Leibniz-Institut für
Astrophysik Potsdam

Faint blue white dwarfs (FBWDs) in *Gaia* colour-magnitude diagrams

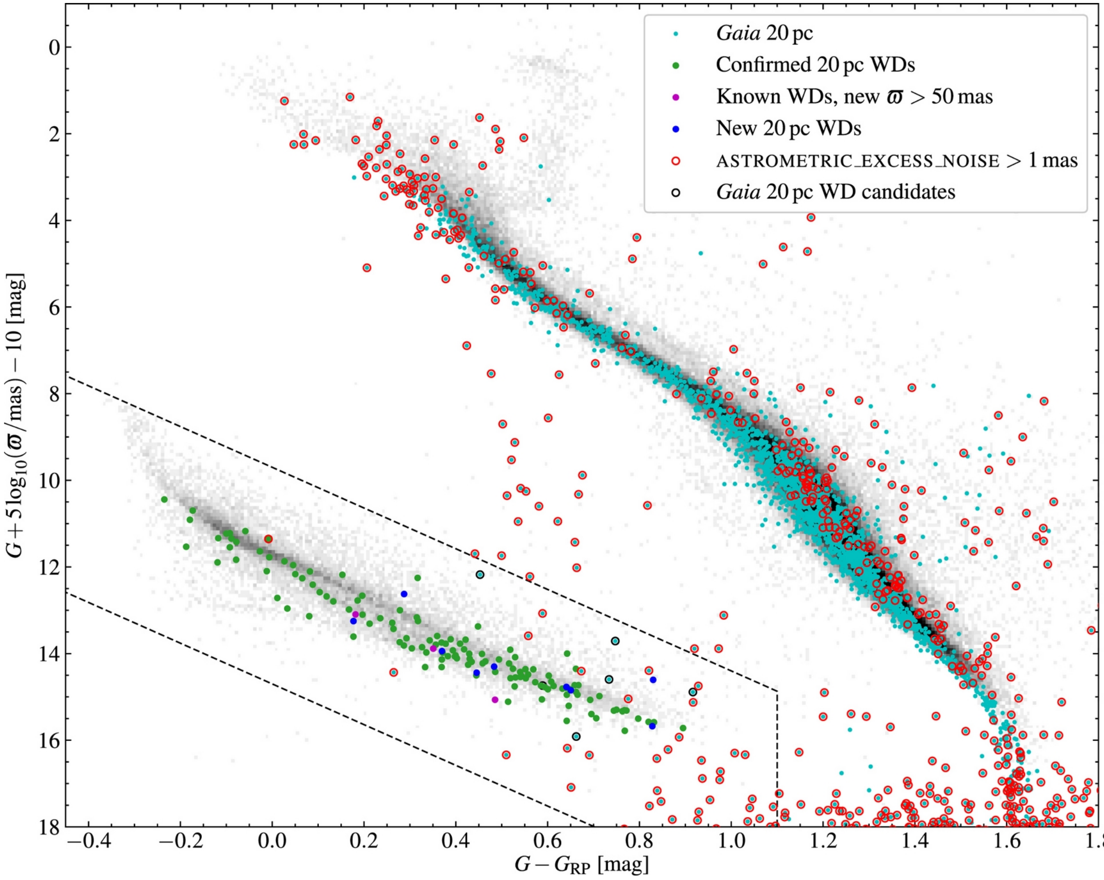
Ralf-Dieter Scholz / MWLV+DGGH meeting / 10 November 2022

White dwarfs (WDs) in the Solar neighbourhood observed by *Gaia* - I.

- The nearest (well-measured and almost complete) 20 pc sample
  - 139 WDs, incl. 9 *Gaia* DR2 discoveries **(Hollands et al. 2018)** but also 1 *Gaia* DR1+UCAC5/URAT discovery within 10 pc **(Scholz et al. 2018a)** (with a very small proper motion !)
  - additional 5 previously known WDs in *Gaia* EDR3
  - all 144 nearby WDs fall in the colour-magnitude box defined by **Hollands et al. (2018)**

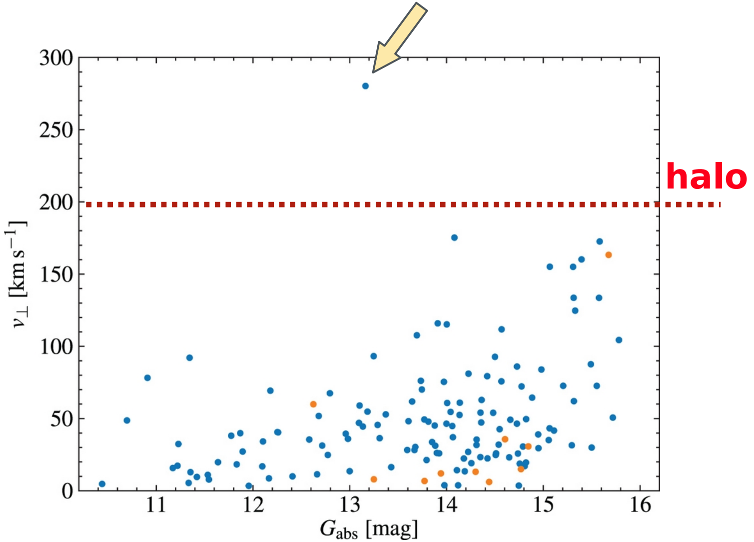
The Gaia DR2 20 pc sample

Hollands et al. (2018)



their Fig.1: colour-magnitude diagram (CMD)

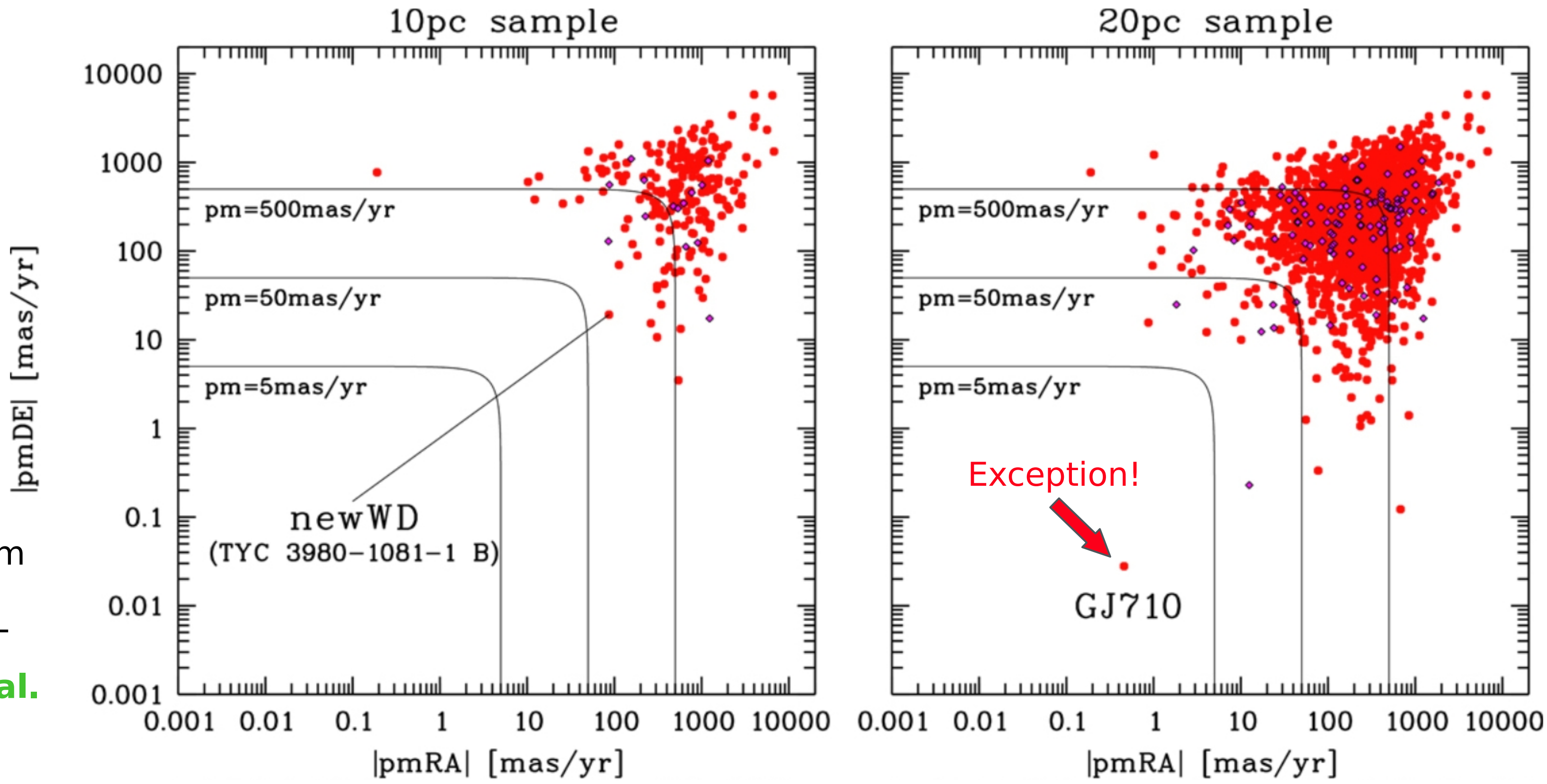
WD 1756+827 = LHS 56



their Fig.6: tangential velocities

Proper motions of nearby stars

Selected *Gaia* DR2 data of hight astrometric quality **(Scholz 2020)**



New WD from *Gaia* DR1 + UCAC5/URAT **(Scholz et al. 2018a)**

White dwarfs (WDs) in the Solar neighbourhood observed by *Gaia* - II.

