Accurate spectroscopy of M dwarfs

a possible link to understand planet formation

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Outline

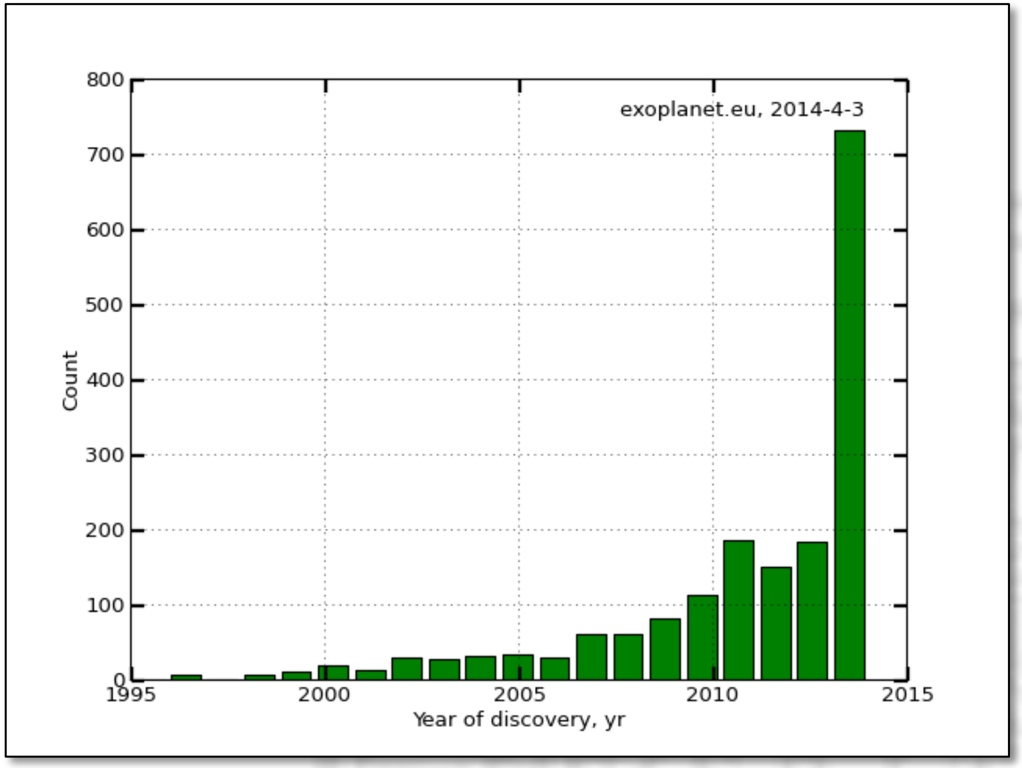
- Detection techniques of exoplanets
- Planetary formation theories
- Why do we work with M dwarfs
- What are the problems with working with M dwarfs
- The project outline
- First results

Finding an exoplanet

First planet discovered around a MS star was in 1995. The planet is 51 Peg - a $0.5M_J$ with a 4.3 day period.

(Mayor & Queloz 1995)

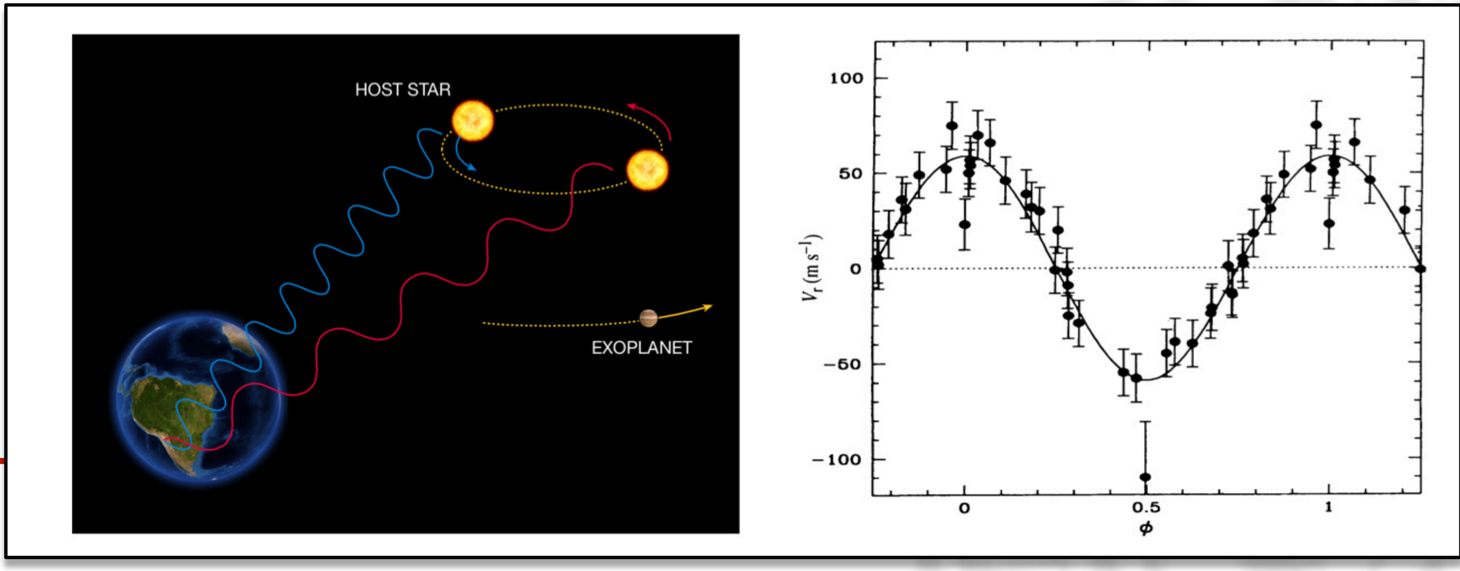
Total: 1780 planets
RV: 556 planets
Transit: 1131 planets



Radial velocity technique

- Detection more massive and/or closer planets is easier, especially around less massive stars
- For an Earth-mass planet a 1 $M_\odot$ gives K ~0.10 ms^{-1} while for a star with 0.3 $M_\odot$ gives K ~0.30 ms^{-1}

