Subaru users meeting
January 11, 2017

LAMOST/Subaru study for 500 very metal-poor stars

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NAOJ

What can we learn from metal-poor stars

- **Nucleosynthesis by first stars**

  →mass and evolution of first stars, and super nova explosion

- **Early chemical evolution**

  →constraints on galaxy formation models

- **Individual nucleosynthesis processes**

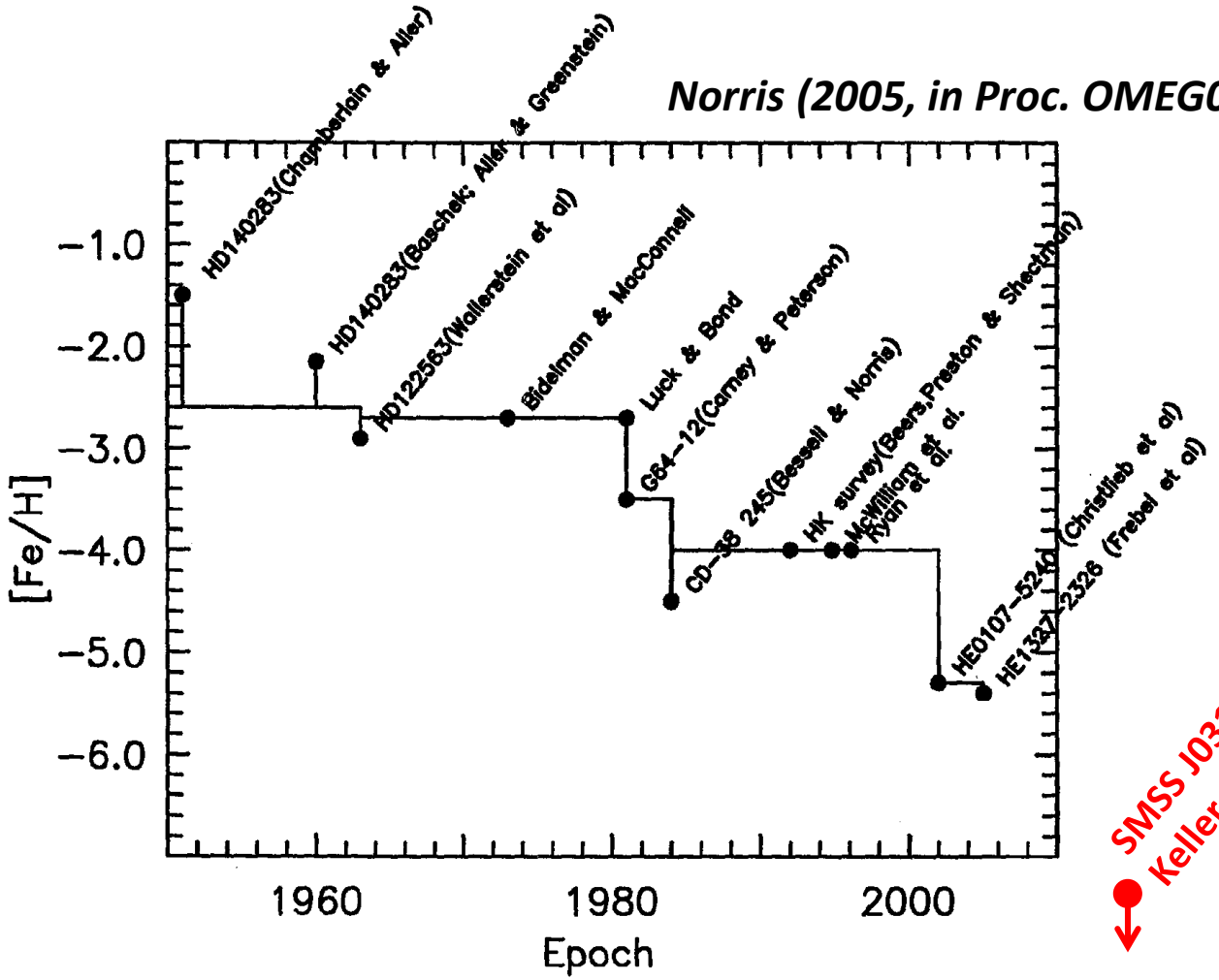
  big-bang nucleosynthesis (Li), heavy elements

- **Evolution of low-mass stars and binary systems**

Searches for metal-poor stars and follow-up high-resolution spectroscopy

Progress of searches for most metal-poor stars

Fe abundances (relative to the solar value)



Searches for metal-poor stars

- **HK survey (1980s-)**

  ***Beers et al. 1985, 1992*, etc.**

  -objective prism survey for Ca II H and K lines (R~800)

  -*B*~<15

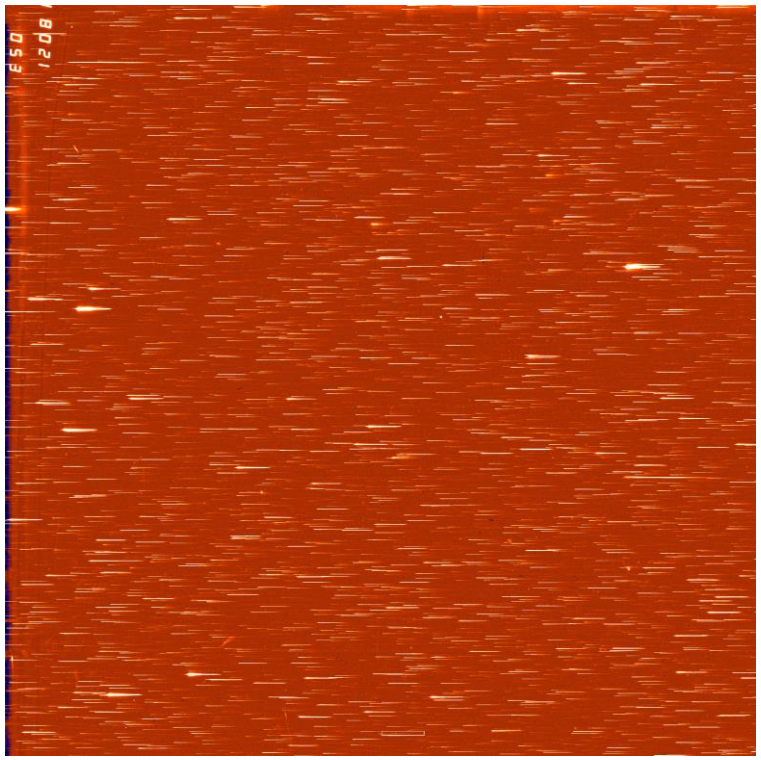
T.C. Beers

Curtis Schemidt (CS) CTIO, e.g. BPS CS22892-052
Burell Schmidt (BS) KPNO, e.g. BPS BS16934-002

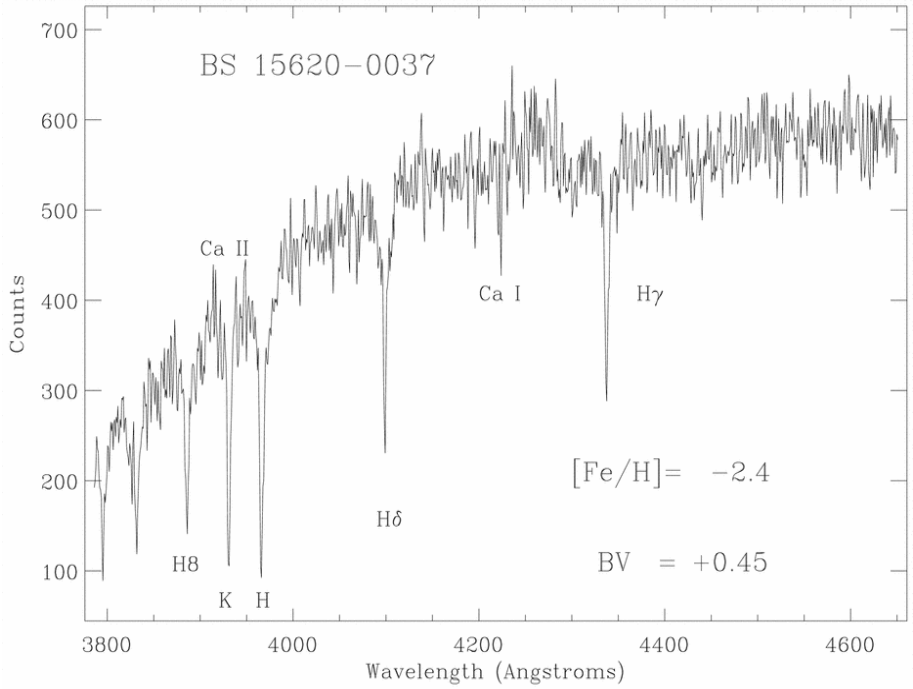
HK-II : re-analysis of the plates of HK survery

Objective prism survey of metal-poor stars (1980s～)

①wide-field spectroscopic survey



②follow-up medium resolution spectroscopy



Follow-up spectroscopy with Subaru/HDS for HK survey sample

- First Light of Subaru/HDS in 2000

Follow-up with Subaru/HDS (2000～)
Topics:
-r-process-enhanced stars (Honda et al. 2004)
-CEMP stars: s-process from CEMP-s, and establishing “CEMP-no” class (Aoki et al. 2002)

Searches for metal-poor stars

- **Hamburg/ESO survey (1990s-)**

  stellar content: *Christlieb et al. 2001* etc.

