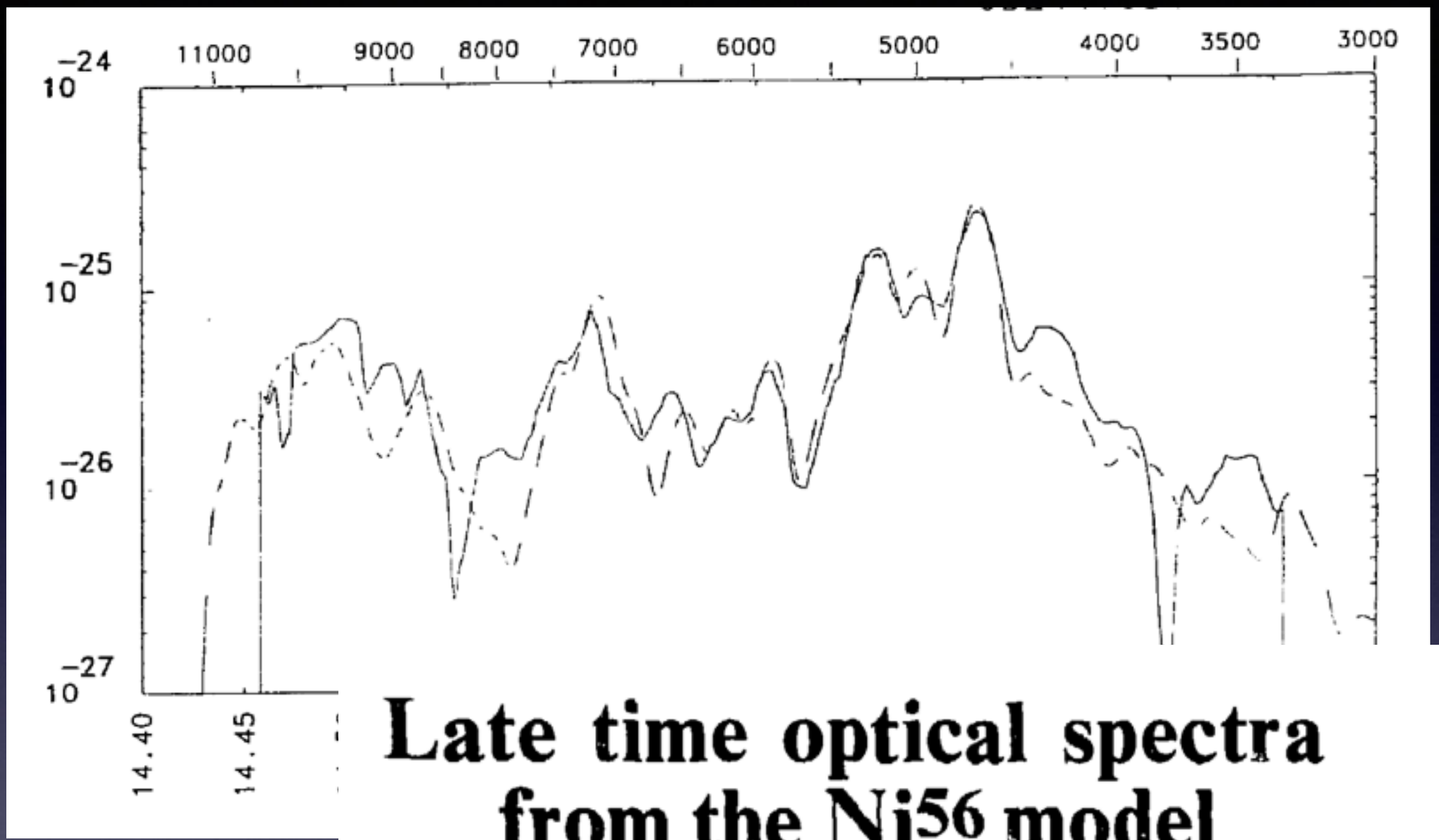
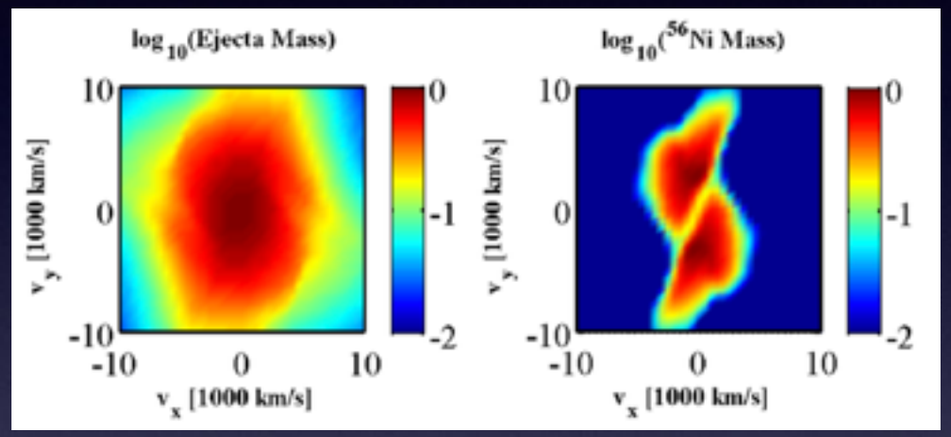
Axelrod 80, 1972E Kirshner+1973

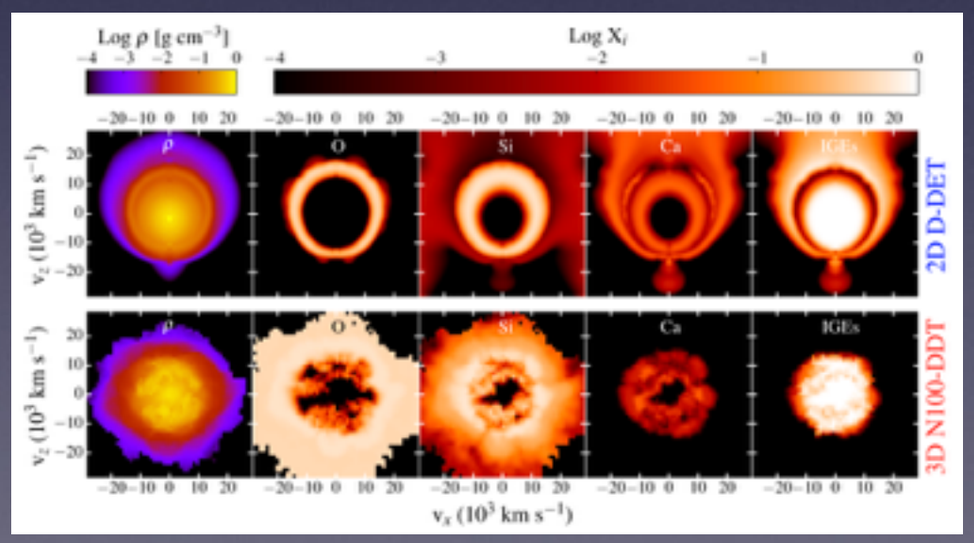


Late time optical spectra from the Ni^{56} model for Type I Supernovae

Timothy Stephen Axelrod
(Ph.D. Thesis)

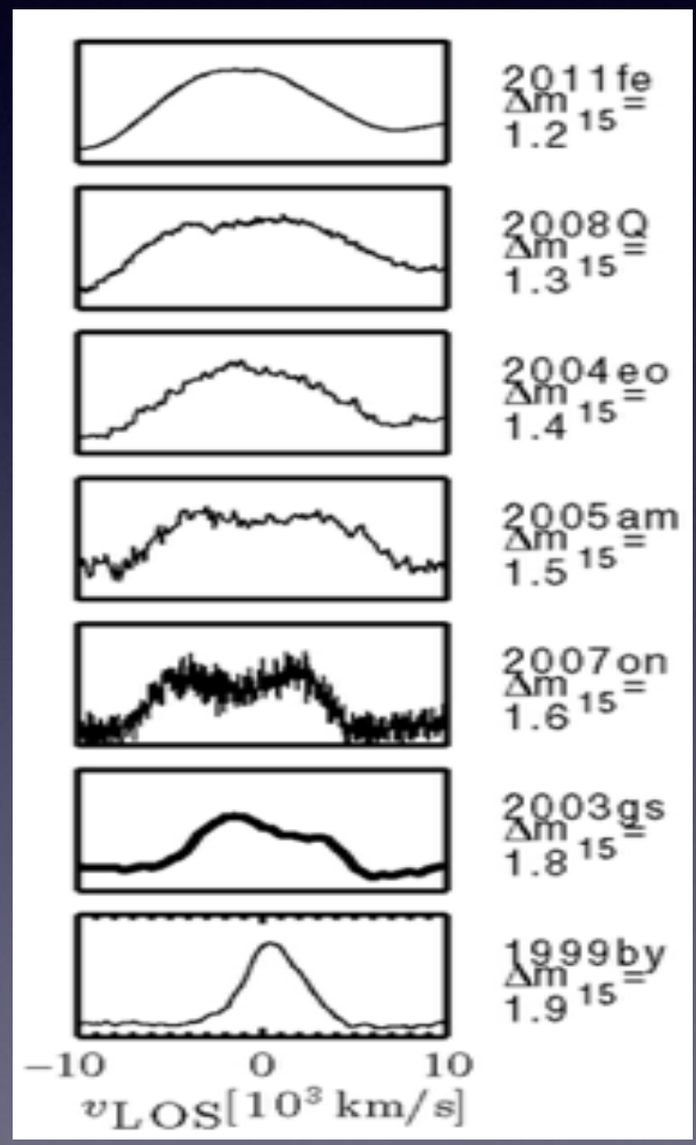
A powerful reachable(?) goal for nebular modelling:





?

Line shapes

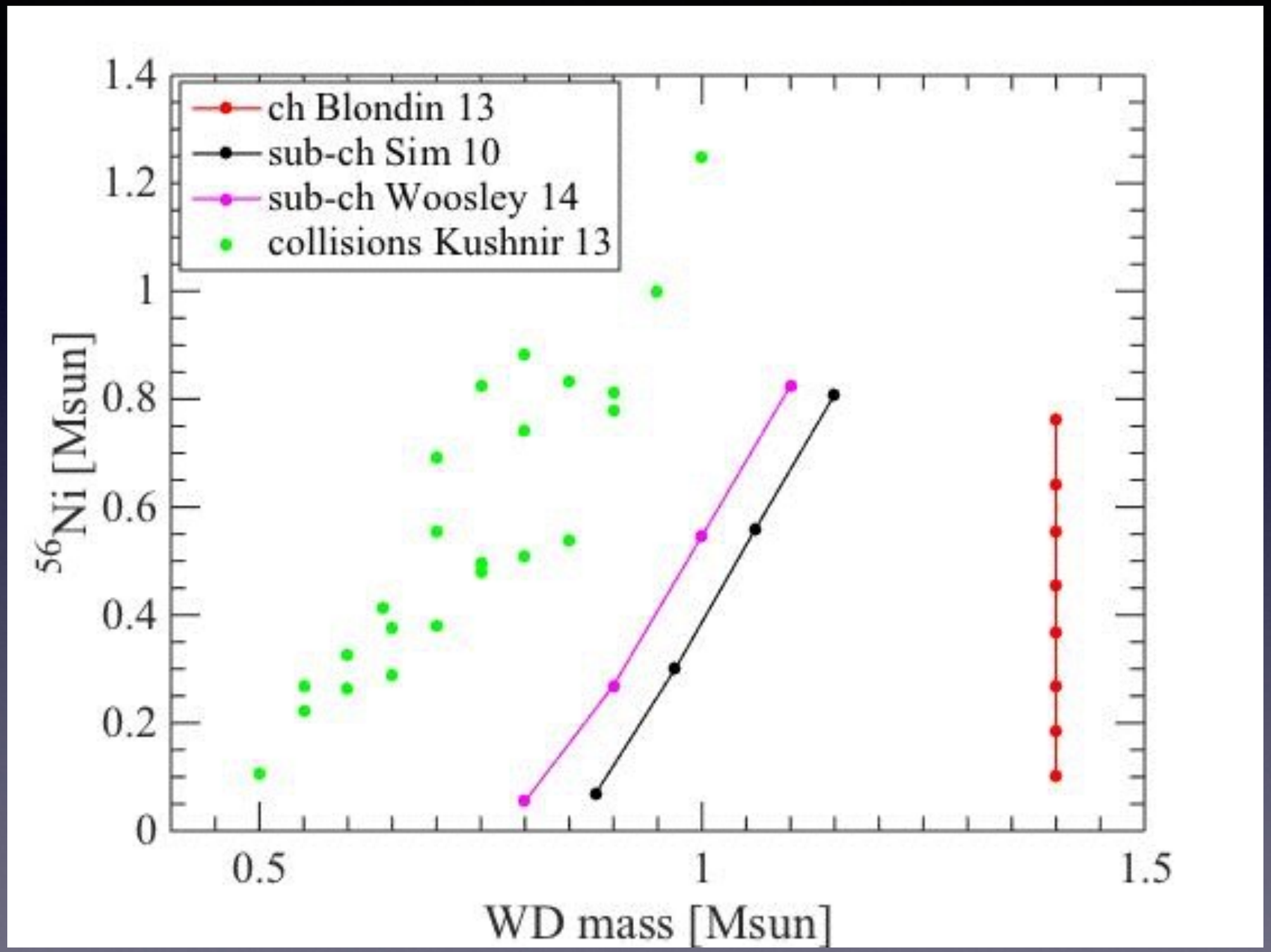


^{56}Co 5900 A feature

We don’t know how supernovae explode

Type Ia's: What ignites ~1% of White Dwarfs and produces some Ni56?

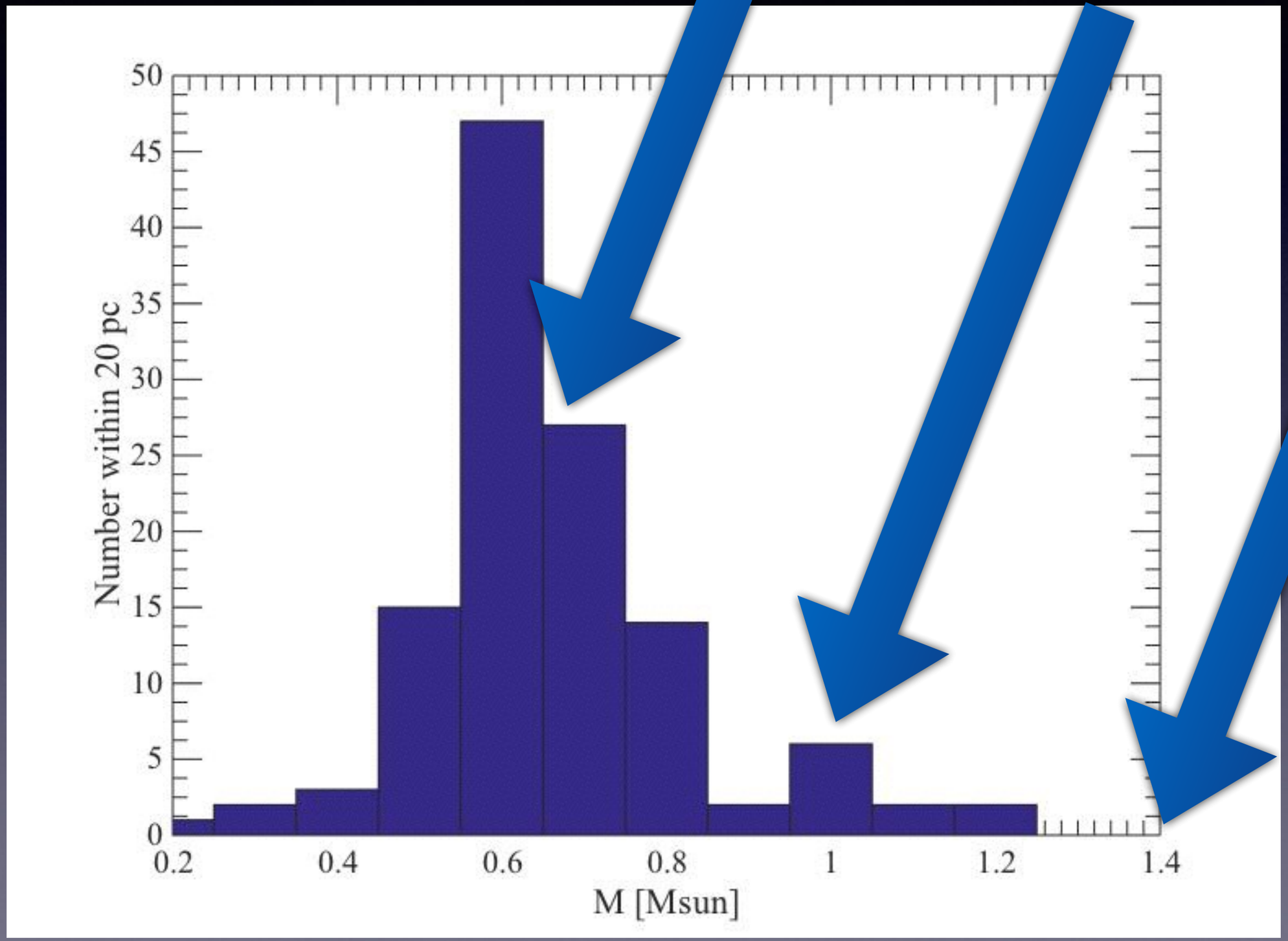
WD Mass vs ^{56}Ni



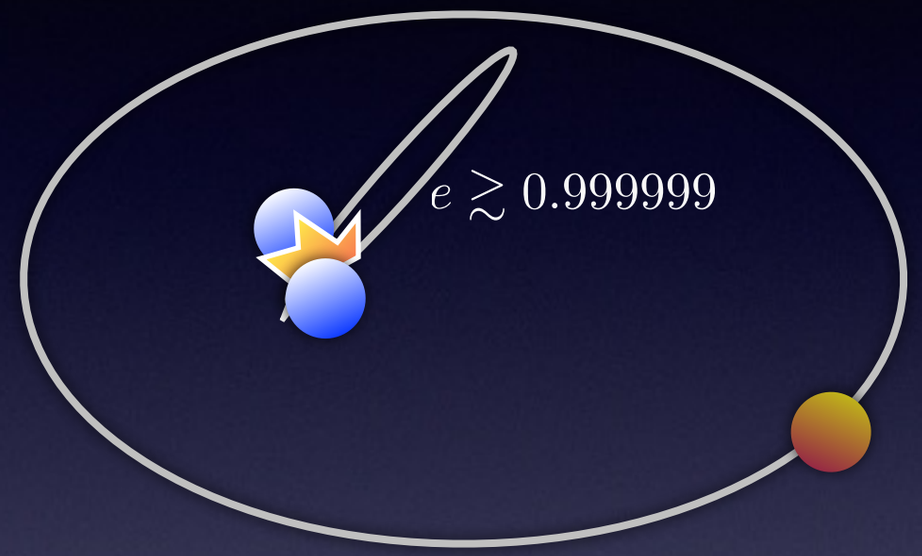
Possibilities: Collide two of these

Detonate (?) one of these (sub-ch)

Torture (??) one of these (chandra)



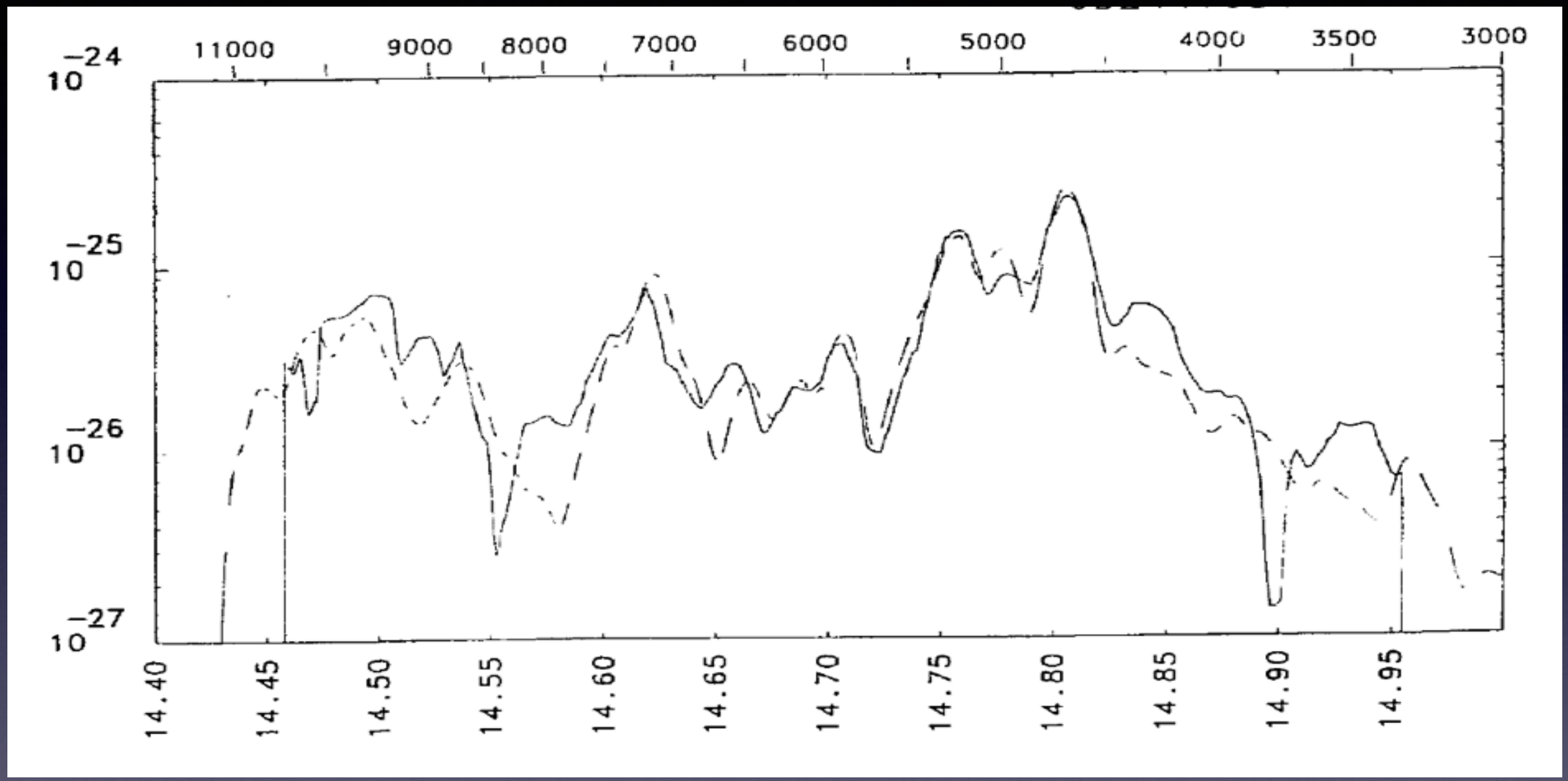
Collisions are great:
* ignition
* some Ni56
* faint in ellipticals
* correct physical WLRs (Wygoda Sunday)
* double peak/shifts nebular