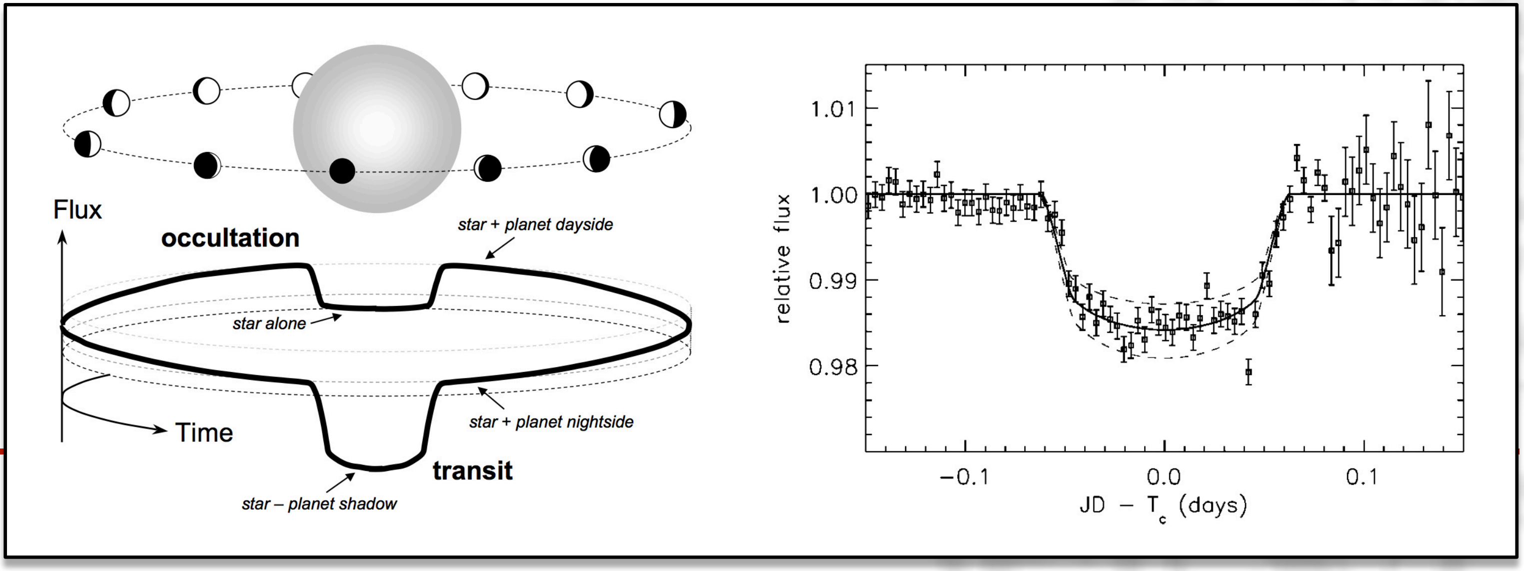
$$K = \left(\frac{2\pi G}{P}\right)^{1/3} \frac{M_P \sin i}{(M_P + M_*)^{2/3}} \frac{1}{\sqrt{1-e^2}}$$



Transit technique

- Only possible to observe a transit within an angular range very close to an edge-on configuration
- For solar-type star ΔF will be approximately ~1%, while for M dwarfs ~ 11%

$$\frac{\Delta F}{F} \simeq \left(\frac{R_P}{R_*}\right)^2 \qquad p = \frac{R_*}{a} \simeq 0.005 \left(\frac{R_*}{R_\odot}\right) \left(\frac{a}{AU}\right)^{-1}$$



Planet formation theory

Two dominating theories for planet formation: Core accretion and gravitational instability

- Gravitational instability – independent of metallicity
- Core accretion – dependent of metallicity

Metallicity is an indication of the composition of the original circumstellar disk, from where the star and possible exoplanets are formed

M dwarfs

The faintest, smallest and coolest class of the stars at the Main Sequence, and the most longed-lived

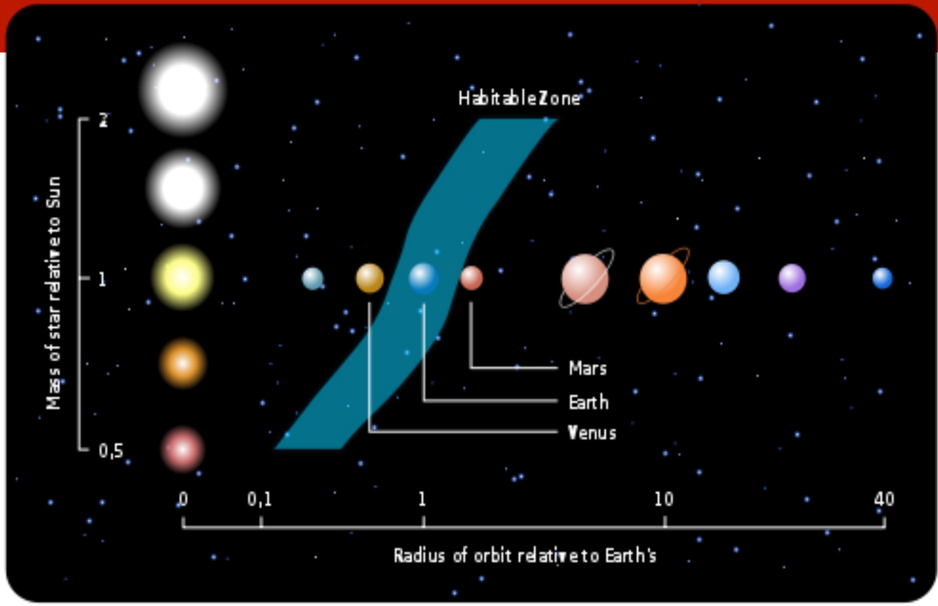
- 2400-3700 K
- $\leq 0.08\ L_{\odot}$
- 0.08-$0.6\ M_{\odot}$
- 0.1-$0.6\ R_{\odot}$

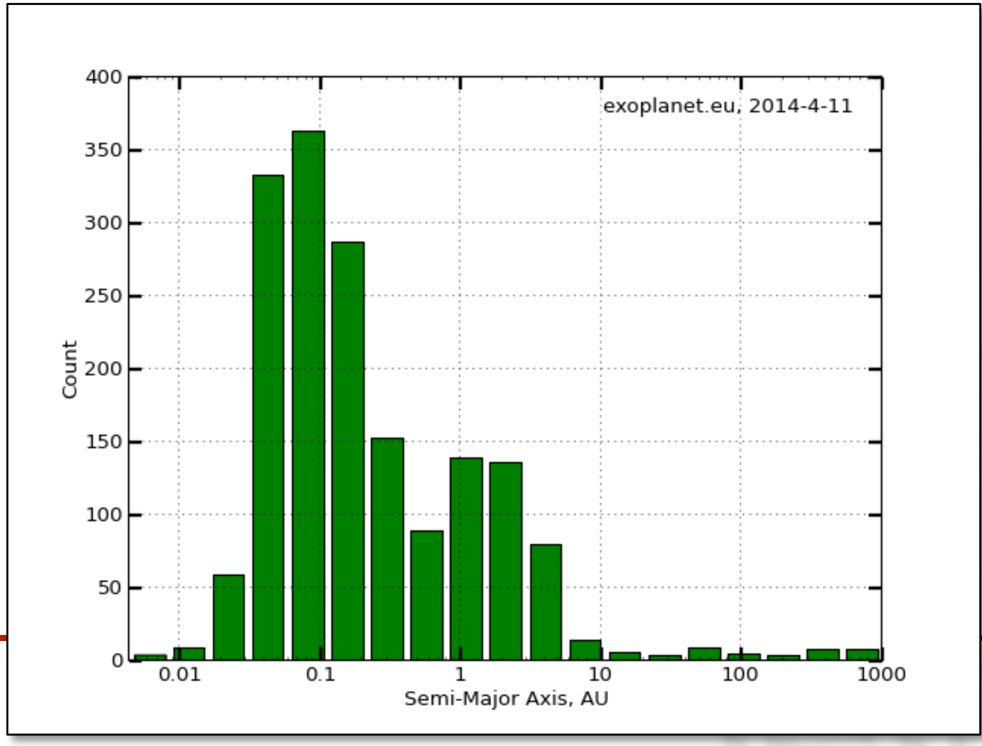
M dwarfs are estimated to ~70% of all stars in the Galaxy, representing half of the baryonic matter

Why work with M dwarfs?