  → e.g. HE0107-5240 ([Fe/H]=-5.3, Christlieb et al. 2002)

N. Christlieb

Follow-up with Subaru/HDS (2003～)

Topics:

-most metal-poor stars (Frebel et al. 2005)

-CEMP stars (Aoki et al. 2007)

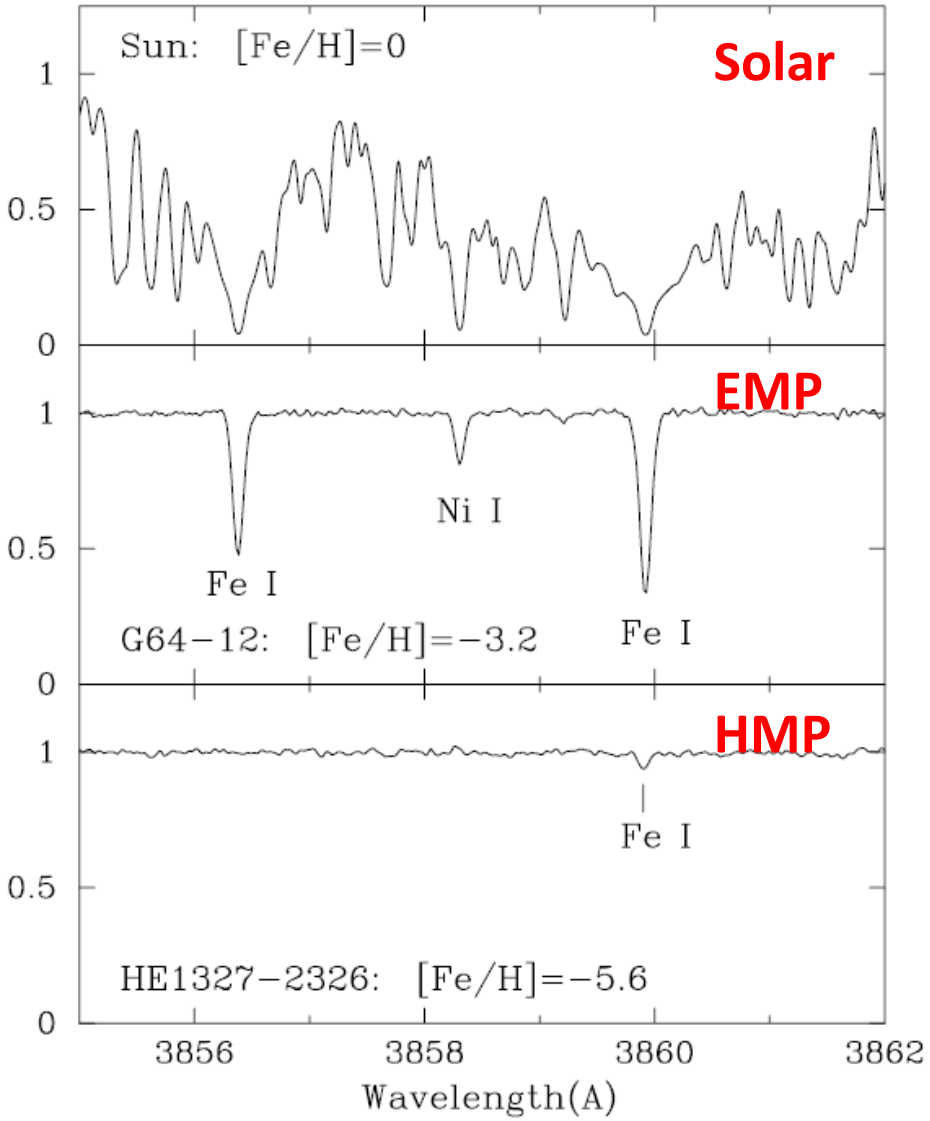
-Li (Aoki et al. 2009)

The 2nd HMP star HE1327-2326

Frebel et al. (2005)

very weak Fe lines
→[Fe/H]=-5.4

detection of CH molecular bands
→excess of carbon



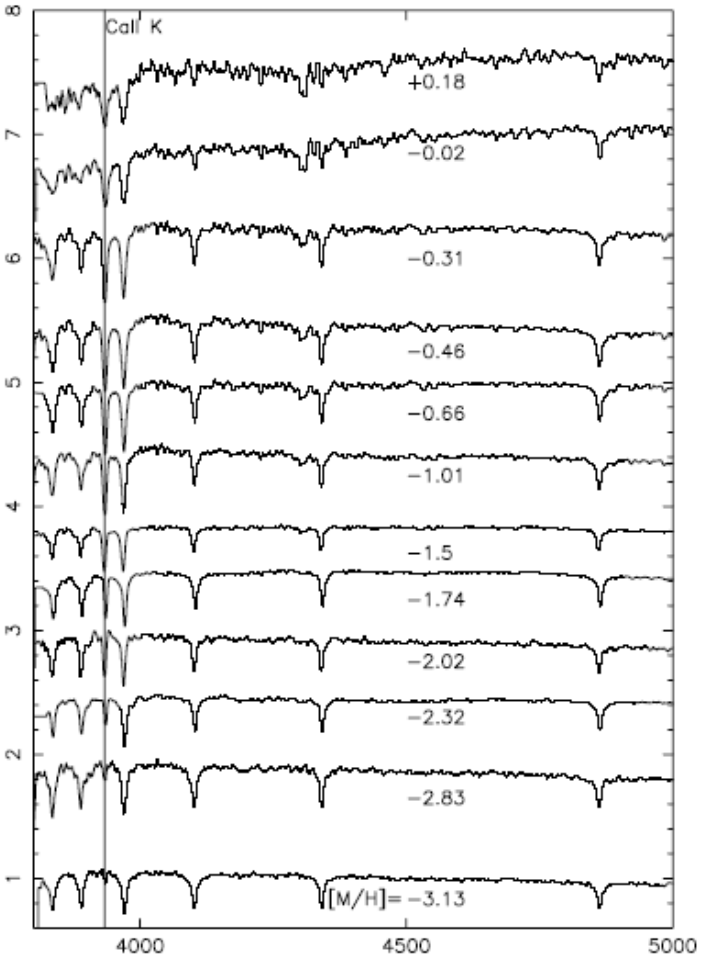
SDSS/SEGUE

Searches for very/extremely metal-poor stars by SDSS/SEGUE

The 2.5m telescope at Apache Point Observatory

- Imaging/spectroscopic surveys
- <u>Surveys of Galactic stars 240,000</u>

R~2000



Wavelength (A)

SDSS/SEGUE

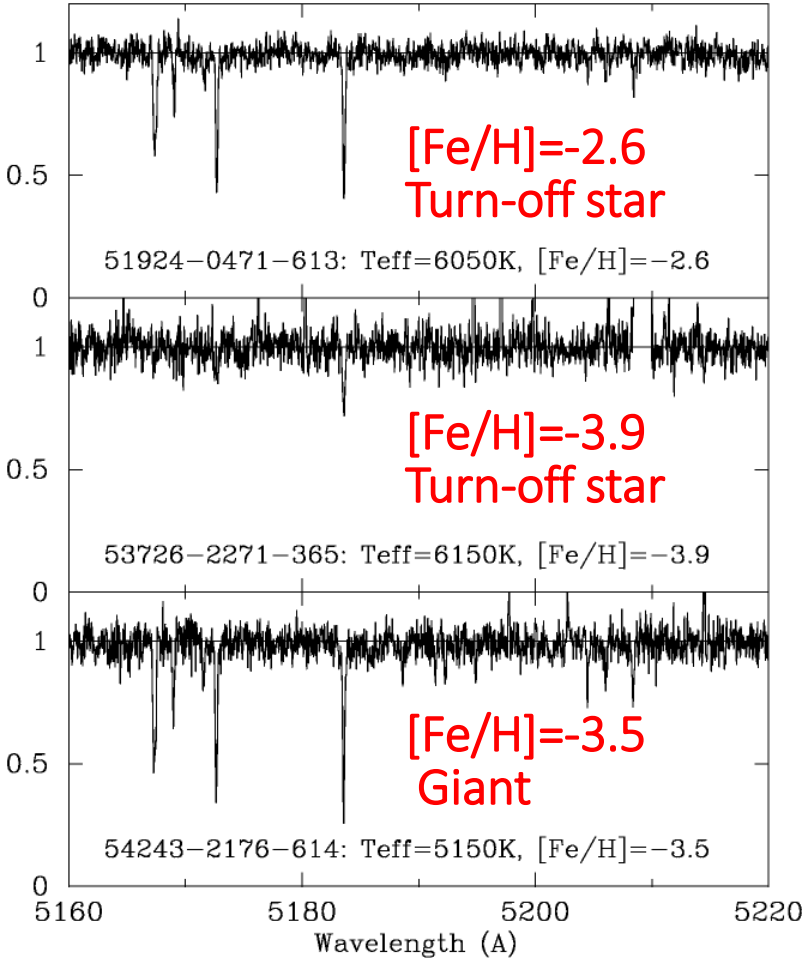
Follow-up high resolution spectroscopy with Subaru for selected SDSS objects

Intensive program:
Follow-up with Subaru/HDS for 150 objects (2008-2009)

Topics:

-chemical compositions of 137 very/extremely metal-poor stars (*Aoki et al. 2013*)

-binary frequency (*Aoki et al. 2015*)