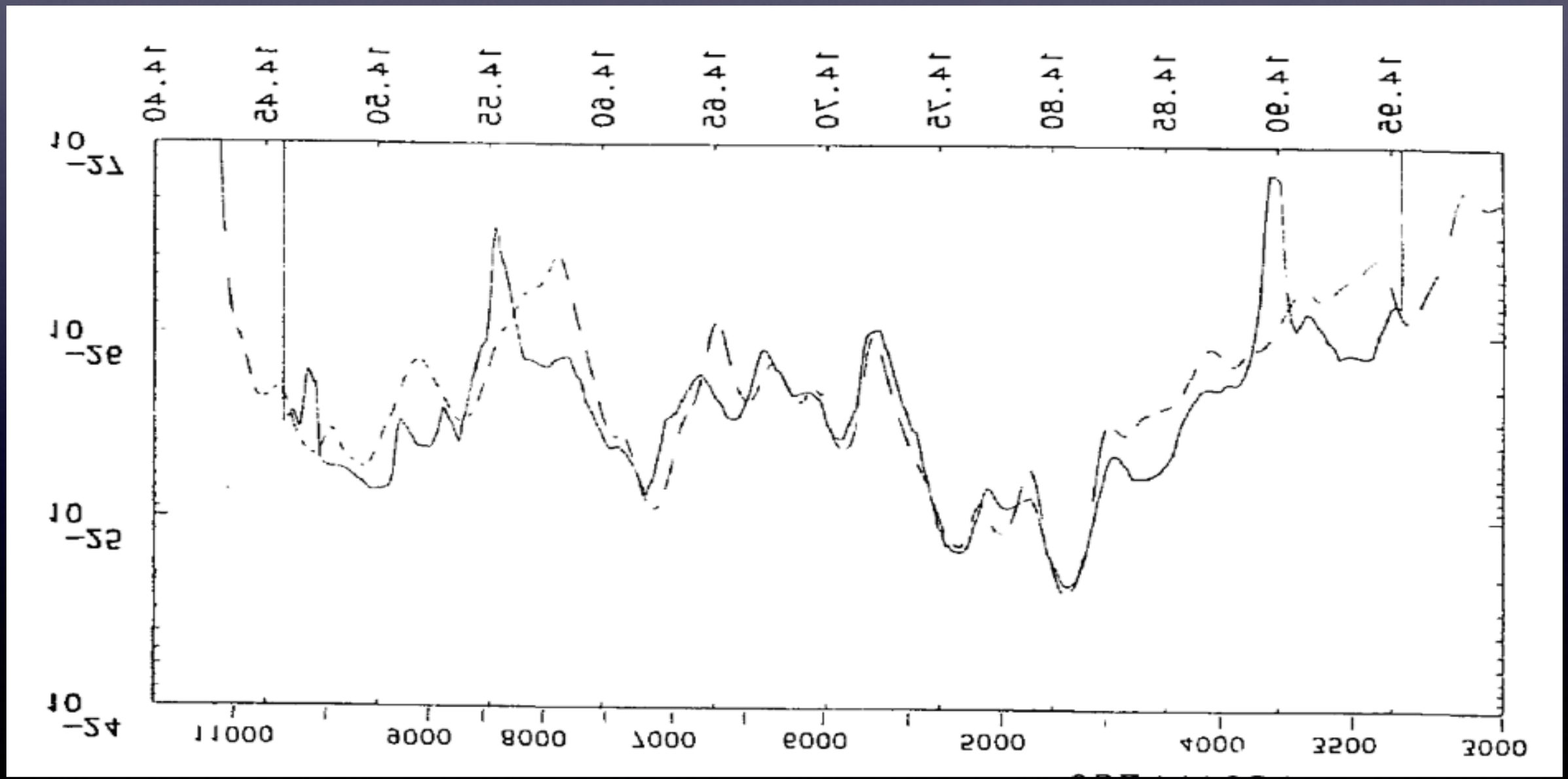


Serious Challenges:
* Rate
* double peak/shifts nebular

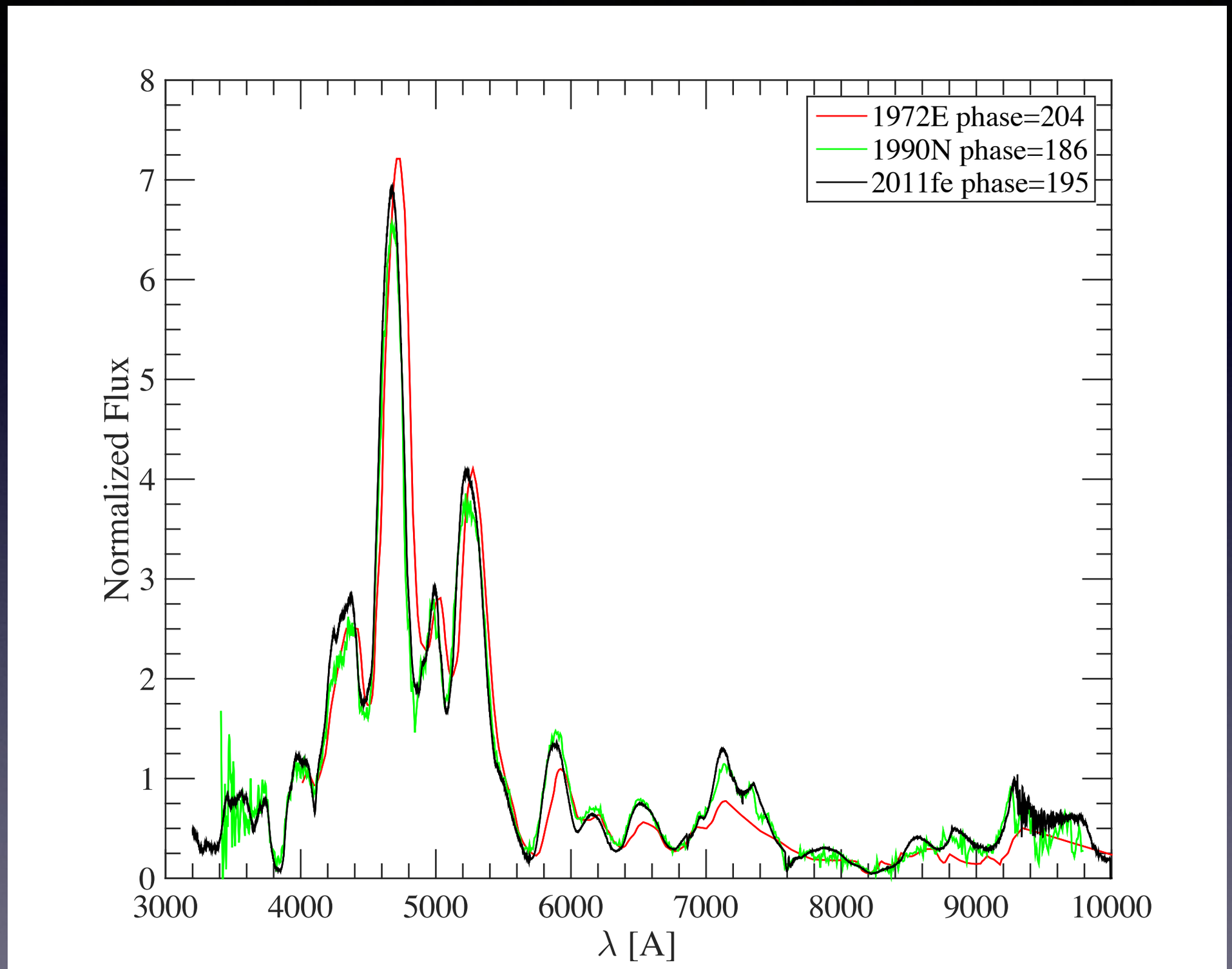
Need study:
* 3D light curves, Spectra, polarisation

Axelrod 80, 1972E Kirshner+1973



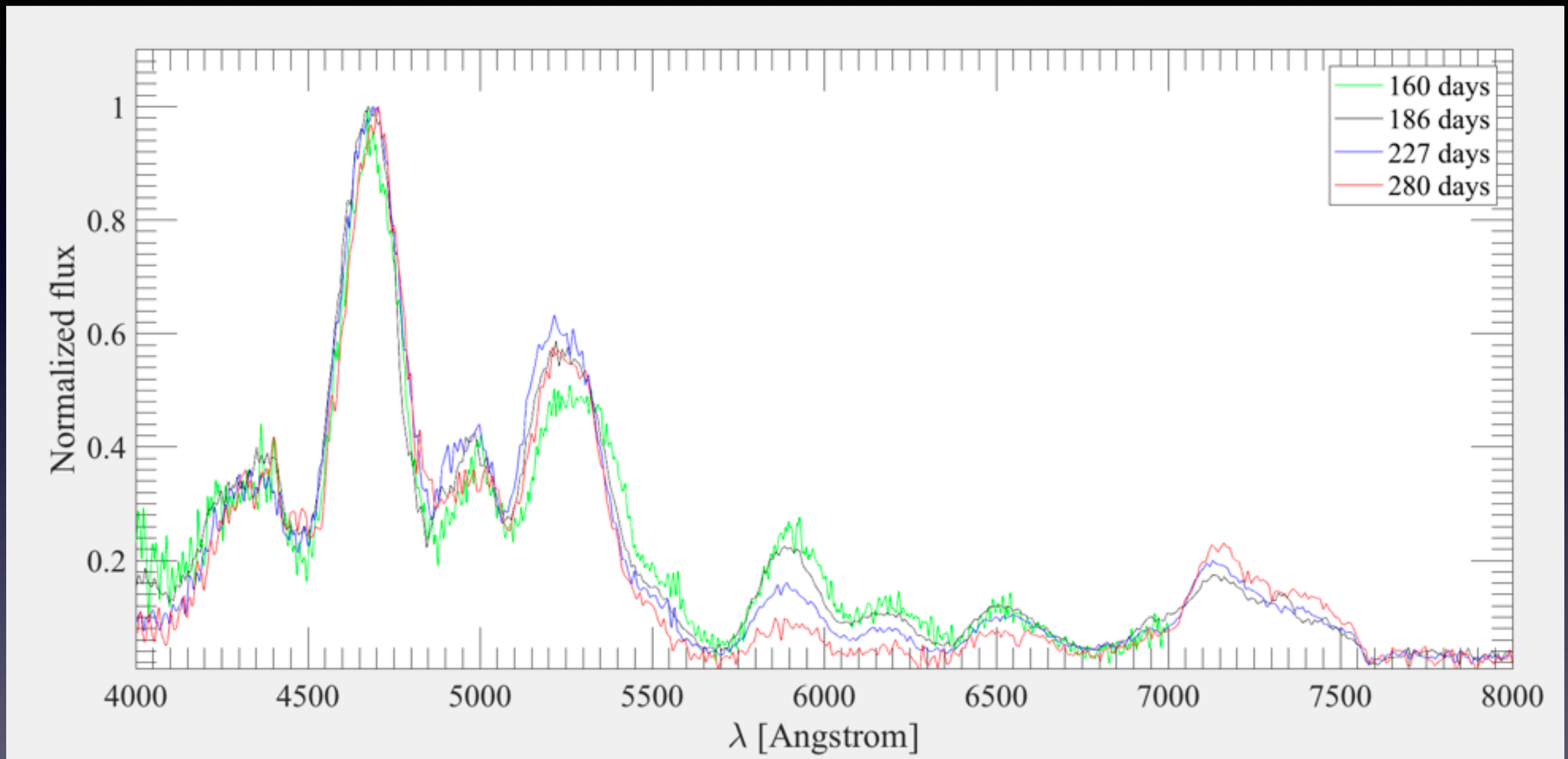

74.40
74.45
74.50
74.55
74.60
74.65
74.70
74.75
74.80
74.85
74.90
74.95
10^{-21}
10^{-22}
10^{-23}
10^{-24}
11000
9000
8000
7000
6000
5000
4000
3200
3000

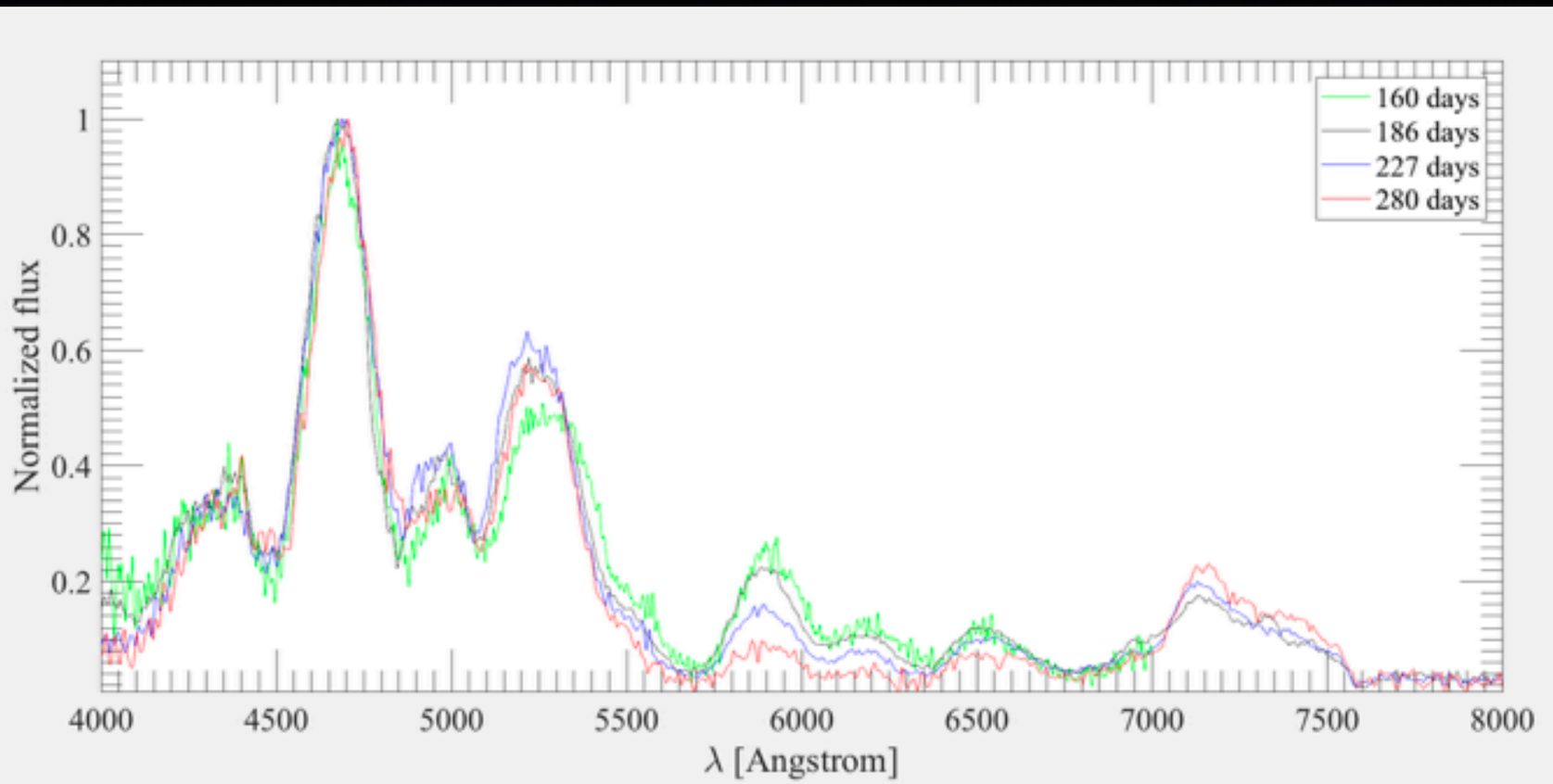
Some more SNe



Very stable. Except for ?

