

Searching for Close Binary Systems

Nao Suzuki (Lawrence Berkeley National Lab)

Close Binary Systems :

1. Gravitational Wave Source
2. Progenitor of Type Ia Supernova

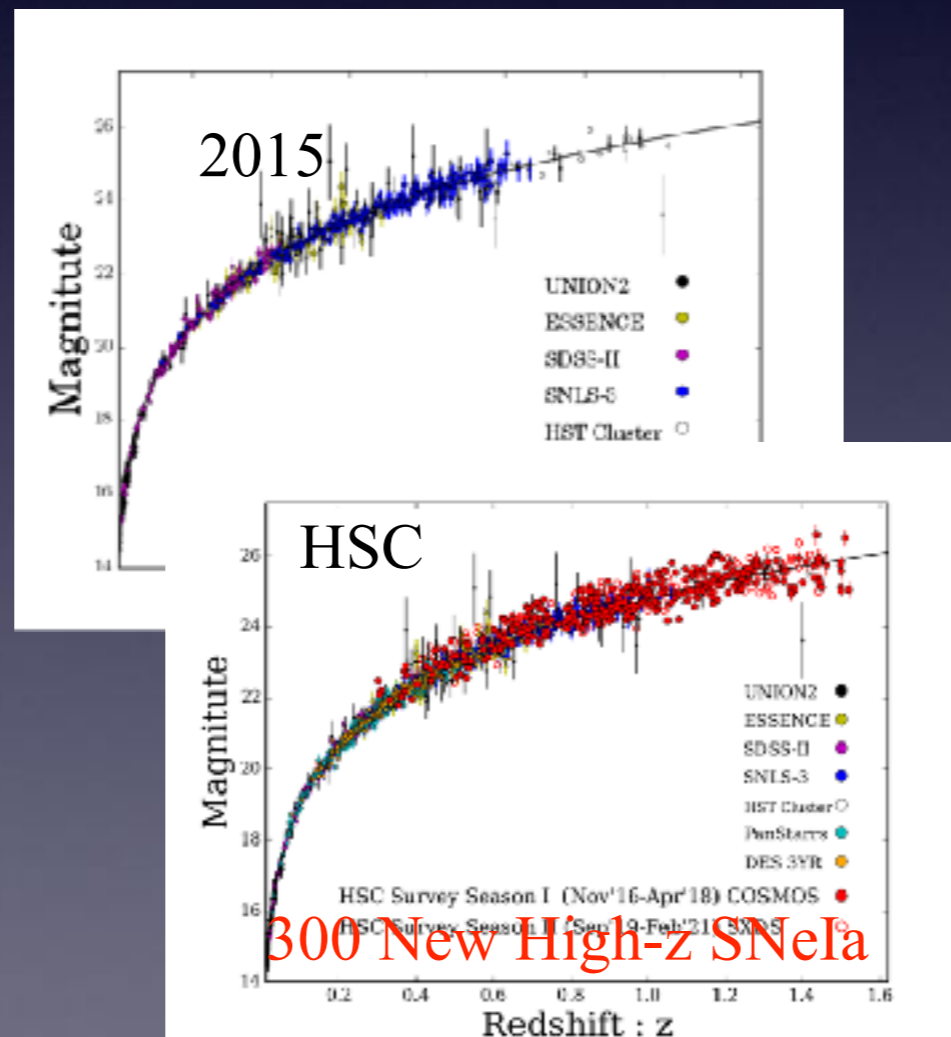
- §1: Close Binaries
- §2: WD Binaries
- §3: Spectroscopic Binaries
- §4: X-ray binaries



White Dwarf-White Dwarf:
Double Degenerate System

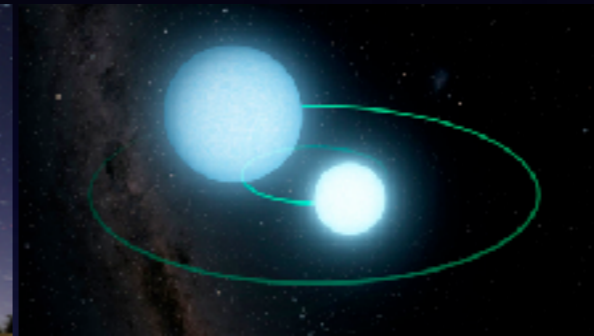
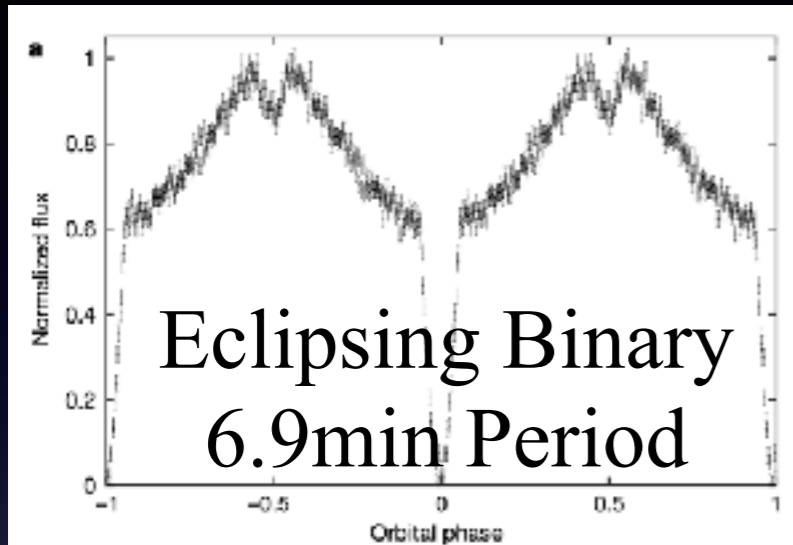


White Dwarf-Main Sequence Star:
Single Degenerate System



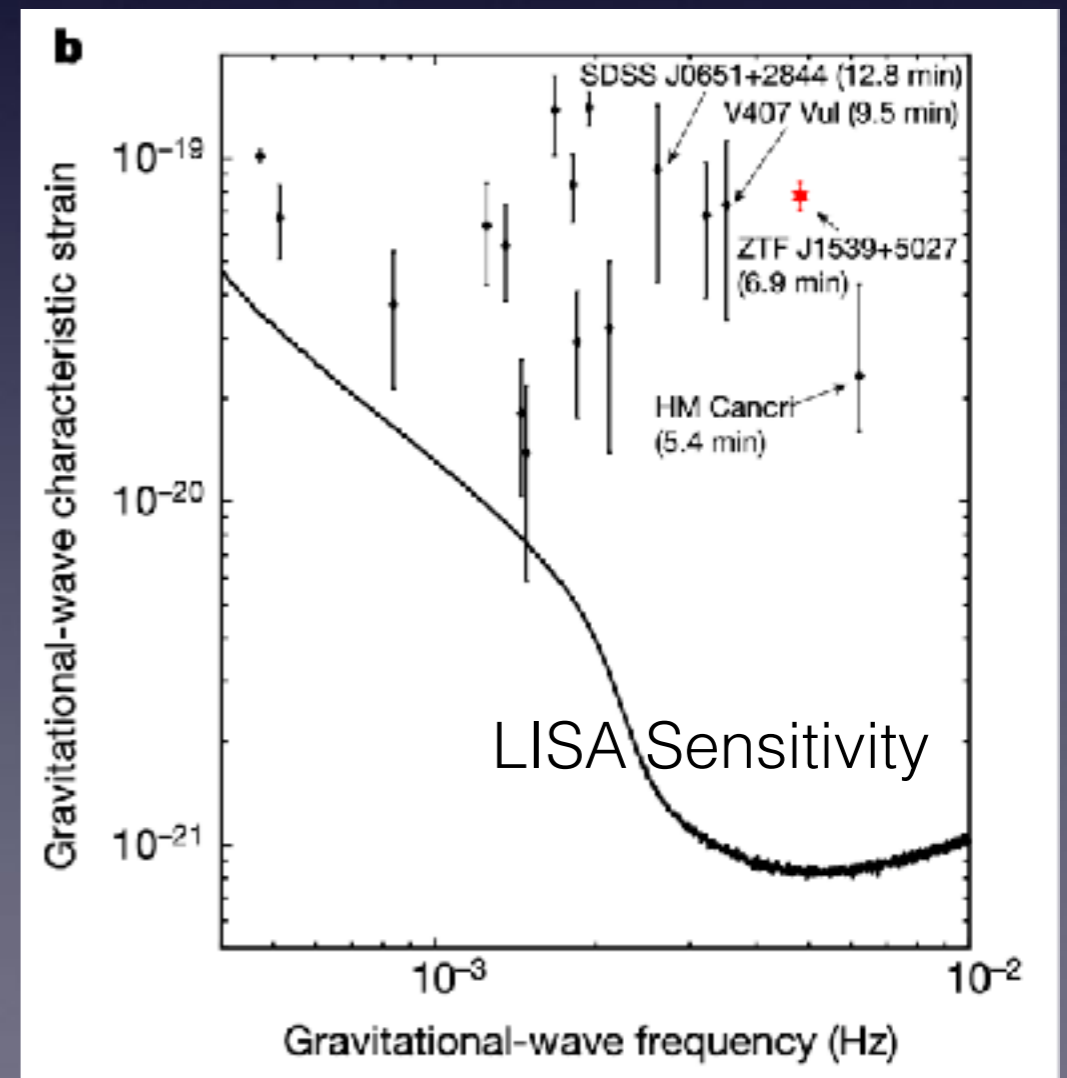
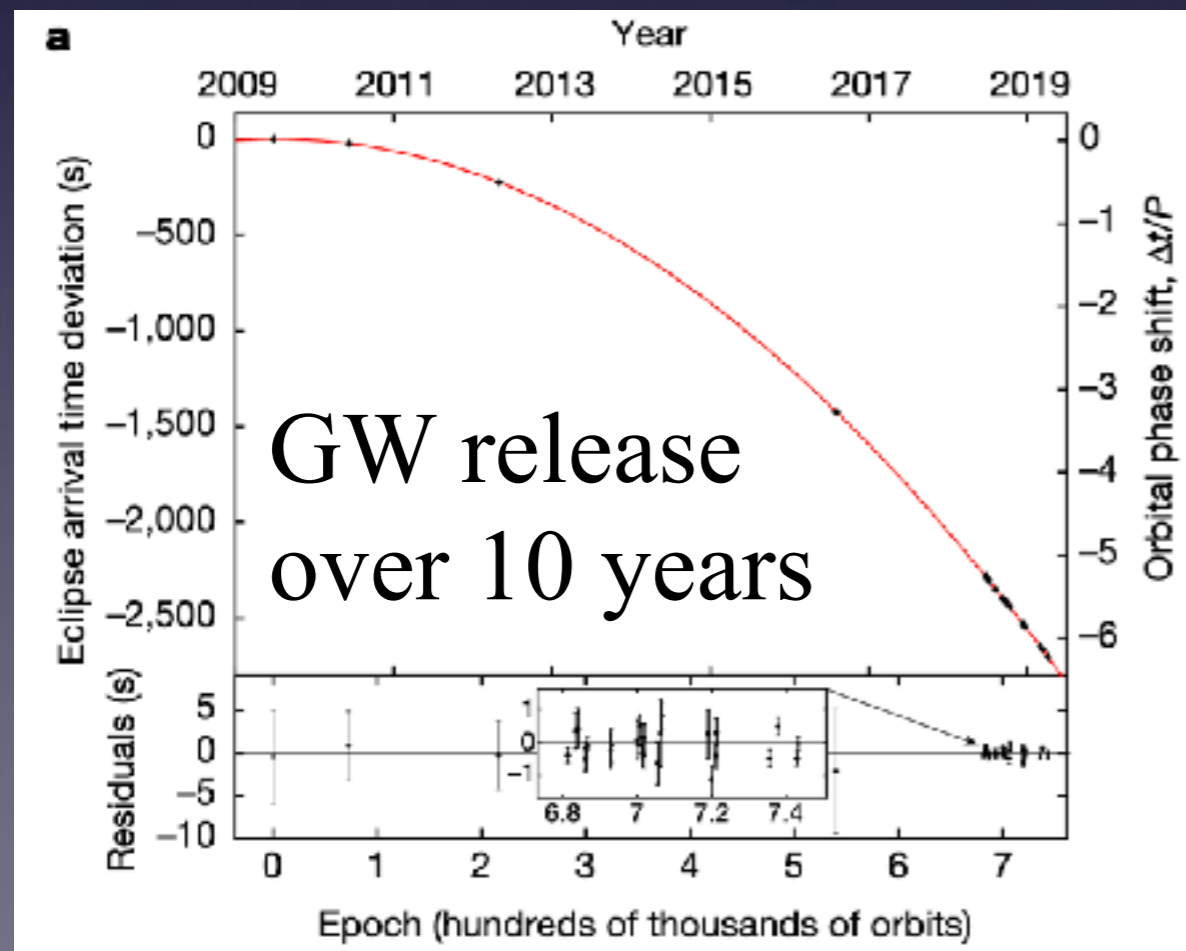
§1 : Close Binaries

