Detailed chemical abundances of M-dwarf planet hosts from APOGEE observations

Diogo Souto

Observatório Nacional - ON/MCTI

+

Katia Cunha

Verne Smith

C. Allende Prieto

Anibal Garcia Hernandez

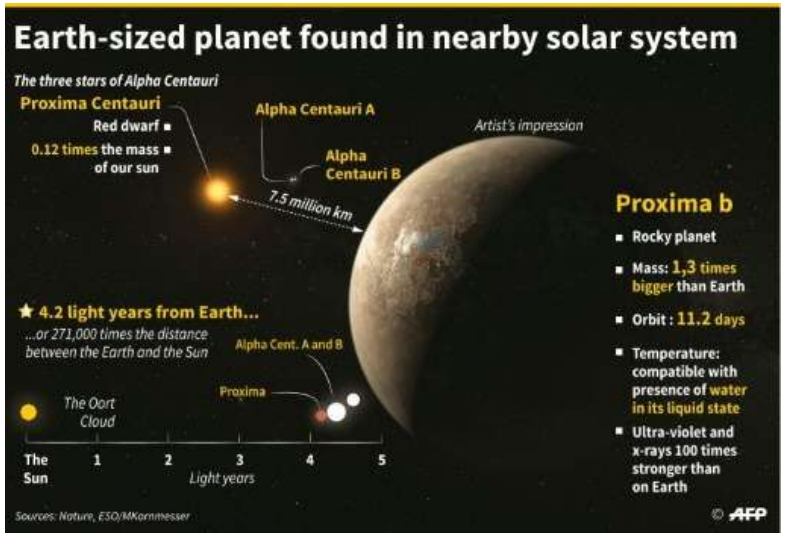
Olga Zamora

Chemical Abundances of M-Dwarfs from the Apogee Survey. I. The Exoplanet Hosting Stars Kepler-138 and Kepler-186

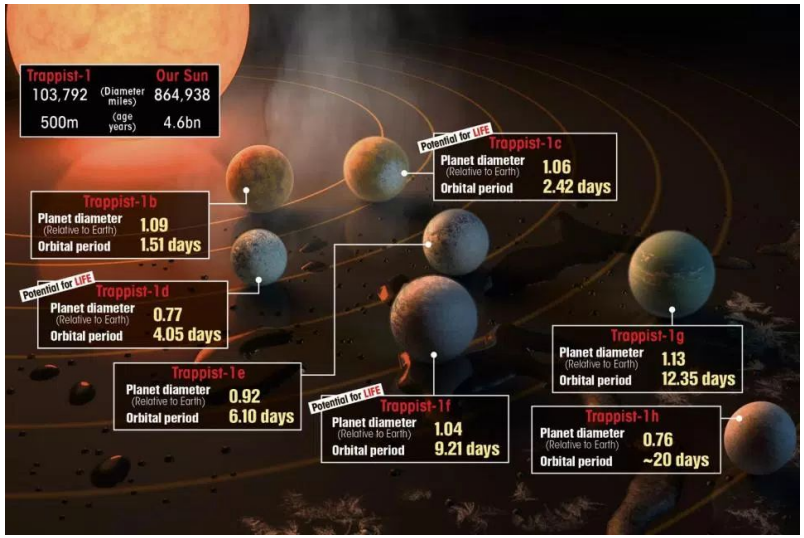
Souto, D., Cunha, K., García-Hernández et al., 2017, ApJ, 835, 239

M-dwarf Stars

- M-dwarf stars are main targets to search for Earth-like exoplanets;
- Future missions as Tess and Plato are going to discover hundreds of thousands Earth-like exoplanet hosting M-dwarfs
- Besides being the most abundant stellar class in Milky Way -- Galactic Archeology implications
- With APOGEE we have opened a new window to the study of chemical abundances in M-dwarfs