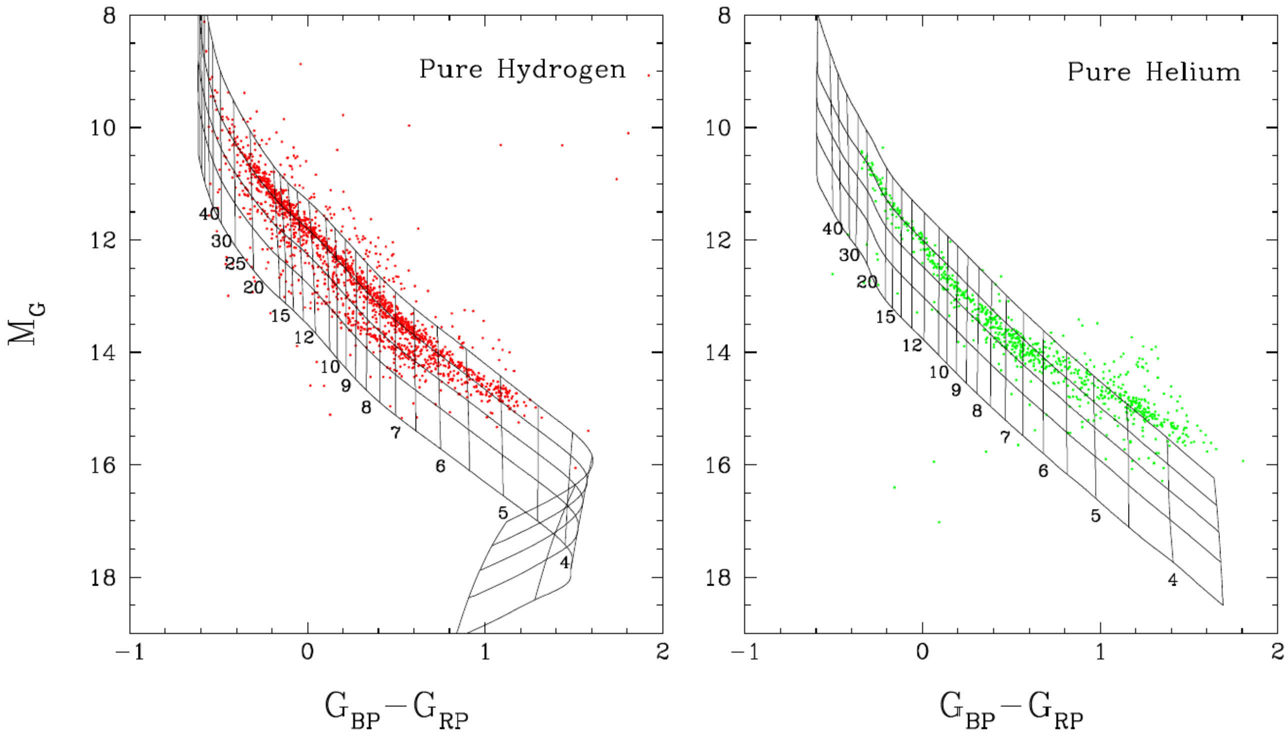
- Much improved knowledge on WDs after *Gaia* DR2, e.g.
  - split in WD sequence due to chemical composition **(Bergeron et al. 2019)**
  - WD catalogue of almost ~500000 objects **(Gentile Fusillo et al. 2019)**
- WDs in the *Gaia* catalogue of nearby stars (GCNS) within 100 pc (based on EDR3)
  - GCNS contains ~500000 stars with measured *G* magnitudes and *G-RP* colours and parallaxes *Plx*>10 mas;
    ~296000 (59%) in „selected“ and ~204000 (41%) in „rejected“ 100 pc sample
  - GCNS paper **(Gaia Collaboration, Smart et al. 2021)** includes WD section & classification
  - updated WD catalogue **(Gentile Fusillo et al. 2021)** with own WD classification using EDR3
  - astrometric+photometric verification of 60 faint blue white dwarfs (FBWDs) below the WD colour-magnitude box **(Scholz 2022)**

Structure in WD sequence → chemical composition

WDs from Montreal WD database within 100pc according to precise *Gaia* DR2 parallaxes

Models for pure Hydrogen and Helium atmospheric composition with 0.4, 0.6, 0.8, 1.0, 1.2 solar masses (from top to bottom) and T_{eff} in units of 10^3 K

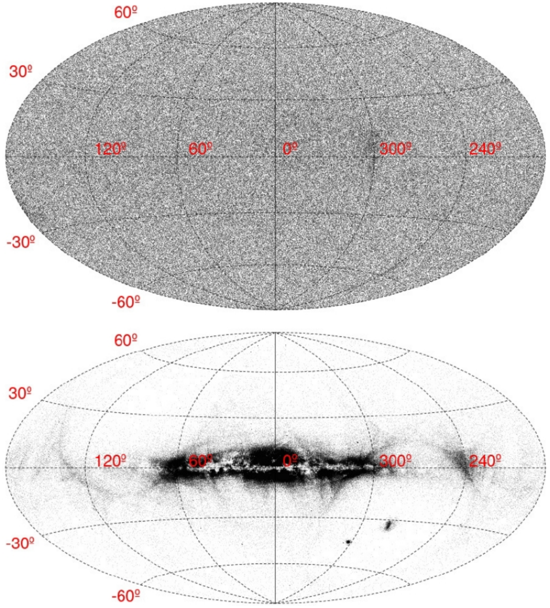
Bergeron et al. (2019)
their Fig.3:



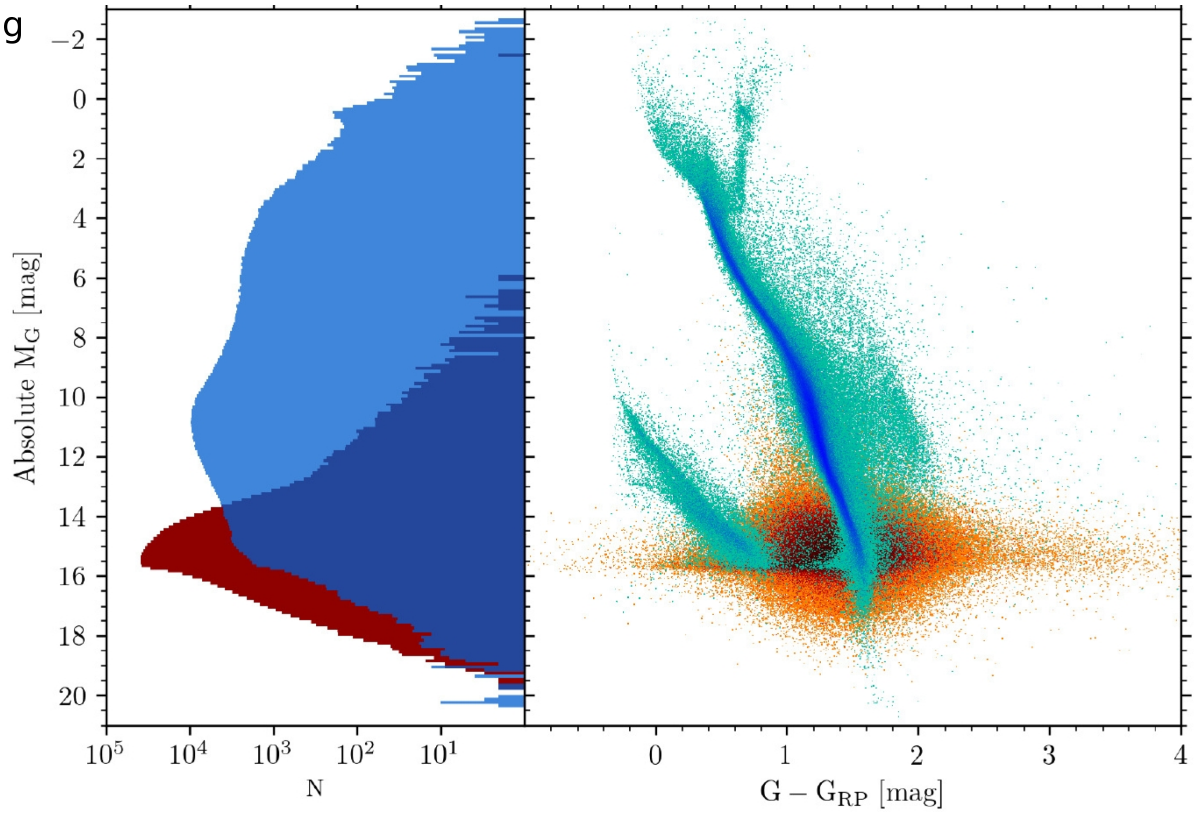
Selected and rejected sources in GCNS generation