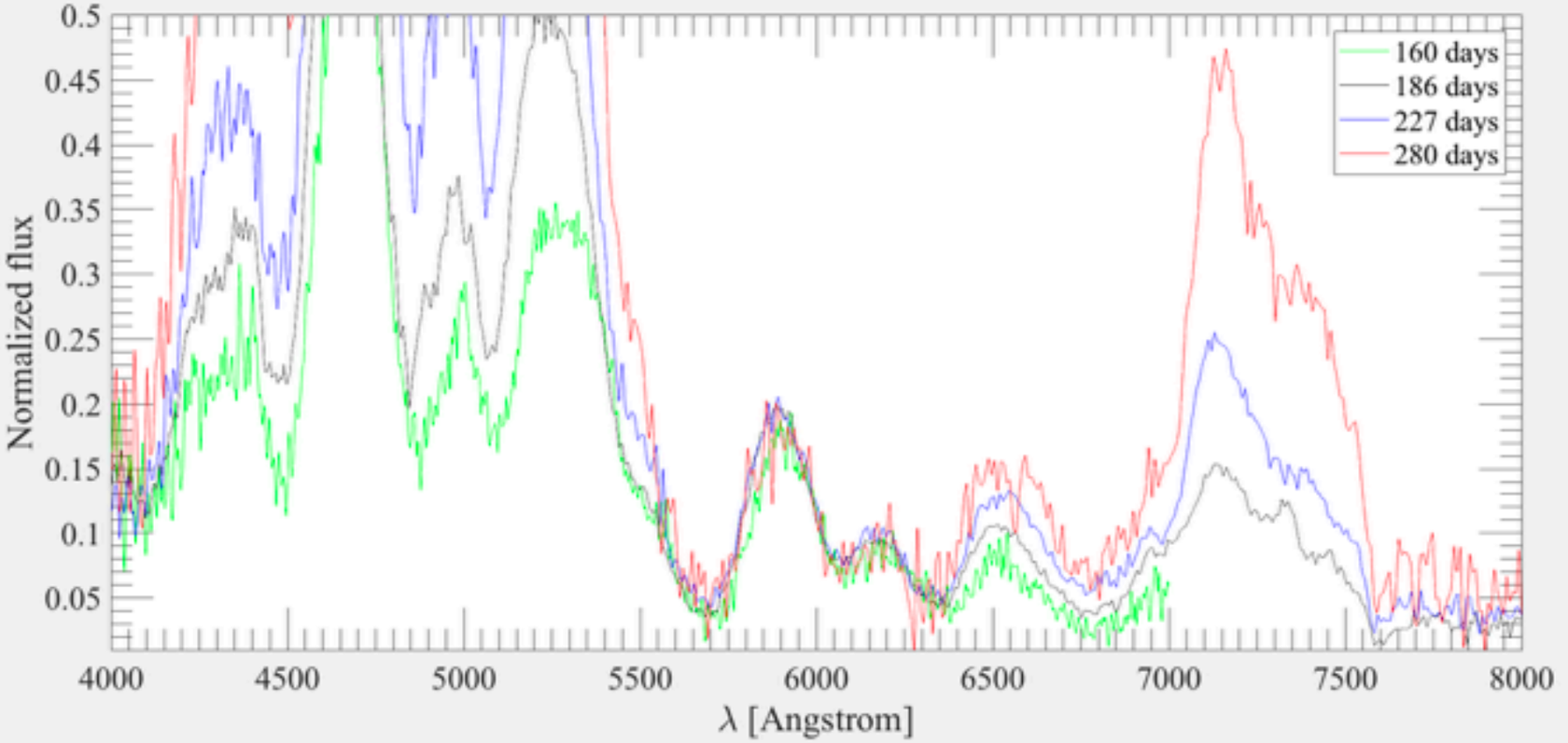
sn 1990N

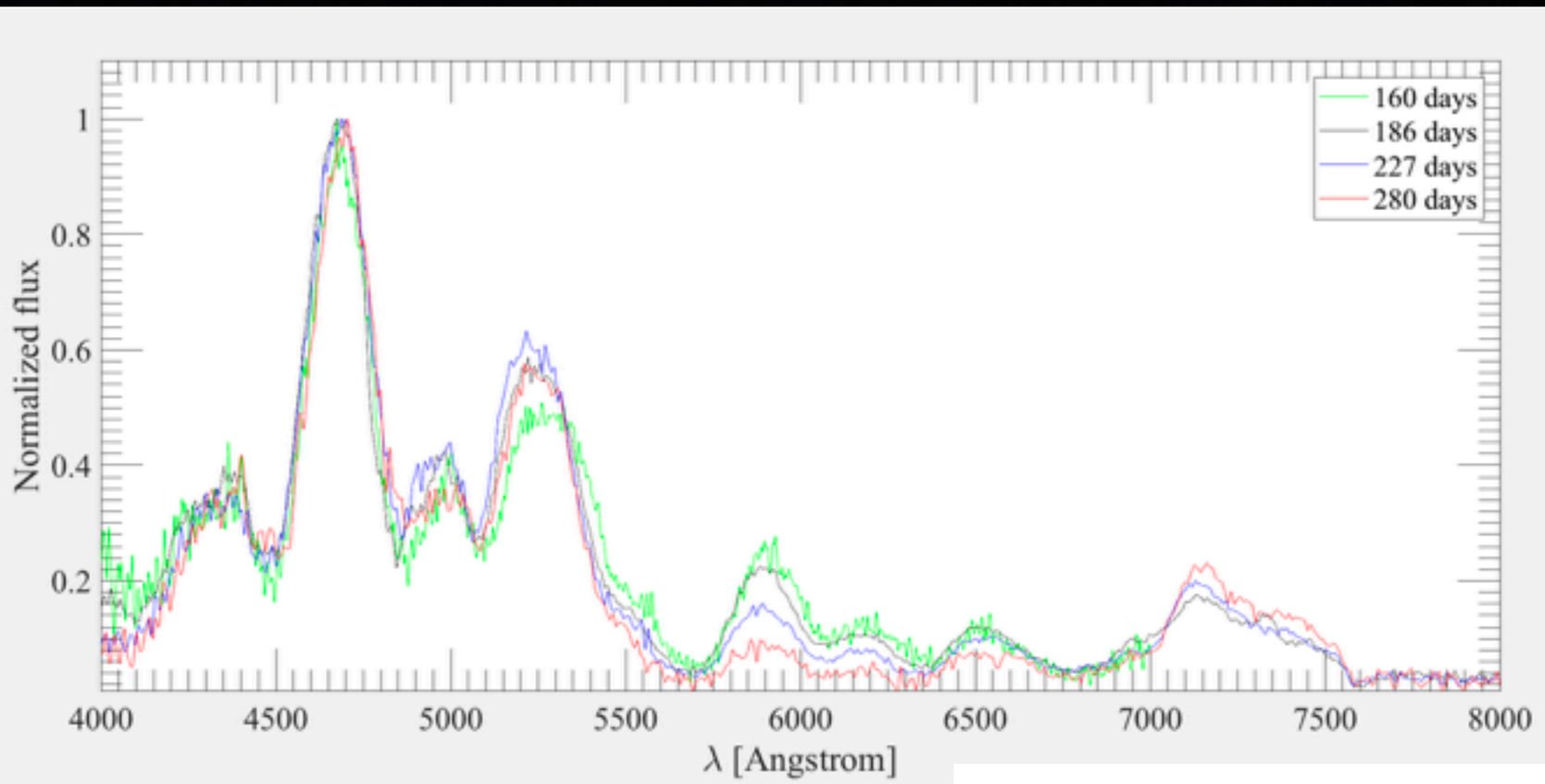




77 day half life

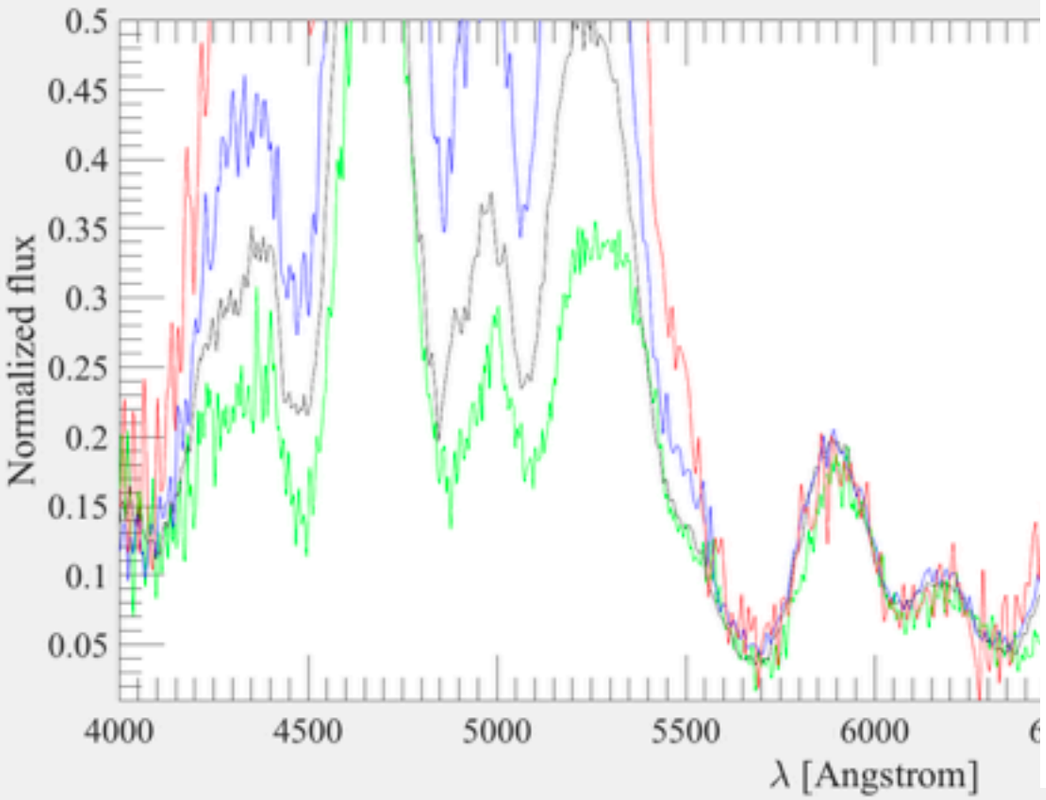
56 Co decay

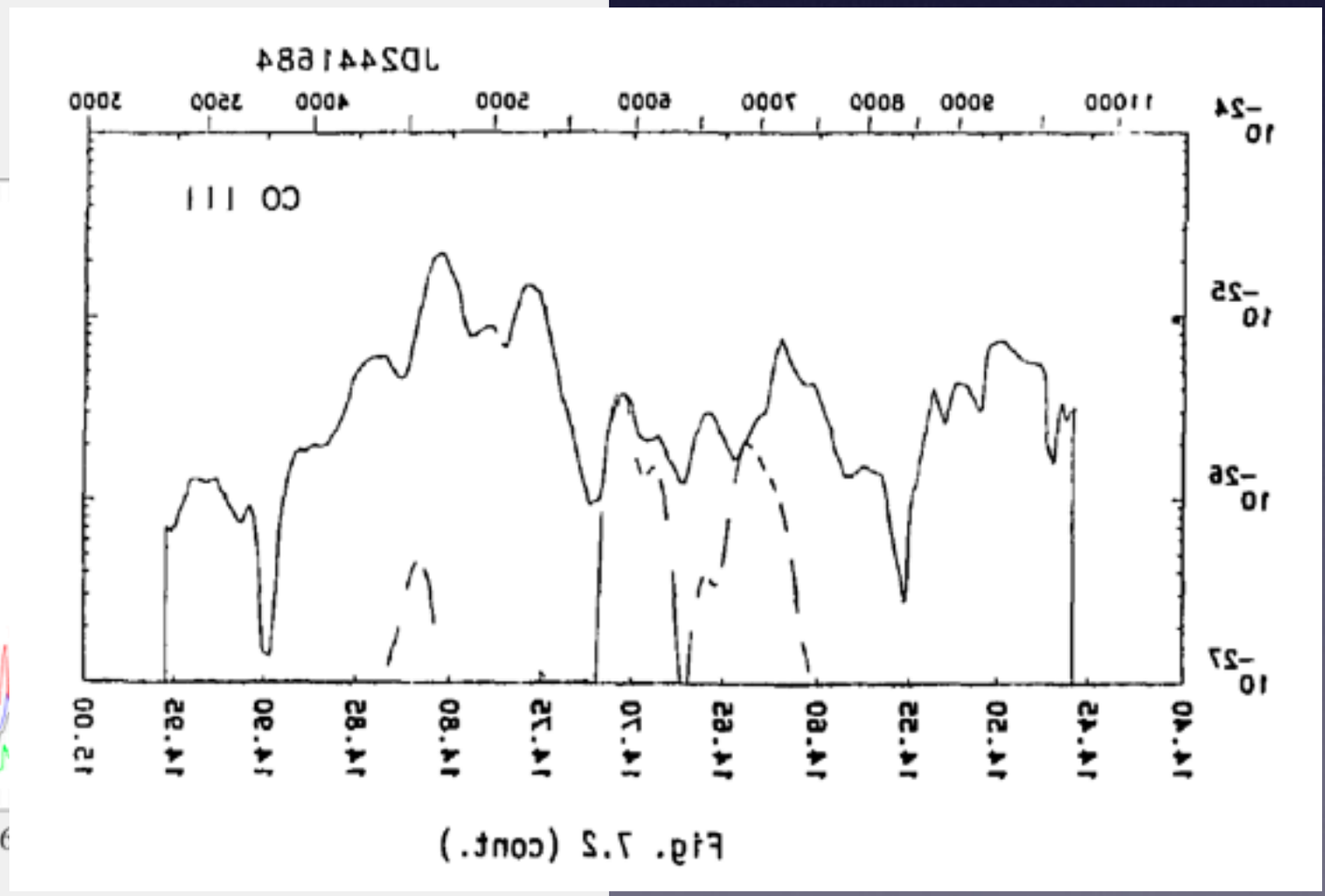




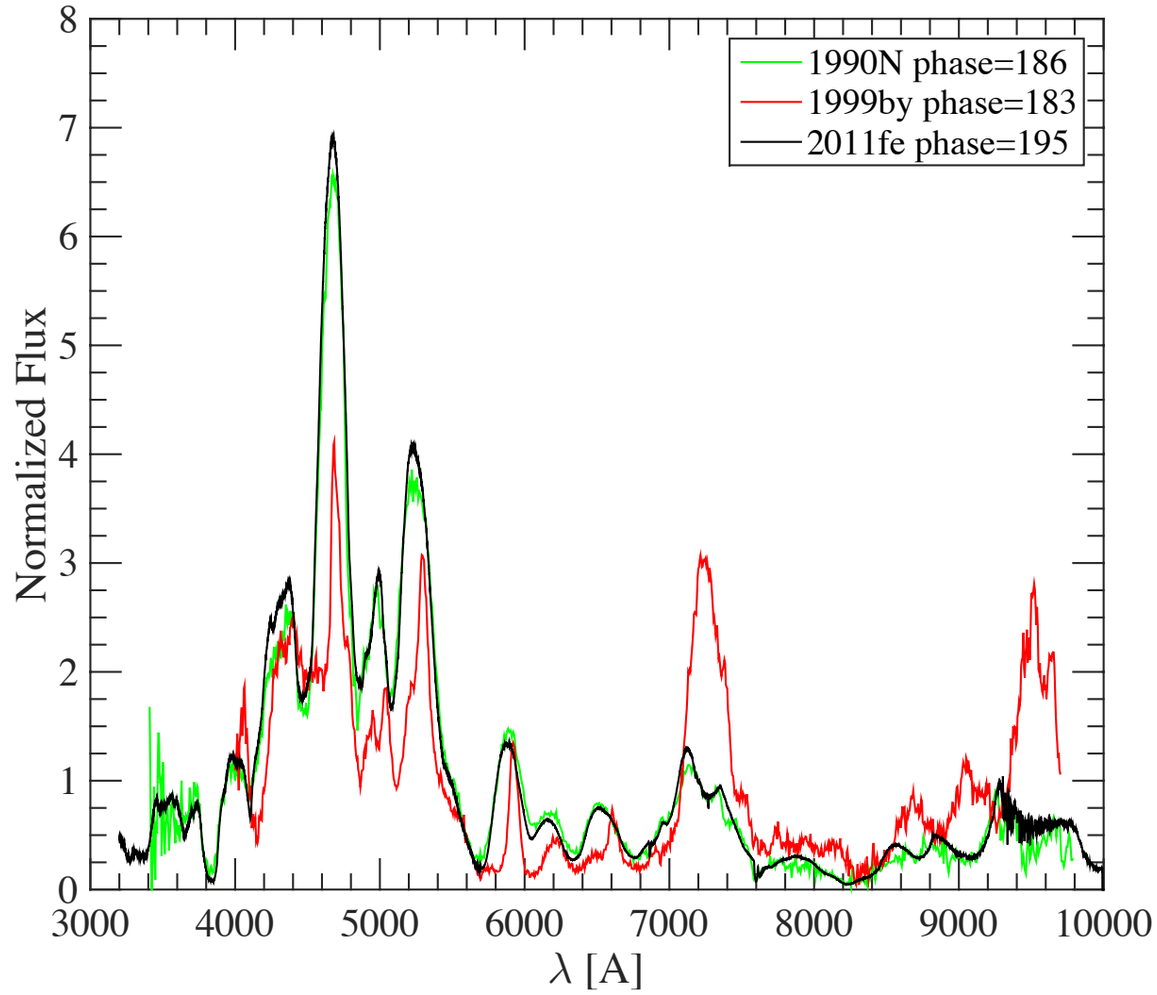
77 day half life

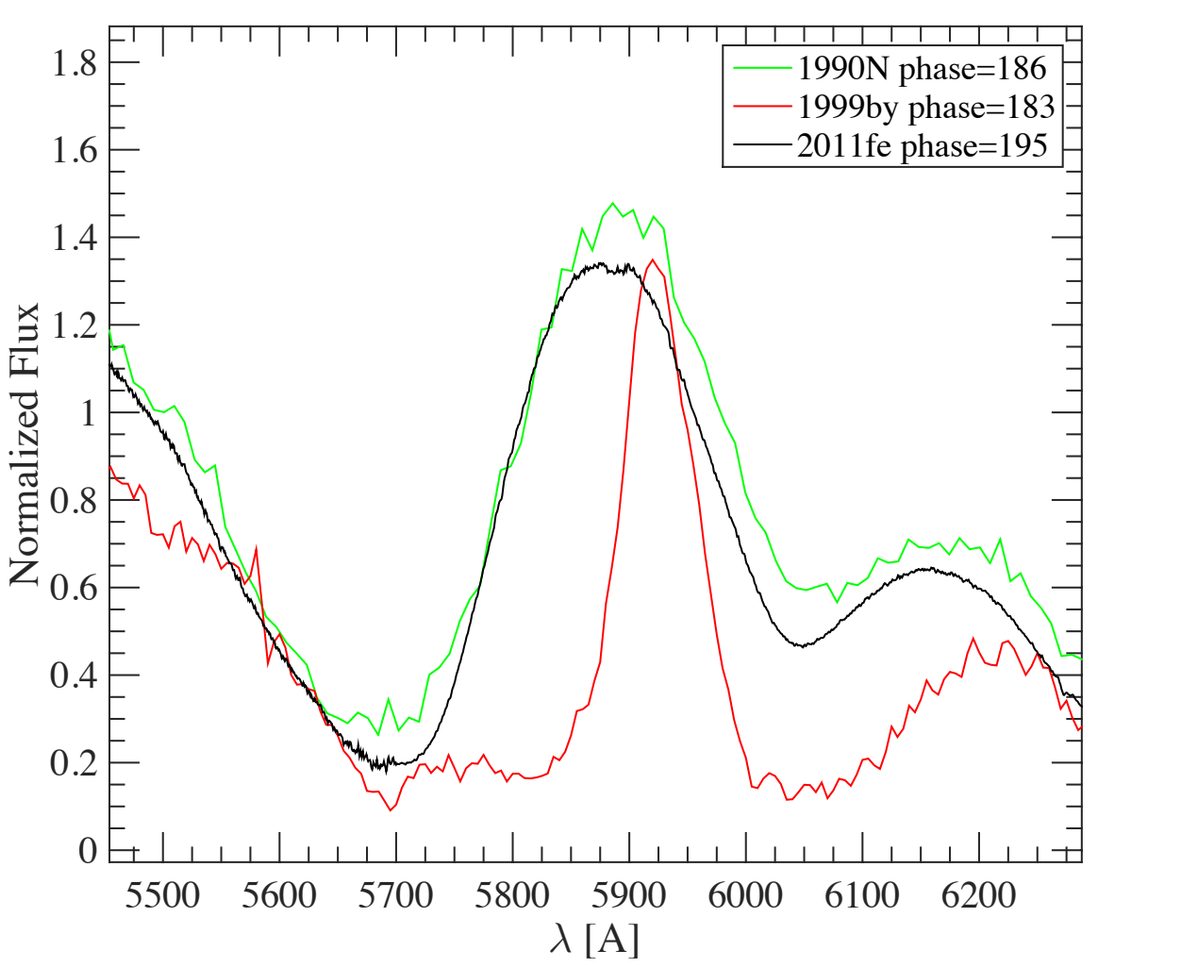
56 Co decay



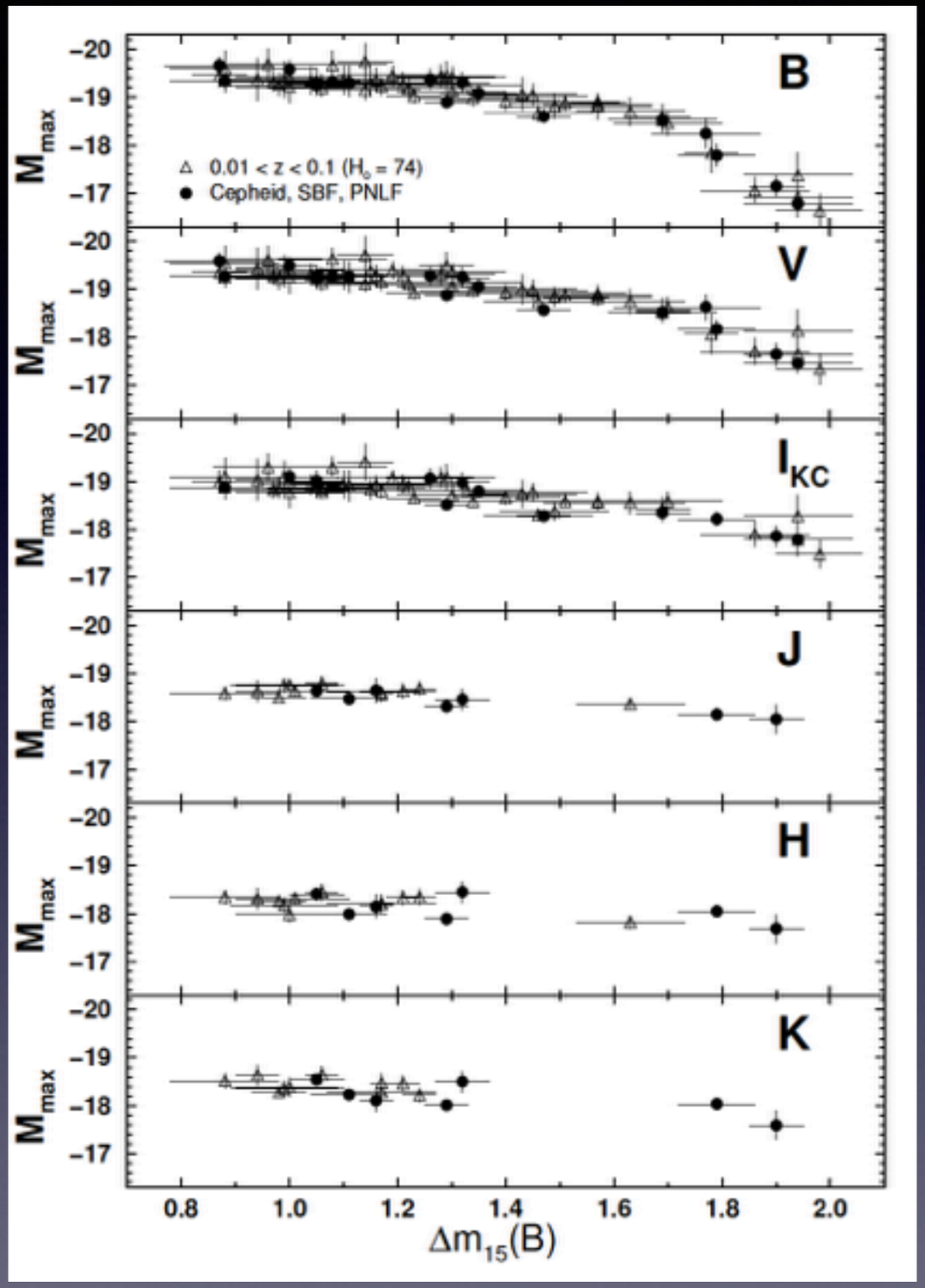


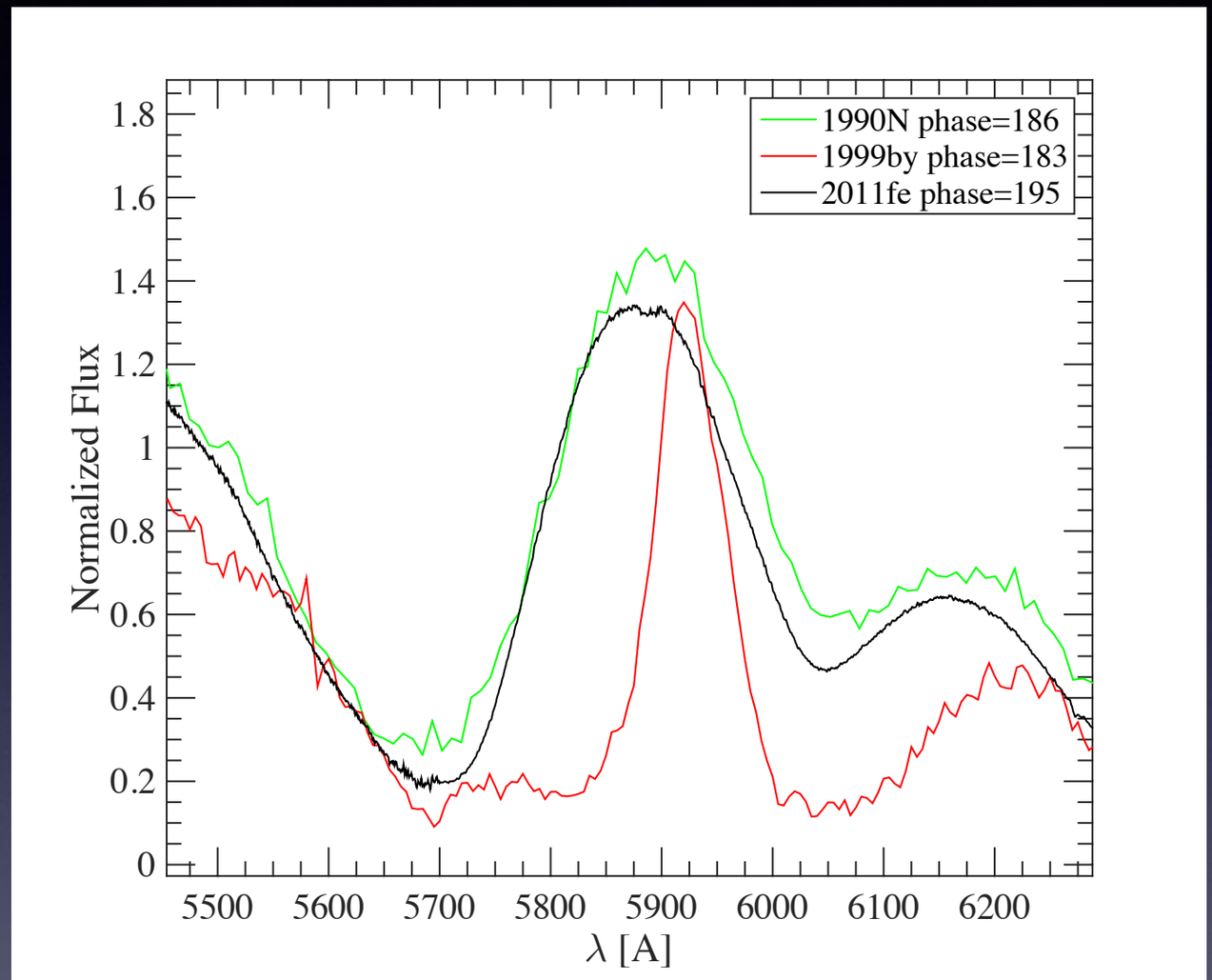
Faint Ia's are much narrower



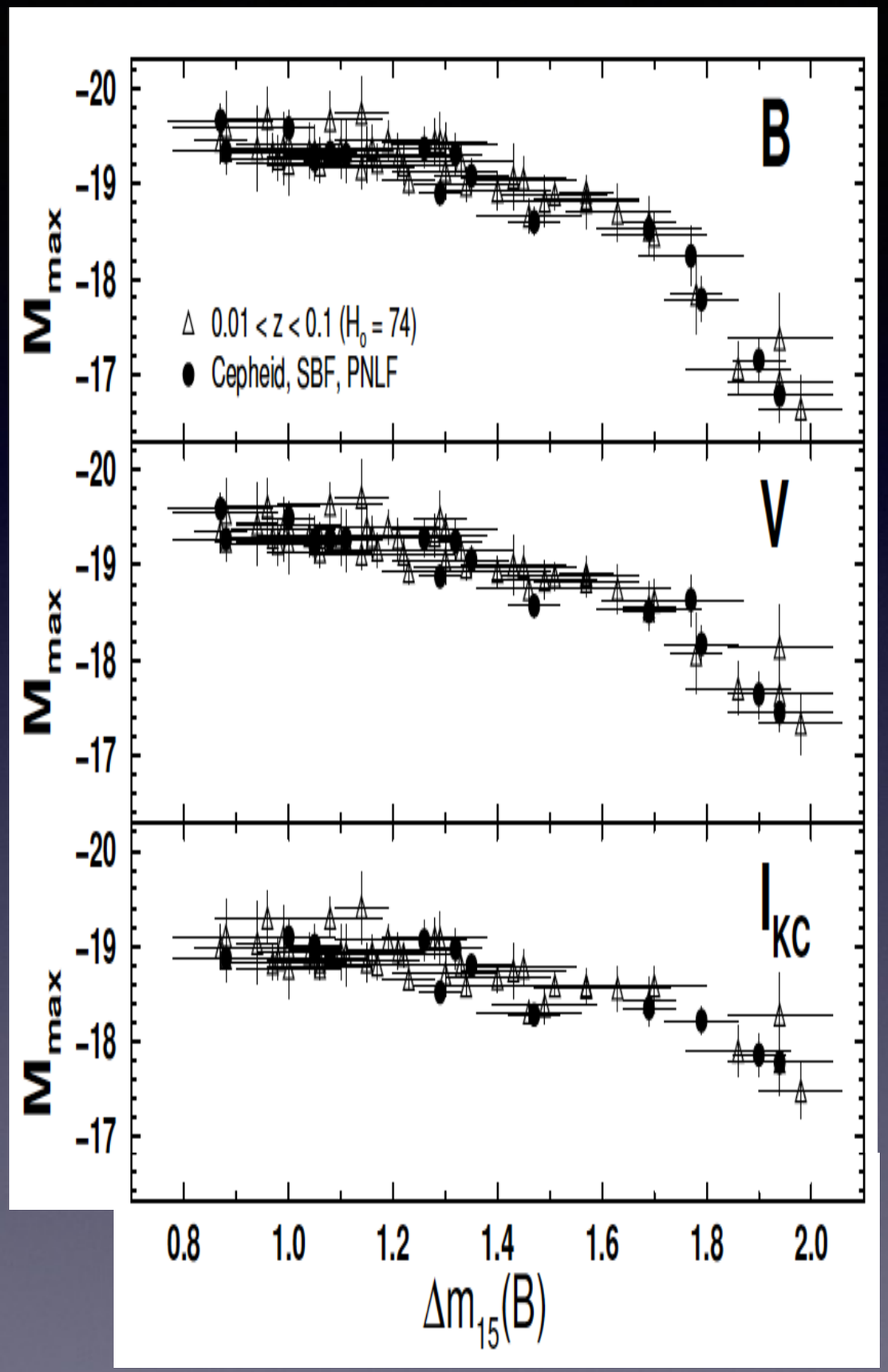


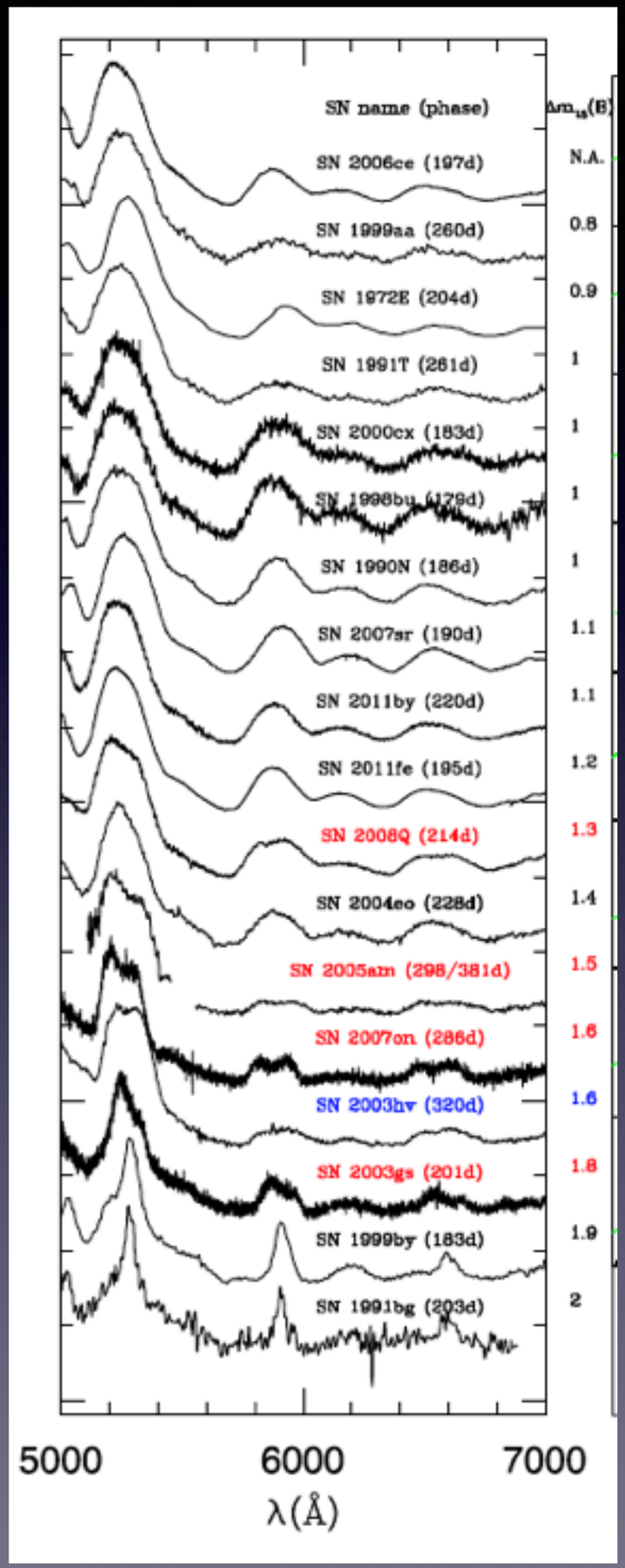
Continuos distribution?



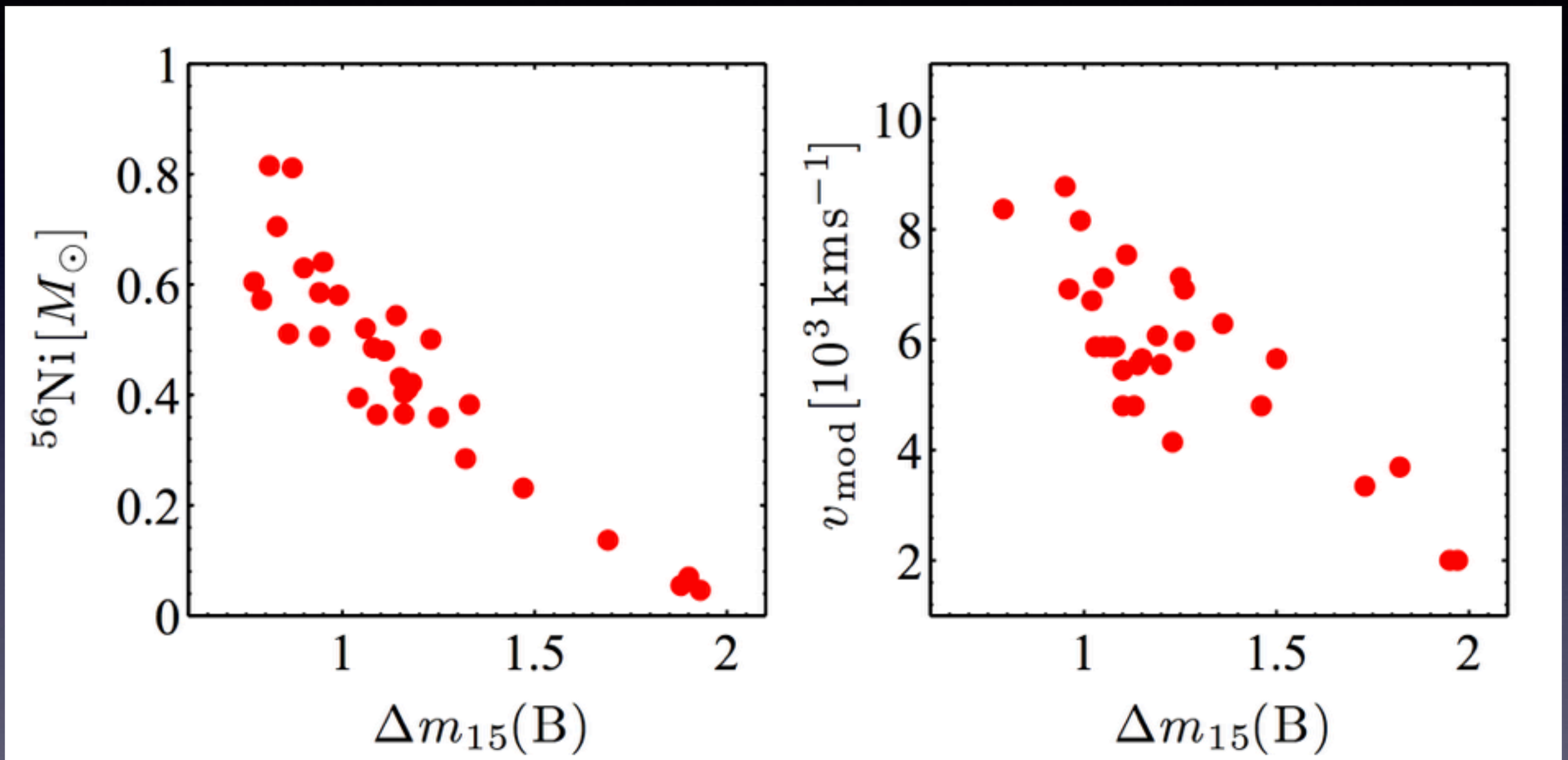


Phillips 05


B
V
I_{KC}
M_{max}
-20
-19
-18
-17
△ 0.01 < z < 0.1 (H_0 = 74)