Zwicky Transient Facility (ZTF) :
Northern Hemisphere Sky Survey



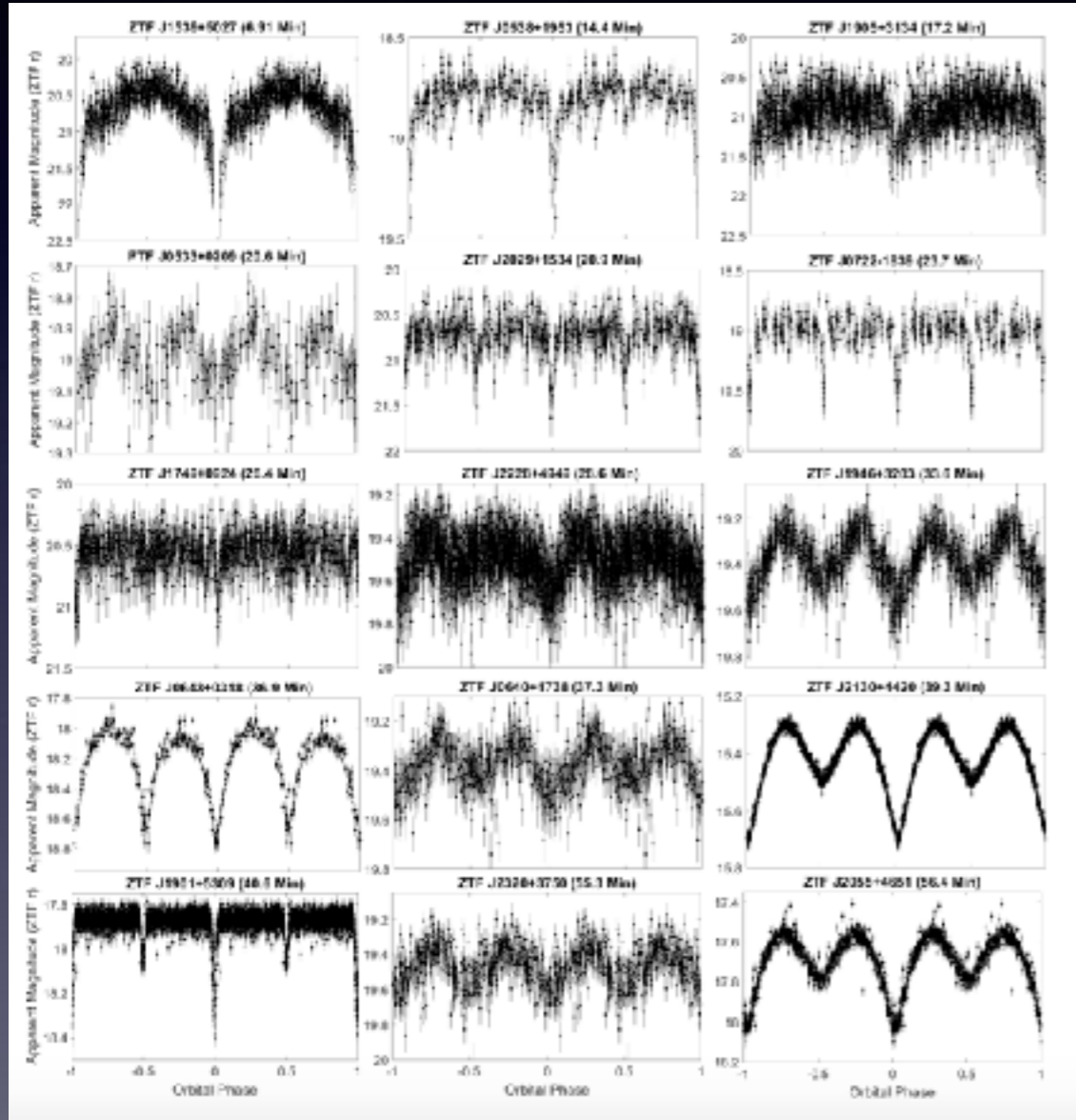
M1: 0.61 M_{\odot}
M2: 0.21 M_{\odot}

Burdge et al. 2019, Nature, 571, 528

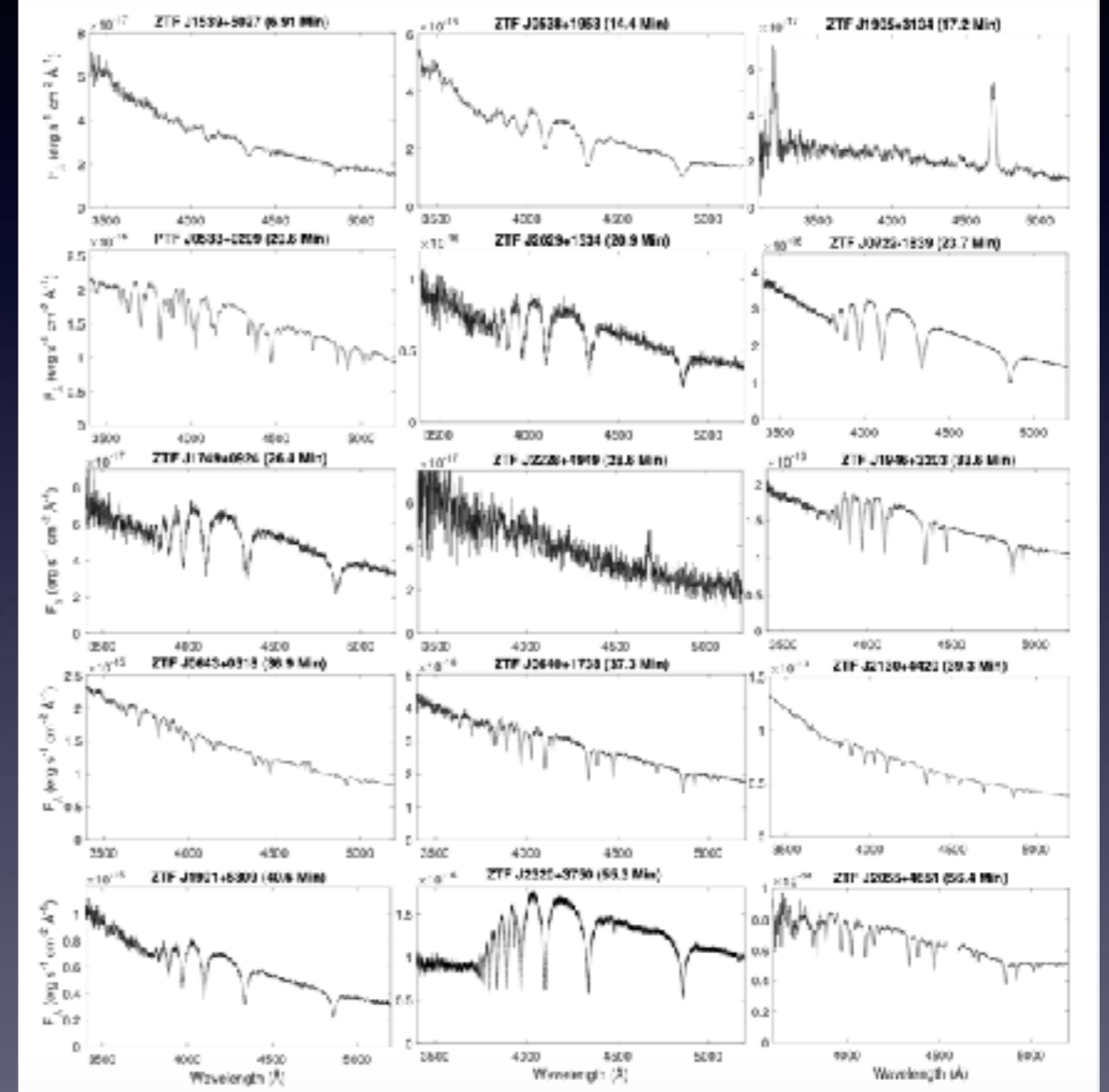


How to find a Close Binary Systems? Eclipsing Binaries

Light Curve Periodicity



Identify with Stellar Spectra



From ZTF Imaging,
Eclipsing binary candidates



Burdge et al. 2020, ApJ, 905, 32

ZTF Camera: FoV: 45 deg²

Spectroscopic Follow-up
Confirmation



SED Machine

20 Binary Systems with Period < 1 hour

Table 1
ZTF/PTF Short-period Binaries

| Name | R.A. (h:m:s) | Decl. (d:m:s) | Orbital Period (minutes) | Nature of Photometric Variability | Spectroscopic Characteristics |
|--------------------|-----------------|------------------|-----------------------------|-----------------------------------|--------------------------------|
| ZTF J1539+5027 (1) | 15:39:32.16 | +50:27:38.72 | 6.91 | Eclipsing+irradiation | DA, double-lined |
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| ZTF J1905+3134 | 19:05:11.34 | +31:34:32.37 | 17.20 | Eclipsing high state AM CVn | Double-peaked He II emission |
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| ZTF J0722-1839 | 07:22:21.49 | -18:39:30.57 | 23.70 | Eclipsing | DA, double-lined |
| ZTF J1749+0924 | 17:49:55.30 | +09:24:32.40 | 26.43 | Eclipsing | DA, double-lined |
| ZTF J2228+4949 | 22:28:27.07 | +49:49:16.44 | 28.56 | High State AM CVn | Double-peaked He II emission |
| ZTF J1946+3203 | 19:46:03.89 | +32:03:13.13 | 33.56 | Eclipsing+Ellipsoidal | DAB/sdB, single-lined |
| ZTF J0643+0318 | 06:43:36.77 | +03:18:27.45 | 36.91 | Accreting He star | He I absorption/He II emission |
| ZTF J0640+1738 | 06:40:18.69 | +17:38:45.01 | 37.27 | Ellipsoidal | sdB, single-lined |
| ZTF J2130+4420 (3) | 21:30:56.71 | +44:20:46.42 | 39.34 | Ellipsoidal | sdB, single-lined |
| ZTF J1901+5309 (4) | 19:01:25.42 | +53:09:29.27 | 40.60 | Eclipsing | DA, double-lined |
| ZTF J2320+3750 | 23:20:20.43 | +37:50:30.84 | 55.25 | Ellipsoidal | DA, single-lined |
| ZTF J2055+4651 (5) | 20:55:15.98 | +46:51:06.45 | 56.35 | Eclipsing+Ellipsoidal | sdB, single-lined |