Smart et al. (2021)

with random forest classifier using
41 (!) EDR3 astrometric features



their Fig.1: sky distributions



their Fig.2: absolute magnitudes and CMD

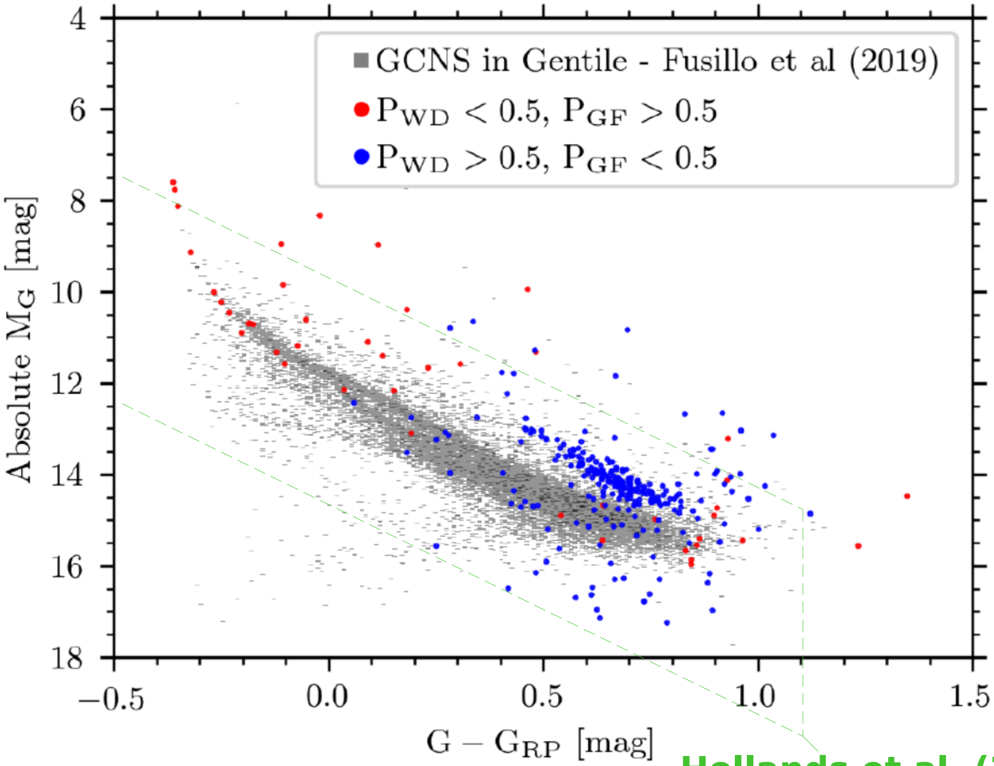
WD classification discrepancies - I

Smart et al. (2021) found some contradicting WD probabilities between the (selected) GCNS sample and the WD catalogue of **Gentile-Fusillo (2019)**:

red points – GCNS algorithm „appears to fail“, in particular for „very bright magnitudes compared with the training data set“

blue points – „due to very restrictive filtering“ in the WD catalogue

Smart et al. (2021)
their Fig.2:

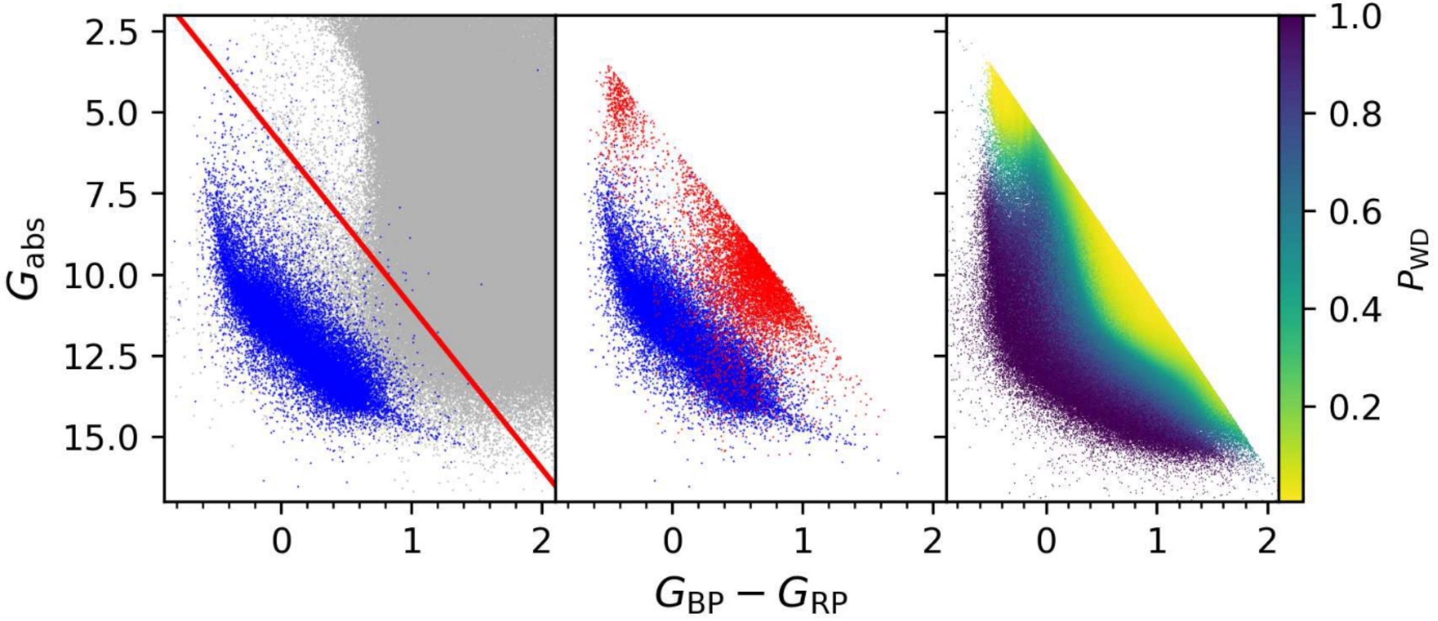


Hollands et al. (2018)

Updated (EDR3-based) WD catalogue

Gentile Fusillo et al. (2021)

their Fig.1:

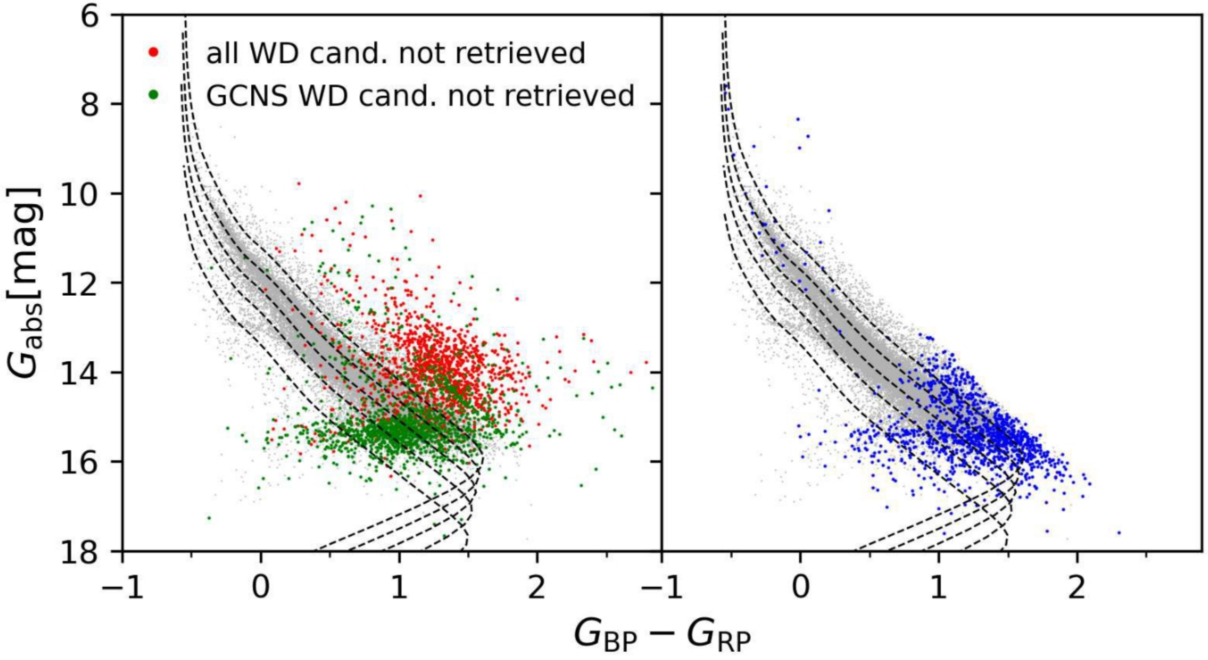


red line – initial cut for selection of WDs
grey points – random sample with RPlx>1
blue points – spectroscopically confirmed SDSS WDs
red points – contaminants

Right panel:
about 1.3 million objects
in their WD catalogue

WD classification discrepancies - II

Gentile Fusillo et al. (2021)
their Fig.11:



Left panel:
GCNS-rejected (red) and GCNS-selected (green) WDs not in WD catalogue of **Gentile Fusillo et al. (2021)**

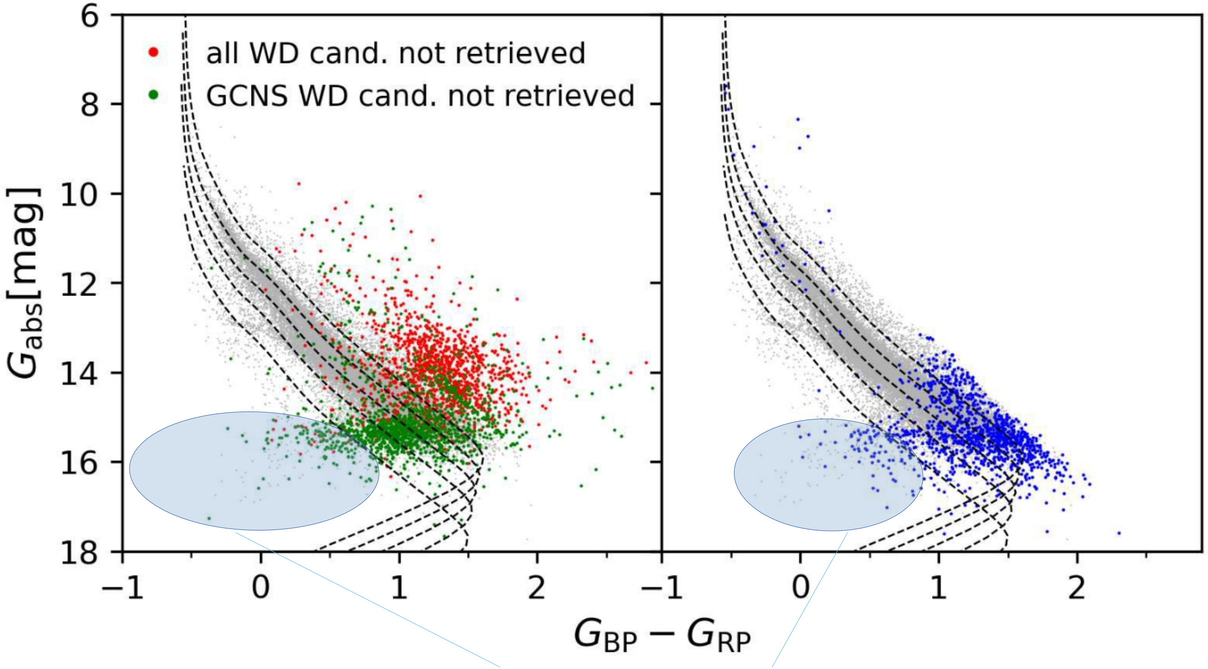
Right panel:
blue points – catalogue WDs not included in GCNS

Grey points – common WDs (WD probabilties > 0.75)

dashed lines – cooling tracks for H-atmosphere WDs of different masses

WD classification discrepancies - II

Gentile Fusillo et al. (2021) their Fig.11:



faint blue white dwarfs (FBWDs)
not matching cooling tracks
(not discussed in **Gentile Fusillo et al. 2021)**

Left panel:
GCNS-rejected (red) and GCNS-selected (green) WDs not in WD catalogue of **Gentile Fusillo et al. (2021)**

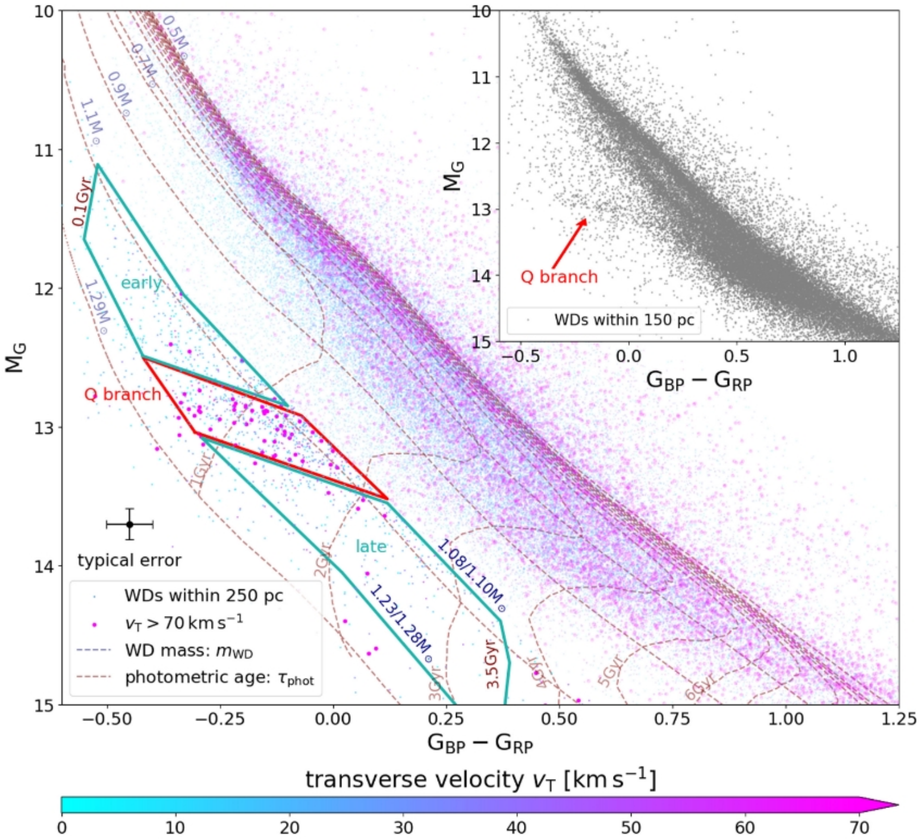
Right panel:
blue points – catalogue WDs not included in GCNS

Grey points – common WDs (WD probabilties > 0.75)

dashed lines – cooling tracks for H-atmosphere WDs of different masses

Cheng et al. (2019)

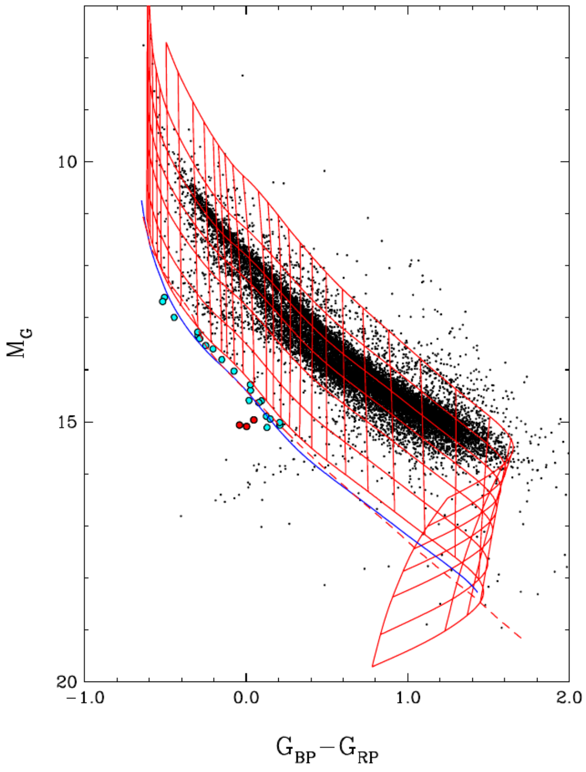
„A cooling anomaly of high-mass WDs“, their Fig.1:



High-mass WDs and their cooling

Kilic et al. (2021)

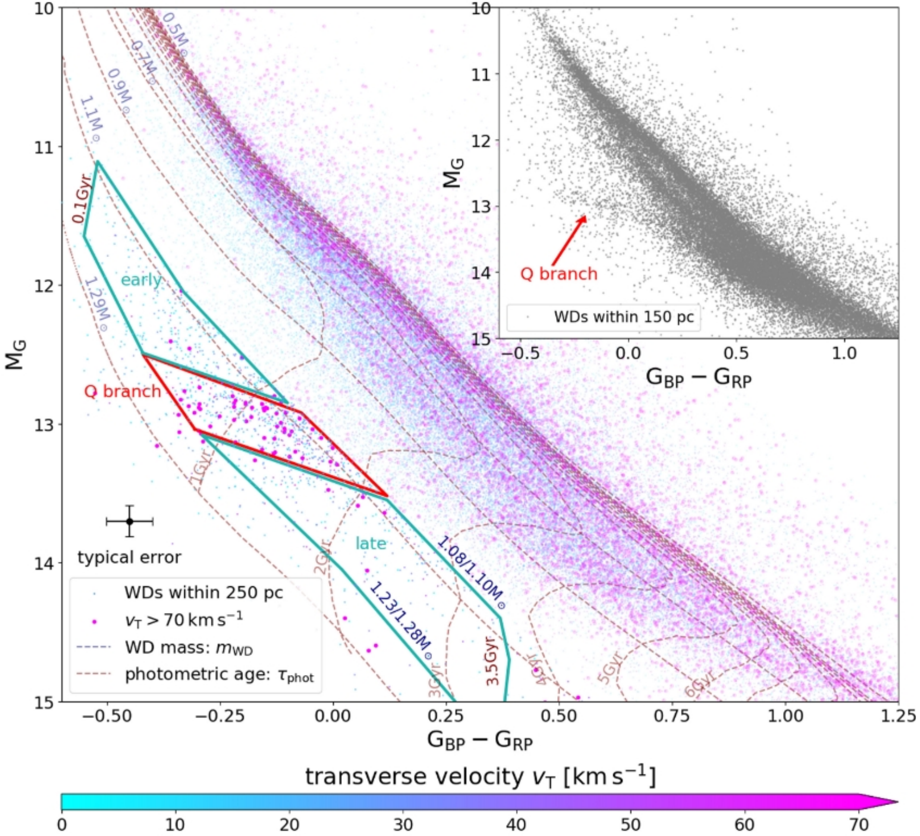
„The most massive WDs in the solar neighbourhood“, their Fig.1:



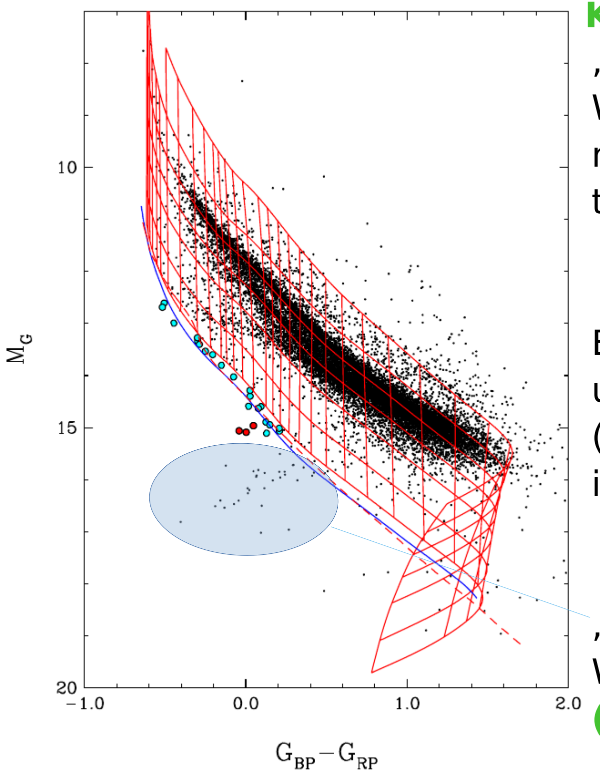
Blue open circles: ultramassive WDs (M_G<~15mag, as in **Cheng et al.**)

Cheng et al. (2019)

„A cooling anomaly of high-mass WDs“, their Fig.1:



High-mass WDs and their cooling



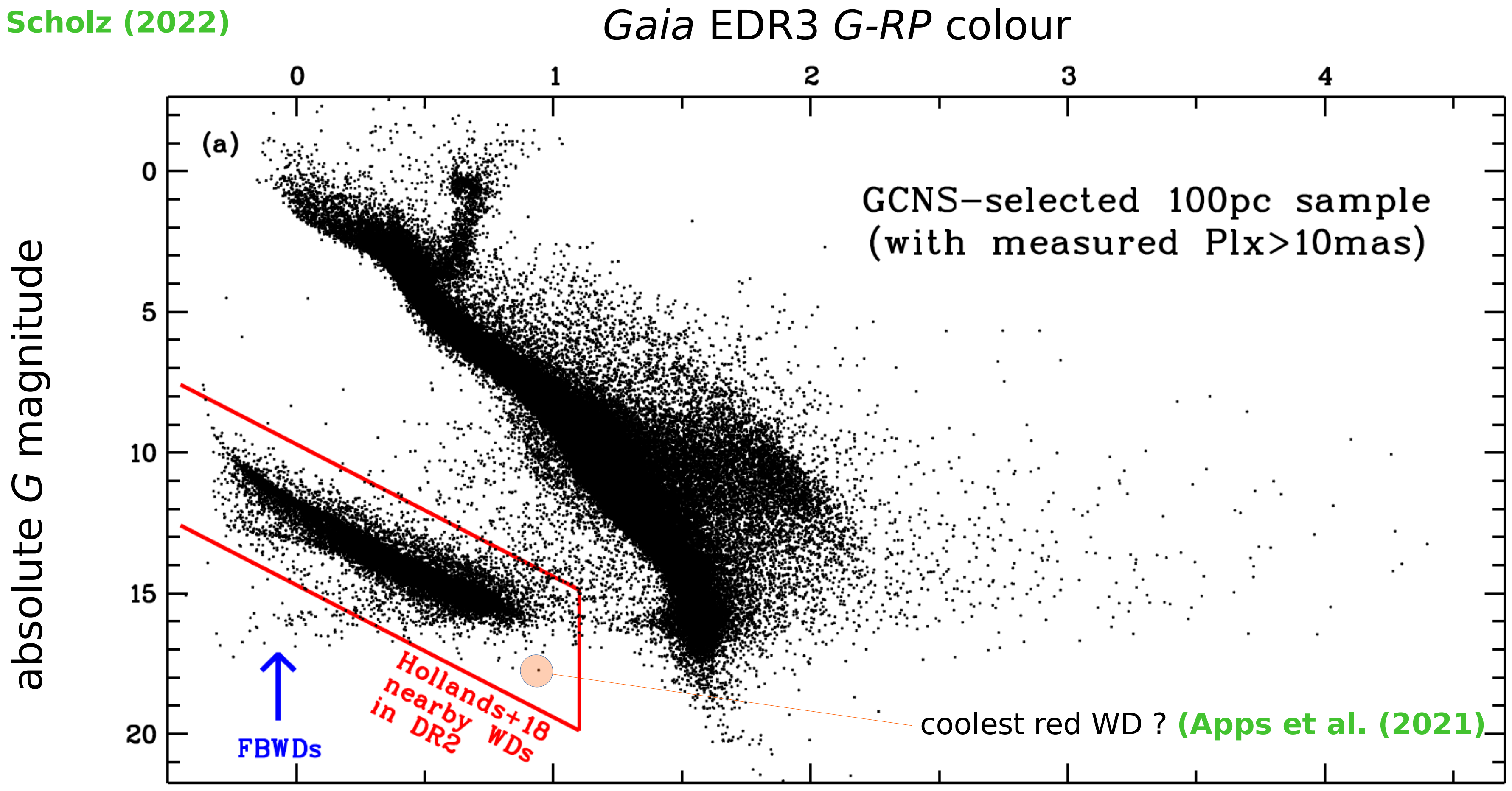
Kilic et al. (2021)

