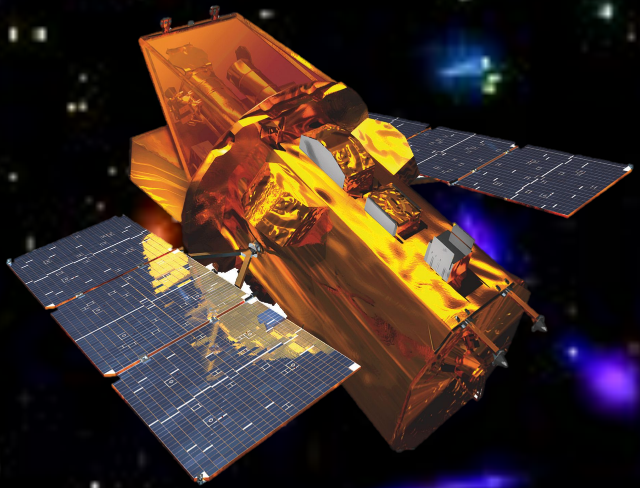
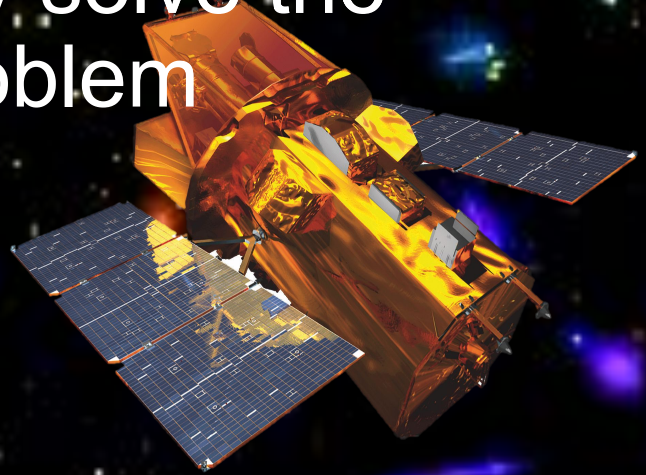
Thermonuclear Supernovae in the Ultraviolet

Peter Brown,
Texas A&M University



- How Swift swiftly opened up a new field
- Standard Candle SNe Ia are not standard in the UV – possibly key to making them better
- Optical weirdos are weirder in the UV
- Early time observations may solve the long-standing progenitor problem



Peter Brown,
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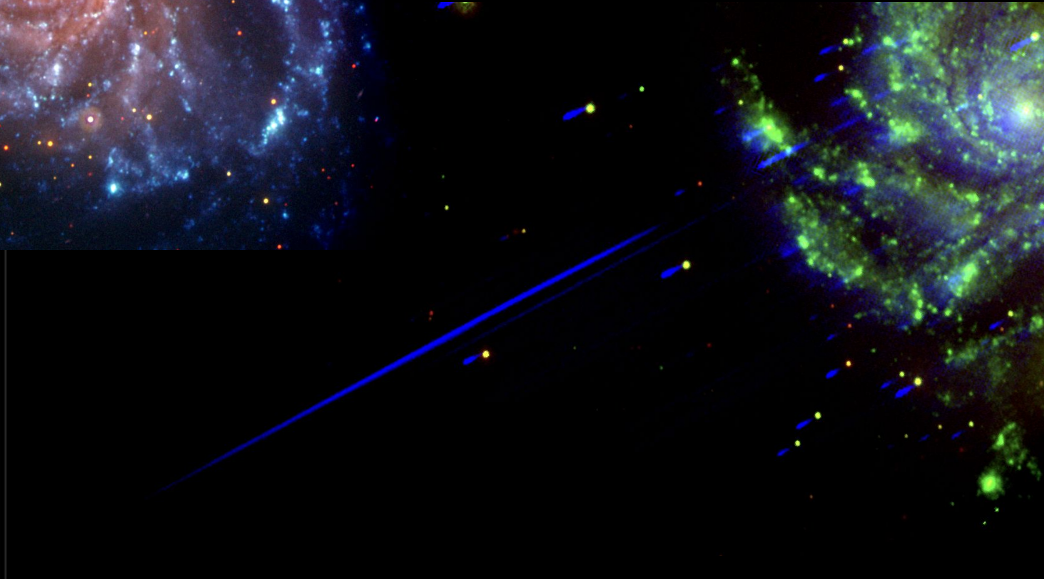
M101 – UVOT first light

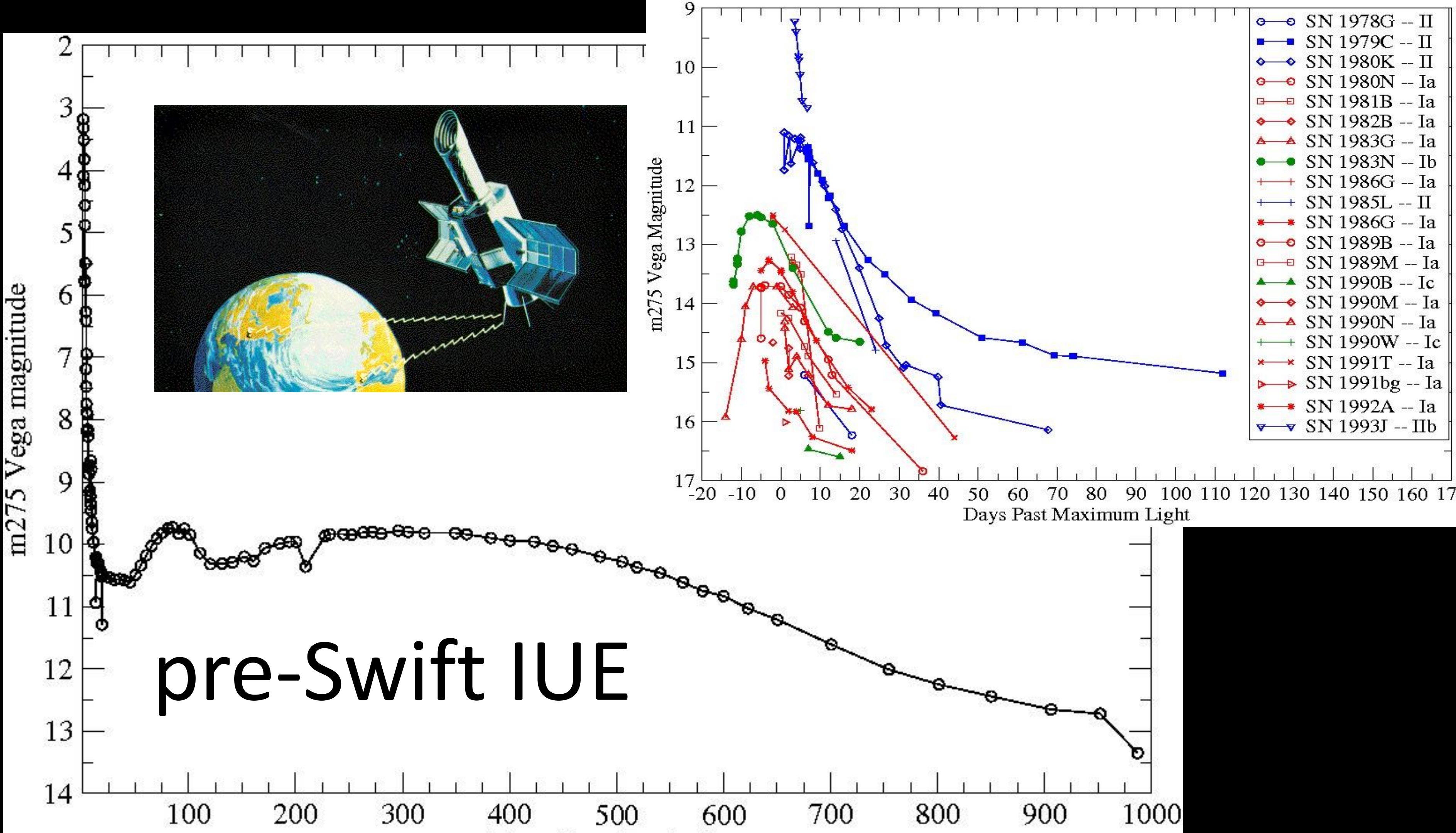
M101 and SN2011fe

M101 and SN2011fe and SN2023ixf



Also twenty years ago .

Twenty years ago . . . and now



pre-Swift IUE

IUE prototyping — UV-blue = II

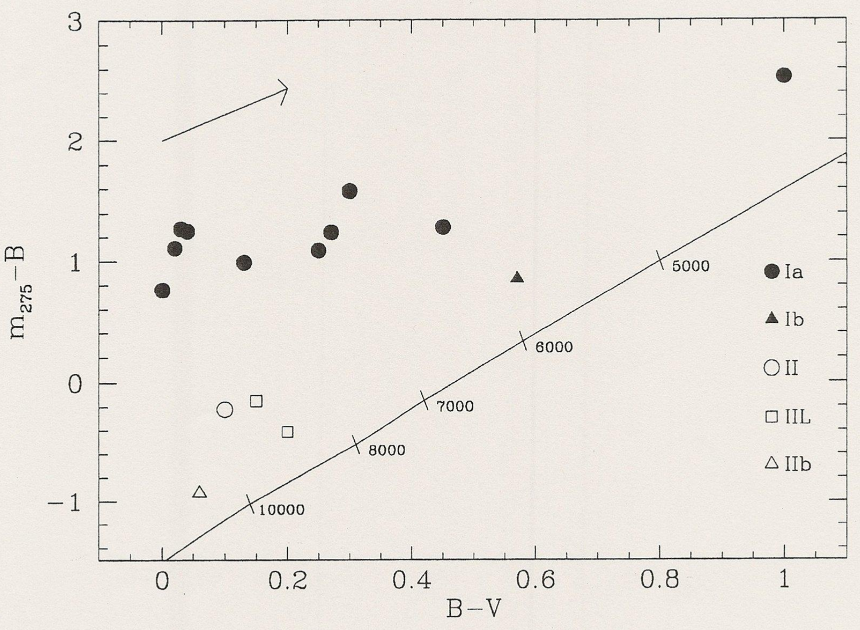
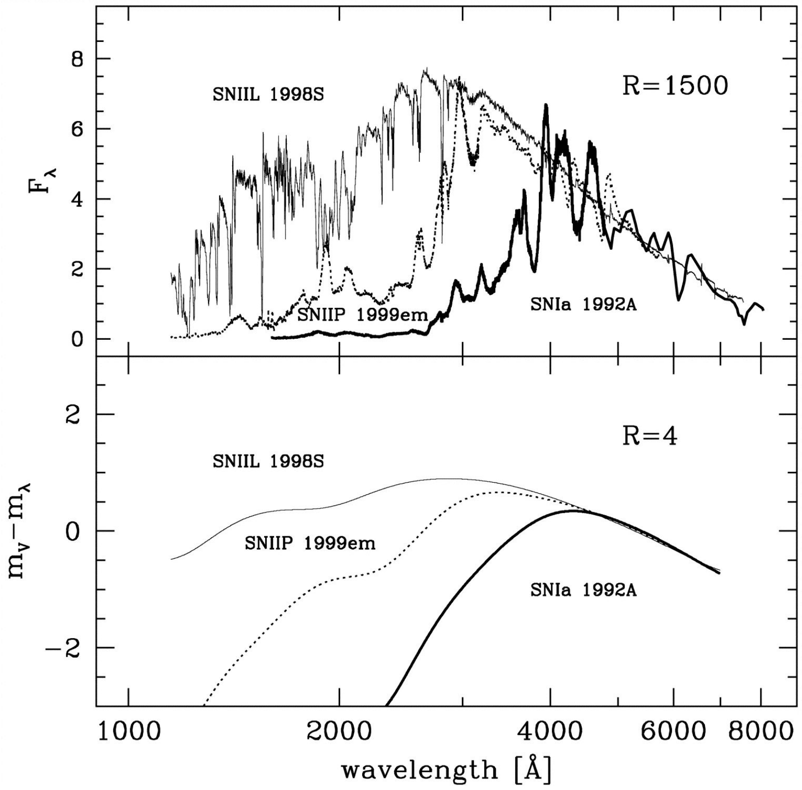


Figure 2: Two colors, m_{275}–B vs. B–V, diagram for SNe near maximum. The line gives the colors of the black body at different temperatures whereas the arrow on the top-left of the figure indicates the reddening line.

Cappelaro, Turatto, & Fernley
1995 IUE ULDA Access Guide #6

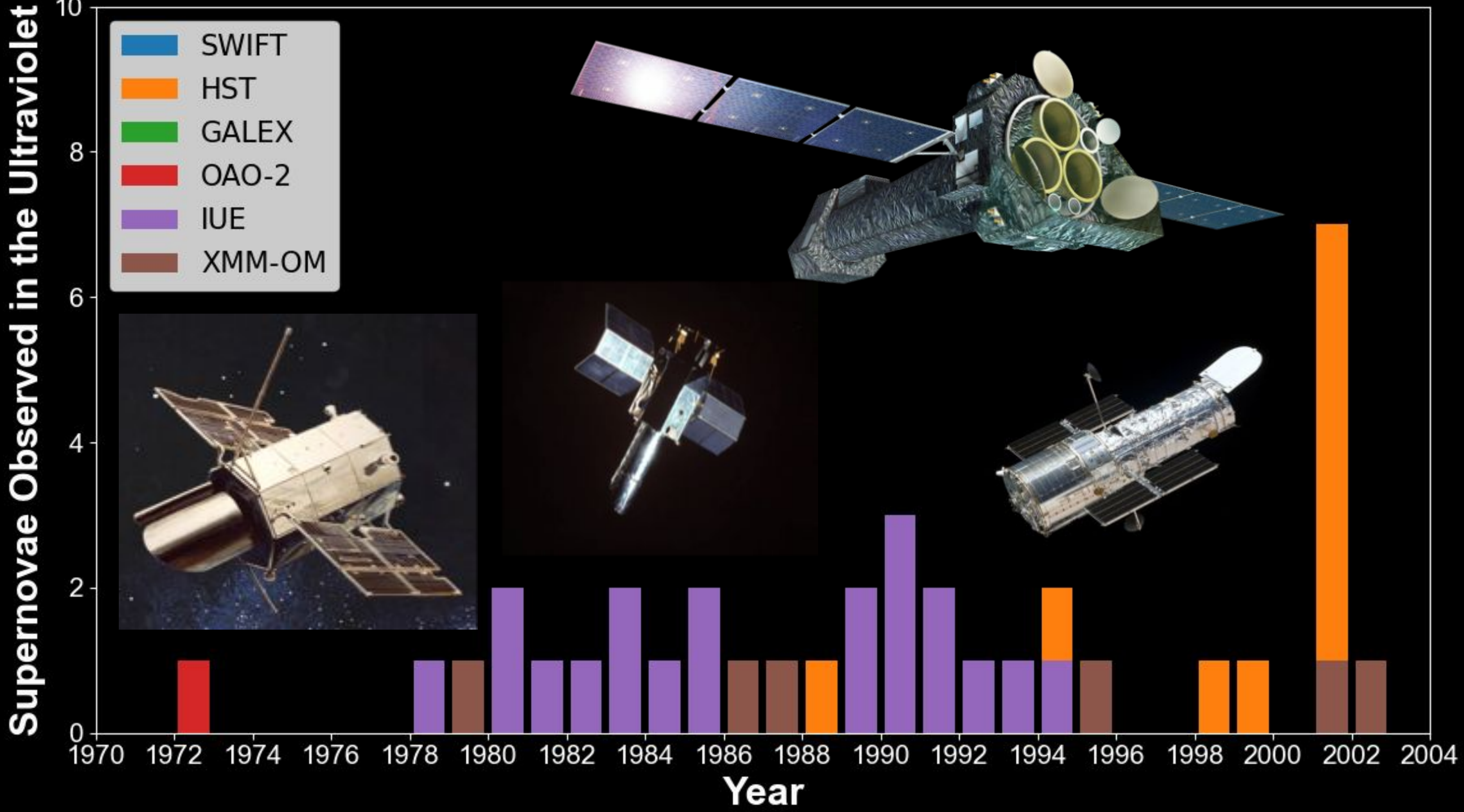


HST Spectroscopy
1 of each type

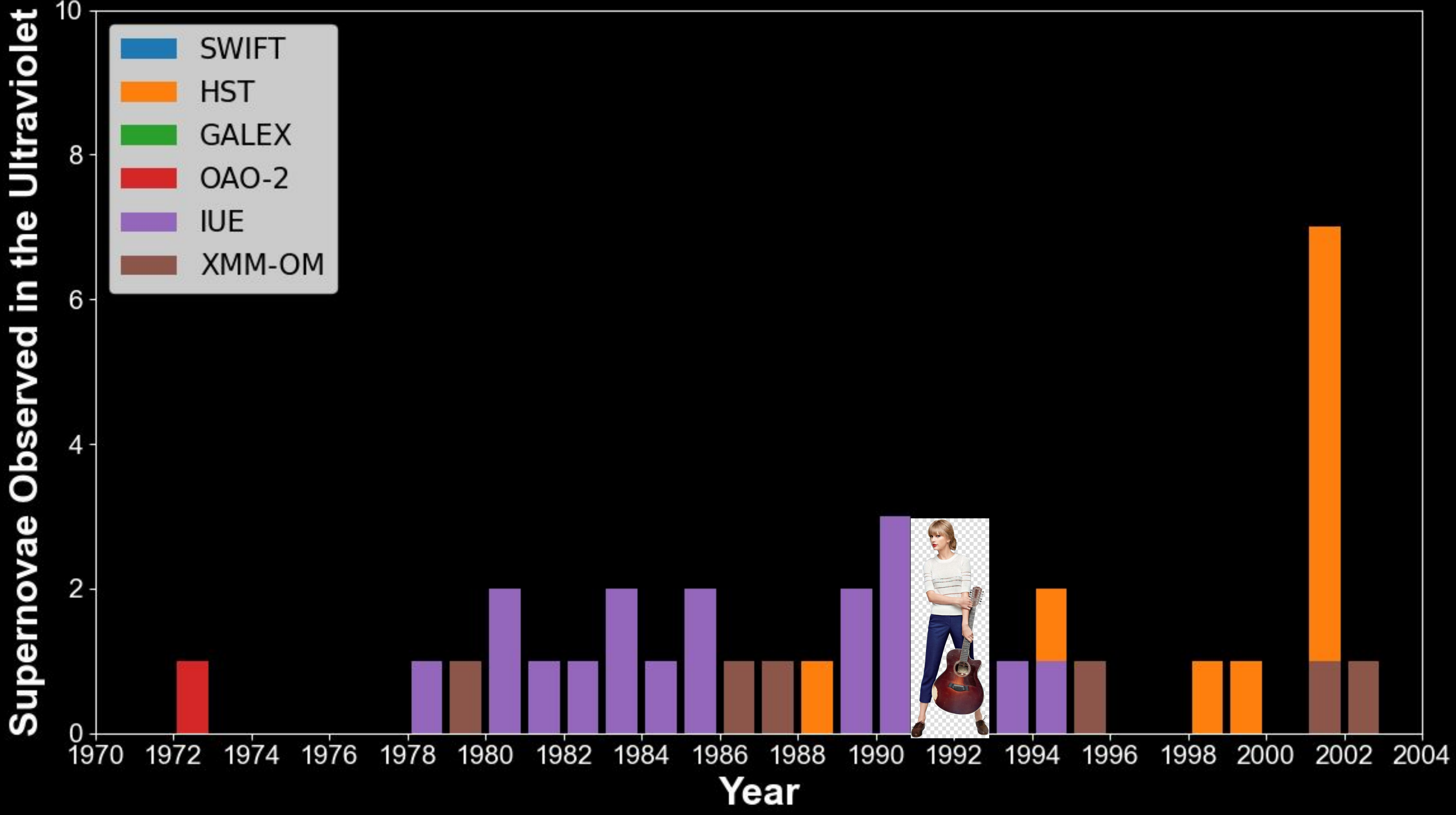
Phototyping for identifying higher redshift SNe Ia for cosmology in Riess+ 2004:

If you see rest-frame UV, it is not a Ia

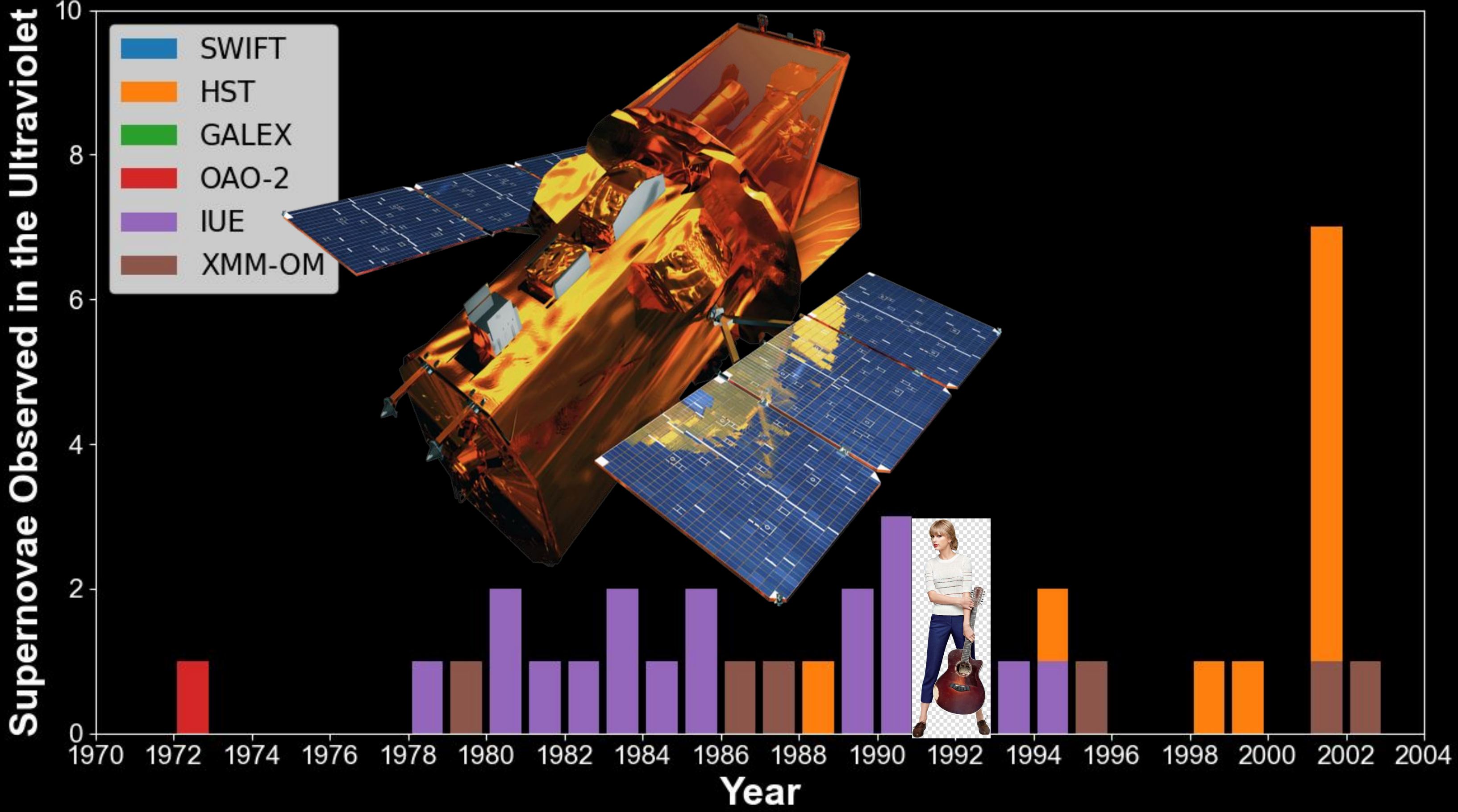
Pre-Swift Ultraviolet Supernovae



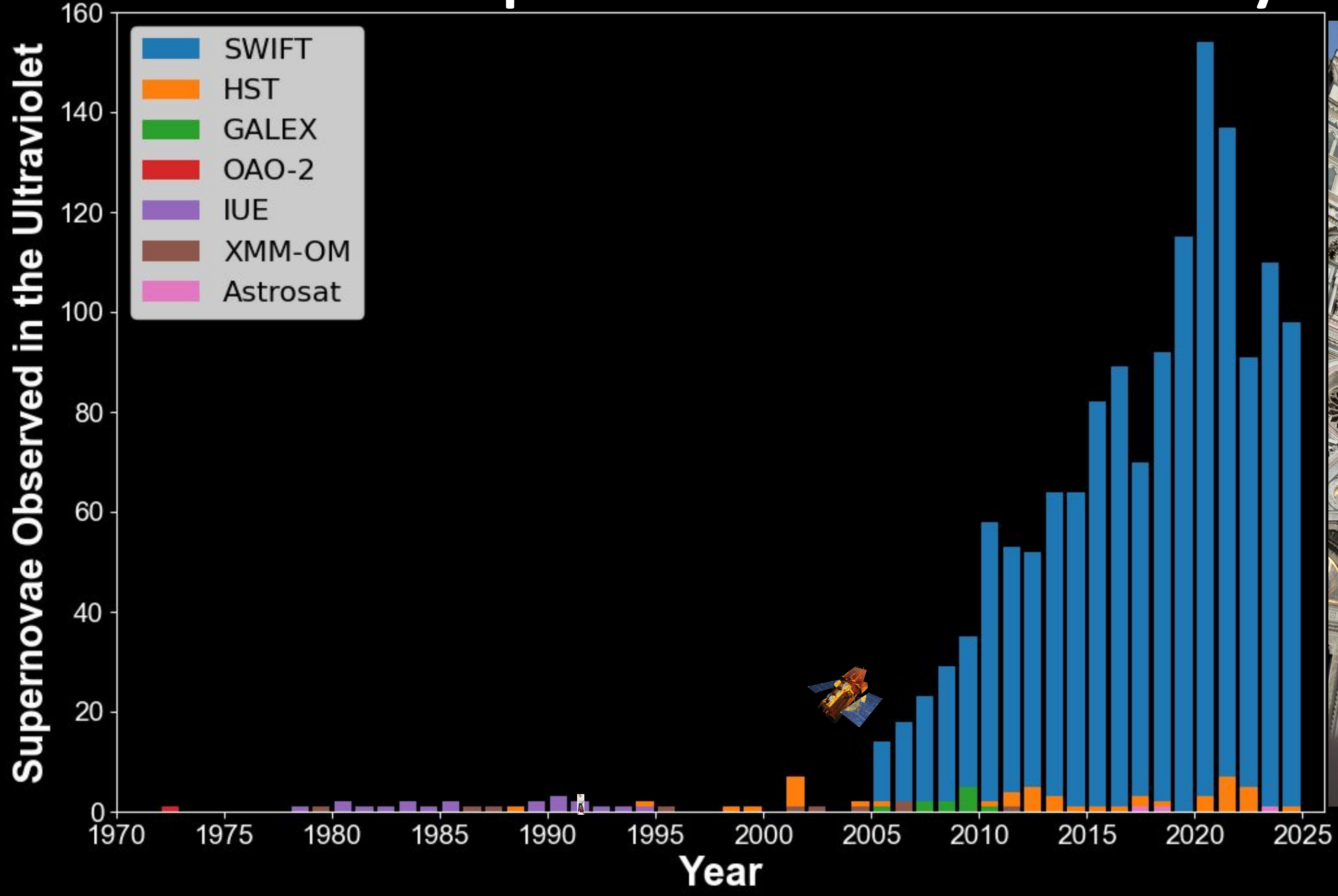
Adding Swift scales for comparison



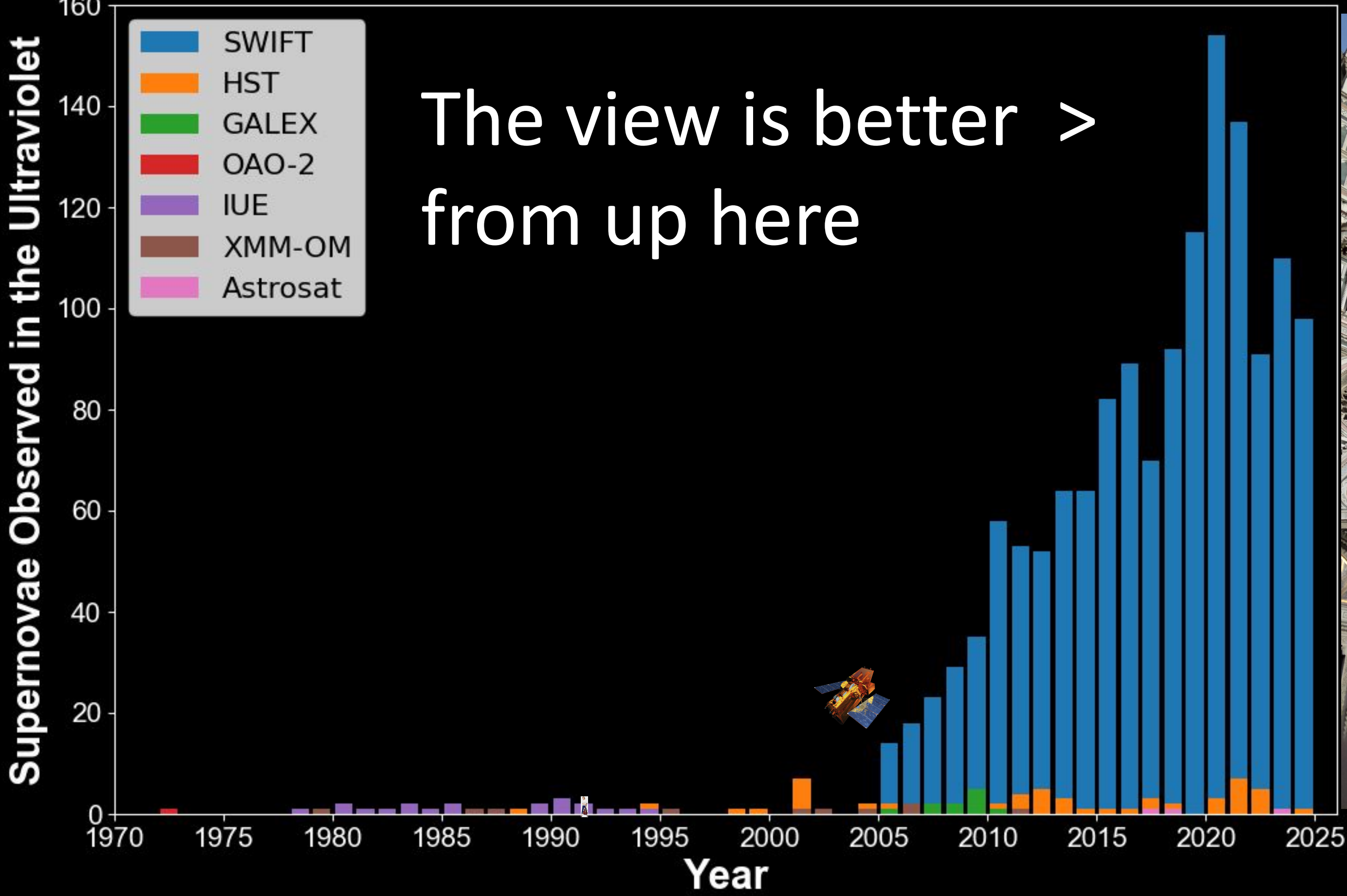
Adding Swift scales for comparison



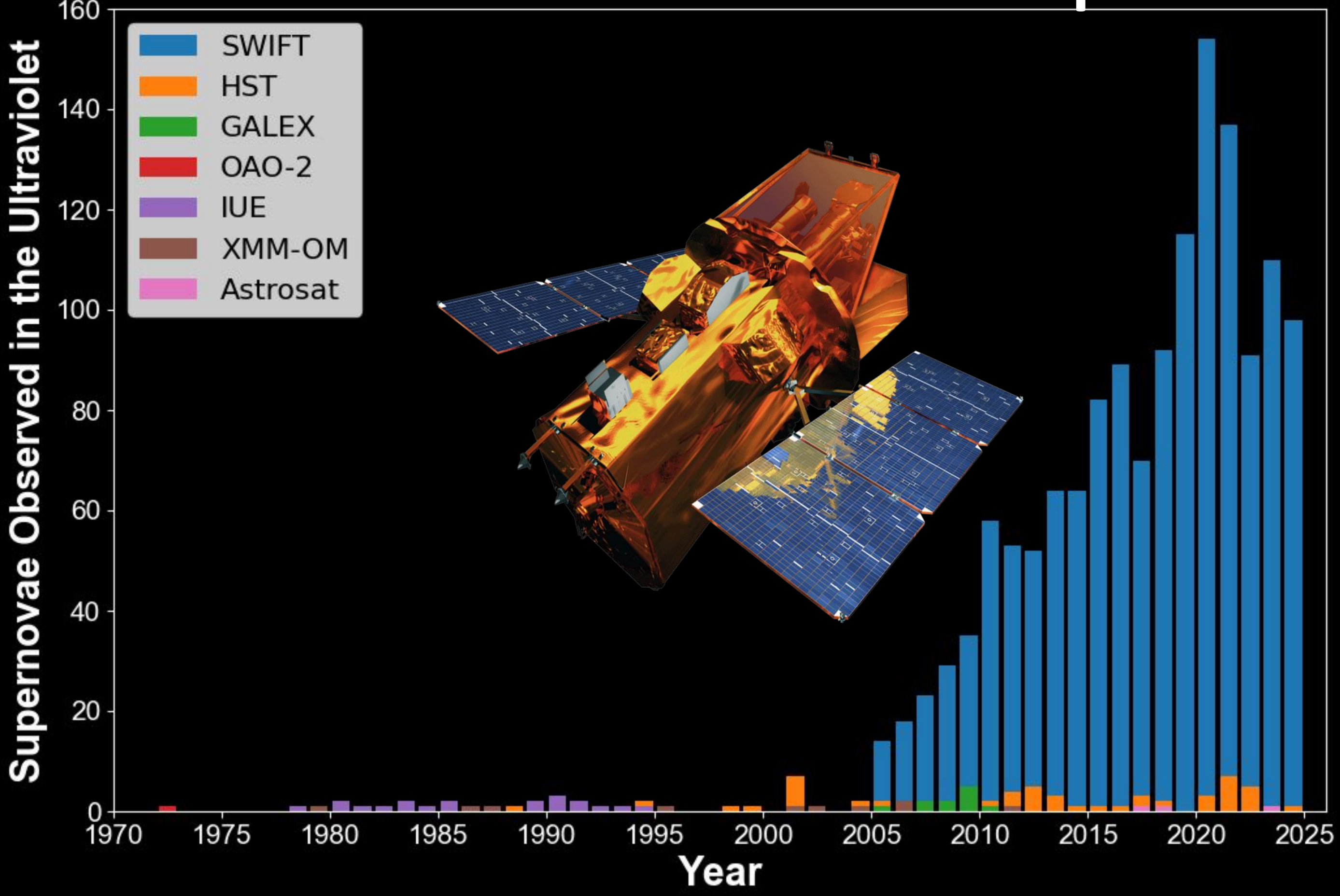
Swift Supernovae scaled by Swift



The view is better >
from up here



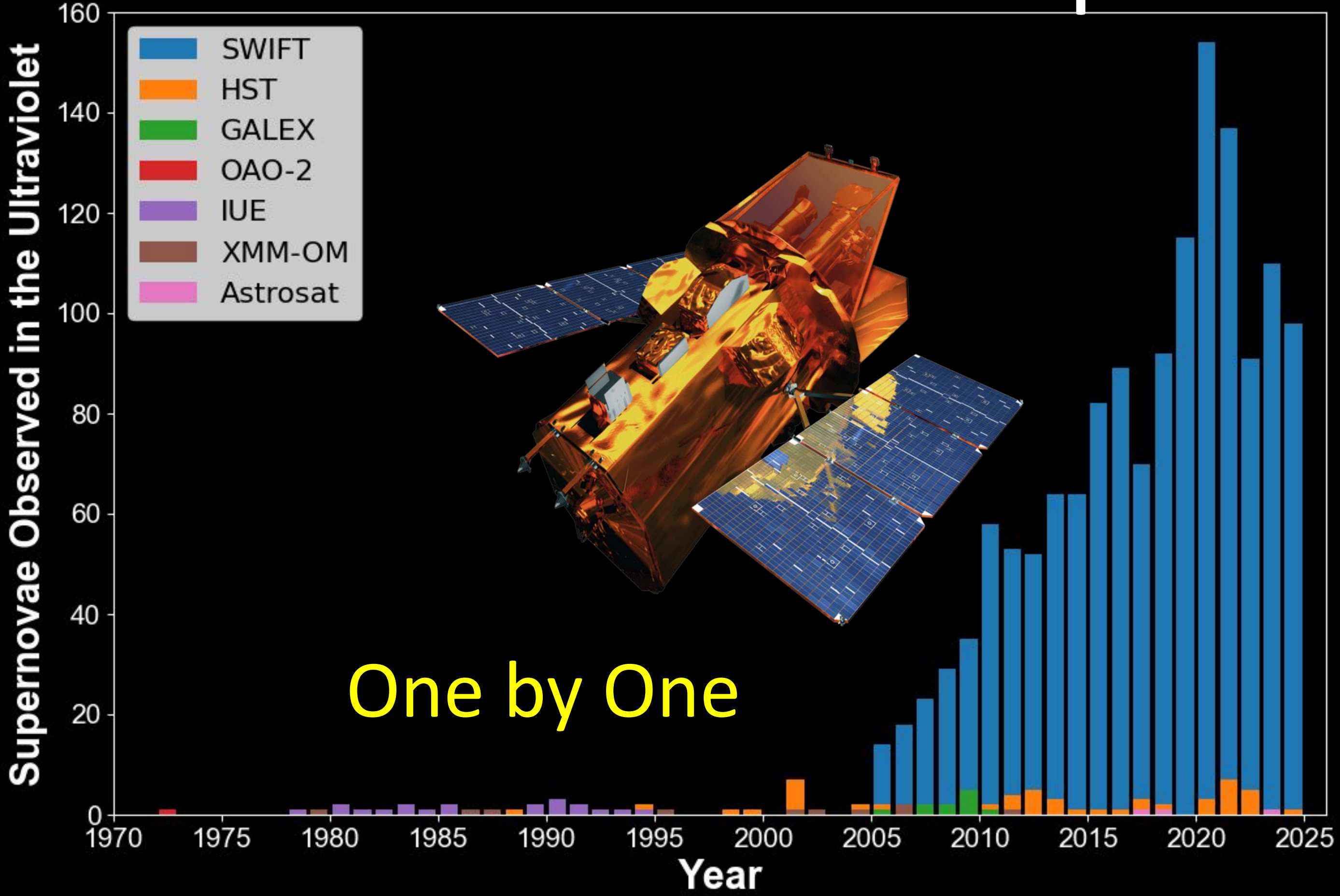
Ultraviolet Supernovae



>1400 SNe

Stefan Salacies
Thomas Masha
Hazem Salem
Kelli Templeton

Ultraviolet Supernovae



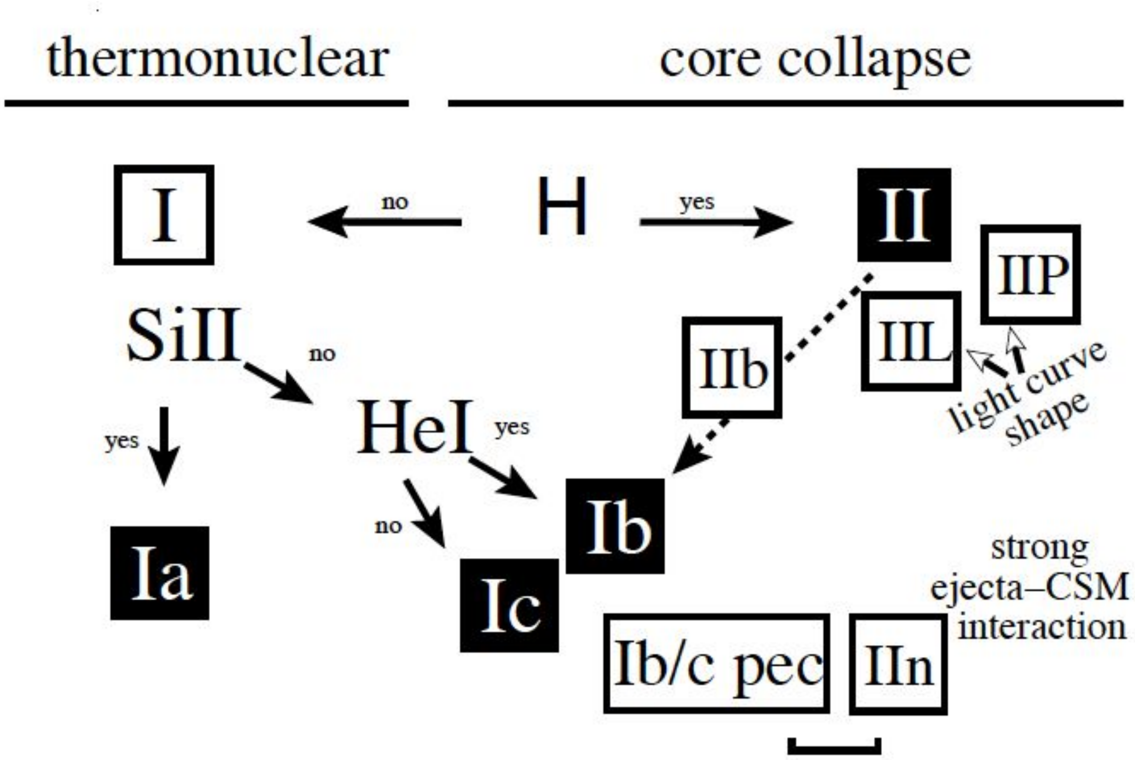
One by One

>1400 SNe

Stefan Salacies
Thomas Masha
Hazem Salem
Kelli Templeton

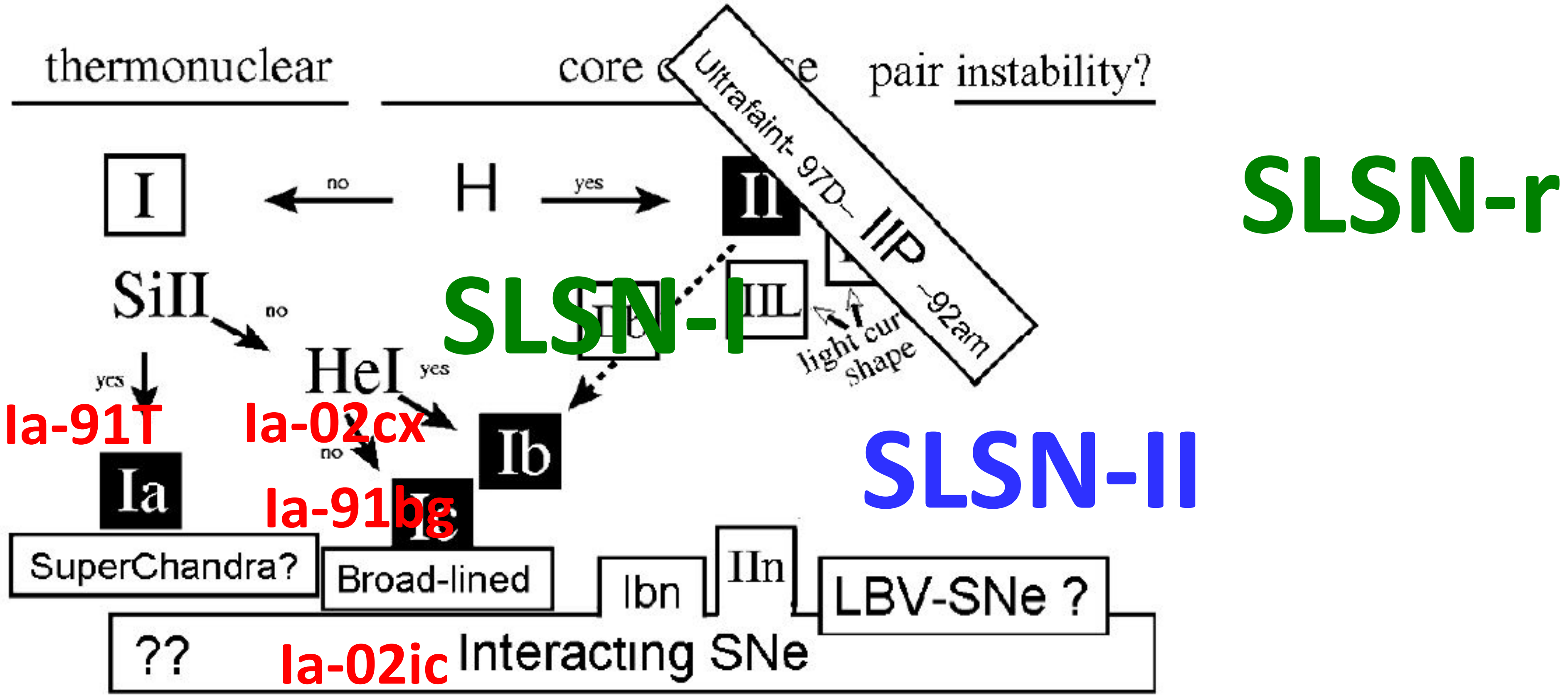
“Pick the best 1 or 2 Supernovae each year”

Supernova Taxonomy 2003

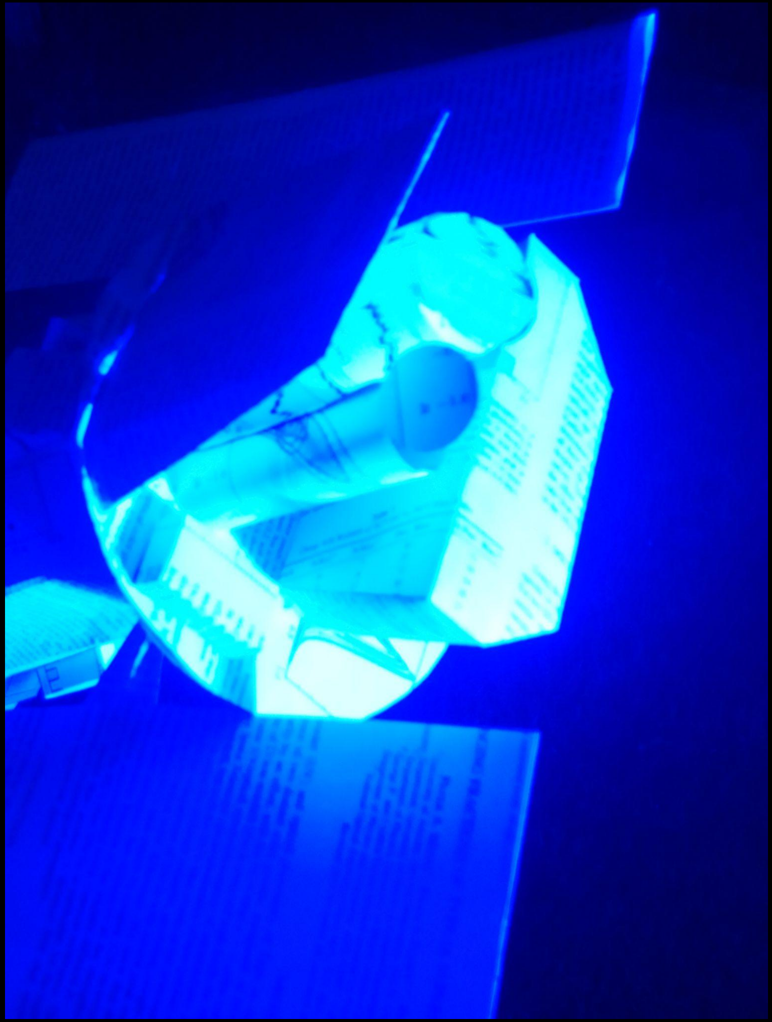


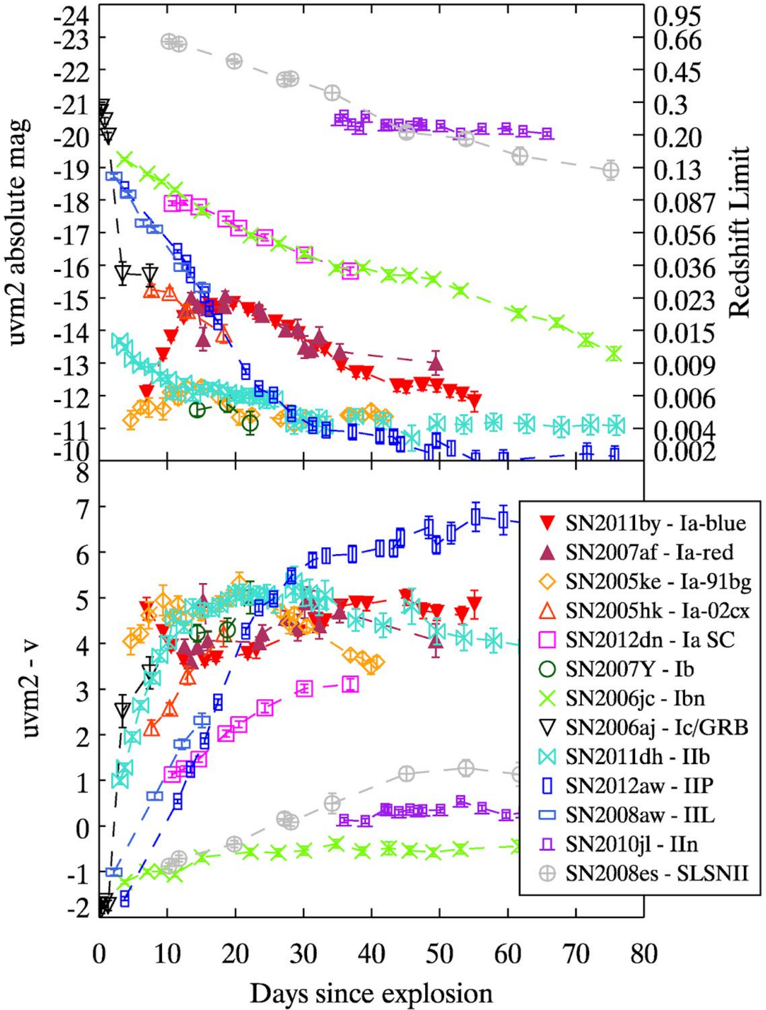
Turatto 2003

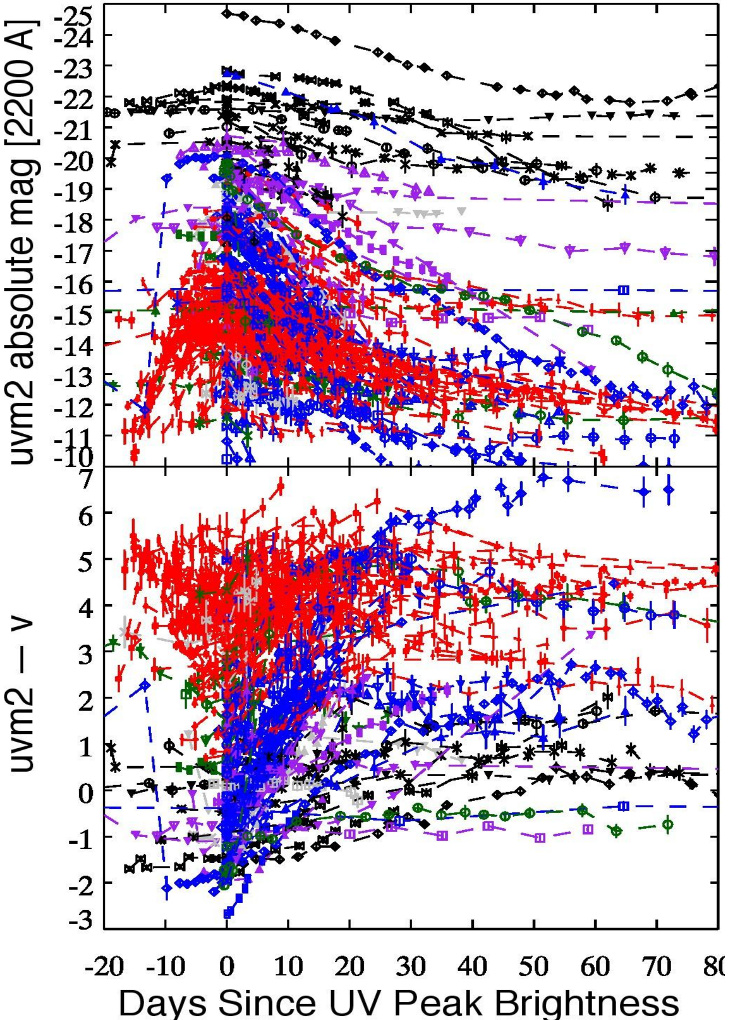
Supernova Taxonomy 2014



Turatto, Cappellaro, & Pastorello 2007 + Gal-Yam 2012

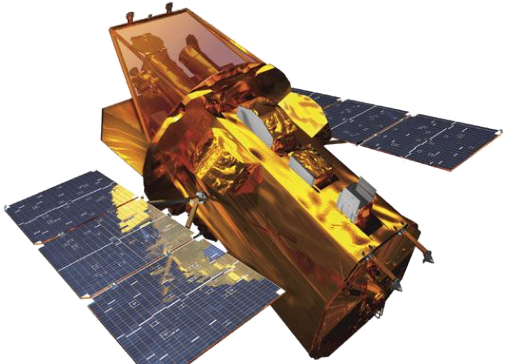



uvm2 absolute mag
Redshift Limit
uvm2 - v
Days since explosion
-24
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10
0.95
0.66
0.45
0.3
0.20
0.13
0.087
0.056
0.036
0.023
0.015
0.009
0.006
0.004
0.002
8
7
6
5
4
3
2
1
0
-1
-2
0
10
20
30
40
50
60
70
80
SN2011by - Ia-blue
SN2007af - Ia-red
SN2005ke - Ia-91bg
SN2005hk - Ia-02cx
SN2012dn - Ia SC
SN2007Y - Ib
SN2006jc - Ibn
SN2006aj - Ic/GRB
SN2011dh - IIb
SN2012aw - IIP
SN2008aw - IIL
SN2010jl - IIn
SN2008es - SLSNII



Hundreds of light curves

Lots of work and science to do



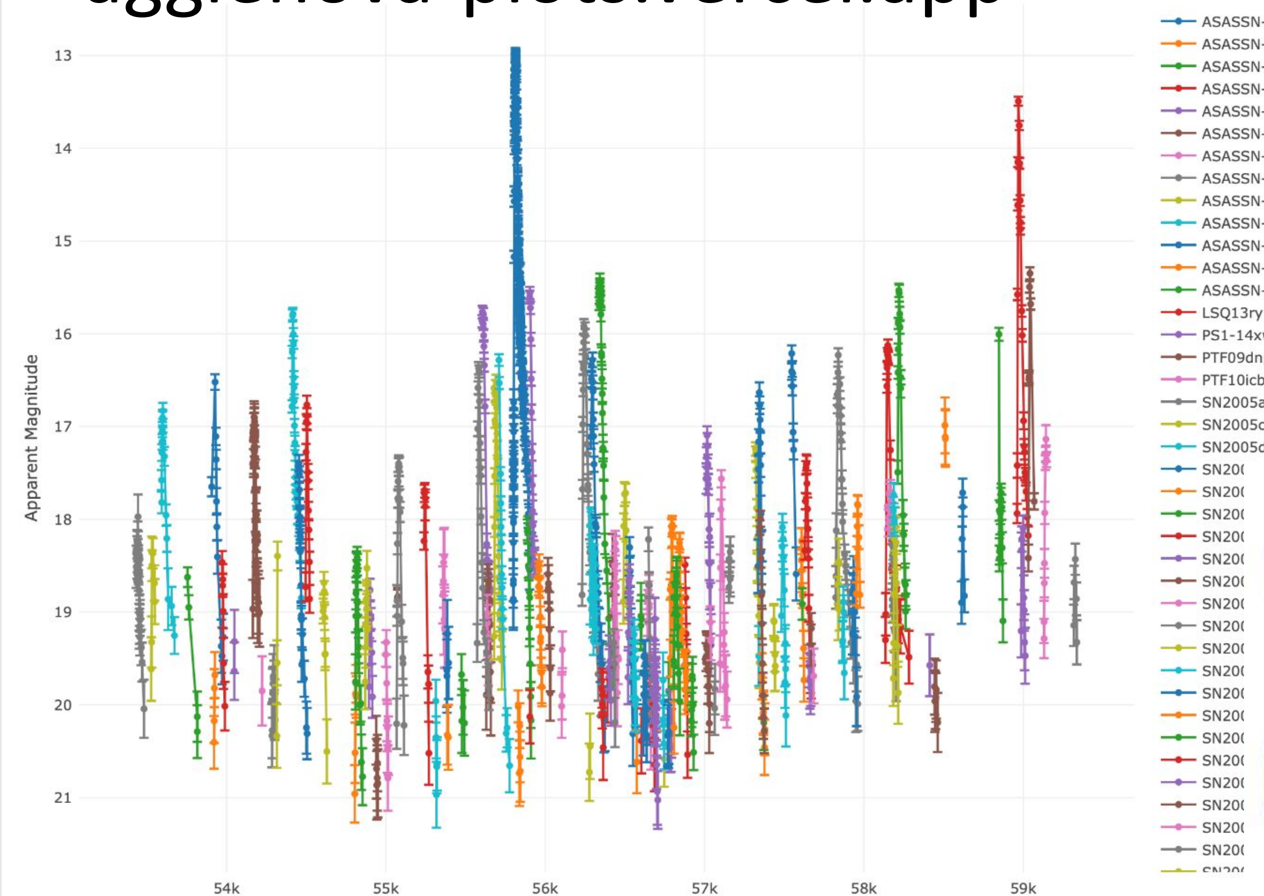
SOUSA

Swift Optical/Ultraviolet Supernova Archive

NASA Astrophysics and Data Analysis Program – funded project to create a database of the UV images and photometry for the ~~300~~+ Swift SNe
~~800~~
1400

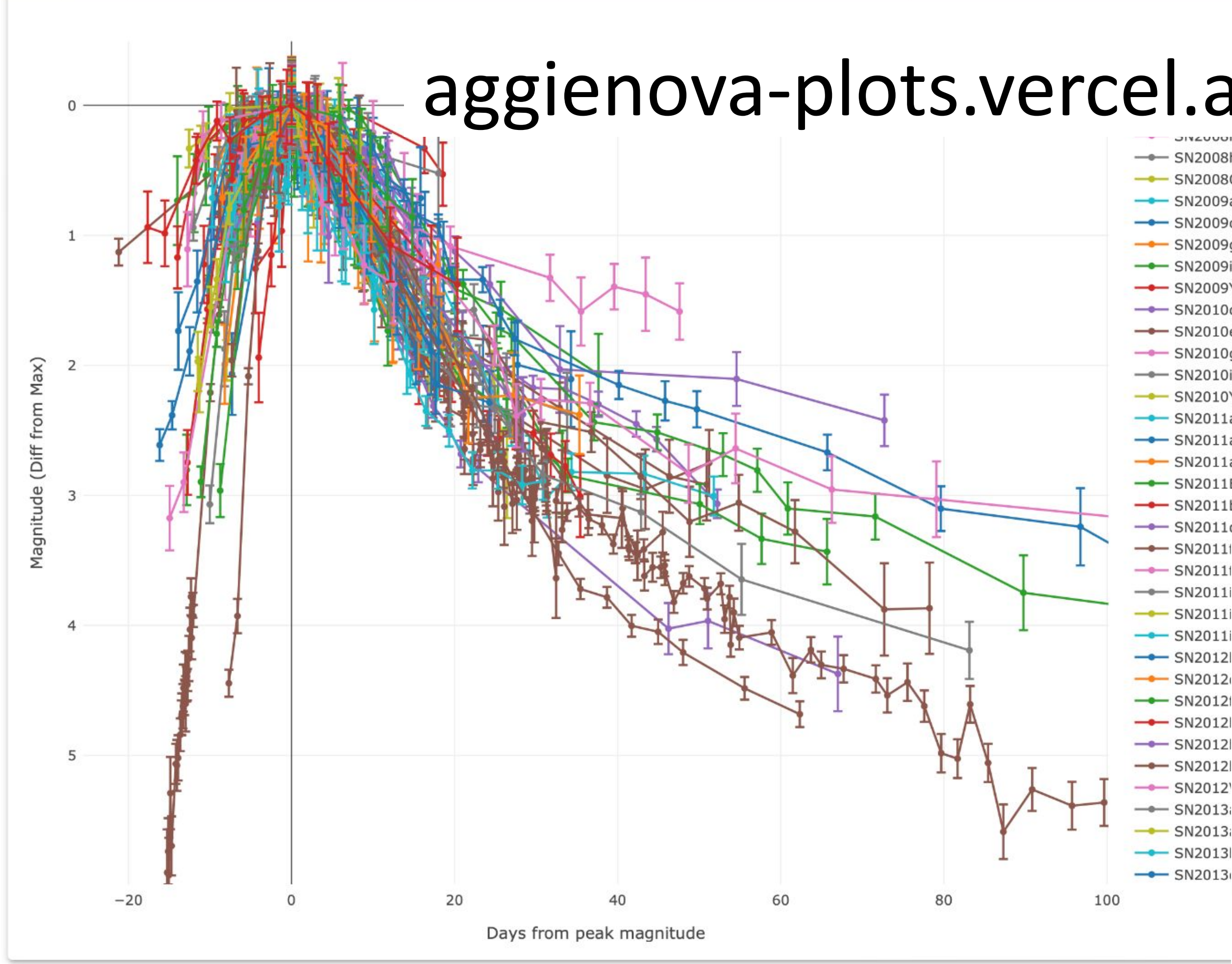
Brown et al. 2014a

kicked off at 2013 NUVA meeting in Garching aggienova-plots.vercel.app

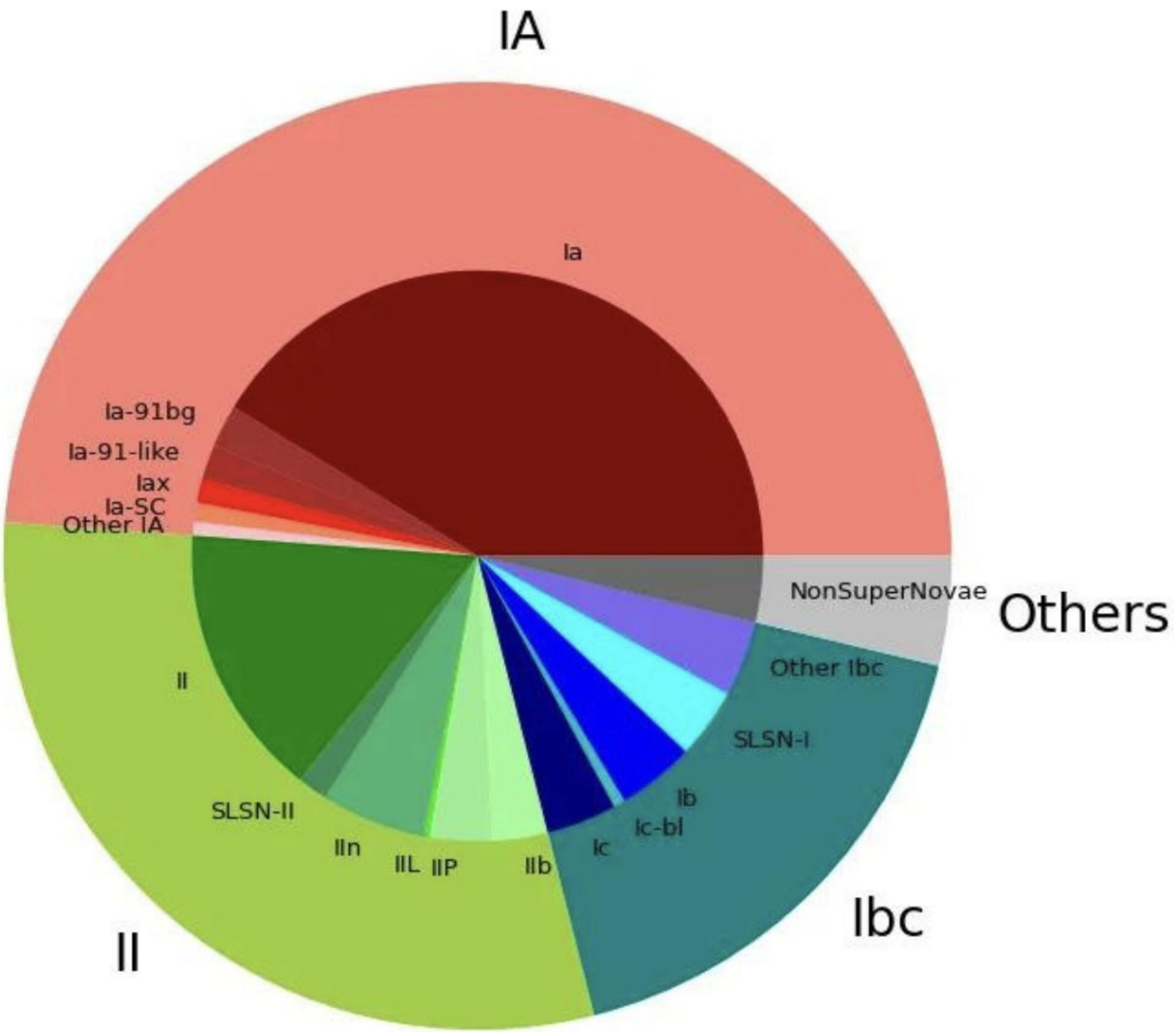


Kevin Lei

aggienova-plots.vercel.app



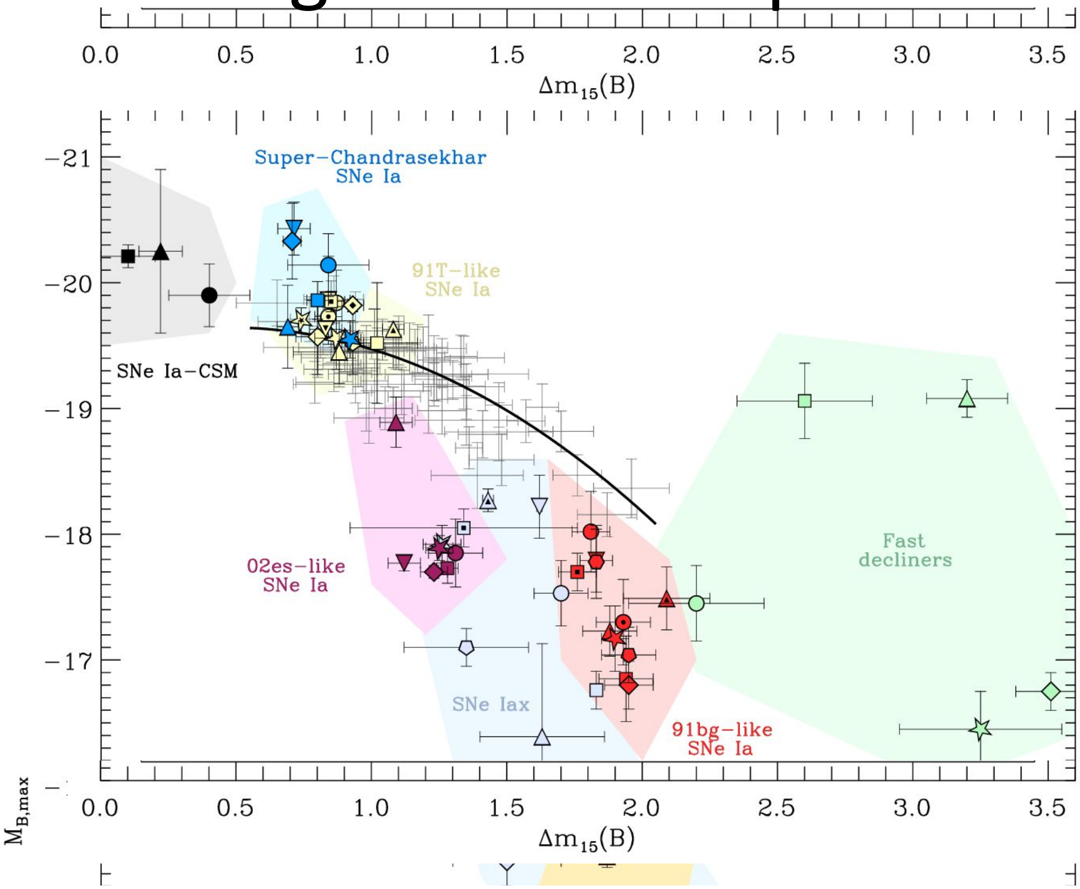
Kevin Lei



Swift Supernovae by Type

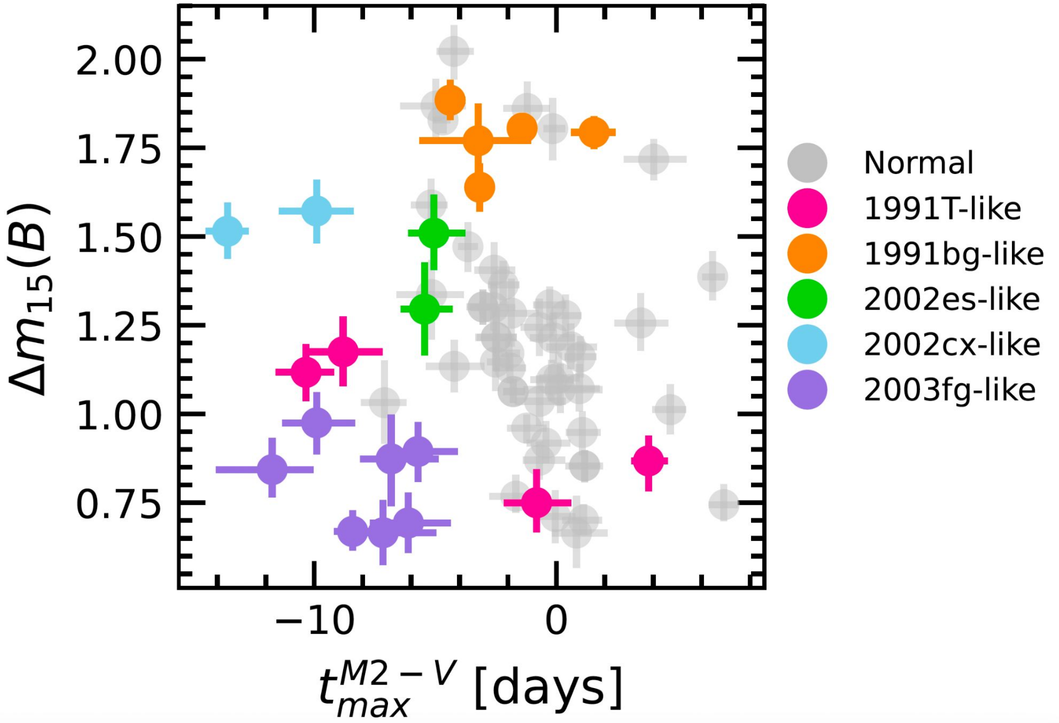
Light Curve Shape

Absolute B Magnitude



Light Curve Shape

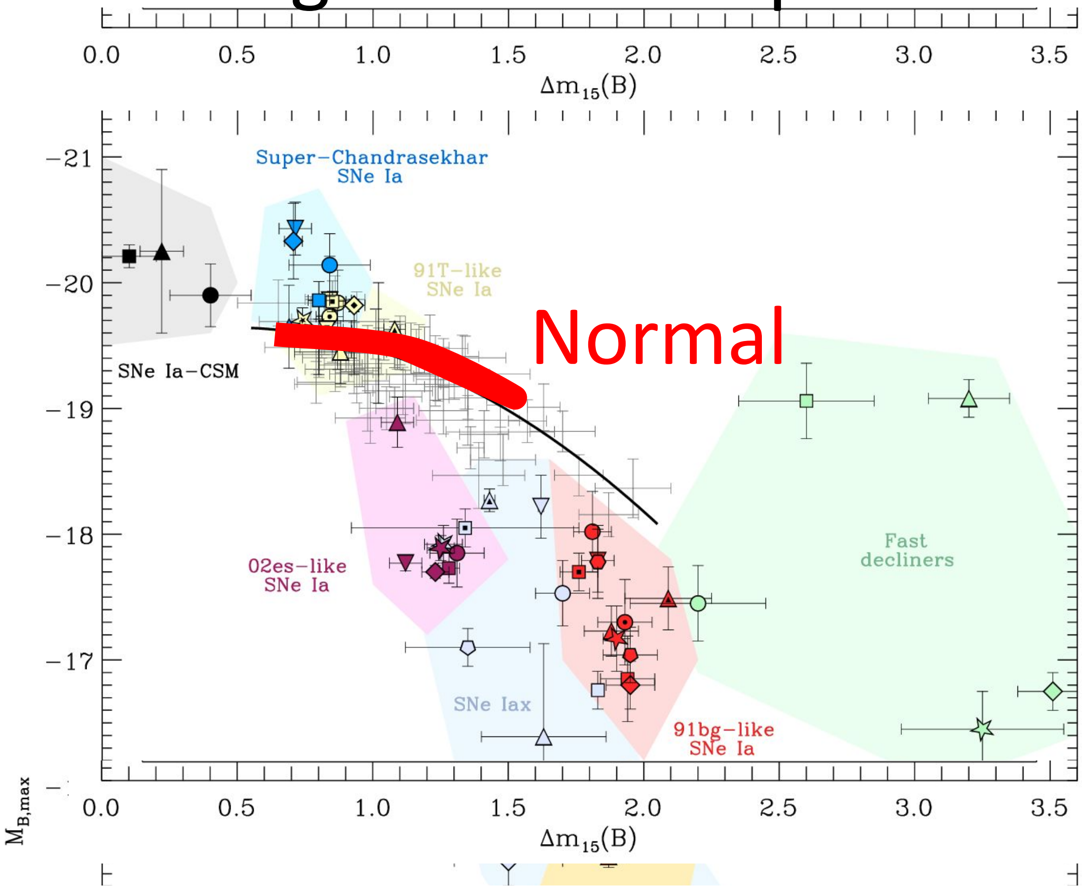
Differentiating SN Ia spectroscopic types with light curve shape and UV-optical colors



see Grace's e-poster

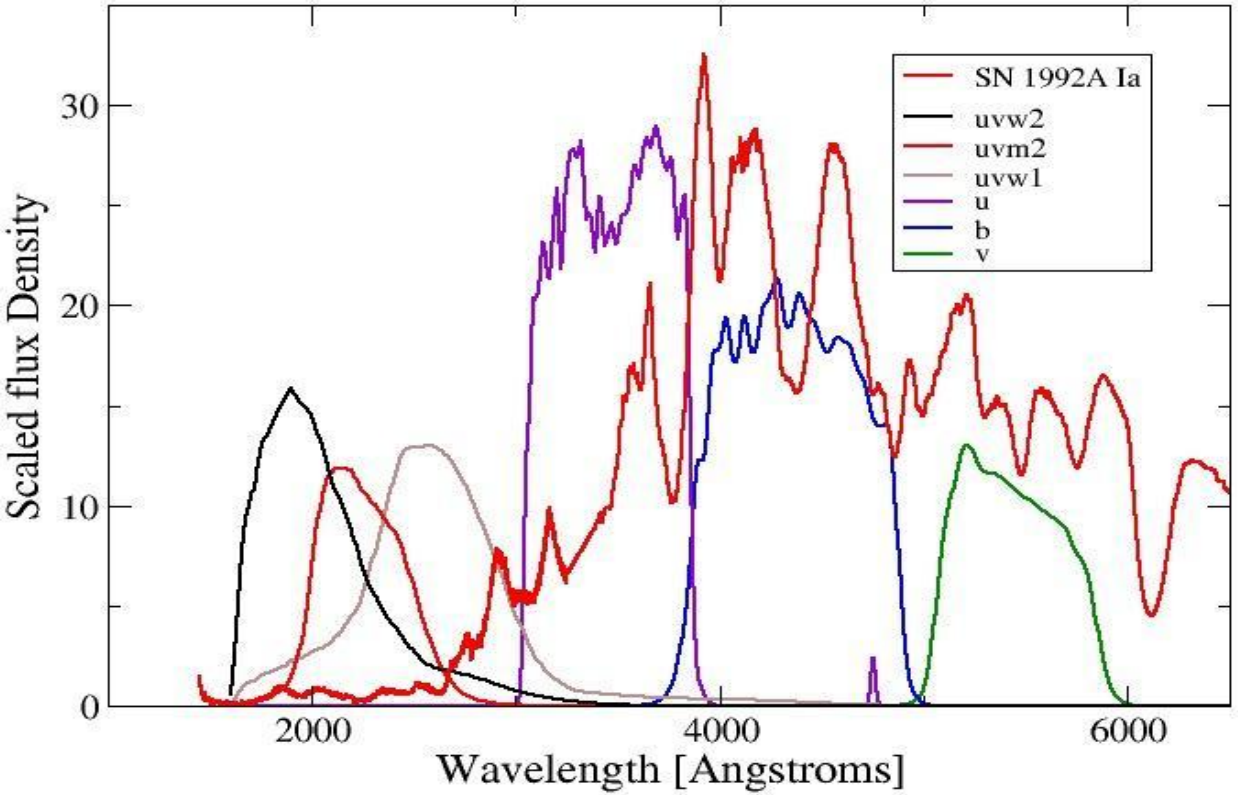
Light Curve Shape

Absolute B Magnitude

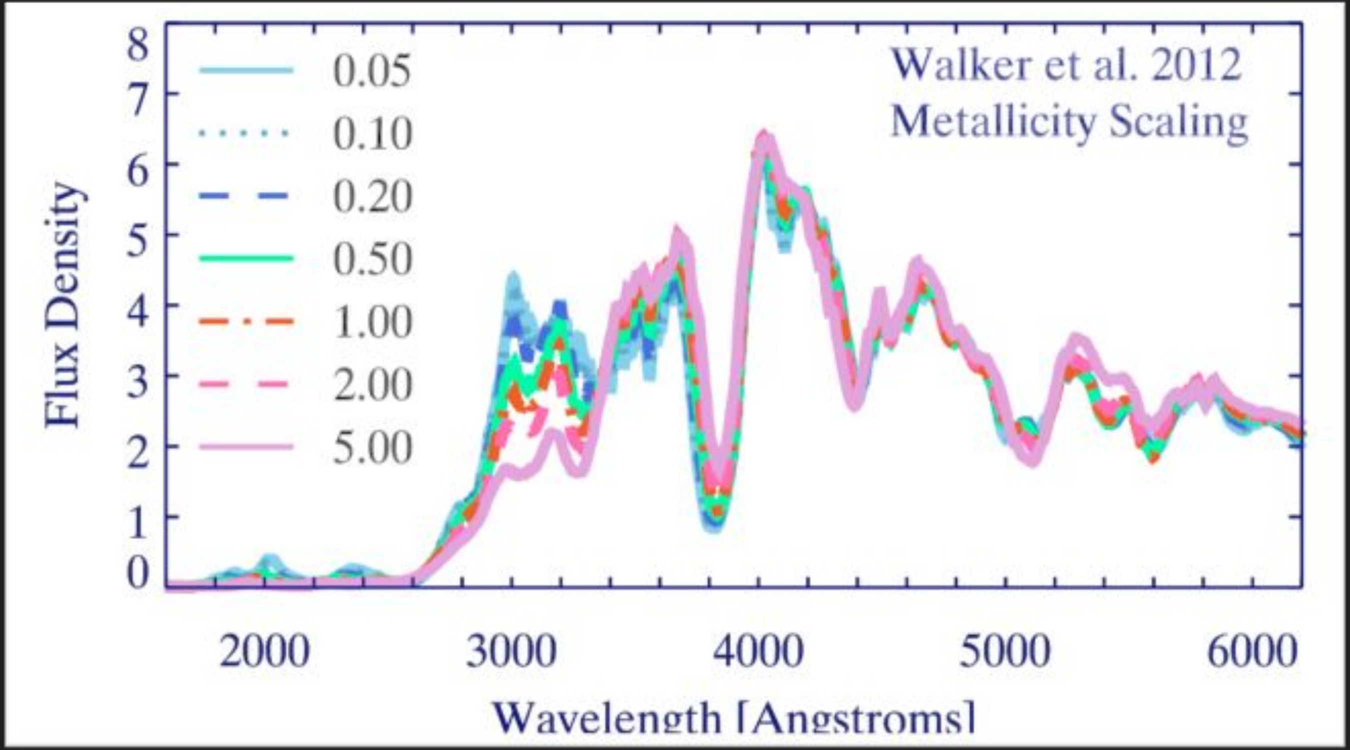


Light Curve Shape

SNe Ia are faint in the UV due to metal line blanketing

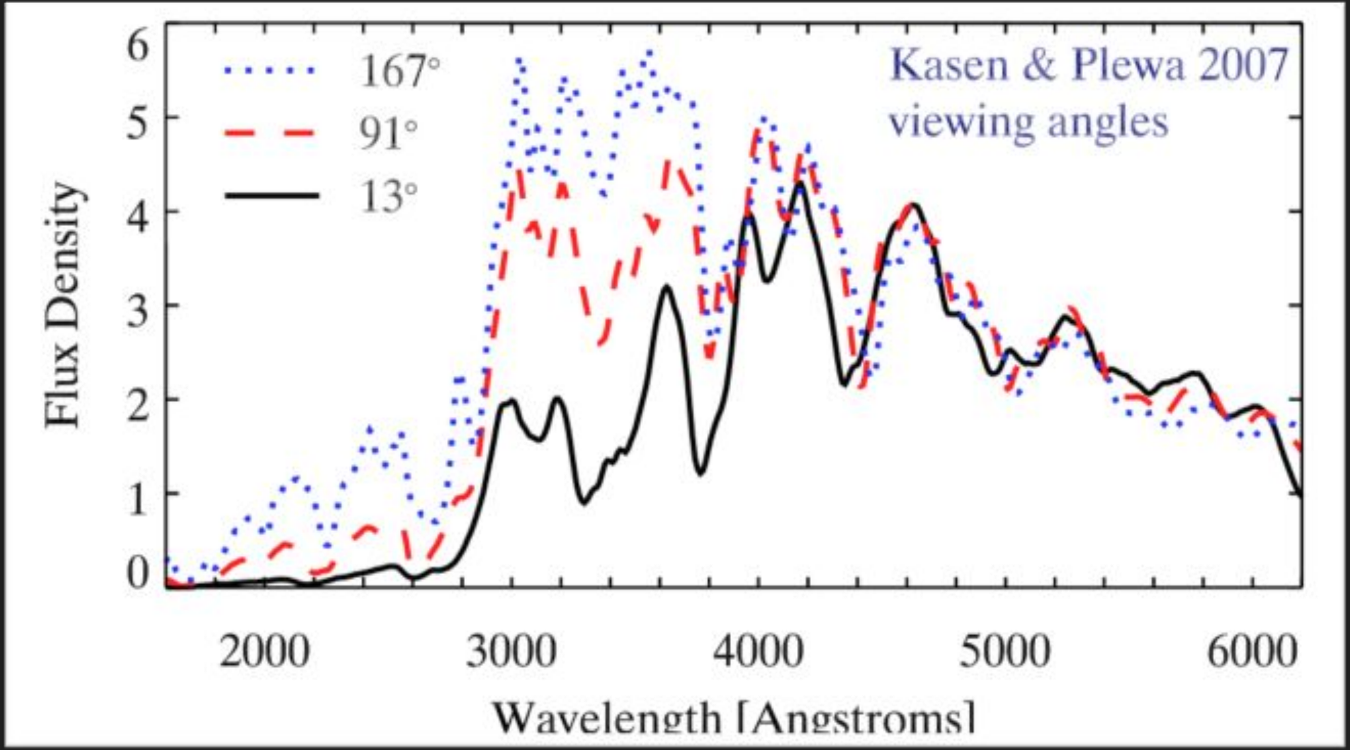


Theoretical models predict the UV is sensitive to composition differences



Would change with redshift !!!

