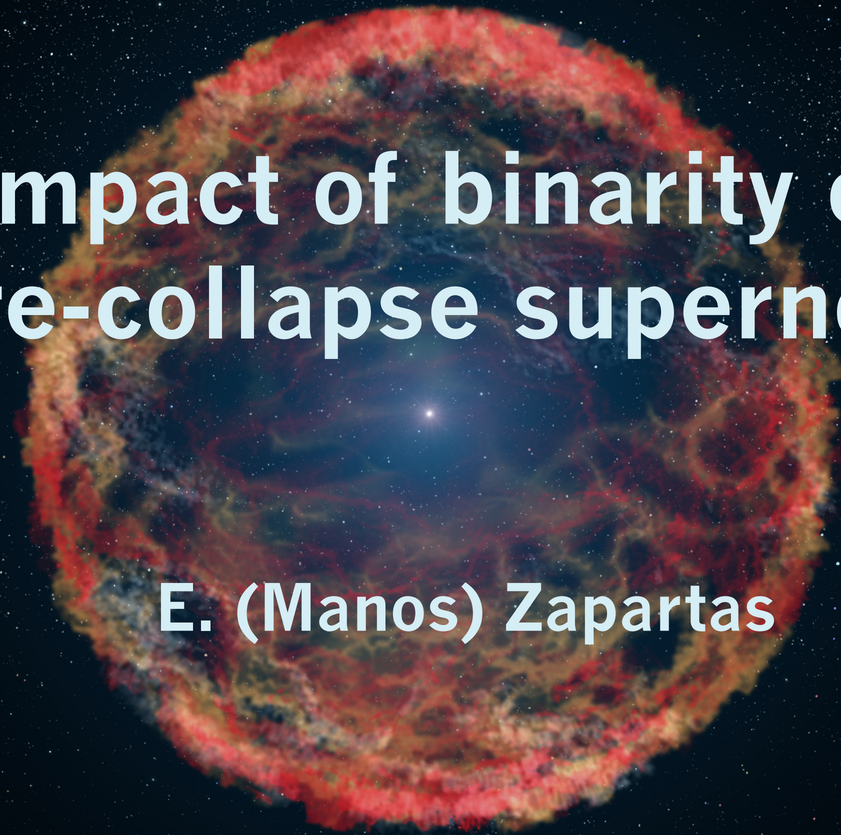
Universiteit van Amsterdam

Anton Pannekoek Institute

BinCosmos

Impact of binarity on core-collapse supernovae

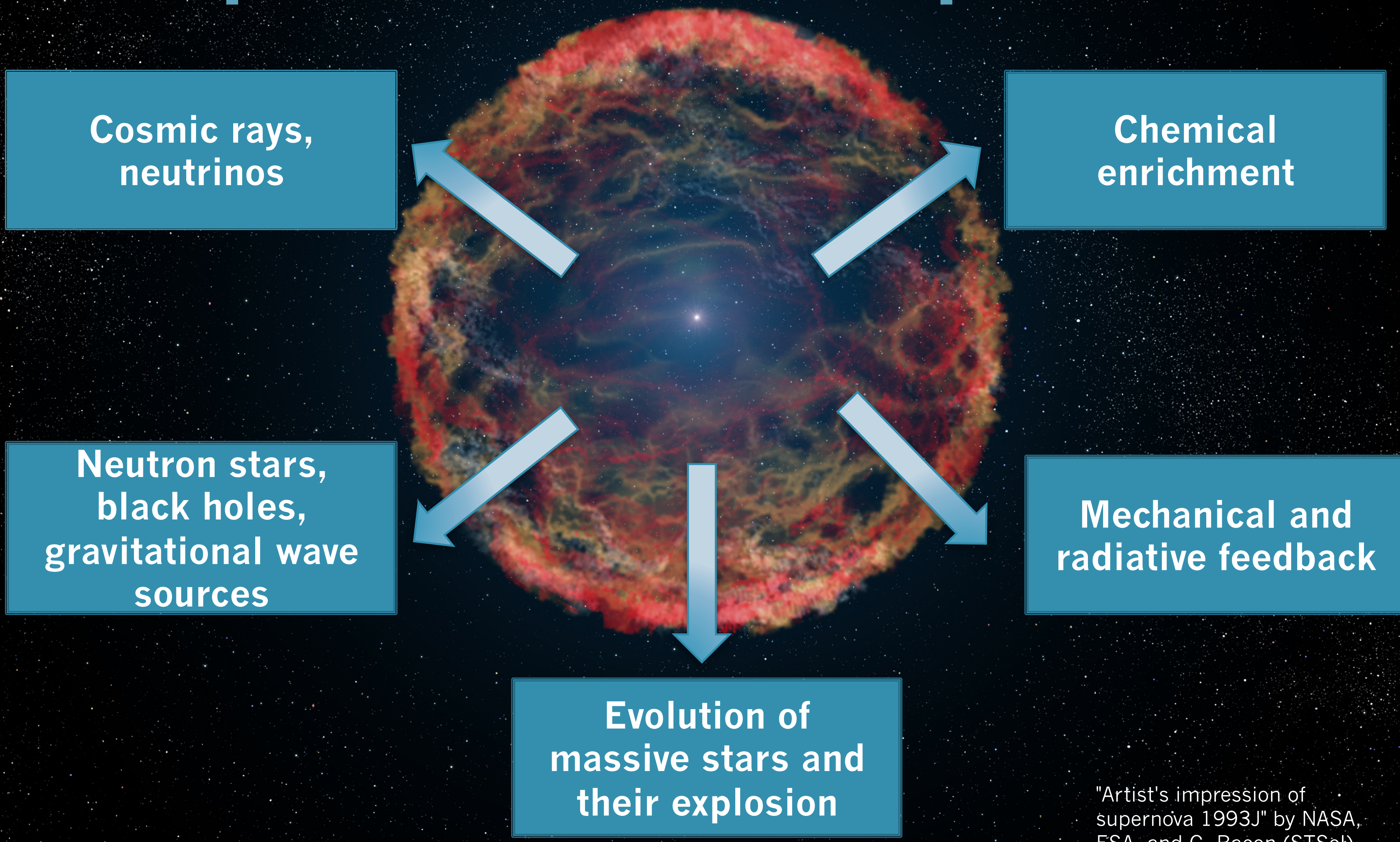


E. (Manos) Zapartas

(Some of the) collaborators:

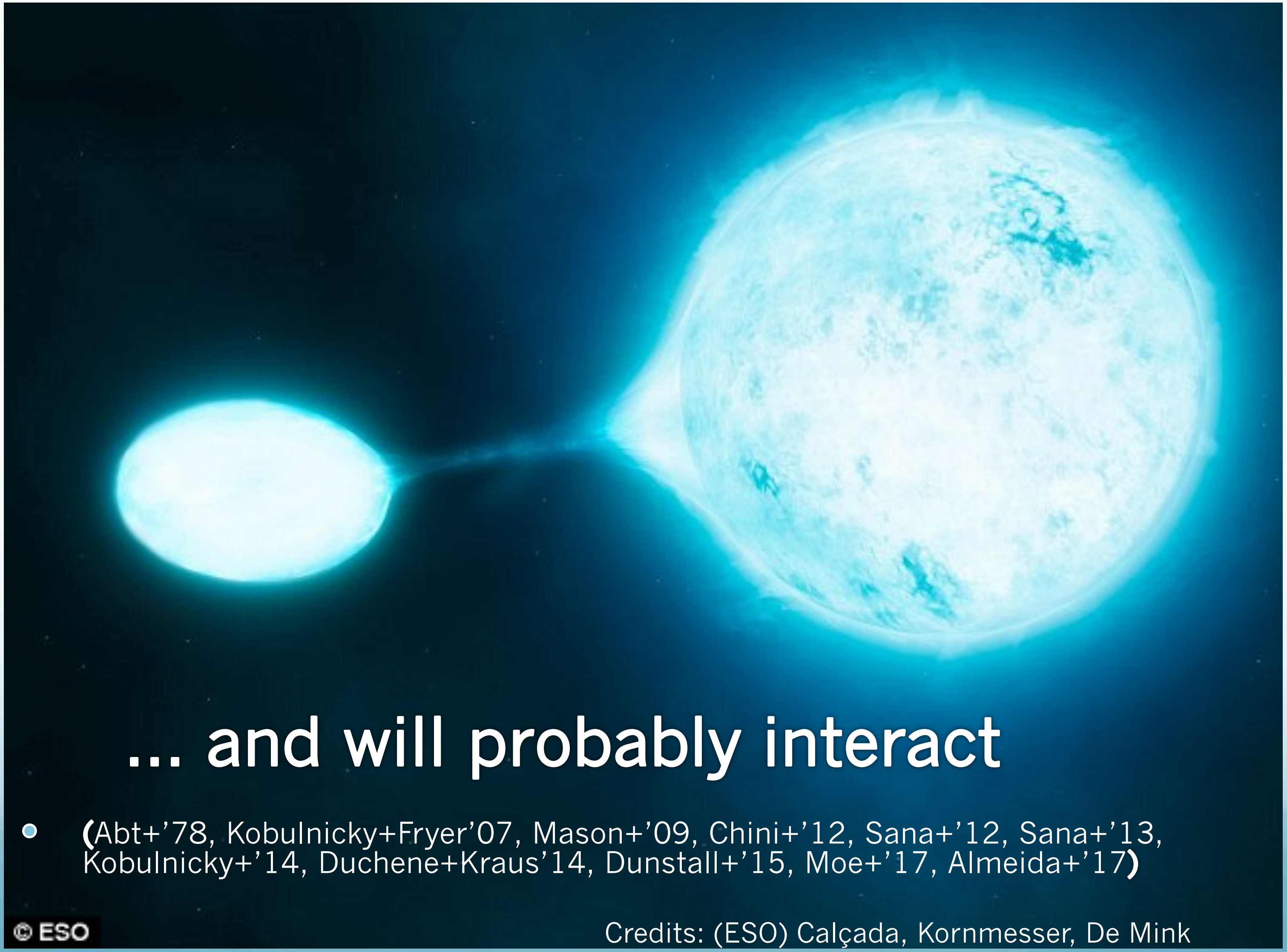
S.E. de Mink, R.G. Izzard, S.-C. Yoon, C. Badenes, S. van Dyk, O. Fox, N. Smith, A. de Koter, M. Renzo, Y. Gotberg, C.J. Neijssel, S. Ryder, A. Schootemeijer

Importance of ccSupernovae



"Artist's impression of supernova 1993J" by NASA, ESA, and G. Bacon (STScI)

Most young massive stars are found in binaries...

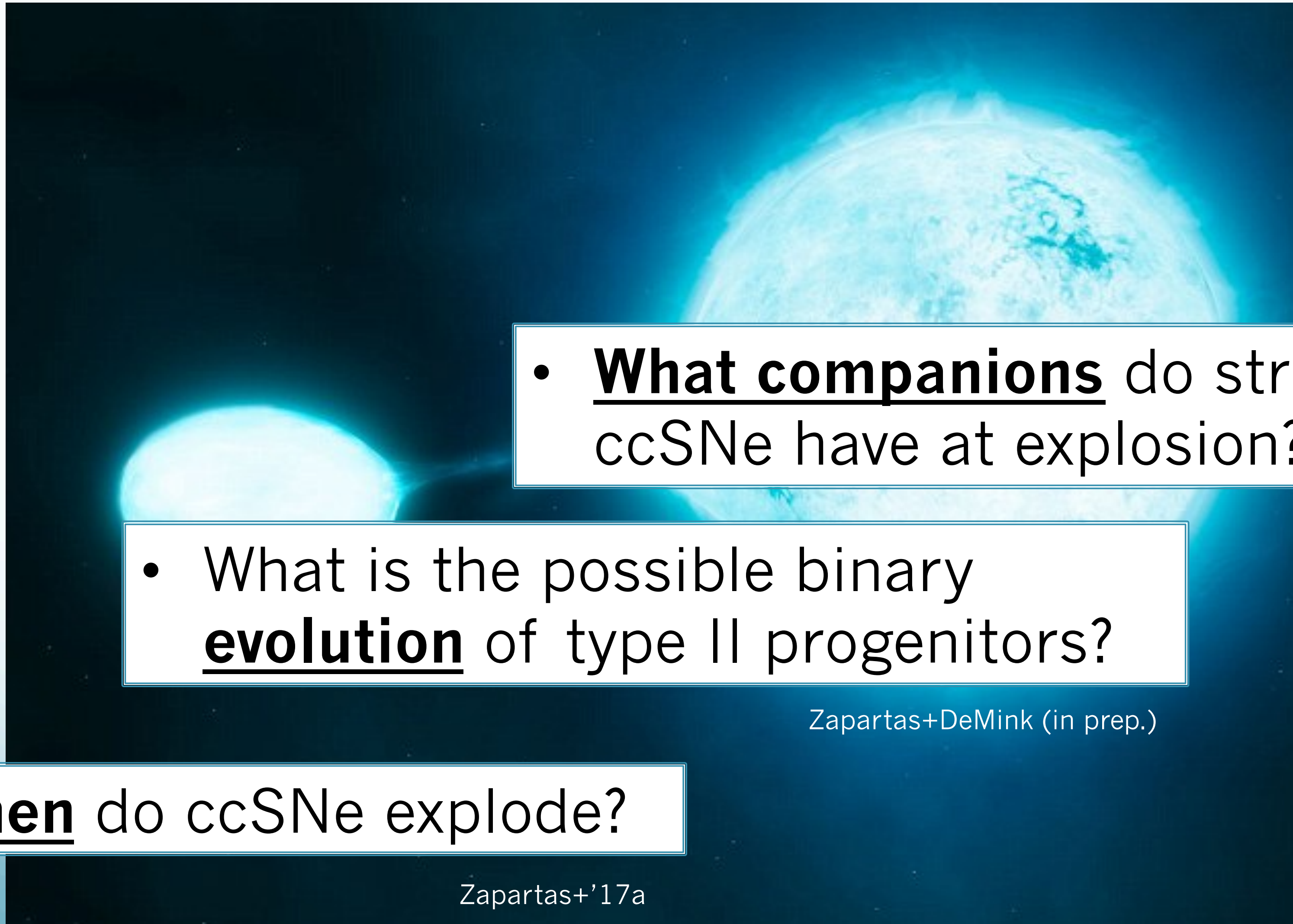


... and will probably interact

- (Abt+'78, Kobulnicky+Fryer'07, Mason+'09, Chini+'12, Sana+'12, Sana+'13, Kobulnicky+'14, Duchene+Kraus'14, Dunstall+'15, Moe+'17, Almeida+'17)

Credits: (ESO) Calçada, Kornmesser, De Mink

Impact of binaries on ccSNe



- **What companions** do stripped-ccSNe have at explosion?

Zapartas+'17b

- What is the possible binary **evolution** of type II progenitors?

Zapartas+DeMink (in prep.)

- **When** do ccSNe explode?

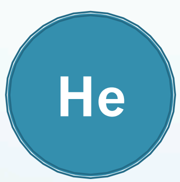
Zapartas+'17a

e.g. Podsiadlowski+'92,'93,'04, De Donder+Vanbeveren'03, Eldridge+'04,'07,'08, Kochanek+'09, Yoon+'10, Vanbeveren+'13, Justhum+'14

Types of ccSNe

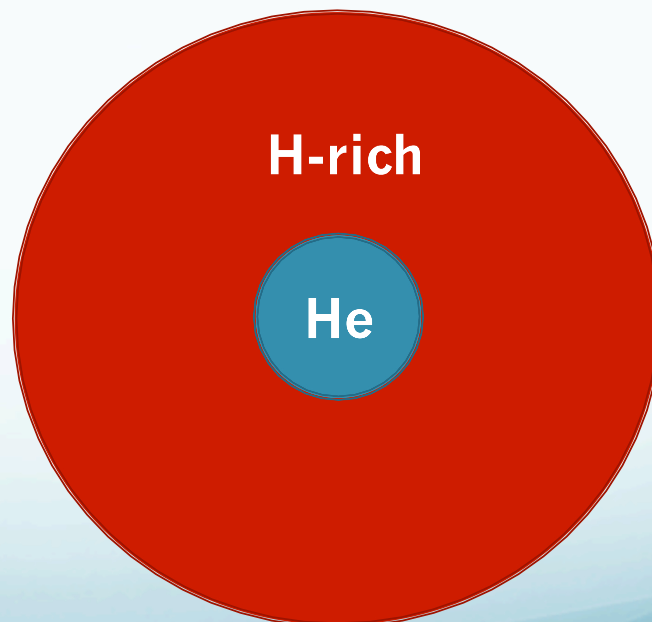
Stripped ccSNe

(Type Ib/c, IIb, Ic-BL, Ibn)



Type II ccSNe

(H-rich Type II-P, II-L, IIn)



Why population synthesis?

