The disappearance of the He-giant progenitor of the Type Ib SN iPTF13bvn and constraints on its companion

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2016 Dec 1

김상철(Sang Chul KIM)


nzstars2016.nz
IAUS 329
The lives and death-throes of massive stars
Auckland, New Zealand | 28 November – 2 December 2016
Grand star-forming region R136 in NGC 2070 (captured by the Hubble Space Telescope) by NASA, ESA
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Characteristics of Supernovae

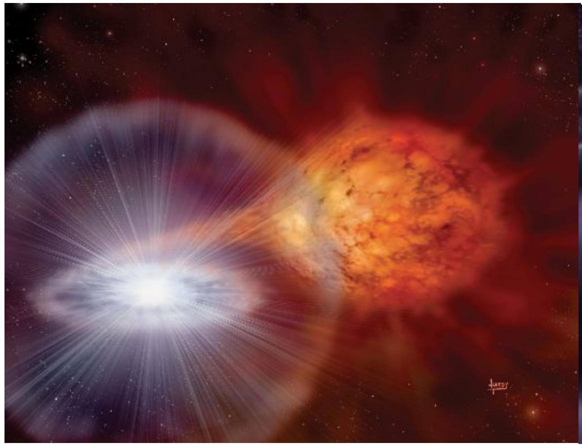
- **Brightest objects in galaxies (M_V = -14 ~ -22)**
- **Typical types**

No H lines (pop II) → Type Ia

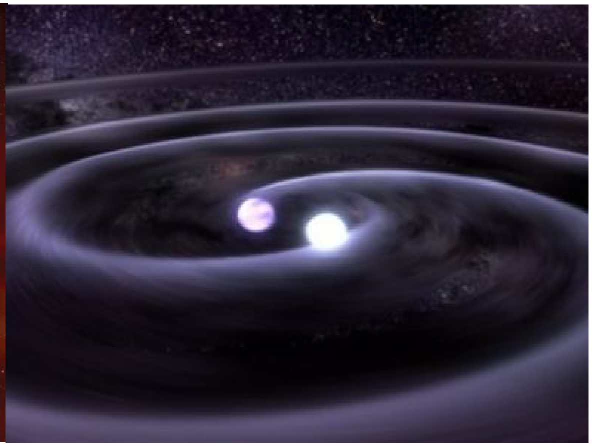
H lines (pop I) → Type II

Ib

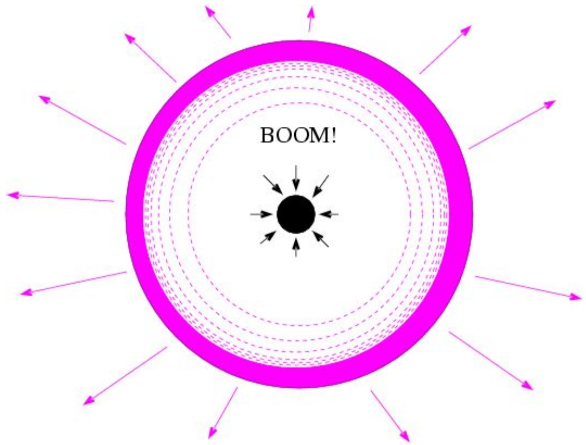
Ic



WD + Giant/MS/He *
(Single Degenerate, SD)



WD + WD
(Double Degenerate, DD)



Core collapse

SNe Ia (thermonuclear stellar explosion)
(WD originated SNe)
백색왜성 기원 초신성

CC SNe

핵붕괴 초신성

http://dujs.dartmouth.edu/2008/05/type-ia-supernovae-properties-models-and-theories-of-their-progenitor-systems
http://wwwmpa.mpa-garching.mpg.de/mpa/research/current_research/hl2013-8/hl2013-8-en.html
http://spiff.rit.edu/richmond/sdss/sn_survey/sn_survey.html