Note. Coordinates and basic photometric and spectroscopic characteristics of the 15 short-period binaries discovered so far using PTF/ZTF data. Coordinates are taken from Gaia DR2 and are in J2015.0. For apparent magnitudes, see Table 2. More precise orbital periods and uncertainties are reported in Table 3. Please note that in the spectroscopic characteristics column, a DA atmosphere indicates a hydrogen rich white dwarf atmosphere, DBA a helium rich with traces of hydrogen atmosphere, and DAB a hydrogen rich with traces of helium atmosphere.

References. (1) Burdge et al. (2019a), (2) Burdge et al. (2019b), (3) Kupfer et al. (2020b), (4) Coughlin et al. (2019), (5) Kupfer et al. (2020a).

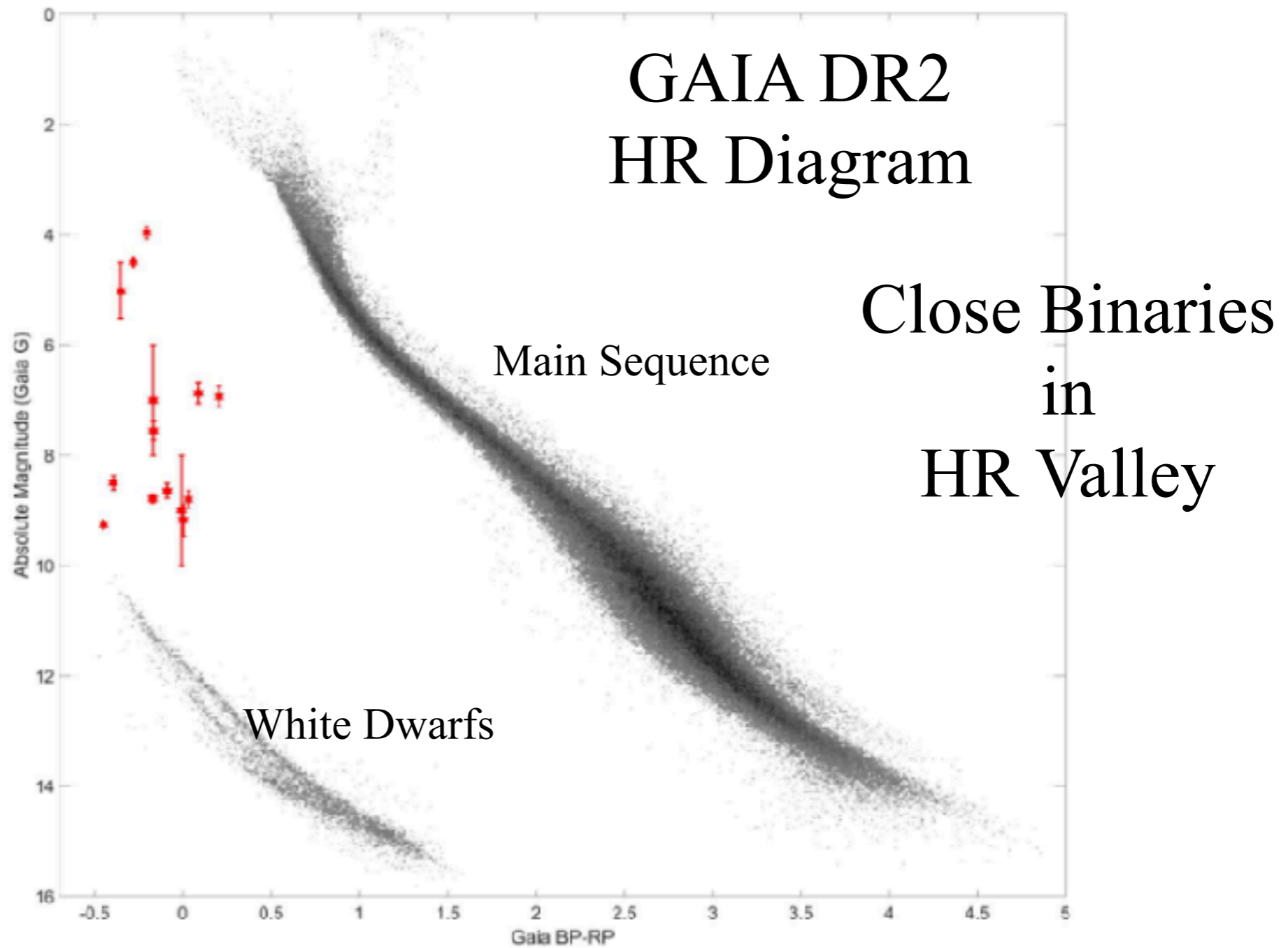
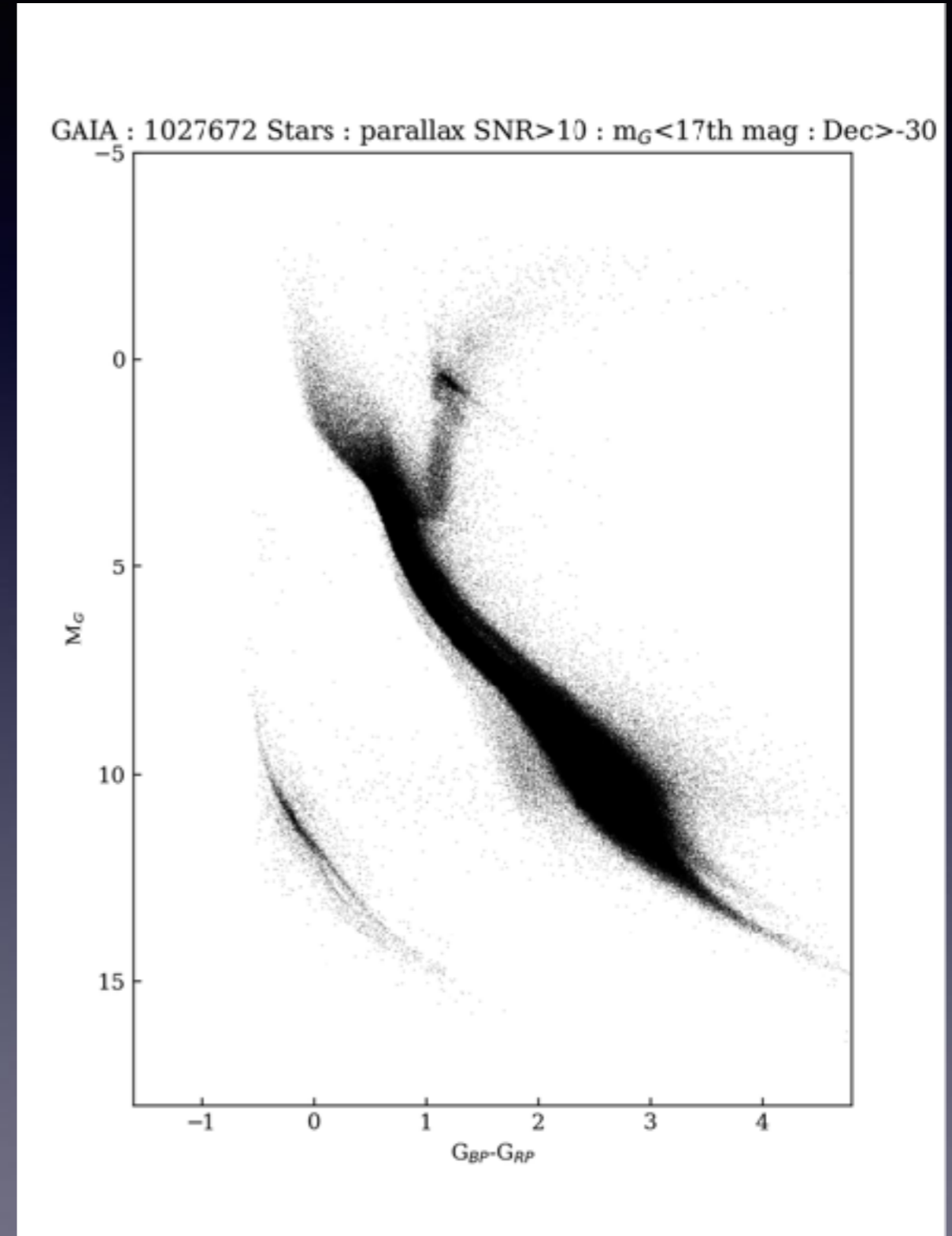
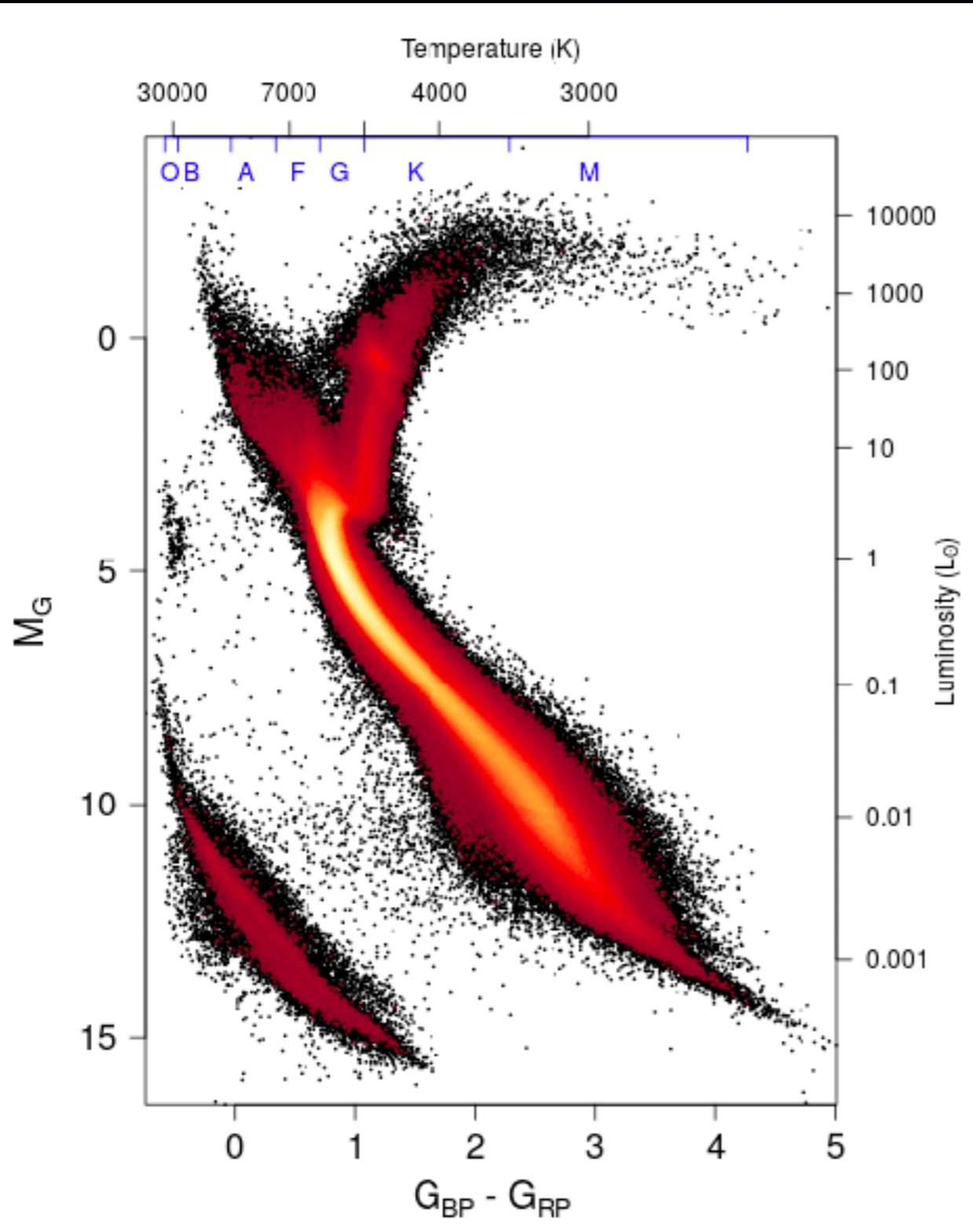


