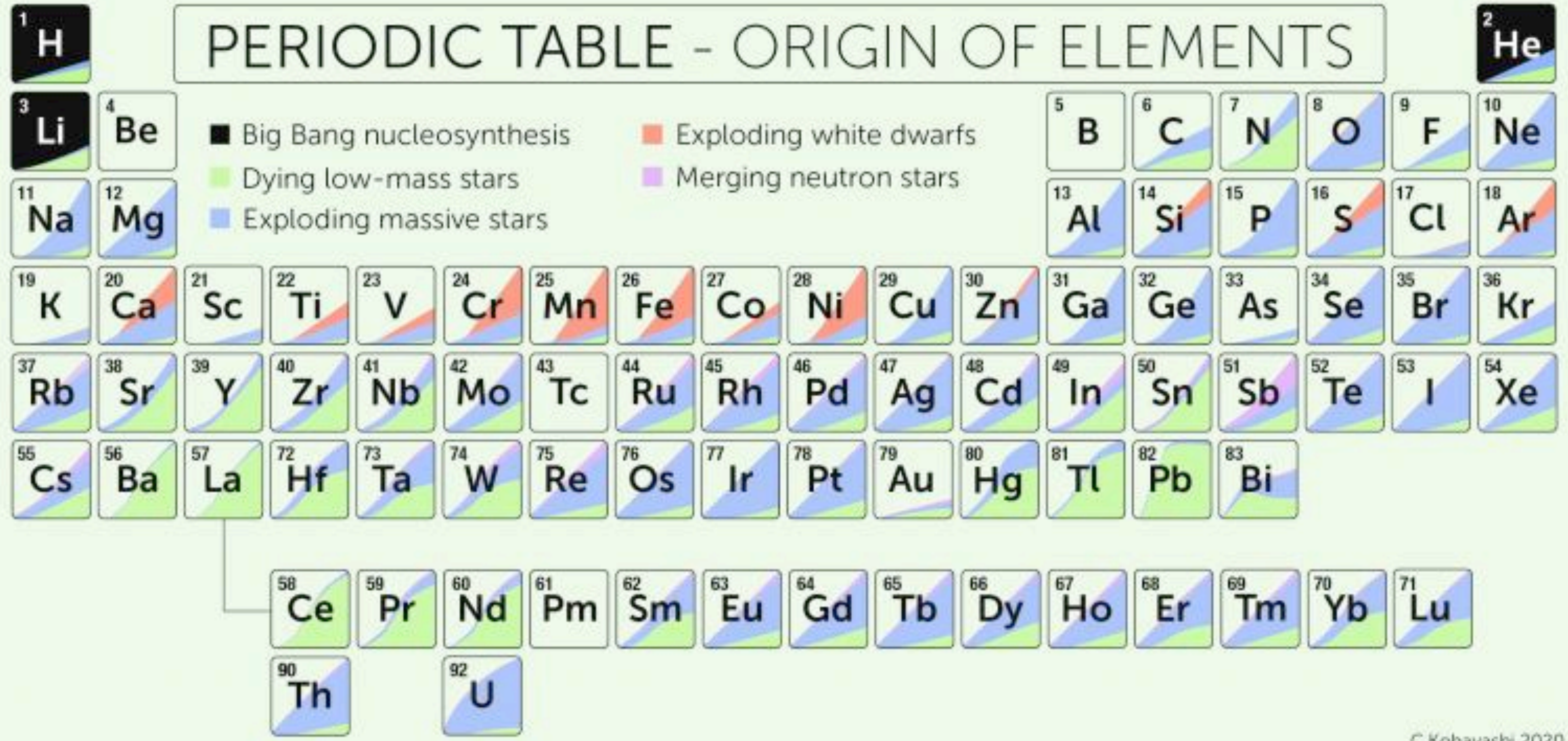


Heavy element signatures in kilonovae observations

Susanna D. Vergani

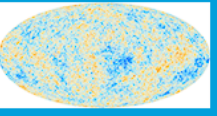
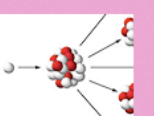






PERIODIC TABLE - ORIGIN OF ELEMENTS



C.Kobayashi 2020

The Origin of the Solar System Elements

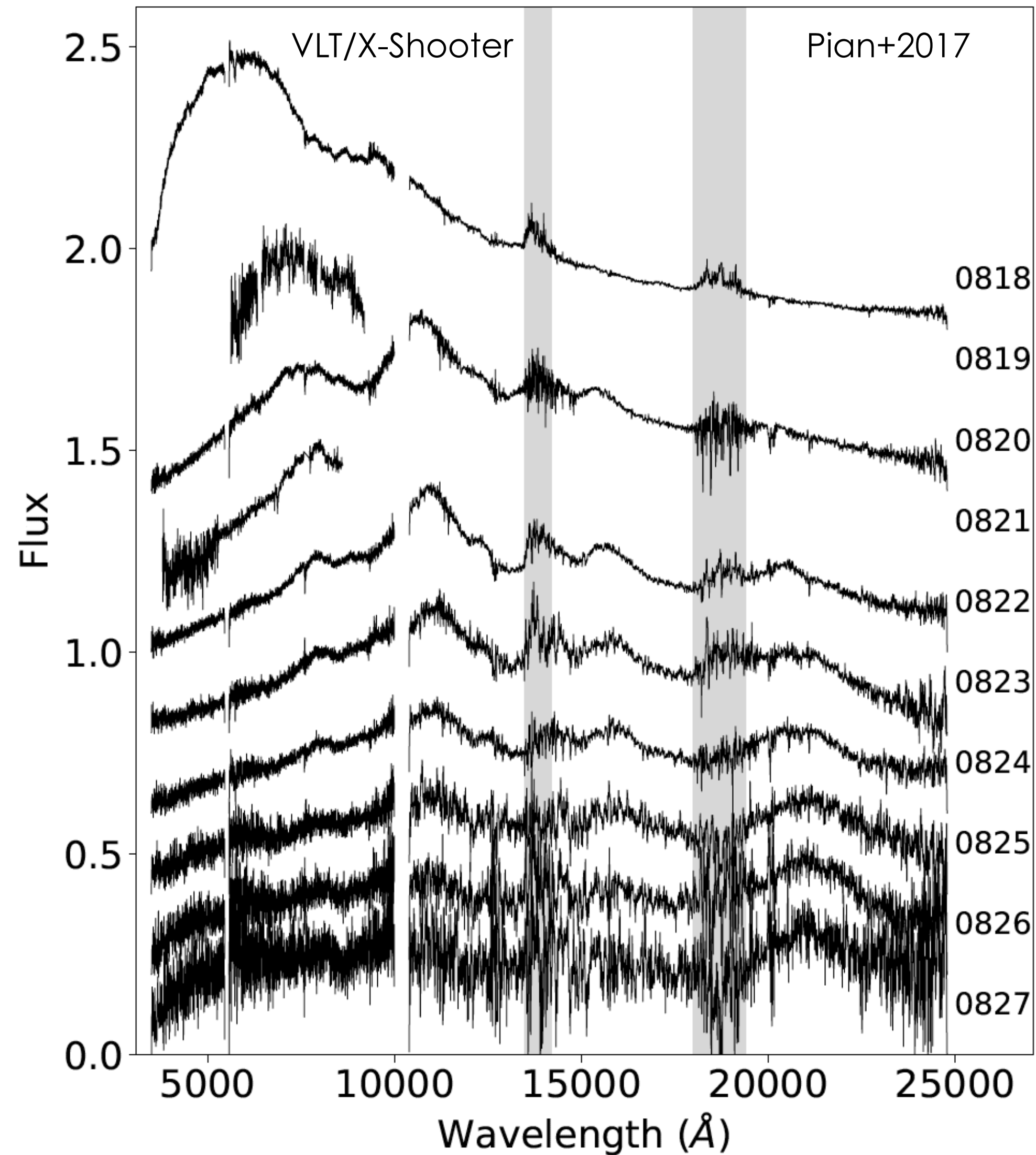
1 H	big bang fusion 										cosmic ray fission 					2 He		
3 Li	4 Be	merging neutron stars 					exploding massive stars 					5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg	dying low mass stars 					exploding white dwarfs 					13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba			72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra																	
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
		89 Ac	90 Th	91 Pa	92 U													

Graphic created by Jennifer Johnson

Astronomical Image Credits:
ESA/NASA/AASNova

GW170817 / AT2017gfo (KN)

Heavy elements produced
by r-process in kilonovae

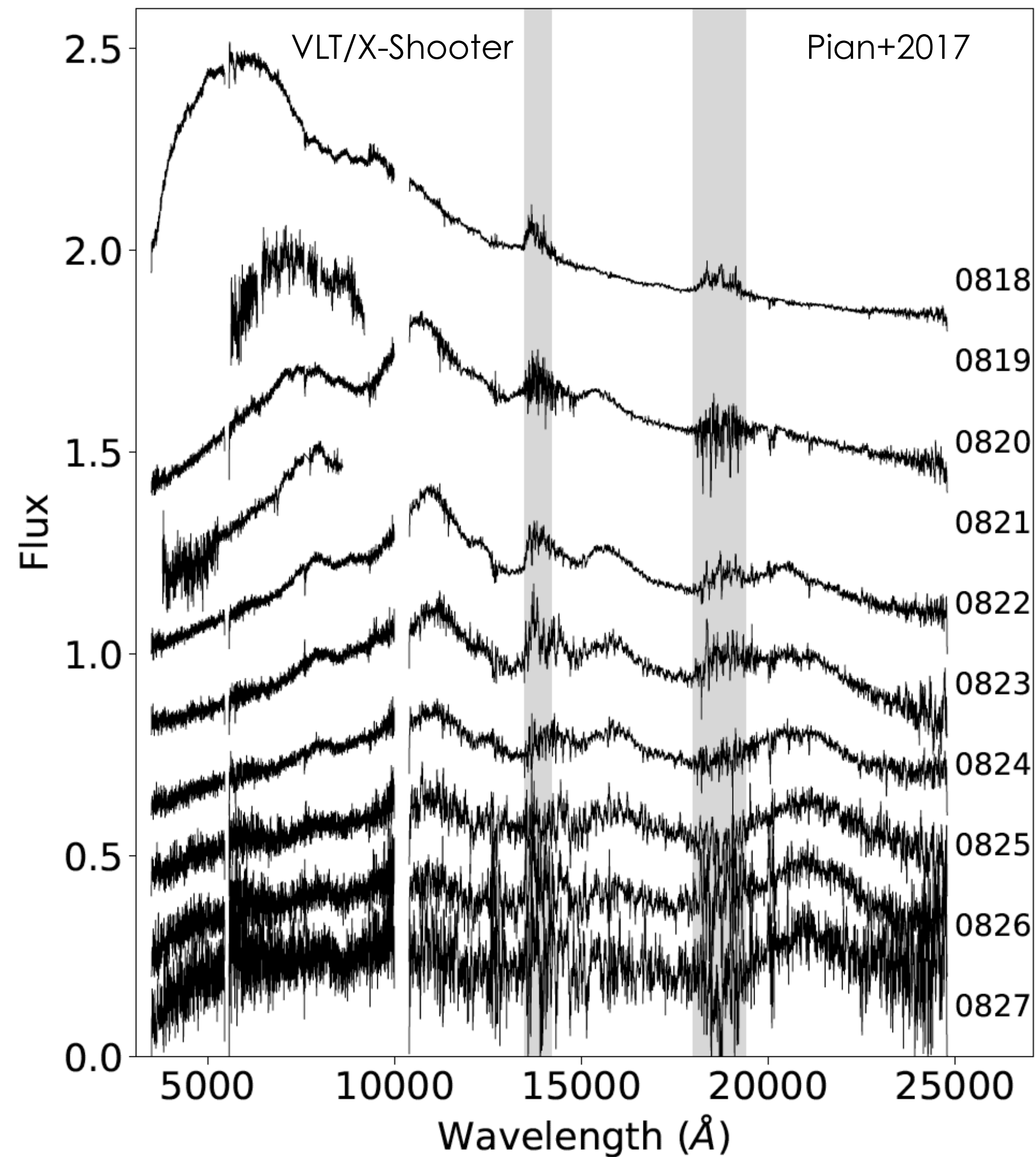


GW170817 / AT2017gfo (KN)

**Heavy elements produced
by r-process in kilonovae**

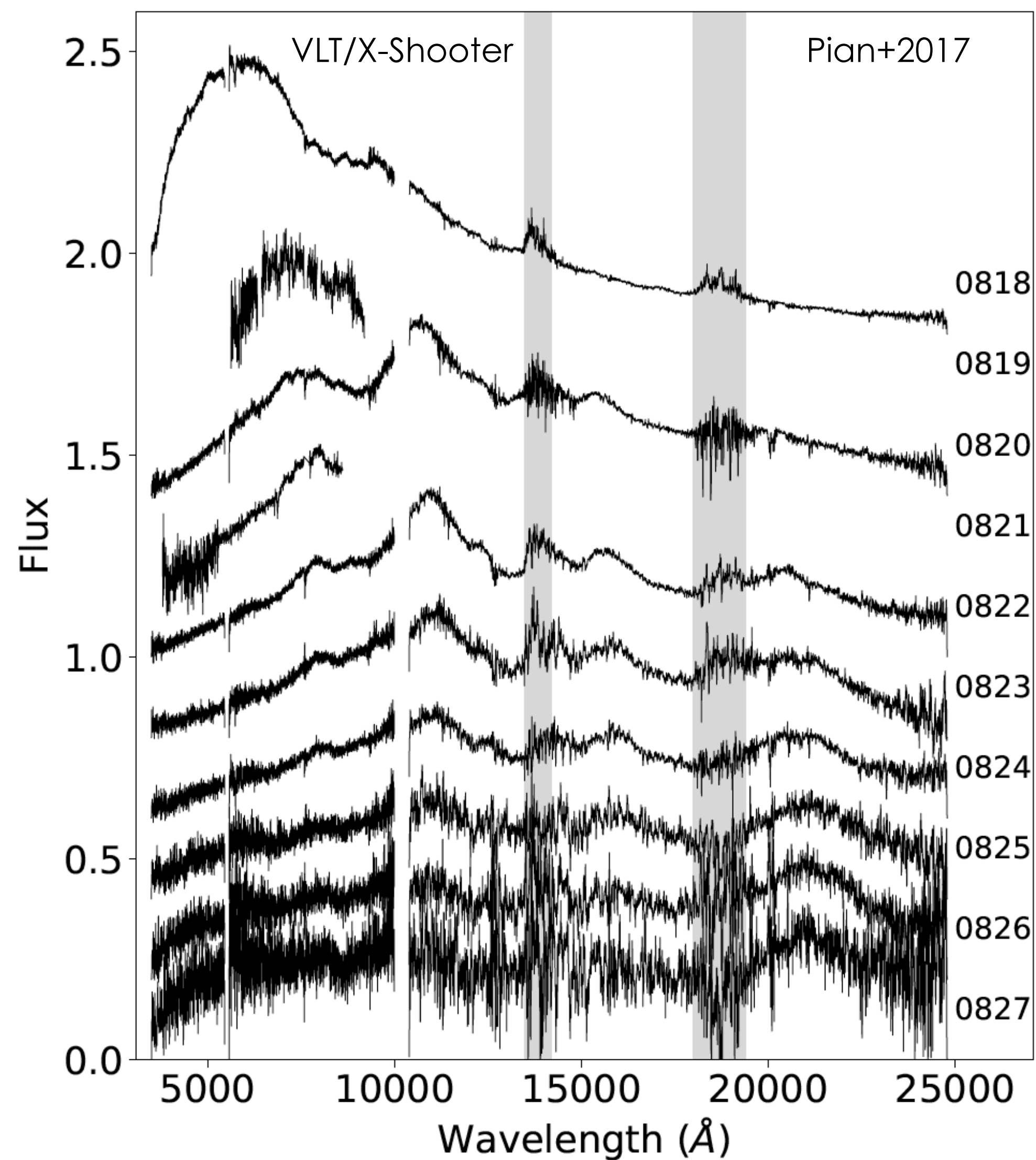
**Which heavy elements are produced
by r-process in kilonovae ?**

How much ?