Source: AFP press

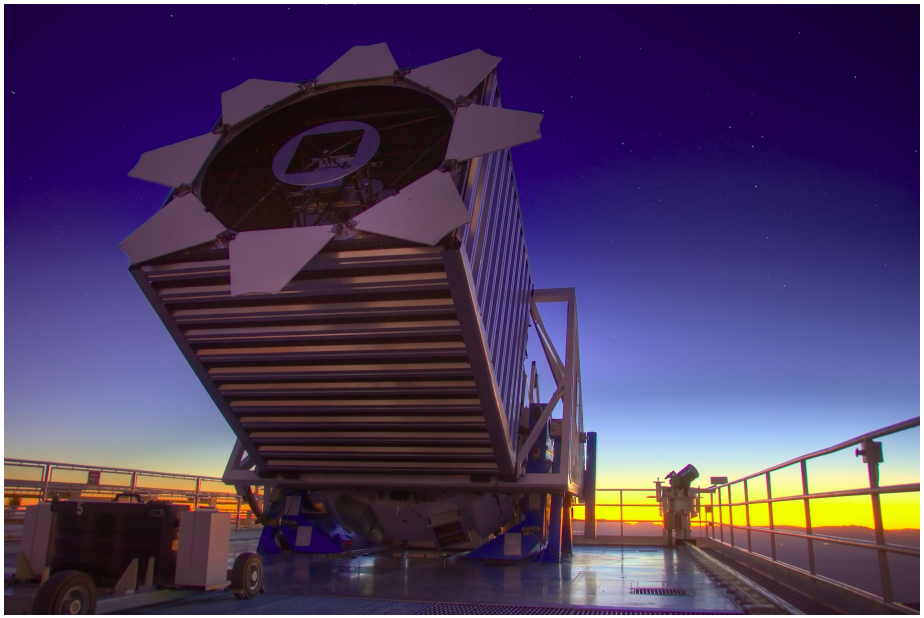


Source: The Sun press

The SDSS-4 APOGEE

- O SDSS (Sloan Digital Sky Survey)
  Dedicated telescope at APO
  - 2.5m diameter
  - Large field of view - 7 degrees²

- O APOGEE (Apache Point Observatory Galactic Evolution Experiment)
  Espectrógrafo APOGEE
  - Criogenic;
  - H-band between 1.51 and 1.69 μm;
  - R = λ/δλ = ~ 22.500;
  - Multi-fiber spectrograph (300).