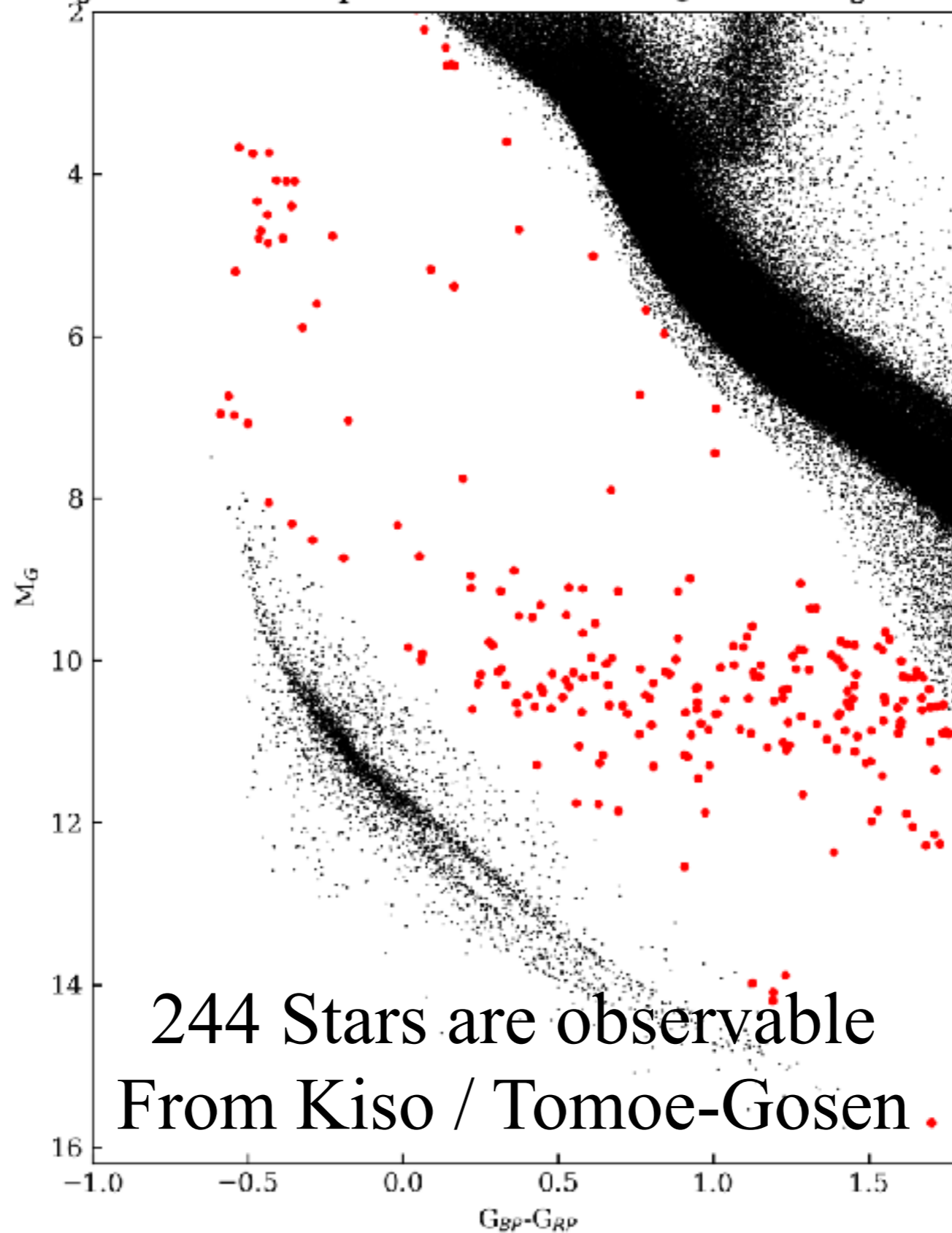
Figure 8. Hertzsprung–Russell diagram illustrating the dereddened locations of 14 binaries in the sample with spectroscopic distances (ZTF J0643+0318 is omitted, as its modeling is ongoing). The red stars represent objects that are in our sample, with absolute luminosities calculated based on their spectroscopic distances. Most objects cluster between absolute magnitudes of 6.5 and 10.0, with the exception of the systems containing either He-burning stars or young and hot He WDs (which contribute significant additional luminosity, dwarfing both the luminosity of the companion WD and any accretion luminosity). The background color–magnitude diagram (CMD) is the sample of all stars in Gaia within 100 pc that have reliable astrometric solutions.

1,027,672 Stars visible from Tomoe-Gosen

DEC > -30, $m < 17$ th mag from GAIA DR3



Target : 244 Stars : parallax SNR > 10 : $m_G < 17^{\text{th}}$ mag : Dec > -30



Back on the Envelope Estimate

0.7 Solar Mass Binary \Rightarrow 2.0 Roche Limit

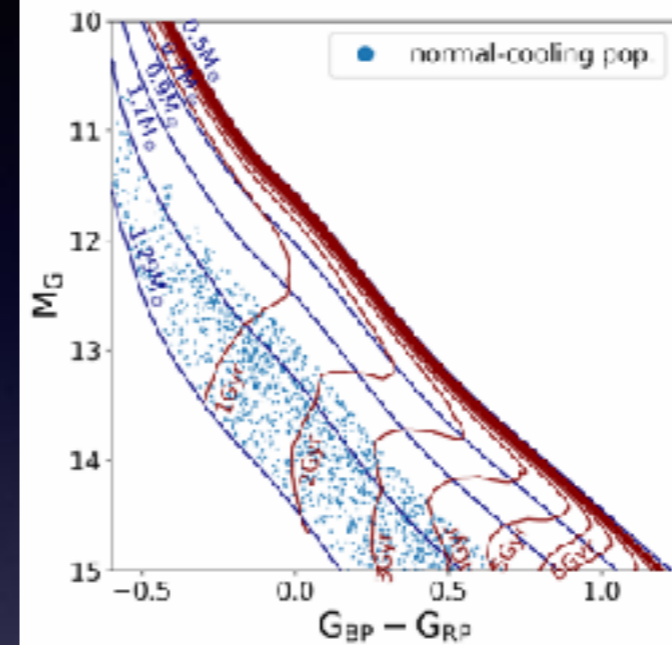
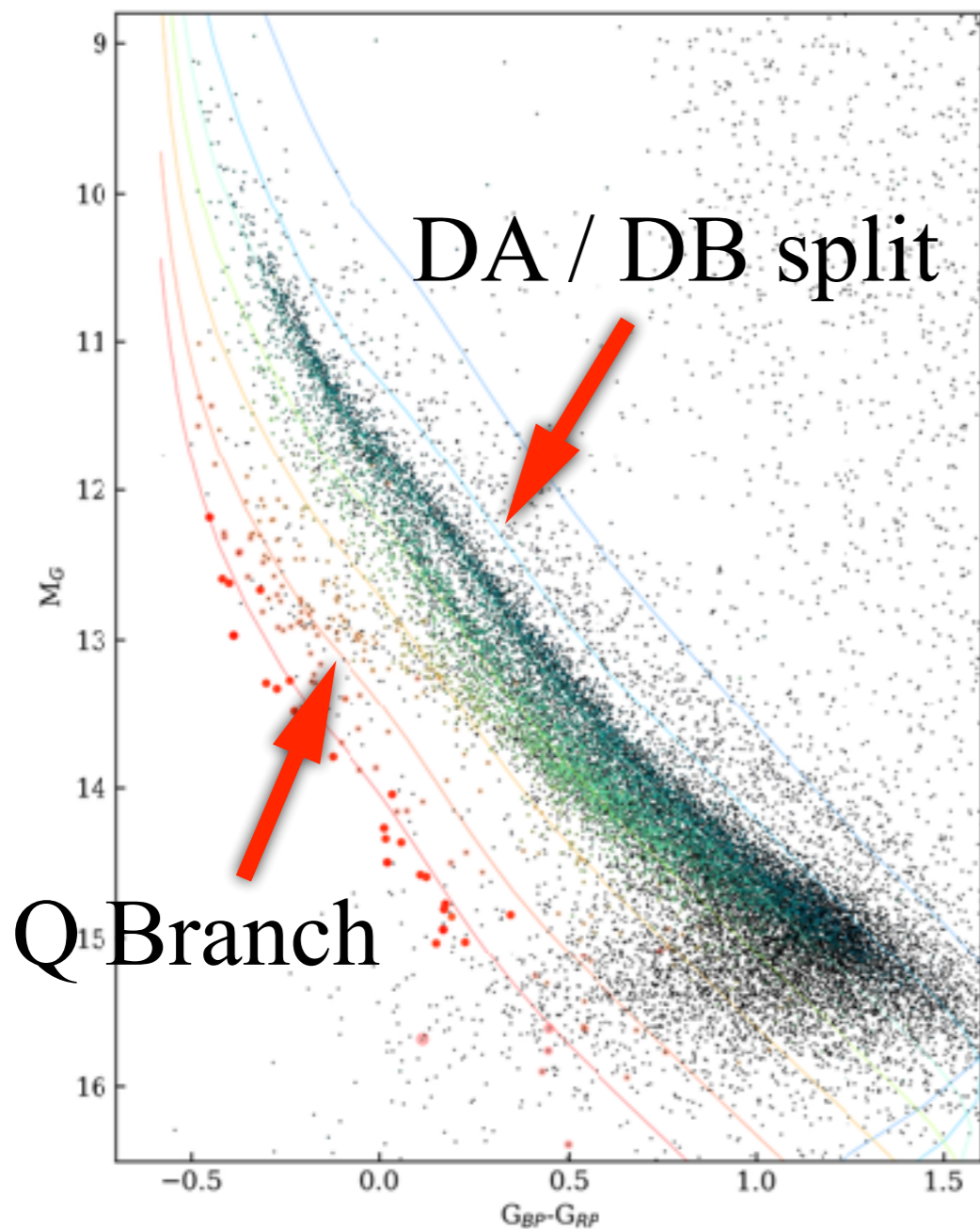
| Period (Min) | Time to Merge (Year) | Relative Fraction |
|--------------|----------------------|-------------------|
| 120 | 1.63×10^8 | 1955.5 |
| 60 | 2.57×10^7 | 307.9 |
| 15 | 6.39×10^5 | 7.63 |
| 7 | 8.30×10^4 | 1.00 |
| 3 | 8.67×10^3 | 0.10 |

