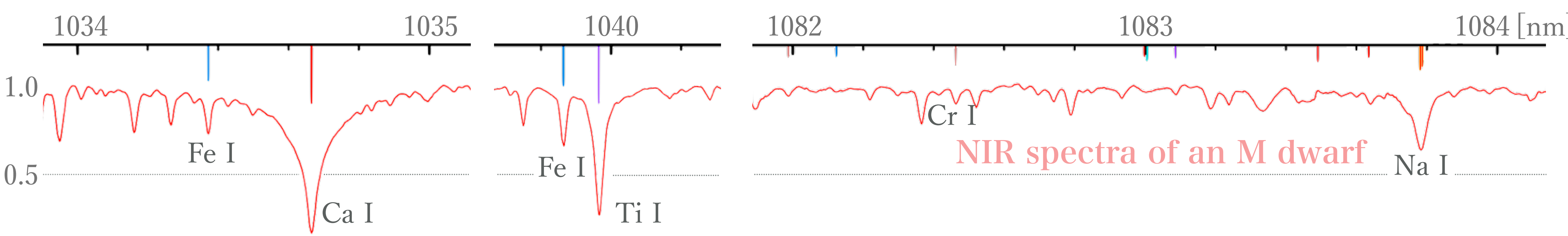
Abundance analysis of individual elements for nearby M dwarfs based on high-resolution near-infrared spectra of Subaru/IRD



Hiroyuki Tako ISHIKAWA (ABC/NAOJ)

Wako AOKI; Takayuki KOTANI; Teruyuki HIRANO; Masayuki KUZUHARA; Masashi OMIYA

Subaru Users Meeting FY2021 on January 11–13, 2022

M dwarf Stars

T_{eff} ~ **2500 – 3900** K

M = 0.08 – 0.6 $M_\odot$

R = 0.1 – 0.6 $R_\odot$

> 70 % of nearby stars

Sun
(G2V)

T_{eff} ~ 5800 K

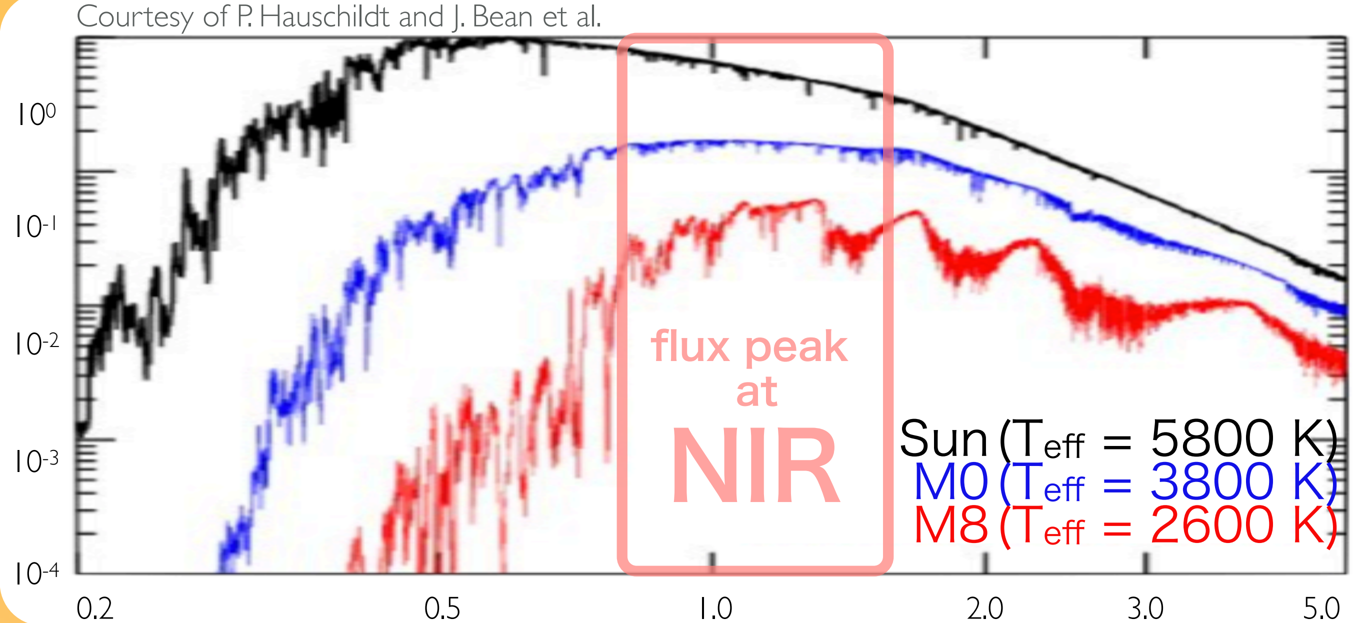
M = 1 $M_\odot$

R = 1 $R_\odot$

⇓

Major target of planet search projects

Courtesy of P. Hauschildt and J. Bean et al.



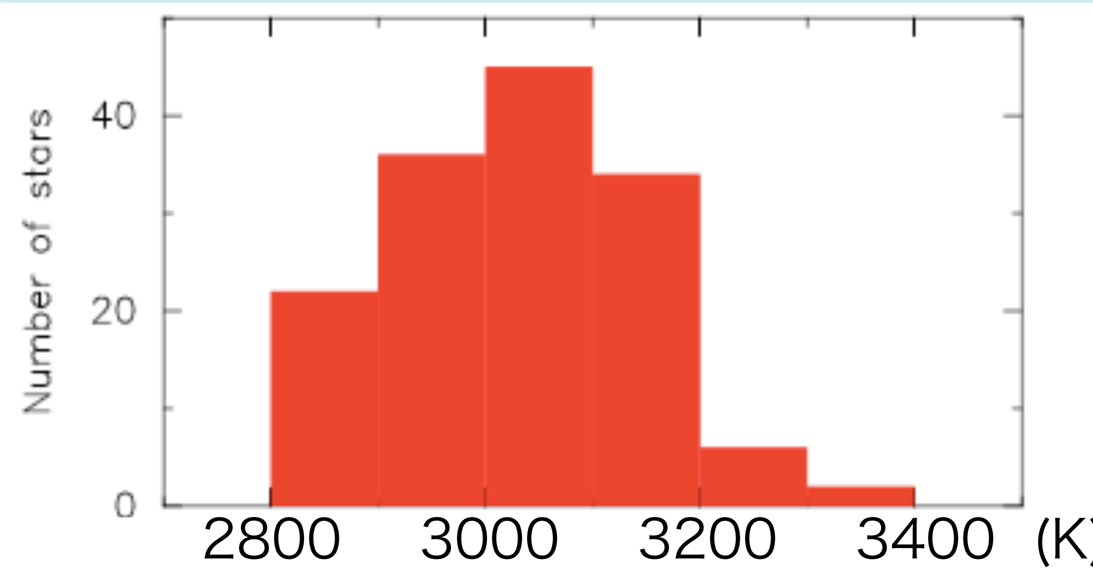
IRD-SSP (= InfraRed Doppler – Subaru Strategic Program)

Radial velocity survey (February, 2019- (5 year))
of nearby **mid-late M dwarfs** (0.1-0.2 M_{Sun})
for **Earth-mass planets**

$$R = \frac{\lambda}{\Delta\lambda} \sim 70{,}000$$

Y, J, H (**0.97-1.75** μm)