„The most massive WDs in the solar neighbourhood“, their Fig.1:

Blue open circles: ultramassive WDs (M_G<~15mag, as in **Cheng et al.**)

„IR-faint (ultracool) WD sequence **(Kilic et al. 2020)**“

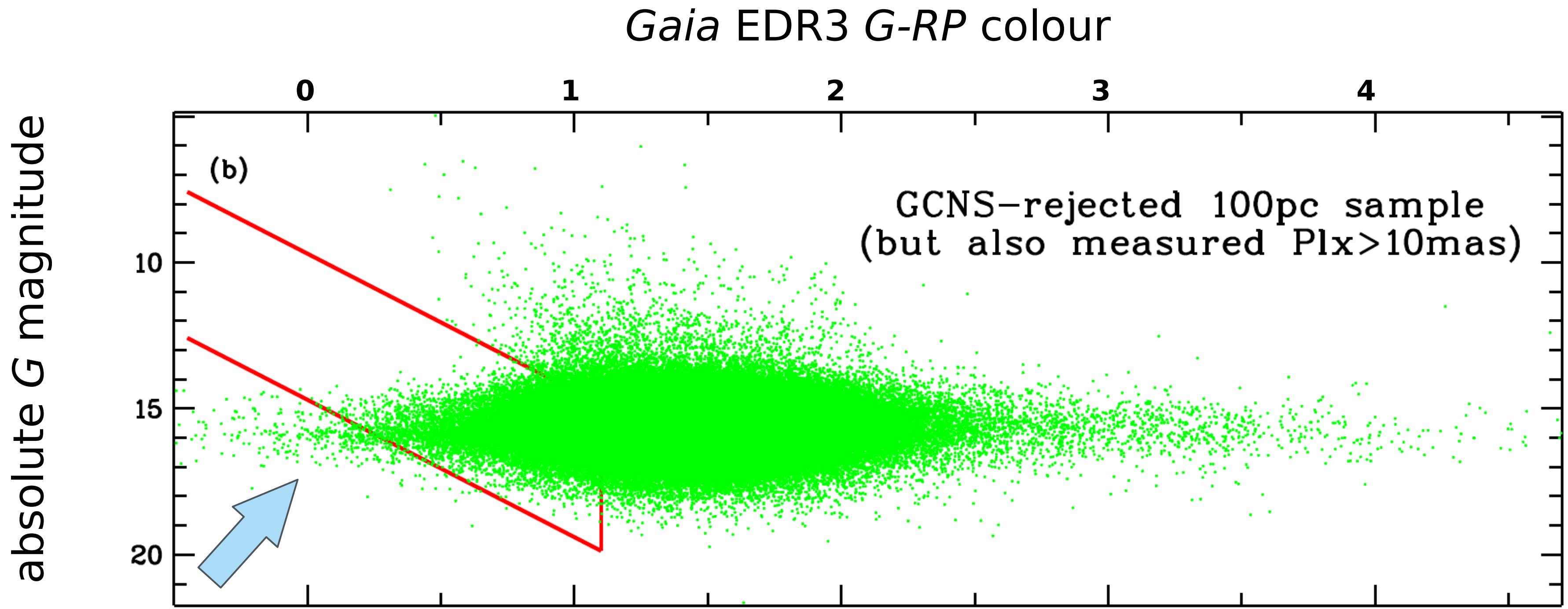
Scholz (2022)


Gaia EDR3 G-RP colour
0
1
2
3
4
(a)
GCNS−selected 100pc sample
(with measured Plx>10mas)
absolute G magnitude
0
5
10
15
20
Hollands+18
nearby WDs
in DR2
FBWDs
coolest red WD ? (Apps et al. (2021))

Scholz (2022)

Is the FBWD sequence contaminated?

>400 GCNS-rejected objects below WD colour-magnitude box, compared to 60 GCNS-selected



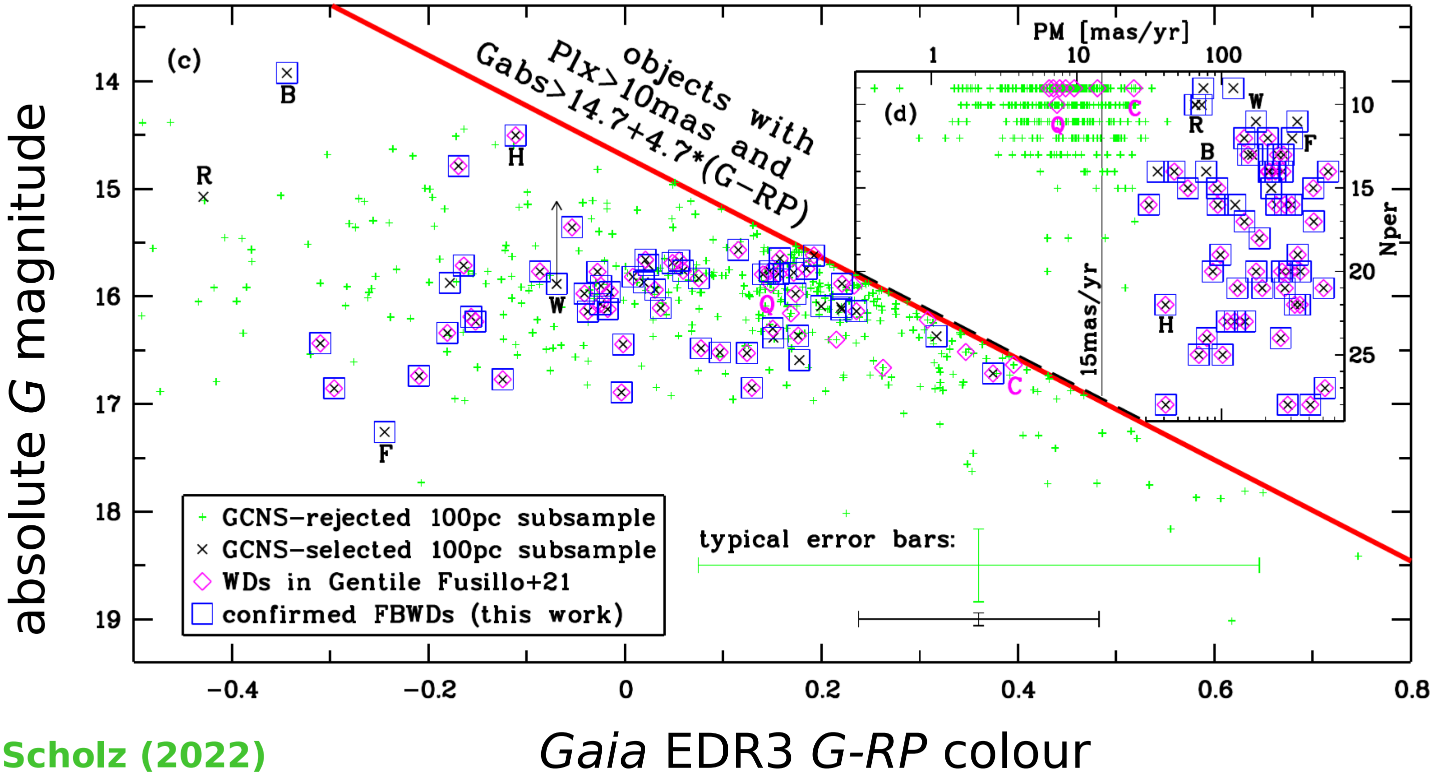
Astrometric and photometric verification of FBWDs in *Gaia* EDR3

Scholz (2022)

- Proper motion check (for *PM*>15 mas/yr) with external catalogues and data from APM, SuperCOSMOS, SDSS, PS1, DESI Legacy imaging surveys (and in some cases VHS)
  a confirmed proper motion was considered as supporting the EDR3 parallax
- Check for crowding effects or close companions
  - Finder chart inspection (also to check the EDR3 *G-RP* colour)
  - Other EDR3 sources at separations <~2 arcsec ?
  - EDR3 common proper motion companions (<3 arcmin) with discrepant parallaxes ?

