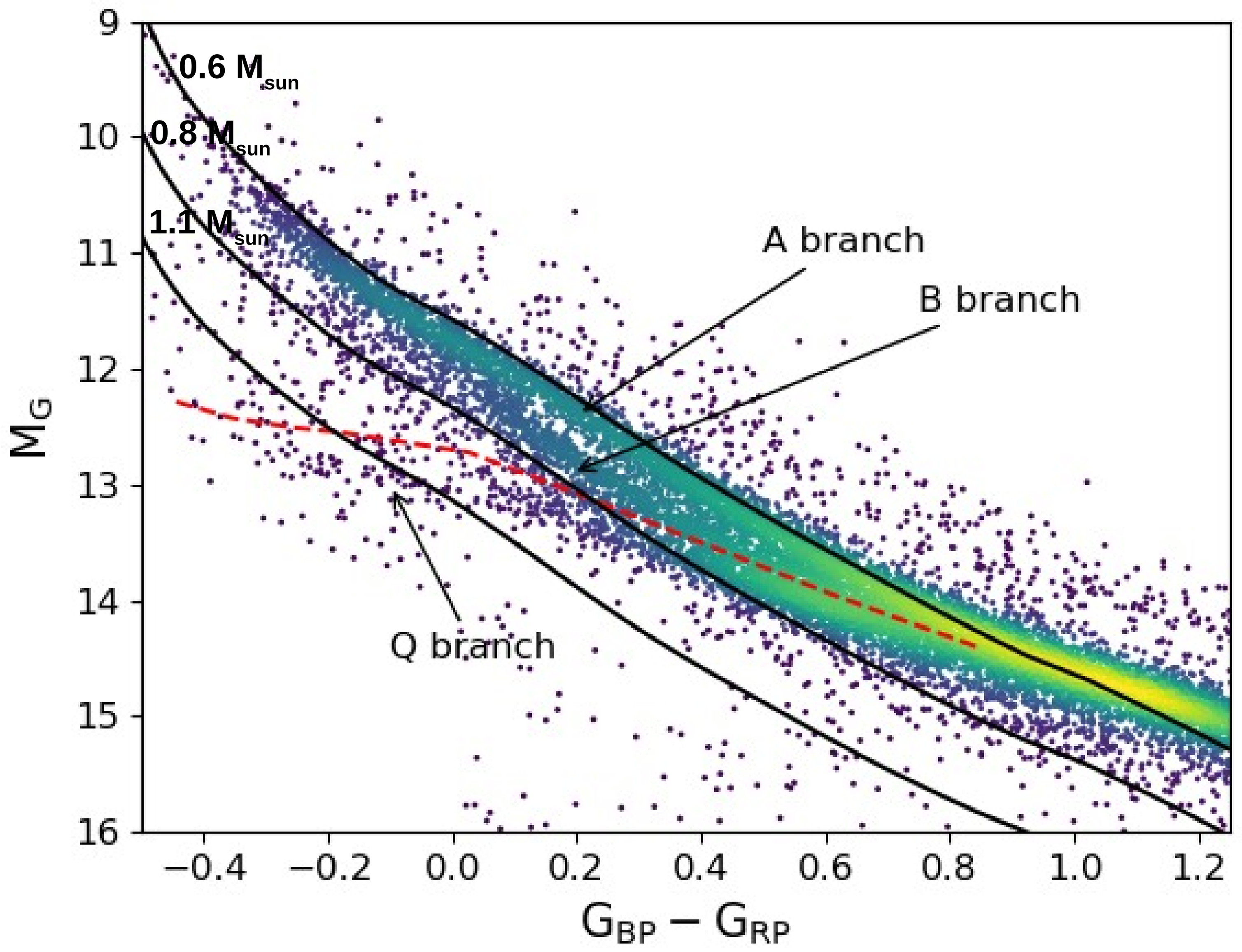
*contact:maria.camisassa@upc.edu

The *Gaia* color-magnitude diagram revealing the physics of white dwarfs

Camisassa M.E.[1] *, Torres, S. [1 2] , Rebassa-Mansergas A. [1 2], Raddi, R.[1]

[1] Departament de Física, Universitat Politècnica de Catalunya, c/Esteve Terrades 5, 08860 Castelldefels, Spain
[2] Institut d'Estudis Espacials de Catalunya (IEEC), c/Gran Capità 2-4, Edif. Nexus 2



The *Gaia* space mission has revealed that the **white dwarf cooling sequence** on the color magnitude diagram **is divided** in **3 branches: A, B, and Q** (1). These branches were not expected in a simple population.