Theoretical models predict the UV is sensitive to asymmetry



Would NOT change with redshift !

The Promise of UV

The UV is sensitive to:

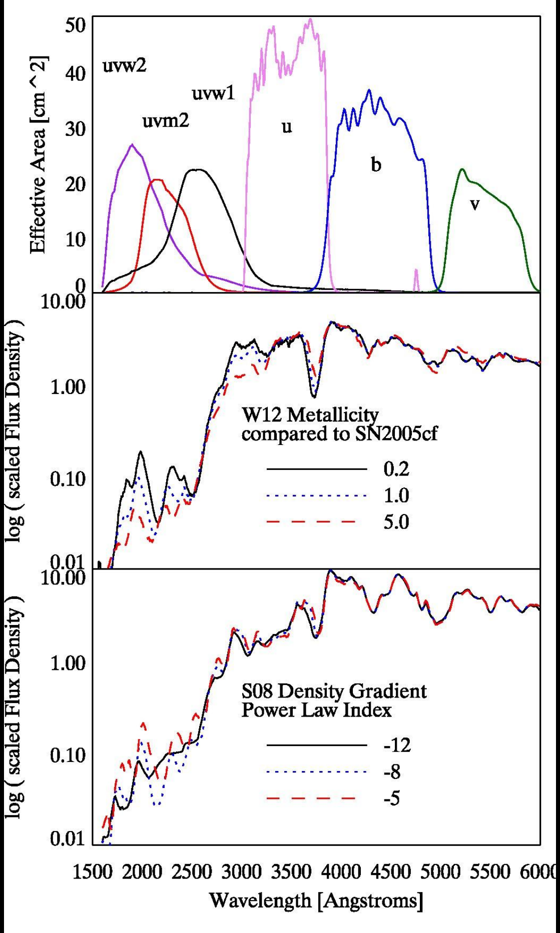
Metallicity

Density structure

Dust reddening

Dust scattering

Interaction



The Promise

The UV is sensitive to:

Metallicity

Density structure

Dust reddening

Dust scattering

Interaction

The Peril

The UV is sensitive to:

Metallicity

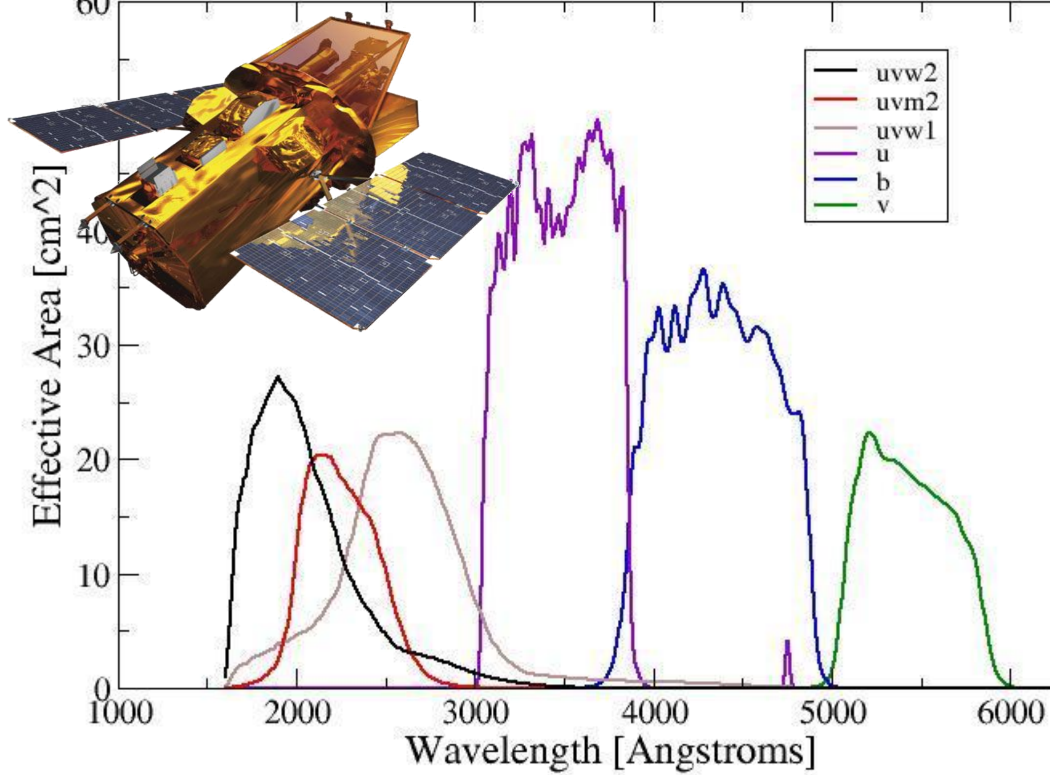
Density structure

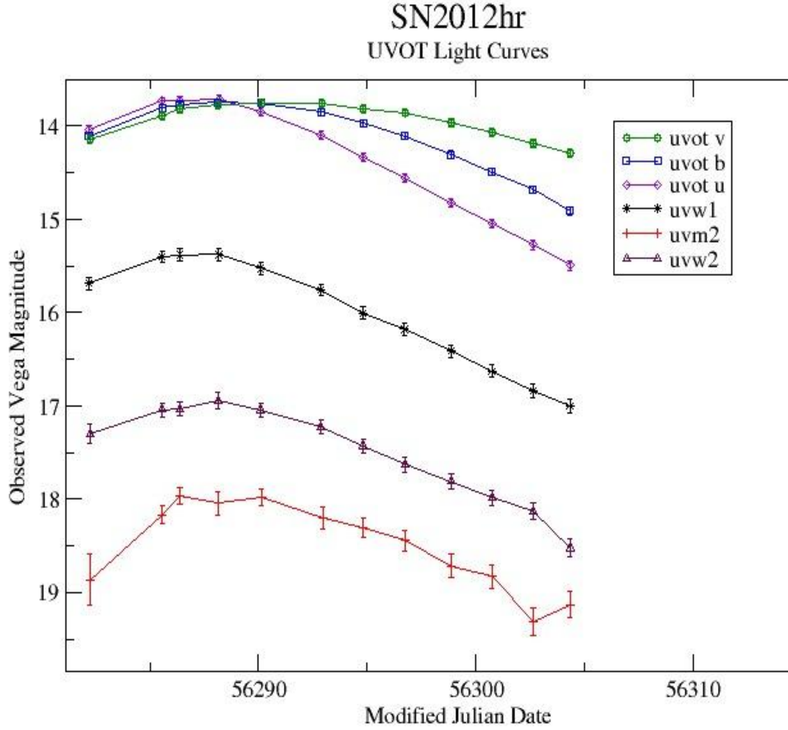
Dust reddening

Dust scattering

Interaction

And you have to go into space!

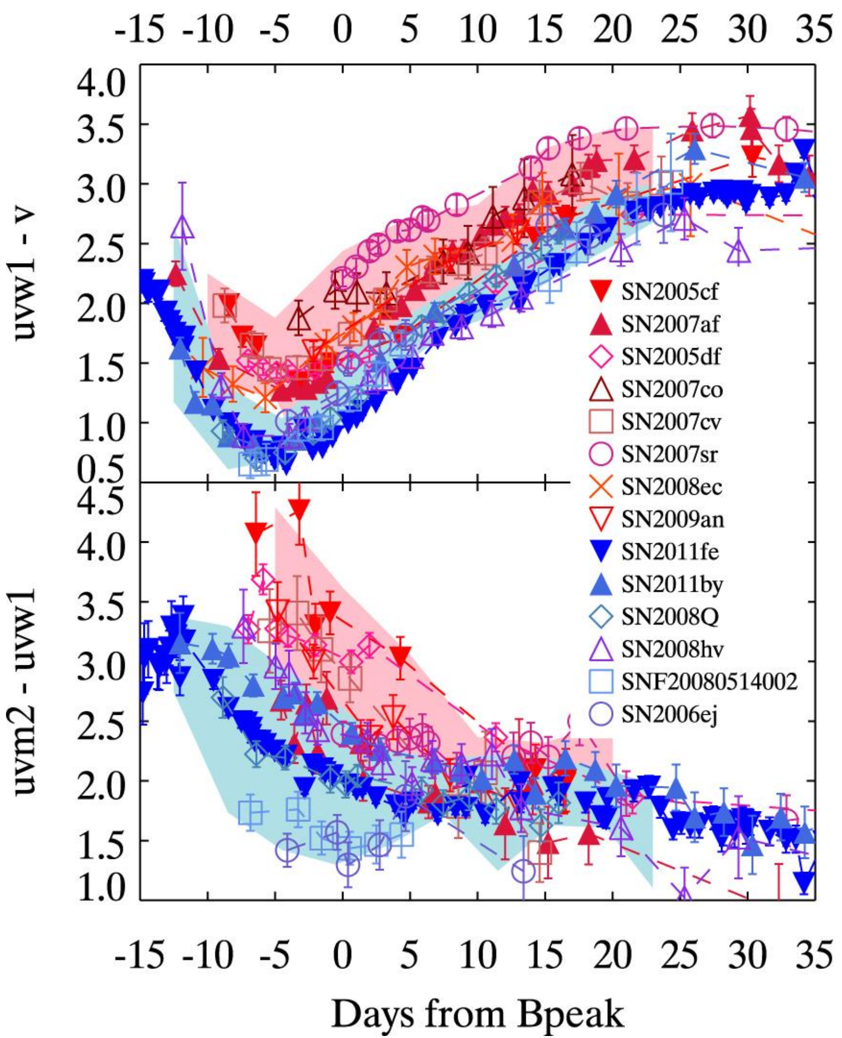




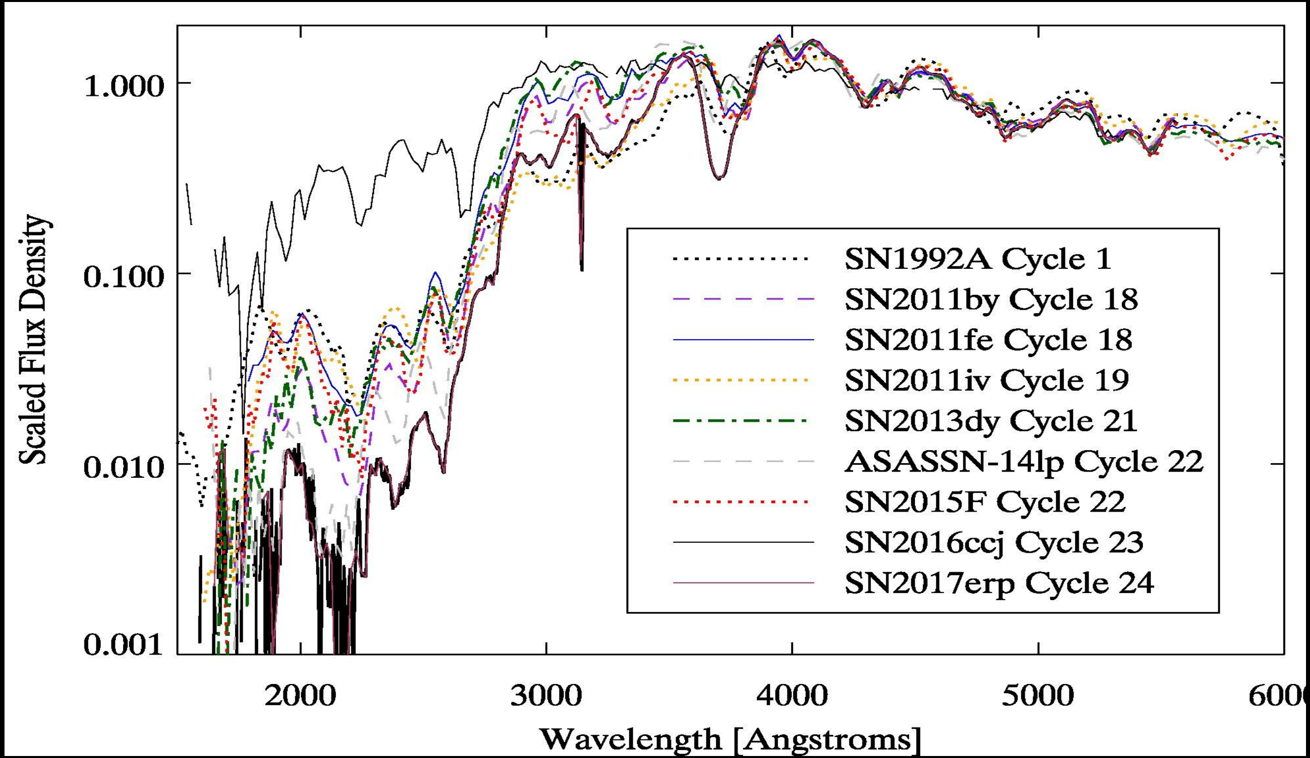
Swift UVOT filters   Swift UVOT light curves

UV color evolution

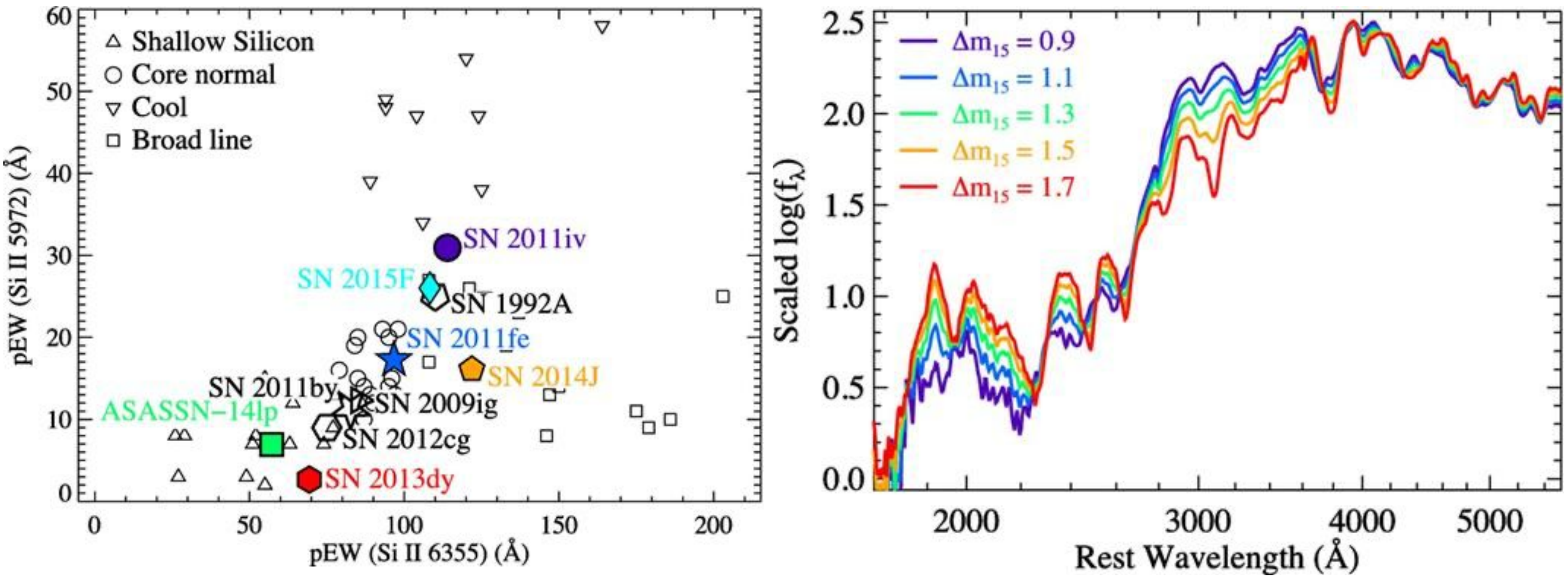
Milne et al. 2013 noted a difference in the near-UV – optical color evolution,
with groups dubbed NUV-red and NUV-blue



HST Ultraviolet Spectroscopy



Growing sample of HST UV spectroscopy



Foley et al. 2016: Ultraviolet Diversity of Type Ia SNe

UV color evolution

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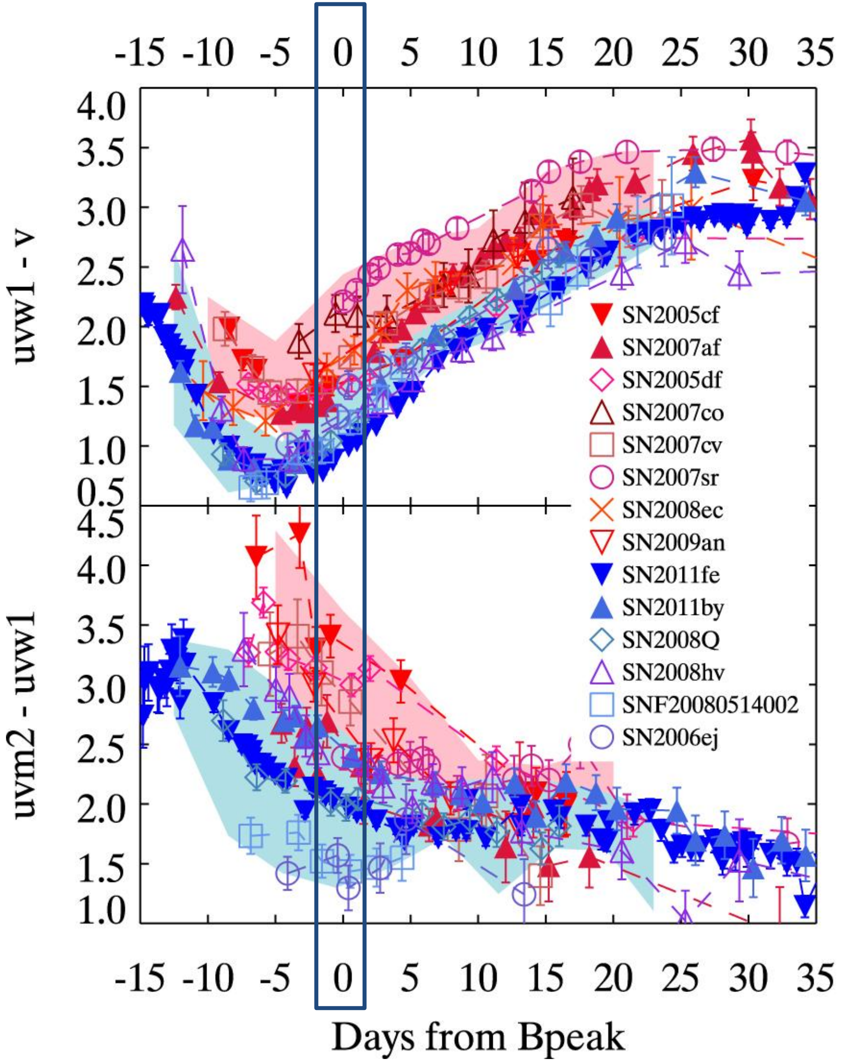
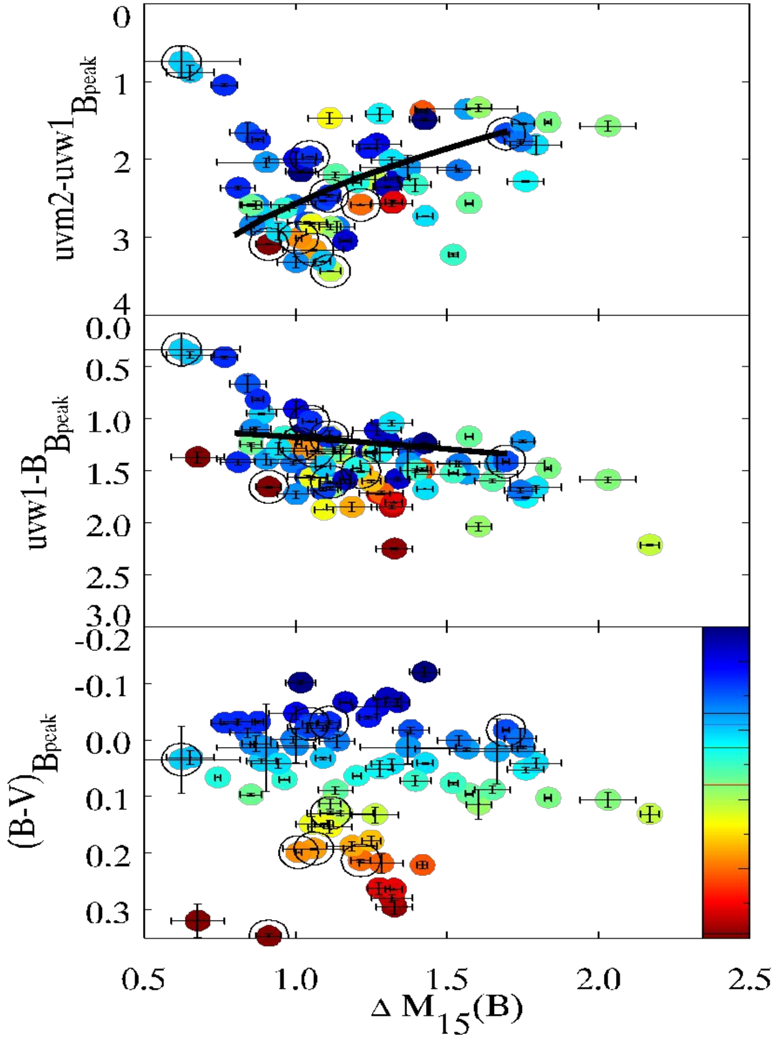


Ultraviolet Diversity of Type Ia Supernovae

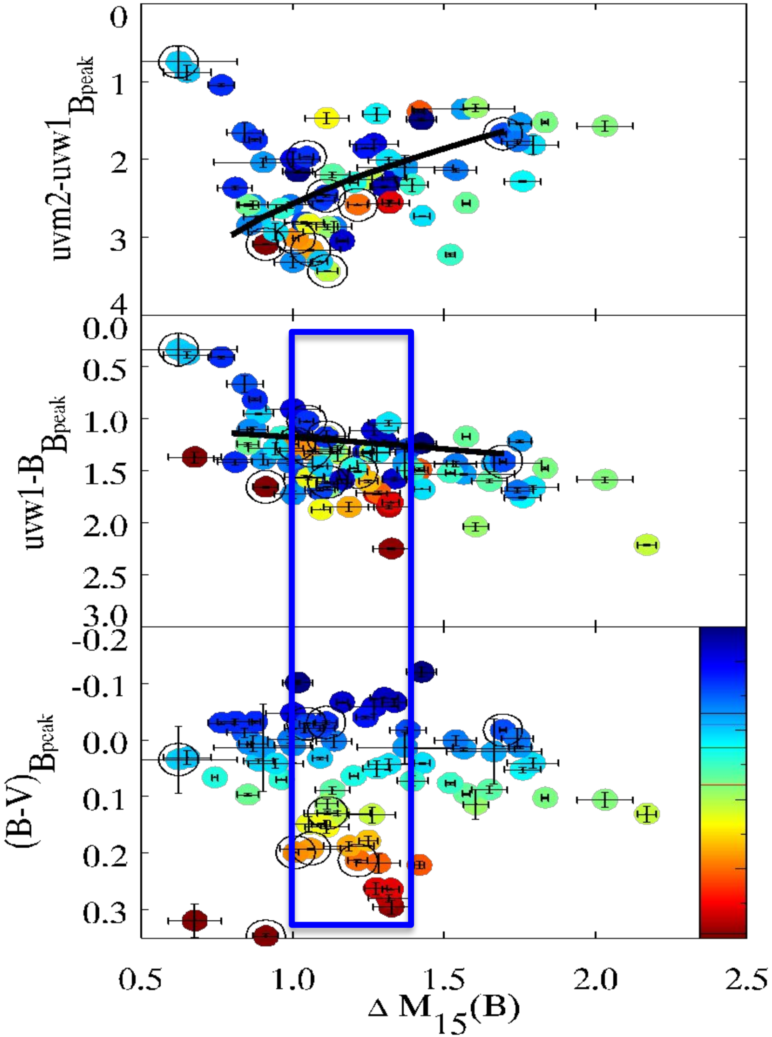
Swift SN Ia colors at maximum light colored by B-V color.

Circled SNe have HST UV spectroscopy

Black line is UV variation model from Foley et al. 2016



Ultraviolet Diversity of Type Ia Supernovae



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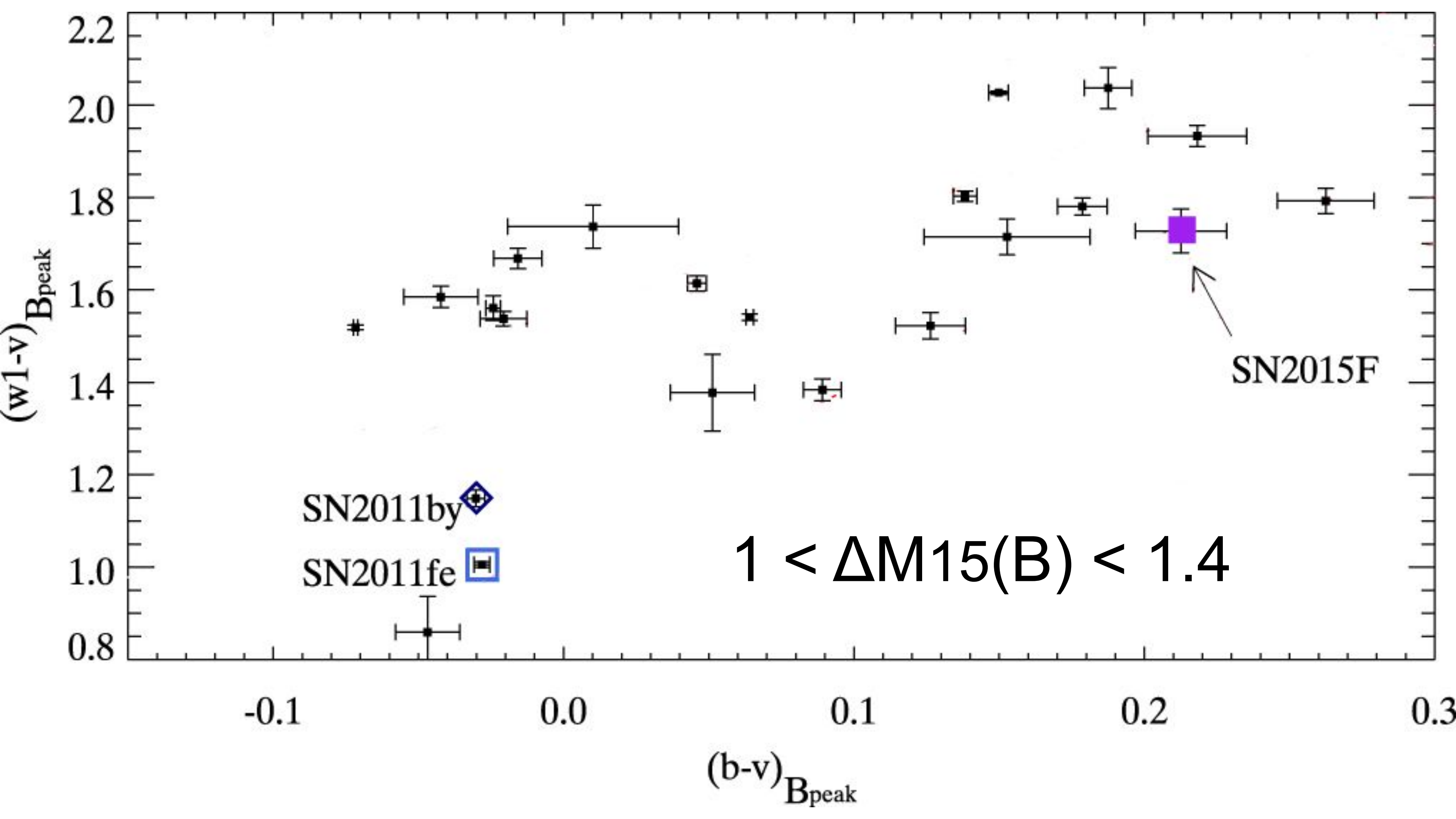
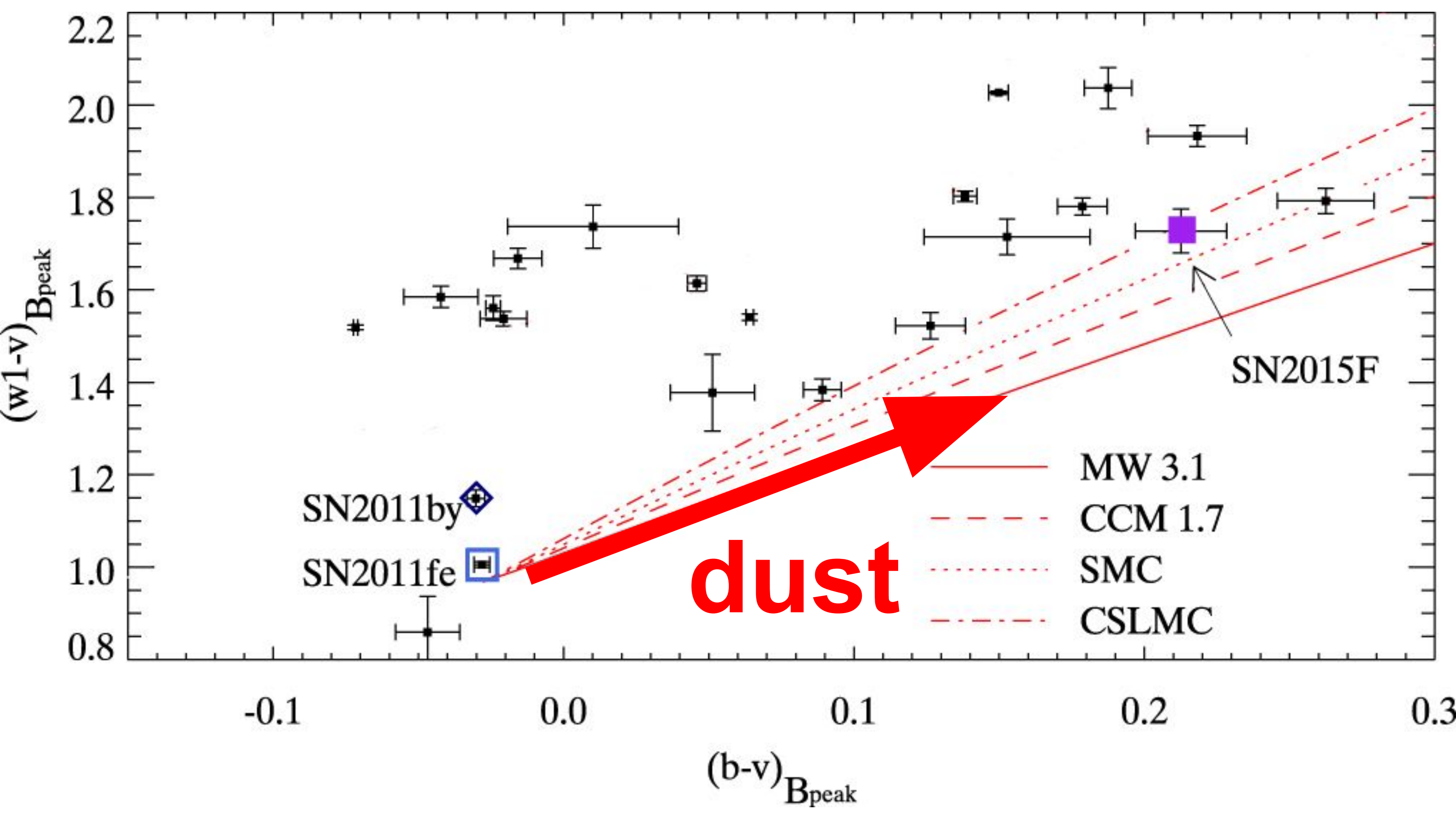
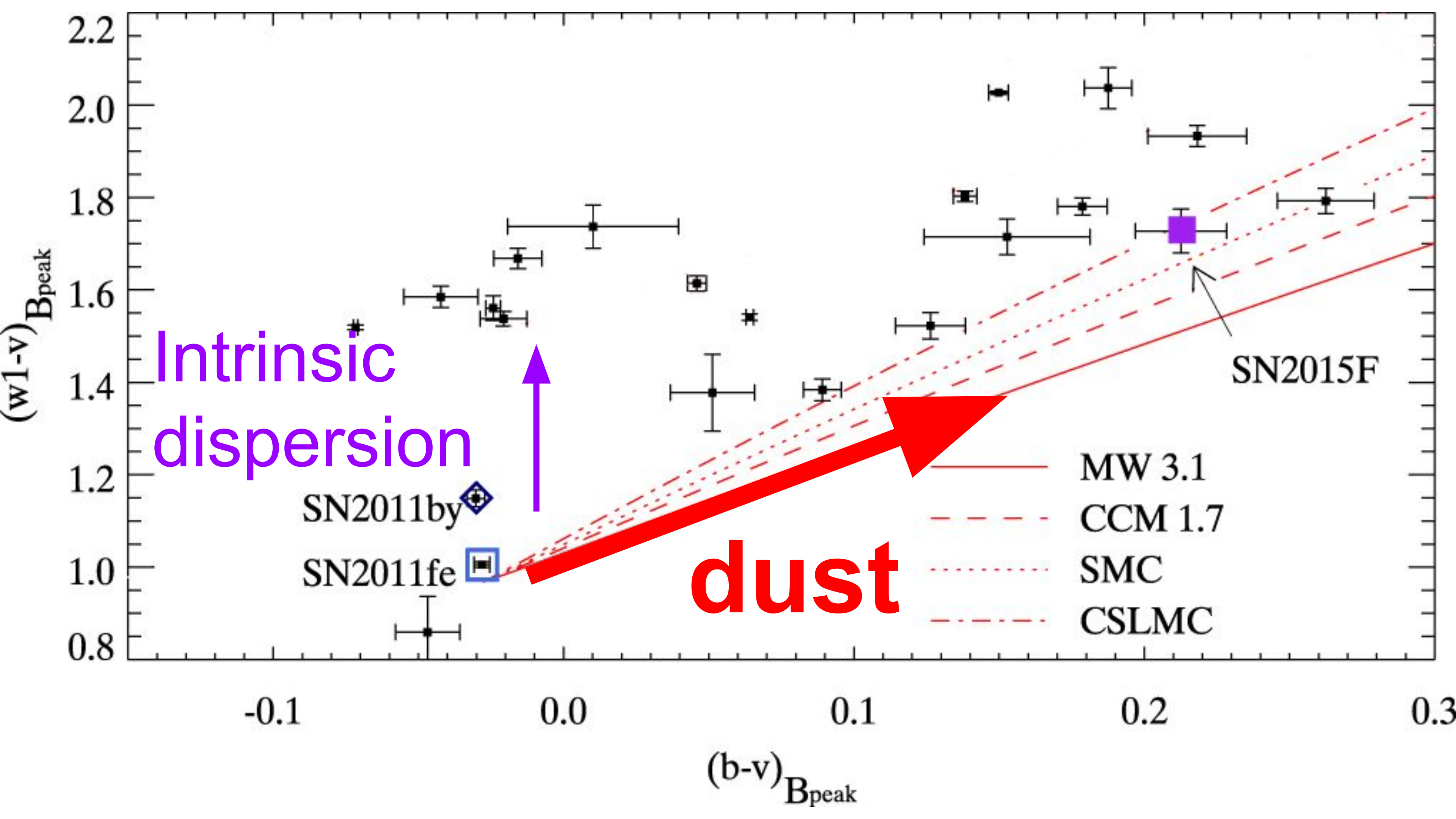