T_{eff} distribution of target candidates



Stellar Elemental Abundance

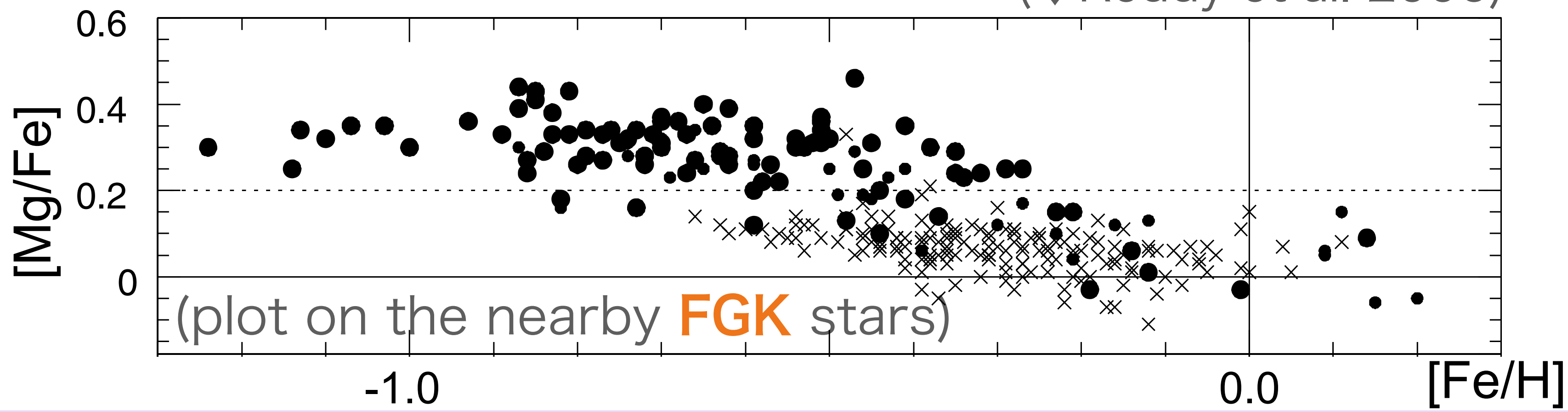
Elemental abundance [X/H] ➡ Important for formation environment and internal structure of orbiting planets

Most previous works on M dwarfs considered [M/H] or [Fe/H] only
➡ Need to know individual [X/H] ……Why?

(Reason 1) Where on the Galactic evolution?

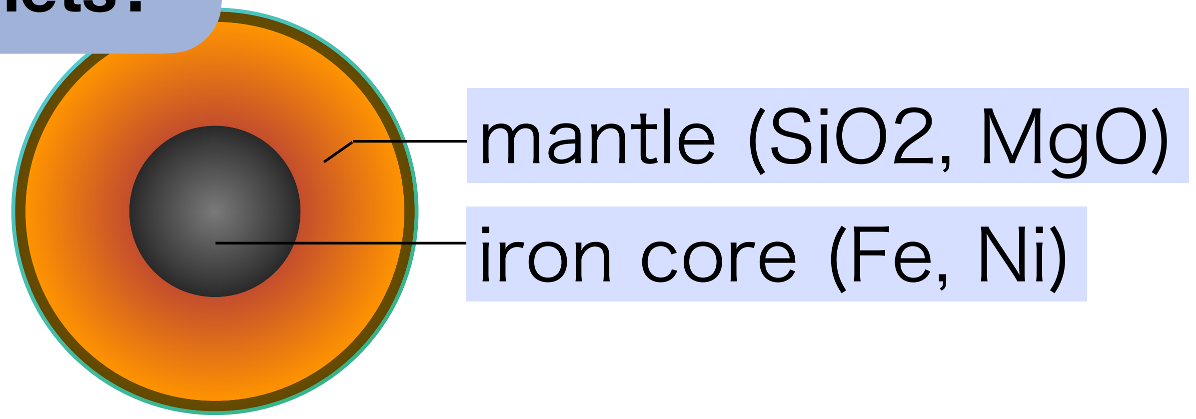
Abundance ratios reflect the formation age + environment

(↓ Reddy et al. 2006)