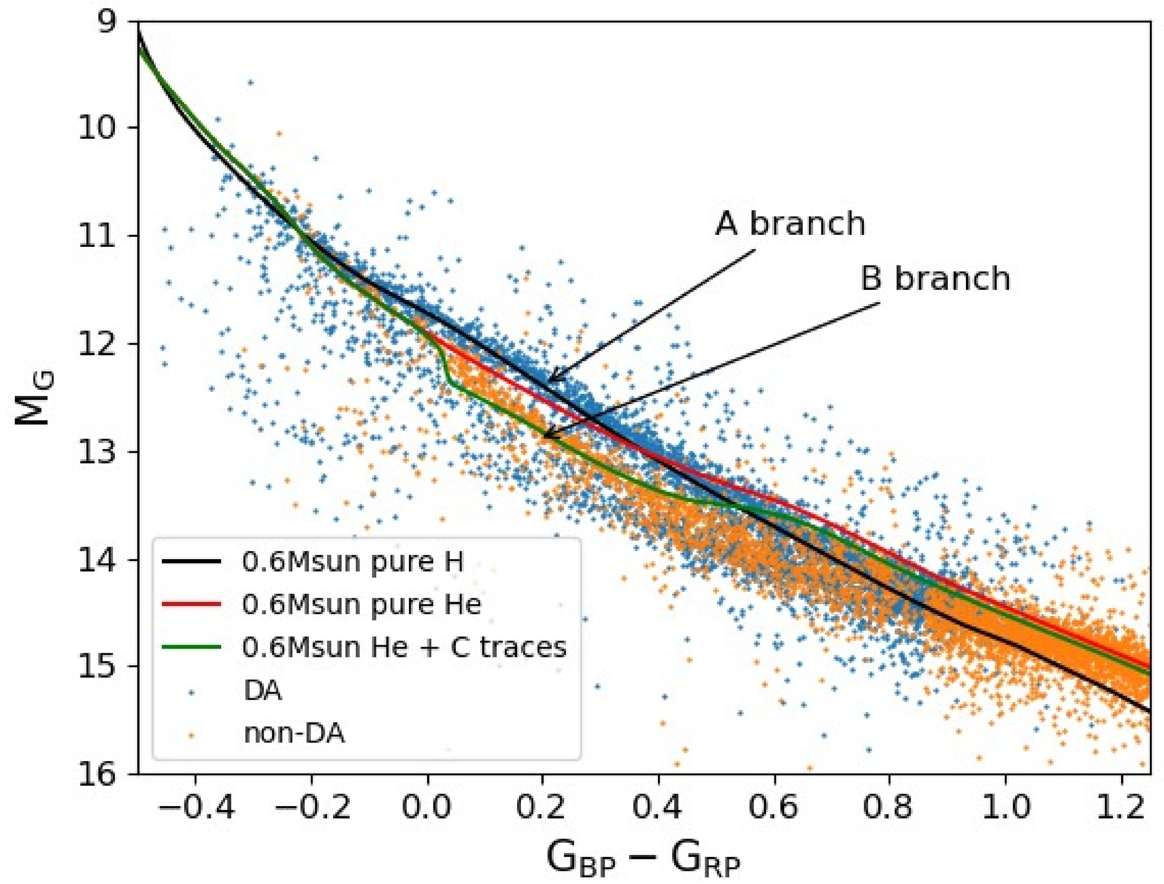
Q branch

The Q branch coincides with the region in the *Gaia* color-magnitude diagram where ^{12}C-^{16}O white dwarfs undergo **core-crystallization** (the dashed red line is indicating the crystallization onset).
During crystallization, energy is released as latent heat and due to phase separation, slowing down the white dwarf cooling rate and leading to the accumulation of white dwarfs on the Q branch. Although for massive white dwarfs (M_{WD}~0.9-1.1M_{sun}), the energy released by crystallization can reproduce the pile-up on the Q branch (2), for ultra-massive white dwarfs (M_{WD}>1.1M_{sun}) that is not the case. This phenomenon is called "**the cooling anomaly of ultra-massive white dwarfs**", and is reflected both in *Gaia* photometry and kinematics (3,4).

Possible solutions for this cooling anomaly:

- **^{22}Ne sedimentation** in ^{12}C-^{16}O white dwarfs with very high ^{22}Ne content can account for such delays (called forever young white dwarfs (3,5))
- **^{22}Ne distillation** process occurring during crystallization in ^{12}C-^{16}O white dwarfs with high ^{22}Ne content (6,7). No models in the literature include this process yet

A-B bifurcation



Based on spectral classification using *Gaia* spectra (8,9), the **A branch** is mainly populated with white dwarfs with **H-dominated atmospheres** (DA, blue dots) and the **B branch** by white dwarfs with **H-deficient atmospheres** (non-DA, orange dots). However, both the 0.6 M_{sun} pure-H-atmosphere (black line) and 0.6 M_{sun} pure-He-atmosphere (red line) evolutionary models overlap the A branch. The B branch coincides with a ~0.8 M_{sun} pure-He evolutionary model, which would imply an unexpected peak in the white dwarf mass distribution.
In cold white dwarfs with He-dominated atmospheres, it is expected that the outer convective zone penetrates into deep carbon-rich layers, leading to a slight carbon contamination in their surfaces at ~ 10,000 K (10). The 0.6 M_{sun} **He-rich white dwarf models that include carbon traces below the detection limit for optical spectroscopy (green line) can accurately reproduce the B branch** (11, 12). Therefore, the B branch is evincing carbon dredge-up by convection in cold He-rich white dwarfs

References

(1) Gaia Collaboration et al. 2018, A&A, 616, A1
(2) Tremblay et al. 2019, Nature, 565, 202
(3) Camisassa et al. 2021, A&A L, 649, L7
(4) Cheng et al. 2019, ApJ, 886, 100
(5) Camisassa et al. 2022, MNRAS, 511, 4
(6) Segretain 1996 A&A v.310, 485-488.
(7) Blouin et al. 2021, ApJL, 911, id.L5
(8) Jímenez- Esteban et al. 2023, MNRAS 518, Issue 4
(9) García-Zamora et al. 2023, A&A, in press
(10) Camisassa et al. 2017, ApJ, 839, 11
(11) Camisassa et al. 2023, A&A, 674, id.A213
(12) Blouin et al. 2023, MNRAS, 523, 3