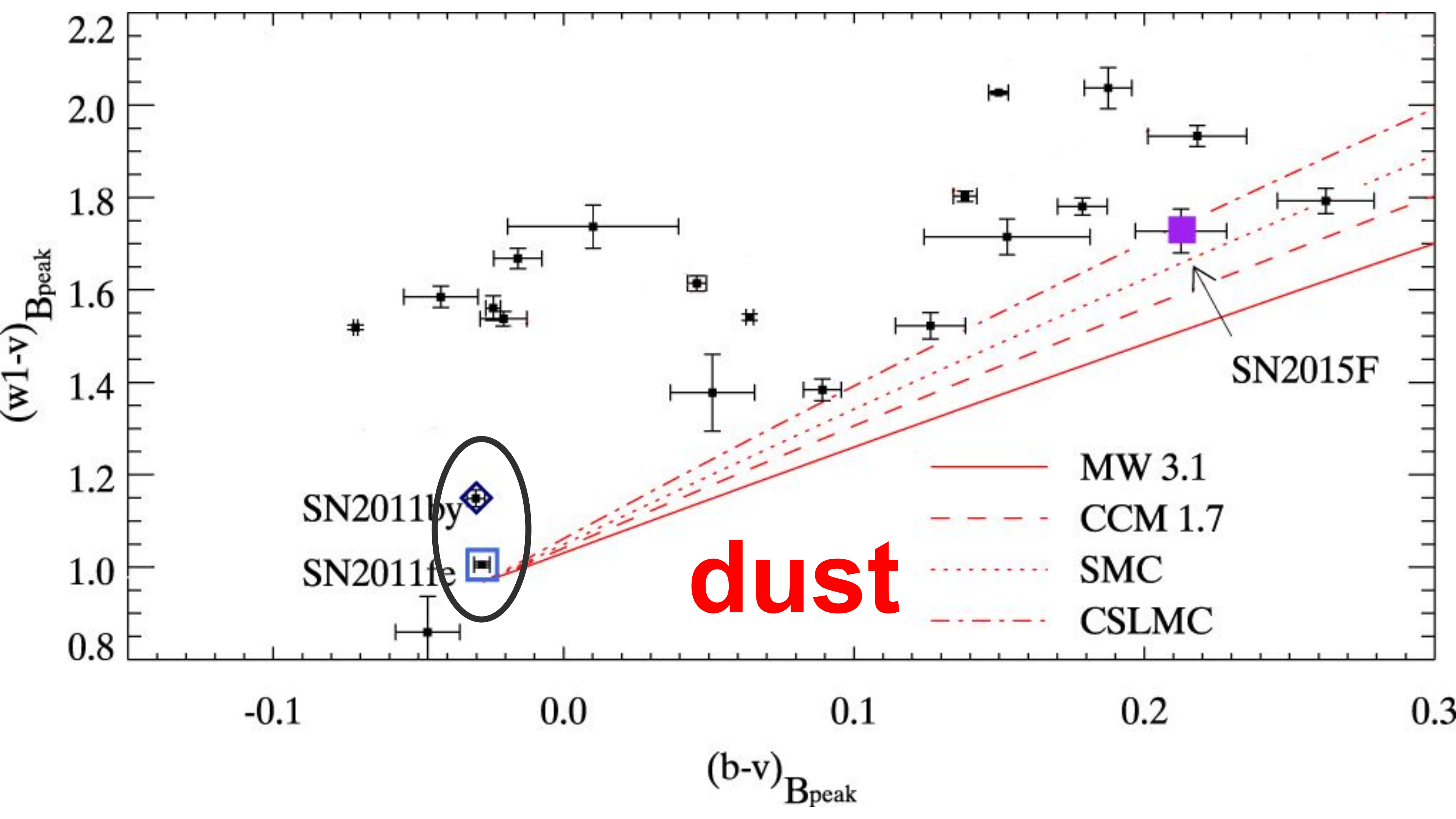
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
$(w1-v)_{B_{peak}}$
-0.1
0.0
0.1
0.2
0.3
$(b-v)_{B_{peak}}$
SN2015F
SN2011by
SN2011fe
1 < ΔM15(B) < 1.4



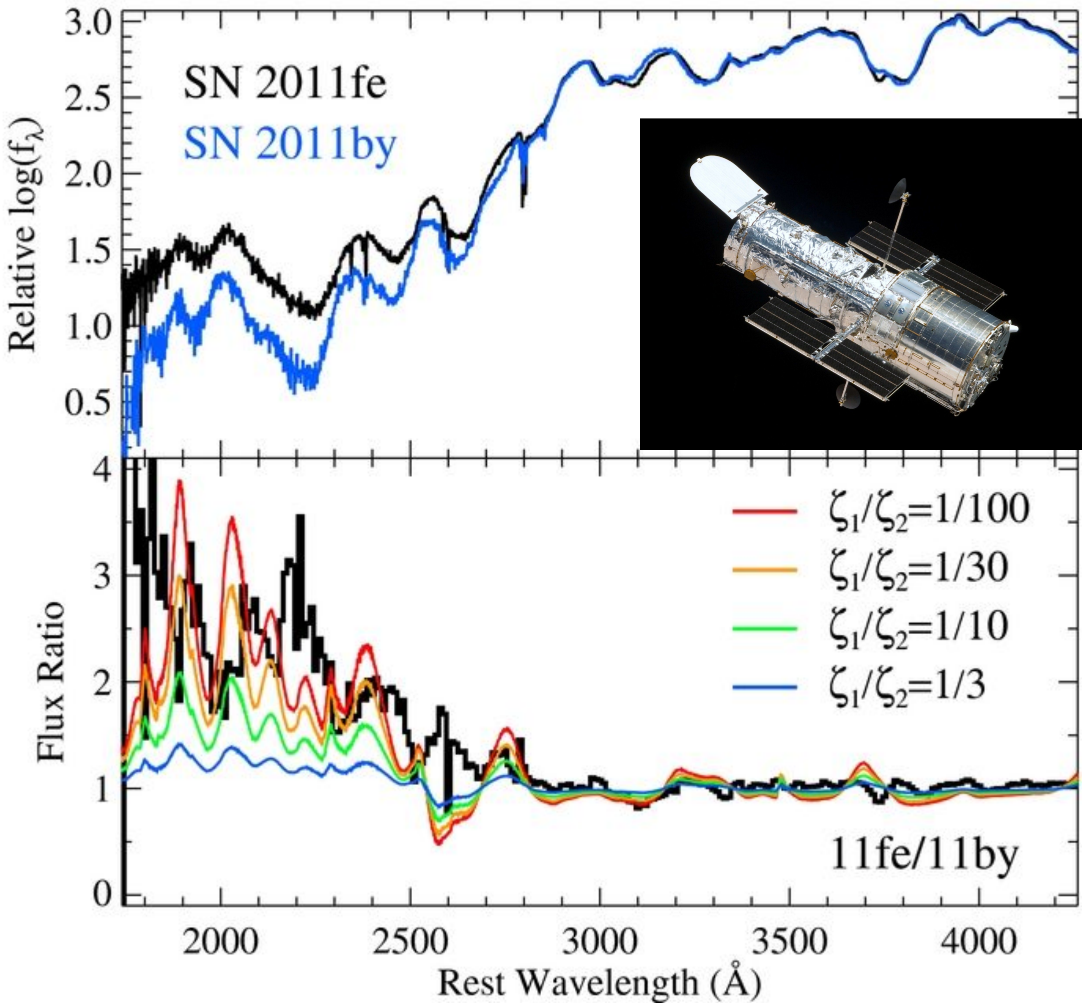
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
$(w1-v)_{B_{peak}}$
-0.1
0.0
0.1
0.2
0.3
$(b-v)_{B_{peak}}$
SN2015F
SN2011by
SN2011fe
dust
MW 3.1
CCM 1.7
SMC
CSLMC



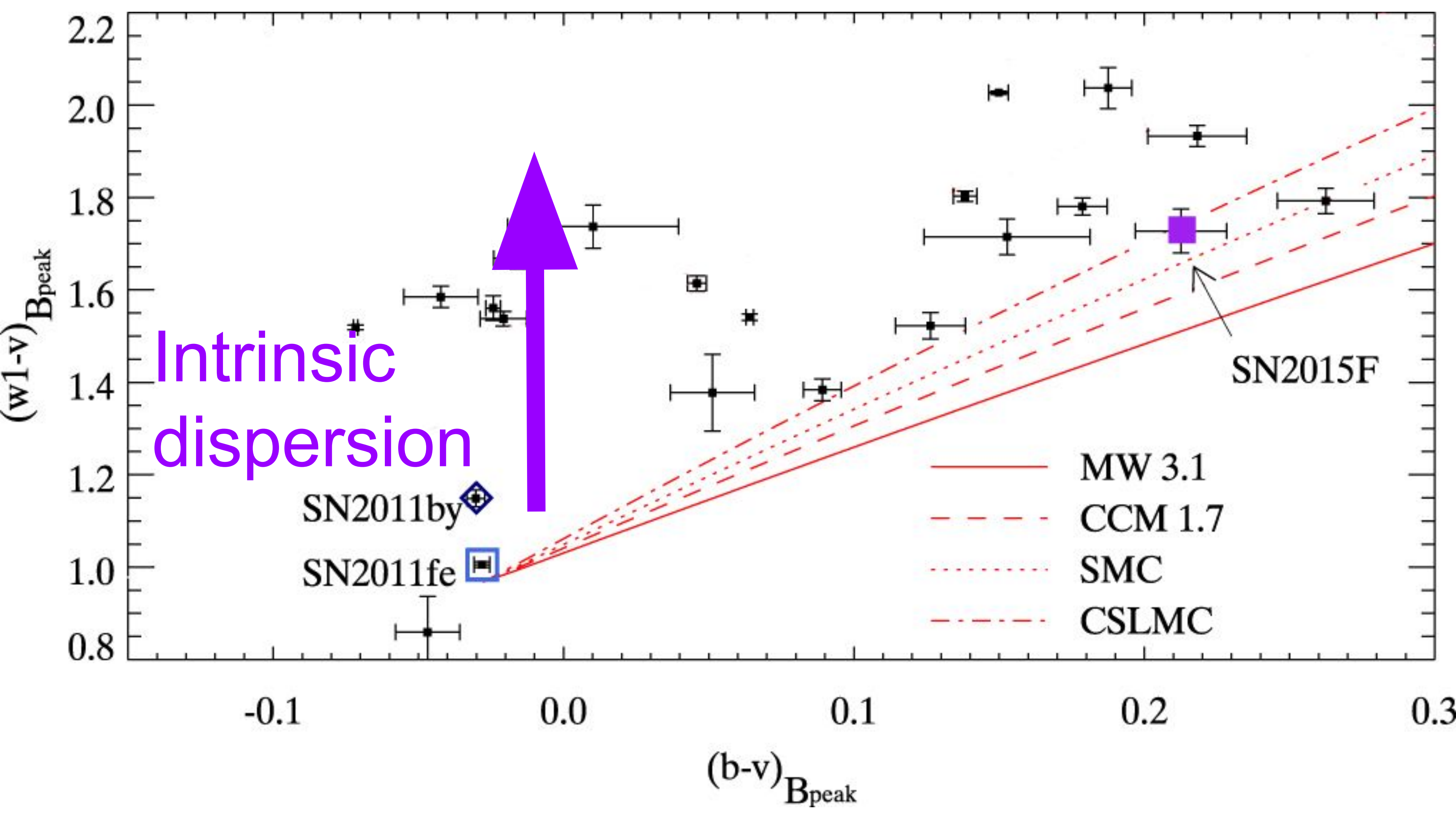
(w1-v)Bpeak
(b-v)Bpeak
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3
Intrinsic dispersion
dust
SN2011by
SN2011fe
SN2015F
MW 3.1
CCM 1.7
SMC
CSLMC



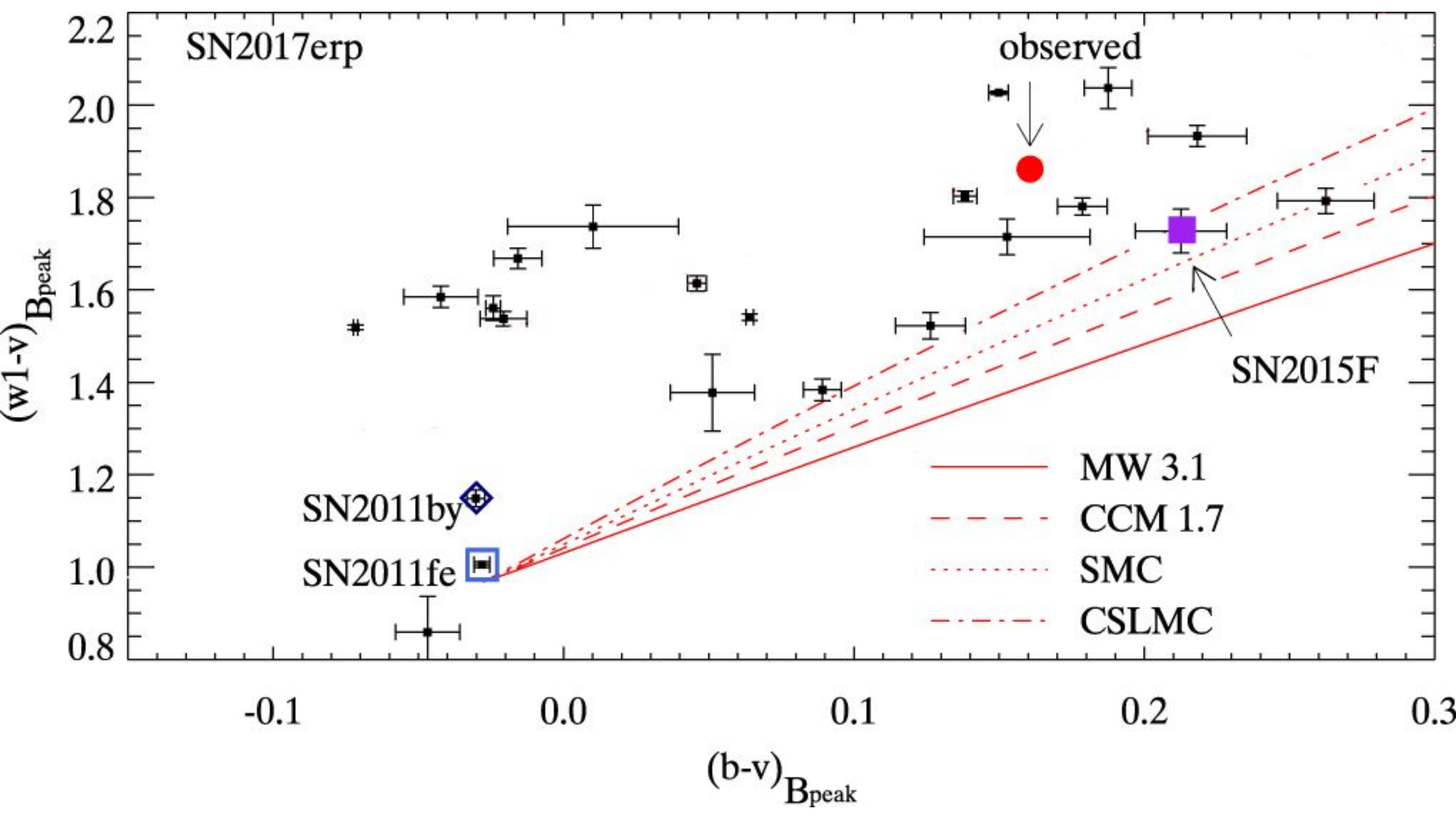
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3
$(w1\text{-}v)_{B_{peak}}$
$(b\text{-}v)_{B_{peak}}$
SN2015F
SN2011by
SN2011fe
dust
MW 3.1
CCM 1.7
SMC
CSLMC

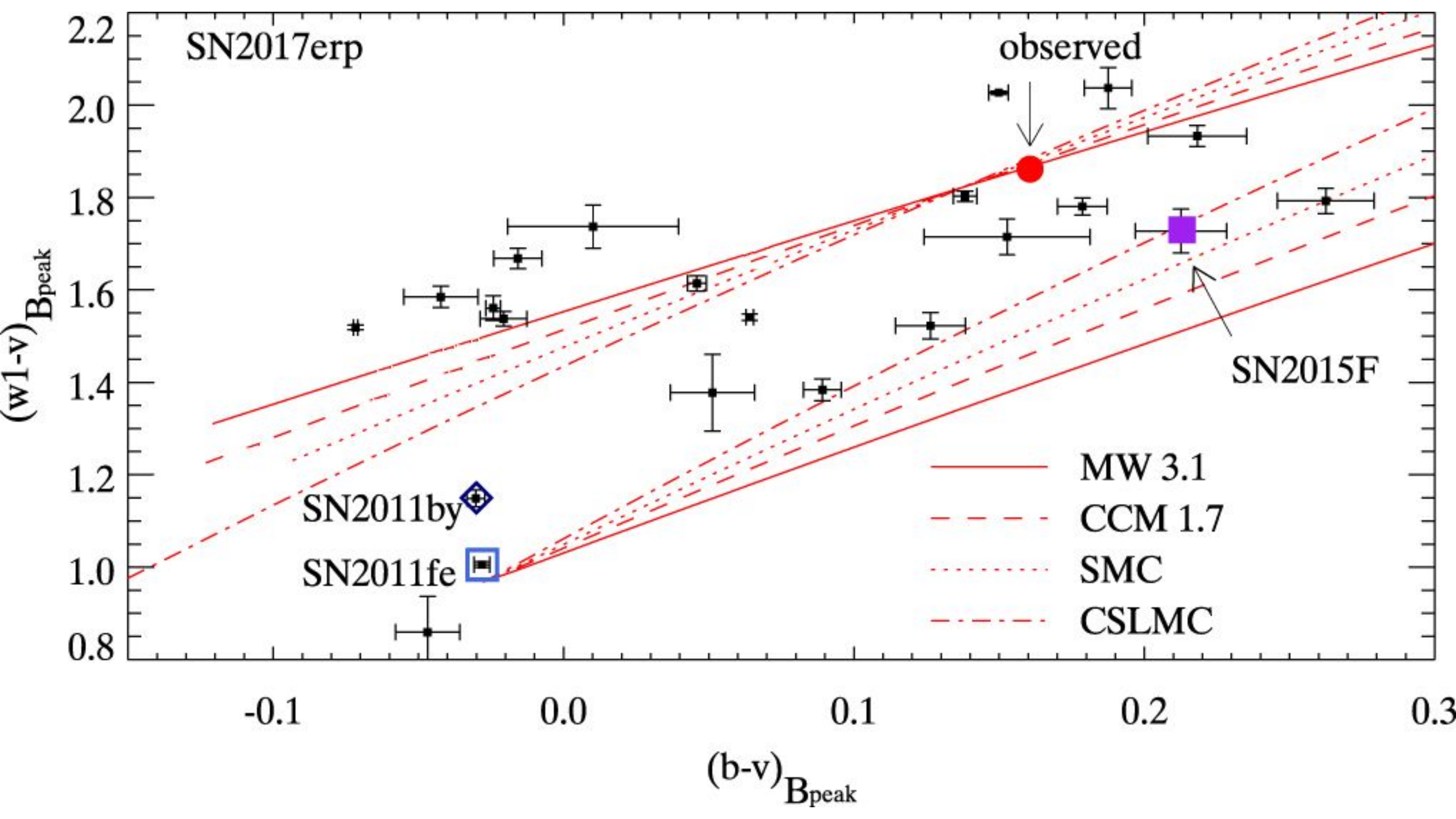


NUV "twins"
SNe 2011fe and
2011by have different
MUV continua (Foley
& Kirshner 2013)
attributed to
metallicity difference
based on Lentz et al.
(2000) models

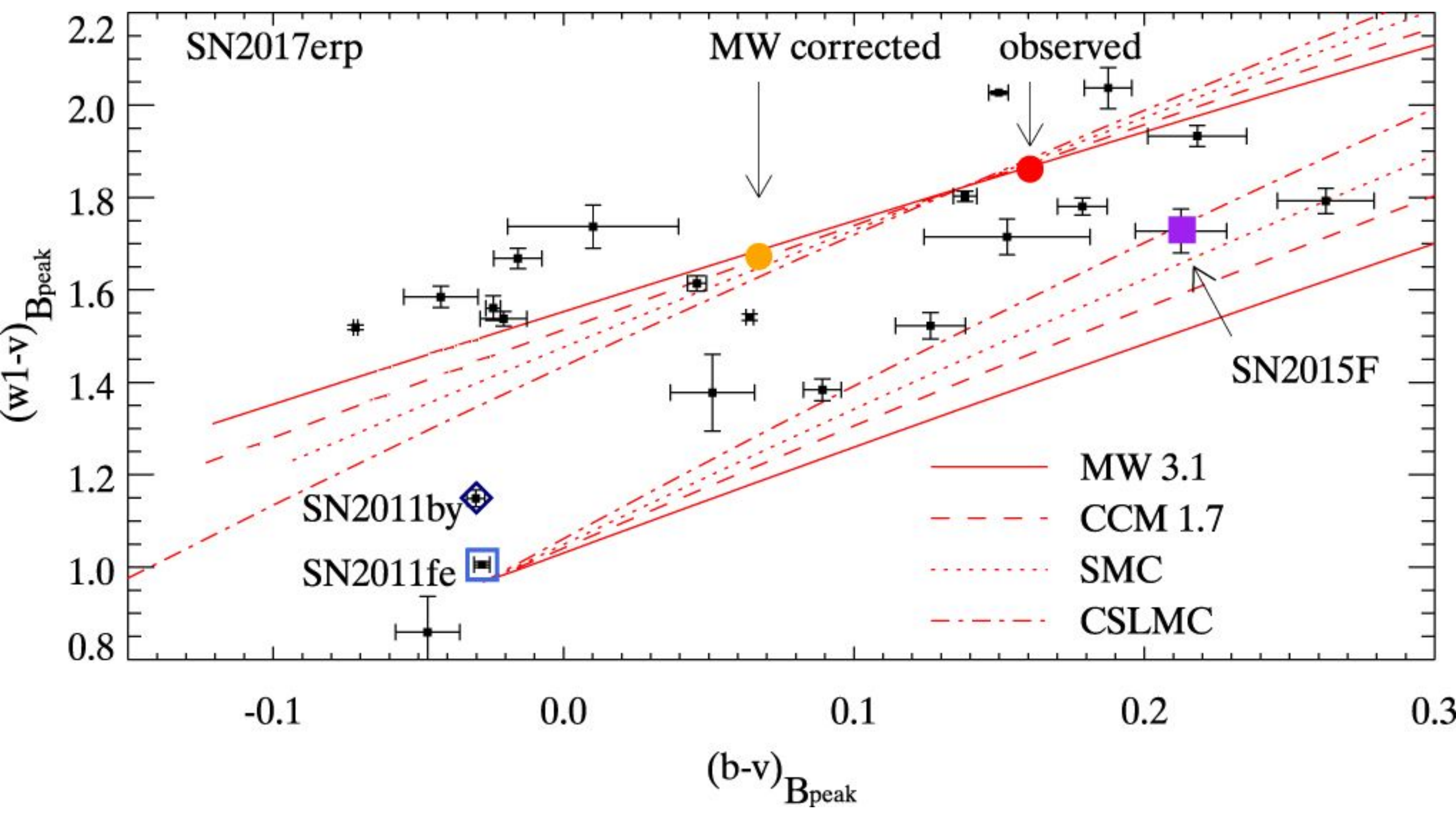


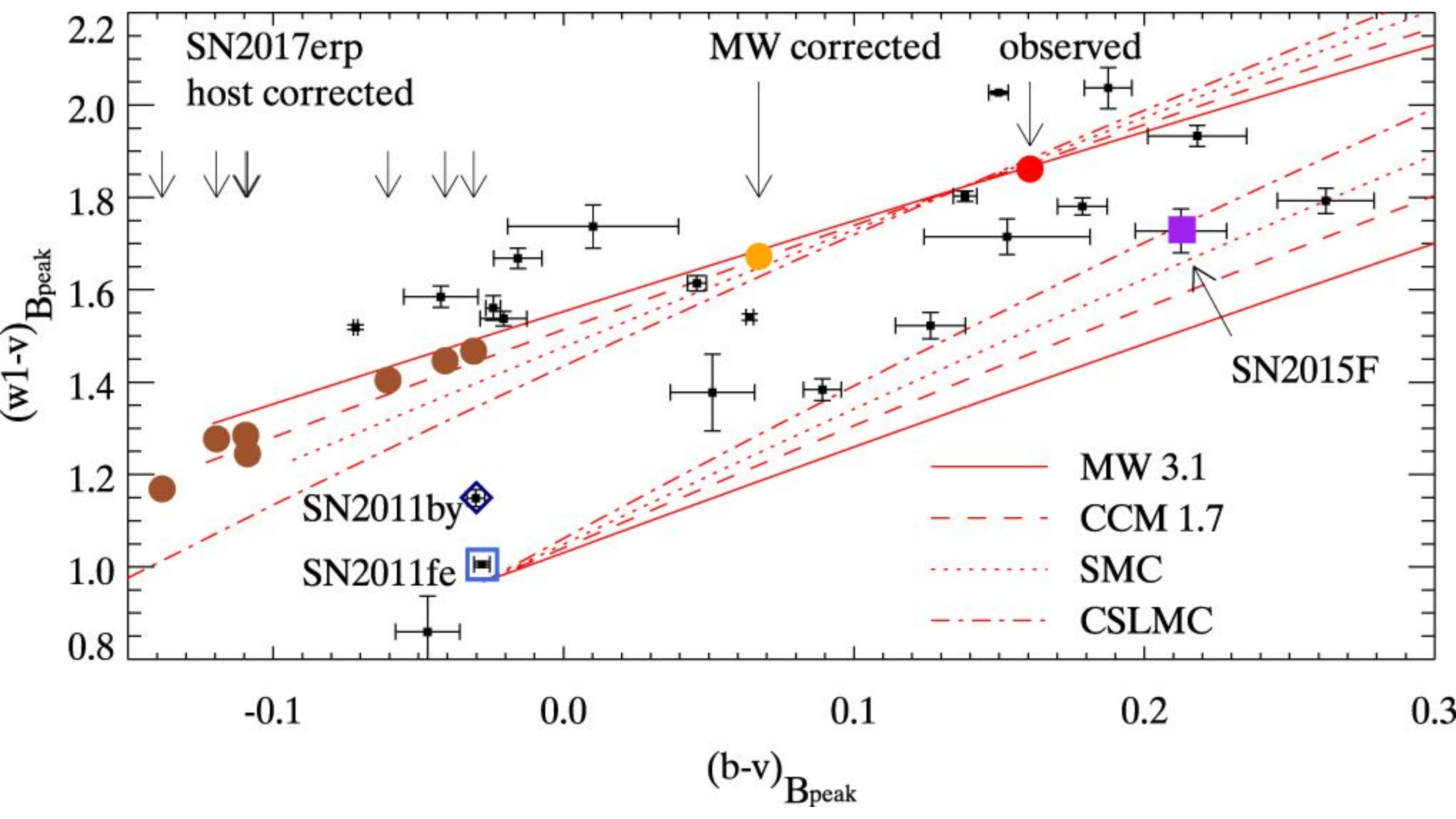
Intrinsic
dispersion
SN2011by
SN2011fe
SN2015F
MW 3.1
CCM 1.7
SMC
CSLMC
$(w1\text{-}v)_{B_{peak}}$
$(b\text{-}v)_{B_{peak}}$


SN2017erp
observed
SN2015F
SN2011by
SN2011fe
MW 3.1
CCM 1.7
SMC
CSLMC
(w1-v)Bpeak
(b-v)Bpeak
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3

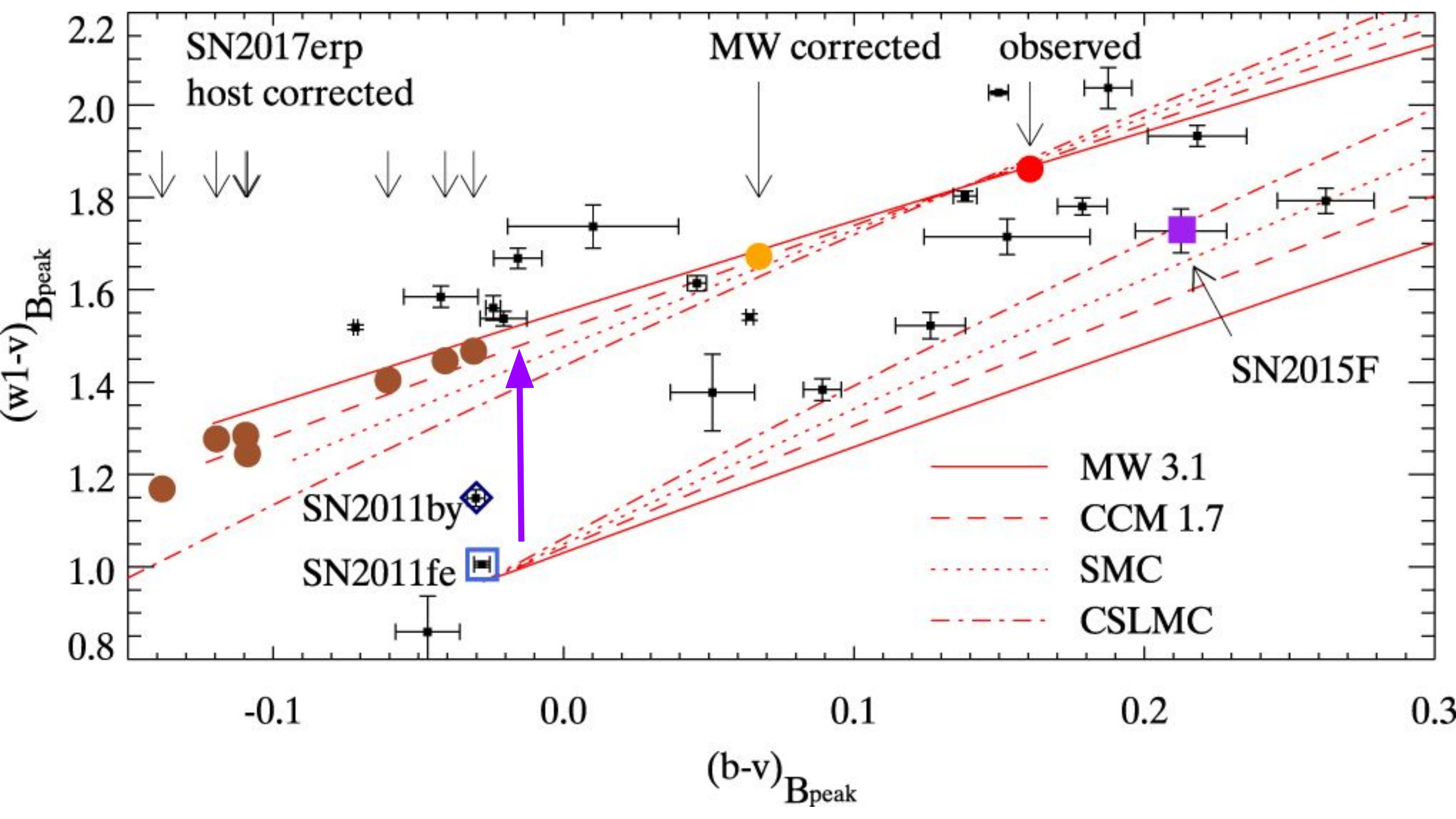


SN2017erp
observed
SN2015F
SN2011by
SN2011fe
MW 3.1
CCM 1.7
SMC
CSLMC
$(w1-v)_{B_{peak}}$
$(b-v)_{B_{peak}}$
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3


SN2017erp
MW corrected
observed
SN2015F
SN2011by
SN2011fe
MW 3.1
CCM 1.7
SMC
CSLMC
(w1-v)Bpeak
(b-v)Bpeak
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3

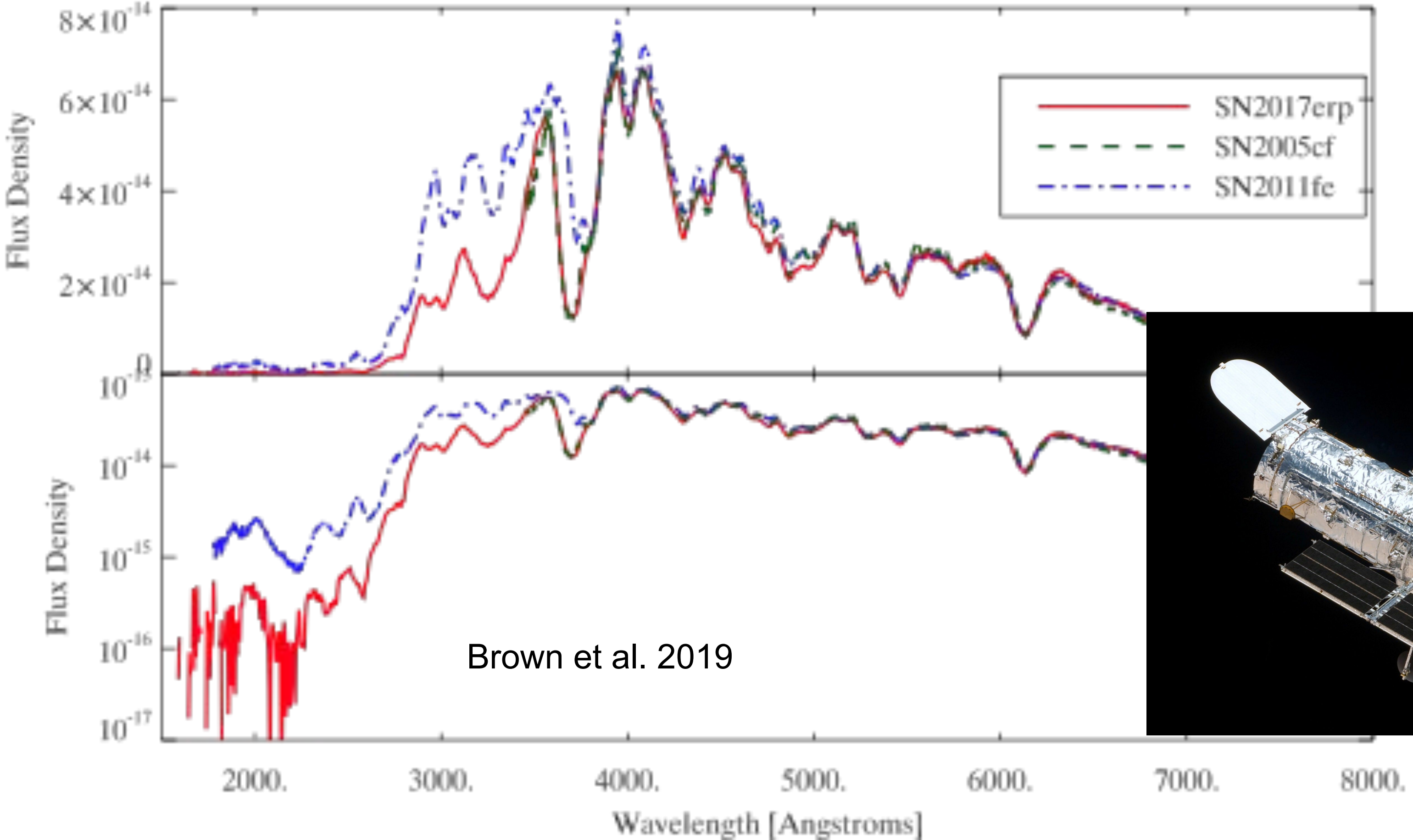


SN2017erp
host corrected
MW corrected
observed
SN2015F
SN2011by
SN2011fe
MW 3.1
CCM 1.7
SMC
CSLMC
$(w1-v)_{B_{peak}}$
$(b-v)_{B_{peak}}$
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3

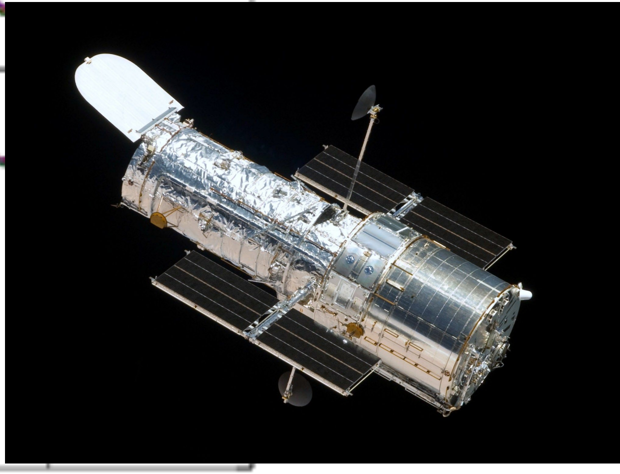


SN2017erp
host corrected
MW corrected
observed
SN2015F
SN2011by
SN2011fe
MW 3.1
CCM 1.7
SMC
CSLMC
(w1-v)$_{B_{peak}}$
(b-v)$_{B_{peak}}$
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
-0.1
0.0
0.1
0.2
0.3