GW170817 / AT2017gfo (KN)

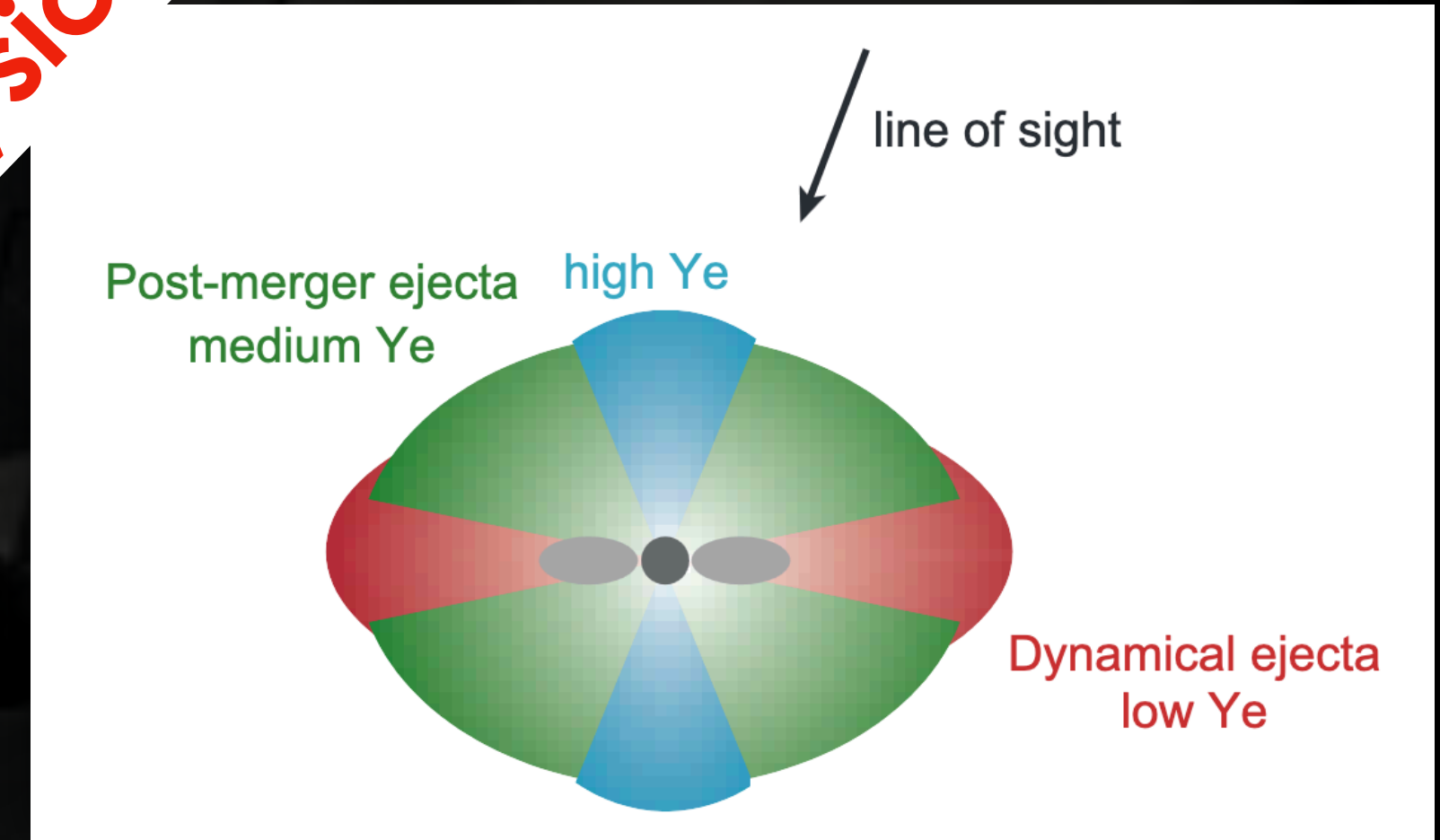
Lots of unknown !



GW170817 / AT2017gfo (KN)

Lots of unknown !

KN physics

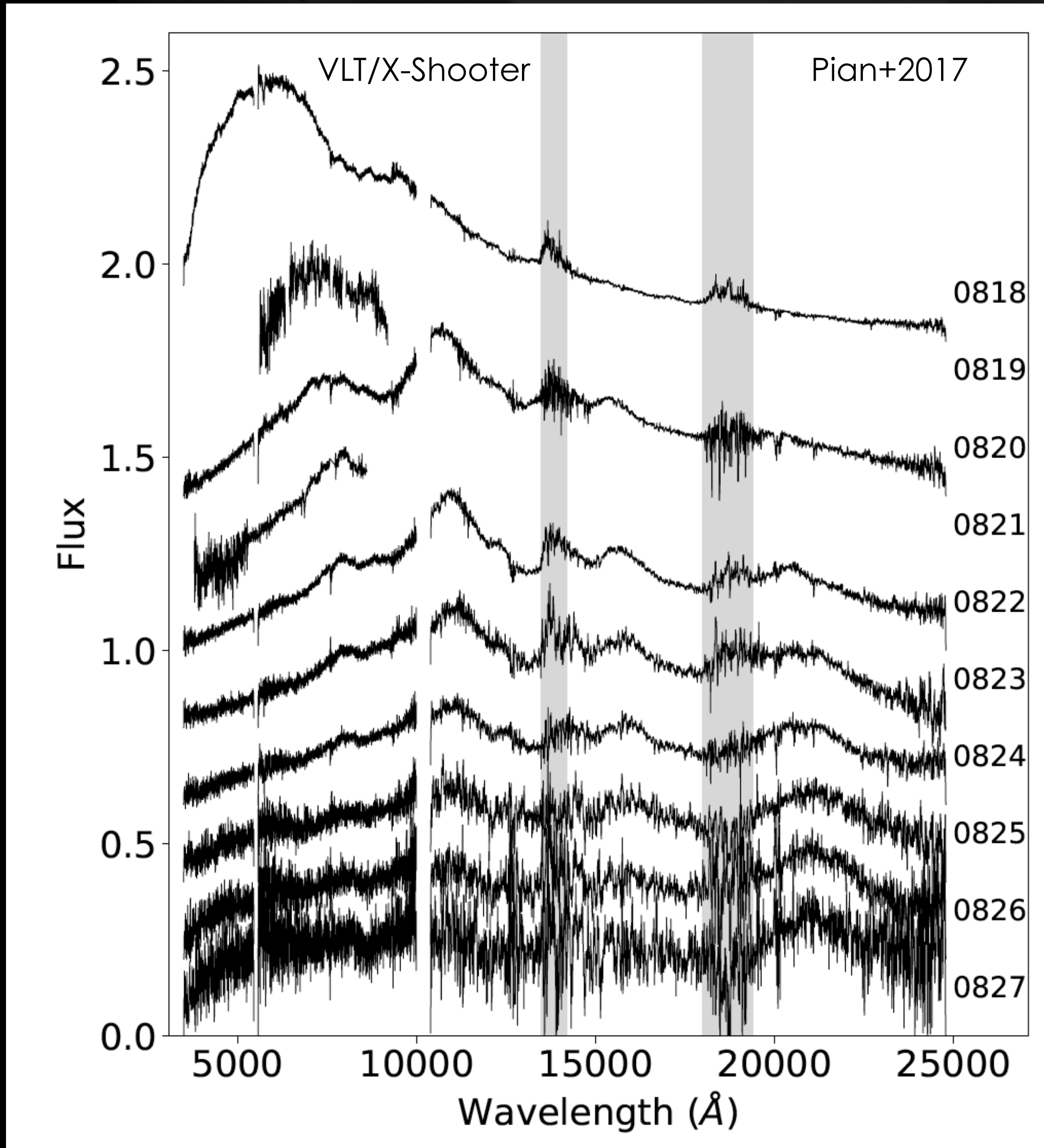


Atomic physics

Atomic transitions

Oscillator strengths

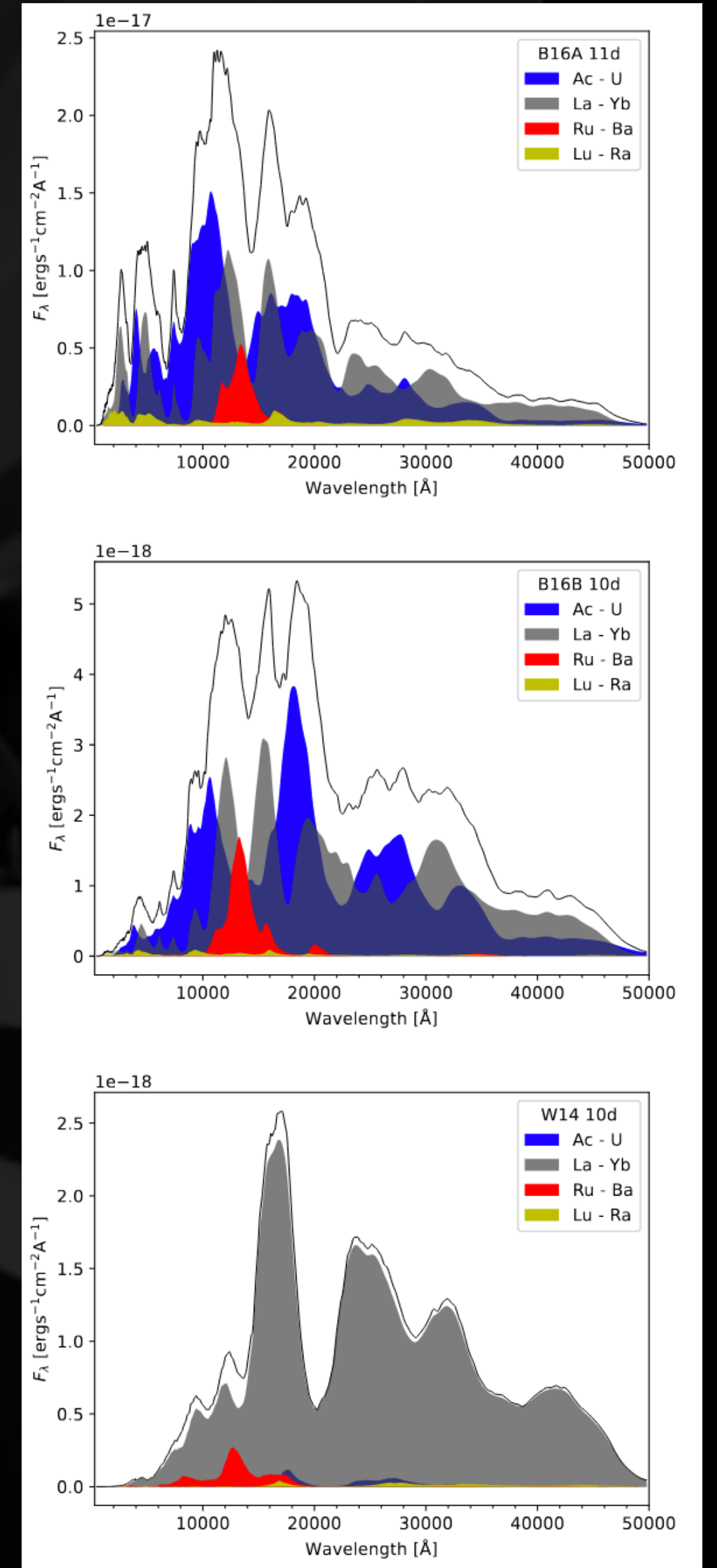
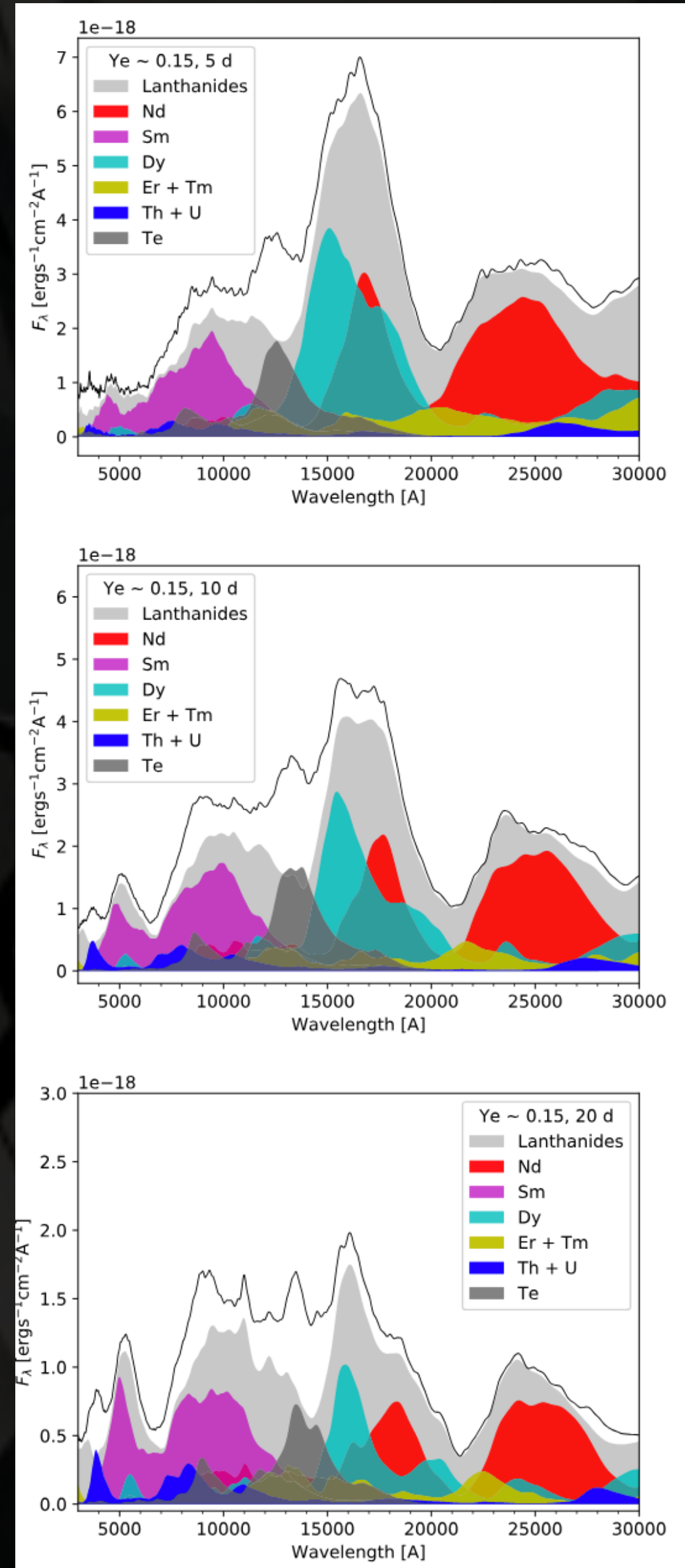
LTE vs Non-LTE models



