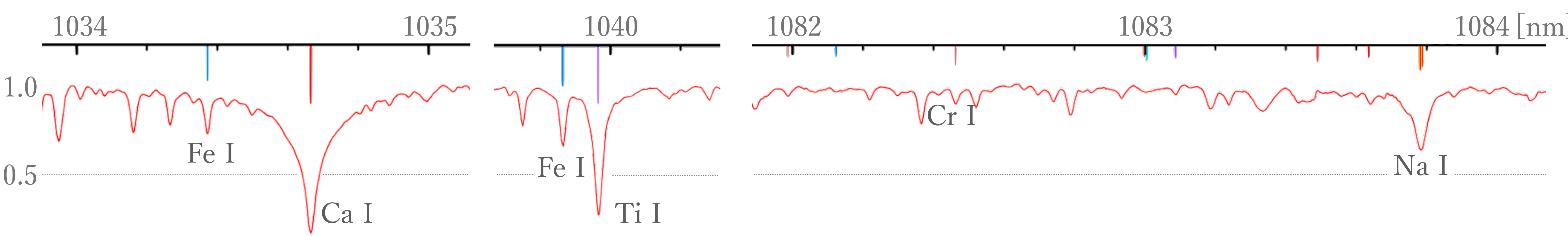
Abundance analysis of individual elements for nearby M dwarfs with high-resolution near-infrared spectroscopy



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Stellar Elemental Abundance

Stellar chemistry ➡ Important for formation environment and internal structure of orbiting planets

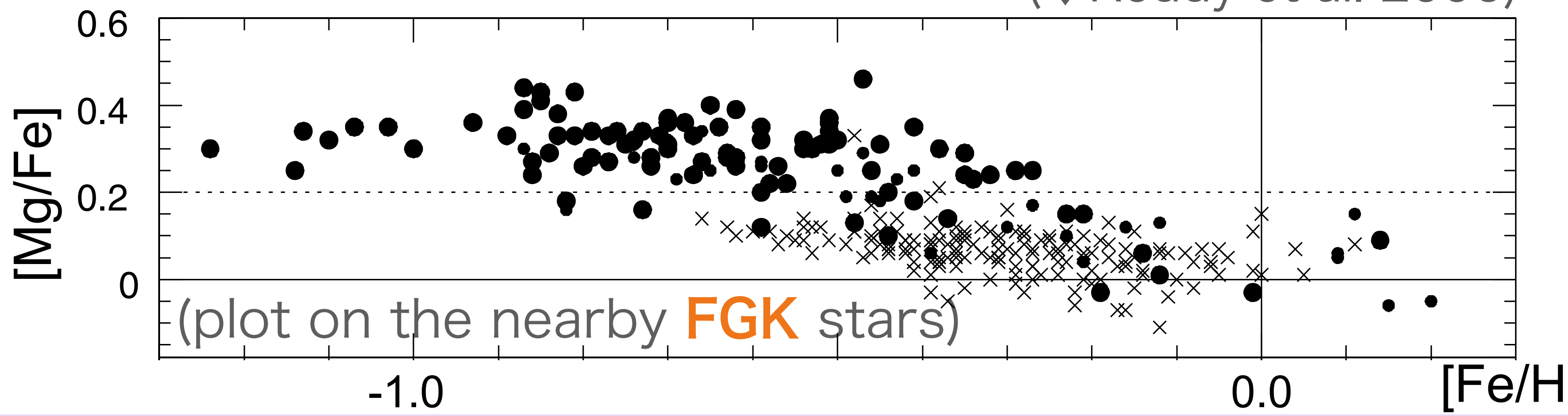
Most previous works on M dwarfs considered [M/H] or [Fe/H] only

➡ Need to know individual [X/H]

(Example 1) Where on the Galactic evolution?

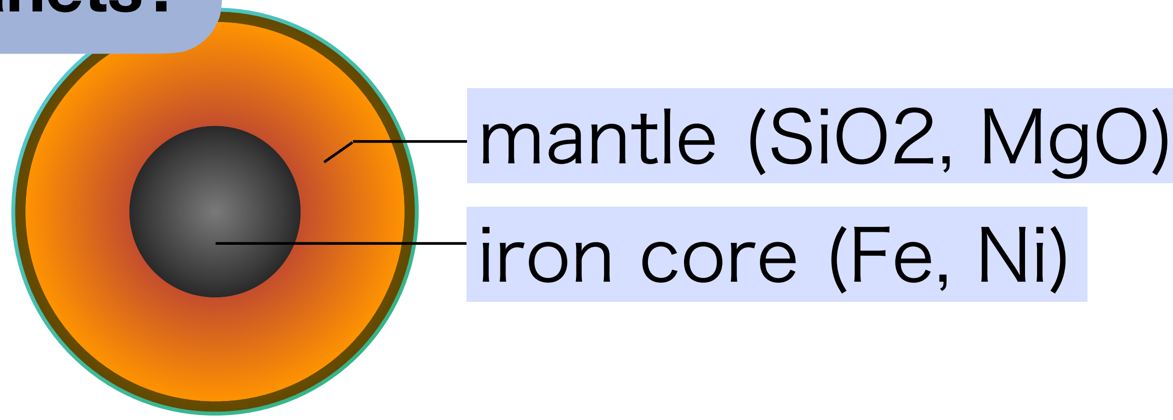
Abundance ratios reflect the formation age + environment

(↓ Reddy et al. 2006)



(Example 2) Internal structure of rocky planets?

mass & radius ↘ mean density —abundance→



M dwarfs

Sun
(G2V)

