EXPANDING THE GAIA LEGACY
THE ROLE OF SPANISH GROUND-BASED FACILITIES
A celebration of the research career of Jordi Torra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

The white dwarf population in the Gaia DR2 era

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1. Introduction

2. White dwarfs in the Gaia era

3. Work in progress

4. Conclusions

1. Introduction

- White dwarfs are the most common fossil stars within the stellar graveyard.
- More than 90% of all main sequence stars will finish their lives as white dwarfs.
- Supported by electron degeneracy, white dwarfs cool down for very long periods of time, allowing us to look back at early times.
- Their structural and evolutionary properties are now reasonably well understood.(Review: Althaus et al. 2010)

1. Introduction

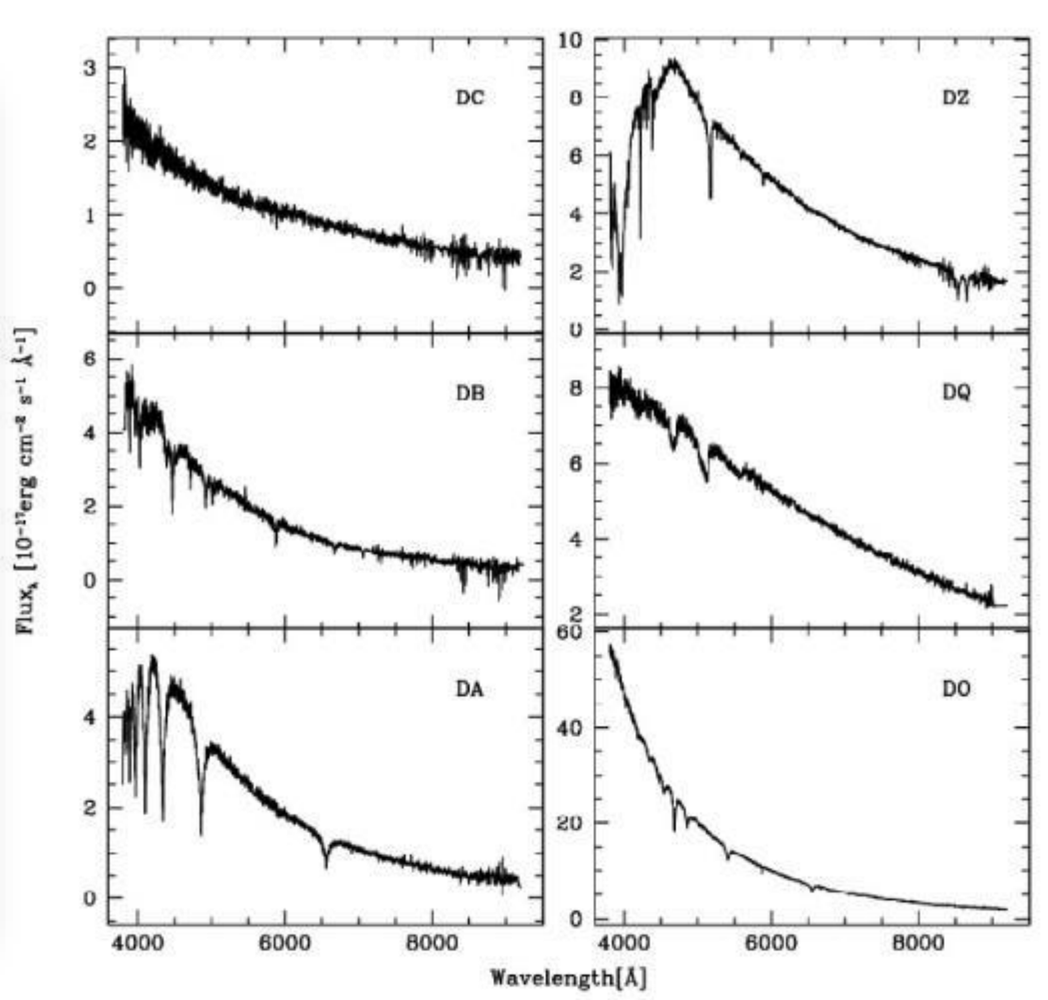
White dwarf datasheet

Mass-core	$0.2<M_{WD}<0.45\ M_0$ => He $0.45<M_{WD}<1.1\ M_0$ => CO $1.1<M_{WD}<1.4\ M_0$=> ONe
Typical mass	$0.6\ M_0$
Radius	R_{Earth}
Density	1×10^9 g/cm^3
Temperature	100,000 K-2,000 K
Luminosity	Log(L/L_0)~2 to -5
Atmosphere	Hydrogen rich (DA) (80%) Helium rich (DB) (20%)
Cooling age	Myr-13 Gyr

1. Introduction

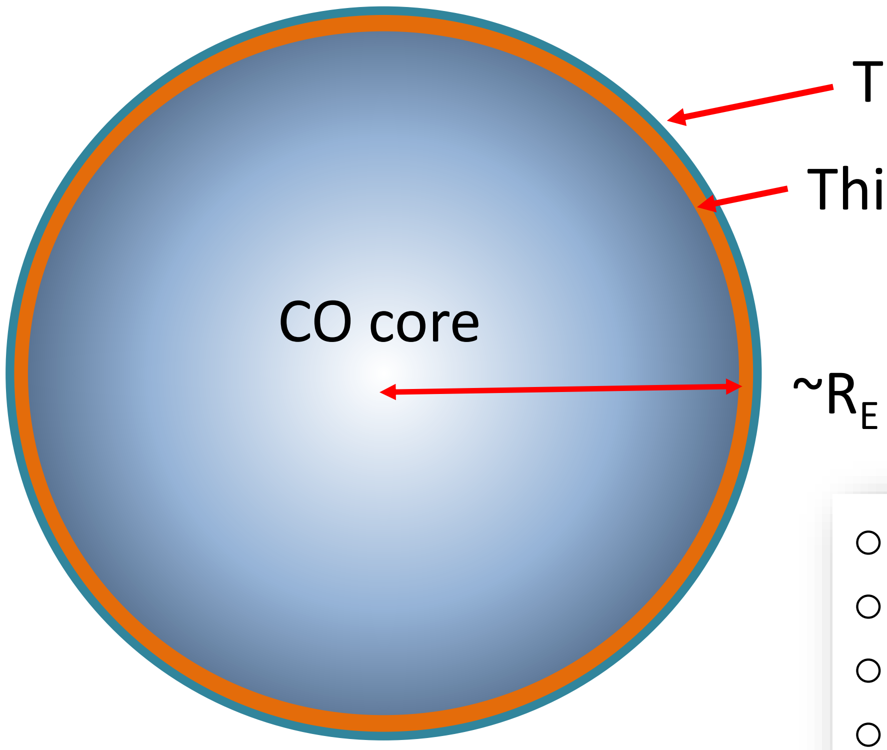
Spectral Type classification

- DA: only Balmer lines
- DB: He I lines, no H or metal present
- It is an observational classification: for T_{eff}<6,000 K all spectra become DC
- In general: 80% DA+20% non-DA



1. Introduction

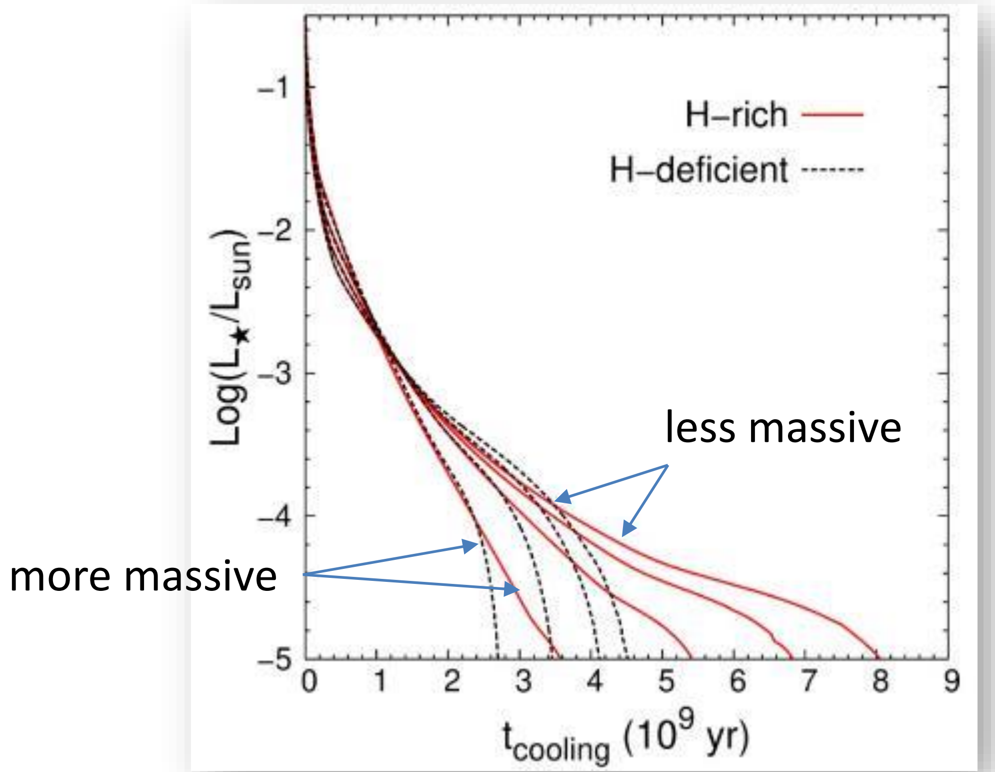
A typical 0.6 M_0 white dwarf



- 0.6 M_o
- 99% Carbon/Oxygen
- 1% Helium
- 0.01 Hydrogen

1. Introduction

The cooling process



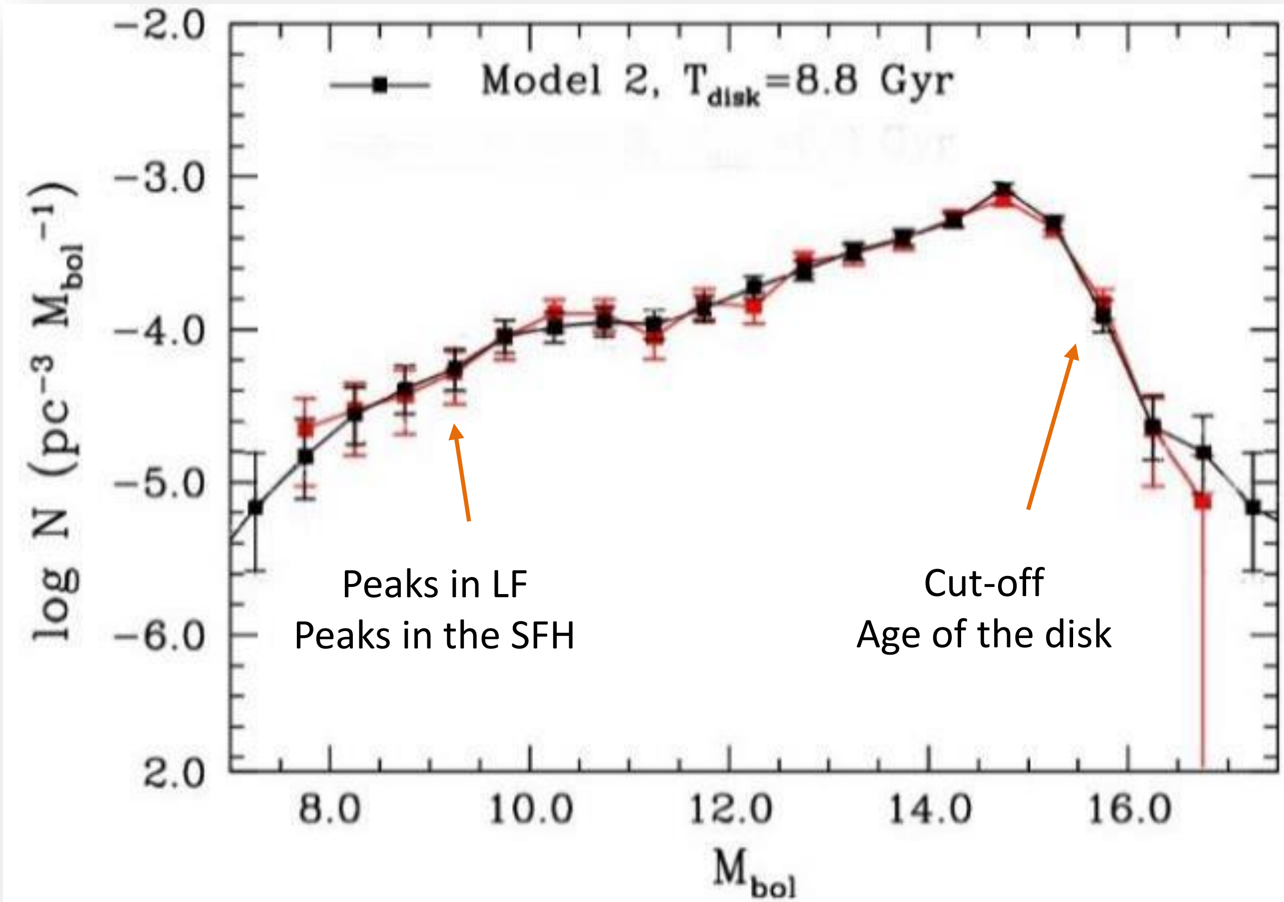
$$T_{total}=T_{pre\text{-}wd}+T_{cooling}$$

1. Introduction

- The Galactic population of white dwarfs carries essential information about several fundamental issues.

