Oxford



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OXFORD

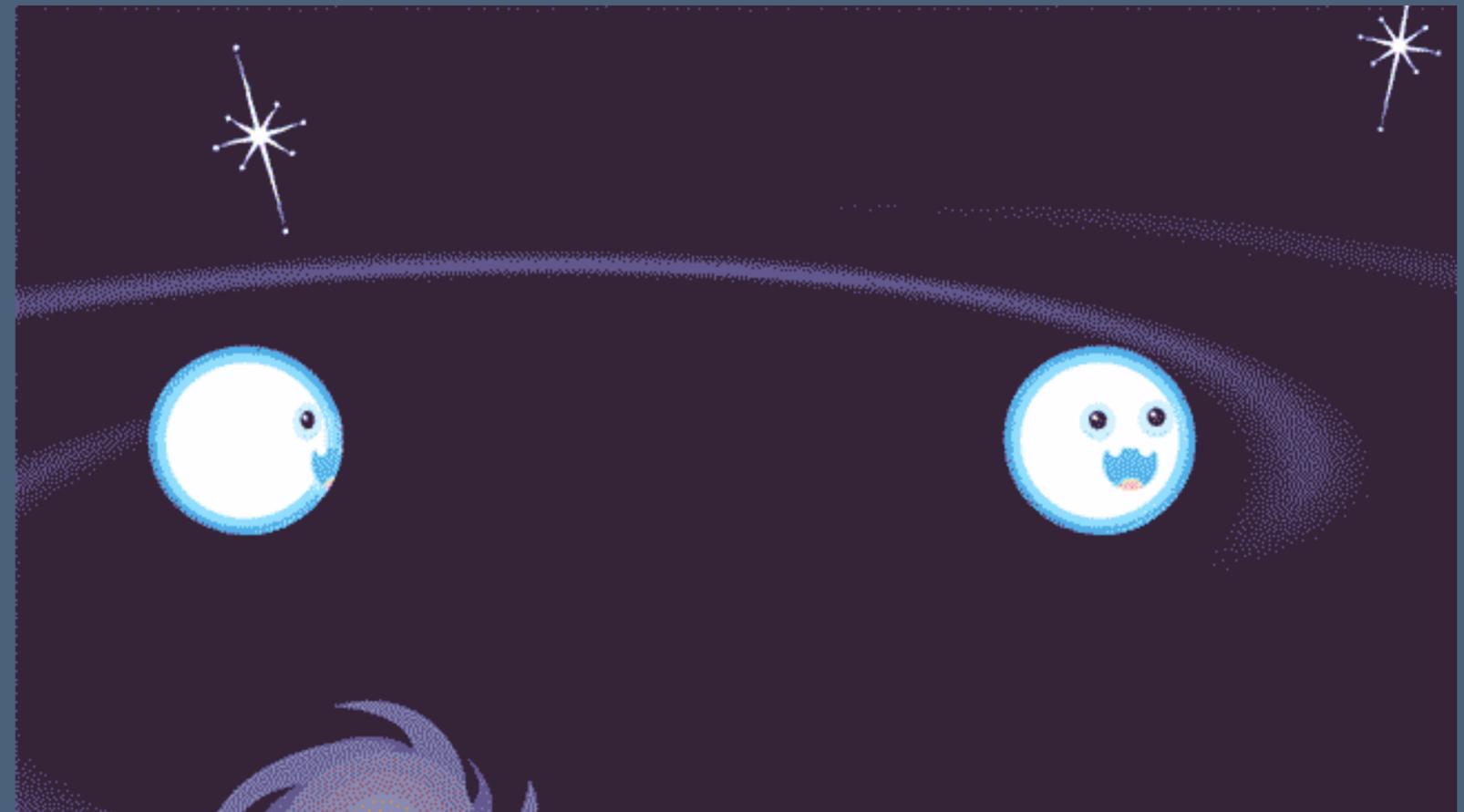
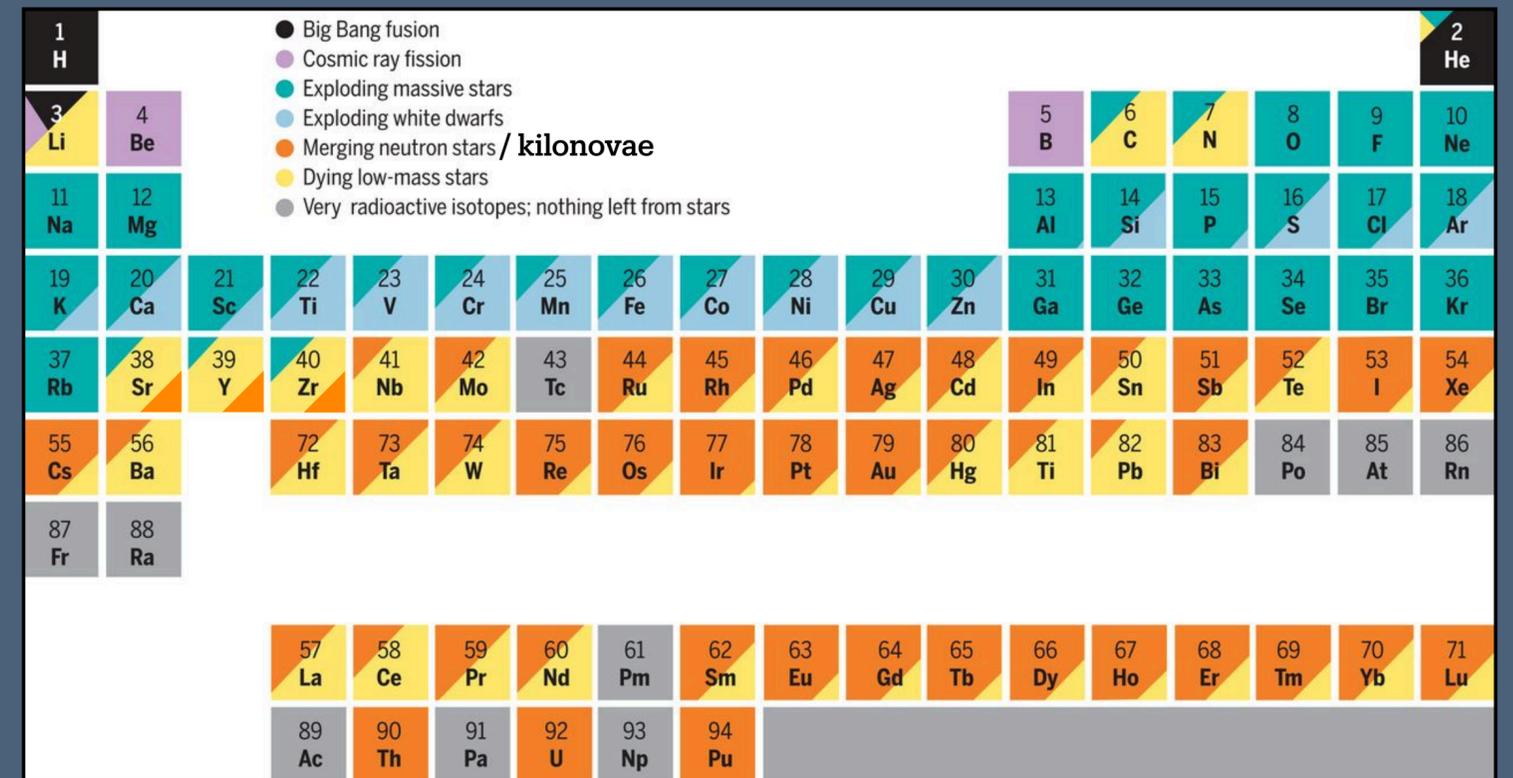
Source of the elements

Johnson2019



Kilonovae

- UV-optical-IR transient associated with neutron star mergers
- Powered by the radioactive decay of freshly synthesised r-process isotopes
- Only known source of r-process elements in the Universe
- Produce detectable gravitational wave and electromagnetic wave signals



