Theoretical expectations on surviving companions in type Ia SNRs

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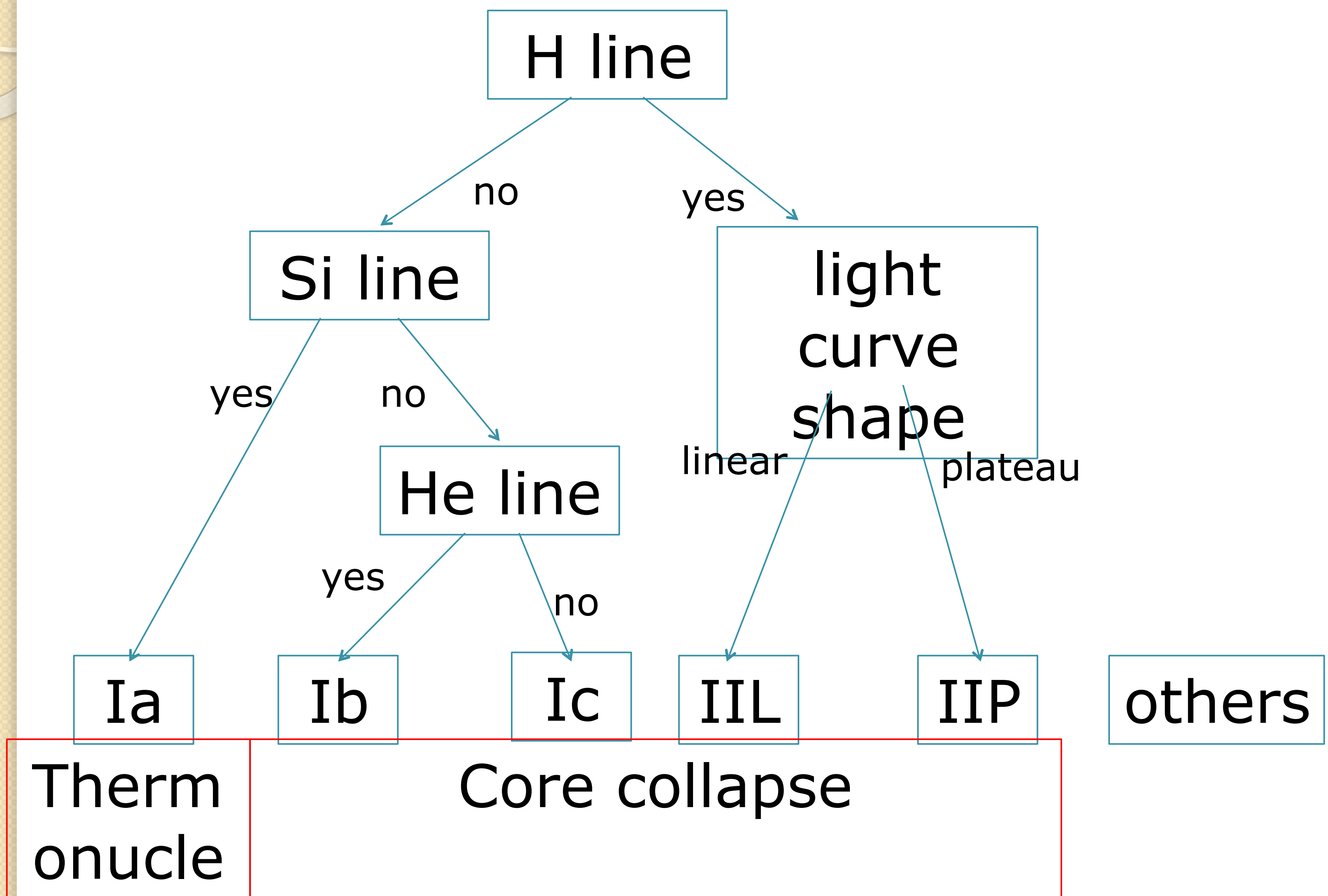
Agenda

- Overview of SN and surviving companions in SNRs
  - Classification of supernovae
  - surviving companions in CCSN
  - surviving companions in SN Ia
    - companions' effects on the SN light curve
    - Trials of direct detection of companions