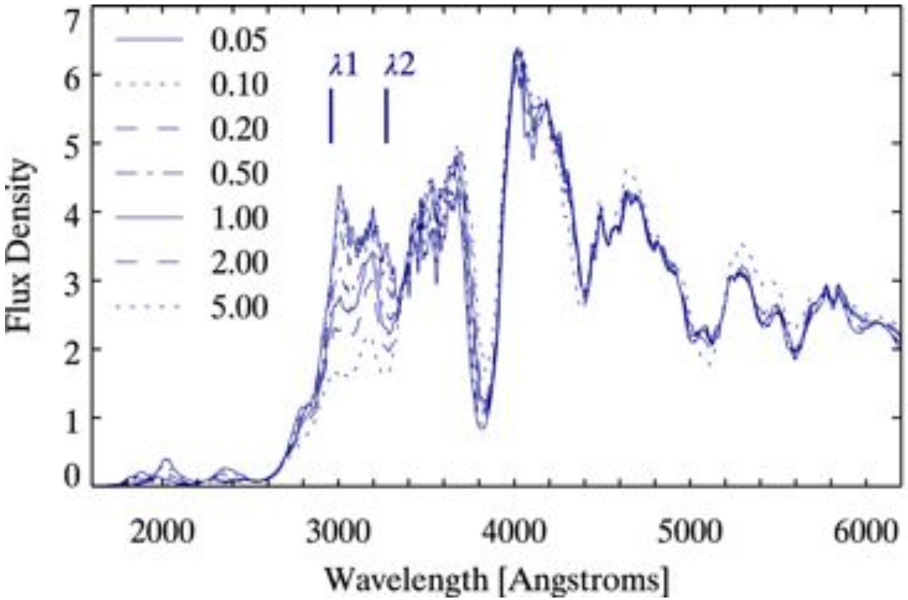
UV differences between SN2017erp and SN2011fe

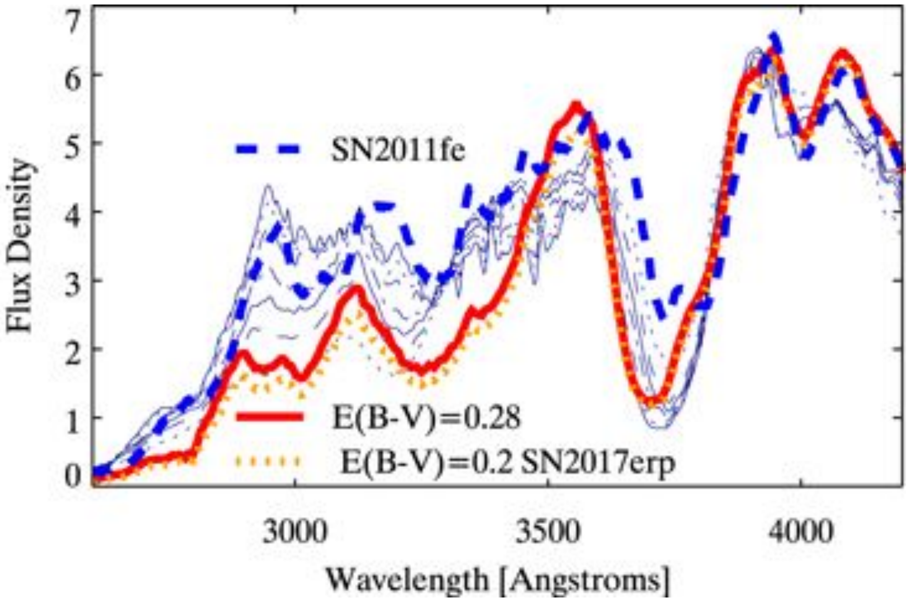


Brown et al. 2019

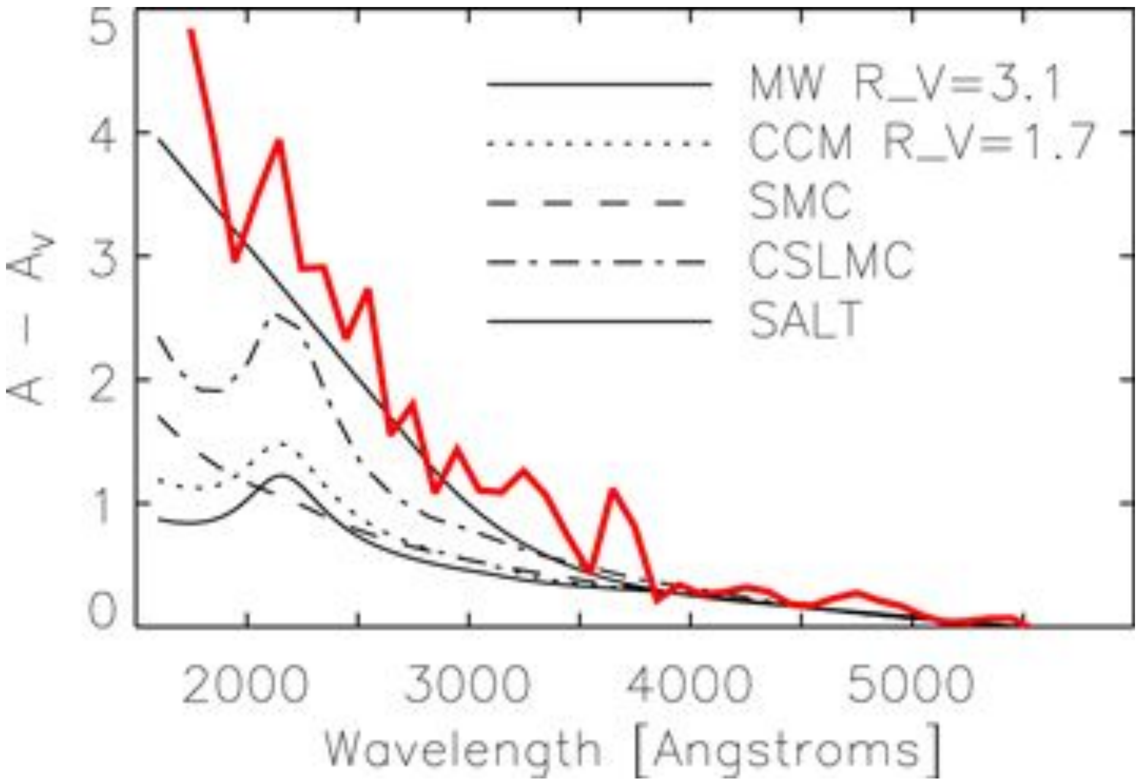


Comparisons with Walker et al. (2012) models point to metallicity as source of near-UV differences

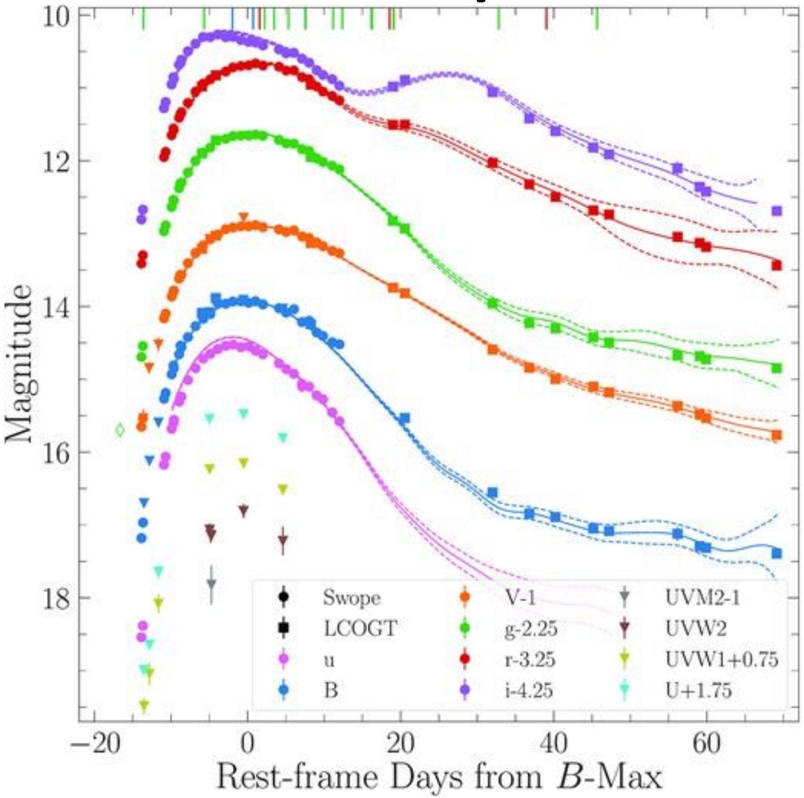




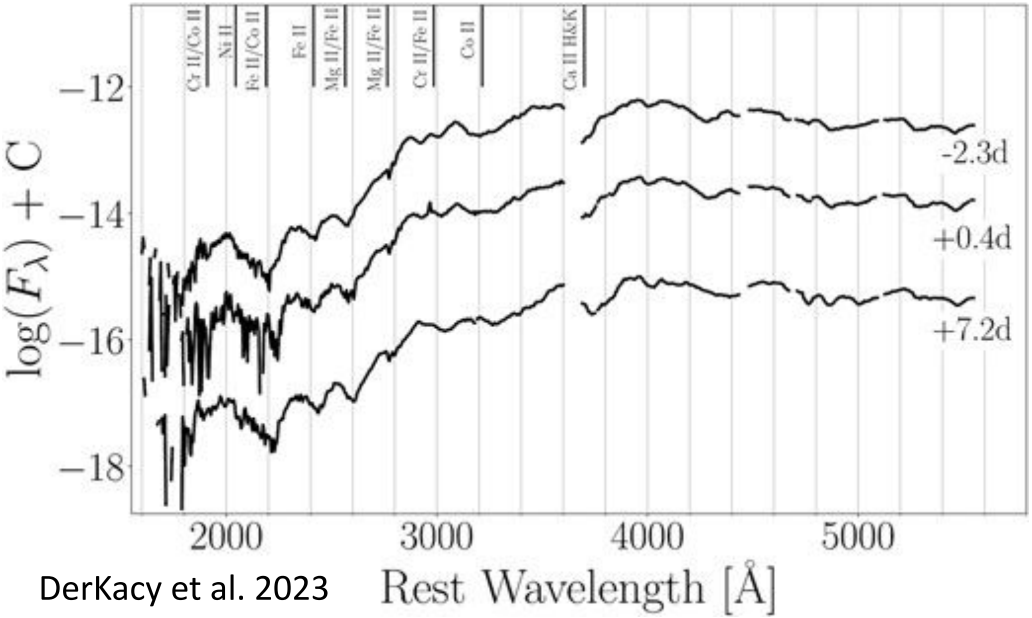
SALT2 color law resembles intrinsic differences in the UV



Early Swift observations enabled HST UV spectroscopy of a red SN Ia

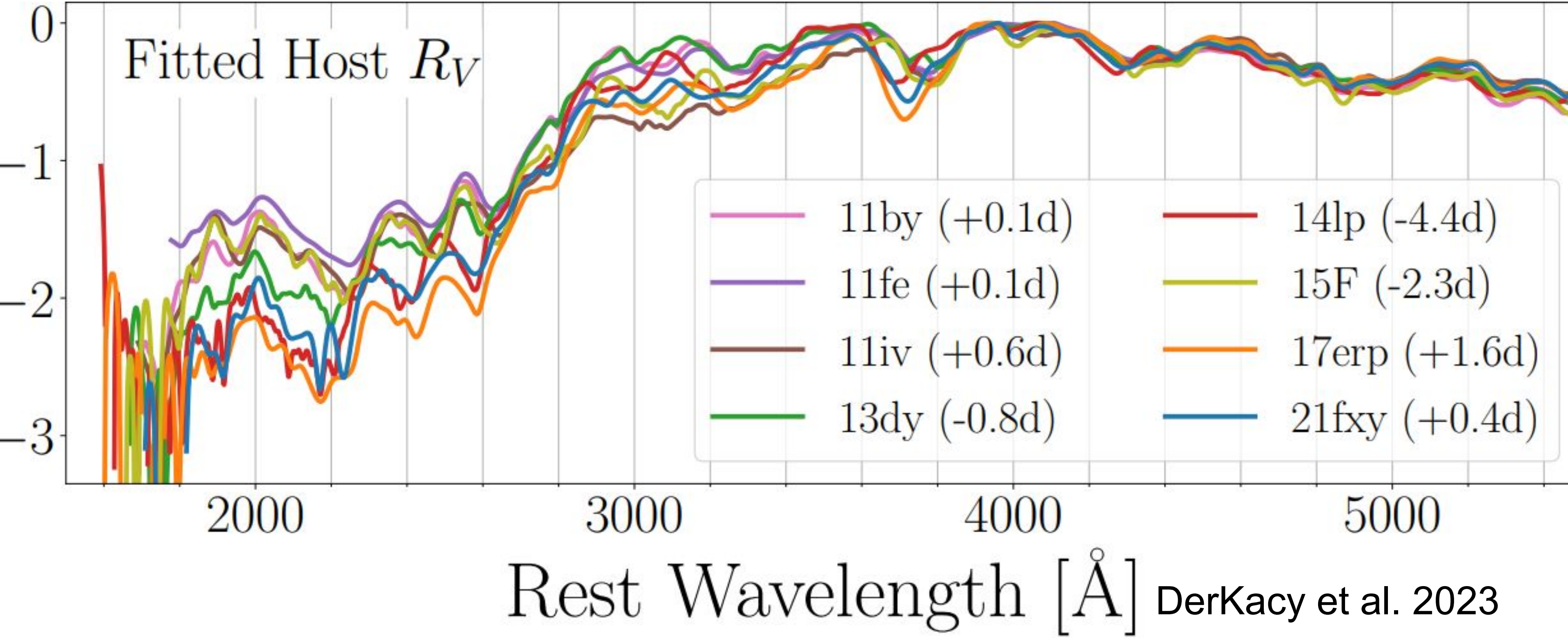


UVOT light curve very poor due to oversubscription and even approved epochs not actually happening.



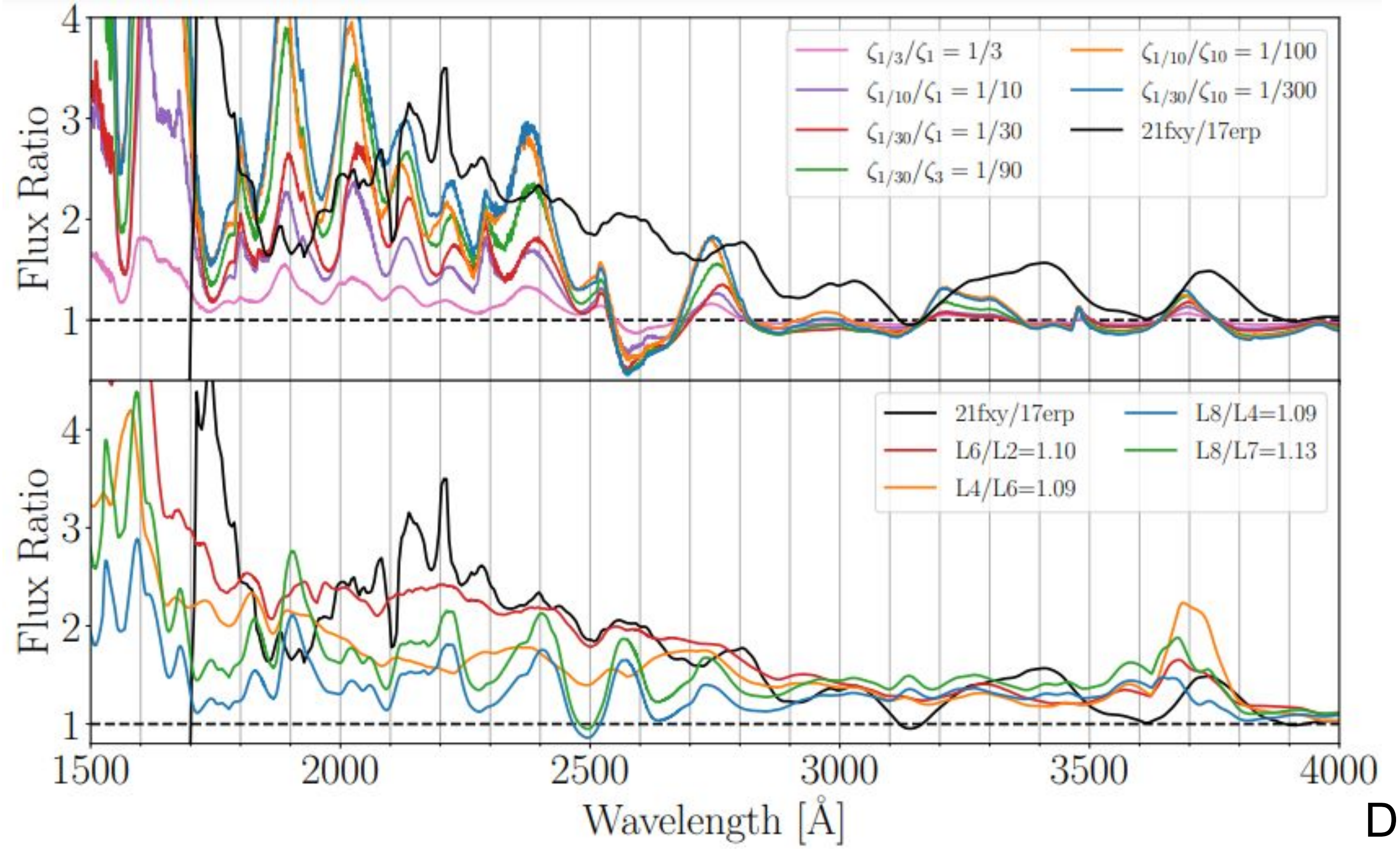
DerKacy et al. 2023

SN2021fxy also has suppressed UV emission



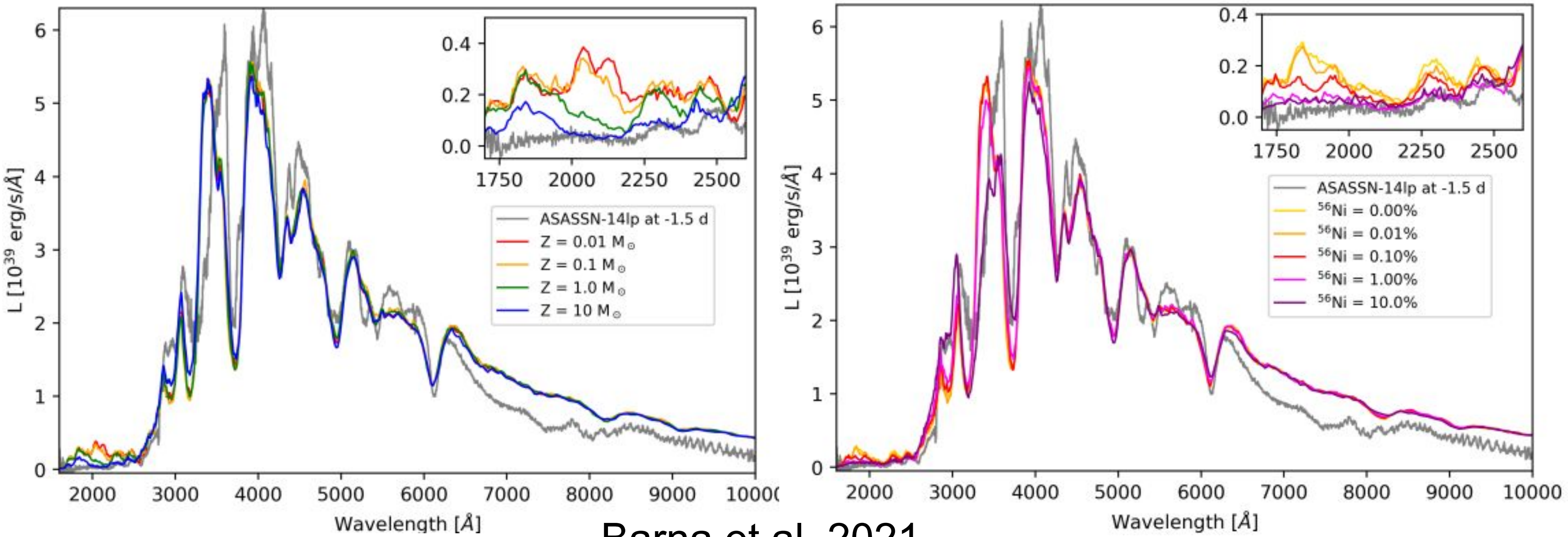
DerKacy et al. 2023

Change in luminosity better match than metallicity

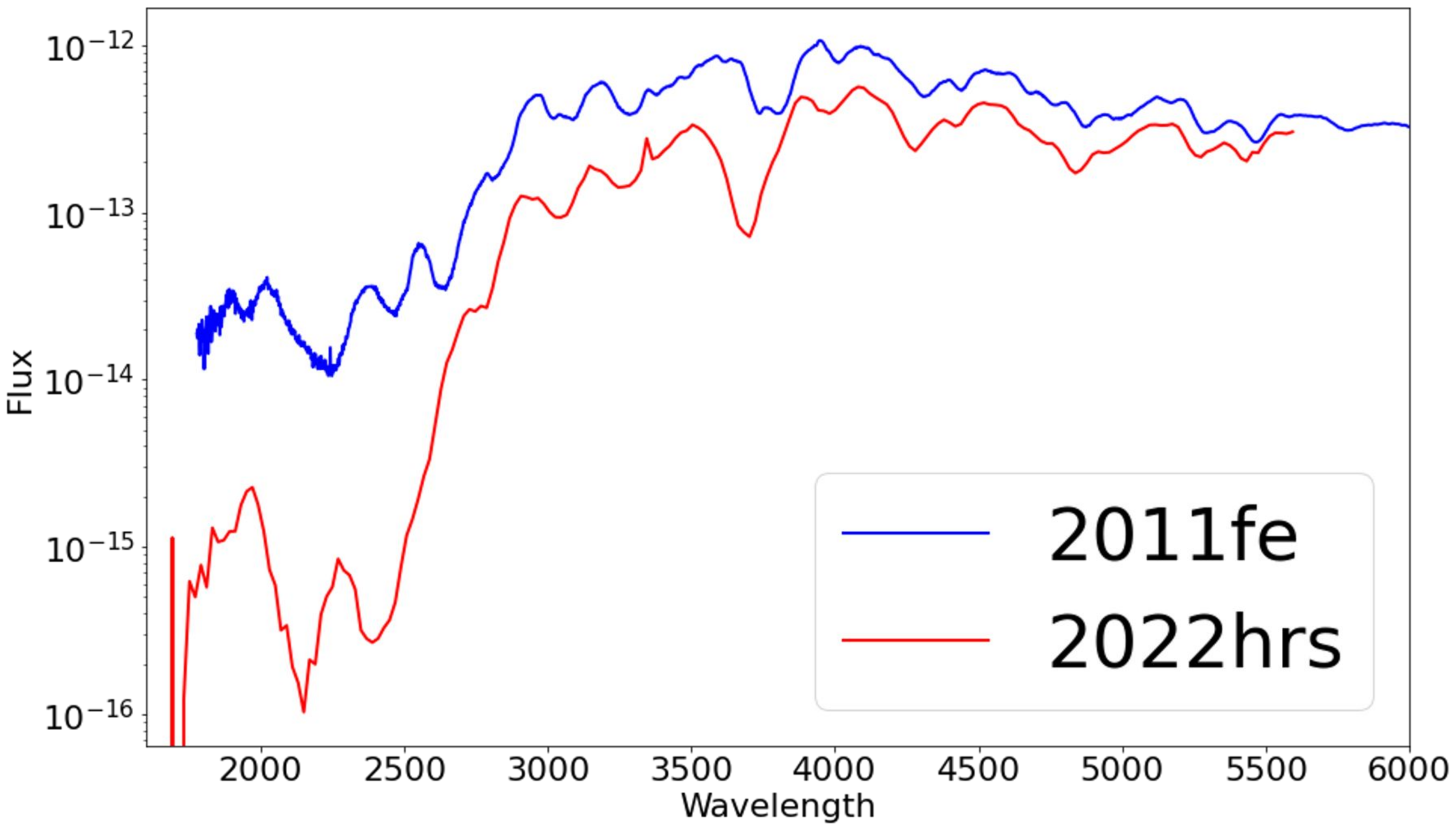


DerKacy et al. 2023

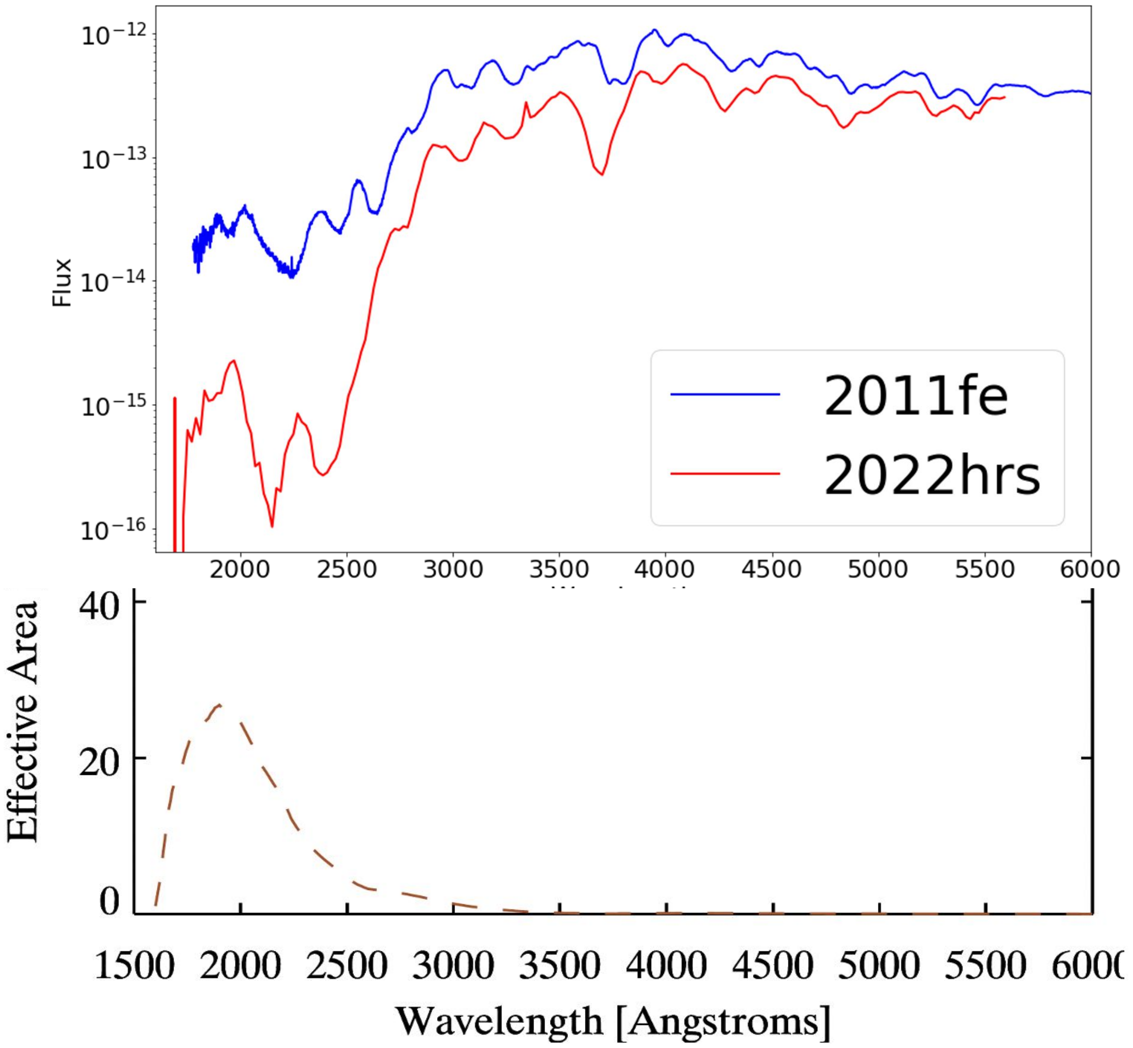
ASASSN-14lp: UV Suppression from high metallicity, high 56Ni fraction, or truncated UV flux at photosphere



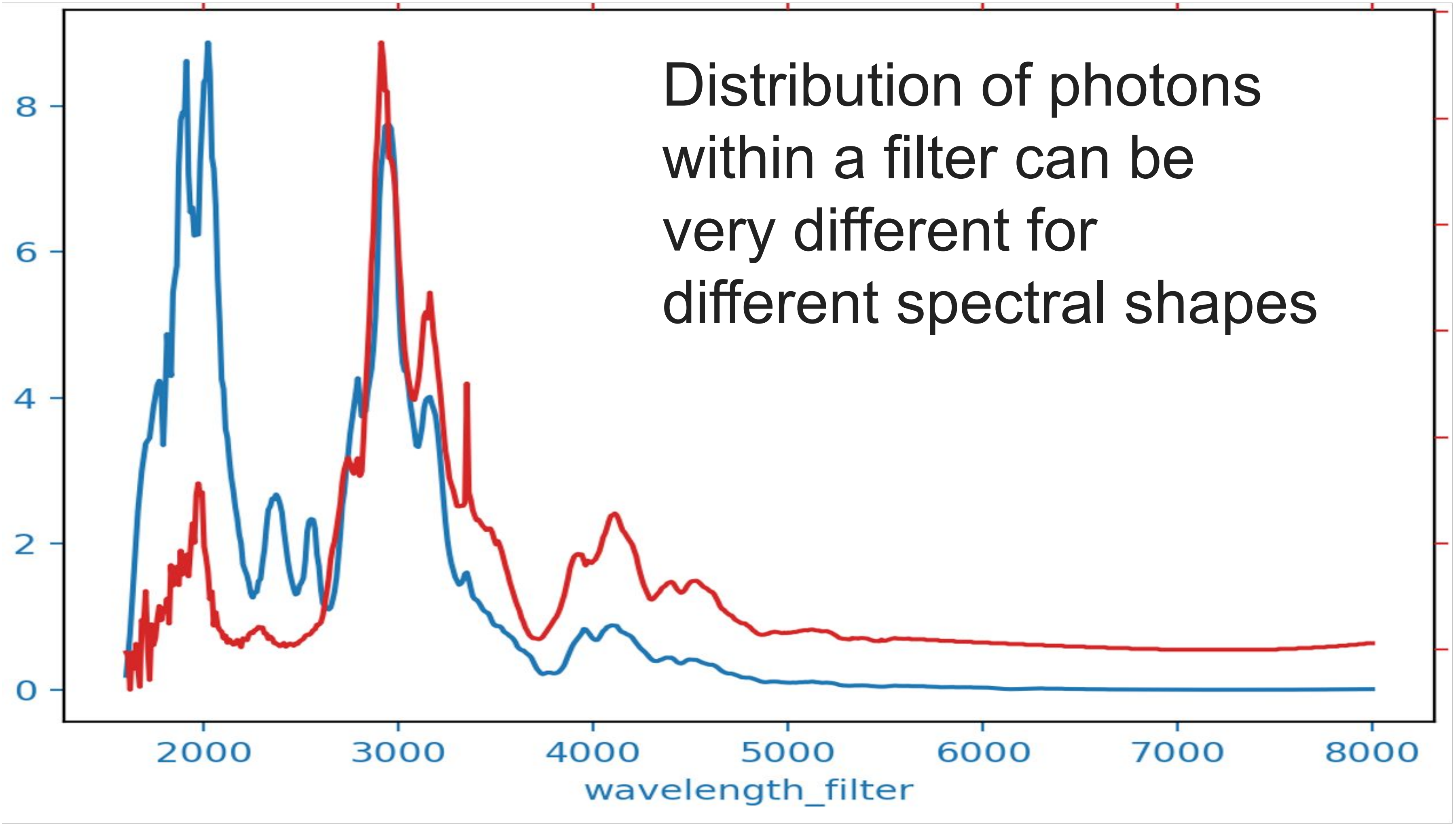
Barna et al. 2021



Flux
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
2000
2500
3000
3500
4000
4500
5000
5500
6000
Wavelength
2011fe
2022hrs

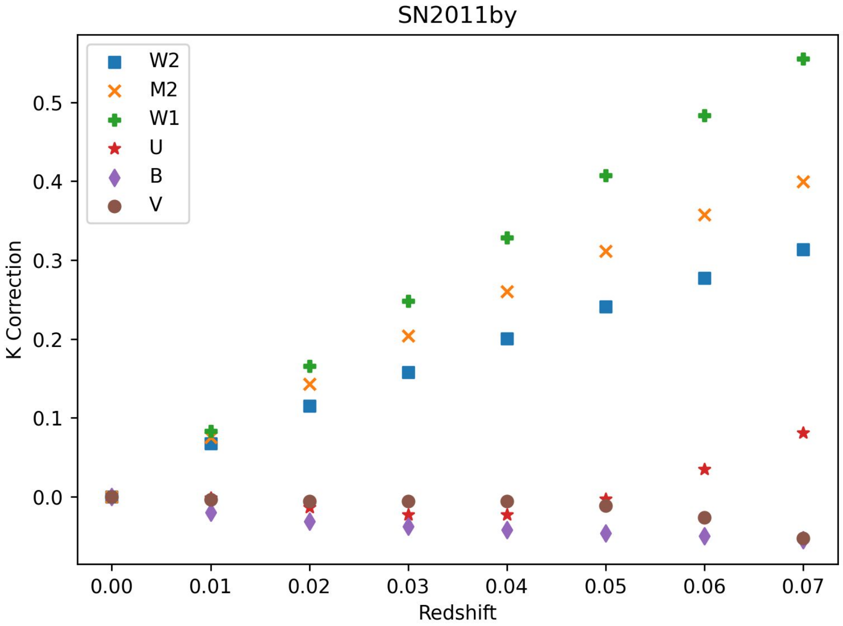


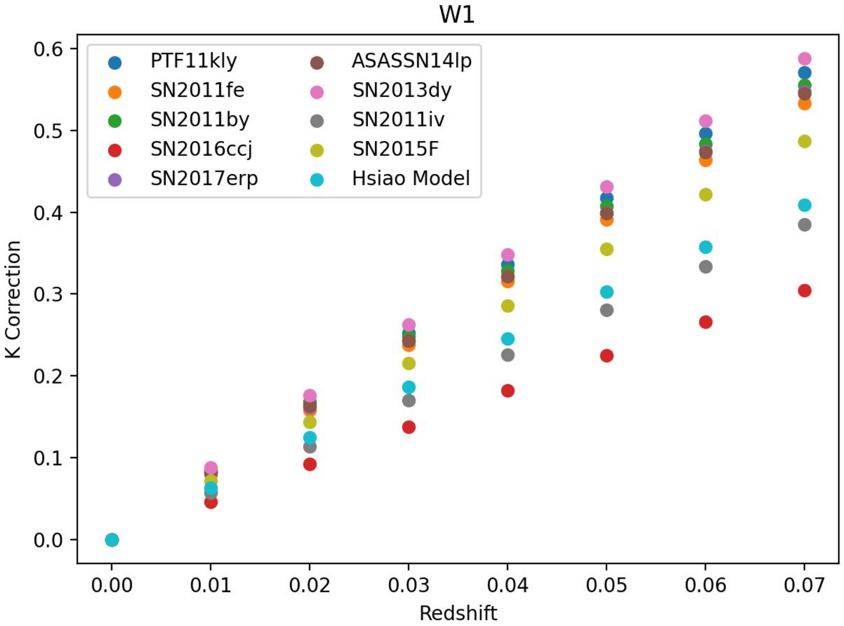
Broadband filters can cross over large spectral changes



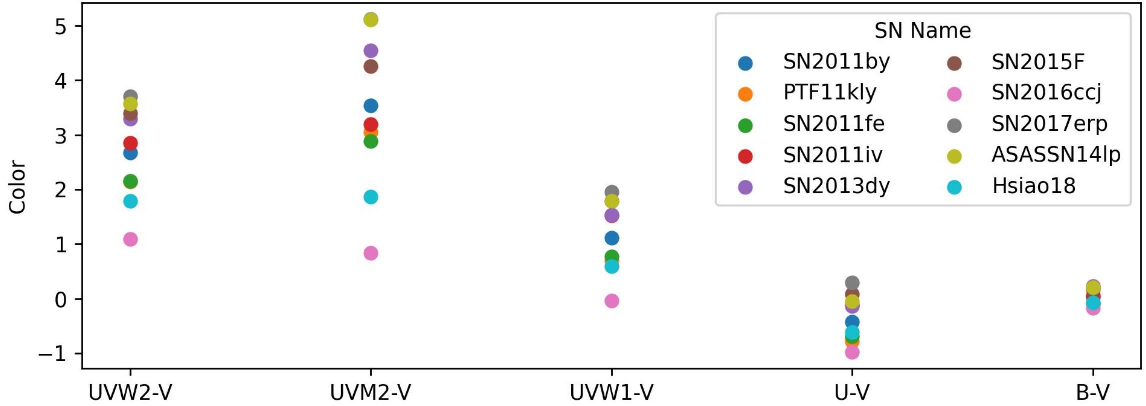
Distribution of photons within a filter can be very different for different spectral shapes
8
6
4
2
0
2000
3000
4000
5000
6000
7000
8000
wavelength_filter

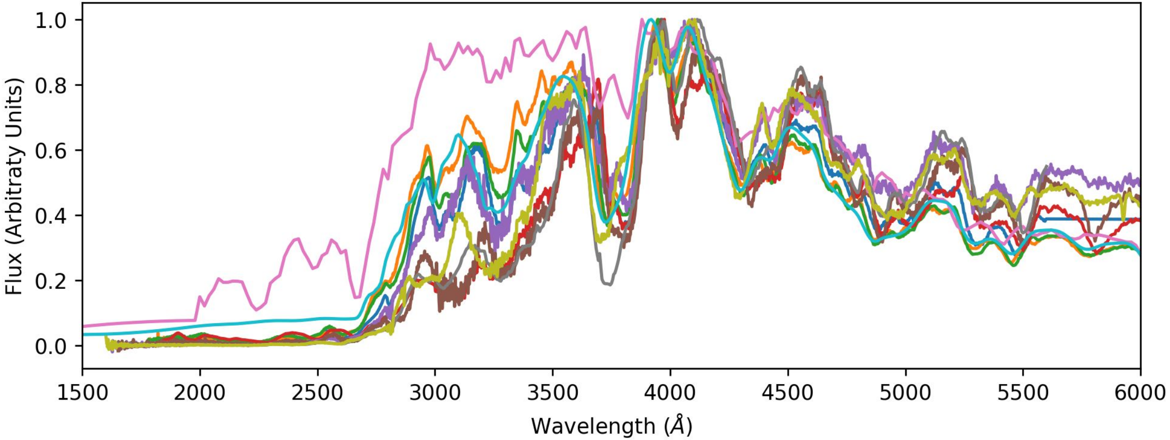
K Corrections are larger and more varied In the ultraviolet filters