● Cepheid, SBF, PNLF
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\Delta m_{15}(B)$

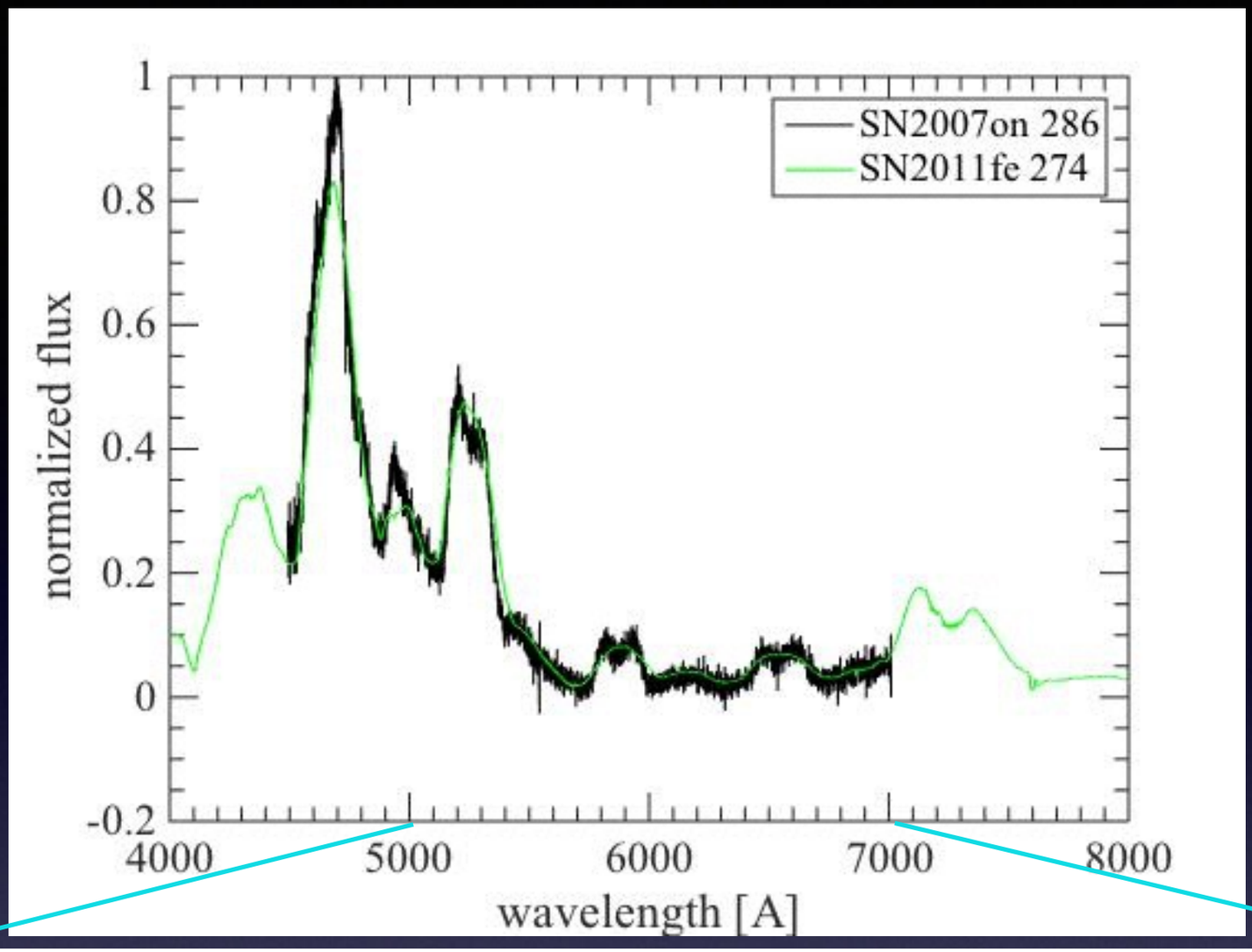

SN name (phase)
$\Delta m_{15}(B)$
SN 2006ce (197d) N.A.
SN 1999aa (260d) 0.8
SN 1972E (204d) 0.9
SN 1991T (261d) 1
SN 2000cx (183d) 1
SN 1998bu (179d) 1
SN 1990N (186d) 1
SN 2007sr (190d) 1.1
SN 2011by (220d) 1.1
SN 2011fe (195d) 1.2
SN 2008Q (214d) 1.3
SN 2004eo (228d) 1.4
SN 2005am (298/381d) 1.5
SN 2007on (286d) 1.6
SN 2003hv (320d) 1.6
SN 2003gs (201d) 1.8
SN 1999by (183d) 1.9
SN 1991bg (203d) 2
5000
6000
7000
λ(Å)

Dong+15

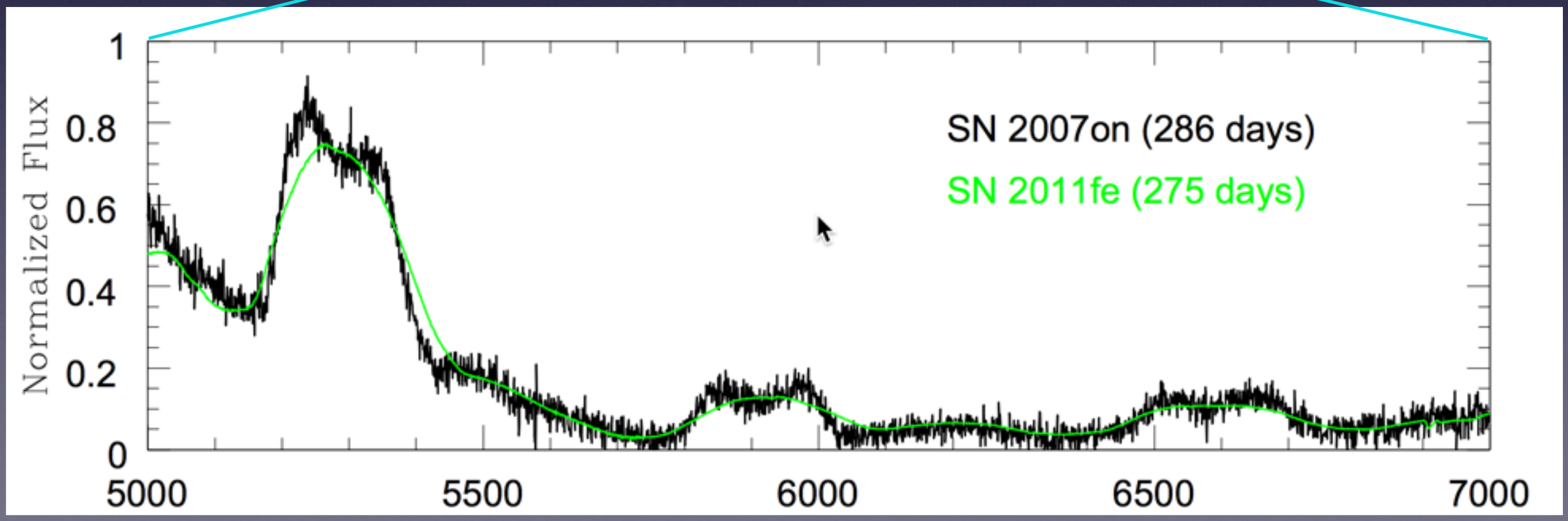


kushnir+ 13

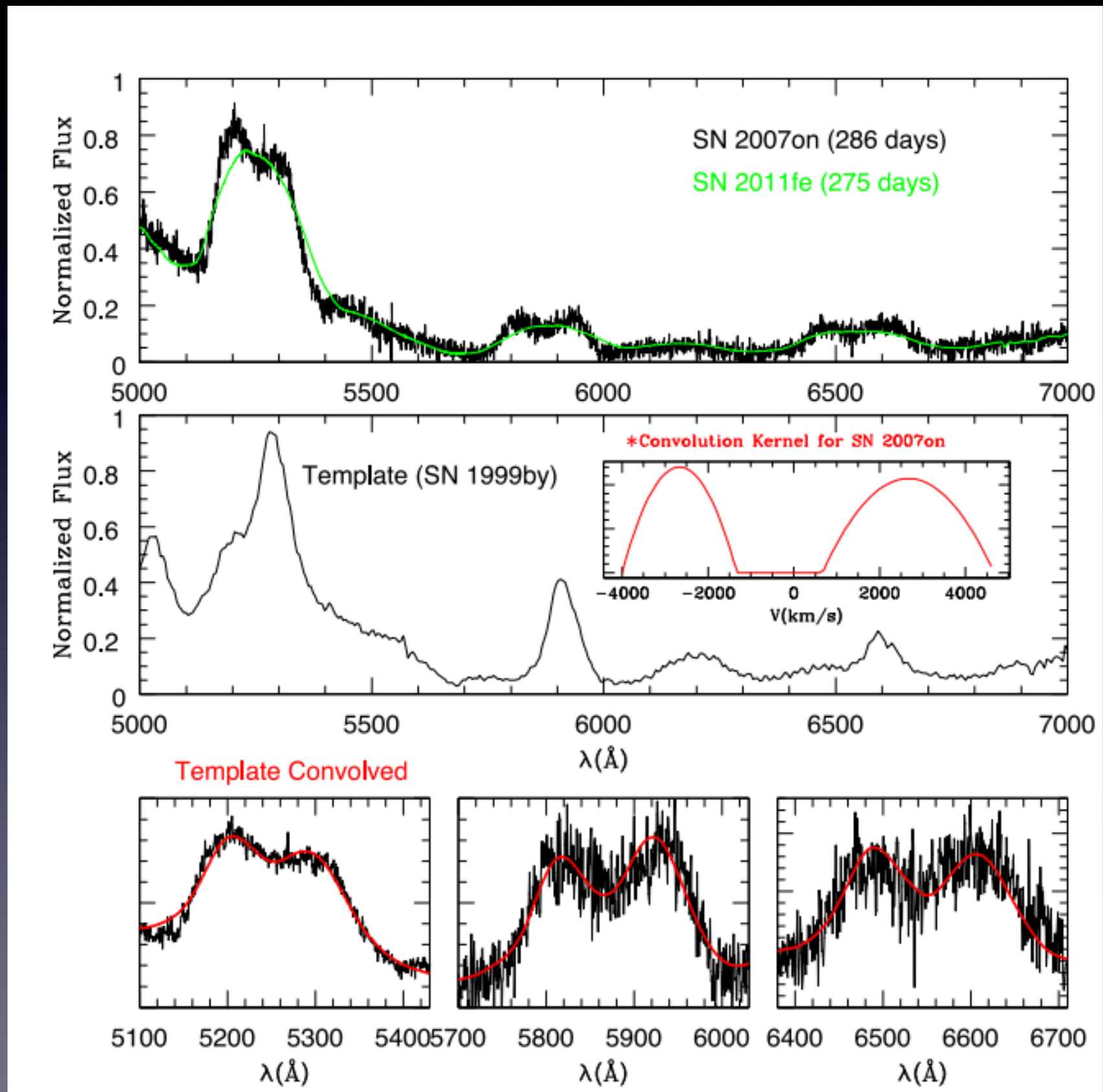
(Mazzali+ 98)