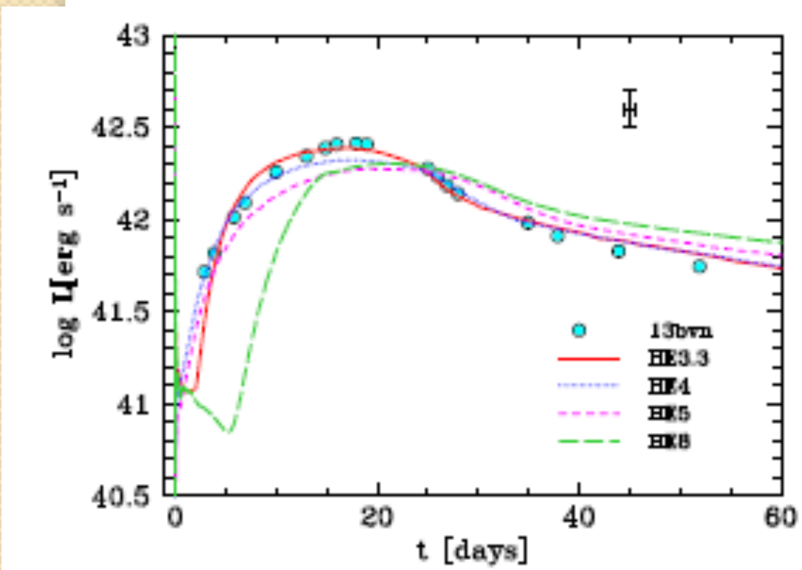
- Overview of our works

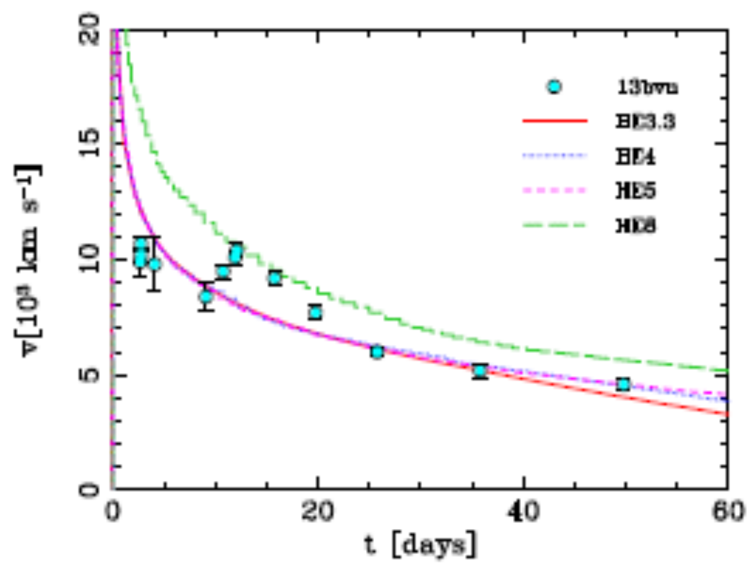
Classification of SN



Companions in CCSN

- iPTF 13bvn is a type Ib SN
  - Progenitor system should be a binary of $\sim 3.5 M_{\odot}$ He star and luminous OB star (Bersten+2014)



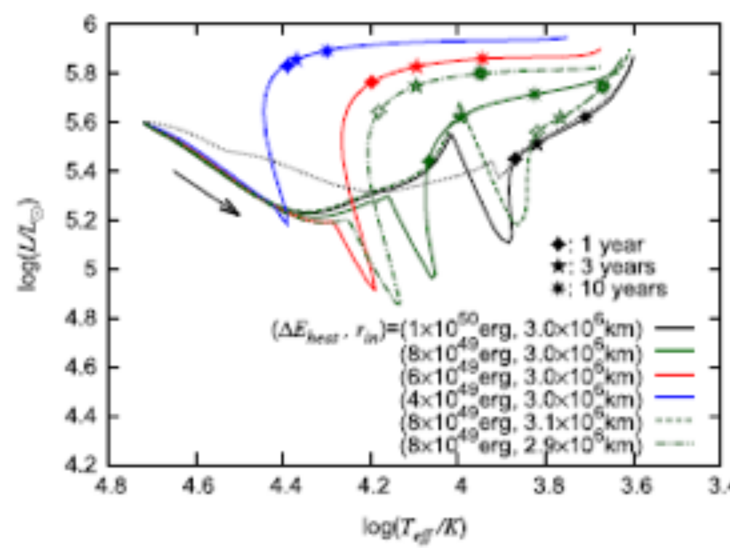


Companions in CCSN

- iPTF 13bvn is a type Ib SN
  - Hirai+2015 numerically simulated the evolution of this binary system
  - They predicted the initial parameter of the binary and the future of the surviving companion

