Identifying Blue Horizontal Branch Stars using Gaia DR3

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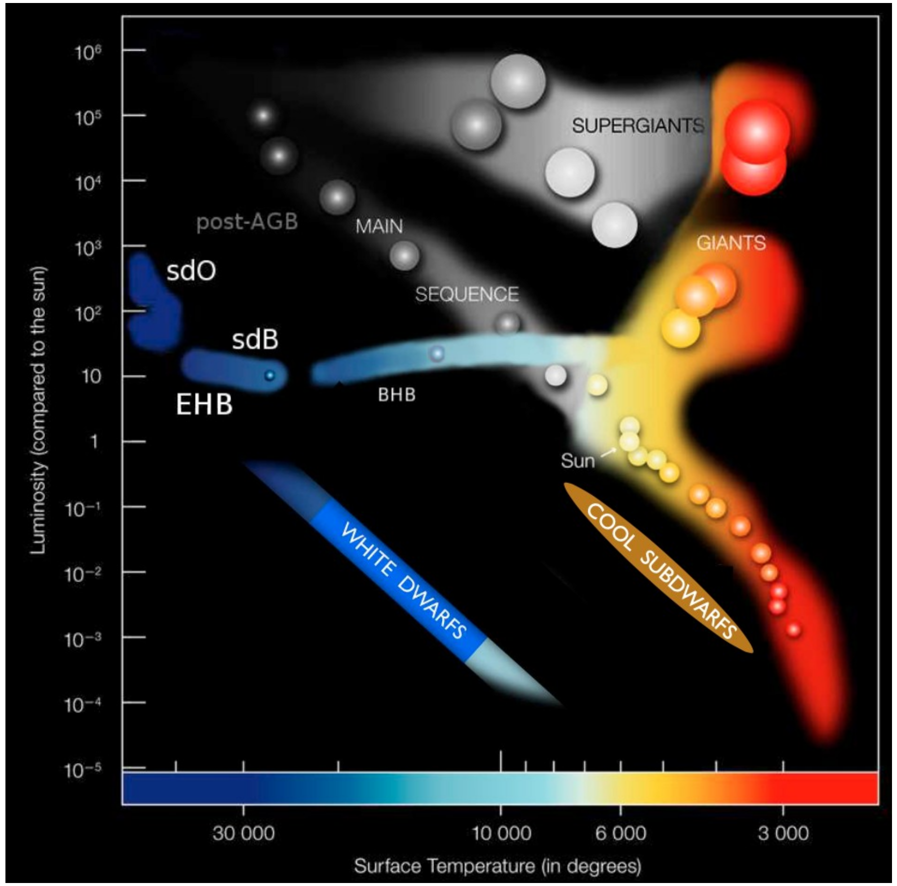
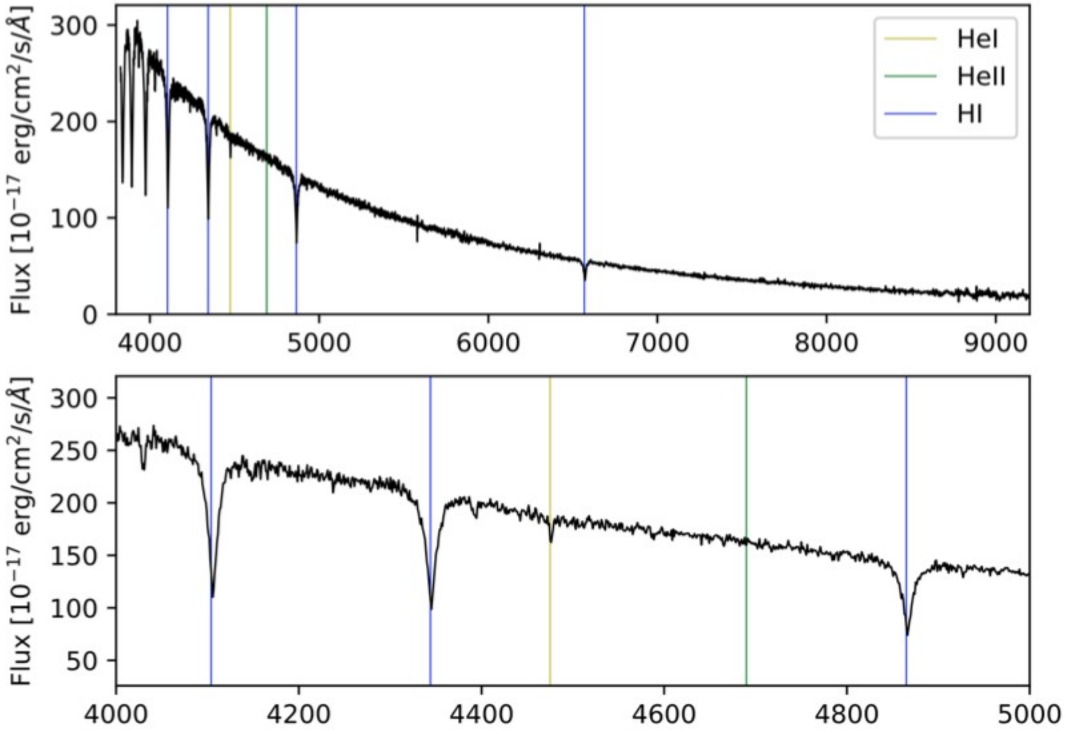
Blue Horizontal Branch Stars



