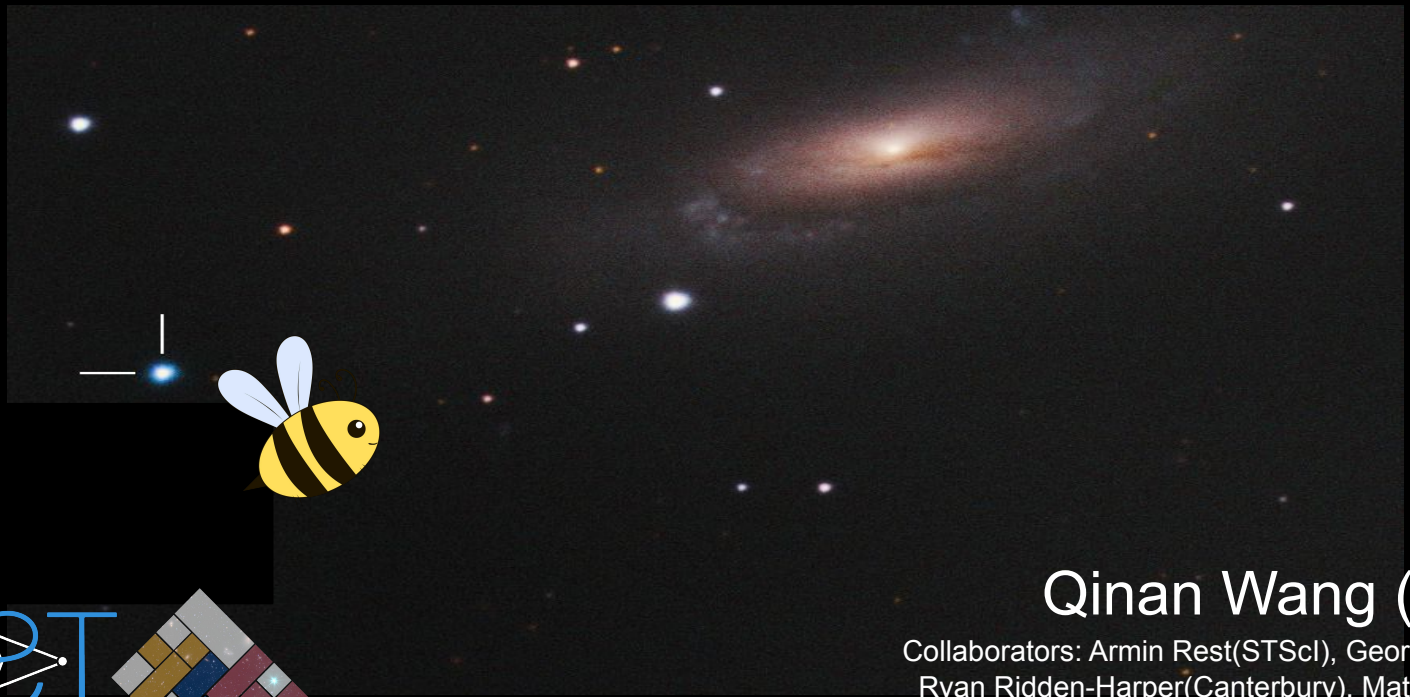
The early excess of SN 2023bee in UV and TESS

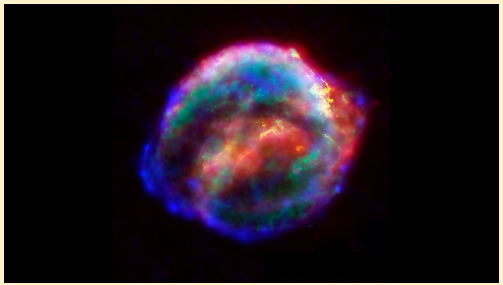


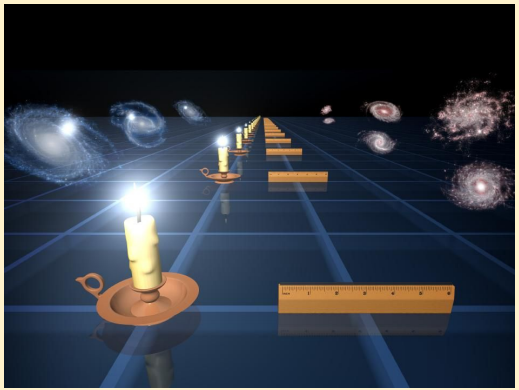
Qinan Wang (JHU)

Collaborators: Armin Rest(STScI), Georgios Dimitriadis(TCD), Ryan Ridden-Harper(Canterbury), Matthew Siebert(STScI), Mark Magee(Warwick), Ryan Foley (UCSC)

Type Ia Supernovae (SNe Ia)

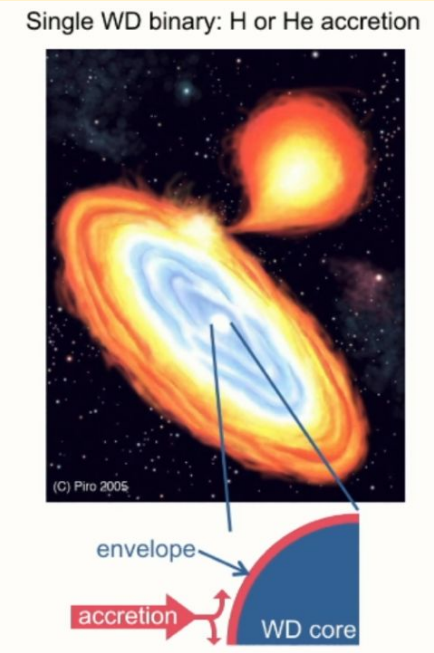
- Lack H & He
- Abundant in intermediate (Si, S) and heavy (Fe, Co) elements
  - Explosion of C/O White Dwarfs when approaching M_{ch}
- Uniform in lightcurve shape (Philips relation)
  - Brighter decay slower
  - Standardizable candle for cosmology!



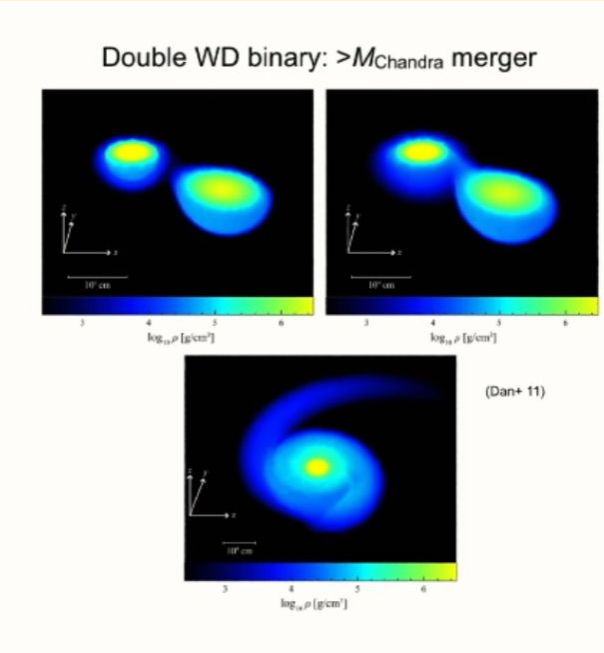


What are the progenitor system?
What's the explosion mechanism?

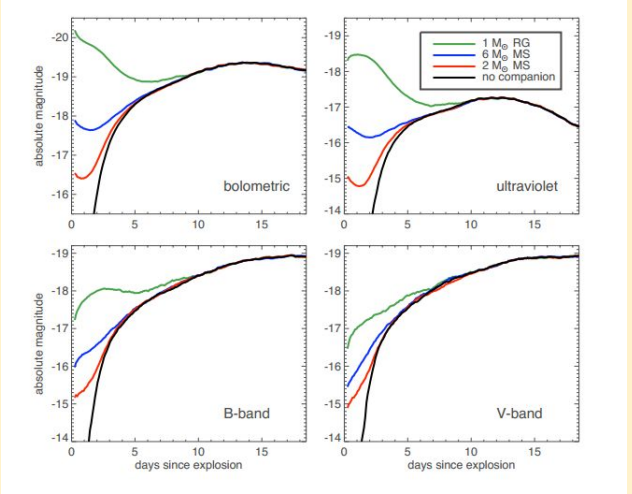
The progenitor should be a C/O white dwarf
What's the companion & mechanism?



Single degenerate (SD)

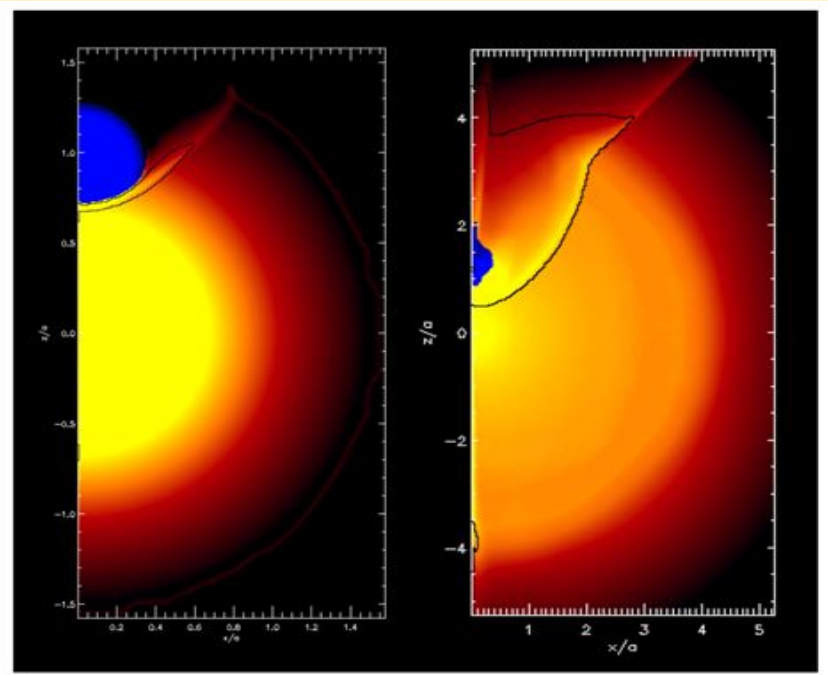


Double degenerate (DD)



Early excess in SD model
(Kasen 2010)

Early lightcurves of SNe Ia: early excess?