Supernova taxonomy

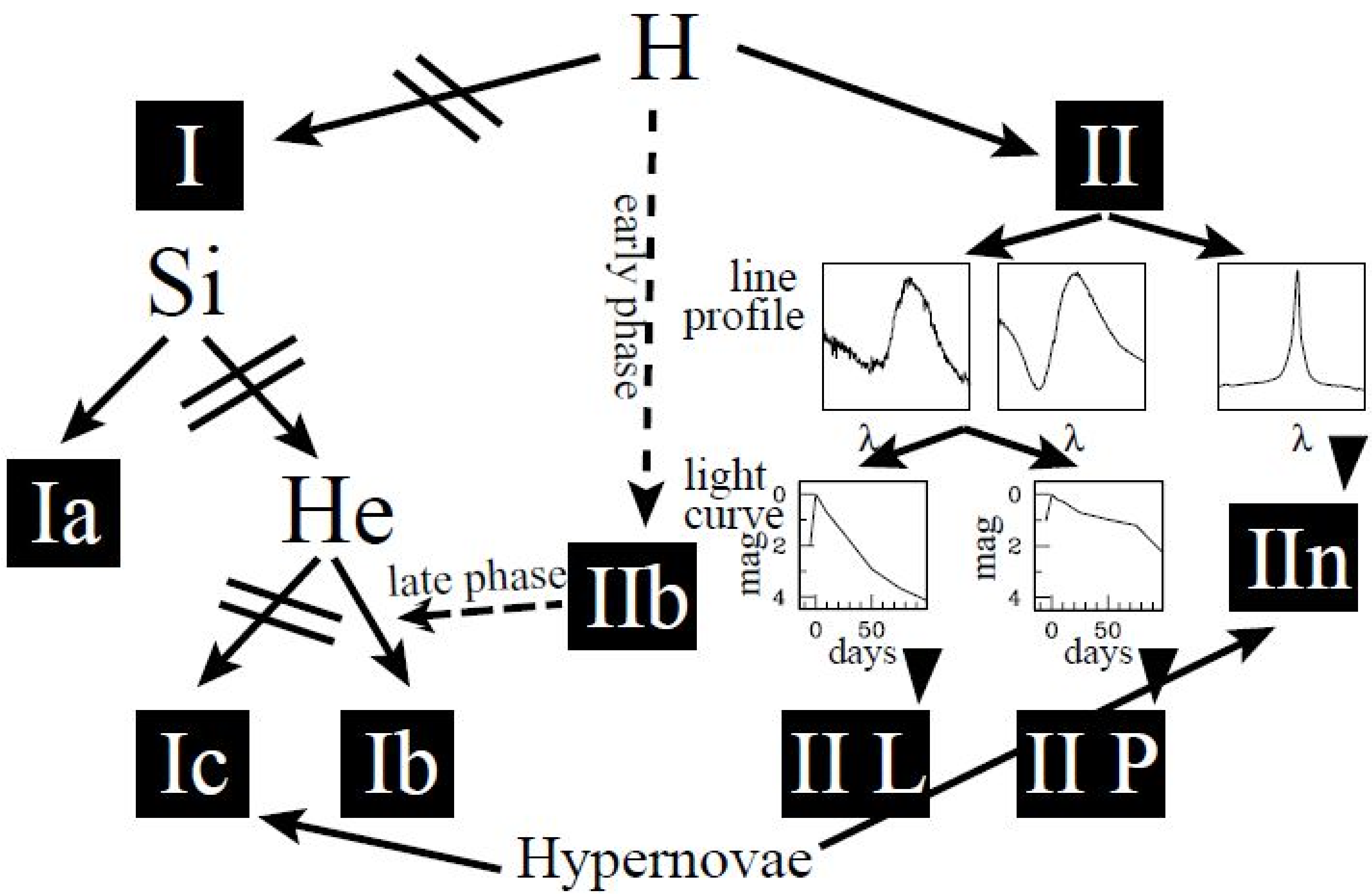
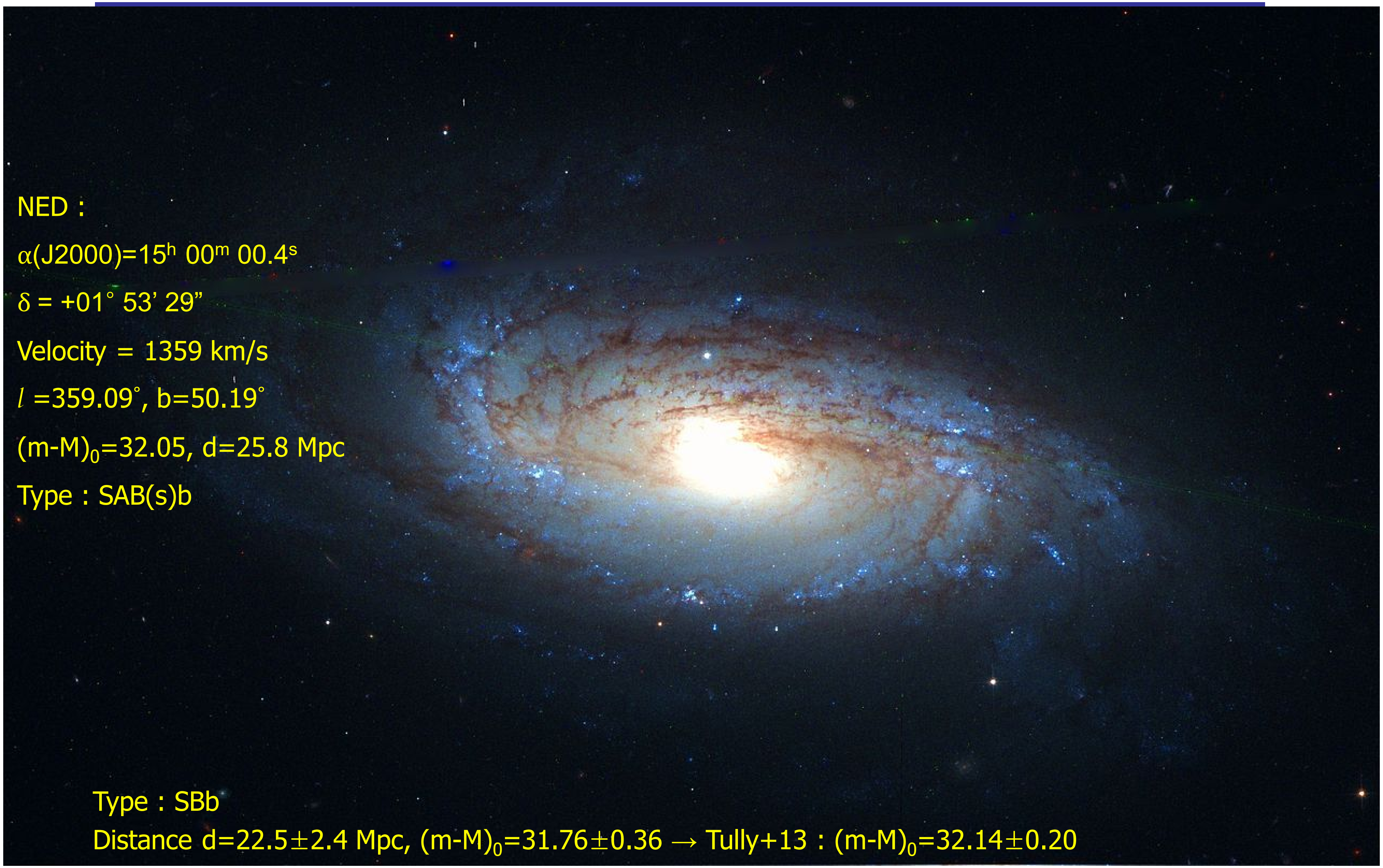