Table 1
Binary Parameters of the Stellar Evolution Calculations with MESA

Model[a]	Age (Myr)	M_1 ($M_\odot$)	M_2 ($M_\odot$)	R_1 ($R_\odot$)	R_2 ($R_\odot$)	P (days)	a ($R_\odot$)
a1.0	0	19.0	18.0	5.65	5.47	2.45	25.5
	10.4	3.48	33.5	44.7	7.72	61.7	219
a0.5	0	19.0	18.0	5.65	5.47	2.45	25.5
	10.2	3.72	25.6	47.8	10.4	62.0	203
b1.0	0	18.0	17.0	5.47	5.30	3.50	31.7
	9.98	4.15	30.9	15.4	8.02	47.9	181
b0.5	0	18.0	17.0	5.47	5.30	3.50	31.7
	9.94	4.23	23.9	10.6	7.76	54.4	184
c1.0	0	15.0	14.0	4.93	4.74	3.30	28.7
	12.5	3.02	26.0	31.8	7.01	63.4	206
c0.5	0	15.0	14.0	4.93	4.74	3.30	28.7
	12.5	3.06	20.0	30.4	6.57	73.3	210

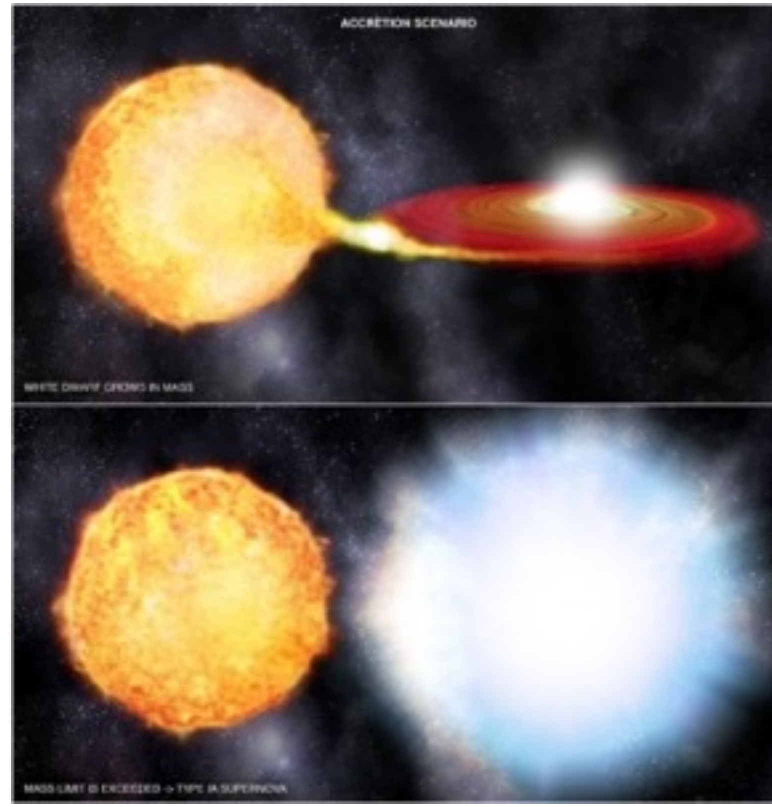


Companions in SN Ia

- SN Ia is thought to be an explosion of a white dwarf (WD) in binary system
- There are mainly two explosion scenarios
  - Single degenerate scenario (SD)
  - Double degenerate scenario (DD)

Companions in SN Ia

- SD scenario (Whelan & Iben 1973)
  - Binary with a WD + a non-degenerate star (main sequence, subgiant, or red giant)
  - Mass transfer to the WD from the companion leads to an explosion
  - The companion survives



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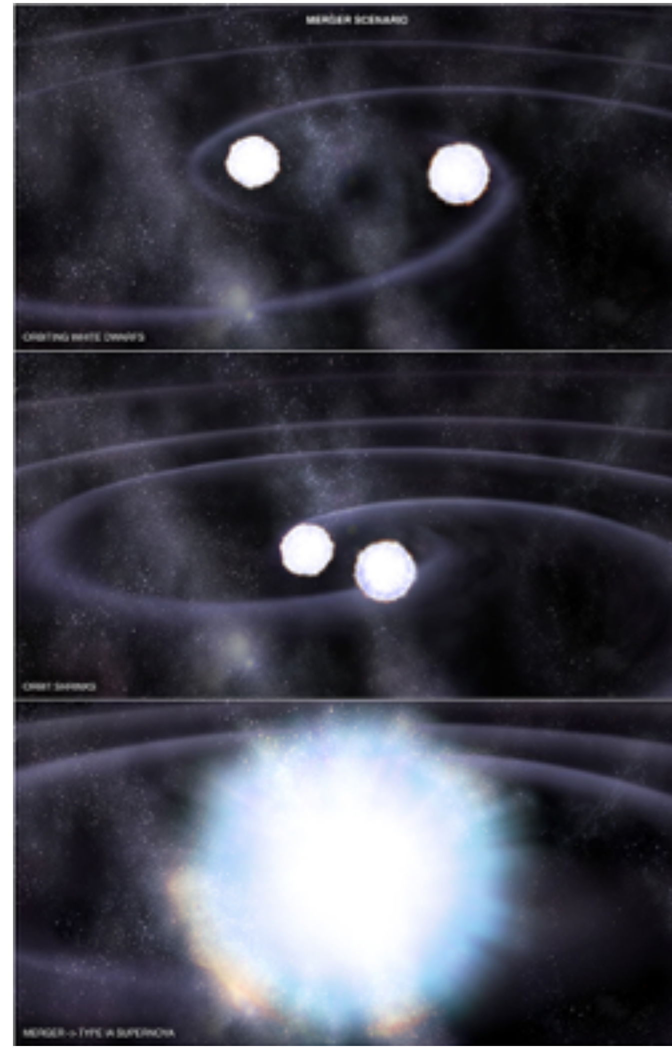
Companions in SN Ia