- The white dwarf luminosity function (García-Berro & Oswalt 2016) provides us with:
  - The age of the Galaxy.
  - The star formation history.
  - The structure and evolution of the Galaxy:
    - Thin and thick disks.
    - The galactic spheroid.
    - The system of open and globular clusters.

1. Introduction



Observed WDLF: Limoges et al. (2015)

Simulated WDLF: Torres & García-Berro (2016)

1. Introduction

- White dwarfs are also important to:
  - Constrain non-standard theories of gravitation.
  - Can be used as astroparticle physics laboratories.
  - Supernova Type Ia models
  - Evaluate the dark matter content of the Galaxy.
- To undertake these tasks two conditions must be fulfilled:
  - Complete observational samples.
  - Accurate cooling sequences.
  - Reliable population synthesis models

1. Introduction

- White dwarfs are reliable **cosmic chronometers.**

  - However, white dwarfs have two major drawbacks, due to
    LARGE SURFACE GRAVITY ACTING IN WD ATMOSPHERES

1. **Radial velocities**: broadening of Balmer's spectral lines, thus generally impeding accurate radial velocity determinations.
   1. SPY project: Pauli et al (2009) ~400 DAs
   2. SLOAN DR12: Anguiano et al. (2016) ~20,000 DAs

2. **Metallicities:** the metal content on these atmospheres sinks well below the deep interior of these stars.
   1. Known parent population: e.g. open/globular clusters
   2. Binary systems, MS+WD: Rebassa et al. (2016)

1. Introduction

2. White dwarfs in the Gaia era

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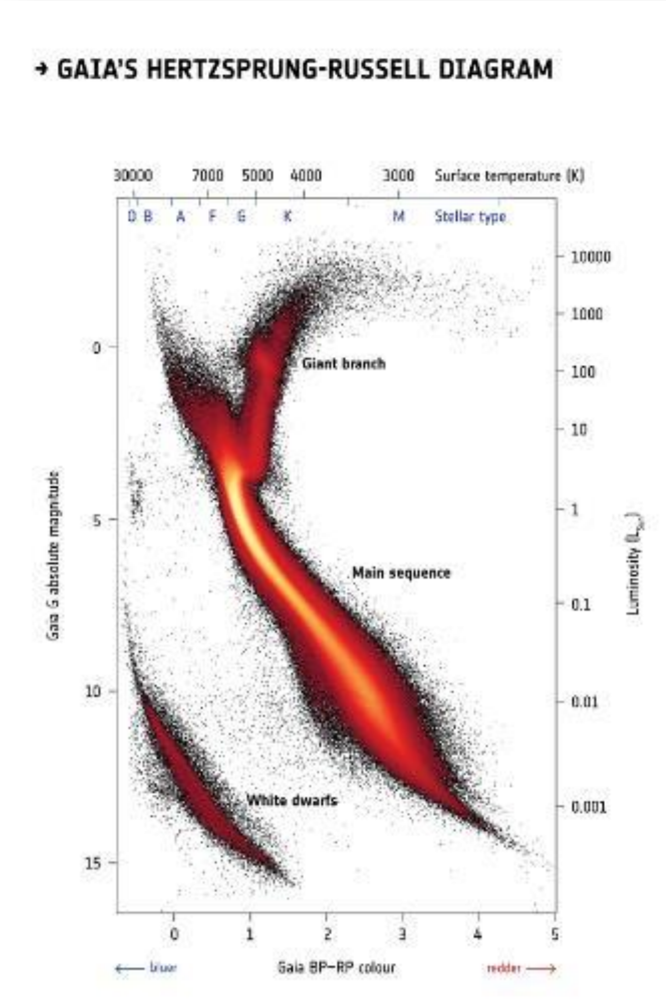
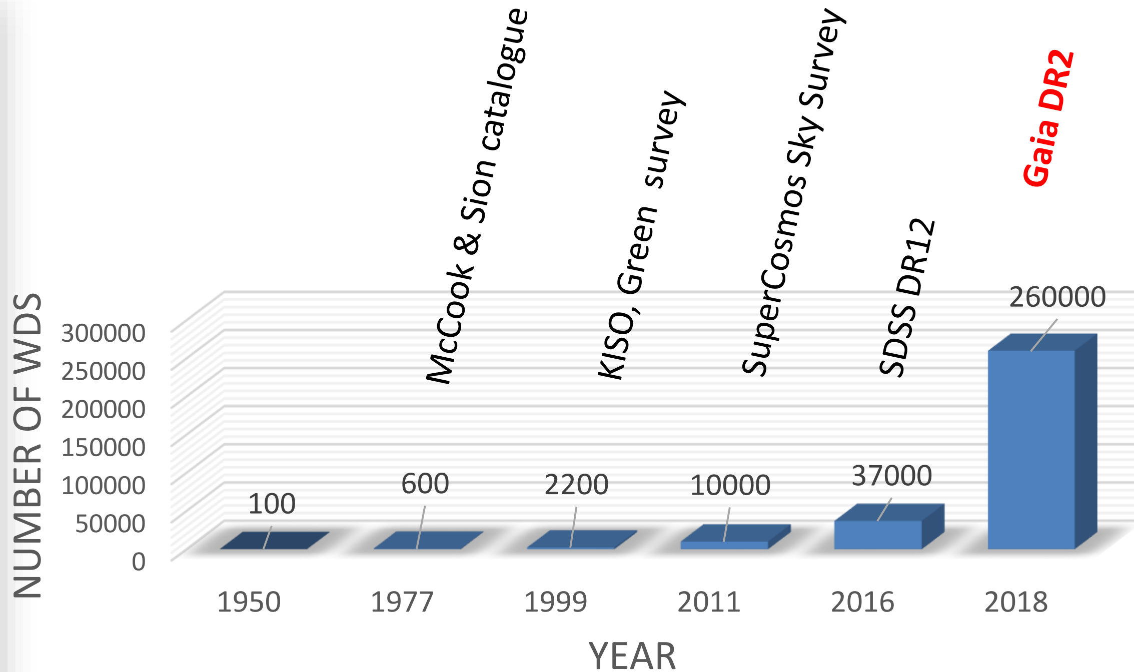
2. White dwarfs in the Gaia era





2. White dwarfs in the Gaia era

- *Gaia* expected numbers: nearly 400 000 WDs up to 400 pc. Torres et al. (2005)

- Up to now, founded in Gaia DR2: 260,000 WDs (Fusillo et al. 2019)

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A *Gaia* Data Release 2 catalogue of white dwarfs and a comparison with SDSS

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ABSTRACT

We present a catalogue of white dwarf candidates selected from the second data release of *Gaia* (DR2). We used a sample of spectroscopically confirmed white dwarfs from the Sloan Digital Sky Survey (SDSS) to map the entire space spanned by these objects in the *Gaia* Hertzsprung–Russell diagram. We then defined a set of cuts in absolute magnitude, colour, and a number of *Gaia* quality flags to remove the majority of contaminating objects. Finally, we adopt a method analogous to the one presented in our earlier SDSS photometric catalogues to calculate a probability of being a white dwarf (P_{WD}) for all *Gaia* sources that passed the initial selection. The final catalogue is composed of 486 641 stars with calculated P_{WD} from which it is possible to select a sample of $\simeq$260 000 high-confidence white dwarf candidates in the magnitude range $8 < G < 21$. By comparing this catalogue with a sample of SDSS white dwarf candidates, we estimate an upper limit in completeness of 85 per cent for white dwarfs with $G \leq 20$ mag and $T_{eff} > 7000$ K, at high Galactic latitudes ($|b| > 20°$). However, the completeness drops at low Galactic latitudes, and the magnitude limit of the catalogue varies significantly across the sky as a function of *Gaia*'s scanning law. We also provide the list of objects within our sample with available SDSS spectroscopy. We use this spectroscopic sample to characterize the observed structure of the white dwarf distribution in the H–R diagram.

Key words: catalogues – surveys – white dwarfs.

2. White dwarfs in the Gaia era

- The most complete volume-limited sample to date
- WD spatial density of $(4.9 \pm 0.4) \times 10^{-3}$ pc^{-3}
- Very low (< 1%) contamination (sdBs & CVs)
- 8,343 CO-core and 211 ONe-core within 100 pc with defined parameters
- Available online **The SVO (Spanish Virtual Observatory) archive of White Dwarfs from Gaia**: svo2.cab.inta-csic.es/vocats/v2/wdw/index.php

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A white dwarf catalogue from *Gaia*-DR2 and the Virtual Observatory

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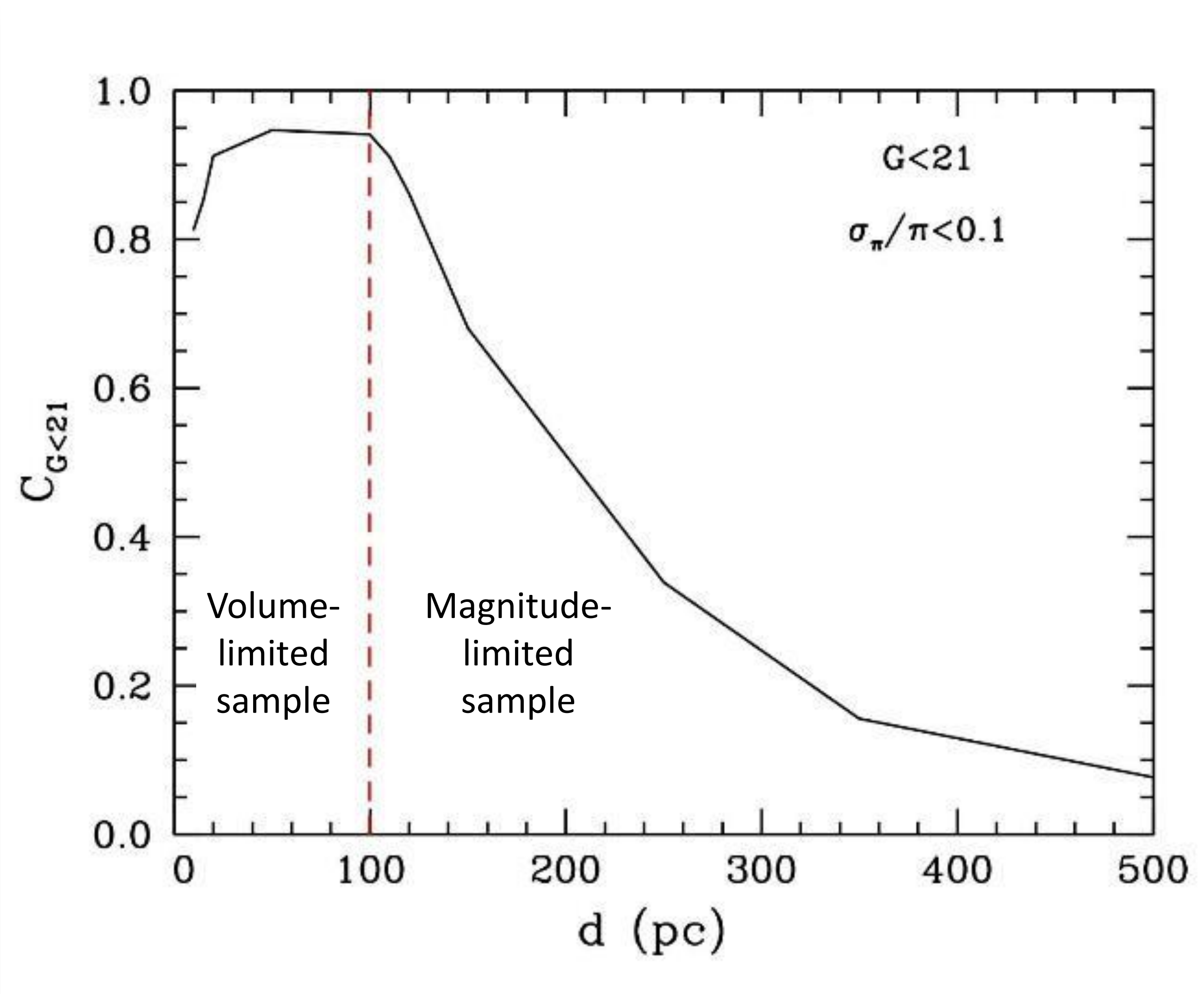
ABSTRACT

