MODEST24

Investigating Blue Straggler Stars of Open Clusters and Fields using AstroSat/UVIT

Kaushar Vaidya

Department of Physics, Birla Institute of Technology and Science Pilani

In collaboration with

Anju Panthi
Vikrant Jadhav
Annapurni Subramaniam
Nagraj Vernekar
Manan Agarwal
Khushboo K. Rao
Sindhu Pandey
Sharmila Rani
Sivarani Tirupathi
Saketh Pinapati

BITS Pilani
Pilani | Dubai | Goa | Hyderabad
UNIVERSITY OF AMSTERDAM
Università degli Studi di Padova
आर्यभट्ट प्रेक्षण विज्ञान शोध संस्थान
Aryabhatta Research Institute of Observational Sciences

UVIT Open Cluster Study (UOCS)

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **511,** 2274–2284 (2022) https://doi.org/10.1093/mnras/stac207
Advance Access publication 2022 January 29

UOCS – VII. Blue straggler populations of open cluster NGC 7789 with UVIT/AstroSat

Kaushar Vaidya [1★†] Anju Panthi,[1★] Manan Agarwal [1] Sindhu Pandey [2★] Khushboo K. Rao [1] Vikrant Jadhav [3,4] and Annapurni Subramaniam[3]
[1]*Department of Physics, Birla Institute of Technology and Science – Pilani, Pilani 333031, Rajasthan, India*
[2]*Aryabhatta Research Institute of Observational Sciences, Manora Peak, Nainital 263001, India*
[3]*Indian Institute of Astrophysics, Sarjapur Road, Koramangala, Bangalore 560034, India*
[4]*Joint Astronomy Programme and Department of Physics, Indian Institute of Science, Bangalore 560012, India*

Accepted 2022 January 18. Received 2022 January 17; in original form 2021 November 23

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **527,** 8325–8336 (2024) https://doi.org/10.1093/mnras/stad3750
Advance Access publication 2023 December 07

UOCS – XI. Study of blue straggler stars in open cluster NGC 7142 using UVIT/*AstroSat*

Anju Panthi,[1★] Kaushar Vaidya [1★] Nagaraj Vernekar [2★] Annapurni Subramaniam,[3] Vikrant Jadhav [4] and Manan Agarwal [5]
[1]*Department of Physics, Birla Institue of Technology and Science, Pilani, Rajasthan 333031, India*
[2]*Dipartimento di Fisica e Astronomia "Galileo Galilei", Università di Padova, Vicolo dell'Osservatorio 3, I-35122, Padova, Italy*
[3]*Indian Institute of Astrophysics, Sarjapur Road, Koramangala, Bangalore 560034, India*
[4]*Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Nussallee 14-16, D-53115 Bonn, Germany*
[5]*Anton Pannekoek Institute for Astronomy & GRAPPA, University of Amsterdam, Science Park 904, NL-1098 XH Amsterdam, the Netherlands*

Accepted 2023 November 28. Received 2023 November 24; in original form 2023 August 1

THE ASTRONOMICAL JOURNAL, 168:97 (11pp), 2024 September https://doi.org/10.3847/1538-388

UOCS XIV: Study of the Open Cluster NGC 2627 Using UVIT/AstroSat

Pinapati Saketh, Anju Panthi, and Kaushar Vaidya
Department of Physics, Birla Institue of Technology and Science, Pilani, Rajasthan-333031, India; f20200966@pilani.bits-pilani.ac.in, p20190413@pilani.bits-pilani.ac.in, kaushar@pilani.bits-pilani.ac.in
Received 2024 April 13; revised 2024 June 16; accepted 2024 June 17; published 2024 July 31

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **516,** 5318–5330 (2022) https://doi.org/10.1093/mnras/stac2421
Advance Access publication 2022 August 29

UOCS –VIII. UV study of the open cluster NGC 2506 using *ASTROSAT*★

Anju Panthi,[1†] Kaushar Vaidya [1†] Vikrant Jadhav [2,3,4†] Khushboo K. Rao [1] Annapurni Subramaniam,[2] Manan Agarwal [5] and Sindhu Pandey [6]
[1]*Department of Physics, Birla Institute of Technology and Science, Pilani 333031, India*
[2]*Indian Institute of Astrophysics, Sarjapur Road, Koramangala, Bangalore 560034, India*
[3]*Joint Astronomy Programme and Department of Physics, Indian Institute of Science, Bangalore 560012, India*
[4]*Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune, Maharashtra 411007, India*
[5]*Department of Physics and Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[6]*Aryabhatta Research Institute of Observational Sciences, Manora Peak, Nainital 263001, India*

Accepted 2022 August 23. Received 2022 August 23; in original form 2022 May 16

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **527,** 10335–10347 (2024) https://doi.org/10.1093/mnras/stad3887
Advance Access publication 2023 December 18

UOCS-XII. A study of open cluster NGC 6940 using UVIT/*AstroSat* cluster properties and exotic populations

Anju Panthi★ and Kaushar Vaidya ★
Department of Physics, Birla Institute of Technology and Science, Pilani 333031, Rajasthan, India

Accepted 2023 December 14. Received 2023 December 12; in original form 2023 September 22

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **525,** 1311–1328 (2023) https://doi.org/10.1093/mnras/stad2385
Advance Access publication 2023 August 7

Field blue straggler stars: discovery of white dwarf companions to blue metal-poor stars using UVIT/AstroSat

Anju Panthi,[1★] Annapurni Subramaniam,[2★] Kaushar Vaidya [1★] Vikrant Jadhav [3] Sharmila Rani,[2] Sivarani Thirupathi[2] and Sindhu Pandey [4]
[1]*Department of Physics, Birla Institute of Technology and Science, Pilani, Rajasthan-333031, India*
[2]*Indian Institute of Astrophysics, Sarjapur Road, Koramangala, Bangalore 560034, India*
[3]*Helmholtz-Institut für Strahlen-und Kernphysik, Universität Bonn, Nussallee 14-16, D-53115 Bonn, Germany*
[4]*Aryabhatta Research Institute of Observational Sciences, Manora Peak, Nainital 236002, India*

Accepted 2023 July 31. Received 2023 July 27; in original form 2023 May 15

What are blue straggler stars (BSS)?

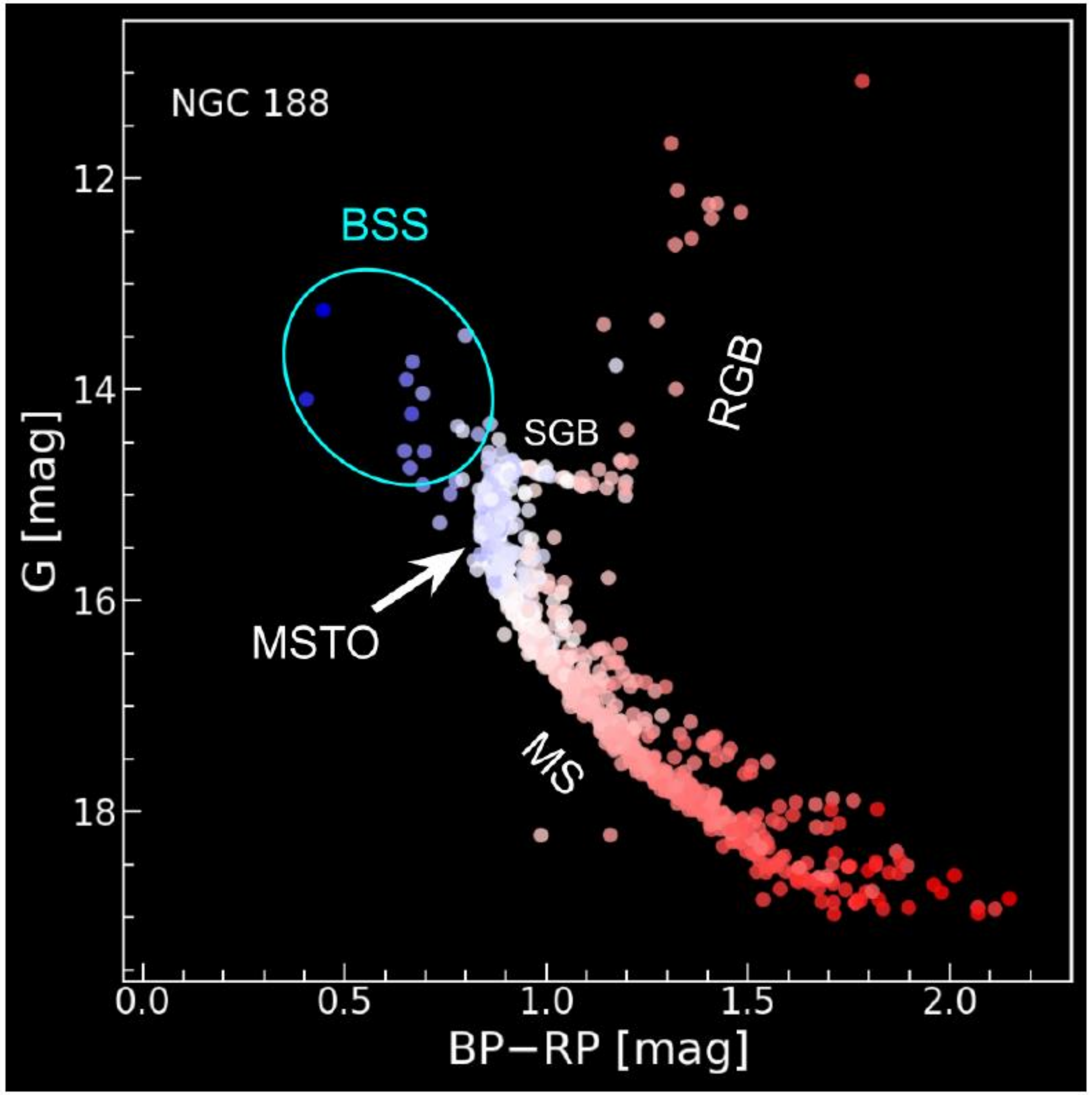
Stars that are "Brighter and Bluer" compared to the **main-sequence turnoff (MSTO)** of a star cluster

What are blue straggler stars (BSS)?

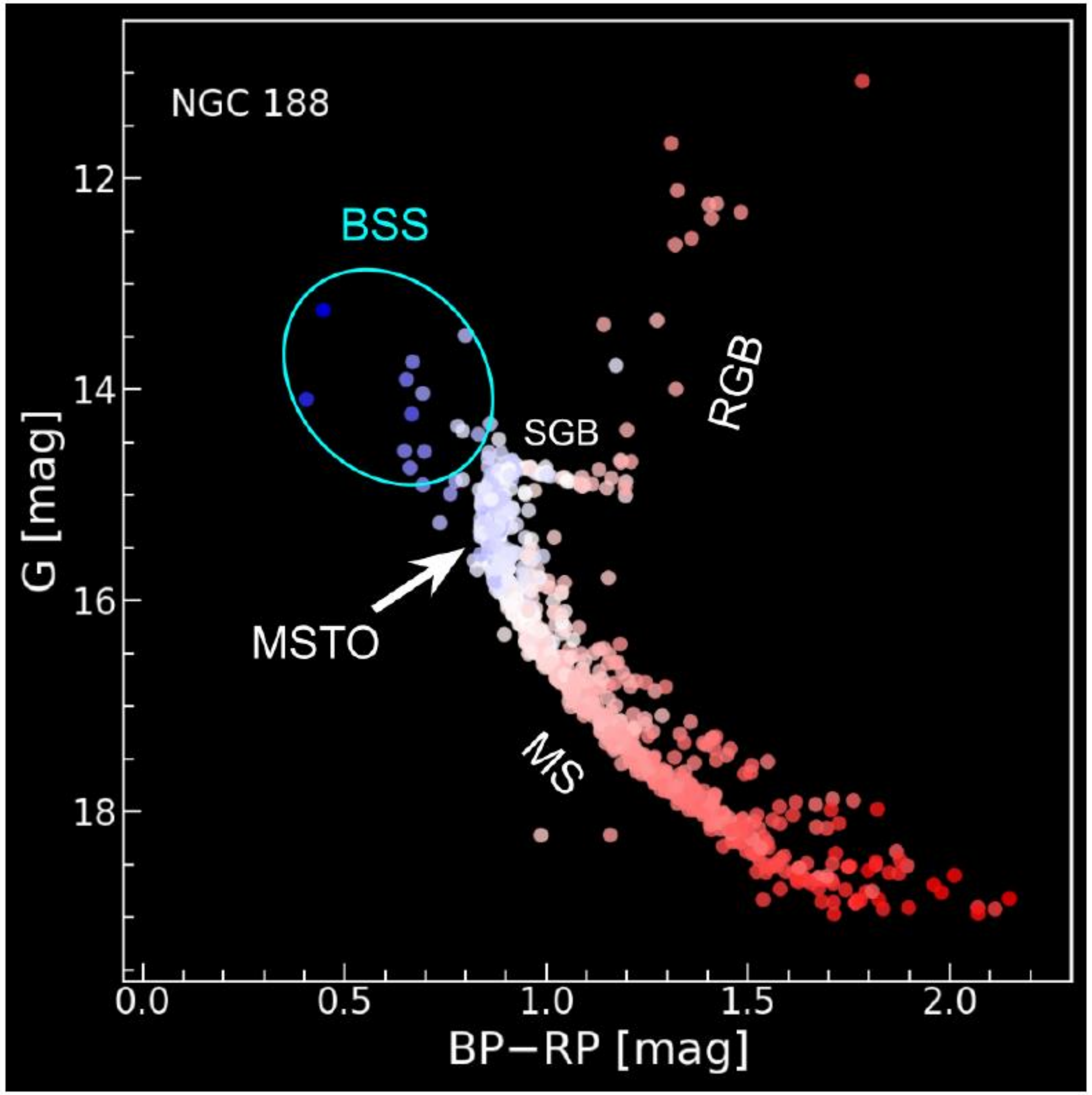
Stars that are “Brighter and Bluer” compared to the **main-sequence turnoff (MSTO)** of a star cluster

↓

Extended main-sequence lifetimes



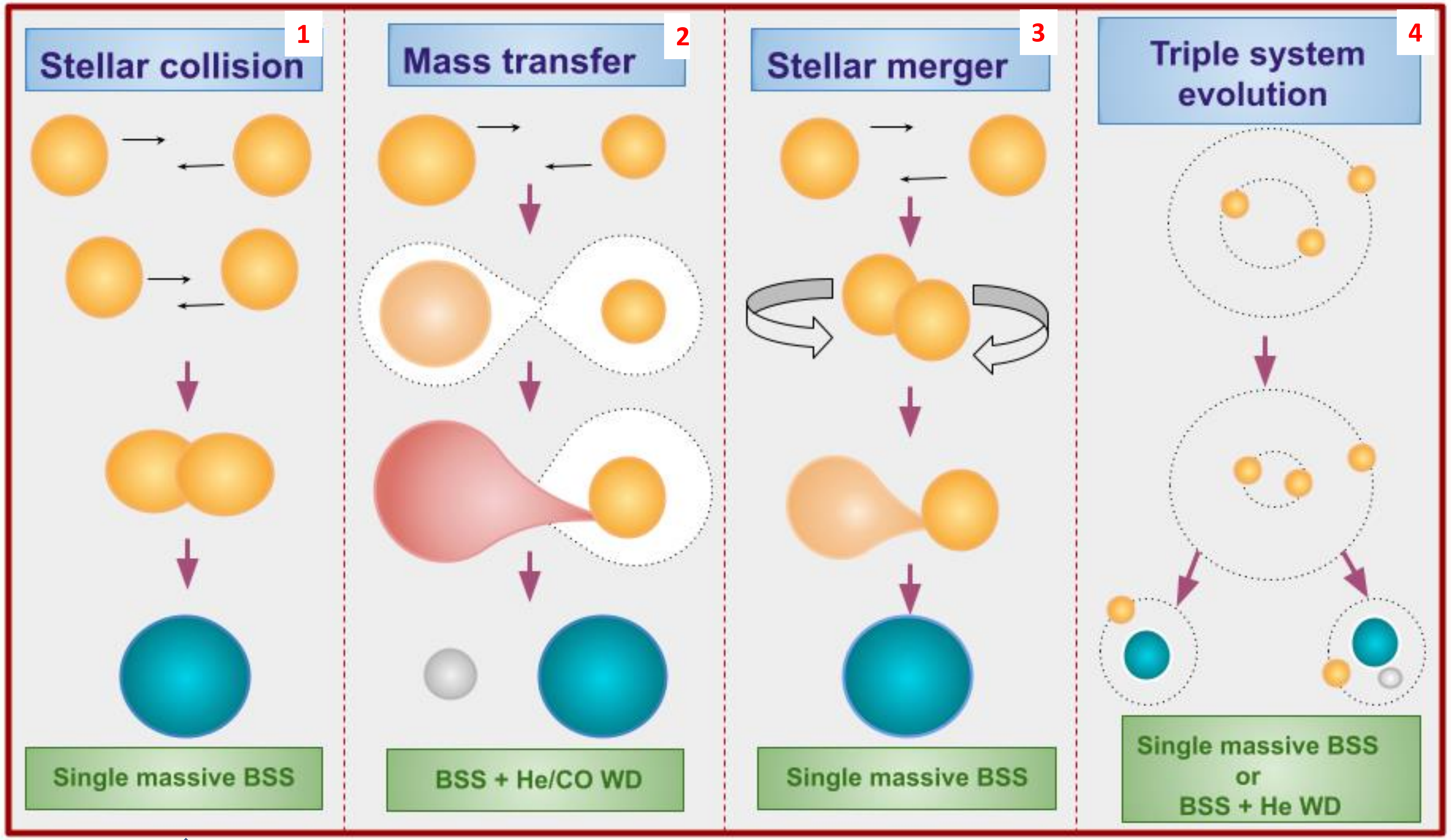
A color-magnitude diagram of NGC 188 from Rao et al. (2023) showing cluster members (membership probabilities > 0.6).