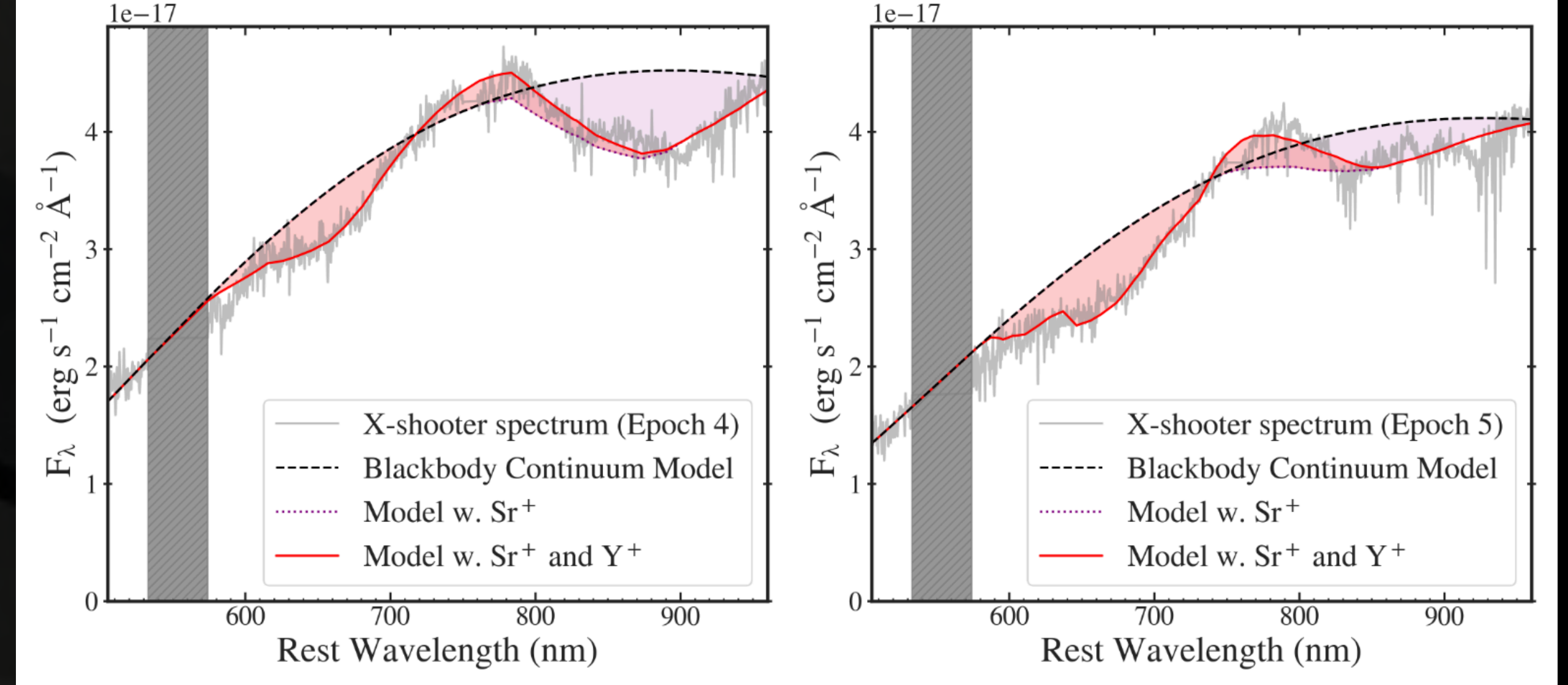
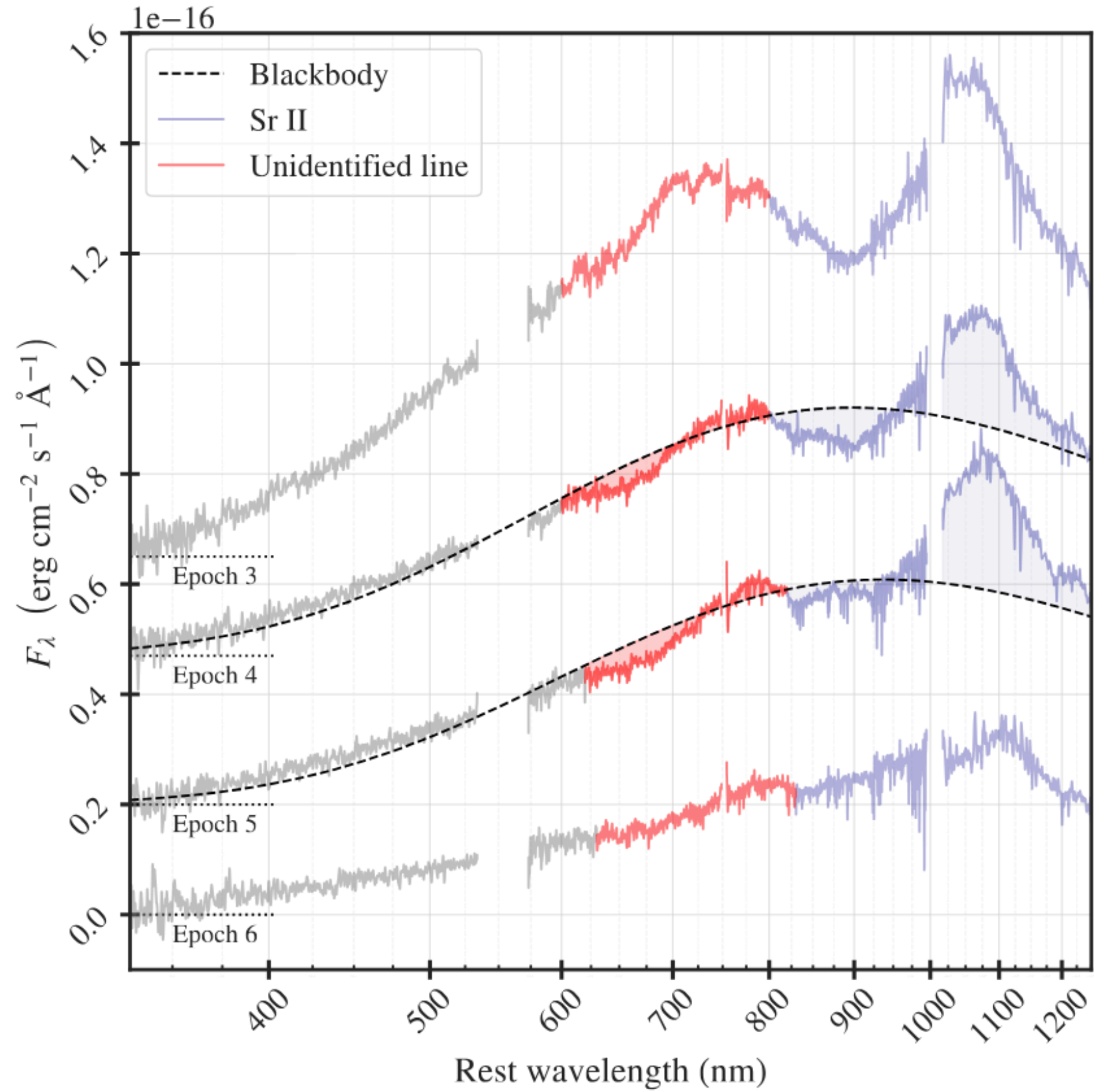
Many works in the last years
on opacities and atomic transitions
of different elements
Specifically carried out for KN applications

Development of 3D KN and radiative transients models
TARDIS (SPARK+TARDIS)
POSSIS

Development of non-LTE spectral synthesis codes
SUMO (1D)



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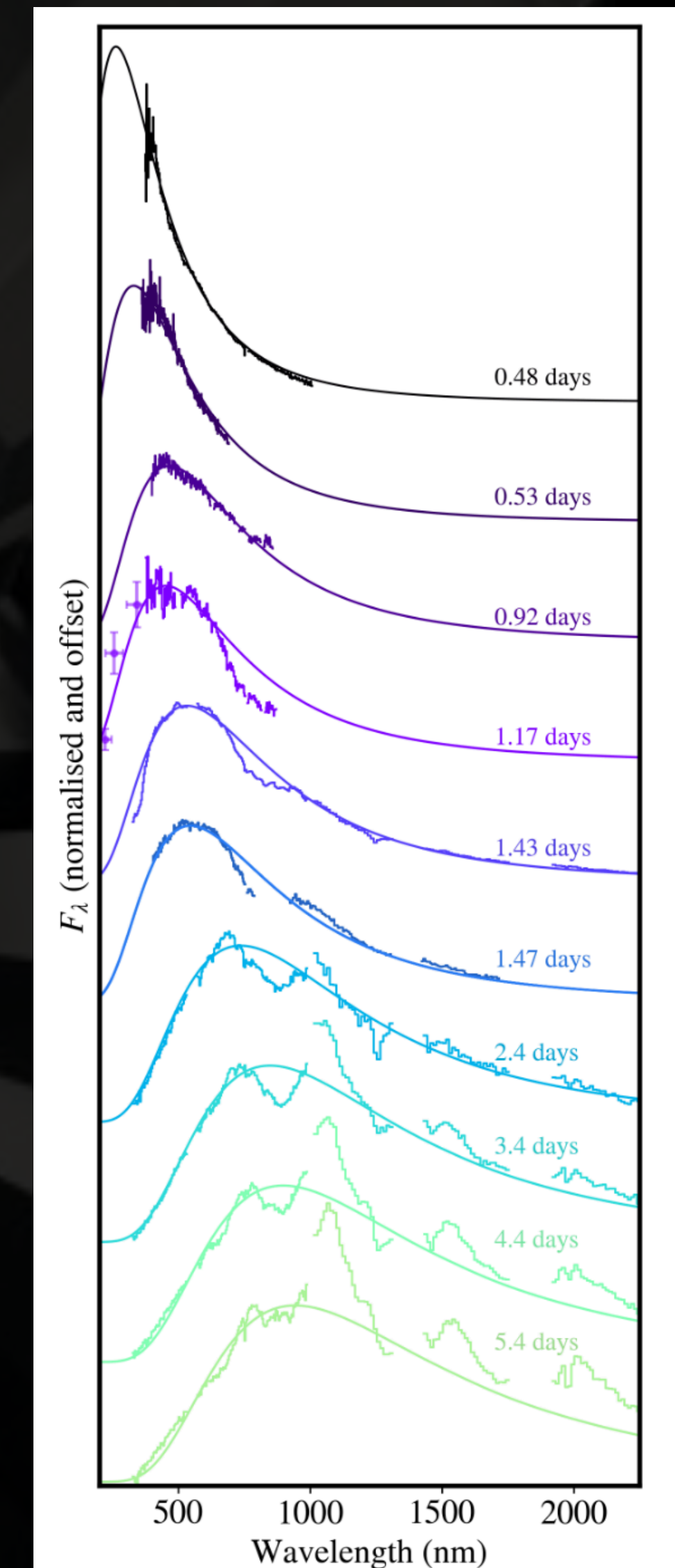
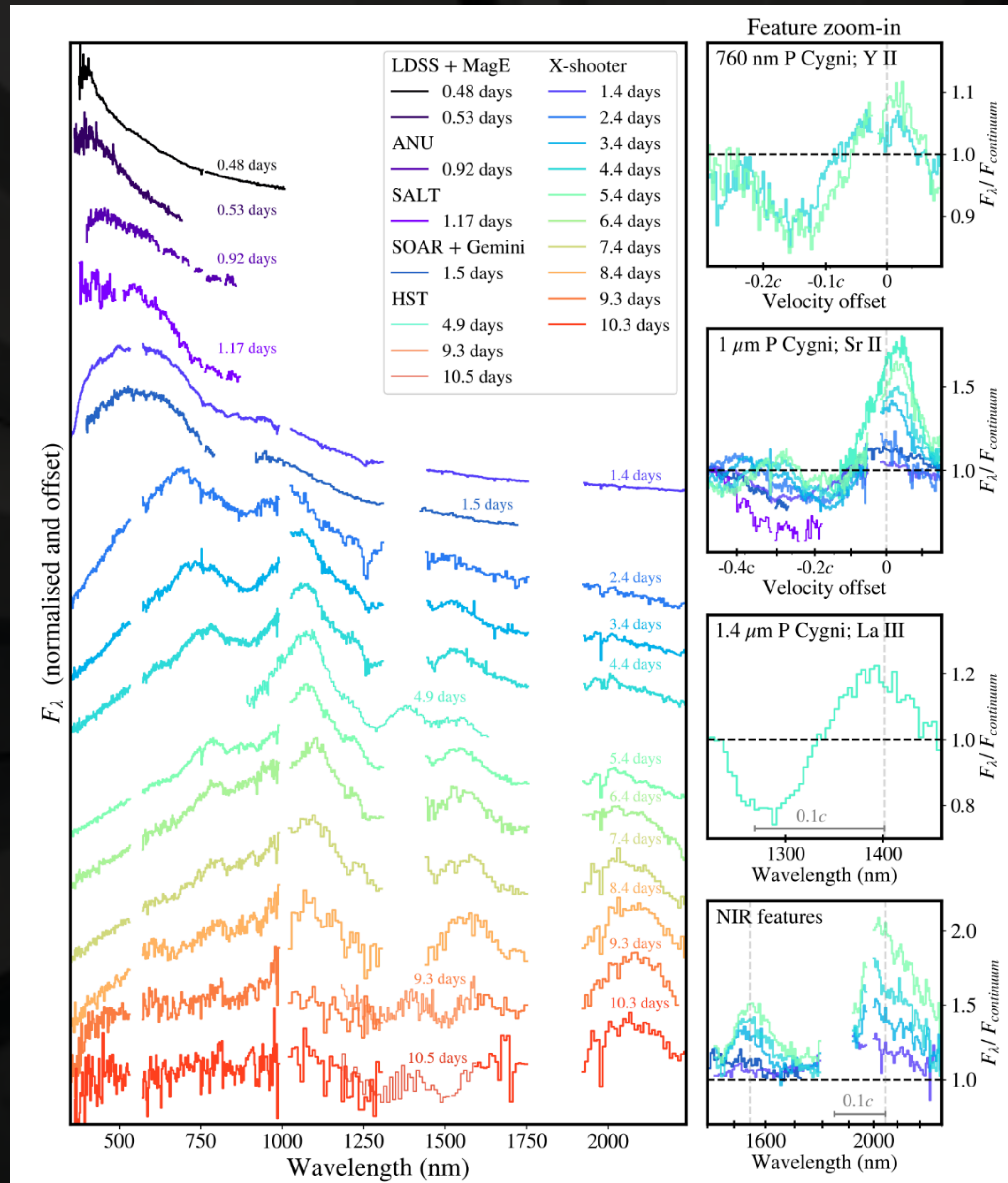