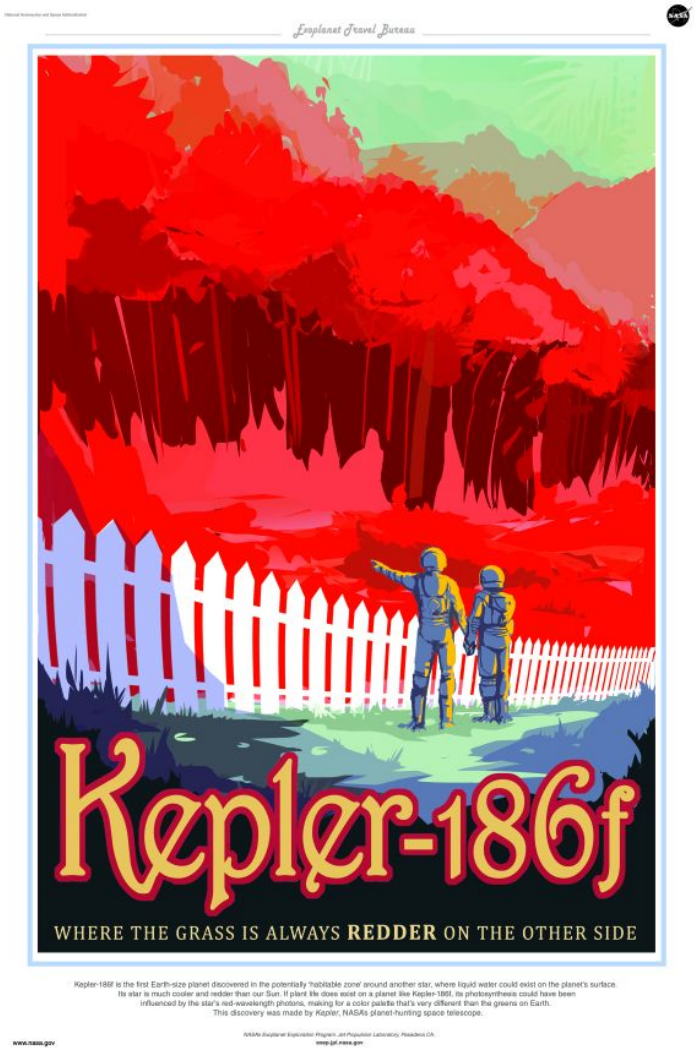


Source: http://www.sdss.org/

Kepler 138 and Kepler 186

- Sample:
  - Sample: two M-dwarf stars having low mass exoplanets detected by the kepler mission;
  - **Kepler-138** is a system with three exoplanets with Kepler-138b was characterized as having Mars-like size (Jontof-Hutter et al., 2015);
  - **Kepler-186** has 5 exoplanets detected and Kepler-186f is an exoplanet with similar size as us Planet Earth and also located in HZ (Quintana et al., 2014);

- Goals:
  - Proof-of-concept paper showing that APOGEE can be used to determine individual abundances for M-dwarfs