244 Targets x 5% (eclipsing fraction based on TESS)
 \Rightarrow 12 Systems

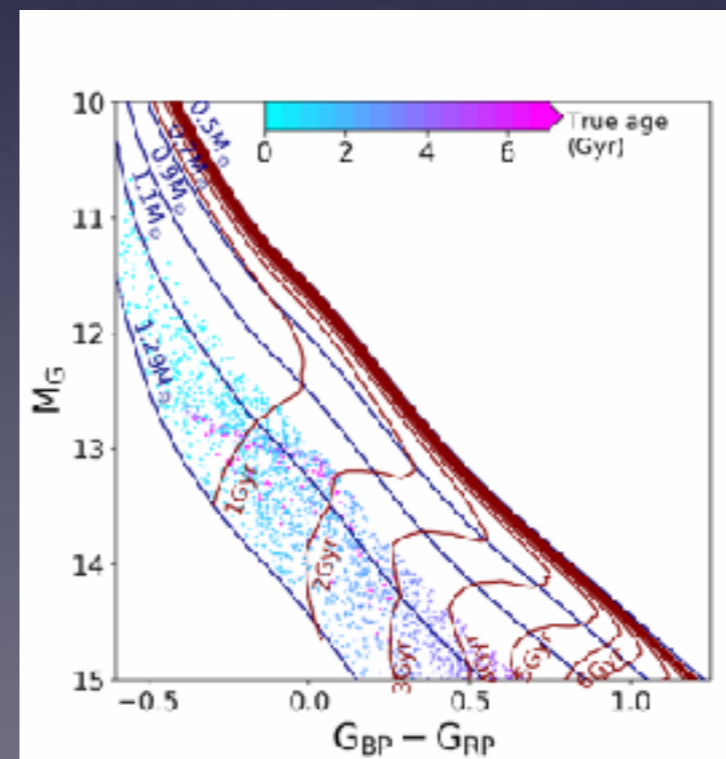
§2 : White Dwarf Binaries

White Dwarf HR diagram

By Sihao Cheng

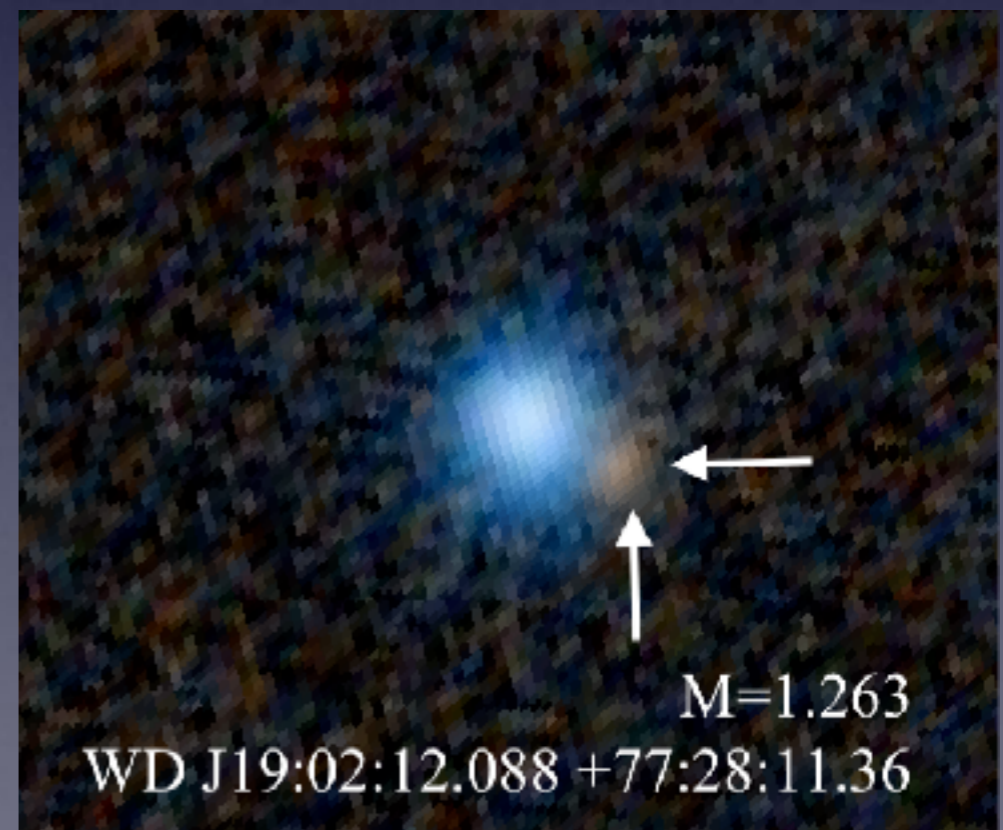
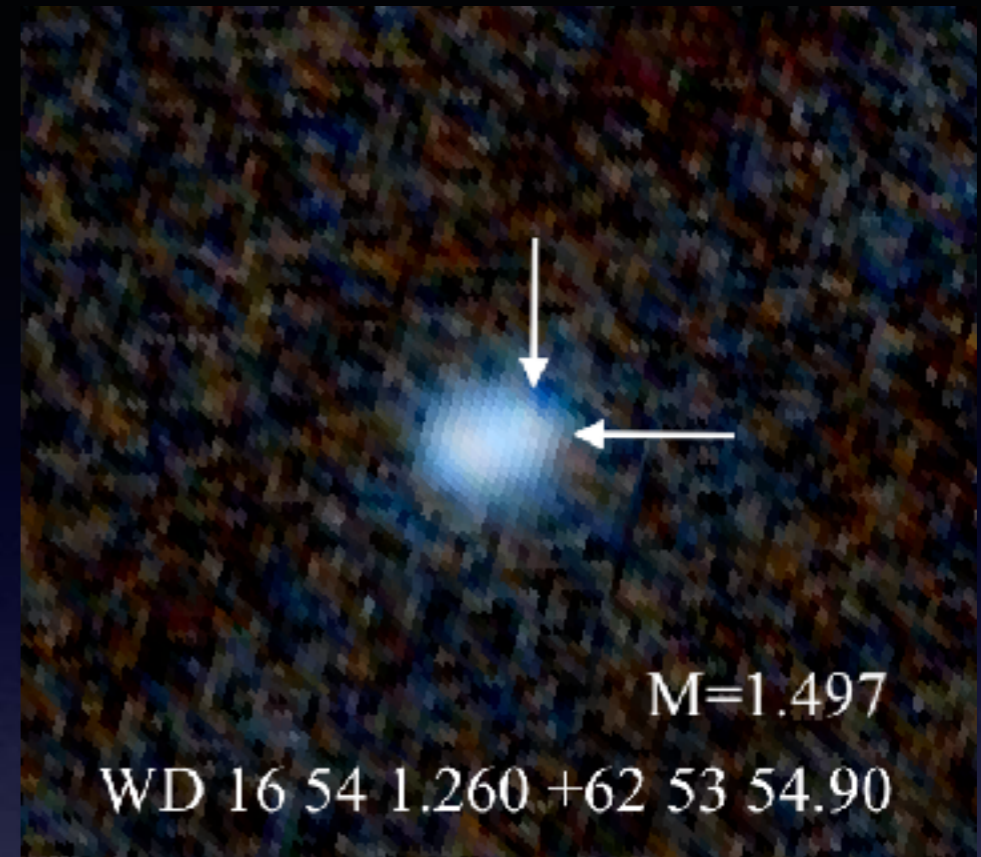
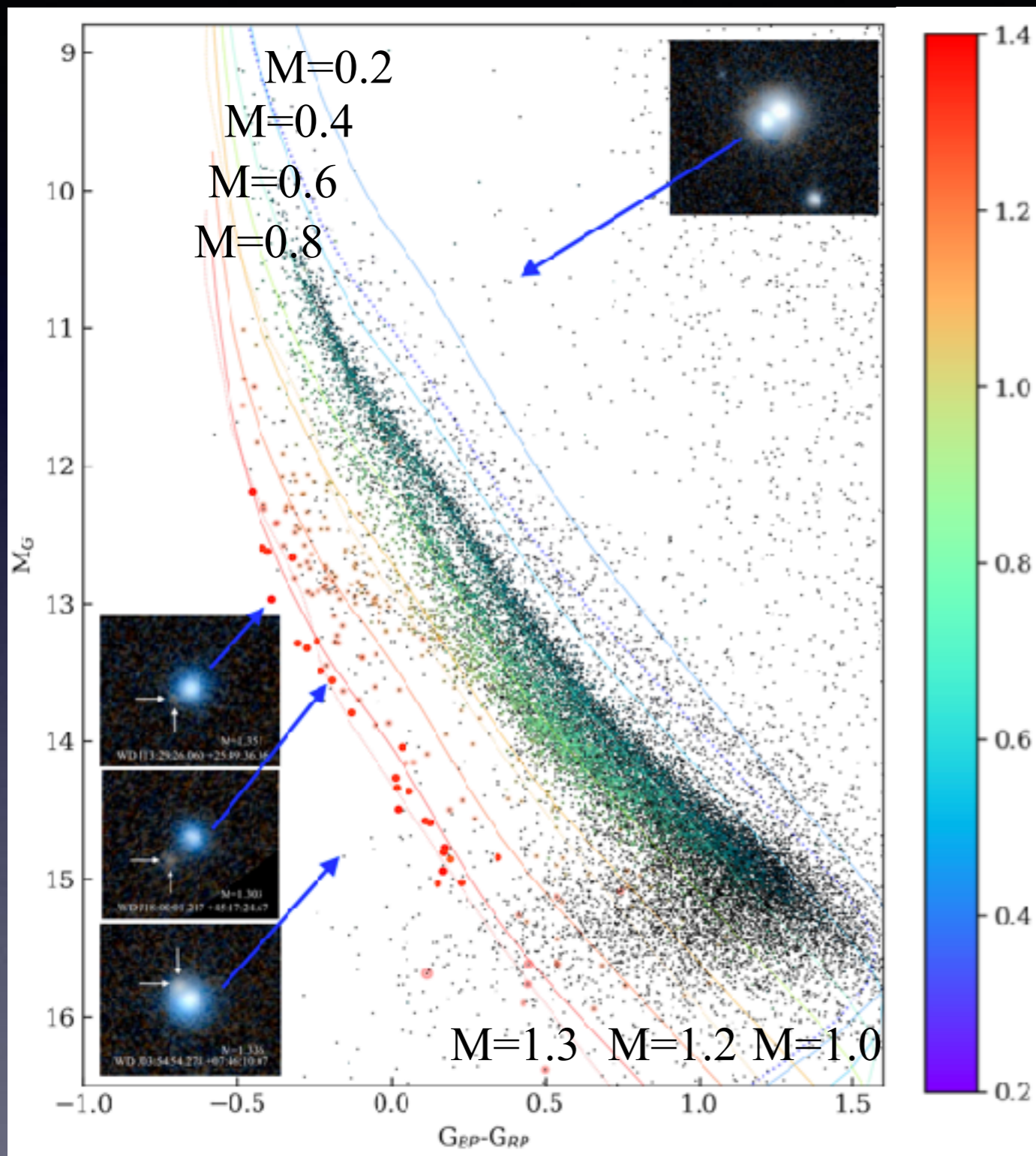