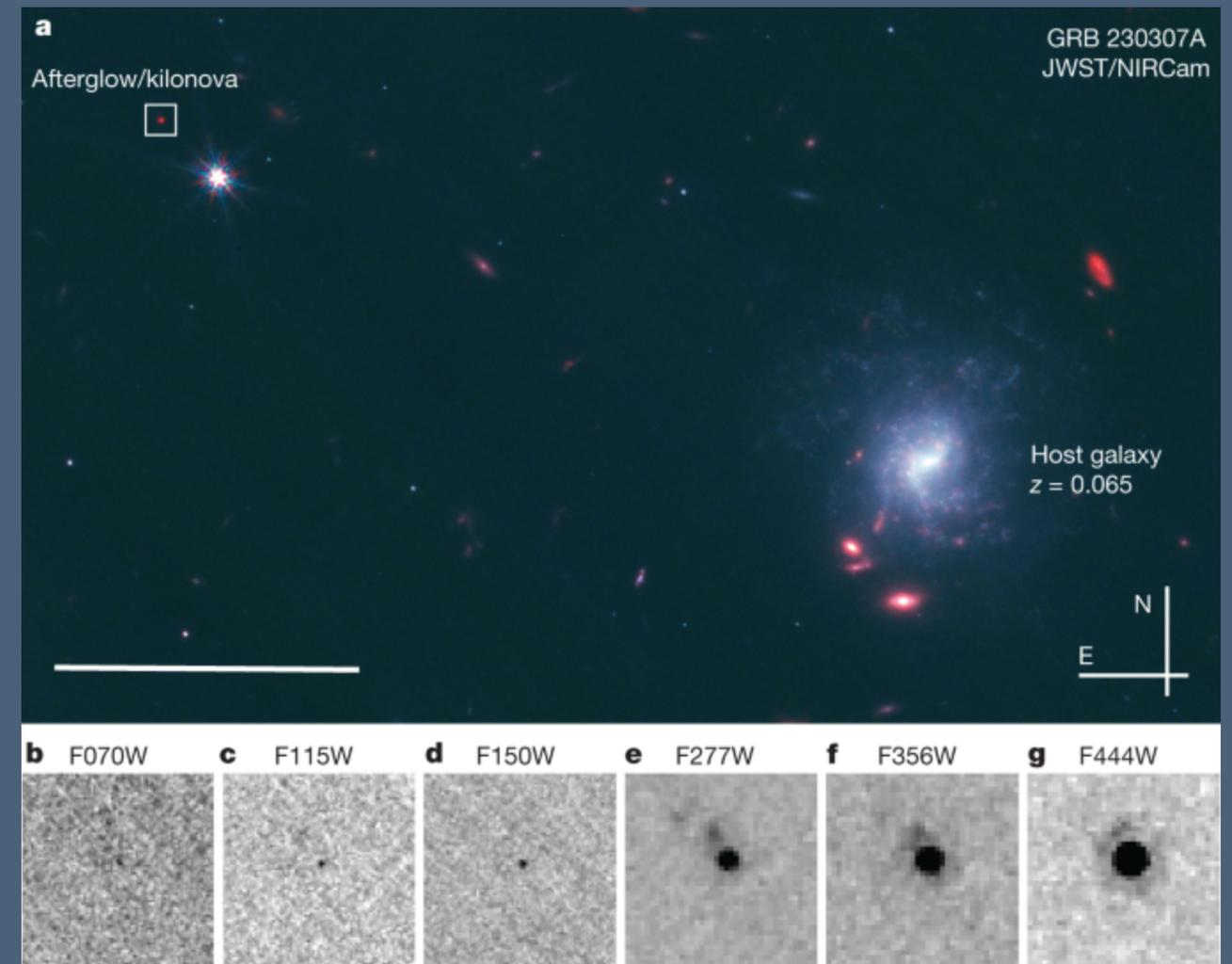
(Spectroscopically) Observed kilonovae

1. GW170817 / GRB170817A / AT2017gfo
 - Discovered through GWs and a GRB
 - 40 Mpc distant

2. GRB230307A / AT2023vfi
 - Discovered through a GRB
 - 300 Mpc distant
 - James Webb Space Telescope observations



ESO

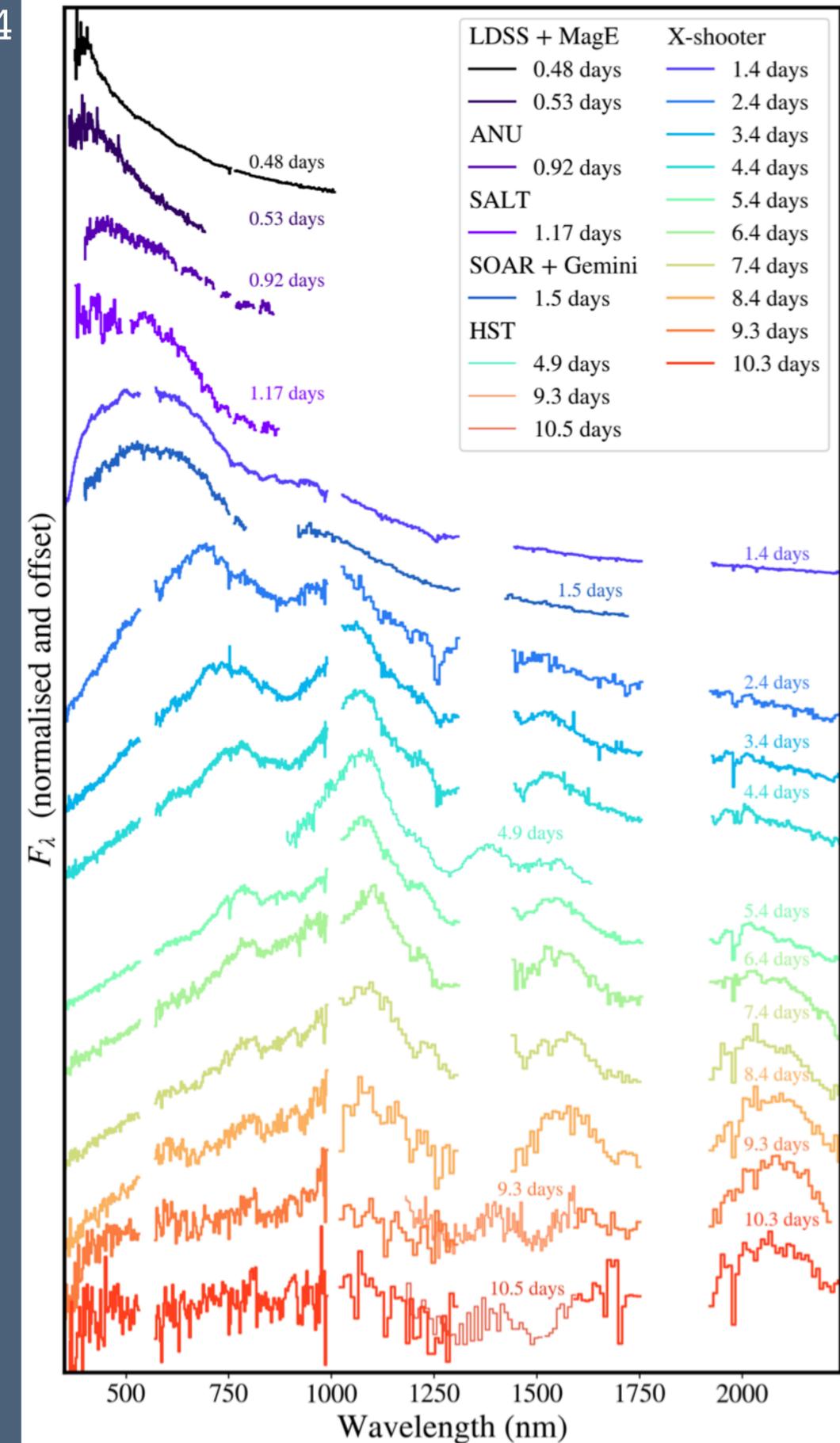
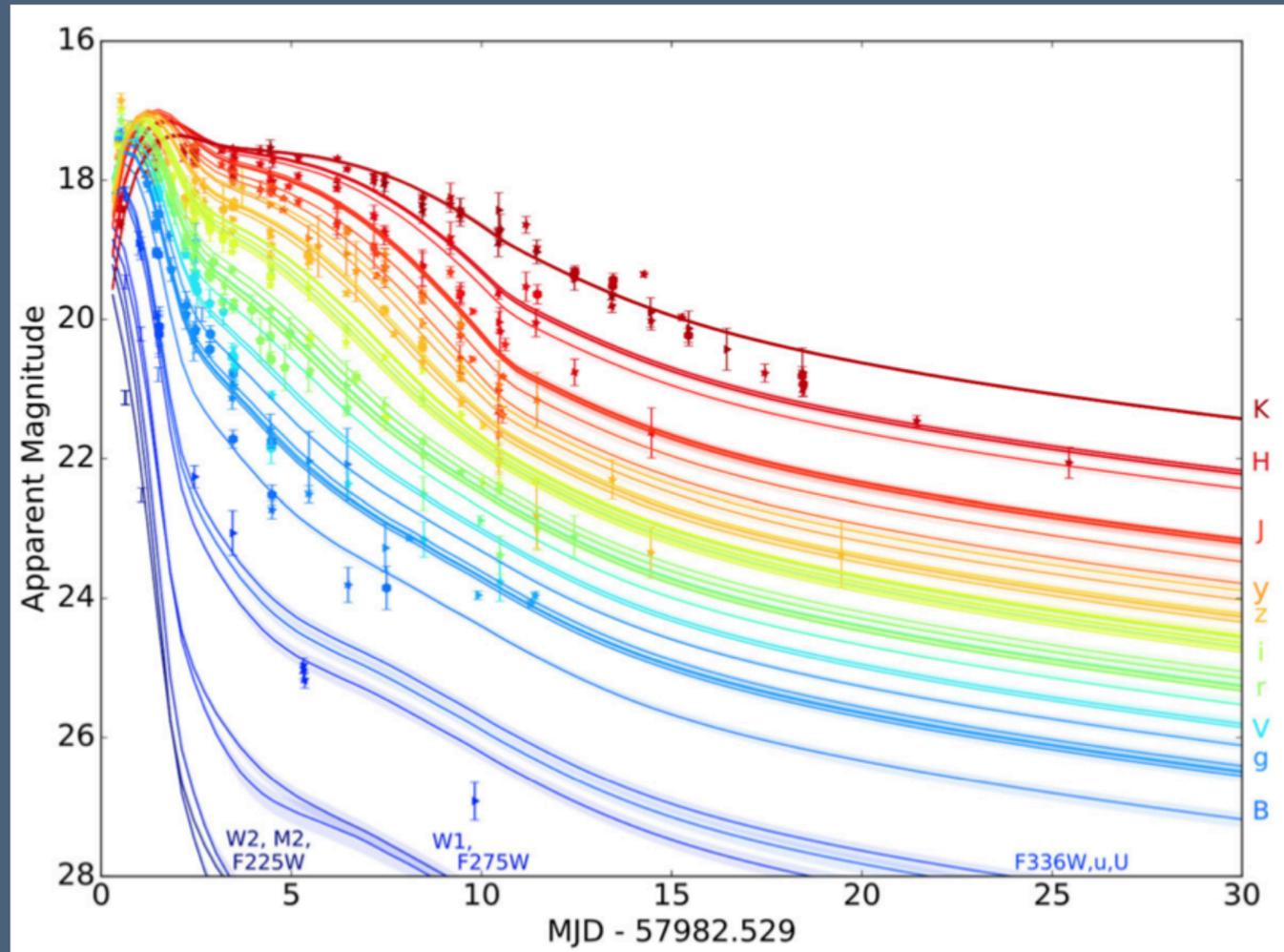


Levan+2024

AT2017gfo

- Photometry:
 - UV — IR
 - 0.45 — 30 days
- Spectroscopy:
 - UV — IR ($\sim 0.3 - 2.5 \mu\text{m}$)
 - 0.5 — 11 days

Villar+2017

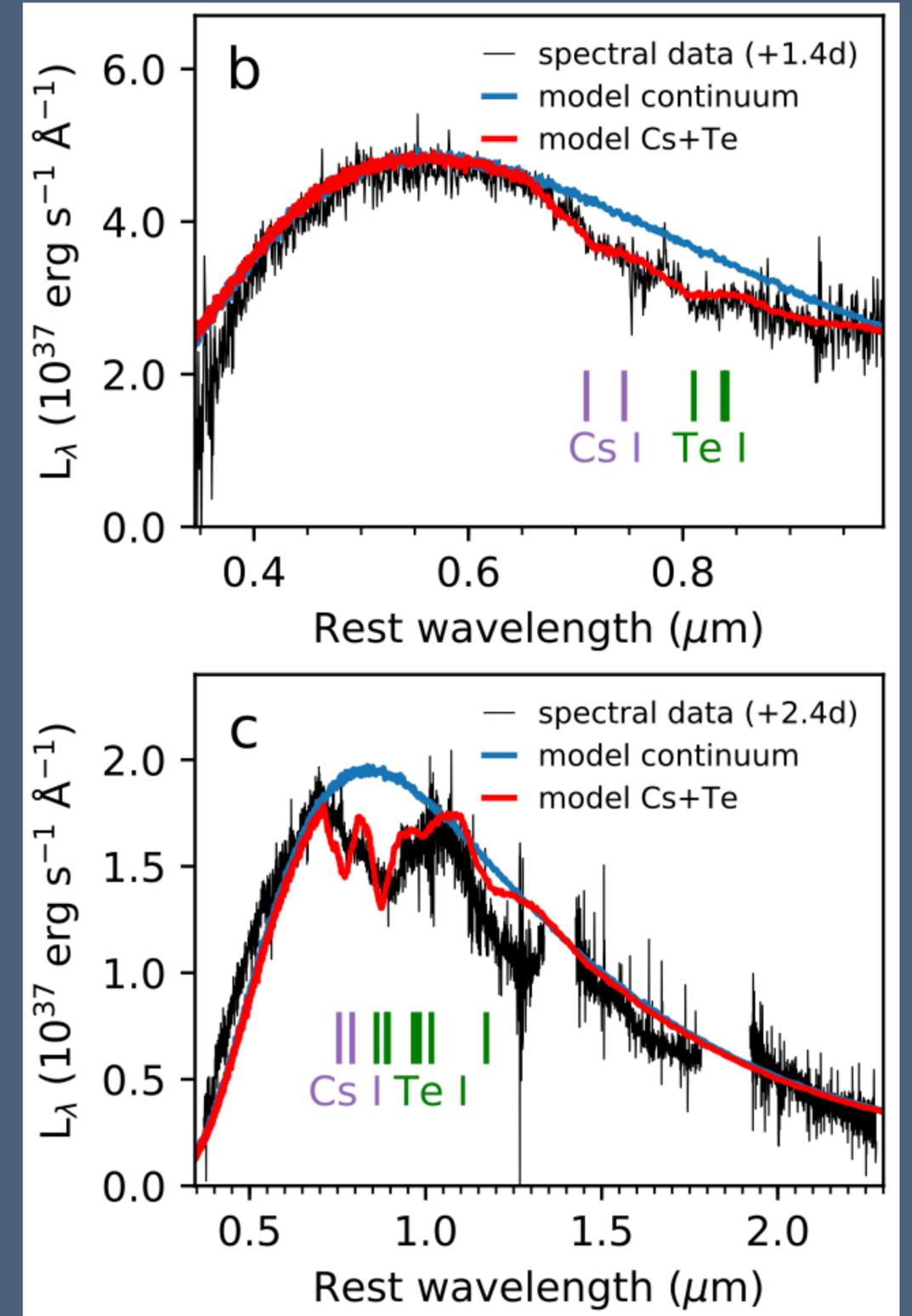


AT2017gfo

- Spectral modelling works (some examples; NOT COMPLETE!)