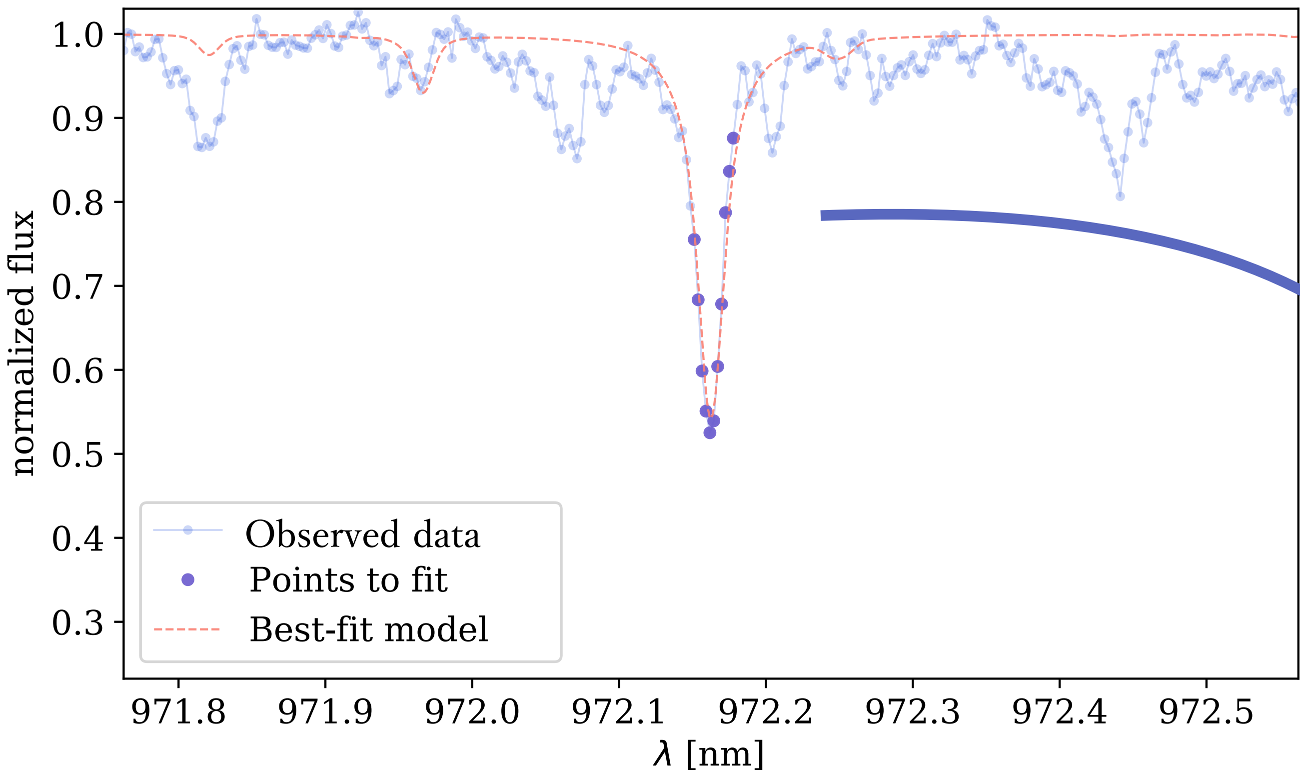


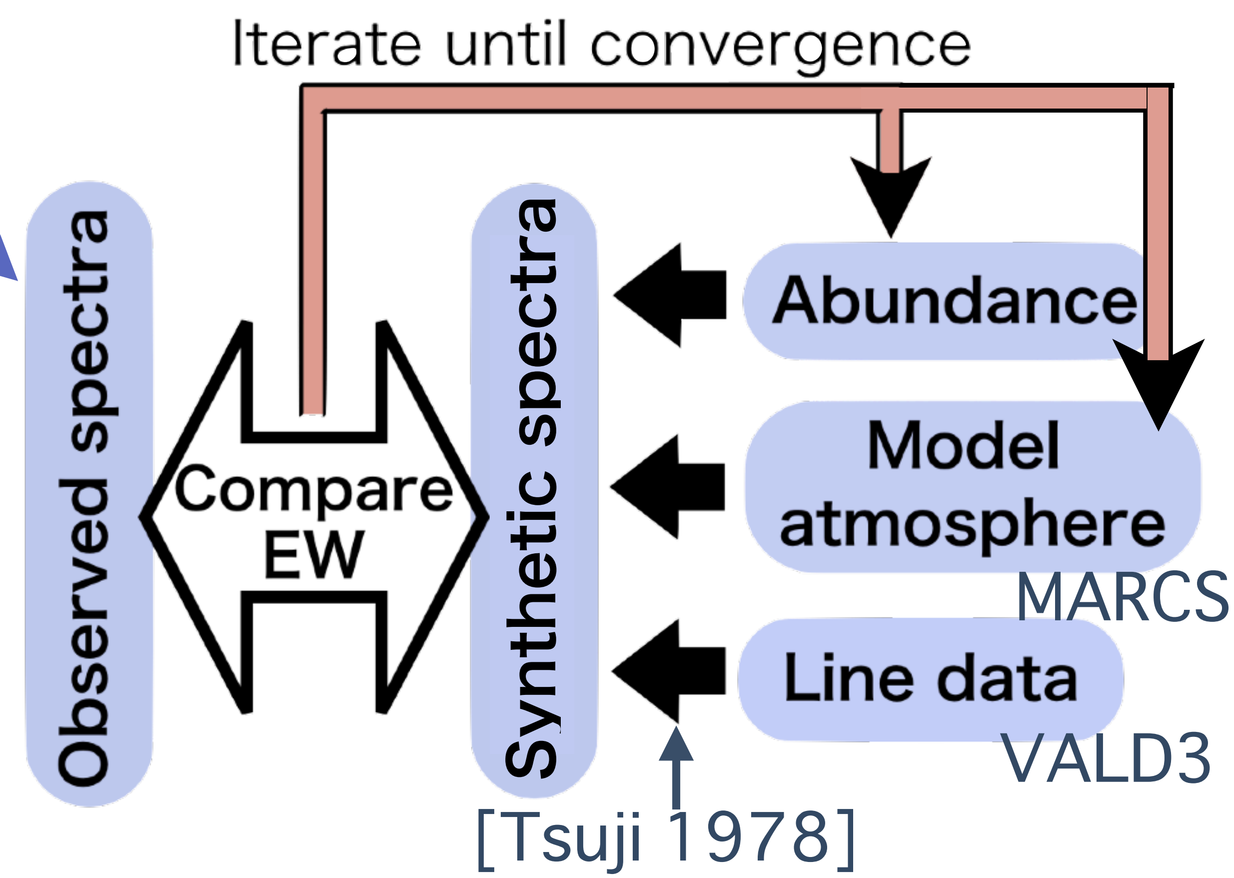
(Reason 2) Internal structure of rocky planets?

mass & radius → mean density → abundance



Analysis; Model Fitting & Equivalent Width Analysis





Automatically fit model spectra to obtain Equivalent width (EW)

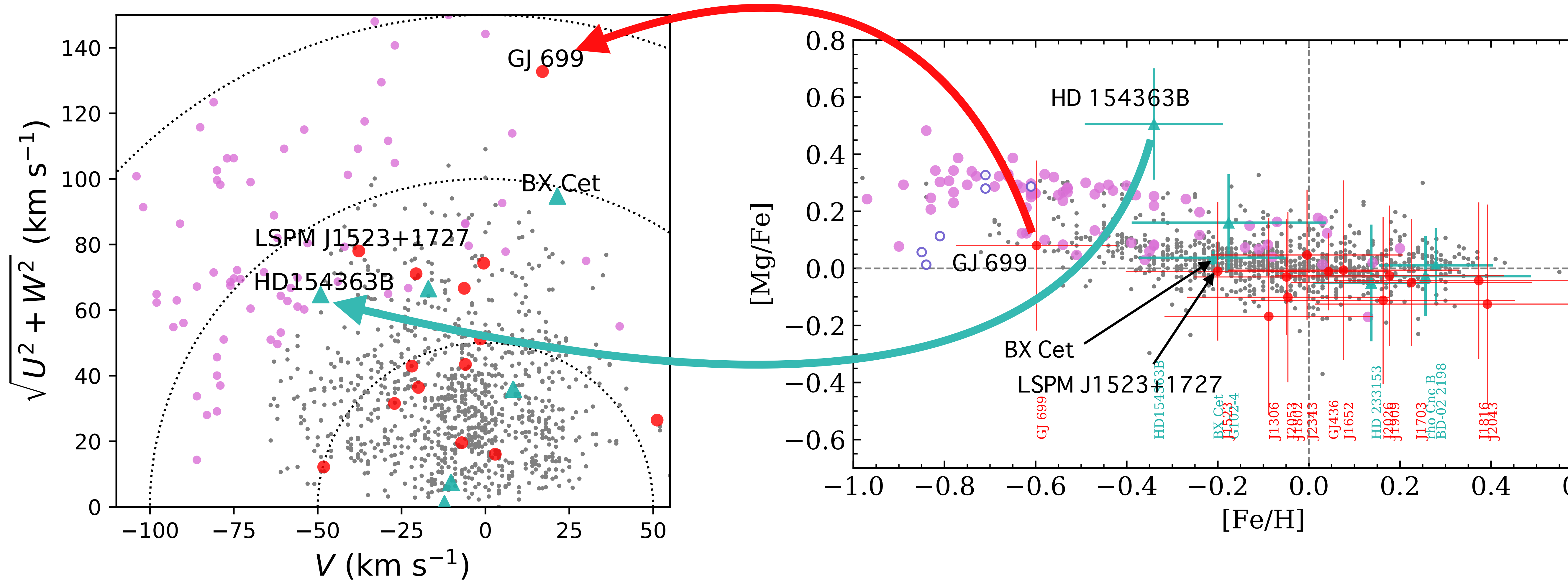
(fixing the wavelength range of each absorption line for all objects)

Iterate the adjustment of [X/H] until the theoretical EW matched the observed EW for each absorption line.

Determine [X/H] for eight elements consistently.

Previous Application (Ishikawa et al. 2021 in press)

Determined elemental abundances of 13 M dwarfs observed in IRD-SSP.