T_{eff} ~ 5800 K

M = 1 $M_\odot$

R = 1 $R_\odot$

T_{eff} ~ **2500 – 3900** K

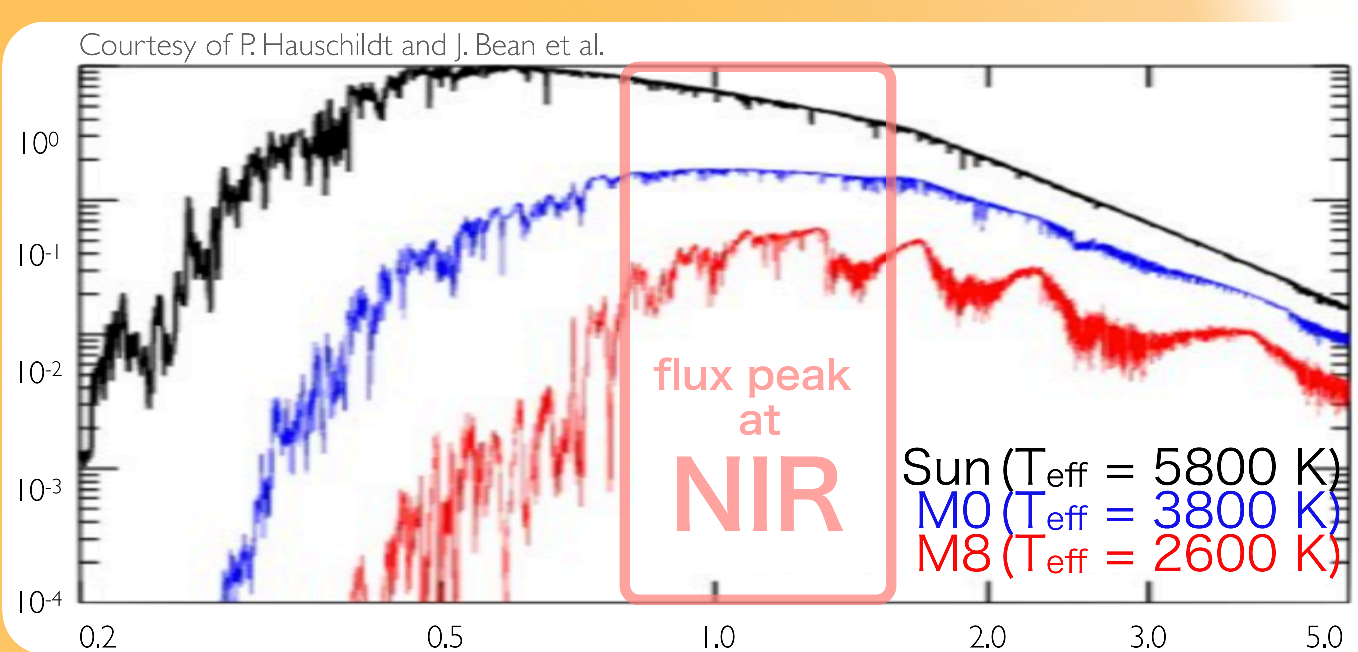
M = 0.08 – 0.6 $M_\odot$

R = 0.1 – 0.6 $R_\odot$

> 70 % of nearby stars

⇓

Major target of planet search projects



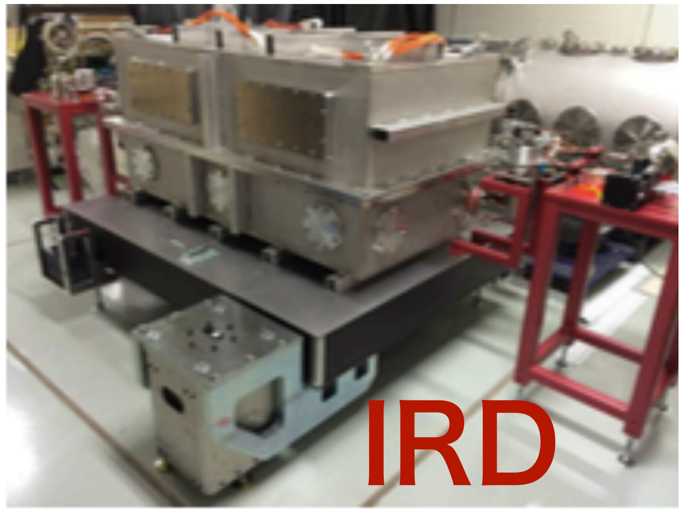
IRD-SSP

(= InfraRed Doppler – Subaru Strategic Program)

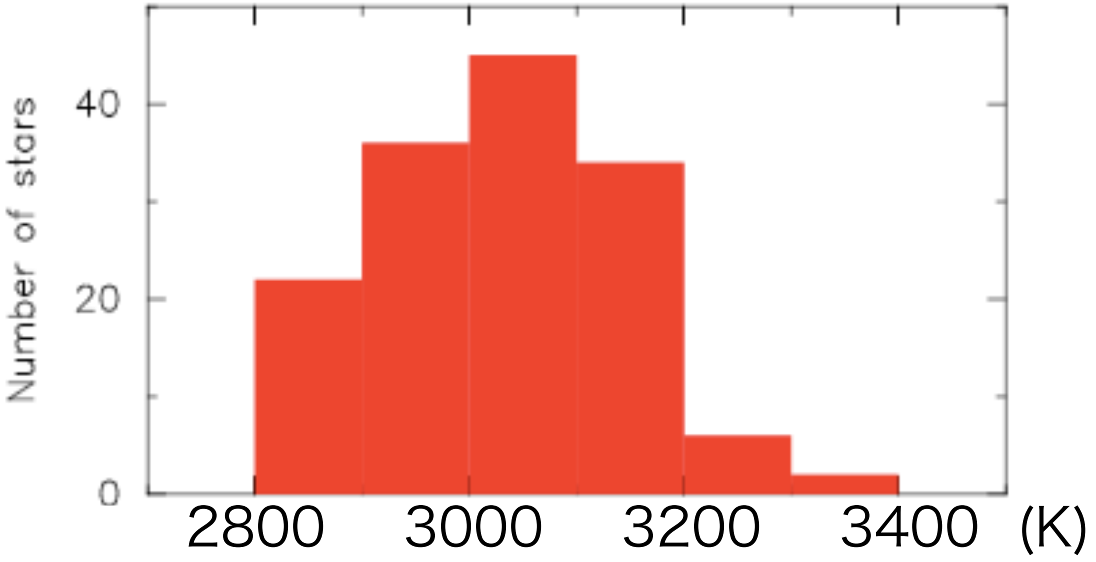
Radial velocity survey (February, 2019- (5 year))
of nearby **mid-late M dwarfs** (0.1-0.2 M_{Sun})
for **Earth-mass planets**

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

Y, J, H (**0.97-1.75** μm)



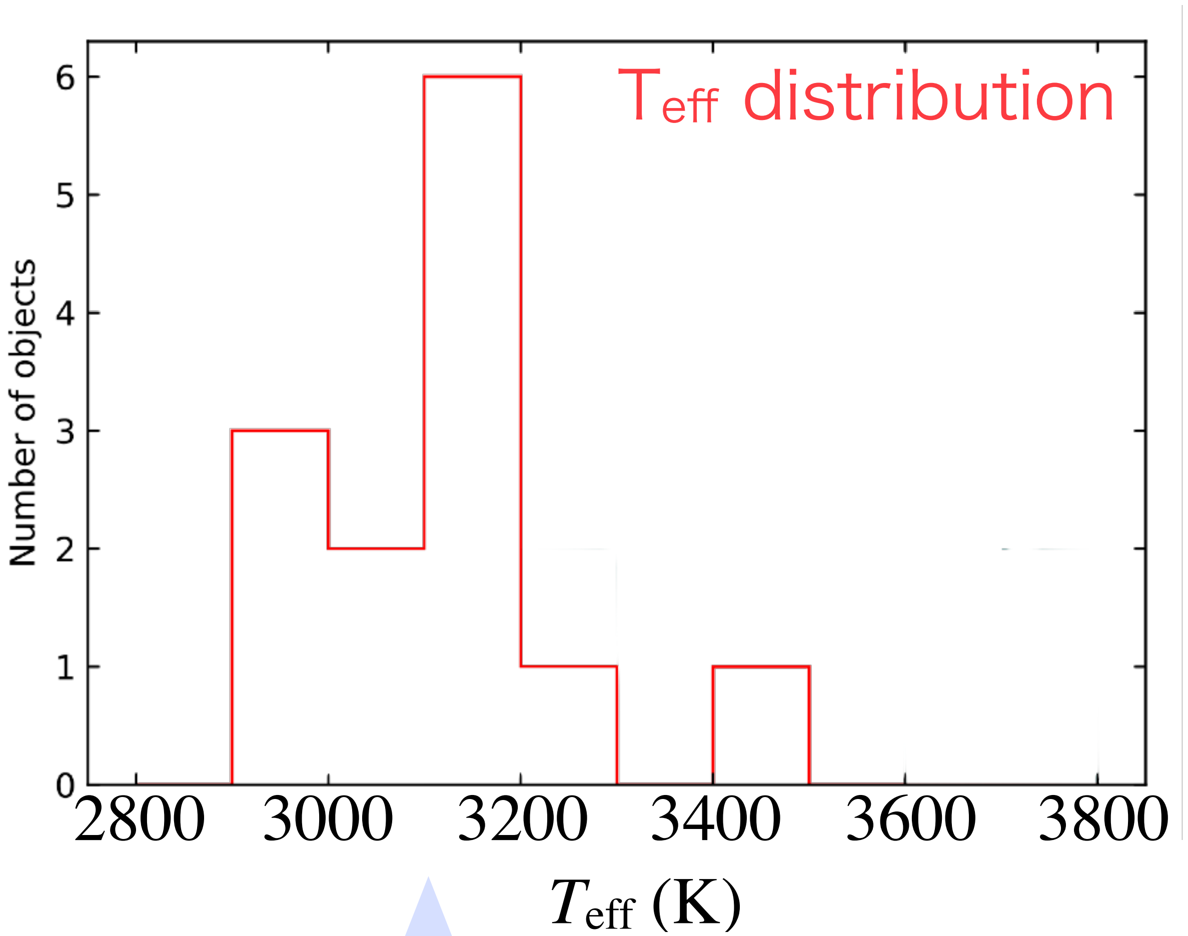
T_{eff} distribution of target candidates