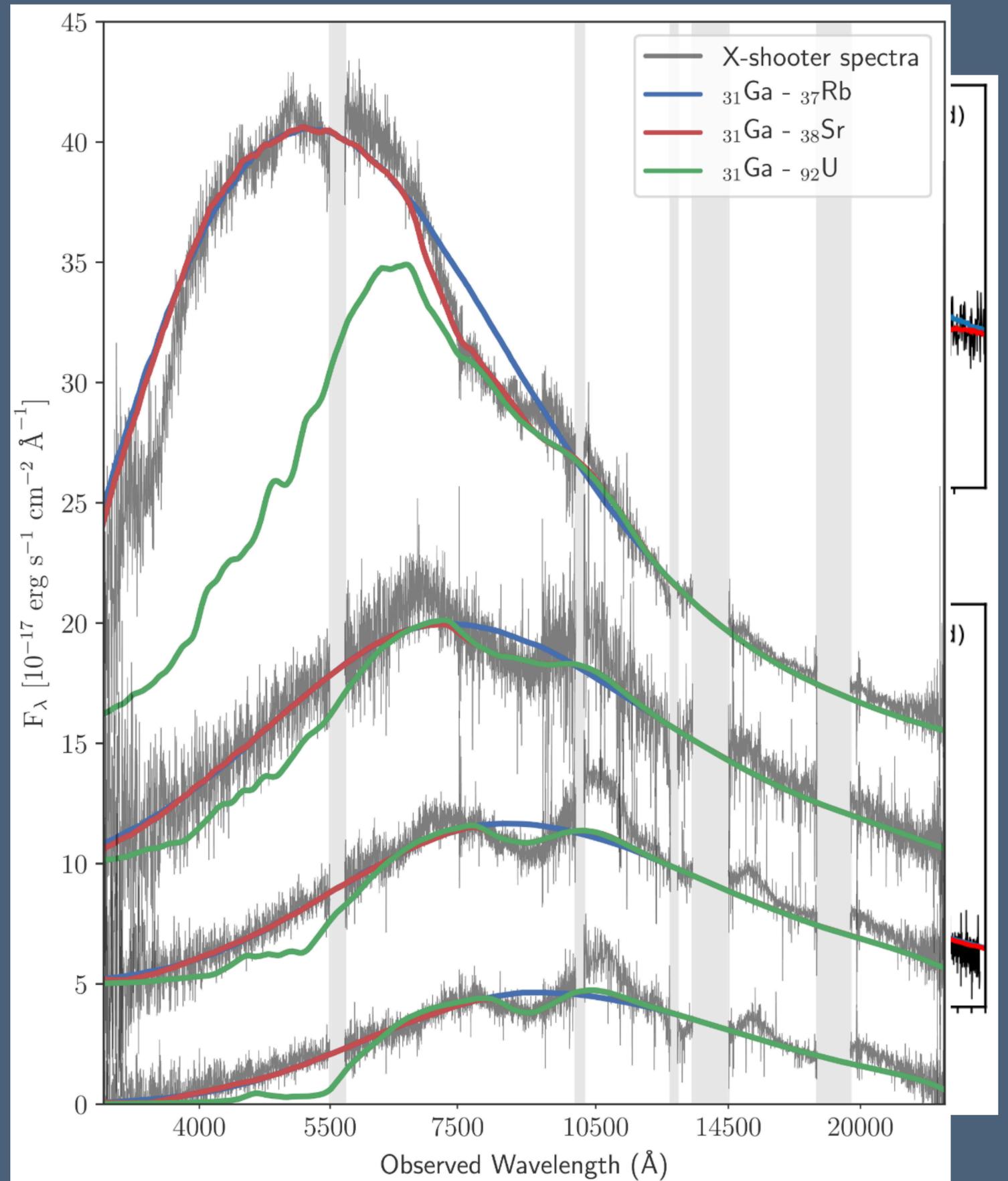
AT2017gfo

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 - Smartt+2017



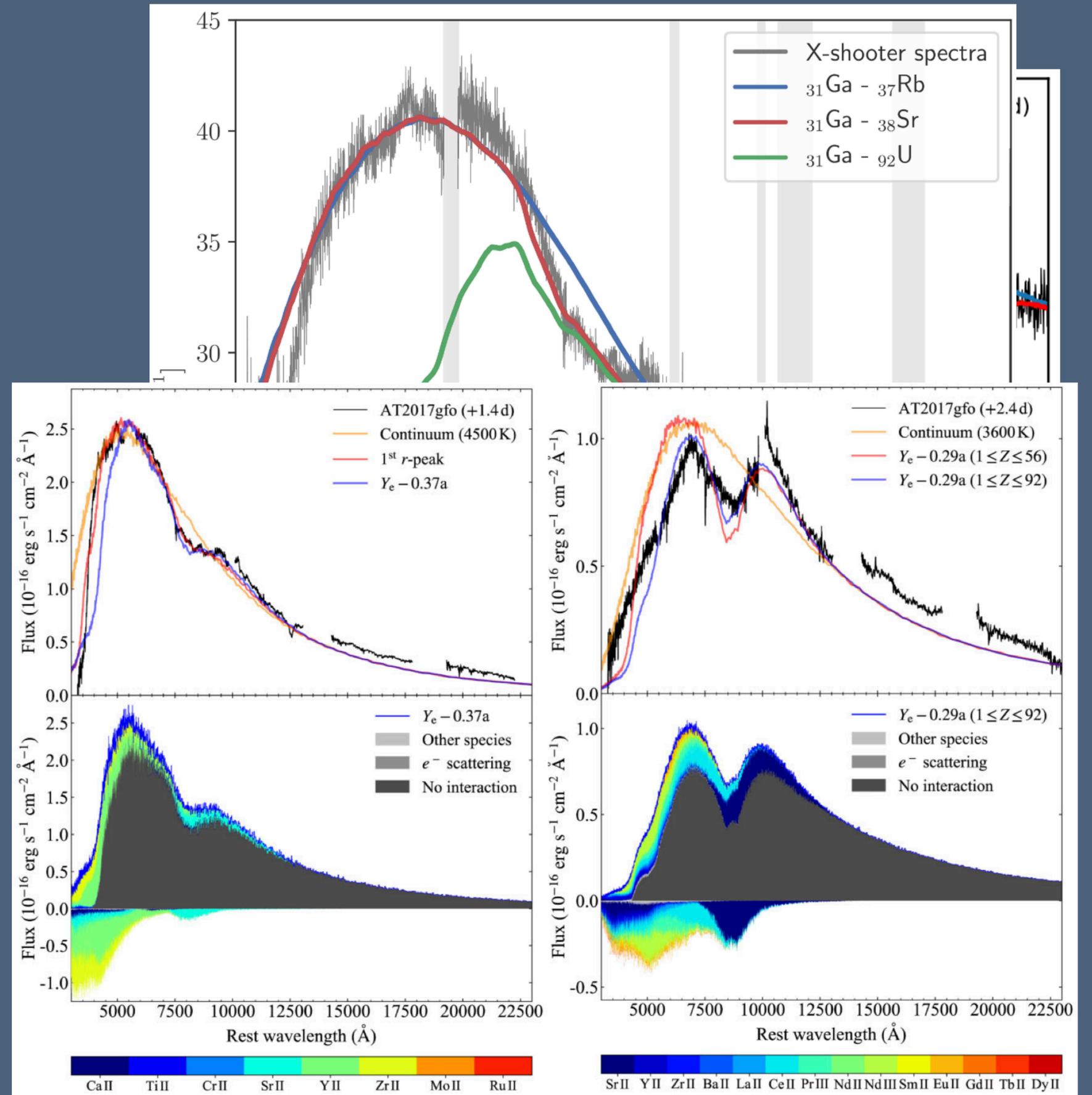
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 - Watson+2019



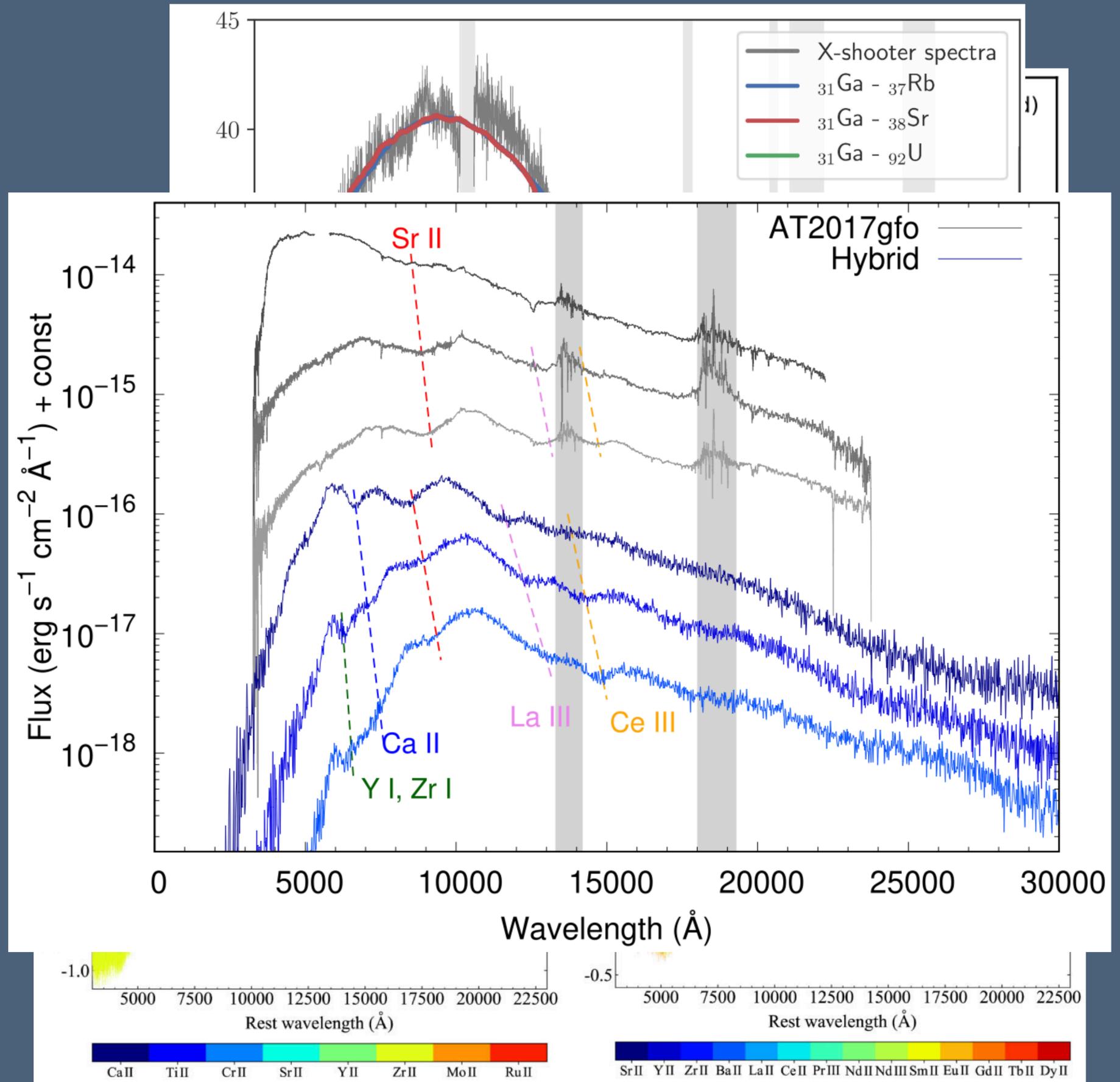
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 - Gillanders+2022



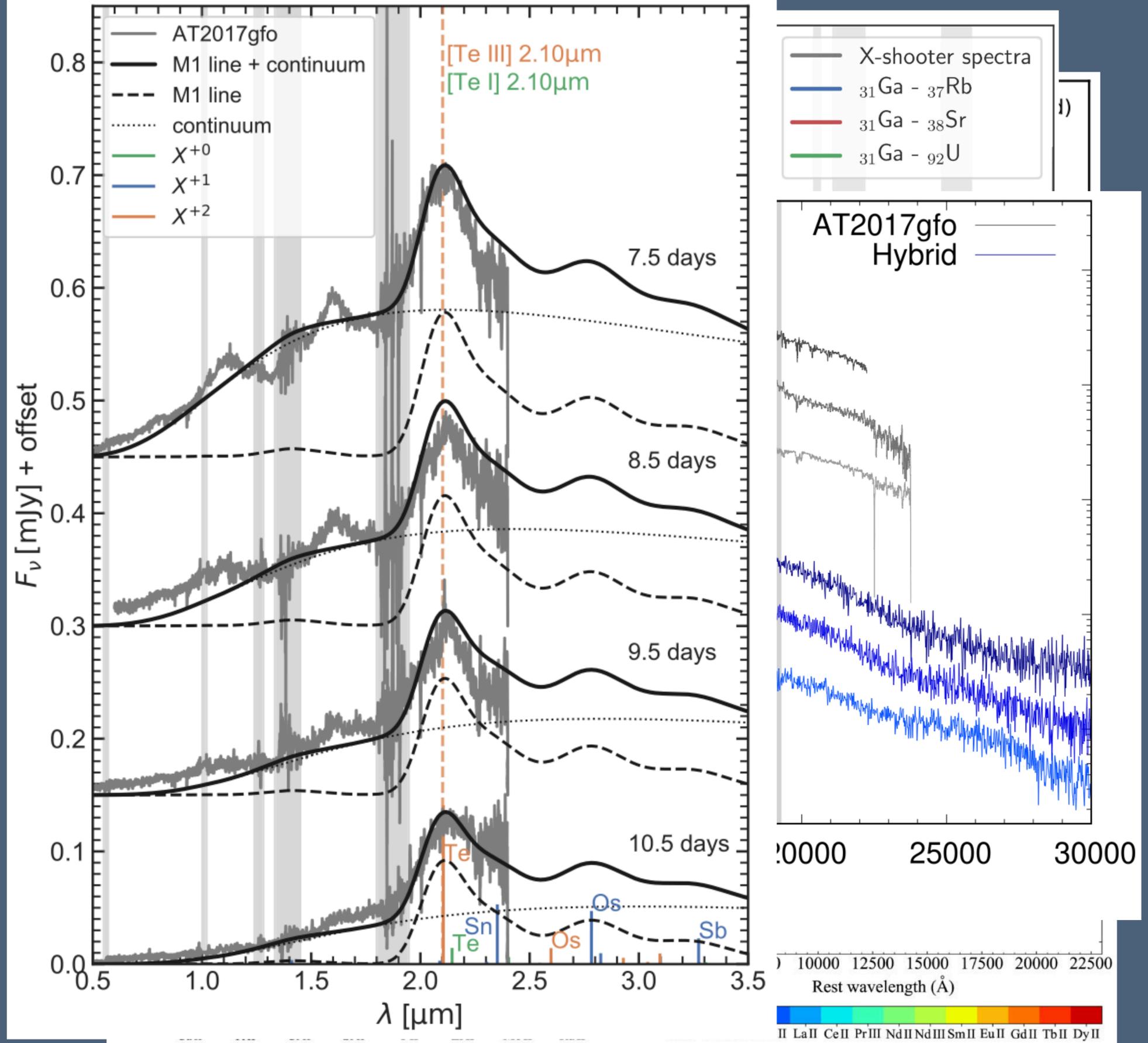
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 - Domoto+2022



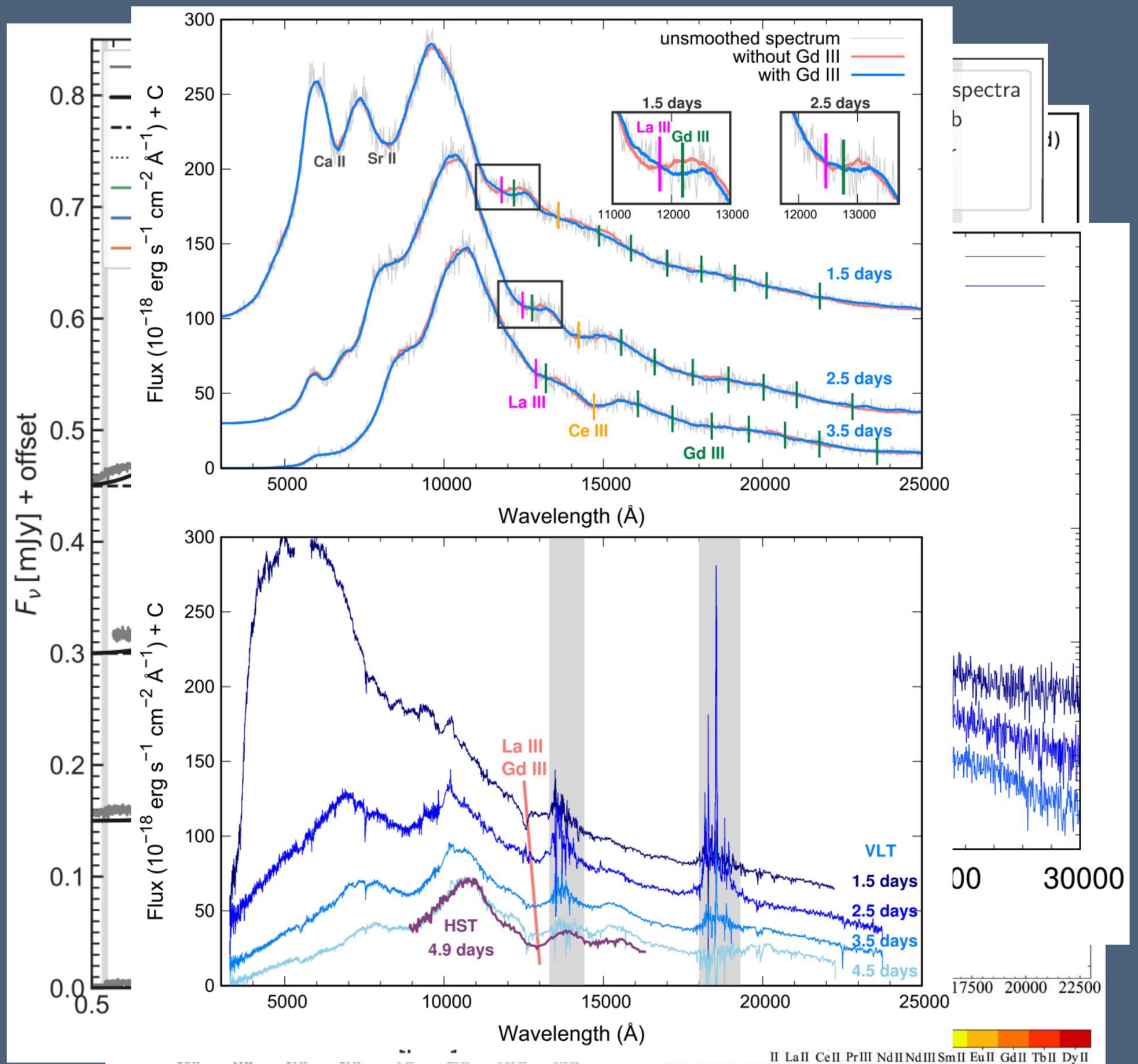
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 - Hotokezaka+2023



