Magnetic field generation in polluted white dwarfs

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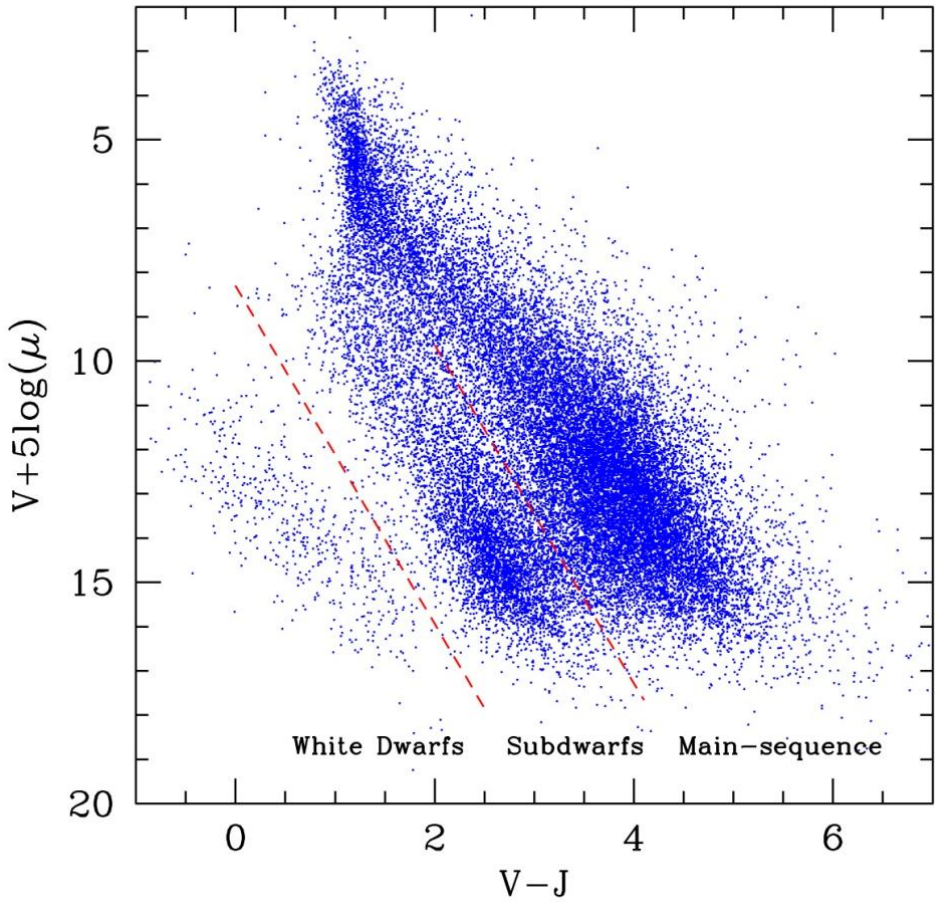
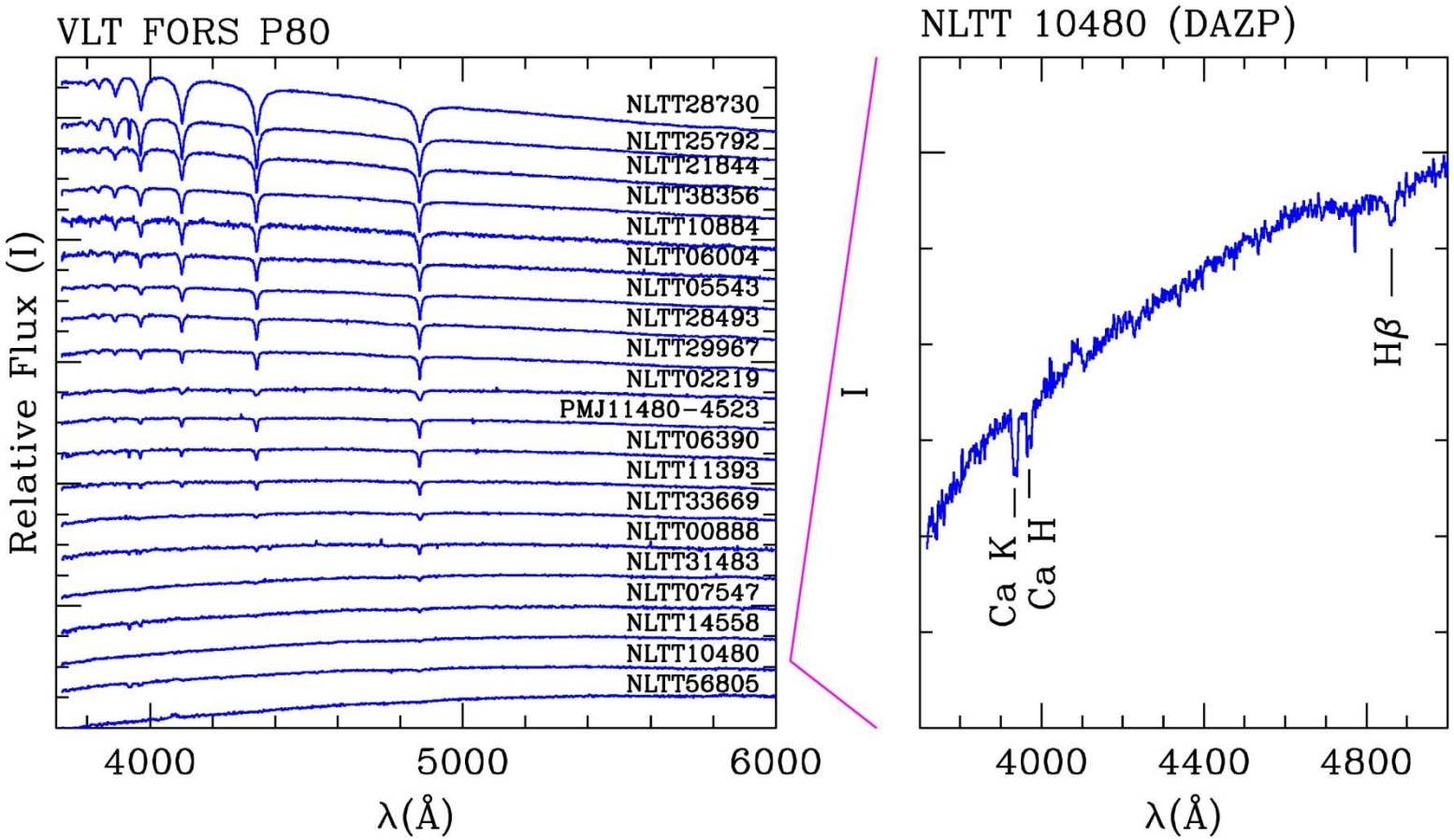
Selection criteria



- rNLTT: μ ≥ 0.2” yr^{-1} (Salim & Gould 2003)
- 35000+ stars
- Selection using the reduced proper motion (RPM) diagram
  - V+5log(μ) vs V-J
  - 400+ WD candidates
  - Obtained low dispersion spectroscopy for 200+ stars (>95% WDs) using NTT/EFOSC, VLT/FORS, CTIO, KPNO, SDSS, APO, SSO.