Kasen 2010: SNe ejecta collide into red giant

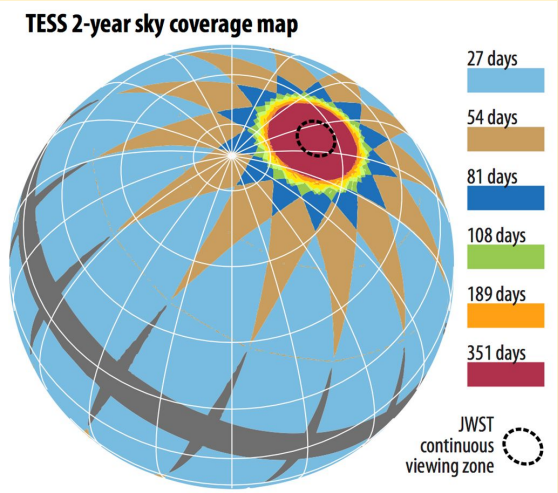
Interaction:
- SD (Kasen10)
- CSM (Piro15)

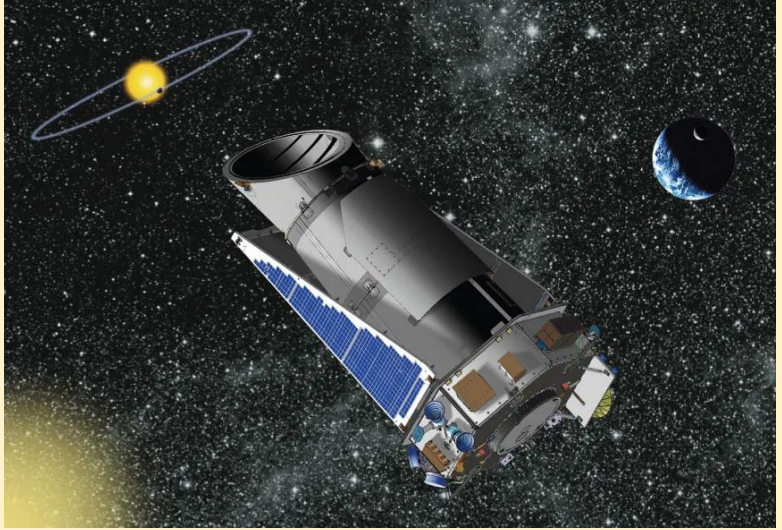
Internal structure:
- Ejecta structure: shallow ^{56}Ni (Piro13)
- Double Detonation: Shell ash (Shen18)
- ….

Early excess

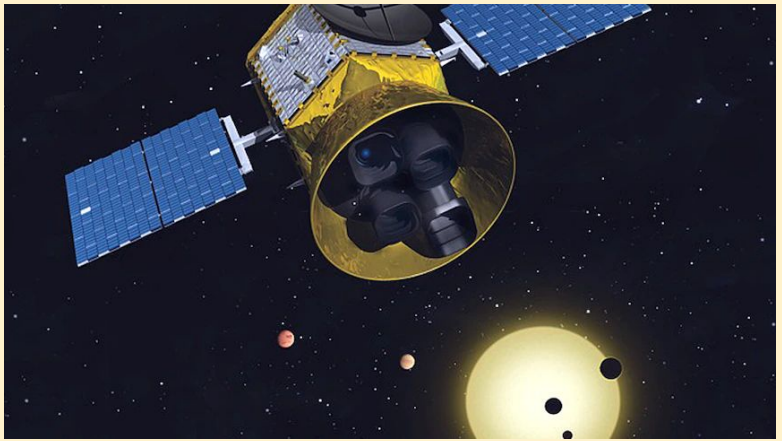
Kepler & TESS telescope

- Large Field-of-View
  - ~100 deg^2 for *Kepler*
  - 2000 deg^2 for *TESS*
- 30/10/3-min cadence



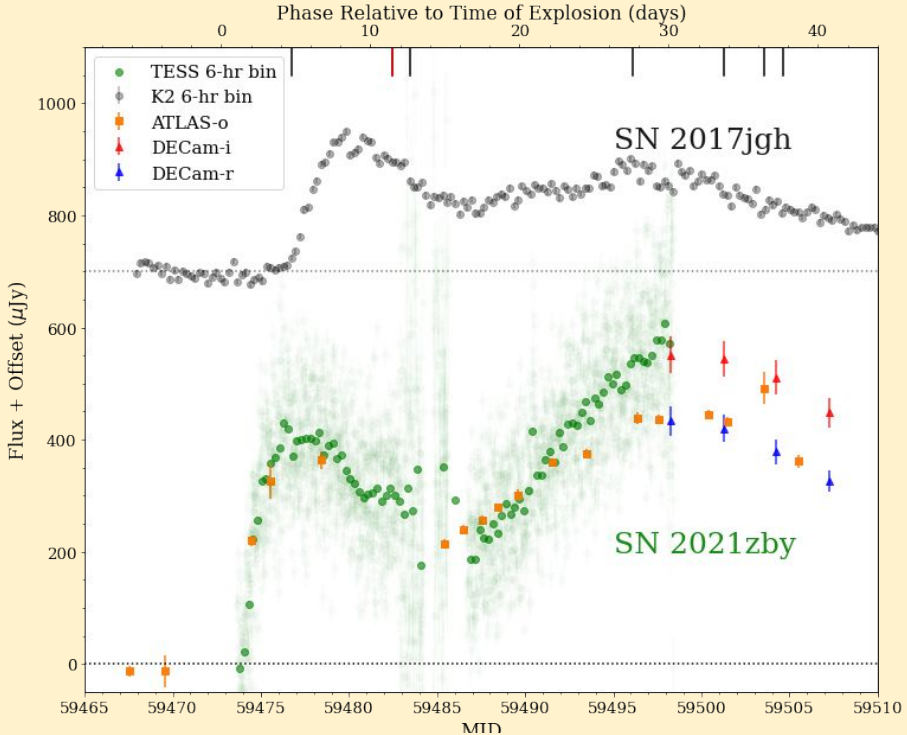


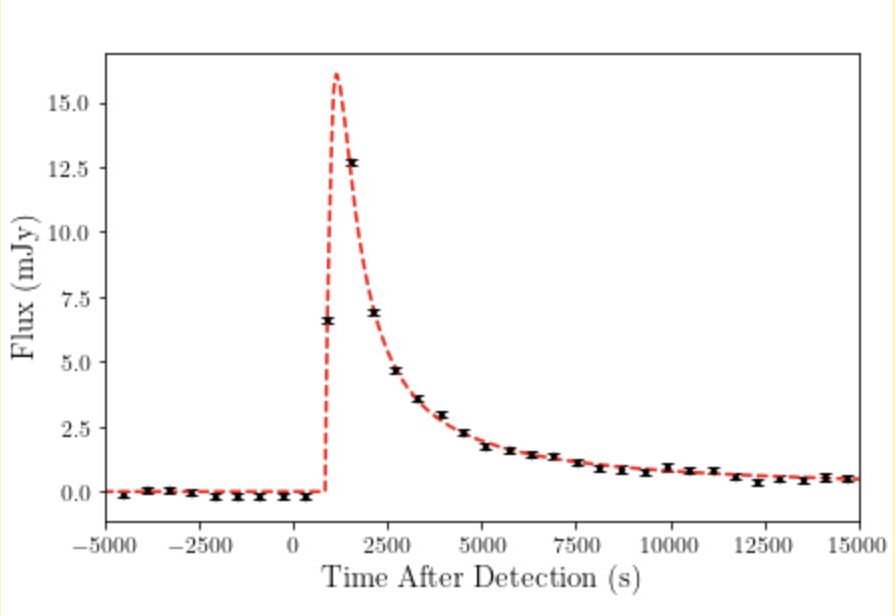
Kepler



TESS

Past & ongoing research with *Kepler & TESS*

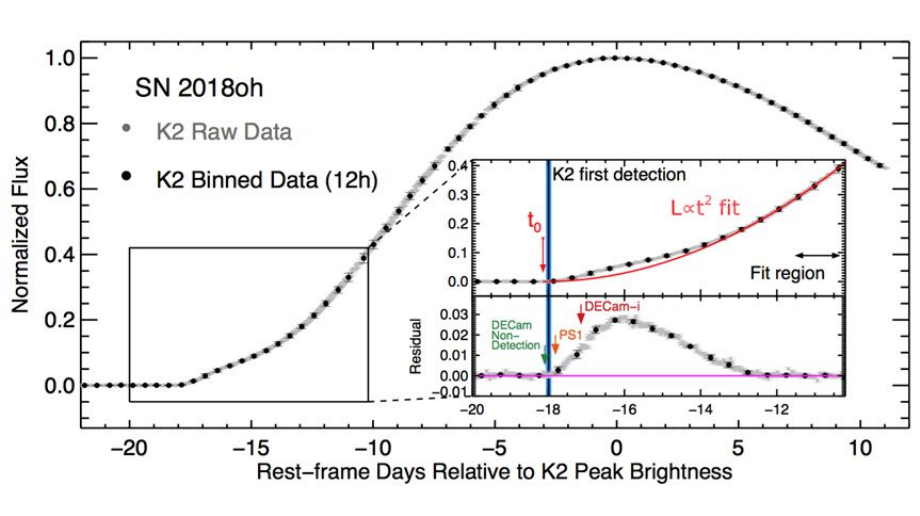




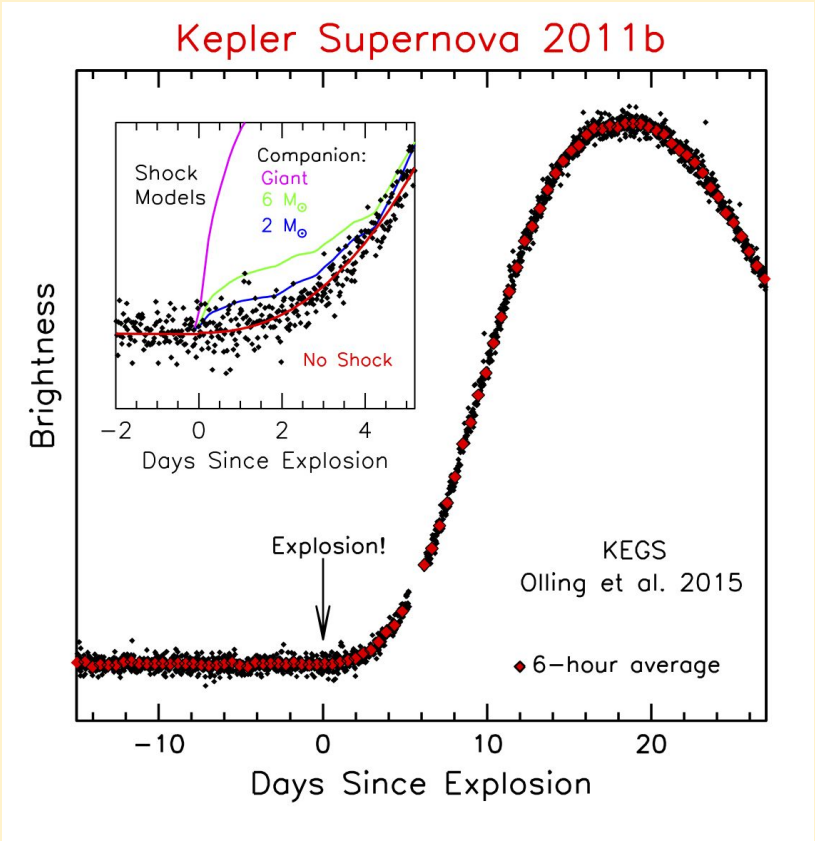
Shock cooling peak of SNe IIb (Armstrong+21, Wang+23)