Binary_c: a rapid stellar evolutionary code

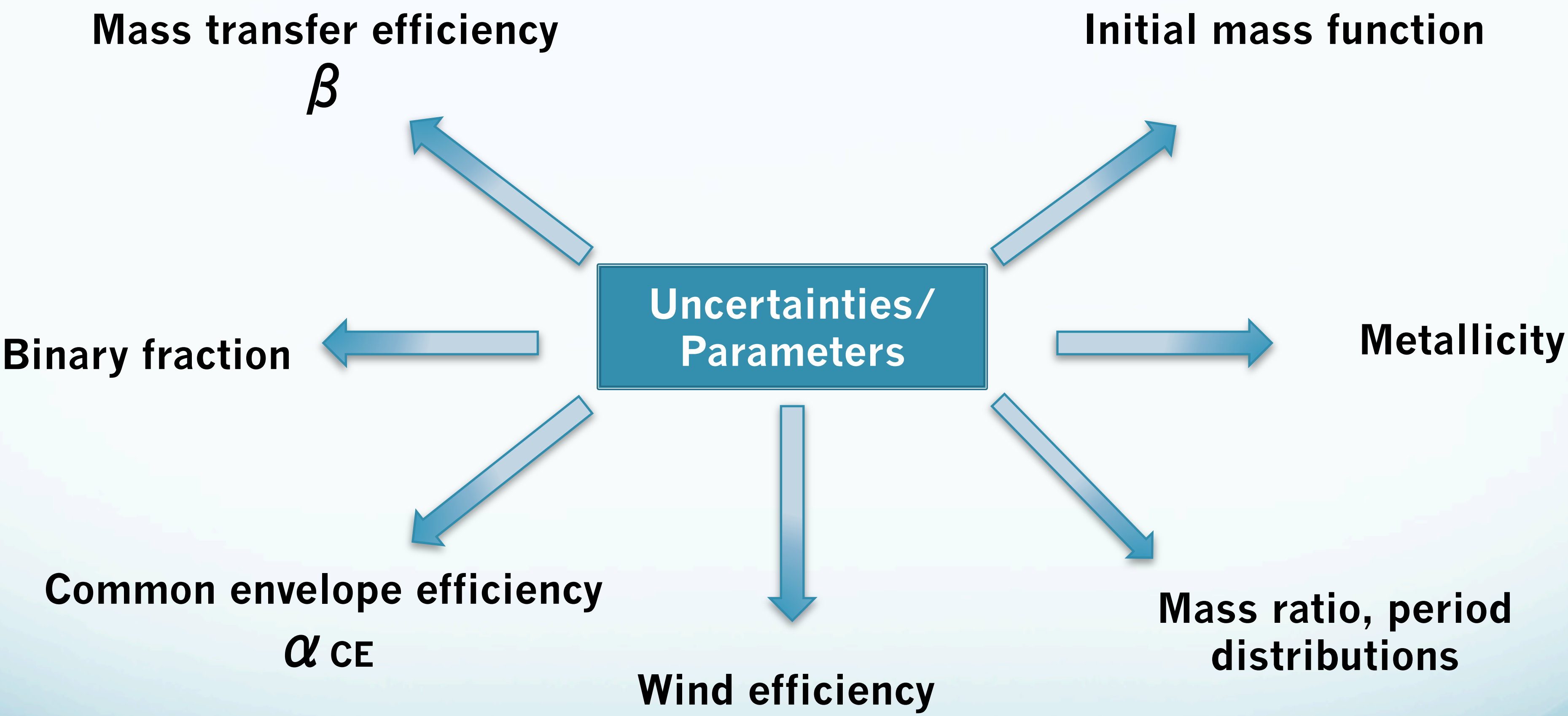
(Izzard+'04,'06,'09, Hurley+ '00,'02, De Mink+ '13,Schneider+ '15)

Upcoming/Existing Automated **Transient Surveys**

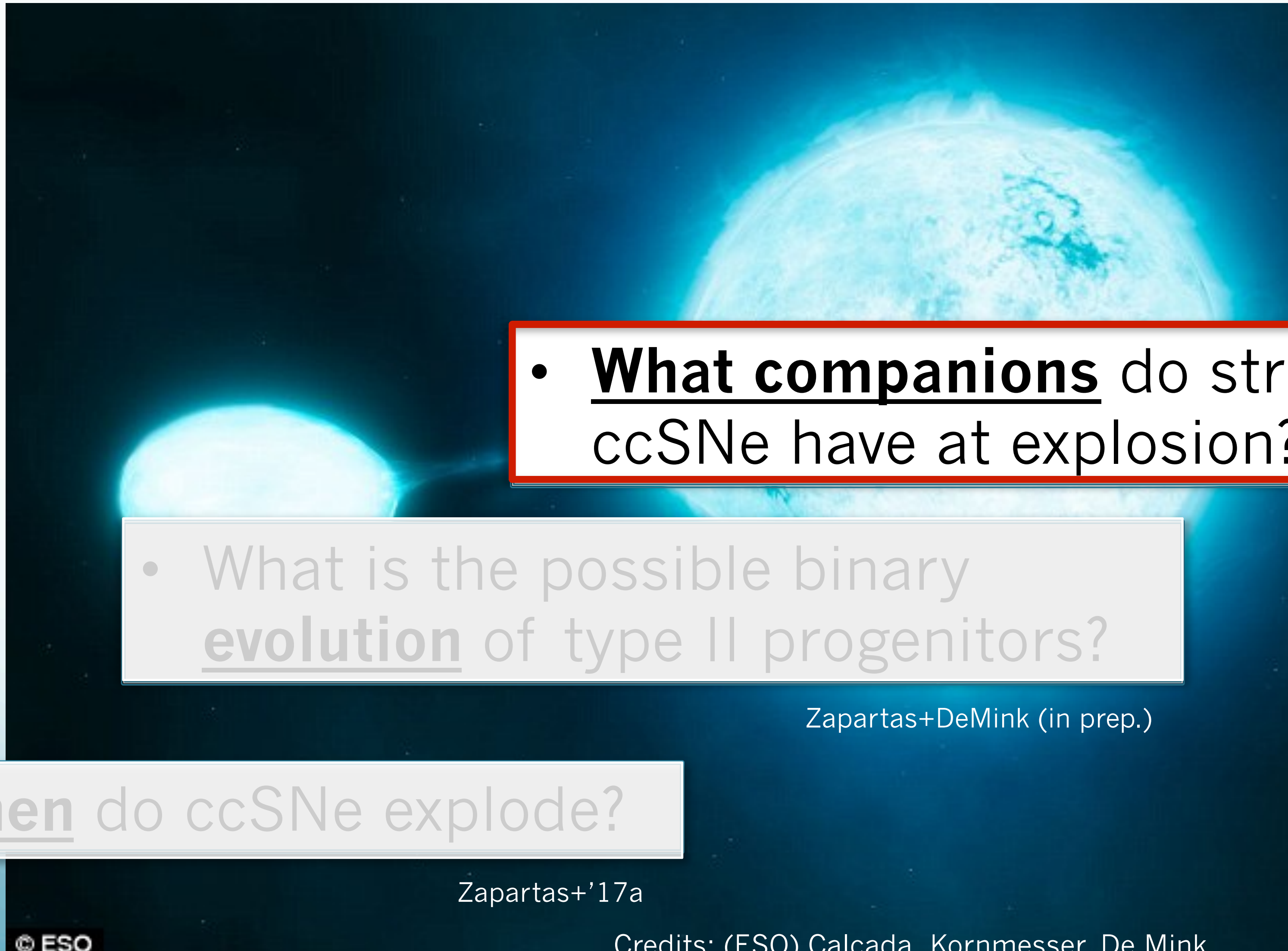
PALOMAR TRANSIENT FACTORY

ASAS SN

How robust are our predictions?



Impact of binaries on ccSNe



- **<u>What companions</u>** do stripped-ccSNe have at explosion?

Zapartas+'17b

- What is the possible binary **<u>evolution</u>** of type II progenitors?

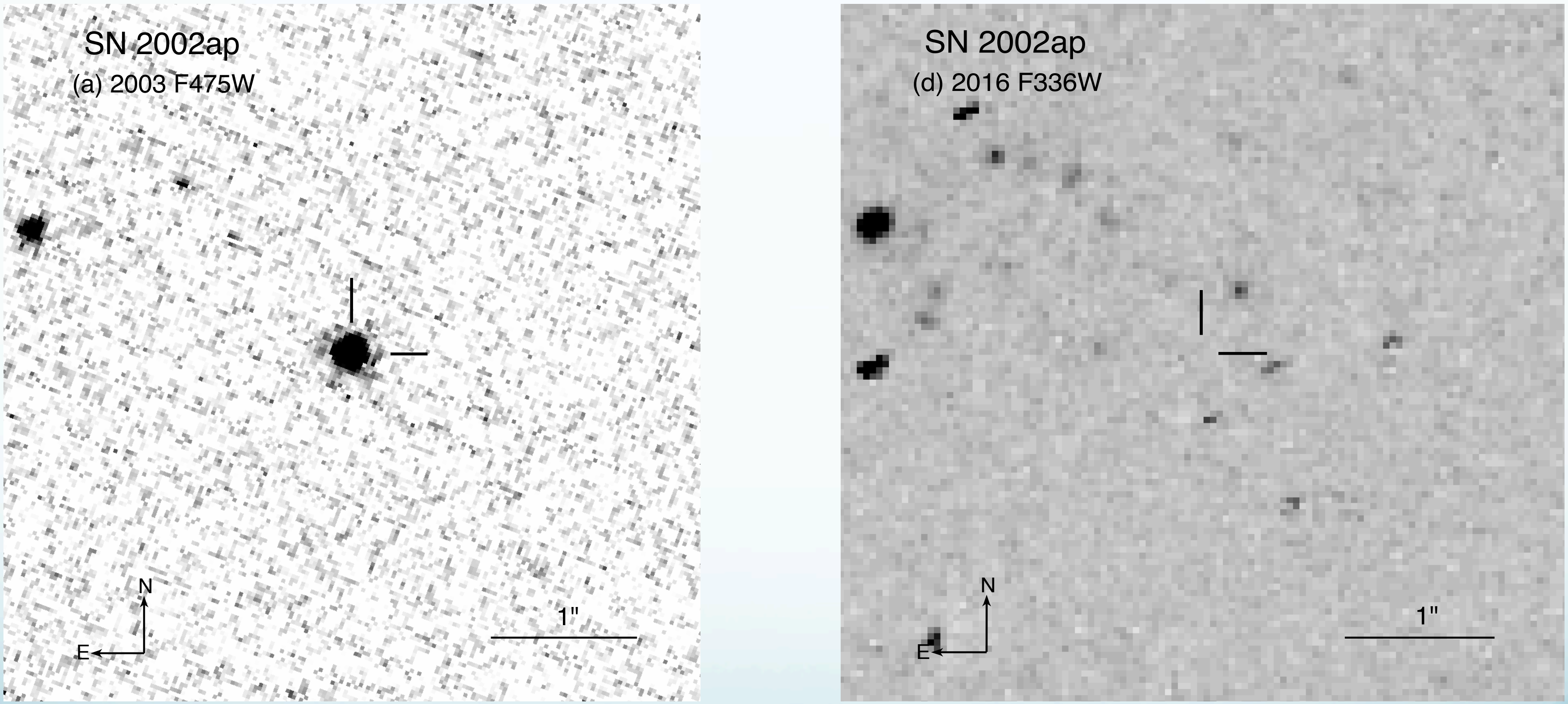
Zapartas+DeMink (in prep.)

- **<u>When</u>** do ccSNe explode?

Zapartas+'17a

Credits: (ESO) Calçada, Kornmesser, De Mink

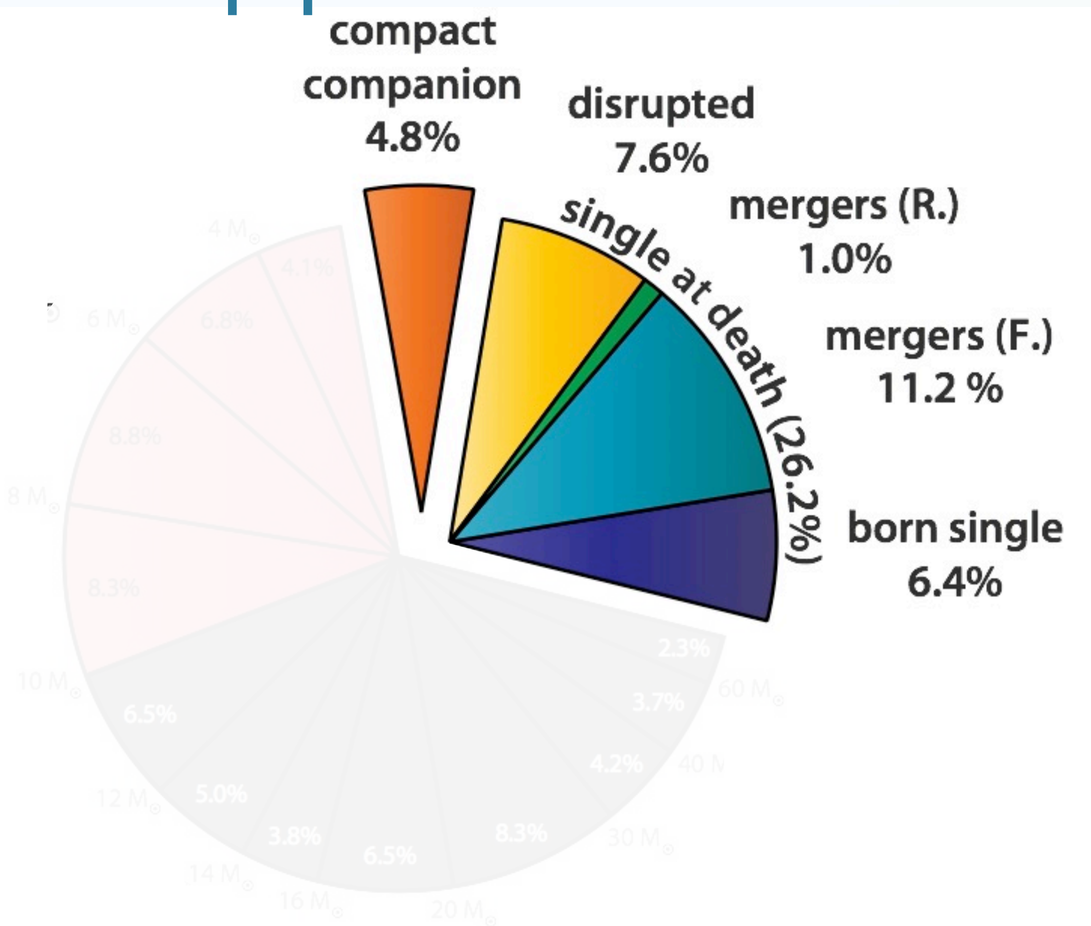
Companion search for SN2002ap



Zapartas+'17b

e.g. Maund+ '04,'15, Ryder+ '06, Fox+ '14, Follateli+ '14,'16, Van Dyk+ 16, Kochanek+ '17

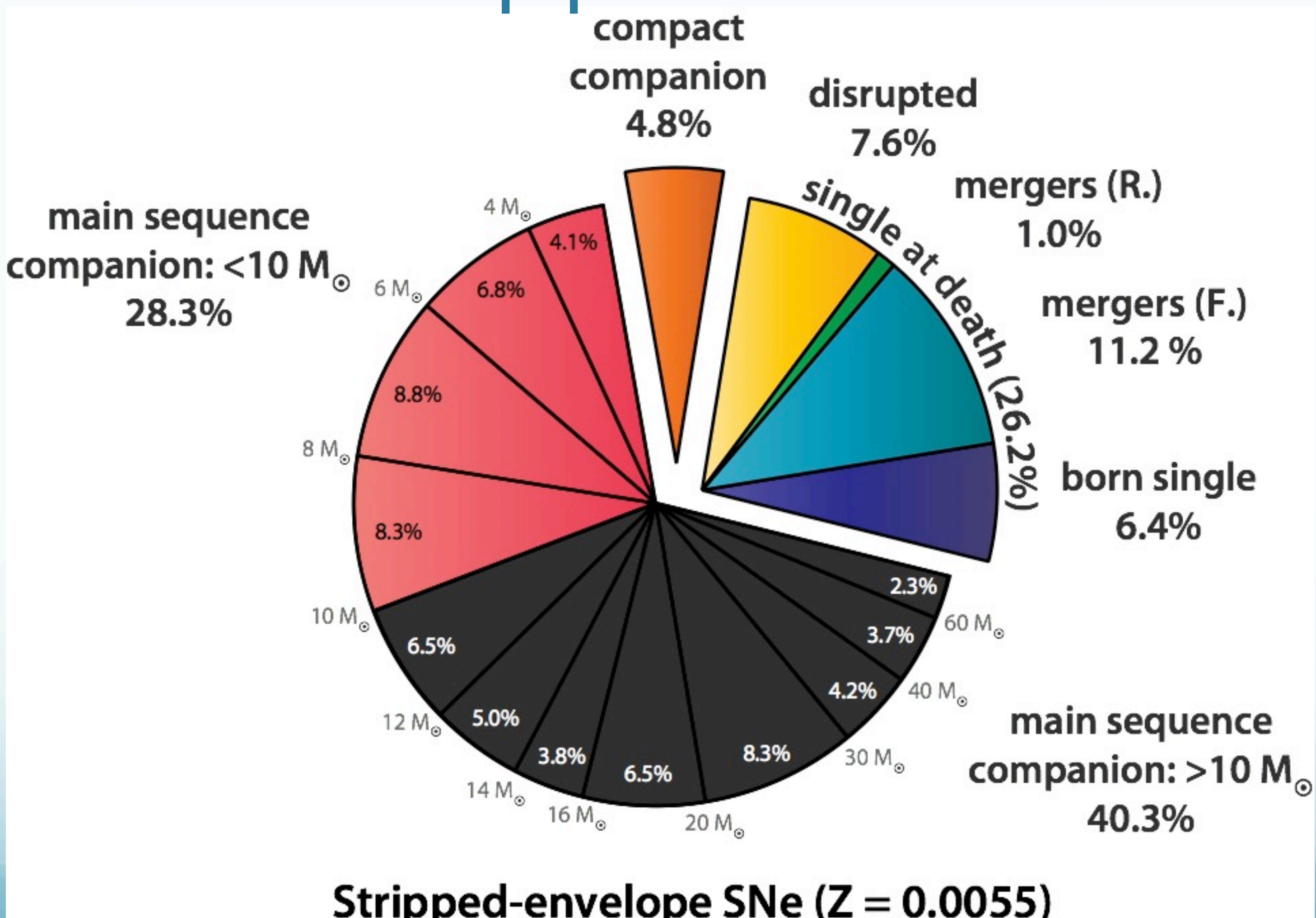
Companions of stripped ccSNe



Stripped-envelope SNe (Z = 0.0055)