Sample of hydrogen-rich WDs



Kawka & Vennes (2012)

Kawka & Vennes (2011)

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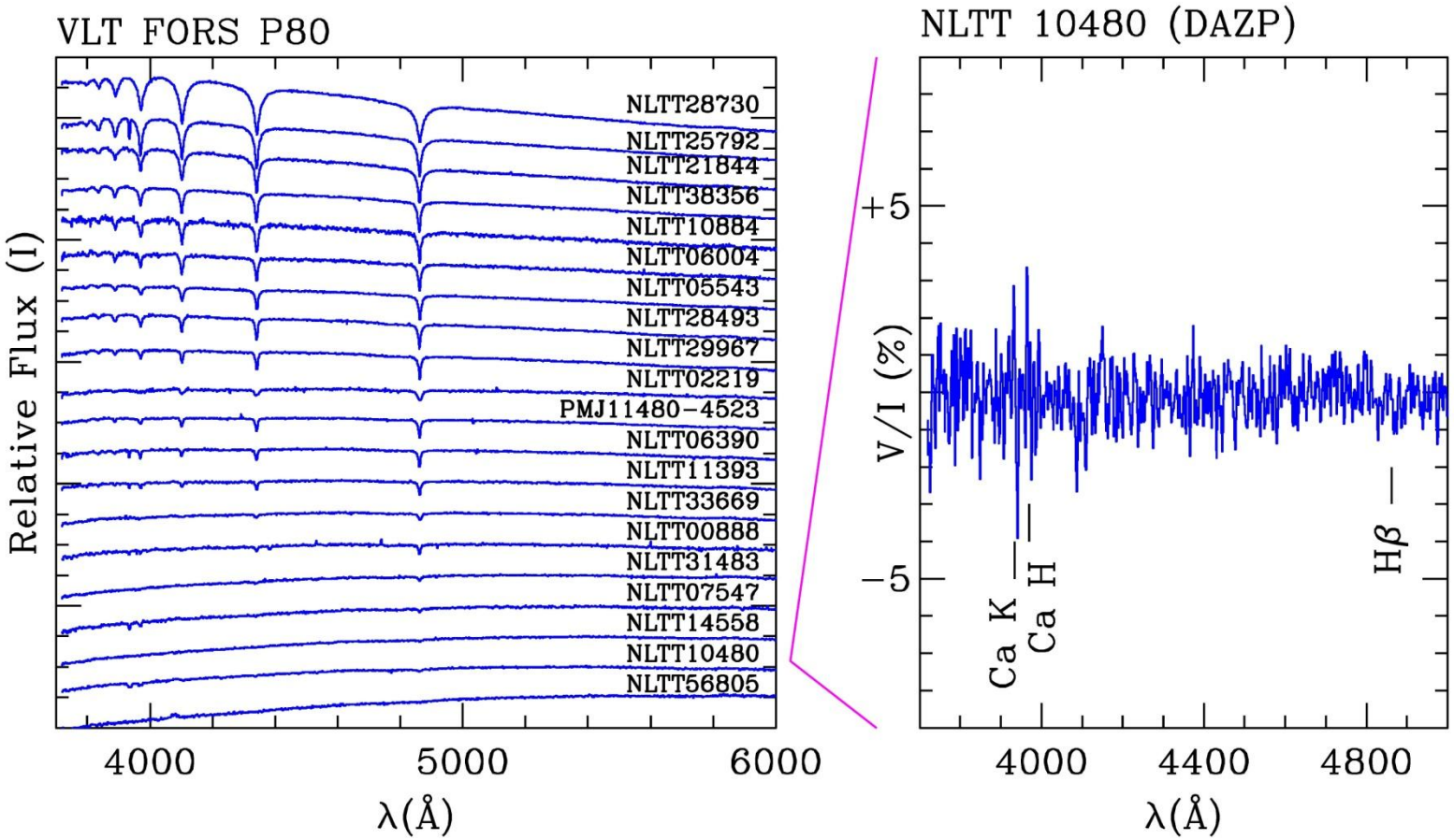