GRB afterglows (Ruxburgh in prep)

Past research with *Kepler & TESS*

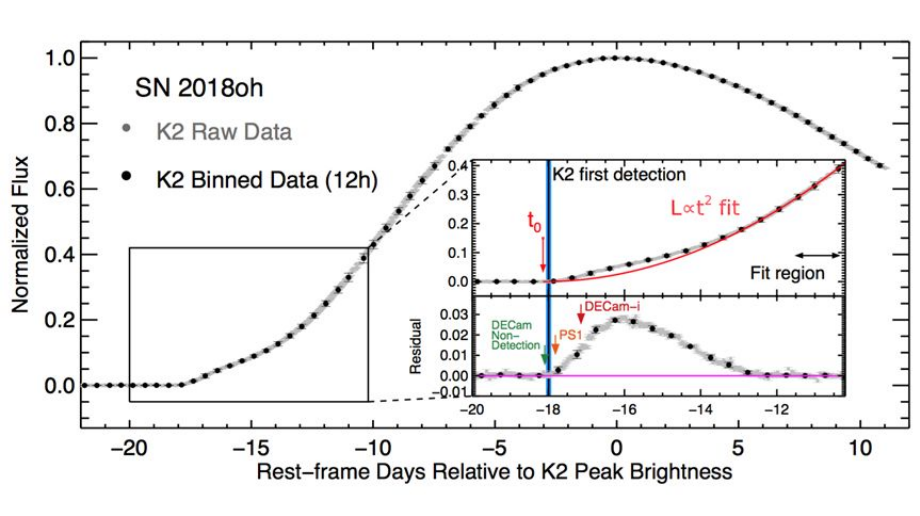


SN Ia with early bump: SN 2018oh (Dimitriadis+18a)

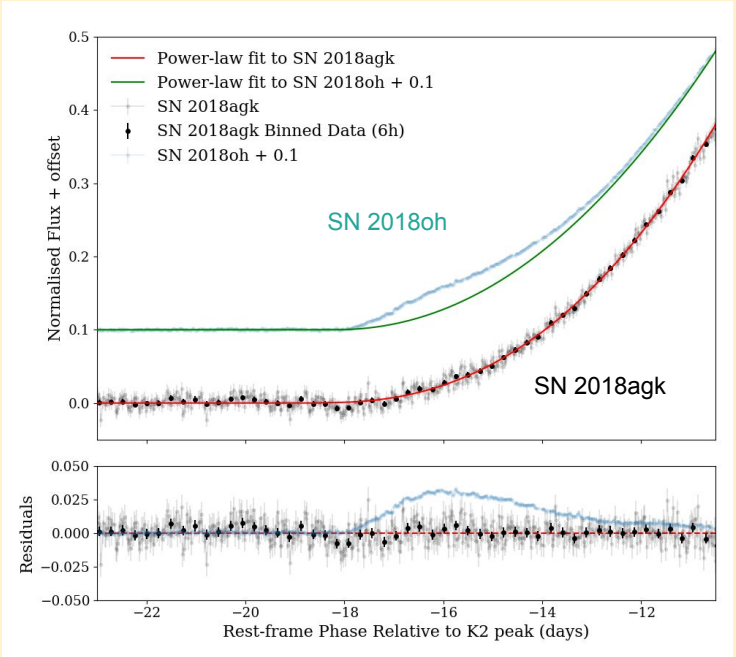


3 SN Ia without early bump: Olling+15

Past research with *Kepler & TESS*



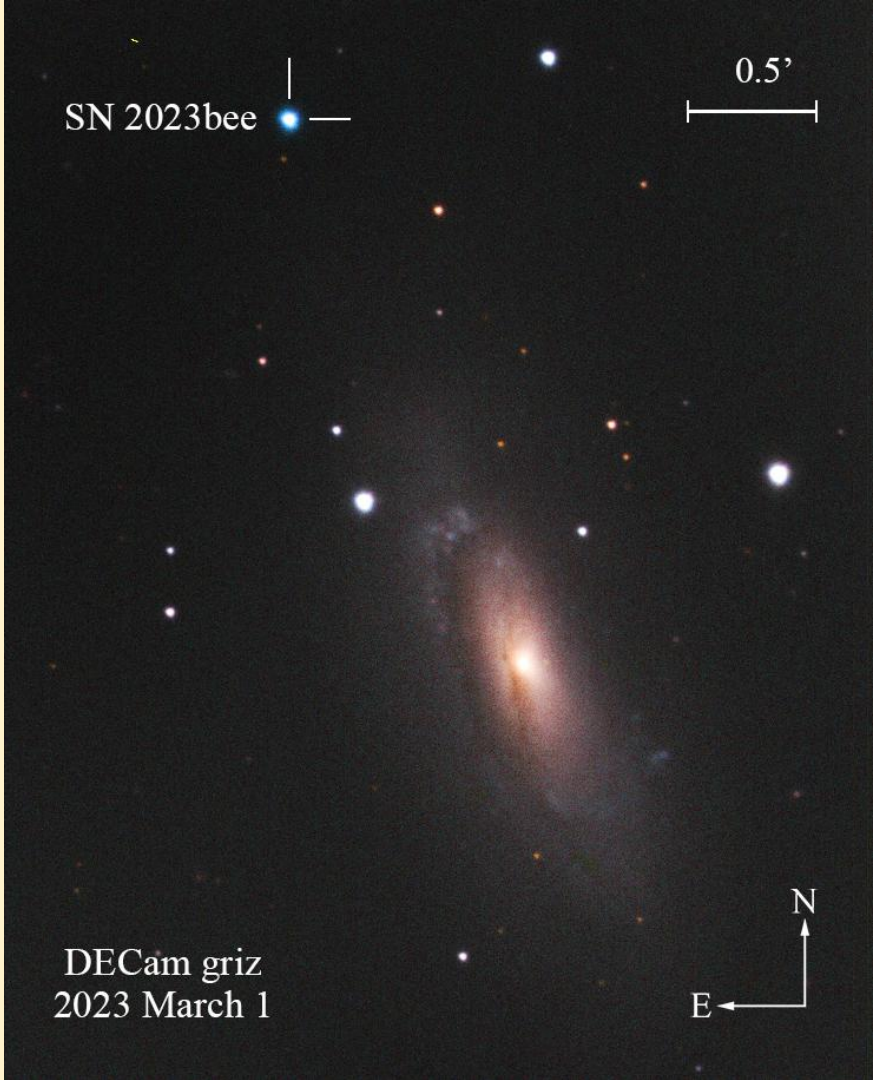
SN Ia with early bump: SN 2018oh (Dimitriadis+18a)



SN Ia with early bump: SN 2018agk (Wang+21)

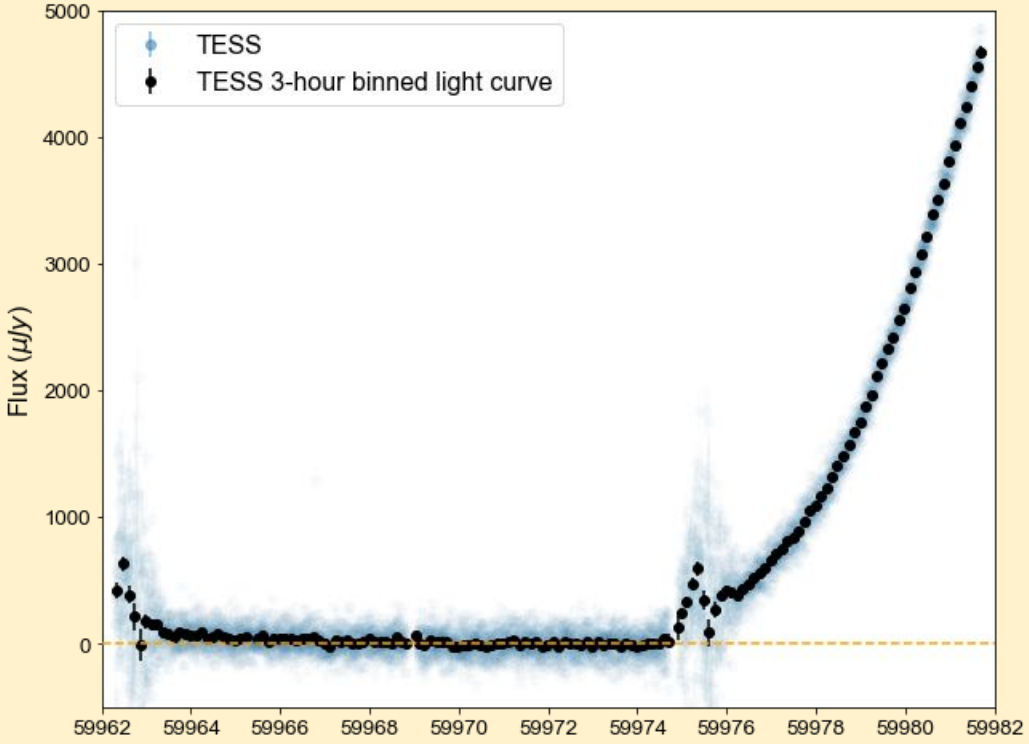
SN 2023bee

- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!