A color-magnitude diagram of NGC 188 from Rao et al. (2023) showing cluster members (membership probabilities > 0.6).

Why do BSS lag in their evolution?

Formation Mechanisms



Not viable in open clusters and fields

1 Hills & Day 1976, Hurley et al. 2005, Chatterjee et al. 2013, Leonard 1989

2 McCrea 1964, Webbink 1976, Chen & Han 2008

3 McCrea 1964, Perets et al. 2009

4 Kozai 1962, Perets et al. 2009

Kaushar Vaidya @ MODEST24

Where are BSS found?

- Globular clusters (Sandage 1953)
- Open clusters (Leiner et al. 2021, Jadhav and Subramaniam 2021)
- Galactic fields (Preston et al. 1994)
- Dwarf galaxies (Momany et el. 2007)
- Numbers of BSS range from **10 to 400** in globular clusters (Bailyn 1995, Davies et al. 2004)
- Numbers of BSS range from **1 to ~35** in open clusters (Jadhav and Subramaniam 2021)

Field Blue Metal-Poor (BMP) Stars

- Preston and Snedon (2000) and Carney et al. (2001) found **high-velocity**, **blue metal-poor stars** having **main-sequence gravities**

Field Blue Metal-Poor (BMP) Stars

❖ Preston and Snedon (2000) and Carney et al. (2001) found **high-velocity**, **blue metal-poor stars** having **main-sequence gravities**

Intermediate-age Dwarf galaxy stars accreted by Milky-Way Galaxy

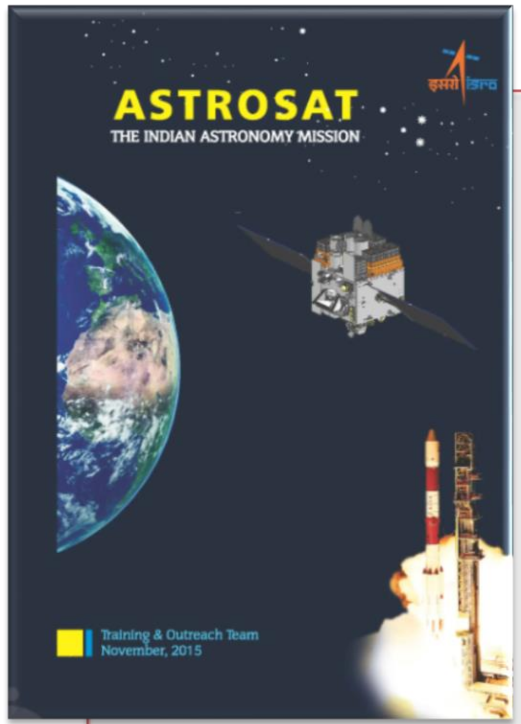
Field Blue Stragglers

Field Blue Metal-Poor (BMP) Stars

- 2/3rd of BMP are **single-lined spectroscopic binaries** (Preston et al. 2000)
- A fraction also shows enhancement in C, Sr, and Ba

Motivation

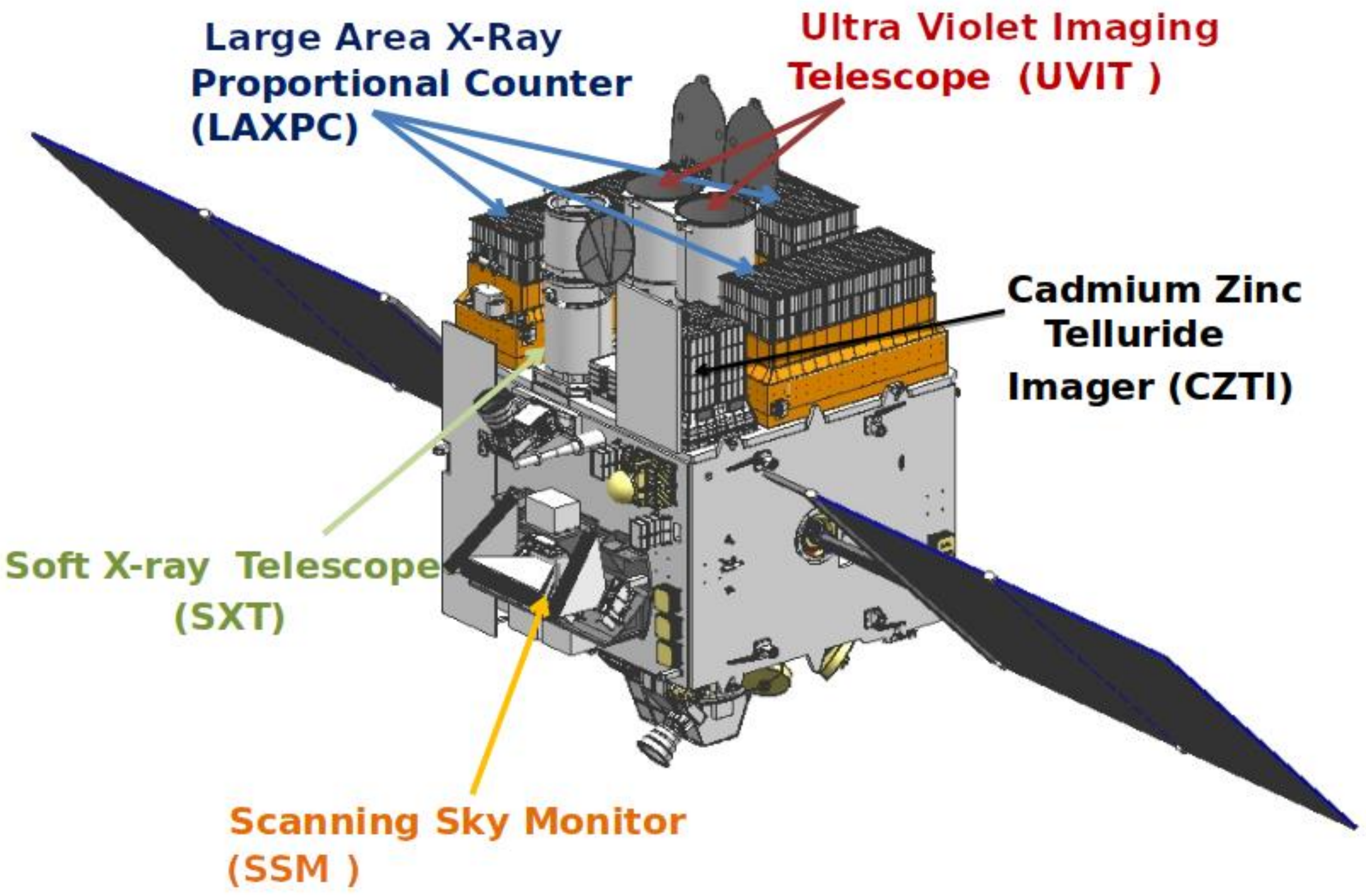
- Investigate the formation mechanisms of BSS (Geller & Mathieu 2011; Gosnell et al. 2014; Subramaniam et al. 2016)
- Know the relative importance of different formation mechanisms in diverse environments



UV imaging observations to identify BSS and search for hot companions

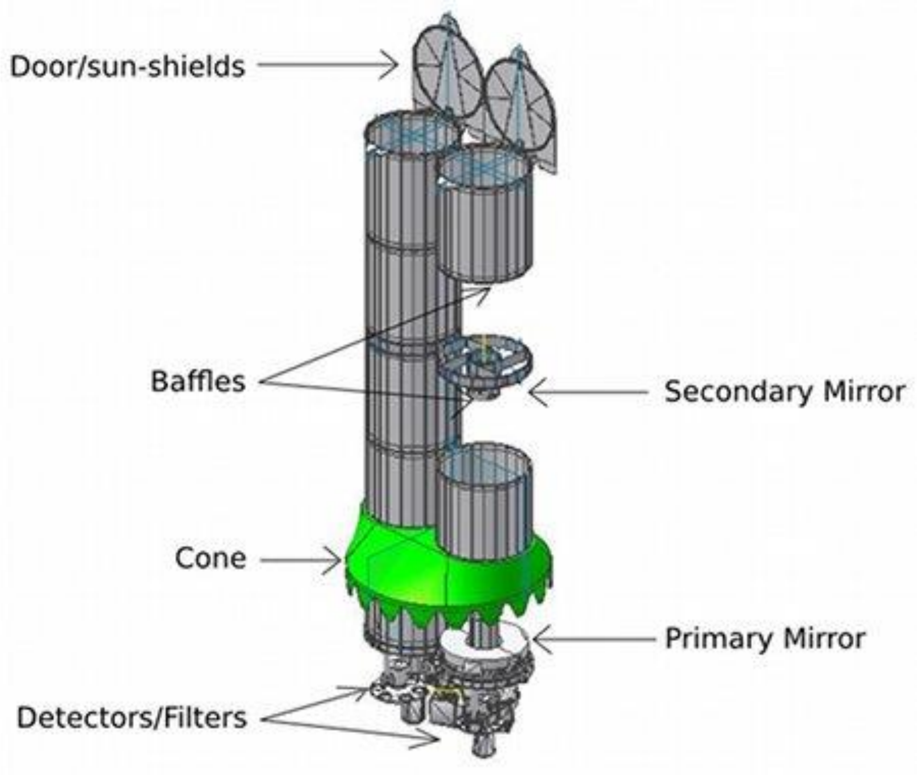
Search for variable signature and obtain the parameters of binary components

Ultraviolet Imaging Telescope (UVIT)

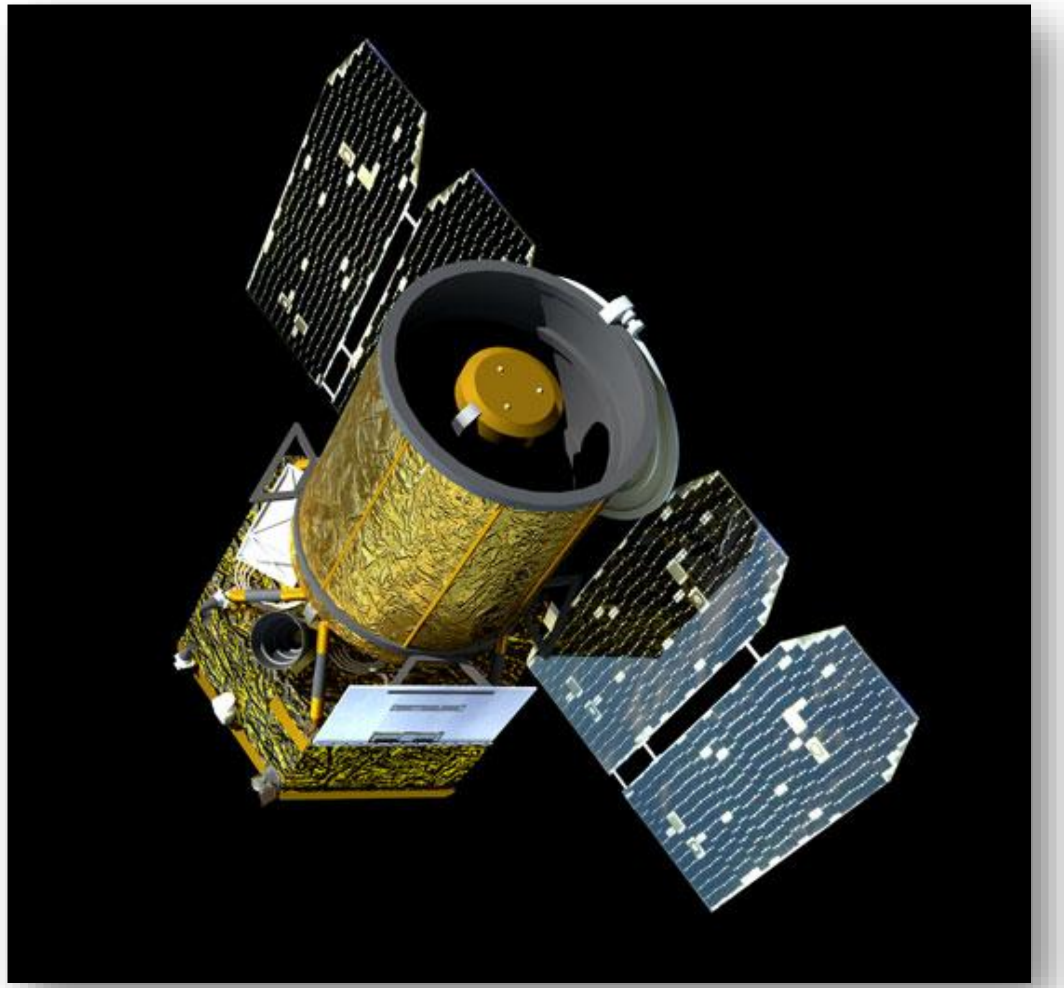


Agrawal, P. C. et al. (2016)

- Two 38 cm telescopes: FUV (130 nm -180 nm), NUV (200-300 nm) & VIS (350-550 nm)
- Spatial resolution of 1.2” (NUV filter) & ~ 1.5” (FUV filter) (GALEX ~ 5”)
- Field of view of 0.5 degree (GALEX ~ 1.2 degrees)



Tandon et al. (2017)



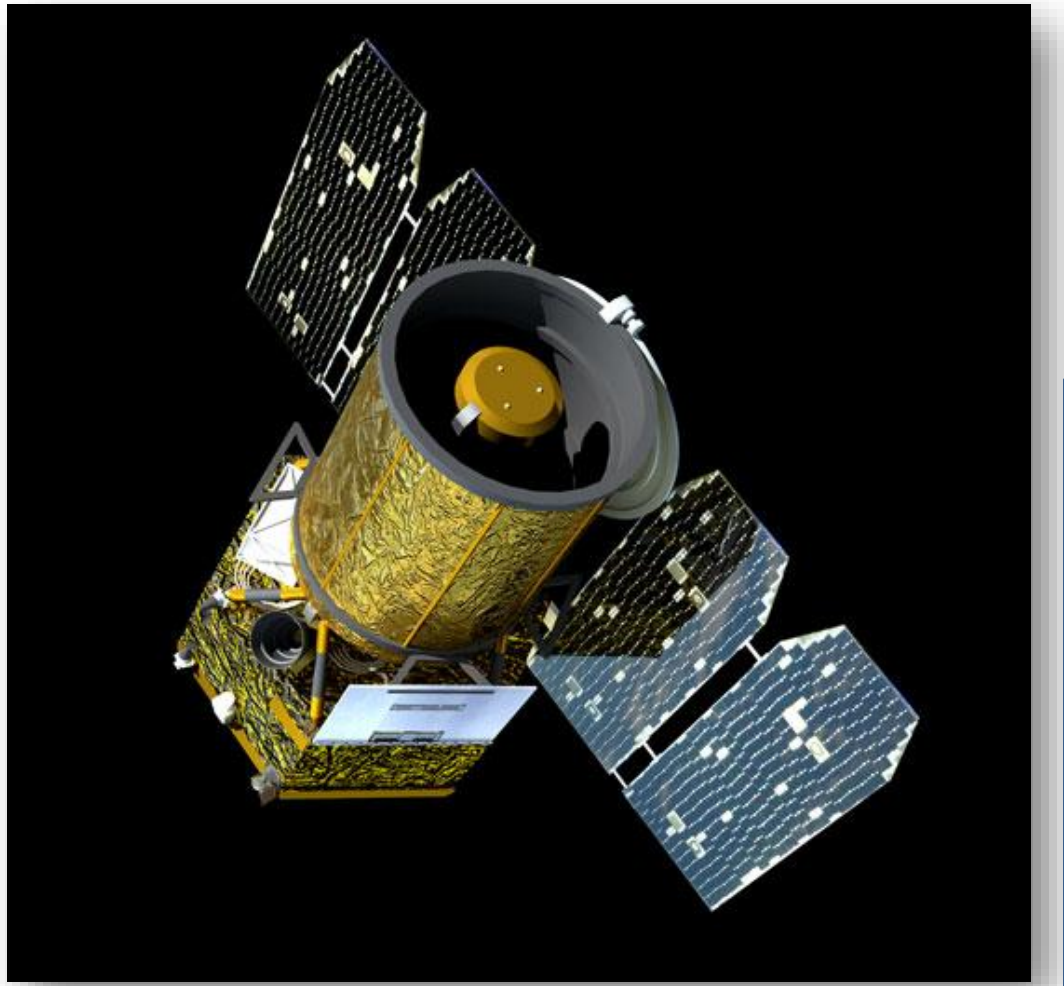
GALEX (1350 Å - 2800 Å)