  - Initially 13 elements could be studied (C, O, Na, Mg, Al, Si, K, Ca, TI, V, Cr, Mn, and Fe)



Source: Nasa

We adopt photometric calibrations to derive stellar parameters - Teff and log g.

Teff from Mann et al. (2015) using the colors **V-J e r-J**

log g from Bean et al. (2006) plus Delfosse et al. (2000) stellar masses.

Table 1
Adopted Photometry and Atmospheric Parameters

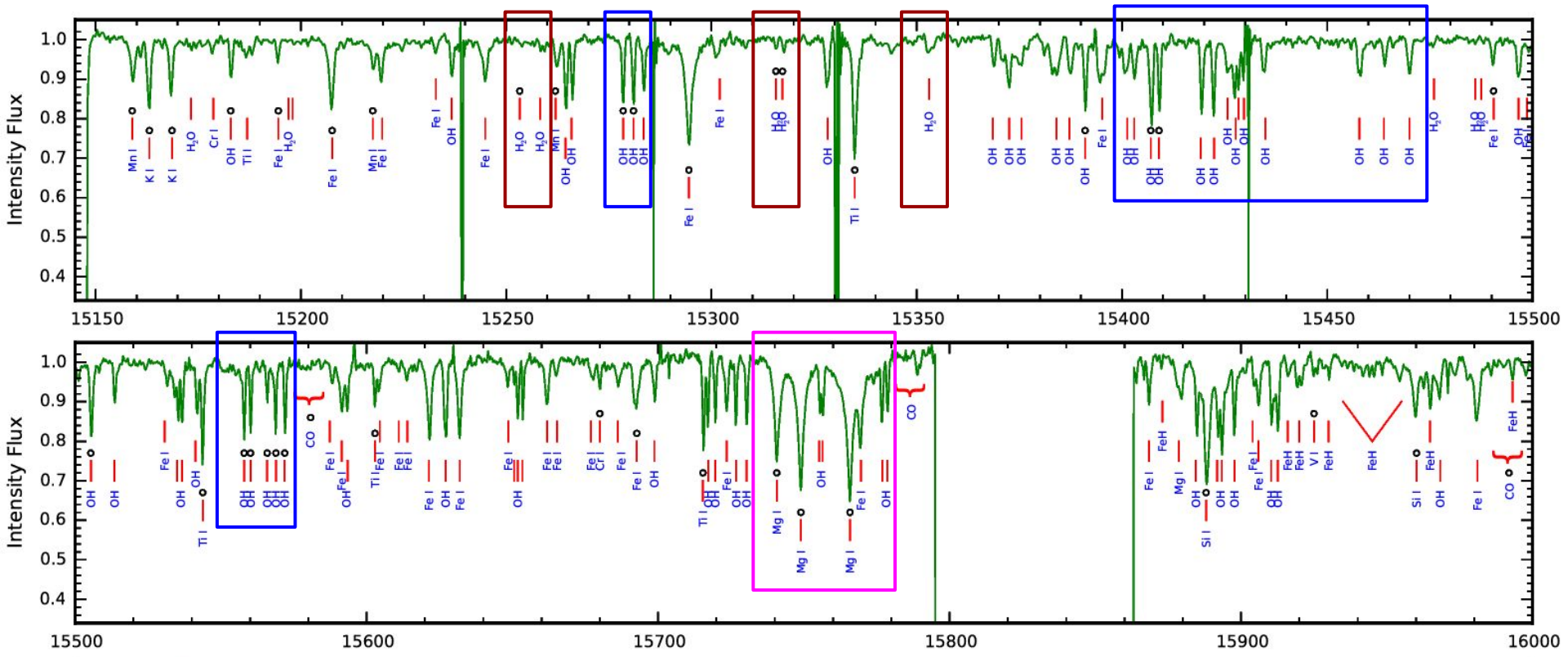
	Kepler-138	Kepler-186
V	13.168	15.290
J	10.293	12.473
H	9.680	11.824
Ks	9.506	11.605
r	12.529	14.664
d (pc)	66.5	151.0
$T_{\rm eff}$ (K)	3835 ± 64	3852 ± 64
log g	4.64 ± 0.10	4.73 ± 0.10
$M/M_{\odot}$	0.59 ± 0.06	0.52 ± 0.06