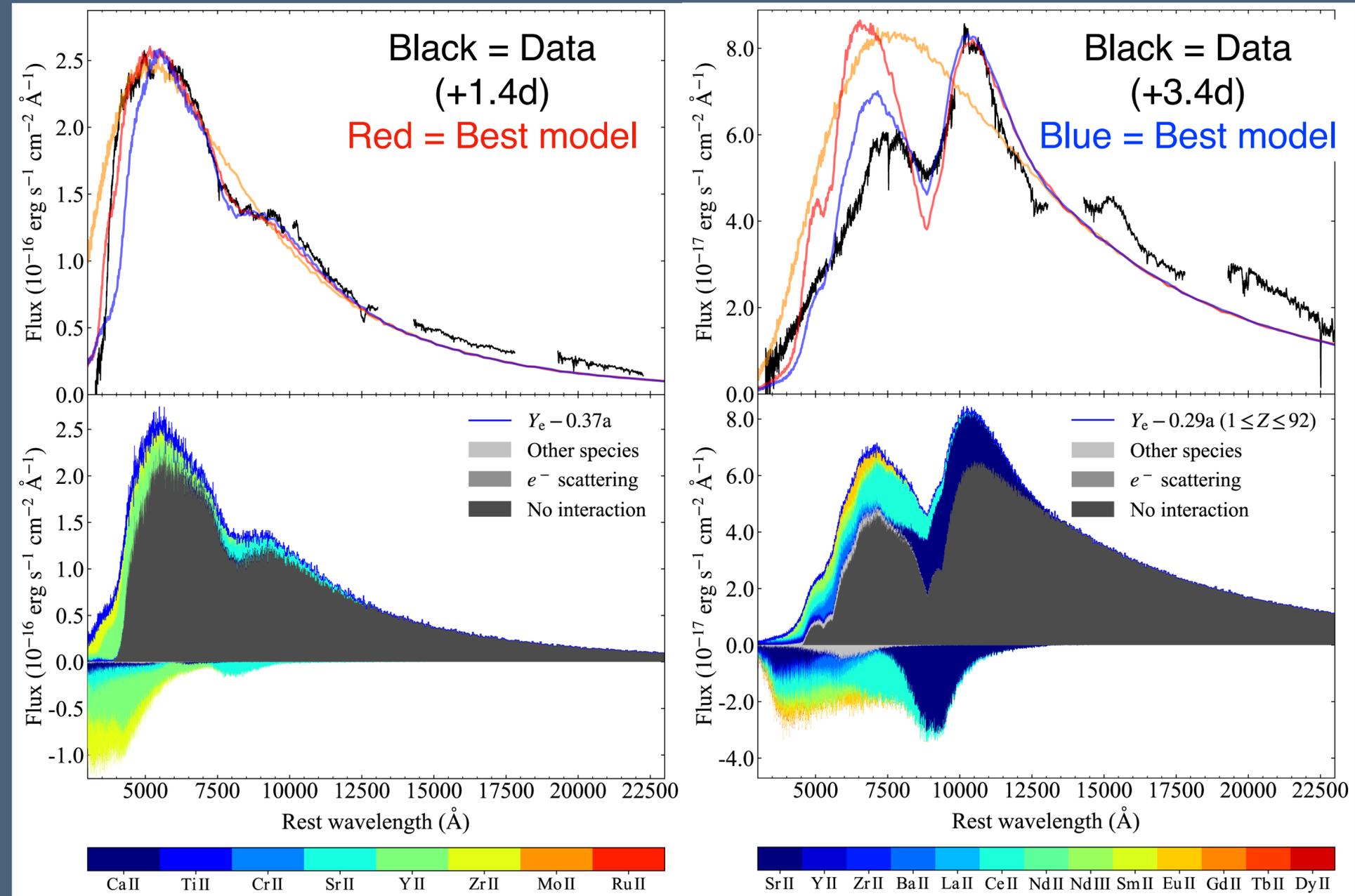
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 - Hotokezaka+2023
 - Rahmouni+2025



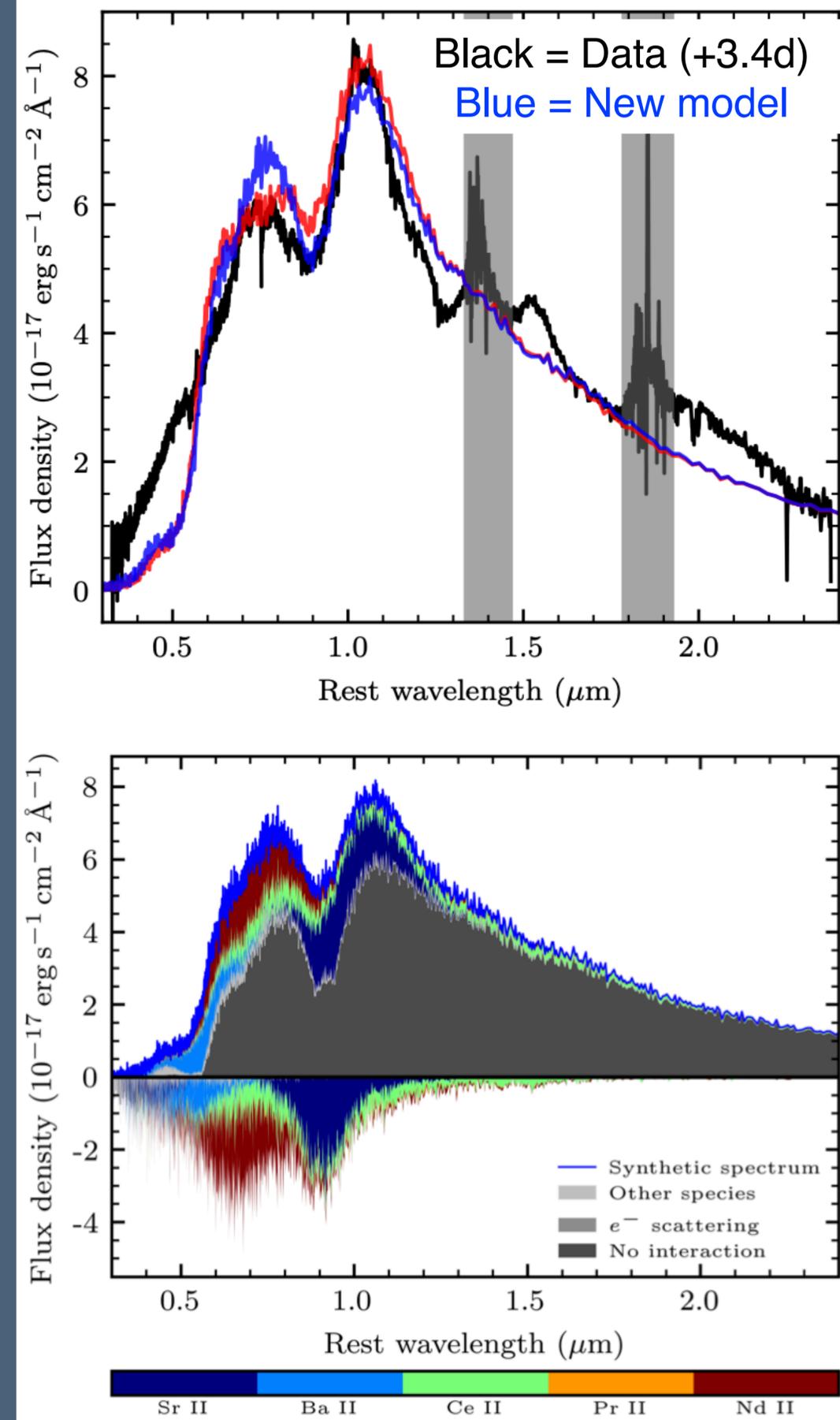
Spectral modelling

- We use the radiative transfer code TARDIS combined with realistic composition profiles from a merger simulation
- At +1.4 days, the model composition is dominated by first r-process peak
- Subsequent phases require a different composition: first r-peak AND heavier lanthanide elements (mass fraction of ~5%)



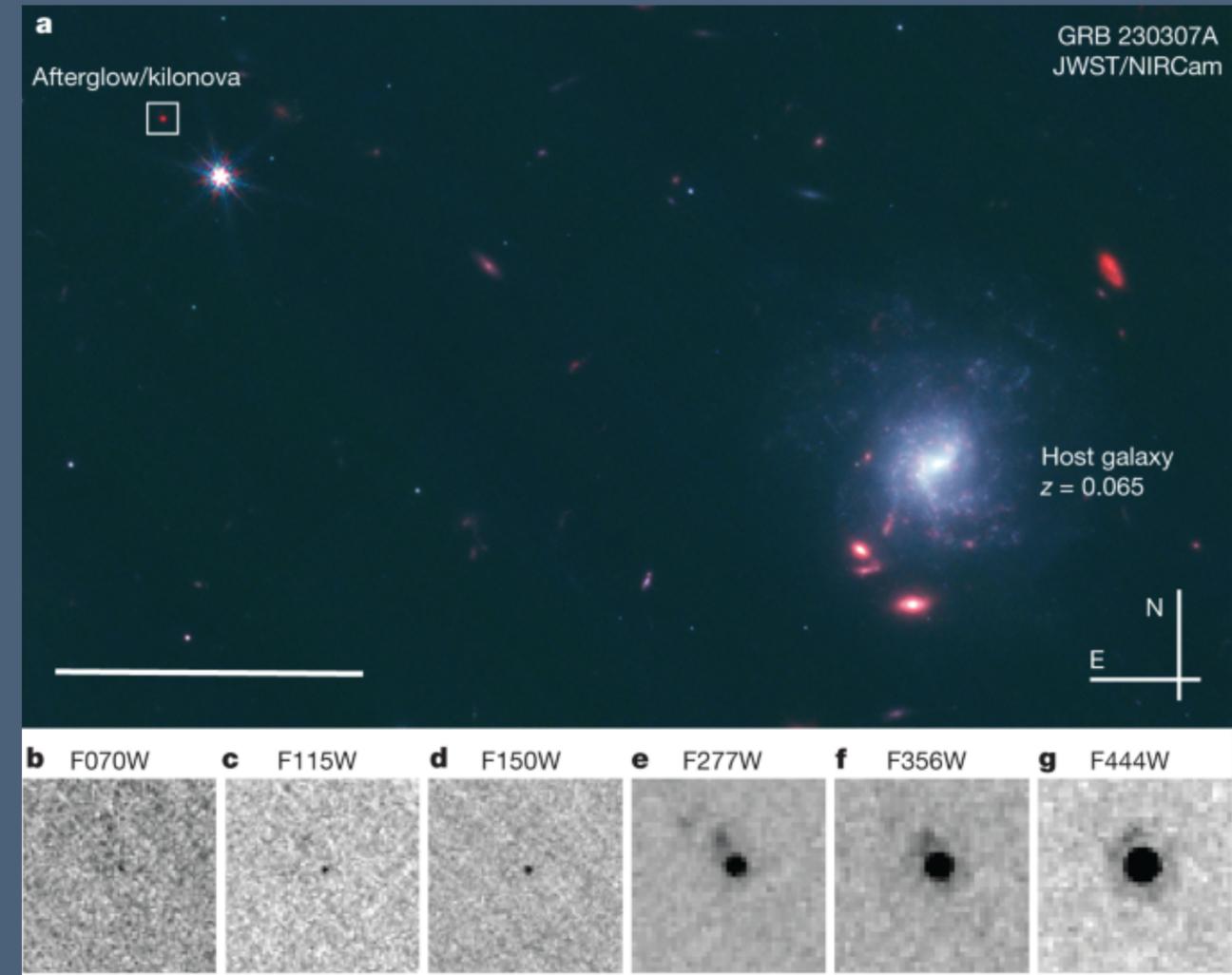
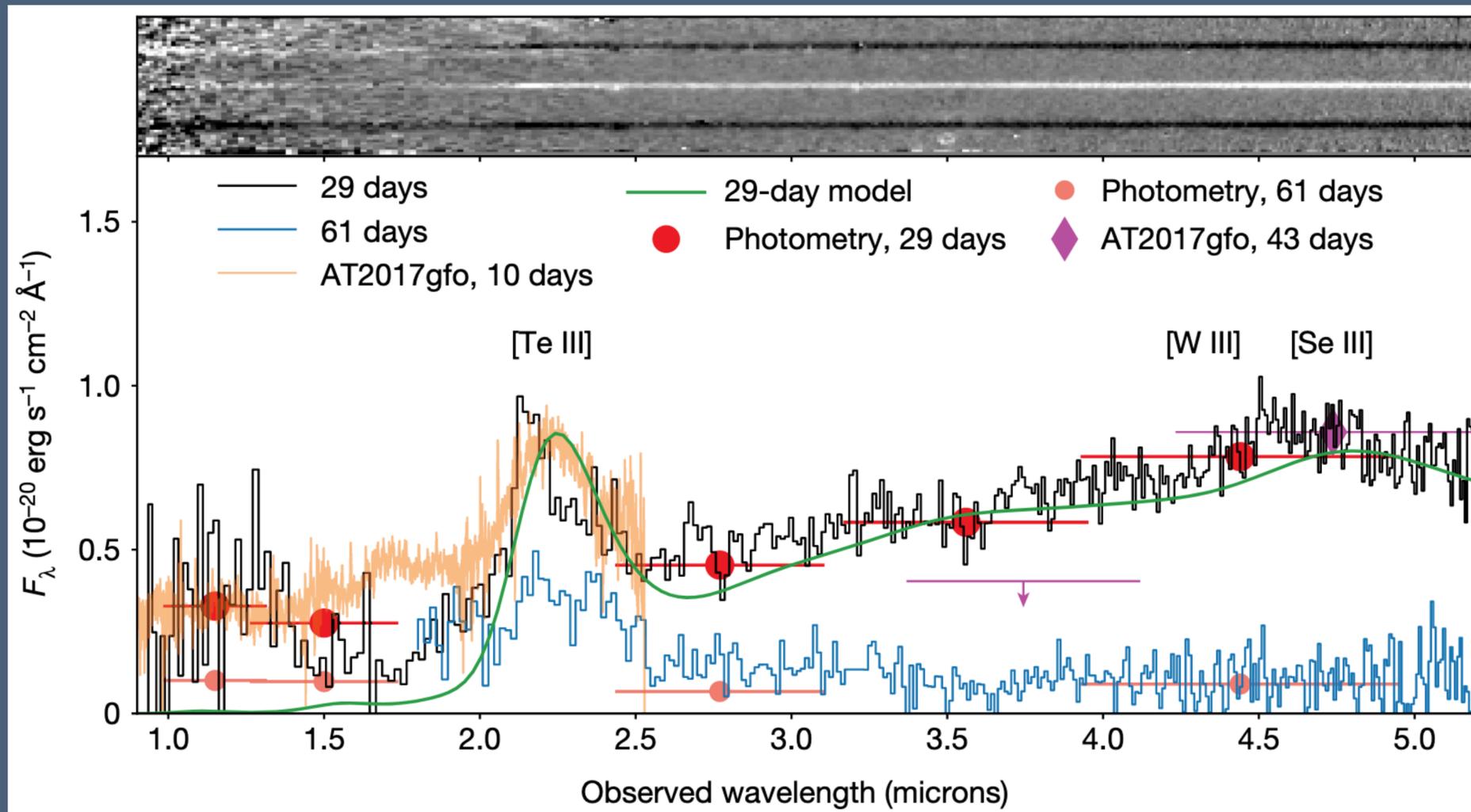
Spectral modelling