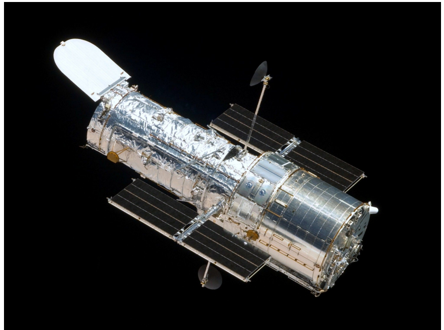


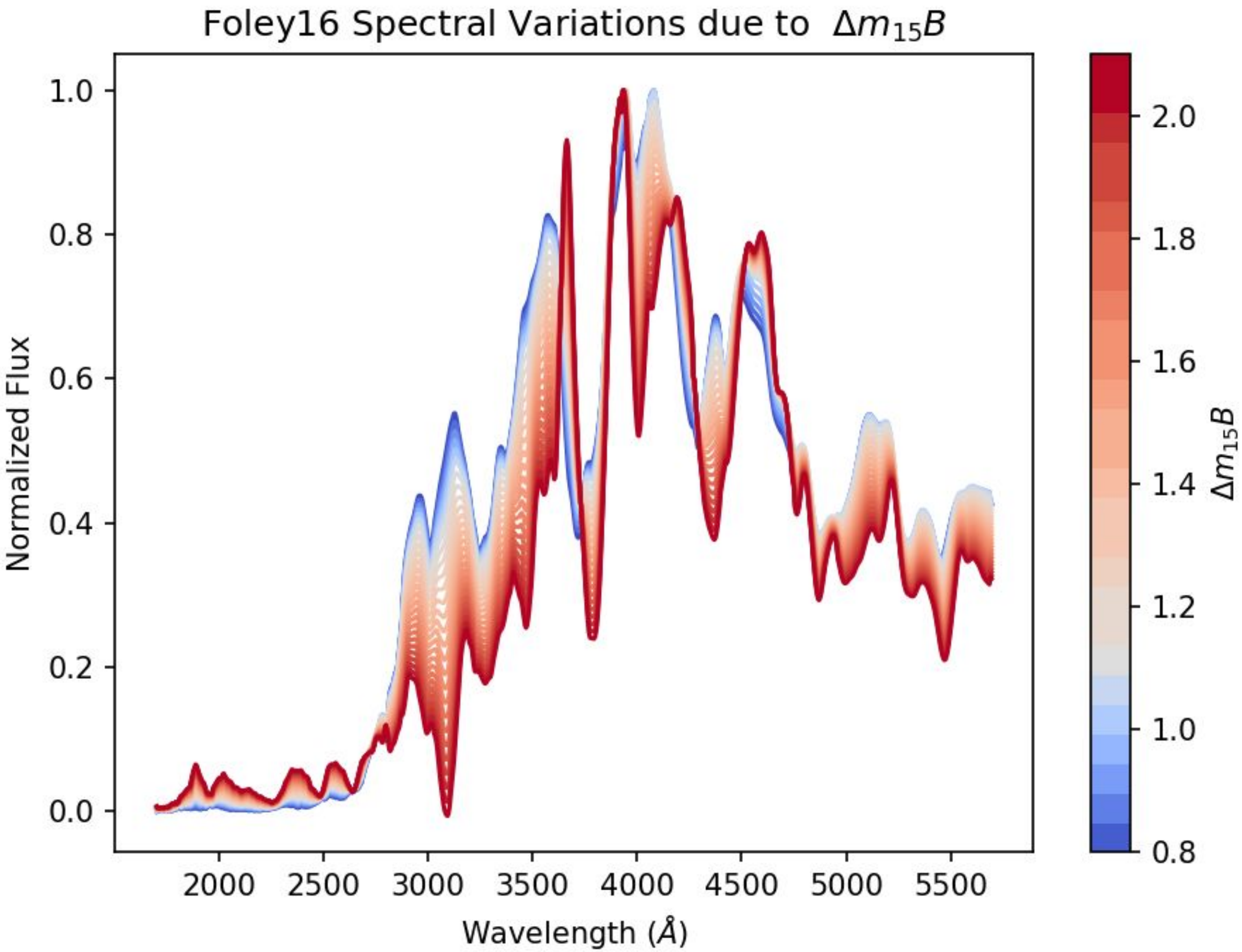


A Template Spectral Library is used to find and/or create spectra which match the observed photometry (Devarakonda 2023)



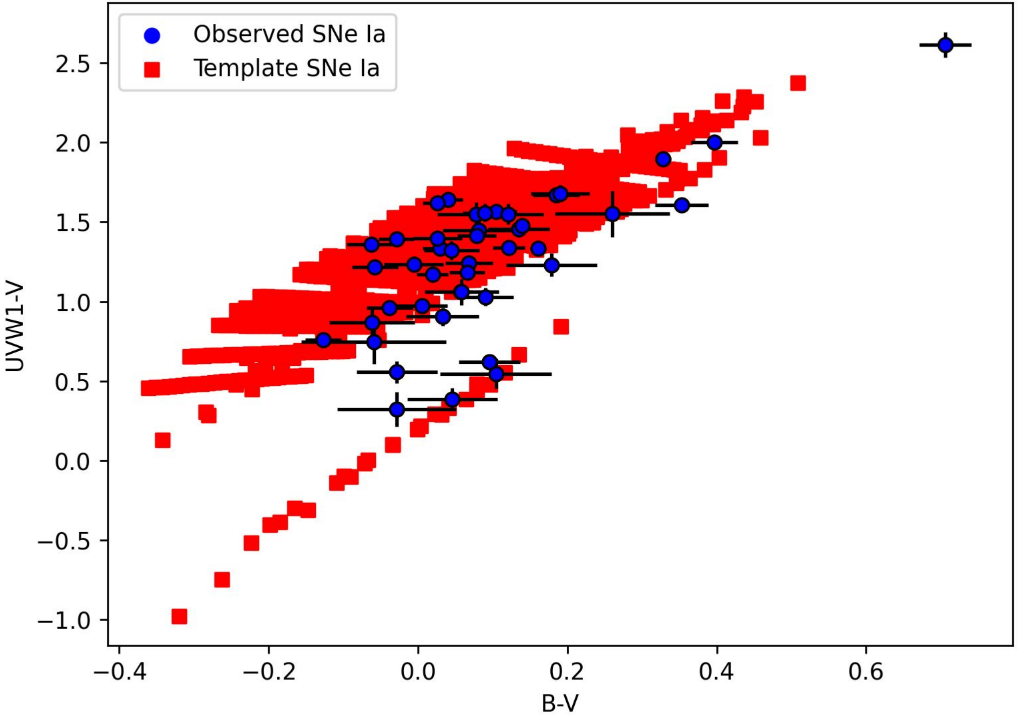




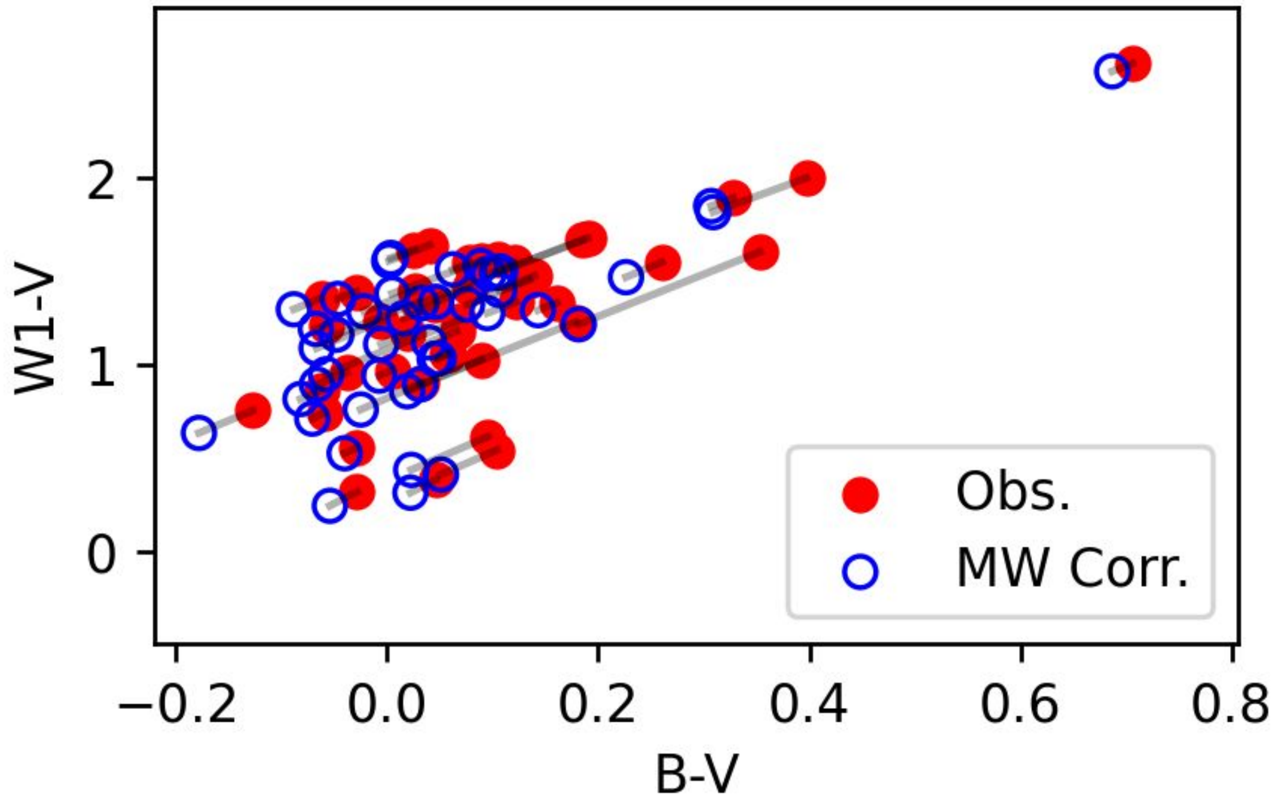


Foley16 Spectral Variations due to $\Delta m_{15}B$
Normalized Flux
1.0
0.8
0.6
0.4
0.2
0.0
2000
2500
3000
3500
4000
4500
5000
5500
Wavelength ($\AA$)
$\Delta m_{15}B$
2.0
1.8
1.6
1.4
1.2
1.0
0.8

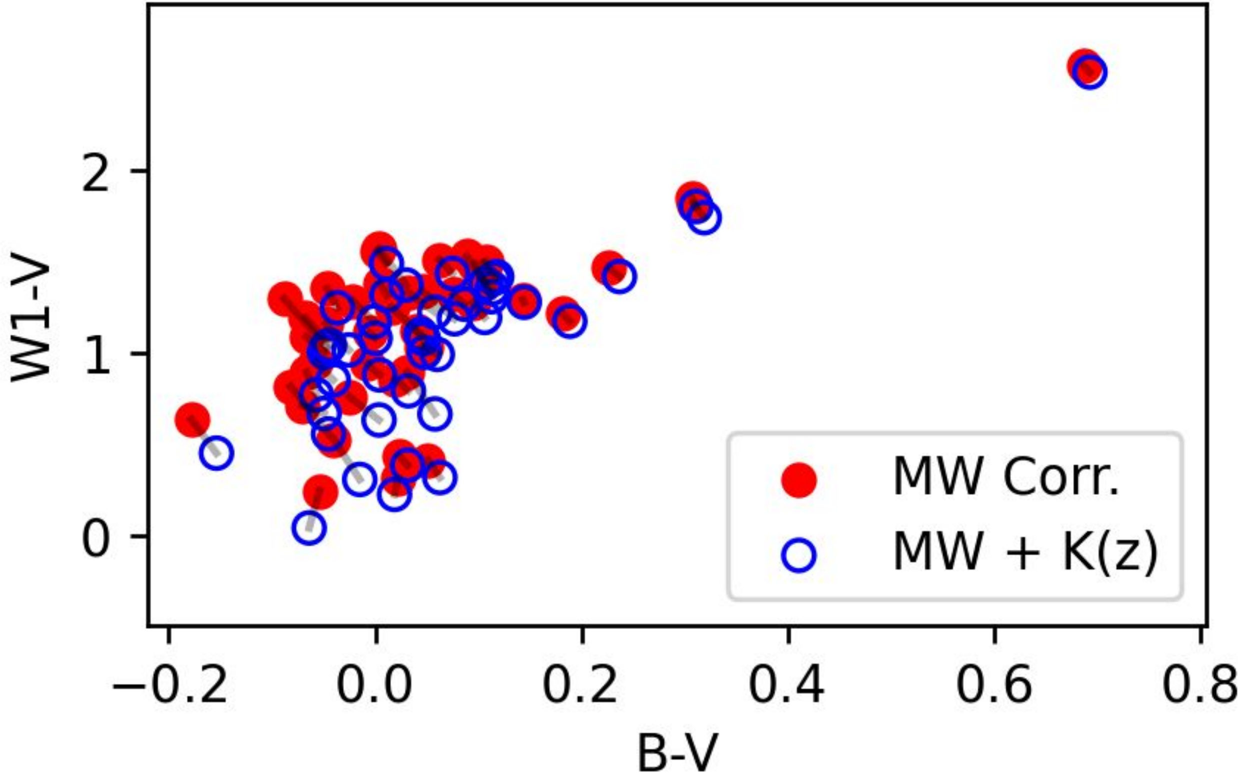
Template models are reddened by different amounts to cover the color-color space of the photometry. The best matches to the observed photometry are used.



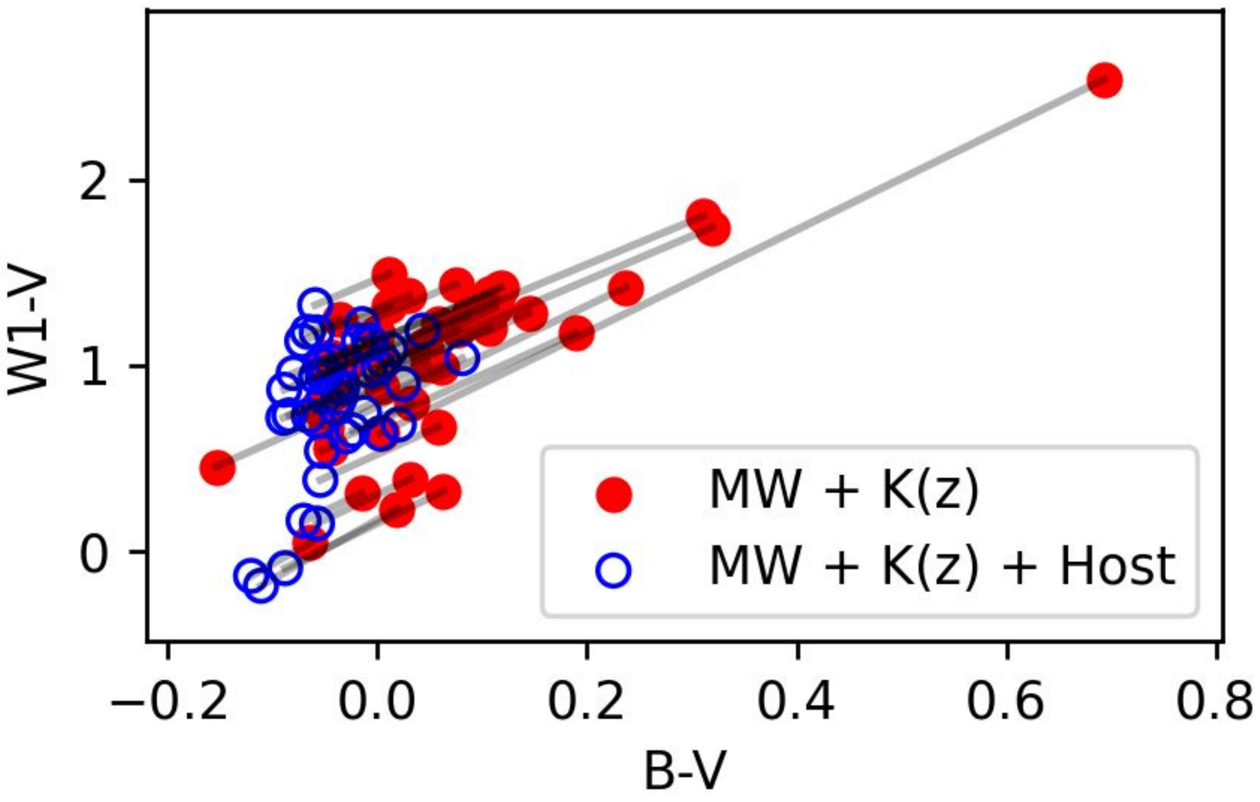
These observer-frame models can be used to compute the appropriate correction for MW



Deredshifting these models can be used to compute the appropriate correction for k corrections

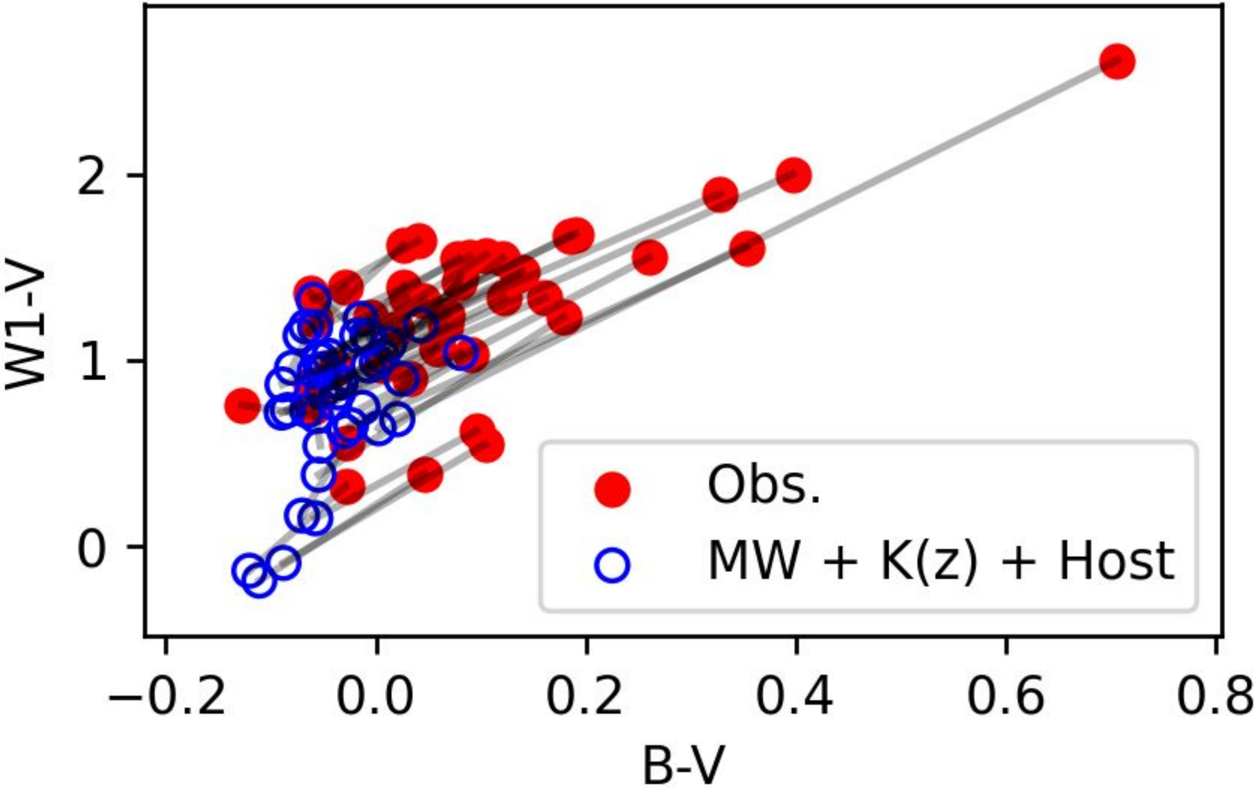


The dredshifted models can be used to compute the appropriate correction for host reddening



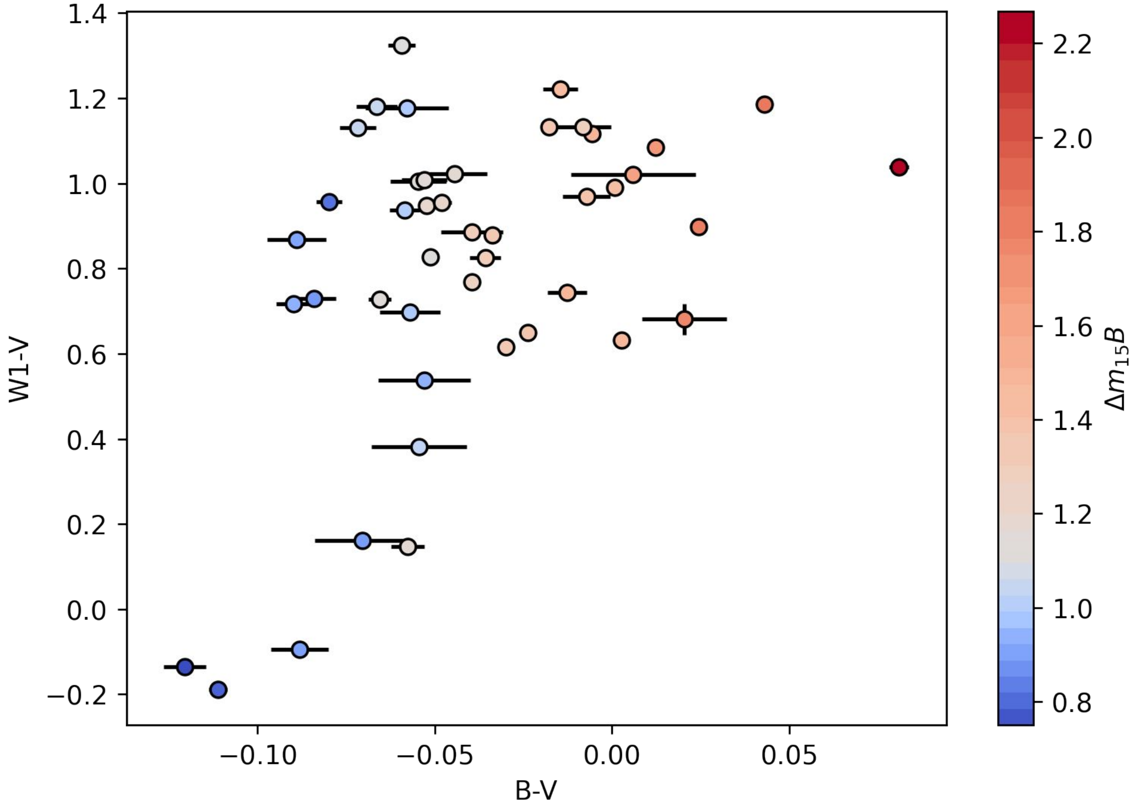
Here we have assumed intrinsic B-V colors based on light curve shape from Phillips et al. (1999)

Combined Corrections



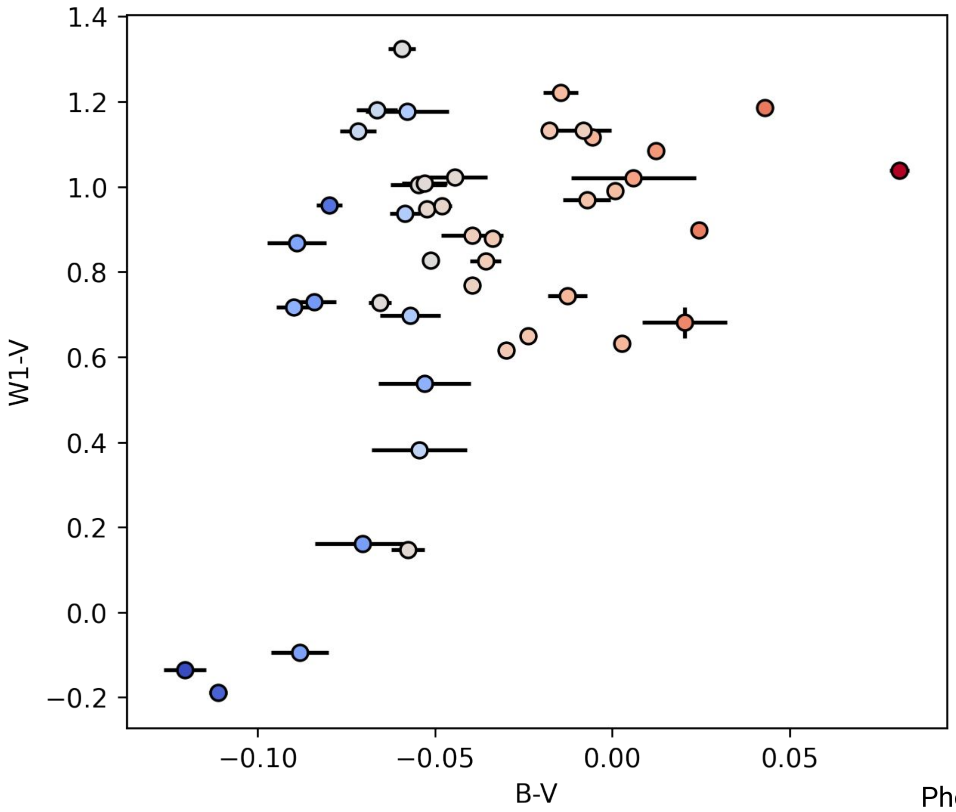
Devarakonda (2023)

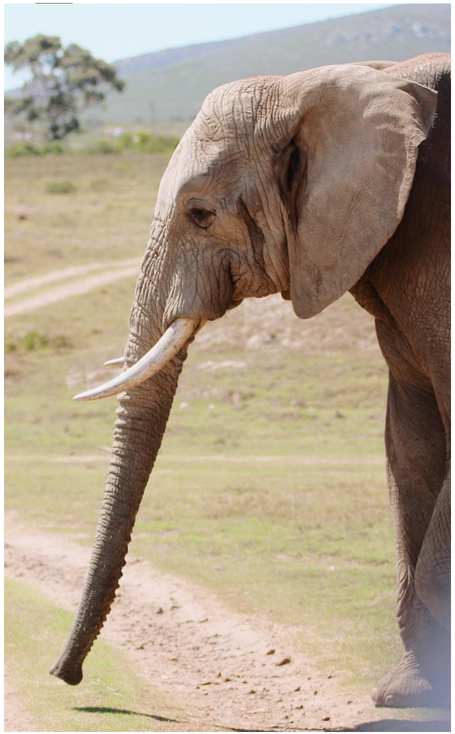
Final “intrinsic” colors



Properly corrected colors can be better correlated with SN and host properties to explain the UV diversity independent from spectroscopy

Final “intrinsic” colors





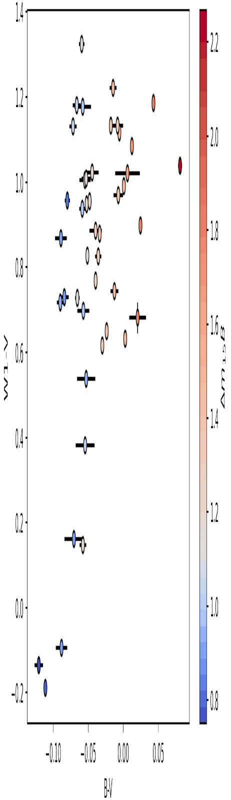
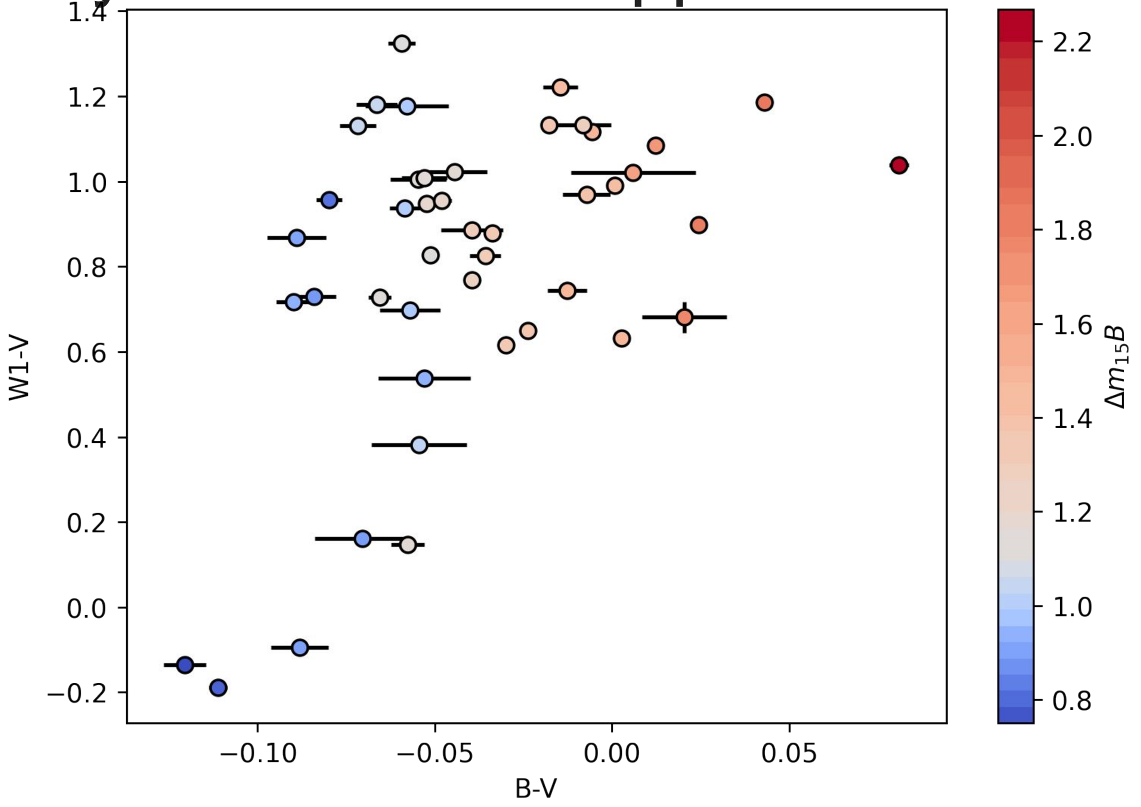
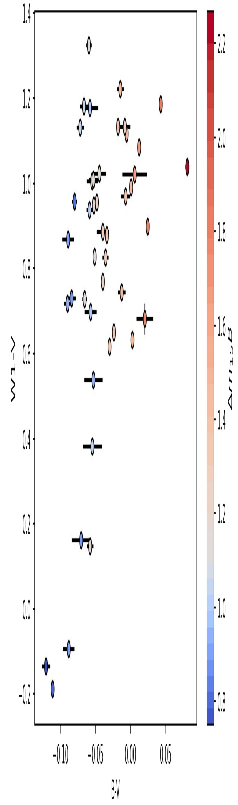


Photo by Gina Alexandra Jacobs:
https://www.pexels.com/photo/african-elephant-in-savannah-16049579/

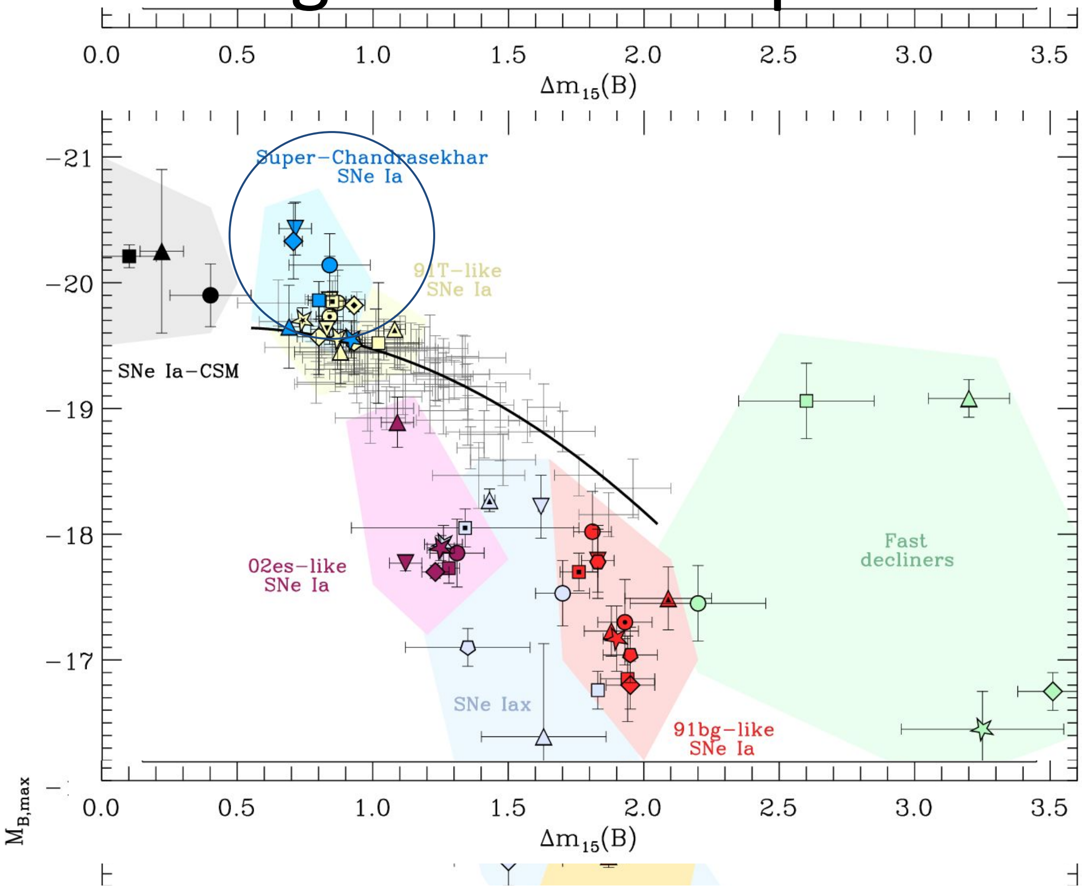
UV dispersion much larger –
Stay tuned for the application to a larger sample



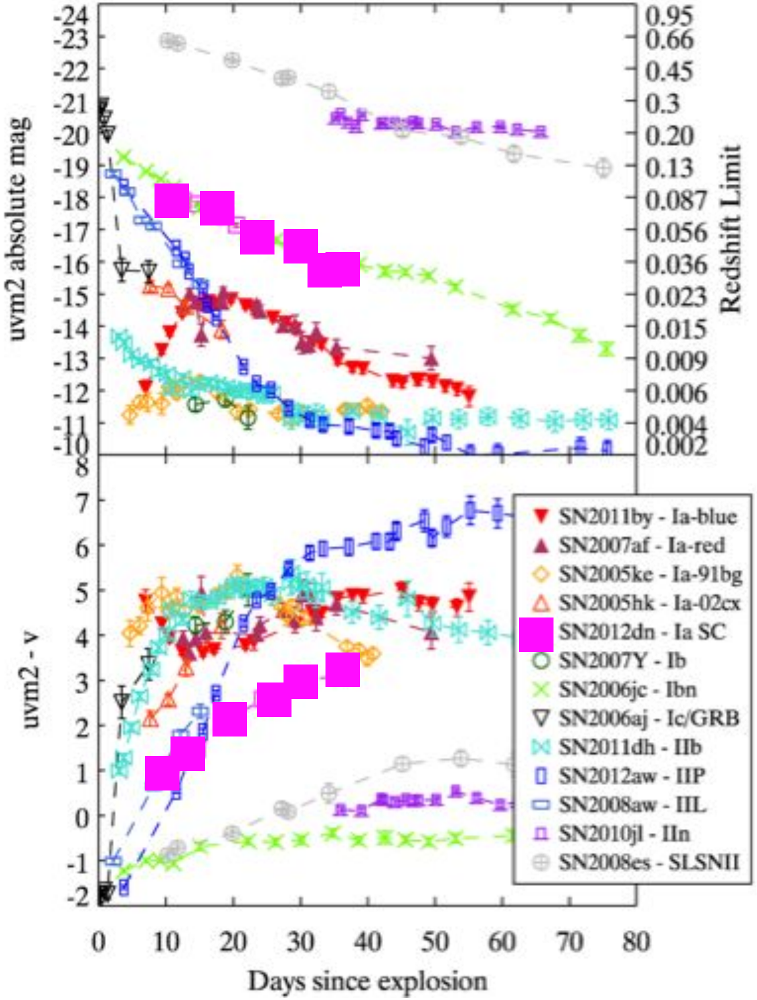


Light Curve Shape

Absolute B Magnitude



Light Curve Shape



SuperC SNe Ia

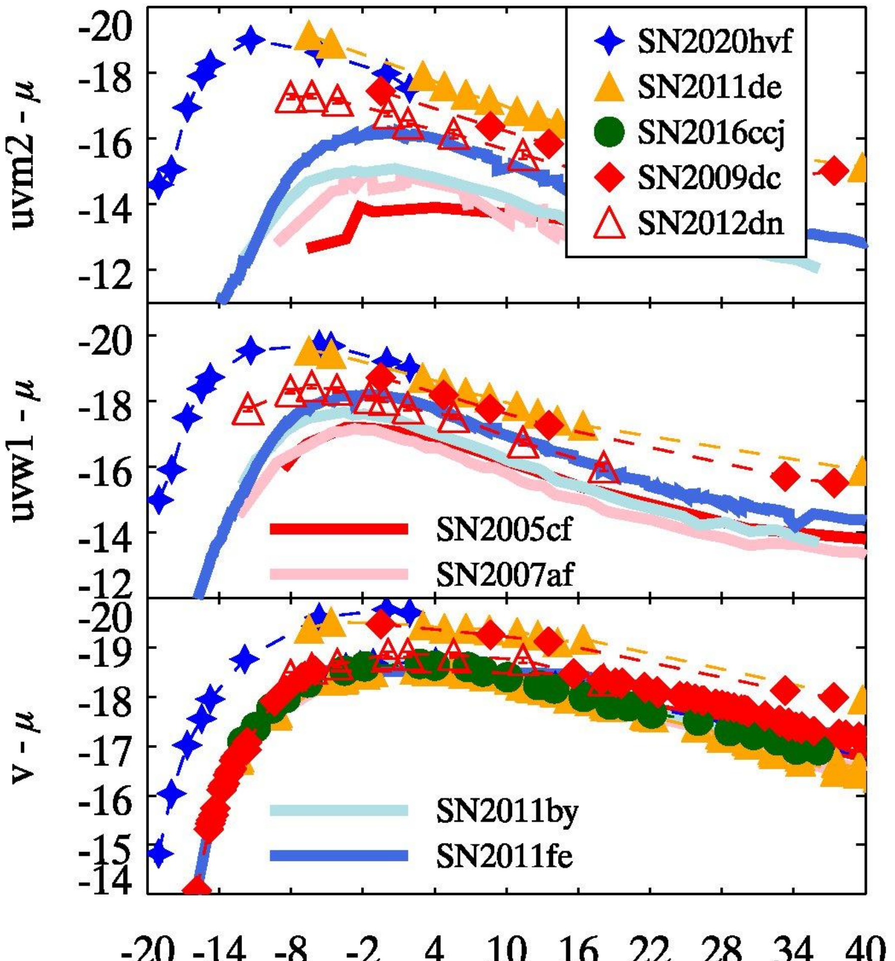
Hotter, more ionized explosion
Excess flux from H-poor interaction?