We present a catalogue of 73 221 white dwarf candidates extracted from the astrometric and photometric data of the recently published *Gaia*-DR2 catalogue. White dwarfs were selected from the *Gaia* Hertzsprung–Russell diagram with the aid of the most updated population synthesis simulator. Our analysis shows that *Gaia* has virtually identified all white dwarfs within 100 pc from the Sun. Hence, our sub-population of 8555 white dwarfs within this distance limit and the colour range considered, $-0.52 < (G_{BP} - G_{RP}) < 0.80$, is the largest and most complete volume-limited sample of such objects to date. From this sub-sample, we identified 8343 CO-core and 212 ONe-core white dwarf candidates and derived a white dwarf space density of $4.9 \pm 0.4 \times 10^{-3}$ pc^{-3}. A bifurcation in the Hertzsprung–Russell diagram for these sources, which our models do not predict, is clearly visible. We used the Virtual Observatory SED Analyzer tool to derive effective temperatures and luminosities for our sources by fitting their spectral energy distributions, that we built from the ultraviolet to the near-infrared using publicly available photometry through the Virtual Observatory. From these parameters, we derived the white dwarf radii. Interpolating the radii and effective temperatures in hydrogen-rich white dwarf cooling sequences, we derived the surface gravities and masses. The *Gaia* 100 pc white dwarf population is clearly dominated by cool (~8000 K) objects and reveals a significant population of massive ($M \sim 0.8\,M_\odot$) white dwarfs, of which no more than ~30–40 per cent can be attributed to hydrogen-deficient atmospheres, and whose origin remains uncertain.

2. White dwarfs in the Gaia era



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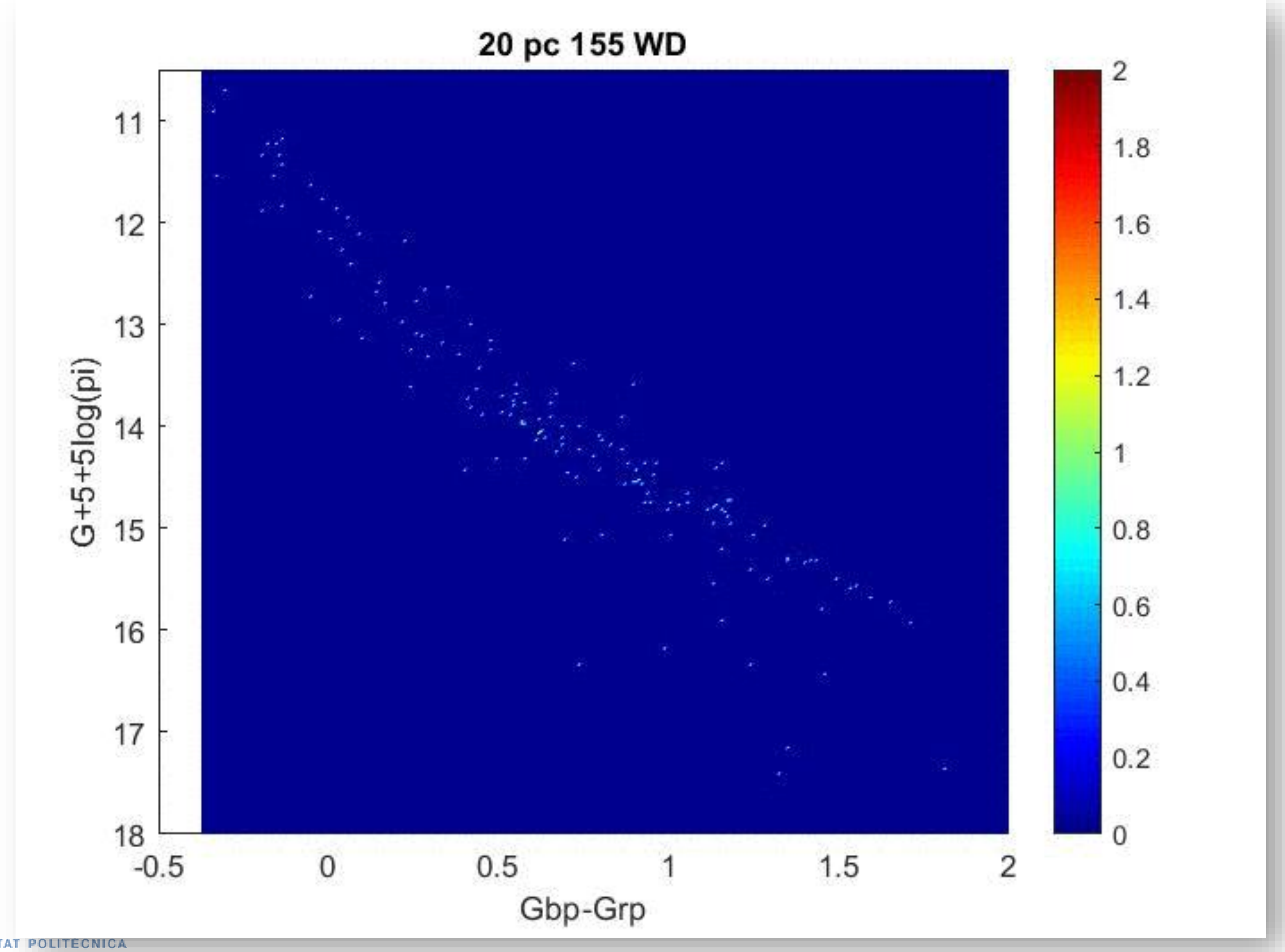
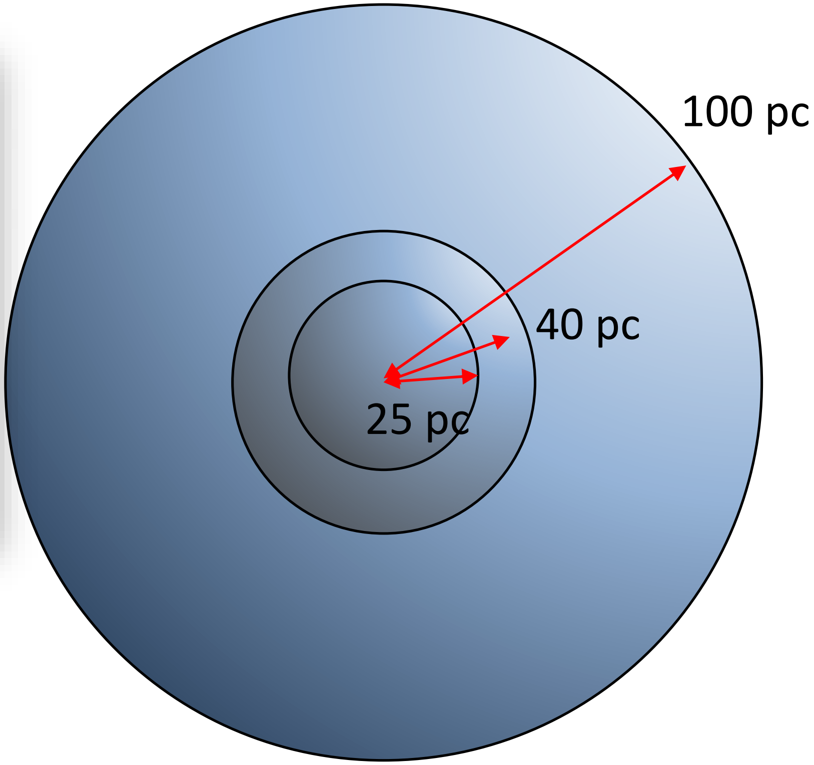
2. White dwarfs in the Gaia era



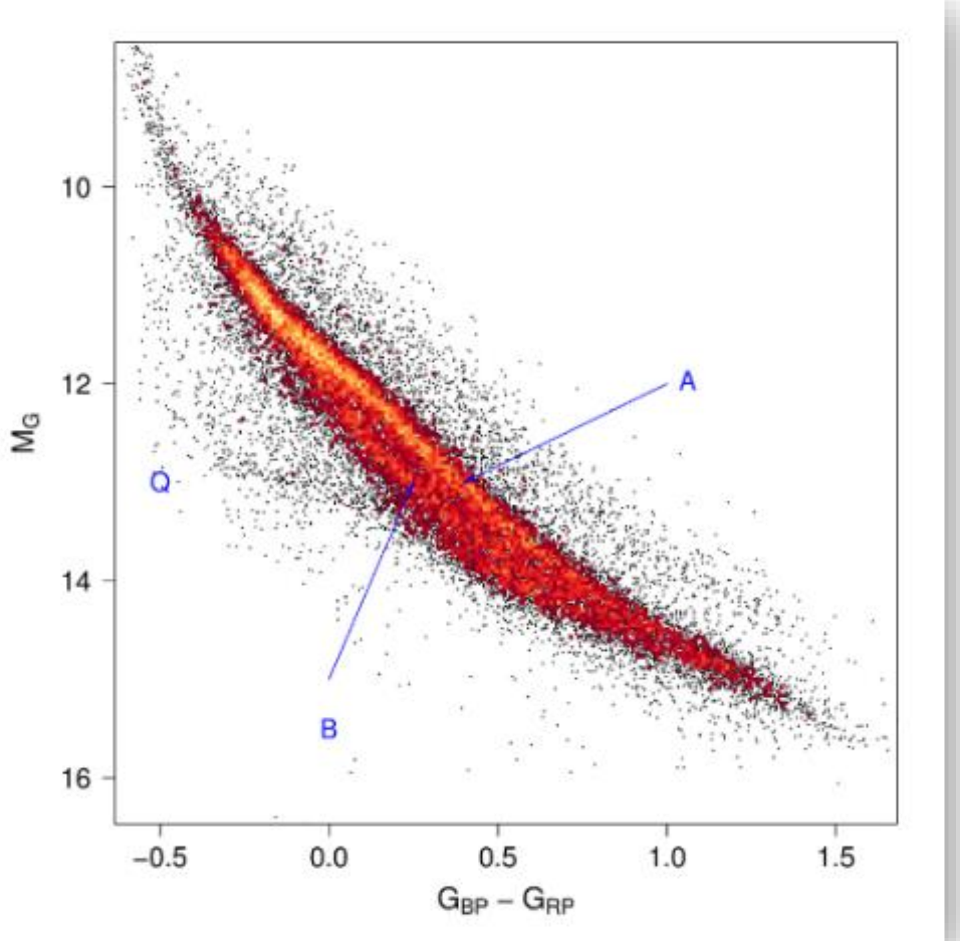
Completeness of the sample

	Year	Size	# WDs
Holberg et al.	2008	20 pc	129
Limoges et al.	2015	40 pc (NH)	~600
Oswalt et al.	2016	25 pc	232
Jiménez-Esteban et al.	2018	100 pc	~14,000