- DD scenario (Iben & Tutukov 1984)
  - Binary with two WDs
  - Merger of the WDs leads to an explosion
  - No stars are left in the remnant



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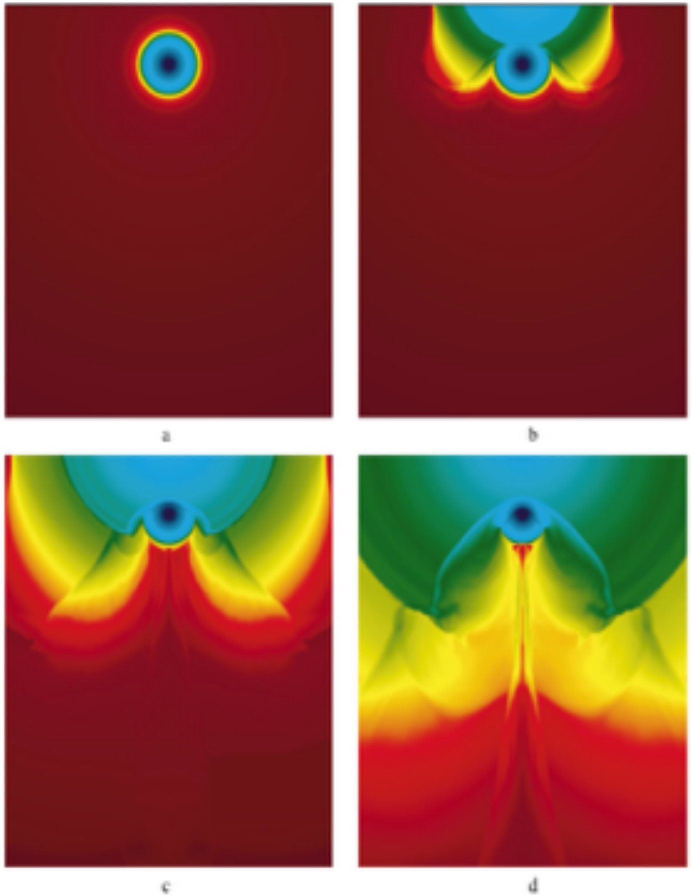
Companions in SN Ia

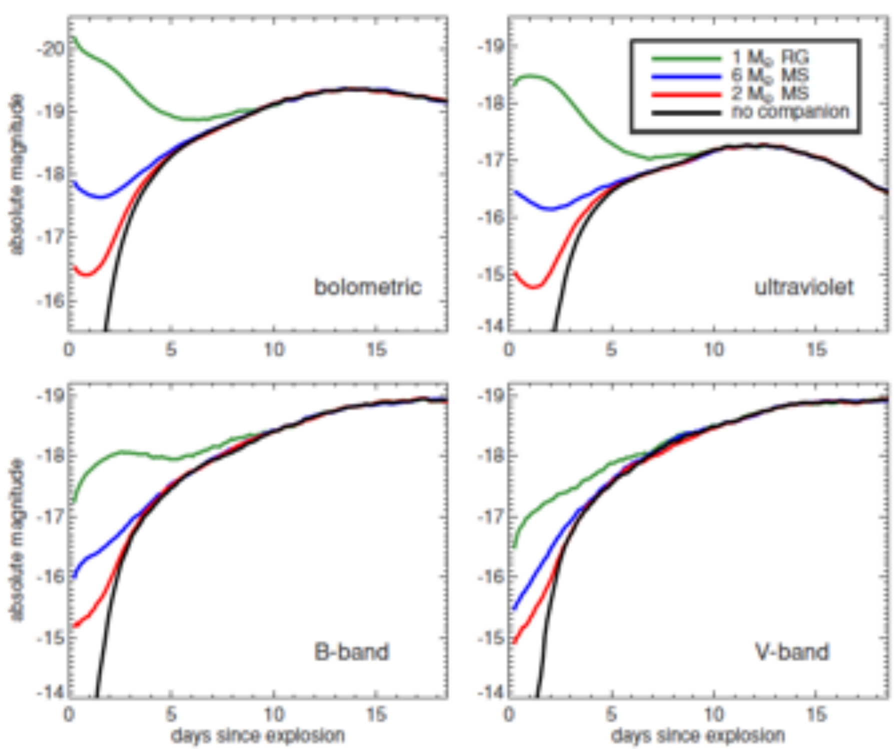
- In SD scenario, SN ejecta collide with the companion
  - The collision make an asymmetry in the ejecta
  - The companion is influenced by the collision