SN2007on 286
SN2011fe 274
normalized flux
1
0.8
0.6
0.4
0.2
0
-0.2
4000
5000
6000
7000
8000
wavelength [A]

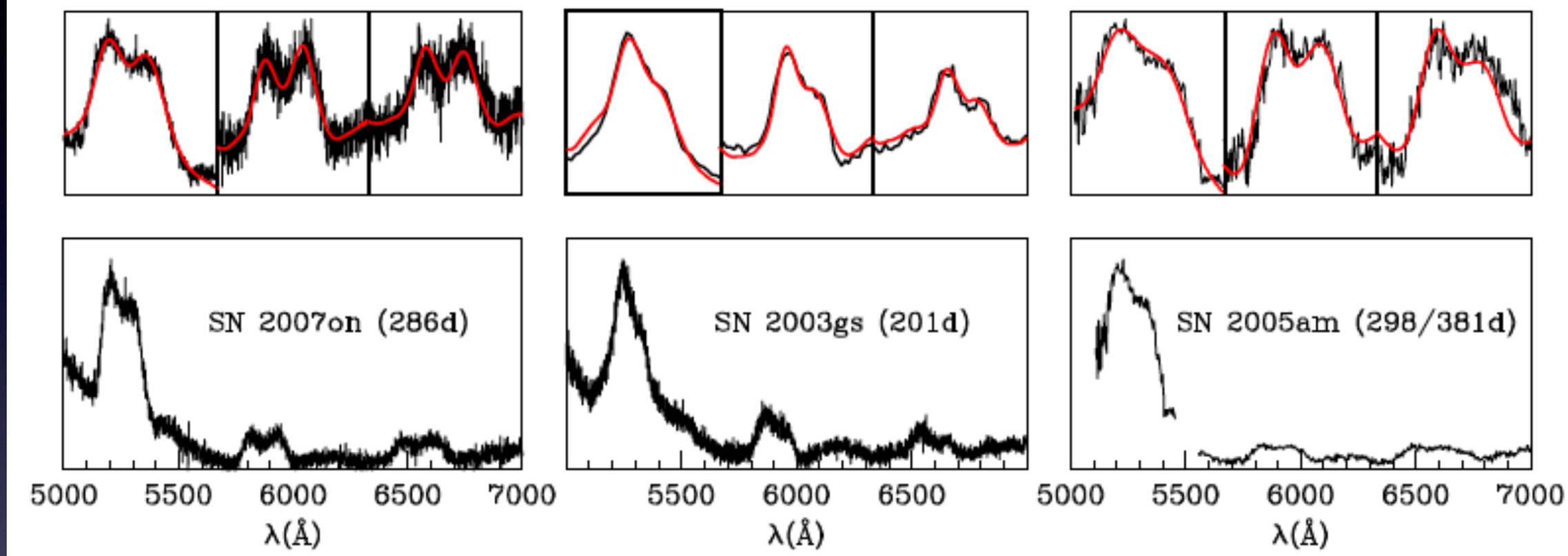
Dong+15


SN 2007on (286 days)
SN 2011fe (275 days)
Normalized Flux
1
0.8
0.6
0.4
0.2
0
5000
5500
6000
6500
7000

Let nature do the nebular modelling

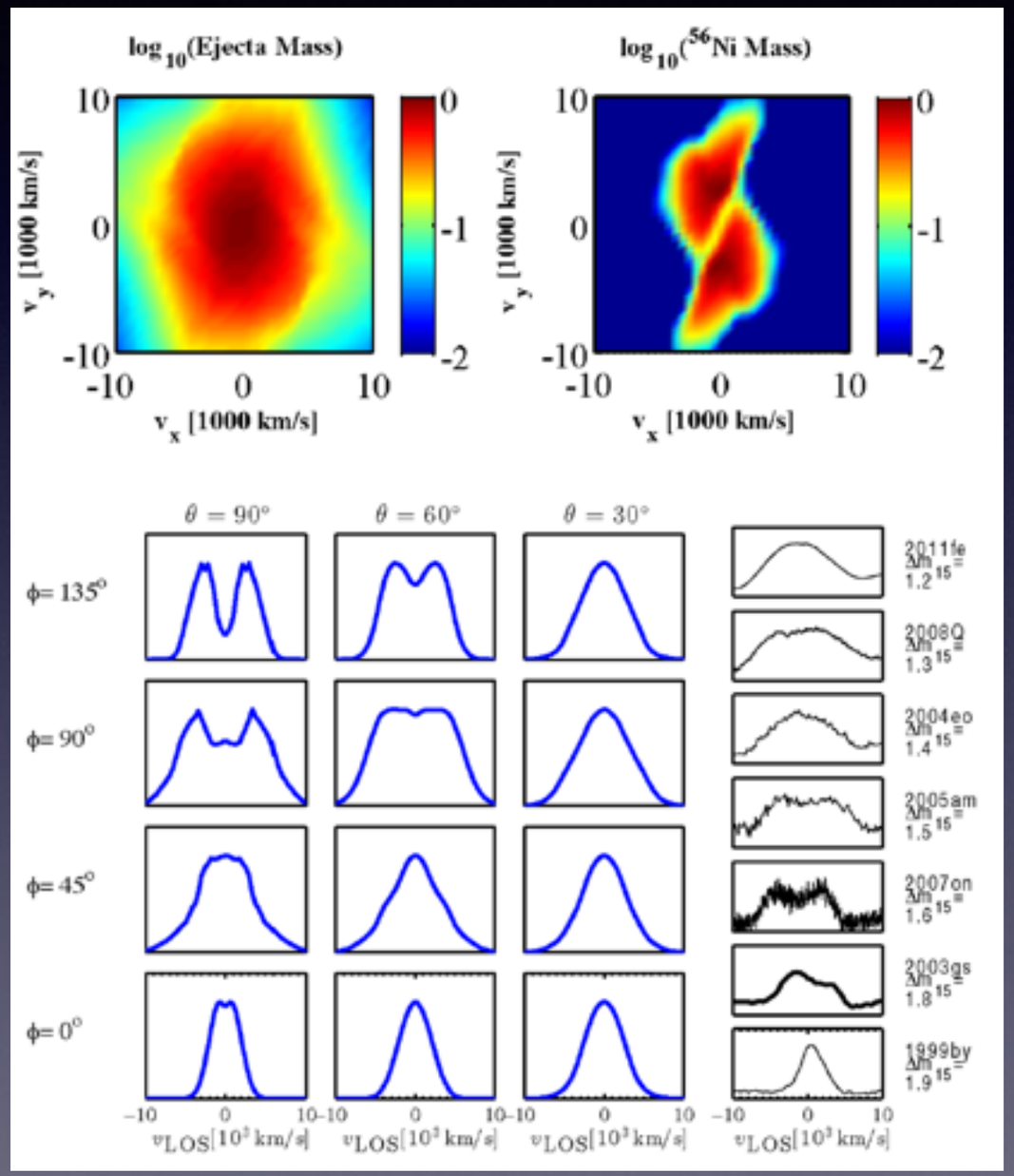


Dong+15


SN 2007on (286d)
SN 2003gs (201d)
SN 2005am (298/381d)
5000
5500
6000
6500
7000
λ(Å)

Collision at non-zero impact parameter

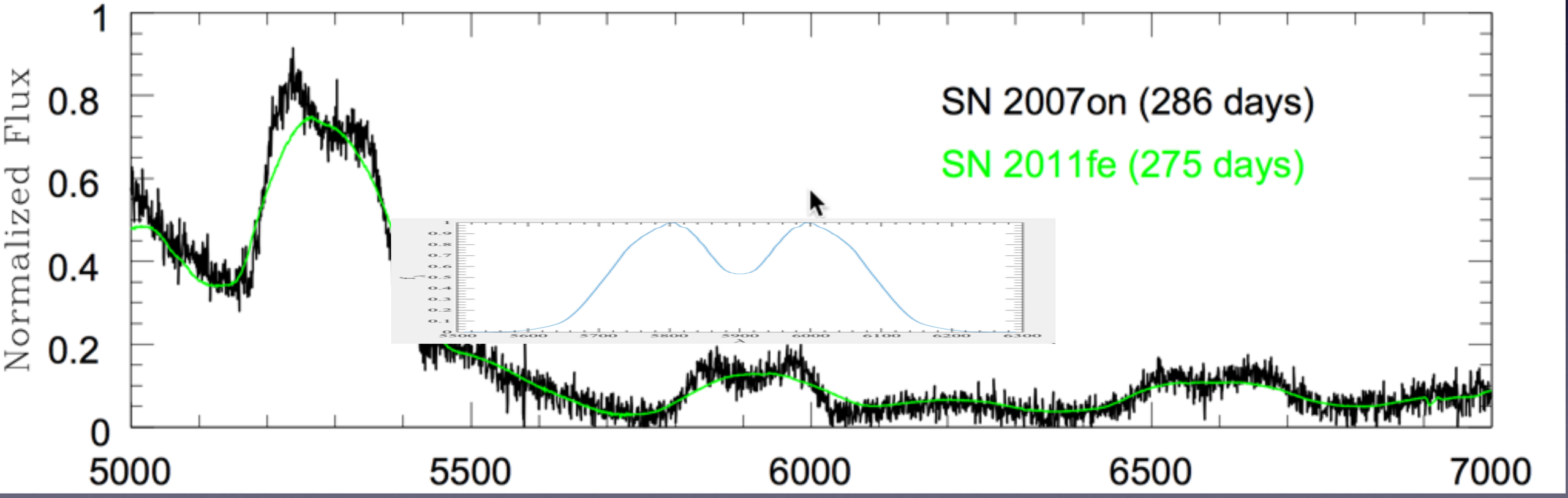
0.64 Msun WDs



Dong et. al. 2015

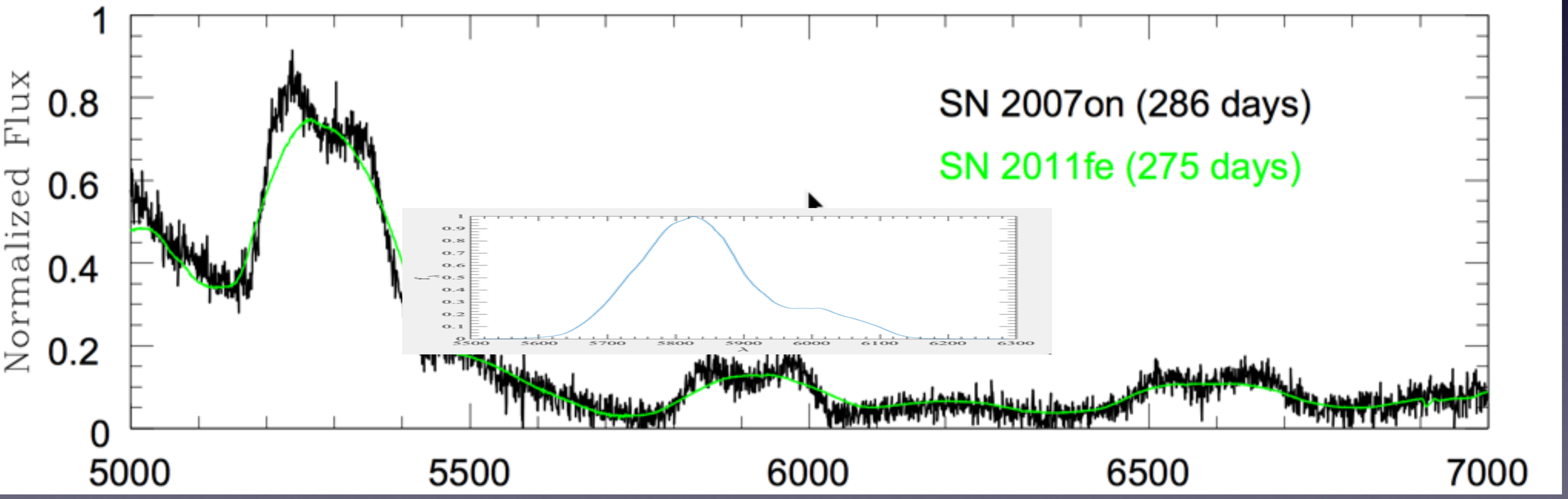
Other ideas ?

Prediction I (Kushnir+)
Some bright Ia's with very large double peak



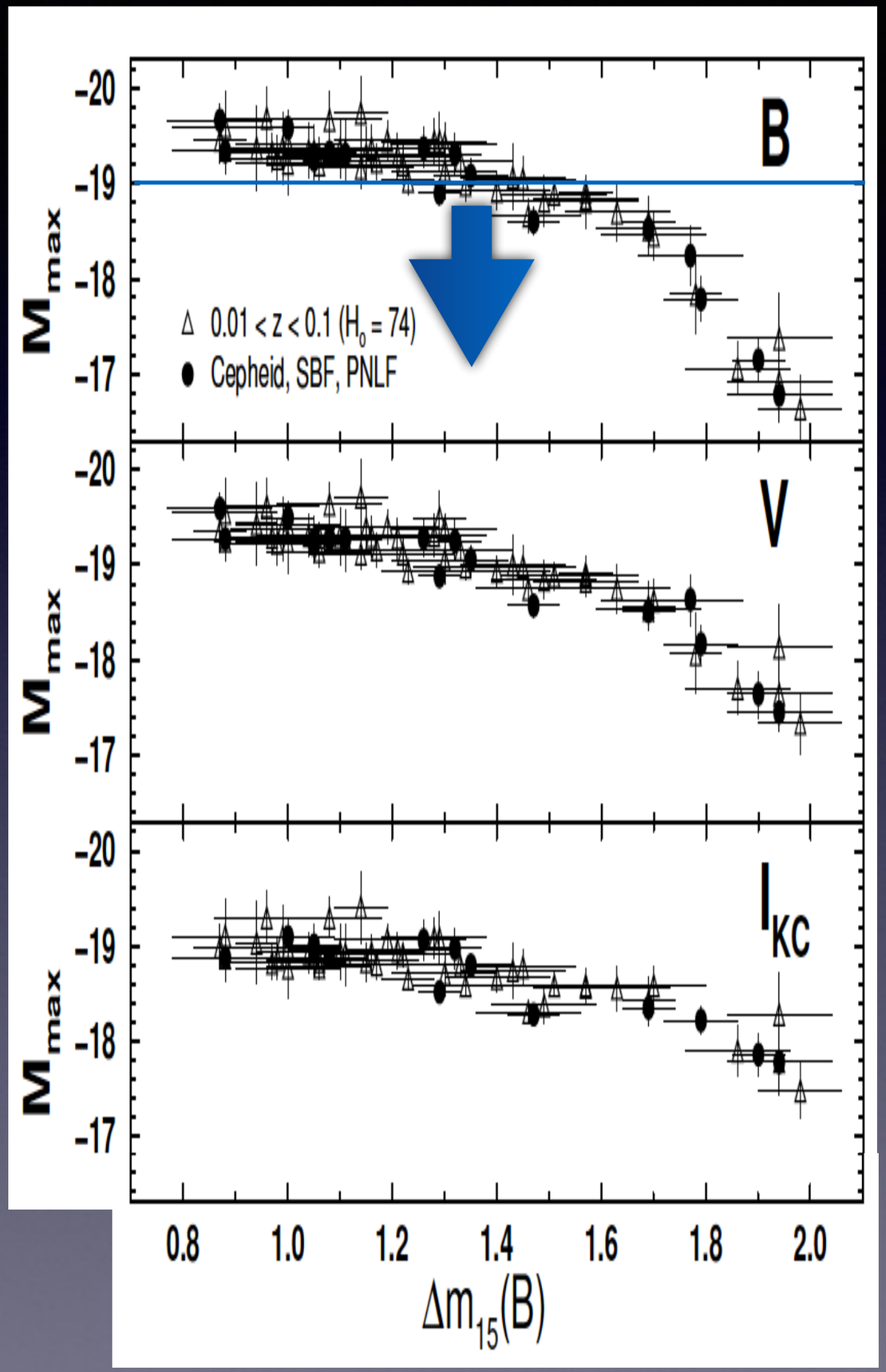
0.9 - 0.9 collision, b=0.5 RWD, >0.7 Msun Ni56

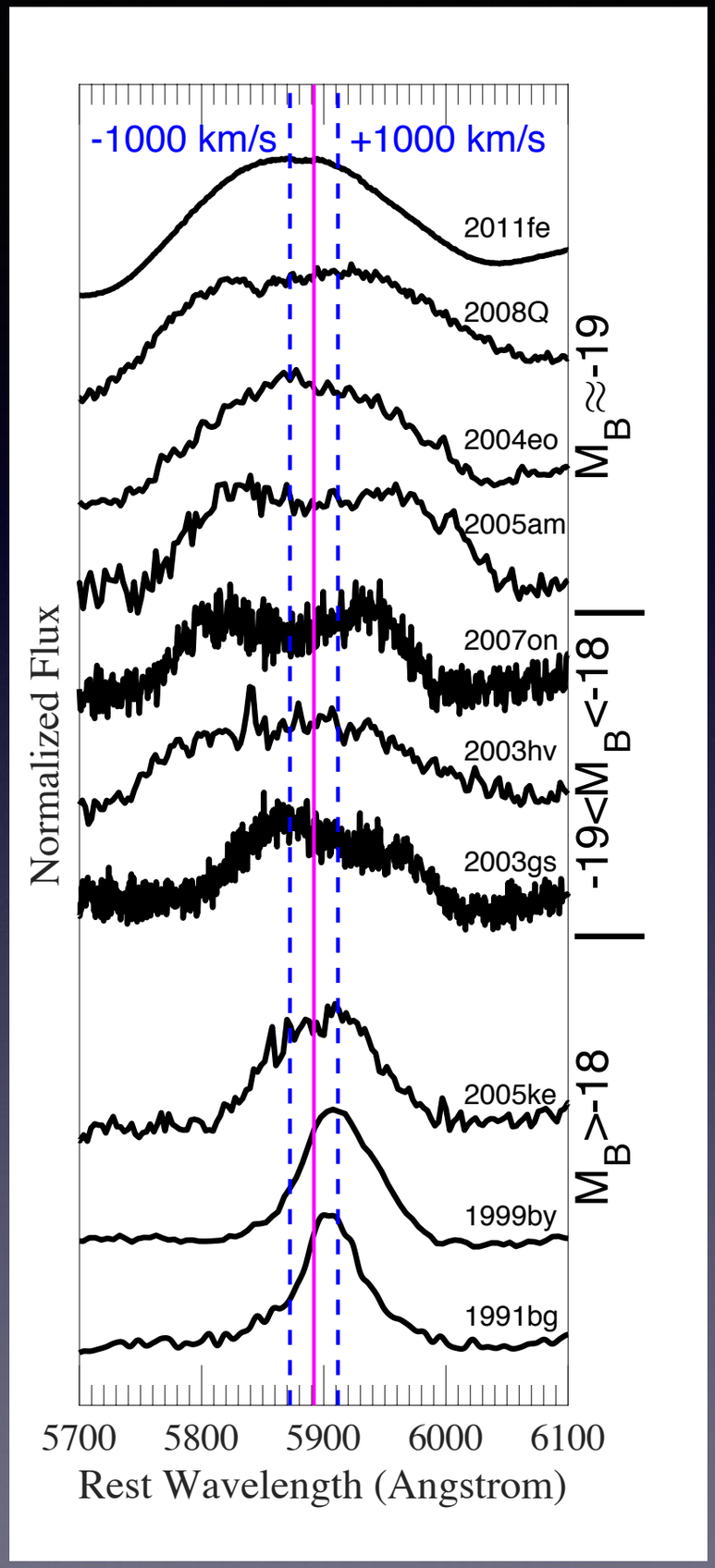
Prediction 2(Kushnir+) Some bright Ia's with very shifted peak



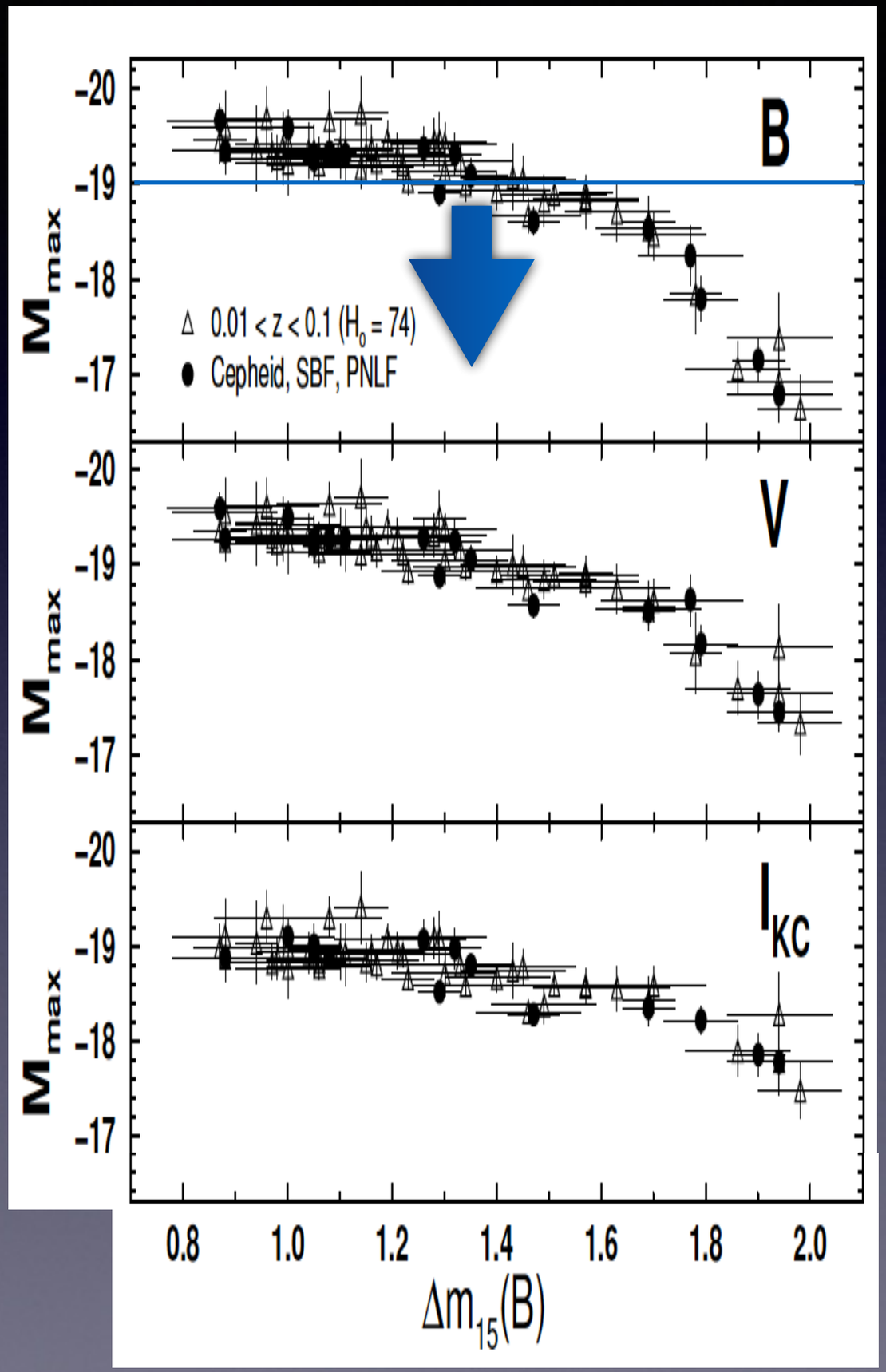
0.9 - 0.8 collision, b=0.5 RWD, >0.45 Msun Ni56