Individual abundances were determined from spectral synthesis:

- Derived atmospheric parameters
- 1-D LTE plane parallel Marcs model atmospheres (Gustafsson et al. 2008);
- Updated APOGEE line lists: H_2O (Barber et al. 2006) + FeH (Hargreaves et al. 2010);
- Turbospectrum code (Plez 2012).

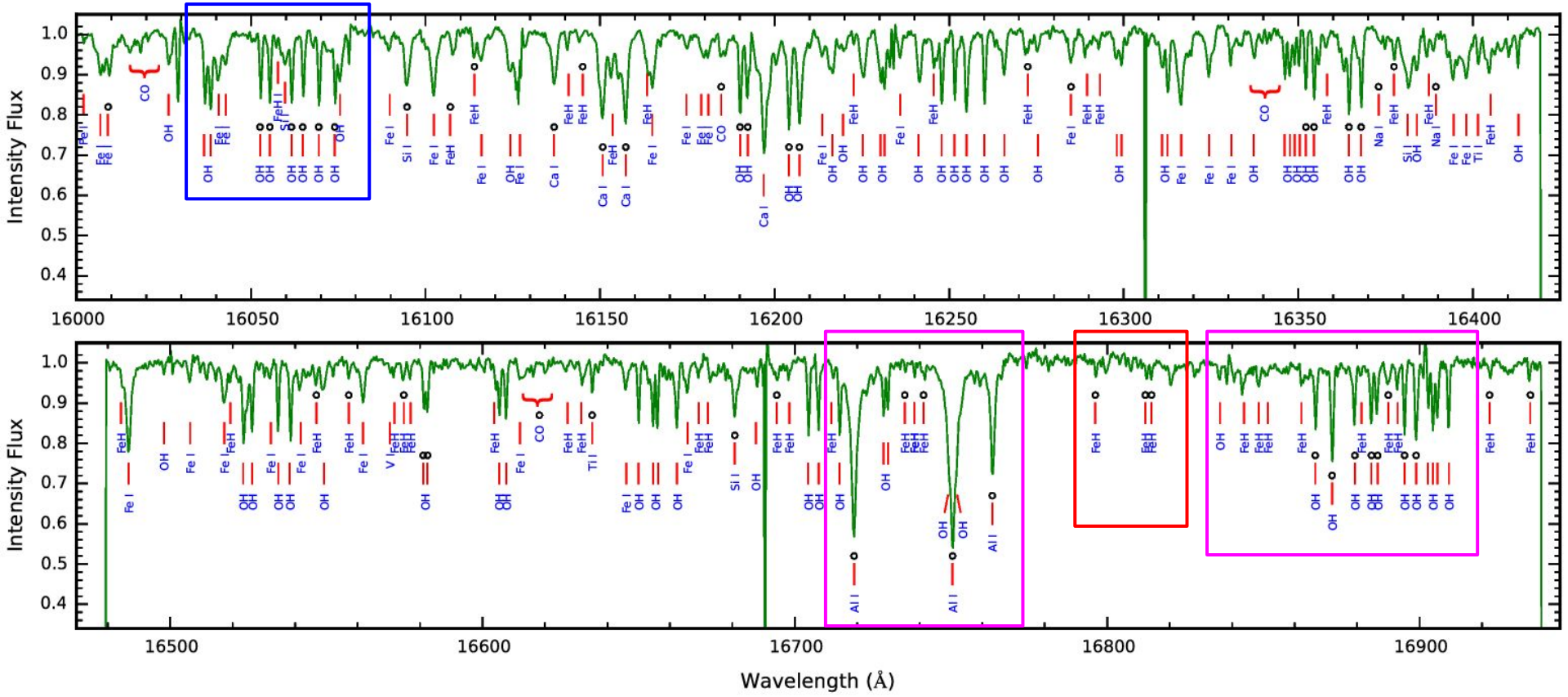
- H-band spectral lines of M-dwarfs with Teff ~ 3800 K
  - Most dominated by OH lines
  - Lines of H_2O molecule are less present in ~3800 K;
  - FeH lines are mostly in the red chip

Observed spectra of Kepler 138 - very high signal to noise ratio!