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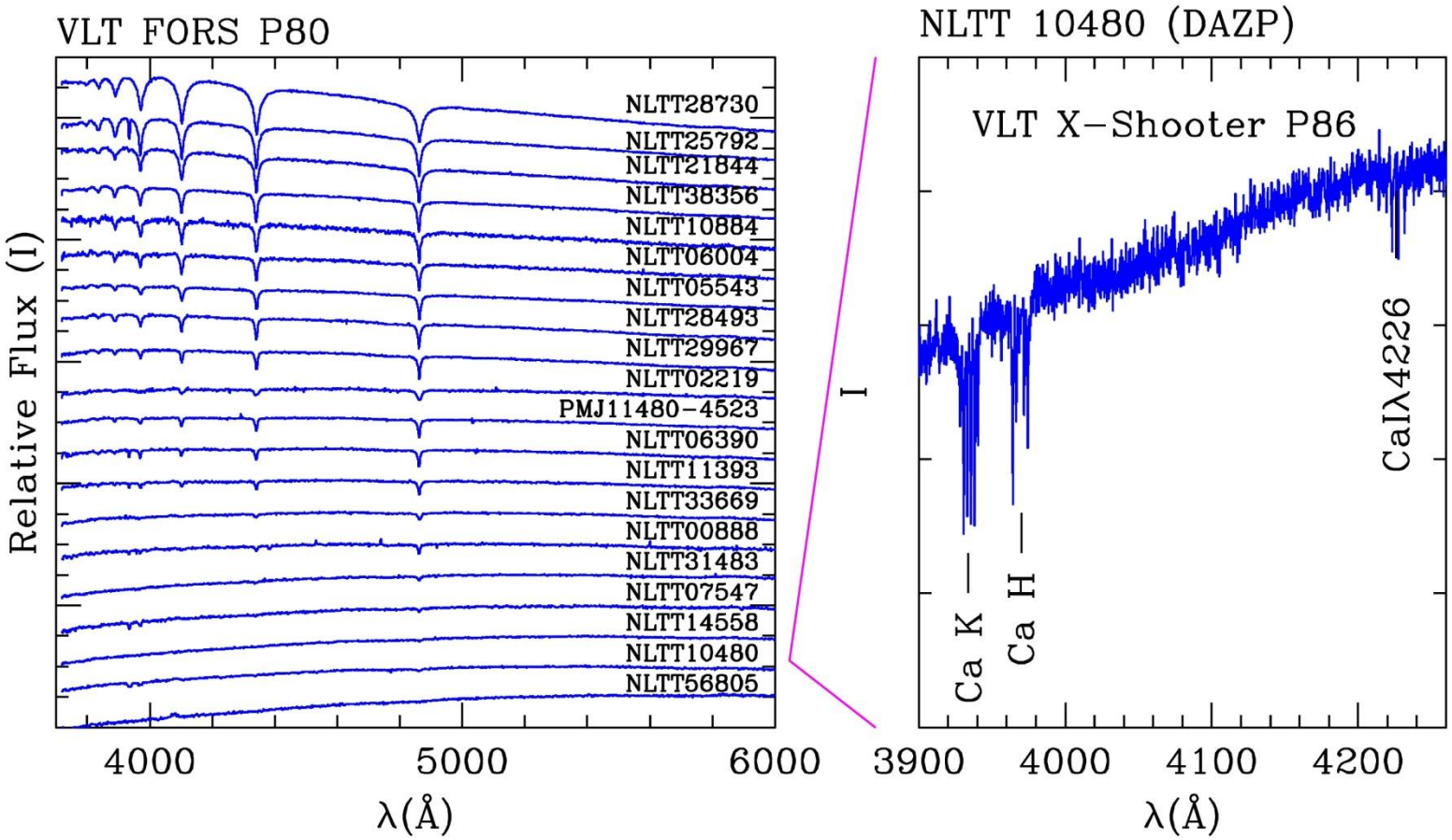

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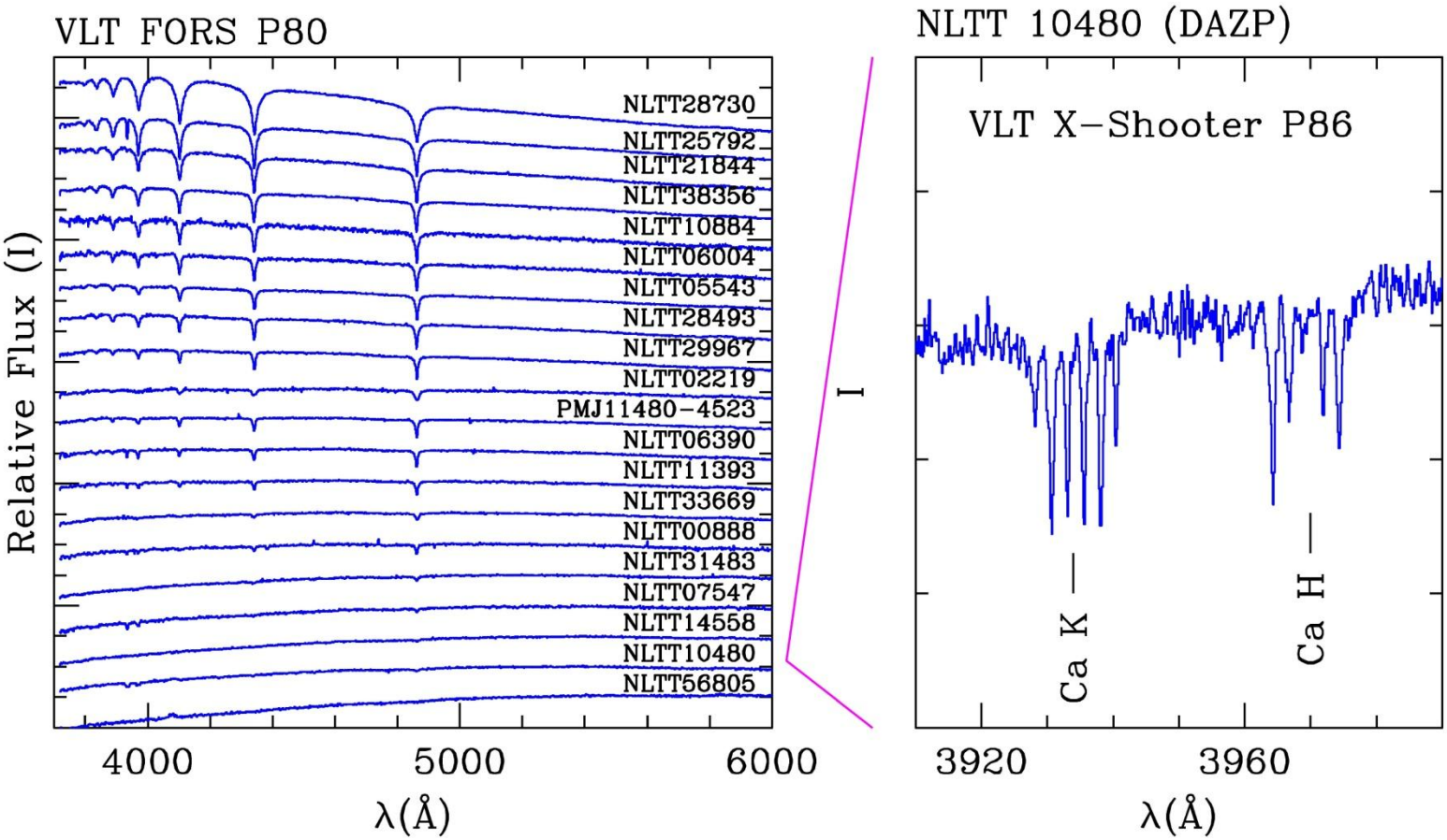