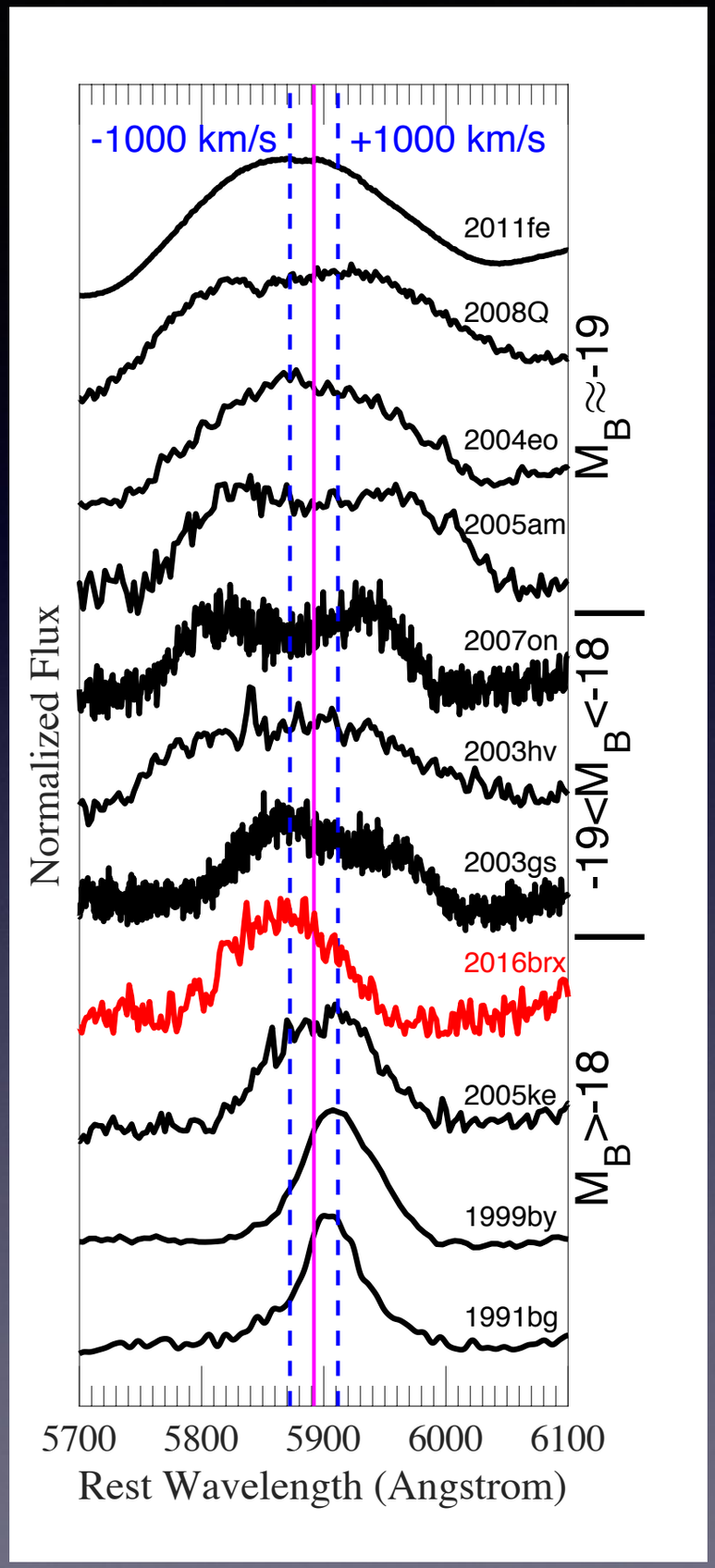
Continuos distribution?



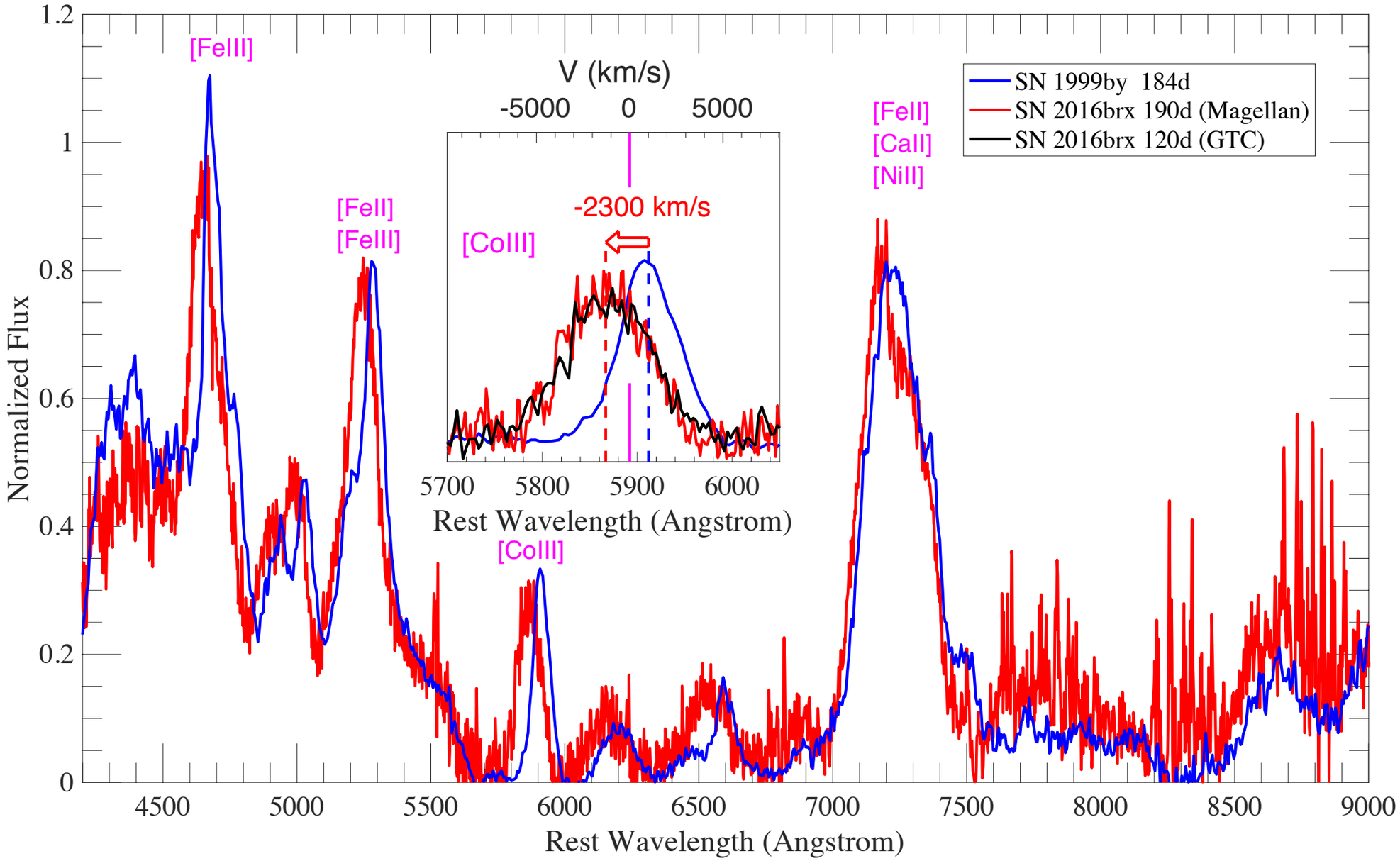


Continuos distribution?

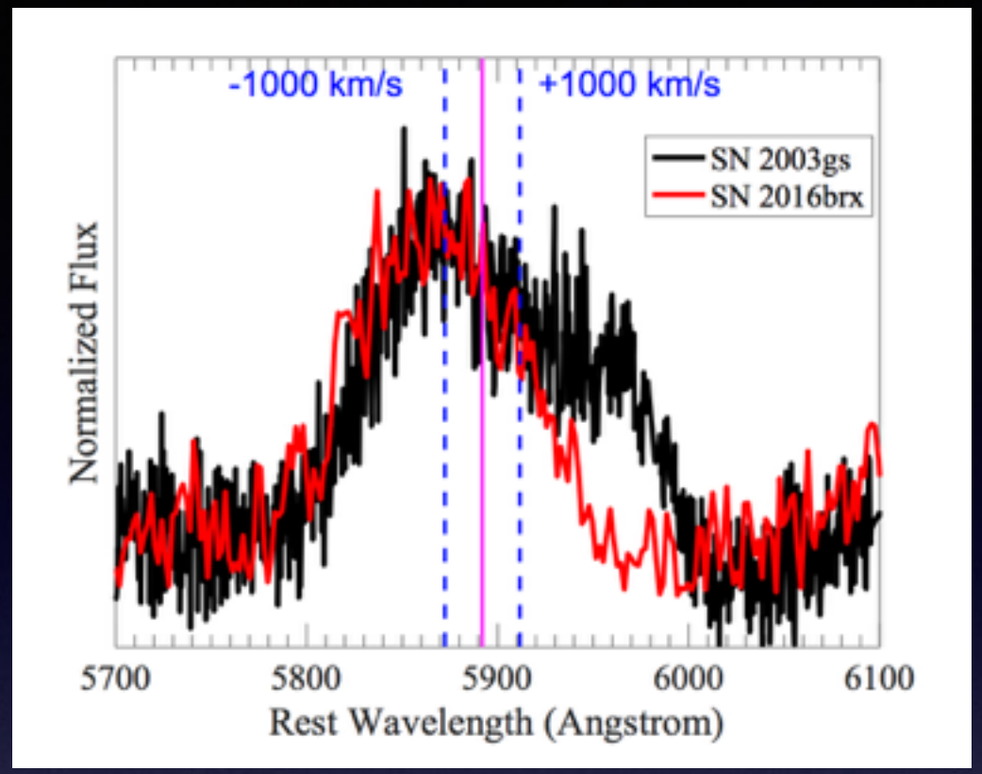


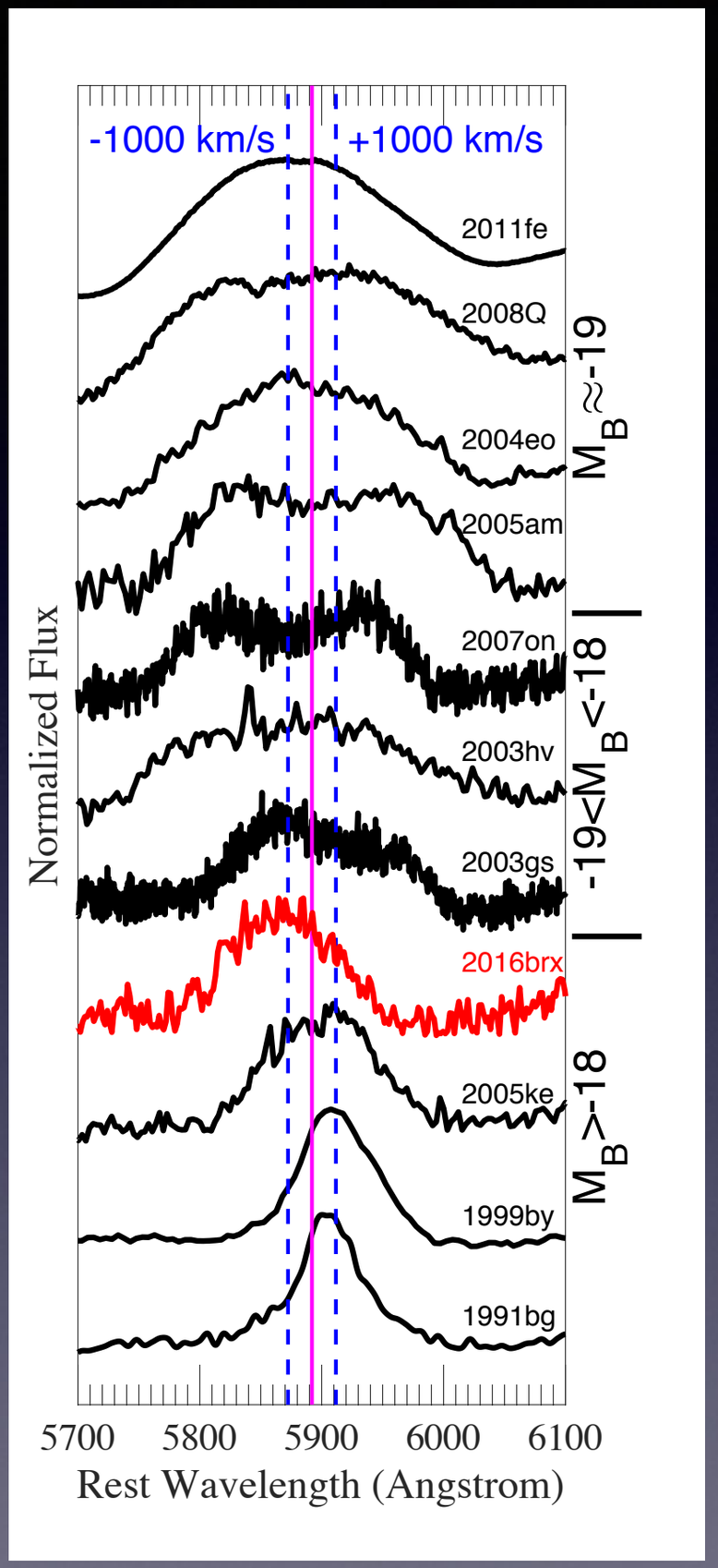


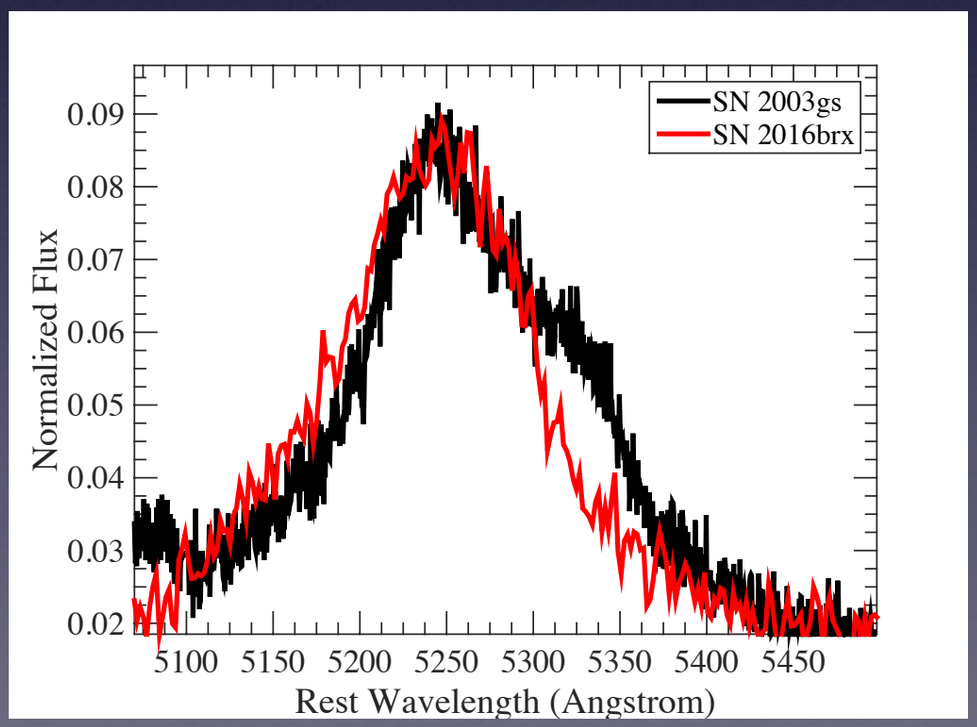
Dong+ 18


[FeIII]
[FeII]
[FeIII]
[CoIII]
[FeII]
[CaII]
[NiII]
V (km/s)
-5000
0
5000
-2300 km/s
SN 1999by 184d
SN 2016brx 190d (Magellan)
SN 2016brx 120d (GTC)
Normalized Flux
1.2
1
0.8
0.6
0.4
0.2
0
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
Rest Wavelength (Angstrom)
5700
5800
5900
6000
Rest Wavelength (Angstrom)
[CoIII]

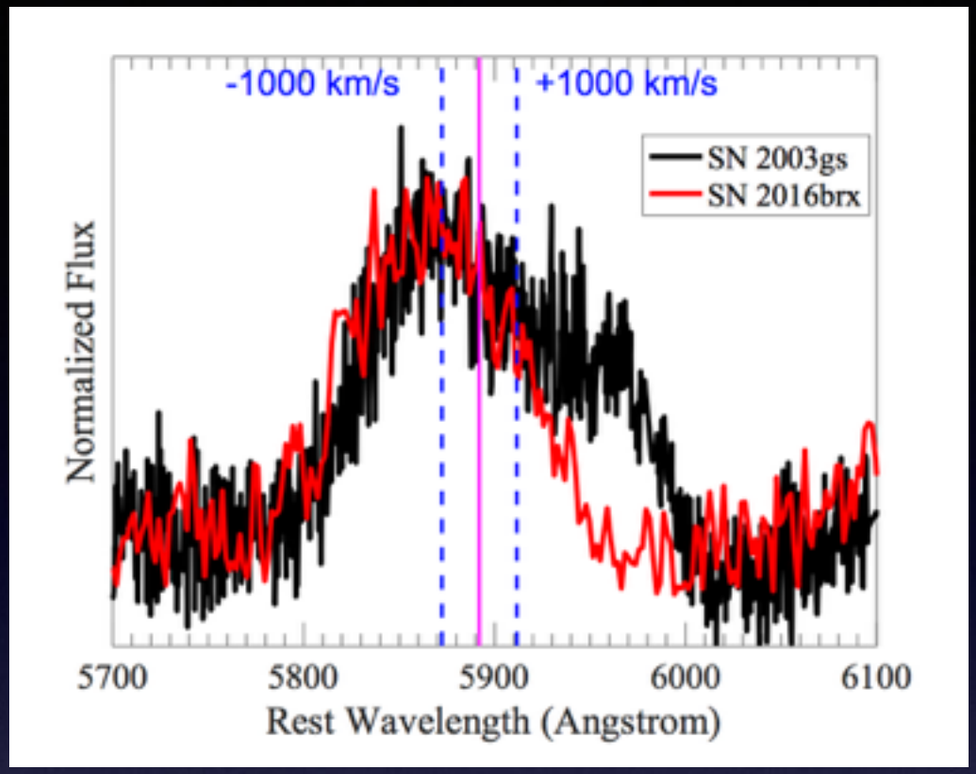
Dong+ 18

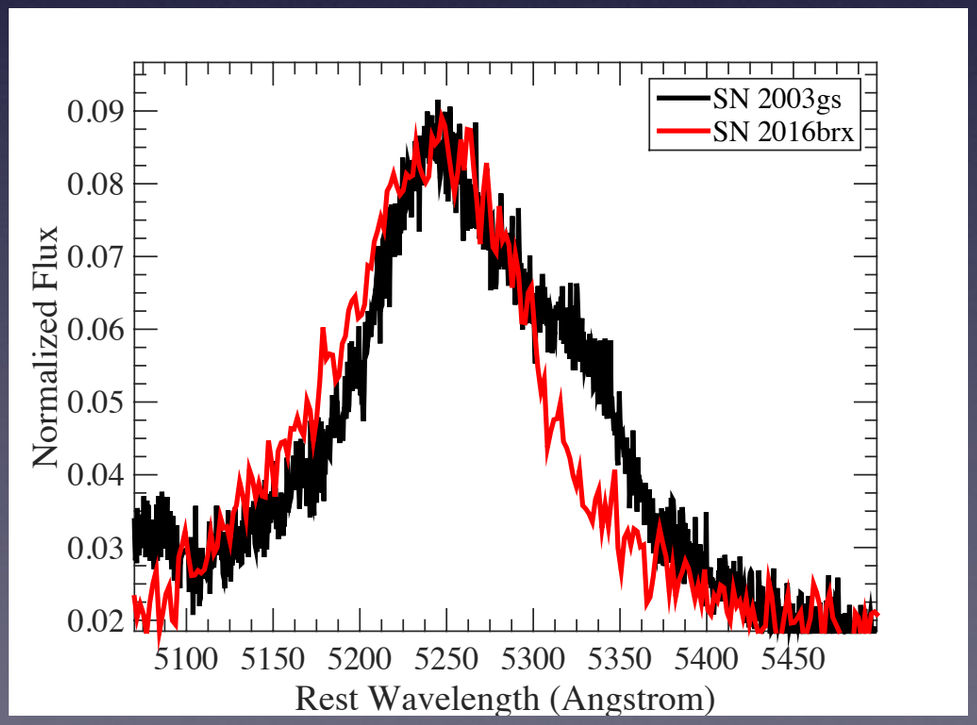

-1000 km/s
+1000 km/s
SN 2003gs
SN 2016brx
Normalized Flux
5700
5800
5900
6000
6100
Rest Wavelength (Angstrom)

