Stellar archaeology with Gaia: the galactic white dwarf population

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Gaia WGB6

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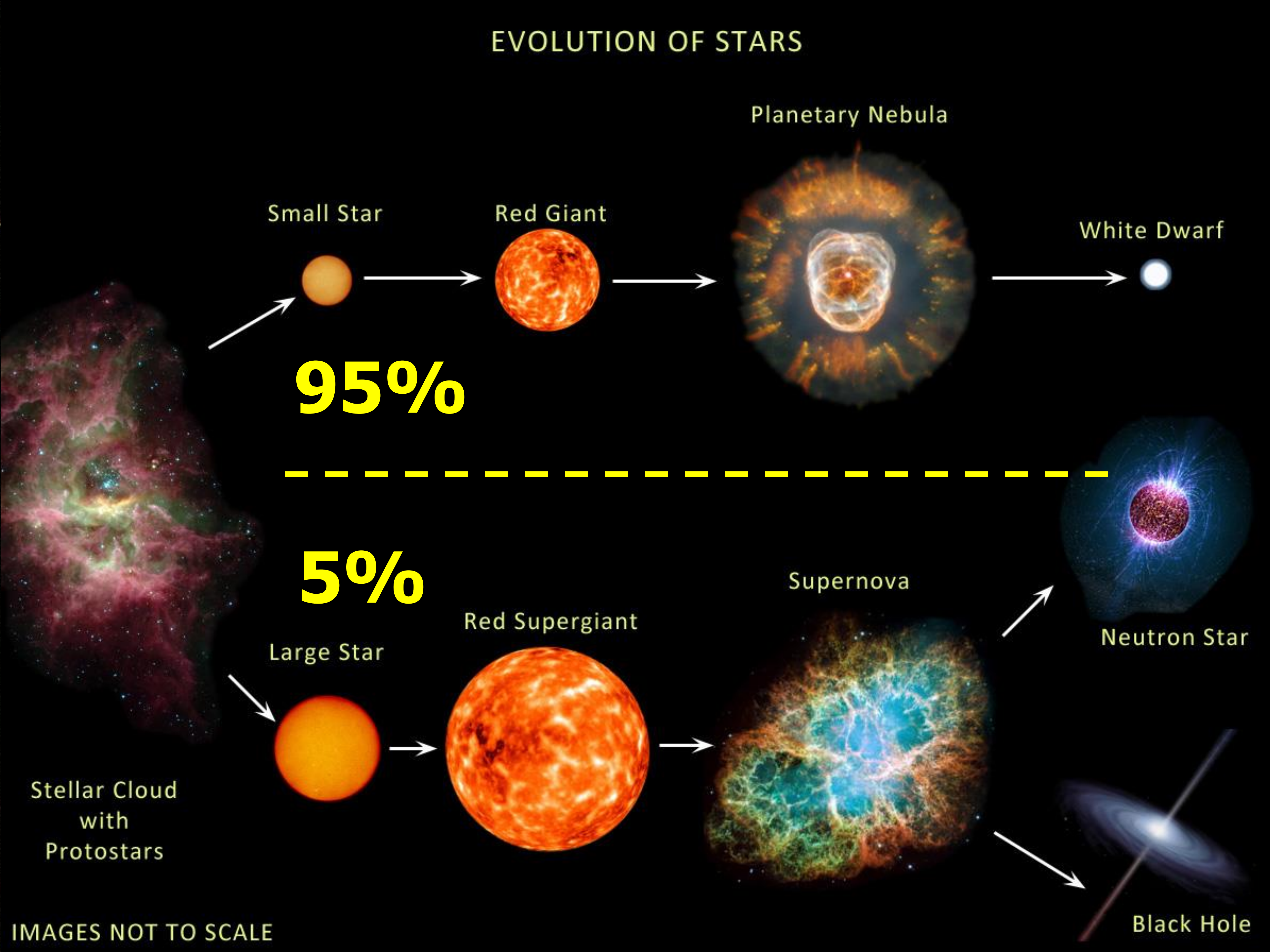
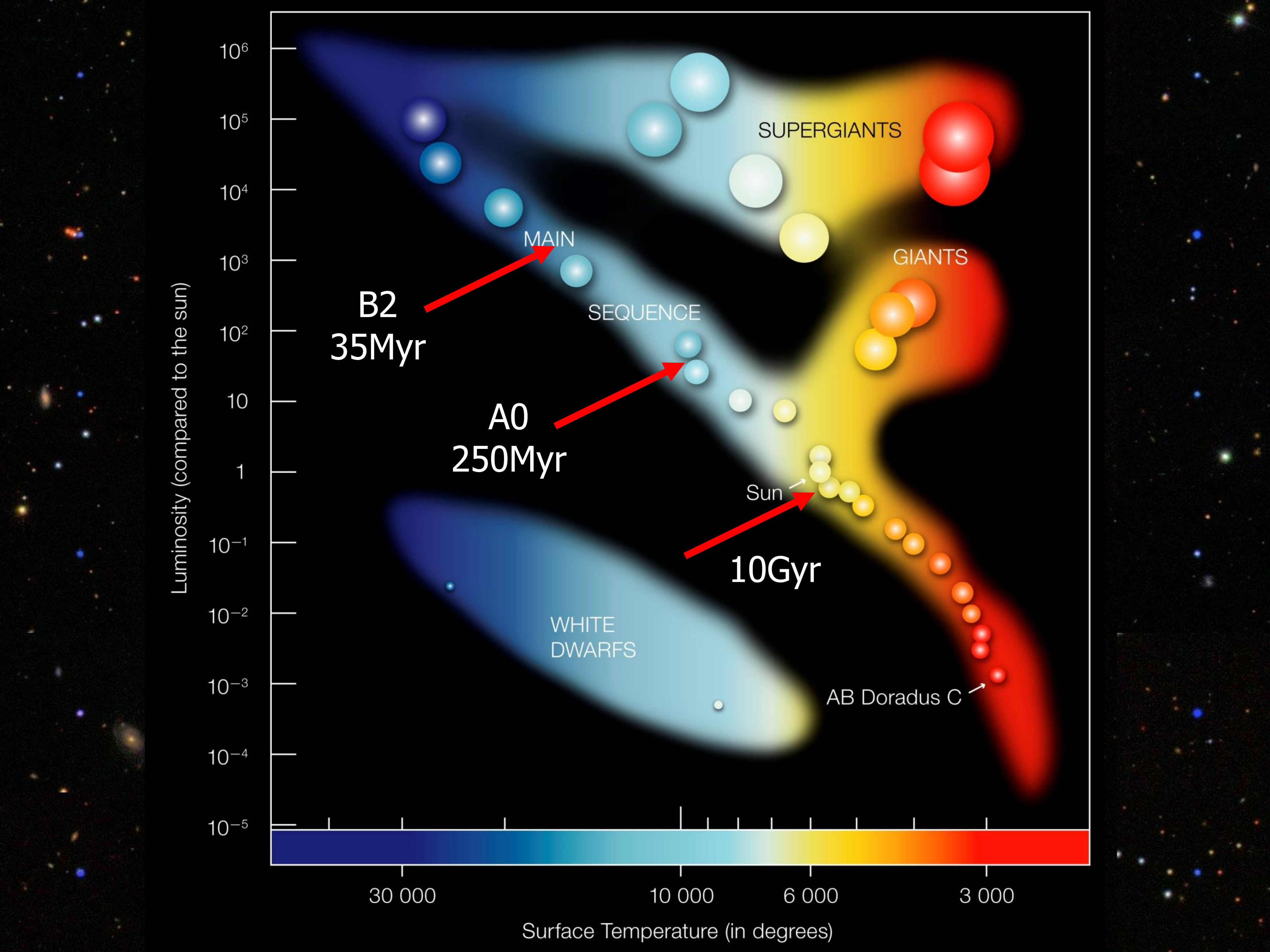
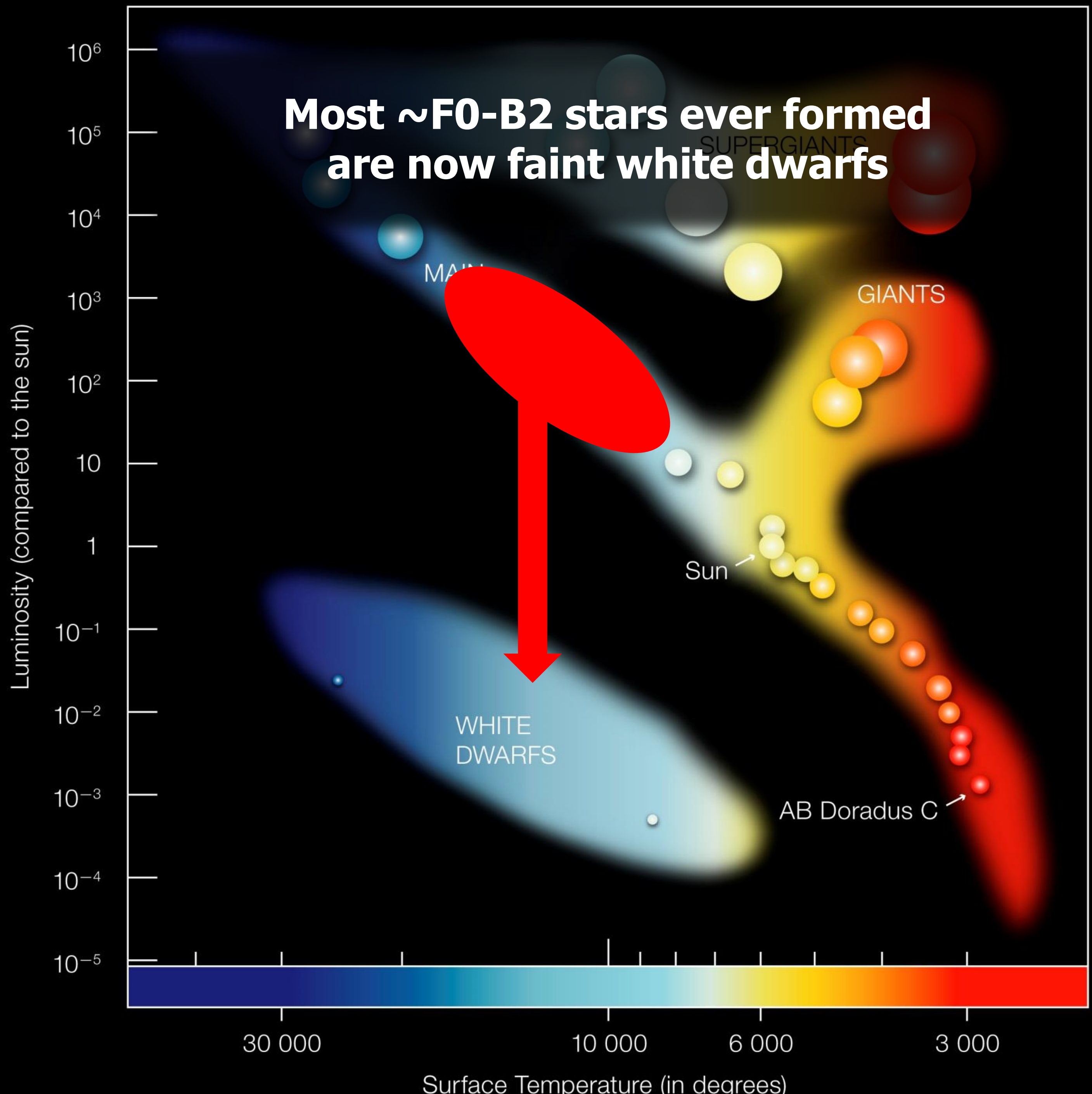

EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
95%
5%
Supernova
Red Supergiant
Large Star
Neutron Star
Stellar Cloud
with
Protostars
Black Hole
IMAGES NOT TO SCALE



SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
Sun
AB Doradus C
B2
35Myr
A0
250Myr
10Gyr
Luminosity (compared to the sun)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
30 000
10 000
6 000
3 000
Surface Temperature (in degrees)

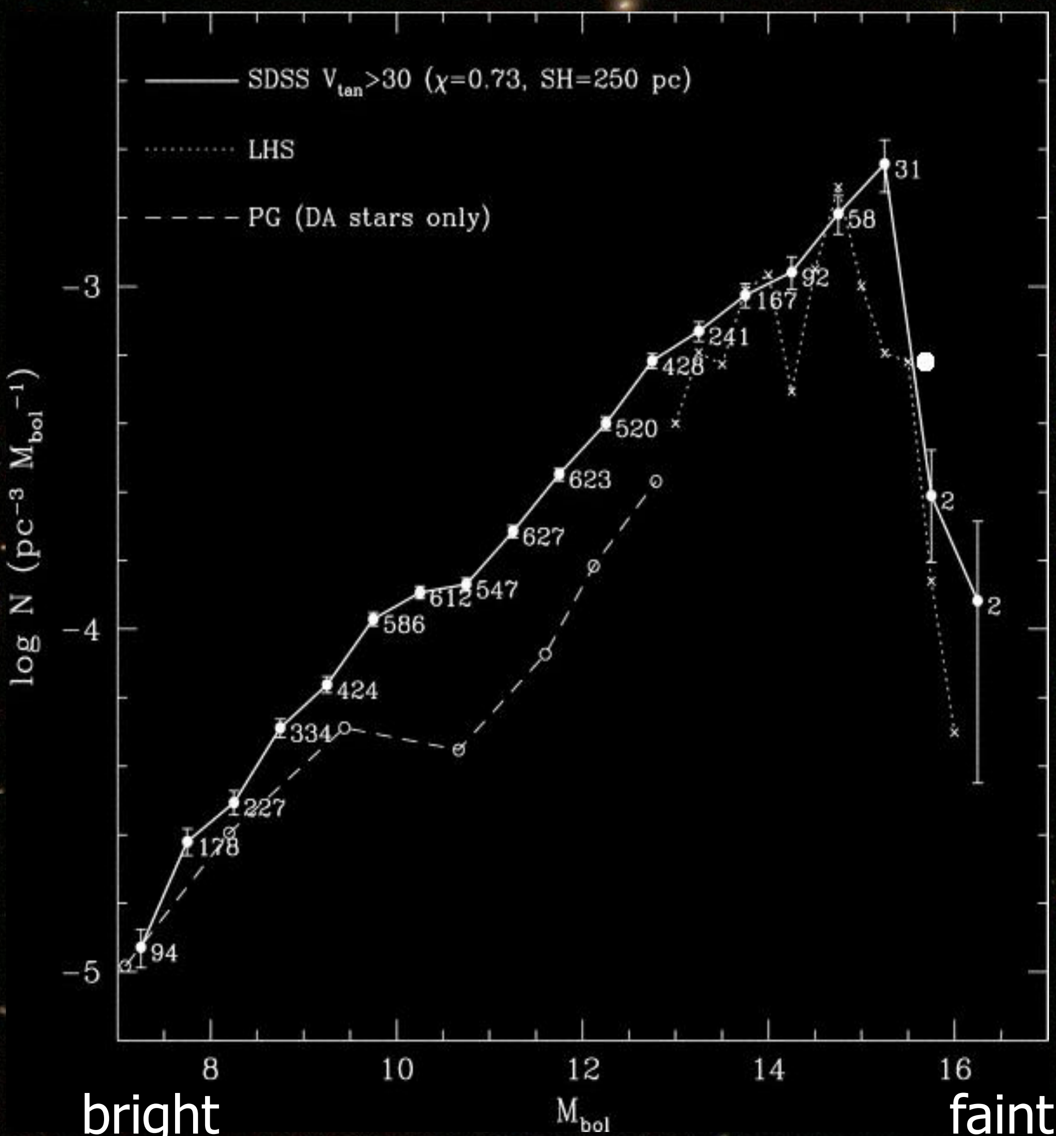
Most ~F0-B2 stars ever formed are now faint white dwarfs



Stellar archeology

- ~95% of all stars end as white dwarfs
- Teff, mass ⇒ cooling age ⇒ (stellar models) ⇒ total age
- Key population to probe star formation history