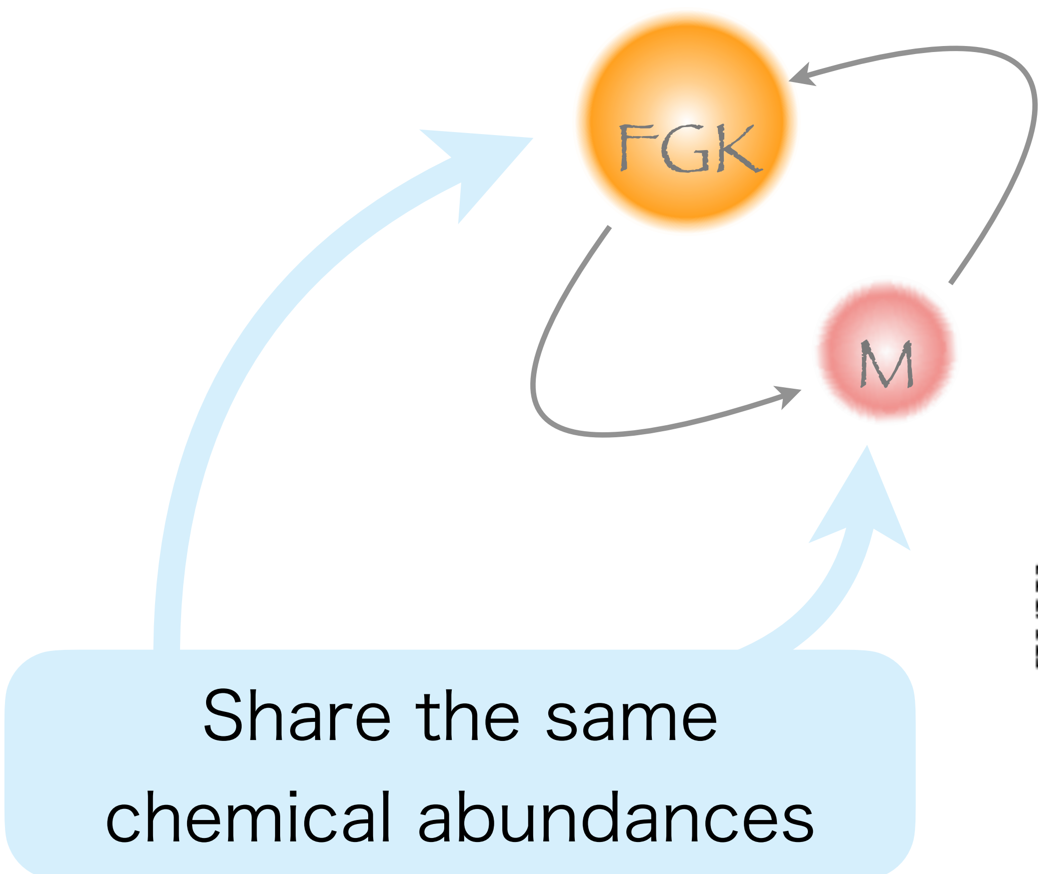


Similar [X/Fe] vs [Fe/H] distribution to those known for FGK was plotted.

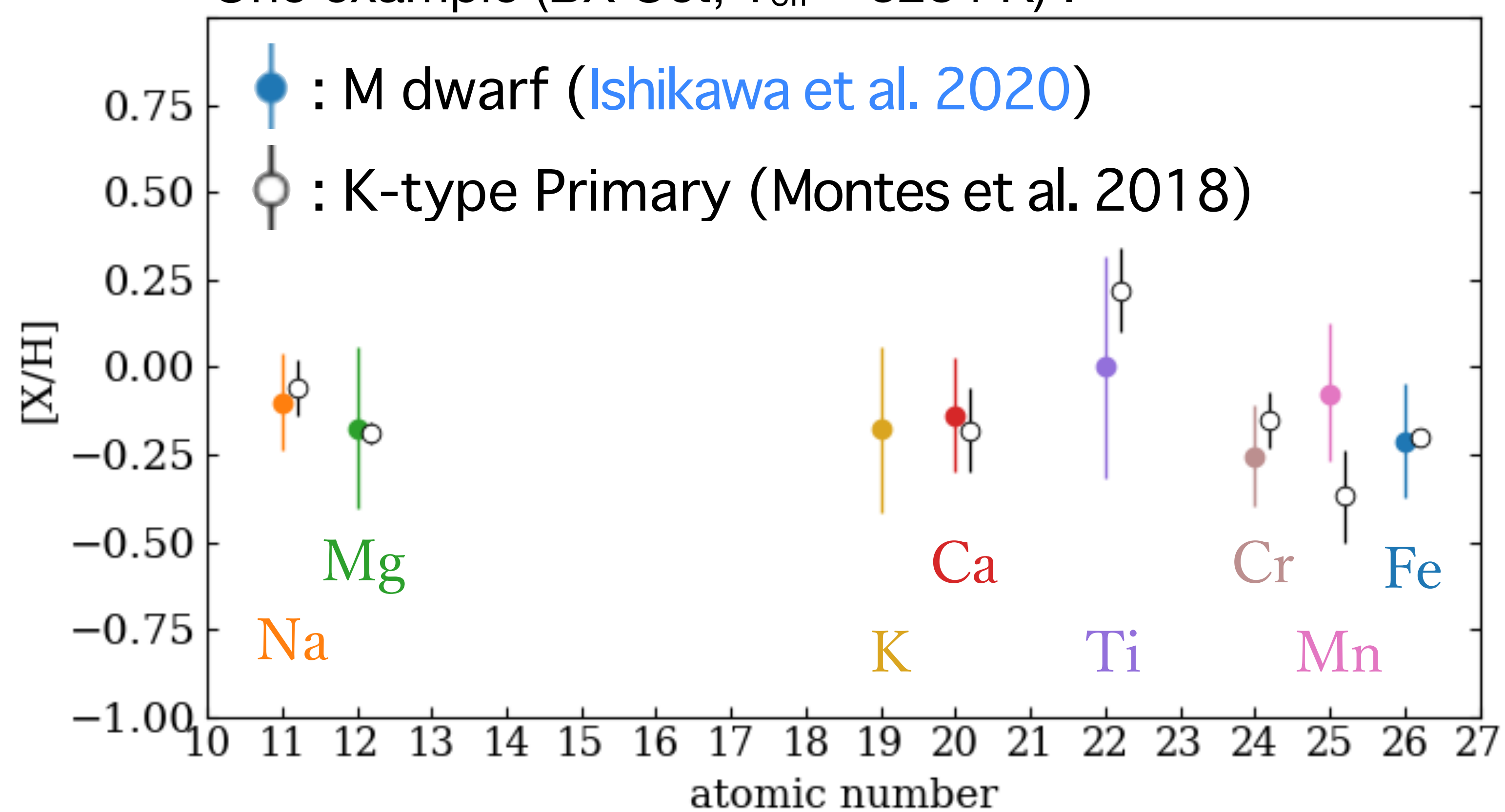
M dwarfs with relatively lower metallicity show more different galactocentric velocities than the Sun.