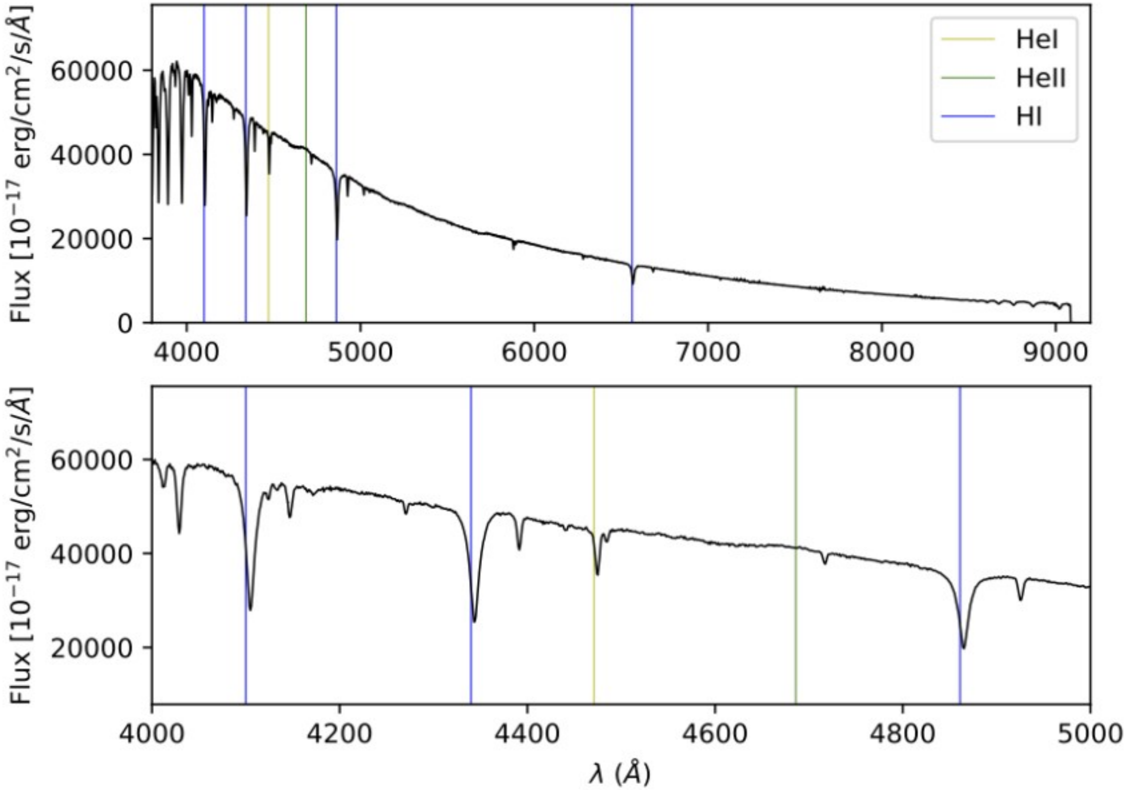
From Heber (2009); copyright Annual Review of Astronomy & Astrophysics

- Develop from low-mass main sequence stars
  ();
- Leaves the main-sequence once core hydrogen burning ceases;
- Inert Helium core contracts heating the Hydrogen shell
  where fusion begins. Star evolves onto the Red Giant Branch;
- Large amount of the outer envelope is lost by the strong solar wind;
- Inert Helium core continues to contract and becomes electron degenerate;
- Temperature in the Helium core rises enough for fusion to begin;
- Core becomes non-degerate in seconds – Helium flash occurs;
- Star moves to the BHB with masses of