Since they are so numerous M dwarfs are of interest for several reasons:

- Stellar and galactic evolution
- Low-mass end of the initial and present mass function
- Larger chance to find planets within the *habitable* zone
- Possible planet – host star connections


Habitable Zone
Mass of star relative to Sun
2
1
0,5
Mars
Earth
Venus
0
0,1
1
10
40
Radius of orbit relative to Earth's


exoplanet.eu, 2014-4-11
Count
400
350
300
250
200
150
100
50
0
0.01
0.1
1
10
100
1000
Semi-Major Axis, AU

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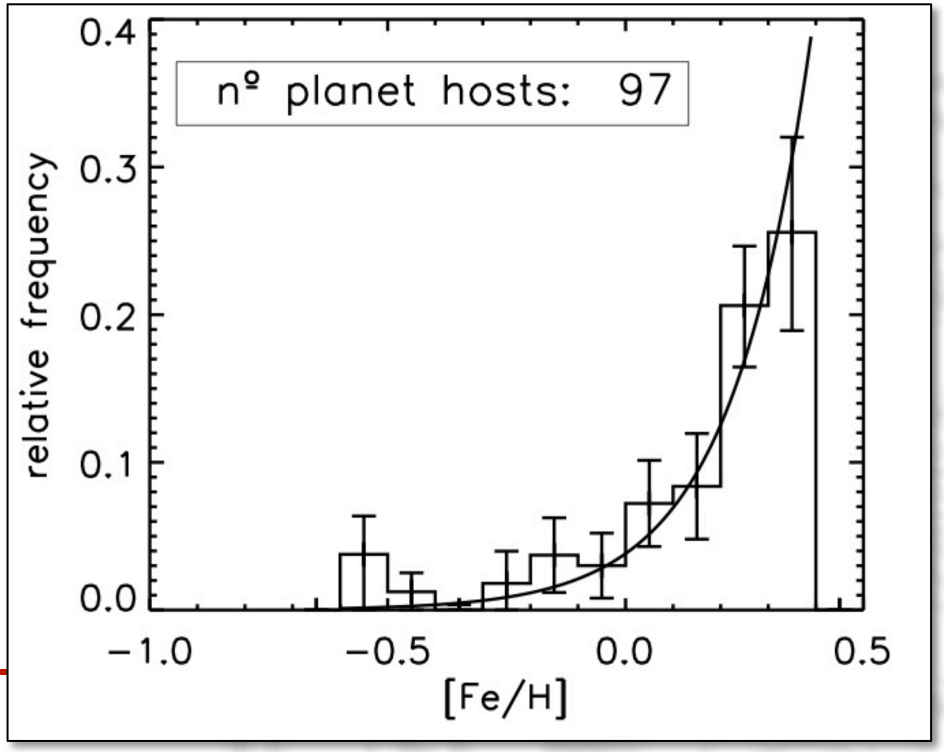
Planet-metallicity correlation

- Giant planet FGK hosts have enhanced metallicity compared to the sun

(e.g. Gonzalez 1997; Santos et al. 2004; Fischer & Valenti 2005; Sousa et al. 2011)

- Core accretion models can reproduce the observed correlation with metallicity

(e.g. Ida & Lin 2004a; Benz et al. 2006; Mordasini et al. 2009b, 2012)

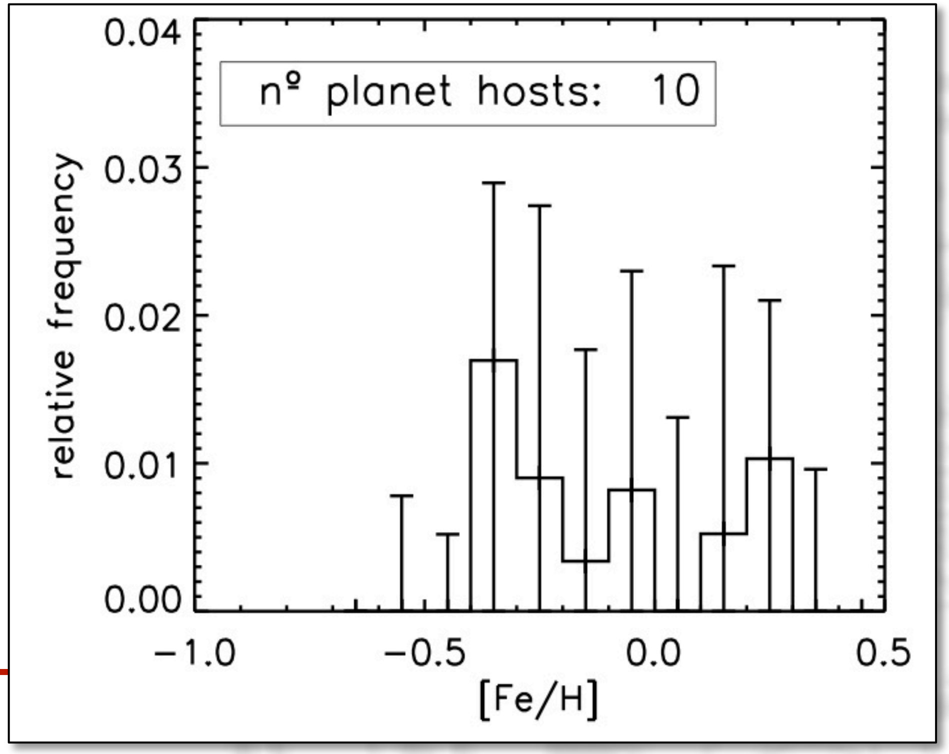


Sousa et al., 2011

- For Neptunian and super-Earth the correlation vanishes for FGK host stars

(e.g. Sousa et al. 2008; Ghezzi et al. 2010; Sousa et al. 2011; Mayor et al. 2011; Buchhaveet al. 2012)

- Core accretion models also predict this. Planets with $M < 30\ M_E$ should be evenly distributed across all [Fe/H] ranges