Previous method–verification with FGK+M binaries

(Ishikawa et al. 2020)



One example (BX Cet; T_{eff} = 3284 K) :

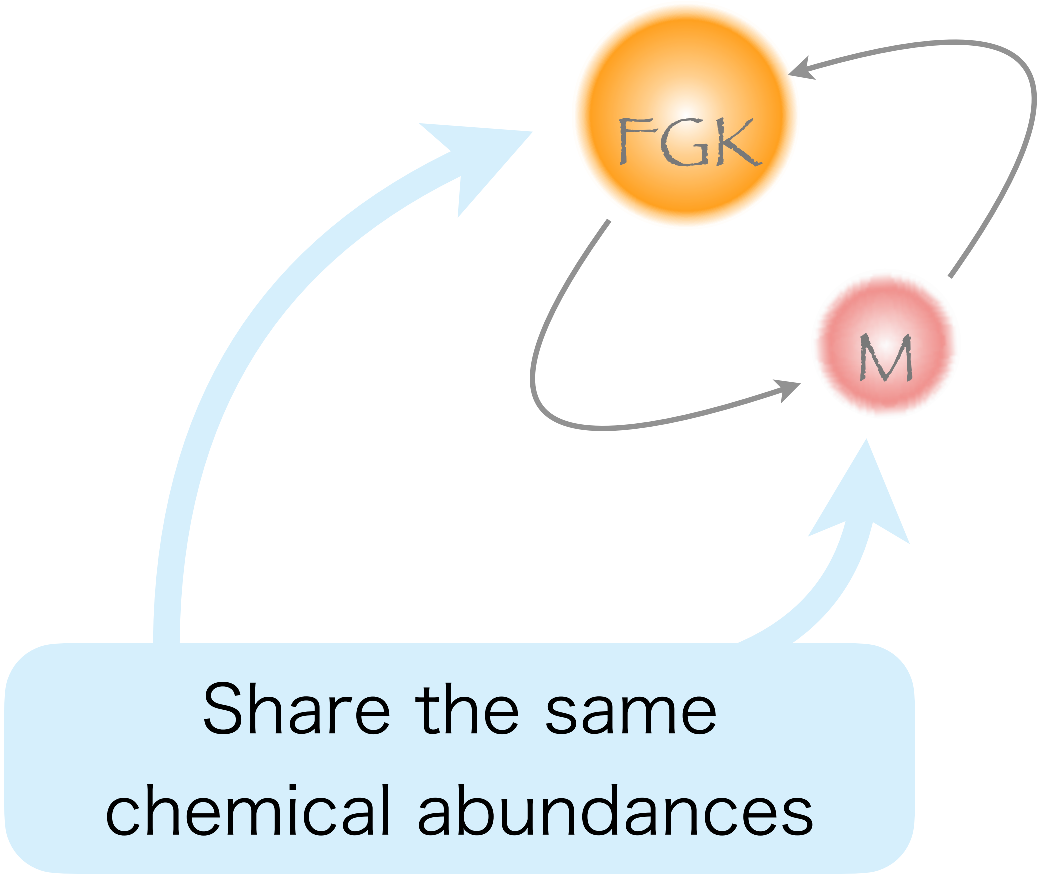


We used the spectra of NIR channel of CARMENES

Our results of M dwarfs agree with the abundances of the primary stars (determined by high-dispersion visible spectroscopy) within the estimated error (∼0.2 dex).

Previous method–verification with FGK+M binaries

(Ishikawa et al. 2020)



Name	$T_{\rm eff}$ (K)	$\log g$
HD 233153	3765 ± 60	4.70 ± 0.13
HD 154363 B	3658 ± 67	4.79 ± 0.21
BX Cet	3284 ± 60	4.94 ± 0.13
G 102-4	3246 ± 57	4.97 ± 0.20
ρ^{01} Cnc B	3166 ± 61	4.94 ± 0.14

Small sample and ununiform $T_{\rm eff}$ distribution

$\Longrightarrow$ Need more sample of M dwarfs in binary!

Especially need to improve the reliabitily of low $T_{\rm eff}$ (Teff<~3000 K)objects