Zapartas+'17b

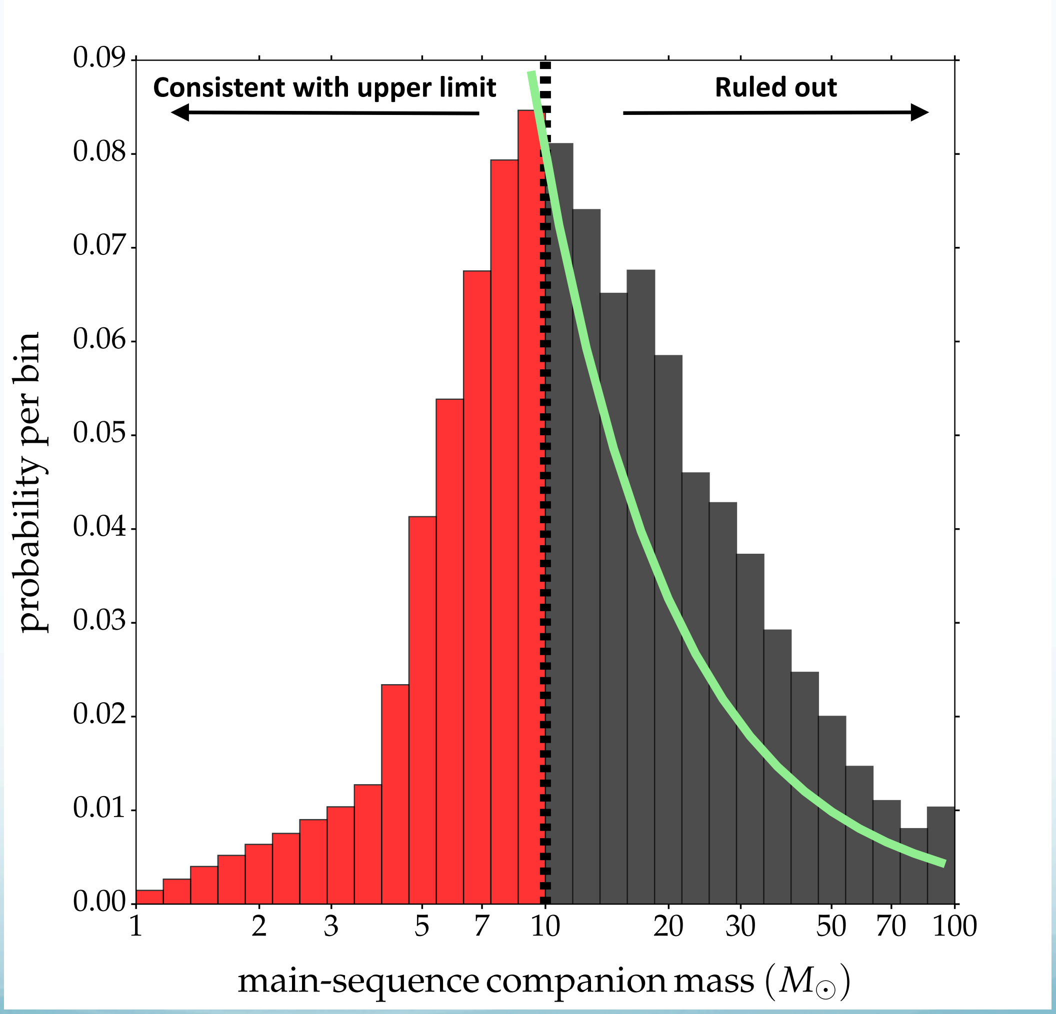
Companions of stripped ccSNe



e.g. Kochanek+'09, Moriya+'15, Liu+'15

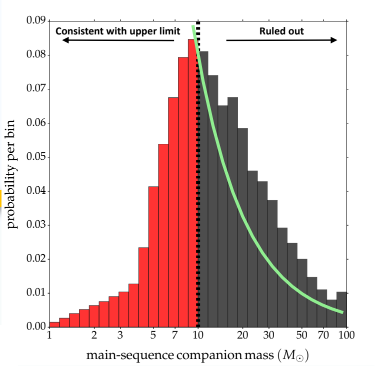
Zapartas+'17b

Mass distribution of main-sequence companions

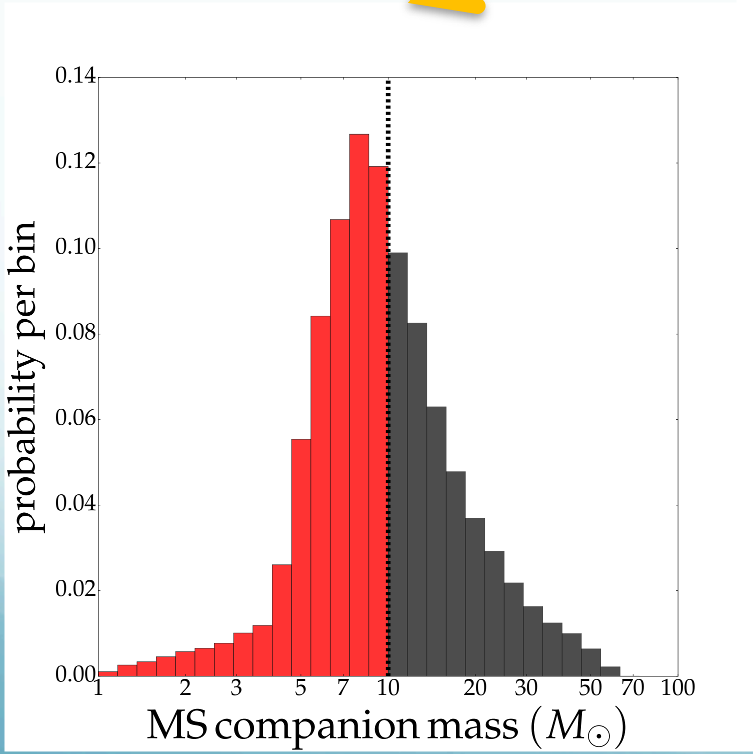


Zapartas+'17b

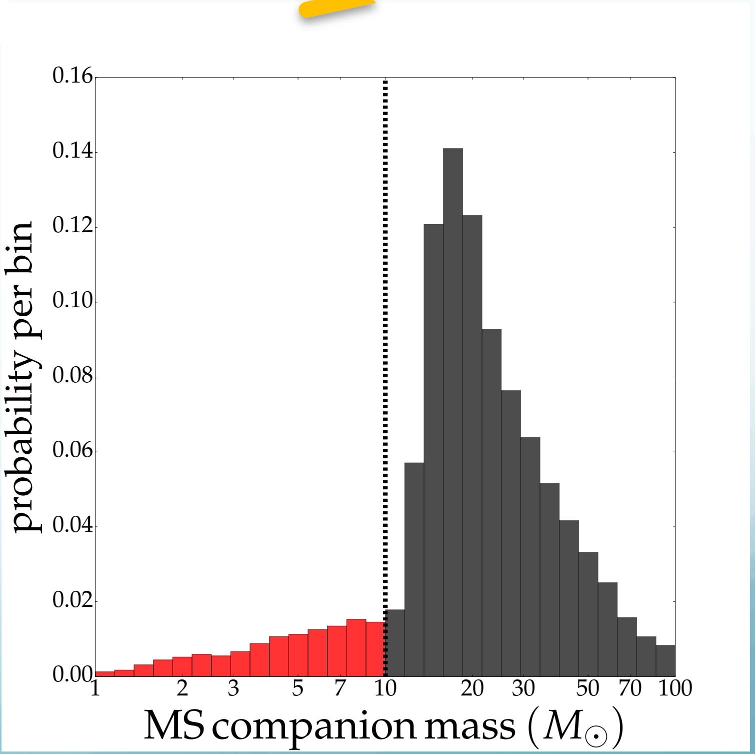
Variations in the mass distributions



non-conservative mass transfer

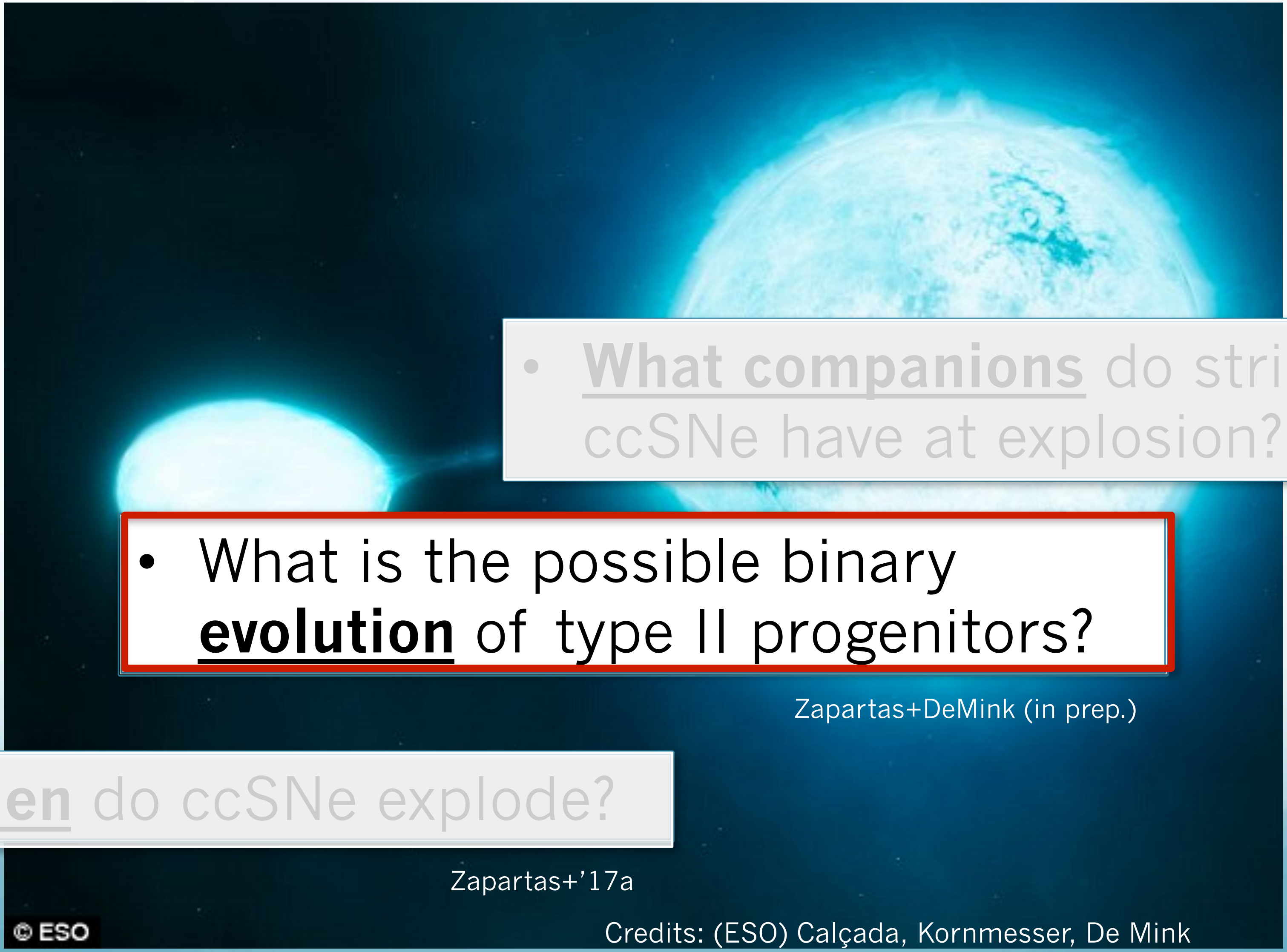


fully conservative mass transfer



Zapartas+'17b

Impact of binaries on ccSNe



- **What companions** do stripped-ccSNe have at explosion?

Zapartas+'17b

- What is the possible binary **evolution** of type II progenitors?

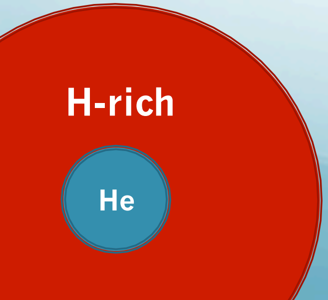
Zapartas+DeMink (in prep.)

- **When** do ccSNe explode?

Zapartas+'17a

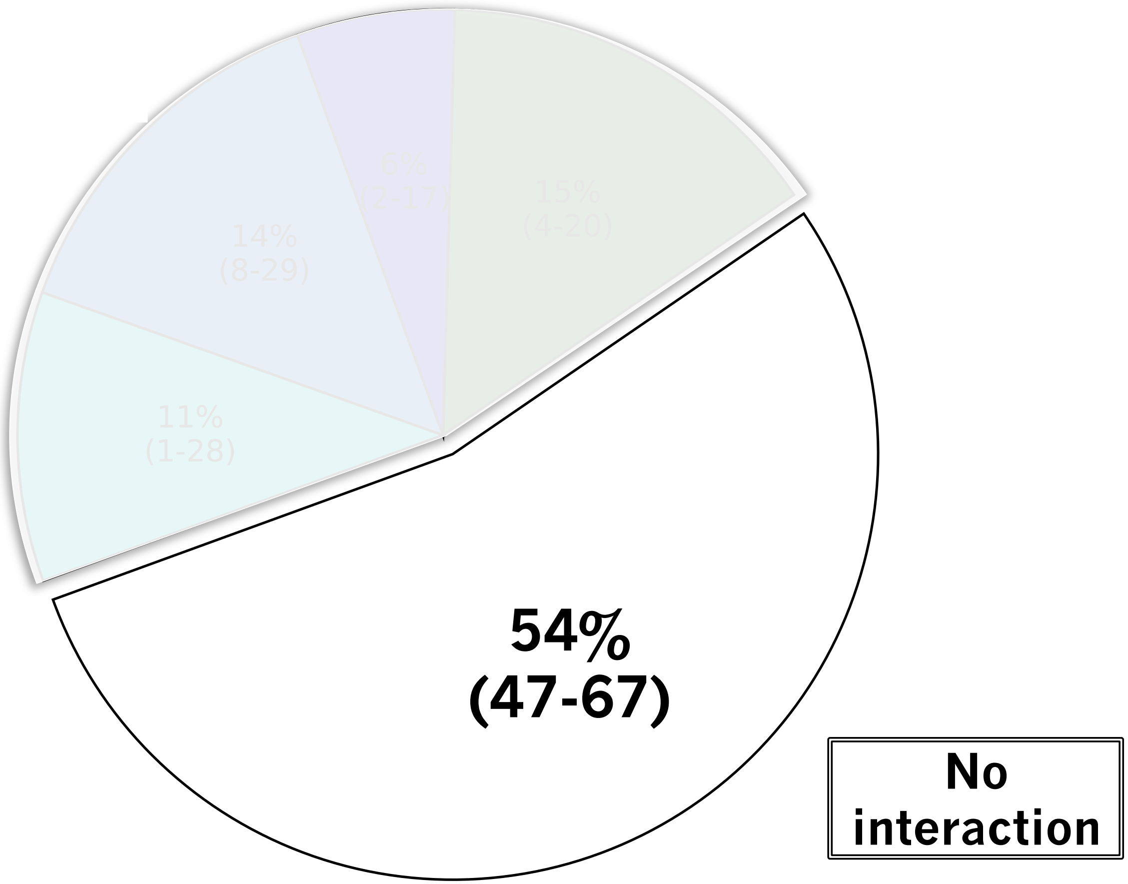
Credits: (ESO) Calçada, Kornmesser, De Mink

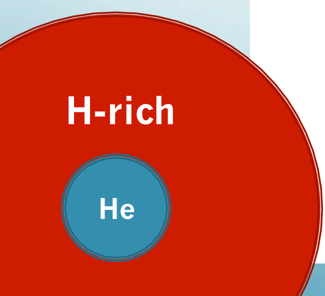
Progenitor **evolution** of SN type II



Zapartas+DeMink (in prep.)

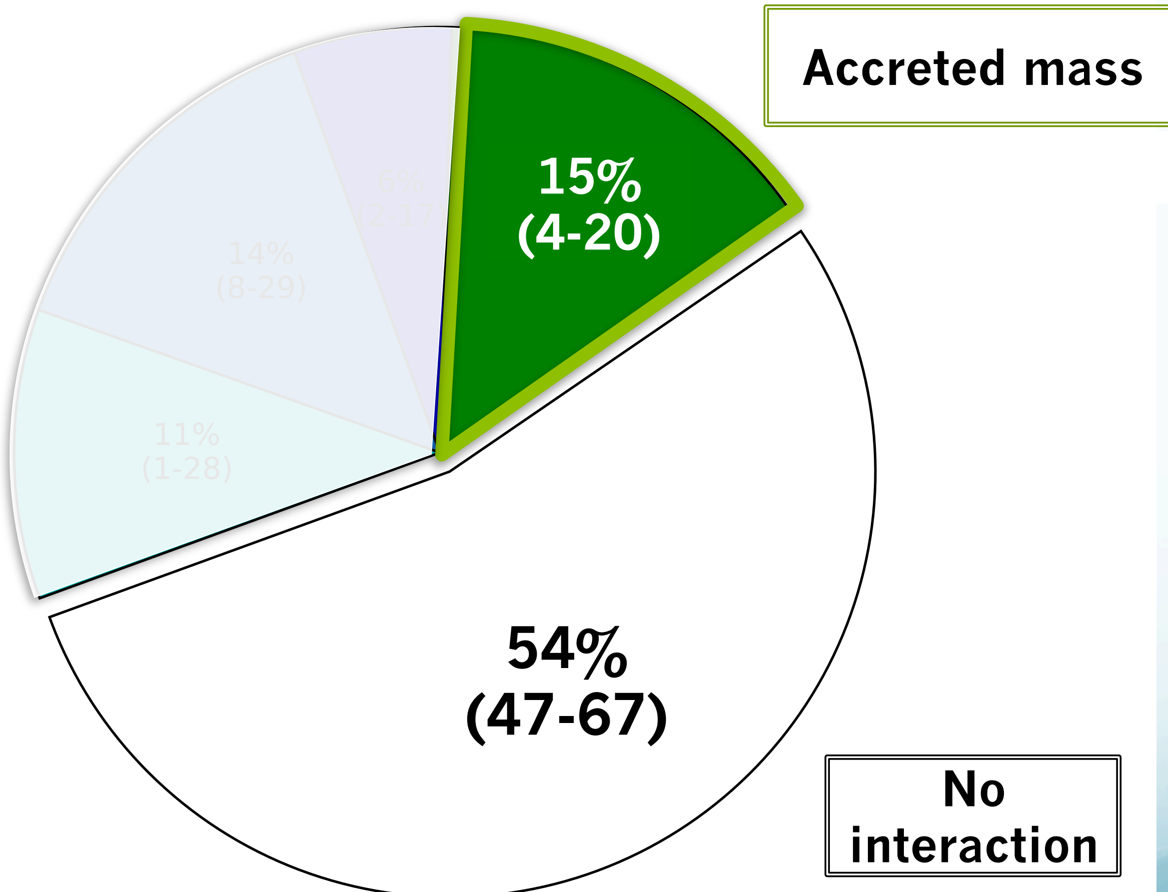
Progenitor **evolution** of SN type II

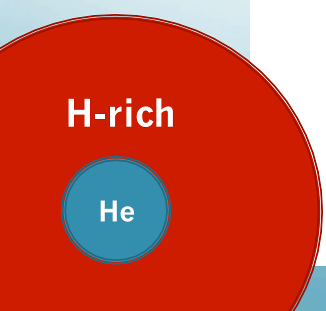




Zapartas+DeMink (in prep.)