BHB stars versus main-sequence 1 of 2



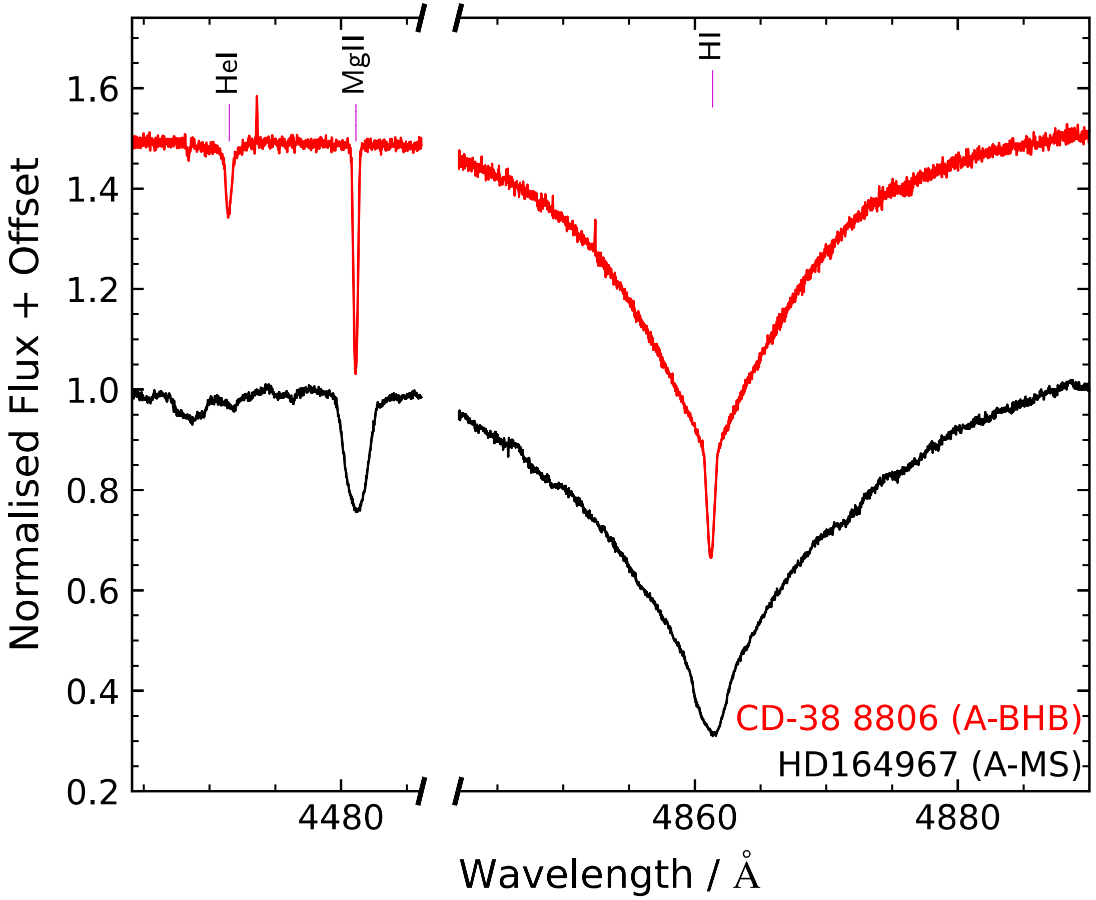
From Geier et al. (2015); A&A, 577, A26

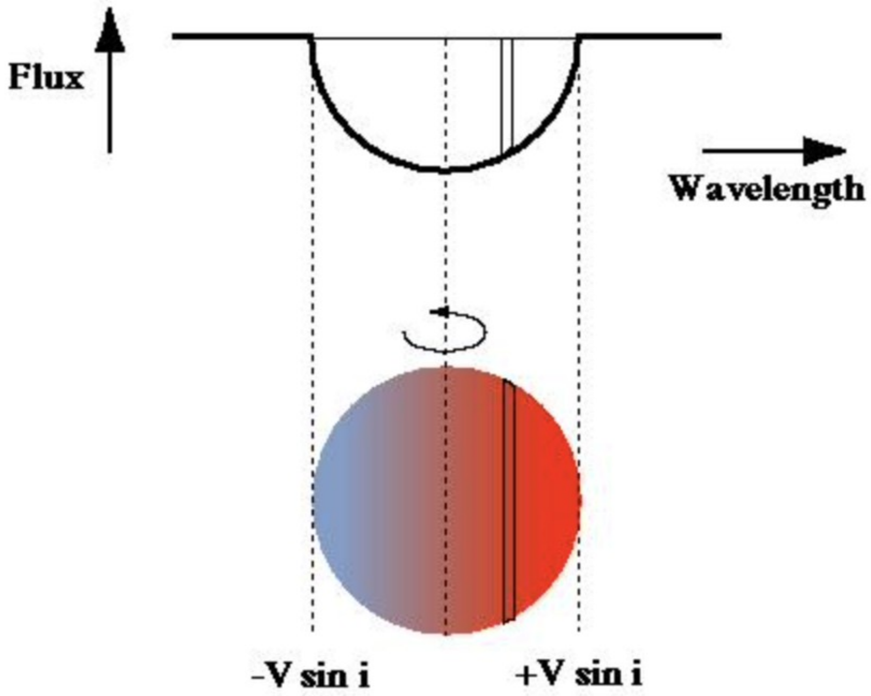


From Culpan et al. (2021); A&A 654, A107

- BHB Characteristics:
  - Old, metal-poor, population II stars
  - Core He burning, H burning envelope
  - Sharper absorption lines
- MS Characteristics:
  - Younger, higher metallicity
  - Deeper He lines
  - Rounded absorption lines due to high rotation

BHB stars versus main-sequence 2 of 2





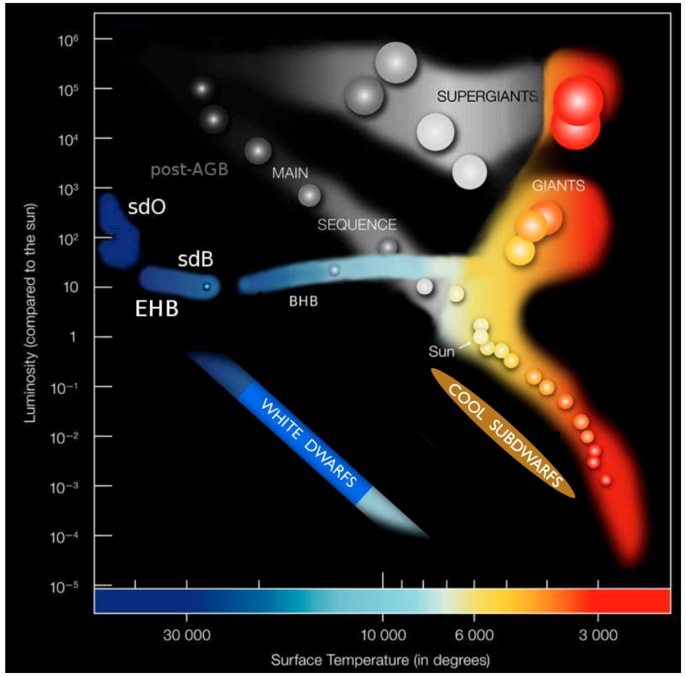
From Geier et al. (2015); A&A, 577, A26

Gaia DR3 – A new era in mapping the Milky Way

From: ESA/ATG medialab; background: ESO/S. Brunier

- The full astrometric solution — positions on the sky (α, δ), parallaxes, and proper motions — for around 1.46 billion (1.46 109) sources;
- G magnitudes for around 1.806 billion sources;
- G_{BP} and G_{RP} magnitudes for around 1.54 billion and 1.55 billion sources, respectively.