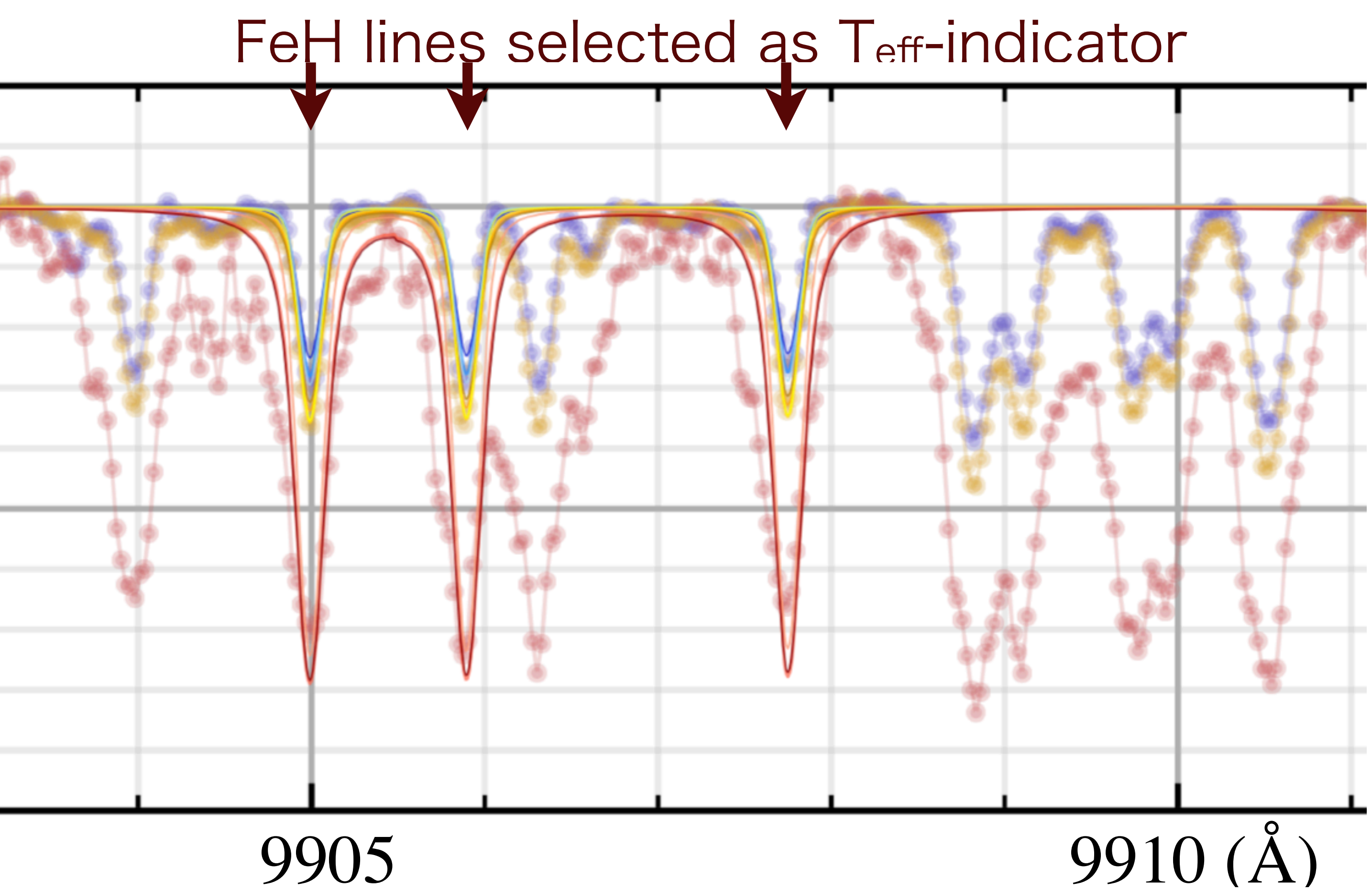
Targets and Data

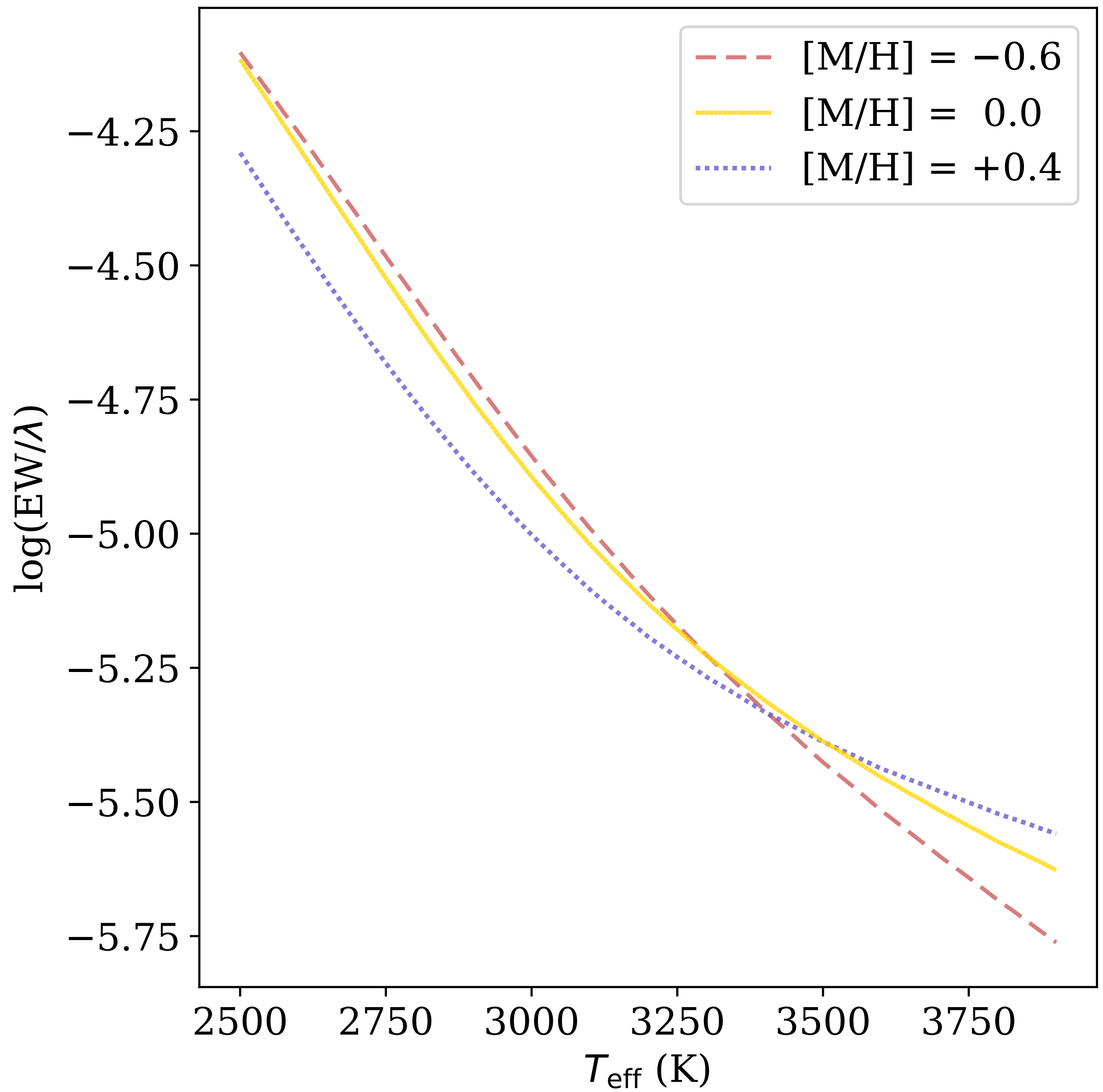
We observed M dwarfs in FGK+M binary systems with
CAHA 3.5m + **CARMENES**
Subaru + **IRD** (that can uniquely target cooler ones!)

Name	T_{eff}	logg	instrument
HD 263175 B	3709	4.8037	CARMENES
GJ 387B	3690	4.76655	CARMENES
HD 97584 B	3476	4.81703	CARMENES
HD 138367 B	3767	4.60505	CARMENES
GJ 695 B	3252	4.69531	IRD
GJ 695 C	3196	NaN (4.7)	IRD
HD 183870 B	3099	4.97372	IRD
GJ 777 B	3147	5.00354	IRD

logg (surface gravity) is from TESS Input Catalog (TIC)