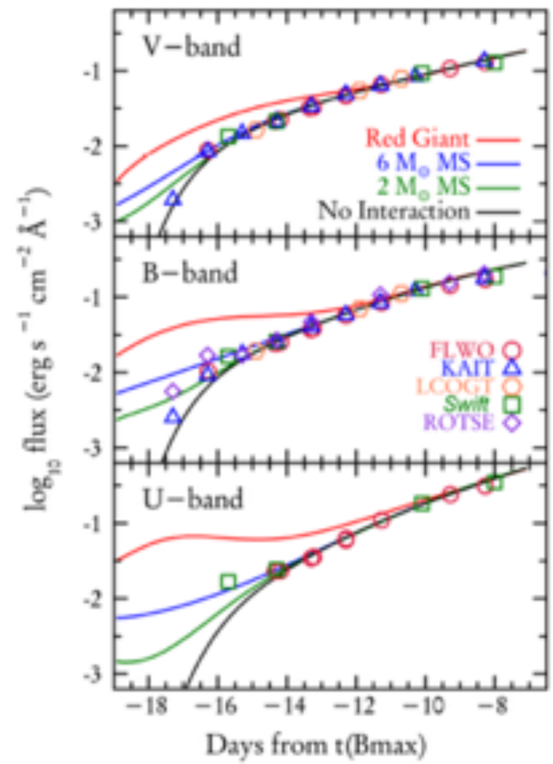


Marietta et al (2000)

Companions' effect on light curves and spectra

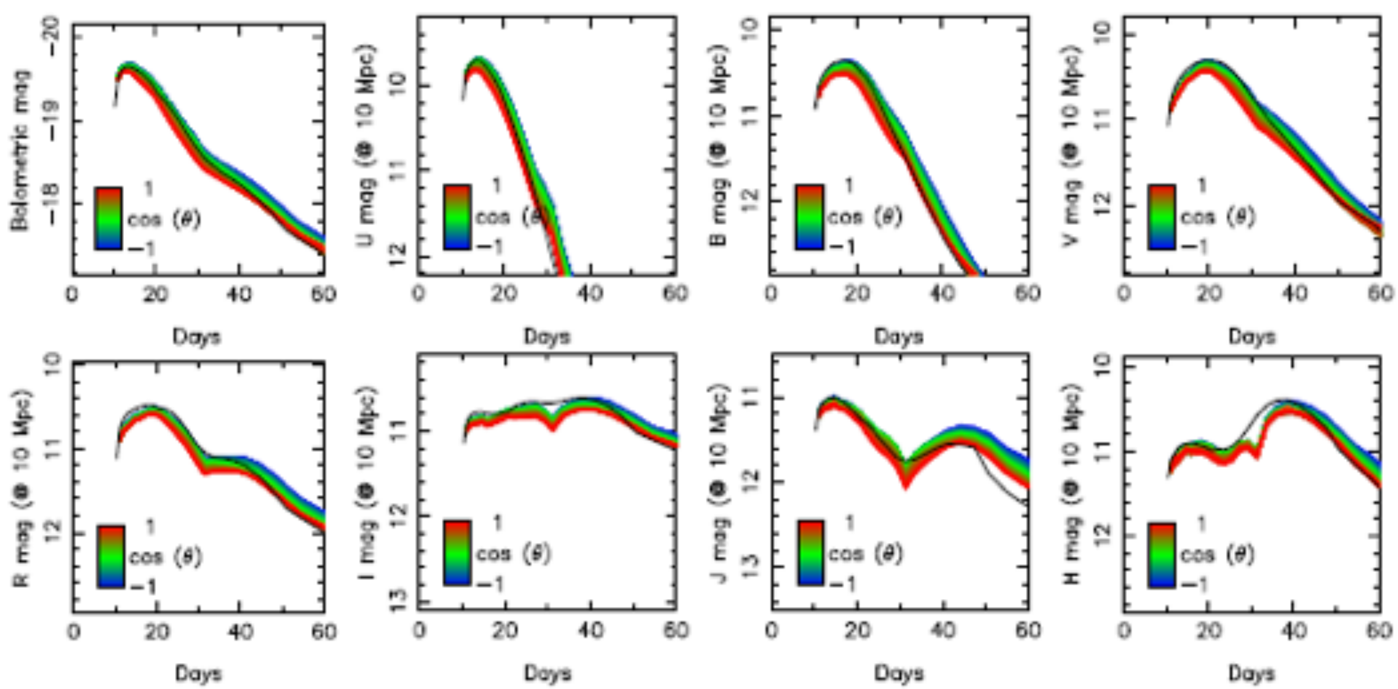
- Kasen (2010) numerically simulated the companion's effect on light curves
- This effect was reported to be observed (Marion+2015, right figure)