Sneppen+ series of papers

GW170817 / AT2017gfo

Sneppen+ series of papers

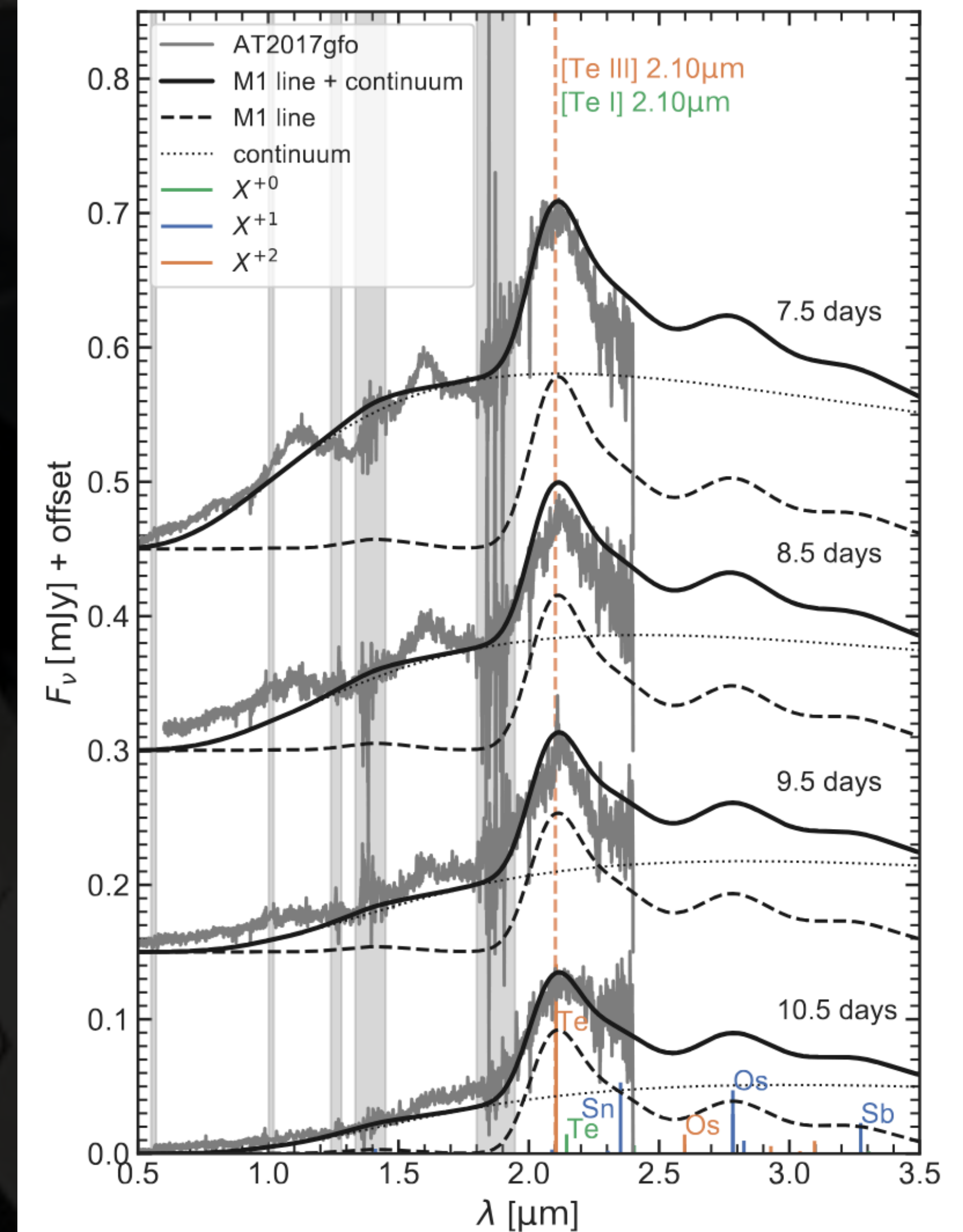
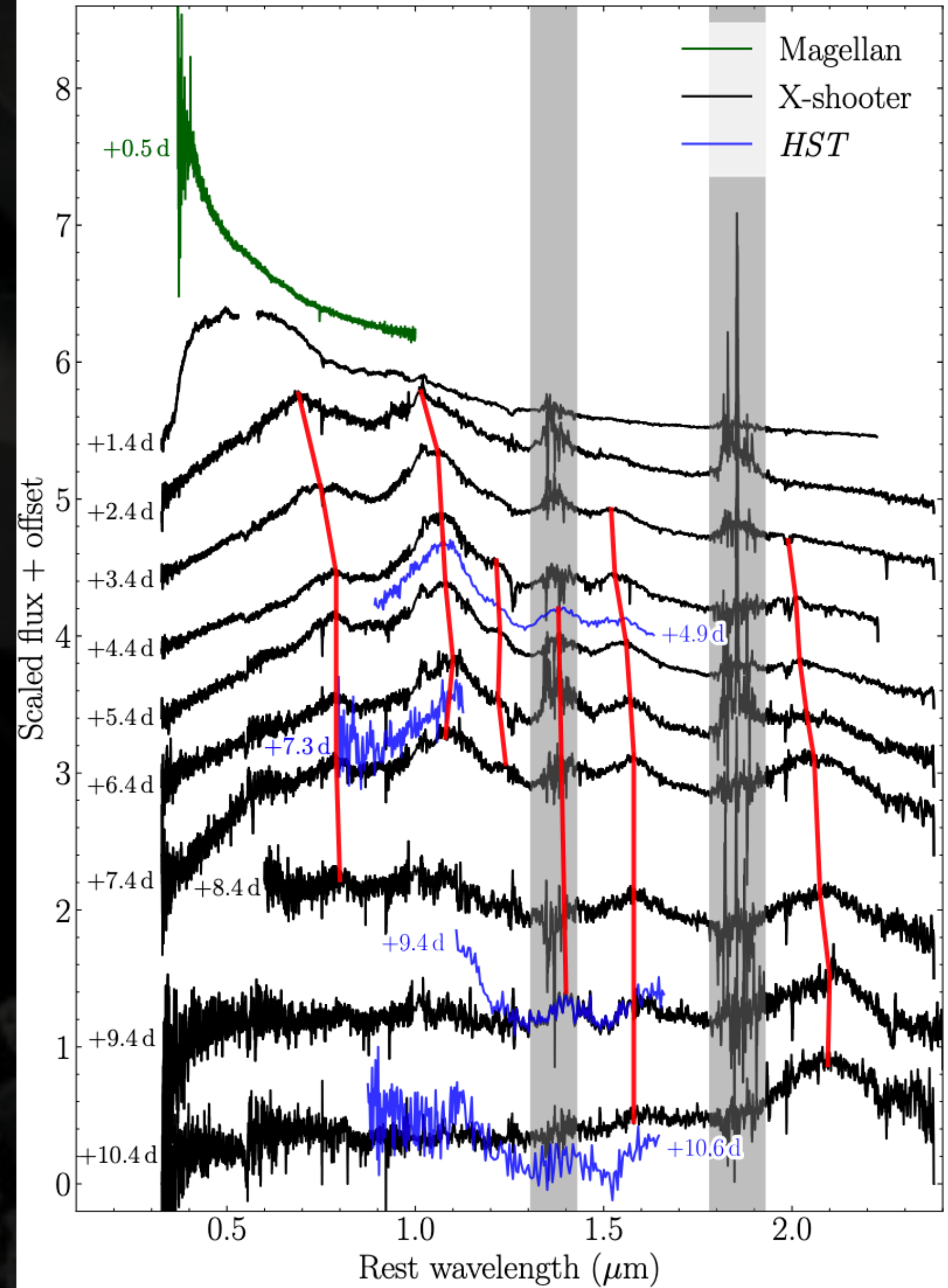
La III, Ce III, Te III



GW170817 / AT2017gfo

Gillanders+ 2024

Hotokezaka+ 2023



Te $\sim 10^{-3} M_\odot$

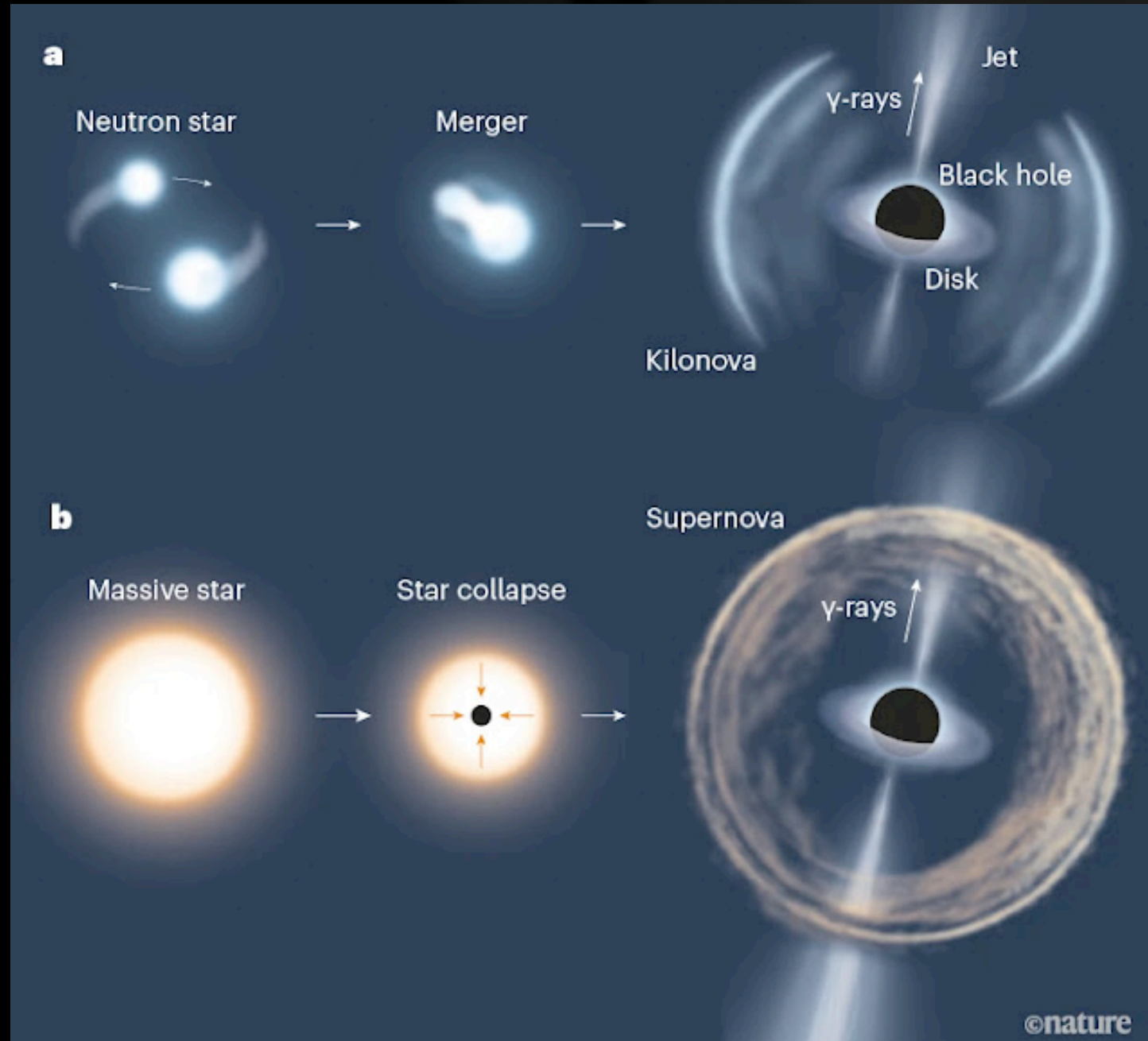
**Lot of activity but...
...No other BNS GW-EM detections**

The answer is always Gamma-ray bursts :)

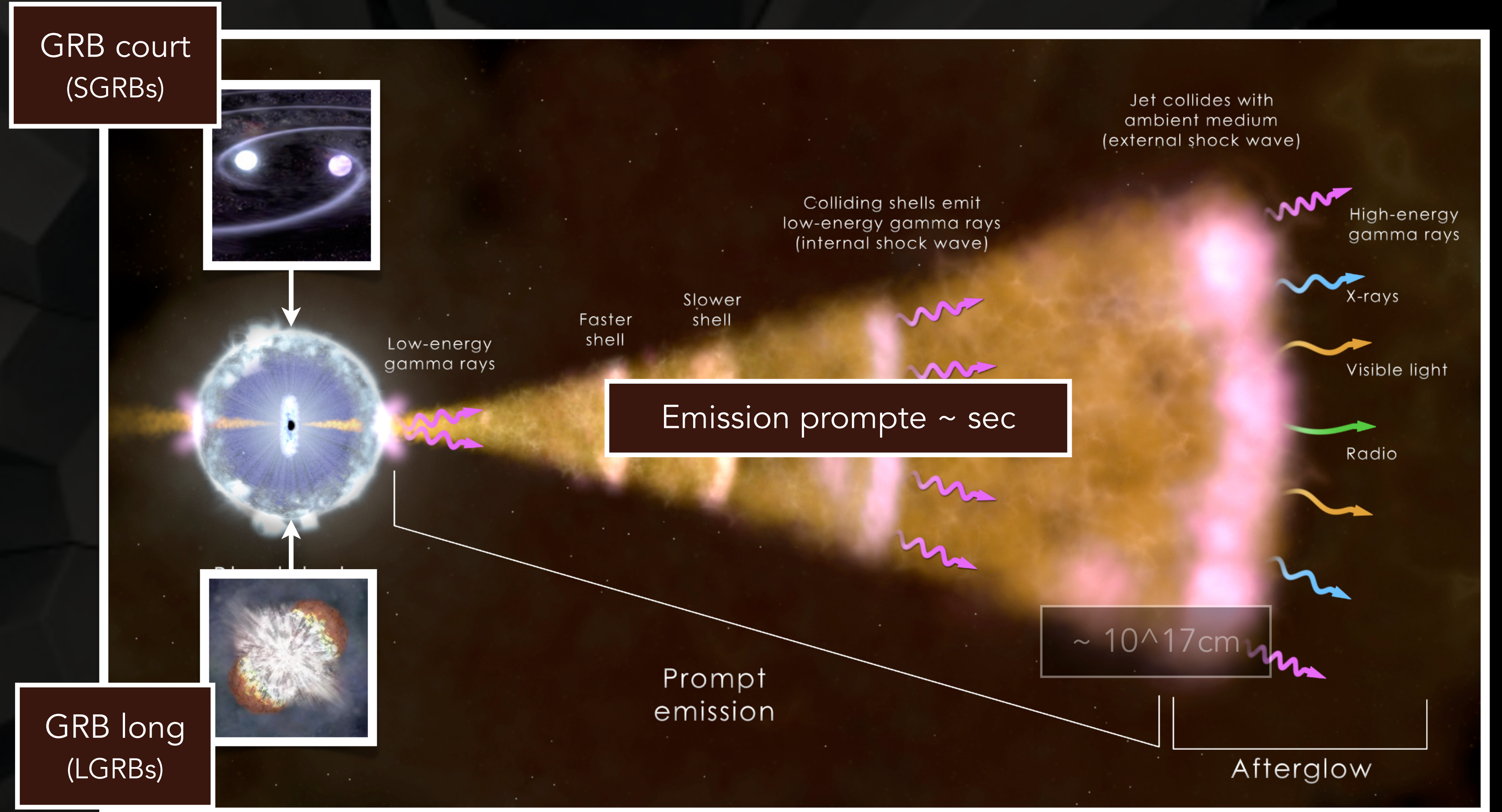
Les Sursauts gamma (GRBs)