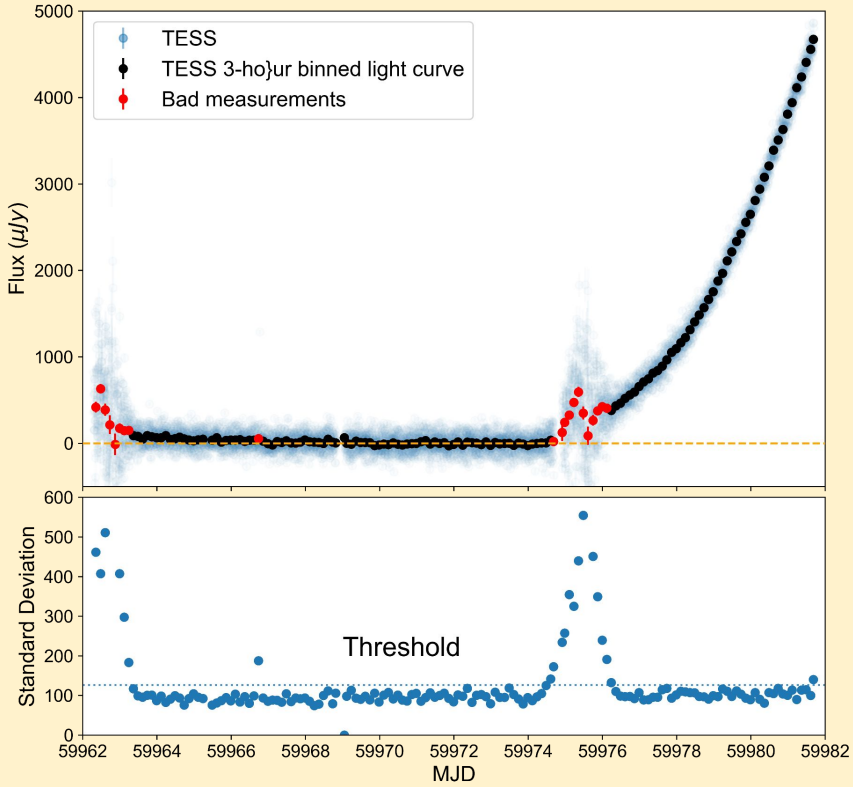
SN 2023bee: *TESS*

- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!
- Most prominent bump! ...or just noise?



SN 2023bee: *TESS*

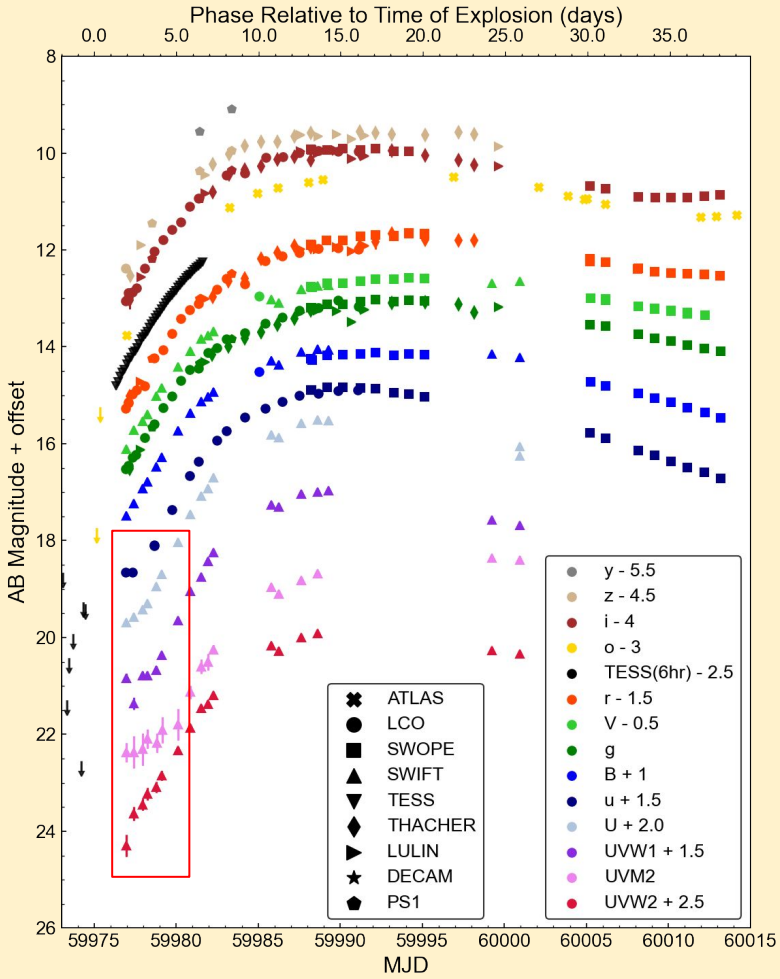
- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!
- The prominent bump turns out to be fake, but early excess still exists



Noise cut on *TESS* light curve (Wang+21)

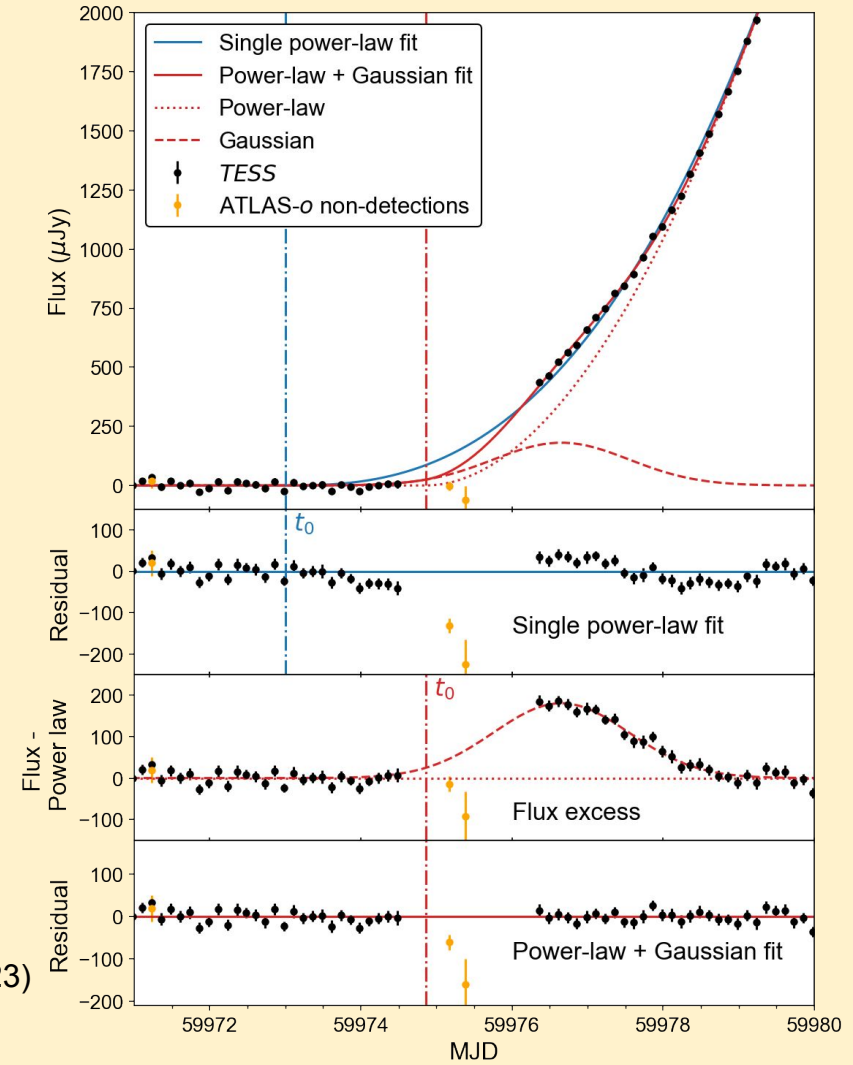
SN 2023bee: photometry

- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!
- Clear excess in swift
- Confirmed in optical bands with power-law fit.



SN 2023bee: excess

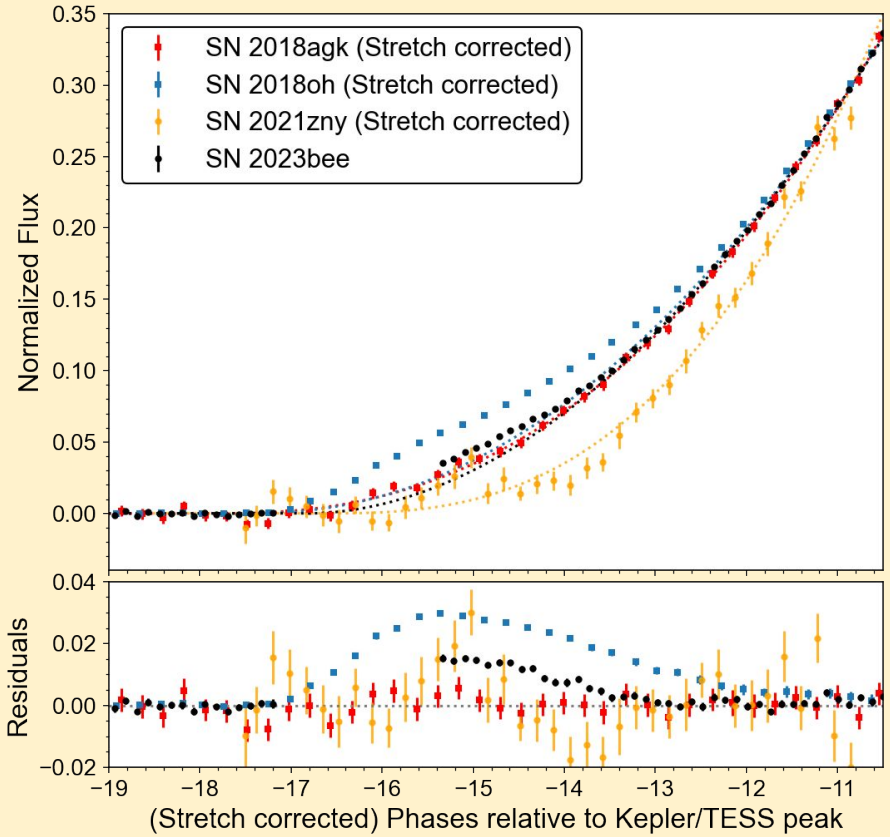
- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!
- Clear excess in swift
- Confirmed in optical bands with power-law fit.