Sousa et al., 2011

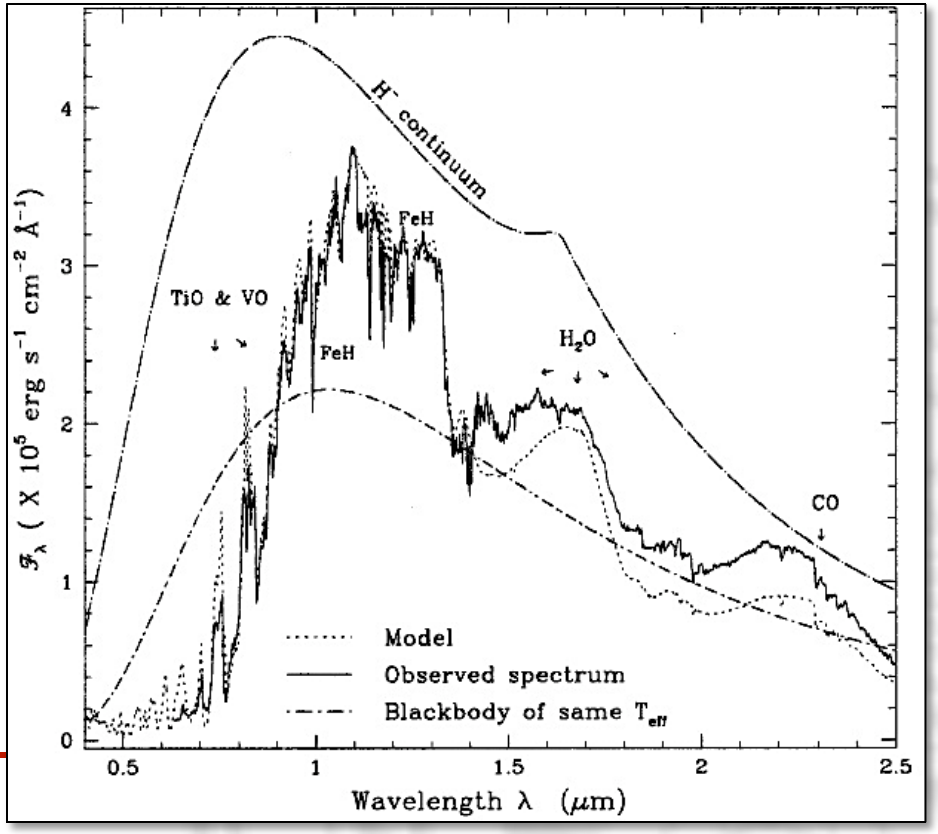
But all the observational evidence so far have been for FGK dwarfs

… what is the case with M dwarfs?

Why it's so complicated to determine the metallicity in M dwarfs?

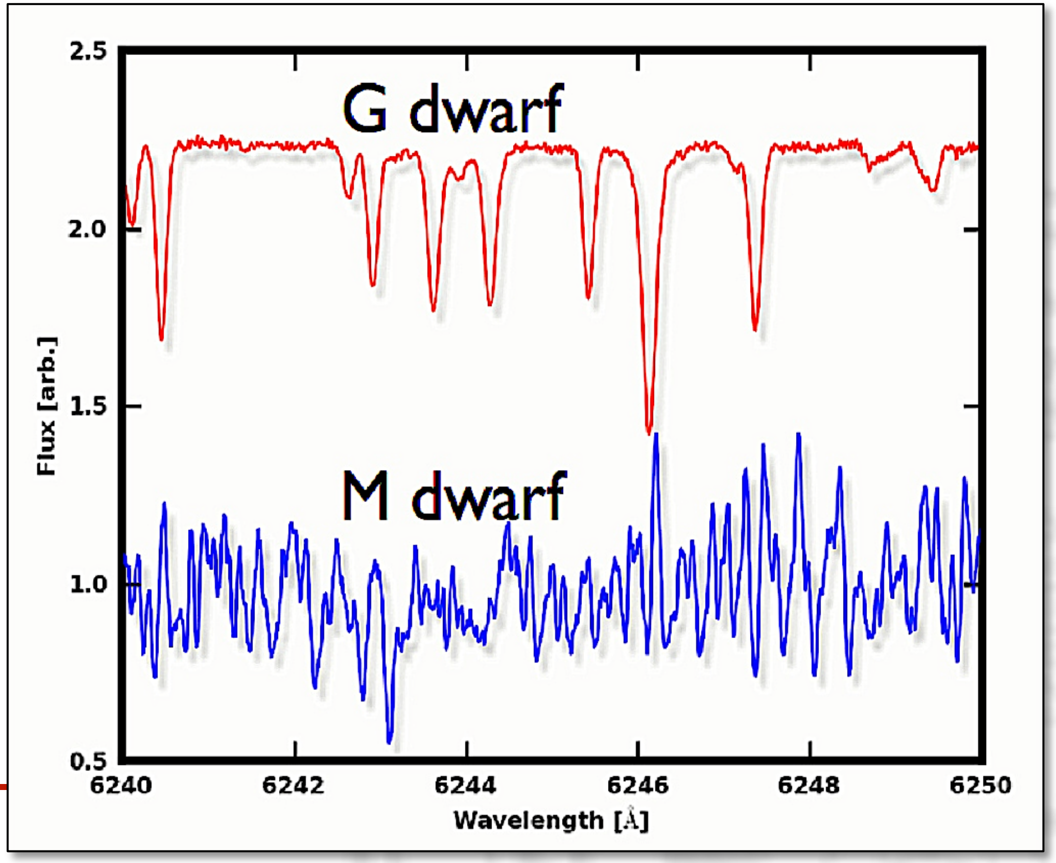
1. M dwarfs are intrinsically faint and have highly complex spectra

2. Continuum opacity is mainly dominated by the H^- ion for FGK dwarfs, while for M dwarfs transitions of elements like TiO, VO, FeH, H_2O and CO becomes important



Allard & Hauschildt (1995)

- Abundance of diatomic and triatomic molecules in the photospheric layers gives a forest of weak lines, especially in optical wavelengths
- Gives large problem to identify the continuum level – i.e. the reference level
- However, the situation highly improve in the infrared