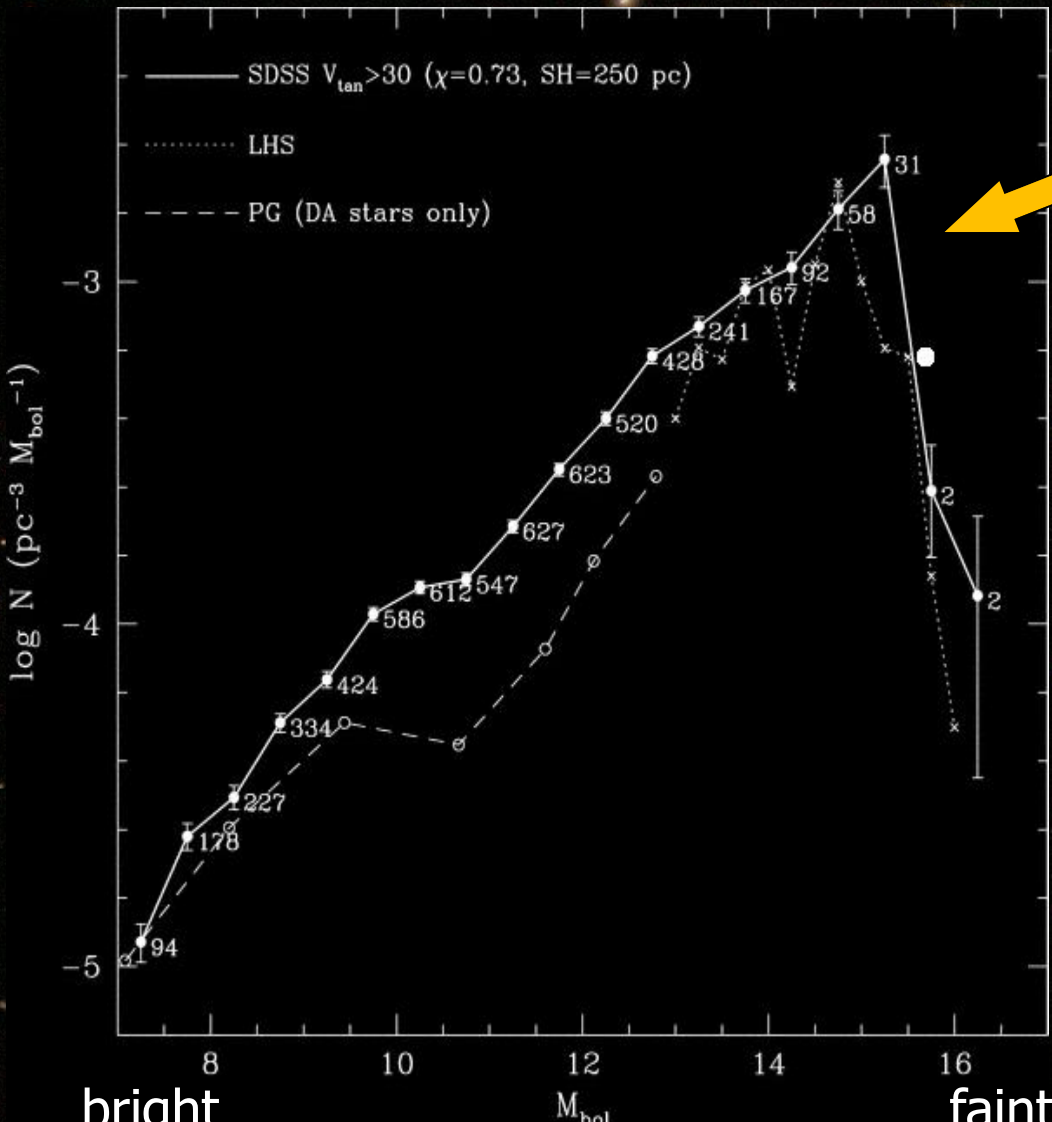
White Dwarf Luminosity Function



bright
hot
young

faint
cool
old

White Dwarf Luminosity Function



bright
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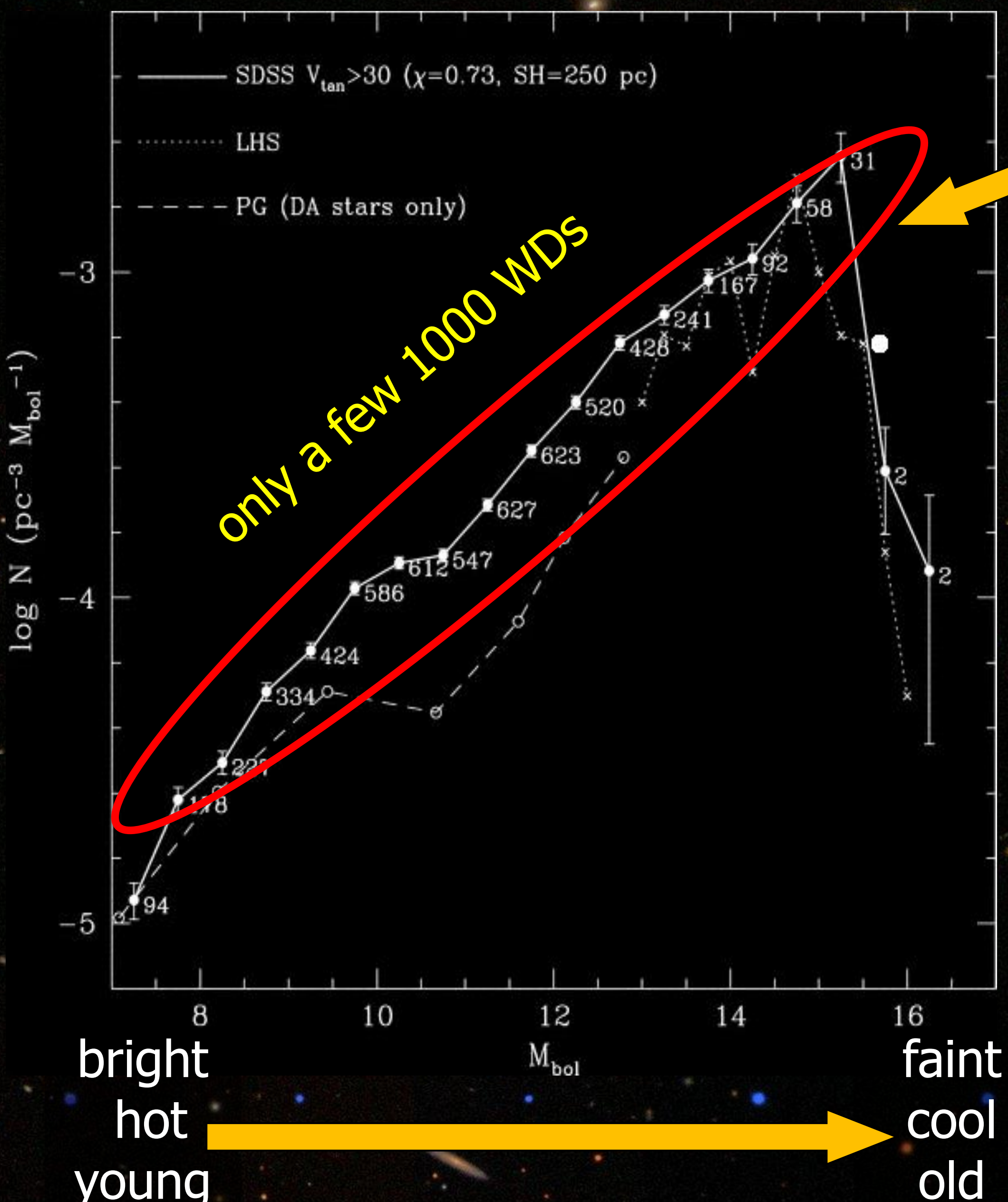
Cut-off at faintest, coolest, oldest white dwarfs

Cut-off in the white dwarf luminosity function due to the limited age of the Galaxy

Even the oldest white dwarfs (9-11 Gyrs) are still visible in the solar neighborhood

⇒ Measure the age of the Galaxy (e.g. Oswalt et al. 1996, *Nature* 382, 692)

