David A. Dunlap Department of
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

Constraints on the Progenitor and any Surviving Companion to Stripped Envelope Supernova SN2017gax

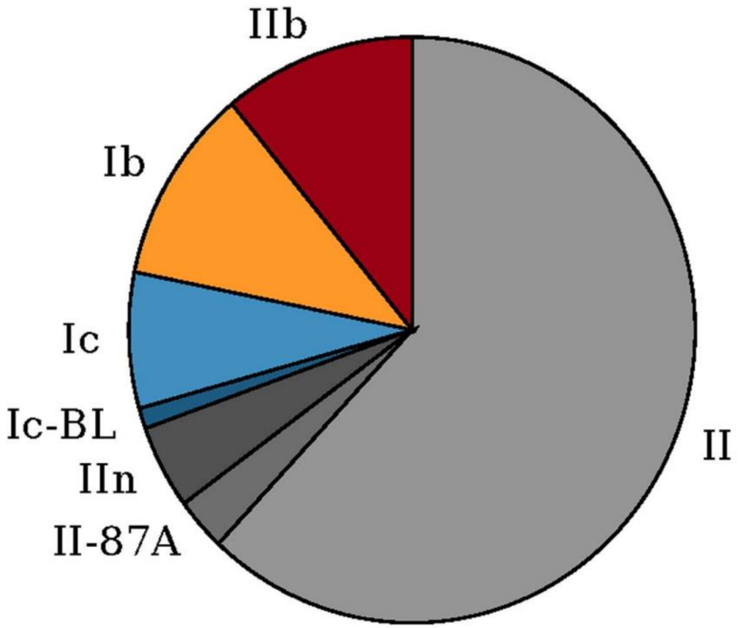
Jianing (Jenny) Su[1], Maria Drout[1], Manos Zapartas[2], Ori Fox[3] + Collaborators

[1] University of Toronto, [2] Institute of Astrophysics-FORTH, [3] STScI

Contact: jennyjn.su@mail.utoronto.ca

Background

- Stripped envelope supernovae (SESNe) progenitors:
  - Higher mass stars with strong winds (i.e. Wolf Rayet stars)
  - Lower mass stars with binary interactions
- 70% massive stars will interact with a binary (Sana et al. 2012)
- ~ 1/3 CCSNe are SESNe (Shivvers et al. 2017)
- Type Ibc usually have low M_{ej} (Drout et al. 2011; Lyman et al. 2016)



Shivvers et al. 2017

Motivation

- 3 candidate/confirmed direct detections of Type Ibc SN
  - Type Ib iPTF13bvn (Cao et al. 2013; Kim et al. 2015; Eldridge and Maund 2016)
  - Type Ib SN2019yvr* (Kilpatrick et al. 2021)
  - Type Ic SN2017ein* (Dyk et al. 2018; Xiang et al. 2019)
- **SN2017gax**: one of the only SESNe to date with deep HST imaging both pre- and post- explosion images
  - Spoiler: both non-detections

* candidates

SN2017gax: Classification and Host

- Type Ic
- Located in NGC1672
- Distance: 15.9±0.9 Mpc from TRGB
- Low reddening: Av~0.04 mag (MW + host galaxy)
  - Measured with both NaID absorption lines and multi-band SN color templates (Stritzinger et al. 2018)
- Paper on explosion properties led by Emily Hoang (UC Davis)

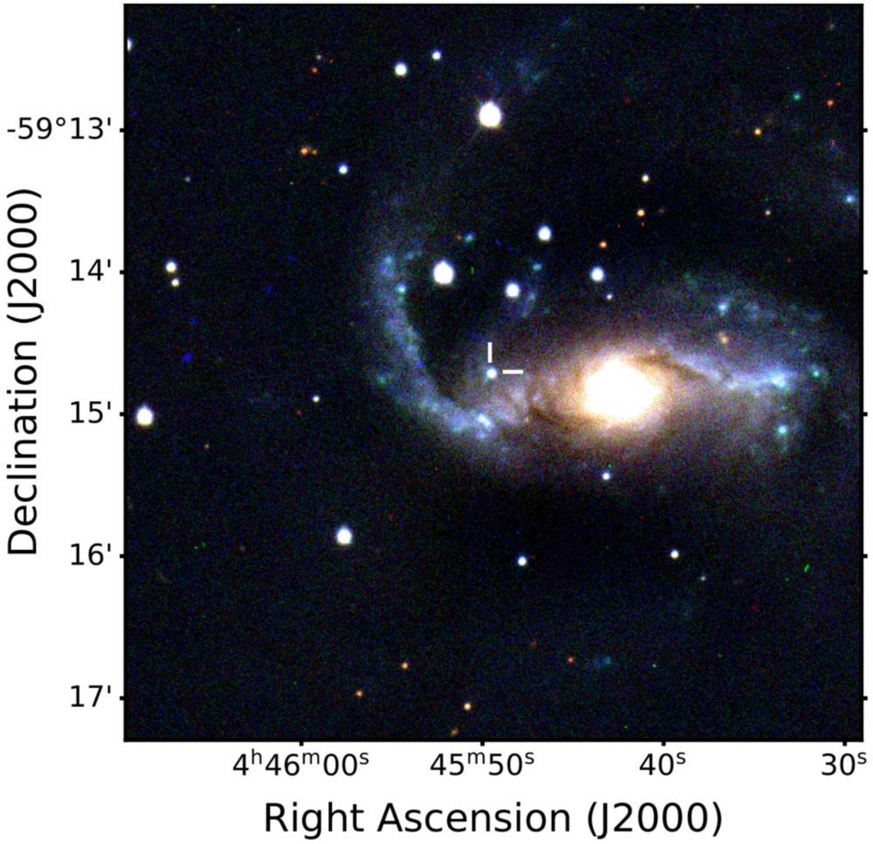
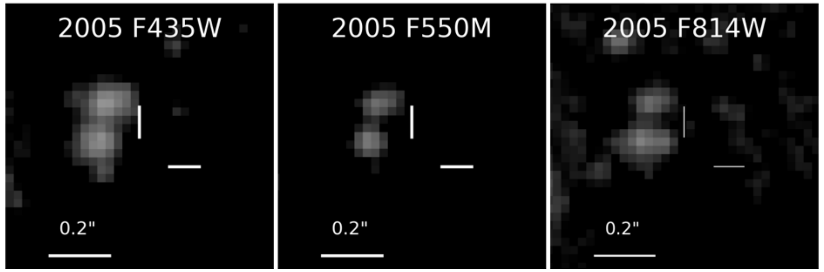


Image taken by the Las Cumbres Observatory in *gri* shows NGC1672, the host galaxy of SN2017gax

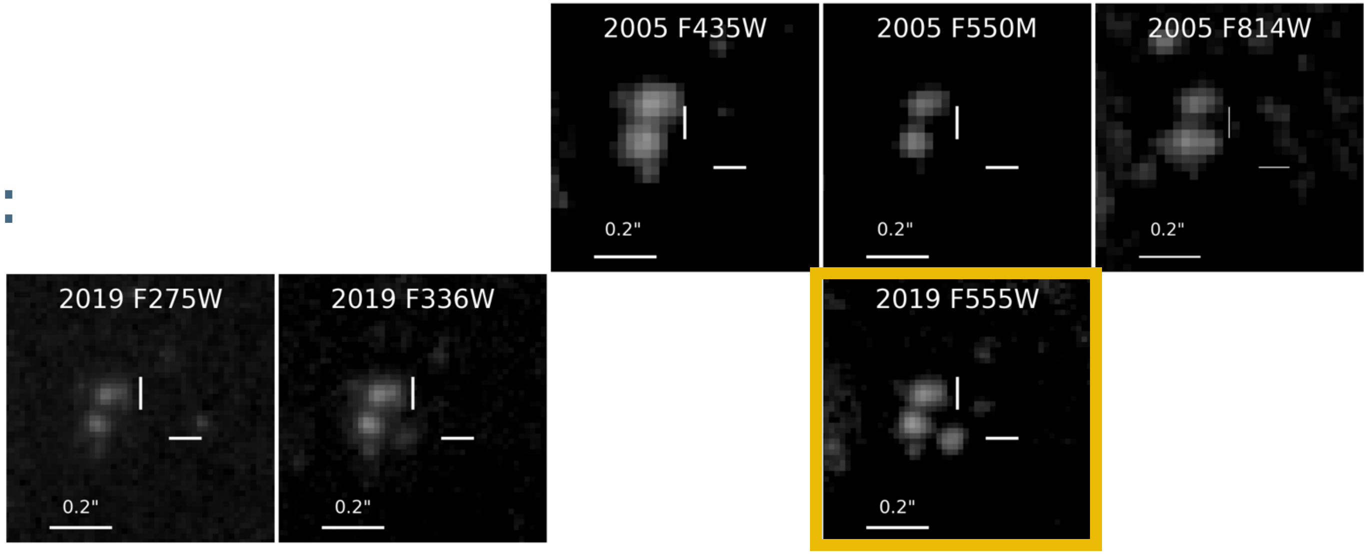
HST images of SN2017gax Explosion Site Spanning 18 Years

- 2005 (12yr prior explosion): non-detection
- 2019 (2yr after explosion): light from SN
- 2020 (3yr after explosion): dust echo?
- 2023 (6yr after explosion): non-detection



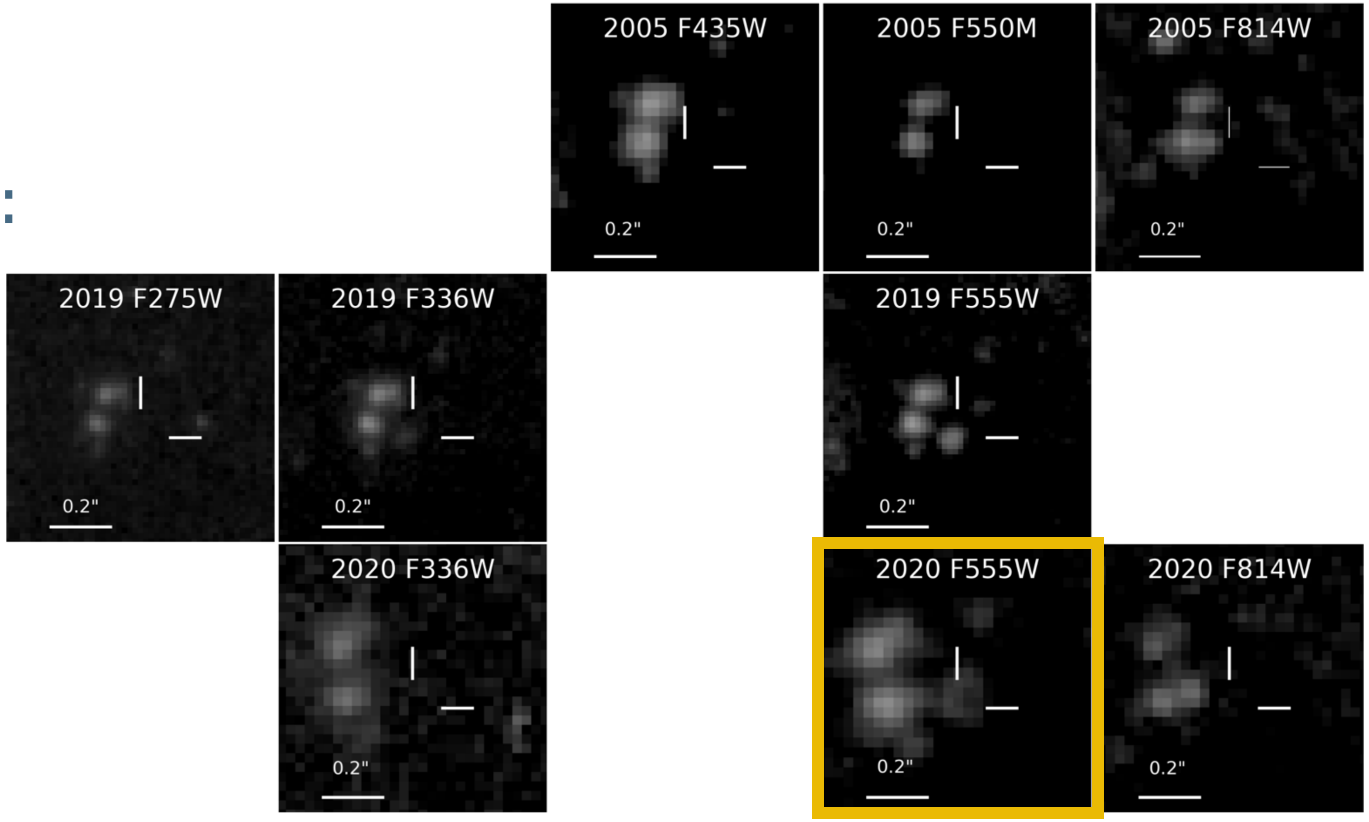
HST images of SN2017gax Explosion Site Spanning 18 Years

- 2005 (12yr prior explosion): non-detection
- 2019 (2yr after explosion): light from SN
- 2020 (3yr after explosion): dust echo?
- 2023 (6yr after explosion): non-detection



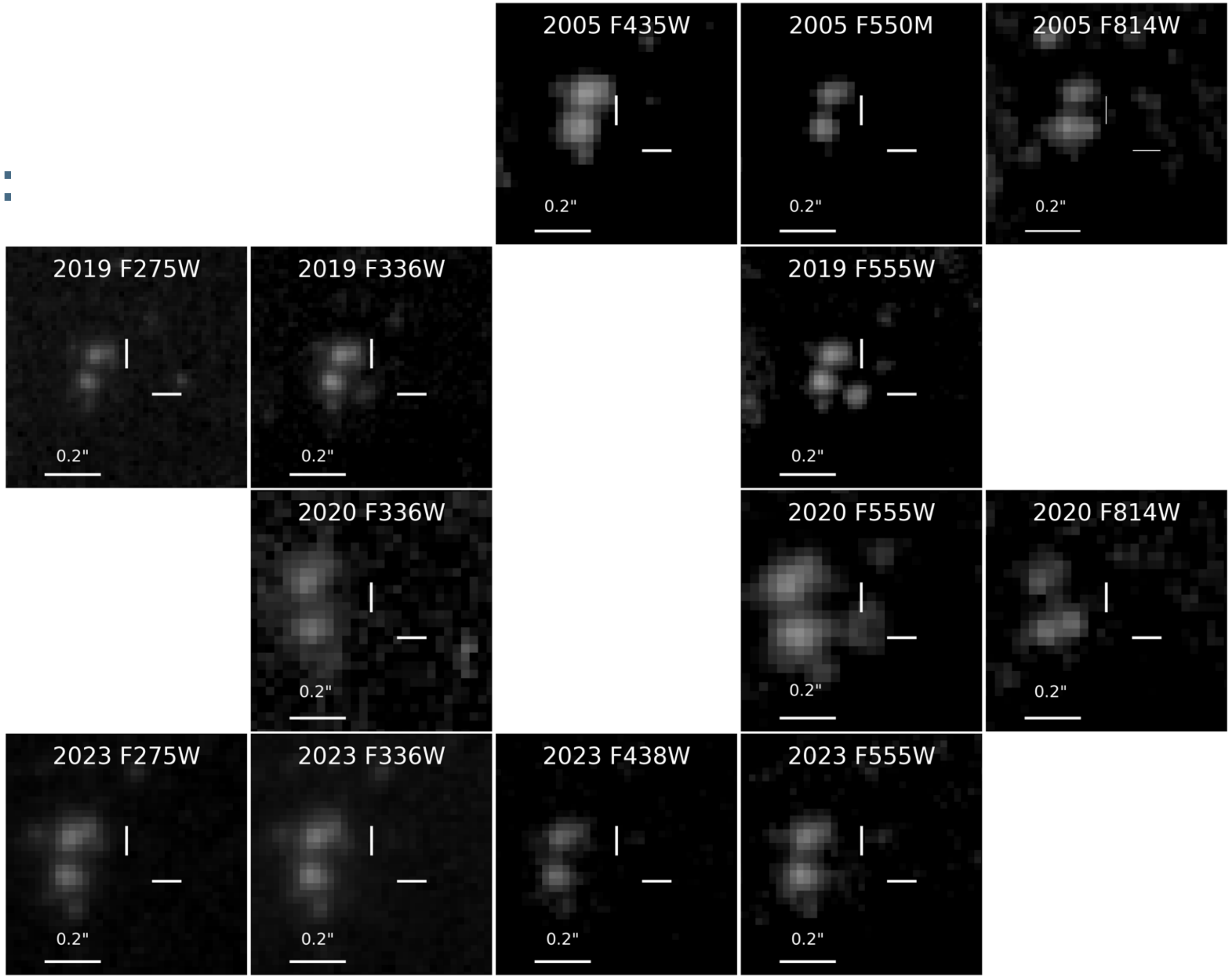
HST images of SN2017gax Explosion Site Spanning 18 Years