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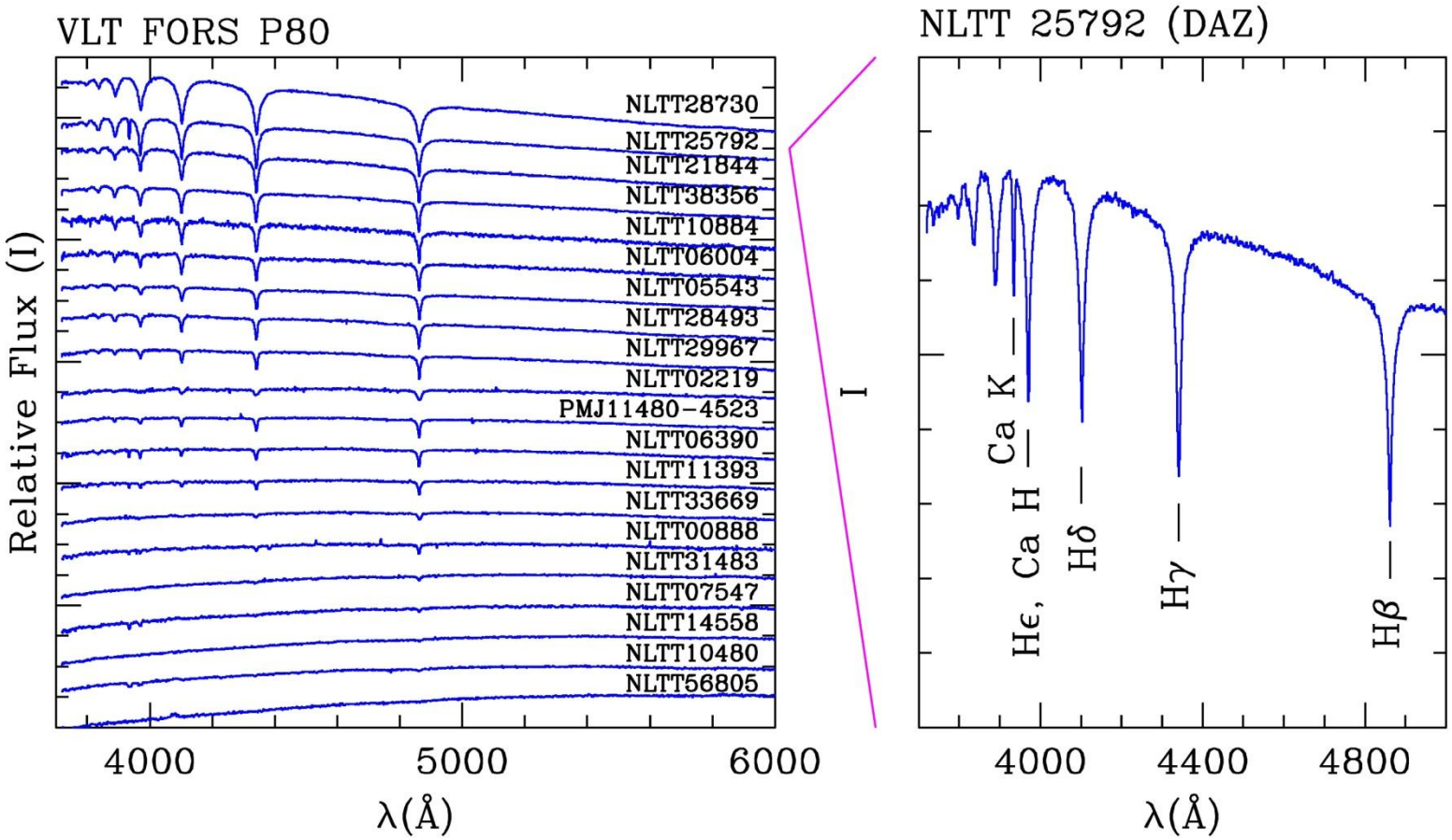

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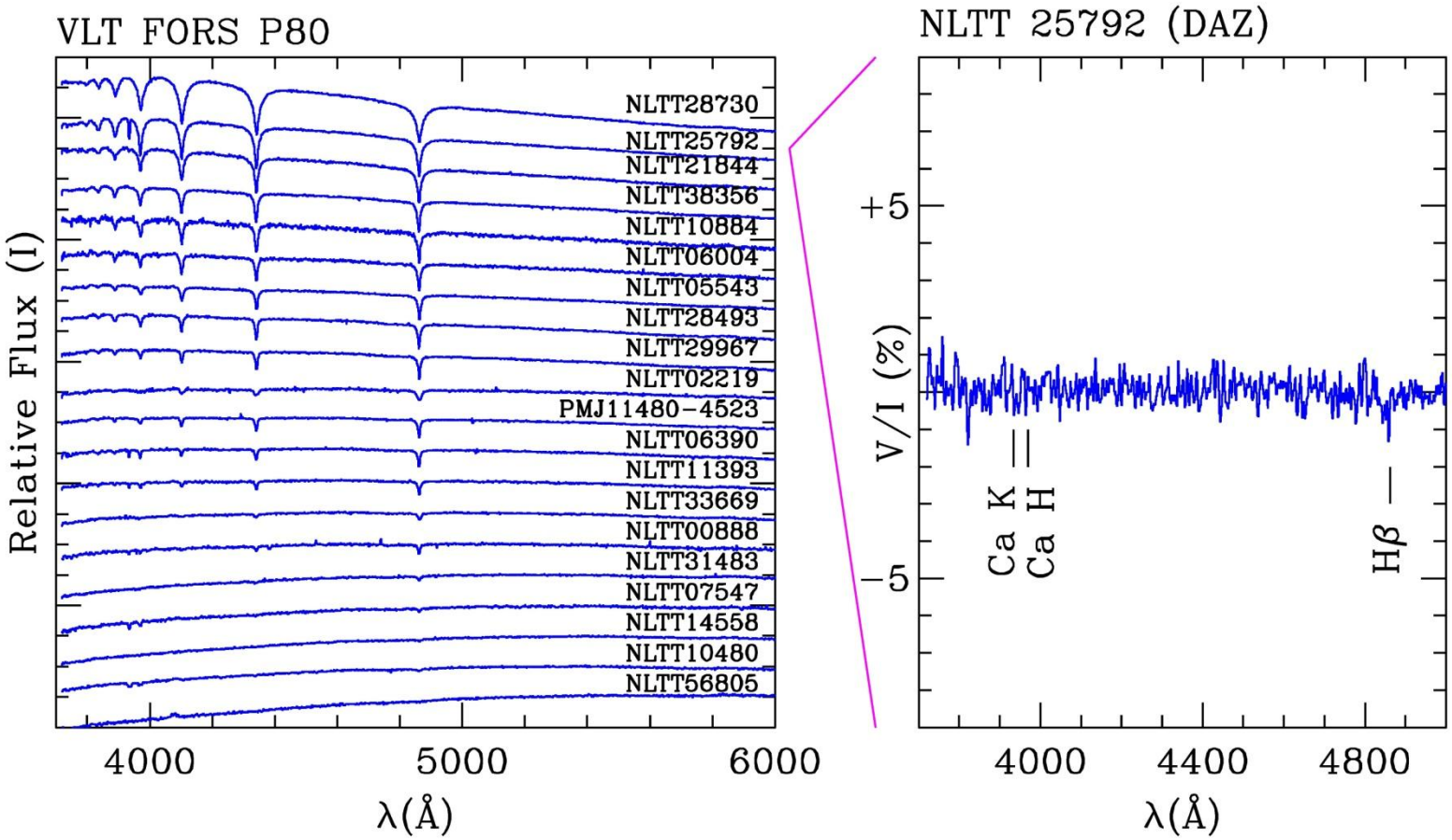