White Dwarf Luminosity Function



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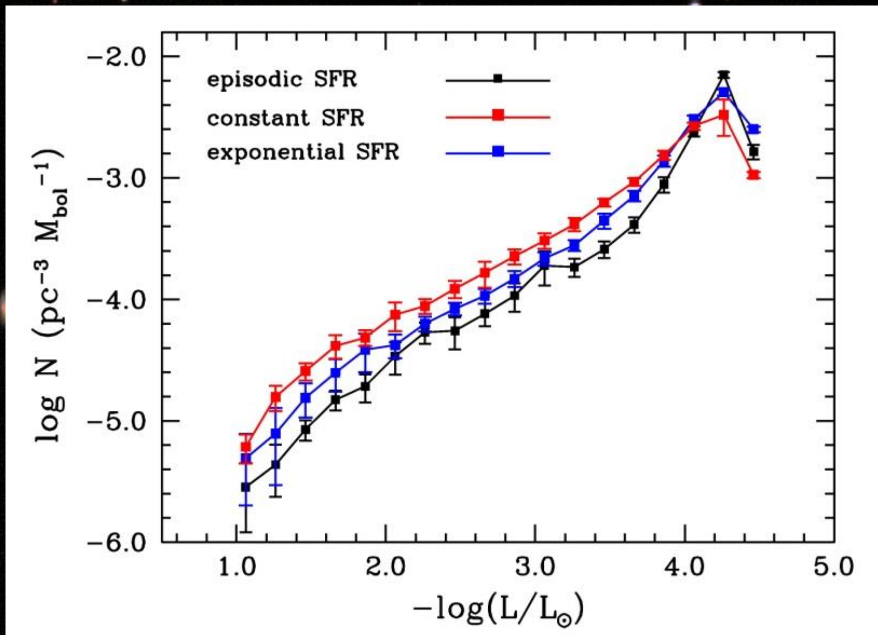
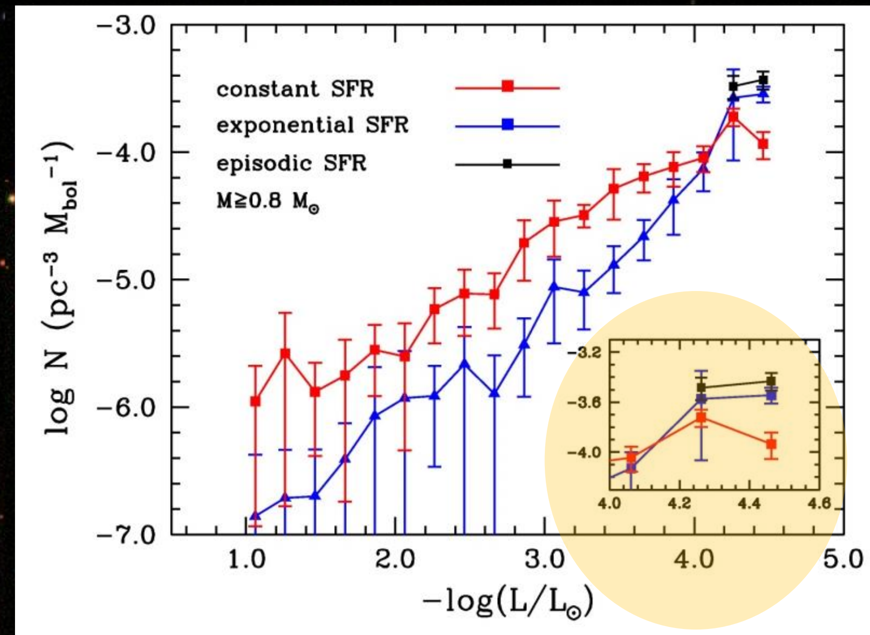
$\Rightarrow$ Measure the age of the Galaxy (e.g. Oswalt et al. 1996, *Nature* 382, 692)

Luminosity functions from non-standard SFR as $f(M_{wd})$

All white dwarfs



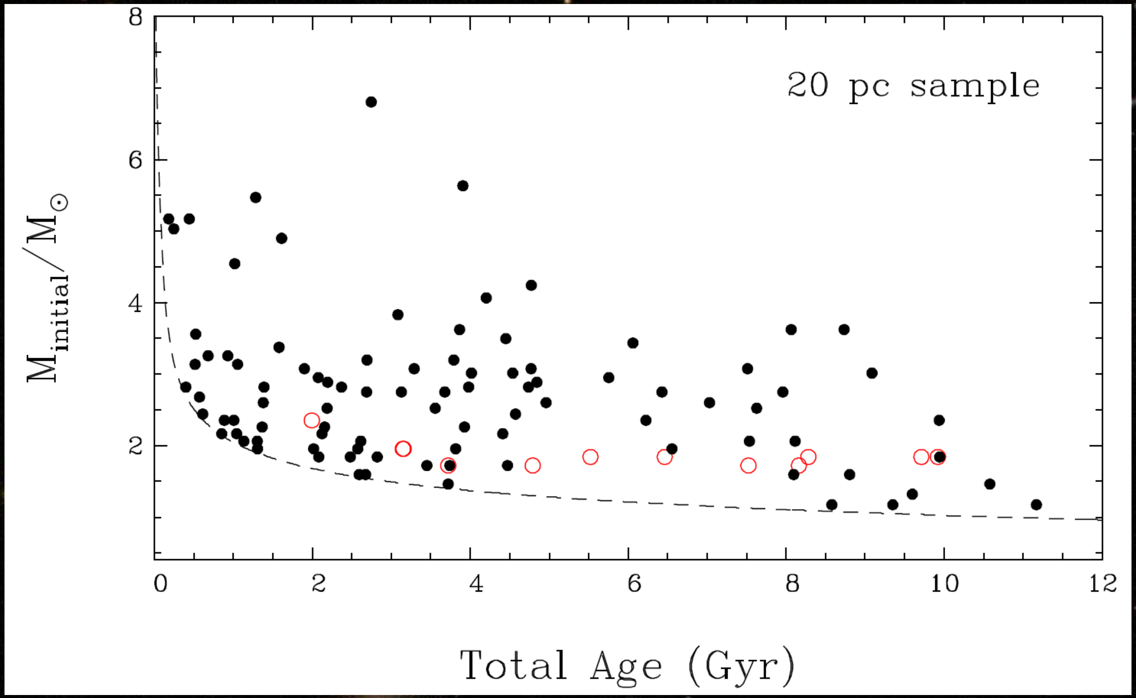
Massive WD=early-type progenitors

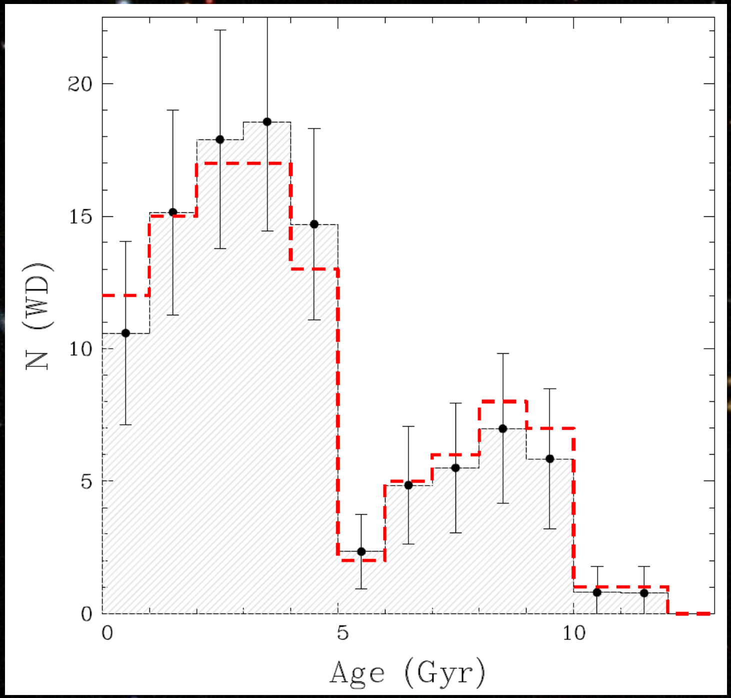


1 - Exponential SFR: $\Psi \approx \exp(-t/\tau)$ where τ=25Gyr
2 - Episodic SFR: 1 Gyr after the formation of the disk, lasting for 3 Gyr