jets ultra-relativistes associés à la formation cataclysmique de trous noirs

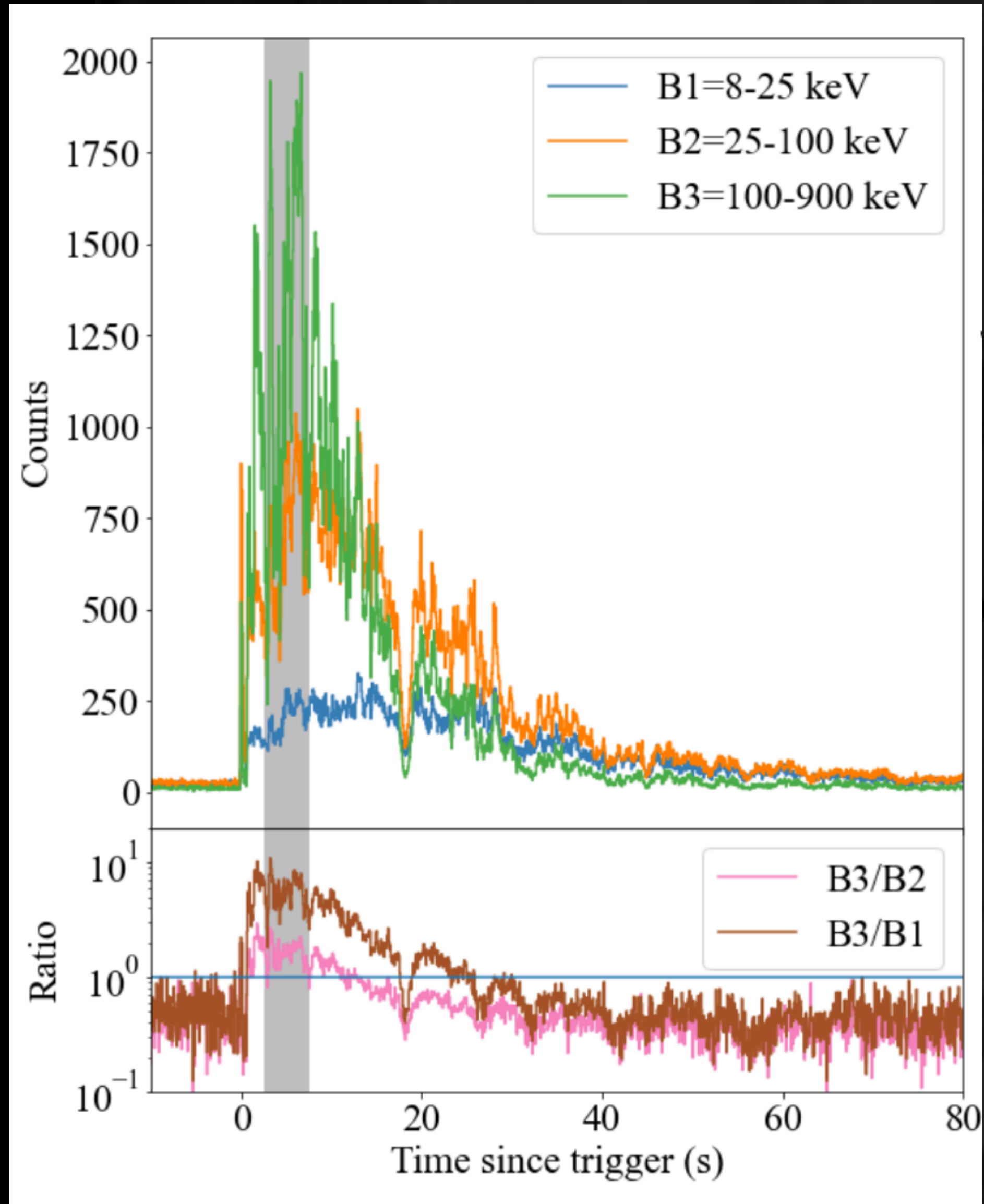
coalescence d'objets compacts
(Kilonova)



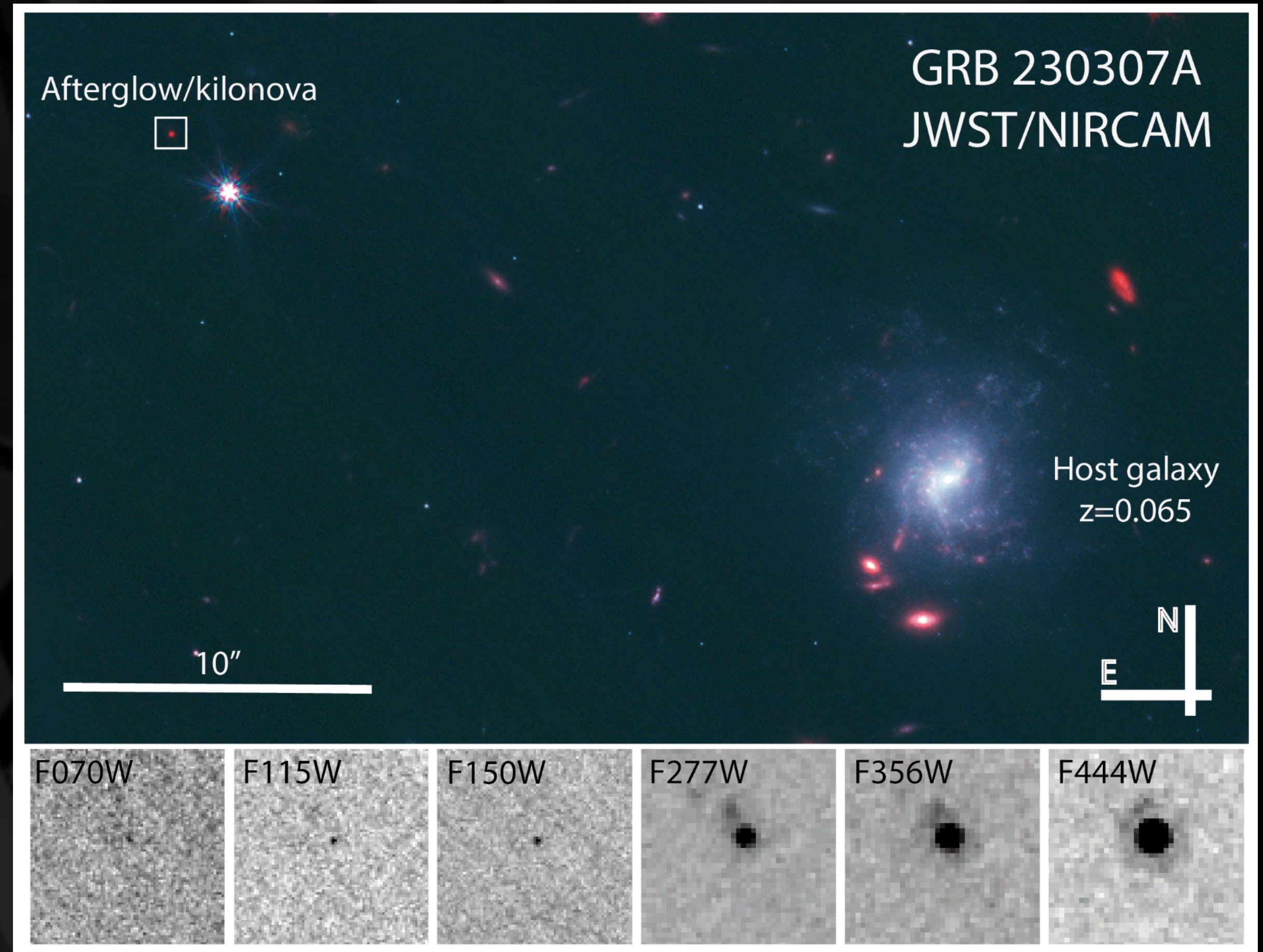
explosion d'une étoile très massive
(Core-collapse supernova)



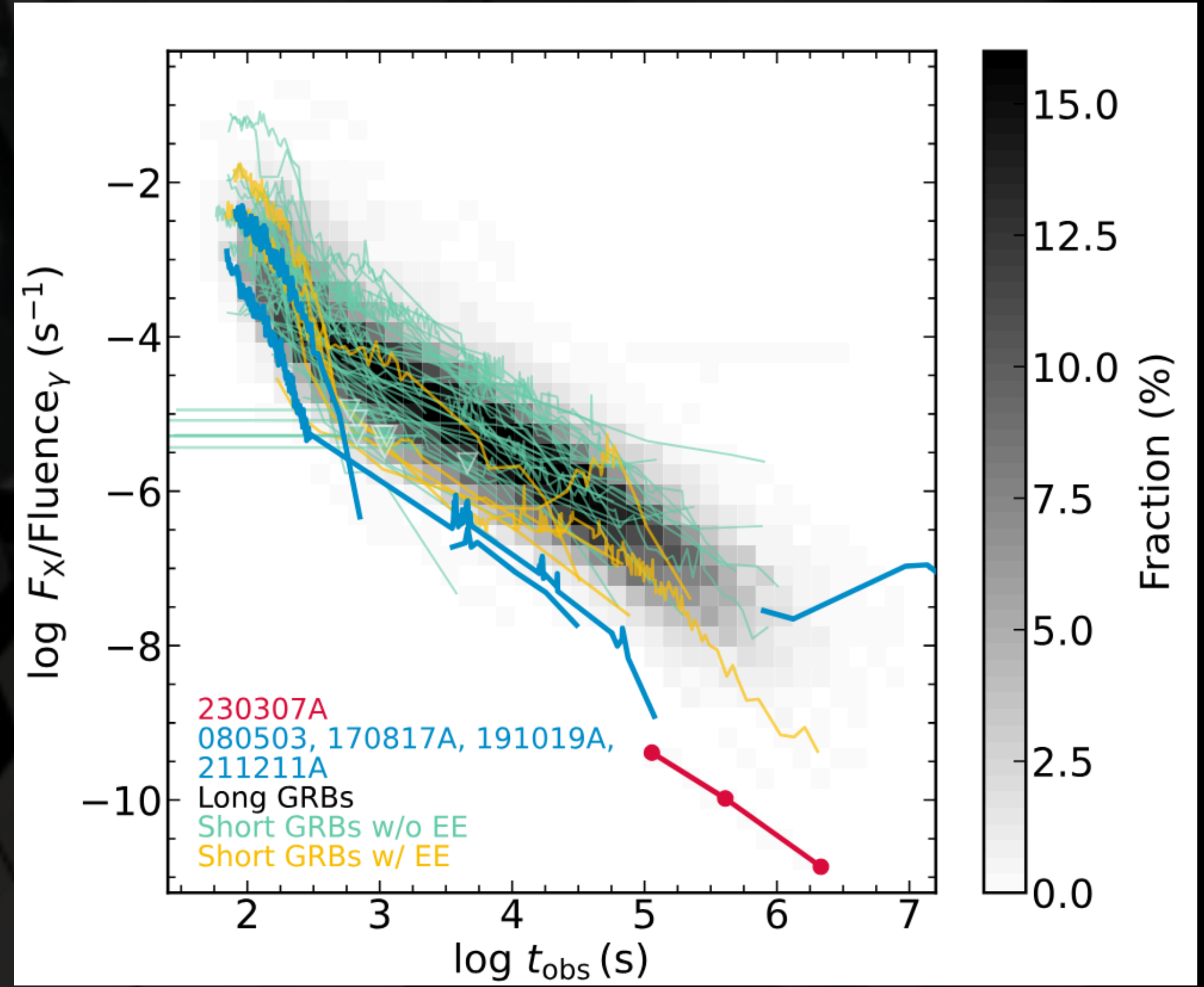
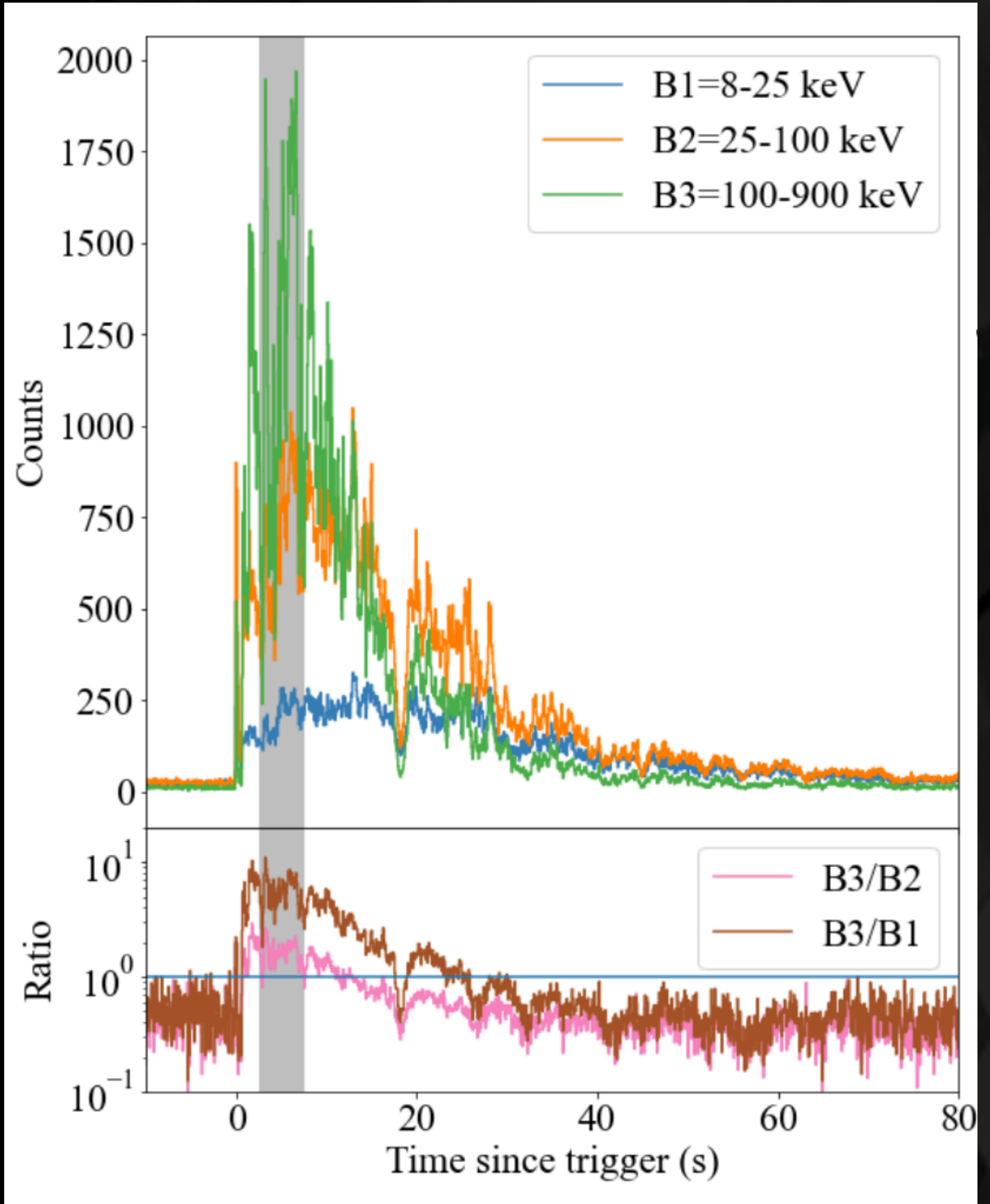
Credits: NASA