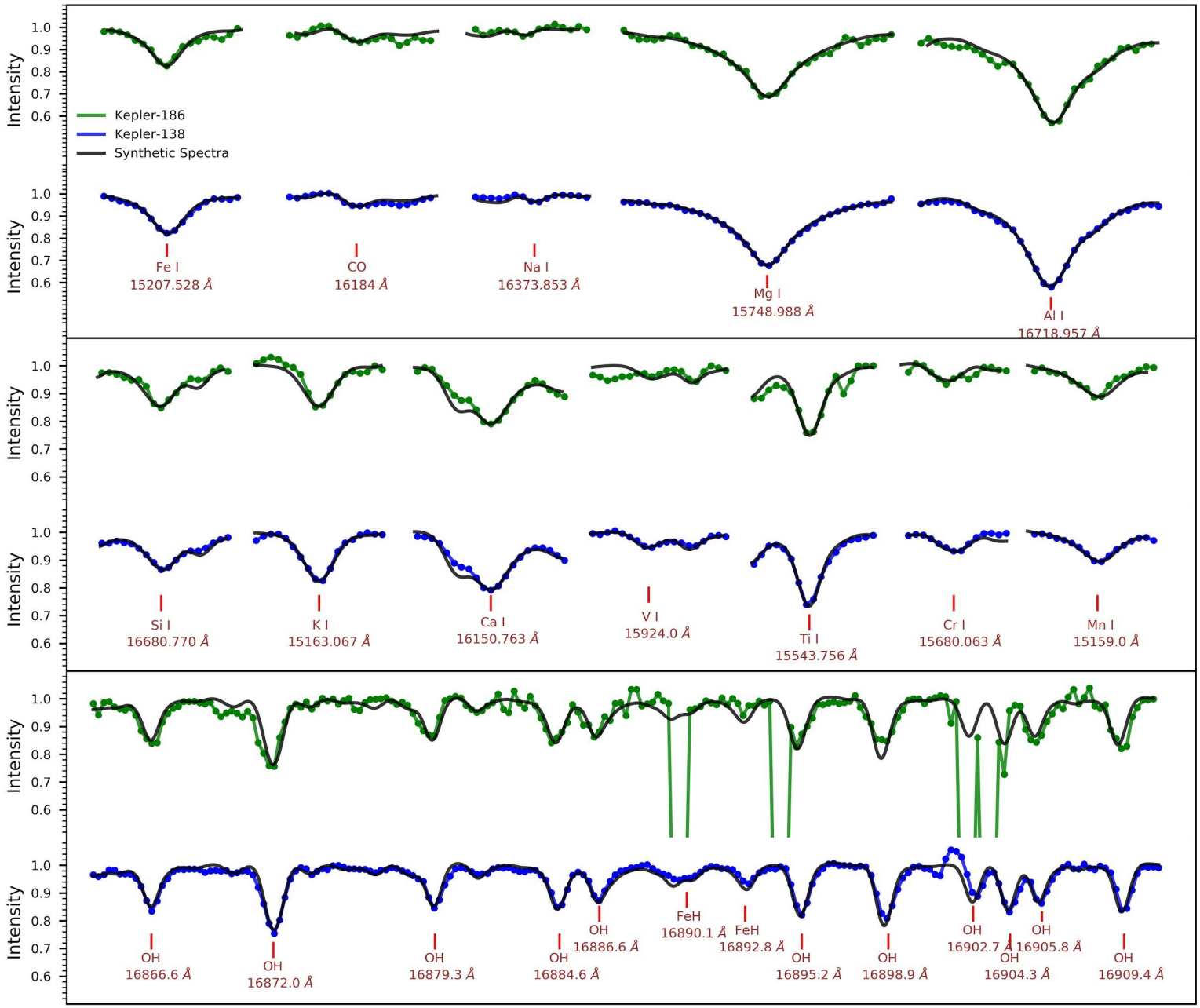


- H-band spectral lines of M-dwarfs with Teff ~ 3800 K
  - Most dominated by OH lines
  - Lines of H_2O molecule are less present in ~3800 K;
  - FeH lines are mostly in the red chip

Observed spectra of Kepler 138 - very high signal to noise ratio!



Spectral Synthesis Example



- First results
- Both stars has sub solar metallicity: [Fe/H] ~ -0.10
- Kepler-186 is silicon rich, **[Si/Fe] = +0.18** and Kepler-138 is not: **[Si/Fe] = 0.00**.