Figure 2. The detailed classification of SNe requires not only the identification of specific features in the early spectra, but also the analysis of the line profiles, luminosity and spectral evolutions

Cappellaro & Turatto (astro-ph/0012455)

Host galaxy, NGC 5806



Reddening : E(B-V)=0.045 to 0.17±0.03 mag

(Eldridge & Maund 16)

iPTF13bvn

NGC 5806

Explosion date :

2013 June 15.67

SN position :

α(J2000)=15^h 00^m 00.152^s,

δ(J2000)= +01° 52' 53.17"

1σ, 3σ error circles

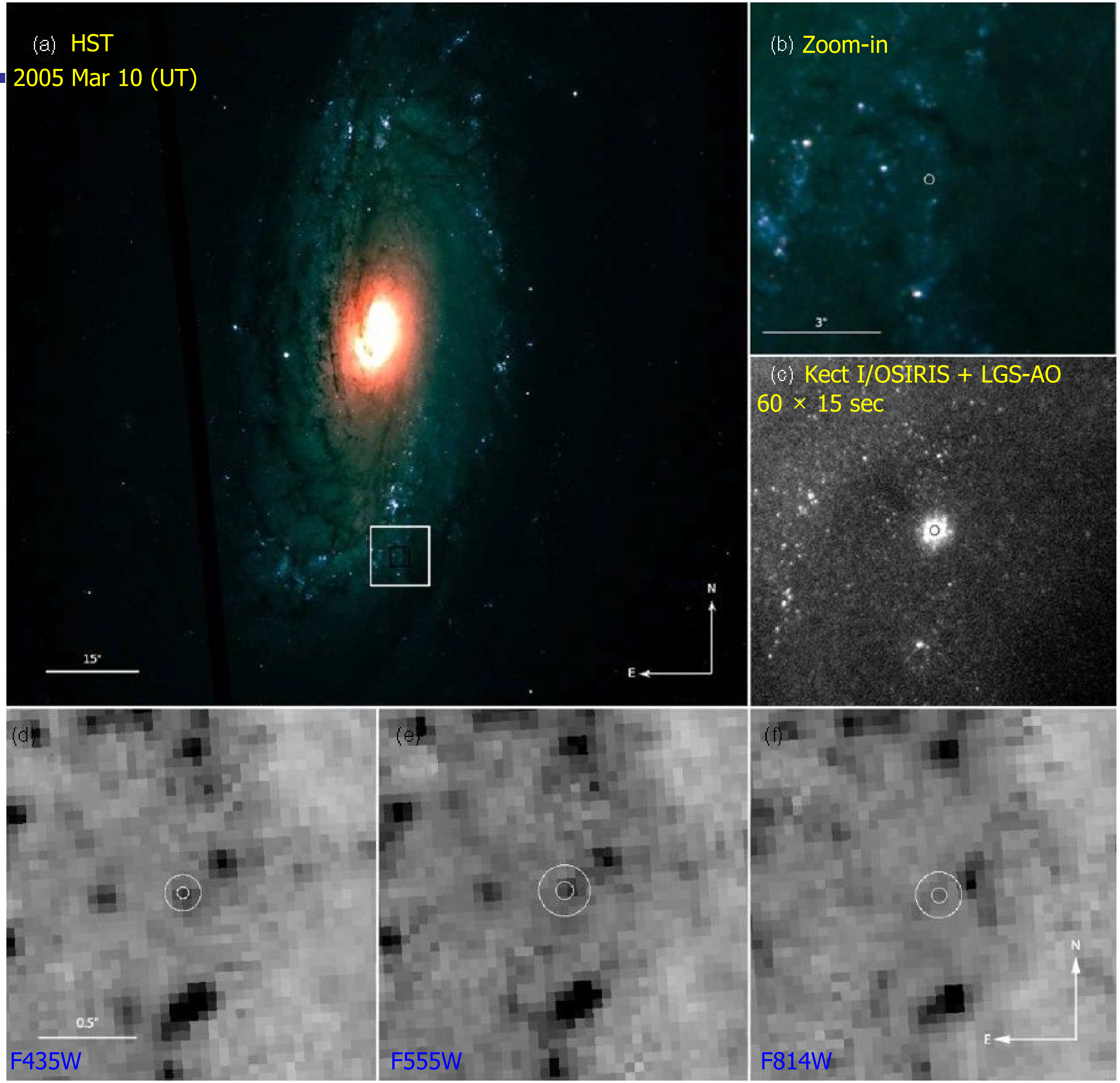
Progenitor candidate :