Single power-law and power-law+Gaussian fit to *TESS* light curves (Wang+23)

SN 2023bee: excess

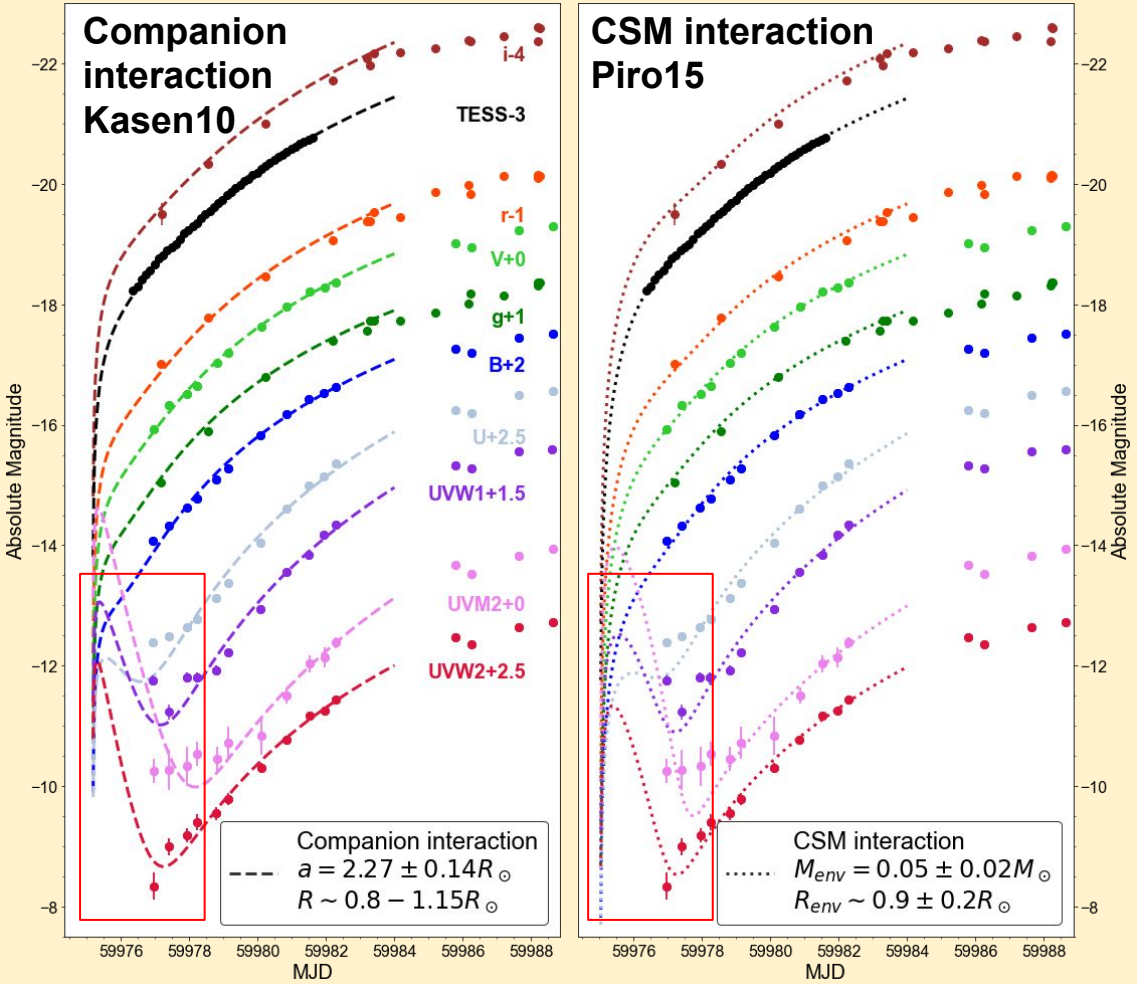
- Discovered by DLT40 on Feb 1
- SN Ia in NGC2708!
- Clear excess in swift
- Confirmed in optical bands with power-law fit.
- Relatively weak excess compared to SN 2018oh



Comparing the rise of SN 2023bee with other SNe Ia in *Kepler/TESS* (Wang+23)
Notice that SN 2021zny is a 03fg-like SN Ia

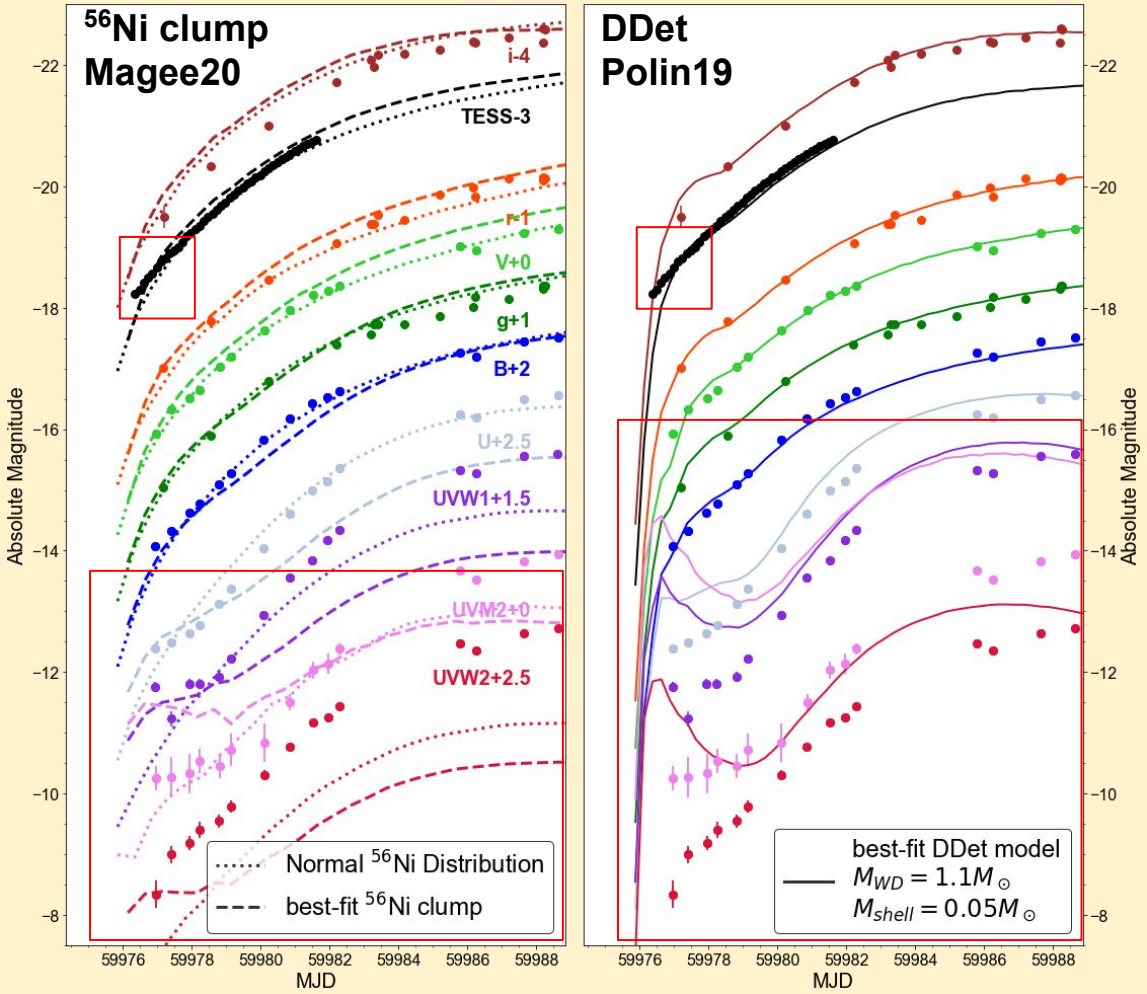
SN 2023bee: model fit

- Model fit: no model can reproduce the smooth rise in UV and optical simultaneously