Table 4
Mean Abundances and Uncertainties

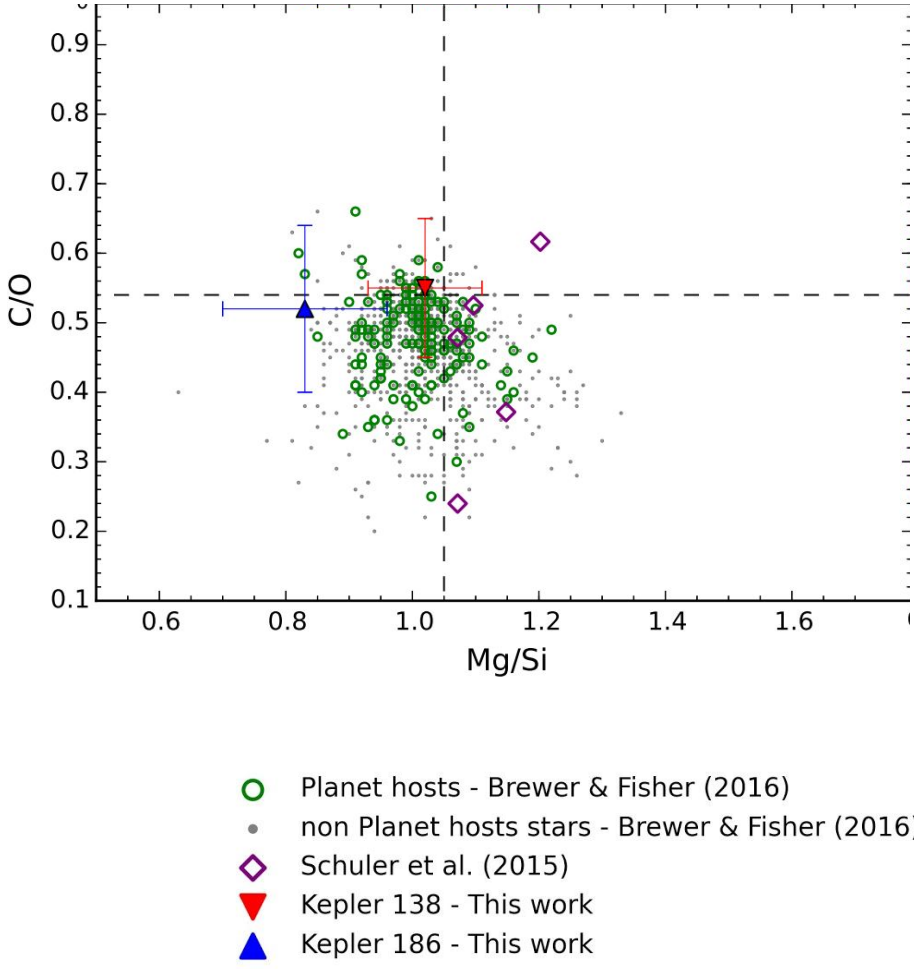
Element	Kepler-138	σ	Kepler-186	σ
[C/H]	−0.15	0.024	−0.08	0.062
[O/H]	−0.16	0.086	−0.08	0.103
[Na/H]	−0.07	0.076	−0.01	0.094
[Mg/H]	−0.10	0.152	+0.00	0.162
[Al/H]	−0.24	0.106	−0.20	0.120
[Si/H]	−0.09	0.156	+0.10	0.166
[K/H]	−0.17	0.051	−0.25	0.076
[Ca/H]	−0.06	0.047	−0.01	0.073
[Ti/H]	−0.19	0.089	−0.16	0.105
[V/H]	−0.21	0.024	...	...
[Cr/H]	−0.03	0.045	−0.04	0.073
[Mn/H]	−0.14	0.058	−0.09	0.081
[Fe/H]	−0.09	0.087	−0.08	0.104
[C/O]	0.01	0.077	+0.00	0.095
[Mg/Si]	−0.01	0.037	−0.10	0.068

Possible connections with exoplanets;

- Kepler-186 is silicon rich, **[Si/Fe] = +0.18** and Kepler-138 is not: **[Si/Fe] = 0.00**.

- C/O ratio control ice chemistry in protoplanetary disk (Bond et al. 2010);
  - Kepler 138 (C/O = 0.55);
  - Kepler 186 (C/O = 0.52);

- Mg/Si can affect core-to-mantle mass ratios in rocky exoplanets, (Unterborn, Dismukes & Panero 2016);
  - Kepler 138 (Mg/Si = 1.02);
  - Kepler 186 (Mg/Si = 0.82);



The lower ratio in Mg/Si could indicate a rocky exoplanet without tectonic plates, decreasing habitability chances!
(Unterborn et al. 2016, 2017)

HZ + Earth mass exoplanets are only a small piece of the puzzle,
A lot more to understand about habitability

Take aways

APOGEE is pioneering the detailed chemical study of M-dwarfs

Detailed abundances for 13 elements can be studied from APOGEE spectra

Even in the habitable zone, Kepler-186f may be unsuitable for life as we know

@diogo_souto