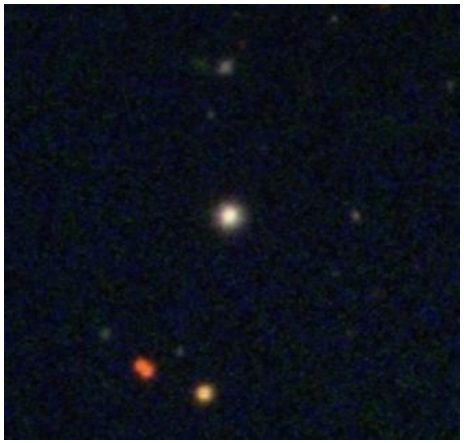
Discovery of a low-mass star with peculiar chemical composition

Aoki, Tominaga, Beers, Honda, Lee (2014, Science)

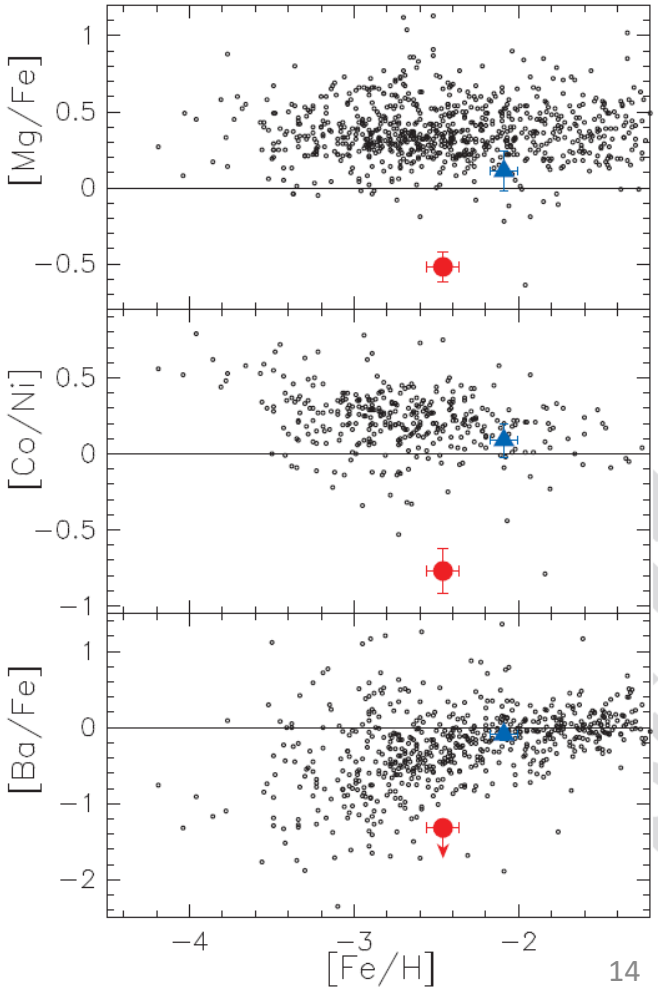
SDSS J001820.51-093939.2

- A low-mass main-sequence star
- [Fe/H]=-2.5
- Low C, Mg, Co, Ba etc. abundances
  → excess of Fe

→signature of first generation very massive star?



Taken from SDSS



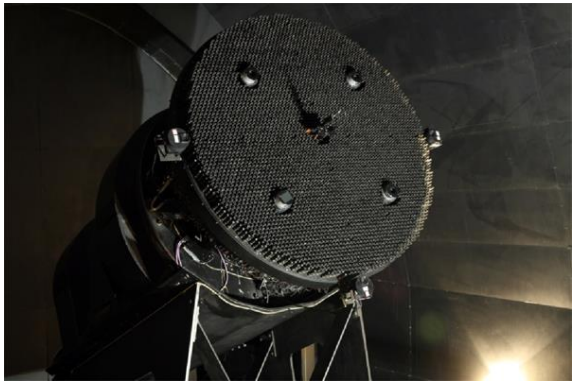
LAMOST

JSPS-CAS joint program:
Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

Subaru intensive program:
LAMOST/Subaru study for
500 very metal-poor stars

LAMOST survey

-R=1800
-4000 fibers
-r<19



Fibers on the focal plane

- LAMOST Experiment for Galactic Understanding and Exploration (LEGUE)
- Target selection: random selection for a given magnitude/temperature range
  cf. SDSS/SEGUE
- Data Release 3 (DR3): 5.7 million spectra including 4 million AFGK stars

Members in Japan

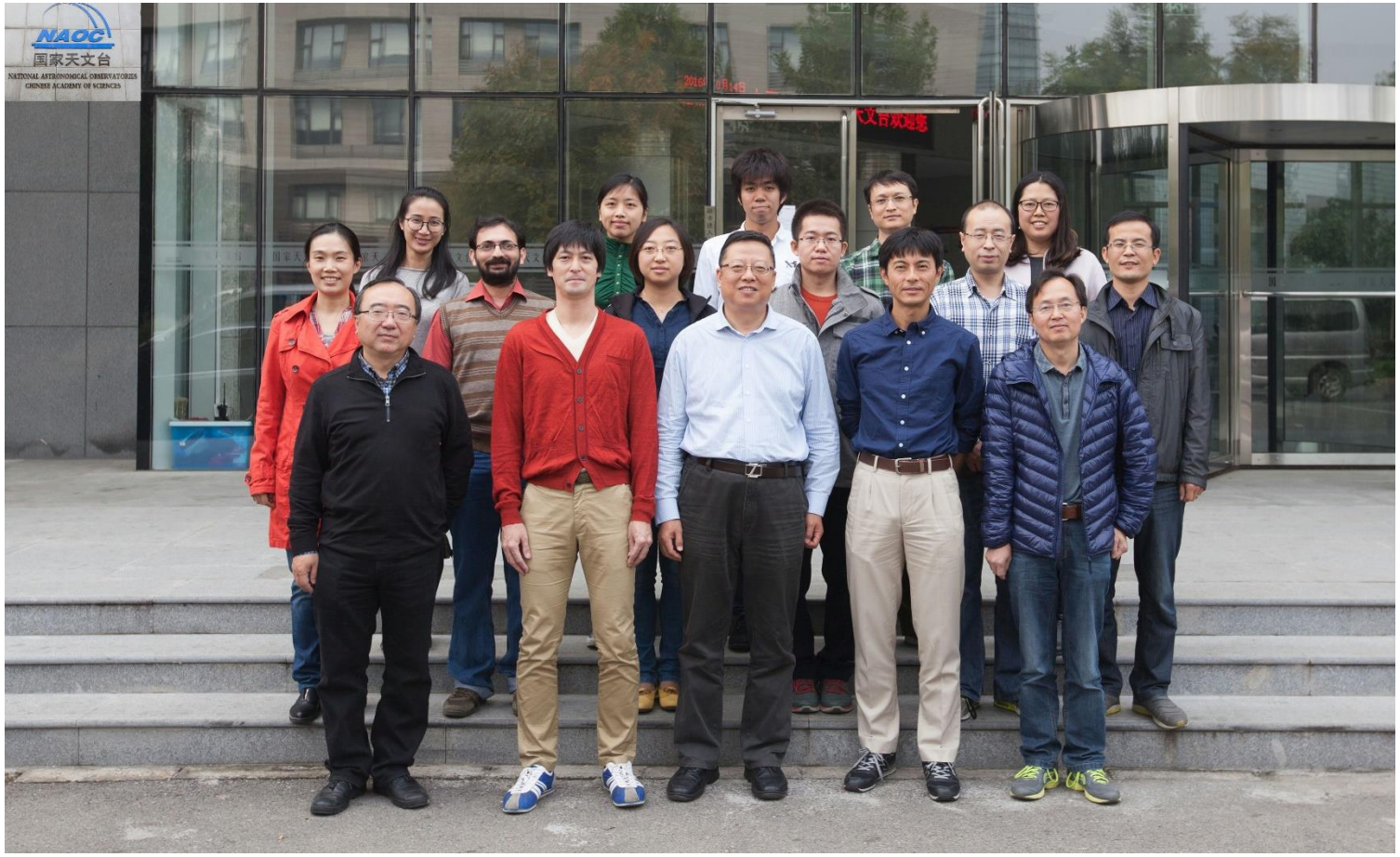
Wako Aoki 青木 和光	NAOJ/TMT-J Associate professor	Stellar abundances, high-resolution spectroscopy
Nobuo Arimoto 有本 信雄	NAOJ/Subaru professor	Galactic Archaeology
Takuma Suda 須田 拓馬	Univ. of Tokyo Assistant professor	Stellar evolution Database
Satoshi Honda 本田 敏志	Univ. of Hyogo researcher	Stellar abundances, high-resolution spectroscopy
Miho Ishigaki 石垣美歩	Univ. of Tokyo, IPMU researcher	Stellar abundances, high-resolution spectroscopy
Tadafumi Matsuno 松野 允郁	Sokendai/NAOJ PhD student	Stellar abundances, high-resolution spectroscopy
Misa Aoki 青木 みさ	ICU PhD student	Stellar abundances, high-resolution spectroscopy