Analysis; T_{eff} estimated from FeH lines



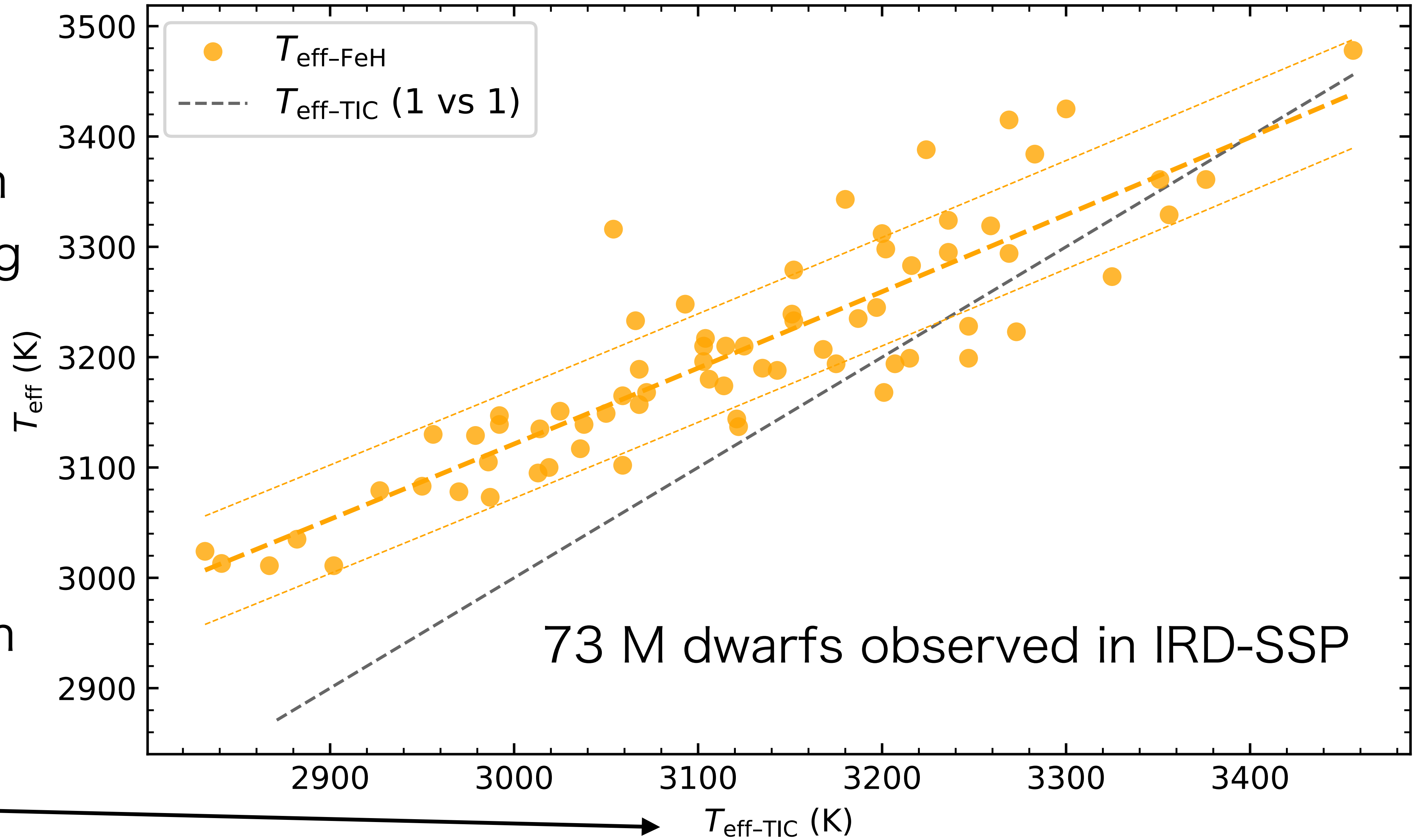


Many FeH molecular lines that are sensitive to the T_{eff}.

Analysis; Teff estimated from FeH lines

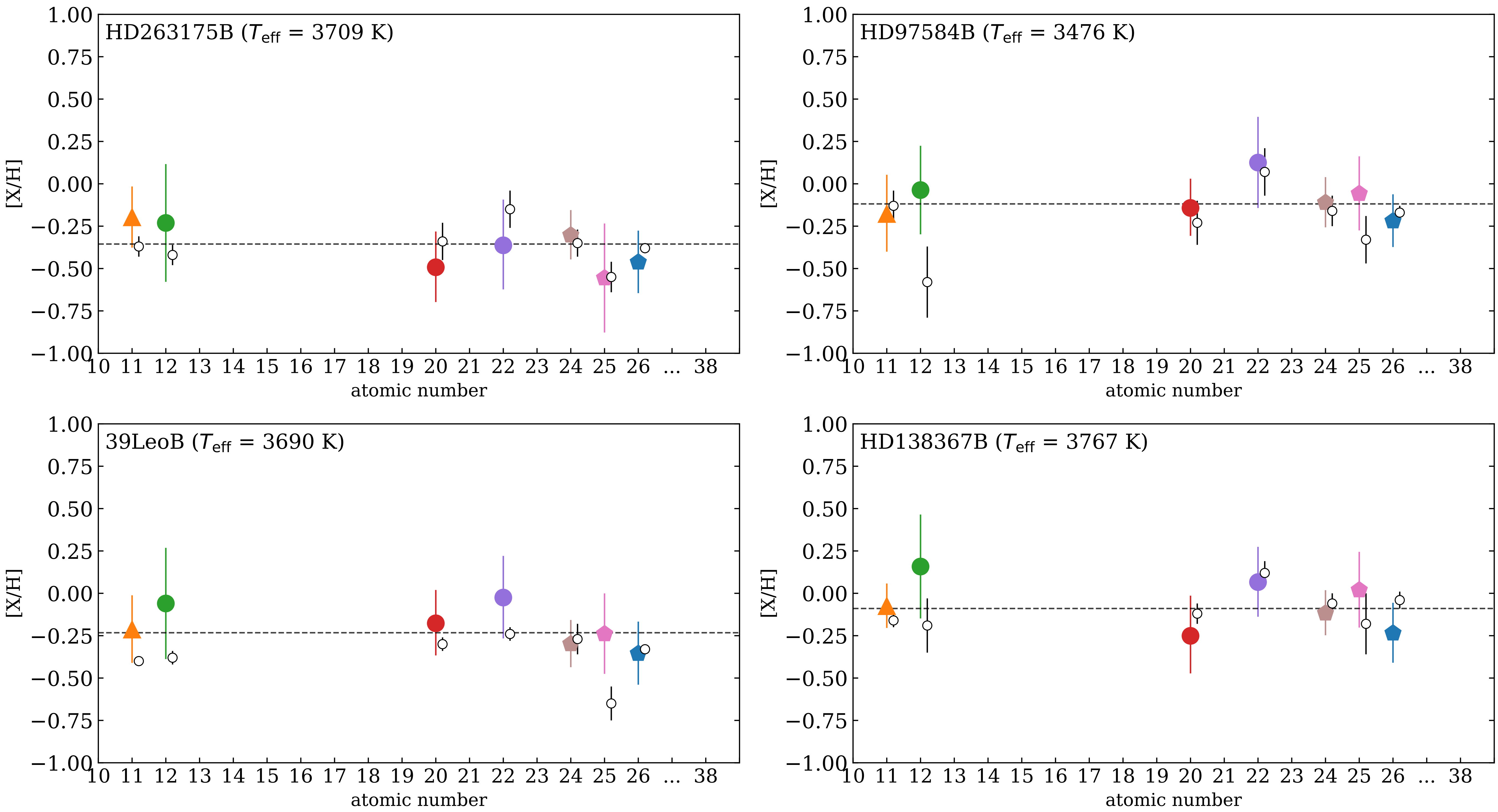
T_{eff} estimated from FeH lines, assuming [Fe/H]=0.0

T_{eff} from TIC, which is estimated from Gaia colors



The two T_{eff} share the a common trend but there seems to be an offsets between them.