Gaia DR3 Colour Magnitude Diagram



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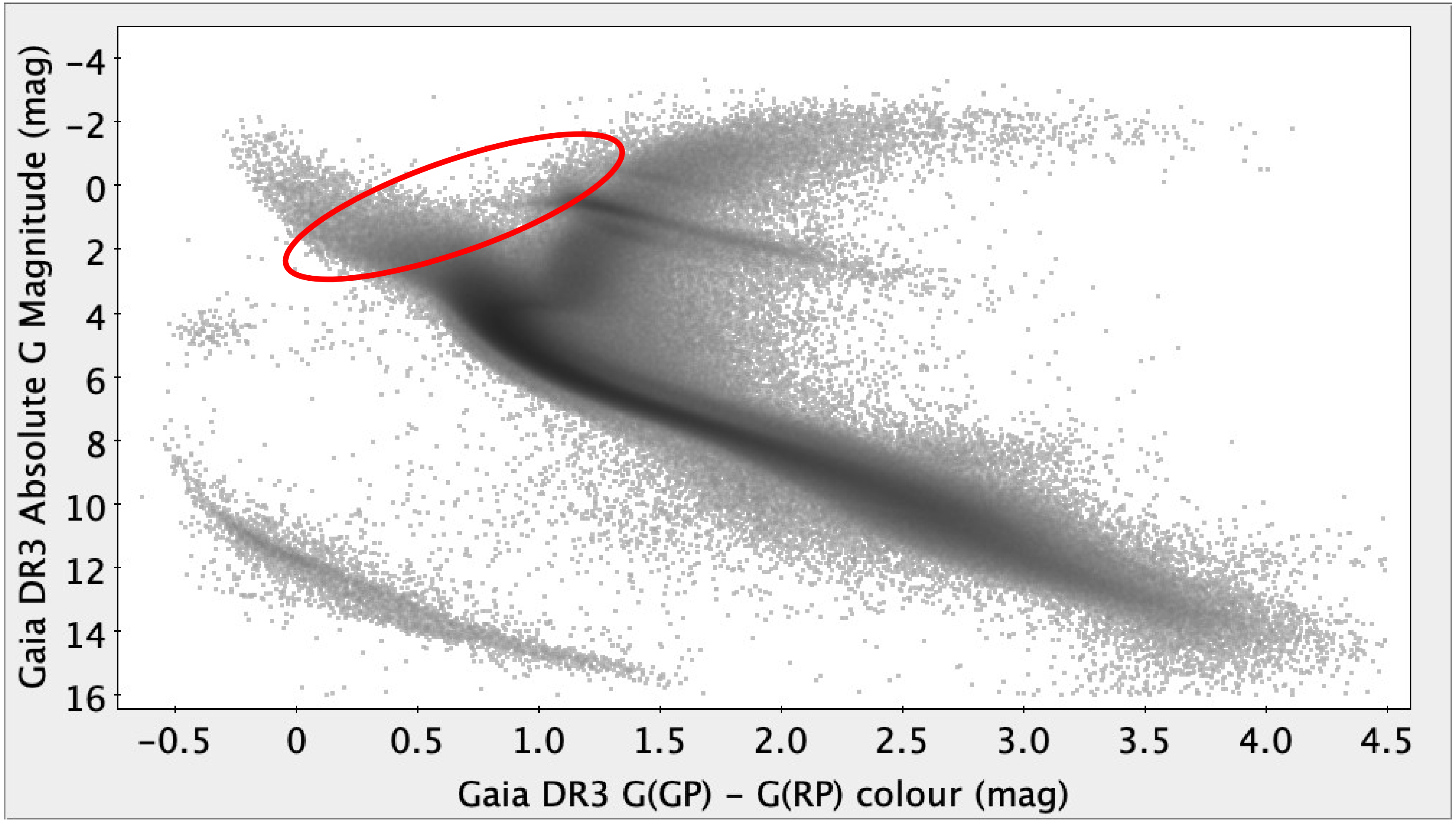
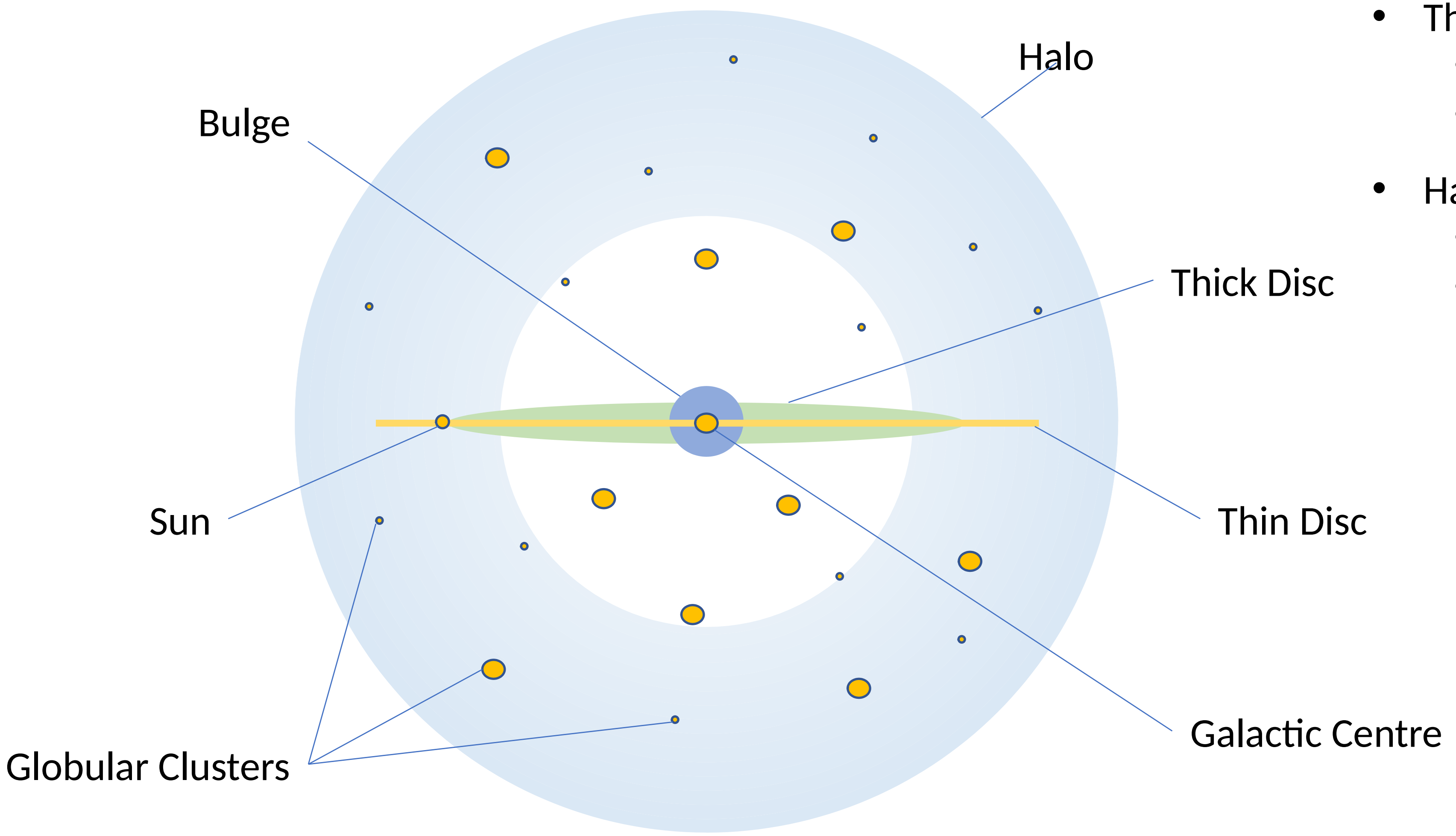
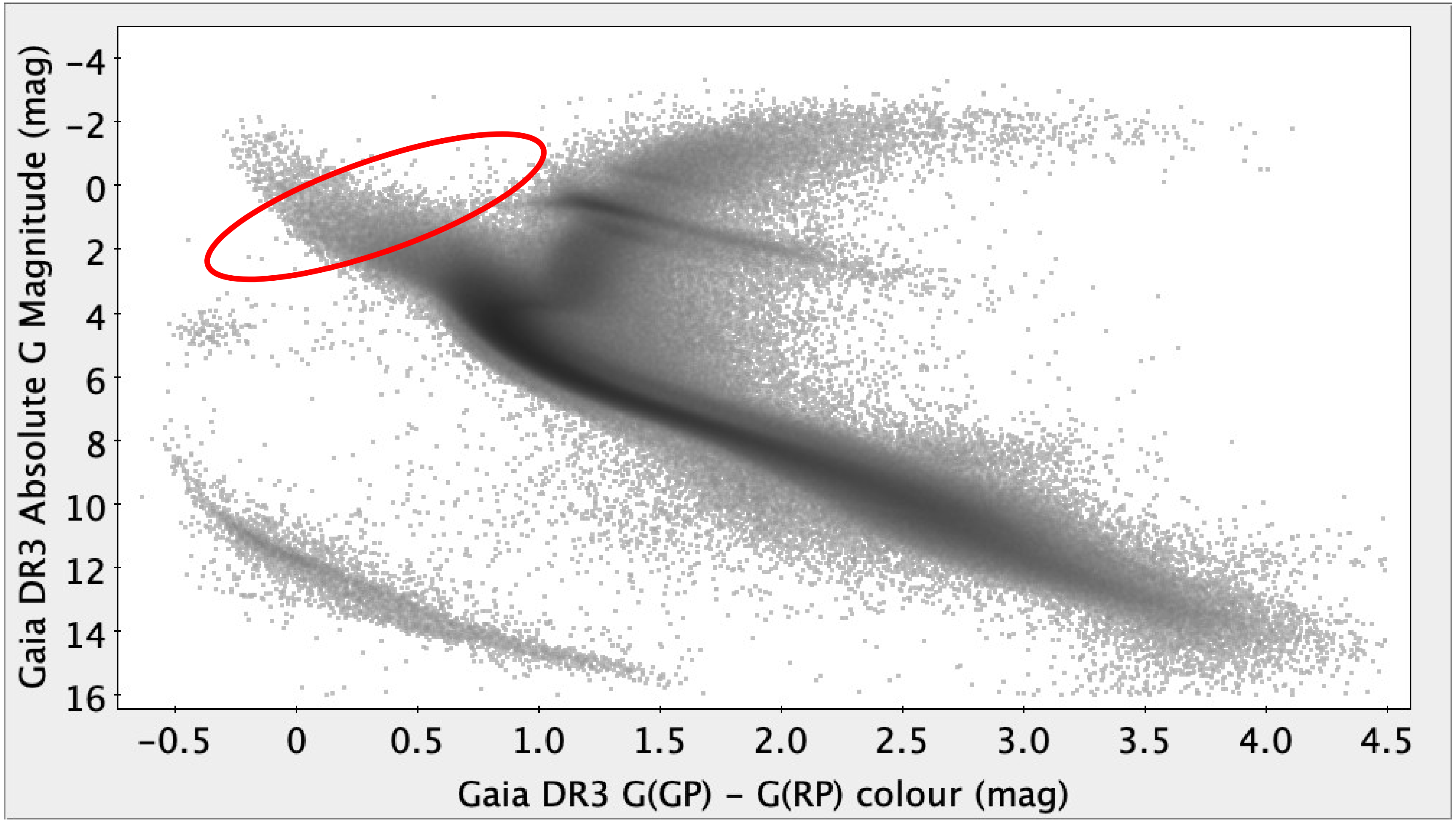