NAOC team

趙　剛 Gang Zhao	Chief Professor	Chinese PI
陳玉琴 Yuqin Chen	Professor	Galactic evolution, clusters
趙景昆 Jingkun Zhao	Professor	Streams, moving groups
李海宁 Haining Li	Associate Professor	MP stars, target selection, observation
談克峰 Kefeng Tan	Associate Professor	Chemically peculiar & super Li-rich stars
邢千帆 Qianfan Xing	Assistant Professor	Alpha-abnormal stars, observation
翟　萌 Meng Zhai	PhD. Student	Data analysis, observation
張世琳 Shilin Zhang	PhD. Student	Data analysis, observation
施建荣 Shi Jianron	professor	Li-rich giants / metal-poor stars in Kepler field

Norbert Christlieb (Heidelberg)

2016 October collaboration meeting in Beijing

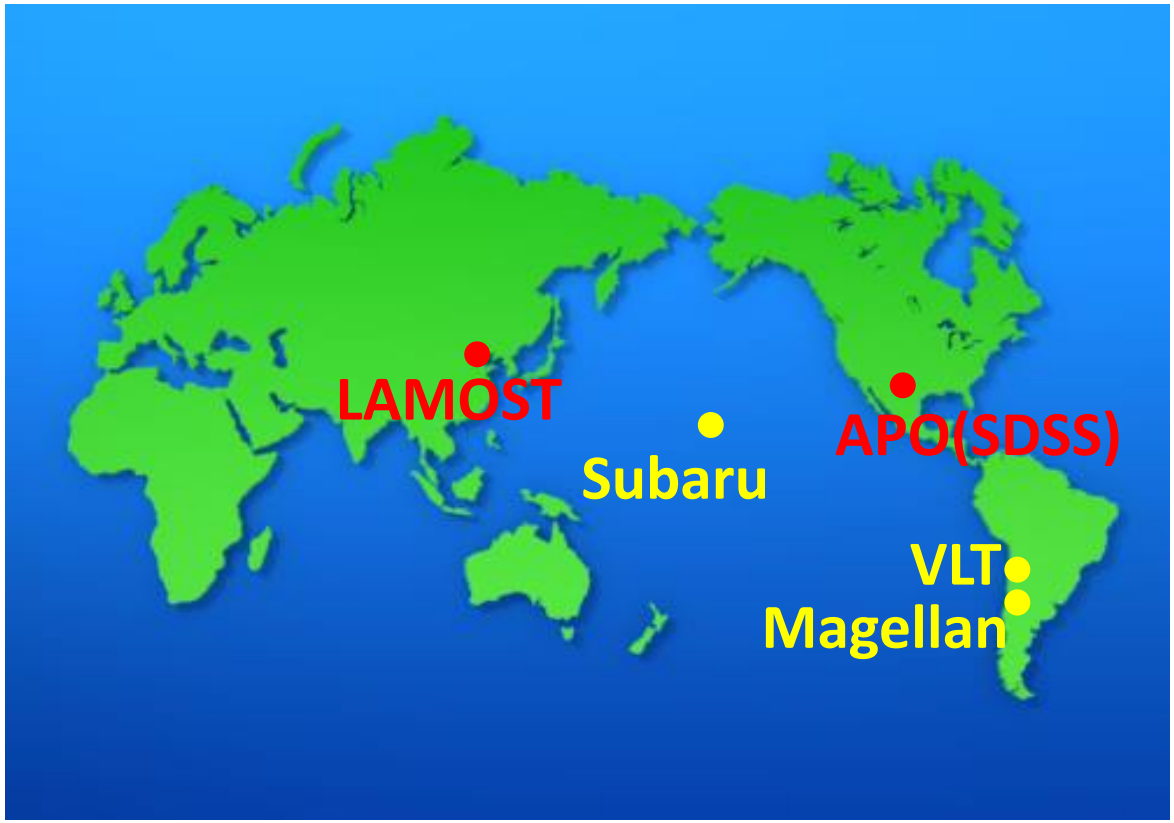


History of the collaboration

Japan-China collaboration on high resolution spectroscopy from ～2002

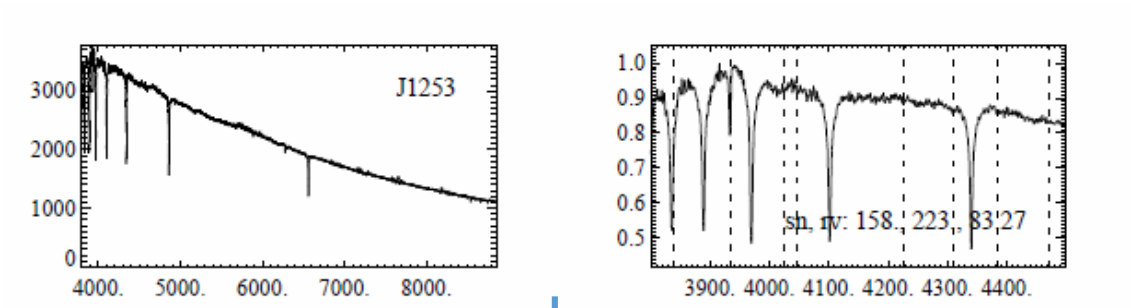
“2nd Sino-German workshops” in Hamburg (September 2007)

Survey telescopes and large telescopes

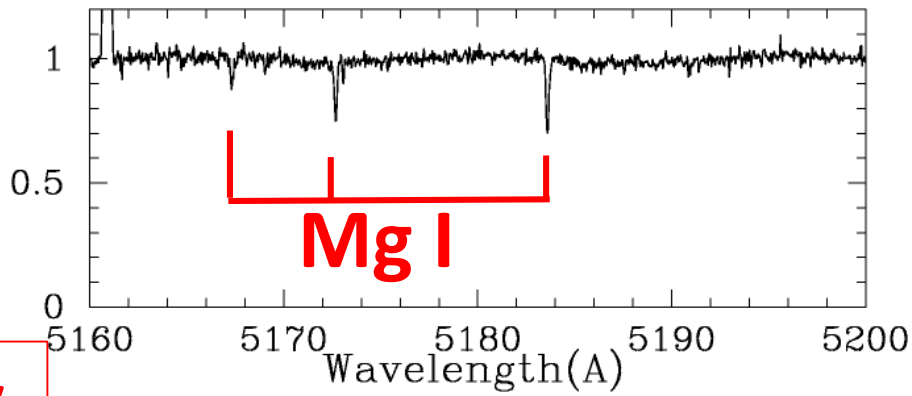


Target selection from LAMOST sample

LAMOST medium resolution spectra



Subaru high-resolution follow-up spectroscopy



J1253+0753 [Fe/H]=-4.0 main-sequence turn-off

LAMOST covers relatively bright stars (V<14)

LAMOST high-resolution follow-up before the intensive program

- **Subaru**

  -(2013 service programs)

  -2014 May: 2 nights

  -2015 March: 2 nights

  -2015 November: 2 nights

  Li et al. (2015a,b) on UMP & r-process-enhanced star

  Matsuno et al. (2017) on Li in CEMP stars

- **Magellan telescope**

  Li et al. (2015)

Subaru intensive program: LAMOST/Subaru study for 500 very metal-poor stars

- **Searches for rare but key objects:**
  - -signature of first stars
  - -neutron-capture element-enhanced stars
- **Statistics of very metal-poor stars:**
  - -metal-poor tail of the metallcity distribution function
  - -binary frequency from double-lined binaries
  - -trend and scatter (or clustering) of elemental abundance ratios

Subaru intensive program: LAMOST/Subaru study for 500 very metal-poor stars

→ double the sample of very metal-poor stars with chemical abundance measurements by homogeneous analysis

- Main sample
  -Extremely metal-poor ([Fe/H]<-3) stars
  -Bright (V<14) very metal-poor ([Fe/H]<-2) stars

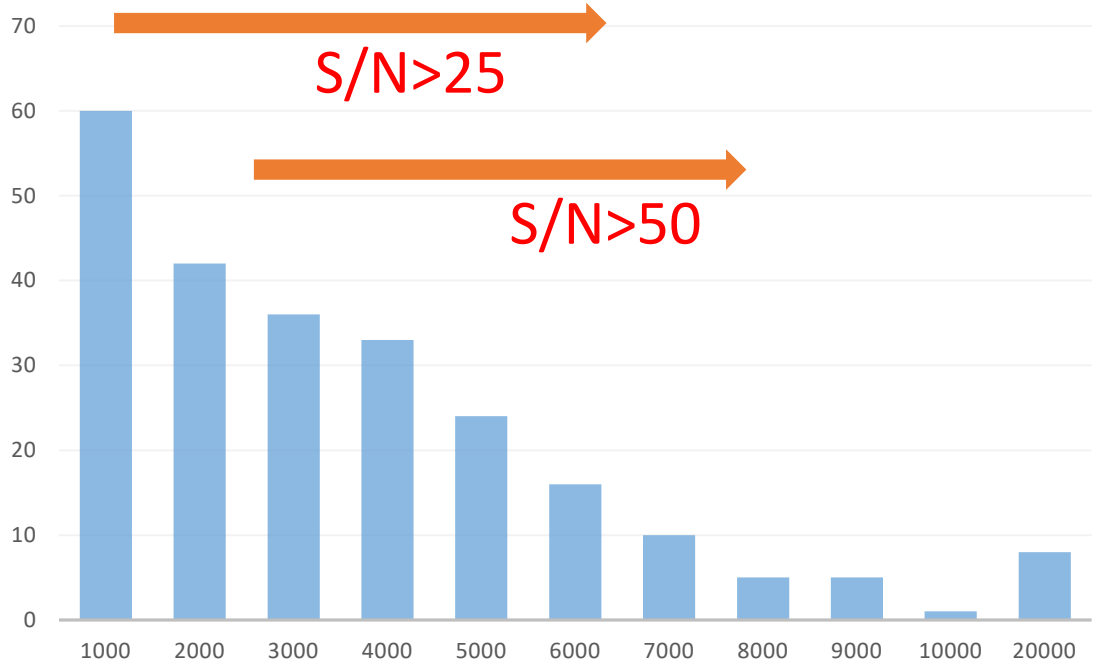
- Some specific topics
  -Alpha-rich/poor stars
  -Li-rich giants
  -Moving group members