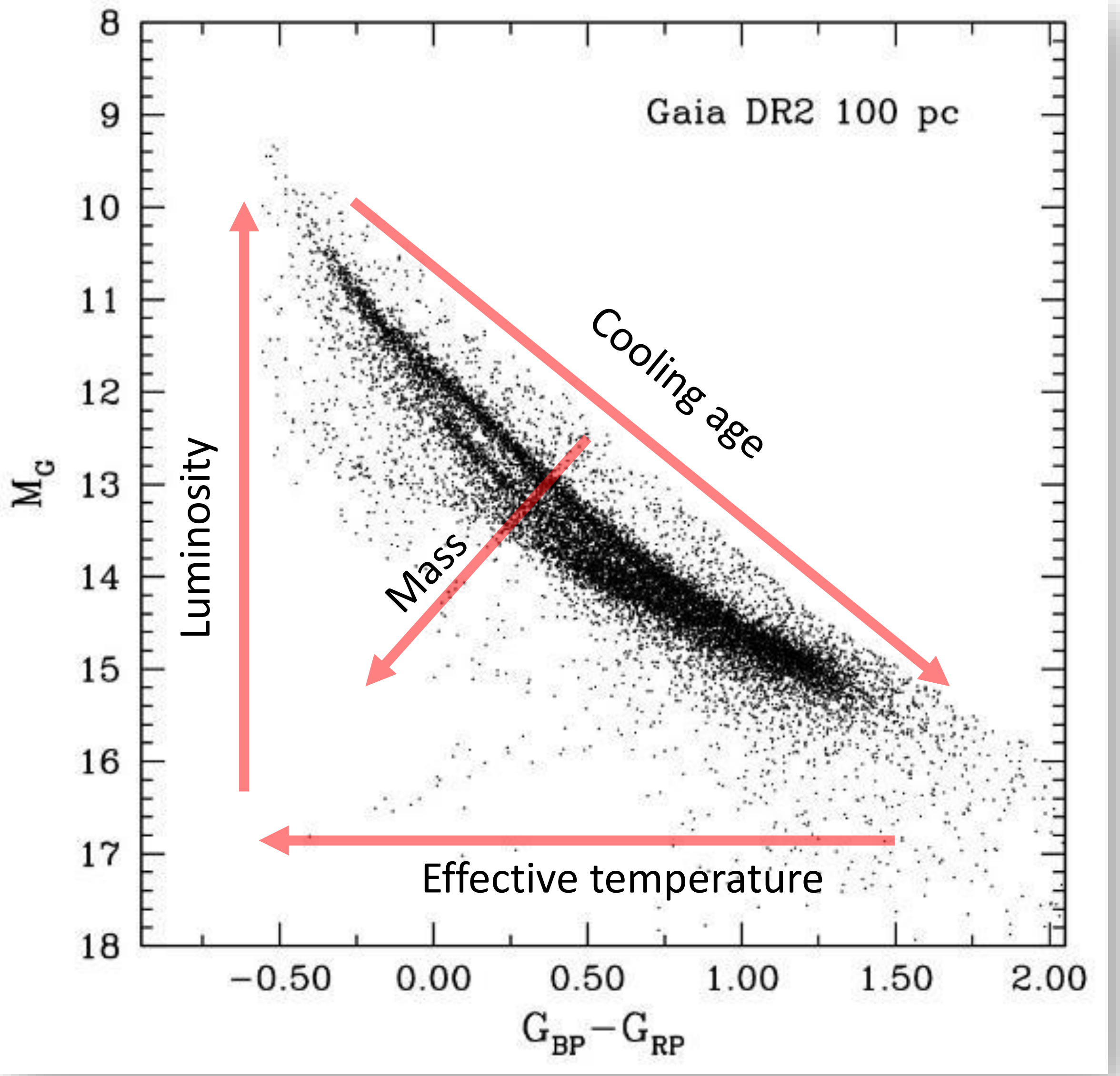
2. White dwarfs in the Gaia era

HR-diagram for 100 pc Gaia DR2 sample



- A & B bifurcation
  - DA/DB tracks?
  - Mergers?
  - SFR?
- Q: q-branch
  - Crystallization: May be but too thin

2. White dwarfs in the Gaia era



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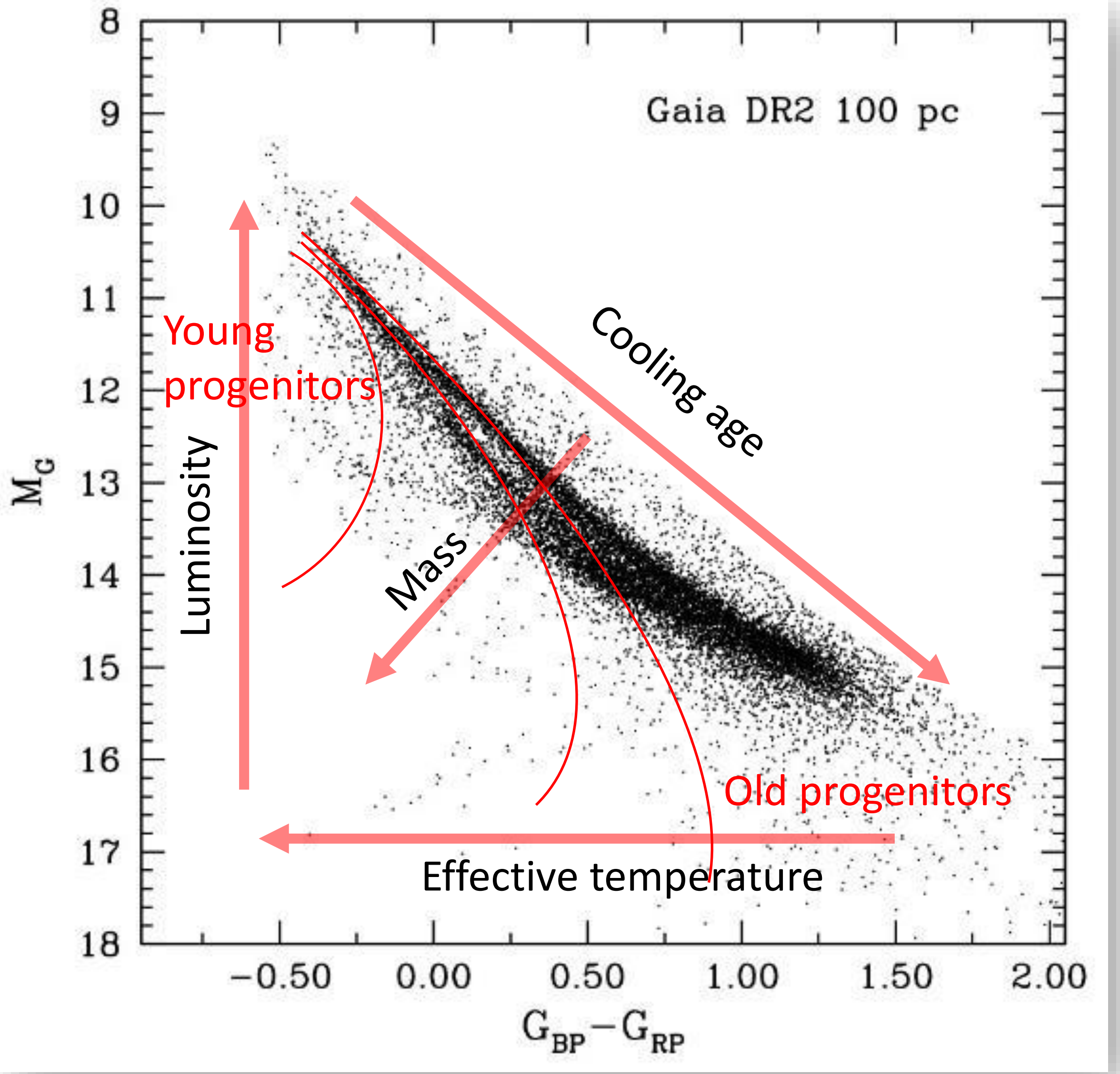
2. White dwarfs in the Gaia era



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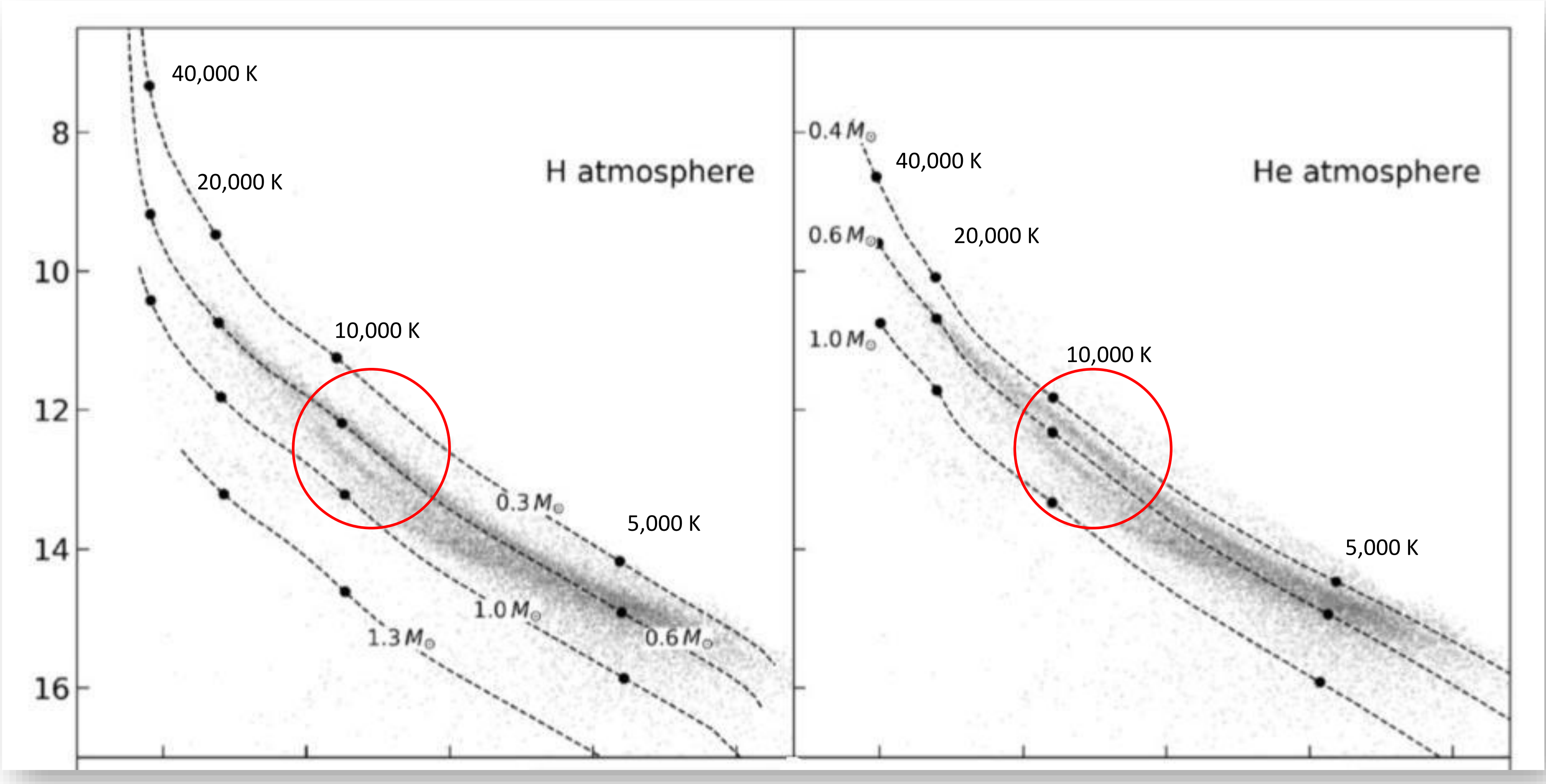

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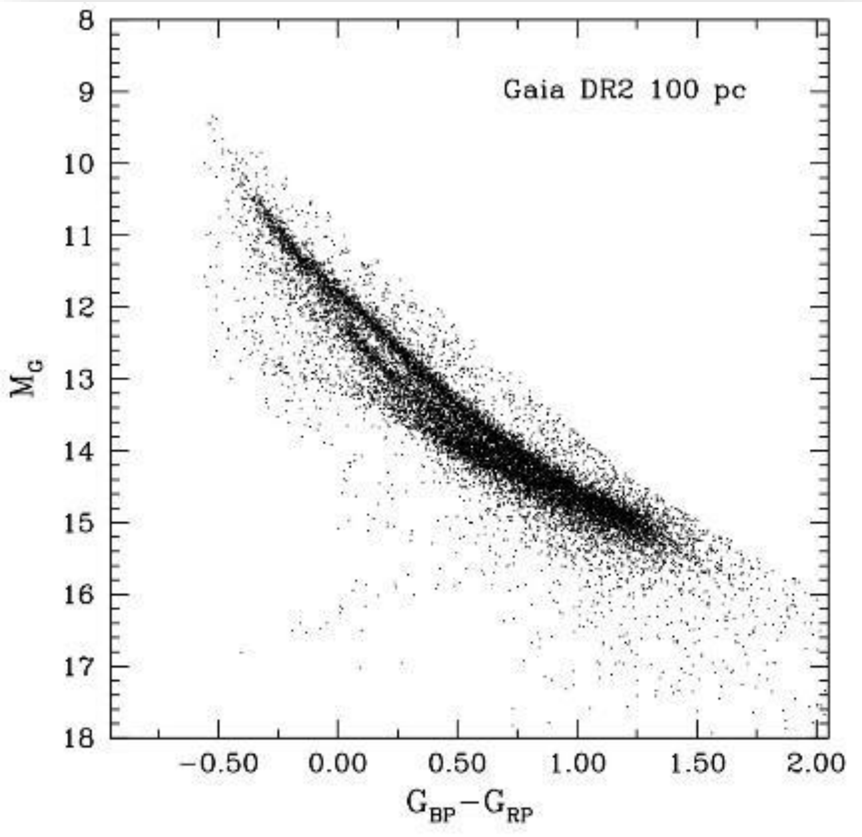