Massive white dwarfs rapidly track changes in SFR

The local sample: 117 white dwarfs within 20pc



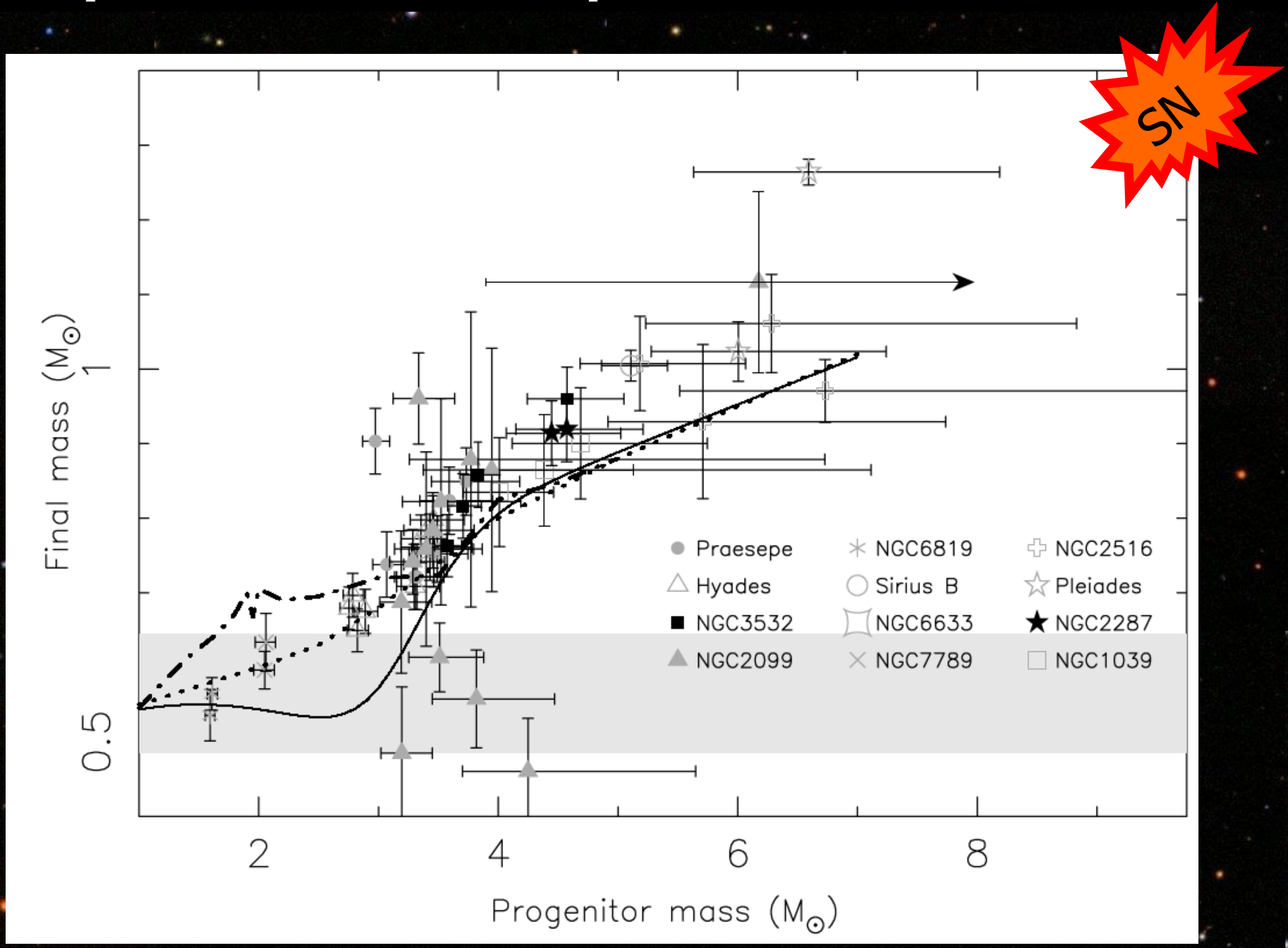


Tentative evidence of enhanced star formation over the past ~5Gyr

Tremblay et al. 2014, ApJ 791, 92

The initial-mass final-mass relation

mostly based on WDs in open clusters & stellar models



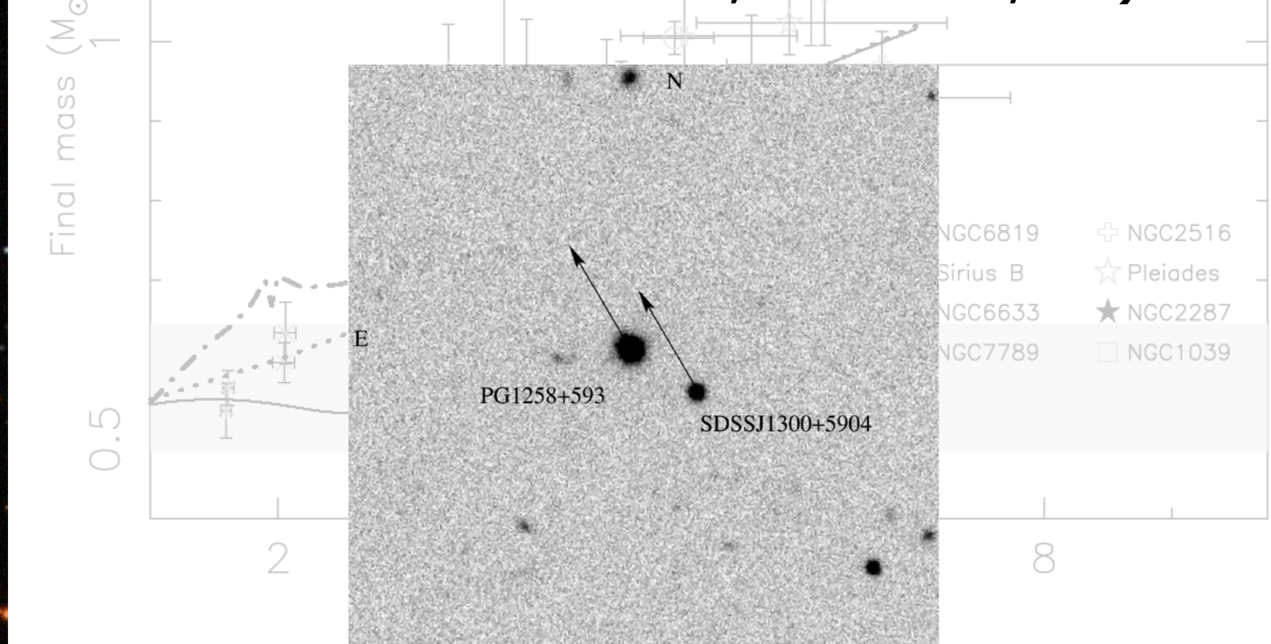
Dobbie et al. 2009, MNRAS 395, 2248

The initial-mass final-mass relation

mostly based on WDs in open clusters & stellar models

Gaia ⇨ IMFM relation from common proper motion pairs

**(e.g. Catalan et al. 2008, A&A 477, 213;
Girven et al. 2010, MNRAS 404, 159)**



Dobbie et al. 2009, MNRAS 395, 2248

Stellar archeology

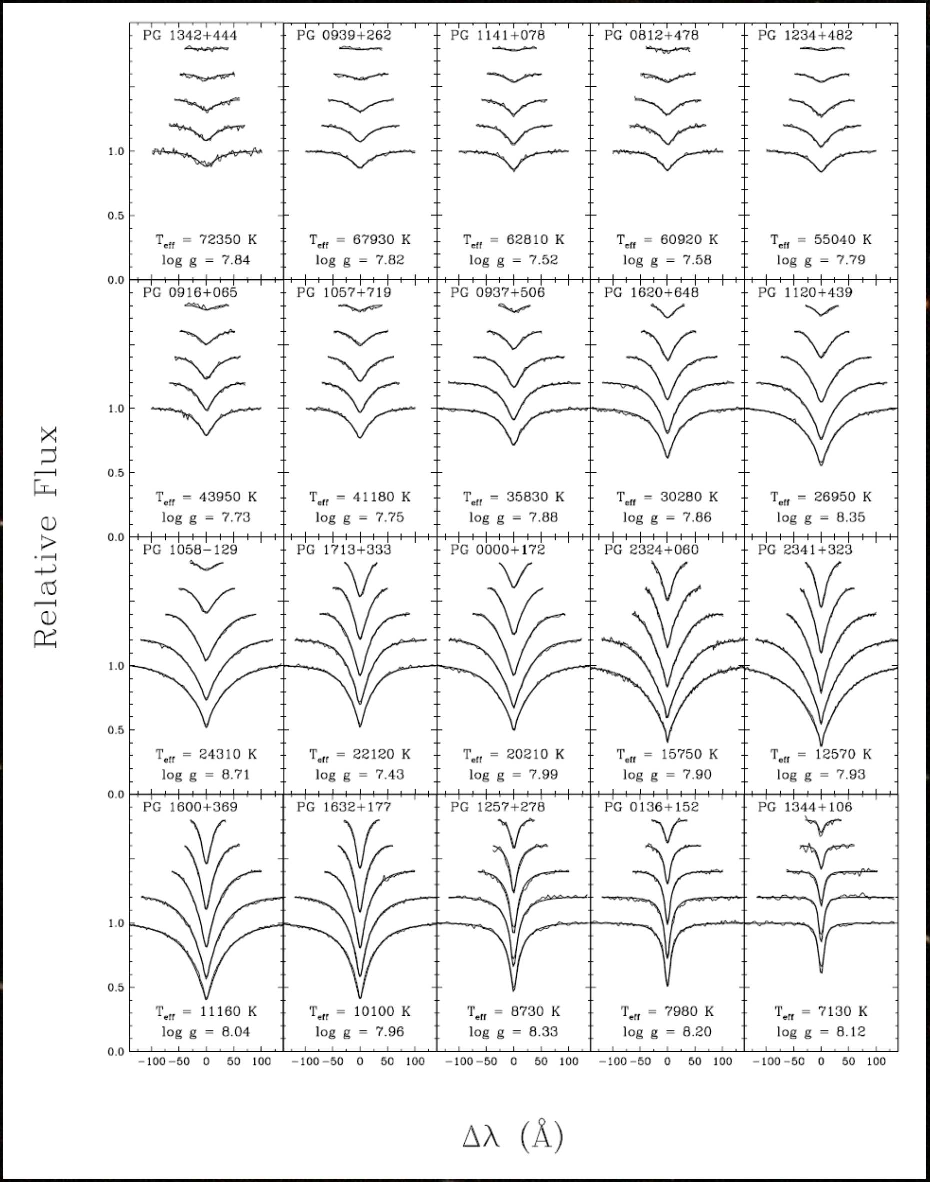
- Gaia will identify ~400,000 white dwarfs