F435W=25.80±0.12 mag

F555W=25.80±0.11 mag

F814W=25.88±0.24 mag

First detection of SN Ib/c progenitor!



Cao+13 (ApJ 775 L7)

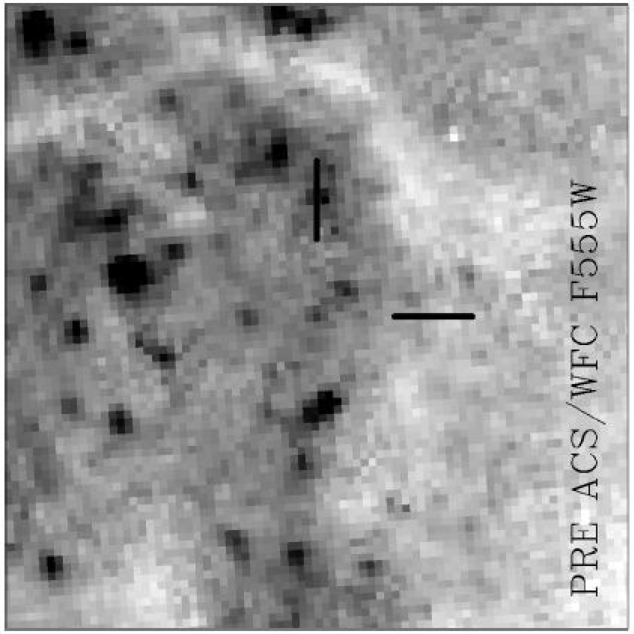
Late-time Observations

- HST/WFC3 (Wide Field Camera 3) / UVIS (Ultraviolet-Visible channel)
- 2015 June 26 (+740 d post-explosion)
- F438W : 2×2680 s, F555W : 2860 + 2750 s

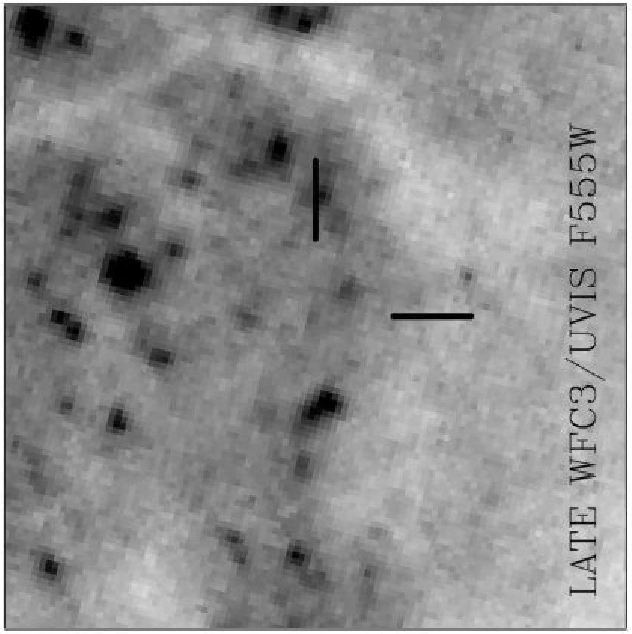
F438W=26.48±0.08 mag

F555W=26.33±0.05 mag

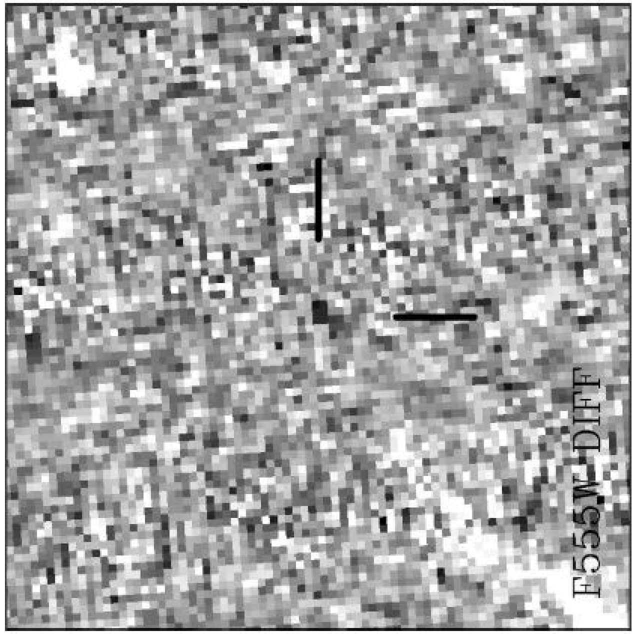
Pre-explosion



Late-time



Difference image (pre – post)