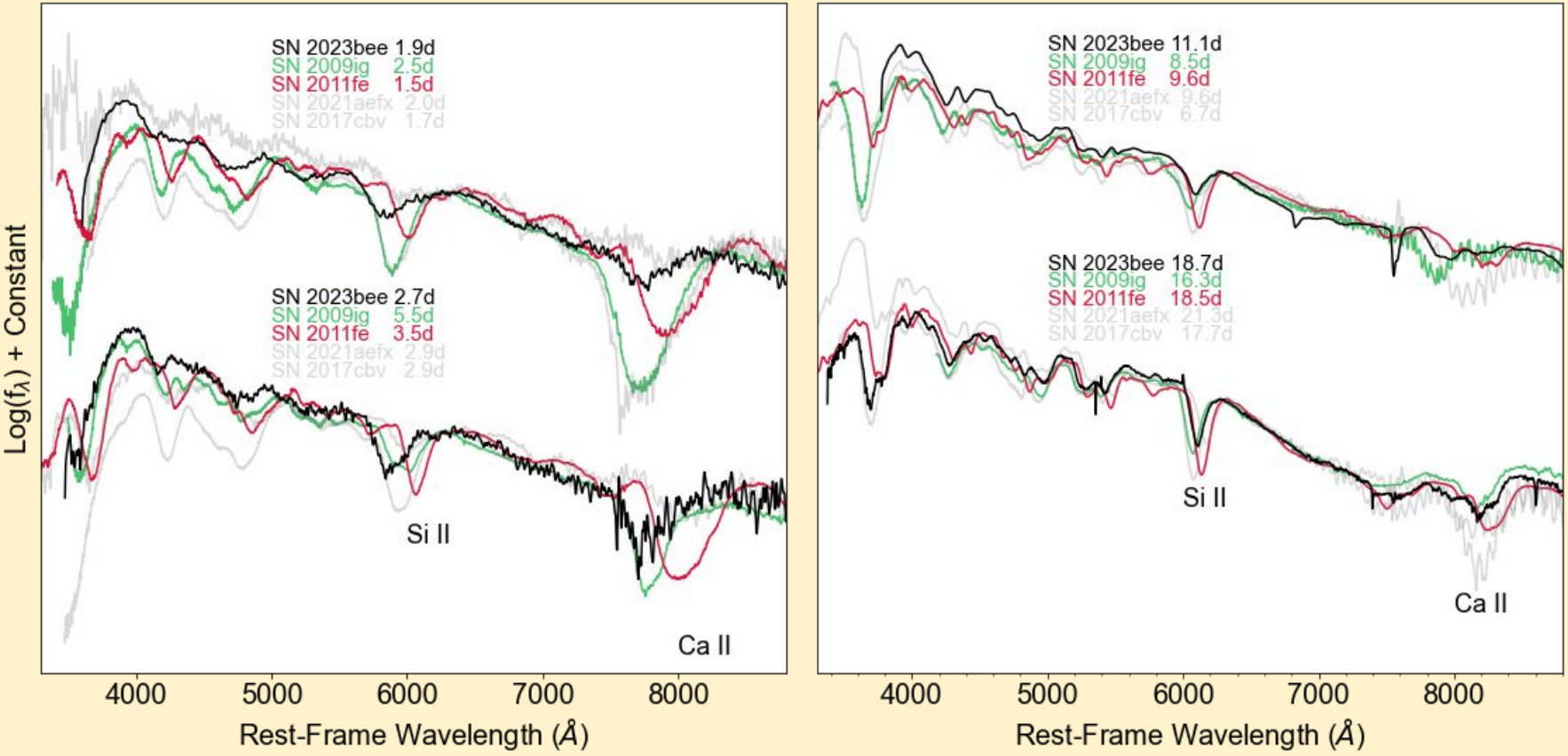


SN 2023bee: model fit

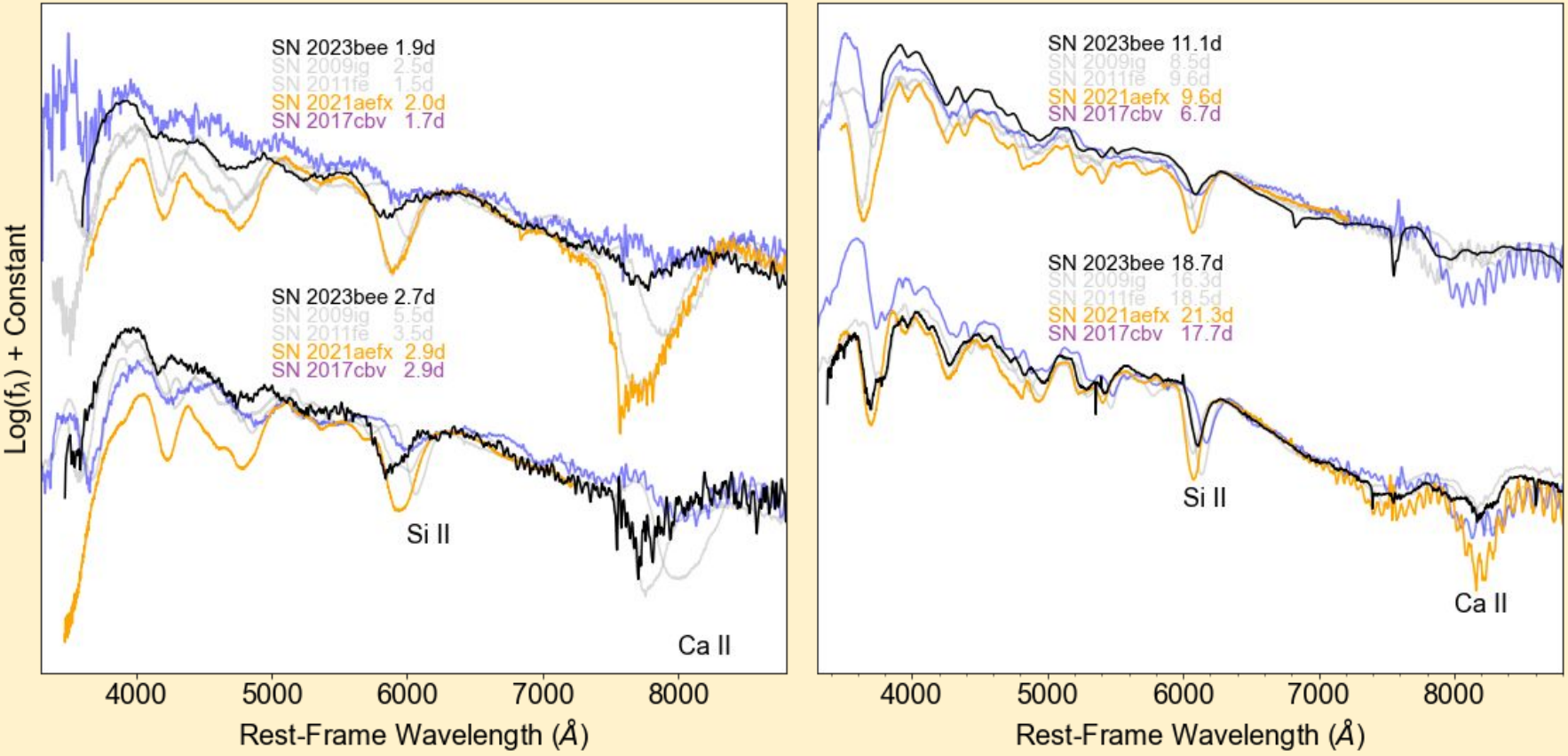
- Model fit: no model can reproduce the smooth rise in UV and optical simultaneously
- Need better modelling for early UV light curve!



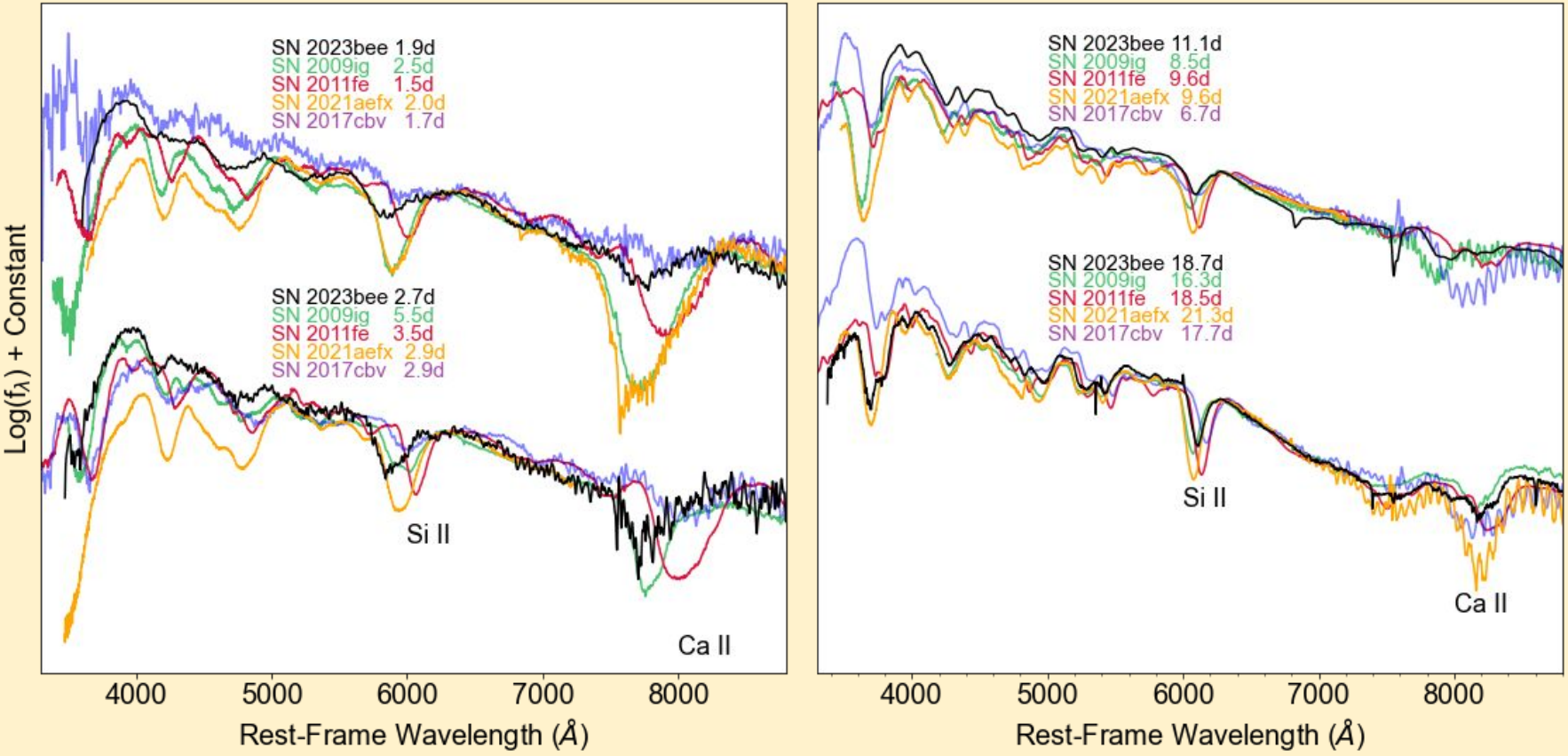
Comparison with spectra of SNe Ia without early excess



Comparison with spectra of SNe Ia with early excess

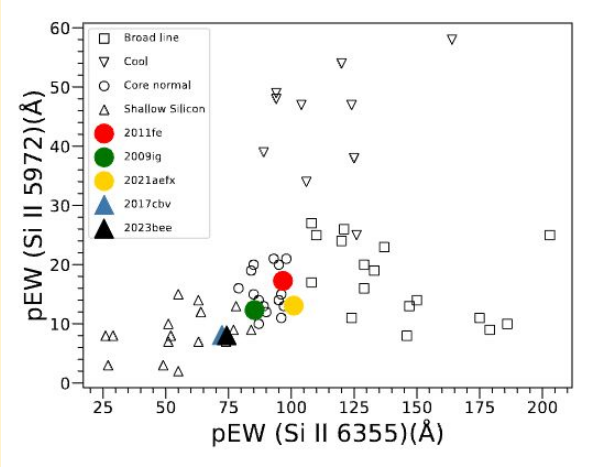


SN 2023bee: spectra

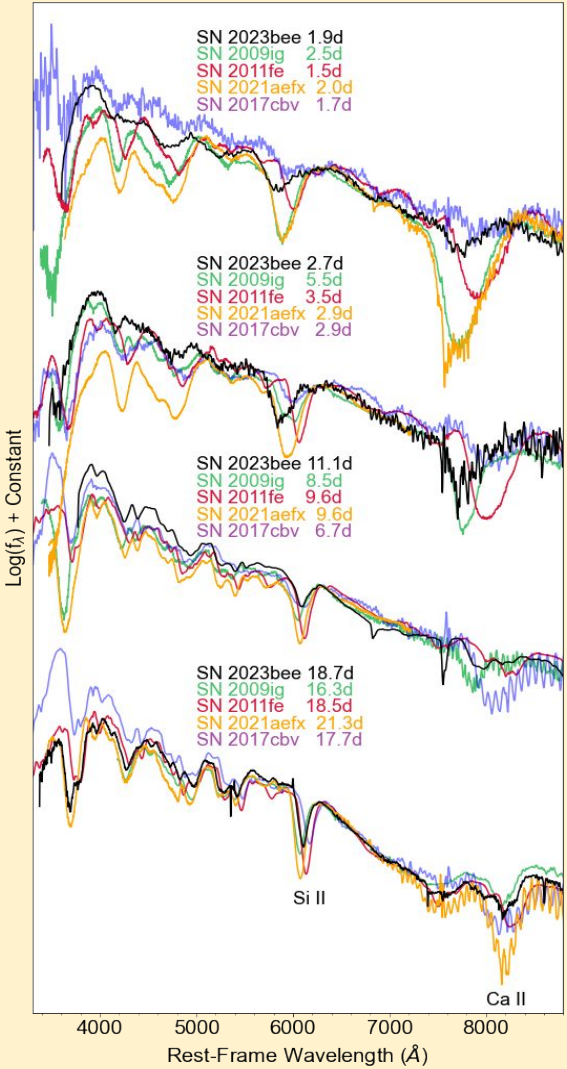


SN 2023bee: spectra

- Two spectra around the early excess
- High velocity features at early time
- Relatively shallow line features
    - Stronger continuum?