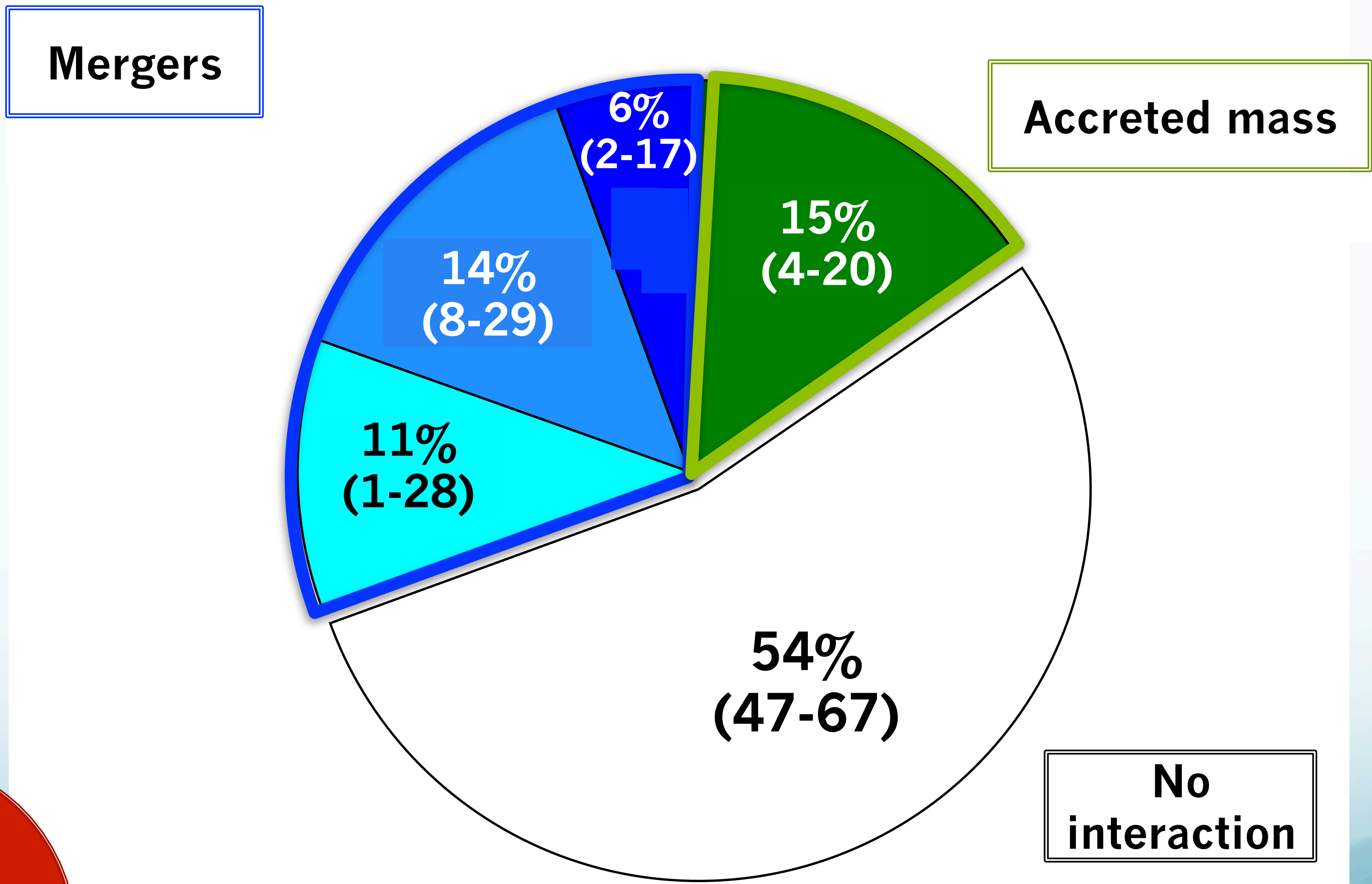
Progenitor **evolution** of SN type II





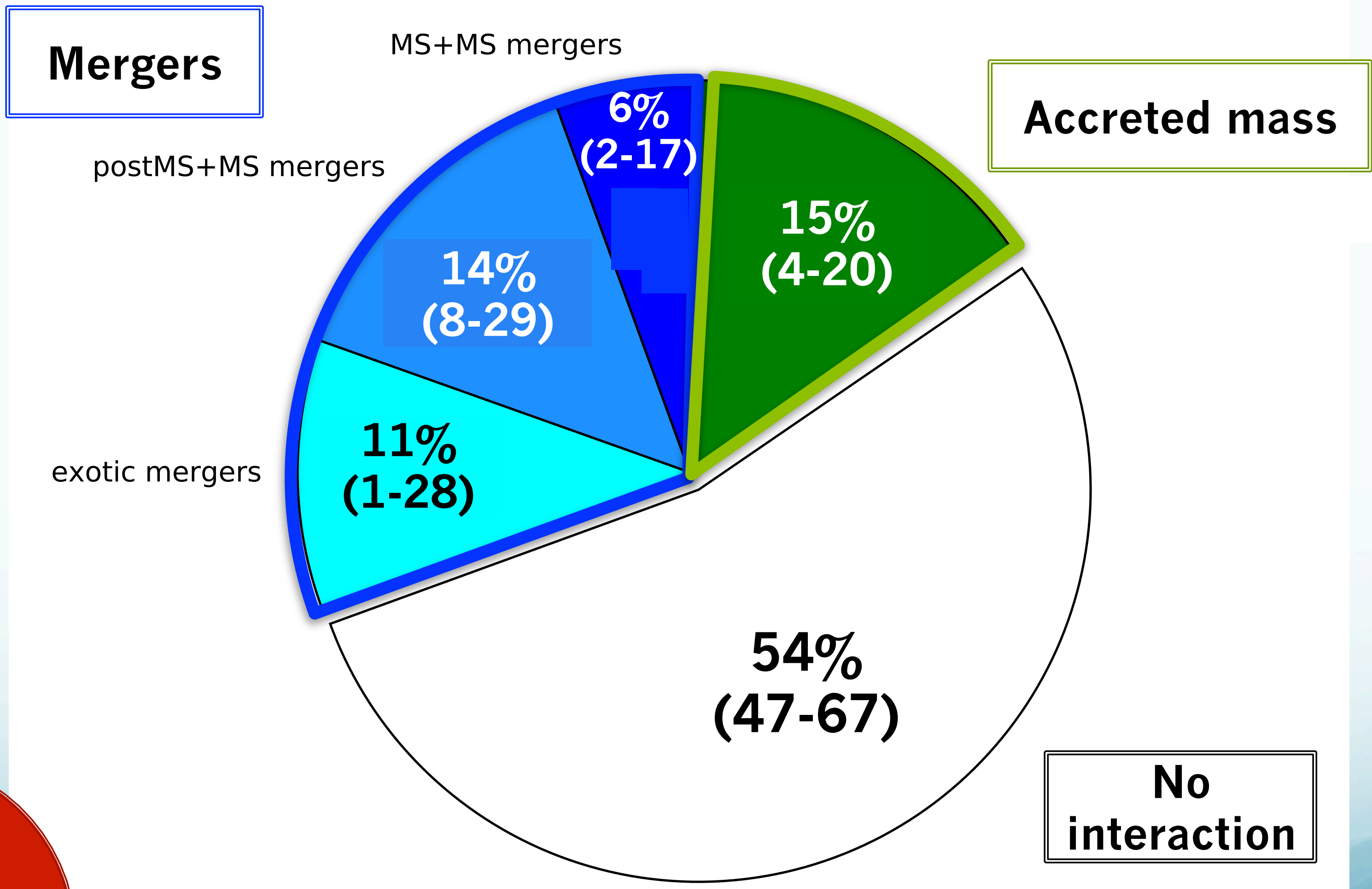
Zapartas+DeMink (in prep.)

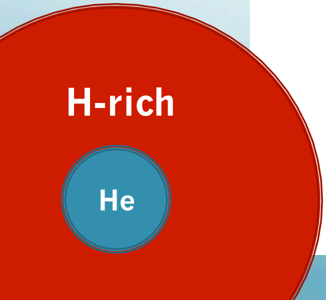
Progenitor **evolution** of SN type II



Zapartas+DeMink (in prep.)

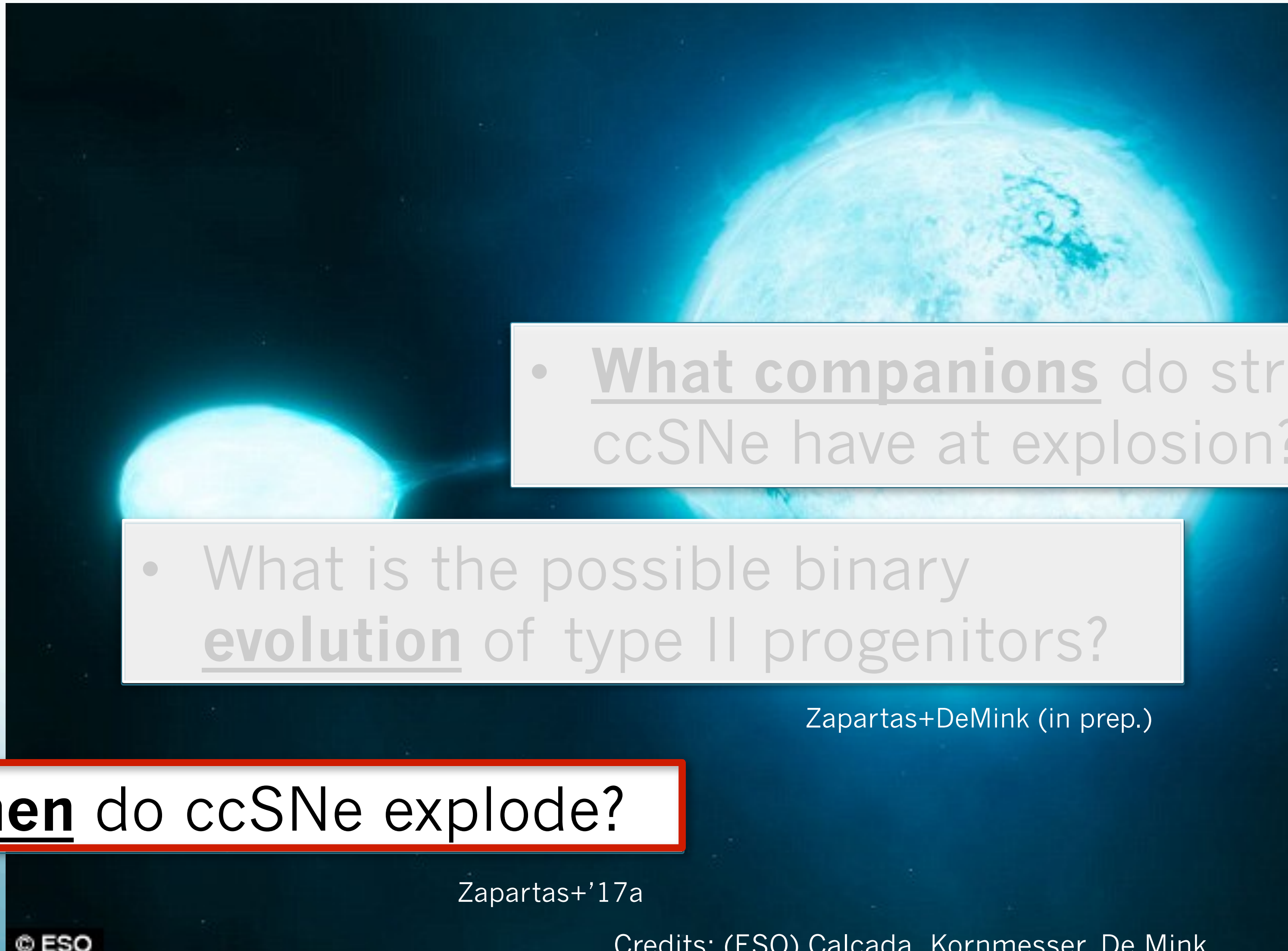
Progenitor **evolution** of SN type II





Zapartas+DeMink (in prep.)

Impact of binaries on ccSNe



- **What companions** do stripped-ccSNe have at explosion?

Zapartas+'17b

- What is the possible binary **evolution** of type II progenitors?

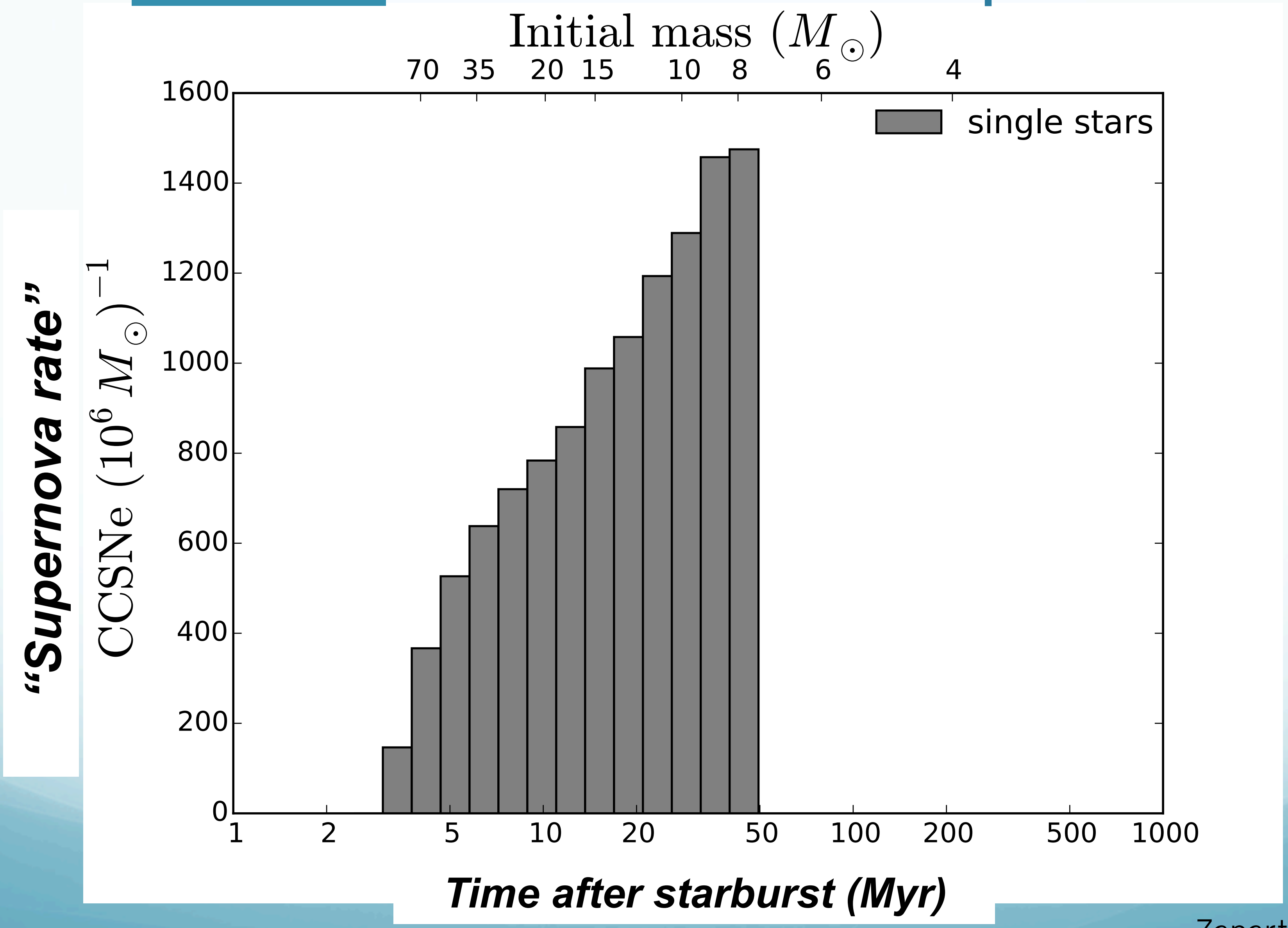
Zapartas+DeMink (in prep.)

- **When** do ccSNe explode?