- Same study as Gillanders+2022, but with inclusion of improved lanthanide atomic data from Flörs+2025
- Better characterisation of overall opacity contribution
- New lanthanide mass fraction estimate: $\sim 0.25\%$



AT2023vfi

- Just the second spectroscopically confirmed kilonova!
- Two epochs of imaging + spectroscopy with JWST

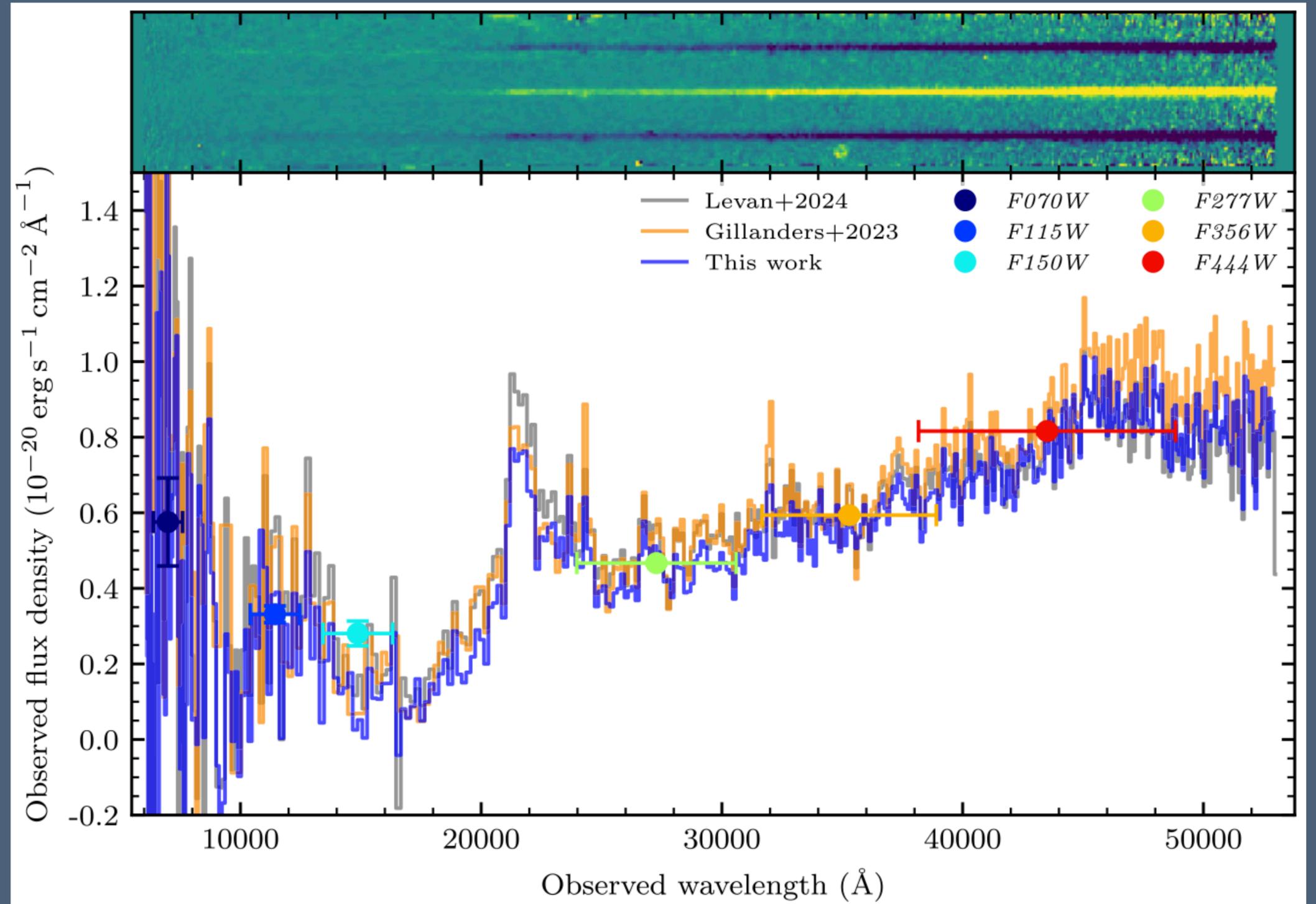


Levan+2024

AT2023vfi

Gillanders+Smartt2025

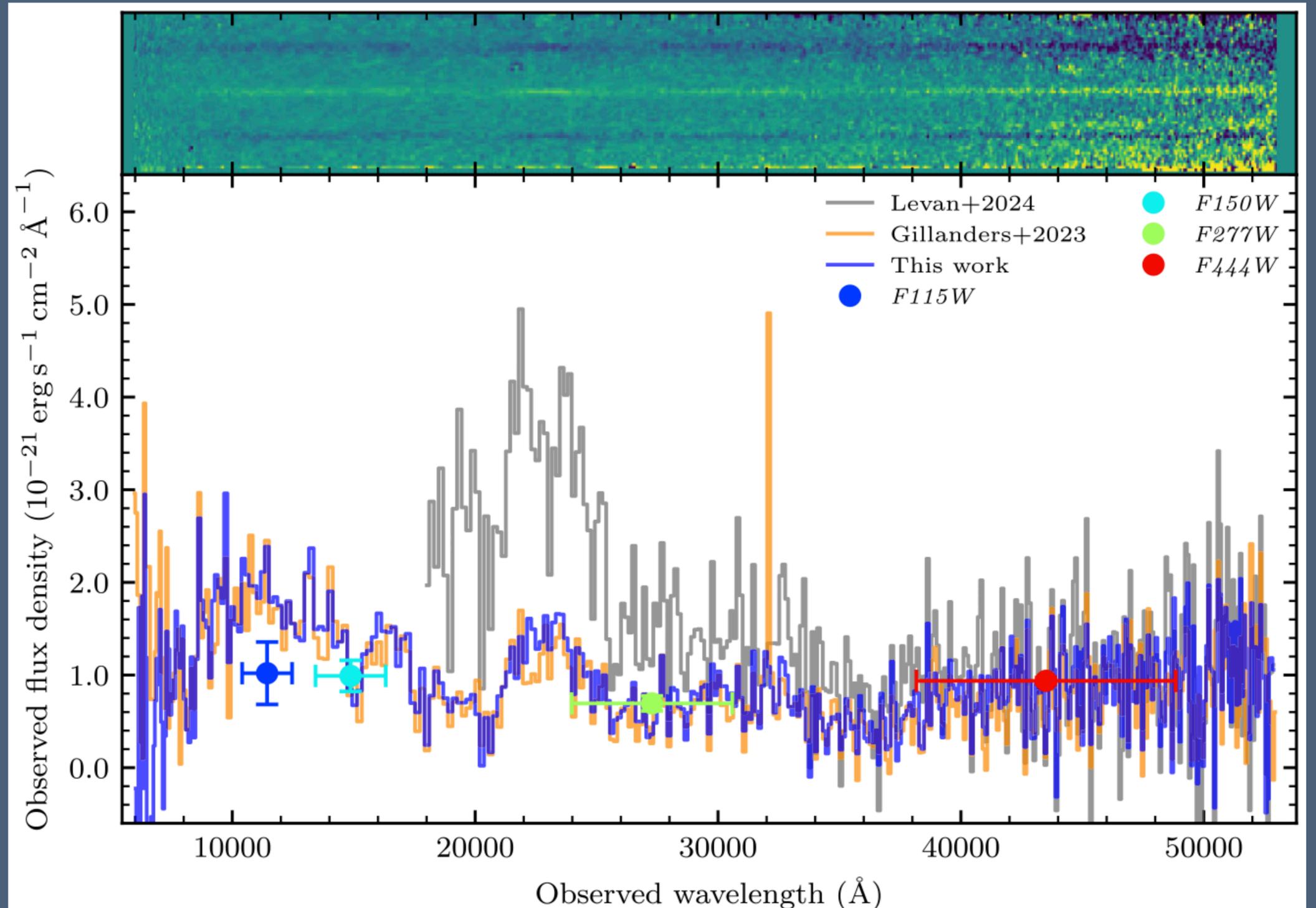
- Two JWST spectra obtained @ 29, 61 days
- Optimal reduction, extraction + calibration to maximise science utility



AT2023vfi

Gillanders+Smartt2025

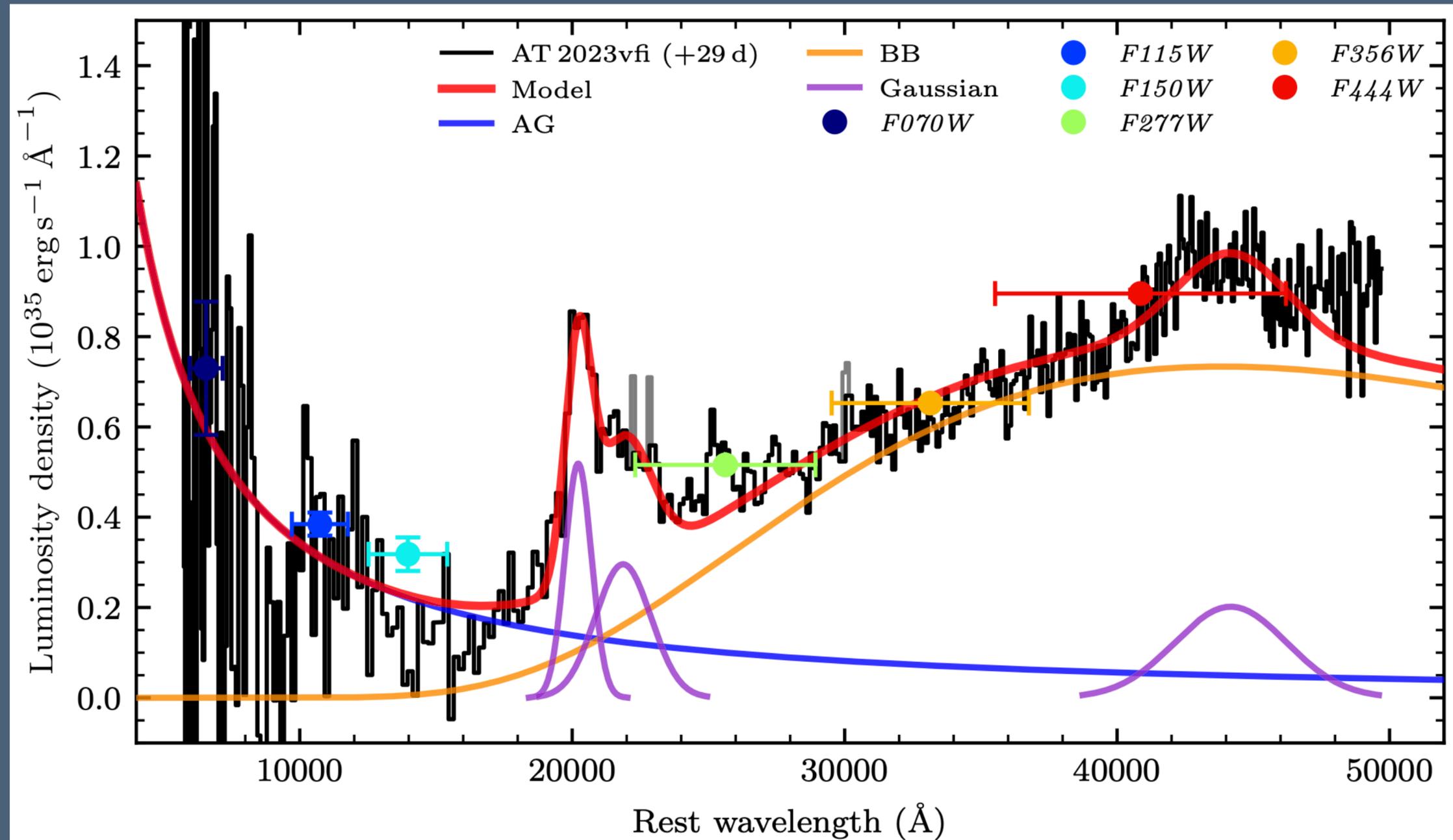
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AT2023vfi

Gillanders+Smartt2025

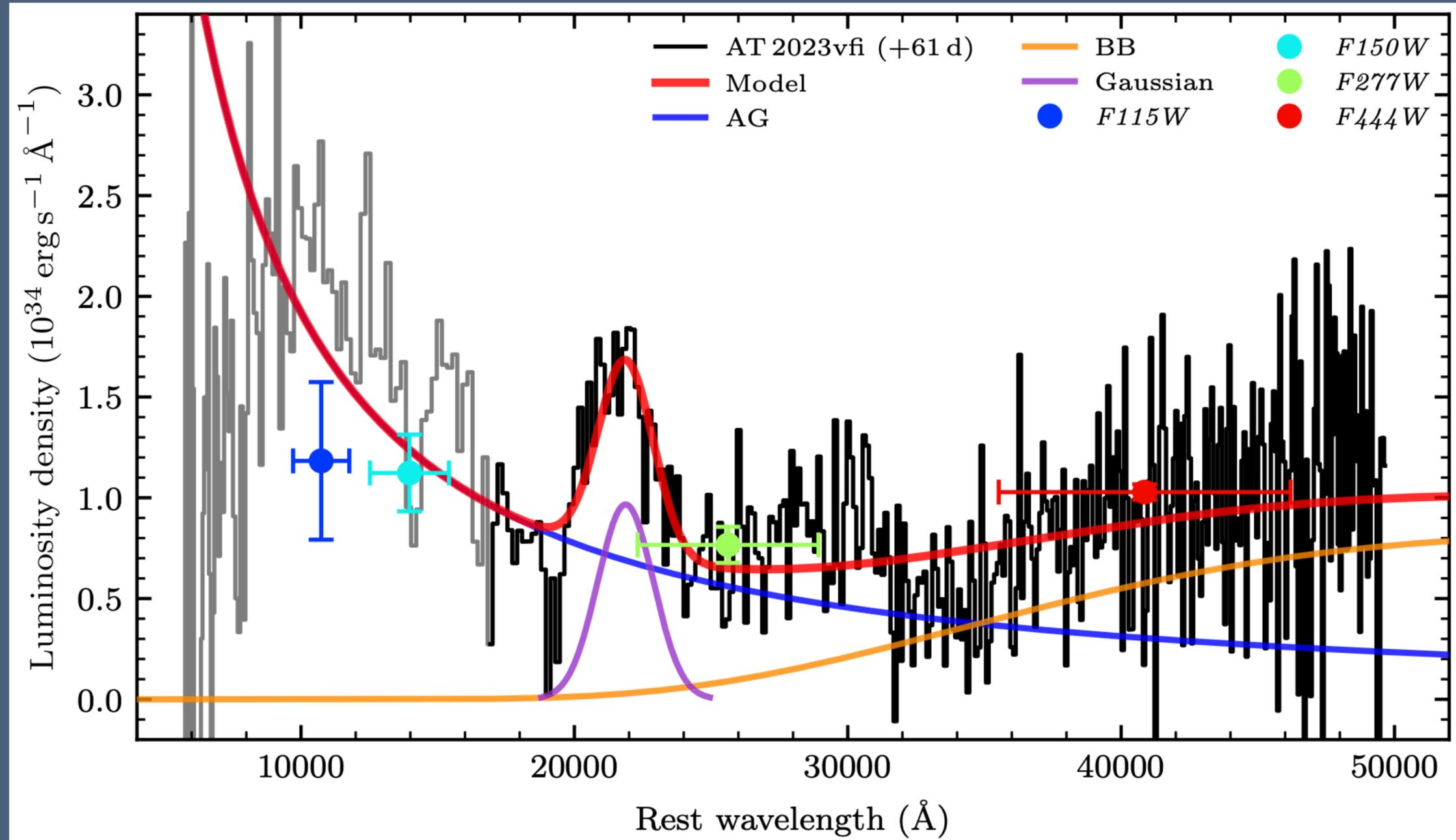
- Fit the data with simple empirical models
 - Afterglow + blackbody + emission feature(s)
- Many candidate line IDs spanning all three r-process peaks (Te, Ce, Er, W, Os, Pt)