Comparison between the spectra of SN 2023bee with SN2021aefx (with early excess) and 2009ig&2011fe (no early excess)



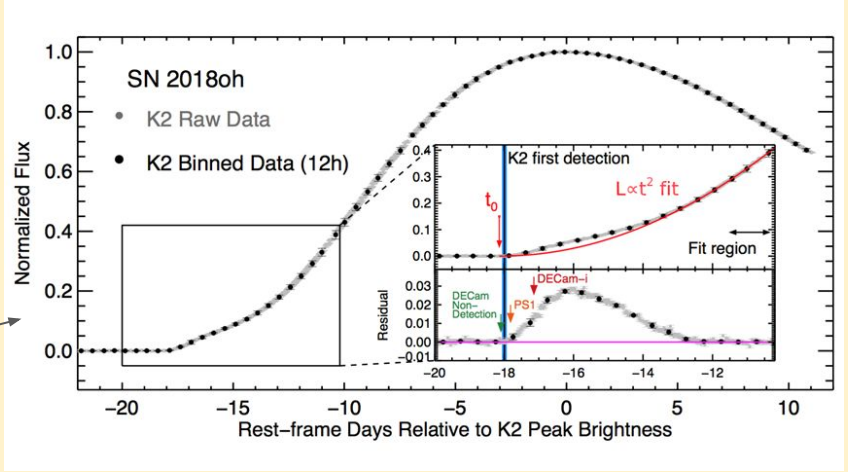
Summary on SN 2023bee

- Brightest SN Ia observed by *TESS.*
- Clear excess in swift and optical bands**.**
- Model fit: no model can reproduce the smooth rise in UV and optical simultaneously
- Spectra around the early excess: diversity in SNe Ia with early excess?
- (Near) future work:
    - nebular phase spectra, searching for narrow H/He features
    - modelling spectroscopic evolution

Beyond SN 2023bee

What's the rate of early excess?

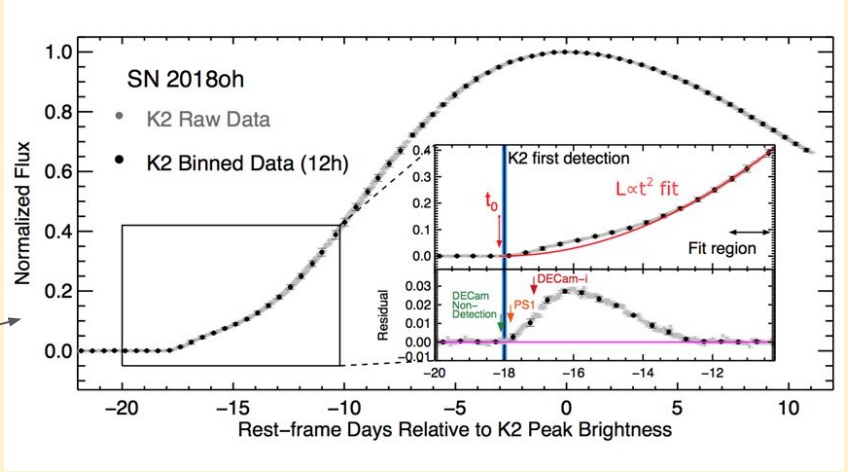
- Normal SNe Ia with early excess in *Kepler/TESS*
  - SN 2018oh, brightest SN Ia in *Kepler*
  - SN 2023bee, brightest SN Ia in *TESS*



Beyond SN 2023bee

What's the rate of early excess?

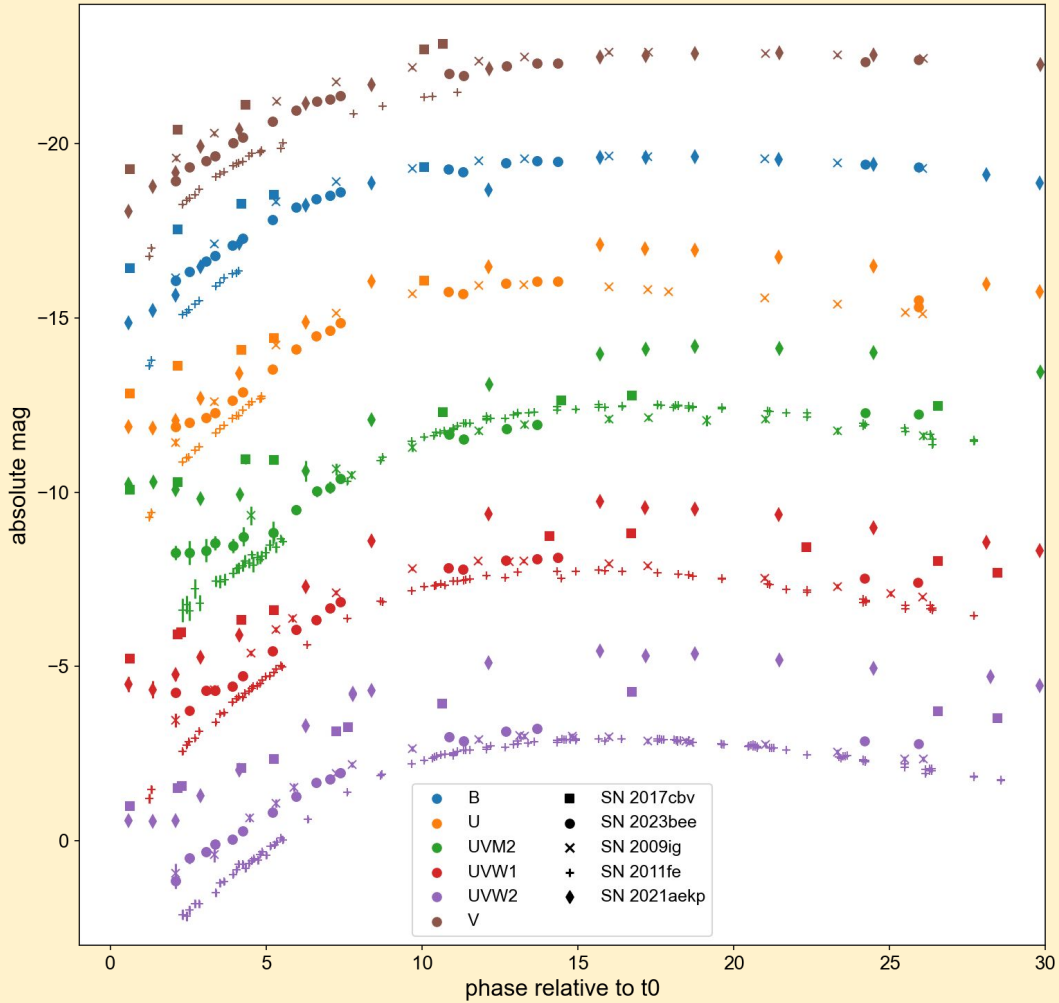
- Normal SNe Ia with early excess in *Kepler/TESS*
  - SN 2018oh, brightest SN Ia in *Kepler*
  - SN 2023bee, brightest SN Ia in *TESS*

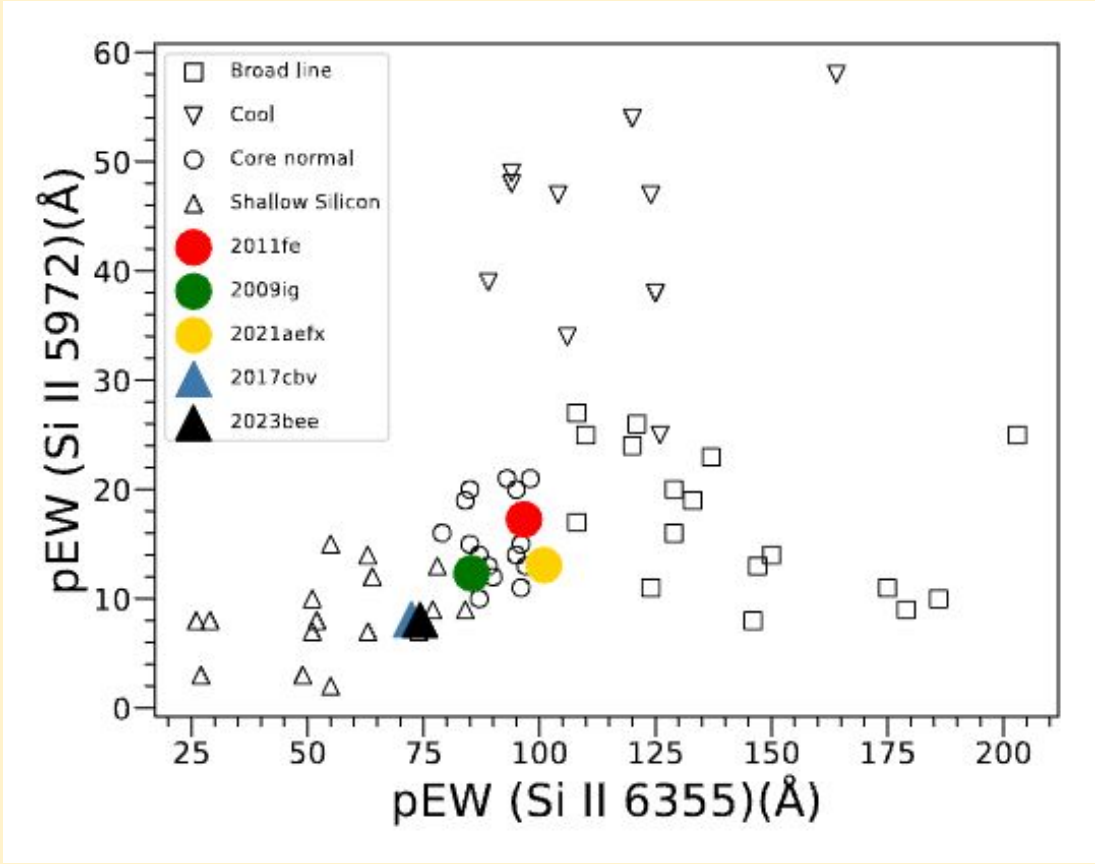


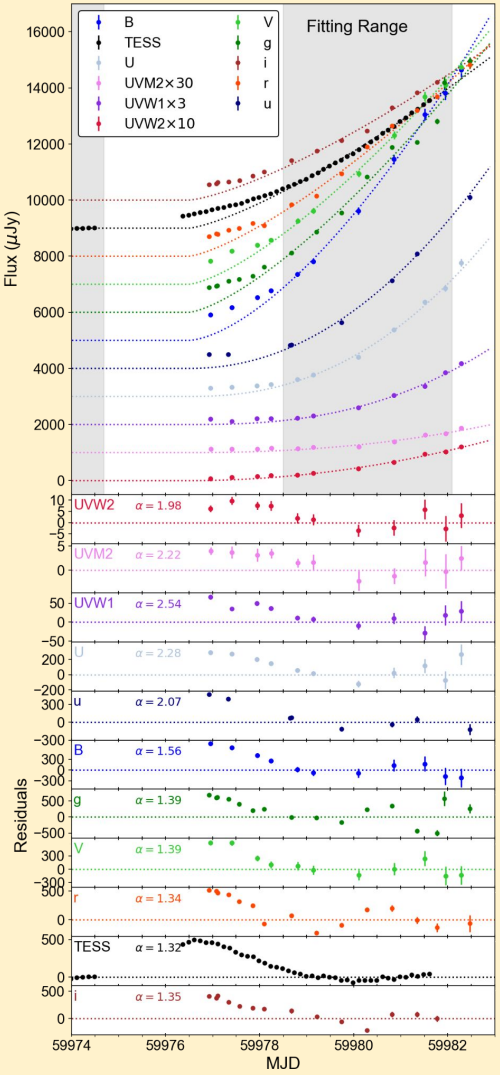
- **None** of the rest SNe Ia in *Kepler* (~10, Olling+15, Wang in prep)
- Systematic study on 24 SNe Ia in first 6 months of *TESS*: **non-detection** (Fausnaugh+21)
- We are actively tracking SNe Ia in *TESS* but didn't see any other prominent bump…
- ZTF sample : 3 in 30 for SNe Ia with z<0.07 (Deckers+2022)
  - After efficiency correction: **18±11%**