Intensive program: observations in 2016

Date	Weather		# of objects
April 26 (half night)	Clear		12
April 27 (half night)	Clear		12
May 20	Clear		24
May 22	Clear		35
May 23	Clear		37
May 27	Clear		22
May 28	Clear	Partially lost by high humidity	26
November 16	Clear	2” seeing	35
November 17	Clear	Telescope trouble (3 hours)	14
November 18	Clear	Telescope trouble	0
November 19	Clear/cloudy	Partially lost by high humidity	17

Spectra obtained in 2016 April-May runs

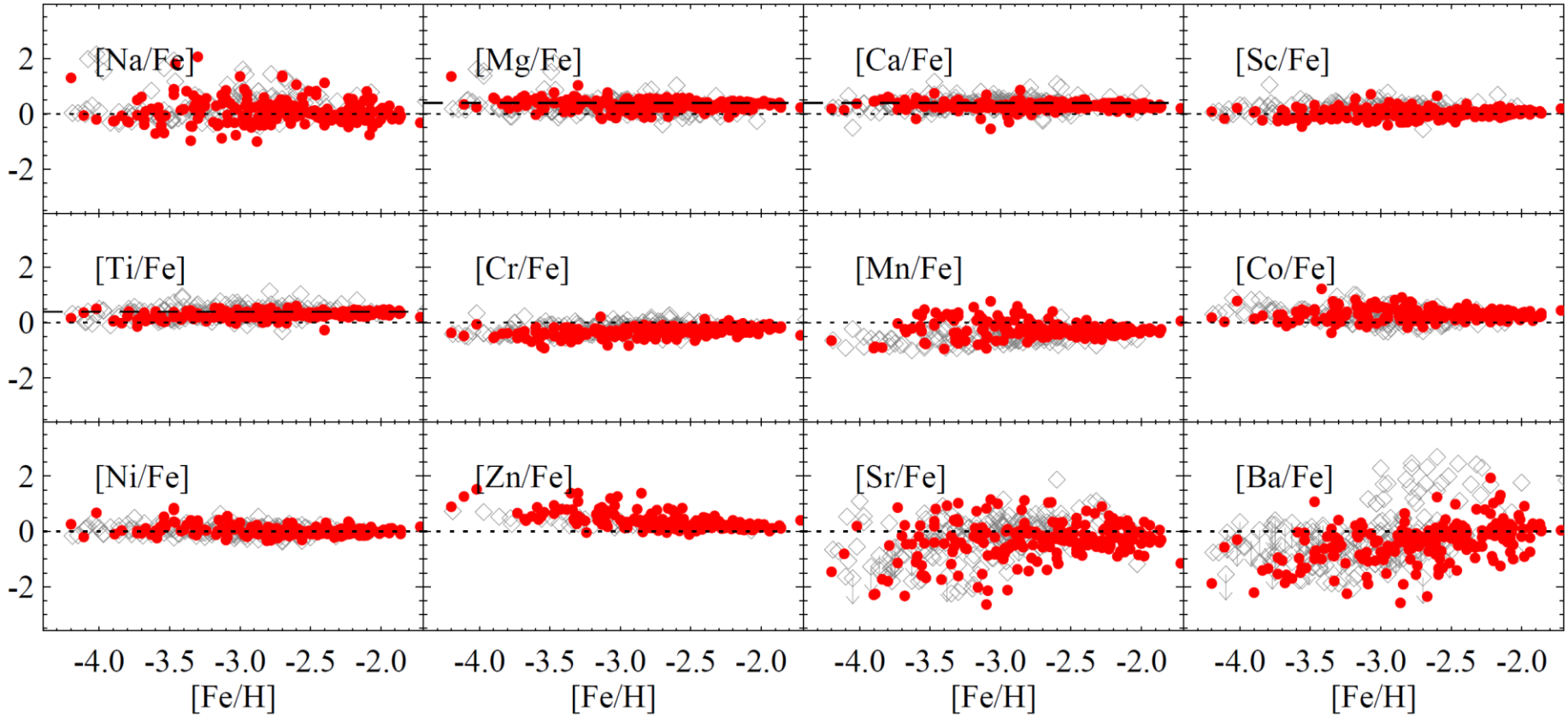
- About 240 stars (very metal-poor candidates) by 10 nights (~8 useful nights). Standard abundance analysis is conducted for ～160 stars.



Large sample of metal-poor stars

Elemental abundances for 230 very metal-poor stars (including stars observed in normal programs) have been obtained