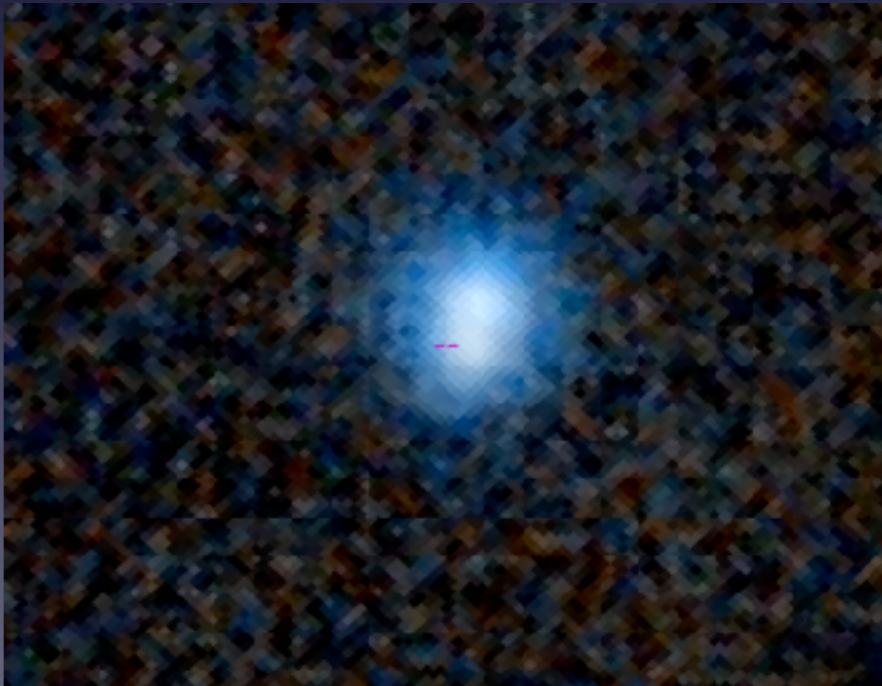
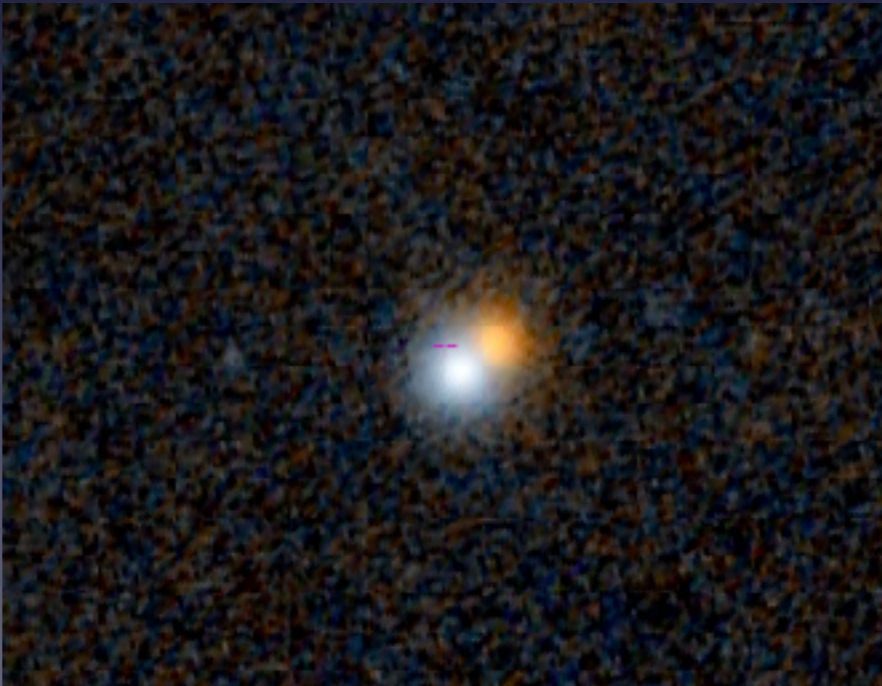
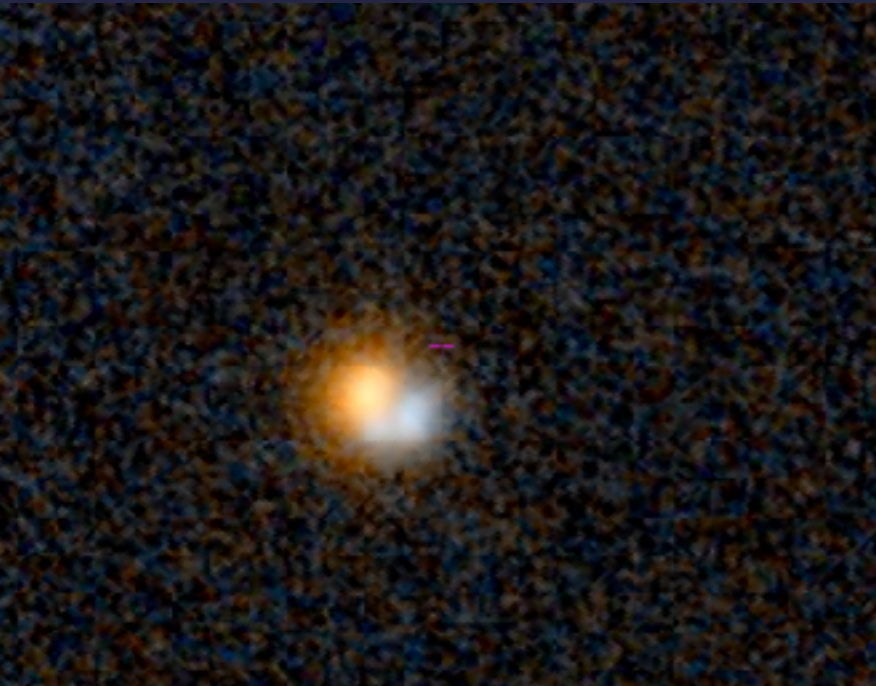
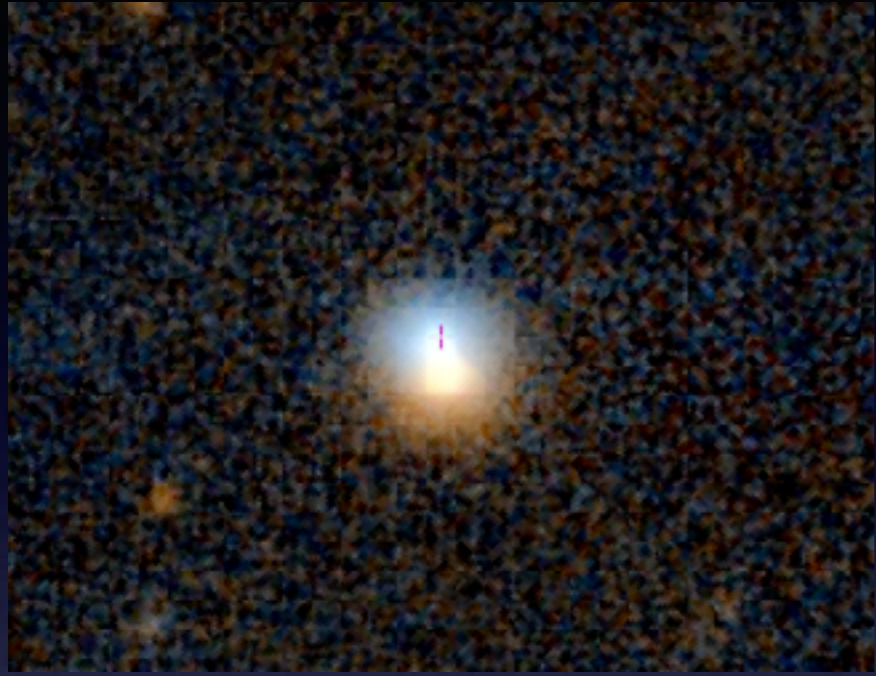
Cooling