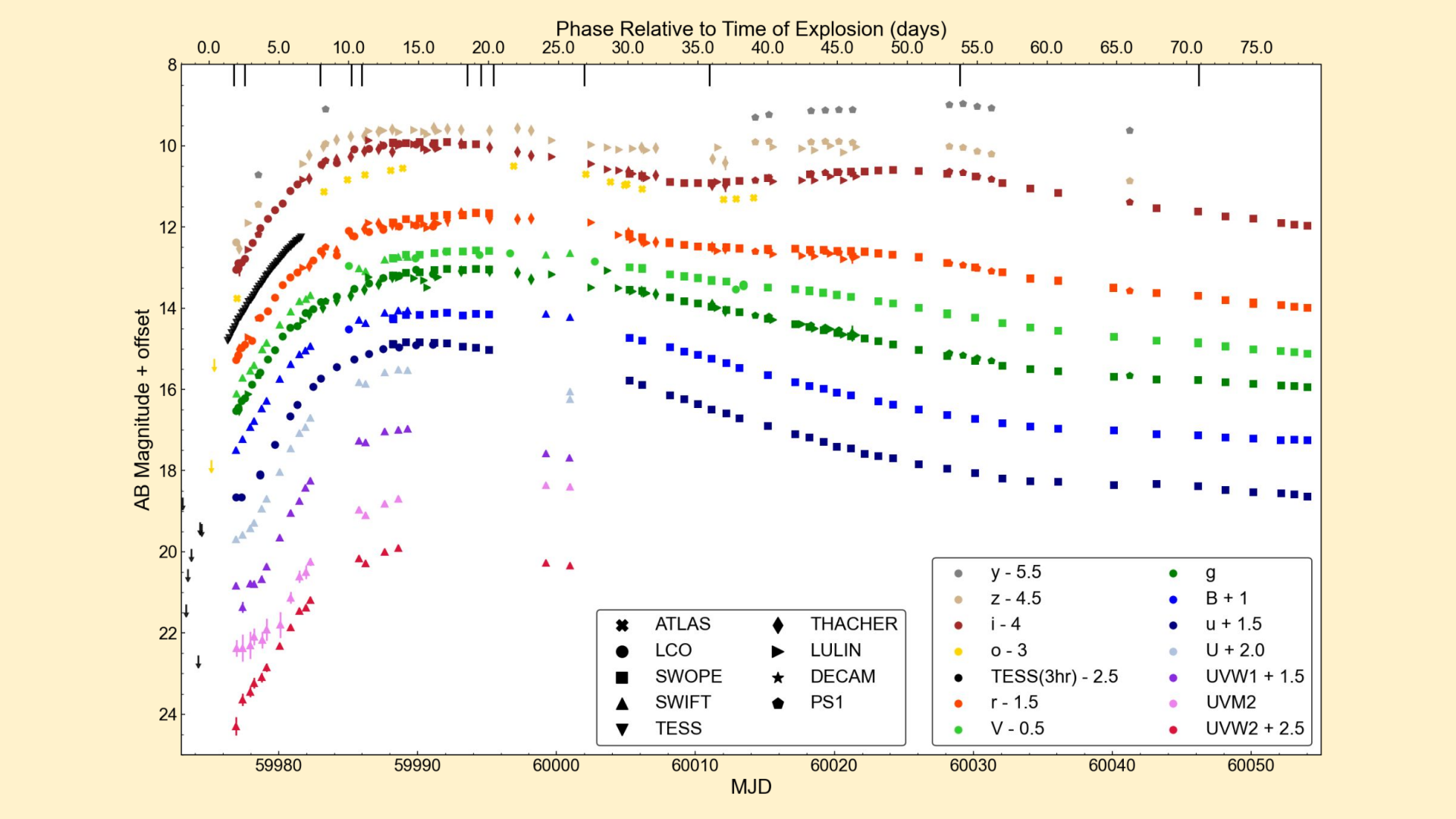
Tension?

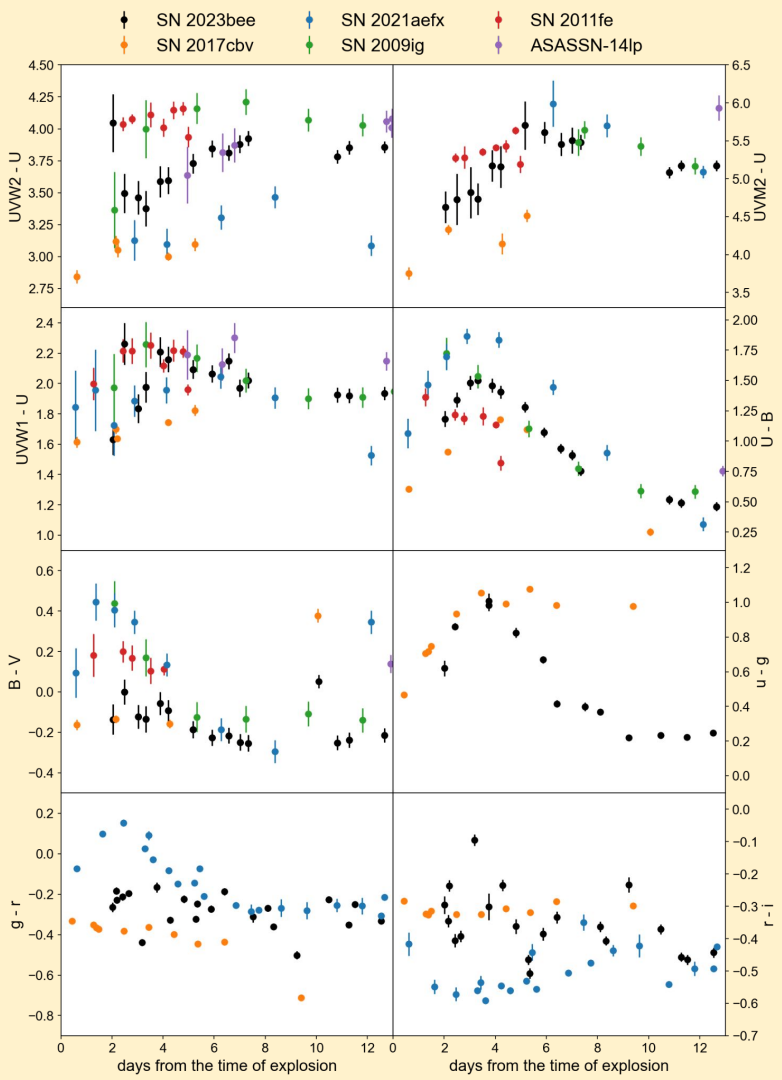
A complete efficiency and contamination analysis is necessary…


absolute mag
phase relative to t0
−20
−15
−10
−5
0
0
5
10
15
20
25
30
B
U
UVM2
UVW1
UVW2
V
SN 2017cbv
SN 2023bee
SN 2009ig
SN 2011fe
SN 2021aekp


Broad line
Cool
Core normal
Shallow Silicon
2011fe
2009ig
2021aefx
2017cbv
2023bee
pEW (Si II 5972)(Å)
pEW (Si II 6355)(Å)
0
10
20
30
40
50
60
25
50
75
100
125
150
175
200


B
TESS
U
UVM2×30
UVW1×3
UVW2×10
V
g
i
r
u
Fitting Range
Flux (μJy)
Residuals
UVW2 α = 1.98
UVM2 α = 2.22
UVW1 α = 2.54
U α = 2.28
u α = 2.07
B α = 1.56
g α = 1.39
V α = 1.39
r α = 1.34
TESS α = 1.32
i α = 1.35
MJD


Phase Relative to Time of Explosion (days)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
AB Magnitude + offset
8
10
12
14
16
18
20
22
24
MJD
59980
59990
60000
60010
60020
60030
60040
60050
ATLAS
LCO
SWOPE
SWIFT
TESS
THACHER
LULIN
DECAM
PS1
y - 5.5
z - 4.5
i - 4
o - 3
TESS(3hr) - 2.5
r - 1.5
V - 0.5
g
B + 1
u + 1.5
U + 2.0
UVW1 + 1.5
UVM2
UVW2 + 2.5


SN 2023bee
SN 2017cbv
SN 2021aefx
SN 2009ig
SN 2011fe
ASASSN-14lp
UVW2 - U
UVM2 - U
UVW1 - U
U - B
B - V
u - g
g - r
r - i
days from the time of explosion
days from the time of explosion

	$M_{Chandra}$, single degenerate	$>M_{Chandra}$, double degenerate merger remnant	Sub-$M_{Chandra}$, dynamically driven double degenerate double detonation
Explode	No detonation transition? Peculiar SN Iax class?	Can't avoid off-center ignition	Needs more study, but currently plausible
Light curves & spectra	Problematic Phillips rel'n Decent spectra	Problematic Phillips rel'n Decent spectra	Not yet, but hopefully with multi-D and non-LTE
Early excess?	Giants ruled out; MS/sG interaction for few?	If C giant, large radius → shock interaction	Excess from shocked helium shell for few?
Surviving ex-companion?	Should see for some		First ever surviving companion detection!
No H or He seen	But SNe Ia-CSM?		
Nothing seen pre-explosion	Should see for some	If C giant, $L \sim L_{Edd}$	
Rates	Off by orders of magnitude in old population		
Lum. function evolution	No reason to link explosion properties to age	No reason to link explosion properties to age	
Neutron-rich nucleosynthesis	Overproduction of Ni?	Overproduction of Ni?	Underproduction of Mn, Ni; is there another source?

Shen, K. talk 2019 spring