Zapartas+'17a

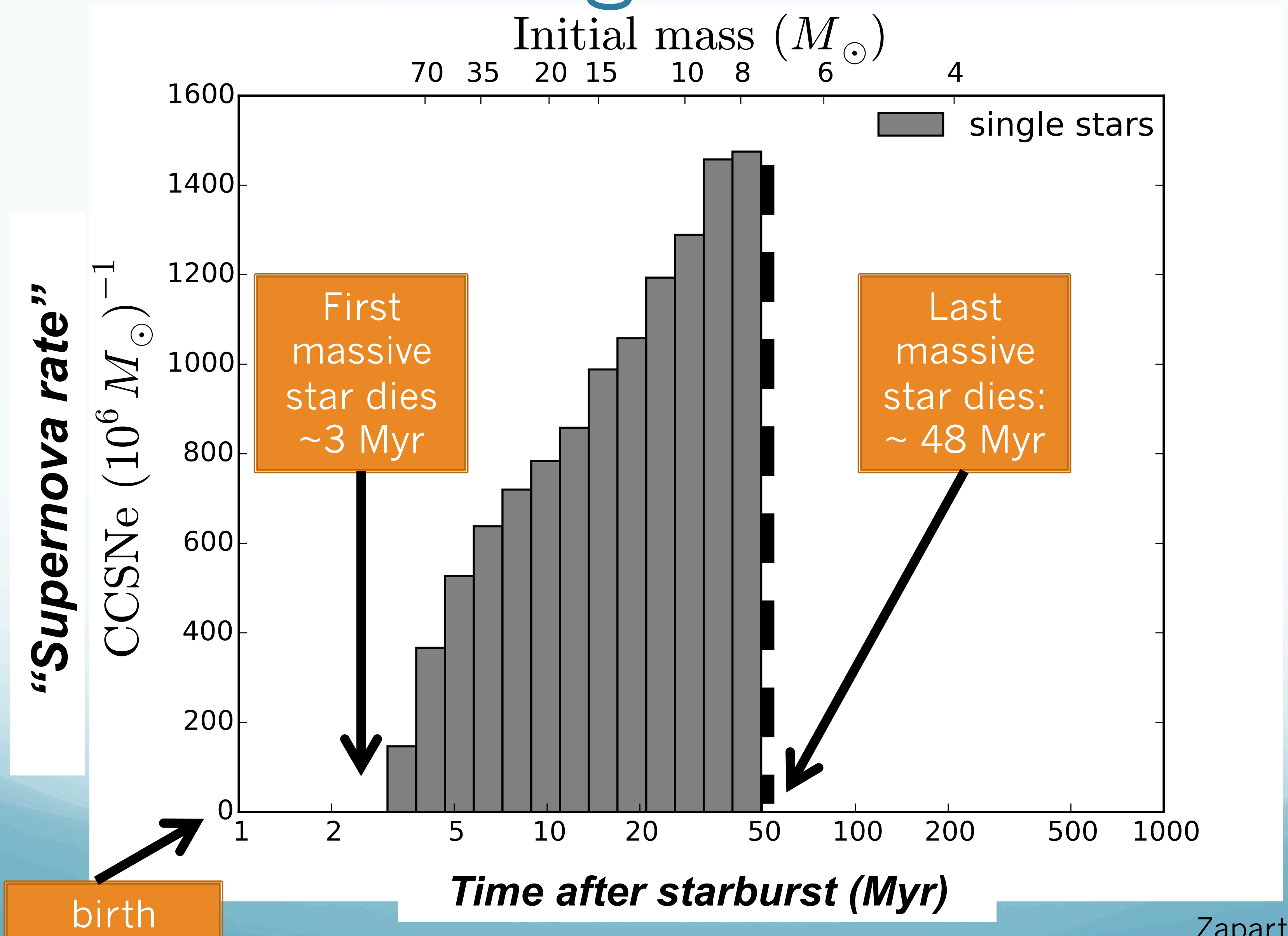
Credits: (ESO) Calçada, Kornmesser, De Mink

When do ccSNe explode?