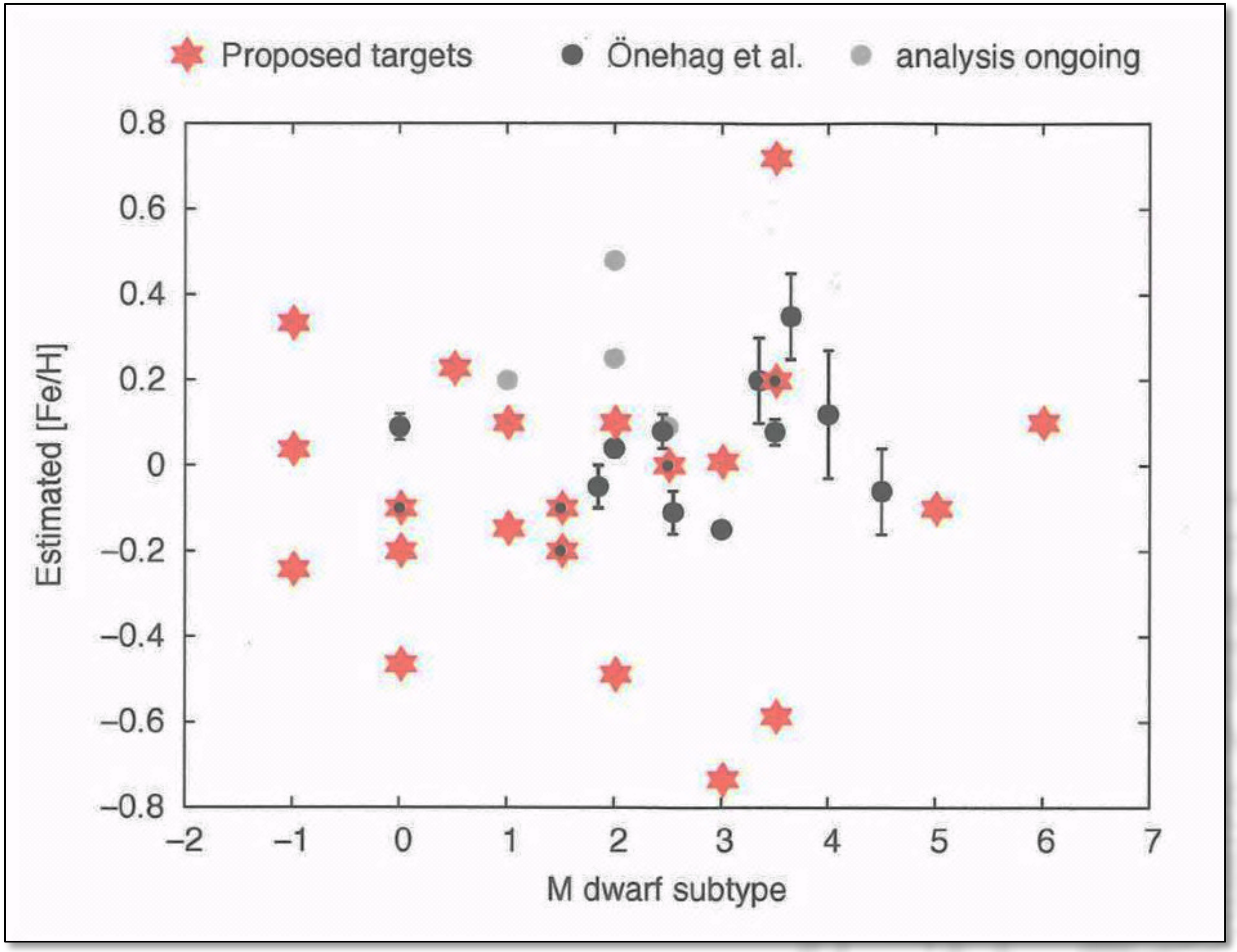
Bonfils et al., 2012

The main idea

- Work by Önehag et al, 2012 where they analyzed 12 stars in the J band (1100-1400 nm) gave promising results
- Can check the reliability of the derived abundances using M dwarfs in binary systems with hotter companions
- Observations of two binary systems and 22 single M dwarfs have been done with CRIRES spectrograph, located at one of the 8-m telescopes at the VLT. Resolution ~ 50 000

Outline of the project

- Step 1: Analyze two M dwarfs in binary system
- Step 2: Expand the sample to larger range of metallicity and effective temperature
- Step 3: Use this sample with high precision determined metallicity to derive a relationship between photometric colors and metallicity for M dwarfs
- Step 4: Obtain a large enough sample to statistically investigate a possible planets – metallicity connection for M dwarfs


Proposed targets
Önehag et al.
analysis ongoing
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
Estimated [Fe/H]
−2
−1
0
1
2
3
4
5
6
7
M dwarf subtype