- *100% complete within ~50pc*, 50% within ~300pc

- Initial-final mass relation ⇨ galactic life cycle of matter
- Luminosity function of thin/thick disc & halo
  ⇨ star formation rate history
- Add main-sequence star counts ⇨ initial mass function

Need temperatures and masses for Gaia WDs

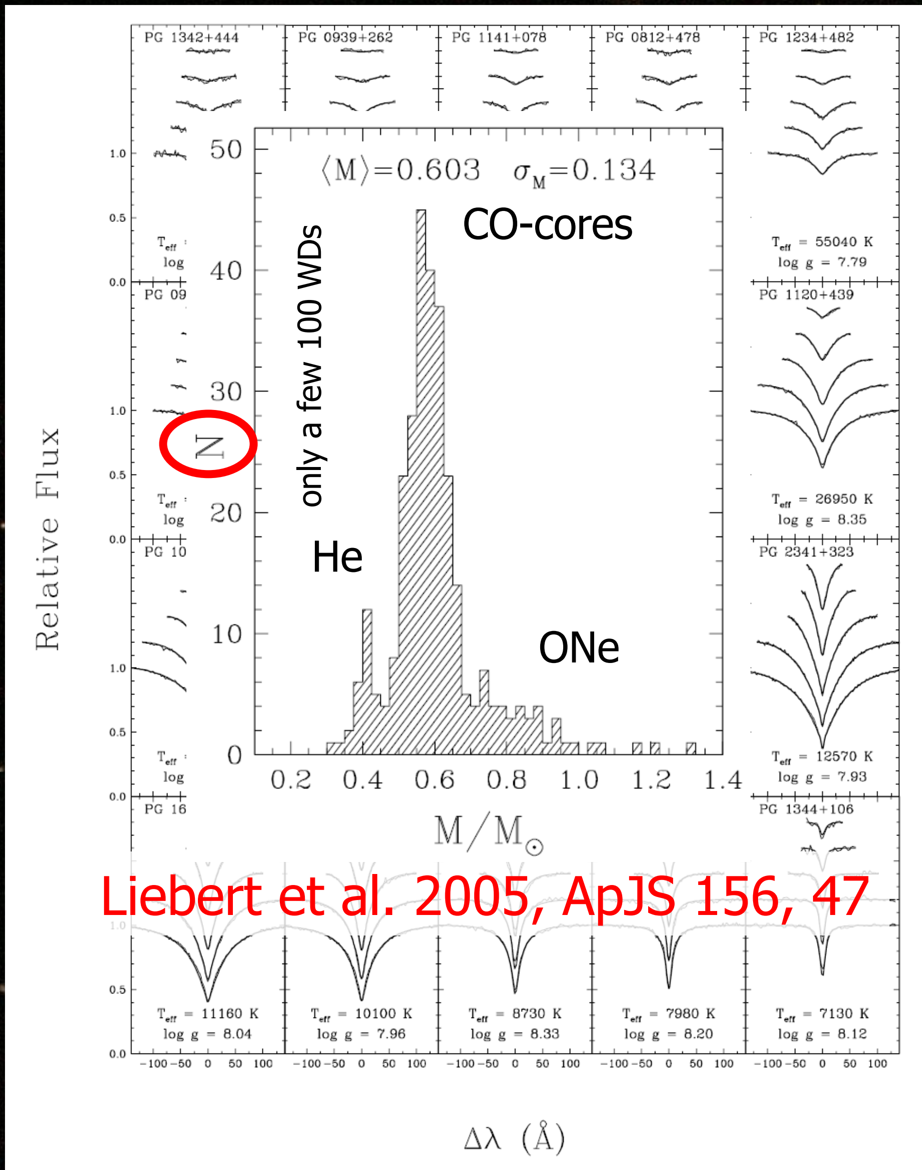
(see e.g. Torres et al. 2005, MNRAS, 360, 1381; Jordan 2007, ASP Conf. Series, 372, 139)

Spectroscopic mass measurements



- Teff and log g from fitting spectral models to the Balmer lines
- Higher Balmer lines essential for accurate log g (Kepler et al. 2006, MNRAS 372, 1799)
- Evolution sequences provide the cooling age, mass, radius
- Gaia distances will improve accuracy

Only ~1000 white dwarfs with accurate masses!