2MASS (12350 Å - 21590 Å)

GAIA (5109 Å - 8578 Å)

PANSTARRS (3900 Å - 5400 Å)

WISE (33526 Å - 280883 Å)



GALEX (1350 Å - 2800 Å)

2MASS (12350 Å - 21590 Å)

GAIA (5109 Å - 8578 Å)

Cluster Membership

PANSTARRS (3900 Å - 5400 Å)

WISE (33526 Å - 280883 Å)

Target Clusters

Name	Age (Gyr)	[Fe/H]	Distance (pc)	E(B-V)
NGC 7789	1.6	−0.02	2075	0.28
NGC 2506	2	−0.52	3110	0.08
NGC 7142	4	0	2000	0.1
NGC 6940	1	−0.09	770	0.4
NGC 2627	1.9	−0.10	1837	0.1

Cluster Membership

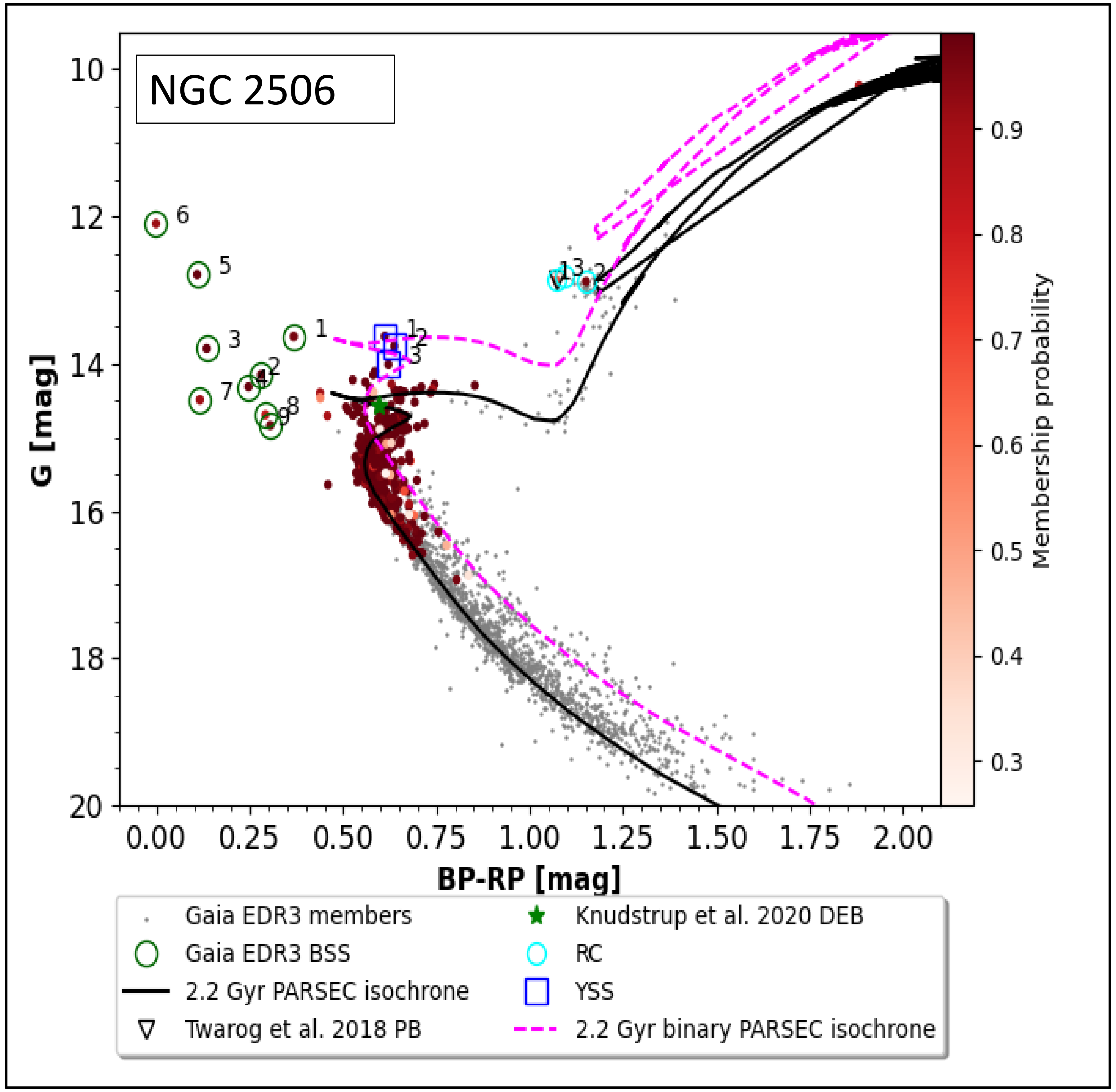
- **ML-MOC** (Agarwal et al. 2021) on Gaia DR3 data
- Identification of cluster members down to G = 20 mag
- Estimated contamination: 2 – 12% (Agarwal et al. 2021)
- Estimated completeness: 90% till G = 19 mag (Bhattacharya et al. 2022)

UV Photometry

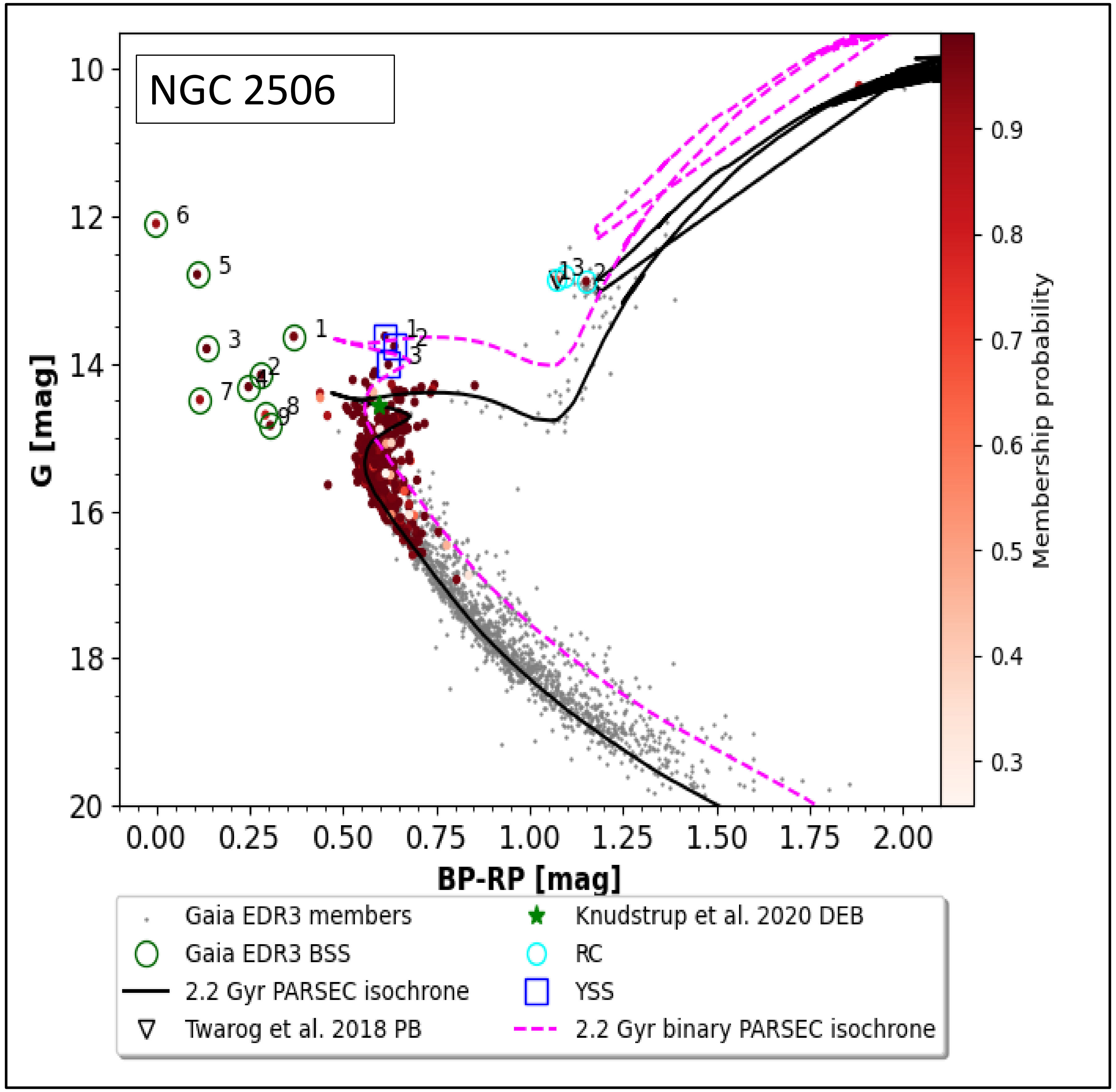
- **CCDLAB** (Postma et al. 2017) to convert Level-1 data into science-ready images
- Photometry using IRAF (Barnes 1993)
- Aperture correction, PSF correction, and Saturation correction to obtain final magnitudes in NUV and FUV in AB magnitude system

Details of UVIT Observations

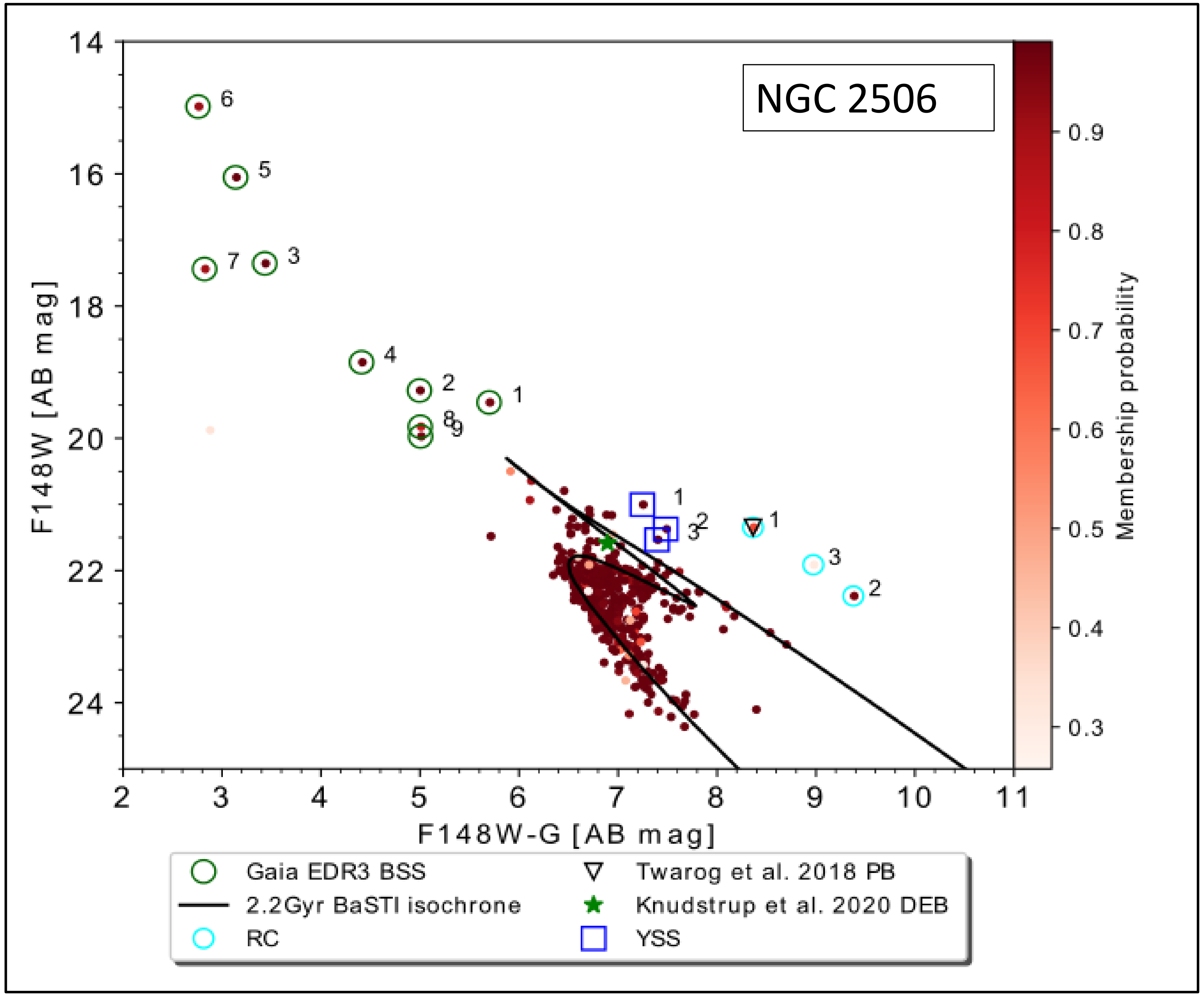
Cluster	Observation Date	Filters	Exposure (sec)
NGC7789	July 2017	FUV: F169M NUV: N245M N263M N279N	609 3219 1142 1021
NGC2506	October 2019	FUV: F148W F154W F169M	9224 7499 7027
NGC7142	June 2018	FUV: F148W	2280
NGC6940	June 2018	FUV: F169M	2000
NGC2627	June 2020	FUV: F148W F169M	1370 4062
Fields	**Sep 2021**	**FUV: F148W** **F169M**	**200-2000**