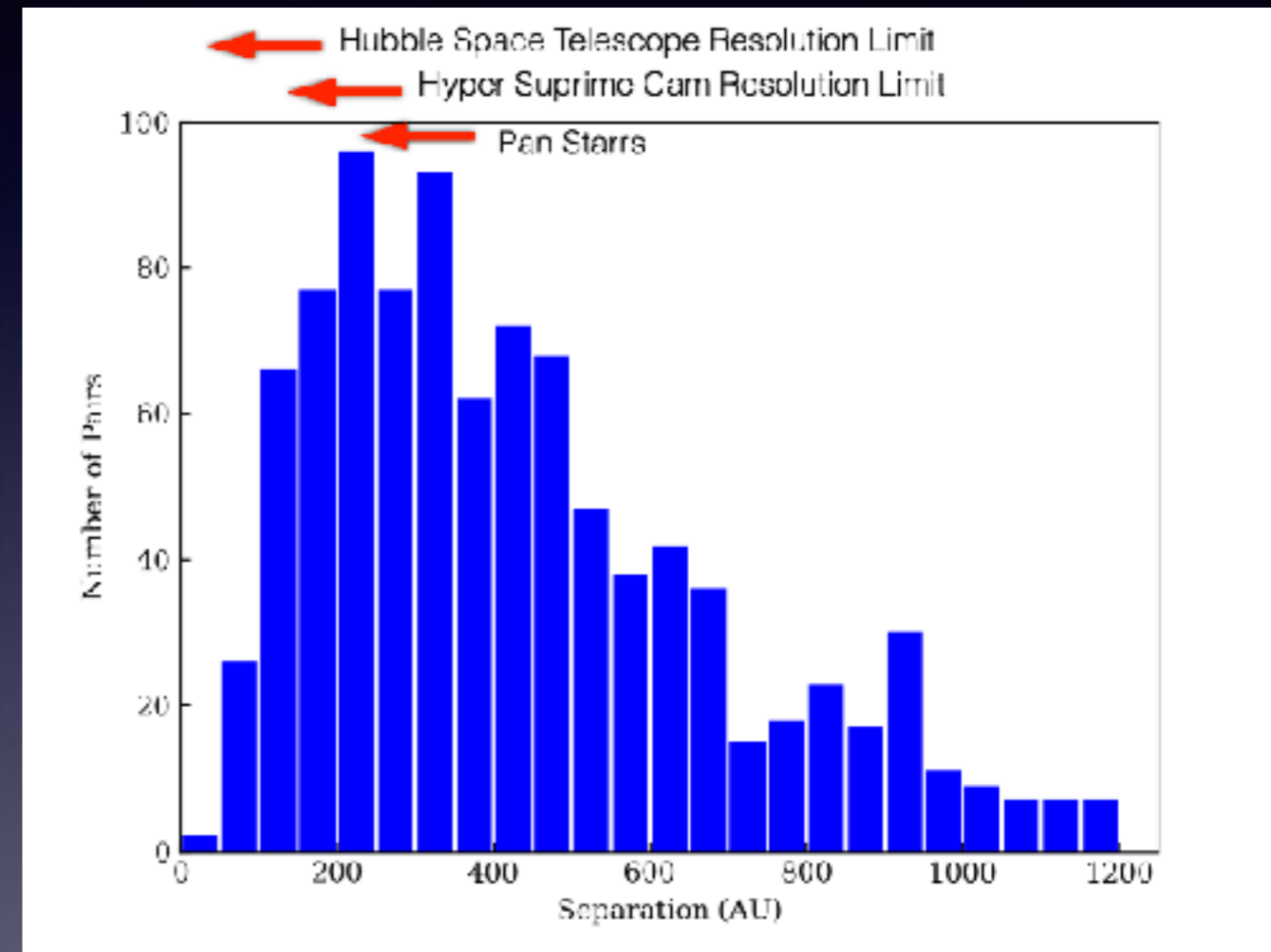
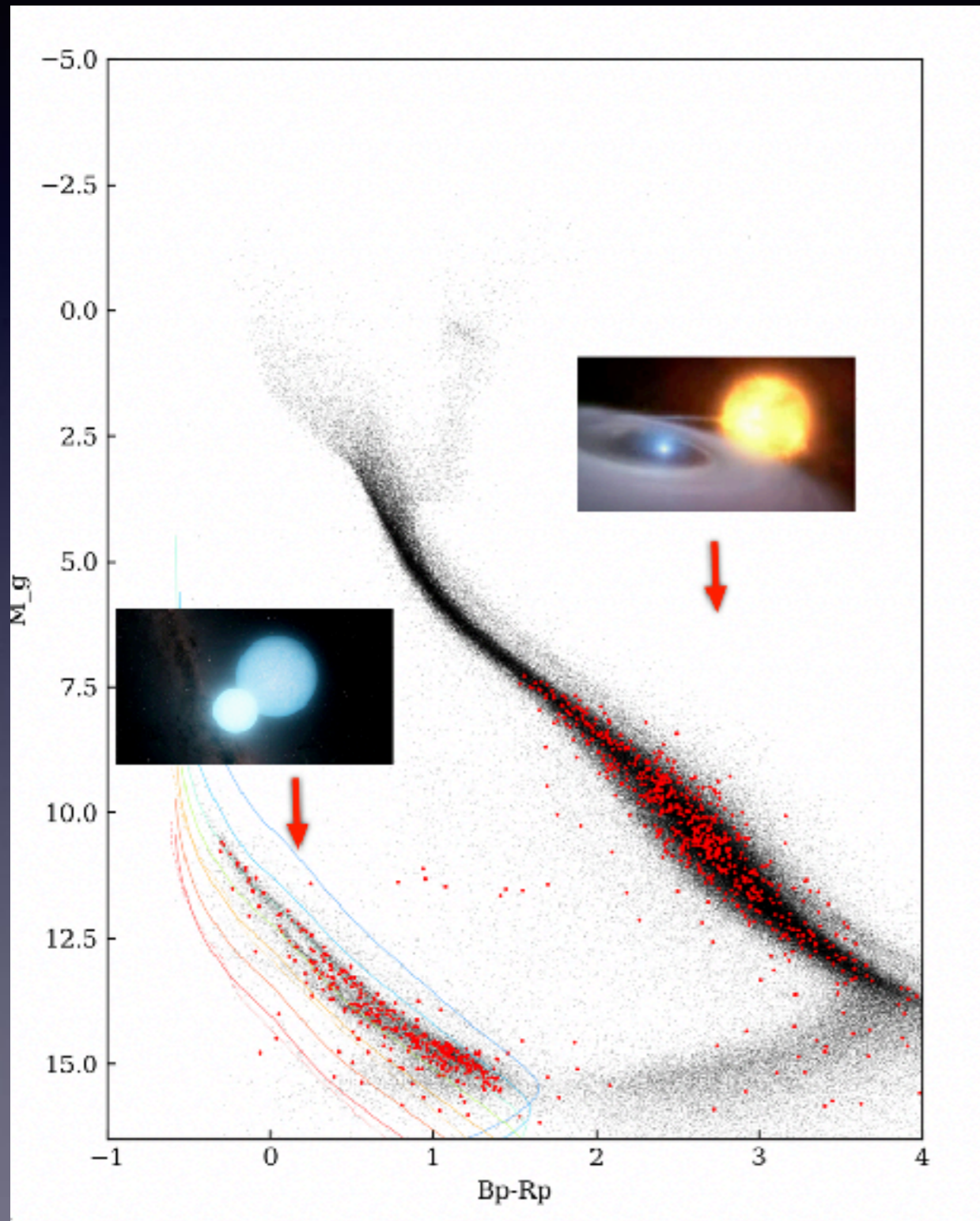
Delayed Cooling

Finding Companions





White Dwarf Resolved Binaries



$P=120$ min : Distance=0.003AU

Finding Unresolved WD Binaries

20 Binary Systems with Period < 1 hour

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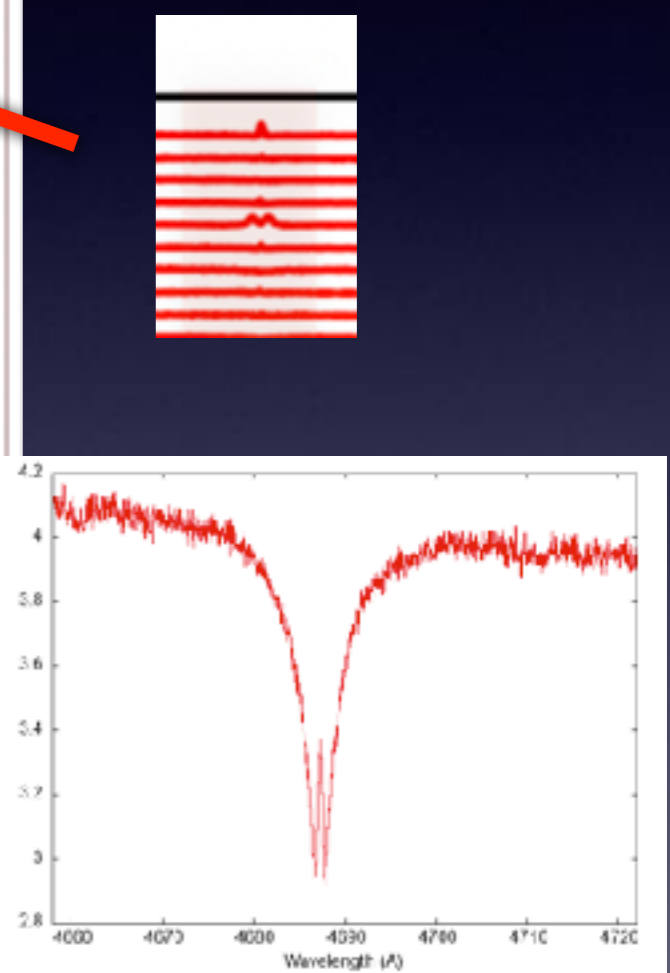
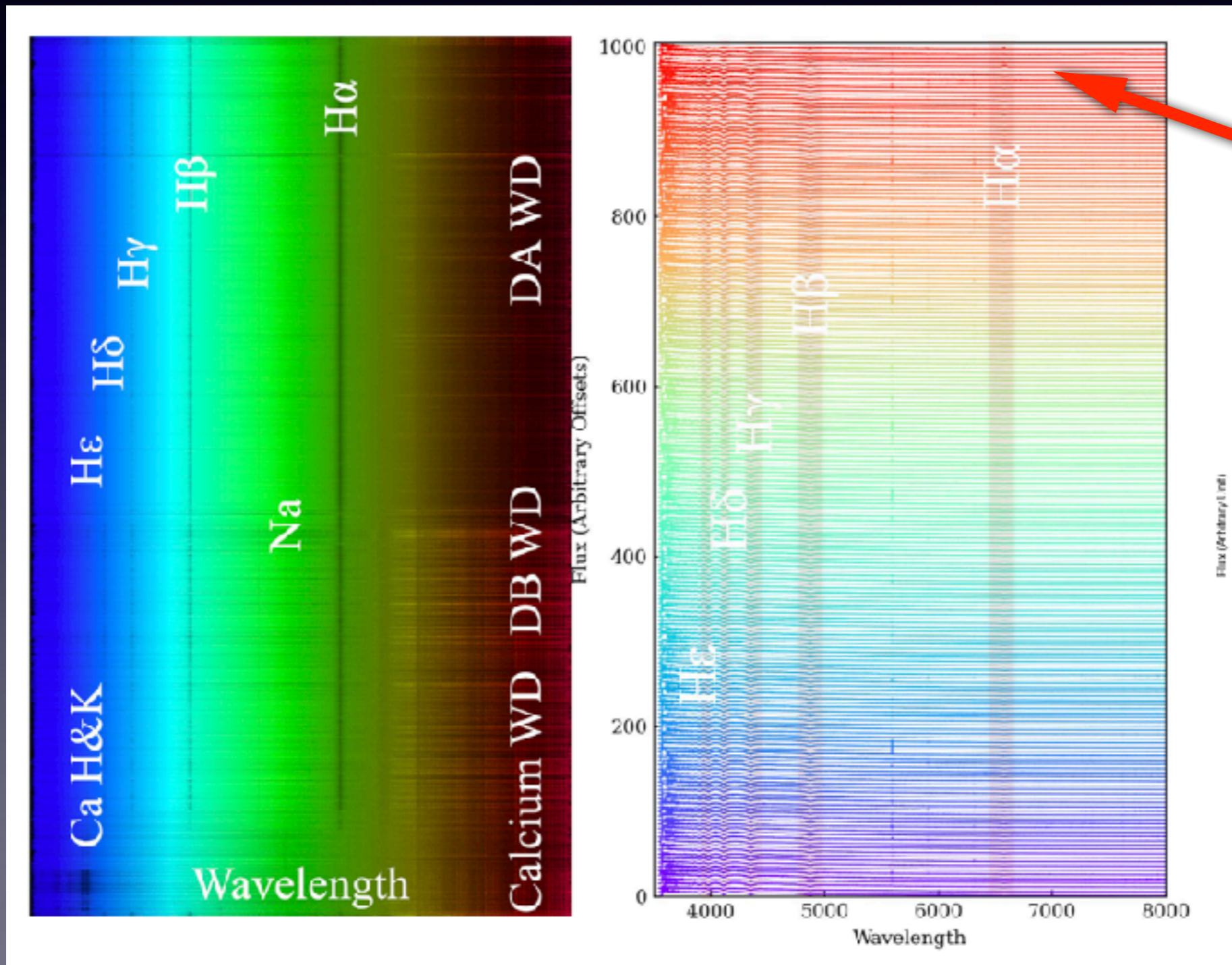
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§3 : Spectroscopic Binaries