H-N. Li

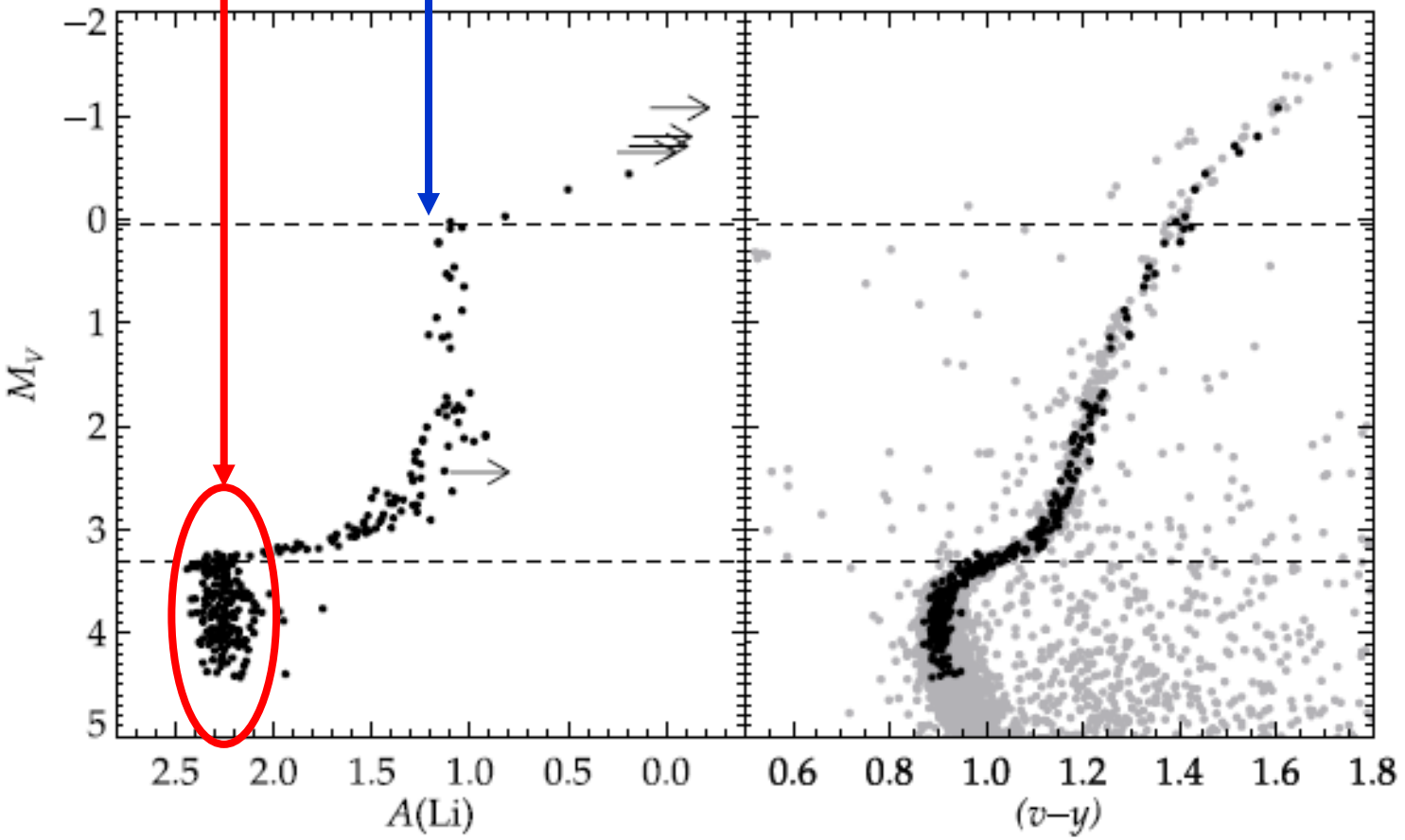


Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

Depletion of Li in red giants

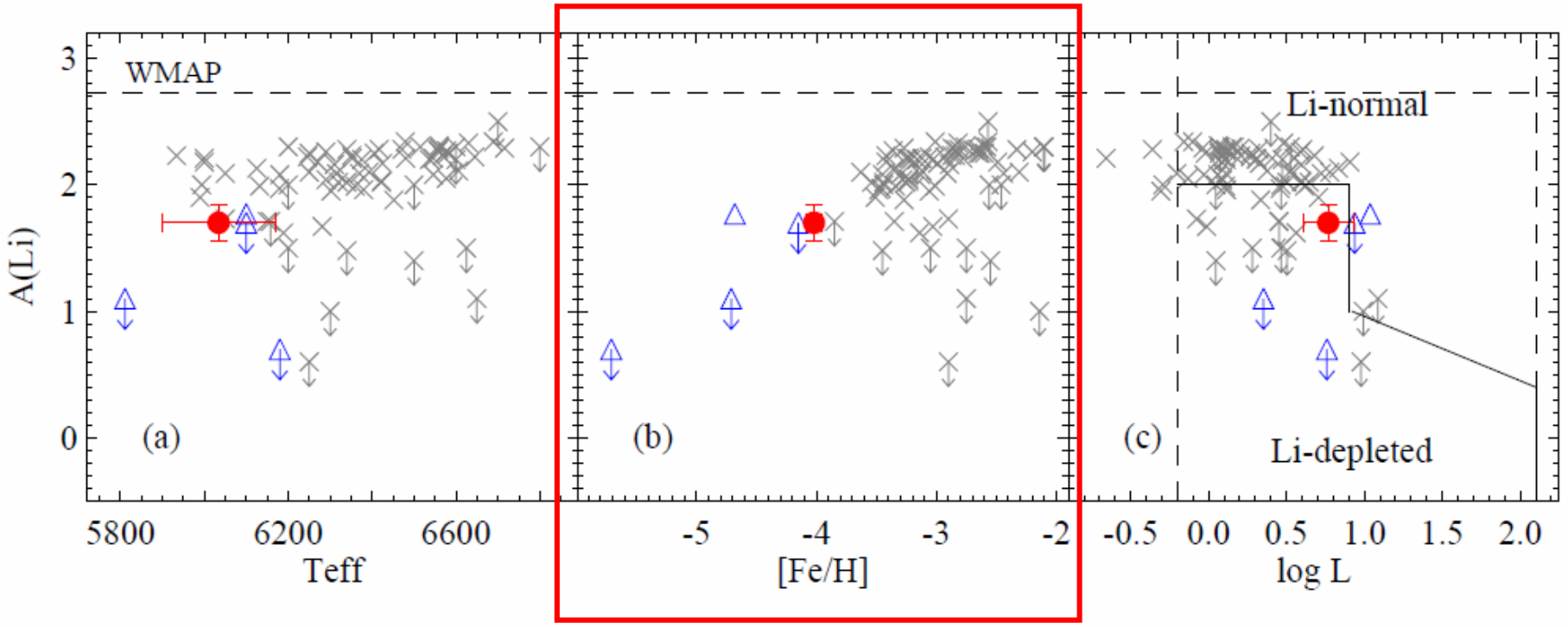
Lind et al. (2009)



Early result 1. new ultra metal-poor stars

The second example of Li detection in Ultra Metal-Poor ([Fe/H]<-4) stars

Li, Aoki et al. (2015, PASJ)



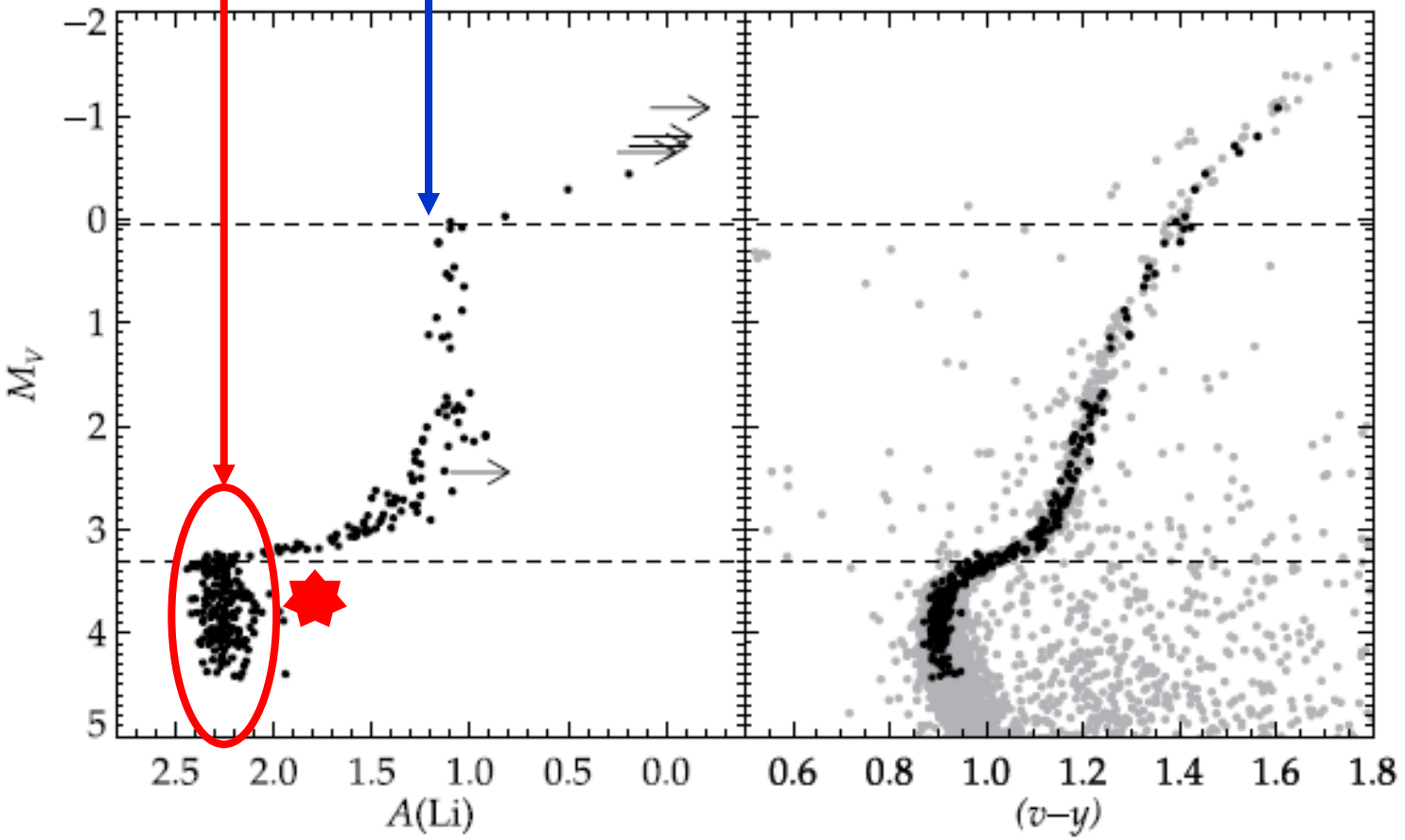
→Li depletion in the most metal (iron)-poor stars ([Fe/H]<-4)

Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

Depletion of Li in red giants

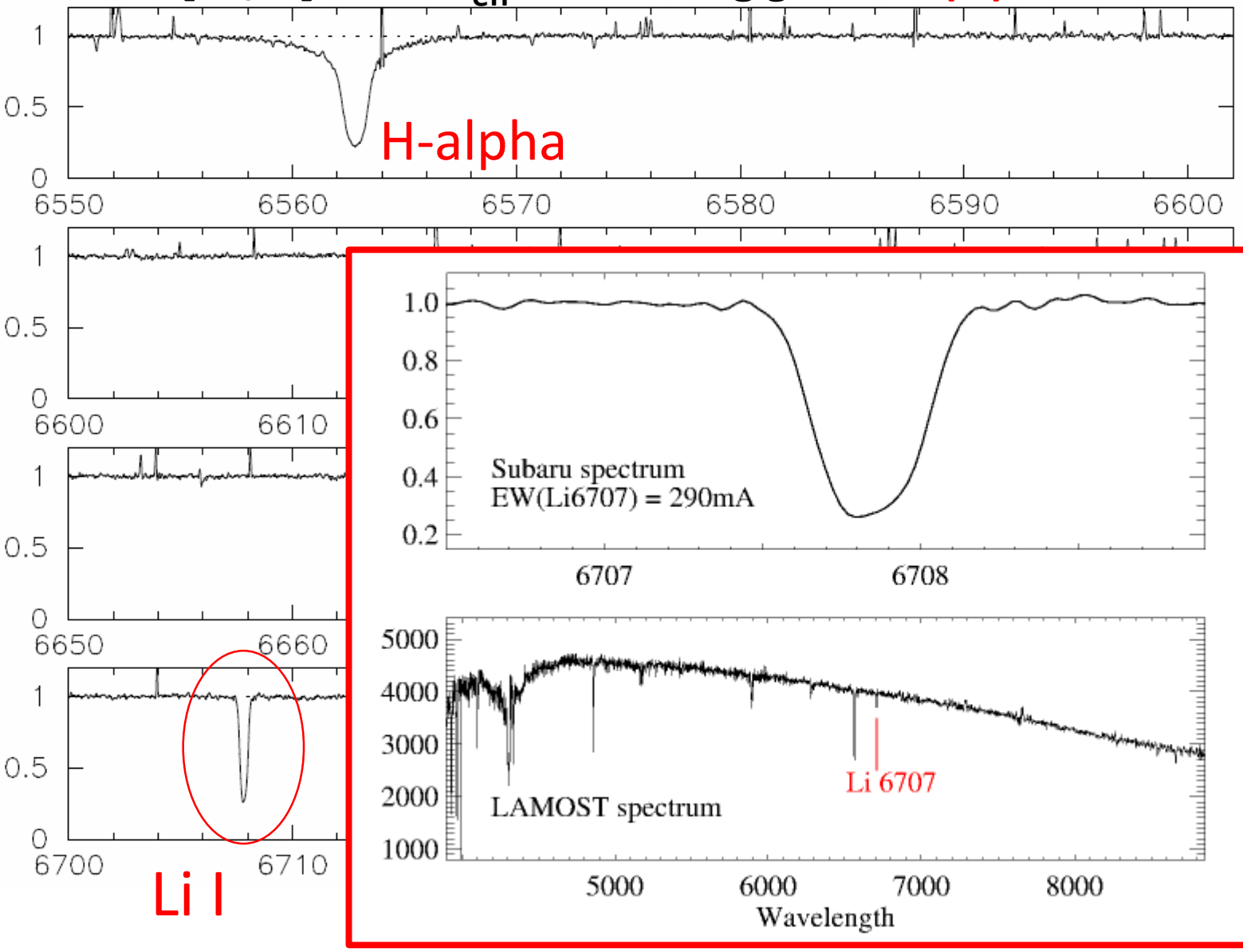
Lind et al. (2009)



Early result 2. Super Li-rich red giant!