Targets and Data

We analyzed 13 M dwarfs (including RV standards) for which high quality “template spectra” were obtained in IRD-SSP.

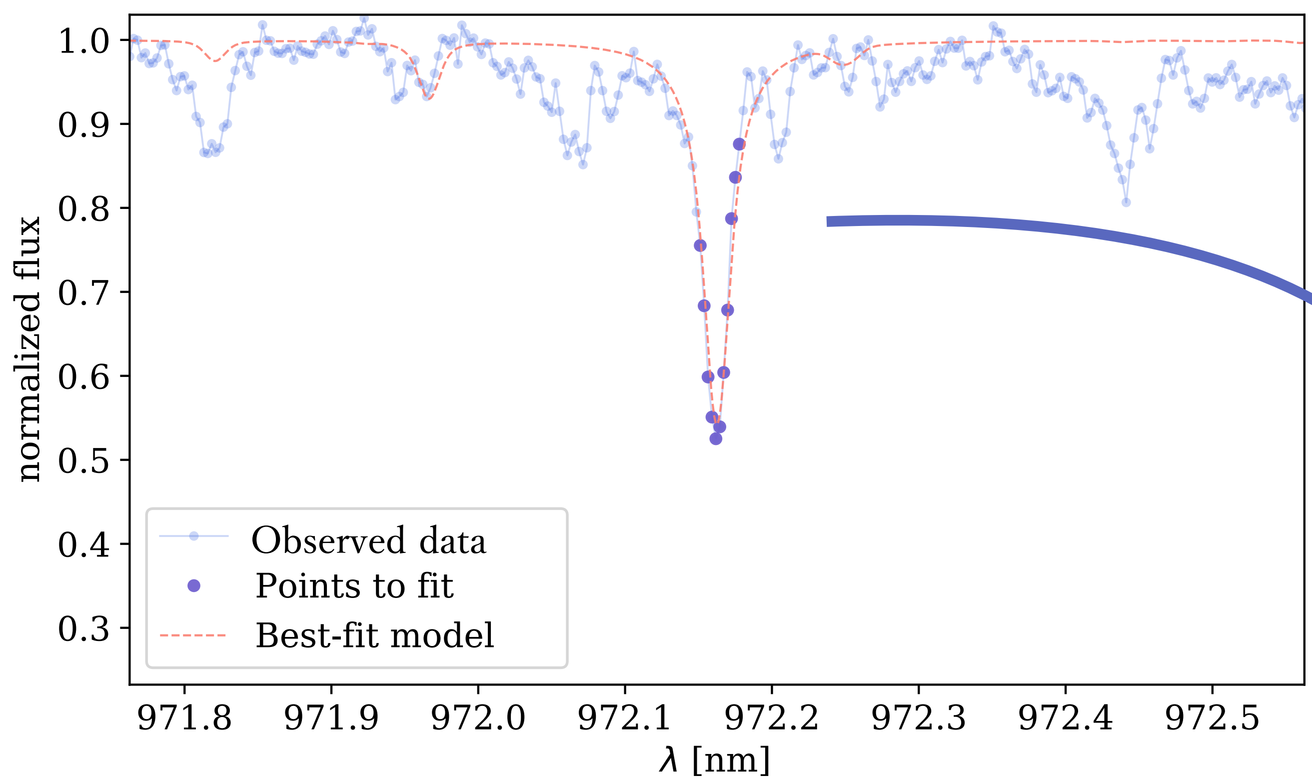
- **Telluric absorptions** are removed by the model fitting (LBLRTM) and by taking advantage of the wavelength shift over seasons
- **High-S/N ratio**
- Instrumental broadening profiles (**IP**) are deconvolved