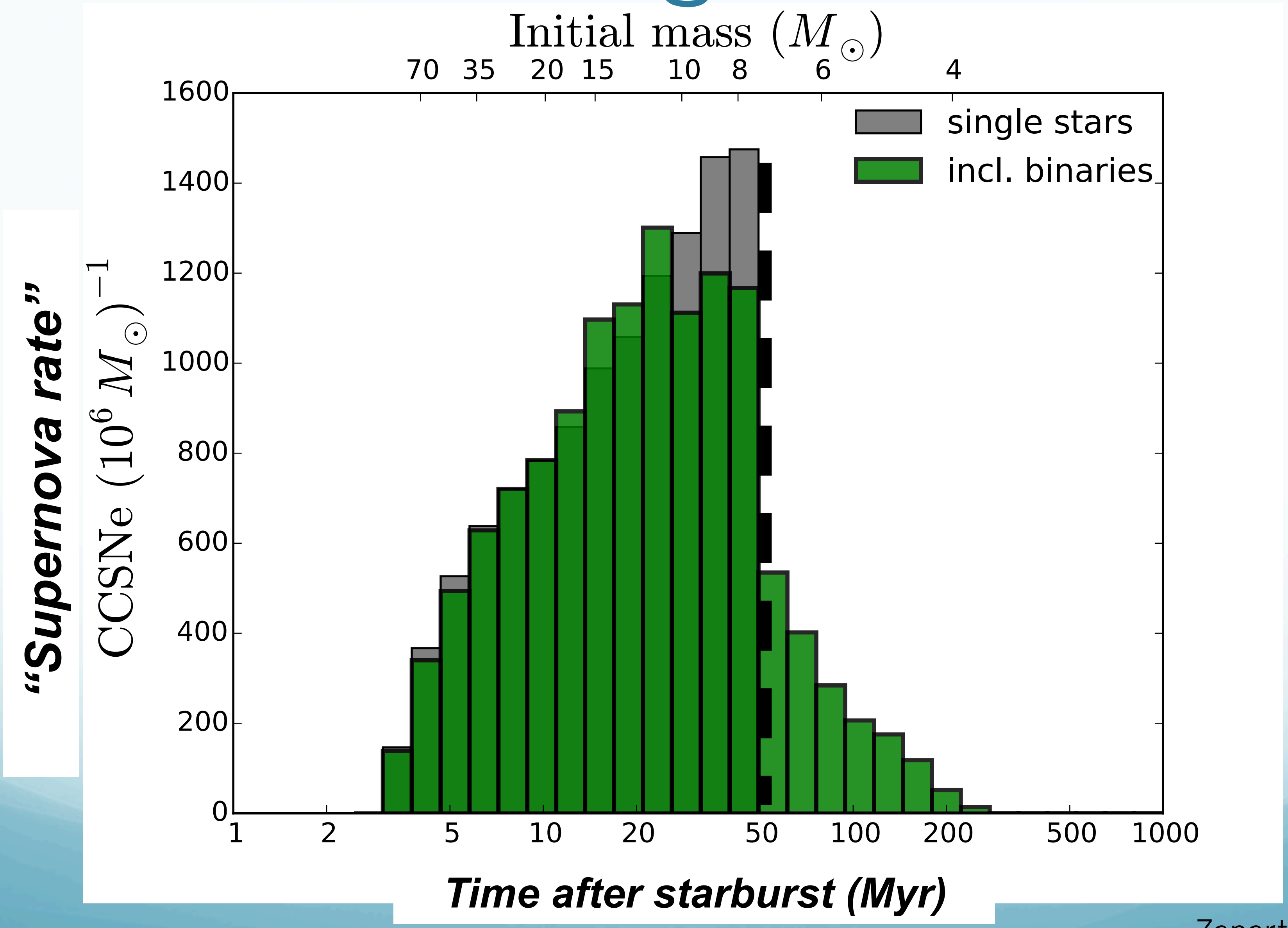
Zapartas+'17a

Single stars



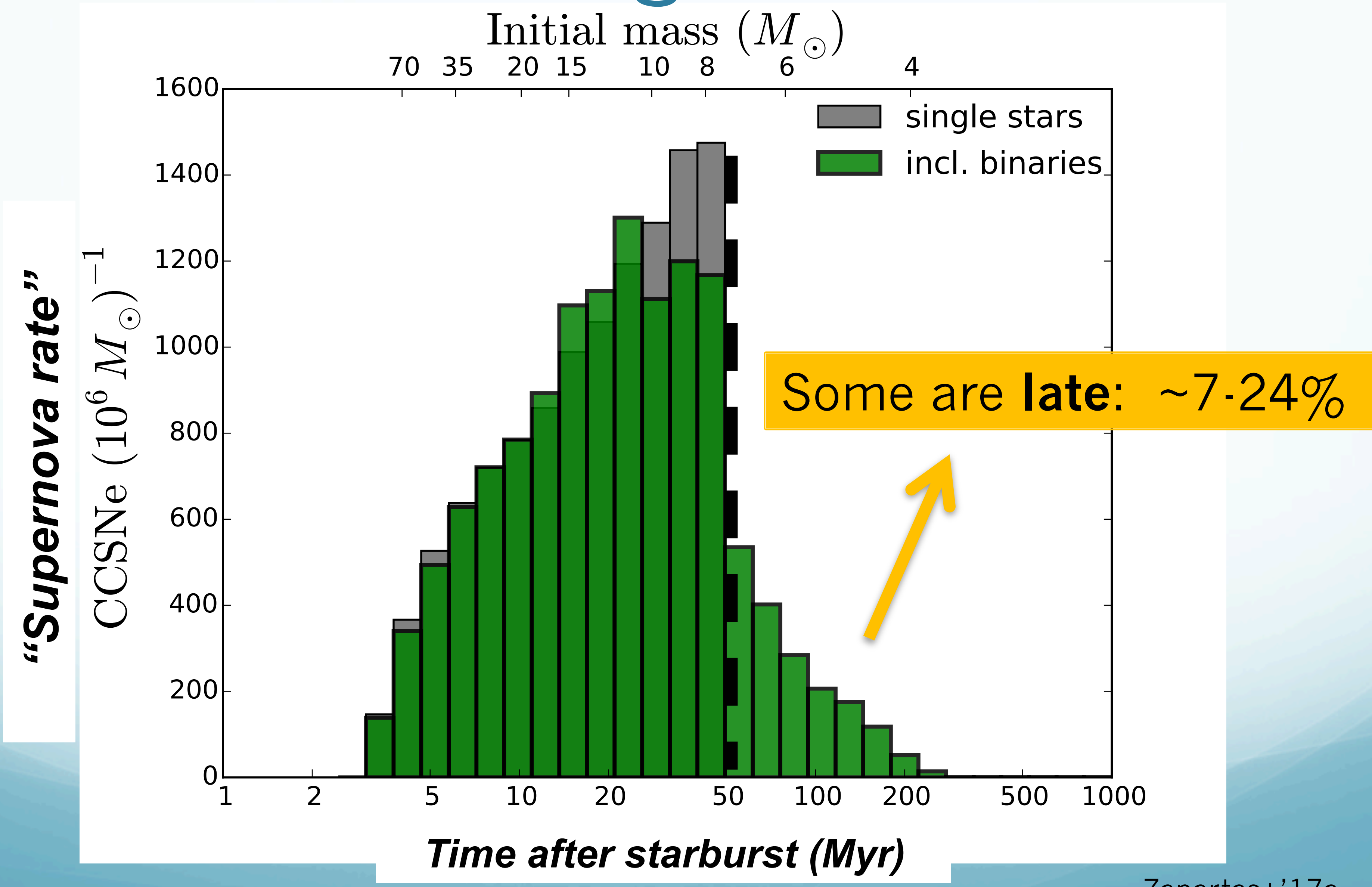
Zapartas+'17a

Including binaries



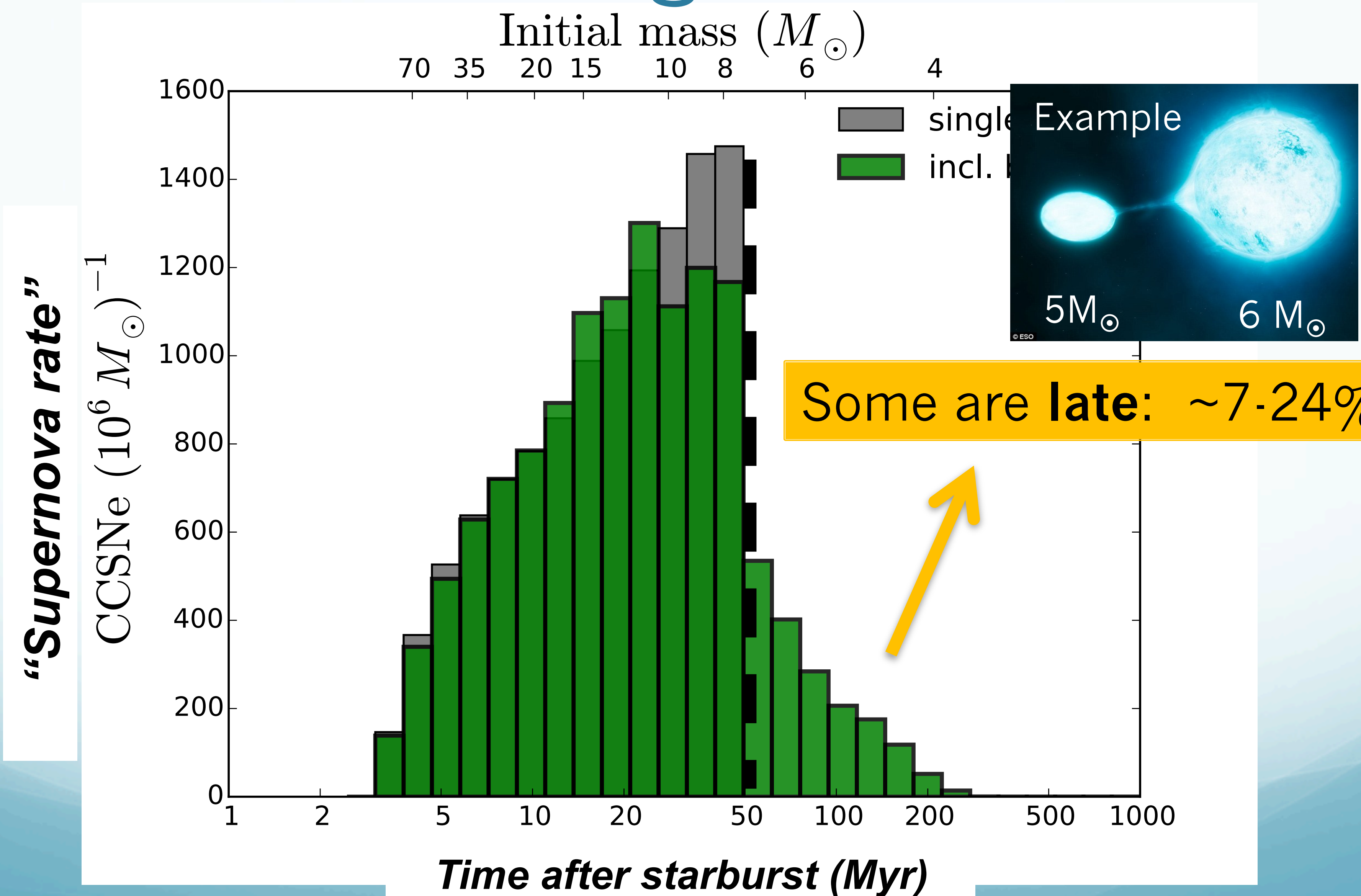
Zapartas+'17a

Including binaries



Zapartas+'17a

Including binaries

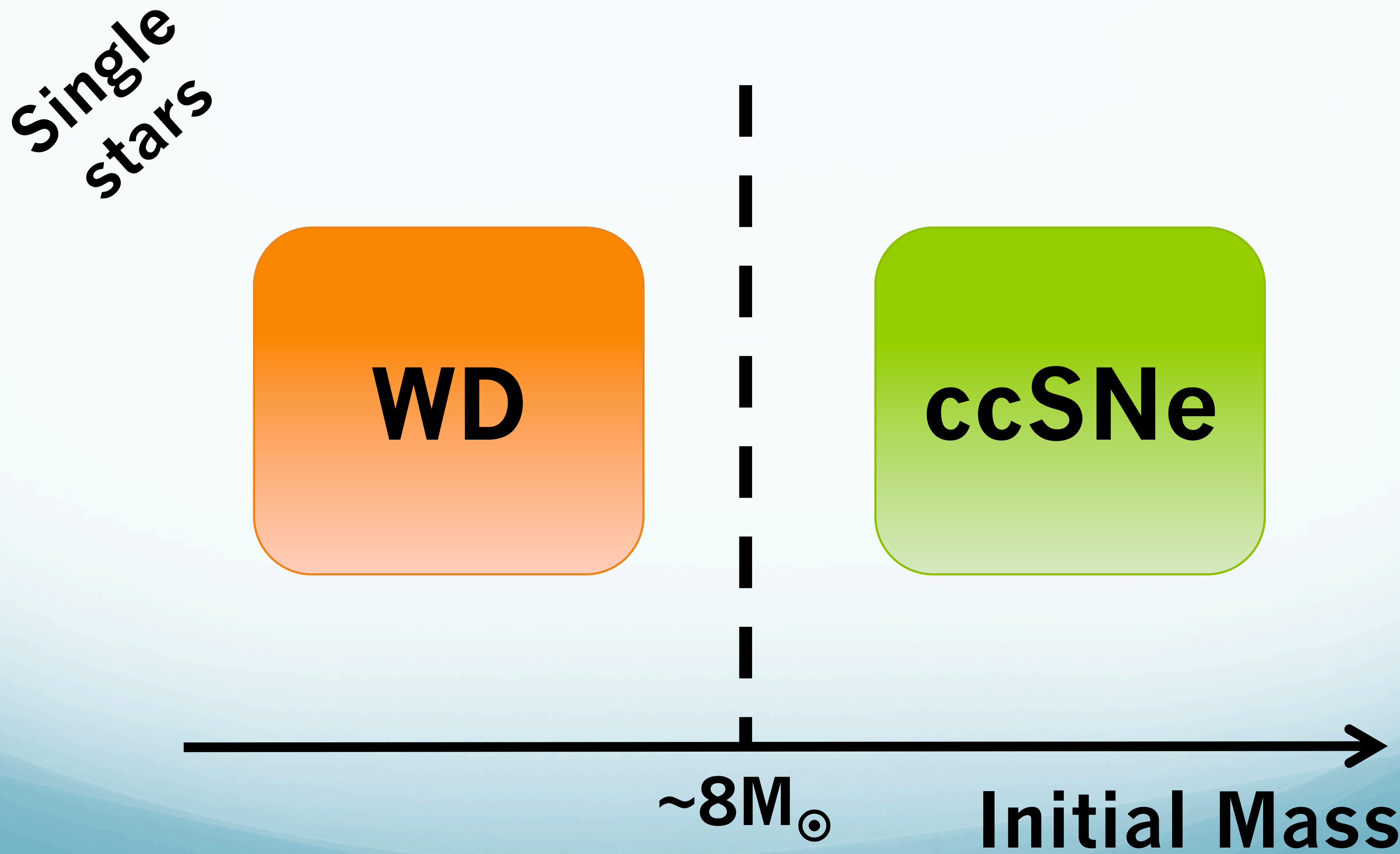


Some are **late**: ~7-24%

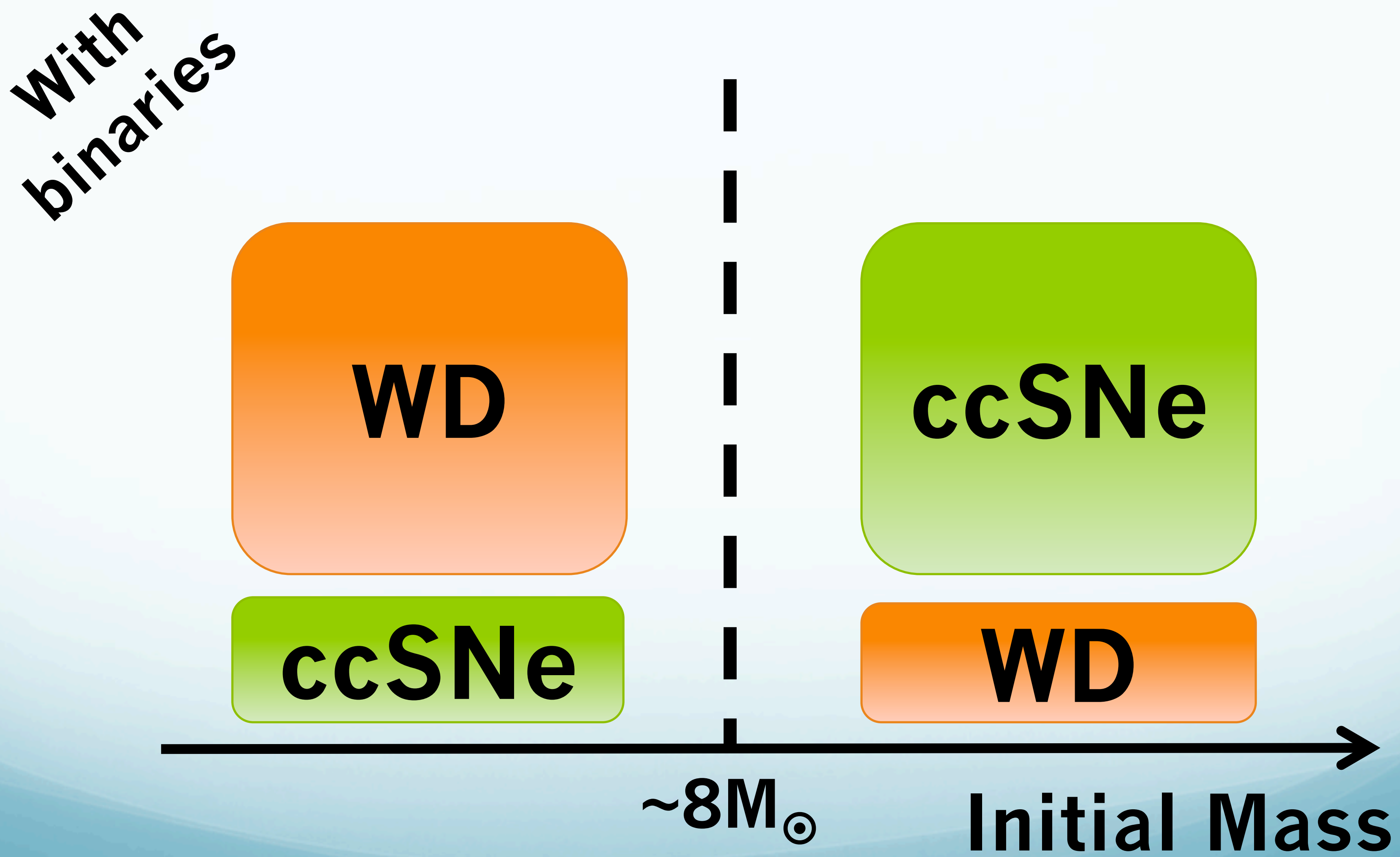
De Donder+Vanbeveren'03,'98, Xiao+Eldridge'15

Zapartas+'17a

Which stars explode in ccSNe?

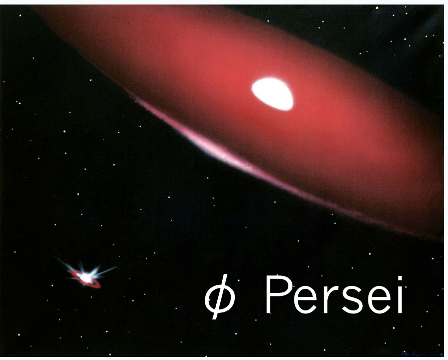


Which stars explode in ccSNe?



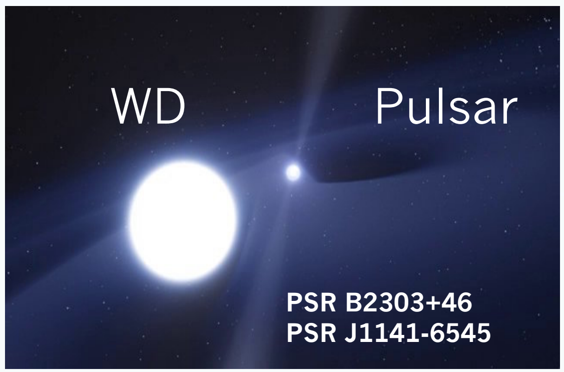
Possible observational signature of late ccSNe

Progenitor?



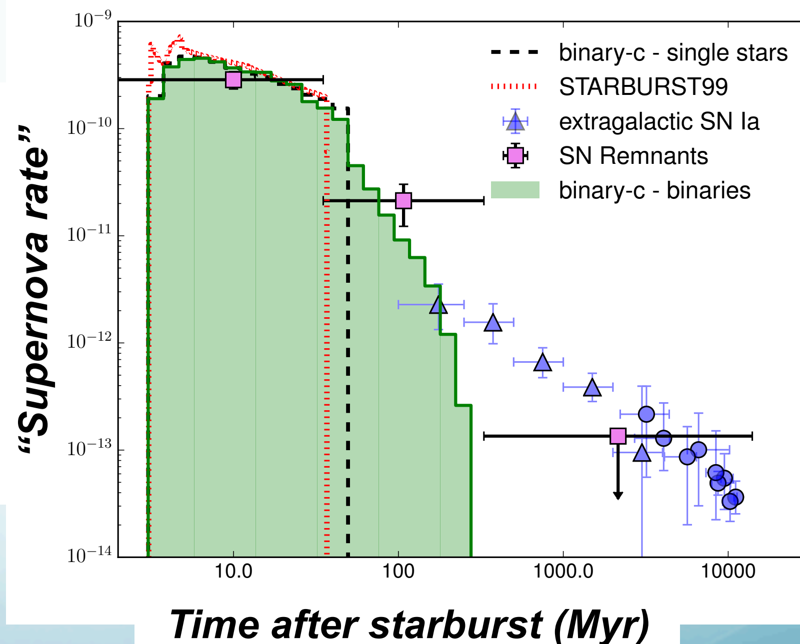
e.g.Mourard+'15
Pols '07
Vanbeveren+'98
Schootemeijer+(subm.)

Descendant?

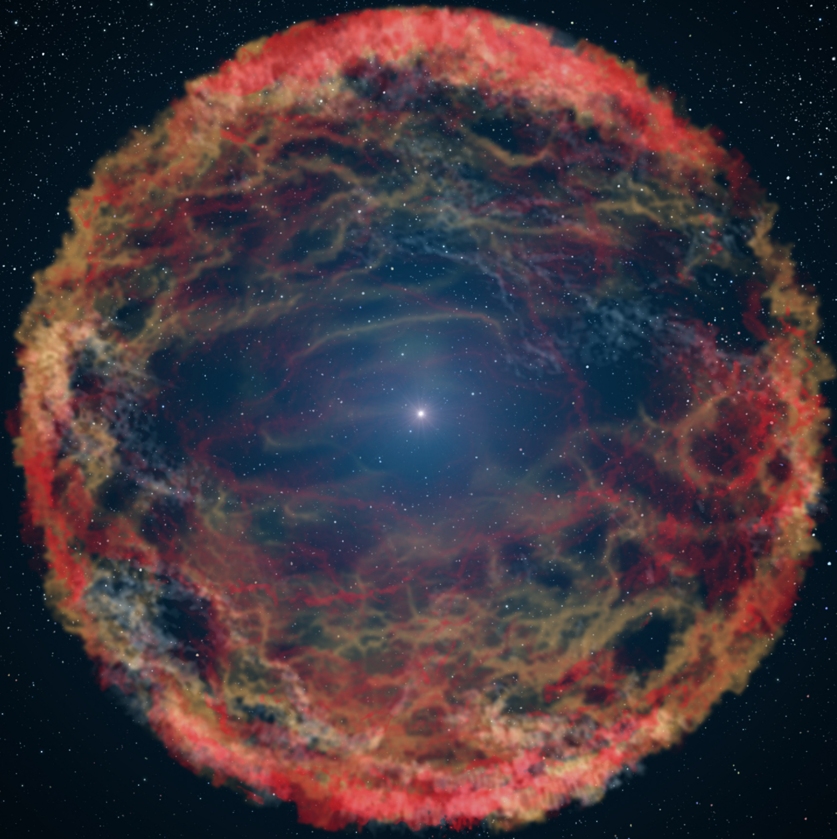


e.g.Portegies Zwart+Yungelson '99
Tauris+Sennels'00
Davies+Ritter+King'02
Kalogera+'05
Church+'06

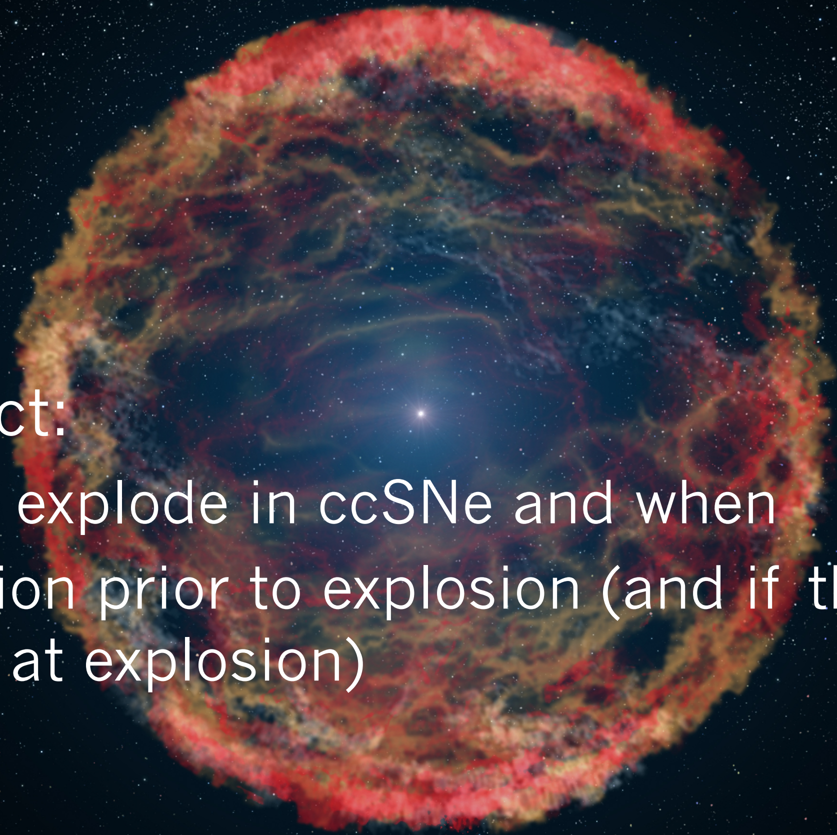
DTD through SN Remnants



Take home message



Take home message



- Binaries affect:
  - which stars explode in ccSNe and when
  - their evolution prior to explosion (and if they have a companion at explosion)

Take home message

- Binaries affect:
  - which stars explode in ccSNe and when
  - their evolution prior to explosion (and if they have a companion at explosion)

Thank you!

Backup slides

How robust are our predictions?

	Symbol	Standard models[a]	Model variations
Physical assumptions			
- mass transfer efficiency	β	β_{th}	0, 0.2, 1
- angular momentum loss	γ	$\gamma_{orb,acc}$	0, γ_{disk}
- mass loss during merger of two MS stars	μ_{loss}	0.1	0, 0.25
- mixing during merger of two MS stars	μ_{mix}	0.1	0, 1
- natal kick compact remnant (km s^{-1})	σ	265	σ_0, ∞
- common envelope efficiency	α_{CE}	1	0.1, 0.2, 0.5, 2, 5, 10
- envelope binding energy	λ_{CE}	$\lambda_{Dewi+00}$	0.5
- critical mass ratio for merger from MS donor	$q_{crit,MS}$	0.65	0.25, 0.8
- critical mass ratio for unstable mass transfer for HG donor	$q_{crit,HG}$	0.4	0, 0.25, 0.8, 1
- stellar wind mass loss efficiency parameter	η	1	0.33, 3
- maximum single star equivalent birth mass for ccSN ($M_\odot$)	$M_{max,cc}$	100	20, 35
- minimum metal core for ccSN ($M_\odot$)	$M_{min,metal}$	1.37	1.3, 1.4
Initial conditions			
- slope initial mass function	α	−2.3	-1.6, -2.7, -3.0
- slope initial mass ratio distribution	κ	0	-1, 1
- slope of initial period distr.	π	$\pi_{Opik24,Sana+12}$	-1, 1
- metallicity	Z	0.014	0.0002, 0.004, 0.008, 0.02, 0.03
- binary fraction[a]	f_{bin}	0.7 , 0.0[a]	0.3, 1, $f_{bin}(M_1)$
- normalization parameter ($M_\odot$)	M_{low}	2	1, 3

Late ccSNe: ~15%

variations: 7 - 24%

De Donder+Vanbeveren'03,'98, Xiao+Eldridge'15

Zapartas+'17a

Standard assumptions

- **Physical processes**
  - Stellar evolutionary models *(Pols+ '98, H00)*
  - Stellar winds & Mass loss *(Vink+ '00,'01,'05, Nieuwenhuijzen +de Jager'90, Hurley+'02)*
  - Tidal interaction: *(Hurley+'02, Zahn+ '89)*
  - Accretion & spin up: *(Hurley+'02, de Mink+ '13)*
  - Treatment of mergers & rejuvenation: *(Hurley+'02, de Mink+ '14)*
  - Common Envelope Evolution: (*Webbink '84, Dewi+Tauris'00)*
  - Supernova kicks: *(Hurley+'02, Hobbs+'05)*
  - Final masses & Compact objects: *(Hurley+'00)*

- **Initial conditions**
  - Binary fraction 70% or 50% for massive star *(Sana+ '12, Moe+'16)*
  - Initial Mass Function : $\alpha =$ -2.3 for massive stars *(Kroupa '01)*
  - Mass ratio: flat distribution *(Sana+ '12, Kobulnucky+ '14)*
  - Orbital period:
    - favors close systems *(Sana+'12)* , flat distribution*(Öpik '24, Kouwenhoven+'07)*