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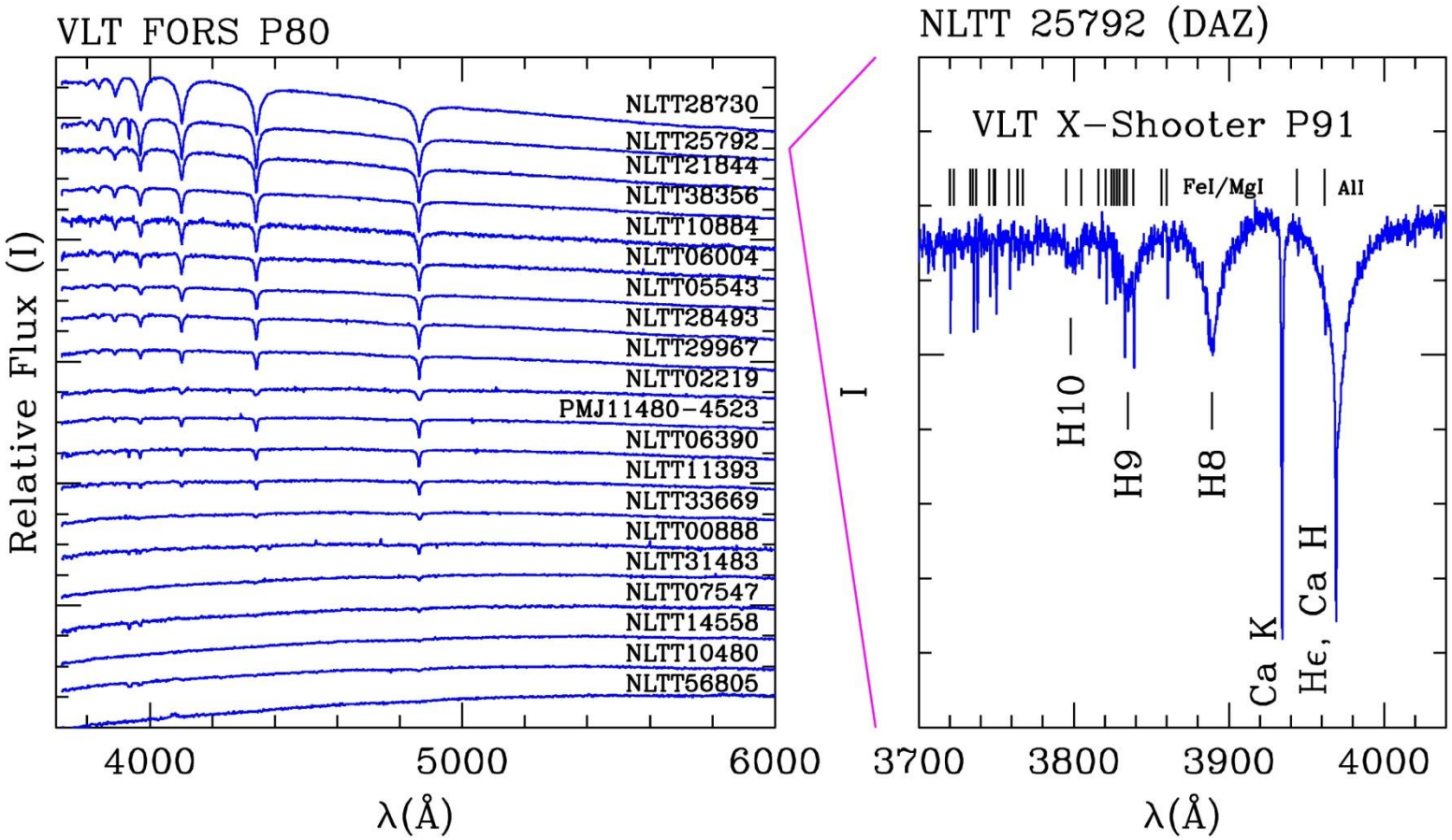
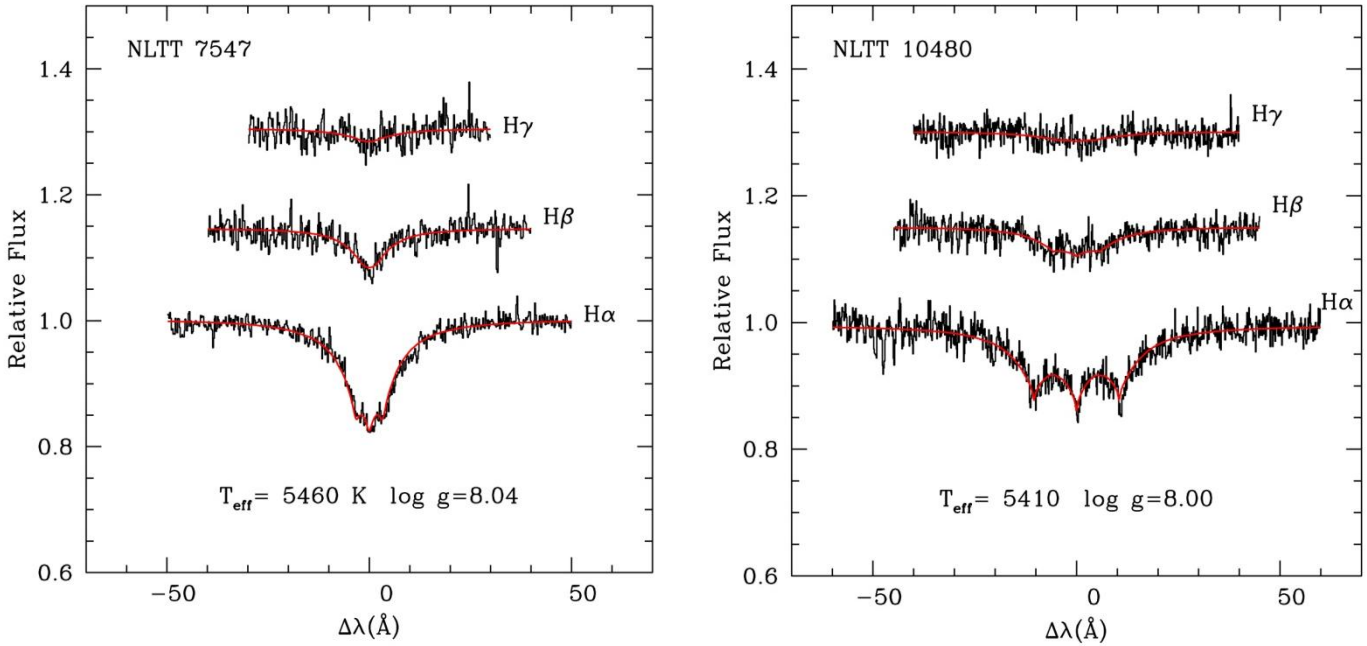