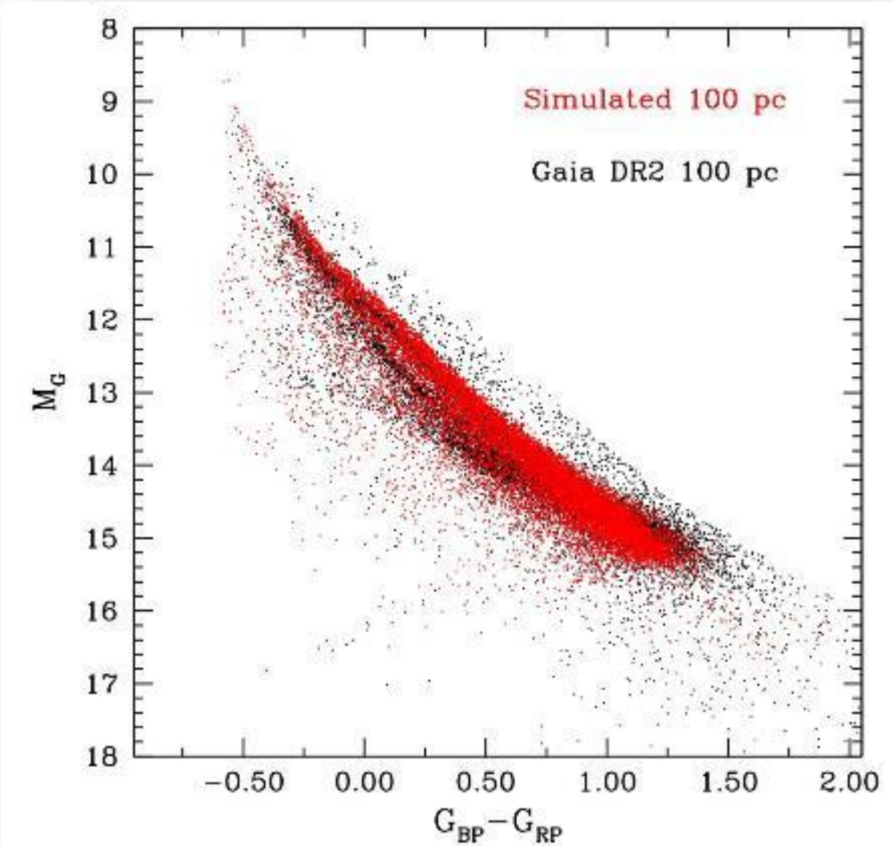

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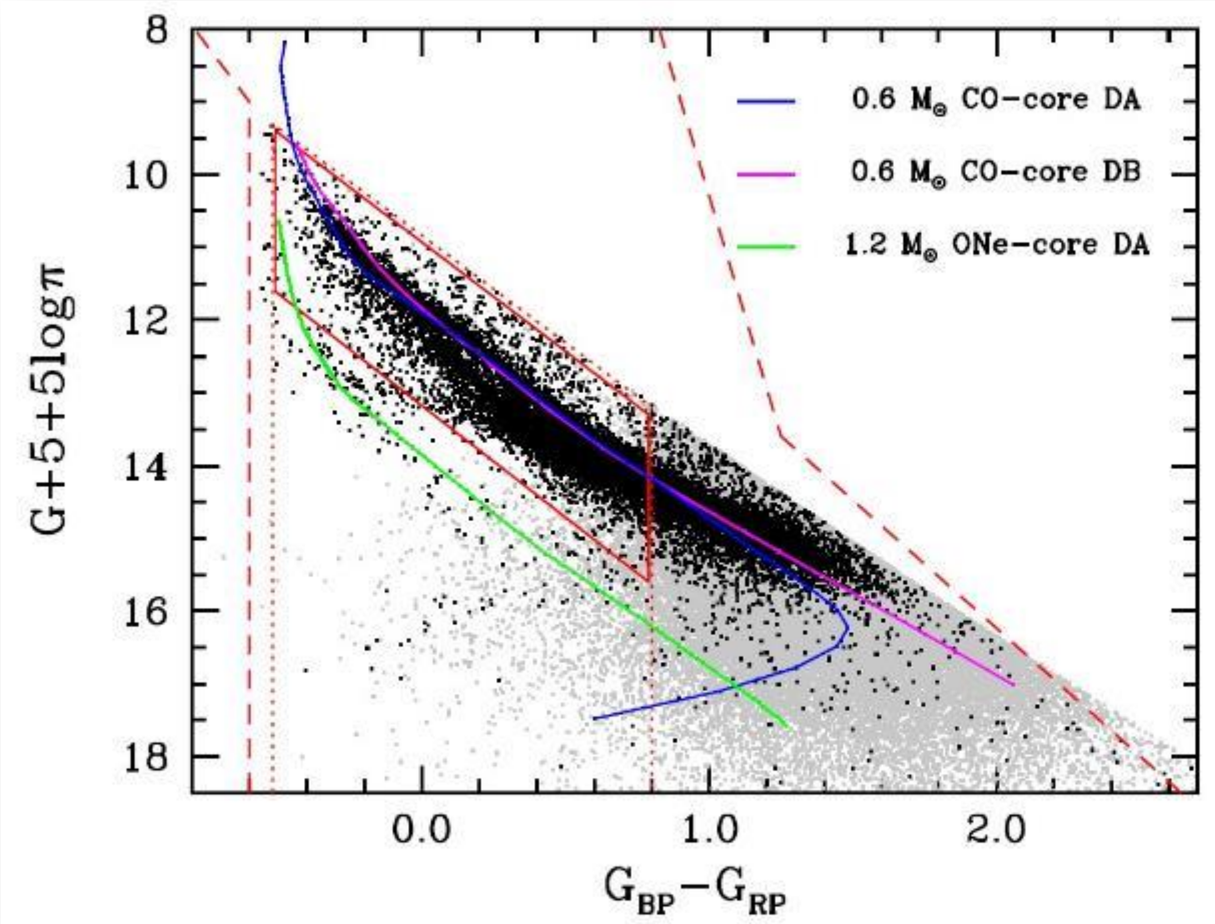

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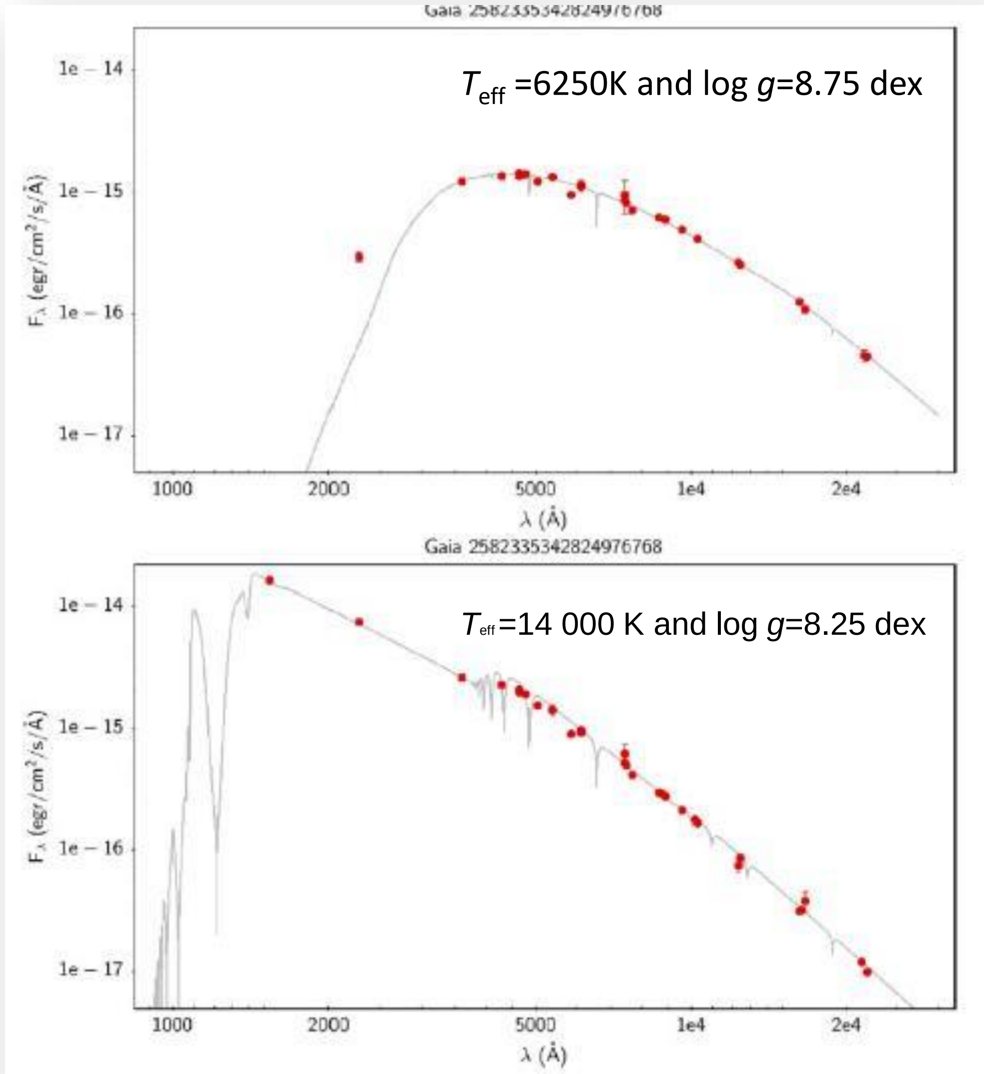

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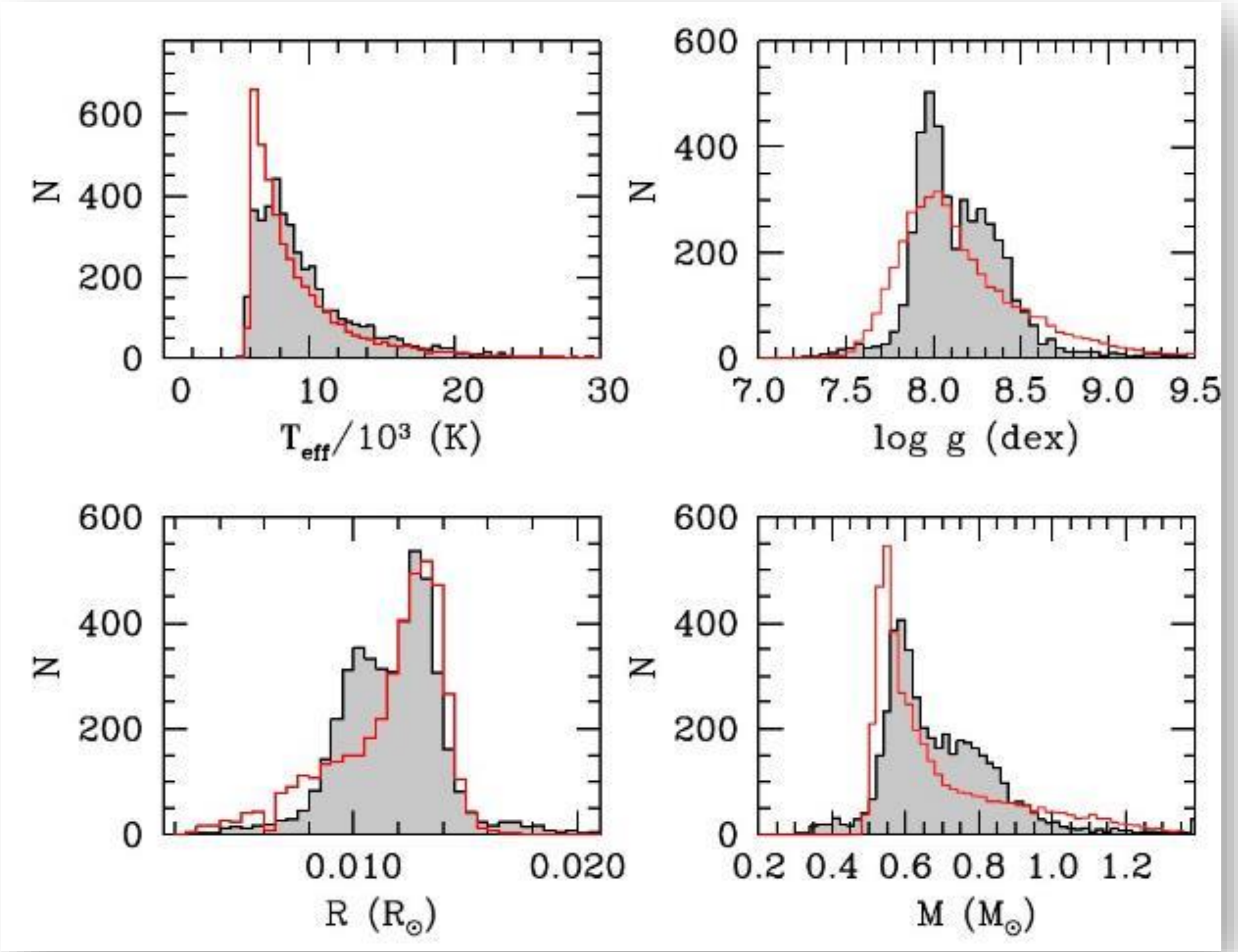