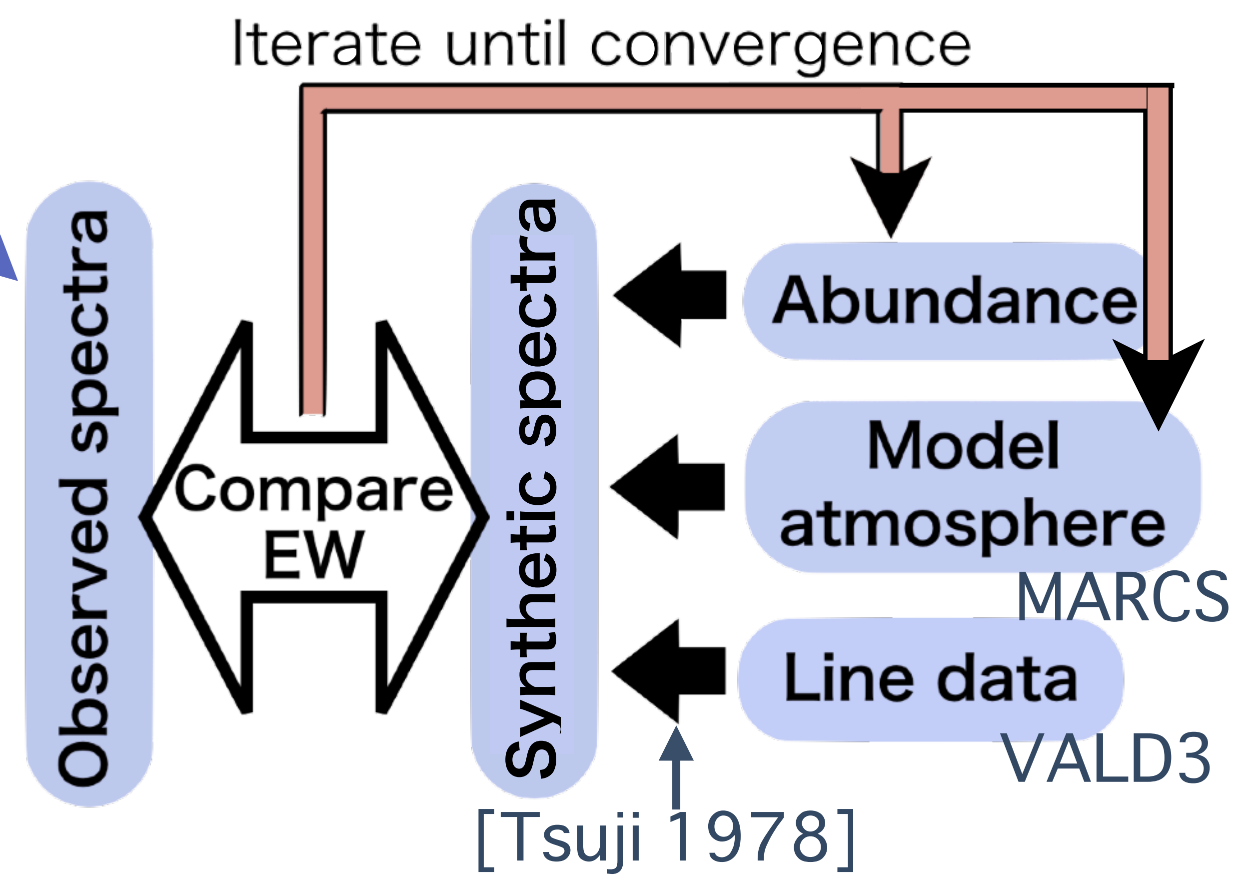


Below 3200 K
for the first time!

* T_{eff} from TESS Input Catalog (TIC)

Model Fitting & Equivalent Width Analysis





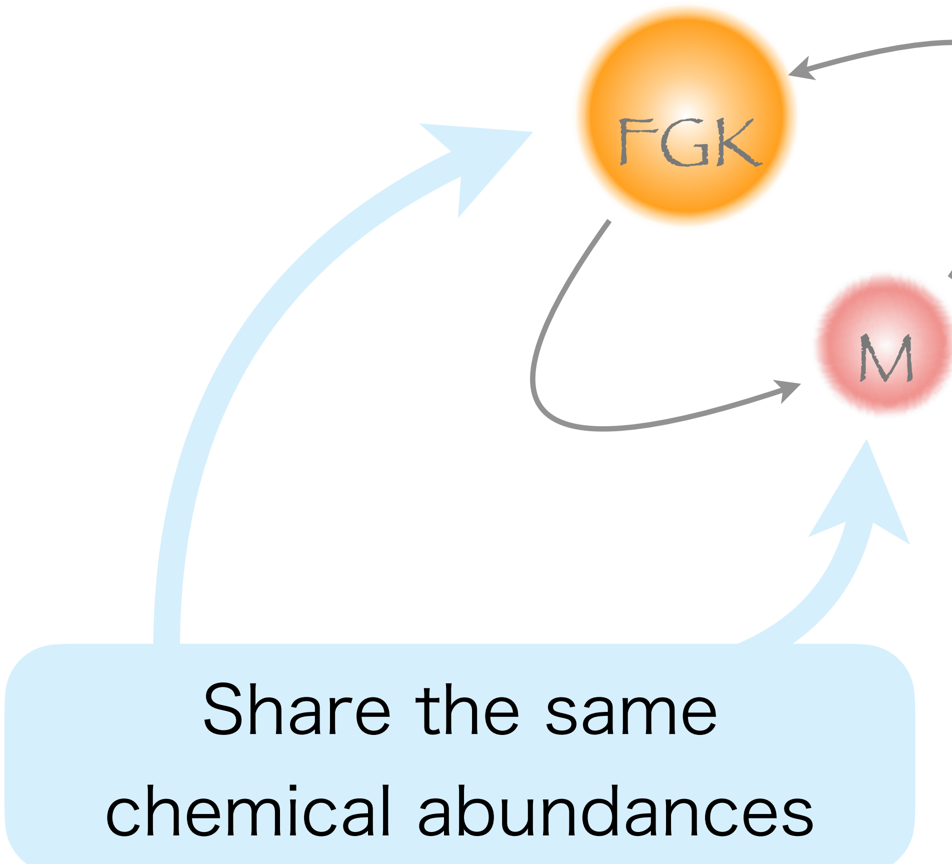
Automatically fit model spectra to obtain Equivalent width (EW) (fixing the wavelength range of each absorption line for all objects)

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

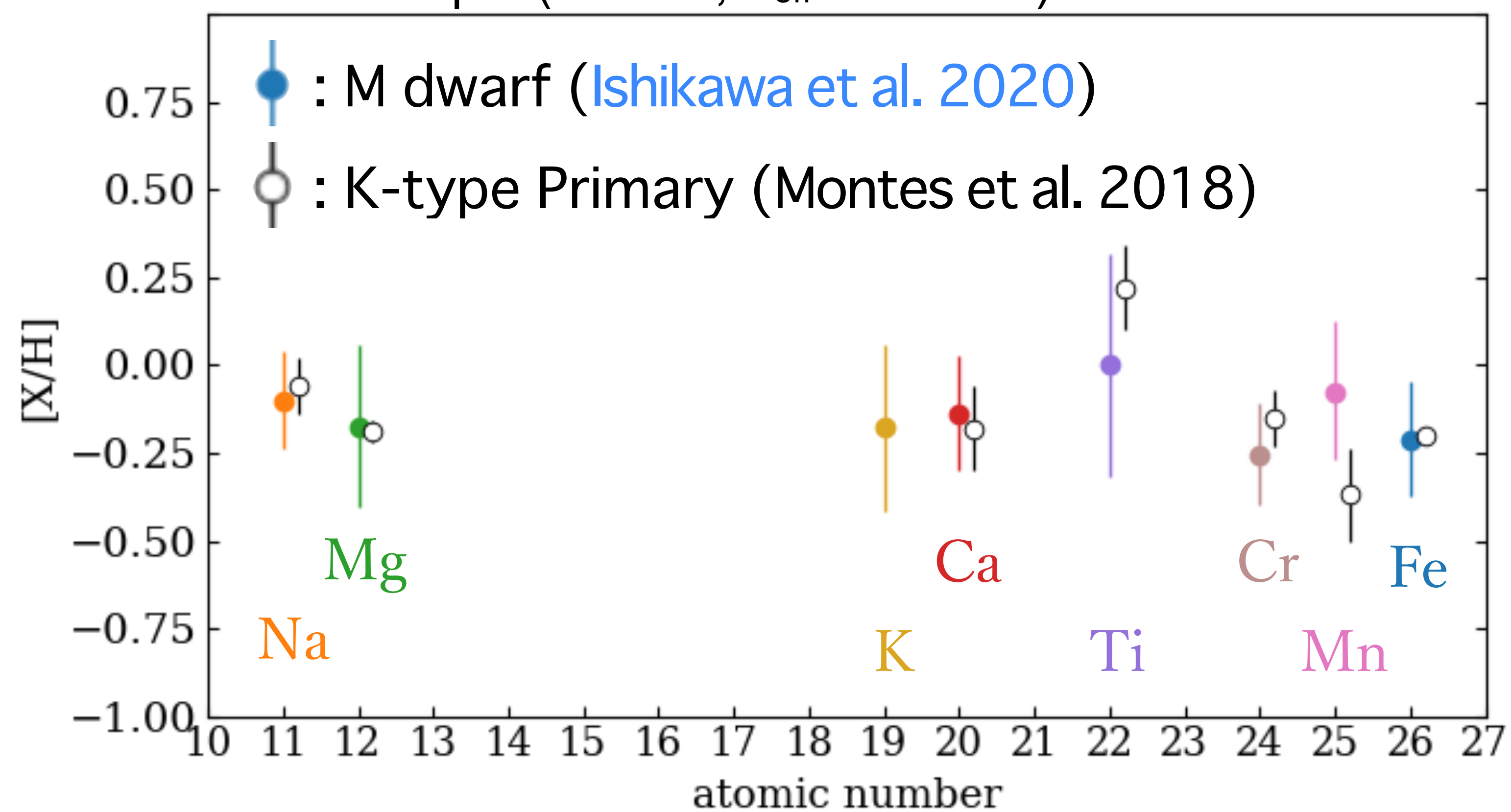
Determine [X/H] for eight elements consistently.