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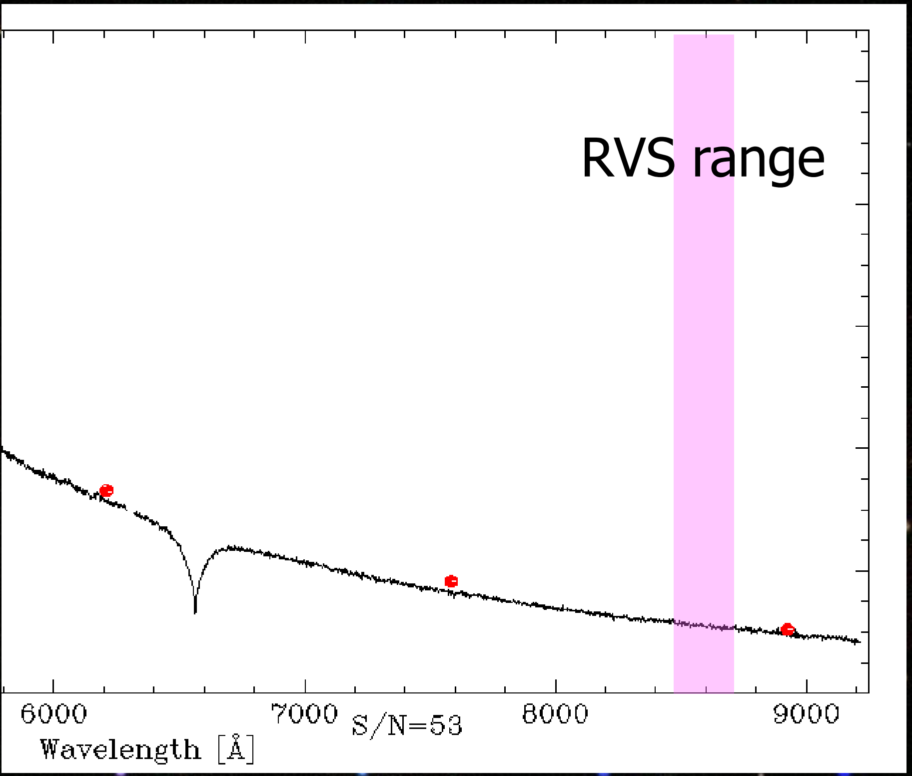
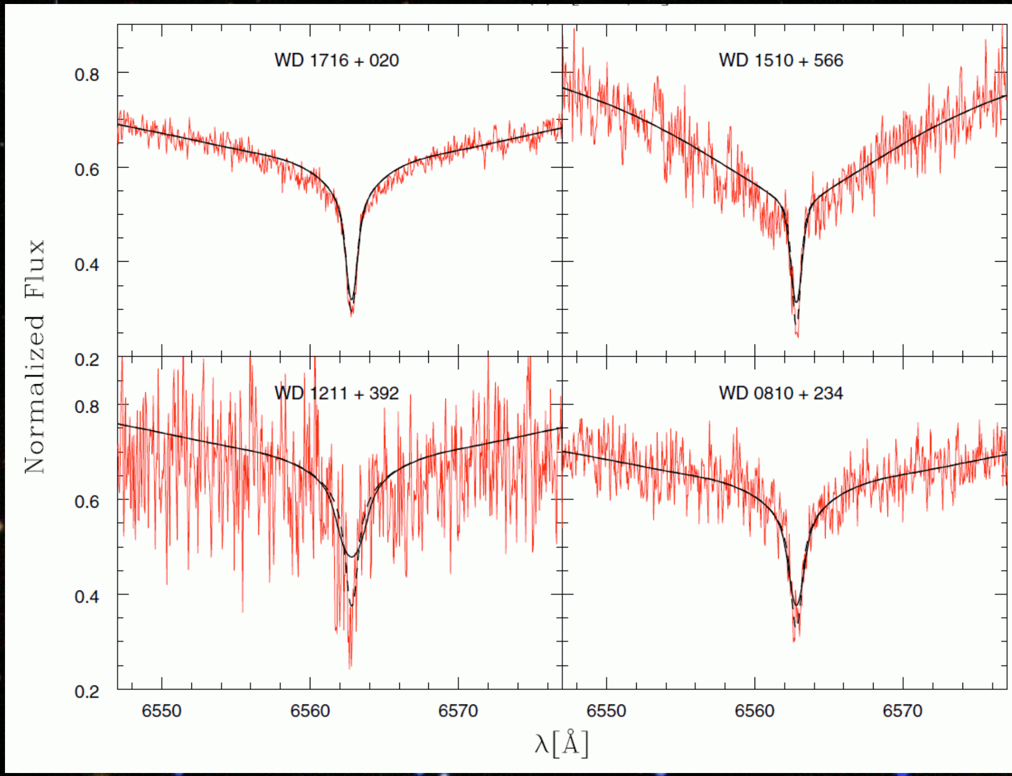
- Gaia BP/RP too low resolution for spectral modelling!

intermediate (R~5000) resolution spectroscopy covering 3800–6800Å

GAIA RVS data provide *no* radial velocities for WDs!

... necessary for full 3D velocity / galactic orbit reconstruction ....





(Karl et al. 2005, A&A 434, 637)

intermediate resolution (R~5000) spectroscopy of the sharp Hα NLTE core

Outliers (aka oddballs, freak stars...)

Short-lived phases in white dwarf evolution and the extremes of parameter space are *rare!*

- Hot carbon-rich white dwarfs : merger products, "failed SNIa"
  (Dufour et al. 2007, *Nature* 450, 522)
- Dynamically active planetary debris disks around white dwarfs
  (Gänsicke et al. 2006, *Science* 314, 1908)
- End states of close binary evolution
  (Littlefair et al. 2006, *Science* 314, 1578)
- Bare oxygen-neon cores, descending from near the core-collapse boundary
  (Gänsicke et al. 2010, *Science* 327, 188)
- Detection of water-bearing extra-solar asteroids
  (Farihi et al. 2013, *Science* 342, 218)

Conclusions

Gaia will identify a few 100000 white dwarfs

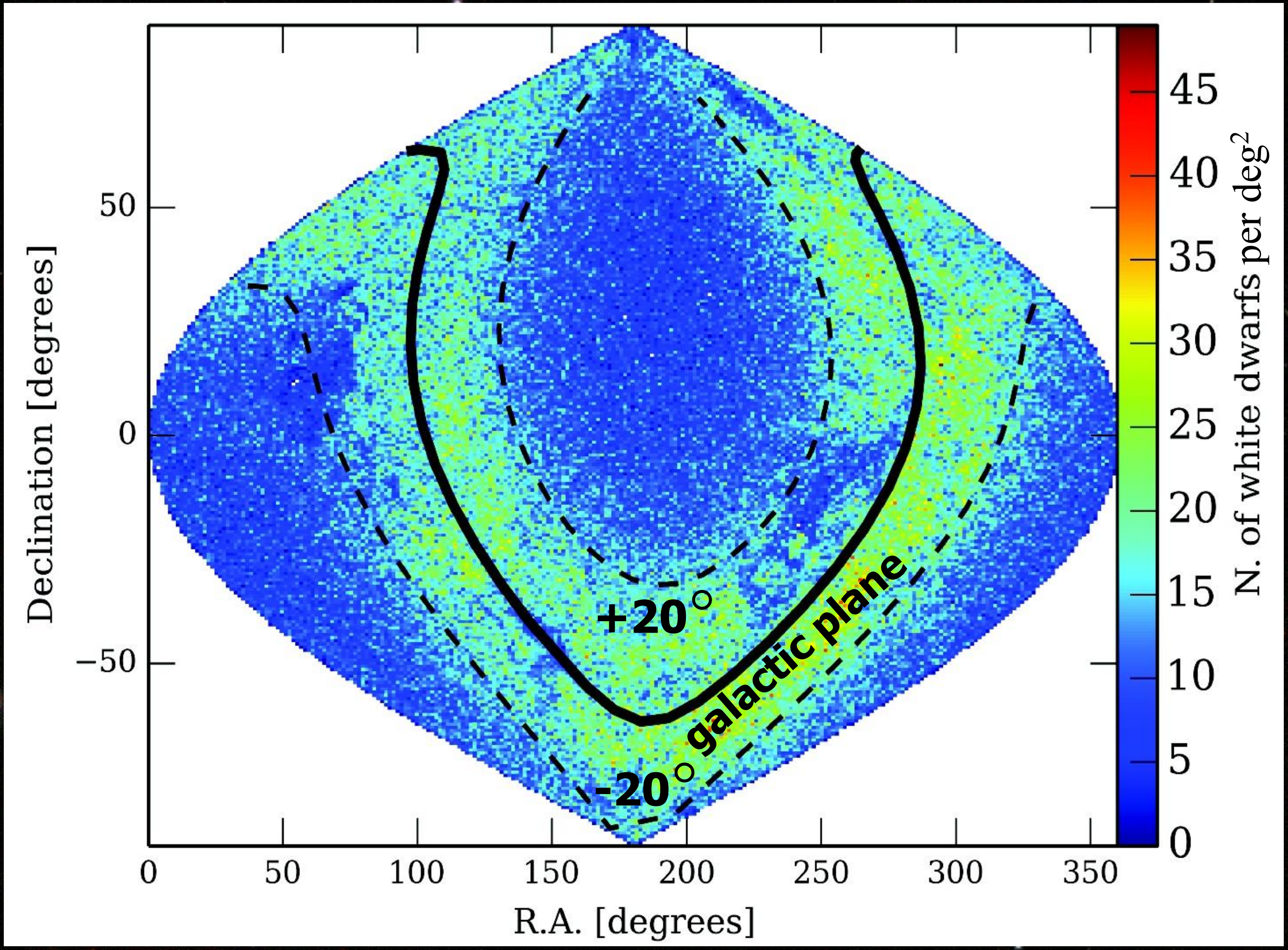
- Accurate mass-dependent luminosity function as tracer of galactic SFR
- Initial-to-final mass relation in HD
- Huge resource for stellar, binary & planetary evolution

Gaia follow-up requirements:

- Blue coverage down to ≈ 3800Å ⇨ accurate Teff, mass, age
- Resolution $\lambda/\Delta\lambda \approx 5000$ ⇨ measure radial velocities from Hα

Gaia WD population G≤20 (GUMS-10)