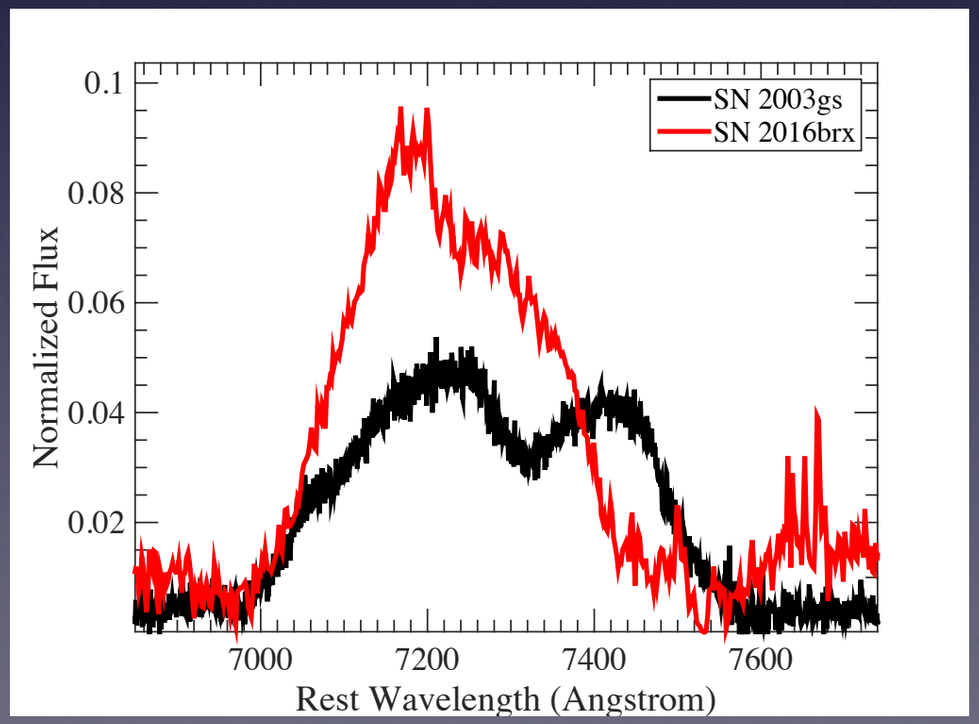

-1000 km/s
+1000 km/s
2011fe
2008Q
2004eo
2005am
2007on
2003hv
2003gs
2016brx
2005ke
1999by
1991bg
Normalized Flux
M_B≲-19
-19<M_B<-18
M_B>-18
5700
5800
5900
6000
6100
Rest Wavelength (Angstrom)


SN 2003gs
SN 2016brx
Normalized Flux
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
5100
5150
5200
5250
5300
5350
5400
5450
Rest Wavelength (Angstrom)

Dong+ 18


-1000 km/s
+1000 km/s
SN 2003gs
SN 2016brx
Normalized Flux
5700
5800
5900
6000
6100
Rest Wavelength (Angstrom)


SN 2003gs
SN 2016brx
Normalized Flux
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
5100
5150
5200
5250
5300
5350
5400
5450
Rest Wavelength (Angstrom)


SN 2003gs
SN 2016brx
Normalized Flux
0.1
0.08
0.06
0.04
0.02
7000
7200
7400
7600
Rest Wavelength (Angstrom)

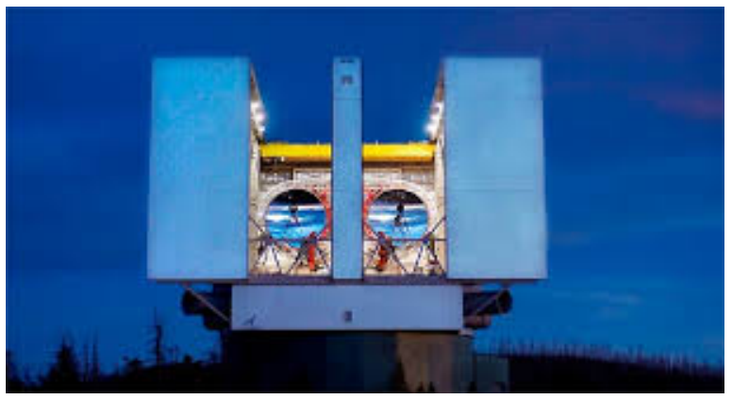
Dong+ 18

100IAS: the nebular-phase spectra from 100 supernovae IA Survey

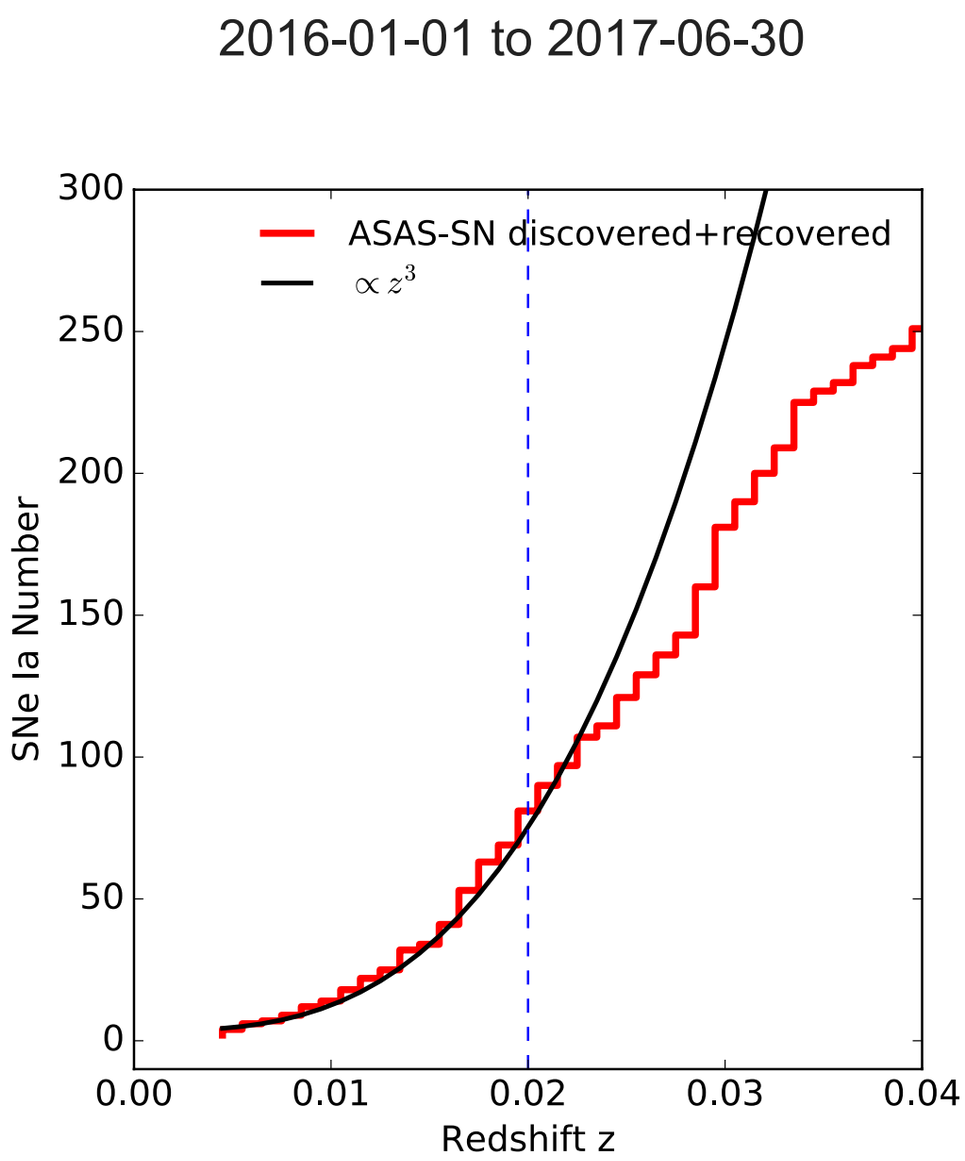
- A large and homogeneous sample (~100) of Nebular-Phase spectra in about 3-4 years: March 2016 –

With: Subo Dong, Doron Kushnir, Jose Prieto + ASAS-SN team

- Magellan: Juna Kollmeier, Nidia Morrell, Jose Prieto, Mark Phillips et al.
- LBT: Kris Stanek, Ben Shappee, Jonathon Brown et al.
- GTC: N. Elisas-Rosa et al.
- VLT: Jose Prieto et al.
- Gemini: A. Gal-Yam et al.

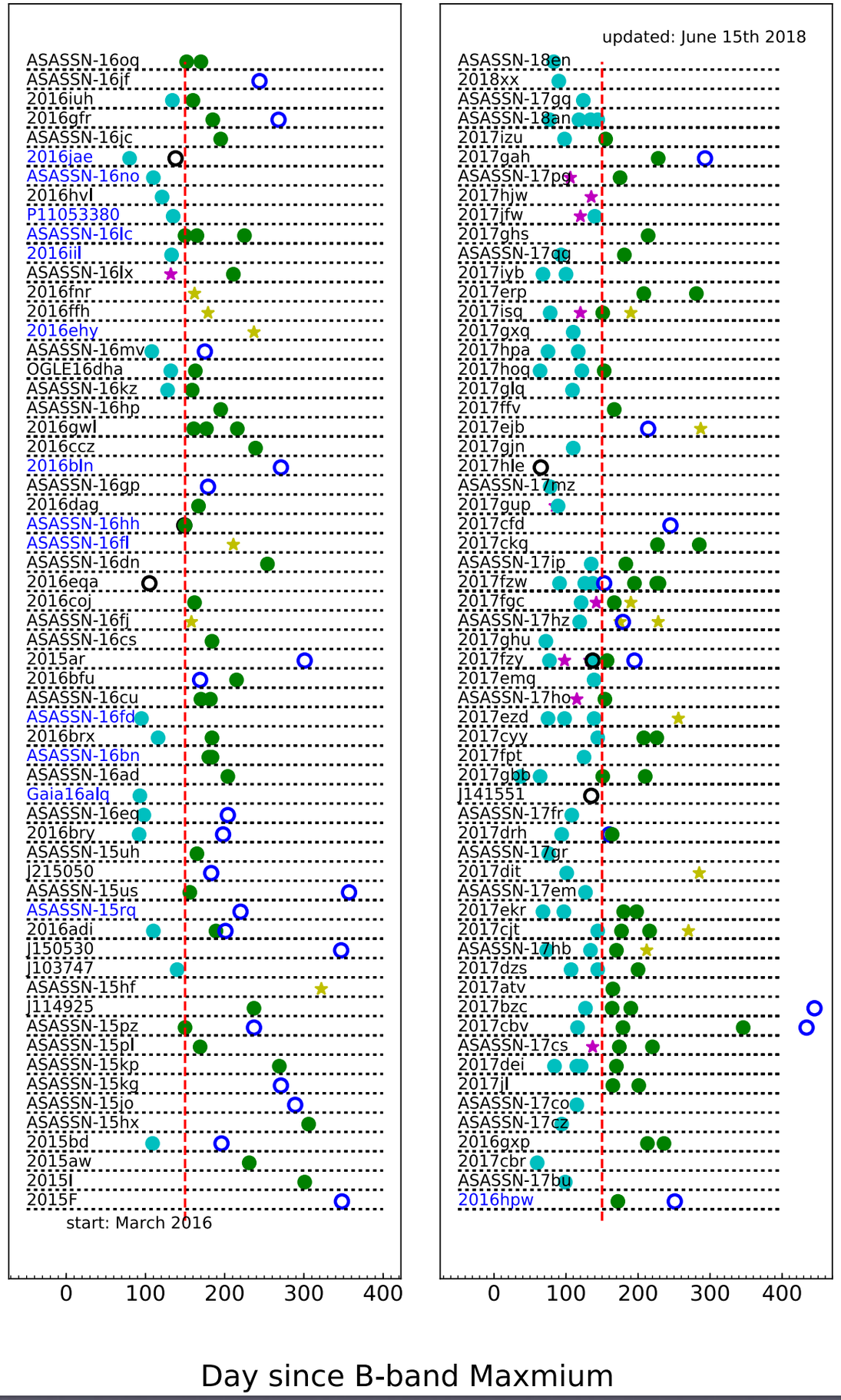




A volume-limited, minimally-biased SNe-Ia sample (z<0.02)



PhD thesis project of Ping Chen (PKU-KIAA)

time



reduced
phase>150 days
high SNR

Magellan 2 hrs
r mag <~23

What do ions do?