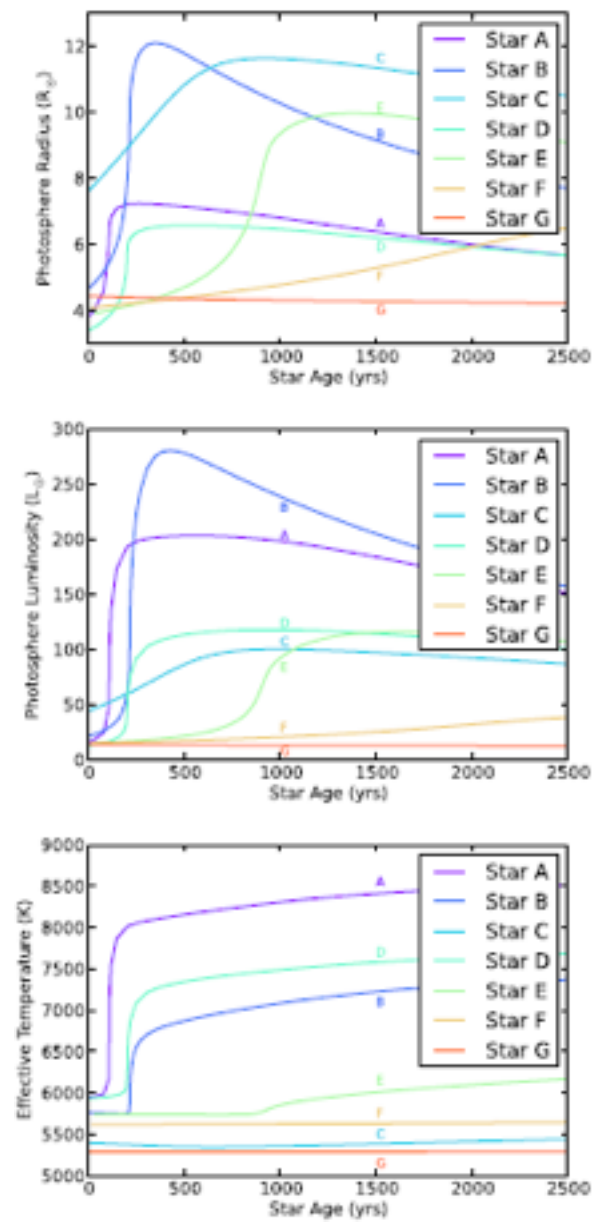
Companions' effect on light curves and spectra

- Light curve variation can be reproduced by the effect of ejecta-companion interaction (Maeda+ 2014)



Direct detection of surviving companions?

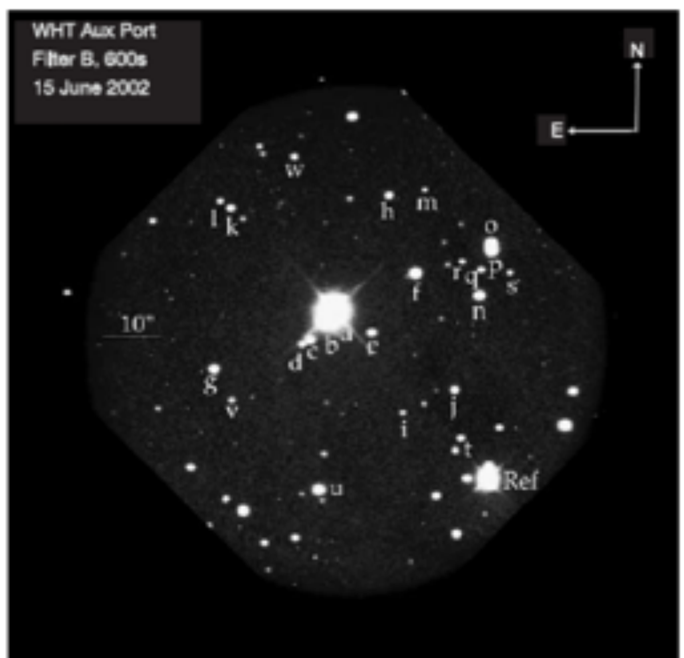
- Pan+ (2012) numerically simulated the evolution of surviving companions in Tycho SNR
  - Some cases have similar features as the observed candidate
  - However, the luminosity and radius differ by the factor of 2
  - Tycho G cannot completely be ruled out as a survivor



Direct detection of surviving companions?