Finding Unresolved WD Binaries

SDSS 26,801 Spectra

Entropy based Kullback-Leibler divergence

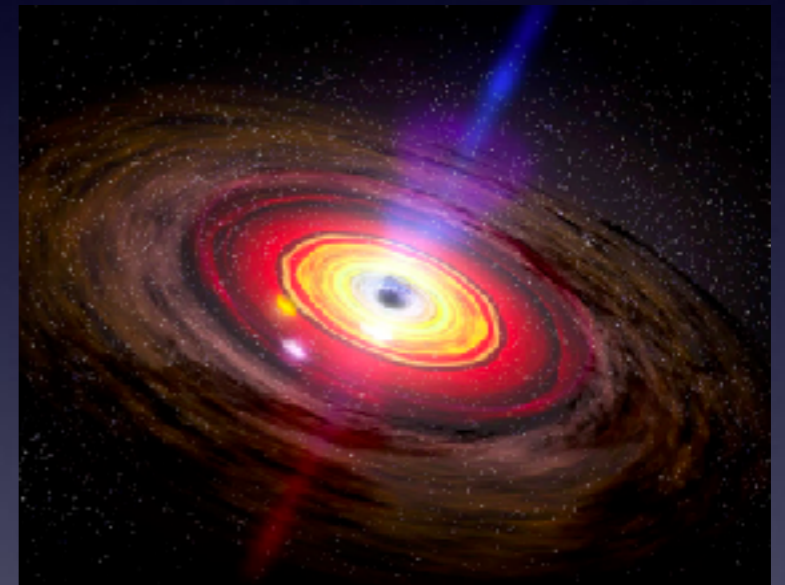


Roughly
5%
1000 WDs

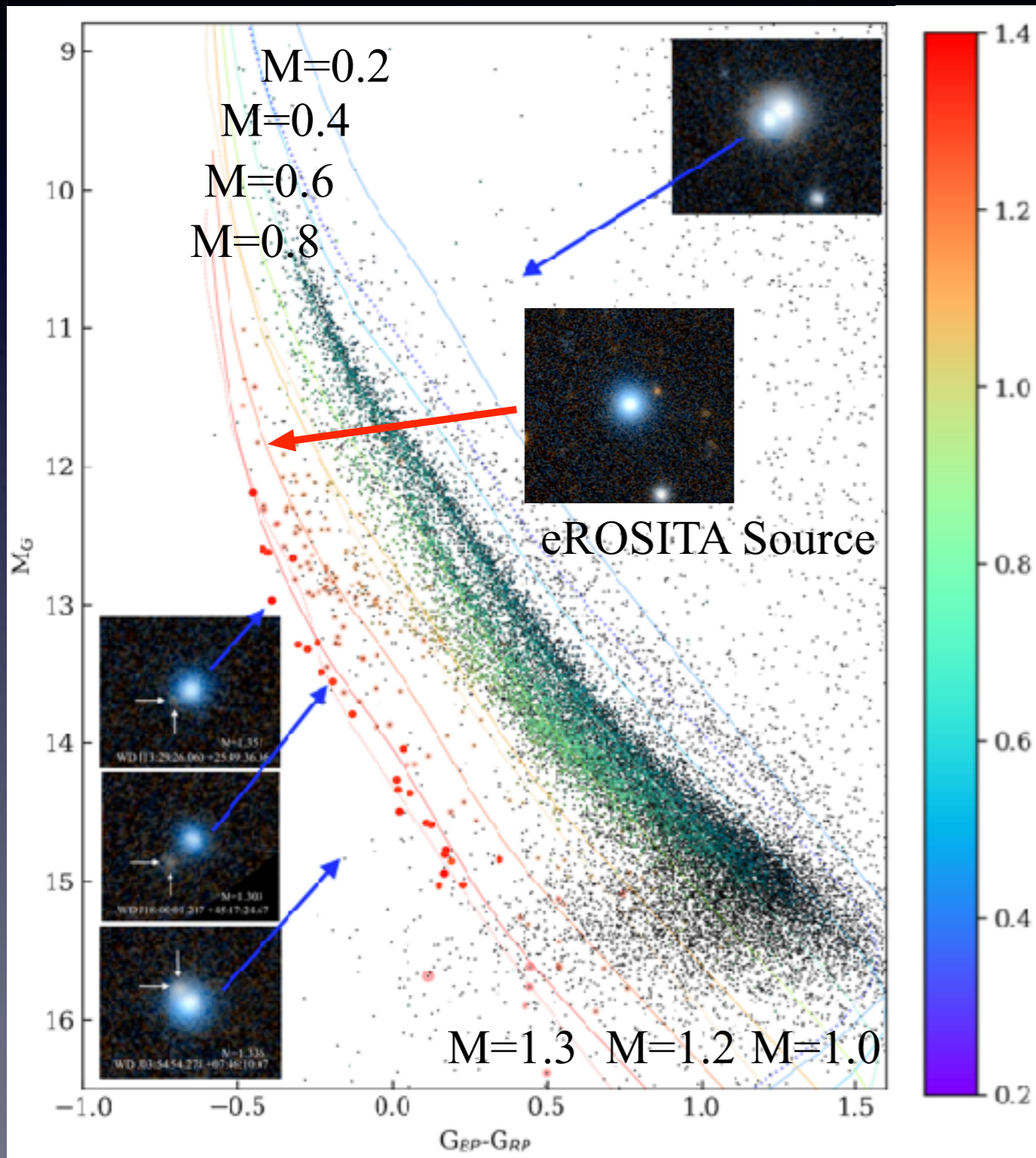
§4 : X-ray binaries

Back on the Envelope Calculation

- Closest Black Hole Candidate \Rightarrow 290 pc
- 10^8 Black Holes in Milky Way
- Roughly 1/1000
- Within 200pc, 1,807,116 GAIA stars
- 2000 BHs?
- Half of the population is in binary \Rightarrow 1000 BHs
- Natural to believe “Blackhole - White Dwarf” Binary exists!



Blackhole - White Dwarf Candidate

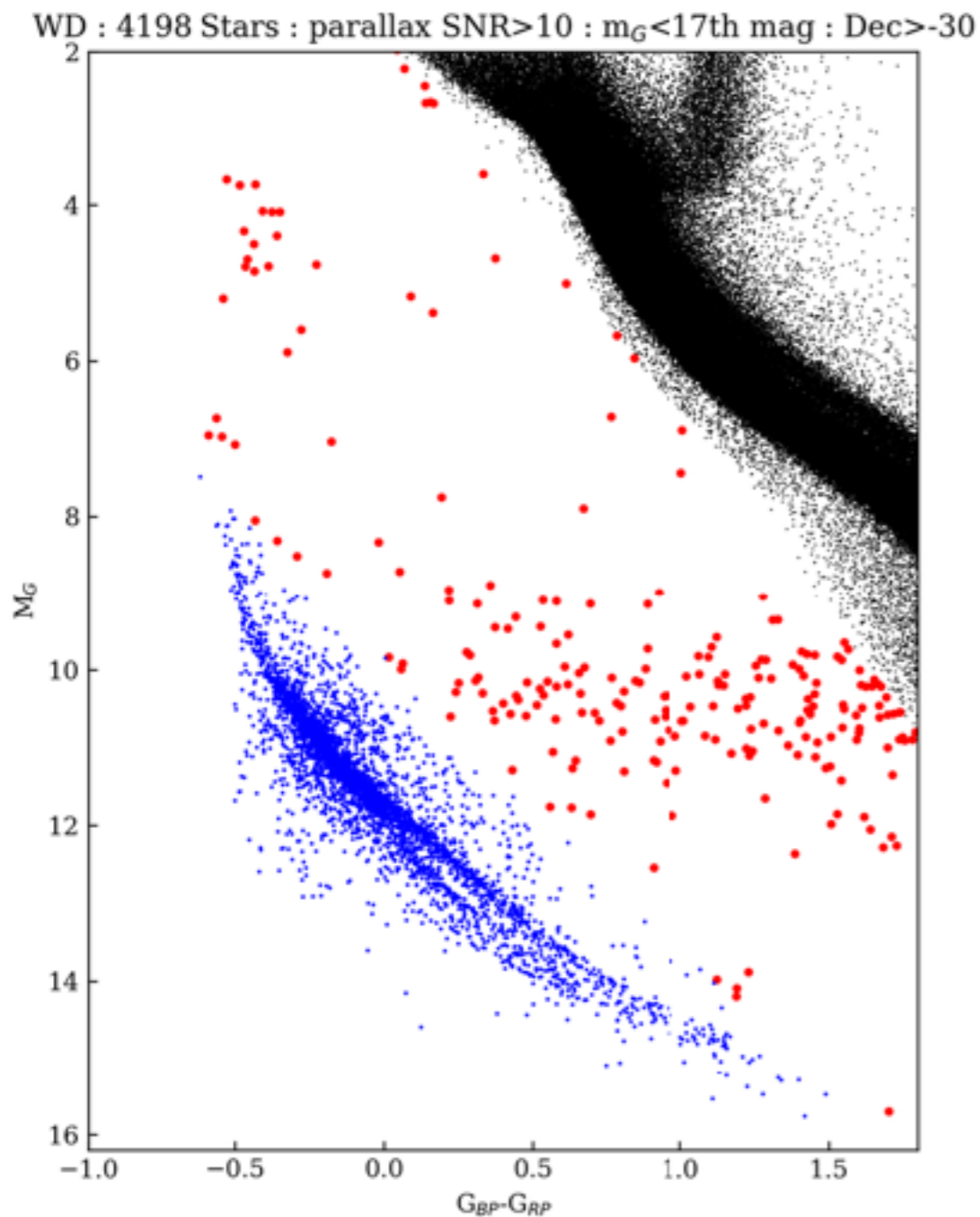


eROSITA Counter-Part 8 Systems



Tomoe-Gozen Proposal

- Monitor 244 HR Valley Stars
- 4198 White Dwarfs x eROSITA sources
- 244+4198=4442 Stars to be recorded!
- Spectroscopic Follow-up by Lick (KAST / APF)



Science Goals:

Binary Census = GW Background = SNIa Progenitor

Discover Closest Blackhole through Binary Motion