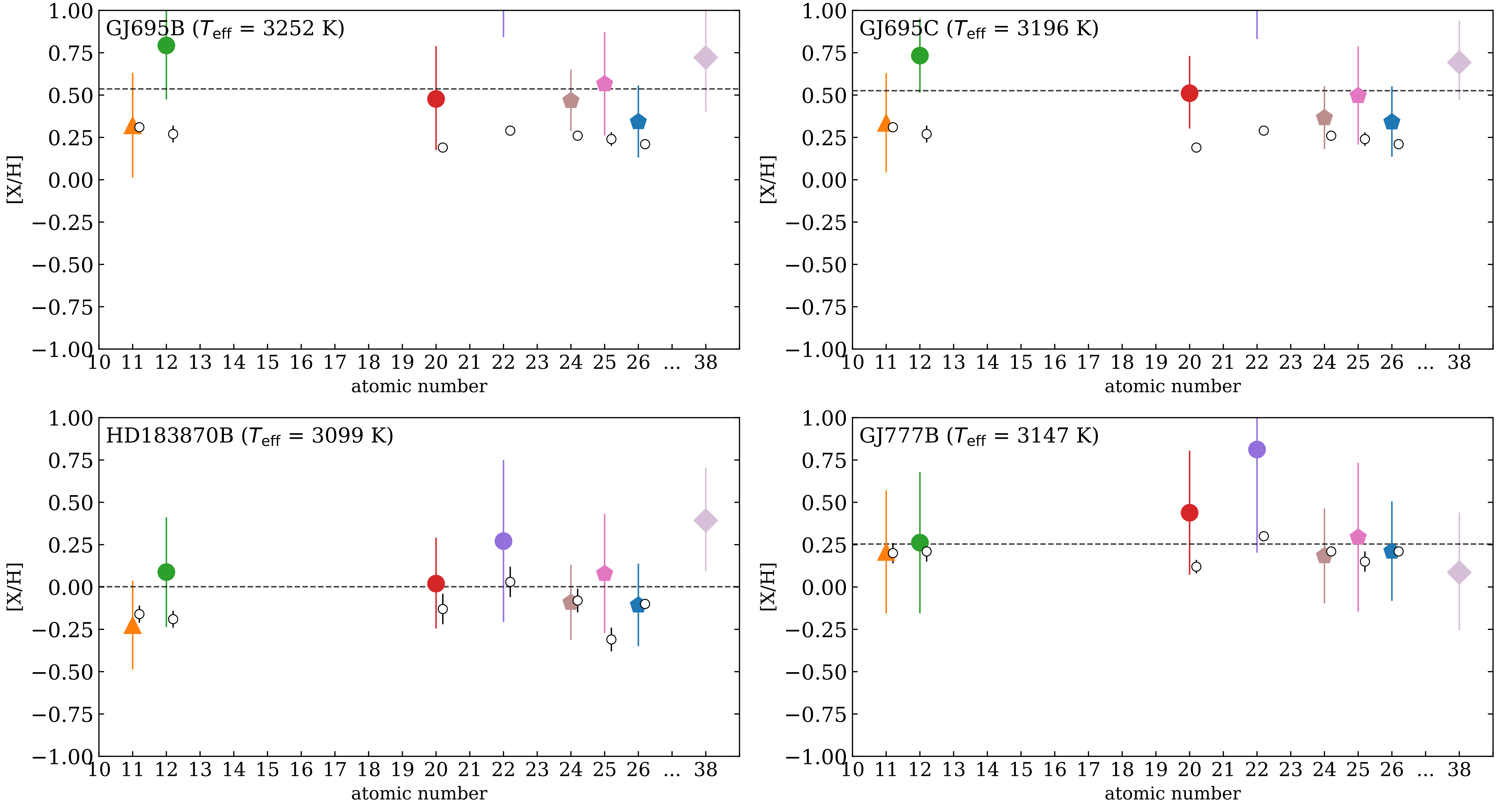
Results (CARMENES targets; relatively warmer 4)



Open circles: Abundances of primaries taken from Montes et al. 2018

Filled circles: Abundances of M dwarfs in this study

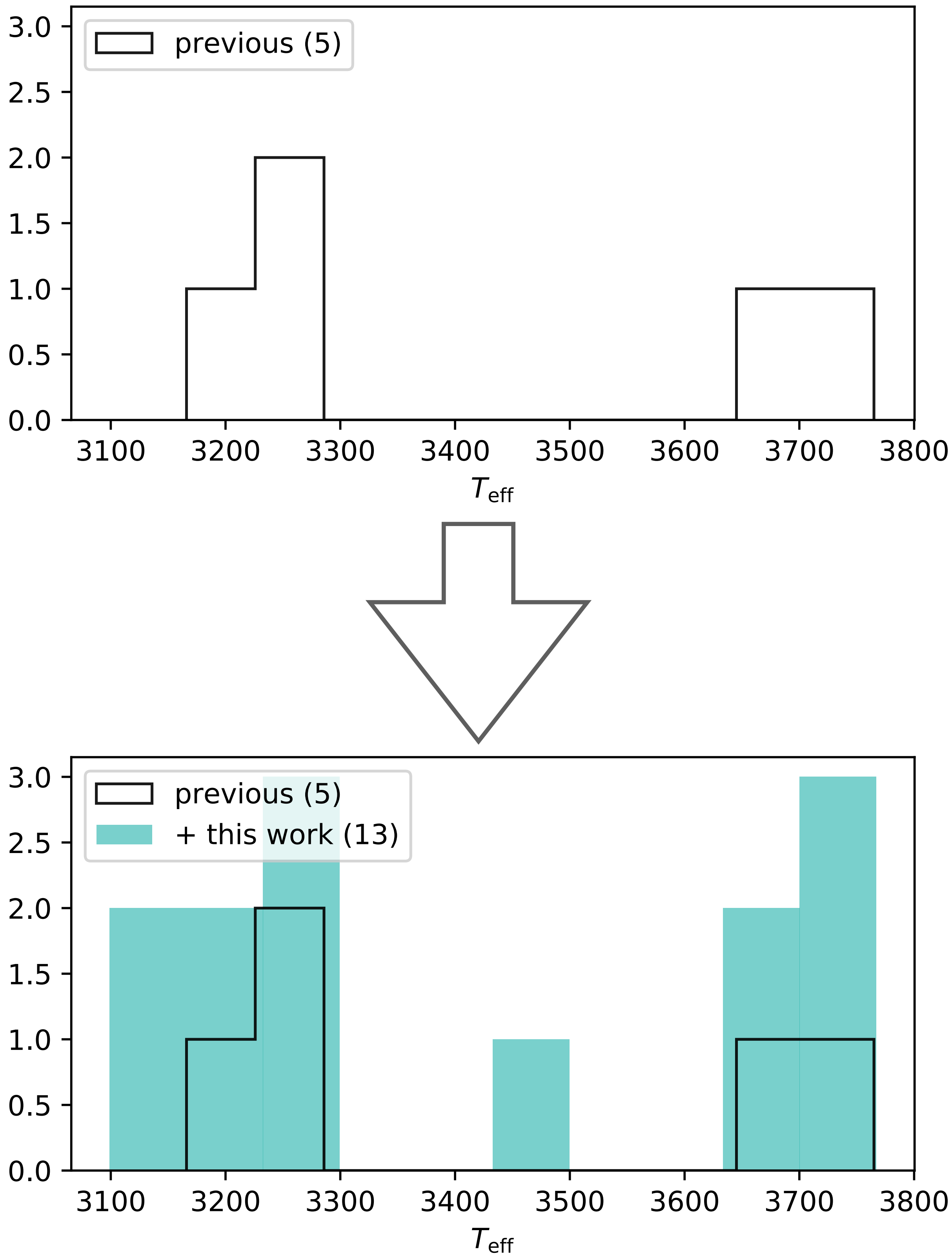
Results (IRD targets; relatively cooler 4)



Generally agreed with the primaries' abundance.

Two M dwarfs in GJ695 system show abundances that are relatively higher than the abundance of the primary star, but are in good agreement with each other.

Future; Extension of sample



The number of samples used for binary verification **increased more than twice** from Ishikawa+2020.

$T_{\rm eff}$ distribution is **not uniform** yet.

Summary

What we did

Conducted method-verification of abundance analysis of M dwarfs using 8 M dwarfs in binaries and confirmed agreement.

Future prospects

Continue extending binary-verification to larger sample, especially including late-Ms.

Determine composition of all targets of IRD-SSP will lead to a further understanding of abundance distribution of M dwarfs and help to explore the relations between M dwarfs' chemistry and the nature of orbiting planets.