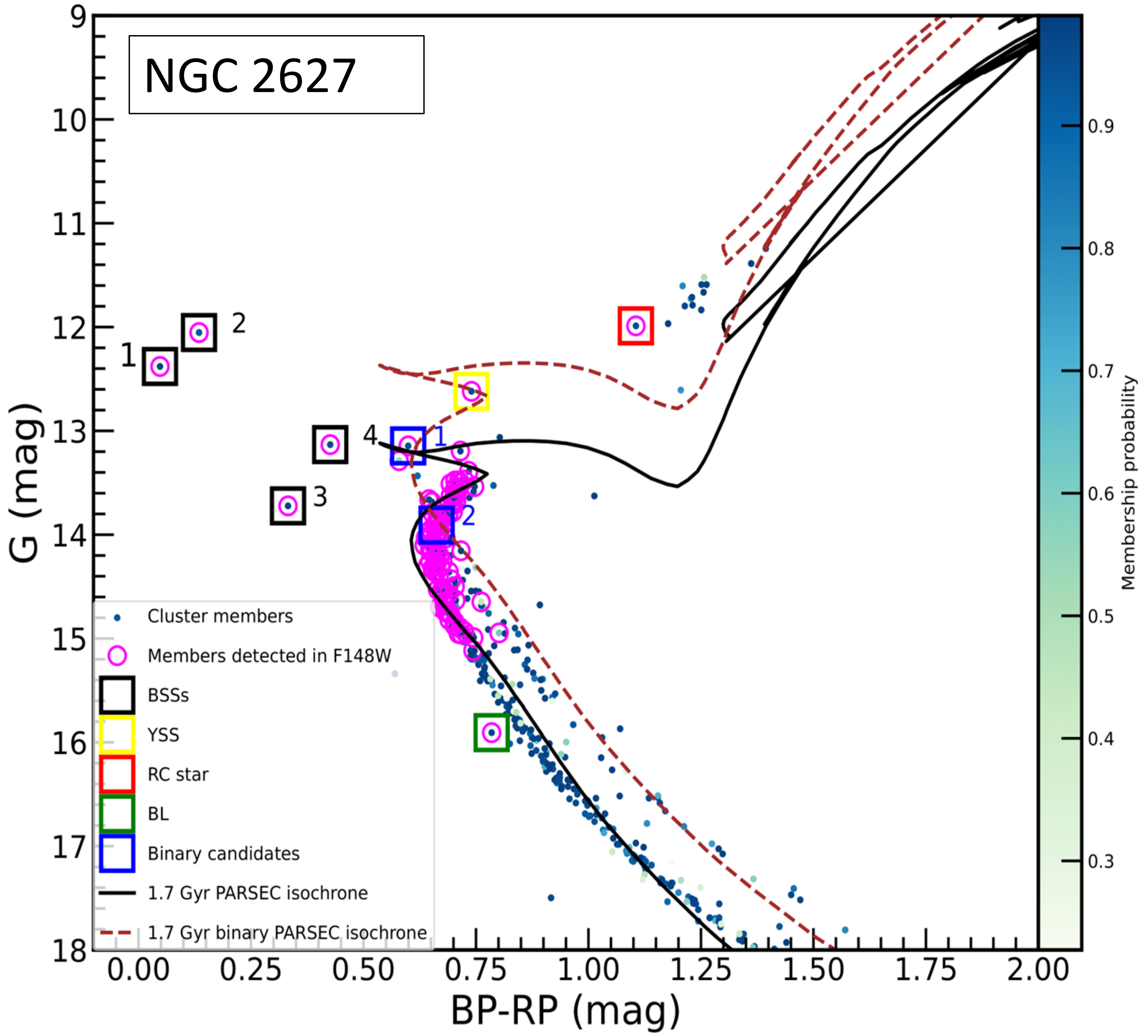
Distance: 3110 pc; E(BP-RP) = 0.155; A_G : 0.39



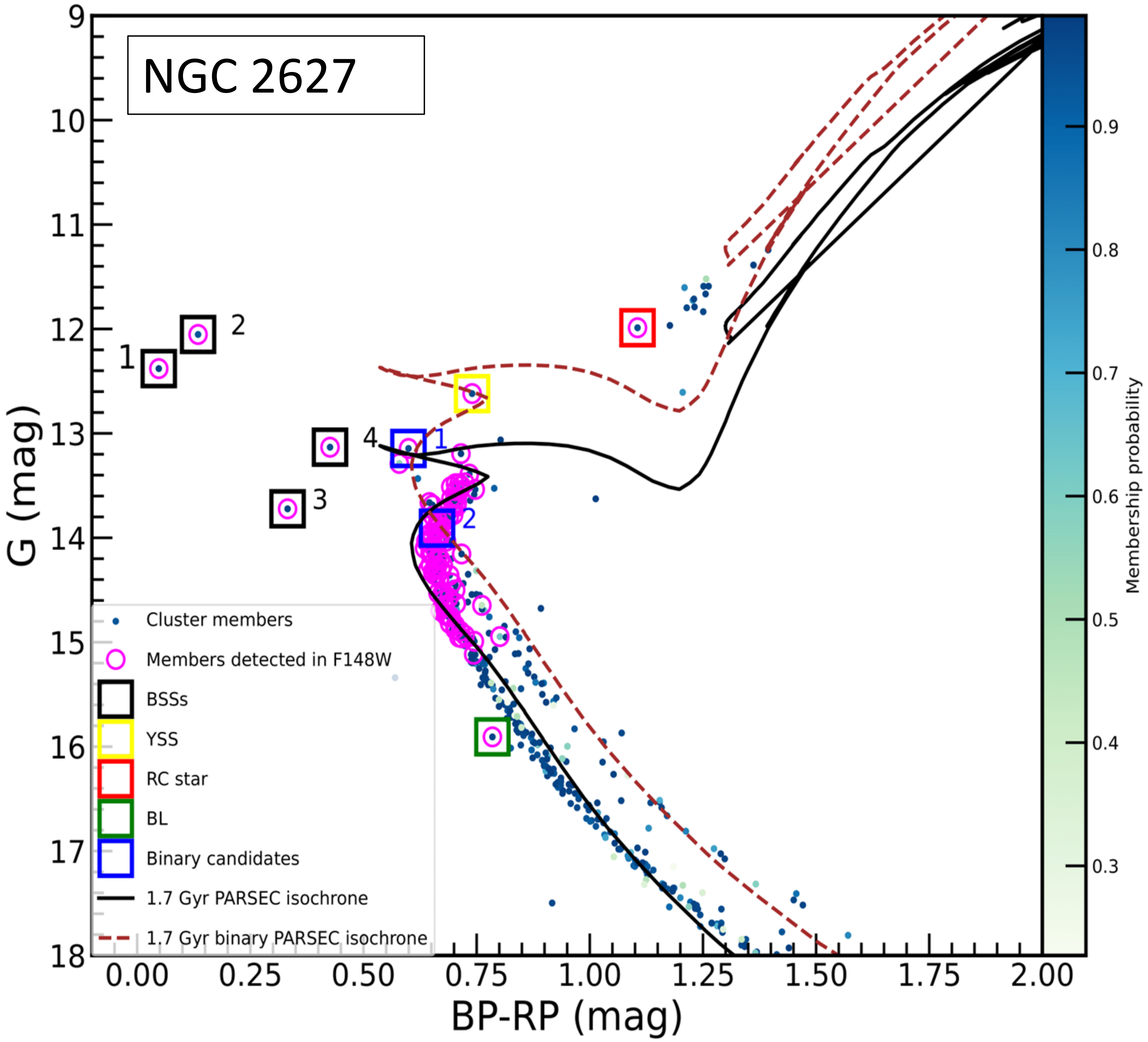
Distance: 3110 pc; E(BP-RP) = 0.155; A_G : 0.39

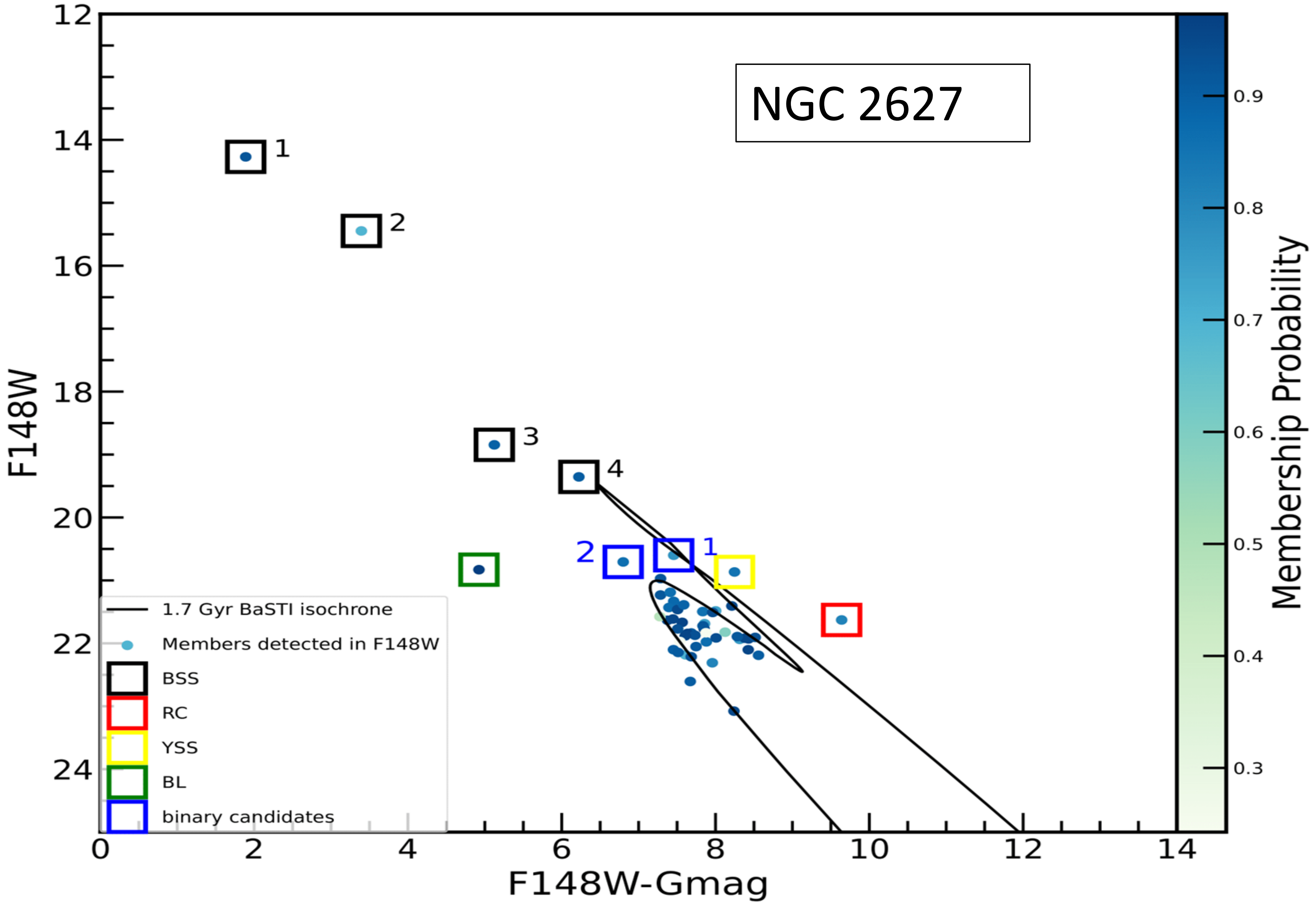


E(F148W-G) = 0.473; A_{F148W} : 0.721



Distance: 1837 pc; E(BP-RP) = 0.155; A_G : 0.39





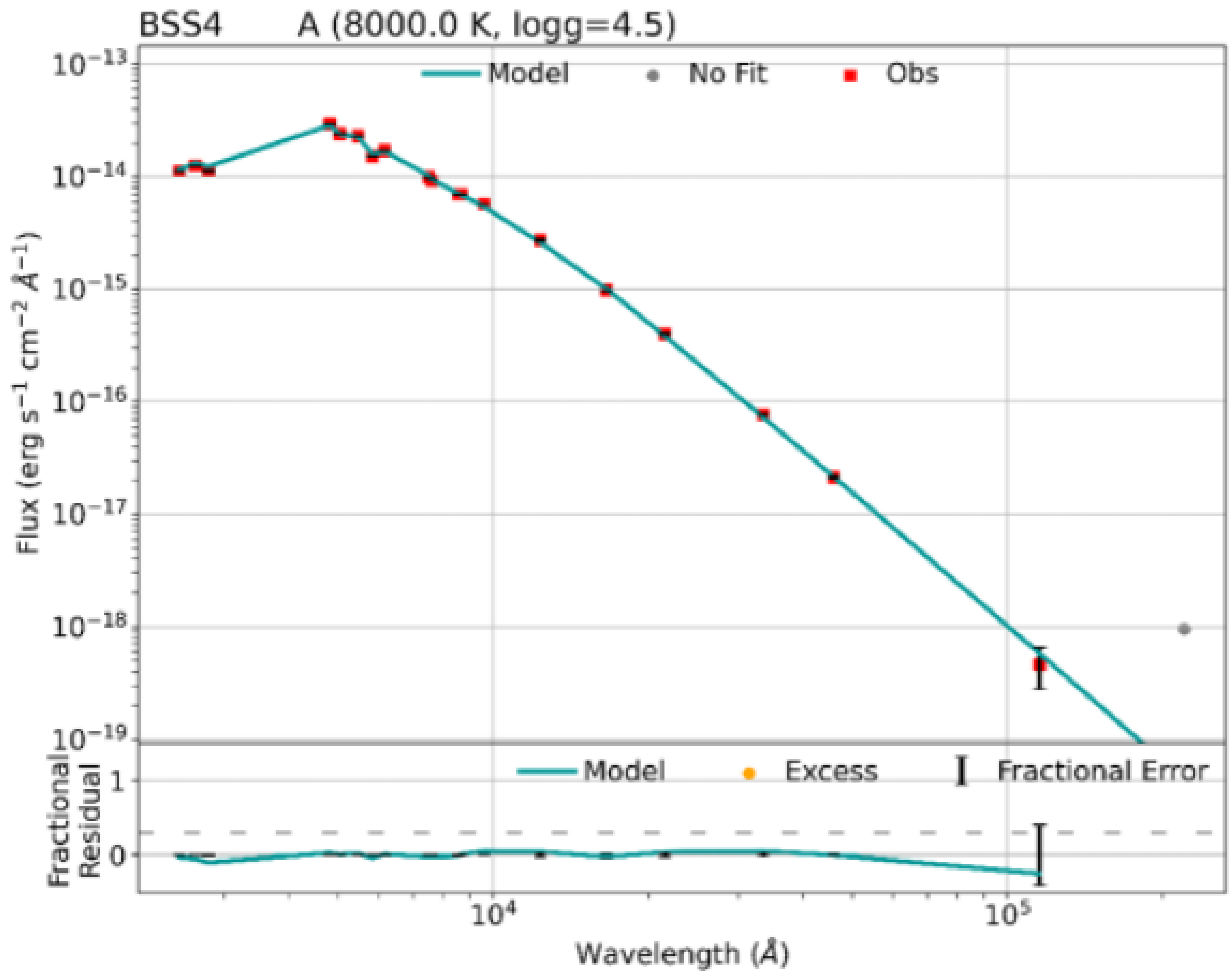
Distance: 1837 pc; E(Bp-Rp) = 0.12; A_G : 0.372

E(F148W-G) = 0.35; A_{F148W} : 0.741

Kaushar Vaidya @ MODEST24

Construction of Spectral Energy Distributions

- SEDs constructed using Virtual Observatory of SED Analyzers (VOSA)
  - Compilation of photometry
  - Correction of extinction (Fitzpatrick 1999, Indebetouw 2005)
  - Calculation of synthetic photometry based on model (Single: Kurucz stellar models by Castelli et al. 1997; Binary: Koester et al. 2010)
- SED fitting by minimization of χ^2
- Multi-wavelength photometry from UV to Mid-IR



Kaushar Vaidya @ MODEST24

BSS SEDs showing UV-excess in Clusters and Fields

Cluster name	Single-component SEDs	Excess in UV fluxes
NGC 7789	8 BSS	7 BSS
NGC 2506	4 BSS	3 BSS
NGC 7142	0	7 BSS
NGC 6940	1 BSS	0
NGC 2627	2 BSS	2 BSS

Galactic Fields	10 BMP	17 BMP

BSS SEDs showing UV-excess in Clusters and Fields

Cluster name	Single-component SEDs	Excess in UV fluxes
NGC 7789	8 BSS	7 BSS
NGC 2506	4 BSS	3 BSS
NGC 7142	0	7 BSS
NGC 6940	1 BSS	0
NGC 2627	2 BSS	2 BSS

Galactic Fields	10 BMP	17 BMP

Chromospheric Activity (Hall 2008)

Hot Spots (Kouzuma 2019)

Coronal Activity (Stelzer et al. 2016)

A hot companion

?