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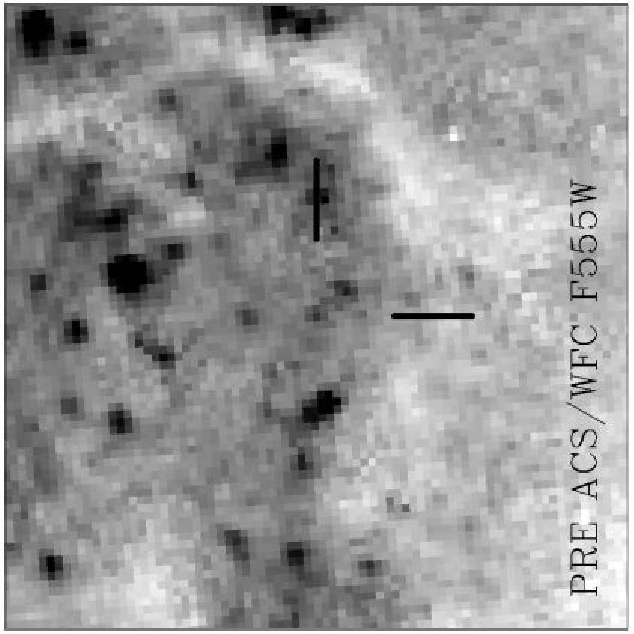
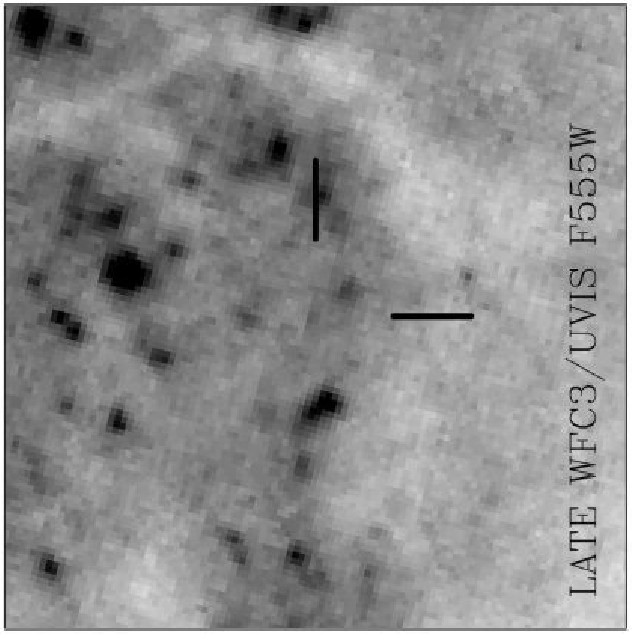
F435W=25.80±0.12 mag → F438W=26.48±0.08 mag : 0.68 mag fainter

F555W=25.80±0.11 mag → F555W=26.33±0.05 mag : 0.53 mag fainter

Pre-explosion



Late-time



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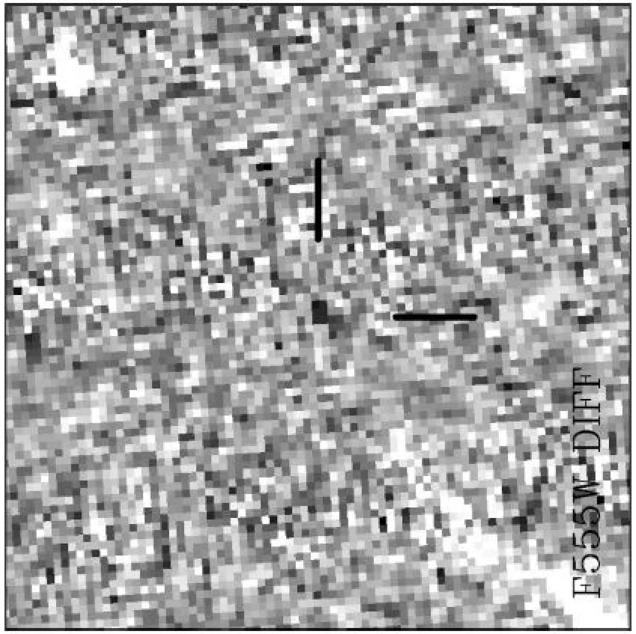

→ Progenitor candidate was the progenitor!
Now, the progenitor has disappeared!

Photometry

Pre-explosion	Post-explosion
$-6.15 \leq M_{F435W} \leq -6.89$	$-5.47 \leq M_{F435W} \leq -6.21$
$-6.1 \leq M_{F555W} \leq -6.71$	$-5.57 \leq M_{F555W} \leq -6.18$

Table 1. Photometry of iPTF13bvn.

Date	Phase[a] (d)	$m(B/F438W)$ (mag)	$m(V/F555W)$ (mag)
2013/08/06	53.93	18.2	–
2013/09/10	88.84	–	17.8
2014/04/18	324	21.1	21.2
Expected	740	26.0	28.0
2015/06/26	740	26.5	26.3
Expected	1001	29.6	29.7

Note. [a]with respect to the explosion date 2013 June 15.67, Cao et al. (2013)

→ Progenitor decay rate prediction ~ observation results
This flux arises from the SN itself!