- 2005 (12yr prior explosion): non-detection
- 2019 (2yr after explosion): light from SN
- 2020 (3yr after explosion): dust echo?
- 2023 (6yr after explosion): non-detection



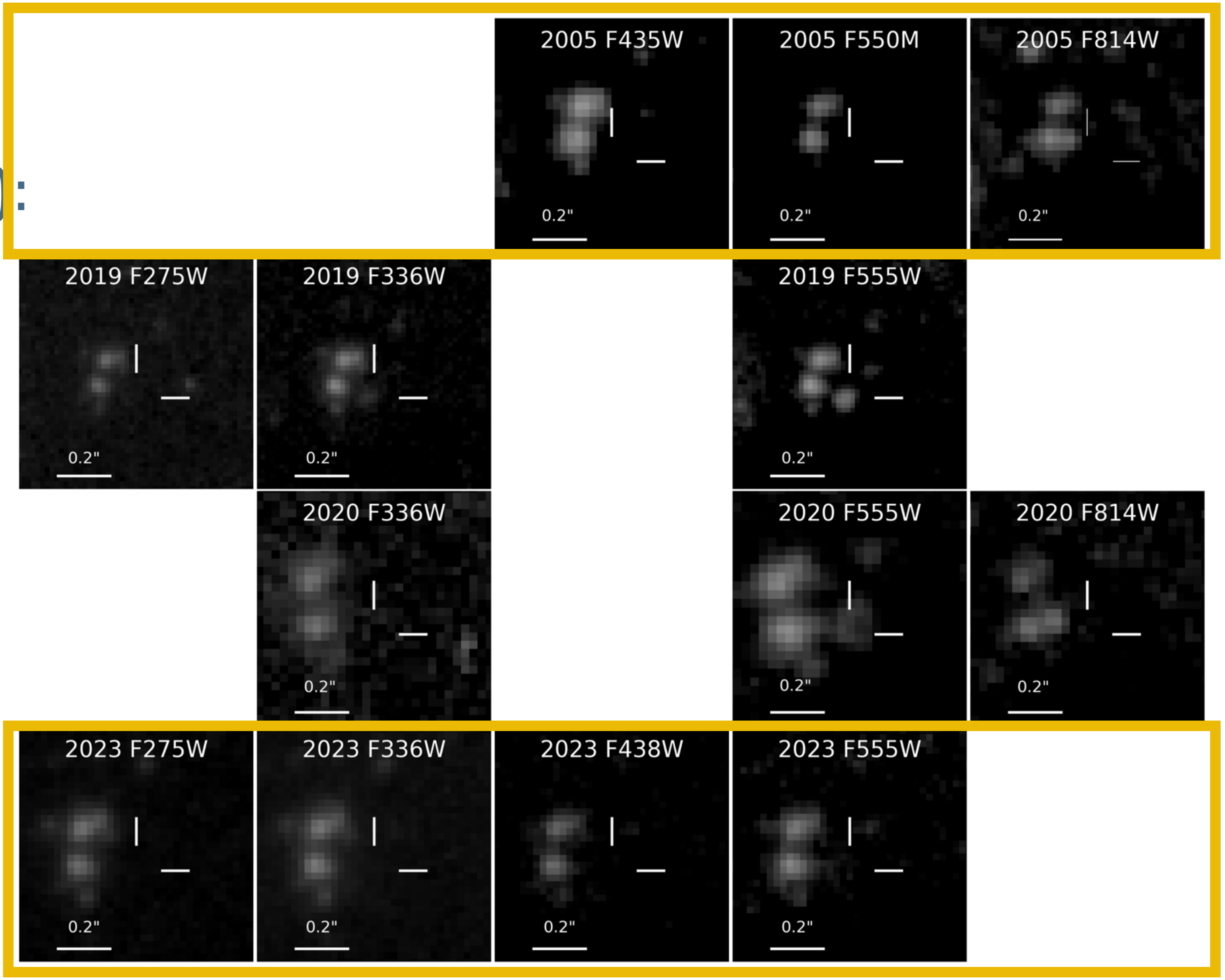
HST images of SN2017gax Explosion Site Spanning 18 Years

- 2005 (12yr prior explosion): non-detection
- 2019 (2yr after explosion): light from SN
- 2020 (3yr after explosion): dust echo?
- 2023 (6yr after explosion): non-detection



HST images of SN2017gax Explosion Site Spanning 18 Years

- 2005 (12yr prior explosion): non-detection
- 2019 (2yr after explosion): light from SN
- 2020 (3yr after explosion): dust echo?
- 2023 (6yr after explosion): non-detection



Constraints on the Progenitor System

- Goal: find allowed and ruled-out areas on an HR diagram for both the **progenitor star** and any **binary companion**
- Using a combination of H-rich and H-poor models

Companion star   Progenitor star

Constraints on the Progenitor System

Select a set of synthetic spectra with varying T and compositions (ie H-poor and H-rich)

Constraints on the Progenitor System

Select a set of synthetic spectra with varying T and compositions (ie H-poor and H-rich)

→

Scale the spectra so that the integrated L spans over a range

Constraints on the Progenitor System

Select a set of synthetic spectra with varying T and compositions (ie H-poor and H-rich)

→

Scale the spectra so that the integrated L spans over a range

→

Perform **synthetic photometry** on each spectral model

Constraints on the Progenitor System

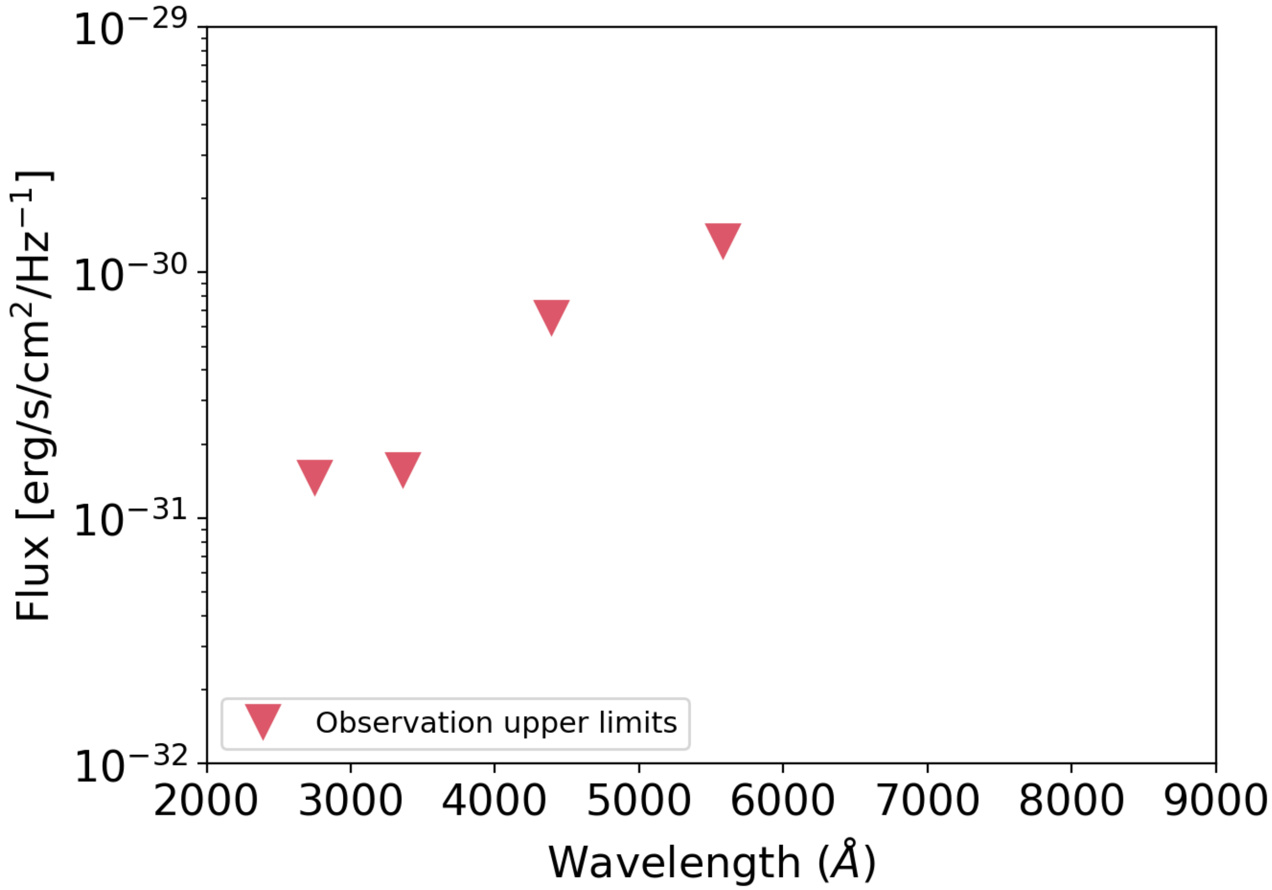
Select a set of synthetic spectra with varying T and compositions (ie H-poor and H-rich)

Scale the spectra so that the integrated L spans over a range

Perform **synthetic photometry** on each spectral model

Any system with magnitudes brighter than our HST upper limits is ruled out

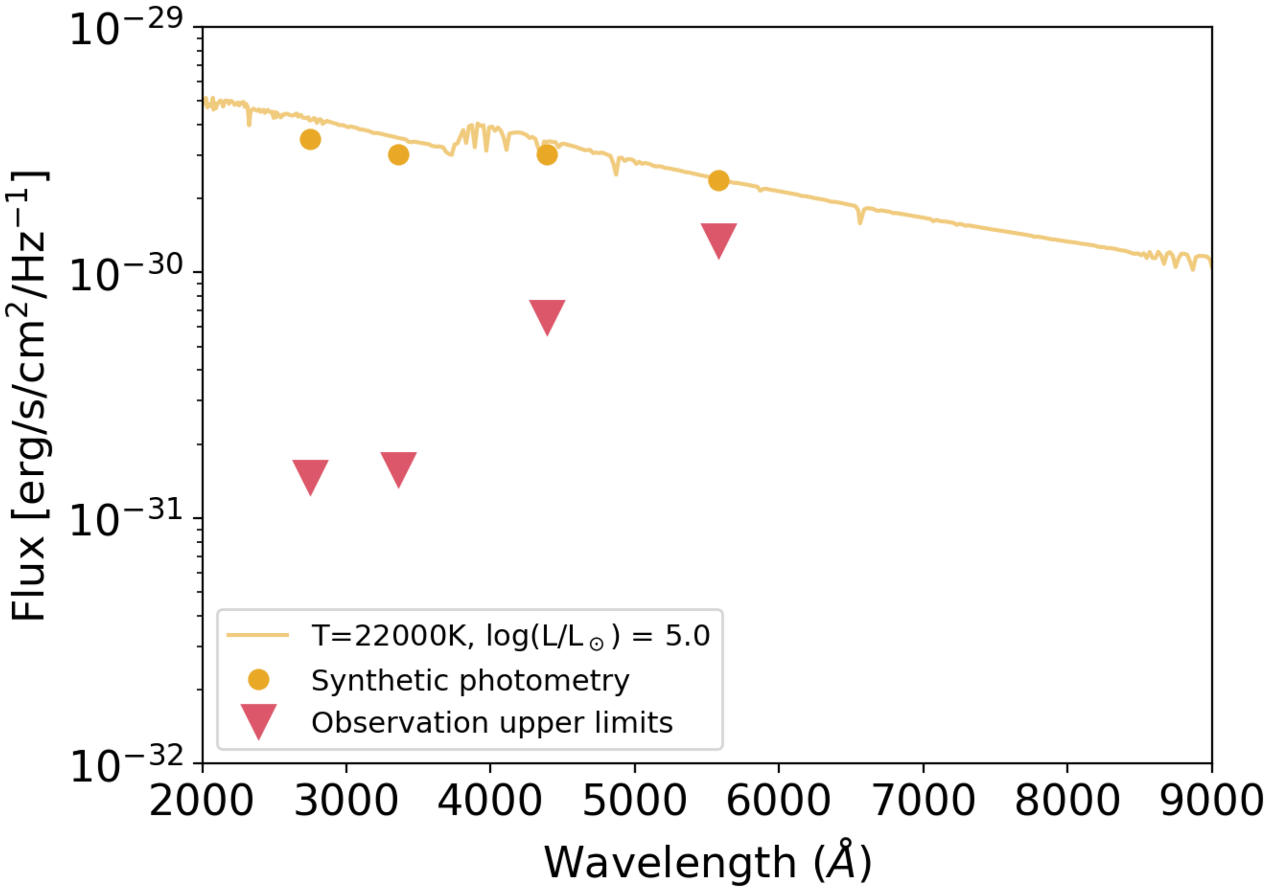
Post-explosion constraints on L of any companion as a function of T