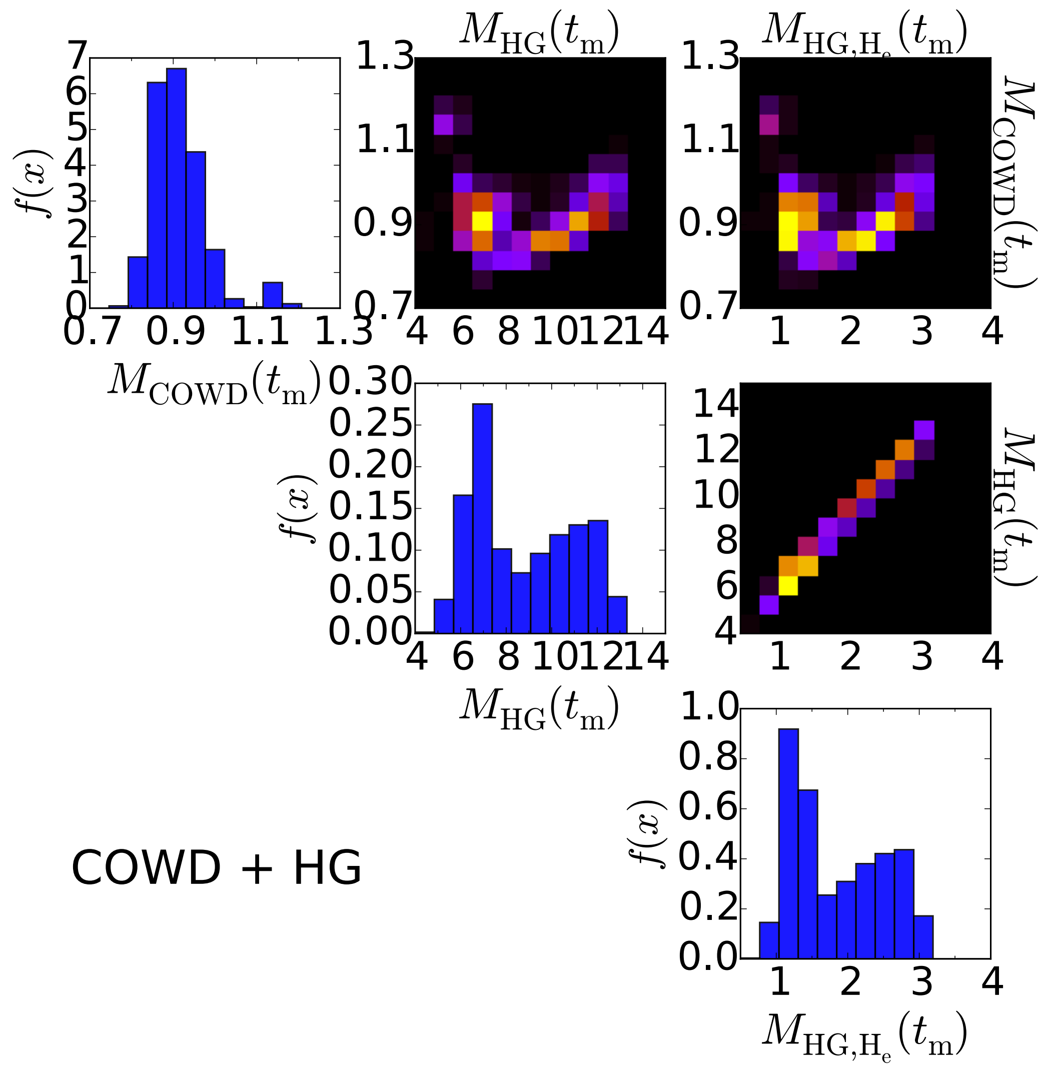
Id	Description		f_{late}	$t_{50\%,late}$ (Myr)	$t_{90\%,late}$ (Myr)
00	**Standard Simulations**		**14.2%**	**71.0**	**143.5**
Physical assumptions					
01	mass transfer efficiency	$\beta = 0$	9.7%	67.7	131.9
02	””	$\beta = 0.2$	12.1%	61.5	151.4
03	””	$\beta = 1$	21.9%	78.2	143.5
04	angular momentum loss	$\gamma = 0$	15.1%	68.9	146.9
05	””	$\gamma = \gamma_{disk}$	13.7%	68.1	133.5
06	mass loss during merger	$\mu_{loss} = 0$	15.4%	71.0	151.4
07	””	$\mu_{loss} = 0.25$	14.8%	67.7	136.7
08	mixing during merger	$\mu_{mix} = 0$	14.8%	68.9	142.6
09	””	$\mu_{mix} = 1$	15.6%	68.9	140.0
10	natal kick compact remant	$\sigma = \sigma_0$	15.3%	70.1	142.6
11	””	$\sigma = \infty$	14.5%	68.9	141.7
12	common envelope efficiency	$\alpha_{CE} = 0.1$	15.7%	75.4	146.1
13	””	$\alpha_{CE} = 0.2$	16.5%	77.2	157.9
14	””	$\alpha_{CE} = 0.5$	16.9%	71.4	150.5
15	””	$\alpha_{CE} = 2.0$	12.8%	67.3	136.7
16	””	$\alpha_{CE} = 5.0$	7.6%	61.5	134.3
17	””	$\alpha_{CE} = 10.0$	6.7%	61.1	139.2
18	envelope binding energy	$\lambda_{CE} = 0.5$	15.8%	74.9	172.8
19	critical mass ratios for contact	$q_{crit,MS} = 0.25$	14.4%	71.0	144.3
20	””	$q_{crit,MS} = 0.8$	15.1%	68.1	139.2
21	””	$q_{crit,HG} = 0.0$	14.8%	77.7	171.8
22	””	$q_{crit,HG} = 0.25$	13.9%	71.9	146.1
23	””	$q_{crit,HG} = 0.8$	19.8%	71.4	122.0
24	””	$q_{crit,HG} = 0.99$	22.0%	75.4	132.7
25	wind mass loss efficiency	$\eta = 0.33$	14.5%	71.9	147.8
26	””	$\eta = 3.0$	15.2%	67.3	135.9
27	exclusion WD mergers*		11.7%	72.3	154.2
28	threshold for core collapse	$M_{max,cc} = 35$	15.1%	71.4	145.2
29	””	$M_{max,cc} = 20$	18.2%	71.4	145.2
30	””	$M_{min,metal} = 1.30$	14.7%	79.6	162.8
31	””	$M_{min,metal} = 1.40$	15.8%	59.3	124.2
Initial conditions					
32	initial mass function	$\alpha = -1.6$	8.1%	66.9	131.9
33	””	$\alpha = -2.7$	18.5%	74.9	152.3
34	””	$\alpha = -3.0$	24.0%	72.3	149.6
35	initial mass ratio distribution	$\kappa = -1$	12.2%	62.2	124.2
36	””	$\kappa = +1$	17.5%	73.6	146.9
37	initial period distribution	$\pi = +1$	10.3%	69.3	135.9
38	””	$\pi = -1$	20.9%	77.7	151.4
39	metallicity	$Z = 0.0002$	10.2%	93.6	205.8
40	””	$Z = 0.001$	10.9%	86.6	176.0
41	””	$Z = 0.004$	12.3%	79.6	157.9
42	””	$Z = 0.008$	13.4%	75.8	144.3
43	””	$Z = 0.02$	14.5%	66.9	132.7
44	””	$Z = 0.03$	14.3%	64.5	131.1
45	binary fraction	$f_{bin} = 0.3$	6.7%	71.4	145.2
46	””	$f_{bin} = 1.0$	19.2%	68.9	142.6
47	mass dependent binary fraction	$f_{bin}(M_1)$	11.3%	68.5	137.5
48	normalization parameter	$M_{low} = 1M_\odot$	14.0%	71.4	145.2
49	””	$M_{low} = 3M_\odot$	14.0%	71.2	145.2

Zapartas+’17a

Simulation	$t_{50\%,\mathrm{all}}$ (Myr)	$t_{90\%,\mathrm{all}}$ (Myr)	f_{late}
Single stars			
- STARBURST99 (default)	15.0	32.7	0%
- STARBURST99 (modified)	16.4	36.7	0%
- BRUSSELS (DV03)	23.1	39.7	0%
- BPASS v2.0	17.0	50.1	0%
- **this work**	**19.6**	**41.6**	**0%**
Including binary stars			
- BRUSSELS (DV03)	31.5	112.7	23%
- BPASS v2.0	17.7	63.1	8.5%
- **this work**	**21.5**	**60.7**	**14.2%**

Zapartas+'17a

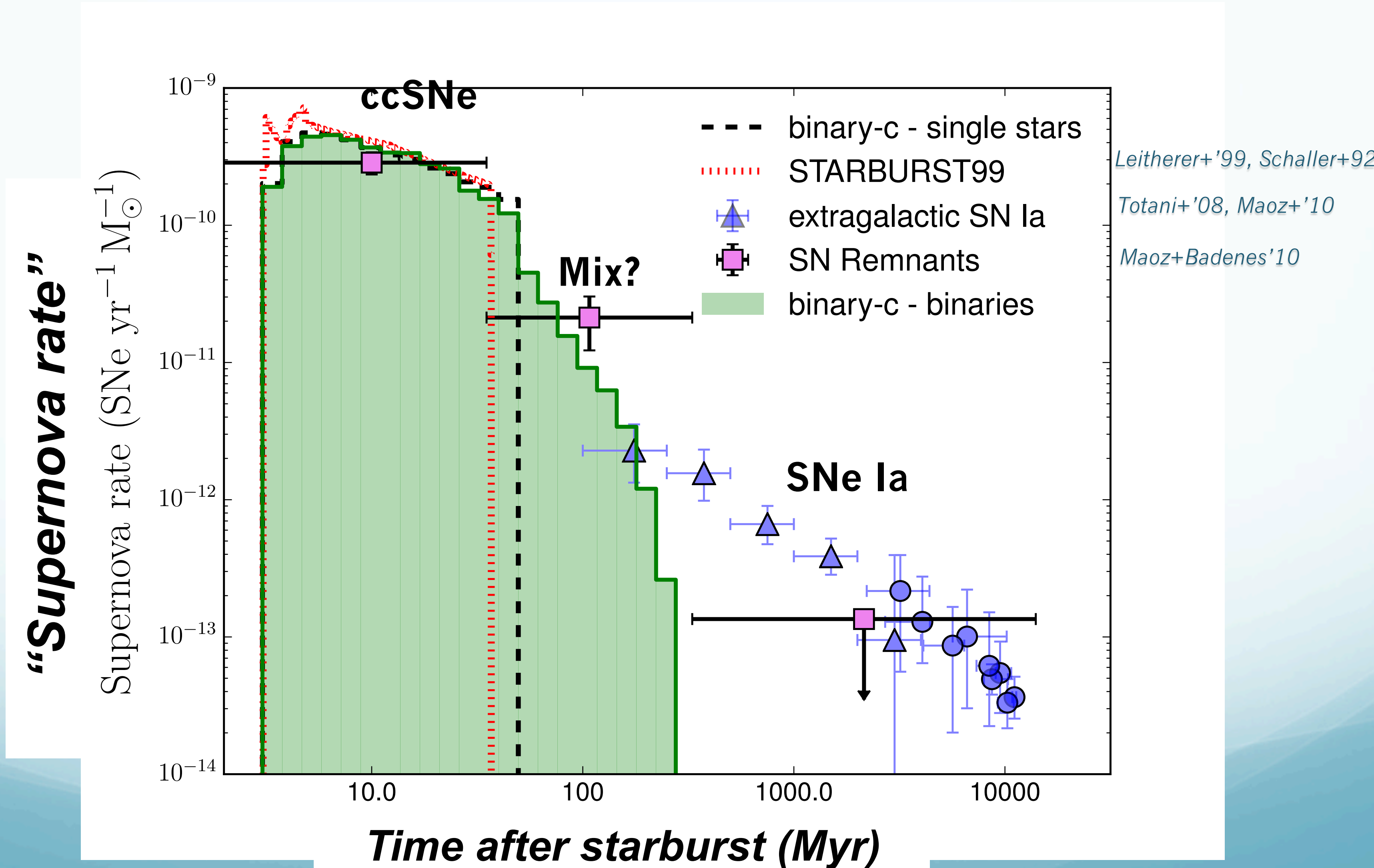
COWD mergers



COWD + HG

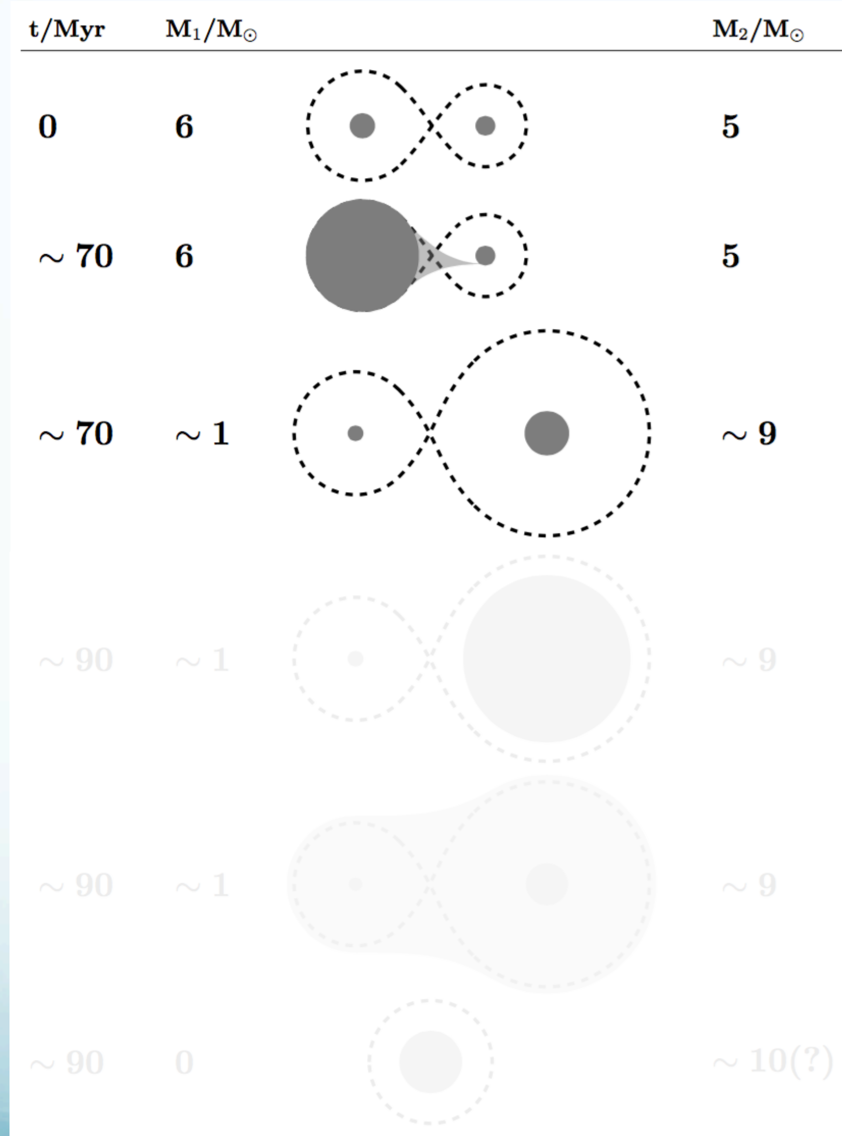
Zapartas+’17a

Possible observational signature of late ccSNe



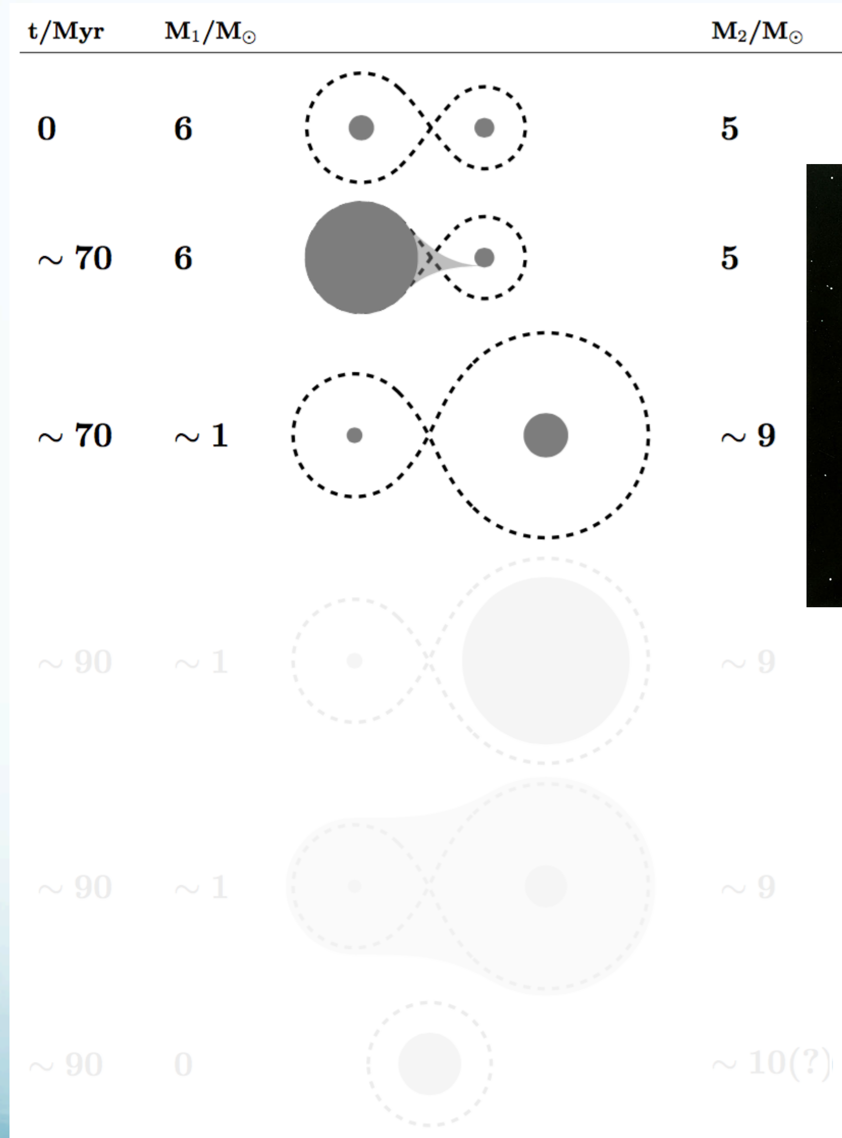
Zapartas+'17a

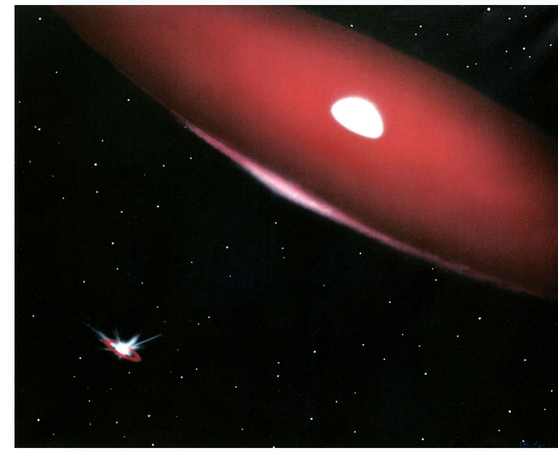
Channels for late ccSNe (15%) from intermediate-mass binaries