Outline of the project

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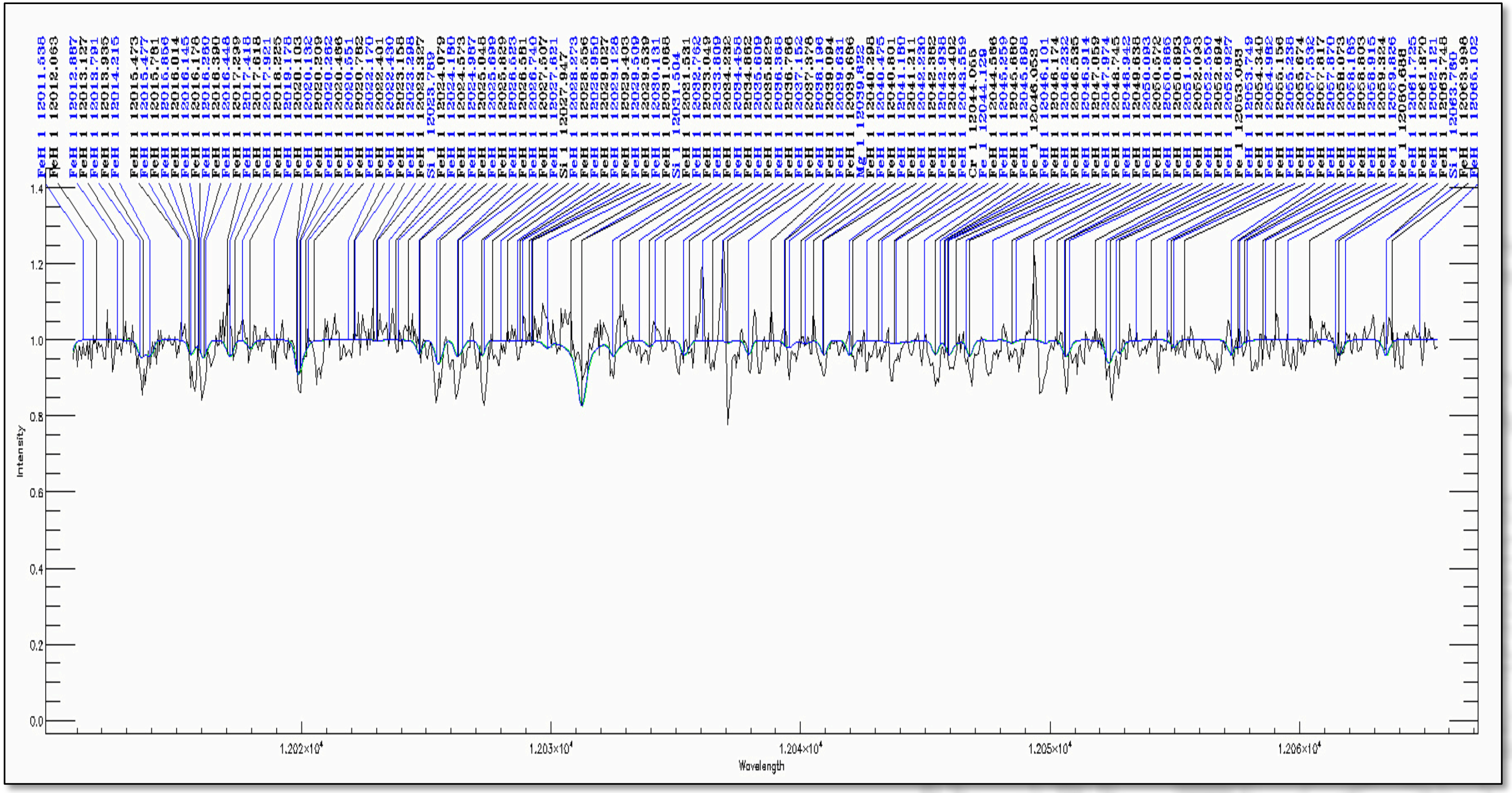
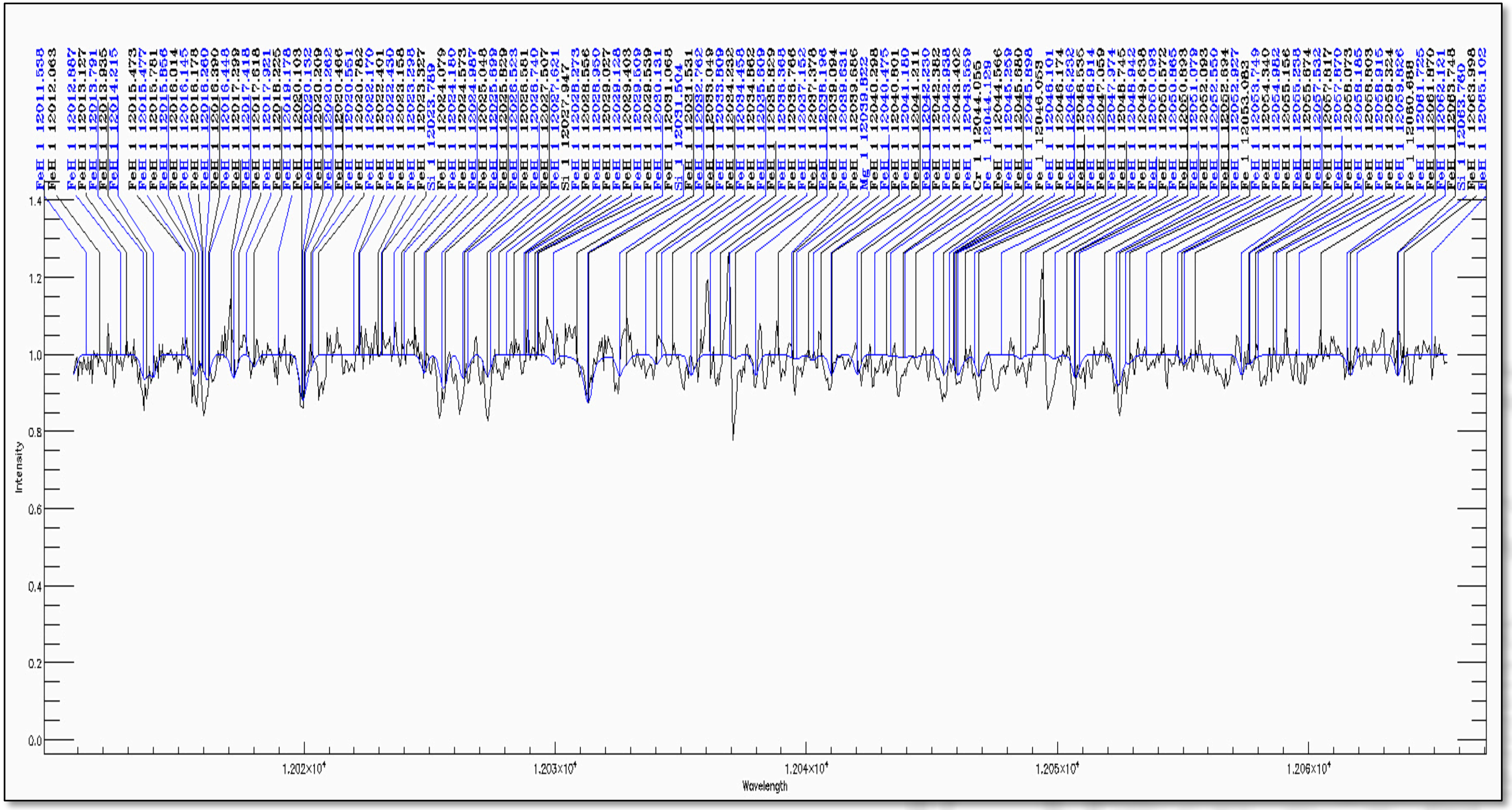
Results - T_{eff} adjustment