Upper limits

Post-explosion constraints on L of any companion as a function of T

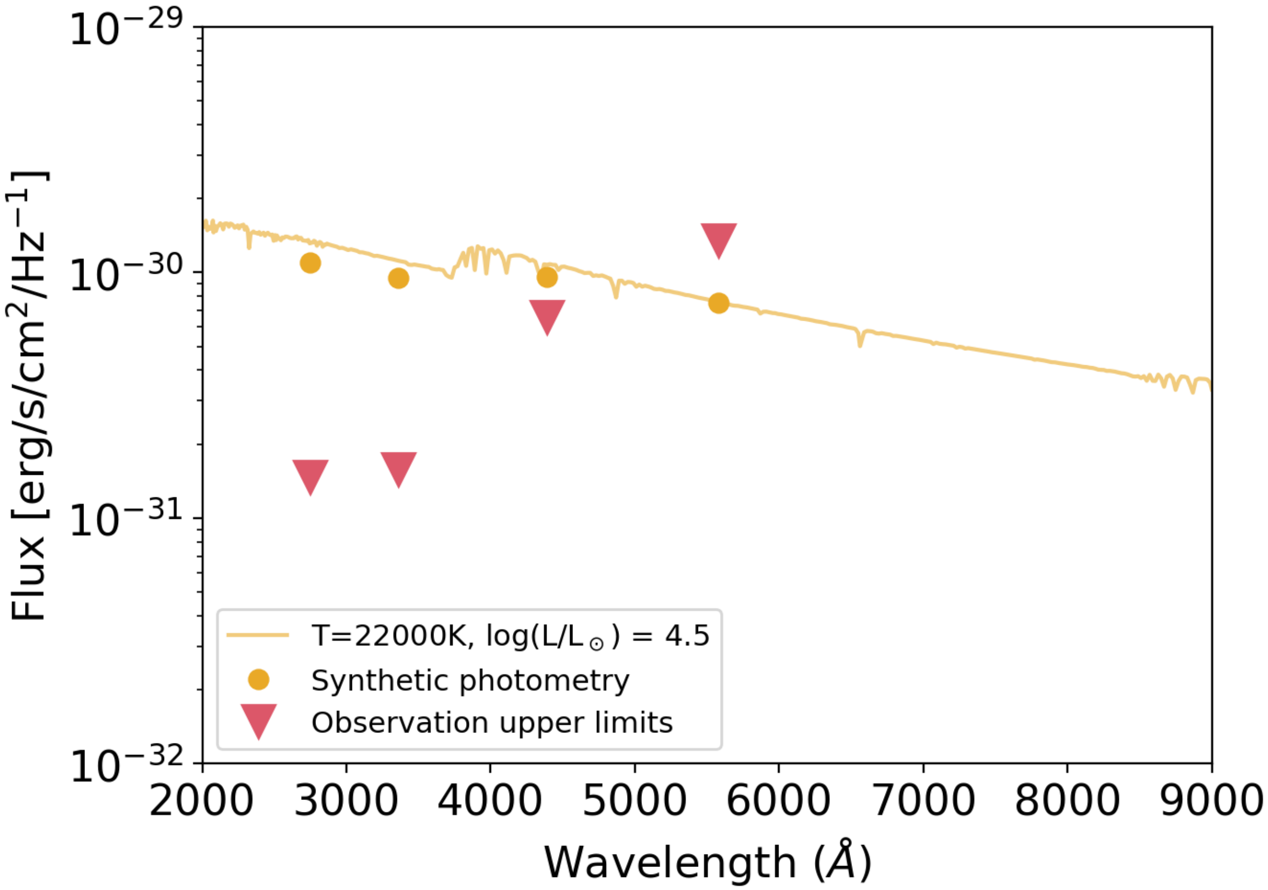
T=22000K
Log($L/L_\odot$)=5.0



Not allowed

Post-explosion constraints on L of any companion as a function of T

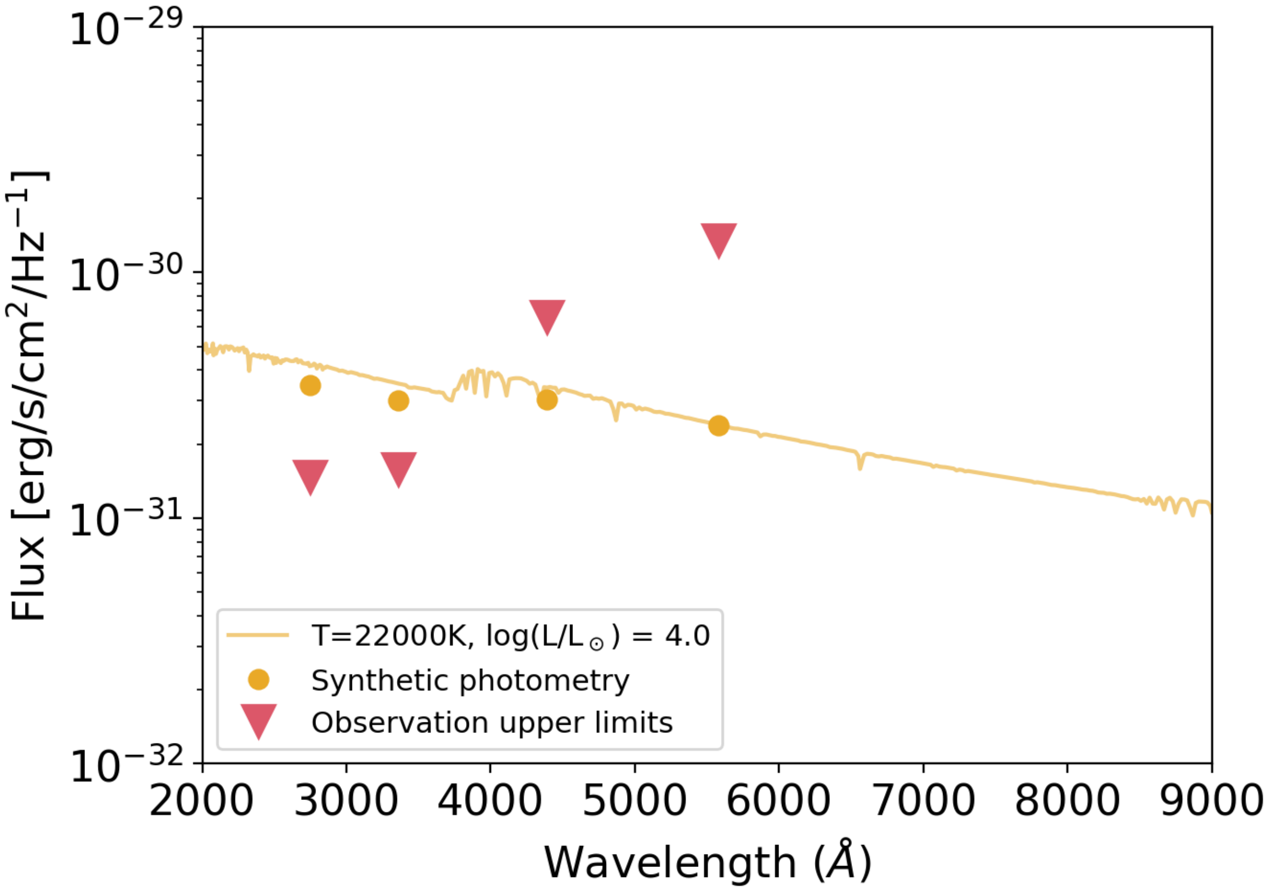
T=22000K
Log(L/L$_\odot$)=4.5



Not allowed ❌

Post-explosion constraints on L of any companion as a function of T

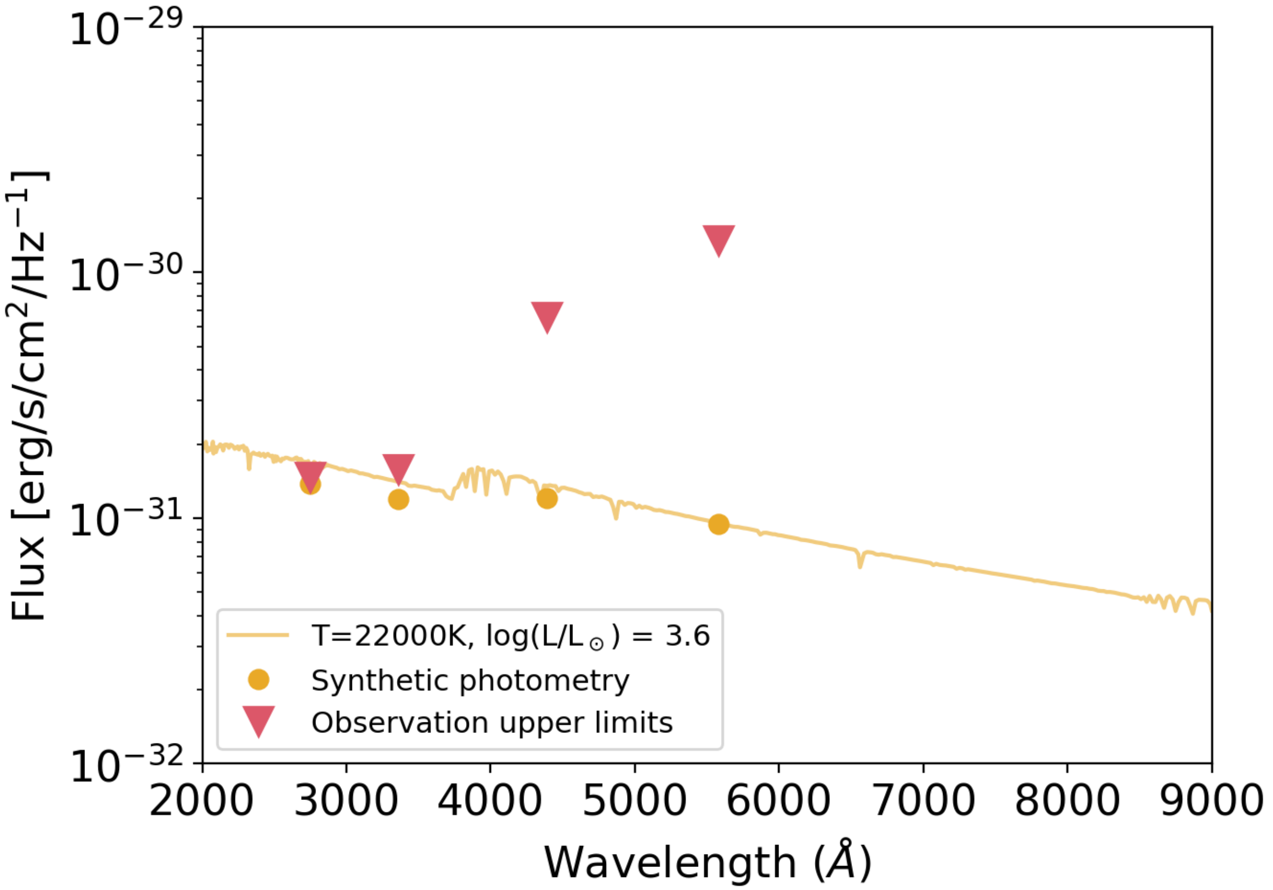
T=22000K
Log($L/L_\odot$)=4.0



Not allowed

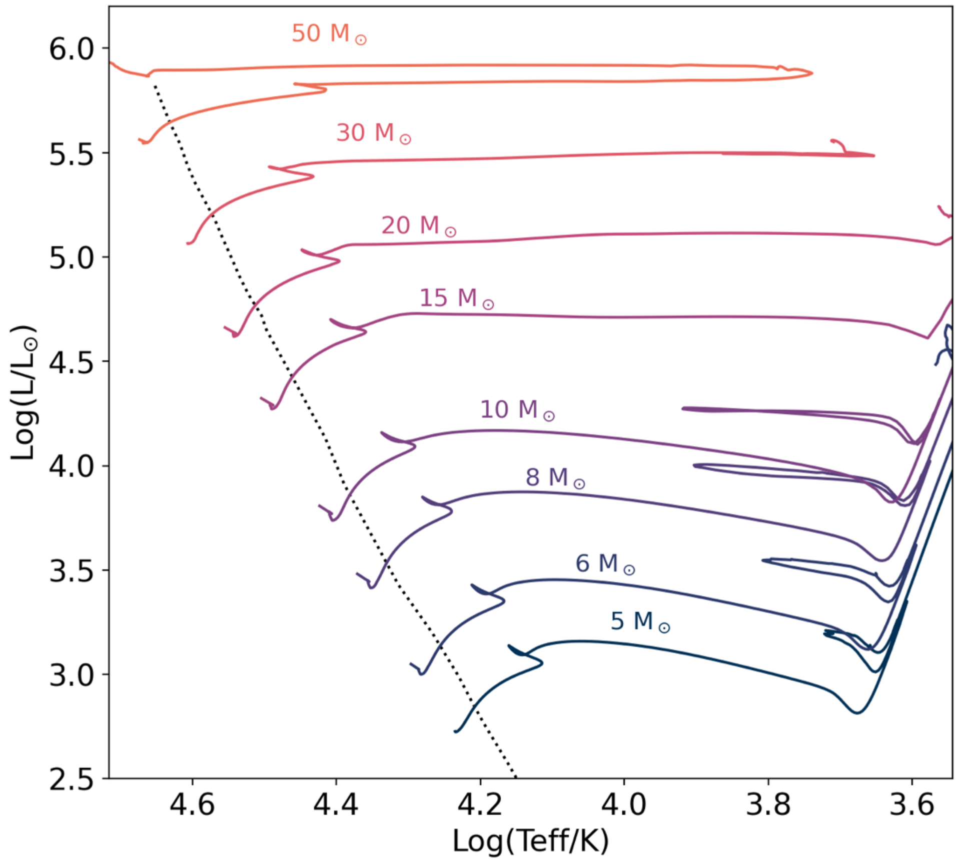
Post-explosion constraints on L of any companion as a function of T

T=22000K
Log($L/L_{\odot}$)=3.6



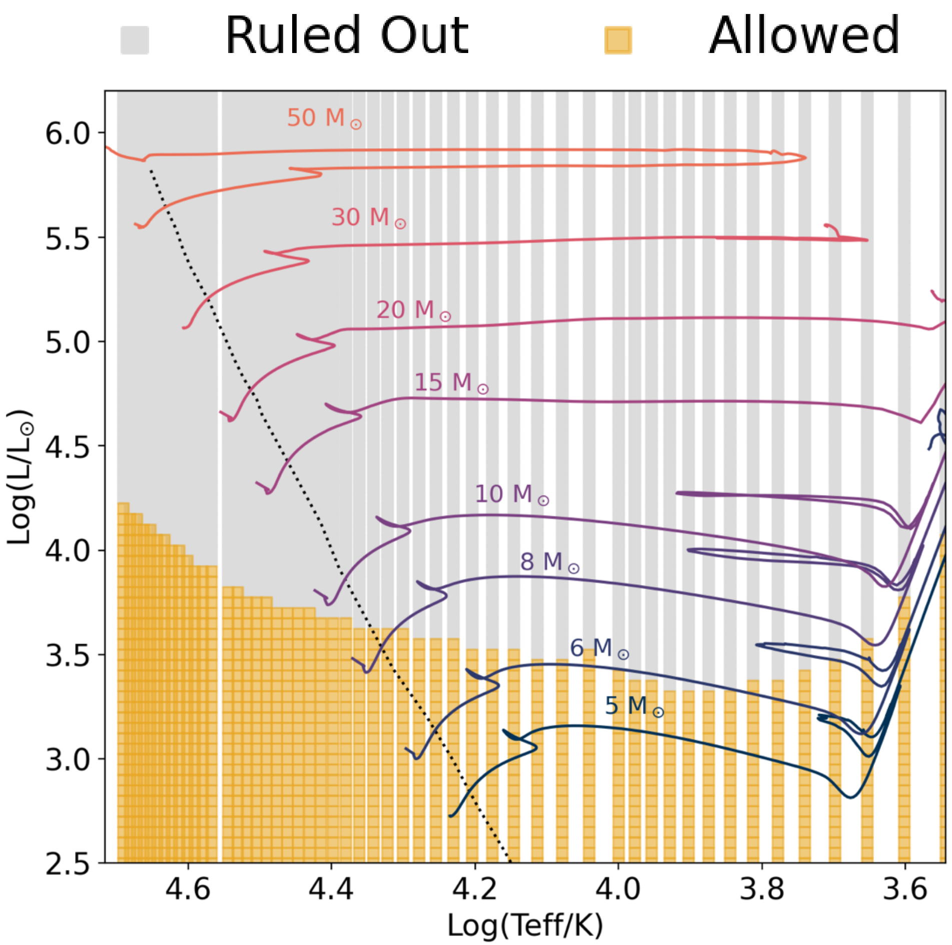
Allowed!