Levan+2024

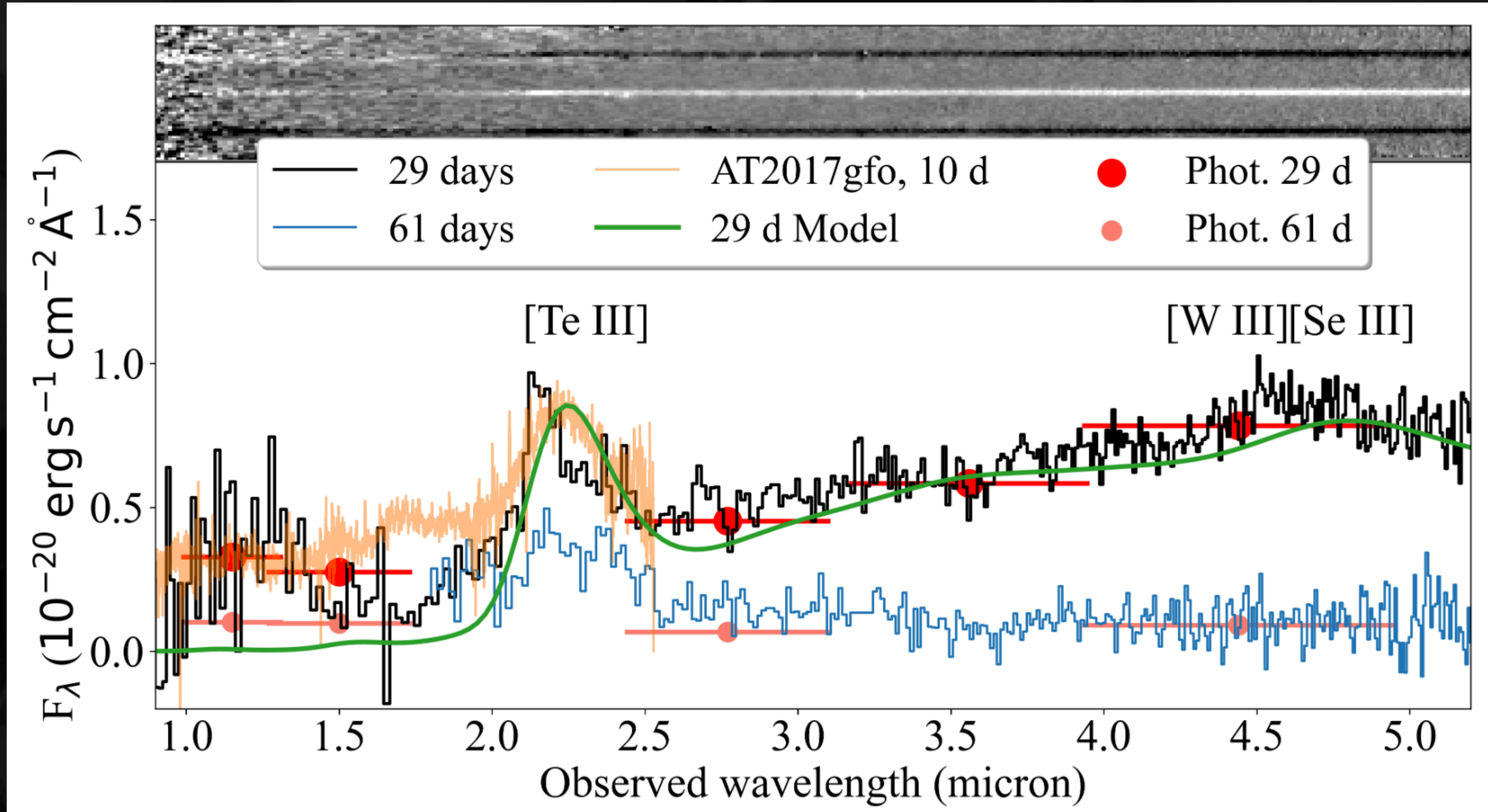


Levan+2024

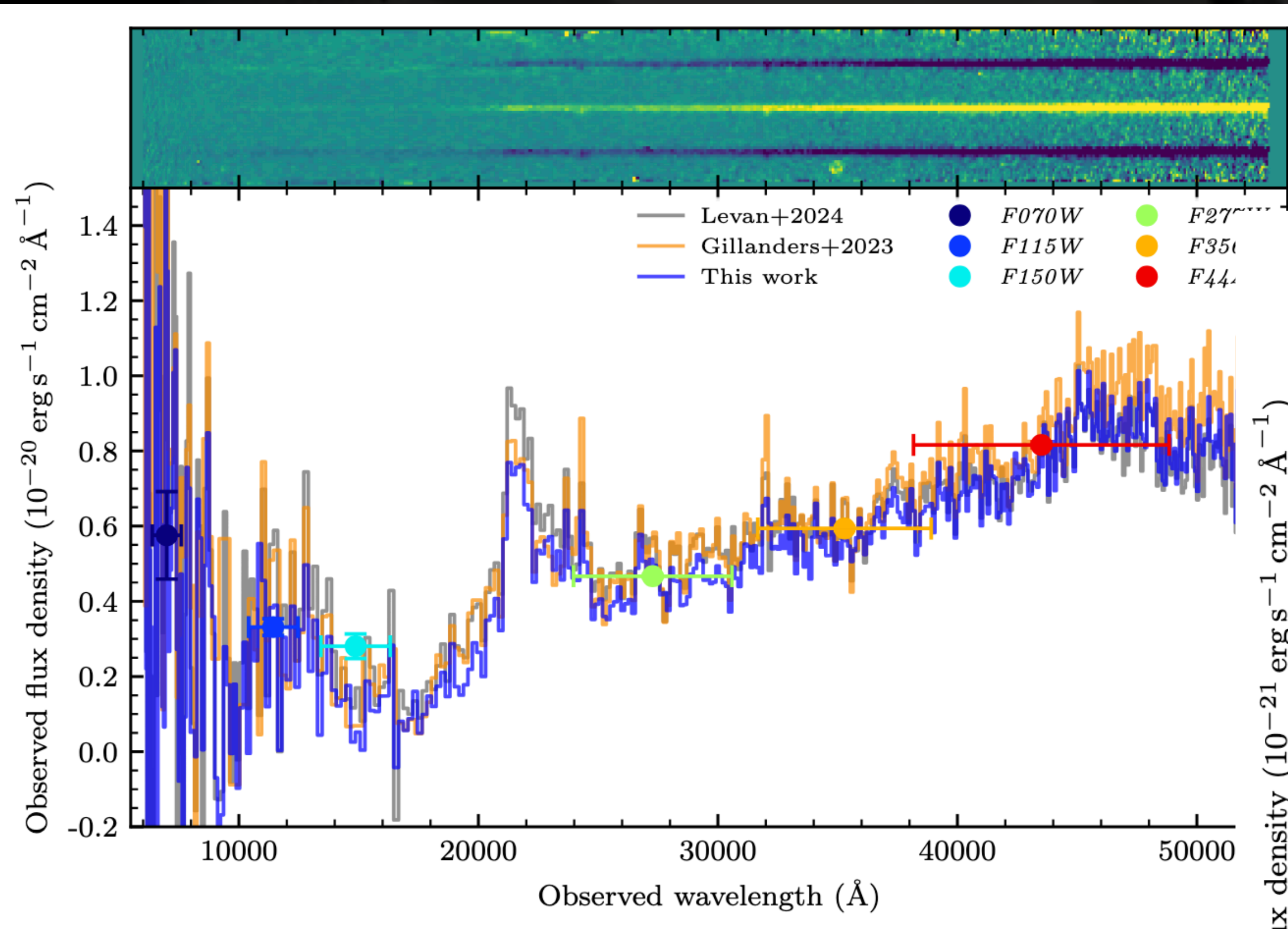


GRB230307A / AT2023vfi (KN)

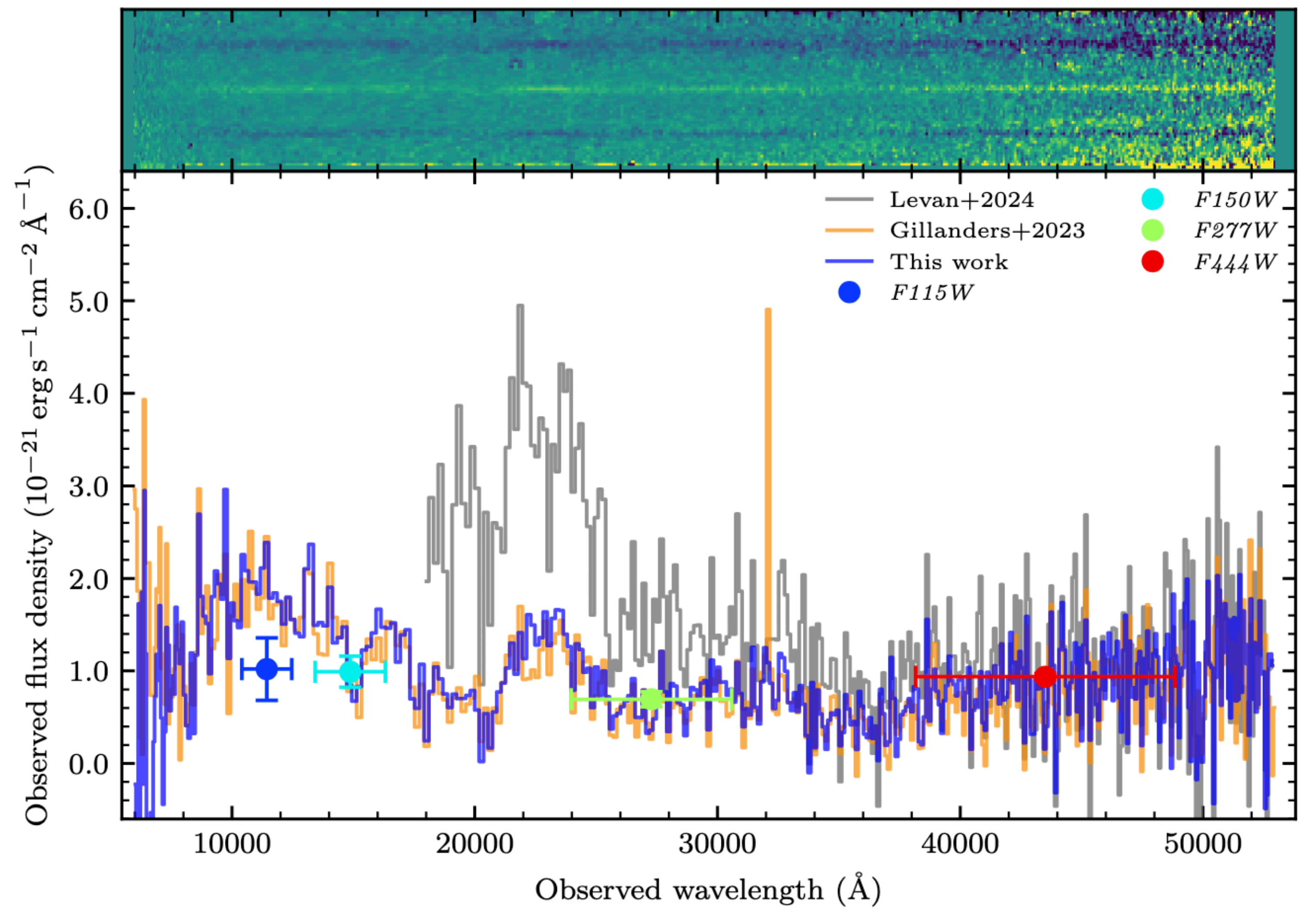
Levan+2024



GRB230307A / AT2023vfi (KN)