2. White dwarfs in the Gaia era

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Random Forest identification of the thin disc, thick disc, and halo *Gaia*-DR2 white dwarf population

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ABSTRACT

Gaia-DR2 has provided an unprecedented number of white dwarf candidates of our Galaxy. In particular, it is estimated that *Gaia*-DR2 has observed nearly 400 000 of these objects and close to 18 000 up to 100 pc from the Sun. This large quantity of data requires a thorough analysis in order to uncover their main Galactic population properties, in particular the thin and thick disc and halo components. Taking advantage of recent developments in artificial intelligence techniques, we make use of a detailed Random Forest algorithm to analyse an 8D space (equatorial coordinates, parallax, proper motion components, and photometric magnitudes) of accurate data provided by *Gaia*-DR2 within 100 pc from the Sun. With the aid of a thorough and robust population synthesis code, we simulated the different components of the Galactic white dwarf population to optimize the information extracted from the algorithm for disentangling the different population components. The algorithm is first tested in a known simulated sample achieving an accuracy of 85.3 per cent. Our methodology is thoroughly compared to standard methods based on kinematic criteria demonstrating that our algorithm substantially improves previous approaches. Once trained, the algorithm is then applied to the *Gaia*-DR2 100 pc white dwarf sample, identifying 12 227 thin disc, 1410 thick disc, and 95 halo white dwarf candidates, which represent a proportion of 74:25:1, respectively. Hence, the numerical spatial densities are $(3.6 \pm 0.4) \times 10^{-3}\,\mathrm{pc}^{-3}$, $(1.2 \pm 0.4) \times 10^{-3}\,\mathrm{pc}^{-3}$, and $(4.8 \pm 0.4) \times 10^{-5}\,\mathrm{pc}^{-3}$ for the thin disc, thick disc, and halo components, respectively. The populations thus obtained represent the most complete and volume-limited samples to date of the different components of the Galactic white dwarf population.

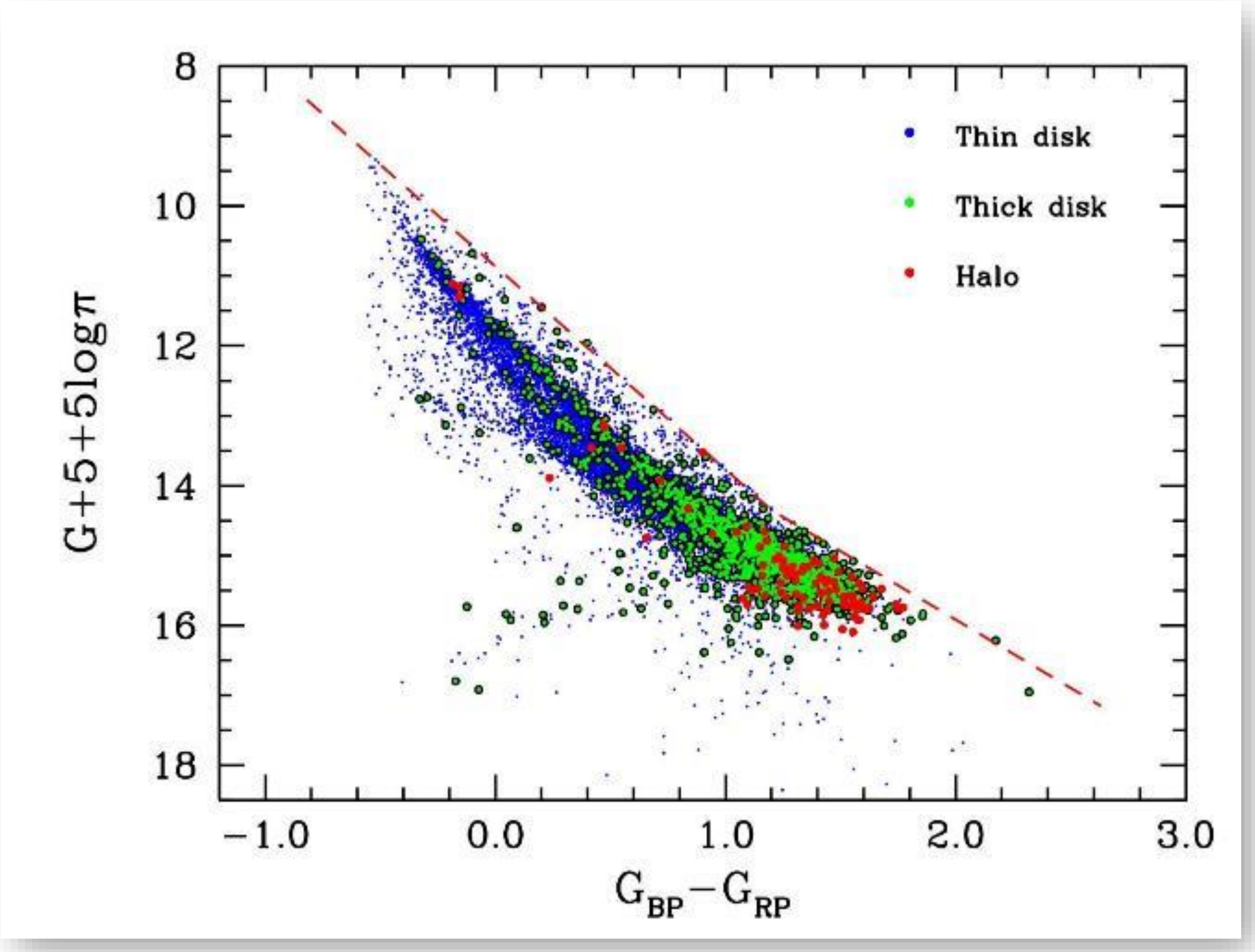
2. White dwarfs in the Gaia era

- We used and Artificial Intelligent algorithm based on Random Forest method
- Analyze an n-dimensional space:
  - (α, δ, π, G, G_{BP}, G_{RP} , μ_{α}, μ_{δ}, H, $V_{tan.}$)
- Random forest algorithm
  1. Training ↔ Synthetic sample
  2. Testing ↔ Synthetic sample. Score: ~86%
  3. Classifying ↔ The 100 pc *Gaia* sample

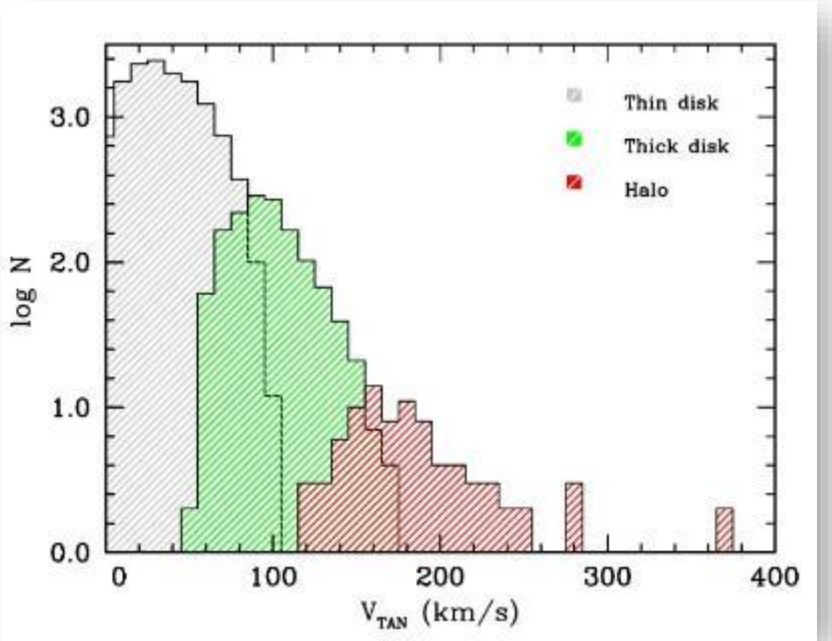
- Results

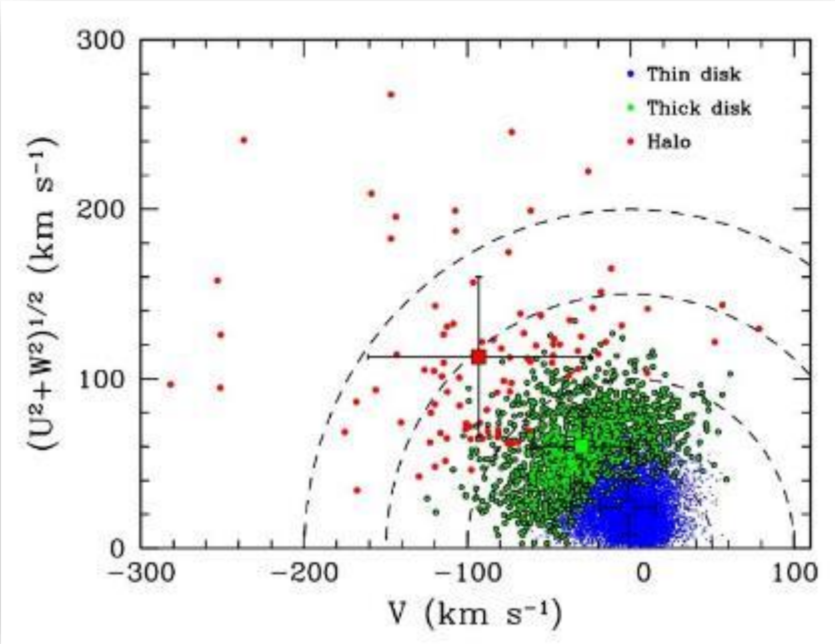
	N_WDs	%
Thin	12227	89
Thick	1410	10
Halo	95	~1

2. White dwarfs in the Gaia era



2. White dwarfs in the Gaia era





2. White dwarfs in the Gaia era

- Analyzed 3733 WDs VOSA identified infrared-excess in 77 candidate; 52 of which are new.
- Fraction of infrared-excess WDs due to the presence of circumstellar disk ~2.6%

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Infrared-excess white dwarfs in the *Gaia* 100 pc sample

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ABSTRACT
We analyse the 100 pc *Gaia* white dwarf volume-limited sample by means of VOSA (Virtual Observatory SED Analyser) with the aim of identifying candidates for displaying infrared excesses. Our search focuses on the study of the spectral energy distribution (SED) of 3,733 white dwarfs with reliable infrared photometry and $G_{BP} - G_{RP}$ colours below 0.8 mag, a sample which seems to be nearly representative of the overall white dwarf population. Our search results in 77 selected candidates, 52 of which are new identifications. For each target we apply a two-component SED fitting implemented in VOSA to derive the effective temperatures of both the white dwarf and the object causing the excess. We calculate a fraction of infrared-excess white dwarfs due to the presence of a circumstellar disk of 1.6±0.2%, a value which increases to 2.6±0.3% if we take into account incompleteness issues. Our results are in agreement with the drop in the percentage of infrared excess detections for cool (<8,000 K) and hot (>20,000 K) white dwarfs obtained in previous analyses. The fraction of white dwarfs with brown dwarf companions we derive is ≃0.1–0.2%.

Key words: (stars:) white dwarfs – (stars:) circumstellar matter – (stars:) brown dwarfs – (astronomical data bases:) virtual observatory tools

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2. White dwarfs in the Gaia era

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Astronomy & Astrophysics

Letter to the Editor

Gaia DR2 white dwarfs in the Hercules stream

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ABSTRACT

Aims. We analyzed the velocity space of the thin- and thick-disk *Gaia* white dwarf population within 100 pc by searching for signatures of the Hercules stellar stream. We aimed to identify objects belonging to the Hercules stream, and by taking advantage of white dwarf stars as reliable cosmochronometers, to derive a first age distribution.
Methods. We applied a kernel density estimation to the UV velocity space of white dwarfs. For the region where a clear overdensity of stars was found, we created a 5D space of dynamic variables. We applied a hierarchichal clustering method, HDBSCAN, to this 5D space, and identified those white dwarfs that share similar kinematic characteristics. Finally, under general assumptions and from their photometric properties, we derived an age estimate for each object.
Results. The Hercules stream was first revealed as an overdensity in the UV velocity space of the thick-disk white dwarf population. Three substreams were then found: Hercules a and Hercules b, formed by thick-disk stars with an age distribution that peaked 4 Gyr in the past and extends to very old ages; and Hercules c, with a ratio of 65:35 of thin to thick stars and a more uniform age distribution that is younger than 10 Gyr.