LAMOST

[Fe/H]=-3.3, T_{eff}=5200K, log g=2.2, A(Li)～3.0

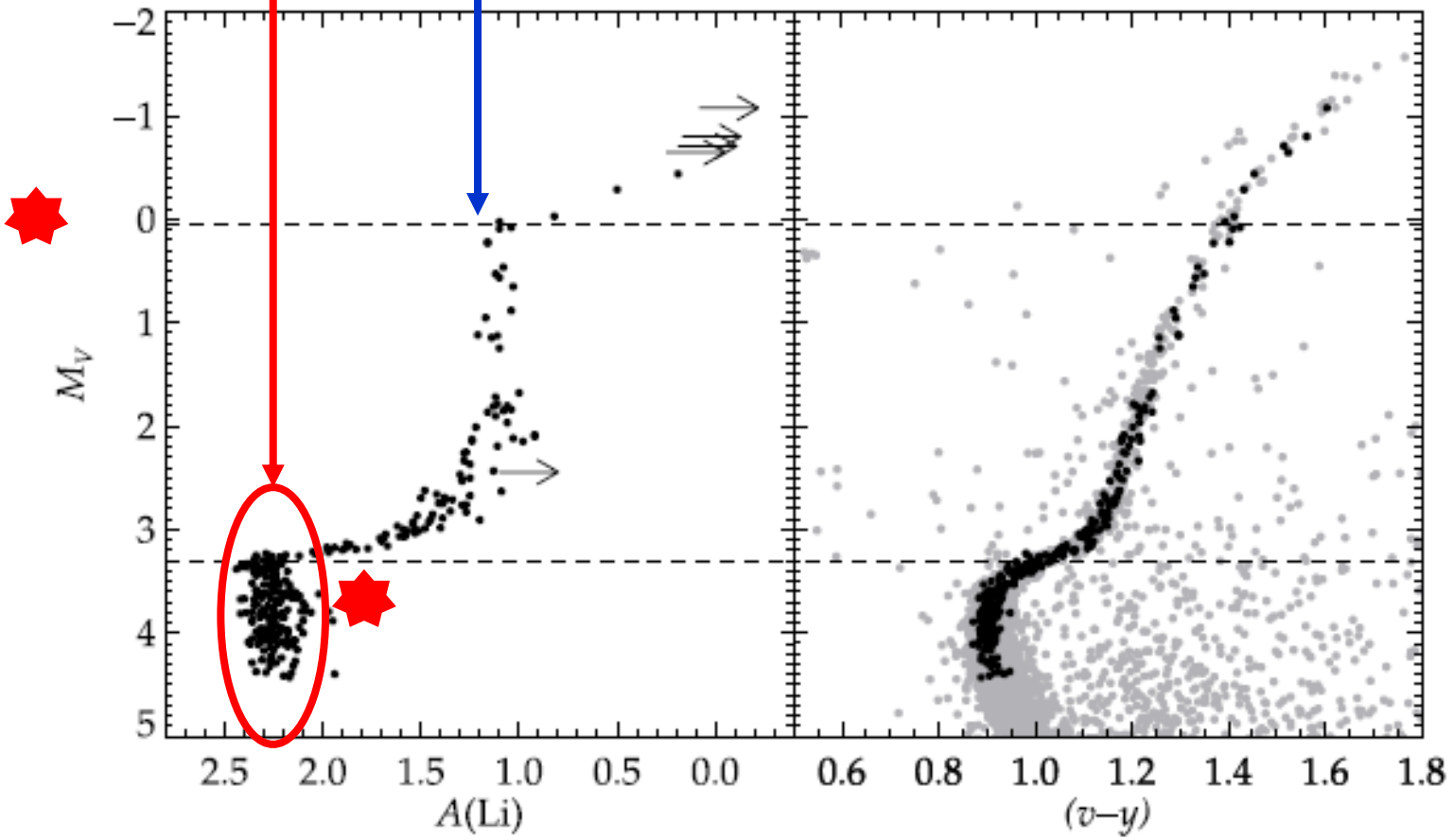


Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

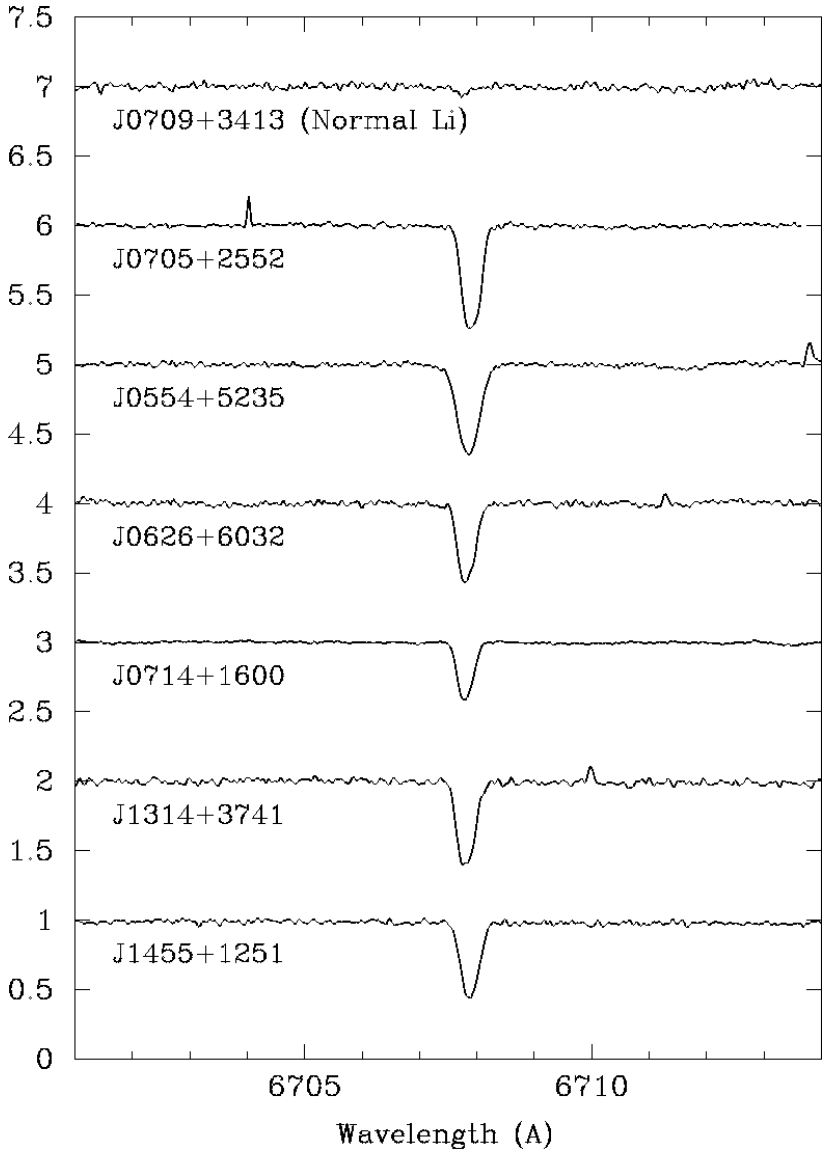
Depletion of Li in red giants

Lind et al. (2009)



Super Li-rich stars found by LAMOST/Subaru study

- **Candidates are selected from LAMOST low-resolution spectra.**
- **A dozen of stars show extremely strong Li absorption lines.**
- **All are red giants with very low metallicity ([Fe/H]~<-2.5). They are clearly distinguished from normal giants in which Li line is very weak.**
- **The Li would be produced by Cameron-Fawler mechanism, but the mixing between the surface and internal layers of stars is unknown. Large sample of Li-rich stars could provide a hint to solve the mistery.**