(c)
Zoom to CMD region of FBWDs

(d)
EDR3 proper motion *PM* vs.
number of visibility periods *Nper*

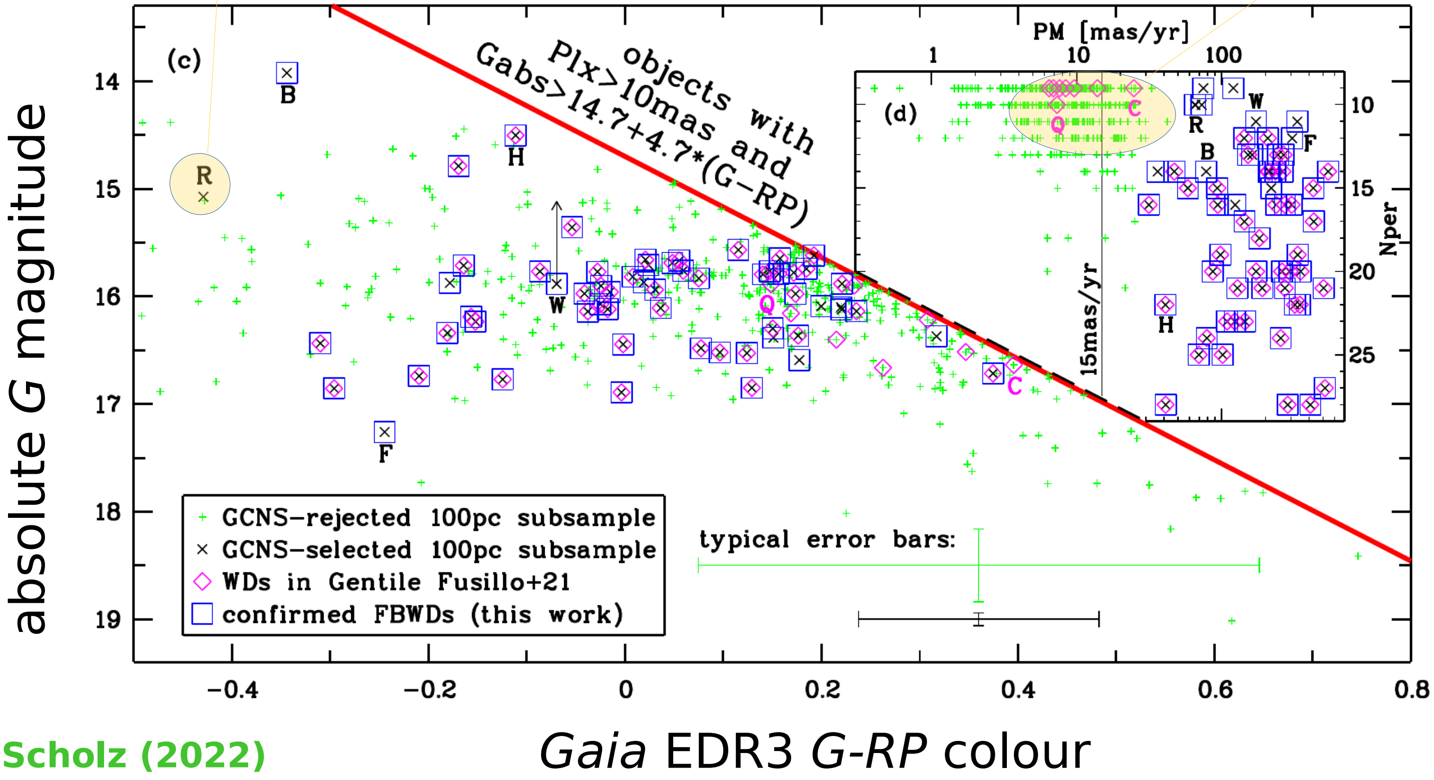


Scholz (2022)

R = is not a WD, appears very red in PS1 and VHS, has close CPM companion affecting *Gaia* colour

~70 GCNS-rejected objects (+) with *PM*>15 mas/yr failed proper motion check

All 8 GCNS-rejected objects in WD catalogue of **Gentile Fusillo et al. (2021)** have *Nper*<11, and very small *Gaia PM*



Q = QSO candidate **(Bailer-Jones et al. 2019)**

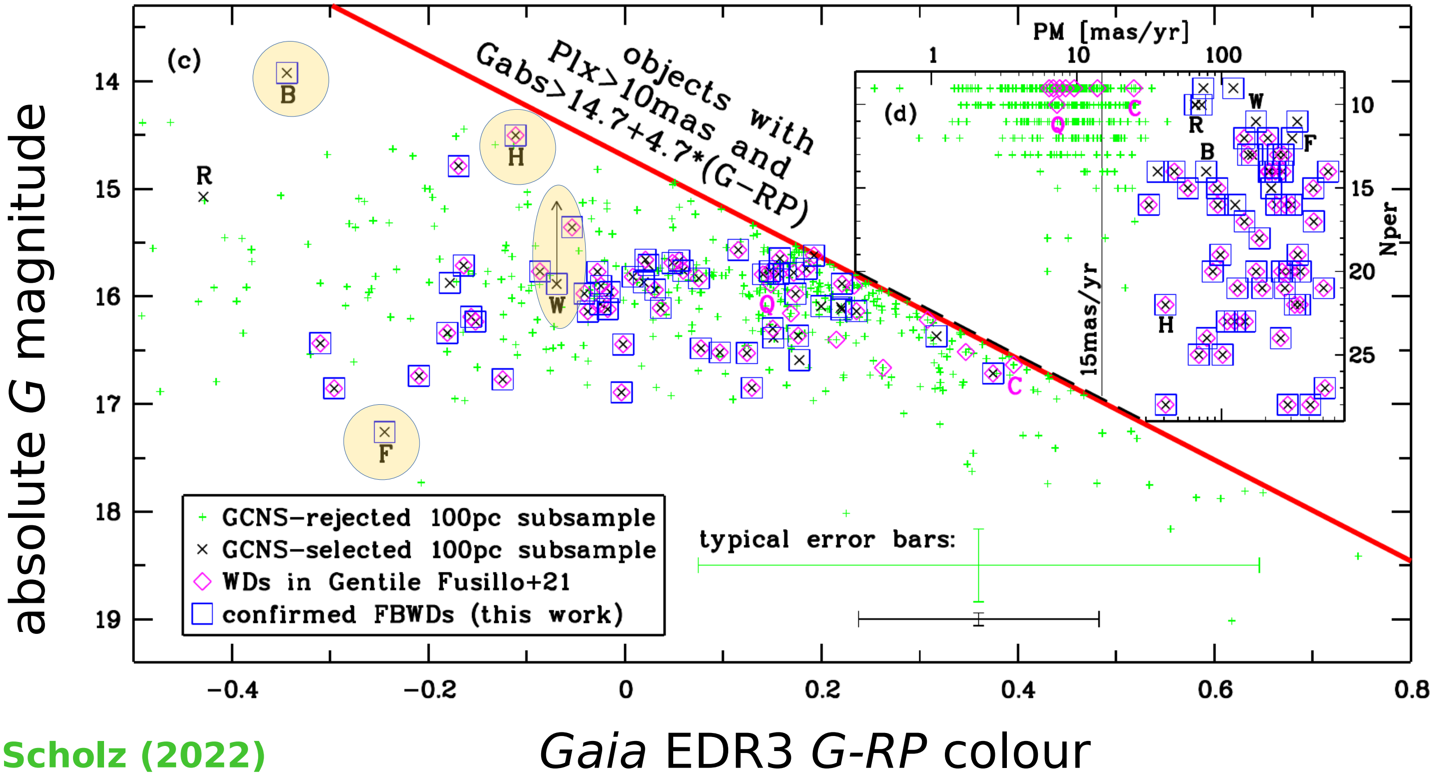
C = *PM*~25 mas/yr confirmed, but large parallax error + CPM companion with much smaller parallax!