Post-explosion constraints on L of any companion as a function of T



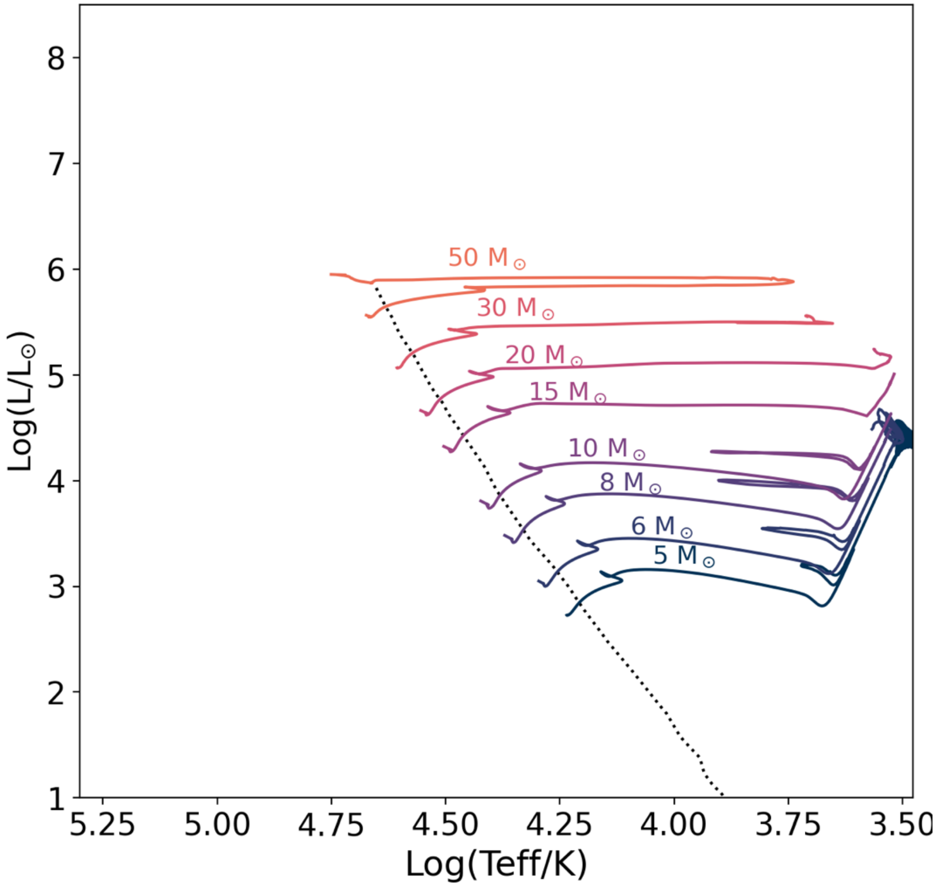
- MIST evolutionary tracks

Post-explosion constraints on L of any companion as a function of T



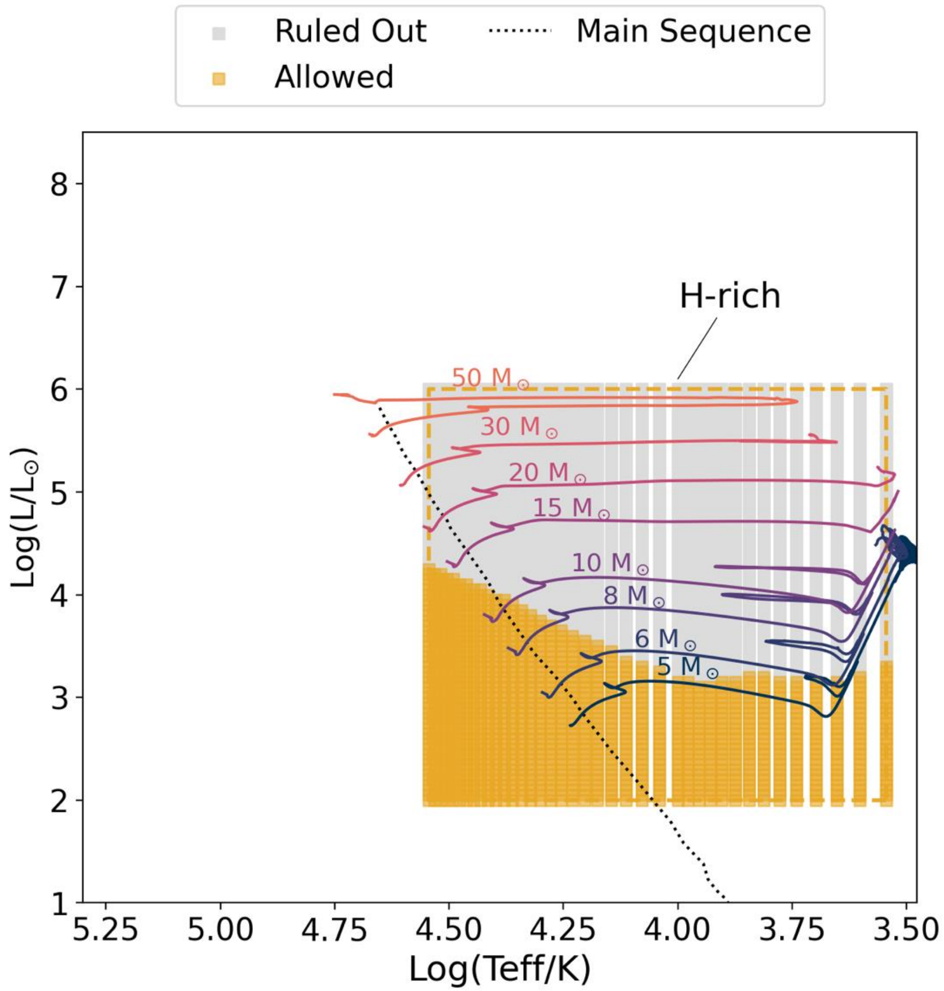
- Kurucz (1993)'s H-rich models
- We can rule out MS companions with $\log(L/L_\odot) > 3.6$

Pre-explosion constraints on L of progenitor and any companion as a function of T



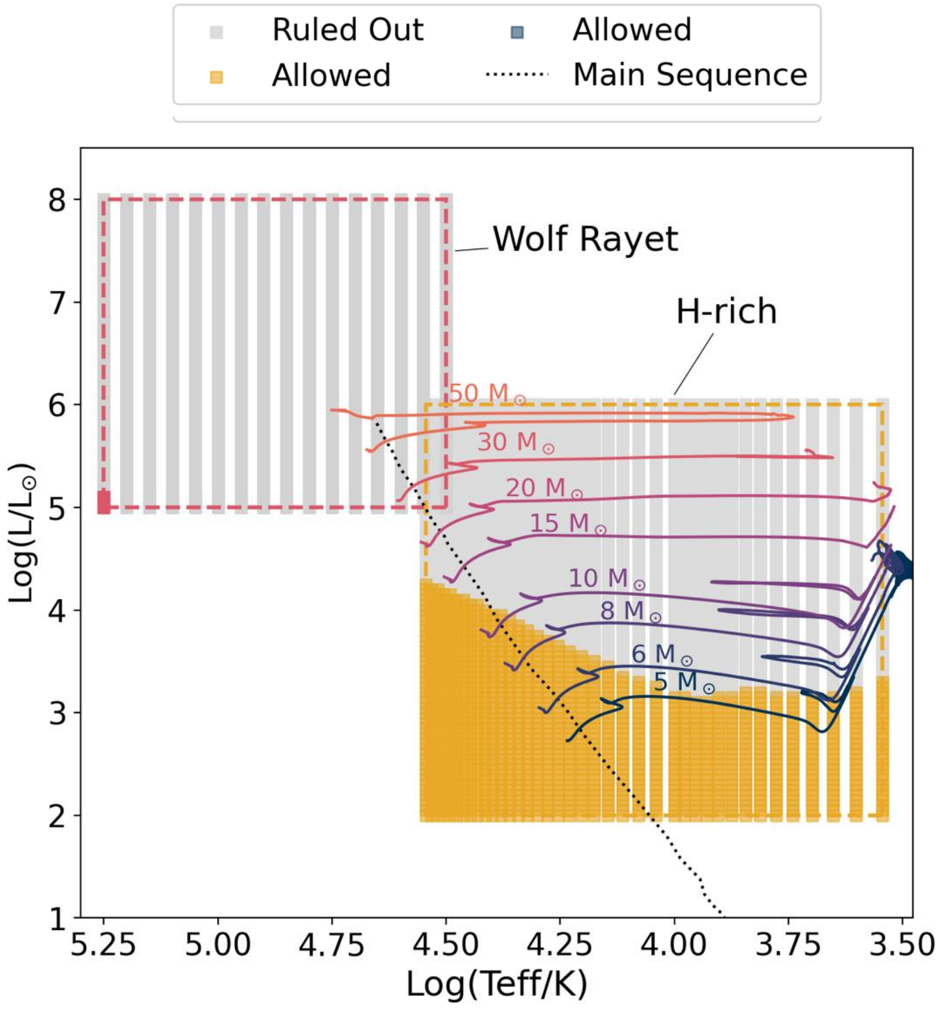
- MIST evolutionary tracks

Pre-explosion constraints on L of progenitor and any companion as a function of T



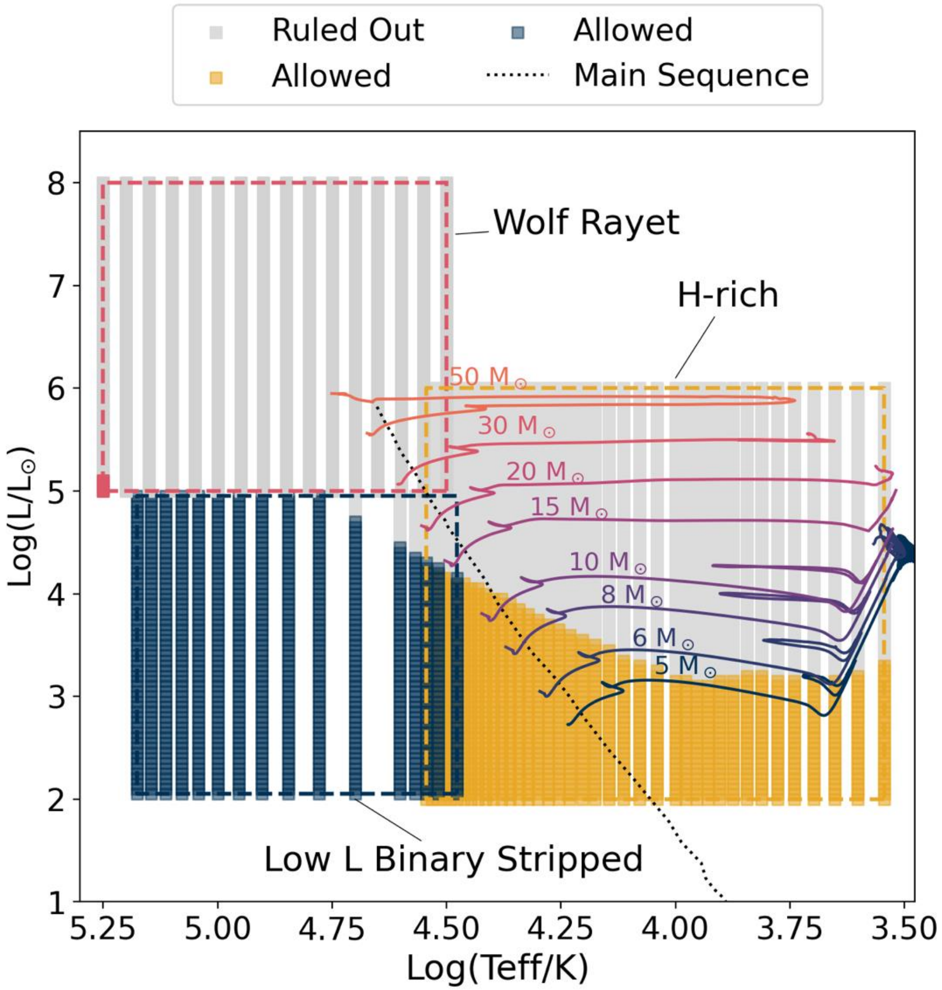
- Kurucz (1993)'s H-rich models

Pre-explosion constraints on L of progenitor and any companion as a function of T