Galactic Structure and Properties

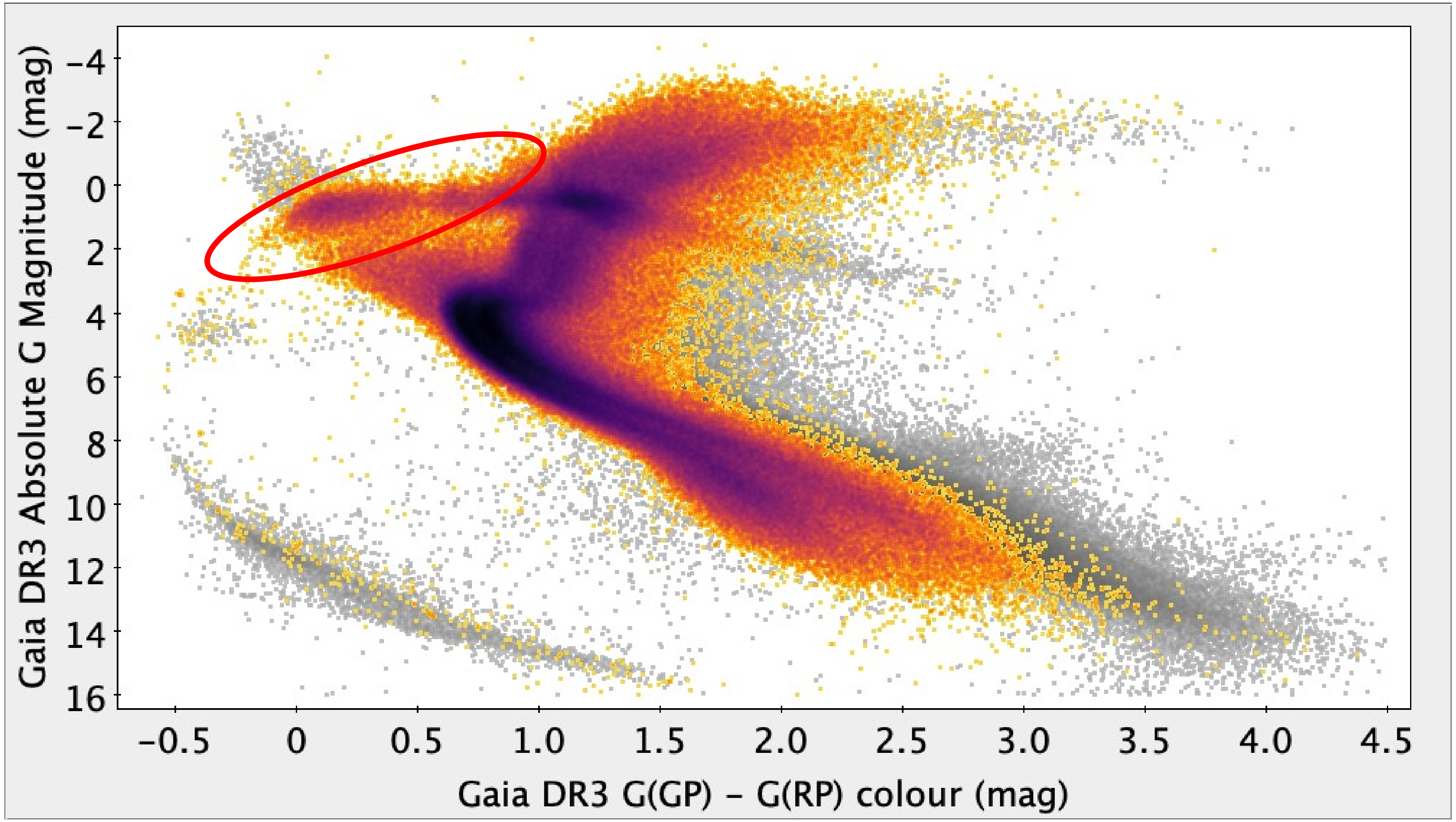


- Thin Disc:
  - Stellar age 1-10 billion years
  - High rotation rate
- Halo:
  - Stellar age 13 billion years
  - Low rotation rate