The method was verified with FGK+M binaries

(Ishikawa et al. 2020)



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



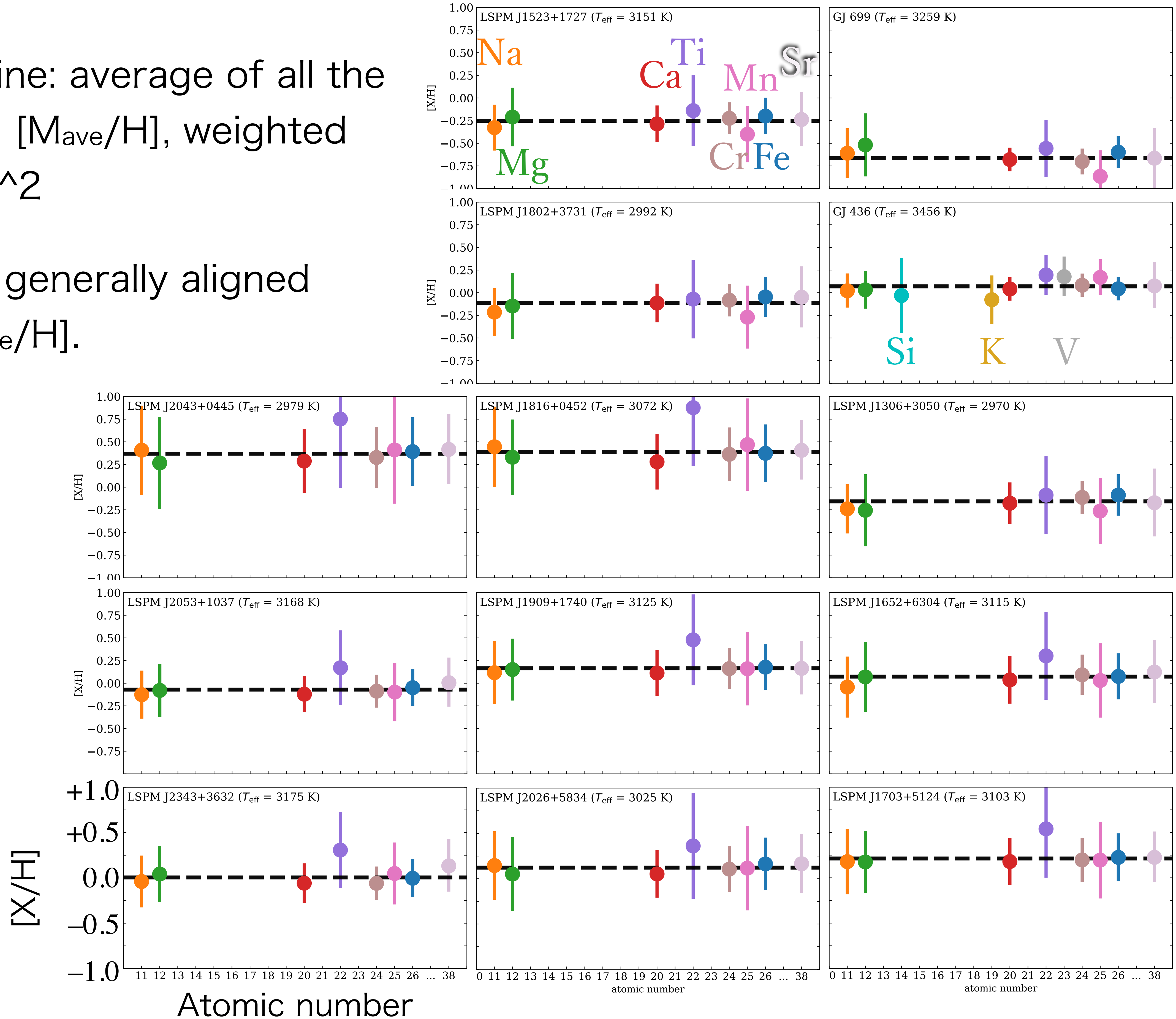
We used the spectra of NIR channel of CARMENES

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).

Results: [X/H] of individual elements

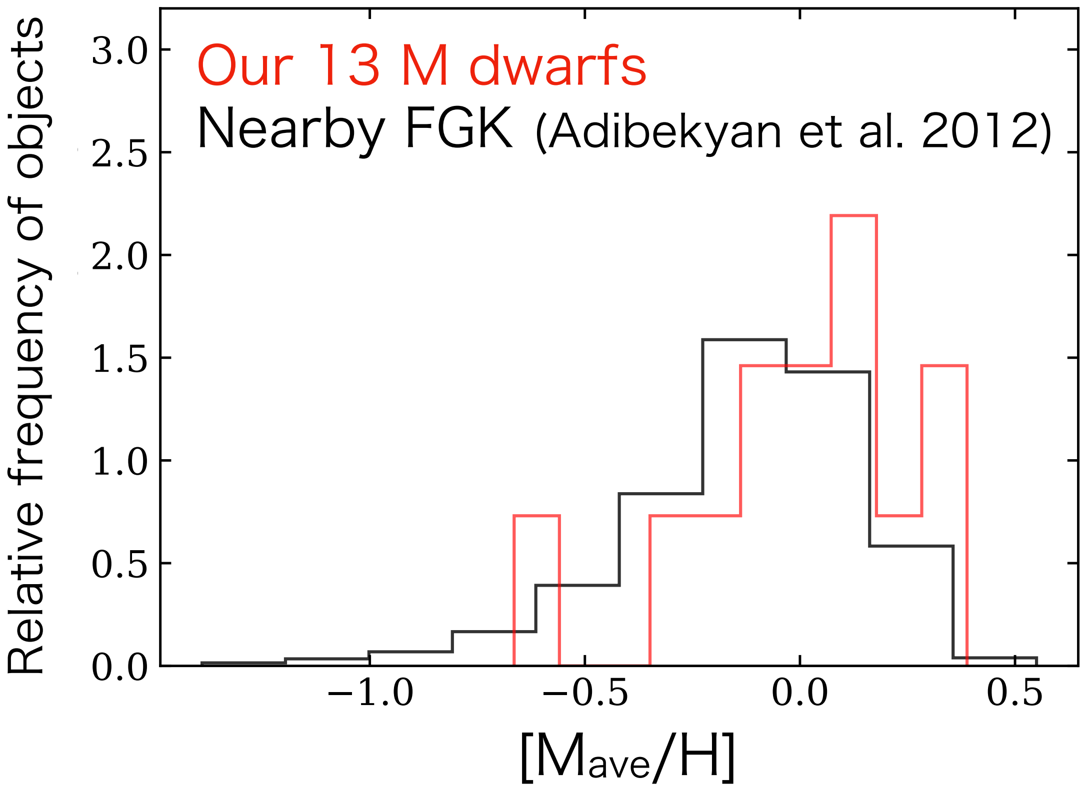
Dashed line: average of all the elements [M_{ave}/H], weighted by $(1/\sigma)^2$

All [X/H] generally aligned with [M_{ave}/H].