BSS SEDs showing UV-excess in Clusters and Fields

Cluster name	Single-component SEDs	Excess in UV fluxes
NGC 7789	8 BSS	7 BSS
NGC 2506	4 BSS	3 BSS
NGC 7142	0	7 BSS
NGC 6940	1 BSS	0
NGC 2627	2 BSS	2 BSS

Galactic Fields	10 BMP	17 BMP

Chromospheric Activity (Hall 2008)

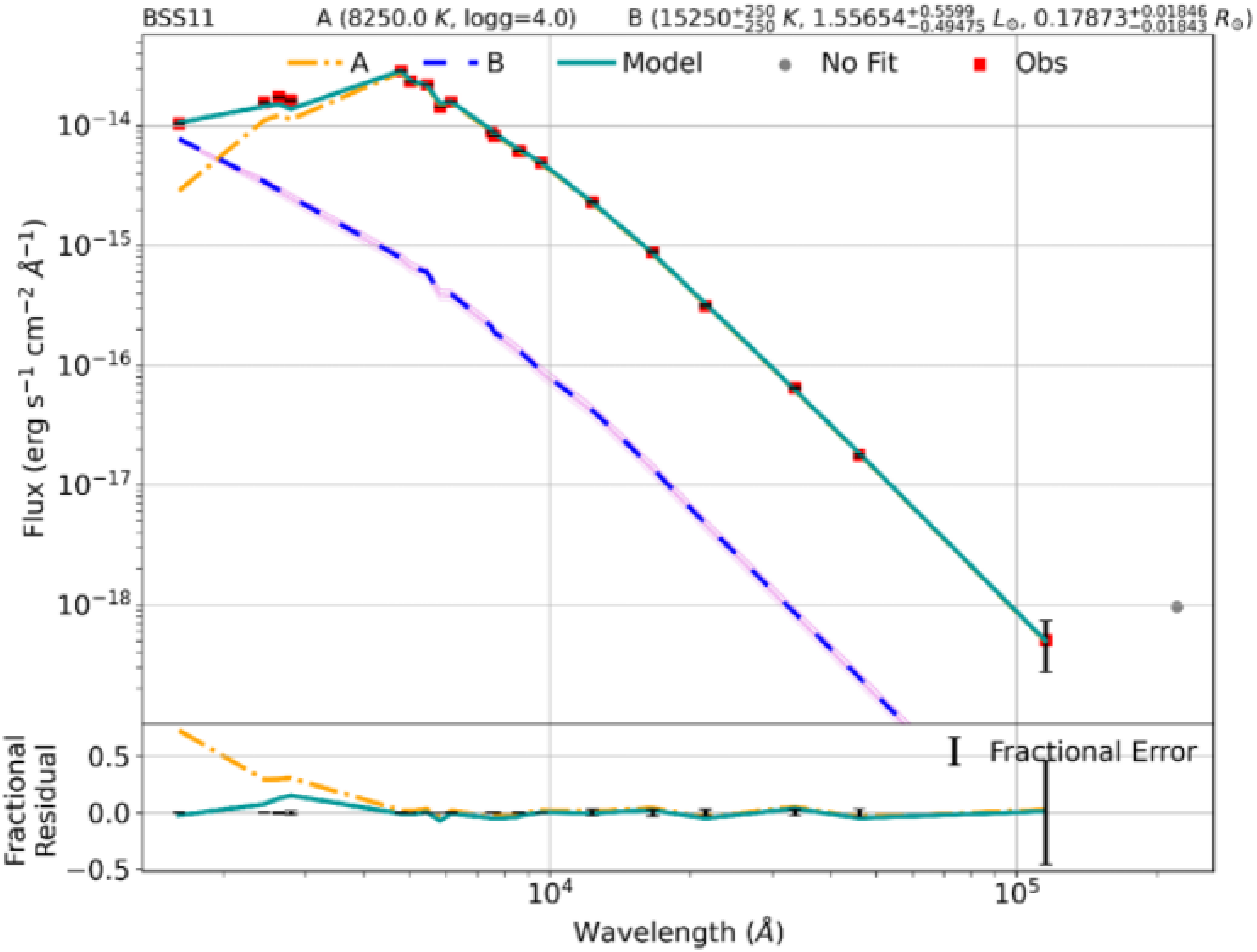
Hot Spots (Kouzuma 2019)

Coronal Activity (Stelzer et al. 2016)

A hot companion

?

14/19 BSS not detected in XMM/Chandra. The remaining not observed by XMM/Chandra



BSS11
A (8250.0 K, logg=4.0)
B (15250$^{+250}_{-250}$ K, 1.55654$^{+0.5599}_{-0.49475}$ $L_\odot$, 0.17873$^{+0.01846}_{-0.01843}$ $R_\odot$)
A
B
Model
No Fit
Obs
Flux (erg s^{-1} cm^{-2} Å^{-1})
Fractional Error
Fractional Residual
Wavelength (Å)

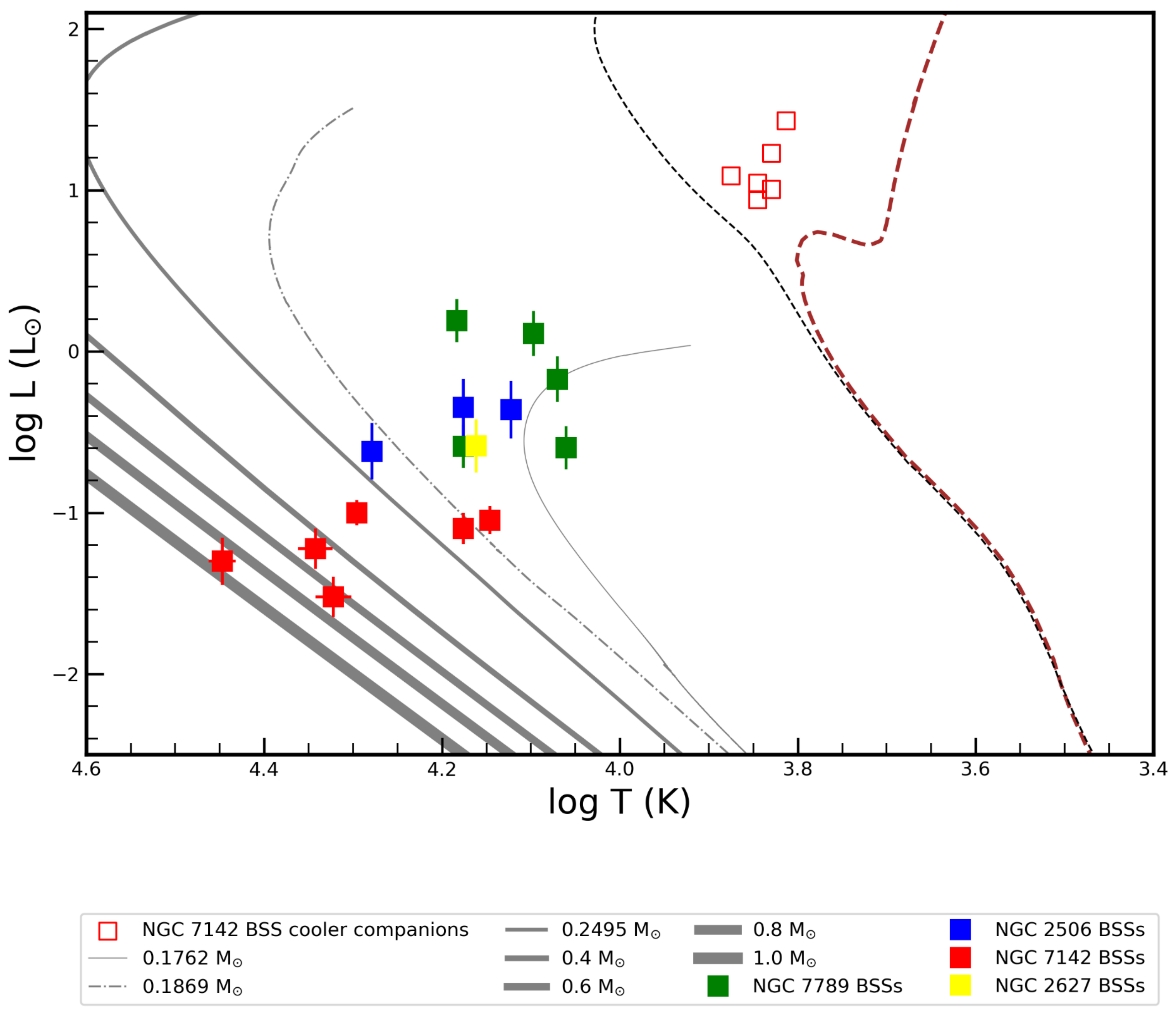
BSS Properties

Target	Objects	Temperature (K)	Luminosity ($L_\odot$)	Radius ($R_\odot$)
NGC 7789	BSSs	7250 – 10250	7.43 – 122.8	1.62 – 4.08
NGC 2506	BSSs	7750 – 9750	10.58 – 84.37	1.51 – 3.38
NGC 7142	BSSs	6500 – 7500	8.72 – 26.97	2.04 – 4.09
NGC 6940	BSSs	8500	32.58	2.63
NGC 2627	BSSs	8000 – 10750	10.55 – 60.03	1.69 – 2.86

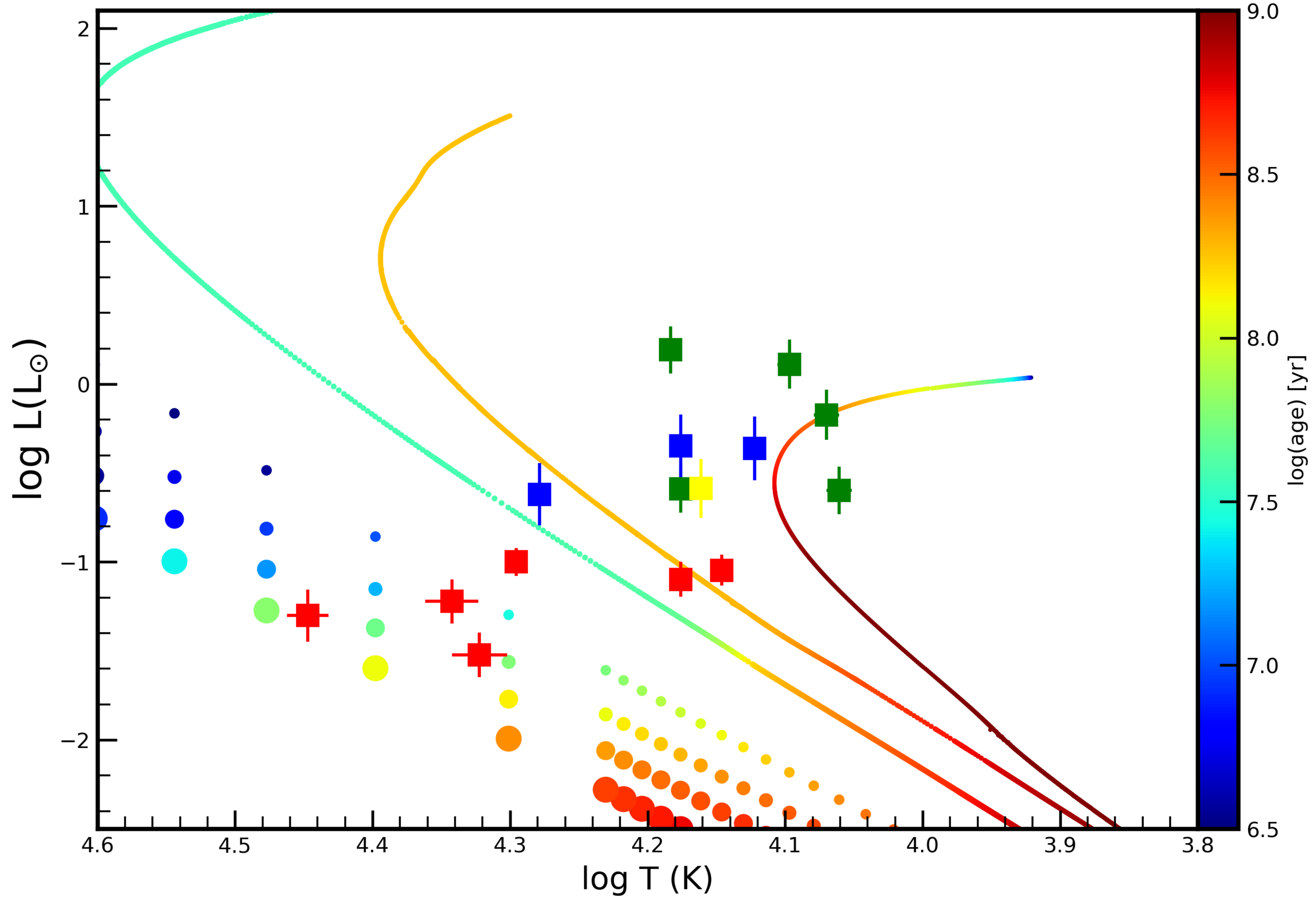
Hot Companions of BSS and their Properties

Target	Objects	Temperature (K)	Luminosity ($L_\odot$)	Radius ($R_\odot$)
NGC 7789	BSSs	11750 – 15500	0.25 – 1.55	0.069 – 0.242
NGC 2506	BSSs	13250 – 19000	0.24 – 0.44	0.05 – 0.13
NGC 7142	BSSs	14000 – 28000	0.03 – 1.01	0.01 – 0.05
NGC 6940	BSSs	-	-	-
NGC 2627	BSSs	14500	0.26	0.08

Hot components on the H-R Diagram



H-R Diagram showing the PARSEC isochrones fitted to our oldest cluster, NGC 7142. The white dwarf cooling curves of extremely low-mass are taken from Althaus et al. (2013), low-mass are taken from Panei et al. (2007), and normal mass and high mass are taken from Tremblay et al. (2011).



H-R Diagram same as above, but with cooling ages of white dwarfs of different masses shown in the color bar on the right axis.

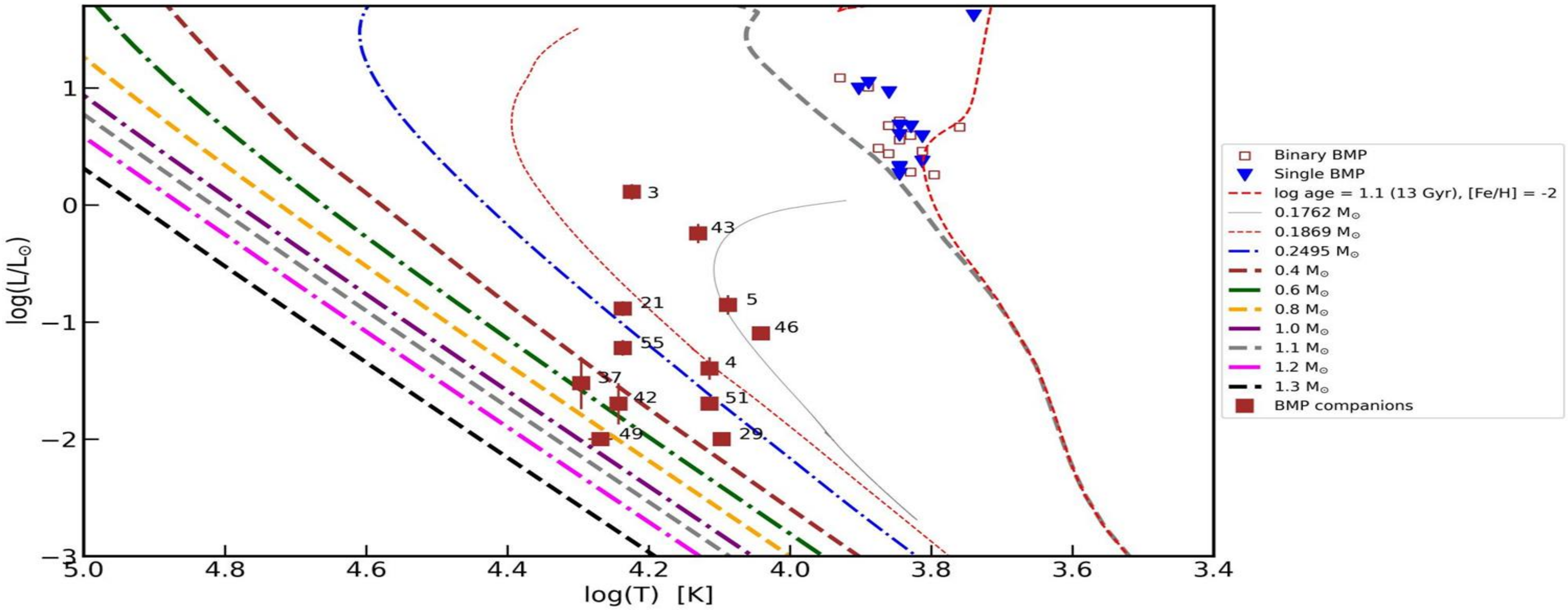
Based on the cooling ages of white dwarfs, the mass transfer in these BSS ended around 10 Myr to 1 Gyr ago.