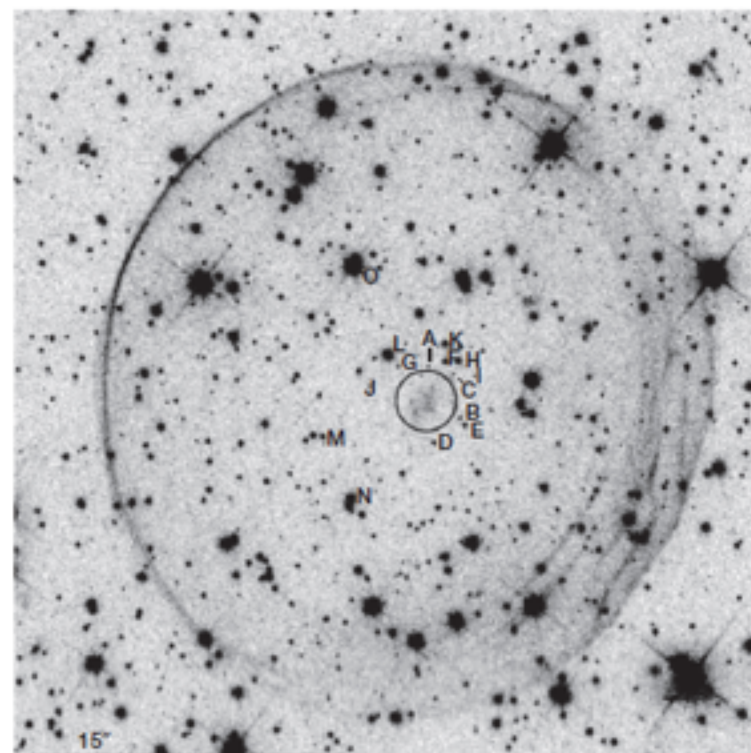
- Ruiz-Lapuente+ (2004) found the candidate for the surviving companion (Tycho G) in Tycho SNR (type Ia)
- Tycho G is a G0-2 type dwarf

a



No detection of surviving companions

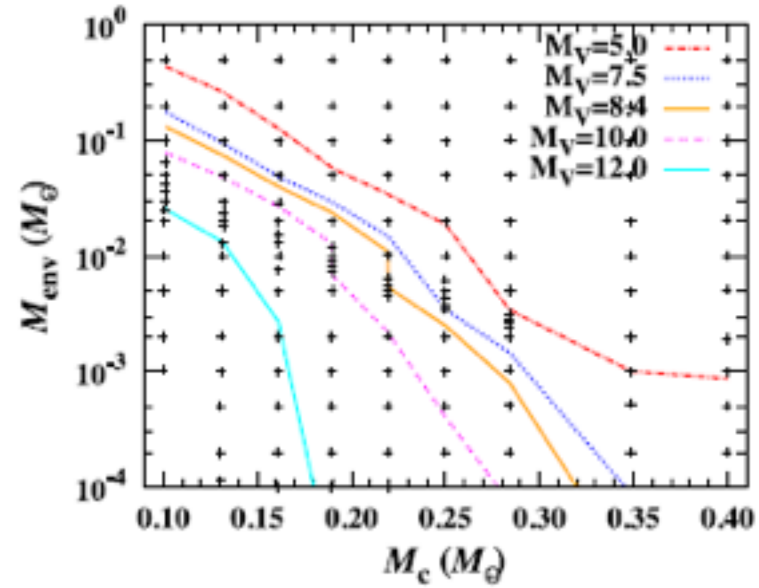
- Schaefer & Pagnotta (2012) reported no-detection of survivor in SNR 0509-67.5
  - A type Ia SNR
  - Age : 400±50 yrs
  - Limit : Mv=+8.4



No detection of surviving companions

- Our previous work (Noda+ 2016) followed the evolution of surviving companions in WD+RG binary case

- The survivor's luminosity has strong dependence on the core mass of RG and the mass residual envelope
- In some parameter ranges, survivor can avoid the detection of SNR 0509-67.5