Kawka & Vennes (2012)

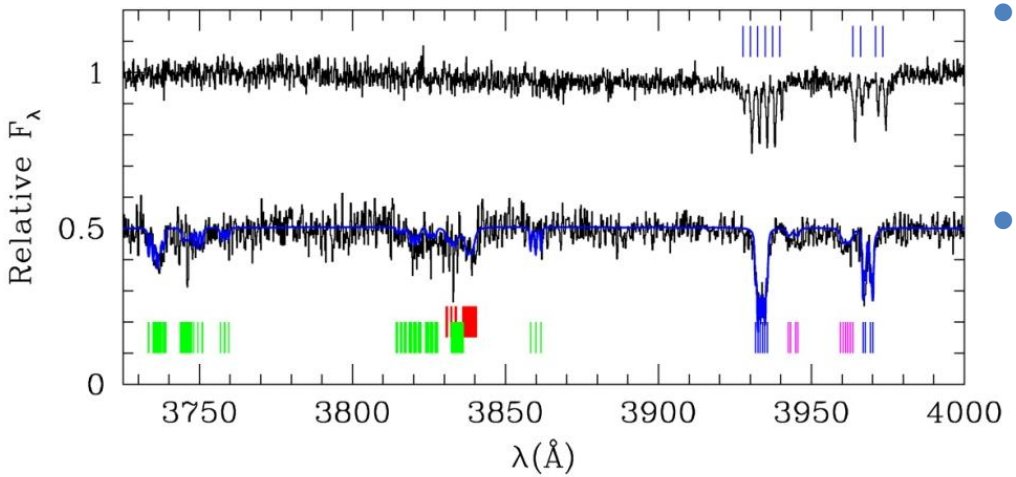
Vennes & Kawka (2013)

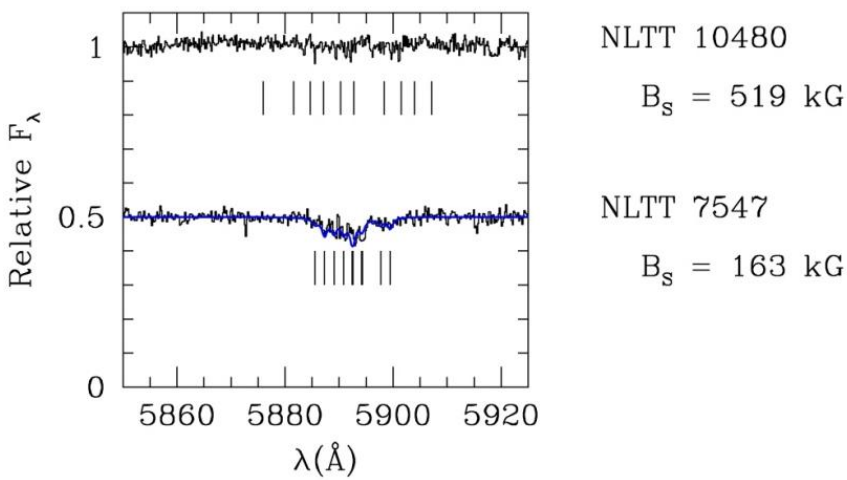
Cool magnetic DAZs



- We continued to obtain X-shooter spectra for several DAZs and found some to be magnetic – NLTT10480 (Kawka & Vennes 2011), NLTT53908 (Kawka & Vennes 2014) and NLTT7547 (Kawka & Vennes, in prep).
- This is in addition to NLTT43806 (Kawka & Vennes 2006, Zuckerman et al. 2011), G77-50 (Farihi et al. 2011) and WD2105-820 (Koester et al. 2009, Landstreet et al. 2012)

Metal lines in magnetic fields





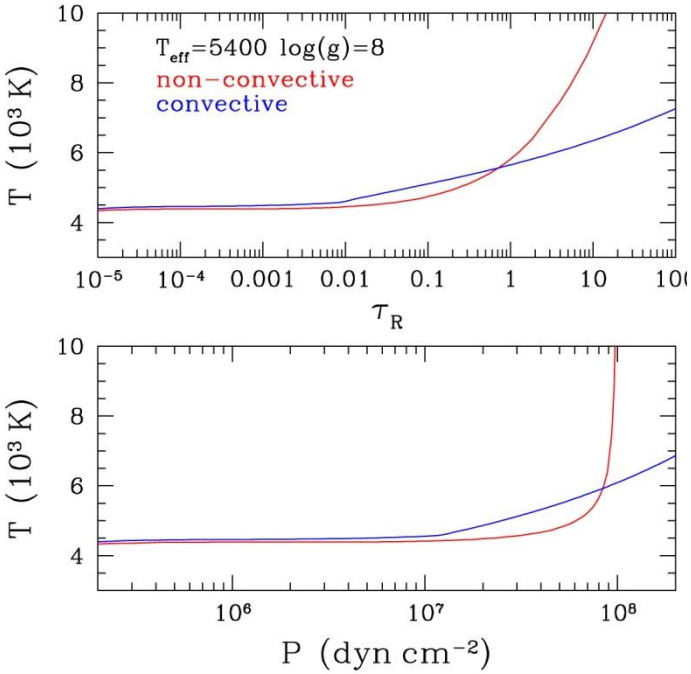
- In this field regime we can assume the anomalous Zeeman effect.
- Levels are split into *2J+1* components defined by the magnetic quantum number *m=-J,...,J*
- Allowed transitions *Δm=0,±1*