Credit: Bill Pounds

Channels for late ccSNe (15%) from intermediate-mass binaries

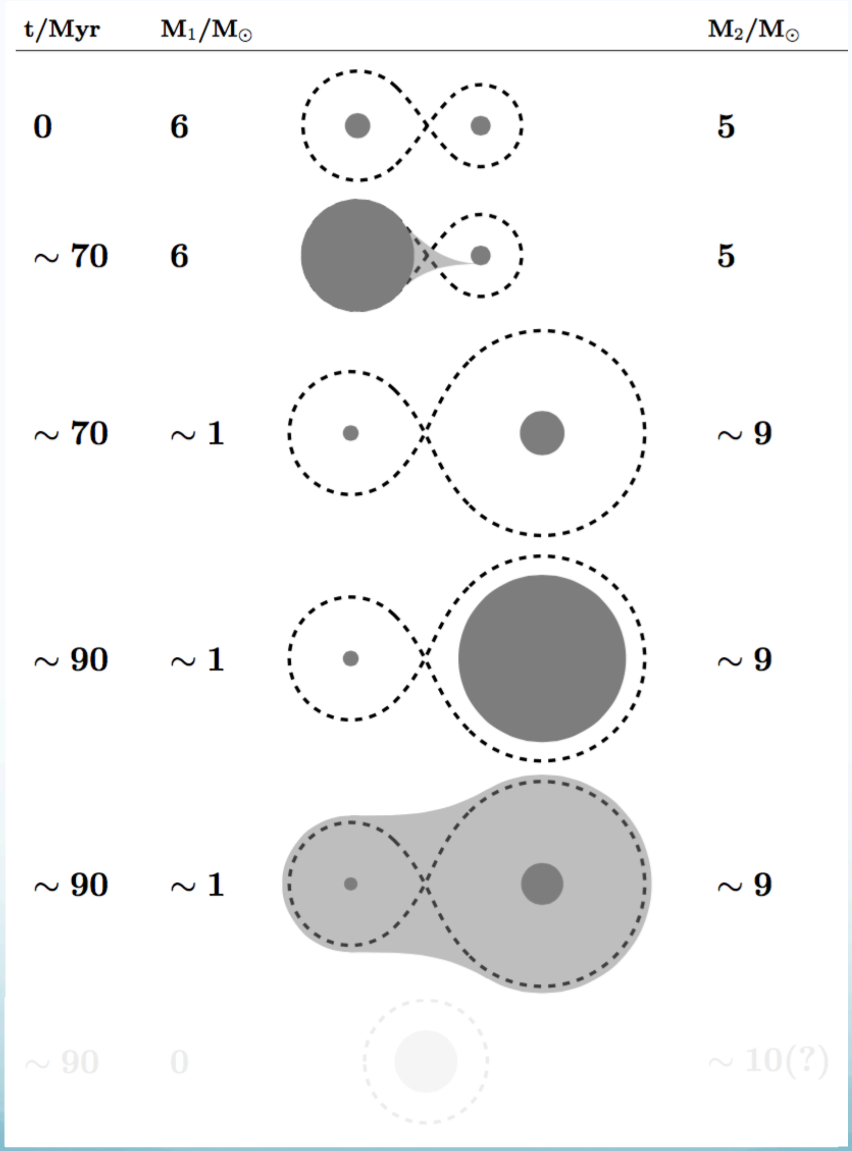




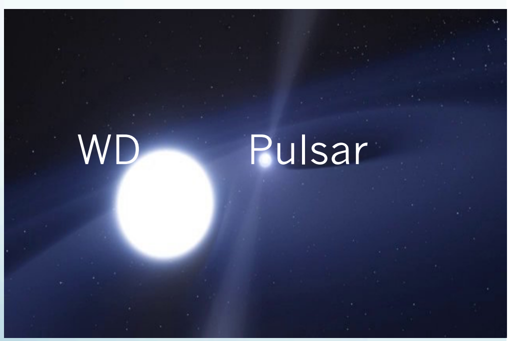
ϕ Persei ?

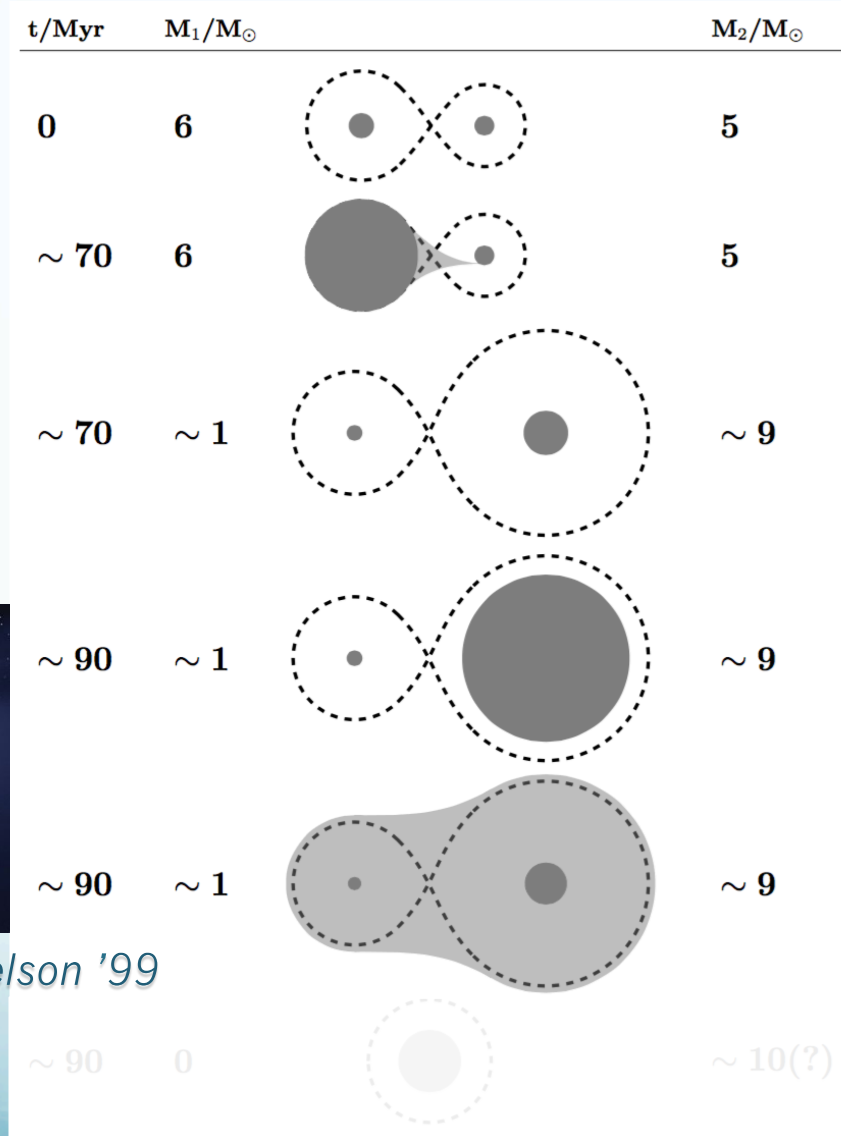
e.g. *Mourard+'15*
Schootemeijer+(in prep.)
Pols '07
Vanbeveren+'98

Channels for late ccSNe (15%) from intermediate-mass binaries



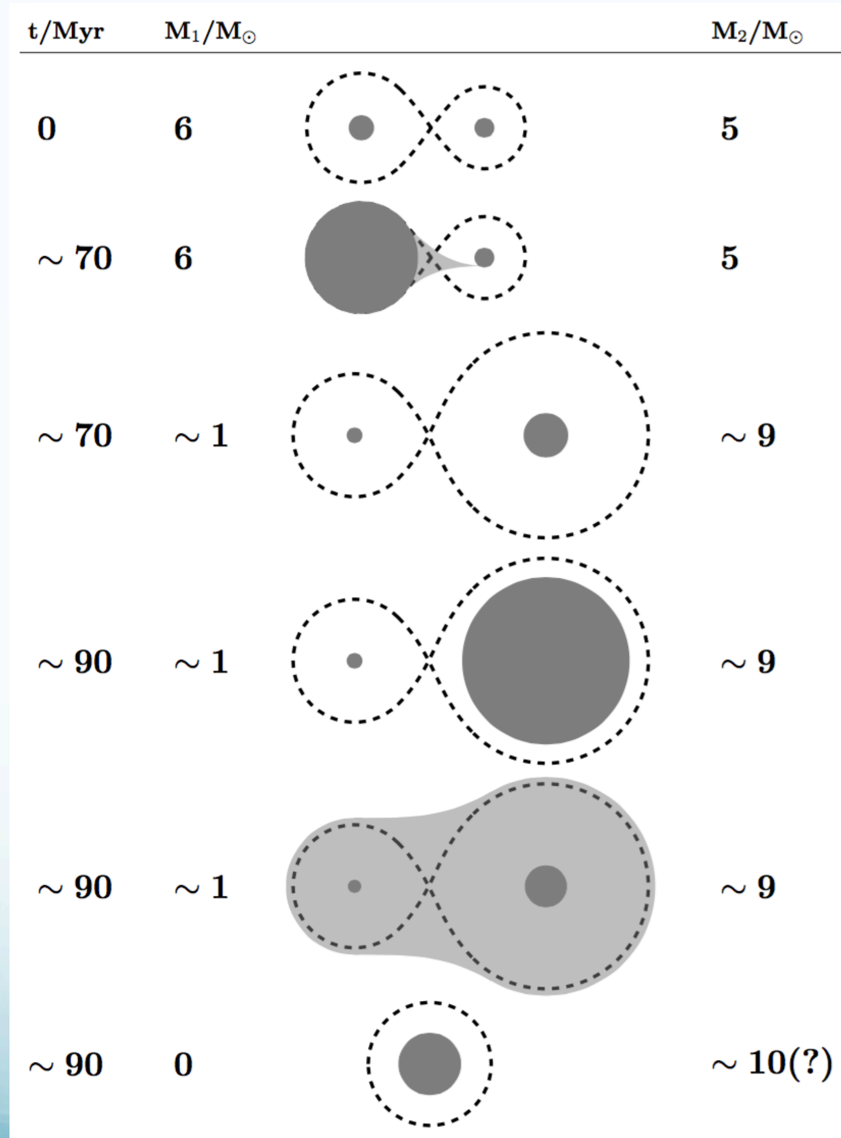
Channels for late ccSNe (15%) from intermediate-mass binaries





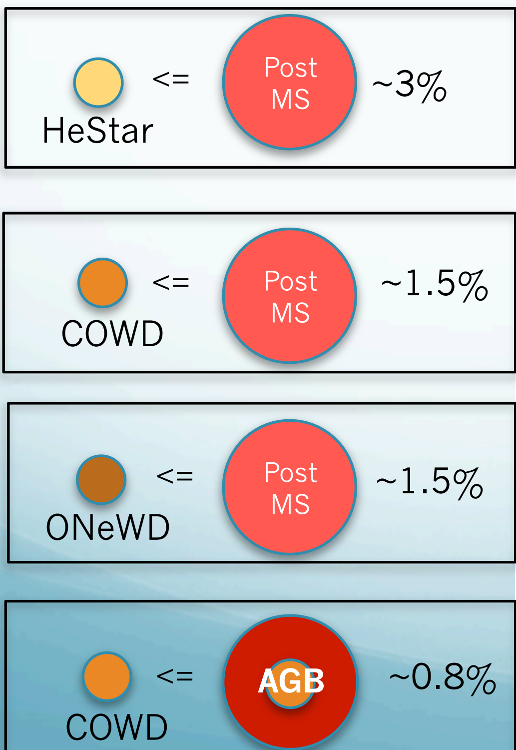
e.g. *Portegies Zwart+Yungelson '99*
Tauris+Sennels'00
Davies+Ritter+King'02
Kalogera+'05
Church+'06

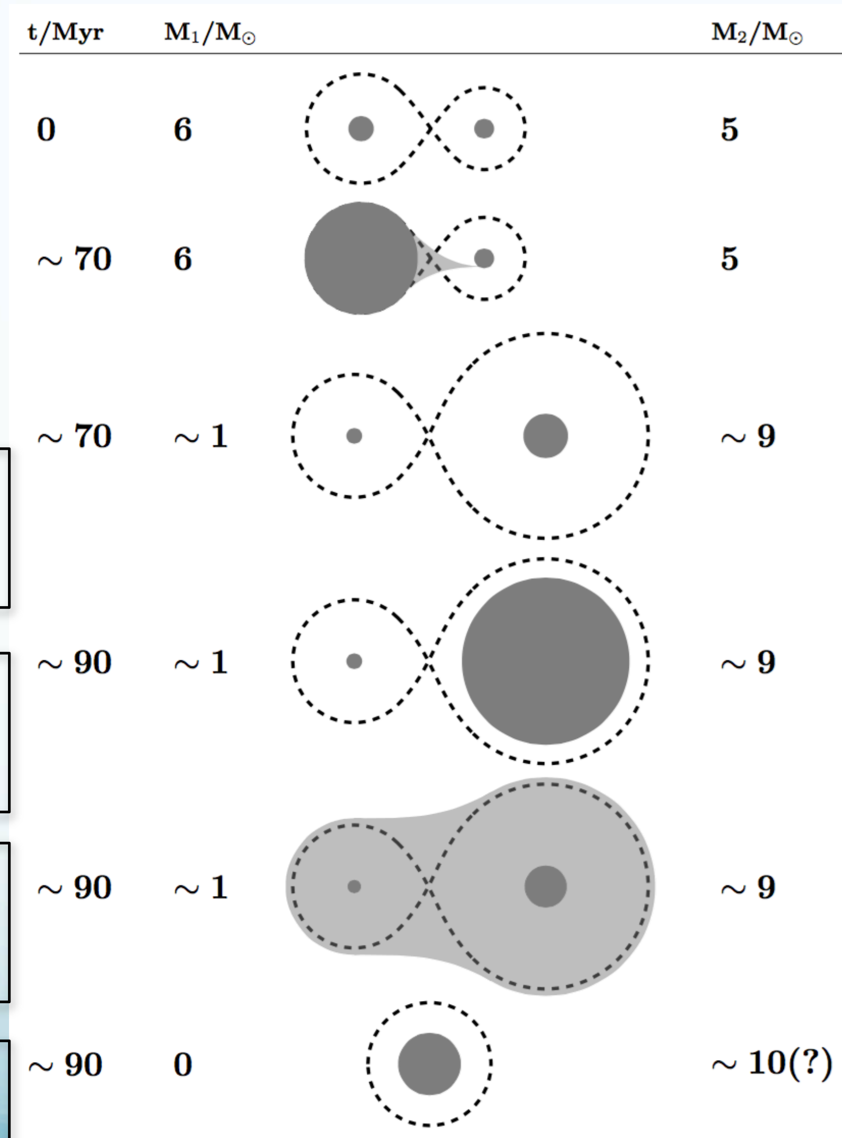
Channels for late ccSNe (15%) from intermediate-mass binaries



e.g. *Sparks+Stecher'74*
Sabach+Soker'14

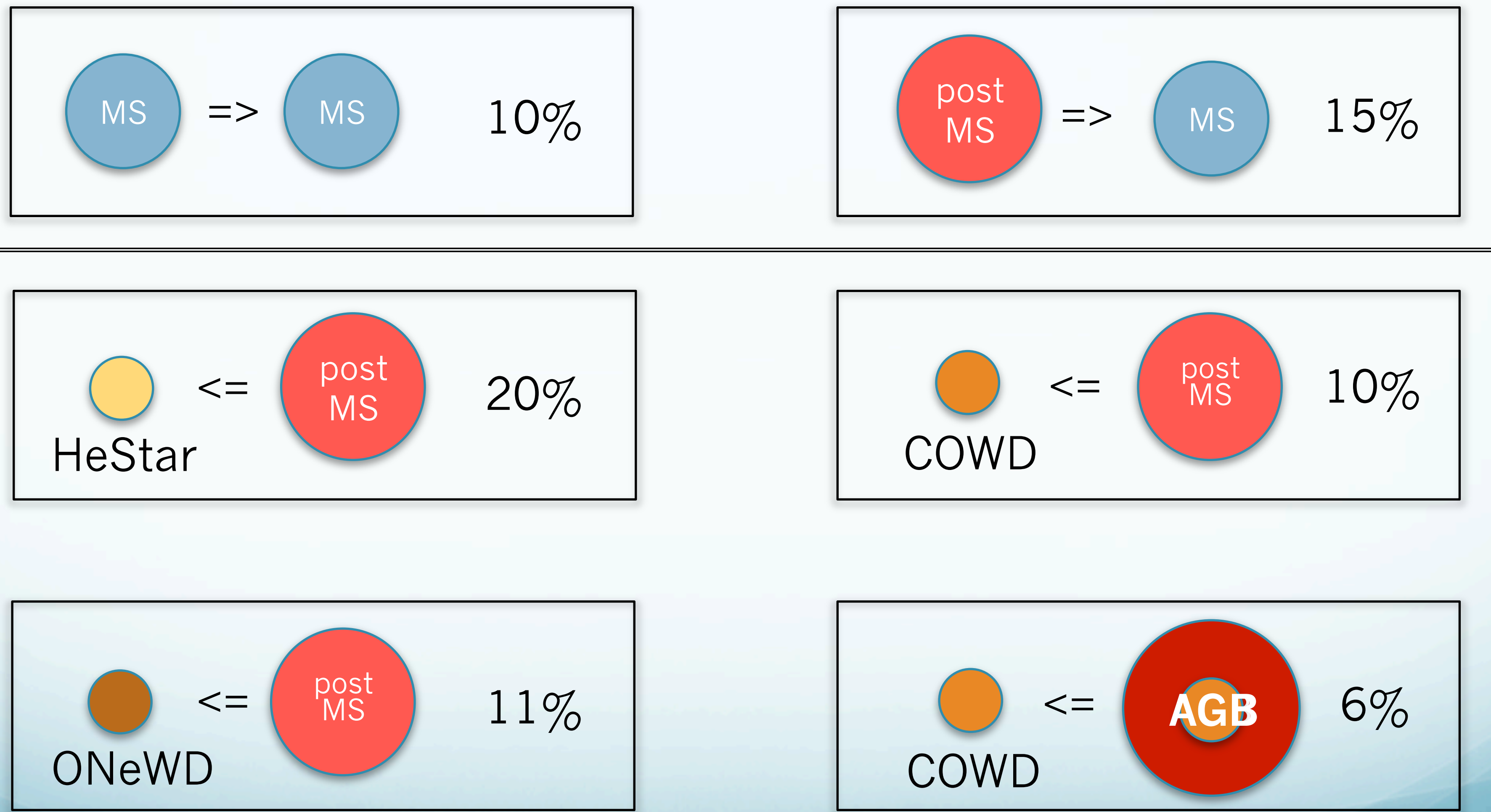
Channels for late ccSNe (15%) from intermediate-mass binaries





e.g. Sparks+Stecher'74
Sabach+Soker'14

Channels for late SN (15% of total)



Zapartas+'17a