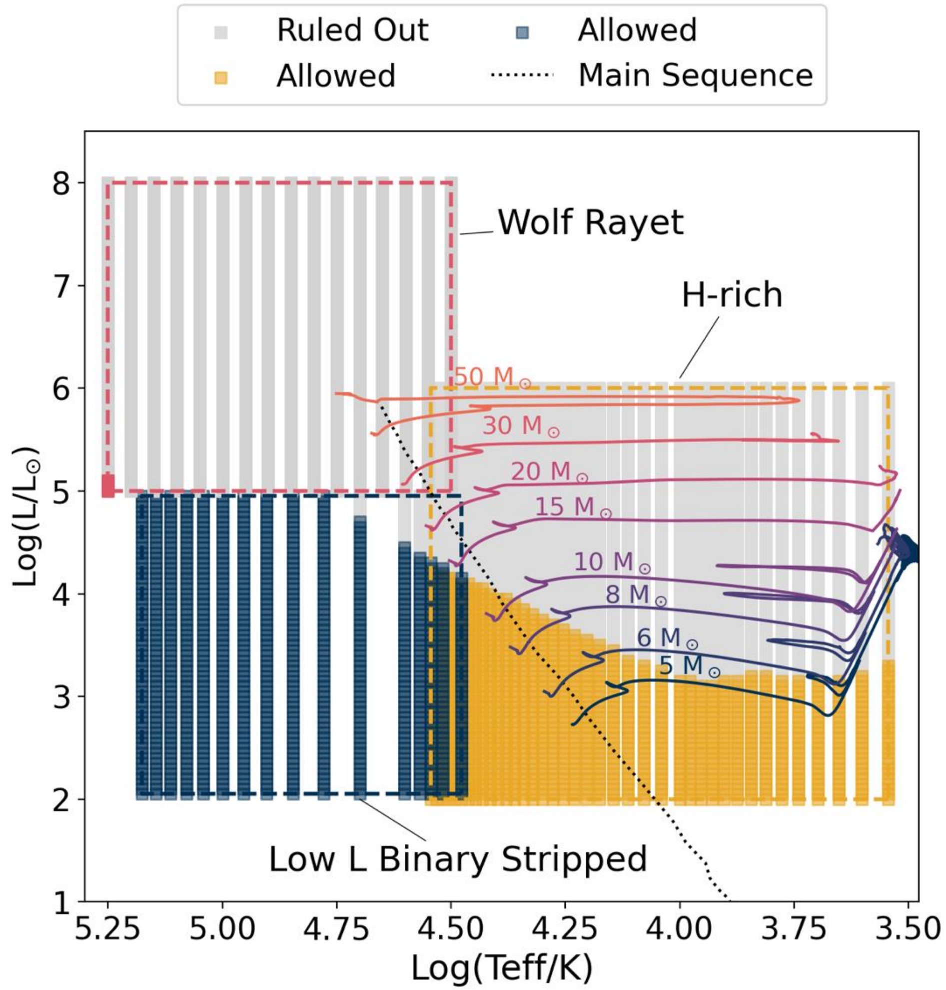
- Potsdam Wolf Rayet models (Hamann & Grafener 2004; Todt et al. 2015)
- Ruled out most luminous WR models for the progenitor

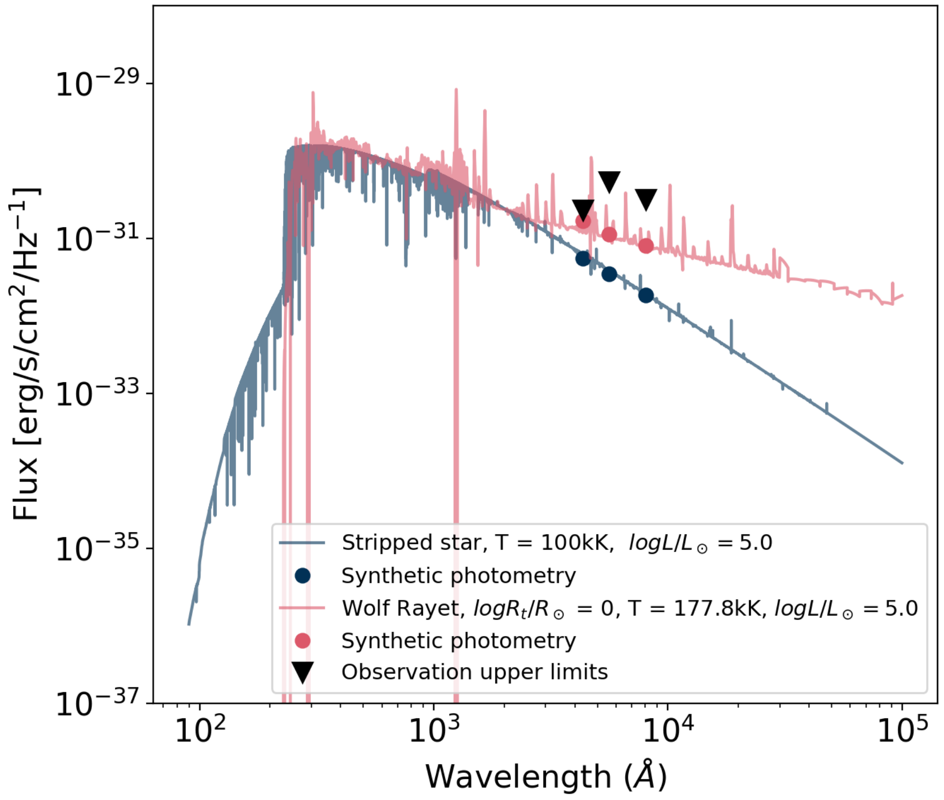
Pre-explosion constraints on L of progenitor and any companion as a function of T



- Gotberg et al. (2023) weak-wind stripped star models

Pre-explosion constraints on L of progenitor and any companion as a function of T





Examples of both a WR and a He star model (with weaker winds) allowed by our pre-explosion upper limits

POSYDON Binary Population Synthesis Models

- POSYDON: detailed stellar structure and binary evolution simulations
  - Provides predictions for a population of SESN progenitors (and their companions) at time of explosion

Fragos et al. 2023
Andrews et al. in prep

POSYDON Binary Population Synthesis Models

- POSYDON: detailed stellar structure and binary evolution simulations
  - Provides predictions for a population of SESN progenitors (and their companions) at time of explosion

Fragos et al. 2023
Andrews et al. in prep

Progenitor spectrum + Companion spectrum

POSYDON Binary Population Synthesis Models

- POSYDON: detailed stellar structure and binary evolution simulations
  - Provides predictions for a population of SESN progenitors (and their companions) at time of explosion

Fragos et al. 2023
Andrews et al. in prep

POSYDON Binary Population Synthesis Models

- POSYDON: detailed stellar structure and binary evolution simulations
  - Provides predictions for a population of SESN progenitors (and their companions) at time of explosion

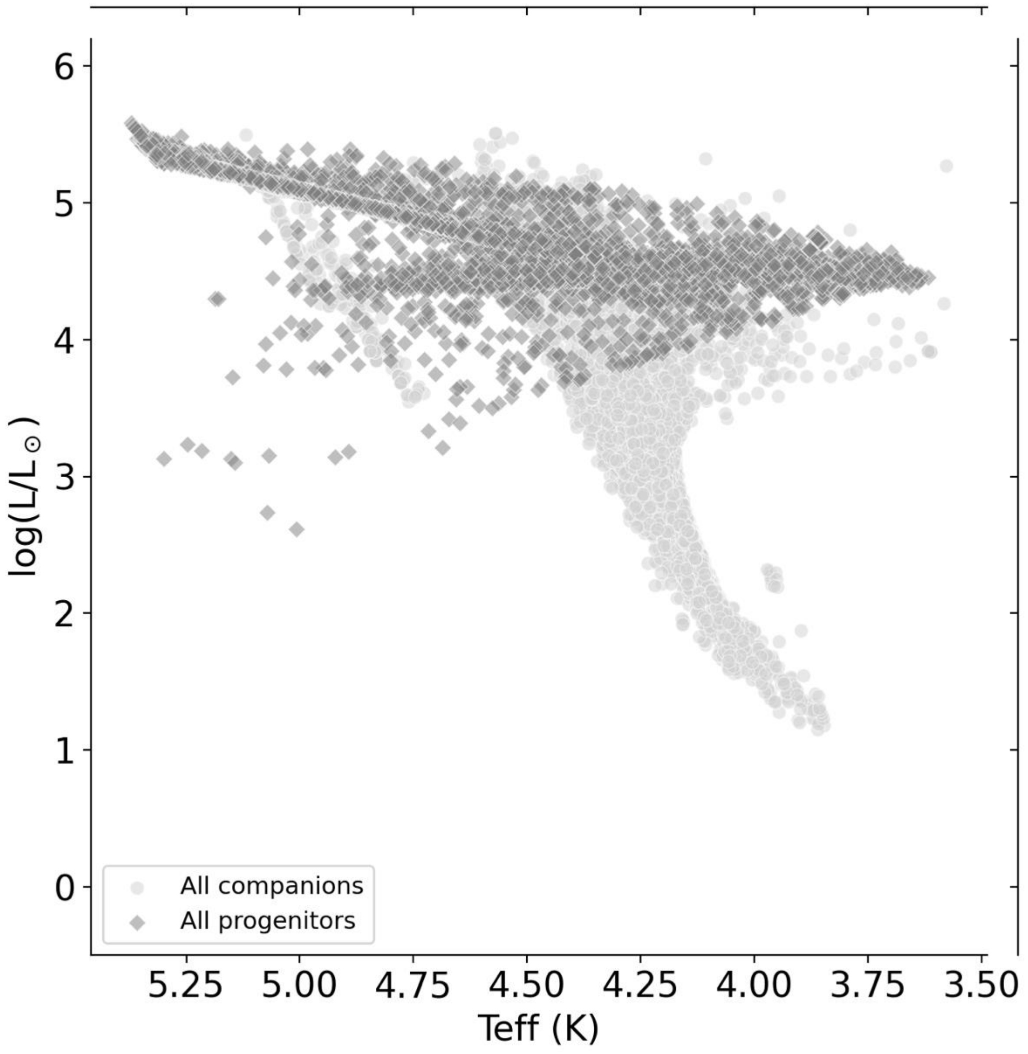
Fragos et al. 2023
Andrews et al. in prep

Progenitor spectrum + Companion spectrum → Synthetic photometry on the summed spectrum → Any system with magnitudes brighter than our pre-explosion HST upper limits is ruled out

POSYDON Binary Population Synthesis Models

- All >13000 exploding Type Ibc systems

◇ Progenitor ○ Companion

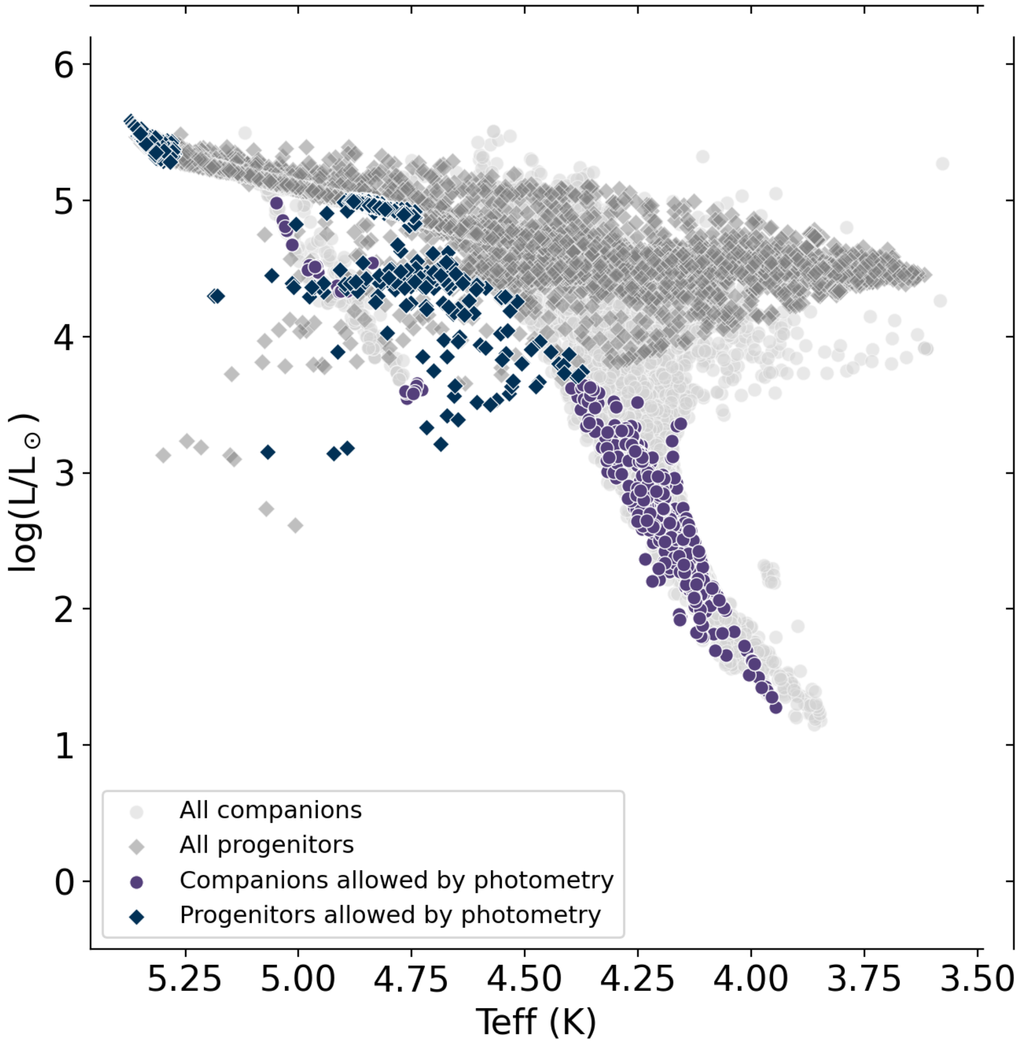


POSYDON Binary Population Synthesis Models

- All >13000 exploding Type Ibc systems

◇ Progenitor ○ Companion

- Only **~5%** systems are allowed with our HST upper limits



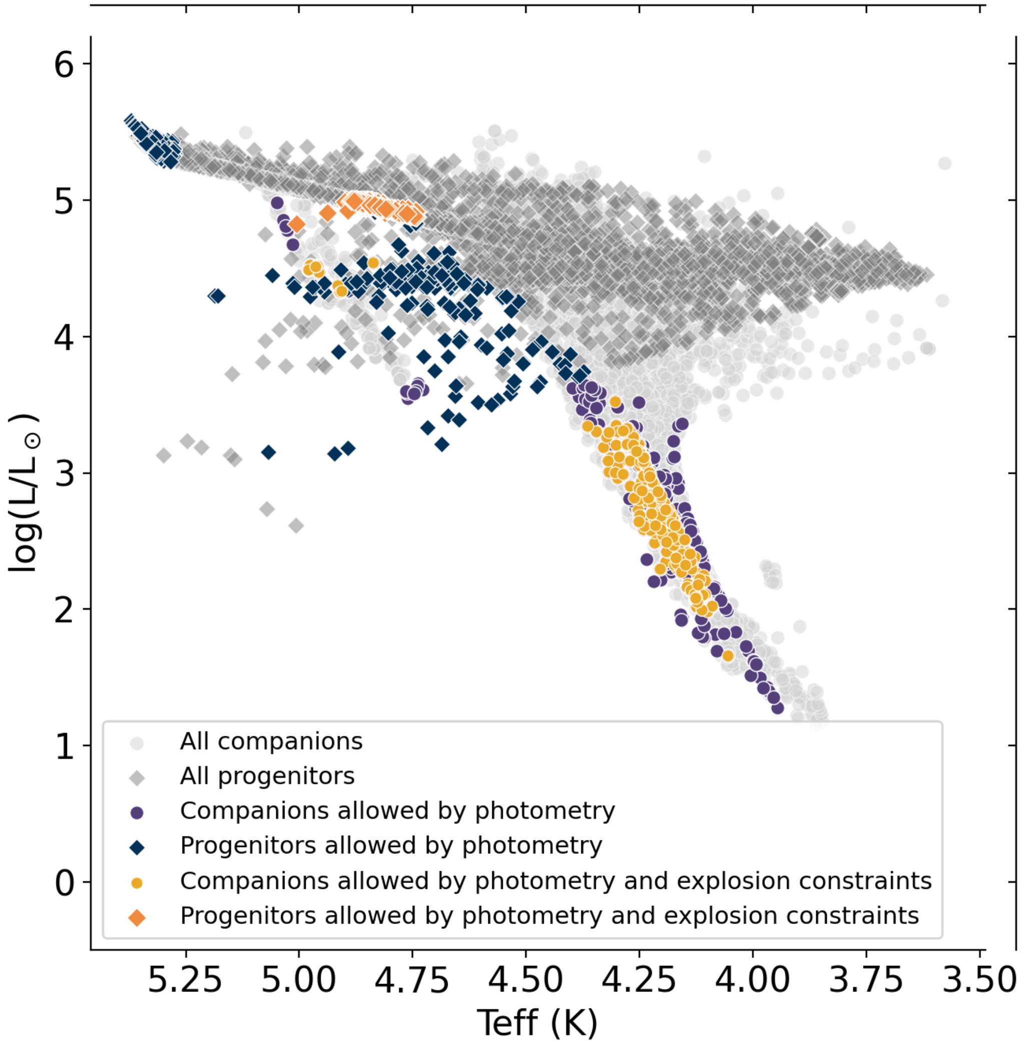
POSYDON Binary Population Synthesis Models