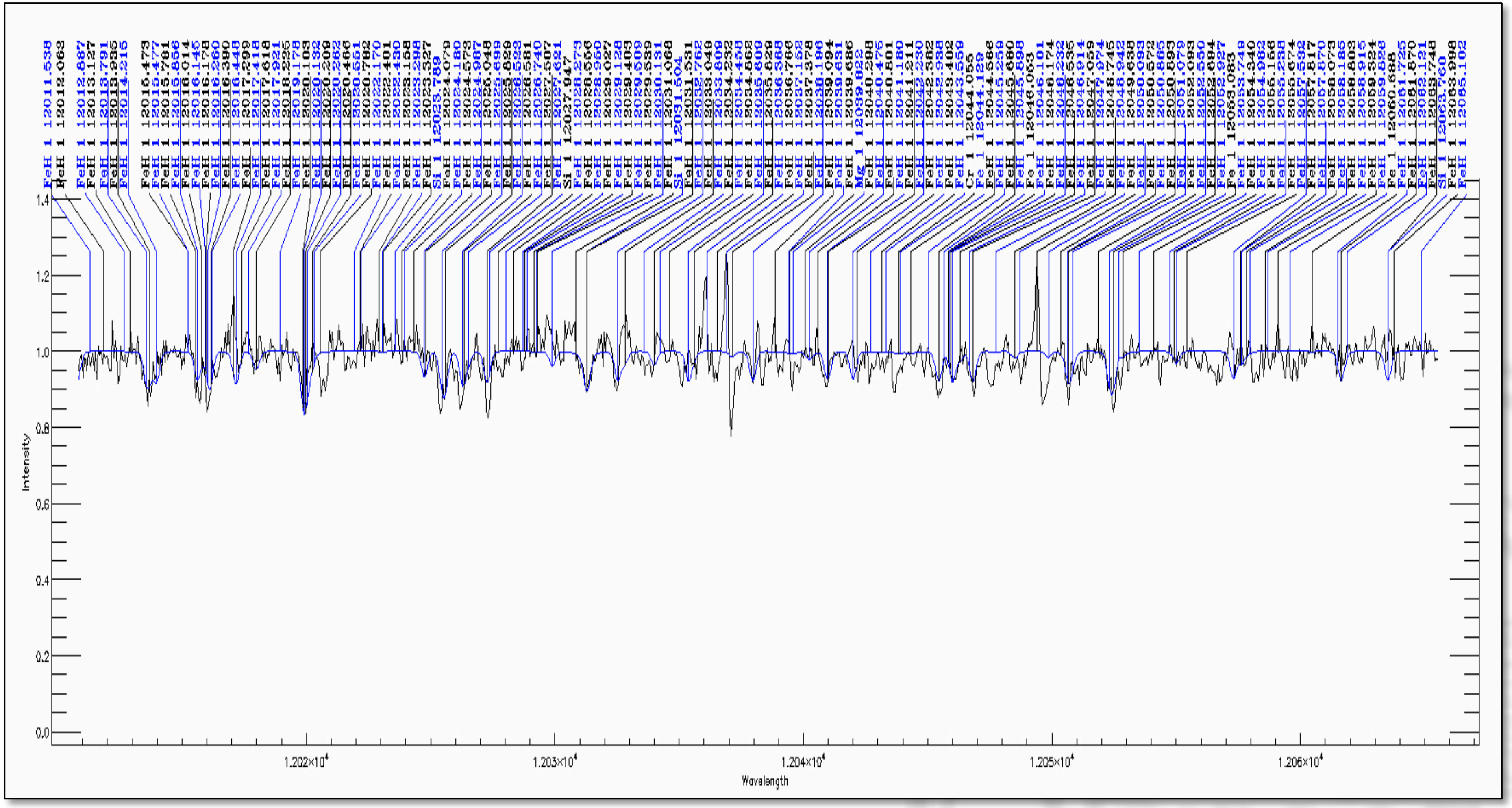
Effective temperature: 3600 K



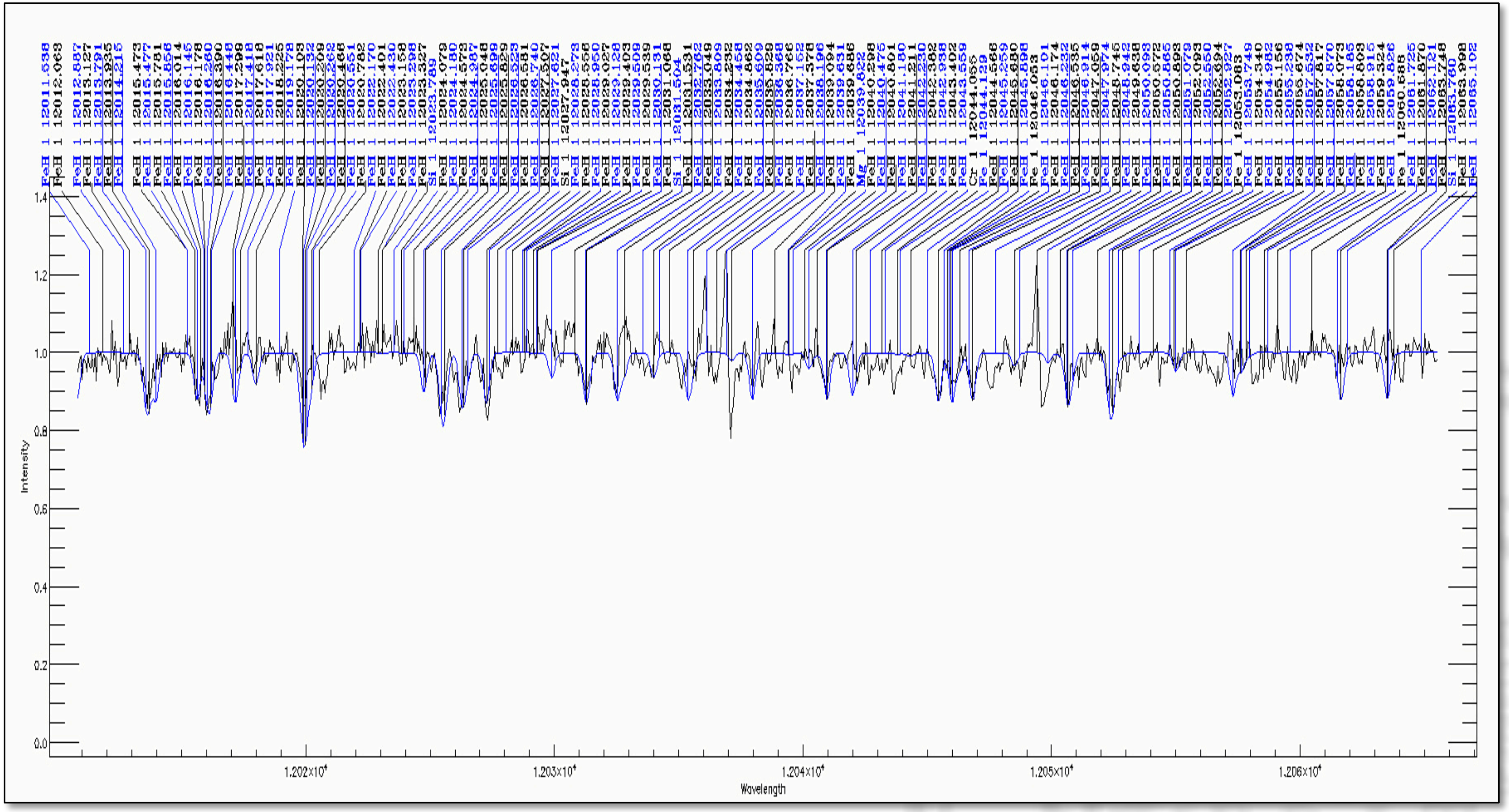
Effective temperature: 3400 K



Effective temperature: 3200 K



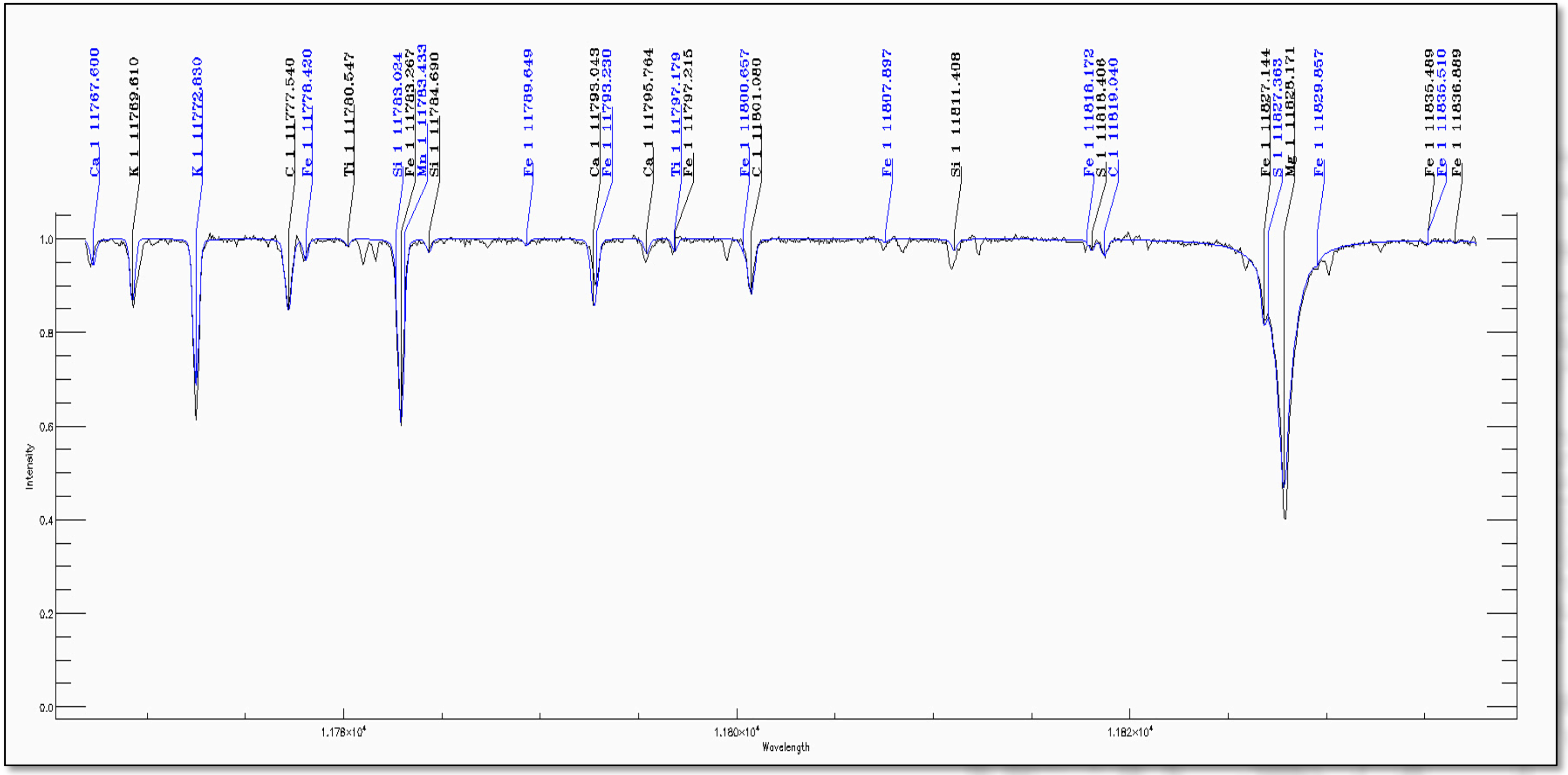
Effective temperature: 3000 K



Results – metallicity of the G dwarf

31 lines – Ca 1(3), Ca 2 (1), Ti 1(1), Fe 1(16), Mg 1(2), Cr 1(1), Si 1(7)

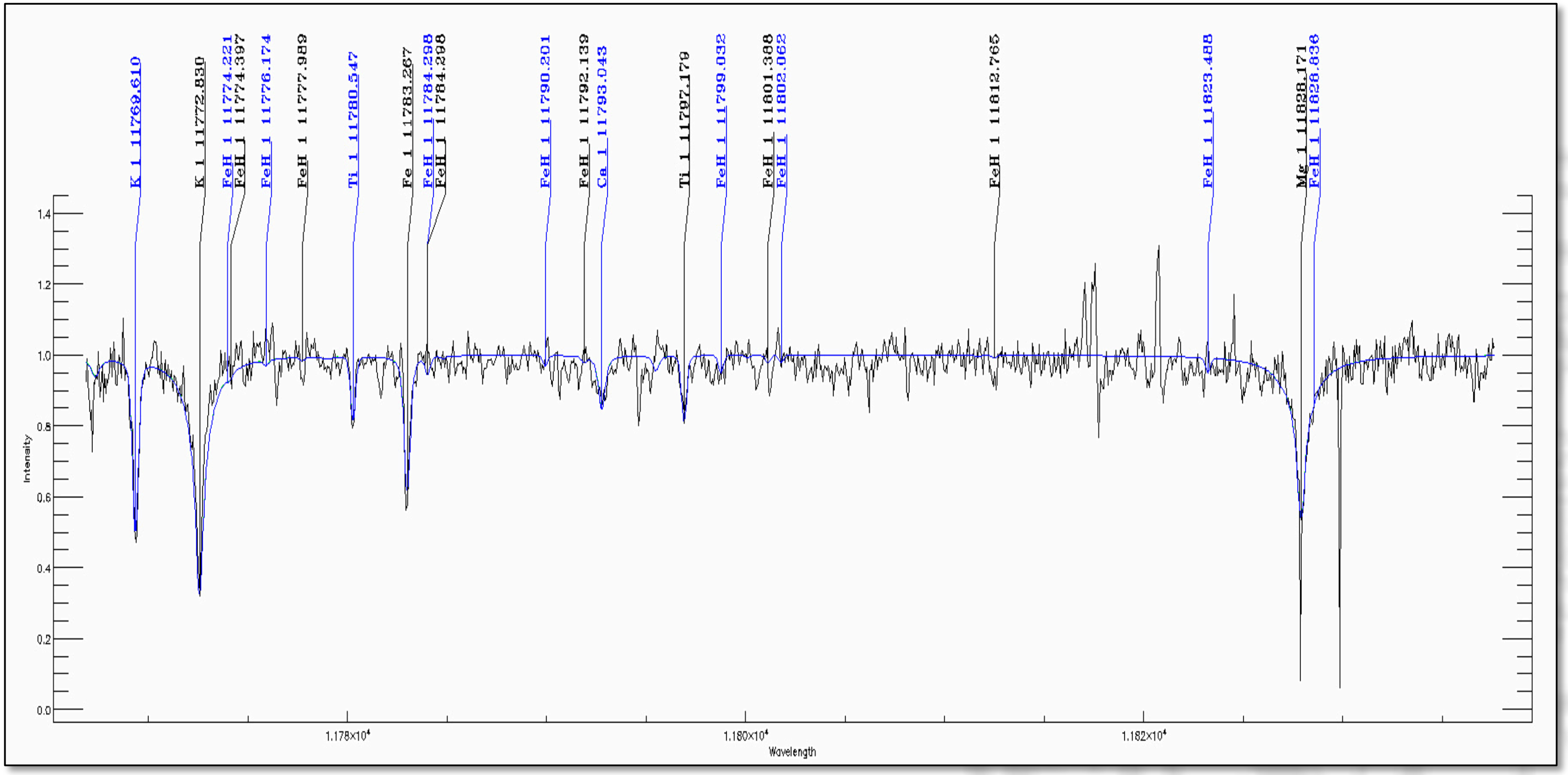
- Derived metallicity: 0.15 dex
- Average literature value: 0.13 dex (spread 0.06 dex)



Results – metallicity of the M dwarf

14 lines – Ca 1(4), Ti 1(5), Fe 1(2), Mg 1(1), S 1(1), Cr 1(1)

- Derived metallicity: 0.12 dex
- Difference between primary and secondary: 0.03 dex



Conclusion

- Analysis of HIP12048 gives results in agreement with the literature values
- The difference between the derived metallicity value for the G dwarfs companion and the M dwarfs companion agrees very well
- This gives further proof that the method yield reliable abundance determination – i.e. we can use high-resolution spectroscopy in the infrared to obtain accurate metallicities for M dwarfs

Thank you everyone for your attention

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