Key words. white dwarfs – Galaxy: kinematics and dynamics – solar neighborhood – methods: data analysis

3. White dwarfs in the Hercules stream

1. A clear overdensity is revealed in the UV-plane

2. We created a 5D space:

$$U, V, V_{pec} \equiv (U^2 + V^2 + W^2)^{1/2}, V_{Toomre} \equiv (U^2 + W^2)^{1/2} \text{ and } V_{\Delta E} = (U^2 + 2V^2)^{1/2}$$

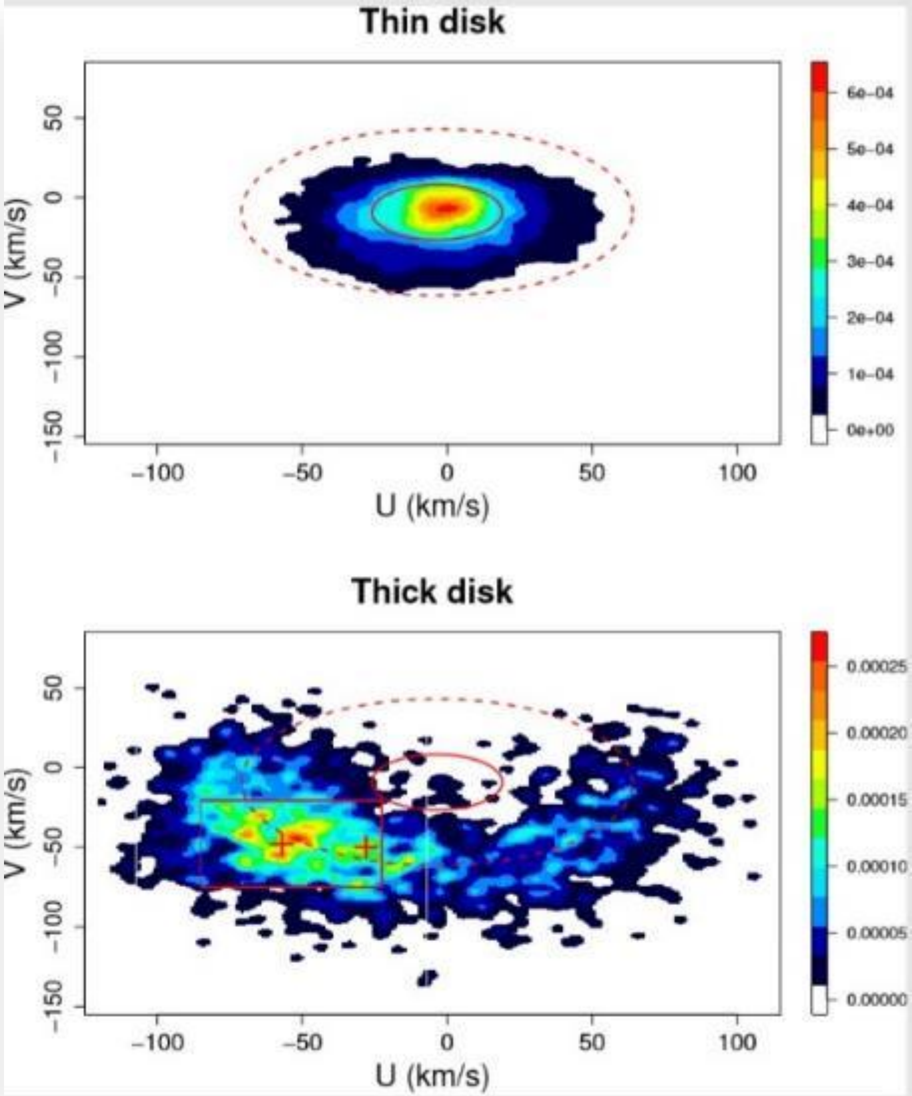
3. Then apply to it a hierarchical clustering algorithm, HDBSCAN

   - Three groups were founded: Her *a*, Her *b* and Her *c*

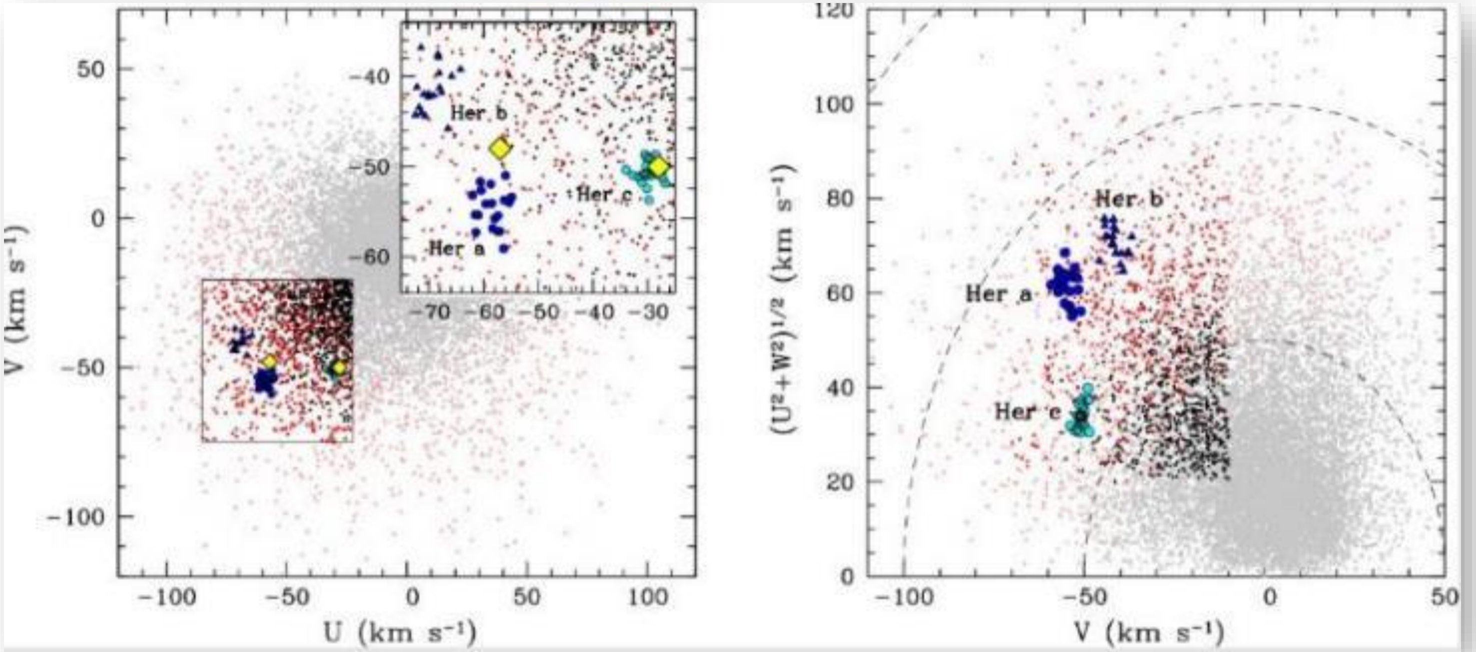
4. Age estimation was done:

   - We assumed DAs models, Z=0.01 for thin, Z=0.001 for thick WDs
   - From (M_G, G_{BP}-G_{RP}) we interpoled in self-consistent cooling sequences
   - Finally we obtained the total age of the white dwarf

2. White dwarfs in the Gaia era

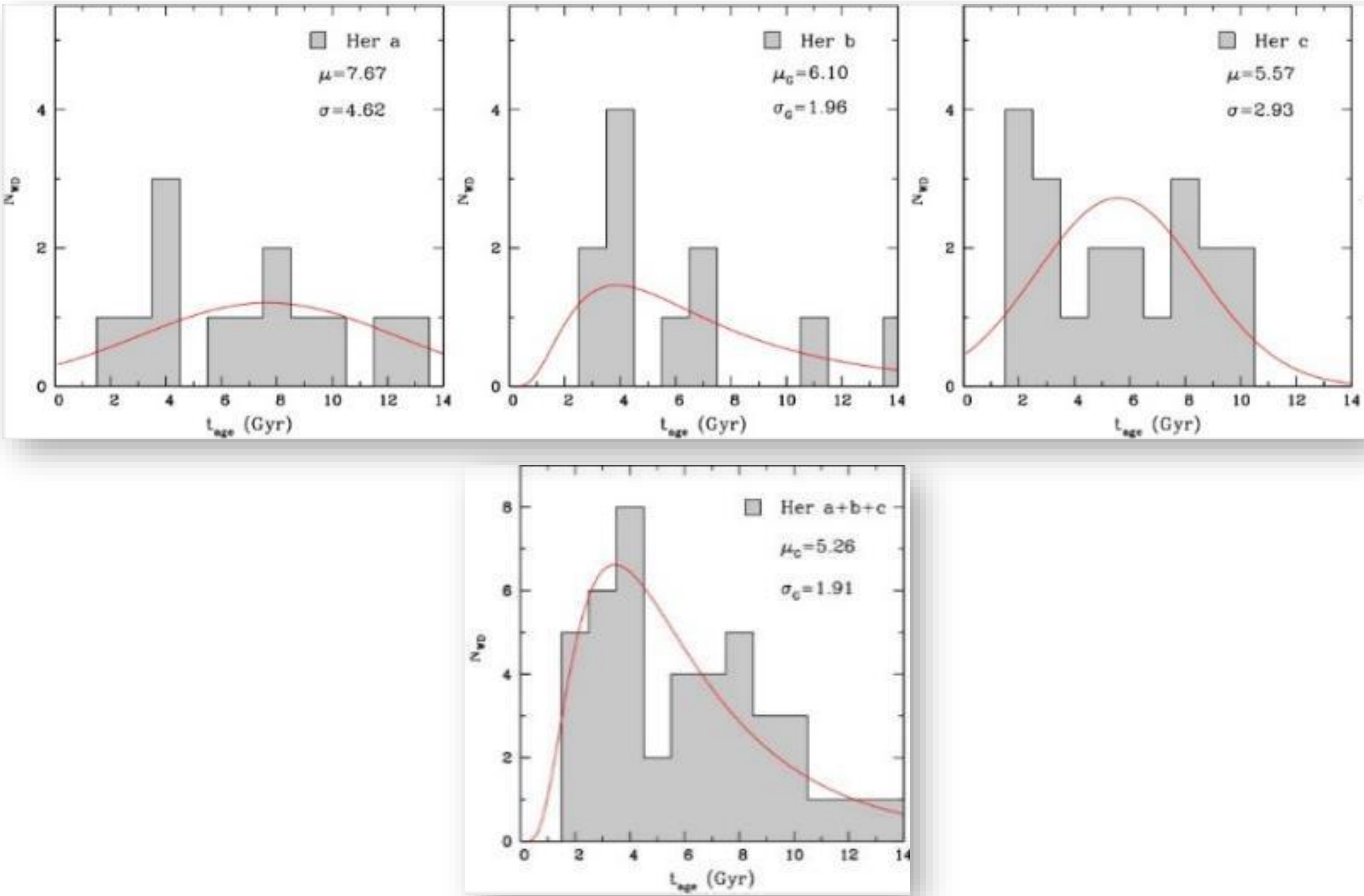


3. White dwarfs in the Hercules stream



Group	# WDs	(U,V) km/s	population
Her a	19	(−59±2,−55±3)	100% thick-disk
Her b	18	(−69±2,−41±2)	95% thick-disk+5% thin-disk
Her c	20	(−30±2,−51±1)	35% thick-disk+65% thin-disk