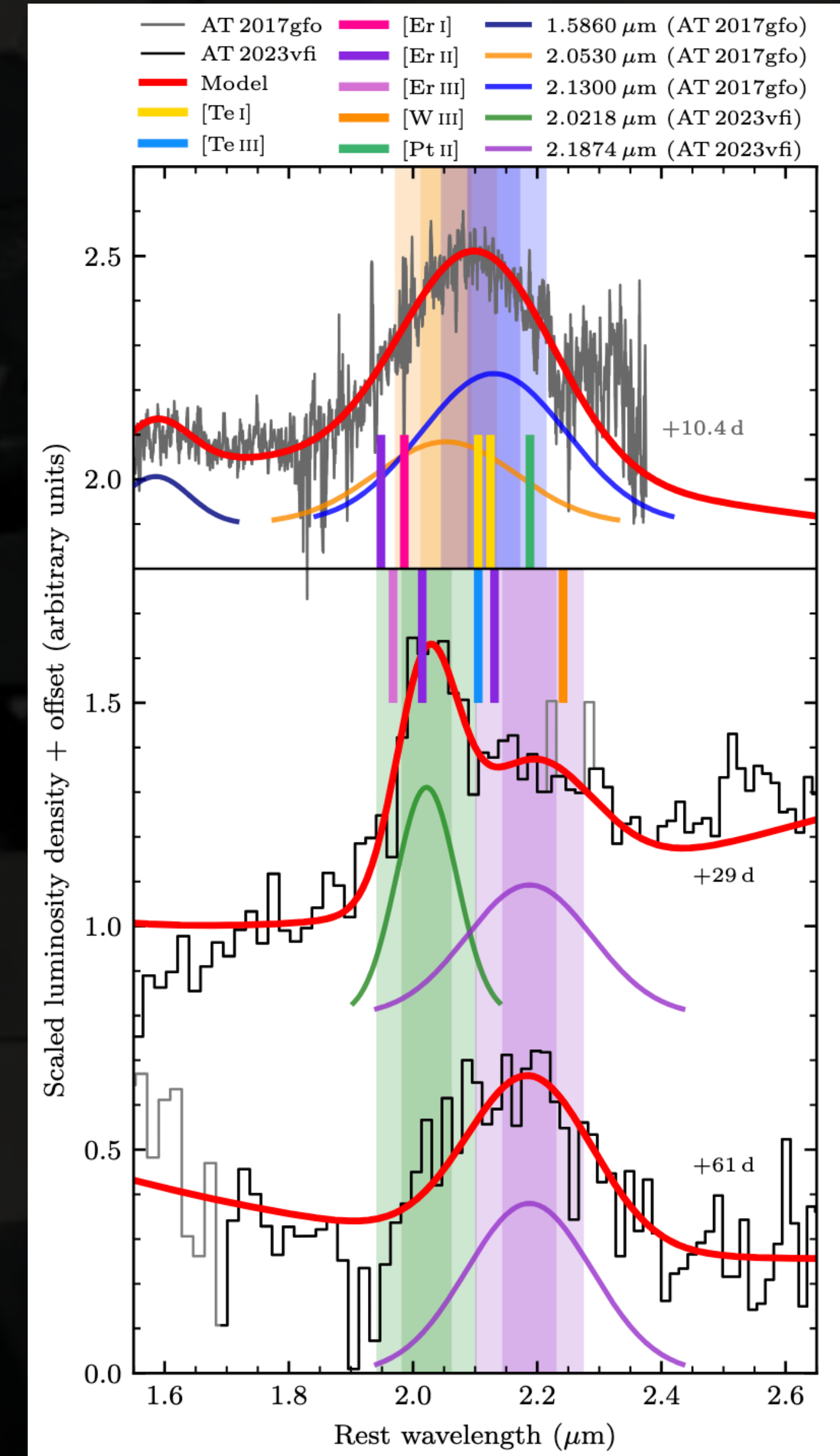
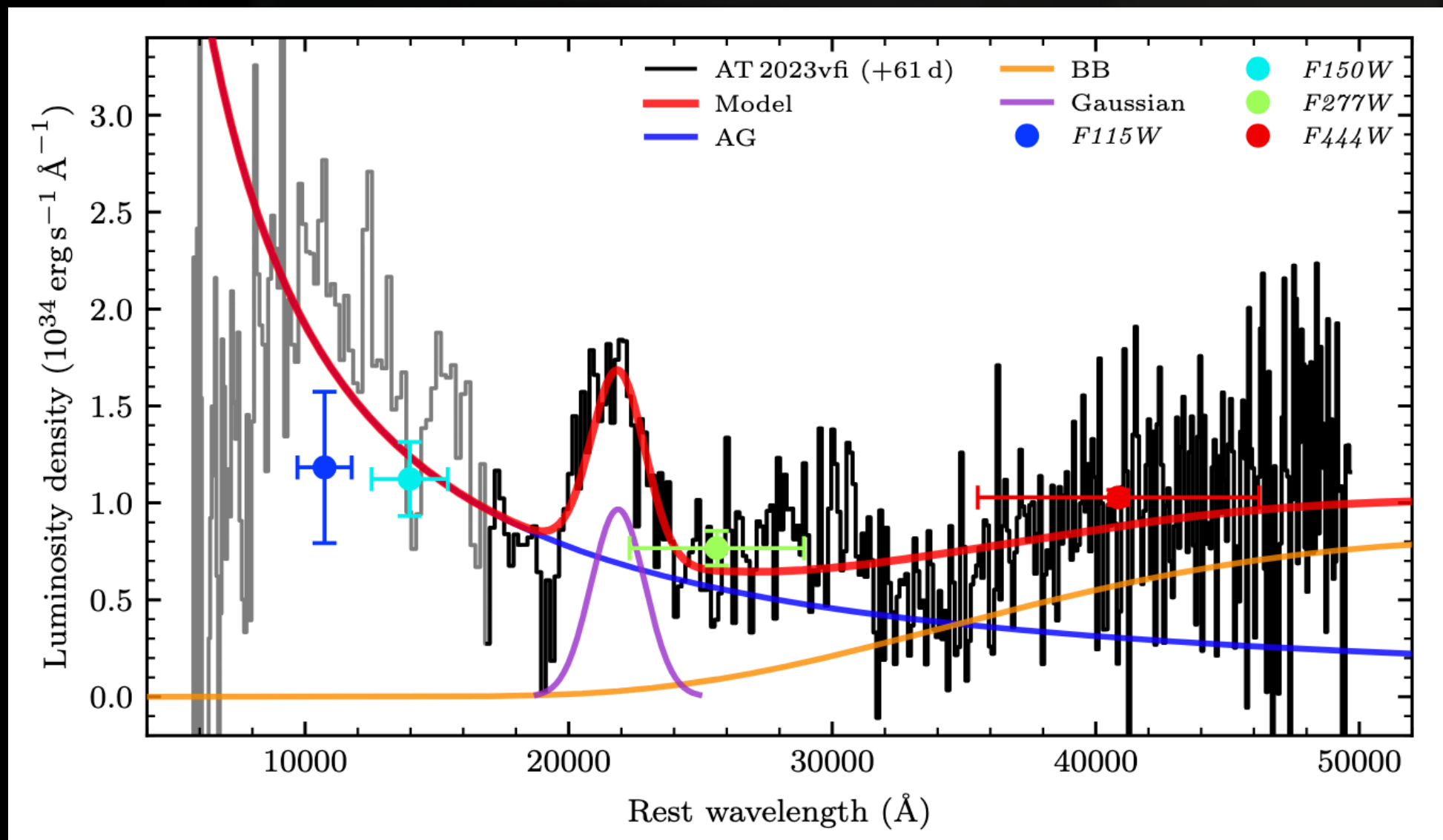
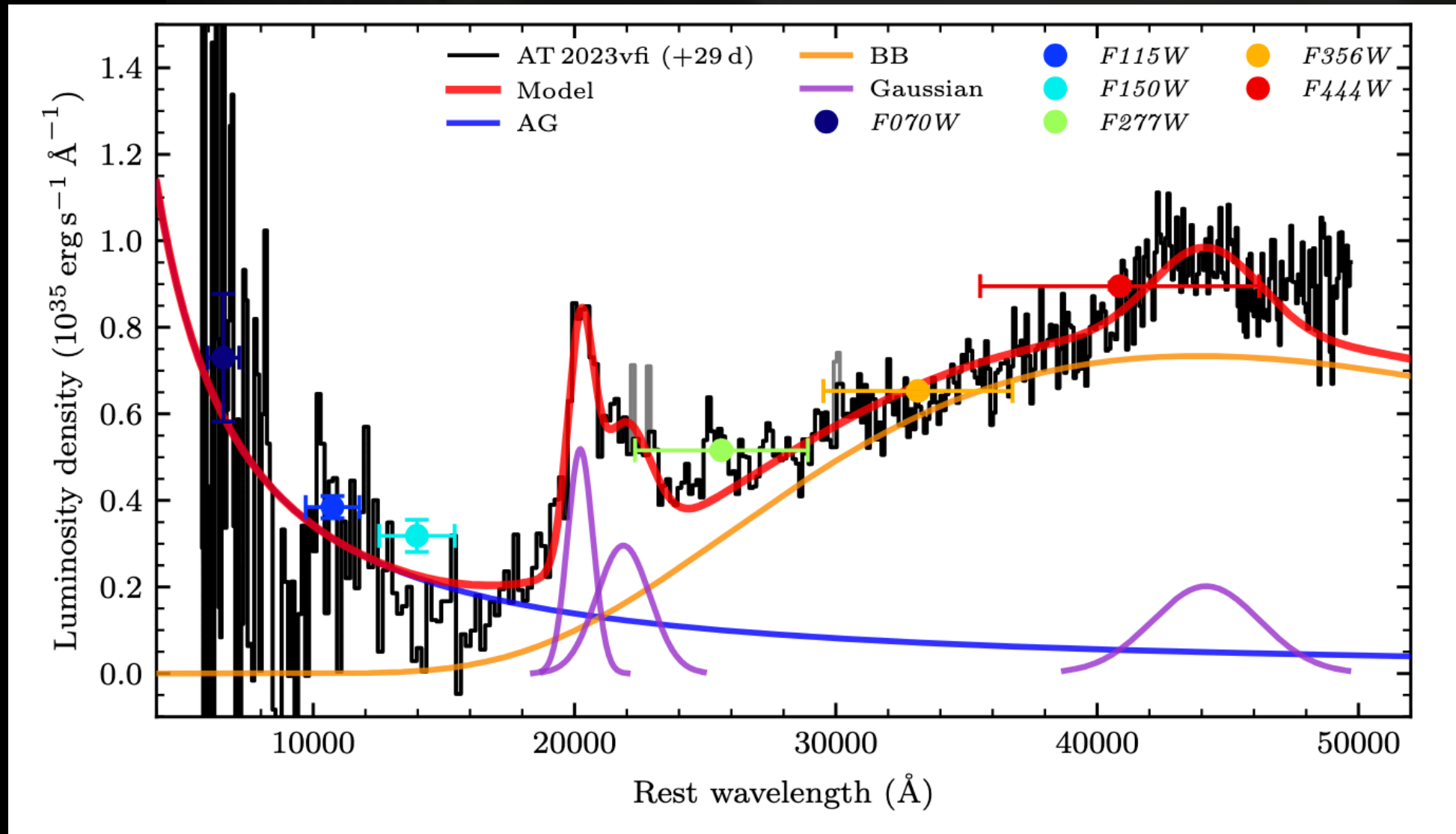


Gillanders+ 2024

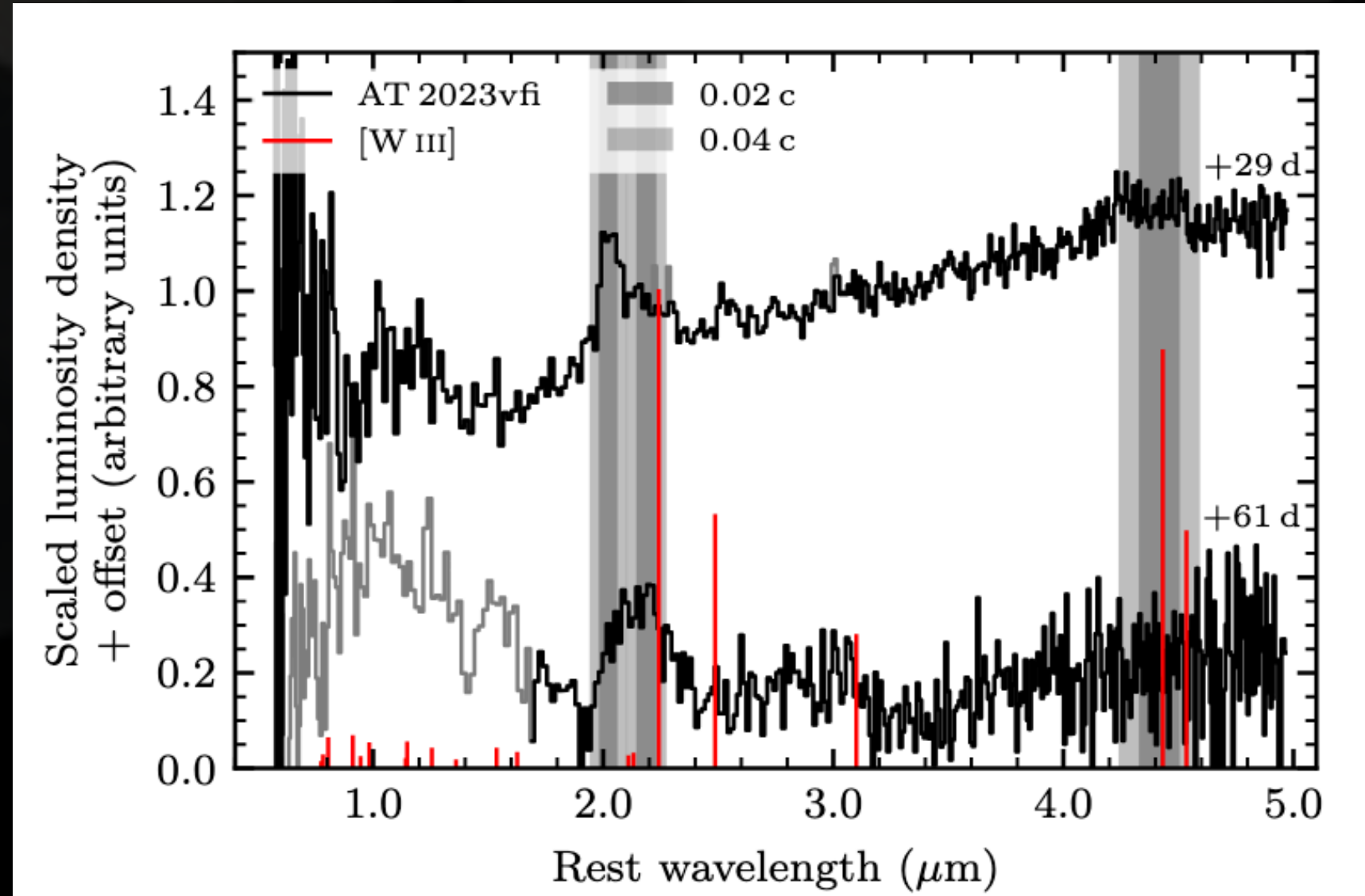
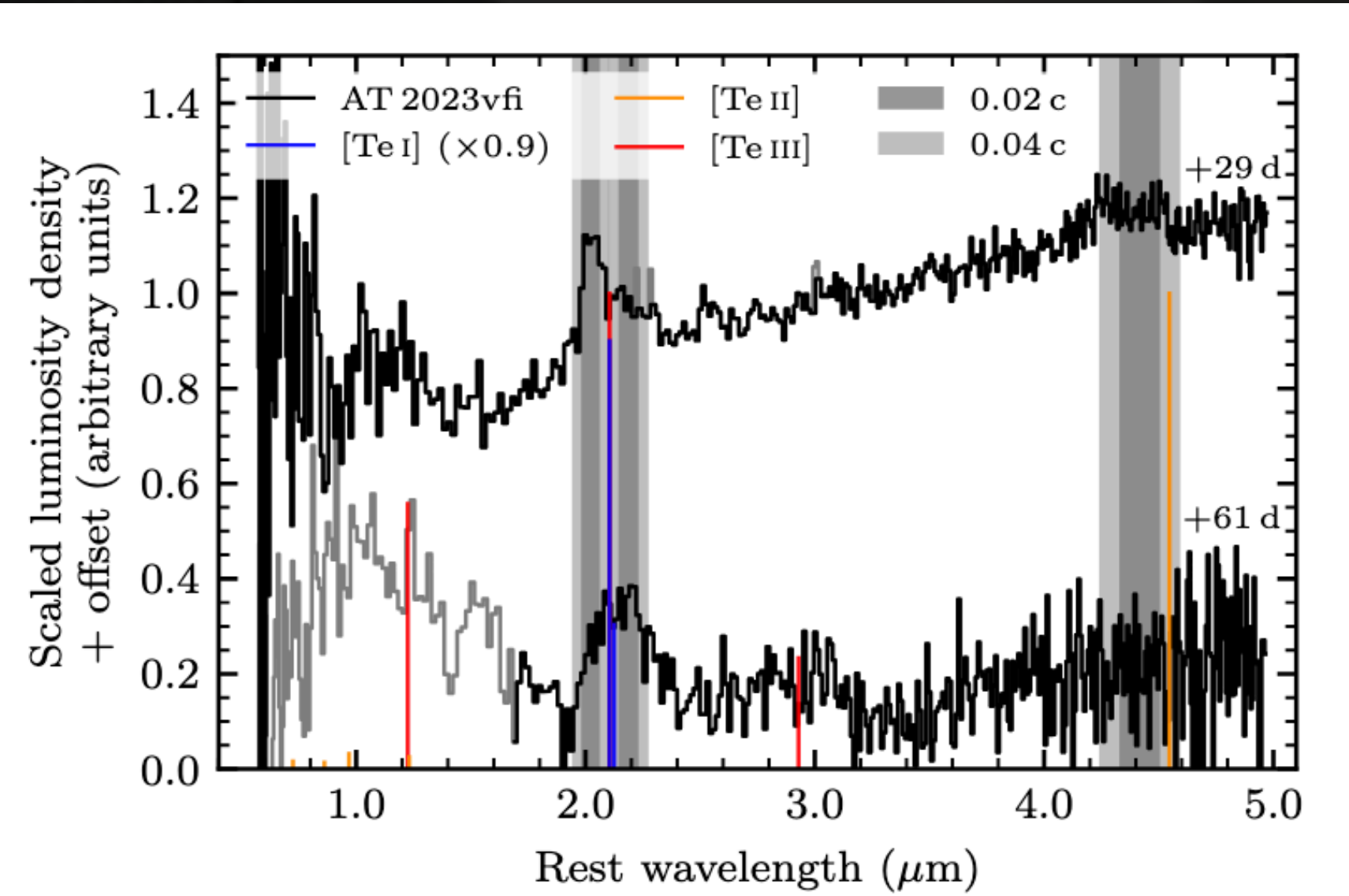


GRB230307A / AT2023vfi (KN)