Brown et al. 2015
arXiv:1505.01368v1

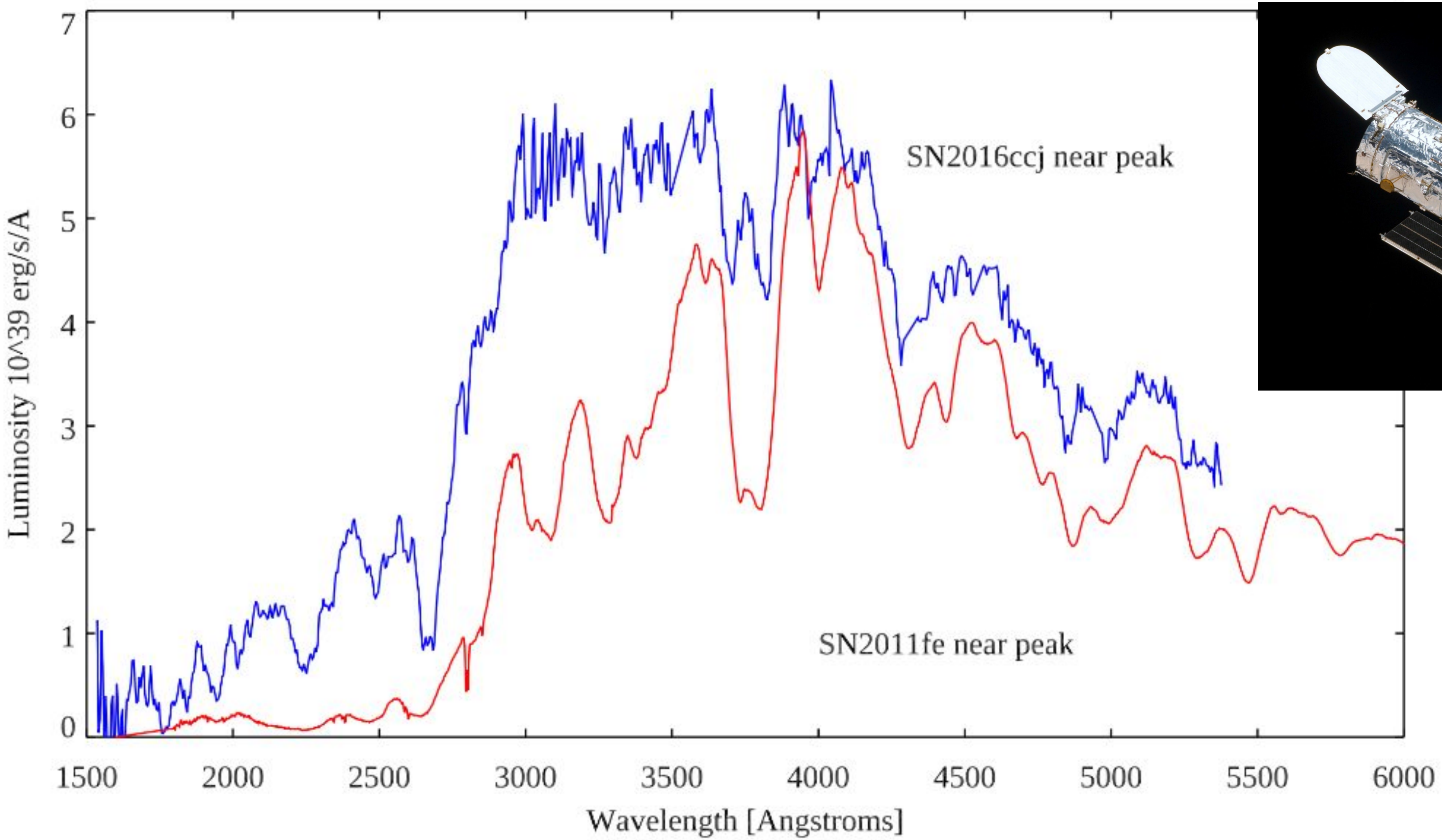
The “standard” candles are already much more diverse in the UV.

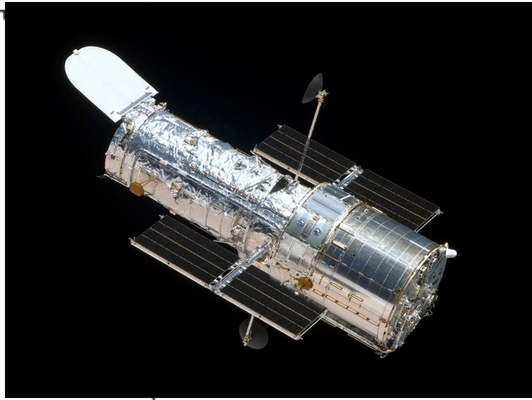
Extreme subclasses are even more extreme in the UV.

Combining the photometric samples of Swift/UVOT with HST spectroscopy is a powerful synergy

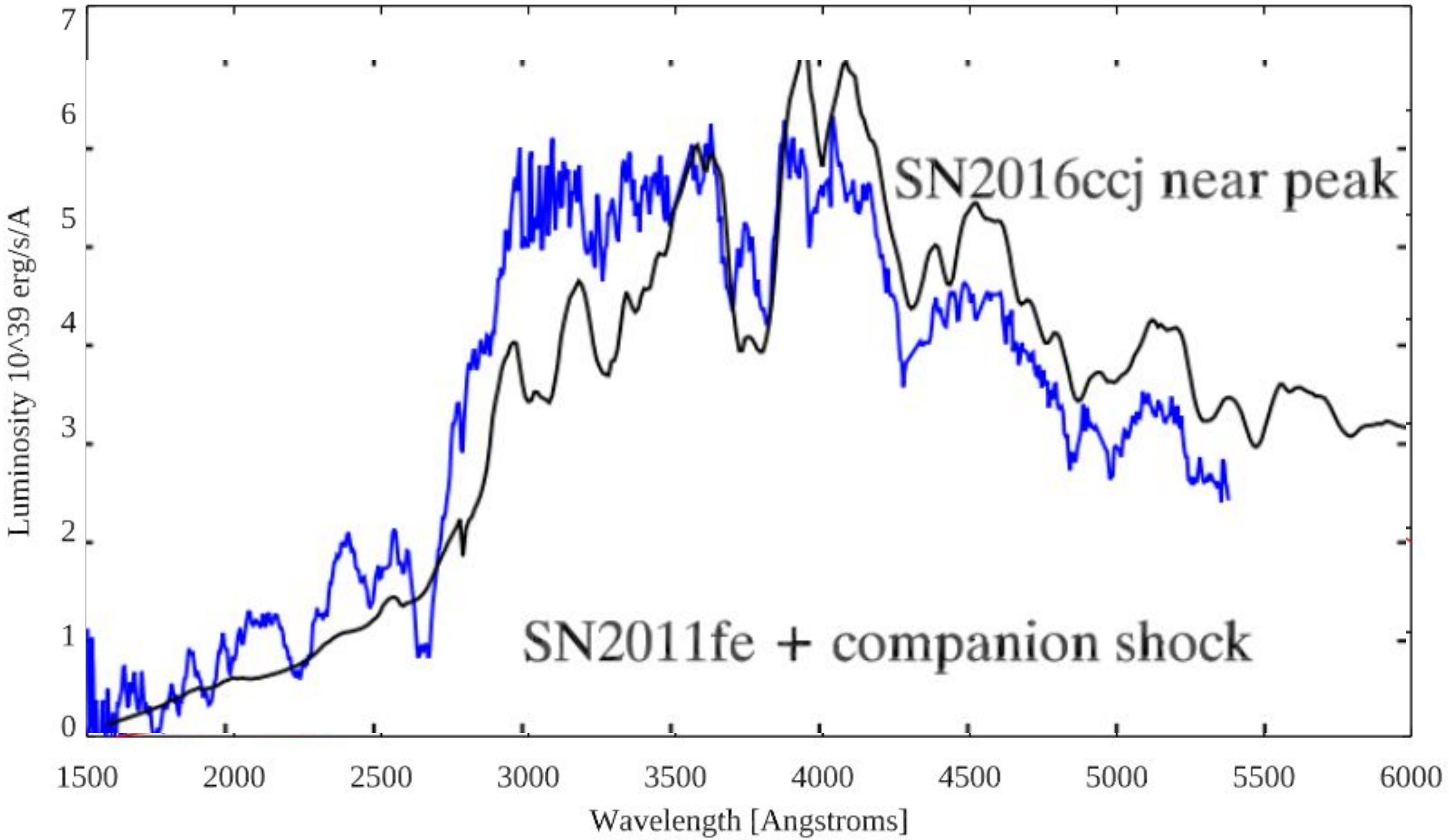


UV Spectra of SN2016ccj show UV absorption features



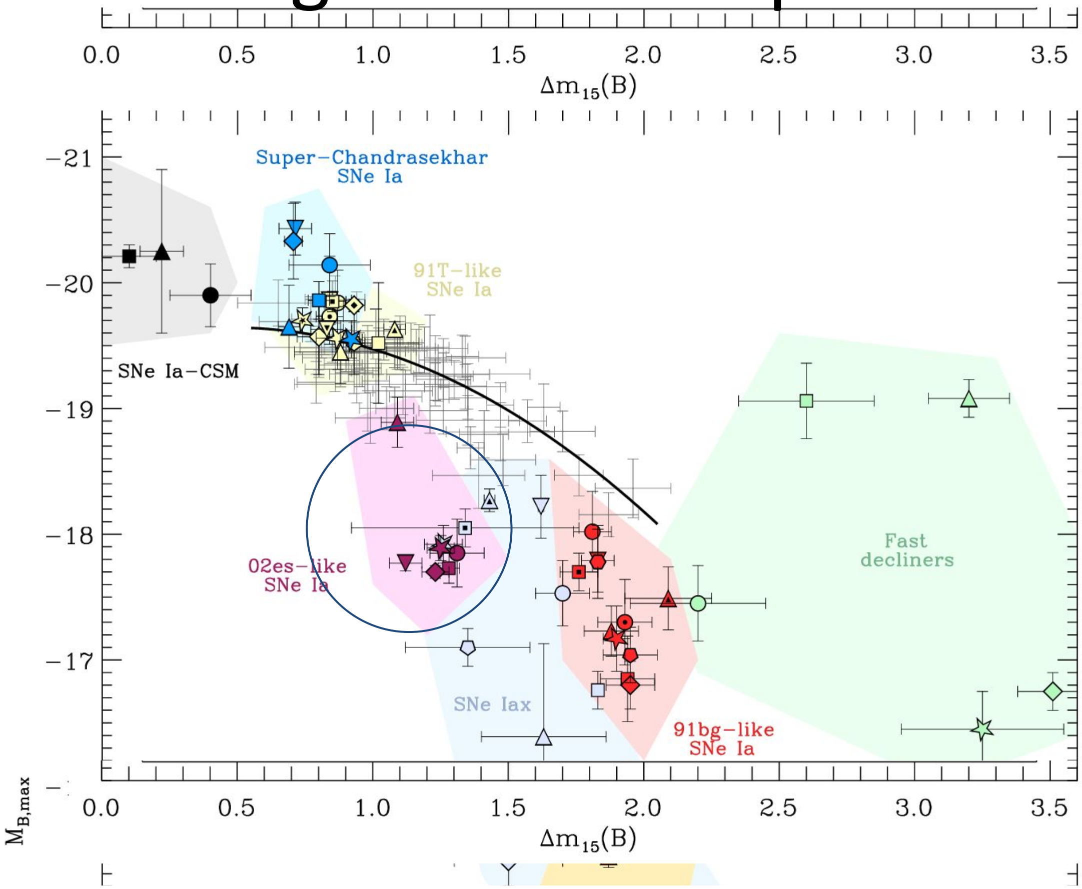


UV Spectra of SN2016ccj reject BB addition to flux



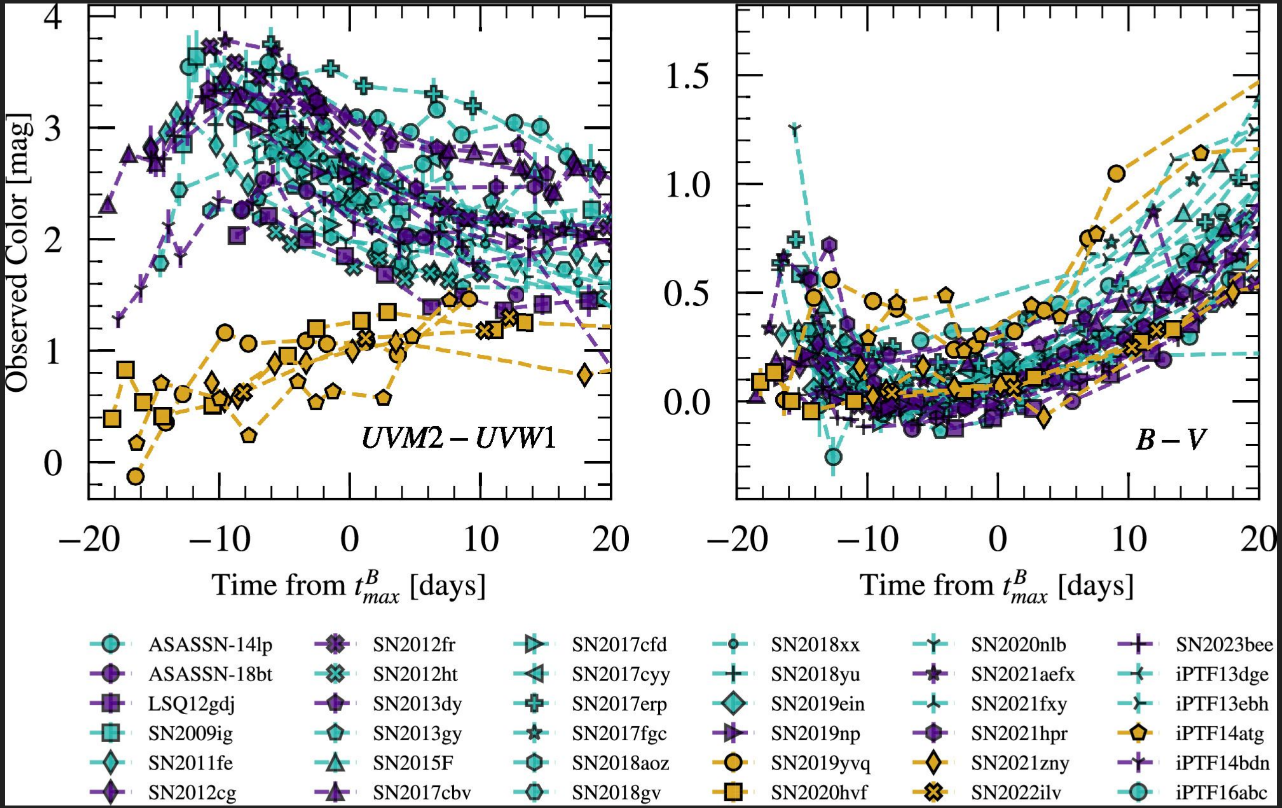
Light Curve Shape

Absolute B Magnitude



Light Curve Shape

Supernova Ia subclasses with early bumps have consistently bluer UV colors – SuperC and 02es-like

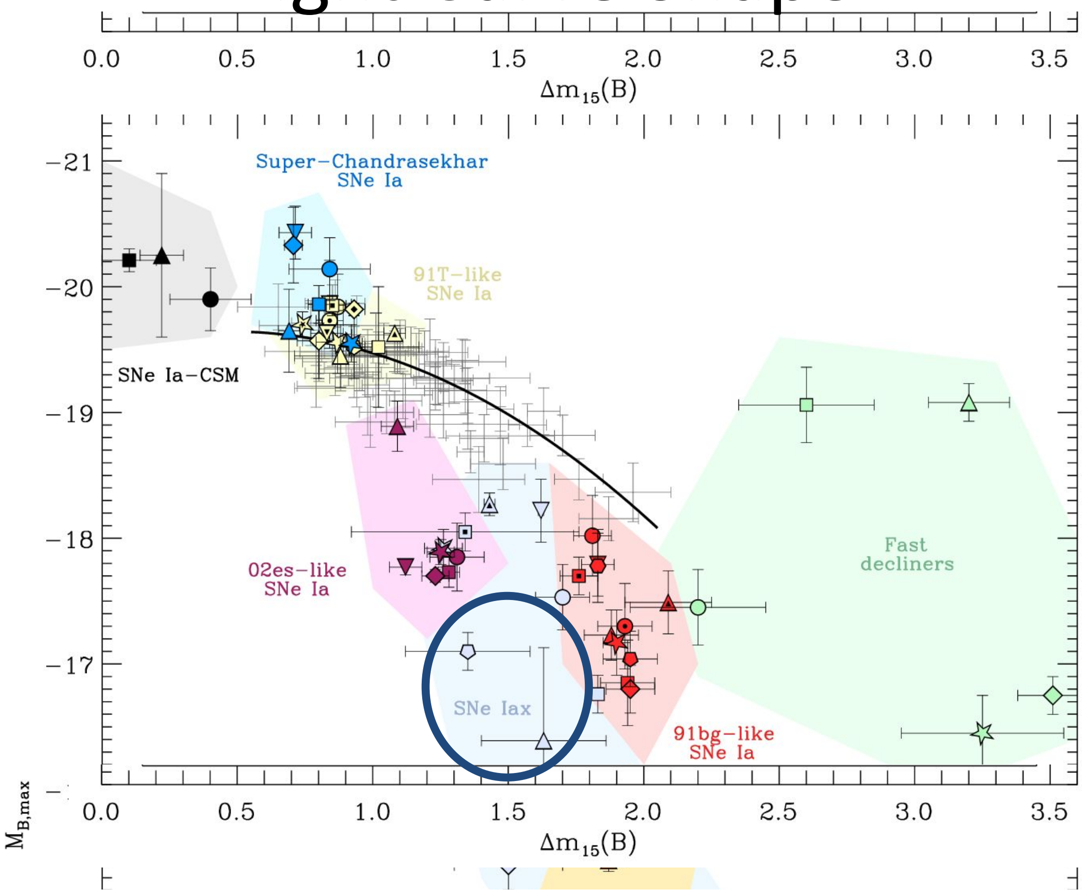


Hoogendam et al. 2024

Check out his e-poster and talk to him at a break

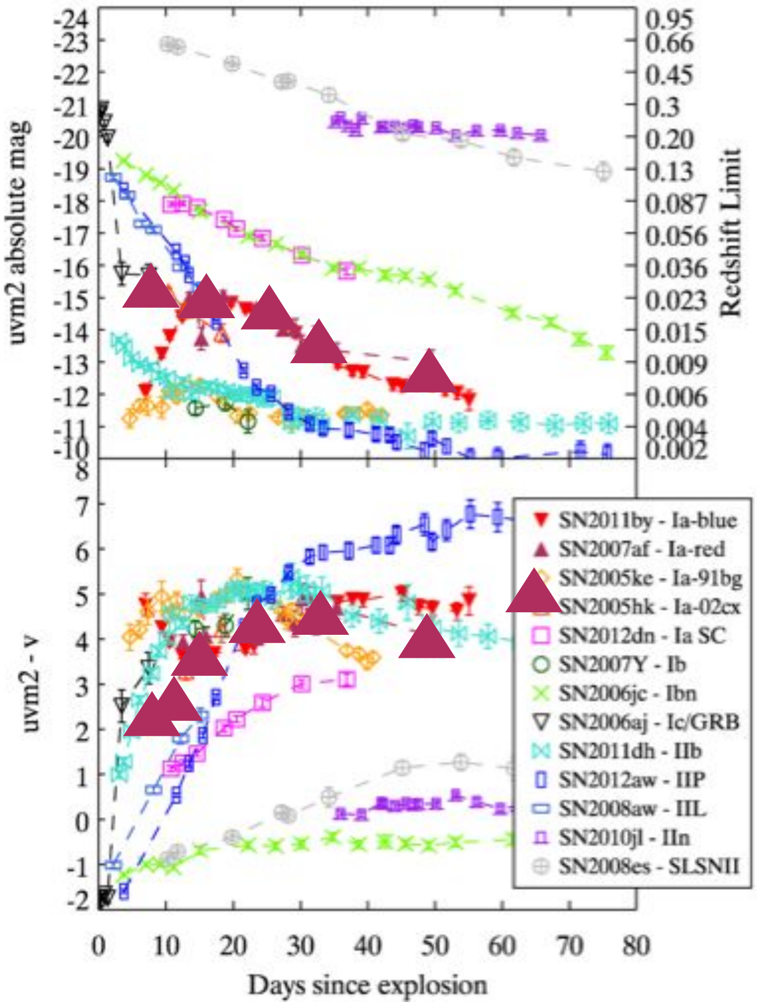
Light Curve Shape

Absolute B Magnitude



Light Curve Shape

Thermonuclear Iax



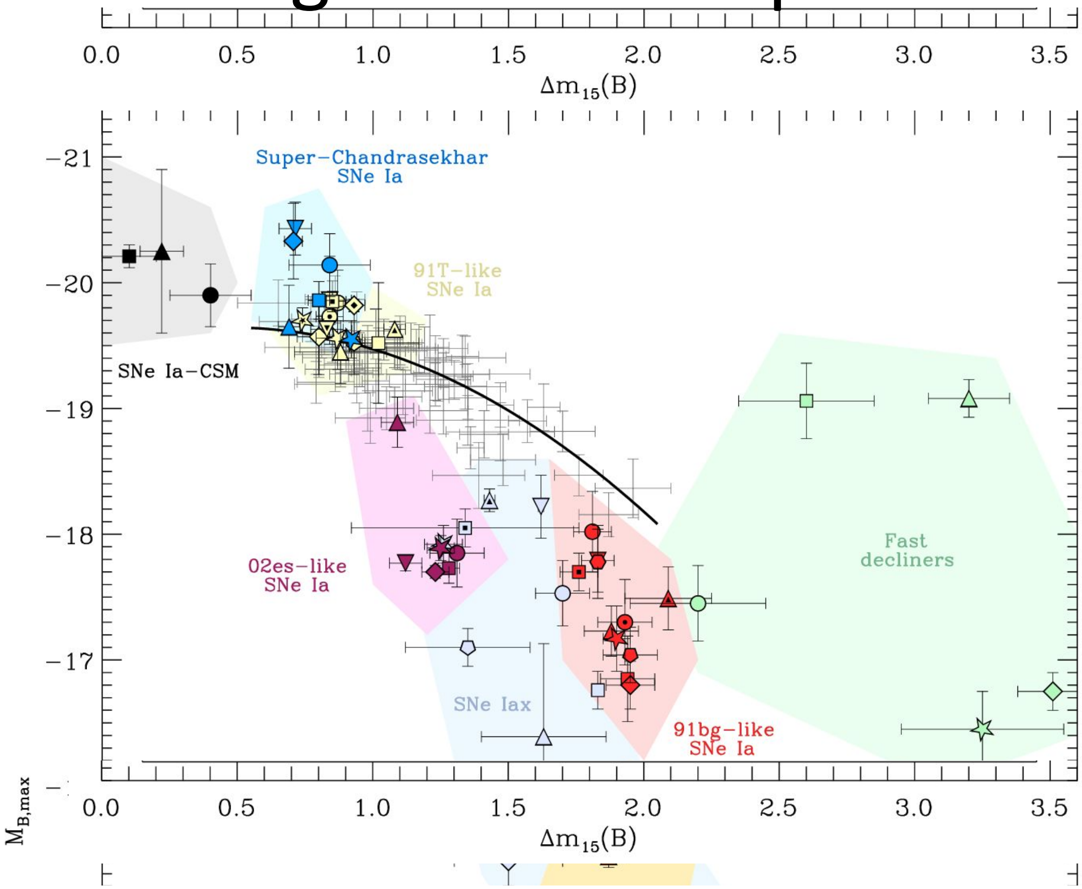
Hotter, more ionized explosion

Excess flux from H-poor interaction?

Brown et al. 2015
arXiv:1505.01368v1

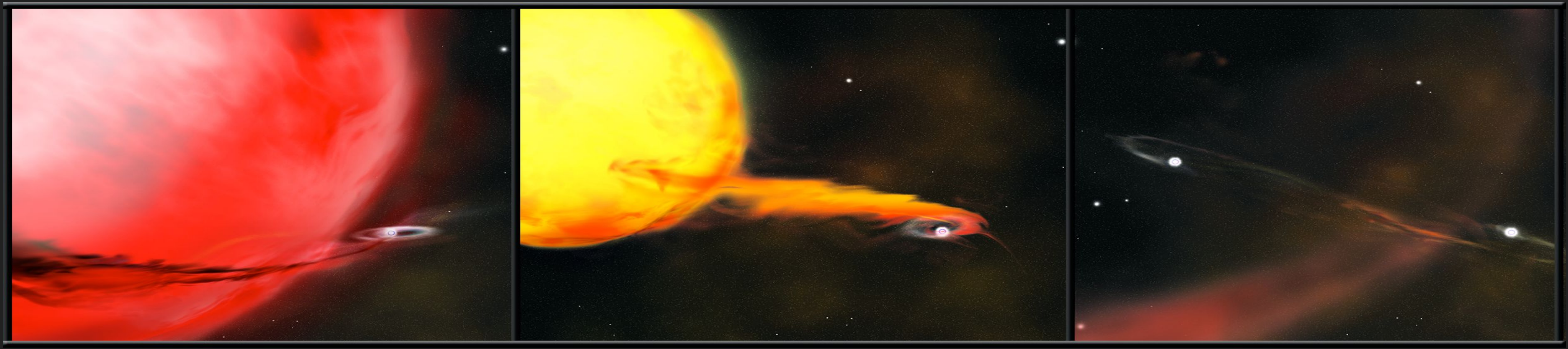
Light Curve Shape

Absolute B Magnitude



Light Curve Shape

What are the progenitor systems of Type Ia Supernovae?



Red giant

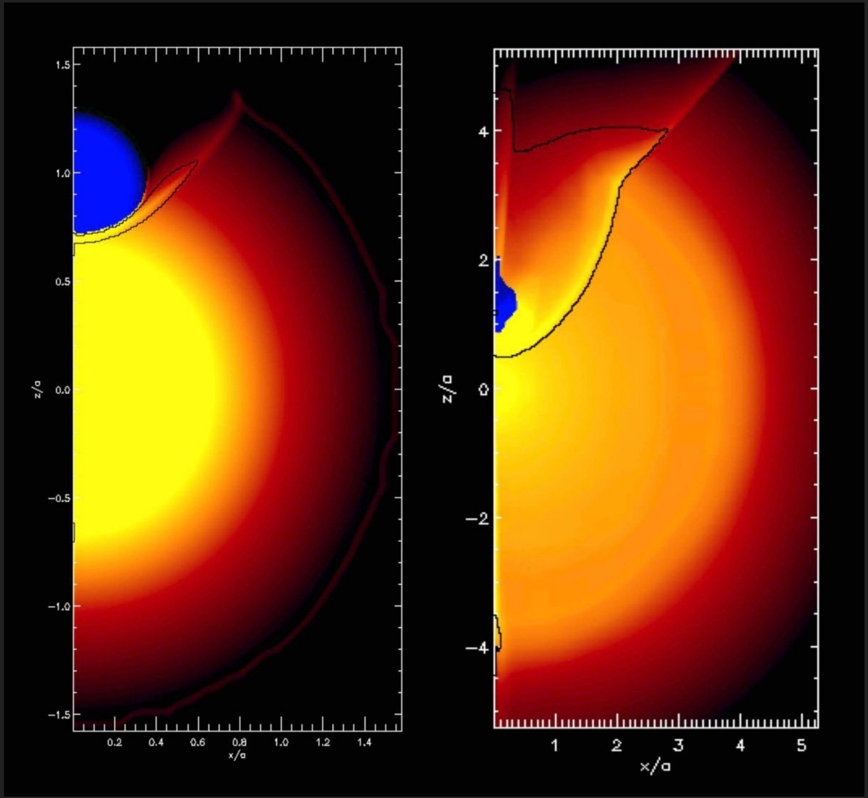
Main sequence

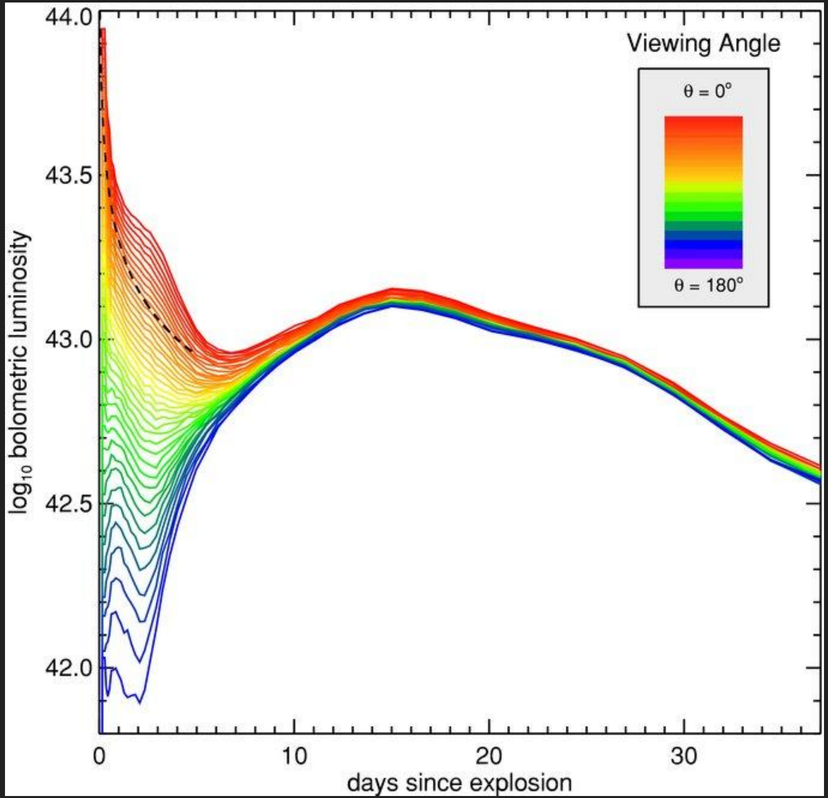
Second White Dwarf

Single Degenerate
(only 1 white dwarf)