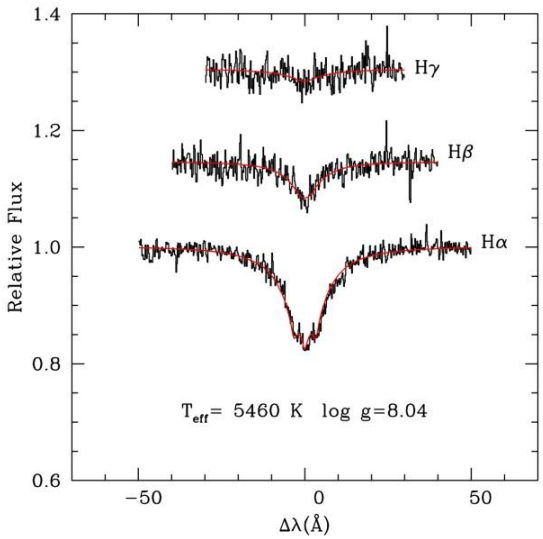
$$\Delta\lambda = \frac{eB\lambda^2}{4\pi m_e c^2}(g_l m_l - g_u m_u)$$

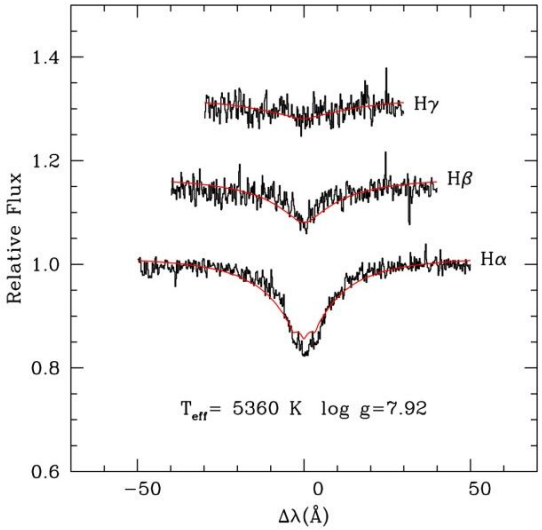
$$\Delta\lambda \approx 4.67\times10^{-7}\,\lambda^2 B(g_l m_l - g_u m_u)$$

- *log(Na/H) = -8.5, log(Mg/H) = -8.0, log(Al/H) = -9.0, log(Ca/H) = -10.0, log(Fe/H) = -8.7*

Convection suppression – is it physical?