Results:

Metallicity



Metallicity distribution comparable to FGK stars (* Not conclusive being small sample)

The wide spread over almost 1 dex
-> Interesting to compare with planetary characteristics!

Results: [X/Fe] distribution

- Thin
- Thick
- Halo

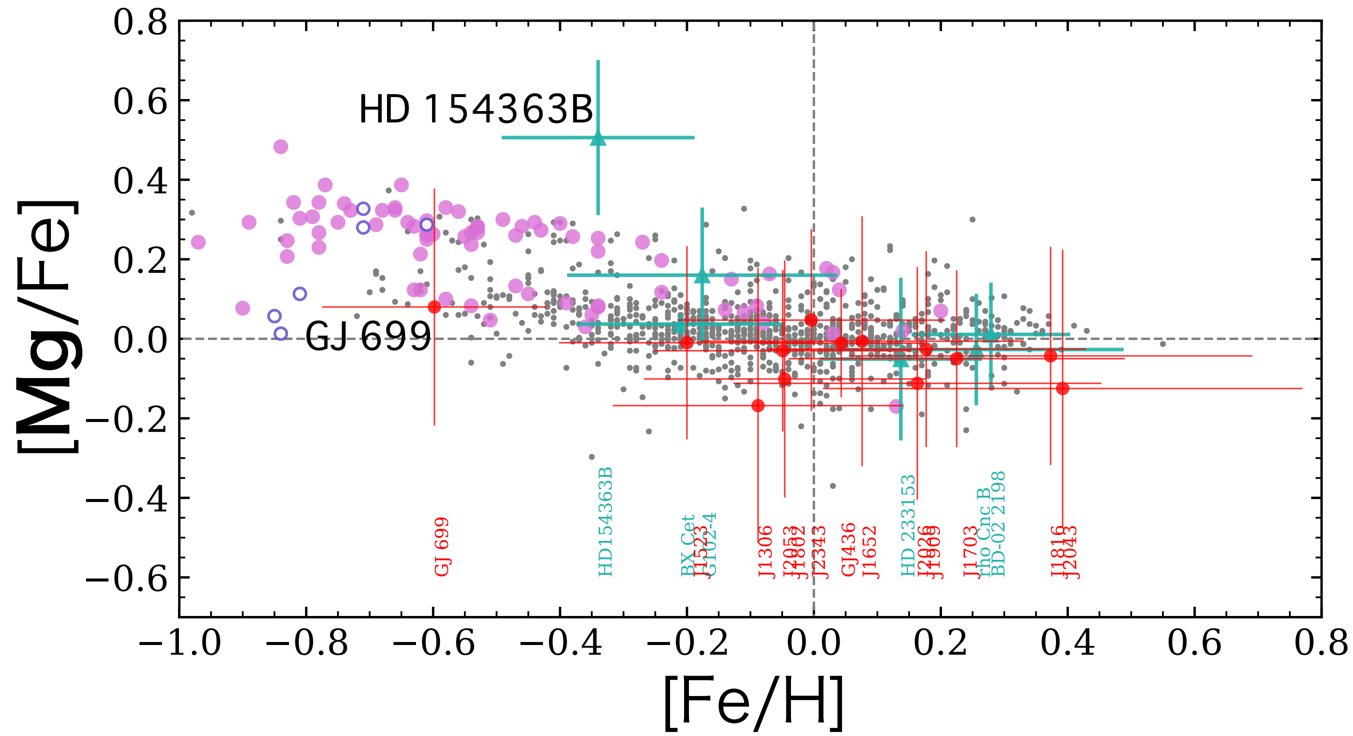
} FGK stars in HARPS-GTO targets (Adibekyan+ 2012)

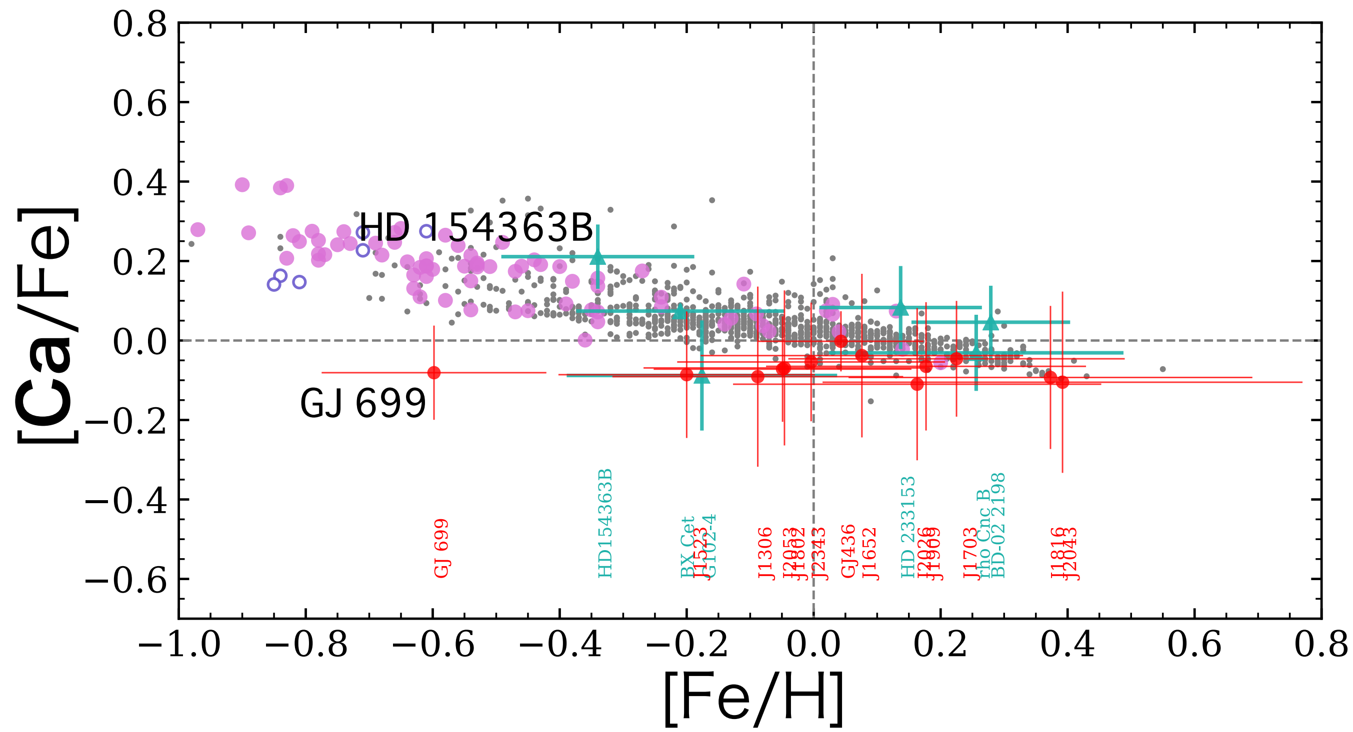
- M dwarfs from Ishikawa et al. (2020)
- M dwarfs in IRD-SSP targets

Distribution of Abundance ratios **[X/Fe] vs [Fe/H]** are important indicators of **Galactic chemical evolution**.