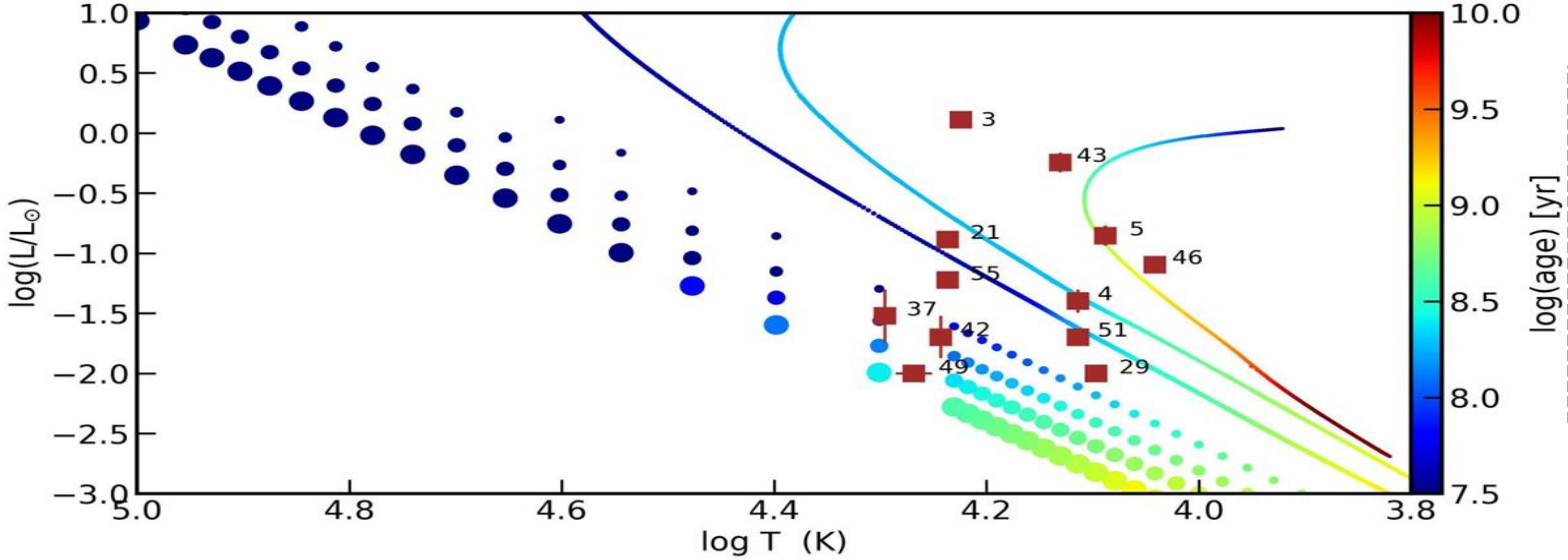
Best-fit SED parameters of single BMP stars

	Temperature (K)	Luminosity ($L_\odot$)	Radius ($R_\odot$)
Galactic fields BSSs	5500 – 8000	1.04 – 40.01	0.92 – 7.66

Best-fit SED parameters of hot companions of BMP stars

	Temperature (K)	Luminosity ($L_\odot$)	Radius ($R_\odot$)	Mass ($M_\odot$)
Galactic fields BSSs	11000 – 19750	0.01 – 0.57	0.01 – 0.14	0.17 – 0.8





Based on the cooling ages of white dwarfs, the mass transfer in these BSS ended around 30 Myr to 3 Gyr ago.

Implications on Formation Channels - BSS

- Total BSS studied – 33
- Single-component SEDs – 15
- Binary-component SEDs – 15
    - Extremely low-mass white dwarf companion – 10
    - Low-mass white dwarf companion – 2
    - Normal-mass white dwarf companion – 2
    - Massive white dwarf companion - 1

Implications on Formation Channels - BSS

- Total BSS studied – 33
- Single-component SEDs – 15
- Binary-component SEDs – 15
  - Extremely low-mass white dwarf companion – 10 → Case-A/Case-B
  - Low-mass white dwarf companion – 2 → Case-A/Case-B
  - Normal-mass white dwarf companion – 2
  - Massive white dwarf companion - 1

Implications on Formation Channels - BSS

- Total BSS studied – 33
- Single-component SEDs – 15
- Binary-component SEDs – 15
  - Extremely low-mass white dwarf companion – 10
  - Low-mass white dwarf companion – 2
  - Normal-mass white dwarf companion – 2
  - Massive white dwarf companion - 1

Case-A/Case-B

Case-C

Implications on Formation Channels – BMP

- Total BMP studied – 27
- Single-component SEDs – 10
- Binary-component SEDs – 12
  - Extremely low-mass white dwarf companion – 6
  - Low-mass white dwarf companion – 3
  - Normal-mass white dwarf companion – 2
  - Massive white dwarf companion - 1

Implications on Formation Channels – BMP

- Total BMP studied – 27
- Single-component SEDs – 10
- Binary-component SEDs – 12
  - Extremely low-mass white dwarf companion – 6
  - Low-mass white dwarf companion – 3
  - Normal-mass white dwarf companion – 2
  - Massive white dwarf companion - 1

Case-A/Case-B

Implications on Formation Channels – BMP

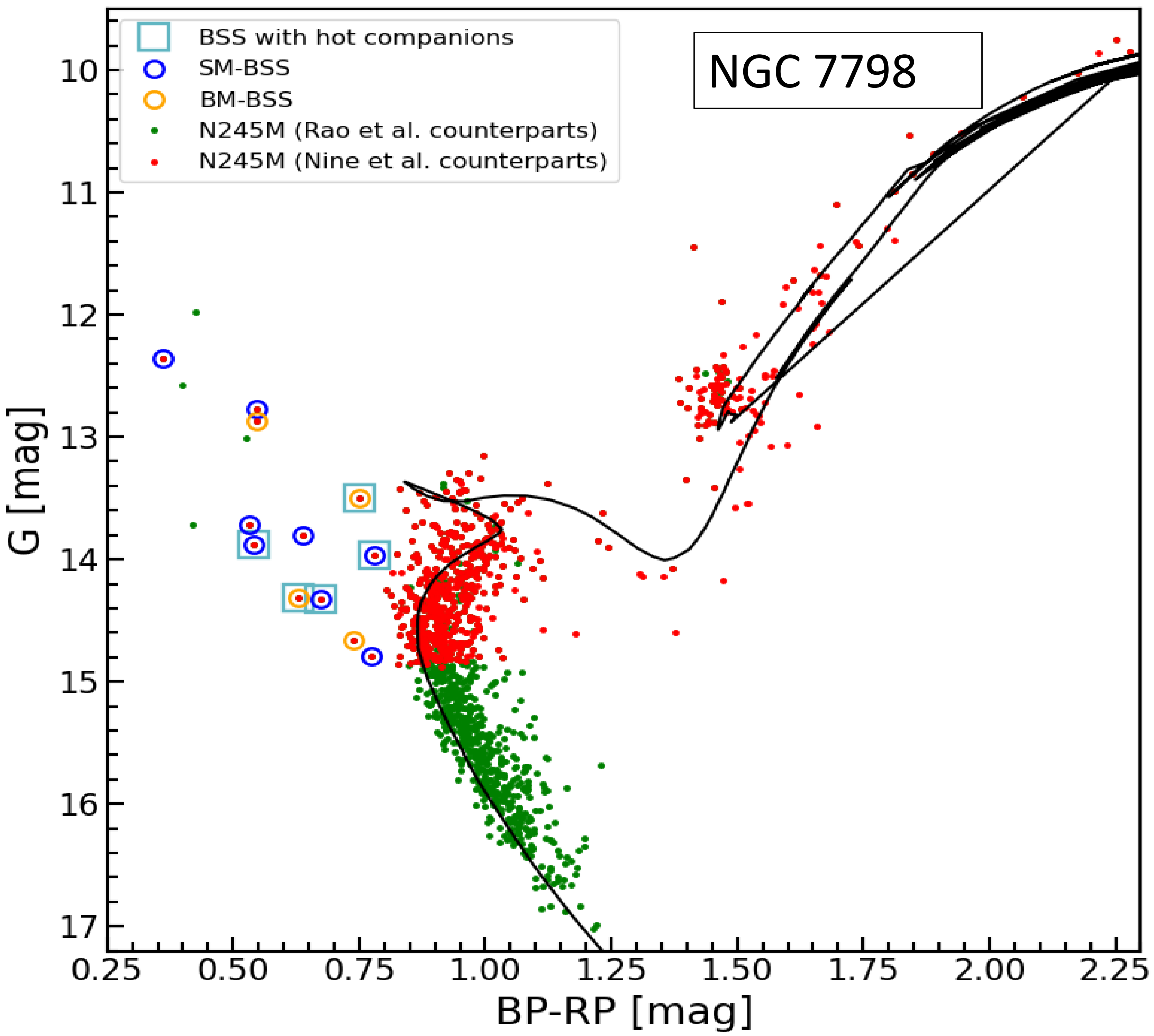
- Total BMP studied – 27
- Single-component SEDs – 10
- Binary-component SEDs – 12
  - Extremely low-mass white dwarf companion – 6 → Case-A/Case-B
  - Low-mass white dwarf companion – 3 → Case-A/Case-B
  - Normal-mass white dwarf companion – 2 → Case-C
  - Massive white dwarf companion - 1 → Case-C

CONCLUSION & FUTURE WORK

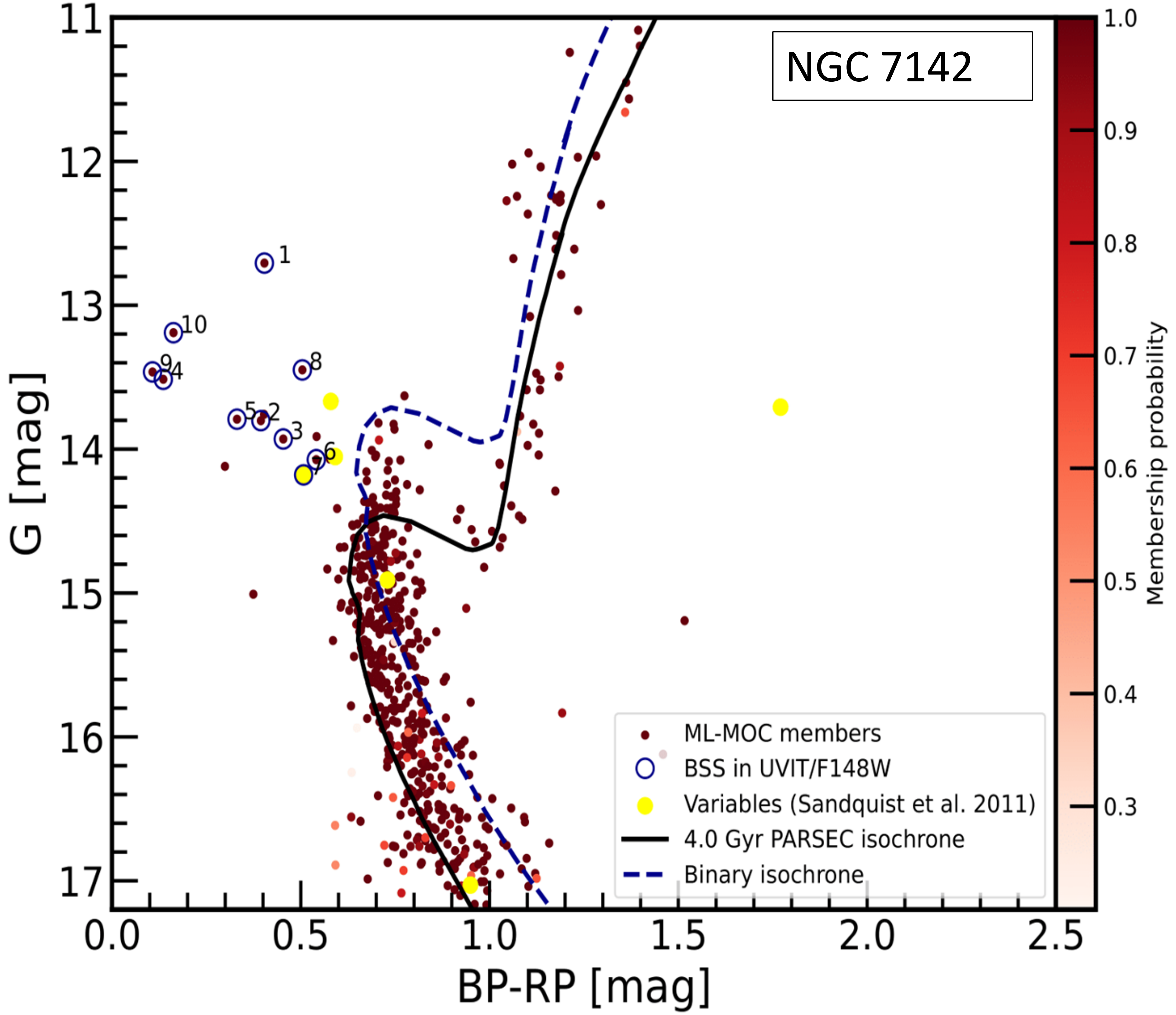
- About 45% of BSS, as well as BMP stars, may have formed via mass transfer.
- Spectroscopic data for abundances and binarity information, and construction of detailed formation histories using MESA or other suitable models would be valuable.

Thank You!!!