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Kuncarayakti+15 measured too high V-band decay rate (1.55 mag / 100 d) than those for B-, R-bands (1.13, 1.32).

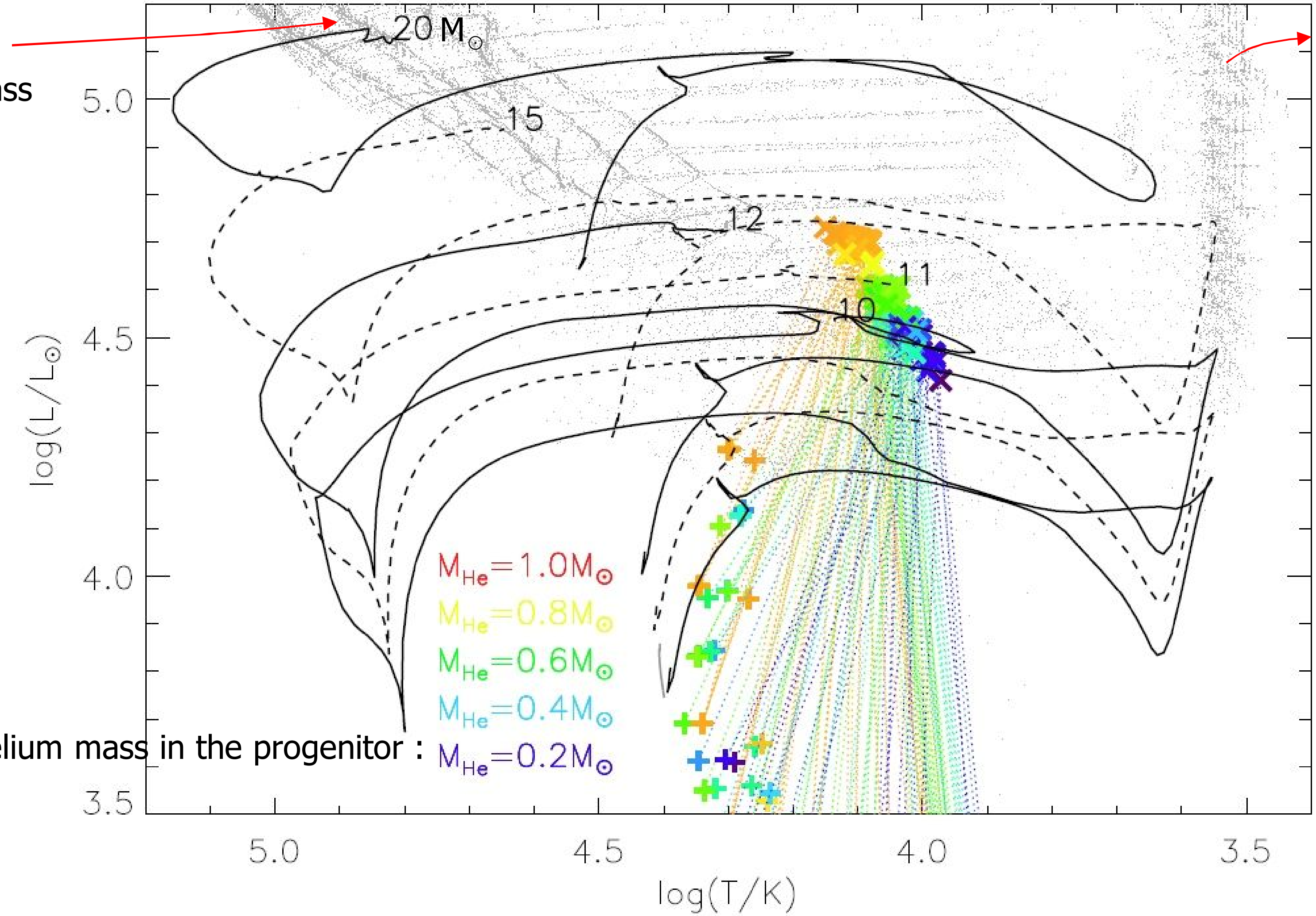
Fremling+ : similar evolution to SN 2011dh
Ergon+15 : 2011dh → LC flatten at ~450 d

Numerical Method

- Binary Population and Spectral Synthesis (BPASS) code (http://bpass.auckland.ac.nz/) v2.0 (Eldridge+08, 13, 15)

•Resulting matching models : Fig. 2, HR diagram – possible binary progenitor models

Primary initial mass



All possible progenitors of SNe

Helium mass in the progenitor :