- All >13000 exploding Type Ibc systems

◇ Progenitor ○ Companion

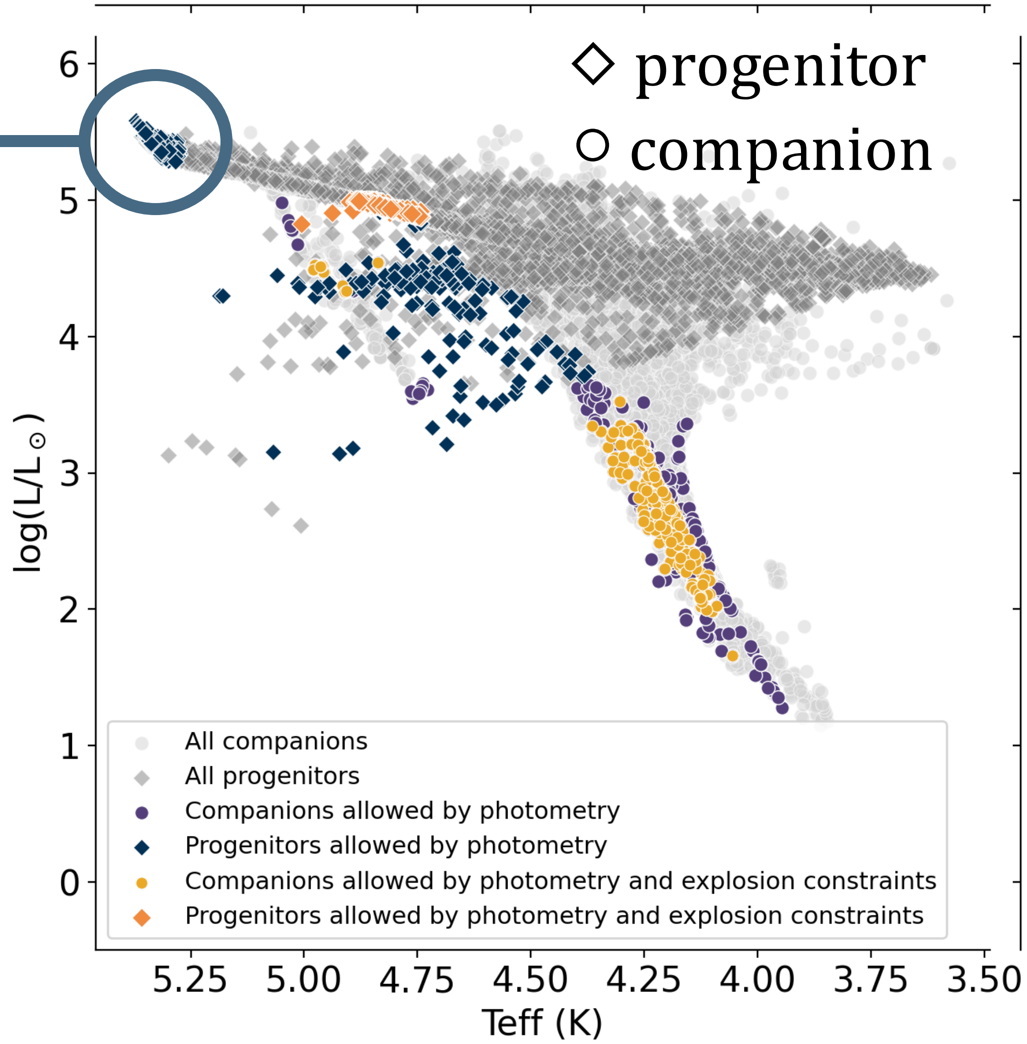
- Only **~5%** systems are allowed with our HST upper limits

- Only **~2%** systems are allowed after additionally applying explosion constraints from modelling the SN lightcurves (analysis done by Hoang et al. in prep)
  - $R < 30R_{\odot}$ and $2.5M_{\odot} < M_{ej} < 4M_{\odot}$



POSYDON Binary Population Synthesis Models

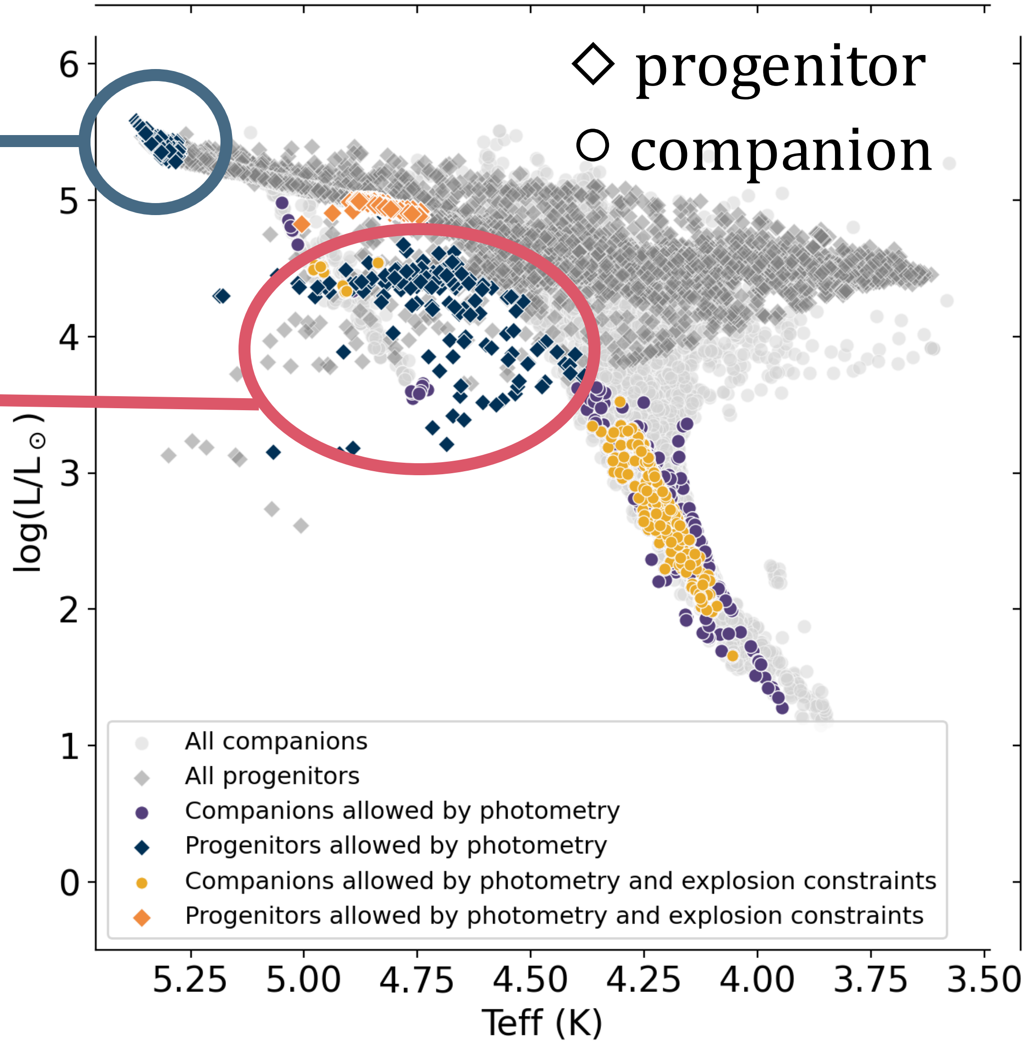
Ruled out due to high ejecta masses, $M_{ej} > 4M_{\odot}$



POSYDON Binary Population Synthesis Models

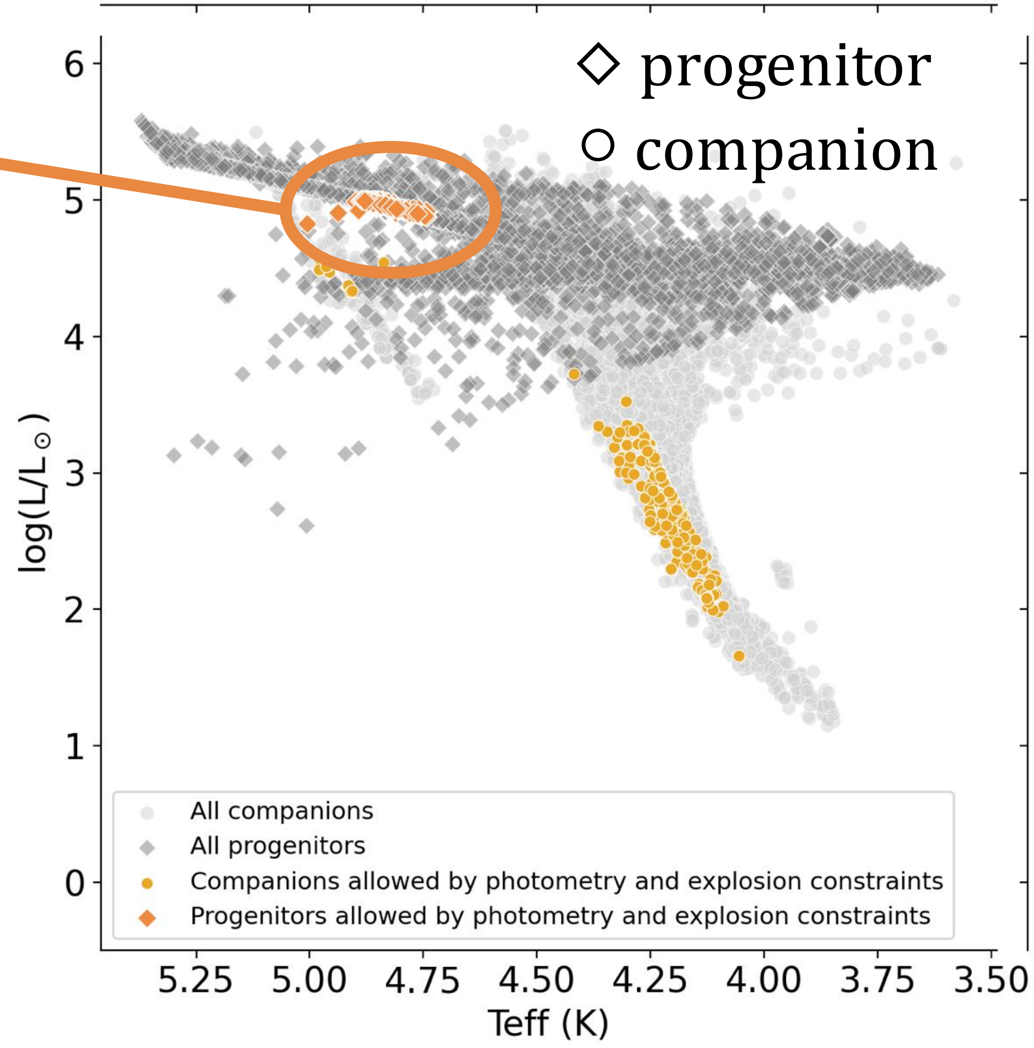
Ruled out due to high ejecta masses, $M_{ej} > 4M_{\odot}$

Ruled out due to low ejecta masses, $M_{ej} < 2.5M_{\odot}$



Stripped star wind mass loss assumptions in POSYDON

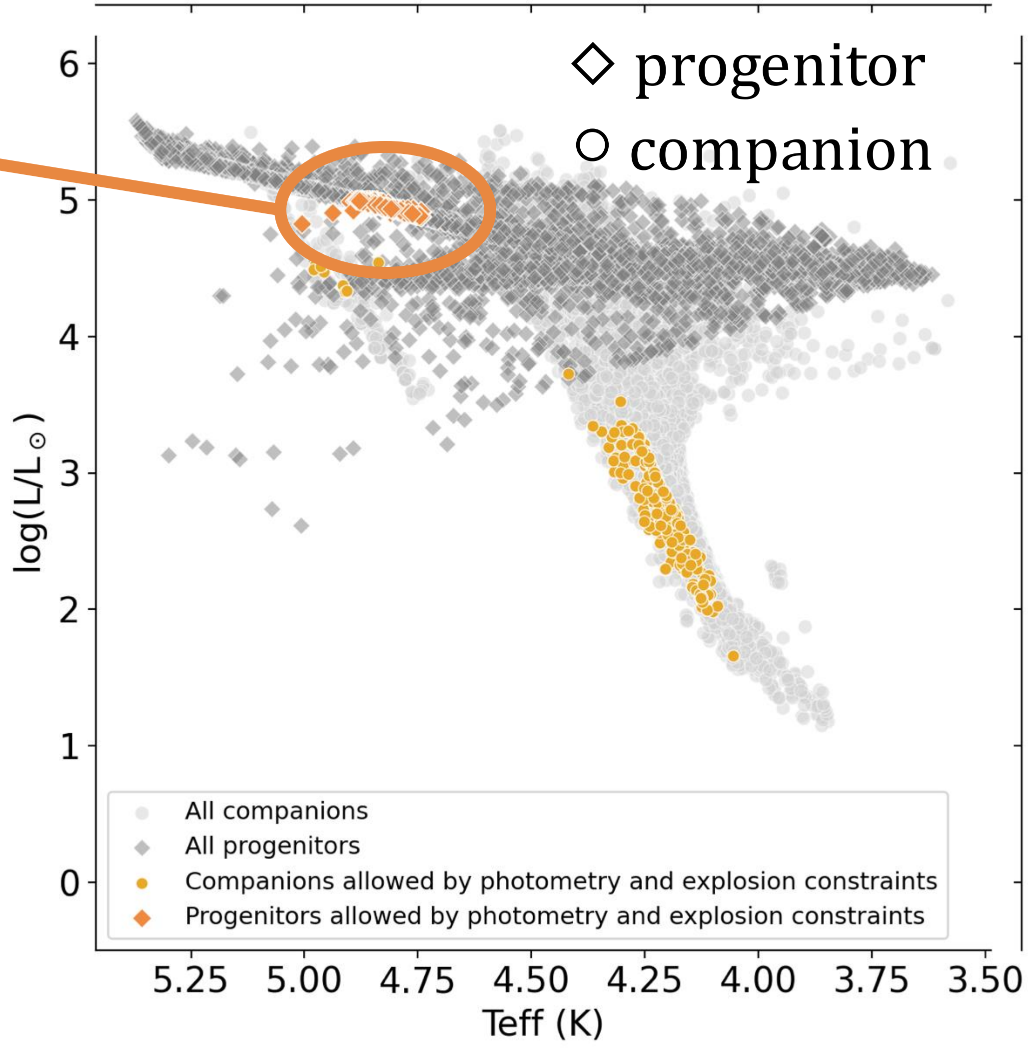
- Only a small range of progenitors are allowed once ejecta mass constraint is imposed