decay ~ 100 days

ionization/recombination ~ days

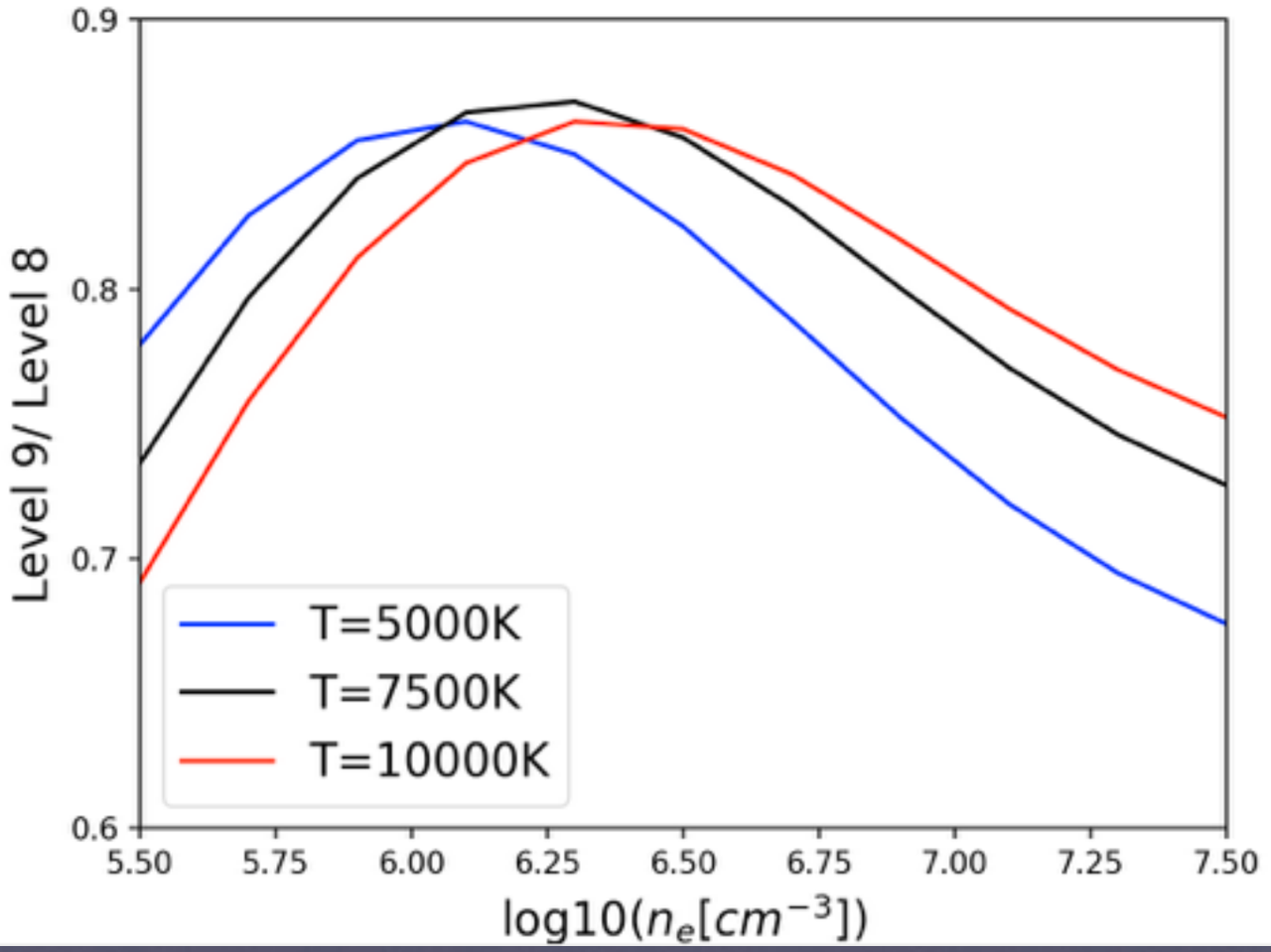
collision ~ 1000 seconds

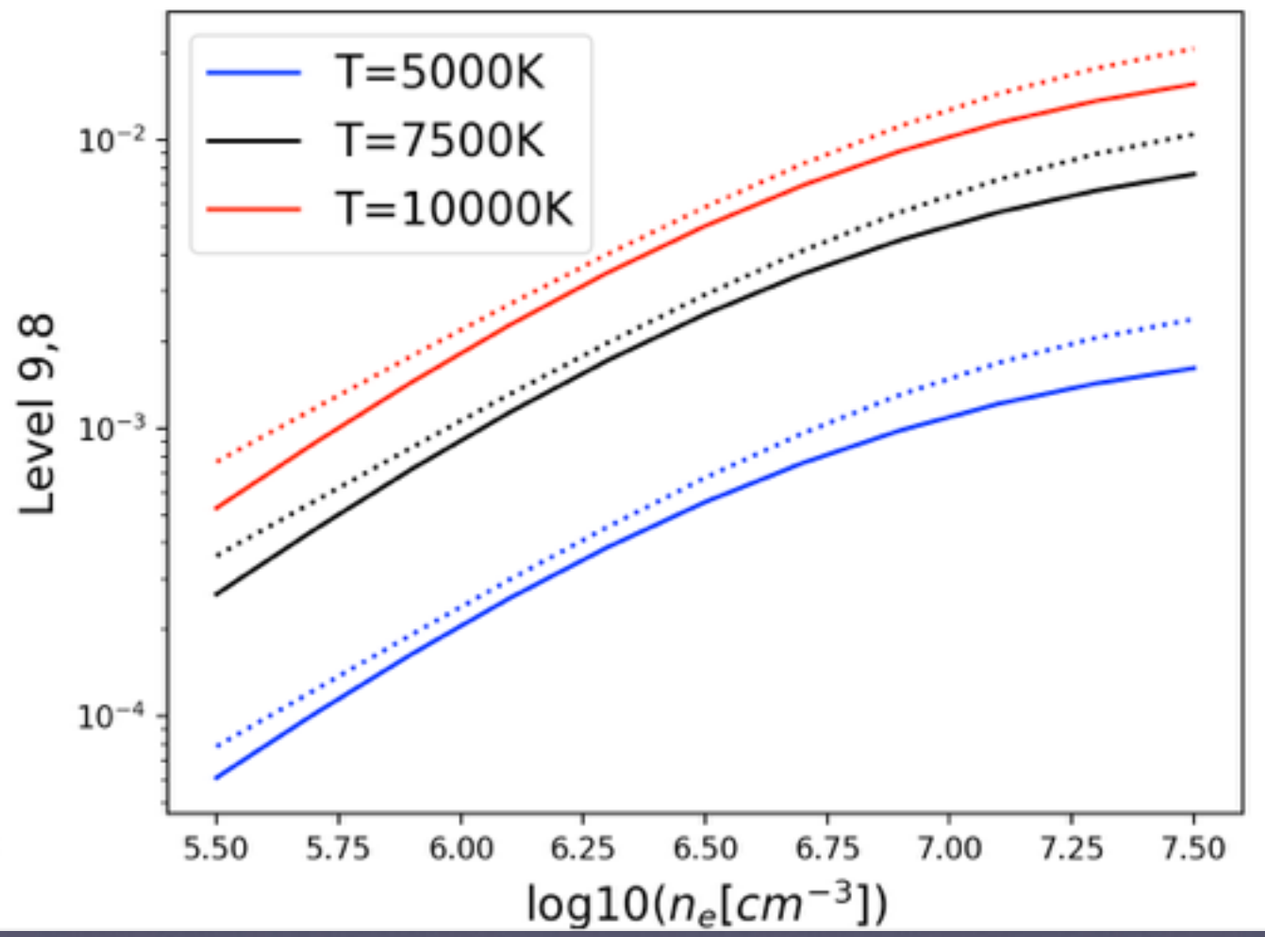
radiative decay~ 1 seconds

Co III - Collisional radiative equilibrium

5888 9->2
5906 8->1
6127 9->3
6195 8->1

Using Storey&Sochi+ 16 atomic data

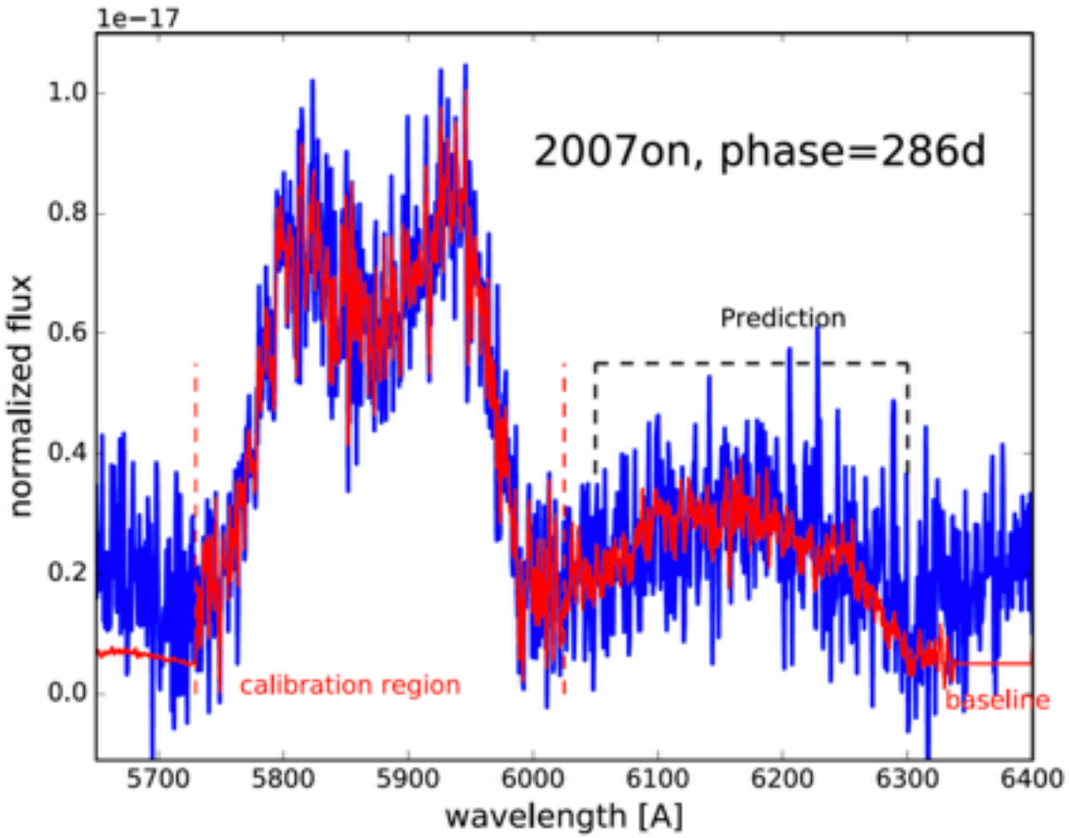


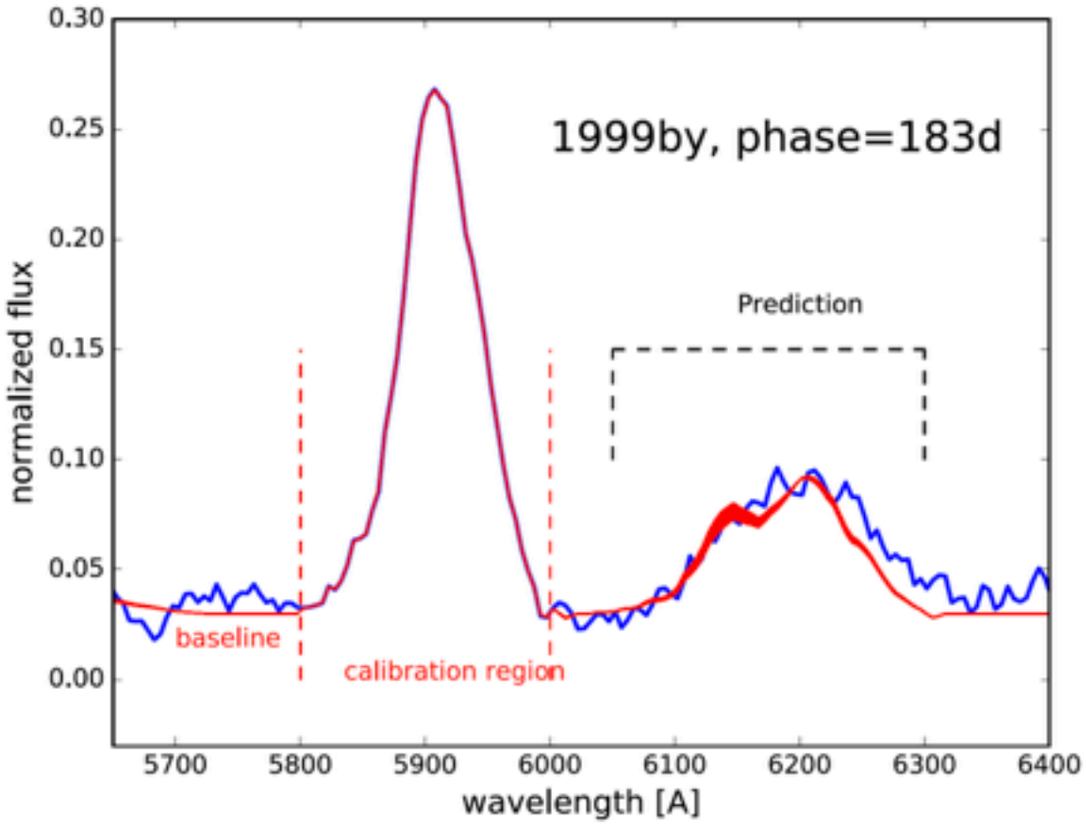


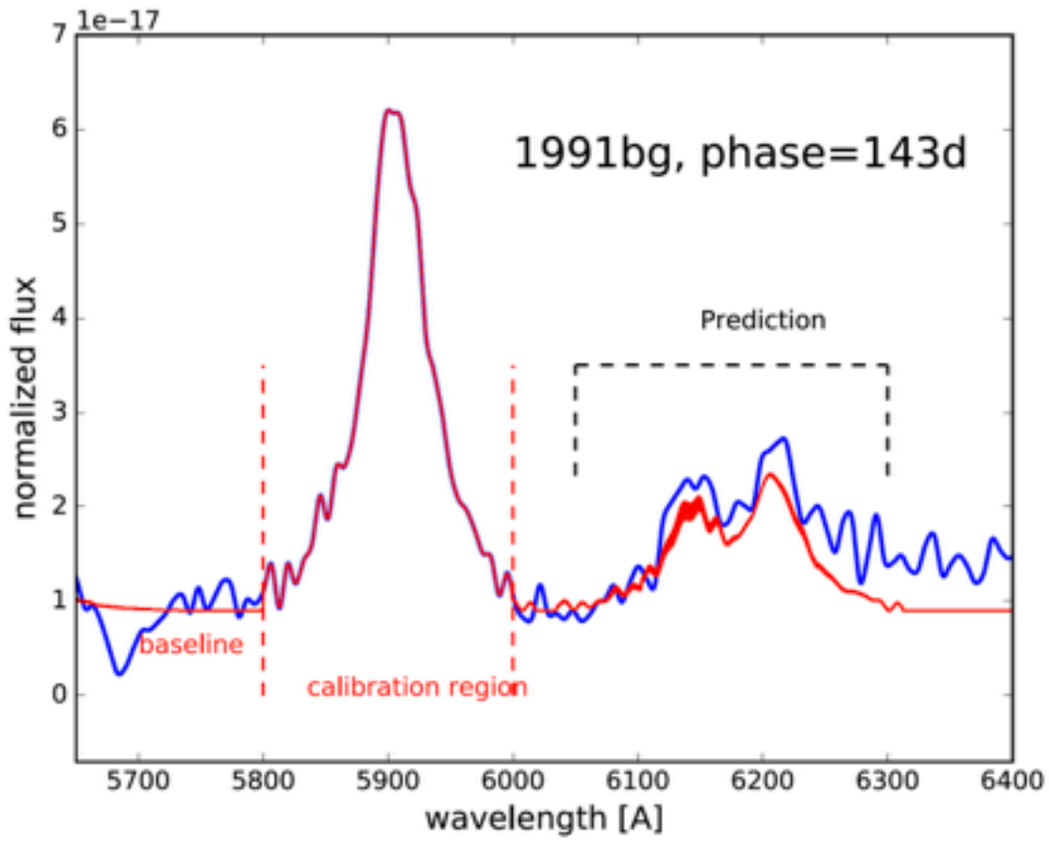
Brandt+18 in prep

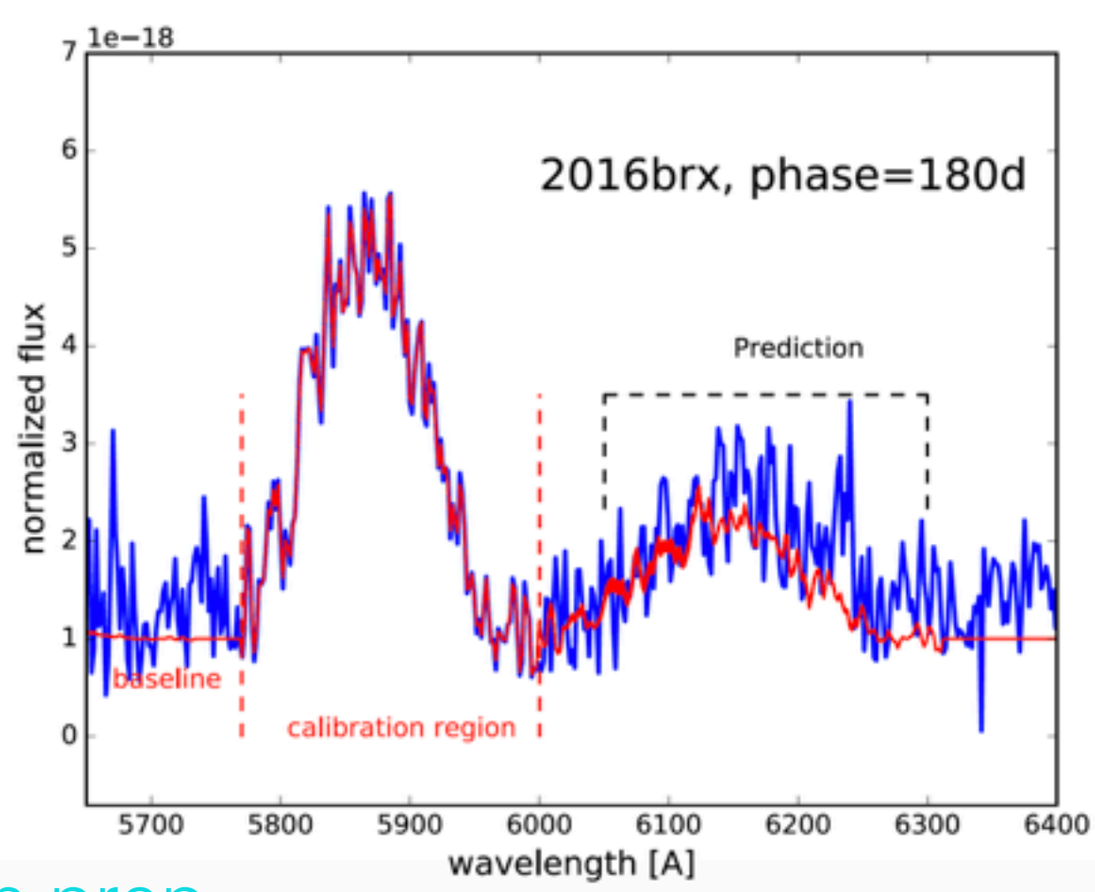
Level 8,9 - $3d^7$ a^2G

8: J=9/2 E=2.1eV 9: J=7/2 E=2.2eV

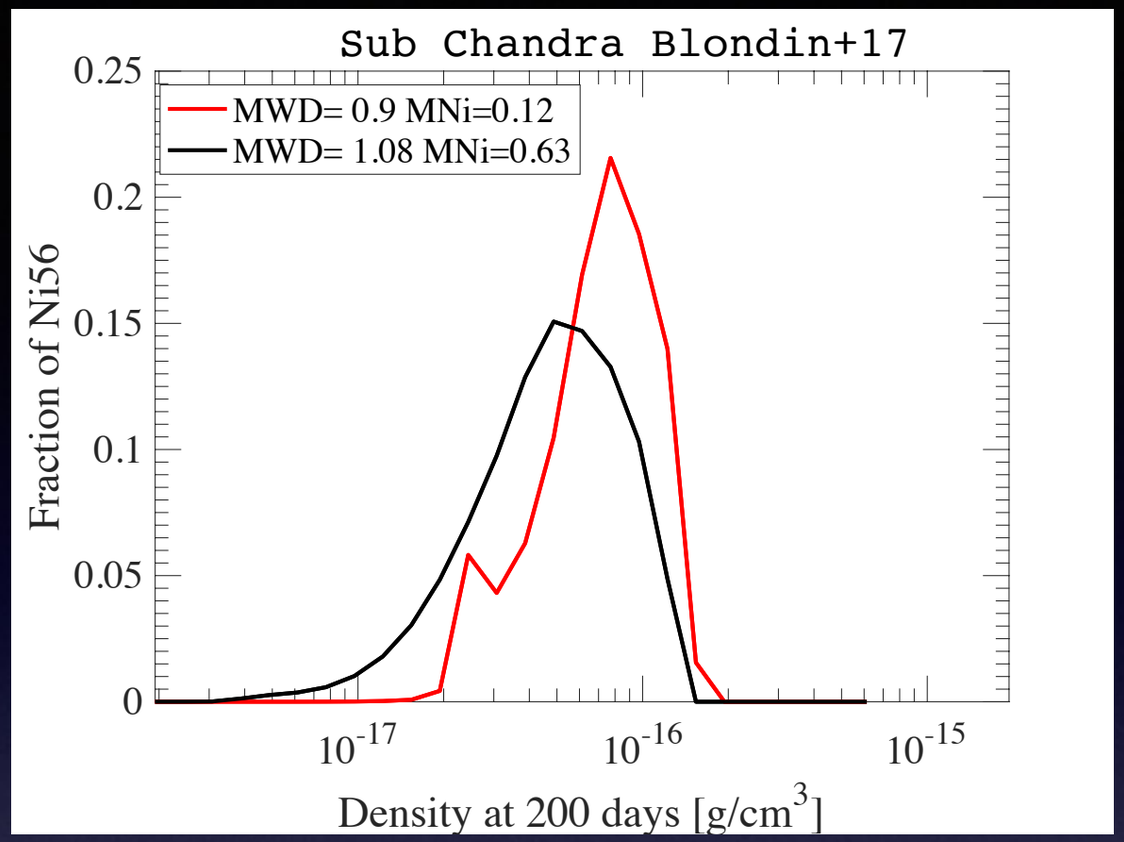


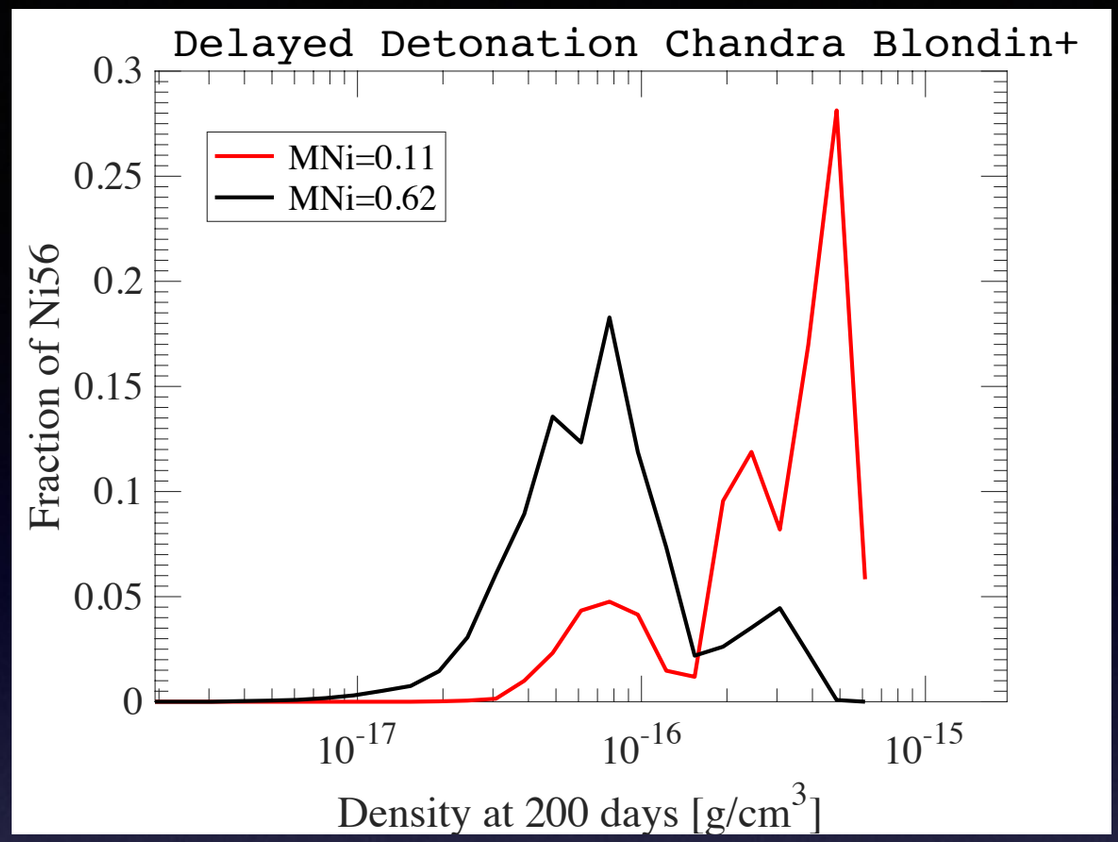


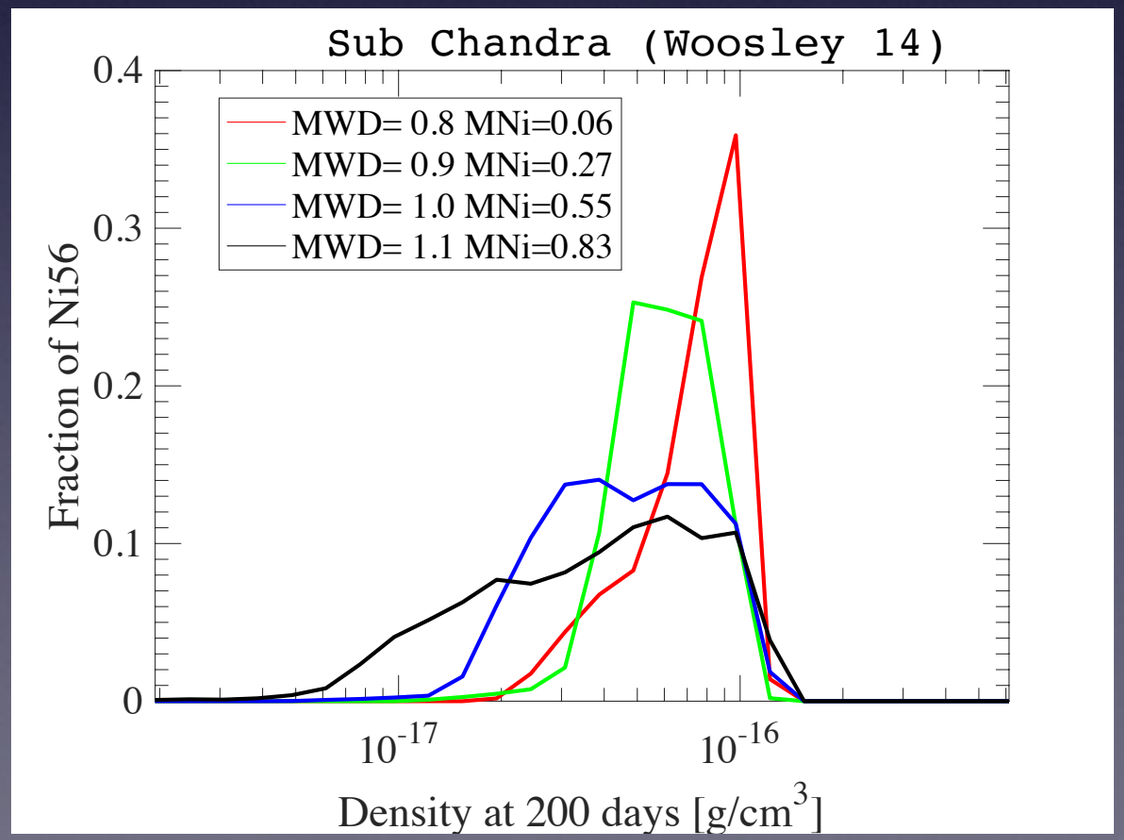


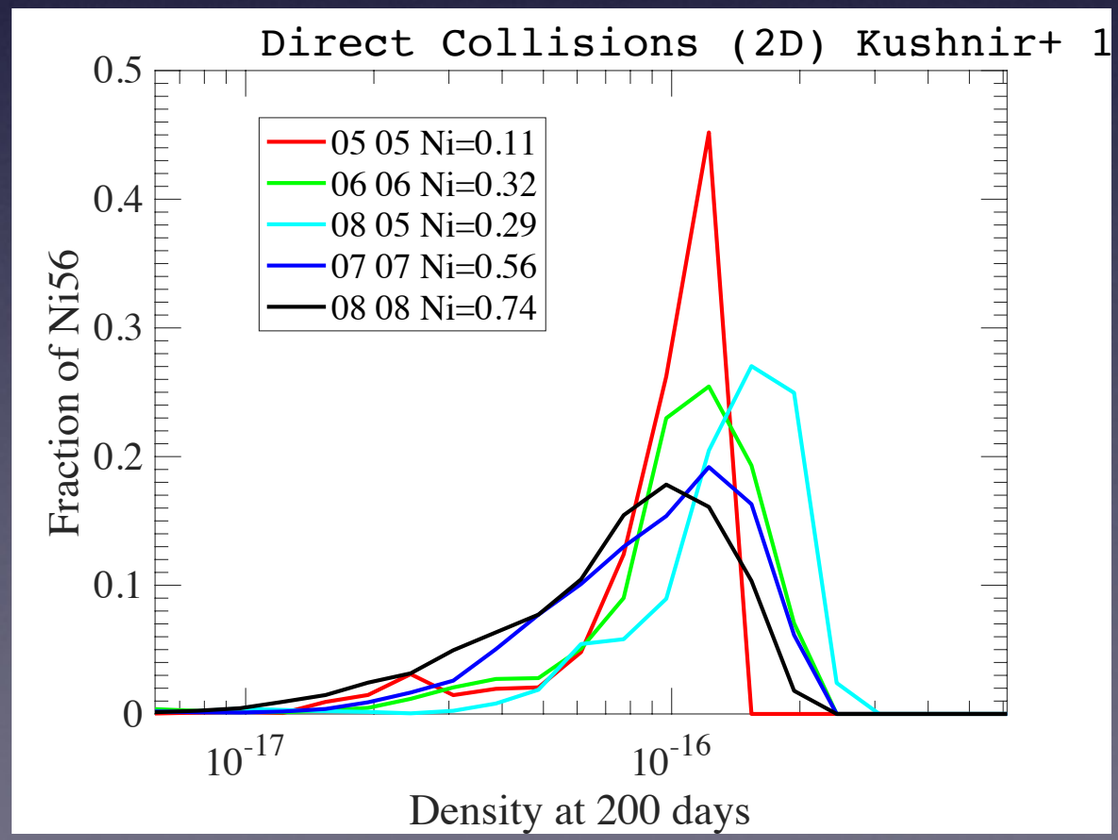


Brandt+18 in prep


Sub Chandra Blondin+17
MWD= 0.9 MNi=0.12
MWD= 1.08 MNi=0.63
Fraction of Ni56
Density at 200 days [g/cm3]


Delayed Detonation Chandra Blondin+
MNi=0.11
MNi=0.62
Fraction of Ni56
Density at 200 days [g/cm3]


Sub Chandra (Woosley 14)
MWD= 0.8 MNi=0.06
MWD= 0.9 MNi=0.27
MWD= 1.0 MNi=0.55
MWD= 1.1 MNi=0.83
Fraction of Ni56
Density at 200 days [g/cm3]


Direct Collisions (2D) Kushnir+ 1
05 05 Ni=0.11
06 06 Ni=0.32
08 05 Ni=0.29
07 07 Ni=0.56
08 08 Ni=0.74
Fraction of Ni56
Density at 200 days

Sub Chandra Blondin+18 MNi=0.12Msun