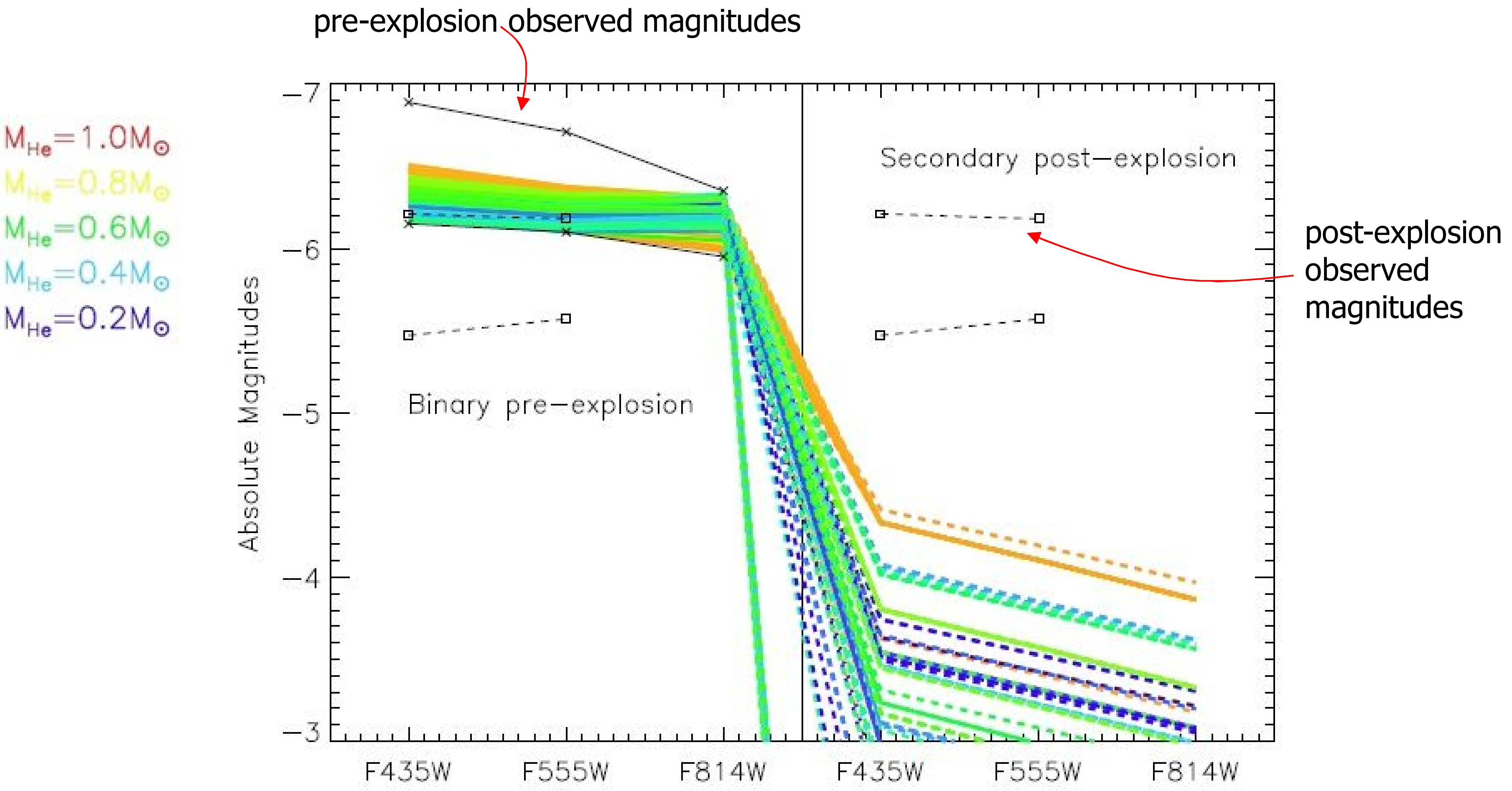
× progenitor, + companion

Spectral Energy Distribution (SED)

Fig 3, Progenitor - Magnitudes expected from the BPASS models

For low- and high-extinction values

Observed magnitude error : ±0.3 mag



Preferred progenitor – cooler helium giant

Mean Parameters for the progenitor and the companion

Table 2. Physical parameters of the binary progenitor models which match the observed constraints on the progenitor of iPTF13bvn.

Primary parameter	Value	Secondary parameter	Value
$M_{1,i}/M_\odot$	11.0 ± 1.2	$M_{2,i}/M_\odot$	5.8 ± 2.9
$M_{1,f} M_\odot$	2.4 ± 0.4	$M_{2,f}/M_\odot$	5.0 ± 4.5
$\log(L_1/L_\odot)$	4.6 ± 0.1	$\log(L_2/L_\odot)$	1.1 ± 2.9
$\log(T_{1,\mathrm{eff}}/K)$	4.06 ± 0.04	$\log(T_{2,\mathrm{eff}}/K)$	4.0 ± 0.4
$\log(R_1/R_\odot)$	1.71 ± 0.04	$\log(R_2/R_\odot)$	0.4 ± 0.3
$M_{\mathrm{ejecta}} M_\odot$	0.95 ± 0.4		
$M_{\mathrm{He}} M_\odot$	0.6 ± 0.2		
System parameters			
$\log(P_i/\mathrm{d})$	1.9 ± 0.5	$\log(a_f/R_\odot)$	1.8 ± 0.2
Age/Myr	24 ± 5	Z	0.027 ± 0.013