Well studied in FGK stars, but this is the first time to present that for M dwarfs!

→ looks comparable to nearby FGK





Results:

[X/Fe] distribution

- Thin
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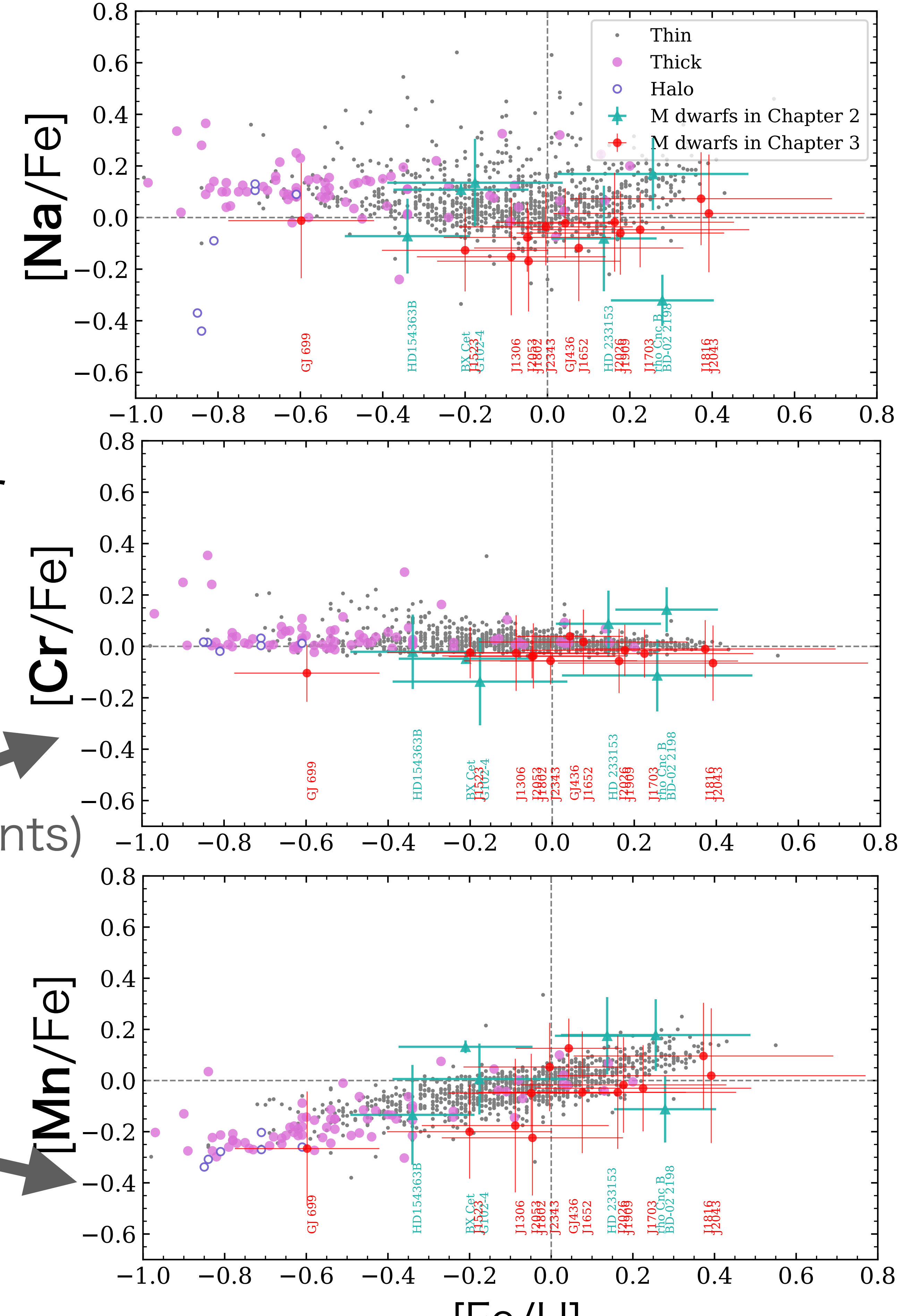
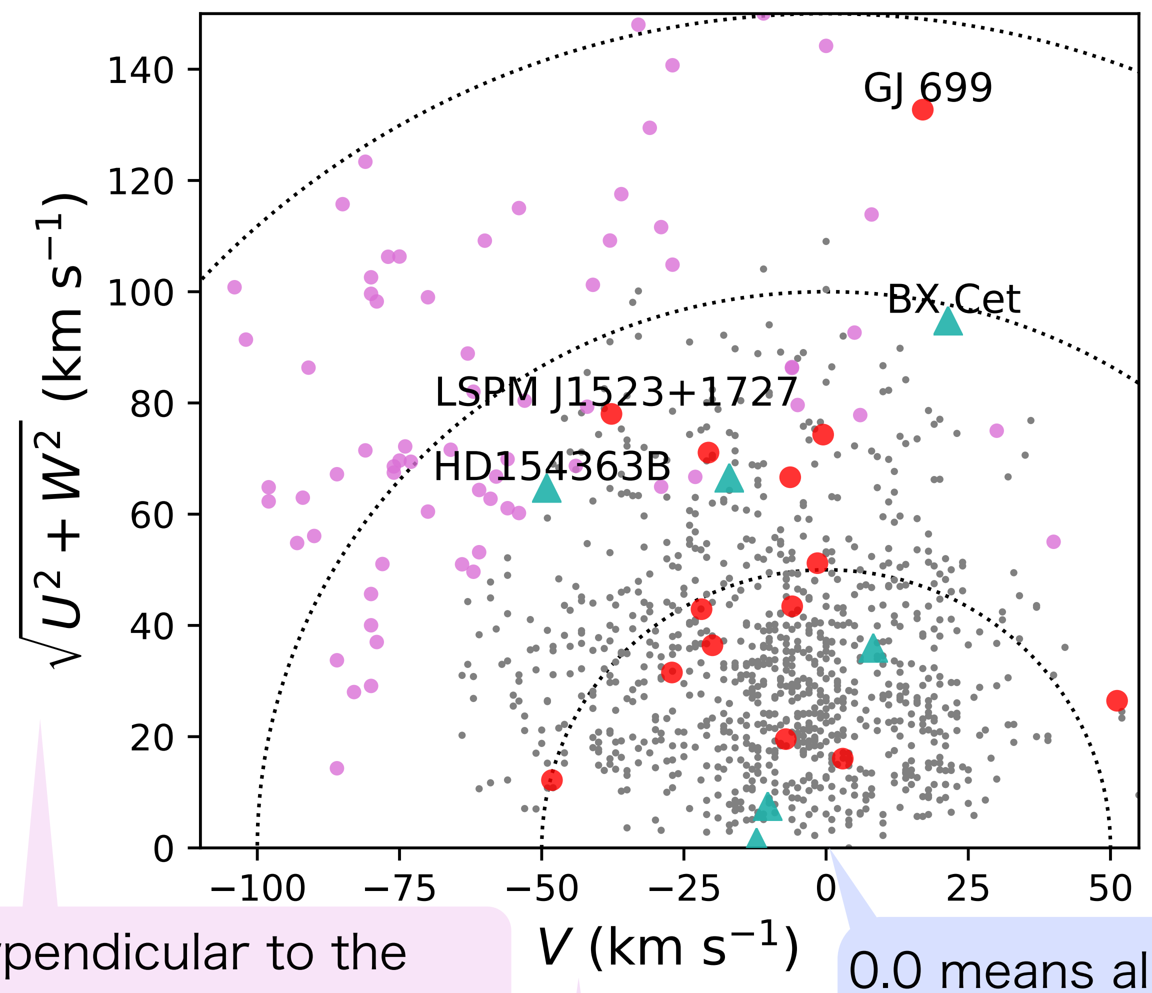
Na, Cr, and Mn also show similar trends to FGK stars

Tightly aligned
(similarity due to Iron-peak elements)

Upward trend (contribution of Type Ia supernovae?)