Other expectations on surviving companions

- Langer+(2000) followed the binary evolution to the SN Ia (MS+WD case)
  - They found that light element (Li,Be,B) on the surface of MS is depleted by the mass transfer
  - Ratio of CNO isotopes in the surface of MS is changed

Nr.	$M_{MS,i}$ $M_\odot$	$M_{MS,f}$ $M_\odot$	ΔM $M_\odot$	ΔM_{wind} $M_\odot$	^{3}He	^{4}He	^{12}C	^{13}C	^{14}N	^{15}N	^{16}O	^{17}O	^{18}O	^{23}Na
3	2.1	1.66	0.44	0.00	6.71	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	2.0	1.55	0.45	0.00	7.91	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
13	1.8	1.35	0.45	0.00	14.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
29	2.1	0.74	1.36	0.72	4.33	1.00	0.08	2.22	4.61	0.06	1.00	2.92	0.02	1.06
31	2.1	0.79	1.31	0.66	6.65	1.04	0.15	3.66	4.28	0.07	1.00	2.39	0.05	1.07
32	2.0	1.05	0.95	0.31	7.45	1.01	0.91	7.28	1.12	0.34	1.00	1.00	0.77	1.00
35	2.0	0.66	1.34	0.69	4.10	1.07	0.08	1.91	4.60	0.06	0.99	6.27	0.03	1.07
36	1.9	1.17	0.73	0.09	16.8	1.01	0.99	1.48	1.00	0.89	1.00	1.00	0.99	1.00
37	1.9	0.93	0.97	0.33	14.4	1.03	0.69	10.7	1.80	0.22	1.00	1.02	0.46	1.00
38	1.8	1.15	0.65	0.00	22.6	1.00	0.99	1.10	1.00	0.97	1.00	1.00	0.99	1.00
39	1.8	1.15	0.65	0.00	26.9	1.01	0.99	1.30	1.00	0.93	1.00	1.00	0.99	1.00
45	1.7	1.06	0.64	0.00	28.1	1.01	0.99	1.64	1.00	0.90	1.00	1.00	0.99	1.00
54	1.9	1.25	0.65	0.21	218	1.00	0.98	2.42	1.00	0.71	1.00	1.00	0.96	1.00
55	1.9	1.12	0.78	0.34	172	1.02	0.80	11.1	1.38	0.20	1.00	1.01	0.55	1.00
60	1.8	1.31	0.49	0.04	209	1.00	0.99	1.05	1.00	0.98	1.00	1.00	1.00	1.00
61	1.8	1.07	0.73	0.29	281	1.02	0.85	9.80	1.26	0.24	1.00	1.01	0.65	1.00
62	1.7	1.25	0.45	0.00	195	1.00	0.99	1.02	1.00	0.99	1.00	1.00	1.00	1.00
63	1.7	1.23	0.47	0.13	474	1.00	0.97	1.98	1.00	0.79	1.00	1.00	0.97	1.00
64	1.6	1.15	0.45	0.00	208	1.00	0.99	1.02	1.00	0.99	1.00	1.00	1.00	1.00
65	1.6	1.13	0.47	0.03	622	1.00	0.99	1.13	1.00	0.97	1.00	1.00	0.99	1.00
67	1.5	1.06	0.44	0.00	706	1.00	0.99	1.09	1.00	0.98	1.00	1.00	1.00	1.00

Our current work (preliminary)

- We are now simulating the effect of SN ejecta on the surface abundance of surviving companions

Possible ejecta's effect
- Envelope stripping
- Envelope heating
- Surface pollution*

(FLASH code is employed)
→
Simulated surface pollution by the ejecta. The companion models are 1 and 5 solar mass main sequence.

Elements	Solar Abundance Asplund+ 2009	Ejecta contribution	
		1 solar mass	5 solar mass
H	7.15E-01		
C	2.31E-03	1.00E-08	7.40E-09
O	5.61E-03	4.90E-08	2.50E-08
Ne	1.22E-03	1.30E-09	9.00E-10
Mg	6.83E-04	3.50E-09	1.70E-09
Si	6.48E-04	1.20E-07	1.00E-07
S	3.02E-04	7.40E-08	6.50E-08
Ar	6.46E-05	1.50E-08	1.40E-08
Ca	6.26E-05	1.40E-08	1.60E-08
Fe	1.27E-03	7.30E-04	2.00E-04

(mass fraction)

Summary

- CCSN and SN Ia both have chances to be accompanied with companions
- Surviving companions are important to distinguish the progenitor scenario of SN Ia
- The companions have influence on the light curve
- Direct detection of the companion is also important method