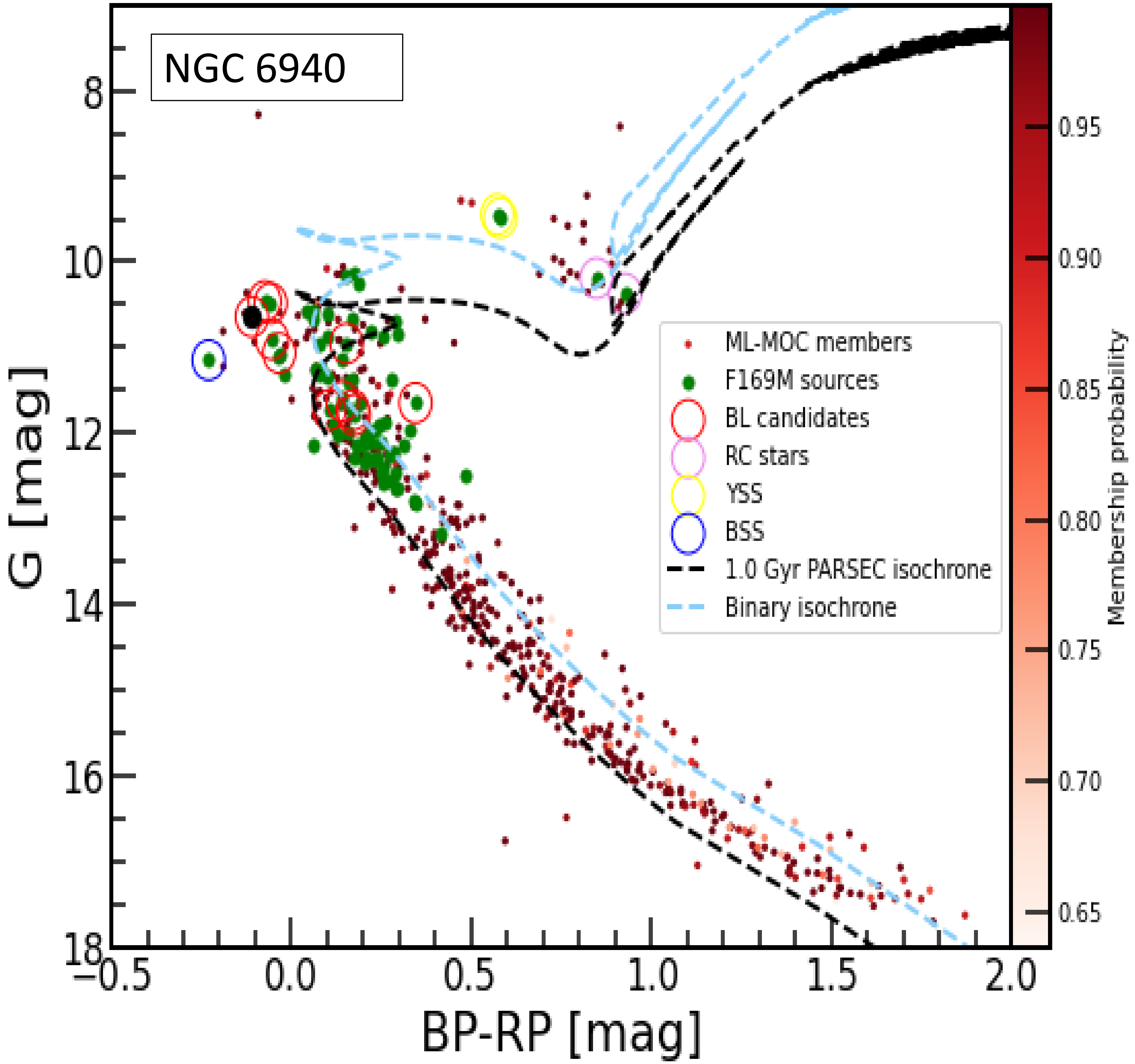
EXTRA SLIDES



Distance: 2000 pc; E(BP-RP) = 0.375; A_G : 0.39, Age: 1.6 Gyr



Distance: 2368 pc; E(BP-RP) = 0.03; A_G : 0.09, Age: 4.0 Gyr



Distance: 2368 pc; E(BP-RP) = 0.03; A_G : 0.09, Age: 4.0 Gyr

NGC 7789 – Best-fit parameters of BSS and Hot Companions

Name	Component	log g	T_{eff} [K]	R [$R_\odot$]	L [$L_\odot$]	Scaling factor	N_{fit}	χ_r^2 ($\chi^2_{r,\mathrm{single}}$)	vgf_b
BSS2	single	4.0	8750 ± 125	3.04 ± 0.152	47.7 ± 4.81	1.18E-21	18	286.1	0.77
BSS3	single	4.0	8750 ± 125	2.09 ± 0.104	22.4 ± 2.25	5.46E-22	20	289.5	0.51
BSS4	single	4.5	8000 ± 125	2.28 ± 0.114	19.0 ± 1.91	6.61E-22	20	86.7	0.19
BSS5	A	4	8000 ± 125	1.79 ± 0.089	11.75 ± 1.18	4.082E-22	13	101.0 (500.8)	0.091
	B	9.5	15000^{+250}_{-250}	0.075 ± 0.007	$0.258^{+0.093}_{-0.082}$	7.213E-25	–	–	
BSS6	A	3.5	7250 ± 125	2.50 ± 0.125	15.32 ± 1.54	7.82E-22	17	67.9 (396.7)	0.59
	B	9.5	11750^{+250}_{-250}	0.197 ± 0.020	$0.672^{+0.255}_{-0.221}$	4.98E-24	–	–	
BSS7	single	3.5	7500 ± 125	1.62 ± 0.081	7.43 ± 0.74	3.86E-22	20	278.5	0.38
BSS8	A	4	7750 ± 125	1.90 ± 0.094	11.52 ± 1.16	4.55E-22	13	79.2 (879)	0.087
	B	9	15500^{+250}_{-250}	0.069 ± 0.007	$0.253^{+0.090}_{-0.080}$	6.193E-25	–	–	–
BSS9	single	4	7500 ± 125	1.72 ± 0.086	8.37 ± 0.84	3.77E-22	14	79.7	0.12
BSS10	A	5	7250 ± 125	3.13 ± 0.156	24.4 ± 2.45	1.25E-21	13	143.7 (722.4)	0.53
	B	9.5	12500^{+250}_{-250}	0.242 ± 0.025	$1.293^{+0.48}_{-0.42}$	7.47E-24	–	–	–
BSS11	A	4	8250 ± 125	2.08 ± 0.104	18.0 ± 1.82	5.51E-22	17	110.3 (134.5)	0.089
	B	9.5	15250^{+250}_{-250}	0.178 ± 0.018	$1.556^{+0.55}_{-0.49}$	4.06E-24	–	–	–
BSS12	single	4.5	9750 ± 125	2.99 ± 0.149	81.6 ± 8.31	1.14E-21	16	64.1	5.12
BSS13	single	4.5	8500 ± 125	2.97 ± 0.148	42.1 ± 4.57	1.13E-21	20	747.5	3.32
BSS14	single	5	10250 ± 125	3.16 ± 0.158	102.1 ± 10.3	1.28E-21	16	59.1	1.47
BSS15	single	4.5	9500 ± 125	4.08 ± 0.204	122.8 ± 12.3	2.12E-21	16	47.4	0.82
BSS16	single	4.5	9500 ± 125	1.84 ± 0.092	25.0 ± 2.50	4.29E-22	12	158.3	1.08

NGC 2506 – Best-fit parameters of BSS and Hot Companions

Name	Component	log g	Luminosity ($L_\odot$)	T_{eff} (K)	Radius ($R_\odot$)	χ_r^2 ($\chi^2_{r,single}$)	Scaling factor	N_{fit}	vgf$_b$ (vgf$_{b, single}$)
BSS1	A	3.5	31.18 ± 9.05	7750 ± 125	3.10 ± 0.44	308.06 (649)	5.06E-22	16	0.15 (0.25)
	B	7.5	$0.44^{+0.22}_{-0.19}$	13 250 ± 250	0.13±+0.02	–	8.24E-25	–	
BSS2	A	3.0	19.30 ± 5.60	8000 ± 125	2.29 ± 0.33	266.26 (694)	2.77E-22	14	0.03 (0.16)
	B	8.0	$0.45^{+0.23}_{-0.20}$	15 000 ± 250	0.10 ± 0.01	–	5.21E-25	–	
BSS3	Single	4.0	31.58 ± 9.16	9250 ± 125	2.19 ± 0.31	48.32	2.53E-22	18	0.58
BSS5	Single	4.5	84.37 ± 24.49	9500 ± 125	3.38 ± 0.49	13.26	6.03E-22	14	0.54
BSS7	Single	4.5	18.40 ± 5.34	9750 ± 125	1.51 ± 0.21	68.83	1.21E-22	17	0.57
BSS8	A	3.0	12.06 ± 3.50	8250 ± 125	1.70 ± 0.24	596.22(1864)	1.52E-22	18	0.91 (1.51)
	B	7.5	$0.24^{+0.12}_{-0.11}$	19 000 ± 250	0.05 ± 0.01	–	1.19E-25	–	
BSS9	Single	3.0	10.58 ± 3.07	8250 ± 125	1.60 ± 0.23	2389	1.35E-22	16	1.59

NGC 7142 – Best-fit parameters of BSS and Hot Companions

Name	Component	Luminosity $[L_\odot]$	T_{eff} [K]	Radius $[R_\odot]$	χ^2_r	Scaling factor	N_{fit}	vgf_b
BSS 1	A	26.97 ± 0.03	6500 ± 125	4.09 ± 0.01	25.11 (211.7)	1.51E-21	15	0.55 (1.94)
	B	$0.08^{+0.02}_{-0.01}$	$15\,000 \pm 125$	0.04 ± 0.0	–		–	–
BSS 2	A	10.11 ± 0.01	6750 ± 125	2.35 ± 0.00	267.90 (3647.01)	5.03E-22	15	0.24 (1.42)
	B	0.05 ± 0.02	$28\,000 \pm 1000$	0.01 ± 0.0	–		–	–
BSS 3	A	11.00 ± 0.01	7000 ± 125	2.25 ± 0.00	41.74 (111.4)	4.62E-22	15	0.15 (5.11)
	B	$0.06^{+0.02}_{-0.01}$	$22\,000 \pm 1000$	0.02 ± 0.00	–		–	–
BSS 5	A	12.27 ± 0.01	7500 ± 125	2.08 ± 0.00	159.45 (439.1)	3.93E-22	15	0.25 (2.61)
	B	0.03 ± 0.01	$21\,000 \pm 1000$	0.01 ± 0.00	–		–	–
BSS 7	A	8.72 ± 0.01	7000 ± 125	2.04 ± 0.07	78.92 (376.08)	3.77E-22	15	0.57 (0.94)
	B	0.1 ± 0.02	$19\,750 \pm 250$	0.03 ± 0.0	–	–	–	
BSS 8	A	16.87 ± 0.02	6750 ± 125	3.01 ± 0.11	38.23 (302.1)	8.22E-22	15	0.12 (2.75)
	B	0.09 ± 0.02	$14\,000 \pm 125$	0.05 ± 0.00	–		–	–

NGC 6940 – Best-fit parameters of BSS

Name	Luminosity	T_{eff} ($L_\odot$)	Radius (K)	χ_r^2 ($R_\odot$)	Scaling factor	N_{fit}	vgf_b
BSS1	32.58 ± 0.02	8500 ± 125	2.63 ± 0.01	4.21	3.53	11	0.27

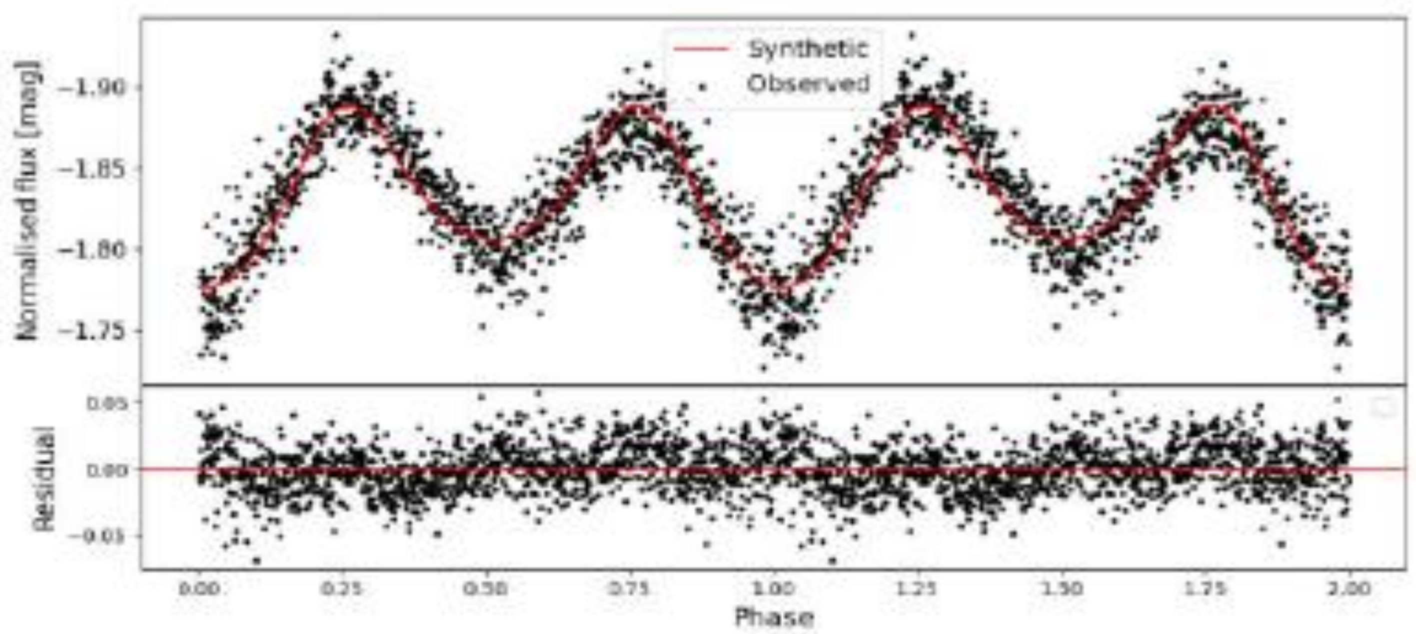
NGC 2627 – Best-fit parameters of BSS and Hot Companions

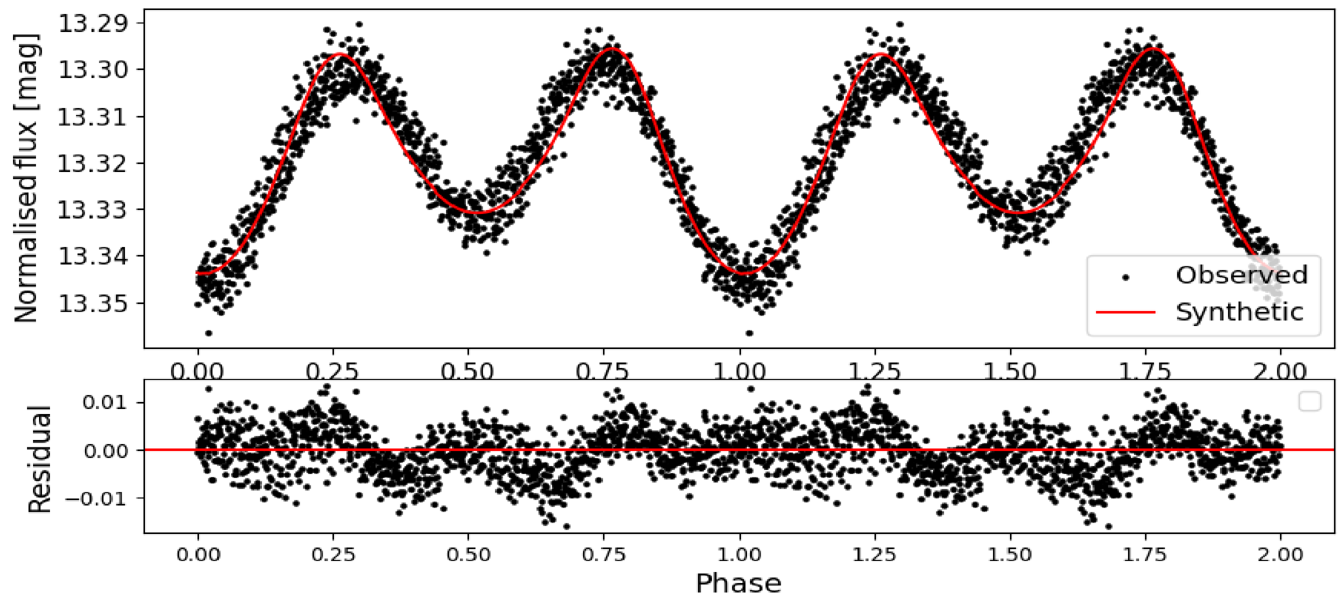
Name	RA	DEC	Component	logg	T_{eff} (K)	L ($L_\odot$)	R ($R_\odot$)	χ^2_r	vgf_b
BSS3	129.26101	-29.83087	A	3.5	8000±125	10.55±2.99	1.69 ± 0.23	668.61	4.68
			B	8.5	14500±250	0.26±0.12	0.08 ± 0.01	99.94	0.81

BMP – Best-fit parameters of field BSS and Hot Companions

		$[L_\odot]$	[K]	$[R_\odot]$				
Name	Component	Luminosity	T_{eff} $[L_\odot]$	Radius [K]	χ_r^2 $[R_\odot]$	Scaling factor	N_{fit}	vgf_b
BMP2	A	1.29 ± 0.05	5750 ± 125	1.14 ± 0.02	14.58	4.971E-22	12	0.51
	B	2.60 ± 0.11	7000 ± 125	1.09 ± 0.02	–	4.574E-22	–	–
BMP3	A	13.88 ± 0.96	7750 ± 125	1.69 ± 0.05	79.12 (199.7)	1.54E-21	13	0.79 (13.4)
	B	$1.29^{+0.21}_{-0.19}$	16750 ± 250	0.14 ± 0.01	–	8.87E-24	–	
BMP4	A	3.83 ± 0.22	7000 ± 125	1.33 ± 0.03	54.54 (92.98)	5.05E-22	13	2.97 (3.13)
	B	$0.04^{+0.01}_{-0.01}$	13000 ± 250	0.04 ± 0.00	–	4.76E-25	–	
BMP5	A	5.75 ± 0.54	8000 ± 125	1.24 ± 0.07	157.93 (168.5)	1.94E-22	12	3.42 (4.65)
	B	$0.14^{+0.03}_{-0.03}$	12250 ± 250	0.08 ± 0.00	–	5.75E-24	–	
BMP21	A	3.04 ± 0.16	7500 ± 125	1.03 ± 0.02	13.01 (44.77)	1.77E-22	13	1.57 (2.12)
	B	$0.13^{+0.02}_{-0.02}$	17250 ± 250	0.04 ± 0.00	–	1.10E-22	–	–
BMP29	A	1.73 ± 0.04	6250 ± 125	1.12 ± 0.01	5.33 (41.05)	1.09E-21	15	0.22 (0.31)
	B	$0.01^{+0.01}_{-0.00}$	12500 ± 250	0.02 ± 0.00	–	8.11E-21	–	–
BMP37	A	2.78 ± 0.03	7250 ± 125	1.05 ± 0.00	40.71 (17.42)	4.34E-22	16	0.19 (3.08)
	B	$0.03^{+0.02}_{-0.01}$	19750^{+1250}_{-1000}	0.01 ± 0.00	–	8.13E-26	–	
BMP42	A	2.02 ± 0.15	6750 ± 125	0.91 ± 0.03	6.18 (91.72)	3.52E-22	20	0.15 (2.43)
	B	$0.02^{+0.01}_{-0.01}$	17500 ± 250	0.01 ± 0.00	–	6.88E-26	–	–
BMP43	A	11.01 ± 0.45	7750 ± 125	1.76 ± 0.03	58.39 (133.72)	2.54E-21	14	3.67 (7.12)
	B	$0.57^{+0.12}_{-0.10}$	13500 ± 250	0.14 ± 0.01	–	1.73E-23	–	–
BMP46	A	3.88 ± 0.08	6750 ± 125	1.44 ± 0.01	43.46 (108.51)	2.06E-21	15	0.4 (5.54)
	B	$0.08^{+0.01}_{-0.01}$	11000 ± 250	0.08 ± 0.00	–	5.07E-24	–	–
BMP49	A	2.94 ± 0.04	6750 ± 125	1.25 ± 0.00	2.31 (47.37)	1.28E-20	10	0.12 (3.87)
	B	$0.01^{0+.00}_{-0.00}$	18500^{+250}_{-500}	0.01 ± 0.00	–	2.96E-24	–	–
BMP51	A	4.94 ± 0.09	6250 ± 125	1.92 ± 0.01	150.3 (430.8)	1.00E-20	17	0.55 (2.90)
	B	$0.02^{+0.00}_{-0.00}$	13000^{+250}_{-250}	0.03 ± 0.00	–	1.27E-20	–	–
BMP55	A	4.75 ± 0.29	7250 ± 125	1.38 ± 0.04	4.46 (513.43)	4.20E-22	14	0.27 (1.87)
	B	$0.06^{+0.02}_{-0.01}$	17250^{+250}_{-500}	0.03 ± 0.00	–	1.90E-25	–	–