Summary and future prospect

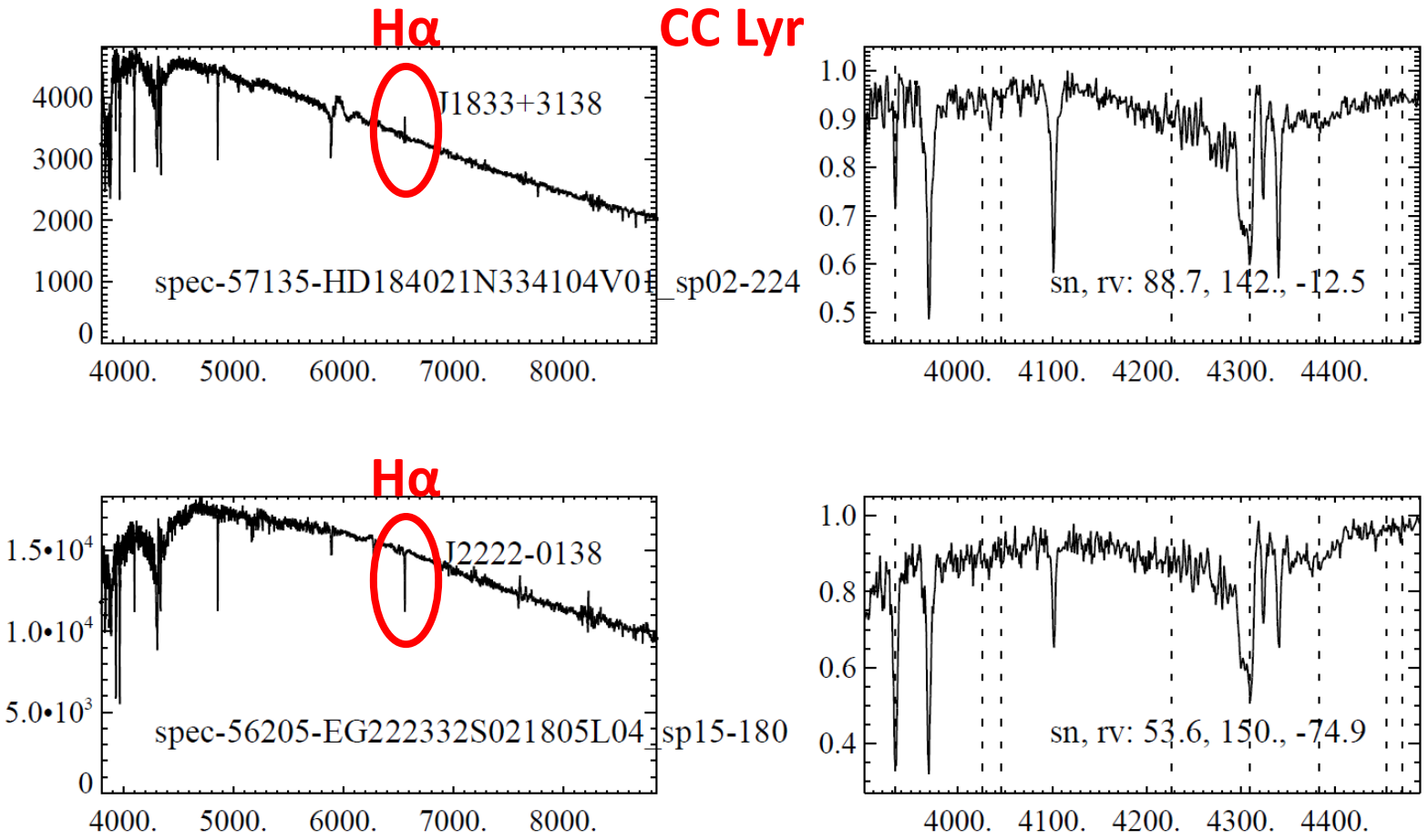
- **High resolution follow-up spectroscopy have been conducted for candidates of metal-poor stars discovered by large surveys (HK, HES, SDSS/SEGUE)**
- **LAMOST is providing huge samples of metal-poor stars and other chemically/kinematically interesting objects. We are conducting follow-up spectroscopy with Subaru for 500 stars**

◆ **LAMOST objects studied with Subaru are relatively bright, providing good sample for detailed abundance studies.**

◆ **Combining kinematics data provided by Gaia**

Re-discovery of metal-poor post-AGB star CC Lyr by LAMOST

LAMOST low-resolution spectra (R=1800) used for searching for very metal-poor stars



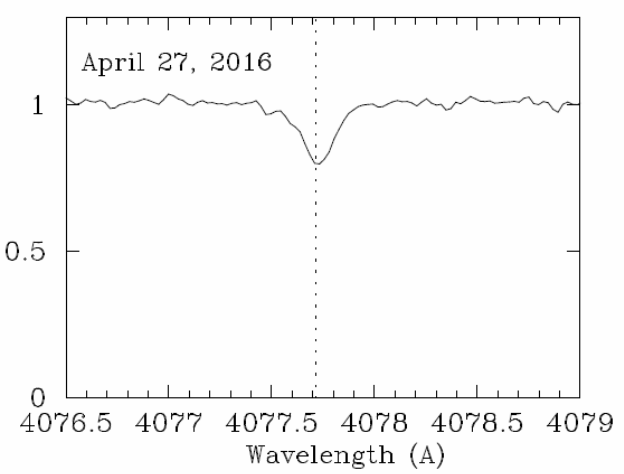
Chemical abundance of CC Lyr

- **Stellar parameters adopted from Maas et al. (2007)**

  Teff=6250K, log g=1.0, [Fe/H]=-3.5, ξt=3.5 km/s

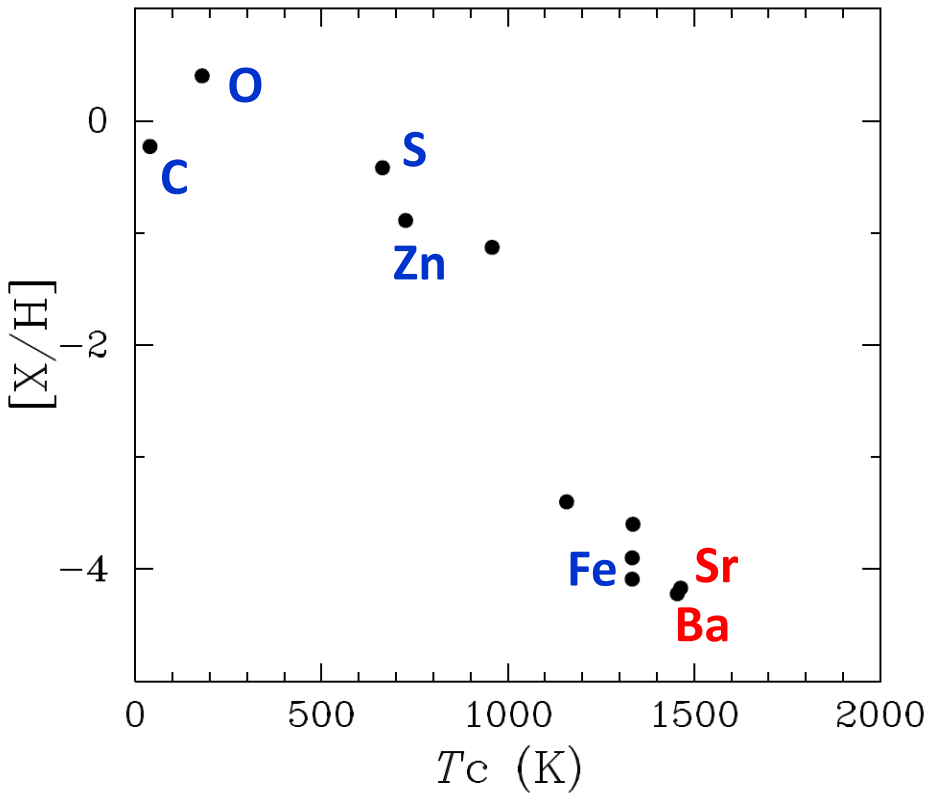
- **Examine wide range of parameters and model atmospheres for [Fe/H]=-3.5 and [Fe/H]=0**

New detection of Sr



→no excess of neutron-capture elements

Aoki et al. (2017)



Time variation of spectral lines

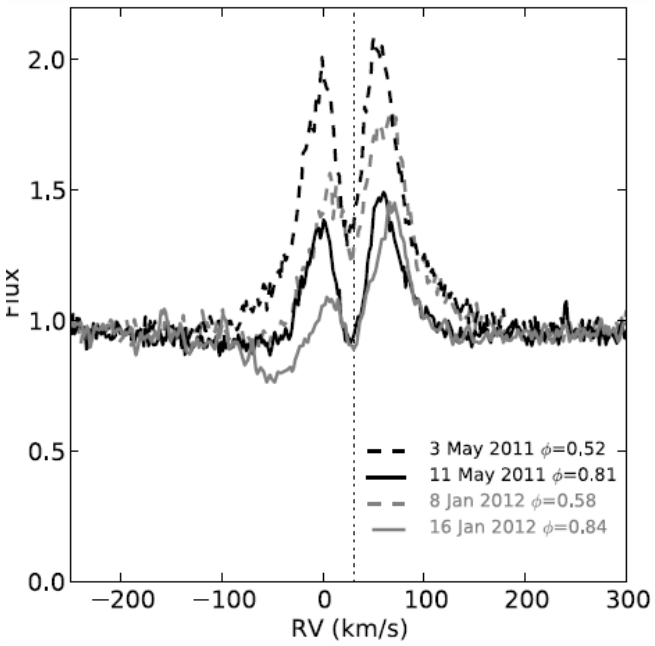
H alpha emission

- **Double peaks**
- **Central absorption does not show velocity shift with pulsation phase**

→absorption and emission by circumstellar matter

IRAS11472-0800

Van Winkel et al. (2012)



60km/s