AT2023vfi

Gillanders+Smartt2025

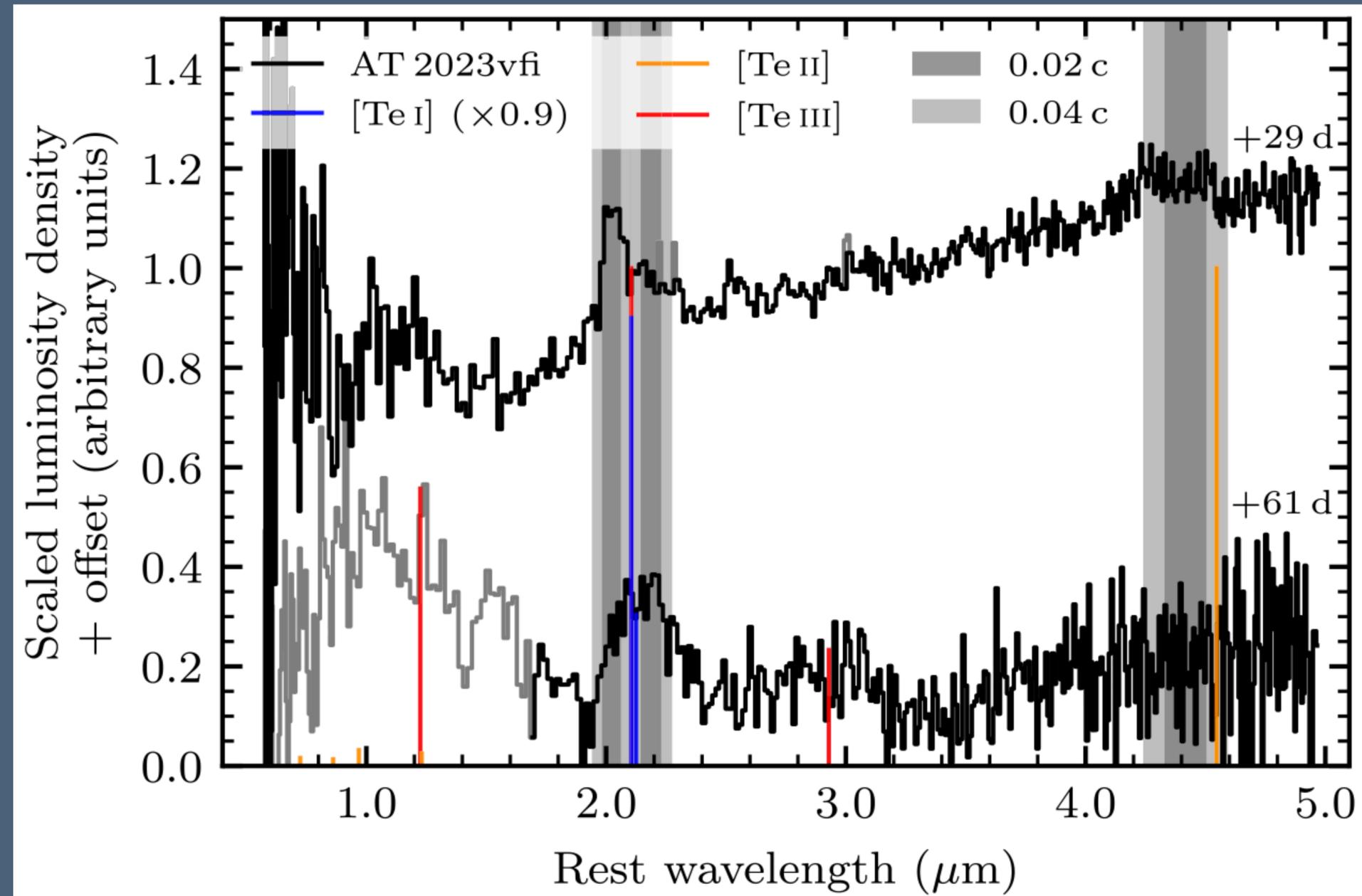
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Leading candidate line ID: [Te III]

Gillanders+Smartt2025

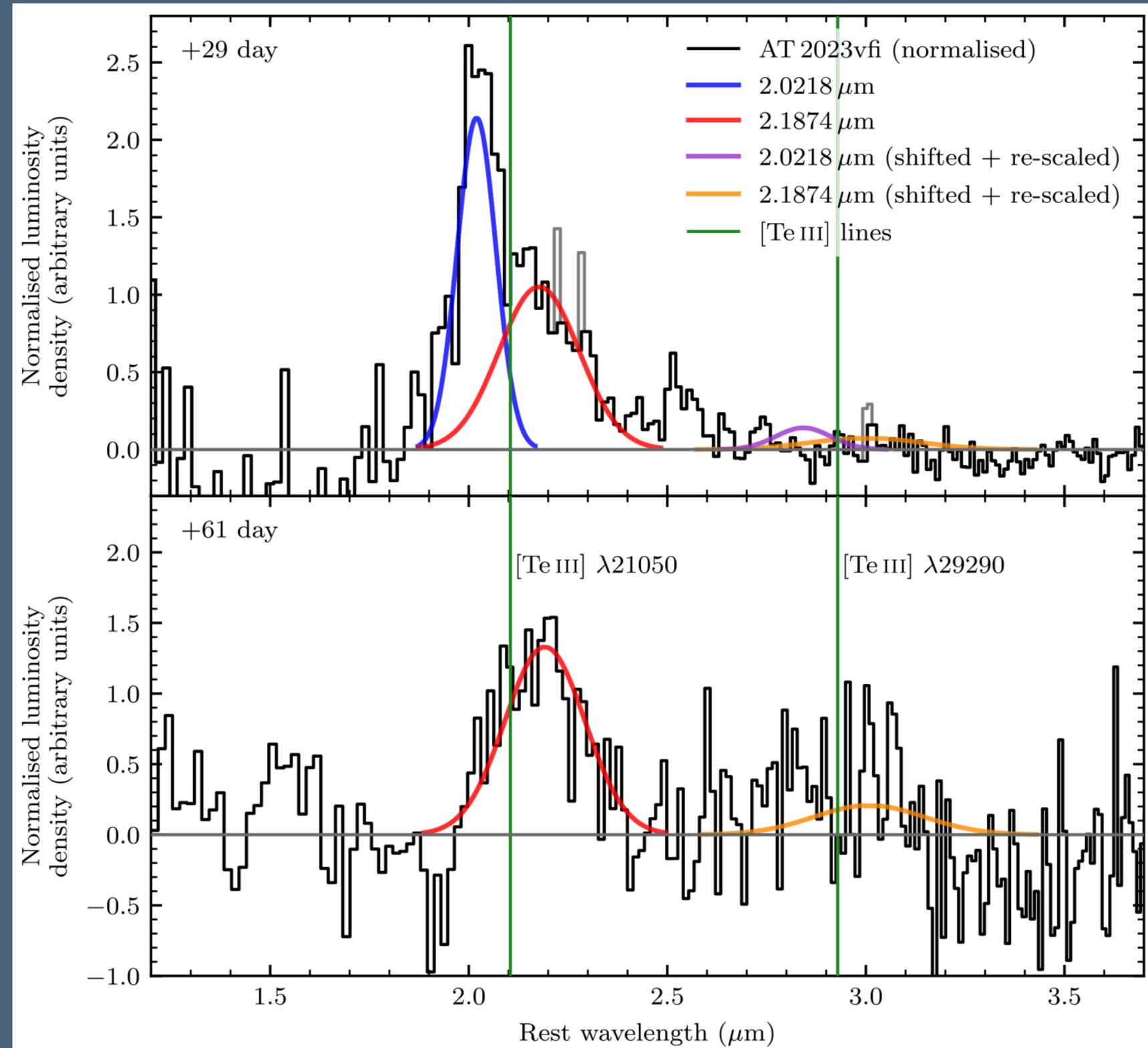
- [Te I] $\lambda 21049$, [Te II] $\lambda 45466$, [Te III] $\lambda 21050$ lines all $\approx 0.04 c$ offset from emission features
 - Inhomogeneous distribution?
 - Opacity effects?
 - Blended with other species?



Detectability of other [Te III] lines

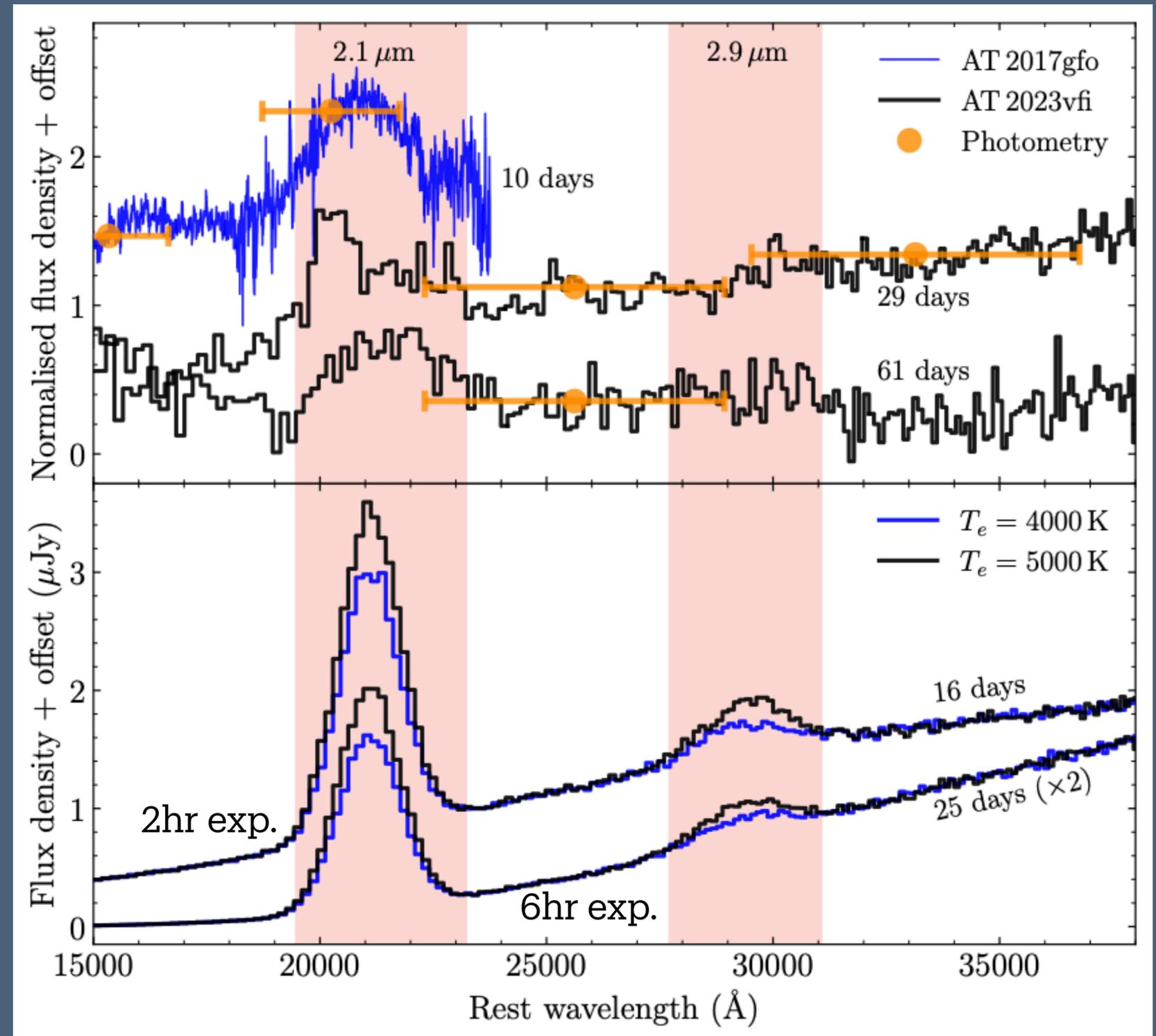
Gillanders+Smartt2025

- What about other [Te III] lines?
Are they detectable?
 - Strongest: $\lambda_{\text{vac}} = 21050 \text{ \AA}$
 - Next strongest: $\lambda_{\text{vac}} = 29290 \text{ \AA}$
- Not observable in AT2023vfi, but maybe next time?