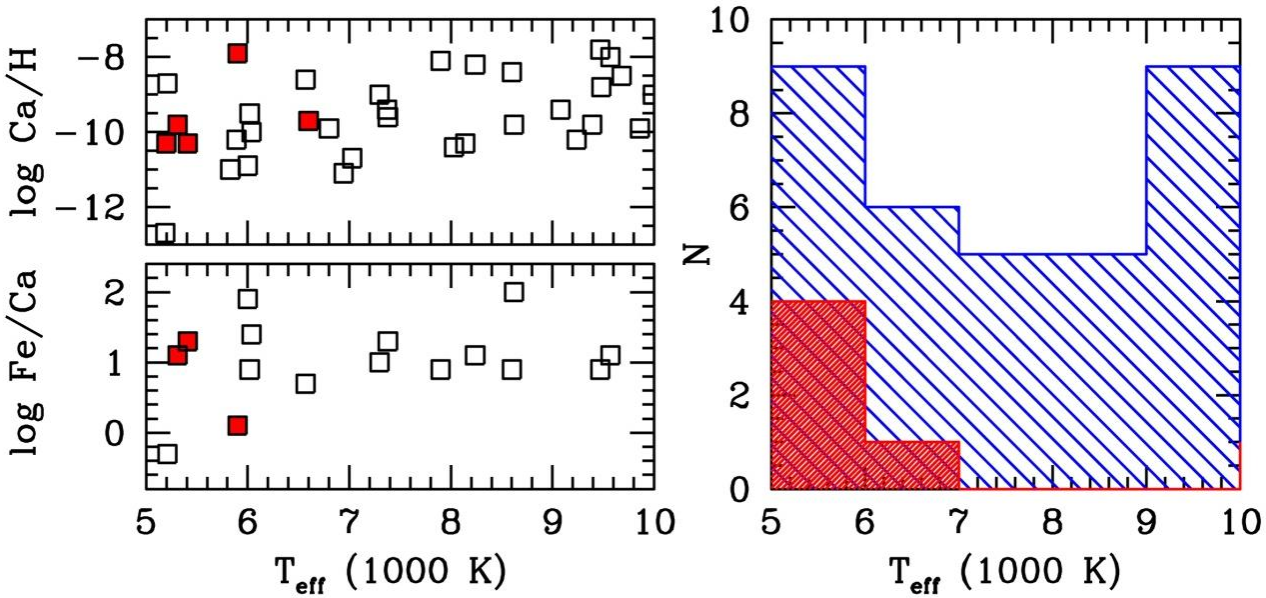






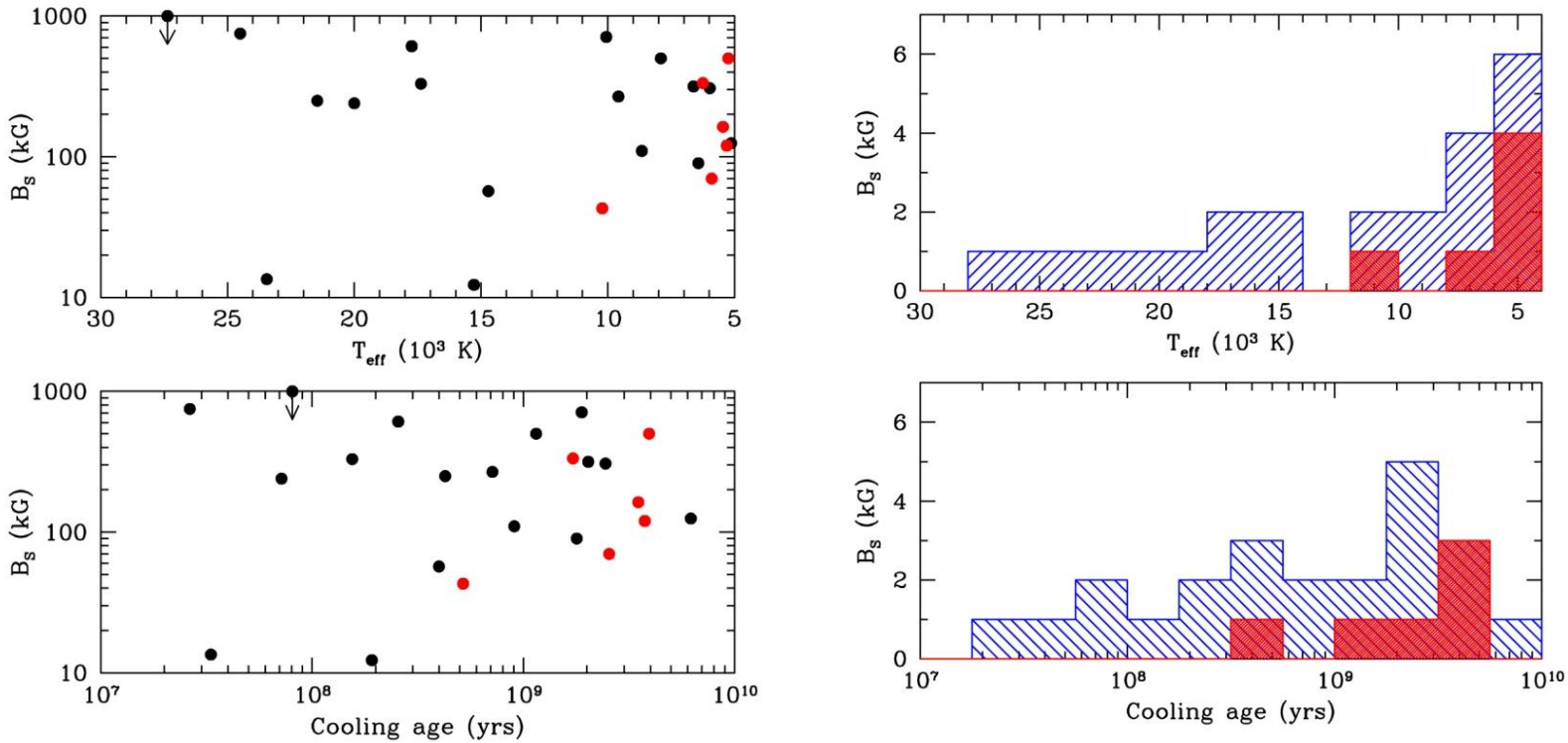
- Valyavin et al. (2014) proposed that convection is suppressed in magnetic WDs
- Tremblay et al. (2015) showed using MHD simulations that convection is suppressed
  - Effect of magnetic fields on the stellar structure can be estimated from plasma-β Parameter (thermal-to-magnetic pressure ratio) - $\beta = \frac{8\pi P}{B^2}$ (β < 0.2 in NLTT7547)

Incidence of magnetism



- Incidence of magnetism among cool DAZs appears to be high
- Incidence of magnetism in the Solar neighbourhood is 13 – 21% (Kawka et al. 2007)
- Higher incidence of magnetism is also observed in cool DZ white dwarfs (Hollands et al. 2015)

In reverse - incidence of pollution



- Selected all know magnetic H-rich white dwarfs with B_S < 1 MG
- We see an enhanced incidence of DAZ among cool/old magnetic white dwarfs
- Where are the warm/hot magnetic DAZs?

Formation of magnetic fields

Three formation scenarios

- Fossil field – remnants of magnetic Ap and Bp stars
  - Magnetic flux ($B_{WD}/B_{MS} = (R_{MS}/R_{WD})^2$ of Ap/Bp stars and magnetic white dwarfs are similar, suggesting they are evolutionarily linked
  - Whether a fossil field can survive the various stages of evolution is unknown, however Tout et al. (2004) postulates that a star can conserve its fossil magnetic field if it remains partly radiative throughout its lifetime.
  - This model cannot explain the lack of progenitors to magnetic cataclysmic variables (≈ 25% of CVs are magnetic: Wickramasinghe & Ferrario 2000)

Formation of magnetic fields

- An alternative model was proposed - merging binaries
  - Can explain the higher mass average (M_{ave}~ 0.8 $M_{\odot}$) of magnetic white dwarfs compared to non-magnetic white dwarfs (M_{ave}~ 0.6 $M_{\odot}$)
- Three different merging scenarios were proposed:
  - Common envelope scenario: the magnetic field is generated via a differential rotation in the hot outer parts of the degenerate core where the strongest fields are created if the merged objects are differentially rotating near break-up (Tout et al. 2008, Wickramasinghe et al. 2014)
  - Disk field model: a low mass star is tidally disrupted by its proto-white dwarf companion during a common envelope phase forming an accretion disk and the field is generated via a dynamo in the disk and then transferred to the degenerate core via accretion (Nordhaus et al. 2011)
  - Double degenerate model: a hot, convective, differentially rotating corona of two merging white dwarfs can produce high magnetic fields (Garcia-Berro et al. 2012)

Formation of magnetic fields

- Briggs et al. (2015) show that the majority of magnetic fields (in the merger scenario) would form within a common envelope with less than 1% being formed via the merger of a double degenerate system.
- The third model proposed is that low magnetic fields ($B \lesssim 0.1$ MG) are produced by phase separation during WD crystallization (Isern et al. 2017)
  - White dwarfs begin to crystallize at sufficiently low temperatures and as a result phase separation of the main elements (in most cases O and C) occurs.
  - This leads to an unstable, convective liquid mantle on top of a solid core which produces a dynamo, similar to planets like Earth and Jupiter, allowing the creation of a magnetic field.
- Maybe more than one process is responsible for producing the observed magnetic field distribution.

Summary

- As part of our survey of high proper motion white dwarfs, we discovered a few cool magnetic and polluted white dwarfs
- In these cool atmospheres, convection is predicted to be suppressed by the presence of a magnetic field, however “switching of convection” does not seem to model the observed Balmer lines very well.
- Incidence of magnetism in cool white dwarfs appears to be significantly enhanced.
- Formation of magnetic white dwarfs may involve more than one process.