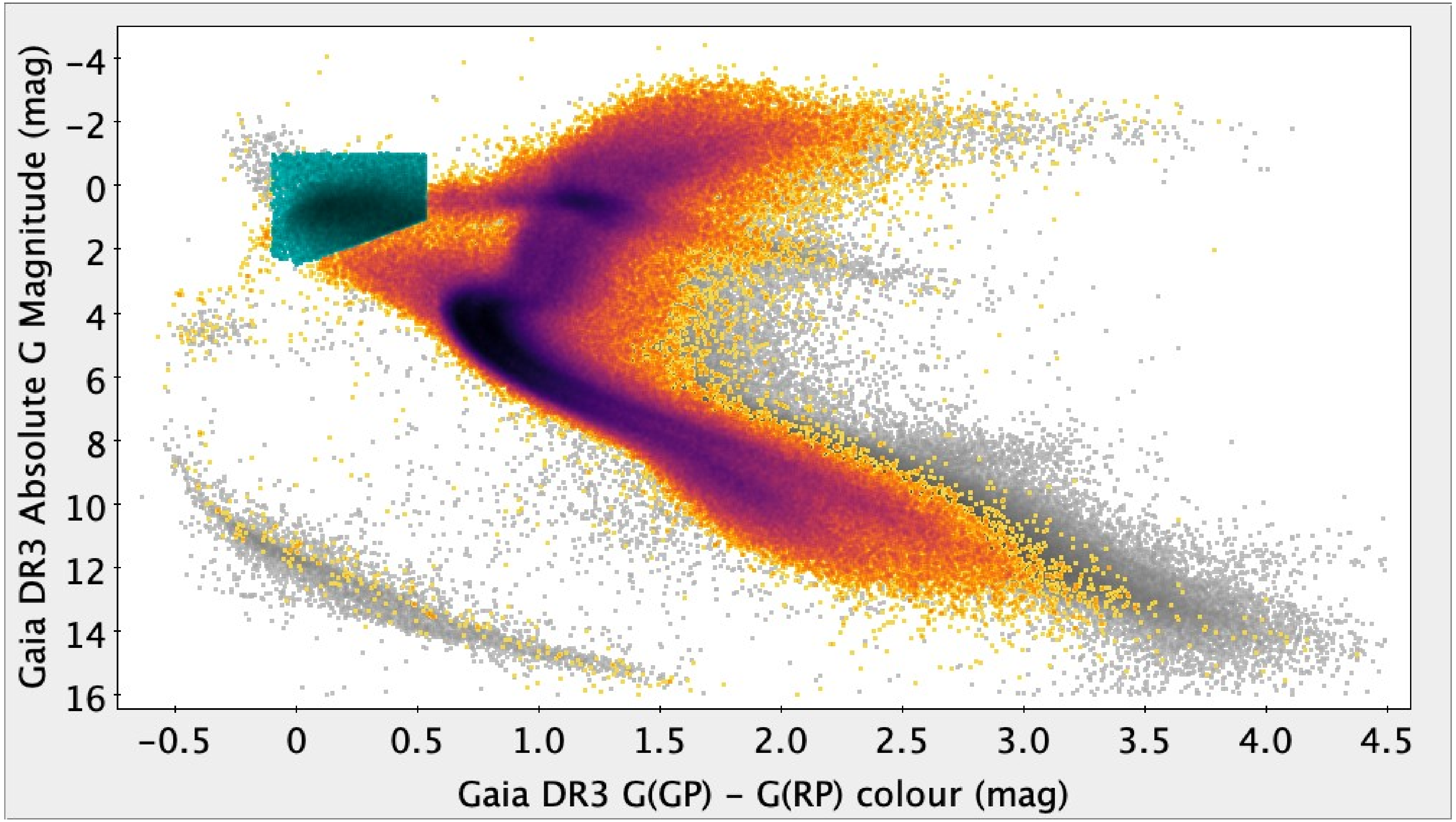
Gaia DR3 Colour Magnitude Diagram



Gaia DR3 CMD – High Radial Velocity



Gaia DR3 BHB Region Selection



Vt > 145; -0.1 < bp_rp < 0.53; -1 < abs_g_mag < -2.77 bp_rp + 2.5

Gaia DR3 – good but not perfect

- Gaia DR3 Outputs:
  - Parallax (mas)
  - Proper motion (mas/yr)
  - Apparent G magnitude (mag)
  - Colour (mag)

- Subsequent calculations:
  - Absolute G Magnitude from parallax and apparent magnitude
  - Tangential velocity from parallax and proper motion

Need to define quality criteria to ensure that our selection is valid

Gaia DR3 – Quality Criteria – 1 of 3

- Parallax:
  - Parallax > 0;
  - Parallax error < 20%

- Proper Motion:
  - Proper motion error < 20%

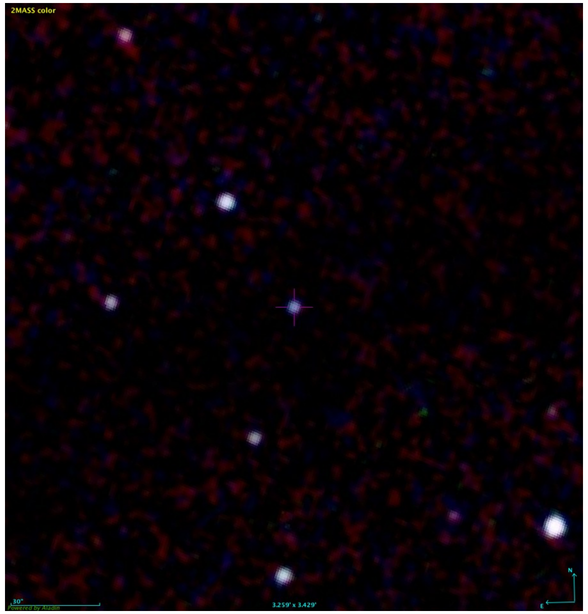
- Photometry:
  - Use the quality criteria derived in Riello et al. 2020
  - -0.6 < phot_bp_rp_excess_factor_corrected < 0.6

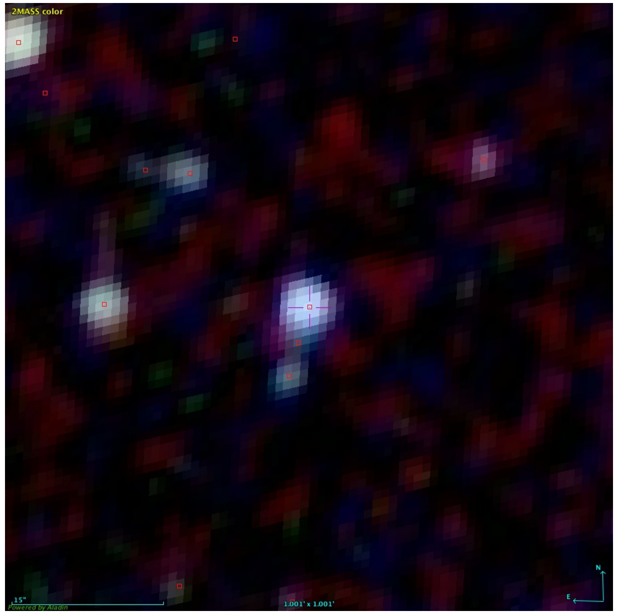
- Astrometry:
  - Use the quality criteria derived in Lindegren et al. 2021
  - astrometric_sigma_5d_max < 1.5

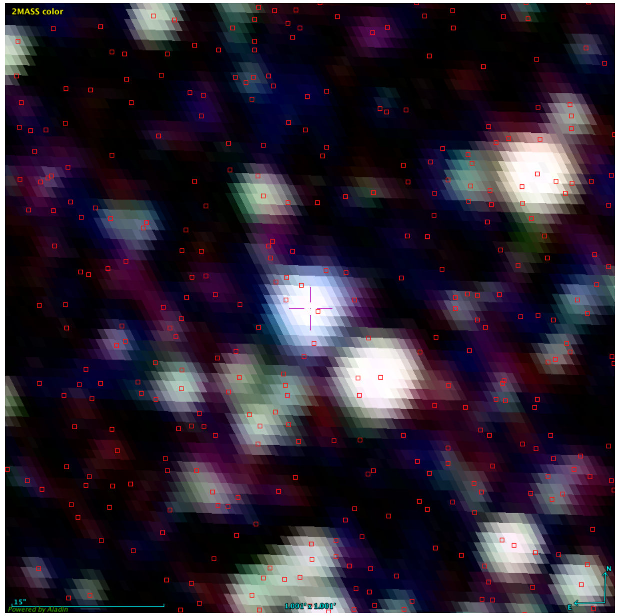
Gaia Early Data Release 3: The astrometric solution – Lindegren et al. A&A 649, A2 (2021);
Gaia Early Data Release 3: Photometric content and validation – Riello et al. A&A, 649, A3(2021)

Gaia DR3 – Quality Criteria – 2 of 3

The probability of adverse effects on Gaia’s astrometric and photometric measurements increases in crowded regions.