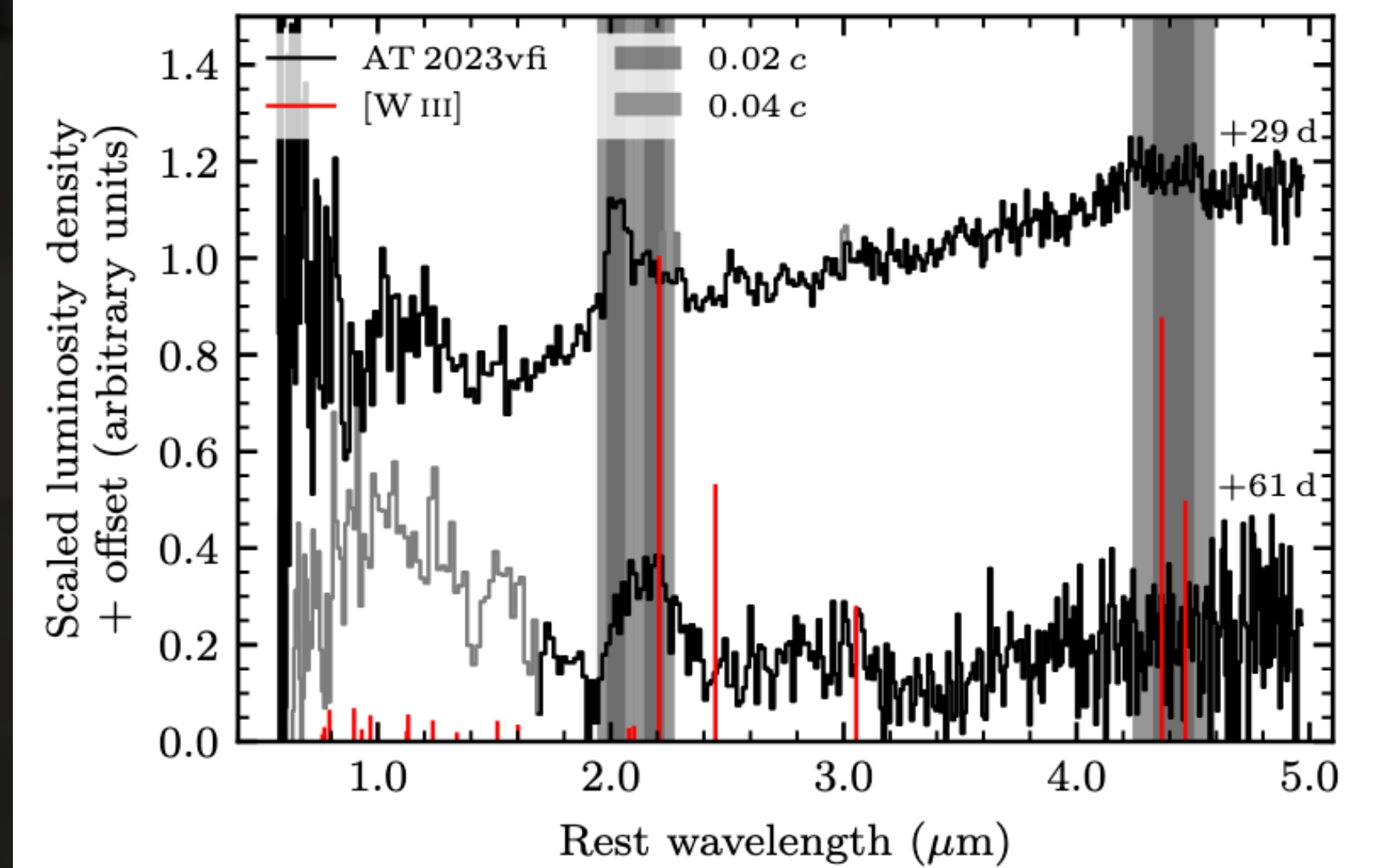
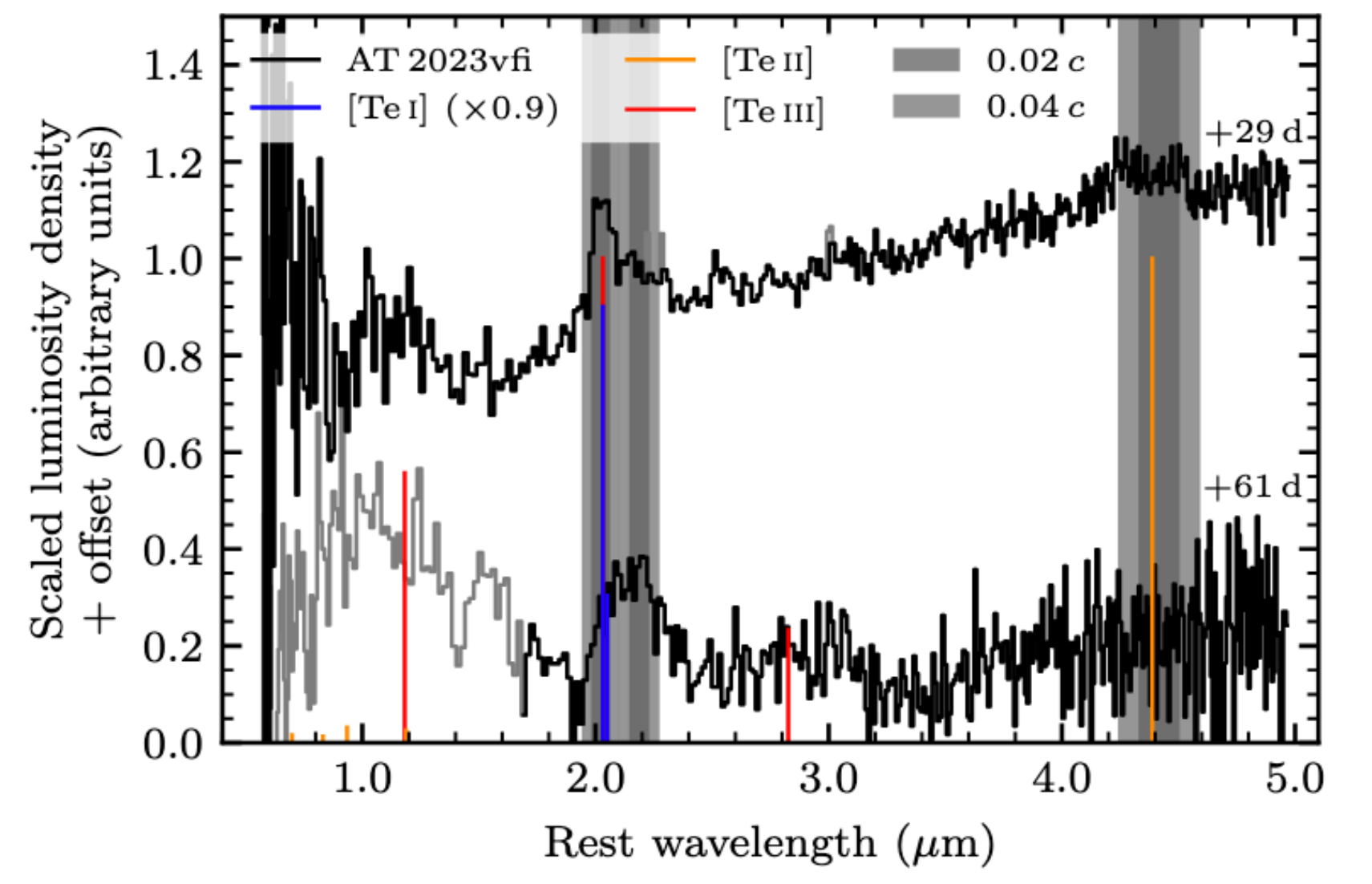
Gillanders+ 2024



GRB230307A / AT2023vfi (KN)



Gillanders+ 2024



Conclusions

Amazing developments on all sides :

Theoretical models

Transfer and spectral synthesis codes

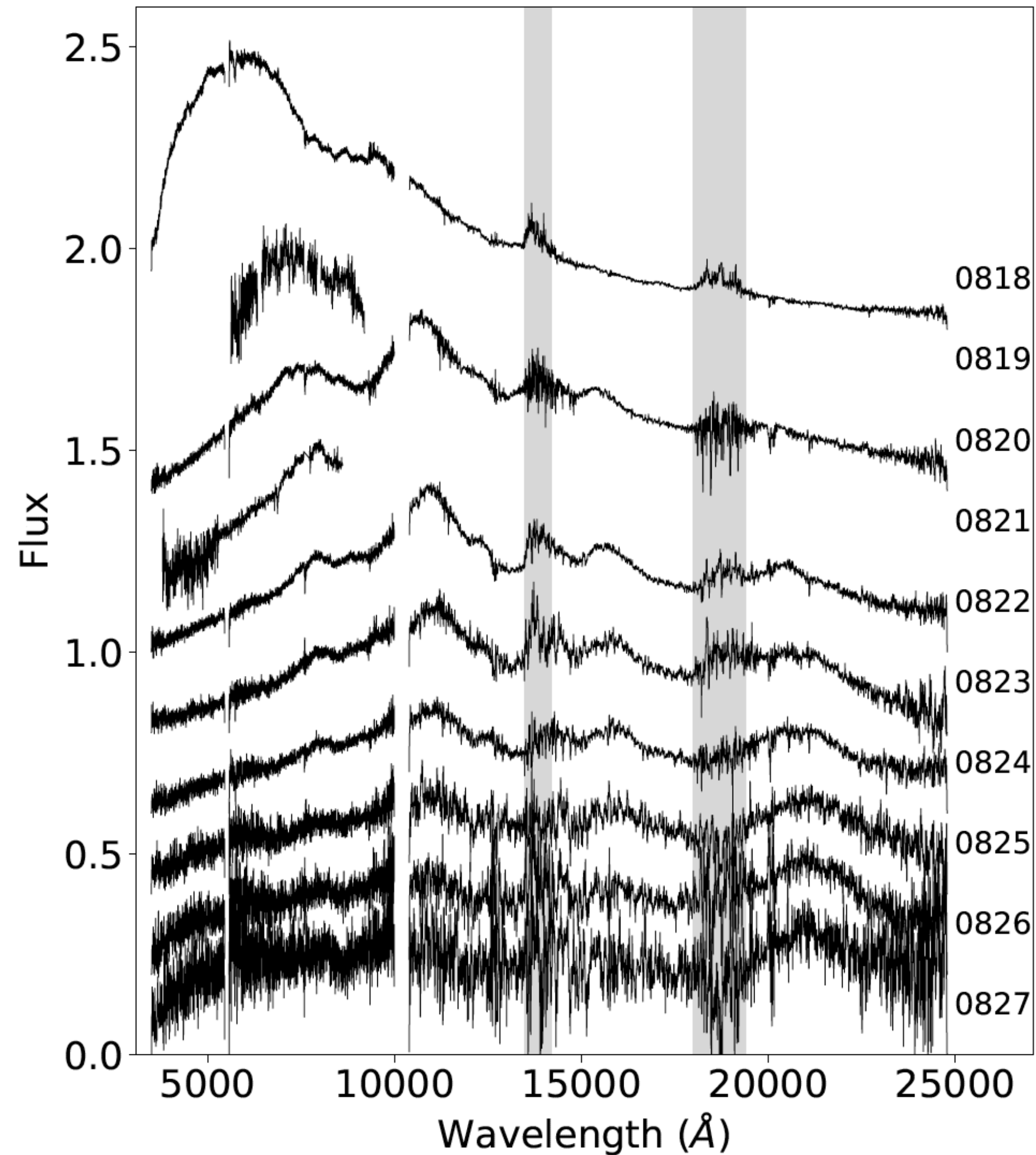
Atomic data

Observations and their interpretation

The answer is always Gamma-ray bursts :)

GW170817 / AT2017gfo (KN)

Lots of unknown !



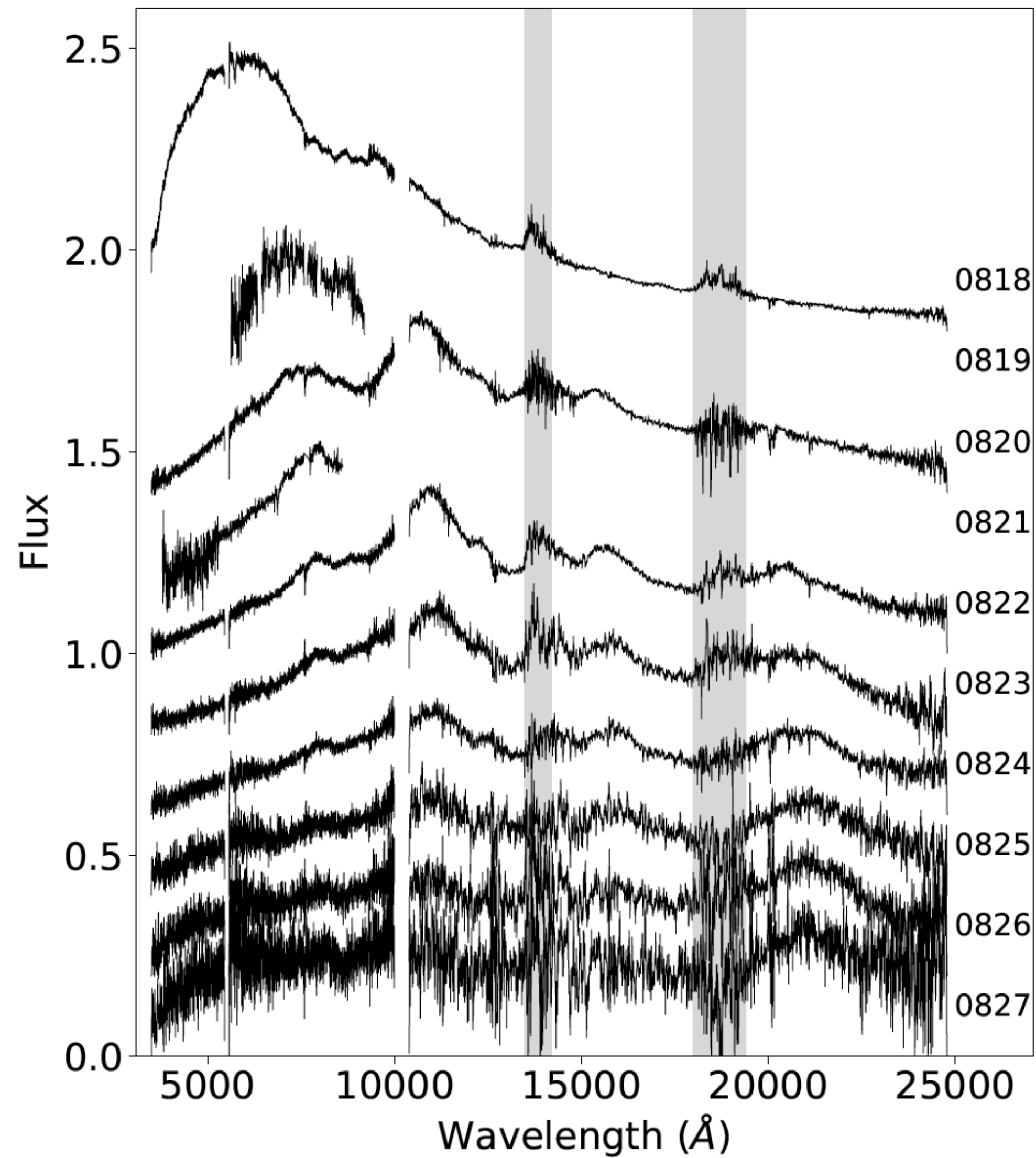
Atomic physics

Atomic transitions

Oscillator strengths

Non-LTE models

GW170817 / AT2017gfo (KN)



KN physics