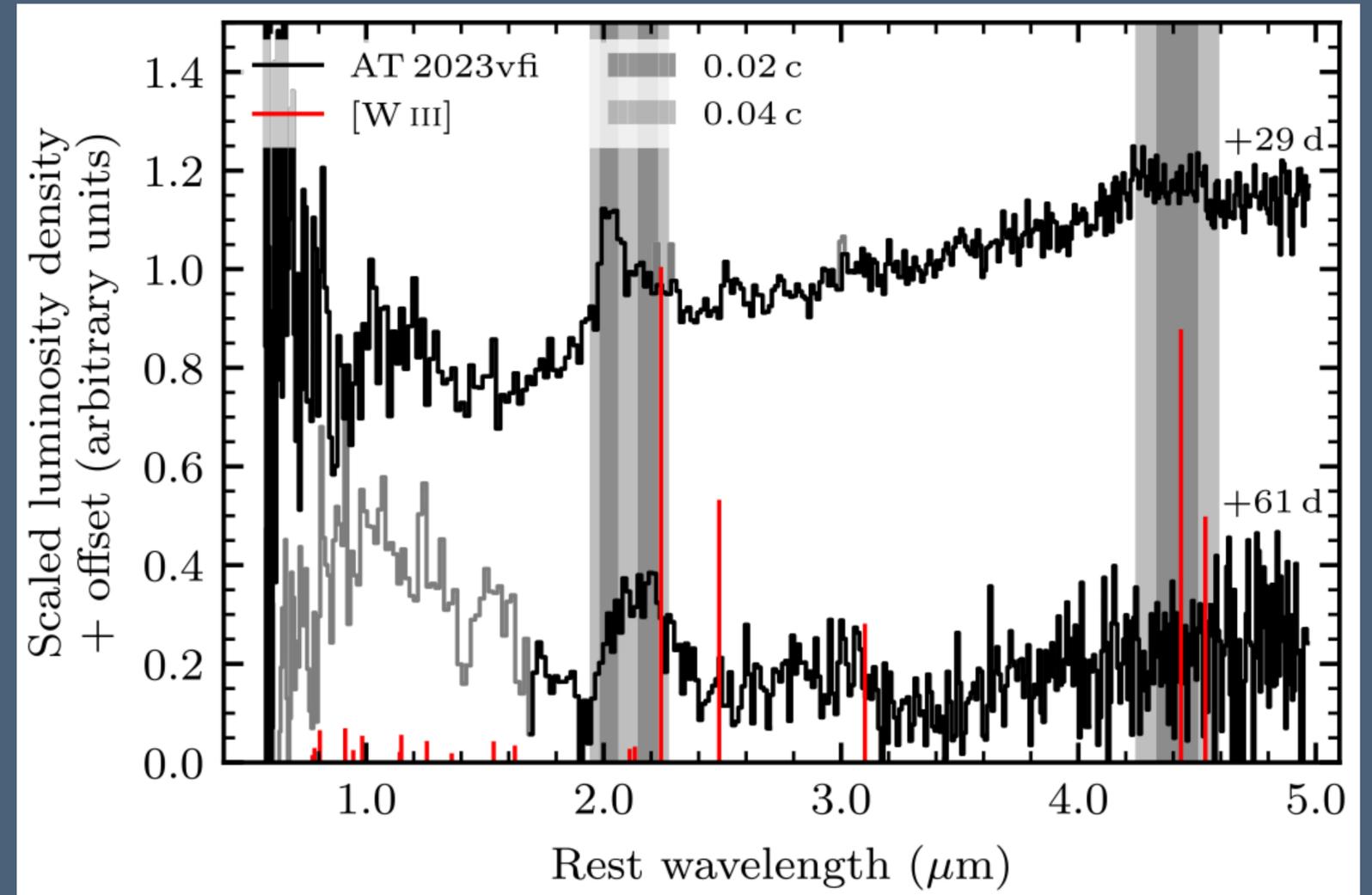
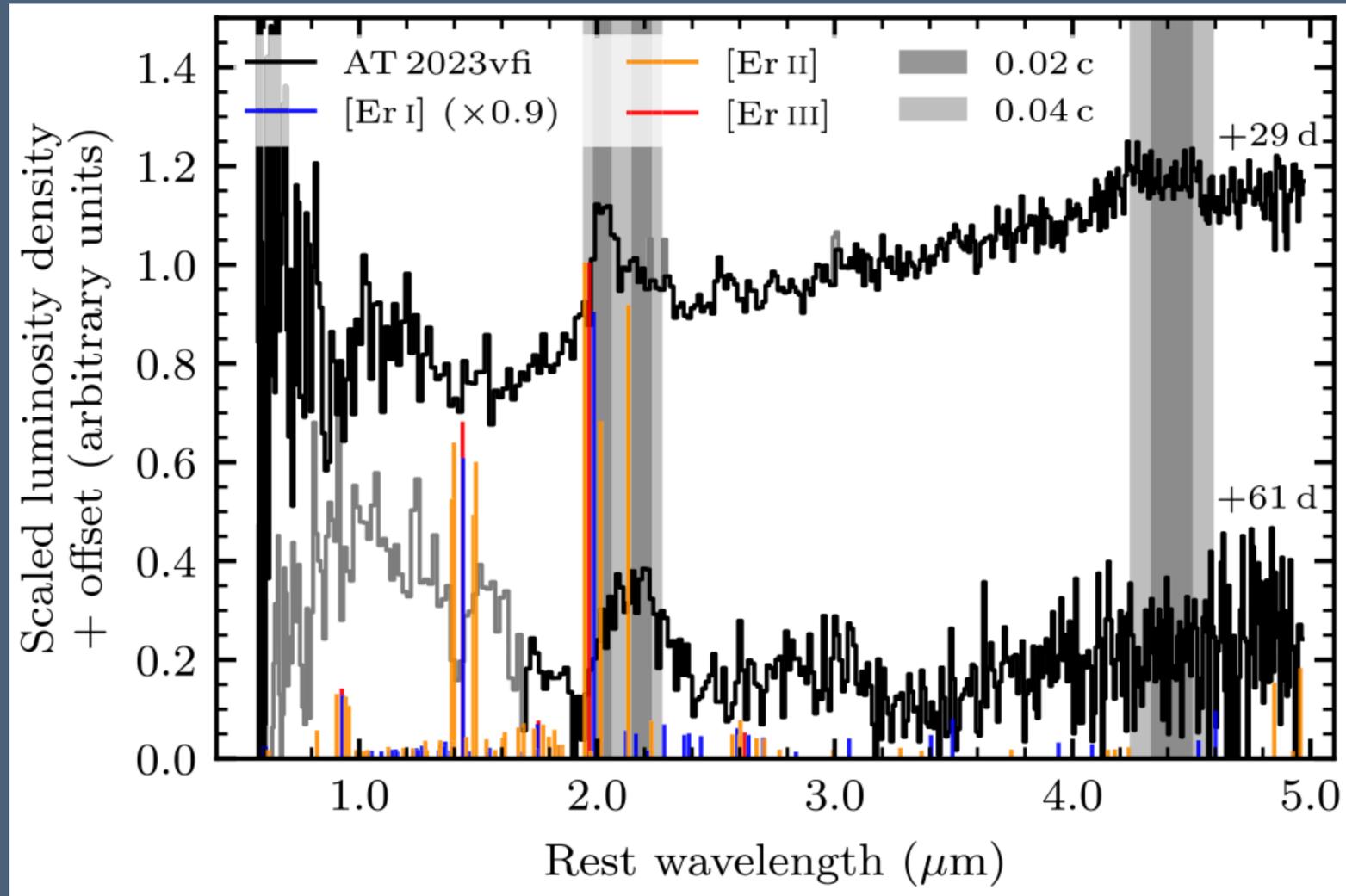


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 - Model KN @ 200 Mpc 



Other candidate line IDs



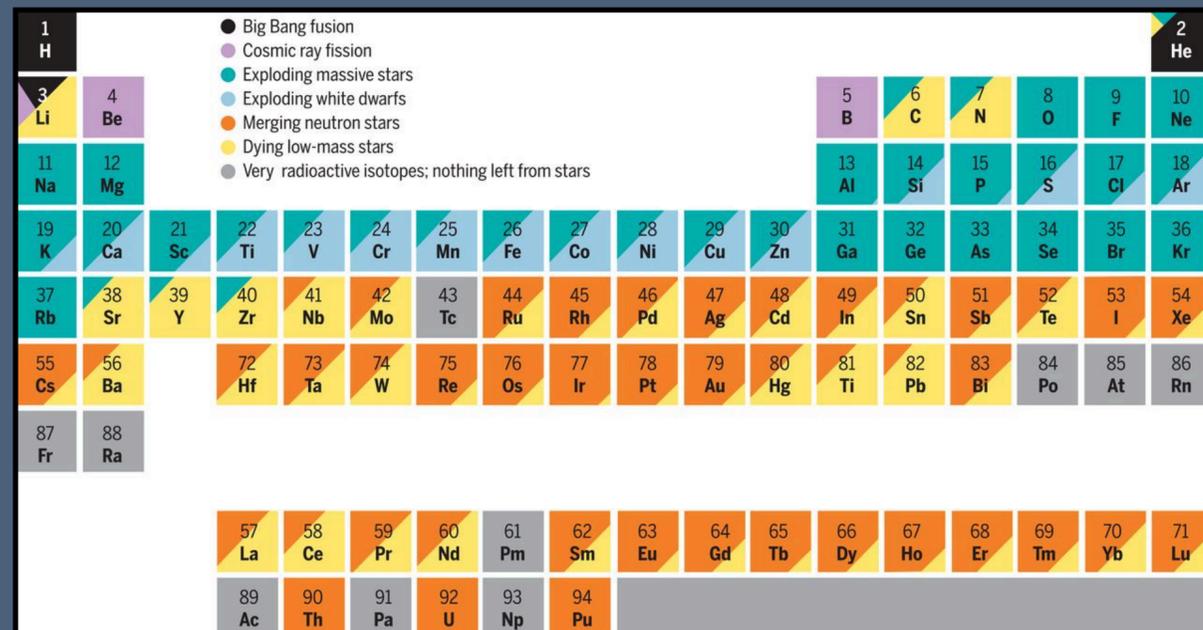
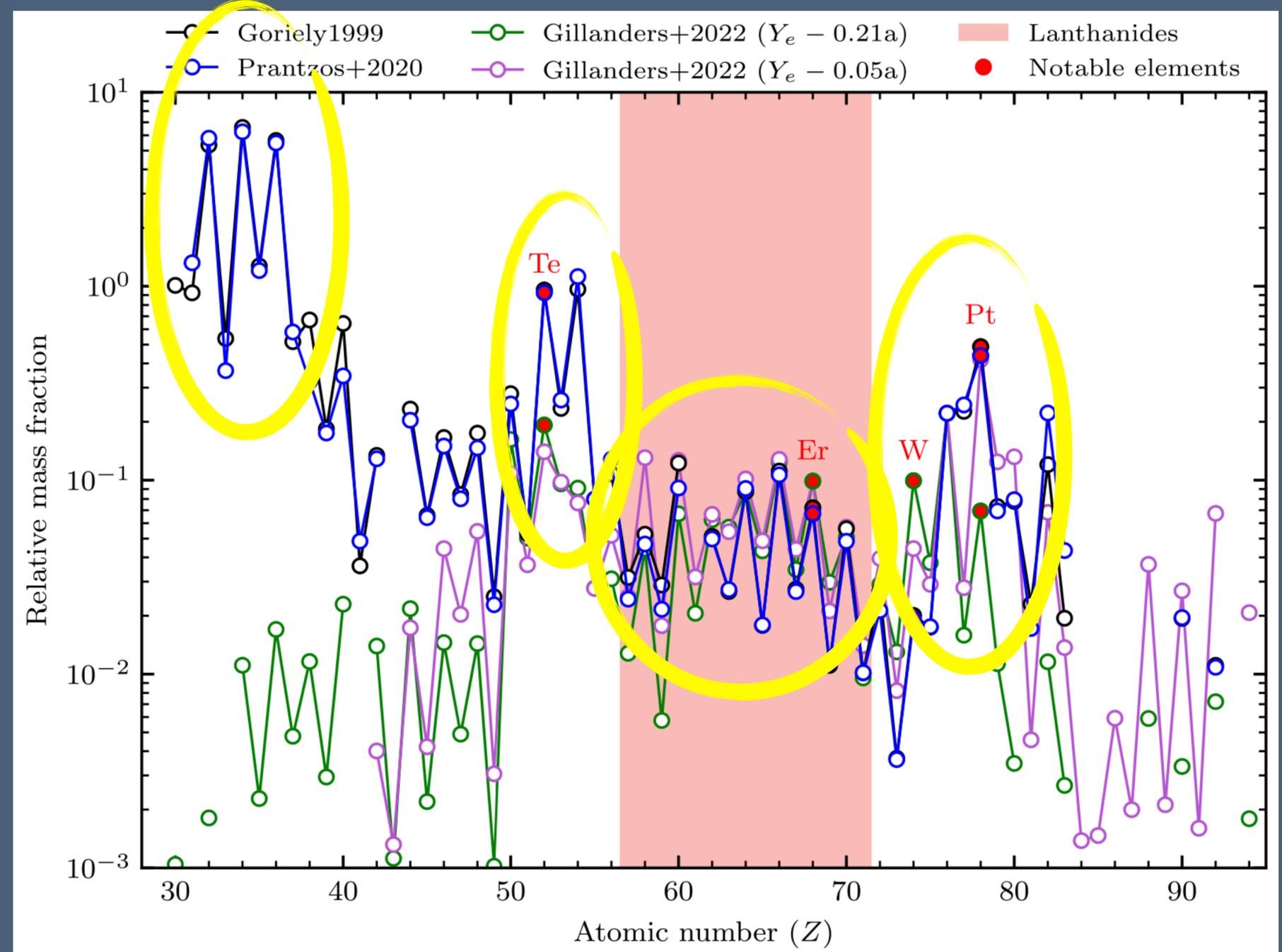
Gillanders+Smartt2025