~10-25 white dwarfs per deg^2



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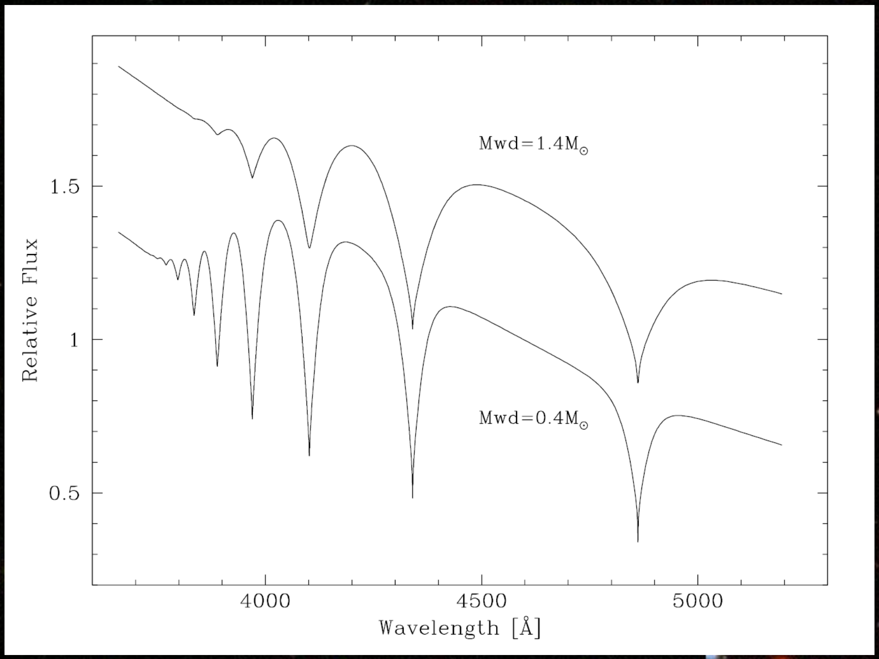
WEAVE / 4MOST / DESI:

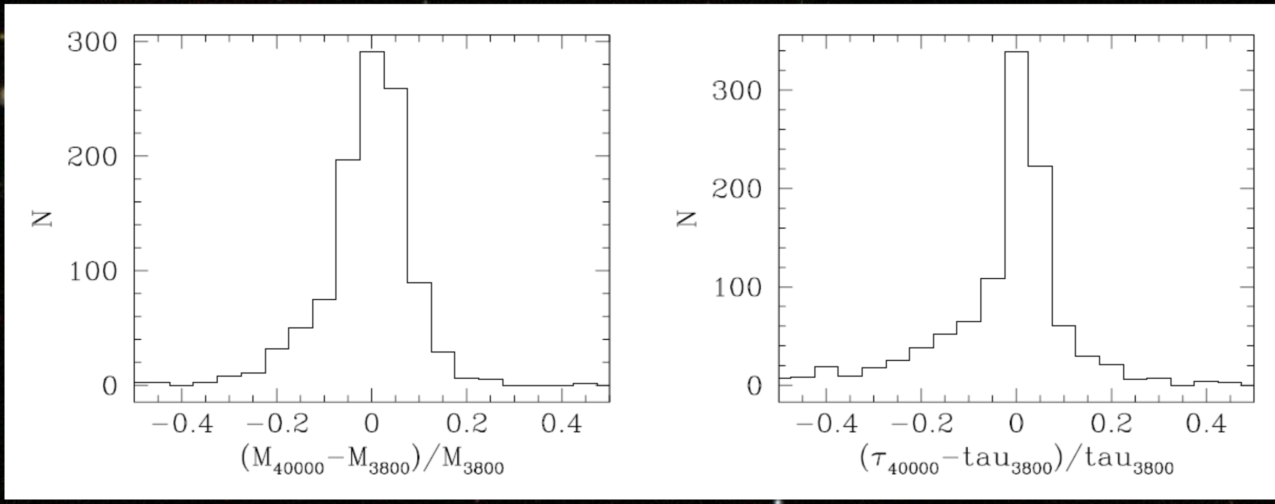
- ≈10-25 white dwarfs per square degree
- 1-3% of the fibres will be sufficient to observe *all* Gaiawhite dwarfs
- White dwarfs are excellent flux / telluric calibrators

Higher Balmer lines are essential for Mwd & Tcool

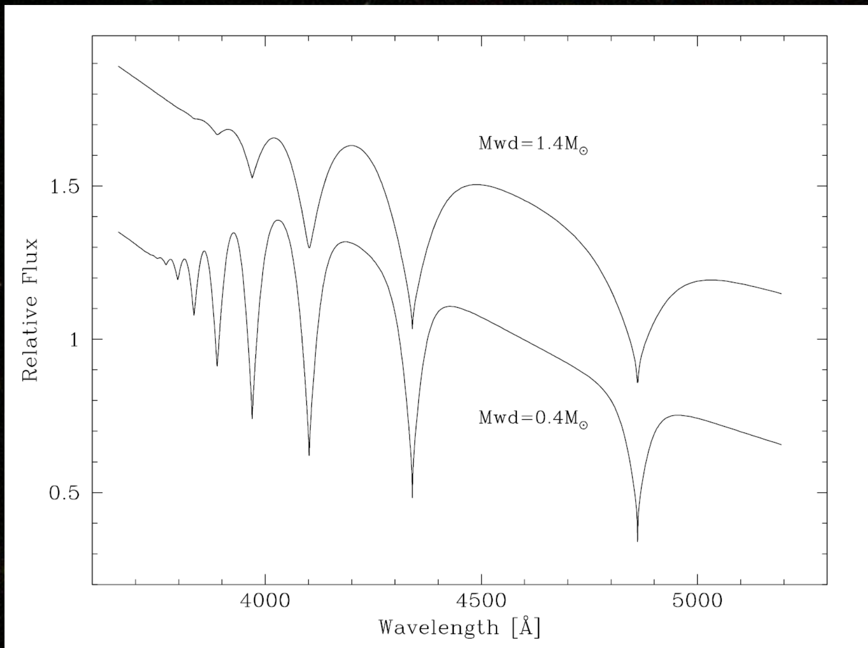


High & low mass WD @ T=20000K

A wavelength cut-off at ~4000Å would result in ~30% of all white dwarfs having mass / cooling age uncertainties > 10%, adding substantial noise to the GAIA white dwarf LMF!

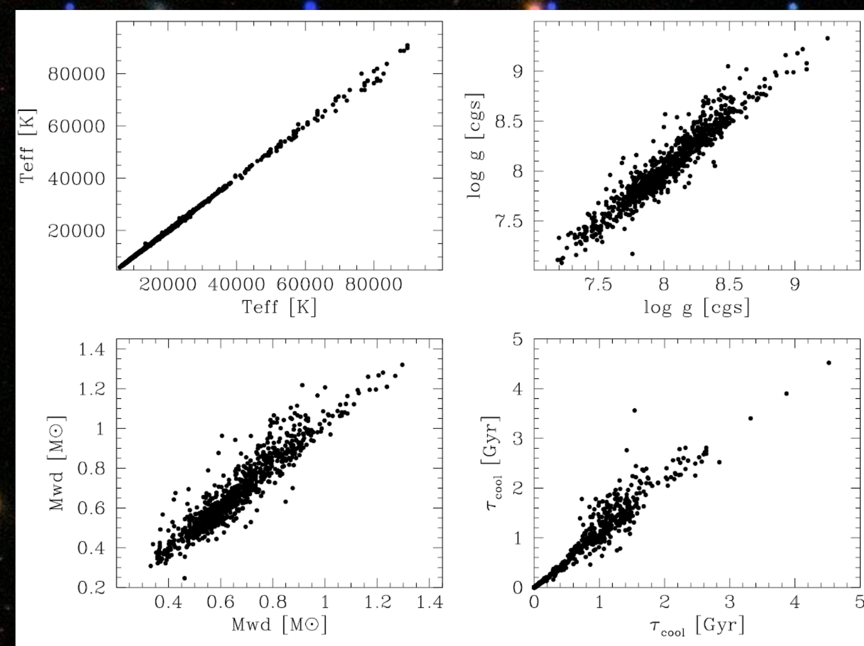


Higher Balmer lines are essential for M_{wd} & T_{cool}



High & low mass WD @ T=20000K

1100 white dwarfs from SDSS



Hα-Hε (3800-6800Å)

Hα - Hδ (4000-6800Å)