Scholz (2022)

59 of 60 GCNS-selected candidates confirmed as FBWDs:

B = brightest (M_G~13.9mag)
F = faintest (M_G~17.3mag) – cf. cool red WD **(Apps et al. (2021)**

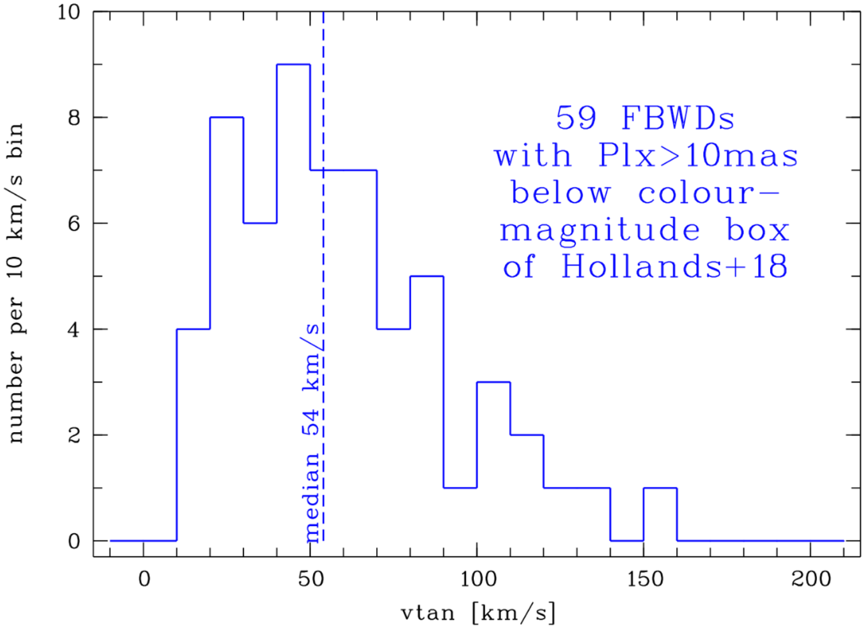
H = classified as high-mass WD by **Cheng et al. (2019)**

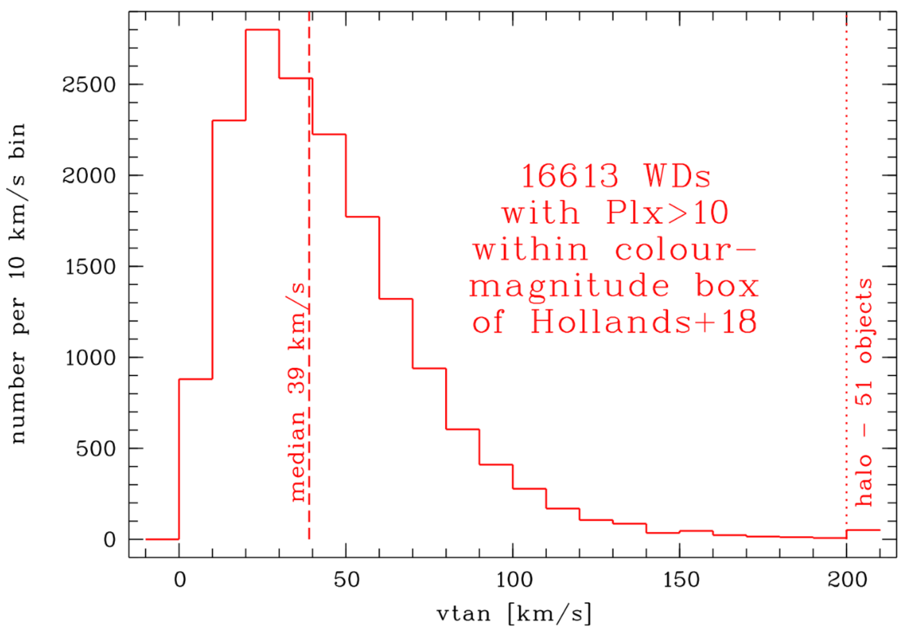


W = blue foreground object in GC region, has red CPM companion with slightly smaller and more precise parallax → would change its absolute magnitude as indicated by arrow

Scholz (2022)

Relatively high tangential velocities of FBWDs





FBWDs are rare – comparable to numbers of halo WDs, the nearest FBWD is at 29 pc

Only <17000 WDs within 100 pc
→ most WDs in catalogue of **Gentile Fusillo et al. (2021)** are hot & more distant

Summary (Scholz 2022)

- **All GCNS-rejected FBWD candidates, incl. 8 objects from WD catalogue of Gentile Fusillo et al. (2021) and ~70 objects with EDR3 PM>15 mas/yr, were not confirmed**
  - their EDR3 astrometry+photometry is much less accurate than of GCNS-selected objects
  - most of them (85%) are in crowded regions (Galactic centre, Magellanic clouds)
- **All but one (59 of 60) GCNS-selected candidates were confirmed as FBWDs**
  - their EDR3 proper motions were confirmed with external data
  - 52 of 59 were also measured in PS1 or Legacy surveys (22 in both) as blue objects
  - 13 of 60 were not listed in WD catalogue of **Gentile Fusillo et al. (2021)**
- **FBWDs form a real sequence in Gaia CMDs**
  - of rare objects (0.25% of all WDs) – similar to number of halo WDs
  - with relatively high proper motions and tangential velocities
  - possibly containing old and very massive WDs (cf. **Cheng et al. 2019, Kilic et al. 2021**)
  - most likely representing IR-faint (ultracool) WDs (cf. **Kilic et al. 2020**)

FBWDs = ultra-massive WDs in general relativity ? **Althaus et al. (2022)**

their Fig. 5a:

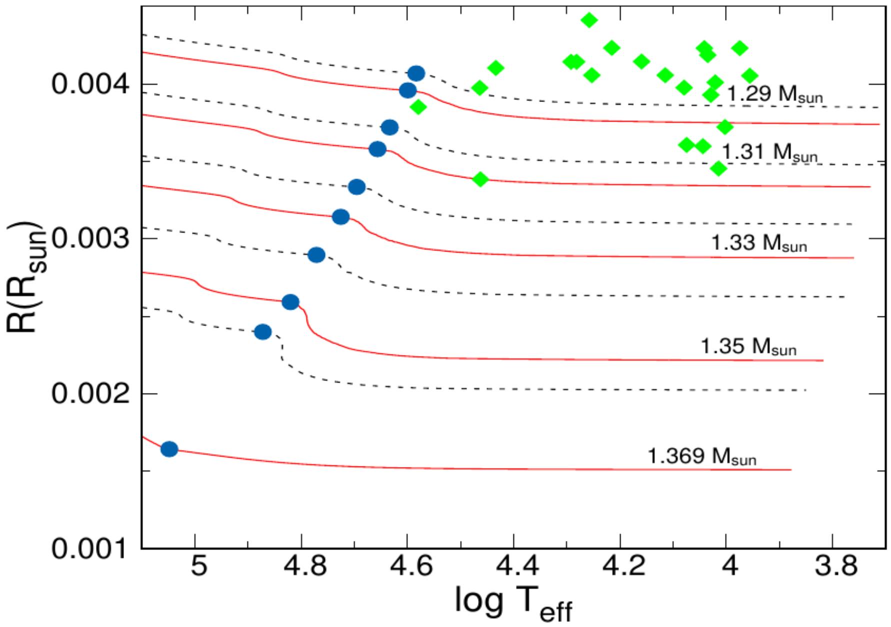
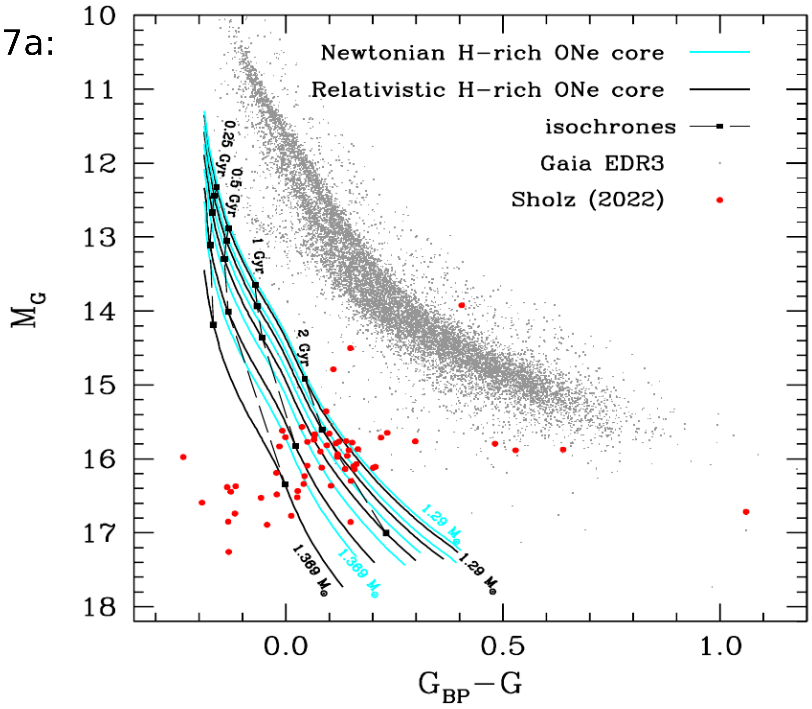


Fig. 7a:



Dotted lines: Newtonian case
Red solid lines: general relativity case
Blue circles: onset of core crystalisation
Green diamonds: most massive WDs of **Kilic et al. (2021)**

Cyan lines: Newtonian cooling sequences
Black lines: general relativistic cooling sequences
Grey dots: Gaia WD population within 100 pc
Red circles: FBWDs of **Scholz (1922)**