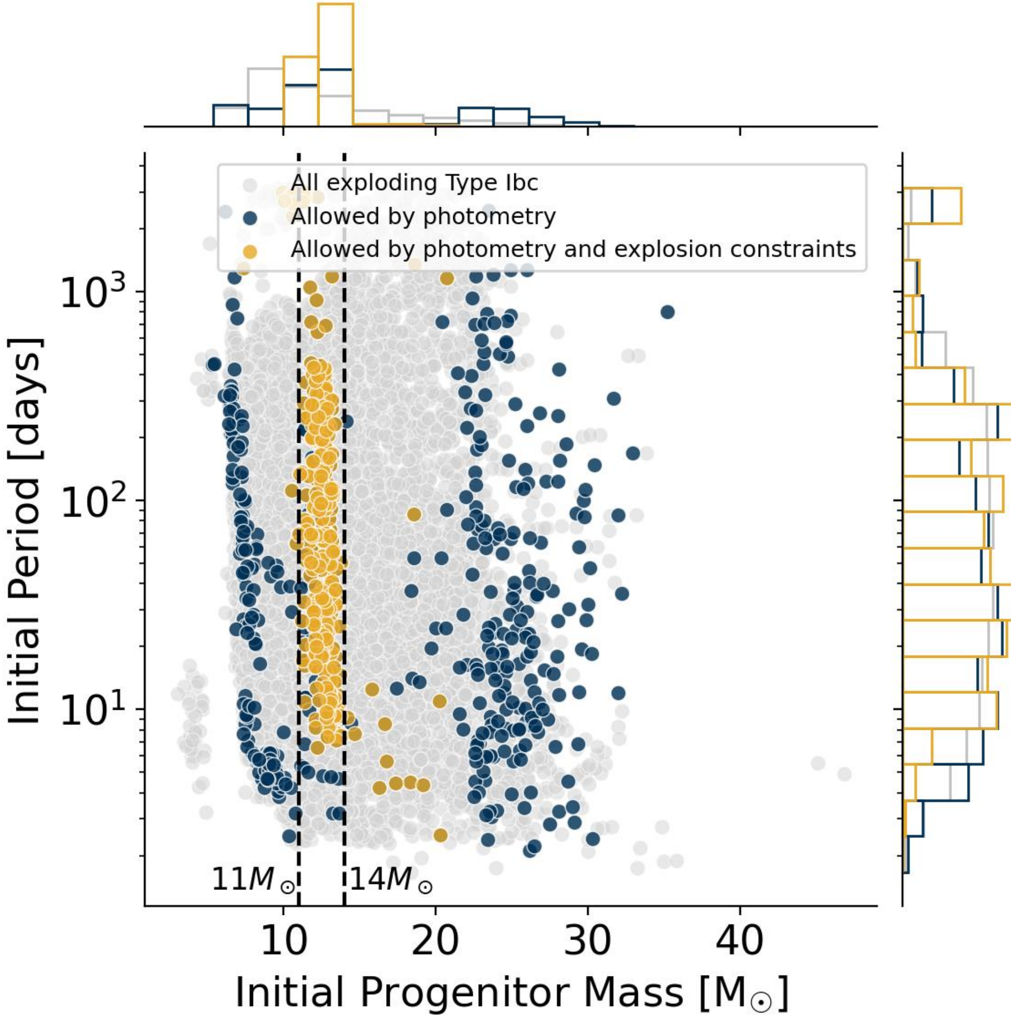
Stripped star wind mass loss assumptions in POSYDON

- Only a small range of progenitors are allowed once ejecta mass constraint is imposed
- **Caveat**: POSYDON may be using mass loss rates too high for intermediate luminosity stripped stars

  → Under-predicting ejecta masses

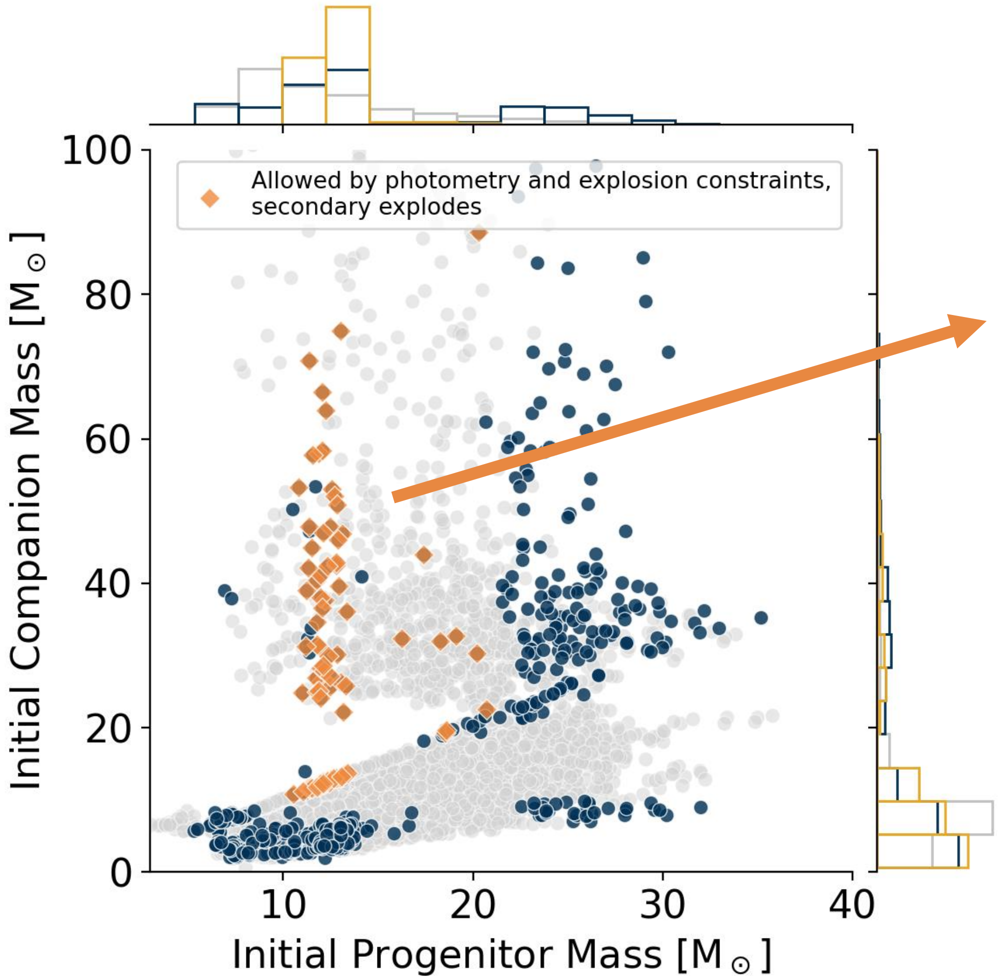


Initial binary system



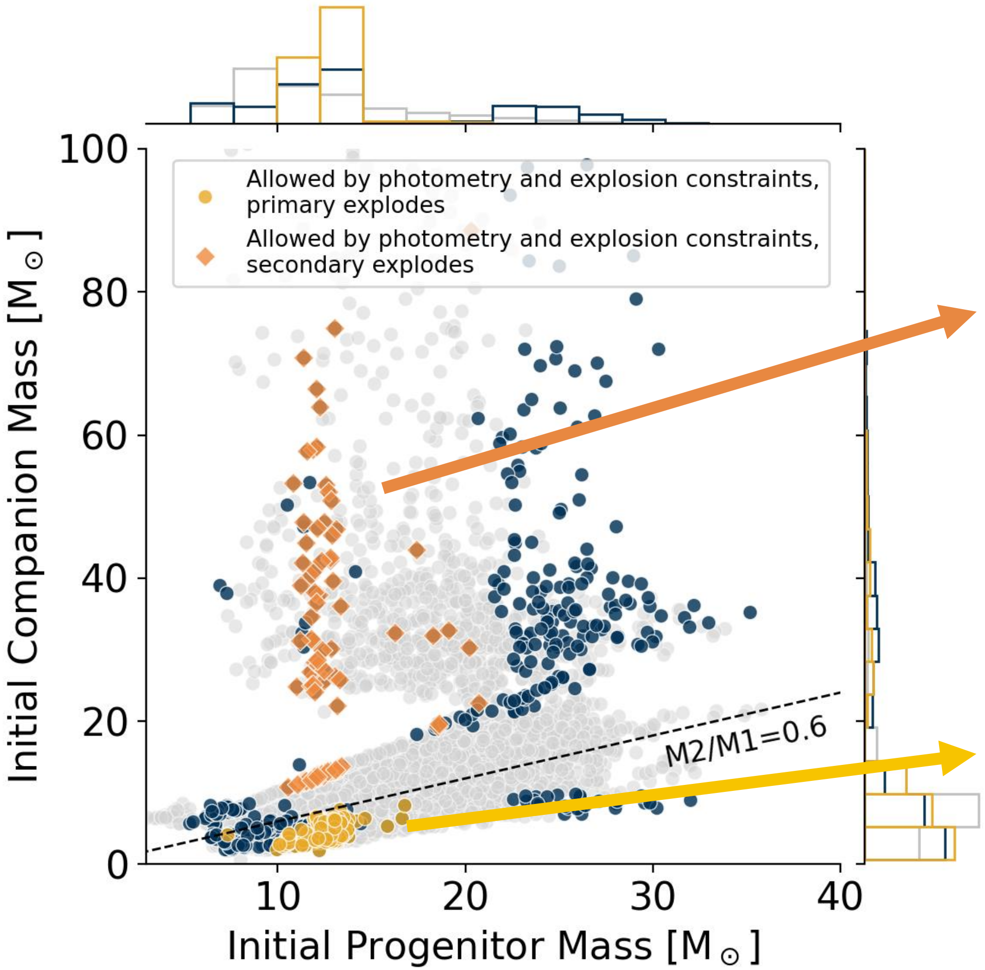
- ~91% of allowed progenitor initial masses are within 11-14 $M_\odot$
- Initial period range (tens-hundreds days) suggests most come from case B mass transfer
- Note: none of the single star Type Ibc progenitors predicted by POSYDON are allowed within our constraints

2 classes of systems allowed by our constraints



The exploding star is the secondary. The primary star already exploded, no longer contributing light.

2 classes of systems allowed by our constraints



The exploding star is the secondary. The primary star already exploded, no longer contributing light.

High mass ratio systems (M2/M1)<0.6, where the low mass companion is faint.

Sample Study

- **~9+** observational data points to nearby SESNe and growing
  - 6 Type Ib/c (3 detections, 3 upper limits)
  - 3 IIb (1 upper limit)

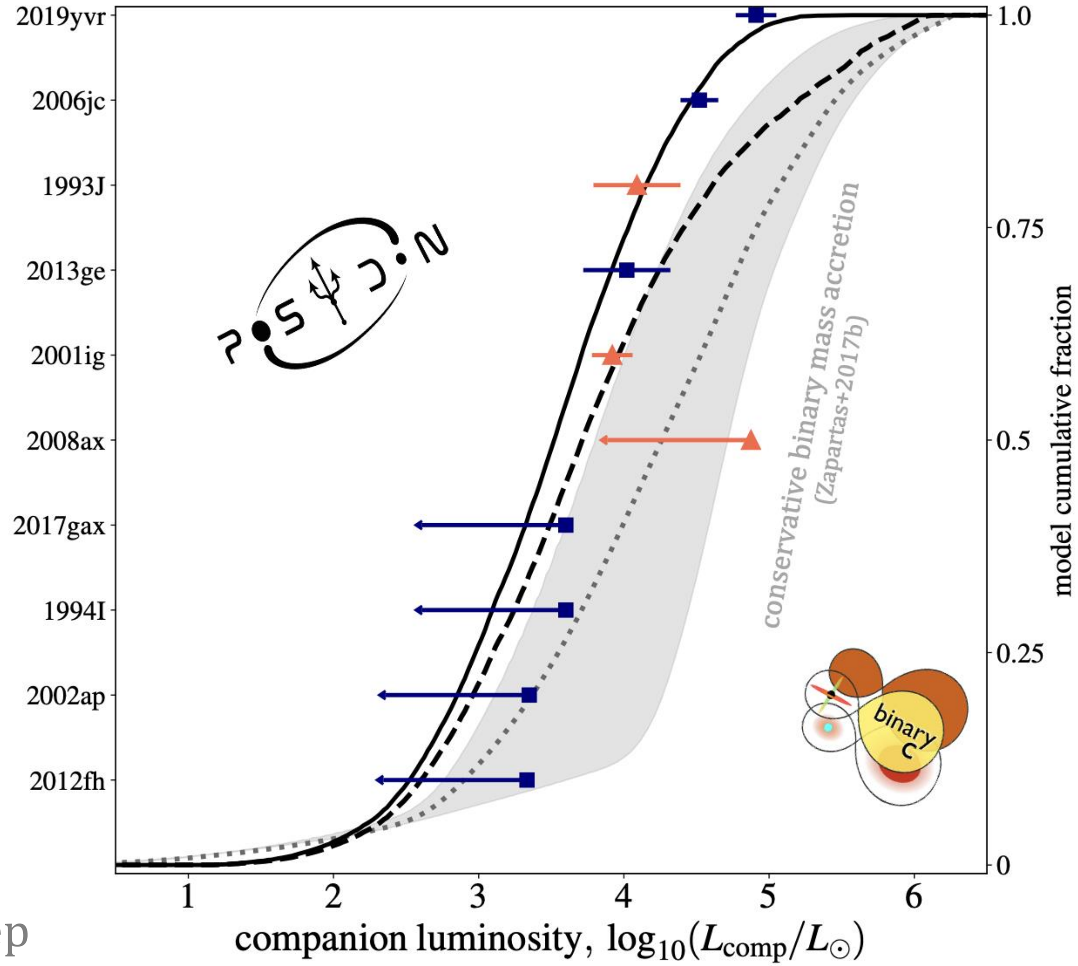
SN	Method of companion constraint	SN Type	Citations for companions
1993J	post-SN	Type IIb	Maund et al. (2004), Fox et al. (2014)
1994I	post-SN	Type Ic	Van Dyk et al. (2016)
2001ig	post-SN	Type IIb	Ryder et al. (2006, 2018)
2006jc	post-SN	Type Ibn	Maund et al. (2016); Sun et al. (2020)
2008ax	post-SN	Type IIb	Folatelli et al. (2015)
2002ap	post-SN	Type Ic-BL	Zapartas et al. (2017a)
2013ge	post-SN	Type Ib/c	Fox et al. (2022)
2019yvr	pre-SN	Type Ib	Sun et al. (2022)
2012fh	post-SN	Type Ib/c	Williams et al. in prep.
2017gax	post-SN	Type Ib/c	Currently analyzing
2016coi	post-SN	Type Ic?-BL	Currently analyzing
2013bvn	post-SN	Type Ib	Data arriving soon