2. White dwarfs in the Gaia era



1. Introduction

2. White dwarfs in the Gaia era

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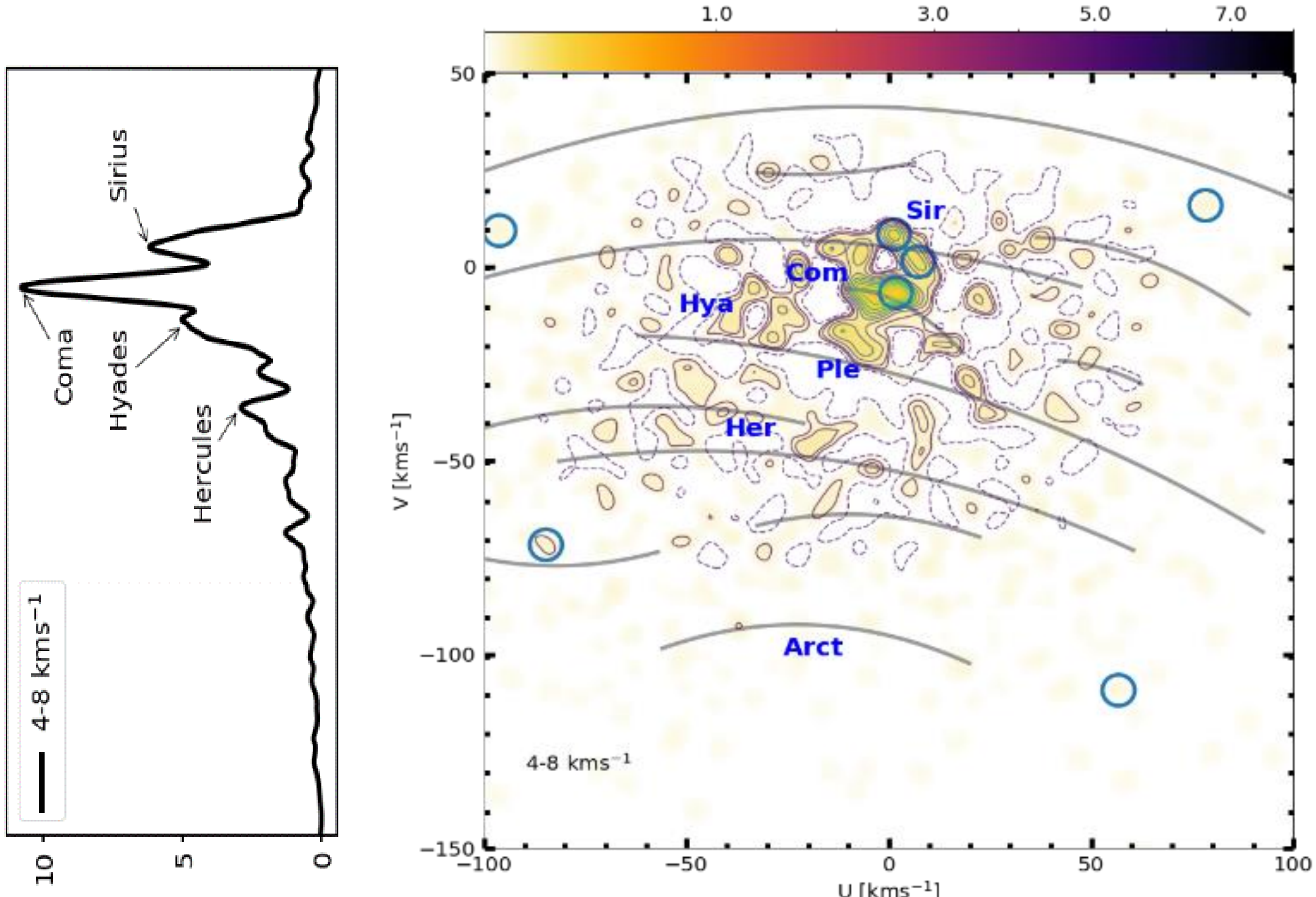
4. Conclusions

3. Work in progress

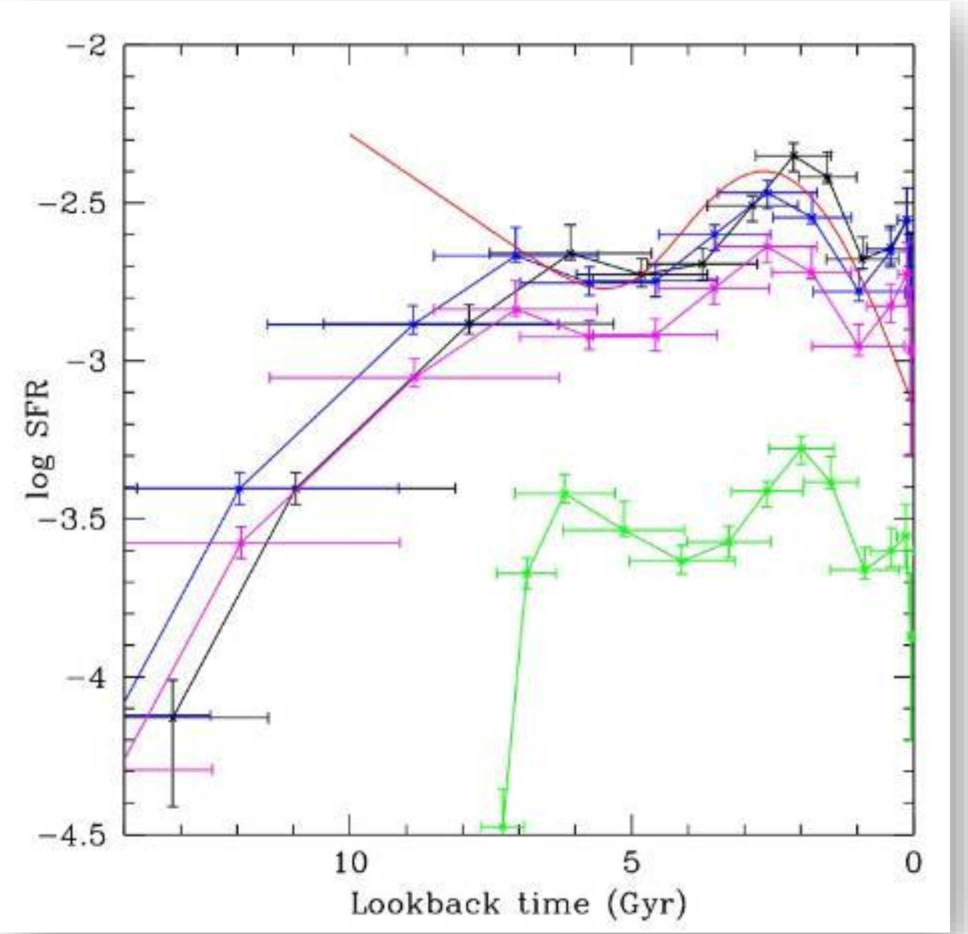
More stellar stream signatures



P. Ramos private communication

3. Work in progress

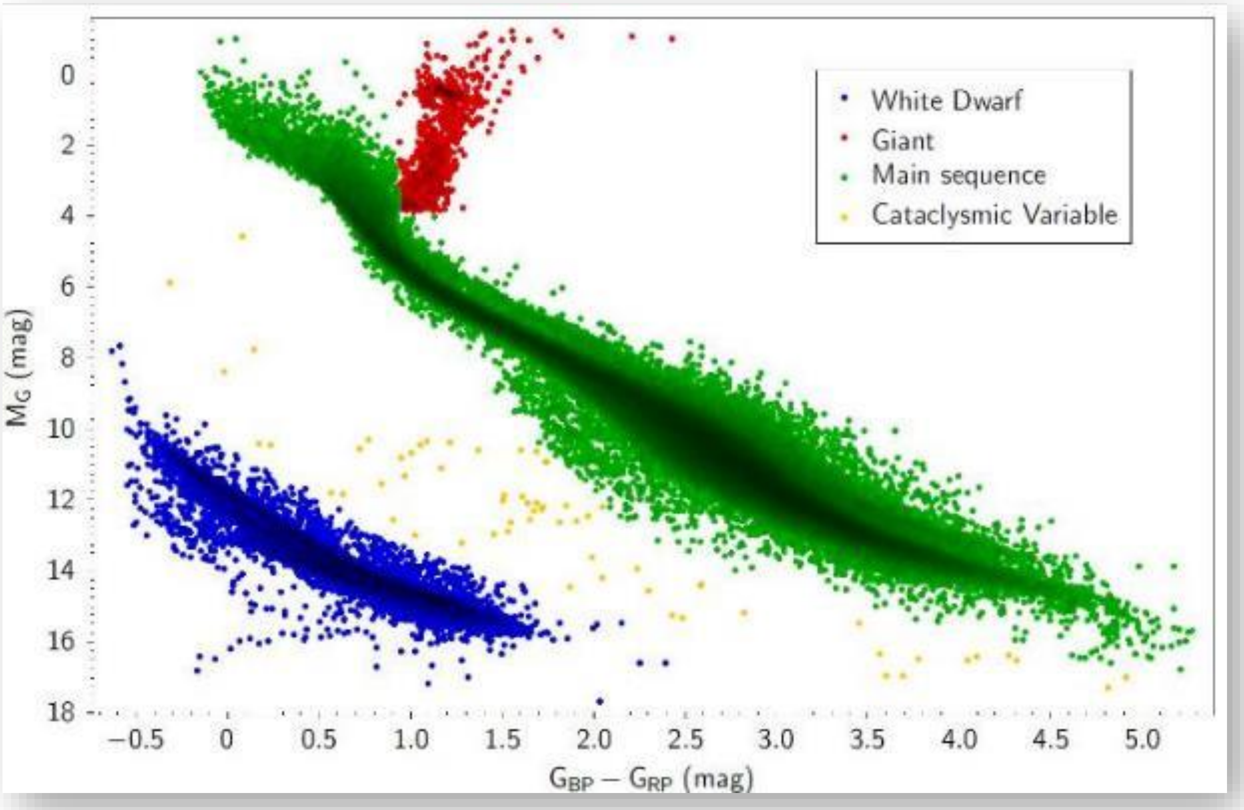
Star formation history



Isern. J. ApJ Letters, 2019

3. Work in progress

Binary white dwarf population



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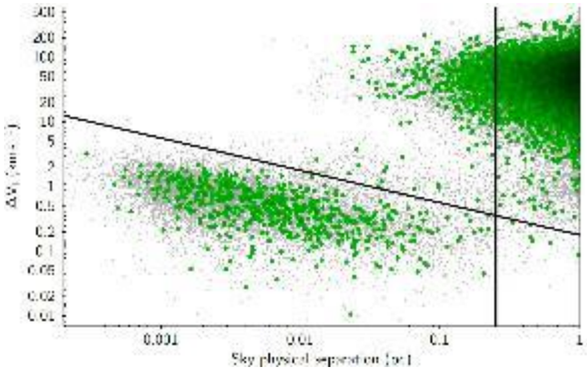
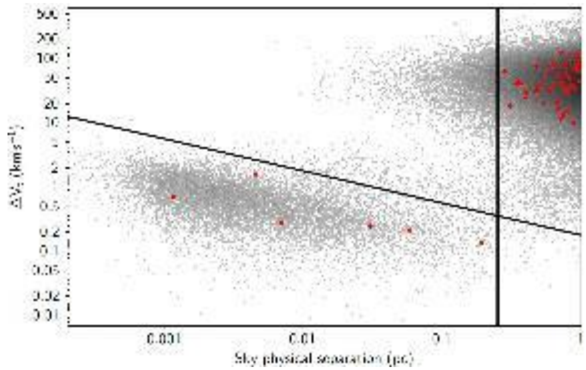
3. Work in progress

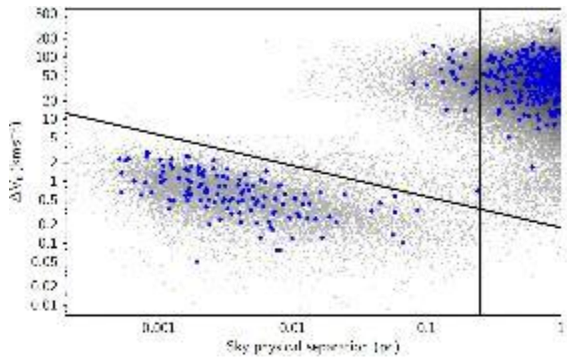
WD+MS



WD+RG



WD+WD



659 WD+MS comoving pairs: **6.3%** of the entire 100 pc WD population
132 WD+WD " " : **1.3%** " " " " " "
6 WD+RG " " : <<**1%** " " " " " "

Population synthesis of the single+binary WD population

- Binary fraction f_{bin}
- Initial mass ratio distribution, $n(q)=M_2/M_1$
- Initial separation, a
- Percentage of mergers

1. Introduction

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4. **Conclusions**

4. Conclusions

1. **White dwarfs** are reliable **cosmochronometers** and , despite the lack of radial velocity and metallicity measurements, they carry important information about history and structure of our Galaxy.

2. ***Gaia DR2*** has provided a wealth astrometric and photometric information
    1. Nearly ~300,000 white dwarfs candidates
    2. Complete sample up to 100 pc

3. **Hercules** and other streams have been detected for the first time in the white dwarf population.

4. White dwarfs population (in particular the 100 pc sample) can be used as a **testbed** for **Galactic models.**

EXPANDING THE GAIA LEGACY
THE ROLE OF SPANISH GROUND-BASED FACILITIES
A celebration of the research career of Jordi Torra

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The white dwarf population in the Gaia DR2 era

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Coordination: Red Española de Explotación Científica de Gaia