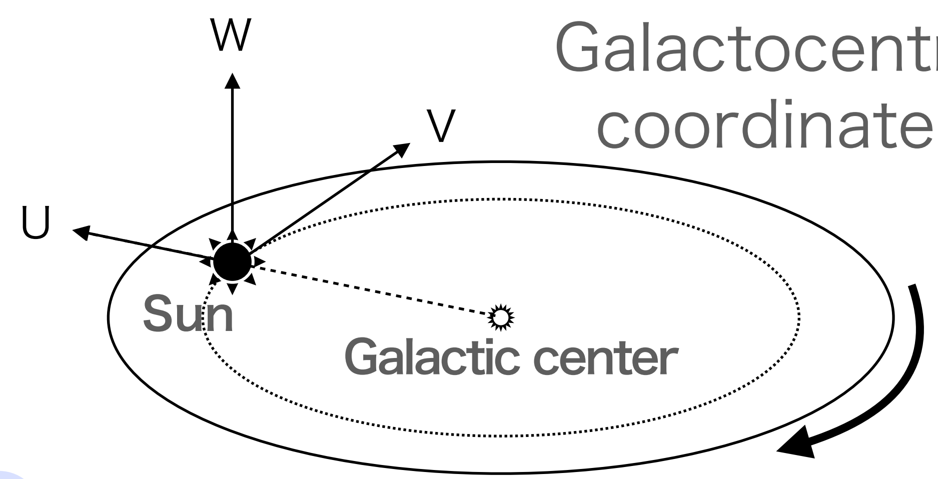
Discussion: Kinematics



Perpendicular to the Galactic rotation

Galactic rotation direction

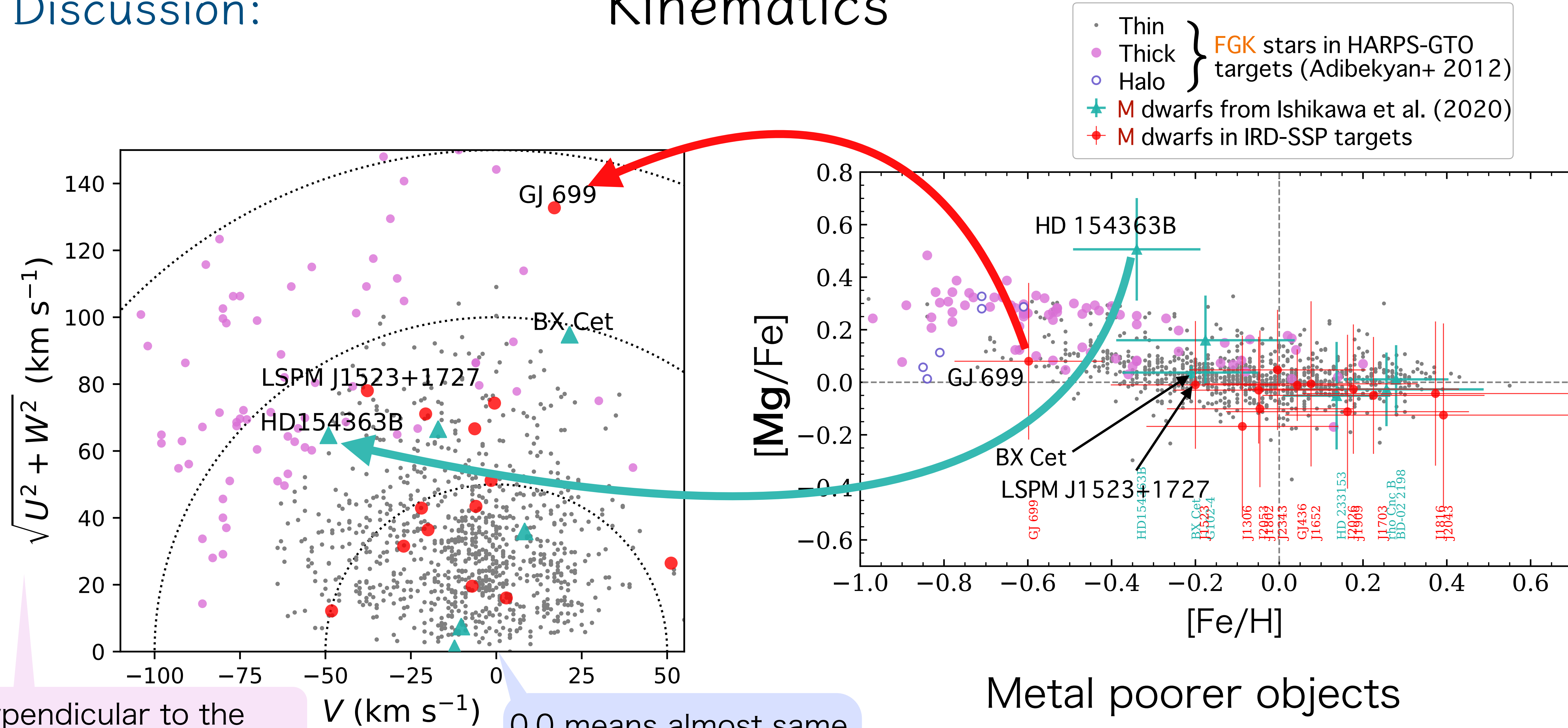
0.0 means almost same circular motion as Sun



Galactocentric coordinates

Calculated the space velocities UVW from radial velocities measured from IRD spectra and astrometric measurements from Gaia

Discussion: Kinematics



Perpendicular to the Galactic rotation

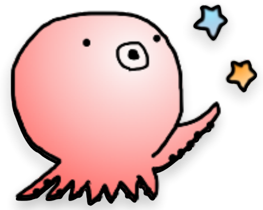
Galactic rotation direction

0.0 means almost same circular motion as Sun

Metal poorer objects show higher v_{tot}

In addition to abundance patterns, kinematics suggest a few targets belong to Galactic thick disk.

Enabled comparison of abundance patterns and kinematics for M dwarfs!



Summary

What we did

Abundances of 8 elements are determined for 13 nearby M dwarfs including > 10 objects with $T_{eff} < 3200$ K for the first time.

What we found

Distributions of [Fe/H] and [X/Fe] are comparable to those of FGK stars in the solar neighborhood. (from –0.6 to +0.4 dex)

Metallicity distribution and kinematics suggest that a few of them belong to the Galactic thick disk.

Future prospects

Extension to 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.