Zapartas et al. in prep

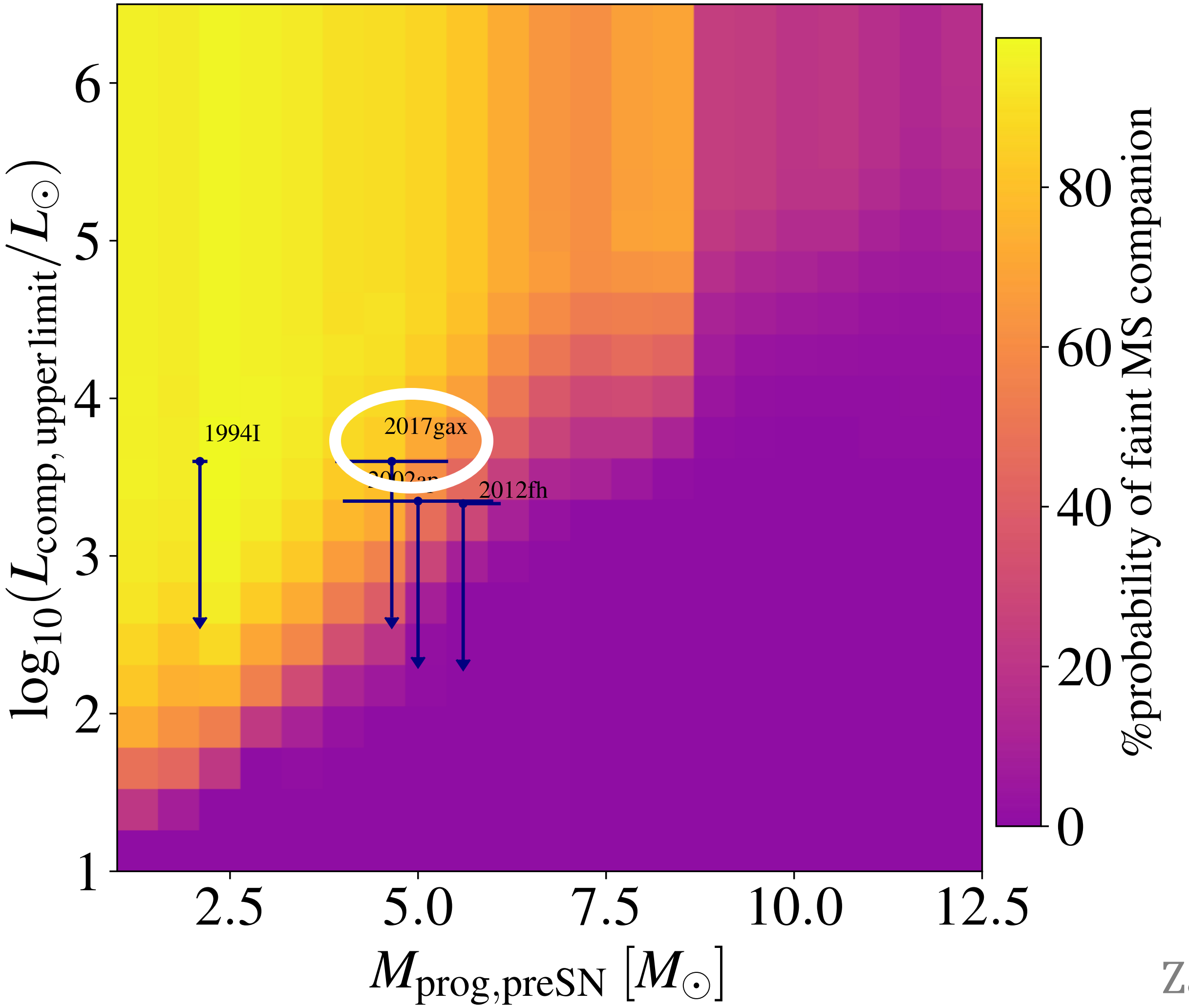
Implications on mass transfer efficiency

- Cumulative distribution of companion luminosities
- Observations favor non-conservative mass transfer

Zapartas et al. in prep



Probability of faint MS companion



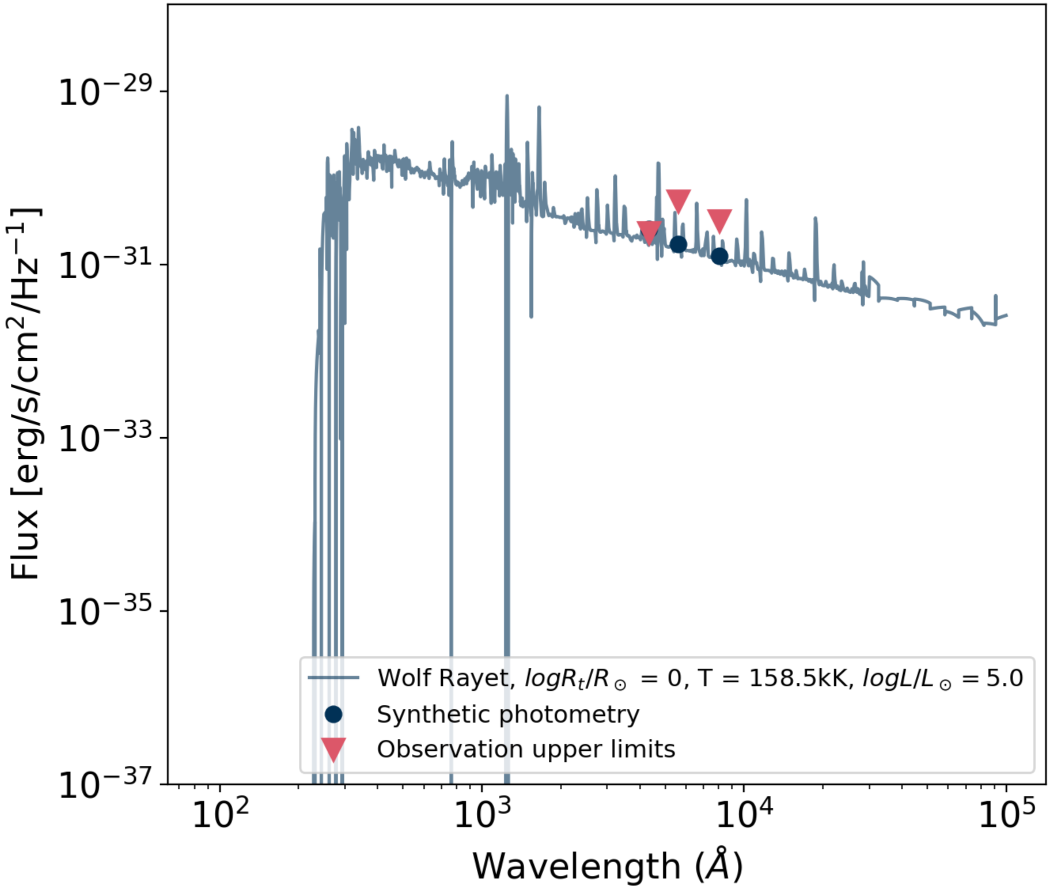
Zapartas et al. in prep

Summary

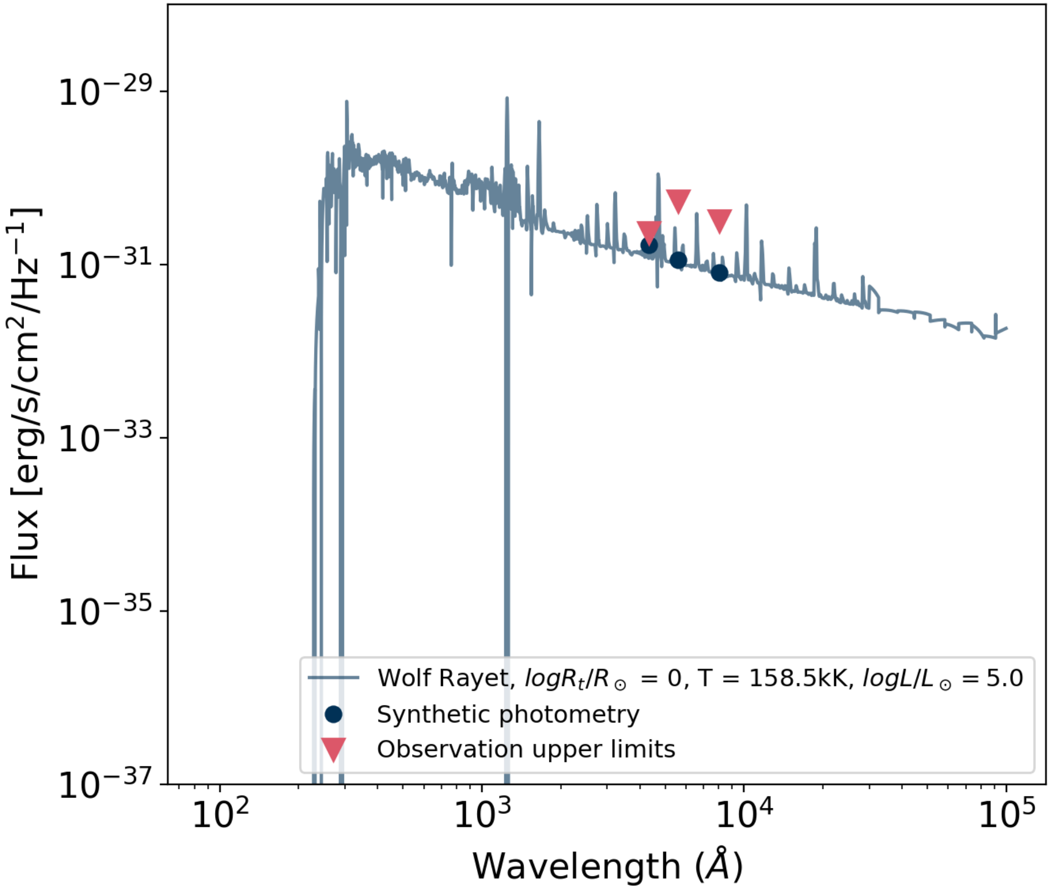
- We constrained the luminosity of both progenitor and any companion as a function of temperature
- With POSYDON, we found two classes of possible systems:
  i. the progenitor is the secondary star in the initial binary, thus not contributing light to the system,
  ii. High initial mass ratios ($M2/M1<0.6$) with a low-mass companion and underwent non-conservative mass transfer.
- Future work: sample study of constraints on any surviving companions and the progenitor star

Extra Slides

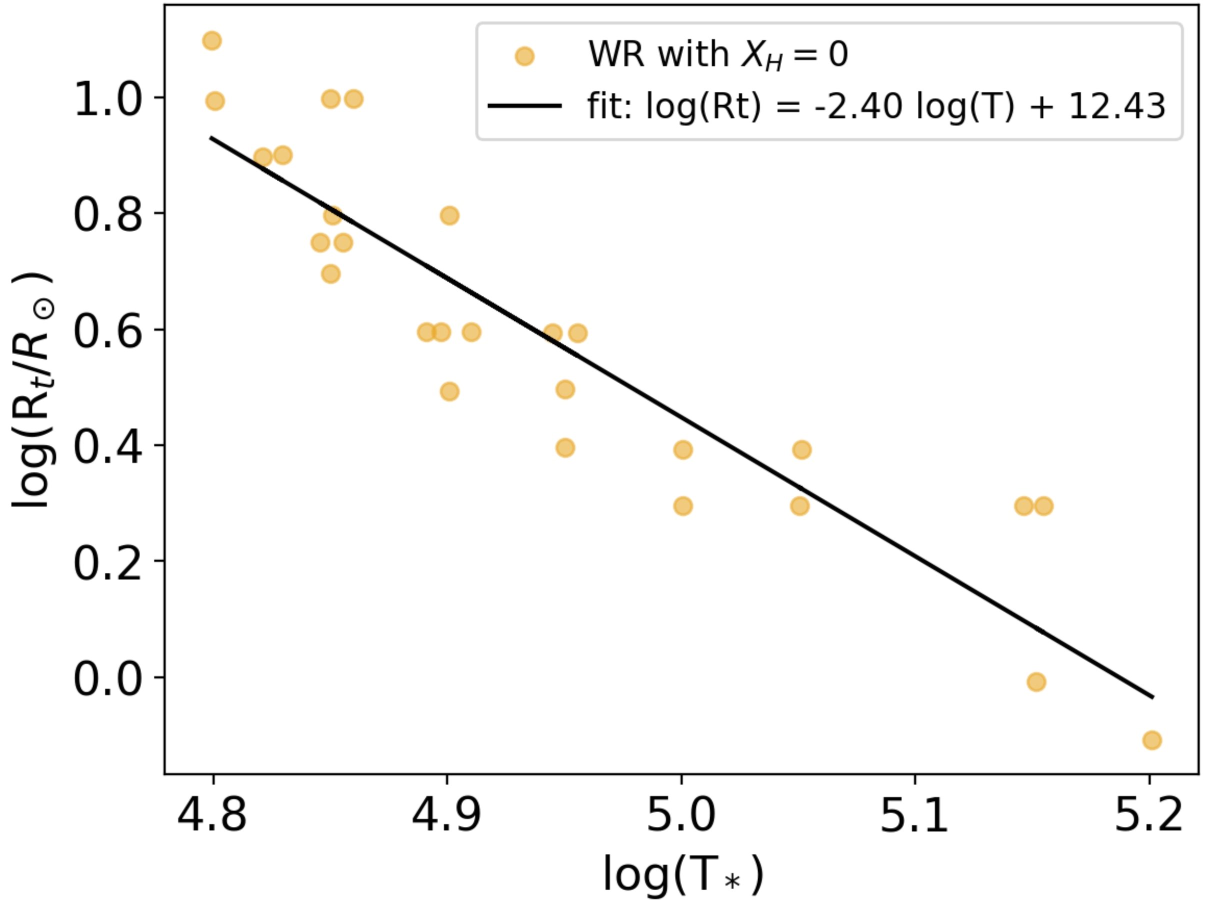
WR model, not allowed



WR model, allowed



Transformed radius for WR models



Data from Hainich et al. 2014

Assessing extinction by comparing multi-band lightcurves to Stritzinger et al. (2018) templates