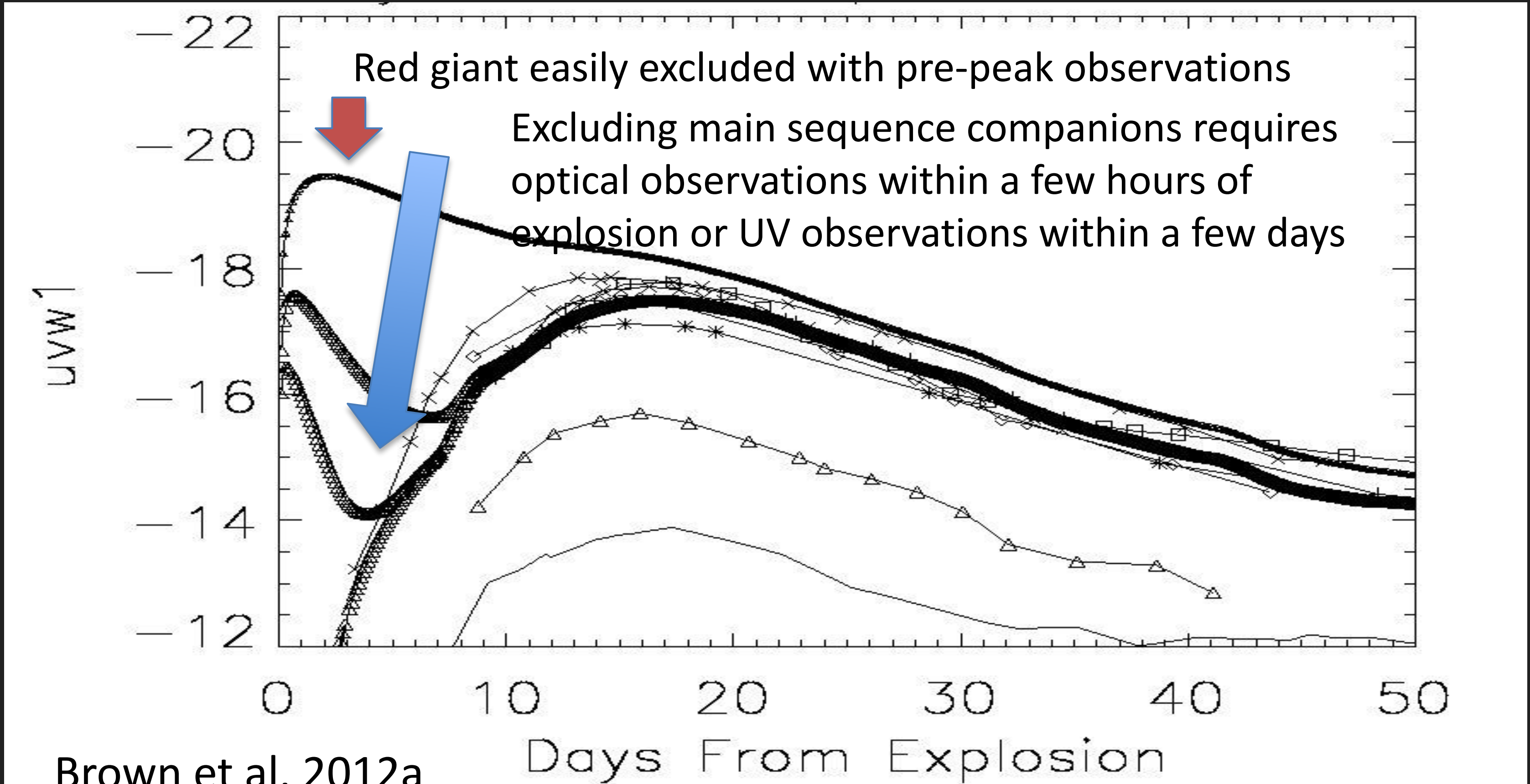
Double Degenerate

SEEING THE COLLISION OF A SUPERNOVA WITH ITS COMPANION STAR Kasen 2010



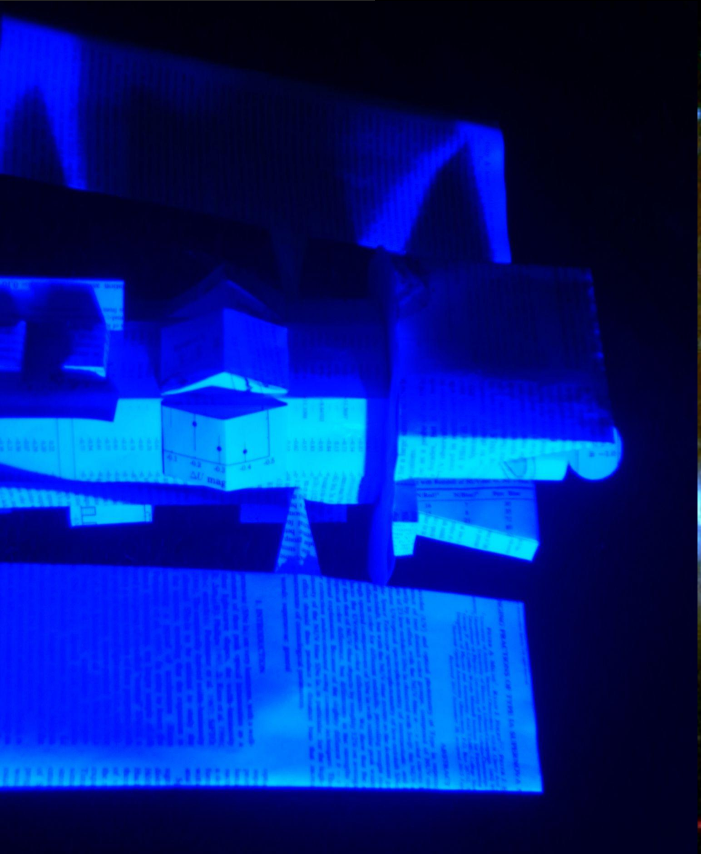


None of the Swift supernovae showed* signs of shock in the ultraviolet

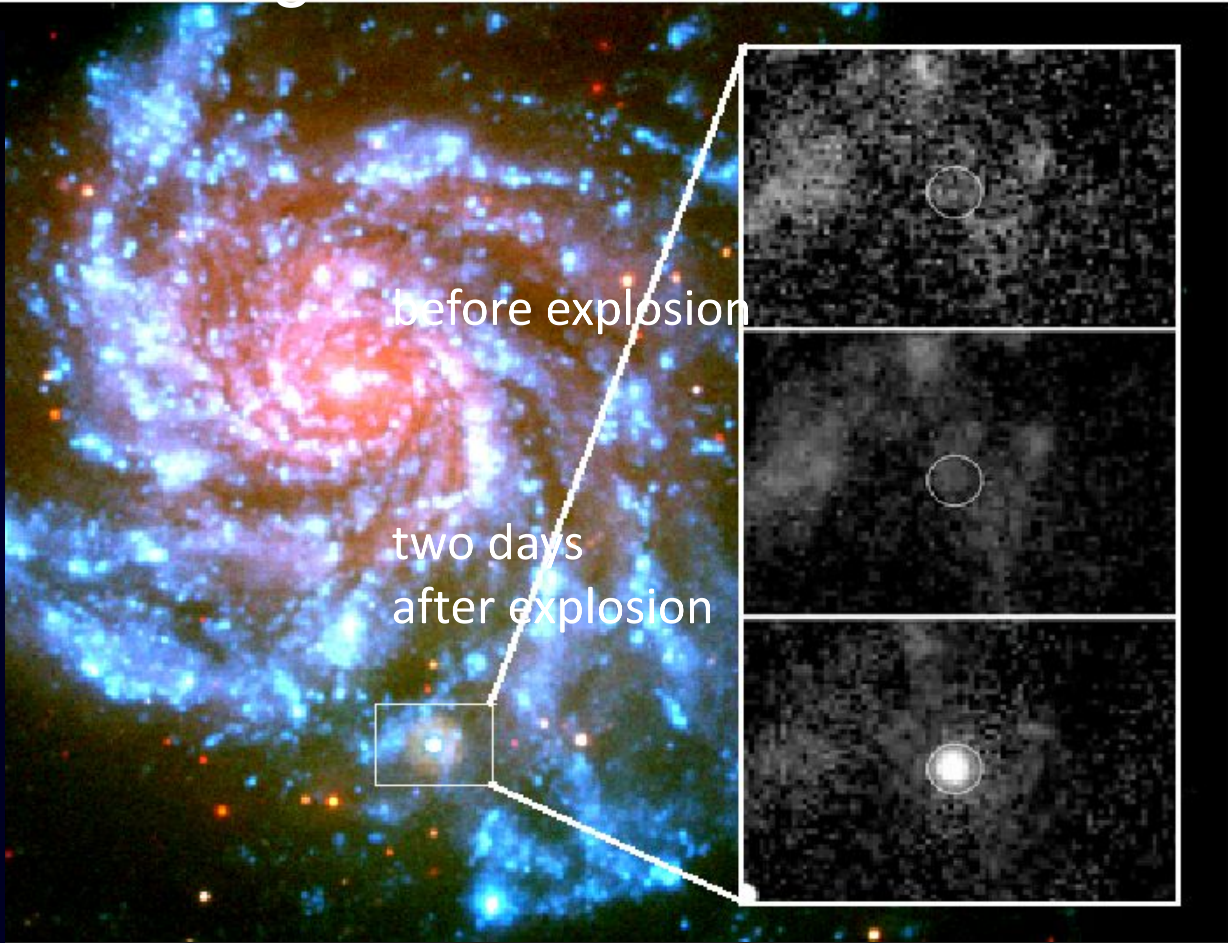


Brown et al. 2012a

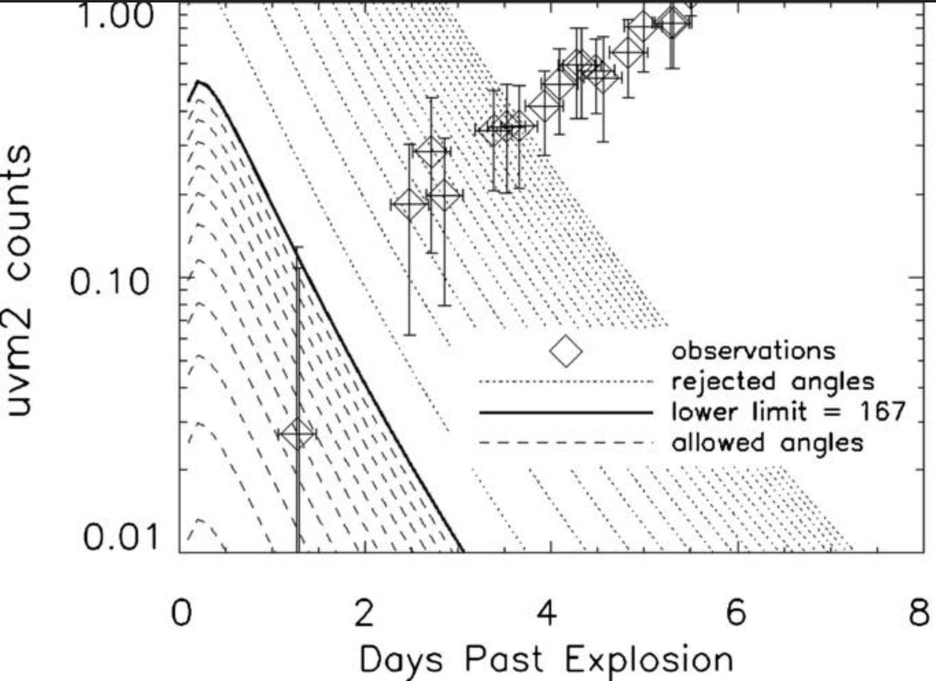
SN2011fe – no signs of UV shock

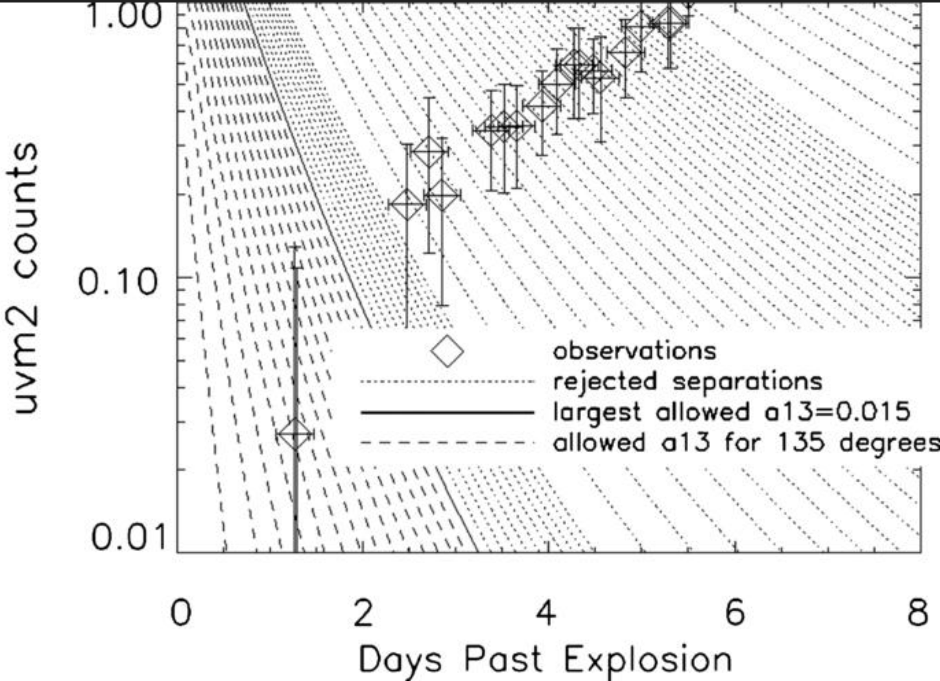


Brown et al. 2012b

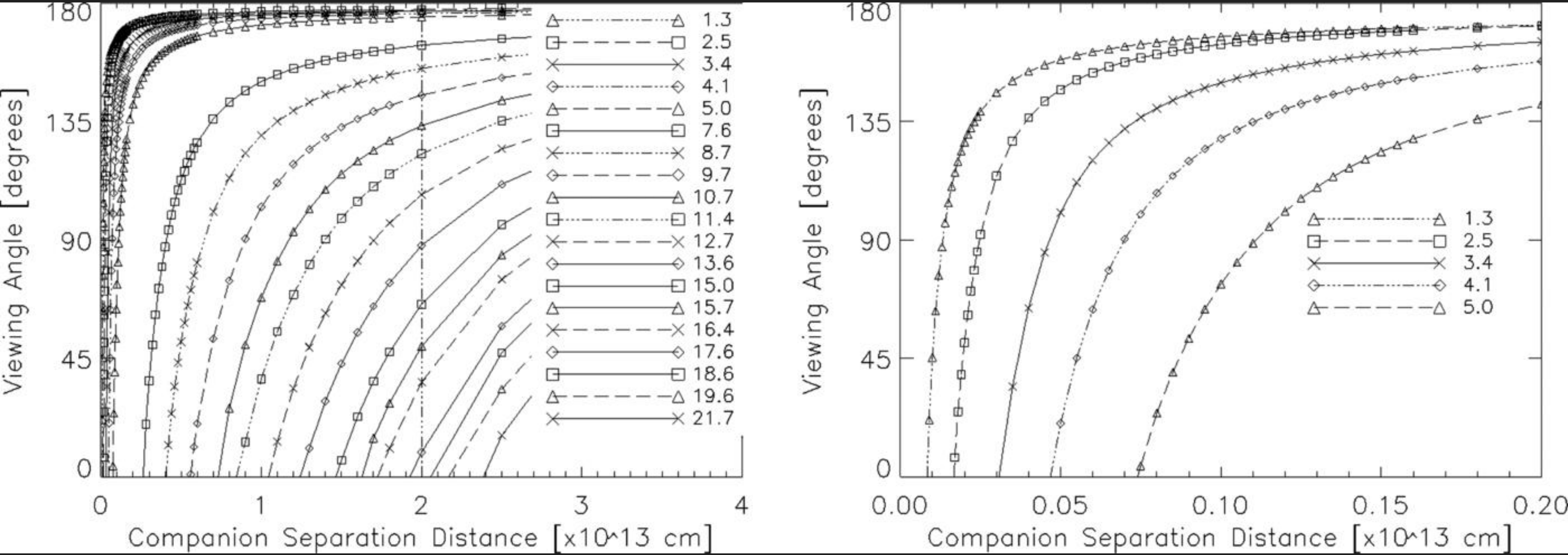


Early UV observations constrain the viewing angle and separation/size of progenitor





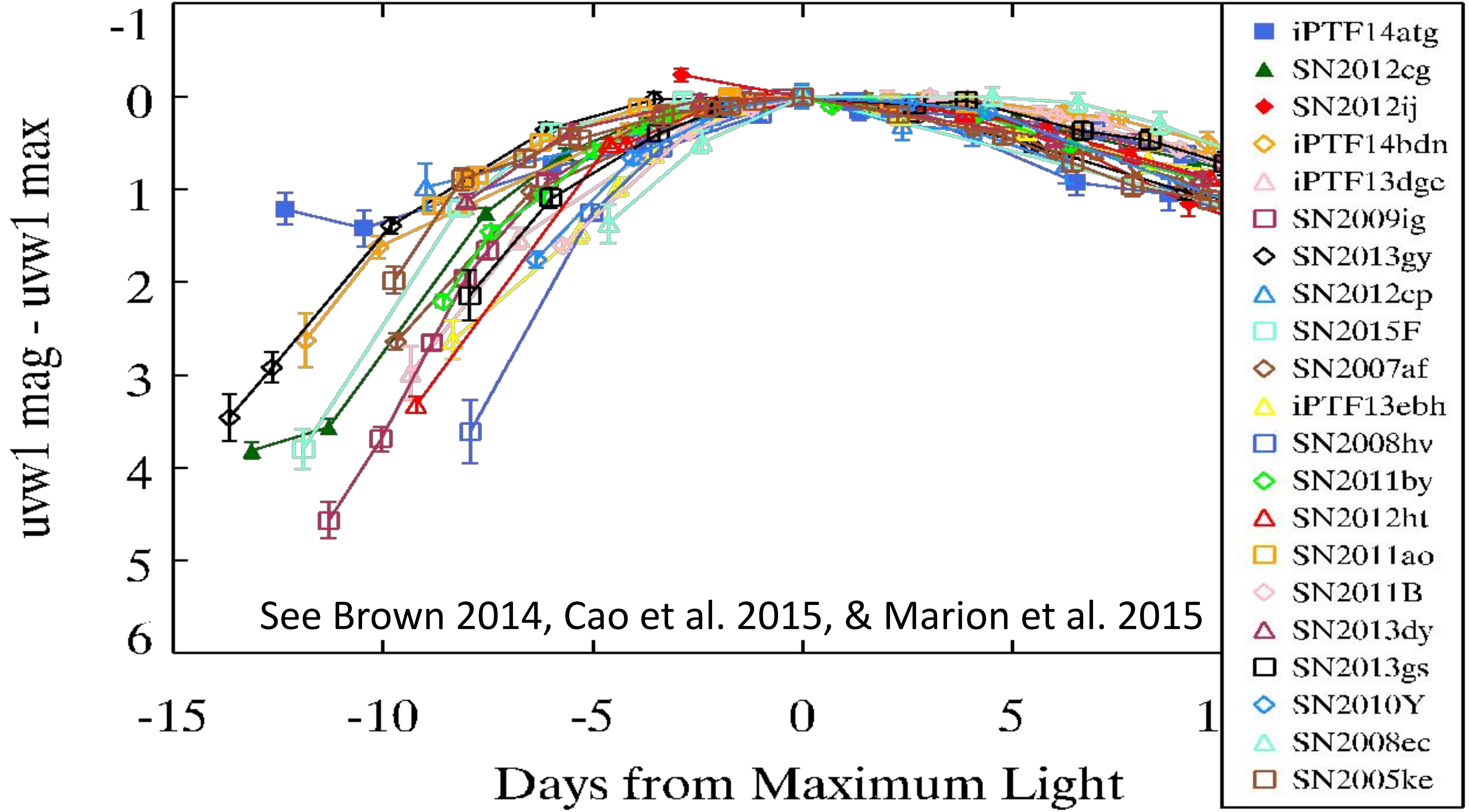
Phase Space is best constrained with earlier, shorter wavelength observations

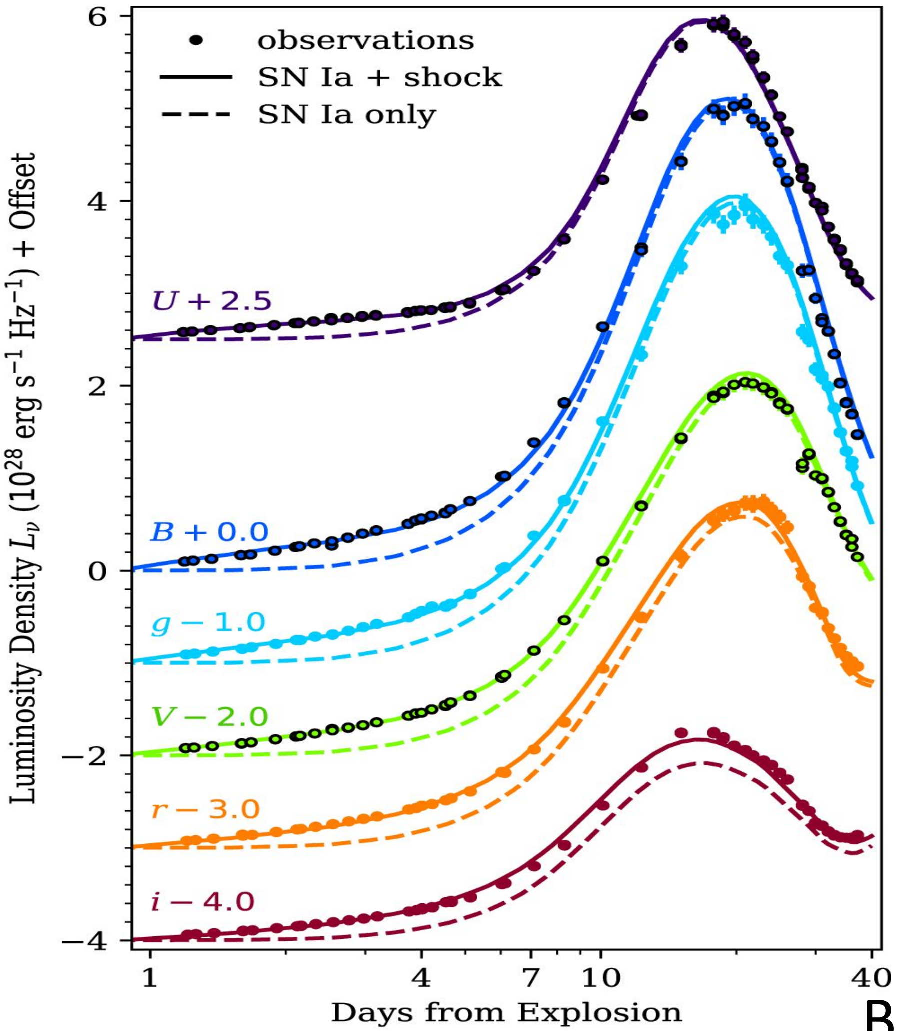


Region to the right of curve is excluded

Brown et al. 2012

A few UV-bright and/or early peaks?

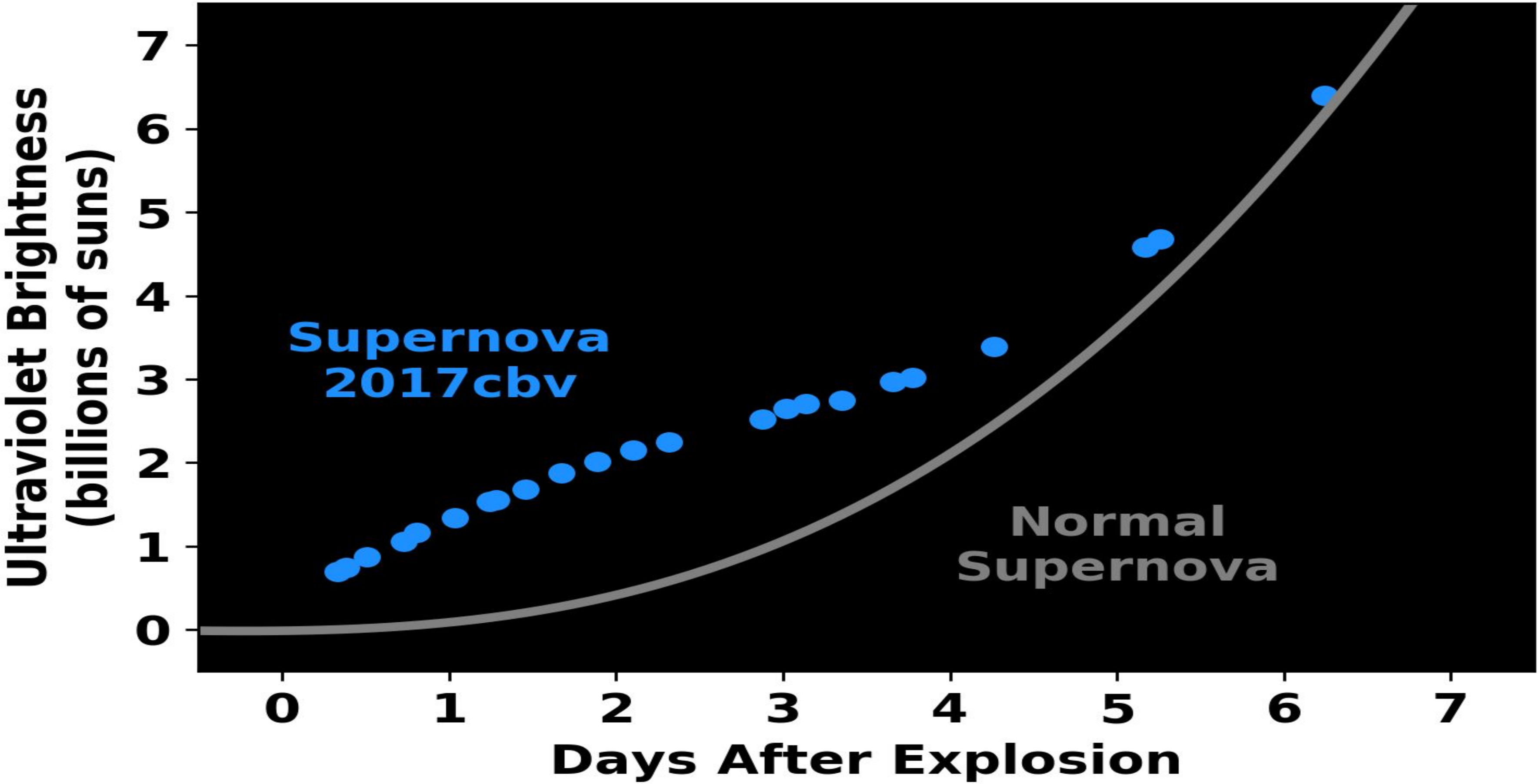




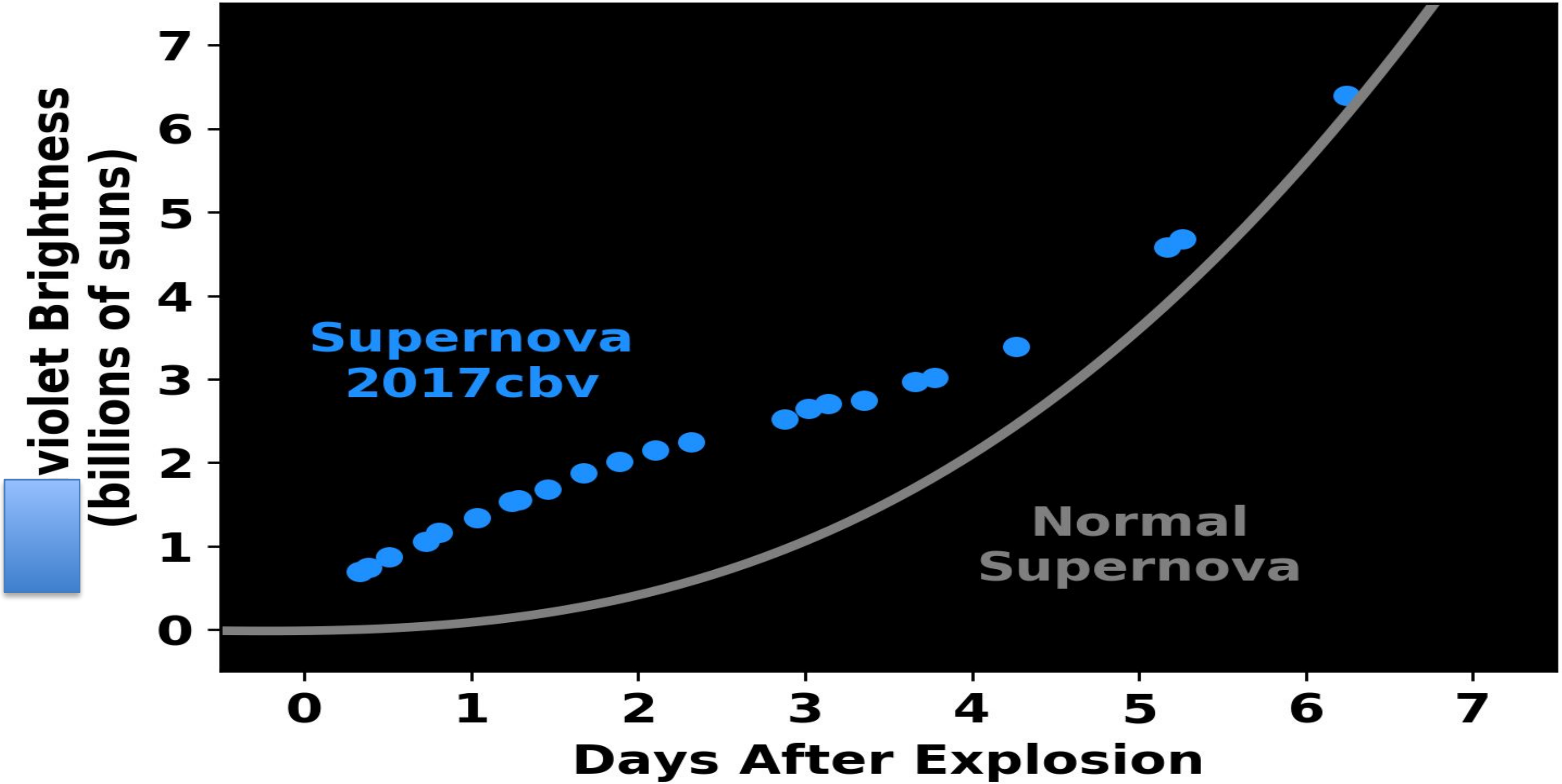
Early blue optical excess seen in SN2017cbv a shock signature?

Hosseinzadeh et al. 2017

But see also Hosseinzadeh et al. 2017

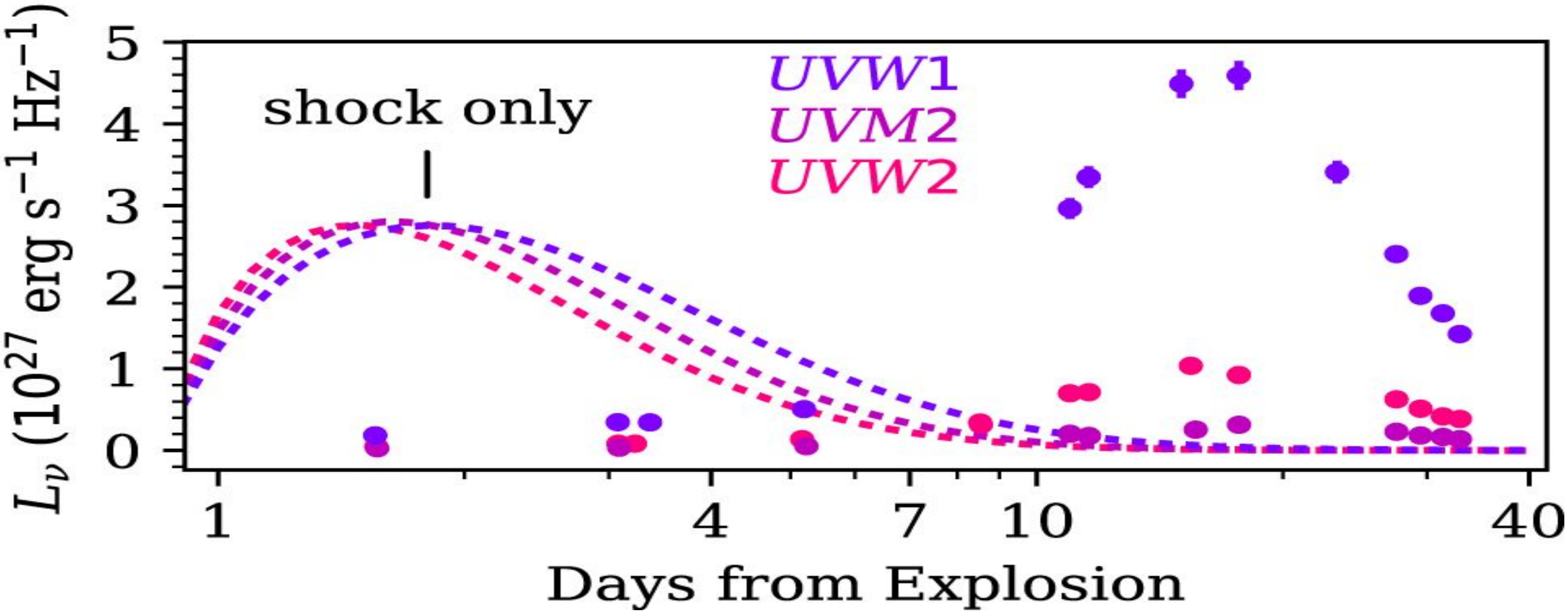


From LCO press release



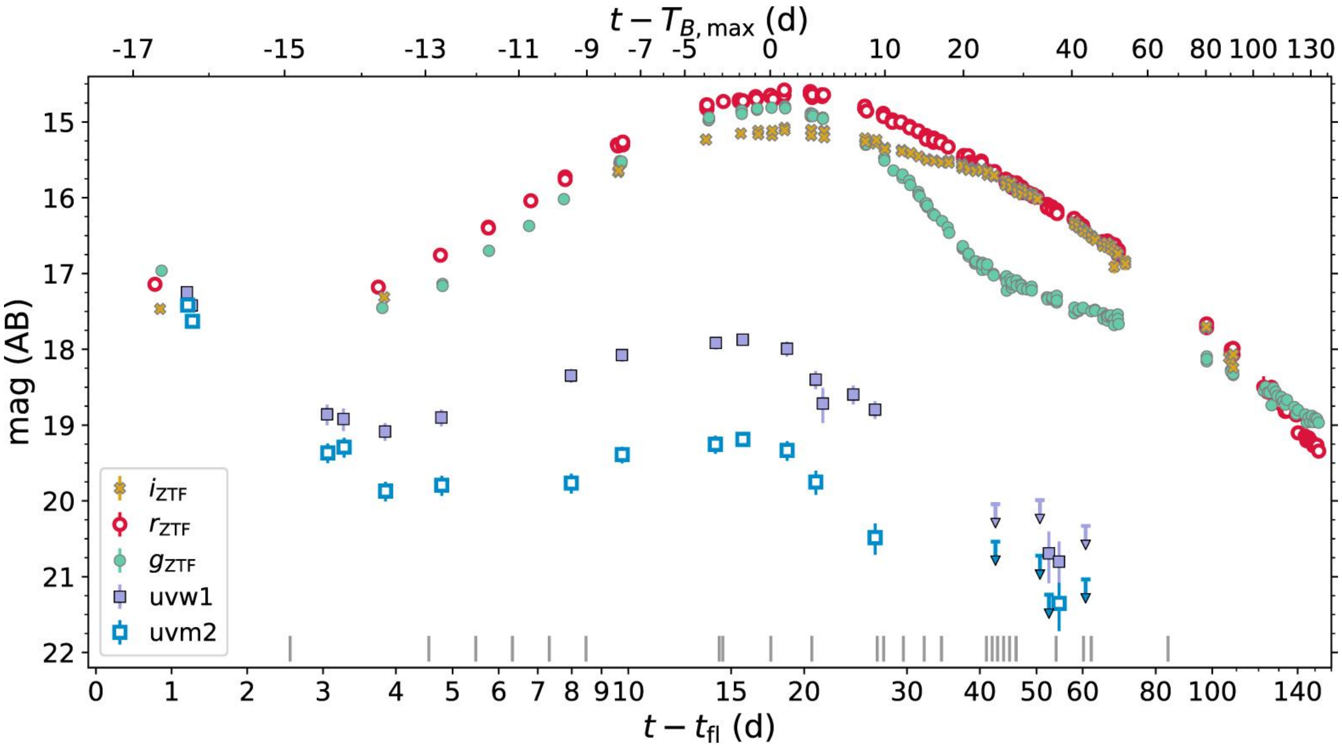
From LCO press release

But no shock seen in the space-UV

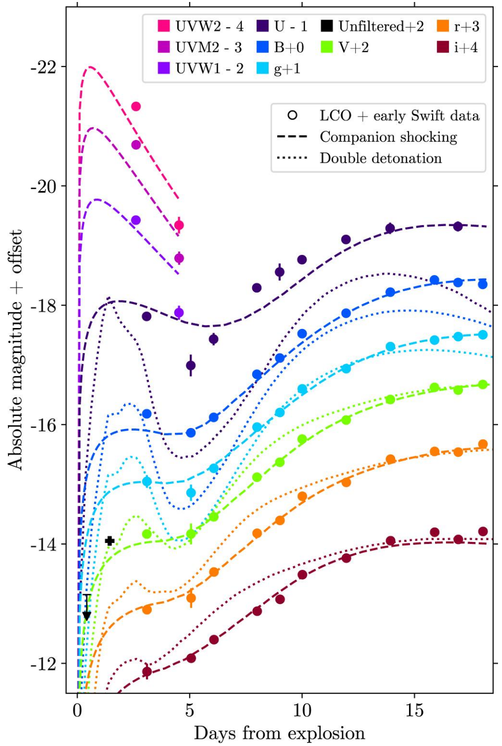


Hosseinzadeh et al. 2017

Early UV flash in iPTF14atg and SN2019yvq



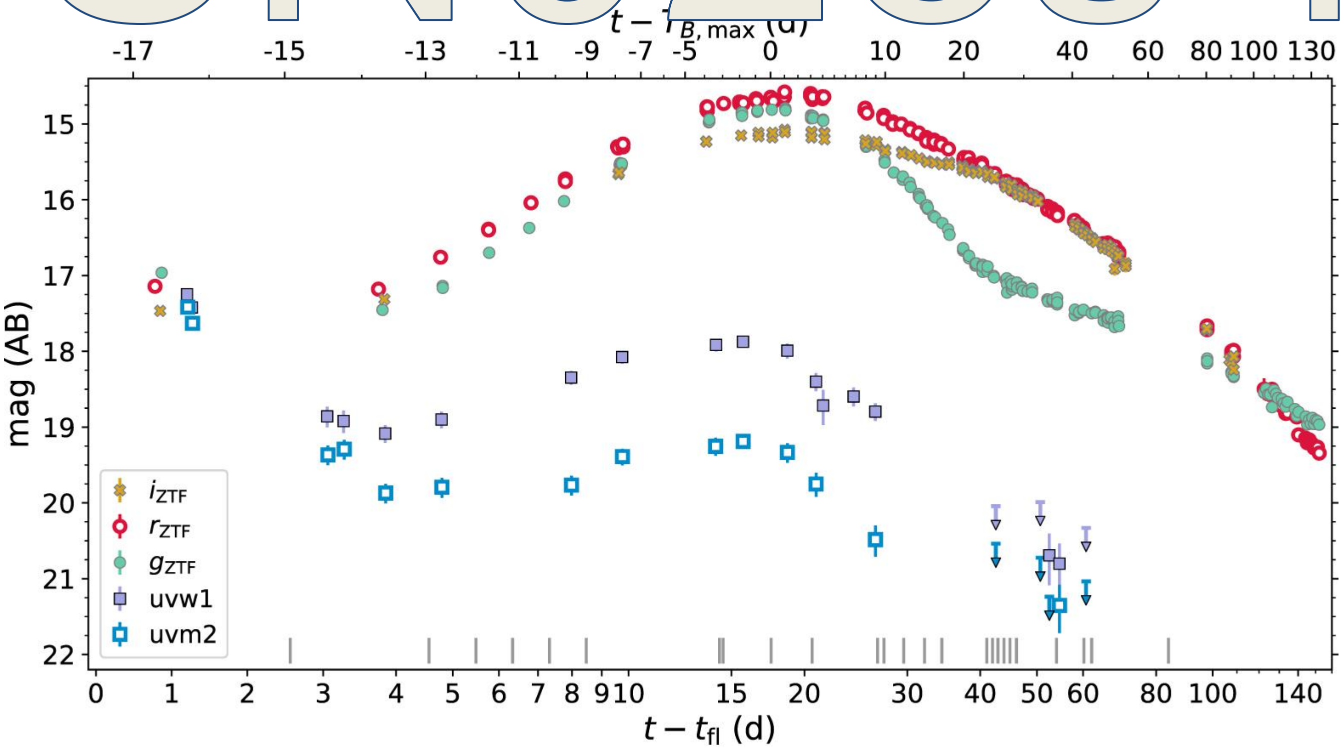
Miller et al. 2020



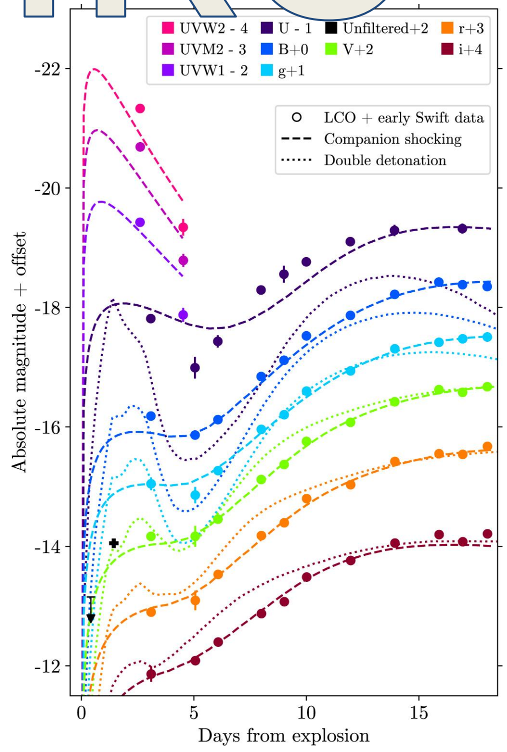
Burke et al. 2021

Early UV flash in iPTF14atg and SN2019yvq

SN02es-like



Miller et al. 2020



Burke et al. 2021

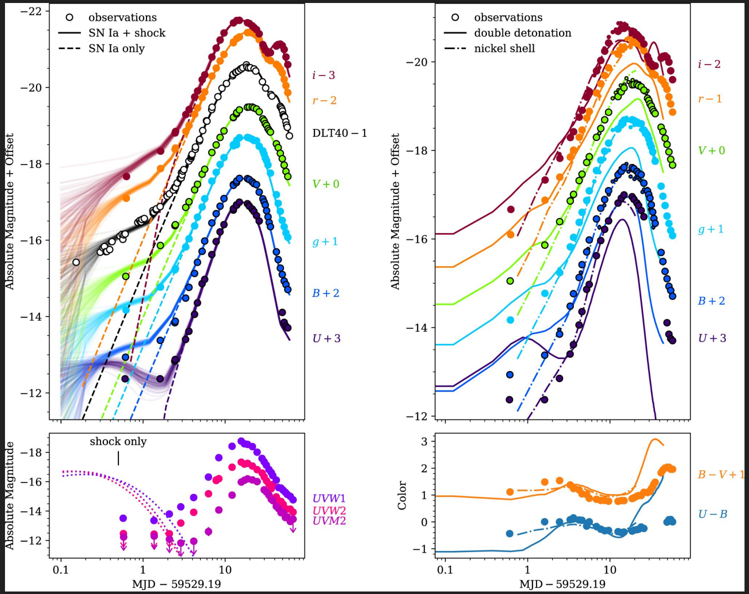
What is the origin of the UV excesses?

What is the origin of the blue excesses which are faint in the UV?

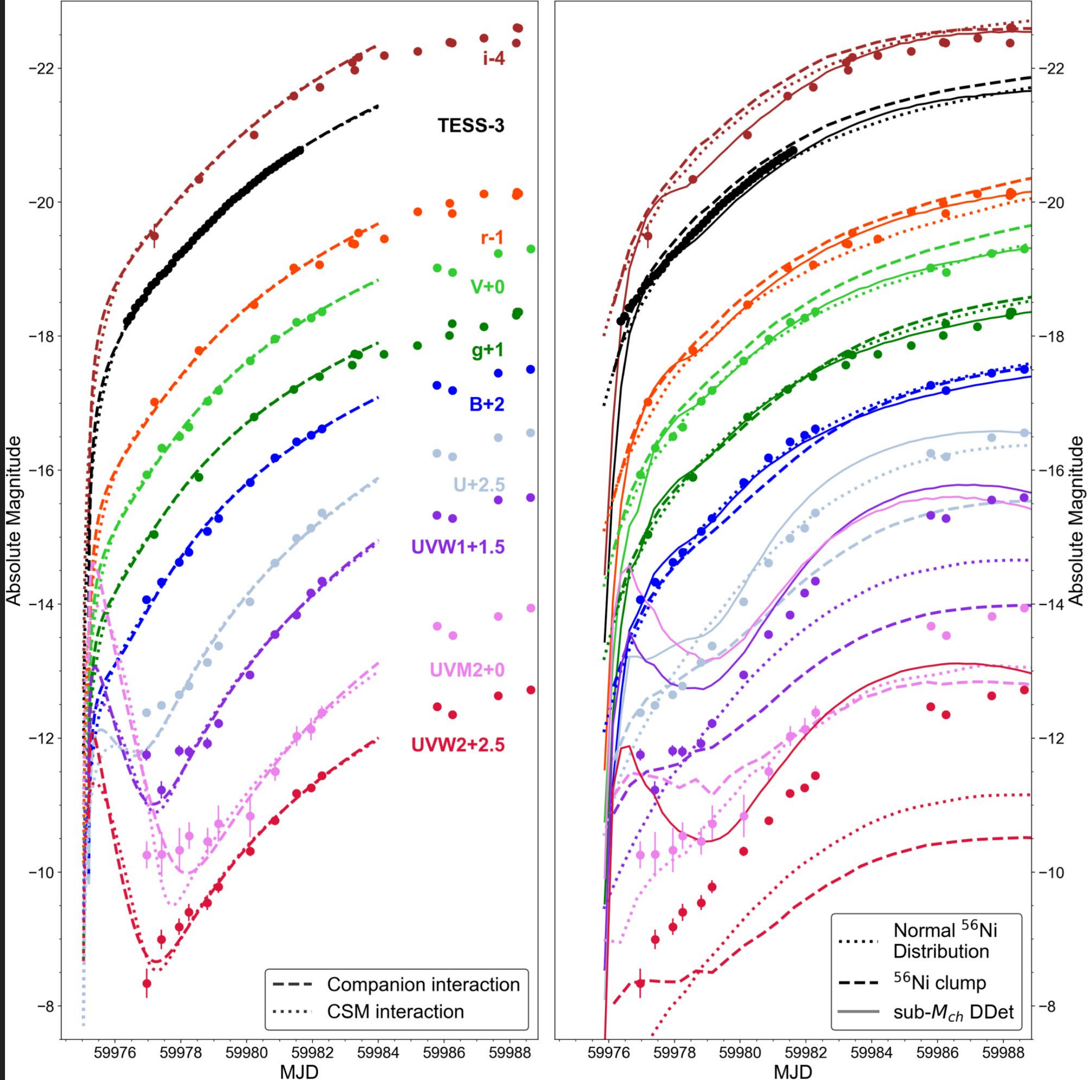
Are there multiple progenitor channels?

Are there other effects going on?

Early UV observations are the best constraints on companion interaction and Ni distribution



^ SN2021aefx Hosseinzadeh+2022
SN2023bee Wang et al. 2024 ->



Early UV observations of Type Ia SNe are the current frontier to understanding the progenitors and explosion mechanisms – if the theorists catch up

Ultrasat will make a definitive statement on the rate and magnitude of early excesses

- Swift swiftly opened up a new field
- Standard Candle SNe Ia are not standard in the UV – possibly key to making them better
- Optical weirdos are weirder in the UV
- Early time observations may solve the long-standing progenitor problem

Swift has a legacy of observations with current strategies to continue advancing the field.