* See subsequent works on Te, W by
Mulholland+2024, McCann+2025

Candidate summary

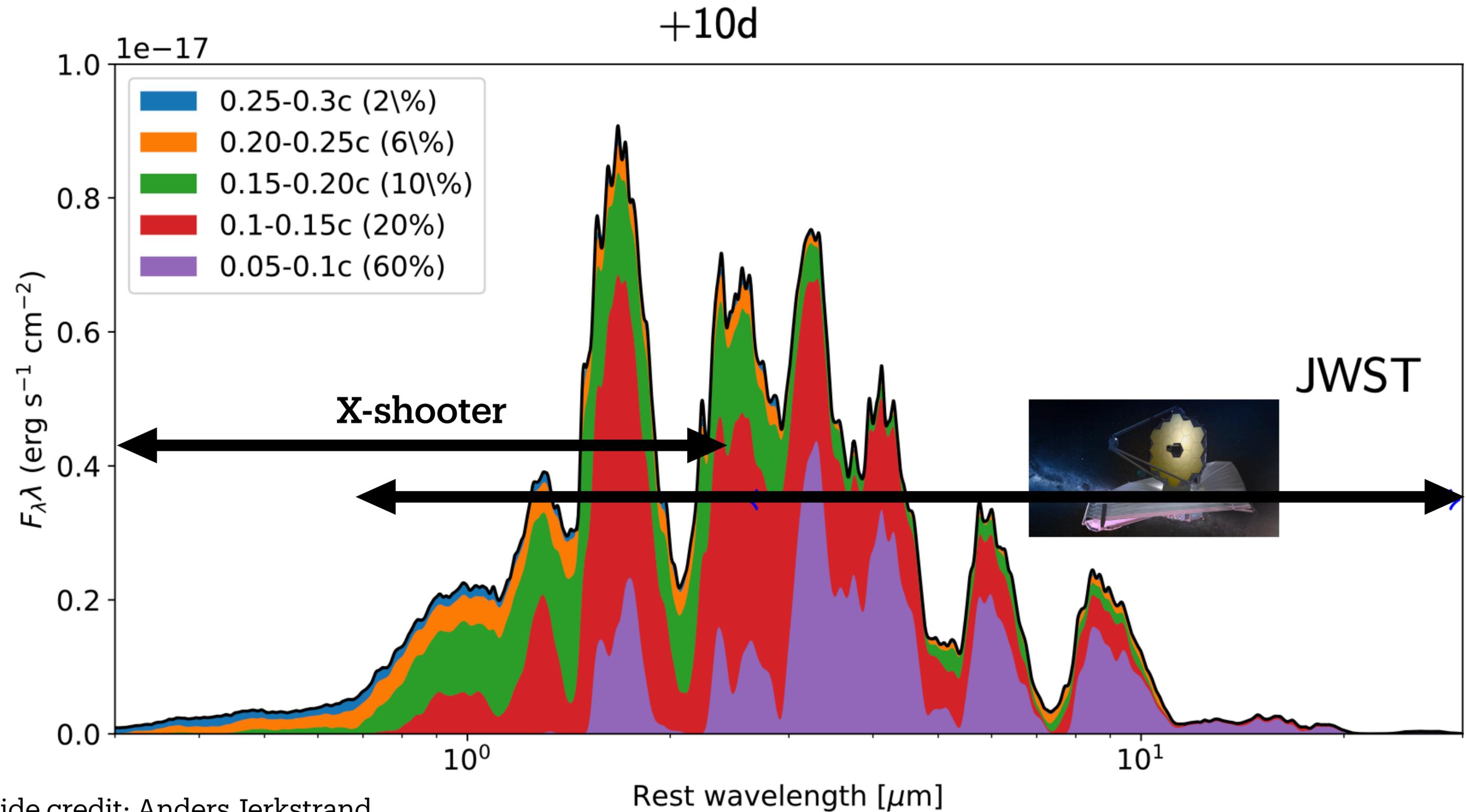
- Candidate species from second and third r-process peaks (+ a lanthanide)
- Most viable is Te III, but further analysis (and observations) needed!
- Also favour Er I-III, W III

Gillanders+Smartt2025



Johnson2019

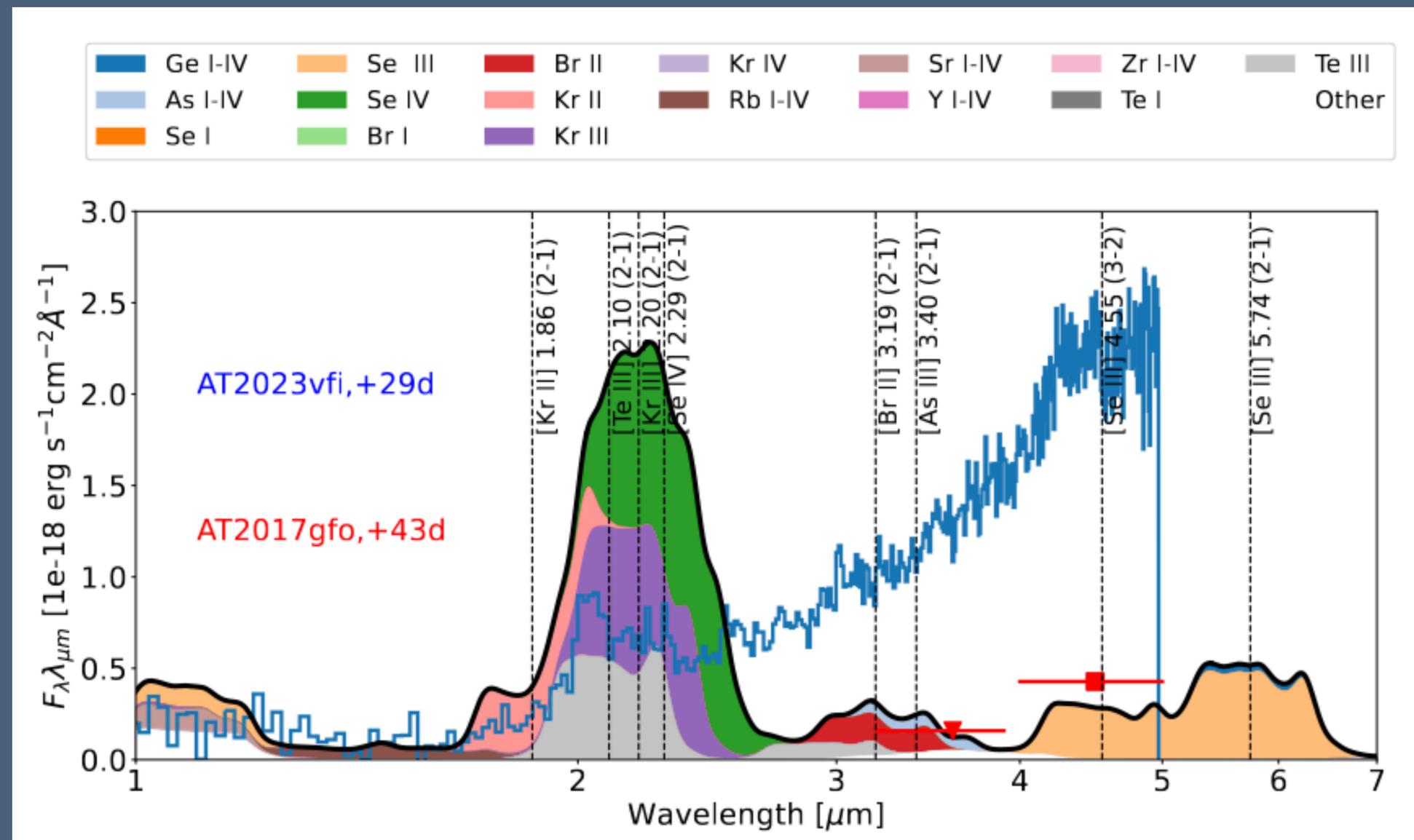
Only long wavelengths probe the main composition



SUMO modelling

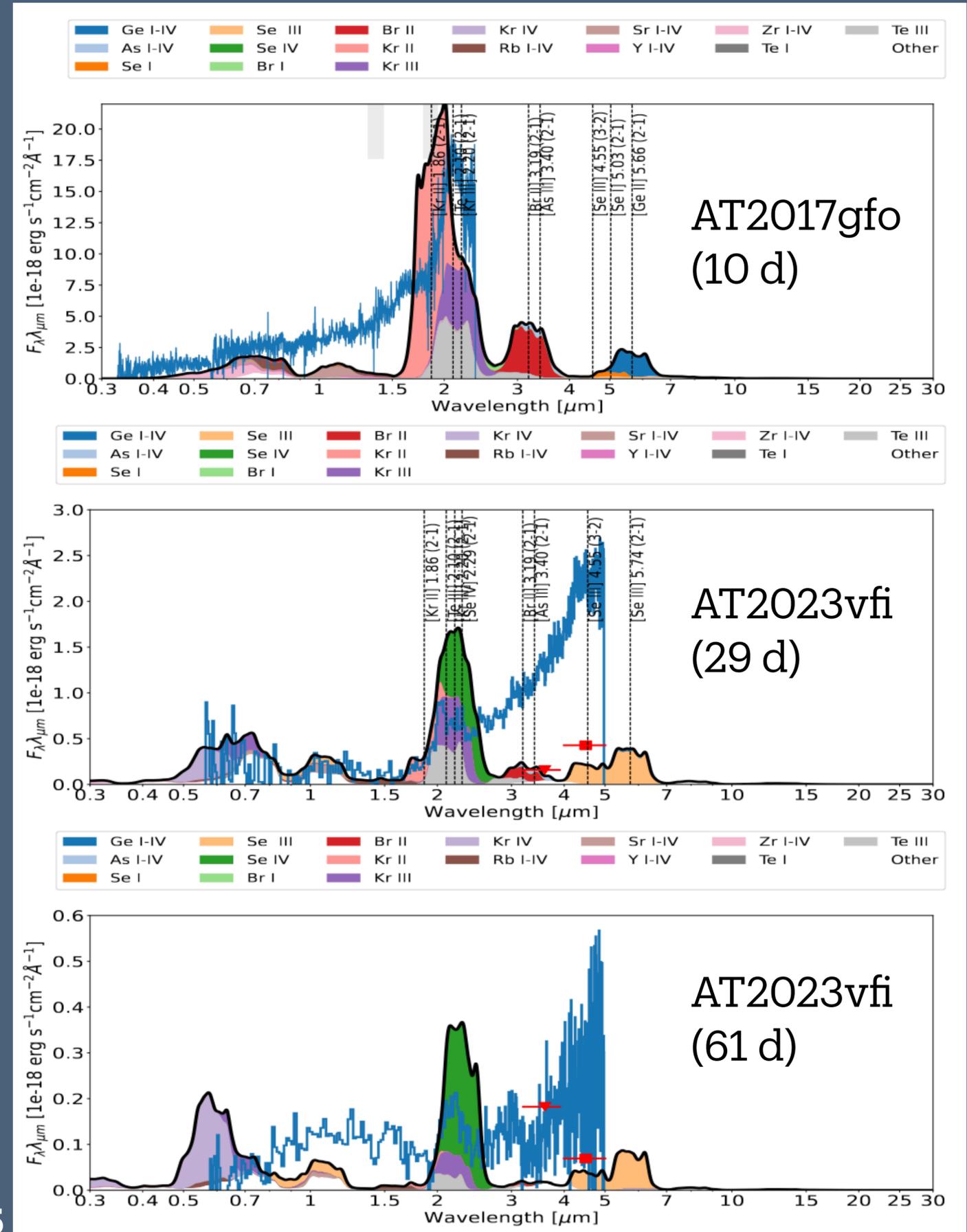
- Comparison of detailed non-LTE KN model (40 d) with AT2023vfi (29 d)
- Emission at $\sim 2.1 \mu\text{m}$ (but blended)
- Unable to match the continuum

Jerkstrand...Gillanders+2025



SUMO modelling

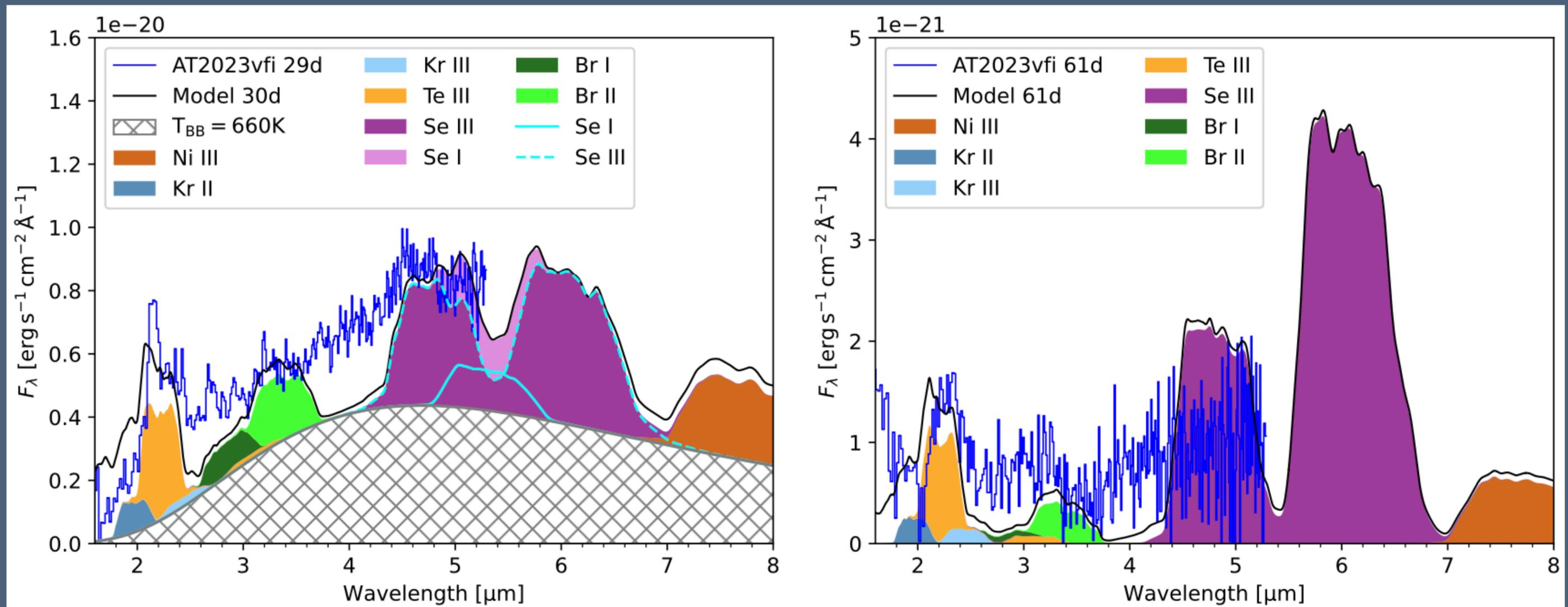
- Comparison of detailed non-LTE KN models with observations
- Emission at $\sim 2.1 \mu\text{m}$ (but blended)
- Unable to match the continuum
- Good step forward, but further work needed



Observational outlook for future KNe

- Only one(!!!) GO Cycle 4 proposal approved for KN observations (July 2025 — June 2026)
- Cycle 5 (July 2026 — June 2027) results to be announced “*Early-to-mid March 2026*”

JWST Cycle 5 proposal; PIs: Gillanders, Pognan



Conclusions

NASA

- Kilonovae are a promising avenue for detecting r-process spectral signatures
- JWST is especially important as the premier space-based, IR observatory
- AT2023vfi surprisingly(?) smooth
- Leading candidate ion in the data is Te III (also favour Er, W, Pt)
 - More/Better modelling is needed
 - We really need more KNe !!!