R_1~51.3 $R_\odot$

P_i~79.4 d

--> not more massive than 20 $M_\odot$

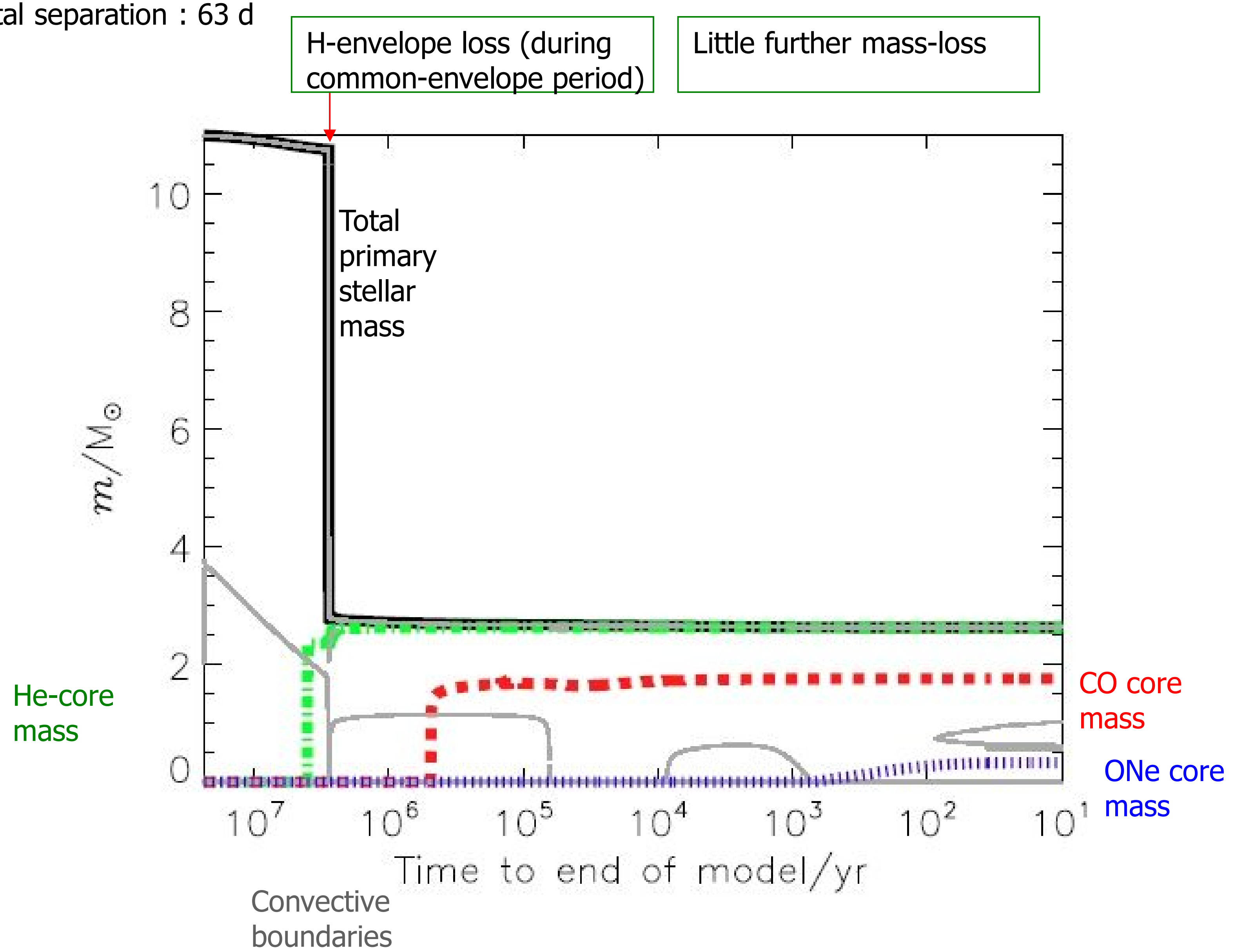
Primary initial mass : M_i ~ 10 - 12 $M_\odot$
Secondary initial mass : M_i ~ 5.8 $M_\odot$ (otherwise, should be seen in the post-explosion images)

Evolution of an example progenitor

Fig 4, Kippenhahn diagram

Initial masses : 11, 5.5 $M_\odot$

Initial orbital separation : 63 d



Long-term evolution

- In a sufficiently long observation → expected : late-time image of the companion
  as the SN should have faded below the companion mag
- (e.g.) 1000 d (=2yr 9mo) after the explosion
  → SN ~ 29.6 mag (M ~ -2.1)
  → companion : brightest at 27.7 mag (M ~ -4)
  unless BH or NS

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~2016 March 16

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Summary

- Post-explosion observations of SN Ib iPTF13bvn

- SN brightness at +740 d : below the level of the pre-explosion source
  → the progenitor has exploded → now disappeared!

- Late-time brightness
  → progenitor initial mass : $10 \leq M \leq 12\ M_{\odot}$
  → companion star : $M \leq 10\ M_{\odot}$

- Progenitor would have been a He-giant

- In a sufficiently long observation → expected : late-time image of the companion
  as the SN should have faded below the companion mag

- A suggestion that
  if SNe Ibc progenitors are low-mass He-giants
  → progenitors may be bright
  → companions are also low-mass stars, and most likely faint/difficult to observe