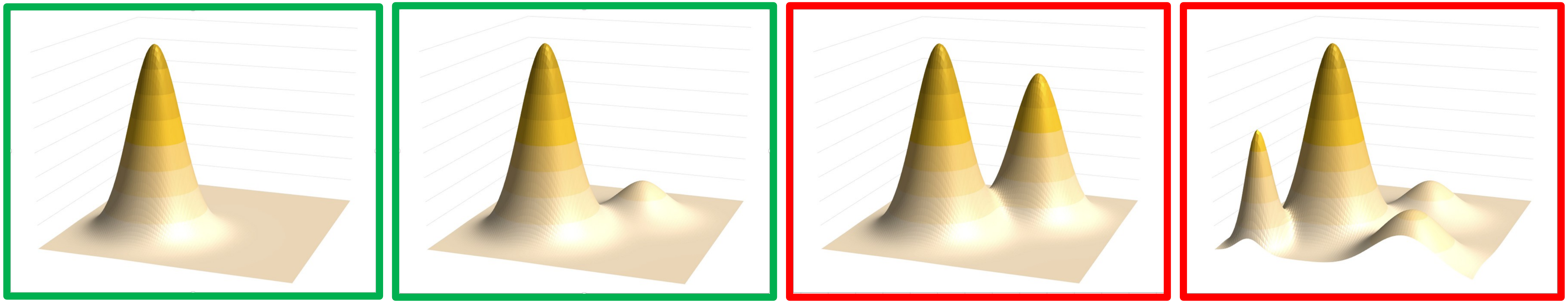




- Only use stars when one of the following conditions are met:
    - There are no apparent neighbours within 5 arcsec
    - At least 70% of the G-band flux from a5 arcsec radius region comes from the BHB candidate itself

Gaia DR3 – Quality Criteria – 3 of 3

The probability of adverse effects on Gaia’s astrometric and photometric measurements increases in crowded regions.



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Spectroscopy Project – BHB Binarity – 1 of 2

- Motivation:
  - Prove that BHB stars evolve from main-sequence stars without the need for stellar interactions with other external factors
- Method:
  - Acquire spectra for BHB candidates over several epochs to identify radial velocity variations caused by orbiting binary companions;
  - Compare the number of BHB binary systems to the population seen in main-sequence objects
- Task for the Spectroscopy groups
  - Create a list of BHB candidates that can be observed from Ondrejov this week by considering their apparent magnitude (how bright they are) and their position on the sky
  - Crossmatch your list with SIMBAD
  - Prioritise and order these candidates for observations on each night
  - Classify the BHB candidate star (SED and visual inspection)
  - Determine the radial velocity (line shifts)

Spectroscopy Project – BHB Binarity – 2 of 2

- Products / Results required
  - An observation plan coordinated between the groups
  - Consider and justify the compromise between acquiring spectra for as many objects as possible and acquiring multiple epoch spectra for individual objects. Don’t forget that some of these objects have had spectra acquired previously!
  - Do not assume that observations are possible all night every night – have contingency plans / prioritisations

Thank you!

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Backup Slides

BHB Balmer Line Width Vs Blue Stragglers and MS Stars

As stated in Xue et al. 2008:(arXiv:0801.1232)
The Milky Way's Circular Velocity Curve to 60 kpc and an Estimate of the Dark Matter Halo Mass from the Kinematics of ~2400 SDSS Blue Horizontal-Branch Stars

BHB stars have lower surface gravities than blue stragglers and higher temperatures than old, halo population main sequence stars.

Balmer line profile is sensitive to both surface gravity and temperature

Discriminate between BHB and BS by looking at $D_{0.2}$, the width of the Balmer line at 20% below the local continuum.

Distinguish between BHB and MS stars by using f_m, the flux relative to the the continuum at the line core

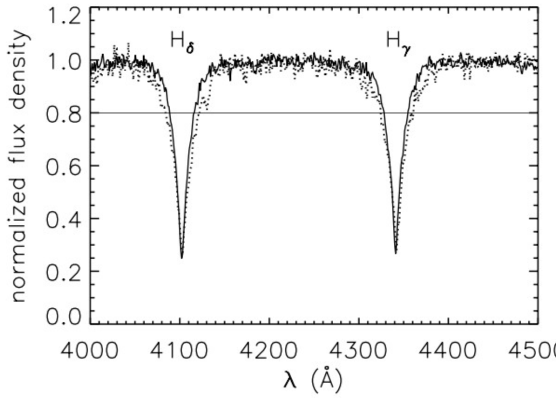

FIG. 3.—Normalized spectrum of a BHB star (*solid line*) and a BS star (*dotted line*) of similar effective temperatures in the Hγ–Hδ region. Although subtle, one can notice that the BS star's Balmer lines are wider at 20% below the local continuum than those of the BHB star. These effects arise due to the higher gravity of the BS star.

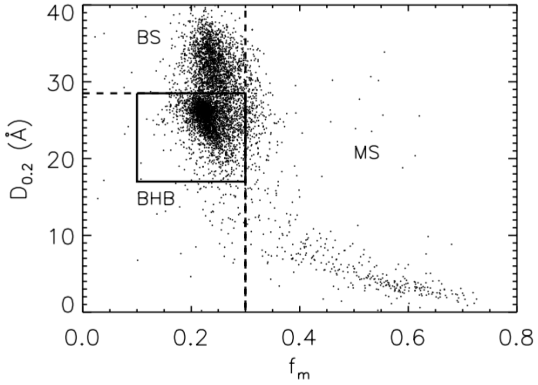

FIG. 4.—Parameters f_m and $D_{0.2}$, as determined from the Hδ line, for stars brighter than $g = 18$ and passing the color cuts shown in Fig. 1. The stars with $f_m \geq 0.30$ are too cool to be BHB stars, while the concentration of stars with $D_{0.2} \geq 28.5$ Å is due to BS stars with higher surface gravity. The stars that lie well outside the main locus are the result of poor parameter determinations due to missing spectroscopic data at the location of the Hδ line. The region enclosed by the box is used as the BHB selection criterion for the Hδ, $D_{0.2}$, and f_m method.