BSS in Eclipsing Binaries: TESS Light curve Analysis





	BSS		Hot Component	
Object	Temperature (K)	Radius ($R_\odot$)	Temperature (K)	Radius ($R_\odot$)
BSS1	6000	3.55 ± 0.12	15000 ± 4500 15000 ± 125 (SED)	0.038 ± 0.011 0.04 ± 0.01 (SED)
BSS7	7000	5.69 ± 0.29	20000 ± 7000 19750 ± 250 (SED)	0.037 ± 0.013 0.03 ± 0.01 (SED)

Nine et al. (2019)	Vaidya et al. (2022)
❖ 4 SB1 BSS and 8 single member BSS based on multi-epoch WOCS radial velocity survey	All 12 BSS detected in UVIT NUV filters, and 9 in the FUV filter
❖ WOCS 20009 (p~ 4190 days, e~0.27) WOCS 10011 (p ~ 517 days, e ~ 0.37)	WOCS 20009 and WOCS 10011: Extremely low-mass white dwarf companion → Case-A/Case-B. Formation may be in a triple system!
❖ WOCS 5011 (p ~ 2710 days, e ~ 0.67) WOCS 36011 (p ~ 217 days, e ~ 0.54)	Both fit a single component. White dwarf may be below our detection limit (< 11000 K)
❖ WOCS 25008 – A δ Scuti variable (p ~0.0955 days, e ~)	Found to have an extremely low-mass white dwarf companion
❖ WOCS 27010 and WOCS 15015 are single members	Found with extremely low-mass white dwarf companions Possibly the binaries are having lower inclination angle orbits

12 BMP stars fitted with the binary SEDs: FBSS candidates

- **8 are SB1 / binary candidates**
- **3 are RV constants (orbits of these binary systems may be of low inclination)**
- **No information of binarity of remaining 1 BMP star**

10 BMP stars fitted with the single component SEDs : possibly no mass transfer

- **7 are known to be SB1s (WD companion may have cool down)**
- **2 are RV constant stars**
- **1 is a SB2**

12 BMP stars fitted with the binary SEDs: FBSS candidates

- **4 enhanced in [Sr/Fe] and [Ba/Fe]**

  3 ELM / LM WDs **(either intrinsic to the star or acquired in other process before MT)**

  1 normal mass WD **(in agreement with the enhancements)**

- **6 deficient in [Sr/Fe] and [Ba/Fe]**

  4 ELM / LM WDs **(in agreement with the deficiency)**

  1 normal mass, 1 high mass WD

10 BMP stars fitted with the single component SEDs : possibly no mass transfer

- **3 deficient in [Sr/Fe] and [Ba/Fe]** **(In agreement with the single star)**
- **4 enhanced in [Sr/Fe] and [Ba/Fe]** **(May be intrinsic to the star)**

Mass Transfer in a Binary

Case A

- Compact binary systems (p < 10 days)
- Mass-transfer when primary on main-sequence
- Single massive BSS or short-period binary BSS.

Case B

- Binary systems (p ~ 10-500 days)
- Mass-transfer when primary on red giant
- Short period binary BSS with He White Dwarf (0.45 M_{sun}) as a companion

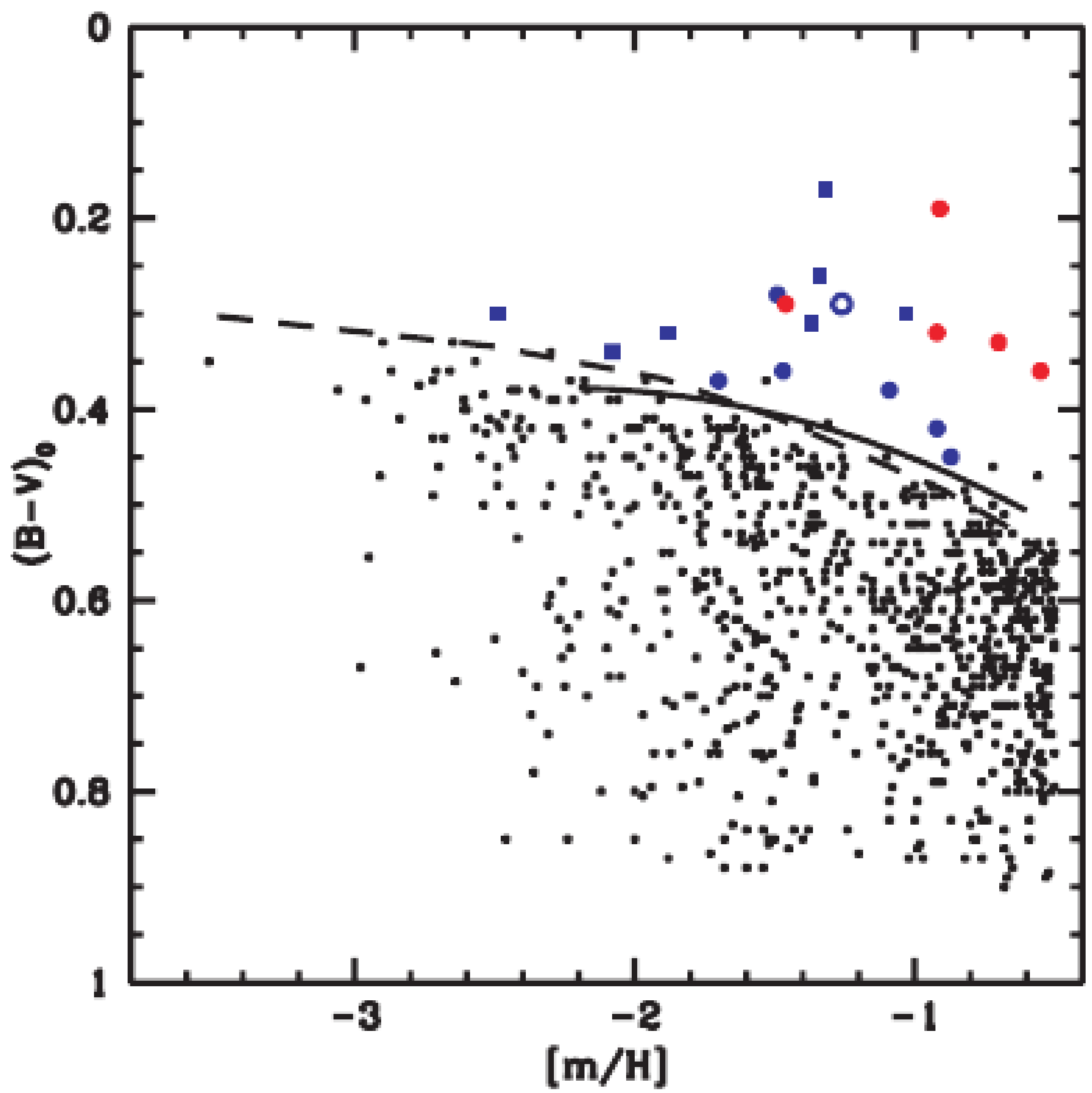
Case C

- Binary systems (p ~ 500-2000 days)
- Mass-transfer when primary on asymptotic giant
- Binary BSS with CO White Dwarf (0.45 M_{sun}) as a companion

Case D

- Binary systems (p ~1000-10000 days)
- Mass-transfer when primary on asymptotic giant
- Binary BSS with CO White Dwarf (0.45 M_{sun}) as a companion

Field Blue Metal-Poor Stars

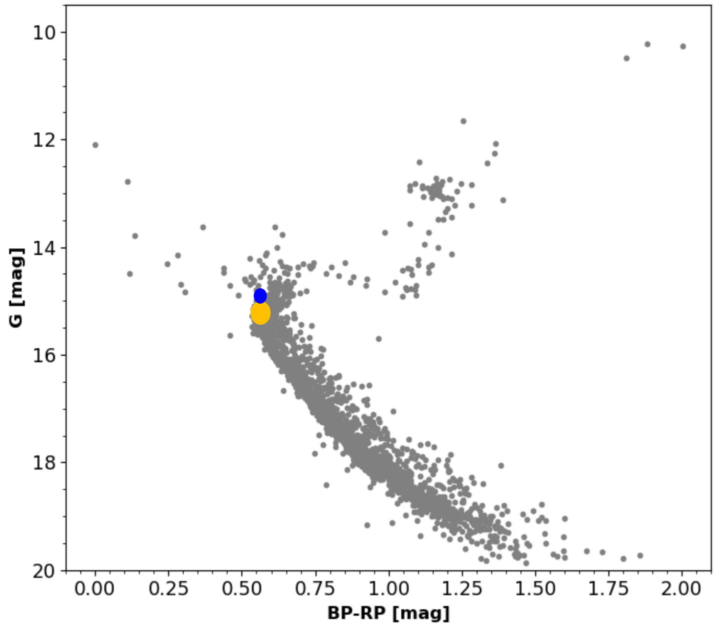


A color-metallicity diagram from Carney et al. (2005) showing the selection of BMP stars. Solid line shows observed correlation between B-V color and metallicity of globular clusters. Dashed line shows the theoretical relation considering an age of 11 Gyr of clusters.

- Nature controversial – field blue stragglers OR accreted from dwarf satellite galaxy
- 2/3rd of BMP are single-lined spectroscopic binaries (Preston et al. 2000)
- A fraction also show enhancement in C, Sr, and Ba (Mass transfer)

Mass Transfer in a Binary

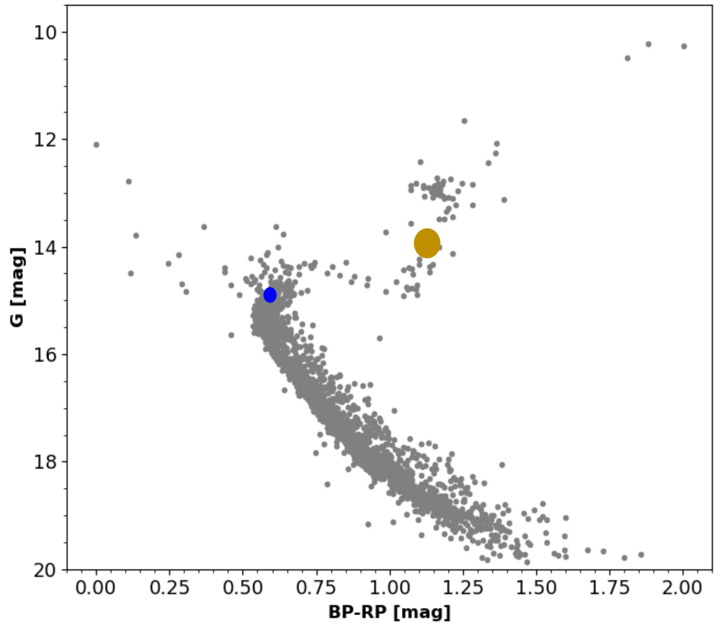
Case-A



Single massive BSS or short-period binary BSS

Webbink 1976

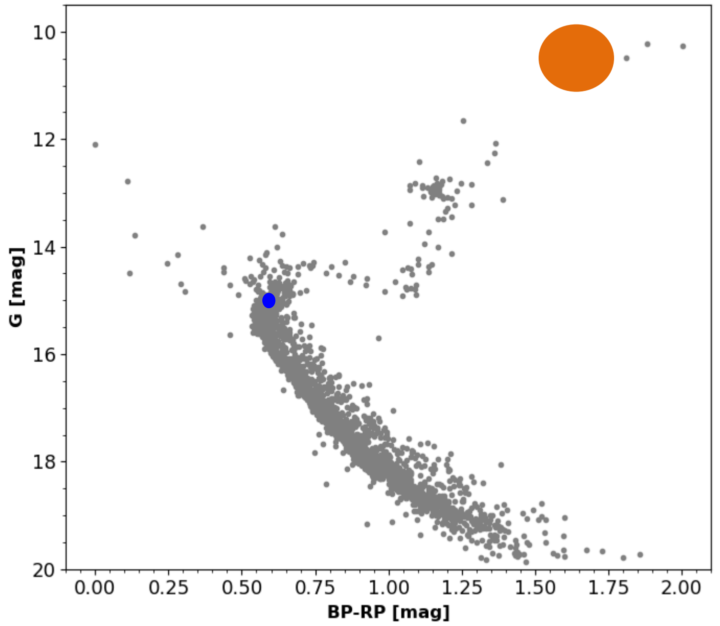
Case-B



BSS + He core WD ($M < 0.4\ M_\odot$)

McCrea 1964

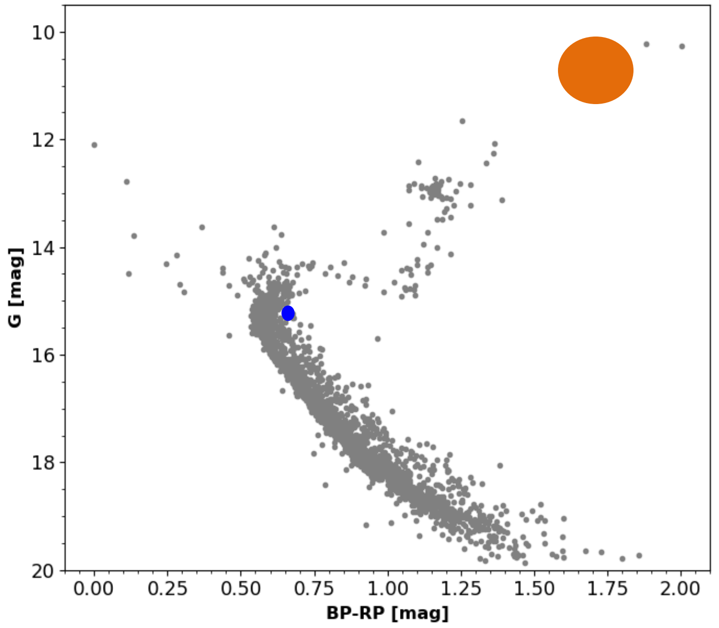
Case-C



BSS+ CO core WD ($0.4\ M_\odot < M < 0.6\ M_\odot$)

Chen & Han 2008

Case-D



BSS+ CO core WD ($0.4\ M_\odot < M < 0.6\ M_\odot$)

Abate et al. 2013

BSS SEDs showing UV-excess in Clusters and Fields

Cluster name	Single-component SEDs	Excess in UV fluxes	Binary-component SEDs
NGC 7789	8 BSS	7 BSS	5 BSS
NGC 2506	4 BSS	3 BSS	3 BSS
NGC 7142	0	7 BSS	6 BSS
NGC 6940	1 BSS	0	0
NGC 2627	2 BSS	2 BSS	1 BSS

Galactic Fields	10 BMP	17 BMP	12 BMP